Beyond the WIMPs?

New Detectors for New Dark Matter Ideas

Kathryn Zurek
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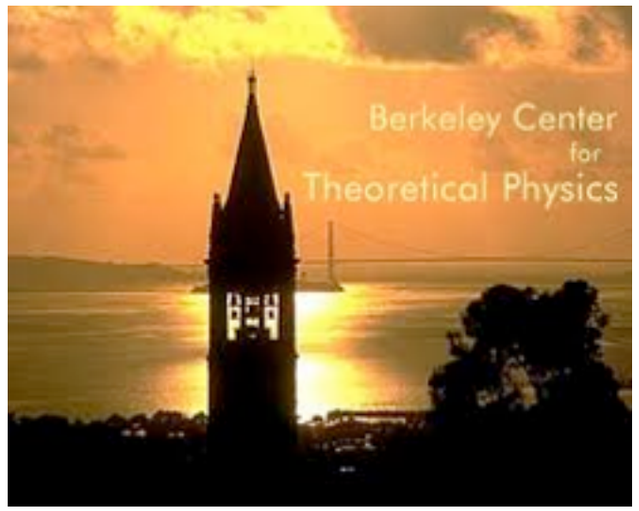
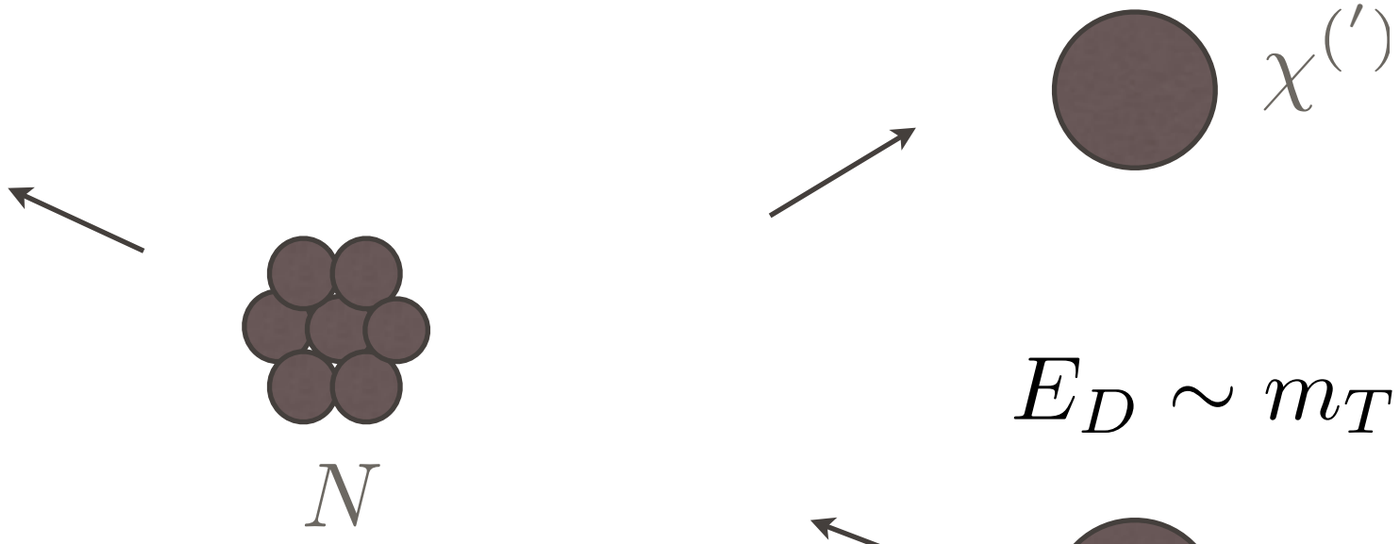
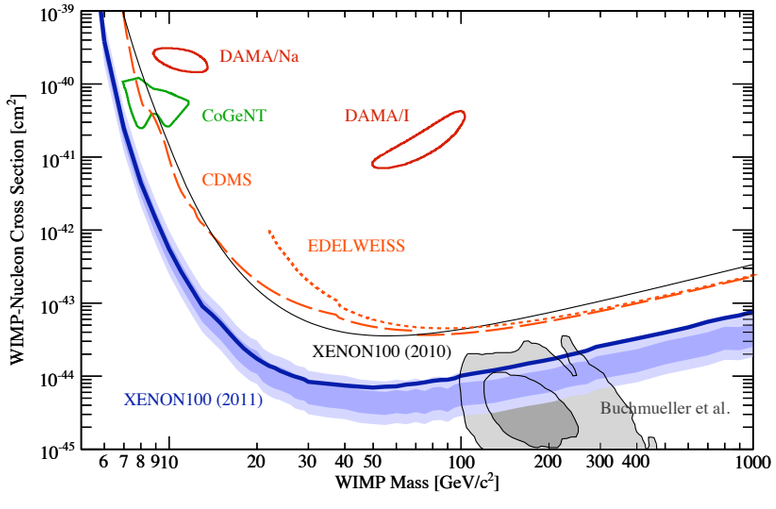


DM Detection Basics

- 1.) Rare interactions of DM on earth

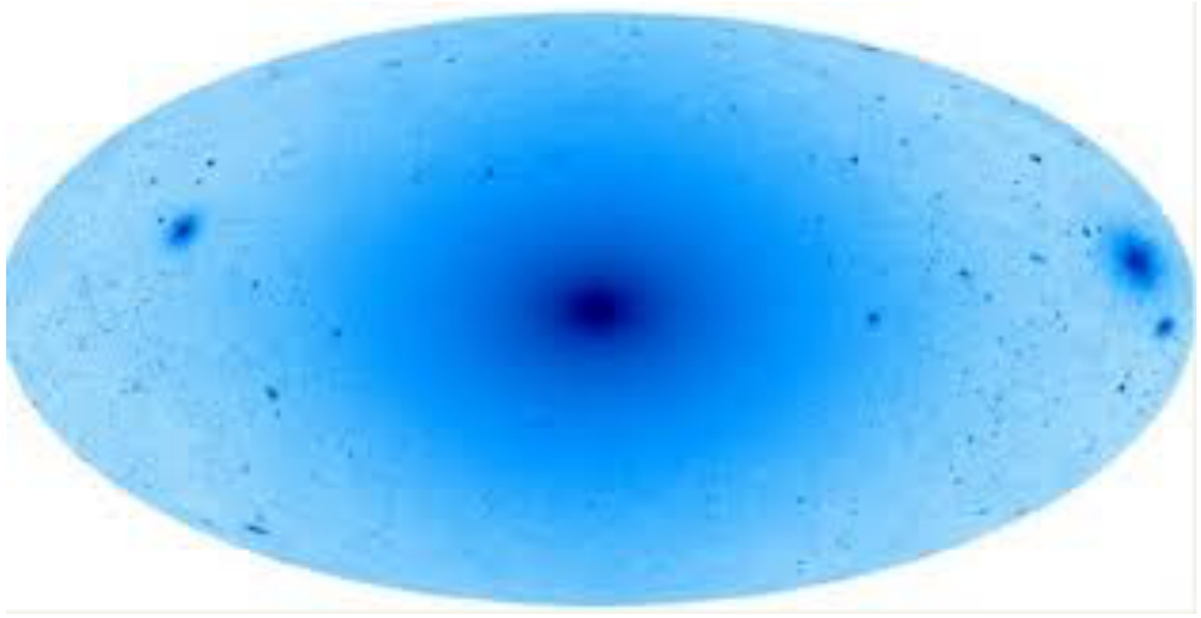


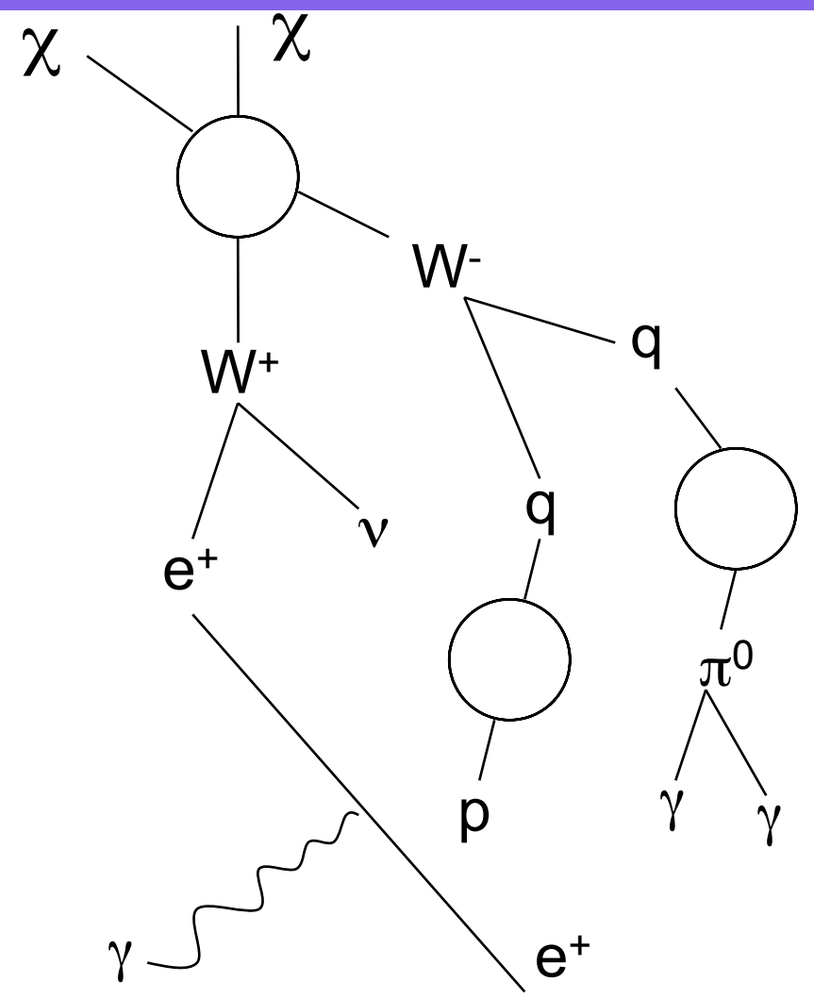
$$E_D \sim m_T v^2 \sim 50 \text{ keV}$$

