NEW LARGE X-SECTION PHYSICS AT THE LHC - THE DYNAMICS*

My talks in previous years have linked the uniquely unitary **Critical** $\mathbb{P}^*$ *to* **QCD**$_S$ **= QCD +** *a color sextet quark sector* $\{\longrightarrow$ *EW sym-breaking & dark matter*$\}$ *with, I argued, very large LHC x-sections & exposed in double* $\mathbb{P}$ *exchange* $(FP420$ & $CMS/TOTEM)$.

Consistency *dictates* QCD_S *be embedded in* **QUD*** **- a massless** *SU(5) theory whose* $\{$*uniquely unitary?*$\}$ **bound-state S-Matrix** *may, perhaps, be that of the* **Standard Model.**

This talk *focuses on the importance for LHC* $(\&\ Tevatron\ ?)$ *x-sections of the QUD dynamics of* **wee-gluon massless fermion anomalies & sextet color factors.**

$*$ *The RFT Critical* $\mathbb{P}$ *(alone) satisfies all high−energy unitarity constraints.*
$*$ *Quantum Uno/Unification/Unique/Unitary/Underlying Dynamics*
$*$ *Presented at the 6th Manchester Forward Physics Workshop , Dec. 2008.*

QUD $\longleftrightarrow$ **SU(5)** *gauge theory with* **massless, left-handed,** *fermions in the representation* $5 \oplus 15 \oplus 40 \oplus 45^*$. QUD is anomaly free, just asymptotically free, & uniquely contains the EW symmetry-breaking sextet sector.

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

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

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

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

Not only does **QUD** *contain* **QCD**$_S$, *but both the triplet quark & lepton sectors are amazingly close to the SM !!! There are three "generations"* — $\{1\},\{2\},\{3\}$.

It is important that **QUD is real wrt SU(3)xU(1)$_{em}$.** *That the SU(2)xU(1) quantum numbers are not quite right* $\{$*although the lepton anomaly is correct*$\}$ $\Longrightarrow$

to be physically realistic, all elementary leptons & quarks must be confined $\{$**& massless !!**$\}$

$\left\{ \textit{The dynamics will be an extension of that giving confinement \& the Critical } \mathbb{P} \textit{ in } QCD_S \right\}$

If the dynamics is as I outline, QUD could provide a profoundly significant, remarkably economic, & certainly unconventional, unification & origin for the Standard Model {**unique unitary S-Matrix ?**}

All particles are bound states with dynamical masses {*no Higgs' field*}
&, although the underlying SU(5) gauge symmetry is confined,

the S-Matrix interactions are exactly those of the SM.

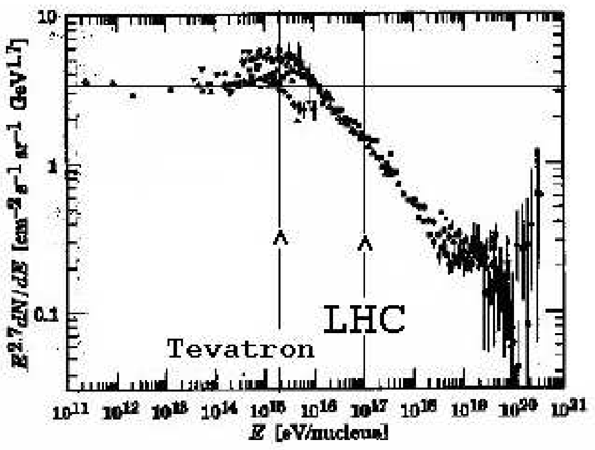
Beyond *the SM generations, there is* **only**

1. *A sextet quark sector that minimally, & naturally, solves two major mysteries*
   Sextet pions $\longrightarrow$ $W^{\pm}, Z^0$ **masses, & sextet neutrons** $\longrightarrow$ **dark matter !**
2. *A "lepton-like" octet quark sector which does not give additional states but (according to my arguments) is buried in all states as UV anomaly poles*
   $\longrightarrow$ **SU(5) invariant leptons & hadrons in SM generations.**
3. *A pair of exotically charged quarks.* **Nothing else !!**

Although the physics of QUD is both novel & radical, I believe it is consistent with all established SM physics & also explains many puzzles. Unfortunately, the multi-regge arguments that I use to uncover it are so erudite that, most likely, general interest will come only after

AN EXPERIMENTAL DISCOVERY $\{FP420$ $\&/or$ $CMS/TOTEM$ *(or even the Tevatron)* **– please discover asap !!** $\}$

COSMIC RAYS already suggest that new large x-section physics including



dark matter could appear at the LHC !!

The spectrum knee occurs between Tevatron and LHC energies. It is remarkably well-established, yet not understood. Although, dark matter was unknown, a major threshold for **neutral particles,** *unobserved in detectors, was initially suggested* $\{\sim$ *40 years ago !* $\}$. *Underestimation of the energy would pile-up events as a "knee".*

If the dark matter x-section is large at the LHC, a link to the knee is surely inevitable !!

