Sustaining Wavefunction Coherence via Topological Impedance Matching: Stable Polarized Muon Beams at 255 x 255 GeV/c?

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(Dated: January 1, 2020)

“What the Hell is Going On?” is Peter Woit’s ‘Not Even Wrong’ blog comment on Nima Arkani-Hamed’s view of the barren state of LHC physics, the long-dreaded Desert[1].

Two essential indispensibles - geometric wavefunctions and quantized impedances of wavefunction interactions - are absent from particle theory, the community oblivious, mired in the consequent four decades of stagnation. Synthesis of the two offers a complementary Standard Model perspective, examining not conservation of energy and its flow between kinetic and potential of Hamiltonian and Lagrangian, but rather what governs amplitude and phase of that flow, quantum impedance matching of geometric wavefunction interactions. Applied to muon decay, the model suggests that translation gauge fields (RF cavities) of relativistic lifetime enhancement might be augmented by introducing rotation gauge fields of carefully chosen topological impedances to an accelerator.

Introduction and Historical Perspective

Professor Rubbia calls for courage[2] in the desert revealed by the LHC - one Higgs, no SUSY, and the purported death of naturalness[3–14]. The search is on for successors to protons at 14 TeV. While viable alternatives to 100 TeV LEP/LHC clones[15] are welcome, courage was indeed required for him to take the stand from which he speaks, knowing full well the difficulty of the venture he advocates. Such daring inspires one to follow the bold lead, if only for lack of common sense buttressed by almost total ignorance of muon physics. In beginner’s mind are many possibilities.

One possibility is to forestall decoherence[16, 17] by tuning accelerator impedances seen by muon wavefunctions to minimize differential phase shifts between modes, phase shifts generated by muon excitation of vacuum wavefunction impedances[18, 19]. Tuning an accelerator to minimize decoherence of spin is a classical example[20, 21]. This note examines the possibility of regulating relative phase of coupled modes of a single muon wavefunction, as opposed to regulating relative spin precession of two unentangled wavefunctions.

An absolutely essential component of the accelerator physicist’s toolkit, impedance got lost in particle physics with the expert practice of setting fundamental constants $(h, c, G, Z_0, ...)$ to dimensionless unity. Arguably not a good idea, particularly when ignoring concepts already unfamiliar, but if you’re Feynman you can wing it. He had an EE student do a thesis on impedance matching to the maser[22], mentions matching in 1D in the path integral book[23], but never figured out just how and where it fits in quantum mechanics. Almost everyone else forgot.

An exception was Bjorken, whose 1959 thesis[24] presented an approach summarized[25] as

“...an analogy between Feynman diagrams and electrical circuits, with Feynman parameters playing the role of ***resistance****, external momenta as current sources, and coordinate differences as voltage drops. Some of that found its way into section 18.4 of...”* the canonical text[26]. (bold emphasis added)

While analyzing dispersion relations, Bjorken discovered an analogy between the electrical engineer’s circuit components and Feynman parameters of the regularization that precedes renormalization, and anticipated that

“This circuit analogy will be very valuable to us, because we can use intuitive understanding as well as the established lore and theorems of circuit theory in analyzing a Feynman diagram.”[26]

As presented there, units of Feynman parameters are [sec/kg], units of mechanical ***conductance***, not resistance[27].

He and those of similar interests (including the present author[28]) were thrown off by what appears to be a topological inversion in our systems of units. Intuitively one might think more seconds per kilogram would mean less mass flow, higher resistance. However [sec/kg] are units of conductance, not resistance. In SI units less time for the same distance a unit mass travels means more resistance, not less. This electromechanical inversion sheds light on how the anticipated intuitive advantage was lost, and remains so in particle physics.

Point being this: Bjorken’s Feynman parameters are the impedance mismatches that render QED finite[29].

That which governs amplitude and phase of energy transmission, of information communication in wavefunction interactions, is absent from the particle theorist’s toolkit, not to be found in curriculum, textbooks, or journals. Given that wavefunction fields of quantum field theory are quantized, it is unavoidable that impedances of wavefunction interactions will likewise be quantized[30, 31].

To explore interactions requires understanding vacuum wavefunctions in the geometric representation of Clifford algebra, and manifestation via four fundamental constants that define the electromagnetic coupling constant α.

1. Vacuum Wavefunction

The fundamental concept of impedance matching, of that which governs amplitude and phase of energy transmission, is one of two essential ingredients lost in quantum mechanics. The other is that which possess the property of impedance quantization, the geometric wavefunction of Clifford algebra. The original intent of Grassman and Clifford[32–34] was to develop a language not of numbers or symbols but rather of geometric objects. Clifford himself called it Geometric Algebra. While it attracted considerable interest, with Clifford's early death in 1879 the absence of an advocate to balance the powerful Gibbs and Heaviside contributed to its eventual neglect. GA was

"...largely abandoned with the introduction of what people saw as a more straightforward and generally applicable algebra, the vector algebra of Gibbs... This was effectively the end of the search for a unifying mathematical language and the beginning of a proliferation of novel algebraic systems...[35].

It resurfaced in the 1920s with the unintuitive matrix representation of Pauli and Dirac, absent the original intent and lacking conceptual simplicity and visualization of the geometric representation. It was recovered and extended by David Hestenes in the 1960s[36, 37]. Another four decades passed before he was awarded the 2002 Oersted medal for "Reforming the Mathematical Language of Physics" by the American Physical Society[38]. It remains for the most part still lost in physics[39–46], like impedance quantization absent from the toolkit.

Naive realists[47] want **vacuum wavefunctions** visualized in physical space. GA is perfectly suited to the task. Pauli σ matrices are the SU(2) representation of SO(3), the basis of space in the geometric representation, wherein the vacuum wavefunction is modeled by fundamental geometric objects of Euclid - point, line, plane, and volume elements. These comprise the eight components of a minimally complete Clifford algebra of space - one scalar, three vectors (orientational degrees of freedom), three bivector area elements, and one trivector volume element[48], as shown in figures 1 and 6. Dirac γ matrices are basis vectors of spacetime in the geometric representation.