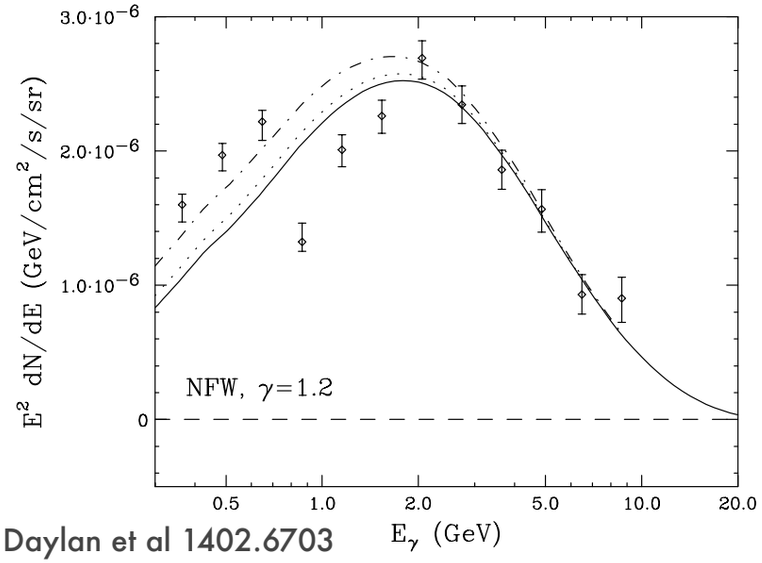


DM Detection Basics

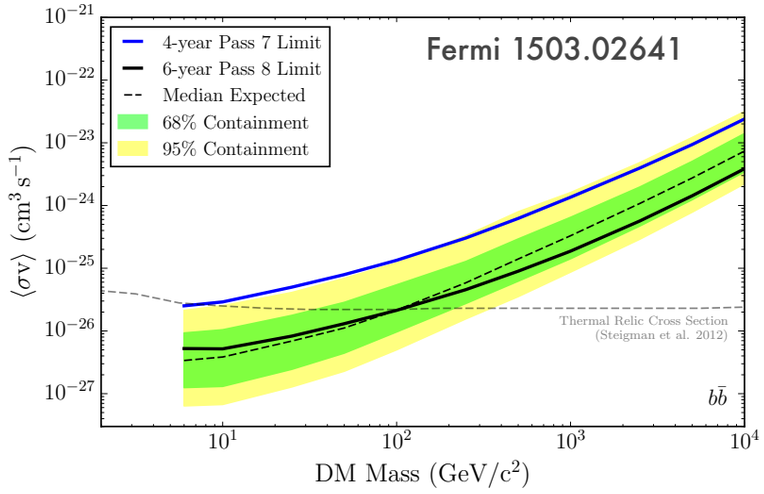
- 2.) Rare annihilations

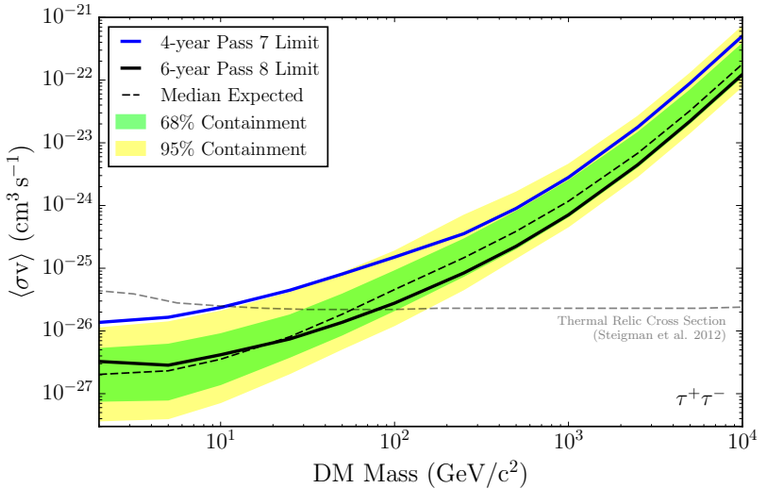






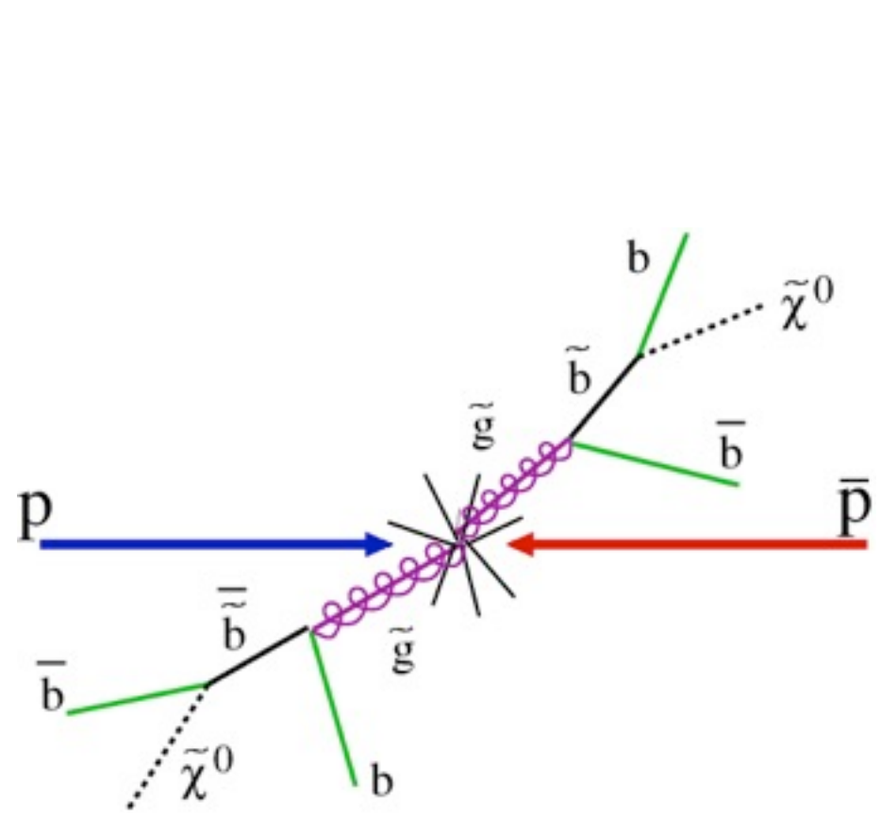
Daylan et al 1402.6703

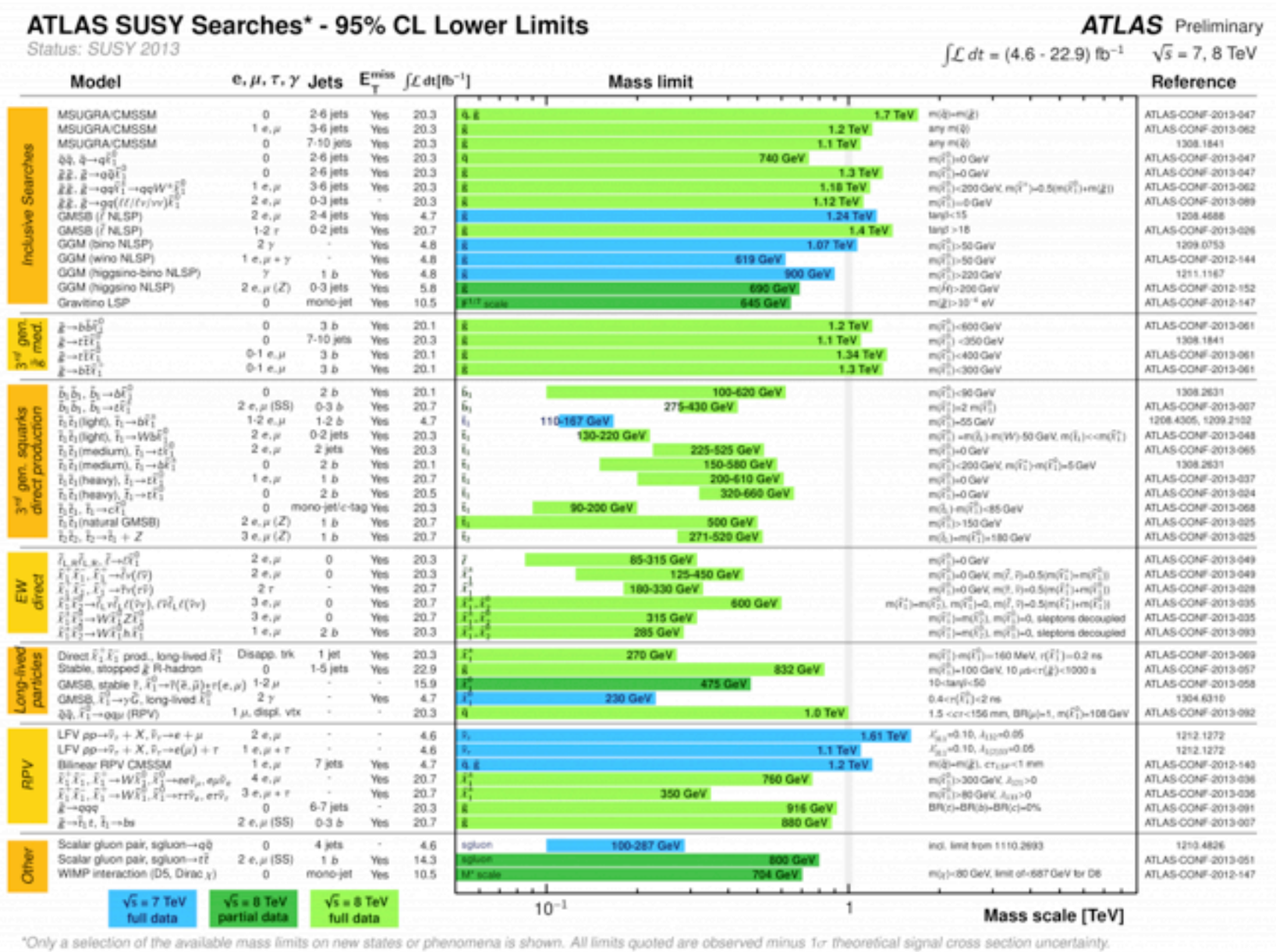




DM Detection Basics

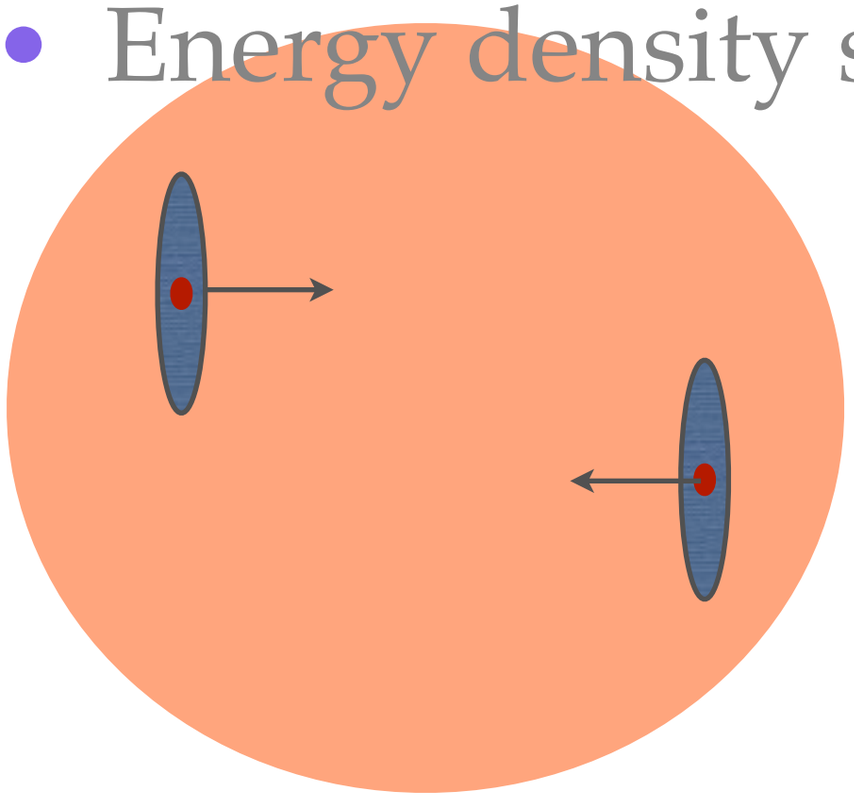
- 3.) Direct production





Aimed for WIMP

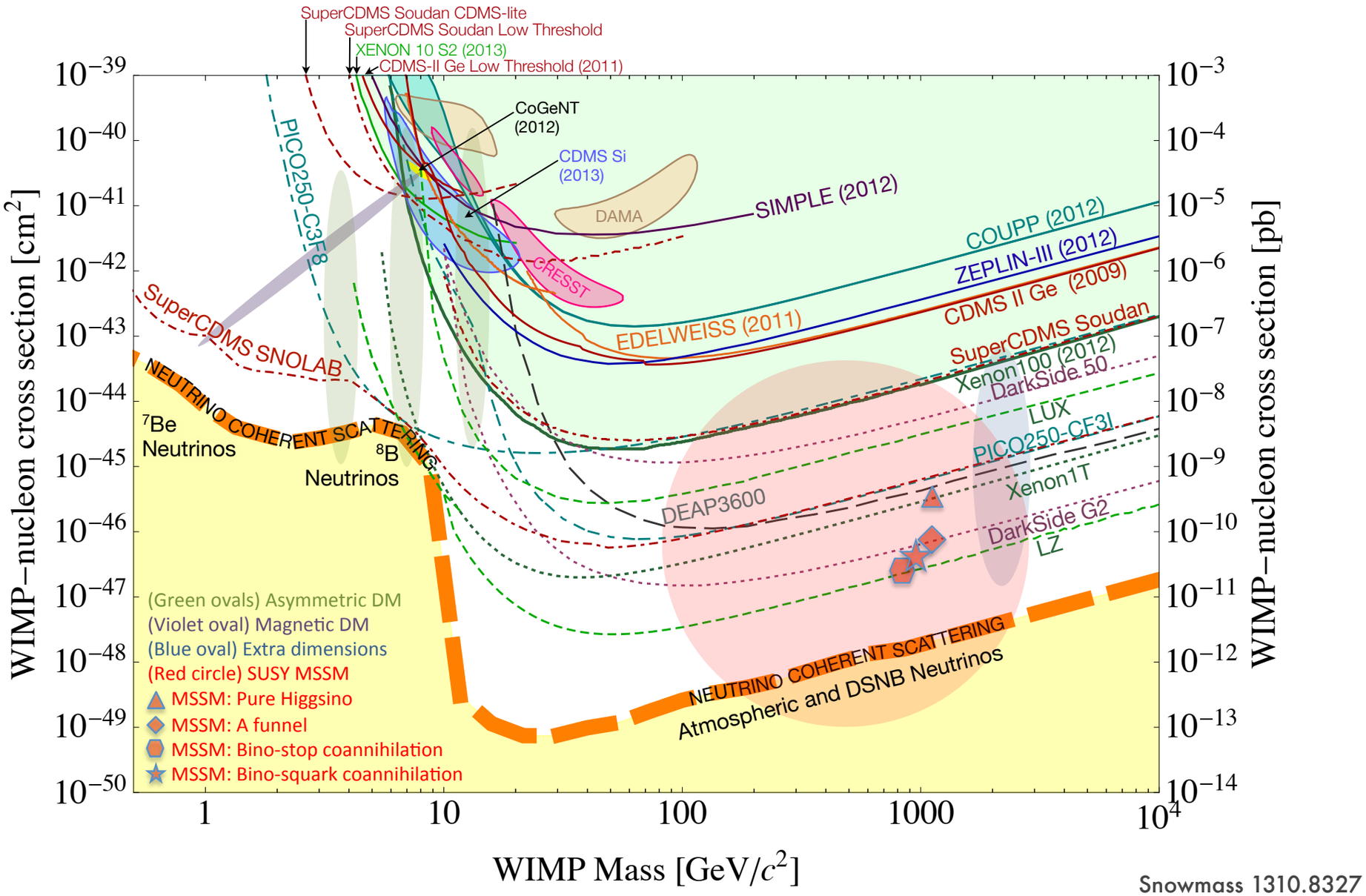
- Energy density set by annihilations



$$\sigma_{ann} \simeq 3 \times 10^{-26}\ \mathrm{cm}^3/\mathrm{s} \sim \frac{g_{wk}^4}{4\pi(1\ \mathrm{TeV})^2}$$

- Macroscopic quantity (energy density) linked to microscopic quantity (cross-section)

Why Beyond the WIMP?



