The “Crisis in Fundamental Physics”
- Will the LHC Pomeron End it ? *

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Abstract

SU(5) gauge theory with massless left-handed fermions in the representation $5 \oplus 15 \oplus 40 \oplus 45^*$ (QUD) may have a bound-state S-Matrix that, uniquely, contains the asymptotically unitary Critical Pomeron and which might also reproduce the full Standard Model. If so, QUD would provide an underly-ing unification for the Standard Model in which very similar massless fermion anomaly dynamics is responsible for the physics of the strong and electroweak interactions and all particle masses are generated dynamically. The color sextet quark sector, responsible for both electroweak symmetry-breaking and dark matter in QUD, is predicted to produce large cross-section effects at the LHC, with the pomeron as a vital diagnostic - via TOTEM/CMS and FP420.

In this talk, the multi-regge construction of high-energy QUD amplitudes is outlined as is, briefly, the LHC pomeron physics. Surrounding motivational issues (particularly outstanding QCD problems) and consequences are also discussed. The S-Matrix anomaly physics is conceptually and philosophically radical with respect to the current theory paradigm. As a consequence, QUD could provide a welcome way out of the current “Crisis in Fundamental Physics” with, potentially, it’s novel physical applicability resolving a variety of Standard Model and, perhaps also, cosmology problems - it has zero vacuum energy.

*Presented at the 5th Manchester Forward Physics Workshop, Dec. 2007.
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1. INTRODUCTION.

As I suggested\[1\] at this meeting last year, SU(5) gauge theory with massless left-handed fermions in the representation $5 \oplus 15 \oplus 40 \oplus 45^*$, which I refer to as $\text{QUD}^\dagger$, may have a bound-state S-Matrix that, uniquely, contains the Critical Pomeron and which might also reproduce the full Standard Model. According to my arguments, strikingly simple massless fermion anomaly physics would then provide a very special underlying unification of the strong and electroweak interactions. All particle masses would be dynamical and, remarkably, although there is an underlying SU(5) gauge symmetry there would be no new S-Matrix interactions beyond those of the Standard Model.

That the Critical Pomeron uniquely satisfies all the constraints of t- and s-channel multiparticle unitarity could, perhaps, imply that QUD is unique as a field theory generating a unitary massive particle S-Matrix. (Most likely, only the S-Matrix is well-defined non-perturbatively.) In total, the implications of QUD’s existence are so far reaching that, initially, “the willing suspension of disbelief”\[3\] may be required to even consider it. Almost certainly, experimental discovery will be required to produce the serious interest that I believe is merited. Fortunately, if QUD does underly the Standard Model, the color sextet quark sector producing both electroweak symmetry-breaking and dark matter should be dramatically evident via large cross-section effects at the LHC - particularly in the double pomeron cross-section that TOTEM/CMS and FP420 will measure.

As part of this talk\[4\], I will outline the multi-regge construction that potentially relates the QUD high-energy S-Matrix to the Standard Model. To carry through the full program\[5\] outlined is an enormous challenge that badly needs the extra participation that experimental encouragement would surely bring. I will briefly review the relevant LHC pomeron physics but will not discuss at all the related Cosmic Ray, Tevatron, and $S\bar{p}pS$ evidence that I have described elsewhere\[1, 6\].

A major focus of the talk will be on surrounding motivational issues and consequences. In particular, why high-energy unitarity could be essential in providing the key to new physics, will be clear from my discussion of existing problems in the formulation of QCD. The search for the unitary Critical Pomeron then leads to the novel dynamics which underlies the existence of the QUD high-energy S-Matrix - the central element being the color compensation of perturbative reggeon exchanges by anomalous wee gluons coupled to massless fermion anomalies. For the strong interaction QCD sector the anomalies are infra-red, while in the electroweak sector the interactions remain effectively perturbative at low energy because the anomalies

\[\dagger\text{Quantum Uno/Unification/Unitary/Underlying Dynamics}\]
involve infinite fermion transverse momenta. In general, the dynamics (the absence of a Higgs’ field included) is both conceptually and philosophically radical with respect to the current theory paradigm, which is (presumably) a major reason why QUD has not emerged in direct unification searches. In fact, the current theory paradigm is actually in a crisis mode of serious self-doubt that QUD could provide a very welcome way out of. As I will describe, it is just because the physical applicability of QUD is at variance with conventional wisdom that it could, potentially, resolve a wide range of existing puzzles in the Standard Model (and cosmology - it has zero vacuum energy).

2. THE CRISIS

Arguments by leading theorists (Weinberg[7], Susskind[8], and others[9]) have led to what Smolin[10] has called a “Crisis in Fundamental Physics”. The crisis is epitomized by asking the following question - based on the “string-theory landscape”.

“With an infinity of universes proposed, and more than $10^{400}$ theories, is experimental proof of physical laws still possible?”

A retreat to the (end of science?) “anthropic principle” - physical parameters are determined by the existence of life - is a common response. Adding to the bewilderment (says Smolin), in the 35 years since the formulation of the Standard Model, all proposals for “new physics”, including GUTS, supersymmetry, technicolor, string theory and (most recently) extra dimensions, have failed to make any contact with experiment - even while introducing a wide variety of interactions, particles, and new parameters. (The last discovery of a new interaction was, of course, much more than 35 years ago!) To quote Schroer’s opening line[9]

“There can be no doubt that after almost a century of impressive success fundamental physics is in the midst of a deep crisis.”

Theoretically, there are far too many (ill-defined) candidate new theories, while experimentally there are none! Searching for new theories via the symmetry-based aesthetics championed by much of the theory community has not found a focus, even though there has been no shortage of imagination! Doubling the number of particles to achieve supersymmetry, when not a single partner has been seen, and adding extra dimensions that “curl up” out of our sight both seem far-fetched to “real world” theorists, as well as many experimenters. (If neither is discovered at the LHC, this will surely be the historical perspective !) Indeed, all of the theoretical constructs that lead to the epitome question above are pure speculation for which there is no experimental evidence. In this sense, the “crisis” is entirely self-induced by theorists.
Apparently, there is insufficient constraint (either theoretical or experimental) on the development of new ideas and there is much concern[9, 10] that a major change may be needed in the paradigm underlying the current formulation of particle theory.

### 3. THE PARADIGM?

In 1999 Gross[11] discussed how the discovery process that led to QCD invalidated the preceding attempt to obtain a strong interaction theory by bootstrapping a (supposed to be unique) unitary S-Matrix. He stated a commonly held opinion.

“We now know that there are an infinite number of consistent S-Matrices that satisfy all the sacred principles. One can take any non-abelian gauge theory, with any gauge group, and many sets of fermions ... The hope for uniqueness must wait for a higher level of unification.”

