

MonoHiggsology

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Vernon Barger = Born Engraver

(or perhaps Ravenger, whatever that is!)

So how did he turn out to be such a

phenomenal phenomenologist!

I had 15 publications with Vernon from 1980 to 1995, and one stood out.

I was first author and Vernon was last!

Ma/Phillips/Barger, Phys. Rev. D33, 1300 (1986), based alphabetically on Hawaii/Rutherford/Wisconsin.

It also has the distinction of receiving not a single citation!

With apology to Leon Lederman:

There is only one God.

There is only one **God particle**.

There is only one goddamn particle.

There is only one **Higgs boson**.

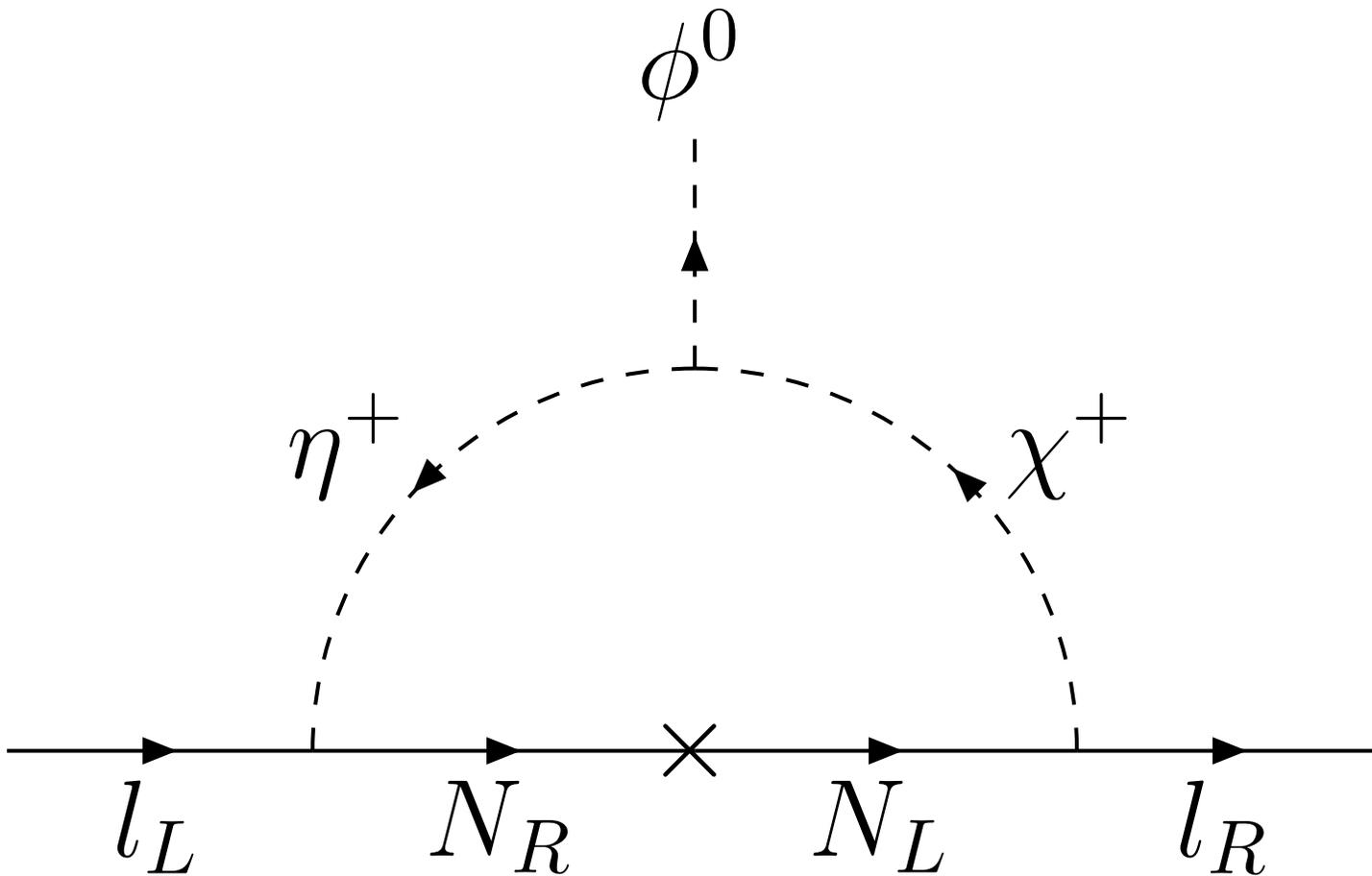
E. Ma, Phys. Rev. Lett. 112, 091801 (2014).

