HIDDEN SYMMETRIES IN **DARK** MATTER

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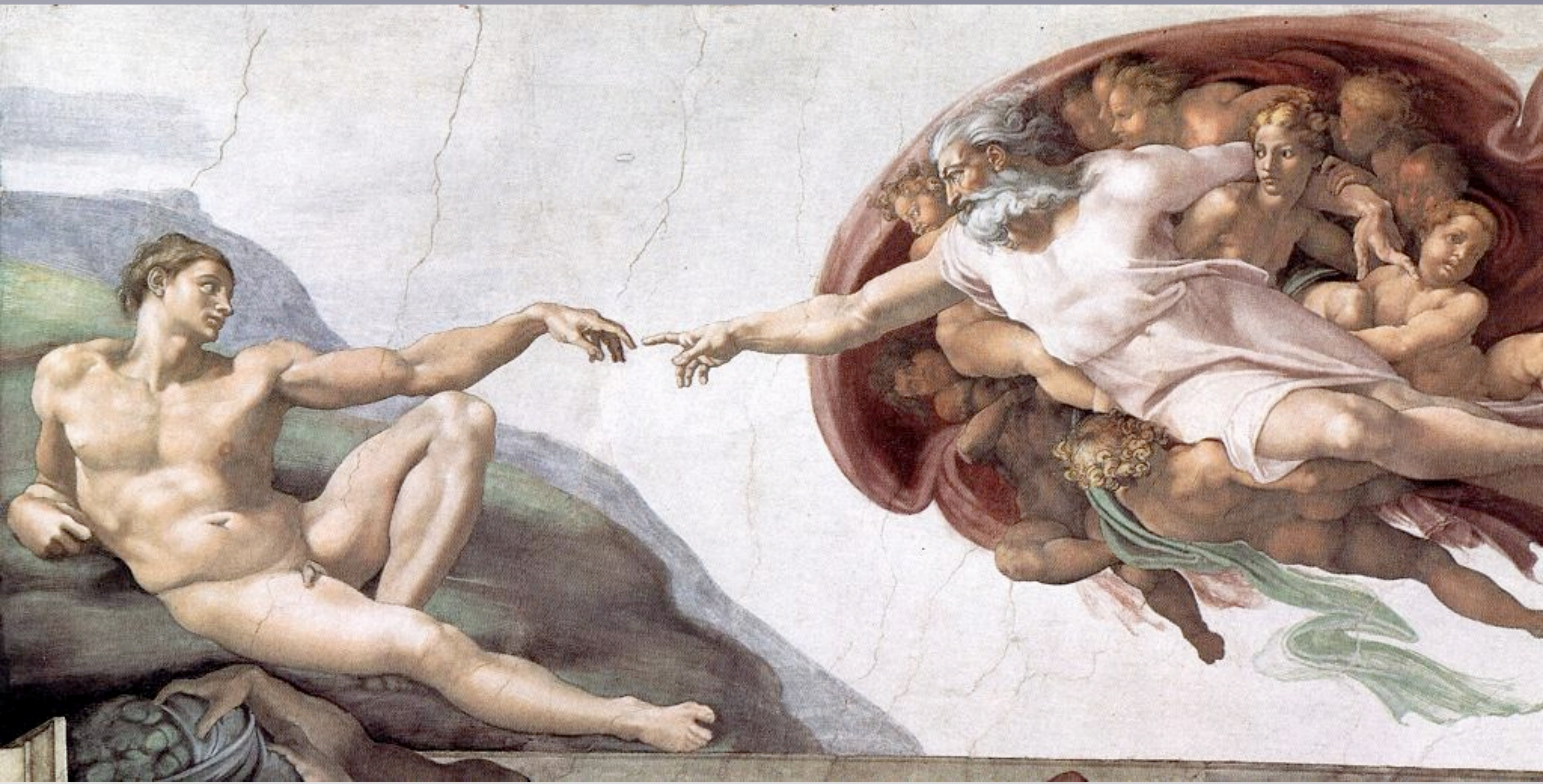
HOW THE WIMP IS USUALLY EXPLAINED



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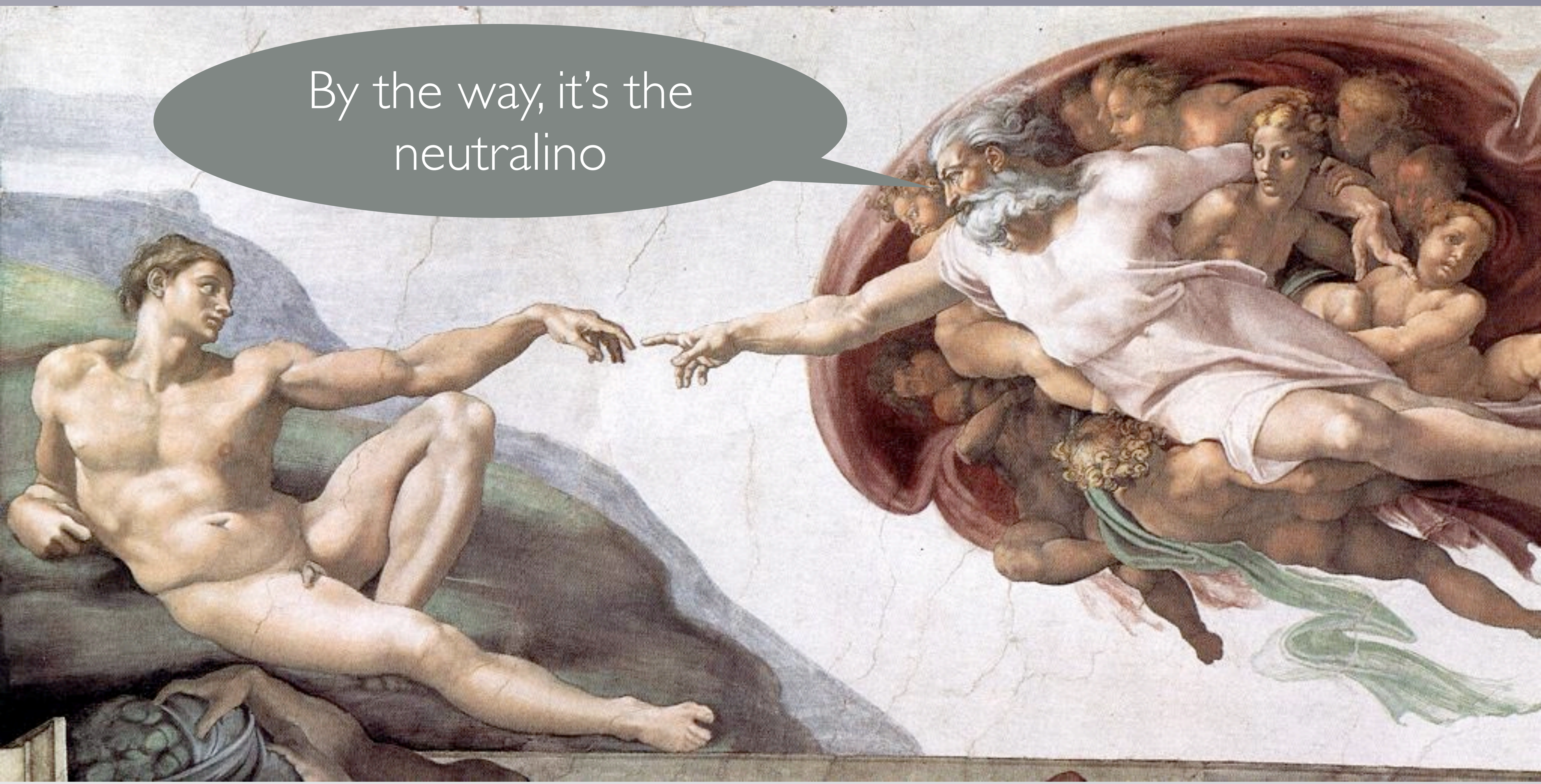

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- In gauge-mediated SUSY, the LSP can't be the DM

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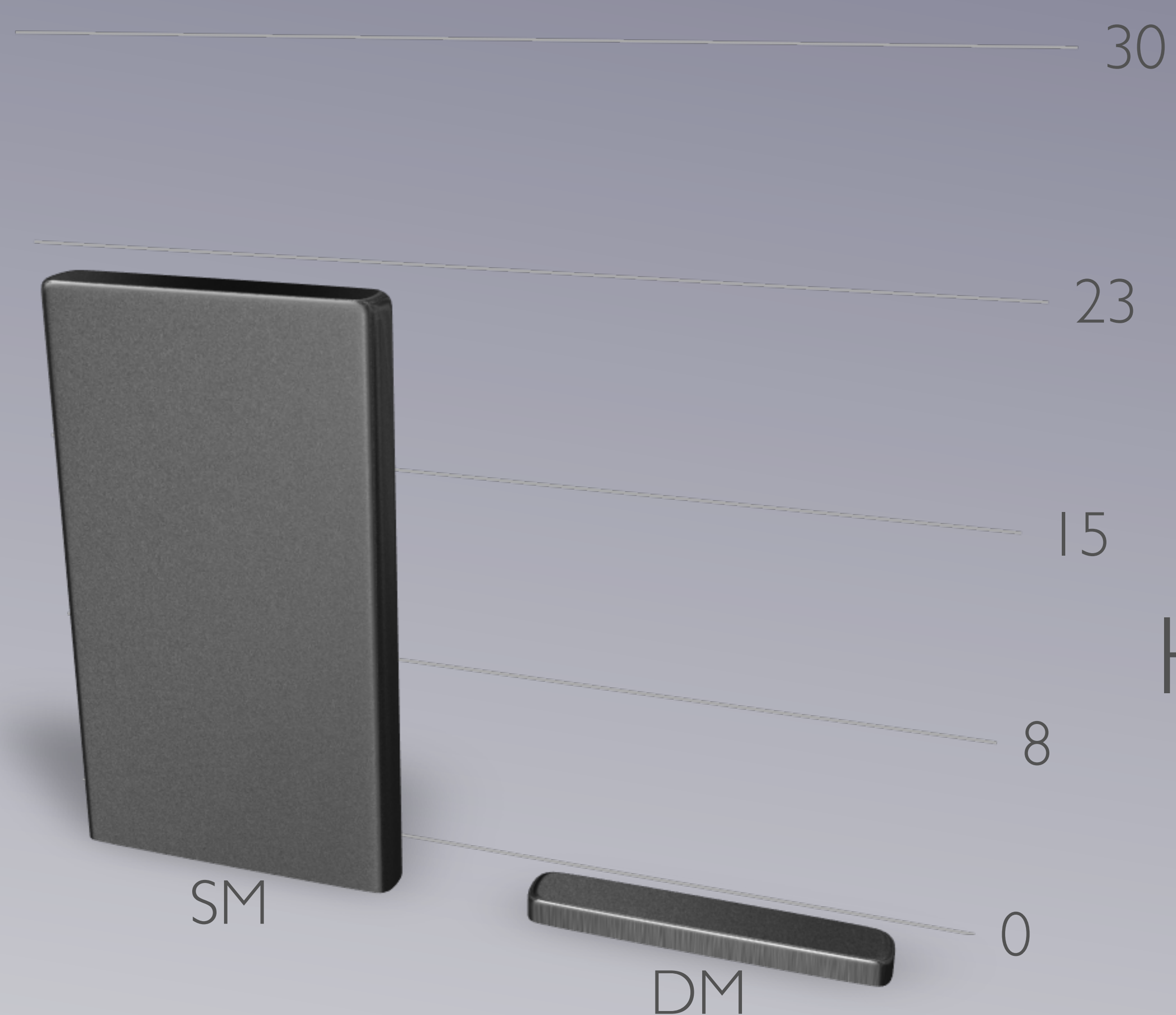

How we view DM symmetries

Baryon #, Lepton #, flavor, SU(3), SU(2),U(1)...

R-Parity

WHY HIDDEN SYMMETRIES?

- It's what we see in the Standard Model
  - Proton stability (Baryon number)
  - Matter density in the universe (baryon chemical potential)
  - Multiple states of matter
    - Composite (atomic states, excited nuclear states)
    - Fundamental symmetries (SU(3)-flavor)
  - Forces
    - Composite (rho, pions)
    - Fundamental (gauge forces)

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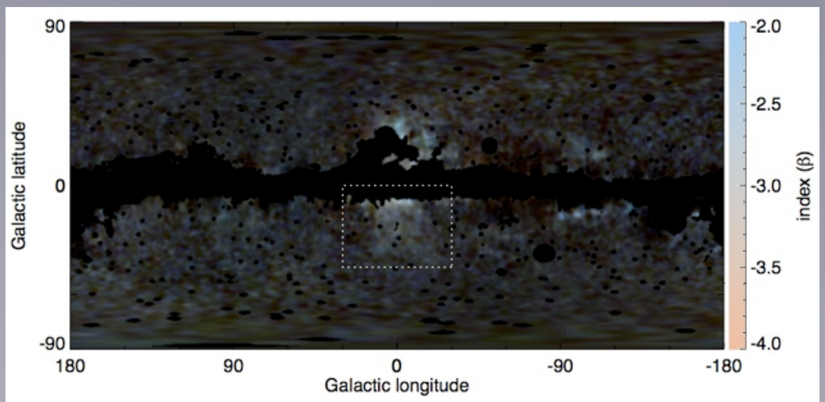
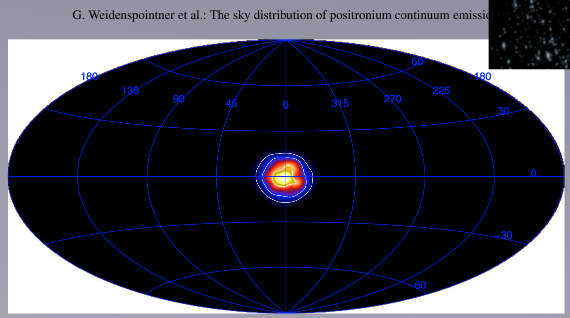
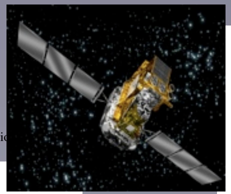
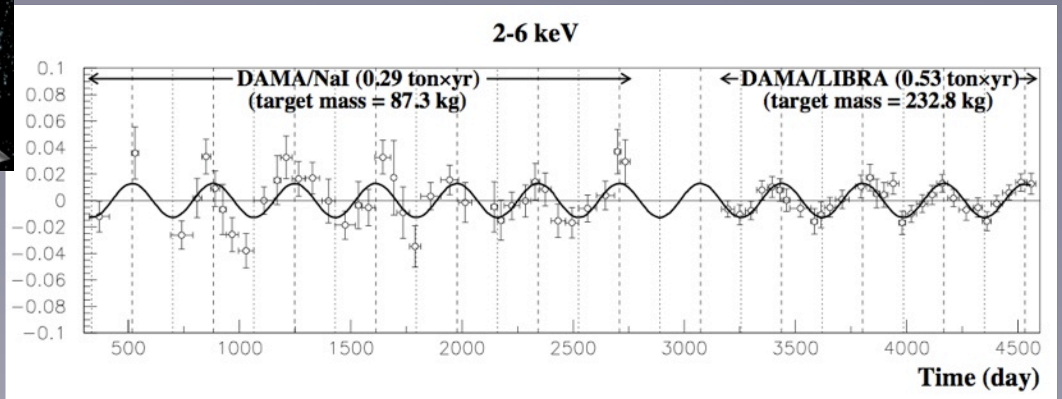
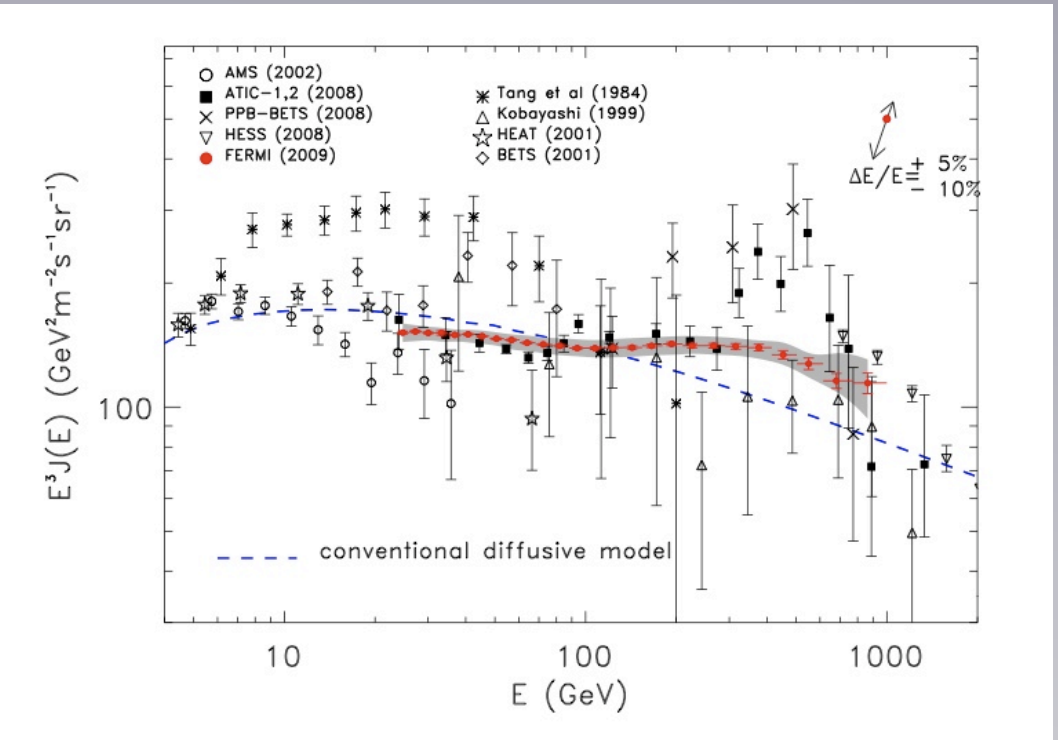
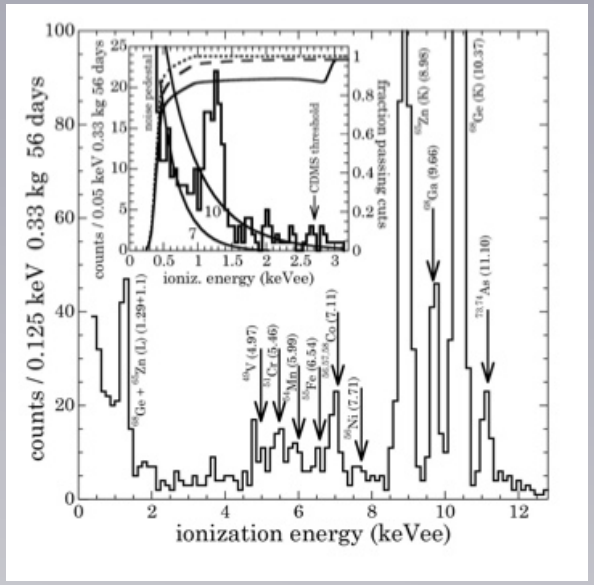


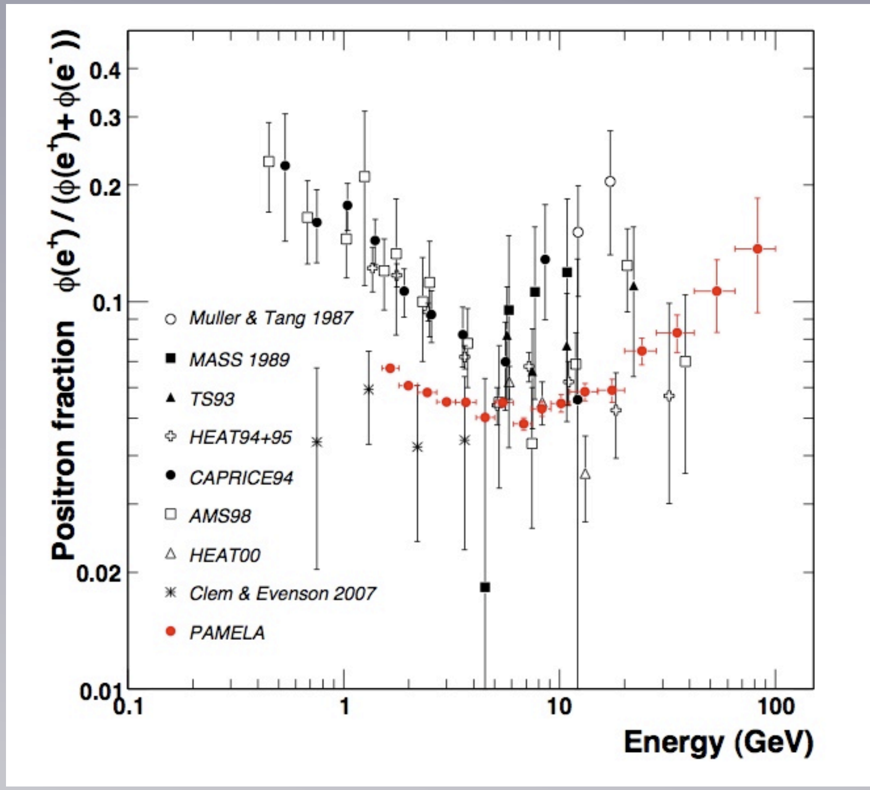


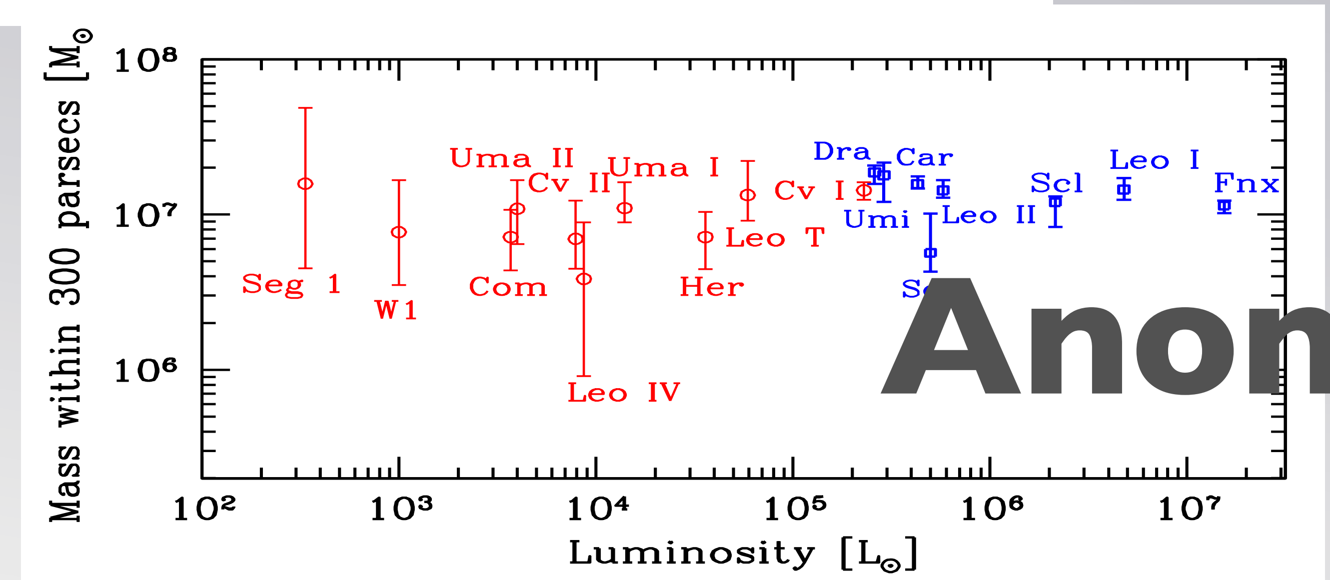




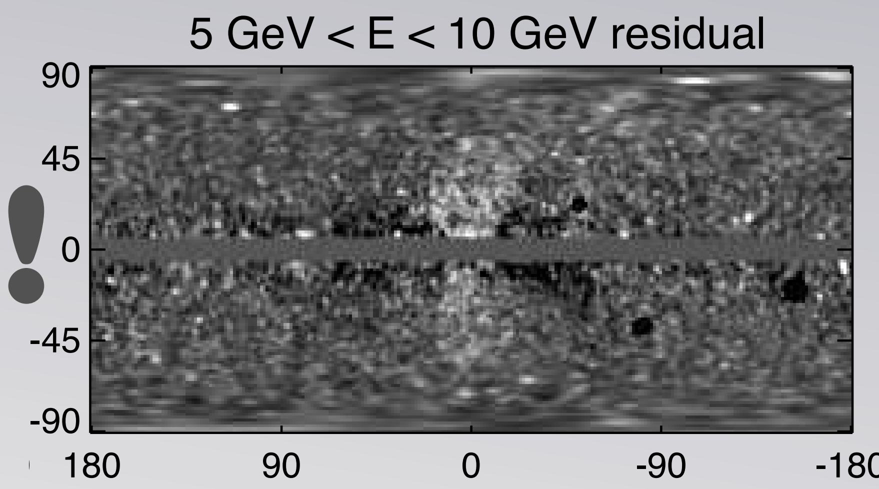








Anomalies!



