String theory and the crisis in particle physics II
or the ascent of metaphoric arguments

Dedicated to the memory of Juergen Ehlers

(invited contribution to IJMPD)

Bert Schroer
CBPF, Rua Dr. Xavier Sigaud 150
22290-180 Rio de Janeiro, Brazil
and Institut fuer Theoretische Physik der FU Berlin, Germany

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Abstract

This is a completely reformulated presentation of a previous paper with the same title; this time with a much stronger emphasis on conceptual aspects of string theory and a detailed review of its already more than four
decades lasting history within a broader context, including some little-known details. Although there have been several books and essays on the sociological impact and its philosophical implications, there is yet no serious attempt to scrutinize its claims about particle physics using the powerful conceptual arsenal of contemporary local quantum physics.

I decided to leave the previous first version on the arXiv because it may be interesting to the reader to notice the change of viewpoint and the reason behind it.

Other reasons for preventing my first version to go into print and to rewrite it in such a way that its content complies with my different actual viewpoint can be found at the end of the article.

The central message, contained in sections 5 and 6, is that string theory is not what string theorists think and claim it is. The widespread acceptance of a theory whose interpretation has been obtained by metaphoric reasoning had a corroding influence on the rest of particle physics theory as will be illustrated in several concrete cases.

The work is dedicated to the memory of Juergen Ehlers with whom I shared many critical ideas, but their formulation in this essay is fully within my responsibility.

1 An anthology of the crisis in the foundations of particle physics

There can be no doubt that after almost a century of impressive success fundamental physics is in the midst of a deep crisis. Its epicenter is in particle theory, but its repercussions may influence the direction of experimental particle physics and affect adjacent areas of fundamental research. They also led to quite bizarre ideas in the philosophy of fundamental sciences, which partially explains why they attracted much general interests beyond the community of specialists in particle physics.

One does not have to be a physicist in order to be amazed when reputable members of the particle physics community [1] recommend a paradigmatic change away from the observational based setting of physics which, since the time of Galileo, Newton, Einstein and the protagonists of quantum theory and quantum field theory has been the de-mystification of nature by mathematically formulated concepts with experimentally verifiable consequences. The new message which has been formed under the strong influence of string theory is that it is scientifically acceptable to use ones own existence in reasonings about theoretical physics matter even if this leads to a vast collection of in principle unobservable concepts such as multiverses and parallel worlds. This new physics excepts metaphors (but calls them principles as e.g. the anthropic principle); its underlying philosophy resembles religion with its unobservable regions of heaven and hell rather than physics as we know it since the times of Galileo. It certainly amounts to a rupture with natural sciences and with the accompanying philosophy of enlightenment. despite all assurances to the contrary it looks like a parallel universe avatar of intelligent design.
Instead of “cogito ergo sum” of the rationalists, the new anthropic maxim coming from this new doctrine also attaches explanatory power to its inversion: I exist and therefore things are the way they are since otherwise I would not exist. Its main purpose is to uphold the uniqueness of the string theorists dream of a TOE. Even with an enormous number of different solutions with different fundamental laws and fundamental constants one is able to claim that these describe actually existing but inaccessible parallel worlds or multiverses of a unique multiverse TOE. Anthropic reasoning here is not meant as a temporary auxiliary selective device, pending better understanding and further refinements of the theory, but rather as the endpoint of a theory. The logic behind this doctrine vaguely resembles the "if you cannot solve a problem then enlarge it" motto of some politicians.

The invocation of the anthropic principle serves the purpose to uphold the holy Grail of string theory as a TOE. To demonstrate the physical relevance of string theory it would suffice to show that there is one solution which looks like our universe; but whereas the number of solutions has been estimated, nobody has an idea how to arrange such a search. How can one find something in a haystack if one does not even know how to characterize our universe in terms of moduli and other string-theoretic notions which fix what string theorists call the vacuum?

In his vein one could even propose the idea that all possible QFT models taken together form a unique TOE called the TOE of local quantum physics. In this case the underlying principles (Poincaré covariance, causal locality and positive energy) are even known. By this semantic trick we can claim that we have been dealing with a TOE for almost one century without having been fully aware of it.

To be fair, the anthropic dogma of a multiverse instead of a universe i.e. the belief that all these different solutions with quantum matter obeying different laws (including different values of fundamental constants) exist and form "the landscape" is not shared by all string theorists.

Although such a picture is still confined to a vocal and politically unfluent minority in particle theory, it is not difficult to notice a general trend of moving away from the traditional scientific setting based on autonomous physical principles towards more free-wheeling metaphoric consistency arguments. It seems that as some physicists are moving away from religion, theology takes its payback by the increase of metaphoric physical arguments. Ironically the new aggressive science-based atheists are strong defenders of the metaphors about the string-inspired multiverse.

The ascend of this metaphoric approach is strongly supported by the increasing popularity of string theory and the marketing skill of its proponents to secure a lavish funding. This, and certainly not the extremely meager physical results, is what at least partially accounts for its present hegemony status in particle theory. Whereas the attraction it exerts on newcomers in physics is

\[\textsuperscript{1}\text{This is in fact the point of view in [2] where an even more extreme concept of physical reality is proposed which consists in claiming mathematically consistent theory attains a physical reality in at least one universe of the multiverse.}\]
often its career-accelerating quality, the broader scientifically interested public finds the media hype, which highlights its "revolutionary" achievements highly entertaining. There are also more general sociological reasons which even in the absence of a TOE quality aggravate scientific progress, some of them will be mentioned in the last two sections.

Parallel to this development, the particle physics community experienced a deepening frustration as a result of inconclusive or failed attempts to make further progress with the standard model. This model has remained particle physics finest achievement ever since its discovery more than three decades ago. It continued the line of moving towards unification which started already with Faraday, Maxwell, Einstein Heisenberg and others. This kind of unification has been the result of a natural process of the development of ideas, i.e. the protagonists did not set out with the aim to construct a TOE, rather the unification was the end result of a natural unfolding of ideas following the intrinsic theoretical logic but with observations and experiments having the ultimate power to decide whether a mathematically consistent theory is also realized in nature. The relation of this old-fashioned unification to the modern TOE is not unlike that of the old style capitalism to its unleashed globalized counterpart. Whereas the old version still showed social responsibility, the new one is mainly about hegemony i.e. power and glory. There and here ethical erosions have left their mark.

A previous IJMPD-invited version of this article was stopped at proofreading. One reason is that I got disenchanted with my style of criticism which often was as metaphoric as the subject which it aimed to criticize. As a result the present version became more mathematical and conceptual. I also was able to enrich the historical part with additional facts. Additional more specific and personal reasons will be explained in the last section.

The detailed mathematical content of my critique of string theory is very different from that of high energy experimentalists as Burton Richter who among other things calls supersymmetry a "social construct". It is also different from that of condensed matter theoreticians as Phillip Anderson and Robert Laughlin who use their rich professional experience in their own very successful area in order to criticize string theory on its total lack of observable predictions and its almost new age like metaphoric way of arguing. Although I agree with their conclusions I will not repeat their arguments in this essay.

I think a particle theoretician should take his criticism right into the conceptual-mathematical core. Instead of "not even wrong" (which has a metaphorical connotation) one should aim for even wrong. The strongest concrete anti-string argument is that string theorists understanding of string-localization (which led to the name) is really a complete misunderstanding. This will be the main theme in section 4.

Of course a scientific critique cannot answer the question why so many people permit themselves to be led by a TOE into a profound conceptual glitch. This will be left to sociologists and historians of physics who, as a result of the magnitude of the problem, will certainly attract a very interested public who will be eager to understand what happened to the millennium TOE.
Particle physics is a conceptually and mathematically quite demanding science and its progress depends on the one hand on a "into the blue yonder" spirit, but on the other hand, in order to go not astray, it needs the delicate balance with a cutting criticism whose intellectual depth at least matches that of its object. To some extent this is a pure inner theoretical process in which the main issue is that of conceptual consistency. Particle theory is very rich in established fundamental principles and it also has a very strong time-hardened intrinsic logic. Experiments cannot decide whether a theoretical proposal is consistent in its own right, but they can support or reject a theory or select between several consistent theories.

My main thesis is that the conceptual error in string theory occurred right at the beginning i.e. at the time when the dual model passed into string theory. Two previous attempts at a pure S-matrix theory, Heisenberg’s 1943 proposal and the Chew-Mandelstam-Stapp bootstrap idea of the 60s were too vague in order to pinpoint any glitch within them. The dual model/string theory on the other hand replaced the important crossing property by something which is ostensibly formally related, namely the Veneziano-Dolen-Horn-Schmid duality, but whose conceptual status remained unknown. Nevertheless, apart from unitarity, the DHS dual resonance model was much more concrete than any previous S-matrix proposal.

At the time of its inception the dual resonance model was considered as a curiosity by quantum field theorists because despite its roots in Regge phenomenology it was surprisingly precise and explicit and it represented at least some desirable and rather intricate properties of the S-matrix.

The conceptually somewhat opaque relation of infinite particle towers (required by the DHS duality) to the field theoretic crossing\(^2\) of its S-matrix bootstrap predecessor, would have served as an ideal starting point for a systematic investigation of the relation of crossing to QFT as well as crossing to DHS duality. Such a line of research would have possible led to a better understanding of the spacetime origin of DHS duality and a better conceptual positioning of the Nambu-Goto model and string theory.

The rather short interim between the (at that time still fameless) dual model and the later glorious string theory could have served a window for criticism of string theory with a good chance to be listened to, since there were yet no big fan-club which usually blur the critical vision. But probably lack of physical motivation and mathematical attraction for those particle physicists who had the capabilities to investigate such hard conceptional/mathematical problems contributed to this missed opportunity. In those days string theory was not yet that strong protective bulwark for a large community hardened by several revolutions.

The present view of string theorists at their own history is reflected in the several recent 40 year anniversary contributions, some from veterans of the dual model days. They make quite interesting historical reading; but whoever looks

\(^2\)Crossing is one of the most subtle analytic properties of an S-matrix coming from QFT. It relates (a finite number of) particle poles with the scattering continuum. More can be found in section 4.
for critical comments on the strange contradiction between physical misery and social glamour of string theory will be disappointed; even after 40 years the time for a critical evaluation has not yet arrived.

In line with our viewpoint that every speculative idea in particle physics is welcome as long as the balancing critical counterpart is in place, there is no intention to blame persons for ideas which later led to dominating fashions which not only did not live up to their promises but also contaminated particle theory with metaphoric arguments. It is not the protagonists of such ideas but rather our failure to subject them to profound conceptual scrutiny at the right time which derails particle physics.

In the case at hand there was no critical review; not because people in the 70s we are less intelligent than their predecessors, but rather because the TOE based on superstrings dominated the particle physics scene quite rapidly and the leading established and dominating figures, who in earlier times would have taken a critical look at new ideas, became the strongest defenders of a new TOE (presumably as a result of its promise to include quantum gravity). In this way a problem which started in particle physics finally led to the idea of a TOE and became part of the millennium Zeitgeist of power and glory, weakening the conceptual basis of the traditional particle physics approach and pushing it finally into the sidelines.

I have no problem to admire people as Gabrielle Veneziano and the other protagonists of the dual model, even if on the other hand I am convinced that string theory is the first mayor derailment in particle physics. I hope this makes it possible for string theorists to look also at the present scientific criticism with a certain emotional detachment and rational attention.

This intention to go to the conceptual roots also separates the content of the present reworked presentation from its previous version, as well as from the various string-critical books, articles and published statements by particle physicists, philosophers and condensed matter physicists as P. Woit [3], L. Smolin [4] and R. Hedrich [5]. In those articles the consistency of its conceptual-mathematical framework was not the issue; their content is not directed to test the mathematical-conceptual consistency of string theory but their main concern is the lack of tangible results despite of more than four decades of work by hundreds of brilliant minds and, particularly in case of Lee Smolin, the resulting futile consummation of valuable resources. The critical comments of philosophical adversaries of string theory tend to be directed towards its metaphorical anti-Popperian way and its rupture with Heisenberg’s principle of limiting arguments to observables which he and his contemporaries recognized to be absolutely crucial in order to avoid classical arguments contaminating quantum theoretical arguments.

What is somewhat surprising is the conspicuous absence of any profound critique coming from particle theorists, especially from mathematical physicists. A theory with no predictive power could still be consistent, but if it comes with

\[3\] There remains the question however why a permanent member of the Perimeter Institute does not use his influence to create a space for critical discussions about what string theory really is, as opposed to what its supporters think it is.
has a permanent conceptual flaw it should be dismissed; in that case there is nothing which can be learned, even if by luck or coincidence, it "explains" some facts.\(^4\)

The content is structured as follows.

The next section reviews Heisenberg's S-matrix proposal and Stueckelberg's profound criticism on the basis of its macro-causality defects (which led him to the discovery of Feynman rules several years before Feynman). The third section recalls the S-matrix bootstrap program whose lasting merit consists in having added the important on-shell crossing symmetry to the requirements of an S-matrix program. The fourth section analyses the origin of on-shell crossing from off-shell localization concepts and comments on its proximity to the KMS thermal aspect of localization. Section 5 reviews the implementation of duality of the DHS dual resonance model in the setting of charge superselection property of a multi-charge chiral current model with is intrinsic to chiral conformal theories. In this way the differences between duality resulting from the plektonic commutation relations of charge-carrying chiral fields and the particle-based notion of crossing becomes highlighted. The previous results on quantum localization obtained in the fourth section are then used in section 6 to show that string theory contrary to its claims does not deal with string-localized objects in spacetime; its simplest (interaction-free) realization looses its classical string-like appearance under canonical quantization and its associated string fields is pointlike localized but with many more degrees of freedom than those coming from a field theoretic Lagrangian; technically speaking it is a generalized free field with an infinite mass and spin spectrum.

The last two sections attempt to shed some light on how it is possible that a theory with so many conceptual shortcomings and glitches (extending right up to the quantum physical meaning of its name) is selected by a worldwide community of particle physicists to represent the power and glory of the millennium particle physics. So in those sections we leave the ivory tower of particle physics and turn to the millennium Zeitgeist.

Since the mathematical-conceptual content is quite demanding, some statements and arguments will appear more than once in a different formulation and context. It is hoped that using this essay style of shedding light on one aspect from slightly different angles will make the main arguments more accessible.

2 QFT versus a pure S-matrix approach from a historical perspective

Particle physics was, apart from a 10 year period of doubts and confusion around the ultraviolet catastrophe starting in the late 30s, a continuous success story starting from its inception \(^6\) by Pascual Jordan (quantization of wave fields

\(^4\)The reason why the phlogiston theory was able to hold on for some times was that its predictions actually agreed with several observed facts up to Lavoisier’s crucial experiment which brought its demise.
for light and matter) and Paul Dirac (relativistic particles and anti-particles via hole theory) up to the discovery of the standard model. For about 40 years the original setting of Lagrangian quantization, in terms of which QFT was discovered, gave an ever increasing wealth of results without requiring any change of the underlying principles, apart from some conceptual and mathematical refinements in order to adjust the formalism of QT to causal propagation with the velocity of light as the limiting velocity. After the clouds of doubts about the ultraviolet catastrophe dissolved, thanks to the new setting of covariantly formulated perturbative renormalization theory, the conceptional and mathematical improvements reinforced the original principles.

It is interesting to observe that already at the beginning of QFT even its protagonist Pascual Jordan worried about the range of validity of quantization. These doubts originated from his conviction that, although classical analogies allow in many cases rapid access to the new quantum theory of fields in form of important illustrations, in the long run a more fundamental quantum theory should not need the parallelism to the less fundamental classical Lagrangian formalism referred to as quantization, but rather develop its intrinsic arsenal of classification and construction of QFTs, or in his words "without borrowing crutches" from the less fundamental classical theory \[17\]. To turn the argument around: to the extend to which one has to rely on quantization crutches, one has not really reached the core of the new theory.

Jordan’s doubts about the range of validity of that umbilical cord to classical field theory did not originate from any perceived concrete shortcoming of his "quantum theory of wave fields". Rather the state of affairs in which he discovered this new theory did not comply with his philosophical senses; in his opinion this can only be tolerated as a temporary device for a quick first exploration of those parts of the new theory which are in the range of this quantization recipe.

But things did not develop in the direction of Jordan’s plea. The ultraviolet divergence crisis of the 30s ended in the late 40s in the discovery of renormalized QED, a fact which certainly revitalized the Lagrangian approach and pushed the search for an intrinsic formulation into the sideline.

Unfortunately the renormalized perturbation series of quantum field theoretical models diverges, so the hope to settle also the existence problem of QFTs in the Lagrangian quantization setting did not materialize; the success of the renormalized perturbative setting did not lead to a conceptual closure of QFT. However at least it became clear that the old problem of ultraviolet infinities, which almost derailed the development of QFT, was in part a pseudo-problem caused by the unreflective use of quantum mechanical operator techniques for pointlike quantum fields which are too singular to qualify as operators.

Using more adequate mathematical tools in conjunction with a minimality principle which limits the short distance singularity of the undetermined total diagonal contribution in terms of the scaling degree of the uniquely determined non-diagonal part \[8\], one finds that there are local couplings between pointlike fields for which the perturbative iteration either does not require more parameters than there were in the beginning, or adds only a finite number of new couplings which one could have already included in the starting interaction ex-
pressed in terms of Wick-product of free fields. The renormalized theory forms a finite parameter space on which the (Petermann-Stueckelberg) renormalization group acts ergodically. These finite parametric families are conveniently pictured as "islands" in an infinite parameter setting (the Bogoliubov spacetime dependent operator-valued S-functional or the Wilson universal renormalization group setting) within the "sea" of infinitely many coupling functions (which by itself has no predictive power). Since the renormalization group leads from any point on the island in coupling space to any other such point, a QFT cannot provide a method to distinguish special numerical values.

The phenomenon of interaction-caused infinite vacuum polarization clouds (finite in every order perturbation theory) gives rise to a conceptual rupture with QM and leads to a change of parameters in every order. But since these parameters remain undetermined anyhow, this causes no harm. The inexorable presence of interaction-induced vacuum polarization simply prevent one to think of an initial numerical (Lagrangian) value for these parameters which is then changed by a computable finite amount. With other words unlike in QM there is no separable "bare" and "induced" part which only lead to finite values by compensation between them. This is why the Epstein-Glaser renormalization is conceptually preferable. It not only addresses the singular nature of fields but it also exposes the limits of QFT concerning the predictive power about the numerical value of certain parameters in a more honest way.

So when string theorists say that their theory is ultraviolet finite whereas QFT is not, what they really mean in intrinsic terms is their theory is more economical (and hence more fundamental) in that it has only the parameters which describe string interactions i.e. the string tension. But beware, they say that without being able to give a proof.

This implies that in particular that string theory has no vacuum polarization which is of course completely consistent with its on-shell S-matrix character. An S-matrix is the object par excellence without vacuum polarization; in fact Heisenberg’s plea for basing particle physics on the S-matrix was proposed because the S-matrix in contrast to quantum fields is like QM completely free of vacuum polarization and the ensuing apparent ultraviolet problems. But can one really do particle physics without such a central concept as vacuum polarization? By what conceptual trick can an S-matrix theory emulate vacuum polarization? Is the idea of a natural off-shell extrapolation without the guidance of QFT self-deception? Is there really any other way then constructing an S-matrix as the large-time limit of some quantum theory with some spacetime aspects?

Before starting to criticize string theory, one should however look for imperfections in one’s own backyard which in my case means exposing some weak points of QFT.

