DARK MATTER ?

&SUSY

LIGHT HEAVY

DARK MATTER is the name given to material in the Universe that does not emit or reflect light but is necessary to explain observed gravitational effects in galaxies and stars. Dark matter, along with dark energy, totals 96% of the Universe, yet it remains a mystery as to what exactly it *is*.

Acrylic felt, wool felt, and fleece with gravel fill for maximum mass.

Packaged in a black opaque bag designed for concealing contents.

$9.75 PLUS SHIPPING

GLUON PHOTON NEUTRINO TACHYON ELECTRON UP QUARK DOWN QUARK TAU NEUTRINO MUON UP Q
NEUTRON DOWN QUARK TAU GLUON **DARK MATTER** NEUTRINO TACHYON ELECTRON UP QUARK DOW
NEUTRINO MUON UP QUARK PROTON NEUTRON DOWN QUARK TAU GLUON PHOTON NEUTRINO TACHY

The PARTICLE ZOO

Aaron Pierce
University of Michigan
August 28, 2011

A period of rapid experimental progress

- Direct Detection
- Indirect Detection
- Colliders

McKinsey (Wed)

Murgia (Wed)

SUSY Dark Matter Options

- Neutralino: MSSM and beyond.

$$\tilde{\chi}_i^0 = N_{i1}\tilde{B} + N_{i2}\tilde{W}^3 + N_{i3}\tilde{H}_1^0 + N_{i4}\tilde{H}_2^0$$

- Sneutrino: not a your father’s sneutrino
- Gravitino
- Axino-- motivated by strong CP problem
- Another sector?

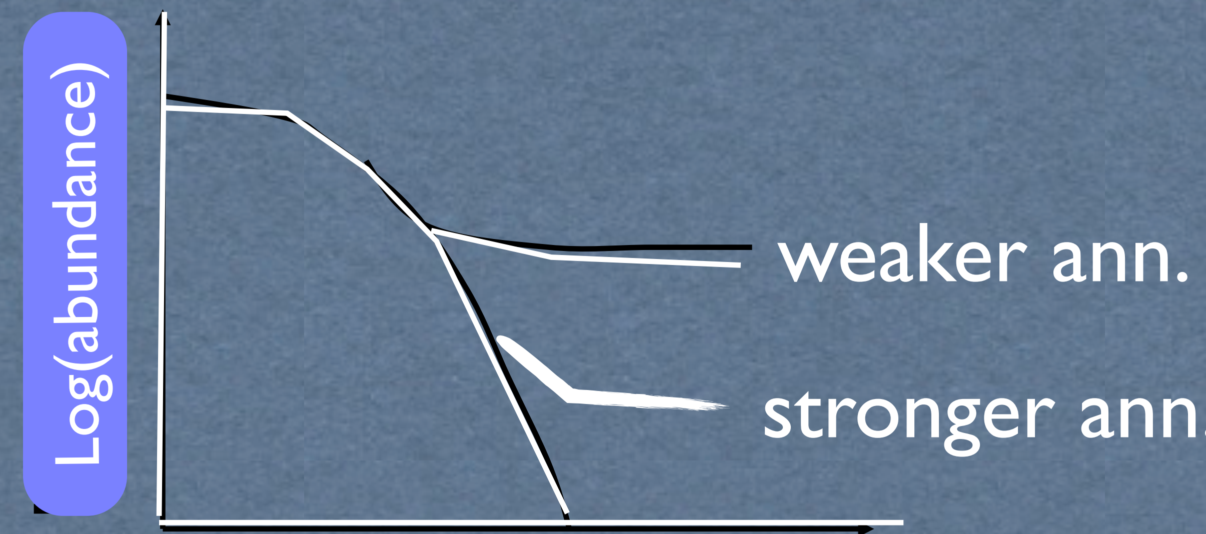
Standard Calculation of How Much Dark Matter...

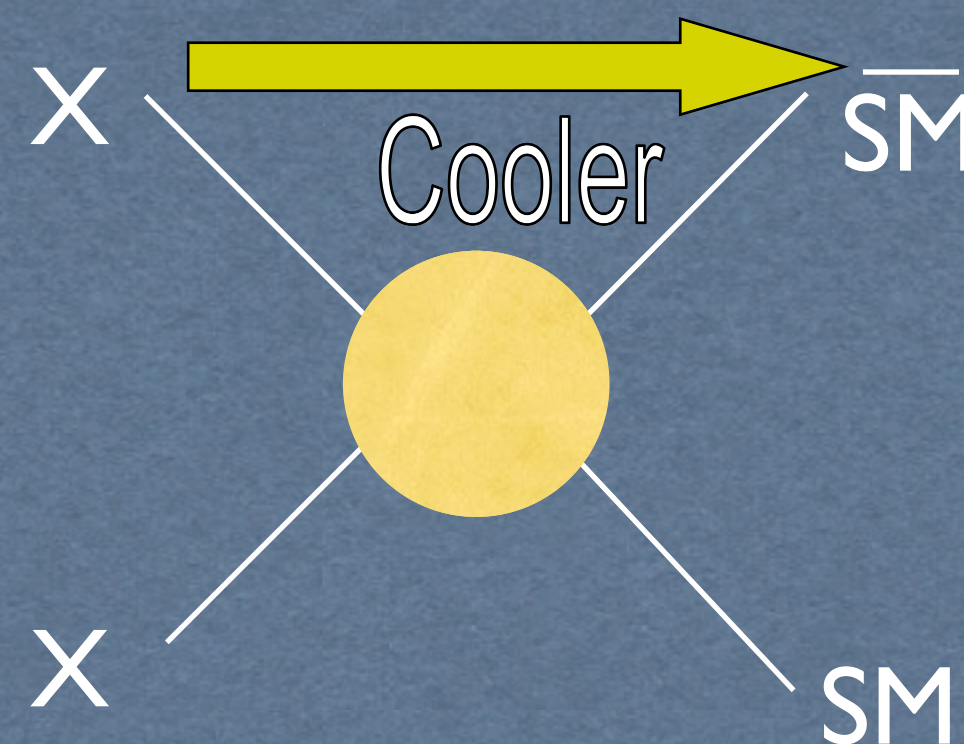
Solve the Boltzmann equation in an expanding universe.

Annihilations try to maintain thermal equilibrium.

Expansion of the Universe prevents this.

Weak scale selected out as special.





Other possibilities

- Non-thermal production (e.g. from moduli, cf. Randall and Moroi)
- Decays from NLSP

Feng, Wed?

- “Freeze-in”

L. Hall, et al. JHEP 1003 (2010) 080.

Direct Detection

- Very naive:

$$\sigma_{SI} \approx \alpha^2 \frac{m_{ne}^2}{M_Z^4} \approx 10^{-38}\mathrm{cm}^2$$

- SUSY Dark Matter is second simplest "weak DM."
  - Majorana: Spin-Dependent Z exchange only
  - Spin-Independent through Higgs

Higgs Boson Exchange

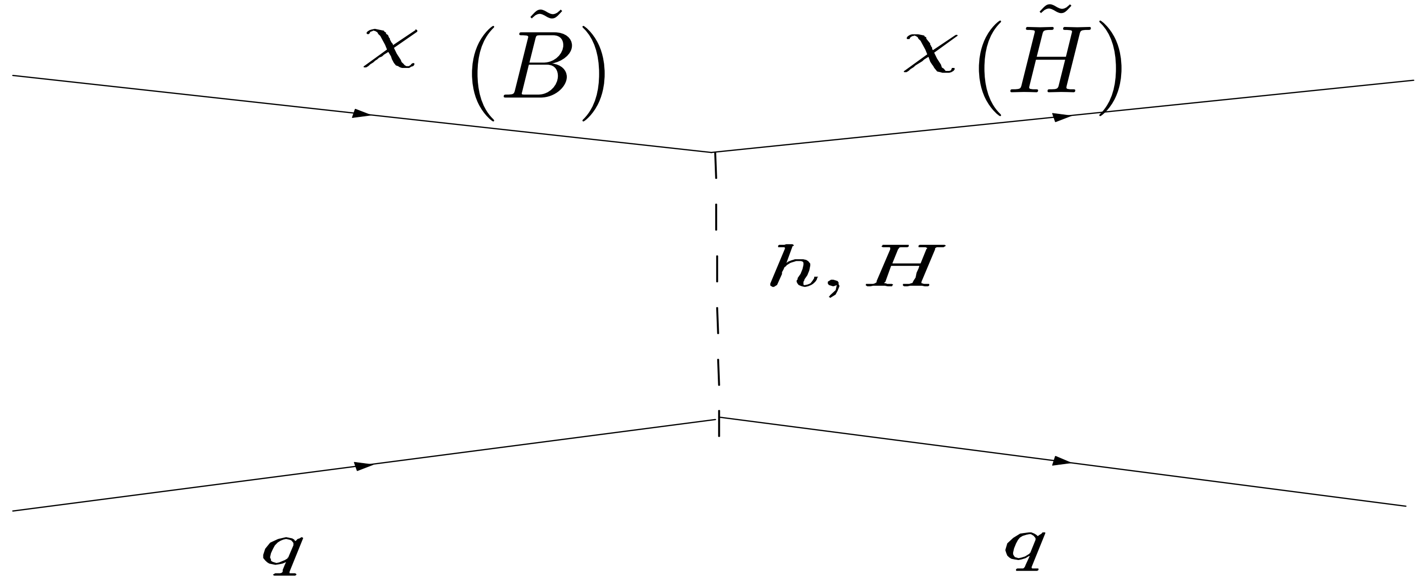
$$\sigma_{\rm SI}(\chi\, N \to \chi\, N) \approx 5\times 10^{-8}\ {\rm pb}\left(\frac{y_\chi}{0.1}\right)^2\left(\frac{115\ {\rm GeV}}{m_h}\right)^4 \qquad \text{(SI typical)}$$

(10^{-44} cm^2)

Cohen, Phalen, AP (2010)

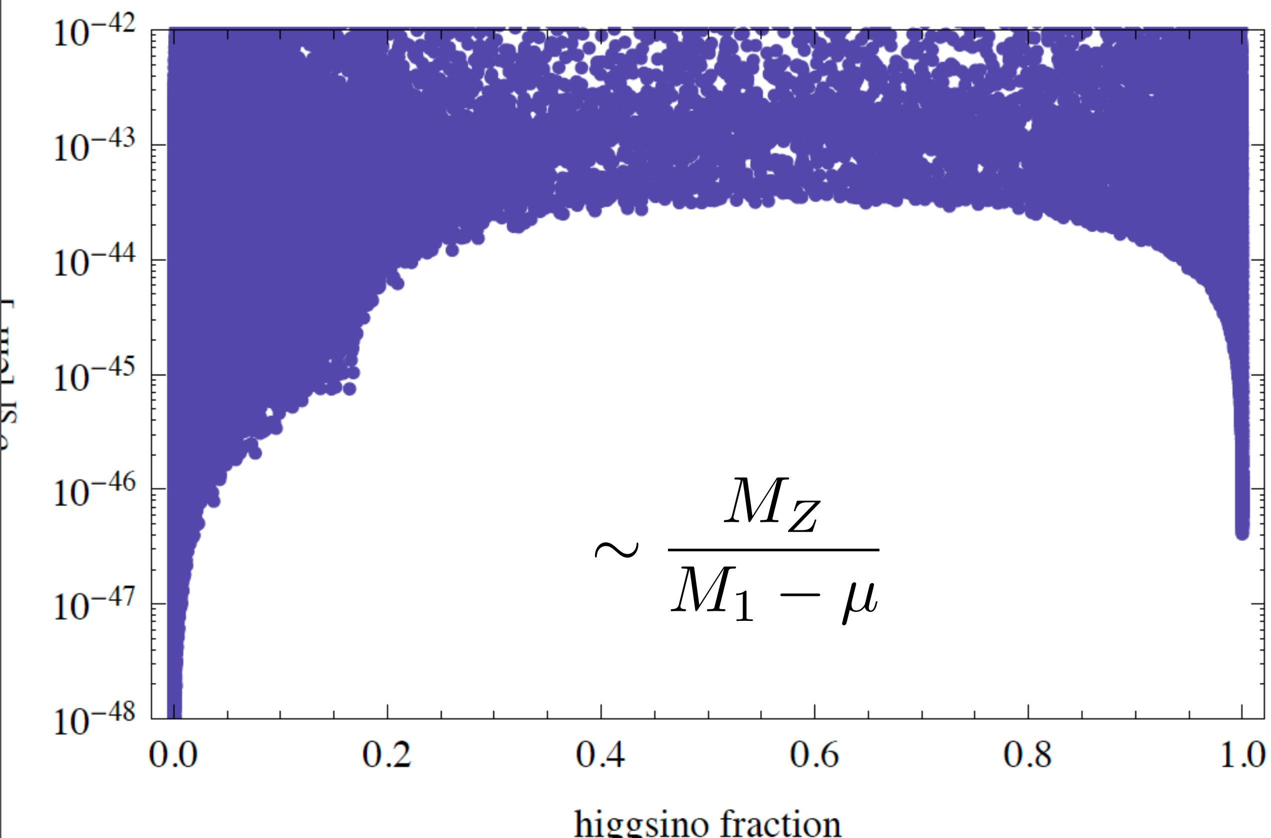
see also Feng and Sanford (2010);

Direct Detection



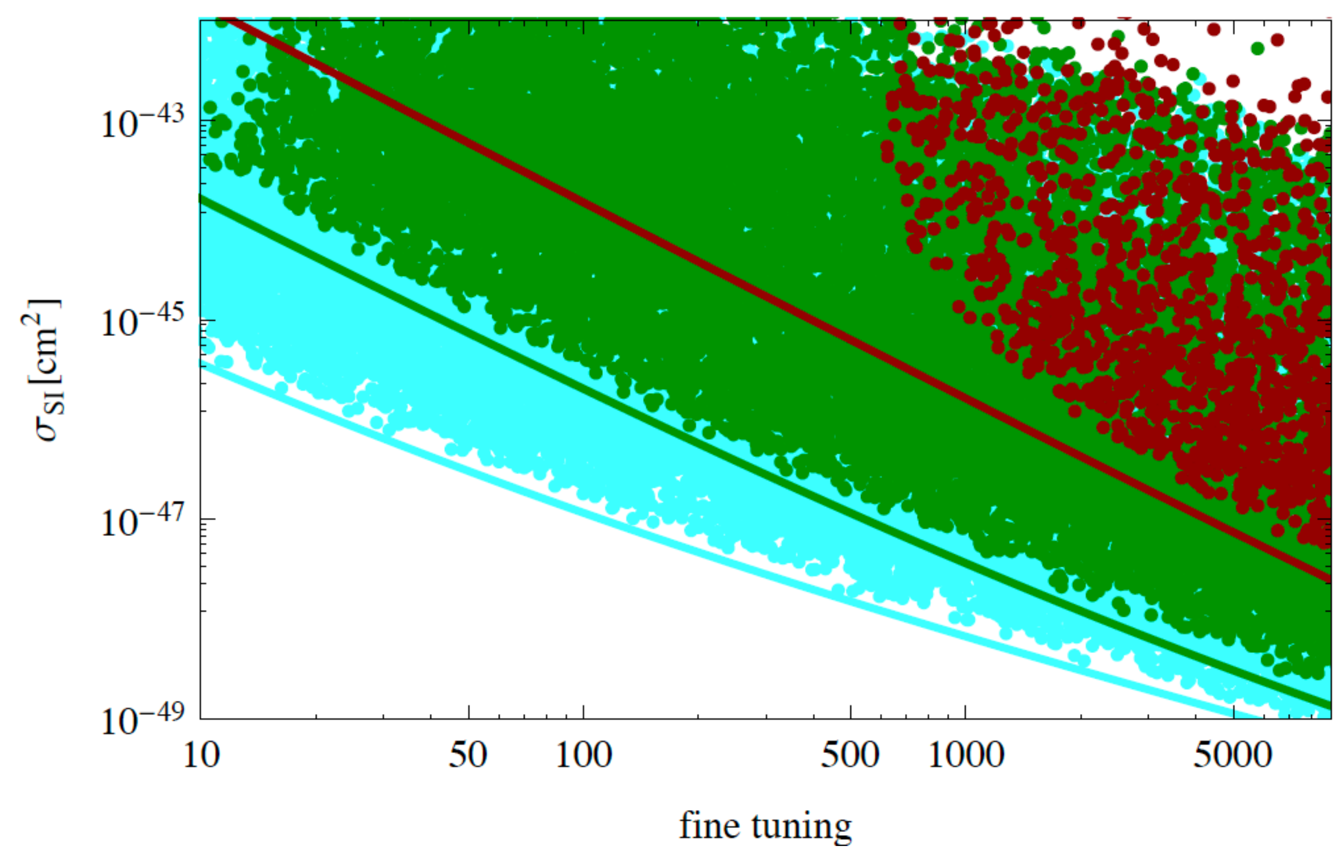
$$\tilde{\chi}_i^0 = N_{i1}\tilde{B} + N_{i2}\tilde{W}^3 + N_{i3}\tilde{H}_1^0 + N_{i4}\tilde{H}_2^0$$

