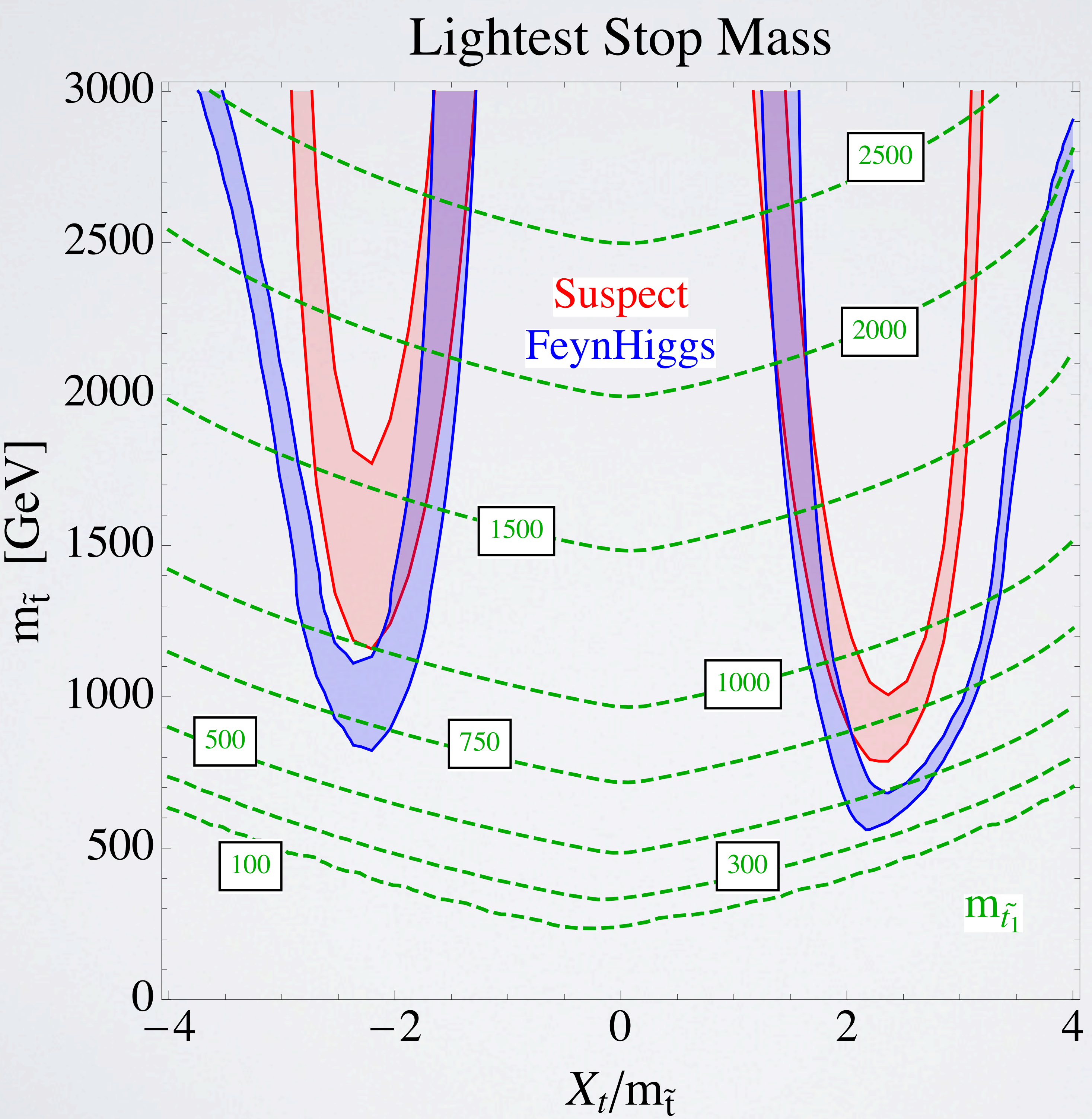
SUSY DARK MATTER IS DEAD. LONG LIVE SUSY DARK MATTER

Neal Weiner
NYU

NATURALNESS, SUSY AND THE HIGGS MASS



IT’S NOT A BUG IT’S A FEATURE

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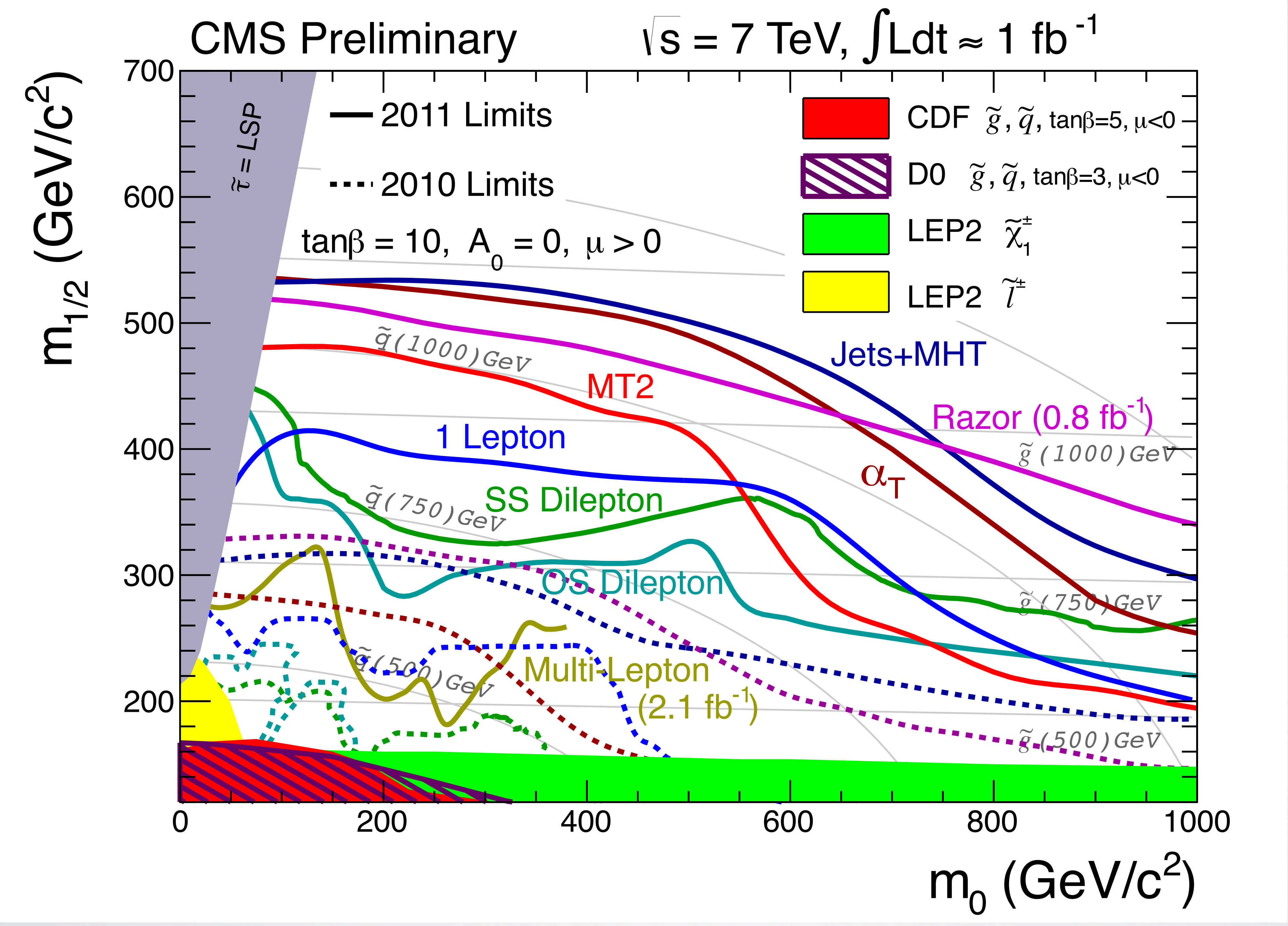

SO WHAT DOES THIS TELL US ABOUT SUSY DM?

Implications of a 125 GeV Higgs scalar for LHC SUSY and neutralino dark matter searches

Howard Baer[a], **Vernon Barger**[b] **and Azar Mustafayev**[c]

Abstract: The ATLAS and CMS collaborations have reported an excess of events in the $\gamma\gamma$, $ZZ^* \to 4\ell$ and WW^* search channels at an invariant mass $m \simeq 125$ GeV, which could be the first evidence for the long-awaited Higgs boson. We investigate the consequences of requiring $m_h \simeq 125$ GeV in both the mSUGRA and NUHM2 SUSY models. In mSUGRA, large values of trilinear soft breaking parameter $|A_0|$ are required, and universal scalar $m_0 \gtrsim 0.8$ TeV is favored so that we expect squark and slepton masses typically in the multi-TeV range. This typically gives rise to an "effective SUSY" type of sparticle mass spectrum. In this case, we expect gluino pair production as the dominant sparticle creation reaction at LHC. For $m_0 \lesssim 5$ TeV, the superpotential parameter $\mu \gtrsim 2$ TeV and $m_A \gtrsim 0.8$ TeV, greatly restricting neutralino annihilation mechanisms. These latter conclusions are softened if $m_0 \sim 10 - 20$ TeV or if one proceeds to the NUHM2 model. The standard neutralino abundance tends to be far above WMAP-measured values unless the neutralino is higgsino-like. We remark upon possible non-standard (but perhaps more attractive) cosmological scenarios which can bring the predicted dark matter abundance into accord with the measured value, and discuss the implications for direct and indirect detection of neutralino cold dark matter.

NATURALNESS, SUSY, HIGGS MASS AND DARK MATTER

Higgs at 125 ⇒ large $m^2_{\tilde{u}}, m^2_{\tilde{q}}$

⇒ large corrections to $m^2_{H_u}$

⇒ Cancel with large μ term

⇒ Higgsino is heavy

⇒ LSP is Bino

⇒ Bino is weakly coupled

⇒ need tuned scenarios

WHAT IS SUSY DM

- A singlet, a doublet and a triplet with some specific couplings

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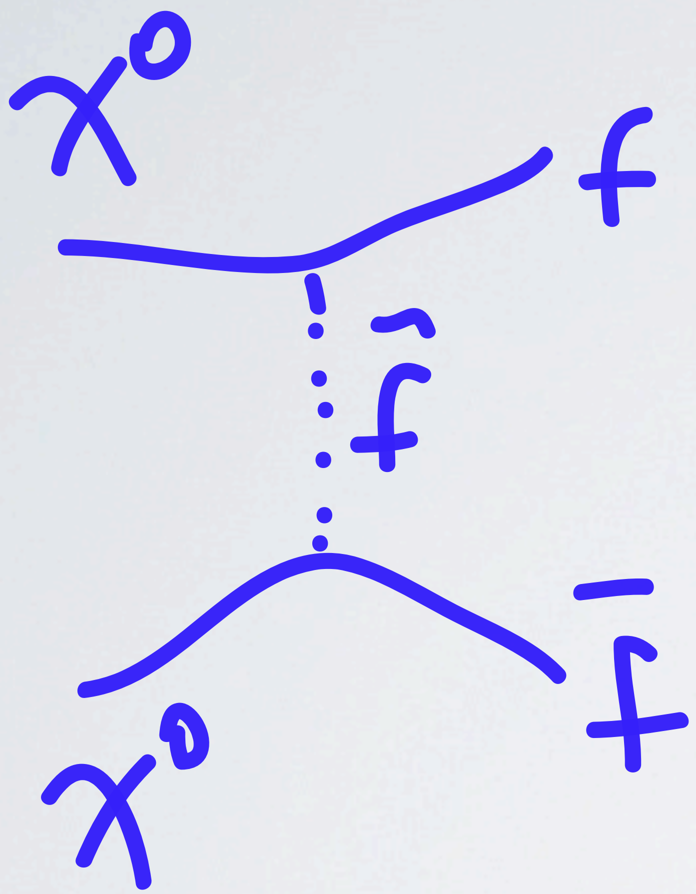

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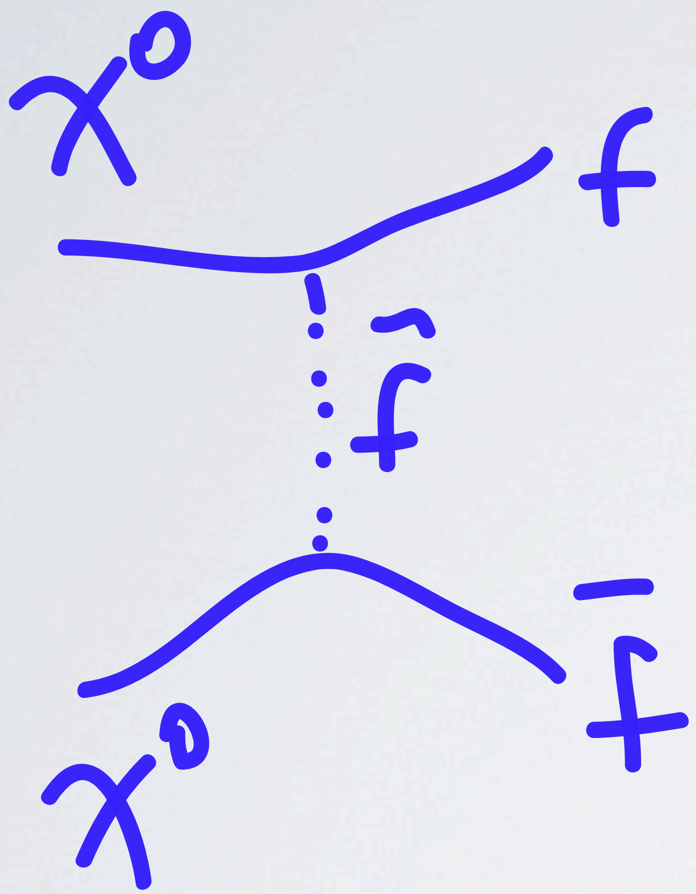

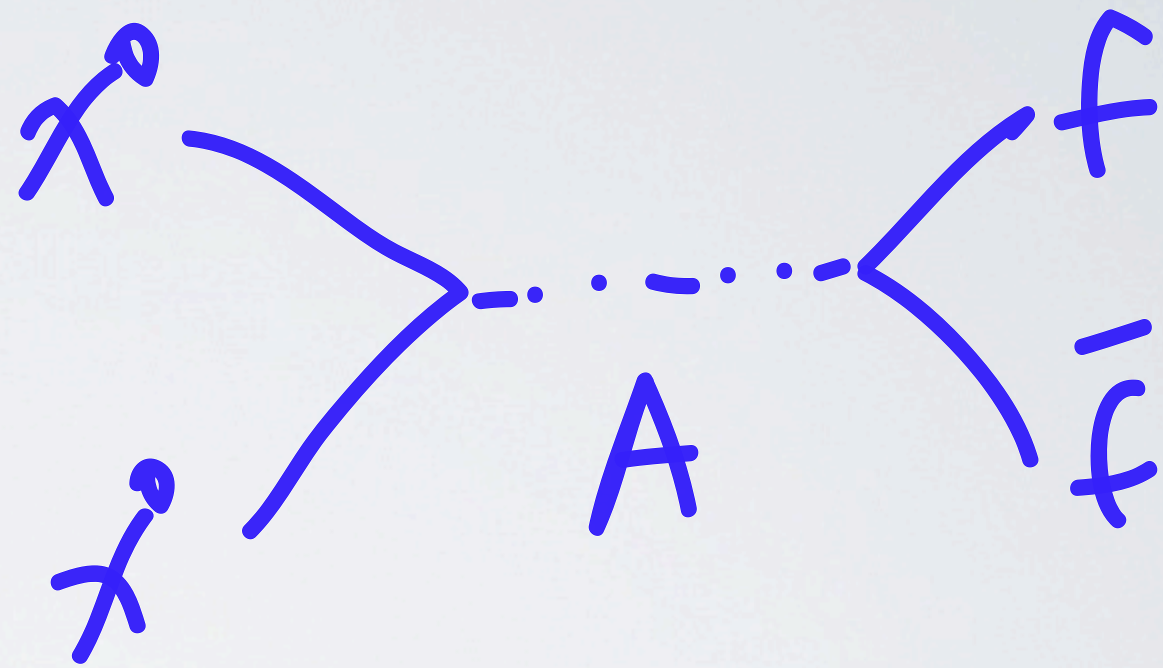

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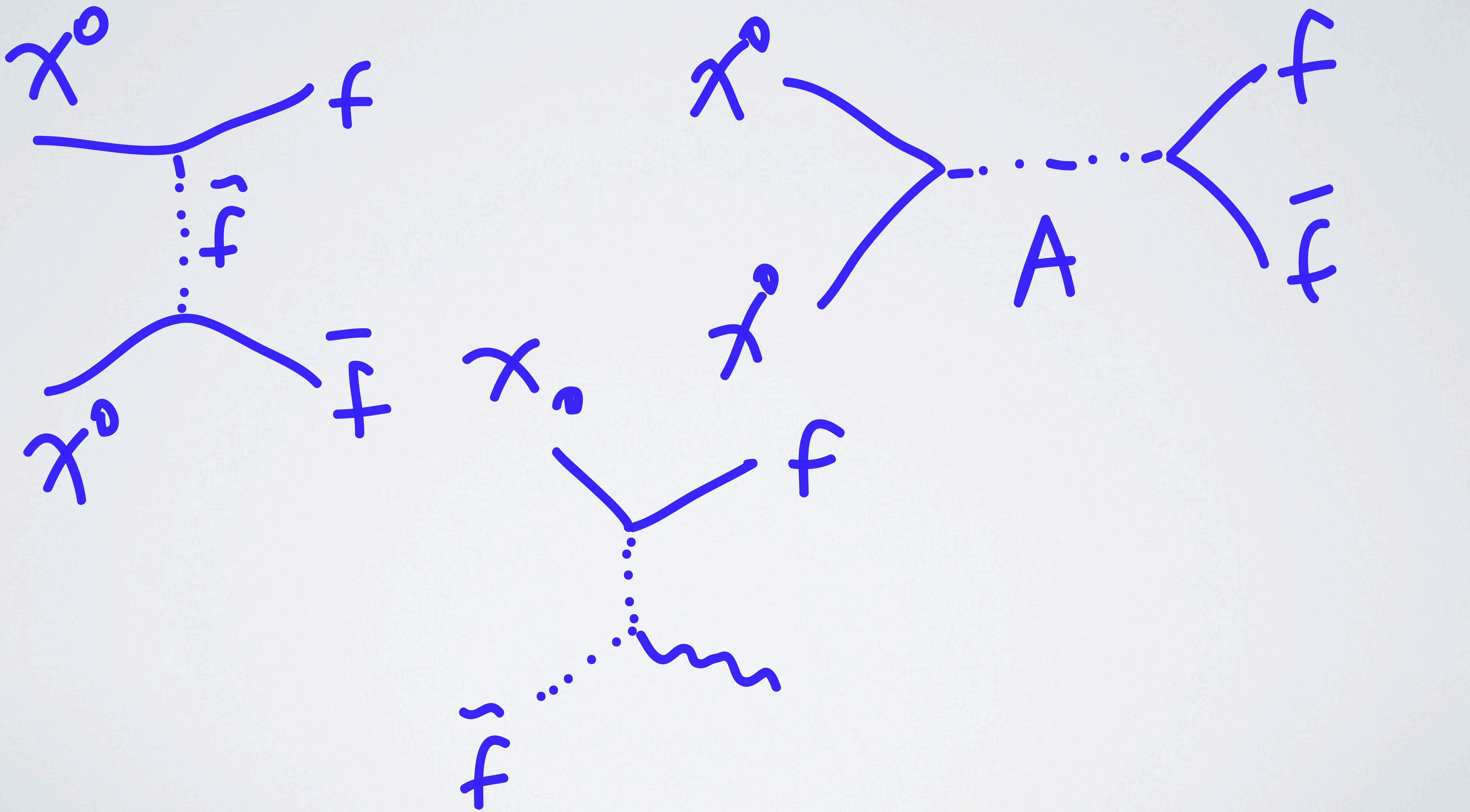
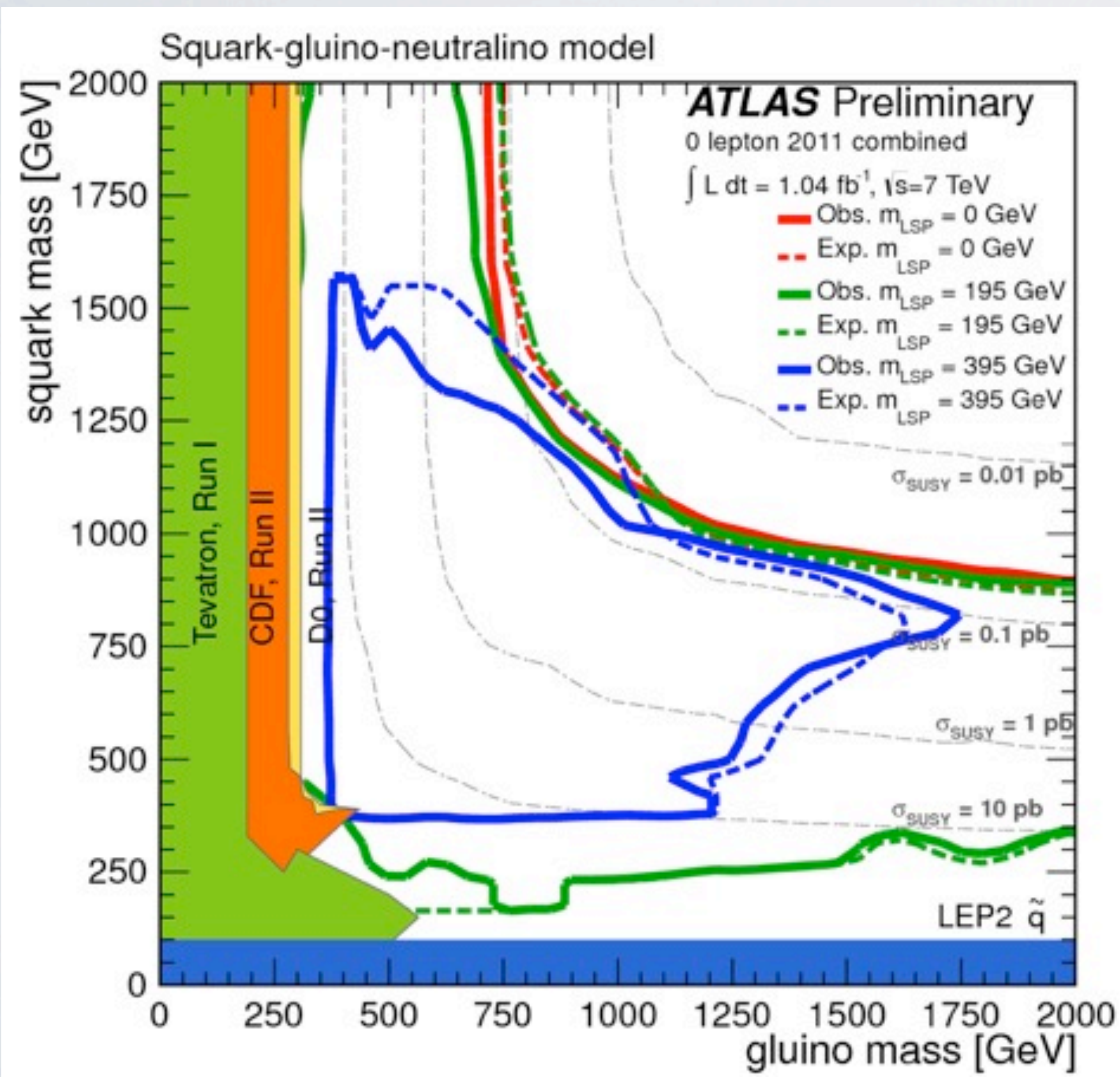
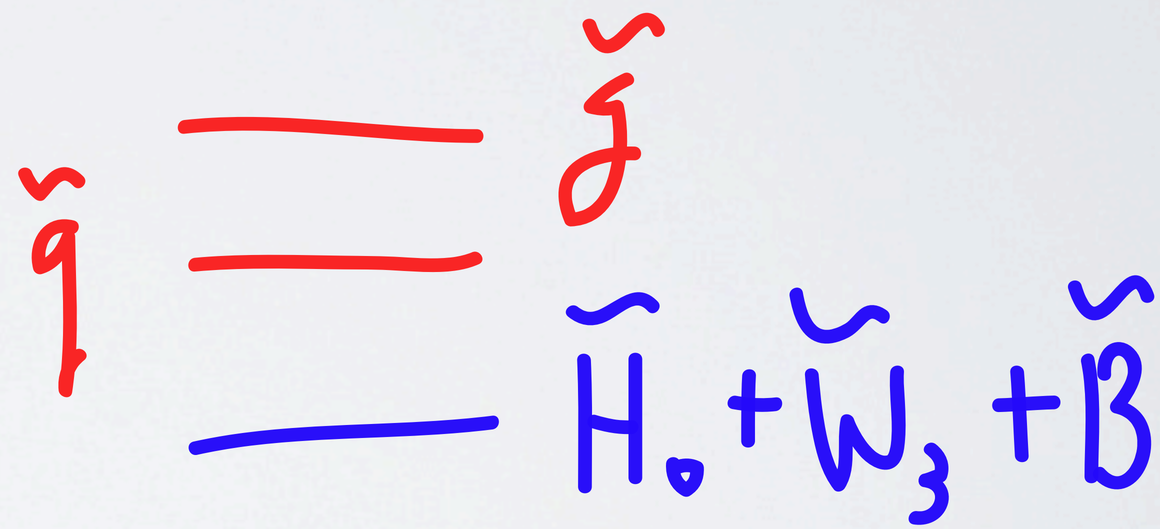


MAYBE IT'S NOT ALL THAT BAD





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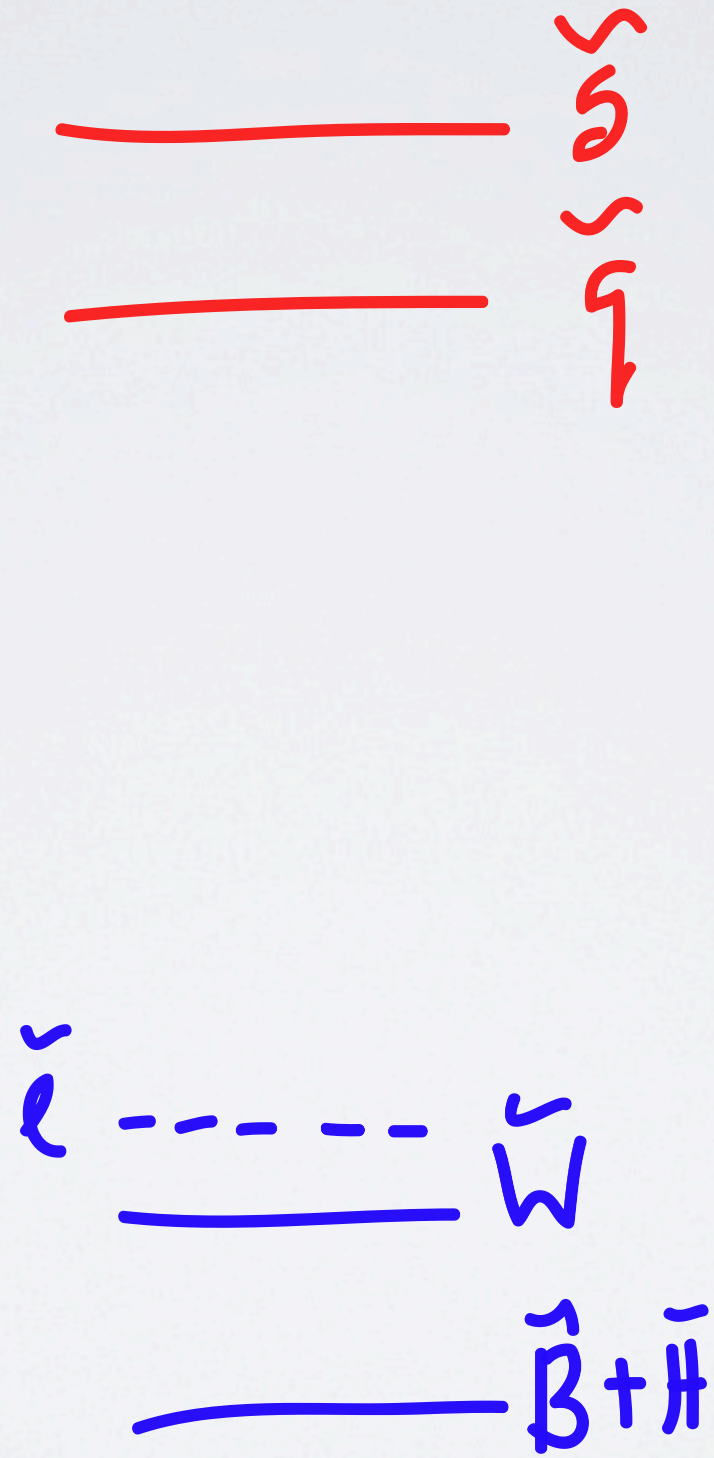

