The One Higgs and its Connections

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One Higgs Does All?

With the discovery of the 125 GeV particle at CERN in 2012, and the absence of any other evidence of new physics, together with subsequent data confirming that it is indeed consistent with being the one predicted Higgs boson of the Standard Model, it has become essential to ask the question: Is that it?

After all, the SM needs just the one Higgs. It is capable of doing it all, i.e. gives masses to the $W^{\pm}$ and Z bosons, as well as all the quarks and charged leptons.

This means that the SM is potentially complete, and there is nothing else fundamental to discover, excepting of course the origins of neutrino mass and dark matter.

On the other hand, the discovered 125 GeV particle may not be exactly the one Higgs predicted by the SM. It may still hold some surprises as its properties are being scrutinized experimentally. On the phenomenological side, it opens up the new possibility to use it as a probe of new physics. On the theoretical side, we may want to understand how this one Higgs occurs in a natural extension of the SM.

More Higgs or One Higgs Does More?

Numerous studies have been made on the extensions of the scalar sector of the SM: PACS category 12.60.Fr. In particular, two-Higgs doublet models abound: Types I, II, X, Y, etc. In all such cases, the linear combination with $\langle \phi^0 \rangle = 174$ GeV, i.e. that of the SM, is in general not automatically a mass eigenstate.

Another often studied scenario is that of flavor symmetry. To realize such a symmetry in a renormalizable theory, the Higgs Yukawa couplings $f_{ijk}\bar{Q}_{iL}d_{jR}\Phi_k$, etc. require that there be more than one Higgs doublet.

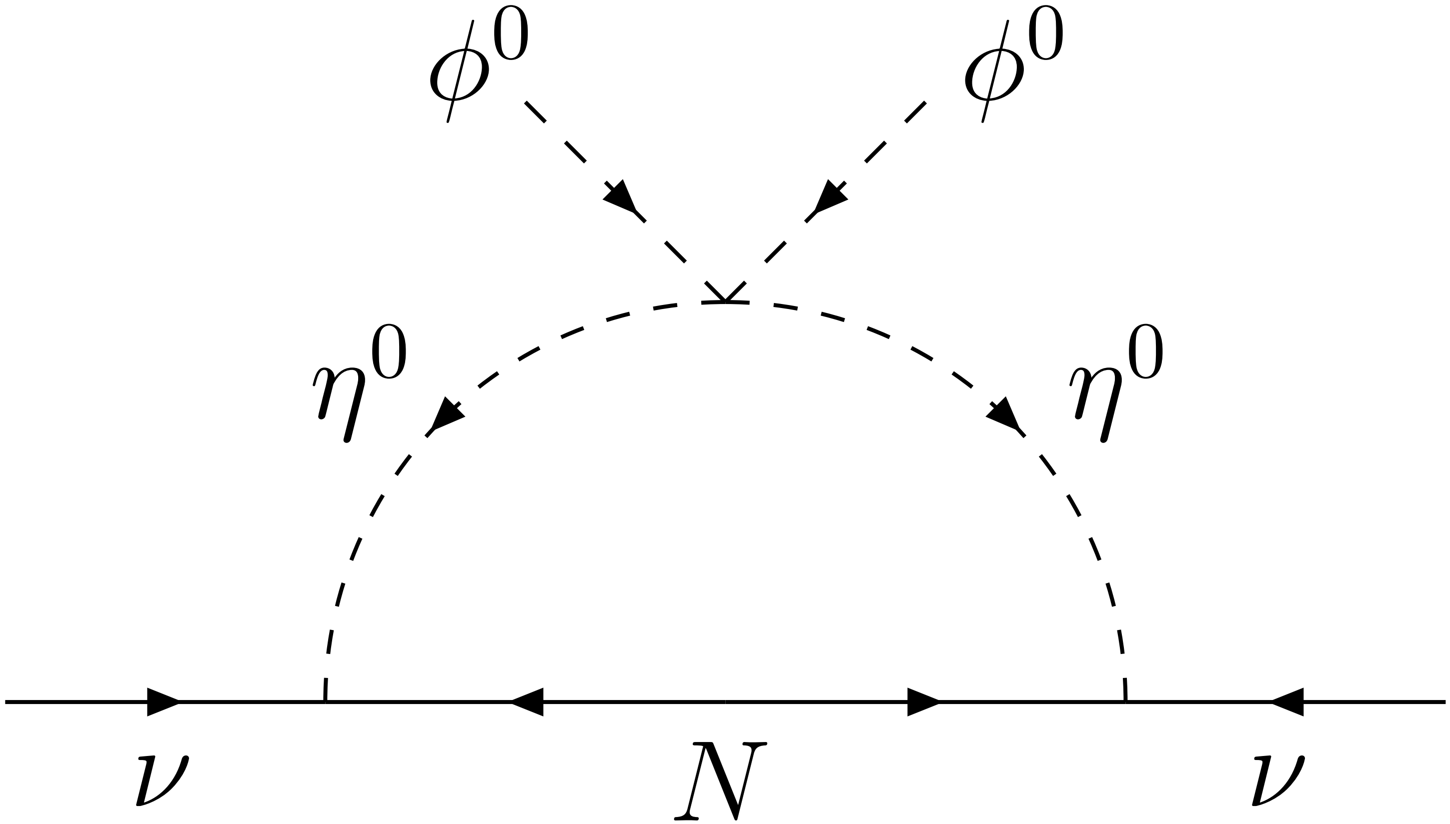
What if there is only One Higgs?,
i.e. a scalar doublet with $\langle\phi^0\rangle = 174$ GeV, which is prevented from mixing with any other scalar by an approximate or exactly conserved symmetry.

The former may be realized in a model of flavor, e.g. $S_3 \times Z_2$, where there are three Higgs doublets, but one is very close to that of the SM because of two approximate residual symmetries. The latter was the inspiration of the scotogenic model [Ma(2006)] of radiative neutrino mass (from the Greek scotos meaning darkness, which identifies this symmetry as Z_2 for dark matter. A second scalar doublet (η^+, η^0) and three neutral fermion singlets $N_{1,2,3}$ are added to the SM which are odd under Z_2, whereas all other (i.e. SM) particles are even. The complex scalar $\eta^0 = (\eta_R + i\eta_I)/\sqrt{2}$ is split so that $m_R \neq m_I$. Let $m_R < m_I$, then η_R is a dark-matter candidate. Alternatively, it may be the lightest N.

Using $f(x) = -\ln x/(1-x)$,

$$(\mathcal{M}_\nu)_{\alpha\beta} = \sum_i \frac{h_{\alpha i} h_{\beta i} M_i}{16\pi^2} [f(M_i^2/m_R^2) - f(M_i^2/m_I^2)].$$

Dark matter is WIMP (freeze-out) or FIMP (freeze-in).


ϕ^0
ϕ^0
η^0
η^0
ν
N
ν

S_3 Model of Quarks

In 2004, Chen/Frigerio/Ma proposed a flavor model of quarks and leptons based on the non-Abelian discrete symmetry S_3: 6 elements with irreducible $\underline{1}, \underline{1}', \underline{2}$ representations. It may be generated by the 2 noncommuting matrices

$$\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}, \quad \begin{pmatrix} \omega & 0 \\ 0 & \omega^2 \end{pmatrix},$$

where $\omega = \exp(2\pi i/3) = -1/2 + i\sqrt{3}/2$. In this basis, if $(\Phi_1, \Phi_2) \sim \underline{2}$, then $(\Phi_2^\dagger, \Phi_1^\dagger) \sim \underline{2}$.

