The violation of isospin symmetry in strong interactions and .511 MeV anomaly: evidence for TGD view of quark color?

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Abstract

In QCD, isospin symmetry of strong interactions is assumed. Therefore the strong interactions in heavy ion collisions should produce equal amounts of charged and neutral kaons. Recently however an anomaly was discovered by Wojciech Brylinski who was analyzing data from the NA61/SHINE collaboration at CERN for his thesis. There was a strikingly large imbalance between charged and neutral kaons in argon–scandium collisions. Instead of being produced in roughly equal numbers, charged kaons were produced 18.4 percent more often than neutral kaons. Now this anomaly has been confirmed. NA61/SHINE's data in collisions with 11.9 GeV cm energy per nucleon pair contradicts the hypothesis of equal yields with a 4.7σ significance.

Unless electromagnetic interactions violating the isospin symmetry manage to cause the isospin asymmetry, the key assumption of QCD that electroweak and color interactions are independent, is wrong. Needless to say, this would mean a revolution in the standard model.

The basic prediction of TGD is that color and electroweak interactions are strongly correlated at the fundamental level and in this article a possible explanation of the anomaly in the TGD framework will be considered. TGD predicts that also leptons have color excitations. There is also new evidence for .511 MeV anomaly in the Milky Way nucleus. The TGD based explanation is in terms of dark electropions with non-standard value of h_{eff} so that it would behave like a dark particle. Electropion would be a bound state of color excited electron and positron. Also muopions and taupions are predicted and there is evidence for them.

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1 Introduction

Phys.org's popular article (see this) tells about a rather surprising finding related to strong interactions. In QCD isospin symmetry is assumed, and the strong interactions in heavy ion collisions should produce equal amounts of charged and neutral kaons. The anomaly was discovered in late 2023, by Wojciech Brylinski who was analyzing data from the NA61/SHINE collaboration at CERN for his thesis. There was a strikingly large imbalance between charged and neutral kaons in argon–scandium collisions. Brylinski found that, instead of being produced in roughly equal numbers, charged kaons were produced 18.4 percent more often than neutral kaons. Now this anomaly has been confirmed. NA61/SHINE's data in collisions with 11.9 GeV cm energy per nucleon pair [C2]) (see this) contradicts the hypothesis of equal yields with a 4.7σ significance.

Unless electromagnetic interactions violating the isospin symmetry manage to cause the isospin asymmetry, the key assumption of QCD that electroweak and color interactions are independent, is wrong. Needless to say, this would mean a revolution in the standard model. Here is the abstract of the article.

Strong interactions preserve an approximate isospin symmetry between up (u) and down (d) quarks, part of the more general flavor symmetry. In the case of K meson production, if this isospin symmetry were exact, it would result in equal numbers of charged (K^+ and K^-) and neutral (K^0 and $\overline{K}^0$) mesons in the final state. Here, we report results on the relative abundance of charged over neutral K meson production in argon and scandium nuclei collisions at a center-of-mass energy of 11.9 GeV per nucleon pair.

We find that the production of K^+ and K^+ mesons at mid-rapidity is (18.4 ± 6.1) per cent higher than that of the neutral K mesons. Although with large uncertainties, earlier data on nucleus-nucleus collisions in the collision center-of-mass energy range $2.6 \leq \sqrt{s_{NN}} \leq 200$ GeV are consistent with the present result. Using well-established models for hadron production, we demonstrate that known isospin-symmetry breaking effects and the initial nuclei containing more neutrons than protons lead only to a small (few percent) deviation of the charged-to-neutral kaon ratio from unity at high energies. Thus, they cannot explain the measurements.

The significance of the flavor-symmetry violation beyond the known effects is 4.7σ when the compilation of world data with uncertainties quoted by the experiments is used. New systematic, high-precision measurements and theoretical efforts are needed to establish the origin of the observed large isospin-symmetry breaking.

The basic prediction of TGD is that color and electroweak interactions are strongly correlated at the fundamental level and in this article a possible explanation of the anomaly in the TGD framework will be considered.

