NEUTRINO MASSES IN THEORIES WITH DYNAMICAL ELECTROWEAK SYMMETRY BREAKING

Robert Shrock + TA
hep-ph/0204141

AND IN THEORIES WITH EXTRA DIMENSIONS

B. Dobrescu, E. Poulou,
H-U Yee + TA
hep-ph/0201131

OUTLINE

1. Dynamical Electroweak Symmetry Breaking

   Technicolor
   Extended Technicolor & Fermion Mass
   Phenomenological Constraints

2. See-Sawing the Neutrinos

3. A Simple Model

4. Computations & Results

TECHNICOLOR

New, strong interaction $SU(N)_{TC}$

$\Lambda_c \simeq 250$ GeV

$\omega_L =$  Composite Goldstone

New, TeV-Scale Physics

Potential Problems

(1) Precision studies "$\Rightarrow$" Few new degrees of freedom at TeV energies.

(2) Top quark mass

QUARK AND CHARGED LEPTON MASSES

(EXTENDED TECHNICOLOR)

MASSLESS

$$\begin{array}{ccccc}
\begin{pmatrix} u \\ d \end{pmatrix}_L & \begin{pmatrix} c \\ s \end{pmatrix}_L & \begin{pmatrix} t \\ b \end{pmatrix}_L & \begin{pmatrix} U \\ D \end{pmatrix}_{L1} & \begin{pmatrix} U \\ D \end{pmatrix}_{L2} \\
u_R & c_R & t_R & U_{R1} & U_{R2} \\
d_R & s_R & b_R & D_{R1} & D_{R2} \\
\begin{pmatrix} \nu_e \\ e \end{pmatrix}_L & \begin{pmatrix} \nu_\mu \\ \mu \end{pmatrix}_L & \begin{pmatrix} \nu_\tau \\ \tau \end{pmatrix}_L & \begin{pmatrix} N \\ E \end{pmatrix}_{L1} & \begin{pmatrix} N \\ E \end{pmatrix}_{L2} \\
e_R & \mu_R & \tau_R & E_{R1} & E_{R2}
\end{array} \quad \cdots$$

$\leftarrow SU(2)_{TC} \rightarrow$

$\longleftarrow SU(5)_{ETC} \longrightarrow$

$\uparrow \Lambda_1 \quad \uparrow \Lambda_2 \quad \uparrow \Lambda_3$

HOW?

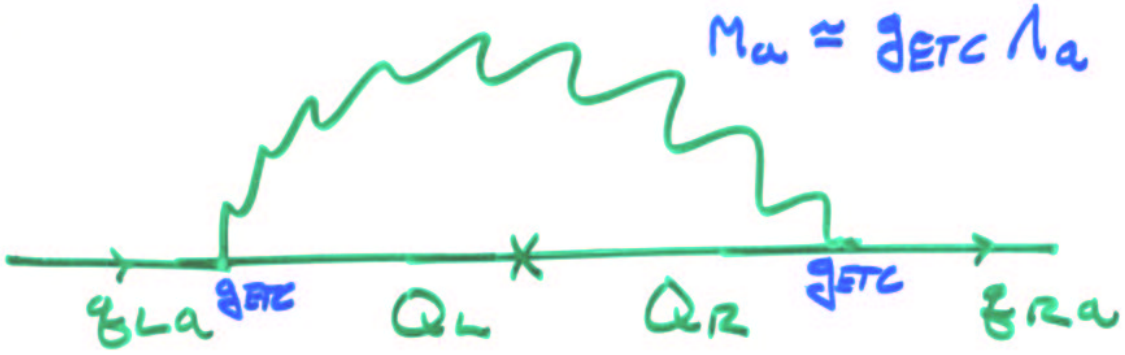
$\simeq 10^3$ TeV $\quad \simeq 50$ TeV $\quad \simeq$ Few TeV

LARGEST SCALE

$$G_{SM} = SU(3)_C \times SU(2)_L \times U(1)_Y$$

$\xrightarrow{?}$ Pati-Salam

QUARK AND CHARGED LEPTON MASSES



$$m_{q_a} \simeq \frac{g_{ETC}^2}{4\pi^2 M_a^2} \left(N_{TC} \Lambda_{TC}^3 \eta_a \right)$$

WALKING ?