For the sextet sector **three related effects** will combine to produce a knee.

1. *Prolific production of EW bosons increases* $<p_\perp>$ *dramatically (as well as increasing neutrino production) - leading to energy underestimation.*
2. *Direct threshold production* $\{\leftrightarrow$ *inclusive* $\mathbb{P}\}$ *of* **dark matter** $\{$*i.e. sextet neutrons*$\}$.
3. *Sextet neutrons will be a major (* **UHE?** *) component of incoming cosmic rays with a (*$\mathbb{P}$*) threshold for atmospheric interaction not far below the knee.*

But, x-sections must be large & must dominate σ_{tot} at the highest energies !!

Crucial related questions $\left\{ \begin{array}{l} \text{i) Can MASSLESS QUD produce SM scales?} \\ \text{ii) Why should a new "large mass sector" have hadronic-size x-sections?} \end{array} \right\}$

An IR fixed-pt $\Longrightarrow$ the QUD coupling is very small $\alpha_u \sim$ 1/120

$\Longrightarrow$ {*probably*} **neutrinos have small mass** *(no color or electric charge).*

$\Longrightarrow$ **SM interaction strengths can not result directly from QUD evolution.**

Instead, in the ∞- momentum dynamics I will describe,

1. *Physical amplitudes are selected by an IR divergence $\longrightarrow$ zero momentum (wee) gluons coupled by anomalies are a component of all reggeon states & interactions.*
2. *The massless fermion anomalies contain chirality transitions* {$\sim$ *condensates*} *that link the SU(5) representations & determine S-Matrix symmetries.*
3. *SU(5) color is confined & all particles are bound-states.* $\Longrightarrow$ α_u *is not physical.*
4. *Reality properties of the fermions* $\Longrightarrow$ **only SM interactions in the S-Matrix.**
5. **Physical couplings involve wee gluon anomaly color factors &**

   sextet factors >> triplet factors $\Longrightarrow$ asymptotic sextet x-sections larger !!!

My analysis of QUD anomaly dynamics relies fundamentally on multi-regge theory. } To give an outline I begin with some basics - a regge pole gives

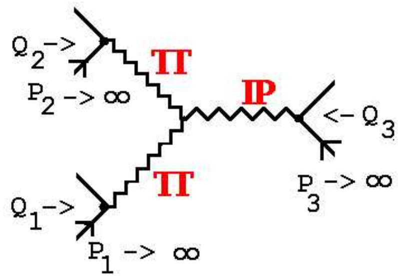
$$A^{+}(s,t) \underset{s\to\infty}{\sim} f(t)\, \frac{s^{\alpha(t)}}{sin\,\frac{\pi}{2}\,\alpha(t)} \Longrightarrow$$

t- *channel bound-state poles* $\big(at\ \alpha(t)=0,2,\ldots\big)$ *can be discovered by*

calculating the $s \longrightarrow \infty$ *(∞-momentum limit) in the cross-channel.*

In multi-regge limits multiple regge poles appear, e.g.

the triple regge limit ->



$P_1, P_2, P_3 \to \infty$ *along distinct light-cones.*

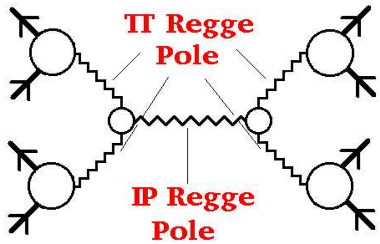
In the P_3 *rest-frame, the 'off-shell' regge pole pions also travel along a light-cone.*

Continuation to $Q_1^2 = Q_2^2 = m_\pi^2$ *gives the on-shell pion amplitude for* $\mathbb{P}$ *exchange.*

Central for my analysis - in ∞-momentum states **universal wee partons** *(with finite momentum) can play the role* of a* **non-trivial vacuum** *(confinement etc.)**
$\longrightarrow$ *bound-states may be obtainable via* **perturbative** *quark/gluon* **reggeon diagrams.**

* $c.f.\ the\ perturbative\ vacuum\ of\ light\!-\!cone\ quantization.$
* $The\ Critical\ \mathbb{P}\ (=regge\ pole\!+\!interactions) \leftrightarrow universal\ wee\ partons.$

In the **"di-triple regge"** *(DTR) limit regge-pole $\pi' s$ scatter via the $\mathbb{P}$. All the $\pi' s$ & the $\mathbb{P}$ have ∞-momentum in some frame & so*



