Asymmetric Dark Matter May Not Be Light

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Outline

Model Building

Dark Matter Predictions

Experimental Prospects

The Dark Sector

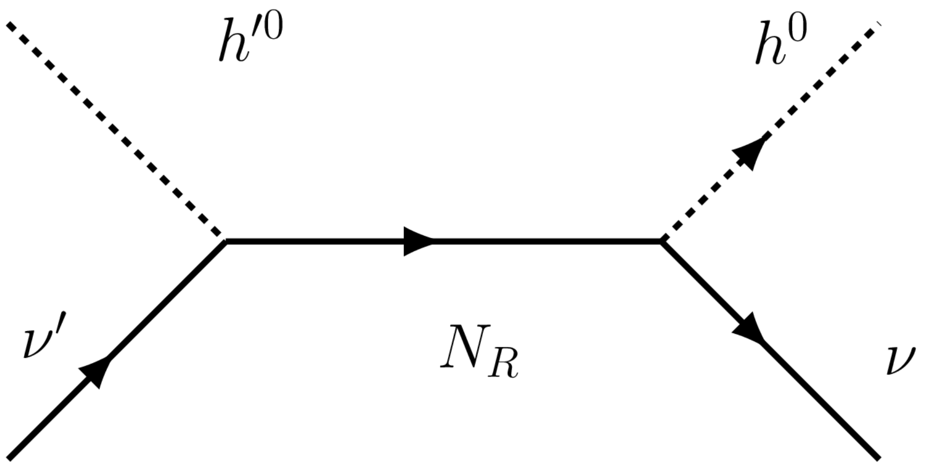
Introduce a minimal dark sector mimicking the SM:

- Gauge group: SU(3)′ × SU(2)′ × U(1)′
- One matter generation
- One Higgs doublet
- One right-handed Weyl neutrino

Portals

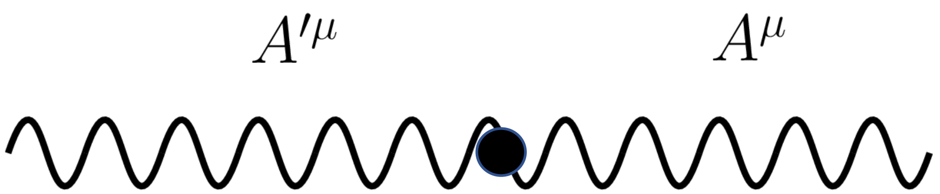
- Neutrino Portal

$$\mathcal{L} \subset y'_N \, \bar{L}'\hat{H}'N_R + y_N\bar{L}\hat{H}N_R + c.c$$



- Vector Portal

$$\mathcal{L} \subset \frac{\varepsilon}{2} F_{\mu\nu}F'^{\mu\nu} + \frac{1}{2} m_{\gamma'}^2 A'_\mu A'^\mu$$

