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COULD THE LHC POMERON BE THE KEY TO EVERYTHING ? *

A color sextet quark sector of QCD could be the origin of EW symmetry breaking. It would dominate UHE x-sections & would explain the CR knee, dark matter, & much more.

It should be **unavoidably seen by FP420 detectors** *via pair production of* W's & Z's. *In this talk I will raise the stakes by describing why*

THE SEXTET SECTOR SHOULD BE PART OF QUD - A UNIQUE SU(5) UNIFIED MASSLESS "THEORY OF MATTER" *(no gravity)* **THAT COULD BE THE ORIGIN OF THE FULL STANDARD MODEL.**

Discovery of the sextet sector would be very close to discovery of QUD **!!!**

* $Presented\ at - Physics\ with\ FP420 - Manchester,\ December\ 2006.$

Key points of my previous talks at this meeting were

1. *High-energy unitarity requires* $\{$*via the Critical* $\mathbb{P}\}$ *an extra quark sector in QCD - asymptotic freedom must be "saturated". The only solution is* **6 color triplet quarks** $+$ **2 color sextet quarks** $\longleftrightarrow$ **"QCD$_S$"**

2. $W^{\pm}$ & Z^0 *will eat the "sextet pions"* $\longrightarrow$ *electroweak symmetry breaking with no new interaction* **(the electroweak scale is the QCD sextet chiral scale !!!)**

3. *The CR knee, & other CR phenomena, suggest a threshold for the expected new physics** *between Tevatron & LHC.* **If so, there must be large x-section effects at the LHC.**

4. **The double $\mathbb{P}$ x-section will be crucial for establishing that the sextet sector has appeared.** $\{$*I will come back to this towards the end.*$\}$

BUT, how is the electroweak anomaly of the sextet sector canceled (??) & how are other particle masses generated ???

* *ARW – Phys. Rev.* D72:036007 (2005).

Some years ago, Kang & I looked at left-handed unified theories and found a remarkable, *but puzzling,* result. *Requiring* **only**

1. **the sextet sector**
2. **asymptotic freedom**
3. **anomaly cancelation**

uniquely selects SU(5) gauge theory with the fermion representation 5 + 15 + 40 + 45* $\longleftrightarrow$

"QUD"

$\{Quantum\ Uno/Unification/Unitary/Underlying\ Dynamics\}$

Amazingly, *the triplet quark and lepton sectors of QUD (which were not asked for !) are very close to the Standard Model !!*

There are 3 "generations" of quarks & antiquarks with charges $\pm 2/3,\ \pm 1/3$ **(and so QUD contains QCD**$_S$**) together with 3 "generations" of leptons.**

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

$$
\begin{aligned}
\mathbf{5} \;&= (\mathbf{3},\mathbf{1},-\tfrac{\mathbf{1}}{\mathbf{3}}))^{\{3\}} + (\mathbf{1},\mathbf{2},\tfrac{\mathbf{1}}{\mathbf{2}}))^{\{2\}} \;, \\
\mathbf{15} \;&= (\mathbf{1},\mathbf{3},\mathbf{1}) + (\mathbf{3},\mathbf{2},\tfrac{\mathbf{1}}{\mathbf{6}}))^{\{1\}} + (\mathbf{6},\mathbf{1},-\tfrac{\mathbf{2}}{\mathbf{3}}) \;, \\
\mathbf{40} \;&= (\mathbf{1},\mathbf{2},-\tfrac{\mathbf{3}}{\mathbf{2}}))^{\{3\}} + (\mathbf{3},\mathbf{2},\tfrac{\mathbf{1}}{\mathbf{6}})^{\{2\}} + (\mathbf{3}^*,\mathbf{1},-\tfrac{\mathbf{2}}{\mathbf{3}}) + (\mathbf{3}^*,\mathbf{3},-\tfrac{\mathbf{2}}{\mathbf{3}}) \\
&\qquad + (\mathbf{6}^*,\mathbf{2},\tfrac{\mathbf{1}}{\mathbf{6}}) + (\mathbf{8},\mathbf{1},\mathbf{1}) \;, \\
\mathbf{45}^* &= (\mathbf{1},\mathbf{2},-\tfrac{\mathbf{1}}{\mathbf{2}}))^{\{1\}} + (\mathbf{3}^*,\mathbf{1},\tfrac{\mathbf{1}}{\mathbf{3}}) + (\mathbf{3}^*,\mathbf{3},\tfrac{\mathbf{1}}{\mathbf{3}}) + (\mathbf{3},\mathbf{1},-\tfrac{\mathbf{4}}{\mathbf{3}}) \\
&\qquad + (\mathbf{3},\mathbf{2},\tfrac{\mathbf{7}}{\mathbf{6}}))^{\{3\}} + (\mathbf{6},\mathbf{1},\tfrac{\mathbf{1}}{\mathbf{3}}) + (\mathbf{8},\mathbf{2},-\tfrac{\mathbf{1}}{\mathbf{2}})
\end{aligned}
$$