CONSEQUENCES OF HIDDEN SYMMETRIES

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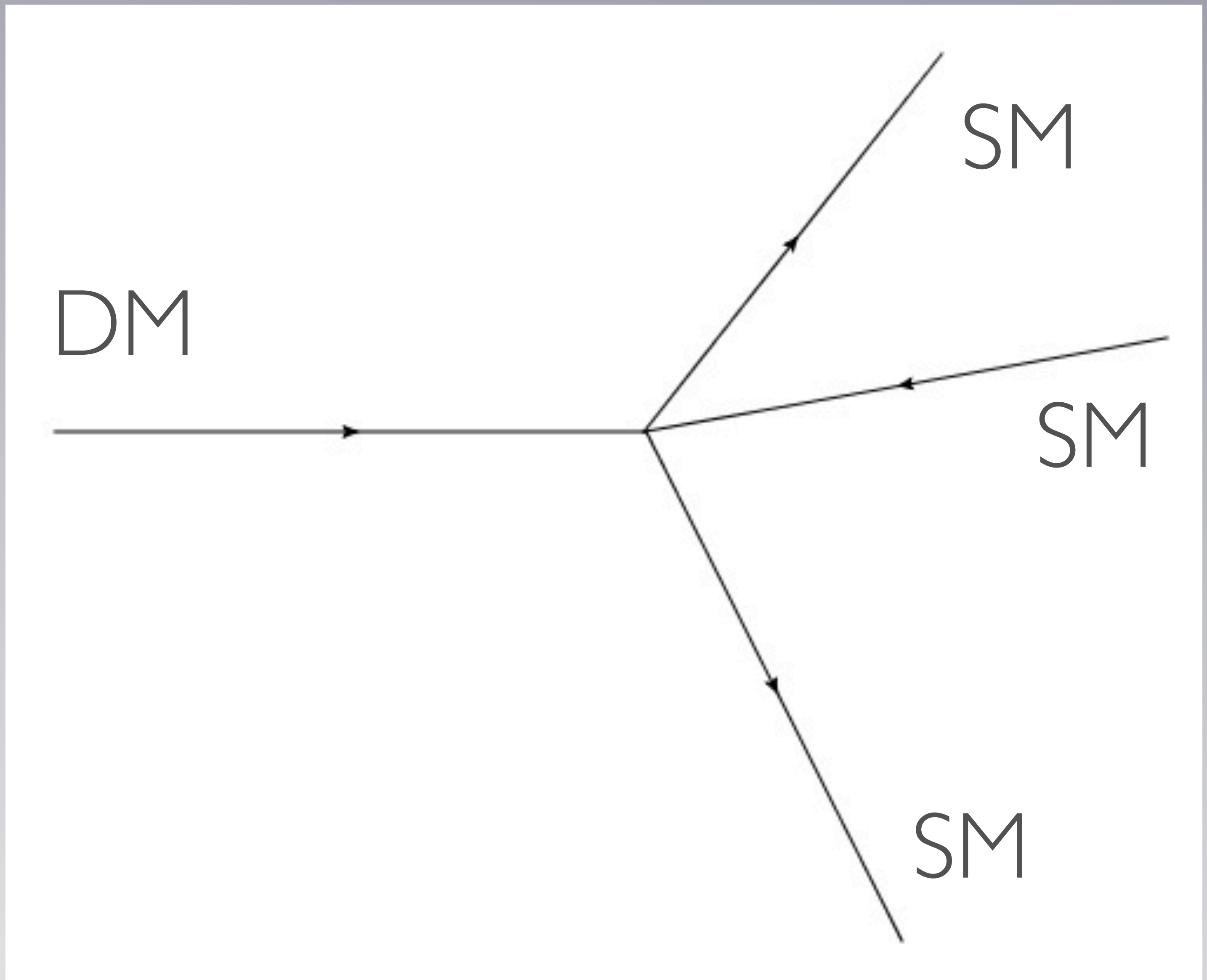
- New/excited states of DM (implications for direct, indirect searches)
- New forces of DM (implications for direct, indirect, and DM structure)

THE PARITY

- Why is DM stable?
  - Need at least a parity to forbid



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m_t [GeV]	$172.7 \pm 2.9 \pm 0.6$	172.7 ± 2.8	0.0
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	80.392 ± 0.039		0.4
M_Z [GeV]	91.1876 ± 0.0021	91.1874 ± 0.0021	0.1
Γ_Z [GeV]	2.4952 ± 0.0023	2.4968 ± 0.0011	−0.7
$\Gamma(\text{had})$ [GeV]	1.7444 ± 0.0020	1.7434 ± 0.0010	—
$\Gamma(\text{inv})$ [MeV]	499.0 ± 1.5	501.65 ± 0.11	—
$\Gamma(\ell^+\ell^-)$ [MeV]	83.984 ± 0.086	83.996 ± 0.021	—
σ_{had} [nb]	41.541 ± 0.037	41.467 ± 0.009	2.0
R_e	20.804 ± 0.050	20.756 ± 0.011	1.0
R_μ	20.785 ± 0.033	20.756 ± 0.011	0.9
R_τ	20.764 ± 0.045	20.801 ± 0.011	−0.8
R_b	0.21629 ± 0.00066	0.21578 ± 0.00010	0.8
R_c	0.1721 ± 0.0030	0.17230 ± 0.00004	−0.1
$A_{FB}^{(0,e)}$	0.0145 ± 0.0025	0.01622 ± 0.00025	−0.7
$A_{FB}^{(0,\mu)}$	0.0169 ± 0.0013		0.5
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g_L^2	0.30005 ± 0.00137	0.30378 ± 0.00021	−2.7
g_R^2	0.03076 ± 0.00110	0.03006 ± 0.00003	0.6
$g_V^{\nu e}$	-0.040 ± 0.015	-0.0396 ± 0.0003	0.0
$g_A^{\nu e}$	-0.507 ± 0.014	-0.5064 ± 0.0001	0.0
A_{PV}	-1.31 ± 0.17	-1.53 ± 0.02	1.3
$Q_W(\text{Cs})$	-72.62 ± 0.46	-73.17 ± 0.03	1.2
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$\frac{\Gamma(b\to s\gamma)}{\Gamma(b\to Xe\nu)}$	$3.35^{+0.50}_{-0.44} \times 10^{-3}$	$(3.22 \pm 0.09) \times 10^{-3}$	0.3
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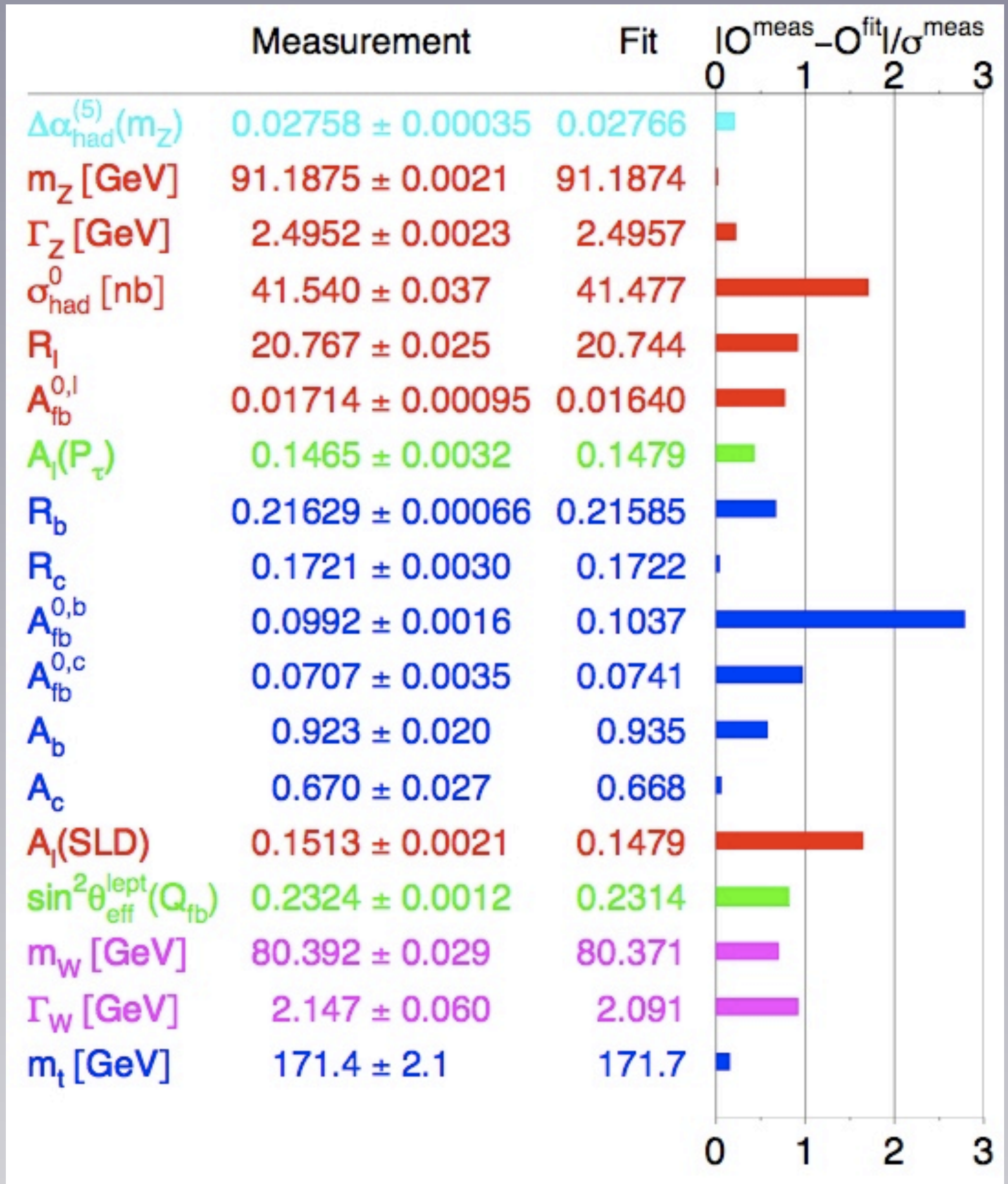

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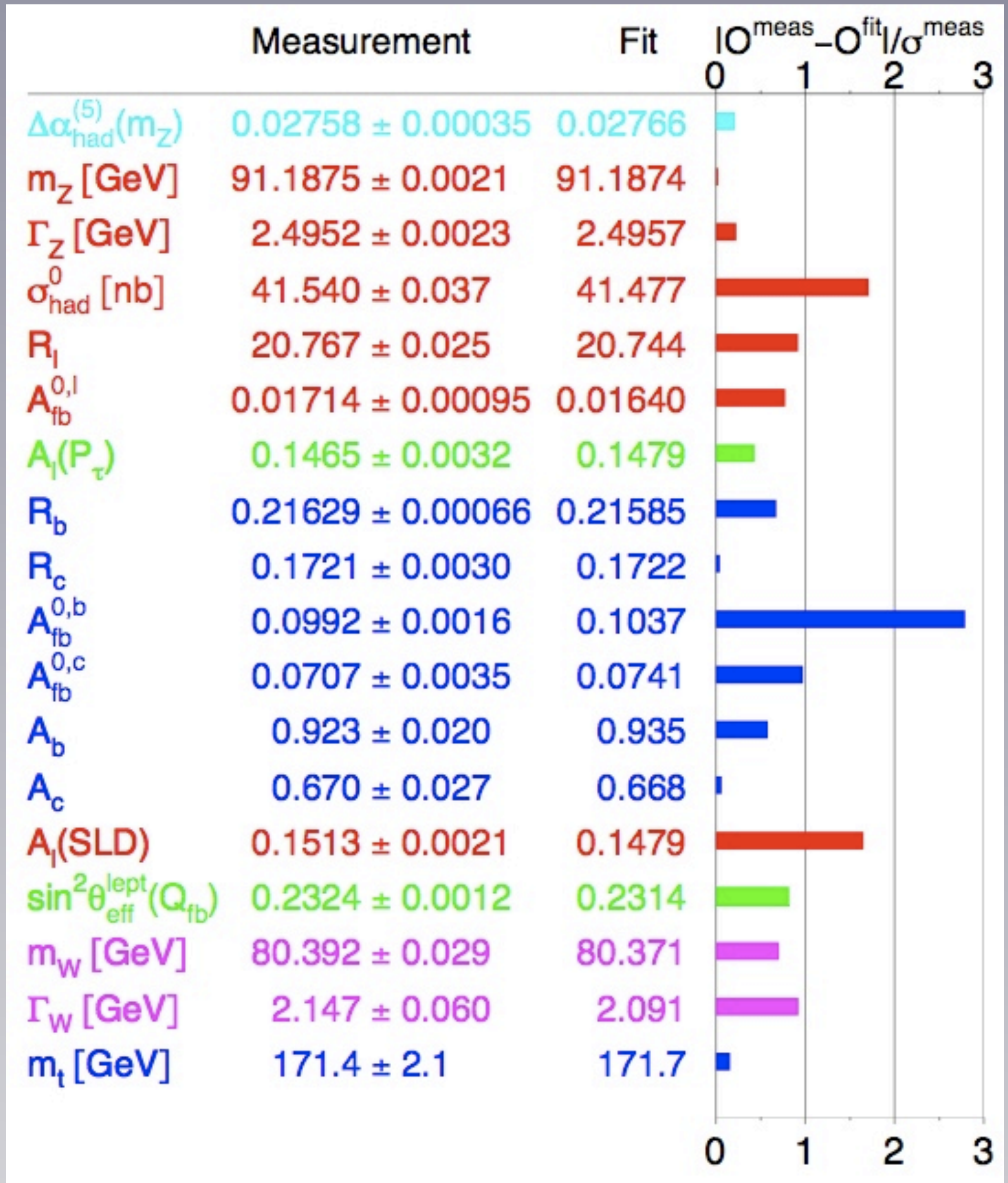
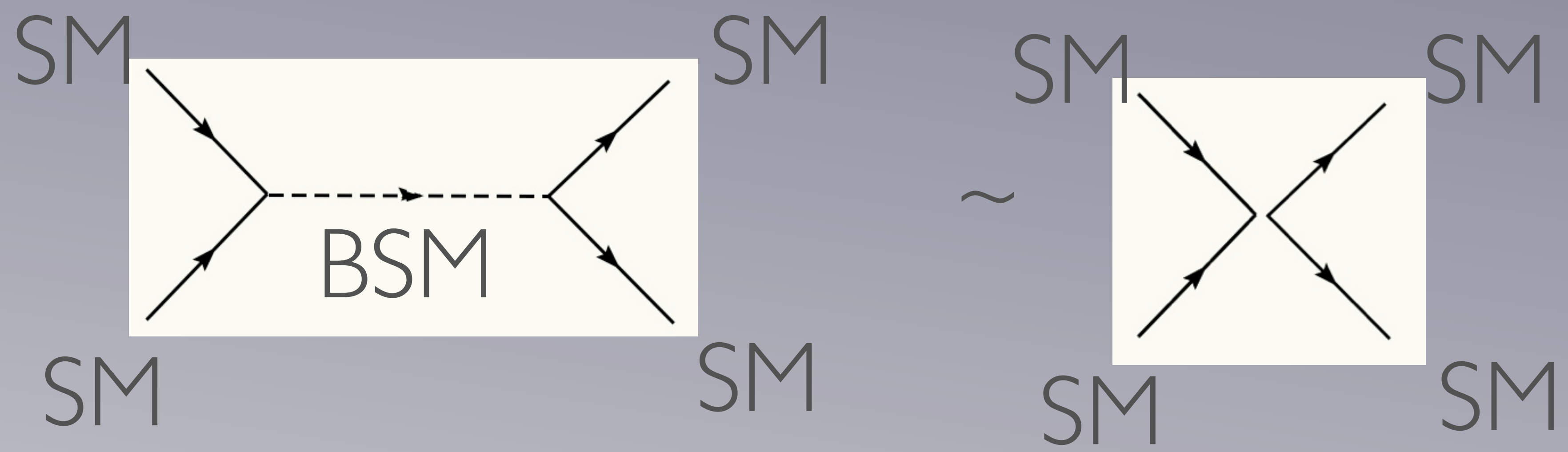


In general, new physics at the weak scale should have shown up in these precision studies

T-PARITY (CHENG AND LOW)

- The problem arises from diagrams



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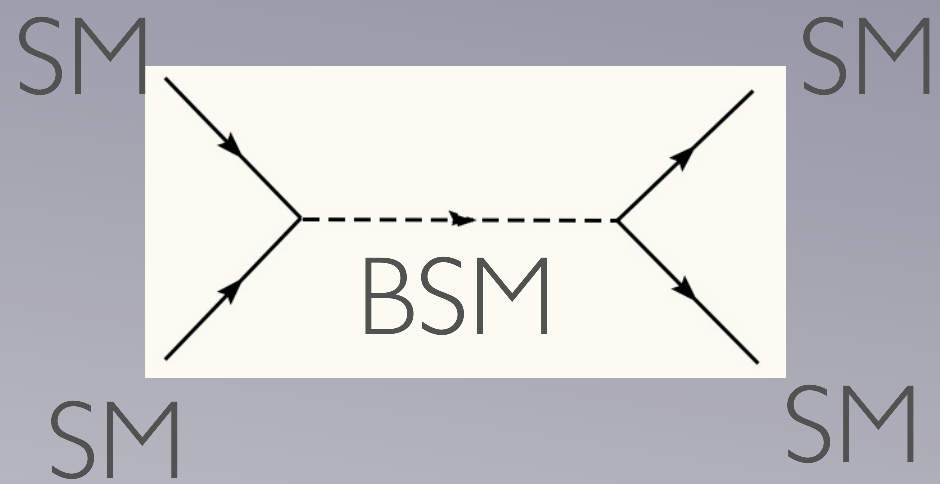

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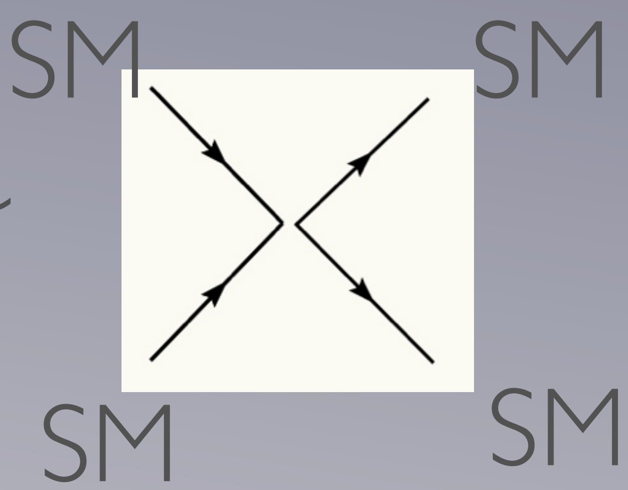

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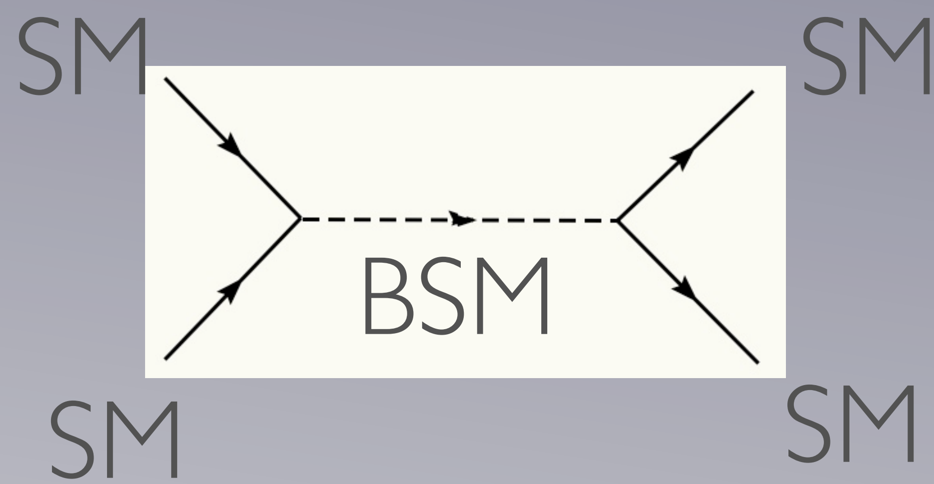

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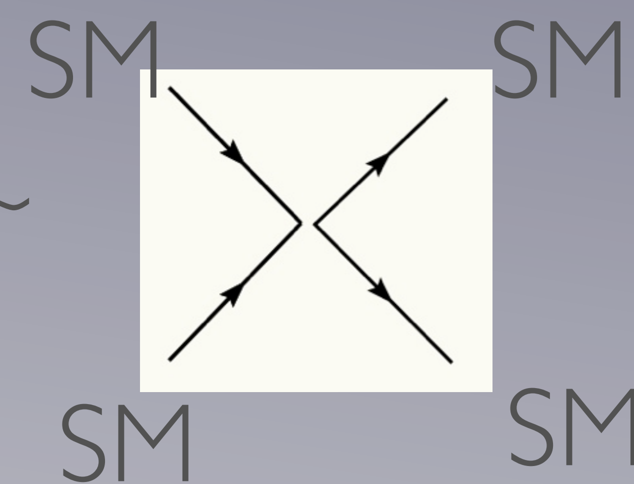

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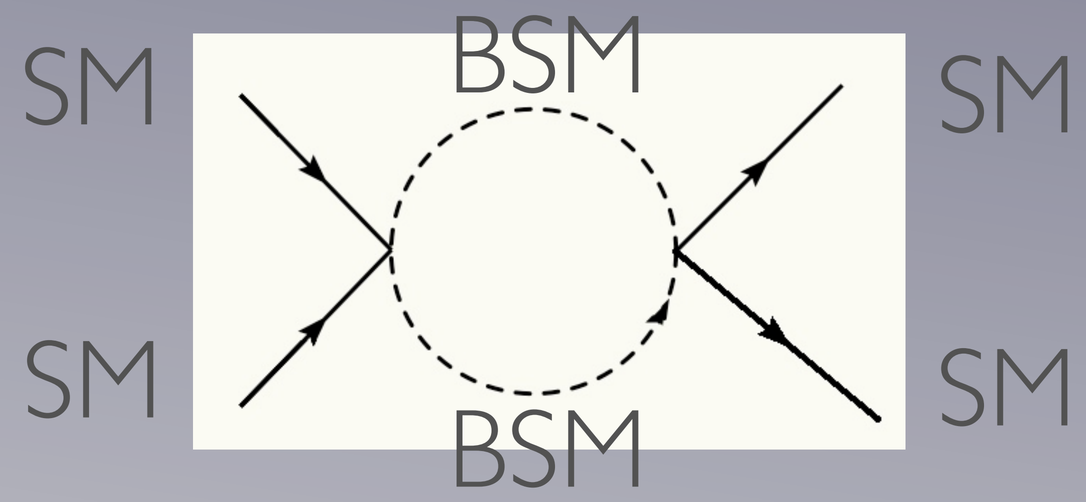
Problem is presence of single BSM field in diagram
If only even numbers of BSM fields were allowed, this term is forbidden!

