Quartified Quarks and Leptons :

A Baseball Diamond Symmetry

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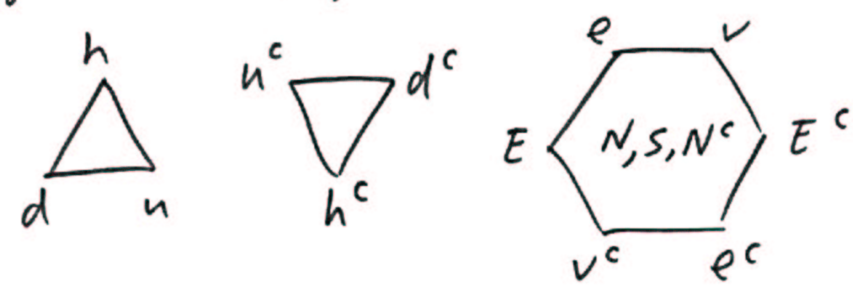
U C Riverside

* From trinification to quartification by stretching the "moose"
* Leptons and quarks are interchangeable at high energy. They only appear to be different at low energy.

$SU(3)_C \times SU(3)_L \times SU(3)_R$ trinification

De Rujula, Georgi, Glashaw (84)
Babu, He, Pakvasa (86)
Lazarides, Panagiotakopoulos, Shafi (93)
Willenbrock (03)

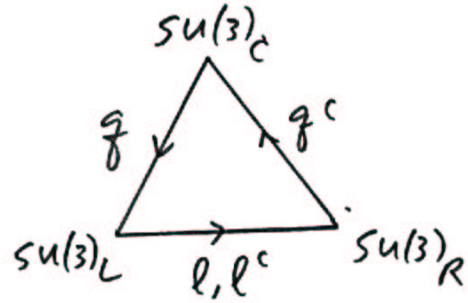
$q \sim (3, 3^*, 1)$, $q^c \sim (3^*, 1, 3)$, $l, l^c \sim (1, 3, 3^*)$



reduces to $SU(3)_C \times SU(2)_L \times SU(2)_R \times U(1)_{B-L}$

to $SU(3)_C \times SU(2)_L \times U(1)_Y$

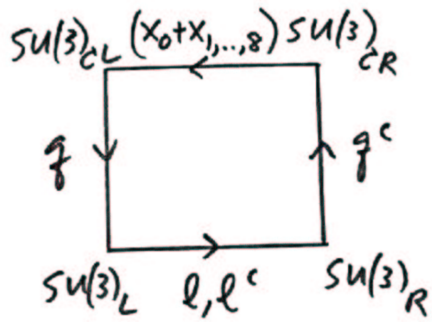
Note : No proton decay.



"moose" [Georgi (86)]

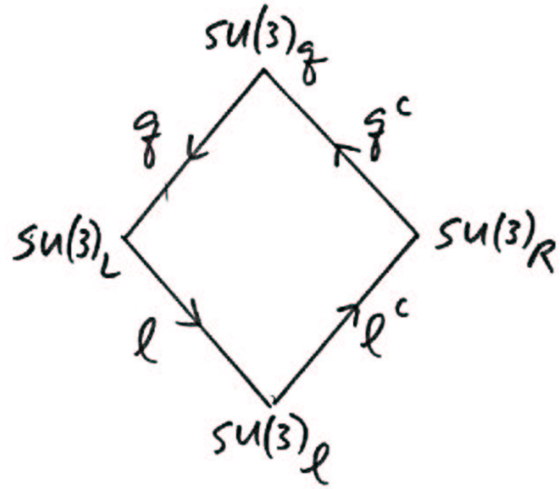
"quiver [Douglas, Moore (96)]

Arkani-Hamed, Cohen, Georgi (01)



reduces to chiral color model of Frampton, Glashow (87)

$SU(3)_q \times SU(3)_\ell \times SU(3)_L \times SU(3)_R$ quartification



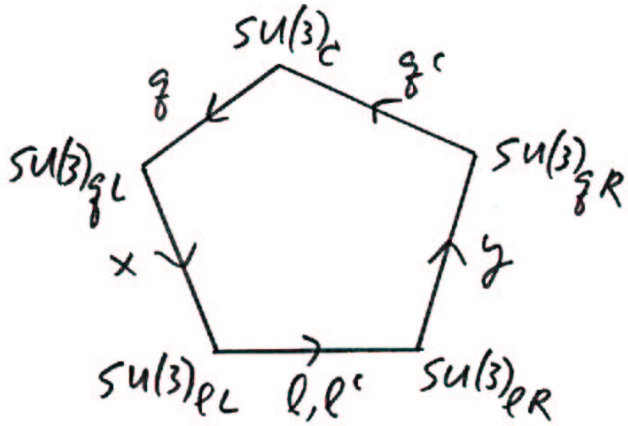
$SU(3)_\ell \to SU(2)_\ell \times U(1)_\ell$

$$Q = I_{3L} - \frac{Y_L}{2} + I_{3R} - \frac{Y_R}{2} - \frac{Y_\ell}{2}$$

reduces to leptonic color model of

Foot, Lew (90)