NEUTRINO MASSES

N_{ETC} Left-Handed Neutrinos

$$\eta_L = \left(\{\nu_e\}, N_1, N_2, \cdots \right)_L$$

Right-Handed, Electroweak Singlet Neutrinos

$$\chi_R = \left(\chi_1, \chi_2, \cdots \chi_{n_s} \right)_R$$

MASS POSSIBILITIES

1) Left-Handed Majorana
2) Dirac
3) Right-Handed Majorana

LH Majorana

$$\sum_{i,j=1}^{N_{ETC}} n_{iL}^{T}\, C\, (M_L)_{ij}\, n_{jL} + h.c.$$

$C = i\gamma_2\gamma_0$

Only TC-Inv. Entries

Dirac

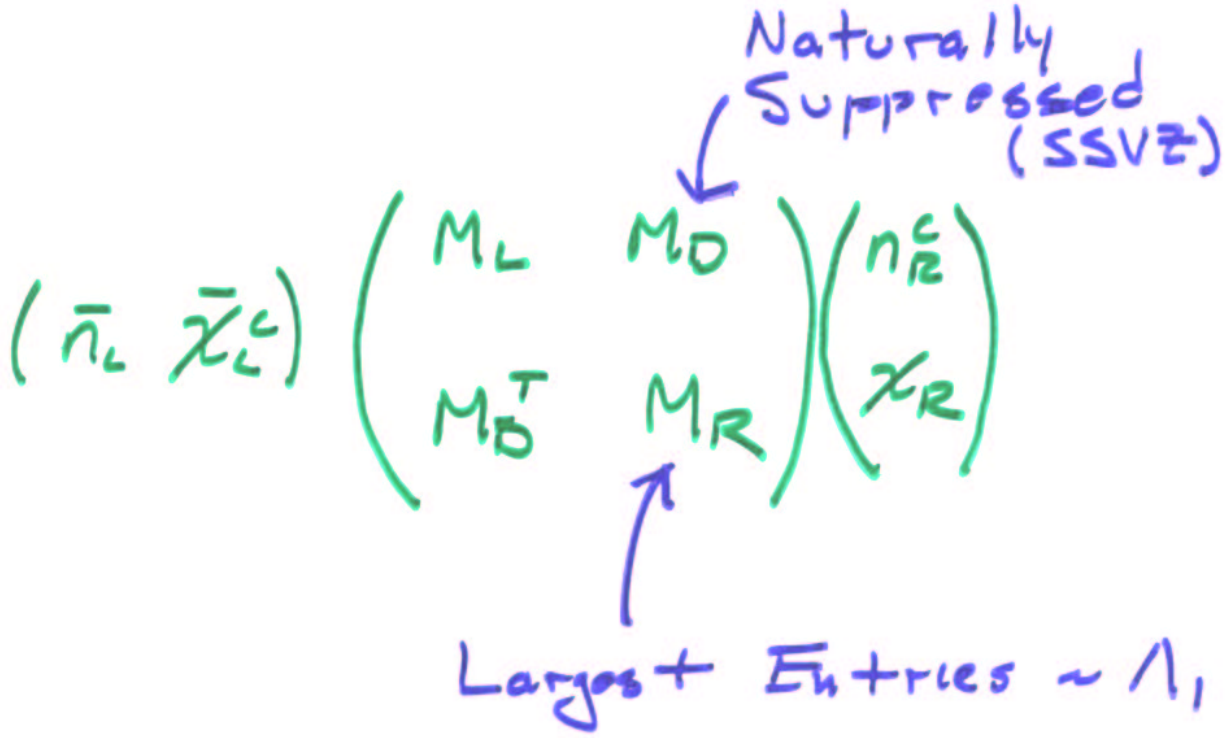
$$\sum_{i=1}^{N_{ETC}} \sum_{j=1}^{n_s} \bar{n}_{iL}\, (M_D)_{ij}\, \chi_{jR} + h.c.$$

RH Majorana

Only TC-Inv Entries

$$\sum_{i,j=1}^{n_s} \chi_{iR}^{T}\, C\, (M_R)_{ij}\, \chi_{jR} + h.c.$$

Full Mass Matrix



Effective Field Theorist

Integrate out all but the lightest degrees of freedom $\Longrightarrow$ Smaller Matrix

THE MODEL (~ AT 1994)

$$G = SU(5)_{ETC} \times SU(2)_{HC} \times G_{SM}$$

Quarks + Charged Leptons (Inc. Technis)	$(5,1)_L$	
Left-Handed Neutrinos	$(5,1)_L$	$L=1$
Right-Handed Neutrinos	$(\bar{10},1)_R$	$L=1$
Hypercolored "Neutrinos"	$(10,2)_R$	

