LHC card games: bringing about retrocausality?

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Abstract

The model of Nielsen and Ninomiya claims that “the SSC (Superconducting Supercollider) were stopped by the US Congress due to the backward causation from the big amounts of Higgs particles, which it would have produced, if it had been allowed to run”. They also proposed to play a card game and if the “close LHC” card is drawn (with probability $\sim 10^{-6}$), really close LHC on the eve of Higgs particle discovery to avoid more severe bad luck. Crazy? Probably. But paraphrasing Salvador Dali, if you believe that you and me are smarter in physics than Nielsen and Ninomiya, don’t read this article, just go right on in your blissful idiocy. Therefore, I will try to make sense of backward causation. It turns out that not only the backward causation makes perfect sense in some models of possible reality, but that Nielsen and Ninomiya really have a chance to close LHC by a card game. The only thing they need is to be smart enough to manage to develop their theory up to the level of brilliance beginning from which it becomes a part of the fabric of reality. We hope, however, that they will use their outstanding abilities to bring about some more interesting future.

1 Introduction

In a number of seemingly crackpot papers [1, 2, 3, 4, 5], Nielsen and Ninomiya have developed a theory that is undoubtedly crazy. But craziness is not always the reason to reject a theory. If it were we would not have
neither relativity nor quantum mechanics today. Nielsen and Ninomiya base their theory over Feynman’s approach to quantum mechanics which at first sight also seems crazy. Freeman Dyson recollects: Thirty-one years ago, Dick Feynman told me about his “sum over histories” version of quantum mechanics. “The electron does anything it likes,” he said. “It just goes in any direction at any speed, forward or backward in time, however it likes, and then you add up the amplitudes and it gives you the wave-function.” I said to him, “You’re crazy.” But he wasn’t [6]. Therefore, let us take closer look to the idea of Nielsen and Ninomiya.

According to Feynman’s approach to quantum mechanics [7], to find the probability $P_{ba}$ for a quantum system’s transition from a state $|a>$ to a state $|b>$, Nature applies three simple rules:

- Explore all “paths” connecting $|a>$ to $|b>$.
- A complex number of unit magnitude
  \[ A(\text{Path}) = \exp \left( \frac{i}{\hbar} S(\text{Path}) \right), \]  
  called the amplitude, is prescribed to each path.
- The probability $P_{ba} = |A|^2$ is proportional to the squared modulus of the complex number $A$ which is just the sum
  \[ A = \sum_{\text{all paths}} A(\text{Path}). \] (2)

The quantity $S(\text{Path})$ plays the central role in the above scheme and is called action. Usually it is assumed that the action is a real number. Therefore all these complex numbers have unit magnitude and hence if we restrict the system in such a way that the only one path connecting $|a>$ and $|b>$ remains then $P_{ba}(\text{Path}) = \text{const.}$ irrespective of the path chosen. However, the phases of amplitudes may be different and when there are many paths connecting $|a>$ and $|b>$, the probability $P_{ba}$ depends strongly on how these amplitudes interfere with each other.

The novelty of Nielsen and Ninomiya’s approach is that they ask what will happen if we allow imaginary part in the action. Then the equality of paths is broken down because $P_{ba}(\text{Path}) \sim \exp \left[ -2 \text{Im}(S)/\hbar \right]$ and certain
trajectories whose actions have large positive imaginary parts will be highly suppressed.

There is nothing bizarre or unprecedented in considering imaginary parts of the actions. It was shown by Schwinger long ago [8] that the effective action for a constant electric field develops a positive imaginary part. Schwinger interpreted this imaginary part as an indication that the QED vacuum in a background electric field is unstable and in strong enough fields a kind of vacuum electrical breakdown due to spontaneous electron-positron pair production takes place [9].

The imaginary part of the action arises also quite naturally in the WKB description of quantum tunneling. In a tunneling event there are two separated classical turning points which are joined by a classically forbidden trajectory. The probability of tunneling is related to the imaginary part of the action for this classically forbidden trajectory. The most impressive application of this kind of the imaginary part of the action is, probably, the derivation of the Hawking radiation as a tunneling event [10].

Of course, it will be very interesting to experimentally confirm Schwinger’s insight about the imaginary part of the Euler-Heisenberg-Schwinger (EHS) action because there are some theoretically embarrassing moments about this effective action. Namely, the effective EHS action exhibits mysterious statistics reversal: beginning from a microscopic theory of fermion pair vacuum fluctuations we end with the effective EHS action which have a form typical for bosons in a thermal bath, while for the spin-0 effective action the form is typical for fermions in a thermal bath [11]. Besides, the temperature of the thermal bath itself differs from the corresponding Hawking-Unruh temperature by a factor two and nobody knows why [11]. Interestingly, Schwinger mechanism seems to be testable experimentally in graphene which mimics effective relativity with massless fermions [12].

