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THE LHC POMERON AND UNIFICATION OF THE STANDARD MODEL*

Unitarity may be the key to the origin & unification of the Standard Model !

The RFT "Critical Pomeron" uniquely *satisfies high-energy unitarity &* **leads directly to** *a very special underlying field theory.*

- **For the Critical** $\mathbb{P}$ *to be produced* **in QCD,** *a high mass, strongly interacting,* **sextet quark sector** *must be the source of EW symmetry breaking.*
- *The sextet sector embeds* **uniquely** *in* **QUD** * **- a massless SU(5) theory** *with a* **bound-state S-Matrix** *that could be that of the* **Standard Model !!!**

QUD could be the "ORIGIN OF MATTER". If so, it will be DRAMATICALLY EVIDENT AT THE LHC & the $\mathbb{P}$ WILL BE THE MAIN DIAGNOSTIC.

* *Quantum Uno/Unification/Unitary/Underlying Dynamics*

* *Presented at the Small−x and Diffraction Workshop Fermilab, March 2007.*

A paper entitled **"A Massless Theory of Matter"** is in preparation -

" In this paper we will discuss a theory, which we refer to as QUD, that it appears might provide a complete and self-contained origin for the Standard Model. We will present arguments that SU(5) gauge theory with the combination of left-handed, massless, fermion representations

$$5 + 15 + 40 + 45^*$$

has a bound-state S-Matrix which contains only the interactions of the Standard Model and also has, qualitatively at least, the correct low mass spectrum.

If the states and high-energy amplitudes can be constructed as we will describe, all the necessary elements of the Standard Model are present in QUD in an extraordinarily economic manner. Moreover, a sector responsible for both electroweak symmetry breaking and dark matter is also present. All particles, including neutrinos, appear as massive bound-states and there is no Higgs field. The different coupling strengths, multiple mass scales, and multigenerational structure, should also all appear - but only in the S-Matrix!

An essential, but very unconventional, element in the emergence of the Standard Model S-Matrix from QUD is that electroweak symmetry breaking is associated with a new, high mass, sector of the (QCD) strong interaction. This new strong sector is predicted to produce dramatic, large cross-section, effects at the LHC - in addition to providing a natural explanation for the existence and predominance of dark matter, the cosmic ray spectrum knee, and other cosmic ray phenomena. "

It will be at least another 6 months before the paper appears !

Discovery of QUD at the LHC would lead to a revolution !!

Experimentally

- *The new physics will be, large cross-section, strong interaction physics - including the production of dark matter !! The ILC would be completely wrong - as the next machine. A higher-energy SSC would be the obvious choice. (e-p would also help.)*

Theoretically — QUD has very unexpected & unconventional properties.

- *As a field theory, it is* **massless** *& the coupling is very small ($\longrightarrow$ small ν masses ?)*

$$\alpha_u << O(1/50) \leftrightarrow \text{an IR fixed-point} \quad (\sim \text{ conformally invariant})$$

- *Most likely, the full field theory is defined only perturbatively - at large momentum.*

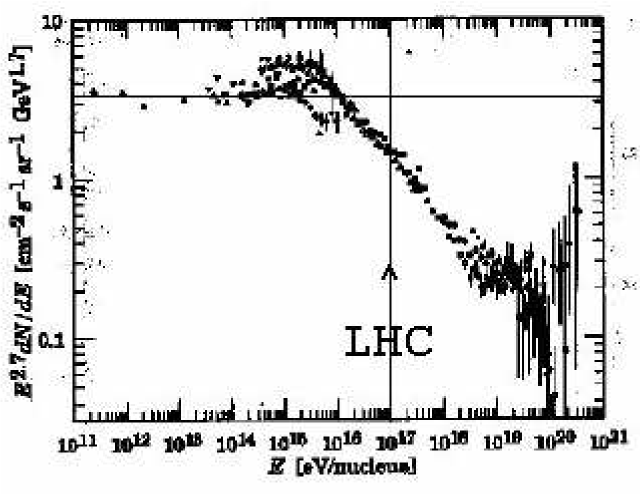
- **The S-Matrix is the "physical" content of the theory**
  - a major break with the current theoretical paradigm.
  (IR anomaly domination $\longrightarrow$ only a small subset of the field theory degrees of freedom are used in the S-Matrix.)