In fact, this statement is “breathtakingly misleading” - to use Bill Clinton’s phrase[12]. Gauge theory S-Matrices can only be calculated perturbatively. In D=4 the perturbation expansion for every field (and string) theory is wildly divergent and, almost certainly, can not be summed. There is no non-perturbative formulation of any theory that can derive S-Matrix amplitudes - let alone discuss unitarity.

Nevertheless, it became accepted that general principles, including (most particularly) non-perturbative unitarity, are irrelevant in the search for a physical theory. The conventional wisdom developed that the Standard Model is a well-defined lagrangian quantum field theory, since it was assumed that once perturbative renormalizability had been proved all the desired properties of a full, non-perturbative, field theory would also be satisfied§ - with a unitary S-Matrix automatically included. From this viewpoint, the Standard Model fits the experimental data but, otherwise, is just one of an infinity of renormalizable field theories that nature could have chosen. Progress beyond the Standard Model would only be determined by new experimental phenomena that would have to be similarly fitted by an enlarged field theory. Since such phenomena had yet to be discovered and long distance physics was well understood via QCD, they would necessarily have to occur at a short distance not yet explored. Given the viewpoint expressed by Gross, theorists speculating about new physics that might appear were not fettered by any fear that the long-distance physics demand for unitarity of the physical S-matrix could make any significant selection amongst candidate theories.

The general assumption was that there should be a unifying quantum field theory that would include the Standard Model (and which, if the quantization of

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§Even though it was acknowledged that a mathematical effort of unimaginable, herculean, magnitude would be required to prove this[13].
gravity is to be included, should embed in a string theory - the search for which became, of course, the major preoccupation of the theory community over the last two decades, culminating in the epitome question of the last Section). The unifying field theory would be detected via the required additional interactions. The extra, far from trivial, assumption had to be made that there would be no conflict between the intrinsic non-perturbative applicability of QCD (involving confinement) and the perturbative applicability of the electroweak sector. Although there was no explicit understanding of how it could happen, it was believed that a transition from perturbative to non-perturbative confinement physics would simply be a consequence of the evolution of couplings with the scale involved.

Gross[11] also argued that the regge region had been given too much attention*. He said that short-distance experiments provide the most information and that regge behavior is merely

“an interesting, unsolved, and complicated problem for QCD”

If the arguments that lead me to QUD are correct, this widely held view could not be further from the truth. The regge region is where, a priori, the connection between perturbative and non-perturbative physics should be explicitly evident (since a mixture of small and large momenta is involved). Indeed, regge-region (reggeon) unitarity is deeply related to other fundamental problems in the formulation of QCD (that I will discuss below) and is central, I will argue, in the construction of a fully unitary gauge theory. The viewpoint that the more difficult dynamical problems in QCD can be put aside because they are not fundamental for going beyond the Standard Model, has clearly been a major factor in allowing the unlimited speculation that has produced the theory “crisis”. It should be noted that the freedom of invention associated with the guiding principle/paradigm that progress will come via inspired guesses for missing short-distance physics, combined with experimental verification via related rare processes, has not yet received any experimental confirmation and, most importantly, there is no historical precedent for assuming that it will.

Indeed, as we discuss next, the long distance and regge region physics of QCD is not well understood and our argument will be that it is by getting this physics right that we are led directly to the underlying physics of the full Standard Model.

4. QCD PROBLEMS

There are three interconnected, unresolved, problems for the standard formulation of QCD.

*Experimenters working on diffraction have lived with this attitude for a long time.
1. The Spectrum of States

The conventional wisdom is that the physical states are determined by the two principles of color confinement and (when quarks are involved) chiral symmetry breaking. Neither principle has been proved, although there is also no experimental violation of either principle. However, if color confinement is the only feature constraining the field theory degrees of freedom appearing in physical states, then glueballs should be everywhere. As Chanowitz says[14],

“Glueballs are a dramatic consequence of the local, unbroken, non-Abelian symmetry that is the unique defining property of QCD. ... The prediction that glueballs exist is simple and fundamental but has proven difficult to verify”.

In fact,

*not a single glueball has been seen (unambiguously) in any experiment[15].*

Apparently, there is a major limitation on the degrees of freedom - physical states must contain quarks?? This problem has received only limited theoretical attention, in part because there is no resolution within the standard formulation of QCD.

2. The Parton Model

Factorization theorems say that leading-twist perturbation theory is consistent with the parton model - leading to the “QCD-improved parton model”. However, even though it is the basis of all perturbative applications, there is

*no derivation of the parton model in QCD.*

As elaborated on at length in [16], the true parton model envisaged by Feynman requires that infinite momentum hadrons have quark/gluon wave functions. This is a very intricate requirement that has no reason to be true if there is a non-trivial, confining, vacuum. (Even though it is probably essential for asymptotic freedom to be maximally applicable.)

For the desired wave-functions to exist, the “wee partons” - with finite momentum in the infinite-momentum frame (and zero momentum at finite momentum) - must play the role of the vacuum and so must be universal. As illustrated, schematically, in Fig. 1, the wee partons in a hadron dominate pomeron exchange. For wee partons to be universal, the pomeron must have the factorization properties of a regge pole.

This problem has also not received much attention, presumably because the parton model, like confinement, works so well that (since QCD is obviously correct!!) it can only be that it is indeed valid in QCD.
3. The Pomeron

A priori, the perturbative BFKL pomeron should appear at large $k_\perp$ - together with an odderon. However, as Ewerz says[17],

“QCD predicts the existence of the perturbative pomeron and of the odderon. Both of them appear to be rather difficult to observe experimentally.”

In fact,

*there is no (unambiguous) evidence for the BFKL pomeron and, essentially, zero evidence for the odderon.*

At small $k_\perp$, it is established experimentally that the pomeron couples directly to quarks (c.f. total cross-sections) and that it has the factorization properties of a regge pole.

Apparently, BFKL gluons (which would be directly related to a sub-set of glueballs) could well be absent in physical high-energy amplitudes. Moreover, quarks should be the essential elements of the high-energy states. The BFKL pomeron has received so much attention and has produced such an enormous literature that there is major resistance, by theorists, to acknowledging the lack of experimental confirmation that is, nevertheless, well-known to experimenters.

The BFKL pomeron also has serious theoretical problems. Firstly, it violates both s- and t-channel multiparticle unitarity[18] (with higher-order corrections, very likely, making the problem worse). Secondly, because it is not a regge pole, wee parton factorization is absent and Reggeon Field Theory (RFT) can not be used to obtain higher-order contributions[18, 20] via reggeon unitarity.