The "generations" $\{1\},\{2\},\{3\},$ *are scattered amongst the separate representations.* **It will be very important later that the complete representation is real, i.e. is a vector theory, wrt SU(3)xU(1)$_{em}$.**

But, the SU(2)xU(1) quantum numbers are not quite right. *Also, there are (unwanted ?) color octet quarks with lepton-like electroweak quantum numbers.*

It was very frustrating that we had arrived at a unique theory that is almost, but not quite, the Standard Model !!

- *As massless field theories QUD & QCD$_S$ have similar, very special, UV & IR properties.*

  $=>$ the high-energy bound-state S-Matrix can be constructed via multi-regge theory & **infra-red chiral anomalies.**

- *Only after I understood the physics of massless QCD$_S$, did it become apparent to me what the true role of QUD could be.*

I realized, incredibly, that QUD could be to the full Standard Model what QCD is to the hadronic sector !!!! *In the QUD bound-state S-Matrix*

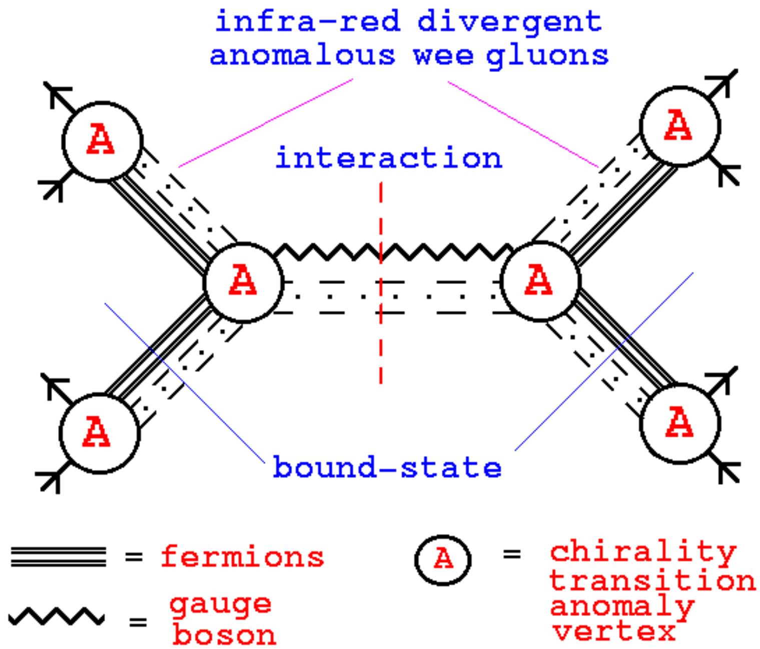
SU(5) COLOR is CONFINED, not just SU(3) color, & so **ALL ELEMENTARY GAUGE BOSONS AND FERMIONS ARE CONFINED - AND MASSLESS.**