TGD predicts that also leptons have color excitations. There is also new evidence for .511 MeV anomaly in the Milky Way nucleus. The TGD based explanation is in terms of dark electropions with non-standard value of h_{eff} so that it would behave like a dark particle. Electropion would be a bound state of color excited electron and positron [K3]. Also muopions and taupions are predicted and there is evidence for them [C6, C7, C1].

2 TGD view of the standard model interactions and of the isospin anomaly

In the following the key ideas of TGD are summarized, the differences between TGD based and standard model descriptions of standard model interactions are discussed, and a simple quantitative model for the isospin anomaly is considered.

2.1 Basic ideas of TGD

Consider first the basic ideas of TGD relevant to the model of the isospin anomaly.

1. At the fundamental level, both classical electroweak, color and gravitational fields are geometrized [L5, L6]. Once the space-time as a 4-surface in $H = M^4 \times Cq$ is known, all these classical fields are fixed. This choice is unique also from the existence of the twistor lift of the theory: M^4 and Cq are the only 4-D spaces allowing twistor space with Kähler structure.

Also the number theoretical vision, involving what I call $M^8 - H$ duality [L2], allows only H.

By general coordinate invariance at the level of H, 4 coordinates of H fix these classical fields so that very strong correlations between classical fields emerge. In particular, electroweak and color fields are strongly correlated. This means a profound difference from QCD.

2. The notion of a particle generalizes at topological and geometric level. Point-like particles are replaced by 3-D surfaces. Fermionic degrees of freedom correspond to second quantized free spinor fields of H restricted to the space-time surface. Only leptons and quarks are predicted and family replication phenomenon is understood in terms of the genus of a apartonic 2-surface [K1]. The light-like orbit of the partonic 2-surfaces carries fermion and antifermion lines identified as boundaries of strong world sheets in the interior of the space-time surface. In the simplest model, one can assign gauge boson quantum numbers to fermion-anti-fermion pairs and the quark model of hadrons generalizes.

The construction of Quantum TGD relies on two complementary visions of physics: physics as geometry and physics as number theory.

1. The construction of quantum TGD as a geometrization of physics leads to the notion of World of Classical Worlds (WCW) consisting of space-time surfaces in H obeying holography necessary for getting rid of path integral plagued by divergences. Holography means that 3-D data -a 3-surface - fixes the space-time surface as analog of Bohr orbit for 3-D particles so that in geometric degrees of freedom TGD is essentially wave mechanics for 3-D particles.

   WCW spinors correspond to Fock states for the second quantized fermions of H and gamma matrices are super generators for the infinite-D symmetries of WCW. A huge generalization of conformal symmetries of string models and symplectic symmetries for H is involved.

   Conformal symmetries emerge from holography= holomorphy vision leading to an exact solvability of classical TGD. Space-time surfaces are roots for pairs $f = (f_1, f_2)$ of analytic functions $H \rightarrow C^2$ of one hypercomplex coordinate and 3 complex coordinates of H. The field equations are extremely nonlinear partial differential equations but reduce to purely algebraic equations. As long as the classical action is general coordinate invariant and depends only on the induced fields, the space-time surfaces are minimal surfaces irrespective of the choice of the action. The maps $g = (g_1, g_2) : C^2 \rightarrow C^2$ act as dynamical symmetries. The hierarchies of polynomials in extensions E of rationals define hierarchies of solutions of field equations.

2. Number theoretical vision emerged first from the p-adic mass calculations leading to excellent predictions for particle masses. The basic assumption was conformal invariance and p-adic thermodynamics allowing to calculate mass squared as a p-adic thermal expectation mapped to a real mass squared by canonical identification [L1]. p-Adic length scale hypothesis stating that physically preferred primes $p \simeq 2^k$, was an essential assumption. In particular, Mersenne primes and Gaussian Mersenne primes satisfy this condition. Also powers of small primes $q > 2$, in particular $q = 3$ can be considered in the p-adic length scale hypothesis [L7]. Both the function pairs (f_1, f_2) and (g_1, g_2) allow to identify candidates for p-adic primes as analogs of ramified primes associated with algebraic extensions of E, in particular those of rationals.