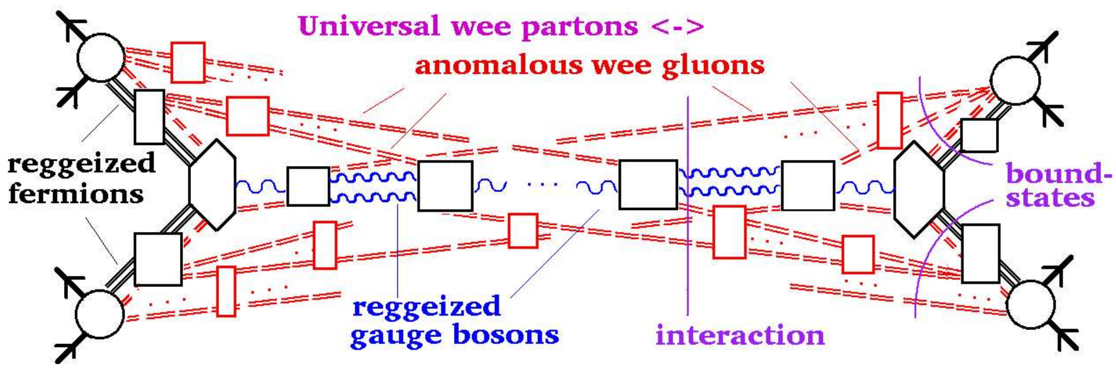
In the DTR limit both bound-states ($\pi' s$) & interactions ($\mathbb{P}$) can appear as perturbative parton (reggeon) states $\{>>$ *parton model* $\}$

- provided universal wee partons carry vacuum properties. In fact, we will see that

what I refer to as **"anomalous" wee gluons** *are universal in all states & interactions.*

E.g.

a typical 'low–order' DTR amplitude



Comprehensively extracting SM states & interactions {including the Critical $\mathbb{P}$} is an enormous challenge. I will build up the full complexity in stages!

Reggeon Diagrams $\{a\ crash\ course\}$ **-**

1. *In (multi-)regge limits large light-cone momenta are routed through feynman diagrams so that internal particles are maximally close to mass-shell & have large relative rapidities.*

   $\longrightarrow$ $k_\perp$ *diagram integral* ($\leftrightarrow$ *on-shell lines contracted) multiplied by rapidity logarithms.*

2. $\Big\{$ *Summing rapidity logarithms via j-plane reggeon propagators* $\longrightarrow$ *reggeon diagrams.* $\left\{ \begin{matrix} Many\ feynman\ diagrams \\ \longleftrightarrow\ 1\ reggeon\ diagram \end{matrix} \right\}$

My use of QUD reggeon diagrams *to construct DTR amplitudes in the small* $k_\perp$ *region is* **very different** *from the large* $k_\perp$ **use of QCD diagrams by BFKL.**

- *I start with massive gauge boson reggeons* $\{by\ adding\ scalars\ with\ VeV's\}$ *that are gauge-invariant & carry global color.*
- *In the massless* $\{scalar\ decoupling\}$ *limit color is "confined" by IR divergences.*
- *With a* $k_\perp$ *cut-off until the last stage* $\{only\ an\ asymp{-}free\ scalar\ remains\}$ *complimentarity justifies restoring the color symmetry in stages -*

SU(2) $\longrightarrow$ **SU(3)** $\longrightarrow$ **SU(4)** $\longrightarrow$ **SU(5)** $\left\{ \begin{matrix} Also\ necessitated\ by\ the \\ supercritical\ \mathbf{P}.\ Resolves \\ the\ Gribov\ ambiguity. \end{matrix} \right\}$

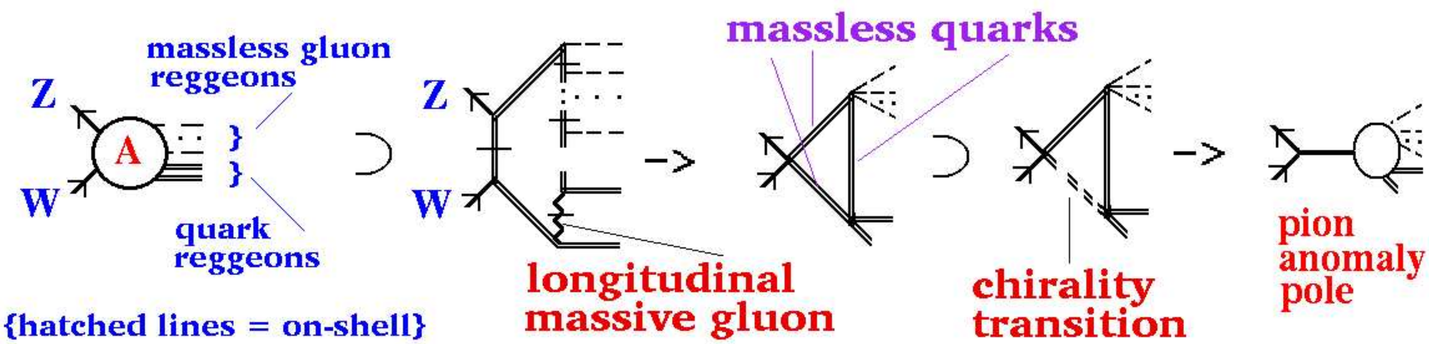
Higher-order reggeon interactions -

- *internal particles with finite relative rapidity* $\longrightarrow$ *fewer $k_\perp$ loops* $\longrightarrow$ *couplings with more structure.*
- **Fermion loop** *interactions appear & the* **triangle anomaly** *is generated.*

