

# The potential importance of low luminosity and high energy at the LHC

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Low luminosity runs at higher LHC energy could provide definitive evidence for an electroweak scale sextet quark sector of QCD that produces electroweak symmetry breaking and dark matter within the bound-state S-Matrix of QUD - a massless, weak coupling, infra-red fixed-point, SU(5) field theory that might underly and unify the full Standard Model.

## 1. Introduction

The “nightmare scenario” seems to be emerging at the LHC. A resonance has been discovered that looks a lot like a Standard Model Higgs boson, but no other new physics is seen! In particular, the much anticipated manifestation of supersymmetry has not happened. Theoretical inconsistency implies there must be more, but there is no indication what to look for and there is much concern that the current theoretical framework for new physics searches may be seriously misdirected.

QUD<sup>1</sup> is a massless, weak coupling, infra-red fixed-point, SU(5) field theory that I have discovered as having a massive bound-state S-Matrix that is generated by infra-red chirality transition anomalies and that, uniquely, contains the unitary Critical Pomeron. Unbelievably (almost!), QUD might also underly and unify the S-Matrix of the full Standard Model. Moreover, unitarity may require the presence of a Higgs-like boson resonance.

If the QUD S-Matrix is the origin<sup>2</sup> of the Standard Model then, in addition to small neutrino masses, the only “new physics” is an electroweak scale, strongly interacting, sextet quark sector of QCD that provides electroweak symmetry breaking and dark matter, but is hard to isolate at large  $p_{\perp}$ . The dynamics is conceptually radical (within today’s theory paradigm), and a calculational procedure has still to be developed. Nevertheless, the implications of QUD’s existence are overwhelming. Suggestive evidence already exists and low luminosity runs at higher LHC energy could be definitive.

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<sup>1</sup> Quantum Uno/Unification/Unique/Unitary/Underlying Dynamics

<sup>2</sup> The Standard Model could be reproducing the “Unique Unitary S-Matrix.”

## 2. The Critical Pomeron and the Formulation of QUD

The Reggeon Field Theory Critical Pomeron is the only known description of rising total cross-sections<sup>3</sup> that satisfies full multiparticle t-channel unitarity and all s-channel unitarity constraints. The supercritical phase occurs *uniquely* in superconducting QCD, and the critical behavior appears when asymptotic freedom is saturated. Saturation is achieved with 6 color triplet quarks and 2 color sextet quarks and is physically realistic if “sextet pions” produce electroweak symmetry breaking!

QCD sextet quarks with the right electroweak quantum numbers, plus the electroweak interaction, embed uniquely (with asymptotic freedom and no anomaly) in QUD, i.e., SU(5) gauge theory with left-handed massless fermions in the  $5 \oplus 15 \oplus 40 \oplus 45^*$  representation. Under  $SU(3) \otimes SU(2) \otimes U(1)$

$$5 = (3, 1, -\frac{1}{3}) + (1, 2, \frac{1}{2}), \quad 15 = (1, 3, 1) + (3, 2, \frac{1}{6}) + (6, 1, -\frac{2}{3}),$$

$$40 = (1, 2, -\frac{3}{2}) + (3, 2, \frac{1}{6}) + (3^*, 1, -\frac{2}{3}) + (3^*, 3, -\frac{2}{3}) + (6^*, 2, \frac{1}{6}) + (8, 1, 1),$$

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

Astonishingly, there are 3 “generations” of both leptons and triplet quarks, and QUD is vector-like wrt  $SU(3) \times U(1)_{em}$ .  $SU(2) \times U(1)$  is not quite right, but if the anomaly-dominated S-Matrix can be constructed via multi-regge theory, as I have outlined [1], all elementary fermions are confined and Standard Model interactions and states emerge.

## 3. QUD Multi-Regge Theory

In multi-regge limits, infinite momentum bound-states and interactions can be studied using  $k_{\perp}$  reggeon diagrams. The removal of fermion masses introduces “anomaly vertices” and after the (crucially ordered) removal of gauge boson masses and a cut-off  $k_{\perp}^{\lambda}$ , an overall divergence<sup>4</sup> produces a “wee parton vacuum” of universal anomalous wee gauge bosons (SU(5) adjoint  $C \neq \tau$ ) as illustrated in Fig. 1. The surviving interactions couple via anomalies and preserve the vector  $SU(3) \times U(1)$  symmetry. They are

1. *Even Signature Critical Pomeron*  $\approx SU(3)$  gluon reggeon + wee gauge bosons. No BFKL pomeron and no odderon.
2. *Odd Signature Photon*  $\approx U(1)_{em}$  gauge boson + wee gauge bosons.
3. *Electroweak Interaction*  $\approx$  left-handed gauge boson, mixed with sextet pion (via anomalies), + wee gauge bosons.

