Title: Hunting for WIMPs: How low should we go?

Date: Oct 17, 2017 01:00 PM

URL: http://pirsa.org/17100079

Abstract: Direct detection experiments are rapidly improving their sensitivity to weak scale Dark Matter. A particular interesting (and minimal) possibility is that the Dark matter interacts with ordinary matter via the exchange of weak bosons: the W, Z, and Higgs. Dark matter with substantial coupling to the Higgs boson is already under significant tension from limits on spin-independent scattering. We comment on the power of spin-dependent scattering as a probe of Z-mediated dark matter, both in a simple effective theory, and in the so-called Singlet-Doublet Model, which we argue is a useful benchmark. We also review the case where the cosmology of the WIMP is dominated by co-annihilation processes, focusing on the stop co-annihilation region of the Minimal Supersymmetric Standard Model, and discuss prospects for direct detection in this case.

Hunting for WIMPs: how low should we go?

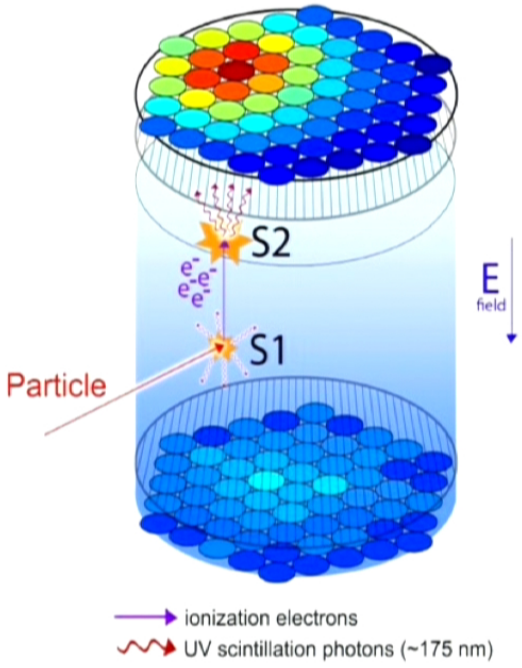
Aaron Pierce
Michigan Center for Theoretical Physics

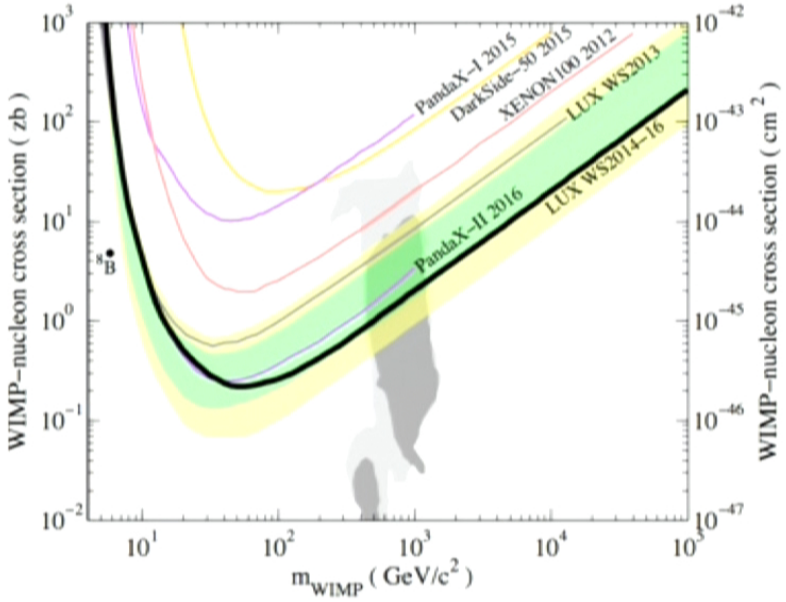
Perimeter Institute
October 17, 2017

with J. Kearney and N. Orlofsky 1611.05048, PRD
and N. Shah and S. Vogl 1706.01911

Outline

- Where are the WIMPS?
  - Higgs
  - Z Mediation
    - Singlet Doublet Dark Matter
  - Co-annihilation





LUX [arXiv: 1608.07648]

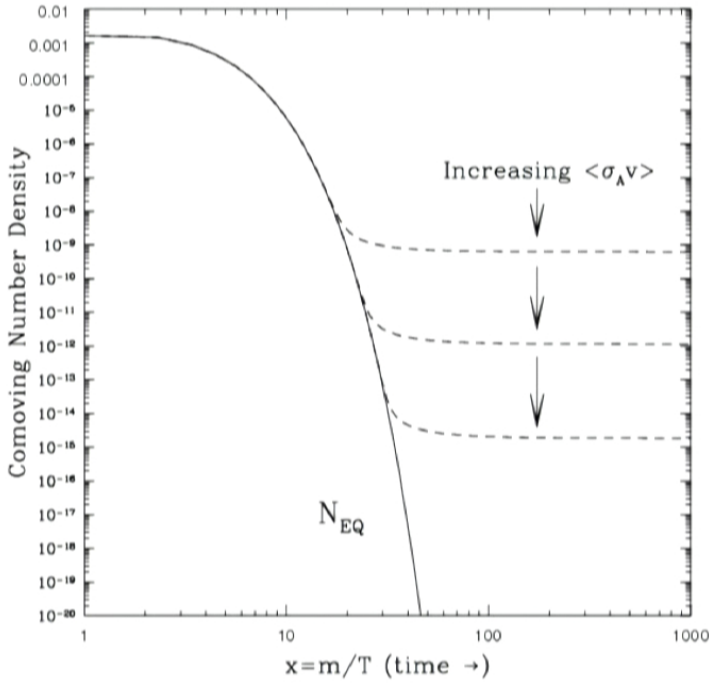
THEORETICAL PHYSICS

Textbook Calculation of How Much Dark Matter...

Solve the Boltzmann equation in an expanding universe.

Annihilations try to maintain thermal equilibrium.

Expansion of the Universe prevents this.



Kolb&Turner

THEORETICAL PHYSICS

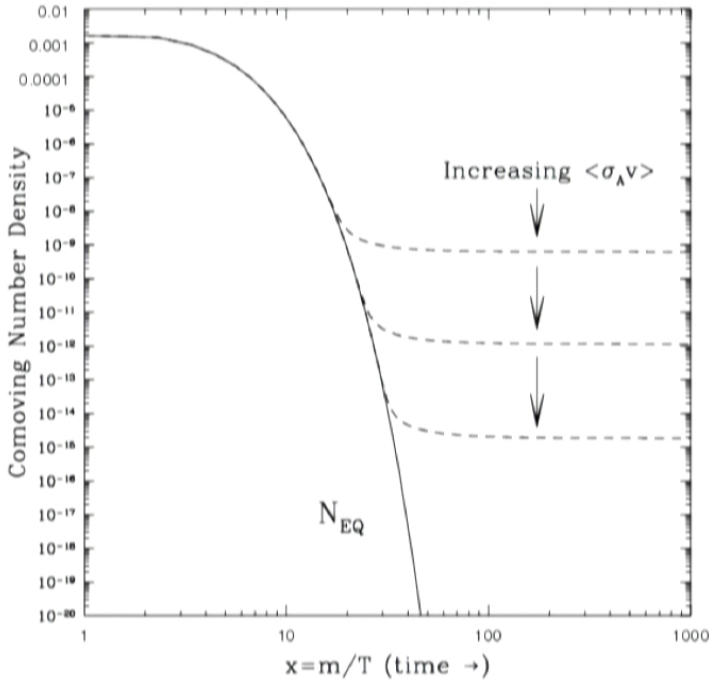
Textbook Calculation of How Much Dark Matter...

$$\langle \sigma v \rangle = \frac{\alpha^2}{m^2}$$

$$m Y_{FO} \approx T_{eq} \quad \text{(matter-rad equality)}$$

$$Y_{FO} \equiv \frac{n_{FO}}{s} = \frac{1}{M_{pl} \langle \sigma v \rangle T_{FO}}$$

$$m \approx \alpha \sqrt{T_{eq} M_{pl}}$$



Kolb&Turner

WIMP with a capital W

Wimp Miracle?