With a $k_\perp$ cut-off, fermion loops have no Ward identity zeroes

$\Longrightarrow$ **extra infra-red divergences.**

Most important are divergences coupled to IR **anomaly poles** *generated by a zero momentum chirality transition, e.g.*



The first color restoration - (vector) SU(2) $\longrightarrow$ **"anomalous wee gluon"**

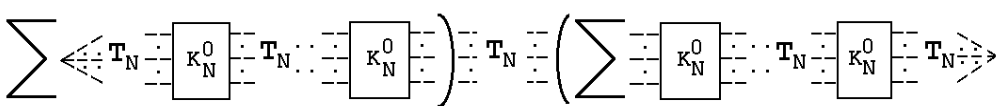
divergences $\longleftrightarrow$ $I = 0$ **sets of massless reggeized gluons**

with color parity C $\neq$ *the signature* τ *& with all* $k_\perp$*'s scaled uniformly to zero.*

- *For SU(2), only* $\tau = -C = -1$ *is possible* $\leftrightarrow$ $3, 5, \ldots \infty$ *gluon reggeons.*
- *Because the divergent gluons couple only via anomaly pole vertices*

the anomalous wee gluon divergence does not exponentiate but, instead, selects physical amplitudes.

IR fixed-point scaling properties $\Longrightarrow$ *iteration of* $I = 0$ *reggeon kernels reproduces the basic divergence*



- with a factorized residue,

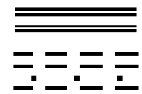
$$\longrightarrow \ \frac{1}{J-1} \int \frac{dQ^2}{Q^2} \int \prod_i \frac{d^2 k_i}{k_i^2} \ \delta^2(Q - \sum k_i) \ |M_N^0(J, k_1, \cdots k_N, \lambda_\perp)|^2$$

$\longrightarrow$ **a universal wee gluon component of all reggeon states & interactions.**

States *are chiral Goldstone boson anomaly poles**

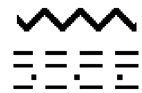
$\leftrightarrow$ *flavor non-zero, color zero, fermion pairs*

+ anomalous wee gluons.

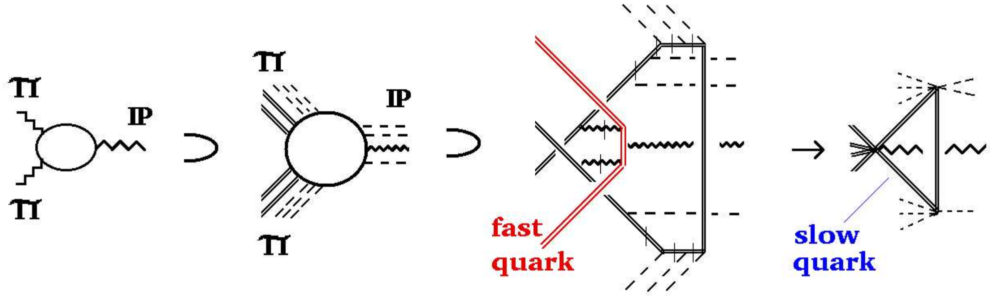


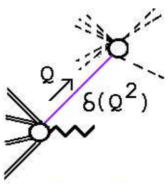
Interactions *are color zero vector boson reggeons*

+ anomalous wee gluons $\longrightarrow$ **regge pole $\mathbb{P}$!!**

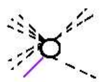


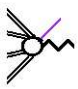
In U(1) channels anomaly poles give $k_\perp$ δ-functions in vertices, e.g.



→ 

factorization

 = **WEE GLUON ANOMALY COLOR FACTOR** <-> ∞ sum over all wee gluons coupling to the slow quark loop

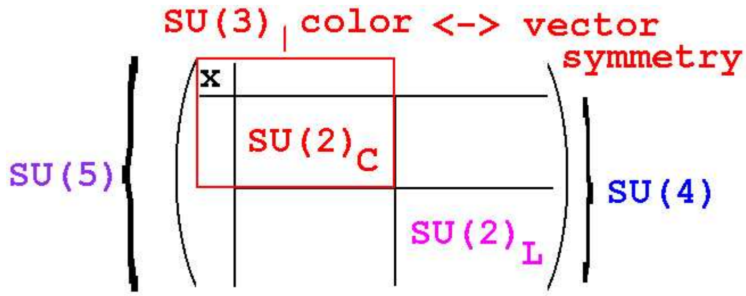
 = **PERTURBATIVE COUPLING** <-> **ADDITIVE QUARK MODEL**

$\Longrightarrow$ *in QUD the $\mathbb{P}$ couples more strongly to sextet states than to triplet states*