Tempering a neutralino: direct detection implications



Perelstein and Shakya;1107.5048

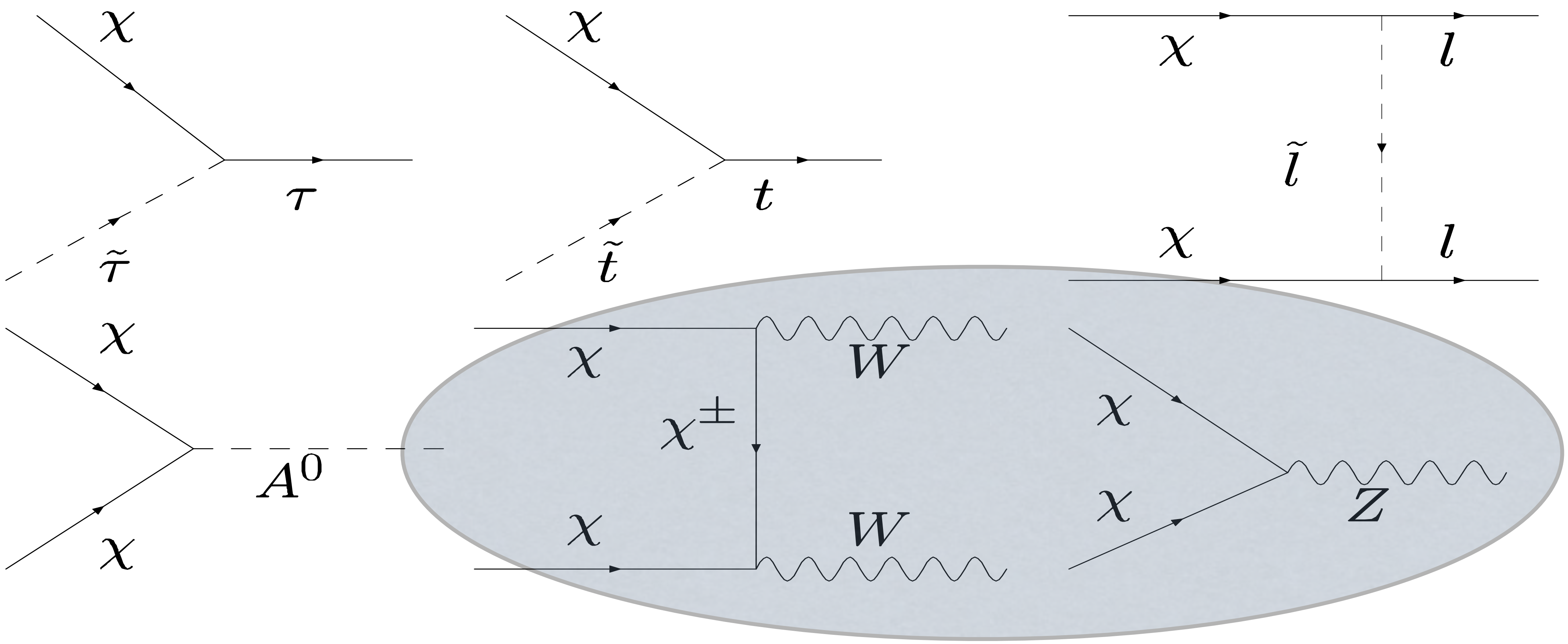
Parallel 6:H

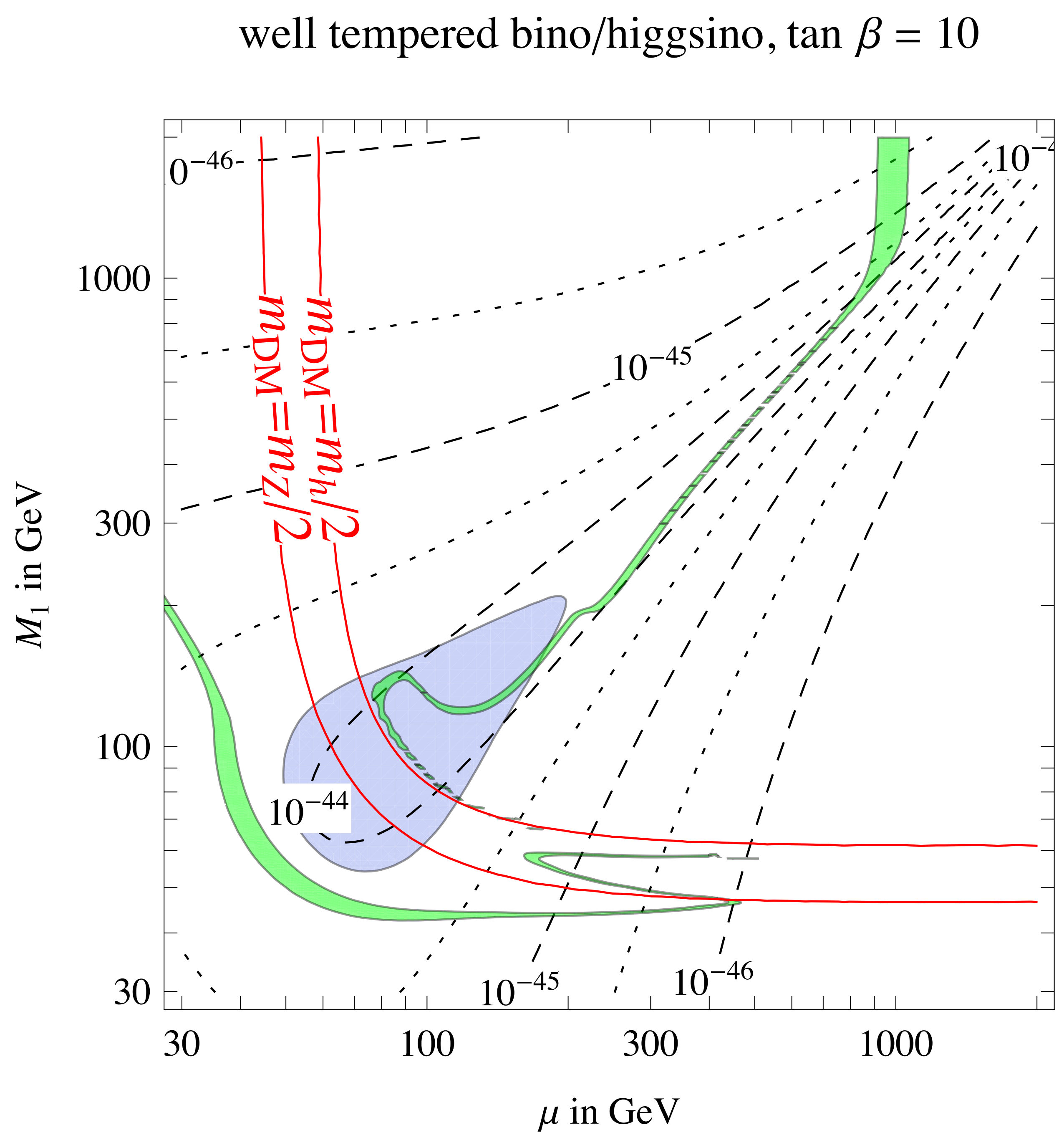


$$m_Z^2 = \frac{|m_{H_d}^2 - m_{H_u}^2|}{\sqrt{1-\sin^2(2\beta)}} - m_{H_u}^2 - m_{H_d}^2 - 2|\mu|^2.$$

see also (e.g.): Amsel, Freese, Sandick, 1108.0448; Kitano, Nomura (2006);
Mandic, Murayama, AP, Gondolo (2000)

Annihilation





Farina, et al., 1104.3572

Implications of DD

Well-Tempered

neutral higgses

large tan beta

stau

coannihilation

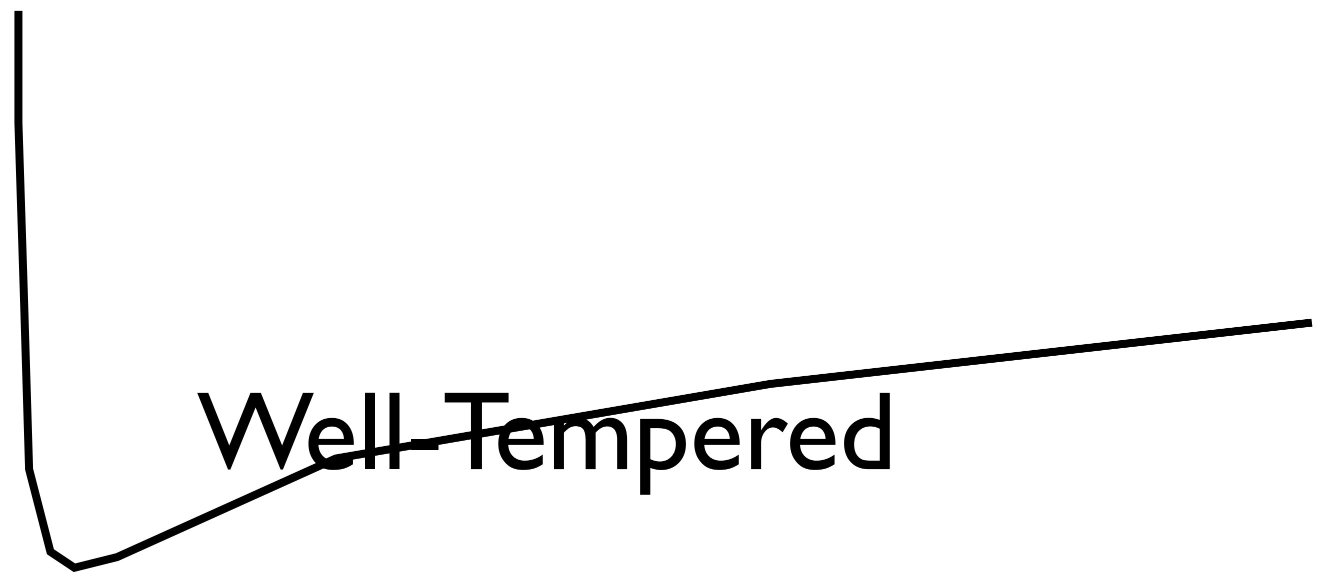
Resonance

stop

coannihilation

Farina, et al., 1104.3572

What is coupling to the proton?



Well-Tempered

neutral higgses

large tan beta

stau

coannihilation

Resonance

stop

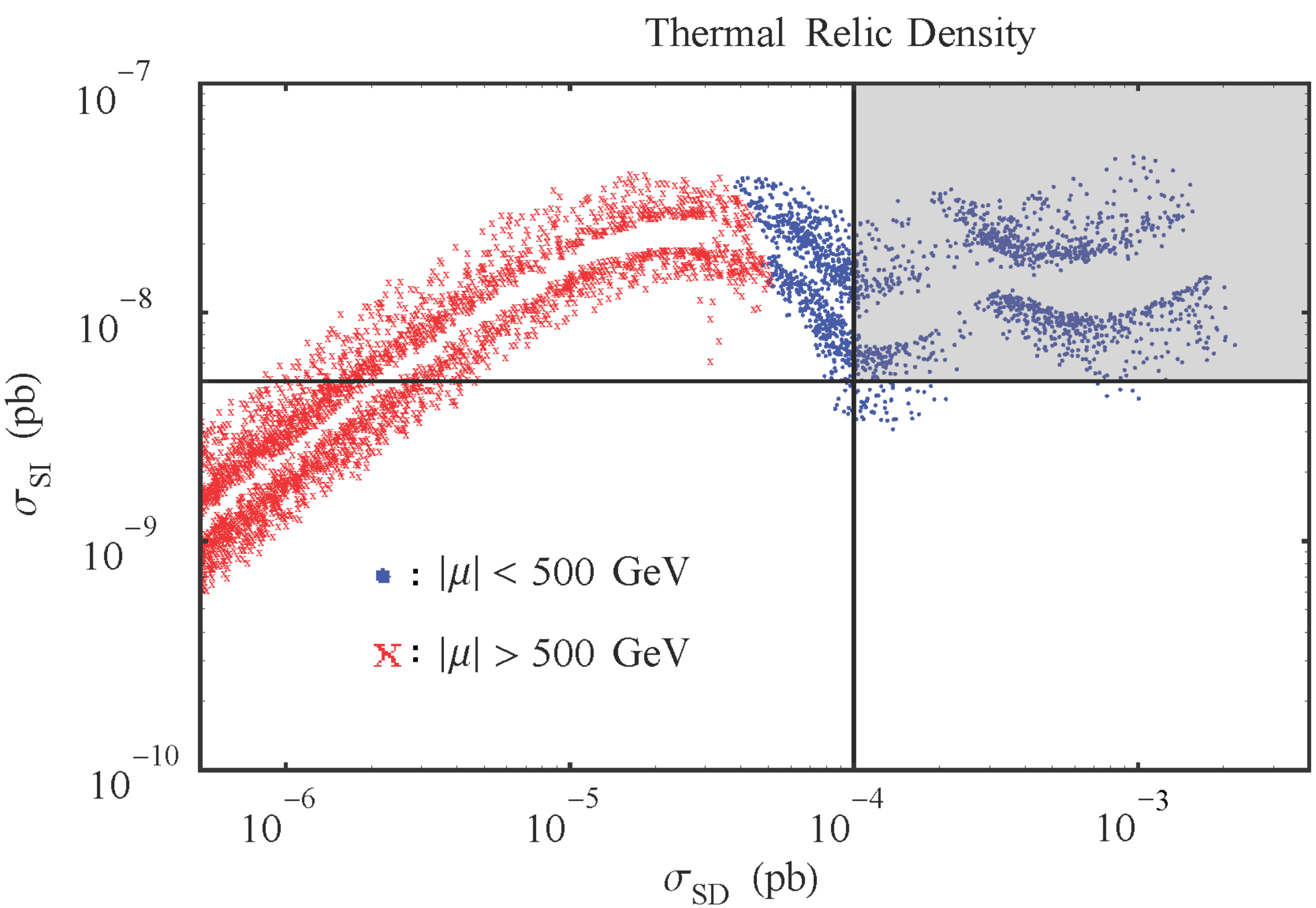
coannihilation

~Factor 2.5

Using "lattice value" of Giedt, Thomas, Young; 0907.4166, T&Y, 0901.3310, see also MILC, 0905.2432

