The Search for Dark Matter

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With thanks to Lawrence Krauss,
Nicole Bell, Tom Weiler, Jay Newstead and others

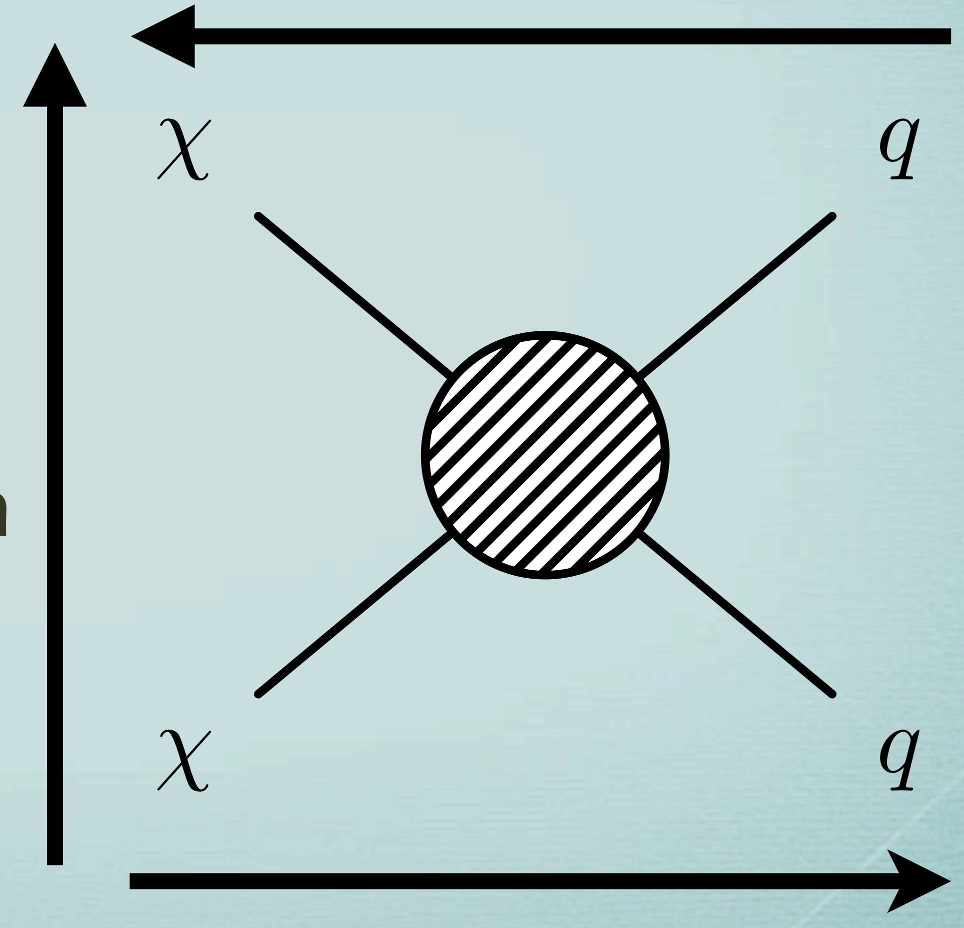
2012-07-12
SF12

Dark Matter Searches

- WIMPs do interact with SM particles, just very weakly
- Several ways to search for these interactions, regardless of the underlying particle physics:

Production:
Accelerator Searches

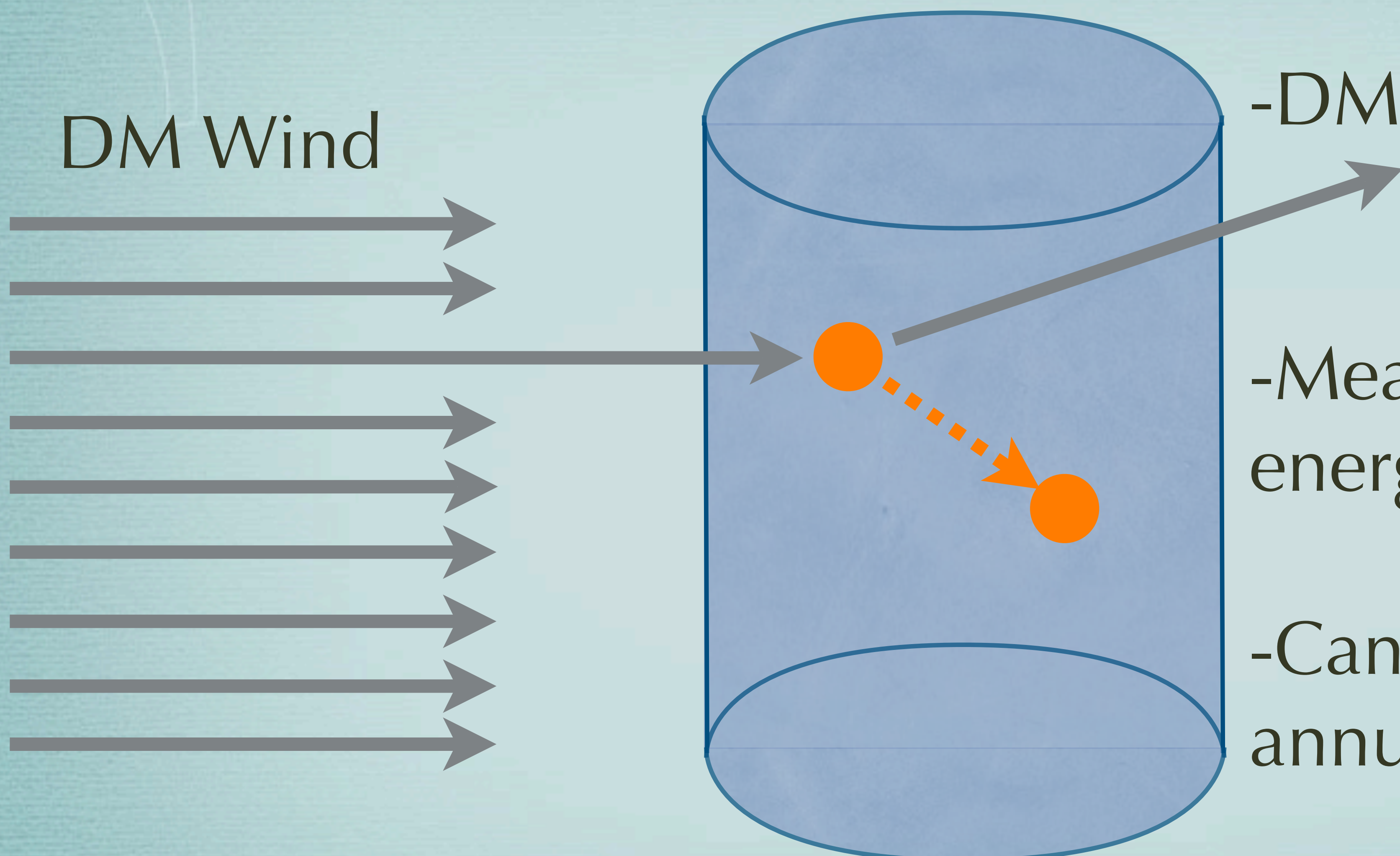
Scattering:
Direct Detection



Annihilation:
Indirect Detection

- Each technique has its own strengths and challenges

Direct Detection



-DM scatters off nucleus

-Measure transferred energy

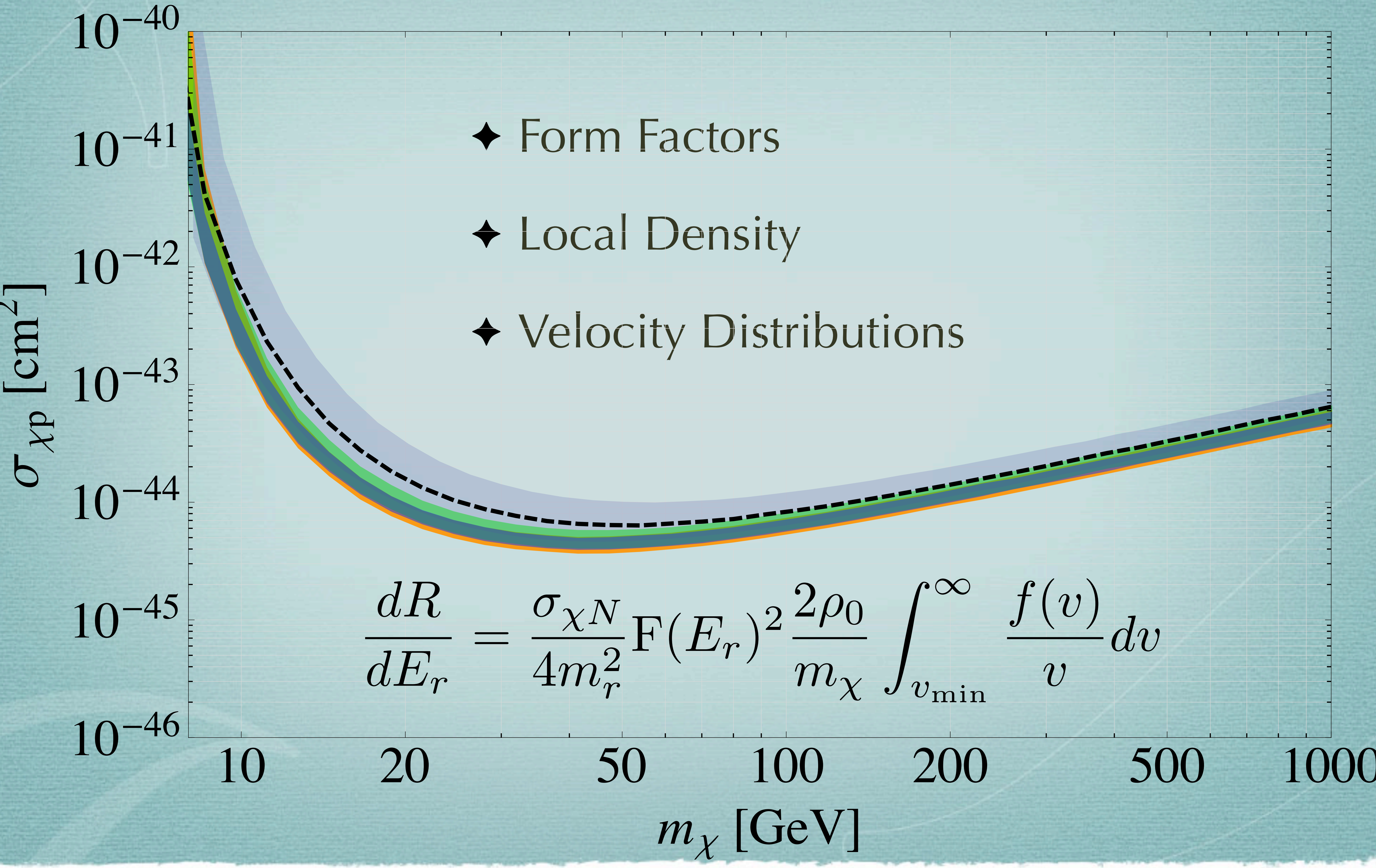
-Can search for daily or annual modulation

Direct Detection

- Good hope for a 'smoking gun'
- Can extract both mass and cross section from a signal (although some degeneracies)
- Constraints apply to wide range of DM models