The use of imaginary part of the action by Nielsen and Ninomiya is, however, conceptually different. They want this imaginary part to suppress all histories of the universe except a few, ideally just one history, with pre-selected initial conditions. Such a super-theory will be superdeterministic: if you know exact form of action, both real and imaginary parts, you can predict everything which will happen or happened in this universe.

Of course Nielsen and Ninomiya do not yet have such a theory and I doubt they ever will. However, they develop an embryonic version of it which predicts a large positive imaginary part of the action for every history in which large numbers of Higgs bosons are produced. Therefore, such histories
are exponentially suppressed and never realized.

Up to this point, Nielsen and Ninomiya’s theory, although extravagant, is completely scientific. Moreover, it has a great virtue which every good scientific theory is supposed should have: it is falsifiable. It makes a strong prediction that LHC will never succeed in production of large numbers of Higgs bosons.

However, Nielsen and Ninomiya go beyond this point. They claim that the real reason why the SSC (Superconducting Supercollider) was canceled by USA Congress was that if it had been allowed to run it would have produced big amounts of Higgs particles and such a history is suppressed by the corresponding large imaginary part in the action. Similarly, a bad luck is awaiting to LHC too. To avoid severe potentially harmful accidents which can “naturally” stop LHC if their theory is true, Nielsen and Ninomiya suggest to play a card game. Take about one million cards most of which say “Go on with LHC, discover Higgs boson and be happy” but few of them prescribe some restrictions on allowed LHC energy or luminosity. And just one card says “Stop LHC and never turn it on”. If the “Close LHC” card is drawn, this improbable event, according to Nielsen and Ninomiya, will indicate that their theory of imaginary action is true and we must really close LHC, otherwise some natural or political catastrophic event will do it instead of us.

What we can say about this borderline-crackpot suggestion? First, it does not follow from the Nielsen and Ninomiya’s particular form of the imaginary action. This action simply says that any history with large amounts of produced Higgs particles is extremely improbable. But there is nothing in it which indicates that the history in which LHC is closed by Nielsen and Ninomiya’s card game is more probable than the history in which LHC is simply blown up by terrorists: in both case the LHC will be unable to produce Higgs particles and frankly speaking the second case gives even more guarantees that it never will. Therefore, Nielsen and Ninomiya here are implicitly assuming that we have free will to choose between histories whose imaginary actions are close enough and somehow the histories with less harm to humans are more probable.

Besides, there is one logical loophole in the argumentation of Nielsen and Ninomiya. Suppose their theory is true and all universe histories with big chunks of produced Higgs particles are exponentially suppressed. Does then it mean that LHC will never be able to produce significant amount of Higgs particles? Not necessarily, in light of Multiverse theory.
The Multiverse theory [14, 15, 16] is in every bit more miraculous than Nielsen and Ninomiya’s theory. For example it predicts that about $10^{10^{29}}$ m away there is an exact copy of your [15] reading the copy of this article. Nevertheless, the Multiverse theory is considered as completely respectable, even mainstream theory and many prominent physicists are confident in it. For example, Martin Rees is sufficiently confident about the multiverse to bet his dog’s life on it, Andrei Linde is ready to bet his own life, and Steven Weinberg has just enough confidence to bet the lives of both Andrei Linde and Martin Rees’s dog [14].

The Multiverse theory has two implications for the Nielsen and Ninomiya’s hypothesis. Firstly, it asserts that there is a parallel universe in which the Nielsen and Ninomiya’s card game has been already played and as a result of the game’s outcome the analog of LHC was closed (however this does not prove that Nielsen and Ninomiya’s imaginary action theory is true. Even without this theory, there is a non-zero probability that certain authorities can make a foolish decision). Secondly, even if Nielsen and Ninomiya’s theory is true, there exists a universe in which the exponentially small probability that LHC will be successful is realized. To the delight of high-energy physicists, there is no reason why this universe could not be our own.

Therefore, I think, we have every reason not to worry about LHC card games. The Multiverse theory kills the super-determinism of the Nielsen and Ninomiya’s proposal. In fact, we could not compute our own future even if we had the knowledge of the entire state of multiverse, because there are infinitely many copies of us and our universe and their histories will eventually deviate, but there is no way to determine what particular copy you and me belong to [15].

