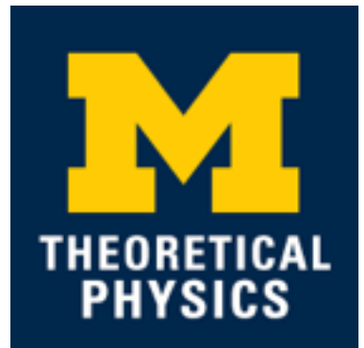
Hunting for WIMPs: how low should we go?

Aaron Pierce
Michigan Center for Theoretical Physics

TevPA 2017
August 10, 2017

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



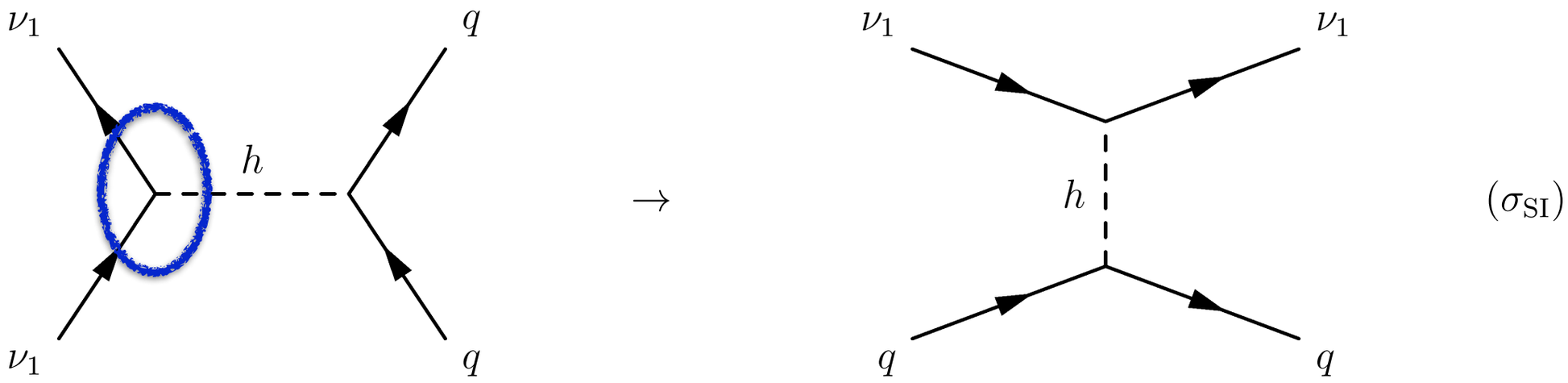
WIMP with a capital W

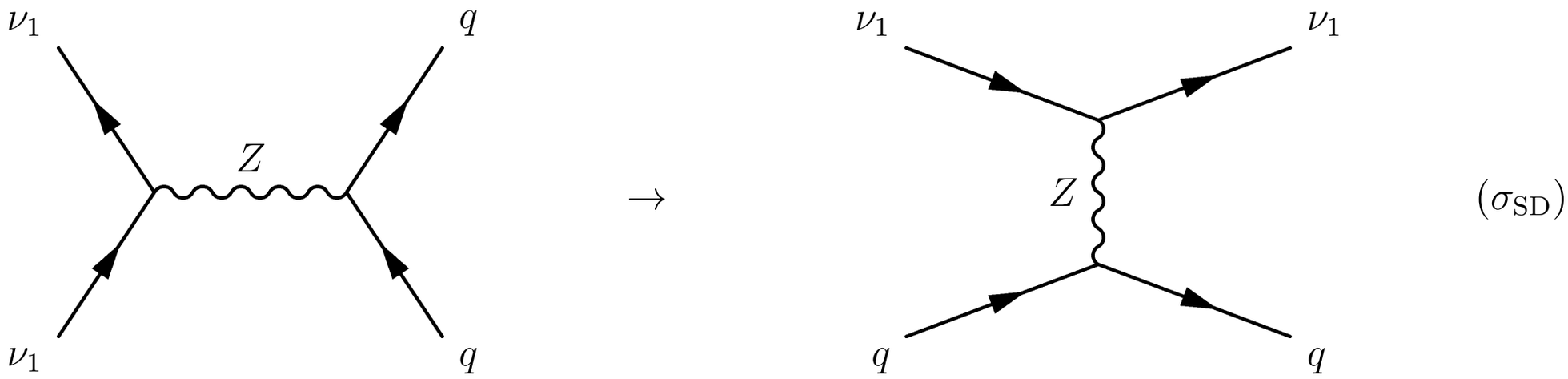
- Cosmology and direct detection are really controlled by interactions with gauge/ SM Higgs boson

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

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

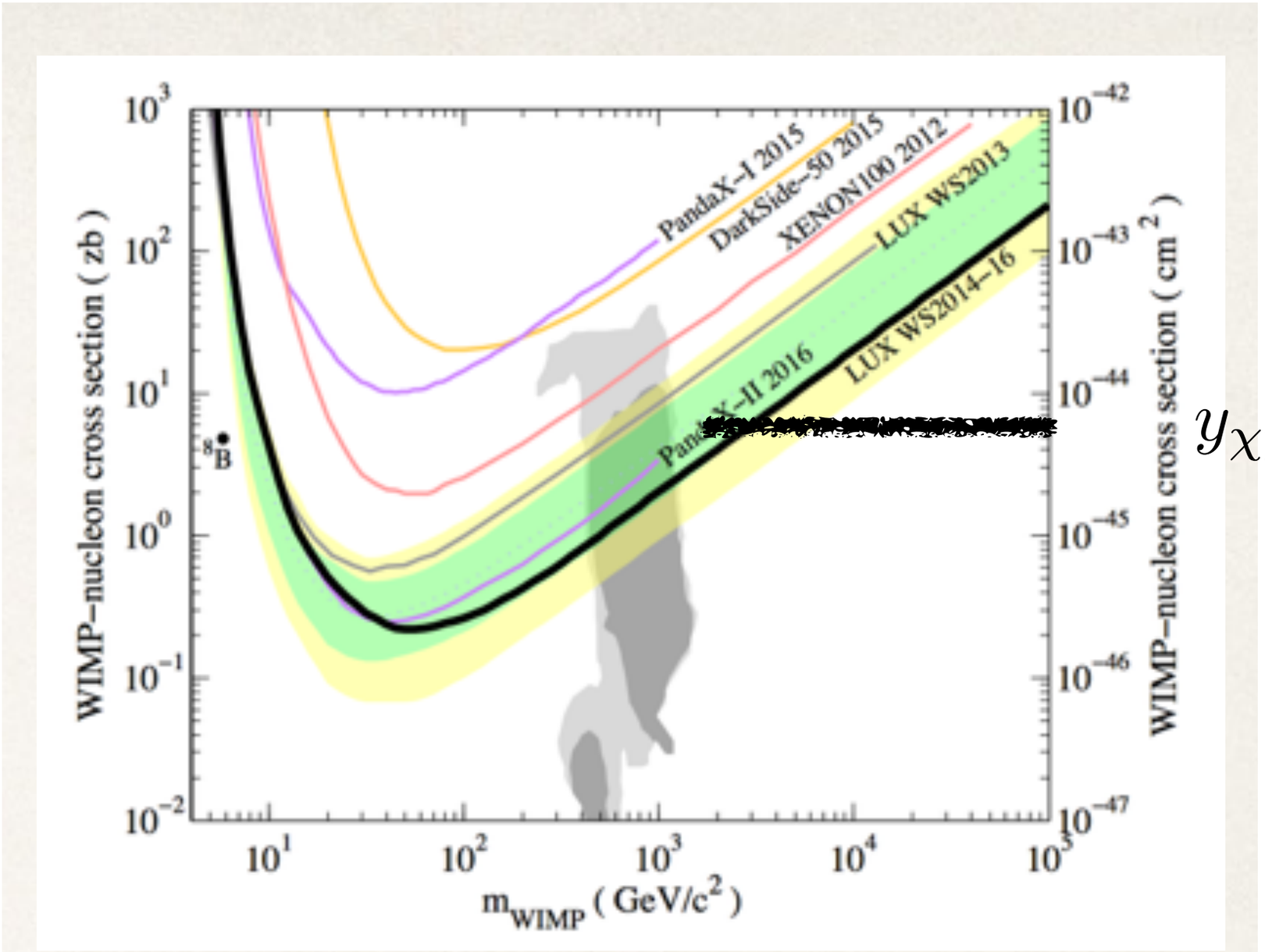
THEORETICAL PHYSICS





THEORETICAL PHYSICS

Spin Independent Scattering



LUX [arXiv: 1608.07648]

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

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

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

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(!)

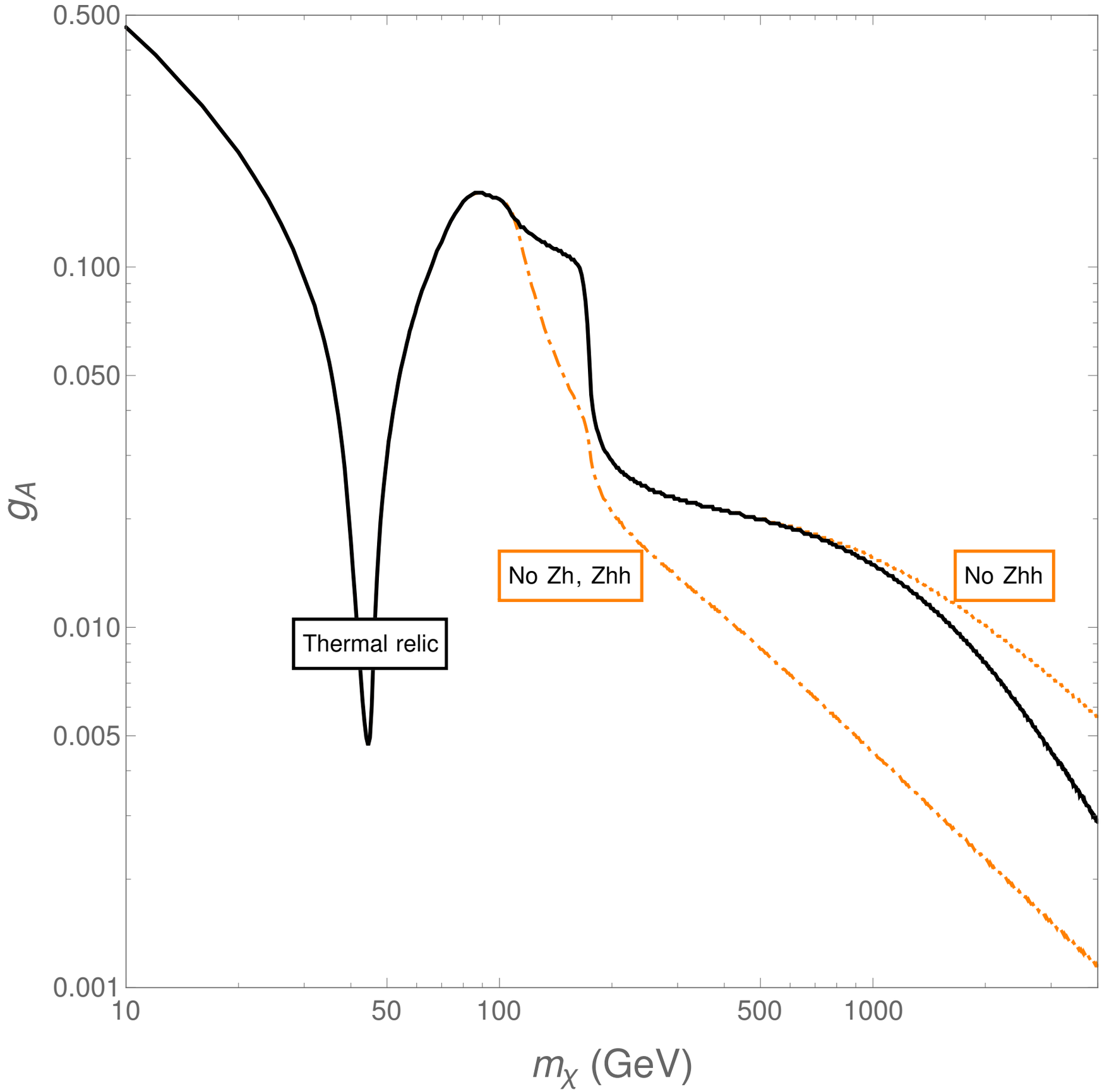
Also:

de Simone et al, arXiv:1402.6287;

