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** $\Longrightarrow$ **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 !!**

* *Could the Standard Model be reproducing the* **"Unique Unitary S-Matrix" ?**

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 Connnects Uniquely to Superconducting QCD $\longrightarrow$

$$\textbf{Critical } \mathbb{P} \quad \longleftrightarrow \quad \textbf{max N}_f \equiv \textbf{16 triplet quarks } \{\textbf{unrealistic !!}\}$$

$$\equiv \quad \textbf{QCD}_S = \textbf{QCD}_{n_q=6} + \{\textbf{sextet doublet}\}$$

- physically realistic if π_6's produce EW symmetry breaking!!!

FORMULATION OF QUD

Appropriate QCD 6's + EW interaction *embed* **uniquely** $\{$*asym free & no anomaly*$\}$ *in*

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

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

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

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

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

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

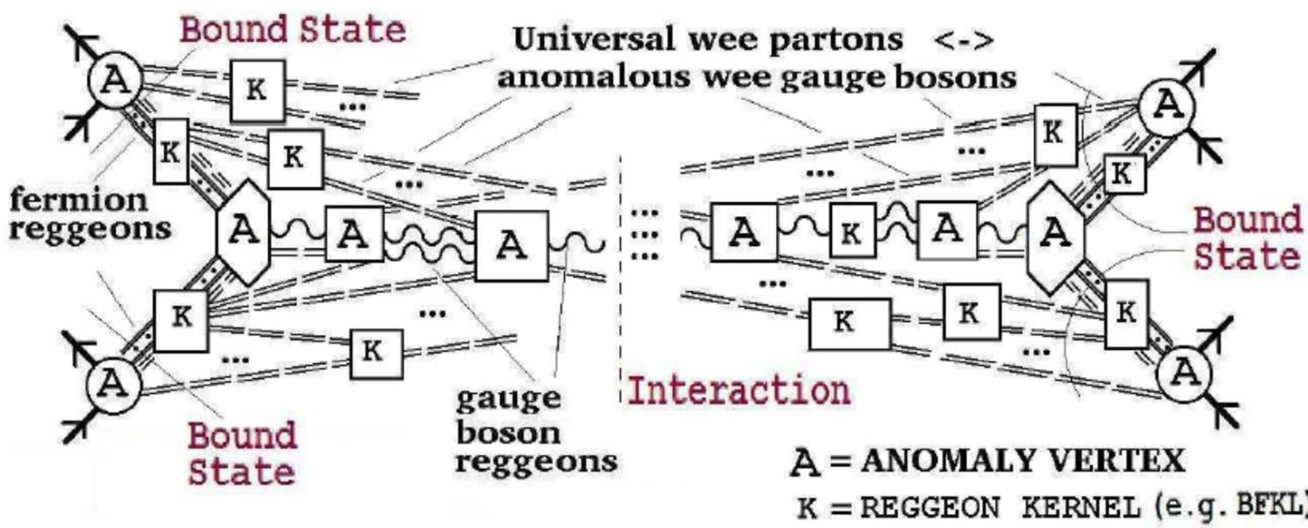
all elementary fermions are confined

& SM interactions and states emerge as follows *!!!*

QUD MULTI-REGGE THEORY

In multi-regge limits, bound-states & interactions *can be studied using* $k\perp$ **reggeon diagrams** (∞ *sums of feynman diagrams*) *containing gauge boson & fermion reggeons.* Removing masses & a cut-off $k_{\perp}^{\lambda}$ $\longrightarrow$ **anomaly vertices** & an overall divergence* $\longrightarrow$ **"wee parton vacuum"** universal anomalous wee gauge bosons {*SU(5) adjoint* $C \neq \tau$}