CHIRAL

ANOMALY FREE

NO STERILE NEUTRINOS

SYMMETRY BREAKING

$SU(5)_{ETC}$ breaks in stages down to $SU(2)_{TC}$ as it gets strong and the $SU(2)_{HC}$ gets strong.

$$E = \Lambda_1 \simeq 10^3 \text{ TeV}$$

Strong $SU(5)_{ETC}$: $(\bar{10},1) \times (\bar{10},1) \to (5,1)$

$$SU(5)_{ETC} \longrightarrow SU(4)_{ETC}$$

$$(\bar{10},1)_R \overset{SU(4)}{=} (\bar{4},1)_R + (\bar{6},2)_R$$
$$\alpha_{i,R} \qquad \Sigma_{ij,R}$$

$$\boxed{\langle \varepsilon_{ijkl}\, \Sigma_R^{ij\,T} C\, \Sigma_R^{kl} \rangle \sim \Lambda_1^3 \qquad |\Delta L| = 2}$$

$E = \Lambda_2 \simeq 50\,TeV$

Strong $SU(4)_{ETC}$ + Strong $SU(2)_{HC}$

Detailed Pattern: Relative Strengths

(A) $(4,2)_R \times (6,2)_R \longrightarrow (\bar{4},1)$

$SU(4)_{ETC} \longrightarrow SU(3)_{ETC}$

$(4,2) \overset{SU(3)}{=} (1,2) + (3,2)$

$(6,2) \overset{SU(3)}{=} (3,2) + (\bar{3},2)$

$E = \Lambda_1 \simeq$ Few TeV

$(3,2)_R \times (3,2)_R \longrightarrow (\bar{3},1)$

$SU(3)_{ETC} \longrightarrow SU(2)_{TC}$

QUARKS + CHARGED LEPTON SECTOR

Plausible Mass Scales

CKM Structure

More ingredients

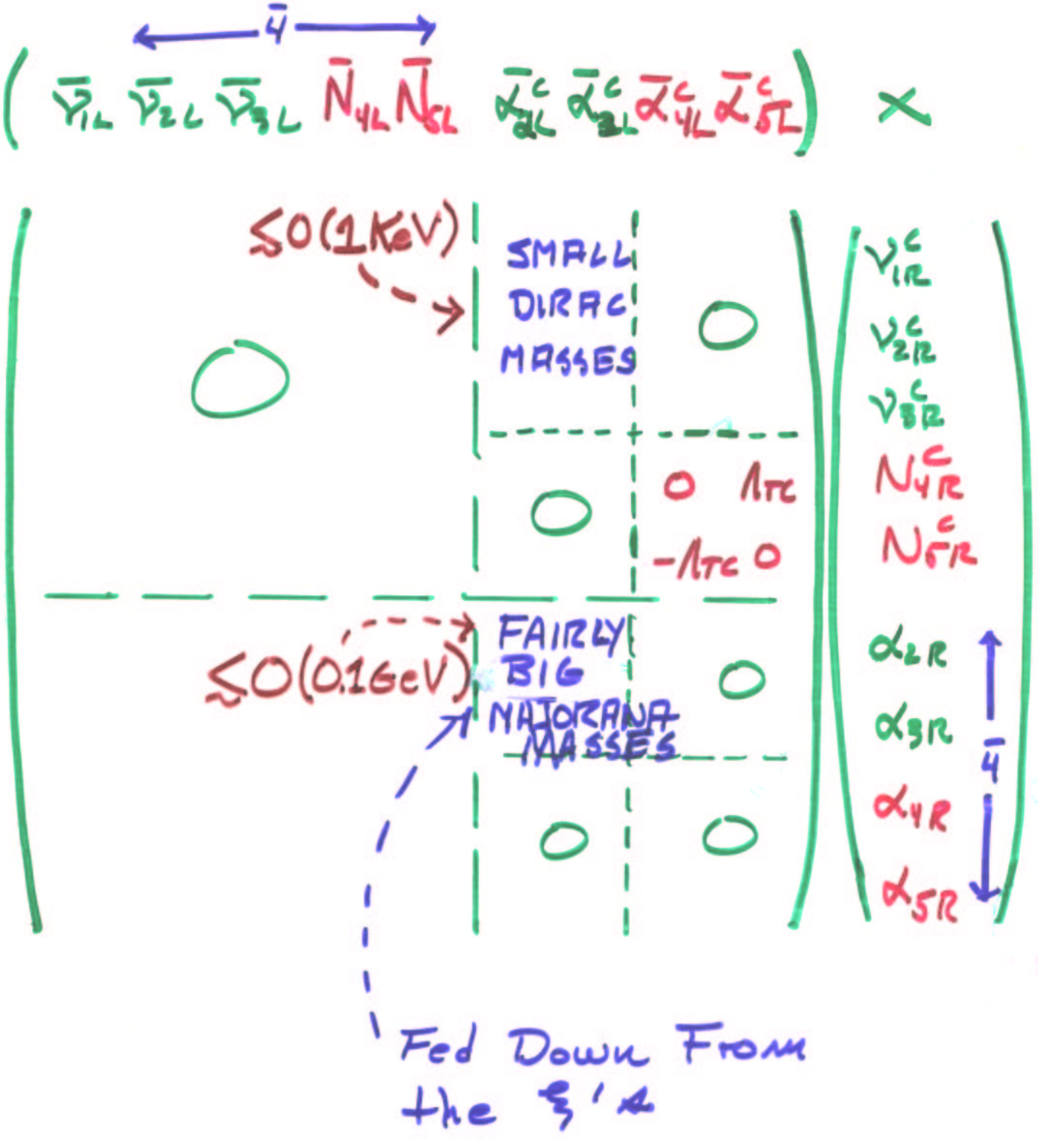
Pseudo-Nambu-Goldstone Bosons

Pati-Salam Unification

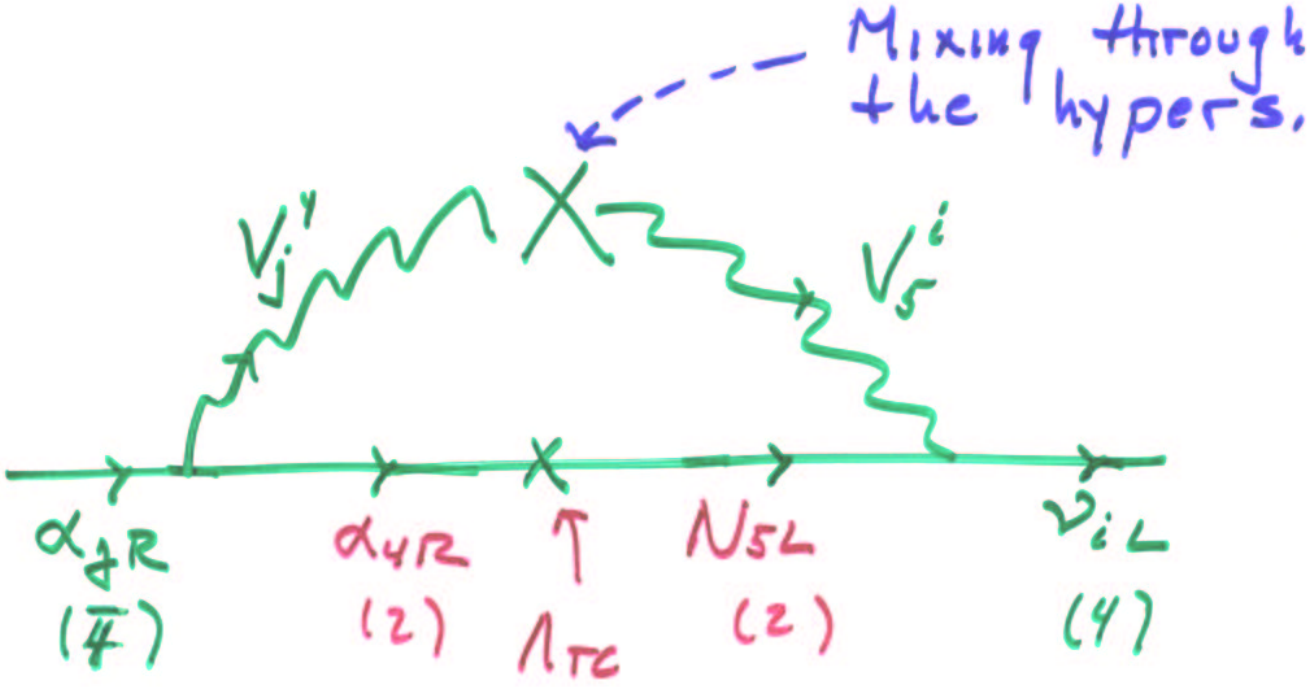
NEUTRINO SECTOR

Try to explain it within it.