- *All particles are bound-states & masses are generated by reggeization, mixing & anomaly interactions, but only in the S-Matrix.*

There is no Higgs field

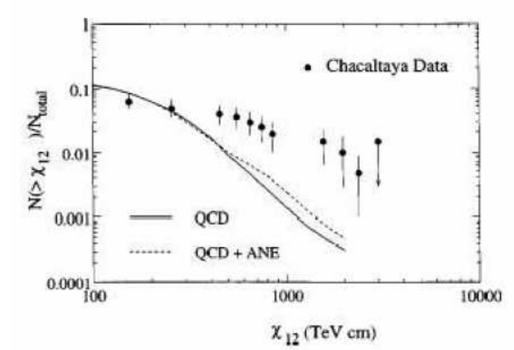
- *In the high-energy S-Matrix, IR chirality fluctations produce a* **wee gluon critical phenomenon** *which selects the Standard Model interactions (including the Critical* $\mathbb{P}$*) as a reflection of the gauge group conjugacy properties of the fermions.*

IN COSMIC RAYS there is good evidence of a strong interaction change *(of the right kind)* **at high energy -**

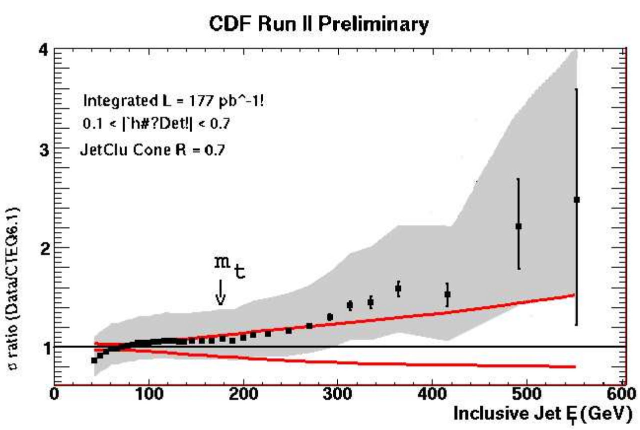


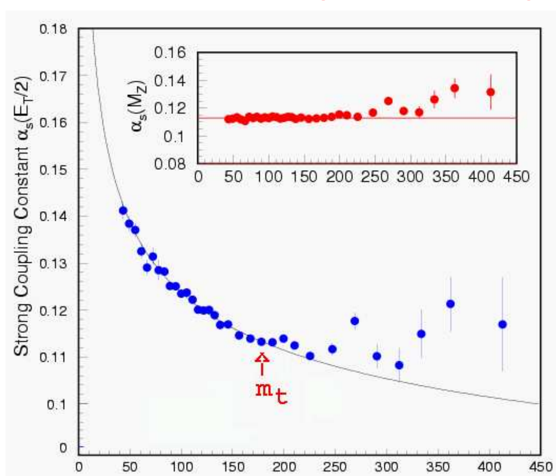
$\leftarrow$ **knee** $\equiv$ energies too low because of un-detected **“dark matter”** $\{$**stable, massive, neutral, particles**$\}$

$+$ big increase in $< p_\perp >$ $\longrightarrow$



AT THE TEVATRON *there is also indication that a change is coming*





New QCD physics begins with the top ??

THE PATH TO QUD

1. *The Reggeon Field Theory* **Critical $\mathbb{P}$ is the only known asymptotic solution of full multiparticle unitarity** *in both the t and s channels.*
2. *Supercritical RFT matches with SU(3) gauge theory & the Critical $\mathbb{P}$ occurs in QCD when asymptotic freedom is "saturated". The only realistic quark content is*

   6 color triplet quarks $+$ 2 color sextet quarks $\leftrightarrow$ "QCD$_S$"
3. $W^{\pm}$ & Z^0 *eat the "sextet pions" & EW symmetry breaking occurs - without any new interaction* **(the EW scale is the QCD sextet chiral scale $\leftrightarrow$ Casimir scaling !!!)**
4. **To cancel the EW anomaly & to generate particle masses, the sextet sector should be embedded in a left-handed unified theory.**
5. **Requiring the sextet sector + asymptotic freedom + anomaly cancelation uniquely selects SU(5) gauge theory with the fermion representation**

   5 + 15 + 40 + 45* $\leftrightarrow$ QUD

Amazingly, the triplet quark and lepton sectors (although not asked for) are very close to the Standard Model !!

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

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

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

The "Standard Model" quark & lepton generations $\{1\},\{2\},\{3\},$ *are scattered amongst the separate SU(5) representations. In addition, there is* **only**

1. **a sextet sector producing EW symmetry breaking (& dark matter !)**
2. **octet quarks with lepton EW quantum numbers** *(crucial - later!)*
3. **a pair of exotically charged quarks**

Nothing else !!