With apology to J. R. R. Tolkien:

Three families of quarks and leptons,

one Higgs to rule them all,

and in the darkness bind them.



Application to Froggatt-Nielsen: Consider

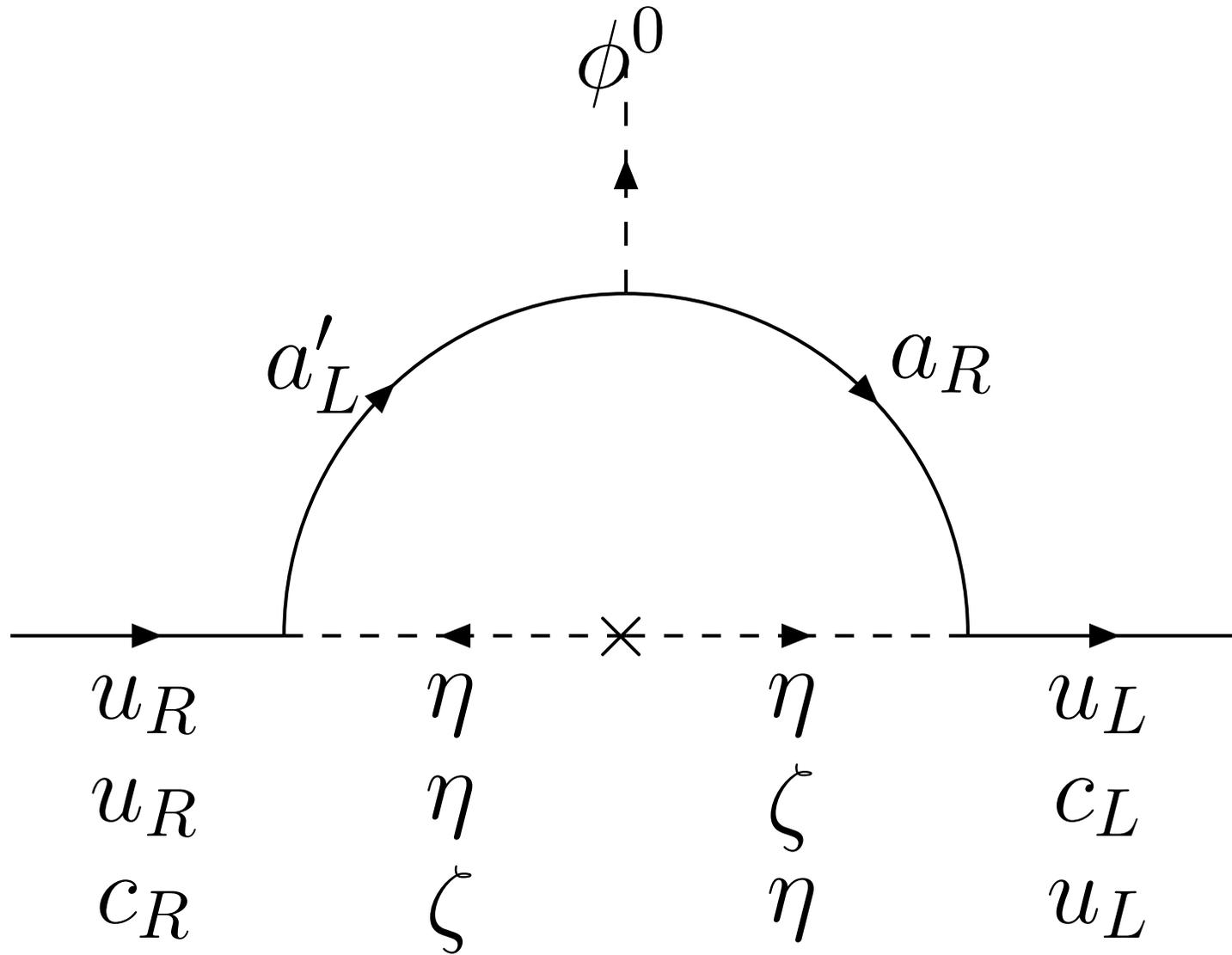
$$(c, s)_L, c_R \sim 0, \quad (u, d)_L \sim 1, \quad u_R \sim -1, \quad \eta \sim 1.$$

Allowed Yukawa couplings are then

$$\bar{c}_L c_R \bar{\phi}^0, \bar{c}_L u_R \bar{\phi}^0 (\eta/\Lambda), \bar{u}_L c_R \bar{\phi}^0 (\eta/\Lambda), \bar{u}_L u_R \bar{\phi}^0 (\eta/\Lambda)^2.$$

