Direct Detection:

Where Are We and Where Are We Going?

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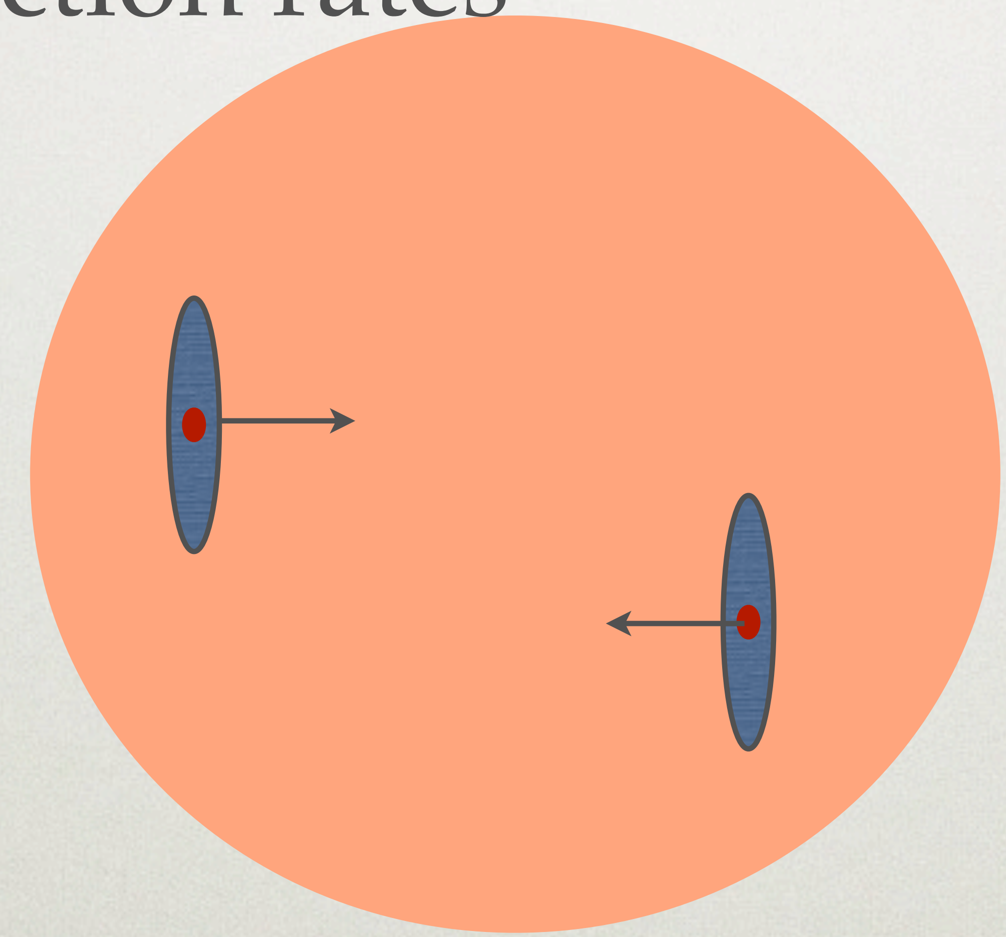
Why the (sub-)Weak Scale is Compelling

- Abundance of new stable states set by interaction rates



Freeze-out

Measured by WMAP + LSS

$$\Gamma = n\sigma v = H \qquad \Longrightarrow \sigma \sim \frac{1}{(100\mathrm{GeV})^2}$$

