The Potential Importance of Low Luminosity and High Energy at the LHC

The “nightmare scenario” seems to be emerging at the LHC. A resonance that looks a lot like a Standard Model Higgs boson, BUT - no other new physics is seen!!

- Theoretical inconsistency $\implies$ there must be more but (from current LHC results) there is no indication what to look for ??

- QUD* is a massless, weak coupling, IR fixed-point, SU(5) field theory that has

\{I have argued\} a massive bound-state S-Matrix, generated by infra-red chirality transition anomalies, that uniquely contains the unitary Critical Pomeron.

Unbelievably \{almost!\}, QUD might also underly & unify the full Standard Model.

* Quantum Uno/Unification/Unique/Unitary/Underlying Dynamics
If the QUD S-Matrix is the origin* of the Standard Model then, in addition to small neutrino masses, the only “new physics” is

- an EW scale strongly interacting sextet quark sector of QCD that provides EW symmetry breaking & dark matter, but is hard to isolate at large $p_\perp$.

This is conceptually radical & much development is still needed to develop a predictive, calculational, framework. Nevertheless, the implications are overwhelming, & suggestive evidence already exists.

- Low luminosity runs at higher LHC energy could play a crucial role !!
THE CRITICAL POMERON

Uniquely, the Reggeon Field Theory **CRITICAL POMERON** has been shown to satisfy full multiparticle t-channel unitarity & all high-energy s-channel unitarity constraints.

Supercritical RFT Connects Uniquely to Superconducting **QCD**

\[
\text{Critical } P \iff \max N_f \equiv 16 \text{ triplet quarks } \left\{ \text{unrealistic} \right\}
\]

\[
\equiv \text{ QCD}_S = \text{ QCD}_{n_q=6} + \left\{ \text{sextet doublet} \right\}
\]

- physically realistic if \( \pi_6 \)'s produce EW symmetry breaking!!!
FORMULATION OF QUD

Appropriate QCD 6’s + EW interaction \textit{embed uniquely} \{asym free & no anomaly\} in

\textbf{QUD} \equiv SU(5) \text{ gauge theory with } l\text{-handed } 5 \oplus 15 \oplus 40 \oplus 45^* \text{ massless fermions.}

Under $SU(3) \otimes SU(2) \otimes U(1)$

\begin{align*}
5 &= (3, 1, -\frac{1}{3}) + (1, 2, \frac{1}{2}) , \\
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})
\end{align*}

\textbullet \text{ Astonishingly } !!! - \text{ there are 3 “generations” of both leptons & triplet quarks, & QUD is vector-like wrt } SU(3) \times U(1)_{em}. \text{ } SU(2) \times U(1) \text{ is not quite right, but if the anomaly-dominated S-Matrix can be constructed via multi-regge theory } \{\text{as I have outlined}\},

\text{all elementary fermions are confined}

& SM interactions and states emerge as follows !!!
In multi-regge limits, bound-states & interactions can be studied using $k_\perp$ reggeon diagrams ($\infty$ sums of feynman diagrams) containing gauge boson & fermion reggeons. Removing masses & a cut-off $k_\perp^\lambda \rightarrow$ anomaly vertices & an overall divergence* → “wee parton vacuum” universal anomalous wee gauge bosons \{SU(5) adjoint $C \neq \tau$\}

* after elaborate cancelations of reggeization IR divergences.
INTERACTIONS

The surviving interactions couple via anomalies & preserve the vector \(SU(3) \times U(1)\) symmetry. They are

1. **Even Signature** \(\{\text{Critical}\}\) Pomeron \(\approx SU(3)\) gluon reggeon + wee gauge bosons (anomalies \(\rightarrow\) triple pomeron vertex). **NO BFKL IP, & 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 SM values* \(\{\alpha_{QCD} >> \alpha_{QU} \approx \frac{1}{120}\}\)
ANOMALY POLE BOUND STATES

Bound-states involve anomaly poles due to chirality transitions, e.g. Goldstone $\pi$’s in QCD

Within QCD, confinement & chiral symmetry breaking coexist with a “parton model”

- **Bound-states** are triplet or sextet quark mesons & baryons. \( \{ \text{the proton} & \neuson \text{ (≡ sextet neutron → dark matter)} \text{ are stable} \} \). NO hybrids, NO glueballs.
- Sextet color factors $\gg$ triplet $\implies$ sextet masses (↔ EW scale) $\gg$ triplets.
- **Wee gluon color factors** $\implies$ large $P^P$ couplings to sextet states $\implies$ large high-energy $x$-sections & couplings to high-multiplicity hadron states \( \leftrightarrow ImP \)
Within QUD, octet quark UV anomaly poles $\rightarrow$ SM generations. Lepton bound states contain three elementary leptons $\rightarrow$