Wavefunction interactions are modeled by geometric products, multiplying not numbers or symbols but geometric objects, changing dimensionality, making geometric algebra unique in the ability to handle geometric and topological dynamics in all dimensions. In GA the term grade[49] is preferred over dimension, in hope of minimizing confusion between physical dimensions and degrees-of-freedom.

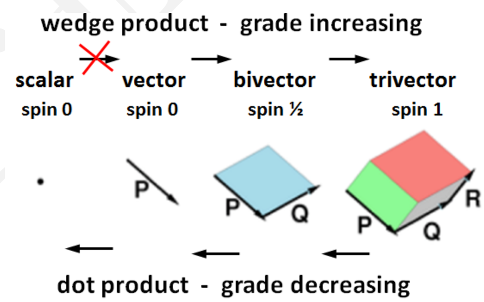

FIG. 1: 3D algebra of space[51]

Given two vectors a and b, the geometric product ab changes grades. In the product $ab = a \cdot b + a \wedge b$, two grade 1 vector bosons are transformed into a grade 0 scalar boson and grade 2 bivector fermion. Taken together, these comprise a minimally complete 2D Clifford algebra (perhaps bringing to mind Higgs/W/Z/top[50]).

The product turns fermions into bosons, and bosons into fermions. Dynamic supersymmetry emerges naturally, as does time in the grade increase from 3D space to 6D phase space generated by wedge products of two wavefunctioins (figures 1 and 6). In flat 4D Minkowski spacetime there is but one time for the three orientational degrees of freedom. However, wavefunctions require independent phases for all three[14]. The 'natural' space of quantum mechanics is the 6D phase space so familiar to accelerator physicists, with wavefunction amplitude and phase substituted for beam position and momentum. If one wants a relativistic quantum theory, it must be formulated not in 4D spacetime, but rather in 6D phase space. Implicit in this is quantum mechanics of 6D phase space is fundamental and special relativity of 4D Minkowski spacetime emergent.

Wavefunction interactions are **two-body**[28], background independent[52], the two wavefunctions at top and left of figure 6 interacting to generate the scattering matrix.

Special relativity is **three-body**, three two-body interactions, each with Mach's third-body 'observer' in the background. Lorentz transform is Pythagorean theorem, the triangle. QM is fundamental, SR emergent. Relativistic correlation between nodes of the impedance network of figure 4 and unstable particle lifetimes could not exist if this were not true. Three body potential is inverse square, the potential of topological impedances. We seek to augment muon wavefunction lifetime enhancement of emergent SR, the relative slowing of differential phase shifts due to self-excitation of the fundamental QM vacuum wavefunction[17], by introducing additional topological impedances.

Geometric algebra is unique in the ability to handle geometric and topological dynamics. However, it appears to harbor a broken topological symmetry. The *"...problem is that even though we can transform the line continuously into a point, we cannot undo this transformation and have a function from the point back onto the line..."* [53].

Grade increasing operations conserve topological symmetry of wedge and dot products, with the exception of wedge products of scalars, as indicated by the red x-out of figure 1. Scalars are point objects having no spatial dimensionality, cannot raise or lower grades, break topological grade-changing symmetry of the products. This is of particular interest for the Higgs, the sole standard model scalar[3, 5–13], the first of several ways in which topology enters our search for an approach to stable muon beams.

2. Physical Manifestation

Physical manifestation of vacuum wavefunction interactions follows from introducing the dimensionless electromagnetic coupling constant $\alpha = e^2/4\pi\epsilon_0\hbar c$. Combinations of the fundamental constants e, ϵ_0, $\hbar$, and c permits assignment of topologically appropriate quantized E and B fields to the eight vacuum wavefunction components, and to calculate quantized impedance networks of wavefunction interactions[30, 31], yielding the S-matrix of figure 6 and impedance network of figure 4.

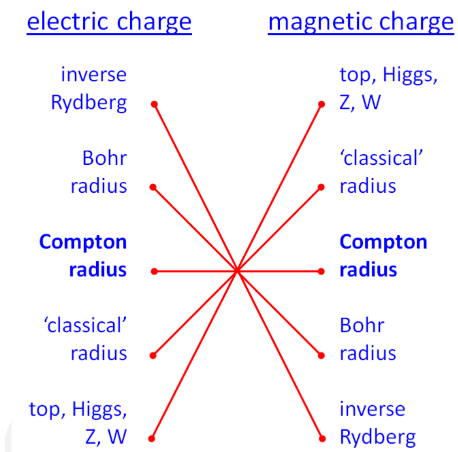

FIG. 2: Topological inversion of fundamental lengths by magnetic charge

The photon is our fiducial in measurements of the properties of space. Topological duality[54] arises from the difference in coupling to the photon of magnetic and electric charge. If we take magnetic charge g to be defined by the Dirac relation $eg = \hbar$, then e is proportional to $\sqrt{\alpha}$ whereas g varies as $1/\sqrt{\alpha}$. The fundamental lengths of figure 2, precisely spaced in powers of α, are inverted for magnetic charge[55]. The Compton wavelength $\lambda = h/mc$ is independent of charge.

With electric charge, fundamental lengths correspond to specific physical mechanisms of photon emission or absorption, matched in both quantized impedance and energy. Inversion results in mismatches in both.

Magnetic charge g is 'dark', cannot couple to the photon, not despite but rather because of its great strength. The α-spaced lengths of figures 2-4 correspond to physical mechanisms of photon absorption and emission. Bohr radius cannot be inside Compton wavelength in basic QED photon-charge coupling, Rydberg cannot be inside Bohr,... specific physical mechanisms of photon emission and absorption no longer work[56].

This is the second way (more to come) in which topology enters our search for an approach to stable muon beams.