2.2 How does the TGD view of standard model interactions differ from the standard model view?

TGD based vision standard model interactions differs in several respects from the standard view.

1. In TGD, elementary particles correspond to closed monopole flux tubes as analogs of hadronic strings connecting two Minkowskian space-time sheets by Euclidean wormhole contacts. The light-like orbits of wormhole throats (partonic orbits) carry fermions and antifermions at light curves located at light-like 3-surfaces, which define interfaces between Minkowskian string world regions and Euclidean regions identified as deformed CP_2 type extremals.

2. The basic difference at the level of H spinor fields is that color quantum numbers are not spin-like but are replaced with color partial waves in Cq. Color degrees of freedom are analogous to the rotational degrees of freedom of a rigid body. An infinite number of color partial waves emerges for both quarks and leptons. In TGD, color and electroweak degrees of freedom are strongly correlated as is also clear from the fact that color symmetries correspond to the non-broken symmetries as isometries of Cq and electroweak symmetries correspond to the holonomies of Cq, which are automatically broken gauge symmetries.

   The spectrum of color partial waves in H is different for U and D type quarks and for charged leptons and neutrinos. The triality of the partial wave is zero for leptons and 1 *resp.* -1 for quarks *resp.* antiquarks. At the level of fundamental fermions, which do not correspond as such to fermions as elementary particles, there is a strong violation of isospin symmetry.

The physical states are constructed using p-adic thermodynamics [K2] [L1] for the scaling generator L_0 of the conformal symmetries extended to the space-time level and involve the action of Kac-Moody type algebras. The basic challenge of the state construction of the physical states is to obtain physical states with correct color quantum numbers.

1. General irrep of $SU(3)$ is labelled by a pair (p,q) of integers, where p *resp.* q corresponds intuitively to the number of quarks *resp.* antiquarks. The dimension of the representation is $d(p,q) = (1/2)(p+1)(q+1)(p+q+2)$

   The spinors assignable to left and right handed neutrino correspond to representations of color group of type (p,p), where the integers and only right-handed neutrino allows singlet $(0,0)$ as covariantly constant Cq spinor mode. $(1,1)$ corresponds to octet 8. Charged leptons allow representations of type $(3+p,p)$: $p=0$ corresponds to decuplet 10. Note that $(0,3)$ corresponds to $\overline{10}$.

   Quarks correspond to irreps of type obtained from leptons by adding one quarks that is replacing $(p+3,p)$ with $(p+4,p)$ ($p=0$ gives $d=20$) or (p,p) with $(p+1,p)$ ($p=1$ gives $d=42$). Antiquarks are obtained by replacing $(p,p+3)$ replaced with $(p,p+4)$ and (p,p) with $(p,p+1)$.

2. Physical leptons (quarks) are color singlets (triplets). One can imagine two ways to achieve this.

   Option I: The conformal generators act on the ground state defined by the spinor harmonic of H. Could the tensor product of the conformal generators with spinor modes give a color singlet state for leptons and triplet state for quarks? The constraint that Kac-Moody type generators annihilate the physical states, realizing conformal invariance, might pose severe difficulties.

   In fact, TGD leads to the proposal that there is a hierarchical symmetry breaking for conformal half-algebras containing a hierarchy of isomorphic sub-algebras with conformal weights coming as multiplets of the weights of the entire algebra. This would make the gauge symmetry of the subalgebra with weights below given maximal weight to a physical symmetry.

   Option II: The proposal is that the wormhole throats also contain pairs of left- and right-handed neutrinos guaranteeing that the total electroweak quantum numbers of the string-like closed monopole flux tube representing hadron vanishes. This would make the weak interactions short-ranged with the range determined by the length of the string-like object.