- Cosmology and direct detection are really controlled by interactions with gauge/ SM Higgs boson

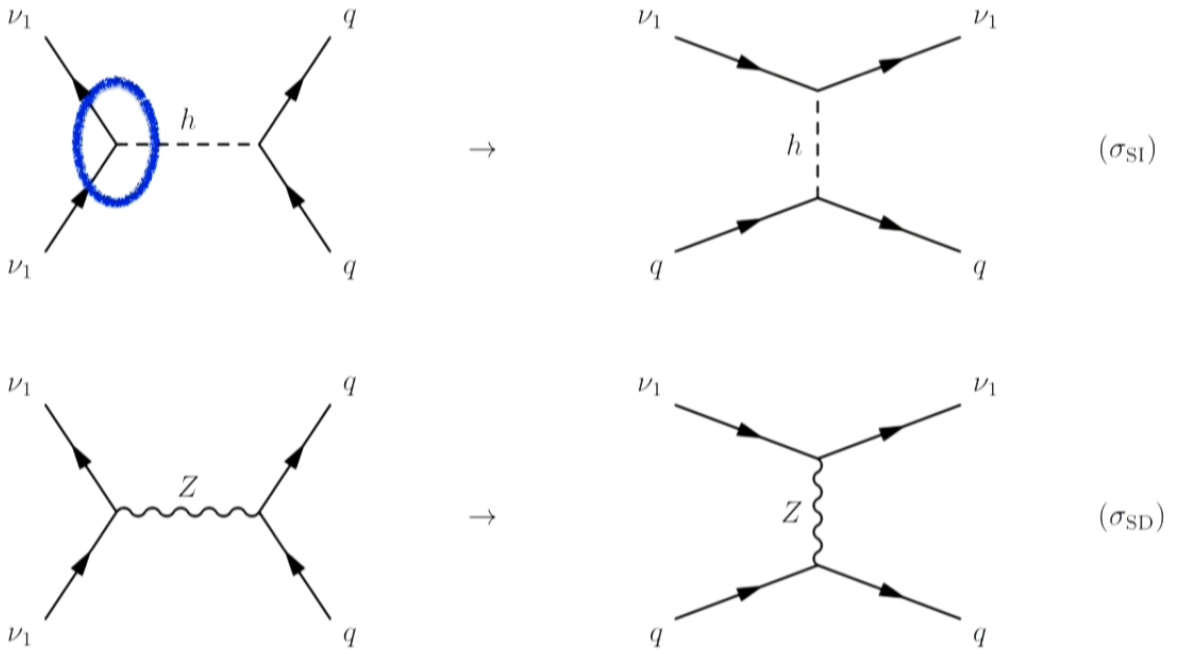
- e.g. Singlet-doublet model, split SUSY…

$\sqrt{T_{eq} M_p} \approx 60$ TeV

fig: Josh Ruderman

https://arxiv.org/pdf/1109.2604.pdf

THEORETICAL PHYSICS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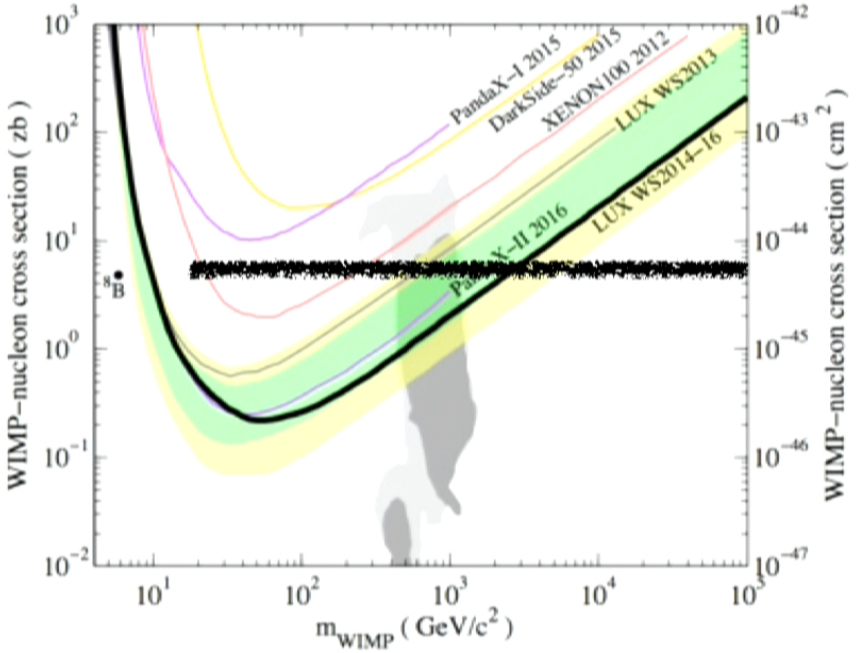
Spin Independent Scattering



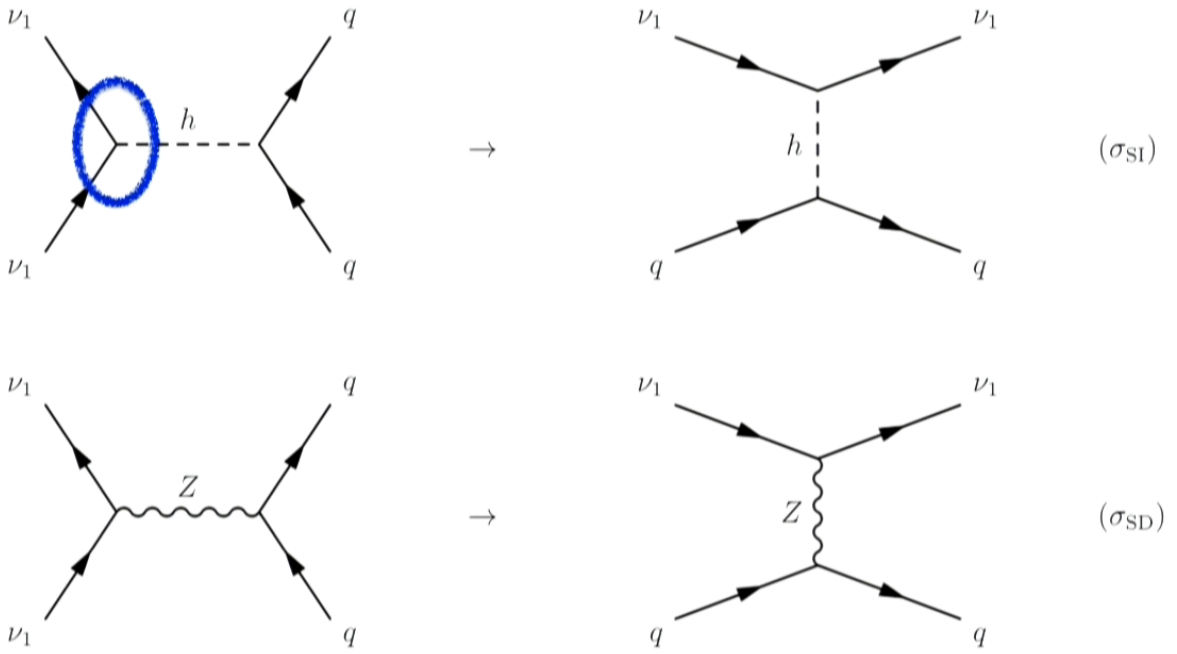
$y_{\chi\chi h} = .1$

LUX [arXiv: 1608.07648]

$Z^\mu \bar{\chi}\gamma_\mu\chi$

Dirac DM coupling to Z ~ 10 $\quad \sigma \approx \text{few} \times 10^{-40}$

THEORETICAL PHYSICS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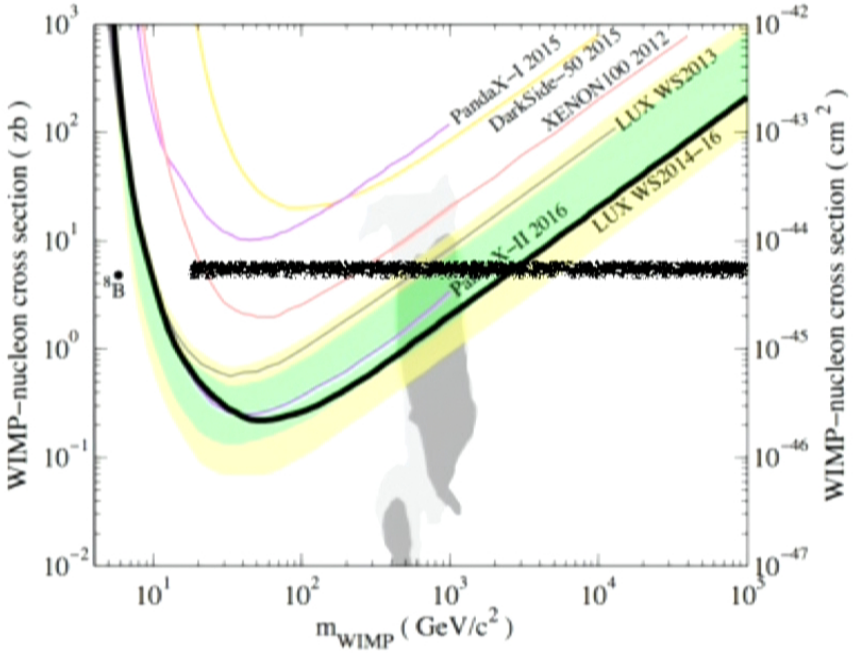

