Theoretical Results on Dark Matter

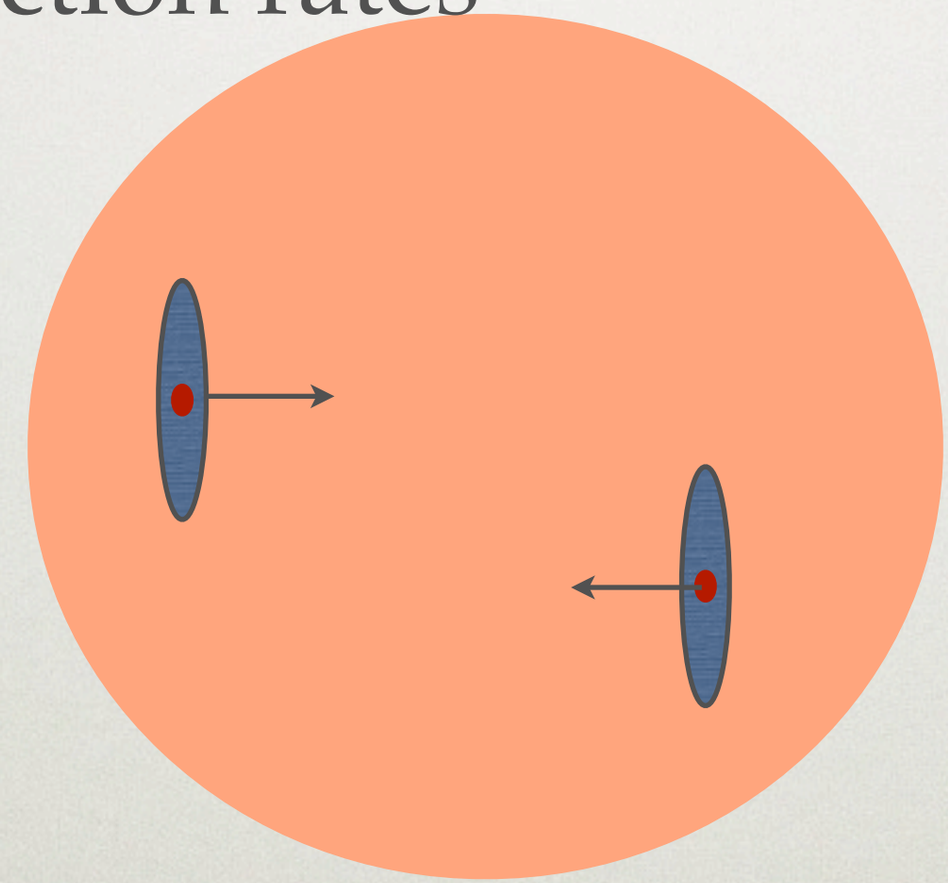
Kathryn M. Zurek
University of Michigan

Agenda

- The most prominent DM candidate: the SUSY WIMP. How does it stand with new experimental constraints? Direct and Indirect Detection
- Looking beyond the SUSY WIMP. Sub-10 GeV WIMP. Theories. Direct and Indirect Detection. Implications for Collider Experiments.

Why the Weak Scale is Compelling

- Abundance of new stable states set by interaction rates

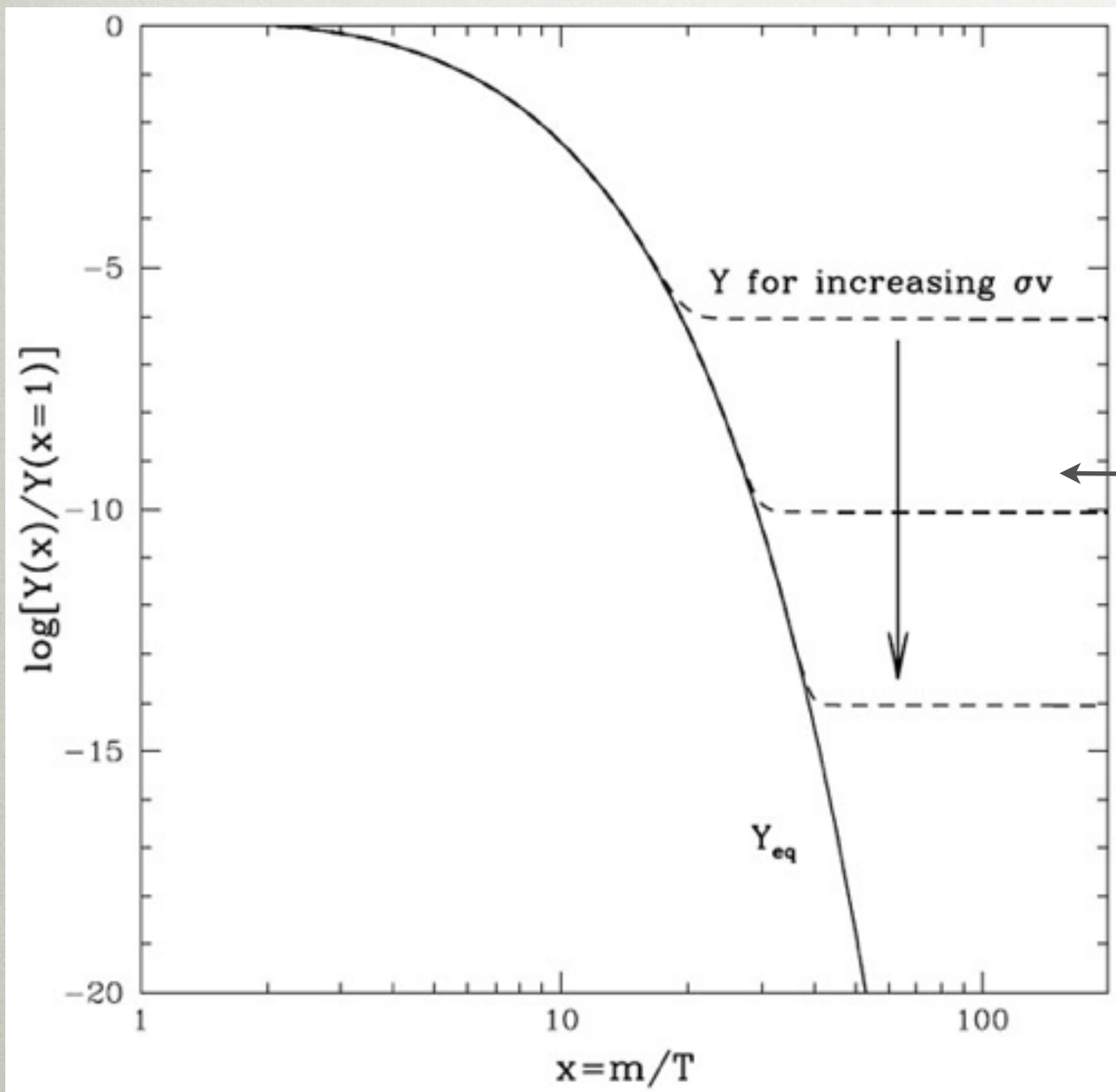


Freeze-out

Measured by WMAP + LSS

$$\Gamma = n\sigma v = H$$

Why the Weak Scale is Compelling



Kolb and Turner

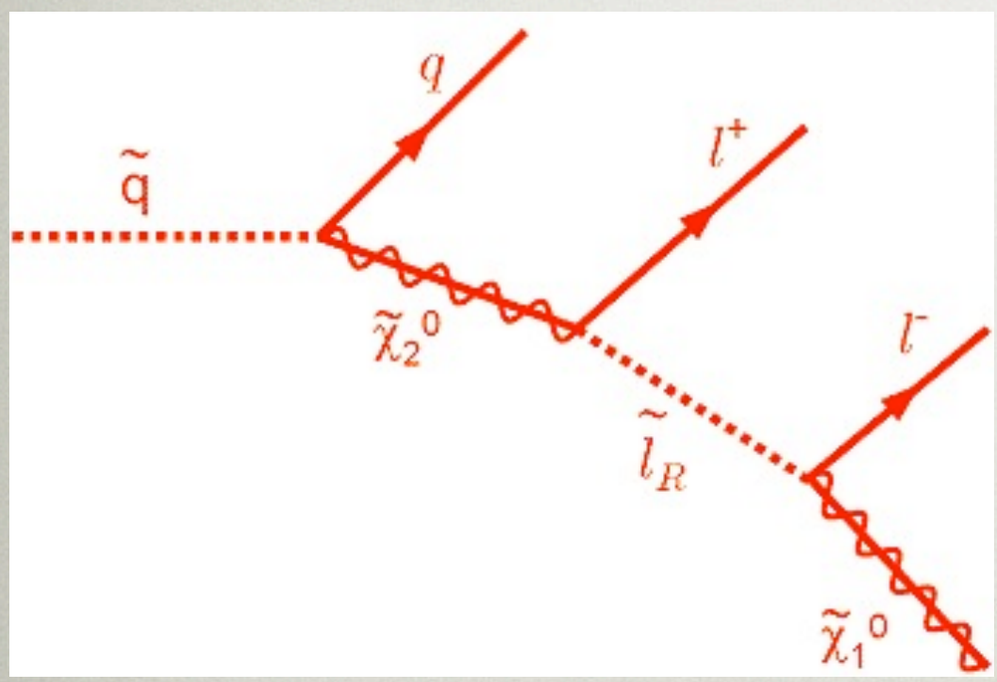
Meausured by CMB plus large scale structure

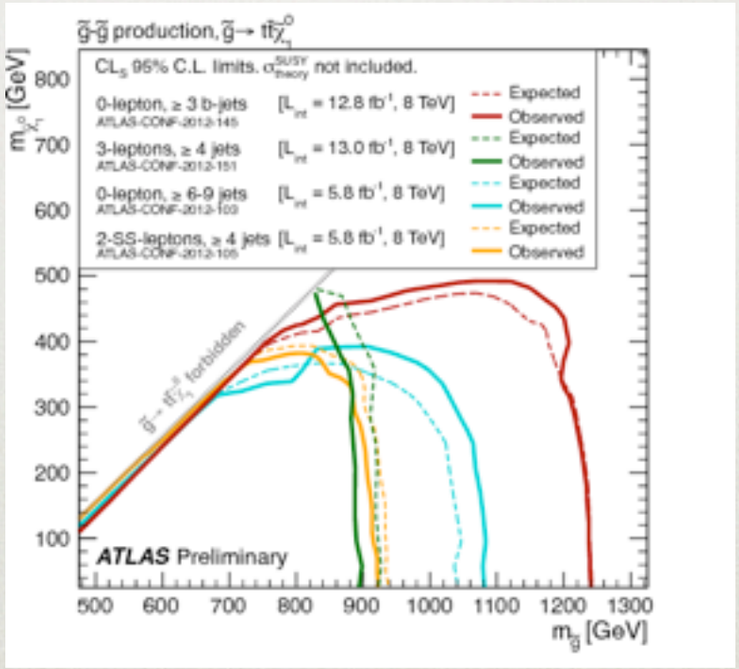
$$\langle \sigma v \rangle \simeq 3 \times 10^{-26}\ \mathrm{cm}^3/\mathrm{s}$$

