Why 33... 1?

3331 strikes again

Mario Reig López

Universitat de València

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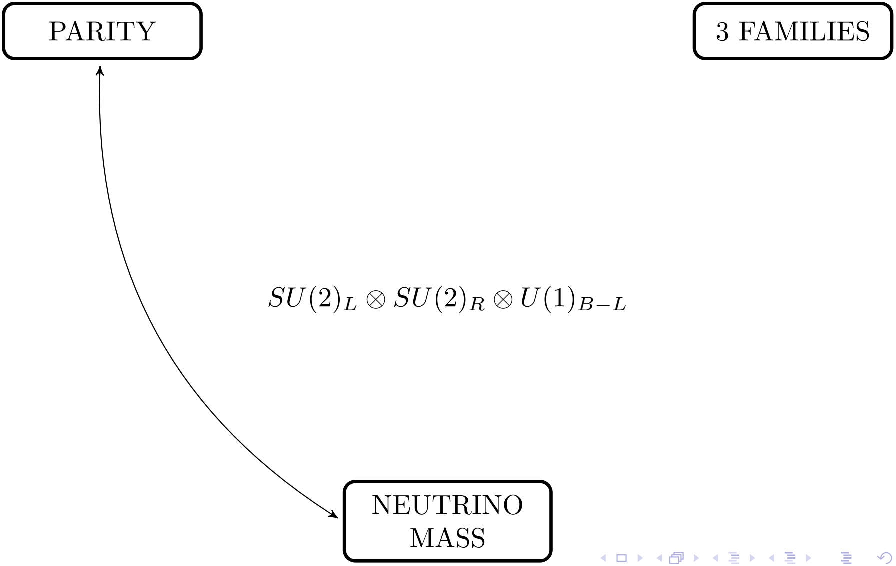
Motivation

- Why not?

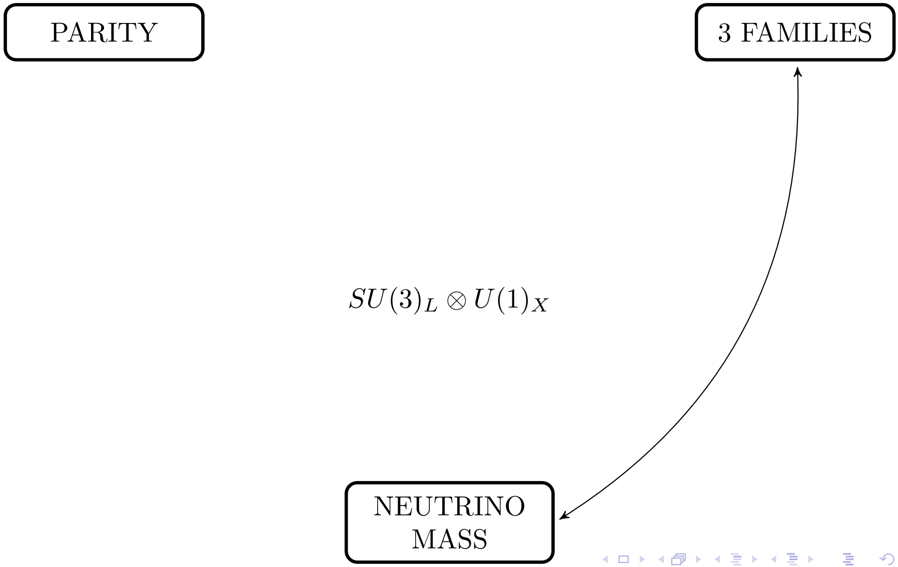
+ We are physicists, please try again...

- Mmmm let me think...