local density = 0.3 GeV/cm^3

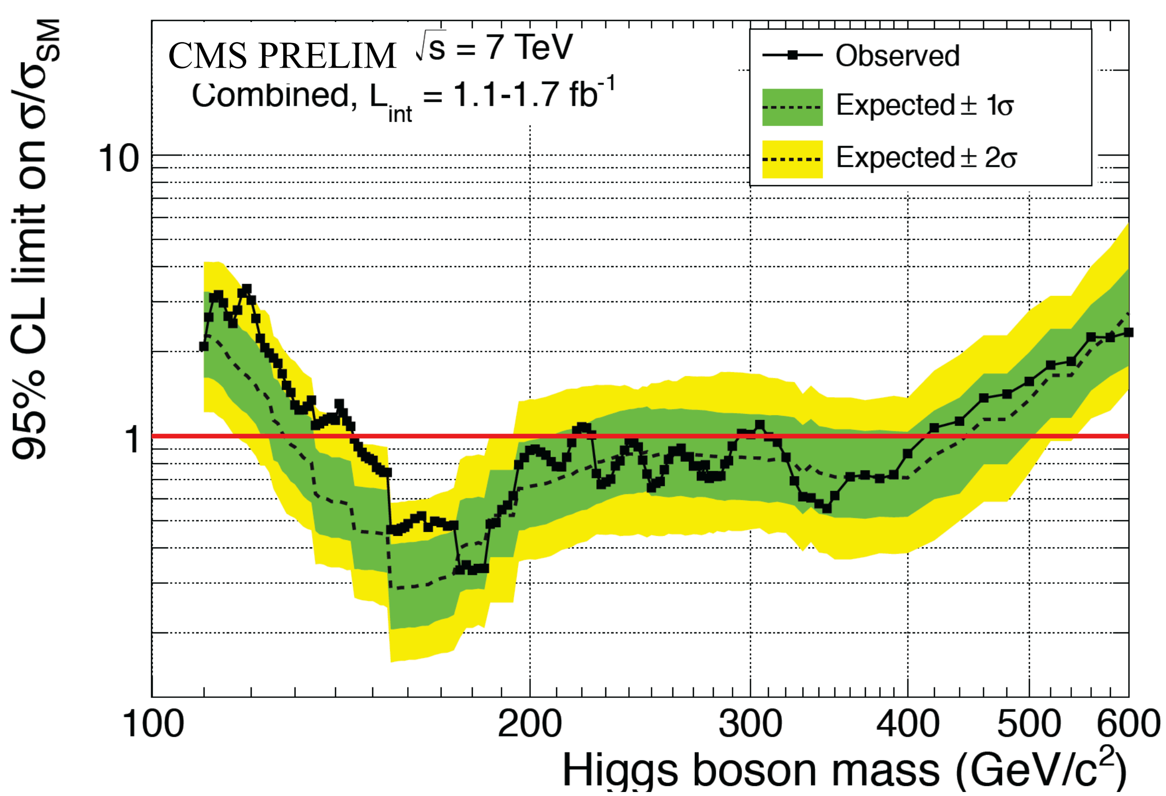
Correlations

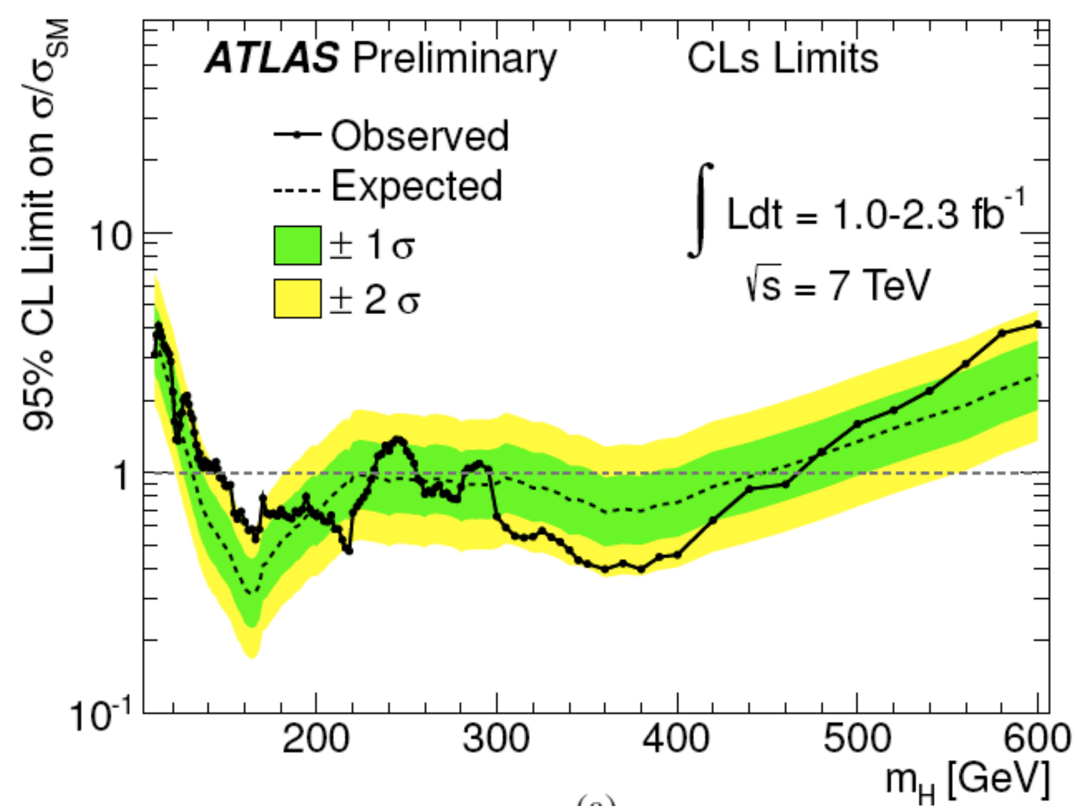


Cohen, AP, Phalen,

Phys.Rev.D81:116001,2010

Higgs from Lepton-Photon?



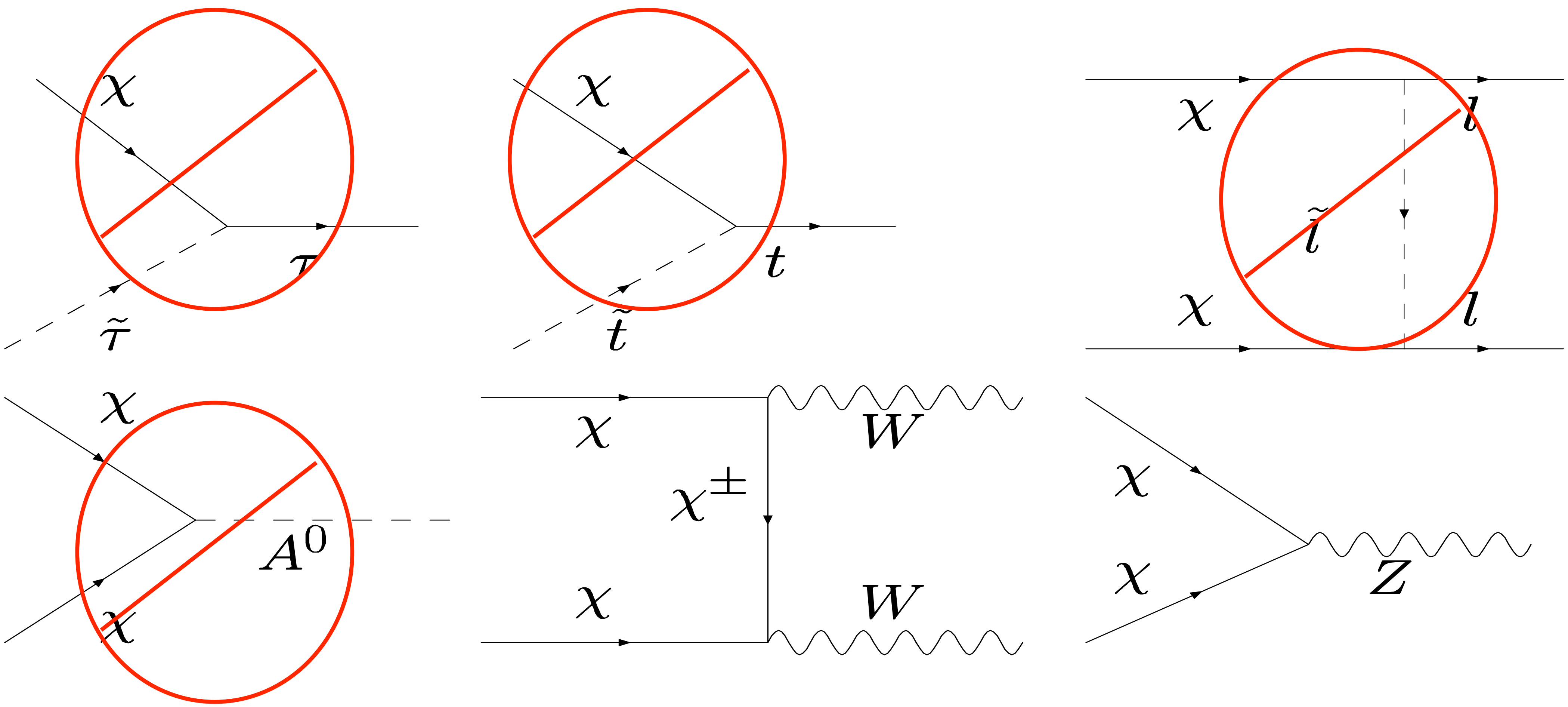


Light Higgs still ok.

115 GeV? 140 GeV?

Split Susy: Dimpoulos, Arkani-Hamed; Giudice, Romanino;

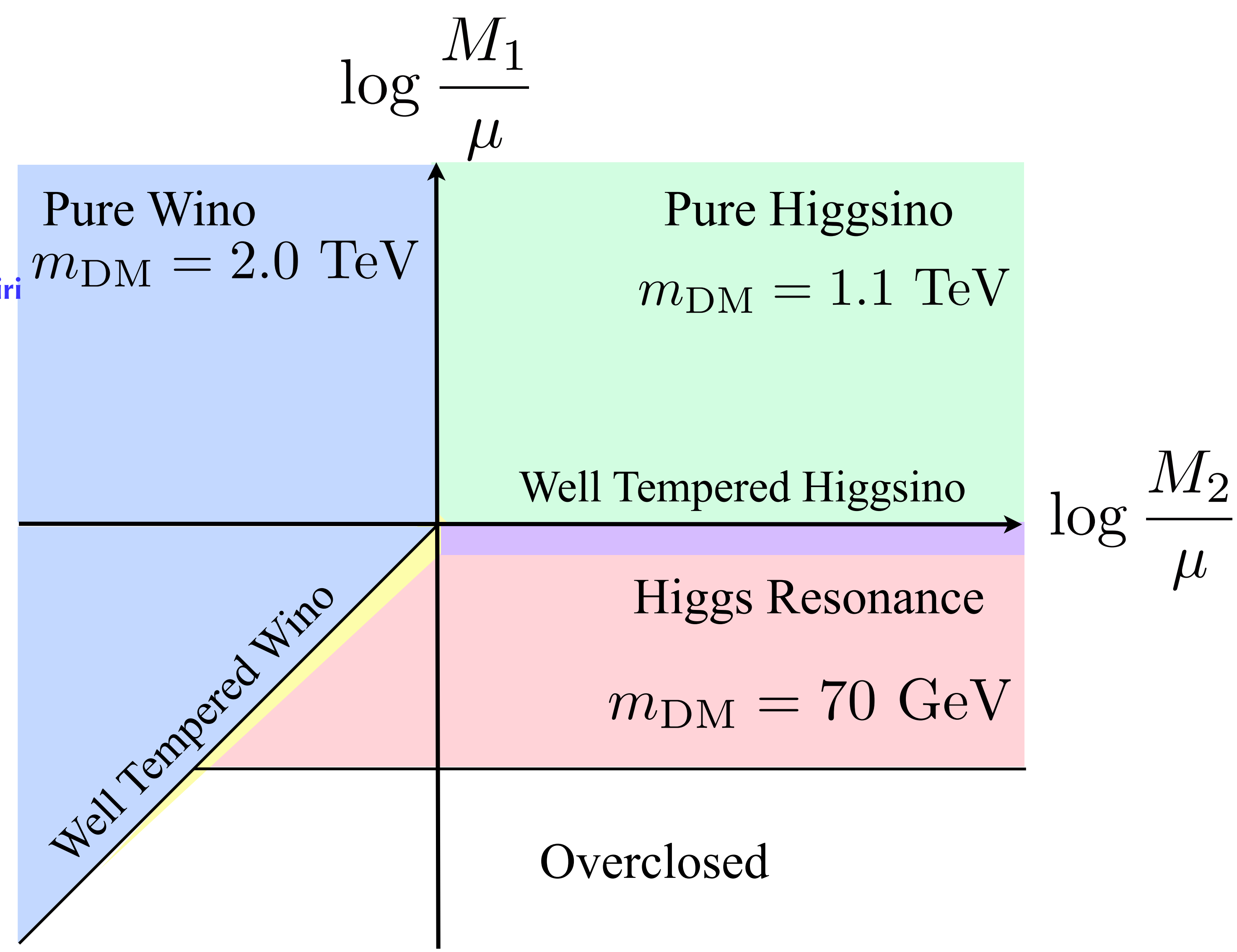
Split SUSY removes exceptions



Split SUSY Dark Matter

2.7 TeV

J. Hisano, S. Matsumoto, M. M. Nojiri

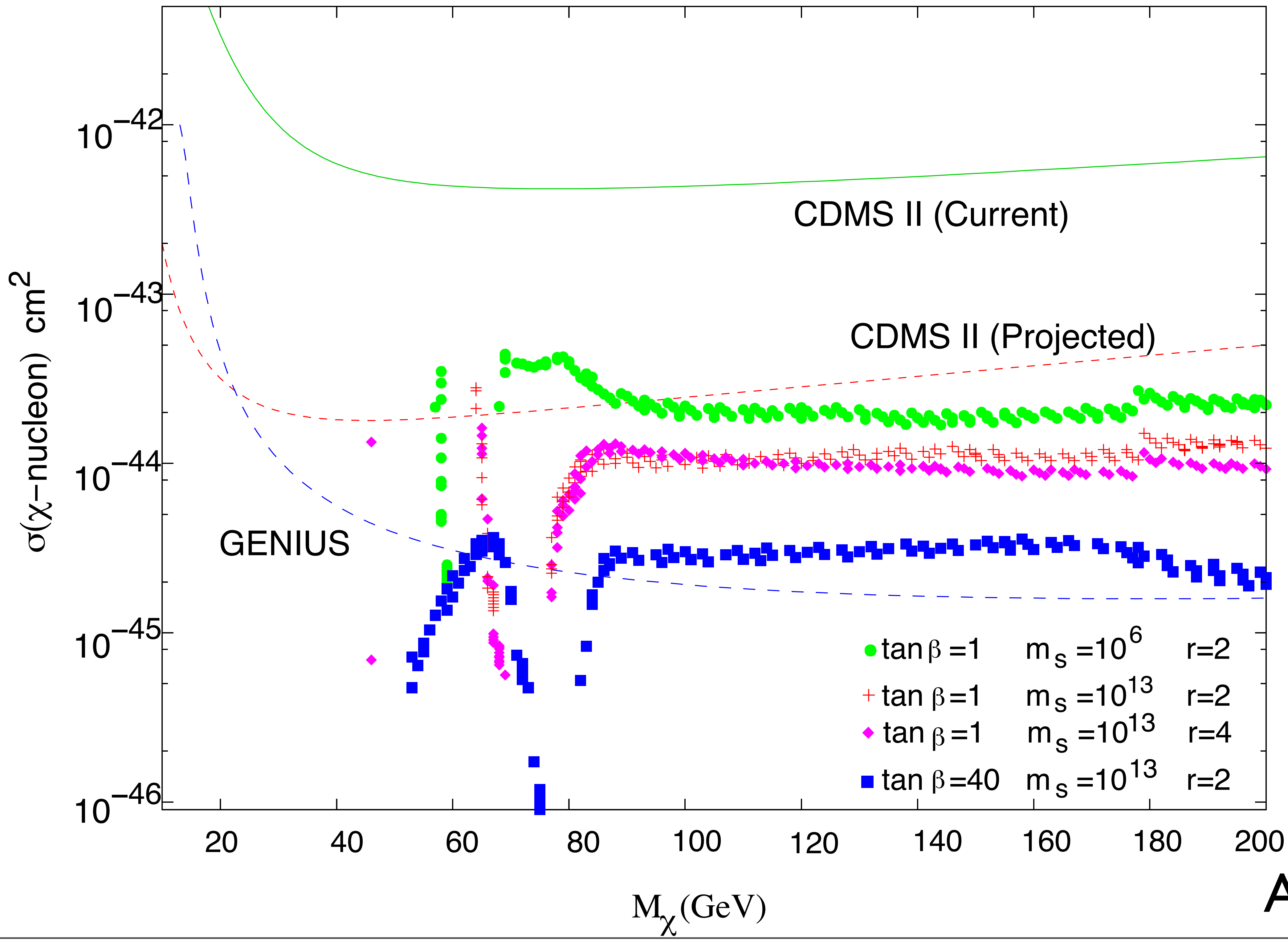


Alves, Izaguirre, Wacker

A. Masiero, S. Profumo and P. Ullio

see also: Guidice, Romanino (2004); AP (2004)