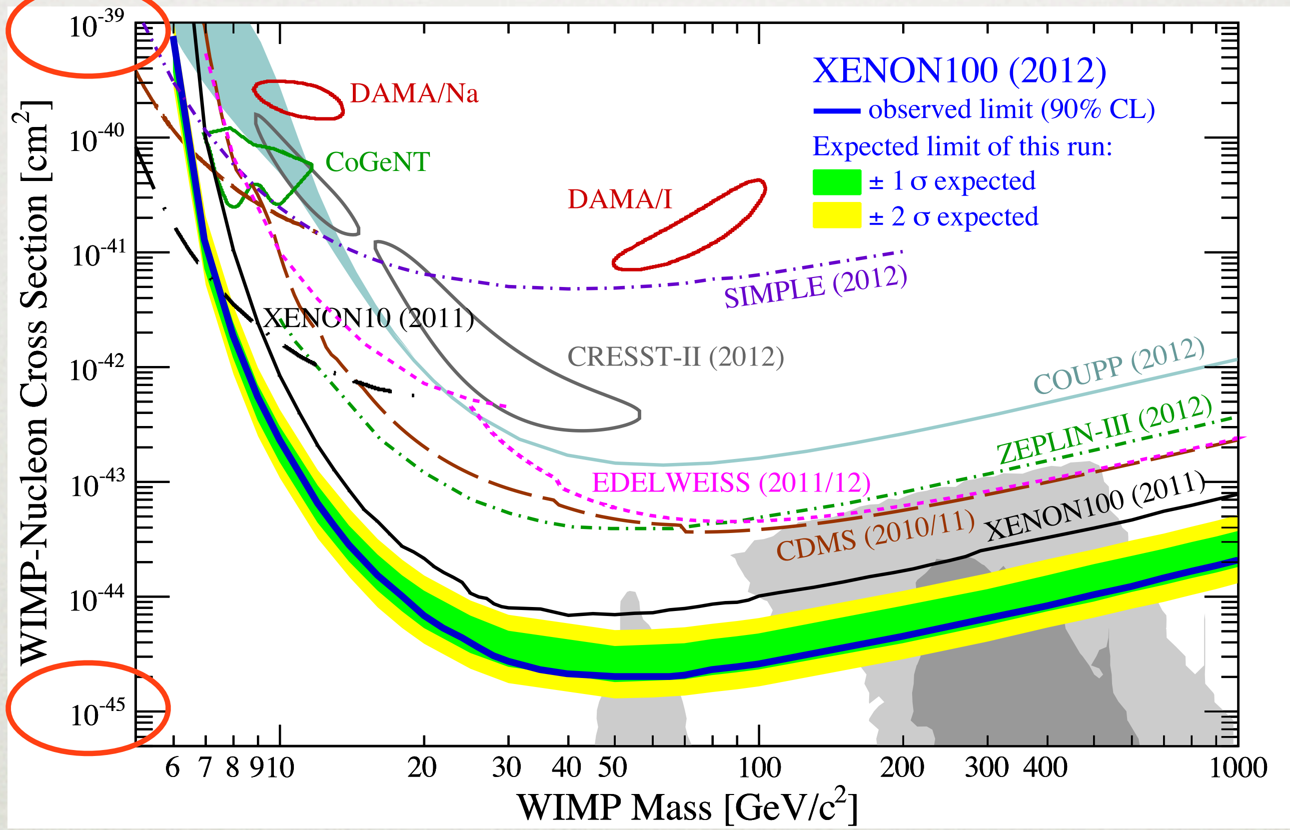
Idea Focus: Supersymmetry

- Provides sharp predictions
- Must be neutral $\tilde{\nu}$ $\tilde{B},\ \tilde{W}_3,\ \tilde{H}$
- Sneutrino scatters through Z
- Neutralino does not because operator vanishes identically for Majorana fermion $\bar{\chi}\gamma^\mu\chi\bar{N}\gamma_\mu N$

Sub-Weakly Interacting Massive Particles

Scattering through the Z boson: ruled out

$$\sigma_n \sim 10^{-39} \text{ cm}^2$$

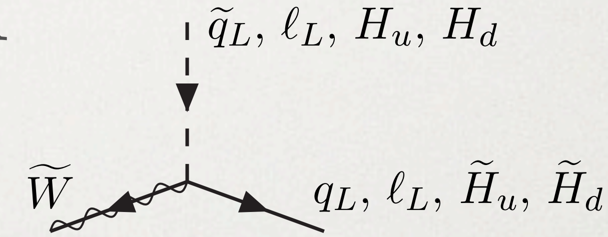


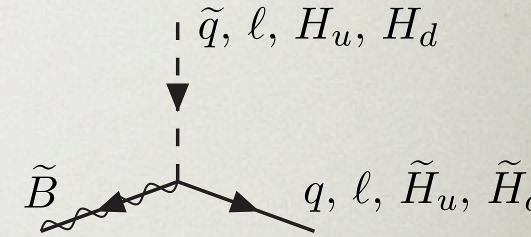
Next important benchmark:
Scattering through the Higgs

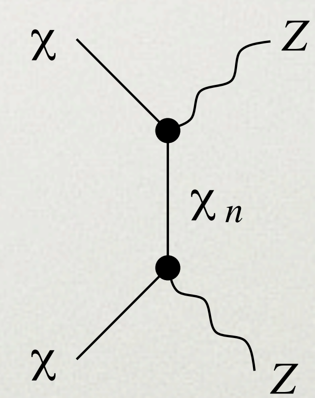
$$\sigma_n \sim 10^{-45-46} \text{ cm}^2$$

Are there ways around for the Neutralino?

- Make the Neutralino a pure state -- coupling to Higgs vanishes
- However, Wino and Higgsino pure states can be probed by indirect detection







Large!

$$\langle \sigma v \rangle \sim \left(\frac{2\ \text{TeV}}{m_\chi} \right)^2 10^{-26} \text{cm}^3/\text{s}$$

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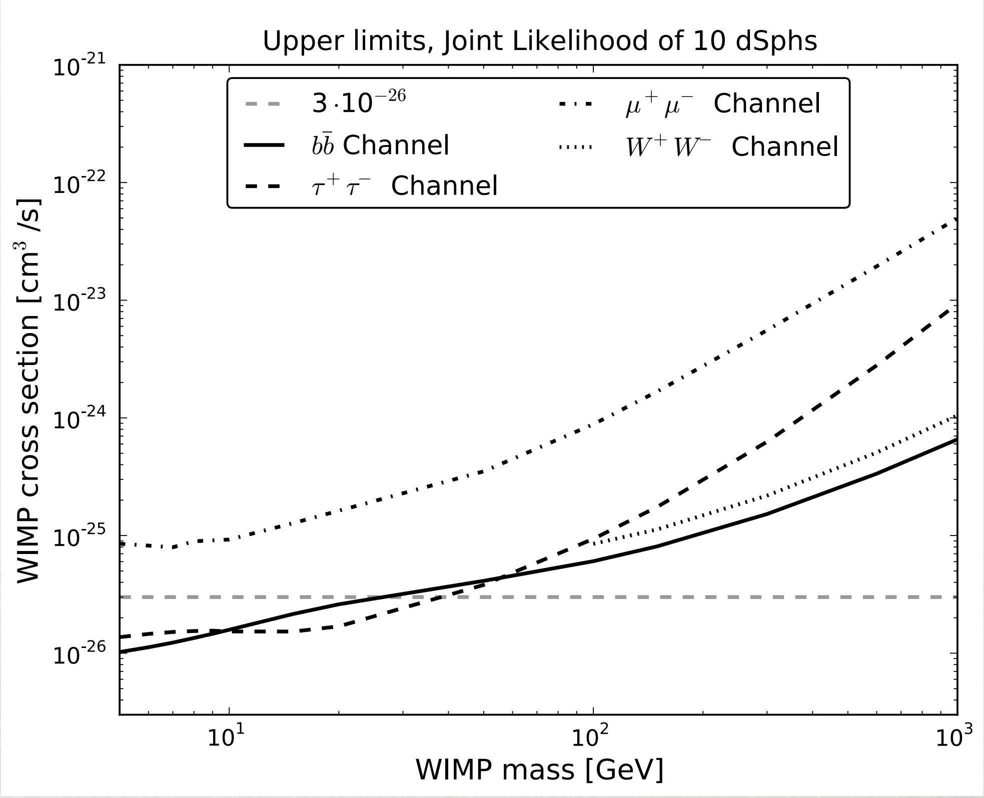