That the gluonic degrees of freedom involved in the physical states and amplitudes of QCD are more restricted than conventionally assumed, and that this may be related to the wee parton physics underlying the parton model, is the vital, conceptually radical, message that will take us beyond the Standard Model to QUD.
5. THE CRITICAL POMERON AND QUD

The Critical Pomeron[2] is obtained as a fixed-point renormalization group solution of RFT and uniquely satisfies both \( s \)- and \( t \)-channel multiparticle unitarity. It was originally formulated as an elementary regge pole plus interactions for two reasons. Firstly, as noted above, the pomeron is approximately a regge pole phenomenologically and, secondly, \( t \)-channel reggeon unitarity is satisfied[20] by the build-up of the RFT interactions of a regge pole. As we noted in the last Section, a third reason is provided by requiring the factorization property needed for the existence of a parton model - for which the pomeron must be a single regge pole (plus interactions).

In a gauge theory, and QCD in particular, reggeon diagrams (transverse momentum diagrams containing “reggeized” gauge boson and fermion regge pole propagators) provide a well-established perturbative description of high-energy regge behavior. If a QCD parton model can be derived then, a priori, these diagrams might be expected to provide the appropriate technology. An immediate problem is that if confinement is to appear, it can only be via infra-red divergences. That the Critical Pomeron, along with the wee partons required for the parton model, can indeed be obtained from infra-red divergent reggeon diagrams is a highly non-trivial construction that it has taken me many years to formulate. As I describe below, a very special version of QCD (QCD\(_S\)) is required, which then has to be embedded in a unique larger theory - QUD. Confinement is indeed part of the outcome, but there is a much stronger restriction, than simple zero color, on the gluon degrees of freedom.

It might be anticipated that a major restriction on field theory degrees of freedom would involve fermion anomalies. Moreover, only the anomalies of massless fermions have infra-red significance. As we will see, it is novel massless fermion anomaly dynamics that strongly restricts the physical degrees of freedom in both QCD\(_S\) and QUD. Longitudinal gluon interactions allowed[16] by the Gribov quantization ambiguity also play a crucial role. My uncovering of this dynamics relates back to the controversy[19] that occurred thirty years ago concerning the properties of a unitary supercritical RFT phase. To satisfy reggeon unitarity in this phase, a “pomeron condensate” has to be produced by the wee partons in a hadron[20]. Obtaining this condensate from the infra-red divergences of reggeon diagrams, is the key to understanding the origin of the Critical Pomeron in both QCD\(_S\) and QUD.

Before describing the dynamics, we first summarize the path that connects the Critical Pomeron to QUD and describe the basic properties of this theory.
5.1 The Path to QUD

1. The first step is to match supercritical RFT with the superconducting phase of SU(3) gauge theory in which the color symmetry is reduced to SU(2).

2. The next step is to show that the Critical Pomeron occurs in unbroken QCD when asymptotic freedom is “saturated”. This is achieved with six color triplet quarks plus two color sextet quarks - giving what we call “QCD$_S$”.

3. Adding the electroweak sector, the $W^\pm$ and $Z^0$ eat the “sextet pions” and electroweak symmetry breaking occurs - with no new interaction! The electroweak scale is the QCD sextet chiral scale - in agreement with Casimir scaling!

4. To cancel the electroweak short-distance anomaly and to generate masses, the sextet sector is embedded in a left-handed unified theory. Asking for the appropriate electroweak quantum numbers for the sextet sector, together with asymptotic freedom and anomaly cancelation, uniquely selects SU(5) gauge theory with the fermion representation

$$5 \oplus 15 \oplus 40 \oplus 45^* \leftrightarrow \text{QUD}$$

5.2 SU(3)xSU(2)xU(1) properties of QUD

QUD contains QCD$_S$ and under $SU(3) \otimes SU(2) \otimes U(1)$ the SU(5) representations give

- $5 = (3, 1, -\frac{1}{3})^3 + (1, 2, \frac{1}{2})^2$,
- $15 = (1, 3, 1) + (3, 2, \frac{1}{6})^1 + (6, 1, -\frac{2}{3})$,
- $40 = (1, 2, -\frac{3}{2})^3 + (3, 2, \frac{1}{6})^2 + (3^*, 1, -\frac{2}{3}) + (3^*, 3, -\frac{2}{3}) + (6^*, 2, \frac{1}{6}) + (8, 1, 1)$,
- $45^* = (1, 2, -\frac{1}{2})^1 + (3^*, 1, \frac{1}{3}) + (3^*, 3, \frac{1}{3}) + (3, 1, -\frac{4}{3}) + (3, 2, \frac{7}{6})^3 + (6, 1, \frac{1}{3}) + (8, 2, -\frac{1}{2})$

The requested sextet sector is shown in bold face. The triplet quark and lepton sectors, which were not asked for, are amazingly close to the Standard Model! There are three “generations”, labeled by $\{1\}, \{2\}$ and $\{3\}$. The electroweak $SU(2) \otimes U(1)$ quantum numbers are not quite right and so to be physically relevant this sector,
like the QCD sector, can not be perturbative. After the initial discovery\textsuperscript{[22]} of QUD it was very frustrating that no form of symmetry breaking appeared able to give the Standard Model directly. Only after I fully understood the anomaly dynamics producing the QCD\textsubscript{S} S-Matrix, did I realise that QUD could give the Standard Model S-Matrix via the same dynamics. For this, it is very important that the lepton anomaly is correct and that there are three sets of triplet quark/antiquark pairs with charges $\pm \frac{2}{3}$ and $\pm \frac{1}{3}$. It is also crucial that, as can be seen from the above representation decompositions, QUD is charge conjugate, and therefore vector-like, only with respect to $SU(3) \otimes U(1)_{em}$.

It is surely remarkable that by simply asking for a sextet quark sector capable of producing electroweak symmetry breaking, we are led to a minimal SU(5) theory that, via the dynamics that I outline next, contains just enough, and only enough, to produce all the states and interactions of the Standard Model. As we will see, beyond the potential quark and lepton generations there is only

1. A sextet quark sector that, as a complex $SU(3)$ representation with a large color casimir, produces a new large mass strong interaction sector that is responsible for both electroweak symmetry breaking and dark matter.

2. A “lepton-like” octet quark sector that, as a real $SU(3)$ representation, provides a short-distance anomaly contribution which produces $SU(5)$ invariant leptons that have no strong interaction and that, together with similarly produced hadrons, form Standard Model generations.