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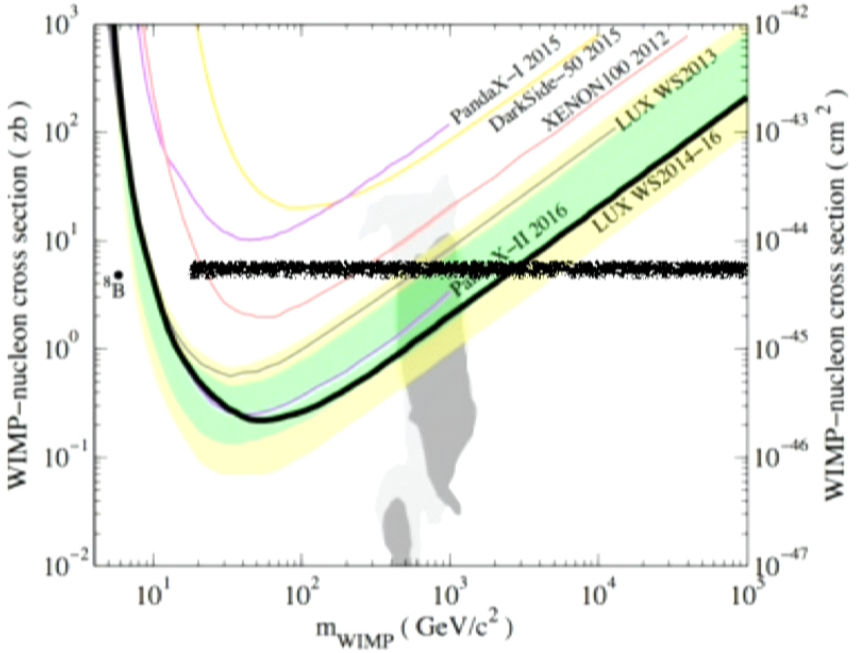

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THEORETICAL PHYSICS

Z-mediated Dark Matter

$$\mathcal{L} \supset \frac{c}{2\Lambda^2}(iH^\dagger D_\mu H + \text{h.c.})\bar{\chi}\gamma^\mu\gamma^5\chi$$

$$\mathcal{L} \supset -\frac{g_2}{4c_W}\frac{cv^2}{\Lambda^2}Z_\mu\bar{\chi}\gamma^\mu\gamma^5\chi$$

Also χ-χ-Z-h and χ-χ-Z-h-h contact interactions(!)

Also:
de Simone et al, arXiv:1402.6287;
Arcadi, Mambrini and Richard, arXiv:1411.2985,
Berlin, Escudero, Hooper and Lin, arXiv 1609.09079;

THEORETICAL PHYSICS

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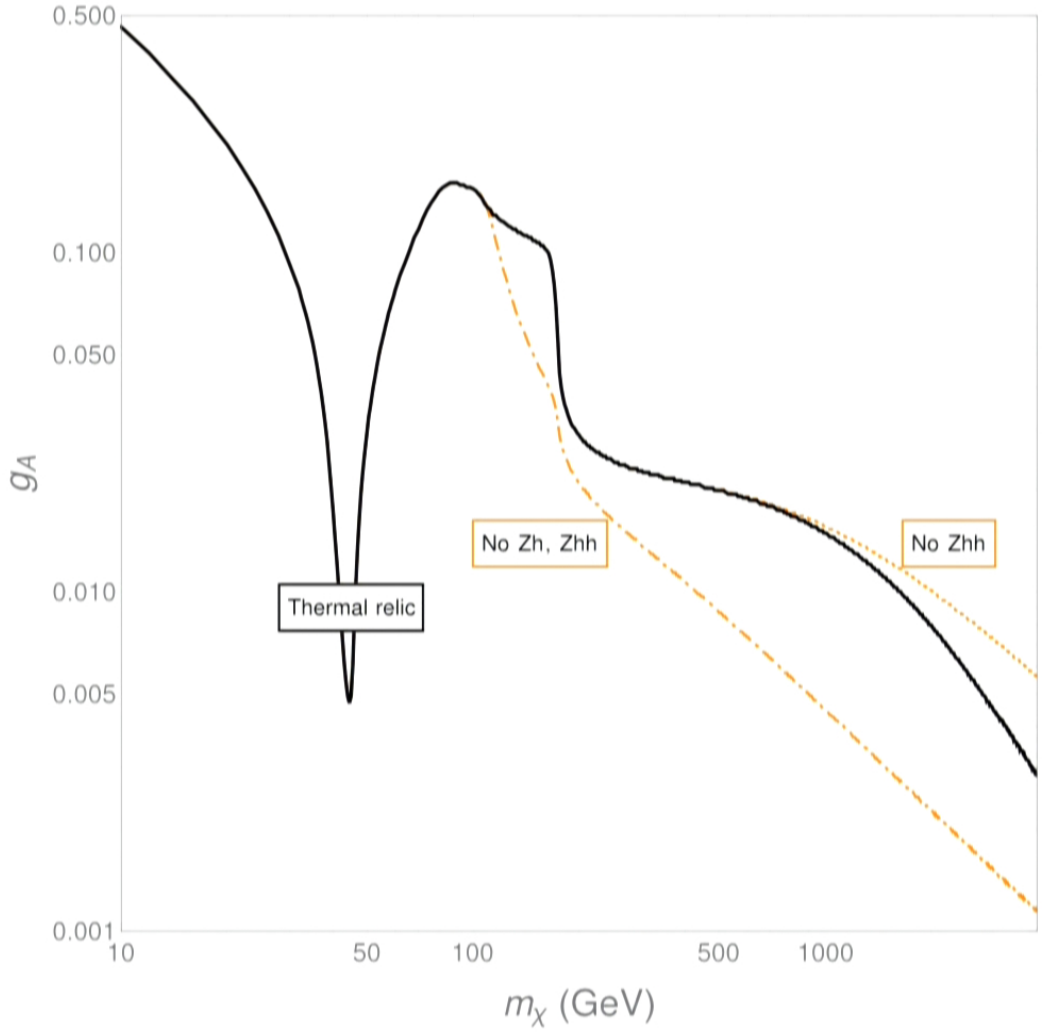
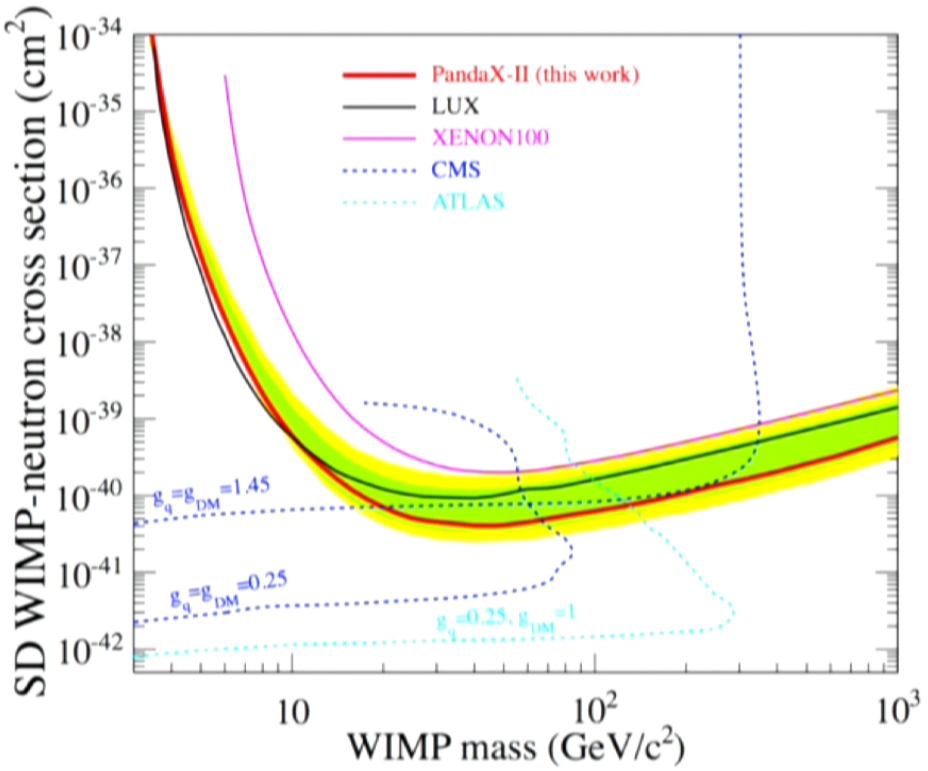


THEORETICAL PHYSICS

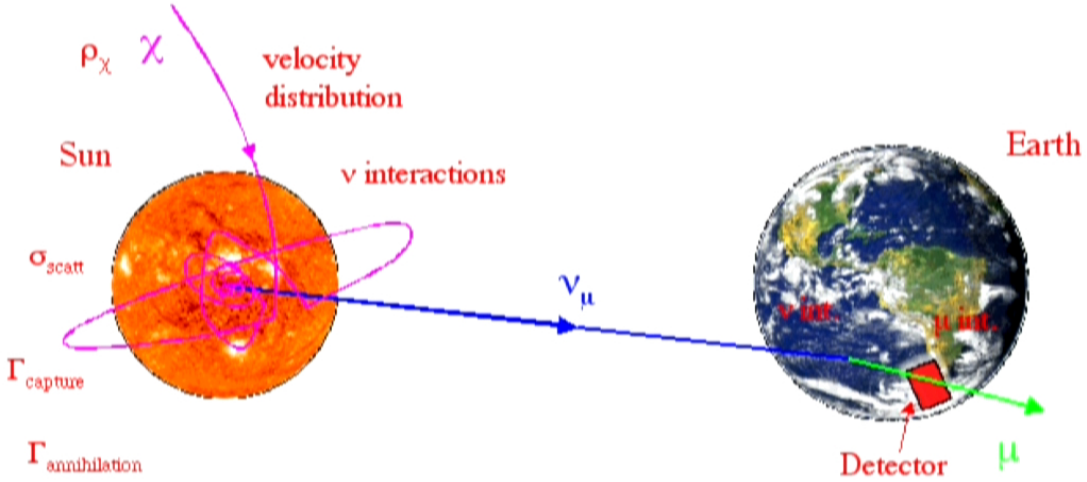
Spin Dependent



PandaX
[arXiv: 1611.06553]