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

Anomaly interactions $\implies$ all leptons have mass. Anomaly color factors

$\rightarrow M_{\text{hadrons}} >> M_{\text{leptons}} >> M_{\nu', s} \sim \alpha_{QUD}$

$e \approx$ elementary, $\mu \sim e$ but more massive !!
“TOP & HIGGS” PHYSICS

The primary decay of the sextet $\eta$ is (cf. $\eta \rightarrow \pi^+ \pi^- \pi^0$)

$$\eta_6 \rightarrow W^+ W^- Z^0 \rightarrow W^+ W^- b \bar{b}$$

dominant SM $t \bar{t}$ decay mode

- The $\eta_6$ resonance produces SM “$t \bar{t}$ events”
- experimentally hard to distinguish from SM top physics.
- sextet quark mass scale - not “bizarre” large triplet quark mass!!

Two QUD triplet quark generations $\rightarrow$ SM hadrons. The third is

$$(3, -\frac{1}{3}) \equiv [3,1, -\frac{1}{3}] \in [5], \quad (3, \frac{2}{3}) \in [3,2, \frac{7}{6}] \in 45^*$$

The physical $b$ quark is a mixture of the three QUD generations.
• Two “exotic” triplet quarks with charges -4/3 & 5/3 have no chiral symmetry $\iff$ no light (anomaly pole) bound-states.

• The l-handed “top quark” ($t_{QL}$) forms an EW doublet with an exotic quark $\implies$ low mass $t_{QL}$ states will be destabilized.

$\eta_t \approx t_{QR} \bar{t}_{QL}$ remains as a “constituent $t_Q$ state”. Mixing with the sextet $\eta \rightarrow$ two mixed-parity scalars - the $\eta_6$ with EW scale mass & the $\eta_3$ with mass between triplet & sextet scales $\sim 125$ GeV $\equiv$ \{“QUD Higgs” $\equiv$ “top/anti-top” resonance\}

Regge behavior requires cancelations $\equiv$ Tree-unitarity $\implies$ \{hopefully\} combined $\hat{\eta}_3$ & $\hat{\eta}_6$ couplings are comparable to SM Higgs couplings.
The $\eta_6$ in the Z-pair x-section, at the “$t\bar{t}$” threshold, is direct evidence for QUD. Currently, more visible in the lower luminosity 7 GeV data - suggesting ultra-high luminosity is missing QUD x-sections.
Large $\mathbb{P}$ couplings to $\pi_0$’s \{≡ longitudinal $W$’s/Z’s\} $\implies$ large rapidity-gap x-sections for multiple $W$’s/Z’s ($WW$, $ZZ$, $WWZ$, $ZZZ$, ...) above the EW scale

- including a large double-$\mathbb{P}$ x-section for $Z^0$ & $W^\pm$ pairs - could some events be identified, partially or fully, via jets ??

- correlated, much larger, x-sections for multiple $W$’s/Z’s, over a wide range of rapidities, with high associated hadron multiplicity ($\leftrightarrow \text{Im}\mathbb{P}$)

At higher energies, multiple sextet baryons - “neuson” \{dark matter\} & “prosons” - similarly produced.

Growing x-sections, coupling $\mathbb{P}$ & EW physics, should be looked for at the highest LHC energy. But,

LOW LUMINOSITY IS ESSENTIAL !!!!
Some “interpreted” existing evidence?

1. “Heavy Ion” UHE cosmic rays are dark matter neusons.
2. The cosmic ray spectrum knee is due to arriving/produced neuson thresholds.
3. Enhancement of high multiplicities & small $p_{\bot}$ at the LHC reflects a sextet generated triple pomeron coupling.
4. “Top quark events” are due to the $\eta_6$ resonance - interference with the background produces the Tevatron asymmetry.
5. $Z$ pairs produce a high mass excess cross-section, with the $\eta_6$ appearing at the “$t\bar{t}$ threshold” - most visibly in the CMS lower luminosity 7 GeV data.
6. The 125 GeV Higgs is the QUD $\{t_Rt_L + \eta_6\}$ resonance.
7. The AMS $e^+/e^-$ ratio reflects EW scale CR production of W’s & Z’s (+ neuson/antineuson annihilation?)
8. Low luminosity Tevatron/LHC events with a $Z$ pair + high multiplicity of small $p_{\bot}$ particles, $\neq$ SM, = QUD. $\{\text{next}\}$
9. TOTEM+CMS missing momentum $\leftrightarrow Z\bar{Z} \rightarrow \nu$’s $\{\text{coming up}\}$
Suggestive events were seen with initial low luminosity at both the Tevatron & the LHC. Also, very interesting events were seen in the recent TOTEM-CMS low luminosity run. The CDF $Z^0 Z^0$ event below was recorded in 2004 - before pile-up!!! First counted, then rejected - one electron insufficiently isolated, then counted.