Quark and lepton assignments under S_3:

$L_e = (\nu_e, e), \; Q_1 = (u, d), \; \Phi_3 = (\phi_3^0, \phi_3^-) \sim \underline{1},$

$e^c, \mu^c, u^c, c^c, d^c, s^c \sim \underline{1}, \quad \tau^c, t^c, b^c \sim \underline{1}',$

$(L_\mu, L_\tau), (Q_2, Q_3), (\Phi_1, \Phi_2) \sim \underline{2}.$

Yukawa invariants: $\underline{2} \times \underline{1} \times \underline{2}, \quad \underline{2} \times \underline{1}' \times \underline{2}, \quad \underline{1} \times \underline{1} \times \underline{1},$

thus

$$\mathcal{M}_{u,d} = \begin{pmatrix} g_3^u v_3^* & g_4^u v_3^* & 0 \\ 0 & g_1^u v_1^* & -g_2^u v_1^* \\ 0 & g_1^u v_2^* & g_2^u v_2^* \end{pmatrix}, \begin{pmatrix} g_3^d v_3 & g_4^d v_3 & 0 \\ 0 & g_1^d v_2 & -g_2^d v_2 \\ 0 & g_1^d v_1 & g_2^d v_1 \end{pmatrix}.$$

Note that (v_1, v_2) in $\mathcal{M}_d$ is replaced by (v_2^*, v_1^*) in $\mathcal{M}_u$.

This is important in getting a realistic V_{CKM}.

Let $v_3 = 0$ and $v_1 = v_2$ (i.e. $S_3 \rightarrow Z_2$), then $\mathcal{M}_{u,d}$ are both rotated by $\pi/4$, so their mismatch is zero, i.e. perfect alignment with $\theta_{23} = 0$. Hence this residual symmetry is a good explanation of why V_{CKM} is almost diagonal. Its breaking occurs when $v_3 \neq 0$ and $v_1 \neq v_2$, which may be assumed to be small naturally.

In the lepton sector, $\mathcal{M}_l$ is just like $\mathcal{M}_d$, but $\mathcal{M}_\nu$ may be chosen to be diagonal if it is Majorana. Hence $\nu_\mu - \nu_\tau$ mixing is predicted to be maximal, i.e. $\theta_{23} = \pi/4$, in agreement with experiment.

The original 2004 model mainly dealt with the lepton sector and predicted very small θ_{13}, in disagreement with present data. However, it neglected $e - \mu$ mixing which is generally present, so the model is still viable.
What about the quark sector? [Ma/Melic(2013)]
Consider first only the 2 heavy quark families with (Φ_1, Φ_2). Let

$$V_{12} = \mu_1^2(\Phi_1^\dagger\Phi_1 + \Phi_2^\dagger\Phi_2) - \mu_2^2(\Phi_1^\dagger\Phi_2 + \Phi_2^\dagger\Phi_1) +$$

$$\frac{1}{2}\lambda_1(\Phi_1^\dagger\Phi_1+\Phi_2^\dagger\Phi_2)^2+\frac{1}{2}\lambda_2(\Phi_1^\dagger\Phi_1-\Phi_2^\dagger\Phi_2)^2+\lambda_3(\Phi_1^\dagger\Phi_2)(\Phi_2^\dagger\Phi_1).$$

This is invariant under S_3 except for the soft μ_2^2 term which breaks S_3 to Z_2 $(\Phi_1 \leftrightarrow \Phi_2)$. The Z_2 symmetry enforces $\langle \phi_1^0 \rangle = \langle \phi_2^0 \rangle = v = 123$ GeV, resulting in the mass eigenstates:

$$h^0 = \phi_{1R} + \phi_{2R}, \quad m^2 = 2(2\lambda_1 + \lambda_3)v^2,$$
$$H^0 = \phi_{1R} - \phi_{2R}, \quad m^2 = 2\mu_2^2 + 2(2\lambda_2 - \lambda_3)v^2,$$
$$A = \phi_{1I} - \phi_{2I}, \quad m^2 = 2\mu_2^2,$$
$$H^\pm = (\phi_1^\pm - \phi_2^\pm)/\sqrt{2}, \quad m^2 = 2\mu_2^2 - 2\lambda_3 v^2.$$

At this level, h^0 is even under Z_2 and is naturally identified with the SM Higgs. The other scalars are odd under Z_2. Note that if $\mu_2^2 = 0$, then A would be massless.

The $c-t$ and $s-b$ mass matrices are both of the form

$$\mathcal{M} = \begin{pmatrix} f_1 v & -f_2 v \\ f_1 v & f_2 v \end{pmatrix} = \frac{1}{\sqrt{2}} \begin{pmatrix} 1 & -1 \\ 1 & 1 \end{pmatrix} \begin{pmatrix} f_1\sqrt{2}v & 0 \\ 0 & f_2\sqrt{2}v \end{pmatrix}.$$

Consequently, the physical s, b quarks couple to h^0 according to $(m_s/2v)\bar{s}s + (m_b/2v)\bar{b}b$ as in the SM. The other scalar couplings are given by

$$\mathcal{L}_Y = \frac{m_s}{\sqrt{2}v}\left[H^+\bar{t}_L + \left(\frac{H^0 + iA}{\sqrt{2}}\right)\bar{b}_L\right] s_R$$

$$+ \frac{m_b}{\sqrt{2}v}\left[H^+\bar{c}_L + \left(\frac{H^0 + iA}{\sqrt{2}}\right)\bar{s}_L\right] b_R + H.c.,$$

which maintains the Z_2 symmetry with t, b odd and c, s even. This forbids $b \to s\gamma$ but allows $B_s - \bar{B}_s$ mixing. The coefficient of the $(\bar{s}_L b_R)^2$ operator is

$$\frac{m_b^2}{4v^2}\left(\frac{1}{m_H^2} - \frac{1}{m_A^2}\right).$$

The coefficient of the $(\bar{s}_L b_R)(\bar{s}_R b_L)$ operator is

$$\frac{m_s m_b}{4v^2}\left(\frac{1}{m_H^2} + \frac{1}{m_A^2}\right).$$

The hadronic matrix element of the former (latter) gives $-23.87 \times 10^{-6}\ \mathrm{GeV}^3$ and $1.20 \times 10^{-6}\ \mathrm{GeV}^3$.

The experimental value $\Delta m_{B_s} = 1.164 \pm 0.005 \times 10^{-11}$ GeV agrees with the Standard-Model prediction to within 10%, so we obtain

$$\left| -23.87 \left(\frac{1}{m_H^2} - \frac{1}{m_A^2} \right) + 1.20 \left(\frac{1}{m_H^2} + \frac{1}{m_A^2} \right) \right| < 1.16,$$

where $m_{H,A}$ are in units of TeV.

If $m_H = m_A$, then $m_{H,A} > 1.44$ TeV.

If $m_H = 1$ TeV, then $1.03 < m_A < 1.08$ TeV.

If $m_H = 0.7$ TeV, then $0.73 < m_A < 0.75$ TeV.

Add Φ_3 with $\langle \phi_3^0 \rangle = v_3 << v$, then $\mathcal{M}_{d,u}$ are diagonalized on the left by

$$V_d = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c' & -s' \\ 0 & s' & c' \end{pmatrix} \begin{pmatrix} c_d & -s_d & 0 \\ s_d & c_d & 0 \\ 0 & 0 & 1 \end{pmatrix},$$

where $s'/c' = v_2/v_1$, and

$$V_u = \begin{pmatrix} 1 & 0 & 0 \\ 0 & s' & -c' \\ 0 & c' & s' \end{pmatrix} \begin{pmatrix} c_u & -s_u e^{i\delta} & 0 \\ s_u e^{-i\delta} & c_u & 0 \\ 0 & 0 & 1 \end{pmatrix}.$$

Hence $V_{CKM} = V_u^\dagger V_d =$

$$\begin{pmatrix} c_u c_d + c'' s_u s_d e^{i\delta} & -c_u s_d + c'' s_u c_d e^{i\delta} & s'' s_u e^{i\delta} \\ -s_u c_d e^{-i\delta} + c'' c_u s_d & s_u s_d e^{-i\delta} + c'' c_u c_d & s'' c_u \\ -s'' s_d & -s'' c_d & c'' \end{pmatrix},$$

where $s''/c'' = (c'^2 - s'^2)/2s'c'$. Using the 2012 PDG values, we obtain

$$s'' = 0.04135, \;\; s_u = 0.08489, \;\; s_d = 0.20983,$$

with $\cos\delta = -5.47 \times 10^{-3}$, and
$J_{CP} = s_u c_u s_d c_d (s'')^2 c'' \sin\delta = 2.96 \times 10^{-5}$.