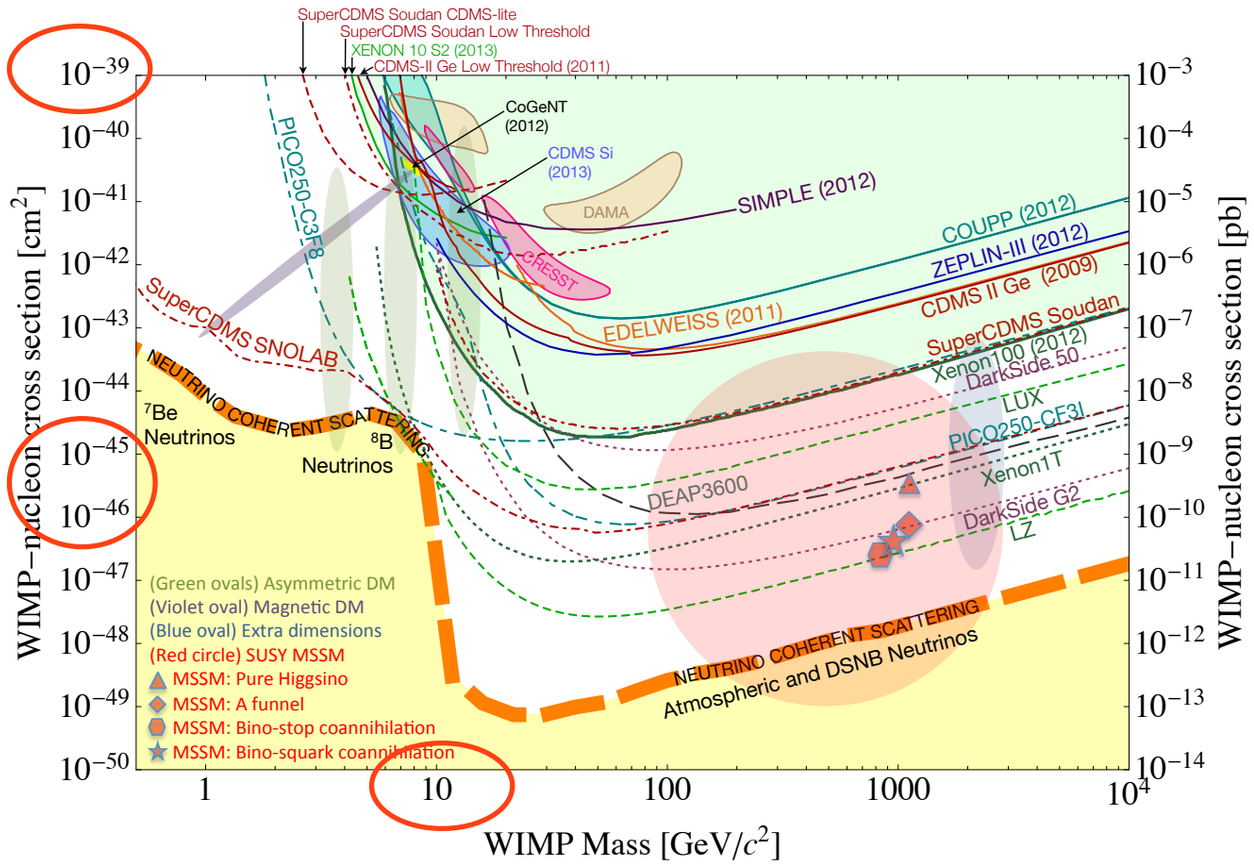
Snowmass 1310.8327

Harsh experimental scrutiny

Sub-Weakly Interacting

Scattering through the Z boson: ruled out

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

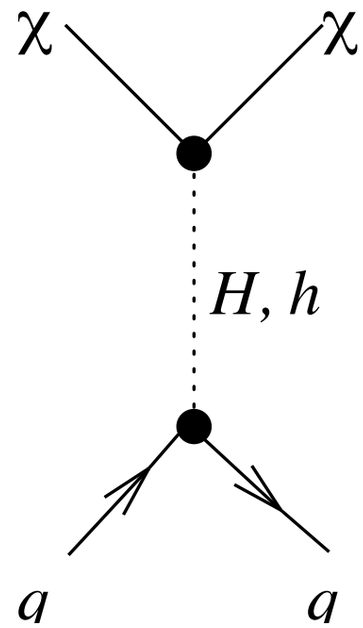


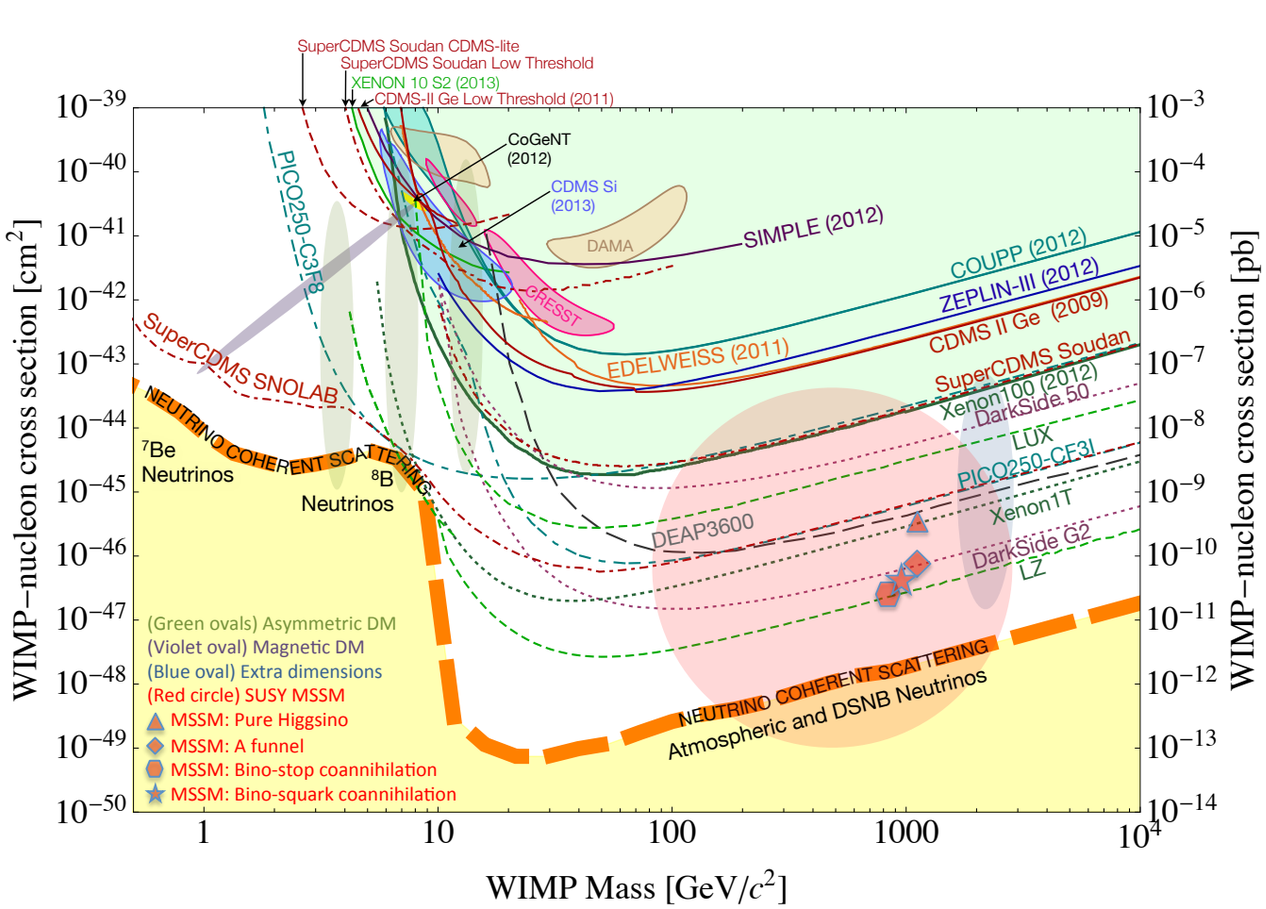
Next important benchmark: Scattering through the Higgs

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

A Tale of (two)Higgs Scattering

$$\sigma_n \approx 8.3 \times 10^{-42}\,\mathrm{cm}^2 \left(\frac{Z_d}{0.4}\right)^2 \left(\frac{\tan\beta}{30}\right)^2 \left(\frac{100\,\mathrm{GeV}}{m_H}\right)^4$$



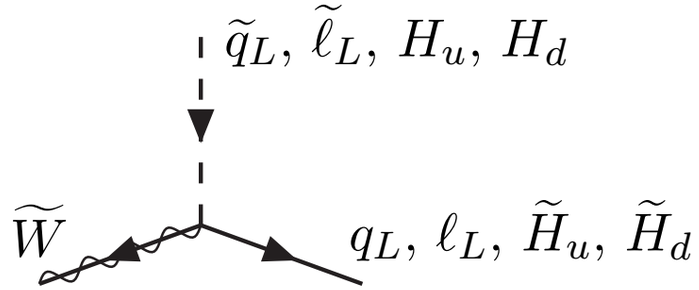


Higgs mediated scattering

MSSM

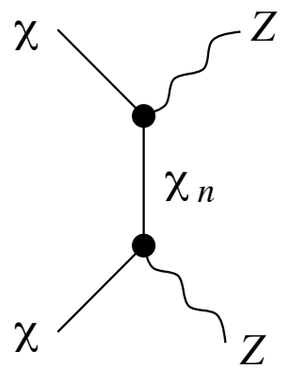
Minimal Supersymmetric Standard Model

- Blob closure is deceptive



- MSSM: Bino, Wino, Higgsino

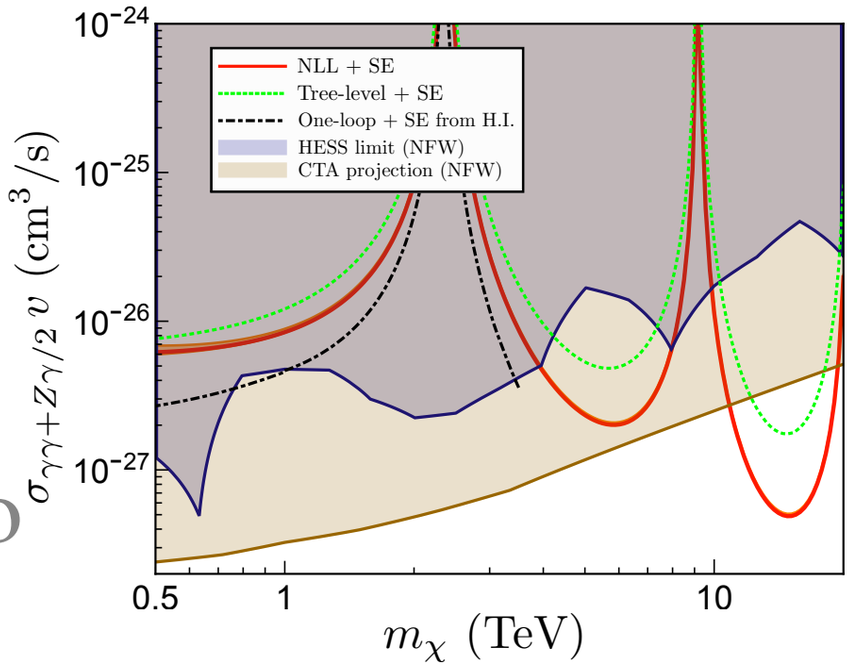
- Pure states do not couple to Higgs at tree level



- Pure wino and Higgsino are viable; do not scatter off nucleon at tree level

- Indirect detection large for wino

Ovanesyan, Slatyer, Stewart

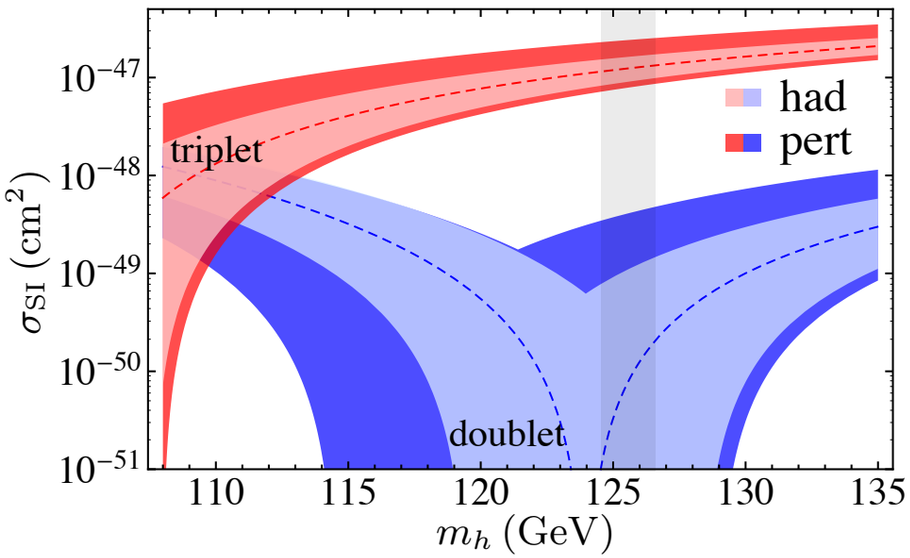


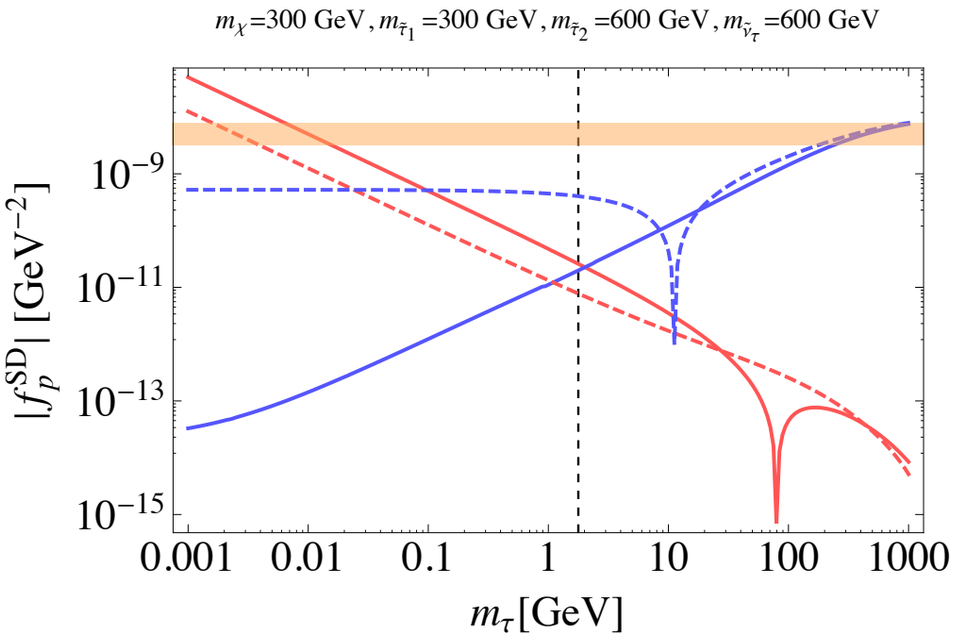
- 1-loop direct detection, wino and Higgsino

- Bino is hard; even 1-loop contribution is suppressed

- Still, some tuning required to remove coupling to Higgs

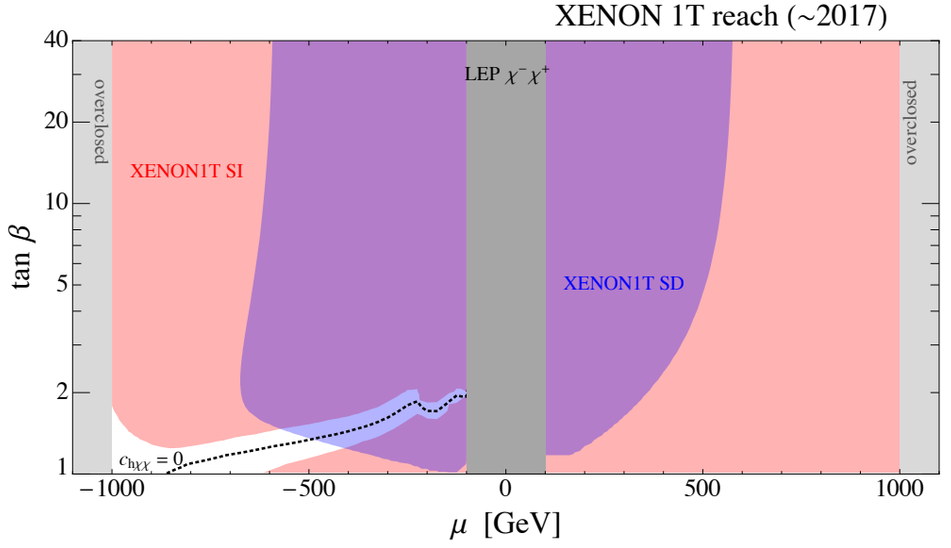
Hill and Solon





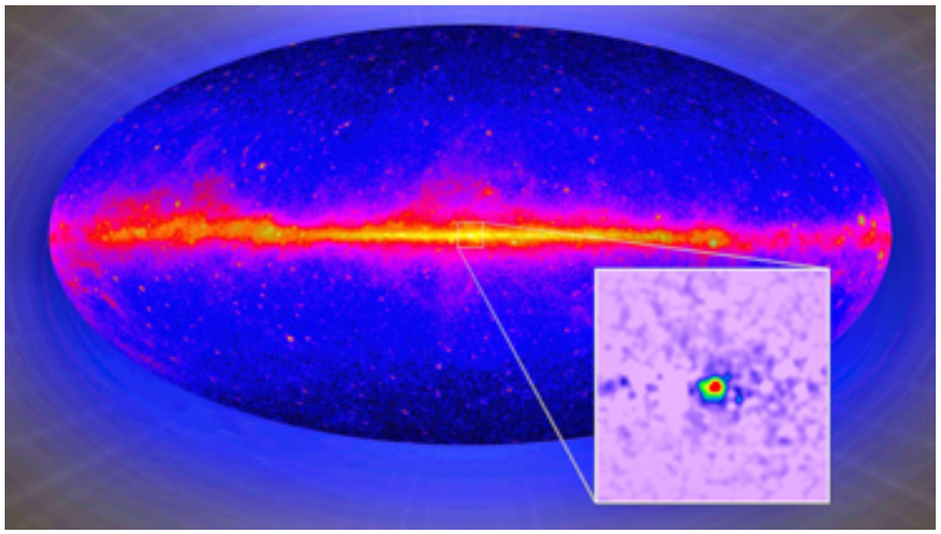
Berlin, Robertson, Solon, KZ

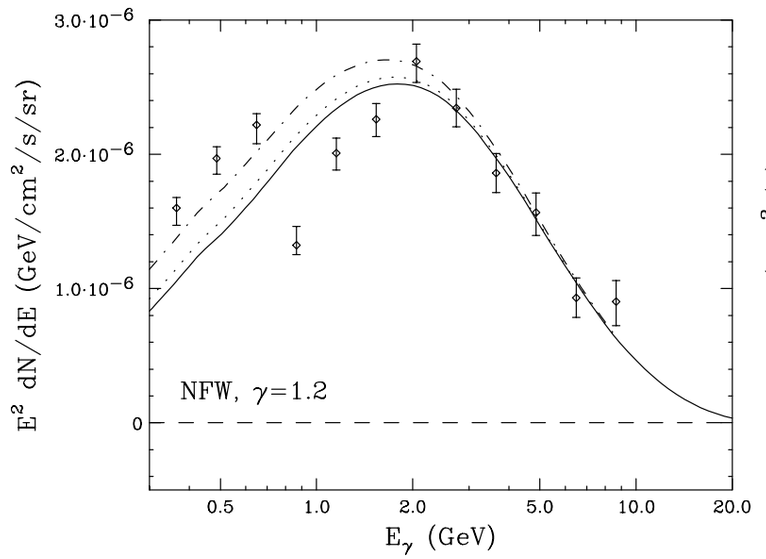
XENON 1T reach (~2017)