* *An anomaly pole can also be represented as a fermion pair state with one of the pair in a, zero momentum, negative energy state.*

Using SU(2)$_C$ to denote the restored symmetry,

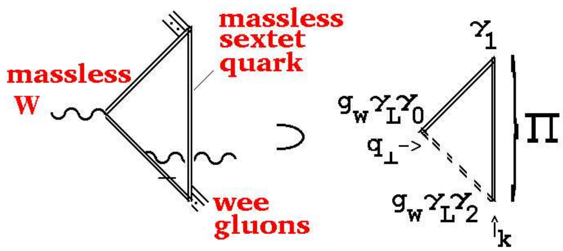
the Goldstones are π_C's, i.e qq, $\bar{q}\bar{q}$, & $q\bar{q}$ pairs in the SU(2)$_C$ wee gluon background.
The q's are **3's, 6's,** *&* **8's** *under SU(3).*
8's *are real wrt SU(3), but contain complex chiral doublets wrt SU(2)$_C$.*



Interactions that will produce SU(3)$_C$ singlets are

- *A massive x gluon in the wee gluon background* $\leftrightarrow$ $\mathbb{P}$.
- *SU(2)$_L$ $\otimes$ U(1) bosons in the wee gluon background* $\leftrightarrow$ *$W^{\pm,0}$, Y.*

Wee gluon anomaly interactions give left-handed $W^\pm \& Z^0$ **a mass** $\leftrightarrow$ **mixing with π_C's.**



$\sim\ g_w^2\,\epsilon_{2301}\,k_3\,q_2^2/q_\perp^2\ \rightarrow$
$M_W^2 \sim g_W^2\,\Sigma \int dk k\ \equiv\ g_W^2\,F_\Pi^2$
$EW\ F_\Pi$ is a QCD scale $\sim$ sextet wee gluon color factor >> triplet factor!

parity violation $\Longrightarrow$ **fermion loop interactions** *exponentiate all divergences involving* **left-handed gauge bosons**

$=>$ **"anomalous wee gluon divergences"** *survive only within a maximal non-abelian vector subgroup*

$\longrightarrow$ **strong interaction $\mathbb{P}$ is a $\{global\}$ SU(3)$_C$ singlet !!!**

Restoring SU(4) symmetry ($SU(2)_C \otimes SU(2)_L \subset SU(4)$) *involves only left-handed & abelian vector bosons & so there are no new divergences.* **But, the states & interactions become SU(4) invariant.**

- *"Leptons" form as bound states of elementary leptons & octet pions.*
- *Under SU(2)$_L \times$U(1) π_8's give $(2,\frac{1}{2}),\ (1,-1),\ \&(3,-1)$ & so elementary lepton components have (up to gauge boson contributions) the SM generation structure.*
- *SU(4) invariant "hadrons" combine π_8's & either π_3's or π_6's.*

The SM could appear, **as SU(5) is restored,** *as follows*

1. **The $\mathbb{P}$ becomes Critical** - *built up from interactions of vector exchanges combined, in an SU(3)$_C$ subgroup, with $\tau = -1$ anomalous wee gluons.*
2. *The anomalous wee gluon component of γ, $W^{\pm}$ & Z^0 becomes an SU(3)$_C$ singlet with $\tau = +1$ ($\leftrightarrow$ $\mathbb{P}$ with zero $k_\perp$).*
3. *The IR contributions of π_8's as complex chiral Goldstones cancel. Instead, they remain $\{in\ all\ states\}$ as UV anomaly poles involving chirality transitions of quarks with energy $= \pm\infty$.*
4. *$\tau = +1$ anomalous wee gluons couple via UV π_8's* **& are present in all interactions** $\leftrightarrow$ **EW interactions & states are SU(5) invariant.**
5. SU(2)$_L$ $\longrightarrow$ sextet SU(2) flavor via anomalies & π_6 mass generation.
6. *UV π_8's in all states $\Longrightarrow$ IR components $\longrightarrow$ the singlet/doublet SM structure.*
7. *The SU(2)$_L \otimes$U(1) IR anomaly $=>$ three generations of leptons & hadrons.*

The SU(3)×SU(2)$_L$×U(1) content of the leptons, expressed as multi-fermion states, is

- (e^-,ν) *candidate* $\leftrightarrow (1,2,-\frac{1}{2})\times(8,1,1)(8,2,-\frac{1}{2})$
  $\leftrightarrow SU(5)\ singlet - 45^*\times 40\times 45^*$