This scheme does not predict any precise value of the measured parameters, but it does provide an understanding of why $(s'')^2, (s_u)^2, (s_d)^2$ are small.

To obtain $v_1 \neq v_2$, the Z_2 symmetry must be broken: add $\mu_3^2(\Phi_1^\dagger\Phi_1 - \Phi_2^\dagger\Phi_2)$. This changes h^0. However, in the limit of large $\mu_2^2 > 0$,

$$h^0 - h^0_{SM} \simeq \frac{(\lambda_1 - \lambda_2 + \lambda_3)(v_1^2 - v_2^2)}{2\mu_2^2}\ H^0,$$

Note that $v_1 = v_2$ implies $h^0 = h^0_{SM}$. Without the $(v_1^2 - v_2^2)/4v^2 = 0.0207$ suppression, $\mu_2 > 10$ TeV.

Adding Φ_3 means the addition of 5 quartic terms invariant under S_3, i.e.

$$(\lambda_4/2)(\Phi_3^\dagger\Phi_3)^2 + \lambda_5(\Phi_3^\dagger\Phi_3)(\Phi_1^\dagger\Phi_1 + \Phi_2^\dagger\Phi_2) + \lambda_6\Phi_3^\dagger(\Phi_1\Phi_1^\dagger + \Phi_2\Phi_2^\dagger)\Phi_3$$

$$+ \left[\lambda_7\Phi_3^\dagger\Phi_1\Phi_3^\dagger\Phi_2 + \lambda_8\Phi_3^\dagger(\Phi_1\Phi_2^\dagger\Phi_1 + \Phi_2\Phi_1^\dagger\Phi_2) + H.c.\right]$$

The λ_8 term may be eliminated by imposing an extra Z_2 symmetry under which Φ_3 and $(u,d)_L$ are odd, and all others even. This Z_2 symmetry is then allowed to be broken softly by the term $\mu_4^2\Phi_3^\dagger(\Phi_1+\Phi_2)$.

As a result, for large $m_3^2 > 0$, $v_3 \simeq -\mu_4^2(v_1+v_2)/m_3^2$.

Hence ϕ_{3R} mixes with $(v_1\phi_{1R} + v_2\phi_{2R})/\sqrt{v_1^2 + v_2^2}$ by $v_3/\sqrt{v_1^2 + v_2^2}$. This means that

$$h^0 - h^0_{SM} \simeq \frac{v_3 m_h^2}{2v m_3^2}\ \phi_{3R}.$$

If the λ_8 term is present, then $h^0 - h^0_{SM} \simeq (2v_3/v)\ \phi_{3R}$ which means that h^0 exchange itself would contribute too much to $K^0 - \bar{K}^0$ mixing.

With the extra Z_2 symmetry, this problem is alleviated.

The exchange of h^0 could induce $K^0 - \bar{K}^0$ mixing, but its contribution is negligible compared to the direct exchange of ϕ_3^0 which has the effective interaction

$$\frac{s_d^2 c_d^2 m_d m_s}{v_3^2 m_3^2} (\bar{d}_L s_R)(\bar{d}_R s_L).$$

Allowing this to be 20% of the experimental measurement $\Delta m_K = 3.483 \pm 0.006 \times 10^{-15}$ GeV, $v_3 m_3 > 6 \times 10^4$ GeV^2 is obtained.

For example, if $v_3 = 10$ GeV, then $m_3 > 6$ TeV.

Experimental Signatures? The scalar spectrum of this model has only one light Higgs boson h^0 which coincides with the SM Higgs to a very good approximation. As for the other two scalar doublets, they are much heavier. The linear combination $\Phi_1 - \Phi_2$ is constrained by $B_s - \bar{B}_s$ mixing to be heavier than about 0.7 TeV, whereas Φ_3 is constrained by $K^0 - \bar{K}^0$ mixing to be heavier than about 6 TeV if $v_3 = 10$ GeV. With these masses, all rare processes involving only quarks but not leptons such as $b \to s\gamma$ are negligible. However, the $s - b$ sector is connected to the $\mu - \tau$ sector:

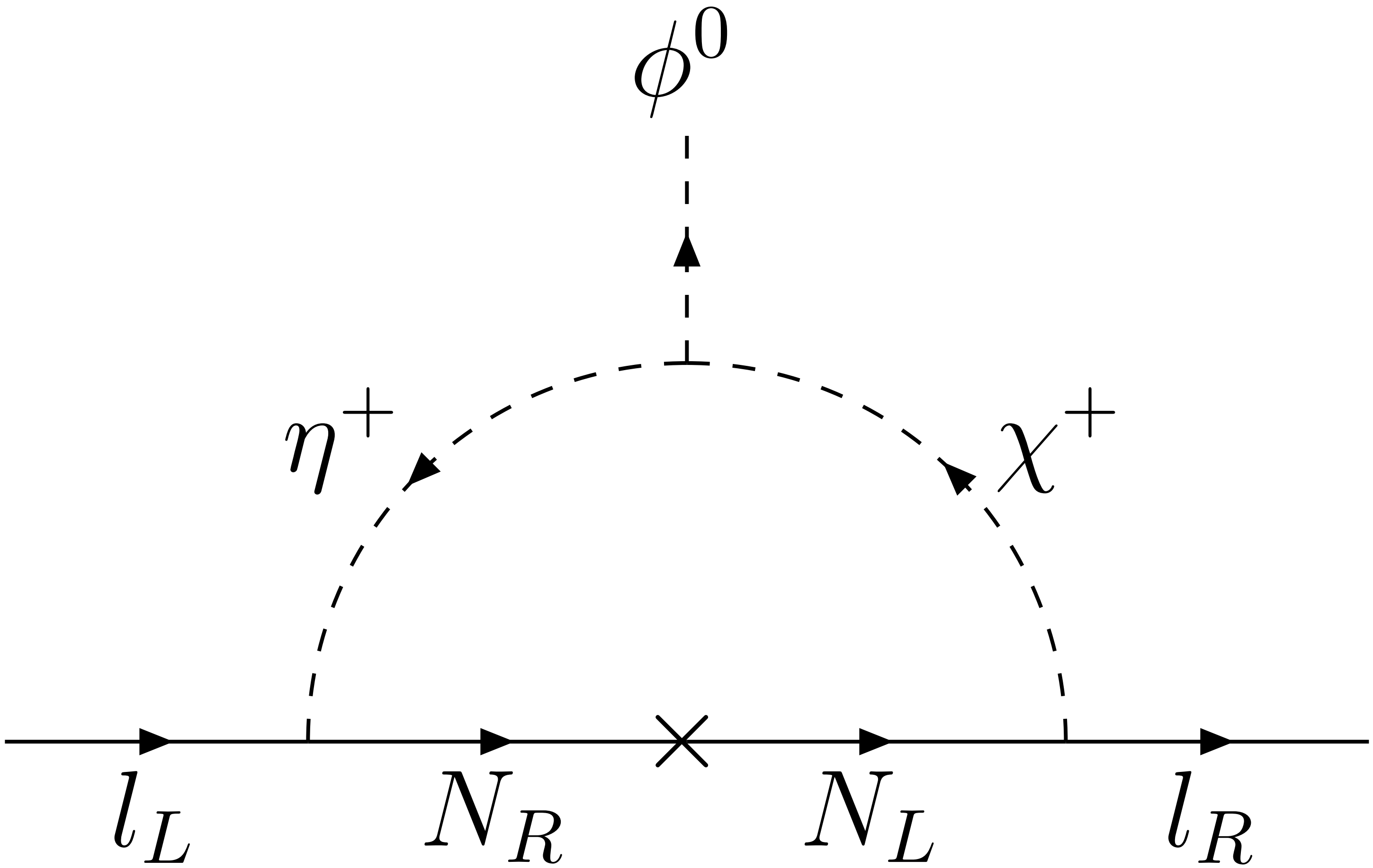
$$\mathcal{L}_Y = \frac{m_\mu}{\sqrt{2}v}\left[H^+\bar{\nu}_{\tau L} + \left(\frac{H^0+iA}{\sqrt{2}}\right)\bar{\tau}_L\right]\mu_R$$
$$+ \frac{m_\tau}{\sqrt{2}v}\left[H^+\bar{\nu}_{\mu L} + \left(\frac{H^0+iA}{\sqrt{2}}\right)\bar{\mu}_L\right]\tau_R + H.c.,$$