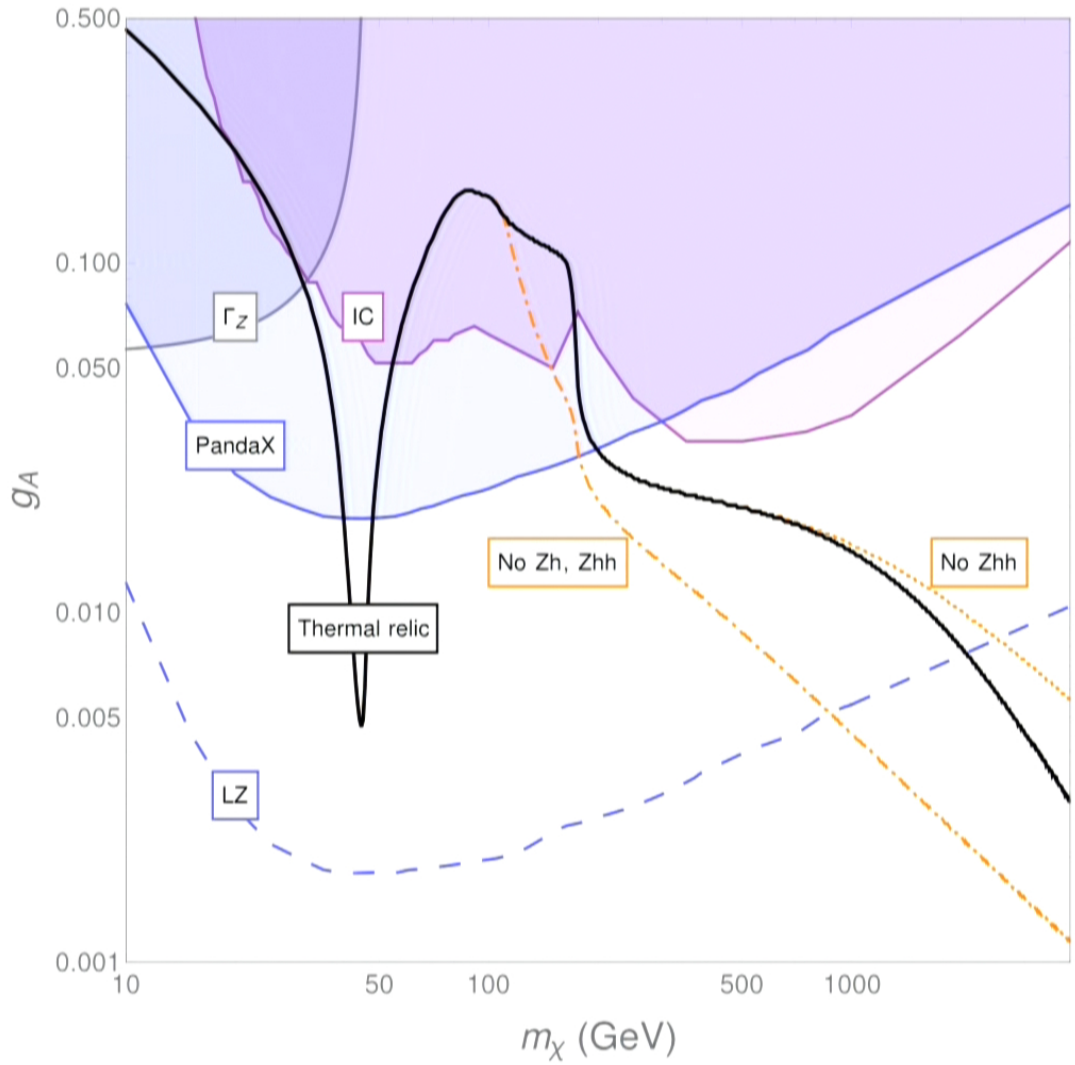
THEORETICAL PHYSICS

Indirect Detection



graphic credit: Joakim Edsjo

THEORETICAL PHYSICS



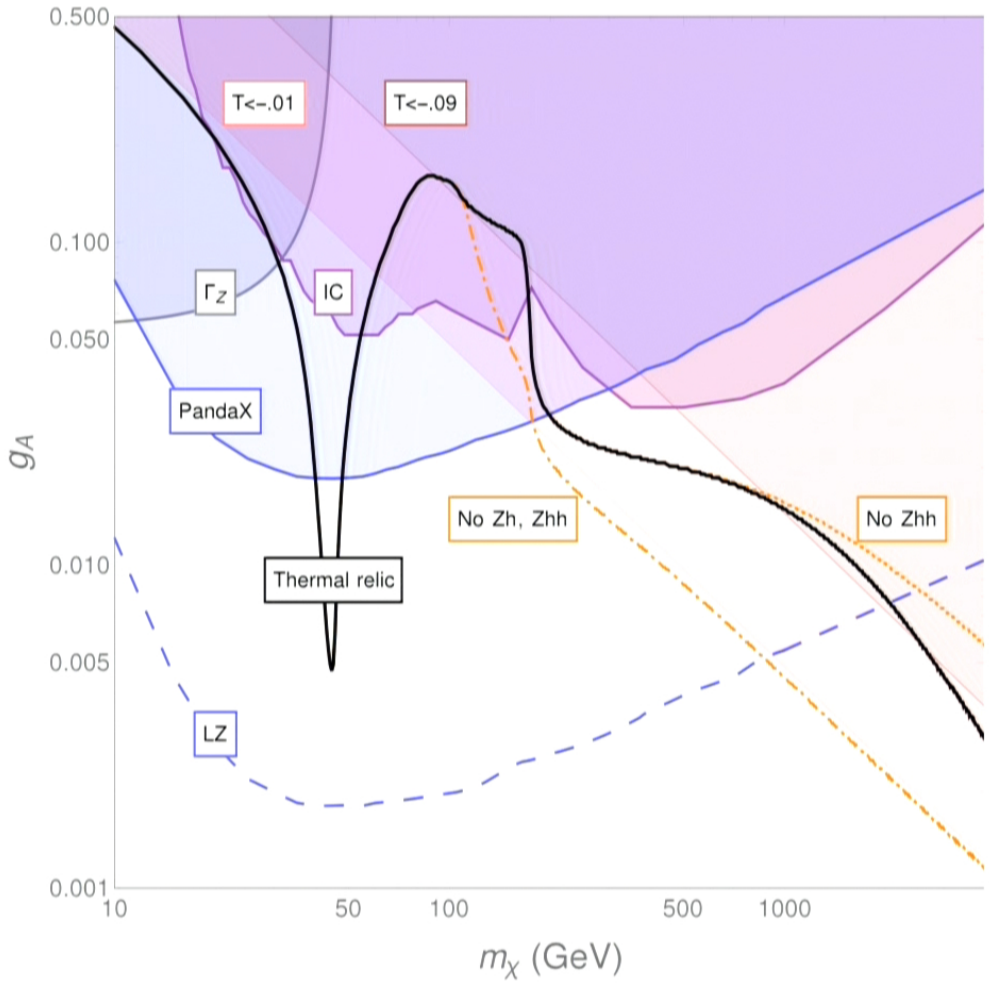
THEORETICAL PHYSICS

Contribution to T parameter

$$\delta\mathcal{L} \supset \frac{c^2 m_\chi^2}{\pi^2 \Lambda^4} \log\left(\frac{\Lambda}{m_\chi}\right) \left|H^\dagger D_\mu H\right|^2$$

$$T = \frac{16\pi}{M_Z^2 \sin^2 2\theta_W} \left[\Pi_{11}^{\text{new}}(0) - \Pi_{33}^{\text{new}}(0)\right]$$

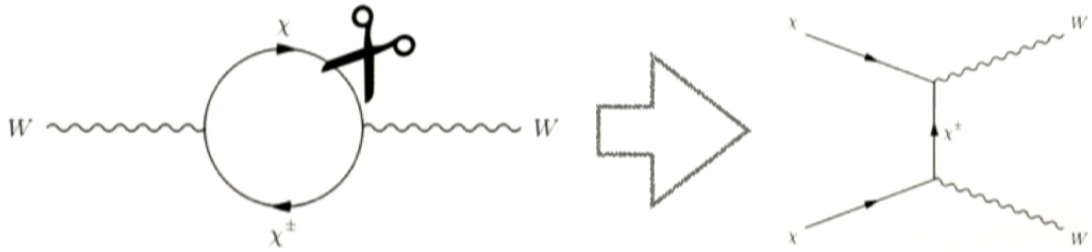
Precision Electroweak Constraints



THEORETICAL PHYSICS

Motivates inclusion of new EW states

e.g., "Cutting the self-energy diagram" argument



Scissors credit: J. Kearney

Z-mediated Dark Matter and EFT

$$\mathcal{L} \supset \frac{c}{2\Lambda^2}(H^\dagger D_\mu H + \text{h.c.})\bar{\chi}\gamma^\mu\gamma^5\chi$$

$$\mathcal{L} \supset -\frac{g_2}{4c_W}\frac{cv^2}{\Lambda^2}Z_\mu\bar{\chi}\gamma^\mu\gamma^5\chi$$