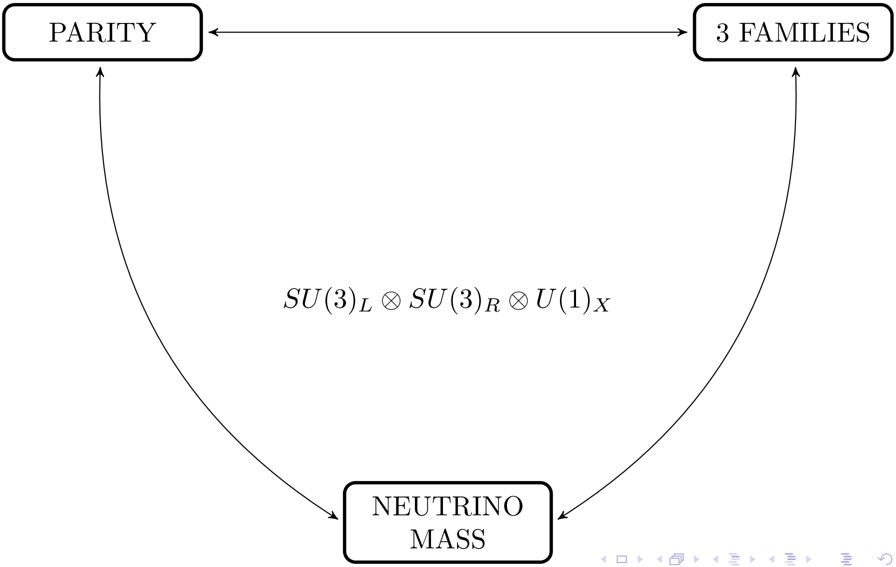
Motivation


PARITY
3 FAMILIES
$SU(2)_L \otimes SU(2)_R \otimes U(1)_{B-L}$
NEUTRINO MASS

Motivation



Motivation


PARITY
3 FAMILIES
$SU(3)_L \otimes SU(3)_R \otimes U(1)_X$
NEUTRINO
MASS

Motivation

- Quantum consistency + QCD asymptotic freedom $\rightarrow$ 3 families.

- Hypercharge anomalies: $[Grav]^2 \otimes U(1)_X$ and $[U(1)_X]^3$ cancelled trivially thanks to LR symmetry.

- Spontaneous parity breaking at high E $\rightarrow$ small neutrino mass.

Particle content: minimal 3331

	ψ^{ℓ}_{aL}	ψ^{ℓ}_{aR}	Q^{α}_{L}	Q^{α}_{R}	Q^{3}_{L}	Q^{3}_{R}	ϕ	Δ_L	Δ_R
$\mathrm{SU(3)_c}$	$\mathbf{1}$	$\mathbf{1}$	$\mathbf{3}$	$\mathbf{3}$	$\mathbf{3}$	$\mathbf{3}$	$\mathbf{1}$	$\mathbf{1}$	$\mathbf{1}$
$\mathrm{SU(3)_L}$	$\mathbf{3}$	$\mathbf{1}$	$\mathbf{3}^*$	$\mathbf{1}$	$\mathbf{3}$	$\mathbf{1}$	$\mathbf{3}$	$\mathbf{6}$	$\mathbf{1}$
$\mathrm{SU(3)_R}$	$\mathbf{1}$	$\mathbf{3}$	$\mathbf{1}$	$\mathbf{3}^*$	$\mathbf{1}$	$\mathbf{3}$	$\mathbf{3}^*$	$\mathbf{1}$	$\mathbf{6}$
$\mathrm{U(1)_X}$	$\frac{q-1}{3}$	$\frac{q-1}{3}$	$-\frac{q}{3}$	$-\frac{q}{3}$	$\frac{q+1}{3}$	$\frac{q+1}{3}$	0	$\frac{2(q-1)}{3}$	$\frac{2(q-1)}{3}$

High-scale seesaw

- $\Phi \sim (3_L, 3^*_R) \rightarrow$ Dirac masses.

- $\Delta_L \sim (6_L, 1_R)$ + $\Delta_R \sim (1_L, 6_R) \rightarrow$ type I and type II seesaw:

$$M_\nu = \begin{pmatrix} M_L & m_D \\ m_D^T & M_R \end{pmatrix}, \quad (1)$$

Particle content: low-scale 3331

	ψ^{ℓ}_{aL}	ψ^{ℓ}_{aR}	Q^{α}_{L}	Q^{α}_{R}	Q^{3}_{L}	Q^{3}_{R}	S_L	ϕ	χ_L	χ_R
$\mathrm{SU(3)_c}$	$\mathbf{1}$	$\mathbf{1}$	$\mathbf{3}$	$\mathbf{3}$	$\mathbf{3}$	$\mathbf{3}$	$\mathbf{1}$	$\mathbf{1}$	$\mathbf{1}$	$\mathbf{1}$
$\mathrm{SU(3)_L}$	$\mathbf{3}$	$\mathbf{1}$	$\mathbf{3}^*$	$\mathbf{1}$	$\mathbf{3}$	$\mathbf{1}$	$\mathbf{1}$	$\mathbf{3}$	$\mathbf{3}$	$\mathbf{1}$
$\mathrm{SU(3)_R}$	$\mathbf{1}$	$\mathbf{3}$	$\mathbf{1}$	$\mathbf{3}^*$	$\mathbf{1}$	$\mathbf{3}$	$\mathbf{1}$	$\mathbf{3}^*$	$\mathbf{1}$	$\mathbf{3}$
$\mathrm{U(1)_X}$	$\frac{q-1}{3}$	$\frac{q-1}{3}$	$-\frac{q}{3}$	$-\frac{q}{3}$	$\frac{q+1}{3}$	$\frac{q+1}{3}$	0	0	$\frac{q-1}{3}$	$\frac{q-1}{3}$

Low-scale seesaw

- $\Phi \sim (3_L, 3^*_R) \rightarrow$ Dirac masses.

- $S_L + \chi_L \sim (3_L, 1_R) + \chi_R \sim (1_L, 3_R) \rightarrow$ inverse ($v_L \rightarrow 0$) and linear seesaw ($\mu \rightarrow 0$):

$$M_\nu = \begin{pmatrix} 0 & y k_1 & y_L v_L \\ y^T k_1 & 0 & y_R v_R \\ y_L^T v_L & y_R^T v_R & \mu \end{pmatrix} . \qquad (2)$$

Low-scale seesaw

The most general scalar potential can be written as

$$V = V_{LR} + V_\Phi + V_{mix} \,,$$

$$V_{LR} = \mu_{LR}^2(\chi_L^\dagger \chi_L + \chi_R^\dagger \chi_R) + \lambda_1[(\chi_L^\dagger \chi_L)^2 + (\chi_R^\dagger \chi_R)^2] + \lambda_2 \chi_L^\dagger \chi_L \chi_R^\dagger \chi_R \,,$$

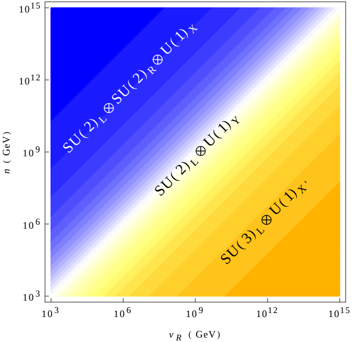
$$V_\Phi = \mu_\Phi^2 \mathrm{Tr}(\Phi\Phi^\dagger) + \lambda_3 \mathrm{Tr}(\Phi\Phi^\dagger)^2 + \lambda_4 \mathrm{Tr}(\Phi\Phi^\dagger\Phi\Phi^\dagger) + f_\Phi(\Phi\Phi\Phi + \mathrm{h.c.}) \,,$$

$$V_{mix} = \lambda_5(\chi_L^\dagger \chi_L + \chi_R^\dagger \chi_R)\mathrm{Tr}(\Phi\Phi^\dagger) + \lambda_6\big(\chi_L^\dagger \Phi\Phi^\dagger \chi_L + \chi_R^\dagger \Phi^\dagger \Phi \chi_R\big) + f_{LR}(\chi_L^\dagger \Phi \chi_R + h.c.) \,, \quad (3)$$

What about SSB?

- Minimization of scalar potential gives us, in both cases:

$$
\begin{aligned}
v_L v_R &\sim k^2 \,, \\
n^2 \lambda &\approx v_R^2 \frac{\lambda'}{2} \,.
\end{aligned}
\tag{4}
$$



To do list:

- CKM mechanism?
- LFV?
- FCNC?
- Dark matter?
- Unification?

THANK YOU!

Based in:

- Three-family left-right symmetry with low-scale seesaw mechanism.
  M. Reig, J.W.F Valle, C.A. Vaquera-Araujo.
  arXiv: 1611.04571 [hep-ph]

- Unifying left-right symmetry and 331 electroweak theories.
  M. Reig, J.W.F Valle, C.A. Vaquera-Araujo.
  arXiv: 1611.02066 [hep-ph]