Leptonic color models from AdS/CFT

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MIAMI'07: 10 years of AdS/CFT, Ft. Lauderdale, USA

Outline

- Motivation for leptonic color models
- Trinification and Quartification
- Obtaining product group GUTs from AdS/CFT
- Quartification from AdS/CFT
- Flipped Quartification

K.S. Babu, T.W. Kephart, H. Päs: arXiv: 0709.0765

Motivation for leptonic color models

Why are quarks different from leptons:

- exist in three colors and transform as triplets under $SU(3)_c$
- carry fractional electric charges

Assume that this difference is a low energy artefact:

- Assume leptonic color $SU(3)_l$ symmetry
- Breaking $SU(3)_l \rightarrow SU(2)_l$ gives unconfined lepton states and explains electric charge differences between leptons and quarks

Foot, Lew 1990; Foot, Lew, Volkas 1991

$\rightarrow$ Possibility to unify $SU(3)_l$ and SM gauge group into the quartification gauge group

$$\boxed{SU(3)_L \times SU(3)_R \times SU(3)_c \times SU(3)_l}$$

Joshi, Volkas, 1992; Babu, Ma , Willenbrock, 2003

Trinification models

Quartification models are a generalization of Trinification models:

$$\boxed{SU(3)_c \times SU(2)_L \times U(1)_Y \to SU(3)_c \times SU(3)_L \times SU(3)_R}$$

De Rujula, Glashow, Georgi, 1984

→ Aesthetic: fermions in (bi-)fundamental representations:

$$3[(3\bar{3}1) + (13\bar{3}) + (\bar{3}13)]$$

with

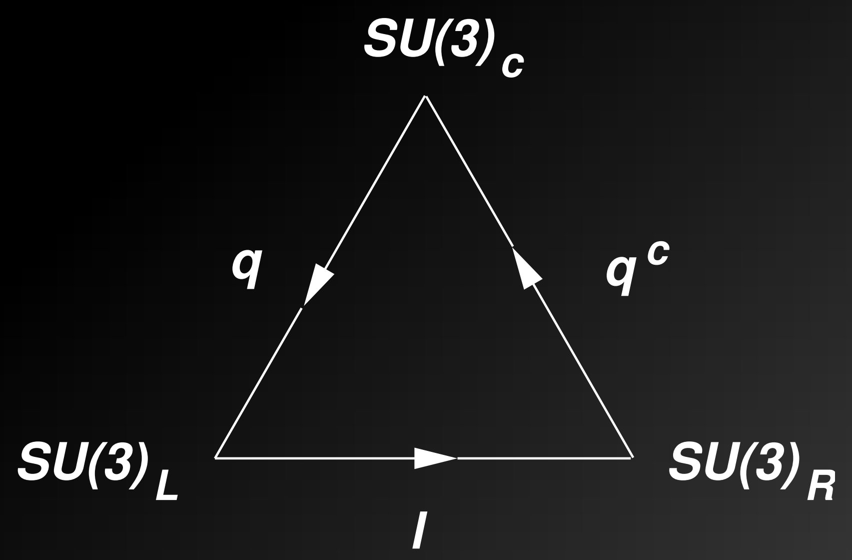
$$l \sim (1, 3, \bar{3}), \quad q \sim (3, \bar{3}, 1), \quad q^c \sim (\bar{3}, 1, 3)$$

→ Attractive: suppressed proton decay rate (only due to Higgs exchange)

Babu, He, Pakvasa, 1986

Fermion content of Trinification models

The fermion content can be arranged into a quiver diagram:



In terms of $SU(3)_L \times SU(3)_R$ one gets:

$$l \sim \begin{pmatrix} N & E^c & \nu \\ E & N^c & e \\ \nu^c & e^c & S, \end{pmatrix}$$

rows: $I_{3L} = (1/2, -1/2, 0)$ and $Y_L = (1/3, 1/3, -2/3)$
columns: $I_{3R} = (-1/2, 1/2, 0)$ and $Y_R = (-1/3, -1/3, 2/3)$