3. Generalized Quantum Impedances: the Unstable Particle Spectrum

Given that fields of quantum field theory are quantized, it is unavoidable that wavefunction interaction impedances are quantized. Impedances are of two types - geometric and topological, scale dependent and scale invariant.

Geometric impedances are scale dependent, include those of monopole-monopole, scalar Lorentz, and dipole-dipole interactions. They correspond to translation gauge fields[57–59]. Associated potentials are $1/r$ and $1/r^3$. They are causal, communicate both amplitude and phase, can be shielded. They are channels of local entanglement.

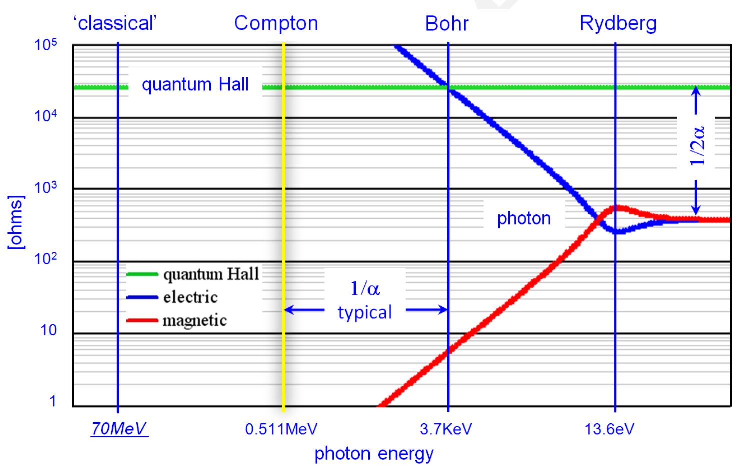

FIG. 3: 13.6 eV photon impedance match to Hydrogen atom[61].

Topological impedances are scale invariant, associated with $1/r^2$ potentials of anomalies in both classical and quantum mechanics[60]. They include vector Lorentz of quantum Hall (green in figure 3) and Aharonov-Bohm effects, chiral, centrifugal, Coriolis, and three-body impedances. They correspond to rotation gauge fields. They can do no work - resulting motion is perpendicular to applied force. They communicate only phase, a relative property, not a single measurement observable, are acausal, cannot be shielded, are channels of both local and non-local entanglement.

The photon is apparently unique among elementary particles, having both the scale invariant 377 ohm far-field and scale dependent near-field inductive dipole (blue) and capacitive monopole (red) impedances shown in figures 3 and 4. In figure 3 the E and B flux quanta of the 13.6 eV impinging photon decouple, their relative phase shifted by the electron wavefunction electric dipole moment (not shown in figure 3, large blue diamonds in figure 4). The photon near-field scale dependent impedances match photon energy to the scale invariant quantum Hall impedance (numerically equal to the centrifugal impedance) at the Bohr radius, yielding dissociation. Topological impedances present a third way (more to come) in which topology enters our search for an approach to stable muon beams.

Impedances of figures 3 and 4 are parametric [62–65], the nonlinear mechanism of noiseless frequency domain energy translation essential in wavefunction interactions, and relentlessly problematic in quantum interpretations[66, 67].