Clearly, the SU(2)xU(1) quantum numbers are **not quite right,** *when compared directly with the Standard Model. Note, however, that the complete representation is real, i.e. is a vector theory, wrt SU(3)xU(1)$_{em}$.*

THE ROLE OF QUD

That confining QUD might give the Standard Model S-Matrix became apparent to me **only after** *I understood the dynamics of* **high-energy QCD$_S$,** *whereby the S-Matrix is dominated by anomaly vertices containing zero momentum fermion chirality transitions.*

- *The chirality transitions play a similar role to condensates*

  - but only in the S-Matrix !!

- *In QCD$_S$, because it is a vector theory that conserves parity, the chirality transitions lead only to chiral symmetry breaking & color parity breaking by the $\mathbb{P}$.*

- *Correspondingly, because QUD is vector-like only wrt an SU(3)xU(1) subgroup, the chirality transition anomaly vertices naturally select the interactions of the Standard Model.*

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

For the Standard Model to emerge, it must have the same relationship to QUD that the hadronic sector has to QCD !!!! **All hadrons & leptons have to be QUD bound-states &, also, all Standard Model interactions have to be composite**

MULTI-REGGE ANOMALY AMPLITUDES

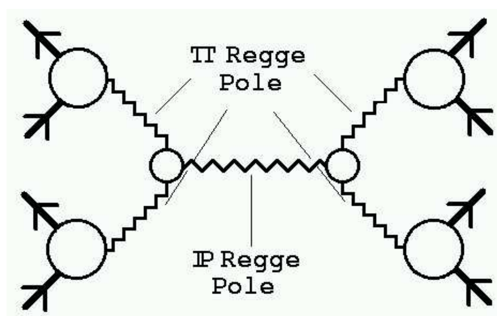
To find bound-state scattering amplitudes we have to utilise multi-regge theory. The multi-regge region is where the abstract properties of the S-Matrix are the most powerful.

- *Multiparticle dispersion & complex angular momentum theory $=>$ multi-regge amplitudes are controlled, in the J-plane, by*

"reggeon unitarity" *.*

Using reggeon unitarity, gauge theory multi-regge amplitudes can be constructed with reggeon diagrams.

e.g.



Scattering amplitudes for bound-state regge poles are contained in di-triple-regge amplitudes.

Our use of reggeon diagrams in the $k_\perp$ IR region *is very different from BFKL.*

- *We start with massive, gauge-invariant, gauge boson & fermion reggeons carrying global color.*
- *In the massless limit, exponentiating IR divergences "confine" color.*
- *We take the massless limit (& confine color) in stages & impose a $k_\perp$ cut-off, until the last stage - when, as we discuss next, an asymptotically-free scalar field can be used.*
- *With a cut-off, fermion loop interactions,* **including anomaly vertices containing chirality transitions,** *do not have Ward identity zeroes.*

QCD$_S$ & QUD share three, closely related, very important properties.

1. ***Asymptotic freedom is saturated.***
2. ***An infra-red fixed-pt*** *($\leftrightarrow$ small β-function)*
   $\longrightarrow$ **scaling reggeon kernels.**
3. *SU(3)/SU(5) color can be broken to SU(2)/SU(4) with an asymptotically-free scalar field*
   $\longrightarrow$ **CSQCD$_S$/CSQUD** (colorsuperconducting QCD$_S$/QUD)

$=>$ The high-energy states and amplitudes of QCD$_S$/QUD can be obtained* from those of CSQCD$_S$/CSQUD.

Scaling reggeon kernels are crucial for the extraction of physical amplitudes via anomaly-coupled infra-red divergences & the absence of a cut-off is essential for the reggeon critical phenomenon that occurs as the full color group is confined.

*Note that the resulting anomalies produced in QCD$_S$/QUD are, effectively, a resolution of the Gribov quantization ambiguity.

For QCD$_S$ & QUD we first confine SU(2) color.