Fermion content of Trinification models

$$q \sim \begin{pmatrix} d & u & h \\ d & u & h \\ d & u & h \end{pmatrix}, \quad q^c \sim \begin{pmatrix} d^c & d^c & d^c \\ u^c & u^c & u^c \\ h^c & h^c & h^c \end{pmatrix}$$

columns in q: $I_{3L} = (-1/2, 1/2, 0)$, $Y_L = (-1/3, -1/3, 2/3)$
rows in q^c: $I_{3R} = (1/2, -1/2, 0)$, $Y_L = (1/3, 1/3, -2/3)$

Electric charge operator:

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

- Exotic fermions $h(h^c)$, $E(E^c)$, and N, N^c, S: charges $\mp 1/3$, ∓ 1, 0
- Trinification models can be embedded into E_6 but have no quark-lepton-symmetry!

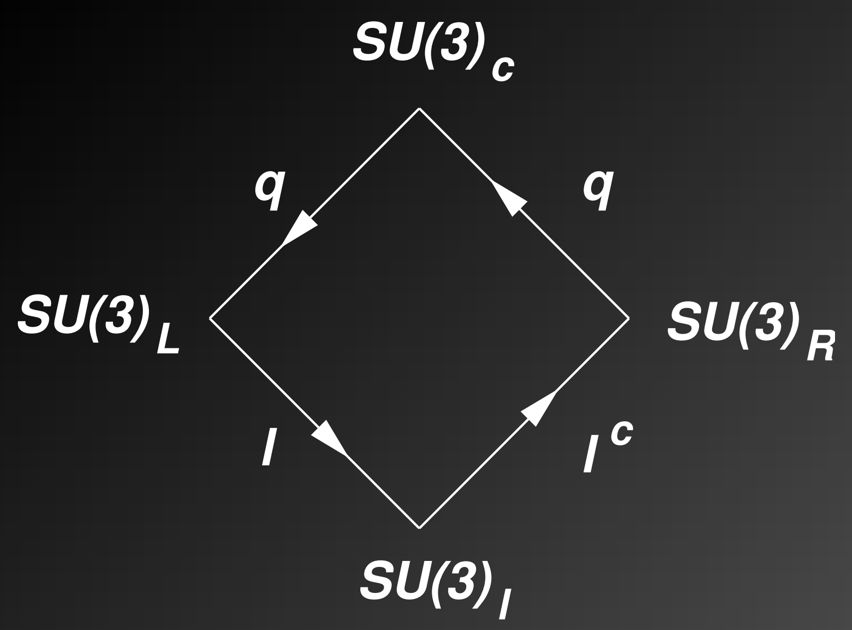
Quartification models

Gauge group:

$$SU(3)_l \times SU(3)_L \times SU(3)_c \times SU(3)_R$$

with fermions in bi-fundamental representations:

$$3(3\bar{3}11) + (13\bar{3}1) + (113\bar{3}) + (\bar{3}113)$$



and electric charge operator:

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

Fermion content of Quartification models

Lepton content:

$$l \sim \begin{pmatrix} x_1 & x_2 & \nu \\ y_1 & y_2 & e \\ z_1 & z_2 & N \end{pmatrix}, \quad l^c \sim \begin{pmatrix} x_1^c & y_1^c & z_1^c \\ x_2^c & y_2^c & z_2^c \\ \nu^c & e^c & N^c \end{pmatrix}$$

l columns: $Y_l = (-1/3, -1/3, 2/3)$ rows: $I_{3L} = (1/2, -1/2, 0)$, $Y_L = (1/3, 1/3, -2/3)$
l^c rows: $Y_l = (1/3, 1/3, -2/3)$, columns: $I_{3R} = (-1/2, 1/2, 0)$,
$Y_L = (-1/3, -1/3, 2/3)$

New particles:

- N and N^c: neutral
- $SU(2)_l$ doublet leptons (x, y, z): charges $(1/2, -1/2, 1/2)$
  (x^c, y^c, z^c): charges $(-1/2, 1/2, -1/2)$

Interesting feature: gauge coupling unification without supersymmetry

Babu, Ma , Willenbrock, 2003

Product group GUTs from AdS/CFT

Maldacena 1997: IIB superstring theory compactified on $AdS \times S^5$ is dual to N=4 SUSY CFT

Frampton 1998: $\mathcal{N}=4$ SUSY can be broken down to $\mathcal{N}=0,1$ SUSY by orbifolding $S^5 \to S^5/\Gamma$ where Γ is a discrete group:
$\Gamma \subset SU(4) \sim O(6)$ of $S^5 \Rightarrow \mathcal{N}=0$
$\Gamma \subset SU(3) \subset O(6)$ of $S^5 \Rightarrow \mathcal{N}=1$

$\to$ remnants of conformality property can help to solve the hierarchy problem

Kachru, Silverstein 1998; Frampton, Vafa, Kephart, Mohapatra,...:
AdS/CFT/Conformality model building

Choose $N=3$ in large N expansion and orbifold with $Z_n \Rightarrow$ gauge group $SU(3)^n$

Fermions: 4 of $SU(4)$ isometry must be complex for chiral fermions
Scalars: $6=(4 \otimes 4)_{\rm antisym}$ of SU(4) isometry must be real for consistent embedding (Frampton, Kephart, 2004)

Kephart, Päs, 2001; Kephart, Päs, 2004:
$\to$ systematic scans of $\mathcal{N}=0$ and $\mathcal{N}=1$ SUSY models from $\Gamma = Z_n$ orbifolds
check for chiral fermion content and consistenct with phenomenology

Leptonic color models from AdS/CFT

To obtain

$$\boxed{SU(3)_l \times SU(3)_L \times SU(3)_c \times SU(3)_R}$$

with all four coupling constants equal:

$\rightarrow$ Look for Z_n orbifold with $n = 4z$, $z \in \mathrm{Z}$
$\Rightarrow SU(3)^4$, $SU(3)^8$,... $SU(3)^{4z} \rightarrow SU(4)^n$
with each factor being the diagonal subgroup of z of the original groups

n=4: no viable model with chiral fermions

n=8: 24 possible symmetry breaking patterns - two possible models:

- one full quartifications model: $4 = (\alpha^1, \alpha^1, \alpha^3, \alpha^3)$

$$3[(3\bar{3}11) + (13\bar{3}1) + (113\bar{3}) + (\bar{3}113)]$$

- one hybrid trinification-quartification model: $4 = (\alpha^1, \alpha^4, \alpha^5, \alpha^6)$

$$2[(3\bar{3}1) + (13\bar{3}) + (\bar{3}13)] + (3\bar{3}11) + (13\bar{3}1) + (113\bar{3}) + (\bar{3}113)$$

Quartification from Ads/CFT

Fermions: $4 = (\alpha^1, \alpha^1, \alpha^3, \alpha^3) \rightarrow$

$$2[(3\bar{3}111111) + (311\bar{3}1111)]_F + \text{cyclic permutations}$$

Scalars: $6 = (4 \otimes 4)_{\text{antisym}}$

$$[(31\bar{3}11111) + 4(3111\bar{3}111) + (311111\bar{3}1) + h.c.]_S + \text{cyclic permutations}$$

$SU(3)^8 \rightarrow SU(3)^4$ by assigning VEVs to

$$(31\bar{3}11111)_S, (131\bar{3}1111)_S, (111131\bar{3}1)_S, (1111131\bar{3})_S$$

$\Rightarrow$ chiral $SU(3)^4$ Fermions:

$$4[(3\bar{3}11) + (13\bar{3}1) + (113\bar{3}) + (\bar{3}113)]_F$$

and scalars

$$10[(31\bar{3}1) + (131\bar{3}) + h.c.]_S + 2[(8111) + (1811) + (1181) + (1118)]_S$$

problem: few scalars, SSB to the SM requires leptonic color condensate, difficult for small Λ_{lCD}