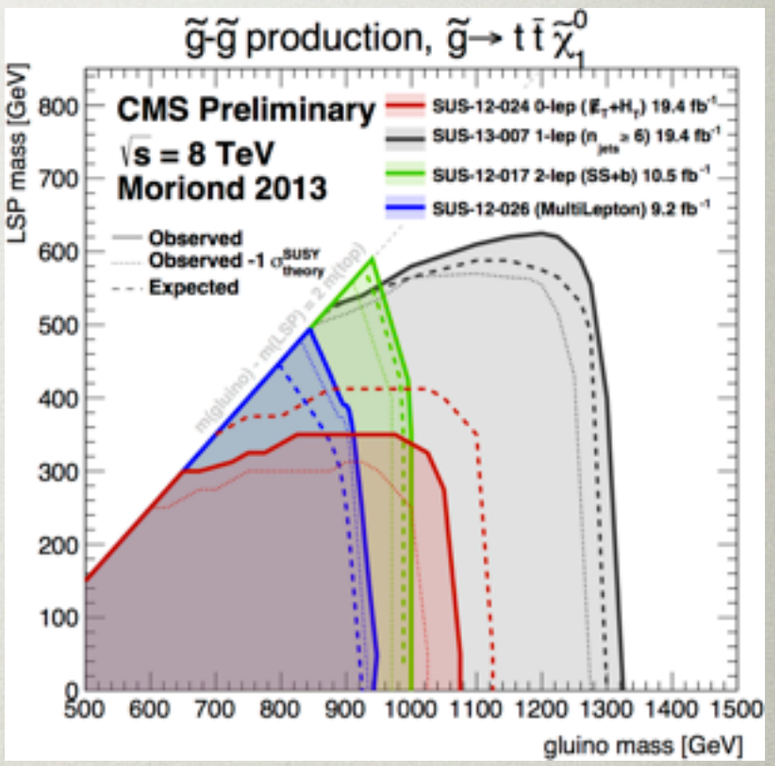
$$\simeq \frac{1}{(20\ \mathrm{TeV})^2}$$

Idea Focus: Supersymmetry

- Provides sharp predictions
- Must be neutral $\tilde{\nu}$ $\tilde{B},\ \tilde{W}_3,\ \tilde{H}$

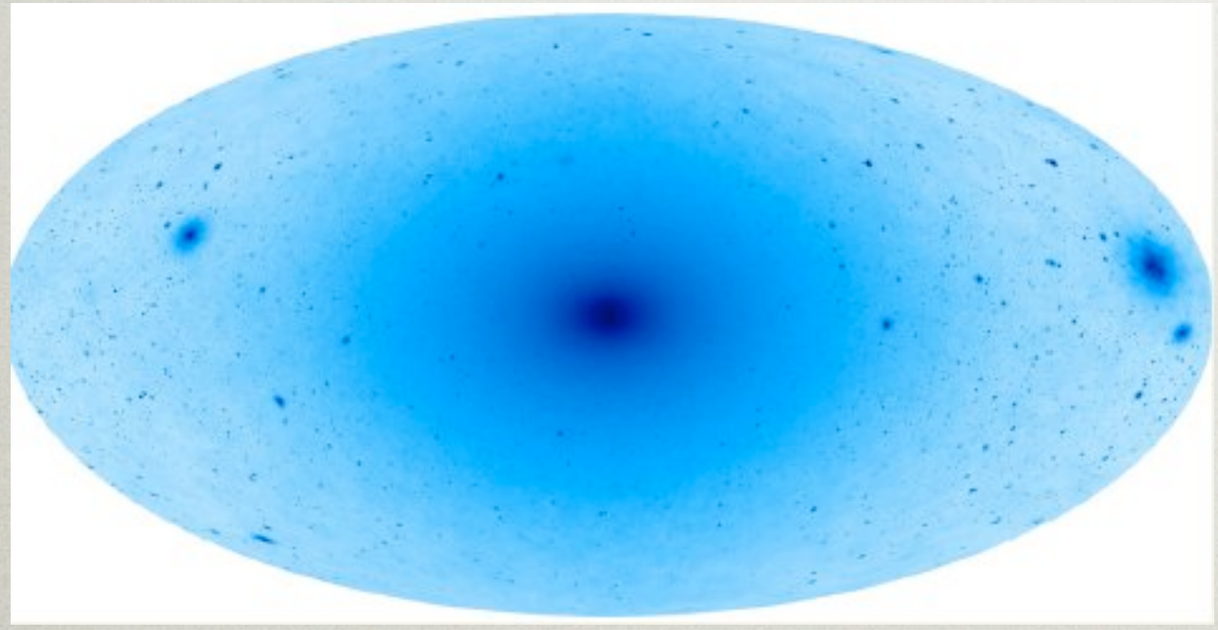


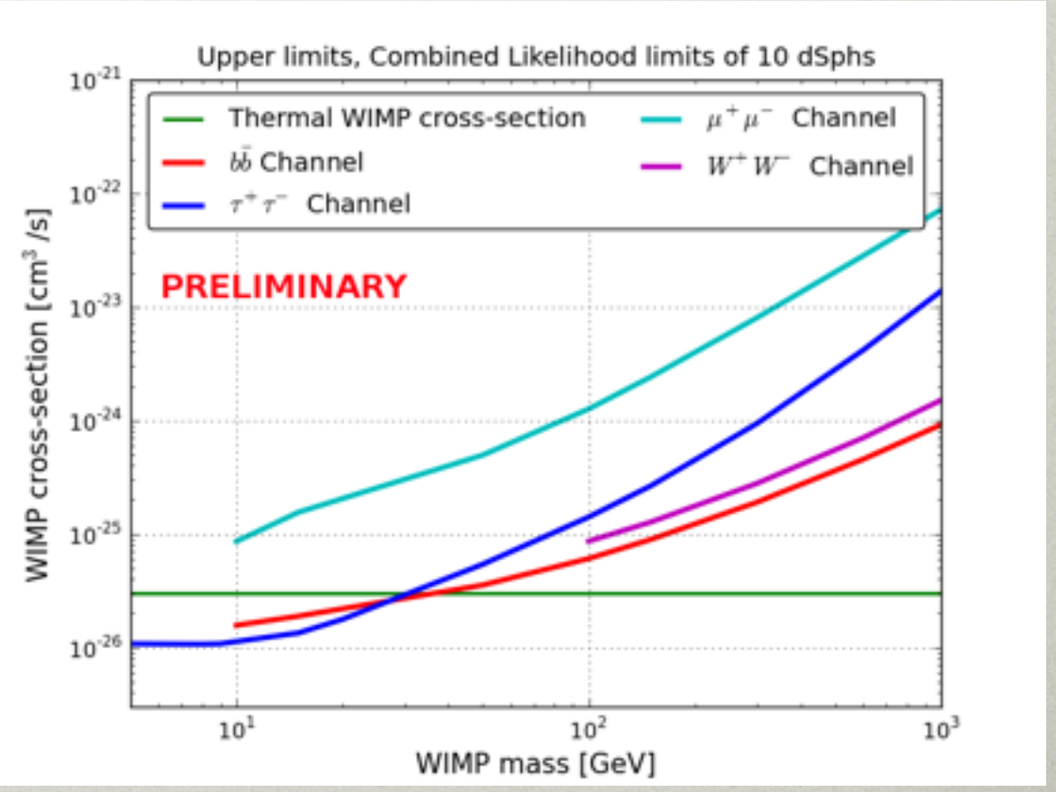




Idea Focus: Supersymmetry

- Direct and indirect detection experiments provide a more direct handle on DM itself
- Indirect detection is a probe of relic density setting annihilation rate

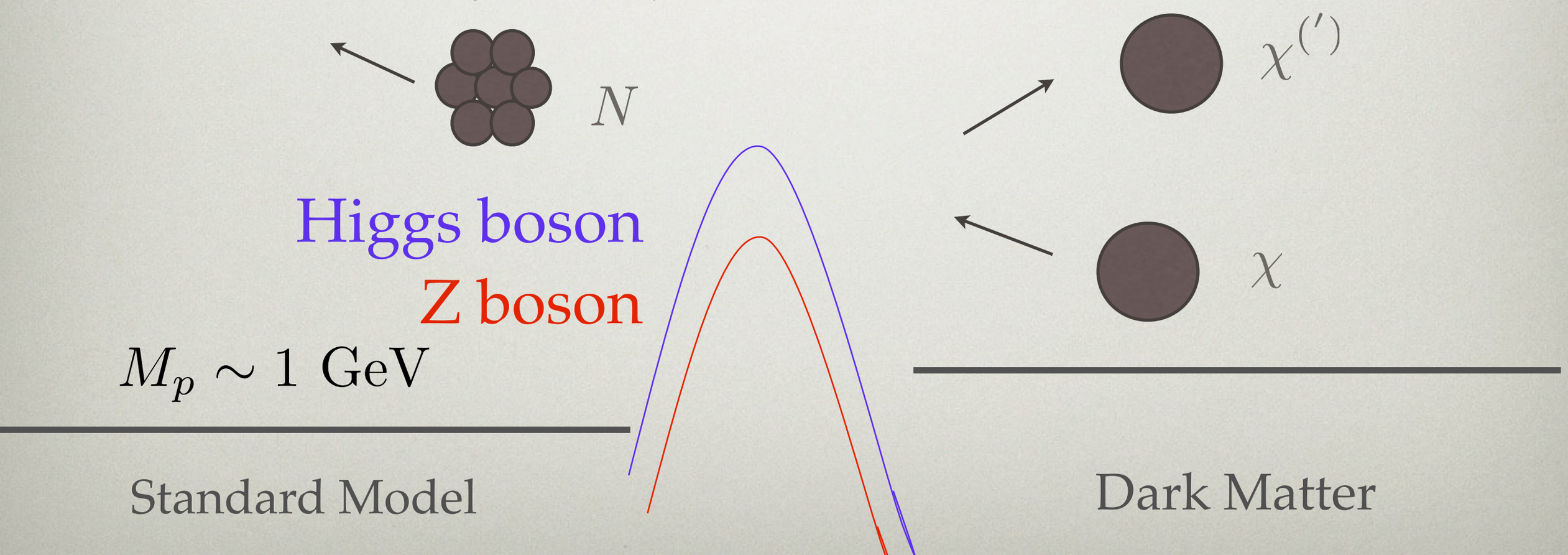




Fermi

Direct Probe

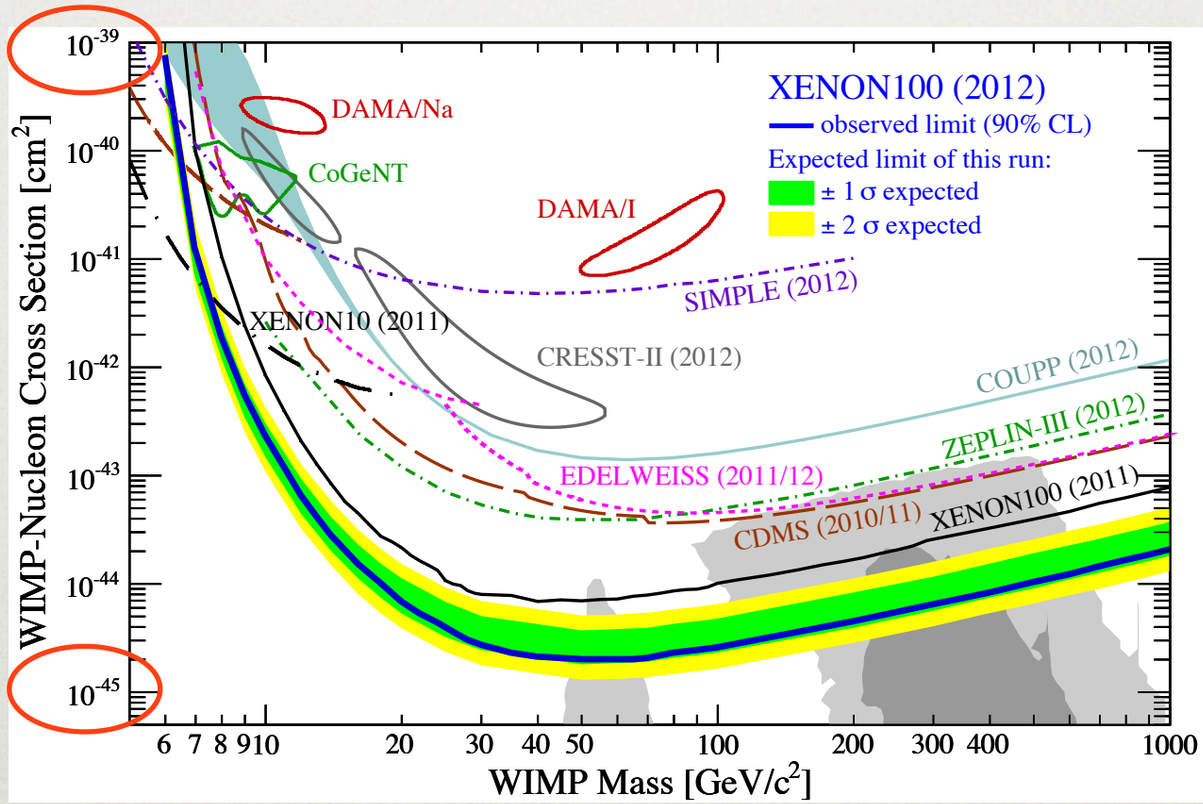
- Direct detection: direct probe of couplings to nucleons
- Sneutrino scatters through Z
- Neutralino does not because operator vanishes identically for Majorana fermion $\bar{\chi}\gamma^{\mu}\chi\bar{N}\gamma_{\mu}N$