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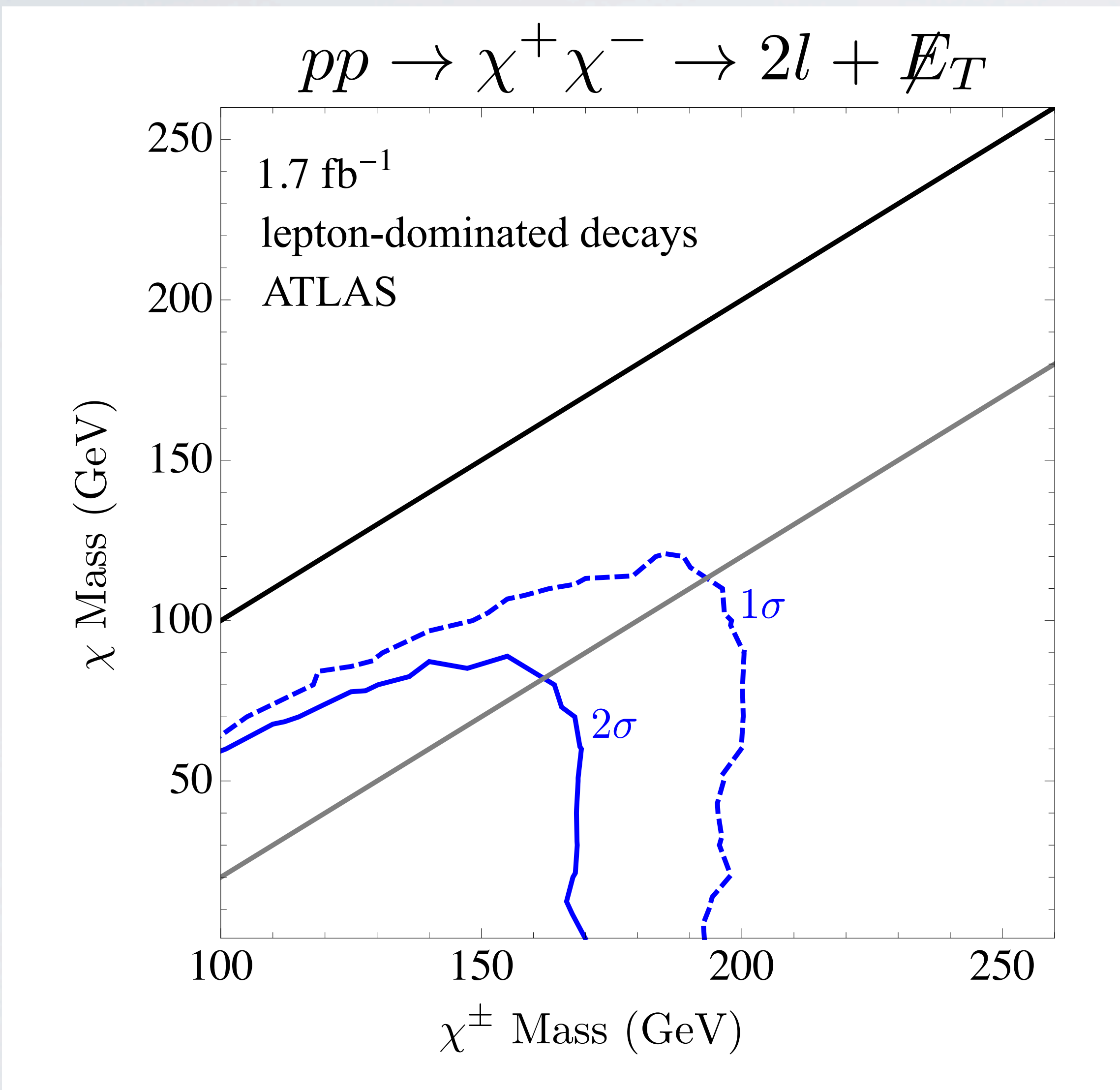
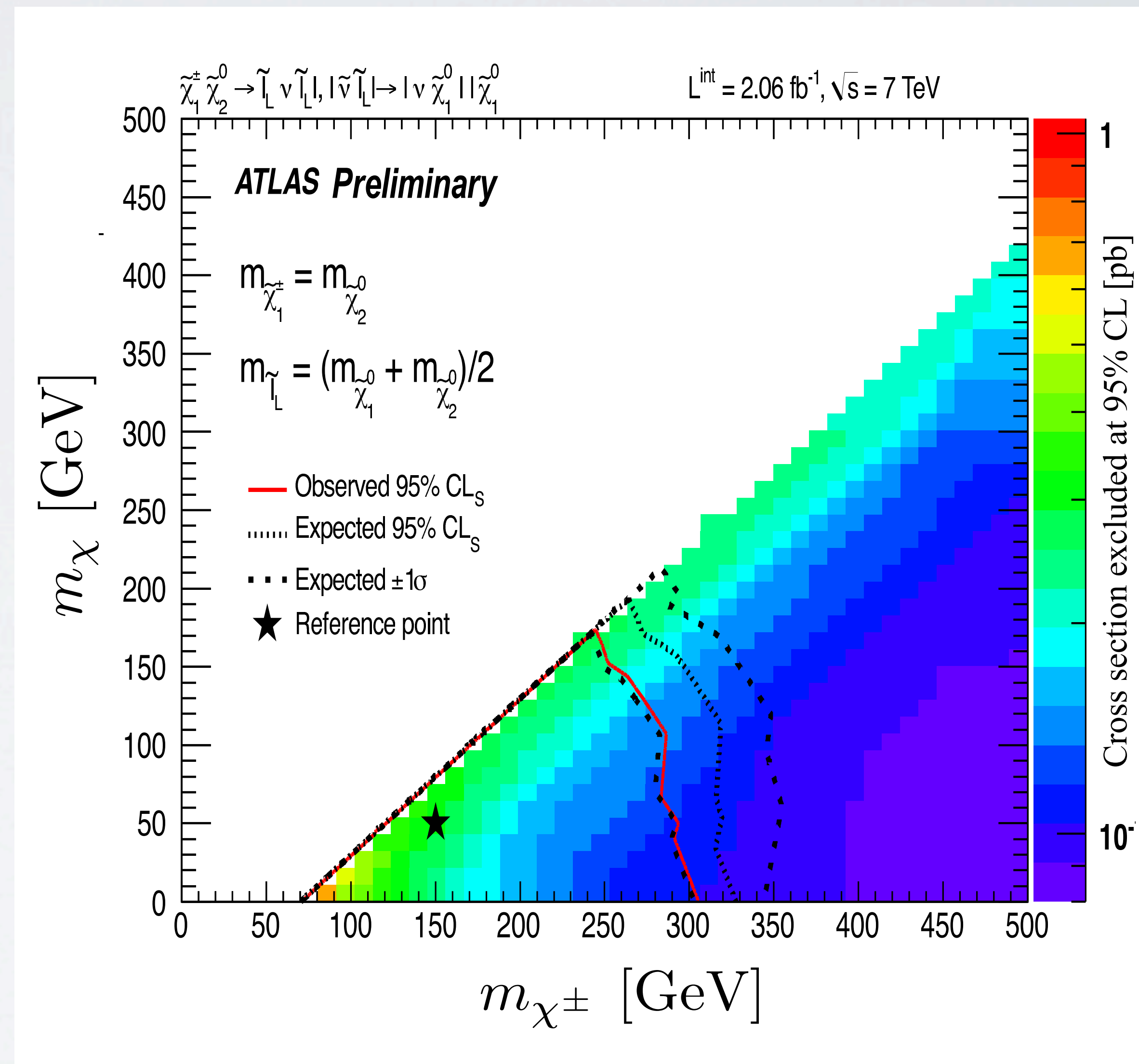




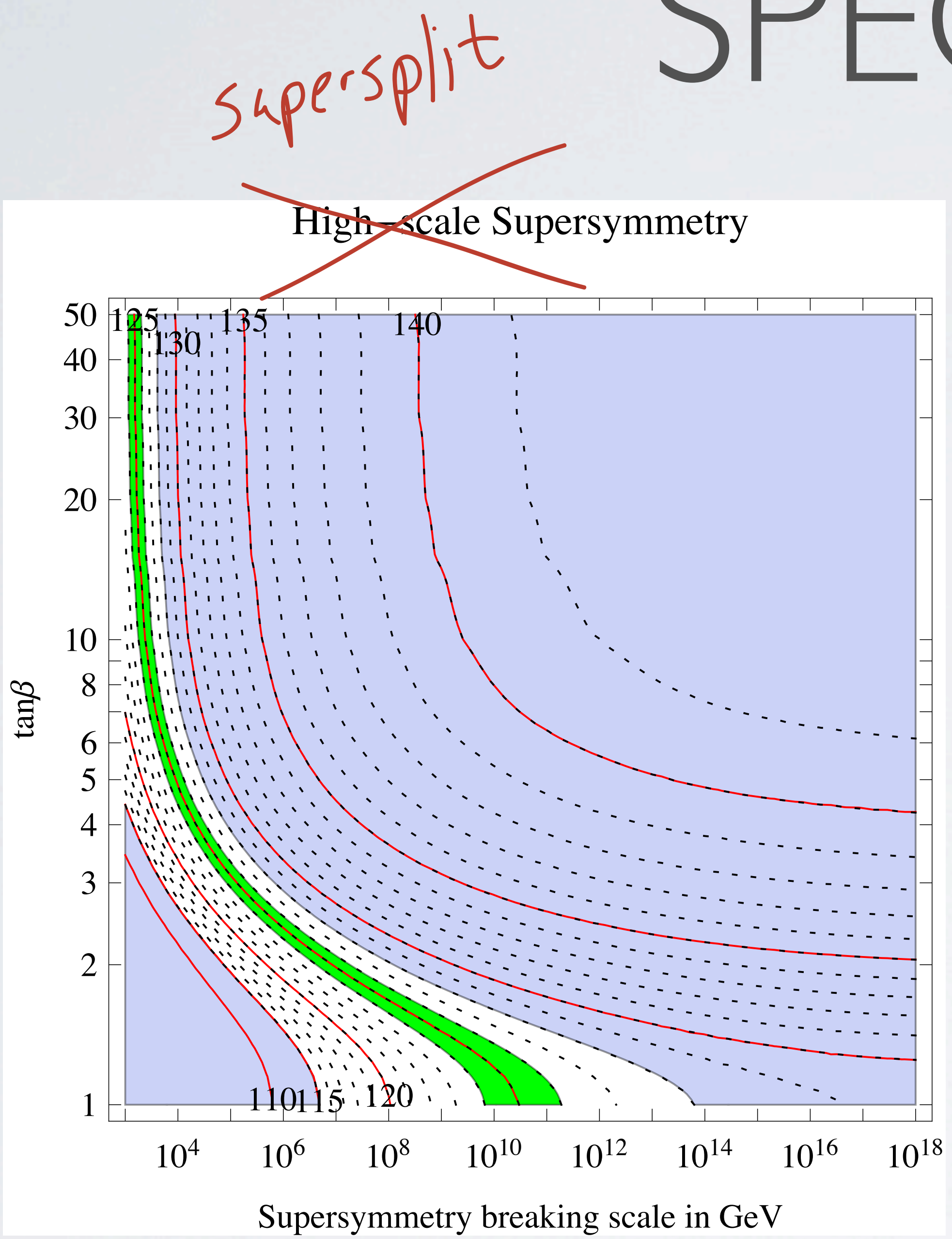
ATLAS-CONF-2012-023

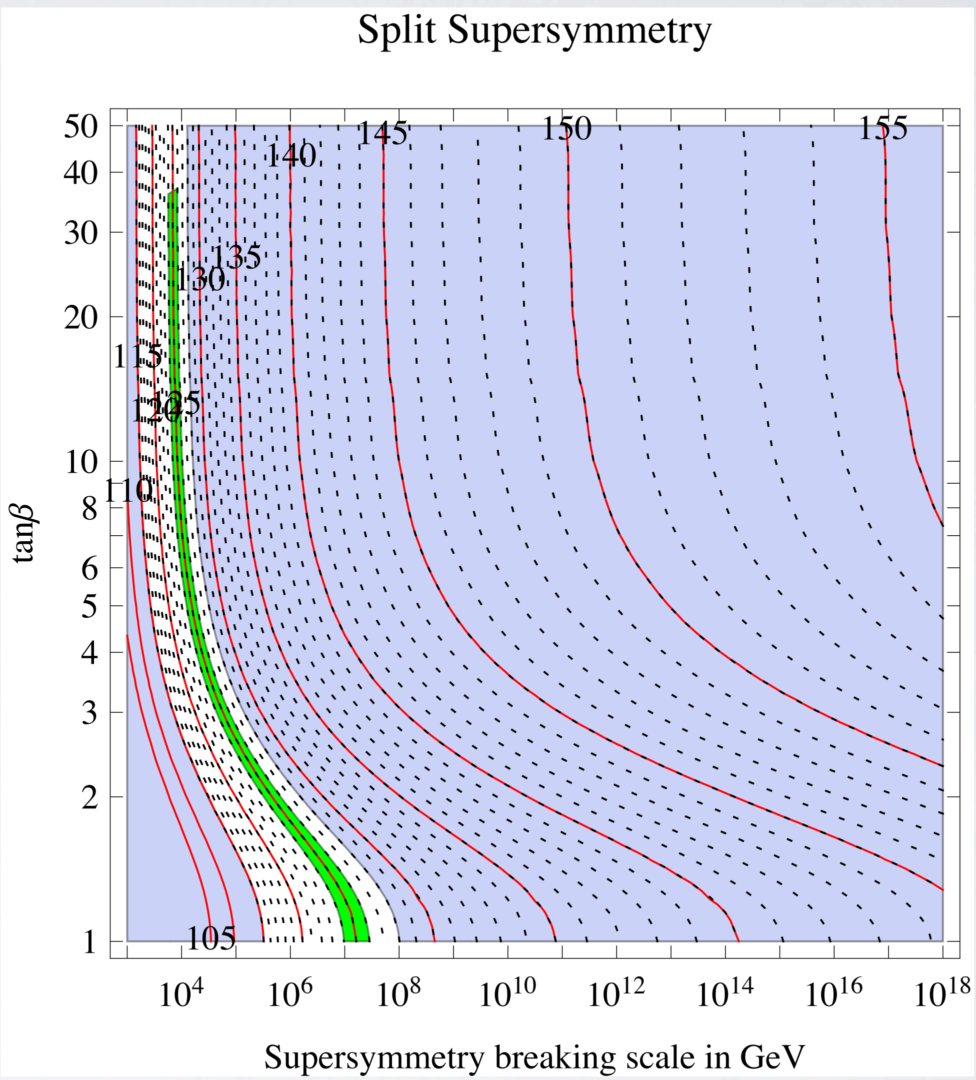
cf M. Lisanti's talk

LSP DARK MATTER

- If you tune your initial conditions (e.g. CMSSM) LSP WIMPs are often tuned
- If you give up on preconceived notions of unified soft breaking parameters (“chaotic SUSY”), LSP dark matter is pretty easy

IMPLICATIONS FOR SUSY SPECTRA





Giudice + Strumia

JUST GO WITH IT

A SIMPLE, UNNATURAL SCENARIO

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- So SUSY looks tuned
  - 1%, .1%, something

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A SIMPLE, UNNATURAL SCENARIO

- So SUSY looks tuned
  - 1%, .1%, something
- So maybe we just embrace that
- Q: What is the nicest scenario modulo this?

A SIMPLE, UNNATURAL SCENARIO

- Usual approach to SUSY breaking

$$\int d^4\theta\, X^\dagger X\, Q^\dagger Q \Rightarrow m_{\tilde{q}}^2$$

$$\int d^2\theta\, X\, W_\alpha W^\alpha \Rightarrow m_\lambda \lambda\lambda$$

$$\langle X \rangle = \theta^2 F$$

X is a pure singlet!

A SIMPLE, UNNATURAL SCENARIO

- Anomaly mediated SUSY breaking

$$\int d^4\theta\, X^\dagger X\, Q^\dagger Q \Rightarrow m_{\tilde{q}}^2$$

$$m_X = \frac{g^2}{16\pi^2} b_{eff}\, m_{3/2}$$

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Separation of ~ 100 between scalars and inos

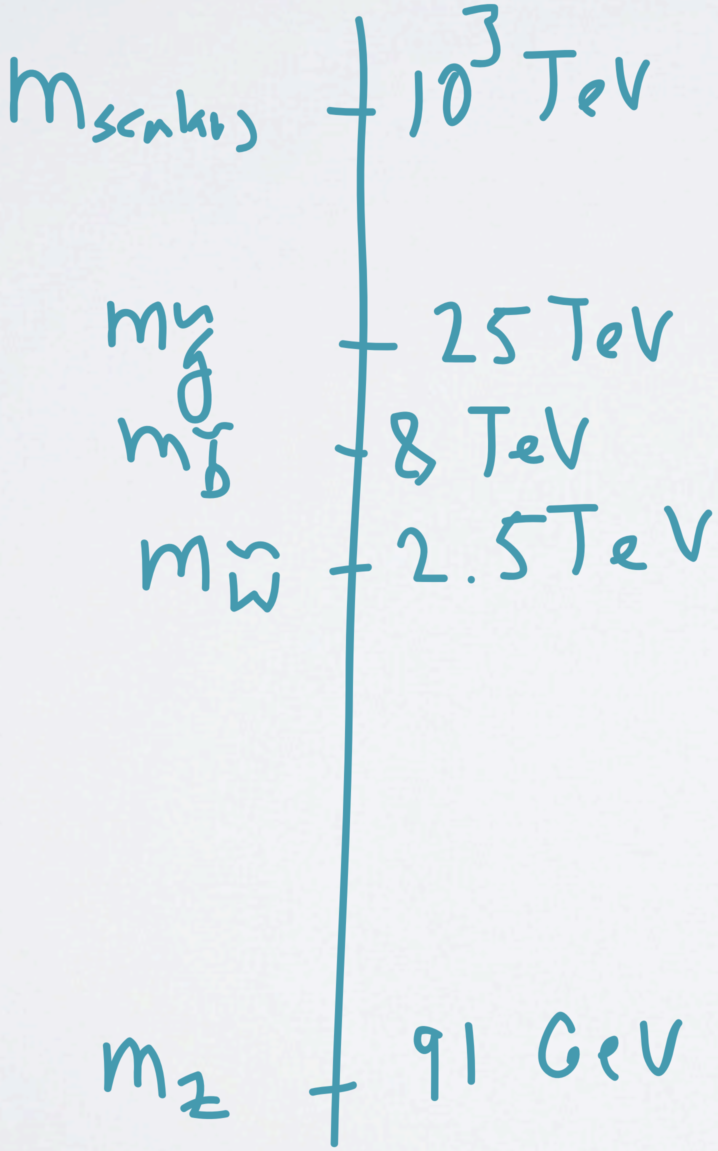
so what sets the scale?

DARK MATTER

- The LSP generically (but not exclusively) the Wino
- To be DM *or not overclose the universe* mW<2.5 TeV

THE SPECTRUM

a "natural" spectrum



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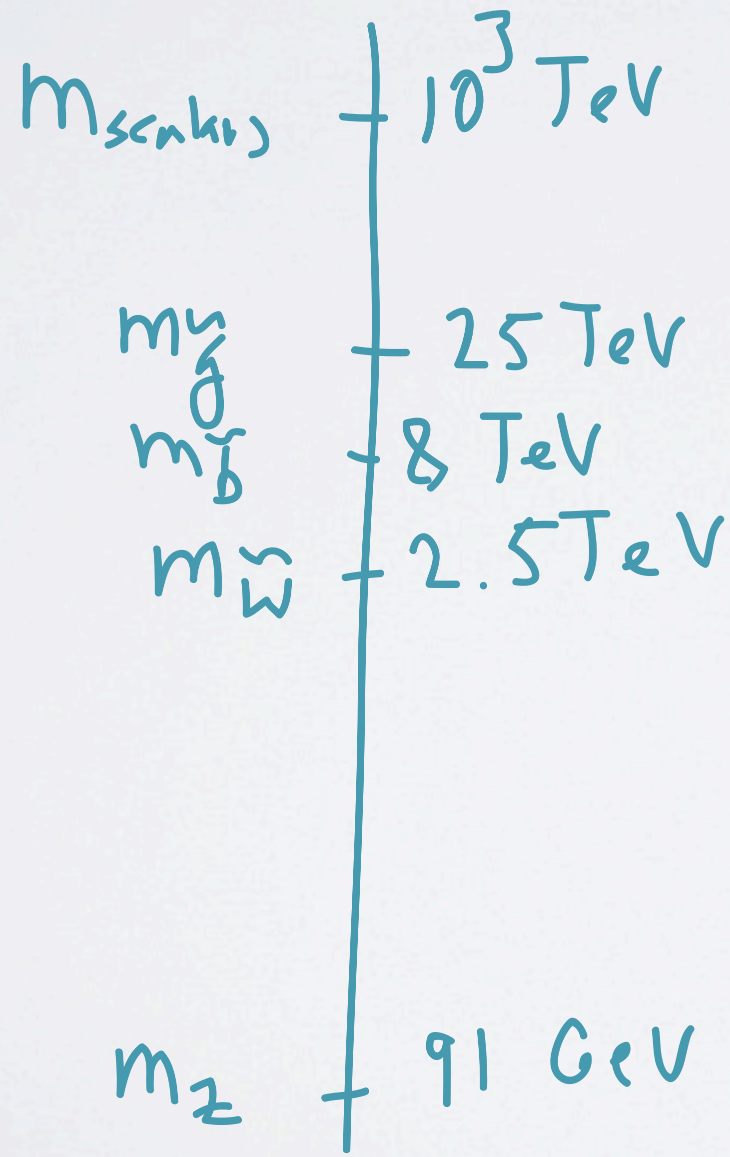


There are a lot of nice things about this spectrum

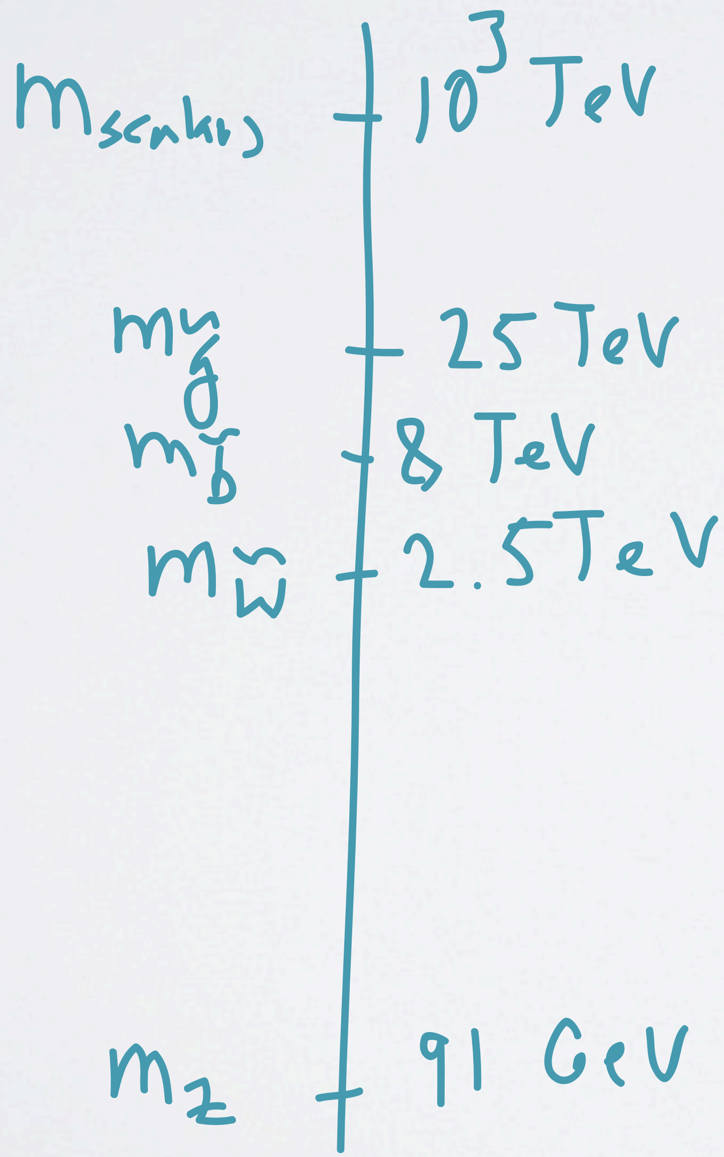
1) b-tau unification works nicely

2) flavor becomes a non-issue for SUSY

3) it's consistent with our non-observation of SUSY so far

THE SPECTRUM

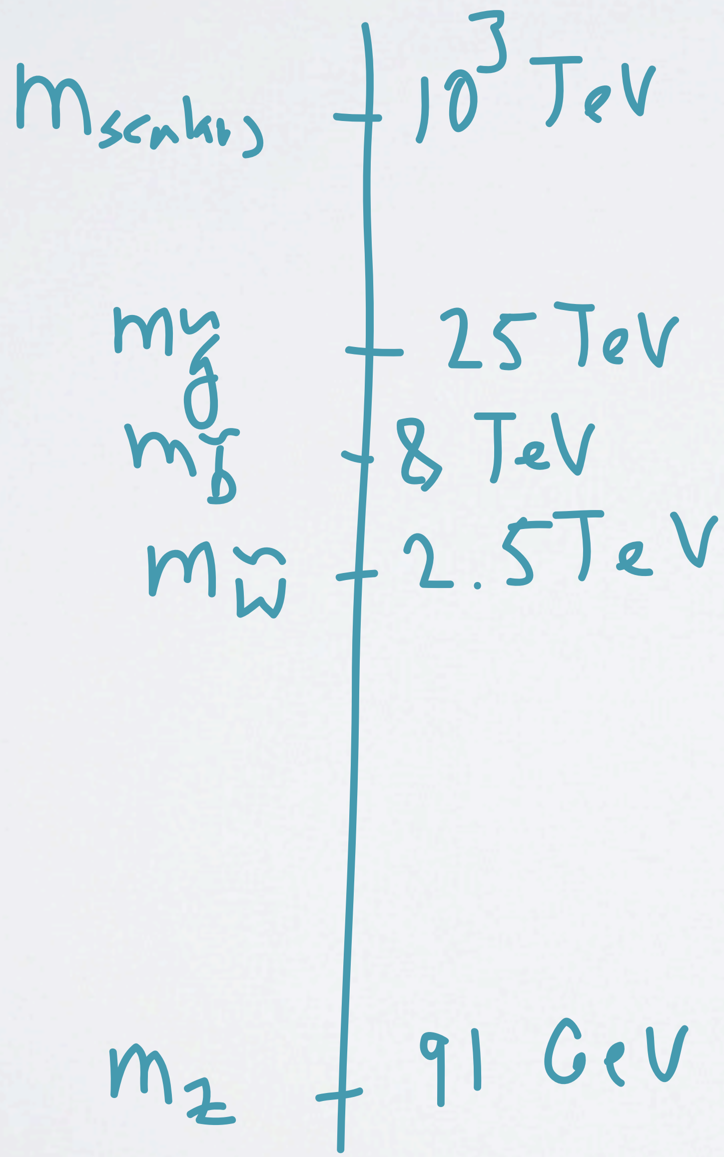
a "natural" spectrum



But this spectrum will not be discovered at the LHC

THE SPECTRUM

a "natural" spectrum



Are we hosed?