Anomaly color factors, in wee gauge boson infinite sums, enhance couplings — hopefully to Standard Model values ( $\alpha_{QCD} \gg \alpha_{QUD} \sim \frac{1}{120}$ ).

<sup>3</sup> A necessity to match with an asymptotically-free gauge theory at short distances.

<sup>4</sup> After elaborate cancelations of reggeization of infra-red divergences.

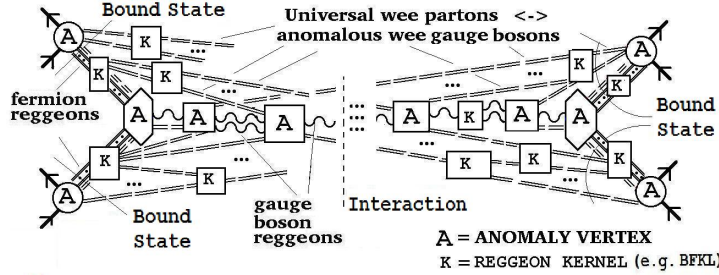


Fig. 1. The general form of divergent Reggeon diagrams.

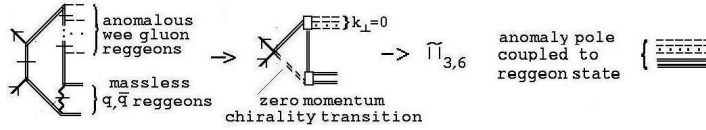


Fig. 2. The anomaly pole Goldstone pion.

Bound-states involve anomaly poles due to chirality transitions, e.g., Goldstone pions in QCD as illustrated in Fig. 2. Within QCD, confinement and chiral symmetry breaking coexist with a “parton model.”

- Bound-states are triplet or sextet quark mesons and baryons. The proton and neutron (“dark matter” sextet neutron) are stable. There are no hybrids and no glueballs.
- Sextet anomaly color factors are much larger than triplets and so (electroweak scale) sextet masses are correspondingly larger.
- Wee gluon color factors give large pomeron couplings to sextet states, producing large high-energy  $x$ -sections and large couplings to (pomeron producing) high-multiplicity hadron states.

Within QUD, ultra-violet octet quark anomaly poles produce Standard Model generations of physical hadrons and leptons. Lepton bound states contain three elementary leptons:

- $(e^-, \nu) \leftrightarrow (1, 2, -\frac{1}{2}) \times \{(1, 2, -\frac{1}{2})(1, 2, \frac{1}{2})\}_{AP} \times \{(8, 1, 1)(8, 2, -\frac{1}{2})\}_{UV}$
- $(\mu^-, \nu) \leftrightarrow (1, 2, \frac{1}{2}) \times \{(1, 2, -\frac{1}{2})(1, 2, -\frac{1}{2})\}_{AP} \times \{(8, 1, 1)(8, 2, -\frac{1}{2})\}_{UV}$
- $(\tau^-, \nu) \leftrightarrow (1, 2, -\frac{3}{2}) \times \{(1, 2, \frac{1}{2})(1, 2, \frac{1}{2})\}_{AP} \times \{(8, 1, 1)(8, 2, -\frac{1}{2})\}_{UV}$

Anomaly interactions imply  $M_{hadrons} \gg M_{leptons} \gg M_{\nu's} \sim \alpha_{QUD}$ . The electron is almost elementary (the anomaly pole is, effectively, a minimal disturbance of the Dirac sea). The muon has the same constituents in a more massive dynamical configuration!

#### 4. “Top” and “Higgs” Physics

The primary decay of the “sextet  $\eta$ ” is  $\eta_6 \rightarrow W^+ W^- Z^0 \rightarrow W^+ W^- b\bar{b}$  (cf.  $\eta \rightarrow \pi^+ \pi^- \pi^0$ ). Since this is the dominant Standard Model  $t\bar{t}$  decay mode, the  $\eta_6$  resonance produces events that are experimentally hard to distinguish from Standard Model top physics. However, it is the sextet quark mass scale that is involved, and not a “bizarrely large” triplet quark mass!