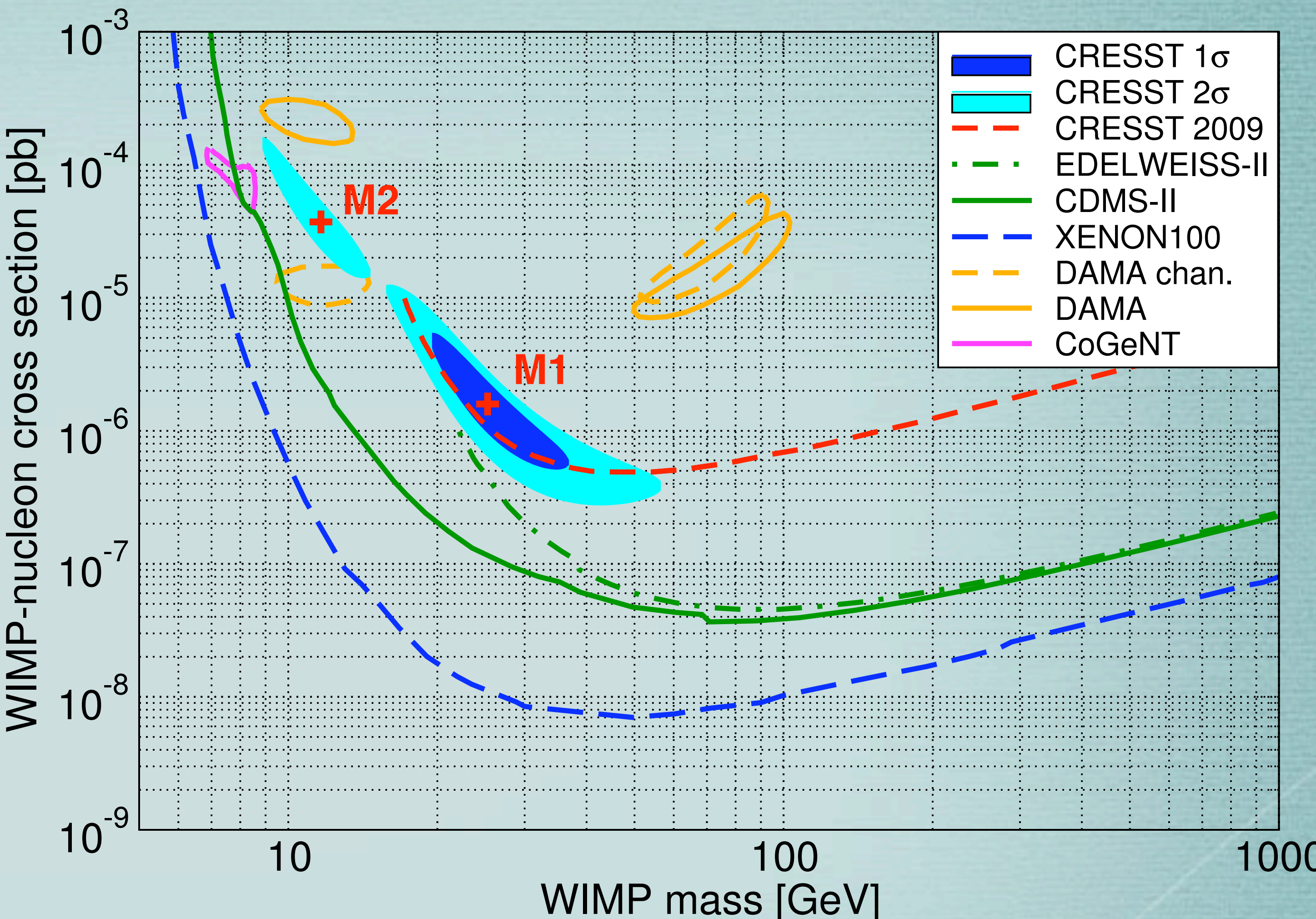
- Small signal, large background
- Requires big detectors, deep underground
- Astrophysical uncertainties

Uncertainties



Signal?

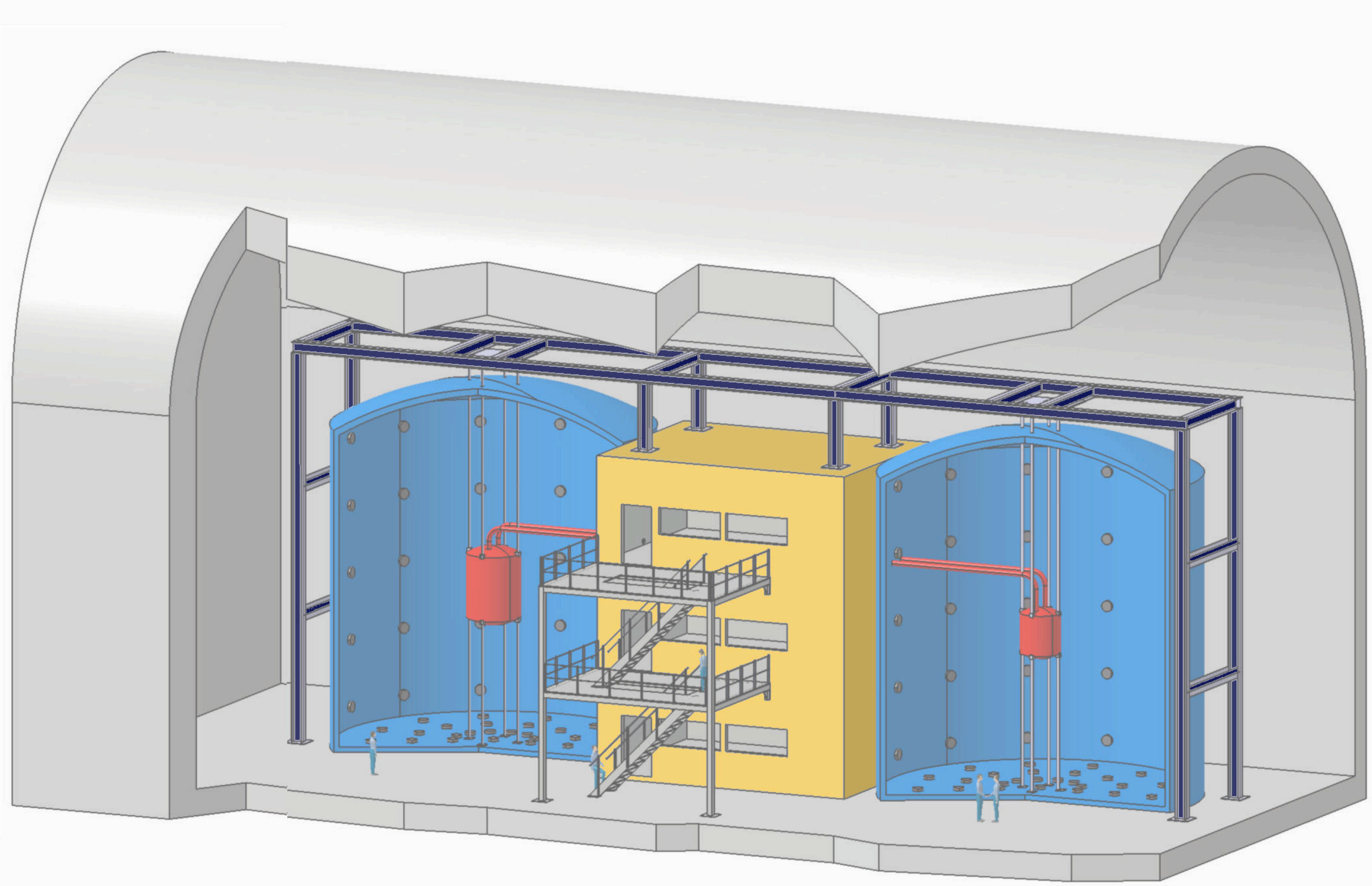
- Several experiments reporting signals
- Appears to be incompatible with limits from other detectors
- Could be inelastic scattering, Mirror DM, or an unexplained background