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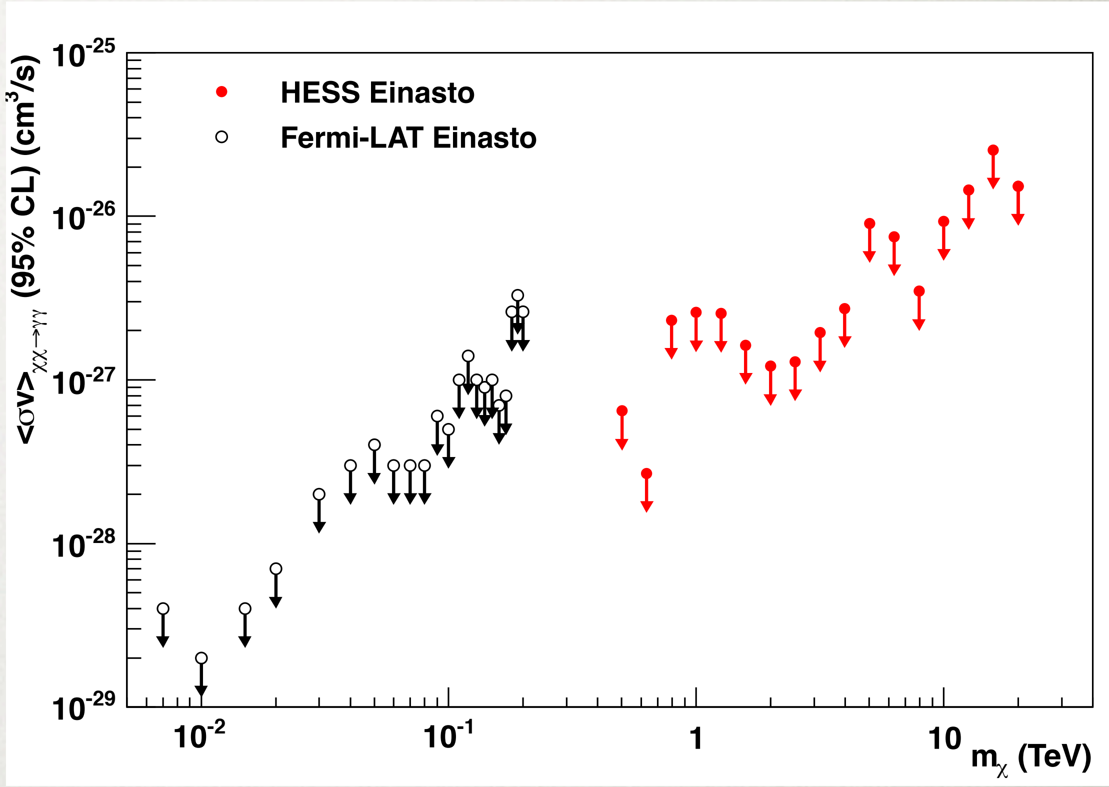