Split Supersymmetry



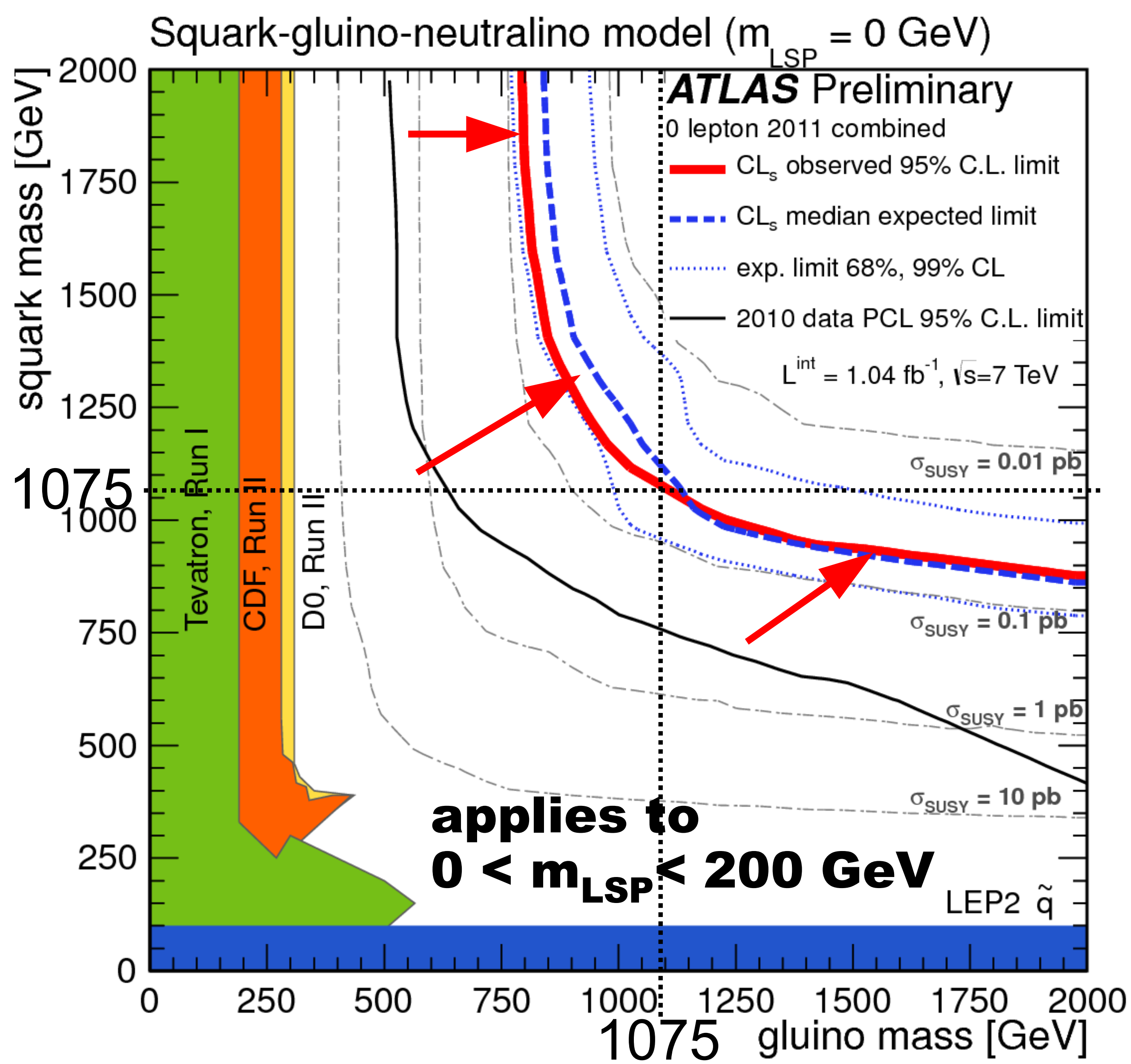
AP, (2004)

What about the LHC?

Executive Summary

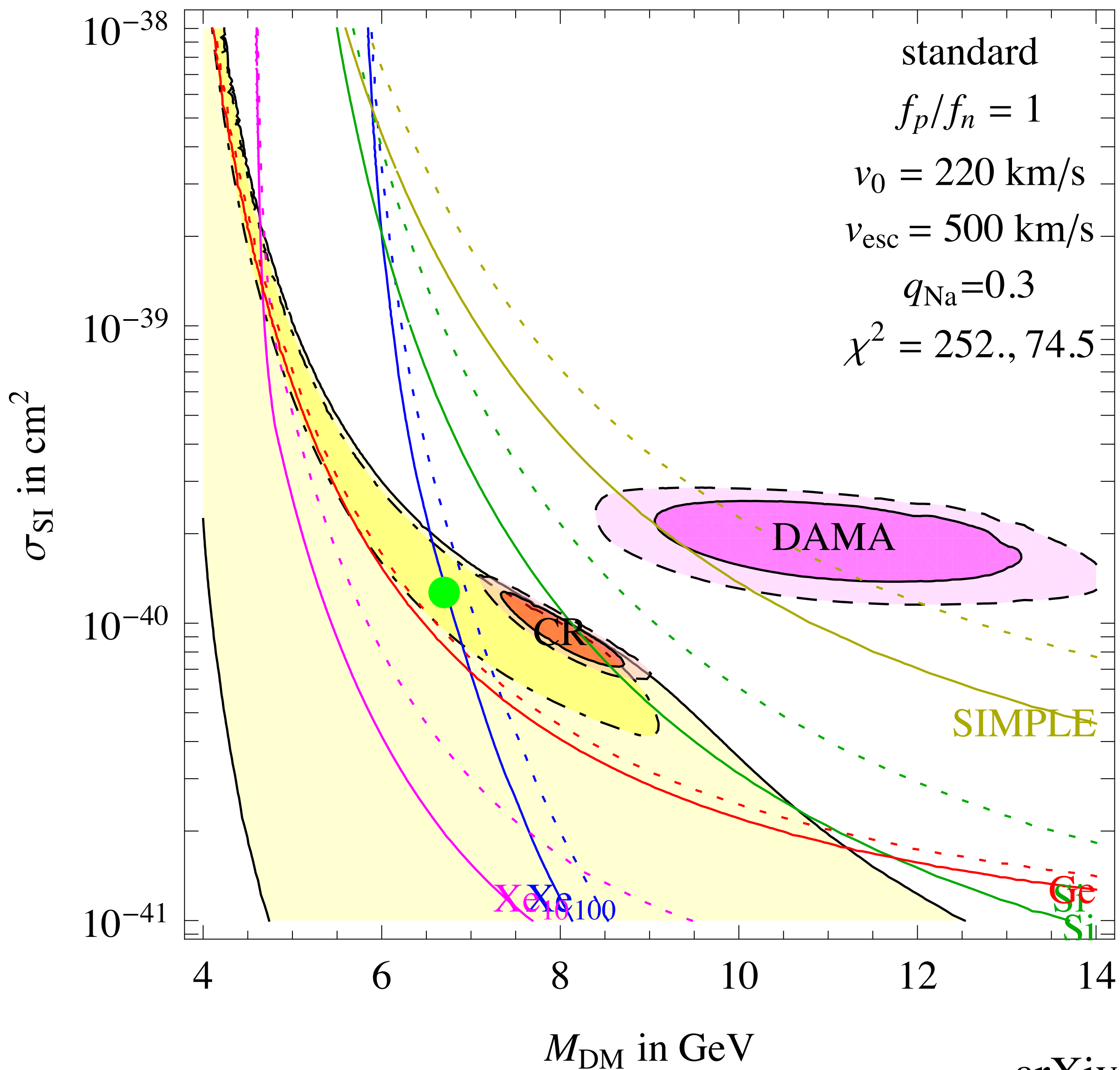
- We are at the mercy of the spectrum of the colored objects.
- Dark Matter tied to TeV scale, but
  - even in “SUSY” could be heavy, e.g. ~2.5 TeV wino
  - even if light, how to see?

No sign of colored beasts+ MET



Light Dark Matter?

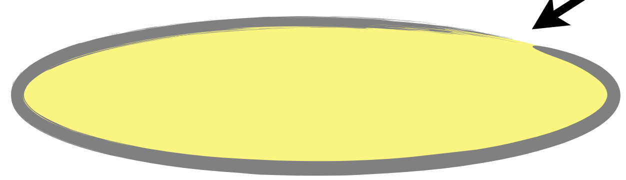
See Hooper;
Kelso, Parallel
Session 7:A



Farina, et al.
arXiv:1107.0715v1 [hep-ph]

Overlap?

Increased
Quenching factor.



Isospin violation
(Cheng, Li, AP,
Weiner, Yavin,
JCAP (2010); Feng
et al, PLB (2011))
can improve the
situation further.

Light Dark Matter (next week)

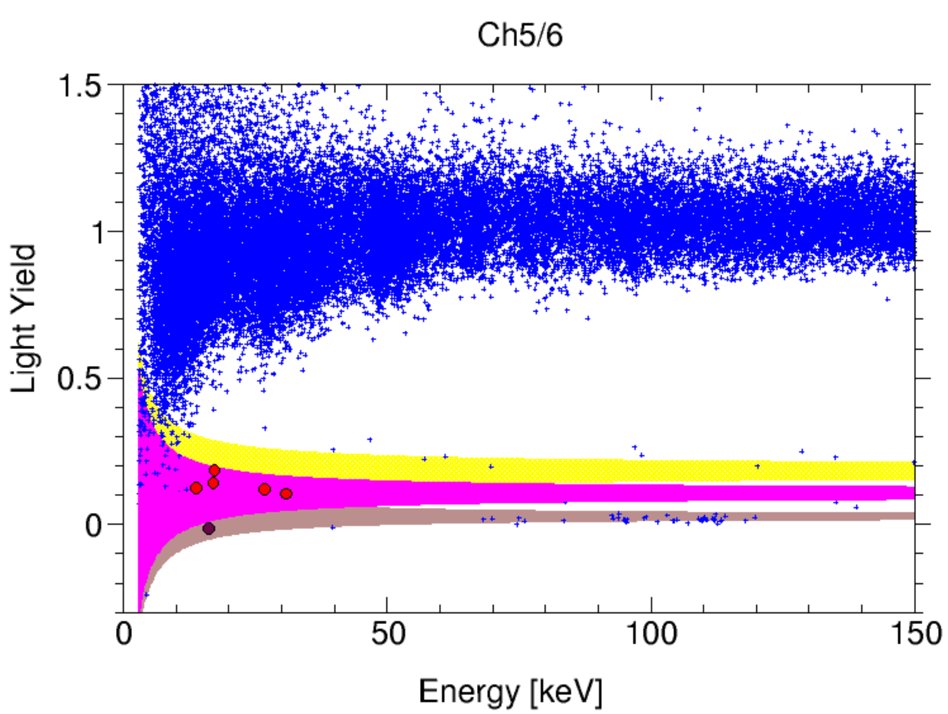
2011 MUNICH TAUP

12th International Conference on **Topics in Astroparticle and Underground Physics**

Press conference
During the TAUP2011 Conference in Munich there will be a press conference to brief journalists about the latest results concerning the TAUP2011 research topics. We would like to invite journalists in particular to the following event

TAUP2011 in Munich - Press conference
Latest results from the CRESST Experiment provide an indication of dark matter

The press conference will be held on 6. September 2011 starting at 2:00 pm.

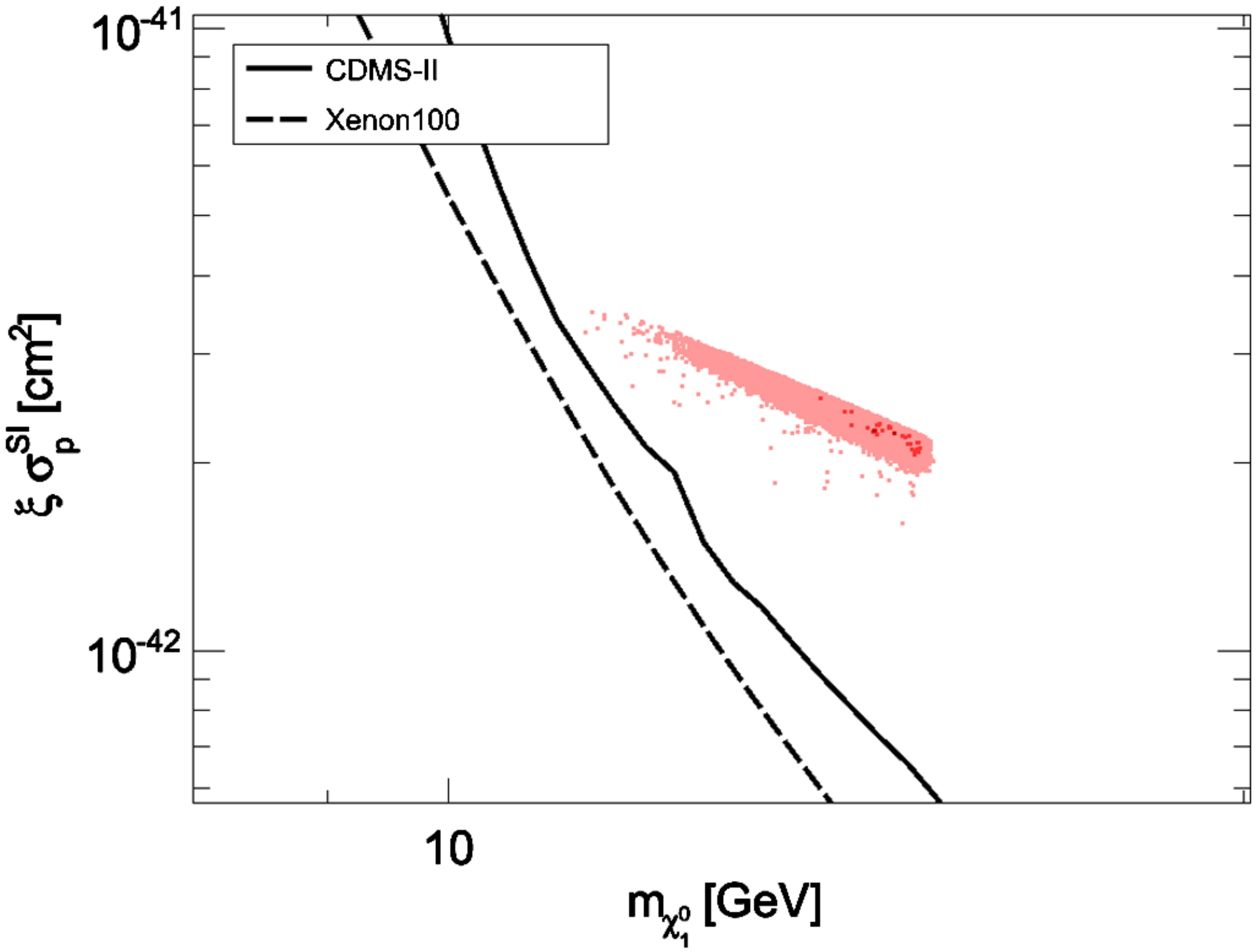


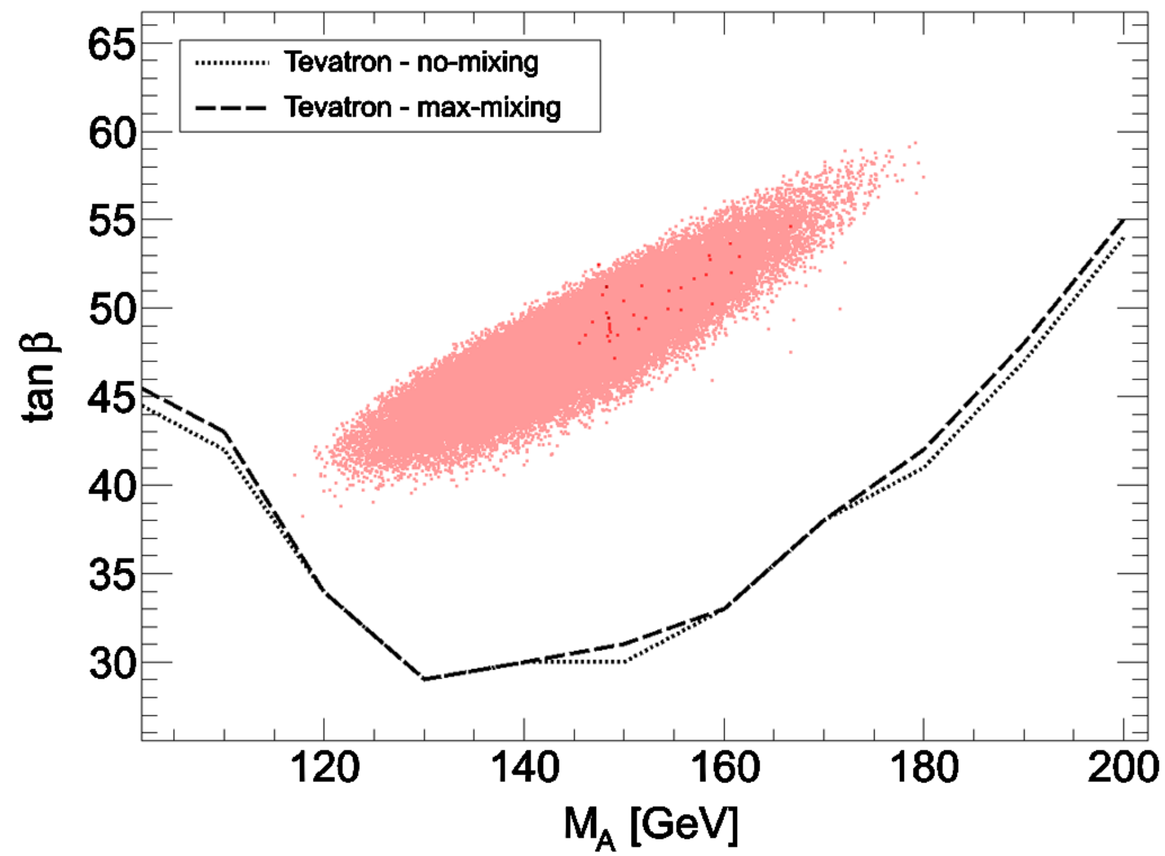
CRESST at iDM July 2010

Also, stay tuned for COUPP

MSSM?