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5I am referring here to the Epstein Glaser formulation which produces the renormalized finite result directly by treating the fields in every order according correctly according to their singular nature. The avoidance of intermediate cutoffs or regularizations maintains the connection with the quantum theoretical Hilbert space structure of QFT.
The power counting restriction to \( \dim \mathcal{L}_{\text{int}} = d \) (spacetime dimension)\(^6\) is quite severe because for \( d = 4 \) it only allows (without using "ghost crutches") pointlike fields \( \Phi \) with \( \dim \Phi < 1 \). In addition massless vectorpotentials (and more generally the potentials associated with the Wigner massless finite helicity representations) cannot be pointlike covariant objects within a (ghost-free) Wigner Fock representation; the best one can do is to describe them by semi-infinite stringlike-localized fields \( A_\mu(x,e) \) with the spacelike unit vector \( e \) being the string direction (no relation of string localization to string theory, as will become clear in later sections). These massless string potentials exists for all higher helicities and as a result of their non-compact localization they all have scale equal to one which makes them ideal candidates for fulfilling the renormalizability criterion in trilinear and quadrilinear interactions. This is not a technical side remark but the result of the fundamental quantum requirement that the generalized potentials associated to the massless generalized field strengths\(^7\) ought to be objects in physical space.

The requirement of finding pointlike localized composite fields imposes a severe restriction on the interactions which turn out to be equivalent to the gauge invariance in a gauge theoretic formulation using ghosts. The basic generating fields are stringlike localized but these fields have composites which are usual pointlike fields.

As mentioned in case of massive higher spin fields the string localization has the same short distance improving effect even though there is no argument necessitating stringlike localized potential for the description of the Wigner representation space which can be perfectly described in terms of pointlike field strengths. For the time being the requirement to be able to formulate renormalizable interactions is the only one but there is also a rather subtle indication of their presence in the free theory via the violation of Haag duality for multiply connected causally closed spacetime regions \(^{10}\). The relation between the stringlocalized potential and the pointlocalized field strengths changes drastically in the presence of selfinteracting potentials.

A perturbation approach for stringlike localized representation of free fields has not yet been formulated. Instead one evades the No-Go theorem from Wigner’s representation theoretical approach by maintaining pointlike covariant localization and instead sacrificing the Hilbert space setting through the introduction of (BRST) ghost fields. This gauge field formalism makes helpful contact with classical gauge theory (where the Hilbert space aspect plays no role) and permits the use of the well-known pointlike renormalization machinery whose perturbative version does not care about indefinite metric. A consistent descend to the physical representation in a ghost-free Hilbert space

\(^{6}\)The \( \mathcal{L}_{\text{int}} \) is only a name for the interaction in terms of free fields. The causal perturbative approach (in contrast to the functional integral setting) does not use the Lagrangian formalism but only this local interaction term whereas e.g. the functional integral approach is limited to free fields which are of the Euler-Lagrange type.

\(^{7}\)For \( s+2 \) the field strength is the (linearized) Riemann tensor and the potential is a string-localized linearized metric tensor \( g_{\mu\nu}(x,e) \) localized along the line \( x+R\mu e \) (see section 4). The string localization comes from quantum requirements and has no counterpart in the classical theory.
is guarantied by the cohomological properties of the BRST ghost formalism. There are however conceptual limitations of this formalism (in particular with respect to the Higgs issue) which will be mentioned in a later section.

This short account of the history of QFT and particle physics contains most of the ideas which are needed for the formulation of the standard model which places QED, the weak interaction and the QCD setting of strong interactions under one common gauge theoretic roof. But it also was meant to expose the gaping unfinished areas of QFT. Anybody who claims that QFT is a closed subject and that its innovative role has passed to string theory does not know what he is talking about. The unification which led to the standard model is natural i.e. the desire to obtain a TOE was not the motivation. Whether the running coupling constants of the three interactions really come together at a sufficiently high energy and whether gravitation can be incorporated remain open questions outside the standard model.

One of the marvelous achievements of the post QED renormalization theory is a clear understanding of the particle-field relation (not to be confused with the particle-wave dualism in QM) in the presence of interactions. Whereas in free field theories Heisenberg observed the presence of vacuum fluctuations due to particle-anti-particle pairs in states obtained by the application of (Wick) composites to the vacuum, the real surprise came when Furry and Oppenheimer discovered that in interacting theories even the Lagrangian field generates vacuum polarization upon application to the vacuum state. Different from the case studied by Heisenberg, the interaction-caused pairs increase in number with the perturbative order and form a vacuum polarization cloud containing an infinite number of virtual particles. This observation challenges the naive identification of particles and fields which is the result of a simple-minded conceptual identification of QFT as a kind of relativistic QM. Although one-particle states exist in the Hilbert space and the global operator algebra certainly contains particle creation/annihilation operators, \textit{compactly localized subalgebras}\footnote{The only localization which allows PFGs is the non-compact wedge-like localization \cite{11}.} in interacting QFTs contain no vacuum-polarization-free generator (PFGs) i.e. no operator which creates a one-particle state from the vacuum without contamination from vacuum polarization.

The particle field relation was partially unveiled when in the post QED renormalization period it became clear that apart from one-particle states \textit{QFT is not capable to describe interacting particles at a finite time}; as a result of the ubiquitous presence of vacuum polarization clouds it is only possible to have an asymptotic description when, barring long range forces and infrared problems, the localization centers of particle are far removed from each other so that the interaction does not matter. In fact the elaboration of scattering theory as a structural consequence of causal locality, energy-momentum positivity and the presence of a mass gap in the late 50s and early 60s was one of the finest conceptual achievements of particle theory.

As mentioned in the previous section, the idea of a pure S-matrix theory as a remedy against the ultraviolet catastrophe of the old (pre-renormalization)
QFT was first proposed by Heisenberg\(^9\). The S-matrix models with which he illustrates his paper resulted from a naive unitarization of the interaction Lagrangian (see next section). Heisenberg’s proposal was immediately criticized by Stueckelberg who pointed out that, although it was Poincaré-invariant and unitary, it did not meet the requirements of macro-causality (see next section).

In the next section we will use Heisenberg’s construction and isolate the problem on which every pure S-matrix theory failed: fitting together unitarity and Poincaré covariance with macrocausality (notably the cluster factorization property). Clustering is the spacelike aspect of macro-causality which is indispensable for any S-matrix whether its comes from QFT or any other theory of interacting particles. In QFT and other off-shell implementations of particle interactions, the clustering property is implemented on correlation functions or (similar to nonrelativistic QM) through asymptotic additivity of the interaction-dependent generators of the Poincaré group. Its validity for the asymptotic configurations is then a side result of the proof of asymptotic convergence. With other words, the highly nonlinear on-shell unitarity requirement is trivialized by showing that it results from the large time limiting of more easily implementable linear additive clustering properties for correlation functions.

A long time after the Heisenberg proposal went into oblivion and QFT experienced a strong return in the form of renormalized quantum electrodynamic, ideas about the S-matrix returned again, this time as the result of the uselessness of perturbative arguments in strong interactions between mesons and nucleons. They led to the S-matrix bootstrap by Chew and Mandelstam with some ideological backing by Stapp. There was also a popular version intermingled with Buddhism by F. Capra which was aimed at the (in those years very strong) world-wide Hippy community.

The analytic aspects of QFT correlations, which follow from locality and spectral properties, imply an attribute which was first seen in Feynman diagrams within a fixed perturbative order. Restricting the external legs of these graphs to the mass-shell in order to obtain perturbative contribution to the S-matrix, one could show that the different S-matrix elements belonging to different distributions of n-particles into \( k \) incoming and \( l \) outgoing particles are connected by an analytic continuation. The surprising aspect (which was not trivial even with Feynman graphs) was that this was possible without leaving the complexified mass shell. With other words crossing is not a symmetry but rather an analytic on-shell mark left by the spacelike commutativity of QFT. Although there is no general proof of crossing for generic particle configuration, most particle physicists would agree that highlighting this property will remain as one of the few legacies of that bootstrap period.

The bootstrap community never exhibited a model in which this new property is nonperturbatively realized, in fact the concept of a model hardly makes sense in the bootstrap setting of a TOE, it is either everything or nothing. On

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\(^9\)The concept of a unitary scattering operator as a mapping incoming multiparticle configurations into outgoing in the limit of infinite timelike separations was introduced independently by Wheeler and Heisenberg. However the idea of a pure S-matrix theory as an antidote against the pre-renormalization pretended ultraviolet catastrophe is attributed to Heisenberg.
the other hand, as in Heisenberg’s first approach, macro-causality and in particular the cluster factorization of $S$ was not even mentioned; one can safely assume that after its importance was pointed out in the work of Stueckelberg (shortly after Heisenberg) it was again forgotten.

There exists an exceptional situation in $d=1+1$ which is related to the kinematical equality of the energy-momentum delta function with the product of two one-particle delta functions. This has the effect that the cluster property cannot separate the 2-particle interacting contribution from the identity term of $S$. In this case it is possible to classify pure 2-particle elastic $S$-matrices and represent the n-particle amplitude in terms of the two-particle amplitude through a combinatorial formula [30] which is compatible with the $d=1+1$ cluster decomposition. Purely elastic relativistic scattering in higher spacetime dimension is only possible in the relativistic quantum mechanics of direct particle interactions [16] but not in QFT.

3 Unitarity and macro-causality in relativistic particle theories

There are three fundamental requirements which every $S$-matrix of relativistic particle physics must obey (and there is no dispense for string theory which claims to be as an $S$-matrix theory of relativistic particles) namely: Poincaré invariance, unitarity and macro-causality. None of these concepts requires to introduce fields; macrocausality is a very weak version of causality which can be formulated and understood in terms of only particle concepts. To avoid misunderstandings, there are analytic properties of scattering amplitudes as, e.g. the crossing property, for which the necessary analytic continuation takes place inside the complex mass shell; but such on-shell properties cannot be traced back to principles referring to particles only. Rather they must be understood as being an on-shell imprint of the causal locality principles of an underlying local quantum physics i.e. the on-shell particle objects are only the projection screen for analytic manifestations which originate from off-shell causal locality properties.

As a pedagogical exercise which leads us right into the problematic aspects of pure $S$-matrix theories let us revisit the situation at the time when Stueckelberg criticized Heisenberg’s $S$-matrix proposal.

As a way out of the ultraviolet catastrophe, Heisenberg suggested that avoiding local excitations of the vacuum (caused by interacting theories with a maximal velocity) by sidestepping Lagrangian quantization and the ensuing pointlike localized singular fields in favor of an $S$-matrix Ansatz could solve the ultraviolet problem. His rather concrete proposals consisted in expressing the unitary $S$-matrix in terms of a Hermitian phase operator $\eta$. In modern notation his proposal reads
\( S = \exp i \eta \quad (1) \)

\[ \eta = \sum_{n=1}^1 \int \ldots \int \eta(x_1, \ldots x_n) : A_{in}(x_1) \ldots A_{in}(x_n) : dx_1 \ldots dx_n \]

\[ \eta_{Hei} = g \int : A_4^1(x) : d^4x \]

where the on-shell coefficient functions of \( \eta \) are chosen to be Poincaré invariant and subject to further physically motivated restrictions. In fact one such restriction which he suggested was that the on-shell \( \eta \) should be close to a Lagrangian interaction i.e. have local coefficient functions as illustrated in the third line. It is customary to split off the identity operator from \( S \) and formulate unitarity in terms of a quadratic relation for the T-operator

\[ S = 1 + iT \quad (2) \]

\[ iT - iT^* = TT^* \]

In this form the unitarity is close to the optical theorem and convenient for perturbative checks.

Unitarity and Poincaré invariance are evidently satisfied if the (possibly singular) functions \( \eta(x_1, \ldots x_n) \) are Poincaré invariant, but what about macrocausality? For spacelike separation one must require the so called cluster factorization property. If there are \( n+m \) particles involved in the scattering (the sum of incoming and outgoing particles) and one forms \( k \) clusters (again containing in and out) and then separates these clusters by large spacelike translations, the S-matrix must factorize into the product of \( k \) smaller cluster S-matrices referring each describing the scattering associated with a cluster. For the simplest case of two clusters

\[ \lim_{a \to \infty} \langle g_1, \ldots g_m | S | f_1, \ldots, f_n \rangle = \langle g_1, \ldots | S | f_1, \ldots \rangle \langle \ldots g_m | S | \ldots f_n \rangle \quad (3) \]

where the first factor contains all the \( a \)-translated wave packets i.e. the particles in the first cluster and the second factor contains the remaining wave packets. In massive theories the cluster factorization is rapidly attained. This asymptotic factorization property is usually written in momentum space as

\[ \langle q_1, \ldots q_m | S | p_1, \ldots p_n \rangle = \delta - \text{contribution} + \text{products of lower delta contributions} \quad (4) \]

i.e. the S-matrix contains besides the connected contribution the disconnected parts which consists of products of connected amplitudes referring to processes with a lesser number of particles. The connected parts have the correct smoothness properties as to make the formulas meaningful.

For timelike separated clusters the fall-off properties for large cluster separations are much weaker. In fact there are inverse power law corrections in the asymptotic timelike cluster distance. With the correct \( i \varepsilon \) prescription (the same as Feynman’s, but here only in the large timelike asymptotic limit) they
define what is referred to as causal re-scattering or the causal one-particle structure; The correct singularity structure prevents the use of QT to construct time machines\textsuperscript{10}.

For explanatory purpose of causal re-scattering imagine a kinematical situation where the third particle enters the future cone of an interaction region of particle 1 and 2 a long time after the 1-2 interaction happened, and then scatters with the outgoing first particle leaving particle 2 undisturbed. In the limit of infinite timelike separation the connecting line of 1 and 3 i.e. which describes the trajectory after 1 leaves the first process and moves to the scattering region with 3, the 1-3 intermediate propagator must coalesce with a causal propagator. i.e. asymptotically this must be the Feynman propagator which is the only one-particle propagator consistent with the causal structure of the re-scattering.

Whereas the cluster factorization of a Heisenberg Ansatz is obeyed by only imposing the connectedness property on the \( \eta \) coefficient functions, it is not possible to satisfy the causal one-particle structure with a finite number of terms in \( \eta \); in fact no pure S-matrix scheme has ever been devised which secures the validity of the causal one-particle structure in the presence of unitarity.

At this point the weakness of a pure S-matrix approach as advocated by Heisenberg becomes exposed since there are certain properties which one can formulate for the matrixelements of S but the non-linearity of the unitarity requirements prevent their on-shell implementation "by hand". It is off-shell QFT and its asymptotic timelike convergence, better known as scattering theory, which saves us for spending the rest of our days with S-matrix tinkering. The QFT correlation functions are the natural arena for implementing causality properties; the observables are Hermitian and not unitary and the building up of S-matrix unitarity is part of the asymptotic convergence whose existence is guarantied by the properties of the correlations.

This problem of causal re-scattering in a Heisenberg S-matrix setting, and more generally in any pure S-matrix formulation, was what finally convinced Stueckelberg \[14\] that a pure S-matrix approach is not feasible.

The S-matrix is without doubt the most important observable concept in particle physics, but it should remain the "crown" of the theory and not its foundation nor its principal computational tool. This was at least the gist of Stueckelberg’s critique on Heisenberg’s program when he pointed out that to reconcile macro-causality with unitarity "by hand" (i.e. without a an off-shell setting which naturally unites these seemingly ill-fitting on-shell concepts) one runs into insoluble problems.

Interestingly enough Stueckelberg then combined his idea of the causal one particle structure with postulating pointlike interaction vertices and in this way came to Feynman rules several years before Feynman. For showing that this prescription leads to on-shell unitarity, he lacked the elegance of the formalism of QFT in which the on-shell unitarity (and all the other properties of S) is

\textsuperscript{10}A model which was later shown\textsuperscript{13} to lead to timelike precursors (as the result of the presence of complex poles) was the Lee-Wick model.
derived from simpler properties of correlation functions.

A systematic step for step derivation from a covariant Tomonaga setting of QFT, including the Schwinger or Feynman formalism of renormalization, and with particular care concerning the perturbative connection between QFT and the S-matrix, was given by Dyson. It was also Dyson who raised the first doubts about the convergence of the renormalized perturbative series.

The conceptually opaque status of perturbation theory lend importance to a purely structural derivations of particles properties and scattering data directly from the quantum field theoretic principles. Without having mathematically controllable models at one's disposal, structural arguments became increasingly important. Since despite all the difficulties to construct interacting models there was no problem to define in mathematical clear terms what are the requirements which are characteristic for QFT, the proof of the existence of an S-matrix including all its properties (e.g. dispersion theory, high energy bounds,..) from those well formulated requirements of QFT was a quite pragmatic endeavour, even though it was often referred to as "axiomatic". At least the original motivation for engaging in axiomatic QFT was driven by the pragmatic desire to go beyond divergent perturbative series. One of the high points of that research was the derivation of Kramers-Kronig type of dispersion relation and their experimental verification which strengthened the case for locality of interactions up to the present.

All this was achieved less than a decade after Stueckelberg's criticism of a pure S-matrix approach and the discovery of renormalized perturbation theory by Tomonaga, Schwinger, Feynman and Dyson and forms the backbone of the LSZ and Haag-Ruelle scattering theory.

As indicated above, the basic simplification of the problem of macro-causality for the S-matrix consisted in the realization that its representation as the large time scattering limit defuses the rather intractable nonlinear problem of implementing macro-causality in the presence of unitarity by delegating it to simpler linear (off-shell) properties for correlation functions. The problem with the nonlinear unitarity condition is that in such a two step process delegated to the linear problem of demonstrating the existence of an isomorphism between two in and out free fields and the macro-causality of the S-matrix follows from the on-shell preservation of certain properties being related to off-shell micro-causality and spectral properties (energy positivity). The connection between off-shell local quantum physics and the on-shell S-matrix also shows the futility to invert this connection via scattering theory by hand (this does not prevent string theorists to contemplate such off-shell extrapolations). An S-matrix fulfilling the crossing property can however be shown to admit only one inverse scattering solution if one assumes that the formfactors of the local quantum theory are also bound together by crossing. Unfortunately such uniqueness arguments have, apart from the family of two-dimensional factorizing models, not led to

\footnote{Such inverse scattering problems show very clearly the conceptual advantage of formulating QFT in terms of spacetime-indexed nets of algebras rather than in terms of pointlike field coordinatizations of the Lagrangian quantization. The crossing symmetric S-matrix is not capable to highlight individual field coordinatizations, it only fixes the local net.}
concrete constructions.

There is another particle physics setting for which a Poincaré invariant unitary macro-causal S-matrix arises through scattering theory in the large time asymptotic limit: Direct Particle Interaction (DPI). It forgoes micro-causality and fields and only retains Poincaré covariance and macro-causality. It is certainly more phenomenological than QFT since it contains interaction functions instead of coupling strength.

The reason why it is mentioned here (even though we are not advocating its use outside medium energy pion-nucleon physics) is because its very existence not only removes some prejudices and incorrect folklore (including the belief that relativistic particle interactions are necessarily QFTs or that a clustering S-matrix matrix can only arise from a QFT setting), but it also indicates what has to be added/changed in order to arrive from particle interactions to a full QFT setting. In other words it exposes some of the nuts and bolts behind the field theoretic elegance.

Relativistic QM of particles is based on the Born-Newton-Wigner localization, whereas the causal localization of QFT, which incorporated the finiteness of the propagation speed, is related to the Poincaré representation theory via modular theory (next section). The B-N-W localization of wave packets is sufficient for recovering the forward lightcone restriction for 4-momenta associated with events which are separated by large distances. Although this suffices to obtain a Poincaré invariant macro-causal S-matrix, it prevents the existence of local observables and vacuum polarization. For a presentation of the differences and their profound consequences see [9].

This DPI scheme introduces interactions between particles within a multi-particle Wigner representation theoretical setting by generalizing the Bakamjian-Thomas two-particle interacting Poincaré generators [16]. But whereas in the nonrelativistic QM the additivity of the interaction potentials trivializes the problem of cluster factorization, there is now no such easy connection between the modification of the n-particle Poincaré generators and the nature of the interactions. Nevertheless, by using the notion of scattering equivalences one can arrive at a cluster factorization formula for the interacting Poincaré generators and the Moeller operators and hence also the S-matrix [16][9]. A scattering equivalence consists in a unitary transformation which changes the representation of the Poincaré generators but maintains the S-matrix. In the Coester-Polyzou DPI scheme the iteratively defined (according to particle number n) interacting Poincaré generators lack the large distance additivity associated with clustering and a scattering equivalence transformation carried out for each n rectifies this situation.