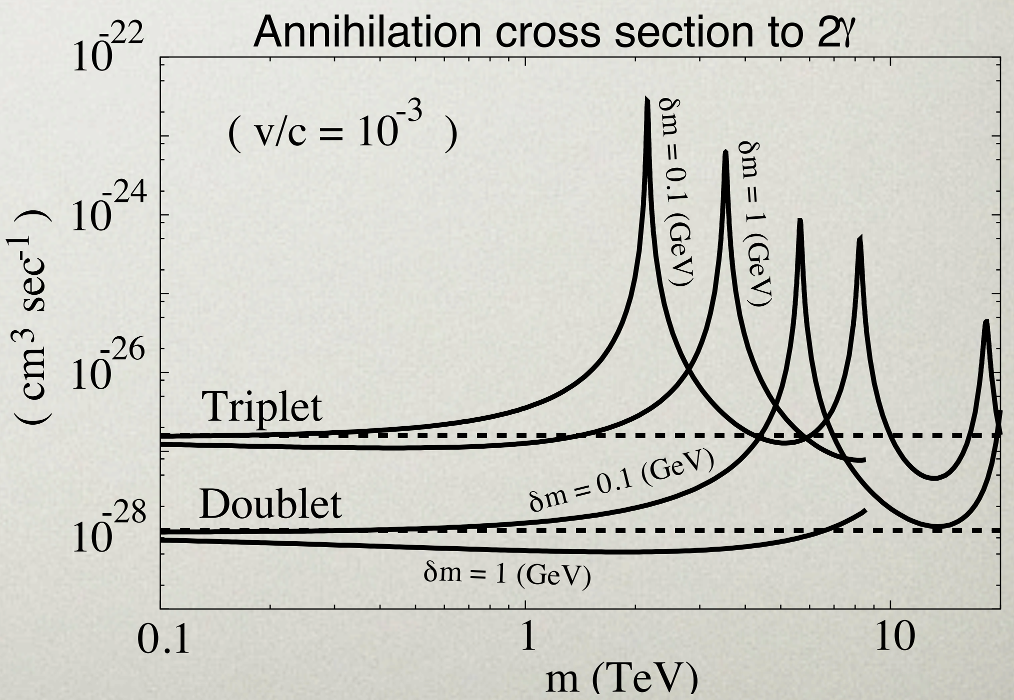
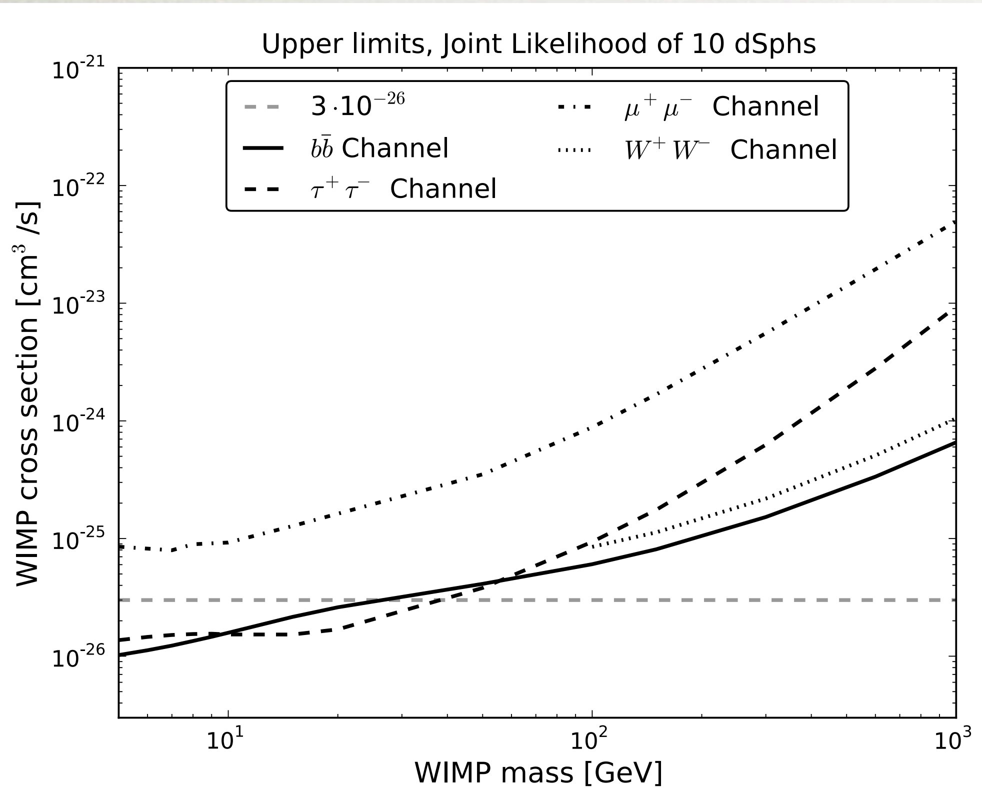
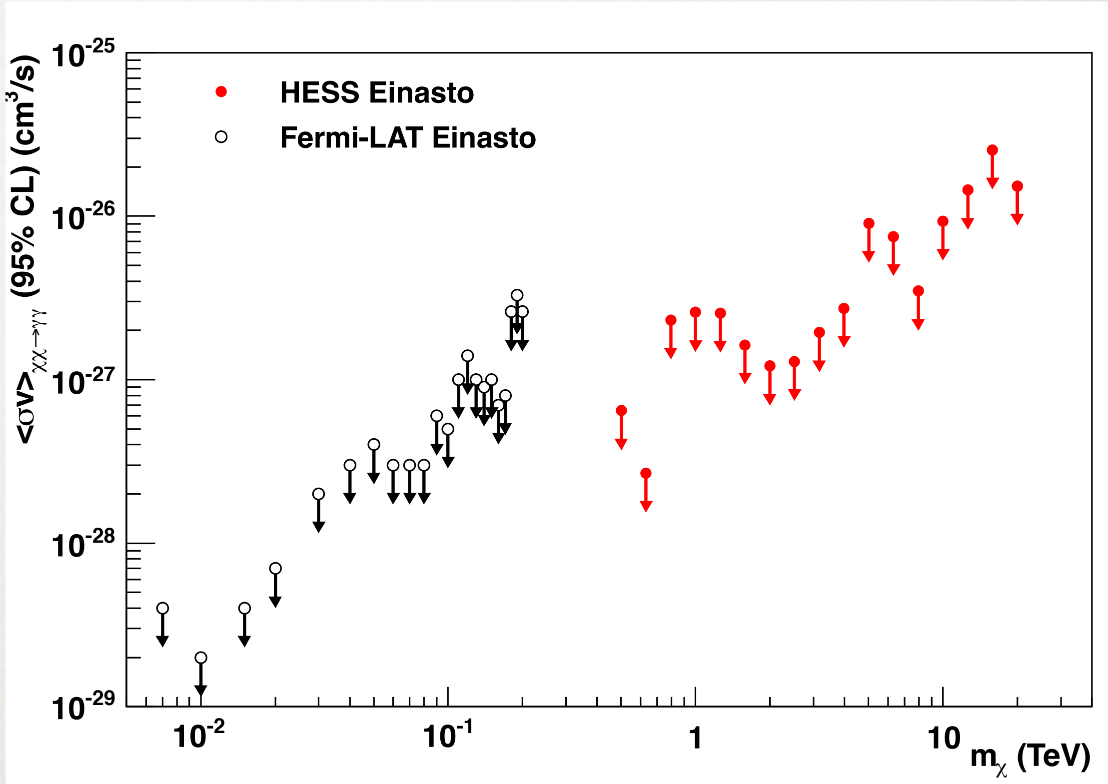