A NIGHTMARE SCENARIO?

- If nature is like this, is that it for particle physics?

SQUEEZING THE SPECTRUM

In the presence of additional matter, anomaly mediation can be modified

$$\int d^4\theta \, \phi^\dagger \phi \left(M\bar{M} + M^\dagger M + \bar{M}^\dagger \bar{M} \right)$$

$$\int d^4\theta \, \frac{\phi^\dagger}{\phi} M\bar{M} \rightarrow \int d^2\theta \left(1 - \theta^2 m_{3/2}\right) m_{3/2} M\bar{M}$$

Nelson, NW

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opposite from usual sign

Nelson, NW

A MESSENGER IN ANOMALY MEDIATION

$$m_3 \sim (-3 + 2N_f)\alpha_3$$

$$m_2 \sim (1 + 2N_f)\alpha_2$$

$$m_1 \sim \left(\frac{33}{5} + 2N_f\right)\alpha_1$$

N_f	m_3	m_2	m_1
0	9	1	3
1	1	1	1.4
2	1	1.4	1.4
3	1.5	1.1	1
4	2	1.2	1

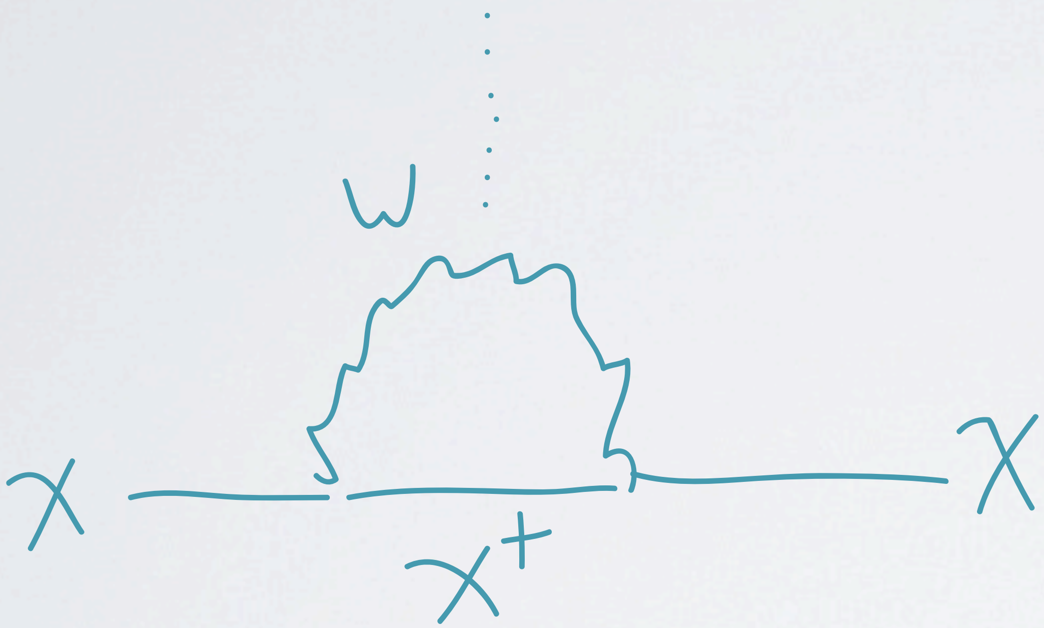
In general a *squeezed* spectrum

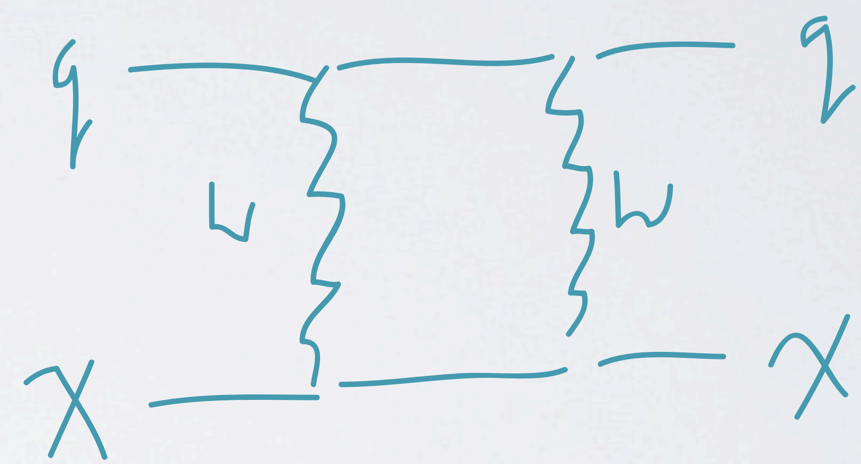
A NIGHTMARE SCENARIO?

- What is nature is **not** kind to us?

A NIGHTMARE SCENARIO?

- Direct detection: Triplet (Wino) has **no** coupling to Z, **no** tree level coupling to Higgs

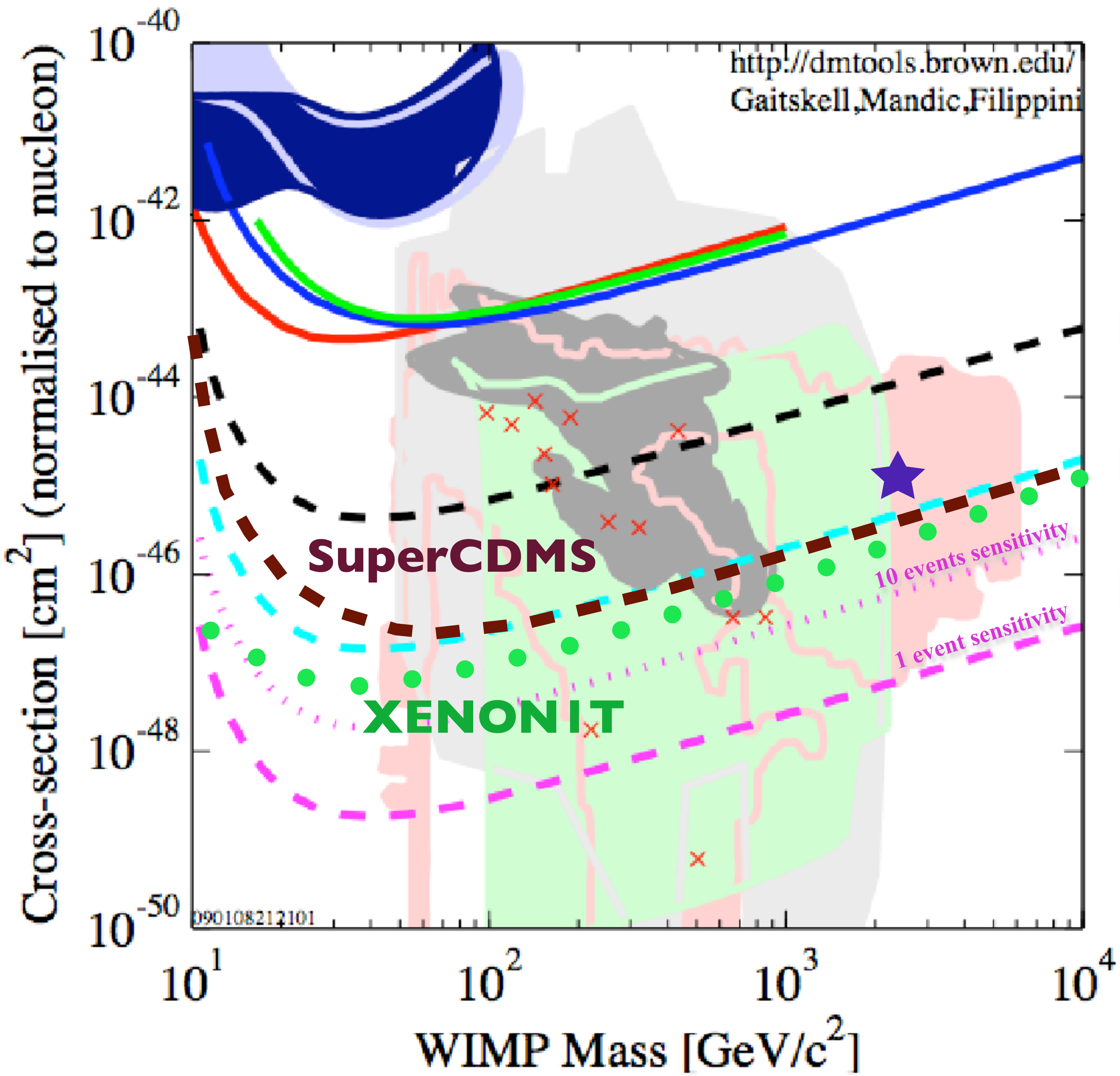




$$\sigma_n \sim 10^{-45}\ \mathrm{cm}^2$$

Nojiri et al; Cirelli + Strumia

A NIGHTMARE SCENARIO?



- Projections based on
  - Known background levels
  - Previously obtained e⁻ attenuation lengths and discrimination factors

LUX (constr: 2008-2009, ops: 2010-2011)
100 kg x 300 days

LZ3 (constr: 2010-2011, ops: 2012-2013)
1,500 kg x 500 days

LZ20 (constr: 2013-2015, ops: 2016-2019)
13,500 kg x 1,000 days

- Fiducial volumes selected to match < 1 NR event in full exposure

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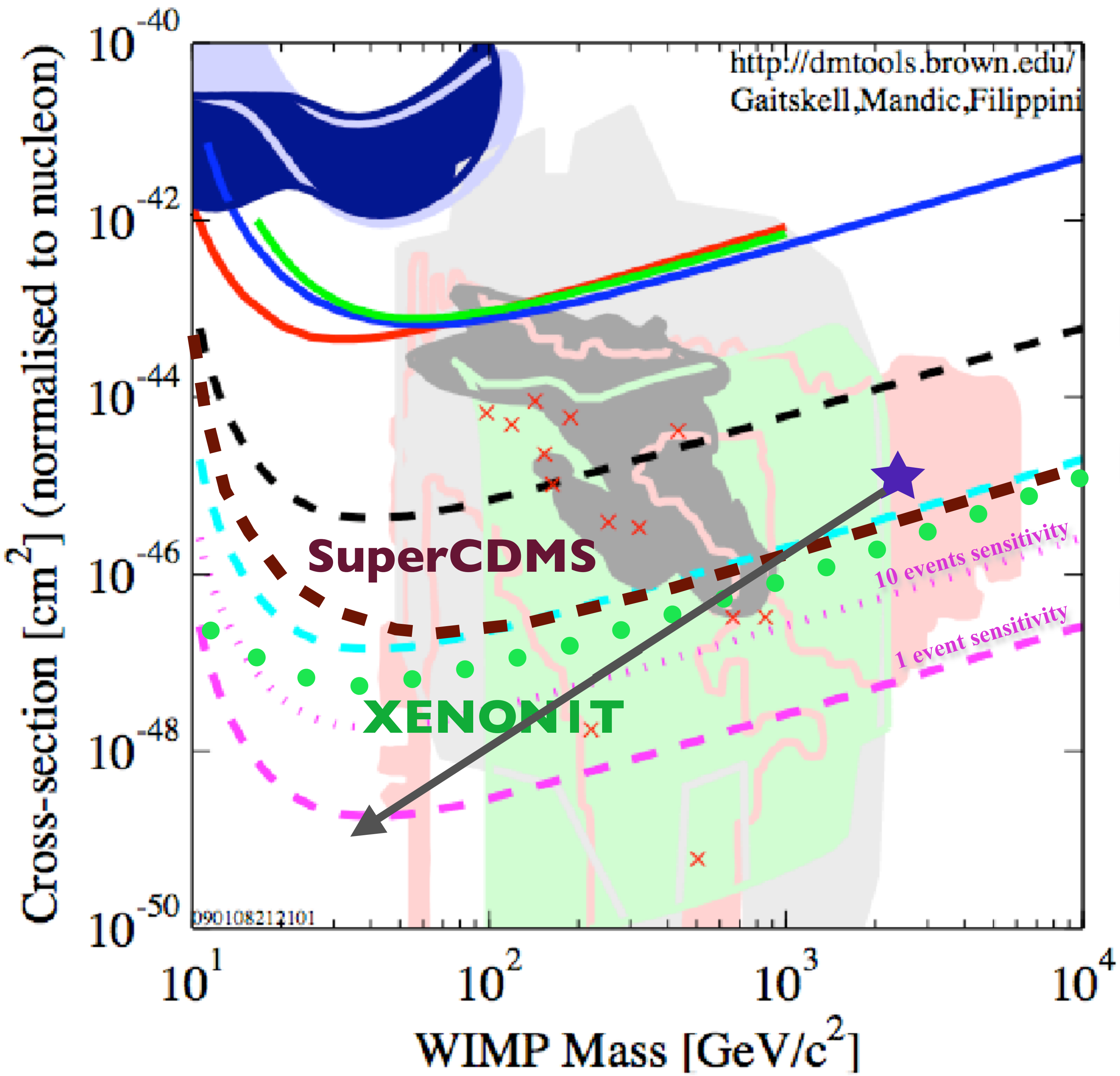

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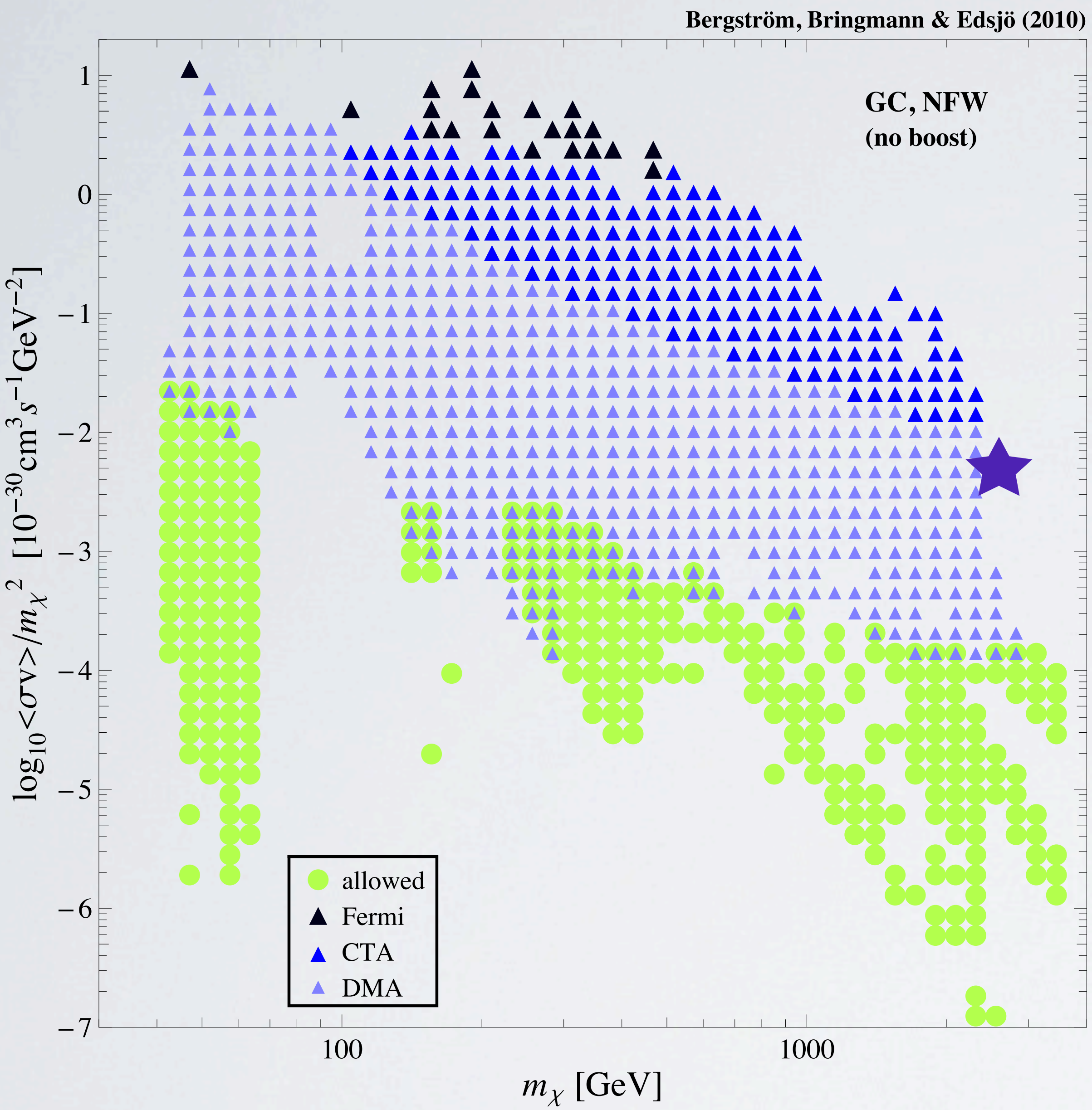
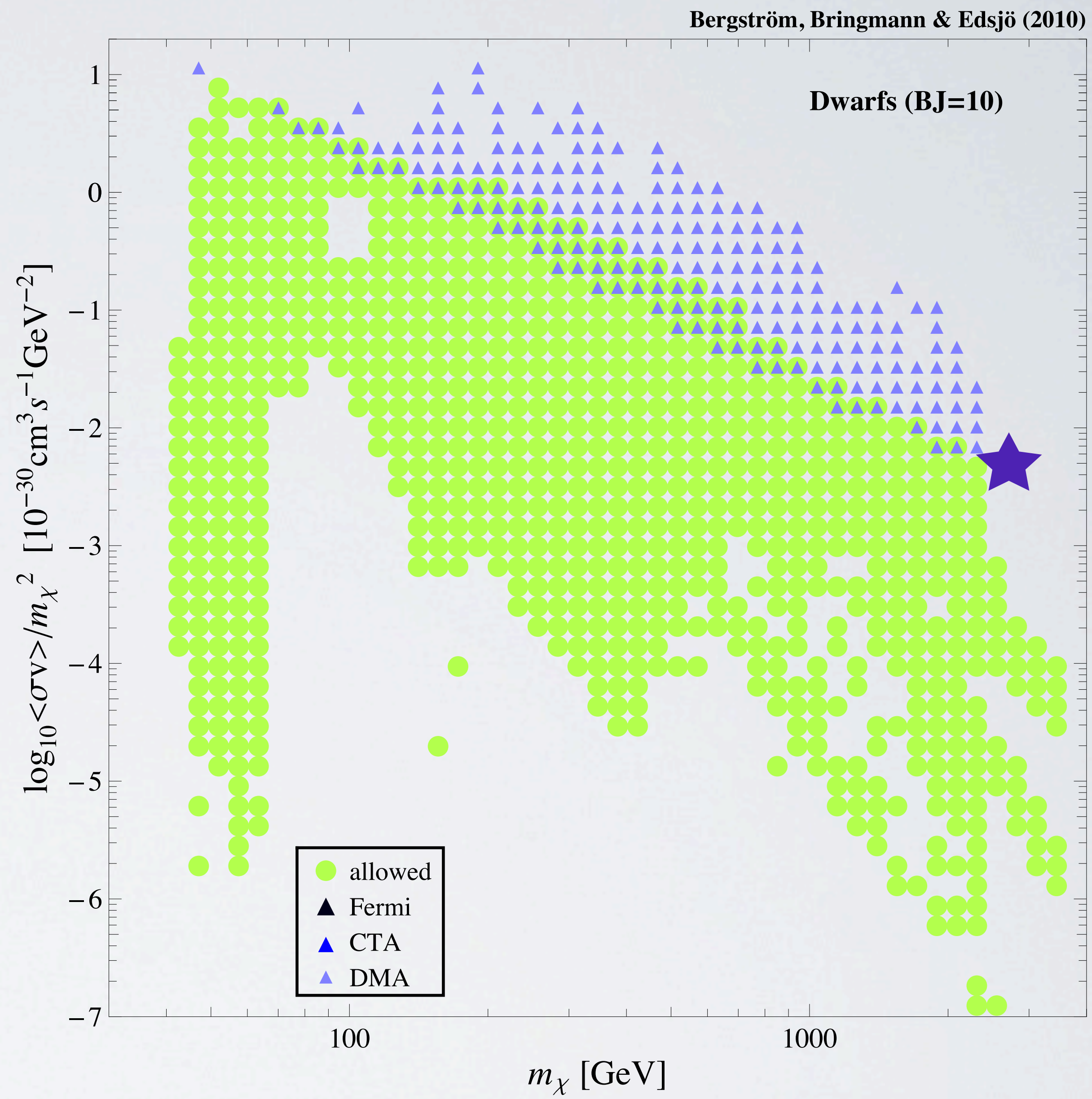
$$\sigma_0 \rho \sim \sigma_0 \rho_0 \left(\frac{2.5\,\mathrm{TeV}}{m_\chi}\right)^2$$

INDIRECT HANDLES





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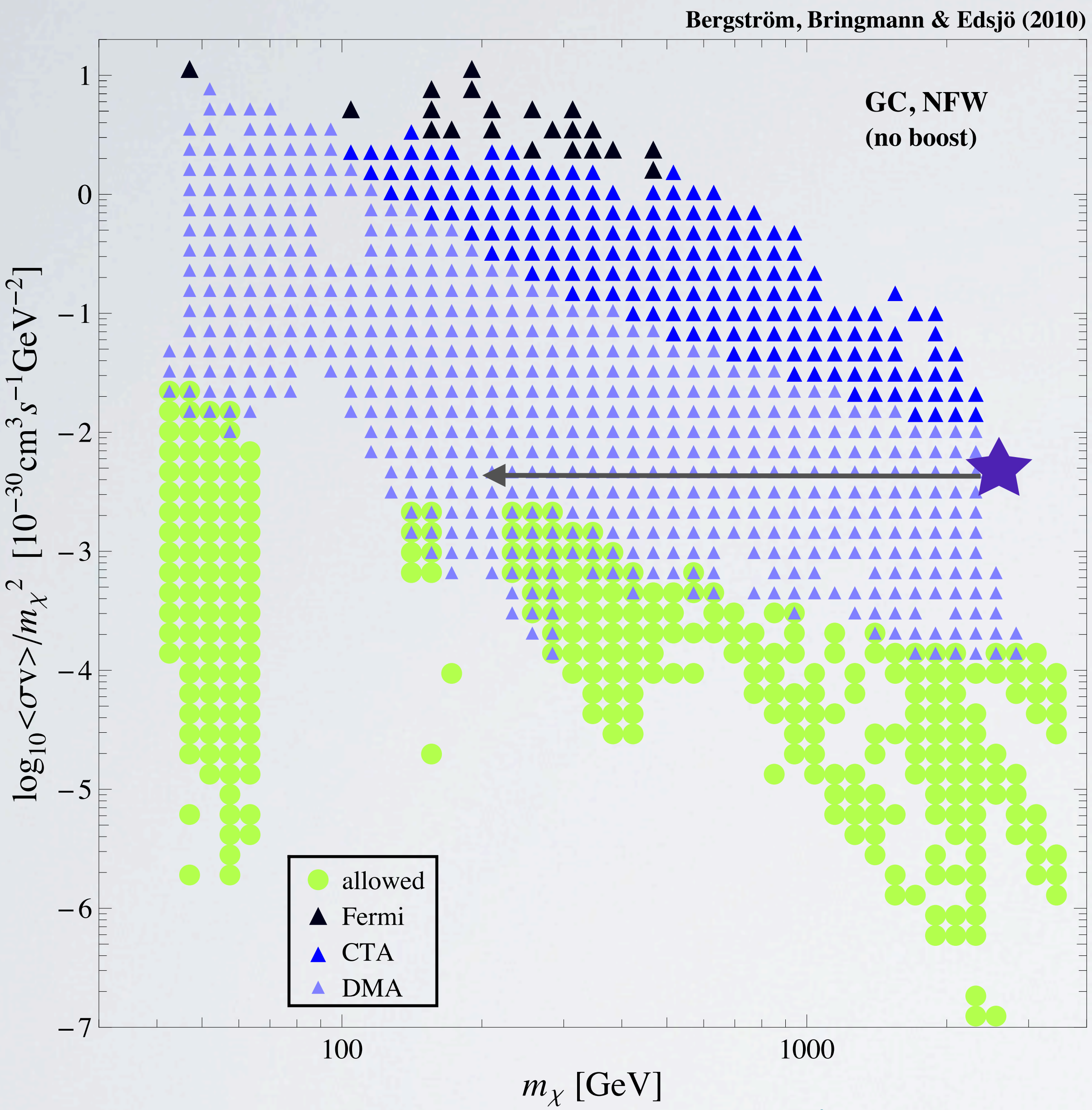

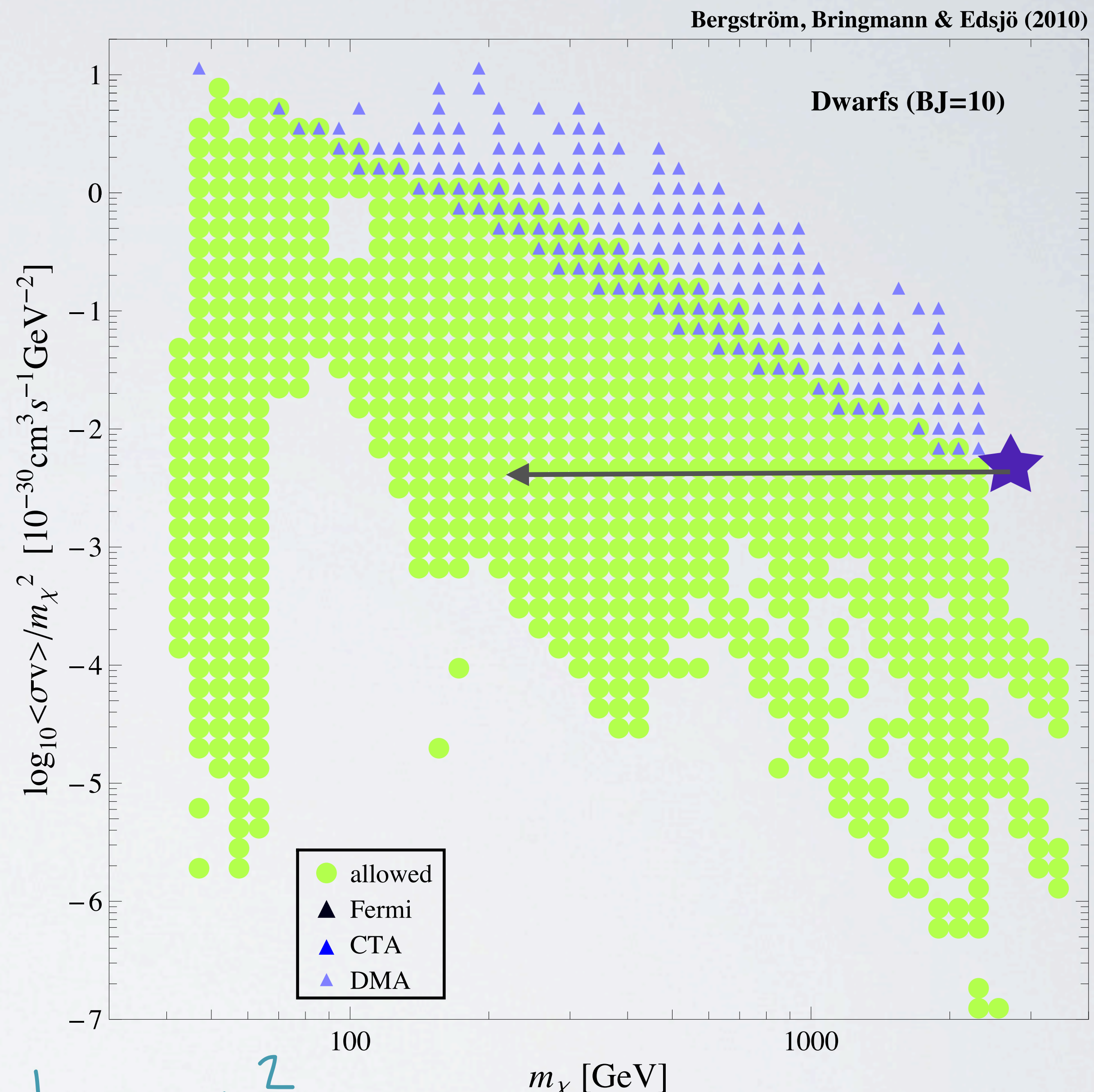

$\sigma \sim \frac{1}{m_\chi^2}$ $\quad \rho \sim \frac{1}{\sigma} \sim m_\chi^2$

$\frac{\rho^2 \sigma}{m_\chi^2} \sim \text{const}$

MEASURING A MASS WITH DIRECT DETECTION

- Can we set the scale for the next collider with a WIMP search?