Sub-Weakly Interacting Massive Particles

Scattering through the Z boson: ruled out

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

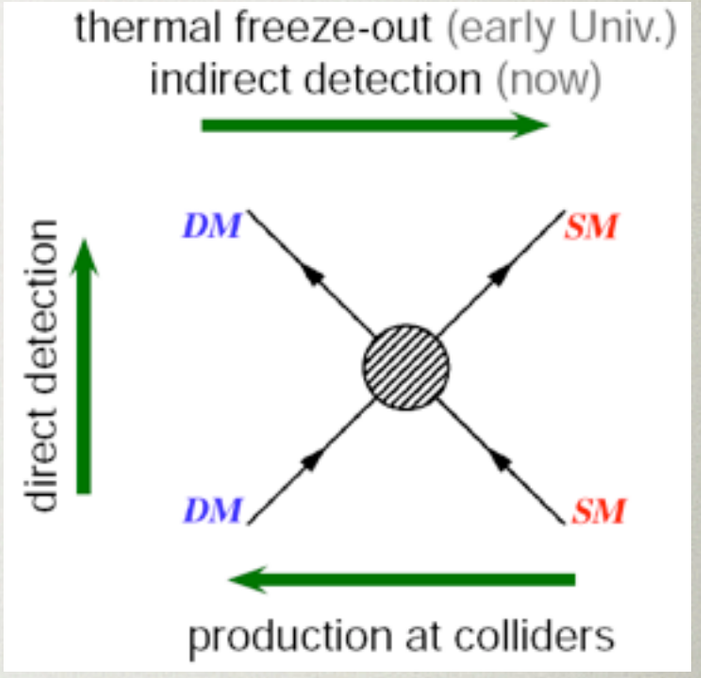


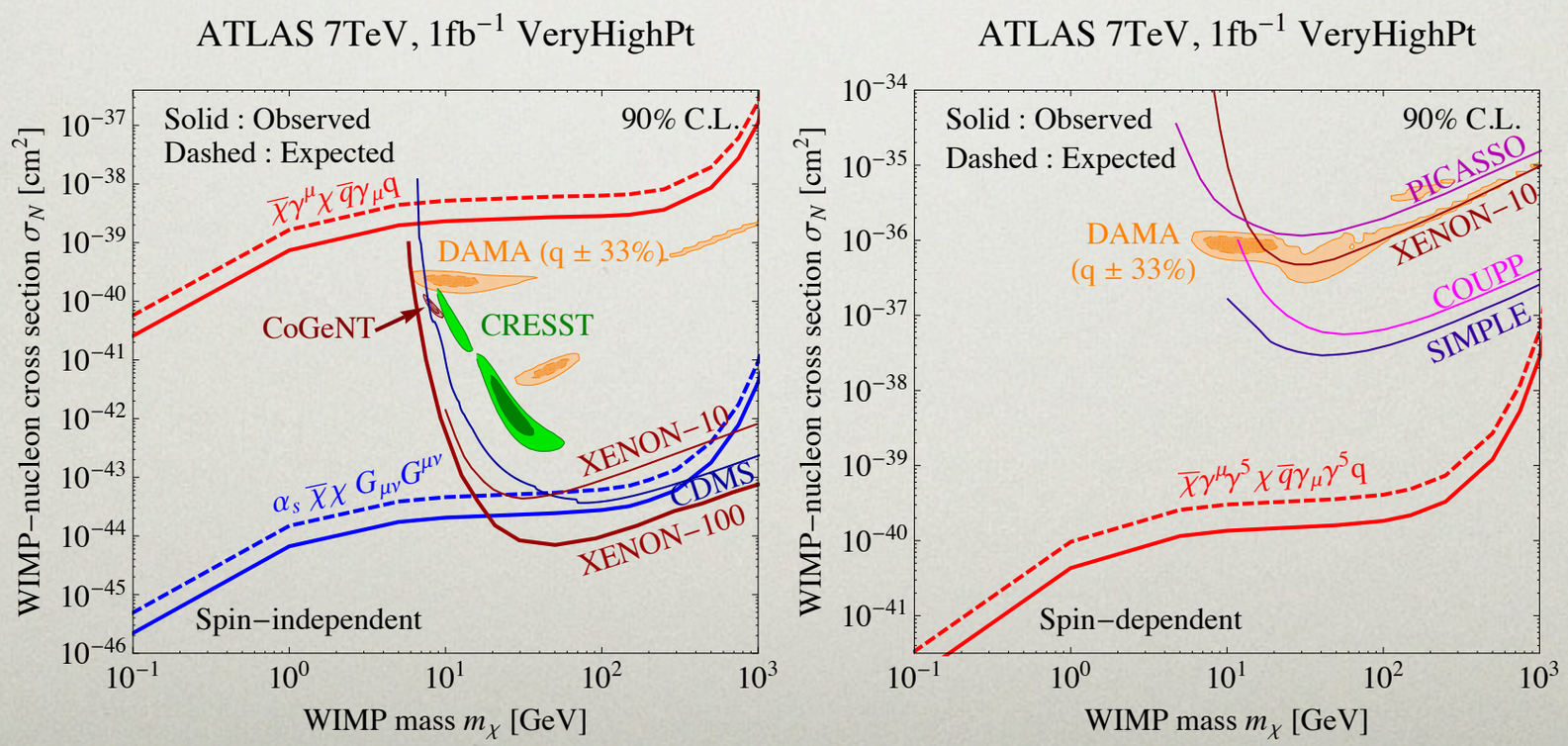
Next important benchmark:
Scattering through the Higgs

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

Monojets at LHC

- Probes direct coupling to nucleon
- Not competitive with DD for spin-independent scattering with DM mass above 10 GeV

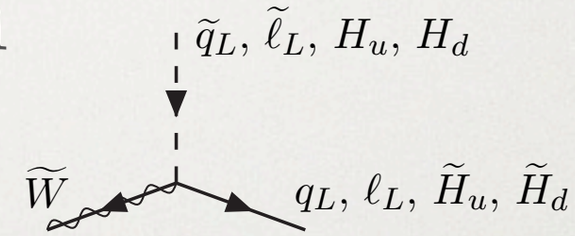


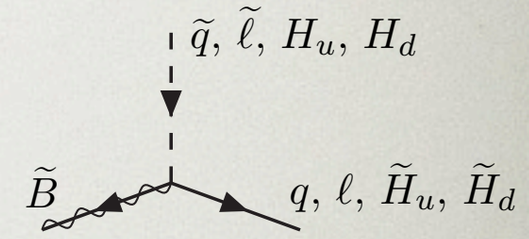


Fox, Harnik, Kopp, Tsai

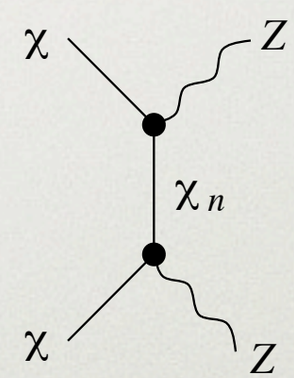
Are there ways around for the Neutralino?

- Make the Neutralino a pure state -- coupling to Higgs vanishes





- However, Wino and Higgsino pure states can be probed by indirect detection



Large!

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

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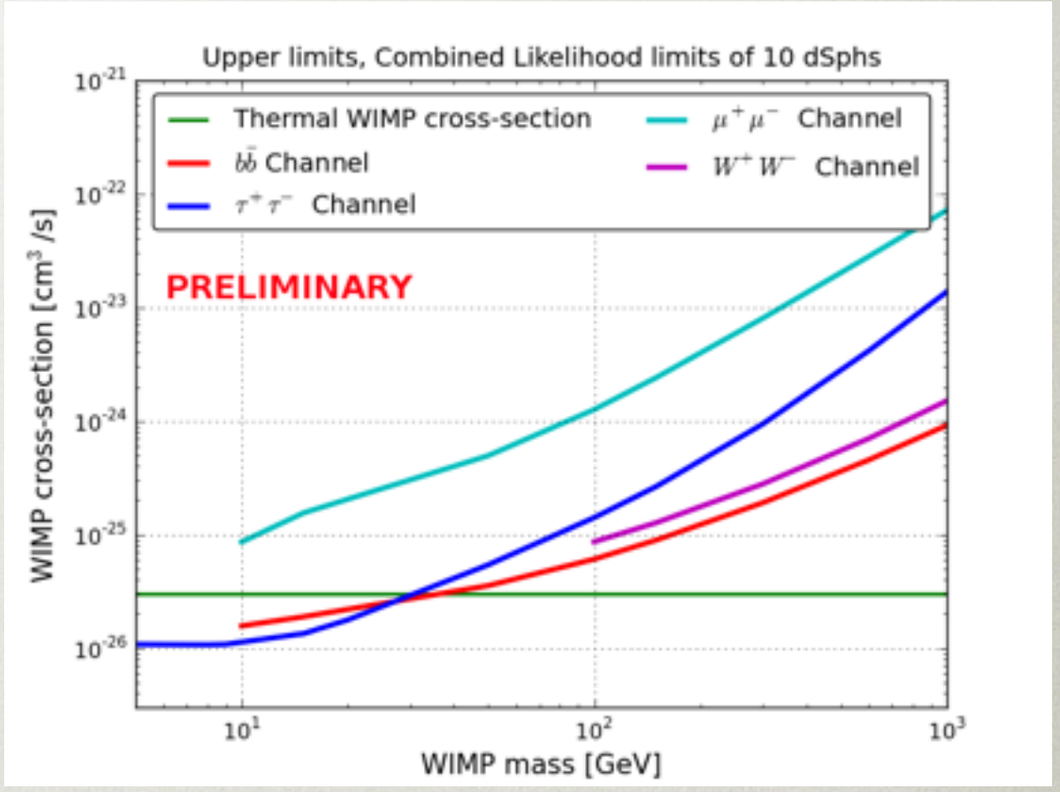