  - elementary ' e^-/ν *' +* π_8
- e^+ *candidate* $\leftrightarrow (1,3,1)\times(8,2,-\frac{1}{2})(8,2,-\frac{1}{2})$
  $\leftrightarrow SU(5)\ singlet - 15\times 45^*\times 45^*$

  - elementary ' e^+ *' +* π_8
- (μ^-,ν) *candidate* $\leftrightarrow (1,2,\frac{1}{2})(1,2,-\frac{1}{2})(1,2,-\frac{1}{2})\times(8,1,1)(8,2,-\frac{1}{2})$
  $\leftrightarrow SU(5)\ singlet - 5\times 45^*\times 45^*\times 40\times 45^*$

  - elementary ' e^-/ν *' + elementary '* $e/\bar{e}$ *' pair +* π_8
- (τ^-,ν) *candidate* $\leftrightarrow (1,2,-\frac{3}{2})(1,2,\frac{1}{2})(1,2,\frac{1}{2})\times(8,1,1)(8,2,-\frac{1}{2})$
  $\leftrightarrow SU(5)\ singlet - 40\times 5\times 5\times 40\times 45^*$

  - higher-charge elementary lepton + elementary ' $\bar{e}\bar{e}$ *' pair +* π_8

QCD within QUD - the states are

1. triplet mesons & nucleons
2. sextet "pions" & "nucleons" (P_6 & N_6)
3. no *hybrid sextet/triplet quark states*
4. no *glueballs.*

Consistent with, but much less than, confinement & chiral symmetry breaking.

- *Sextet pions* $\rightarrow$ $W^{\pm}$ & Z^0 $\Longrightarrow$ *sextet nucleons are the* **only new states.**
- *Sextet quarks have zero current mass* $\Longrightarrow$ N_6 **is stable** $\rightarrow$ **DARK MATTER**

  $\{$*electric charge* $\Longrightarrow$ P_6 *is heavier - in contrast to the triplet sector*$\}$
- **The Critical $\mathbb{P}$** $\Longrightarrow$ **the parton model, no BFKL pomeron & no odderon.**

Compared to conventional QCD, the states are fewer & the interaction is simpler - in agreement with experiment !!

N_6**'s** *have a very strong, very short range, QCD self-interaction* $\{\rightarrow$ *clumps?*$\}$ *& a QCD interaction with normal matter only at very high energy* $\{$*see below*$\}$*.* N_6 *production will dominate UHE x-sections & early universe stable matter formation (& explain the CR knee!)*

The bound-state mass spectrum will involve a combination of effects.

1. *Perturbative reggeization is a very small effect, since α_u is so small.*
2. **Wee gluon anomaly interactions** $\{which\ need\ to\ be\ catalogued\}$ **will mix** *the reggeon states & introduce couplings* **involving wee gluon color factors.**
3. *Regge trajectories, including wee gluon interactions, can probably be obtained via* **a t-channel "perturbative" dispersion relation procedure.**
4. The SU(3) strong interaction will be emphasized by both **color factors & by the resulting high mass sector.** Electroweak charges will also play a role.
5. **There is no symmetry that would be in conflict with the SM mass spectrum.**

A wide range of scales should emerge & in bound-states **all fermions will, effectively, have constituent masses.** *Connecting the η_6 to top production suggests*

$$m_{q_6} \sim m_{top} \implies m_{N_6} \sim 500\, GeV$$

- *In general, a better understanding of* **anomaly interactions & related wee gluon distributions** *is needed to determine if, & how many, parameters are involved.*
- *Presumably, CP violation can be introduced via the anomalies, but is it essential?*

Most importantly - for high-energy sextet cross-sections,

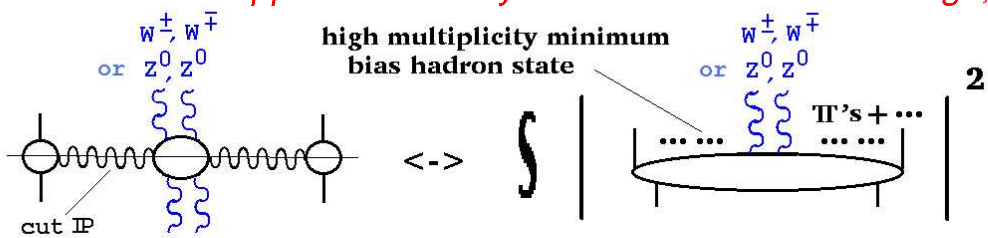
fermions in the wee gluon anomaly interactions should remain "massless"

$\{\leftrightarrow$ *transitions of the underlying QUD massless Dirac sea.*$\}$ **Consequently,**

if experiment determines that sextet sector x-sections are not suppressed by the EW mass-scale & *(as wee gluon color factors imply) sextet state couplings to the* $\mathbb{P}$ *are larger than triplet couplings. this will be direct evidence for the underlying massless theory.*

The $\mathbb{P}$ *is the link between the triplet & sextet sectors. "Sextet thresholds" correspond to the appropriate* $\mathbb{P}$ *process & sextet states will dominate asymptotically.*

Sextet states will first appear inclusively via "cut" double $\mathbb{P}$ *exchange,*

$e.g.$ 

Has this been seen at the Tevatron ? $\longrightarrow$

- will dominate the production of multiple EW bosons & sextet baryons

- including Dark Matter sextet neutrons - at the LHC.