D.Albornoz Vasquez,G. Belanger, C. Bœhm, A. Pukhov, and J. Silk
PHYSICAL REVIEW D **82,** 115027 (2010)

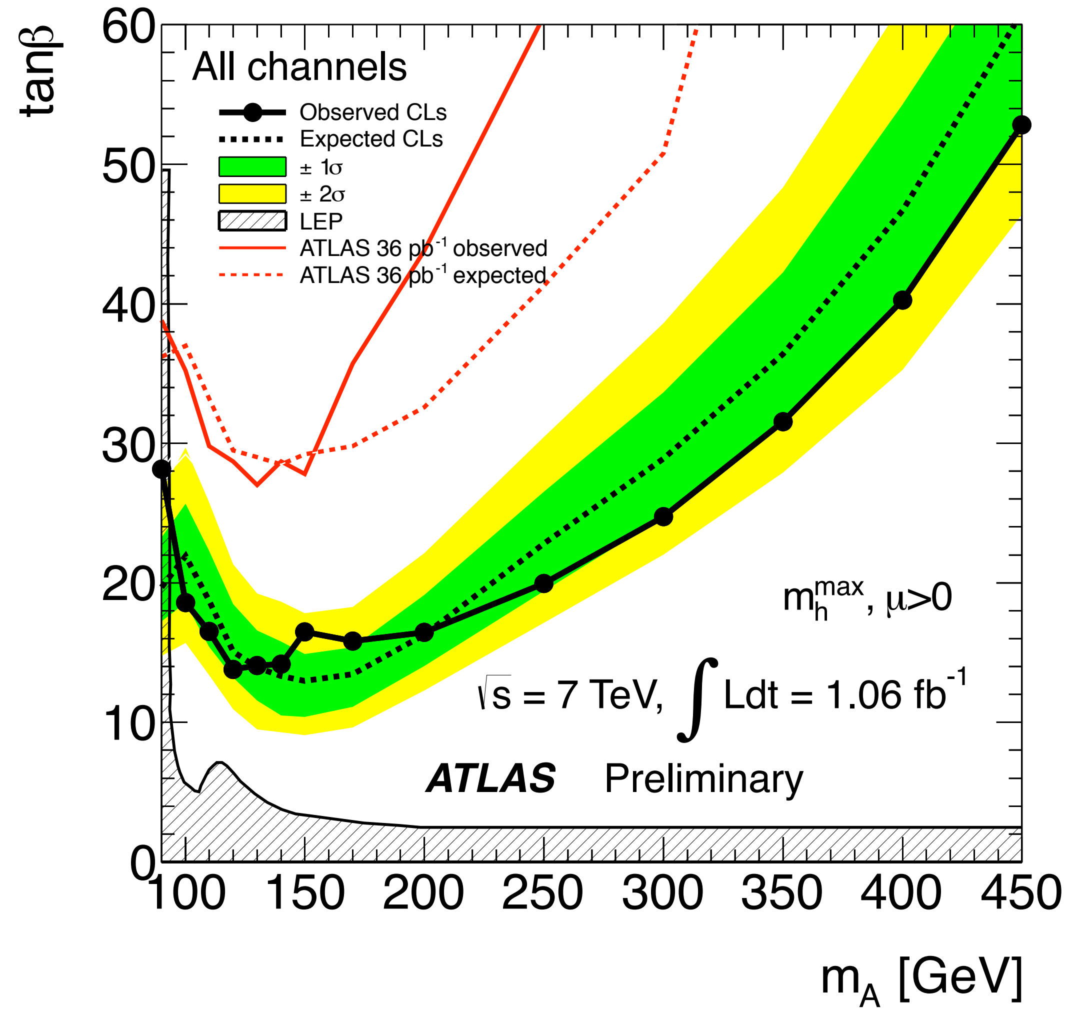




$M_1 \in [1, 100]$ GeV, $M_2 \in [100, 2000]$ GeV,
$\mu \in [0.5, 1000]$ GeV, $\tan\beta \in [1, 75]$,
$m_{\tilde{l}} \in [100, 2000]$ GeV, $m_{\tilde{q}} \in [300, 2000]$ GeV,
$A_t \in [-3000, 3000]$ GeV, $m_A \in [100, 1000]$ GeV.

Also (e.g.):
Feldman, Liu, Nath, Piem (2010)
Kuflik, AP, Zurek (2010);

MSSM Pseudoscalar Higgs Update

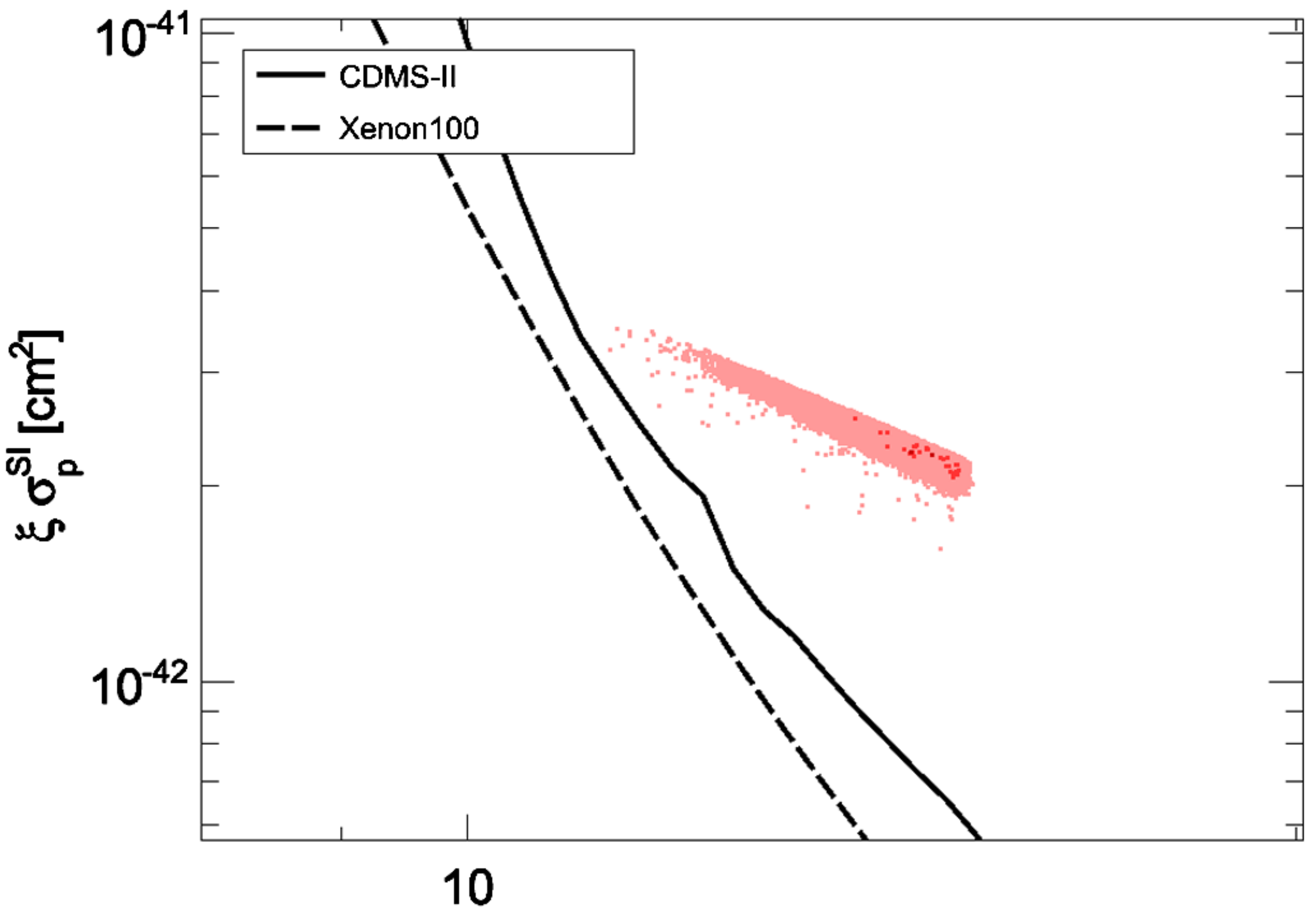


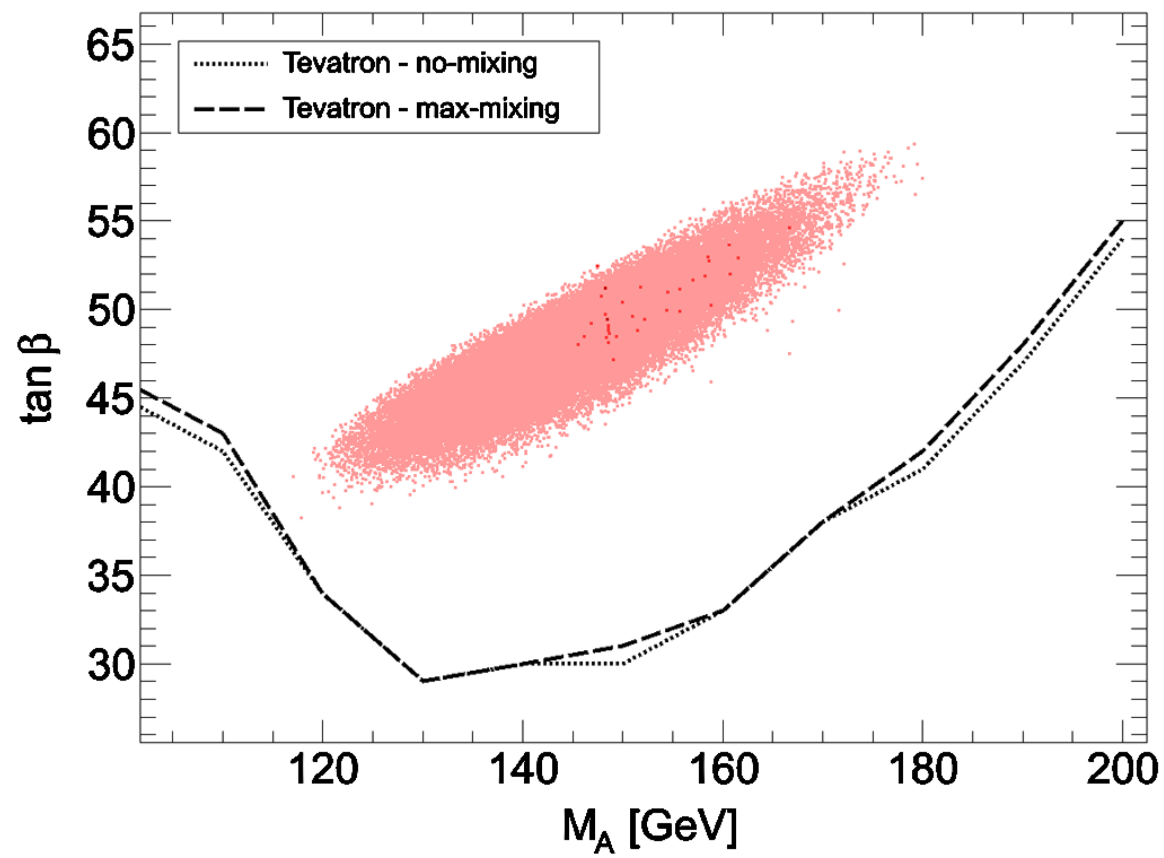
(Lepton-Photon)

Expected and observed exclusion limits based on CLs in the $m_A - \tan\beta$ plane of the MSSM derived from the combination of the analyses for the eμ, $l\tau_{had}$ and $\tau_{had}\tau_{had}$ final states. The dark green and yellow) bands correspond to the ±1σ and ±2σ error bands, respectively.

MSSM?

PHYSICAL REVIEW D **82,** 115027 (2010)





NMSSM has trouble too, e.g. Cumberbatch, et al., arXiv: 1107.1604v1

ATLAS (LP 2011)

Why would Dark Matter be light?

- Asymmetric Dark Matter
  D. B. Kaplan; Nussinov; Chivukula; D. E. Kaplan, Luty, Zurek; Kitano&Low

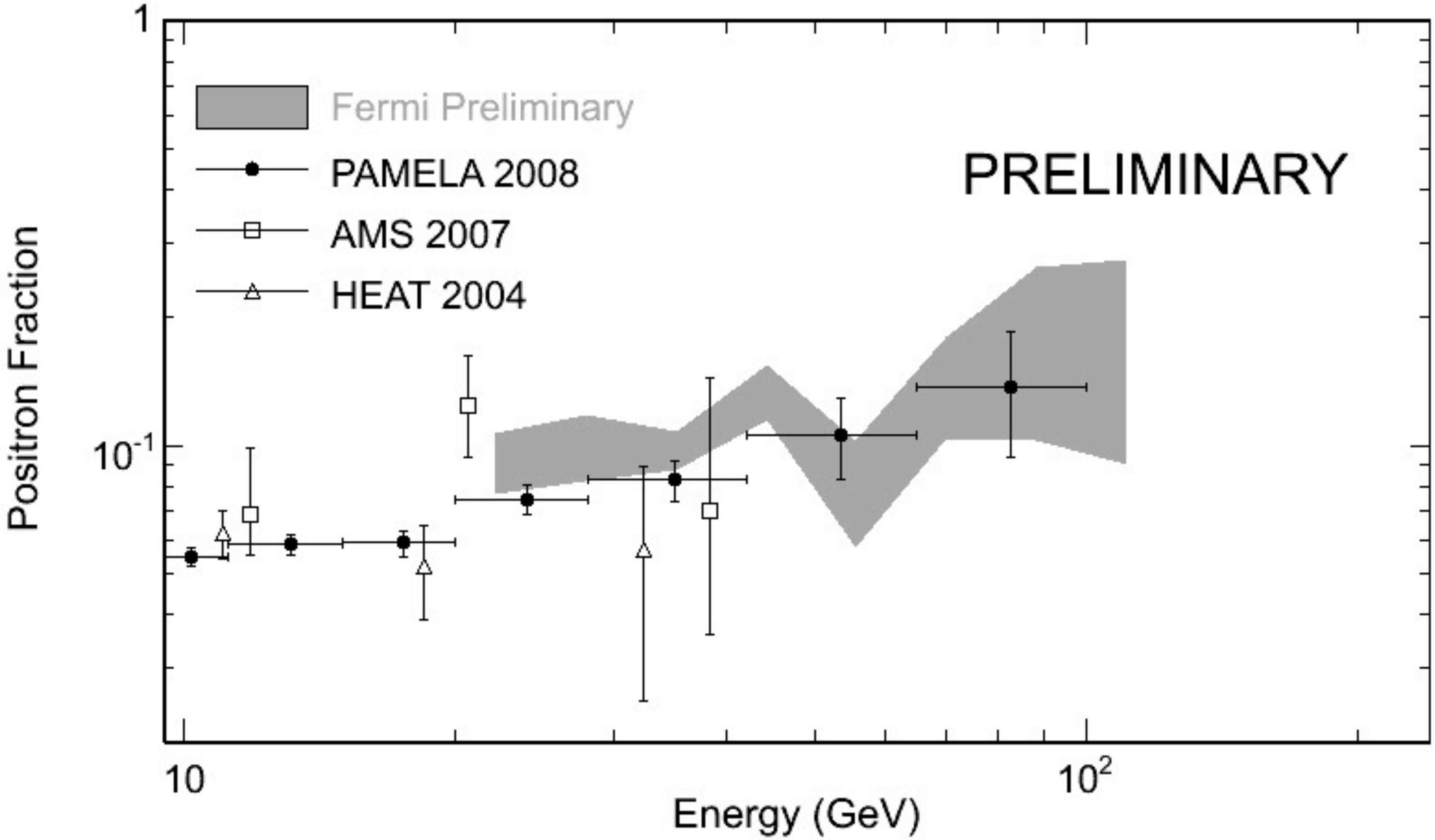
$$\Omega_{\rm DM} \sim 5\,\Omega_{\rm baryon}$$

- Scale "derived" from the Weak scale, and is morally a loop factor smaller.