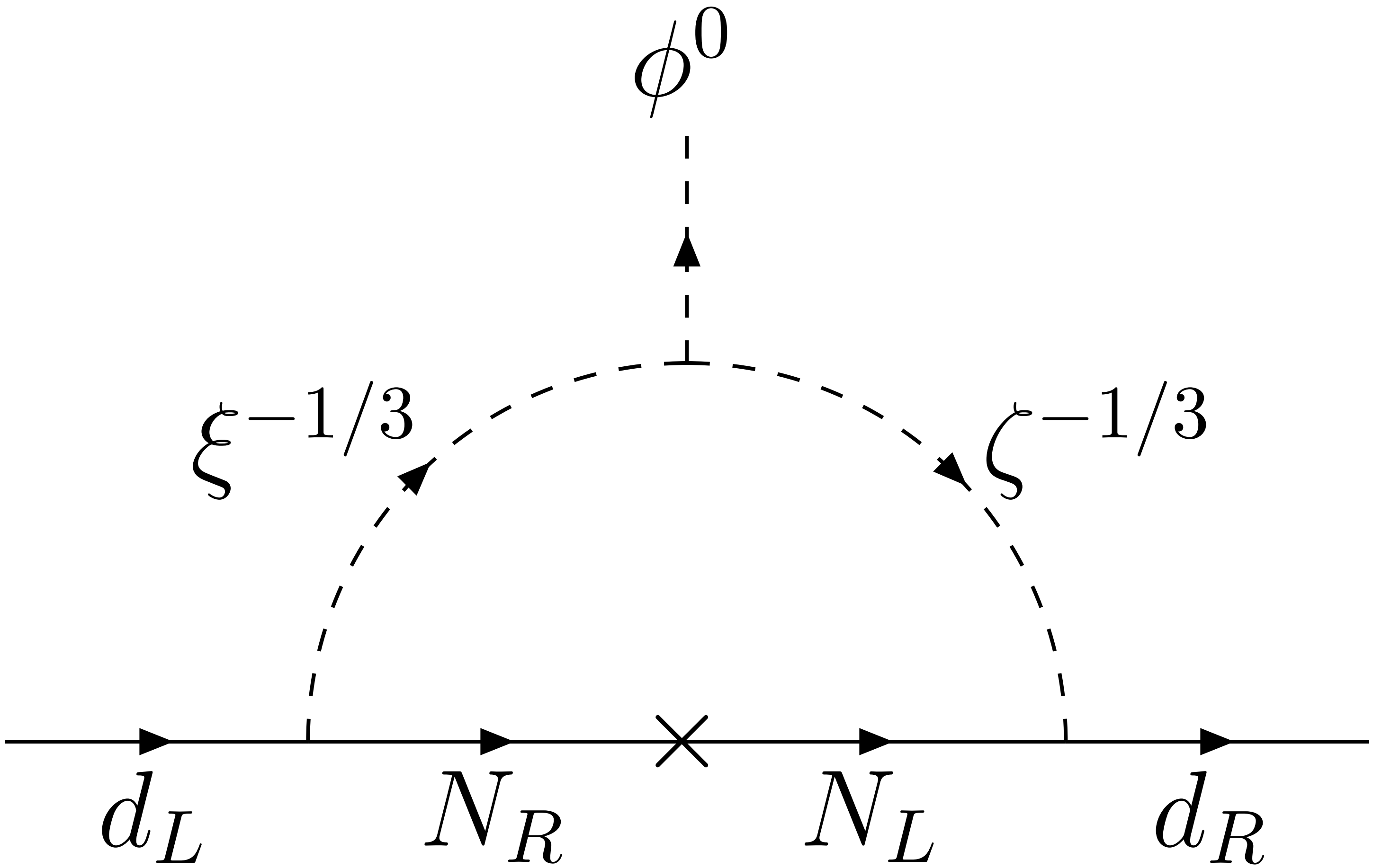
This means that the decay $b \to s\tau^-\mu^+$ ($B_s \to \tau^+\mu^-$) proceeds through the exchange of $H^0 + iA$ with a possible branching fraction of 10^{-7}, but $b \to s\tau^+\mu^-$ ($B_s \to \tau^-\mu^+$) will be suppressed by $(m_\mu/m_\tau)^2$. Given that $B(B_s \to \mu^+\mu^-) \simeq 2.8 \times 10^{-9}$ has been seen at LHCb, our unique prediction is verifiable in the future.

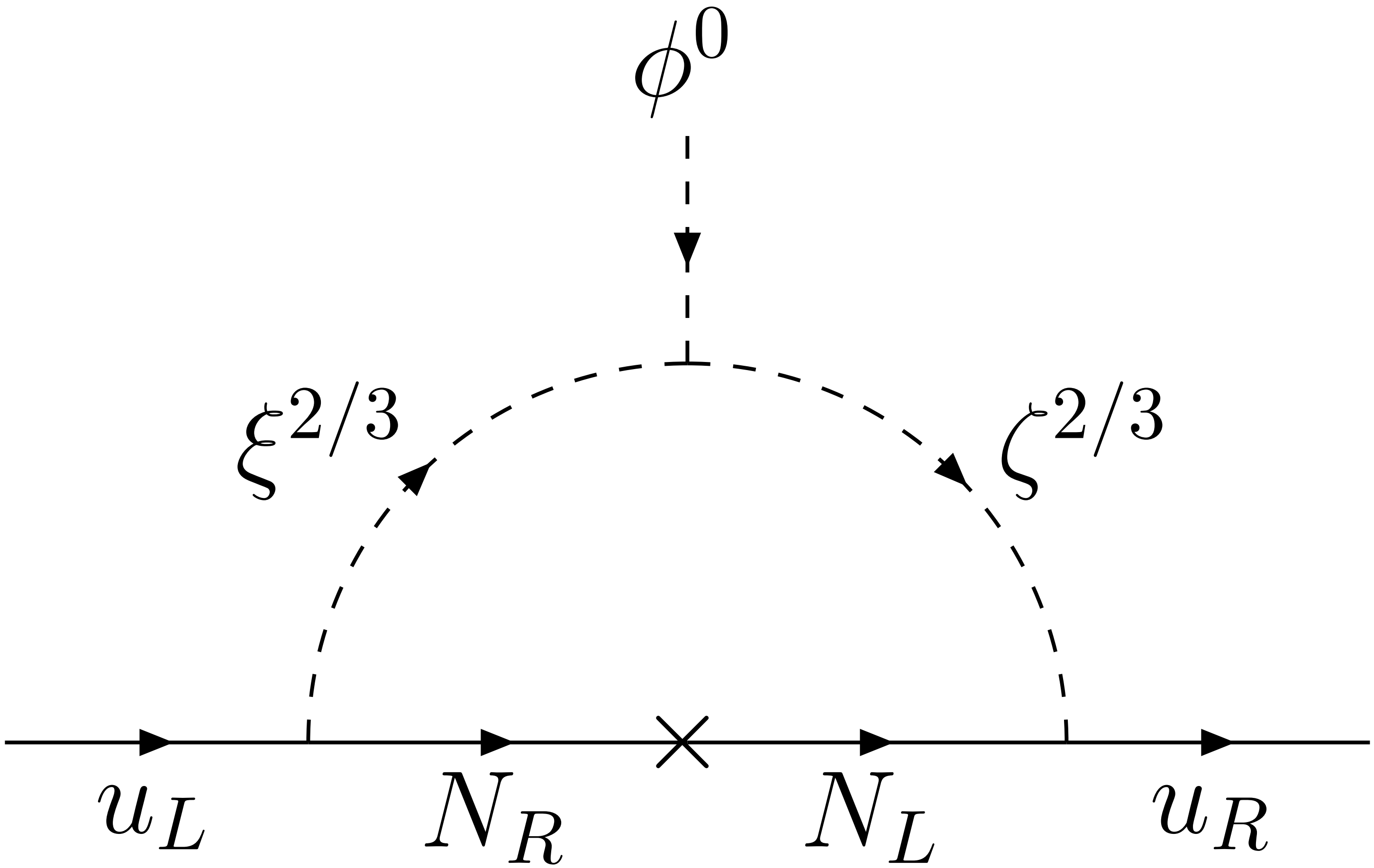
The Dark Matter and Flavor Connection

The Higgs connection to W, Z bosons is fundamental to the SM and should not be changed.