General Form of Divergent Reggeon Diagrams



**after elaborate cancelations of reggeization IR divergences.*

INTERACTIONS

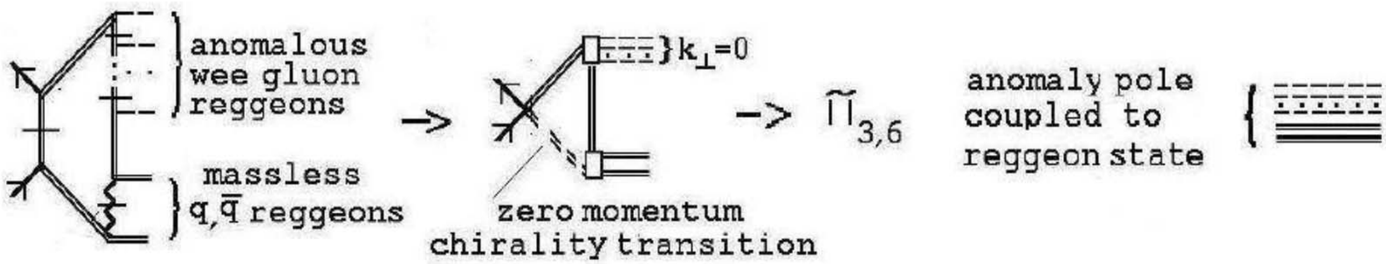
The surviving interactions couple via anomalies & preserve the vector SU(3)xU(1) symmetry. **They are**

1. **Even Signature** {*Critical*} **Pomeron** $\approx$ *SU(3) gluon reggeon* + *wee gauge bosons* **(anomalies $\longrightarrow$ triple pomeron vertex).** **NO** BFKL $\mathbb{P}$, & **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** $\{\alpha_{QCD} >> \alpha_{QUD} \sim \frac{1}{120}\}$

ANOMALY POLE BOUND STATES

Bound-states *involve anomaly poles due to chirality transitions, e.g. Goldstone π's in QCD*



Within QCD, confinement & chiral symmetry breaking coexist with a **"parton model"**

- **Bound-states are triplet or sextet quark mesons & baryons.** $\{$*the proton & neuson* ($\equiv$ sextet neutron $\longrightarrow$ **dark matter**) *are stable*$\}$. **NO** hybrids, **NO** glueballs.
- **Sextet color factors** $>>$ **triplet** $\Longrightarrow$ **sextet masses (**$\leftrightarrow$ **EW scale)** $>>$ **triplets.**
- *Wee gluon color factors* $\longrightarrow$ **large $\mathbb{P}$ couplings to sextet states** $\longrightarrow$ **large high-energy x-sections & couplings to high-multiplicity hadron states** $\{\leftrightarrow Im\mathbb{P}\}$.

Within QUD, octet quark UV anomaly poles $\longrightarrow$ SM generations. Lepton bound states contain three elementary leptons $\longrightarrow$

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

Anomaly interactions $\Longrightarrow$ all leptons have mass. *Anomaly color factors*

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

$e \approx$ elementary, $\mu \sim e$ but more massive !!

"TOP & HIGGS" PHYSICS

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

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

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

- **The η_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 $\longrightarrow$ SM hadrons. The third is

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

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 $\leftrightarrow$ no light (anomaly pole) bound-states.
- The l-handed “top quark” (t_{QL}) forms an EW doublet with an exotic quark $\Longrightarrow$ low mass t_{QL} states will be destabilized.

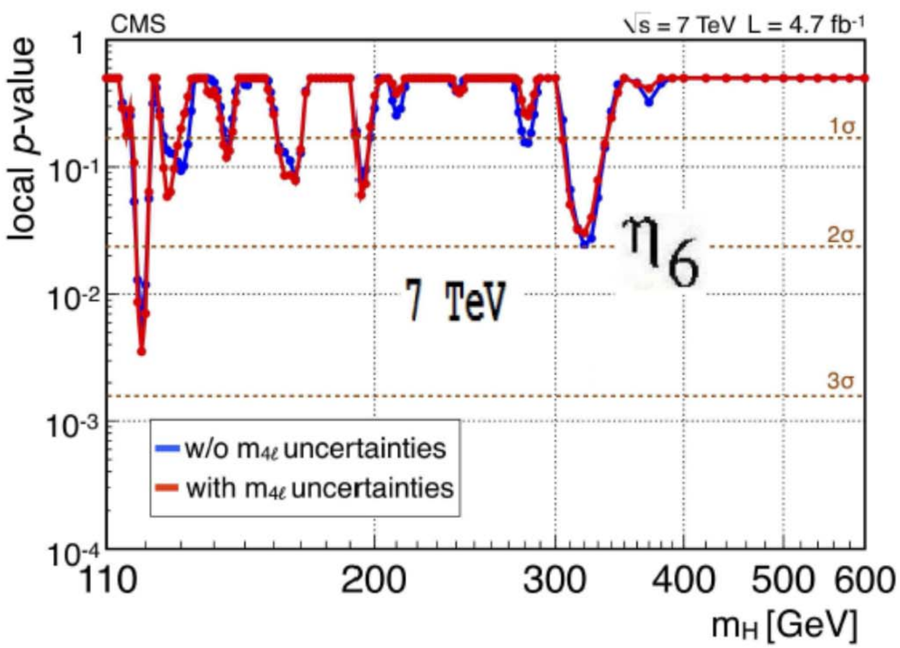
$\eta_t \approx t_{QR}\bar{t}_{QL}$ remains as a “constituent t_Q state”. Mixing with the sextet $\eta \longrightarrow$ two mixed-parity scalars - the η_6 with EW scale mass & the η_3 with mass between triplet & sextet scales $\sim$ **125 GeV ???** $\{$*“QUD Higgs”* $\equiv$ *“top/anti-top” resonance*$\}$