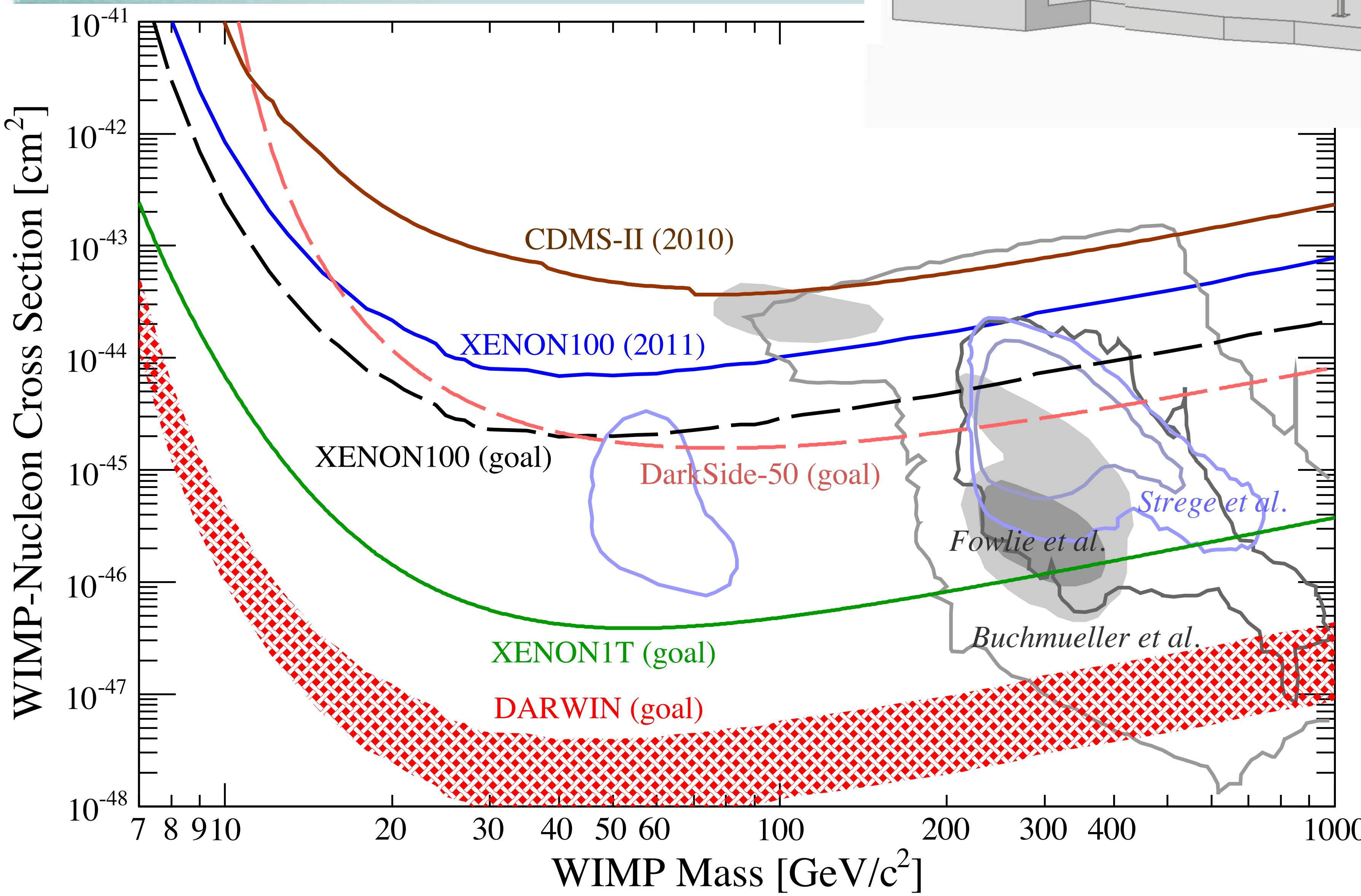


CRESST-II arXiv:1109.0702

DARWIN

Multi-Ton scale Liquid Xenon+Liquid Argon Direct Detection Experiment

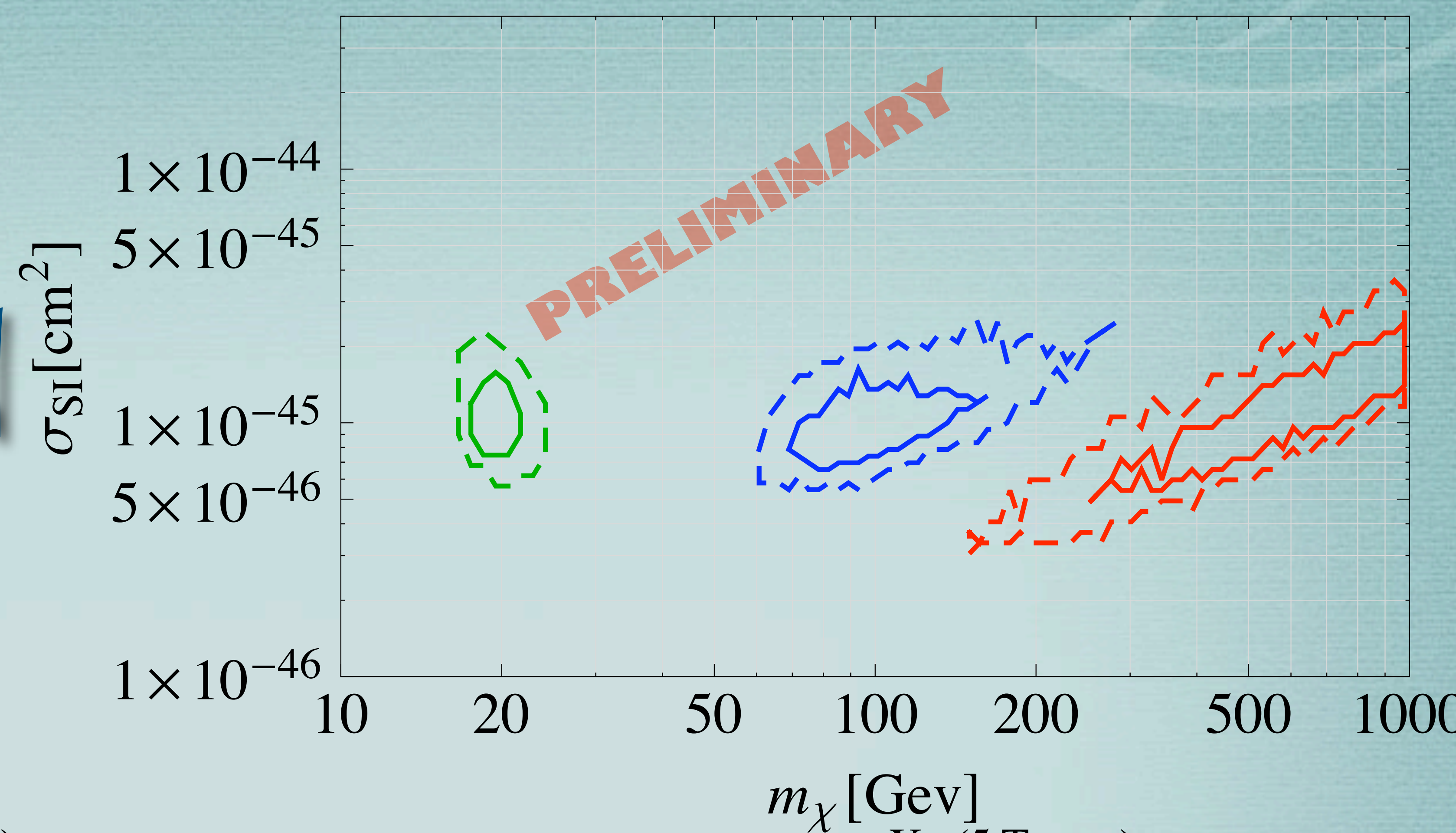




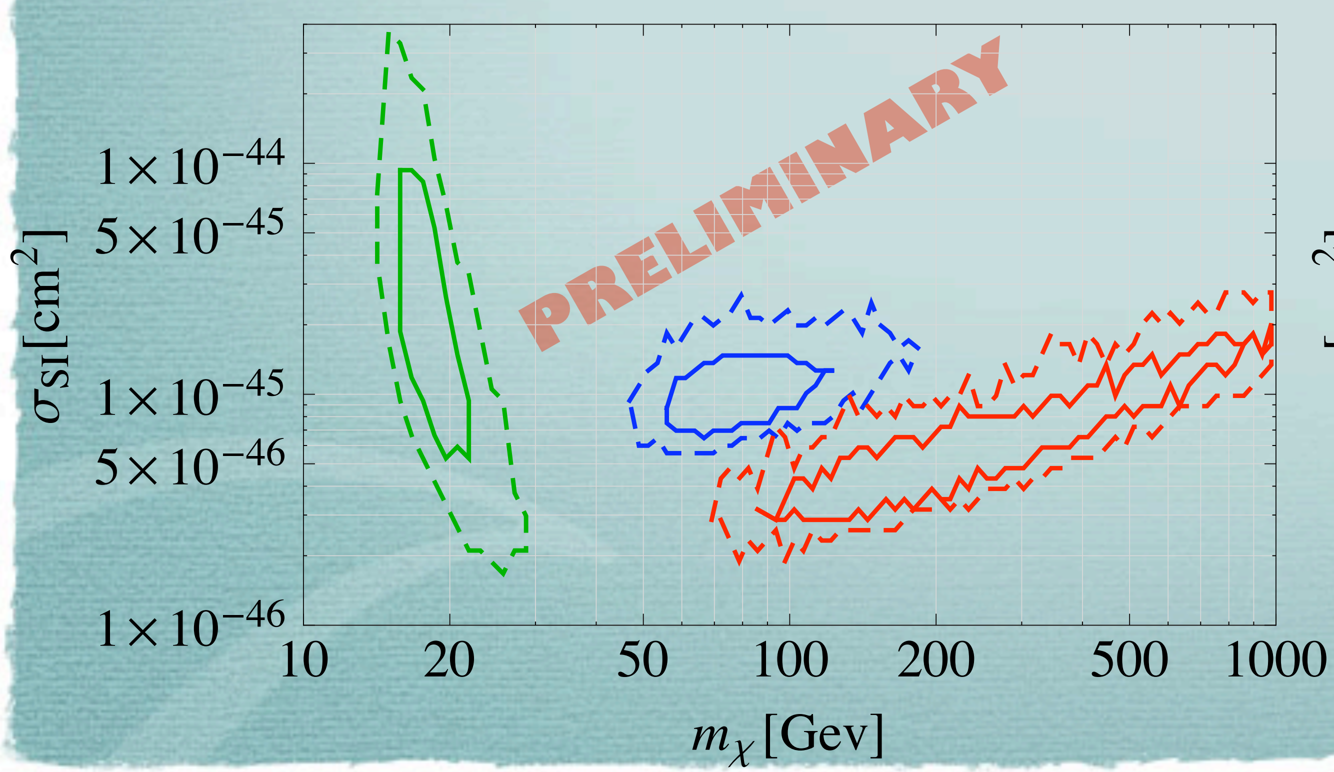
DARWIN

Thanks to Jayden Newstead

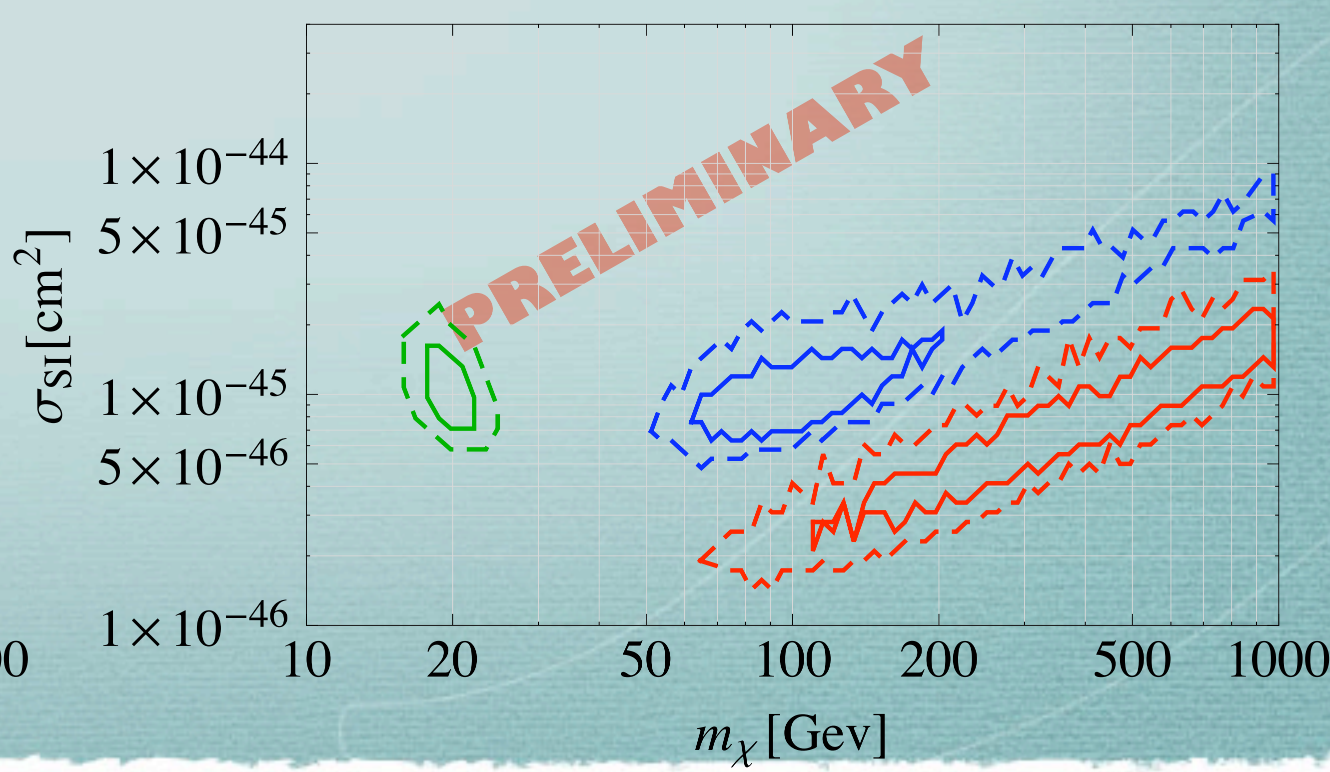
Xe (5 T year) + Ar (10 T year)



Ar (10 T year)



Xe (5 T year)



Indirect Detection

- DM annihilates to standard model particles,
  Observed flux of particles provides an upper limit on the signal from DM annihilation
- Use this to find upper limit on the cross section to a particular final state
- Annihilation signal from a nearby source:

$$\frac{d\Phi}{dE} = \frac{\langle \sigma_A v \rangle \mathrm{Br}}{2} \frac{\mathcal{J}_{\Delta\Omega}}{\mathrm{J}_0} \frac{1}{4\pi m_\chi^2} \frac{dN}{dE}$$

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Thermally averaged cross section,

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Thermally averaged cross section,

The spectrum per annihilation

Indirect Detection

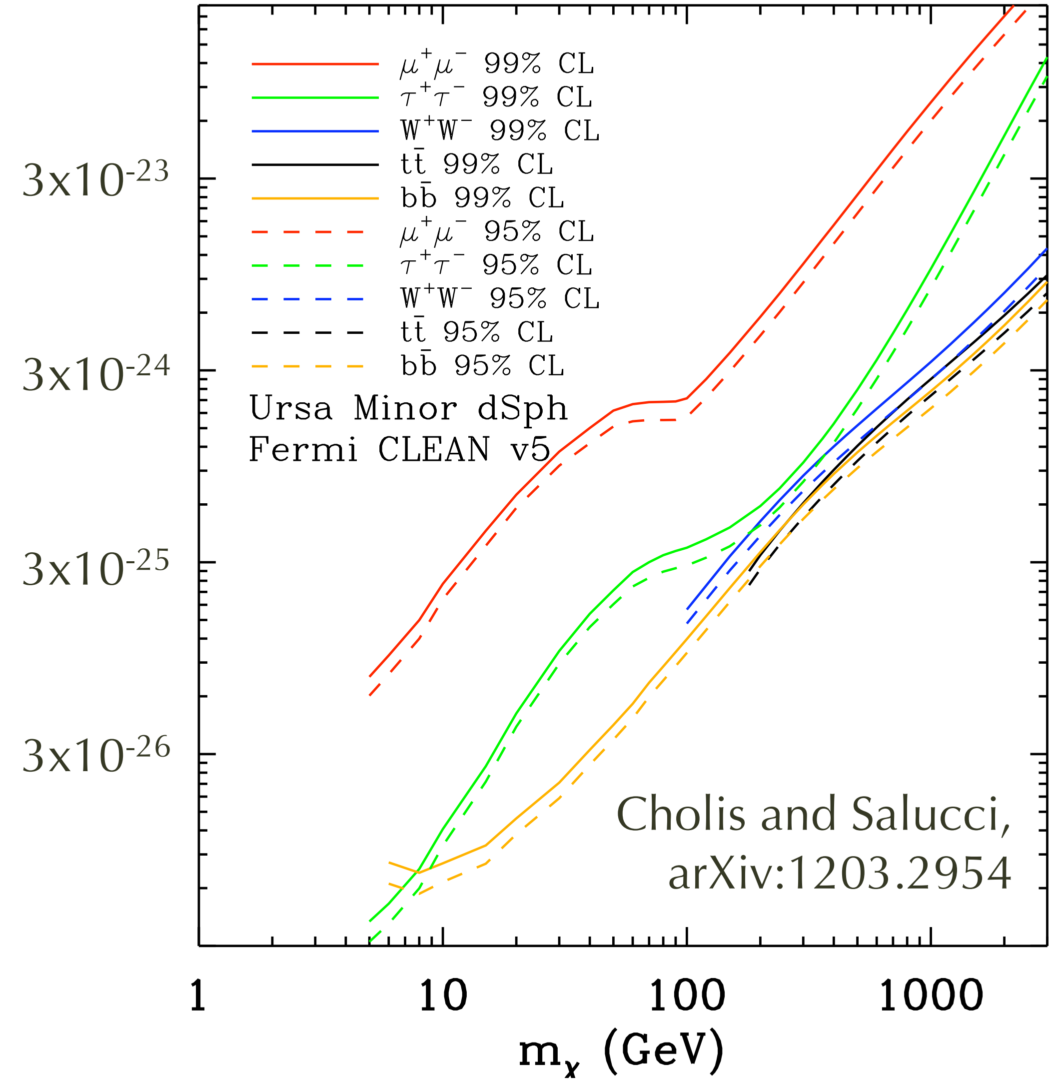
- Look for unexplained excesses, lines
- Great way to test models
- Can be robust, model independent