Hisano, Matsumoto, Nojiri, Saito

Are there ways around for the Neutralino?





- Bino escapes $\mu \gg M_1 \sim m_{wk}$
- Pay a fine-tuning price

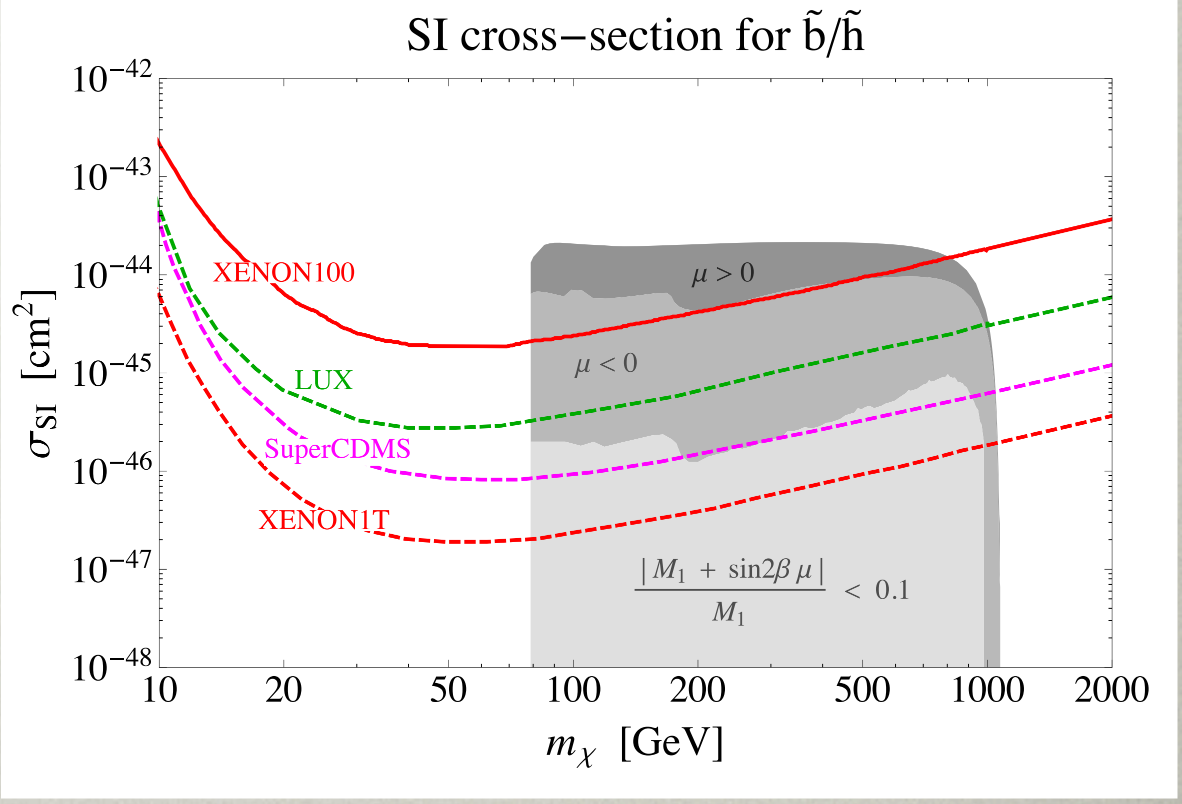
$$m_Z^2 = \frac{|m_{H_d}^2 - m_{H_u}^2|}{\sqrt{1-\sin^2(2\beta)}} - m_{H_u}^2 - m_{H_d}^2 - 2|\mu|^2$$

Are there ways around for the Neutralino?

- Tune away the coupling to the Higgs
- Smaller cross-sections correspond to more tuning in the neutralino components

m_χ	condition
M_1	$M_1 + \mu \sin 2\beta = 0$
M_2	$M_2 + \mu \sin 2\beta = 0$
$-\mu$	$\tan\beta = 1$
M_2	$M_1 = M_2$