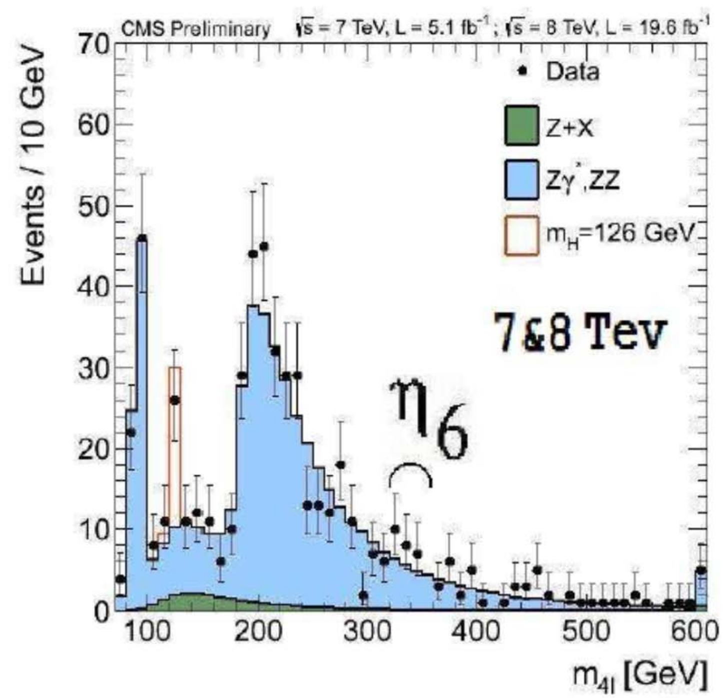
Regge behavior requires cancelations $\equiv$ Tree-unitarity

$\Longrightarrow$ $\{$*hopefully*$\}$ **combined $\hat{\eta}_3$ & $\hat{\eta}_6$ couplings are comparable to SM Higgs couplings.**

AT THE LHC ??

The η_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 π_6's $\{\equiv$ *longitudinal W's/Z's*$\}$ $\Longrightarrow$ **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** $(\leftrightarrow Im\mathbb{P})$

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 !!!

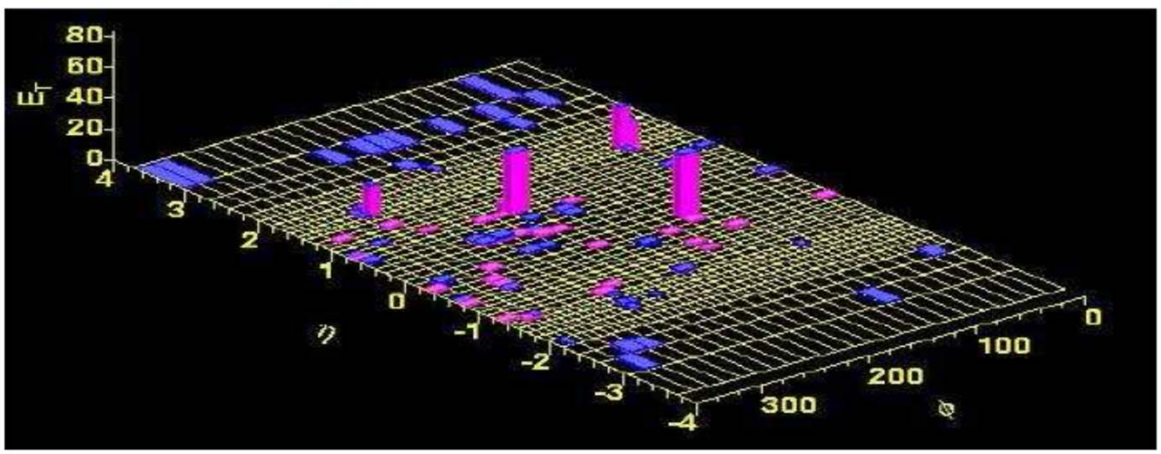
Some “interpreted” existing evidence ?