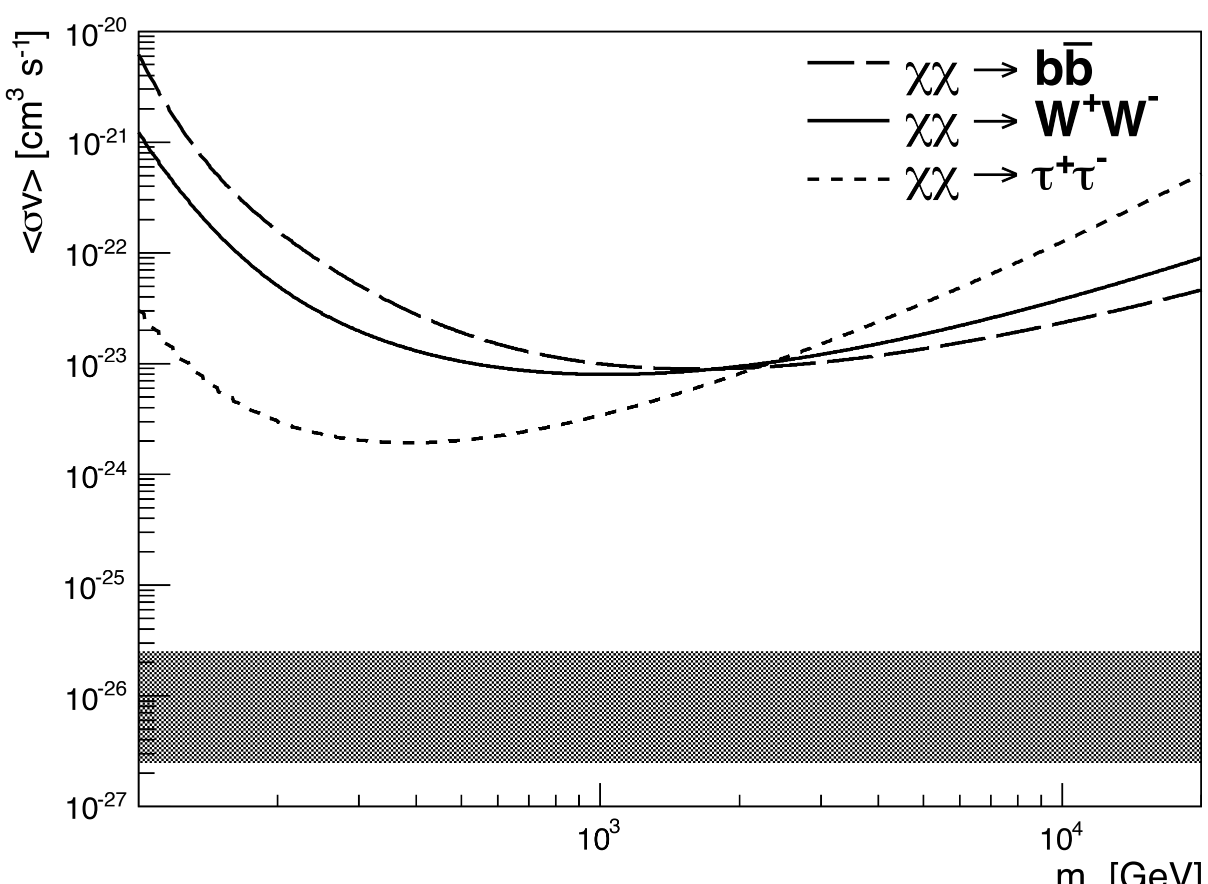
- Can't constrain total annihilation cross section
- Hard to find a 'smoking gun'
- Astrophysical backgrounds and uncertainties