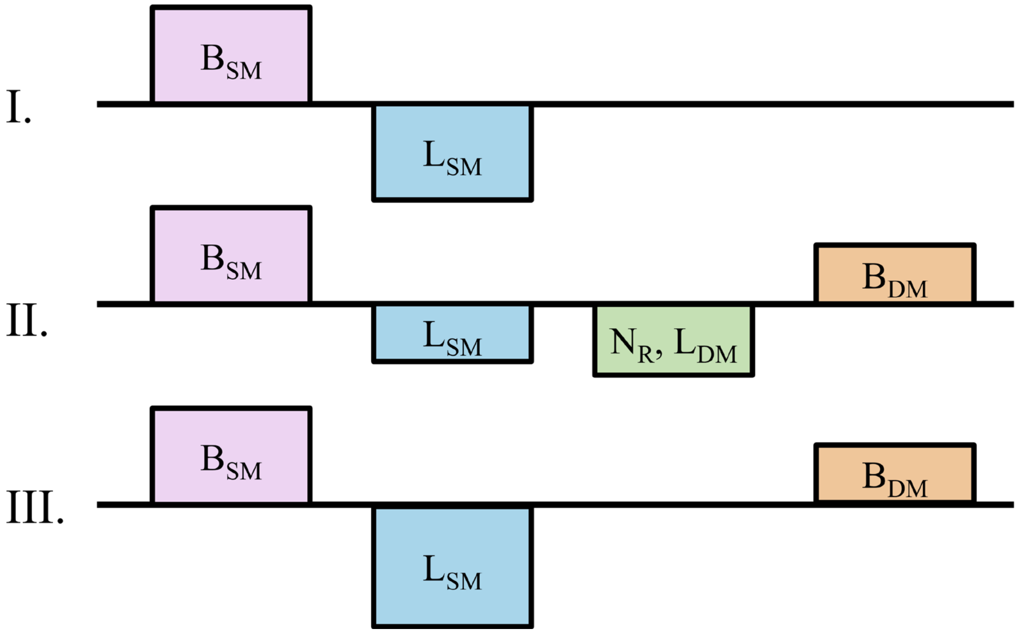


Asymmetry Transfer

I. SM Electroweak Baryogenesis generates equal B_{SM} and L_{SM} asymmetries

II. The neutrino portal transfers some SM lepton asymmetry over to the dark leptons and dark sphalerons convert it into dark baryon asymmetry

III. Right-handed neutrino decays back into the SM



Equilibrium Thermodynamics

- Assuming all species are ultra relativistic, the Boltzmann equation simplifies to

$$n_{+} - n_{-} = \frac{g\,T^3}{3}\left[\frac{\mu}{T}\right] \; (bosons)$$

$$n_{+} - n_{-} = \frac{g\,T^3}{6}\left[\frac{\mu}{T}\right] \; (fermions)$$

- Up to a numerical factor, particle/antiparticle asymmetry can be represented by its chemical potential.
- We can use $B_{tot} - L_{tot}$ conservation and all available interactions to find B' & L' in terms of initial B asymmetry.

Dark Matter Masses

Dark Sector EW Phase Transition	Dark Baryon Number	Dark Lepton Number	Predicted DM Mass	
1^{st} order	$B' = -\frac{72}{535}B$	$L' = \frac{168}{535}B$	$\bar{p}'$ & π'	18.7 GeV
			$\bar{n}'$	37.4 GeV
Crossover	$B' = -\frac{120}{1427}B$	$L' = \frac{360}{1427}B$	$\bar{p}'$ & π'	29.9 GeV
			$\bar{n}'$	59.9 GeV