Also:

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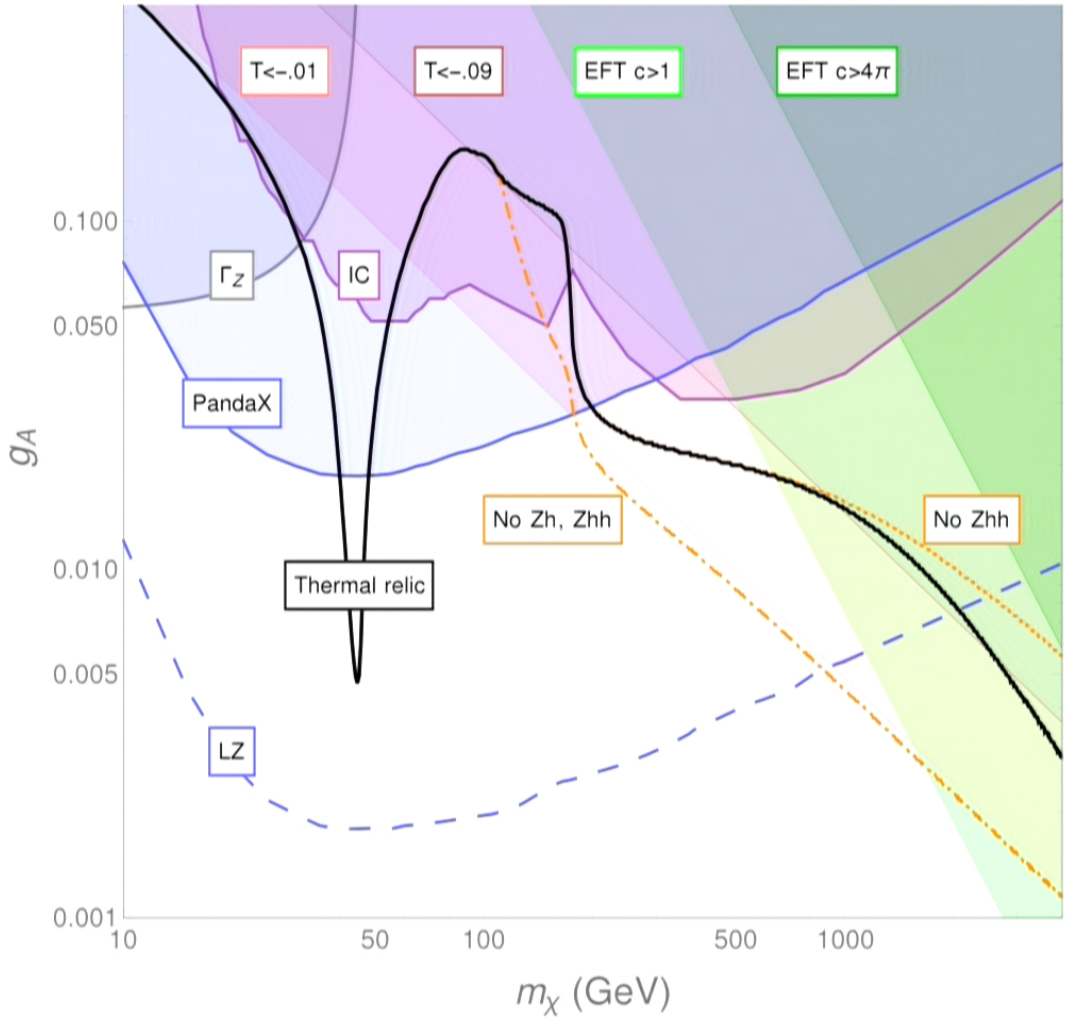
THEORETICAL PHYSICS

Effective Field Theory Validity



THEORETICAL PHYSICS

Singlet-Doublet Dark Matter

$$\mathcal{L} \supset -yDHN - y^c D^c \tilde{H} N - M_D D D^c - \frac{M_N}{2} N^2 + \text{h.c.}$$

- Dirac doublet, D/Dc and Majorana N.
- Similar to Higgsino/Bino sector of the MSSM, but without all the pesky symmetry.
- Gives couplings to h and Z
- Ensures approximate unification (cf. split SUSY)

  Arkani-Hamed, Dimopoulos, and Kachru hep-th/0501082;

  Mahbubani, Senatore [hep-ph/0510064] D'Eramo [arXiv:0705.4493]

  Enberg et al. [arXiv:0706.0918] Cohen, Kearney, AP, Tucker-Smith [arXiv: 1109.2604]

THEORETICAL PHYSICS

Spin-Independent Coupling?

- There is a direct detection "blind spot"

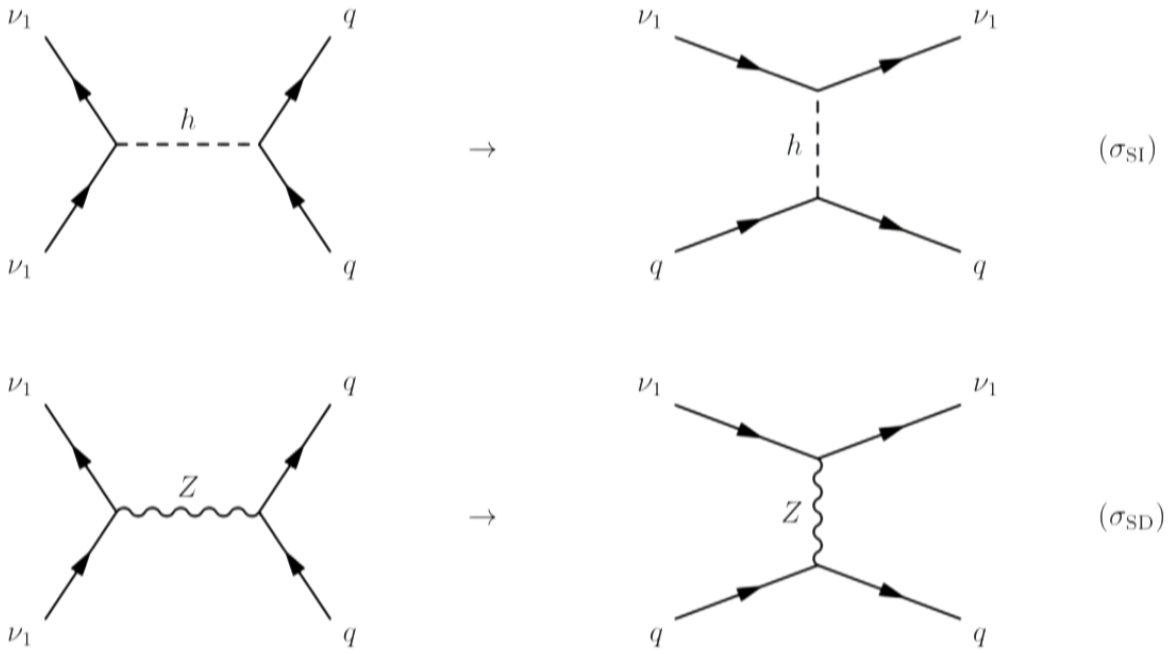
Cohen, Kearney, AP, Tucker-Smith [arXiv:1109.2604] Cheung, Hall, Pinner, Ruderman [arXiv:1211.4873]

$$y^c_{\rm BS} = -y\frac{M_N}{M_D}\left(1 \pm \sqrt{1-\left(\frac{M_N}{M_D}\right)^2}\right)^{-1}$$