It is interesting to note that the use of scattering equivalences is not the only difference to nonrelativistic QM; DPI theories also do not admit combining the different n’s into a second quantization Fock formalism. This last property is not independent of the necessity to use scattering equivalences in order to implement clustering.

One starts with a B-T two-particle interaction and compute the 2-particle Moeller operator and the associated S-matrix as a large time limit of propaga-

17
tion operators. As in the nonrelativistic case the two-particle cluster property is satisfied for short range two particle interactions. For 3 and more particles the construction of cluster factorizing Poincaré generators and S-matrices require the iterative application of scattering equivalences. The so constructed 3-particle S-matrix clusters with respect to the 2 particle S-matrix in the previous step and it also contains a 3-particle connected part which vanishes if any one of the particles is removed to spacelike infinity. It is interesting that the Poincaré generators as well as the S-matrix always contain a nontrivial connected part, i.e. in contrast to nonrelativistic scattering the occurrence of direct higher particle induced interactions cannot be prevented.

In the original formulation the scattering was purely elastic, but later it was shown that an extension with particle creation channels is possible. Hence the characteristic difference of DPI to QFT is not the presence of creation/annihilation channels but rather the inexorable presence of interaction-induced infinite vacuum polarization clouds in QFT.

As mentioned before such a scheme is purely phenomenological since the interactions are not given in terms of coupling constants but rather coupling functions [16].

An S-matrix with all the above properties fulfills the requirements of a conjecture by Weinberg [17]. But the S-matrix is not that of a QFT and does not even agree for low energies with that coming from a QFT. Nuclear physicists introduced this scheme precisely because quantum chromodynamics at those energies does not permit any nonperturbative treatment and they wanted to have a approximation scheme which is not completely phenomenological i.e. at least not at variance with those macro-causality principles which can be formulated for systems containing two nucleons in the presence of a small number of mesons at relativistic energies (which allow already for meson creation). In fact the DPI setting strictly is a S-matrix theory because off-shell there are no covariant objects as conserved currents unless one constructs them ”by hand” (i.e. they are not natural objects within the DPI formalism). Their introduction would require to go significantly beyond the DPI scheme. The same applies to the incorporation of particle creation which also has to be introduced by hand through the additional coupling of creation channels.

QFT and DPI are the only known settings for which an S-matrix with the above properties can be derived and which also have been reasonably well understood from a conceptual/mathematical viewpoint. For DPI the mathematical existence of models and their construction is handled in terms of well-known functional analysis concepts as in ordinary QM. In case of QFT this is much more difficult in view of the fact that the perturbative series is divergent and the sometimes provable Borel resummability does not by its own establish existence. Therefore it is deeply satisfying that its most intrinsic (field coordinatization-independent) formulation in terms of spacetime localized operator algebras has led to a nonperturbative existence proof and an explicit construction of form-factors and the S-matrix for the special family of interacting factorizable models. Hopefully this will be the beginning of a new nonperturbative understanding which at the end may turn out to be the realization of an intrinsic QFT without
quantization ”crutches”.

The main aim of this article is to put forward arguments showing that string theory is not what most people think it is and for what it received its name namely a theory of an infinite collection of particles (a particle tower) whose mass spectrum originates from a string which vibrates in spacetime. The idea that it generalizes the pointlike localized fields of QFT is a metaphor based on the mass spectrum which has no intrinsic meaning in the setting of quantum localization. Since localization is a notorious difficult issue which led to many misunderstandings, the discussion of localization of the objects of string theory requires careful preparation which will be the main theme of the next section.

Even in the simplest case of a free Nambu-Goto Lagrangian the facts contradict the picture of dealing with stringy objects in spacetime: the string fields associated with the N-G model is in fact pointlike localized. Its main difference to Lagrangian QFT is that the N-G string field behaves like a generalized free field which has many more degrees of freedom than a standard Lagrangian quantized field i.e. which accounts for the degrees of freedom in an infinite particle tower. So the classical string aspect of the N-G Lagrangian interpreted as a Lagrangian for a quantum field consists in producing a generalized free field, apart from one tachyon component. For the supersymmetric string which is free of tachyons one has to work with the graded commutator.

The failure of implementing genuine string localization casts serious doubts on the meaning of implementing interactions via the splitting and recombination string associated tubes. The latter method avoids the coupling of string fields (in analogy to the coupling of pointlike fields) which has not led to useful insight. Instead one replaces it by something which is formulated on the level ”first quantization”. An interaction for a finite number of strings is then implemented ”by hand” i.e. instead of doing this in a Lagrangian setting, one extracts analytic expressions from Euclidean tube pictures in analogy to the conversion of Feynman diagrams into the perturbative analytic contributions of QFT. There is of course a significant conceptual difference, whereas in the QFT setting these are recipes which can be rigorously derived within a well-defined conceptual framework, string theory leaves one empty handed, even after more than 4 decades of its existence.

In order to justify the tube picture as an analogy of particle physics string theorists create a fake world of functional integral representations of the quantum theory of the one-particle spaces. Nobody had ever done relativistic particle theory in such an obscure setting as that proposed by the string theorists as a pedagogical warm up to the functional treatment of string theory. It throws the crystal-clear and complete representation theoretical classification of Wigner into the conceptual mud of extracting infinite measure factors of the diffeomorphism group and similar ill-defined manipulations. This is a significant step behind Wigner’s representation theoretical construction which is totally intrinsic and does not dependent on artistry as extracting infinite gauge group factors not
to mention the completeness of Wigner’s approach. This analogy does not reveal anything about the locality of the ”tubism” of string theory. Even if one closes all eyes with respect to problems of localization, there remains the unsolved problem whether this recipe defines at all a unitary macro-causal S-matrix because in contrast to QFT there is no conceptual basis for why this should be expected.

Nevertheless the critique of string theory cannot be reduced to a simple mistake which can be explained on one page, it rather needs some preparation on the conceptual as well as on the historical side. This is the purpose of the next two sections.

4 On-shell crossing and thermal properties from causal localization

In order to attain a solid vantage point for a critique of string theory, it is necessary to recall the issue of localization which constitutes the basis for the formulation and interpretation of local quantum physics. The easiest access with the least amount of pre-knowledge is through the Wigner one-particle theory.

Wigner discovered [18] that irreducible positive energy ray representations of the Poincaré group come in 3 families: massive particles with half-integer spin, zero mass halfinteger helicity representations and zero mass ”infinite spin” representations. For brevity we will refer to the families using numbers 1,2,3. Whereas the first and the third family are rather large because their Casimir invariants have a continuous range [15], the finite helicity family has a countable cardinality labeled by the halfinteger helicities. All up to present in the laboratory observed particles are in the first two families. The fact that no objects have been observed which fit into the third family should not trick us into dismissing these positive energy representations since the nature of observed dark matter is still unknown [20]. Here the third kind objects mainly serve the purpose to explain what indecomposable string-like localization means.

The three families have quite different causal localization properties. Let us first look at the one with the best (sharpest) localization which is the representation family of massive particles. For pedagogical simplicity let us consider the Wigner representation of a scalar particle with the representation space

\[ H_{Wig} = \left\{ \psi(p) \left| \int \left| \psi(p) \right|^2 \frac{d^3p}{2p^0} < \infty \right\} \right. \] (5)

We now define a subspace which, as we will see later on, consists of wave function localized in a wedge. We take the standard \( t - x \) wedge \( W_0 = (x > |t|, x, y \)

\[ (u_{Wig}(a,\Lambda)\psi)(p) = e^{ipa}\psi(\Lambda^{-1}p) \]

\[13\]Whereas for the massive family this is the value of the mass operator, the continuous value in case of the infinite spin family is the Casimir eigenvalue of the faithfully represented Euclidean group \( E(2) \) (the little group of a lightlike vector).
arbitrary) and use the $t-x$ Lorentz boost $\Lambda_{x-t}(\chi) \equiv \Lambda_W(\chi)$

\[
\Lambda_W(\chi) : \begin{pmatrix} t \\ z \end{pmatrix} \rightarrow \begin{pmatrix} \cosh \chi & -\sinh \chi \\ -\sinh \chi & \cosh \chi \end{pmatrix} \begin{pmatrix} t \\ z \end{pmatrix}
\]  

(6)

which acts on $H_W$ as a unitary group of operators $u(\chi) \equiv u(0, \Lambda_{x-t}(\chi))$ and the $x-t$ reflection $j : (x,t) \rightarrow (-x,-t)$ which, since it involves time reflection, is implemented on Wigner wave functions by an anti-unitary operator $u(j)$. One then forms the unbounded “analytic continuation” in the rapidity $U_W(\chi \rightarrow -i\pi \chi)$ which leads to unbounded positive operators. Using a notation which harmonizes with that of the modular theory in mathematics [19], we define the following operators in $H_W$

\[
\delta^{it} = U_W(\chi = -2\pi t) \equiv e^{-2\pi iK} 
\]

\[
\mathcal{S} = j\delta^{\frac{1}{2}}, j) = U_W(j), \delta^{it} \mid_{t=-i} \n\]

\[
(\mathcal{S}\psi)(p) = \psi(-p) 
\]

Since the anti-unitary operator $j$ is bounded, the domain of $\mathcal{S}$ consists of all vectors which are in the domain of $\delta^{\frac{1}{2}}$. With other words the domain is completely determined in terms of Wigner representation theory of the connected part of the Poincaré group. In order to highlight the relation between the geometry of the Poincaré group and the causal notion of localization, it is helpful to introduce the real subspace of $H_W$ (the closure refers to closure with real scalar coefficients).

\[
\mathcal{R} = \{ \psi | \mathcal{S}\psi = \psi \} 
\]

\[
dom\mathcal{S} = \mathcal{R} + i\mathcal{R}, \mathcal{R} + i\mathcal{R} = H_W, \mathcal{R} \cap i\mathcal{R} = 0
\]

(8)

The reader who is not familiar with modular theory should notice that these modular concepts are somewhat unusual and very specific for the important physical concept of causal localization; despite their physical significance they have not entered the particle physics literature. One usually thinks that an unbounded anti-unitary involutive ($\mathcal{S}^2 = 1$ on $\dom\mathcal{S}$) operator which has two real eigenspace associated to the eigenvalues $\pm 1$ is an absurdity, but its ample existence is the essence of causal localization in QFT.

The second line (8) defines a property of an abstract real subspace which is called standardness and the existence of such a subspace is synonymous with the existence of an abstract $\mathcal{S}$ operator.

The important analytic characterization of modular wedge localization in the sense of pertaining to the dense subspace $\dom\mathcal{S}$ is the strip analyticity of the wave function in the momentum space rapidity $p = m(c\chi, p_\perp, s\chi)$. The requirement that such a wave function must be in the domain of the positive operator $\delta^{\frac{1}{2}}$ is equivalent to its analyticity in the strip $0 < \chi < i\pi$ and the

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14The unboundedness of the $\mathcal{S}$ involution is of crucial importance in the encoding of geometry into domain properties.
action of \( s \) relates the particle wave function on the lower boundary of the strip which is associated to the antiparticle wave function on the negative mass shell. This relation of particle to antiparticle wave functions is the conceptual germ from which the most fundamental properties of QFT, as crossing, existence of antiparticles, TCP theorem, spin-statistics connection and the thermal manifestation of localization originate. Apart from special cases this fully quantum localization concept cannot be reduced to supprt properties of classical test functions.

More precisely the modular localization structure of the Wigner representation theory "magically" preempts all these properties of a full QFT on the level of the Wigner representation theory; to be more specific: these one-particle properties imply the corresponding QFT properties via time-dependent scattering theory \[24\]. Hence any modification of any of those fundamental properties (e.g. crossing \( \rightarrow \) Veneziano duality) is changing the principles of local quantum physics on which are the result of more than half a century of successful particle physics and therefore needs very strong scrutiny.

The mentioned one-particle indication of a thermal manifestation follows directly from (7) by converting the dense set \( \text{dom} s \) via the graph norm of \( s \) into an Hilbert space in its own right \( H_G \subset H_{Wig} \)

\[
\langle \psi|1+\delta|\psi\rangle = \langle \psi|\psi\rangle_G
\]

\[
\langle \psi|\psi\rangle_{\text{dom} s} = \int \frac{d^3p}{2p_0} \frac{1}{1+e^{2\pi K}} |\psi_G(p)|^2, \psi_G \in H_G
\]

This formula represent the restriction of the norm to the strip analytic function in terms of Hilbert space vectors \( \psi_G \) which are free of analytic restrictions. The result is the formula for a one point expectation value in a thermal KMS state with respect to the Lorentz boost Hamiltonian \( K \) at temperature \( 2\pi \). As we will see in a moment, the modular relation (7) in the Wigner one-particle setting is the pre-stage for the crossing relation as well as an associated KMS property in an interacting QFT\[15\].

Before we get to that point we first need to generalize the above derivation to all positive energy representations and then explain how to get to the sub-wedge modular localization for compact regions. For the generalization to all positive energy representations we refer the reader to \[21\] \[10\], but since the sharpening of localization is very important for our critique of string theory in the next section, it is helpful to be somewhat explicit on this point.

In the first step one constructs the "net" of wedge-localized real subspaces \( \{\mathcal{R}_W\}_{W \in W} \). This follows from covariance applied to the reference space \( \mathcal{R}_W \). In the second step one aims at the definition of nets associated with tighter localization regions via the formation of spatial intersections

\[
\mathcal{R}(O) \equiv \bigcap_{W \supset O} \mathcal{R}_W \quad (10)
\]

\[15\] The thermal manifestation of localization is the strongest separation between QM and QFT \[9\].
Note that the causally complete nature of the region is preserved under these intersections in accordance with the causal propagation principle which attributes physical significance to the causal closures of regions (this is the reason for the appearance of noncompact or compact conic regions in local quantum physics). In this way localization properties have been defined in an intrinsic way i.e. separate from support properties of classical test functions.

The crucial question is how "tight" can one localize without running into the triviality property $\hat{\mathcal{R}}(\mathcal{O}) = 0$. The answer is quite surprising: For all positive energy representations one can go down from wedges to spacelike cones $\mathcal{O} = \mathcal{C}$ of arbitrary narrow size

$$\hat{\mathcal{R}}(\mathcal{C}) \text{ is standard}$$

$$\mathcal{C} = \{ x + \lambda \mathcal{D} \}_{\lambda > 0}$$

i.e. the non-compact spacelike cones result by adding a family of compact double cones with apex $x$ which arise from a spacelike double cone $\mathcal{D}$ which touches the origin. Since there are three families of positive energy Wigner representation one can ask this question individually for each family.

The family with the most perfect localizability property is the massive one, because in that case each $\hat{\mathcal{R}}(\mathcal{D})$ for arbitrary small double cones is standard. On the opposite side is the third (massless infinite spin) family for which the localization in arbitrarily thin spacelike cones (in the limit seminfinite strings) cannot be improved [22]. The second family (massless finite helicity) is in the middle in the sense that the $\hat{\mathcal{R}}(\mathcal{D})$ spaces are standard but that the useful "potentials" (vector potential in case of s=1) are only objects in Wigner representation space if one permits spacelike cone localized objects i.e. they covariant vectorpotentials cannot be associated with compact spacetime regions.

In fact there exists a completely intrinsic argument on the level of subspaces associated with field strengths which attributes a representation theoretical property to these "stringlike" potentials. It turns out that "duality" relation (Haag duality)

$$\hat{\mathcal{R}}(\mathcal{O}) = \hat{\mathcal{R}}(\mathcal{O}')'$$

in massive representations holds for all spacetime regions including non-simply connected regions. Here the dash on $\mathcal{O}$ denotes the causal disjoint, whereas $\hat{\mathcal{R}}(\mathcal{O}')'$ is the symplectic complement of $\hat{\mathcal{R}}(\mathcal{O})$ in the sense of the symplectic form defined by the imaginary part of the inner product in $H_{\text{Wig}}$. This ceases to be the case for zero mass finite helicity representation where there is a duality defect as soon as $\mathcal{O}$ is multiply connected (example: the causal completion of the inside of a torus at t=0). In that case one finds

$$\hat{\mathcal{R}}(\mathcal{O}) \subset \neq \hat{\mathcal{R}}(\mathcal{O}')'$$

which can be shown to be related to the string-like localization of potentials [10] i.e. this defect is the intrinsic indicator of the presence of stringlike potentials.

\[16\] In d=1+2 there are also plekttonic/anyonic representations which will not be considered here.

\[17\] For halfinteger spin there is a slight change.
These properties of localized Wigner subspaces can easily be converted to the corresponding properties of a system (net) of spacetime indexed subalgebras of the Weyl algebra or (for halfinteger spin) the CAR algebra. Since the reaction between subspaces and subalgebras is functorial, all spatial properties have their operator algebraic counterpart and one obtains (for simplicity we restrict to the bosonic case)

\[
\mathcal{A}(\mathcal{O}) \equiv \text{alg} \left\{ e^{i(a^* (\psi) + h.c.)} \mid \psi \in \mathcal{R}(\mathcal{O}) \subset H_{Wig} \right\}
\]

\[
SA |0\rangle = A^* |0\rangle, \ A \in \mathcal{A}(\mathcal{O}), \ S = J\Delta \frac{\partial}{\partial t}
\]

\[
\Delta_{it} \mathcal{A}(\mathcal{O}) \Delta^{-it} = \mathcal{A}(\mathcal{O}), \ JA(\mathcal{O})J = \mathcal{A}(\mathcal{O})' = \mathcal{A}(\mathcal{O})'
\]

It is important to not to misread the Weyl algebra generator in the first line as an exponential of a smeared field; it is rather a (momentum space) Wigner creation/annihilation operator integrated with Wigner wave functions from \( \mathcal{R}(\mathcal{O}) \) i.e. the functor uses directly the modular localization in Wigner space and does not rely on smeared fields. The antiunitary involution \( J \) not only maps the algebra in its commutant (a general property of the T-T modular theory) but, as a result of Haag duality, also brings the causal commutativity into the game. Modular theory in the general operator algebra setting leads to the modular group \( \text{Ad} \Delta_{it} \) which leaves the algebra invariant and the antiunitary involution which transforms the algebra into its Hilbert space commutant; both operators result from the polar decomposition of the so-called (unbounded) Tomita involution \( S \). The field generators of this net of algebras are of course the well-known singular covariant free fields whose systematic group theoretical construction directly from the Wigner representation theory (except the massless infinite spin representations) can be looked up in the first volume of [23].

For a profound confrontation with string theory, the third Wigner representation family is particularly useful. The history of its unravelling is a very interesting illustration of the intricacies of localization [9], but in order not to loose time let us immediately pass to the final result which consists in the realization that these third kind Wigner representations cannot be point-localized. Unlike the finite helicity representation these for which certain tensor fields (for \( s=1 \) vectorpotentials) are stringlike localized objects in an otherwise pointlike generated representation, the wave functions of the third kind Wigner representations are not compactly modular localizable i.e. all compact intersections of wedge localized spaces are trivial and the smallest noncompact intersections which still lead to standard \( \mathcal{R}(\mathcal{O}) \) are spacelike cones i.e. \( \mathcal{O} = \mathcal{C} \). The Weyl functor maps the spacelike cone-localized subspaces directly into spacelike cone-localized operator algebras.