Arcadi, Mambrini and Richard, arXiv:1411.2985,

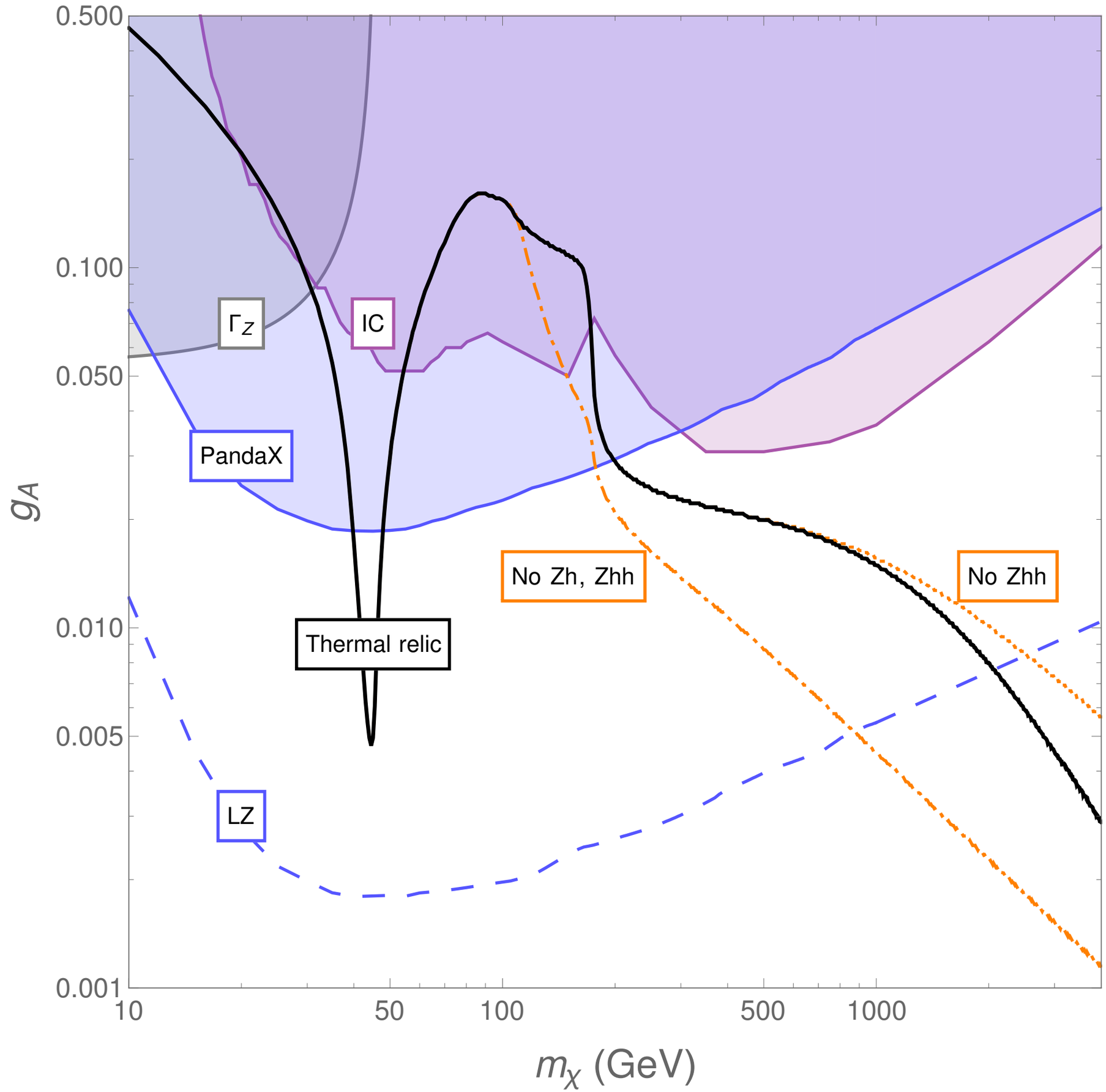
Berlin, Escudero, Hooper and Lin, arXiv 1609.09079;

THEORETICAL PHYSICS



J. Kearney and N. Orlofsky, AP 1611.05048

THEORETICAL PHYSICS



J. Kearney and N. Orlofsky, AP 1611.05048

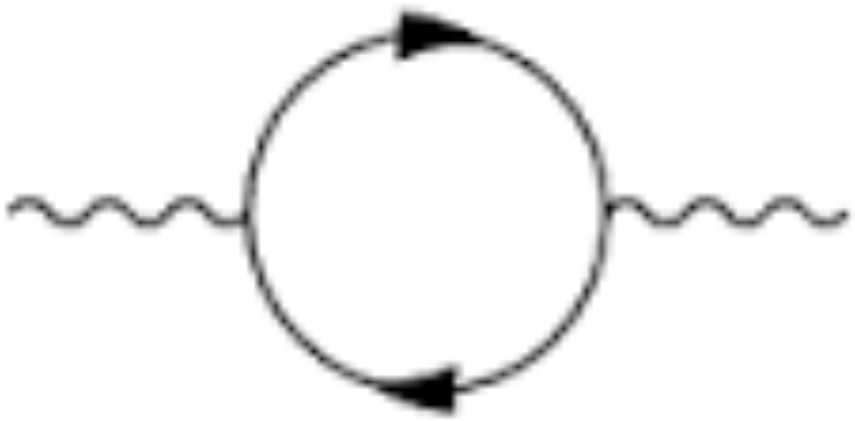
THEORETICAL PHYSICS

Contribution to T parameter

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

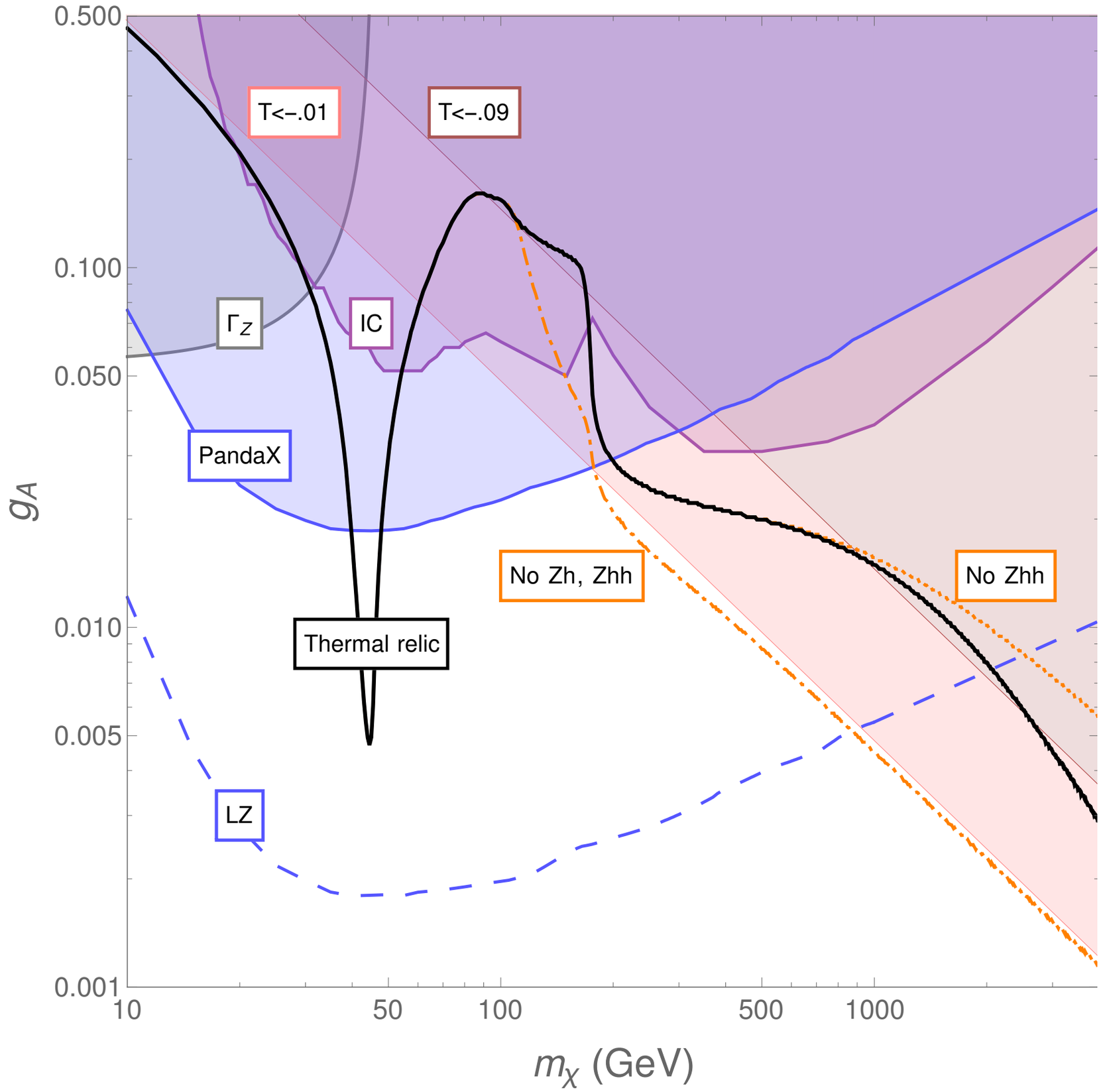
$$\delta\mathcal{L} \supset \frac{c^2 m_\chi^2}{\pi^2\Lambda^4}\log\left(\frac{\Lambda}{m_\chi}\right)\left|H^\dagger D_\mu H\right|^2$$

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



THEORETICAL PHYSICS

Precision Electroweak Constraints

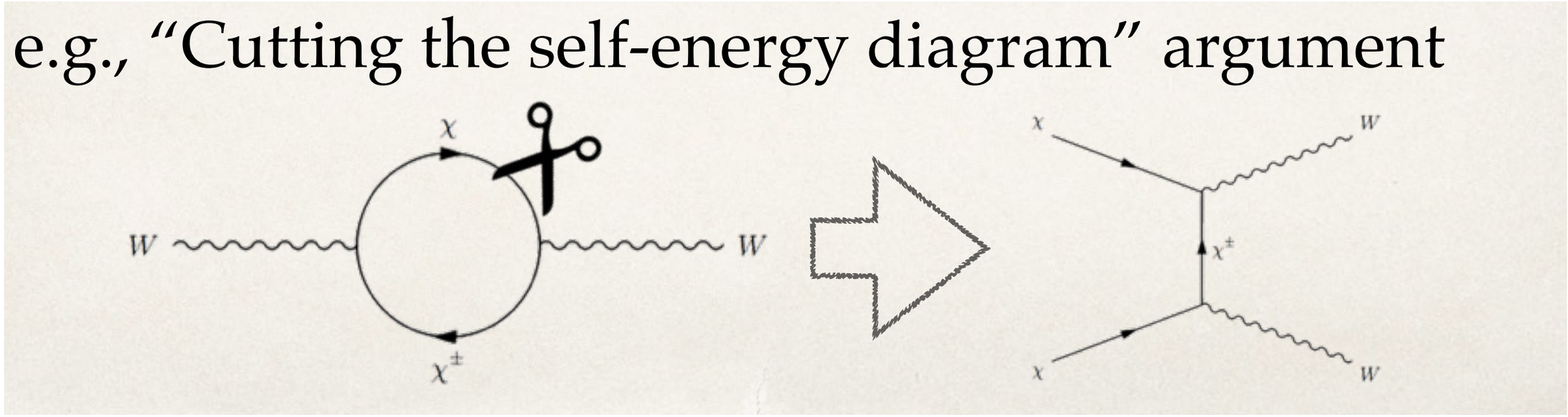


J. Kearney and N. Orlofsky, AP 1611.05048

THEORETICAL PHYSICS

Motivates inclusion of new EW states

e.g., “Cutting the self-energy diagram” argument



Scissors credit: J. Kearney

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]