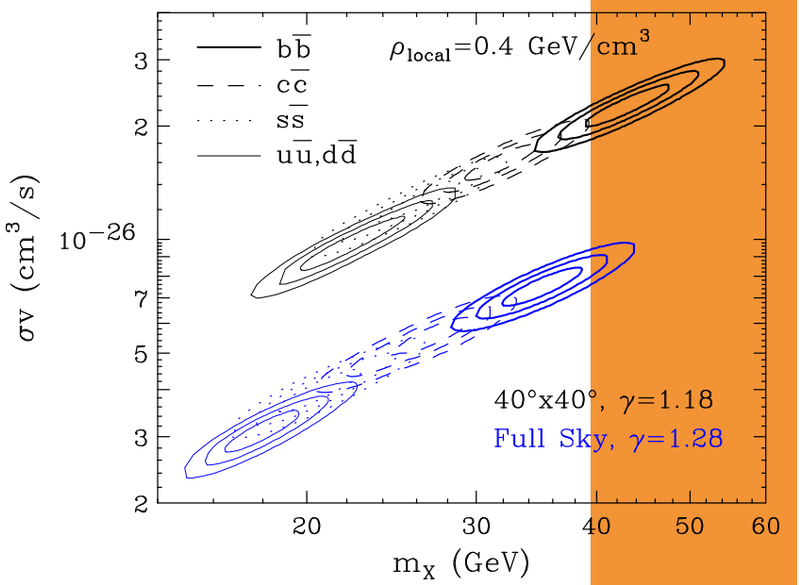
Cheung, Hall, Pinner, Ruderman

- Still room for discovery of WIMP, e.g. galactic center excess



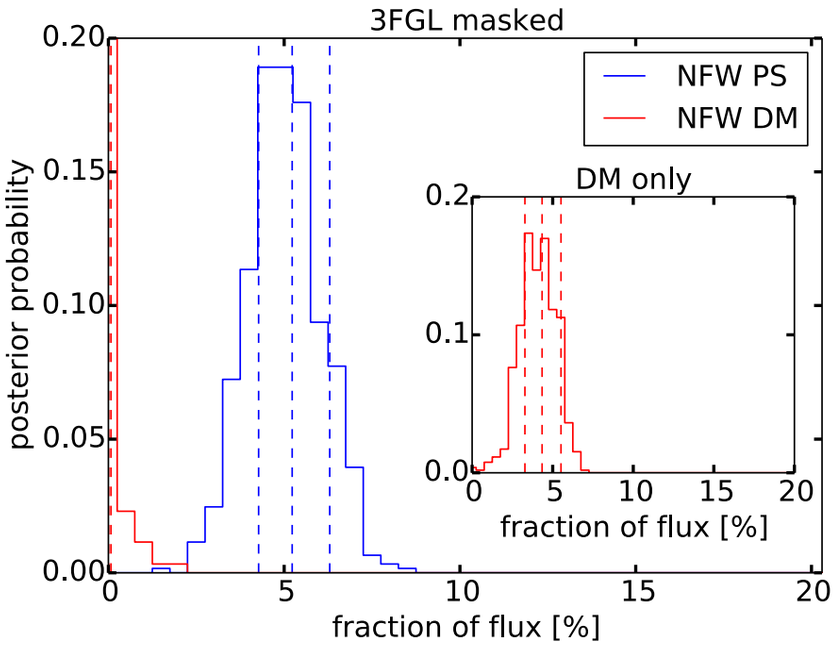


Daylan et al 1402.6703



- Cannot accommodate in minimal SUSY
- LHC and direct detection constraints too strong
- Mixing in singlet makes viable

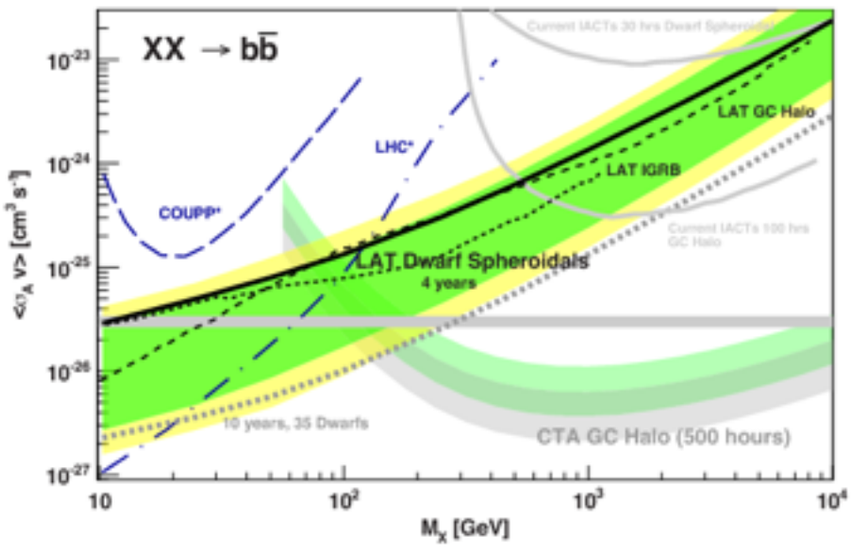
- However, recently shown to be more consistent with unresolved point sources

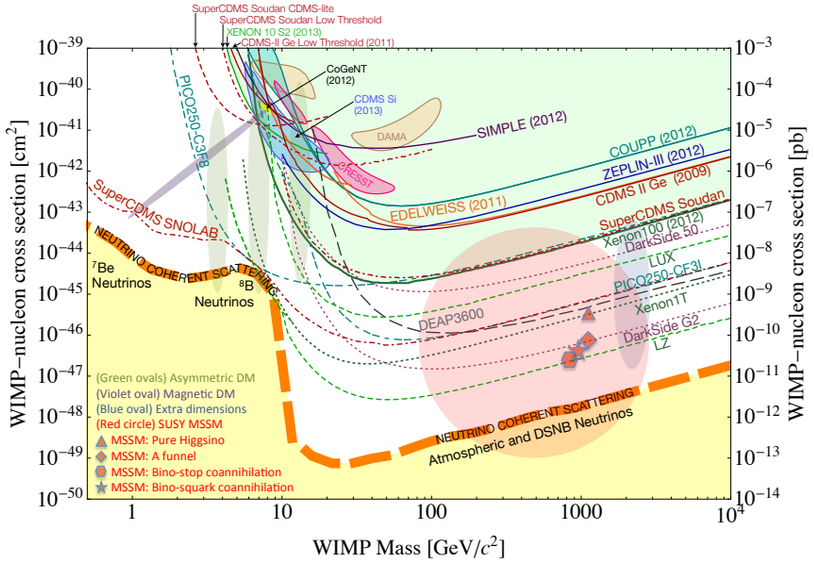


Lee, Lisanti, Safdi, Slatyer, Xue

- Emphasizes that it will be much easier to establish bounds than signal from indirect detection

- Well-defined WIMP-hunting program that will (severely) narrow but not eliminate well-motivated candidates



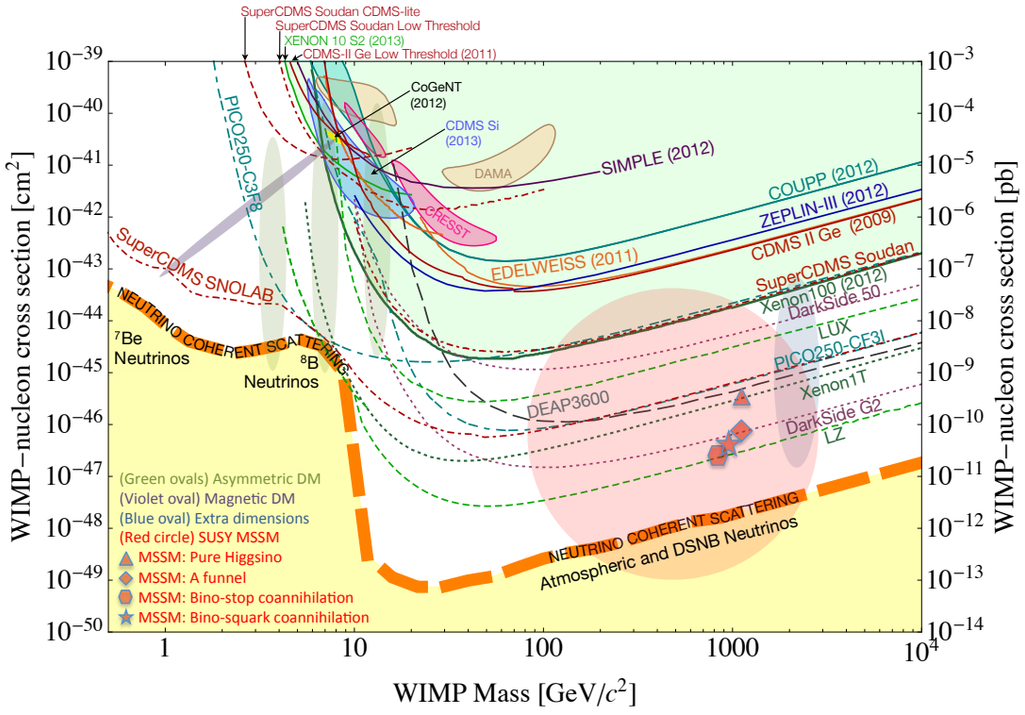


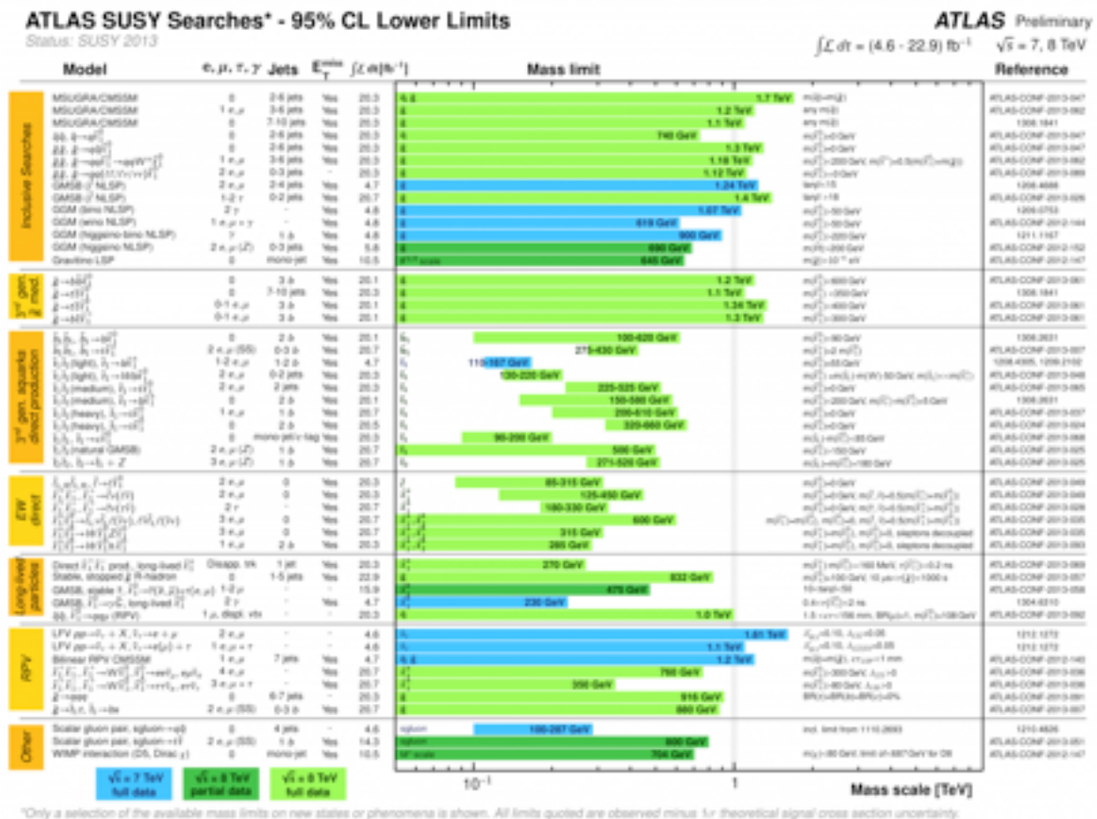
1310.2695

- Program has momentum, is funded, and is being pushed through

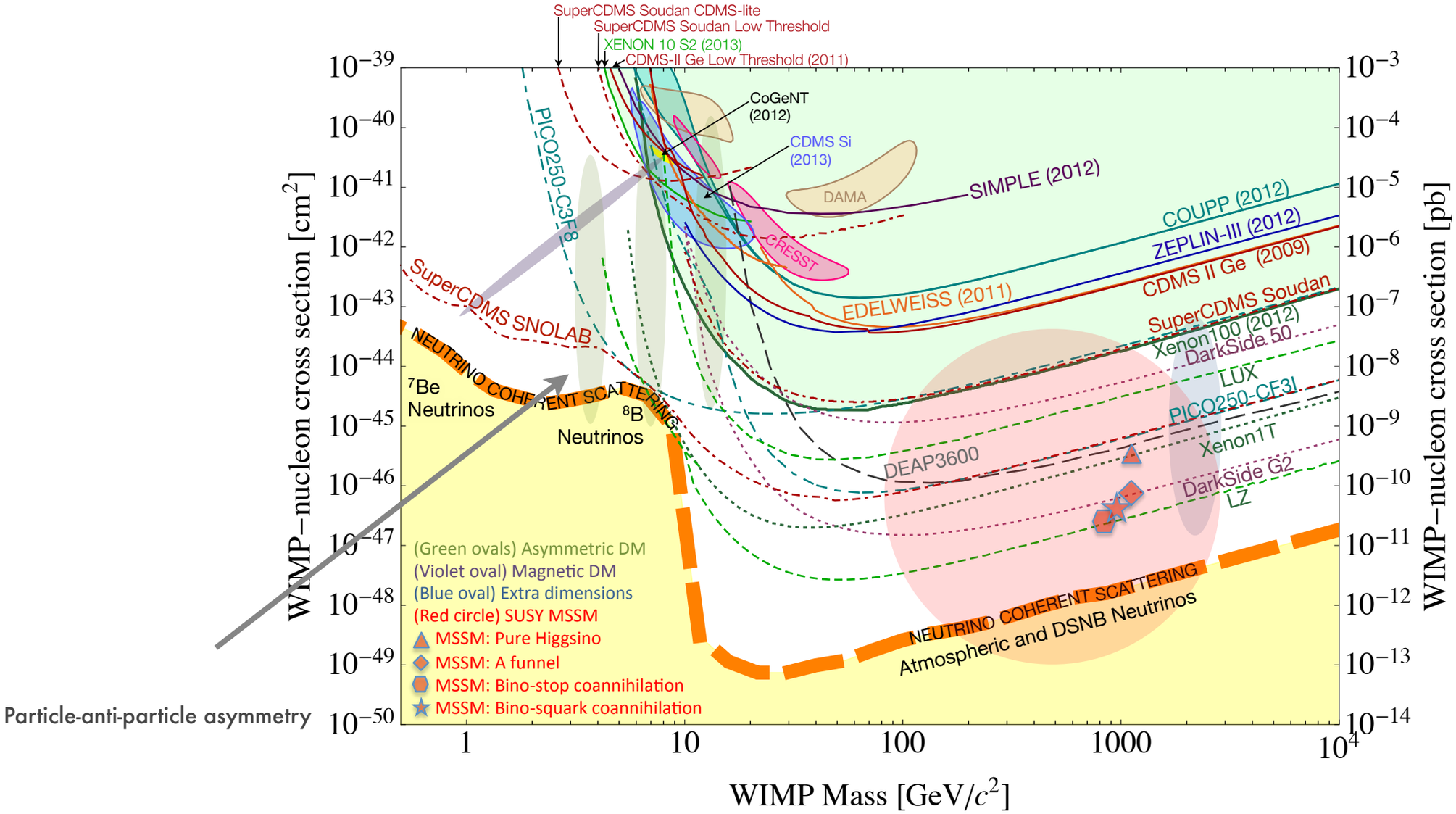
- But what if we aren't looking in the right place?