Fermi

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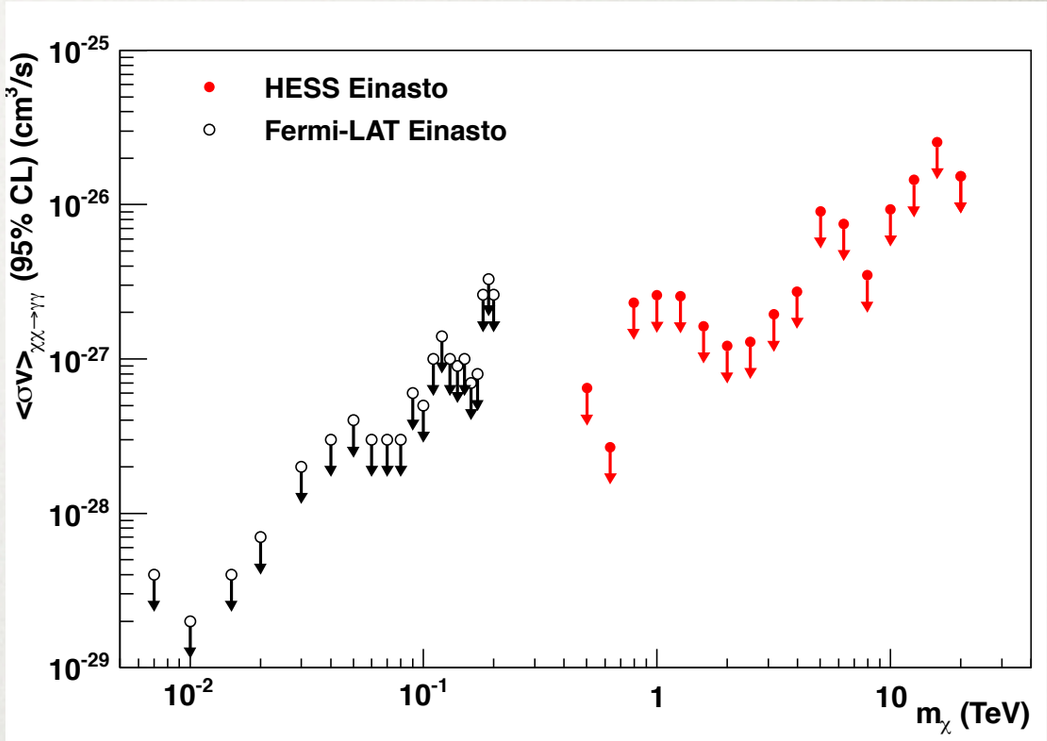
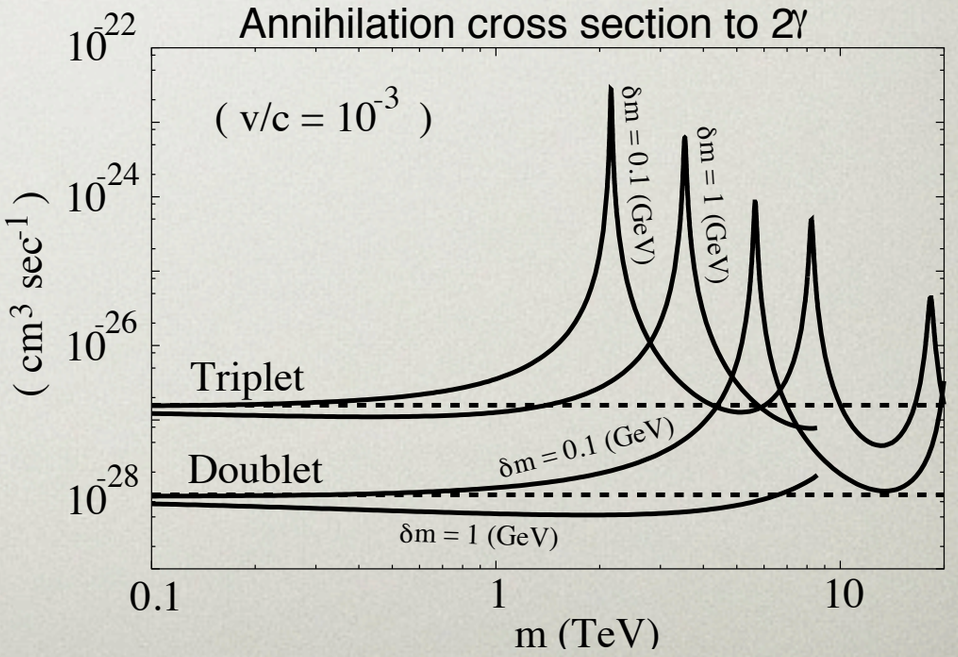




Hisano, Matsumoto, Nojiri, Saito

Are there ways around for the Neutralino?

- Bino escapes

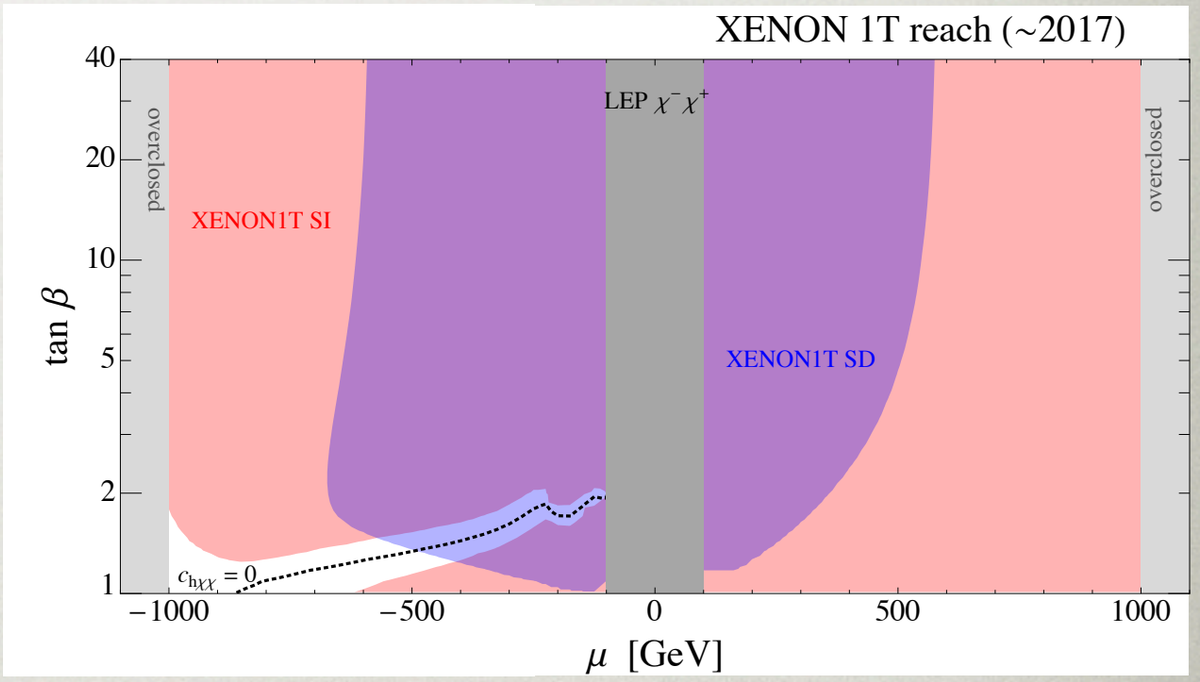
$$\mu \gg M_1 \sim m_{wk}$$

- Pay a fine-tuning price

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

- Also escape in "blind spots"

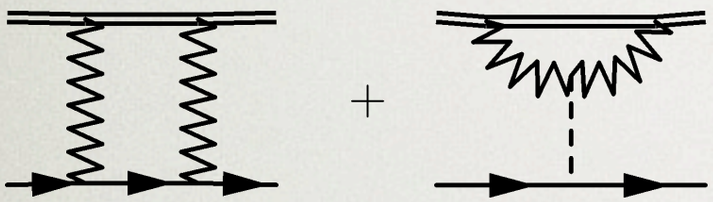
m_χ	condition
M_1	$M_1 + \mu \sin 2\beta = 0$
M_2	$M_2 + \mu \sin 2\beta = 0$
$-\mu$	$\tan\beta = 1$
M_2	$M_1 = M_2$