DIRECT DETECTION UNCERTAINTIES

$$\frac{dR}{dE_R} = N_T M_N \frac{\rho_\chi \sigma_n}{2 m_\chi \mu_{ne}^2} \frac{(f_p Z + f_n (A - Z))^2}{f_n^2} F^2[E_R] \int_{\beta_{min}}^{\infty} \frac{f(v)}{v} dv.$$

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particle physics

PP: Type of interaction, mediator

DIRECT DETECTION UNCERTAINTIES

nuclear physics

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AP: How many particles are there at a given velocity *in the Earth frame*

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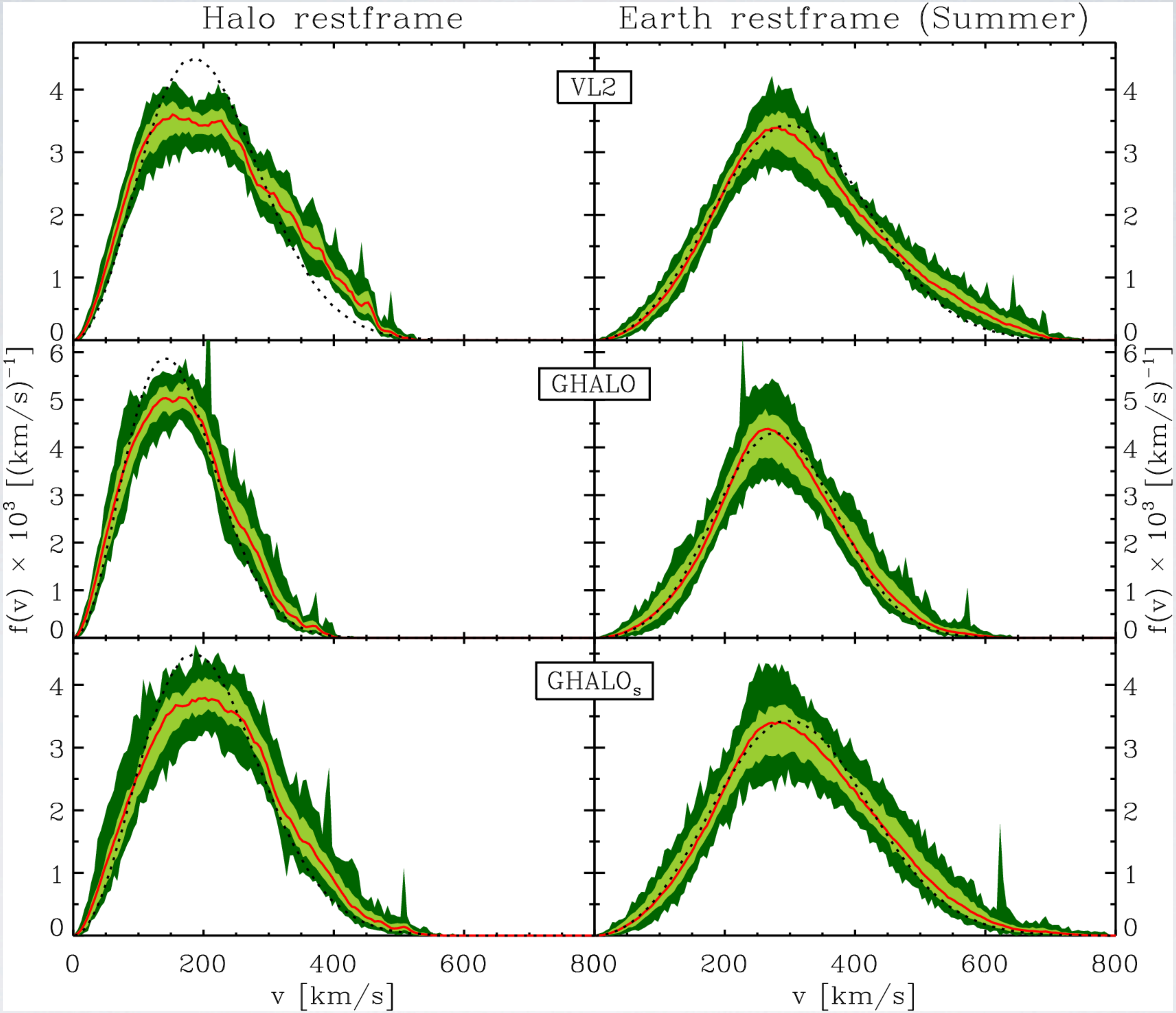
- The *only* relevance of WIMP mass in DD exps is the reduced mass



Kuhlen, et al

MB generally good near the peak, generally not near the tail

TWO KEY POINTS

$$\frac{dR}{dE_R} = \frac{N_T M_T \rho}{2 m_\chi \mu^2} \sigma(E_R)\, g(v_{min})$$

$$g(v_{min}) = \int_{v_{min}}^{\infty} d^3v\, \frac{f(\mathbf{v},t)}{v}$$

$$\sigma_{SI}(E_R) \;=\; \sigma_p \frac{\mu^2}{\mu_{n\chi}^2} \frac{\left(f_p\, Z + f_n\,(A-Z)\right)^2}{f_p^2} F^2(E_R)$$

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1) all the energy dependence is in two functions

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1) all the energy dependence is in two functions

$$v_{min} = \sqrt{\frac{M_T E_R}{2\mu^2}}$$

2) there is a 1-1 mapping between velocity and energy

MEASURING WIMPS

- Suppose you want to compare two experiments, 1 and 2

$$[E^1_{low}, E^1_{high}] \Rightarrow [v^{1,low}_{min}, v^{1,high}_{min}]$$

map the energy range studied in experiment 1 to a velocity space range

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$$[v^{1,low}_{min}, v^{1,high}_{min}] \Rightarrow [E^2_{low}, E^2_{high}]$$

we now have an energy range where the experiments are studying the *same* particles

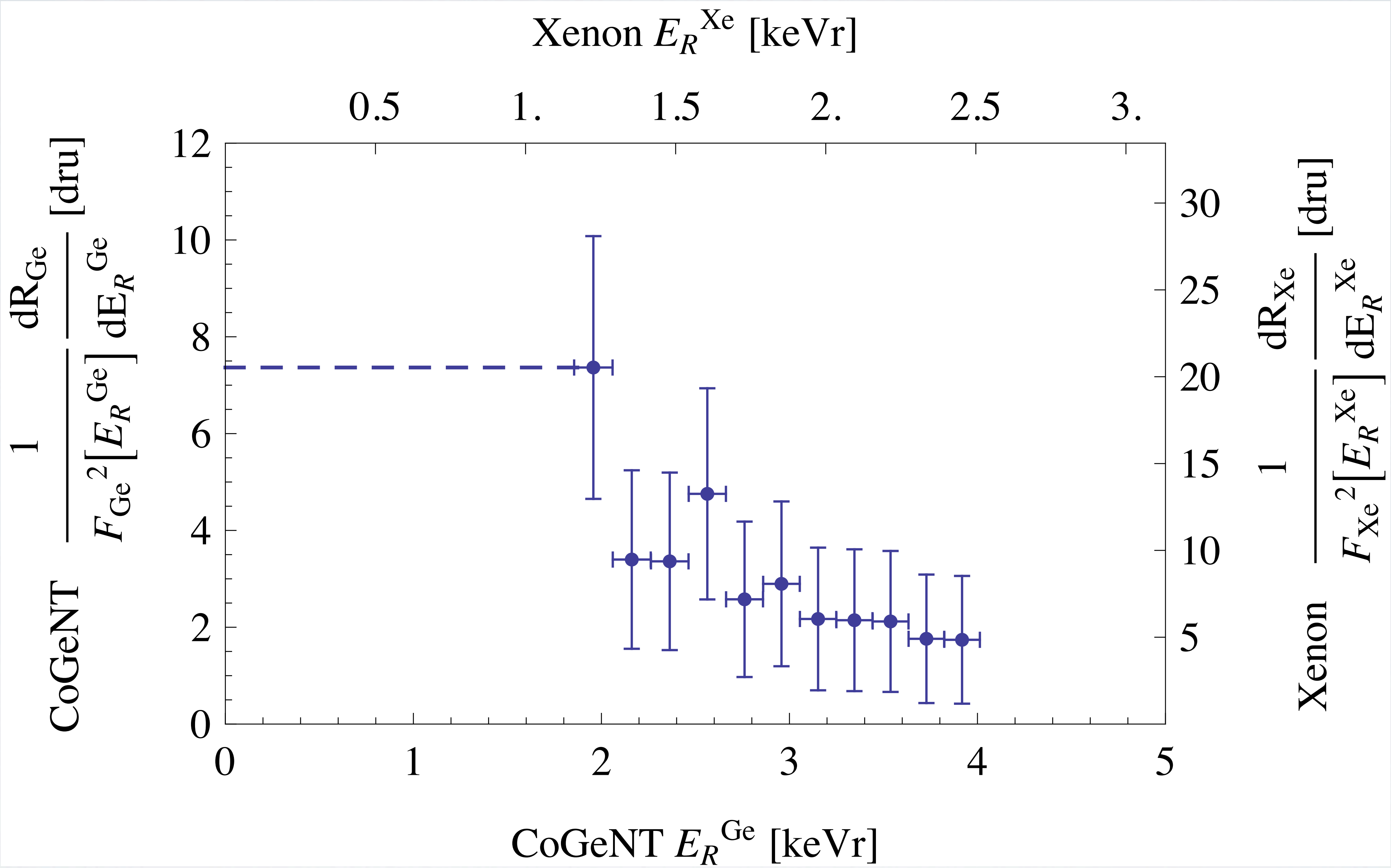
$$[E^1_{low}, E^1_{high}] \Leftrightarrow [E^2_{low}, E^2_{high}]$$

Invert:

$$\frac{dR}{dE_R} = \frac{N_T M_T \rho}{2m_\chi \mu^2} \sigma(E_R)\, g(v_{min}) \longrightarrow g(v) = \frac{2m_\chi \mu^2}{N_T M_T \rho \sigma(E_R)} \frac{dR_1}{dE_1}$$

$$\frac{dR_2}{dE_R}(E_2) = \frac{C_T^{(2)}}{C_T^{(1)}} \frac{F_2^2(E_2)}{F_1^2\left(\frac{\mu_1^2\, M_T^{(2)}}{\mu_2^2 M_T^{(1)}} E_2\right)} \frac{dR_1}{dE_R}\left(\frac{\mu_1^2\, M_T^{(2)}}{\mu_2^2\, M_T^{(1)}} E_2\right)$$

A direct prediction of the rate
at experiment 2 from experiment 1



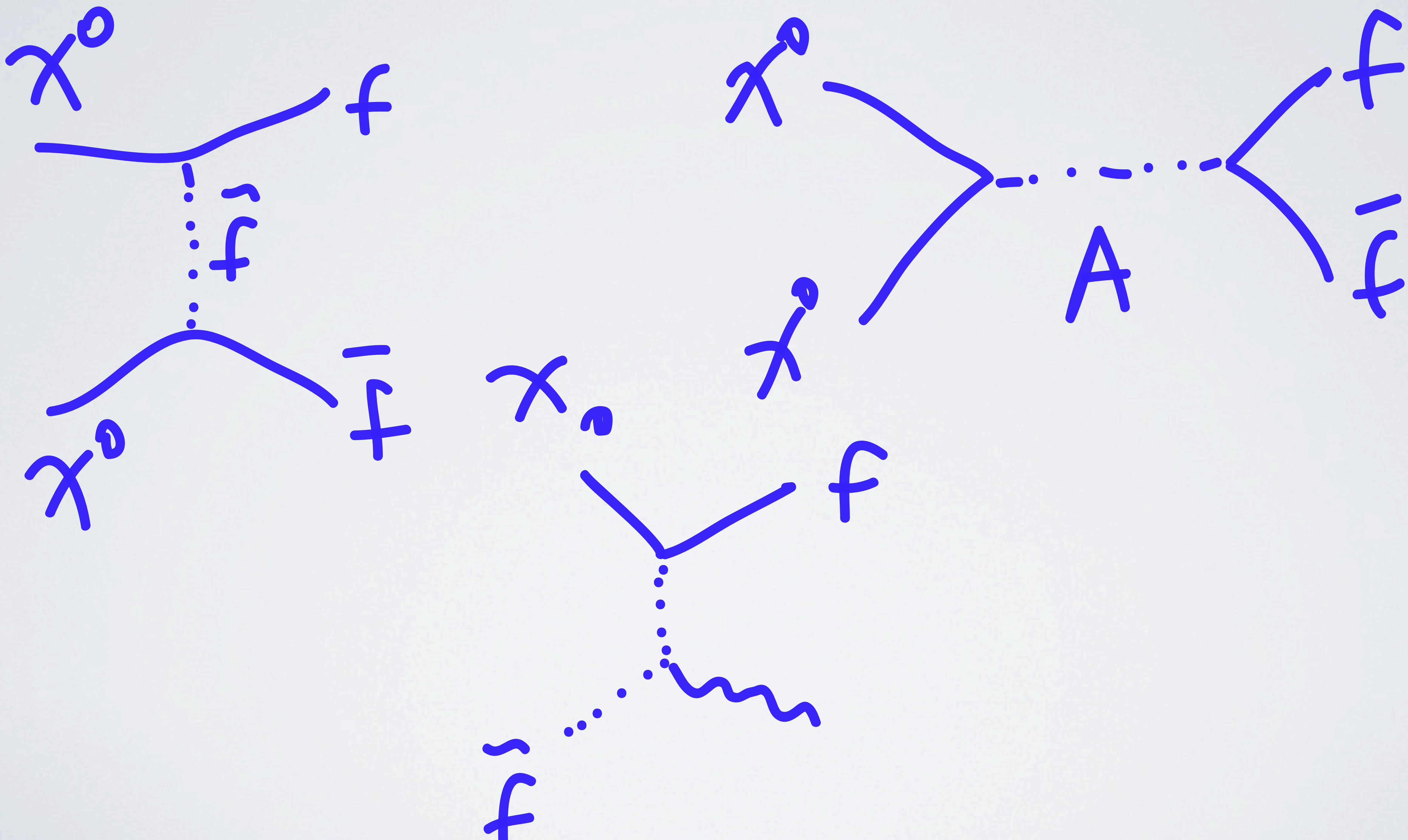
Mapping between two experiments depends *only* on mass

HOW DOABLE IS THIS?

- In progress, but hard

WHAT SUSY DOES FOR YOU

- A singlet, a doublet and a triplet with some specific couplings



WHAT SUSY DOES FOR YOU

- Baryon and lepton number violation operators

LLE UDD LH

QLD

- Hence, a parity *that we invoke by hand*

NEW STATES AT THE WEAK SCALE

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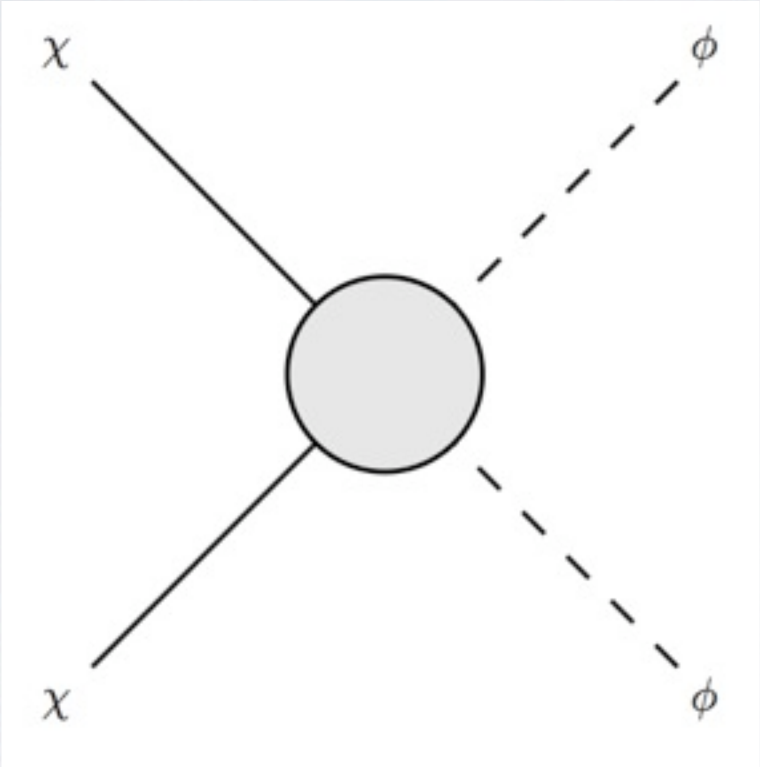
In SUSY the Higgs is light for no good reason!

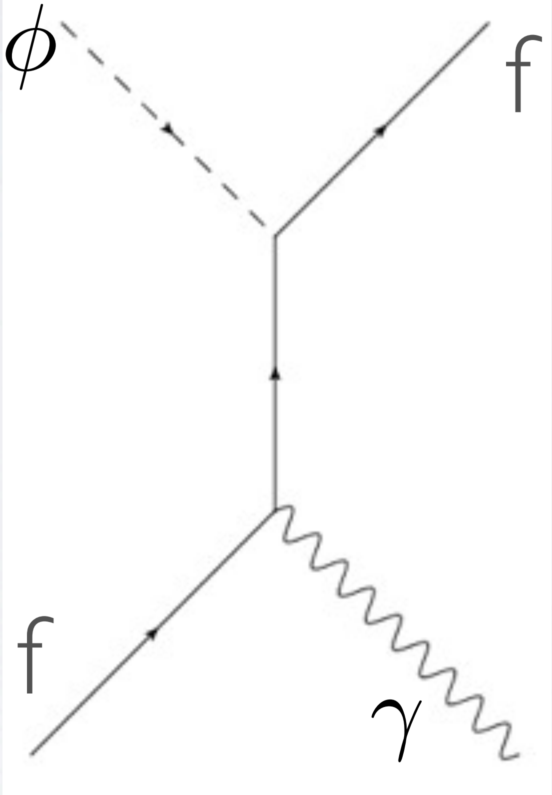
NEW STATES AT THE WEAK SCALE

In SUSY the Higgs is light for no good reason!

"X" may keep other things light, too

SUSY PORTAL DARK MATTER





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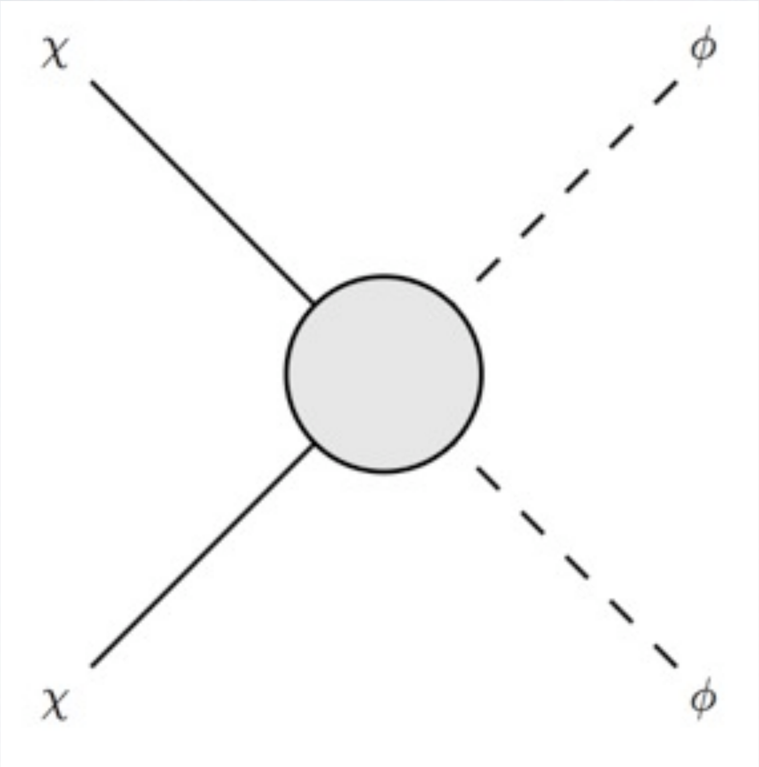

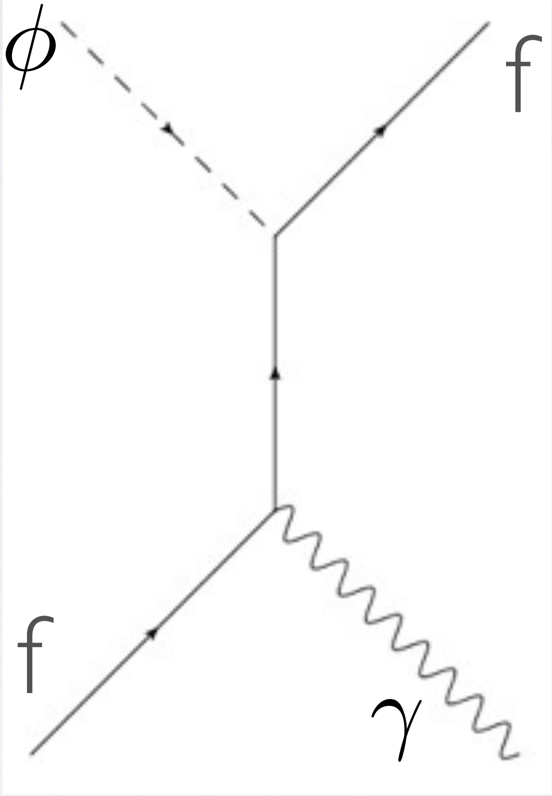

Even with interaction strengths ~ 10^{-8} x SM can maintain equilibrium

SUSY PORTAL DARK MATTER

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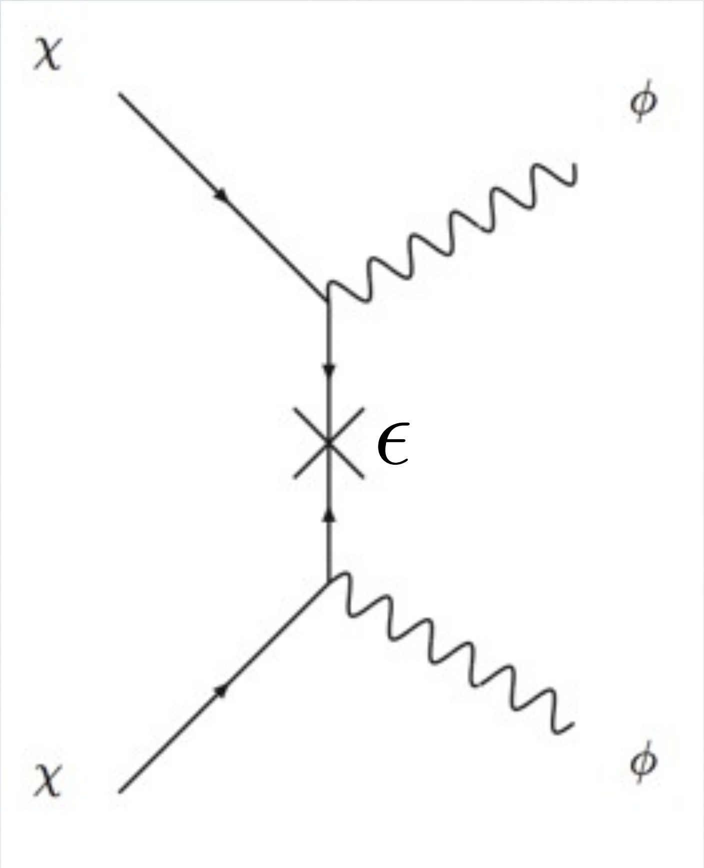
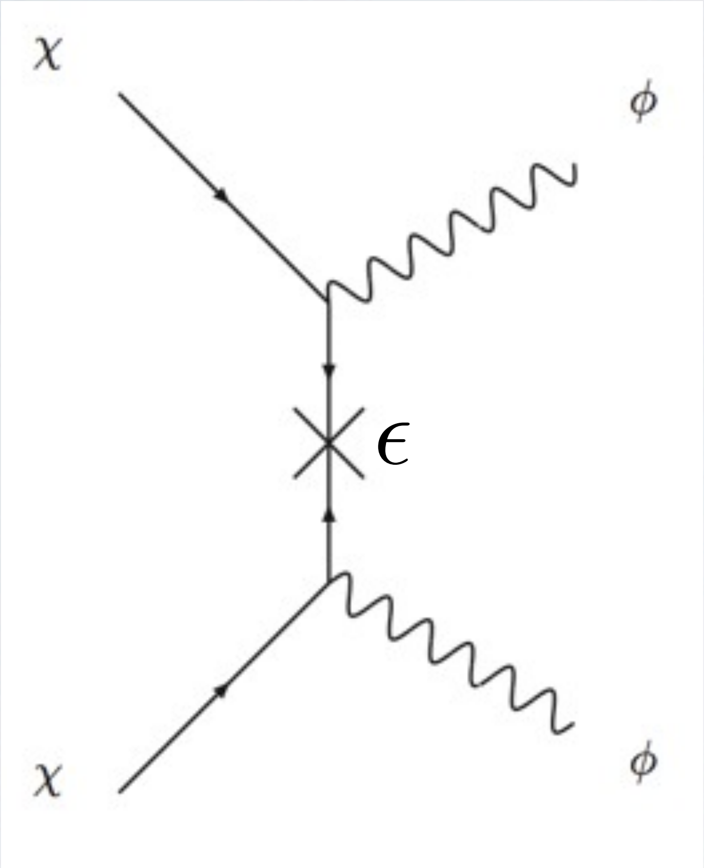