Then process occurs via loop



loops smaller by ~ 1/16π^2
enough to solve problem

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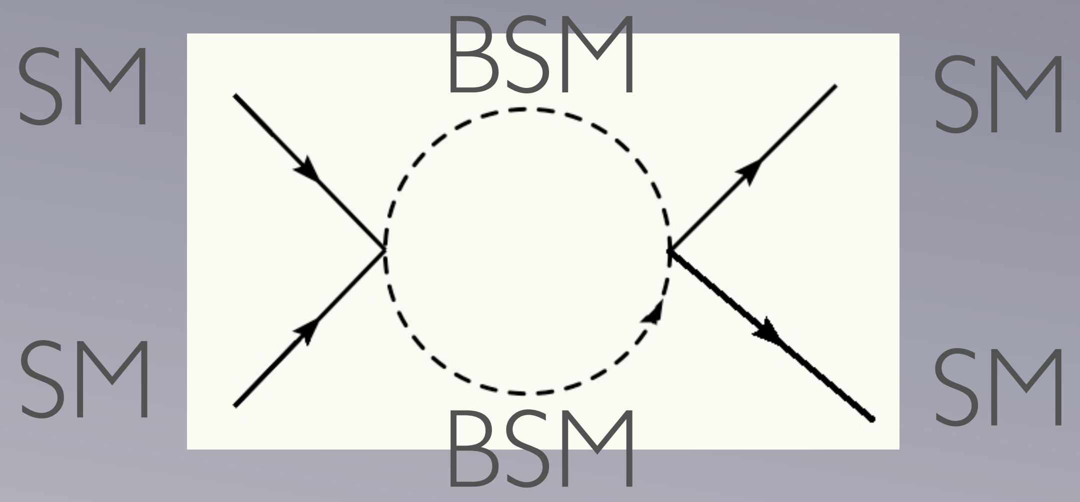

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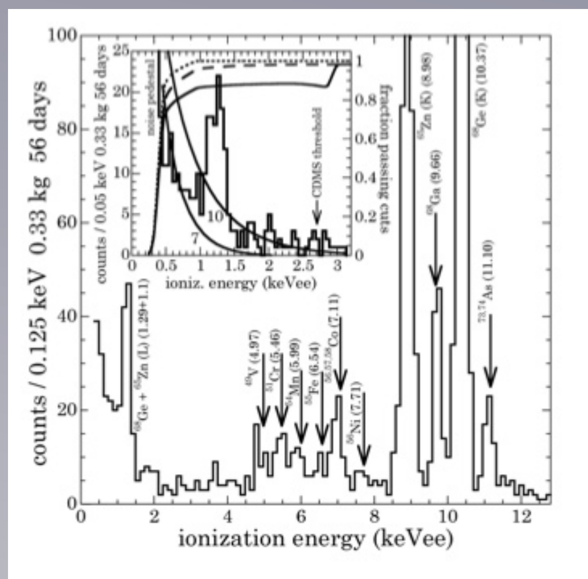
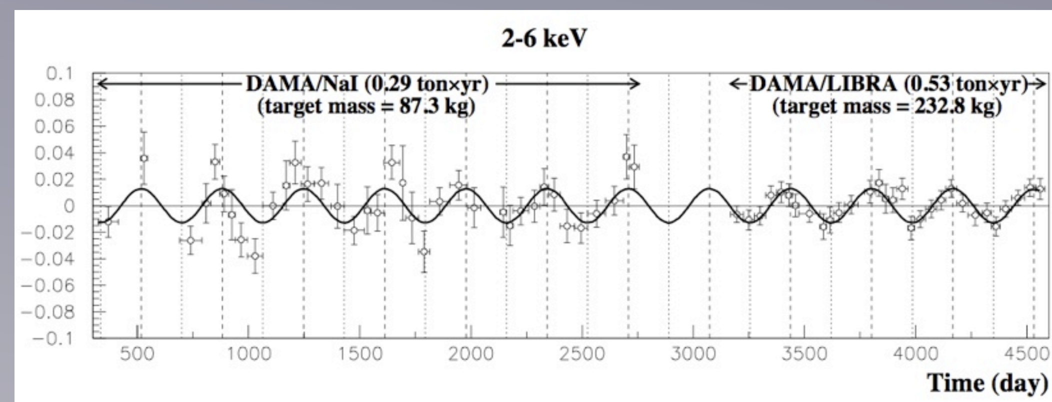
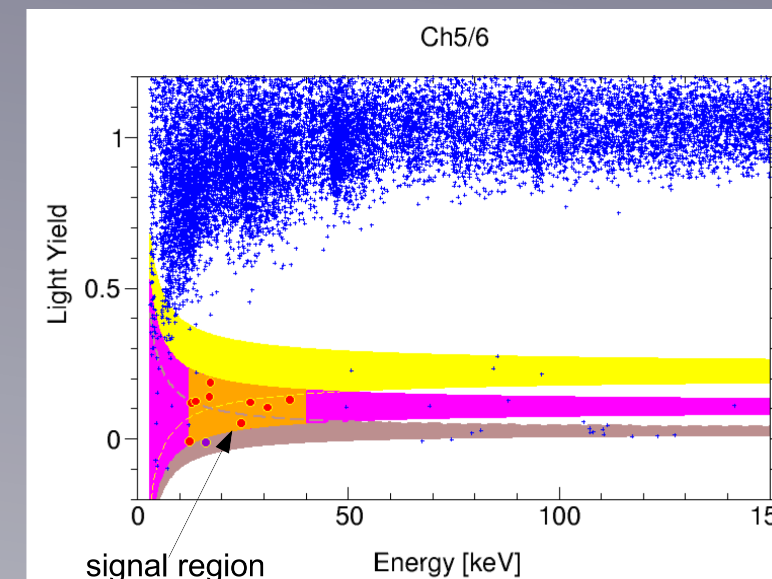
Introduce parity at weak scale => stable DM candidates

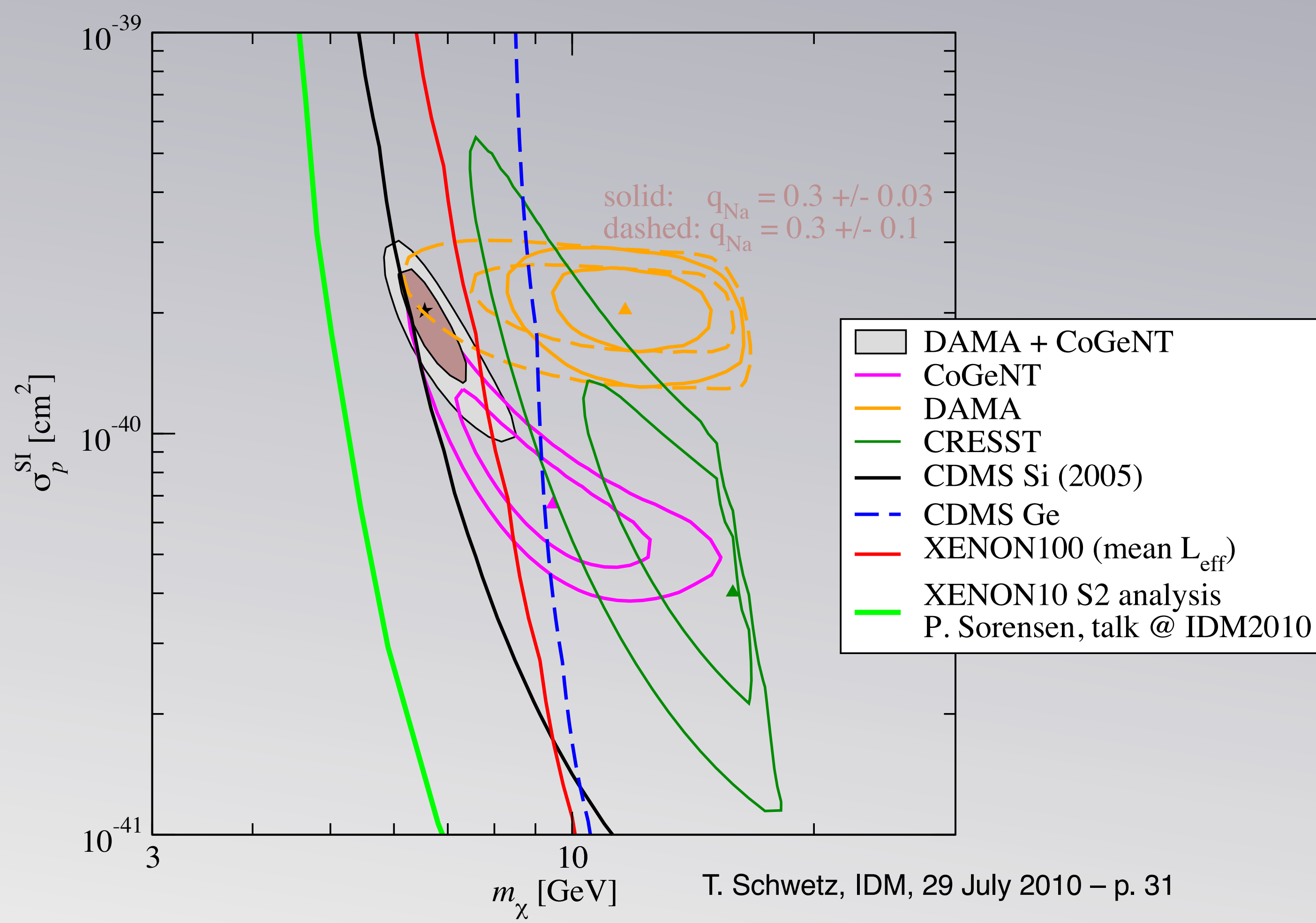
Parities in new physics should be *generic*
=> a stable particle

ANOMALIES 1: LIGHT WIMPS



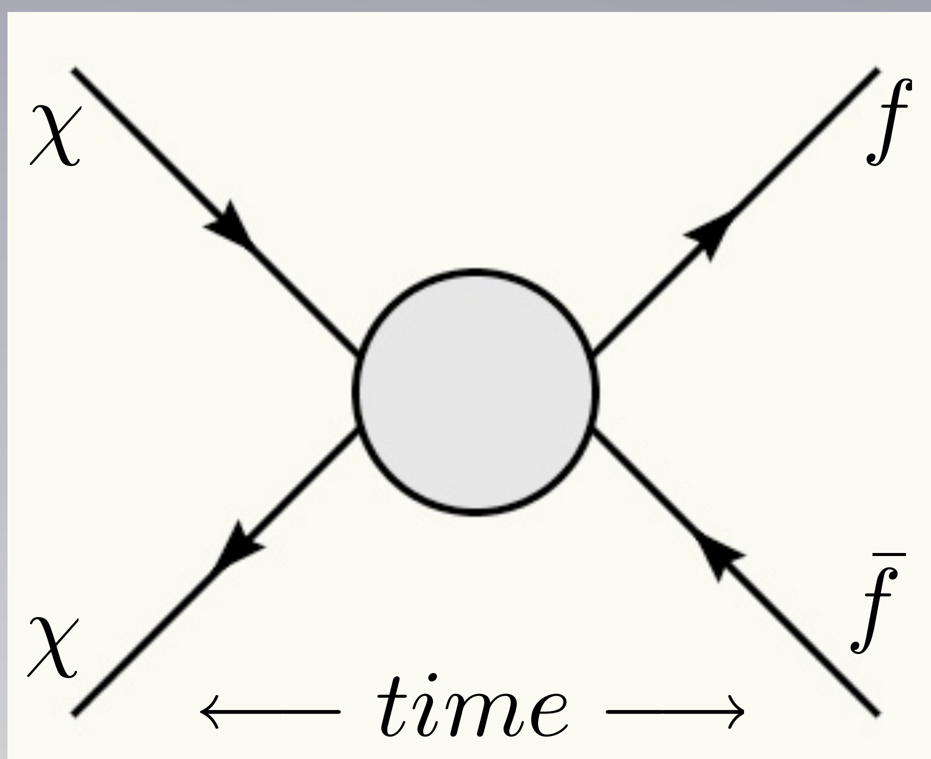


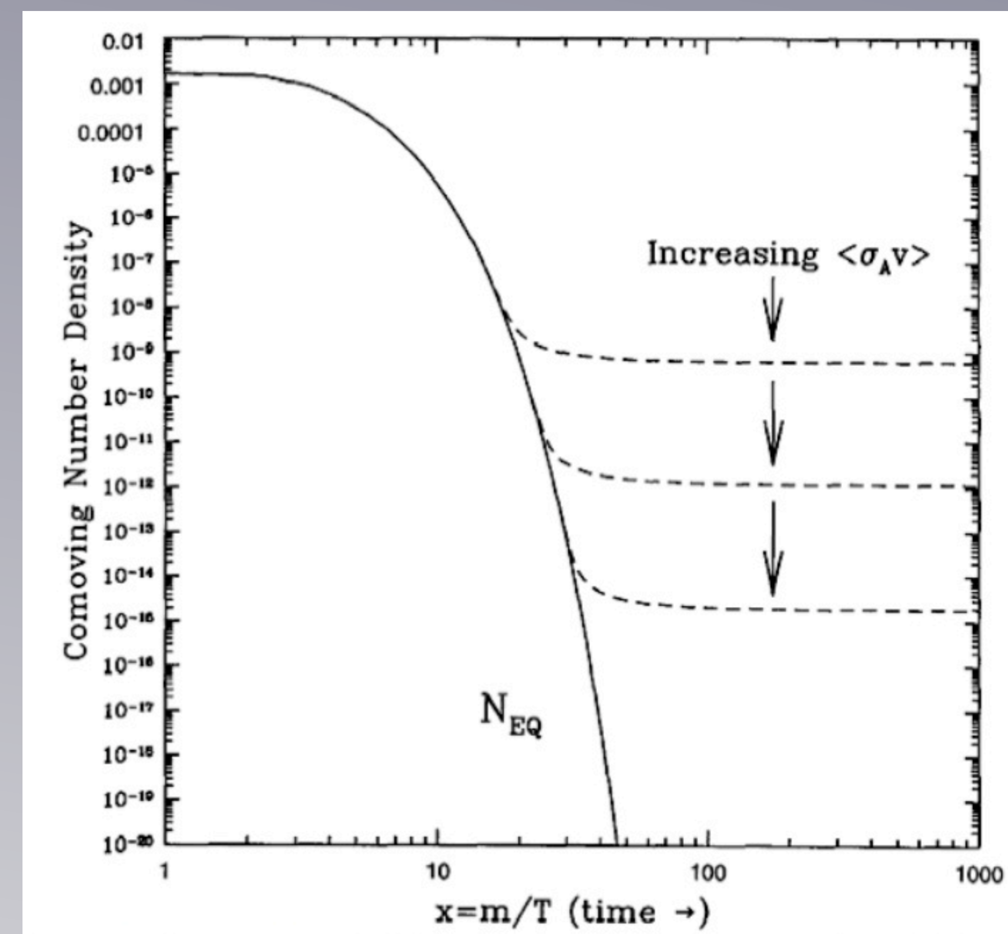




Is such a big cross section at these masses possible?

FREEZEOUT?



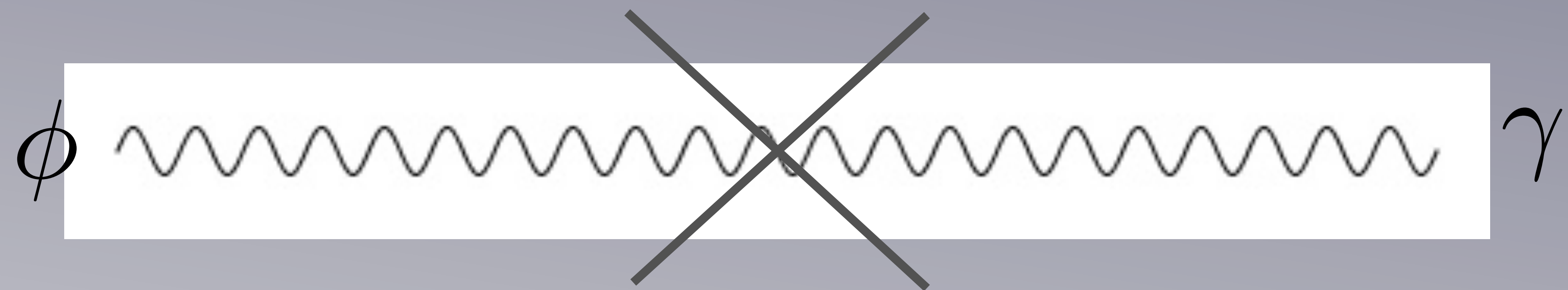


Without a large cross section for annihilation, there would be too much DM

Reasonable for such a light WIMP?

A DARK GAUGE SYMMETRY

$\epsilon F_{\mu\nu} F_d^{\mu\nu}$: φ mixes with the photon



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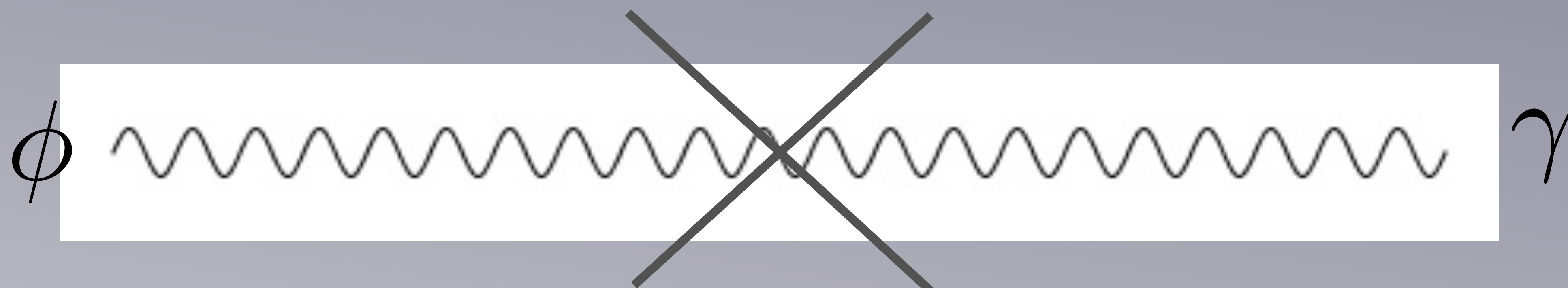
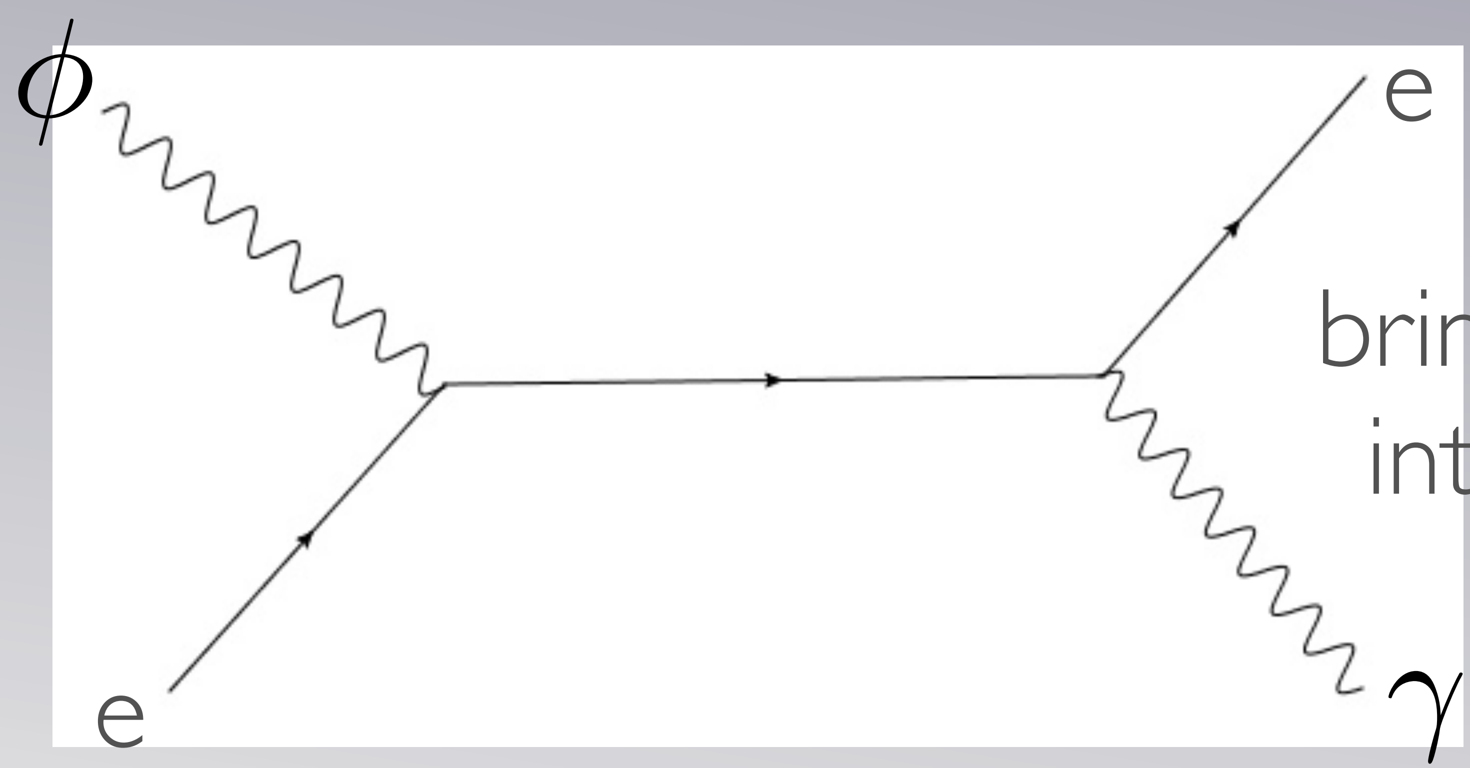
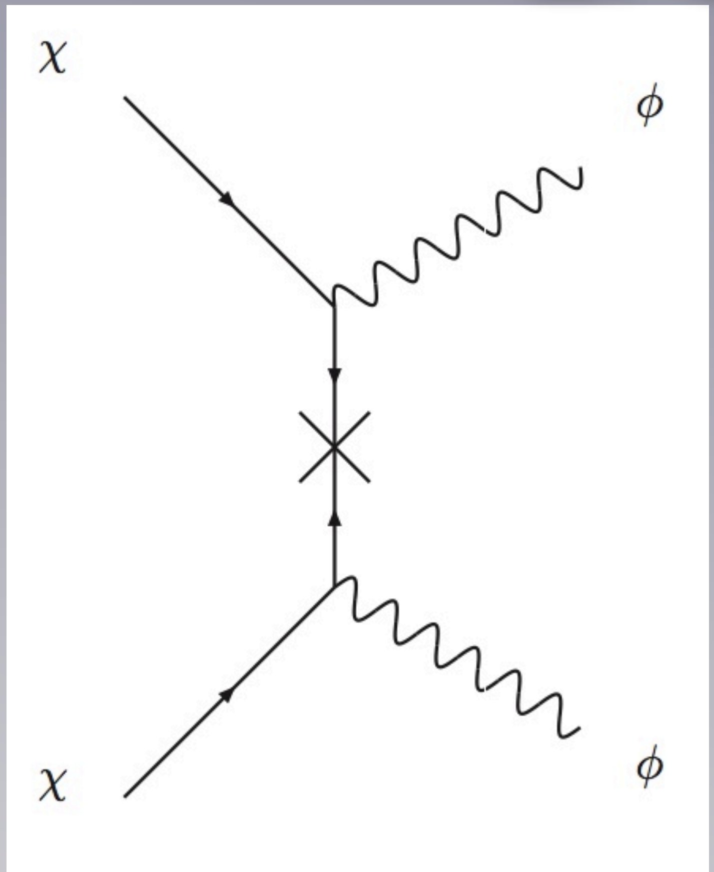