   One must study the tensor products of $\nu_L\overline{\nu}_R$ and $\overline{\nu_L}\nu_R$ states with the leptonic (quark) spinor harmonic to see whether it is possible to obtain singlet (triplet) states. The tensor product of a neutrino octet with a neutrino type spinor contains a color singlet. The tensor product $8 \otimes 8 = 1 + 8_A + 8_S + 10 + \overline{10} + 27$ contains $\overline{10}$ and its tensor product with 10 for quark contains a color triplet.

Number theoretic vision is highly relevant for the model of isospin anomaly.

1. p-Adic length scale hypothesis [L1] can be applied to quarks. The empirical estimates for the masses of u and d type current quarks vary in wide range and have become smaller during years. One estimate (see this is that u quark has mass in the range 1.7-3.3 MeV and d has

mass in the range 4.1-5.8 MeV. The estimate represented in Wikipedia (see this) is consistent with this estimate.

p-Adic length scale hypothesis suggests that the p-adic mass scales satisfy $m(d)/m(u) = 2$ so that $p(d)/p(u) = 1/4$ and $k(d) = k(u) - 2$. For electron the p-adic mass scale corresponds to the Mersenne prime $M_{127} = 2^{127} - 1$ with $k(e) = 127$. $m(u) \simeq 4m_e$ suggests $k(u) = 127 - 4 = 123$ and $k(d) = k(u) - 2 = 121$.

2. The number theoretic vision [L5, L3] implies that coupling constant evolution is discretized and the piece-wise constant values of coupling parameters correspond to extensions of rationals characterizing the classical solutions of field equations as roots $(f_1, f_2) = (0, 0)$. This conforms with the general vision that the TGD Universe is quantum critical. The quantum criticality conforms with the generalized conformal symmetries consistent with the holography= holomorphy vision. p-Adic primes are proposed to correspond to the ramified primes associated to the polynomial pairs and for rational primes one obtains ordinary p-adic primes assignable to ordinary integers.

3. Since u and d quarks correspond to different p-adic length scales they must correspond to different p-adic primes and presumably also to different extensions of rationals. Therefore the color couplings of gluon to a u quark pair and d quark pair are different. This would imply the violation of isospin asymmetry of strong interactions. One expects that the gluon coupling strength α_s depends on the p-adic length scale of the quark and possibly also on the electromagnetic change, and the guess, motivated by QFTs, is that the dependence is logarithmic.

2.3 Could TGD allow to understand the isospin violation of strong interactions

How could one understand the violation of the isospin symmetry of strong interactions in the TGD framework?

1. The formation of $K^+ = u\overline{s}$ and $K^0 = d\overline{s}$ involves strong interaction and therefore exchange of gluons between u and $\overline{s}$ for K^+ and d and $\overline{s}$ for K^0. The emission vertex is proportional to α_s. In TGD, the gluon corresponds to a superposition of $u\overline{u}$, $d\overline{d}$ pairs and also pairs of higher quark generations. Only the $u\overline{u}$ couples to K^+ and $d\overline{d}$ couples to K^0 in the vertex. The gluon exchange vertex is analogous to a vertex for the annihilation of gluon to a fermion pair and the different p-adic length scales for u and d imply that the analog of QCD coupling strength α_s is different $u\overline{u}$ and $d\overline{d}$.

2. For general coupling constant evolution the dependence of length scale is logarithmic. The amplitude for the exchange of gluon characterized by α_s should be larger for $u\overline{u}g$ vertex than $d\overline{d}g$ vertez. The p-adic length scale for u should be by a factor 2 longer than for u. If the coupling constant is proportional to the logarithm, one has $\alpha_s \propto log_2(p(q)) = k(q)$. This would give for the ratio $\Delta g_s/g_s(u) = (\Delta g_s(u) - g_s(d))/g_s(u)$ the estimate $\Delta g_s/g_s(u) \simeq (k(u) - k(d))/k(u) \sim 4/123 \sim 3.3$ percent. For α_s this would give $\Delta\alpha_s/\alpha_s \sim 6.6$ per cent. This is roughly by a factor 1/3 times smaller than the empirical result 18.4 percent. $k(u) - k(d) = 2 \to 6$ giving $k(d) = 123 - 6 = 117$ would produce a better result and give $m(d) \sim 16$ MeV. This looks non-realistic.