To make contact with the standard field formalism one looks at the (necessarily singular) generators of these algebras. For the first two families these are pointlike covariant fields \( \Psi(x) \) apart from the finite helicity potentials which, similar to the generators of the infinite spin class, are described by string-localized field generators \( \Psi(x, e) \) (leaving off the tensor/spinorial indices) which depend in addition to a point \( x \) in \( d \)-dimensional Minkowski spacetime also on a
point in a d-1 dimensional de Sitter space (the spacelike string direction) e. The stringlike localization nature shows up in the support properties of the commutator for whose vanishing it is not sufficient that starting point x and x' are spacelike but rather 

\[ [\Psi(x, e), \Psi(x', e')] = 0 \text{ only for } x + \mathbb{R}_+ e \succ x' + \mathbb{R} e' \quad (15) \]

The basic difference between the second (finite helicity) and third Wigner representation type is that the string field generates subalgebras which are generated by pointlike composites, whereas in case of the third (infinite spin) type there is no pointlike localized composite. The theory also says that there is no need to introduce generators which have a higher dimensional localization beyond point- or semiinfinite string-like. Note that it is of course not forbidden to introduce decomposable string (and higher) localized operators as e.g.

\[ \int \Psi(x) f(x) d^4 x, \text{ suppf } \subset \text{tube} \quad (16) \]

in the limit where the thickness of the tube approaches zero. When we talk about semiinfinite string localization without further specification we mean indecomposable strings. These are strings which in contrast to decomposable strings cannot be observed in a counter since any registration device would inevitably partition the string into the part inside and outside the counter which contradicts its indecomposable nature (this is of course a metaphorical argument which is in urgent need of a more explicit and intrinsic presentation). The string-localized generators of the Wigner infinite spin representation do not even admit pointlike localized composites i.e. net of spacelike cone localized algebras has no compactly localized nontrivial subalgebras. A milder form of string-like generation of representations occurs for the zero mass finite helicity representation family which in some way behaves localization-wise as standing in the middle between massive representation (which are purely point-localized) and the third kind. These representations are fully described in terms of pointlike localized field strength but already before using these representations in interactions it turns out that the additional introduction of "potentials" is helpful. Whereas in the interaction free case there is a linear relation between the observable field strength and its potential whose inversion permits to rewrite the latter as one or more line integral over the former, this feature is lost under suitable interactions i.e. the string localized potential may become an indecomposable string localized generator which cannot be approximated by compactly observables and therefore remains invisible to particle counters.

In the presence of interactions there is no direct algebraic access to problems of localization from the Wigner one-particle theory. In the Wightman setting based on correlation functions of pointlike covariant fields, the modular theory for the wedge region has been derived a long time ago by Bisognano and Wichmann and more recently within the more general algebraic setting by Mund.\footnote{That derivation actually uses the modular properties of the Wigner setting which is connected via scattering theory to the interacting wedge-localized algebras and then as explained above (via intersection) to the modular structure of all local algebras \( \mathcal{A}(\mathcal{O}) \).}
The resulting modular S-operator has the same property as in (14) i.e. the "radial" part of the polar decomposition of the modular involution $S$ is determined solely by the representation theory of the Poincaré group i.e. the particle content whereas the $J$ turns out to depend on the interaction since it is related to the scattering operator $S_{\text{scat}}$

$$J = J_0 S_{\text{scat}}$$

which in this way becomes a relative modular invariant between the interacting and the free wedge algebra. There is no change in the construction of the $A(O)$ by intersecting $A(W)$s. However in the presence of interactions the functorial relation between the Wigner theory gets lost. In fact no subwedge-localized algebra contains any associated PFG (polarization-free-generator) i.e. an operator which creates a one particle state from the vacuum without an additional vacuum polarization cloud consisting of infinitely many particle-antiparticle pairs.

Since the crossing property played a crucial role in S-matrix approaches to particle physics, it pays to spend some time for its appropriate formulation and on its conceptual content. Its most general formulation is given in terms of formfactors which are products of W-localized operators $A_i \in A(W)$ between incoming ket and outgoing bra states

$$\langle \overline{p}_{k+1}, p_{k+2}, \ldots p_n | A | p_1, p_2, \ldots p_k \rangle^\text{in}$$

$$\langle p_{k+1}, p_{k+2}, \ldots p_n | A | p_1, p_2, \ldots p_{k-1} \rangle^\text{in}, \quad A = \Pi_l A_l$$

where the crossed particle is an outgoing anti particle relative to the original incoming particle. Hence all formfactors of $A$ with the same total particle number are related to one "masterfunction" by analytic continuation through the complex mass shell from the physical forward shell to the unphysical backward part. Hence the predictive power of crossing is inexorably connected with the concept of analytic continuation i.e. it is primarily of a structural-conceptual kind. It is convenient to take as the master reference formfactor the vacuum polarization components of $A\Omega$ i.e. the infinite system of components of the infinite vacuum polarization cloud of $A\Omega$. Needless to add that the crossing relation may be empty in case that the operator $A$ cannot absorb the energy momentum difference between the original value and its continued negative backward mass shell value. In this setting the S-matrix arises as a special case for $A = 1$ i.e. an operator which cannot absorb any energy momentum. In this case it is not possible to use the vacuum polarization as a reference and neither leads the crossing of one momentum in the 2-particle elastic amplitude to a meaningful relation (but the simultaneous crossing of two particles in the in and out configuration is meaningful).

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19 $J_0$ is (apart from a $\pi$-rotation around the $z$-axis of the t-z wedge) the TCP operator of a free theory and $J$ is the same object in the presence of an interaction.

20 Since all compactly localized operators can be translated into a common $W$ and since the spacetime translation acts on in and out states in a completely known way this is hardly any genuine restriction.
This is also the right place to correct the cartoon picture of the QFT vacuum as a bubbling soup which for short times, thanks to the Heisenberg uncertainty relation between time and energy, can violate the energy momentum conservation. This is metaphorical humbug: the correct picture is that (modular) localization in QFT costs energy-momentum i.e. in order to split the vacuum into a tensor product with controllable vacuum fluctuations

\[ \Omega \rightarrow \Omega_1 \otimes \Omega_2 \]
\[ A \rightarrow A_1 \otimes A_2 \]

where the index 1 refers say to a compact region e.g. a double cone and 2 refers to is noncompact causal complement one must one must spend an unbounded amount of energy so that the vacuum after the split becomes thermal whereas in QM (the home of the uncertainty relation) the tensor-product splitting of a global system into a box and its complement does not cost anything because localizing in the sense of Born is for free; it is a mental process which is related to information and has nothing to do with thermal properties. The conceptual difference between Born- and modular- localization is considerable and the bad habit of confusing the two is the main cause for the "information paradox".

It is not only string theory which dwells on metaphors, but some of those in QFT e.g. the above mentioned bubbling vacuum at least do not course any serious damage. Another is the idea with strong connection to metaphors is that physical energy momentum is simply the Fourier transform of an x which behaves covariant under translations. The physically correct definition is through the geometric relation between counter events separated by an asymptotically large distance as in scattering theory. The realization that Feynman rules become useless in perturbative situations without spacetime symmetries as for QFT in curved space and that case the perturbative expressions must obey the subtle property of the recently formulated local covariance principle took more than 3 decades to become appreciated.

The origin of the formfactor crossing property lies in the strip analyticity of wedge localized states and correlation function. For wedge localized wave functions this was explained above (7, 9). For simplicity let us limit the interacting situation to the simplest case

\[ \langle 0 | A | p \rangle = \langle -\bar{p} | A | 0 \rangle \]
\[ \langle 0 | AB | 0 \rangle = \langle 0 | B \Delta A | 0 \rangle \]

where in the second line we have written the KMS property for the wedge algebra which is a general consequence of modular operator theory and for the special case of wedge localization agrees with Unruh’s observations about thermal aspects of Rindler localization \((\Delta^t = U^\text{boost}_W(\chi = -2\pi t))\). But how to view the first relation as a consequence of the second? The secret is that although the intersection of the space of one-particle states with that obtained from applying compact localized algebras to the vacuum (and closing in the modular formalism)

\[21\text{The origin of these metaphors seems to be the too literal interpretation of the momentum space Feynman rules.}\]
graph norm) is trivial, that with the noncompact wedge-localized algebra is not; it is even dense in the Hilbert space. Once it is understood that there exists a wedge affiliated operator $B$ which, if applied to the vacuum, generates the one-particle state, one can apply the KMS relation in the second line. The rest the follows from transporting the left side $B$ as $B^*$ to the bra vacuum. The rest follows by rewriting the $B^* \langle 0 |$ as $SB \langle 0 |$ using modular operator theory and using (17). The resulting $\Delta^\frac{1}{2} JB \langle 0 | = \Delta^\frac{1}{2} J_0 B \langle 0 |$ (since the $S_{\text{scat}}$ matrix acts trivially on one-particle states) leads to the desired result. The general form (18) would follow if we could generalize the KMS relation to include operators from the wedge localized in and out free field algebras. Although they share with $\mathcal{A}(W)$ the same unitary Lorentz boost as the modular group, their modular inversions $J$ are not equal and hence additional arguments are required. We will leave the completion of the derivation of crossing to a future publication [26].

Fortunately in order to criticize the string theory interpretation of the canonically quantized Nambu-Goto mode we do not have to go into subtle details. For such bilinear Lagrangians (leading to linear Euler-Lagrange equations) the connection between localization of states and locality of operators is that in free field theory. In this case it is possible to pass from the "first quantized" version directly to its "second quantization" i.e. to the N-G "string field theory". Since the physical content consists of an infinite tower of massive particles (with one layer of finite helicity massless representations), the only question is does the original classical parametrization lead to fields which are decomposable strings or are they point localized? In the first case one could resolve the composite string in terms of a stringy spread of underlying pointlike fields (i.e. the Lagrangian does not directly lead to pointlike objects) whereas in the second case the terminology would not even have a metaphorical meaning. The suspense will be left to the next section.

### 5 A turn with grave consequences

Although the protagonists of the S-matrix bootstrap placed the new and important crossing property into the center of their S-matrix program, they failed to come up with a constructive proposal which could implement this new requirement. Other older requirements, as Stueckelberg’s macro causality, was not even mentioned in their program, they where probably forgotten in the maelstrom of time. The important question in what way (on-shell) crossing is related to the causality principles of QFT went against their ideology which (at least in the later stages) was to cleanse particle physics from the dominance of QFT. In fact most of their efforts were focussed on the elastic scattering amplitude on which Mandelstam’s conjecture concerning the validity of a certain double spectrum representation was tested in terms of which the crossing had a simple formulation.

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22The plane wave relation should be understood in the sense of wave packets from the dense set of strip-analytic wave functions.
The crossing property in the form of the previous section was first noticed in the Feynman perturbation theory where a certain analytic continuation from momenta on the forward to the backward shell only changes the in/out association of the external legs of Feynman graphs within the same perturbative order. Hence crossing relates Feynman graphs in a fixed order with the same total number of legs where the distribution of the momenta between forward/backward mass shell is changed by analytic continuation on the complex mass shell. Whereas unitarity and macro-causality are relativistic particle properties (in the sense that they can be formulated and implemented without mentioning fields), the crossing property is a statement which uses analyticity properties whose origin, as most analytic properties in particle physics, is in local quantum physics and not in (relativistic) QM. Properties of local quantum physics do not permit a natural description in terms of operator tools of QM. The method which is intrinsic to their conceptual structure is that of spacetime indexed operator algebras.

From looking at the original papers it is quite evident that Veneziano [27] had this kind of crossing in mind when he set out to construct an explicit implementation within the Mandelstam setting for 2-2 elastic scattering amplitudes. But being guided by the properties of Γ-functions and the idea to implement crossing with one-particle poles alone (supported by the pole-dominance of Regge pole phenomenology of the day) he arrived at "Veneziano duality" which is different from the kind of crossing which is an on-shell imprint of the causal locality principle. The S-matrix (and more general the formfactor) crossing from QFT is a delicate interplay between a finite number of one-particle poles and the scattering continuum. The Veneziano duality on the other hand required the presence of a tower of particles and no participation of the scattering continuum. The idea of one-particle saturation of scattering amplitudes by an infinite particle tower came from the Regge-pole phenomenology; Veneziano’s merit was to have recognized that this saturation idea harmonized perfectly with properties of gamma functions. But unfortunately it is not compatible with QFT. The consistency of crossing in QFT can be explicitly verified in factorizing models [30]. For the Veneziano duality one could point to string theory neither its conceptual structure nor its mathematical status is known. functions.

Extending the search for an implementation of duality-based on properties of Gamma function, Virasoro [28] arrived at a model with a different and somewhat more realistic looking particle content. The duality setting became more completed and acquired some mathematical charm after in [29] it was extended to n particles. The resulting "dual resonance model" was the missing link from the phenomenological use of Gamma function properties to a conceptually and mathematically more attractive formulation in terms of known concepts in chiral conformal QFT, the new idea being that Minkowski spacetime should be envisaged as the "target space" of a suitably defined chiral model.

It is worthwhile to look at the mathematical formulation and the associated

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29 Note that the notion of target space is well defined only in classical field theories (where fields have numerical values) whereas in QFT its meaning is metaphorical.
concepts in some detail. The conformal model which fits the dual resonance model are the charge creating fields of a multi-component abelian chiral current which are customarily described in the setting of bosonization

\[ \Psi(z, p) = e^{ip\phi(z)} \]  \hspace{1cm} (21)

where the d-component \( \phi(z) \) is the potential of a d-component chiral current \( j(z) = \frac{d}{dz} \phi(z) \), and \( p \) is a d-component numerical vector whose components describe (up to a shared factor) the value of the charge which the \( \Psi \) transfers. The fact that the Hilbert space for \( \phi \) and \( \Psi \) is larger than that of the current \( j \) is the only place where the language of bosonization becomes somewhat metaphoric; this point is taken care of by a proper quantum mechanical treatment of zero modes which appear in the Fourier decomposition of \( \phi(z) \). The n-point functions of the \( \Psi \) are the integrands of the scattering amplitudes; the latter result from the former by \( z \)-integration after multiplication with \( z_i \) dependent factor \[34\]. Hence it is more or less obvious that the energy-momentum conservation of the target theory results from the charge conservation of the conformal source theory. Even for the cluster property one finds a convincing argument in that it corresponds to the cluster decomposition of the auxiliary chiral theory (if one rewrites it in terms of the noncompact parametrization). But it is too early to rejoice since there are still three hard problems ahead: the macro-causal rescattering structure, unitarization and the origin of the restriction to 10 charges for accommodating a Poincaré symmetry in the target space.

Regarding the timelike macro-causality the problem is to avoid falling back behind Stueckelberg. As far as unitarization goes the problem is to find a structural argument which replaces the unitarity-securing scattering theory in favour of some property of the auxiliary chiral conformal QFT.

Whereas the first dual model papers are hard to criticize since they represent at best bits of a new S-matrix theory, the dual resonance model, although being obviously not yet an S-matrix theory as it lacks unitarity, is already a concrete target for criticism. According to its protagonists its n-particle amplitudes should be interpreted as the tree approximation of an unknown unitary S-matrix. The position of the one-particle poles and their residua in the various channels obtained by crossing incoming and outgoing lines and vice versa were shown to be consistent with the required duality property. This is not only a nice mathematical achievement but, ignoring for a moment the unitarity problem, it also secures the validity of the causal one particle structure.

Different from the representation theoretical approach to the Poincaré symmetry a la Wigner, on which QFT is founded, the dual model realizes Poincaré symmetry as a noncompact inner symmetry of a chiral conformal QFT. To be more precise the spacetime symmetry acts on the field-value (target) space which in a Lagrangian quantization approach is the arena for compact internal symmetry actions. The problem at hand is to describe the dual model S-matrix in terms of an auxiliary chiral conformal so that the momenta are the continuous values of an abelian multicomponent current and that the Poincaré group acts unitarily on that spectrum of multi-component charges. The first part of
this requirement is fulfilled thanks to the fact that the chiral abelian current
theory has in contrast to so called rational chiral models a continuous supply
of superselection sectors and so a match with a continuous energy-momentum
spectrum is possible. The second part of this requirement is more difficult to
enforce and indeed it is in general not possible to accommodate a noncompact
internal symmetry group which acts on the target space of a QFT. The fact that
it is possible to obtain a positive energy representation on a suitably restricted
target space in 10 spacetime dimension if one extends the abelian charge chiral
theory by supersymmetry has been verified by computations. Another important
property is the pole structure of the dual model scattering amplitudes (the
particle tower) which must originate from some property of the conformal cor-
relations in terms of which these amplitudes are defined. Here one looks in vain
for an explanation in terms of the intrinsic logic of chiral (source!) model. But
a clarification of this point would be important if, as string theorists do, one
wants to attach a spacetime interpretation in the sense of a worldsheet carved
out by a string. This has not been done despite the fact that this picture is
always inferred and here begins the metaphoric twilight.

Since the dual resonance model is the point of departure of string theory
and extra dimension there is the danger that a large part of physics of the last
two decades is based on metaphoric ideas with doubtful reality content. This
is why I believe that the lack of clarification of duality versus crossing is one
of the most important missed opportunities in the history of physics. Whereas
the field theoretic crossing cannot only be seen in perturbation theory but also
enters as an important tool in the nonperturbative construction of factorising
models, there is not a single example for a dual theory (the dual resonance
model is not a model for an S-matrix).

An equivalent formulation which has the advantage of permitting a interaction-
free Lagrangian presentation for the particle tower spectrum (with the interac-
tions added "by hand") was proposed by Nambu [36] and Goto [37] and in a
more standard functional integral setting by Polyakov [38]. This string the-
ory setting confirmed the restriction of target space to a 10-dimensional super
Poincaré group. But is such an argument acceptable as a prediction that we
are living in a 10 dimensional space with 5 spatial dimensions curled up in such
a way that they have escaped observation? Can the answer to such a funda-
mental almost metaphysical question about the dimensionality of our world be
left to mind games which are orthogonal on those symmetry principles which
incorporate all our past observations? In short, is string theory a metaphorical
aberration or is it a gift of the 21 century which fell by luck into the 20 century?
This is the main question which will be pursued here. We will end this section
by posing a series of critical questions whose further pursuit will constitute an
important part of this article.

- In relativistic theories (whose existence is assumed) in which the S-matrix
arises as a long time limit there is no problem with unitarity and macro-

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24 On higher dimensions observable the representation theory of local of local observables
leads to charge sectors which can only accommodate compact inner symmetry groups [39].
causality of $S$. But what if the S-matrix, or rather what one thinks should be its tree approximation, is the result of phenomenological tinkering which has nothing to do with a large time limit in an underlying QFT? Is the mathematical respectability of a mind game like this a sufficient strong prerequisite for taking it serious as a construction principle in particle physics?

- What is the physical meaning of a purely auxiliary concept as "string" which enters the prescription for the construction of an S matrix. Is the result of the quantization of a classical Nambu-Goto string really a string in the sense of quantum localization; or more pointedly: does the well-known parallelism between pointlike classical fields and their quantized counterparts carry over to strings?

- Does the presence of a zero mass spin=2 particle in a covariant theory with only one parameter (the claimed finiteness of string theory) make it automatically a candidate for QG? What about the local covariance principle which secures background independence?

In the beginning of the 70s better experimental results on high transverse momentum transfer scattering pulled the rug out from under the dual model and all ideas related to Regge phenomenology and made it a conceptual orphan. However some people who invested a lot of time and also some computational ingenuity which led to these surprising (in the sense of not expected by the intrinsic logic of abelian current models) results. The phenomenological start took a sudden theoretical turn without being able to find a conceptual anchor.

6 The ascend of the metaphoric approach to particle physics: string theory

During the first years of its existence the dual model and its various extensions attracted some attention from the Regge phenomenology community; in fact most of the dual model protagonists came from that area. With the ascend of exciting new ideas about strong interactions coming from QCD, which also offered a vast new playground for phenomenologists, the Regge pole era came to an end and with new hadronic large-momentum transfer data arriving, which contradicted the dual model predictions, the dual model formalism finally lost its observational support. In this way it became an "orphan" of particle physics since its modest mathematical charm, which consisted in Euler type of identities between gamma functions, lost its physical attraction.

Although the small community of dual modelists were unshaken in their belief that hidden behind the many unexpected properties there exists a deep new

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25Interestingly enough representations of scattering amplitudes in terms of Gamma functions re-appeared a decade later in connection with two-dimensional factorizing models but this time in complete harmony with unitarity and with the true (QFT) crossing (i.e. these models have a finite number of particles and hence there is no duality).
kind of quantum physics, they hardly made any effort to improve the conceptual understanding of crossing and its relation to duality. This would have been the right time to come to terms with the physical spacetime origin of the on-shell crossing property and possible modifications needed to understand Veneziano duality.