brings dark sector into equilibrium

INTERACTIONS THROUGH A LIGHT SECTOR



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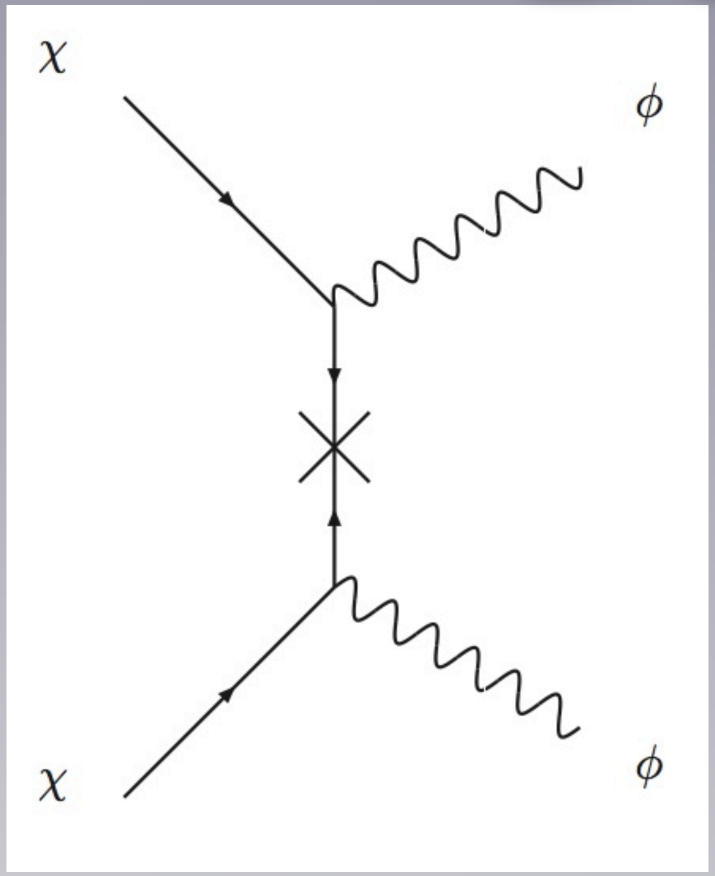
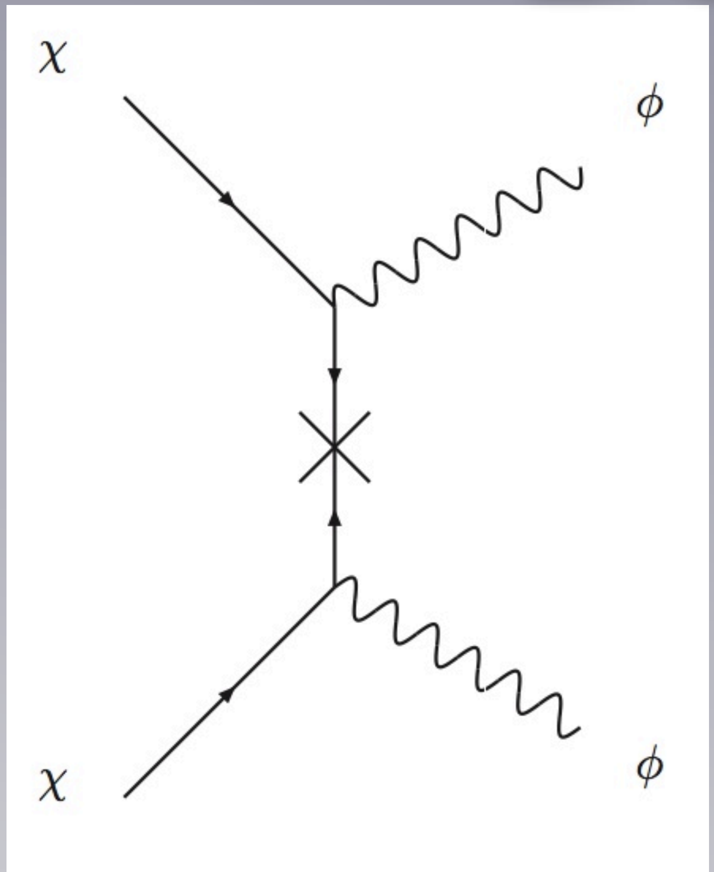
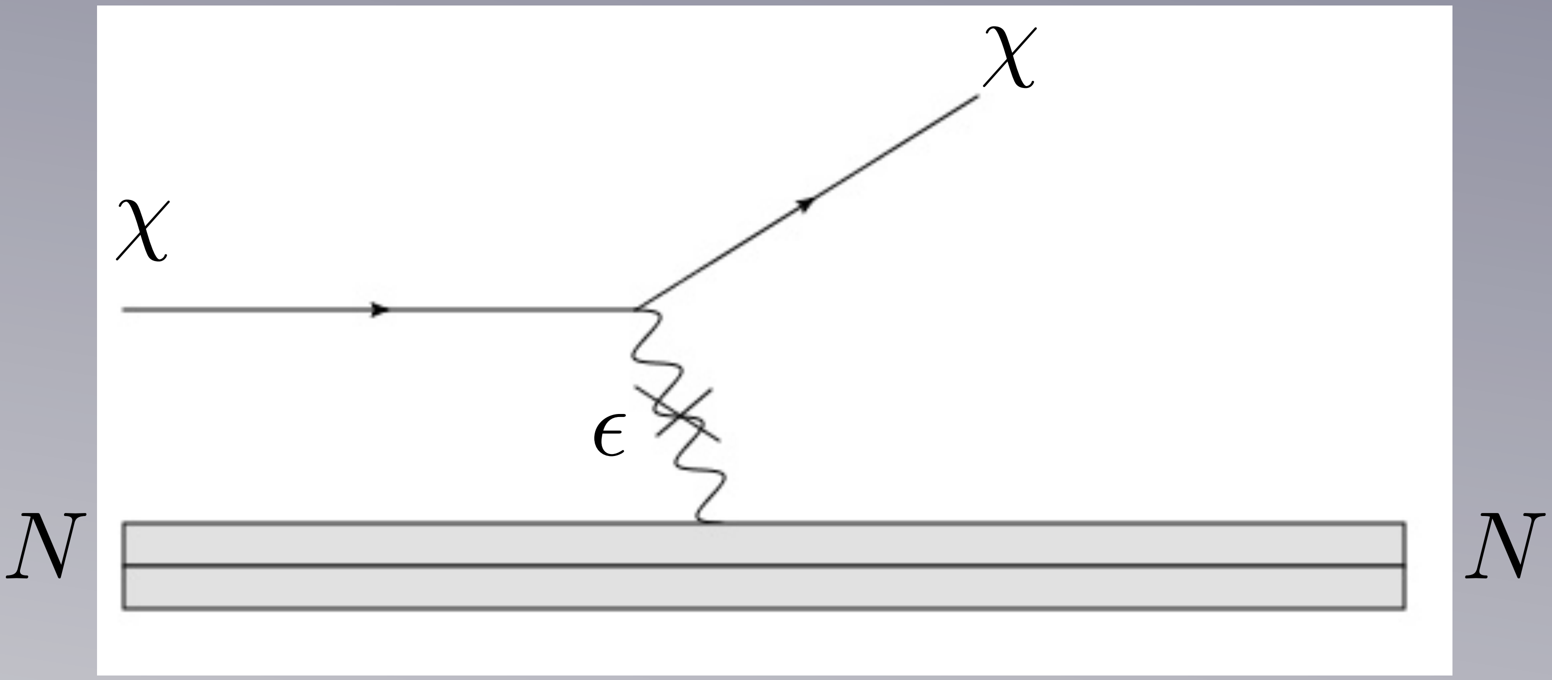


$$\sigma \approx \frac{\alpha_d^2}{m_\chi^2}$$

INTERACTIONS THROUGH A LIGHT SECTOR





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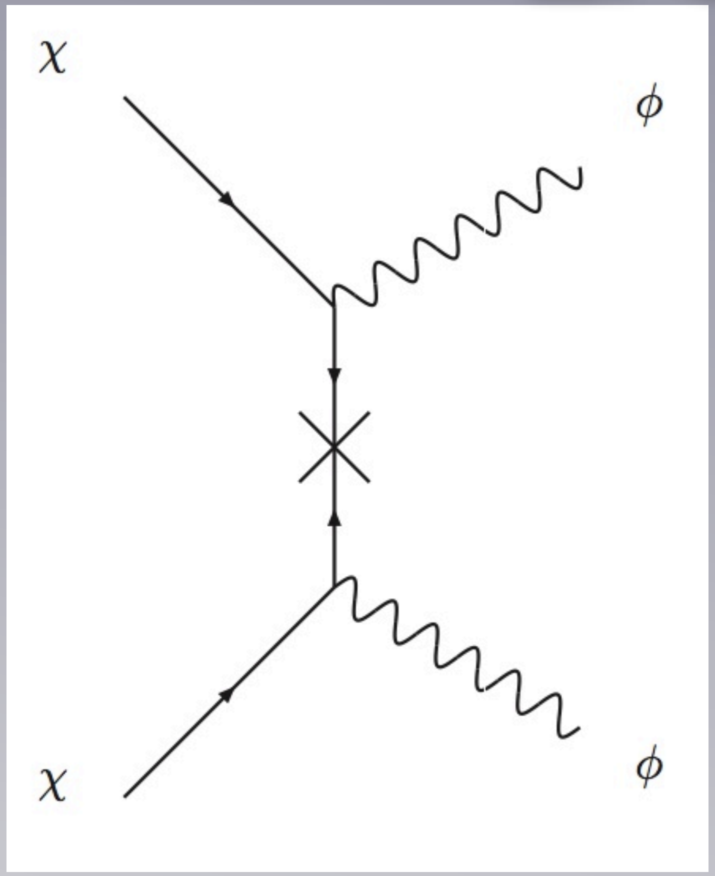

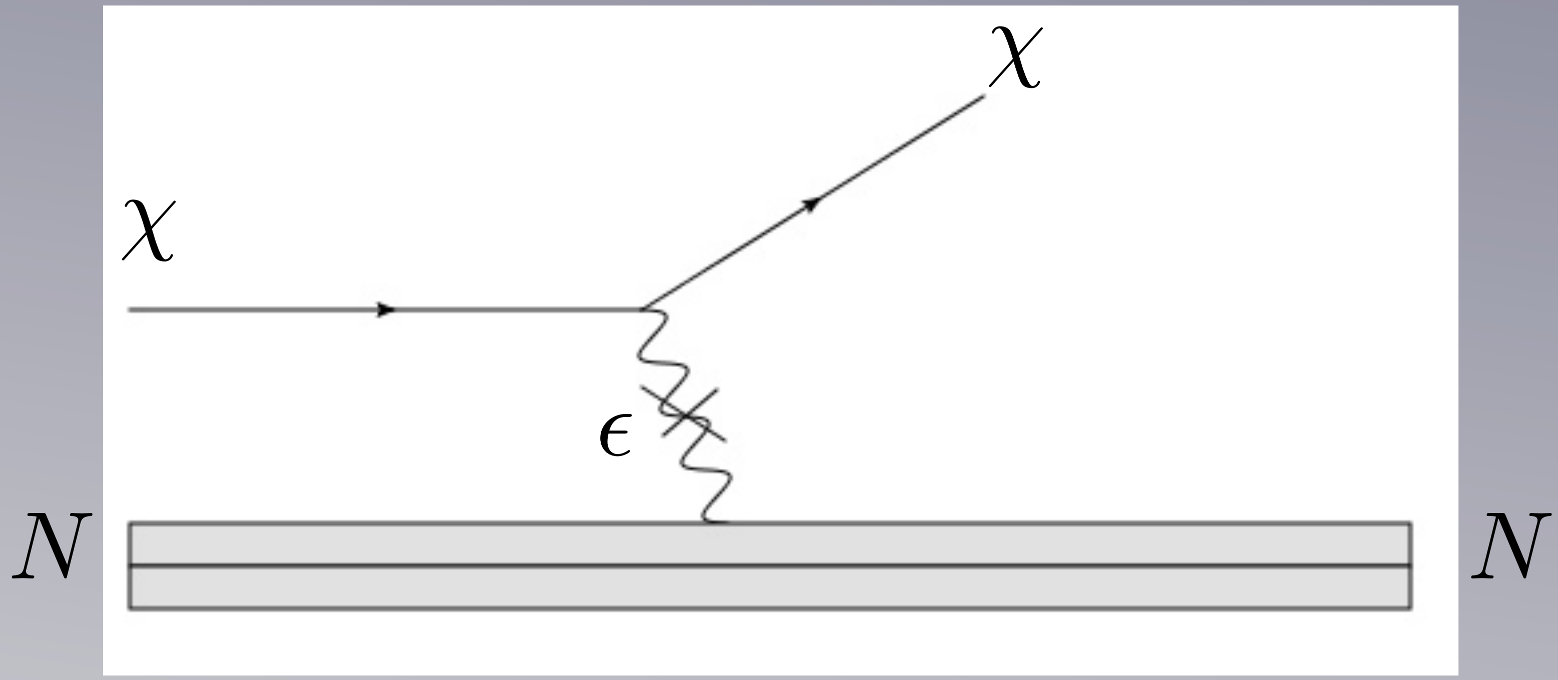

$$\sigma \approx \frac{\alpha_d^2}{m_\chi^2}$$

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

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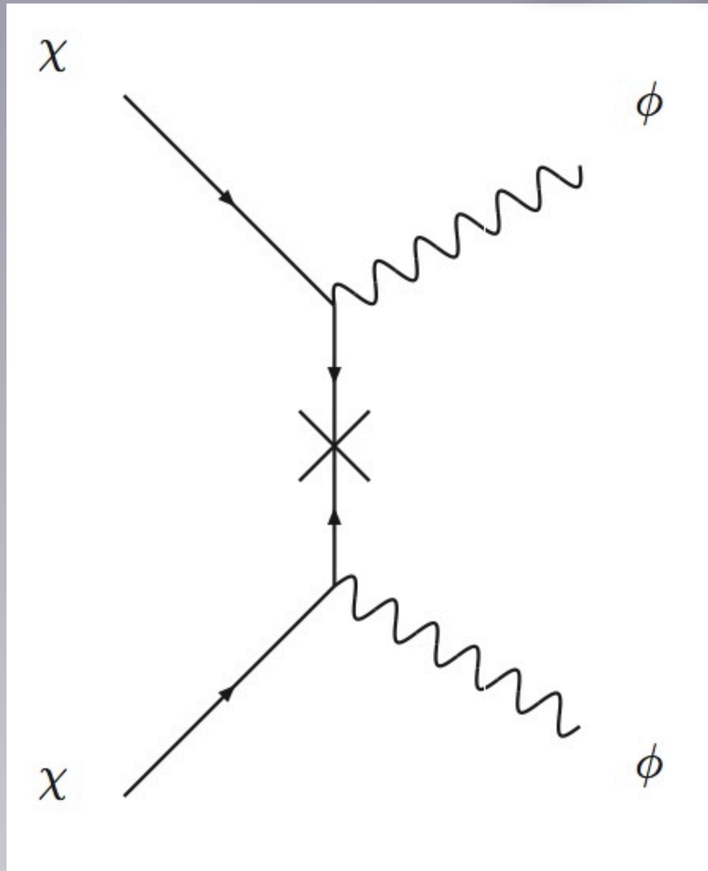
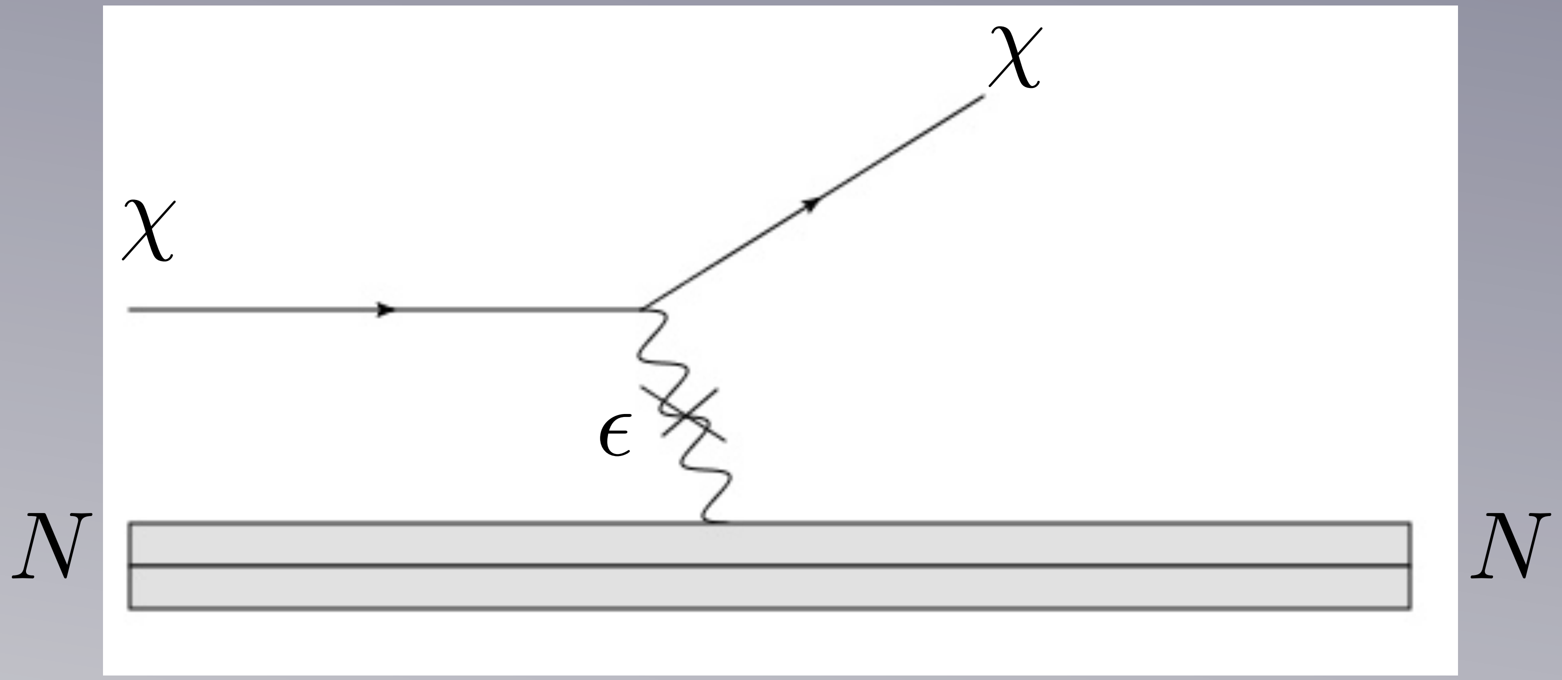




$$\sigma \approx \frac{\alpha_d^2}{m_\chi^2}$$

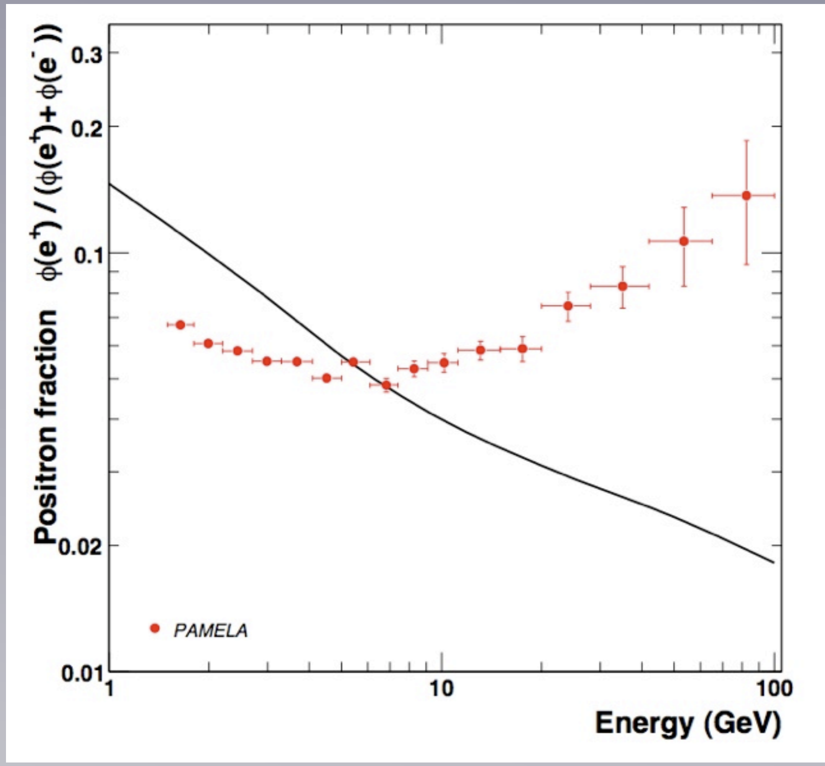
$$\sigma \approx \frac{\alpha_d \alpha_{EM} \epsilon^2}{m_\phi^4}$$

Significant parametric differences - can avoid overclosure and have large cross section

