A Seiberg dual for MSSM: Partially Composite W and Z

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A Toy Model

Goal: A Seiberg dual of the elctroweak sector with fully composite W, Z, and fermions.

- $SU(2)_L$ must be a gauge group of “magnetic” description
- Restrict attention to simplest electric models: $SU(N)$ with F flavors.
- Need $F - N = 2$.
- All $SU(2)_L$ doublets must arise from dual quarks.
- SM contains 14 doublets. Therefore $F \geq 7$.
- Yukawa couplings require $F = 8$ (and $N = 6$).

A Toy Model

Electric theory

	$SU(6)$	$SU(8)_1$	$SU(8)_2$	$U(1)_V$	$U(1)_R$
Q	$\square$	$\overline{\square}$	$\mathbf{1}$	$\frac{1}{24}$	$\frac{1}{4}$
$\bar{Q}$	$\overline{\square}$	$\mathbf{1}$	$\overline{\square}$	$-\frac{1}{24}$	$\frac{1}{4}$

Magnetic theory

	$SU(2)_L$	$SU(8)_1$	$SU(8)_2$	$U(1)_V$	$U(1)_R$
q	$\square$	$\square$	$\mathbf{1}$	$\frac{1}{8}$	$\frac{1}{4}$
$\bar{q}$	$\overline{\square}$	$\mathbf{1}$	$\square$	$-\frac{1}{8}$	$\frac{1}{4}$
M	$\mathbf{1}$	$\overline{\square}$	$\overline{\square}$	0	$\frac{3}{2}$

$$W = y\bar{q}Mq$$

A Toy Model

Embedding the SM gauge group:

$$SU(8)_1 \supset SU(3) \times SU(3) \times SU(2)_{R,1}$$
$$SU(8)_2 \supset SU(3)_G \times SU(3) \times SU(2)_{R,2}$$

Mesons and dual quarks give rise to all SM fields and some exotics:

$$q = \begin{pmatrix} t_n \\ b_n \end{pmatrix}_L, \begin{pmatrix} c_n \\ s_n \end{pmatrix}_L, H_u, H'_d$$
$$\bar{q} = \begin{pmatrix} \nu_e \\ e \end{pmatrix}_L, \begin{pmatrix} \nu_\mu \\ \mu \end{pmatrix}_L, \begin{pmatrix} \nu_\tau \\ \tau \end{pmatrix}_L, \begin{pmatrix} u_n \\ d_n \end{pmatrix}_L, H_d, H'_u$$

$$M = \begin{pmatrix} V_n^{1,j} & V_n^{2,j} & \begin{matrix} \bar{\nu}_e & \bar{e} \\ \bar{\nu}_\mu & \bar{\mu} \\ \bar{\nu}_\tau & \bar{\tau} \end{matrix} \\ C_p^1\, \epsilon_{mnp} + X^1_{m,n} & C_p^2\, \epsilon_{mnp} + X^2_{m,n} & \bar{u}_n \;\; \bar{d}_n \\ \bar{b}_n & \bar{s}_n & S \;\; T^- \\ \bar{t}_n & \bar{c}_n & T^+ \;\; S' \end{pmatrix}$$

A Toy Model

- Add elementary spectators to give large mass to exotics
- A linear combination of $U(1)$'s can be identified with hypercharge
- Both baryon and lepton number are preserved (despite presence of "leptoquarks")
- SUSY breaking terms can generate S and S' vevs giving rise to effective μ-terms
- Magnetic superpotential $\bar{q}Mq$ becomes

$$y\left[L_i H_u \bar{\nu}_i + L_i H_d' \bar{e}_i + Q_1 H_u \bar{u}_1 + Q_1 H_d' \bar{d}_1 + Q_j H_d \bar{d}_j + Q_j H_u' \bar{u}_j\right]$$

- Yukawas diagonal in flavor space
- To reproduce SM Yukawas we need vector-like multiplet for every RH Standard Model field. The mixing with elementary fields will make RH composites heavy and replace them by elementary fields.

Fully or Partially Composite?

- $SU(2)_L$ gauge coupling at the week scale is $g \sim 0.65$
- At the duality scale $|\Lambda|$ the coupling of the composite gauge boson should be $g \sim 4\pi/\sqrt{N}$
- Large logarithmic running is required to reduce coupling to observed level

Fully or partially composite?

- Matching of dynamical scales

$$\Lambda_{\rm el}^{b_{\rm el}} \Lambda_{\rm mag}^{b_{\rm mag}} = (-1)^N \Lambda^{b_{\rm el}+b_{\rm mag}}$$

  relates electric and magnetic couplings

$$\frac{1}{g_{\rm el}^2(|\Lambda|)} = \frac{b_{\rm el}}{8\pi^2} \log\left(\frac{|\Lambda|}{\Lambda_{\rm el}}\right) = -\frac{b_{\rm mag}}{8\pi^2} \log\left(\frac{|\Lambda|}{\Lambda_{\rm mag}}\right) = -\frac{1}{g_{\rm mag}^2(|\Lambda|)}$$

- Magnetic Yukawa contains a factor $\Lambda_{el}/|\Lambda|$.
- Either g_{mag}^2 or y coupling is strong at the matching scale.
- Matching scale is constrained by

$$1 \lesssim y \approx \frac{\Lambda_{el}}{\Lambda} \lesssim 4\pi$$

- Smallest possible magnetic coupling

$$g_{\rm mag}^2(\Lambda_{\rm el}) = \frac{8\pi^2}{F \log\left(\Lambda_{el}/\Lambda\right)} = \frac{8\pi^2}{F \log\left(4\pi\right)} \approx \frac{31}{F}$$