SUSY PORTAL DARK MATTER



$$\sigma \approx \frac{\alpha_d^2}{m_\chi^2}$$

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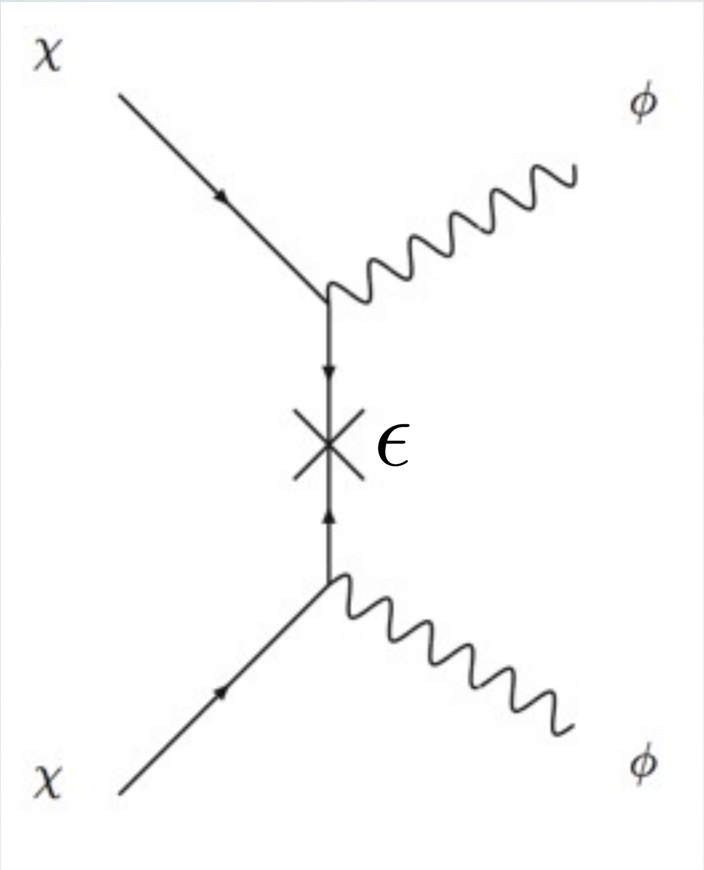

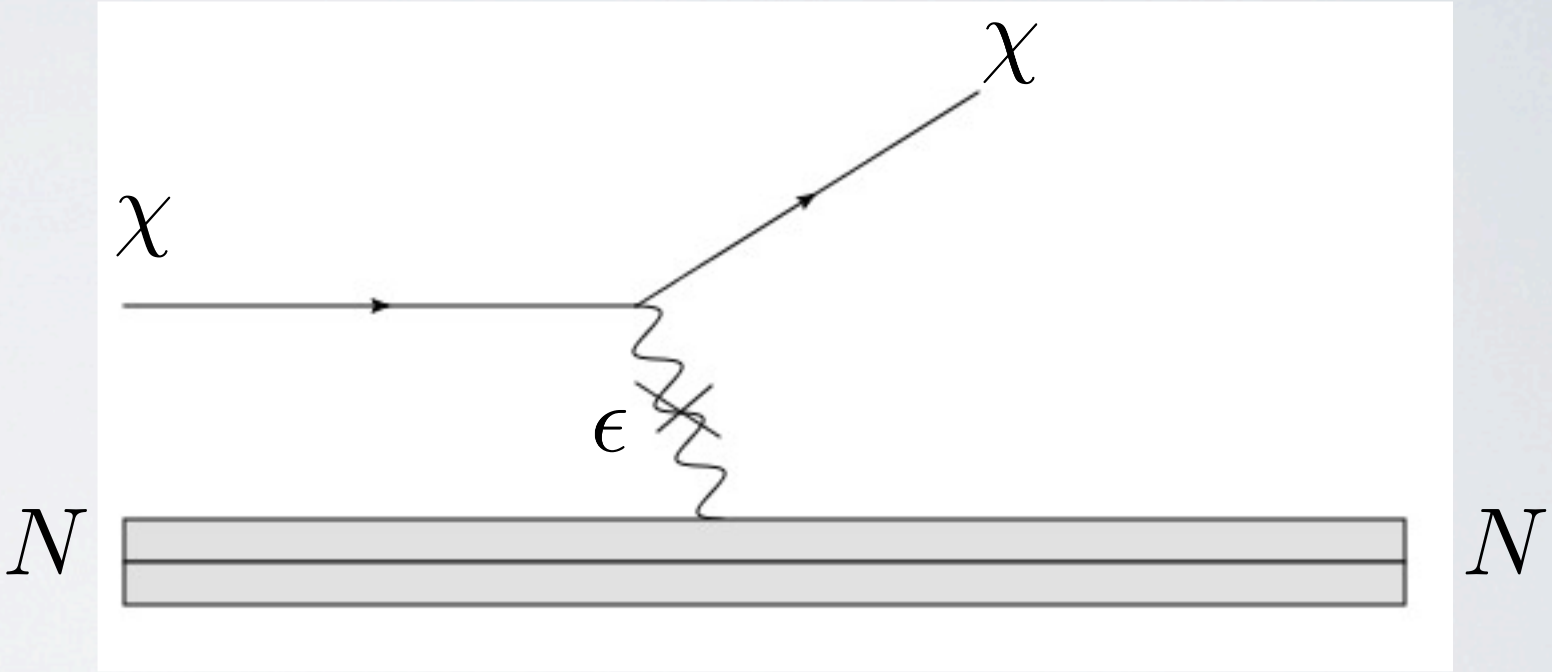

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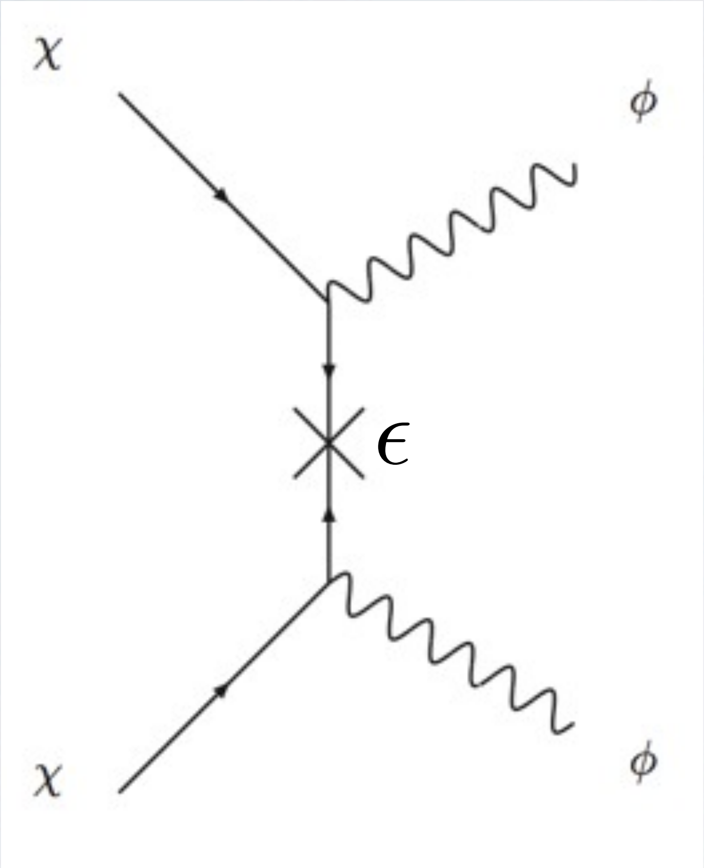

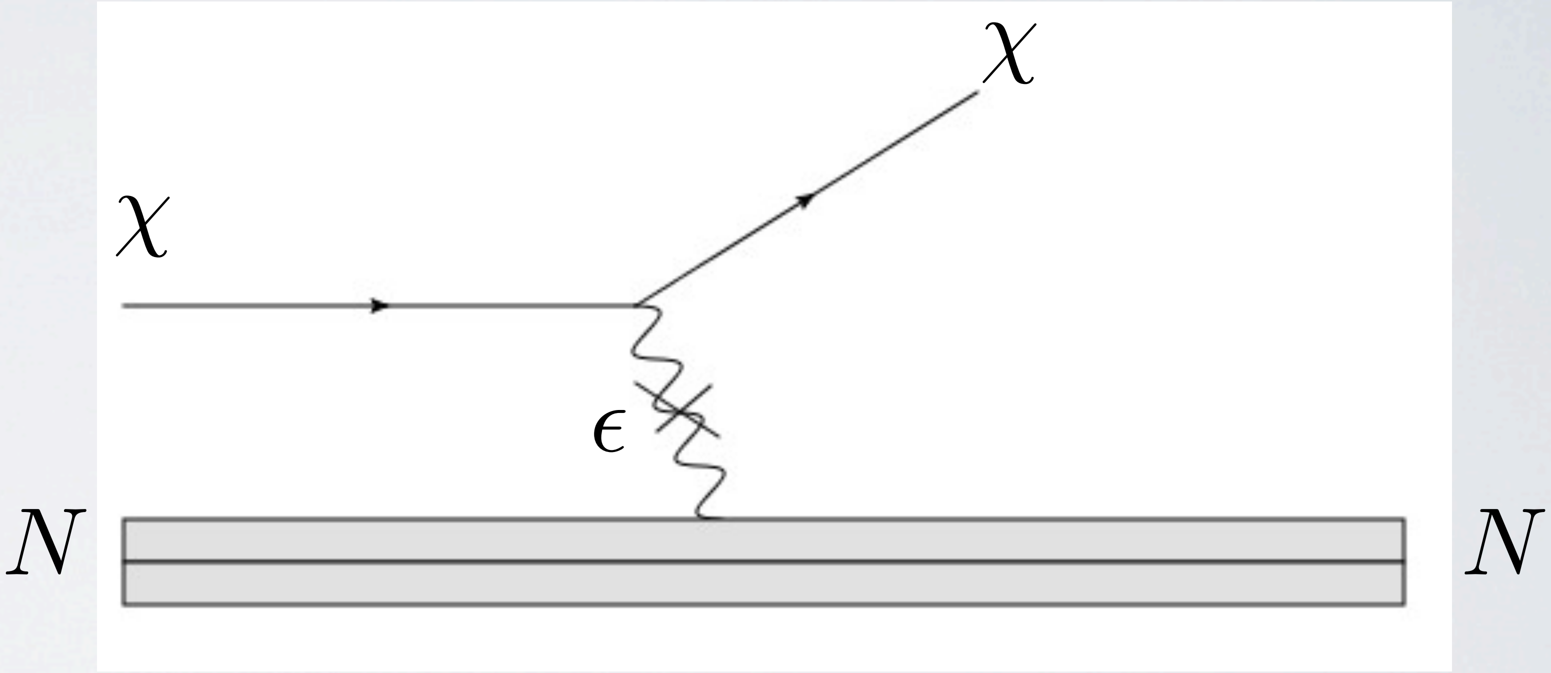

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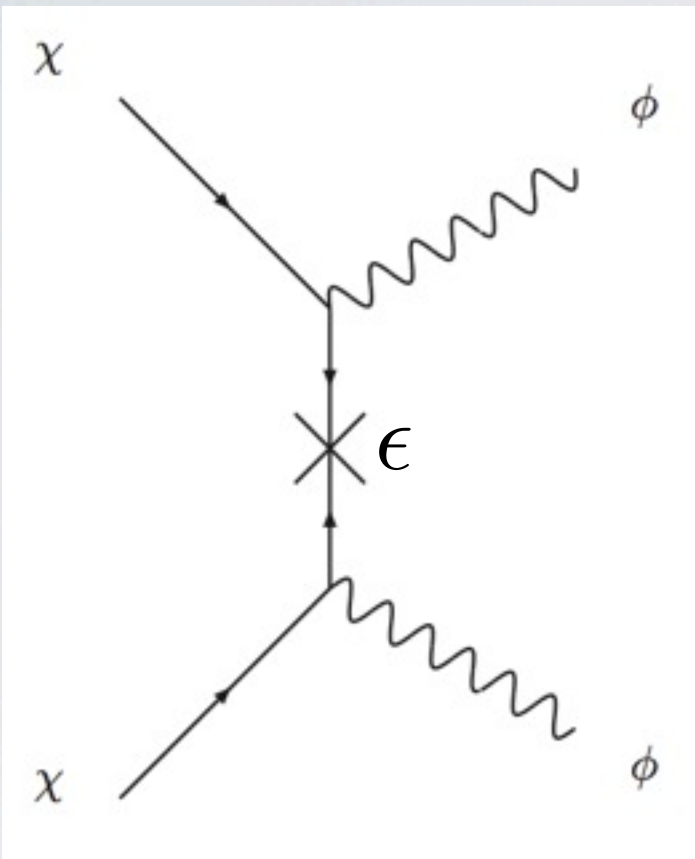
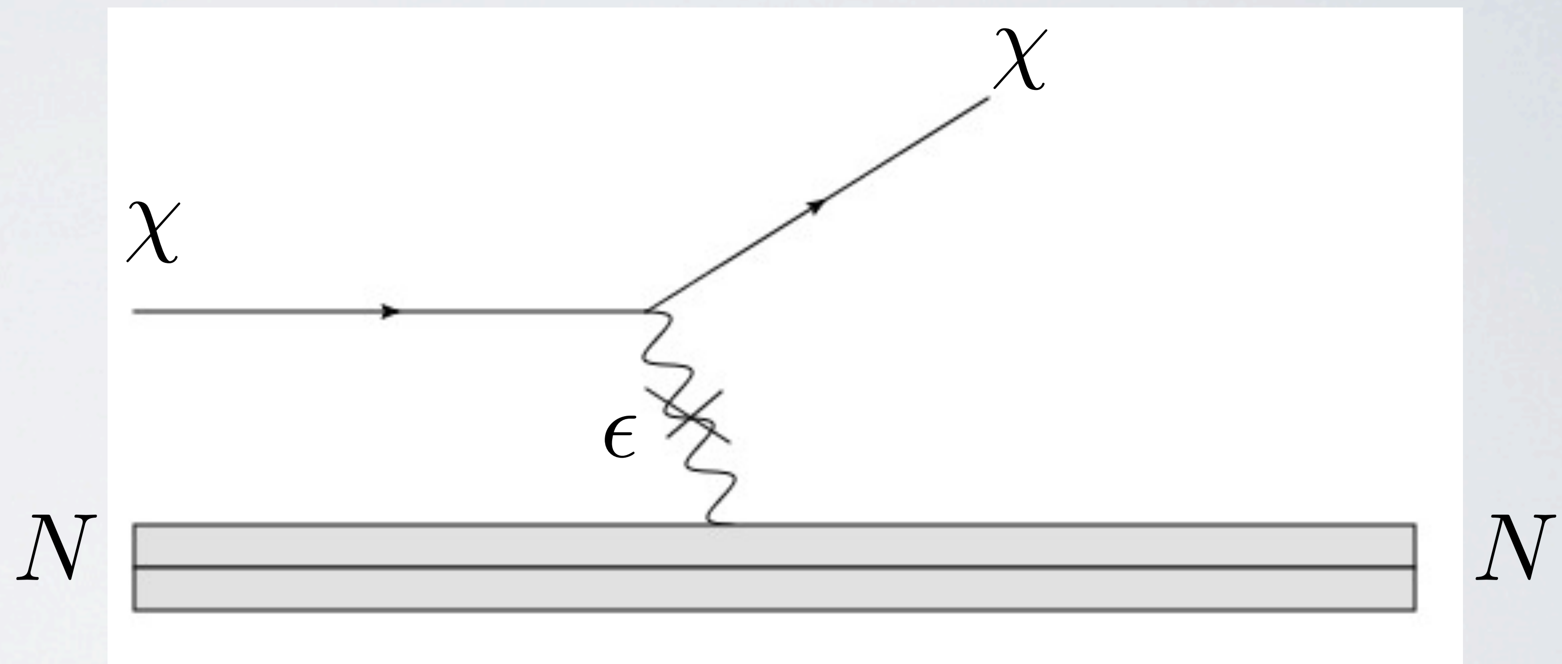




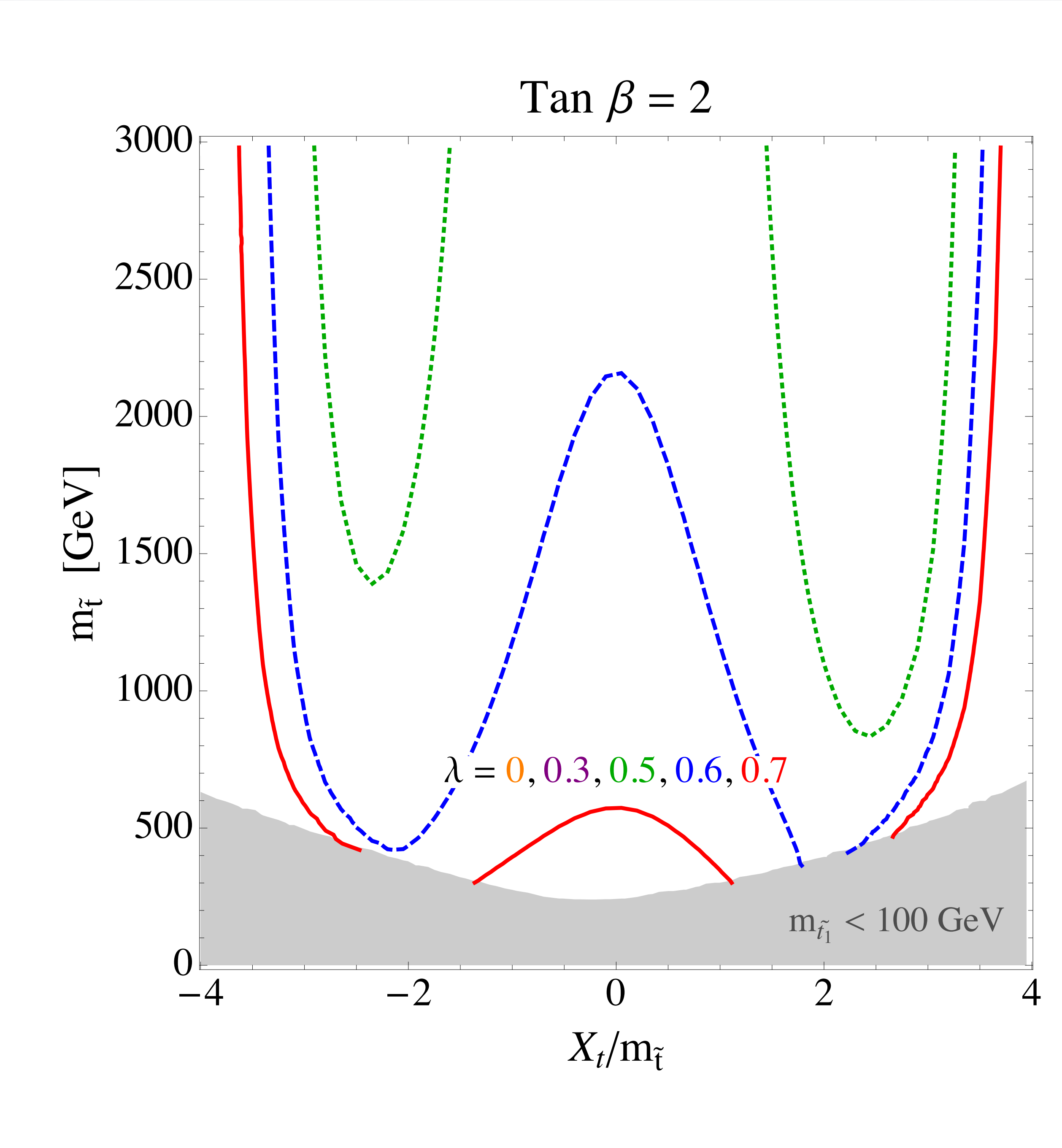
$$\sigma \approx \frac{\alpha_d^2}{m_\chi^2} \qquad \sigma \approx \frac{\alpha_d \alpha_{EM} \epsilon^2}{m_\phi^4}$$

Better chance of seeing with a vector portal

mass can be anything - not necessarily the LSP

THE NMSSM AND DARK MATTER

from Carlos' talk from Hall, Pinner, Ruderman



THE NMSSM

$$W = \lambda S H_u H_d$$

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A complete standard model singlet?

tadpoles? domain walls?

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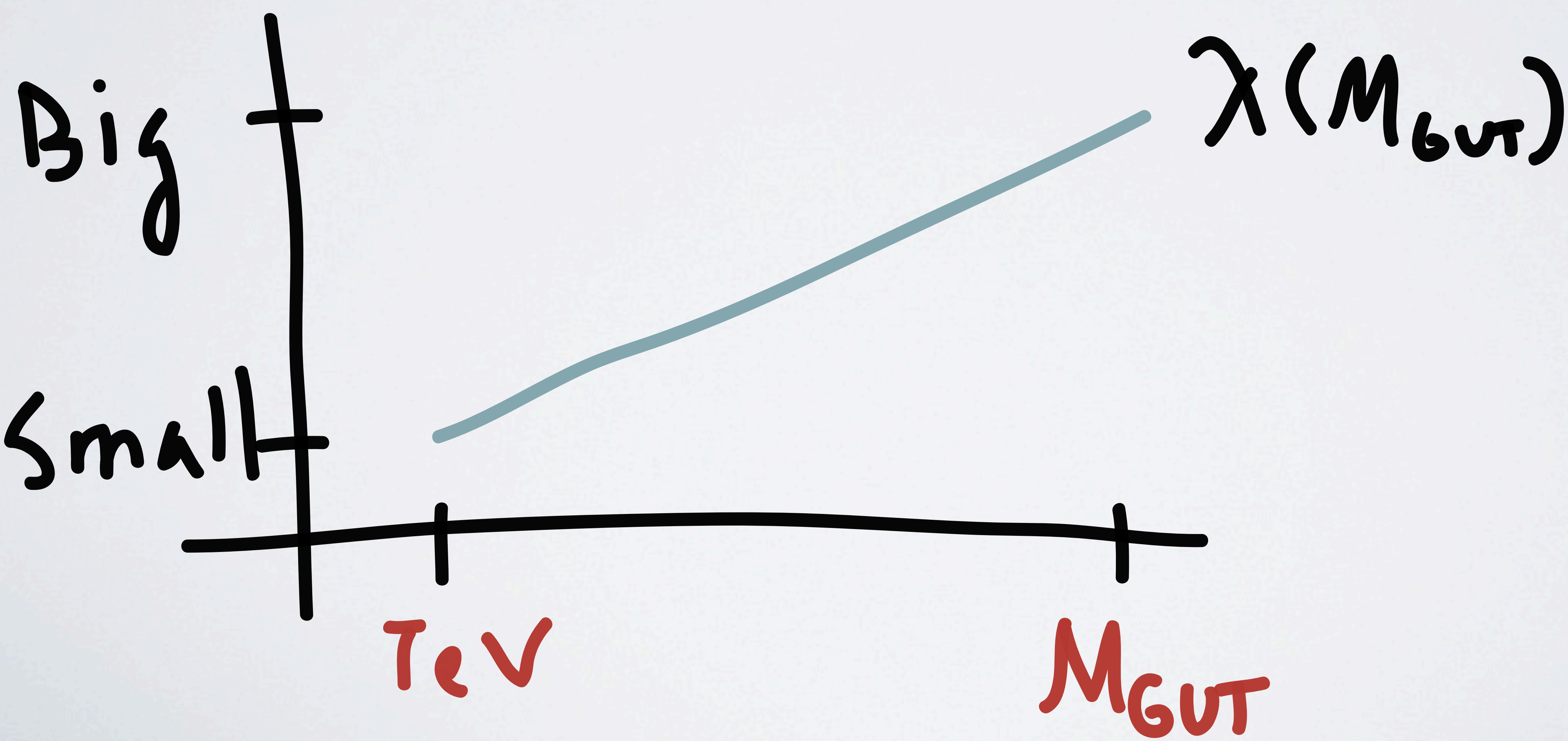
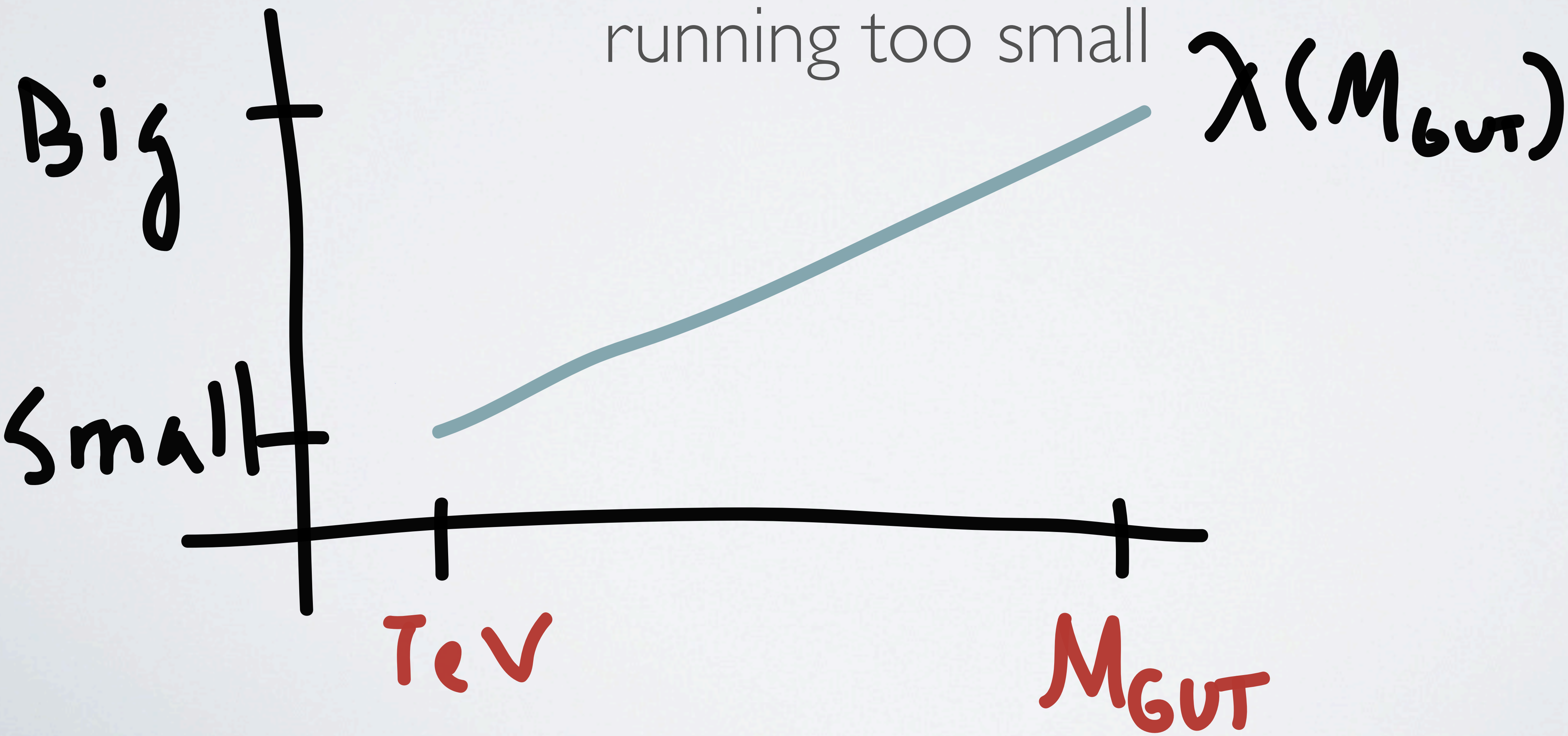