3. Two exotically charged quarks that, apparently, have no dynamical significance.

6. STATES AND AMPLITUDES

A priori, obtaining not only bound states but also their scattering amplitudes, would be considered an impossible task in a gauge theory where there are (according to our own assertion) no off-shell Green’s functions. Fortunately, as we outline below, multi-regge theory (very specially) allows us, in principle at least, to simultaneously construct bound-states and S-Matrix amplitudes, for both QCD\textsubscript{S} and QUD, using perturbative reggeon diagrams. Since multi-regge limits are defined, in effect, so that infinite momentum frame kinematics are introduced in some Lorentz frame for each state and interaction, in the special case that “vacuum properties” are carried by “universal wee partons” as discussed in Section 4, a perturbative starting point may be sufficient to access multi-regge region “non-perturbative” physics. In fact, this physics will emerge in a surprisingly simple manner.
Although the “infinite momentum” description of physical states is likely to be quite different from descriptions at finite momentum there must, of course, be consistency. In fact, since the infinite momentum (or regge) limit is where perturbative and non-perturbative physics must come together, the form of the infinite momentum states can be viewed as a boundary condition determining whether or not candidate bound-states, that appear to be present at finite momentum, can be present when there is a matching with large momentum perturbation theory.

The multi-regge formalism also allows us to systematically build up the effects of massless fermion anomalies at high energy. (We will not attempt to discuss what the corresponding finite energy phenomena might be.) As we will describe, we start in a color-superconducting phase in which all reggeons are massive (i.e the gauge symmetry is spontaneously broken - completely). The reggeons are also gauge-invariant and carry global representations of the gauge group. It is well-known that in the massless limit, the reggeization exponentiation of infra-red divergences “confines” the global color - although color zero massless reggeon states composed of massless gluons remain. In our construction, these states are removed and true confinement is produced by an additional, non-exponentiating, “anomaly divergence”. This divergence will also be the source of the pomeron condensate that we are looking for.

There are two elements that combine to produce the anomaly divergence. The first is “anomalous gluons”, which are configurations of gauge boson reggeons that (in a limited sense) are multi-reggeon generalizations of the well-known “anomaly current”. The second is “reggeon vertex anomalies” which occur in fermion loop effective vertices and provide the couplings for anomalous gluons. As we will describe, when there is a transverse momentum cut-off an infra-red anomaly divergence occurs when the transverse momenta of all anomalous gluons in a multi-regge amplitude are scaled uniformly to zero. In the residue of the divergence, therefore, all reggeons are actually on mass-shell and carry zero transverse momentum. Consequently, they can be referred to simply as “anomalous wee gluons”.

6.1 Anomalous Gluons

For vector reggeons, the signature ($\tau$) of a reggeon state is simply the odd/even number of reggeons. Signature is also related to charge conjugation (C) and parity (P). When parity is conserved, the combination of incoming and outgoing states to which a reggeon combination couples can be assigned a parity which is also carried by the reggeon state. In this case $\tau$ is also the sign obtained by a TCP transformation of the complete coupling. If the scattering particles are scalars, then $T$ simply interchanges the ingoing and outgoing particles, and so it must be that $\tau = CP$. Initially, we define $C$ and $P$ perturbatively so that $C$ includes color charge conjugation.

“Anomalous gluons” are sets of gluon reggeons that carry color zero but have color charge conjugation parity $C$ with $C \neq \tau$, implying that (when parity is con-
served) anomalous gluon couplings must carry $P = -1$. The absence of a d-tensor implies that for SU(2) color only odd signature anomalous gluons are possible. Also, for forward scattering $P = -1$ implies that there must be a perturbative parity change between the initial and the final scattering state. In a helicity-conserving massless vector theory, such a change can only come from an anomaly vertex that contains a zero momentum chirality transition—as we discuss next.

6.2 Reggeon Vertex Anomalies

Anomalies appear in “effective triangle diagram” reggeon vertices that are generated when fermions in large loops are placed on-shell by a multi-regge limit. Examples, derived in my papers, are shown in Fig. 2.

The longitudinal gluon interactions shown are present in the color superconducting

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The “vacuum” presence of anomalous wee gluons in physical states, that we will describe, will modify the definition of charge conjugation and parity in the physical S-Matrix.
phase and their survival in the massless theory is allowed by the Gribov ambiguity. The anomalies occur only in vertices that couple distinct reggeon channels. As a result, when anomalous gluons are a sub-component of a multi-reggeon state they can not have a zero transverse momentum perturbative reggeon interaction with the other (massive) reggeons in the state. This property prevents the exponentiation of the anomaly divergence in a vector theory.

A priori, the effect of the anomalies is dependent on the color symmetry restoration and cut-off removal procedure used. (The procedure we employ has the major justification that it produces a unitary RFT description of the high-energy behavior by exploiting the wee parton Gauss law ambiguity.) It is the Ward identity violation produced by the $k_\perp$ cut-off in anomaly vertices that causes the infra-red anomalous gluon divergence. It is crucial that the residue of the divergence contains anomaly poles that are generated[6] (within the anomaly vertices) by zero momentum chirality transitions.

Anomaly poles have two distinct roles. Poles associated with a flavor anomaly are Goldstone boson particle poles**. As illustrated in the first example of Fig. 2, a Goldstone (pion) pole is produced when a set of anomalous “wee” gluons, with $k_\perp = 0$, couples via an effective triangle diagram to a quark-antiquark pair that also carries a light-like momentum. Poles associated with the U(1) anomaly do not contribute as particle poles but instead contribute as $\delta$-functions that conserve the wee gluon transverse momenta involved in anomaly divergences in distinct reggeon channels - as illustrated in the second example of Fig. 2.

A chirality transition is essential for the generation of an anomaly pole. In effect, these transitions, and the quantum numbers of the amplitudes in which they appear, are a consequence of the initial reggeon mass generation. Since they are also, essentially, the zero momentum propagator contribution to a condensate, they play an analagous role to condensates - but only in the $S$-Matrix. In QCD, the chirality transitions do not conflict with the global color symmetry. Instead, they break both color parity - producing a regge pole pomeron and confinement - and chiral symmetry. In QUD only the vector part of the color group is not in conflict with the chirality transitions and this is why Standard Model interactions emerge.

A comprehensive and detailed analysis of the momentum and color structure of reggeon vertex anomalies is amongst the many areas where much more work will be needed even after we elaborate, in [5], the technical details behind the outline we give in the following. It is important that the chirality transitions appear only in the anomaly interactions and so they do not produce the range of off-shell phenomena that condensates produce. In fact, because the reggeon masses decouple straightforwardly in all non-anomaly reggeon interactions, the associated large $k_\perp$ perturbation theory

**The kinematics responsible for the appearance of a Goldstone boson as an anomaly pole at infinite momentum are detailed in [23].
is given by the massless theory. Provided, therefore, that we limit our discussion to the bound-state S-Matrix we can combine infra-red (effective) symmetry breaking via chirality transitions with asymptotically-free, massless, perturbation theory.