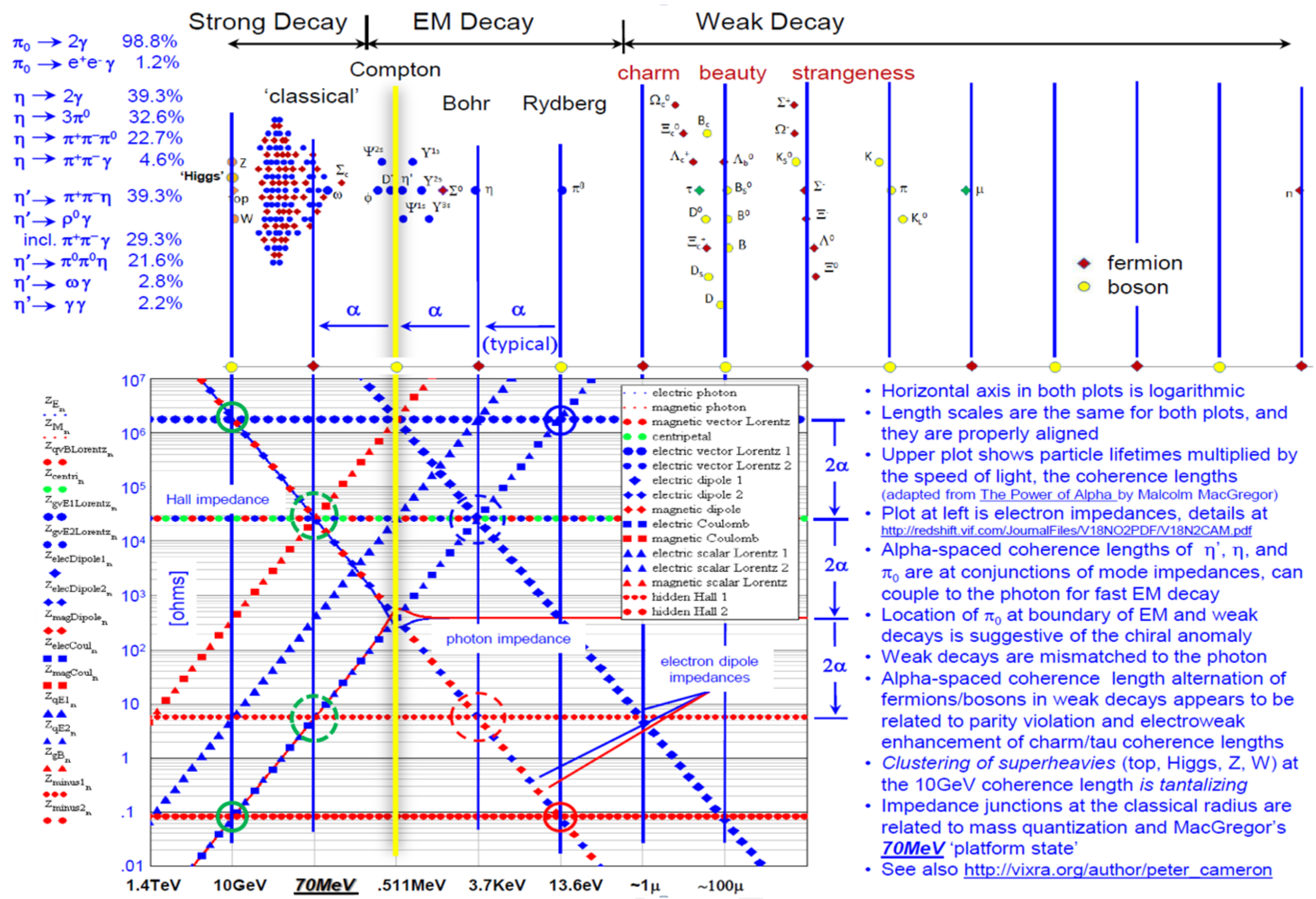

FIG. 4: Modes indicated by colored symbols in figure 6 are plotted in the impedance network at lower left. Phase correlation of unstable particle causal lifetimes/light cone coherence lengths [68–70] with network impedance nodes, both structured in powers of α, follows from the fact that impedances must be matched for the energy transmission essential in decay[71]. Quantum impedance matching offers beyond standard model explanations of particle lifetimes and branching ratios[13, 72]

To calculate quantized impedance networks of wavefunction interactions using Maxwell's equations is a formidably daunting prospect. However, every massive particle has Bjorken's mechanical impedance[27], a straightforward calculation[28], easily converted to electromagnetic via electromechanical oscillators[30]. This simple 1D model yields the impedance network of figure 4, albeit lacking orientational information of the full 3D electromagnetic wavefunction.

The 377 ohm far-field .511 MeV photon of figure 4 encounters four quantized impedances at the electron Compton wavelength - two inductive dipole impedances (diamonds) meeting capacitive Coulomb (squares) and scalar Lorentz (triangles) impedances. Exact matching at the node permits reflectionless energy transfer to this quantum oscillator. The lightest stable rest mass particle, the electron corresponds to the 'mass gap' of quantum field theory[73]. Absence of mode-coupling invariant impedances at 377 ohms is remarkable, related to gauge property of photon.

Photon transition zone dipole impedance inversion of E and B fields in figures 3 and 4 is curious. Monopole mode gives a smooth transition to near field, no inversion. Higher order expansions (tripole, quadrupole,...) are divergent there (problematic for quantizing GR[74]), but identical in both near and far field.

visible and dark wavefunction components				
field	scalar	vector	bivector	trivector
electric	charge	dipole	flux quantum	-
magnetic	-	flux quantum	moment	charge

FIG. 5: Topological Inversion of 3D Clifford algebra

Decoherence of unstable particles follows from differing impedances of the vacuum wavefunction modes they excite[17–19]. Wavefunctions containing both dark and visible components are unstable, decohere as dark/visible differential phase shifts accumulate. Excepting the electron and constantly morphing three-component neutrino, the proton is the only stable particle. Interaction modes containing only visible components are those of the proton, highlighted in green in figure 6. Unstable particles contain at least one dark component, the stable proton none. The possibility exists that stable dark matter is comprised of dark modes only, which far outnumber the visible.