Cheung, Hall, Pinner, Ruderman

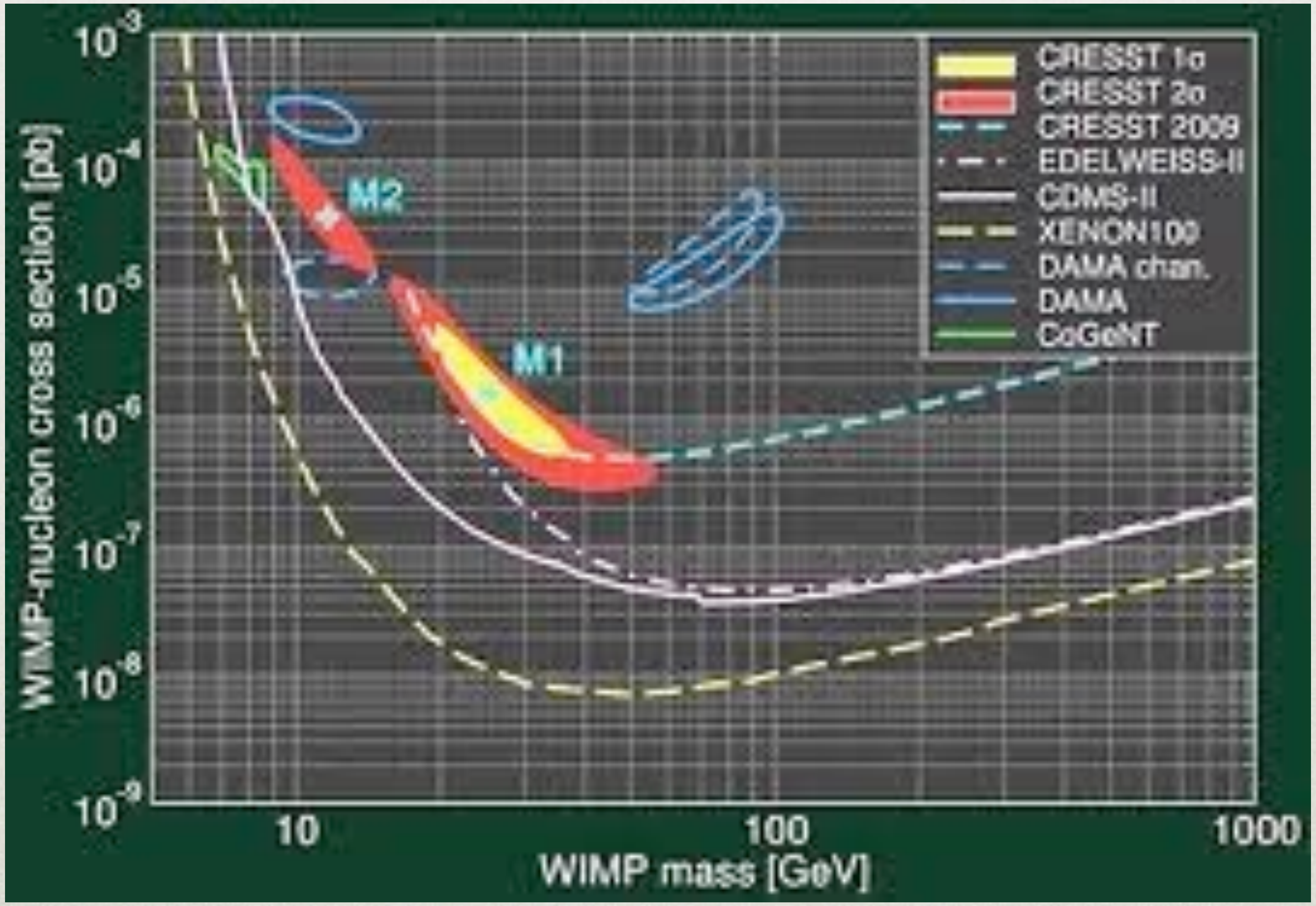


When Should We Start Looking Elsewhere?

- Cannot kill neutralino DM, but paradigm does become increasingly tuned
- Somewhat below Higgs pole -- Neutrino background?
- Well-motivated candidates that are much less costly to probe
- Light WIMPs

Current Sensitivity Limited

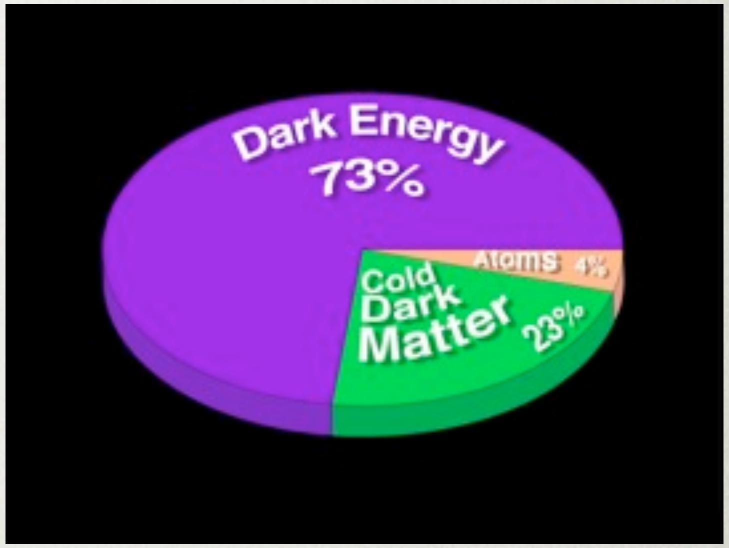
CRESST 2011



DAMA
CoGeNT
CRESST

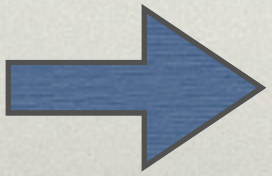
Light WIMPs: Asymmetric Dark Matter

- Standard picture: freeze-out of annihilation; baryon and DM number unrelated
- Accidental, or dynamically related?