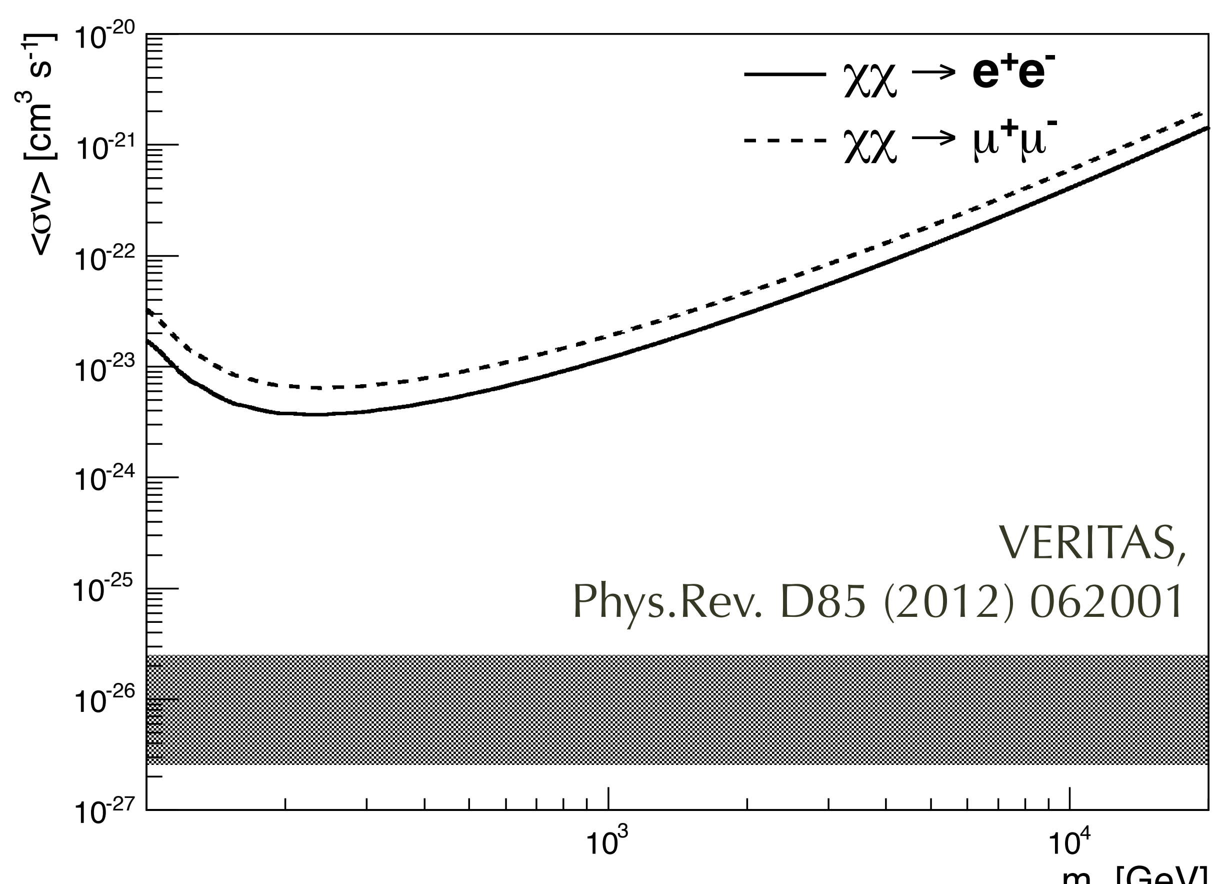
$\langle \sigma_A v_{\rm rel} \rangle$

$[\mathrm{cm}^3\, \mathrm{s}^{-1}]$

Indirect Detection

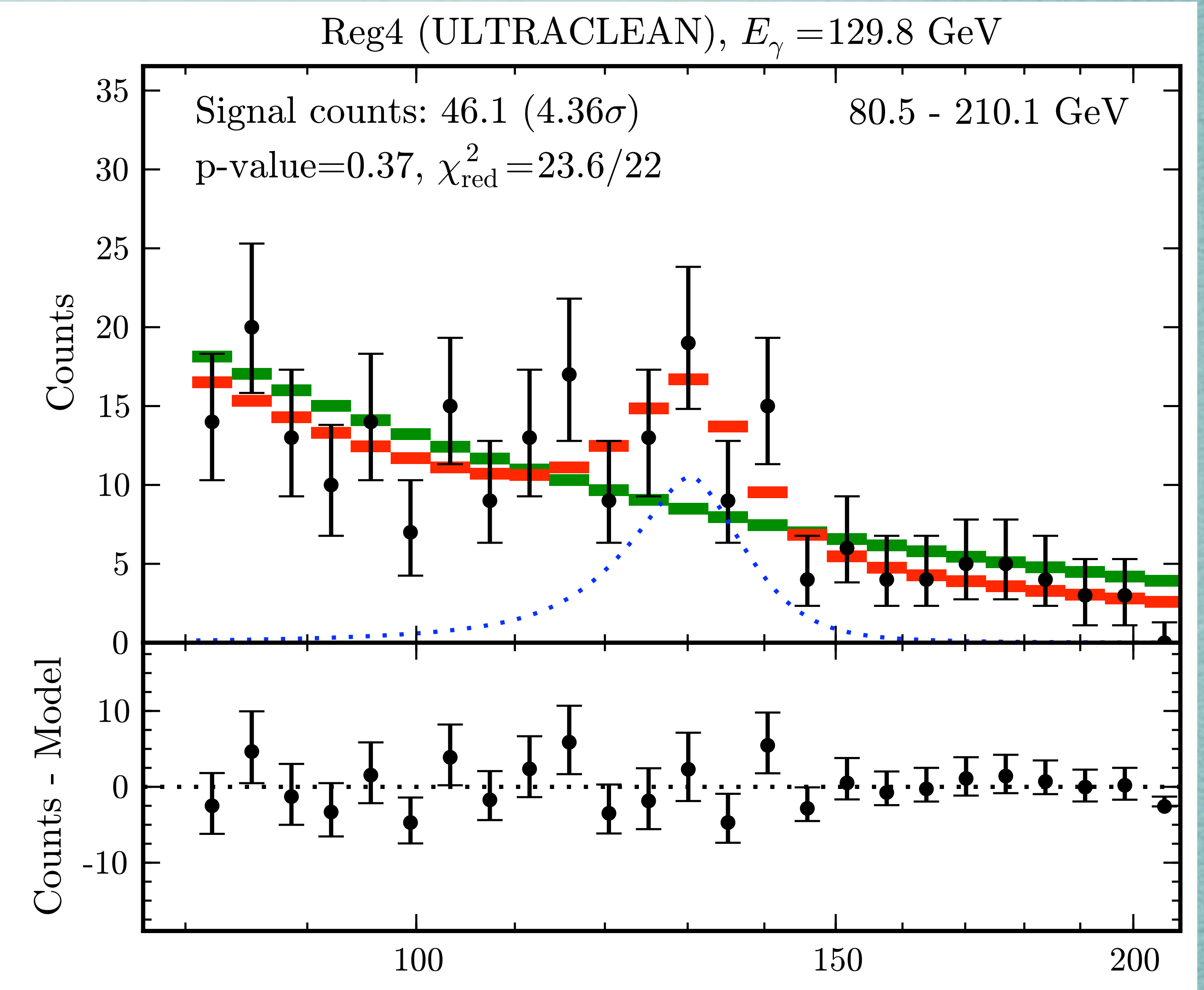






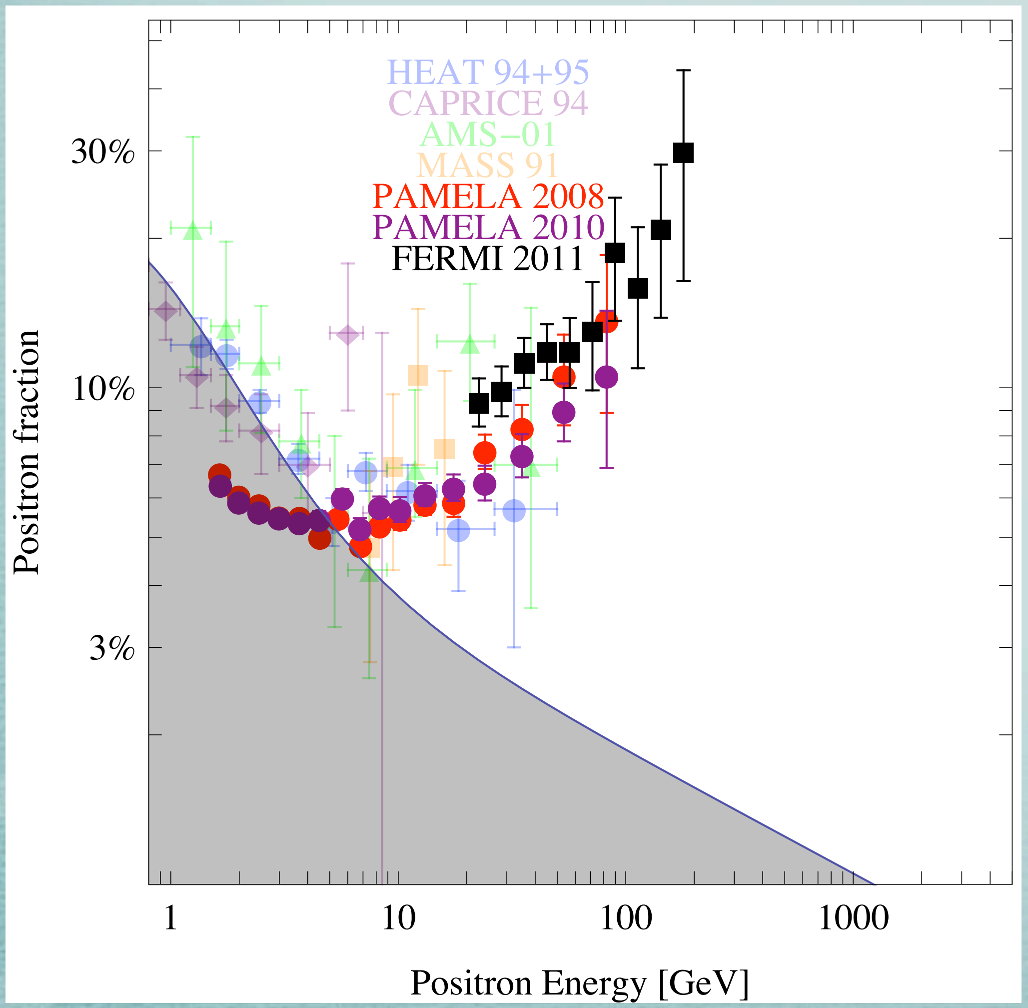
Fermi γ-ray Line

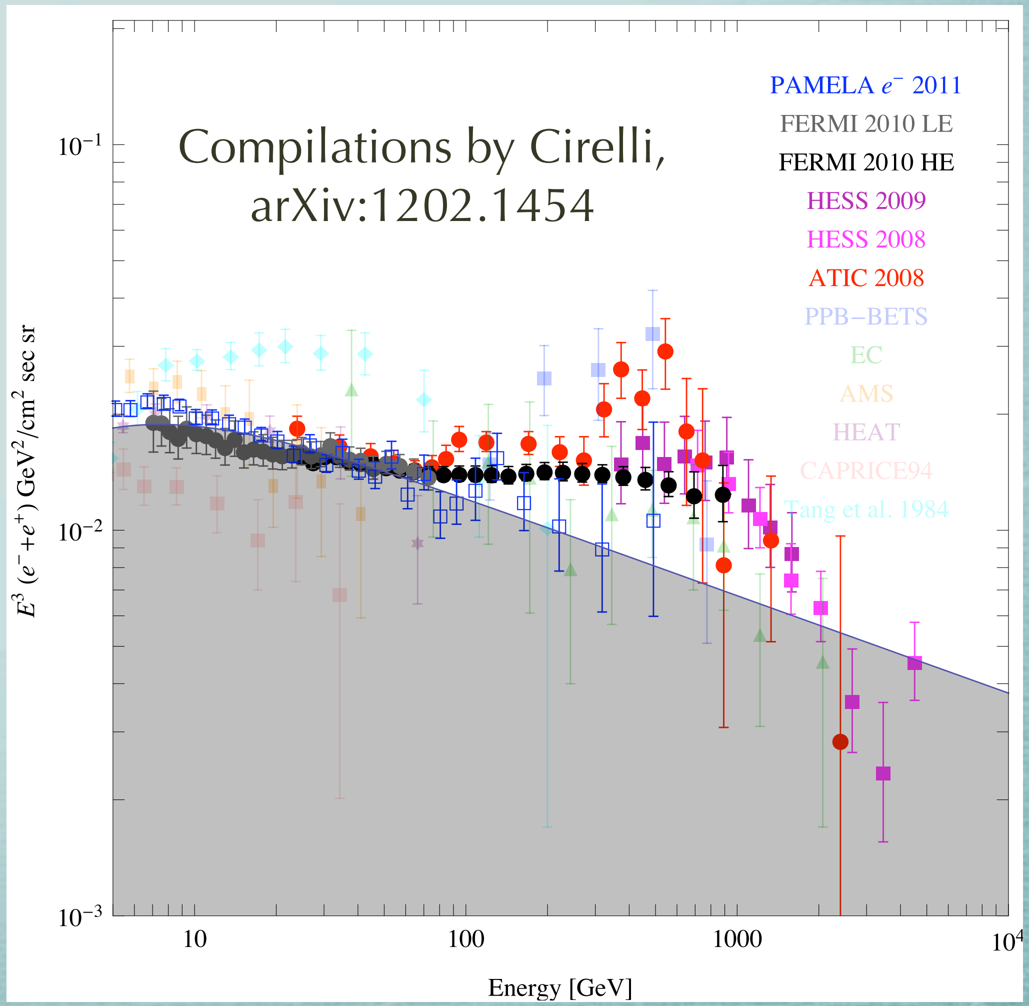
- 3.3σ evidence for a γ-ray line at 130 GeV towards GC
- Dark matter, systematic effect, new background?



Weniger, arXiv:1204.2797

Positron Excess





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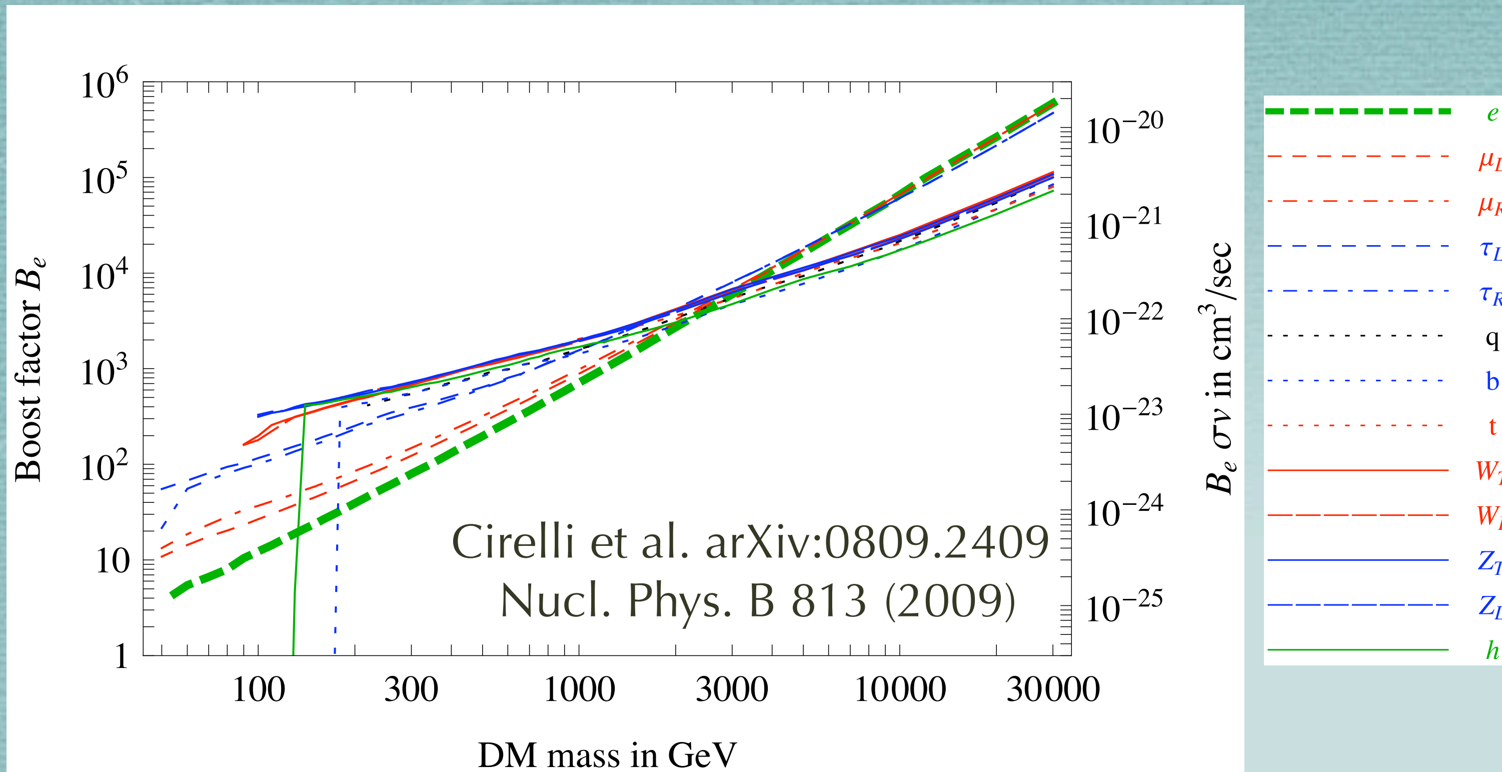
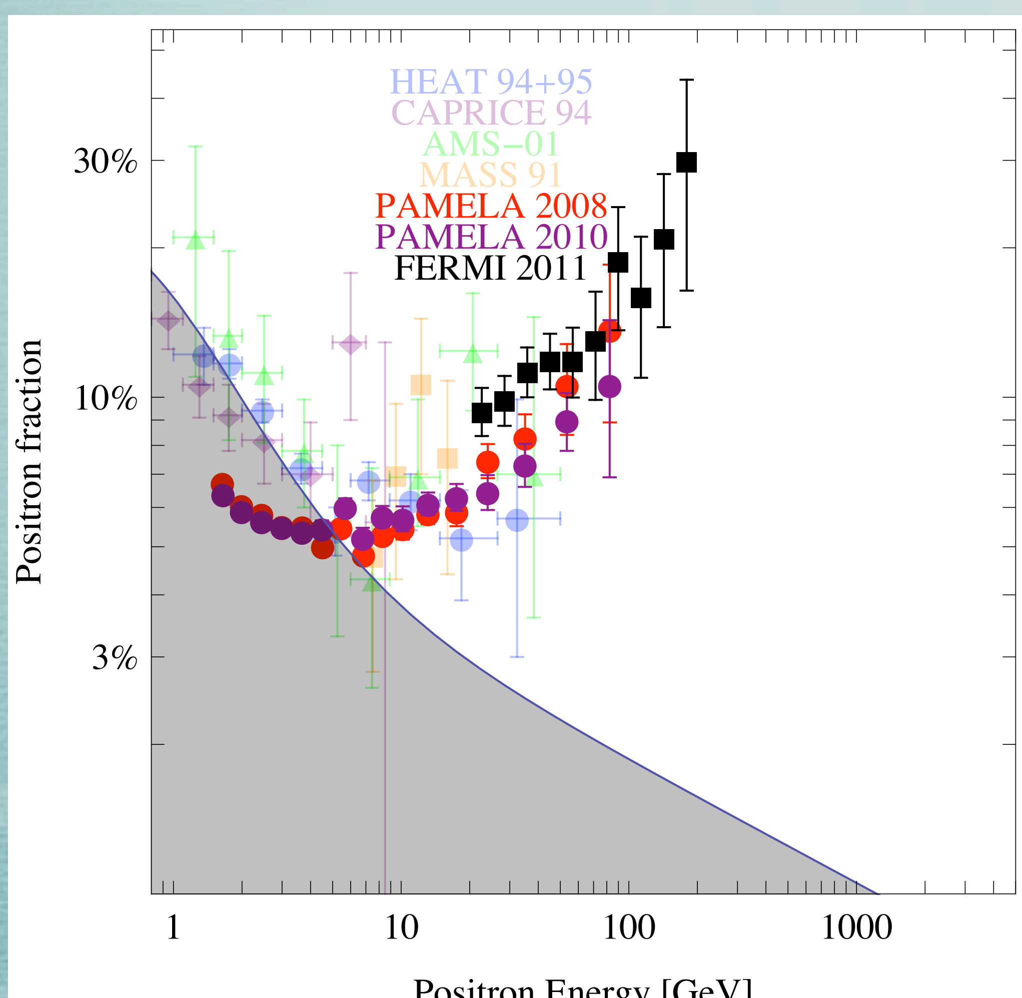
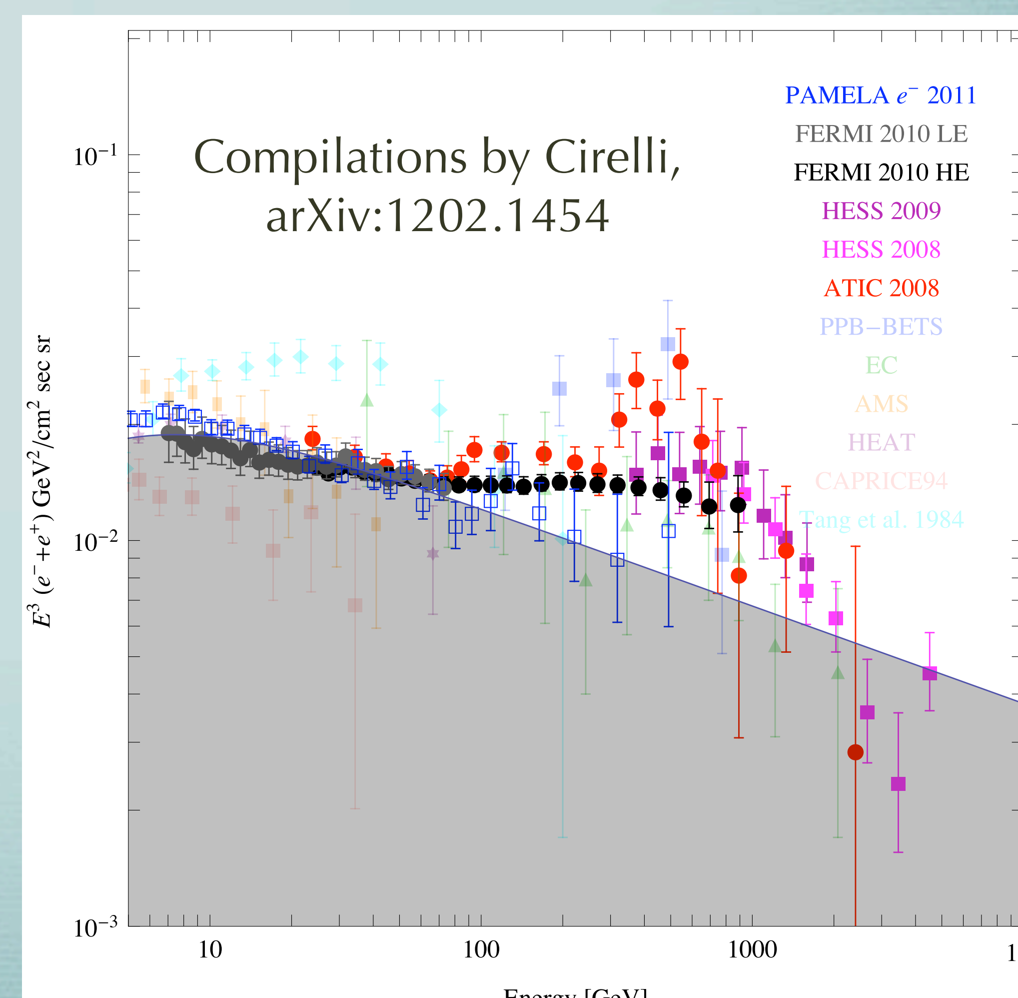
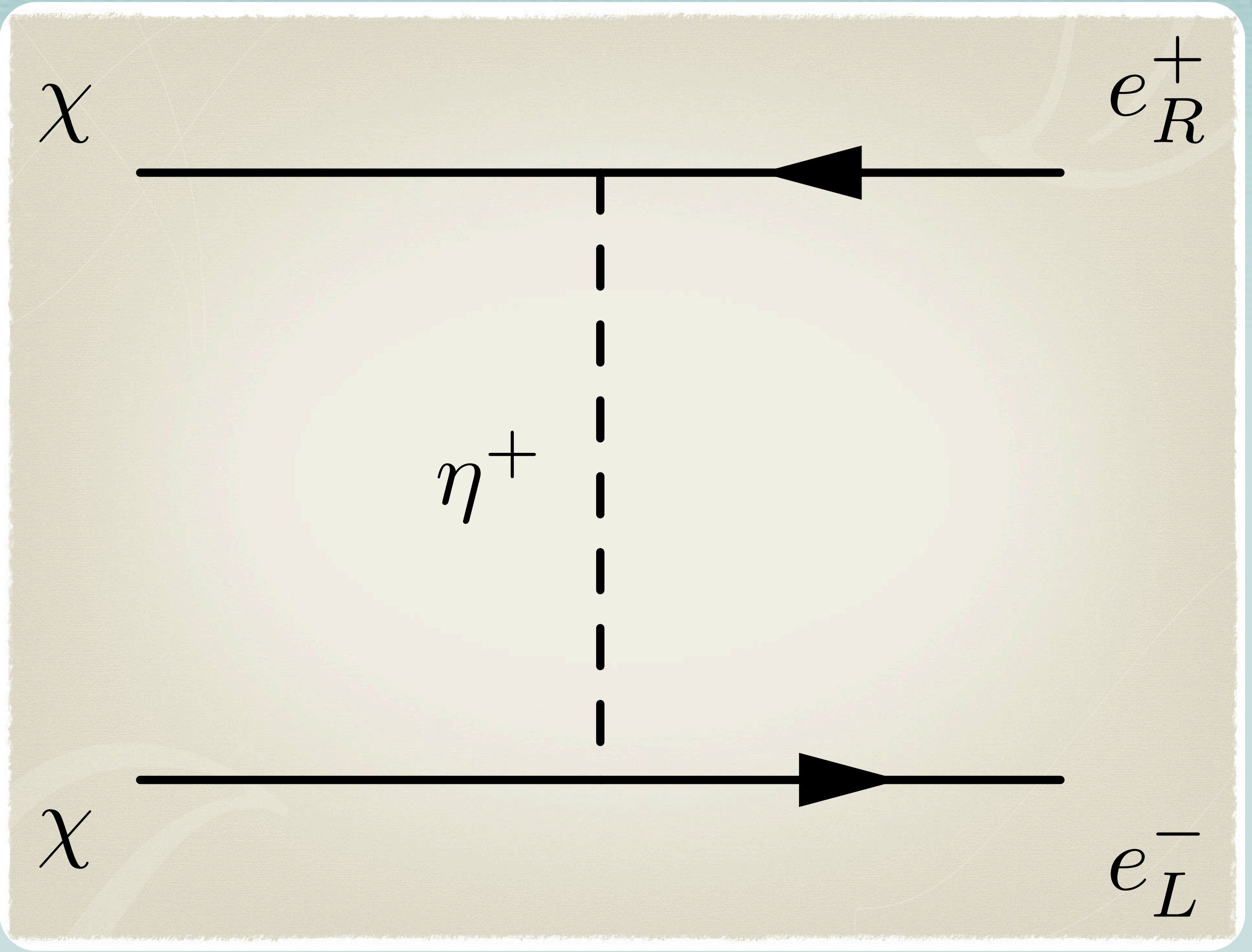