- Two reasons to move beyond WIMP:
  - Simple, “natural” models reside elsewhere
  - Experiments are pointing us in that direction





Ex: Asymmetric DM



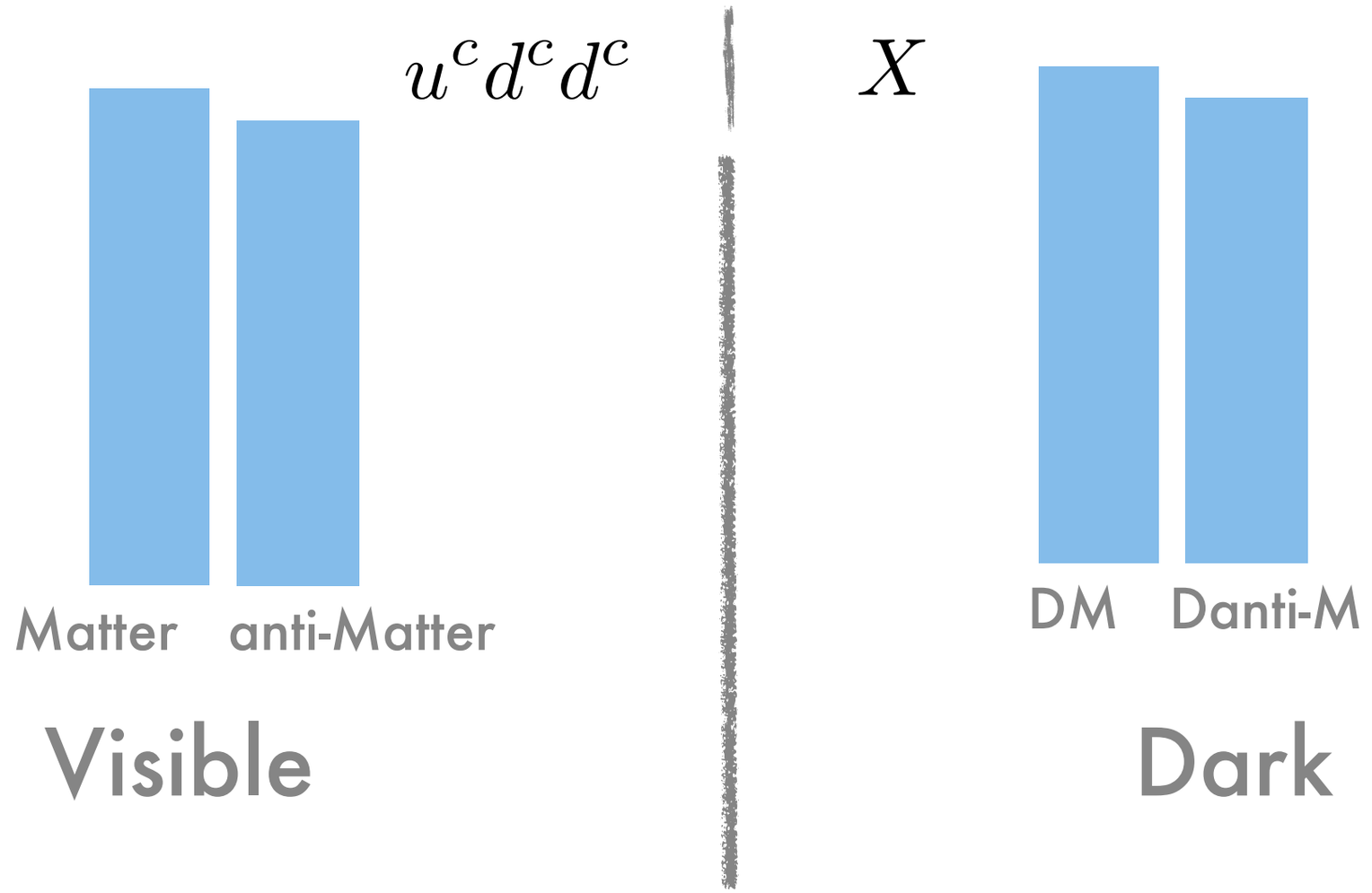
Particle-anti-particle asymmetry

Idea of DM particle-anti-particle asymmetry is old

What's new?