A crucial role is played by

$I = 0$ **"anomalous gluon reggeons" with color parity C $\neq \tau$ - signature.**

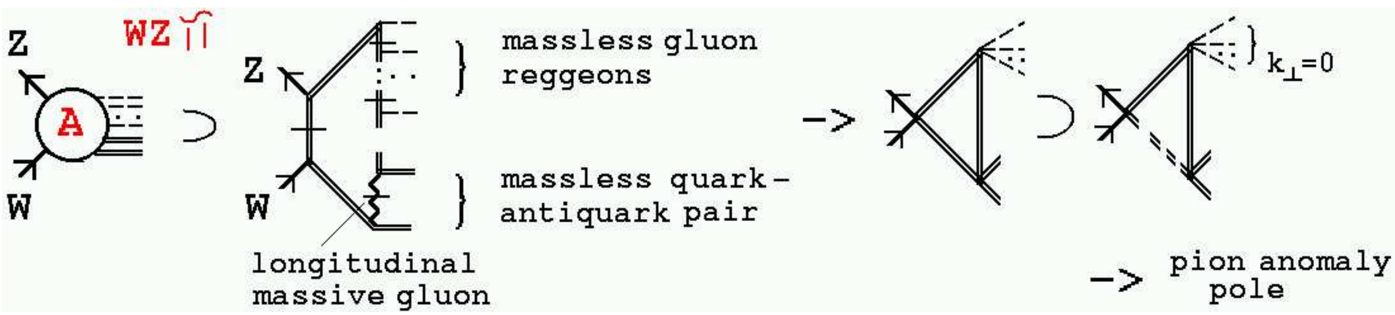
$\tau = CP$ $=>$ *anomalous gluon couplings must have* $P = -1$
$=>$ *a parity change that, in a vector theory, requires* **anomaly vertices containing chirality transitions.**

For SU(2), only $\tau = -1$ *anomalous combinations are possible.*

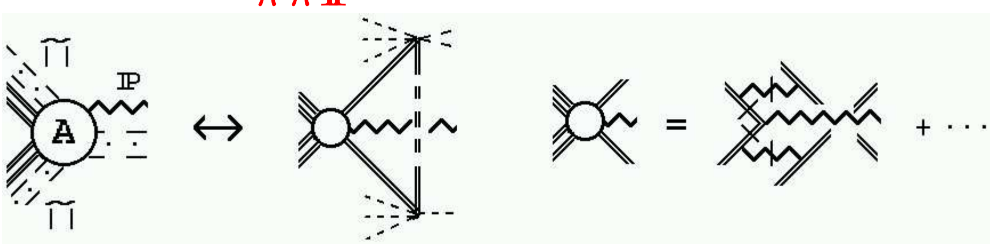
Anomalies can occur only in vertices coupling distinct reggeon channels. Anomaly vertices also contain "anomaly poles" which

- *in flavor channels give Goldstone Boson particle poles*
- *in U(1) channels give* $k_\perp$ *conserving* δ*-functions*

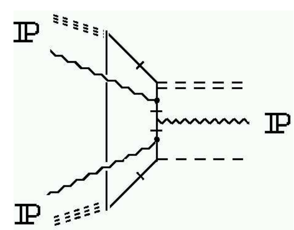
Reggeon interaction anomalies are produced when fermions in large loops are placed on-shell by a multi-regge limit, e.g.