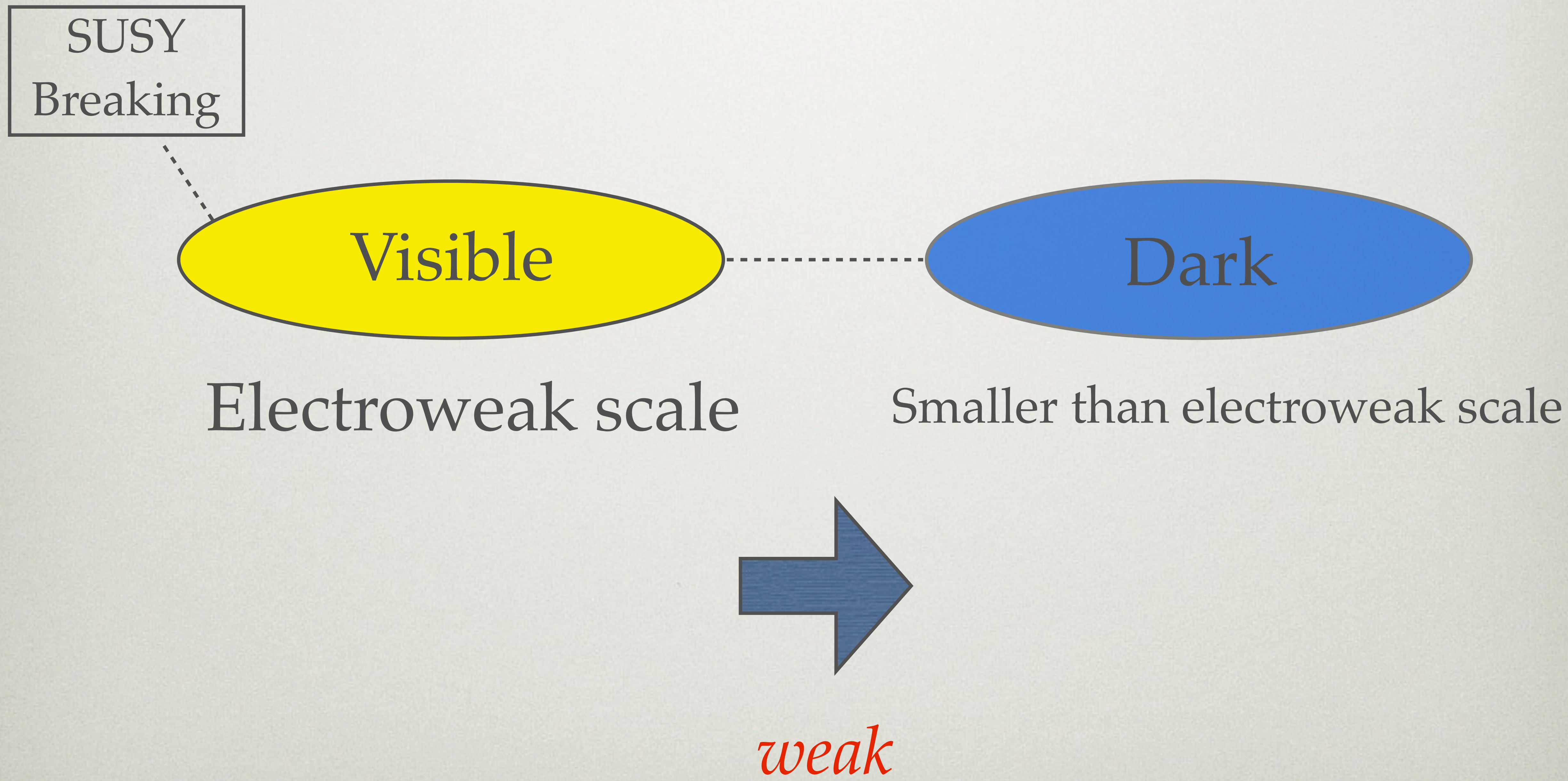


Experimentally, $\Omega_{DM} \approx 5\Omega_b$

Mechanism $n_{DM} \approx n_b$

 $m_{DM} \approx 5m_p$

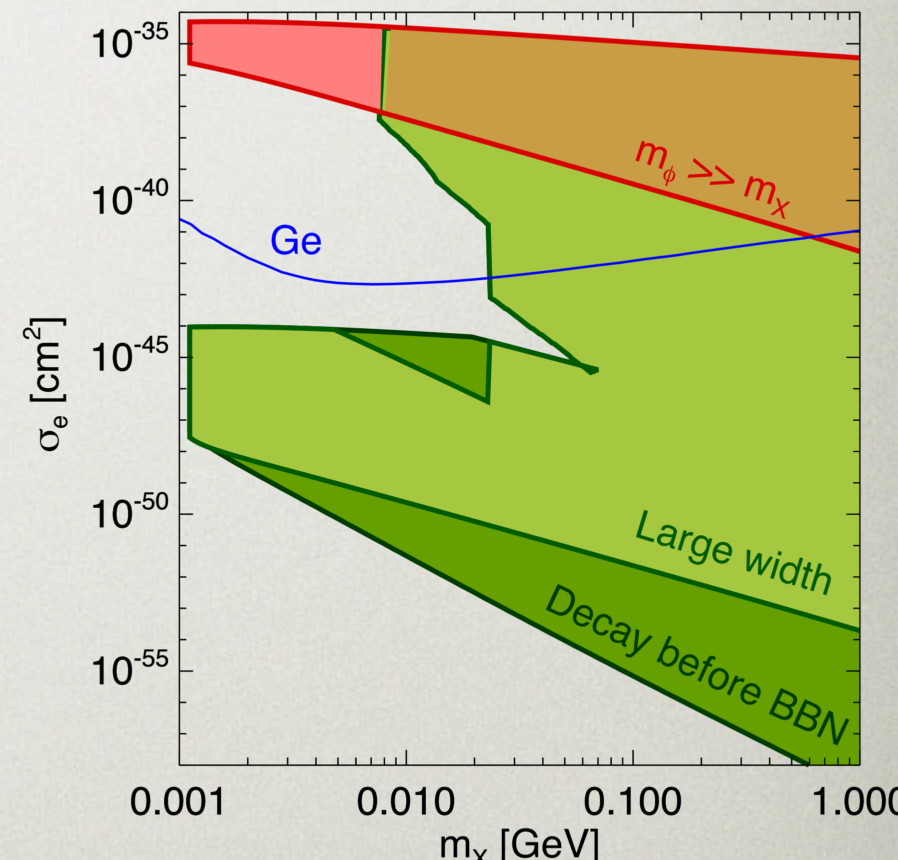
Light WIMPs: Hidden Supersymmetric DM



Hooper, KZ '08
Feng, Kumar '08
Arkani-Hamed, Finkbeiner, Slatyer, Weiner '08

Light WIMPs: Good and Bad for Direct Detection

- Good: definite mass predictions
- Bad: prediction for scattering cross-section in direct detection model dependent
- For very light DM, scattering off electrons is most important process