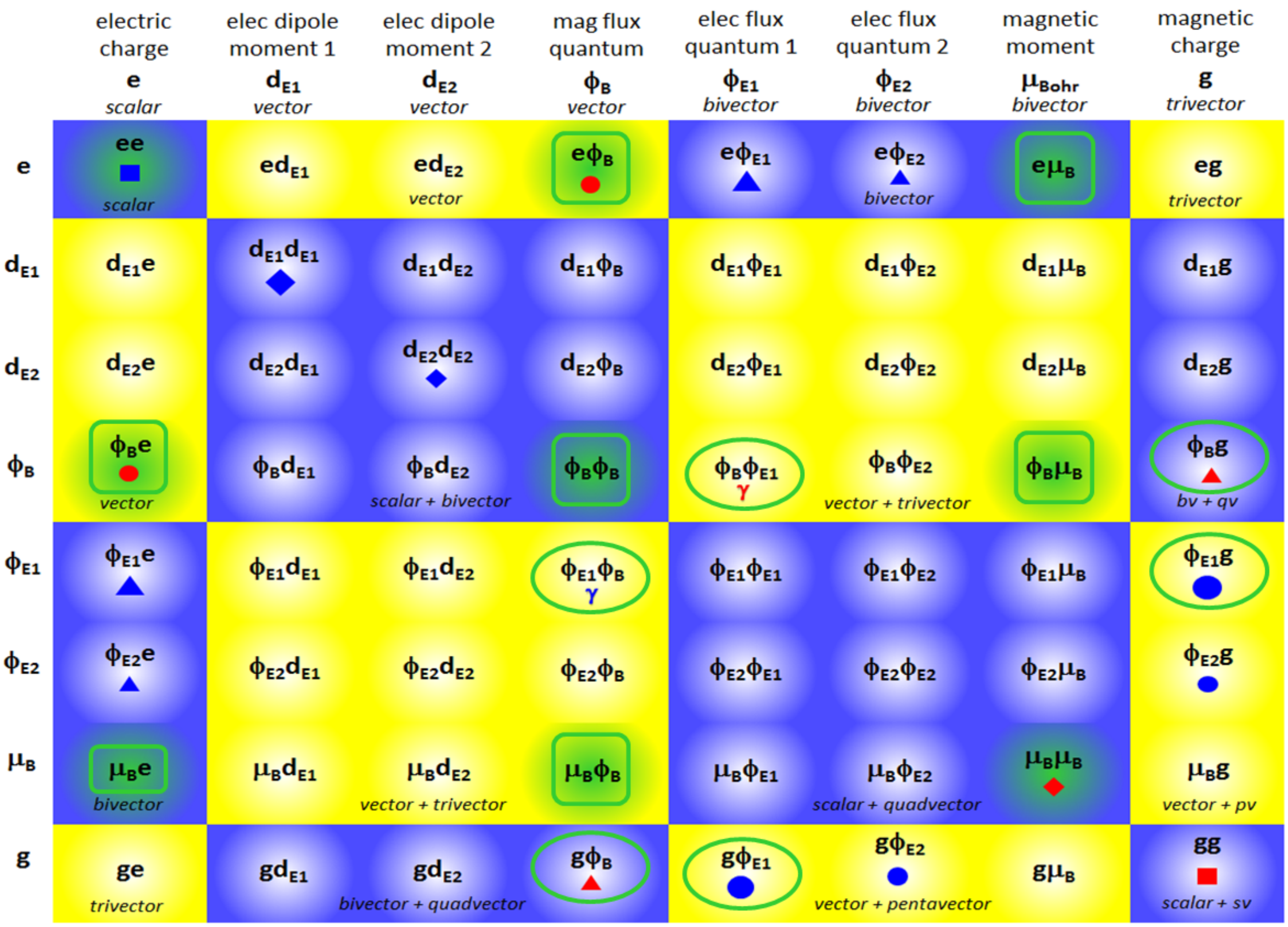

FIG. 6: Impedance representation[75–77] of the S-matrix[78–81] generated by the geometric product of the two eight-component wavefunctions shown at top and left, arranged by geometric grade. Eigenmodes have blue background, transition modes yellow. Modes indicated by colored symbols (diamond, triangle,...) are plotted in figure 4. Muon modes of figure 7 are indicated by rectangles, neutrino by ellipses.

4. Muon Wavefunction

A plausible analysis of proton structure and spin was presented to the 22nd International Spin Symposium in Urbana-Champaign[82, 83]. The stable modes used in that analysis are highlighted in green in figure 6. Topological inversion places the magnetic moment not with the vector electric dipole moments but rather with the axial bivectors, and magnetic flux quantum with the dipoles, the topological poles being at infinity.

In the present analysis our interest is muon wavefunction components indicated by rectangles in figure 6, the 'platform state' transition modes[70] of proton topological mass generation[83]. There we find the two transition modes $e\phi_B$ and $\phi_B\mu_B$ and the vacuum modes $\phi_B\phi_B$ and $e\mu_B$ that they excite, as shown in figure 7. These each comprise a minimally complete 2D Clifford algebra - scalar electric charge e, two vector magnetic flux quanta ϕ_B, and a bivector magnetic moment μ_B. Electric charge and magnetic moment we know as components of the Dirac spinor. What's new in the muon wavefunction is completion of the algebra, completion of the group $Cl(0,2)$ by the two vector bosons, the two identical magnetic flux quanta ϕ_B. One might suppose identity effects play a role in flux coupling of the two muon wavefunction transition modes.

Here we have yet another example of topological symmetry breaking. By the Dirac relation $eg = h/2$, definition of the magnetic flux quantum can be extended to $\phi_B = h/2e = g$. In SI units magnetic flux quantum and charge are numerically equal yet topologically distinct, one a vector and the other trivector, one visible and the other dark.

Muon lifetime/decoherence might then derive from the differing vacuum impedances and phase shifts of the numerically equal but topologically distinct dark magnetic charge g and visible flux quantum ϕ_B, the subtle topological distinction perhaps accounting for the exceptionally long muon and neutron[84, 85] lifetimes of figure 4.

The first column of figure 7 shows four possible modes of the muon, the modes whose decoherence we seek to delay. The first two rows correspond to green-highlighted transition modes of figure 6. Their components comprise a minimally complete 2D Clifford algebra. The last two rows correspond to vacuum wavefunction eigenmodes excited by those same transition modes, likewise a minimally complete 2D Clifford algebra.

muon transition and eigenmodes and decay FGOs			
muon mode	*entering FGOs*	*emerging FGOs*	decay FGOs
$e\phi_B$	scalar + vector	vector	ϕ_B or ϕ_E
$\phi_B\mu_B$	vector + bivector	vector + trivector	ϕ_B or ϕ_E + g
$\phi_B\phi_B$	vector + vector	scalar + bivector	μ_B or ϕ_E + e
$e\mu_B$	scalar + bivector	bivector	μ_B or ϕ_E

FIG. 7: Wavefunction Fundamental Geometric Objects[83]

First row mode $e\phi_B$ is topological, associated with the $1/r^2$ potential of quantum Hall and Aharonov-Bohm effects. Resultant motion is perpendicular to applied force, can do no work, communicates only phase.

Second row mode $\phi_B\mu_B$ is an old friend, first examined in the context of topological mass generation of the nucleon[86], and presented in greater detail in the analysis of proton structure and spin[82, 83]. The vacuum wavefunction is the same at all scales, from Planck length to Compton and deBroglie[96] in quantum mechanics, and to the boundary of the observable universe in quantum gravity[13]. What physics emerges when the vacuum wavefunction is excited depends on excitation wavelength, on the energy. At any Compton wavelength, energy of the second row mode $\phi_B\mu_B$, of moment μ_B in the field of flux quantum ϕ_B, is rest mass of the particle[30, 83, 86].

Third row mode $\phi_B\phi_B$ is comprised of the two vector bosons that completed the 2D Clifford algebra of the muon wavefunction relative to the electron spinor. Energy of the flux quantum ϕ_B when confined to the muon Compton wavelength is again rest mass of the muon. This mode has no inherent dynamics, requires mode coupling to oscillate.

Fourth row mode $e\mu_B$ is the Dirac spinor.