\[ E_T > 500 \text{ MeV} \quad \text{and} \quad p_\perp > 200 \text{ MeV} \]
\[ E_T > 100 \text{ MeV} \]

\[ Z^0 Z^0 \text{ production region} \]

- \[ E_T > 500 \text{ MeV} \] leaves only a few extra particles.
- \[ E_T > 100 \text{ MeV} \], many more (\( \geq 70 \)) fill the rapidity axis away from the very forward \( Z^0 Z^0 \) production region \{almost out of the detector\}, as expected for QUD events!!
- Low luminosity \( \rightarrow 4e \) event very rare in the SM - the very high hadron multiplicity was discovered serendipitously.
- Pile-up made looking for similar events impossible. Was this event part of a (QUĐ predicted) very forward x-section that was almost entirely missed?
The first CMS $Z^0 Z^0$ event (4 $\mu^+$'s), shown below, was recorded when the accumulated luminosity was $\sim 2$-3 pb$^{-1}$. From $\sim 25$ fb$^{-1}$, we might naively expect $\sim 10,000$ $Z^0 Z^0$ events, yet only $\sim 400$ have been seen!!

\[ p_\perp > 1 \text{ Gev} \]

No $p_\perp$ cut-off
• A remarkably clean event, \( p_\perp > 1 \) GeV → only two particles.
• No cut-off → twenty with momenta in one of the two forward directions.
• \( \langle n \rangle \) & \( \langle p_\perp \rangle \) are close to minimum bias.
• Both \( Z^0 \)'s are very central & \( p_\perp (ZZ) \) is unusually low \( \sim 3 \) GeV

This does not look like a hard scattering event! Could it also have been part of a QUAD x-section, containing \( Z^0 \) pair events distributed over a wide range of rapidities, that were largely unseen because of the pile-up due to the luminosity build-up?

CMS 4e event - with pile-up.

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 & photons will surely be very difficult to isolate!
**CMS-TOTEM**

In a special run, $M_{TOT}$ predicted by protons detected via Roman pots was compared with $M_{CMS}$ measured in the central detector. In general

$$M_{CMS} \ll M_{TOT} \quad \iff \quad \text{tracks are seen in T2.}$$

But, in several events no tracks were seen & in a few

$$\Delta M \geq 400 \text{ GeV}$$

e.g. $Z^0 Z^0 \rightarrow 4 \nu$'s

large rapidity QUD ???

---

**ONE EVENT**

- Significant mass discrepancy:
  - RP predicted mass $M(\xi_1 \xi_2) \approx 900$ GeV
  - CMS visible mass $M(CMS) \approx 500$ GeV
- More forward $\eta$ than T2 forbidden
  - $\xi_1$ and $\xi_2$ forbid $\eta > 6.7$ and 6.9 respectively
- Gap definition tolerances applied
  - resolutions, secondaries, pseudorapidity $\leftrightarrow$ rapidity conversion ...
- No tracks observed in T2
  - But tracks are allowed (required) in $\sim$T2 on both sides

$\sim 400$ GeV missing mass?
THE LOW LUMINOSITY FUTURE?

QUD x-sections may increase with energy, but increased high luminosity could still hide signals. Low luminosity runs will be short & focus on small $p_\perp$ physics.

- But CMS-TOTEM is working well - with beautiful double-$\bar{p}$ multi-jet event displays & “missing mass” events recorded. \{c.f. ATLAS-ALFA ??\}
- If some x-section has been missed at high luminosity, $Z^0$ & $W^\pm$ pairs could be seen in the CMS detector.
- The unprecedented wide rapidity coverage of rapidity gaps & hadron multiplicities suggests direct evidence for a link between $\bar{p}$ & EW physics could be seen!!

If the “nightmare scenario” persists after extensive high luminosity running, & significant evidence of new phenomena is seen in brief low luminosity runs, could there be, eventually, a transition to full-time low luminosity - with modified detectors ???
SOME QUD VIRTUES

- QUD is self-contained & 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 substantial evidence of an EW scale strong interaction appears, supporting the existence of QUD, it will have a \{perhaps needed?\} radical effect on the field.

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 EW symmetry breaking & 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 SM scales and masses, with small Majorana neutrino masses due to the very small QUD coupling.**

5. **Despite the underlying SU(5) symmetry, there is no proton decay.**

6. **Particles and fields are truly distinct. Physical hadrons and leptons have equal status. 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.**