Indirect Detection

- Look for (anti-matter) products of residual WIMP annihilations.

Using the Earth as a Magnet

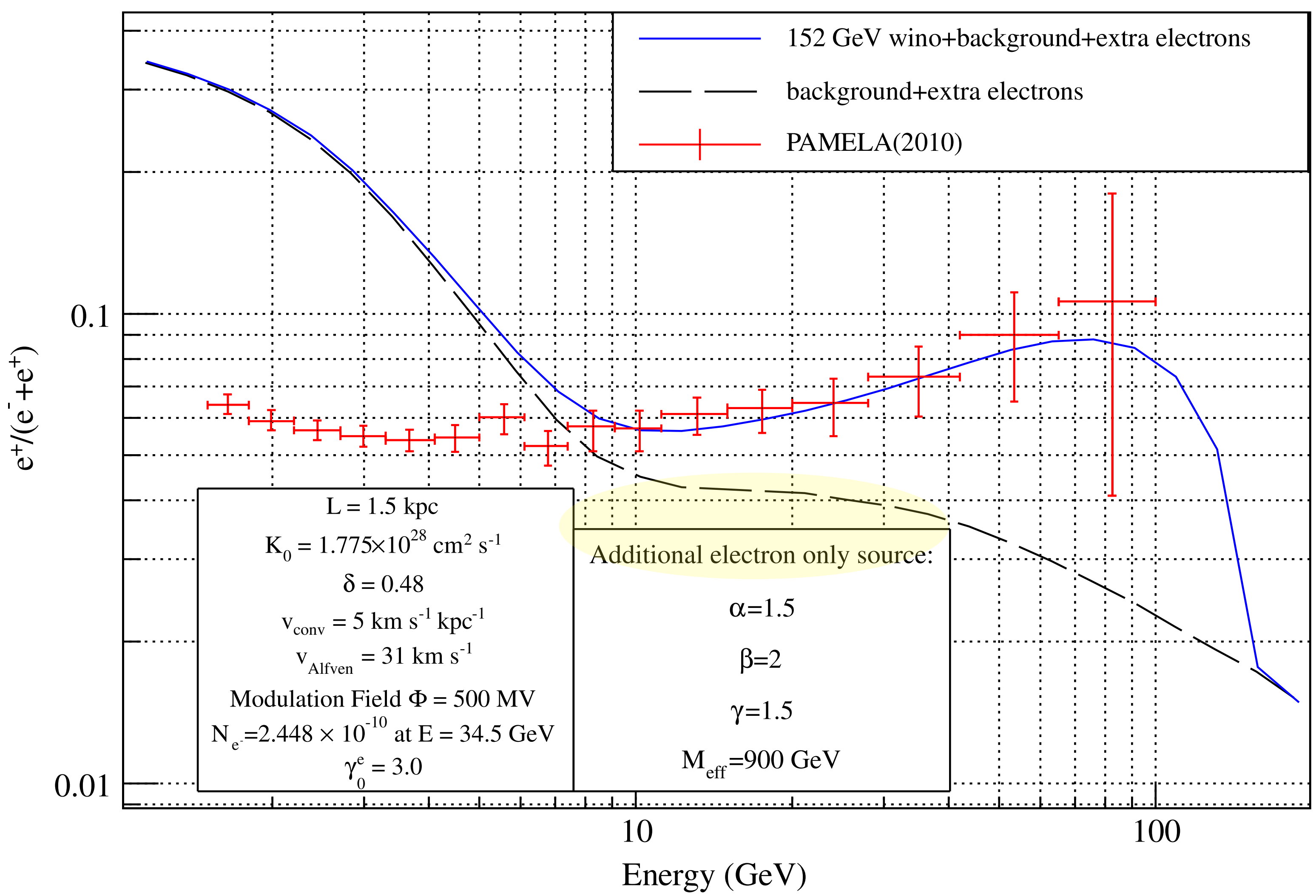


Could be, e.g., pulsars

Large cross section!

Non-thermal Wino

Randall and Moroi



Kane, Lu, Watson

PAMELA + DAMA?

Generate GeV scale: no protons

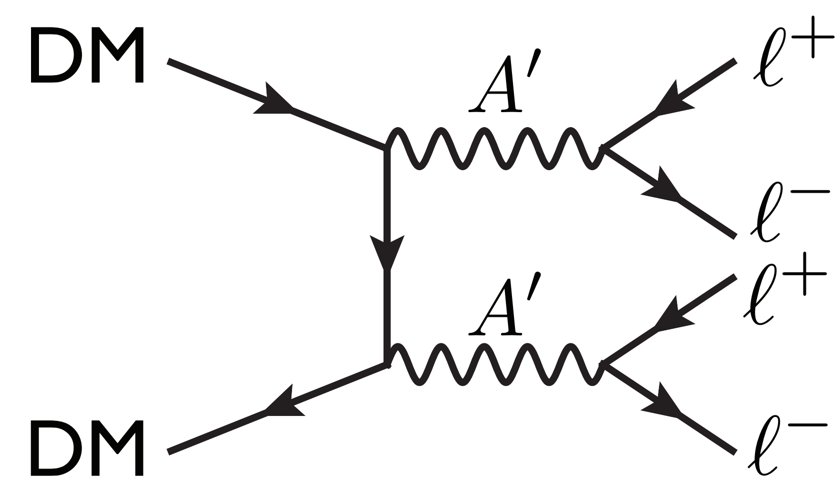
Generate 100 keV scale: inelastic

(Weiner, D.Tucker-Smith)

$$\mathcal{L} \supset -\frac{\epsilon}{2}\int d^2\theta W_Y W_d$$

$$\epsilon \;=\; -\frac{g_Y g_y}{16\pi^2}\sum_i Q_i q_i \log\left(\frac{M_i^2}{\mu^2}\right)$$

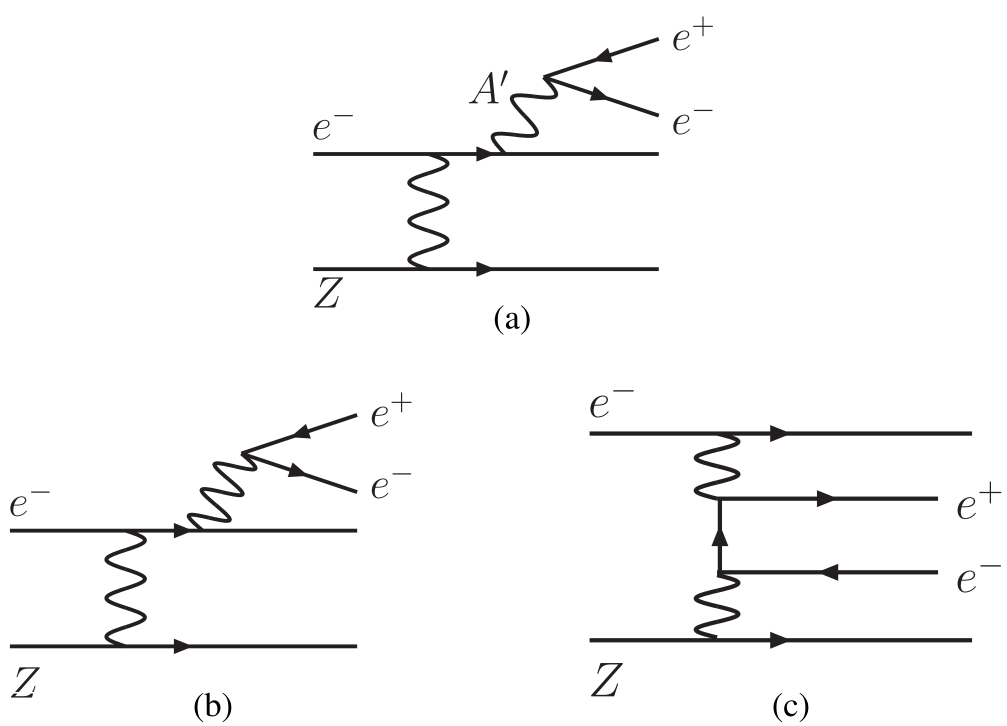
$$\xi \;=\; \epsilon\langle D_Y\rangle = \epsilon\left(-\frac{g' v^2\cos 2\beta}{4} + \xi_Y\right)$$

