Essay

Is the Isospin Symmetry of Strong Interactions Violated at the Quark Level?

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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 argonscandium 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.

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 argonscandium 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 [1]) (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

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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.

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 [7, 8]. 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 [5], 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 [2]. 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 $H \to C^2$ 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 $g = (g_1, g_2) : C^2 \to C^2$ 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 [4]. 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 [9].

   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 [3] [4] 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 [4] 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 [7, 6] 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. $k(u) - k(d) = 2 \rightarrow 6$ 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 $\Delta k_{eff}(u) - k_{eff}(d) \rightarrow \Delta k_{eff} = k(u) - k(d) - 4$. 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.

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