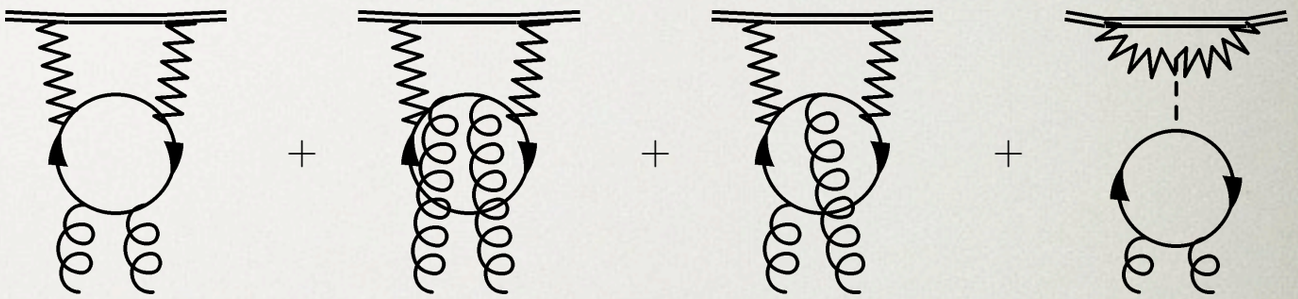


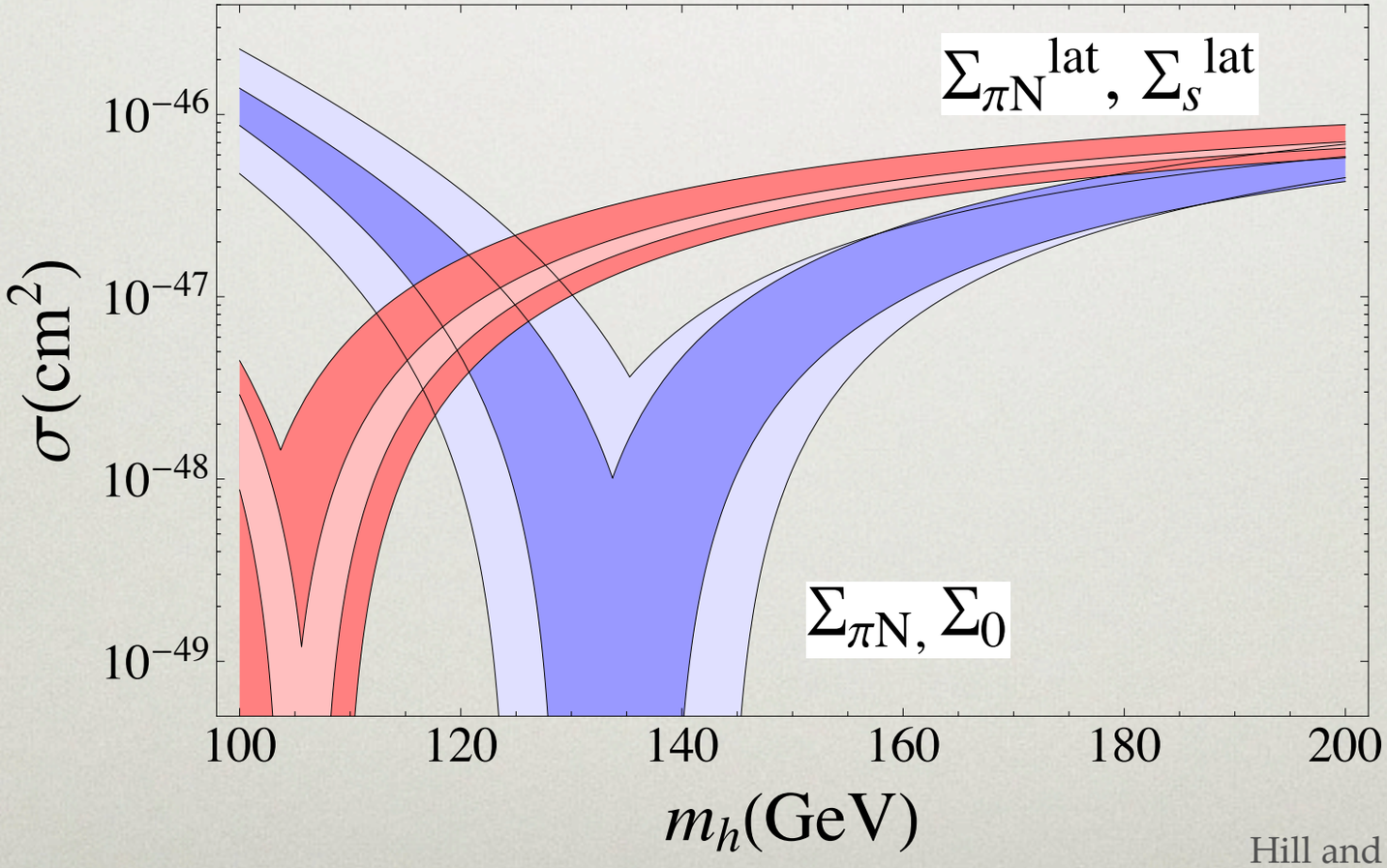
Cheung, Hall, Pinner, Ruderman

- Again pay a fine-tuning price

Direct Detection Through Loops

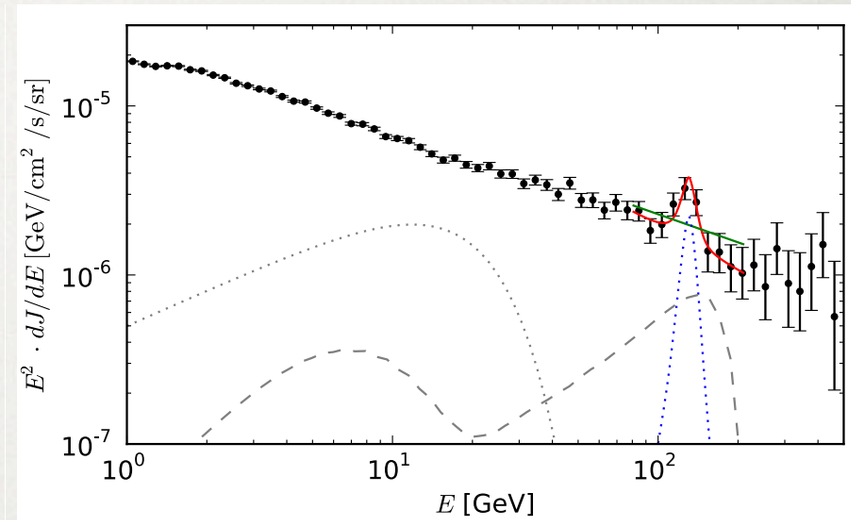




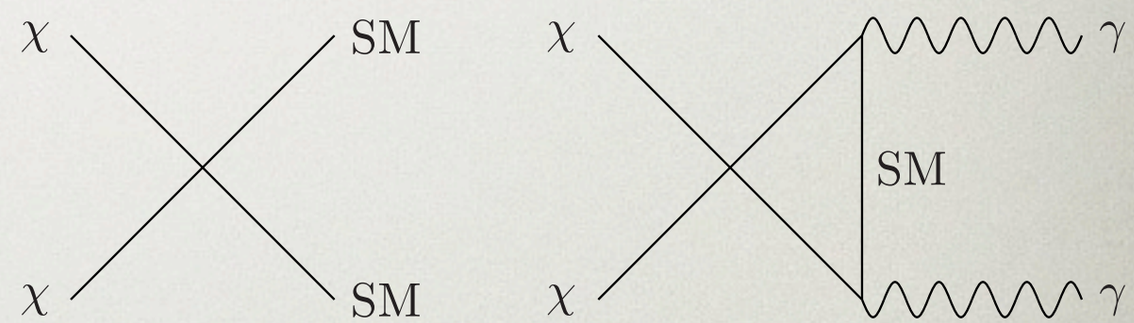


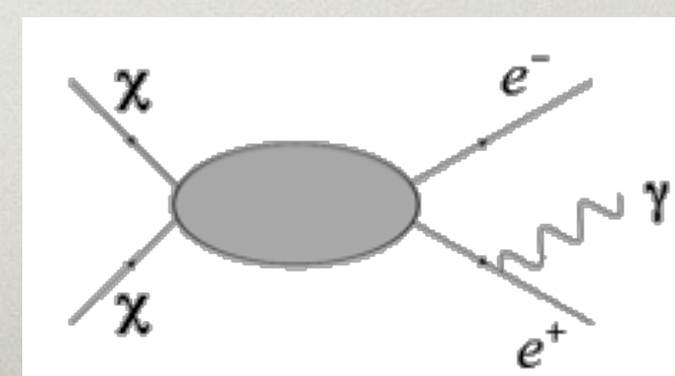
Hill and Solon

A 130 GeV Line in Fermi?



- *Large* rate
- Why no continuum photons?
- Continuum should dominate by $\frac{R_{SM}}{R_{\gamma\gamma}} \sim (\pi/\alpha)^2 \approx 10^5$
- Need special models

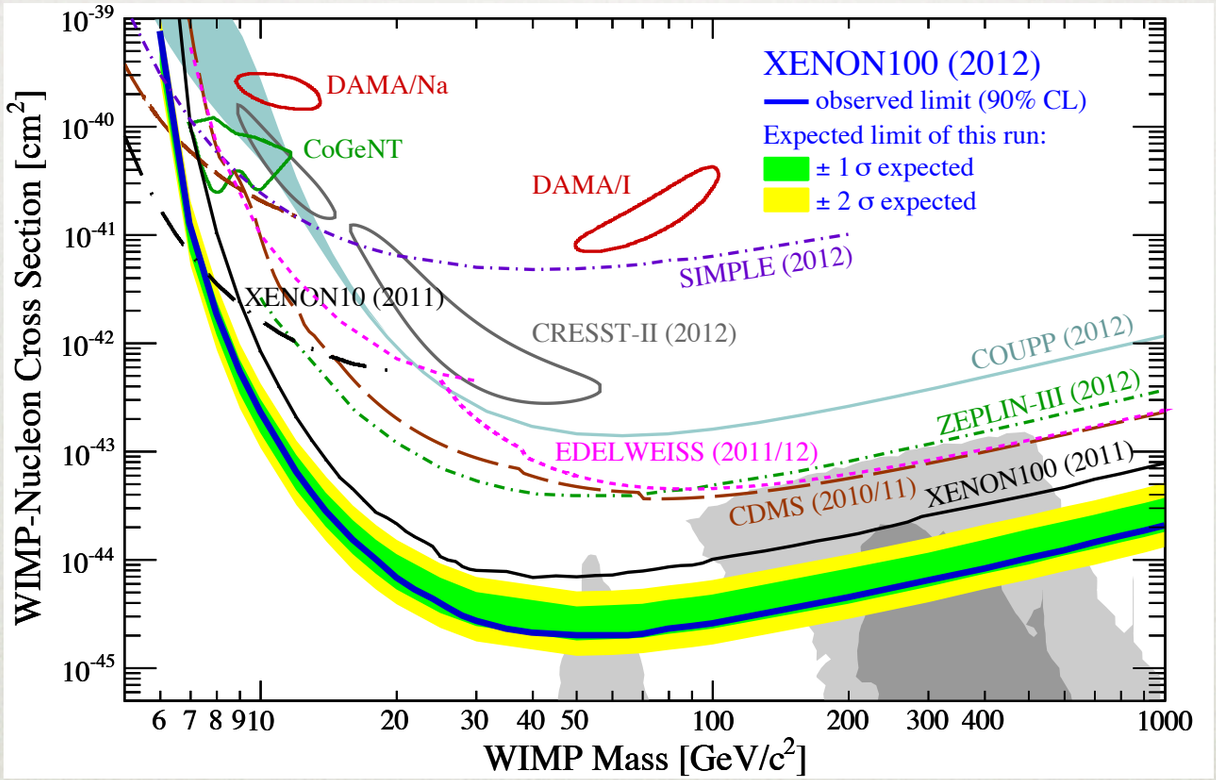




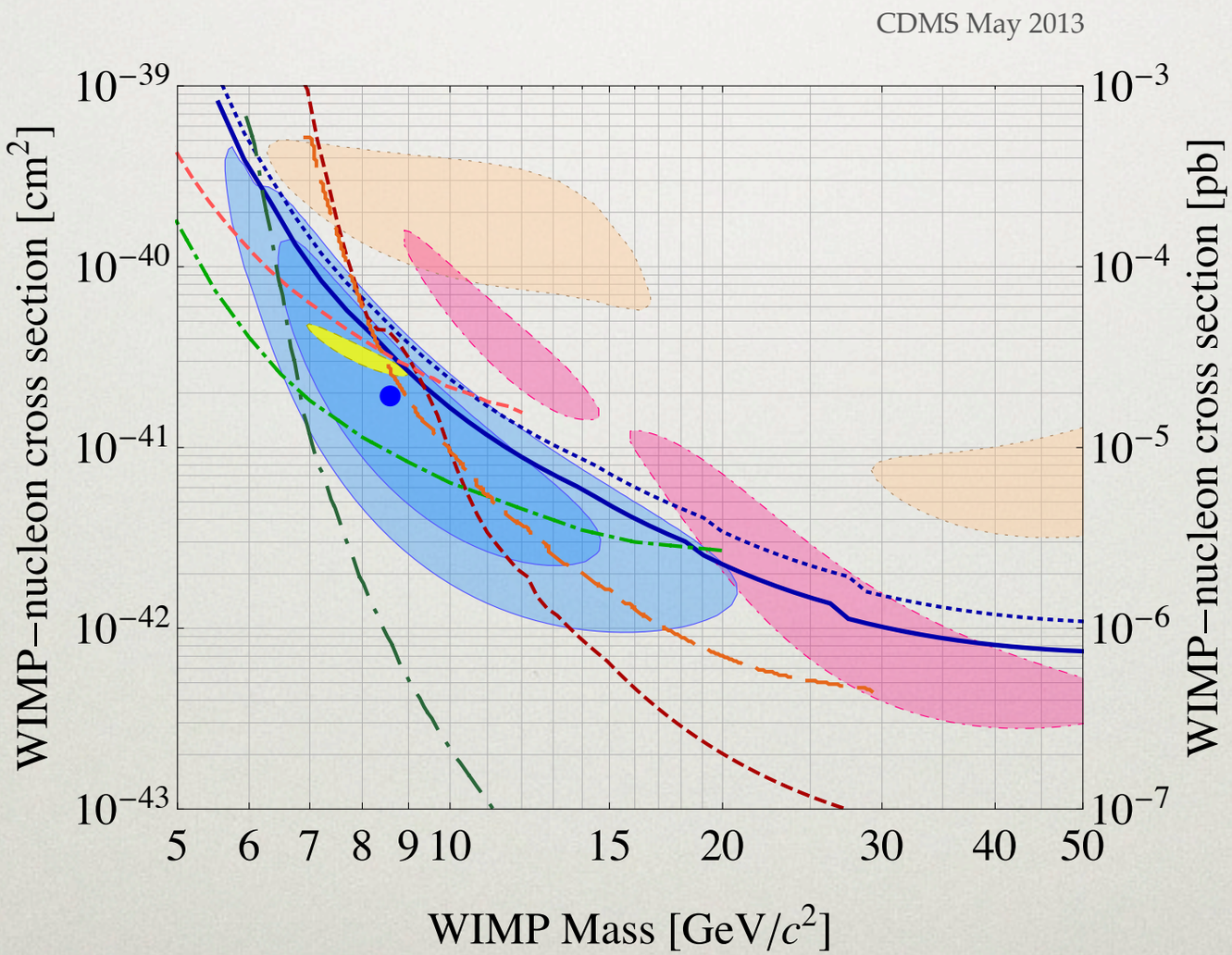
When Should We Start Looking Elsewhere?