THE NMSSM

$$W = \lambda S H_u H_d$$

Yukawa couplings run weak at low energies

But gauge interactions keep it from running too small



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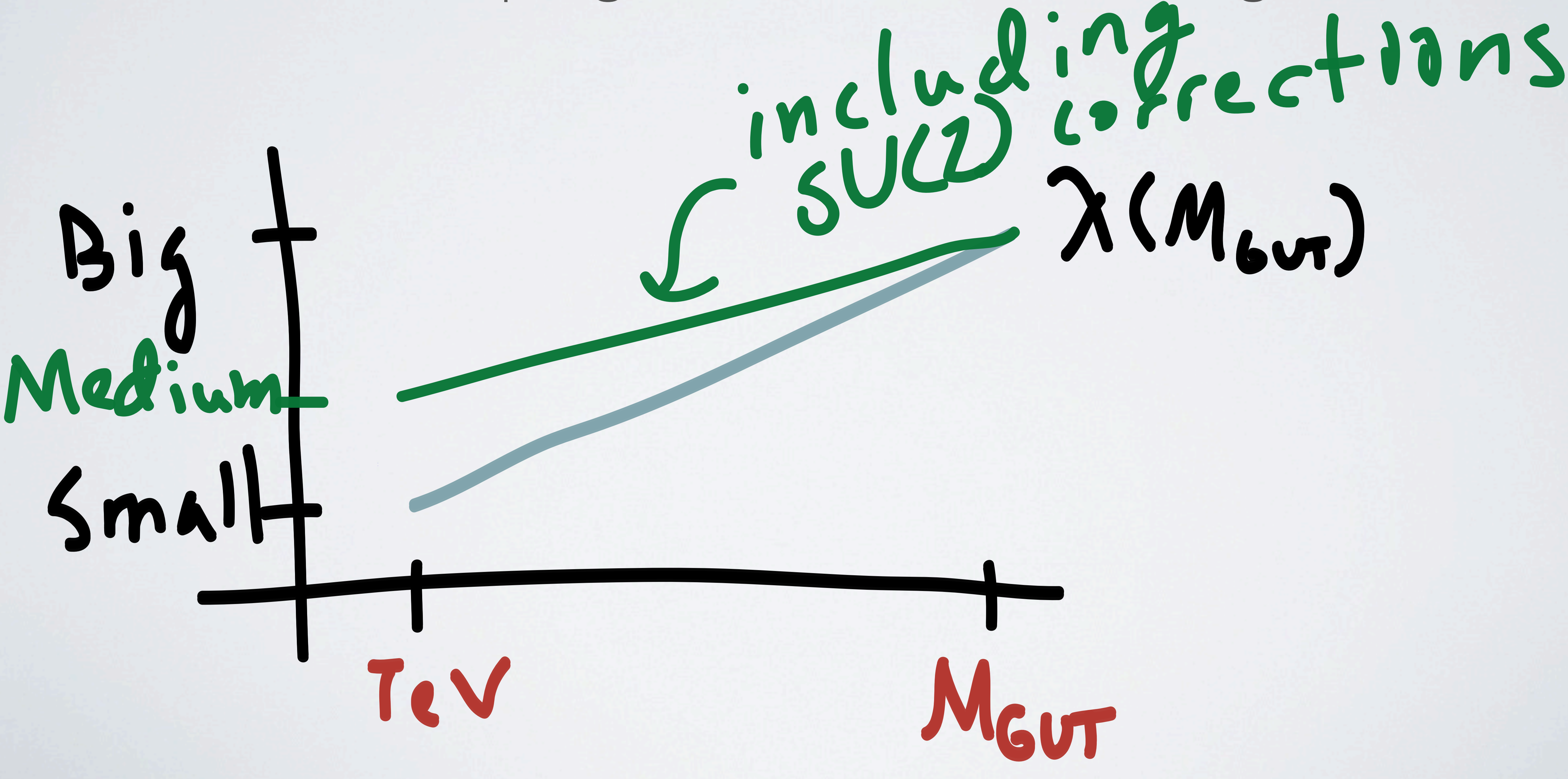

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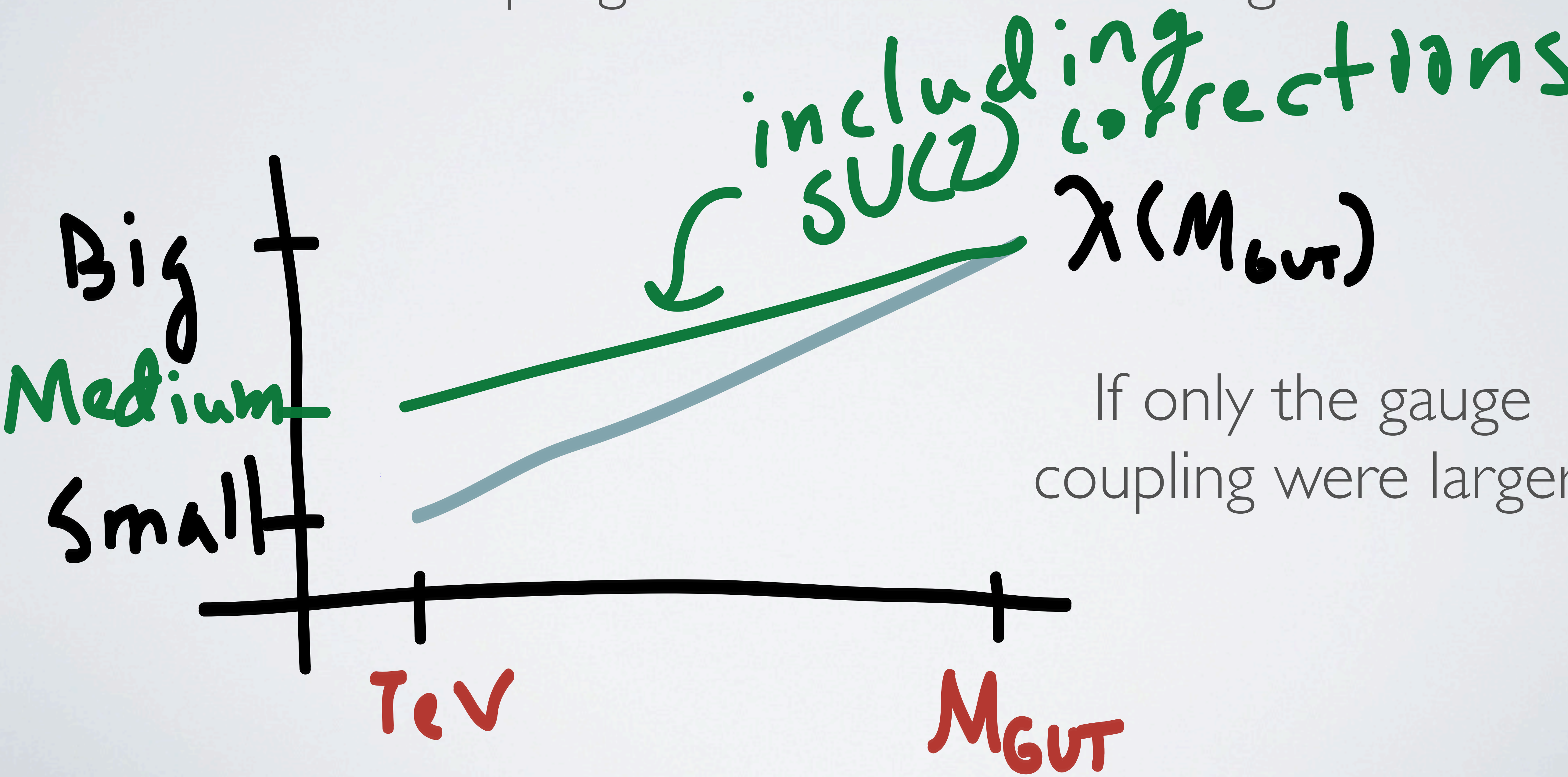

If only the gauge coupling were larger!

REEXAMINING NMSSM

$$W = \lambda S H_u H_d$$

$$\rightarrow \quad V \sim \lambda^2 |h_u h_d|^2$$

REEXAMINING NMSSM

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- Why not think of it as something totally different?

A SISTER HIGGS

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- proposal: h_d is not h_d, it is something else

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- ie $S\, H_u\, \mathbf{\Sigma}_d$
- $\mathbf{\Sigma}_d$ has no direct couplings to any fermions,
- "sister Higgs": Higgs that participates in EWSB but without tree level renormalizeable couplings to SM fermions

D. Alves, P. Fox, NW in progress

$$S H_u H_d \Rightarrow \phi H_u \Sigma_d$$

D. Alves, P. Fox, NW in progress

$$SH_uH_d \Rightarrow \phi H_u \Sigma_d$$

	ϕ	$\bar{\phi}$	H_u	H_d	Σ_u	Σ_d
$U(1)_Y$	0	0	$\frac{1}{2}$	$-\frac{1}{2}$	$\frac{1}{2}$	$-\frac{1}{2}$
$SU(2)_W$	1	1	2	2	2	2
G_s	R	$\bar{R}$	1	1	$\bar{R}$	R

D. Alves, P. Fox, NW in progress

WHY A SISTER HIGGS

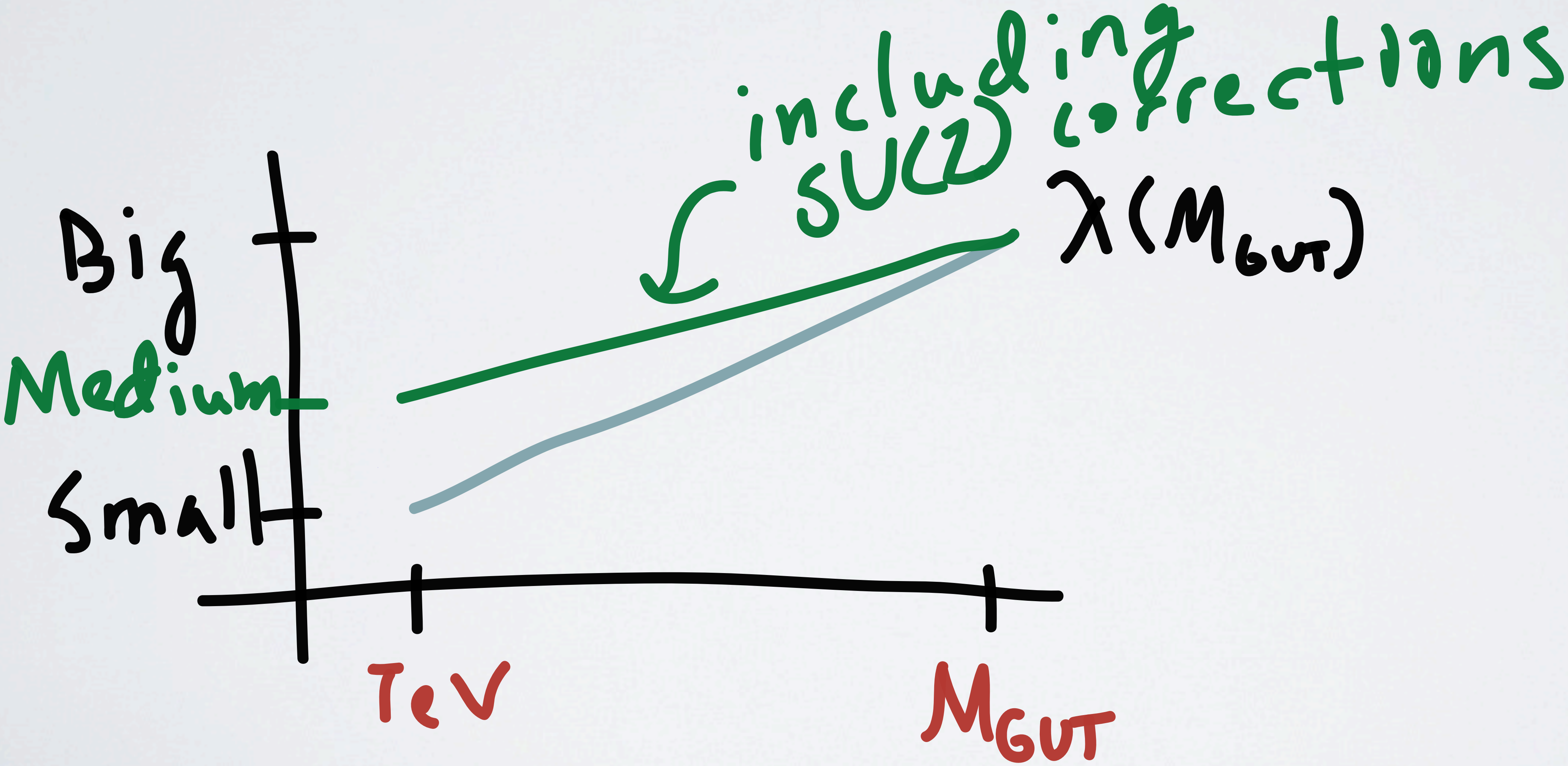
$$S H_u H_d \Rightarrow \Phi H_u \Sigma_d$$

WHY A SISTER HIGGS

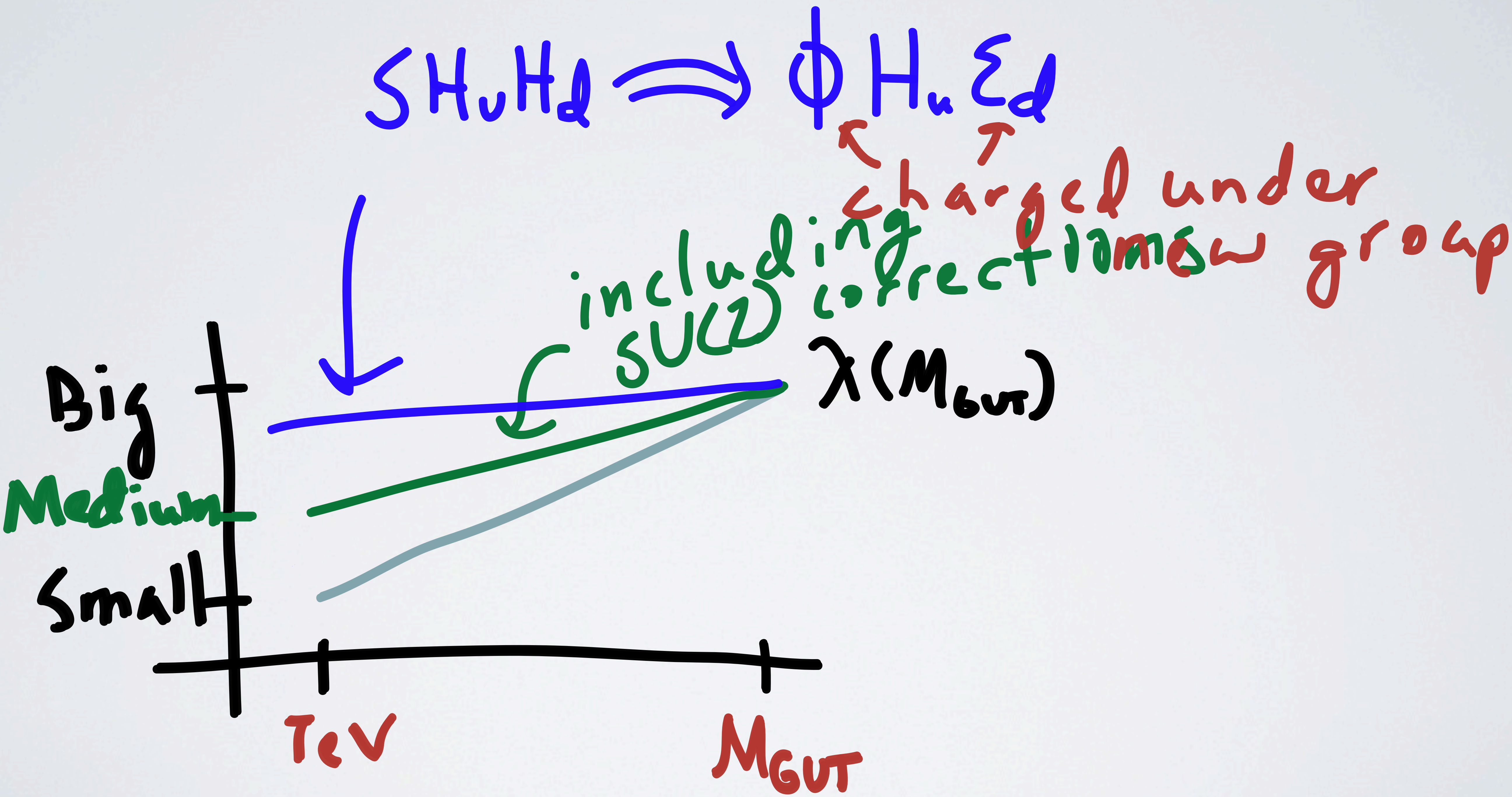
$$S H_u H_d \Rightarrow \Phi H_u \Sigma_d$$

can charge these

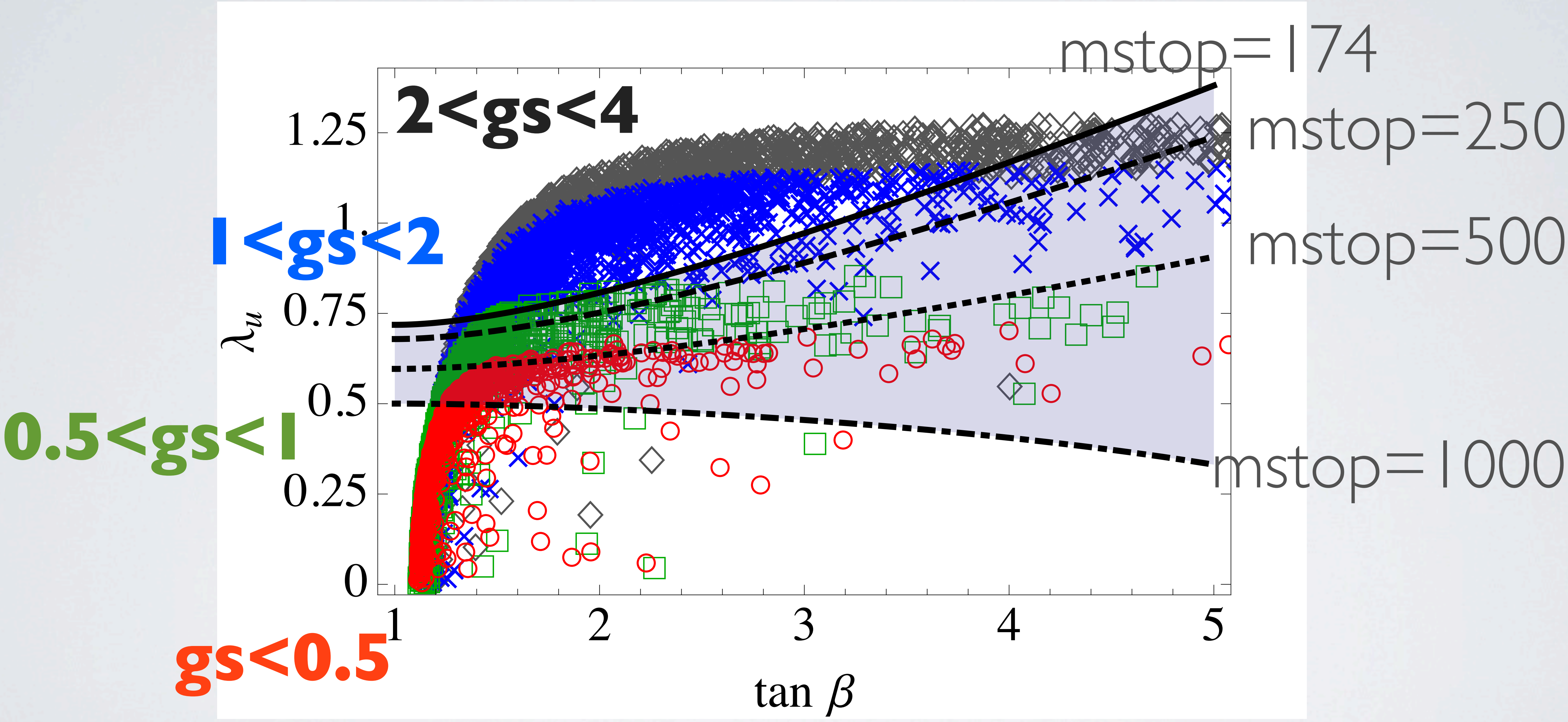
WHY A SISTER HIGGS



WHY A SISTER HIGGS



THE HIGGS MASS WITH A SISTER



DM WITH A SISTER

$\tilde{H}_u \quad \tilde{H}_d \quad \tilde{B} \quad \tilde{W}_3$

$\Sigma_u^0 \quad \Sigma_d^0 \quad \phi \quad \bar{\phi}$

$\tilde{Z}'$

SISTER HIGGS

- Sister Gauge group may be broken to contain a residual U(1)
- Lightest Sister Particle is then stable
- => 'ino like DM but not in cascades

SUSY AND NEW SYMMETRIES RPV

- The lack of MET signals may tell us
  - SUSY is heavy
  - SUSY is squeezed
  - SUSY is hidden (e.g., RPV)
  - None of these things tell us that there is no SUSY DM

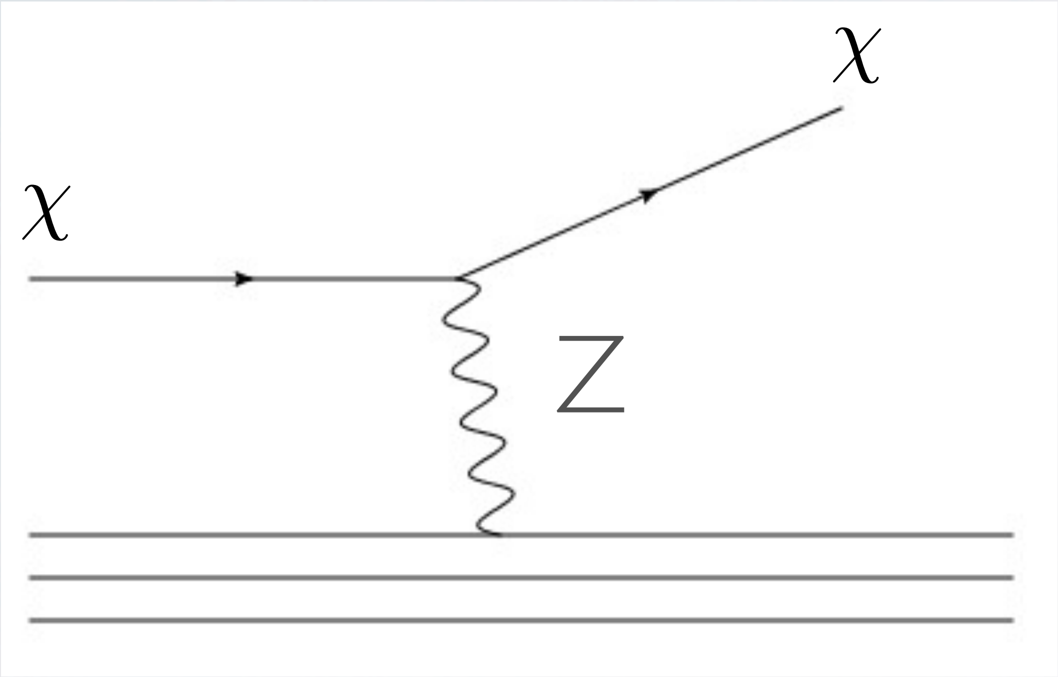
CONCLUSIONS

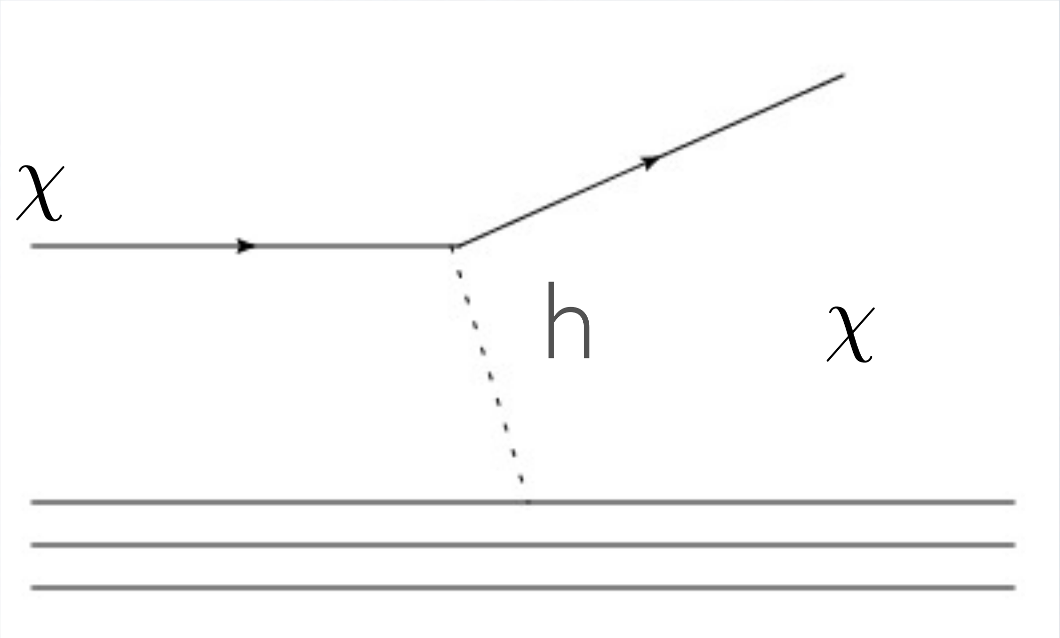
- The absence of spartners and the high Higgs mass may be telling us something:
- A "chaotic" SUSY model can easily have LSPs at low masses
- A "decoupled color" model can have electroweakinos at a light scale
- A "natural" unnatural SUSY model still have gauginos at the TeV scale

CONCLUSIONS

- In the "nightmare" scenario discovery is possible through
  - gluinos (in squeezed spectrum)
  - gluinos (for non-DM or non-thermal winos)
  - direct detection (even at the nightmare points)
- Higgs may be telling us the weak scale is more interesting
  - Other stable particles?
- What is SUSY DM?