Two QUD triplet quark generations give Standard Model hadrons. The third is  $(3, -\frac{1}{3}) \equiv [3, 1, -\frac{1}{3}] \in 5, (3, \frac{2}{3}) \in [3, 2, \frac{7}{6}] \in 45^*$ . The physical b quark is a mixture of all three QUD generations. However, there are two “exotic” triplet quarks with charges  $-4/3$  and  $5/3$  that have no chiral symmetry and so do not produce light (anomaly pole) bound-states. The left-handed “top quark” ( $t_{QL}$ ) forms an electroweak doublet with one of the exotic quarks and so will not appear in low mass states. (The electroweak interaction is enhanced, at high energy, by the sextet quark sector.) The  $\eta_t \approx t_{QR}\bar{t}_{QL}$  remains as a “constituent  $t_Q$  state.” Mixing with the sextet  $\eta$  gives two mixed-parity scalars — the  $\eta_6$  with electroweak scale mass and the  $\eta_3$ , with a mass between triplet and sextet scales that, could be  $\sim 125$  GeV! If so, the “QUD Higgs” is predominantly a “top/anti-top” resonance.

Because QUD interactions are reggeized, intermediate state cancelations must occur that are equivalent to the “tree-unitarity” condition determining electroweak Higgs couplings in the Standard Model. Consequently, the combined  $\hat{\eta}_3$  and  $\hat{\eta}_6$  couplings should reproduce Standard Model couplings and disparities between the 125 GeV resonance and the Standard Model Higgs should be accounted for by the  $\eta_6$ .

#### 5. At the LHC ?

The most direct evidence for QUD is the appearance of the  $\eta_6$  resonance, in the  $Z$ -pair cross section, at the “ $t\bar{t}$ ” threshold. As can be seen from Fig. 3, it is most visible in the lower luminosity 7 GeV data. Is ultra-high luminosity missing QUD cross sections (as we will suggest often in the following)?

Large pomeron couplings to  $\pi_6$ 's ( $\equiv$  longitudinal  $W$ 's/ $Z$ 's) implies large rapidity-gap cross sections for multiple  $W$ 's/ $Z$ 's (i.e. sextet isospin conserving  $WW, ZZ, WWZ, ZZZ, \dots$ ) above the EW scale, including a large double-pomeron cross section for  $Z^0 Z^0$  and  $W^+ W^-$  pairs (some of these events might be identified, partially or fully, via jets). There should also be (correlated) much larger, cross sections for multiple  $W$ 's/ $Z$ 's, over a wide range of rapidities, with high associated hadron multiplicity — that are the intermediate states of the pomeron. At higher energies, multiple sextet baryons — “neusons” (dark matter) and “prosons” will be similarly produced. Growing cross sections, coupling pomeron and electroweak physics

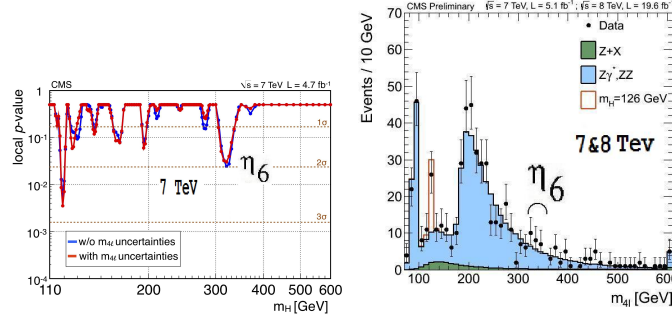


Fig. 3. The  $\eta_6$  at the LHC.

are clearly what should be looked for at the highest LHC energy. However, *low luminosity is essential!*

Existing evidence, appropriately interpreted, includes

1. “Heavy Ion” UHE cosmic rays are dark matter neusons.
2. The spectrum knee is due to arriving/produced neuson thresholds.
3. Enhancement of high multiplicities and small  $p_{\perp}$  at the LHC reflects a sextet anomaly generated triple pomeron coupling.
4. “Top quark events” are due to the  $\eta_6$  resonance — interference with the background produces the Tevatron asymmetry.
5.  $W^+W^-$  and  $Z^0Z^0$  pairs have high mass excess cross sections, with the  $\eta_6$  resonance appearing at the “ $t\bar{t}$  threshold”.
6. The 125 GeV Higgs is the QUD ( $t_R\bar{t}_L + \eta_6$ ) resonance.
7. The AMS  $e^+/e^-$  ratio reflects EW scale CR production of  $W$ ’s and  $Z$ ’s (+ neuson/antineuson annihilation?)
8. Low luminosity Tevatron/LHC events with a  $Z$  pair + high multiplicity of small  $p_{\perp}$  particles, could be QUD (not Standard Model) events.
9. TOTEM+CMS missing momentum events could be  $ZZ \rightarrow \nu$ ’s

## 6. The Low Luminosity Events

Interesting events were seen with initial low luminosity at the Tevatron and the LHC, and also in the recent TOTEM-CMS low luminosity run.