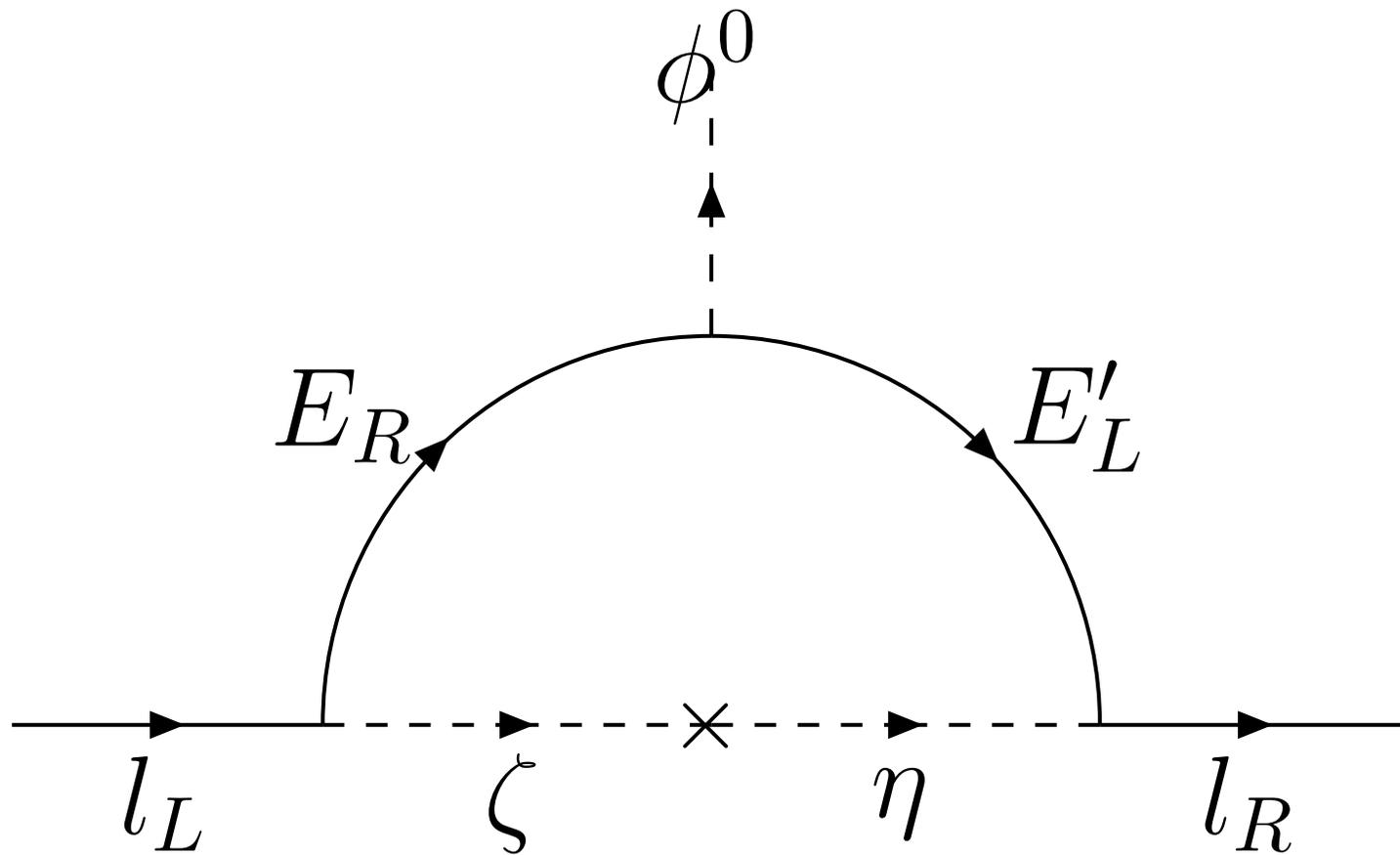
To realize this in a renormalizable theory with the one SM Higgs doublet, postulate a dark sector which includes