Can be found by "low energy theorem"

$$\begin{aligned}\mathcal{L}_{h\chi\chi} &= \frac{1}{2}m_{\chi_i}(v+h)\chi_i\chi_i \\ &= \frac{1}{2}m_{\chi_i}(v)\chi_i\chi_i + \frac{1}{2}\frac{\partial m_{\chi_i}(v)}{\partial v}h\chi_i\chi_i + \mathcal{O}(h^2),\end{aligned}$$

$$\det(M_\chi - \mathbb{1}m_{\chi_i}(v)) = 0.$$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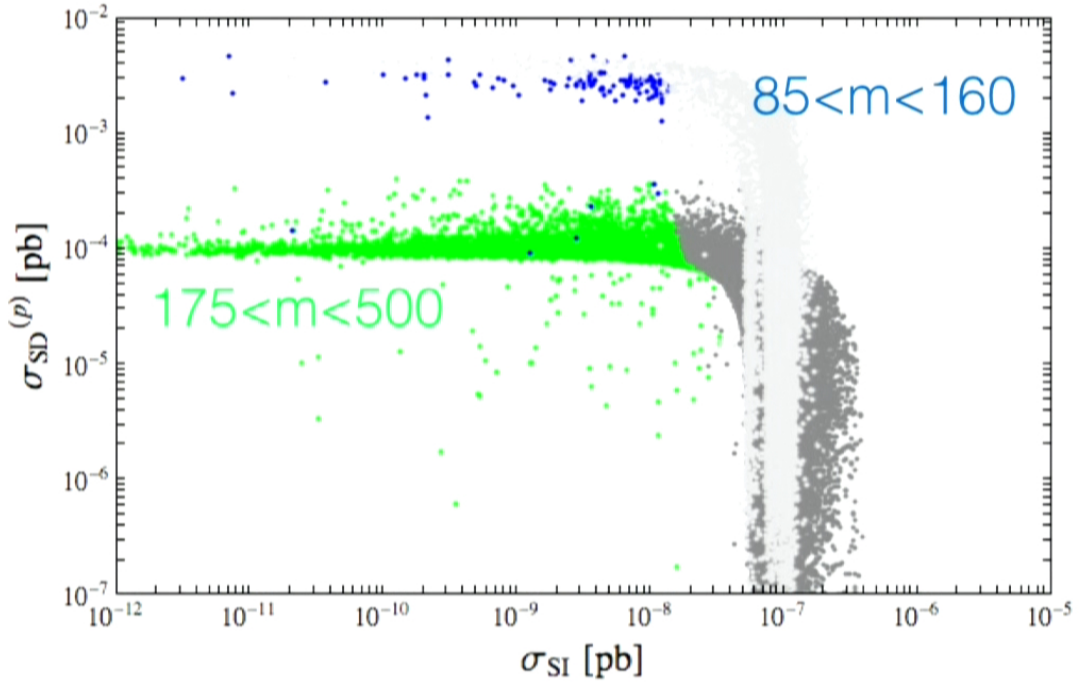
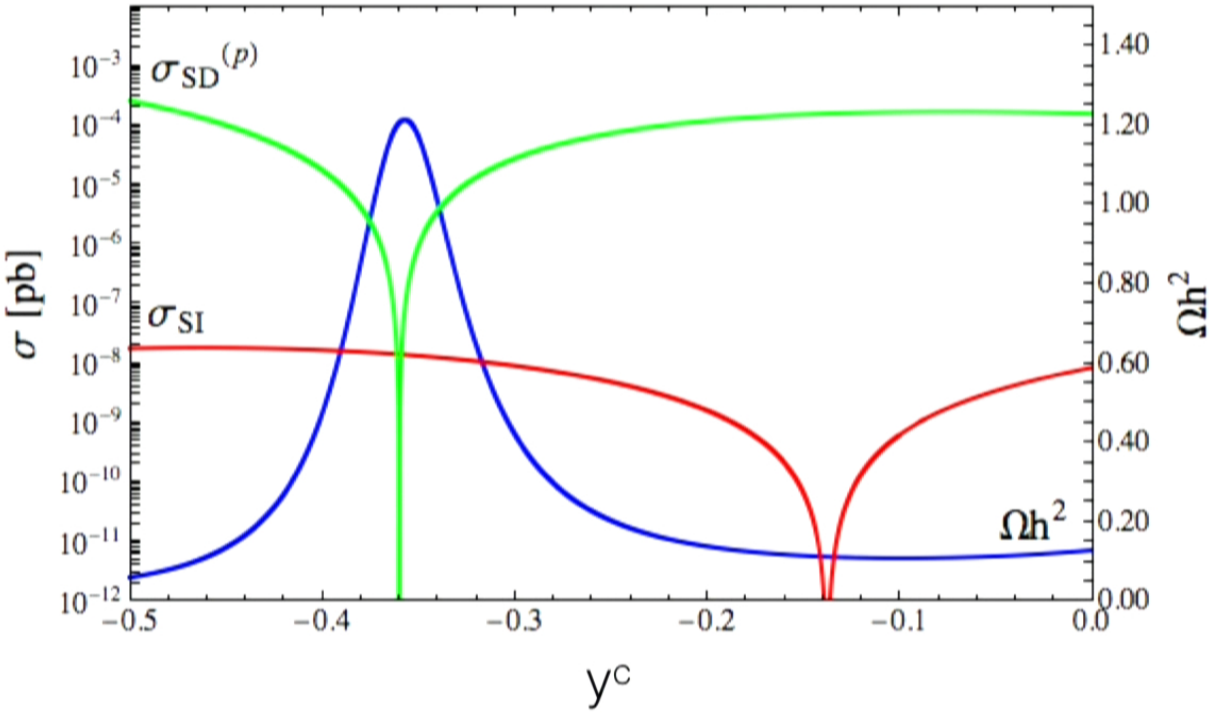


Cohen, Kearney, AP, Tucker-Smith 1109.2604

THEORETICAL PHYSICS



Cohen, Kearney, AP, Tucker-Smith 1109.2604

THEORETICAL PHYSICS

Question:

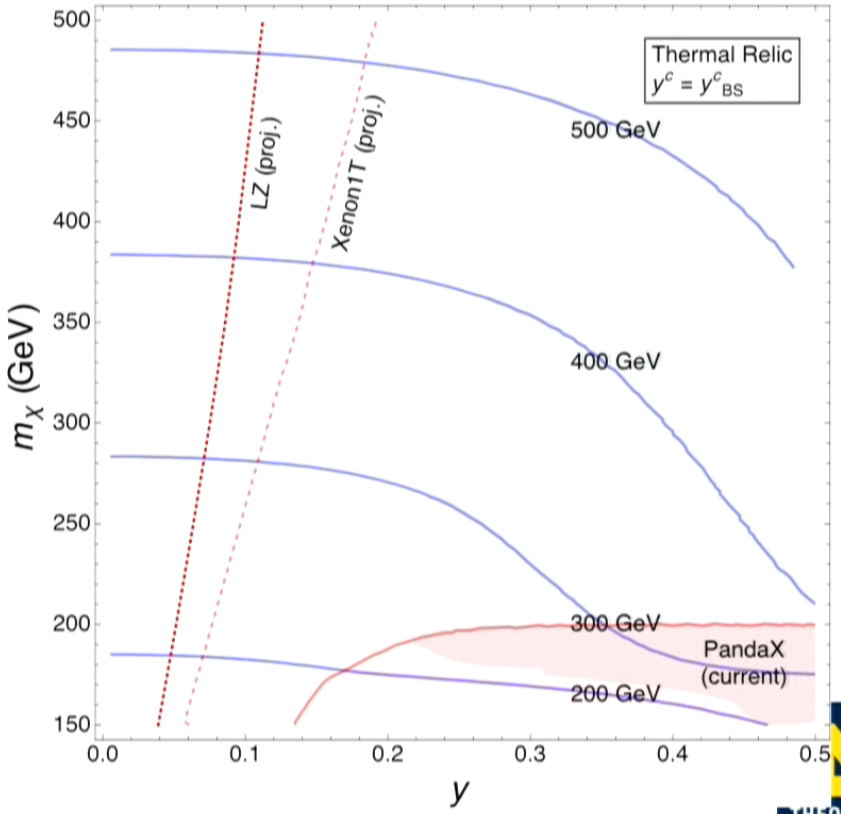
- Suppose Higgs coupling is small (near the blindspot), can we expect to see the Dark Matter through its spin-dependent scattering?

THEORETICAL PHYSICS

Singlet Doublet

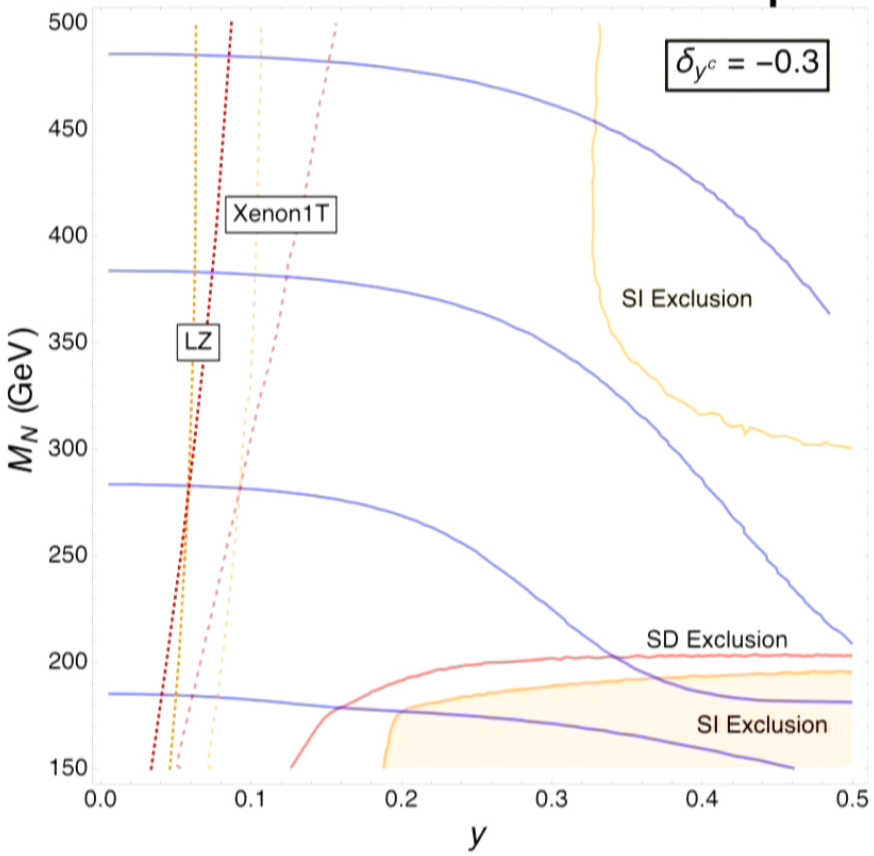
In blind spot (fixes y^c)