Hidden Asymmetric DM

- Higher dimension operator coupling



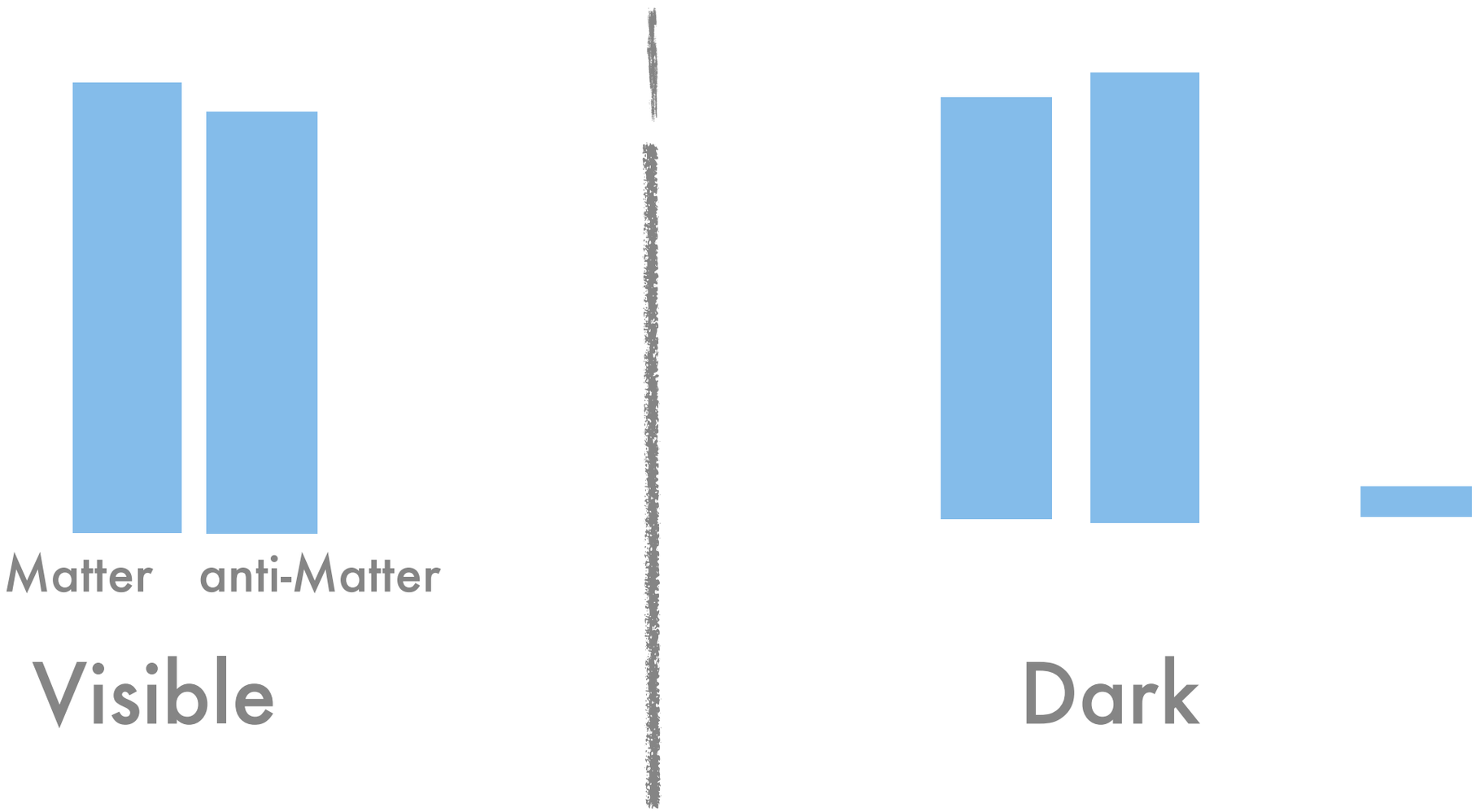
$m_{DM} \approx 5 m_p$

KLZ 0901.4117

Barrier carries B or L

Hidden Asymmetric DM

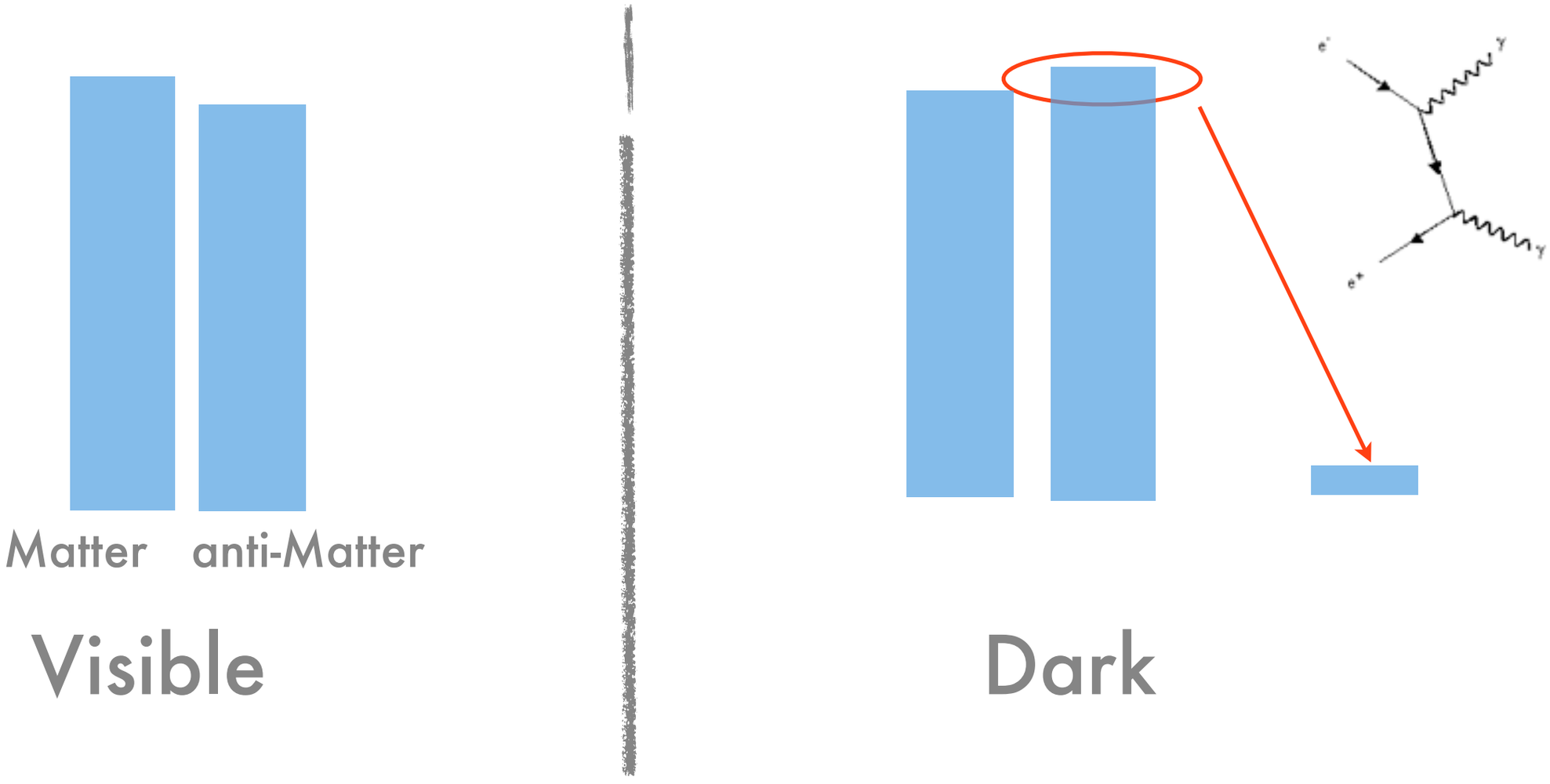
- Higher dimension operator coupling



Barrier carries B or L

Hidden Asymmetric DM

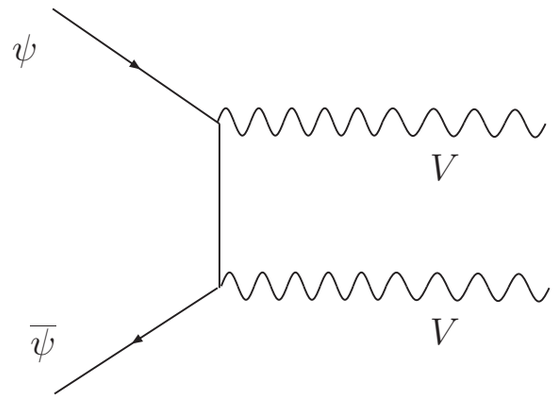
- Higher dimension operator coupling

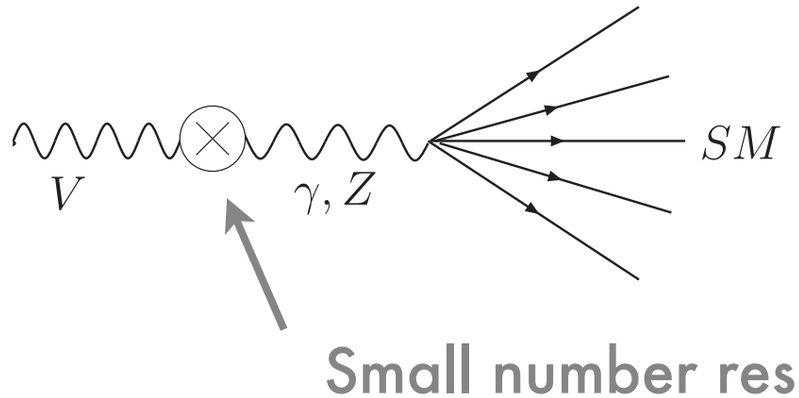


Barrier carries B or L

GeV ➡ MeV Dark Matter

- Secluding DM = model flexibility





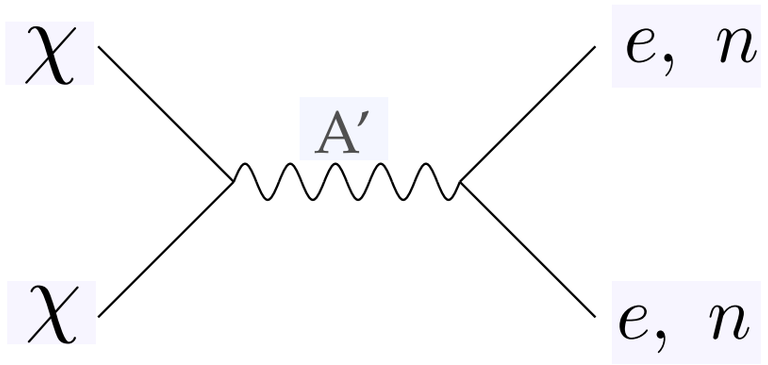
Small number resides here

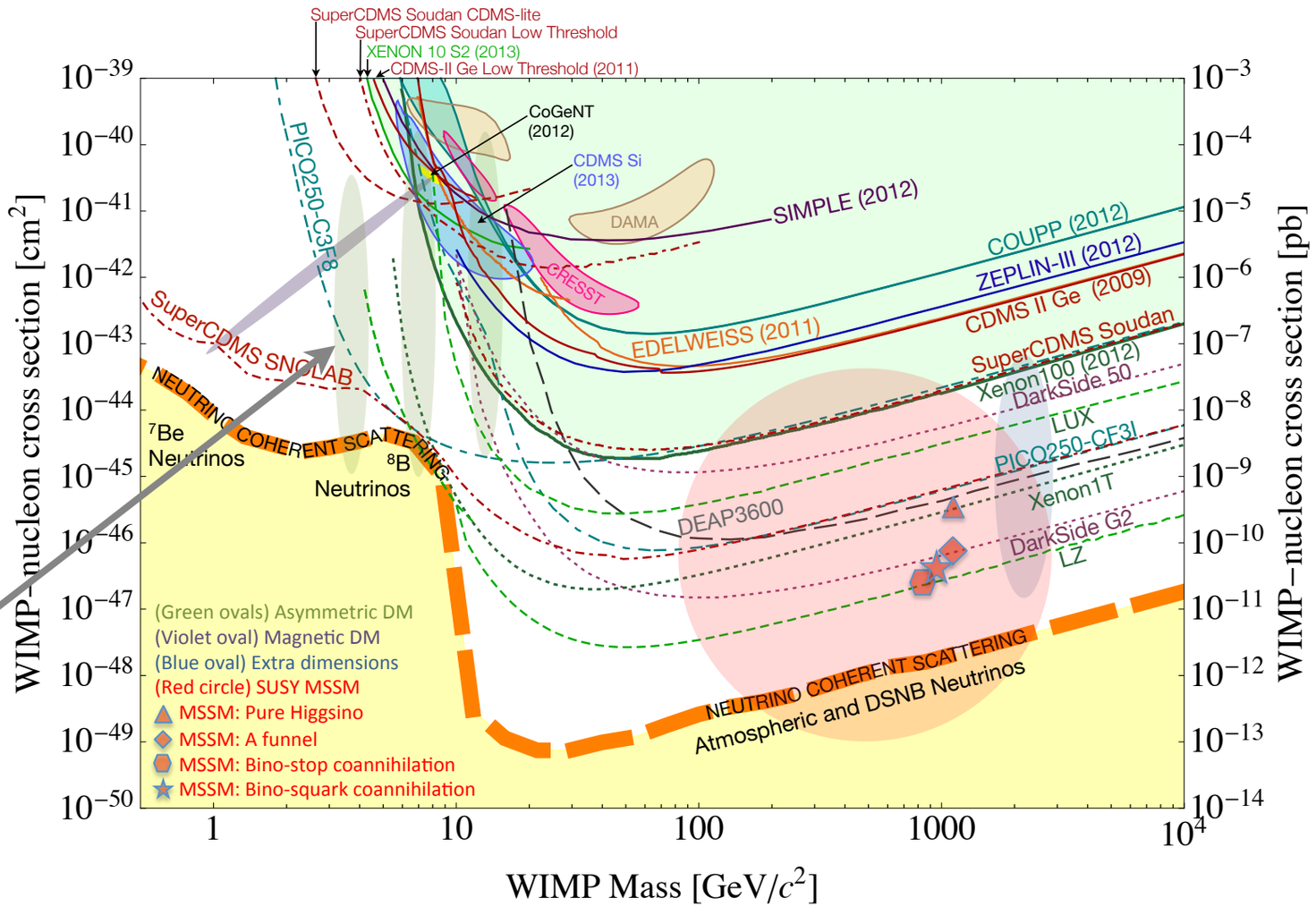
- Secluding DM can be "natural"

Pospelov and Ritz
Hooper, KZ
Feng, Kumar

Amount of SUSY breaking transmitted sets DM mass scale
Small coupling between sectors = small mass

- Presence of dark force mediates DD

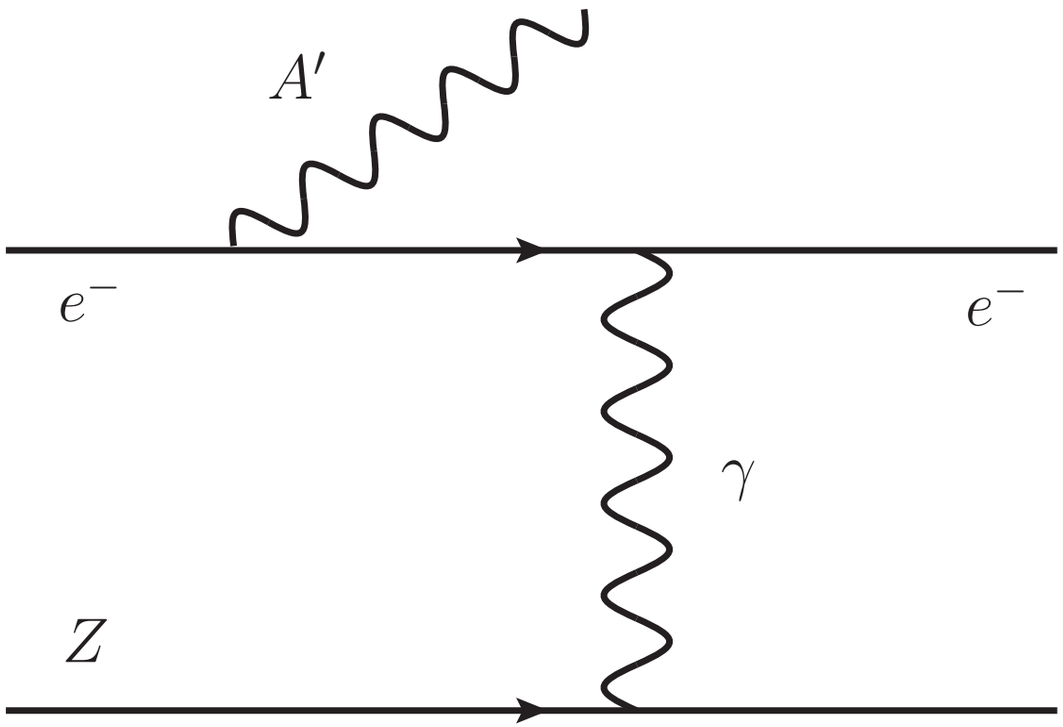




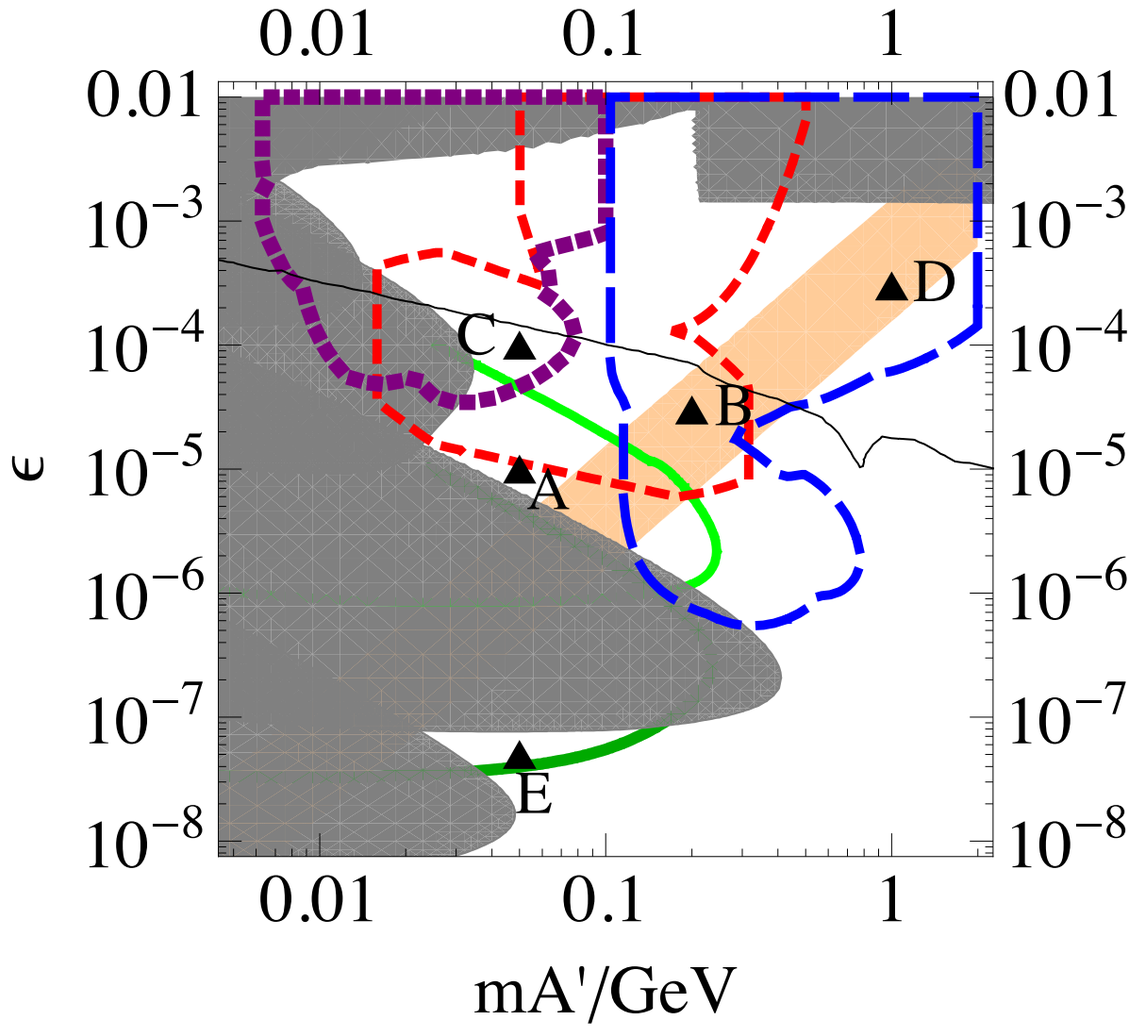
ADM model with dark force
Cohen, Phalen, Pierce, KZ
1005.1655

Theorists Align

- with new experiments

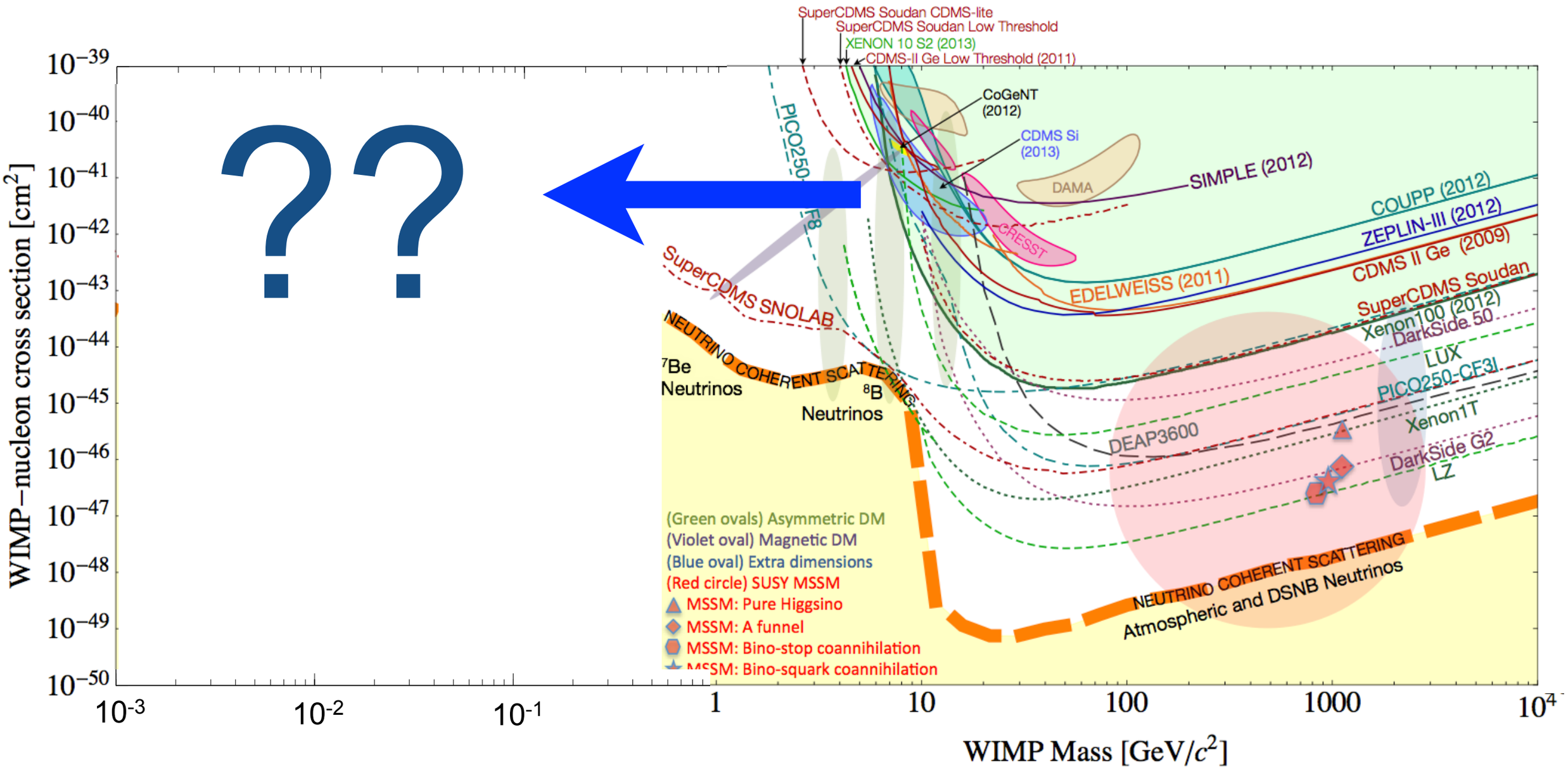


Bjorken, Essig, Schuster, Toro



- What else can we design?