Leptophilic Model



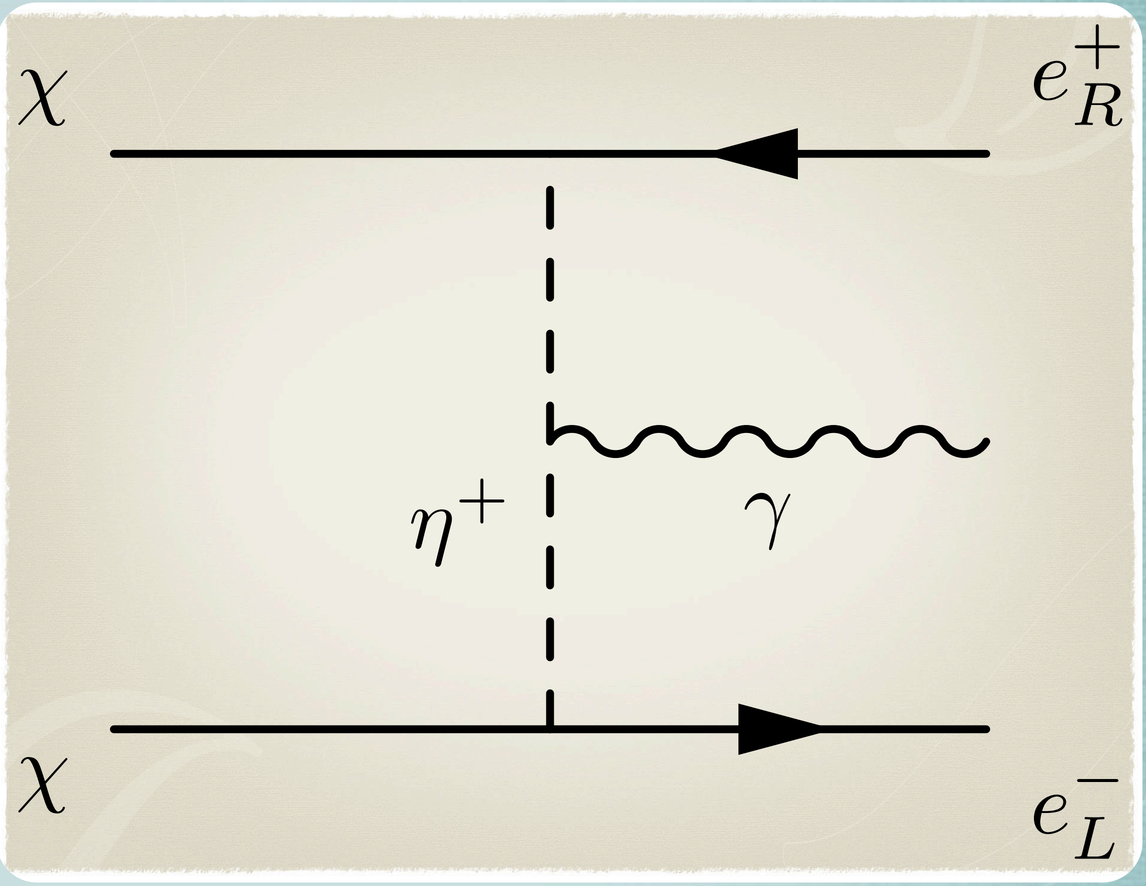
$$\langle \sigma v \rangle = \left(\frac{m_\ell}{E_\ell} \right)^2 a + b v^2$$

Cao et al, Phys.Lett.B,**673**,152 (2009)

Leptophilic Model

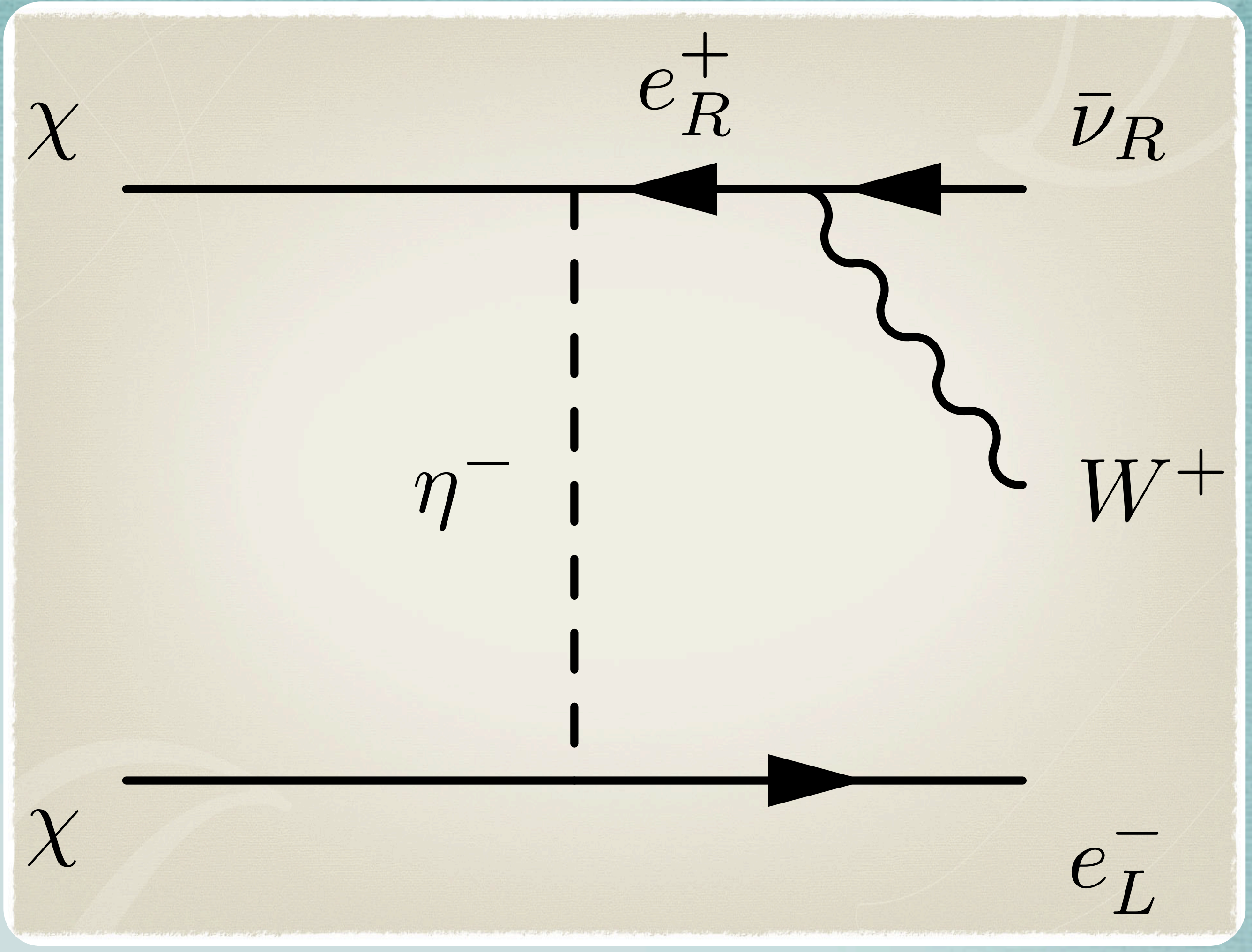
- Emission of high energy photons from the propagator can lift this suppression:

$$\chi\chi \to f\bar{f}\gamma \gg \chi\chi \to f\bar{f}$$



eg Bergstrom, Phys.Lett.B 225, 372 (1989)
Bringmann, Bergstrom, Edsjo, JHEP 0801, 049 (2008)