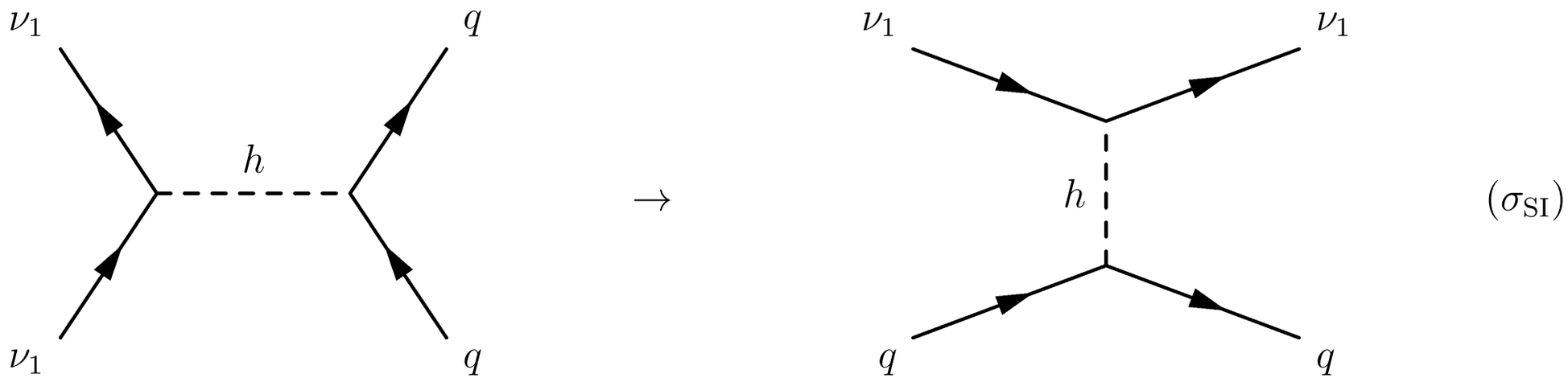
$$y^c_{\rm BS} = -y\frac{M_N}{M_D}\left(1 \pm \sqrt{1-\left(\frac{M_N}{M_D}\right)^2}\right)^{-1}$$

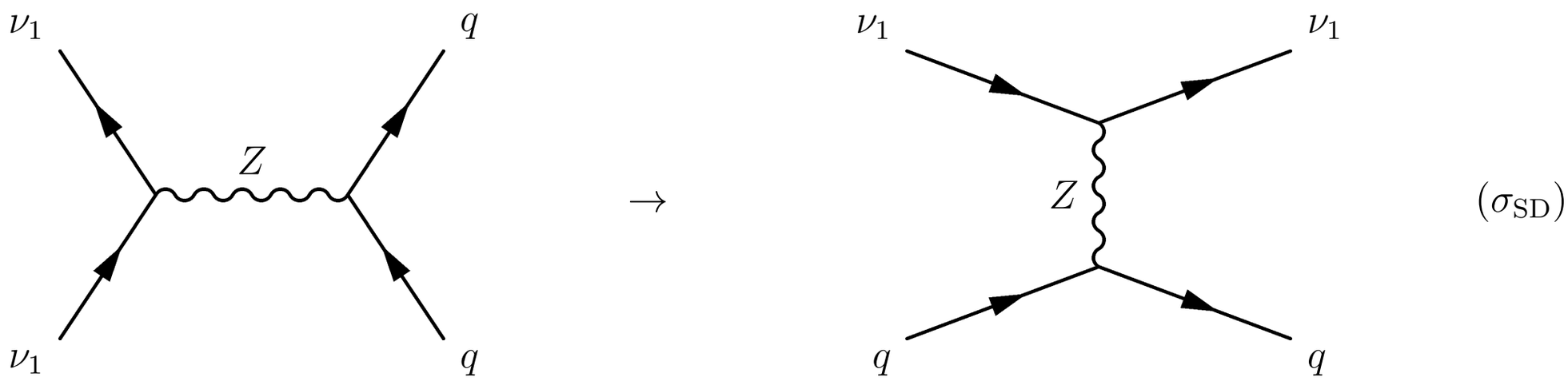
Can be found by "low energy theorem"

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

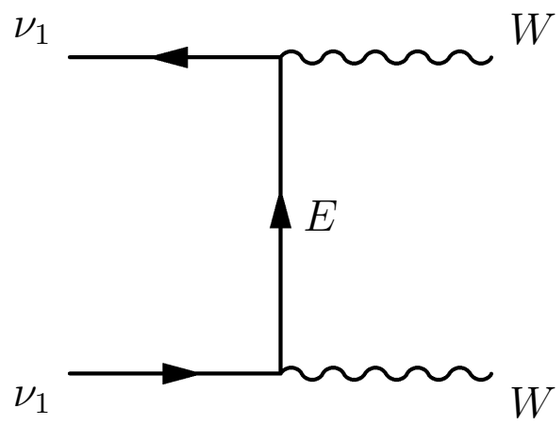
$$\det(M_\chi - \mathbb{1}m_{\chi_i}(v)) = 0.$$

THEORETICAL PHYSICS

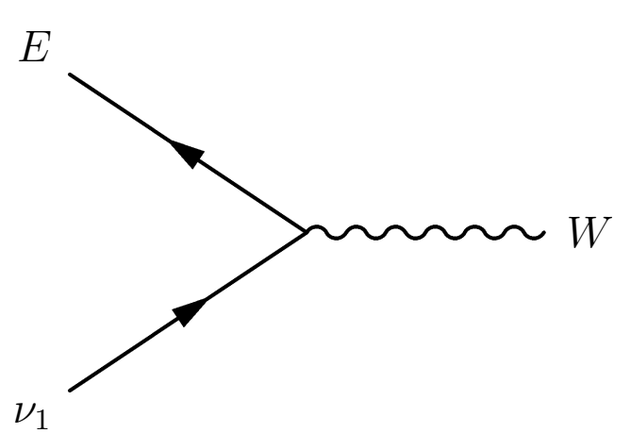




THEORETICAL PHYSICS



$\rightarrow$ No tree-level direct detection analog



$\rightarrow$ No tree-level direct detection analog

THEORETICAL PHYSICS

Question:

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

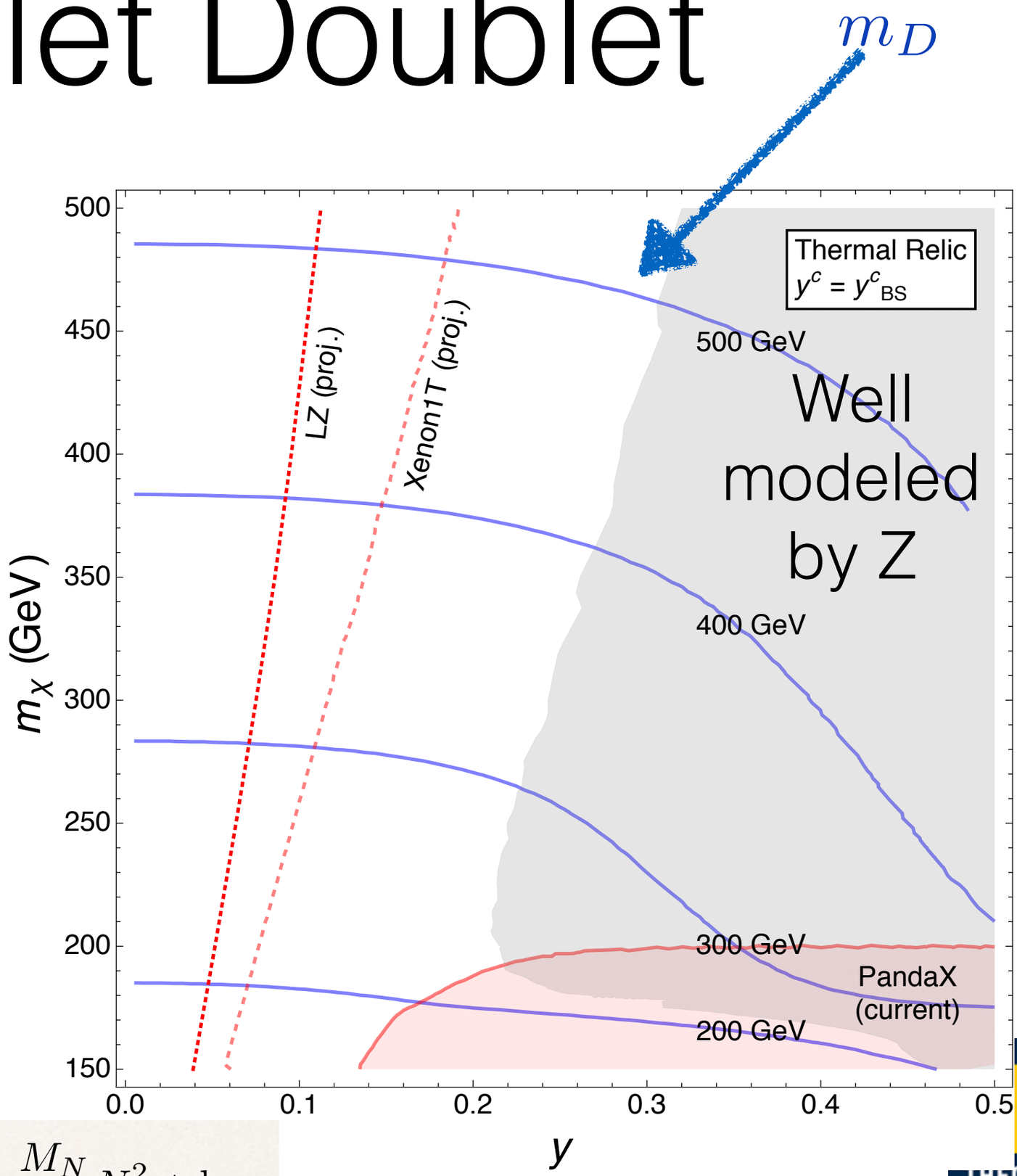
THEORETICAL PHYSICS

J. Kearney and N. Orlofsky, AP 1611.05048

Singlet Doublet

In blind spot (fixes y^c)

Relic density thermal (fixes M_D)