3. g_s can also depend on the em charge of the quark. The dependence must be very weak and logarithmic dependence is suggestive. The dependence can be only on the square of the em charge. What is wanted is $\Delta k_{eff}(u) - k_{eff}(d) \to \Delta k_{eff} = k(u) - k(d) - 4$. The values of $x(q) = (3Q_{em}(q))^2$ for U *resp.* D type quarks are $x(q) = 4 = 2^2$ *resp.* $x_q = 1$ and therefore powers of 2. The simplest quess is that g_s is of the form $g_s(q) \propto log_2(x(q) \times 2^{k(q)})$. This gives $k_{eff}(u) = k(u) + 2$ and $k_{eff}(d) = k(d)$. This would predict $k_{eff}(u) - k_{eff}(d) = k(u) - k(d) + 2 = 4$. This would give $(g_s(u) - g_s(d))/g(d) \simeq 6.6$ percent and $(\alpha_s(u) - \alpha_s(d))/\alpha(d) \simeq 13.2$. This is about 71 per cent from 18.4 per cent. The rather artificial dependence $x(q) = (3Q_{em}(q))^4$ would give 19.2.

2.4 Leptopions as dark matter-like phase and support for TGD view of color

Sabine Hossenfelder told about quite recent finding possibly related to dark matter (see this). The article [C3] "Anomalous ionization in the central molecular zone by sub-GeV dark matter" can be found in arXiv (see this). Here is the abstract of the article:

We demonstrate that the anomalous ionization rate observed in the Central Molecular Zone can be attributed to MeV dark matter annihilations into e^+e^- pairs for galactic dark matter profiles with slopes $\gamma \geq 1$. The low annihilation cross-sections required avoid cosmological constraints and imply no detectable inverse Compton, bremsstrahlung or synchrotron emissions in radio, X and gamma rays. The possible connection to the source of the unexplained 511 keV line emission in the Galactic Center suggests that both observations could be correlated and have a common origin.

I will try to summarize what I understood from Sabine's Youtube talk.

1. It has been observed that from the Central Molecular Zone, where stars are formed, arrives more IR light than expected. Hydrogen forms normally H_2 molecules and they cannot explain the IR light in terms of vibrational excitations. H_3^+ could give rise to the infrared light.

2. There should be a mechanism leading to the formation of ionized H_3 molecules. Electrons could cause the ionization and the proposal is that dark particles in MeV mass range could serve as the source of the ionizing electrons. The proposal is that two dark particles in this energy range annihilate to electron-positron pairs and the electrons ionize the H_3 molecules.

3. There indeed exists evidence for gamma rays with energy 511 eV from the Milky Way center [C4, C5]. And they could be generated in the annihilation of dark particles with mass slightly above MeV to gamma pairs. This would happen in the collisions of these particles and this would require that the dark particles are very nearly at rest.

TGD leads to a much simpler explanation for the findings in terms of particles, whose mass .511 MeV is only slightly above the mass of electron [K3]. They would directly decay to electron positron pairs.

1. The empirical findings motivating this hypothesis emerged already in the seventies from the finding that in heavy ion collisions with collision energy near the criticality to overcome Coulomb wall, anomalous electron-positron pairs were observed with energy, which was twice the rest mass .5 MeV of electrons [K3]. In the standard model, the decay widths of weak bosons do not allow new particles in this mass range and this was probably the reason why the findings were forgotten.

2. An essential role in the explanation is played by the TGD view of color symmetry and dynamics of strong interactions, which both are in some respects very different from the QCD view. This conclusion is supported by the quite recent finding of large isospin breaking in the production of kaon pairs. The production rate for charged kaon is 18.4 per cent higher than for neutral kaons challenging QCD. The explanation that comes to mind is that color gauge coupling slightly depends on the electric charge of the quark besides the weak dependence on the p-adic mass scale of the quark (now u or d quark).

