Novel Higgs signatures from S_3 flavor symmetry

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Introduction

- Permutation group S_3 has been used in the flavor context to address large/small mixing and mild/strong mass hierarchy.
- S_3 is the smallest nonabelian discrete symmetry that contains a 2-dim rep. – we employ that to connect maximally mixed generation.
- **Enlarged Higgs sector: nonstandard couplings to fermions and gauge bosons**

1. Two of the three neutral scalars have *almost* SM-Higgs-like couplings – one at $\sim$ 125 GeV and the other around 600 GeV.
2. One neutral scalar ($\mathbf{h}_a$) has vanishing $\mathbf{h}_a ZZ$ coupling. It has *only* flavor off-diagonal Yukawa couplings with one fermion from third generation. *Similar things for one pseudo-scalar (χ_a).*
3. Perhaps h_a or χ_a is buried in the existing data. We propose rare top decay events w/ several muons with tau tags to unveil them.

Extended Higgs sector

We assign the particles as $(\mathbf{2} \otimes \mathbf{2} = \mathbf{1} \oplus \mathbf{1}' \oplus \mathbf{2}$ and $\mathbf{1}' \otimes \mathbf{1}' = \mathbf{1})$:

$$
\begin{aligned}
(L_\mu, L_\tau) \in \mathbf{2}\,, \qquad L_e, e^c, \mu^c \in \mathbf{1}\,, \qquad \tau^c \in \mathbf{1}'\,, \\
(Q_2, Q_3) \in \mathbf{2}\,, \qquad Q_1, u^c, c^c, d^c, s^c \in \mathbf{1}\,, \qquad b^c, t^c \in \mathbf{1}'\,, \\
(\phi_1, \phi_2) \in \mathbf{2}\,, \qquad \phi_3 \in \mathbf{1}\,.
\end{aligned}
$$

The scalar potential looks like

$$
\begin{aligned}
V \; = \; & m^2\left(\phi_1^\dagger\phi_1 + \phi_2^\dagger\phi_2\right) + m_3^2\phi_3^\dagger\phi_3 + \frac{\lambda_1}{2}\left(\phi_1^\dagger\phi_1 + \phi_2^\dagger\phi_2\right)^2 + \frac{\lambda_2}{2}\left(\phi_1^\dagger\phi_1 - \phi_2^\dagger\phi_2\right)^2 \\
+ \; & \lambda_3\phi_1^\dagger\phi_2\phi_2^\dagger\phi_1 + \frac{\lambda_4}{2}\left(\phi_3^\dagger\phi_3\right)^2 + \lambda_5\left(\phi_3^\dagger\phi_3\right)\left(\phi_1^\dagger\phi_1 + \phi_2^\dagger\phi_2\right) + \lambda_6\phi_3^\dagger\left(\phi_1\phi_1^\dagger + \phi_2\phi_2^\dagger\right)\phi_3 \\
+ \; & \left[\lambda_7\phi_3^\dagger\phi_1\phi_3^\dagger\phi_2 + \lambda_8\phi_3^\dagger\left(\phi_1\phi_2^\dagger\phi_1 + \phi_2\phi_1^\dagger\phi_2\right) + h.c.\right].
\end{aligned}
$$

- Possible to arrange $v_1 = v_2$ as an extremal condition (maximal $\nu_\mu - \nu_\tau$ mixing).
- Efficient check of global stability by going to spherical coordinates.