New DM Experiments



Plot from R. Essig

- Kinematics and experimental viability

- Elastic scattering

$$E_D \simeq q^2/(2m_{e,N}) \qquad q \sim m_X v$$

$$v \sim 10^{-3}$$

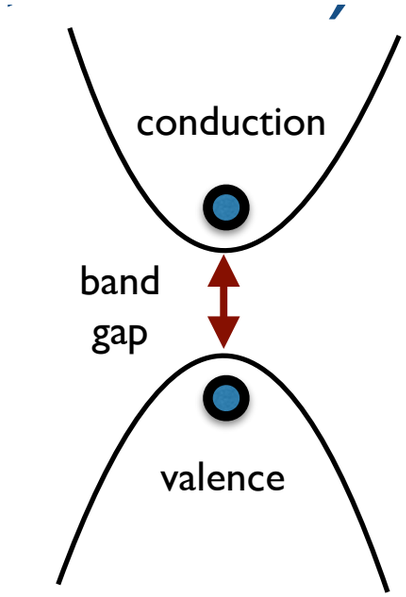
- 1 MeV DM corresponds to 1 eV of energy deposit on *electrons*

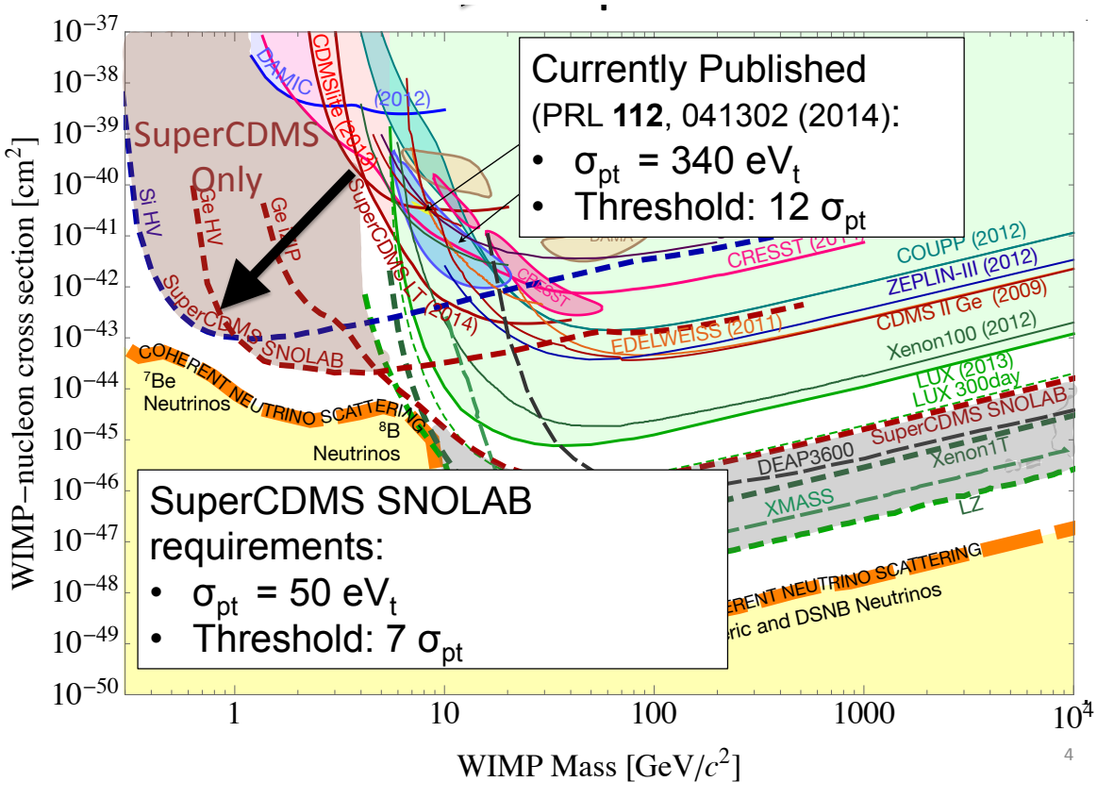
- 30 MeV DM corresponds to 1 eV of energy deposit on *nucleons*

- semi-conductors have ~eV band gaps

Semi-conductor Detectors

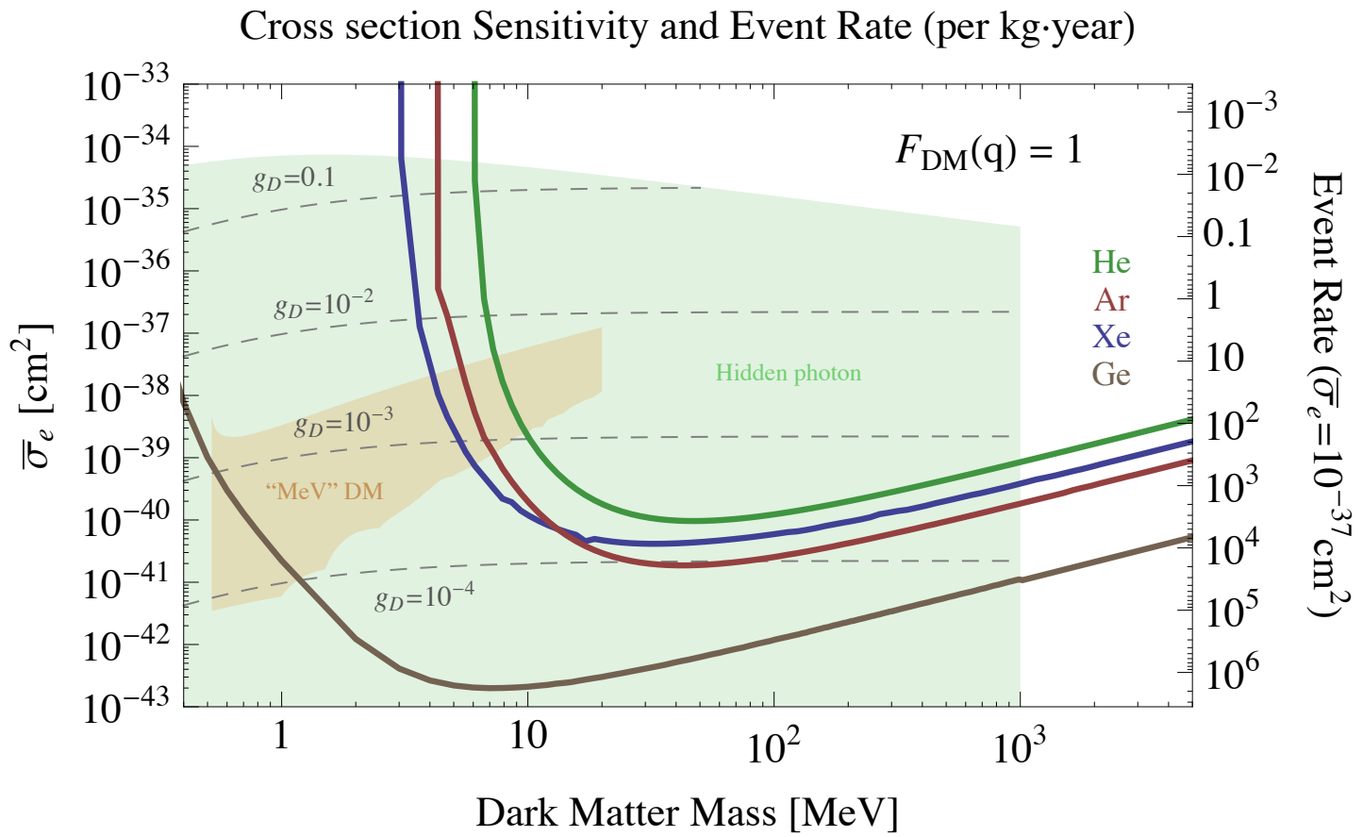
- CDMS -> SuperCDMS Germanium and Silicon
- CDMS: 5 keV nuclear recoil threshold
- Technology optimized for 10 GeV and heavier
- Detectors being redesigned to reach 100's of eV thresholds



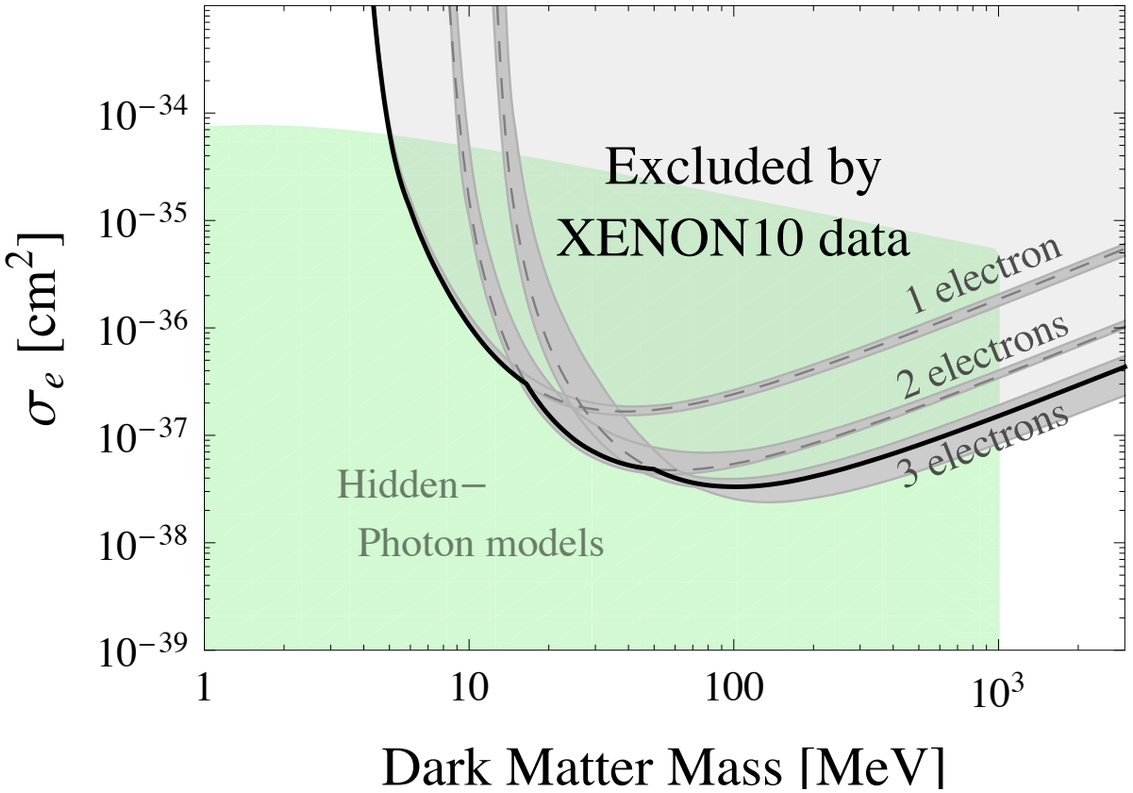


Electron Scattering

Essig, Mardon, Volansky 1108.5383



RE, Manalaysay, Mardon, Sorensen, Volansky



Even lower masses...

- To the warm DM limit around keV

$$E_D \simeq q^2/(2m_{e,N}) \qquad q \sim m_X v$$

- ..... requires new technology; sub-eV thresholds

- To reach keV mass DM must be able to access entire kinetic energy of DM

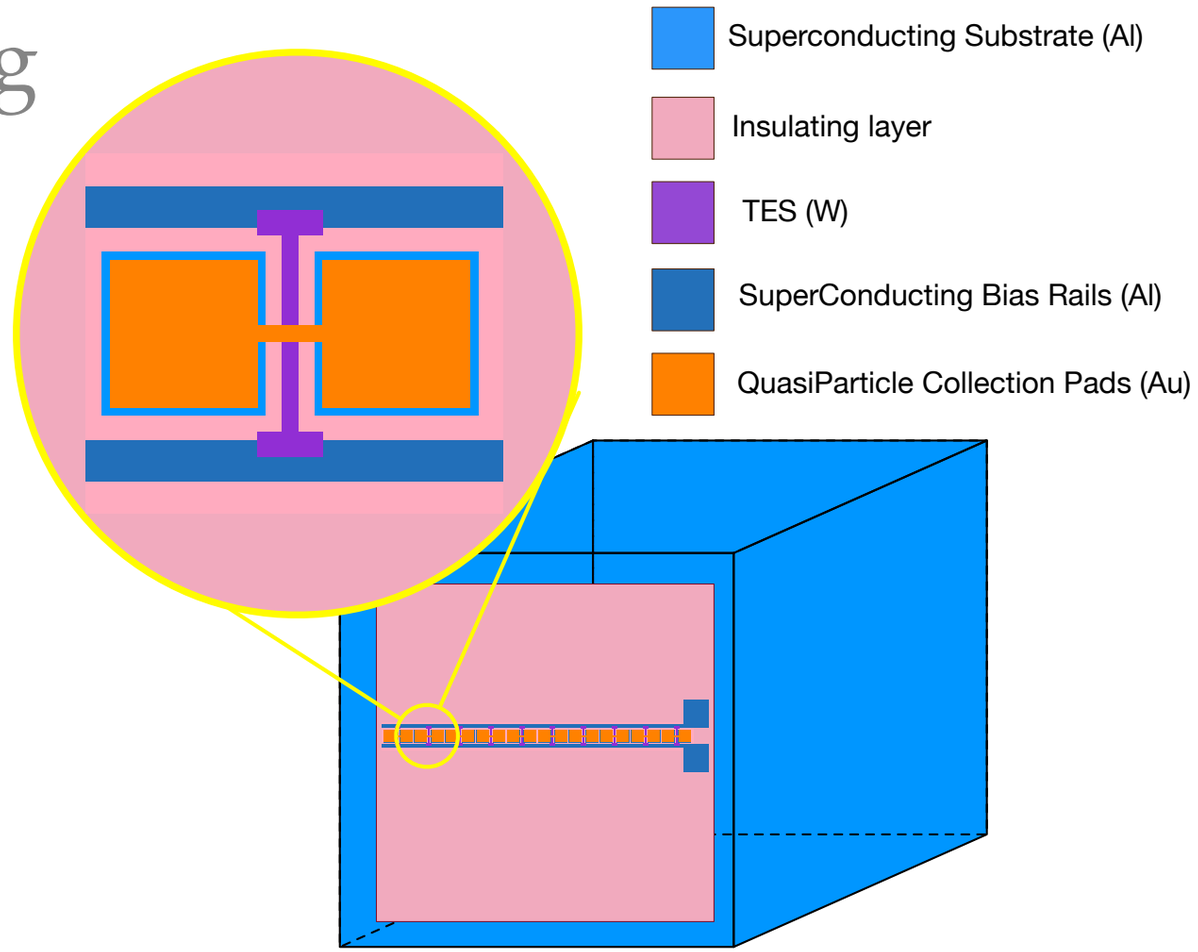
$$E_D = \frac{1}{2} m_X v^2$$

- mX= 1 keV --> ED = 1 meV

SC, Super-light DM

(Superconducting Detectors for Super Light Dark Matter; Hochberg, Zhao, KZ 1504.07237)