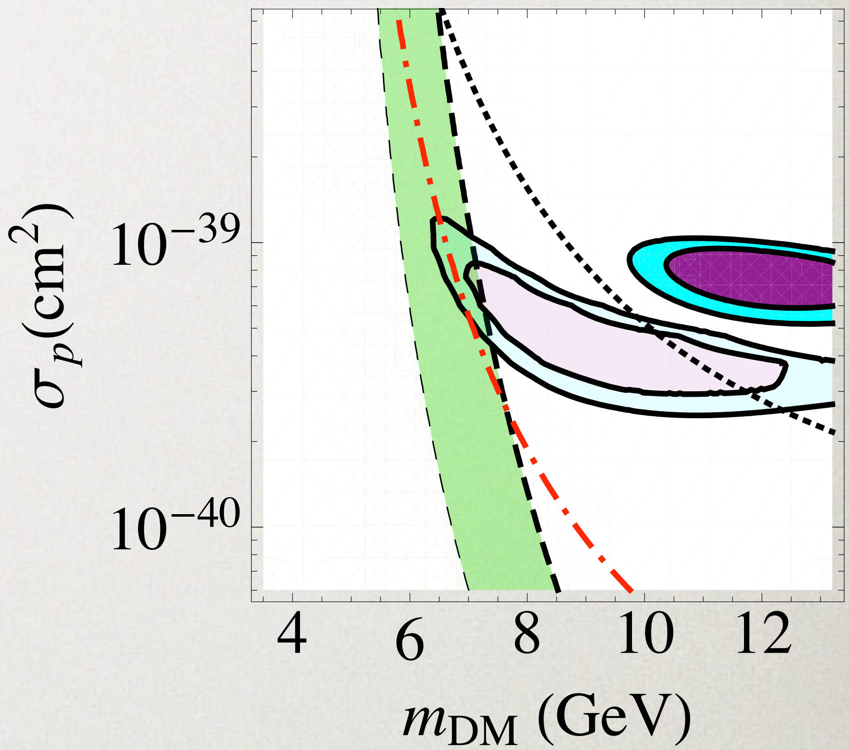


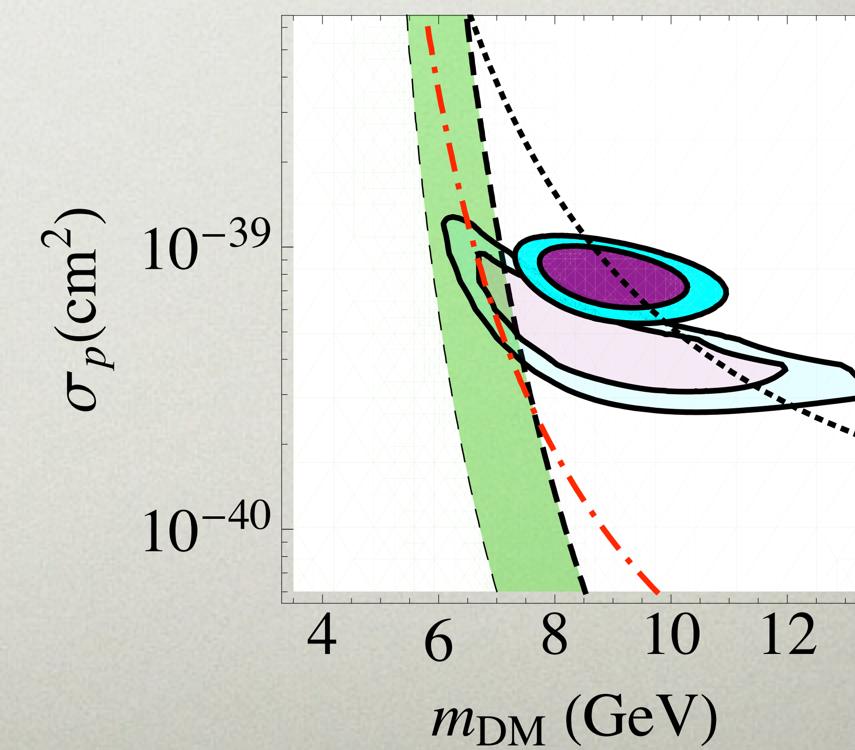
Lin, Yu, KZ 1111.0293
Ge line from Essig, Mardon, Volansky

All complicated by uncertainties ...

Fitzpatrick, KZ 1007.5325

- ... of the experimental kind (how do you calibrate energy?)
- ... of the theoretical kind (how certain are we of the underlying theory?)





$$\mathcal{O}_N = A^\mu \bar{N}(p)\left(F_1(q)(p+p')_\mu + (F_1(q)+F_2(q))2i\Sigma_{\mu\nu}q^\nu\right)N(p').$$

$$\begin{aligned}\mathcal{O}_a &= \bar{\chi}\gamma^\mu\gamma_5\chi A_\mu \\ \mathcal{O}_d &= \bar{\chi}\sigma^{\mu\nu}\chi F_{\mu\nu}/\Lambda\end{aligned}$$

$$\begin{aligned}\sigma_a &= \frac{\mu_N^2}{4\pi(q^2+M^2)^2}\left(\left(4v^2 - q^2\frac{(m_N+m_\chi)^2}{m_N^2 m_\chi^2}\right)F_1^2 + (F_1+F_2)^2 q^2\frac{2}{m_N^2}\right), \\ \sigma_d &= \frac{4\mu_N^2 q^2}{\pi\Lambda^2(q^2+M^2)^2}\left(\left(4v^2 - q^2\left(\frac{1}{m_N^2}+\frac{2}{m_N m_\chi}\right)\right)F_1^2 + (F_1+F_2)^2 q^2\frac{2}{m_N^2}\right)\end{aligned}$$

Thoughts/Studies for Snowmass

- Combining with LHC data, how many supersymmetric models remain?
- What is the cost/benefit for lower WIMP cross-sections?
- What are the prospects for light WIMP detectors?
- Building light WIMP benchmarks?