Spectrum and couplings

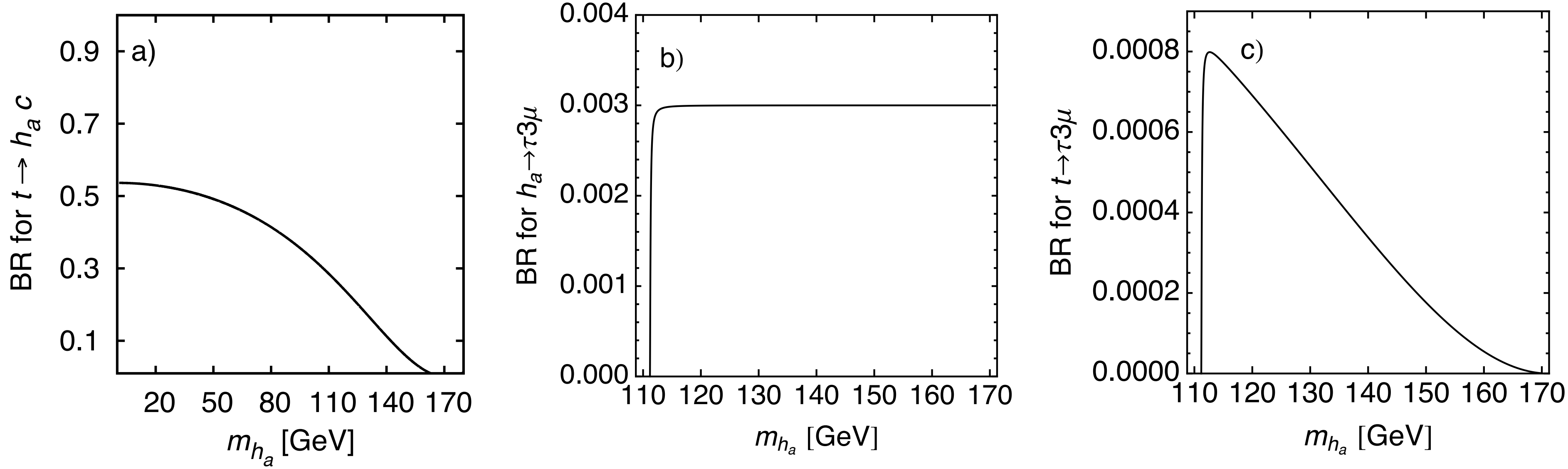
- Three CP-even neutral scalars $(\mathbf{h_a}, \mathbf{h_b}, \mathbf{h_c})$, two CP-odd neutral scalars $(\chi_\mathbf{a}, \chi_\mathbf{b})$, and two sets of charged scalars $(\mathbf{h_a^\pm}, \mathbf{h_b^\pm})$.
- $\mathbf{h_b}$ and $\mathbf{h_c}$ have roughly SM Higgs-like couplings. $\mathbf{h_b}$ can have a mass $\sim$ 125 GeV.
- $\mathbf{h_a}$ and $\chi_\mathbf{a}$ have no 3-point couplings with ZZ or WW. They can evade LEP2 and EWPT bounds - hence, can be very light.
  Reason: Since $v_1 = v_2 = v$, the combination $(h_1 + h_2)$ couples to Z or W as proportional to v, while $h_a \sim (h_1 - h_2)$ decouples as orthogonal combination.
- All other neutral and charged scalars weigh above 550 GeV.

Generic Yukawa structures:

$$Y_a = \begin{pmatrix} 0 & 0 & Y_{13} \\ 0 & 0 & Y_{23} \\ Y_{31} & Y_{32} & 0 \end{pmatrix}, \quad Y_{b,c} = \begin{pmatrix} Y_{11} & Y_{12} & 0 \\ Y_{21} & Y_{22} & 0 \\ 0 & 0 & Y_{33} \end{pmatrix}.$$

How to detect $\mathrm{h_a}$?

$\mathrm{t\bar{t}}$ pair in huge number. Look for rare top decays with several leptons in final state. $\mathbf{h}_a \chi_a Z$ gauge interaction is crucial.



- Assume $m_{h_a} \sim$ (110-120) GeV, and $m_{\chi_a} \sim$ 20 GeV.
- Br($t \to h_a c$) can be 25%, then Br($h_a \to \chi_a Z$) can be almost 100% due to the dominance of the gauge coupling, followed by $\chi_a \to \tau\mu$ (10%) and $Z \to \mu\mu$ (3%).

Outlook

- $\mathbf{h_a}$ or $\chi_\mathbf{a}$ evades LEP/Tevatron/LHC bounds. They may be buried in the data. We are discussing it with some CMS experimentalists.
- Flavor symmetry often attributes *unusual* behavior to new scalars. For them conventional triggers won't work.
- We don't know which flavor symmetry is at work! Preparing a catalog for various exotic decay signatures arising from a wide range of possible flavor symmetry would be very handy for experimentalists.