Electroweak Brem



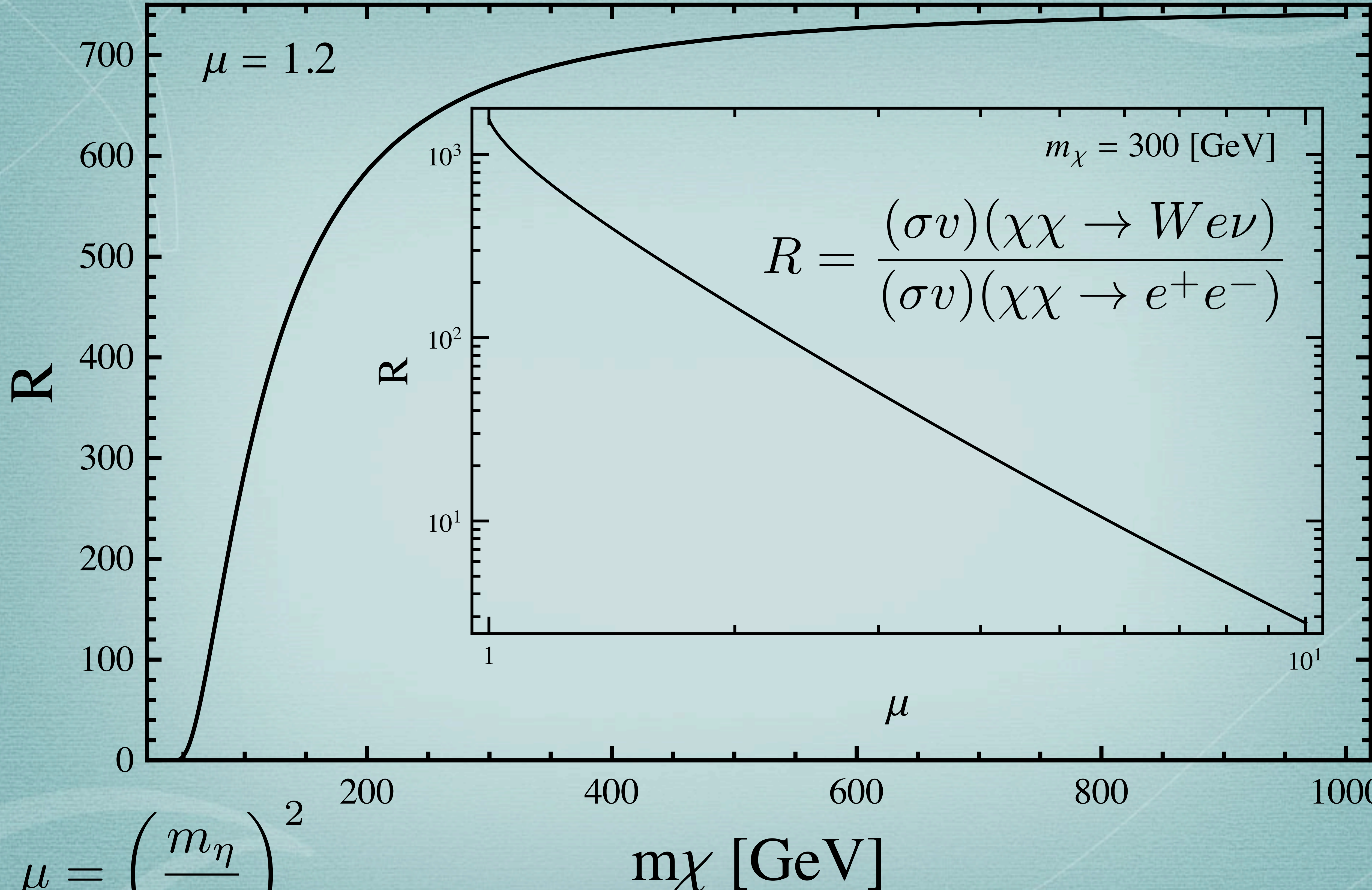
- If one of the particles emits a massive gauge boson ($W^\pm$ or Z), suppression can be lifted!
- Strongest when $\mu = \left(\frac{m_\eta}{m_\chi}\right)^2 \sim 1$

  (coannihilation region in SUSY)

- Boson carries away angular momentum, allowing the final state fermions to be in an unsuppressed spin state

from N. Bell, J. Dent, A. Galea, TJ, L. Krauss & T. Weiler; Phys.Lett. B706 (2011) 6-12

Results

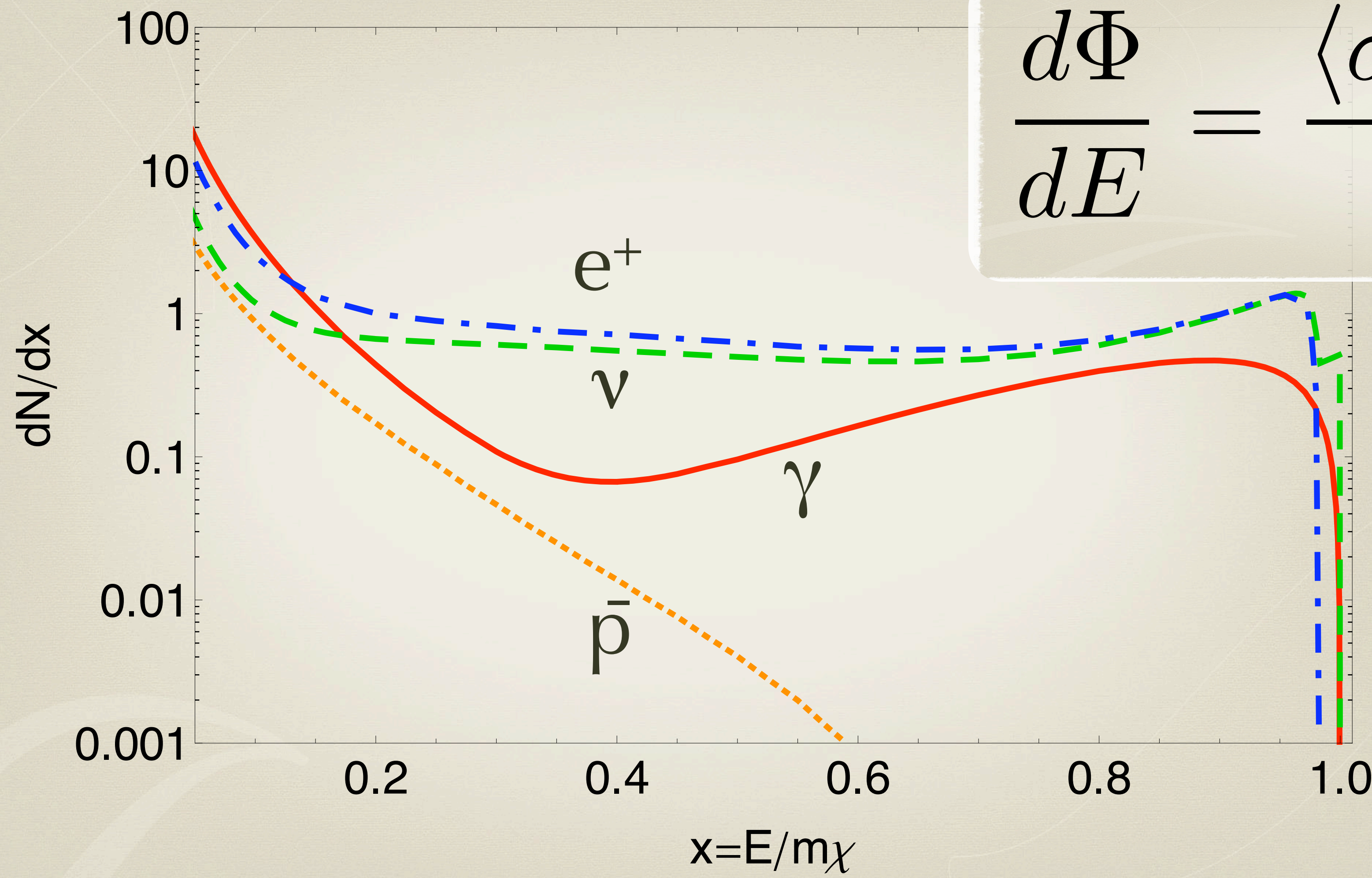


$$\mu = \left(\frac{m_\eta}{m_\chi}\right)^2$$

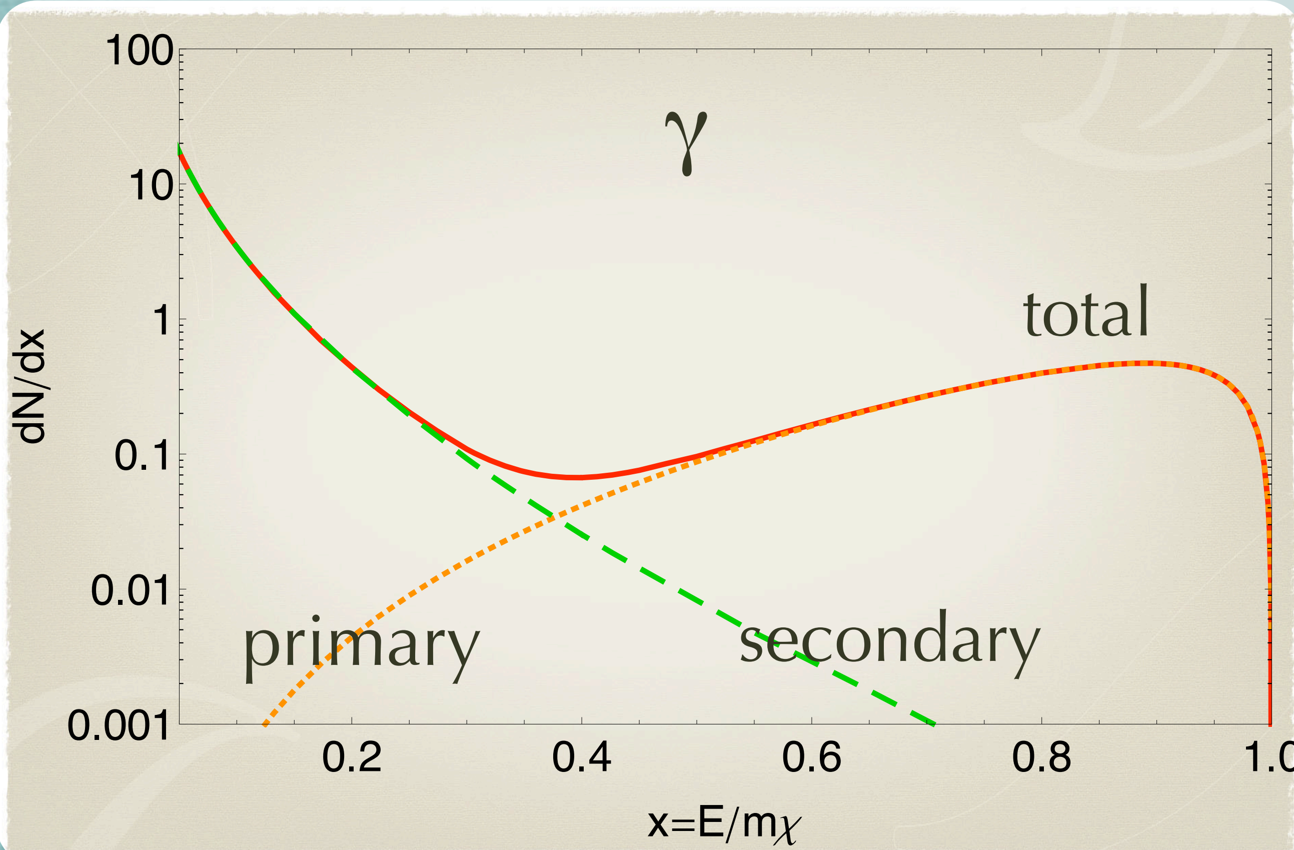
- Can this model reproduce the positron excess without overproducing hadrons?