- Scale of electric description above the Planck scale

$$\Lambda_{\rm el} = M_{EW} e^{\frac{8\pi^2}{6-F}\left(\frac{1}{g^2(M_{EW})} - \frac{F}{31}\right)}$$

A Realistic Model

- Higgs and top are composite
- W and Z are partially composite
- All other SM fermions are elementary

Electric desription:

	$SU(4)$	$SU(6)_1$	$SU(6)_2$	$U(1)_V$	$U(1)_R$
Q	$\square$	$\overline{\square}$	$\mathbf{1}$	1	$\frac{1}{3}$
$\bar{Q}$	$\overline{\square}$	$\mathbf{1}$	$\overline{\square}$	-1	$\frac{1}{3}$

Magnetic description:

	$SU(2)_{\text{mag}}$	$SU(6)_1$	$SU(6)_2$	$U(1)_V$	$U(1)_R$
q	$\square$	$\square$	$\mathbf{1}$	2	$\frac{2}{3}$
$\bar{q}$	$\overline{\square}$	$\mathbf{1}$	$\square$	-2	$\frac{2}{3}$
M	$\mathbf{1}$	$\overline{\square}$	$\overline{\square}$	0	$\frac{2}{3}$

A Realistic Model

$$SU(6)_1 \supset SU(3)_c \times SU(2)_{\text{elem}} \times U(1)_Y$$
$$SU(6)_2 \supset SU(3)_X \times SU(2)_{\text{elem}} \times U(1)_Y$$

Dual quarks:

$$q = Q_3, \mathcal{H}, H_d$$
$$\bar{q} = X, \bar{\mathcal{H}}, H_u$$

Meson:

$$M = \begin{pmatrix} V & U & \bar{t} \\ E & G+P & \phi_u \\ R & \phi_d & S \end{pmatrix}$$

Superpotential (including some tree level terms in electric theory)

$$W \supset yP(\mathcal{H}\bar{\mathcal{H}} - \mathcal{F}^2) + yS(H_u H_d - f^2) + yQ_3 H_u \bar{t} + y\mathcal{H}EX$$

VEV $\langle\mathcal{H}\rangle = \mathcal{F}$ ensures $SU(2)_{mag} \times SU(2)_{elem} \to SU(2)_L$

A Realistic Model

- W and Z are partially composite.

$$\frac{1}{g_L^2} = \frac{1}{g_{elem}^2} + \frac{1}{g_{mag}^2}$$

$$m_{W'} = \sqrt{g_{elem}^2 + g_{mag}^2}\mathcal{F}$$

- W' and Z' must be at a TeV
- For $F = 6$ we find $g_{comp}^2 = 5.2$
- W is $g^2/g_{comp}^2 \sim 8\%$ composite
- W' and Z' coupling to elementary quarks and leptons is suppressed by $g^2/g_{comp}^2 \sim 8\%$

Spectra

Csáki, Randall, Terning

H_1	$125 GeV$	$\tilde{b}_1$	$499 GeV$
$\tilde{t}_1$	$188 GeV$	A_2	$509 GeV$
N_1	$216 GeV$	H_3	$530 GeV$
$H^\pm$	$307 GeV$	$\tilde{t}_2$	$580 GeV$
H_2	$326 GeV$	$\tilde{N}_3$	$602 GeV$
A_1	$368 GeV$	N_4	$635 GeV$
C_1	$406 GeV$	N_5	$805 GeV$
N_2	$426 GeV$	C_2	$876 GeV$

H_1	$125 GeV$	$\tilde{b}_1$	$499 GeV$
$\tilde{t}_1$	$210 GeV$	N_2	$651 GeV$
N_1	$429 GeV$	H_3	$667 GeV$
$\tilde{b}_1$	$501 GeV$	N_3	$700 GeV$
A_1	$572 GeV$	A_2	$720 GeV$
$\tilde{t}_2$	$621 GeV$	N_4	$724 GeV$
$H^\pm$	$626 GeV$	N_5	$806 GeV$
H_2	$627 GeV$	C_2	$881 GeV$

N_1	$88 GeV$	C_2	$415 GeV$
H_1	$128 GeV$	N_4	$434 GeV$
$\tilde{t}_1$	$191 GeV$	H_2	$473 GeV$
N_2	$192 GeV$	$\tilde{t}_2$	$517 GeV$
N_3	$291 GeV$	N_5	$613 GeV$
C_1	$327 GeV$	$H^\pm$	$650 GeV$
$\tilde{b}_1$	$350 GeV$	H_3	$657 GeV$
A_1	$412 GeV$	A_2	$702 GeV$

H_1	$126 GeV$	N_2	$348 GeV$
A_1	$190 GeV$	H_3	$353 GeV$
N_1	$217 GeV$	$\tilde{b}_1$	$400 GeV$
$\tilde{t}_1$	$284 GeV$	A_2	$460 GeV$
H_2	$339 GeV$	$\tilde{t}_2$	$546 GeV$
$H^\pm$	$341 GeV$	N_3	$559 GeV$
C_1	$341 GeV$	N_4	$602 GeV$