- 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



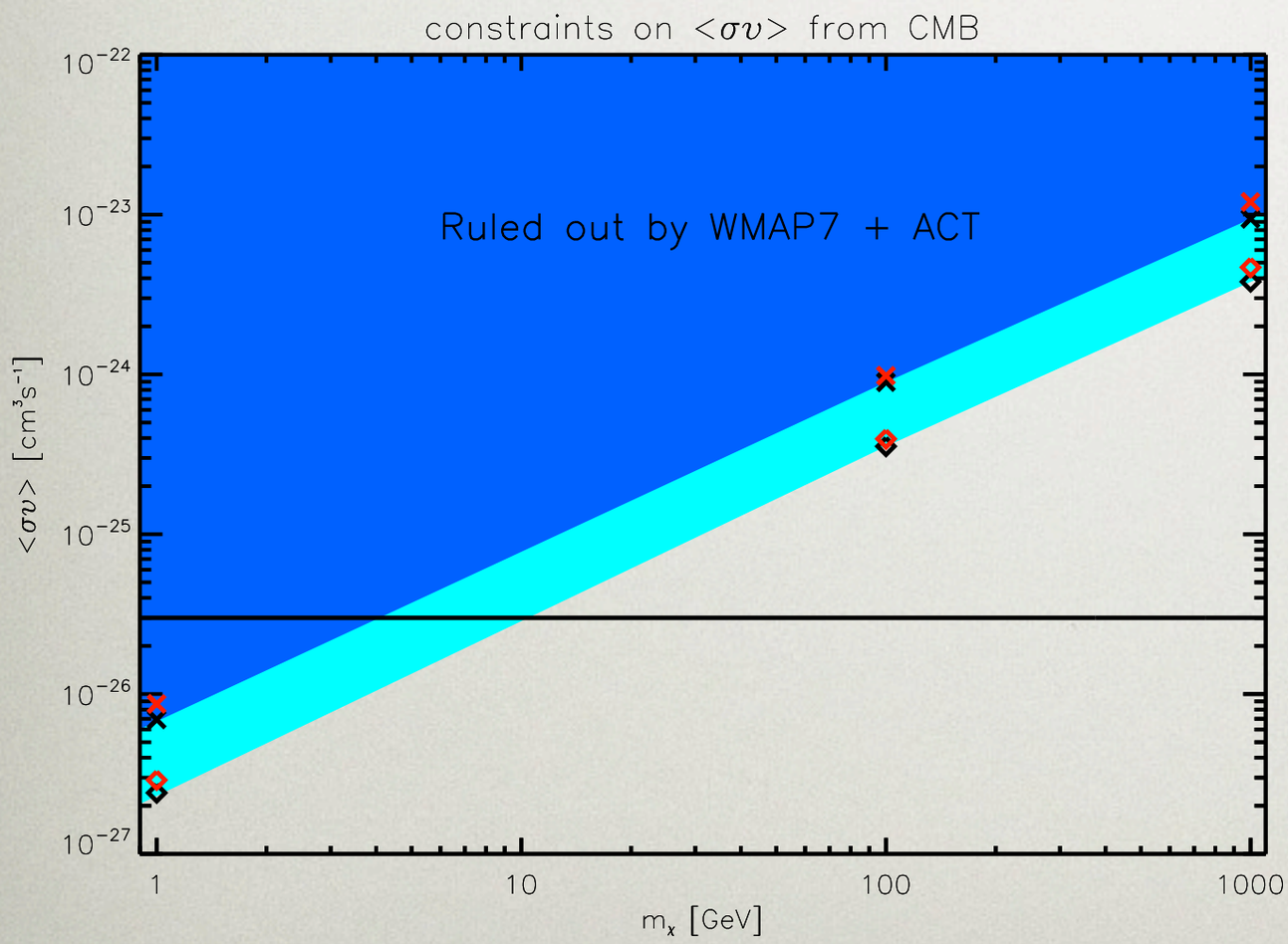
Unless there is a signal ...