Minimal leptonic color from Ads/CFT

Fermions: $4=(\alpha^1,\alpha^4,\alpha^5,\alpha^6)\rightarrow$

$$(3\bar{3}111111)_F+(3111\bar{3}111)_F+(31111\bar{3}11)_F+(311111\bar{3}1)_F+\text{cyclic permutations}$$

Scalars: $6=(4\otimes 4)_{\text{antisym}}$

$$(3\bar{3}111111)_S+(31\bar{3}11111)_S+(311\bar{3}1111)_S+(31111\bar{3}11)_S+(311111\bar{3}1)_S$$
$$+(3111111\bar{3})_S+\text{cyclic permutations}$$

SSB $SU(3)^8\rightarrow SU(3)^4$ by assigning VEVs to

$$(3\bar{3}111111)_S,(11311\bar{3}11)_S,(111311\bar{3}1)_S,(1111311\bar{3})_S$$

$\Rightarrow$ chiral $SU(3)^4$ Fermions:

$$2[(13\bar{3}1)+(113\bar{3})+(1\bar{3}13)]_F+[(3\bar{3}11)+(13\bar{3}1)+(113\bar{3})+(\bar{3}113)]_F$$

⇒ Scalars:

$$3[(3\bar{3}11) + (13\bar{3}1) + (113\bar{3}) + (\bar{3}113) + h.c.]_S$$
$$+4[(31\bar{3}1) + (131\bar{3}) + h.c.]_S + 2[(8111) + (1811) + (1181) + (1118)]_S$$

- VEV to a $(3\bar{3}11)$: 3 family trinification model
- VEVs are given to two $(131\bar{3})$ representations: realistic quark masses and non-zero mixing angles, VEVs to $(3\bar{3}11)$ and to $(311\bar{3})$: $SU(3)_l \to SU(2)_l$
- do we still have gauge coupling unification?

Gauge coupling unification

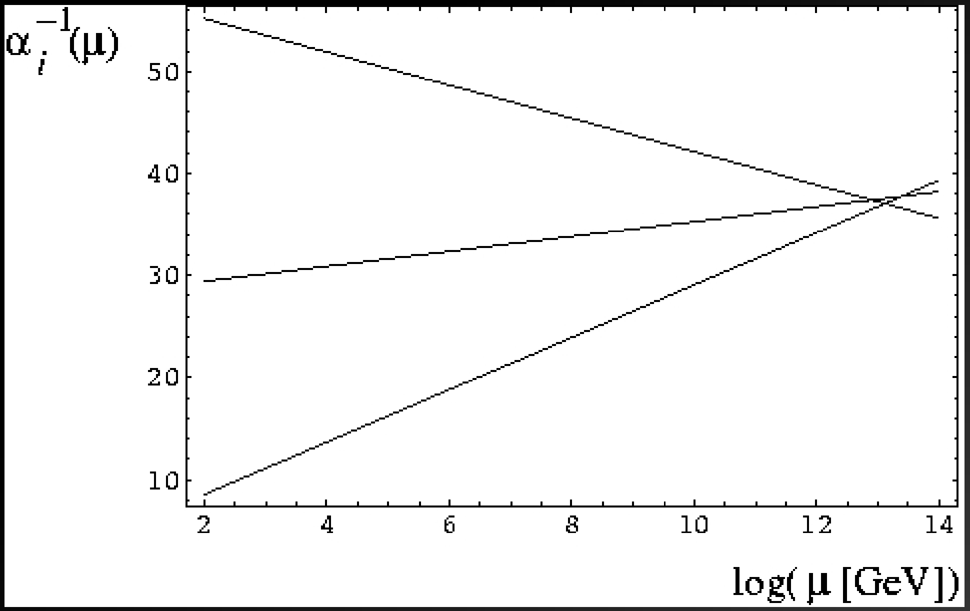
RGEs:

$$\boxed{\frac{1}{\alpha_i(\mu)} - \frac{1}{\alpha_i(\mu')} = \frac{b_i}{2\pi} \ln\left(\frac{\mu'}{\mu}\right)}$$

where b_n are the one-loop beta-function coefficients:

$$b_3 = -11 + \frac{4}{3}N_g,$$
$$b_2 = -\frac{22}{3} + 2N_q + \frac{4}{3}N_t + \frac{1}{6}N_H$$
$$b_1 = \frac{13}{9}N_q + \frac{4}{3}N_t + \frac{1}{12}N_H$$