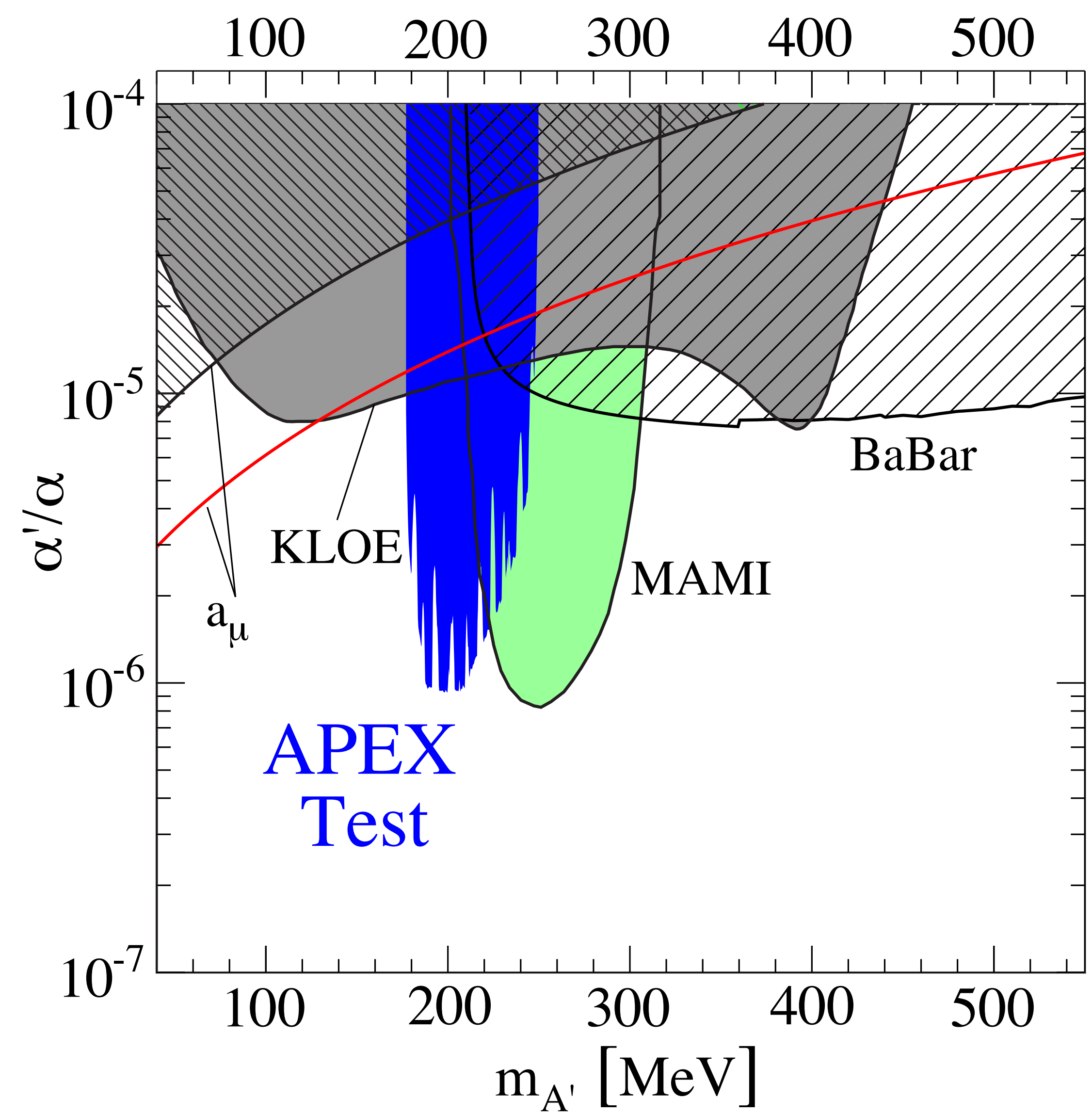


N. Arkani-Hamed, *et al.*, Phys. Rev. D 79 (2009) 015014

Cheung, Ruderman, L-T. Wang, Yavin

APEX&MAINZ



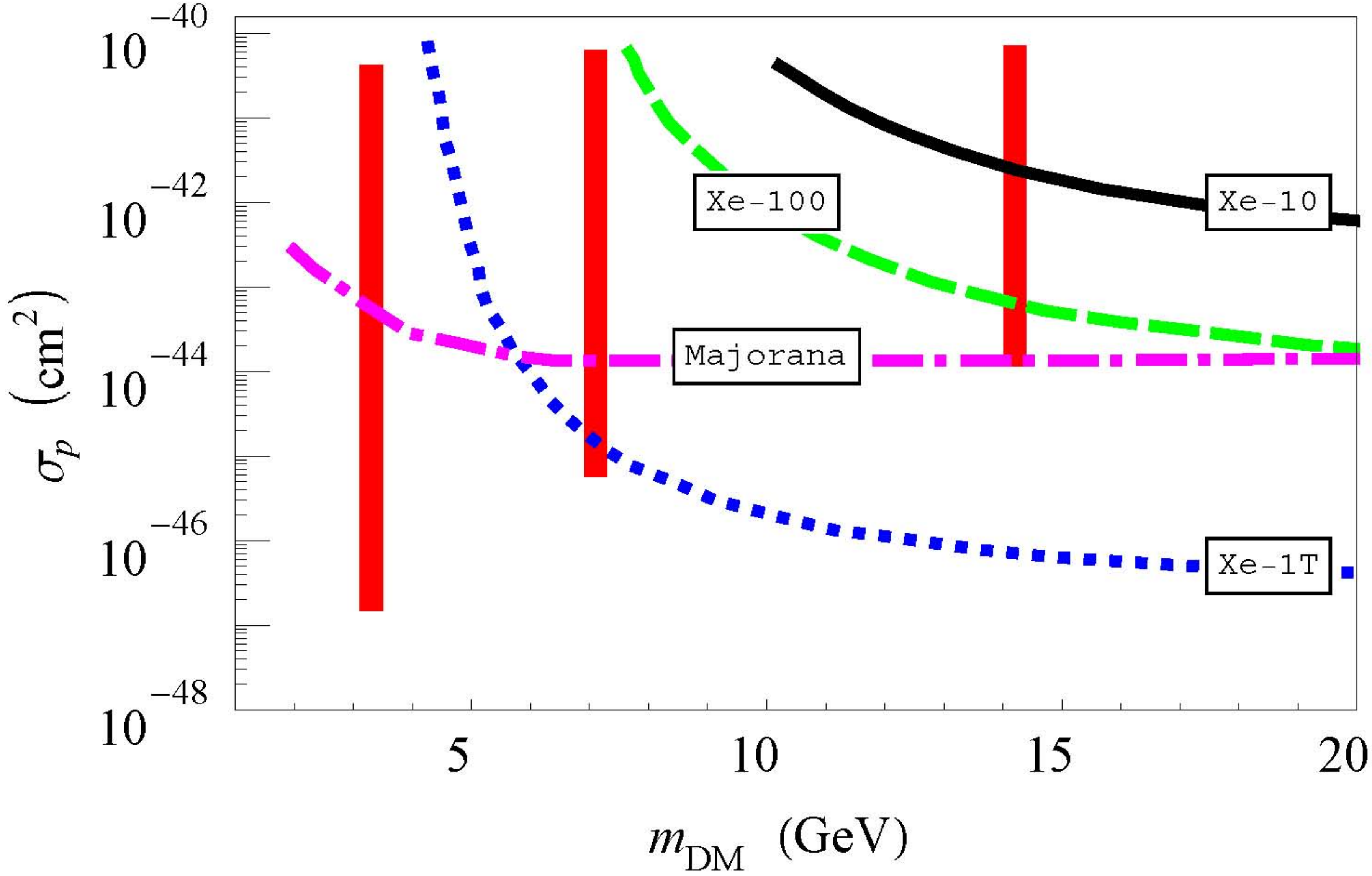


Also: HPS, DarkLight, HIPS

Bjorken, Essig, Schuster, Toro '09

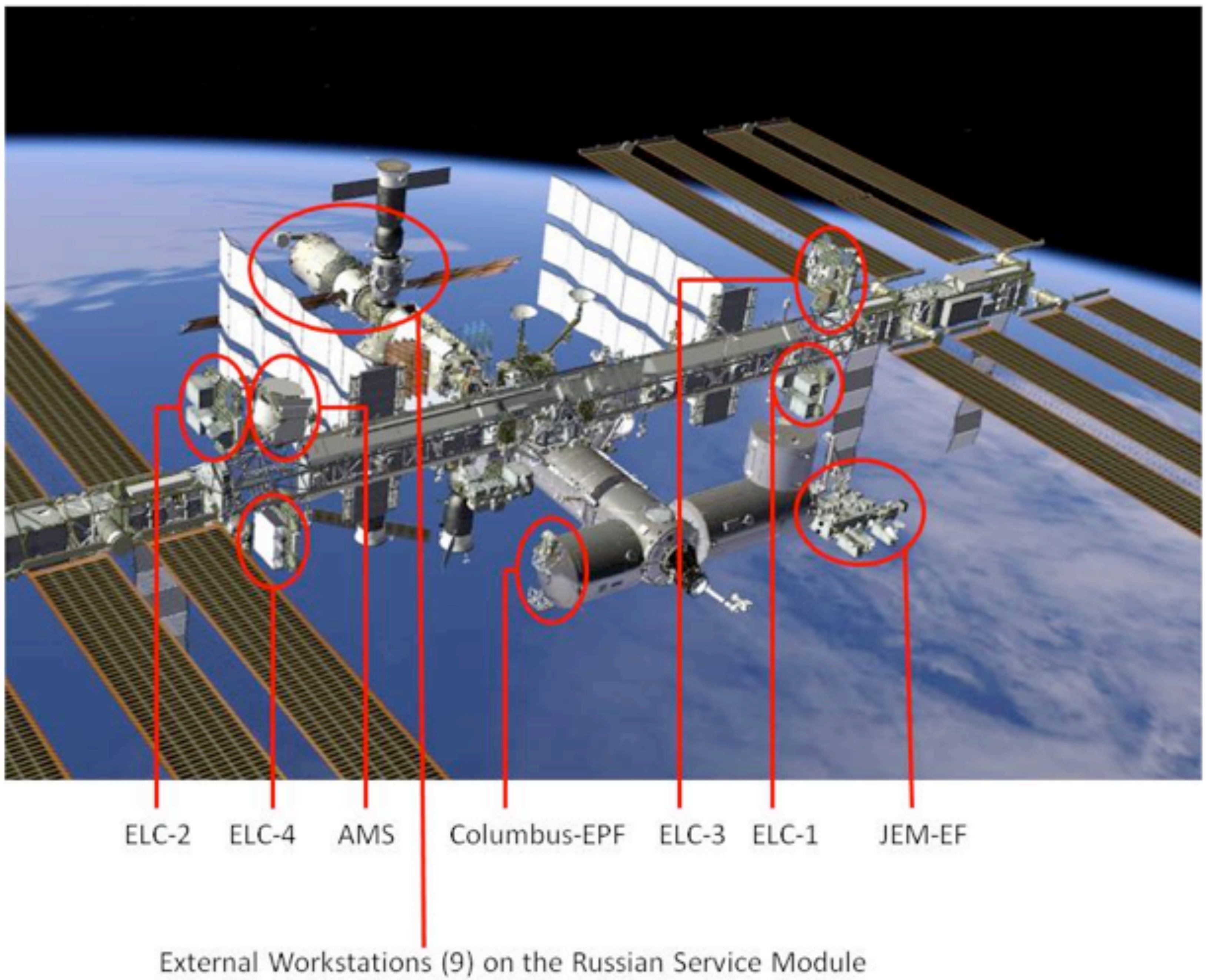
1108.2750 (apex)

Asymmetric Dark Matter with a hidden photon



Cohen, Phalen, AP, Zurek,
Phys.Rev.D82:056001,2010.

Additional Data.



Also, anti-deuterons?

Recent analyses by Cui, Mason, Randall; M. Kadastik, M. Raidal, A. Strumia

FERMI

- Zeroth order statement: center of galaxy good for limits.
- Dwarf galaxies and line signal best discovery channels.

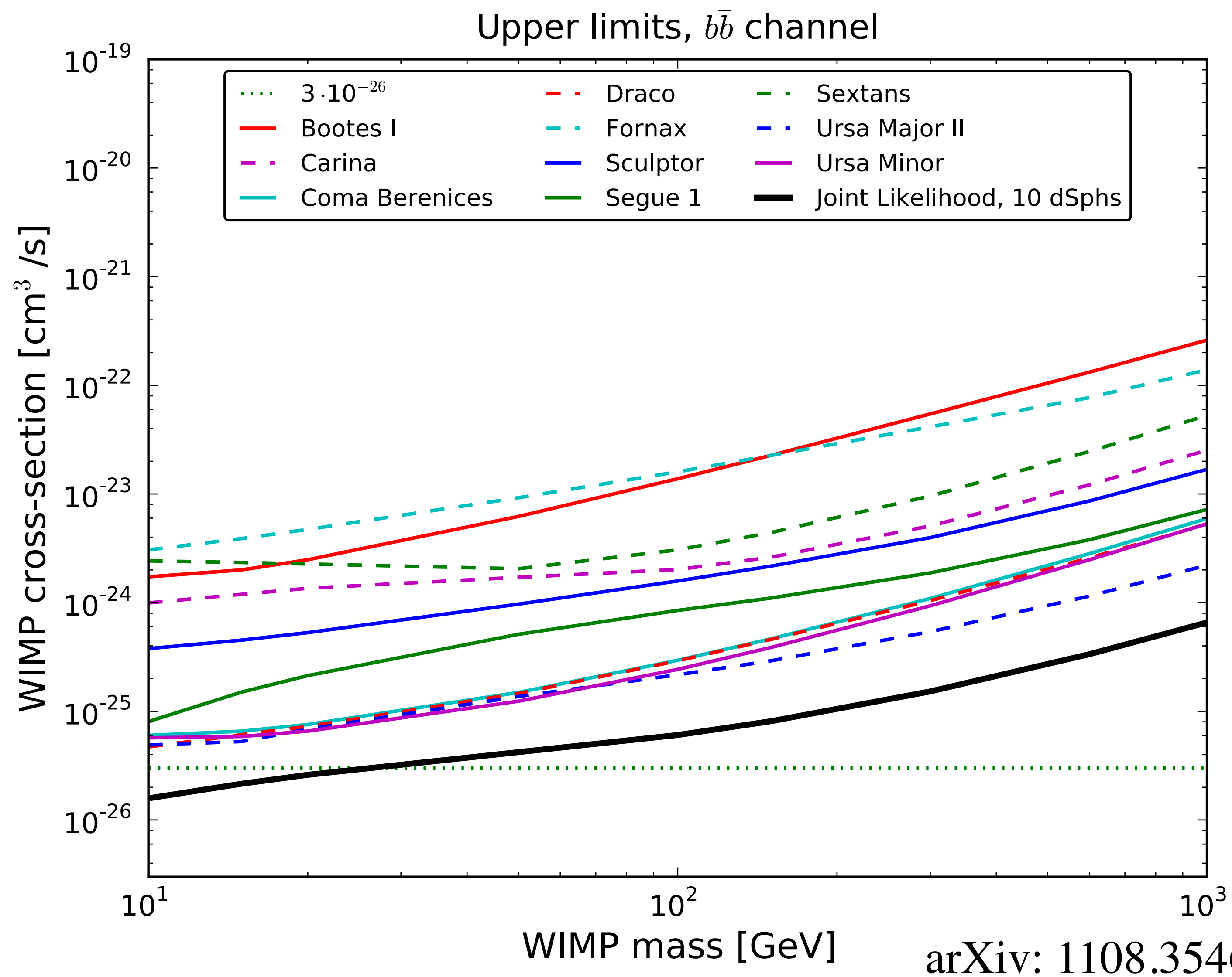
$$\phi_{WIMP}(E,\psi) = J(\psi) \times \Phi^{PP}(E)\ ,$$

$$\Phi^{PP}(E) = \frac{1}{2}\frac{<\sigma v>}{4\pi\, m_{WIMP}^2}\sum_f \frac{dN_f}{dE}B_f,$$

$$J(\psi) = \int_{\mathrm{l.o.s}} dl(\psi)\rho^2(l(\psi)),$$

FERMI

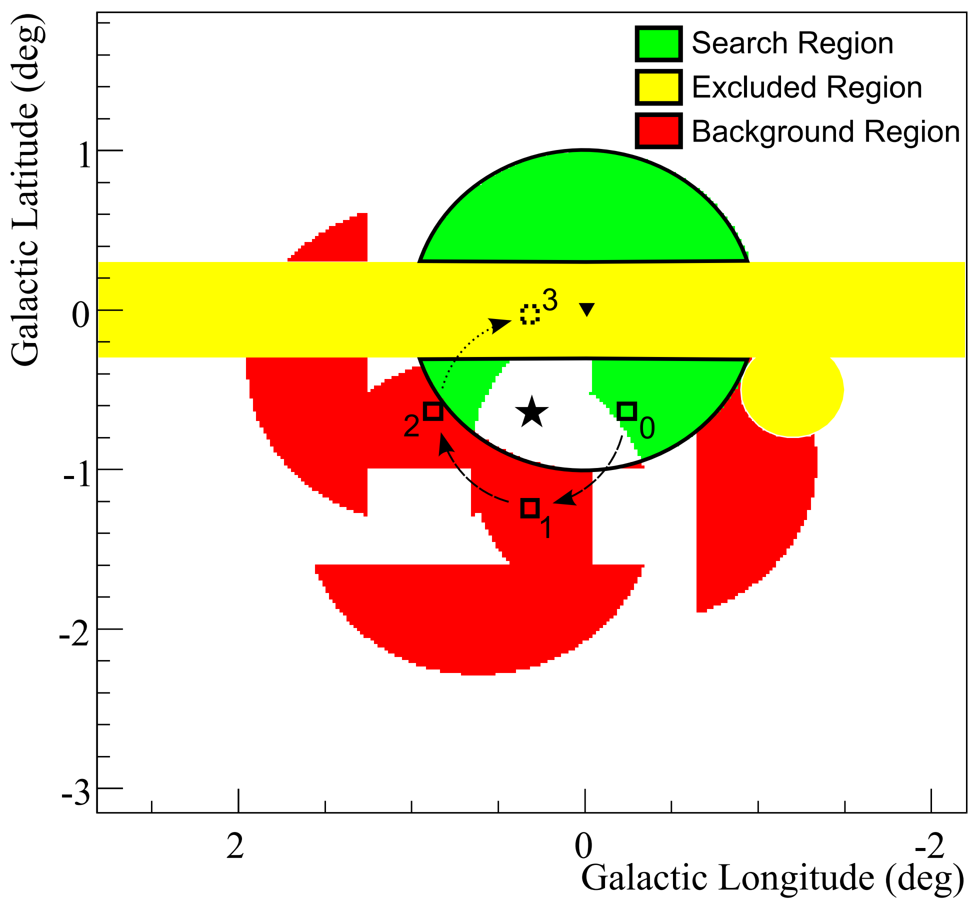
- Dwarf Galaxies:
  - pros:
    - Dark Matter dominated.
    - low backgrounds.
  - cons: low signal rate.



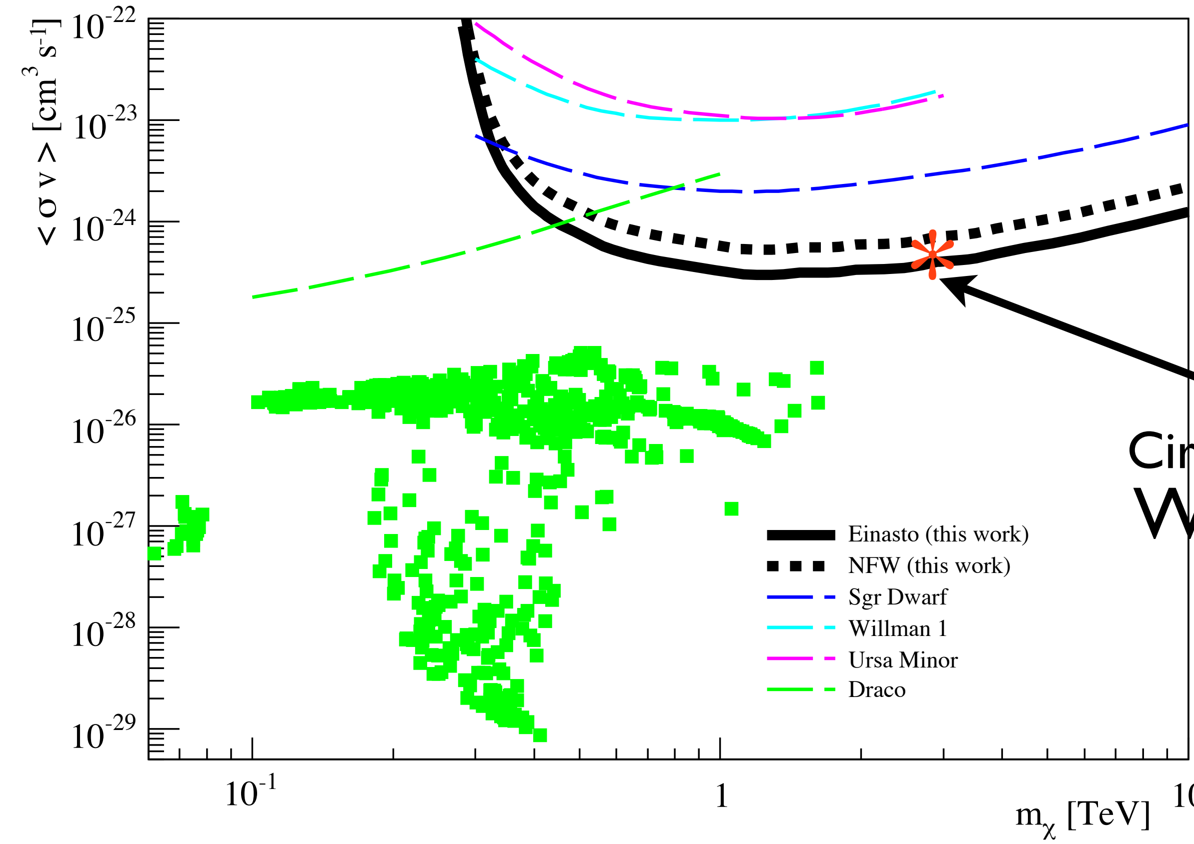
arXiv: 1108.3546

“For the first time, using gamma rays, we are able to rule out models with the most generic cross section (~ $3 \cdot 10^{-26}$ cm^3 s^{-1} for a purely s-wave cross section), without assuming additional astrophysical or particle physics boost factors.”

Very high energy gammas?



Bergstrom&Ulio: also promising for pure higgsino?