Foot, Lew, Volkas (91)



reduces to $SU(3)_C \times SU(2)_q \times SU(2)_\ell \times U(1)_q$
$\times U(1)_\ell$

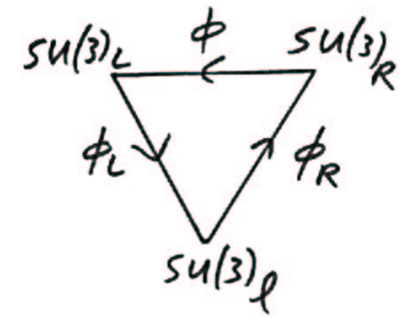
Georgi, Jenkins, Simmons (89)

Rajpoot (90)

Li, Ma (03)

$$\Rightarrow \underbrace{(G_F)^{NC}_{\ell q}}_{\text{NuTeV}} \le \underbrace{(G_F)^{CC}_{\ell q}}_{\beta\ \text{decay}} \le (G_F)^{CC}_{\ell\ell} \le (G_F)^{NC}_{\ell\ell}$$

Higgs sector

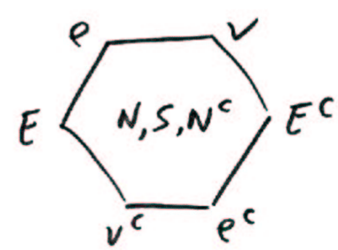


$\Rightarrow \phi \ell \ell^c,\ \phi q q^c,$
$\phi_L \ell \ell,\ \phi_R \ell^c \ell^c$
couplings

$$\ell \sim \begin{array}{c} x \\ y \\ z \end{array} \left(\begin{array}{cc|c} \frac{1}{2} & \frac{1}{2} & 0 \\ -\frac{1}{2} & -\frac{1}{2} & -1 \\ \hline \frac{1}{2} & \frac{1}{2} & 0 \end{array} \right) \begin{array}{c} \nu \\ e \\ N \end{array} \sim \phi_L$$

$$\ell^c \sim \begin{array}{c} z^c \\ y^c \\ x^c \end{array} \left(\begin{array}{cc|c} -\frac{1}{2} & -\frac{1}{2} & 0 \\ \hline \frac{1}{2} & \frac{1}{2} & 1 \\ -\frac{1}{2} & -\frac{1}{2} & 0 \end{array} \right) \begin{array}{c} N^c \\ e^c \\ \nu^c \end{array} \sim \phi_R$$

$\phi^\dagger \sim$



in the $SU(3)_L \times SU(3)_R$ representation

$\langle \phi_R^{N^c} \rangle \neq 0$ breaks $SU(3)_l \times SU(3)_R$

to $SU(2)_l \times SU(2)_R \times U(1)_{lR}$

$\langle \phi_{\nu^c} \rangle \neq 0$ breaks $SU(3)_L \times SU(2)_R \times U(1)_{lR}$

to $SU(2)_L \times U(1)_L \times U(1)_{RlR}$

$\langle \phi_L^N \rangle$ or $\langle \phi_s \rangle \neq 0$ breaks $U(1)_L \times U(1)_{RlR}$

to $U(1)_Y$

<u>Fermion mass terms</u>

$\langle \phi_R^{N^c} \rangle (x_1^c y_1^c - y_1^c x_2^c)$

$\langle \phi_{\nu^c} \rangle \{ \nu^c N,\ h d^c,\ z x^c \}$

$\langle \phi_L^N \rangle (x_1 y_2 - y_1 x_2)$

$\langle \phi_s \rangle \{ N N^c,\ h h^c,\ z z^c \}$

<u>Neutrino Mass</u>

	ν	N^c	N	ν^c
ν	0	0	0	a
N^c	0	0	b	0
N	0	b	0	c
ν^c	a	0	c	0

2 Dirac neutrinos

Roy, Shanker (84)

$a \sim \langle \phi_{N^c} \rangle$, $b \sim \langle \phi_s \rangle$, $c \sim \langle \phi_{\nu^c} \rangle$ $\downarrow$ breaks $SU(2)_R$

Let $a, b \ll c$,

then $m = \pm \frac{ab}{c}$, $\pm c$

e.g. $a \sim 10^2$ GeV, $b \sim 10^3$ GeV,

$c \sim 10^{16}$ GeV, then $m_\nu \sim 10^{-2}$ eV !