However, there is one aspect of the Nielsen and Ninomiya’s theory which deserves to be further scrutinized. They interpret a possible stoppage of LHC by a card game as an example of backward causality, that some event in future (production of Higgs particles) rearranges conditions today in order not to happen. Does this make sense? We need some analysis of the notion of causality to answer this question.

2 What is time?

Causality is intimately related with the notion of time. Therefore, the first question we should try to answer is about the origin of time. Most of the
modern physicists are, perhaps, pretty sure that they know what is time: it is just forth dimension of space-time different from the spatial dimensions in a subtle way summarized in the pseudo-euclidean character of the metric. This attitude goes back to Minkowski: “Henceforth space by itself, and time by itself are doomed to fade away into mere shadows, and only a kind of union of the two will preserve an independent reality” [17].

Ordinary man, however, will not object if I say that space and time are two big differences. “What is meant by the word ‘Time’? There is no scientific answer to this question. What is meant by the word ‘Space’? Here, rational thought may possibly provide us with an answer. Yet a connection exists between Destiny and Time, and also between Space and Causality. What, then, is the relationship between Destiny and Cause? The answer to this is fundamental to the concept of depth experience, but it lies beyond all manners of scientific experience and communication. The fact of depth experience is as indisputable as it is inexplicable” [18]. As we see, Spengler thinks that it is particularly difficult to understanding the concept of time. How fortunate that you and me can live, and sometimes even live very successfully, without thinking on such complicated issues. “The active person lives in the world of phenomena and with it. He does not require logical proofs, indeed he often cannot understand them” [18].

However, the concept of background Minkowski space-time was extraordinary successful in the realm of physics. How much has it enlightened the enigma of time? The most complete exposition of what the special theory of relativity has to say about space-time can be found in the great treatise of Alfred Robb “A Theory of Time and Space” [19]. He used an axiomatic approach and, in fact, has been nicknamed “the Euclid of Relativity” [20]. The basic concept, introduced by Robb, which is at the heart of causal structure of special relativity, is the notion of “Conical Order” [20]. This notion emphasizes an important difference between simultaneity and succession of spatially separated events. Einstein bewildered contemporaries by showing that simultaneity is relative. Conical order, however, enables to introduce an absolute succession between events and define the notions of after and before which are not relative but absolute. Physicists were so mesmerized by Einstein’s great discovery that Robb remains up to now an forgotten hero of relativity. Nevertheless, as the founder of causal theory of time [21], the contribution of Alfred Robb in relativity deserves to be considered as important as achievements of Einstein and Minkowski.

As for Einstein, the devil seduced him to develop general theory of rela-
activity to obscure again the problem of time.

Space-time in general relativity is a four-dimensional pseudo-Riemannian manifold. Its symmetric metric tensor $g_{\mu\nu}$ is dynamical in the sense that it is determined by matter distribution according to the Einstein equations

$$R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R = \frac{8\pi G}{c^4} T_{\mu\nu}. \quad (3)$$

If the energy-momentum tensor $T_{\mu\nu}$ in the right-hand side of this equation is related to the motion of a point particle then equation of motion of this particle follows from (3) itself due to Bianchi identities. This equation simply says that the particle moves along a geodesic. Therefore, beautifully and miraculously, gravity in general relativity emerges as a manifestation of space-time curvature. Usually this aspect of general relativity is considered as revolutionary. However, it is not. As pioneered by Cartan and Friederichs, Newtonian gravity also can be cast in a generally covariant form in which both characteristic features of general relativity, gravity as spacetime curvature and dynamical metric, are realized [22].

What is really specific to general relativity is that the geometry of tangent space to any point is Minkowskian, while in Newton-Cartan theory tangent spaces have Galilean geometry. This makes a big difference as far as the issue of time is concerned.

Newton-Cartan space-times are globally hyperbolic with absolute time and fixed causal structure. In the case of general relativity, the nice Minkowski geometry of tangent spaces allows to introduce conical order and hence causal structures in these tangent spaces. However, it is not clear whether for every pseudo-Riemannian space-time, which follows from the Einstein’s equations (3), these local causal structures could be integrated in a global definition of time.

Indeed, Gödel found a solution that has closed timelike curves through every event [23]. Therefore, our intuitive understanding what time is breaks down in the Gödel’s universe as we cannot define the meanings of ’before’ and ’after’ for events globally.