ANOMALIES II: COSMIC RAYS

ANOMALIES II: COSMIC RAYS

PAMELA sees positrons



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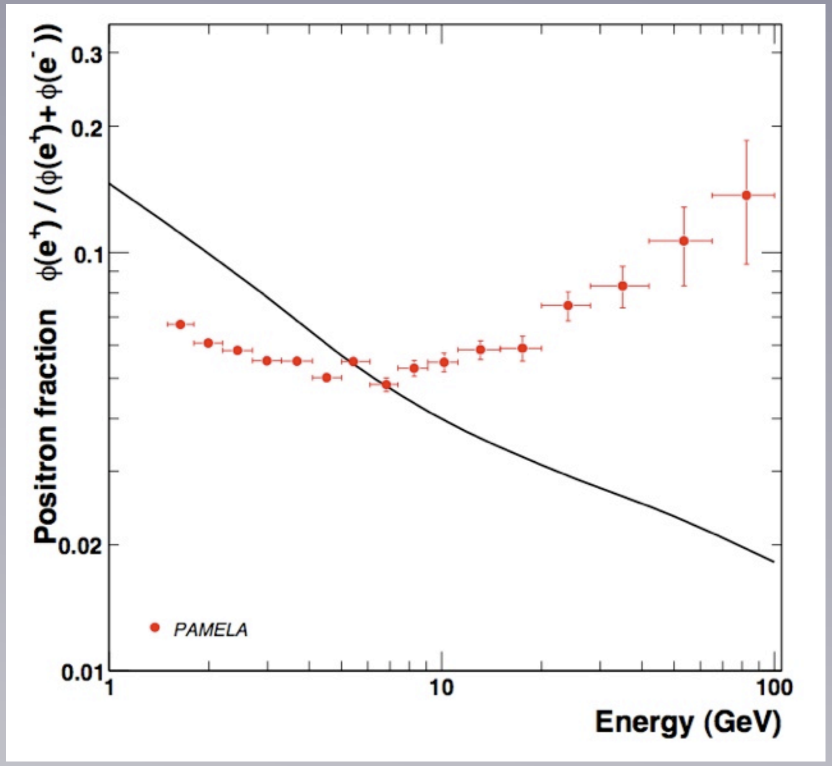
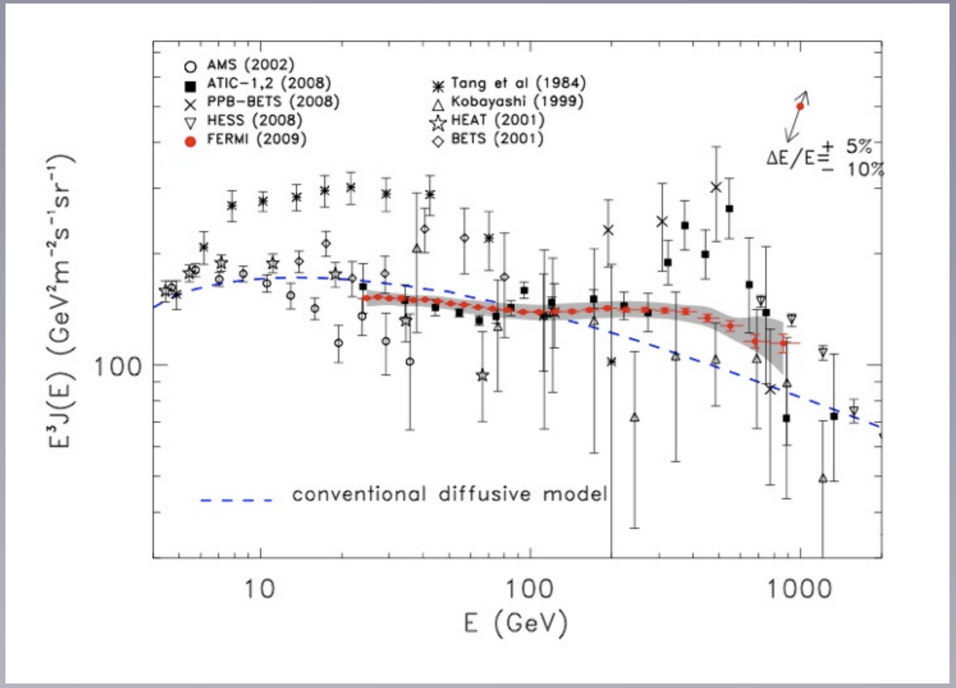


Consistent with Fermi e^+e^-



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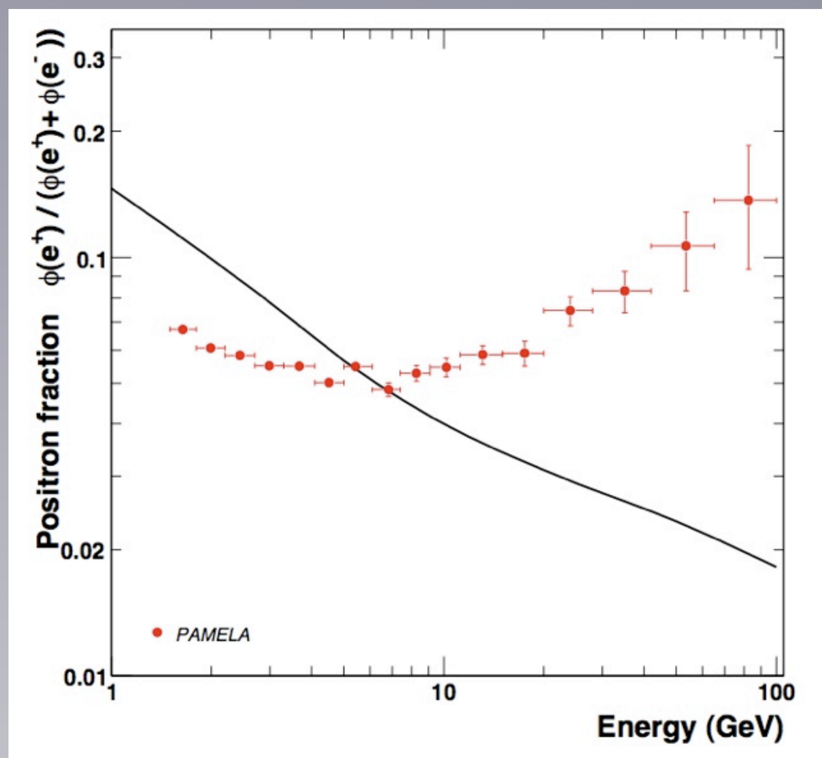
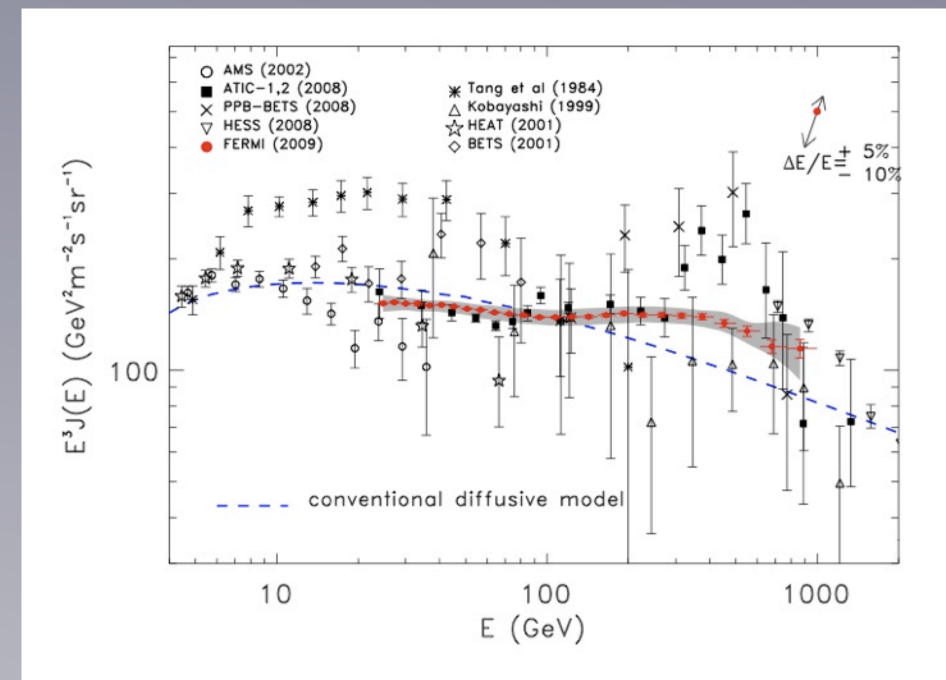
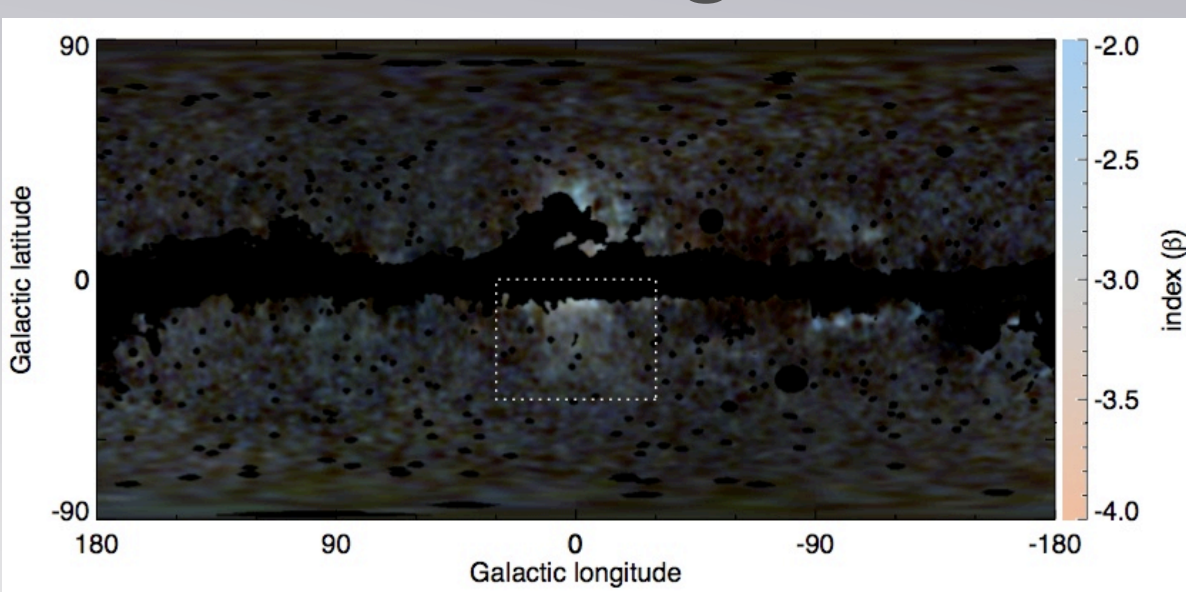




in the galactic center, this produces



synchrotron (WMAP)

ANOMALIES II: COSMIC RAYS

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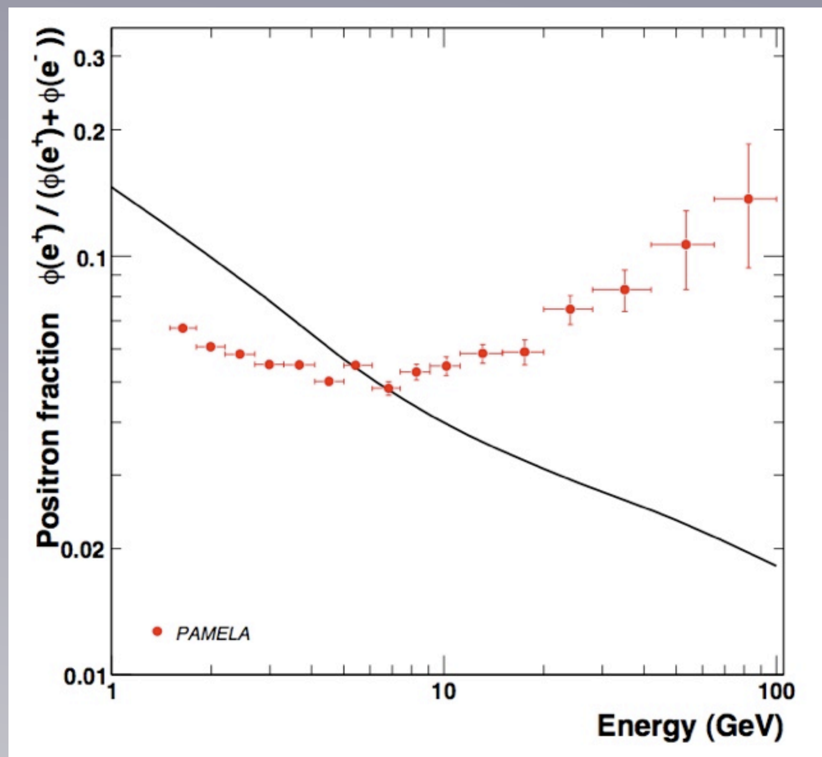

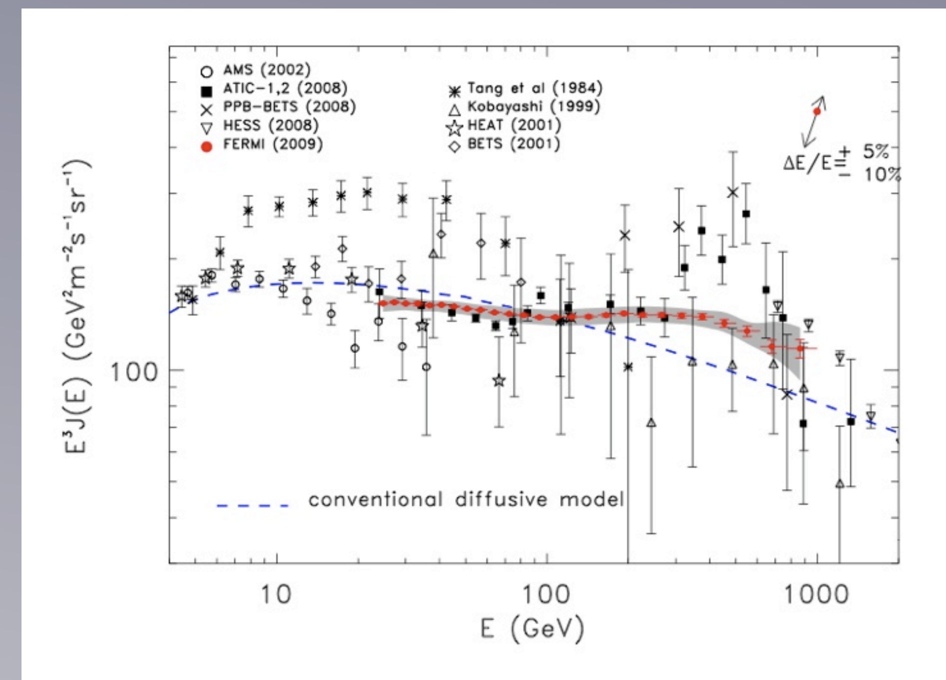

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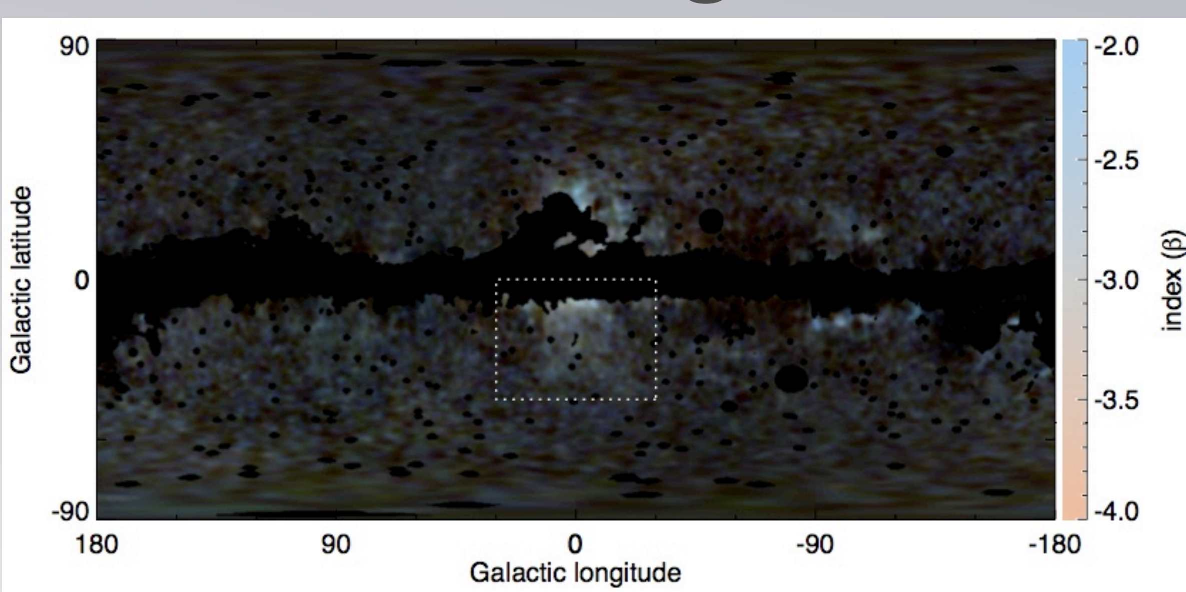
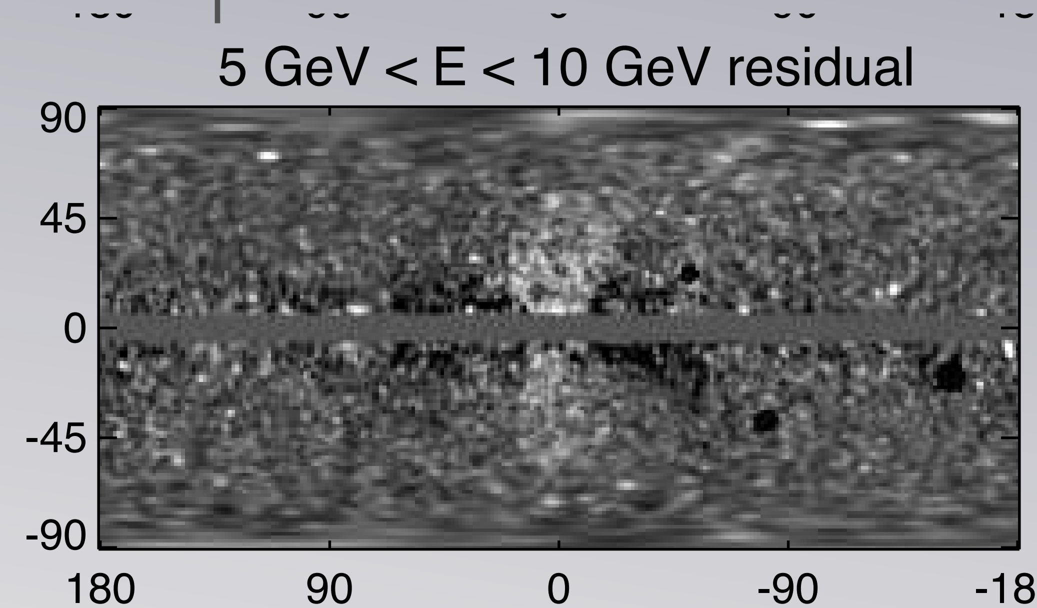


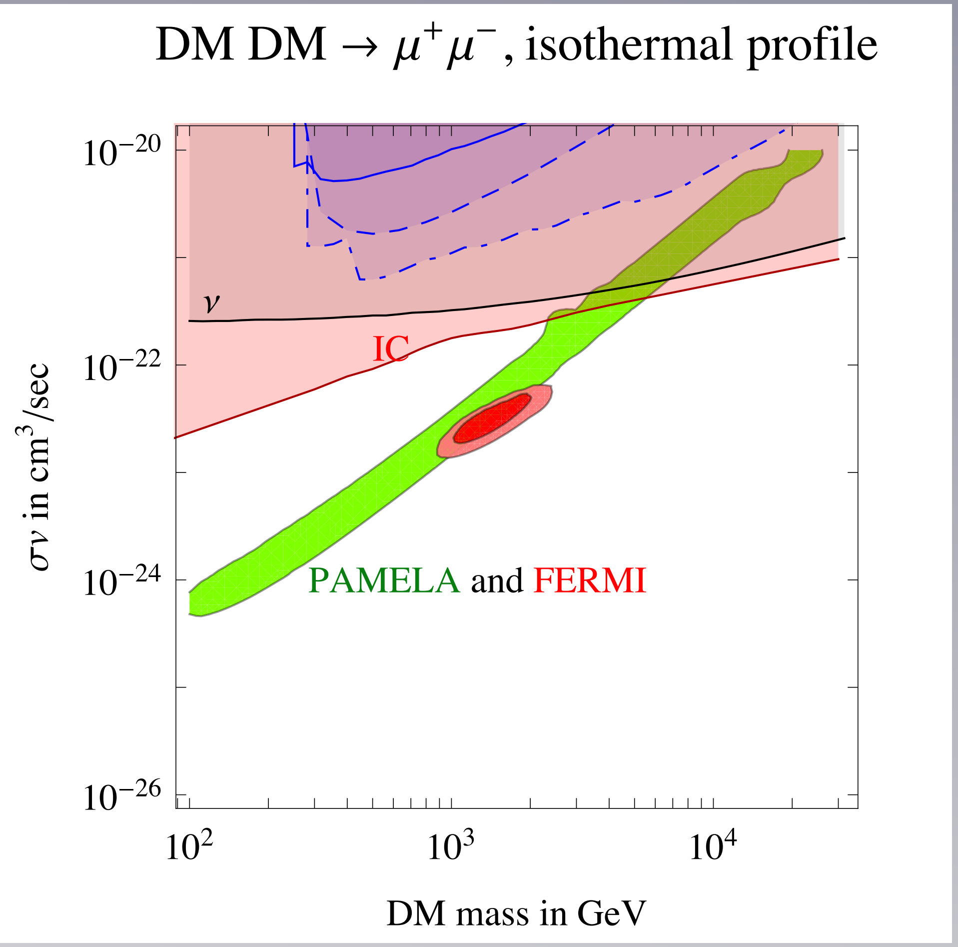


synchrotron (WMAP)

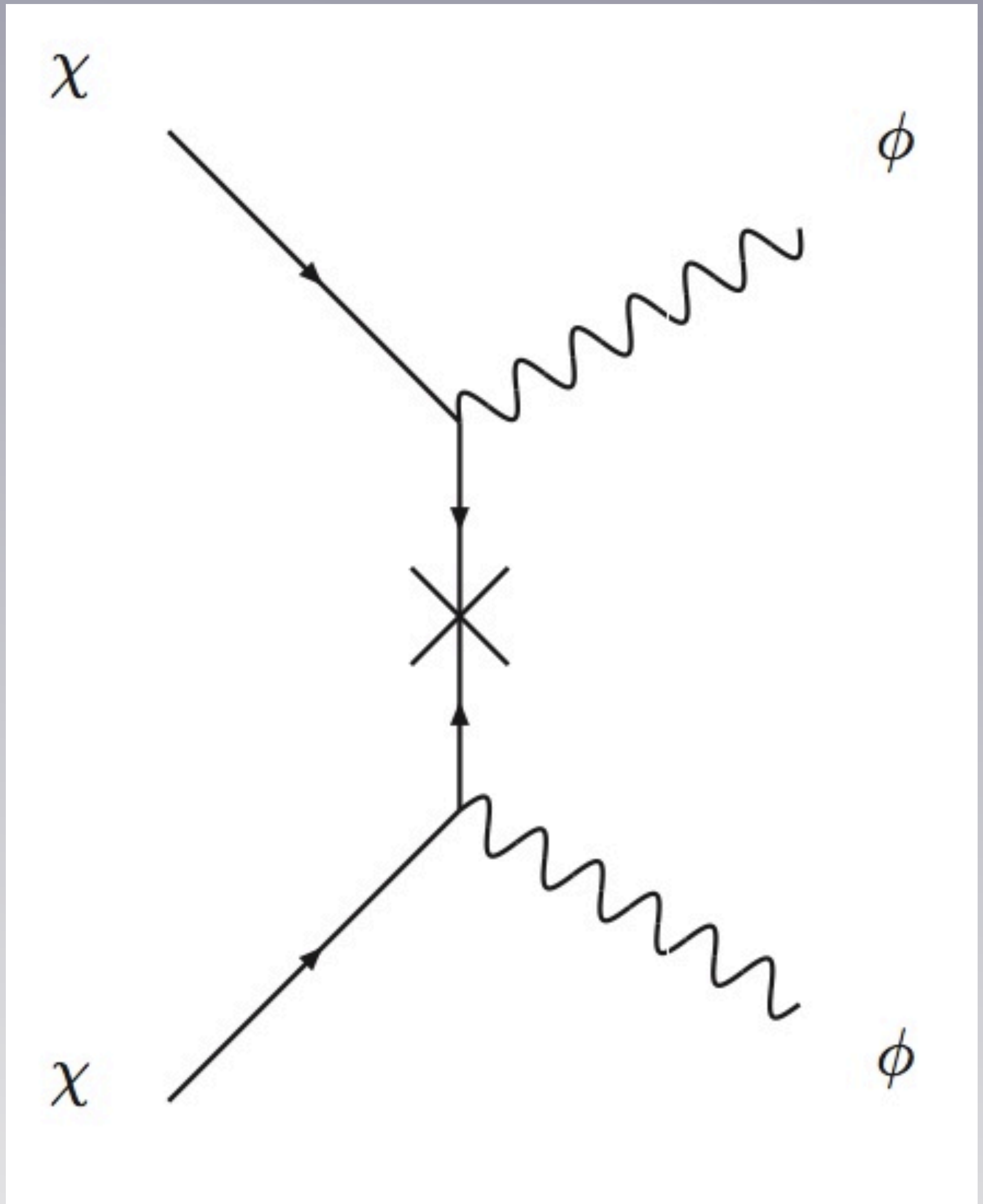
inverse-compton (Fermi)

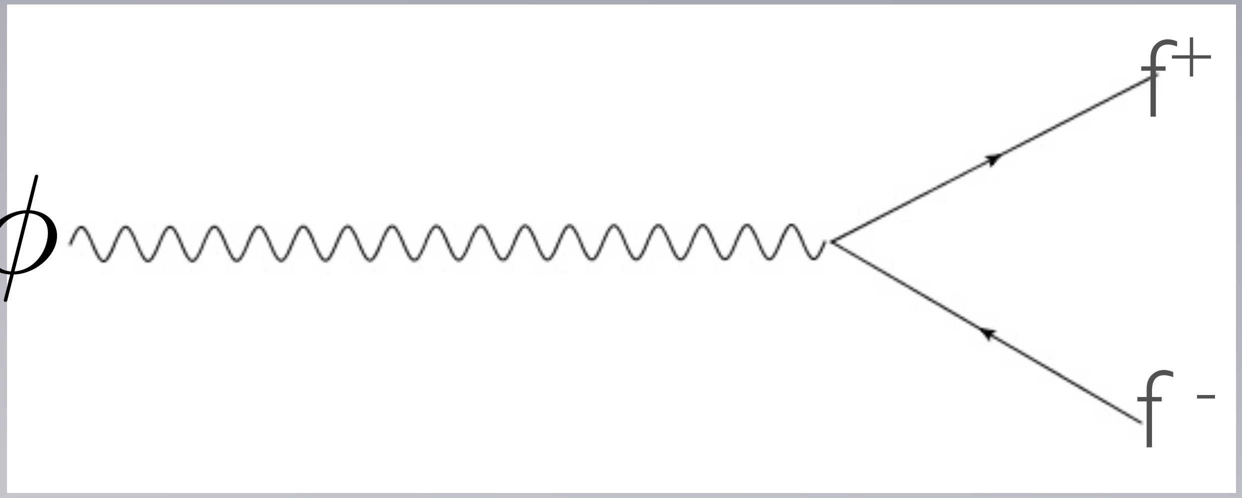
DARK MATTER?