THE TWO CROSS SECTIONS TO THINK ABOUT





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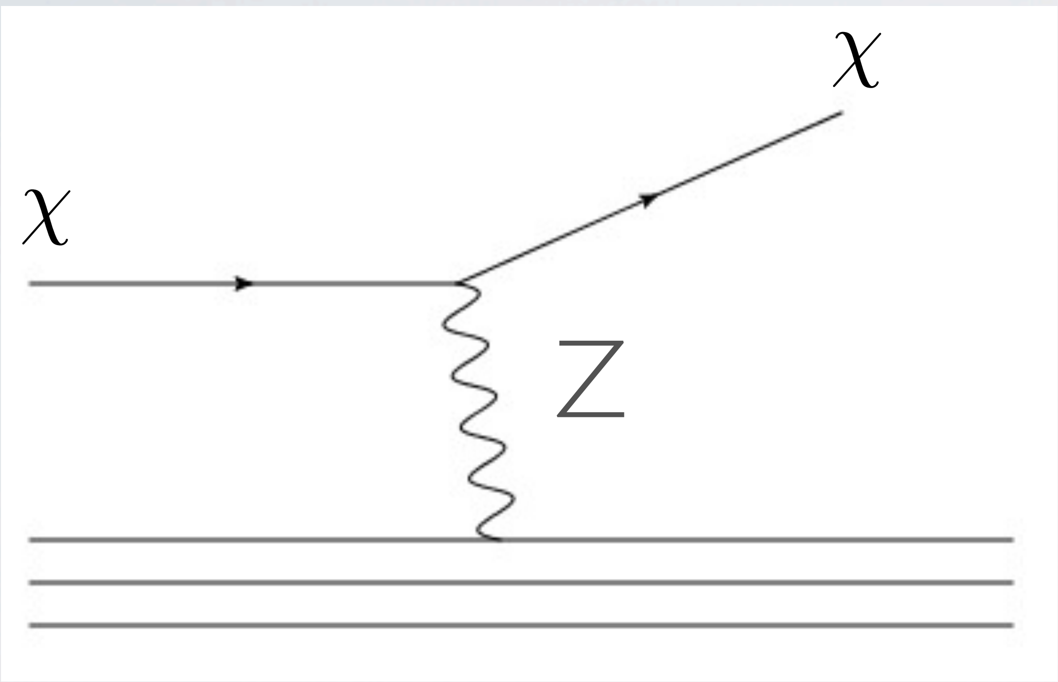
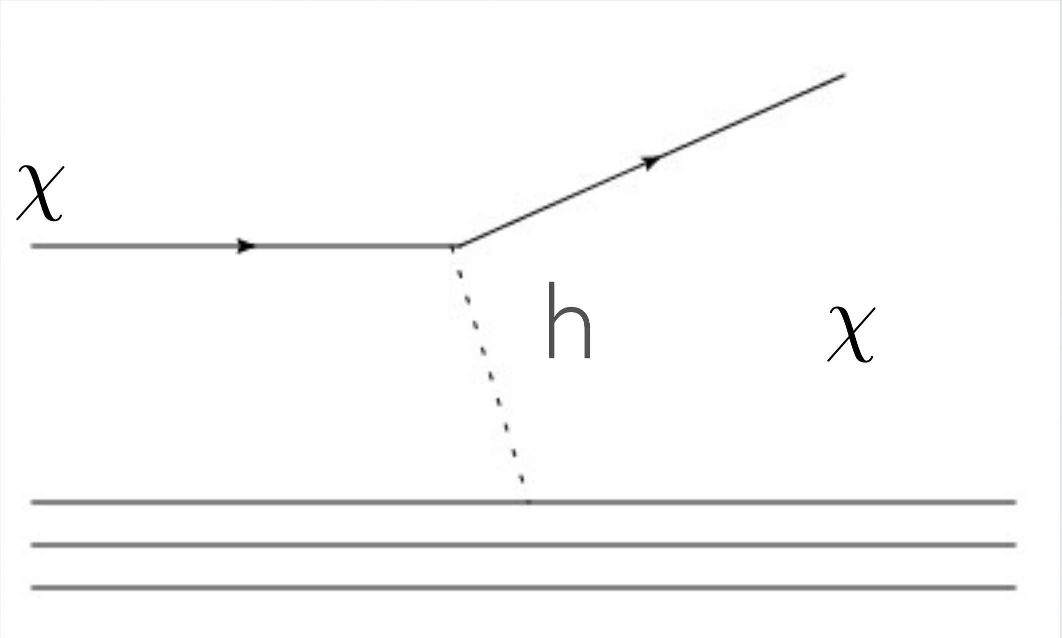
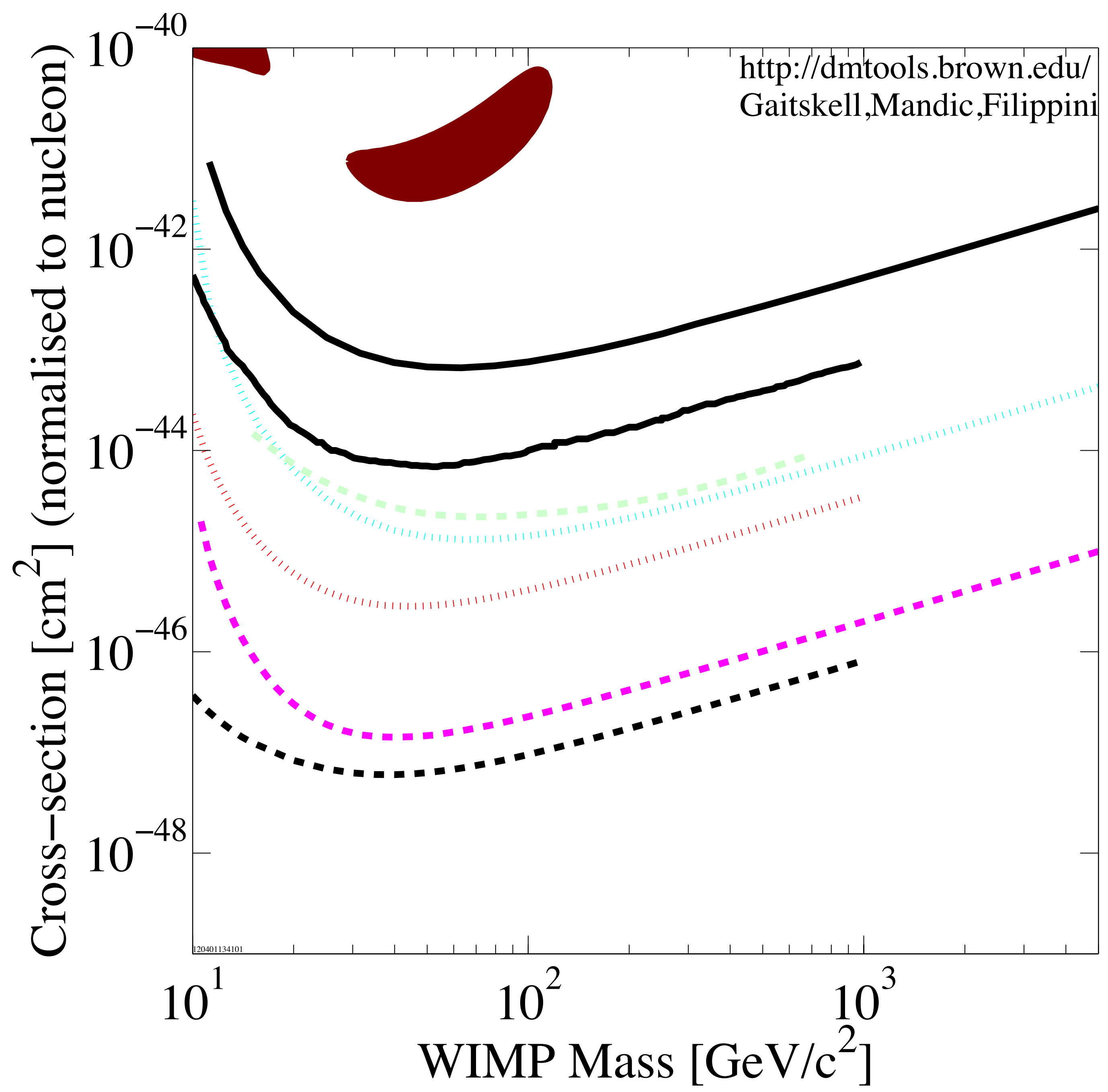




$$\sigma_0 \approx \frac{G_f^2 \mu^2}{2\pi} \sim 10^{-39} \mathrm{cm}^2$$



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Gaitskell,Mandic,Filippini
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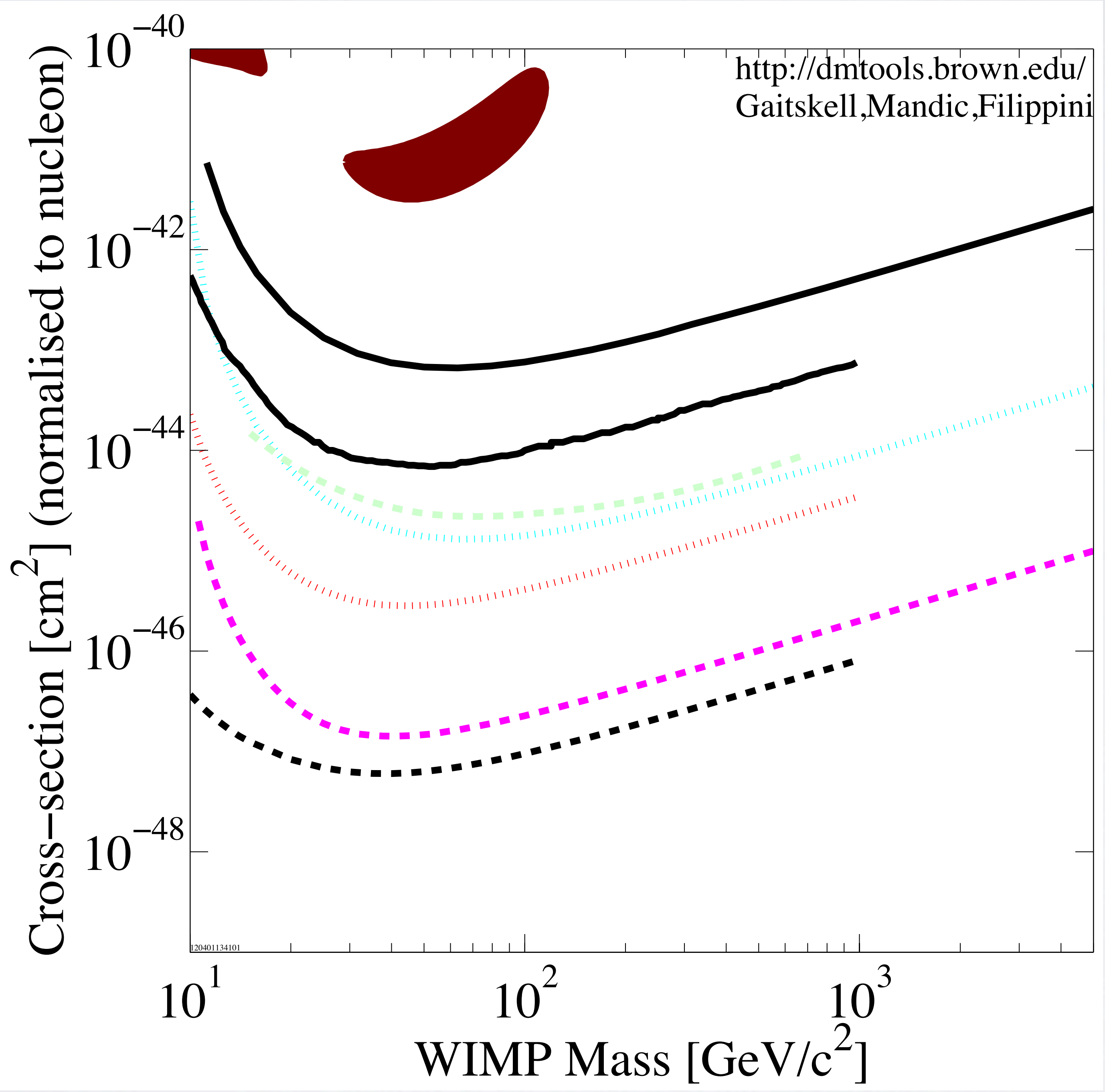

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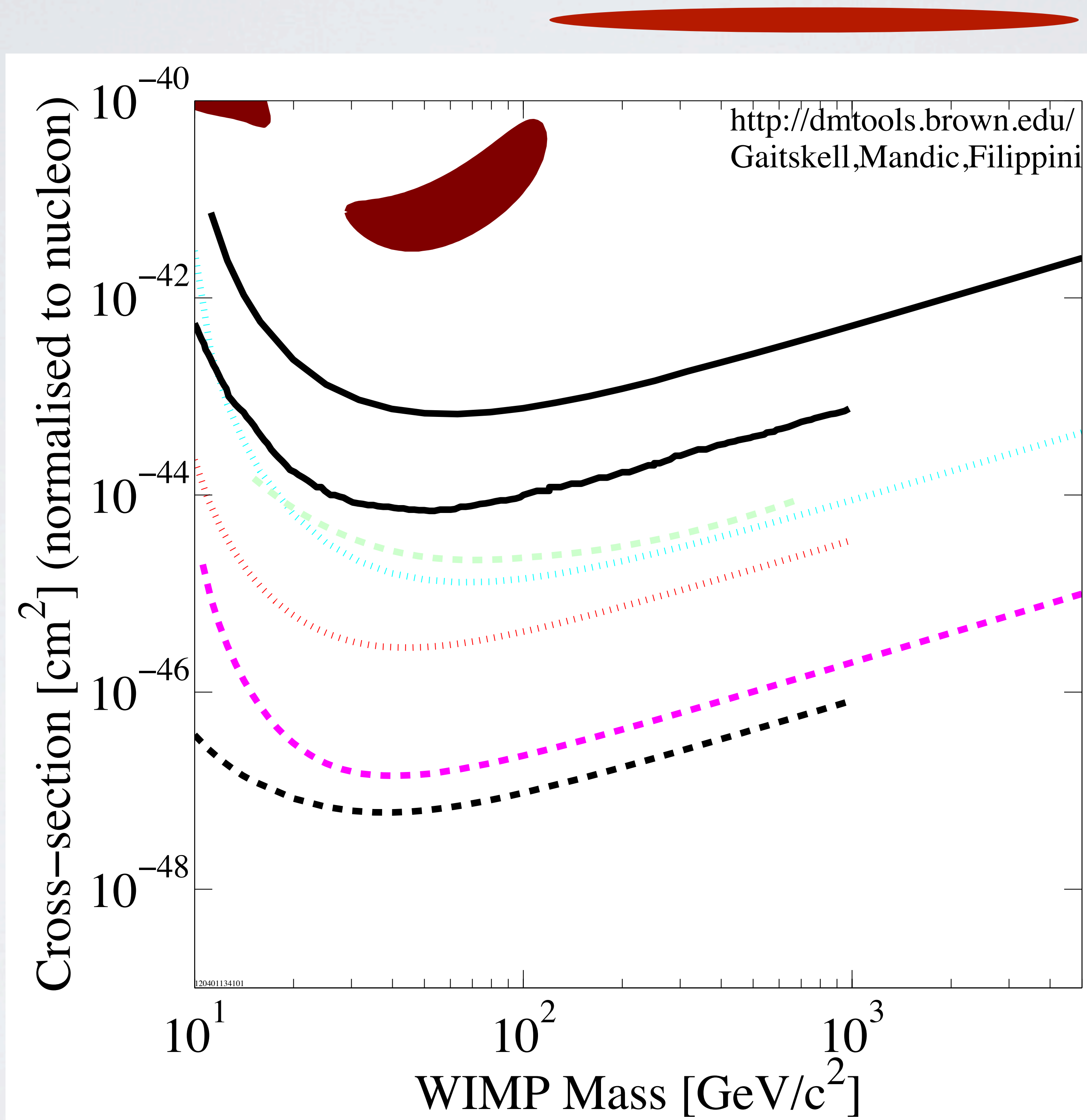
Ruled out
(just a little bit)



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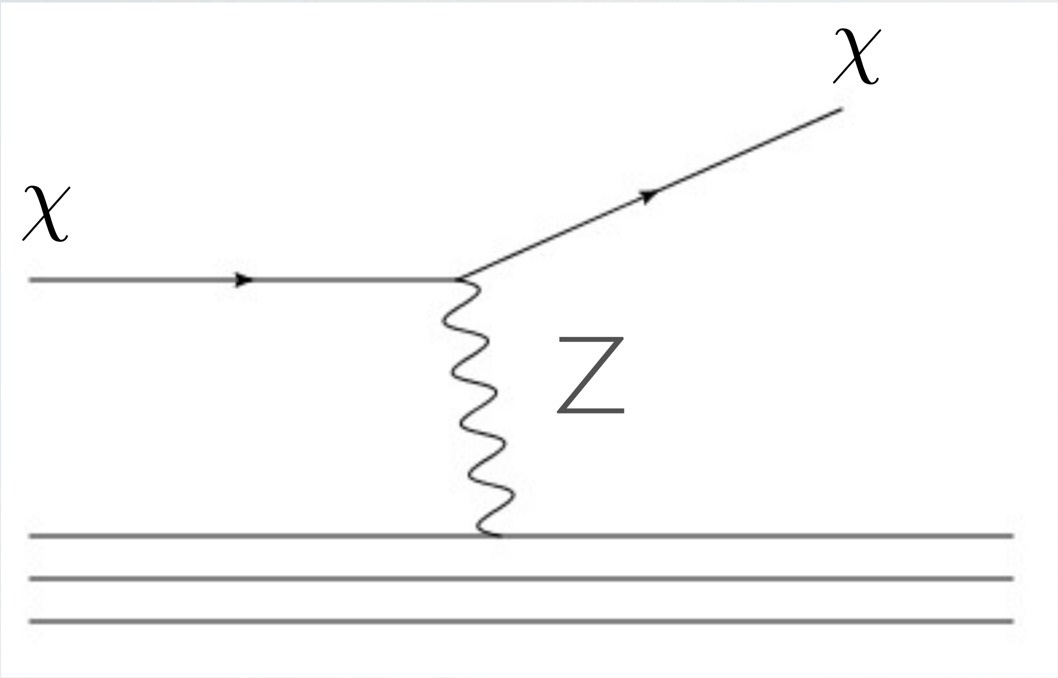

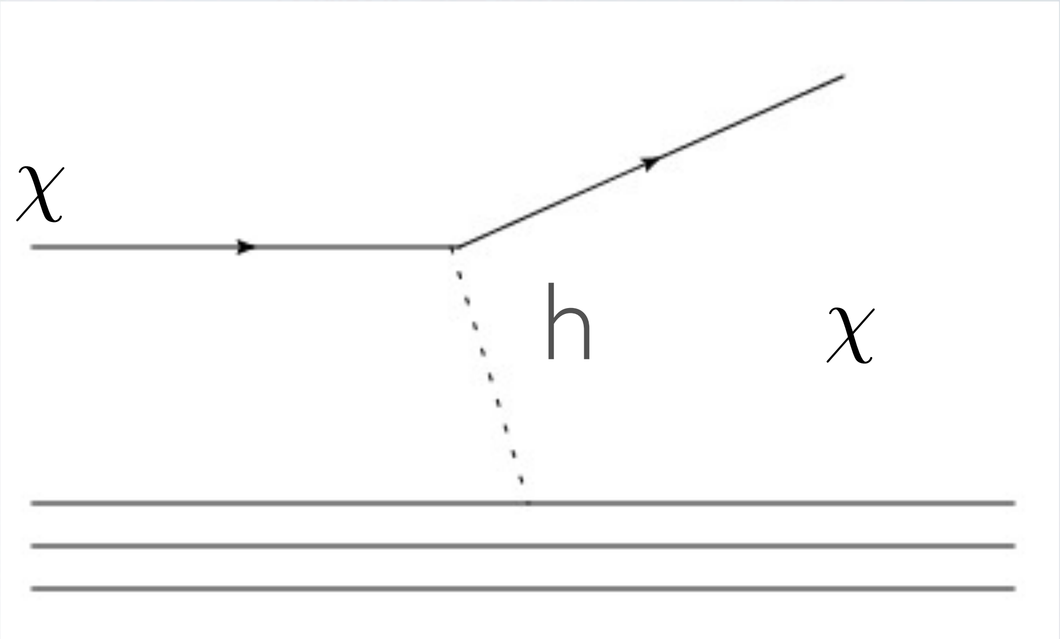

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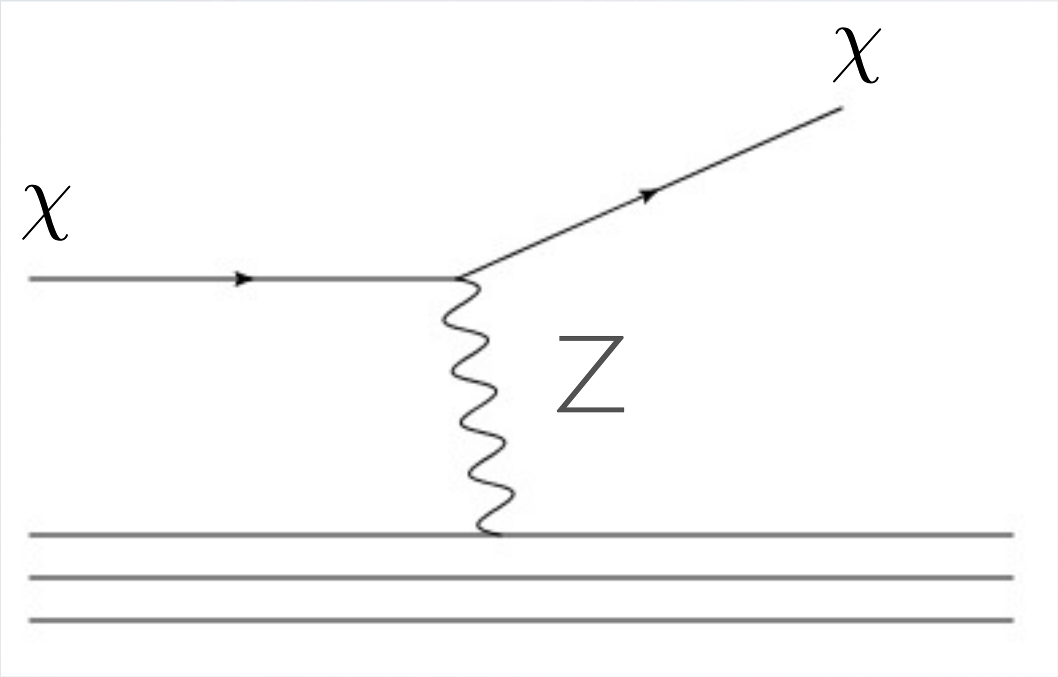

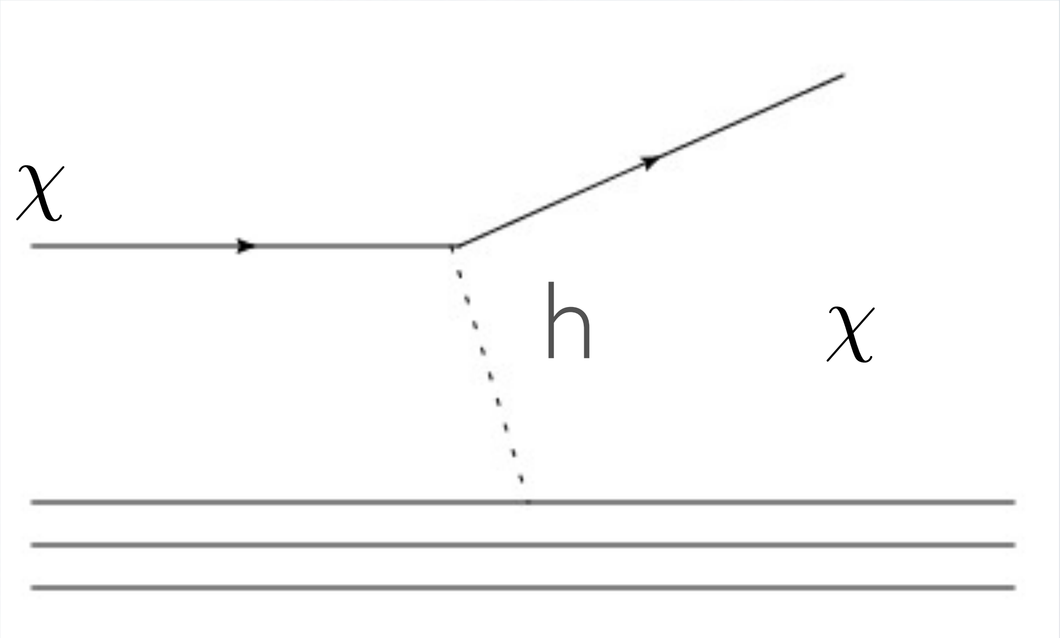

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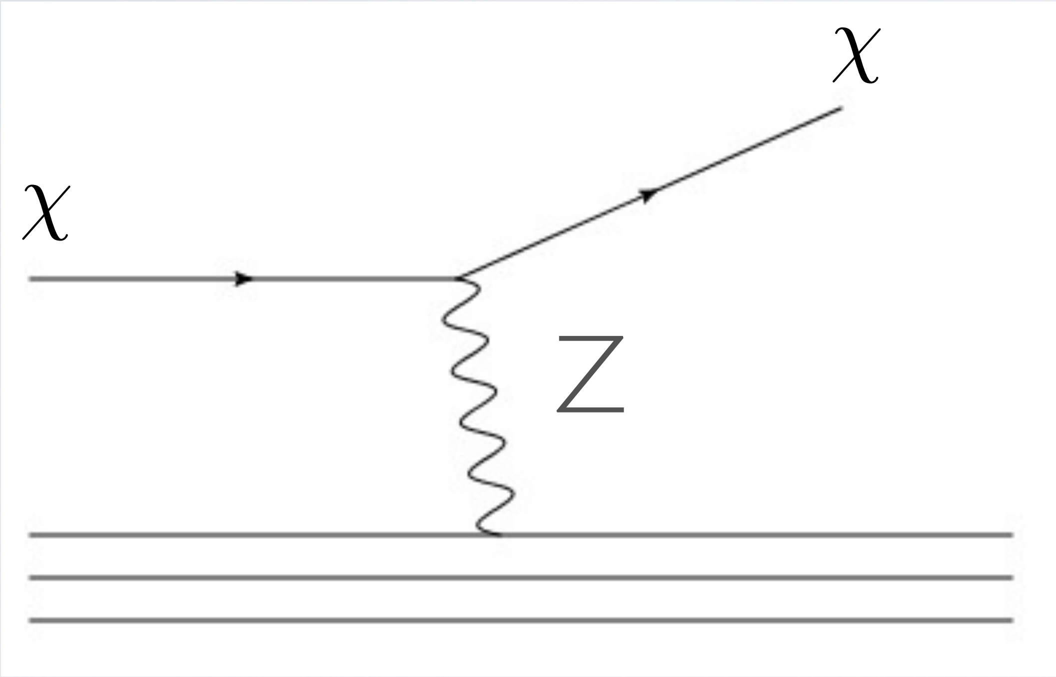

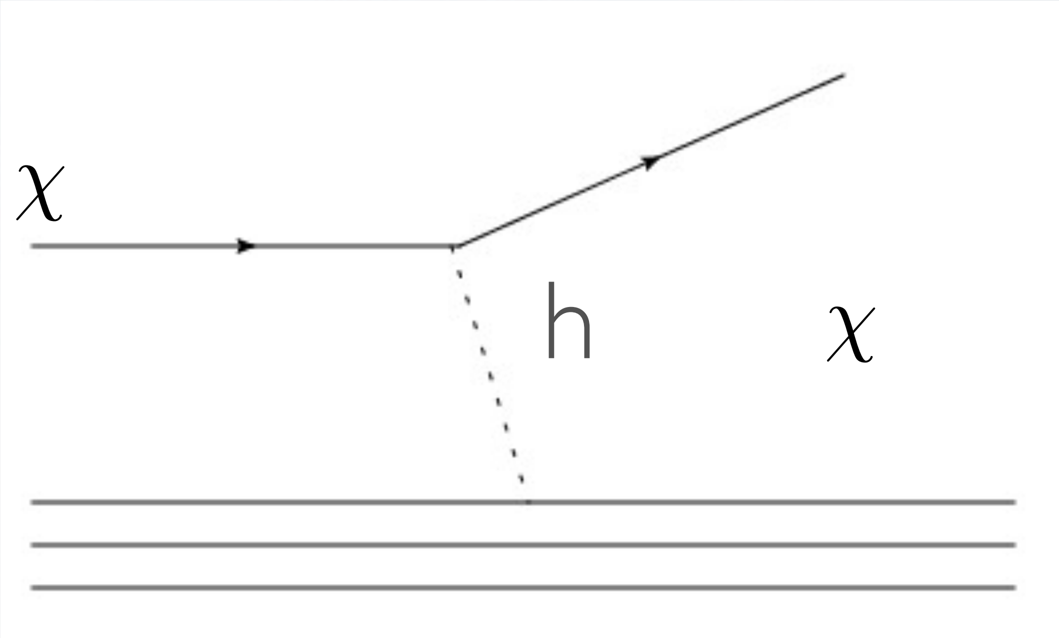

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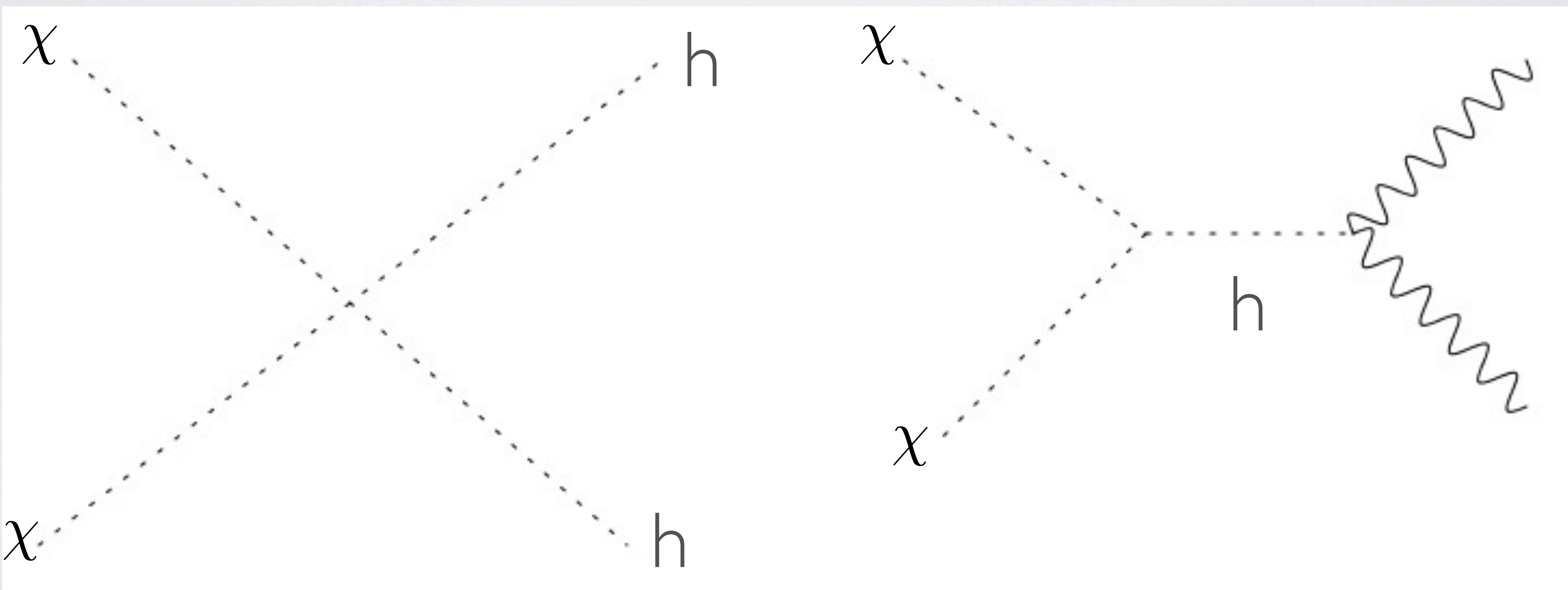
$$\sigma_0 \sim 10^{-39}\mathrm{cm}^2 \times 10^{-6}$$