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

THEORETICAL PHYSICS

Breaking the Crossing Symmetry: Co-annihilation

If χ and Y simultaneously inhabit the thermal bath at freeze-

out

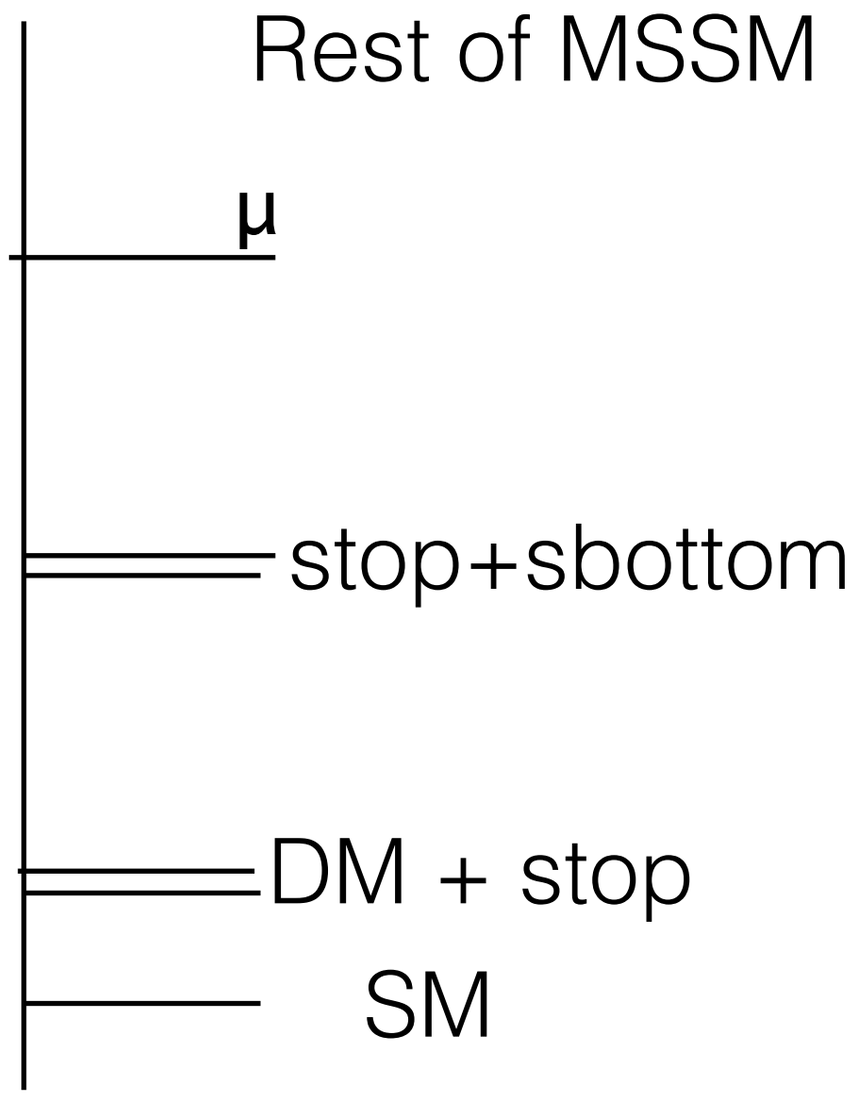
(Boltzman suppression not too large)

$$e^{-\Delta m/T_{FO}} \approx e^{-20\,\frac{\Delta m}{m}}$$

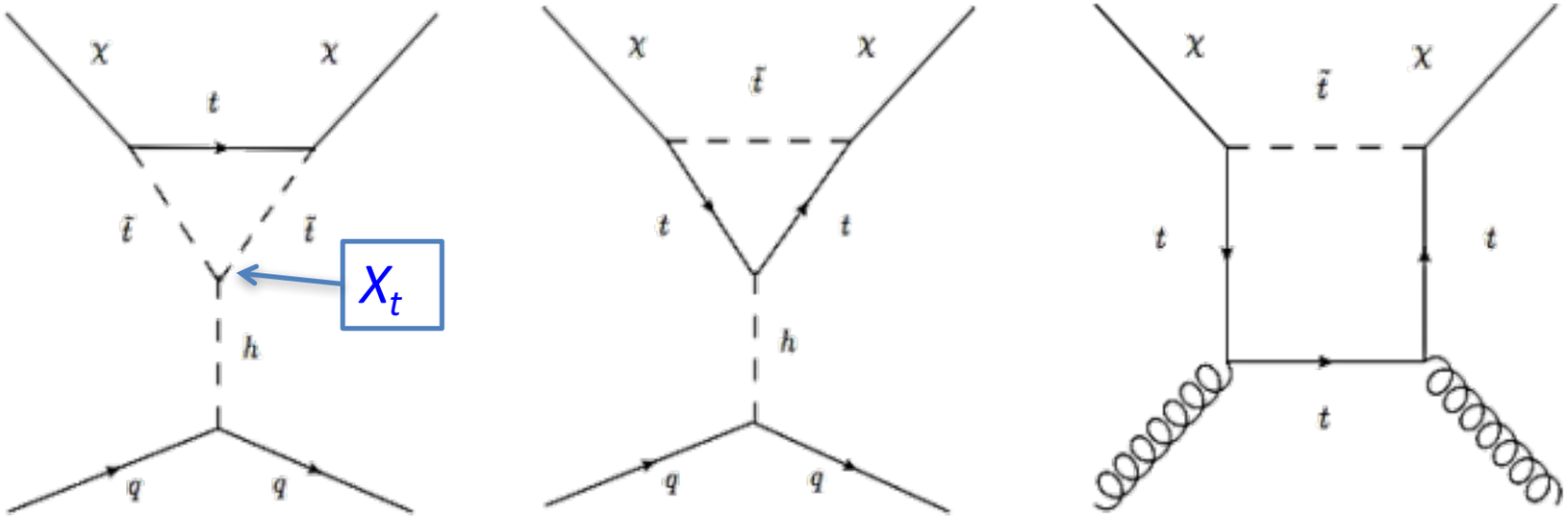
$$\sigma(\chi\chi \to SM)\ \sigma(\chi Y \to SM)\ \sigma(YY \to SM)$$