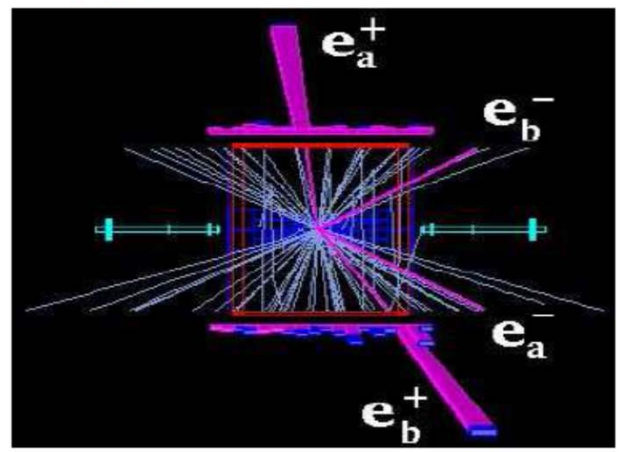
1. “Heavy Ion” UHE cosmic rays are dark matter neusons.
2. The cosmic ray spectrum knee is due to arriving/produced neuson thresholds.
3. Enhancement of high multiplicities & small $p_\perp$ at the LHC reflects a sextet generated triple pomeron coupling.
4. “Top quark events” are due to the η_6 resonance - interference with the background produces the Tevatron asymmetry.
5. Z pairs produce a high mass excess cross-section, with the η_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 $\{t_R\bar{t}_L + \eta_6\}$ 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 $p_\perp$ particles, $\neq$ SM, = QUD. {*next*}
9. TOTEM+CMS missing momentum $\leftrightarrow$ ZZ $\rightarrow$ ν’s {*coming up*}

LOW LUMINOSITY EVENTS

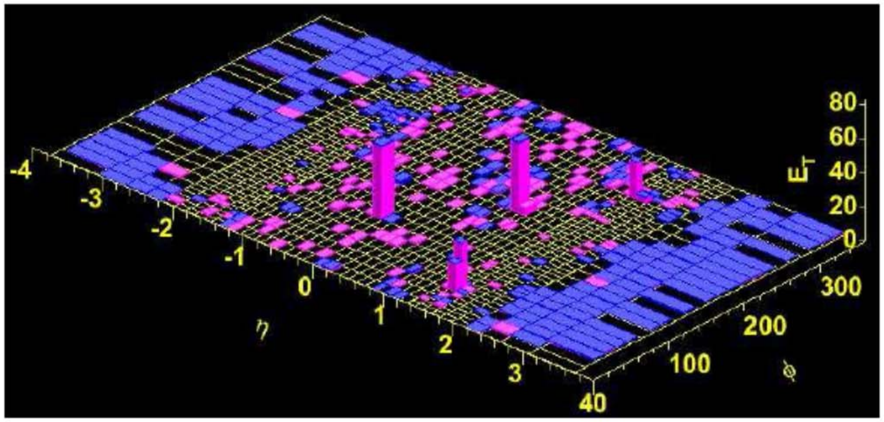
Suggestive events were seen with initial low luminosity at both the Tevatron & the LHC. *Also, very interesting events were seen in the recent TOTEM-CMS low luminosity run.* The CDF $Z^0 Z^0$ event below was recorded in 2004 - before pile-up!!! First counted, then rejected - one electron insufficiently isolated, then counted.

