Minimal Leptophillic Dark Matter

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Outline

Motivation

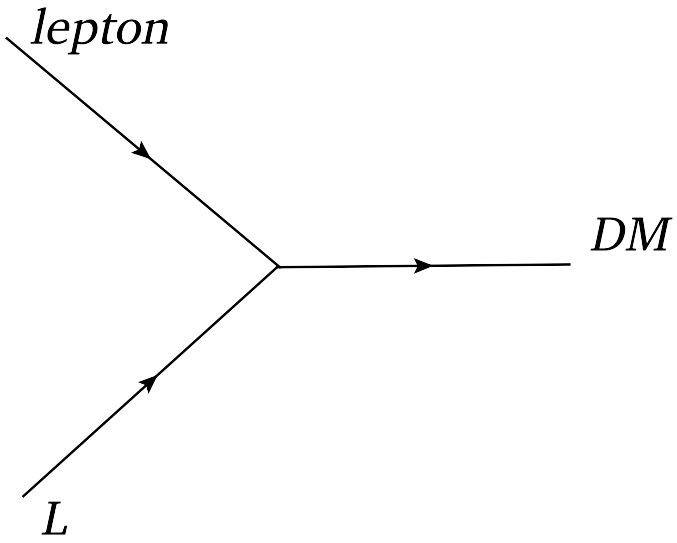
- Many probes of dark matter : collider, direct, indirect detection
- Want to know quantum numbers, interactions with SM or other new particles, compare different experiments
- Either complete theory like SUSY WIMPs, or effective DM:

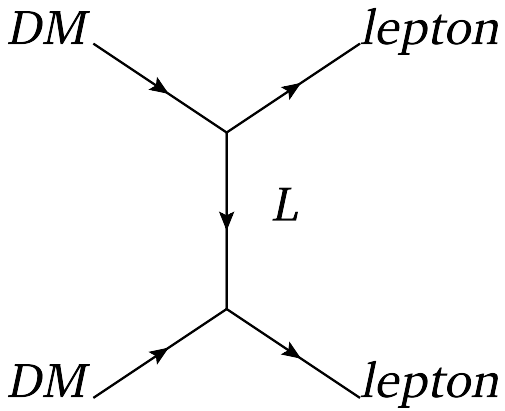
$$\mathcal{L} \sim \frac{1}{M^n} |\mathrm{SM}|^2 |\mathrm{DM}|^2$$

- Useful compromise between complete theory and effective DM:

$$\mathcal{L} \sim \lambda (\mathrm{SM})(\widetilde{\mathrm{SM}})(\mathrm{DM})$$

Effective WIMPs





- Freeze out fixes coupling
- For each point in mass parameter space, calculate collider production, nuclear interaction σ, etc

Models overview

Lepton partners couple to left-handed lepton doublets

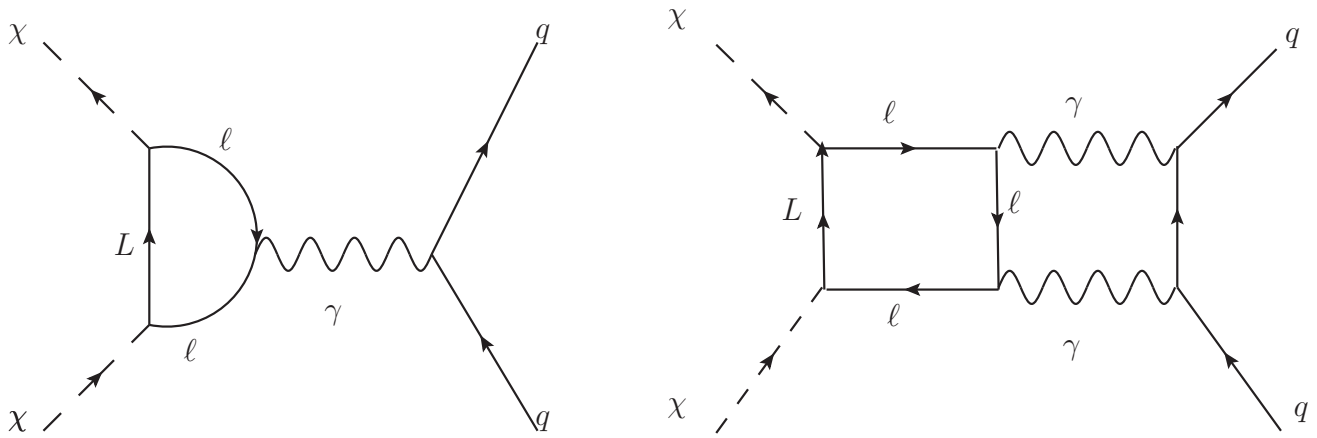
Model Particles		$\mathcal{L}_{\text{int}}$
Dark matter χ	Lepton partner L	
Majorana fermion	Complex scalar	$\lambda(\chi l)L^* + \text{h.c.}$
Dirac fermion	Complex scalar	$\lambda(\chi l)L^* + \text{h.c.}$
Real scalar	Dirac fermion	$\lambda(L^c l)\chi + \text{h.c.}$
Complex scalar	Dirac fermion	$\lambda(L^c l)\chi + \text{h.c.}$