DAMA
CoGeNT
CRESST
CDMS

CMB and DM Annihilation

- In some (currently slight) tension with CMB



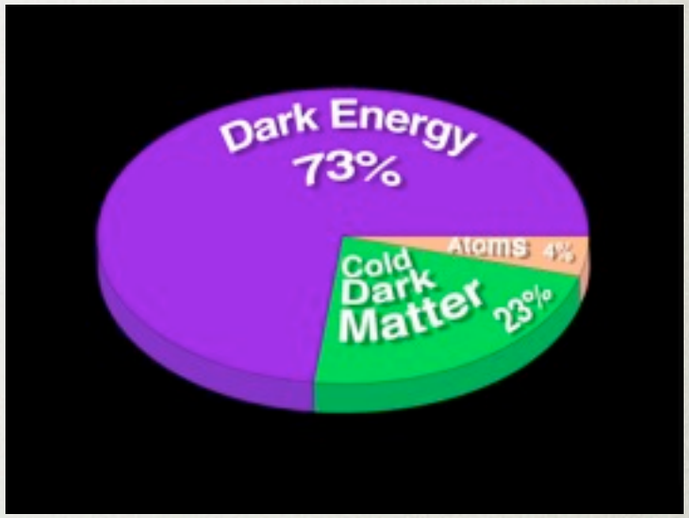
Bertone et al, 1106.1528

Ionizing radiation from DM annihilation would distort microwave photons

DM either does not self-annihilate or has p-wave suppressed annihilation

Light WIMPs: Asymmetric Dark Matter

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

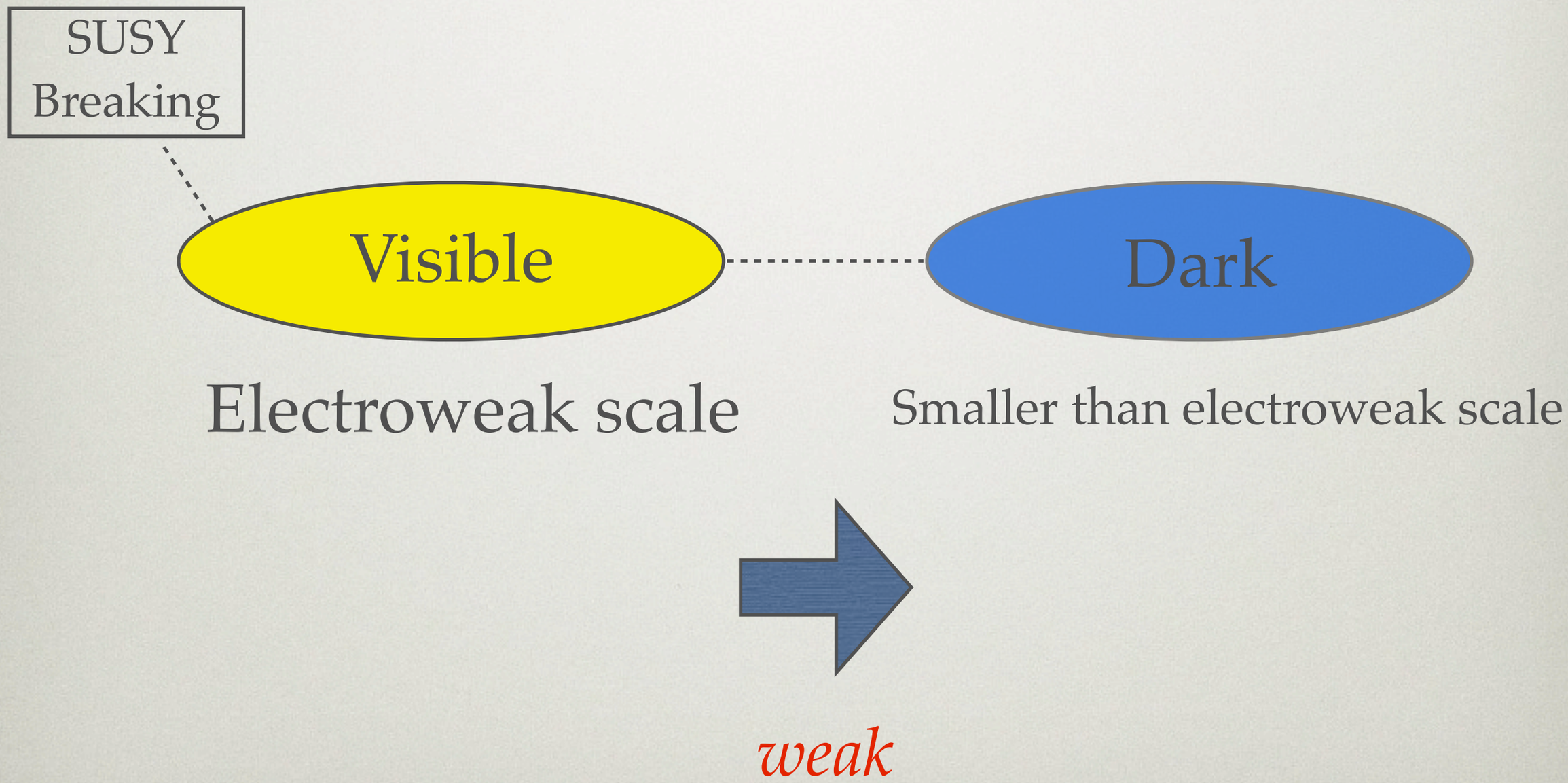


Experimentally, $\Omega_{DM} \approx 5\Omega_b$

Mechanism $n_{DM} \approx n_b$

$\Rightarrow$ $m_{DM} \approx 5m_p$

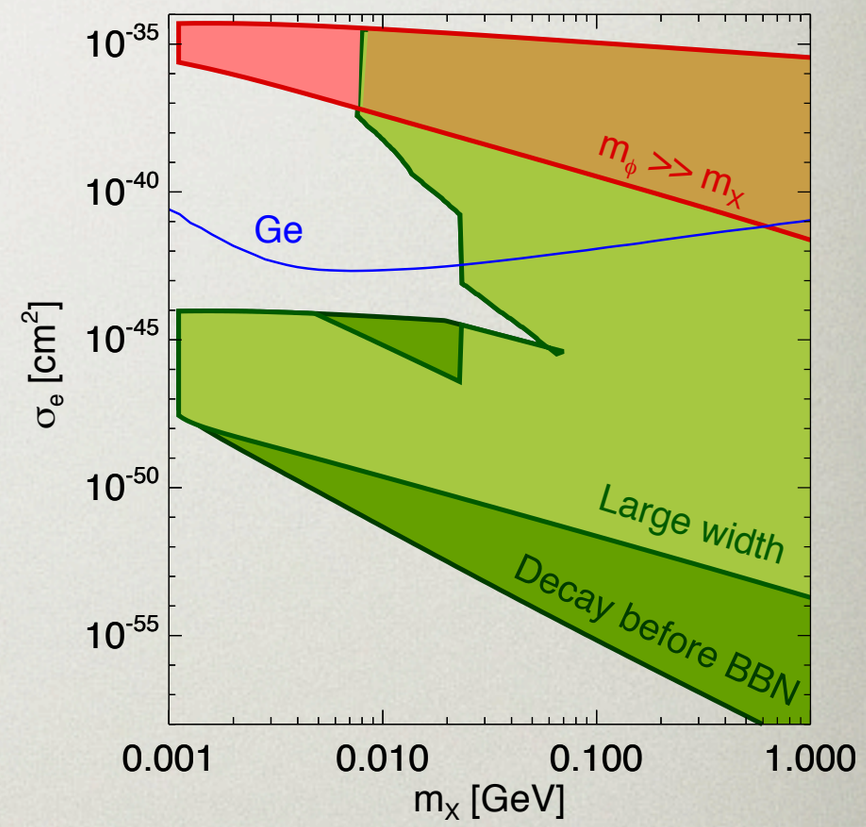
Light WIMPs: Hidden Supersymmetric DM



Hooper, KZ; Feng, Kumar; Arkani-Hamed, Finkbeiner, Slatyer, Weiner

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

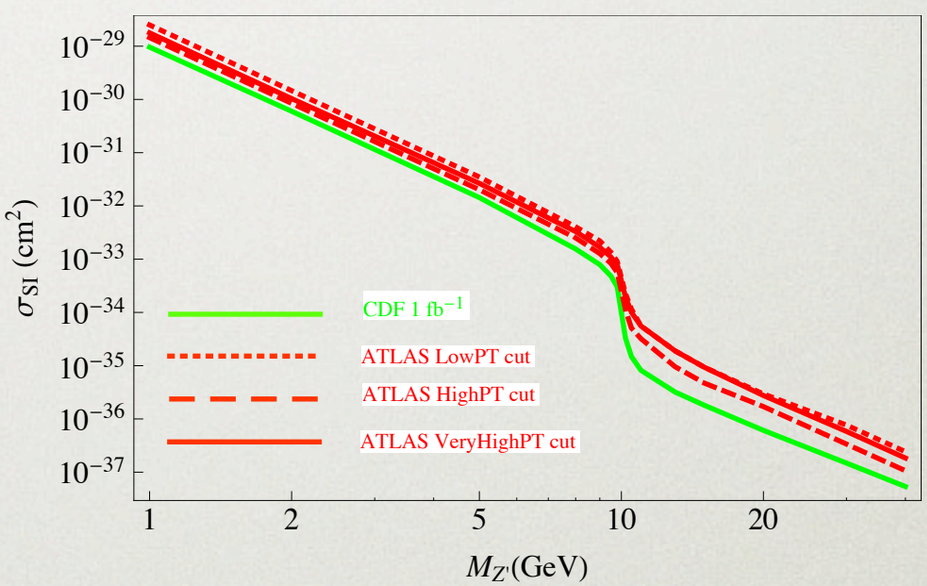


Lin, Yu, KZ

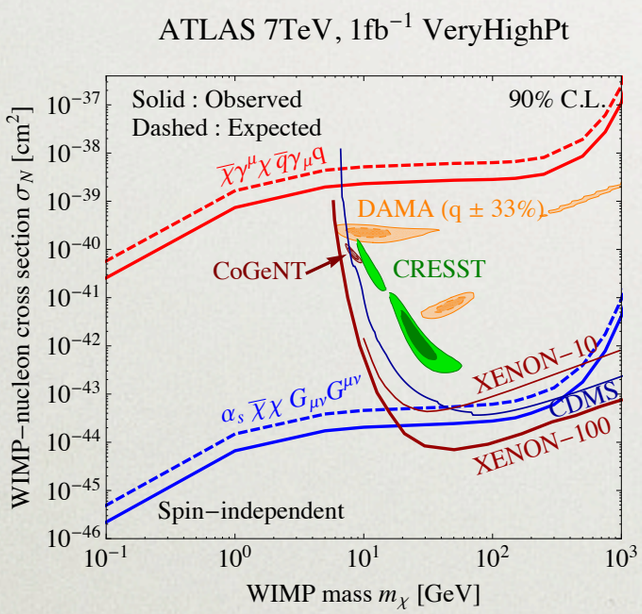
Implications for Colliders

- Monojet constraints only strong for heavy mediators

An, Ji, Wang

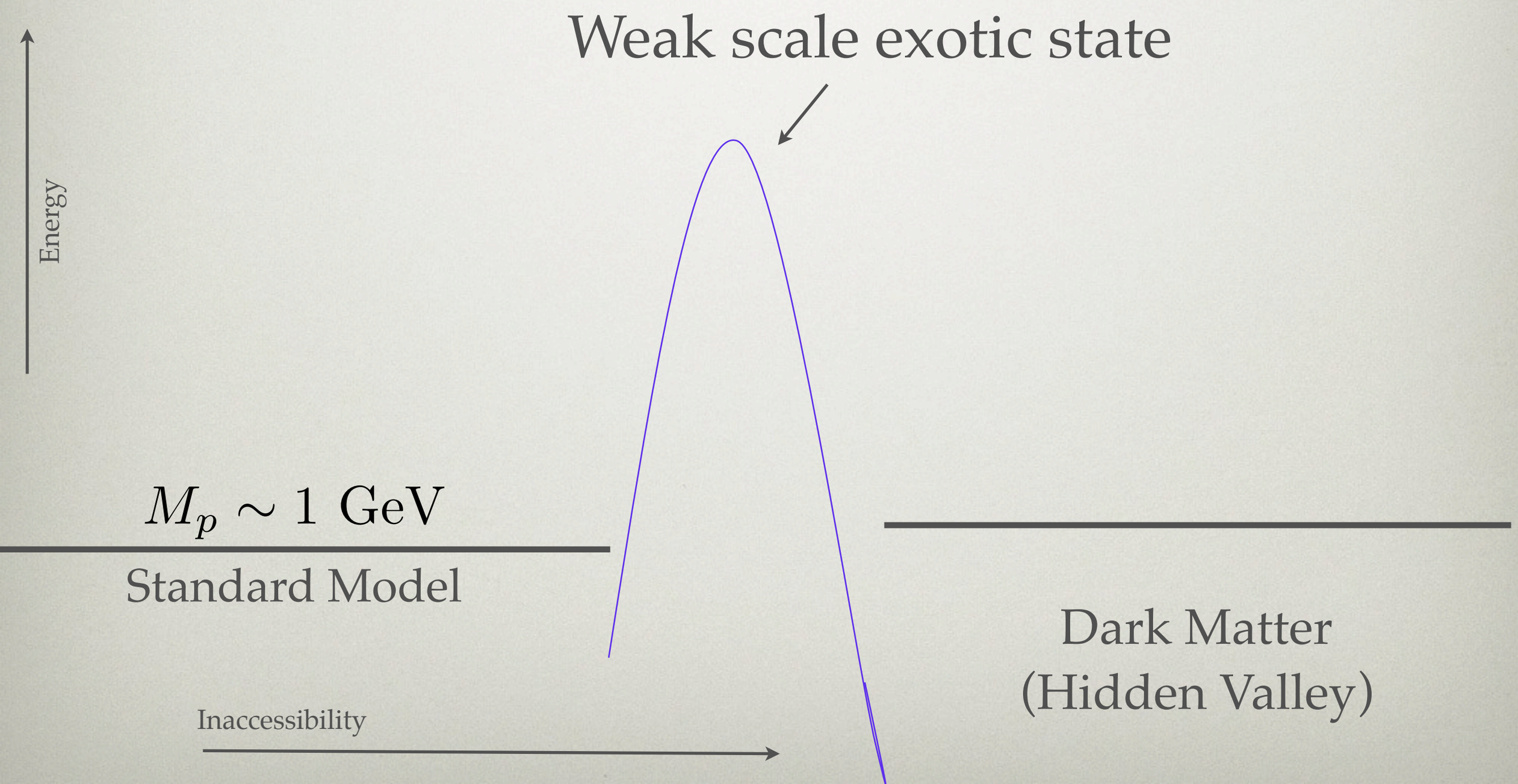


Fox, Harnik, Kopp, Tsai



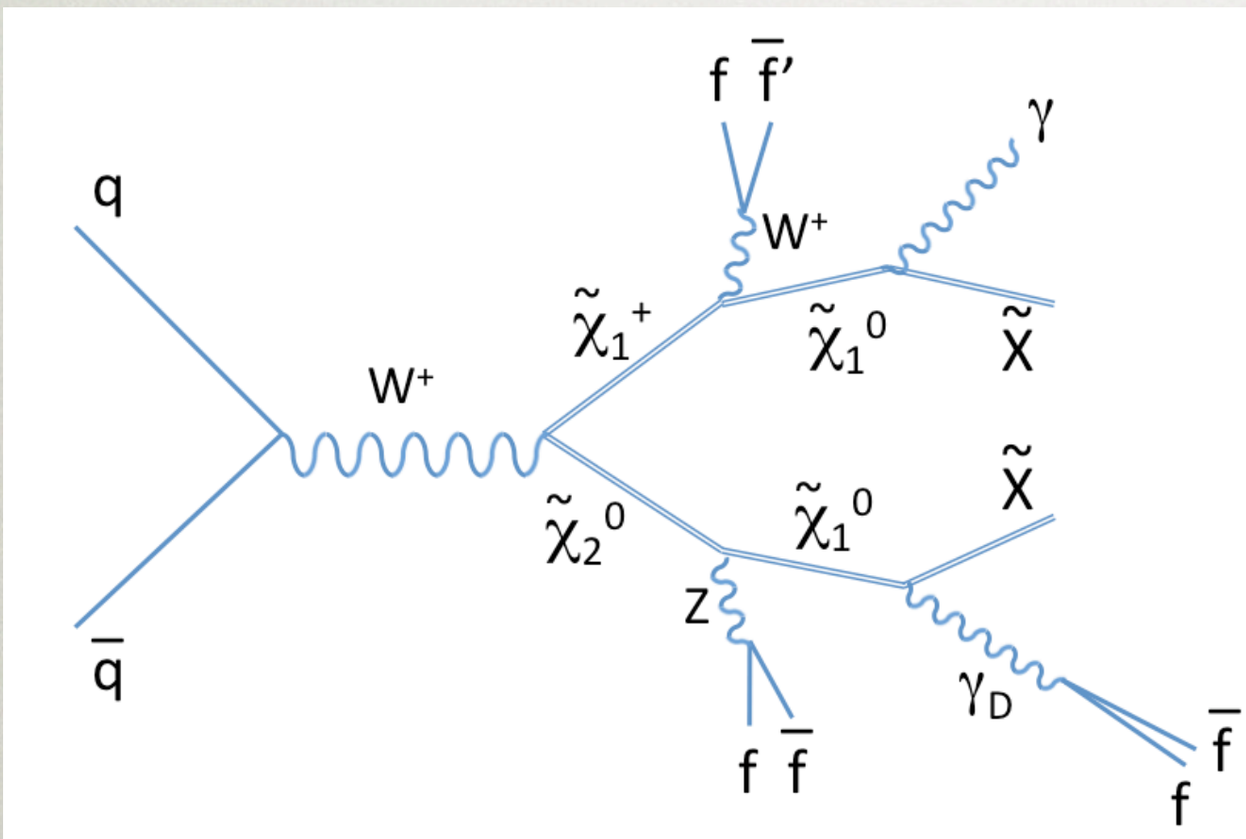
- Light DM signatures resemble "Hidden Valley" signatures. Weak scale states decay into the hidden sector.