Fermilab

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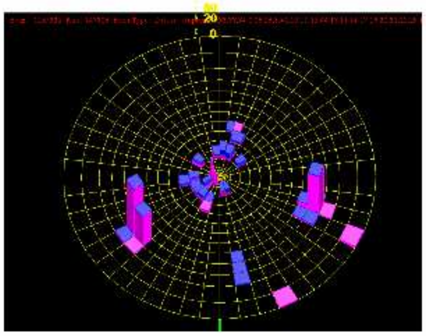

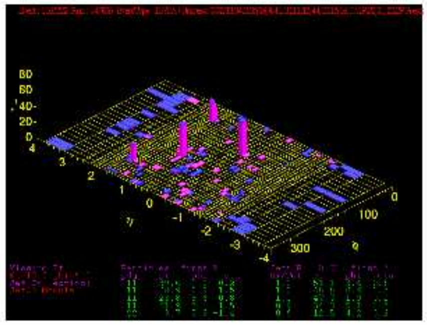

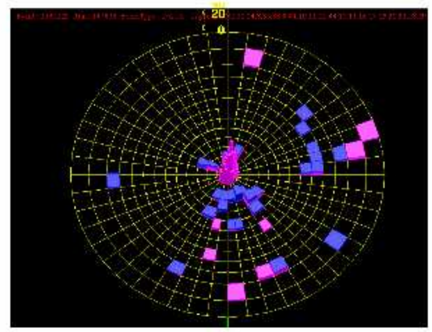

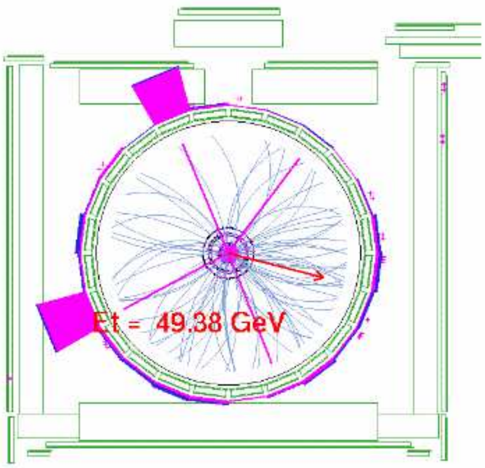

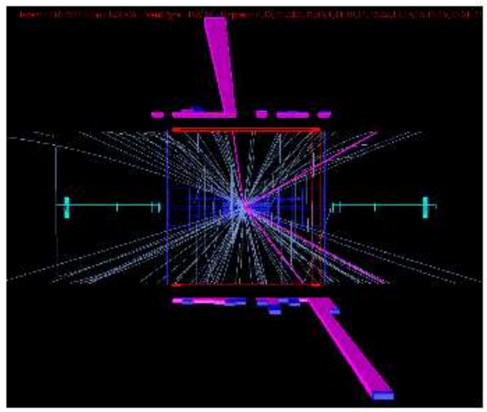

4e
Possible ZZ → 4e

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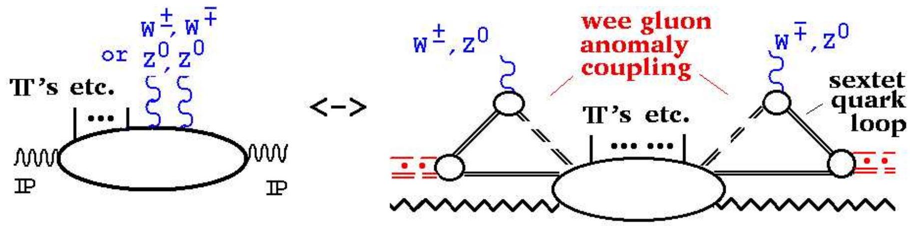
(Shown by Simona Rolli in W&C 4/1/04)

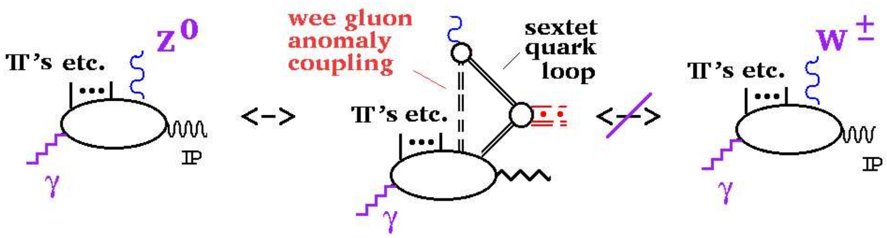
But, *the size of the dark matter x-section will be difficult to establish & the prolific production of EW bosons will have other explanations* $\{e.g.\ black\ holes,\ sphalerons,\ ..\}$.