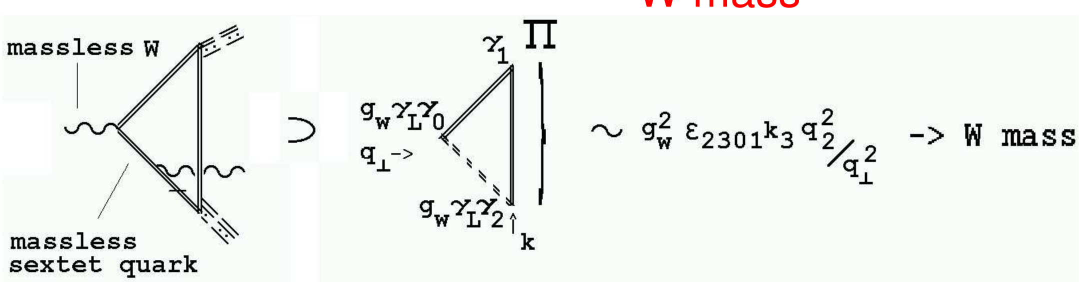
$\pi\pi\mathbb{P}$



$\mathbb{P}\mathbb{P}\mathbb{P}$



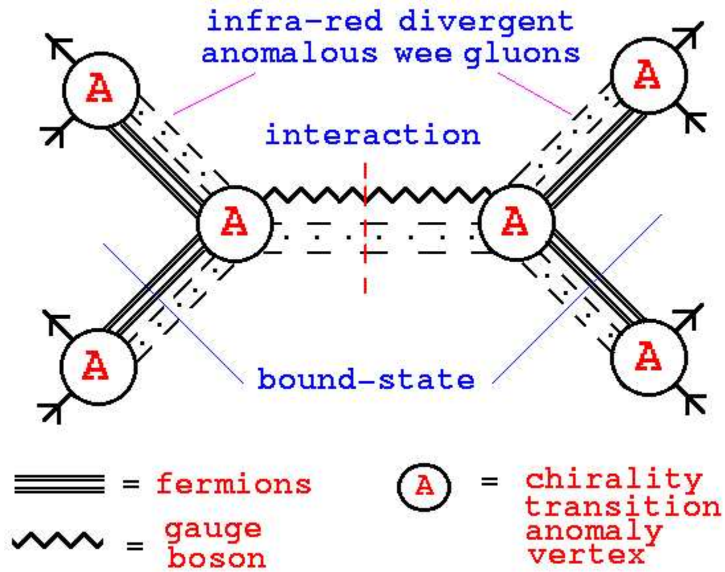
W mass



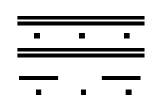
As SU(2) color is confined, with a $k_\perp$ cut-off, all divergences exponentiate, except for **a scaling infra-red divergence** due to

$I = 0$ "anomalous gluon reggeons" coupled via anomaly vertices

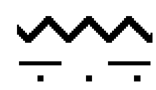
$\rightarrow k_\perp = 0$ "wee gluon condensate" in all physical amplitudes.



bound-states *appear as Goldstone 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 from CSQCD$_S$ i.e. ColorSuperconducting QCD$_S$ ($\leftrightarrow$ SU(2) color).*

- **The physical states of QCD_S are the Goldstones of $CSQCD_S$.**

$\longrightarrow$ **triplet mesons & nucleons**

$\longrightarrow$ **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.

Since the sextet pions are eaten by $W^{\pm} \& Z^0$ the **only new states** *are the sextet nucleons.* **The sextet neutron, the N_6, will be stable & dominate UHE x-sections**

$\longrightarrow$ Production & Dominance of 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**

(The critical phenomenon is all-orders in the triple $\mathbb{P}$ coupling $=>$ arbitrarily large numbers of chirality transitions.)

$=>$ **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 !!

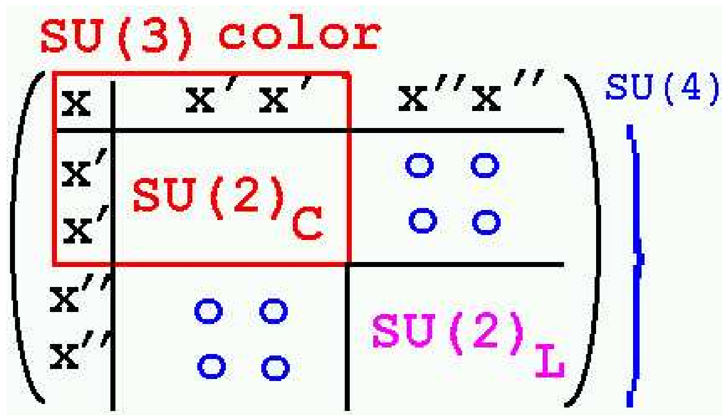
In QUD, parity violation leads to the exponentiation by fermion loop interactions of all divergences involving left-handed gauge boson reggeons

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

$\longrightarrow$ **strong interactions that are $\{$global$\}$ SU(3) color singlets !!!**

To construct QUD states & amplitudes we again start with SU(2)$_C$.

It is a vector symmetry & so the states are Goldstone π_C's, i.e qq, $\bar{q}\bar{q}$, & $q\bar{q}$ pairs in a reggeon condensate. The q's are **3's, 6's,** *&* **8's** *under SU(3).* **8's** *are real wrt SU(3), but contain complex doublets wrt SU(2)$_C$.*



Interactions that will produce SU(3) singlets are

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

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

Restoring SU(4) symmetry to obtain CSQUD *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" and "octet pions".*
- *The SU(2)$_L \times$U(1) quantum numbers of octet π's are* $(2,\frac{1}{2}),\ (1,-1),\ \&(3,-1)$ *& so the elementary lepton component has (modulo gauge boson contributions) the generation structure of the Standard Model.*
- *"Hadrons" form similarly - as dictated by electroweak anomaly cancellation.*