6.3 Multi-Regge Amplitudes Via the Anomaly Divergence

For both QCD$_S$ and QUD we start, as we already noted, with masses for all reggeons (both gauge bosons and fermions). With a $k_\perp$ cut-off in place, we can smoothly restore the gauge symmetry in steps, utilising complimentarity[25], provided the masses are generated by expectation values for fundamental representation scalars. For QCD$_S$, SU(3) color is restored via the two steps

$$\rightarrow SU(2) \rightarrow SU(3)$$

while to reach the SU(5) color symmetry of QUD requires the sequence of limits

$$\rightarrow SU(2) \rightarrow SU(3) \rightarrow SU(4) \rightarrow SU(5)$$

(In fact, we go straight from SU(2) to SU(4).) In both cases, we remove the $k_\perp$ cut-off before the last step (utilising the scalar field asymptotic freedom that results from a very small $\beta$-function).

As the initial SU(2) symmetry is restored, bound-states and interactions emerge together in multi-regge amplitudes containing the anomaly divergence. The simplest examples are “di-triple-regge” amplitudes[20] of the form illustrated in Fig. 3.

![Diagram of di-triple-regge amplitudes](image)

Figure. 3 A Di-Triple-Regge Amplitudes.
Because the gluons involved are anomalous, there are no interactions to exponentiate the divergence. The divergence will also survive[23] self-interactions amongst the anomalous gluons if color zero reggeon interactions have the scaling property that holds when all fermions are massless and there is an infra-red fixed-point[24], as is vitally the case in both massless QCD$_S$ and QUD.

Physical amplitudes are obtained by factoring off the anomaly divergence and interpreting it as an odd-signature anomalous wee gluon “vacuum condensate” that is universally present in all states and interactions. The amplitude given by Fig. 3 can be represented diagramatically as in Fig. 4.

![Diagram of the Physical Amplitude](image)

Figure. 4 The Physical Amplitude, $T =$ Chirality Transition.

The interaction that appears is simply the color zero combination of a finite transverse momentum gauge boson reggeon in the $k_\perp = 0$ wee gluon condensate, but with an anomaly interaction coupling that contains a chirality transition as shown. This is the origin of the pomeron in QCD$_S$ and of the pomeron and the electroweak interactions in QUD. The effect of the anomaly coupling is to produce an even signature pomeron from an odd signature perturbative reggeon. At this stage, electroweak interactions are also even signature. They will become odd-signature as the full gauge symmetry is restored in QUD.

As is also illustrated in Fig. 4, the bound-states are anomaly poles that first appear after the initial SU(2) color restoration. An anomaly pole will survive interactions if it is a Goldstone boson associated with the breaking of a chiral symmetry involving complex conjugate representations of the color group. The bound-states can also be represented as color zero fermion/antifermion combinations in the anomalous wee gluon condensate. Within the effective triangle diagram the anomaly pole results from the production of a fermion pair, one of which is a zero momentum hole state that undergoes the chirality transition to become physical via the compensating anomalous wee gluon emission. Even though it becomes physical, the hole state
remains “soft” while the initially physical fermion carries[23] all the longitudinal momentum. As illustrated in Fig. 4, the hard fermion then couples to the perturbative reggeon that carries the interaction transverse momentum.

According to this last description, the full bound-state interaction can be viewed as a hard perturbative interaction that is accompanied by a color-compensating wee parton “vacuum condensate” component whose coupling is responsible for a “zero-momentum shift of the Dirac sea” in the scattering bound-states. Equivalently, we could drop the reference to the vacuum condensate exchange and instead talk only about a perturbative reggeon exchange that has “vacuum produced” color-compensating, shifts of the Dirac sea within the couplings so that the “perturbative” interaction involves zero color exchange.

### 6.4 The Pomeron Condensate and the Critical Pomeron

A very important consequence of the presence of the wee gluon condensate in bound-states is that, as illustrated in Fig. 5, it is directly responsible for the “vacuum production” of pomerons in higher-order amplitudes that is equivalent to the existence of a “pomeron condensate”. This is the wee parton production of the pomeron condensate that we anticipated in Section 5 would be the clue to the origin of the supercritical pomeron. Indeed, the generated amplitudes are, apparently, just those of supercritical RFT. If the mapping onto supercritical RFT is complete (much remains to be done to establish that it is), the pomeron becomes critical as SU(3) color is restored. The pomeron condensate vertices will be absorbed into regular RFT vertices as the reverse of the process described in [20]. The Critical Pomeron is then even signature and composed entirely of anomalous gluon configurations - including those in the condensate - that do not include BFKL gluons.

![Figure. 5 Pomeron Vacuum Vertices Produced by the Reggeon Condensate](image)

Relating the anomalous gluon emission from anomaly vertices to the (hole) displacement of the Dirac sea that produces the chirality transition, we can describe it as gluon production via a “Fermi surface fluctuation”. The fluctuation can then be viewed as the order parameter of the pomeron phase-transition. In the supercritical phase it is a correlated wee parton “vacuum condensate” introduced by the
color symmetry breaking. At the critical point the Fermi surface fluctuations become dynamical and uncorrelated (i.e. random within the SU(3) color group). These fluctuations then combine with perturbative reggeon exchange to produce the color zero long-range collective phenomenon that is the Critical Pomeron. In QUD, as we discuss further below, the Fermi surface anomalous wee gluon emission (and Critical Pomeron behaviour) is limited to a non-abelian subgroup with vector-like couplings to the sea. Because QUD is vector-like with respect to an SU(3)xU(1) subgroup only, the parity conserving SU(3) color strong interaction emerges.

Note that, because only global color symmetries (and not gauge symmetries) are involved in our reggeon diagram constructions, it is straightforward for color zero reggeon states to be formed from reggeons carrying very distinct transverse momentum (including zero for condensate reggeons).

7. Massless QCD$_S$

The physical states of QCD$_S$ correspond to the Goldstone bosons of the superconducting theory in which only SU(2) color is restored. This includes both quark/antiquark mesons and quark/quark “nucleons”. The nucleons acquire an extra quark as SU(3) color is restored. We have yet to provide a description of how this takes place in reggeon diagrams, but we anticipate that the additional quark will be “soft” and similar, if not identical, to the hole produced quark that is already present. This would produce the additive quark model for total cross-sections and would also imply that both meson and nucleon reggeization are a consequence of quark reggeization.