As explained in a previous section the standard crossing property is an interplay between (a finite number of) particle poles and multiparticle cuts in the analytic scattering amplitude. In particular there is no understanding whether there is any physical property behind the formal manipulation of satisfying the crossing by simply trading the continuum contribution with a tower of particle poles. Veneziano’s construction was not dictated by physical necessity but rather by computational expediency: in the typical physicists way according to the motto: if you cannot solve a problem coming from physical principles, try to invent another similar looking one which you can solve and try to interpret the outcome. It was obvious that the duality requirement does not have a solution with a finite number of particles and it took the mathematical ingenuity of Veneziano to construct a solution with infinitely many particles. In view of the precarious conceptual status of this result makes it understandable that the string interpretation was welcomed as a conceptual salvation since it brought the speculative new ideas nearer to the Lagrangian shore.

In view of the fact that duality was not a property of S-matrices of QFT, and not a consequence of any known physical principle, but rather a result of gamma function “tinkering” combined with “Reggeology”, a profound conceptual study of these observations was warranted; but the problem was not even posed. In d=1+1 the nontrivial family of factorizing models provides explicit and rigorous illustrations of crossing in QFT coming about as a subtle interplay between one-particle poles and the scattering continuum [30][31]. A factorizing model which fulfills duality based on infinitely many one-particle poles does not exist.

In fact it was an uneasy feeling that the dual model was constructed with an excess of sophisticated ”tinkering” and a lack of guiding principles. This theoretical frailty became more apparent, especially after the model lost the protection which it enjoyed under the phenomenological Regge pole umbrella, where the demands on conceptual coherence were less restrictive. Hence the observation that those operator formulas representing the on-shell scattering states of the dual resonance model could be viewed as coming from canonical quantization of a classical relativistic string was considered as an act of conceptual liberation which incorporated the dual model into an apparently conceptually more satisfactory setting. With the picture of a relativistic string in mind, there was hope to obtain an intrinsic access to interactions and to complete the construction of a unitary S-matrix in such a way that the dual resonance model is the lowest order in a new perturbative systematics.

This hope changed to ecstasy when some researchers became aware that in contrast to higher spin (s > 1) QFT which, even within a short distance improving BRST ghost formalism, apparently leads to infinitely many perturbatively undetermined parameters (nonrenormalizability), string theory has basically only one parameter (assuming that it stays finite in every order which
nobody has been able to check).

Naturally the case of s=2 contribution attracted most attention as a result of its promise to lead to a finite theory of quantum gravity. In contrast to QFT, which in addition to perturbative series representation has a wealth of structural theorems, string theory offers nothing like this; perturbative results are only secured (with tremendous computational effort and no gain in physical insight) up to second order and nonperturbative statements (e.g. statements about branes) are not available in the form of structural theorems but remain in the realm of quasiclassical calculations and metaphoric reasoning (even after more than four decades!). So the hope that (super)string theory was the liberating act by which the old phenomenological ideas could be elevated to a new TOE with QG as its shiny byproduct remained unfulfilled but this did not prevent the formation of a large community around string theory.

Instead of entering a point for point critique of the extensive and technically laborious content of string theory, I prefer to focus my critical remarks to what I consider the Achilles heel of string theory, namely its metaphoric relation with those localization concepts which are central for the formulation and interpretation of particle physics.

We know from Wigner’s representation theoretical classification that the indecomposable constituents of positive energy matter are coming in 3 families: the massive family which is labeled by a continuous mass parameter and a discrete spin, a discrete massless family with discrete helicity and finally a continuous zero mass family of with an infinite spin (helicity) tower. Whereas theories involving the first two families have generating pointlike localized field strengths, there are no pointlike covariant generators within the last family; rather the sharpest localized generators in that case are semiinfinite strings localized along the spacelike half-line $x + \mathbb{R}_+ e$, where $x$ is the starting point of the string and $e$ is the spacelike direction in which it extends to spacelike infinity. Their localization shows up in their commutation relation which we presented in (15).

Stringlike localized objects can of course also be constructed in pointlike QFTs; one only has to spread a pointlike field along a string where the spreading has to be done in the sense of distribution theory since the resulting stringlike objects is also singular. Such a string will be referred to as composite or decomposable. It has no fundamental significance and one would not expect such objects from a Lagrangian setting, although its use in special cases may be helpful in exploring the physical content of a model. One very good technical reason for doing this is the fact that the short distance behavior of a spacelike semiinfinite string localized covariant field is better that of its pointlike counterpart. A pointlike free massive vector field $A$ has short distance scaling dimension $sddA = 2$ whereas its string localized counterpart has the lower value $sdd\Phi_A = 1$, in fact the short distance dimension of stringlike massive fields of arbitrary high spin remain at $sdd\Phi = 1$ [10].

Hence a perturbation theory in terms of interactions between such decomposable covariant string localized fields can be expected to enlarge the possibilities for renormalizable interactions, in particular interactions involving higher spin
for which the power counting test\textsuperscript{26} for renormalizability leaves no interactions at all. Of course the inductive perturbation rules (the Epstein-Glaser rules) are different from the pointlike case. The use of stringlike covariant fields is still pretty much in its infancy.

What matters here is that the representations of the third kind of positive energy Wigner matter are indecomposable strings; in fact it is not difficult to argue that the associated QFT has no pointlike localized composite fields and hence no compact localized operators at all \textsuperscript{20}. These representations are therefore excellent illustrations for the meaning of indecomposable stringlike localized fields.

From our previous discussions we know that localization is an autonomous quantum theoretical concept which is governed by the representation theory of the Poincaré group and not by trying to transfer classical localization via quantization into the quantum realm.

It is true that both localization concepts coalesce in the pointlike case. This fact was extremely beneficial for the early birth of QFT more than one decade before Wigner’s path-breaking work on the intrinsic representation theoretic method to classify particles as indecomposable objects. The classical-quantum quantization parallelism was also crucial for the development of the Lagrangian and functional approach. For pointlike generators the quantization approach and Wigner’s representation theoretical method are largely equivalent. The most detailed account of this equivalence can be found in Weinberg’s book \textsuperscript{23} where the group theoretic formulation of Poincaré covariance is used to construct a (countably infinite) family of intertwiners which map the canonical Wigner representation into the non unique covariant (undotted/dotted spinorial) representations.

The third kind of positive energy Wigner representation shows the limitation of pointlike localization and Lagrangian quantization. It is evident that any critique of string theory has to start with a profound review of its localization. The main topic for the rest of this section will be to demonstrate the correctness of the following theses: the objects of string theory are not string-localized in any intrinsic quantum-physical sense.

The above representation theoretical discussion shows that massive states in interaction-free Poincaré-invariant theories can only be string-localized in a decomposable sense i.e. as a pointlike localized state spread over an infinitely thin tube. But there is no possibility of having a massive indecomposable state which would be string-localized whereas a decomposable string state can be written in terms of spread pointlike states.

We all have been exposed to the story of the ”little wiggling strings” (meanwhile there are also the large cosmic strings) in spacetime; this has been the opening mantra with which string theorists usually introduce their talks. Of course the reality content of metaphors is not enhanced by the fact that the storytellers seriously believe in what they are saying. For free strings, more precisely for the string field theory associated with the Nambu-Goto string, this

\textsuperscript{26}Positivity (no ghosts) is always assumed.
issue can and has been completely settled by an explicit calculation of the commutator function which for all bilinear free systems is a c-number which carries the full intrinsic information about quantum localization.

This was done, first by string theorists [32] and afterwards by mathematical physicists [33] and the result in both cases was a point- and not a string-like localization. In other words, there was neither a composite nor a indecomposable string, rather it was pointlike\(^{27}\). If not in the commutator function then where else should the intrinsic meaning of a spacetime string show up? This is precisely the point in the story from the dual model to string theory where metaphors have won over the observable content. According to string theorists the strings themselves remain invisible, the commutator shows only their center of mass position. What is even more surprising is that we (quantum field theorists, mathematical physicists) i.e. a mathematical physicist as [33] who has carefully checked the commutator and also finds a pointlike localization but also concludes that for some reason the string itself remained invisible. This shows the incredible spell of metaphors once they become accepted by a sufficiently large community. In such a sociological environment our often praised scientific objectivity and independence suffers a meltdown (just like public opinion in democratic states on carefully staged media-supported bellicose policy of a governmental elite) and gives way to a preemted obedience.

As expected on the basis of covariance, the putative string field\(^ {28}\) is really an pointlike localized generalized free field with an infinite mass- and spin-spectrum (i.e. a mass-spin tower). The pure bosonic N-G Lagrangian suffers from the tachyon "flaw" i.e. the violation of the positive energy requirement; this is removed by taking the supersymmetric extension of the N-G model which uses the graded commutators.

The infinite mass tower together with the c-number nature of the graded commutator resembles the spectrum of infinite component fields. The metaphoric idea that this N-G model mass-spin spectrum which is reminiscent of a classical string can be interpreted as a result of a string which vibrates in spacetime is contradicted by direct operator calculations. The N-G string is not even a decomposable string in the sense of a pointlike field spread over a infinitely thin tube. Indecomposable stringlike localized objects occur in Wigner’s representation theory but they have nothing in common with the pointlike localized objects of string theory presented in (15).

There is also another reason why in the face of all evidence to the contrary string theorists cling to their string metaphors. It is precisely that metaphoric language which helps them to define their interaction in terms of graphical splitting and recombining euclidean tubes (string "tubism"). This is to be

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\(^{27}\) It could have been that the classical string parametrization of the N-G Lagrangian under canonical quantization passes to a decomposable (composite) string in the aforementioned sense, but this is not the case.

\(^{28}\) Like a monument becomes protected as part of history even if that part of history was anything to be proud about, it is not possible to change terminology in physics just because a misleading name was selected prematurely. This requires the reader to pay attention to not confuse objects of string field theory with string localised objects.
expected since genuine (i.e. non transient) metaphors can only be sustained at the cost of constructing more metaphors ("excuses" in the words of Feynman, who in my view saw some of these problems coming). As long as one accepts the first metaphor, there is no problem with interpreting the interaction but without it there is no motivation.

With the insistence of interpreting the result of the canonical quantization of the Nambu-Goto Lagrangian as an (invisible, apart from the center of mass) string-localized object in spacetime, the metaphoric rubicon has been crossed. As a consequence the metaphoric style has become accepted even on subjects of particle theory which are not directly related to string theory. It is truly amazing to see that almost 90 years after quantum mechanics begun with Heisenberg’s placing observables into the center of the new quantum reality in order to avoid the contradictions caused by the contamination of the new quantum physics with classical pictures, the metaphoric world view is back in strength and it seems to be even embraced by the Zeitgeist.

Metaphors in particle physics are useful as long as they remain transitory devices in the sense of exploring new physics in a still poorly understood conceptual terrain. They may however derail research if it turns out that they are unrelated to the intrinsic meaning of what they represent and people are not aware or have forgotten that they are metaphors. Most physicists of the present generation may not even understand the problem on hand since they attribute concepts used in the construction of a quantum theory erroneously with an intrinsic property of the construct; in the present concrete context they are convinced that the classical string aspect in the classical N-G action (and hence in the functional integral representation) must be somewhere in the associated field theory. Since the commutator of the resulting string field theory turns out to be pointlike localized they invent a string and declare the point to be its center of mass. This metaphoric way of arguing is supported by the historical fact that the quantization of pointlike classical fields leads to pointlike quantum field. This coalescence of metaphoric and intrinsic aspects was an extremely important event because it allowed QFT to be discovered before Wigner’s intrinsic representation theoretical approach. It carries the danger that people generalize it beyond its region of validity.

Precisely in order to avoid such metaphorical projections of classical aspects into QT Heisenberg introduced the notion of "observable". The observable i.e. intrinsic content of the N-G quantum string and its basic difference to standard QFT is the abundance of the pointlike degrees of freedom. String theory has been around for more than four decades and it has not only prepared the ground for the return of metaphors to quantum physics, but it also has led to a loss of fundamental knowledge in particle physics.

29 According to my best knowledge the N-G string field is the only generalized free field which permits a Lagrangian description. Whether this makes this class of models physically more palatable (hitherto such models were mainly used to restrict the postulates of QFT which do not allow them).
In order to avoid any misunderstanding on this point and also not to appear as a schoolmaster in the purity of terminology in particle physics let me emphasize that I am not criticizing the metaphoric and often very imprecise terminology of particle physicists as compared to mathematicians per se. Most physicists get perfectly over their surprise if they discover that Born’s famous article does not contain any x-space probability density involving Schroedinger wave functions but is rather a paper on the notion of the cross section in the Born approximation (the $|\psi(x)|^2$ density was introduced later by Pauli). Neither is he leaving his rocking chair when he looks at Virasoro’s original paper and finds neither the central term nor an algebra with all frequency components. If string theory would be just an inappropriate terminology for something well known or a cautious terminology to avoid premature naive identification (as e.g. M-theory) one could pass to business as usual.

Most of the great conceptual conquests of the post renormalization period in QFT as the derivation of scattering theory and the related very subtle connections between particles and fields have been reduced to computational recipes. As a result these profound conceptual conquests are not passed on to the younger generation. It is simply not true that history from the beginnings of particle physics to string theory is a history of continuous progress. It is not accidental that the rise of metaphoric thinking combine with a “calculate and shut up” attitude coincides with the rise of string theory and other physically unmotivated ideas. But this is not the case, the stringy stuff wiggling in space is not just the stuff on which the Brian Green’s Nova Nova film project is based but rather enter the opening mantras of my highly ...string-theory colleagues. In fact every string theorist I met and conversed with firmly believes that his strings are one-dimensionally extended objects in the same spacetime which serves as the living space of pointlike fields.

The unusual and highly suspicious aspect of string theoretical matter as compared to the Wigner classification of matter was already visible in the dual resonance model [34] in terms of a chiral conformal field theory. Here the arena of the action of the Poincaré group is the target space, a very unusual situation indeed because the target space (a metaphorical quantum analog to the field space of classical fields) is arena of action for internal symmetries and these are usually given in terms of compact groups. However for chiral theories the internal symmetry concepts are less restrictive and it turns out that the kind of conformal theory behind the dual resonance model can have a noncompact (Poincaré) symmetry but only if the target space has 26/10 spacetime dimensions. But no matter whether the Poincaré group acts on source or target space, modular localization, which as emphasized before is always intrinsically related to the representation of the Poincaré group, is the sovereign over quantum localization and not some classical string aspect of a N-G Lagrangian. This means in particular that the classical string localization is irrelevant for the quantum localization but certainly plays a role in the arrangement of the irreducible components within a generalized free field. The difference between classical and quantum string localization can be sharpened and put into the form of the following dictum: indecomposable quantum strings cannot be obtained from
quantization and quantized classical strings do not lead to quantum strings.

The true physical content of the canonical quantization of the Nambu-Goto Lagrangian is that of a generalized free field with infinitely many mass and spin components.\(^30\) Such pointlike fields have different properties from standard Lagrangian fields. Their phase space degrees of freedom have a larger cardinality, and as a consequence they violate the standard properties of thermal behavior (they have a Hagedorn temperature or no temperature states at all) and also those of causal propagation. But apart from the lack of causal propagation (time slice property, causal shadow property) they satisfy all Wightman axioms, including spacelike commutativity. Their existence has been (and still is) taken as an indication that the Wightman axioms are too general and need further restriction.\(^31\) Another case in which such an overpopulation of degrees of freedom appears is the AdS-CFT correspondence in which e.g. a free field on the AdS side is converted into a generalized free field \(^{40}\) on the conformal side.

Not all attempts to make physical sense of the quantum Nambu-Goto model with the help of canonical quantization have ended in metaphors. There however an approach which avoids a canonical quantization by utilizing the fact that the N-G model is classically integrable. In that case it seems to be reasonable to find the classically conserved charges and their Poisson bracket relations and (after verifying that there are no anomalies) to quantize this algebraic structure \(^{41}\). In this case there is no problem with re-parametrization invariance nor with locality since the conserved charges are global reparametrization-invariant quantities and the construction of the positive energy representations of their Poisson bracket structure reinterpreted as an operator commutation structure is an eminent reasonable procedure. However it is known that the content of such a theory is inequivalent to the string theoretic quantization of the Nambu-Goto Lagrangian \(^{42}\). The latter is driven by the aim to obtain a Lagrangian canonical setting for the dual model and not by understanding the intrinsic quantum content of the classical N-G equation viewed as a integrable model.

Related to the wrong metaphor of the N-G strings being little (or in more recent times also large) stringy objects in the sense of localization in spacetime\(^32\) is the enormous regression of string theory in all matters which are related to spacetime localization concepts. One of the most impressive achievements after the discovery of renormalized QED was the derivation of time-dependent scattering theory and the closely connected improvement in the understanding of the rather subtle connection between particles and fields. Problems which appear insoluble in a pure S-matrix approach, as unitarity and macro-causality, became linearized and hence manageable in the setting of correlation functions of fields. The corresponding nonlinear properties for the S-matrix which resisted

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\(^{30}\) Usually the name generalized free field is reserved for a fields whose c-number (anti)commutator has contribution from many (possibly continuous) masses and spin.

\(^{31}\) This was noticed quite early in the history of QFT and let to the "time-slice" requirement

\(^{32}\) Unfortunately after having used erroneous terminology for more than 4 decades there is no way avoiding its continued use.
attempts to implement them by "hand" are then delegated to the (successful) proof of asymptotic convergence for large times. Assuming that crossing holds for formfactors (a reasonable extrapolation of what has been proven in QFT) though one cannot show the existence of an associated QFT, at least its uniqueness can be established [15].

String theory regresses on all these points, it remains a cooking recipe without any concepts which could explain the validity of those properties which are indispensable for any kind of particle physics as unitarity macro-causality and crossing in the sense of section 4. If this regress would be of a transitory nature on the way to something deeper which contains the previous concepts on which the great physical successes of QFT is founded, one could live with it for a limited amount of time; but are more than 4 decades still a reasonable amount? The most devastating effect of string theory is that it has led to a kind of (often arrogant) new type of particle physicists who thinks what he learned under the label QFT as a preparation for string theory suffices for doing particle physics. The fact that he cannot understand structural nonperturbative results of QFT is of no concern because he accepted the (blatantly wrong) message that QFT is, apart from some computational details, a closed subject.

The real damage caused by the 4 decade lasting reign of string theory is not that it leads to conceptual confusions and has not produced any physically tangible result, but rather that is wiped out fundamental knowledge which will slow down future progress in a post string era.

7 TOE time, or particle theory in times of crisis

Although among experts there is general agreement that particle physics is in the midst of a crisis, not all share the optimism of some about a new orientation coming out of the new generation of LHC experiments. Indeed it is difficult to imagine that experiments can give new conceptual directions in a situation in which the experimental planning and the interpretation of measured results depends metaphors as placeholders of principles. In addition there ideas, as supersymmetry which are veterans in holding out against all absence of any evidence. In its long history of more than 40 years and thousands of publication there has been no meaningful theoretically consistent idea of a controllable breaking. Why such such a social construc disappear with a whimper in the tunnels of the LHC? Certainly not because of any new incompatibilities with observations; if against all odds it happens it will be the result of exhaustion in finding excuses. Feynman saw the danger in this observation-resistant and revolution-hardened return of metaphoric reasoning when he commented on one occasion that string theory uses excuses instead of arguments.

The diagnosis about the underlying causes varies widely according to age and background. An often heard opinion is that the ascend of metaphoric ideas and the increasing popularity of theories of everything is the result of stagnation.

As far as I know the first TOE came with the German name, it was the Heisenberg Weltformal (a nonlinear spinor theory). Pauli supported it at the beginning but later (after
in the mainstream of particle physics, i.e. that of QFT in general and of the standard model in particular. The difficult and time-consuming way to make genuine progress is not on par with people who are after rapid success; they look wistfully at the beginning of the standard model when it was possible to get progress with a relative modest amount of knowledge and hardly any new concepts and no new formalism. It is much more groovy to contemplate about a theory of everything than to labor with an unfinished theory with more than 20 parameters, especially if the Zeitgeist permits to make a good living by expanding the metaphors of a TOE.