Griest and Seckel, Phys.Rev. D43 (1991) 3191-3203

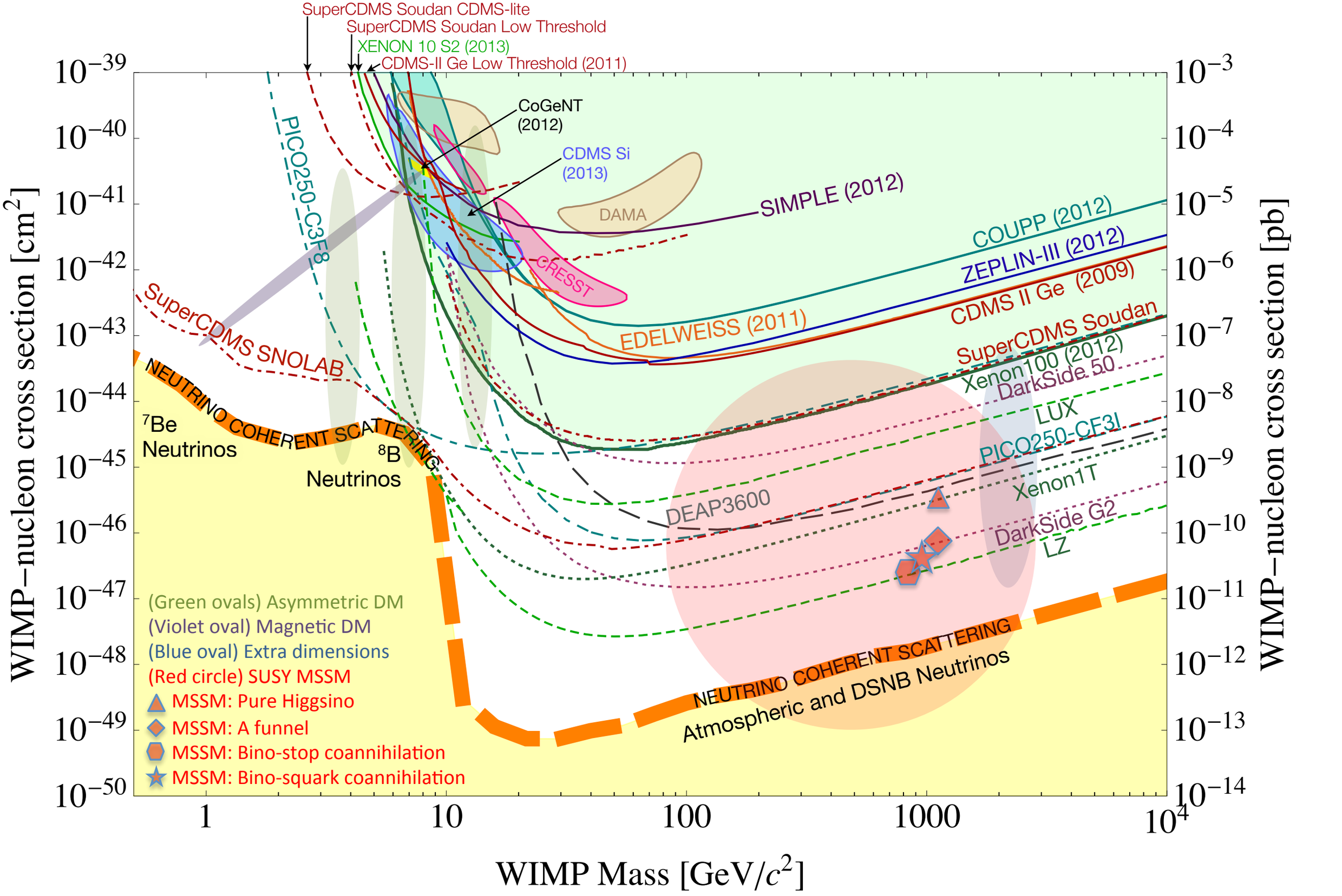
THEORETICAL PHYSICS


Rest of MSSM
μ
stop+sbottom
DM + stop
SM

Loop Induced Dark Matter Couplings



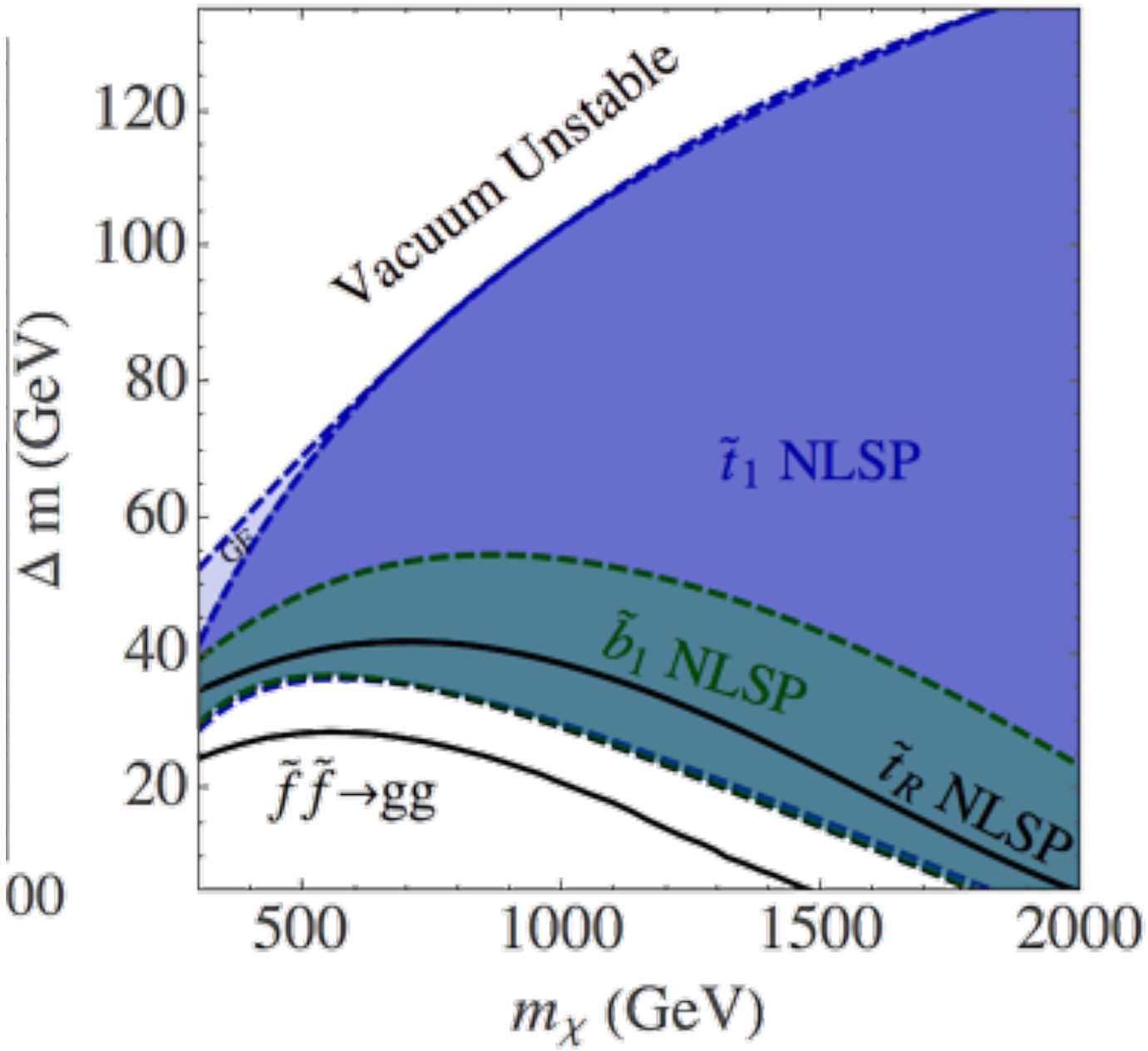
THEORETICAL PHYSICS



Snowmass 1310.8327

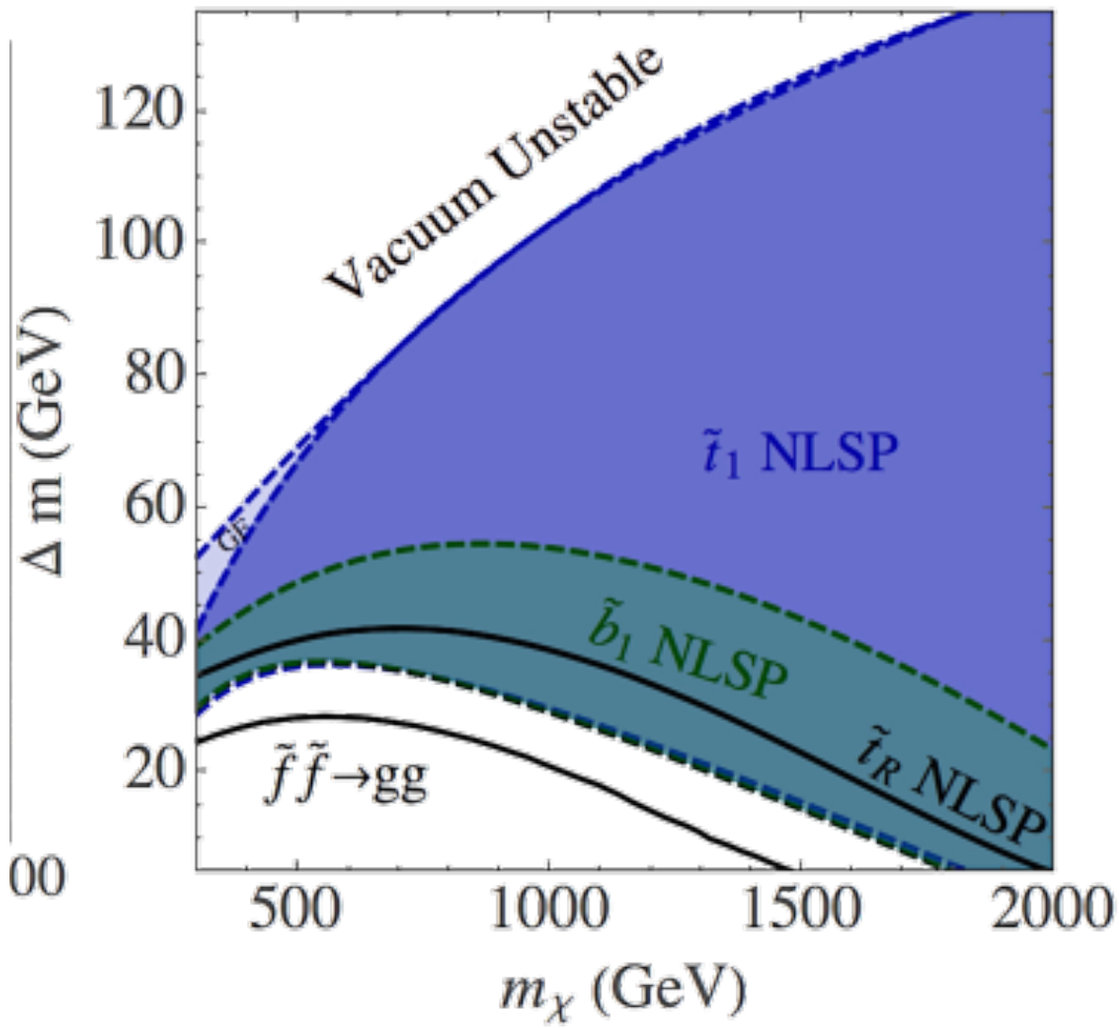
THEORETICAL PHYSICS

Mass Splitting

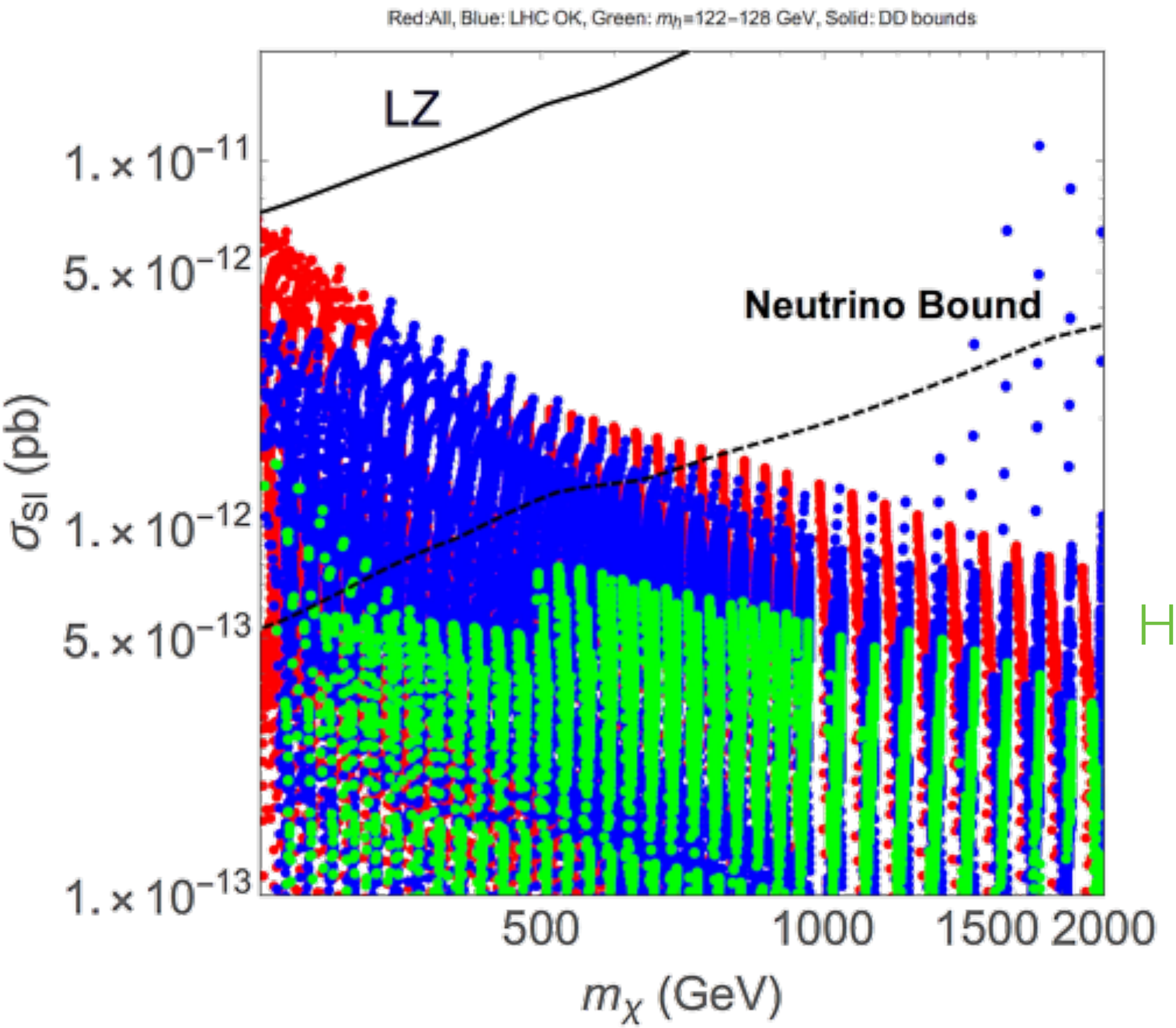


THEORETICAL PHYSICS

Mass Splittings



THEORETICAL PHYSICS