$E_T > 500$ **MeV** $p_\perp > 200$ **MeV**

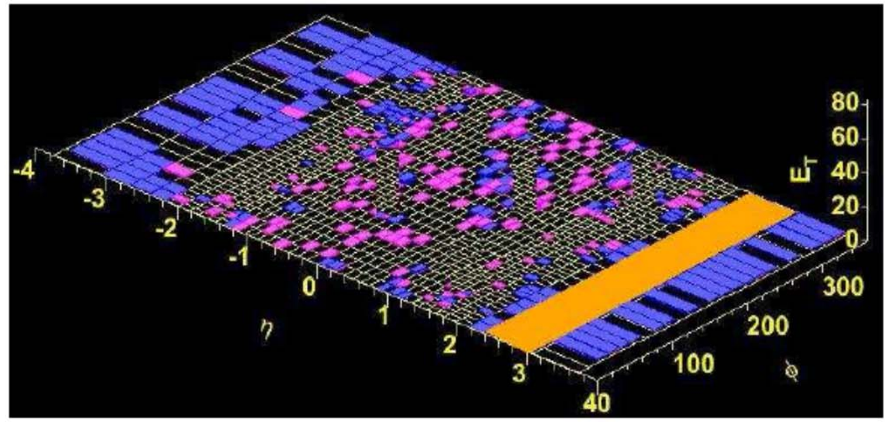




$E_T > 100$ **MeV**

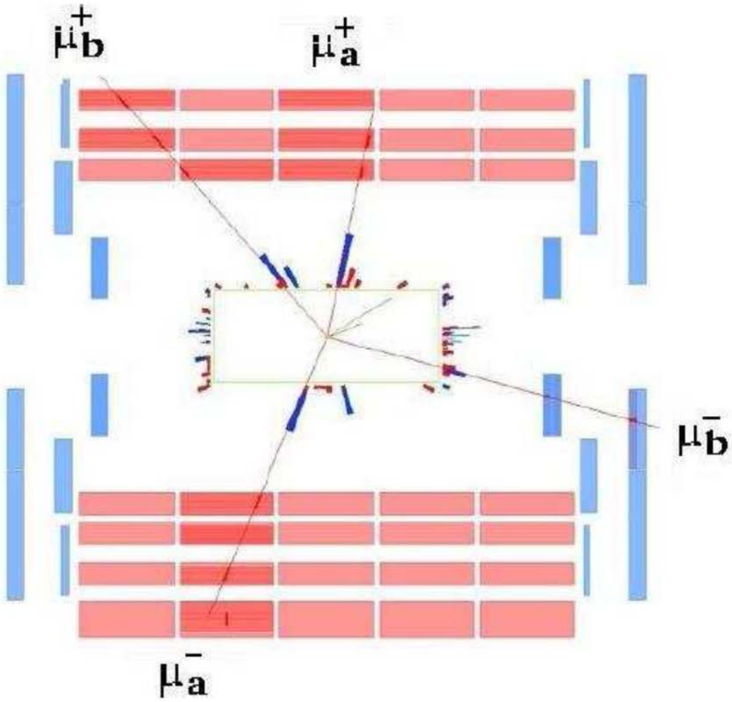


$Z^0 Z^0$ **production region**

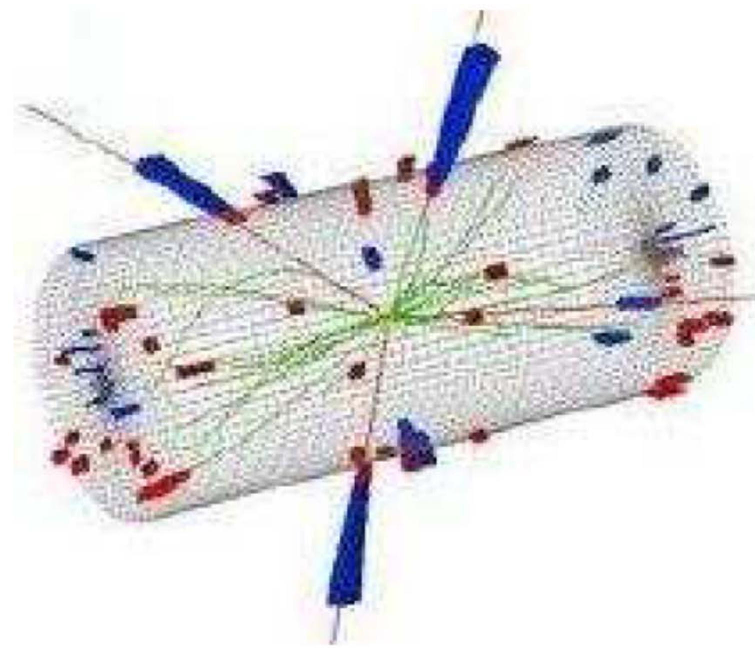


- $E_T > 500$ **MeV leaves only a few extra particles.**
- $E_T > 100$ *MeV , many more ($>$ 70) fill the rapidity axis away from the very forward* $Z^0 Z^0$ *production region* $\{$*almost out of the detector!*$\}$*, as expected for QUD events!!*
- Low luminosity $\leftrightarrow$ 4e event very rare 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 (QUD 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 ~2-3 pb^{-1}. **From ~25 fb^{-1}, we might naively expect ~ 10,000 $Z^0 Z^0$ events, yet only ~ 400 have been seen!!**



$p_\perp > 1$ Gev

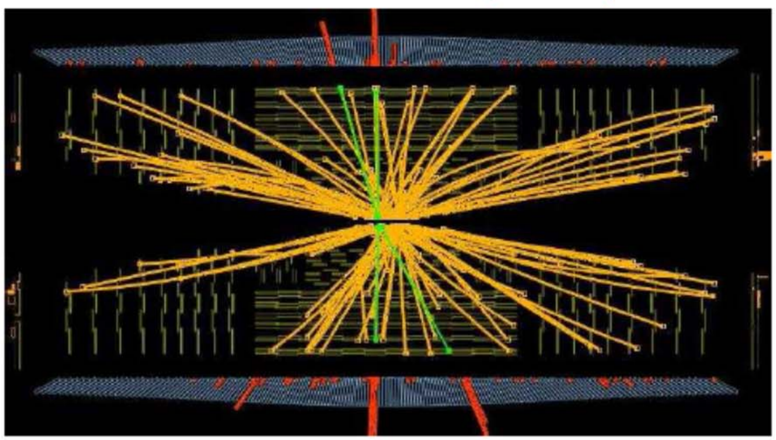


No $p_\perp$ cut-off

- A remarkably clean event, $p_\perp > 1$ GeV $\longrightarrow$ only two particles.
- No cut-off $\longrightarrow$ twenty with momenta in one of the two forward directions.