The **SU(3)$\times$SU(2)$_L\times$U(1) content of the bound-state leptons is**

- (e^-,ν) *candidate*

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

- e^+ *candidate*

$$\leftrightarrow\ (1,3,1)\times(8,2,-\tfrac{1}{2})(8,2,-\tfrac{1}{2})$$
$$\leftrightarrow\ SU(5)\ singlet\ -\ 15\times 45^*\times 45^*$$

- (μ^-,ν) *candidate*

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

- (τ^-,ν) *candidate*

$$\leftrightarrow (1,2,-\tfrac{3}{2})(1,2,\tfrac{1}{2})(1,2,\tfrac{1}{2})\times(8,1,1)(8,2,-\tfrac{1}{2})$$
$$\leftrightarrow\ SU(5)\ singlet\ -\ 40\times 5\times 5\times 40\times 45^*$$

- *Hadrons similarly contain three triplet quarks + octet pions*

As SU(5) symmetry is restored $\{$*my current understanding*$\}$

- **The $\mathbb{P}$ becomes critical** - *as an SU(3) subgroup interaction that is summed over subgroups.*
- *The $\gamma, W^{\pm} \& Z^0$ wee gluon component becomes even signature.*

The octet quarks *(at first sight unwanted)* **are fundamental for SU(5) invariance & the generation structure of states.**

- *The octet π's are no longer Goldstones & so aquire large $k_\perp$.*
- *SU(3) reality $=>$ octet π's have no (anomaly) coupling to the $\mathbb{P}$*

  $=>$ **leptons have no strong interaction & no IR SU(3) mass generation.**
- Because the octet π's are at large $k_\perp$ the SU(2)$_L$$\otimes$U(1) symmetry will appear in low $k_\perp$ interactions (via sextet SU(2) flavor).
- *The SU(2)$_L$$\otimes$U(1) anomaly $=>$ three generations of "hadrons" & "leptons".*
- *SU(2)$\otimes$U(1) quantum numbers of the octet π's $=>$ low $k_\perp$ states will have the singlet/doublet structure of the Standard model.*

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 should 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. *QUD is contained in a single SO(10) representation - the* **144***. Although there is no S-Matrix for the enlarged representation (according to our arguments), this could be relevant for $\{$string?$\}$ unification with gravity?*

It is remarkable that the idea that the new physics underlying EW symmetry breaking is strong interaction physics seems to lead to such a unique & definitive picture.

Much of what I have described needs to be better established and very many questions remain to be answered. 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 what should be seen at the LHC & how double $\mathbb{P}$ processes can provide the definitive proof that a sextet sector has appeared.

What Should be Seen at the LHC ?

Because large cross-sections are involved, the appearance of the a sextet sector should, at first sight, be obvious. The immediate evidence will be that

- *multiple vector boson and jet x-sections are* **much, much, larger** *than expected, producing a dramatic rise in the average* $|p_\perp|$.

  $<p_\perp>$ **should undergo a major increase from the low energy hadron scale & move significantly towards the EW scale.**

- **But,** *there will be other explanations - black holes, sphalerons, etc.*

- $N_6 \bar{N}_6$ *pair production* $\{$*dark matter*$\}$ *should be seen - with the* N_6 *mass, perhaps,* $\sim 500\, GeV$.

  This will be difficult to detect, since missing energies of several hundred GeV *will be common.*

  Also the low energy N_6 hadronic x-section (in a calorimeter) is probably small.

- $P_6 \bar{P}_6$ *pair production should be seen - assuming the* P_6 *is not too unstable.*

- *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 clean & well 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.*$\}$

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

When $|k_\perp|$ is EW scale, the double $\mathbb{P}$ $W\&Z$ pair amplitude for producing jets is comparable with a standard jet amplitude that has, apart from anomaly loops that are O(1), the same propagators & couplings.

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

The $\{\mathbb{P}W^+W^-\mathbb{P}\}$ & $\{\mathbb{P}Z^0Z^0\mathbb{P}\}$ 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, the "extremely large x-section" could be detected by* TOTEM *in combination with the CMS central detector (if it is operational) where it should be straight-forward 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 during the high luminosity running & should surely see the enhanced x-section (whether or not it has been seen by CMS/TOTEM) - if it is present !!*

- **With the planned parameters for FP420,**

  the $W \& Z$ 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 forward pots.* **It will be a spectacular process to look for.**

- *The tagged protons determine a very massive state was produced.*
- *No charged particles are 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^0 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