Leptophillic direct detection signals

- WIMP-electron scattering (WES)
- requires non-negligible momentum for electron
- WIMP-atom scattering (WAS)
- suppressed by electron wave function overlap
- loop-mediated WIMP-nucleus scattering (WNS) : loop suppression $(\frac{\alpha_{\rm em} Z}{\pi})^2$

$$R^{WAS} : R^{WES} : R^{WNS} \sim 10^{-17} : 10^{-10} : 1$$

Loop mediated scattering

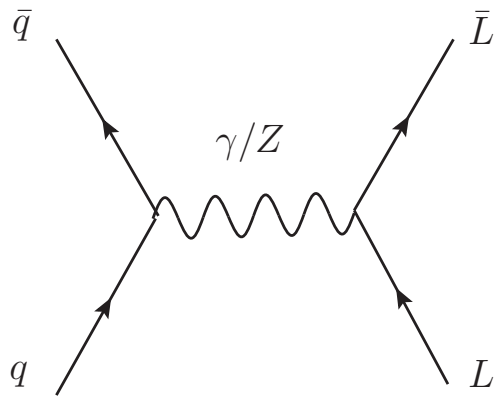


- one-loop charge radius interaction for Dirac and Complex Scalar DM

$$\frac{d\sigma_{b_\chi}}{dE_R} = \frac{m_N}{2\pi v^2} Z^2 e^2 b_\chi^2 F^2[E_R]$$

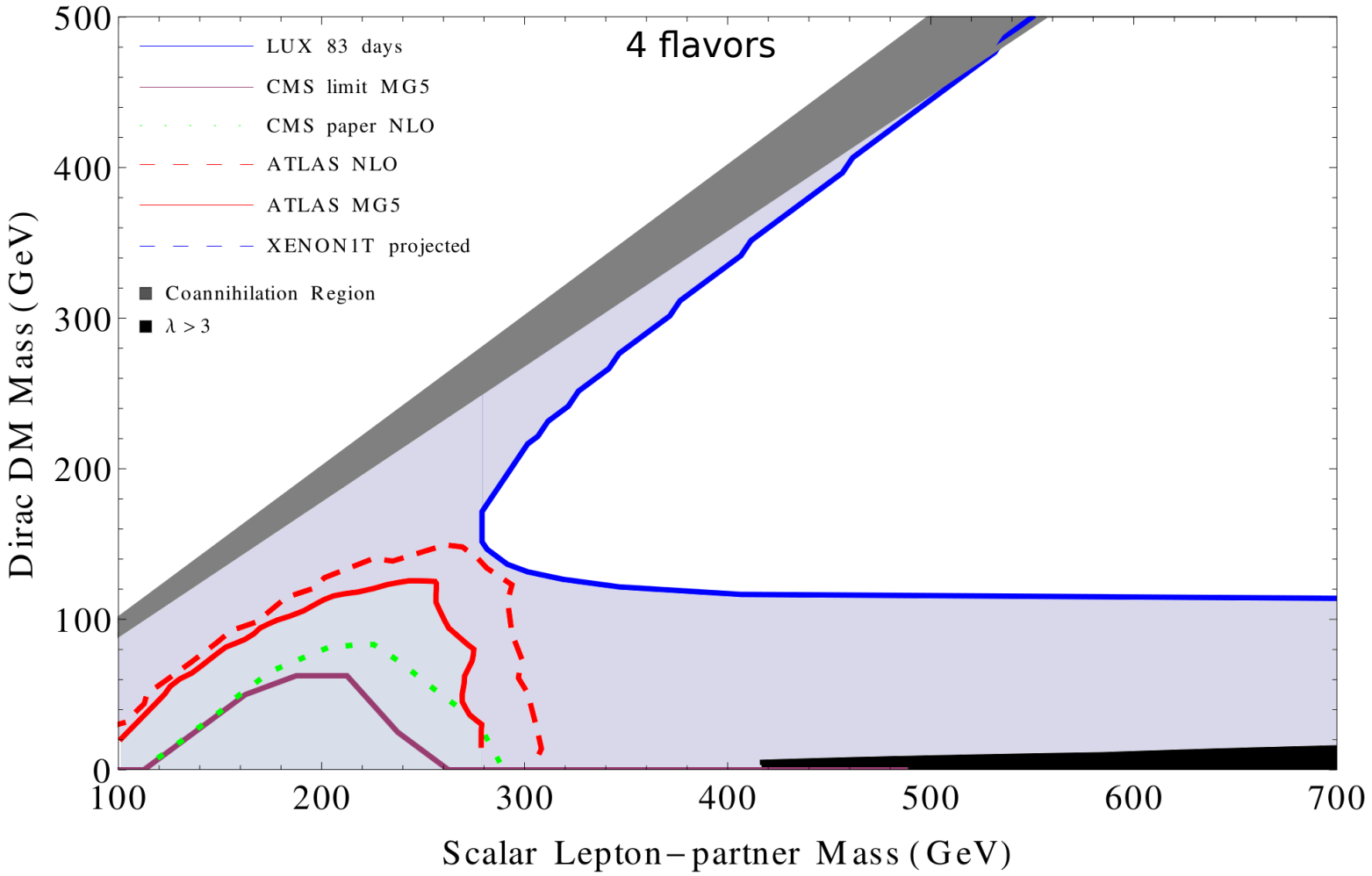
- same form as usual SI cross section
- charge radius vanishes for Real and Majorana, only two loop diagrams
- reduced far below current and projected SI bounds