<u>Note</u> : u, d, h have $B-L = \frac{1}{3}$

ν, e, N " $B-L = -1$

"larks" : x, y, z " $B-L = 0$

Particle content

Below electroweak scale, it is the same as the SM, except ν is Dirac, with partner N^c.
[$N-\nu^c$ is superheavy.]

d-h sector

	d^c	h^c
d	$\langle\phi_N\rangle$	0
h	$\langle\phi_{\nu^c}\rangle$	$\langle\phi_s\rangle$

$d-h^c$ is light
$h-d^c$ is superheavy

$x-y^c-z$ sector

	x^c	y	z^c
x	$\langle\phi_{N^c}\rangle$	$\langle\phi_L^N\rangle$	0
y^c	$\langle\phi_R^{N^c}\rangle$	$\langle\phi_N\rangle$	0
z	$\langle\phi_{\nu^c}\rangle$	0	$\langle\phi_s\rangle$

$x^c-(y^c, z)$ is superheavy,
$x-y \sim$ TeV
$z^c-(z, y^c) \sim$ TeV

I have assumed that $\langle\phi_L^N\rangle \sim \langle\phi_s\rangle \sim$ TeV, in which case there is a TeV Z' gauge boson in this model.

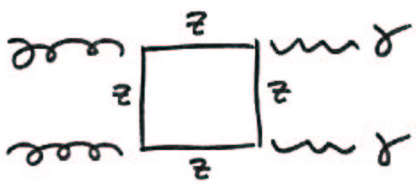
If $\langle\phi_L^N\rangle \gg \langle\phi_s\rangle \sim$ TeV, then the Z' as well as the $x-y$ larks would be heavy $\sim \langle\phi_L^N\rangle$.

If $\langle\phi_L^N\rangle < \langle\phi_s\rangle \sim$ TeV, then Z' is TeV heavy, but the $x-y$ larks may be lighter and become observable.

* In all cases, $z^c-(z, y^c)$ larks are $\sim \langle\phi_s\rangle \sim$ TeV.

There are also 3 massless $SU(2)_\ell$ "stickons". They will form "stickballs".

* In QCD, the glueballs are unstable because they are heavier than the mesons. Here the "mesons" are much heavier, so the "stickballs" are rather stable :



$$QCD: \beta(g) \propto -\frac{33+2n_q}{3} = -7 \quad (n_q = 6)$$

$$SU(2)_\ell : \beta(g) \propto -\frac{22+2n_\ell}{3} = \begin{cases} -\frac{14}{3} & (n_\ell = 3) \\ -\frac{22}{3} & (n_\ell = 0) \end{cases}$$

$\Rightarrow$ "stickballs" are lighter than glueballs

Minimal Model

$\langle \phi_R^{N^c} \rangle \sim \langle \phi_L^N \rangle \sim \langle \phi_{\nu^c} \rangle \sim 10^{16}$ GeV

$\Rightarrow [SU(3)]^4$ breaks at 10^{16} GeV to $SU(3)_q \times SU(2)_\ell \times SU(2)_L \times U(1)_Y$

$\langle \phi_N \rangle \sim \langle \phi_{N^c} \rangle \sim 10^2$ GeV breaks $SU(2)_L \times U(1)_Y$ to $U(1)_Q$

$\langle \phi_S \rangle$	$\langle \phi_\nu \rangle$	$m\{\nu\text{-}N^c\}$	$m\{z^c\text{-}(z, y^c)\}$	
0	0	0	0	
TeV	0	10^{-2} eV	TeV	← choose
TeV	$\neq 0$	$O(\phi_\nu)$	TeV	

Phenomenology of larks

$z^{(\frac{1}{2})}$ and $z^{(-\frac{1}{2})}$ are confined by $SU(2)_\ell$ to form $\lambda^+, \lambda^0, \lambda^-$ bound states

λ^0 decays into 2 stickballs immediately, but $\lambda^\pm$ are stable, just as the proton and antiproton (in isolation) is stable.

The atomic and nuclear physics of $\lambda^\pm$ are different because there is no analog of the neutron.