It is true that many ideas which looked promising at the beginning (as e.g. the unification through a confluence of the three couplings at a suitably high energy) became frozen in time. But perhaps the stagnation of the mainstream of particle physics is itself already the result of deeming it unprofitable to make any long time conceptual investment if a sufficiently large community thinks that pursuing a TOE can bring rapid progress.

A theory whose intrinsic properties are unknown, apart from unresolved metaphors, is a breeding ground of further-going metaphoric thinking. This is particularly evident in the application of string theory to what its admirers consider its central achievement: the famous AdS-CFT holography. This is an exemplary case where one metaphor begs the next one, and as such it is extremely informative for the points raised in this essay; so let us look at this issue with some care.

Already in the 60s the observation that the 15-parametric conformal symmetry which is shared between the conformal of 3+1-dimensional compactified Minkowski spacetime and the 5-dim. Anti-de-Sitter (the negative constant curvature relative of the cosmologically important de Sitter spacetime) brought a possible field theoretic relation between these theories into the foreground; in fact Fronsdal suspected that QFTs on both spacetimes share more than the spacetime symmetry groups. But the modular localization theory which could convert the shared group symmetry into a relation between two different spacetime ordering devices for the same abstract quantum matter substrate was not yet in place at that time. Over several decades the main use of the AdS solution (without its covering manifold), similar to Goedel's cosmological model with self-closing timelike worldlines, has been to show that Einstein-Hilbert field equations besides the many desired solution (as the Robertson-Walker cosmological models and the closely related de Sitter spacetime) also admit unphysical solutions which lead to time machines, wormholes etc., and therefore should be further restricted.

The AdS spacetime lost this purpose of only providing counterexamples and began to play an apparently more constructive role in particle physics when the

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Feynman’s criticism) turned against it. My later Brazilian collaborator visited Munich at the end of the 50s and got so depressed about the circus around this Weltformel that he had doubts about his decision to go into particle physics. Fortunately that TOE remained a local event.

34The discovery of QED two decades before was hard work because all the renormalization technology and its conceptual basis had to be developed.
string theorist placed it into the center of a conjecture about a correspondence between a particular maximally supersymmetric massless conformally covariant Yang-Mills model in $d=1+3$ and a supersymmetric gravitational model. The first paper was by J. Maldacena \cite{44} who started from a particular compactification of 10-dim. superstring theory, with 5 uncompactified coordinates forming the AdS spacetime. Since the mathematics as well as the conceptual structure of string theory is poorly understood, the string side was identified with one of the supersymmetric gravity models which, in spite of its being non-renormalizable, admitted a more manageable Lagrangian formulation and was expected to have a similar particle content as the less understood superstring theory from which it originated. On the side of CFT Maldacena placed a maximally supersymmetric gauge theory of which calculations, which verify the vanishing of the low order beta function, already existed. The vanishing of the beta-function is certainly a necessary prerequisite for conformal invariance. The arguments involved perturbation theory and additional less controllable approximations.

The more than 5,000 follow up papers on this subject did essentially not change the status of the conjecture. But it was the kind of sociological backup which elevated the Maldacena conjecture the most important result of string theory and its putative connection with the still elusive quantum gravity.

The conceptual situation became somewhat more palatable after Witten \cite{45} and Polyakov et al \cite{46} exemplified the ideas in the field theoretic context of a $\Phi^4$ coupling on AdS using a D-dimensional Euclidean functional integral setting, thus placing it into a form which is closer to the old Fronsdal setting. Of course unlike the supersymmetric Yang-Mills theory this self-coupled model is not expected to lead to a conformal theory as the result of a trace anomaly for the energy-stress tensor. The correspondence argument for the self-coupled scalar field ignores this anomaly and consists in subjecting the conformally invariant building blocks namely the propagator and the pointlike vertices to the requirements of the AdS-CFT holography.

The model-independent structural properties of the AdS-CFT correspondence came out very clearly in Rehren’s \cite{47} algebraic holography. The setting of local quantum physics (LQP) is particularly suited for questions in which one theory is assumed as given and one wants to construct its corresponding model on another spacetime. Using methods of local quantum physics one can solve such problems of isomorphisms between models in a purely structural way i.e. without being forced to actually construct a model on either side of the correspondence.

Since generating pointlike fields are coordinatizations of spacetime-indexed operator algebras and, as with numerical valued coordinates in geometry, such coordinatizations are highly nonunique and certainly not intrinsic an algebraic formulation of a correspondence is more appropriate. For certain structural questions i.e. whether the inverse scattering problem for an S-matrix with the crossing property has a unique QFT to which it is the S-matrix the algebraic formulation is the only meaningful one. It is not surprising that holographic changes of spacetime encodings are more tricky if expressed in terms of relations between pointlike fields. For example a standard pointlike quantum field
on AdS has very non-standard behavior on the conformal side; there is an overabundance of degrees of freedom which is of course what one expects of a correspondence in which a collection of degrees of freedom which was natural in 5 spacetime dimension is squeezed into 4 dimensions. This can be nicely illustrated in case of a free AdS field which under the correspondence becomes a generalized free field with a continuous distribution of masses which carries the anomalous dimension of the conformal generalized free field [48].

Here some informative historical remarks about generalized free fields are in order. They were introduced in the late 50s by W. Greenberg and their useful purpose was (similar to AdS in classical gravity) to test the physical soundness of axioms of QFT in the sense that if a system of axioms allowed such solutions which appeared unphysical, it needed to be further restricted [39] (in that case the so-called causal completion or time-slice property excluded generalized free fields). The unphysical aspect of the generalized free field consisted in the breakdown of the causal shadow property i.e. the operator algebra in a space-time region generated by certain generalized free fields are much smaller than the operator algebras of their causal completions. Another related failure is the existence of a limiting temperature (the Hagedorn temperature) or even worse, the nonexistence of temperature states altogether. The fact that there have been many papers in string theory about systems with the Hagedorn temperature does not mean that nature has become more lenient with respect to older physical principles. Not anything which originates these days from a physicist is "physical"; we are not yet living in a Tegmark world [2] where every mathematical belch finds its physical realization in some universe of his conceived multiverse.

In the opposite direction the degrees of freedom of a ”normal” CFT become "diluted" on AdS. There are not sufficient degrees of freedom for arriving at nontrivial compactly localized operators, the cardinality of degrees of freedom is only sufficient to furnish noncompact regions as AdS wedges with nontrivial operators, whereas the compactly localized double cone algebras remain trivial (multiples of the identity). In the setting based on fields this means that the restriction on testfunction spaces is so severe that pointlike field $A_{\text{AdS}}(x)$ at interior points $x \in \text{int}\text{AdS}$ do not exist in the standard sense as operator-valued distributions on Schwarz spaces. They exist on much smaller test function spaces which contain no functions with compact localizations.

Rehren’s structural analysis adapted to the functional setting in order to allow a comparison was dismissed by string theorists. Comparing the formal transcription of Rehren’s approach to a functional integral setting it was indeed difficult to see any relation with Witten’s functional integral treatment. But thanks to a functional identity (explained in the Duetsch-Rehren paper) which shows that fixing functional sources on a boundary and forcing the field values to take on a boundary value via delta function in the functional field space leads

\footnote{Here "standard" means originating from a Lagrangian or, in more intrinsic terms, fulfilling the time-slice property of causal propagation. A free field is standard in this sense, a generalized free field with an increasing Kallen-Lehmann spectral function fails to have this property.}
under certain conditions to the same result. In this way the apparent disparity disappeared and there is only one AdS-CFT correspondence within QFT and not two (namely that coming from string theory and that established by Rehren’s) as claimed by string theorists.

Theorems derived with mathematical rigor in a conceptually clear setting mean nothing to people who are convinced to hold a TOE in their hand. Predictably string theorists ignored Rehren’s work even though it was now clear that there was only one correspondence; in those few cases when they mentioned it after being questioned, they expressed their disdain by labelling it as the ”German AdS-CFT correspondence”. Whereas at the time of Feynman they at least had to think about excuses, the increase of power and glory in the meantime has changed that behavior in the sense that has come down to labelling.

As a veteran of QFT one finds oneself asking the question how did one get into this strange movie? Her one depends on guesses. Excluding personal animosities, the only question which comes to ones mind is whether there could be anything in Rehren’s rigorous results which comes into conflict with string ideology. Is it perhaps the before mentioned mismatch between degrees of freedom as compared to the string theorists conjecture that the correspondence should relate two Lagrangian QFT? Maybe this is viewed as a stumbling block on the way to a TOE. The reason why string theorist are unable to see the agglomeration of too many degrees of freedom on the conformal side may be that the uncontrollable approximations they use inevitably also thin out degrees of freedom; perhaps there exists even a meaningful procedure to prepare a thinning out on the AdS side so that the conformal theory will be of the normal kind as we know it from conformal limits of Lagrangian theories (critical limits in universality classes). Unfortunately the run after a TOE leaves such interesting questions on the wayside.

There is however one deeply worrisome aspect of this whole development. Never before in the history of particle physics have there been around 5,000 publication with inconclusive results on such a rather narrow subject. In fact even nowadays, one decade after this gold-digger’s rush about the Maldacena AdS-CFT correspondence started, there is still a sizable number of papers every month by people looking for nuggets at the same place but without bringing Maldacena's gravity-gauge conjecture any closer to a resolution.

Even with making all the allowances in comparison with earlier fashionable ideas in particle theory, this phenomenon is too overwhelming order to be overlooked. Independent of its significance for particle physics and the way it will end, the understanding of what really went on and it was presented by the media will be challenging problem to historians and philosophers of science in years to come. The main stimulus for this work is the hope that an article like this could facilitate their extremely difficult work. Experience with conjectures in particle physics suggests that a claim which remains unproven for 10 years will never be proven. although after the passing of some time it will be, depending on expediency, presented as an established fact. In physics there are no Fermat-like conjectures which, after lying dormant for a long time, are proved or disproved.
Since commentaries like this run the risk of being misunderstood, let me make perfectly clear that particle physics was a speculative subject and it is important that it remains this way. Therefore I have no problem whatsoever with Maldacena’s paper; it is in the best tradition of particle physics which was always a delicate blend of a highly imaginative and innovative contribution from one author with profoundly critical analysis of others. I am worried about the loss of this balance.

My criticism is also not directed against the thousands of authors who have entered this area in good faith believing that they are working at an epoch-forming paradigmatic problem because their peers gave them this impression. A phenomenon which represents the Zeitgeist cannot be pinned to particular persons; this is a theme to which we will return in the last section.

The field theoretic AdS-CFT correspondence is a special case of a holographic projection which maps a QFT onto a lower dimensional QFT on its boundary. The most useful kind of holography is that of a causally closed theory in a bulk to that of its causal boundary. The best studied case is that of a wedge localized algebra and the algebra on its (upper) causal boundary which constitutes half of the lightfront. This algebraic holography uses modular theory which requires to work with localized algebras. Of course once one knows the holographic projection on half the lightfront it is easy to reconstruct the full lightfront algebra. The algebraic lightfront holography can be used to derive a universal area law for the localization entropy associated with a horizon [57].

Another implementation called projective holography consists in applying the holographic projection directly to pointlike fields [51]. This holography on null surfaces is extremely useful because, different from the AdS-CFT holography, it is not a correspondence but rather a projection, in fact the image on the null surface is much simpler than the bulk. This makes it possible to study certain properties which in the bulk would be inaccessible with the present technology.

Even though the bulk algebra is not uniquely determined by its holographic projection, one could hope that with additional assumptions the reconstruction of the bulk could be unique. This is certainly the case if the holography permits a description in terms of generators whose ambient Poincaré transformation properties are known. Interesting nontrivial examples are provided by factorizing models in d=1+1 [55][56]. Different from the AdS-CFT correspondence the lightfront holography has no mismatch between degrees of freedom since as a result of the holographic projection there is a thinning out of degrees of freedom, i.e. their density on the lightfront is natural in terms of the lower dimensional lightfront submanifold.

Whereas the null surface holography admits rich applications, is less clear what the AdS-CFT could offer to a theorist who does not believe in the holy Grail of string theory. For this it is helpful to remind oneself of the intrinsic conceptual meaning of holography. One starts from a theory which consists of

[56] In geometric terms this is a holography between the full AdS bulk and its timelike brane at infinity. All other studied holographies are onto lightlike boundaries.
an abstract algebraic substrate (examples: the CCR or CAR algebras) which is structured with spacetime as an ordering device (in the sense of Leibniz) so that for each (without loss of generality causally closed) spacetime region one has a subalgebra of the global algebra. There is nothing more to a QFT than this spacetime-indexed "net of algebras"; among particle physicists with a profound knowledge of QFT it is well known that the spatial ordering of the algebraic substrate is all there is i.e. every property of quantum matter can be derived from this picture. In this setting holography is a rather radical change of the spacetime ordering device keeping the same material substrate.

From this point of view one potentially interesting application comes to ones mind which is not so different from the lightfront holography: simplification of certain aspects of a conformal QFT (e.g. a supersymmetric Yang-Mills model) in the AdS perspective; despite many interesting analogies between chiral theories and higher dimensional QFT little is known about higher-dimensional conformal QFTs. For this purpose the interpretation on the AdS side is important, what matters is that there are some simplifications i.e. one could be at a lookout for integrable substructures which were too much hidden in the original spacetime ordering. Since such investigations would also be independent on the degree’s of freedom issue this would be a completely incontrovertible meeting ground with string theorists who already started such investigations. In principle such changes of spacetime encoding in order to improve computational accessibility make sense without conformal covariance.

Let me emphasize again that I believe that holography is a technical tool and not a physical principle. It simplifies certain aspects of a QFT at the expense of others (i.e. it cannot achieve miracles). The use of such ideas in intermediate steps may have some technical merits, which is quite a lot in an area where credible nonperturbative statements are hard to come by.

String theory is the first theory (perhaps only the first after the phlogiston theory of burning) which despite missing observational as well as mathematical/conceptual credentials got firmly entrenched in the mainstream of particle physics. The question is how was this possible in a science which is considered to be the home of rationality and observability is a difficult one. Human activities even in the exact sciences are not completely independent of the Zeitgeist and the glory and power of the invigorated post USSR capitalism with its "end of history" frame of mind at the begin of a new millennium was looking for some shiny scientific counterpart whose glory was not clouded by having 20 unexplained parameters around. It was nevertheless the easy and even somewhat (theoretically) unmerited of the standard model which contributed to that somewhat arrogant frame of mind to go all out for a TOE.

String theory was the appropriate vehicle since its mathematics is relatively

\[37\text{In fact there is even a more general (and more abstract) characterization of QFTs in that a net of algebras including its spacetime ordering (and the action of the Poincare group) is uniquely determined in terms of the relative positioning of a finite number of "monads" (copies of the unique hyperfinite type III}_{1} factor algebras) in a common Hilbert space.}\]

\[38\text{Most properties of particle physics are lost in the conformal critical limit, the only candidates which are expected to survive such limits are highly inclusive cross sections.}\]
rich so there was no danger to fall back behind the mathematical sophistication which since the time of Atiyah and Witten dominated parts of QFT. Although there were (and still are as we have seen) many metaphoric aspects concerning its physical-conceptual content, it is certainly less vulnerable to criticism that the previous failed two attempts of a "Weltformel" and of a unique S-matrix bootstrap.

The lack of challenging pronouncements of string theory is rarely the result of fear to damage one's reputation and career although with leading and influential particle physicists enthusiastically supporting this certainly plays a role. But what weighs more heavy here is the fact that the profound knowledge which would be necessary to start a different direction is not passed on; the limited amount of time one has for carving out a career in particle physics excludes the acquisition of potentially important knowledge which may be important for innovative work but which happens not to be in the vicinity of one's line of research. This is of course part of a much wider sociological problem but it is aggravated by string theory since by covering up this problematic it makes it even virtually impossible that anybody acquires that knowledge which could lead to its own demise. Experimental results as those expected from the LHC are hardly capable to bring down string theory. There are simply too many excuses in case of e.g. of a continued trend of no signal for supersymmetry. String theory may be poor in predictions, but it is rich in postdictions.

8 Responsibilities? No scapegoats

In almost all areas of human activities times of crisis are not only times of trying out new directions but also times of lookouts for culprits and scapegoats. Given the necessarily highly speculative nature of particle physics research on fundamental theoretical problems it is self-defeating to give space to the latter activity. It would be a very bad idea to curb the speculative side and restrict particle theory to mathematically controllable publications.

In normal times proposals which do not comply with existing theories often led to new physics; and in order to find out whether a proposal has such a potential one needs some time. To be accepted by the community and be added to the pantheon of physics, a theory must be subject to observational tests and undergo a critical review of its physical conceptual content which certainly includes a clear positioning with respect to the established theory.

String theory was the first such proposal which, as the result of its Planck scale interpretation, was exempt from the observational requirement. In this situation of lack of direct observability, a fundamental theoretical discussion about its conceptual basis would have been of the highest importance and priority. At the time of its existence as phenomenological dual model proposal for strong interaction, there was yet no compelling reason to do this, but when it laid claims to be the first TOE which incorporates gravity, there should have been an extensive discussion. This chance was missed; unlike the similar situation around the S-matrix bootstrap during the 60s, there was no such discussion.
when the dual resonance model changed to string theory. String theory moved
directly from strong interaction phenomenology to a TOE by only adjusting
the numerical string tension from its value in the Regge setting to the Planck
setting which amounts to a jump of 15 orders of magnitude without changing
one iota in the formalism.

Our main criticism of string theory in section 6 was a refutation of its
metaphoric trespassing of Heisenberg’s dictum on quantum observables i.e. the
insistence in attributing to quantum objects an intrinsic interpretation which
is not only independent of classical analogies but also the quantization method
by which the object has been constructed. Contrary to general opinion and
to terminology, the objects associated with the canonically quantized Nambu-
Goto Lagrangian are point-localized generalized free fields and there is no reason
whatsoever to expect that interactions will magically convert them into string-
localized objects. Unfortunately the physical content of string theory hinges
on the string interpretation.

In this context I cannot resist to cite an aphorism (of unknown source),
which perfectly characterizes the problem with metaphors in QFT: something
which looks, moves, smells and sounds like an elephant is really an
elephant; in QFT there is no recourse to metaphors which permit dif-
cerent conclusions. For the case at hand: the N-G quantum object is really
a generalized free field despite the fact that its classical action in a functional
integral representation suggests a string-like localization. Pointlike fields with
an abundance of particles (infinite mass- and spin-towers) do not arise from La-
grangians in QFT, but the N-G Lagrangian does not arise in QFT. Nevertheless
one has all reasons to be surprised about obtaining a generalized free field.

In the concrete application: a relativistic quantum theory whose commu-
tators signal pointlike localization is really a pointlike localized QFT even if it
carries many more degrees of freedom than a standard (Lagrangian, Wightman)
QFT model.

In order to avoid any misunderstanding on this point let me emphasize that
I am not criticizing the somewhat metaphoric style of research of theoretical
physicists as opposed to mathematicians. Most physicists can perfectly live
with the realization that the so-called Born probability density interpretation
of the square of $|\psi(x)|^2$ cannot be found in Born’s paper which rather deals with
the notion of the scattering cross section in the Born approximation. He also
will not leave his rocking chair if he notices that the famous paper by Virasoro
does neither contain the central term nor all the frequencies (he only wrote the
algebra for the parabolic subgroup). If the string in string theory would be
just a misleading name and everybody would know that the N-G Lagrangian

\footnote{Such unfounded expectations of string theorists irritated Feynman and led to his statement that string theorists offer excuses instead of explanations.}

\footnote{Generalized free fields were hitherto only used in order to argue that settings which admit them (as e.g. the Wightman setting) need to be further restricted. Phases space restrictions on the cardinality of degrees of freedom certainly eliminate such fields which lead to abnormal thermal behavior (appearance of a Hagedorn temperature). They have never been observed in nature but do occur in theoretical constructs as e.g. the correspondence of a free AdS field to its conformal lower dimensional image.}
leads to a very special generalized free field and hence the expectation for the interacting case would be a pointlike field with an overpopulated quantum field theoretical phase space the only raised eyebrows would be those of schoolmasters. In that case the way for an intrinsic understanding of the position of the string-induced generalized fields within the enormously large class of pointlike APD fields (abundant phase space degrees) would have been free. By following the autonomous logic of this problem one had (and still has) a chance of a deeper understanding of the the metaphoric idea of a unitary Poincaré group representation on a fluctuating target space of a chiral QFT and its hidden power to tell string theory on what spacetime dimension it has to live.