Collider limits

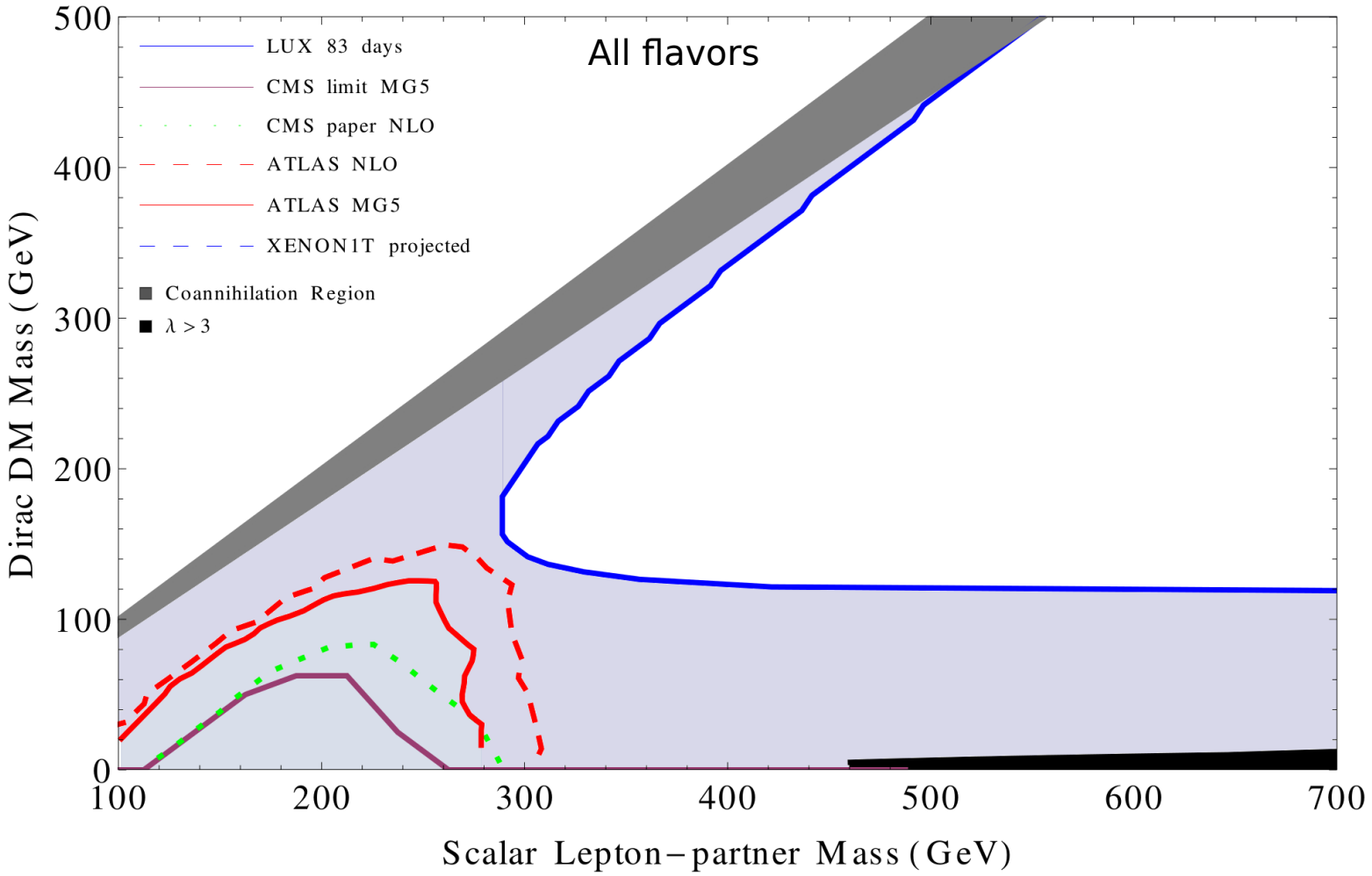


- lepton "partners" produced through γ or Z, and decay into lepton and dark matter
- strongest bounds come from Lepton+MET searches
- only depends on partner type
- no simplified model limits for monolepton