- Cross section is very big
- Cannot be hadronic as no antiproton excess seen (cannot annihilate into quarks or W bosons)



A NEW FORCE = HARD LEPTONS



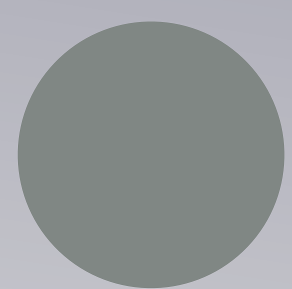


if $m_\varphi < 2$ GeV, no antiprotons

ENHANCED ANNIHILATION

Sommerfeld Enhancement

High velocity



ENHANCED ANNIHILATION

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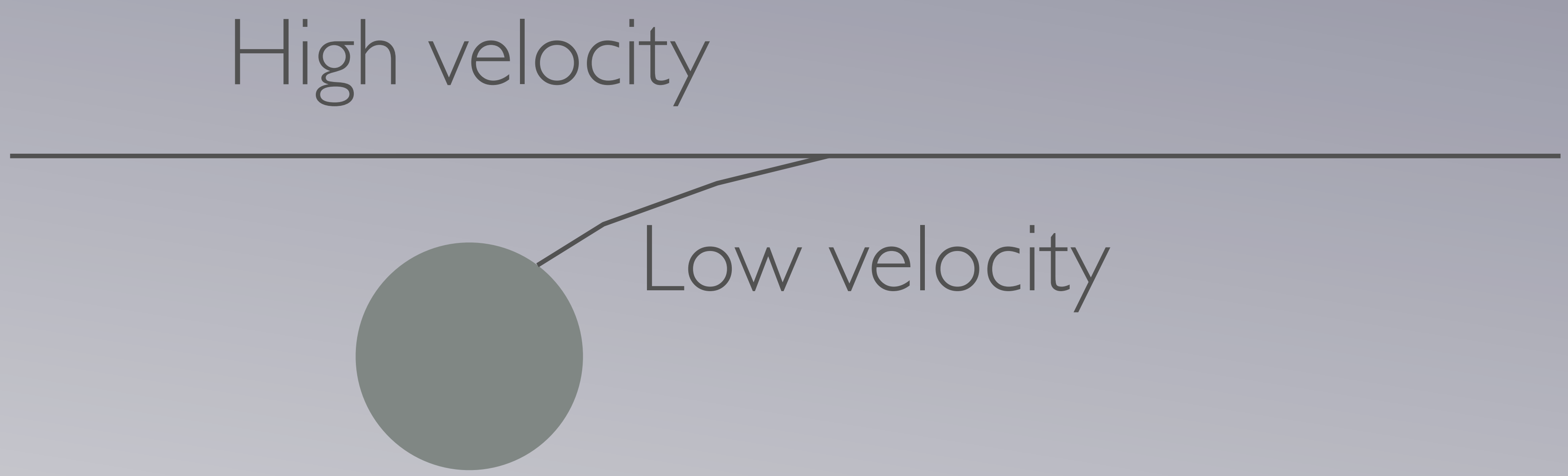

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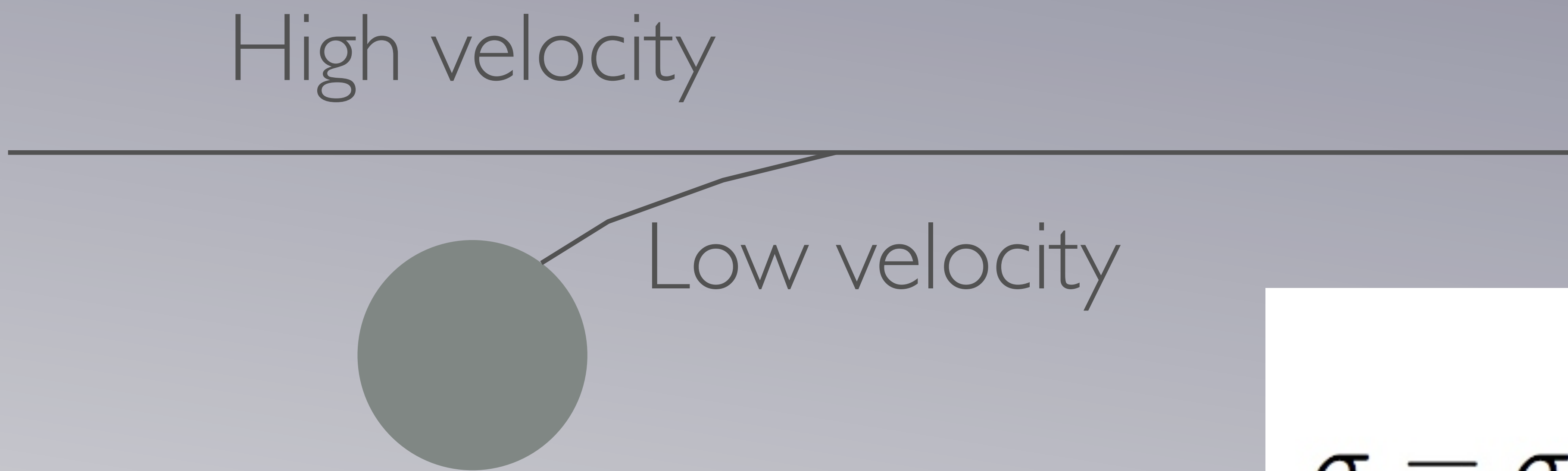

$$\sigma = \sigma_0 \left(1 + \frac{v_{esc}^2}{v^2}\right)$$

ENHANCED ANNIHILATION

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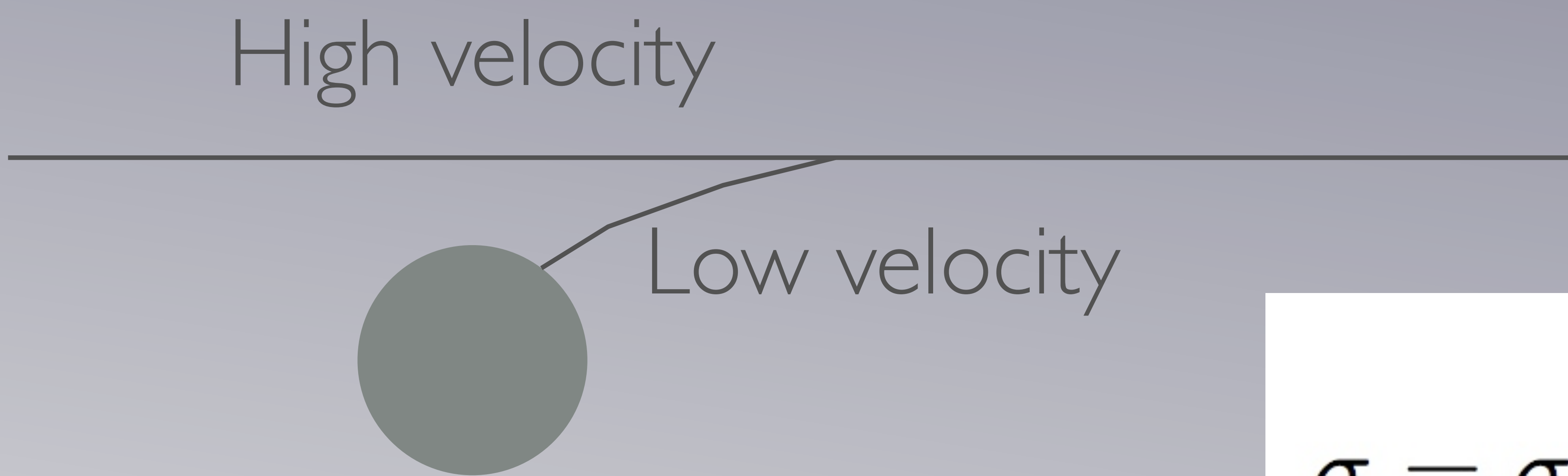


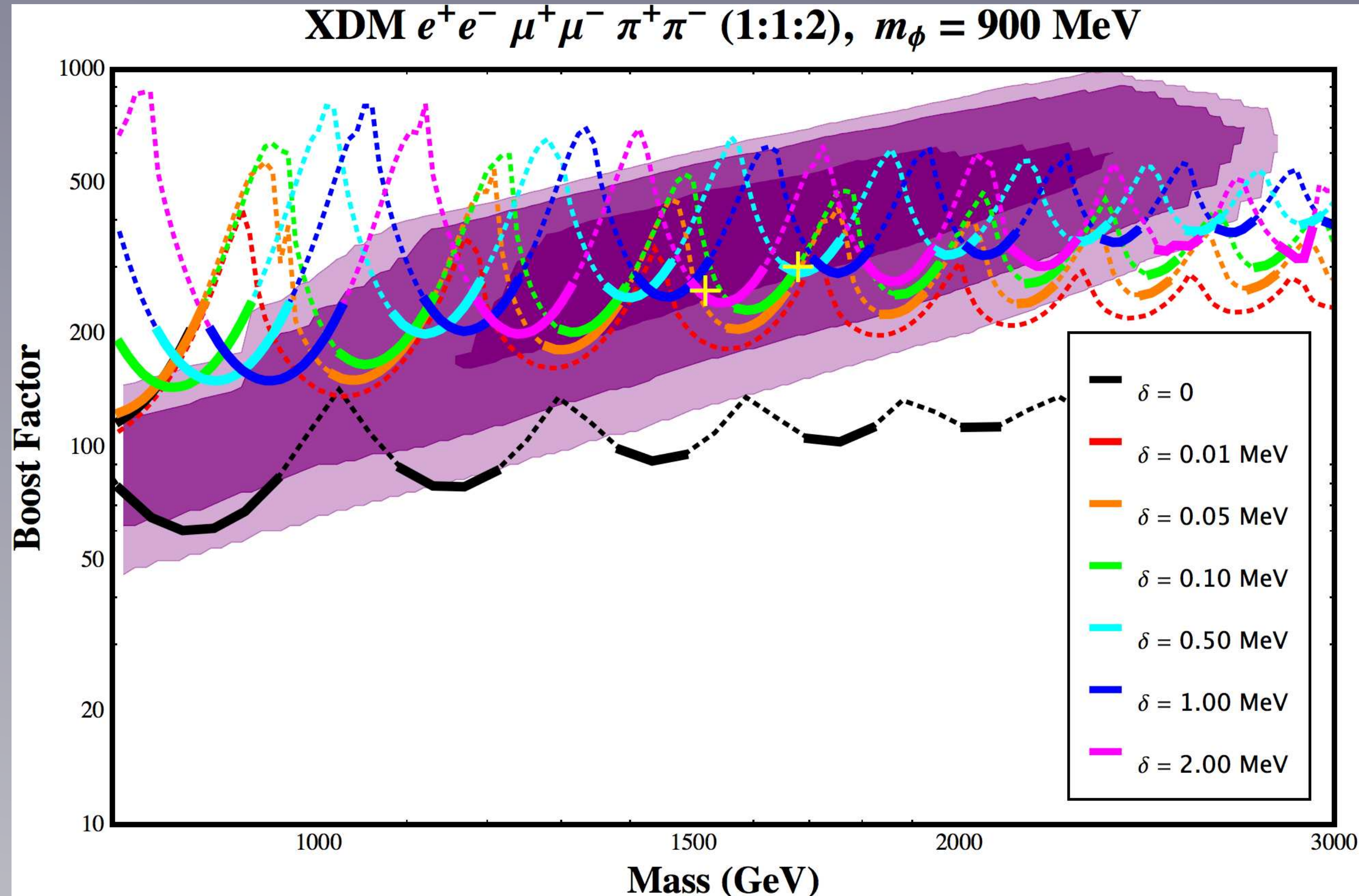
$$\sigma = \sigma_0 \left(1 + \frac{v_{esc}^2}{v^2} \right)$$

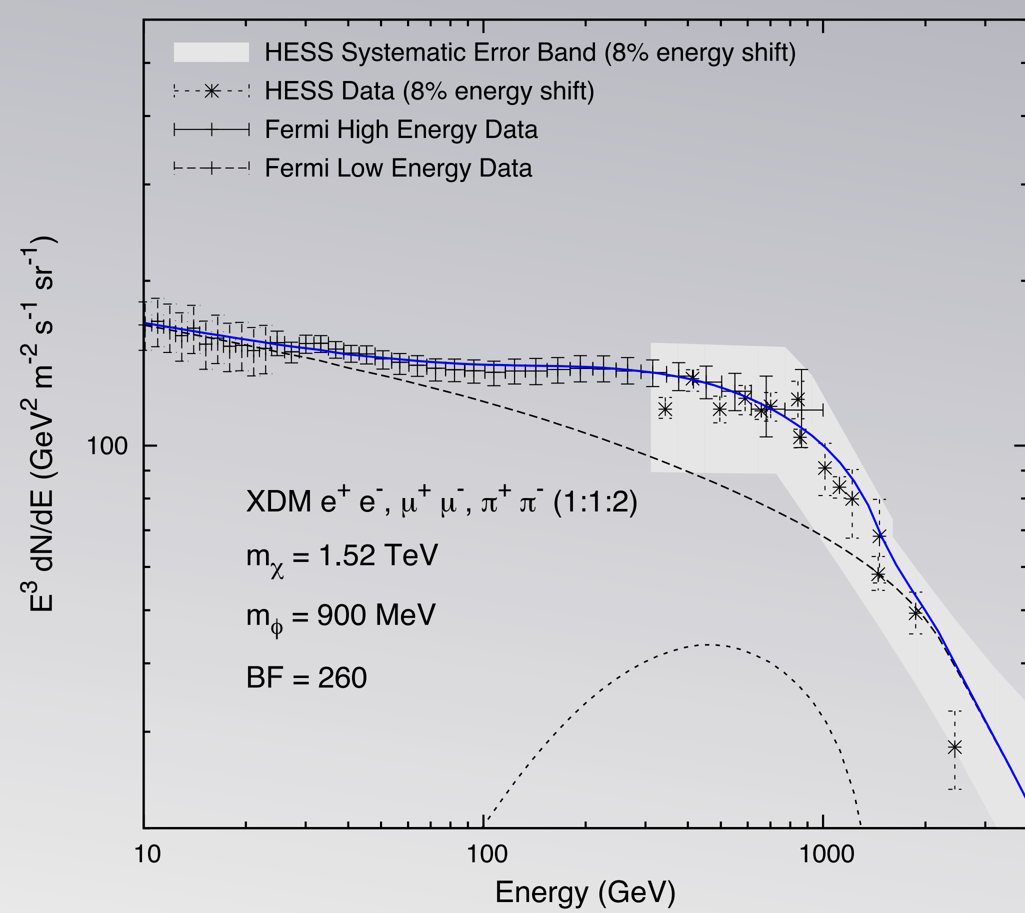
$$\langle \sigma v \rangle = \frac{\pi \alpha}{v} \langle \sigma_0 v \rangle$$

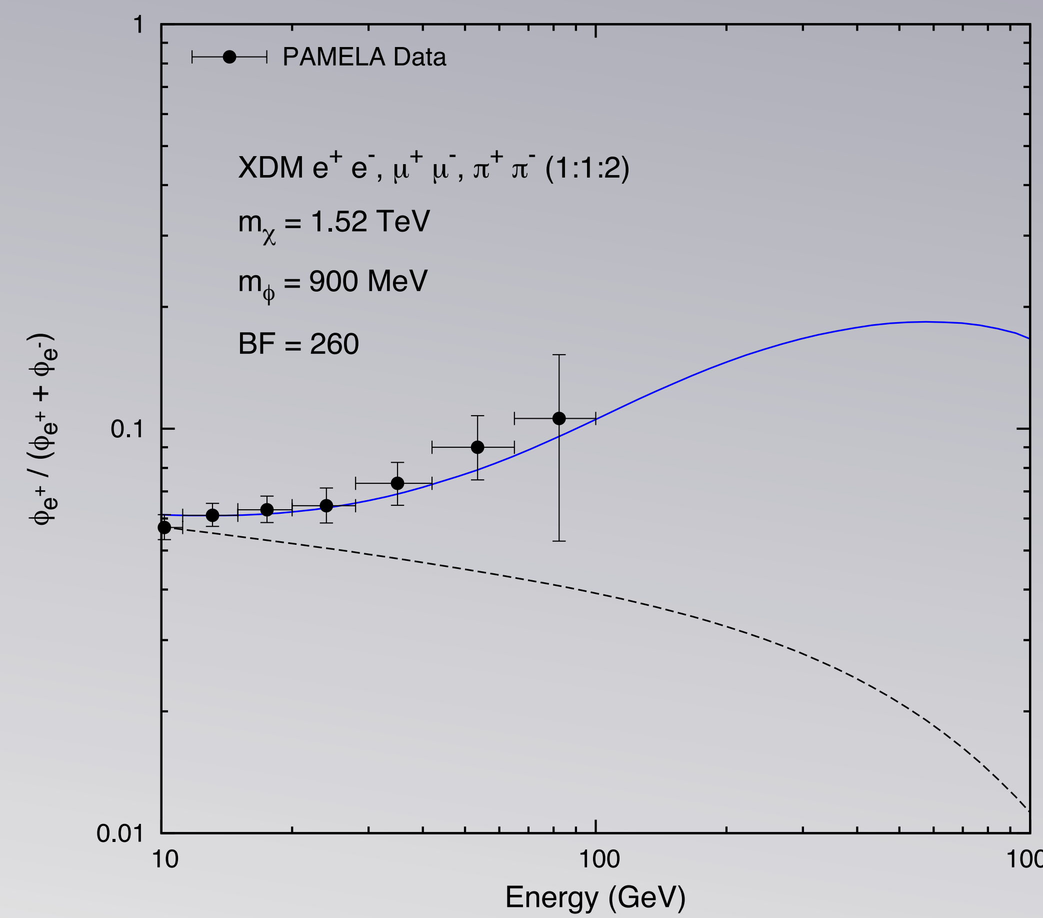
CAN IT WORK?

- yes!

Finkbeiner, et al, 2010





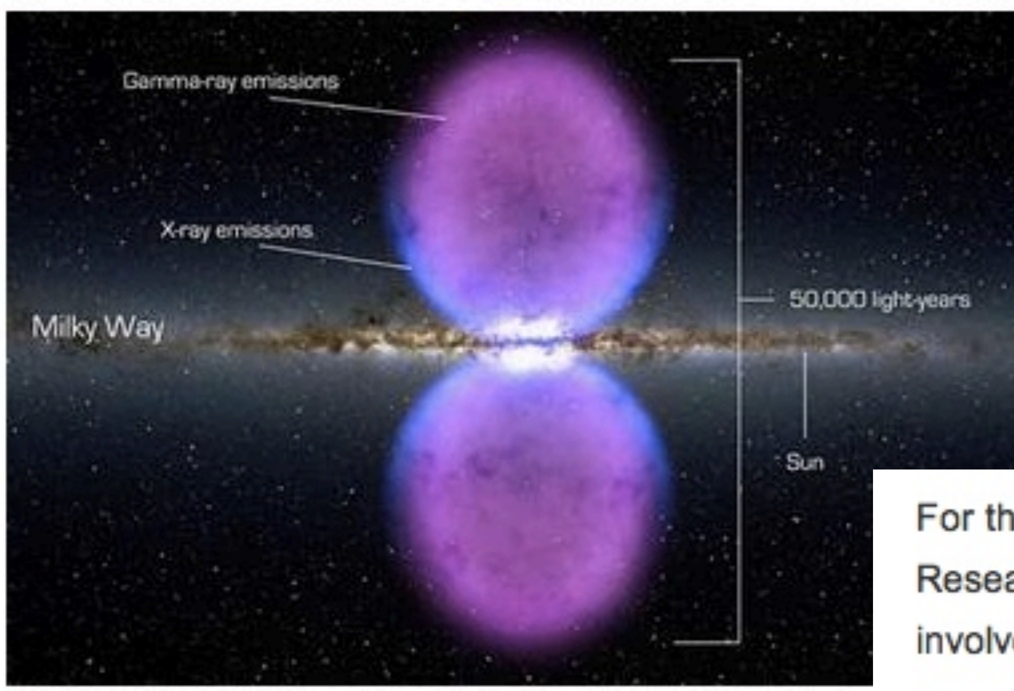


BUBBLES?

The Christian Science Monitor

Milky Way 'bubbles' baffle astronomers searching for dark matter

A team of scientists, using NASA's Fermi Gamma-ray Space Telescope, says a pair of puzzling bubbles gets in the way of their quest to search for dark matter at the core of the Milky Way.



This NASA handout image shows from end to end, the newly discovered gamma-ray bubbles as they extend 50,000 light-years, or roughly half of the Milky Way's diameter.