The first CDF  $Z^0Z^0$  event, shown in Fig. 4, was recorded in 2004 — before pile-up! It was first counted as a  $Z^0Z^0$  event, then rejected because one electron was insufficiently isolated, and finally counted. It has some remarkable features. A cut-off  $E_T > 500$  MeV leaves only a few extra particles, but with  $E_T > 100$  MeV, many more ( $> 70$ ) fill the rapidity

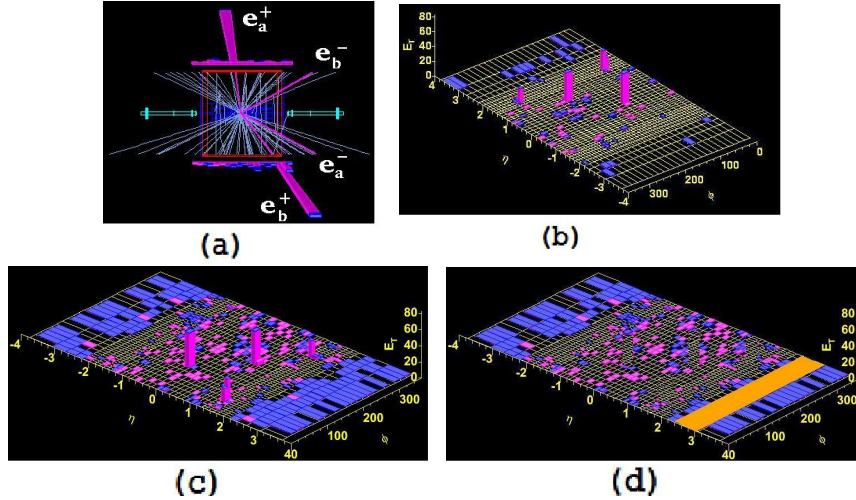


Fig. 4. (a)  $p_{\perp} > 200$  MeV, (b)  $E_T > 500$  MeV, (c)  $E_T > 100$  MeV (d)  $Z^0 Z^0$  production region.

axis away from the very forward  $Z^0 Z^0$  production region which, as shown in Fig. 4(d), is almost out of the detector. While this is *just what would be expected for QUD events*, a 4 electron event would have been very rare in the Standard Model with the very small accumulated luminosity. Also, the very high hadron multiplicity (which was discovered serendipitously) is unexpected in the Standard Model. Unfortunately, pile-up made looking for similar events at the Tevatron impossible. So, was this event part of a (QUD predicted) forward cross section that was almost entirely missed?

The first CMS  $Z^0 Z^0$  event ( $4 \mu's$ ), shown in Fig. 5, was recorded when the accumulated luminosity was  $\sim 2-3 \text{ pb}^{-1}$ . Therefore, naively, from  $\sim 25 \text{ fb}^{-1}$  we might expect  $\sim 10,000$   $Z^0 Z^0$  events, yet only  $\sim 400$  have been seen! It is a remarkably clean event; with  $p_{\perp} > 1$  GeV there are only two extra particles. With no cut-off there are twenty additional particles which all have momenta in one or the other of the two forward directions. Also  $\langle n \rangle$  and  $\langle p_{\perp} \rangle$  are close to minimum bias. Moreover, both  $Z^0$ 's are very central and  $p_{\perp}(ZZ)$  is unusually low  $\sim 3$  GeV. Clearly, this does not look like a Standard Model hard scattering event! Could it also have been part of a QUD cross section, containing  $Z^0$  pair events distributed over a wide range of rapidities, that were largely unseen because of pile-up?

A CMS 4e event with pile-up is shown in Fig. 6. The line of scattering vertices is clear. Not only is it obviously impossible to determine any properties of associated soft hadrons produced with the  $Z^0$  pair, also more forward-going leptons and photons will surely be very difficult to isolate!

