Collider Probes Of Real Triplet Dark Matter

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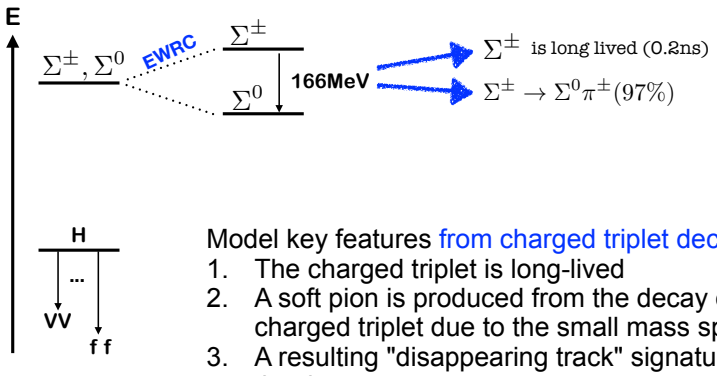
Abstract

We study discovery prospects for the real triplet model at the LHC and a possible future 100TeV pp collider, where the neutral triplet is a dark matter candidate and the charged triplet dominantly decays to the neutral triplet plus a soft pion, yielding a disappearing track in the detector. We find the LHC presently excludes a real triplet lighter than 287GeV with $\mathcal{L}$=36fb^{-1}. The reach will extend to 608GeV and 761GeV with $\mathcal{L}$=300fb^{-1} and 3ab^{-1} respectively. We extrapolate the 13TeV analysis to a prospective 100TeV pp collider and find that a ~3TeV triplet scalar could be discoverable with $\mathcal{L}$=30ab^{-1}, depending on the control of pileup effects. We also investigate the dark matter candidate and corresponding constraints from dark matter direct detection. We find that currently XENON1T can exclude a real triplet dark matter lighter than 3TeV for a Higgs portal coupling of order one or larger, and the future XENON20T will cover almost the entire dark matter viable parameter space except for vanishingly small portal coupling.

Model setup and its key features

$$H = \begin{pmatrix} G^+ \\ \frac{1}{\sqrt{2}}\left(v + h + iG^0\right) \end{pmatrix}, \qquad \Sigma = \frac{1}{2}\begin{pmatrix} \Sigma^0 & \sqrt{2}\Sigma^+ \\ \sqrt{2}\Sigma^- & -\Sigma^0 \end{pmatrix},$$

$$V(H,\Sigma) = -\mu^2 H^\dagger H + \lambda_0 \left(H^\dagger H\right)^2 - \frac{1}{2}\mu_\Sigma^2 F + \frac{b_4}{4}\left[\left(\Sigma^0\right)^2 + 2\Sigma^+\Sigma^-\right]^2 + \frac{a_2}{2} H^\dagger H \left[\left(\Sigma^0\right)^2 + 2\Sigma^+\Sigma^-\right]$$



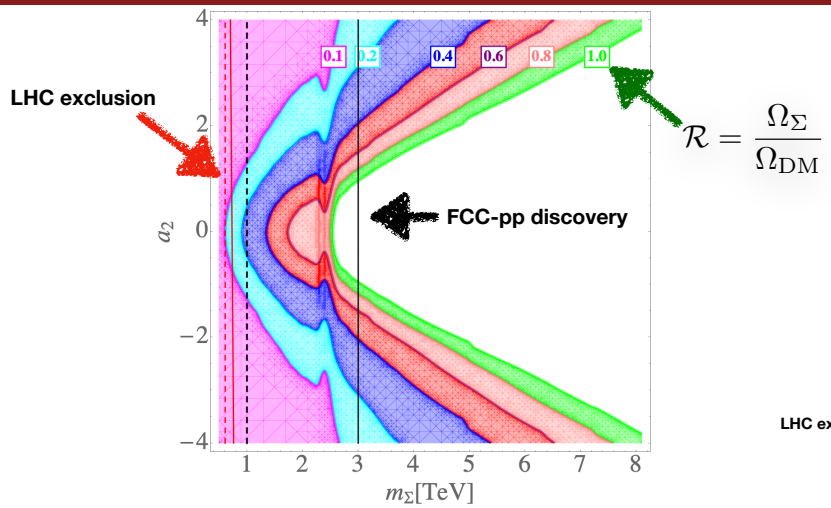
Model key features from the portal coupling:

1. The triplet does not develop a vacuum expectation value after electroweak spontaneous symmetry breaking.
2. The neutral triplet is stable and our DM candidate.
3. The portal coupling a_2 measures the interaction strength between the doublet and the triplet/dark matter.

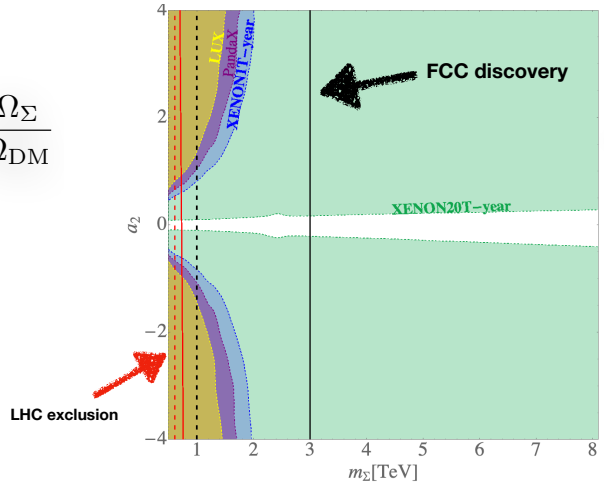
Model key features from charged triplet decay:

1. The charged triplet is long-lived
2. A soft pion is produced from the decay of the charged triplet due to the small mass splitting
3. A resulting "disappearing track" signature at the detector.

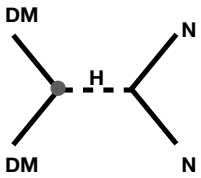
Our key findings and conclusions



$$\mathcal{R} = \frac{\Omega_\Sigma}{\Omega_{\rm DM}}$$



$$\sigma_{\rm SI}^{\rm scaled} \equiv \frac{\sigma_{\rm SI}\Omega h^2}{(\Omega h^2)_{\rm Planck}}$$



1. Current LHC excludes a real triplet dark matter lighter than 287GeV, HL-LHC would extend that to 761GeV.
2. A ~3TeV real triplet dark matter could be discoverable at a future 100TeV pp collider with $\mathcal{L}$=30ab^{-1}.
3. XENON1T excludes a real triplet dark matter lighter than ~2TeV for $|a_2|>1$.
4. XENON20T would cover almost the entire dark matter viable parameter space of the real triplet model.
5. Collider searches and dark matter direction are complementary.

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