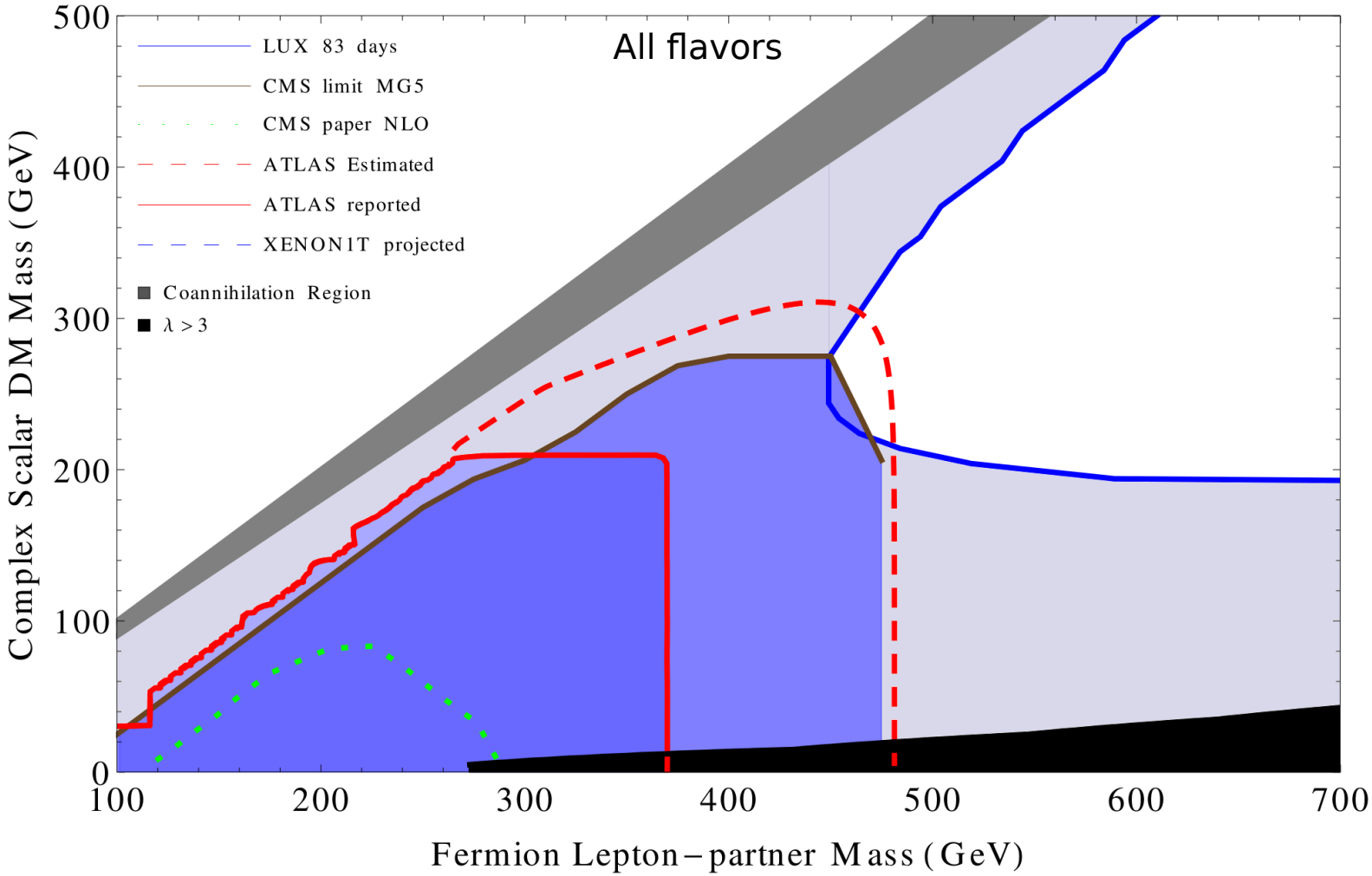
Dirac DM Results



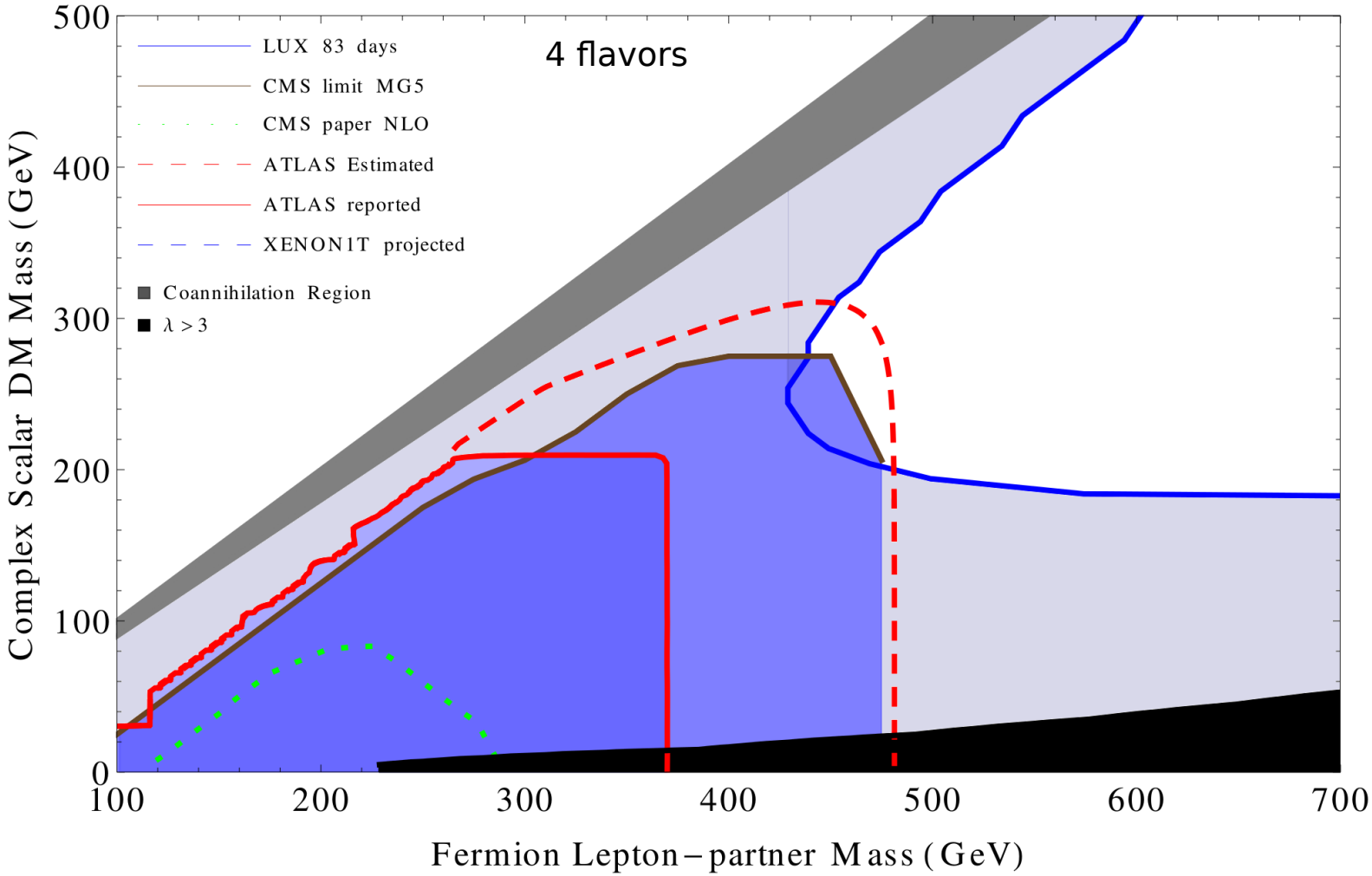
Dirac DM Results



Complex Scalar DM Results



Complex Scalar DM Results



Real scalar and Majorana

- Two-loop suppressed nuclear interaction
- Not probed by current or projected directed detection
- Collider limits same for Real Scalar (Majorana) same as Complex Scalar (Dirac)

- Direct detection better than dilepton searches for Dirac, Complex Scalar
- Direct detection does not probe Majorana, Real Scalar
- ATLAS should have gone to higher masses
- Complementary in a way to the quark-ophillic Effective WIMPs
- ATLAS and CMS should present mono-lepton limits for simplified models

Muon g-2

- Anomalous magnetic moment receives contributions from $\chi - L$ loops

$$\mathcal{M} = ie\bar{u}\left(\gamma^{\lambda} + (a_{\mu}^{SM} + \delta a_{\mu})\frac{i\sigma^{\lambda\beta}q_{\beta}}{2m_{\mu}}\right)u\epsilon_{\lambda}$$