NASA/Newscom

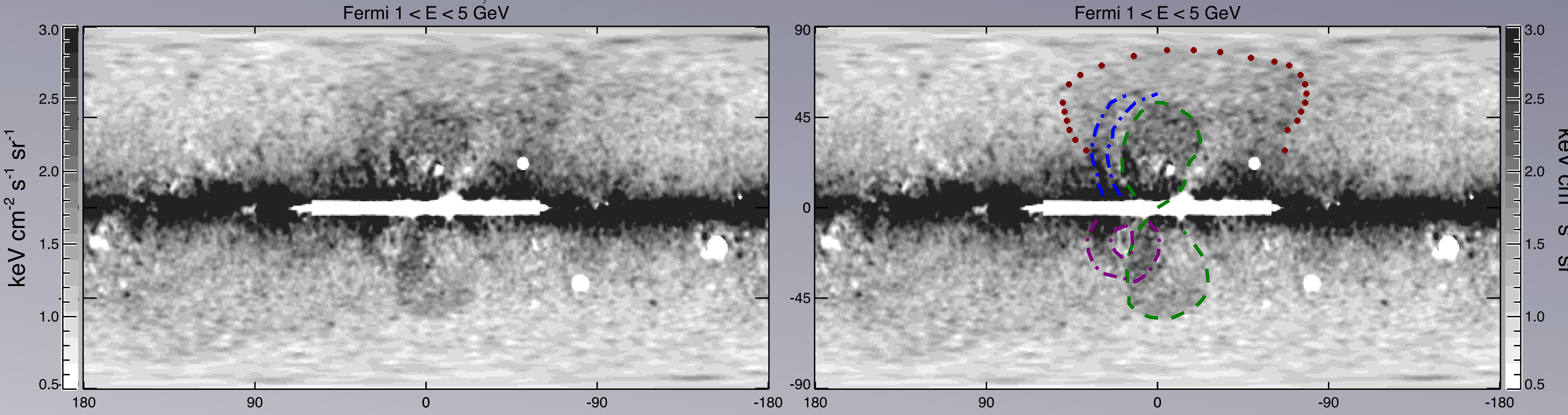
For the moment, the discovery marks a "Hey, Martha!" moment in the annals of astrophysics. Researchers don't know why the bubbles are there. Nor have they identified the violent processes involved in generating the gamma rays that betray the bubbles' presence.

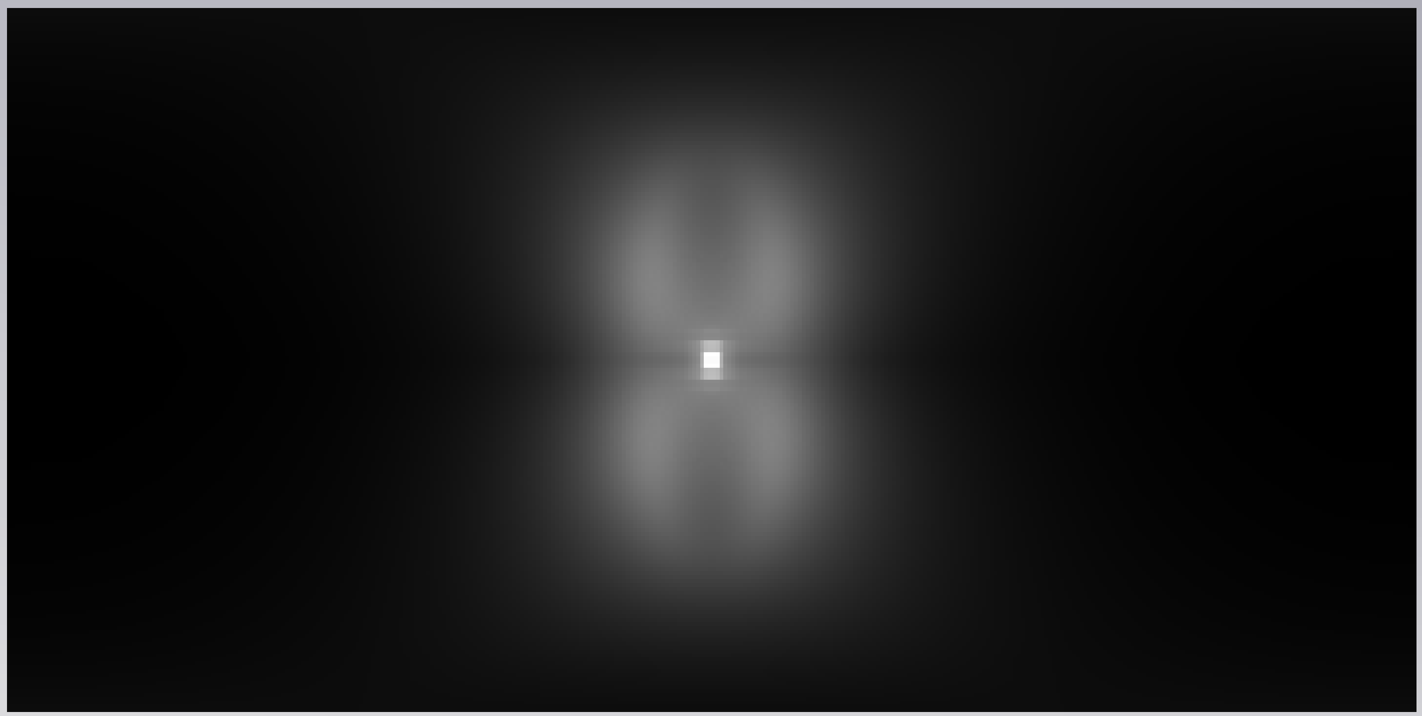
"I like the Isaac Asimov quote that discoveries don't start with: Eureka! I've found it! They start with: That looks funny!" says Douglas Bookbeiner, who led the effort.

Indeed, a galaxy blowing bubbles at temperatures of around 7 million degrees Fahrenheit was not what the team had in mind when it set out taking gamma-ray measurements of the galaxy's center, Dr. Bookbeiner says.

A bubble morphology?

Su, Finkbeiner & Slatyer, '10





DM induced ICS (preliminary Dobler, Cholis, NW)

Anisotropic diffusion/triaxial halos modify DM shape

GALACTIC CENTER SIGNALS

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- BUT
- Either changes in velocities, densities, magnetic fields, etc are causing this
- OR
- signal in GC is caused by some recent major event
- such an event would potentially blow DM-produced material out of the GC
- SO: either it's an interesting DM signal or we can never set diffuse limits from the GC

A NEW FORCE CARRIER

- Dark matter interacting with a new force naturally explains the cosmic ray signatures
- Large cross section (Sommerfeld)
- Lots of leptons (too light to go into much else)
- No anti-protons (too light to make them)

ANOMALIES III: INELASTIC WIMPS

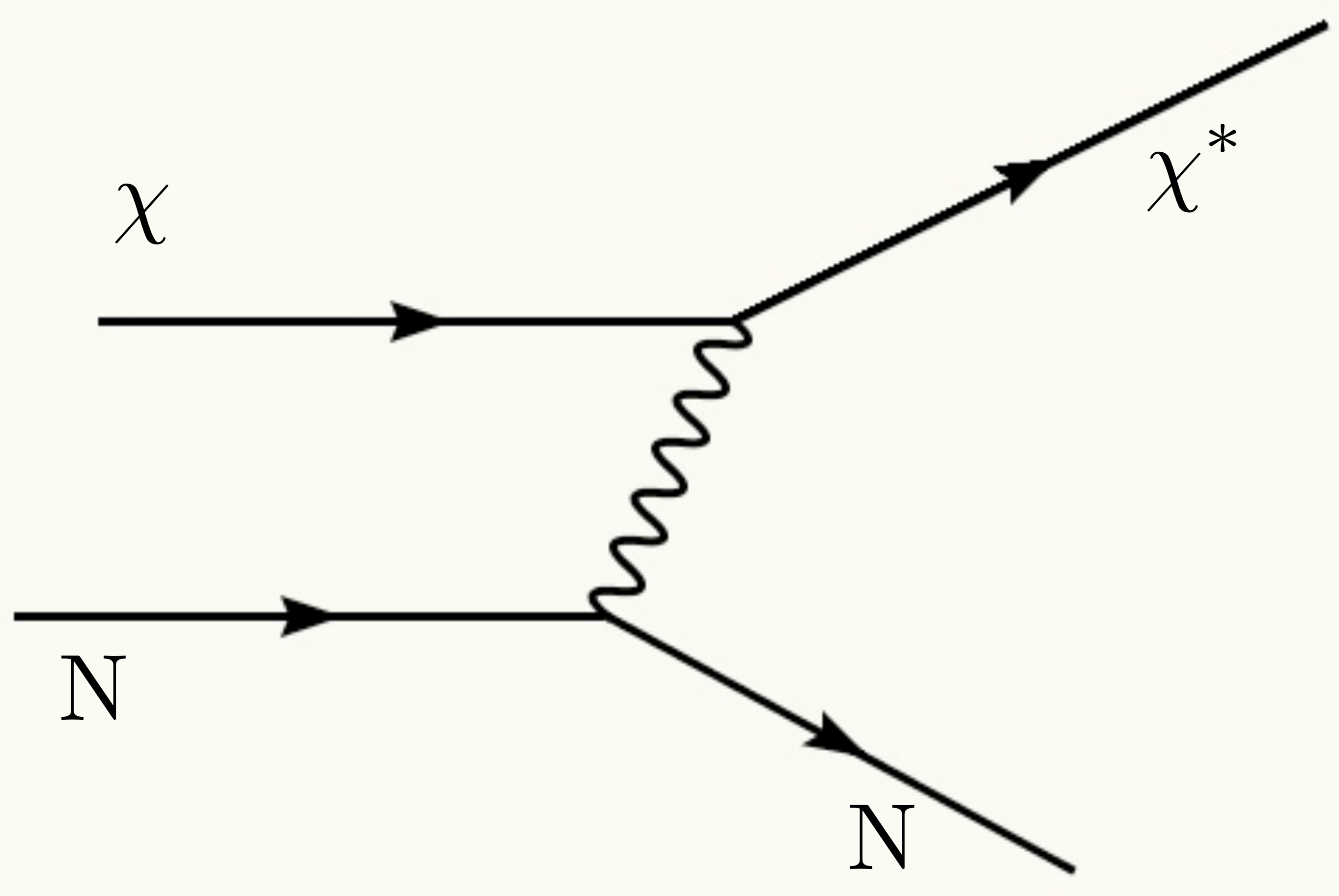
- New symmetries -> new states
- New gauge symmetries -> new states
- How does this impact direct detection?

"INELASTIC" DARK MATTER

D.Tucker-Smith, NW, Phys.Rev.D64:043502,2001;Phys.Rev.D72:063509,2005

- With dark forces, DM-nucleus scattering must be inelastic

- If dark matter can only scatter off of a nucleus by transitioning to an excited state (100 keV), the kinematics are changed dramatically



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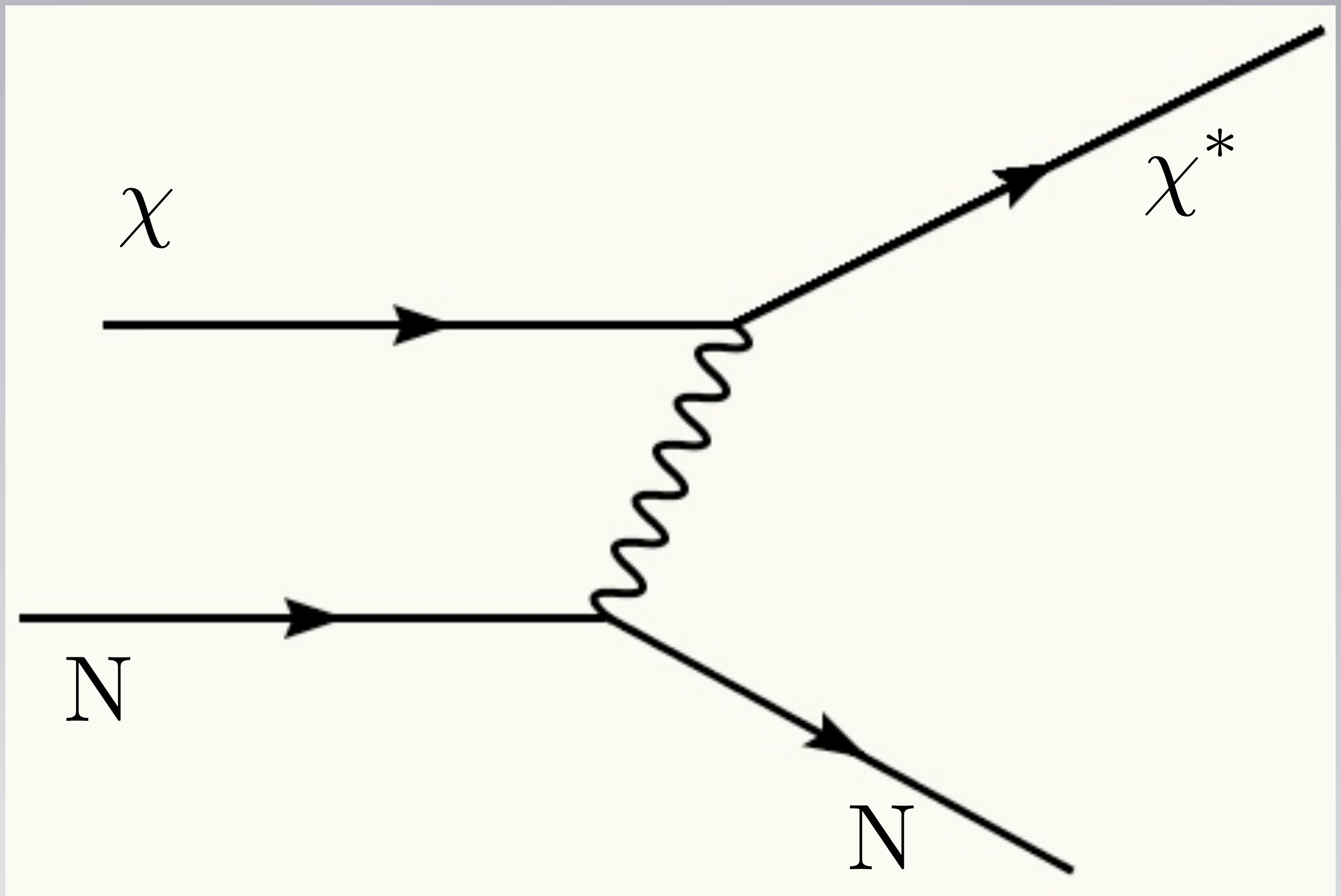
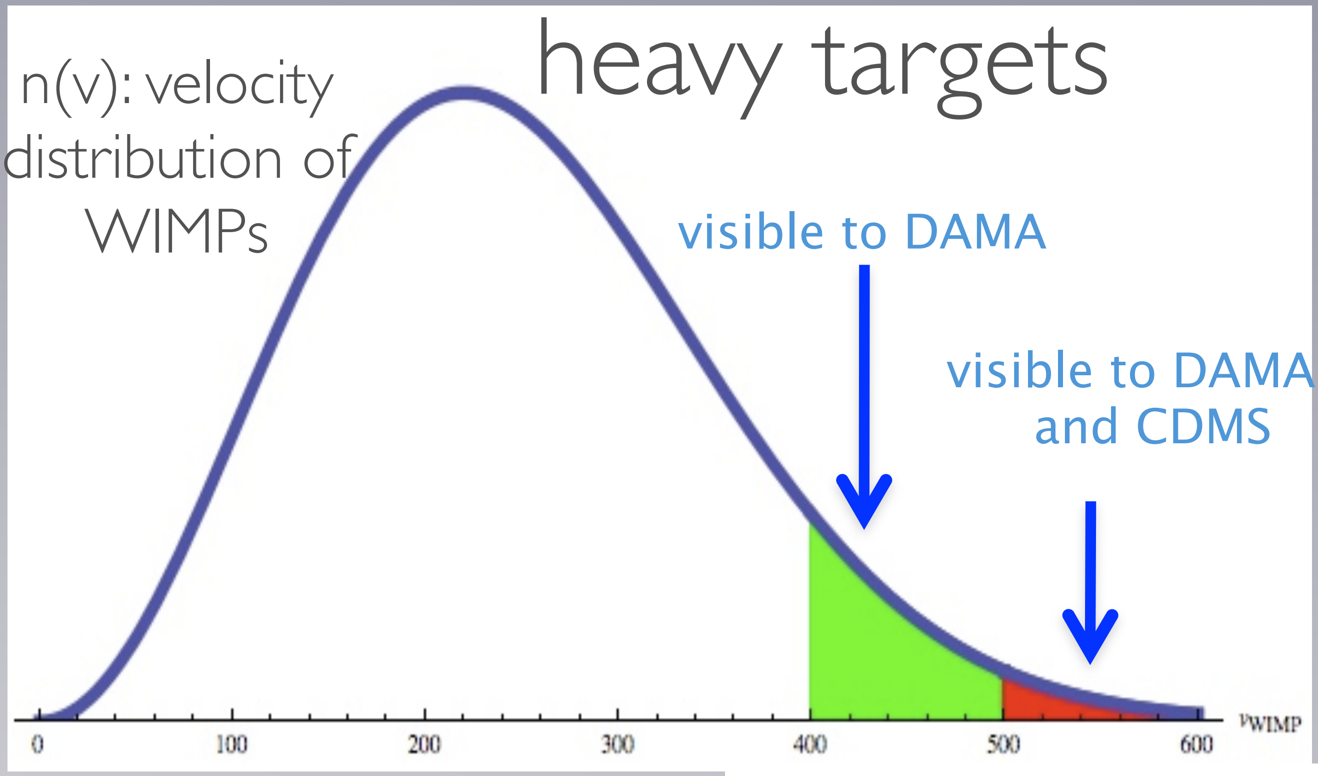
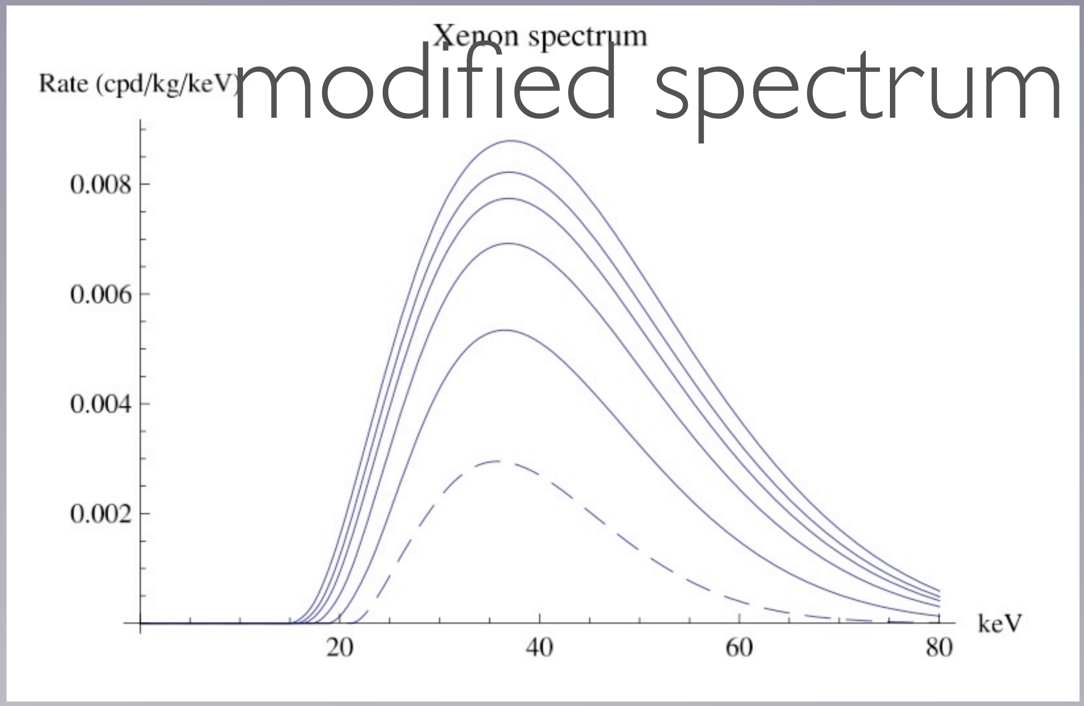
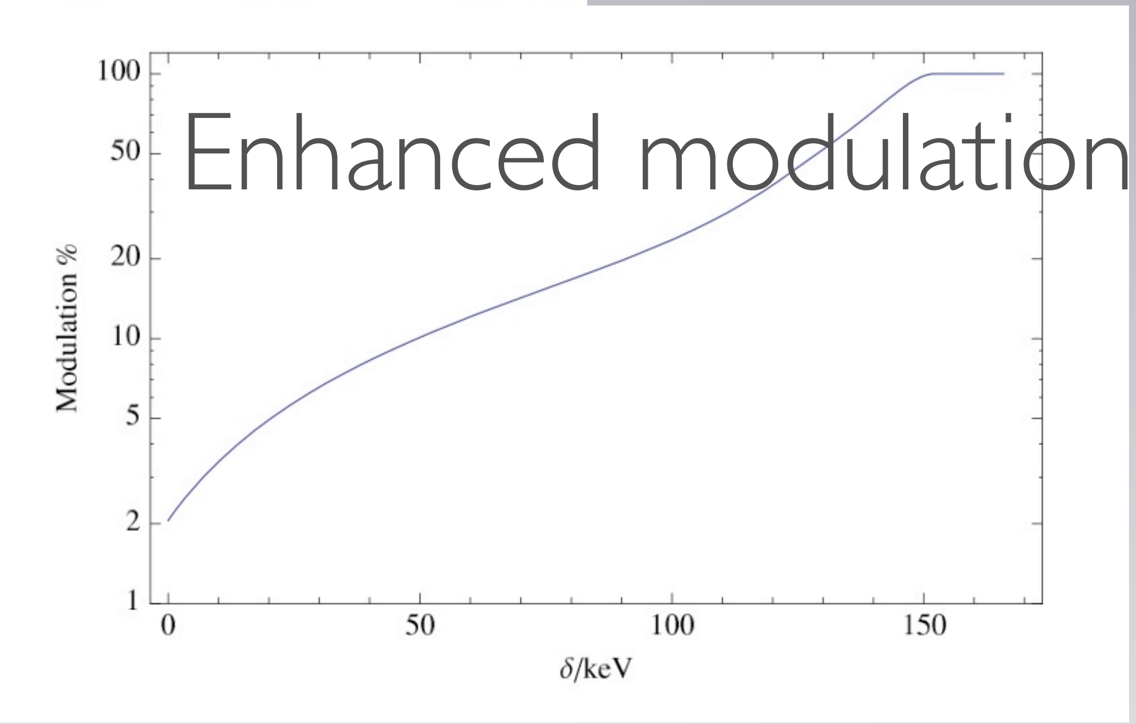