5. Neutrino Wavefunctions

Muon decay $\mu \to e + \nu_\mu + \overline{\nu_e}$ yields an electron, a muon neutrino, and an electron anti-neutrino. With decoherence, what emerges from the interaction algebra is shown in the rightmost column of figure 7. Scalar and bivector of the third row, highlighted in green in the table, can be taken to be electric charge e and magnetic moment μ_B of the Dirac electron spinor. What remains in the rightmost column are neutrino wavefunction components.

Given a muon model comprised of a two-component Dirac electron spinor plus two vectors, so might the three-component neutrino be comprised of a two-component photon plus an additional component. The two flux quanta ϕ_B and ϕ_{E1} of the two photon spin states (circled in figure 7) sit on the skew diagonal of the S-matrix of figure 6, adjacent the main diagonal.

Neutrino lightspeed propagation requires absence of singularities, crossing out scalars and *geometric* vectors in the rightmost column. In addition to bivector ϕ_E, what remains are two vectors ϕ_B (singularities of the *topological* vector ϕ_B are at infinity) and one pseudoscalar g. Of these four, one possibility is a neutrino wavefunction $\psi_\nu = \phi_B\phi_{E1}g$. Such a wavefunction 'tumbles' as it propagates, longitudinal orientation of a given component determining the flavor. Flavor oscillations are driven by the differing 'dark' vacuum impedances excited by topological magnetic charge g of the $g\phi_B$ and $g\phi_{E1}$ modes and the consequent differential phase shifts.

The fourth component, the additional flux quantum ϕ_B, is required to differentiate muon neutrino from electron anti-neutrino, to establish phase difference and opposite chirality. From figure 1 it can be seen that ψ_ν is a fermion. However both spin 1/2 and 3/2 are possibilities, determined by the relative signs of spin 1/2 bivector ϕ_{E1} and spin 1 trivector g.

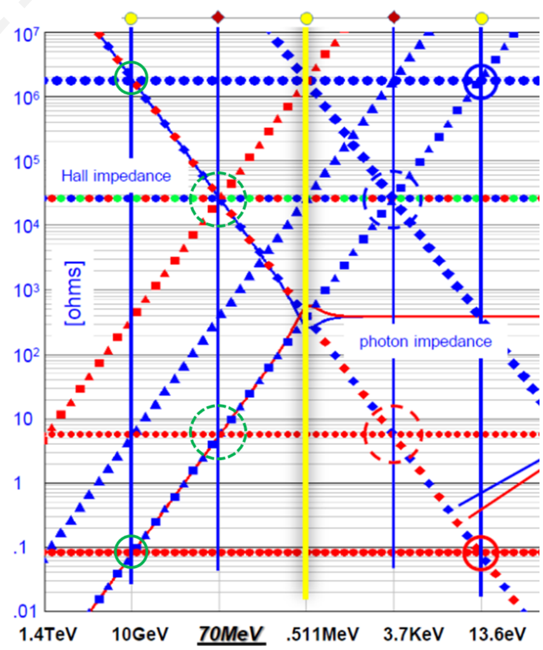

FIG. 8: Neutrino Impedance Network

The three two-body modes $\phi_{E1}\phi_B$ (photon), $g\phi_B$ (scalar Lorentz), and $g\phi_{E1}$ (quantum Hall) are indicated by ellipses in figure 6, and represented by the symbols shown there in figures 4 and 8. Taking the impedance network to be that of the vacuum wavefunction when excited by the neutrino modes, the photon mode $\phi_{E1}\phi_B$ excites the vacuum at the .511 MeV Compton frequency, decoupling the electric and magnetic flux quanta ϕ_{E1} and ϕ_B, the one going to high impedance and the other to low. Both excite nodes at Macgregor's 70 MeV platform state[50] (large broken green circles in figure 8), and beyond at the dominant ∼10 GeV bottomonium decay mode of the superheavies (smaller solid circles), influence of the W manifesting there.

It is perhaps here that can be found origins of chiral symmetry breaking, the solitary left-handed neutrino. The octonion algebra of the eight-component geometric wavefunction is not three-body associative. No problem for the two-body interactions thus far considered[28]. However, introducing the three-component neutrino manifests this broken symmetry. In a big bang (or big bounce) model[13] this would seem to restrict the primordial photon to a pure left-handed state, angular bivector and linear vector momenta antiparallel, perhaps respecting a principle of total momentum conservation in that topological first instant, summing rotational and translational momenta, and possibly accounting for antimatter's absence.

Accepted understanding in the particle physics community is that the neutrino must have rest mass for flavor oscillations. Rationale is that different 'masses' yield different Compton frequencies for the lepton generations, hence the accumulating differential phase shifts required for oscillations. Given that phase is relative, it is not possible to measure directly absolute mass values from flavor oscillations, but rather only to calculate 'mass' differences, the relative phase shifts. The model presented here offers a complementary perspective, one of phase shifts caused by quantized interaction impedances, one that does not require rest mass.

6. Special Relativity and Terrell Rotation

Special relativity is formulated in flat 4D Minkowski spacetime. Only one degree of freedom is required to connect time with space in SR, with the longitudinal axis of relative motion. Relativistic lifetime enhancement $\tau = \gamma\tau_0$ follows from increasing impedance mismatches to decay modes of figure 4 as the muon Compton wavelength shortens due to relativistic mass increase, due to compression of wavefunction fields whose energy is particle rest mass into smaller volumes by **translation gauge fields**, longitudinal E fields of the accelerating cavities supplying the additional energy. At rest we measure the muon mass to be 105 MeV, a factor of 3/2 greater than the 70 MeV coherence line of figure 4[86]. Relativistic mass increase shifts the muon wavelength to the left, distancing it from impedance nodes of muon decay modes at far right of figure 4, increasing the mismatch, thereby prolonging the lifetime.

Terrell rotation [87–90] happens on the light cone in the full 6D phase space. Three degrees of freedom are required for relative phases of the three possible orthogonal orientations of geometric wavefunction modes[14]. Gauge field of Terrell rotation is the **rotation gauge field**, that of the scale-invariant topological impedances. The premise of this note seeks to play upon the difference between the two as a function of Lorentz γ, as shown in figure 9.