Relic density thermal (fixes M_D)



THEORETICAL PHYSICS

Singlet Doublet Away from Blind Spot



$$\delta_{y^c} = \frac{y^c}{y^c_{\rm BS}} - 1,$$

THEORETICAL PHYSICS

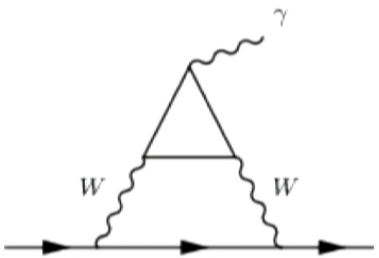
Double Blind spot

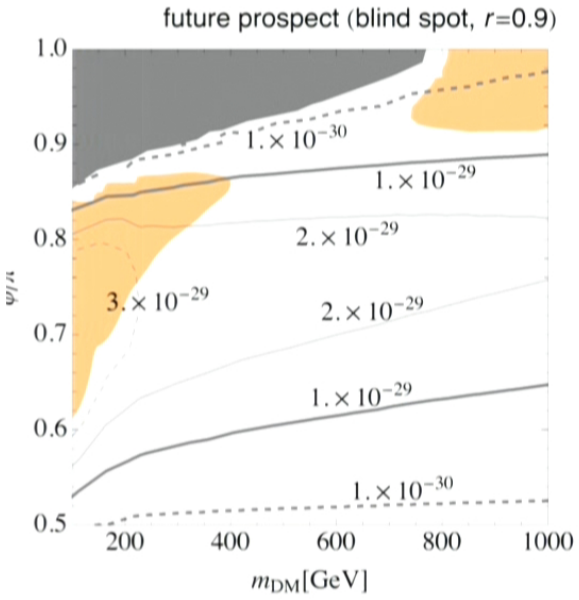
- There is a spot where both the SI and SD vanish.
- Requiring these two couplings to vanishes, along with reproducing the thermal abundance, sets MN =MD=850 GeV. (model building?)

Another caveat

- If willing to tune to the Higgs blindspot, there is one more out (not requiring SD): CP Violation

$$\cancel{CP} \rightarrow \chi\gamma_5\chi\, h \rightarrow (\bar{q}q)(\chi\gamma_5\chi)$$



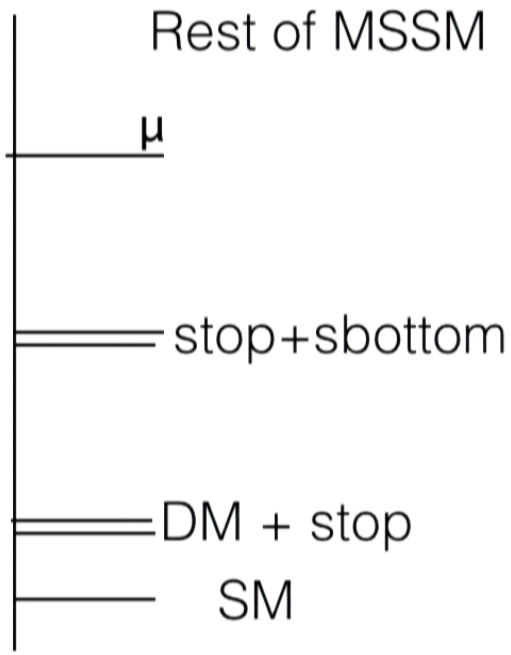


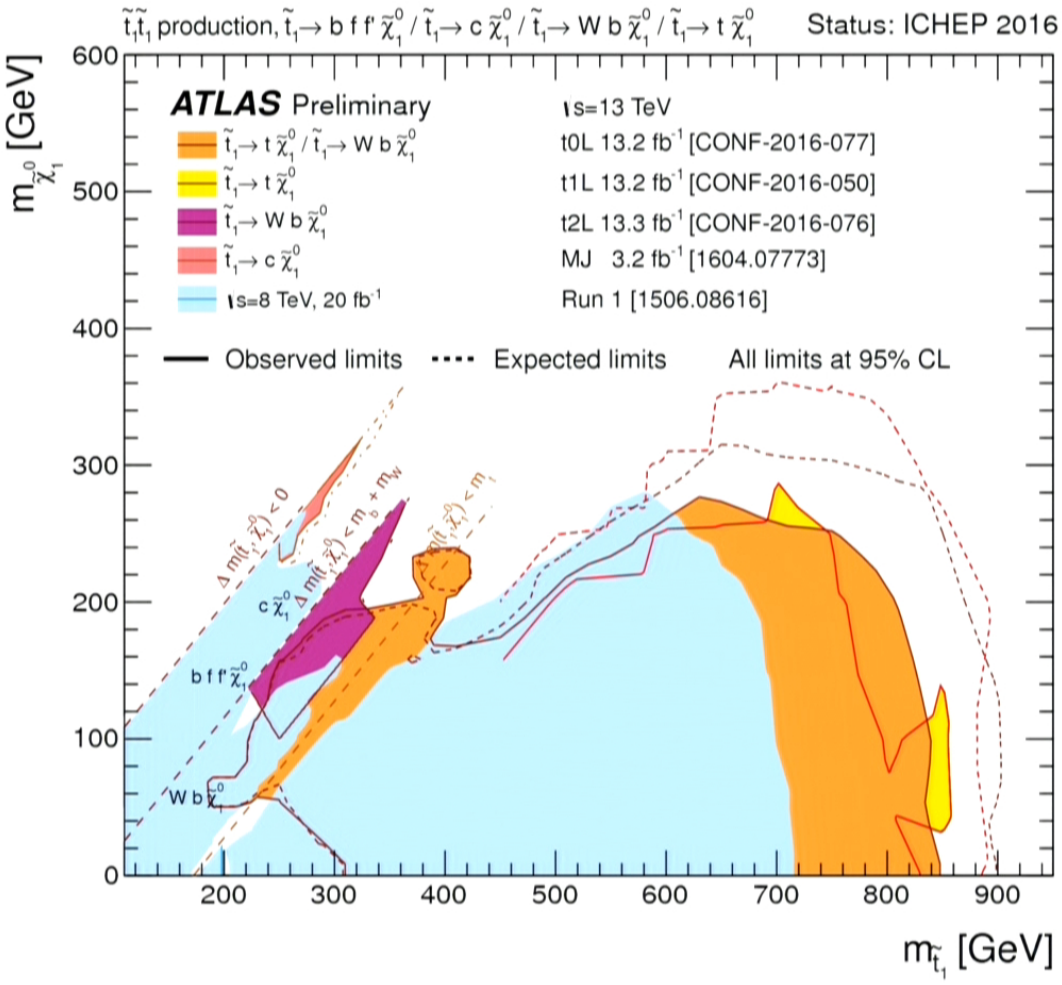
r= ratio of yukawas

T. Abe
arXiv:1702.07236

Outline

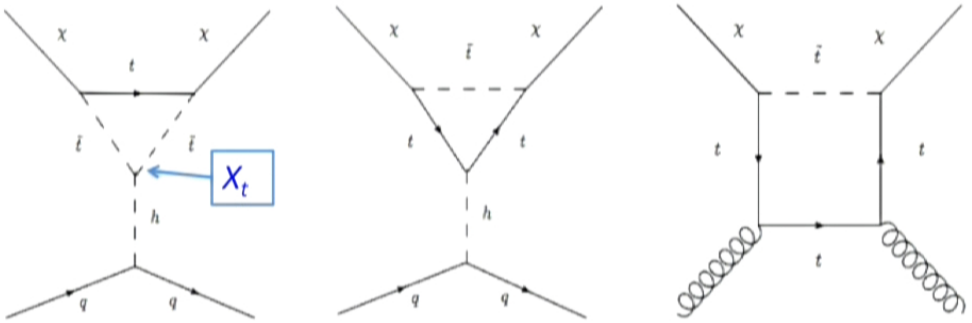
- WIMPS and their probes
- Where are the WIMPS?
  - Higgs Mediation
  - Z Mediation
    - Singlet Doublet Dark Matter
  - Co-annihilation