The only new states that appear, in addition to triplet mesons and nucleons, are sextet “pions” and “nucleons” ($P_6$ and $N_6$). There are no hybrid sextet/triplet quark states and

\begin{center}
no glueballs.
\end{center}

(This spectrum is consistent with, but much less than would be obtained by simply imposing confinement and chiral symmetry breaking.) If the sextet pions are eaten by $W^\pm$ and $Z^0$ vector bosons, the only remaining new states are sextet nucleons. The $N_6$ will be stable[6] and dominate ultra high-energy cross-sections. Sextet neutron matter provides a perfect candidate for dark matter.

As we have already described, the interaction is the Critical Pomeron. In the color superconducting theory (and before interactions in QCD$_S$) the pomeron is a regge pole produced by reggeized gluon exchange in the anomalous wee gluon condensate. This provides the basic interaction which builds up the universal wee
partons needed for the parton model. Compared to conventional QCD, the QCD$_S$ states are fewer and the interaction is simpler - in agreement with experiment!

*There is no BFKL pomeron, and no odderon.*

As part of our solution of the wee parton problem, the non-perturbative physics of confinement and chiral symmetry breaking has a very simple “infinite momentum” diagrammatic representation - supplemented by an RFT critical phenomenon. Correspondingly, the transition from short-distance perturbation theory to the regge region is also simple. In particular, the regge behavior of both the pomeron and hadrons, which is very well established experimentally, is a direct consequence of the regge behavior of gluons and quarks, which is similarly well established theoretically.

We can not apply QCD$_S$, in isolation, to hadronic physics because adding triplet quark masses would destroy the dynamics. Also, there will be a large number of massless triplet quark mesons, which may well threaten the existence of an S-Matrix. The only way, that we know of, to add (effective) quark masses without destroying the dynamics is to embed QCD$_S$ in QUD. Of course, as we have already described, this embedding is also required by the addition of the electroweak interaction.

**8. QUD**

The construction of the bound-states and amplitudes of QUD is considerably more complicated than the QCD$_S$ construction. The most essential new element of the construction is the presence of *fermion loop reggeon interactions* (without an anomaly) that are *parity violating*. With a $k_\perp$- cut-off, these interactions *exponentiate all anomaly divergences involving left-handed reggeon couplings*. The conjugacy properties of QUD then imply that an anomaly divergence can occur only in an SU(3) subgroup and also that only the corresponding chirality transitions can be present. Equivalently, the Dirac sea fluctuations producing wee gluon emissions are necessarily confined to a subgroup with charge conjugate fermion couplings. The result is the *emergence of an SU(3) color singlet strong interaction*. The obvious question is, of course, how is SU(5) invariance maintained? As we will see, the essential element is the presence of the real SU(3) representation octet quarks (which in going from QCD$_S$ to QUD seem, at first sight, to be unwanted!)

We follow the construction process described in Section 6. Using the notation $SU(3)_C \otimes SU_L(2) \otimes U(1)$ to denote the decomposition of subsection 5.2, we identify the various SU(5) subgroups as in Fig. 6. SU(3)$_C$ is, therefore, chosen to be a vector interaction. We restore the SU(2)$_C$ symmetry first, followed by the SU(4) symmetry. Restoring the SU(3)$_C$ symmetry then coincides with the final restoration of the full SU(5) symmetry.
Because SU(2)$_C$ is a vector symmetry, its restoration produces an anomaly divergence which plays the central role of selecting (what will eventually become) the physical states. As in QCD$_S$, these states are identified as anomaly pole Goldstone bosons (\( \pi_C \)'s) with respect to some chiral symmetry that is present at this stage. These will be \( q\bar{q} \), \( \bar{q}q \), and \( q\bar{q} \) pairs in an SU(2)$_C$ condensate, where the \( q \)'s are 3's, 6's, \\& 8's under SU(3)$_C$. Very importantly, 8's are real with respect to SU(3)$_C$, but contain complex doublets with respect to SU(2)$_C$ that will have the chiral symmetry required to produce anomaly pole Goldstone bosons.

An obvious interaction that will be SU(3)$_C$ invariant (after this symmetry is restored) is an SU(2)$_L$$\otimes$U(1) singlet vector boson in the SU(2)$_C$ condensate. This will become the pomeron. Interactions that will similarly become SU(3)$_C$ invariant are the SU(2)$_L$$\otimes$U(1) electroweak bosons - also in the condensate. The SU(2)$_C$ condensate additionally produces wee gluon anomaly interactions, of the kind illustrated as the last example in Fig. 2, that give a mass to the left-handed electroweak bosons, i.e. the \( W^\pm \) and \( Z^0 \).

This process is equivalent to a mixing with the \( \pi_C \) states that, after the restoration of SU(3)$_C$, will be dominantly sextet pions. In the process, the \( W^\pm \) and \( Z^0 \) acquire an anomaly-based flavor symmetry that protects them from an exponentiation that would otherwise destroy the condensate that accompanies their exchange.

Restoring SU(4) symmetry involves only left-handed and abelian vector bosons and so all new divergences exponentiate, leaving only states and interactions that are SU(4) invariant. The SU(2)$_C$ condensate can now be regarded as summed (or averaged) over all SU(2) subgroups within SU(4), with SU(2)$_L$ defined always as the corresponding orthogonal SU(2) group. “Leptons” are present as reggeon bound states of “elementary leptons” and “octet pions” (\( \pi_C \)'s composed of 8's)). “Hadrons”
containing a triplet “pion”, or a triplet “nucleon”, combined with octet quark pions will also be present, as will the analogous sextet states. The SU(2)\(_L\)\(\otimes\)U(1) quantum numbers of octet \(\pi\)’s are such that the elementary lepton components must have (modulo gauge boson contributions) the generation structure of the Standard Model. At this stage, both leptons and hadrons are formed via the same infra-red anomaly dynamics and have essentially the same properties.

The restoration of SU(5) symmetry is an elaborate phenomenon that, as yet, I only partially understand. In outline, the following is what I think happens. Firstly, the pomeron becomes critical - as an SU(3) subgroup interaction that is summed over subgroups. (Again, it is important that the color symmetries discussed here are global symmetries, and not gauge symmetries.) As in QCD\(_S\), the lowest-order pomeron is a vector reggeon exchange accompanied by a color-compensating (reggeon condensate) shift in the Dirac sea within an SU(2) subgroup. To avoid divergence exponentiation, the interactions that build up the Critical Pomeron are necessarily confined to the same SU(3) subgroup.