Question: What about its other connections? It has already been conjectured that it connects to neutrinos only through DM. Why not to (some) quarks and leptons? Ma, PRL 112, 091801 (2014): Instead of the Higgs boson coupling directly to fermions, a flavor symmetry is imposed to forbid certain Yukawa couplings. This symmetry is then broken softly and the fermion gets a radiative scotogenic mass in one loop.


ϕ^0
η^+
χ^+
l_L
N_R
N_L
l_R


ϕ^0
$\xi^{-1/3}$
$\zeta^{-1/3}$
d_L
N_R
N_L
d_R



ϕ^0
$\xi^{2/3}$
$\zeta^{2/3}$
u_L
N_R
N_L
u_R

Anomalous Higgs Yukawa Couplings

An immediate consequence of this scenario is a possible observable deviation of the Higgs Yukawa coupling of $h\bar{\psi}\psi$ which is well-known to be given by m_ψ/v in the SM where $v = 246$ GeV. Fraser/Ma(2014):

In the radiative mechanism for leptons, the doublet (η^+, η^0) and singlet χ^+ mix through the term $\mu(\eta^+\phi^0 - \eta^0\phi^+)\chi^-$, where $\langle\phi^0\rangle = v/\sqrt{2}$. Let the mass eigenstates be $\zeta_1 = \eta\cos\theta + \chi\sin\theta$, and $\zeta_2 = \chi\cos\theta - \eta\sin\theta$ with masses m_1 and m_2, then $\mu v/\sqrt{2} = \sin\theta\cos\theta(m_1^2 - m_2^2)$.

Let $x_{1,2} = m_{1,2}^2/m_N^2$, the one-loop mass is

$$m_l = \frac{f_\eta f_\chi \sin\theta \cos\theta m_N}{16\pi^2} \left(\frac{x_1 \ln x_1}{x_1 - 1} - \frac{x_2 \ln x_2}{x_2 - 1} \right).$$

The Yukawa coupling of h to $\bar{l}l$ is now not exactly equal to m_l/v. It has three contributions, through $\eta^+\eta^-$, $\chi^+\chi^-$, and $\eta^\pm\chi^\mp$. Let $r_{\eta,\chi} = \lambda_{\eta,\chi}(m_N/\mu)^2$, then

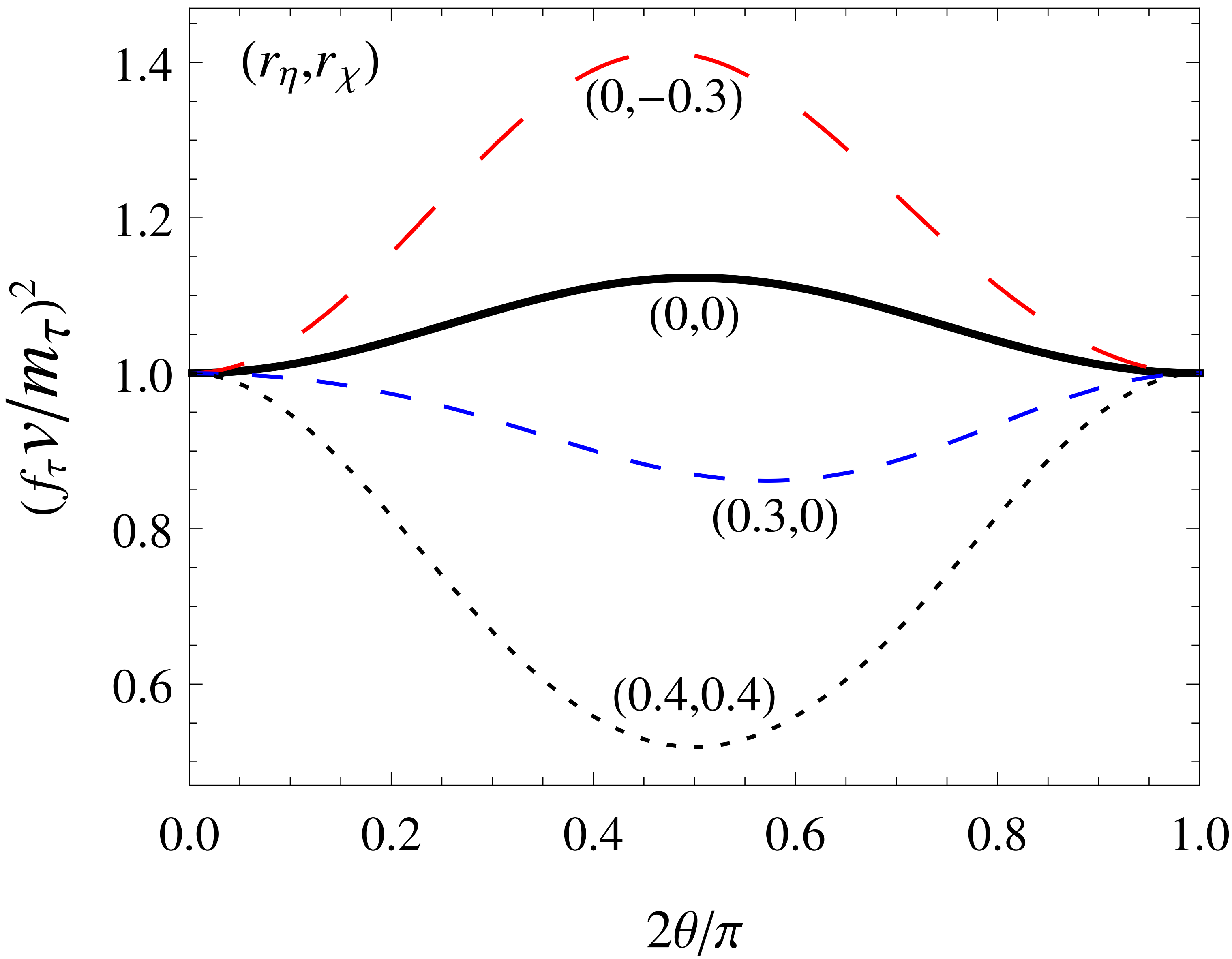
$$\frac{f_l v}{m_l} = 1 + \frac{1}{2}(\sin 2\theta)^2 (a_+ F_+ + a_- F_-),$$

where $a_+ = 1 + (x_1 - x_2)\cos 2\theta (r_\eta - r_\chi)$,

$a_- = (x_1 - x_2)(r_\eta + r_\chi)$, and
$F_+ = [F(x_1,x_1) + F(x_2,x_2)]/2F(x_1,x_2) - 1$,
$F_- = [F(x_1,x_1) - F(x_2,x_2)]/2F(x_1,x_2)$, with

$$F(x_1,x_2) = \frac{1}{x_1 - x_2}\left(\frac{x_1 \ln x_1}{x_1 - 1} - \frac{x_2 \ln x_2}{x_2 - 1}\right).$$

Take for example $x_1 = 3$ and $x_2 = 1$, then $F(3,1) = 0.324$. For m_τ, this yields $f_\eta f_\chi/4\pi = 0.4(m_N/\mu)$ and $\sin 2\theta = \mu v/\sqrt{2} m_N^2$. Hence $m_N > 174$ GeV for $m_N/\mu < 1$. The effect on $(f_\tau v/m_\tau)^2$ is plotted for various values of (r_η, r_χ).