- $< n >$ & $< p_\perp >$ 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 *QUD 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

$$M_{CMS} << M_{TOTEM}$$

$\leftrightarrow$ tracks are seen in T2.

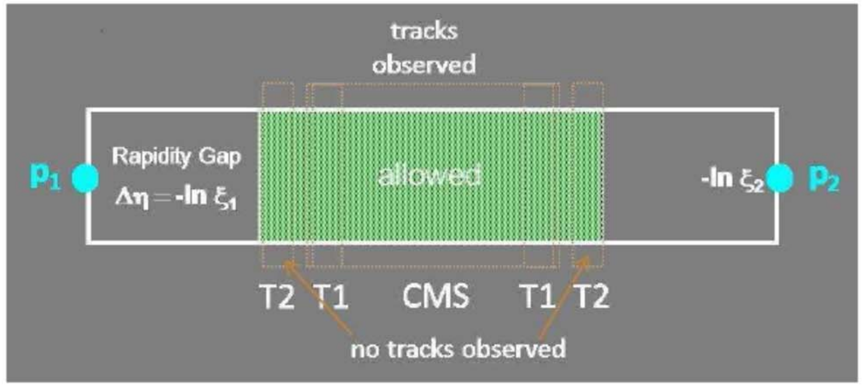
But, in several events no tracks were seen & in a few

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

e.g. $\longrightarrow$

$$Z^0 Z^0 \longrightarrow 4\nu\text{'s}$$

large rapidity QUD ???



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

ONE EVENT

- Significant mass discrepancy:
  - RP predicted mass $M(\xi_1\xi_2) \approx 900$ GeV
  - CMS visible mass M(CMS) ≈ 500 GeV
- More forward η than T2 forbidden
  - ξ_1 and ξ_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 ~T2 on both sides

~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-$\mathbb{P}$ 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 $\mathbb{P}$ & 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.**