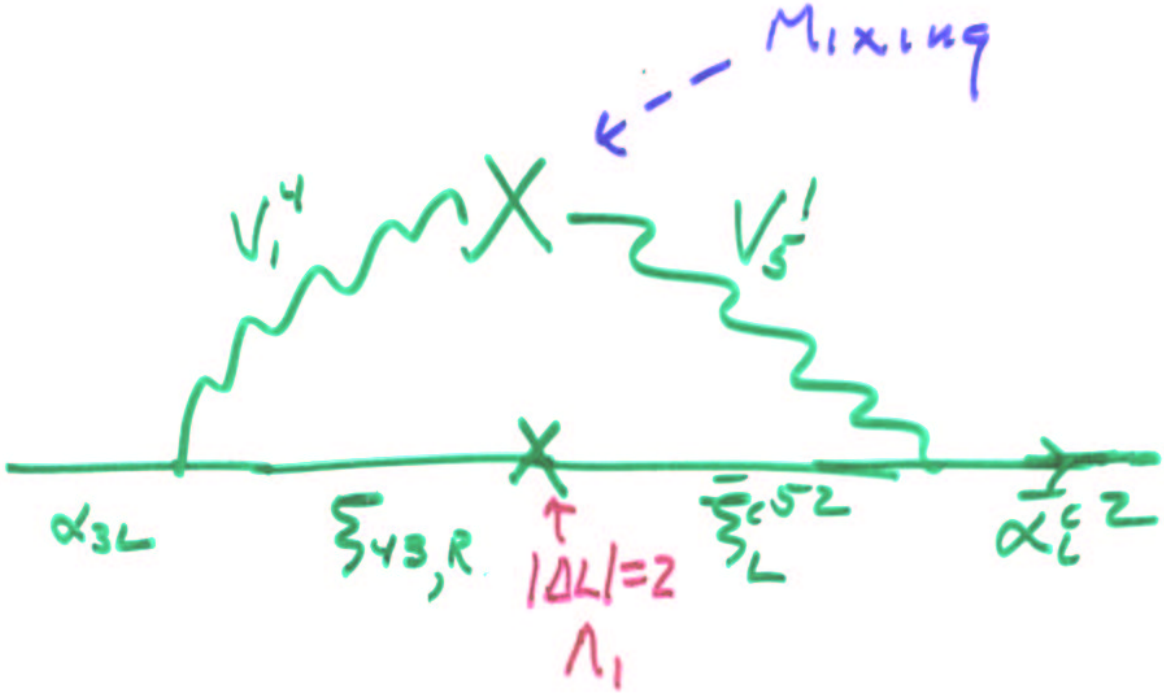
WHAT'S LEFT NEUTRINOWISE?



Small Dirac Masses



Fairly Big Majorana Masses



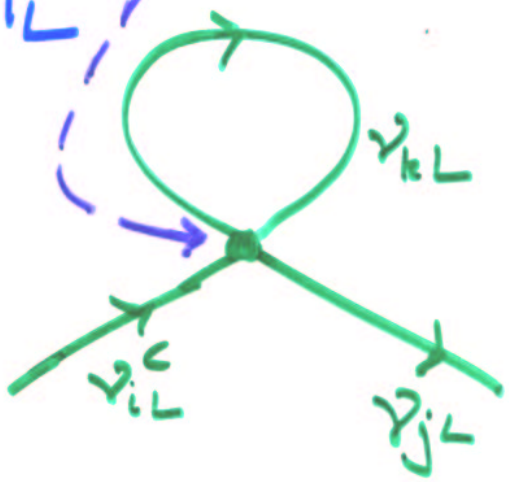
FINAL STEPS

1. Integrate out α_2 and α_3

"Block Seesaw" $\Longrightarrow$ $M_L \sim M_D^T M_R^{-1} M_D$

(One Zero-Eigenvalue)

2. Also get higher-dimension operators, which will induce small corrections to M_L



3. Diagonalize the 3×3 M_L:

- $m_{\nu,\,max} \simeq \dfrac{(1\ \mathrm{KeV})^2}{0.1\ \mathrm{GeV}}$

  $\simeq 0.05\ \mathrm{eV}$

- $\nu_\mu - \nu_\tau$ mixing naturally large

- $m(\nu_1)$ much lighter

SUMMARY

(1) Dynamical Generation of $|\Delta L| = 2$

(2) Natural Seesaw

Suppressed Dirac Masses

No scale above the ETC - Range $\longrightarrow 10^3$ TeV

(3) Do we have the correct such model?

Maybe not.

(4) Details (ν mass spectrum, mixing angles)

In progress