The family of phase curves $\tan(\theta'/2) = \tan(\theta/2)\sqrt{(c-v)/(c+v)}$, where θ is orientation in lab frame and θ' in the particle frame[89], correspond to the difference between relative orientations of two wavefunctions as a function of γ and their separation (normalized to the impact parameter and therefore scale invariant). So for instance the blue 90 degree phase curve corresponds to their closest approach, such that a line joining their trajectories is perpendicular to both. For point particle wavefunctions this phase shift has no meaning beyond ascribing it to some 'internal' degree of freedom. For the full eight-component geometric vacuum wavefunction it represents a rotation gauge field whose phase shift offers the possibility of muon lifetime topological enhancement.

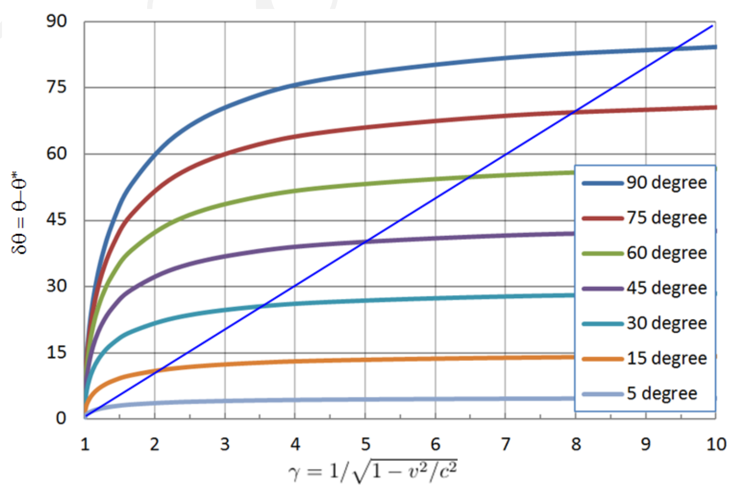

FIG. 9: Lifetime enhancement of special relativity (blue diagonal) and phase shifts of Terrell rotation (left axis) as a function of γ.

Maximal phase shift of 90 degrees comes when $\gamma_{Planck} =\sim 10^{21}$, when muon wavelength is Planck length, transforming muon into antimuon, Hawking's particle-antiparticle pairs. Phase rotates opposite inside the event horizon. This provides a meaningful scale for the blue diagonal of figure 9, which corresponds to lifetime enhancement of special relativity. Scale of the diagonal relative to the $\delta\theta = \theta - \theta'$ axis at left is arbitrary, was chosen to illustrate the contrast between linear dependence of SR lifetime enhancement on γ vs the nonlinear phase dependence of Terrell rotation, suggests different strategies/possibilities for low and high energies.

7. Lifetime Enhancement via Topological Impedance Matching?

At first blink[91] the prospects appear dismal. Strengths of wavefunction α-quantized E and B fields at the muon Compton wavelength are of the order 10^{20} volts/m and 10^{11} Tesla. How can one begin to hope there exists a possibility to significantly influence the dynamics with fields accessible to practical implementation?

We have the muon wavefunction and the vacuum modes it excites in the leftmost column of figure 7, and the neutrino wavefunction $\psi_\nu = g\phi_B\phi_{E1}$ from the rightmost column. Where to go from here? Do we seek to directly delay decoherence of the muon wavefunction, or to block coherence of the virtual neutrino wavefunction before it fully forms? Or search for some other strategy? Where and how in the decay process do we seek to intervene?

Given that the neutrino is present in all weak decays, in the interest of generality to start there seems to be the best choice. The numerically identical yet topologically distinct magnetic flux quantum ϕ_B and magnetic charge g excite slightly different vacuum wavefunction quantized impedances, the differential phase shift responsible for the 'tumbling' mentioned earlier, the neutrino oscillations.

Such an approach, to block coherence of the virtual neutrino wavefunction before it fully forms, might seek to introduce invariant impedances to modify that differential phase shift, to rotate the yet-cohering neutrino wavefunction away from eigenstates permitted by lepton number conservation. The obvious choice is solenoids, longitudinal magnetic field to differentiate between linear superposition of vector flux quantum ϕ_B and virtual acceleration of dark topological trivector magnetic charge g. How much relative phase shift of virtual neutrino wavefunction components is required to measureably forestall coherence? How much field integral is required to accomplish this? What does the experiment look like that seeks to measure it? Does the data already exist, in solenoidal detector fields at collider intersections? Solenoidal fields of muon cooling experiments? Cosmic ray interactions with the earth's magnetic field? Muon g-2 experiments? What can be said about enhancement as a function of muon energy? Of polarization[92, 93]? Of DC solenoid fields vs cavity TE modes?

Impedances of figures 3, 4, and 8 are parametric[62–65], providing the nonlinear mechanism of noiseless frequency domain energy translation essential in wavefunction interactions. If it proves to be that fields achievable in the lab are not adequate, is it possible to take advantage of parametric amplification in providing fields to counter the phase shifts responsible for decoherence? In figures 4 and 8, might the neutrino W nodes at 10 GeV generate phase shifts via excitation at the 13.6 eV nodes at 0.1 ohm and/or 10 megohms, for instance by synchrotron oscillations modulating the intersection with the scale dependent impedances, low impedance nodes at 13.6 eV coupling to high impedance at 10 GeV via the inductive dipole impedances, and/or high impedance at 13.6 eV to low impedance 10 GeV via the capacitive monopole and scalar Lorentz impedances.

Given that figure 9 phase shifts of Terrell rotation are most pronounced at low γ [94], and that wavefunction fields are their weakest there, it would seem the best strategy would be to shift the phase distribution of a collection of muons (and their superposed virtual neutrinos) as much as possible as early as possible, resulting in early decay of some and sustained coherence of others, a broadening of the distribution.