Rest of MSSM
μ
stop+sbottom
DM + stop
SM

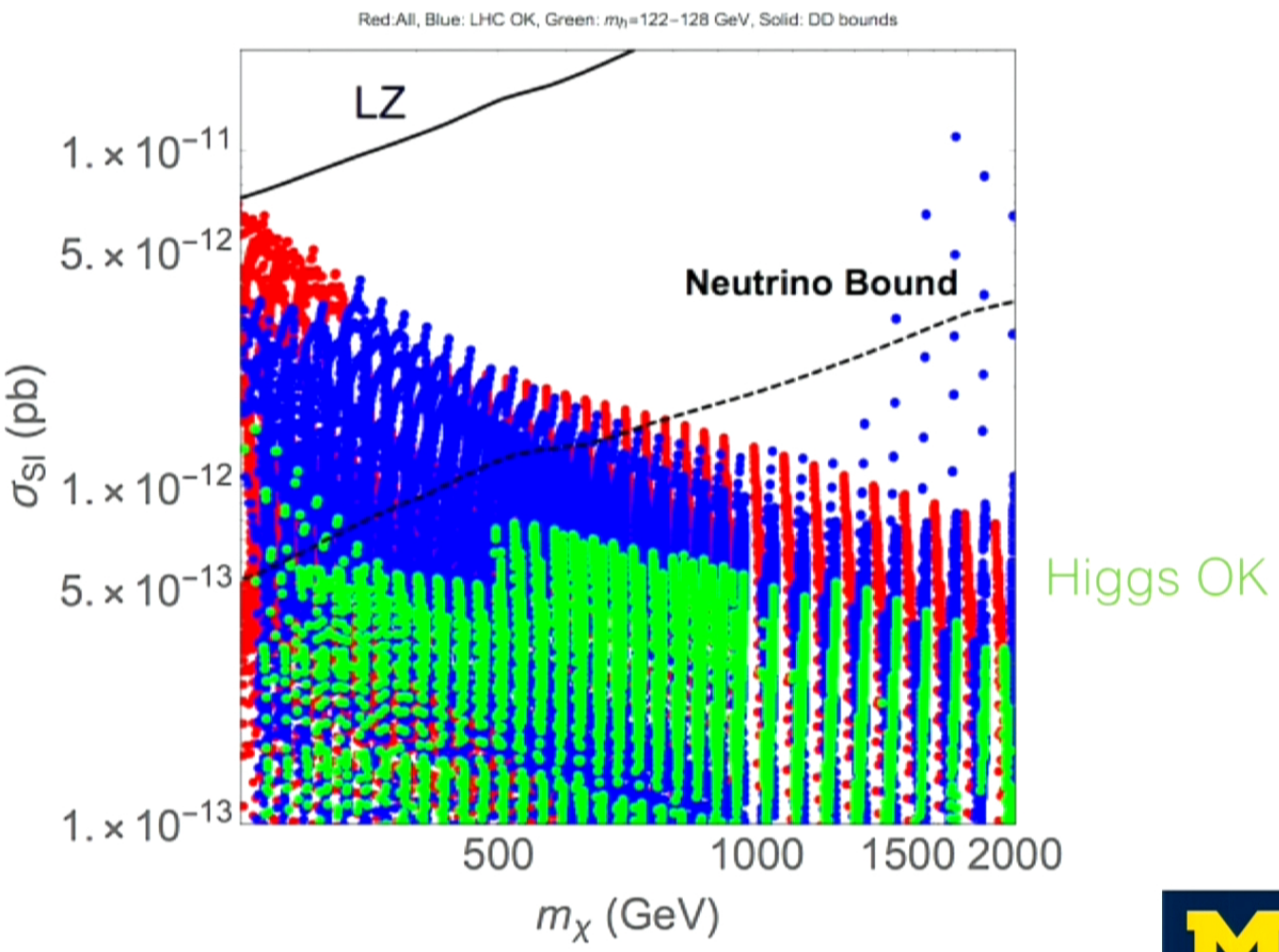


THEORETICAL PHYSICS

Loop Induced Dark Matter Couplings

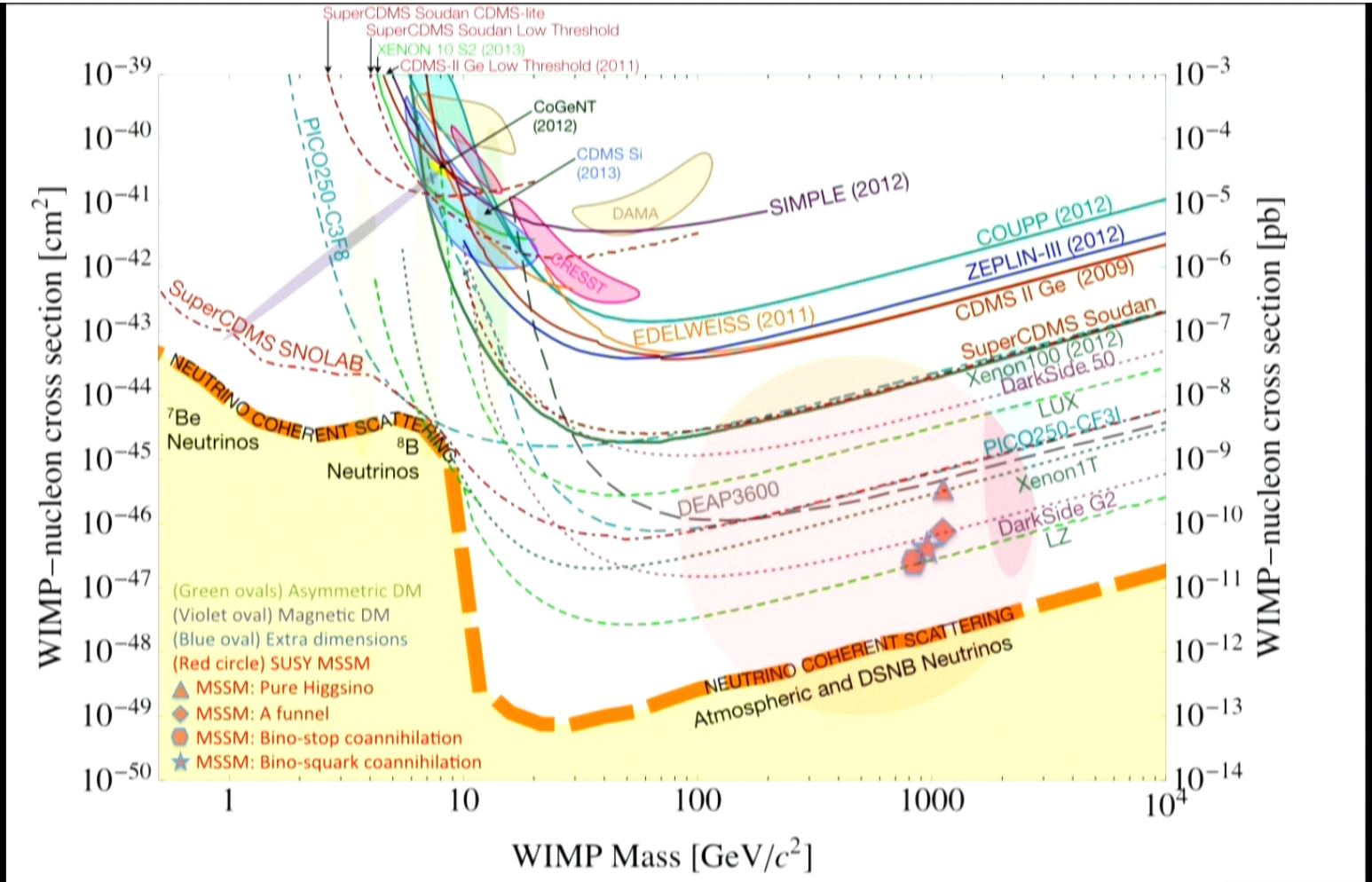


THEORETICAL PHYSICS



Higgs OK

THEORETICAL PHYSICS



Snowmass 1310.8327

THEORETICAL PHYSICS

But…

- It is always possible that there could be “some Higgsino” in the dark matter, in which case, direct detection may have nothing to do with the cosmology.

$$\sigma_{SI} \approx 3 \times 10^{-47} \mathrm{cm}^2 \left(\frac{1\ \mathrm{TeV}}{\mu}\right)^4 \left(\frac{m_\chi}{500\ \mathrm{GeV}}\right)^2 \left(1 + \frac{\mu\, s_{2\beta}}{m_\chi}\right)^2 \left(1 - \frac{m_\chi^2}{\mu^2}\right)^{-2}$$

Conclusion
WIMPs: a Status Report

- Higgs-centric cosmology getting squeezed
- Z-centric cosmology is **exciting now**
  - Symmetry reason for blind spot?
- Co-annihilation-centric cosmology (stop or otherwise) will be very hard for the foreseeable future, but we could get lucky.
- Why co-annihilation? (AP, Kearney, Phys.Rev. D88 (2013) no.9, 095009)

THEORETICAL PHYSICS