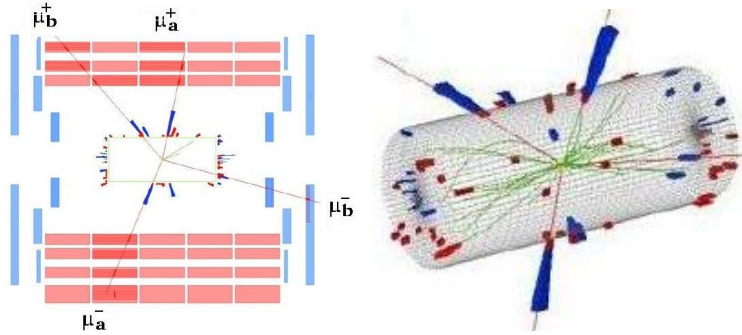


Fig. 5. The first CMS  $Z^0 Z^0$  event.

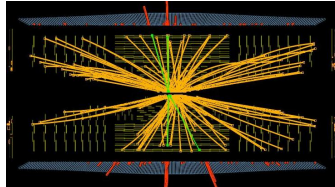


Fig. 6. A CMS  $Z^0 Z^0$  event with pile-up.

In the recent CMS-TOTEM special run, the rapidity coverage was

CMS:  $|\eta| < 5.5$ , T1:  $3.1 < |\eta| < 4.7$ , T2:  $5.3 < |\eta| < 6.5$ , FSC:  $6 < |\eta| < 8$

For events with clearly isolated forward-going protons, and with rapidity gaps imposed outside of T2, the central  $M_{TOT}$  calculated from TOTEM Roman pot measurements was compared with  $M_{CMS}$  measured in the central CMS detector. In events where  $M_{CMS} \ll M_{TOT}$  corresponding additional tracks were generally seen in the TOTEM T2 detector. However, in some events no additional tracks were seen and in a few the missing mass was as high as  $O(400)$  GeV. Could these events include  $Z^0 Z^0 \rightarrow 4\nu$ 's, as part of the large rapidity QUD  $Z^0 Z^0$  cross section?

## 7. The Low Luminosity Future?

QUD cross sections should increase with energy, but increased high luminosity could still hide signals and, moreover, low luminosity runs will be short and focus on small  $p_{\perp}$  physics. However, CMS-TOTEM is working well — with beautiful double-pomeron multi-jet event displays and also “missing mass” events recorded. Assuming a major part of the cross section has been missed at high luminosity, as I have argued, then some  $Z^0 Z^0$  and  $W^+ W^-$  pairs could be seen in the CMS detector, even at low luminosity.

The unprecedented wide rapidity coverage of rapidity gaps and hadron multiplicities suggests that direct evidence for the link between pomeron and electroweak physics, that I have described could be seen!

If the “nightmare scenario” persists after extensive high luminosity running, and significant evidence of new phenomena is seen in brief low luminosity runs, we might hope (very optimistically) that, eventually, there could be a transition to full-time low luminosity — with modified detectors? If it is present, QUD physics would provide a rich and exciting program with a wide variety of phenomena.

## 8. Some QUD Virtues

- QUD is self-contained and is either entirely right, or simply wrong!
- The scientific and aesthetic importance of an underlying massless field theory for the Standard Model can not be exaggerated.

If hard evidence of an electroweak scale strong interaction appears, supporting the existence of QUD, there will be a (*perhaps needed?*) radical redirection of the field, from the pursuit of rare, elusive, probably non-existent, short-distance physics, to the full-scale study of novel high-energy, unexpectedly large cross section, long-distance physics.

Assuming the QUD S-Matrix can be derived as I have outlined, then

1. *The only new physics is a high mass sector of the strong interaction that gives electroweak symmetry breaking and dark matter.*
2. *Parity properties of the strong, electromagnetic, and weak interactions are naturally explained.*
3. *The massless photon partners the “massless” Critical Pomeron.*
4. *Anomaly vertices mix the Reggeon states. Color factors could produce the wide range of Standard Model scales and masses, with small Majorana neutrino masses due to the very small QUD coupling.*
5. *Particles and fields are truly distinct. Physical hadrons and leptons have equal status.*
6. *Symmetries and masses are S-Matrix properties. There are no off-shell amplitudes and there is no Higgs field.*
7. *As a massless, asymptotically free, fixed-point theory, QUD induces Einstein gravity with zero cosmological constant.*

## References

- [1] Considerable background, including references, is provided in a series of papers by A.R. White, arXiv:1106.5662; arXiv:1009.4850; arXiv:0803.1151; arXiv:0708.1306; arXiv:1206.0192; arXiv:1301.5628.