But this is unfortunately not how things developed; the stringy objects wig- gling in spacetime have not been limited to the stuff from which Brian Green composes his Nova videos, but they are rather the core of opening mantra of talkers about string theory. And let me add, every string physicist I talked to believed that string theory describes precisely such objects.

The return to a past which was less strict on observability (at least at the level of a thought experiment) has made a long lasting imprint on particle physics because a misleading metaphor on such a central place once accepted by leading researchers is bound to spread and contaminate the whole setting. Indeed, accepting the first metaphor leads to the second namely defining interaction through Euclidean ”tubism” and so on, up to the point where the whole setting becomes incomprehensible in any autonomous sense. It seems that in this way one becomes well-prepared for the ultimate metaphoric step; the fundamentalist idea of a TOE.

A criticism of its central claim of replacing point- by string- localization as in this essay (but formulated at the right time in the 60s), may not by itself have changed much, but it could at have least prevented the metaphoric excess concerning terminology.

Now, almost 4 decades later, and in spite of worldwide attention and an enormous number of publications, the conceptual status of string theory has remained as obscure as at the beginning. This conceptual uncertainty and in particular the above central metaphor about its localization is the ideal breeding ground for further metaphorical thoughts (even in cases in which completely rational results would be available. One such idea, namely the string theoretical view of the AdS-CFT correspondence and the more than 5,000 publications without credible results was already subjected to a critical review in the previous section.

The present critical situation in particle physics is regrettable, since many of the string theorists are very competent and intelligent people, well prepared to make important observations. Without Maldacena´s contribution the issue of a field theoretic AdS-CFT correspondence would not have arisen and we would still be at the level Fronsdal’s group theoretic observation. Even to people (as myself) who are not able to attribute to it the status of a holy Grail in the string theoretical setting of a TOE containing quantum gravitation, the AdS-CFT correspondence is an interesting observation because it makes one aware that a radical change of the spacetime ordering device brings about a drastic
change of the physics, even if the shared abstract matter substrate is "only" being re-organized in spacetime.

It is regrettable that following the fundamentalism of a TOE seems to make people intellectually arrogant and blind or immune against criticism. An essay like this has hardly any effect on the string community; it would be utterly naive to have illusions on this point. Its only value may be that it facilitates the task of future historians and philosophers of science to understand what happened to particle physics at the end of the millennium. One can be sure that there will be a lot of public interest in work dedicated to obtain some explanations about this strange episode in the midst of the exact sciences.

In the case of the S-matrix bootstrap which preceded string theory (and from which it inherited the idea that the central object should be the S-matrix with crossing property which it then changed to duality), there was substantial criticism. It was not directed against the S-matrix properties as such after all had been abstracted from QFT. Rather the main cause of irritation came from the anti-QFT ideology behind the S-matrix supremacy and the claim of the uniqueness of the solution to those principles (a TOE without gravity). If one removes these excessive claims, the bootstrap framework consists of a list of correct S-requirements, but unfortunately (apart from 2-dim. factorizing models) provides no means for their implementation.

The S-matrix community actually enriched particle physics by making quantum field theorists more aware of the principle of nuclear democracy which is the on-shell relic of Murphy's principle of interacting QFT namely that all states which can be coupled according to their superselected quantum number are actually coupled. The on-shell version of this principle is called the principle of nuclear democracy. It is beautifully realized in the explicitly solved factorizing models. Contrary to a widespread opinion confinement does not contradict nuclear democracy since invisible/confined/dark objects may be associated with seminfinite string localized fields which cannot be produced by ordinary matter but live nevertheless in a common physical Hilbert space non all fundamental may appear on-shell and lead to compactly localized composites which generate ordinary matter.

To say it again, it would be wrong to attribute the demise of S-matrix bootstrap at the time of the strong return of QFT in form of QCD and the discovery of the standard model to errors or shortcomings in the S-matrix postulates. The fierce backlash was rather caused by the loud-mouth attempts of some of its leading defenders to cleanse particle physics from QFT in conjunction with the poverty of credible results.

A convincing argument for the soundness of the underlying S-matrix principles came from the success of the bootstrap program and its extension to the bootstrap-formfactor setting in the context of factorizing models which started in the late 70s. Of course the existence of infinitely many such models for which the classification of bootstrap S-matrix solutions contradicted totally the TOE

41I apologize to the reader for using metaphoric terminology, but in this case I do not know any better formulation which would be suitable in an essay like this.
 expectations; perhaps for this reason did not interest the bootstrap protagonists as Chew, Mandelstam, Stapp. They were after a TOE in the setting of the S-matrix bootstrap and the least they would be interested in (except Mandelstam) was a method for a new nonperturbative constructive setting of factorizing QFT using formfactors of local observables.

The sociological situation at the crucial time of the transmutation of the dual model to the string-theory TOE was quite different. Even though QFT had a strong come back and the standard model was universally hailed as impressive (and from a modern perspective somewhat unmerited and untimely) achievement, for many it did not present a large enough projection screen of their ambitious imagination, in particular because it said nothing about gravity which moved increasingly into the center of interest. There were two ways to pursue such an aim, either follow the reasonably safe but somewhat lengthy and winding path of QFT in CST, hoping that eventually one will get to a point which requires the natural intervention of quantum gravity. The other one followed by the majority was to play a riskier game by trying out more speculative attempts which, if successful, could lead to quantum gravity and possibly the holy Grail of a TOE in what alpinists call a diretissima.

The first path had led to unexpected fundamental insights. Particle physicists became aware of thermal aspects of causal localization which were first noted in a rather abstract mathematical context of QFT and independently in the more concrete physical context of black holes localization on both sides of an event horizon. Extensive investigations, with started with the covariance properties of the energy-stress tensor in curved spacetime, finally led to the discovery of the local covariance principle which states that isometric spacetime submanifolds have unitarily equivalent quantum physics, thus this principle goes a long way towards establishing properties in QFT in CST which strictly speaking were hitherto ascribed to quantum gravity.

There are also recent results about cosmology. In particular there is presently no reason to speak about a cosmological constant trouble since there exists at present there exists no calculation which is consistent with this new principle (the quantum mechanical estimate which led to the well-known much too large value is not consistent).

On the other hand the string theory approach has led to many computations but no physical insight apart from metaphoric scenarios. It is the living demonstration of the "compute and shut up" maxim; whoever wants to see particle theory as an unfolding of principles or at least as a conceptional guide (say on the level of the particle physics discussions of the 60s and 70s) will be disappointed.

In view of the fact that a highly speculative task as research in particle theory depends on a delicate calibration between the inventive and the critical side of

\[\text{Whereas one may have serious doubts about the validity of the well known aphorism about string theory as a theory of the 21st century which fell by look onto the 20. century, its adaptation to the standard model appears more credible.}\]

\[\text{The thermal KMS property is a byproduct of the application of modular operator theory to QFT.}\]
fundamental research, the present situation is worrisome. Even having witnessed the beginnings of string theory one looks in vain for a scientific explanation how a failed phenomenological model coming from the setting of Regge poles could have been elevated by not much more than a "semantic trick" (and a scale-sliding of 15 orders of magnitude) to a trans-Planckian TOE, a truly unique phenomenon in physics which would dwarf any achievement of Galileo, Newton, Einstein, Heisenberg and you name it. There is really nothing which can match the grandeur of superstring theory.

Just imagine for a moment that a particle physicist of the 60s would be time-shifted into the millennium string theory community. The only aspect which would prevent him to think that he is in a madhouse for particle physicists is the presence of some Nobel prize winners. He would listen to praises of string theory as "the gift to the 21st century which fell by luck already into the 20th century" and note with disbelieving amazement that the depth of this theory requires still several decades before one knows what is in it. He also would have to get used to a new deployment of big Latin letters. To him the use of the letter M with the invitation to interpret it as mystic, magic etc. a plea for the use of metaphors in particle theory research. Our hypothetical time-shifted visitor will also still somewhat disbelievingly listen to statements about attempts to make sense of new developments as the following (taken from Wikipedia):

In the 1990s, Edward Witten and others found strong evidence that the different superstring theories were different limits of an unknown 11-dimensional theory called M-theory. These discoveries sparked the second superstring revolution. When Witten named M-theory, he didn't specify what the "M" stood for, presumably because he didn't feel he had the right to name a theory which he hadn't been able to fully describe. Guessing what the "M" stands for has become a kind of game among theoretical physicists. The "M" sometimes is said to stand for Mystery, or Magic, or Mother. More serious suggestions include Matrix or Membrane. Sheldon Glashow has noted that the "M" might be an upside down "W", standing for Witten. Others have suggested that the "M" in M-theory should stand for Missing, Monstrous or even Murky. According to Witten himself, as quoted in the PBS documentary based on Brian Greene's "The Elegant Universe", the "M" in M-theory stands for "magic, mystery, or matrix according to taste."

This playful name-coquetry permits the writer of these lines to avoid to take a stand on the content. Needless to add that the opening mantra for all introductory talks/articles on string theory usually starts with something like this:

String theory is a model of fundamental physics whose building blocks are one-dimensional extended objects (strings) rather than the zero-dimensional points (particles)

In recent times the emphasis on the stringlike localization of their objects as opposed to pointlike has somewhat subsided, but it would probably be too optimistic to think that this could have something to do with a better appreciation of the intrinsic meaning of localization of quantum objects, one of the most subtle in particle physics. To hope for a statement which corrects 4 decades of
incorrect narration about string localization will be in vain; if it happens at all, then only as part of a swan song of string theory.

Of course metaphors in quantum theory were used before, but they only appeared in connection with intuitive arguments were it was clear that they were transitory placeholder i.e. represented an temporary formulation which should be replaced by a intrinsic permanent one.

There is a certain grain of (perverse) truth in string theorists self-defense in hard pressed situations (e.g. panel discussions or interviews) when they adopt the argument of David Gross that notwithstanding all criticism, superstring theory is "the only game in town". Similar to the words of a character in the late Kurt Vonnegut's short story (which Peter Woit [3] used in a similar context):

A guy with the gambling sickness loses his shirt every night in a poker game. Somebody tells him that the game is crooked, rigged to send him to the poorhouse. And he says, haggardly, I know, I know. But its the only game in town.
Kurt Vonnegut, The Only Game in Town [332]

the situation in string theory is self-inflicted, although its defenders make it appear as the result of an inevitable development in particle physics. Self-fulfilling prophesies with disastrous consequences are better known in politics, but it appears that with the widespread acceptance of string theory this is the first time they also entered particle theory although the meaning of "disastrous" in both cases has different dimensions

I do think that pied pipers with their TOE tune have a negative influence on particle physics. They tend to direct the young ambitious minds away from the main line of particle research in which an increasing unification was obtained as a side result of a natural step for step natural development following the intrinsic logic and avoiding jumps which create gaping conceptual holes as the ones which led to string theory.

The new fundamentalist style can only be maintained within a very large worldwide group as part of "big science". Just imagine that somebody would use that metaphoric way of arguing without having a large community behind him. The fear that people could think that he must be off his head would probably prevent him. The metaphoric approach aiming at a TOE within a large TOE receptive community and big science are the prerequisites for sustaining superstring theory. In fact once a bright individual has entered that area he already has accepted the use of metaphoric arguments and he probably will not even become aware that he is moving outside Heisenberg’s notion of quantum observables which bans the use of classical metaphors. prohibits the use of that deep contradiction with the fact that quantum theory started with Heisenberg’s banning metaphorical classical arguments in favor of strict adherence to quantum observables.

For more than three decades considerable intellectual and material resources in the form of funding research laboratories and university institutions have been going into the advancement of string theory. and this has led to a marginalization of other promising areas. So the statement that there is no other game in
town has become true in a very literal material sense. At no time before has a proposal, which for more than four decades did not contribute any conceptual enrichment or observable prediction to particle physics, been propagandized even into the most remote corners.

In front of the scientifically interested public it is not easy these days to raise doubts about the scientific soundness of string theory and extra dimension, because as a traditional scientist one is not accustomed to confront propaganda a la Green [61][62] to which the science interested public is exposed. But inasmuch as in a democratic society it is difficult to blame individuals for deformations, the miscarriage of particle physics can only take place if the educated public, meaning we, starts tolerating or accepting arguments uncritically and allows scientific spin doctors to use the media in order to praise their favorite product. A successful seduction does not only require a skilled seducer, but also people who despite all their knowledge and critical capacities permit themselves to be seduced which is not a good situation for starting a blame game. As political events show, these processes of mass seduction only happen under special circumstances i.e. they are strongly coupled to the Zeitgeist whose direction in particle physics was for a long time coming that of a TOE as a contribution to the millenniums power and glory. This raises the hope of a future change, but unfortunately such long term derailments come at the prize of a lot of destruction which in particle physics amounts to a loss of knowledge.

The long term damage which string theory is causing is not just resulting from a distorted picture of particle physics, as was described in this essay. Highly speculative subjects as particle physics develop in a delicate balance between innovation and critique and are therefore more prone to derailment. The ultraviolet catastrophe and the S-matrix bootstrap were two of the bigger pre-string transitory derailments which dominated the scene for not much more than a decade and they did not led to changes in the way basic courses were structured. So the future physicists having acquired unbiased well-balanced knowledge about particle physics, unlike the above Vonnegut character, never had to confront a "no other game in town" situation as a result of lack of knowledge or misinformation. This situation has changed completely with string theory being the hegemon of particle physics. Large parts of the central concepts of QFT as scattering theory, the subtle connection of particles and fields with localization, i.e. in particular those topics which were explained in this essay are not taught any more. Instead topics as e.g. Calabi-Yao, moduli...which are related with functional representations and have less direct relation to particle physics have replaced them. Since string theory is around for more than four decades it will be extremely difficult to find one’s way out which in turn will lead to a prolongation of the crisis.

Combating the propaganda coming from string theorists and presenting the negative effects of the sociological supremacy of the string theory community is the intention of two recent books [63][64]. Although I would not underwrite each of their arguments I do broadly with their conclusions. In fact the avoidance of being repetitious was one argument for rewriting the present essay in the direction of theoretical consistency problems.
Having stated my viewpoint, the reader will not be surprised that I have no sympathies with TOEs (theories of everything) as a kind of final solution of particle physics although natural gradual unifications as they happened in the past are very desirable. The idea that Einstein’s Deity permits some string theorist to find a closure to fundamental physics, so that for the rest of all days the curiosity of humanity about its material world will end in intellectual boredom (or at best can be re-directed into filling in some technical details, finding new applications or preparing something for the entertainment industry as Brian Green’s cinematic production [61]) appears to me outright quixotic. Ideas like this probably will be cited by historians in a more distant future as representing the hubris and intellectual (not necessarily personal) arrogance of a past millennium Zeitgeist. I hope that if particle physics is not able to find its way back to modesty by itself, that the development and astrophysics and cosmology will help to prod it away from its present metaphoric path.

The perhaps most blunt attacks against the collateral damage of string theory on the basis of the collateral damage it causes came from condensed matter physics notably from the Nobel laureate Robert Laughlin [64]. If the fundamentalist TOE setting needs an extreme counterpart, it is the radical form of the emergence principle as defended by Laughlin. It is hard to agree with an underlying philosophy which negates even those forms of natural forms unification which were very successful in pre TOE times. Even in very successful times (QED, SM) progress in particle physics did not follow Laughlin’s “emergence” catalog.

Solid state physicists as Phil Anderson worry that the significant governmental support which string theory receives maybe to the detriment of research in their own area. From what I was able to observe the main brunt of these regrettable developments caused by letting fundamental physics be dominated by a TOE is string-free particle theory [44].

For a long time physicists were critical of the suggestion that there may be a link between the content of their science and the Zeitgeist. Indeed the interpretation of Einstein’s relativity theory in connection with the relativism of values at the turn of the 19th century is a misunderstanding caused by terminology; relativity is the theory of the absolute i.e. the observer-independent invariants.

A similar sociological question was asked shortly after the discovery of QM. In a book by P. Foreman [63] the author proposes the daring thesis that a theory in which the classical certainty is replace by quantum probability could only have been discovered in war-ridden Germany where Spengler’s book the decline of the west, which represented the post world war I Zeitgeist in Europe, had its strongest impact. I am very sceptical of Foreman’s arguments, I think the more palatable explanation is that the high level of German science especially on theoretical subjects was not at all affected by the destruction of the war; intellectual life remained unaffected, in particular it did not suffer from any state-sponsored anti-semitism.

44At my alma mater (the FU-Berlin), after the discontinuation of QFT the floors were filled with people doing ”ab inicio” calculations of density functionals based on the use of appropriate computational packets.
But for the case at hand I am convinced that the building of the string theory community and its hegemonic power on particle physics is coupled to the millennium Zeitgeist. My arguments are as follows. After the end of the cold war, ideologists proclaimed that global capitalism is the remaining final social order, the end of history \[65\]. The future world was predicted to be democratic and everybody should expect a happy life free of wars and social conflicts. This ideological setting turned out to be quite successful for strengthening the hegemonic grip of globalized capitalism on the world order.

Science is a very important part for the presentation of its power and glory, and a theory of everything for quantum matter at the end of the millennium and the promise of a glorious closure of fundamental physics fell on extremely fertile ground. Superstring theory enjoys strong support in the US; and the European Union together with other states is spending billions of dollars on the LHC accelerator and its five detectors which among other things are designed for the task of finding traces for two of string theories “predictions” namely supersymmetry and extra dimensions. TV series on string theory as \[61\] are unthinkable without the embedding into the millennium’s power and glory Zeitgeist.

It is quite inconceivable, that metaphoric ideas without experimental support would have been compatible with another Zeitgeist. It is impossible that an idea of extra dimension for which there is not the slightest indication from particle physics and which is a graft from the already metaphoric string setting would have been accepted at any previous time.

For a few philosophers and sociologists this surprising regressive development did not come unexpected, especially those of the Frankfurt school of critical theory who anticipated a dialectic change from enlightenment into irrationality in the development of society. According to Horkheimer and Adorno: enlightenment must convert into mythology. Indeed the metaphoric nature of the scientific discourse which gained acceptability through string theory, is the ideal projection screen of a mystical end of time beliefs at the turn of the millennium. No other idea coming from science had such a profound impact on the media and on popular culture. Physics departments at renown universities have become the home for a new type of scientist who spends most of her/his time travelling in order to spread the message of extra dimensions, landscapes of multiverses etc. This had the effect that people outside of science think of intergalactic journeys, star wars, ufos, poltergeists (from extra dimensions) etc. when they hear the word ”superstring” \[66\].

The metaphoric spell of string theory over particle physics cannot be overestimated. Time dependent scattering theory, once one of the high points of a perfect match between applied and structural aspects of QFT has been banalized into a cooking recipe with no reliable knowledge about the resulting properties.

\[45\] In Horkheimer’s words: “If by enlightenment and intellectual progress we mean the freeing of man from superstitious belief in evil forces, in demons and fairies, in blind fate – in short, the from fear – then denunciation of what is currently called reason is the greatest service reason can render.” cited in M. Jay, The Dialectical Imagination. A History of the Frankfurt School and the Institute of Social Research, 1923-1950, Univ. of California Pr., 1996, p. 253.
The corrosive influence of string theoretic metaphors have left their mark even in new textbooks on QFT, were the derivation of time-dependent scattering theory, once the high point of the extremely subtle particle-field relation, has been reduced to a mere recipe, thus copying the recipe style of string theory (where this style is the only possible one). Meanwhile important structural insights attained in a preelectronic era vanished from the collective post-electronic memory. In certain cases they have been re-invented but their remake version remained generally below the conceptual level of the original. It may be interesting to the reader to back this up by the two following concrete illustrations.