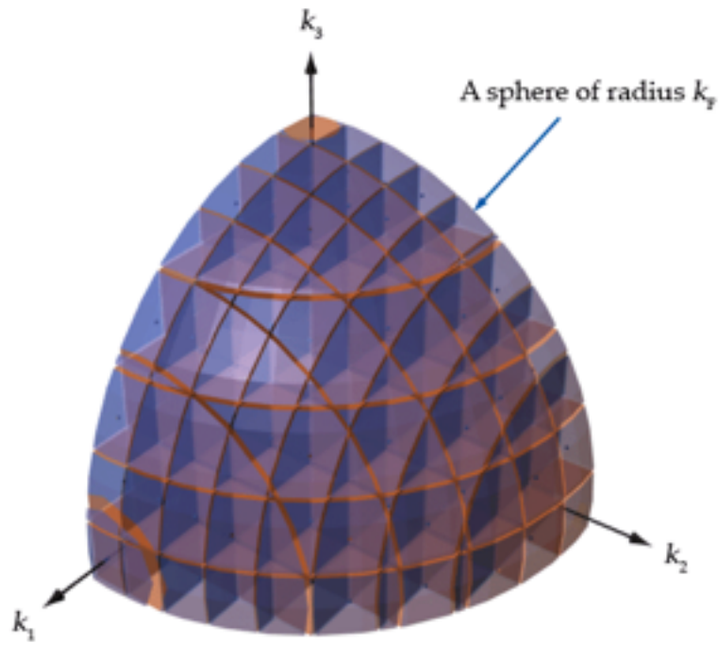
- Superconductors! Cooper pairs have ~meV binding energies
- Above this threshold electrons behave as free electrons in Fermi degenerate metal
- What can such detectors actually observe?

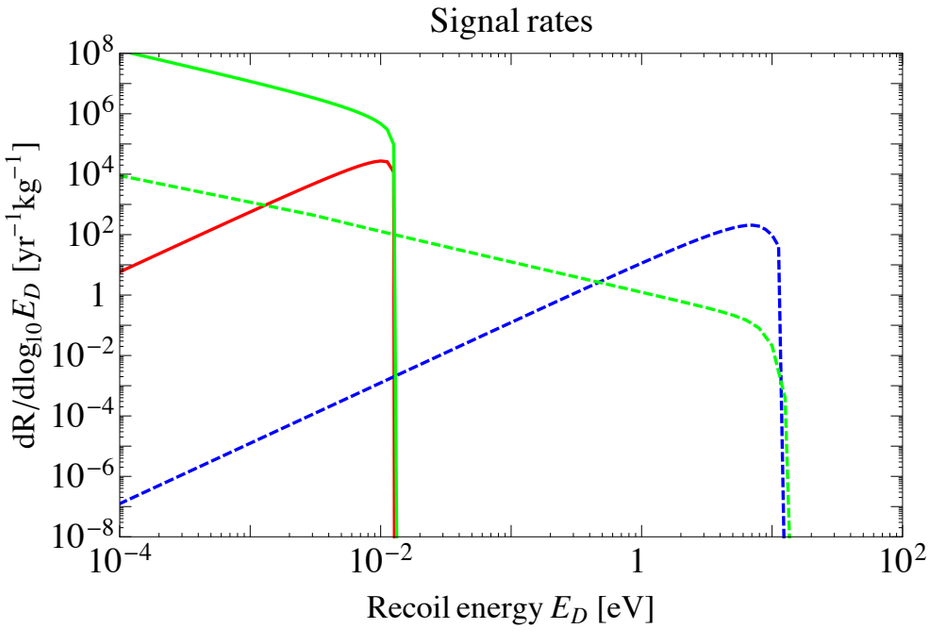


Design by M. Pyle

SC 101

- Superconductors are Fermi degenerate metals with a small gap due to electron pairing
- When deposited energy is larger than gap, scattering is computed as if electrons are free

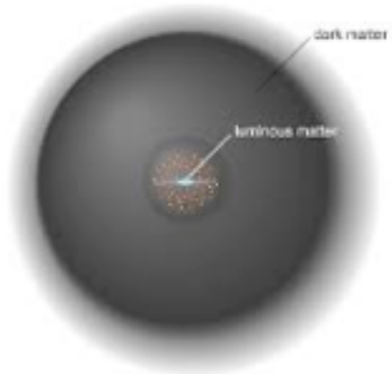


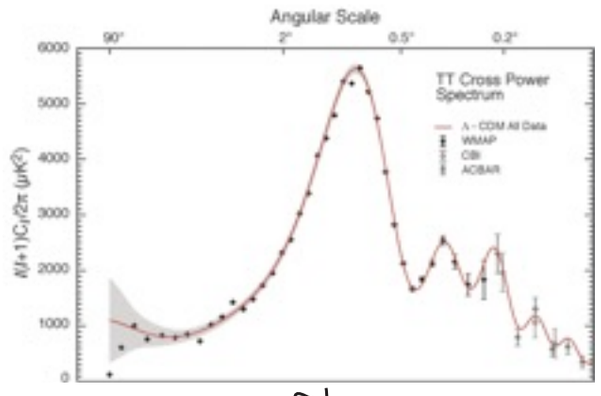


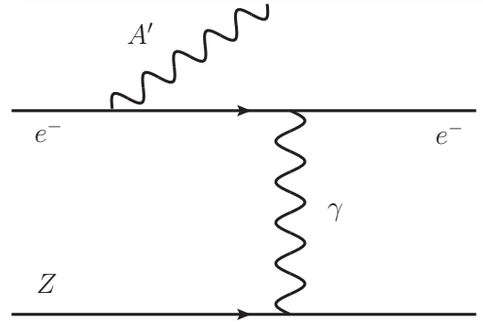
Hochberg, Zhao, KZ 1504.07237

Models of Light DM

- Use what we already know about DM
  - Not too strongly self-interacting
- Not copiously produced in stars
- Not coupled to baryons at CMB epoch
- Not observed in any beam dump experiment

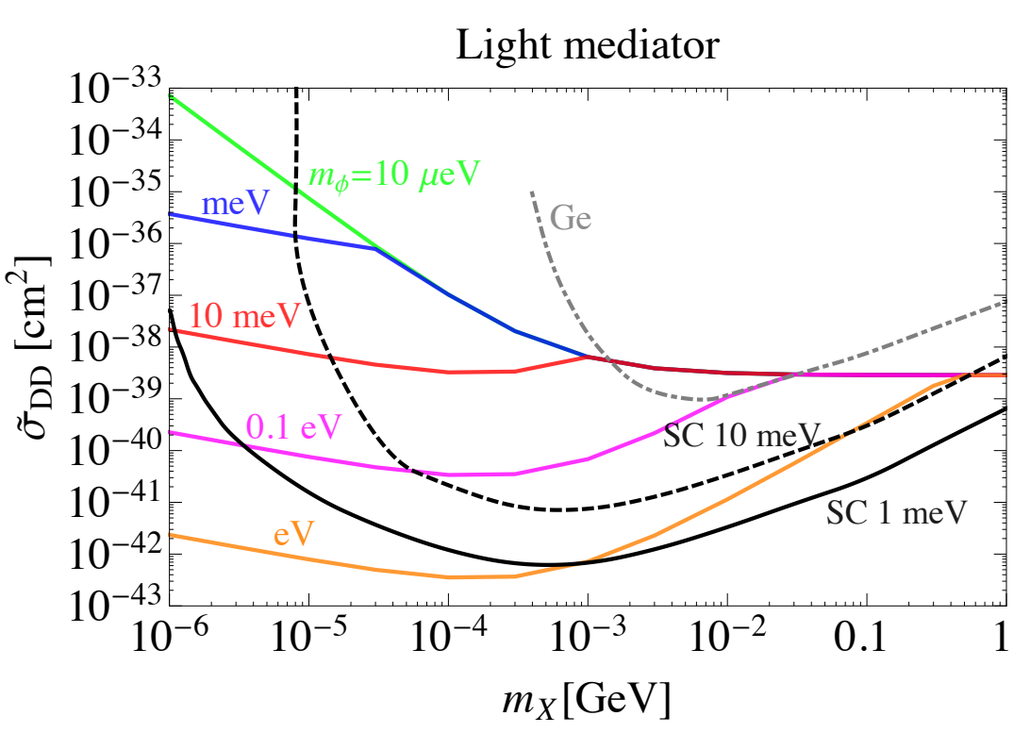


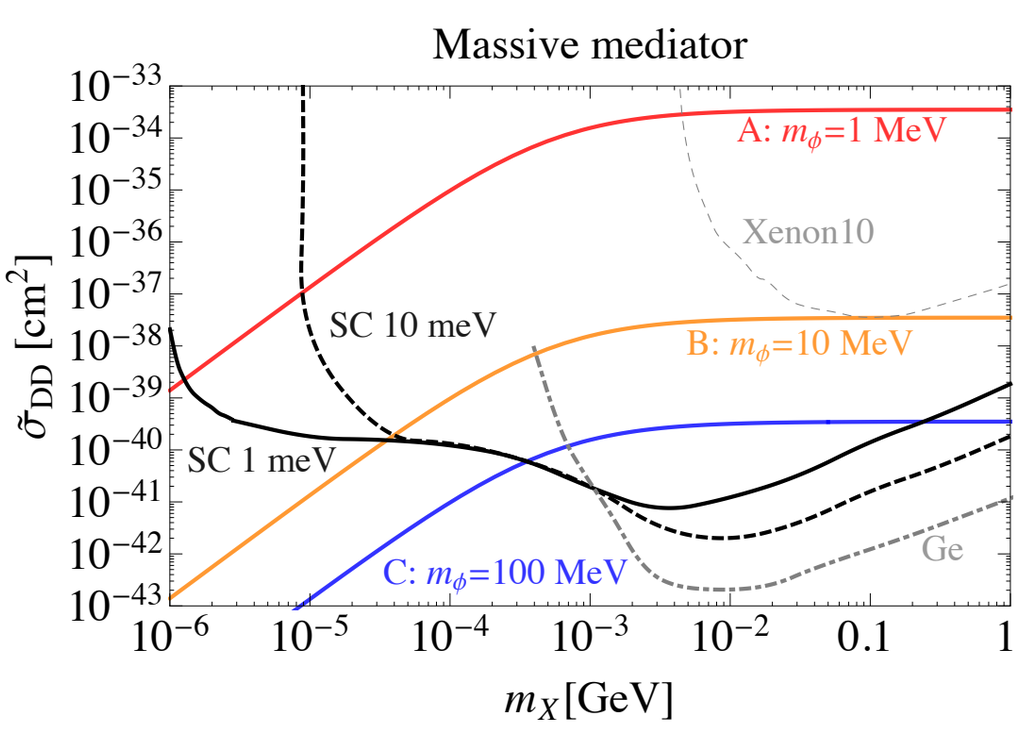




Rates & Constraints

- Stellar + Self-interactions
- Most powerful in light mediator regime



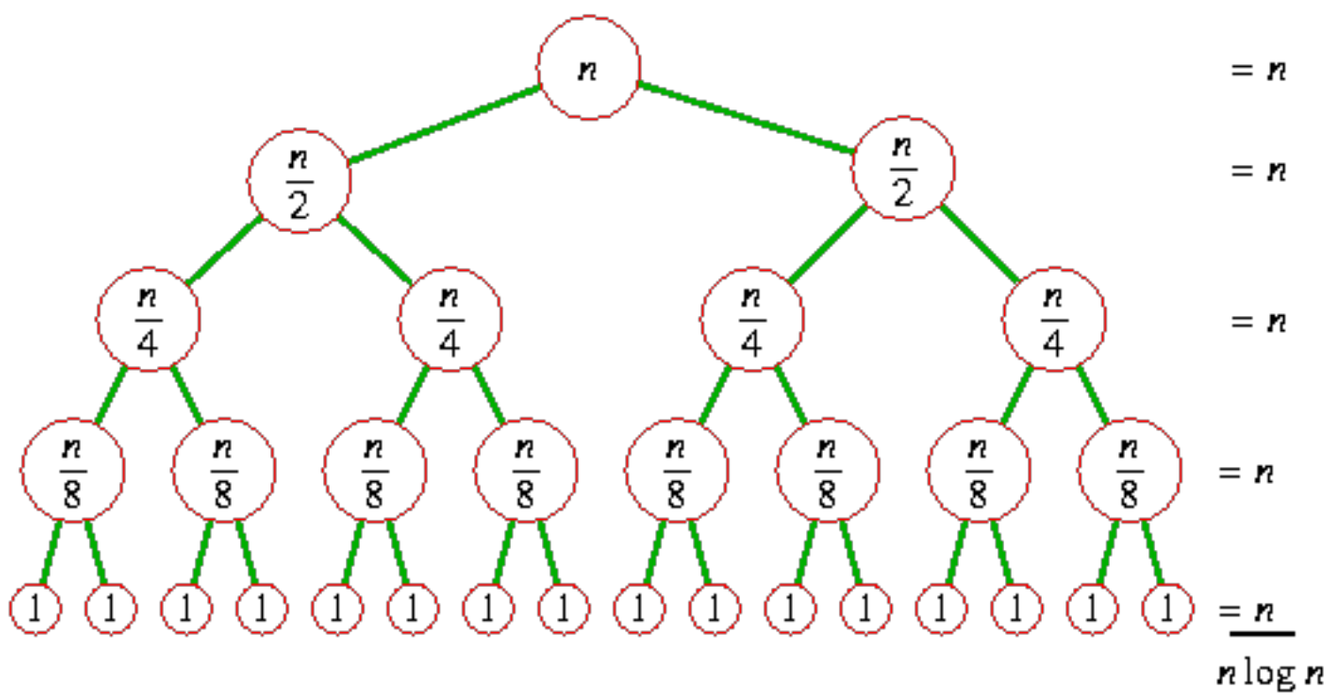


Conclusions, Lessons for Future

- Moving beyond the WIMP happens as we move beyond the weak scale; if we fail to find new physics at weak scale, hunt for DM must continue
- Even if weak scale new physics is discovered, hunt for DM is not complete
- Leverage development of technology for WIMP to broaden searchlight --> natural place to go is lighter; Astrophysics and cosmology will continue to be crucial companions
- Much work remains to fully explore models

Conclusions, Lessons for Future

- Need systematic, multi-pronged approach; probably still too self-limited



Astro Objects

AMS
CDMS
COUPP
CoGeNT
Cresst
DM ICE
Fermi
Icecube
KIMS
LHC
LUX
PAMELA
Panda-X
XENON
....