Higgs OK

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.

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

THEORETICAL PHYSICS

Conclusion
WIMPs: a Status Report

- Higgs-centric cosmology getting squeezed

- Z-centric cosmology is **exciting now**
  - Symmetry reason for blind spot?

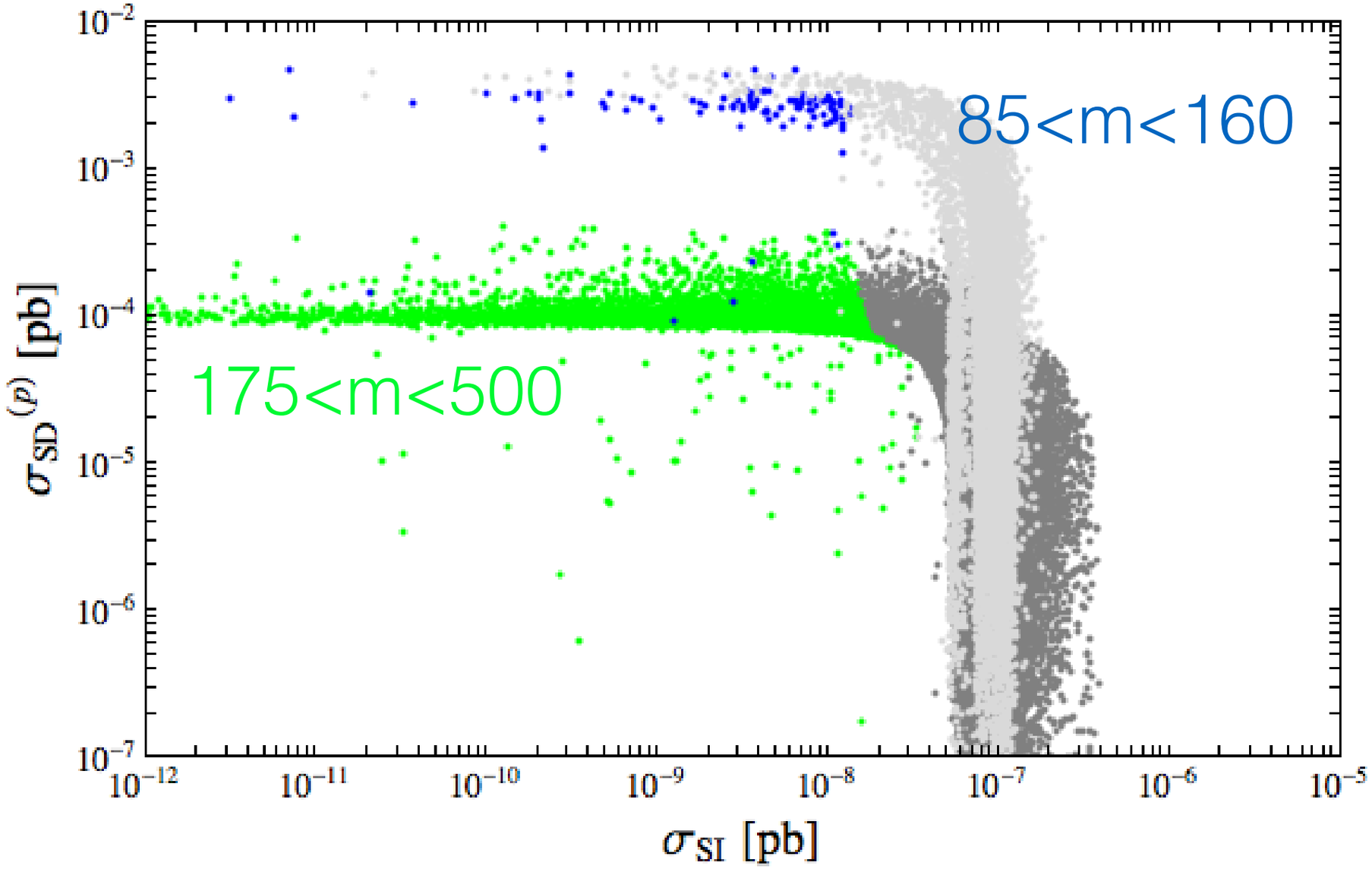
- Co-annihilation-centric cosmology (stop or otherwise) will be very hard for the foreseeable future, but we could get lucky.