Dark Baryon Direct Detection

$\overline{\mathrm{p}}'$ & π' DM

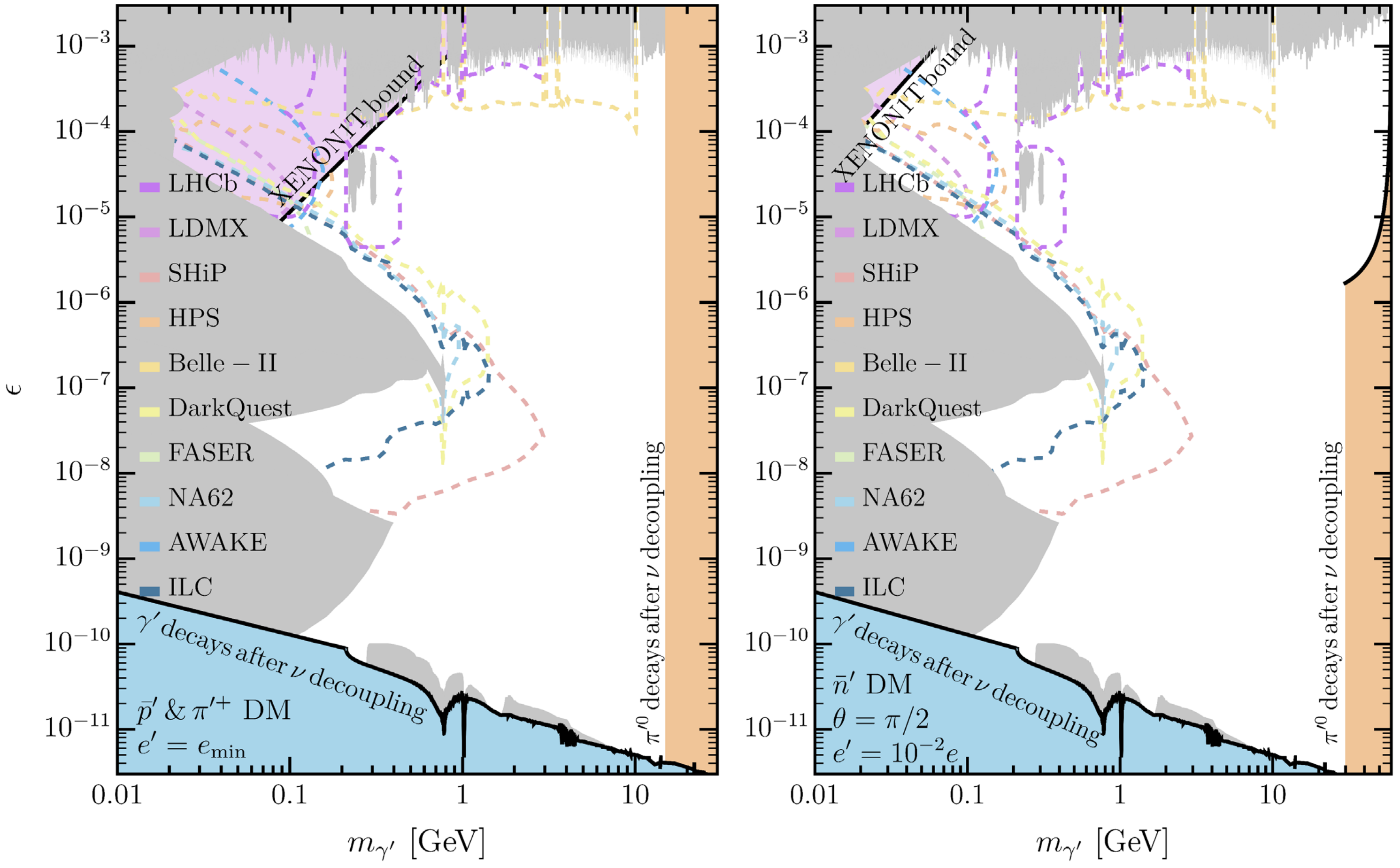
- The scattering cross section for $\overline{\mathrm{p}}'$ & π' DM is
  - $\sigma_{\chi p} \approx \epsilon^2 e^2 e'^2 \frac{m_p^2 m_{\overline{\mathrm{p}}'}^2}{\pi\left(m_p + m_{\overline{\mathrm{p}}'}\right)^4 m_{\gamma'}^4}$
- χ refers to either DM sub-component

$\overline{\mathrm{n}}$ DM

- The scattering cross section for $\overline{\mathrm{n}}$ DM is
  - $\sigma_{\overline{\mathrm{n}}'p} \approx \epsilon^2 e^2 e'^2 g^2 v^2 \frac{m_p^4 m_{\overline{\mathrm{n}}'}^2}{8\pi\left(m_p + m_{\overline{\mathrm{n}}'}\right)^4 m_{\gamma'}^4}$
- Assuming pions, baryons, and quarks have roughly equal masses, the tree-result is
  - $g = -1.91 \frac{y\, m_{u'} m_{d'}}{(m_{u'} + m_{d'}) m_{\overline{\mathrm{n}}'}} \sin(\theta)$
    $\approx -1.91 \sin(\theta)$

Dark Photon Decay

- The viable ADM parameter space as projected onto dark photon mass versus kinetic mixing.
- Existing constraints on visibly decaying dark photons are shaded dark gray, while projected sensitivities are dashed.
- Color-shaded regions are ruled out by too-late decays and direct detection constraints
- Left: DM is 50% $\bar{p}'$ and 50% π'^{+} and $e' = e_{min}$. Right: DM is all $\bar{n}'$ and $e' = 10^{-2}$ e.



Detections at the ILC

Beam Dumps

- ILC beam dumps have the potential to reach higher $m_{\gamma'}$ than SHiP

Dark Spectroscopy

- If ϵ is large, ILC can produce dark hadrons through off-shell dark photons
- Can identify resonance states via photon+missing signature
- Can potentially confirm the SU(3)' gauge group

Exotic Higgs Decays

- Dark Higgs and SM Higgs can mix via quartic coupling $|H'|^2|H|^2$
- SM Higgs → dark states → SM states

Conclusions

- With this new model, we have a simple dark sector which may be “added” onto existing models of electroweak baryogenesis to simultaneously explain DM.
- In the most minimal case, we predict a range of dark matter masses much higher than any previous models of asymmetric dark matter, up to nearly 60 GeV.
- Future experiments like the ILC will probe large swaths of the viable ADM parameter space. It can also probe other predicted interactions such as exotic Higgs decays.

Questions?