$N_g = 3$: number of generations
$N_q = 1$: number of quartification families
$N_t = 2$: number of trinification families
$\sin^2\theta_W(M_{GUT}) = \sum I_{3L}^2 / \sum Q^2 = 9/16$



12 standard Higgs doublets of $SU(2)_L$: 4 Higgs doublets $\rightarrow$ unification at 10^{13} GeV $\rightarrow$ chance to discover multiple Higgs doublets at the LHC

Coupling of the unbroken $SU(2)_l$:

$$b_{2l} = -\frac{22}{3} + \frac{4}{3} N_q .$$

$\Rightarrow \alpha_{2l}^{-1}(M_Z) \simeq 13$ between α_{weak} and α_s, similar phenomenology as in Babu, Ma , Willenbrock, 2003 albeit with higher $\Lambda_{lCD} \sim MeV$

Constraints and consistency

- Hemion masses: quartification scale hemion masses: forbidden by the Z_8 orbifold symmetry

  TeV scale hemion masses: generated by adding non-renormalizable operators suppressed by M_{Planck}

- Electroweak precision data: Singlet and vectorlike symmetry breaking products will not affect EW data

  hemions: vector-like under the SM gauge group, EW effects suppressed by hemion masses

  Flavor changing neutral currents?

- Proton decay: not be mediated by gauge bosons, could be induced via couplings to the extended scalar sector

- Stickballs glueballs of leptonic color SU(2): cold dark matter candidate

Neutrino masses

SSB provides several singlet fermions:

e.g. from the $(3\bar{3}111111)$ representation after assigning VEV to $(3\bar{3}111111)$ scalars
$\longrightarrow$ makes AdS/CFT inspired model superior to the simple quartification model, as a seesaw mechanism

$$m_\nu \sim \frac{m^2_{\bar{\nu}\nu}}{M_{3\bar{3}111111}}$$

can be implemented to generate light neutrino masses without adding right-handed neutrinos by hand

$\longrightarrow$ interesting neutrino sector: multidimensional neutrino mass mnatrices, seesaw II?

$\longrightarrow$ Leptogenesis,....

Flipped Quartification

Quartification models: possible to non-trivially flip order of factor groups

$$SU(3)_L \times SU(3)_R \times SU(3)_c \times SU(3)_l \to SU(3)_c \times SU(3)_L \times SU(3)_R \times SU(3)_l$$

SSB:

- $SU(3)_L \to SU(2)_L \times U(1)_A$
- $SU(3)_R \to U(1)_B \times U(1)_C$
- $SU(3)_l \to SU(2)_l \times U(1)_D$

$$Q = T_3 - \frac{1}{6}A + \frac{1}{2}B - \frac{1}{6}C + \frac{1}{3}D$$

yields all necessary third family states in $SU(2)_l$ singlets except for $(b_R)^c$
$\to$ forms bound state with some $(1,1,2)$ scalar
$\to$ interesting consequences for b-physics

Dent, Kephart, Päs, work in progress

Summary and Conclusions

- Models with the quartification gauge group $SU(3)^4$ are attractive, since they allow for a quark-lepton symmetry
- Interesting variants of such models can be obtained from Z_8 orbifolded AdS/CFT
- Gauge couplings unify
- EW precision, proton decay, neutrino masses, dark matter ok
- Interesting b physics anticipated in “flipped” variants
- New scalars at the LHC