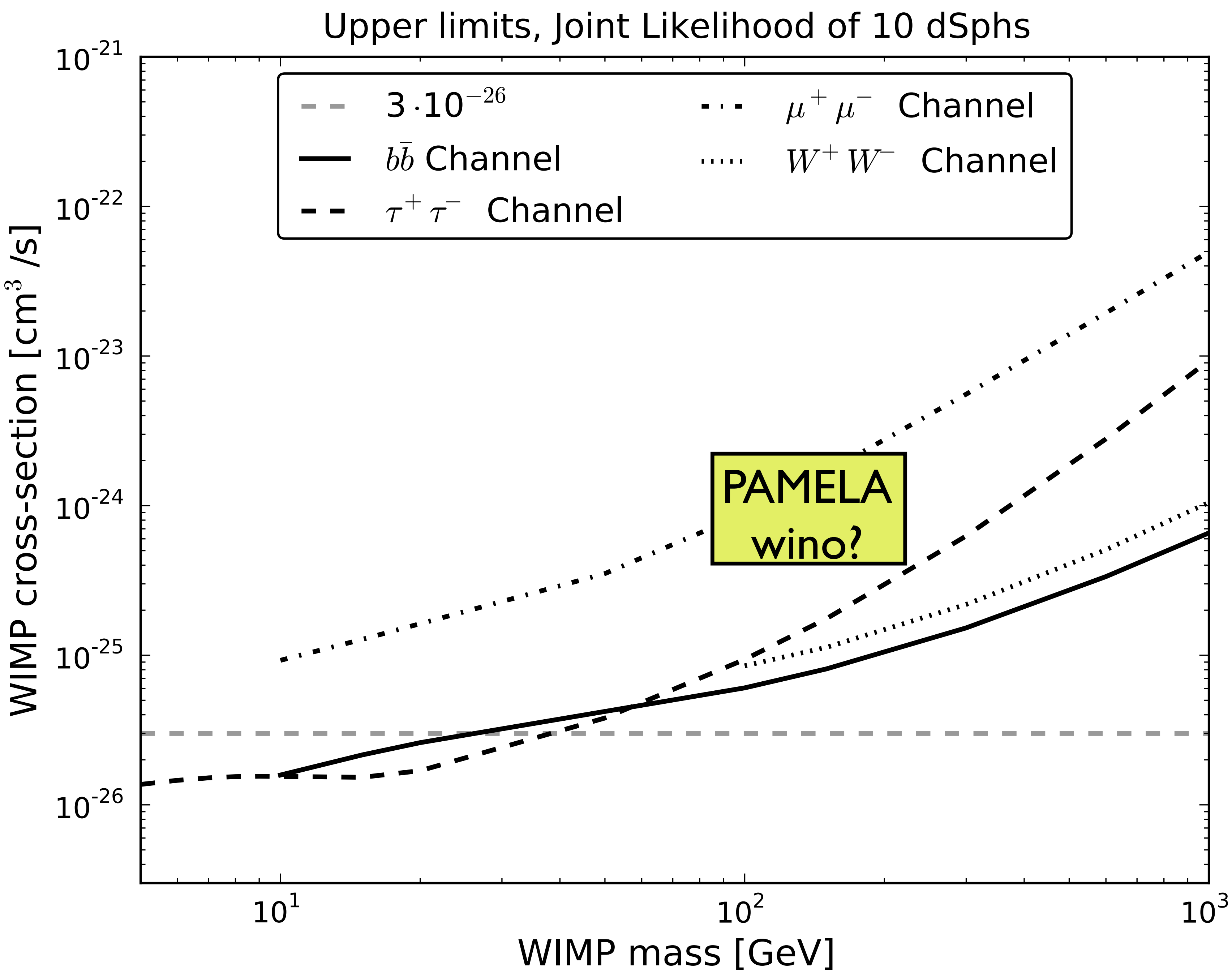
Cirelli, et al. (2007)
Wino->WW

HESS 1103.3266

[Phys. Rev. Lett. 106 (2011) 161301]

N.b. Assumes quark final state, so limits a bit worse on WW. gamma gamma?

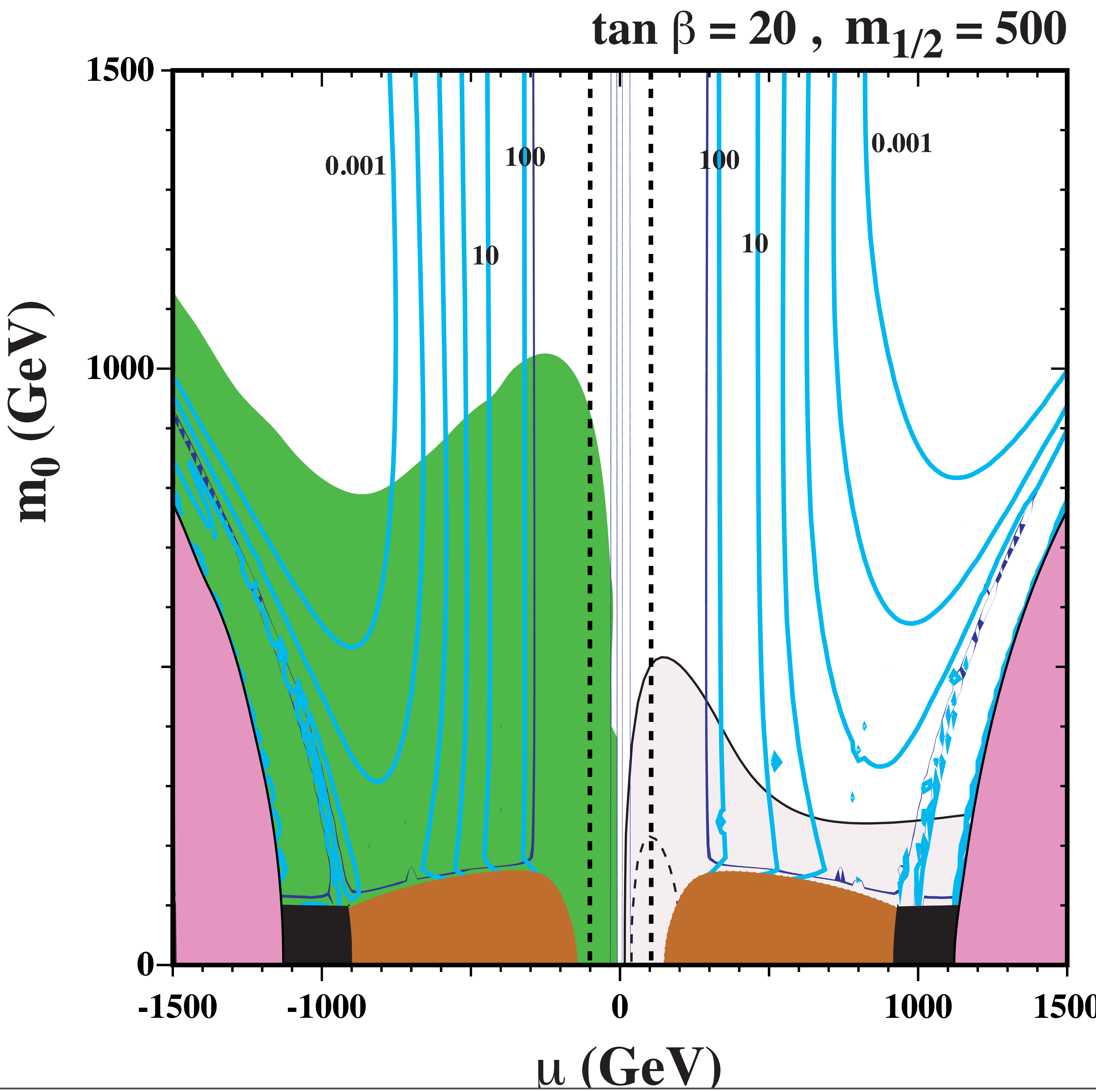
Combined Dwarf Spheroidals



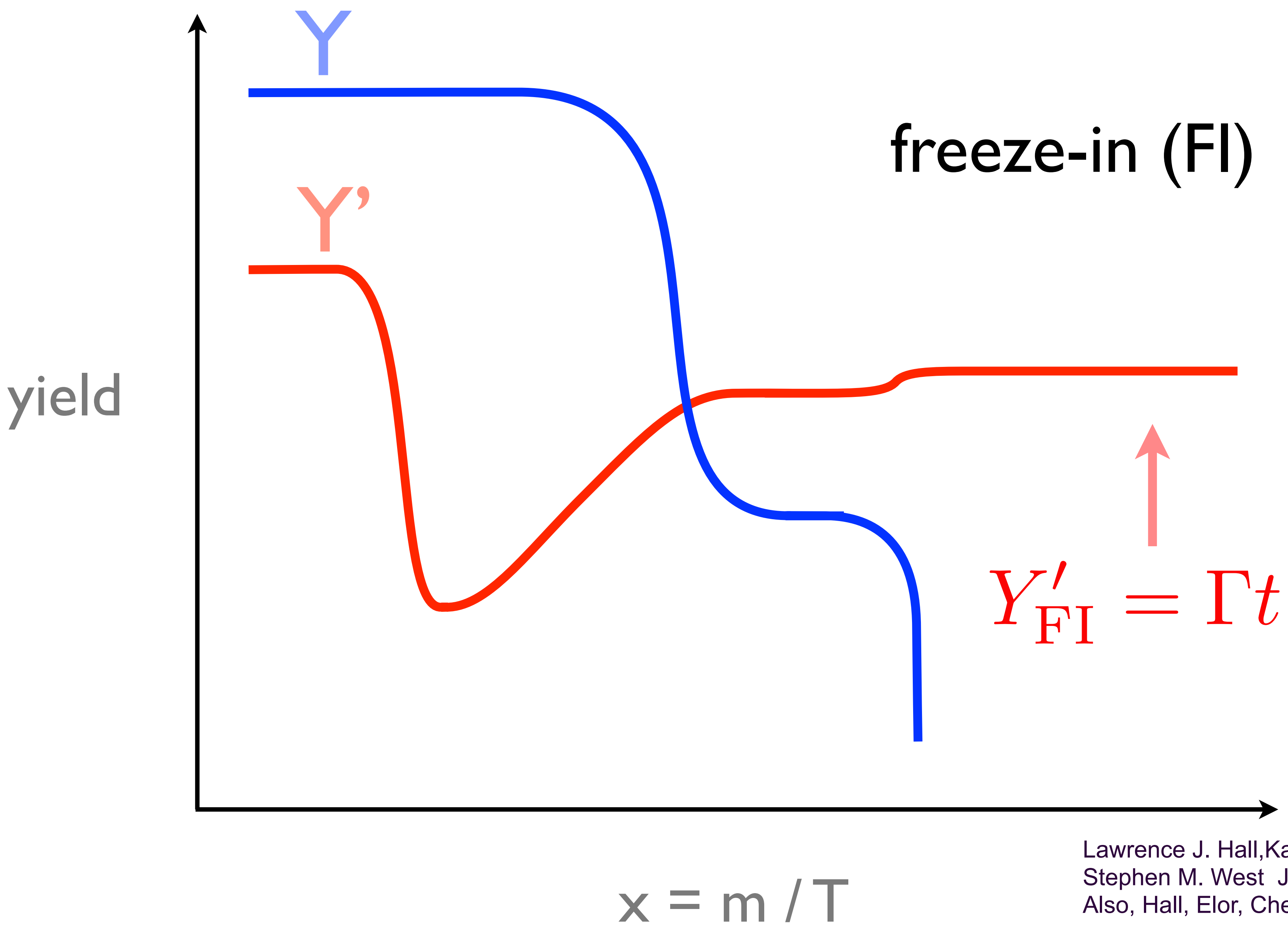
IceCube/DeepCore

- Capture Dark Matter in Sun
- Annihilate to W, top, b, c.... and see subsequent neutrinos.
- Spin-dependent (hydrogen) and Spin-Independent (e.g. oxygen) can be important
  (recently re-emphasized by Ellis, Olive, Savage, Spannos, Phys. Rev. D 81, 085004 (2010))
- Mixed neutralino = good; co-annihilation, pole regions hard.
- Should have a few months of data by now.

MIXED DARK MATTER Good!



Ellis, Olive, Savage, Spanos, 1102.1988

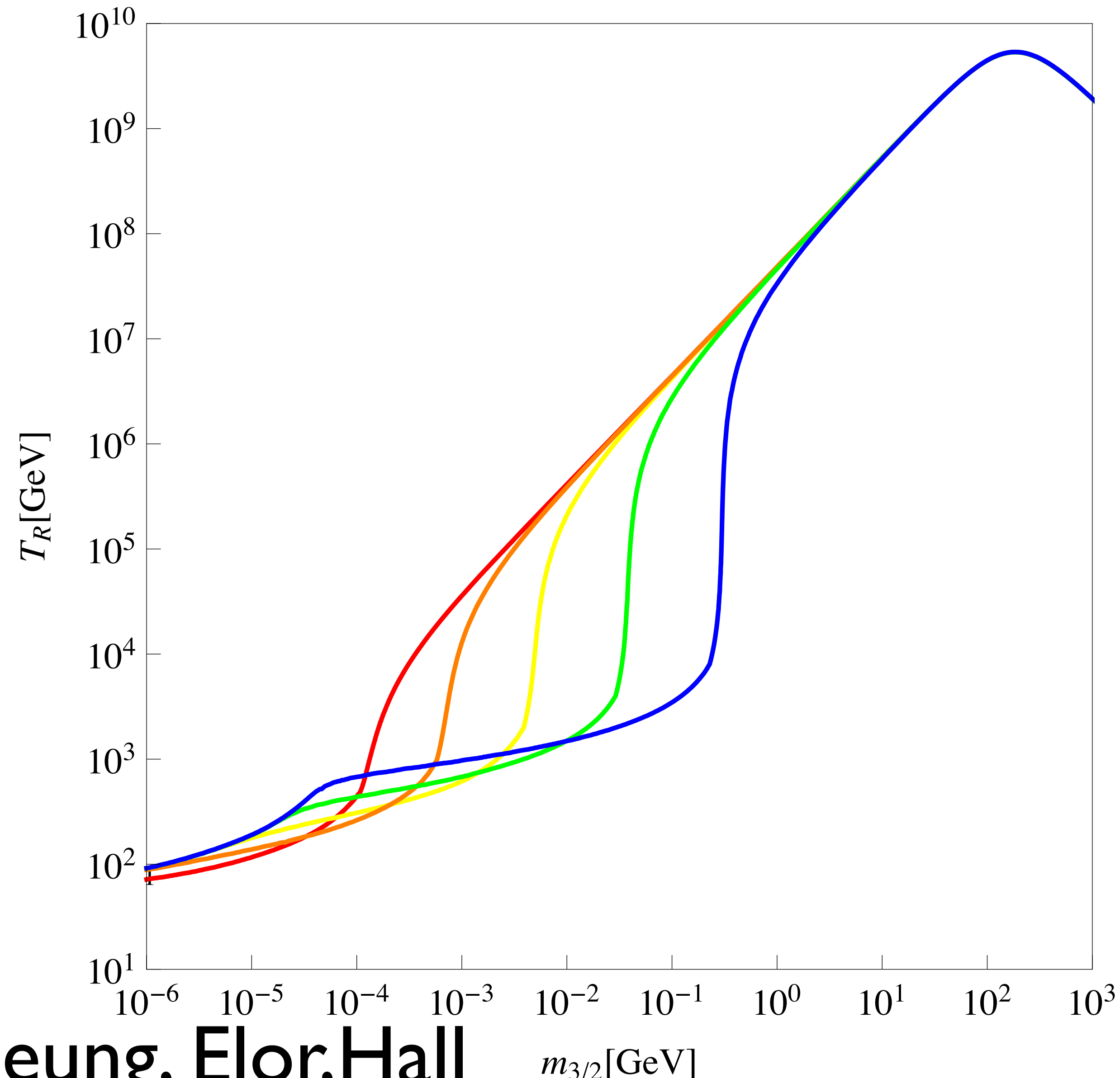


Lawrence J. Hall,Karsten Jedamzik, John March-Russell, ,
Stephen M. West JHEP 1003 (2010) 080 .
Also, Hall, Elor, Cheung, Kumar (in various combinations)

courtesy C. Cheung

Shares some features with superWIMP (Feng, et al)

Gravitino as FIMP



Cheung, Elor, Hall

FIG. 1: Contours of $\Omega_{3/2}h^2 = 0.11$ for gaugino masses fixed to $\{m_{\tilde{b}}, m_{\tilde{w}}, m_{\tilde{g}}\} = \{100, 210, 638\}$ GeV. The {red, orange, yellow, green, blue} contours correspond to universal scalar masses {500 GeV, 1 TeV, 2 TeV, 4 TeV, 8 TeV}.

$$Y_{3/2}^{\rm decay} \simeq \frac{405}{2\pi^4}\sqrt{\frac{5}{2}}\frac{m_{\rm Pl}}{g_*^{3/2}}\sum_i \frac{\Gamma_i}{m_i^2},$$

$$\begin{aligned}\tau_{\rm NLSP} &= 4\times 10^{17}\ {\rm GeV}^{-2} \times \frac{m_{\rm NLSP}}{g_*^3}\left[\sum_i \left(\frac{m_i}{m_{\rm NLSP}}\right)^3\right]^2 \\ &\simeq 7\times 10^{-5}\ {\rm sec} \times \left(\frac{150}{g_*}\right)^3 \left(\frac{300\,{\rm GeV}}{m_{\rm NLSP}}\right)^5 \\ &\quad \left[\frac{9}{11}\left(\frac{m_{\tilde{q}}}{\rm TeV}\right)^3 + \frac{2}{11}\left(\frac{m_{\tilde{g}}}{\rm TeV}\right)^3\right]^2 . \end{aligned} \tag{8}$$

Stop it?

cf. Feng and Smith, Arvanitaki, et al.

Conclusions

- Direct and indirect detection experiments are beginning to probe well-mixed dark matter. Should have an answer there soon.
- For colliders, we are at the mercy of the colored objects. How much fine-tuning can nature stand?