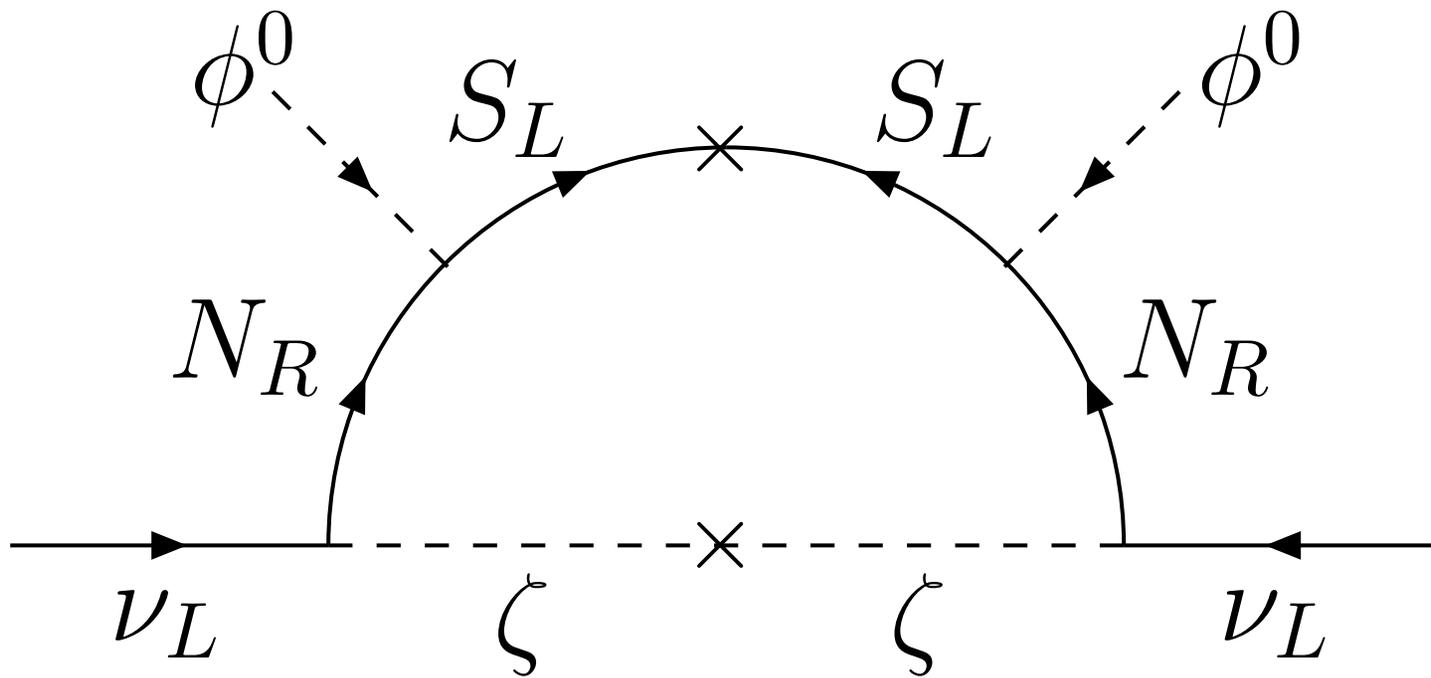
$$(a, v)_{L,R}, a'_{L,R}, v'_{L,R} \sim 0, \quad \eta \sim 1, \quad \zeta \sim 0.$$



In the lepton sector, instead of using neutral fermion singlets $N_{1,2,3}$, consider the original A_4 model and use dark neutral singlet flavons $\zeta_{1,2,3} \sim \underline{\mathbf{3}}, \eta_{1,2,3} \sim \underline{\mathbf{1}}, \underline{\mathbf{1}'}, \underline{\mathbf{1}''}$, connecting to the left-handed lepton doublets and singlets. Heavy dark leptons are added also, i.e. $(N, E)_{L,R}, E'_{L,R}$, as well a light dark fermion singlet S_L . The 3×3 mass matrix spanning (\bar{N}_R, N_L, S_L) is

$$\mathcal{M}_N = \begin{pmatrix} 0 & m_N & m_1 \\ m_N & 0 & m_2 \\ m_1 & m_2 & m_S \end{pmatrix}.$$





The coupling of SM Higgs boson to SS is

$$f_h = \frac{m_N}{v\sqrt{2}} \left(\frac{m_1}{m_N} \right) \left(\frac{m_2}{m_N} \right),$$

and its decay rate is

$$\Gamma_h = \frac{f_h^2 m_h}{8\pi} \sqrt{1 - 4r^2} (1 - 2r^2),$$

where $r = m_S/m_h$. If $f_h \sim 10^{-12} r^{-1/2}$, S may be freeze-in dark matter with the correct abundance. This implies $m_S m_1^2 m_2^2 / m_N^2 \sim 7.6 \times 10^{-18} (\text{GeV})^3$. Let $m_N = 2$ TeV, $m_1 = m_2 = 30$ MeV, then $m_S \sim 38$ keV.

Even though there is only one Higgs boson, its coupling to SM fermions is now not $(m_f/v\sqrt{2})$ as in the SM.
[Fraser/Ma(2014)]

There may also be observable nondiagonal interactions such as $t \rightarrow hc$ as in the recent $Z_3 \times Z_3$ model with Peccei-Quinn symmetry. [Ma(2025)]

To conclude, the SM may be complete as it is.
The rest is in the dark sector.

MonoHiggsology is the future!