- Why co-annihilation? (AP, Kearney, Phys.Rev. D88 (2013) no.9, 095009)

THEORETICAL PHYSICS

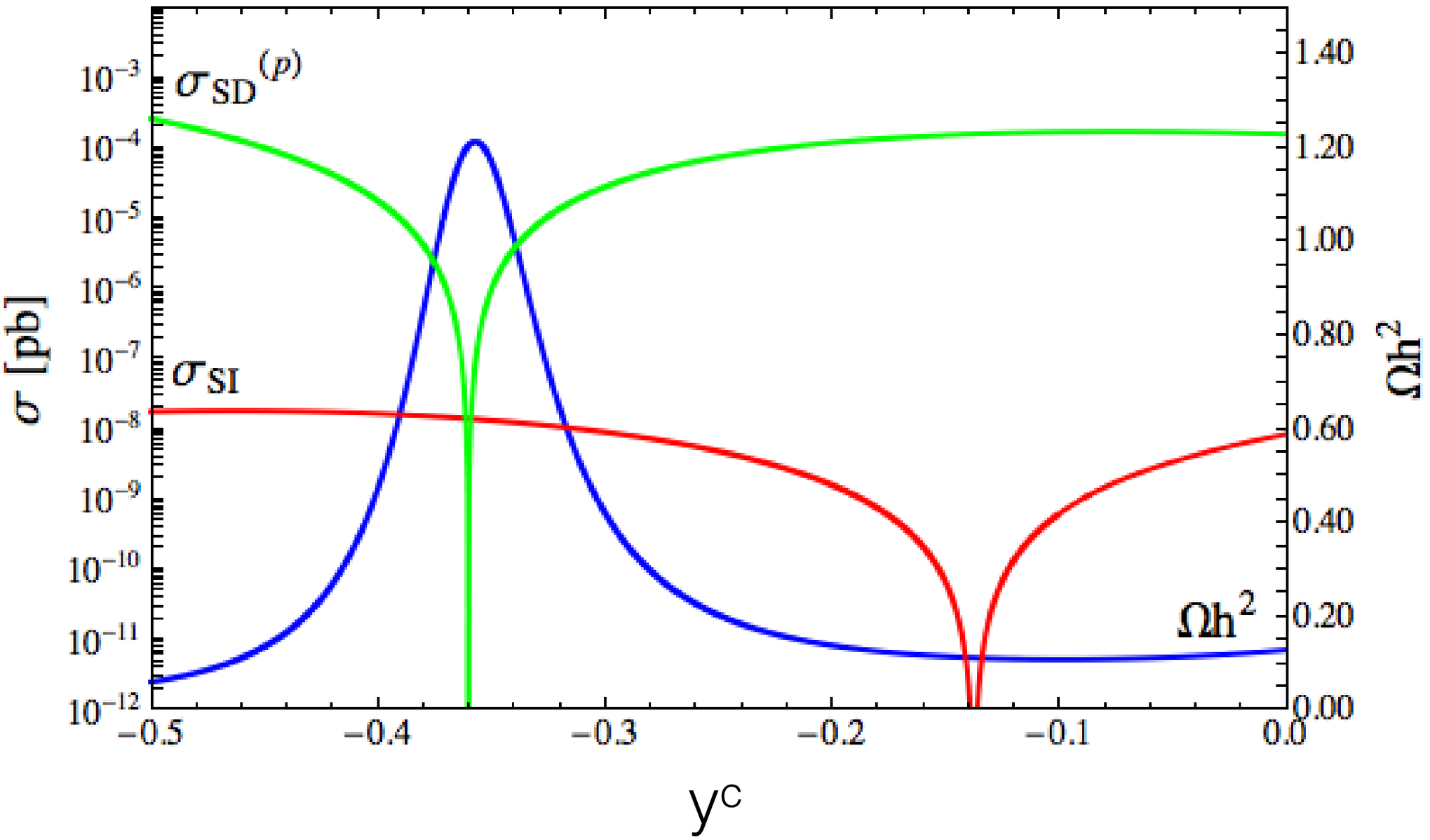
Extra Slides

THEORETICAL PHYSICS



Cohen, Kearney, AP, Tucker-Smith 1109.2604

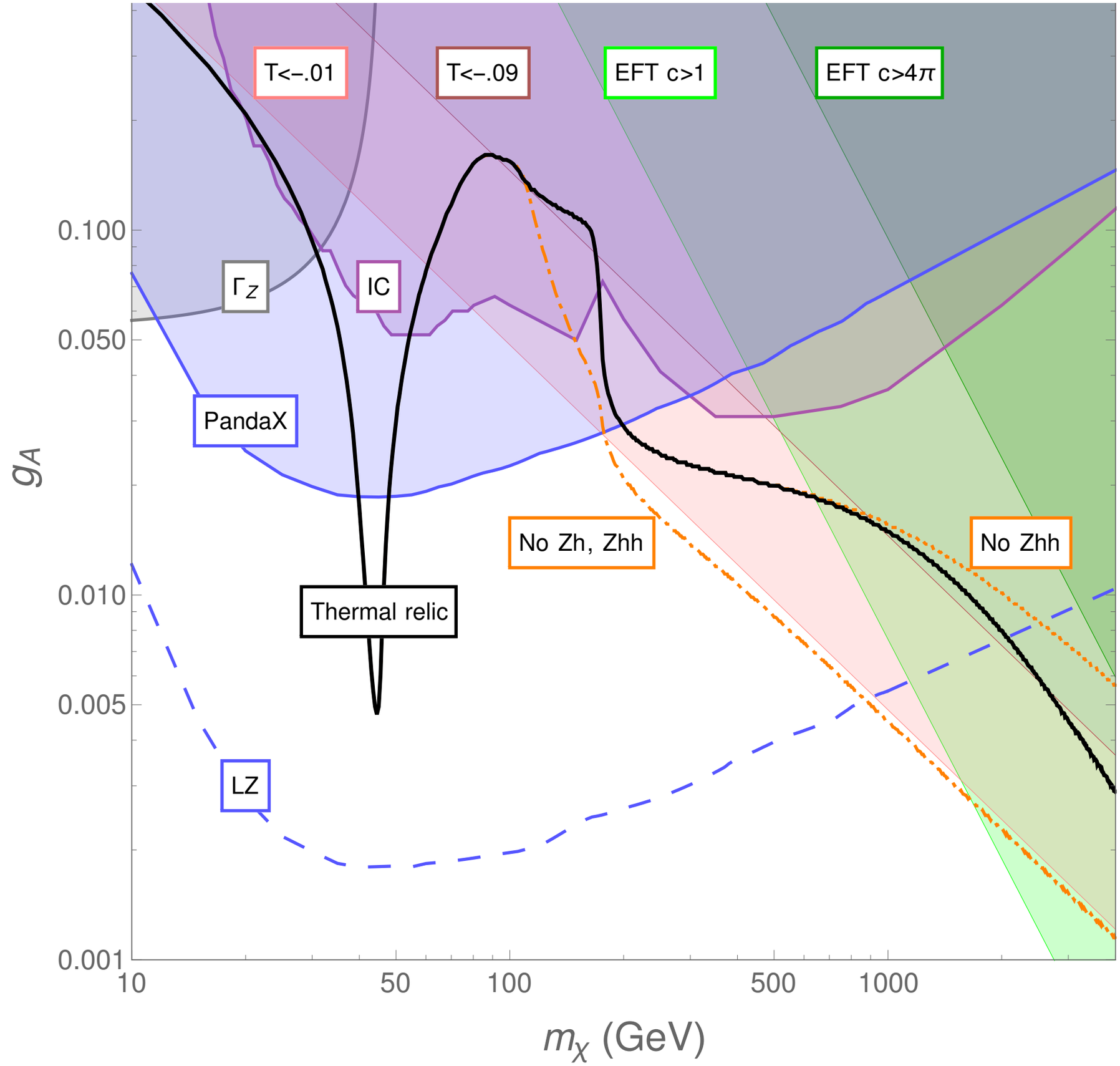
THEORETICAL PHYSICS



Cohen, Kearney, AP, Tucker-Smith 1109.2604

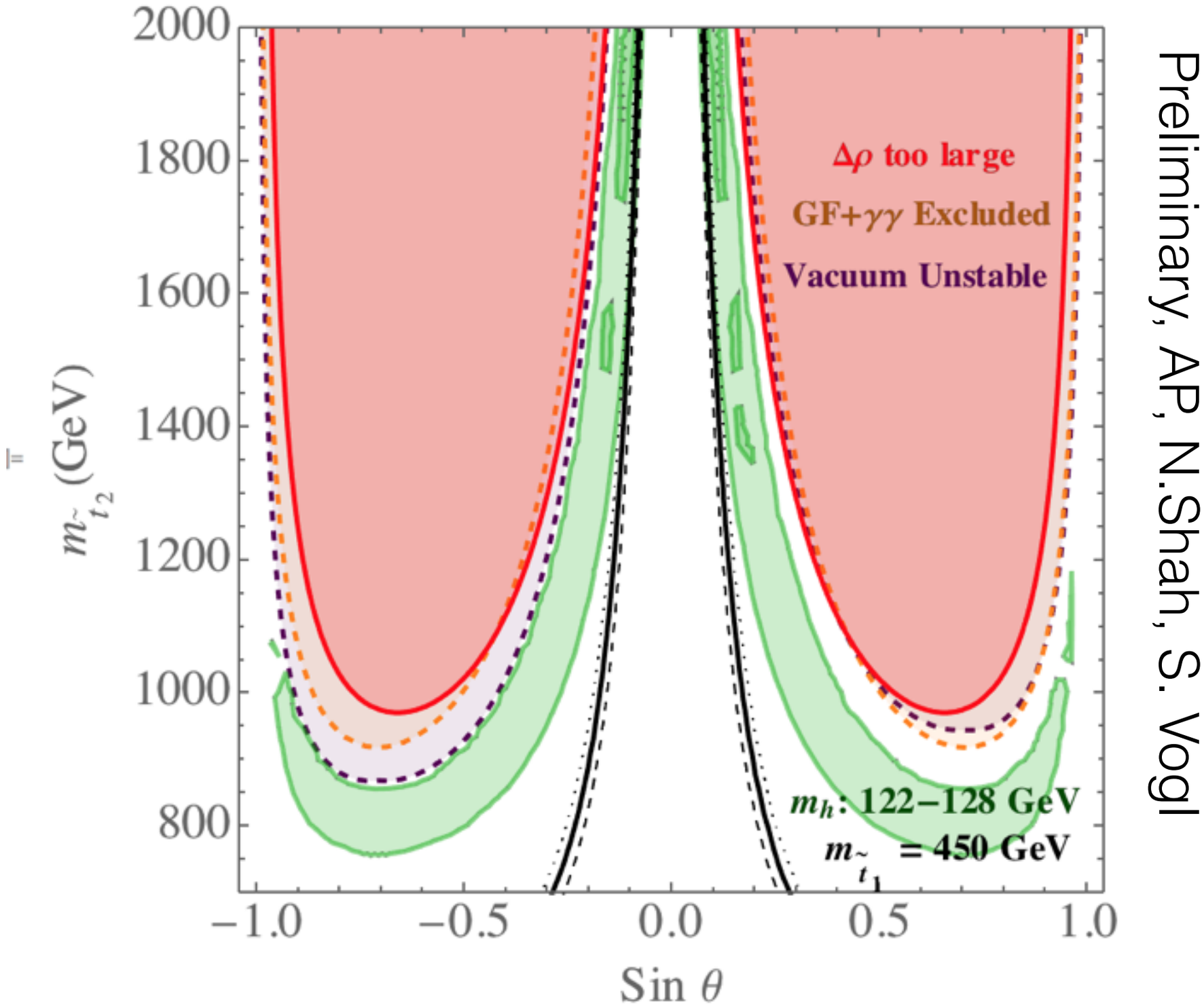
THEORETICAL PHYSICS

Effective Field Theory Validity



THEORETICAL PHYSICS

Both gluino mass signs



Preliminary, AP, N.Shah, S. Vogl

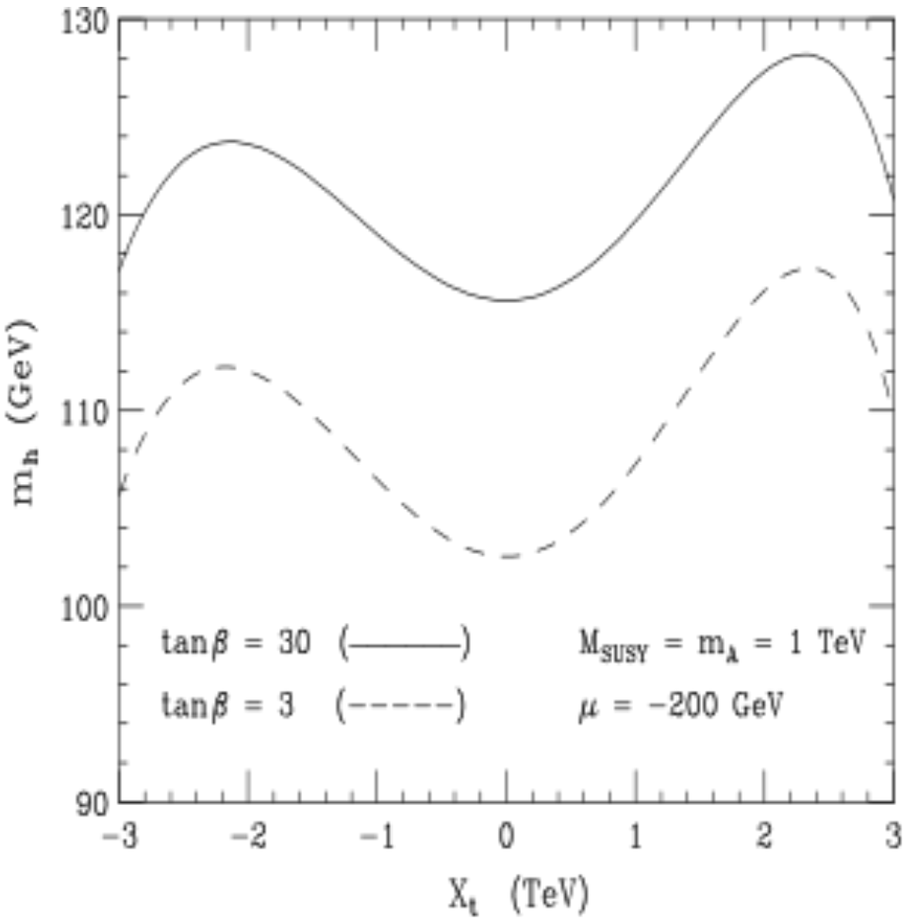
THEORETICAL PHYSICS

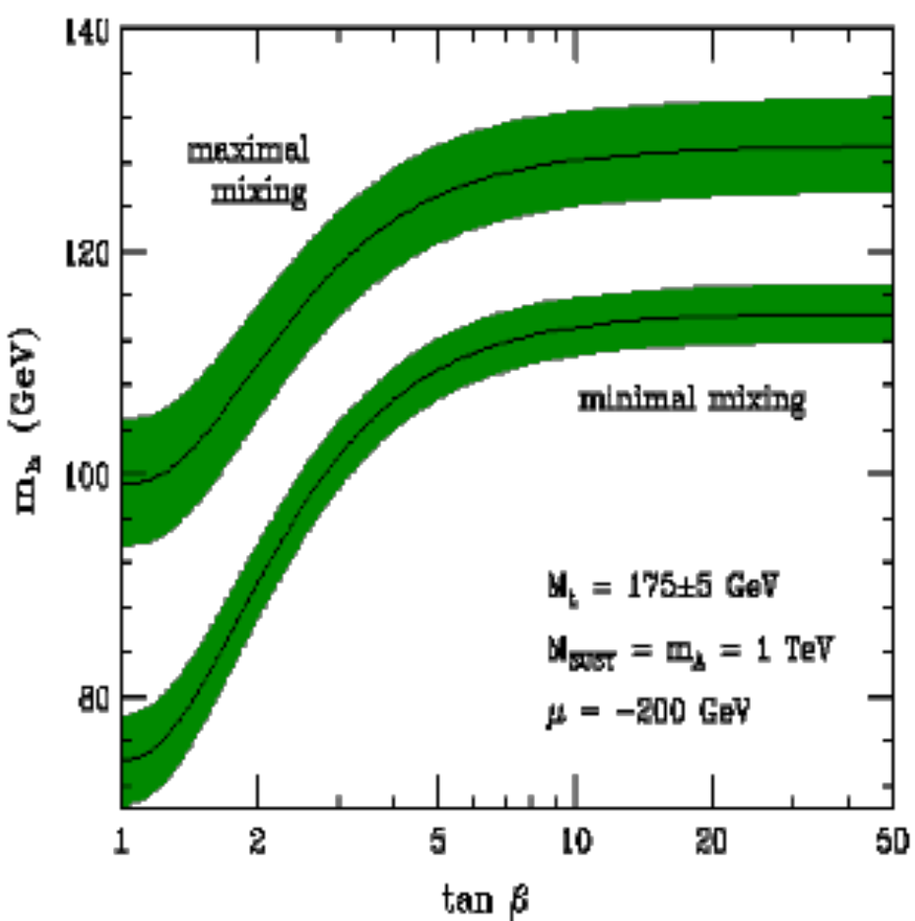
Higgs Mass Calculations

$$\simeq m_Z^2 + \frac{3m_t^4}{2\pi^2 v^2}\left[\ln\left(\frac{M_S^2}{m_t^2}\right) + \frac{X_t^2}{M_S^2}\left(1 - \frac{X_t^2}{12M_S^2}\right)\right]$$

- Long list of 2-loop (and more!) computations:
  - Carena, Degrassi, Ellis, Espinoza, Haber, Harlander, Heinemeyer, Hempfling, Hoang, Hollik, Hahn, Martin, Pilaftsis, Quiros, Ridolfi, Rzehak, Slavich, Wagner, Weiglein, Zhang, Zwirner.