The structural problems behind recent proposal of unparticles have been investigated starting from a study of the Kallen-Lehmann two-point function in as far back as 1963 [67]. After the difficulties with incurable infrared problems one encountered if one applied the Wigner particle picture and (LSZ) scattering theory to electrically charged states it became clear that the only way out was to look for a completely new particle concept. Since the notion of infraparticles is fundamental for the understanding of electrically charges states and their generating charged fields (which, as everybody knows, are not identical with the formal Dirac fields in the standard gauge setting of QED). An important step was the realization that the delocalization of infraparticles is closely related to Gauss law [71] and a spontaneous breaking of Lorentz-invariance.

The theory of infraparticles is an important post renormalization contribution to QED. The state of affairs up to the beginning of the century can be seen by following the list of references in [74]. The main motivation namely to overcome the inadequacy of the mass-gap based particle concept is the same for infraparticles and its recent ”unparticle” [68][75] avatar. But the irony is that the somewhat delocalized infraparticles are the most visible objects in QFT; the way to come to dark matter within QFT is certainly not via unparticles. One needs a much more radical delocalization [69]. Phrases as: the known particle physics is based on theories which have a mass gap or are free in the infrared which appear as the opening mantra in one of the cited papers are plainly contradicted by the structure of QED. The important property is the strength of the interaction in the infrared region; QED has the necessary strength, whereas e.g. a pseudoscalar interaction of nucleons with zero mass pions stays below the critical strength in the infrared and therefore remains within the standard particle setting.

In addition to couplings between massive and massless scalar invariant matter there is also the intimately related question about how to extract particle informations from higher dimensional interacting (appearance of fields with anomalous dimensions) conformal field theories. During the reign of dispersion theory within the S-matrix setting conformal field theories fell into disgrace since there was the suspicion that only free conformal theories are consistent with

46The perturbative manifestation is the appearance of infrared divergencies which can be controlled by passing to inclusive cross sections in which the auxiliary infrared cutoffs of ”virtual” photons compensate with the infrared behavior from summation over real photons in cross sections. Non-perturbatively the LSZ in/out fields vanish because unitarity forces the $\delta$- mass shell singularity to spread and become softer.
scattering. This was put on solid mathematical grounds in [72] where it also argued that, since the scale invariance demands that all multiparticle thresholds fall on top of each other, one should expect that information on highly inclusive processes is retained. The still open problem is whether the inclusiveness demands the summation over only infinitely many outgoing configurations or if also an averaging over incoming ones is required. Again the reader may want to compare this with what is presently coming from the unparticle community.

The Araki-Haag theory of particle counters which played an important role in the infraparticle investigations and also as models of counters for Unruh and black hole Hawking radiation suffered a similar fate, this is at least the impression one gets from looking at [73]. Araki-Haag counters are defined in terms of a subalgebra of the algebra of the so-called *almost local observables* which has the property of insensitivity with respect to the vacuum. These subtle conceptual differences between a relativistic QM (the DPI in section 3) and the omnipresence of vacuum polarizations with all the consequences for localization *thermality* in particular for a universal QFT area law for *localization entropy* with a \( \ln \varepsilon \) increase in the attenuation length \( \varepsilon \) of the vacuum polarization cloud around the horizon [9][56].

The worrisome aspect for the development of particle theory of such rediscoveries which willfully ignore the past in order to receive the maximum amount of attention in the present is obvious, it hampers progress and (if noticed) creates cynics. It is our aim in this essay to highlight these developments. In the case at hand, the early research on infraparticles is not work on a particle physics sideline. It is *the core property of any electrically charged particle* and one may ask the question whether it is in the nature of the turbo particle-particle physics with its instant formation of globalized communities around any metaphoric belch of somebody with a high viewing rate to lead to such Un-particle-physics. Hence the real blame goes to those Journals (presumably their editors) who suffer from a disequilibrium between high viewer ratings (and the ensuing high impact indices) but only command over low quality referees.

To learn more about this problem let us briefly look at one of the biggest goof-ups in history of particle theory. It was the publishing of a wrong article in PRL [76] claiming that Fermi’s famous Gedankenexperiment showing that QED leads to the same finite propagations speed \( c \) as the classical theory is incorrect. The author used the fact the Fermi was not mathematically precise in order to impose his interpretation of localization and propagation (the Born-Newton-Wigner localization) which he had elaborated in many previous articles. This was certainly not what Fermi had in mind. The fact that his article was published in Phys. Rev. Lett., a highly reputable journal, had the awkward consequence that the (at that time) editor of *Nature* wrote an enthusiastic article which raised the feasibility of time machines on the basis of these new “sensational” results. As a consequence the subject was immediately taken up

\[47\text{In the relativistic quantum mechanical DPI scheme of section 3 the vacuum insensitivity requirement poses no problem, but in QFT the response to the vacuum of a strictly localized counter poses a challenge. The conclusions of the authors (who cast doubts on the Unruh effect) apply to the DPI of section 3 but certainly not to QFT.}\]
by almost all prominent daily journals in Europe and the US including of course the NYT.

It was not too difficult to convince the editor to accept a counter article [77] which rectifies the incorrect implementation of the problem. The PRL at that time disposed over excellent referees in particle physics so this affair was probably not caused by an uninformed referee but rather by one who thought that a controversial article in the prestigious PRL is a good starting point for having an academic discussion about this rather subtle issue. I don’t think that he expected an explosion into an international media hype on time machines.

Whereas in the 90s journals still had access to referees with a broad background extending well into the beginnings of renormalization theory, this is not the case anymore, and an editorial board which is capable to accept and correct its misjudgement would not fit into the present Zeitgeist. Using the fashionable metaphors and making the right mix with interspersing noncommittal but nice-sounding expectations about observational consequences usually guaranties journal acceptance, whereas the publication of results with a more mathematically and conceptually demanding conceptual background which overstrain its post standard model readers is rejected, especially if in addition the author is not part of the globalized particle physics community.

Again it may be helpful to back up these claims by a concrete illustration. The point I want to illustrate is that vague metaphoric claims about observable consequences are in and precise statements are out. In my arguments linking ”darkness” of matter to noncompact localization of certain objects (in a theory which also may contain pointlike localizable subobjects) it is an inescapable conclusion that there can be no pair creation of such dark matter from ordinary matter [78] so if the planned experiment shows pair creation, my proposal is out. I could not see any clear conclusion in [68], the style of arguing is phenomenological but if it comes to the results one finds the phrase: my goal here is not to do serious phenomenology. How can a journal that has the highest viewing/impact rating work with such uninformed referees who do not know that the issue of un/infra-particles was a much researched topic more than 2 decades before to which the elite of particle physicists e.g. people as Buchholz [71] and Froehlich [70] contributed? Every charge particle is an unparticle in the sense of the Kallen-Lehmann spectral function [68] and certainly such particle form the backbone of standard, visible particle physics.

It is remarkable that in the rejection of my paper which was not even allowed to go to table of a referee it says ”We have considered your manuscript and conclude that it is not suited for Physical Review Letters. We make no judgment on the correctness or technical aspects of your work. However, from our understanding of the paper’s physics results, context, and motivation, we conclude that your paper does not have the importance and broad interest needed for publication in our journal.” Surely the metaphorical embedding was missing, a zero production cross section it too blunt and lacks any entertaining quality.

So my advice to any young physicist who still has to enlarge his impact measure with the journals of highest viewer ratings is to emulate the style of [68]. Since my main purpose was to confirm my suspicions, I got everything I
wanted (although I should admit in all honesty that I probably would not have withdrawn my contribution in case of its acceptance). To confirm my conclusions I also submitted a paper to another high viewer rating journal namely to JHEP about which I know from some of my colleagues that they encountered problems. This time the difficulty started already with the submission, since the content of my paper did not fit any of the required subject headings. Most of them are about social constructs as D-branes, dS vacua in string theory, intersecting branes models, F- and M-theory, (Alice in the wonderland of the little curled) extra dimensions,....which deserve this characterization from the observational as well as from the mathematical side. There are veteran constructs as supersymmetry which wait for more than 4 decades to receive the observable kiss from the prince and there are titles like AdS-CFT correspondence which one could embrace if there would not be the uneasy feeling that in the JHEP menu they mean something metaphoric. There is absolutely nothing on such topics as charges particles and their delocalation, old but important issues which have not been completely solved. Since my proposal involves selfinteracting spin 1 particles I took gauge theory and received the following rejection.

"The interesting papers by Dr. Schroer do not belong to the areas covered by JHEP, which is confirmed by his difficulties in finding the appropriate keywords, as he himself admits. In view of their strong mathematical orientation, a journal like Commun. Math. Phys. A journal on the foundation of quantum physics (eg Foundation of Physics) could also be envisioned."

This is a silly proposal since my paper has nothing to do with mathematical physics nor with what is commonly understood under "foundation of physics". It is false labelling to name a journal with such a restrictive list a journal of high energy physics. This episode points to a real worrying problem which I have suspected behind the editorial policy of JHEP for a long time: the choice between publishing about a subject developing from the intrinsic logic of known physics and one which comes from social constructs of some physicists is not any more available (there is no category "miscellaneous"). Flagships of this new brand of particle physics as JEHP have already institutionalized the metaphoric style.

These examples underline the main theses of the present essay; particle physics is in a deep crisis if not to say it is in a free fall (and that only those who are in the same reference system are not able to see this). Even if string theory would disappear overnight, the crisis which had been growing with it would not disappear. The content of particle theory has been pressed into social constructs which have nothing to do with the physics nature and in many cases do not even enjoy any mathematical control. Since this situation has never existed before, one wonders if and how such complex personalities as Einstein, Dirac, or Heisenberg would operate in such an environment.

The best metaphor for the present situation which comes to my mind is that of Laokoon fighting the snakes which try to strangle him. These snakes bear the names of all the social constructs in particle theory. The expectation/hope that the LHC may solve all these problems and get rid of them appears utterly naive. How can a machine resolve a messy theoretical situation which does not
make credible predictions? Does anybody seriously believe that a veteran social construct as supersymmetry will fade away with a whimper? And is it possible to re-educate the participants in a 40 year march in the wrong direction in a couple of years as e.g. the German’s were re-educated after world war II?

What is more probable is that an increasing number of people will realize that the promised millennium power and glory was a fake; the money going into particle physics will be cut, the number of particle physicists will go down and if everything goes well there will be a new beginning in which archeological study of pre-electronic work will play an important role. It will be a world in which the solution of important unsolved problems is as important as the pursuit of new discoveries. It certainly will not be a world in which one is forced to follow social constructs which are determined by viewer rates.

The title of this last section is a reminder of the futility of looking for individual scapegoats in connection with the ongoing crisis. Whereas it is true that the uncritical support of prominent theorists has contributed to the present situation, it is equally correct to add that this would not have been possible without the tacit approval of all of us. We all (i.e. we particle theoreticians) have tacitly accepted its growth and some of us have even linked their fortune to it.

The conquest of QED, the first renormalized QFT, was not possible without a major conceptual investment. In comparison the discovery of the standard model was rather straightforward from a conceptual viewpoint; the required improvements were related to renormalization technology of self-interacting massive $s=1$ fields; This (apart from the observational verifications) relatively easy conquest may have given rise to the somewhat presumptuous state of mind which led to the idea of a TOE, thus re-creating that mixture of blindness and intellectual arrogance which already accompanied pre-string proposals of a TOE or Weltformel.

A invariable by-product of TOEs is that they, like ideologies and religious beliefs, have a tendency to attract mentally unbalanced people. As a result of the highly abstract nature of the subject these are people who have a problem not with their intellectual capacity; rather their problem is with the malfunctions of their emotions in that they are unable to control their aggressive behavior against others who do not share their opinions. It is a known fact that e.g. statistically the frequency of Asperger’s syndrome is higher in the community of theoretical physicists and mathematicians than in other professions.

A notorious and quite public case is that of a junior Harvard University professor who drove the abuse of fellow physicists (including myself) to unprecedented heights by calling them all kind of names in public blogs which serve as a critical forum for string theory and related subjects. When this individual was using death threats against a fellow physicists I thought it is time to quit my participation and I also decided to rewrite this essay which contained many reactions to the comments of this individual which after this episode did

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48 According to our best knowledge a renormalizable self-interacting massive $s=1$ particles must be accompanied by a massive scalar particle i.e. one does not have to discover that particular $s=1$ interaction which enters the standard model because there is only one interaction.
not any longer make sense. I thought it was more appropriate to criticize the scientific content of string theory than to comment on the statements of an obviously emotionally disordered individual. No area of human activity is immune against attracting individuals like this and hence string theory should be criticized on its scientific merits and not on the basis of an epiphenomenon.

What really shocked me was not the bizarre behavior of one pro-string individual. Rather it was the silence of his colleagues from the Harvard string/extra dimension group for whom he obviously served as a useful fighter for their course. An episode like this is not covered by the title of this last section.

Acknowledgement 1 I thank Fritz Coester for sharing with me his recollection about the Stueckelberg-Heisenberg S-matrix dispute. I also recollect with pleasure several encounters I had with a young string theorist named Oswaldo Zapata whose growing critical attitude and disenchantment with this area of research led him to the previous version of this article and away from string theory into the philosophy, sociology and history of science.

9 An epilog, reminiscences about encounters with Juergen Ehlers

Shortly after my this year arrival in Berlin I received the sad news about Juergen Ehlers sudden death. As every year, I was looking forward to meet him at the AEI in Golm. Being roughly from the same generation (I am only 4 years younger than Juergen). Having been a member of Pascual Jordan's relativity group (before I decided at the beginning of DESY to continue in particle physics under Harry Lehmann's guidance), we naturally had a similar motivational and philosophical background. Juergen was much more advanced and he together with Engelbert Schnecking (now a retired professor at the NYU) were my role models.

The belief that the delicate equilibrium between speculative attempts at innovation and their critical review is crucial in fundamental physics and the uneasy feeling that we are presently witnessing a derailment towards an unhealthy metaphoric unrestrained speculative side was certainly shared by Juergen. His increasing interest in the foundations of quantum theory and his appreciation of the deep conceptual differences between quantum mechanics and quantum field theory which I supported with my knowledge of local quantum physics was the motor of most of our discussions in his office at the AEI in Golm near Berlin.

Part of this interest originated from Juergen’s interest to understand Jordan’s role as the protagonist of QFT i.e. the physics content of Sam Schweber’s poetic words: "Jordan is the unsung hero of QFT" and why Dirac, who favored for a long time a very successful quantum mechanical particle based setting, finally, at the beginning of the 50’s, came around to adopt the more radical

Historically the notion of antiparticles originated through Dirac's hole theory and not through field quantization.
quantum field setting beyond electromagnetic radiation for all kind of matter and radiation.

In 2004 there was a conference about Jordan’s contributions to the foundations of quantum physics where many of the results lost in time (a collateral damage of the great political upheavals) were reviewed and presented to an astonished audience. While scanning the archives of the CBPF library in Rio de Janeiro (to where I moved after my retirement) I came across a 1929 status report about QFT by Pascual Jordan which was quite a revelation to me. In this report Jordan was pleading for a new QFT which is not based on a classical parallelism. Purely on philosophical grounds he was distancing himself from his only 4 year old brainchild “die Quantelung der Wellenfelder”. The reason why this plea of Jordan resonated with me was that ever since my PhD under Lehmann I was working on an autonomous setting of QFT (algebraic QFT, local quantum physics), a program initiated by Rudolf Haag almost 30 years after Jordan’s plea in his 1929 plenary talk. In view of the total absence of conceptual-mathematical instruments and concepts this spirited plea was truly amazing. After I made these connections in my talk at that conference dedicated to the memory of Jordan and his work Juergen became very interested to learn something about the present status of this program.

At that time Juergen also asked me about my opinion on Jordan’s algebraic construction of magnetic monopoles. Shortly before I had seen a purely algebraic derivation by Roman Jackiew on the arXiv. I wrote to Roman and he was probably as surprised as I to find the full argument with all details in Jordan’s 3 page paper (whose 1934 publication in Zeitschrift fuer Physik “was a burial of first class”, a phrase attributed to the relativist P. Bergmann about publications in Z.f.Ph. during the third Reich).

In Jordan’s work on what is nowadays referred to Transformation Theory (the equivalence of the different formulations of QT) he thanks Fritz London for sending his results on this issue before publication and strongly praises the author for the clarity of his presentation. Whereas I took this as matter of encouragement of a young novice to QT in accordance with the more polite social etiquette of the times, Juergen went to the library and red London’s article. He convinced me that, apart from any politeness, Jordan really had profound scientific reasons to be impressed. London’s article is the first article which connects the different formulations with the appropriate mathematical tools as the concept of Hilbert space and rotations therein (unitary operators). Usually one attributes the implementation of these mathematical notions into QM to John von Neumann and overlooks Fritz London, who wrote this impressive article when he was an assistant at the Technische Hochschule in Stuttgart i.e. when he certainly was not part of the great quantum dialog which started between Goettingen, Copenhagen and Hamburg and spread to other places after London’s publication.

After the Mainz conference [79] on the occasion of Jordan’s 100 birthday, Juergen was engaged in a book project about Jordan and in this context he asked me for some advice. In particular he wanted to know whether Jordan’s several papers on what he called the ”neutrino theory of light” should also
enter such a project. Since Jordan's contemporaries made fun of this pet idea of his\textsuperscript{50} (in one even finds a very funny mocking song), Juergen was in favor of ignoring all of those articles about this topic which looked to him (and even more so to Jordan's contemporaries very suspicious). I finally convinced Juergen not to do this. The series of articles under the title the *neutrino theory of light* have of course nothing to do with neutrinos nor with light; in those articles Jordan discovered what is nowadays called the bosonization of fermions (or fermionization of bosons) which is a typical structural property of 2-dim. conformal theories.

Jordan obviously saw the potential relevance of this property, but unlike Luttinger almost 3 decades later, solid state physics (where low dimensional QFTs in certain circumstances turn out to be very useful) had yet no need for such observations on QFT structures. In order to "sell" his nice field theoretic result he used the very metaphoric "neutrino theory of light" label. The false labeling backfired, the result was not only the mentioned mockery by his contemporaries, but also the fact that when bosonization really became an interesting issue in the 60's, nobody expected a the interesting content about bosonization behind Jordan's metaphoric title; *such things simply did not work well in those times*.

Nowadays papers in which not only the title but also the content is metaphoric have the best chance to be accepted in career supporting journals especially if their content fits with the socially accepted metaphors of their subject lists and in this way they cause the least amount of work to fashion-conscious referees. I reminded Juergen of the actual world we live in, where the combination of metaphoric title with an interesting rather well-defined non-metaphoric content is rare. As a result he told me that he will retain at least one paper of the neutrino theory of light topic from the dawn of bosonization/fermionization. Obviously Juergen realized that in view of the present crisis in particle physics the metaphoric faux pas of Jordan, for which he was mocked by his contemporaries, was a nostalgic memory about better times. With this remark we have returned to main theme of this essay and its wistful contrast with a style of physics of which is so excellently conveyed in the person of Juergen Ehlers.

With all differences in the interpretation of Jordan's legacy removed, I was looking forward to new encounter with Juergen in order to enlarge my feeble knowledge on matters of astrophysics and general relativity (gravitational lensing,...) in order to broaden the basis of my recent interest in dark matter. As a "payback" I wanted to explain to Juergen in more detail the fundamental conceptual differences between QFT and relativistic QM concerning the totally different forms of "entanglement". My aim was to convince him that the black hole information loss (a 40 year old problem which led to a still ongoing controversy) is a pseudo-problem which resulted from confusing the information-based ("Gedanken") entanglement coming from quantum mechanical Born-localization with the kind of entanglement coming from field theoretic localization. The latter leads to the well-known thermal manifestation (includ-

\textsuperscript{50}The critical reaction against the metaphoric "neutrino theory of light" title of Jordan’s papers caused his contemporaries to overlook their very interesting bosonization/fermionization content.
ing a universal area proportionality which has a pure local quantum physical origin independent of the classical area law which Bekenstein derived in Einstein-Hilbert like classical field theories). This time I was much better prepared as last year since I had done a lot of homework [9].

I miss Juergen, I cannot think of anybody as knowledgable, as interested in fundamental questions beyond his own area and at the same time endowed with an amazing critical power.

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