Decaying Into Hidden Sector



Example: Hidden Photons in SUSY HVs

- Targeted searches with simplified topologies

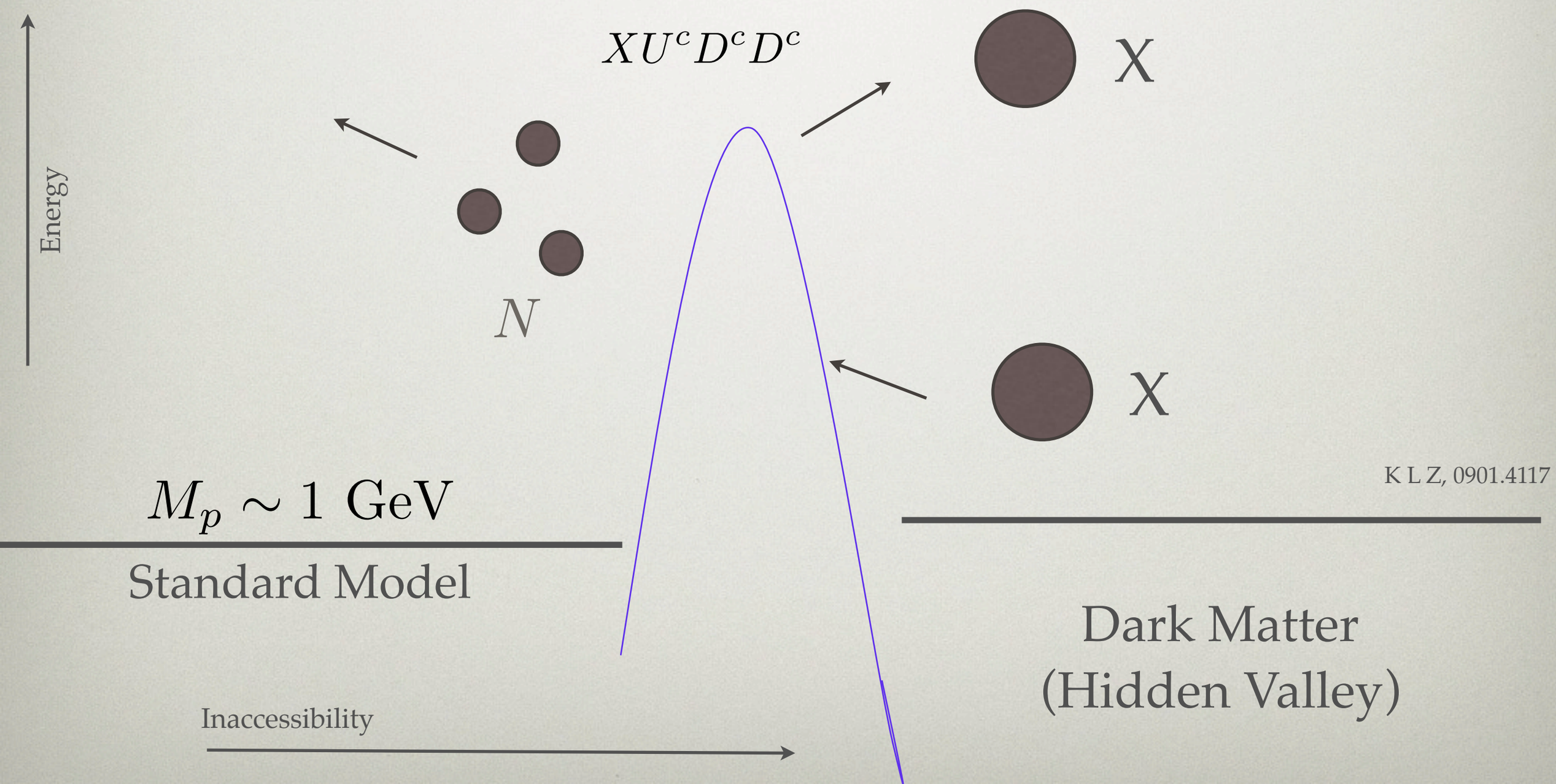


High multiplicities
Low mass resonances

D0: "Search for Dark Photons from SUSY Hidden Valleys"

Decaying Into Hidden Sector

Example: Asymmetric Dark Matter



K L Z, 0901.4117

Decaying Into Hidden Sector

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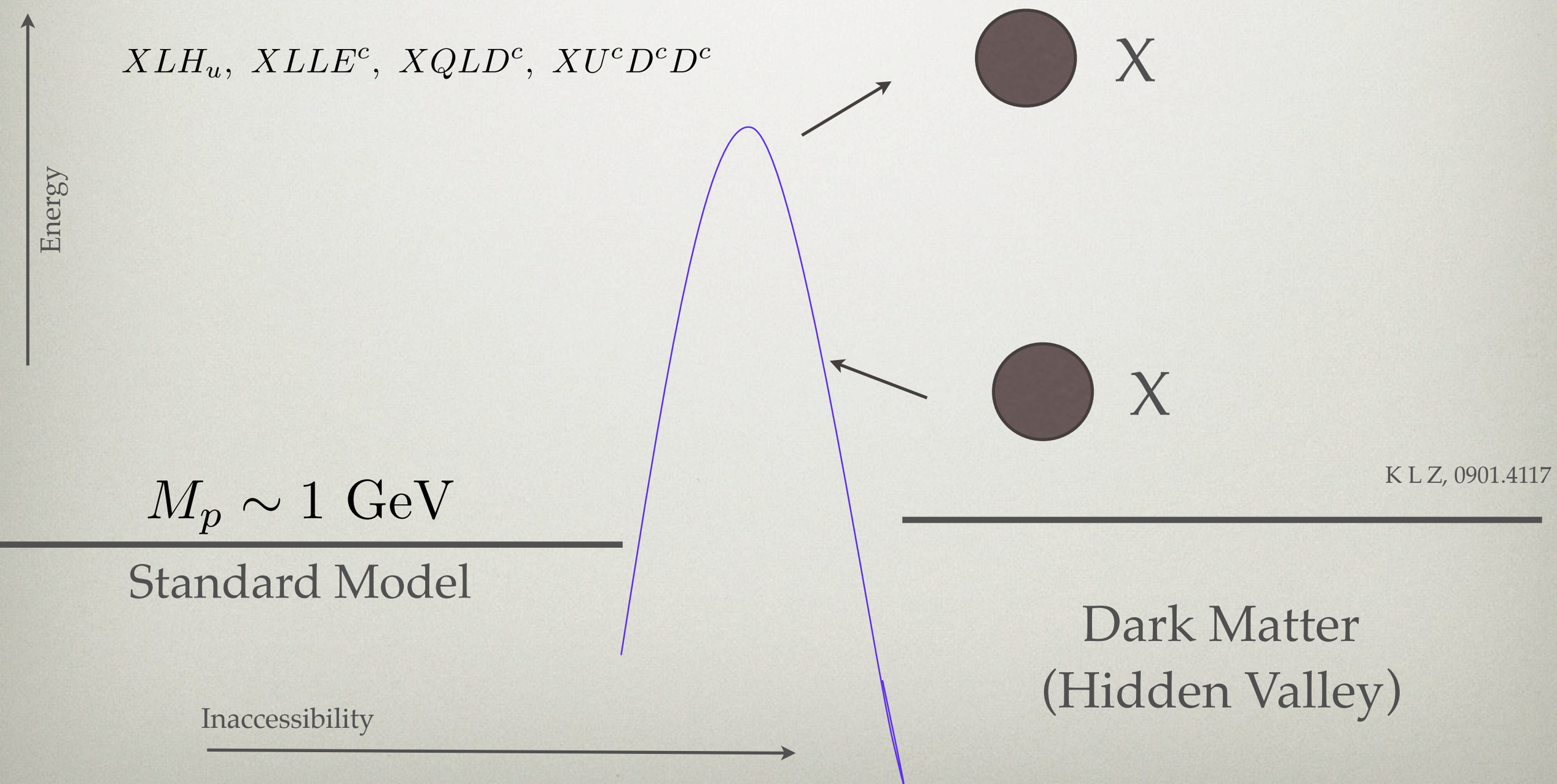
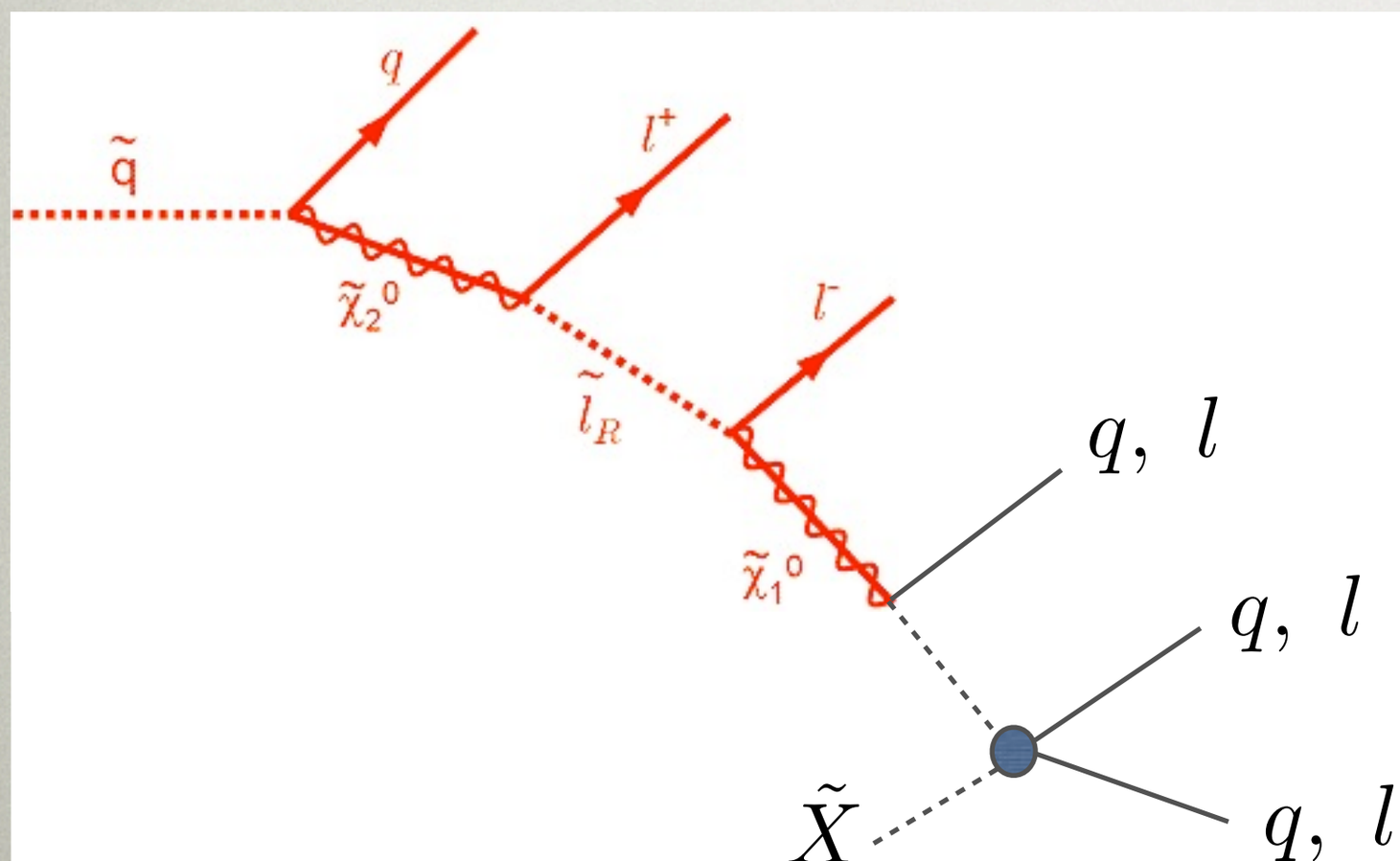


Decaying Into Hidden Sector

- Similar to RPV, but with (reduced) MET
- Lightest ordinary SUSY partner unstable
- Potentially long lifetimes



$$\frac{XU^cD^cD^c}{M},\ \frac{LLE^c}{M},\ \frac{XQLD^c}{M}$$

Theoretical Progress

- Pushed by experimental progress
- SUSY neutralino will become squeezed in the next 5-10 years
- There are well-motivated alternatives at lower mass, including SUSY Hidden Sectors or Valleys and Asymmetric Dark Matter

Experimental Outlook

New searches will be needed in light of the new theoretical models. Some have been devised. (Displaced vertex triggers. Search for low mass resonances. Search for light DM in direct detection. ...)
More are needed.