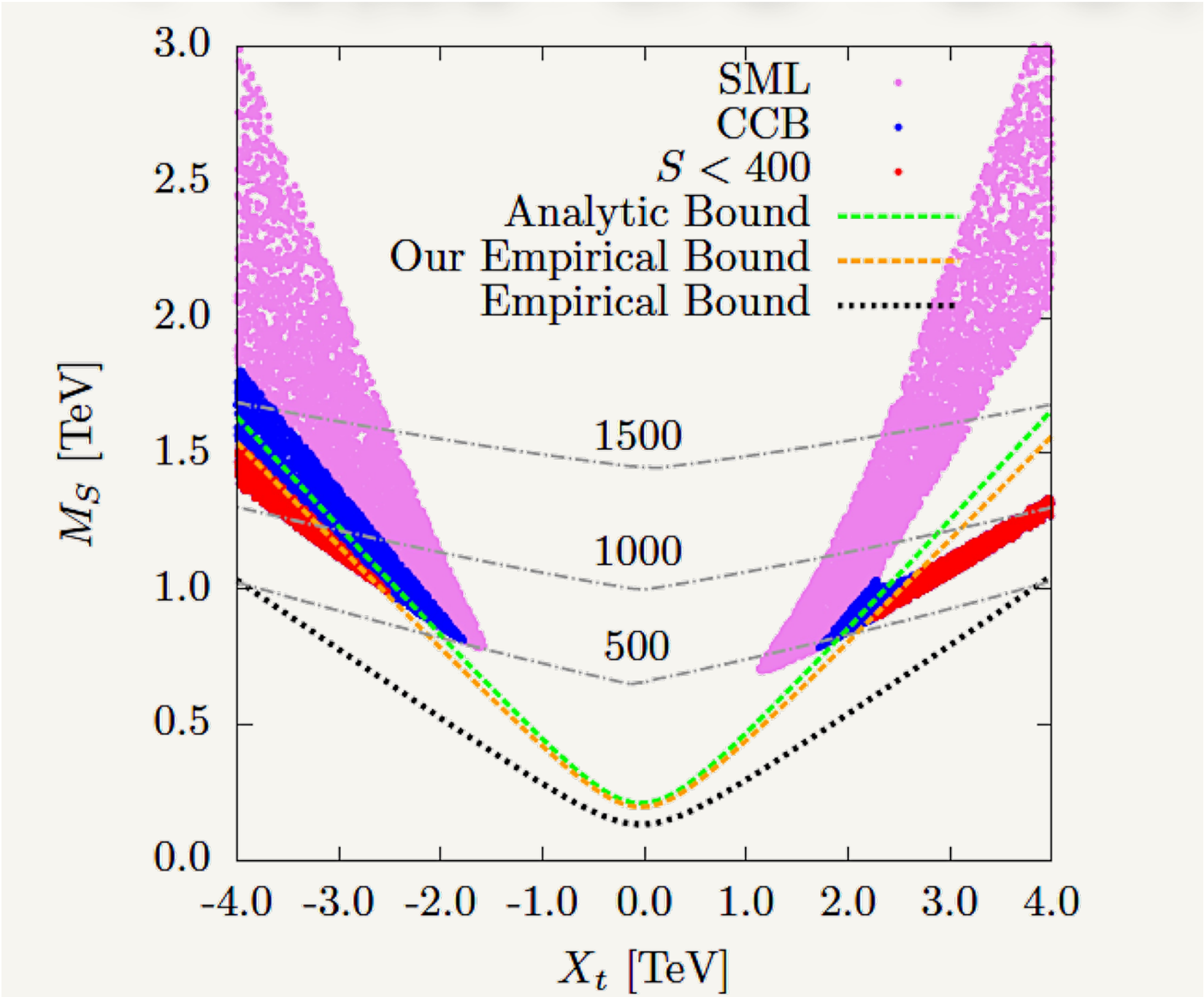
Carena and Haber, hep-ph/0208209





THEORETICAL PHYSICS

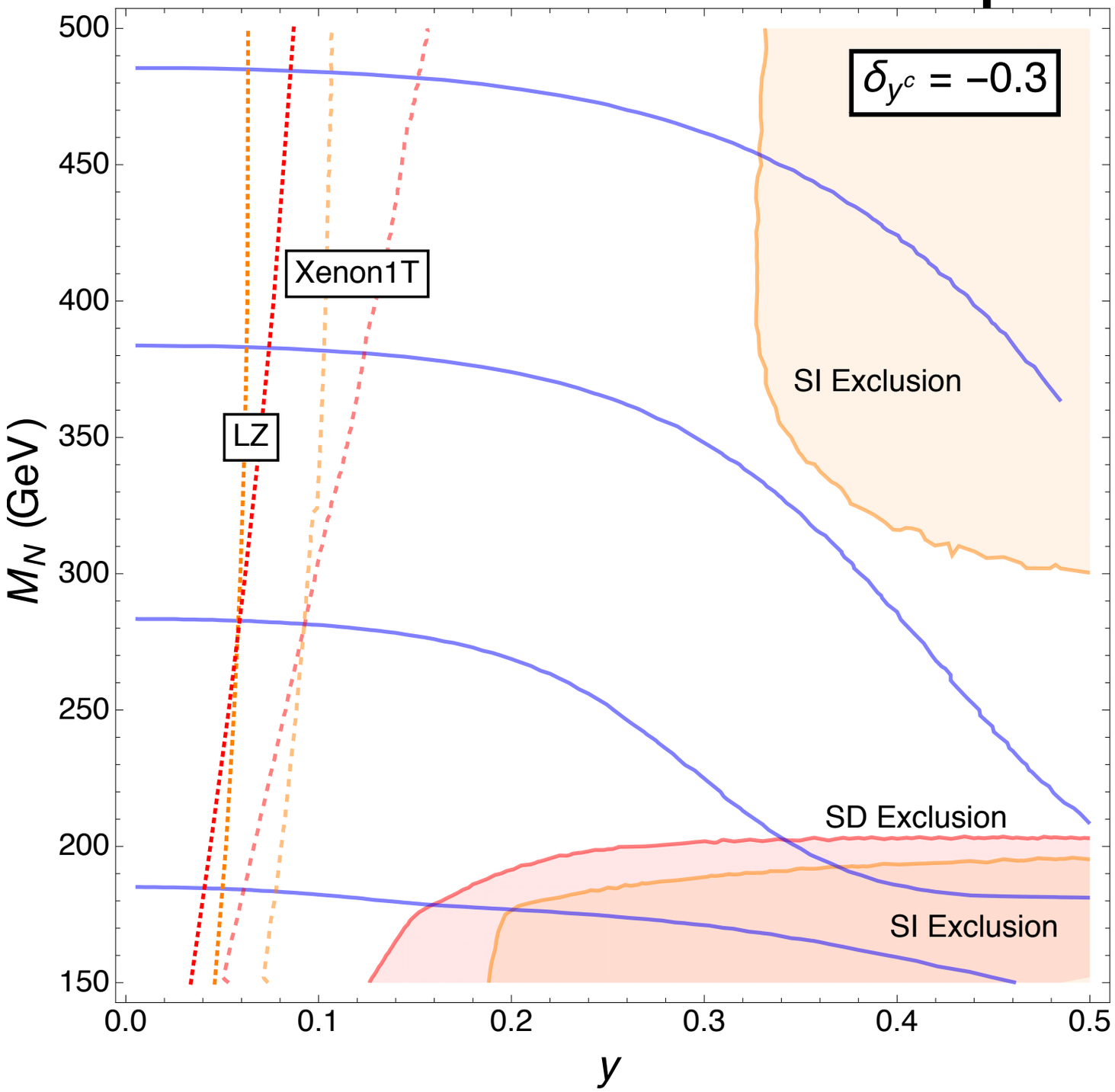
Charge Color-Breaking Vacuua



Morrissey and Blinov 1310.4174

THEORETICAL PHYSICS

Singlet Doublet Away from Blind Spot



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

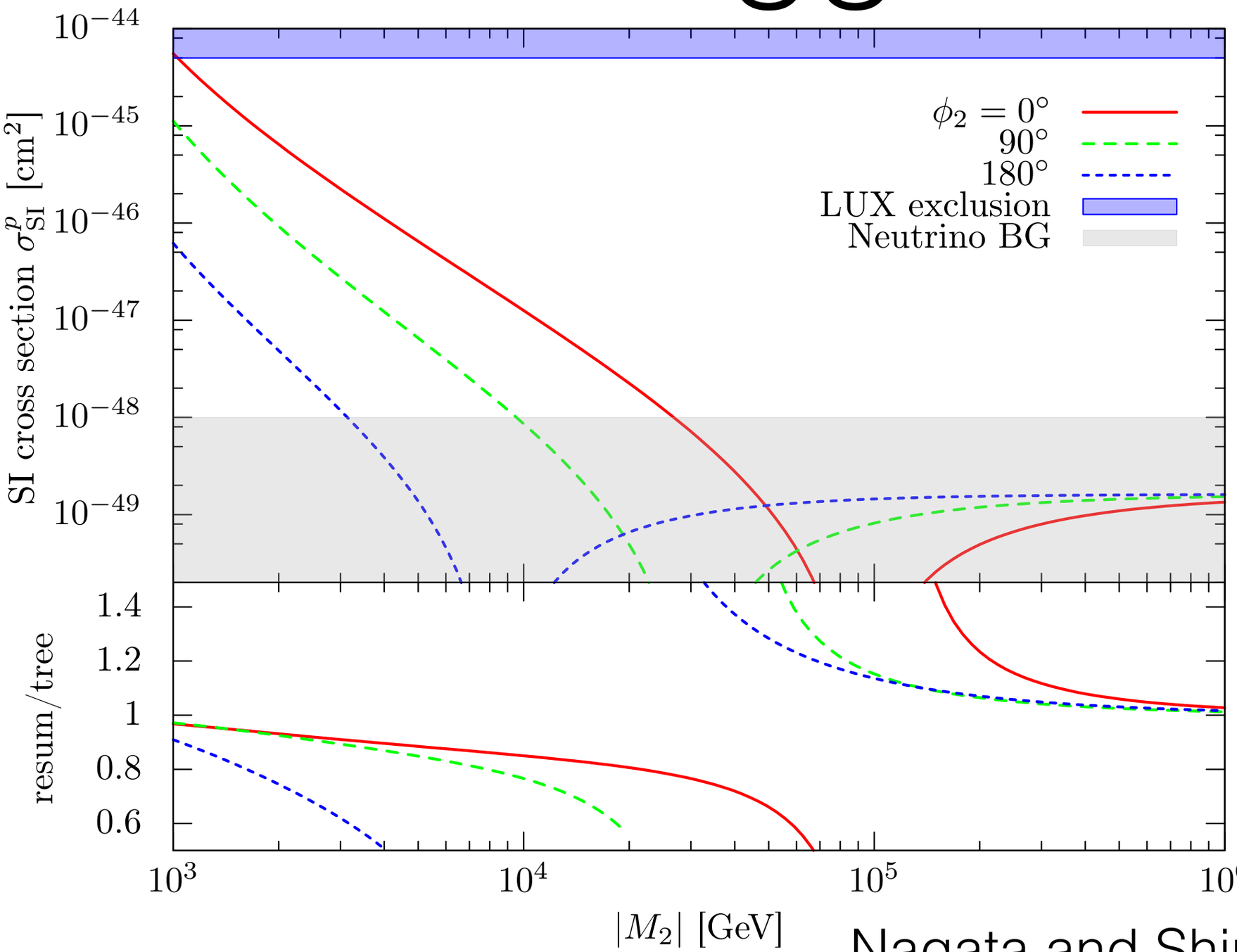
THEORETICAL PHYSICS

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?)

THEORETICAL PHYSICS

“Pure” Higgsino



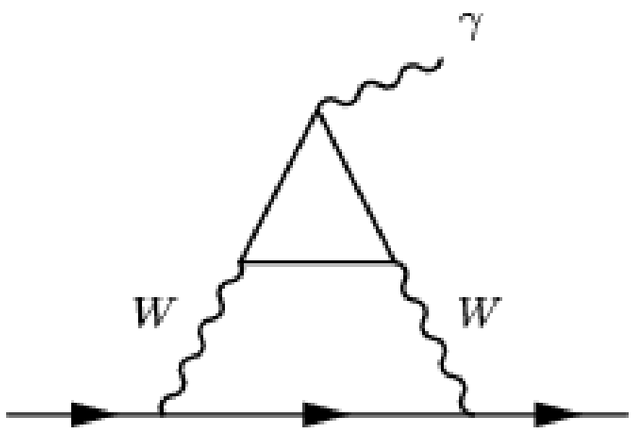
Nagata and Shirai
arXiv:1410.4549

THEORETICAL PHYSICS

Another caveat

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

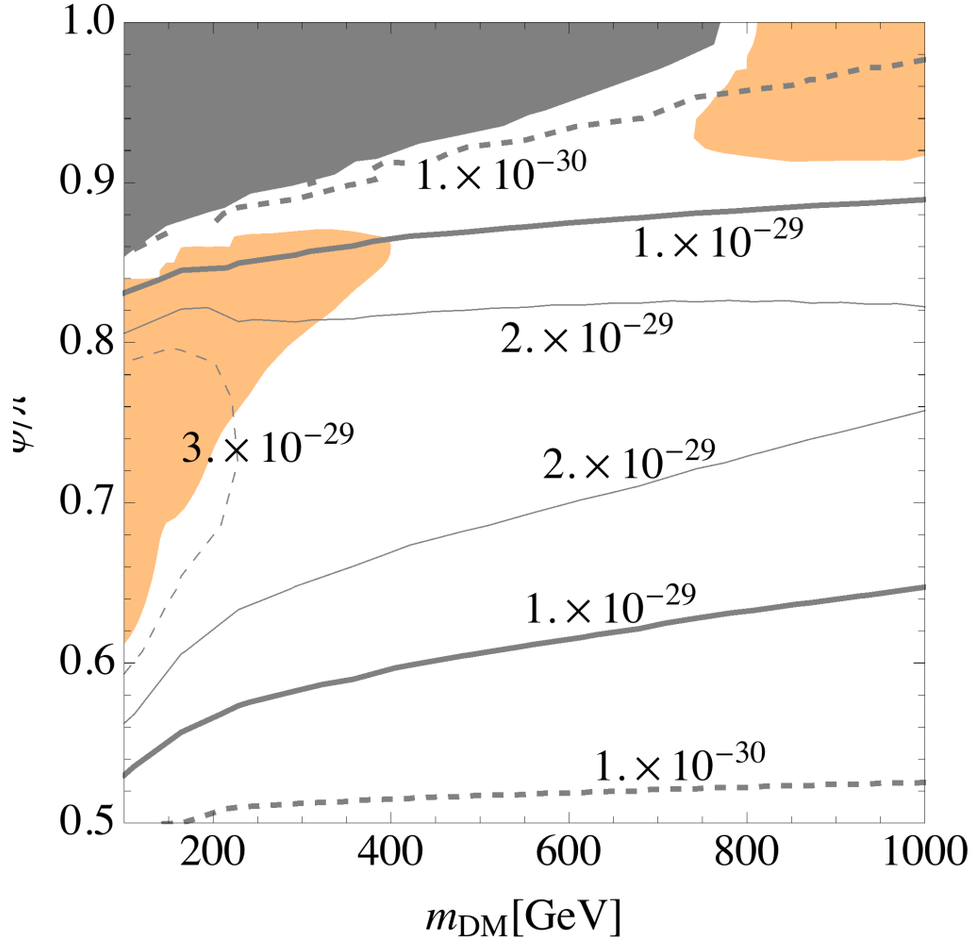
$$\cancel{CP} \to \chi\gamma_5\chi\, h \to (\bar{q}q)(\chi\gamma_5\chi)$$



T. Abe

arXiv:1702.07236

future prospect (blind spot, r=0.9)



r= ratio of yukawas

THEORETICAL PHYSICS