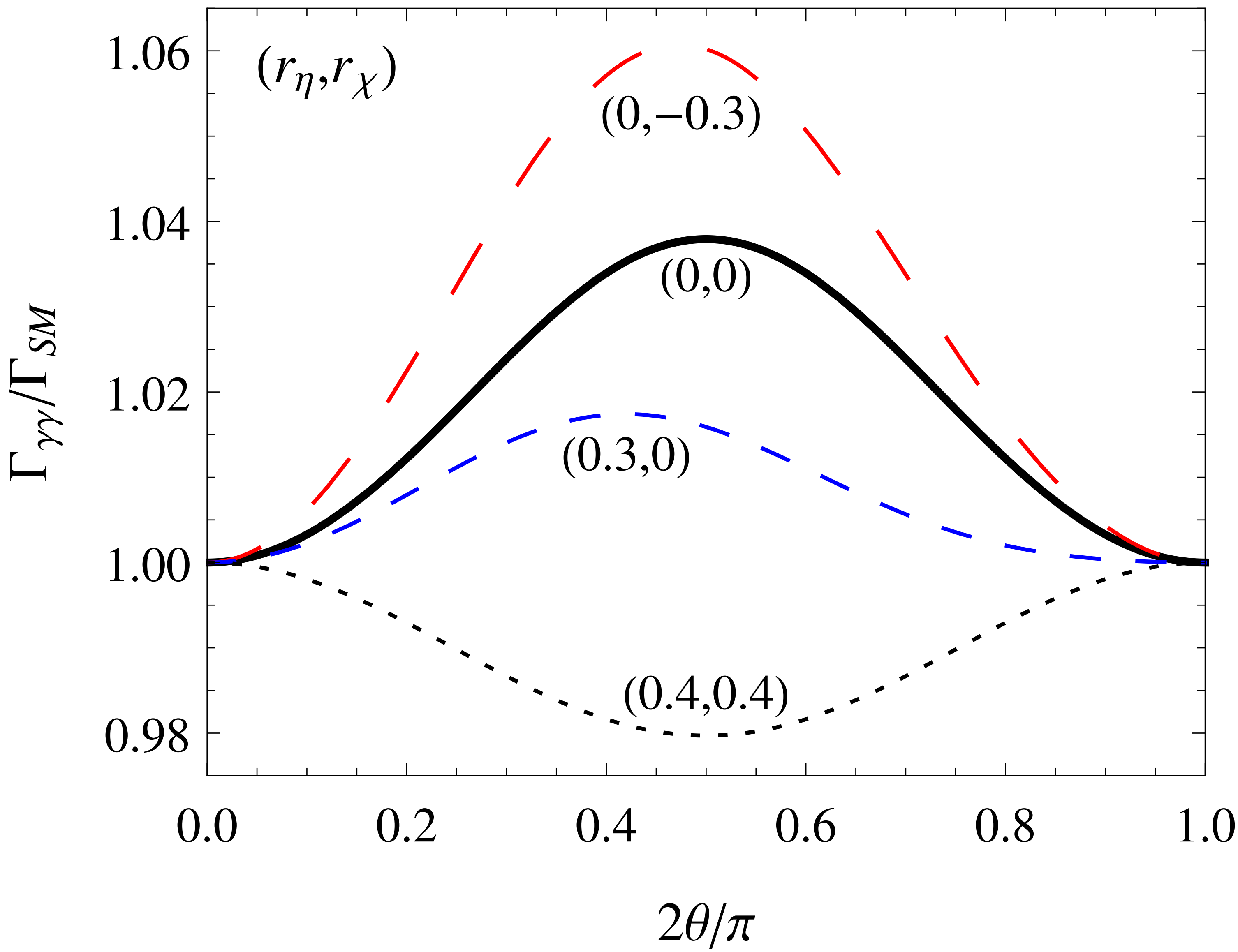
1.4
1.2
1.0
0.8
0.6
(r_η, r_χ)
(0,−0.3)
(0,0)
(0.3,0)
(0.4,0.4)
$(f_\tau v/m_\tau)^2$
0.0
0.2
0.4
0.6
0.8
1.0
$2\theta/\pi$

The charged scalars $\zeta_{1,2}$ also contribute to $h \to \gamma\gamma$. Assuming again $x_1 = 3$ and $x_2 = 1$, and also $\mu/m_N = 1$, $\Gamma_{\gamma\gamma}/\Gamma_{SM}$ is plotted against θ.

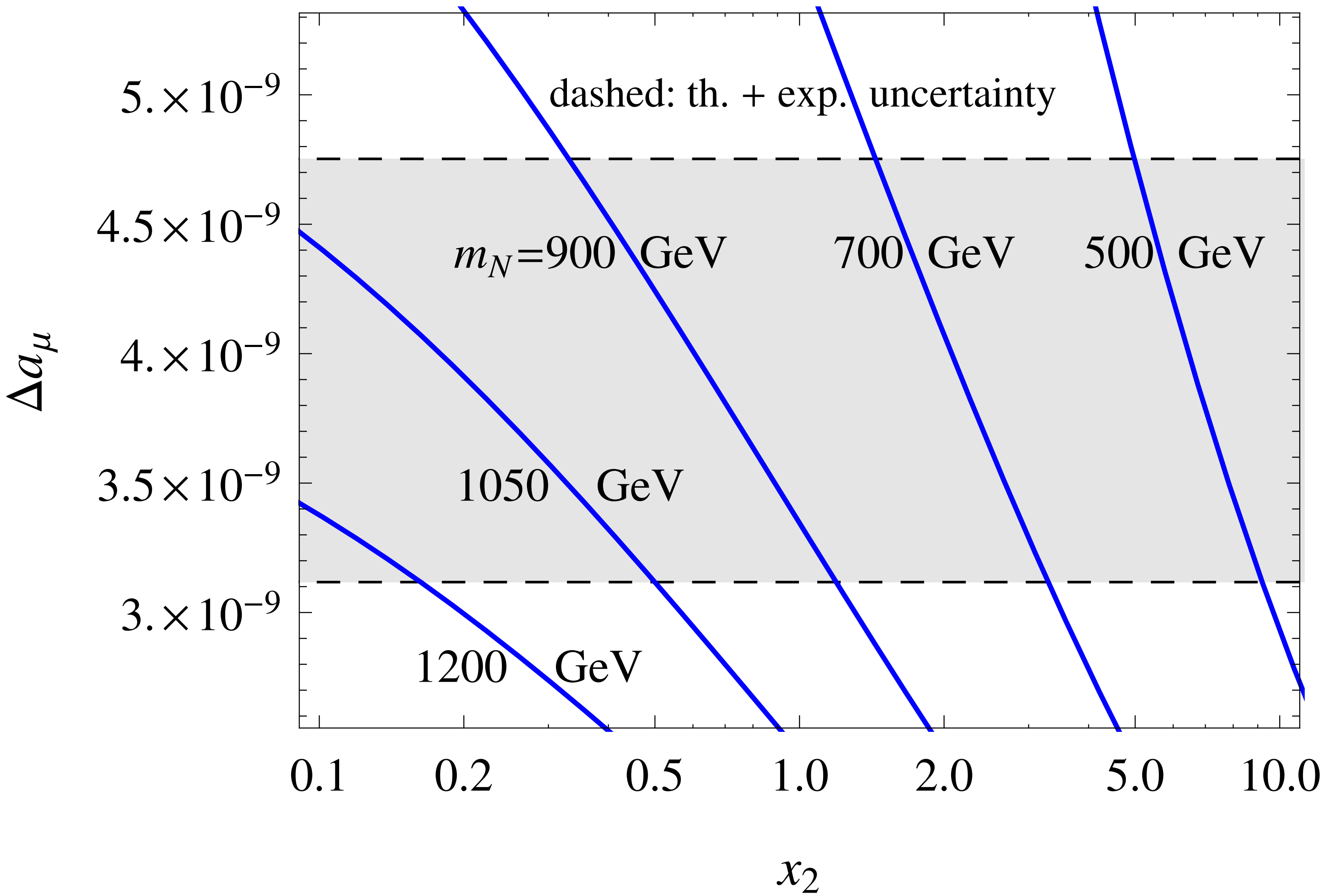
If we apply the same procedure to the muon, then

$$\Delta a_\mu = \frac{(g-2)_\mu}{2} = \frac{m_\mu^2}{m_N^2} \left[\frac{G(x_1) - G(x_2)}{H(x_1) - H(x_2)} \right],$$

where $G(x) = 2x \ln x/(x-1)^3 - (x+1)/(x-1)^2$, and $H(x) = x \ln x/(x-1)$. This is plotted against x_2 with $x_1 = x_2 + 2$ for various m_N.