As I currently understand it, the anomaly role of the octet quarks is at infinite momentum. With SU(3)\(_C\) restored, the octet \(\pi\)’s no longer produce infra-red anomaly pole Goldstone bosons. Instead, as a consequence of our cut-off manipulation, they contribute to bound-states as (what would normally be unphysical) zero mass anomaly poles generated by on-shell quark/antiquark pairs which have infinite, but opposite sign, energies. The cancelation of infra-red Goldstone boson effects has the consequence that the chirality transition is transferred to infinite momentum. As a result, the creation of SU(5) invariant physical states involves shifts of the Dirac sea at both infinite momentum (for SU(3) octets) and zero momentum (for SU(3) triplets and sextets). Therefore, as will be elaborated on in much more detail in [5], the interplay between ultra-violet and infra-red contributions to the triangle anomaly plays a crucial role in the emergence of SU(5) invariance.

SU(3)\(_C\) reality of the octet representation also implies that the octet \(\pi\)’s have no infra-red (anomaly) coupling to the pomeron and so leptons\(^{\dagger \dagger}\) have no strong interaction and no infra-red SU(3)\(_C\) mass generation. With the octet \(\pi\)’s at large \(k_\perp\), the SU(2)\(_L\) symmetry will appear, via the low \(k_\perp\) components of states, as the SU(2) flavor symmetry of the sextet sector. The quantum numbers of the octet \(\pi\)’s should then produce the singlet/doublet structure of the Standard model. If the bound-state lepton contribution to the infra-red SU(2)\(_L\)\(\otimes\)U(1) anomaly has to be equal to the perturbative contribution, the existence of three generations of leptons would be implied. Anomaly cancelation would then require three generations of quark hadrons that similarly contain the octet pions.

\(^{\dagger \dagger}\)A detailed description of lepton states is given in my Fermilab talk listed in [1].
After SU(3)$_C$ restoration the SU(2)$_C$ vacuum condensate contribution to $\gamma, W^\pm$ and $Z^0$ exchange becomes an even signature “condensate” effect that couples only to the large momentum octet component of the states. (The infra-red coupling to hadrons will be part of the interaction in which the pomeron is exchanged along with the $\gamma, W^\pm$ and $Z^0$.) There will also be a condensate coupling to the octet quark component of the states that will be part of the pomeron. Hence, the SU(5) invariant electroweak and strong interactions have very similar origins.

- The electroweak interactions are perturbative reggeon exchanges together with an orthogonal SU(3) singlet anomalous wee gluon exchange that couples via an octet Dirac sea shift at infinite momentum. Apart from the mass generation, therefore, these interactions will effectively be perturbative at low-energy.

- The elementary pomeron (underlying the Critical Pomeron phenomenon) is perturbative reggeon exchange together with anomalous wee gluon exchange, both within an SU(3) subgroup, that couples via a triplet or sextet Dirac sea shift at zero momentum and an octet shift at infinite momentum.

The mass spectrum will be generated by a combination of perturbative reggeization effects, color factors which (via the high mass sector, in particular) will emphasize the SU(3) strong interaction and anomaly interactions (analogous to that generating the $W$ and $Z$ masses) which will mix all the reggeon states. A wide range of scales will clearly emerge. Without a better understanding of the anomaly interactions and the related wee gluon distributions it is unclear, however, how many parameters may be involved. Although CP violation could be a consequence of the anomaly dominance of interactions, with our current very limited understanding of QUD it is certainly not obvious that it is necessary. Nevertheless, given the absence of any conflicting symmetry, there appears to be no reason why the physical mass spectrum could not emerge.

9. A RADICAL PARADIGM CHANGE

That the anomaly-dominated bound-state S-Matrix of a very small coupling ($\alpha_u << 1/50$), massless, fixed-point, field theory is the origin of the Standard Model is a radical proposal that could have many desirable consequences, if it is correct. We anticipate that the full field theory exists only perturbatively (at short distance) and that the S-Matrix scattering amplitudes are the only well-defined non-perturbative elements of the theory (apart, perhaps, from the induced gravity referred to below). As we discuss next, it is essential for the physical applicability of our proposal that this be the case. The theoretical focus on the construction of a unitary particle S-Matrix within a perturbative field theory, rather than on the construction of a full
non-perturbative quantum field theory, could also be the change in paradigm that has been said to be needed to end the “crisis in fundamental physics”. A priori, since massless fields and fermion anomalies are a crucial feature of the dynamics of QUD, it would not be surprising if off-shell fields can not be constructed for the bound-states we have described. The reggeon vertex anomalies that are at the core of our amplitude construction are an S-Matrix phenomenon and, indeed, the general multi-regge formalism has no off-shell parallel. Without this formalism, of course, there would be no possibility to discover the existence of a bound-state S-Matrix.

In the current theory paradigm where, as described in Section 3, it is assumed that (off-shell) field theory amplitudes are the essential elements of a gauge theory, both QCD_s and QUD lie in what is referred to as the “conformal window”. Within this window, the existence of an infra-red fixed-point is anticipated[28] to produce Green’s functions with infra-red conformal properties that would be inconsistent with a massive particle spectrum. It is presumably crucial, therefore, that QUD violate the assumed paradigm by having no non-perturbative off-shell amplitudes. As a bonus(?), the enormous theoretical challenge[13] of constructing a four-dimensional non-perturbative off-shell gauge field theory would, of course, be avoided. Since physical masses and symmetries are bound-state S-Matrix properties, there is also no need for a Higgs’ field to generate masses or to break symmetries‡‡. Therefore, the particular difficulty of constructing an asymptotically-free theory containing scalar fields is similarly avoided. One of the lessons learnt from the focus on the S-Matrix during the bootstrap period was that (in the absence of quantized gravity, at least) the full physics content of a particle theory is contained within the S-Matrix[27]. Therefore, asymptotically-free perturbation theory together with a unitary bound-state S-Matrix within which an infinite momentum parton model is valid, could be sufficient for all physical applications of QUD. Non-perturbative off-shell amplitudes are a luxury that, from our perspective, are not obviously necessary for any physical reason. Indeed, their absence may be a major factor in unraveling many of the mysteries of the Standard Model.

10. CONSEQUENCES

Obviously, an enormous part of the picture I have outlined remains to be established and it would be truly incredible if the Standard Model has the underlying simplicity that I am proposing. However, all the necessary ingredients do seem to be present in QUD and, in strong contrast with the epitome question of Section 2, it is a unique theory which can not be added to or modified in any way. If it is wrong, there is no fallback position and the conclusion has to be that the pursuit of a unitary

‡‡ As we have described, it is the chirality transitions in the anomaly vertices that, in effect, break symmetries in the S-Matrix.
S-Matrix, along the path I have followed, has simply been misguided.

Although it will surely take a long time to develop an in-depth understanding of all aspects of QUD, if my argumentation (or something not too different) can be followed through it is a self-contained theory - with only Standard Model interactions. Assuming this is the case, there would be many benefits and many puzzles would be resolved.