- For fermionic dark matter, contribution is similar to neutralino-slepton loop

$$\delta a_{\mu,fermion} = -\frac{\lambda^2 m_{\mu}^2}{192\pi^2 m_L^2}\frac{2}{(1-r_L)^4}\left(1 - 6r_L + 3r_L^2 + 2r_L^3 - 6r_L ln(r_L)\right)$$

where $r_L \equiv \frac{m_L^2}{m_{\chi}^2}$

- For scalar dark matter, contribution is similar to sneutrino-chargino loop

$$\delta a_{\mu,scalar} = \frac{\lambda^2 m_{\mu}^2}{192\pi^2 m_{\chi}^2}\frac{2}{(1-r_L^{-1})^4}\left(2 + 3r_L^{-1} - 6r_L^{-2} + r_L^{-3} - 6r_L^{-1} ln(r_L)\right)$$

produces the observed excess for $m_{\chi} \sim \mathcal{O}(GeV)$, but already ruled out by LUX in our models

Model		Relic Abundance	Direct Detection
χ	L		
Majorana fermion	Complex scalar	$a \sim m_\ell^2$ $\lambda \sim 0.5 - 3$	Two loop suppressed WNS
Dirac fermion	Complex scalar	$\lambda \sim 0.2 - 1$	One loop charge radius $\sigma_{\text{SI}} \overset{m_L \gg m_\chi}{\sim} \frac{m_p^2}{m_\chi^2} \sigma_{\text{ann}}$