- **All hadrons and leptons would have to be QUD bound-states and all interactions would have to be composite. Is this possible ???**
- **Because QUD is real wrt SU(3)xU(1)$_{em}$ and the lepton and triplet quark sectors are so close to the Standard Model, it could be !!**

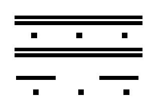
Very briefly -

we construct bound states and interactions similarly in QCD$_S$ and QUD, i.e. via multi-regge amplitudes that contain **infra-red divergent** gauge bosons **coupled to anomalies.**

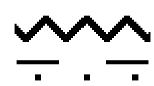
Restoring the gauge symmetry in steps & extracting anomaly infra-red divergences -



bound-states *appear as Goldtsone boson "anomaly poles" formed as color zero combinations of fermions in an "anomalous wee gluon" background* *



interactions *are color zero combinations of a finite transverse momentum gauge boson in the same wee gluon background.*



* $Wee\ gluons \equiv some\ fermions\ are\ in\ negative\ energy\ states$

- *To obtain the states & amplitudes of QCD$_S$, we start in "ColorSuperconducting" QCD$_S$ $\{$SU(3) color $\longrightarrow$ SU(2)$\}$.*
- **The physical states of QCD_S are Goldstones in "$CSQCD_S$".**

$\longrightarrow$ **triplet meson & nucleon states**
$\longrightarrow$ **no hybrid sextet/triplet quark states**
$\longrightarrow$ **sextet "pions" & "nucleons" ($P_6 \& N_6$)**

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

The sextet neutron, the N_6, will be stable & dominate UHE x-sections

$\leftrightarrow$ **Dark Matter !!**

- In CSQCD$_S$, the interaction is a massive gluon reggeon in an anomalous wee gluon condensate $\leftrightarrow$ the "supercritical" $\mathbb{P}$.

$=>$ **In QCD$_S$, the interaction is the Critical $\mathbb{P}$**
$\leftrightarrow$ **regge pole + interactions**

$=>$ **no BFKL pomeron, no odderon, & no glueballs**

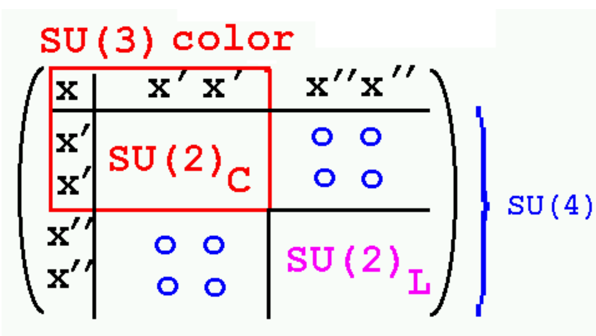
The QCD$_S$ states are much fewer & the interaction much simpler, than in conventional QCD, in better agreement with experiment !!

For QUD, it is crucial that “anomalous” divergences are exponentiated by left-handed gauge bosons.

$=>$ **divergences** $\leftrightarrow$ **maximal non-abelian vector subgroup**

$=>$ **a strong interaction involving only SU(3) singlet combinations !!**

To obtain amplitudes we, again, build up the symmetry in stages



With SU(2)$_C$ (vector) symmetry the states are Goldstone π_C's, i.e qq, $\bar{q}\bar{q}$, & $q\bar{q}$ pairs in a condensate.