1. The physics of the strong interaction (including confinement) and the electroweak interaction is, essentially, the same. Infinite momentum non-perturbative physics is very close to perturbation theory and so has a simple diagrammatic representation - with regge behavior emerging straightforwardly.

2. Parity conservation by the strong interaction and parity violation by the weak interaction are naturally explained by the structure of the anomaly interactions that result from the conjugacy properties of the elementary fermion spectrum. (A mass is generated by anomaly interactions only for left-handed gauge bosons.)

3. The only new physics is the strong interaction color sextet sector. This sector simultaneously explains the two major mysteries of the Standard Model, namely the origin of electroweak symmetry breaking and the nature of dark matter. The sextet meson and baryon sectors separately provide what is, surely, a remarkably economic resolution of these two mysteries. There is already suggestive experimental evidence[1, 6] that this is, indeed, the right "new physics".

4. The underlying gauge symmetry implies that there will be unification of the couplings. The presence of the high-mass strong interaction sector allows this to be achieved without supersymmetry!

5. The mass spectrum is not simply determined by elementary masses and the scale evolution of the couplings. Wee parton anomaly interactions mix the reggeon states and, presumably, introduce parameters. The color factors involved will produce a wide range of scales and masses that could very well produce the Standard Model spectrum, since there is no conflicting symmetry.

6. The smallness of the lightest particle (neutrino) masses should be a direct reflection of the small coupling in the underlying field theory.

7. There is no proton decay, but the experimentally attractive SU(5) Weinberg angle should hold!

8. Because QUD is an asymptotically free, massless, fixed-point theory, it has no vacuum energy and (in the absence of the quantization of gravity) would[29] (perturbatively) induce Einstein gravity with zero cosmological constant.

It should be mentioned that reggeon unitarity could be an insuperable problem for the quantization of gravity. If the graviton appears as a reggeized particle in an S-Matrix, reggeon unitarity implies that the exchange of arbitrary numbers of reggeized
gravitons would produce non-polynomially bounded S-Matrix amplitudes (a non-local
to? This is, perhaps, a major argument against the quantization of gravity.

An underlying field theory for the Standard Model in which no fields have
mass is surely attractive, both theoretically and aesthetically. With regard to the
possible origin of the QUD fermion representation it could be significant that it is
contained in a single anomaly-free SO(10) representation - the 144.

11. WHAT SHOULD BE SEEN AT THE LHC?

Since our proposal is so radical, it is fortunate that there are major experimen-
tal predictions for the LHC, for some of which it will be hard not to acknowledge their
significance - if they are seen. Large cross-section effects are expected that should
make the emergence of the sextet sector obvious. If these effects are not seen then
either my understanding of QUD is wrong or the theory is irrelevant! The following is
a very brief review of what is discussed in much more detail in [6] and is also discussed
in [1].

Most immediately, multiple vector boson and jet x-sections will be much,
much, larger than expected, with $< p_\perp >$ approaching the electroweak scale. For
these phenomena there will, however, be competing explanations, e.g. black holes,
sphalerons, etc.

A priori, $N_6\bar{N}_6$ pair production (dark matter) should be seen - with $m_{N_6} \sim
500 \text{ GeV}$. But, missing energies of several hundred GeV will be common and the
low energy $N_6$ hadronic cross-section (in a calorimeter) is probably small. $P_6\bar{P}_6$ pair
production should be seen (if the $P_6$ is not too unstable). Again, though, will a
massive charged particle with a large production x-section be seen as direct evidence
for the sextet sector?

The double pomeron cross-section could provide the most definitive early evi-
dence for the sextet sector. With the pomerons detected via Roman pots, the environ-
ment is clean. $W$ and $Z$ pairs will be produced in the double pomeron cross-section
via sextet pion anomaly poles and so, as pion pairs dominate the double pomeron
cross-section at low mass, so $W$ and $Z$ pair production will dominate the cross-section
at the electroweak mass scale.

When $|k_\perp|$ is electroweak scale, the double-pomeron $W$ and $Z$ pair amplitude
for producing jets is comparable with a standard jet amplitude that has, apart from
anomaly loops that are presumably O(1), the same propagators and couplings. This
suggests that the jet cross-section from double-pomeron $W$ and $Z$ pairs, produced as
illustrated in Fig. 5,
will be comparable with the non-diffractive jet cross-sections predicted by standard QCD. While the $\Pi W^+ W^- \Pi$ and $\Pi Z^0 Z^0 \Pi$ vertices appearing in Fig. 5 should vary only slowly with $k_\perp$, the $pp \Pi$ vertices have strong $k_\perp$-dependence. This implies there should be an extremely large x-section at small $t$.

In the initial low luminosity running, an “extremely large x-section” could be detected by TOTEM/CMS. There could be spectacular events in which protons are tagged and only (a multitude of) large $E_T$ charged leptons are seen in the central detector. FP420 will take over during the high luminosity running and should surely see an enhanced cross-section, even if it is too small to have been seen by CMS/TOTEM. Most likely, the $W$ and $Z$ pair cross-section will overwhelm all other physics.

A large double-pomeron cross-section for $W$ and $Z$ pairs implies that the longitudinal components of the $W$ and the $Z$ have direct strong interactions. The only known possibility for this is the existence of the sextet sector and, as we have discussed, to give a well-defined theory this sector has to be embedded in QUD!

After $\Pi$, $W/Z$, and jet physics has established that sextet quark physics is definitively discovered, the search for “dark matter” will become all important. The cross-section for double-pomeron production of stable $N_6\bar{N}_6$ pairs (with a pair mass $\gtrsim 1$ TeV) could be large enough that it will be definitively seen by the forward pot experiments. It will be a spectacular process to look for - via the following.

1. The tagged protons determine a very massive state is produced.
2. No charged particles are seen in any of the detectors.
3. Having low energy, the $N_6$ hadronic cross-section will, probably, be small but some hadronic activity may be seen in the central calorimeter.
4. Charged lepton comparison would allow a separation with respect to the multiple $Z^0$ production of neutrinos.

If the $P_6$ is relatively stable, and not too different in mass from the $N_6$ it would, of course, be much simpler to first detect $P_6\bar{P}_6$ pairs.

In [6] we gave a lengthy discussion of the possibility that deep-inelastic diffractive $Z^0$ production (via the longitudinal sextet pion component of the $Z^0$) could be
responsible for events with very large $x$ and $Q^2$ at HERA. DIS diffractive $Z^0$ pro-
duction could also be[30] an important discovery process for the sextet sector at the
LHC and, perhaps, even at the Tevatron.

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