Real scalar	Dirac fermion	$a, b \sim m_\ell^2$ $\lambda \sim 1 - 7$	Two loop suppressed WNS
Complex scalar	Dirac fermion	$a \sim m_\ell^2$ $\lambda \sim 0.5 - 3$	One loop charge radius $\sigma_{\text{SI}} \overset{m_L \gg m_\chi}{\sim} \frac{m_p^2}{m_\chi^2} \sigma_{\text{ann}}$

Leptophillic direct detection signals

- WIMP-electron scattering (WES)
  $\mathcal{O}(KeV)$ requires non-negligible momentum for electron
  $\epsilon_{WES} = \sqrt{2m_e(E_d - E_B)}\,(2l+1)\int \frac{dp\,p}{(2\pi)^3}\,|\chi_{nl}(p)|^2 \sim 10^{-6}$
- WIMP-atom scattering (WAS)
  $\epsilon_{WAS} = \sum |\langle n'l'm'|e^{i(\mathbf{k}-\mathbf{k'})\mathbf{x}}|nlm\rangle|^2 \sim 10^{-19}$,
- loop-mediated WIMP-nucleus scattering (WNS) loop suppression $(\frac{\alpha_{\rm em} Z}{\pi})^2$

$$R^{WAS} : R^{WES} : R^{WNS} \sim \epsilon_{WAS} : \epsilon_{WES}\,\frac{m_e}{m_N} : \left(\frac{\alpha_{\rm em} Z}{\pi}\right)^2$$

$$\sim 10^{-17} : 10^{-10} : 1$$