Two processes where a large LHC x-section $\{or\ a\ small\ Tevatron\ x-section$!!$\}$ *would be direct evidence for the sextet sector are -*

1. Double $\mathbb{P}$ *production of EW boson pairs* $\{+ ...\}$ $\{\sigma_{ZZ} \sim \sigma_{WW}\}$. *Hopefully, this x-section will be unmistakably observed by both CMS/TOTEM & FP420.*



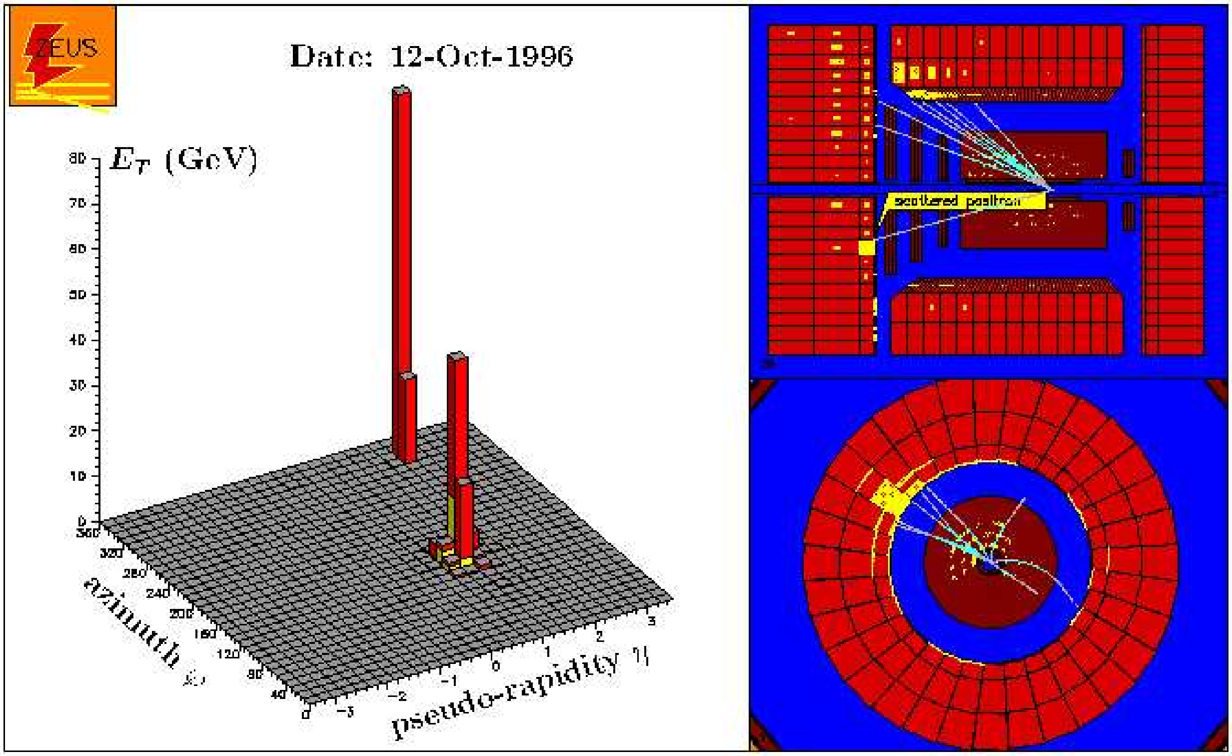
Eventually, $P_6^+ P_6^-$ & $N_6 \bar{N}_6$ *pairs may also be observed in the double* $\mathbb{P}$ *x-section.*



2. Diffractive photoproduction of Z^0 $\{+ ...\}$ $\{\sigma_W = 0$!!!$\}$ *Was this seen with very large* Q^2 *at HERA ?* $\longrightarrow$

Might it be seen at the Tevatron ?

$\{Ask\ Mike$!$\}$



$\theta_e = 15.4^\circ$ $\gamma = 38.6^\circ$ $->$ $x_{DA} = 0.709 \pm 0.034$ $Q^2_{DA} = 46100 \pm 1600\ GeV^2$

$E'_e = 380\ GeV$ $->$ $x_e = 0.605 \pm 0.060$ $Q^2_e = 41000 \pm 3000\ GeV^2$ $\mathbf{M_{jet} \sim 90\ GeV\ (?)}$