How does the TGD based view of color lead to this proposal?

1. Color corresponds to color partial waves in CP_2 and a spectrum of colored spinor harmonics in $H = M^4 \times CP_2$ are predicted for both quarks and leptons in CP_2. The color partial waves correlate with electroweak quantum numbers unlike the observed color quantum numbers. This means large isospin breaking at the fundamental level, where all classical gauge fields and gravitational field are expressible in terms of H coordinates and their gradients and only four of them is needed by general coordinate invariance. One can imagine a mechanism, which guarantees weak screening in scales longer than weak boson Compton length and this mechanism also explains the color quantum numbers of physical leptons and quarks.

   The weak screening above weak scale could take place by a pair of left and right-handed neutrinos assignable to the monopole flux tubes associated with the quark and it would also give the needed additional color charge so that quarks would be color triplets and leptons color singlets.

2. It is however possible to also have color octet and higher triality $t = 0$ excitations of leptons and analogous excitations of quarks [K3]. The particles with mass slightly above $2m_e$ would be analogs of pions, electropions as I have called them. Also muopions and taupions [K3] are predicted and there are experimental indications also for them [C6, C7, C1] but forgotten since they cannot exist in the standard model.

How to understand the darkness of electropions?

1. The darkness of the leptopions and possible other leptomesons could make it possible to avoid the problems with the decay widths of weak bosons. But what could this darkness mean? The experiments of Blackman and others [J1] suggest that the irradiation of the brain with EEG frequencies has behavioral and physiological effects and that these effects are quantal and correspond to cyclotron transitions in a magnetic field of about $2B_E/5$, where B_E is the Earth's magnetic field This does not make sense in standard quantum theory since the value of the Planck constant is more than 10 orders of magnitude too small and the cyclotron energy would be much below the thermal energy. I have proposed that the Planck constant, or effective Planck constant h_{eff}, has a spectrum and its value can be arbitrarily large.

   In the recent formulation of TGD involving number theoretic vision h_{eff} hierarchy follows as a prediction. The large value of h_{eff} would give rise to quantum coherent phases of the ordinary matter at magnetic/field body of the system and these phases would behave like dark matter in the sense that only particles with the same value of h_{eff} can appear in the vertices of TGD analogs of Feynman diagrams.

2. The natural guess is that the 511 keV particle is dark in this number theoretic sense. It would not be created in the decays of ordinary weak bosons unless they themselves are dark with the same value of h_{eff}. The second option is that leptomesons can appear only in the dark phase at quantum criticality associated with the situation in which the Coulomb wall can be overcome. Dark phases in this sense appear only at quantum criticality making possible long range quantum fluctuations and quantum coherence.

3. For along time I thought that the darkness in number theoretic sense could correspond to the darkness of the galactic dark matter but now it seems that this is not the case [L4, L5, L6]. Classically, galactic dark matter could correspond to Kähler magnetic and volume energy of cosmic strings, which are 4-surfaces in $M^4 \times CP_2$ with 2-D M^4 projection. One can of course ask, whether the quantum classical correspondence implies that classical energy equals to its fermionic counterpart in which case these view of dar matter could be equivalent.

   The number theoretic darkness would however make itself visible also in cosmology. The transformation of ordinary particles to dark phases at the magnetic bodies, forced by the unavoidable increase of number theoretical complexity implying evolution, would reduce the amount of ordinary matter and this could explain why baryonic (and also leptonic) matter seems to gradually disappear during the cosmic evolution.

To sum up, the recently observed isospin anomaly of strong interactions together with additional empirical support for the TGD view of color is rather encouraging. This hypothesis is testable without expensive accelerators already now. Only the readiness to challenge the belief that QCD is the final theory of strong interactions would be required and I am afraid that it takes time to reach this readiness.

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