The q's are SU(3) **3's, 6's,** *&* **8's**. **8's** *are real wrt SU(3), but contain complex doublets wrt SU(2)$_C$.*

The exchanges producing interactions are

1. *A massive x gluon in the condensate* $\leftrightarrow$ $\mathbb{P}$.
2. *SU(2)$_L \otimes$ U(1) bosons in the condensate* $\leftrightarrow$ *W$^{\pm,0}$, Y.*
3. *A massive x” boson in the condensate - will be confined by SU(3) color*

Wee gluon interactions give $W^{\pm}$ **&** Z^0 **a mass** $\leftrightarrow$ **mixing with** π_C**'s.**

When SU(4) symmetry is restored, "leptons" appear as bound states of elementary leptons and "octet pions", e.g. the e/ν will be $(1,2,-\frac{1}{2})\times(8,1,1)\times(8,2,-\frac{1}{2})\leftrightarrow$ **SU(5) singlet** $45^*\times 40\times 45^*$**.** *(The μ & the τ contain 3 elementary leptons.)*

When SU(5) symmetry is restored, *I anticipate that*

1. *The $\mathbb{P}$ becomes critical.*
2. *The wee gluon component of the γ & the $W^\pm, Z^0$ becomes even signature (essentially, the zero $k_\perp$ component of the $\mathbb{P}$).*
3. *The octet π's are no longer Goldstones & disappear from the low $k_\perp$ region.*
4. *Also SU(3) reality $=>$ octet π's have no (anomaly) coupling to the $\mathbb{P}$ $=>$* **leptons have no strong interaction and no infra-red SU(3) mass generation.**
5. *Because octet π's contribute only at large $k_\perp$ the SU(2)$_L\otimes$U(1) symmetry will appear in low $k_\perp$ interactions* $(as\ sextet\ SU(2)\ flavor)$.
6. *The SU(2)$_L\otimes$U(1) anomaly $=>$ three generations of "hadrons" and "leptons".*
7. *SU(2)$\otimes$U(1) quantum numbers of the octet π's $=>$ low $k_\perp$ states will have the the singlet/doublet structure of the Standard model.*

The octet quarks (which at first sight seemed unwanted) are fundamental for the underlying SU(5) invariance and the generation structure of states.

- *Much of what I have described needs to be better established and very many questions remain to be answered.*
- *Also, what I am proposing is very radical wrt the current theoretical paradigm !!*
- **I am saying that** *the Standard Model has an underlying unifying field theory,* **but,** *it is massless & has a very small coupling* $(\alpha_u < O(1/50) \leftrightarrow an\ IR\ fixed{-}pt.)$ *It is, almost, conformally invariant.*
- *Mass-scales are generated by reggeization, mixing, & anomaly interactions, but only in the bound-state S-Matrix - which has a very special role.*
- **There is no Higgs field** *- although the* η_6 *is analagous to the Higgs wrt EW symmetry breaking.*

There are many general features that are encouraging, including

1. *The experimentally attractive SU(5) value of the Weinberg angle should hold, even though* **there is no proton decay !**
2. *Small* α_u *could be the explanation of small neutrino masses.*
3. *The existence and dominance of Dark Matter is naturally explained.*
4. *The high mass QCD sector produces unification without supersymmetry.*
5. *There are no unwanted symmetries constraining the mass spectrum.*
6. *The SO(10)* **144** *contains QUD - relevant for* $\{$*string?*$\}$ *unification with gravity?*

- *To suggest that new strong interaction physics beyond the Standard Model is the* **"key to everything"** *& that it should be* **looked for via the $\mathbb{P}$** *is very unconventional.*
- **Of course, the discovery of new large x-section effects at the LHC would soon make the discussion of such physics conventional !!**

Persistently, & singularly, searching for the Critical $\mathbb{P}$, & pushing my specialist knowledge of multi-regge theory to the limits of my understanding (& beyond!), I arrived first at the sextet sector & now, **uniquely,** *at* **QUD.**

Obviously, it would be incredible if the Standard Model, with all of it's complexity, has the underlying simplicity I have suggested. Nevertheless,

all the necessary ingredients are present &, *if the predicted effects of the sextet sector are seen at the LHC,*
interest in QUD will surely rise rapidly!