Quantum mechanics brings another flavor in the problem of time. Time plays a special role in quantum theory. Unlike spatial coordinates, time cannot be represented by a self-adjoint operator and, therefore, is not a physical observable in the normal sense. Pauli’s argument that this is indeed so goes as follows [24]. Suppose there exist a self-adjoint operator $\hat{T}$ canonical conjugate
to the Hamiltonian $\hat{H}$. Then we should have

$$[\hat{H}, \hat{T}] = i\hbar.$$  (4)

But this commutation relation shows that if $|E \rangle$ is an energy eigenstate, then

$$\exp \left( \frac{i}{\hbar} E \hat{T} \right) |E \rangle$$

is also energy eigenstate but with energy eigenvalue $E - E_1$. Therefore, any such operator necessarily implies that the spectrum of Hamiltonian is not bounded from below which excludes most physically interesting systems since they are assumed to have a stable ground state.

Although Pauli’s “theorem” is not mathematically rigorous and there is a loophole in it [24, 25], time undoubtedly plays a subtle role in quantum mechanics. In general relativity, space-time coordinates are mere labels attached to events and true physical results are assumed to be independent of choices of such coordinates. This fact creates problems for interpretation of the meaning of time already at classical level and it is not surprising that the problem of time only becomes more acute when we try to merge quantum mechanics and general relativity in quantum gravity [26].

To conclude, “Although time is a concept that attracted and occupied the thoughts of a countless number of thinkers and scholars over centuries, its true nature still remains wrapped in a shroud of mystery” [27].

3 Are our theories casual?

Anybody who thinks that causality and determinism are simple and transparent notions should consult John Earman’s A primer on determinism to find out that determinism is a vague concept and causation is a truly obscure one [28]. We will not try to enter any deeply into these wilds but only scratch the surface of the problem.

It is usually thought that the classical physics is a paradise for determinism and spacial relativity and quantum physics have spoiled this harmony. Just the contrary. Newtonian world is quite hostile to determinism, quantum mechanics is more deterministic than classical mechanics, and special relativity is our best theory where the most dreams of determinism can be realized. To these dreams, however, general relativity poses new grave challenges [28].
let us briefly indicate just a few examples of acausal behavior of seemingly benign Newtonian systems.

Imagine a system of two equal masses $M$ moving in the $x-y$ plane under Newton’s inverse square force law and the mirror replica of this binary placed symmetrically at a large distance. The fifth mass $m \ll M$ is placed on the $z$-axis which goes through the centers of mass of the planar binary systems.

In his efforts to solve the century-old problem of noncollisional singularities, Xia was able to show [29] that there exists a set of the initial conditions for which the four bodies, constituting binaries in the above construction, will escape to spatial infinity in a finite time, while the fifth small body will oscillate back and forth between these binaries with ever increasing speed.

However classical mechanics is time reversal invariant and the time reverse of the Xia’s construction is an example of “space invaders” [30], particles appearing from spatial infinity in a surprise attack without any apparent cause.

Another example is given by Pérez Laraudogoitia’s beautiful supertask [31]. An infinite set of identical particles is arranged in a straight line. The distance between the particles and their sizes decrease so that the whole system occupies an interval of unit length. Some other particle of the same mass approaches the system with unit velocity. A wave of elastic collisions goes through the system in unit time and all particles come to rest after this collision supertask is over. The time reversal of the Pérez Laraudogoitia’s supertask implies indeterminism because it is the following process: a spontaneous self-excitation propagates through the infinite system of balls at rest causing the first ball to be ejected with some nonzero velocity.

Surprisingly, quantum mechanics is more friendly to determinism than the Newtonian mechanics [32]. Supertasks are possible in quantum mechanics too [33], and there are quantum supertasks in which the spontaneous self-excitation of the ground state is allowed [34]. However, pathologies disappear and the quantum mechanical supertasks are better behaved than their classical counterparts if one demands normalizability of the state vector [34].

Let us mention also Norton’s fascinating example [35, 36]. Suppose an equation of motion for a Newtonian particle is (Norton provides a concrete dome-like construction which leads to this equation of motion)

$$\frac{d^2r}{dt^2} = k\sqrt{r},$$

where $k$ is some dimensionful constant. If the particle is initially at rest at the
origin $r = 0$, then the obvious solution of (5) is $r(t) = 0$. But, surprisingly, there is also a whole class of other solutions

$$r(t) = \begin{cases} 
0, & \text{if } t \leq T, \\
\frac{k^2}{144}(t - T)^4, & \text{if } t > T.
\end{cases} \quad (6)$$

It is easy to check that (6) is a solution of (5) with required initial conditions for any $T > 0$. But then we have an amusing situation: a particle sitting at the apex of the Norton’s dome in the gravitational field begins to move spontaneously, without any cause, at an arbitrary time $t = T$, in some arbitrary radial direction.