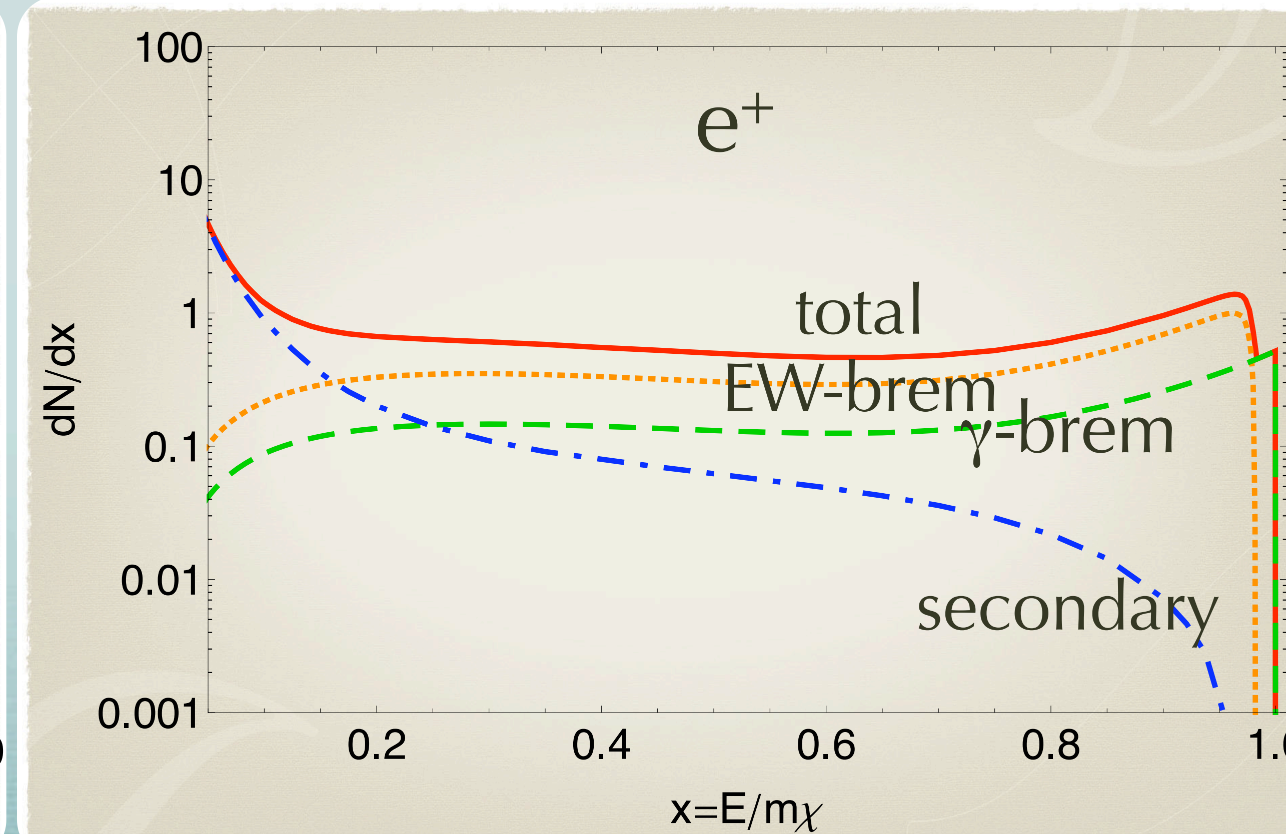
$$\frac{d\Phi}{dE} = \frac{\langle\sigma_A v\rangle \mathrm{Br}}{2} \frac{\mathcal{J}_{\Delta\Omega}}{\mathrm{J}_0} \frac{1}{4\pi m_\chi^2} \frac{dN}{dE}$$

Spectra



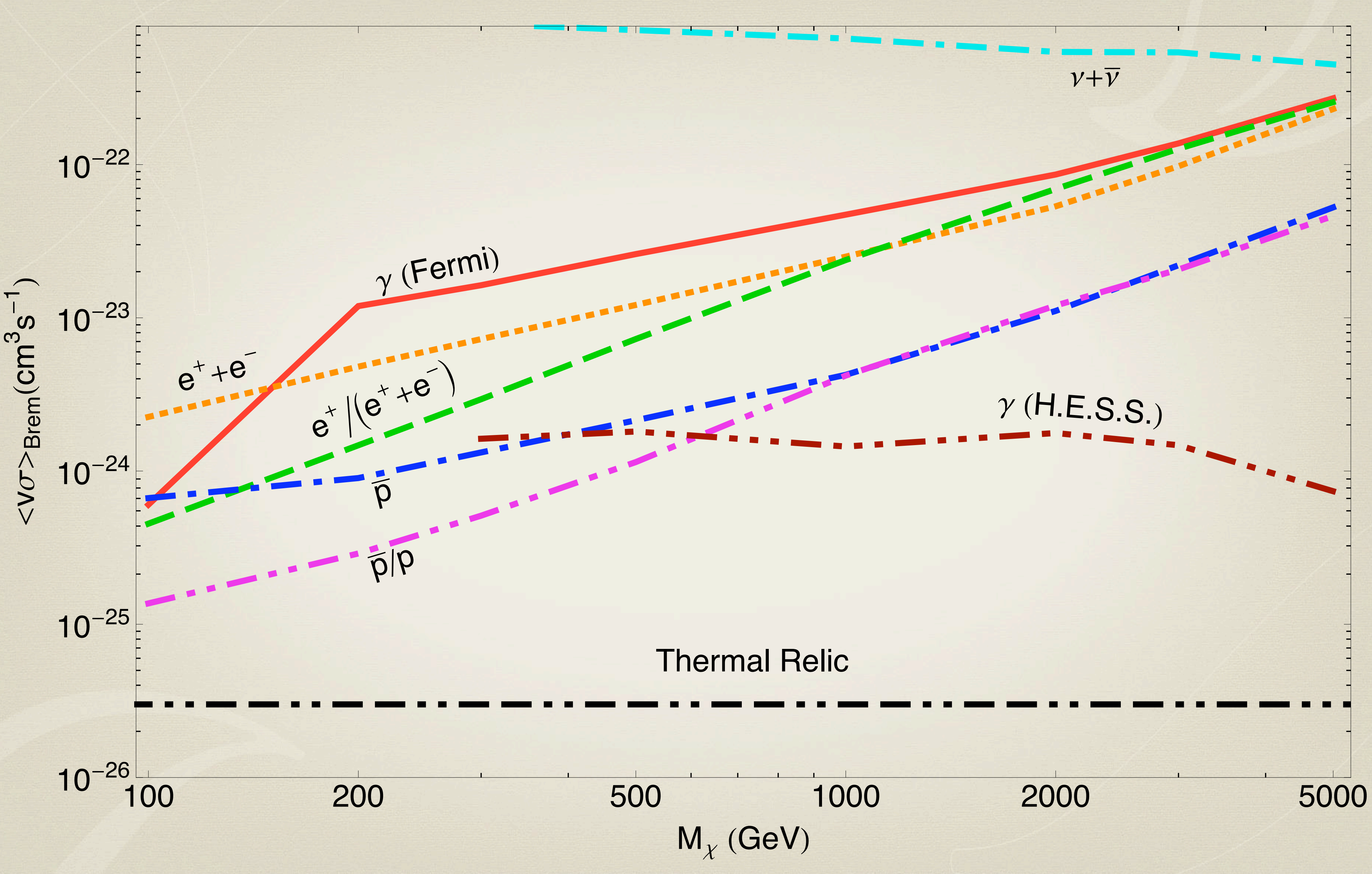
N. Bell, J. Dent, TJ & T. Weiler;
Phys.Rev. D84 (2011) 103517





Constraints

Flux is an upper limit on the signal - Use to find upper limit on $\langle \sigma v \rangle_{\rm Brem}$

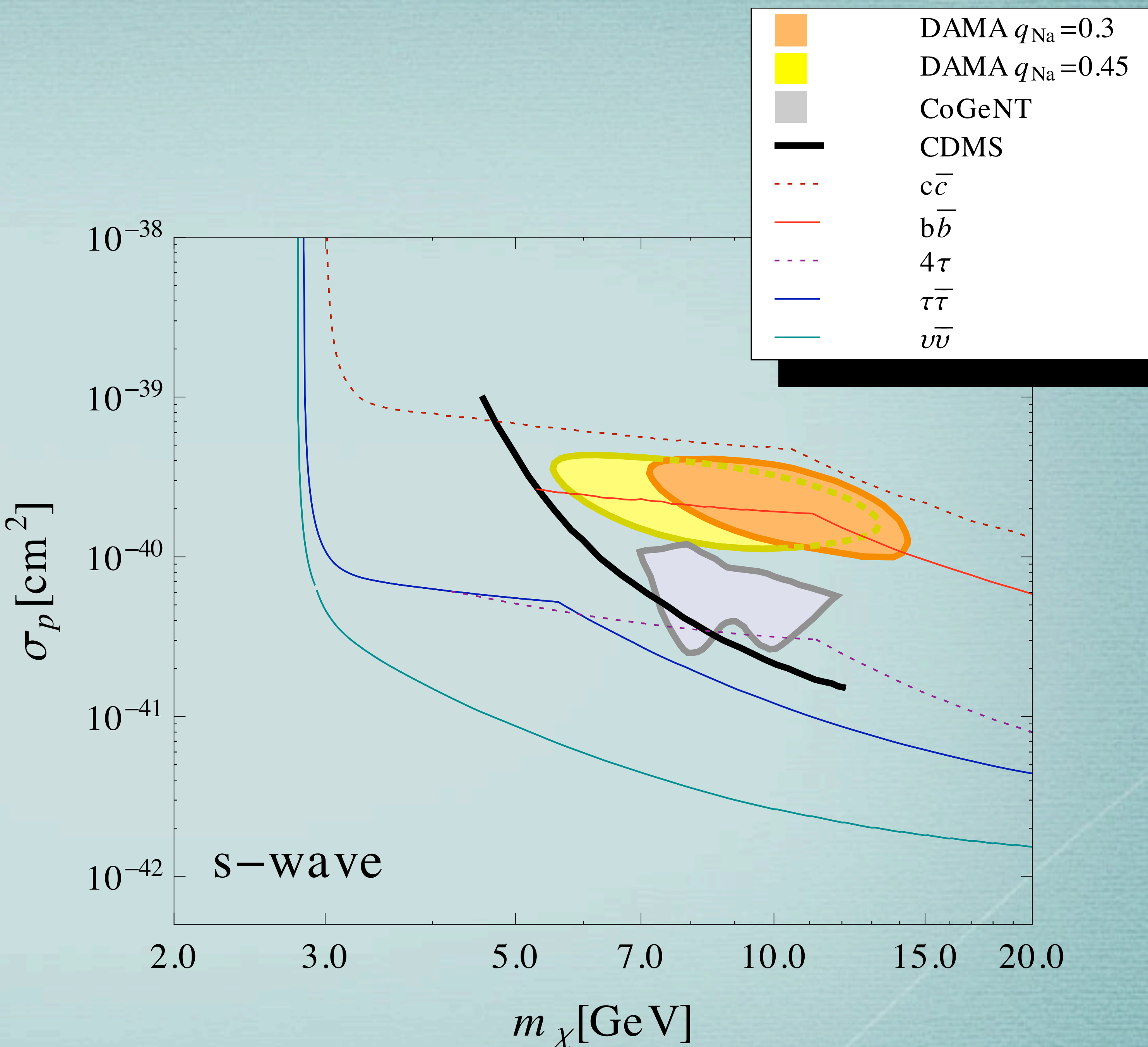


Complementarity

- Candidate signals indicate masses or final states of interest in other experiments, informing future studies in other searches
- Astrophysical and cosmological constraints on DM density reduce uncertainties in both direct and indirect detection

Complementarity

- DM scattering in the Sun can lead to neutrino fluxes from DM annihilation; Requires both direct and indirect detection techniques



Kappl and Winkler, arXiv:1104.0679
Nucl.Phys.B850:505-521,2011

Conclusion

- Search for Dark Matter and its properties is ongoing
- Some tantalizing candidate signals!
- Challenges abound, but future prospects are good