I will finish by briefly reviewing how double $\mathbb{P}$ processes can provide the proof that a sextet sector has appeared.

What Should be Seen at the LHC ?

At high luminosity, major evidence for the sextet sector would be

- *Multiple vector boson and jet x-sections that are* **much, much, larger** *than expected, producing a dramatic rise in the average* $|p_\perp|$
  - from the low energy hadron scale towards the electroweak scale.
- *But, there will be other explanations - black holes, sphalerons, ...*

A priori,

- *the neutral* N_6 $\{$*dark matter*$\}$, *with a best guess mass* $\sim 500\,GeV$, *will be difficult to detect, since missing energies of several hundred* GeV *will be common.*
- *The* P_6, *assuming it is not too unstable, should be seen.*
- *Again, a massive, charged, particle with a large production x-section will not be immediately identified with the sextet sector !*

- **The double $\mathbb{P}$ x-section** could be the most definitive early evidence for the existence of the sextet sector.
- *With the $\mathbb{P}$'s detected via Roman pots, the environment is cleaner & more controlled.*

$W\&Z$ **pairs will be produced in the double $\mathbb{P}$ x-section via sextet pion anomaly poles.** $\{$*As pion pairs dominate the double $\mathbb{P}$ x-section at low mass, so $W\&Z$ pair production will dominate the x-section at the EW mass scale.*$\}$

$=>$ *when $|k_\perp|$ is EW scale, the amplitude is comparable with a jet amplitude that has, apart from anomaly loops that are O(1), the same propagators & couplings*

$=>$ **at large $k_\perp$, double $\mathbb{P}$ $W\&Z$ pairs will give jet x-sections that are comparable with the non-diffractive x-sections predicted by standard QCD.**

Generally, a factor of $\left[\frac{F_{\pi_6}}{F_{\pi_3}}\right]^4 \left(\gtrsim O(10^{12}) \right)$ is involved in relating sextet and triplet sector x-sections.

The central $\{\mathbb{P}W^+W^-\mathbb{P}\}$ & $\{\mathbb{P}Z^0Z^0\mathbb{P}\}$ vertices will vary only slowly with $k_\perp$, but the hadron/$\mathbb{P}$ vertices have strong $k_\perp$-dependence that should give **an extremely large x-section at small t.**

- *In the low luminosity running, this x-section could be detected by TOTEM in combination with the CMS central detector (if it is operational) where it should be straightforward to look for $W\&Z$ pairs.*
- *Some spectacular events would be expected, in which protons are tagged and only (a multitude of) large E_T leptons are seen in the central detector ?*

A very large double $\mathbb{P}$ x-section for $W\&Z$ pairs

$=>$ longitudinal components of $W\&Z$ have direct strong interactions

$=>$ existence of the sextet sector !!!

- **FP420** *will take over later & should surely see the enhanced x-section (whether or not it has been seen by CMS/TOTEM) - if it is present !!*
- **Indeed, with the planned parameters for FP420, the sextet $W\&Z$ pair x-section will overwhelm all other physics.**

After the combination of $\mathbb{P}$, W/Z, & jet physics has established that sextet quark physics is definitively discovered, **the search for "Dark Matter" will become all important.**

The x-section for **double $\mathbb{P}$ production of $\{$stable$\}$ $N_6 \bar{N}_6$ pairs** *(with mass $\gtrsim 1\ TeV$) could be large enough that it will be definitively seen by an optimum combination of forward pots.* **It will be a spectacular process to look for.**

- *The tagged protons determine a very massive state was produced.*
- *No charged particles seen in any of the detectors.*
- *Having low energy, the N_6 hadronic x-section will, probably, be small but some hadronic activity may be seen in the central calorimeter*
- *Charged lepton comparison would allow a separation wrt the multiple Z production of neutrinos.*

If the P_6 is relatively stable, & not too different in mass, it would be much simpler to first detect $P_6 \bar{P}_6$ pairs