8. Claims for Geometric Algebra and the Geometric Wavefunction Interaction Model

It's obvious in a quick browse by a reader even vaguely familiar with the Standard Model that the model presented here is different, quite different. To be so different is a great weakness, makes the model appear irrelevant and easily dismissed. If a valid model, then to be so different will also prove to be its greatest strength, as that permits it to offer a compatible complementary unique perspective in mainstream areas presently regarded as most confounding and paradoxical.

For the purpose of encouraging the reader to invest the modest time and effort needed to properly appraise the model as applied to muon colliders, the following claims are put forth, in the hope that their scope might inspire a hard critical look.

Claims for Geometric Algebra

In the preface to the newly published second edition of his seminal text[36], Professor Hestenes makes four "bold and explicit... claims for innovation" in SpaceTime Algebra, the Pauli and Dirac algebras of 3D space and 4D spacetime:

- STA enables a unified, **co-ordinate free** formulation for all of relativistic physics, including the Dirac equation, Maxwell's equation, and General Relativity. STA is background independent.
- Pauli and Dirac matrices are represented in STA as **basis vectors** in space and spacetime respectively, with no necessary connection to spin.
- STA reveals that the **unit imaginary** in quantum mechanics has its origin in spacetime geometry.
- STA reduces the mathematical divide between classical, quantum, and relativistic physics, especially in the use of **rotors** for rotational dynamics and gauge transformations.

The preface encourages making such claims, lest the innovations be overlooked. "Modestly presenting evidence and arguing a case is seldom sufficient."[36] In this spirit, the following "bold and explicit" claims are made for the model of geometric wavefunction interactions, for the GWI model.

Claims for the GWI Model

- **photon-electron interaction** - Dirac spoke to the core of the model in asserting that
  "Until we have a really satisfactory explanation of how electrons and photons interact, it will hardly be possible to go on and explain the other particles."[95]
  Synthesis of geometric wavefunctions and impedance quantization provides *"a really satisfactory explanation"*.
- **natural** - The model is arguably maximally natural, satisfies the commonly accepted criteria - simplicity, small dimensionless numbers, absence of fine-tuning, scale invariance, robustness, emergence,... most desireable properties given discovery of the desert at the LHC[3–14].
- **gauge invariant** - Impedances shift phases, provide a coherent alternative formulation of the effect of the covariant derivative. GWI is *naturally gauge invariant.*
- **finiteness** - Impedance mismatches provide natural QED cutoffs. Both singularity and the boundary at infinity are decoupled by the infinite quantum impedance mismatches. No renormalization. GWI is *naturally finite.*
- **confinement** - Confinement is the flip side of finiteness. Energy is reflected from mismatches, back to matched impedance nodes at the wavefunction wavelength, be it Planck, Compton, deBroglie[96],... GWI contains the strong and weak nuclear forces, is *naturally confined.*
- **asymptotic freedom** follows from exact matching at wavefunction impedance network nodes.
- **background independence** - In STA, motion is described with respect to the object in question. Similarly, in the two body problem motion is with respect to one of the two. There is no background. GWI is naturally background independent, a requirement for calculating impedances from Mach's principle[28]
- **gravitation** - Matching quantized impedances at the Planck scale reveals an exact identity between electromagnetism and gravity[59].
- **origin of mass** is found in electromagnetic energy of wavefunction fields.
- **all scales** - The model is effective at all scales. Mis-interpretation of the measured running of α results from overlooking impedance quantization, from conflating running and mismatching.[97]
- **heirarchy** - Absence of renormalization and presence of inert vacuum wavefunction in flat space of Pauli and Dirac algebras resolve the heirarchy problems of both Higgs mass and cosmological constant.
- **string theory** - Assignment of E and B fields to the octonion vacuum wavefunction yields a representation of ten 'dimensional' string theory in the ten degrees of freedom of the GWI model in flat 4D Minkowski spacetime.
- **quantum interpretation** - GWI wavefunctions exist as electromagnetic fields configured as geometric objects in 3D space, interacting via Maxwell's equations in a network of quantized impedances.
  Wavefunctions and their interactions can be visualized. This permits resolution of many if not all paradoxes found in proliferating worlds of quantum interpretations[66, 67, 82, 85].

9. Summary

In the Introduction, Professor Rubbia's call for courage set the stage. In response came the conjecture that there might exist a source of phase in rotation gauge fields of well-chosen accelerator impedances to complement the muon lifetime enhancement of the Lorentz transform's translation gauge fields. It was followed by an abbreviated historical persective on the absence of impedance quantization from quantum field theory.

The first section introduced the reader to the vacuum wavefunction of the geometric representation of Clifford algebra - one scalar, three vectors, three bivectors, and one trivector.

The second section assigned topologically appropriate quantized E and B fields to the eight wavefunction components via combinations of the four fundamental constants that define the electromagnetic coupling constant α.

Impedance matching to the hydrogen atom was introduced in the third section and generalized to the unstable particle spectrum, providing beyond Standard Model explanations of lifetimes and branching ratios.

The fourth section employed geometric algebra of muon wavefunction modes (previously identified in an analysis of proton structure and spin) to determine geometric grades of the emerging decay products.

This permitted identification of neutrino wavefunction components in the fifth section.

The differing energy dependencies of muon lifetime enhancement via special relativity (translation gauge field) and topological impedance matching (rotation gauge field) suggested the scheme outlined in sections six and seven, followed by a series of claims for GA and the GWI model.

Conclusion

Hestenes said be bold. Rubbia said have courage. It suffices to be neither bold nor courageous, only tenaciously curious. This draft is highly speculative, surely contains much that is wrong, with many branch points in the perspective outlined here. However, it contains much that is right. Proton stabilizes neutron...

Dedication

Many heartfelt thanks to Professors Alan Krisch and Kent Terwilliger, consummate experimentalists and first-class accelerator physicists, gentlemen kind and true.

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