(r_η, r_χ)
(0,−0.3)
(0,0)
(0.3,0)
(0.4,0.4)
1.06
1.04
1.02
1.00
0.98
0.0
0.2
0.4
0.6
0.8
1.0
$\Gamma_{\gamma\gamma}/\Gamma_{SM}$
$2\theta/\pi$

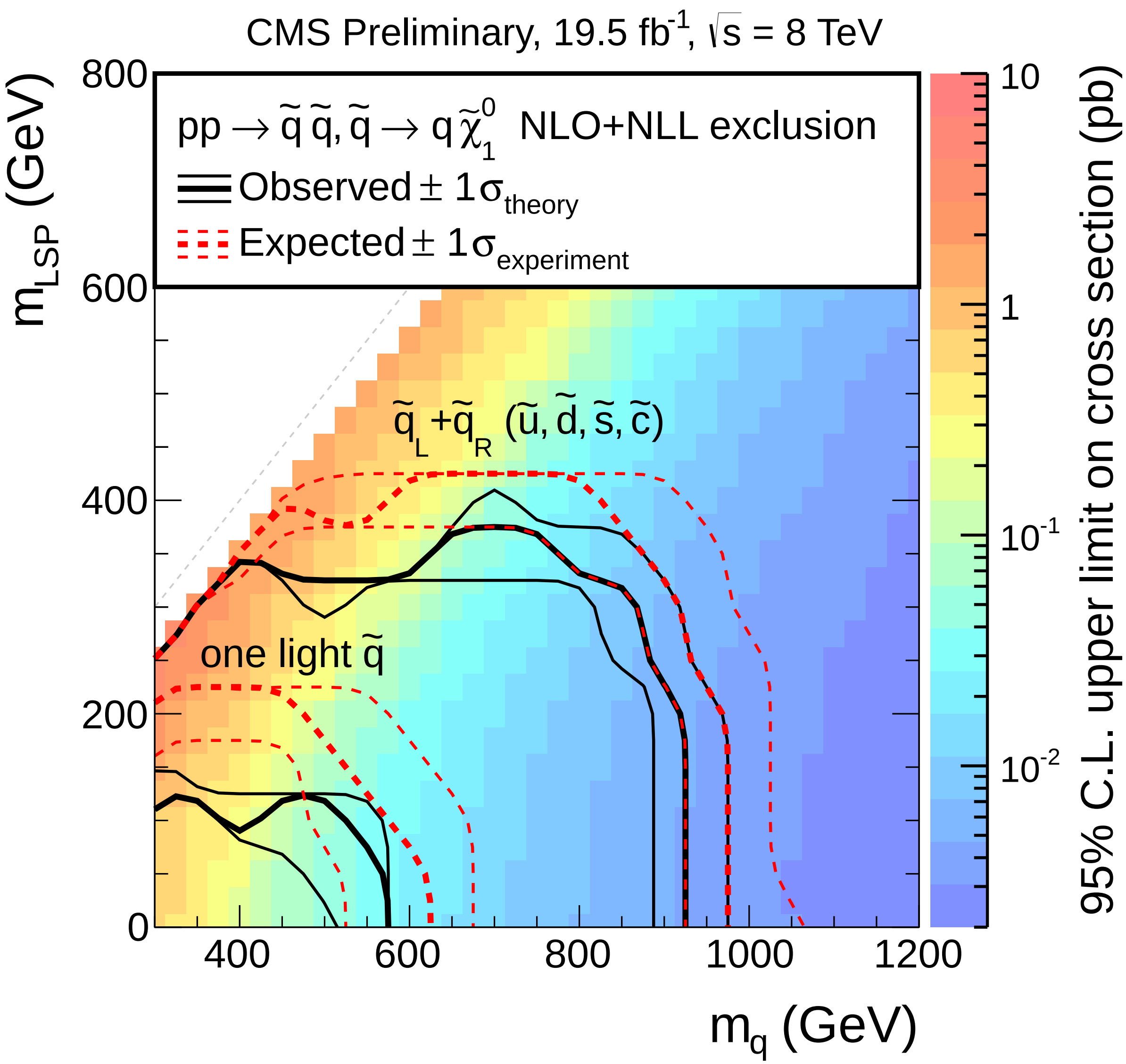


dashed: th. + exp. uncertainty
m_N=900 GeV
700 GeV
500 GeV
1050 GeV
1200 GeV
$5.\times 10^{-9}$
4.5×10^{-9}
$4.\times 10^{-9}$
3.5×10^{-9}
$3.\times 10^{-9}$
Δa_μ
0.1
0.2
0.5
1.0
2.0
5.0
10.0
x_2

Collider Signatures?

The dark-matter singlet neutral fermions $N_{1,2,3}$ carry flavor and their mixing pattern gets transmitted to the quarks, leptons, and neutrinos. Since flavor is organized through them, the production of scalar quarks, then $\tilde{q} \to q_{1,2}N_{1,2}$ with $N_2 \to \eta/\chi + \mu^\pm$ and $\eta/\chi \to N_1 e^\mp$ will result in 2 jets $+\ \mu^\pm + e^\mp +$ missing energy at the LHC.

In contrast, in the Minimal Supersymmetric Standard Model, the neutral gauginos do not carry flavor, so the decays of squarks to dark matter will mostly result in 2 jets $+\ \mu^+\mu^-$ (or e^+e^-) $+$ missing energy instead.