Norton’s dome illustrates well that our implicit beliefs in causality demands some kind of smooth structures (Norton’s dome is $C^1$ but not $C^2$ at the apex). Non-smooth structures open a Pandora box of very strange objects like the Devil’s staircase [37]. Devil’s staircase implies a possibility for a particle to advance forward with a continuous constant velocity which is zero nearly everywhere! Nevertheless, such Cantor functions are not merely pathological oddities as they appear naturally in various areas of mathematics and mathematical physics.

The problem with smooth structures is that for 4-dimensional manifolds there exist different, not diffeomorphic to each other, smoothnesses and what is smooth in one smoothness is not smooth in another. However, there is no physical ground to favor one smoothness over another [38, 39].

To conclude, causality is not a simple notion. Over the centuries there were hard efforts to distillate and make transparent the principle of causality and there is “such a history of persistent failure that only the rashest could possibly expect a viable, factual principle still to emerge” [40].

### 4 Backward causality

At first sight backward causality does not makes sense. However, let us take the following example [41]. Suppose your son was on a ship that has gone down in the ocean two hours previously according to the radio broadcast you just listened. The broadcast have mentioned that there were a few survivors. I expect you immediately to utter a prayer to almighty God that you son should have been among the survivors, and I affirm that such a behavior is the most natural thing in the world.
However, it is logically impossible to alter the past and such a prayer is blasphemous according to orthodox Jewish theologians [41], because we are asking God to perform an impossible thing.

Christian tradition, on the other hand, will bless such a prayer. Are Christians less logical and at error in this case?

If you don’t like the theological example, Dummett provides a magical one [41]. Imagine a tribe that has the following initiation ritual. Every second year the young men have to go off for six days. They travel for the first two days to some isolated place. Then they hunt lions to confirm their manhood. Last two days they spent on the return journey.

The chief of the tribe believes he can influence the outcome of the test if he dance and all the time he eagerly performs this ritual. The weird thing is that the chief continues these dances for the whole six days. In our opinion, the dancing can not bring about the young men’s bravery and, therefore, the chief has wholly mistaken system of causal beliefs. In particular, we consider as especially absurd an idea to continue the dance for last two days after the lion hunting is already over. Can we persuade the chief on the empirical ground that his behavior is absurd? Dummett argues that we can not. The interpretation of empirical data depends on some deeply rooted conceptual beliefs or prejudices. “If we were as convinced as he is of the existence of sorcerers and of mysterious powers, instead of believing in so-called natural causes, his inferences would seem to us perfectly reasonable. As a matter of fact, primitive man is no more logical or illogical than we are. His presuppositions are not the same as ours, and that is what distinguishes him from us” [42].

One of the presuppositions which we take for granted is that the past is fixed in every detail and can not be changed. I agree that under such presupposition backward causality does not make sense. However, is it an absolute logical necessity to stick to this prejudice?

5 A model for backward causality

In fact, such a model was suggested in [43] and is based on a wild but not impossible (especially in the multiverse theory) idea that we live in a computer simulation [44, 45]. During all the history, ancestor worship was very strong religious tradition. it is not unbelievably unrealistic that enormous amounts of computing power will be available in the future. “One thing that later
generations might do with their super-powerful computers is run detailed simulations of their forebears or of people like their forebears. Because their computers would be so powerful, they could run a great many such simulations. Suppose that these simulated people are conscious (as they would be if the simulations were sufficiently fine-grained and if a certain quite widely accepted position in the philosophy of mind is correct). Then it could be the case that the vast majority of minds like ours do not belong to the original race but rather to people simulated by the advanced descendants of an original race” [44].

Now suppose that this high tech substitute of the ancestor worship is self-adaptive. I mean that the rules of this game (which we call natural laws) are not fixed forever but can change defending the participants’ creative output. So to say, we are co-creators of this world not just passive actors. Of course such a world view is strongly anti-Copernicean, contrary to the last centuries scientific mainstream, but I find nothing particularly impossible in it.

In such a virtual reality the past is not fixed in every detail, otherwise it would be a foolish waste of computer memory. Backward causality is a natural thing in such a universe: some details of the past are fixed only when we pay our attention to them from the future.

6 Concluding remarks

Can Nielsen and Ninomiya bring about the closure of LHC by a card game? Yes they can if we live in a kind of virtual universe outlined above. However, our experience with scientific exploration of the world indicates that there is some highly aesthetic underling principles of the fabric of this computer game. Therefore, Nielsen and Ninomiya have to work hard to meet this standards. But are such efforts worthwhile if only LHC closer is at the stake?

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