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

A "MINIMAL MODEL" OF DARK MATTER

Burgess, Pospelov, ter Veldhuis, '01

$$V = \frac{m_0^2}{2} S^2 + \frac{\lambda}{2} S^2 h^2 + \frac{\lambda_S}{4} S^4 + \frac{\lambda_h}{4}\left(h^2 - v_{EW}^2\right)^2 .$$



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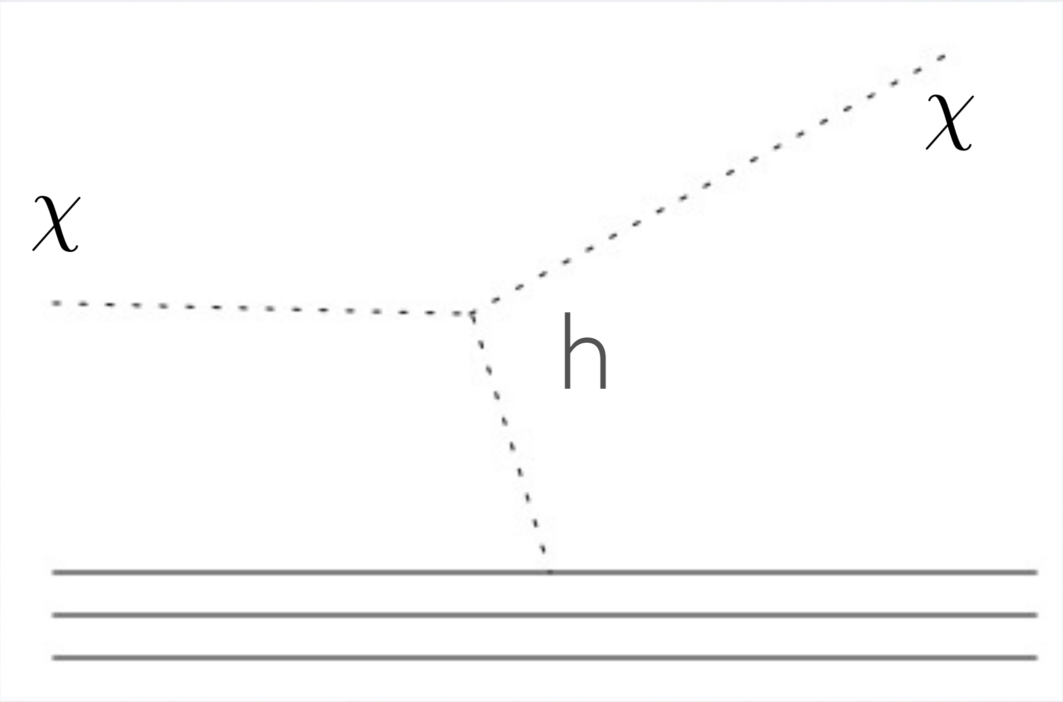

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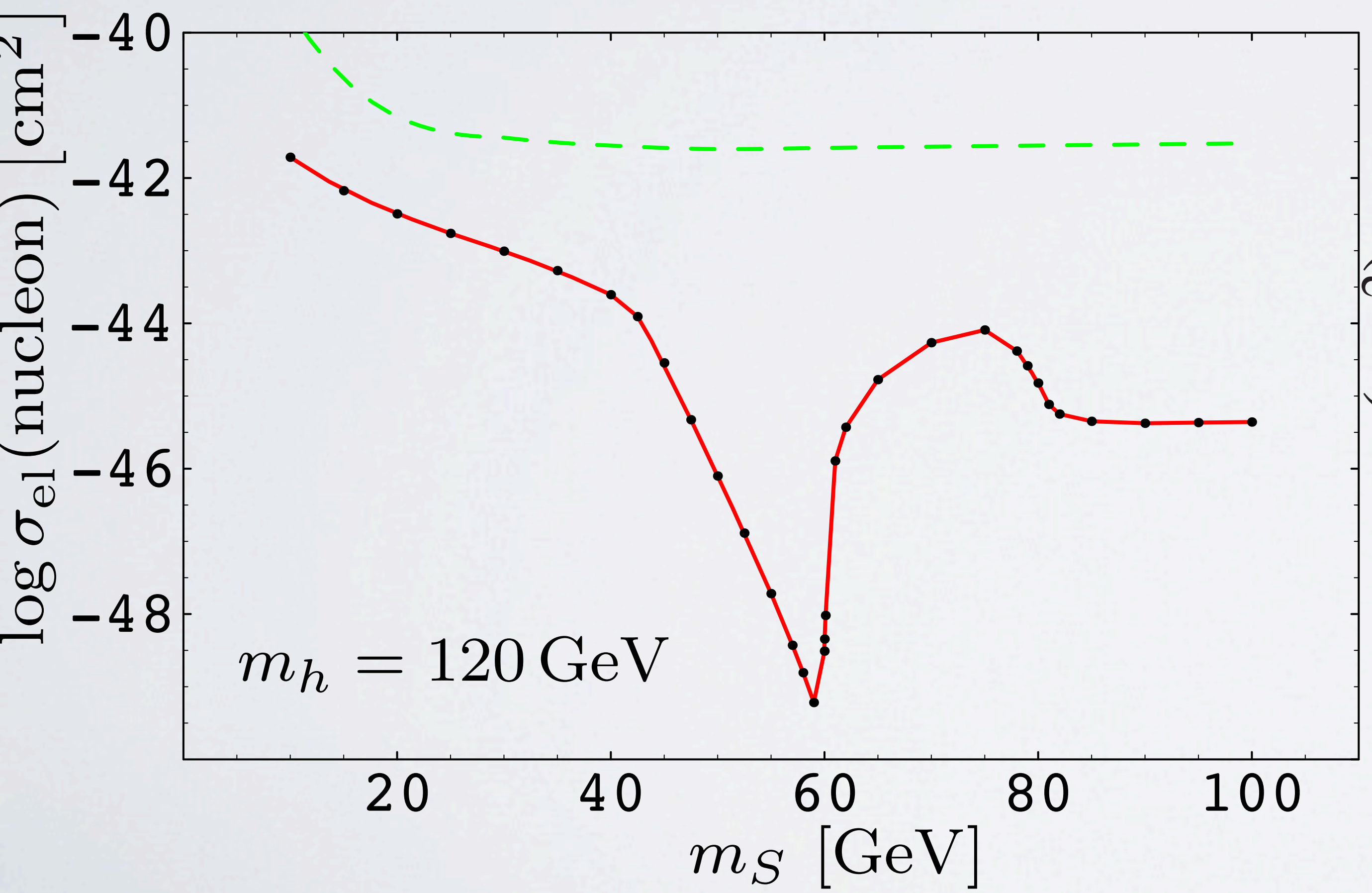
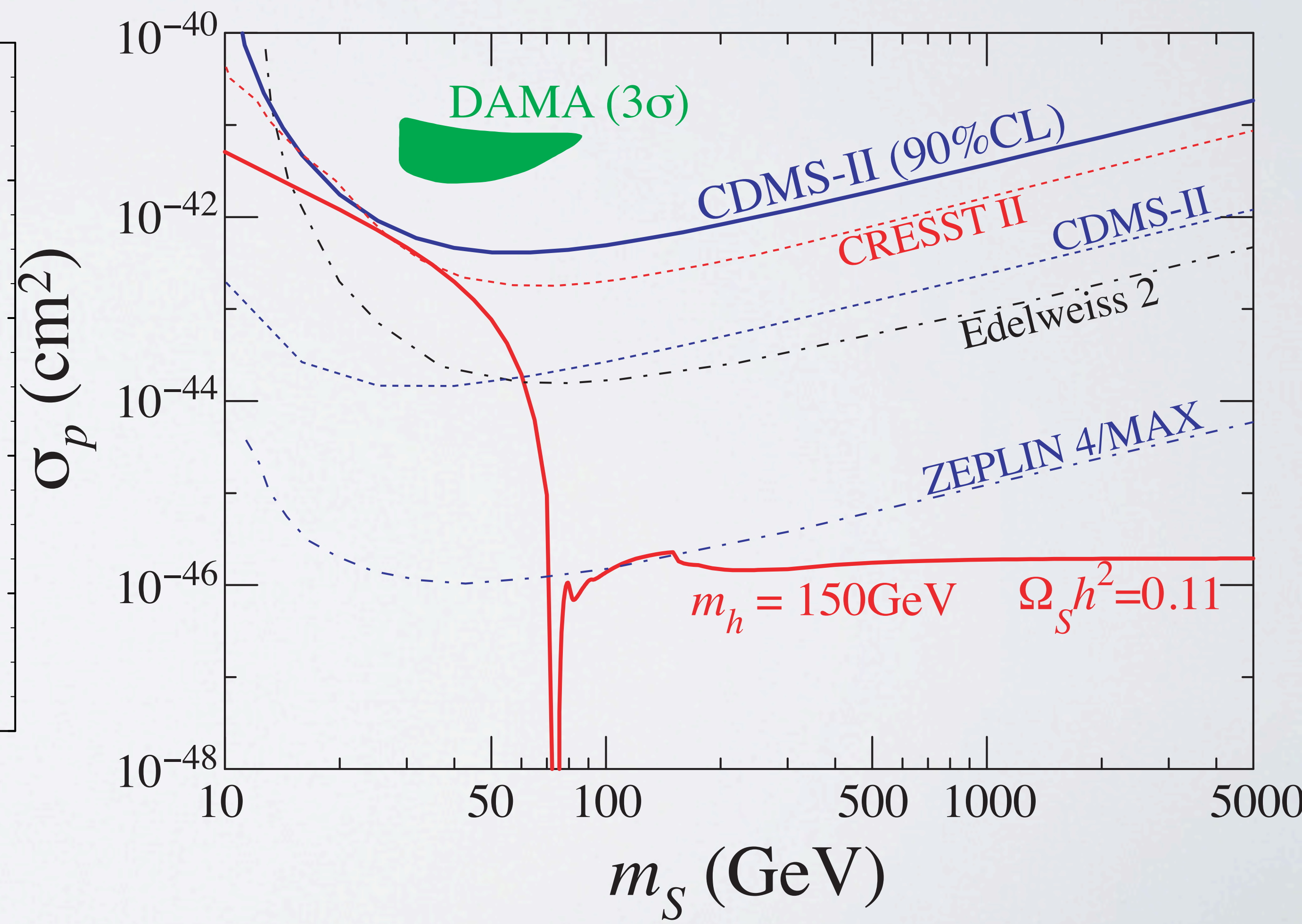
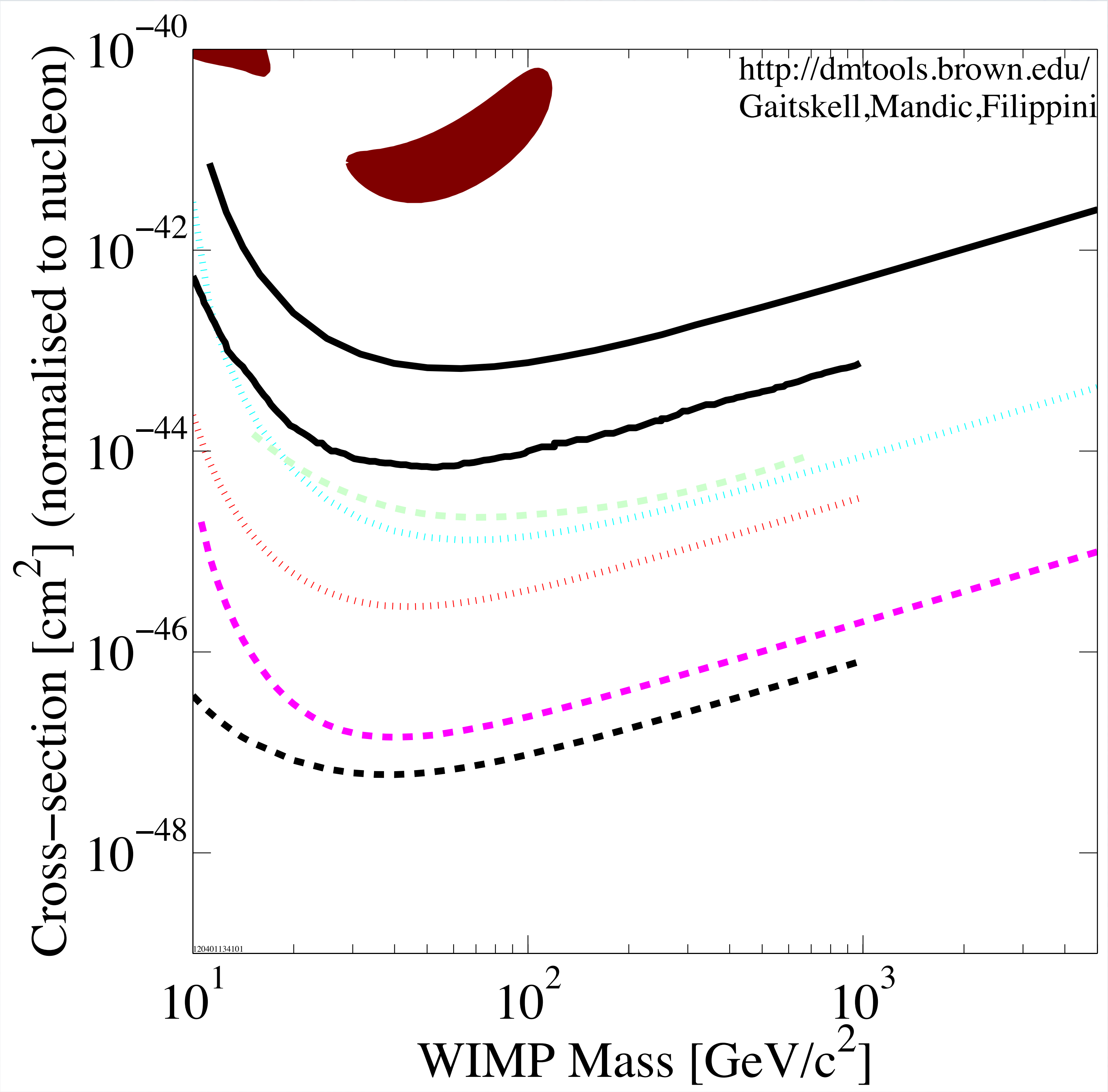




Davoudiasl, Kitano, Li, Murayama '04



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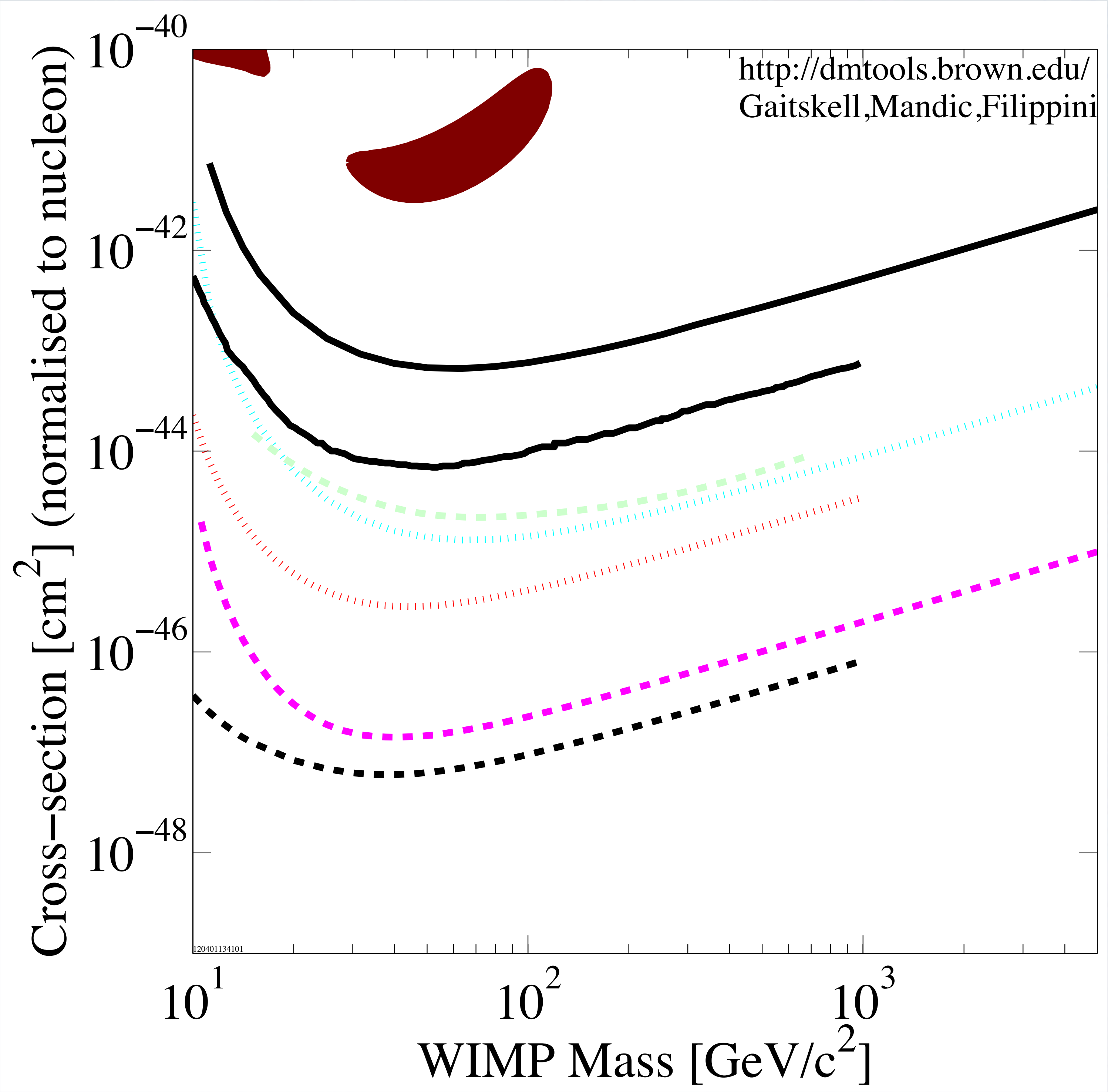

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10⁻⁴⁸
10¹
10²
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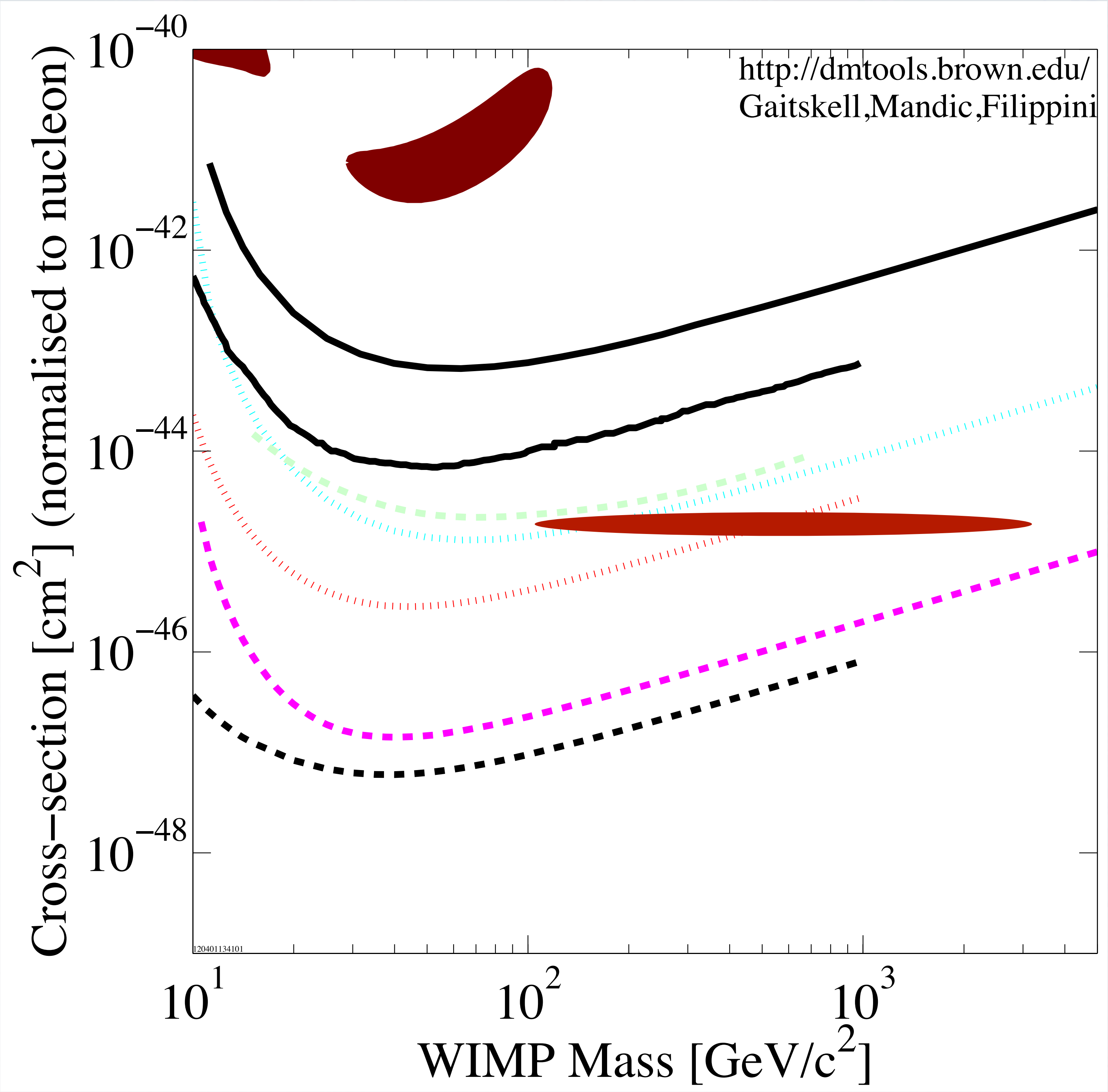
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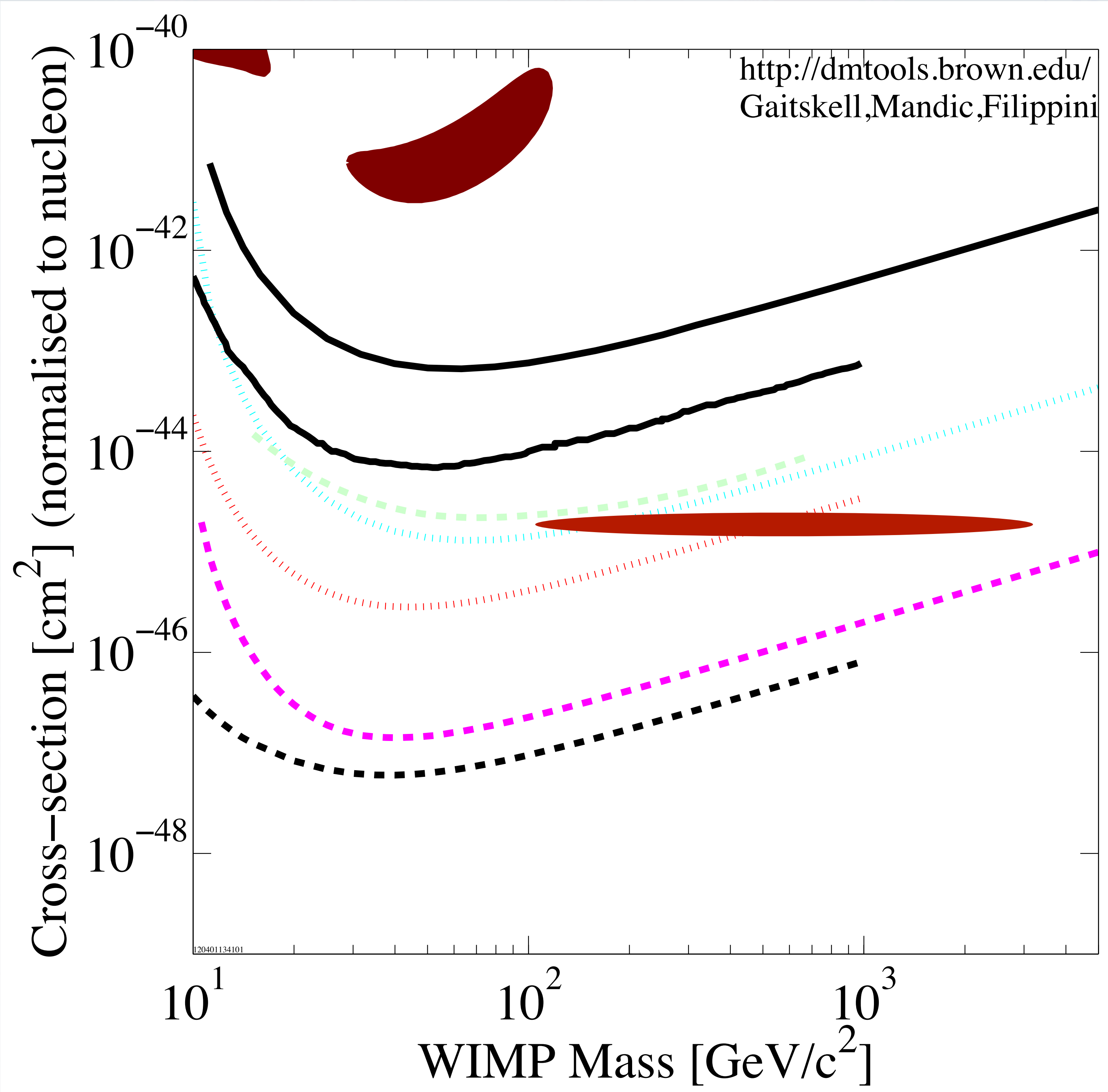

Various physics can move it up or down - but this is a natural starting point