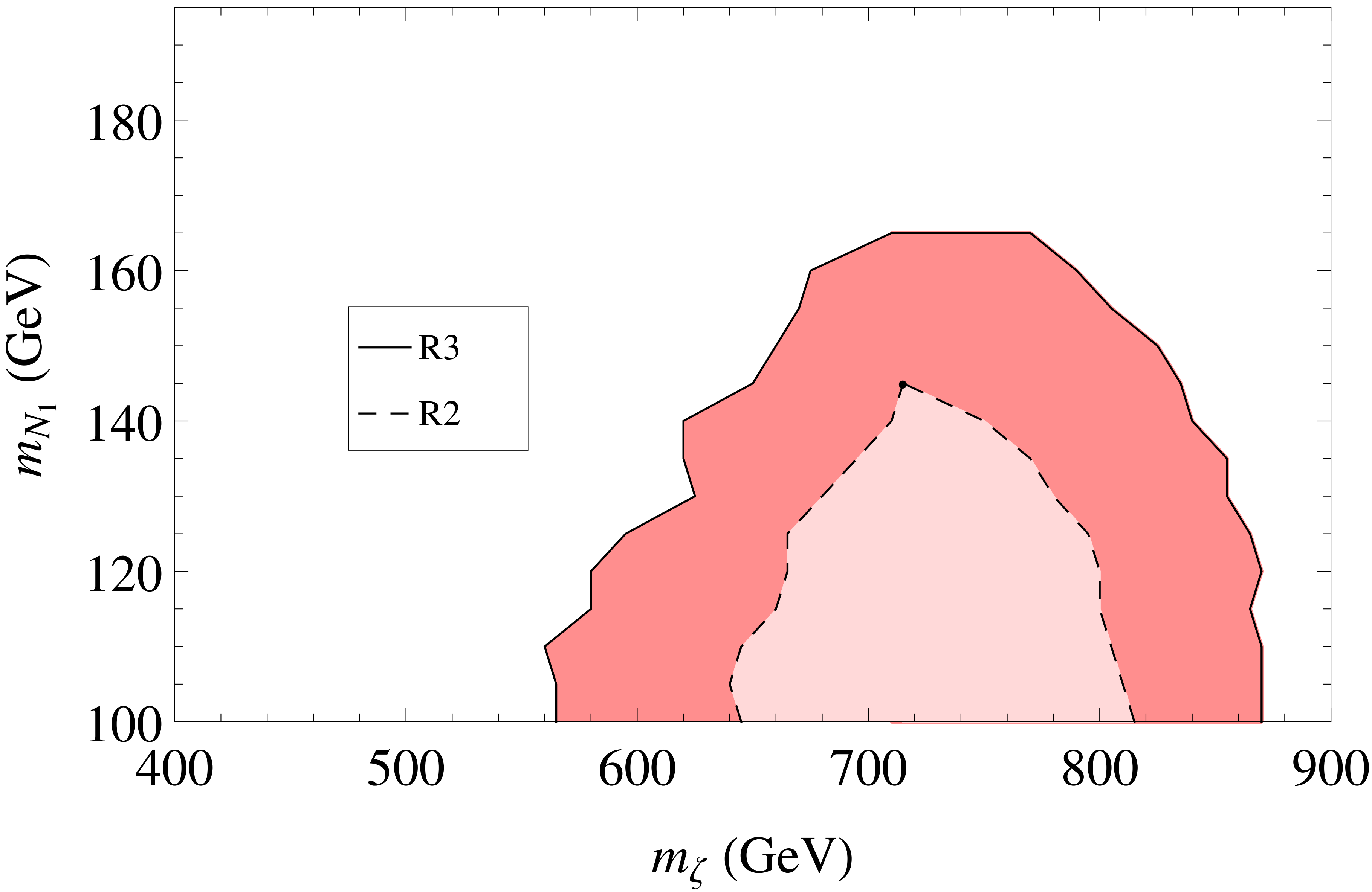


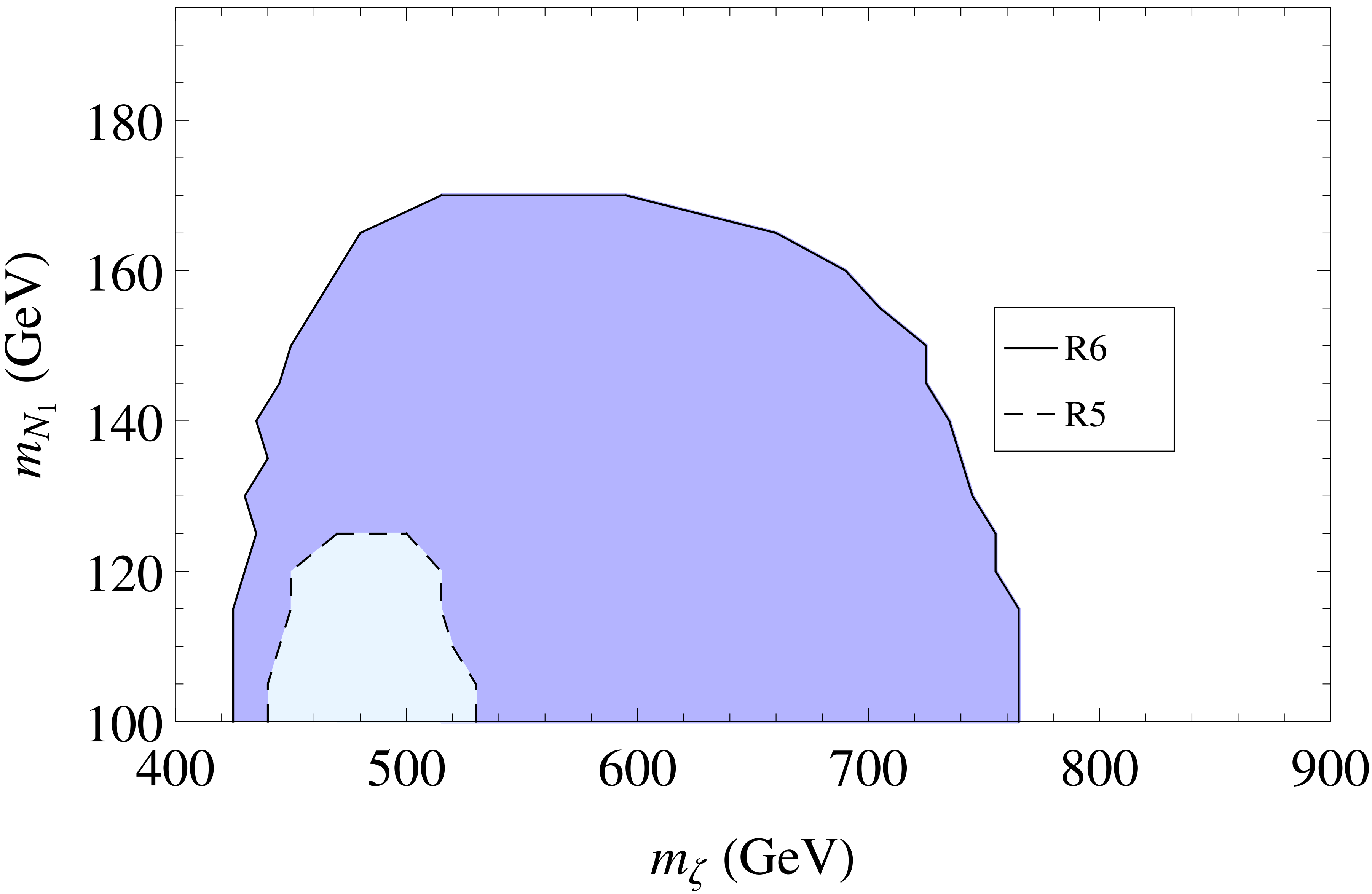
CMS Preliminary, 19.5 fb^{-1}, $\sqrt{s}$ = 8 TeV
pp → $\tilde{q}\tilde{q}$, $\tilde{q} \to q\tilde{\chi}_1^0$ NLO+NLL exclusion
Observed ± 1σ_{theory}
Expected ± 1$\sigma_{experiment}$
$\tilde{q}_L + \tilde{q}_R$ ($\tilde{u}, \tilde{d}, \tilde{s}, \tilde{c}$)
one light $\tilde{q}$
m_{LSP} (GeV)
m_q (GeV)
95% C.L. upper limit on cross section (pb)
0
200
400
600
800
1000
1200
10
1
10^{-1}
10^{-2}

Ma/Natale(2015):

Consider the expected 13 TeV run at the LHC. This signature is observable with $S/N > 5$ where the SM background is mainly $t\bar{t}$ production. Applying the cuts: $|\eta_j| < 3$, $|\eta_e| < 2.4$, and $|\eta_\mu| < 2.5$, we consider four cut regions with $m_{N_2} = 400$ GeV and $m_\chi = 200$ GeV:

R2: $E_T^m > 200$ GeV, $H_T > 600$ GeV, $p_T^j > 30$ GeV, $p_T^l > 20$ GeV;
R3: $E_T^m > 275$ GeV, $H_T > 600$ GeV, $p_T^j > 30$ GeV, $p_T^l > 20$ GeV;
R5: $E_T^m > 200$ GeV, $H_T > 350$ GeV, $p_T^j > 30$ GeV, $p_T^l > 20$ GeV;
R6: $E_T^m > 200$ GeV, $H_T > 350$ GeV, $p_T^j > 150$ GeV, $p_T^l > 25$ GeV.


180
160
140
120
100
400
500
600
700
800
900
m_{N_1} (GeV)
m_ζ (GeV)
R3
R2


180
160
140
120
100
400
500
600
700
800
900
m_{N_1} (GeV)
m_ζ (GeV)
R6
R5

Conclusion

Question: What does the one Higgs really tell us?

The answer may be that flavor and dark matter are also connected and they do so through the one Higgs. This new notion extends the scotogenic neutrino mass to all (or most) quark and lepton masses, with flavored dark matter.

In this framework, the new physics scales responsible for DM and neutrino mass are the same, say 1 TeV. If so, its impact is verifiable in the near future at the LHC.