$$\frac{v^2 \mu_{\chi N}}{2} > \delta$$

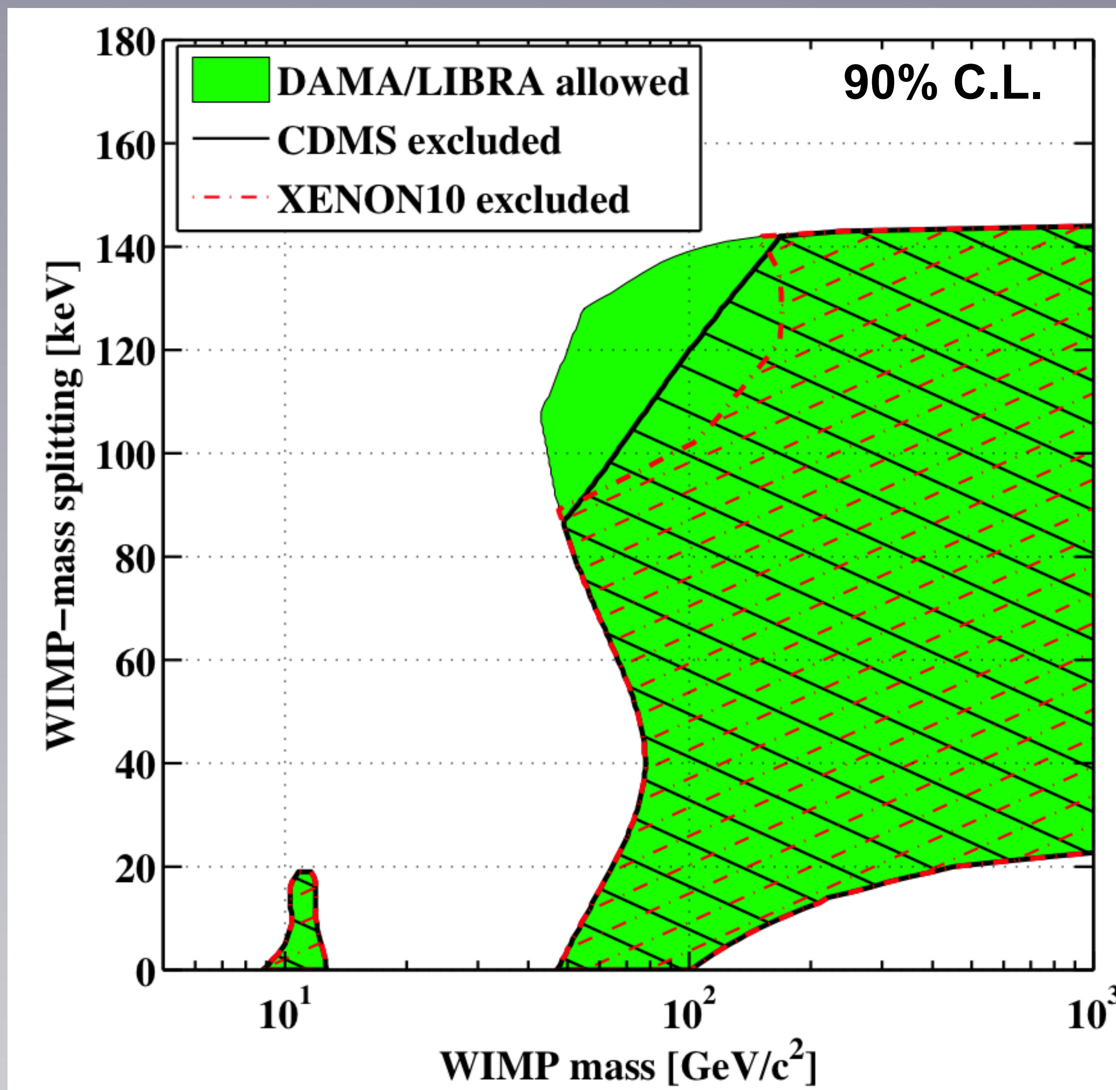
EFFECTS ON WIMP SEARCHES







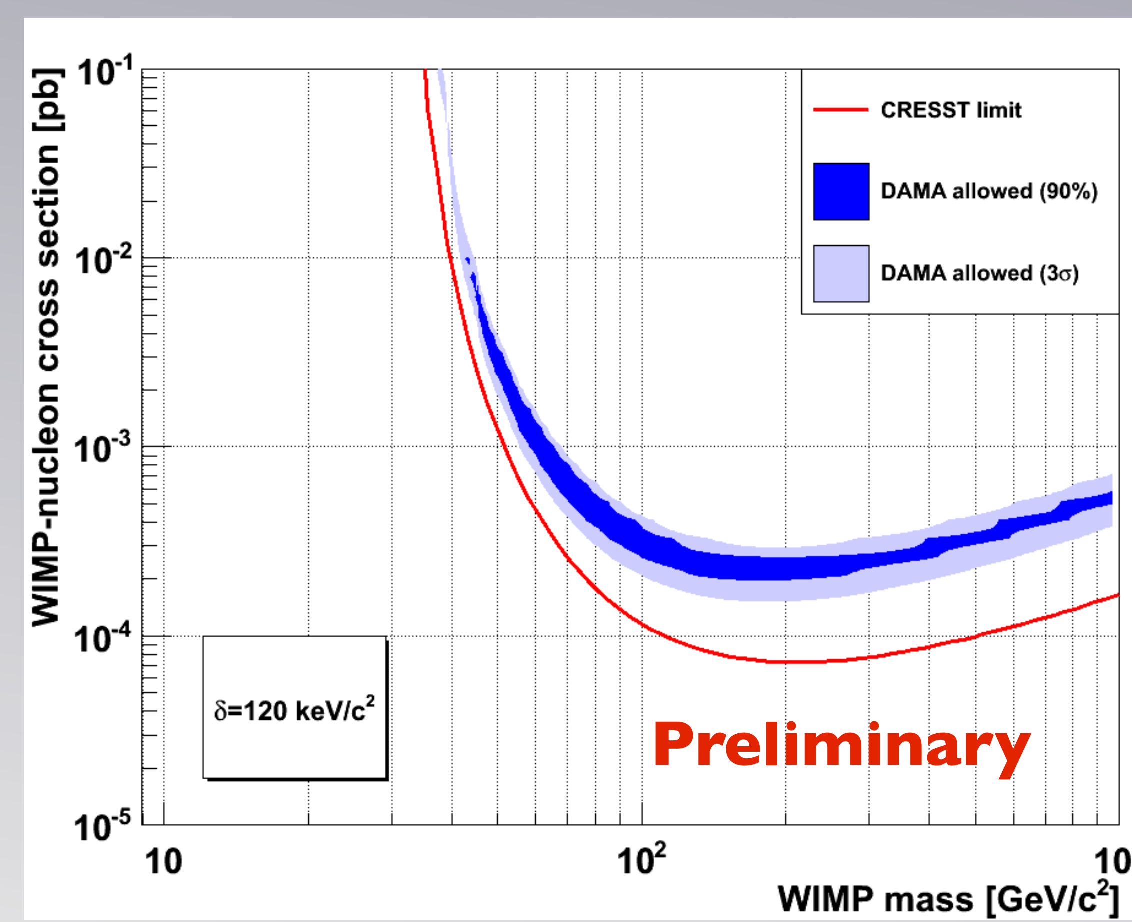
IDM CONSTRAINTS



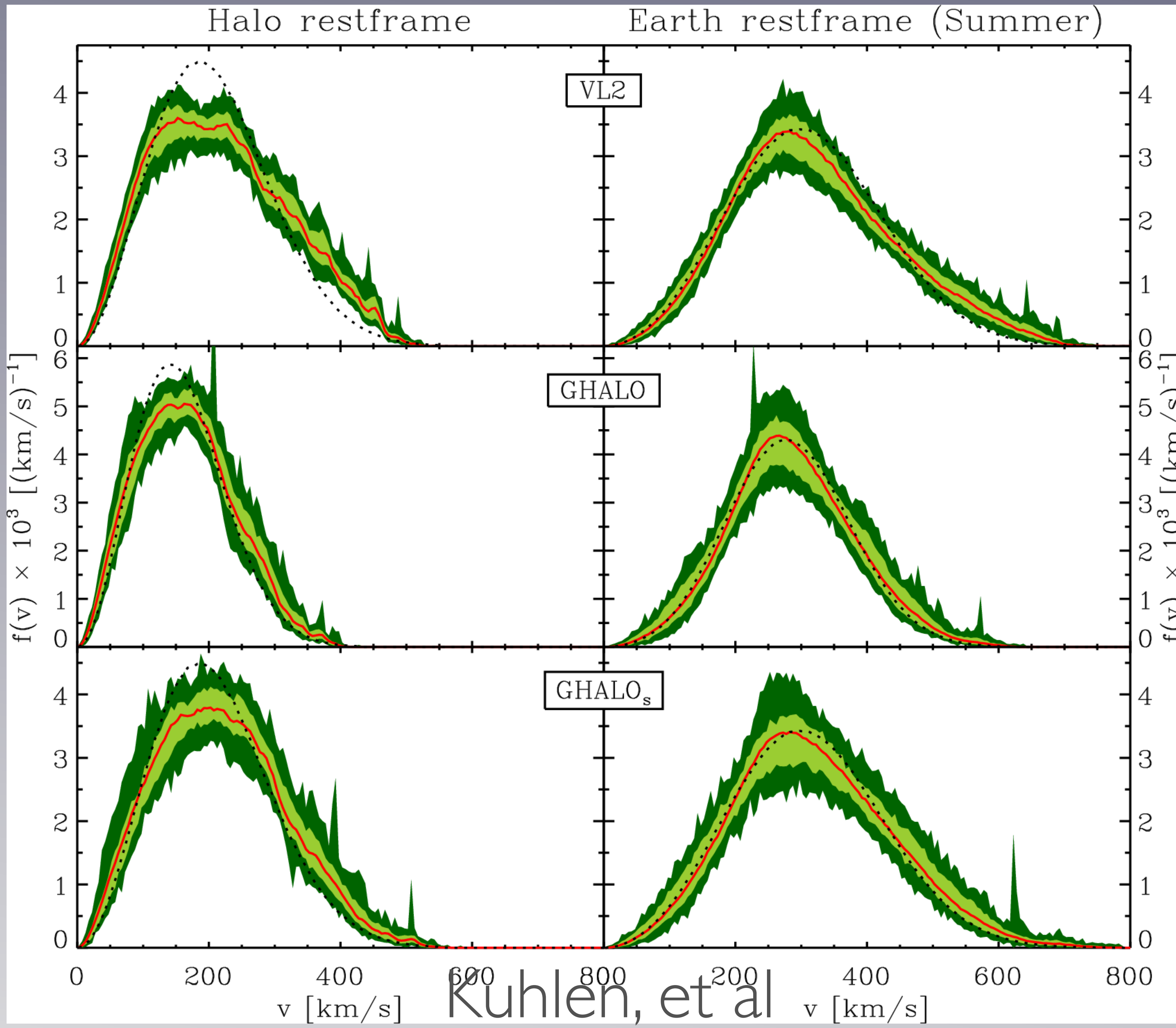
Tight constraints from CDMS, XENON (shown), also ZEPLIN, CRESST

Must be in the highly modulated regime

NB: If WIMP scatters via magnetic dipole, limits are much weaker (Chang, NW, Yavin '10)




HALO
WARS
What you don’t know about the
halo *can* hurt you...



MB generally good near the peak, generally not near the tail
changes x2 or more

ANOMALIES IV: DWARFS

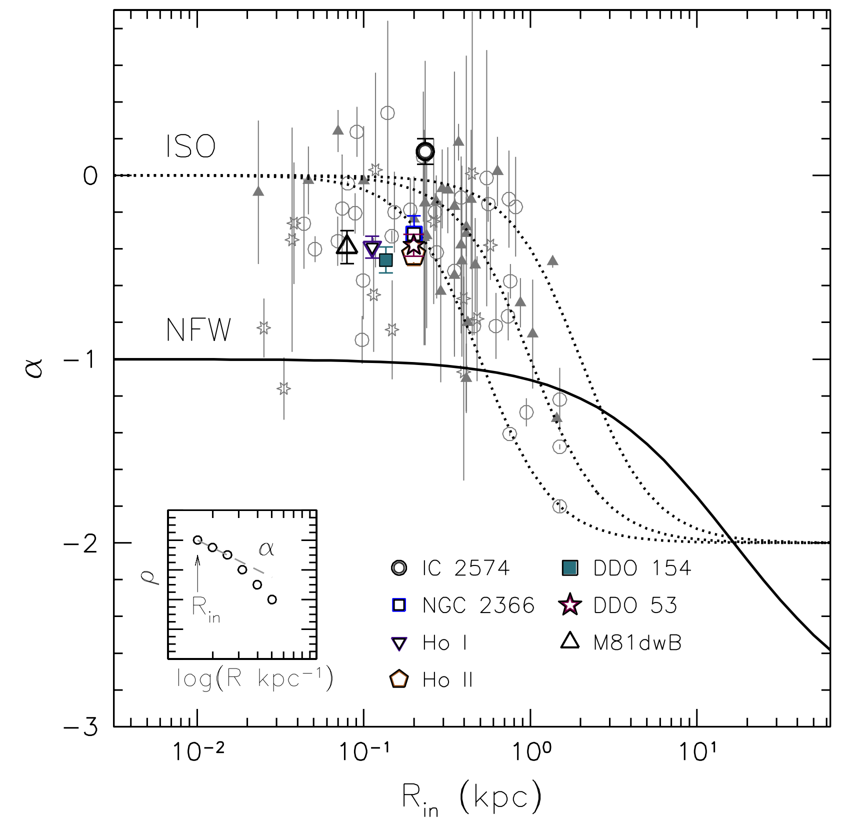
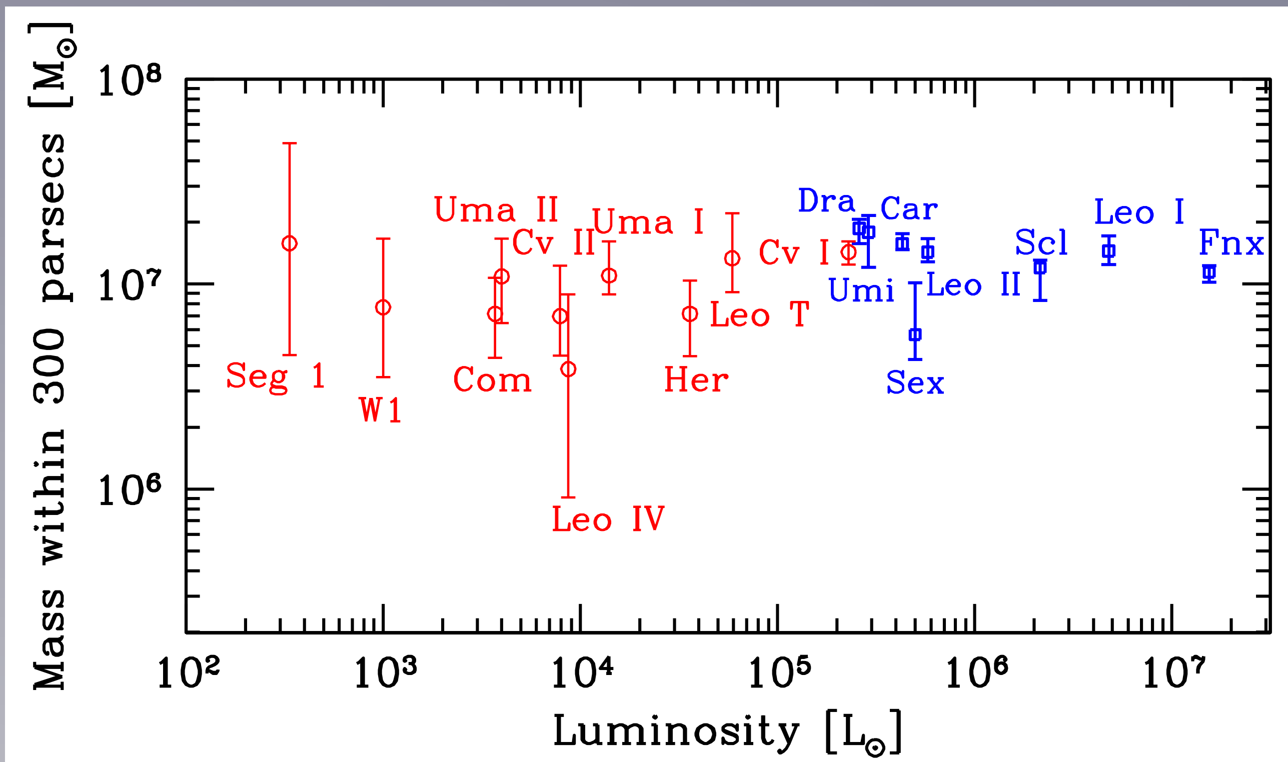


FIG. 8.— The inner slope of the dark matter density profile plotted against the radius of the innermost point. The inner density slope α is measured by a least squares fit to the inner data point as described in the small figure. The inner-slopes of the mass density profiles of the 7 THINGS dwarf galaxies are overplotted with earlier papers and they are consistent with previous measurements of LSB galaxies. The pseudo-isothermal model is preferred over the NFW model to explain the observational data. Gray symbols: open circles (de Blok et al. 2001); triangles (de Blok & Bosma 2002); open stars (Swaters et al. 2003). See Section 6.3 for more discussions.



- Cores in isolated halos should evolve to NFW (Sawala et al '10)

DM INTERACTIONS?

- Spergel & Steinhardt (2000) suggested DM with nuclear-like scattering could generate cores
  - tensions with high velocity systems
  - tensions with low velocity systems

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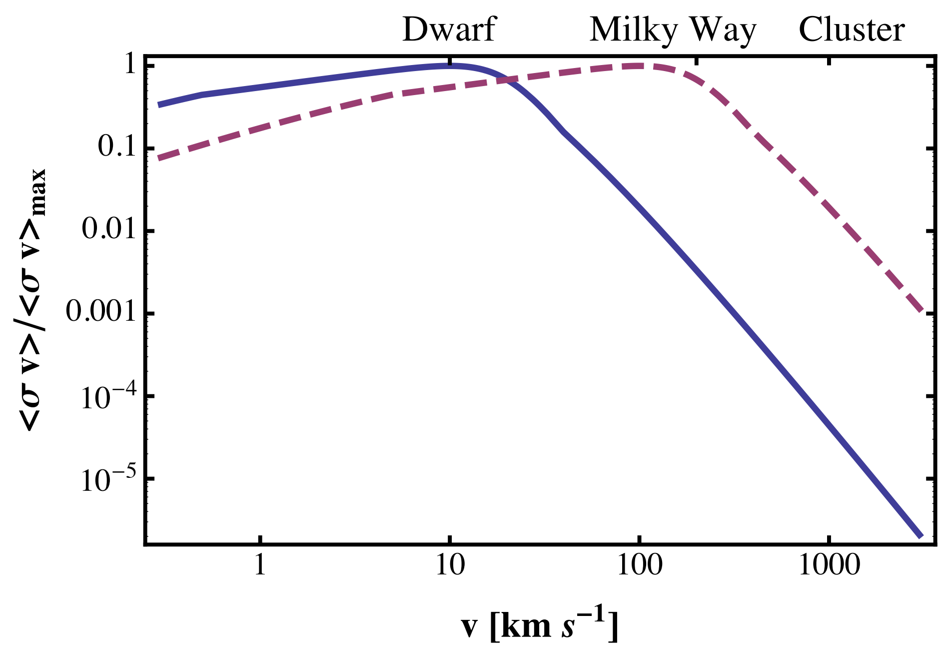

FIG. 1: Dependence of the self-interaction cross-section (σ) on the relative velocity (v) for dark matter interacting through a Yukawa potential. The normalizations of σ and v are set by free parameters in the underlying Lagrangian (see Appendix), and we show two possible curves peaking at $v_\sigma = 10$ km s^{-1} and $= 100$ km s^{-1} (*blue, solid* and *purple, dashed*, respectively).

A. Loeb & NW 2010

Dark forces naturally induce a velocity dependence that remove these tensions (Loeb & NW 2010)

WHAT TO LOOK FOR?

- If Missing Energy is not the signature of the dark sector, what is?
- Many scenarios predict new, light states (~ GeV)

COLLIDER SIGNALS

- Production of Gdark states, yield boosted, highly collimated leptons ("lepton jets")

Arkani-Hamed, NW, '08; Baumgart, Cheung, Ruderman, Wang, Yavin, ' 09; Bai, Han '09

cf "Hidden Valley" models, Strassler and Zurek '06

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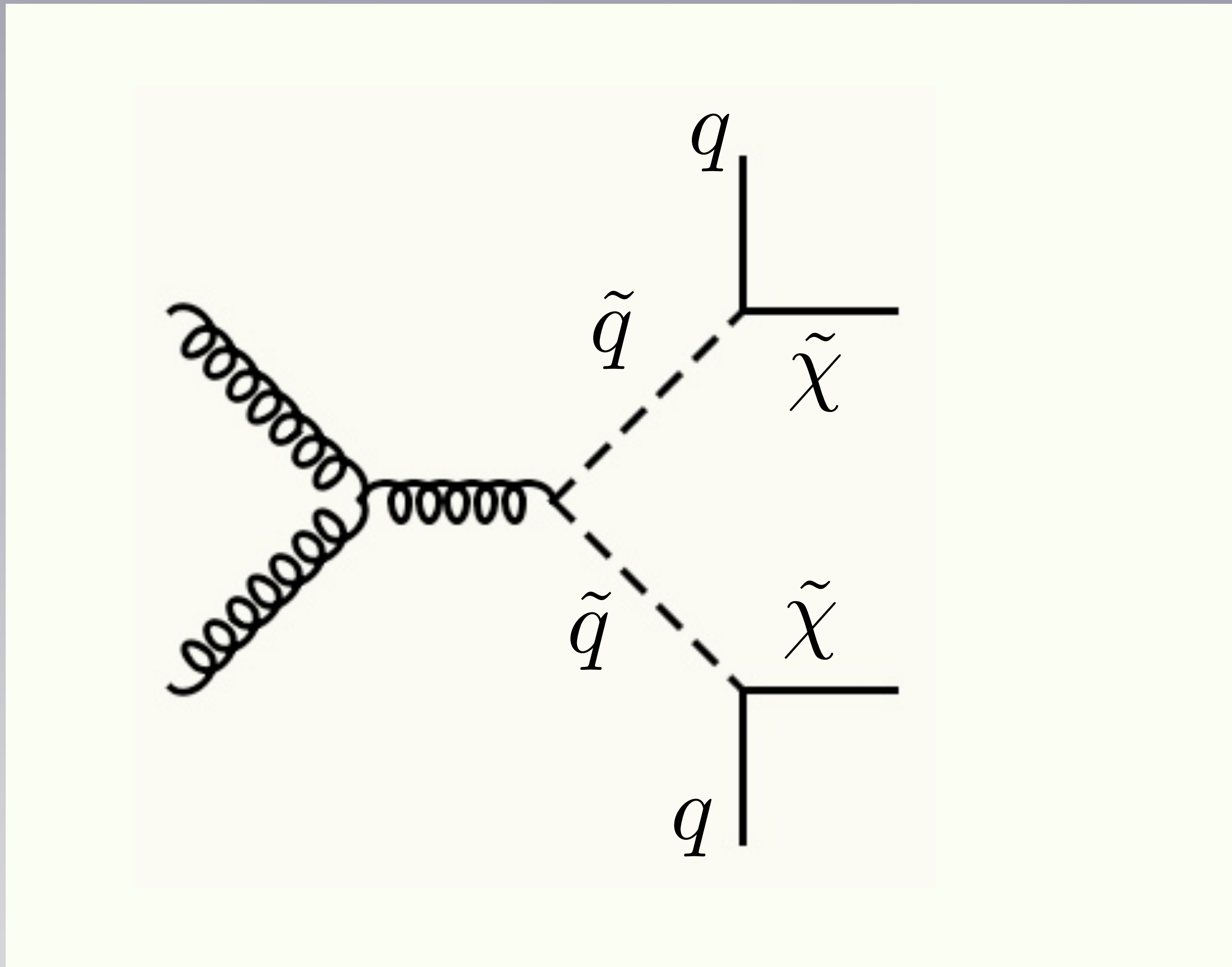

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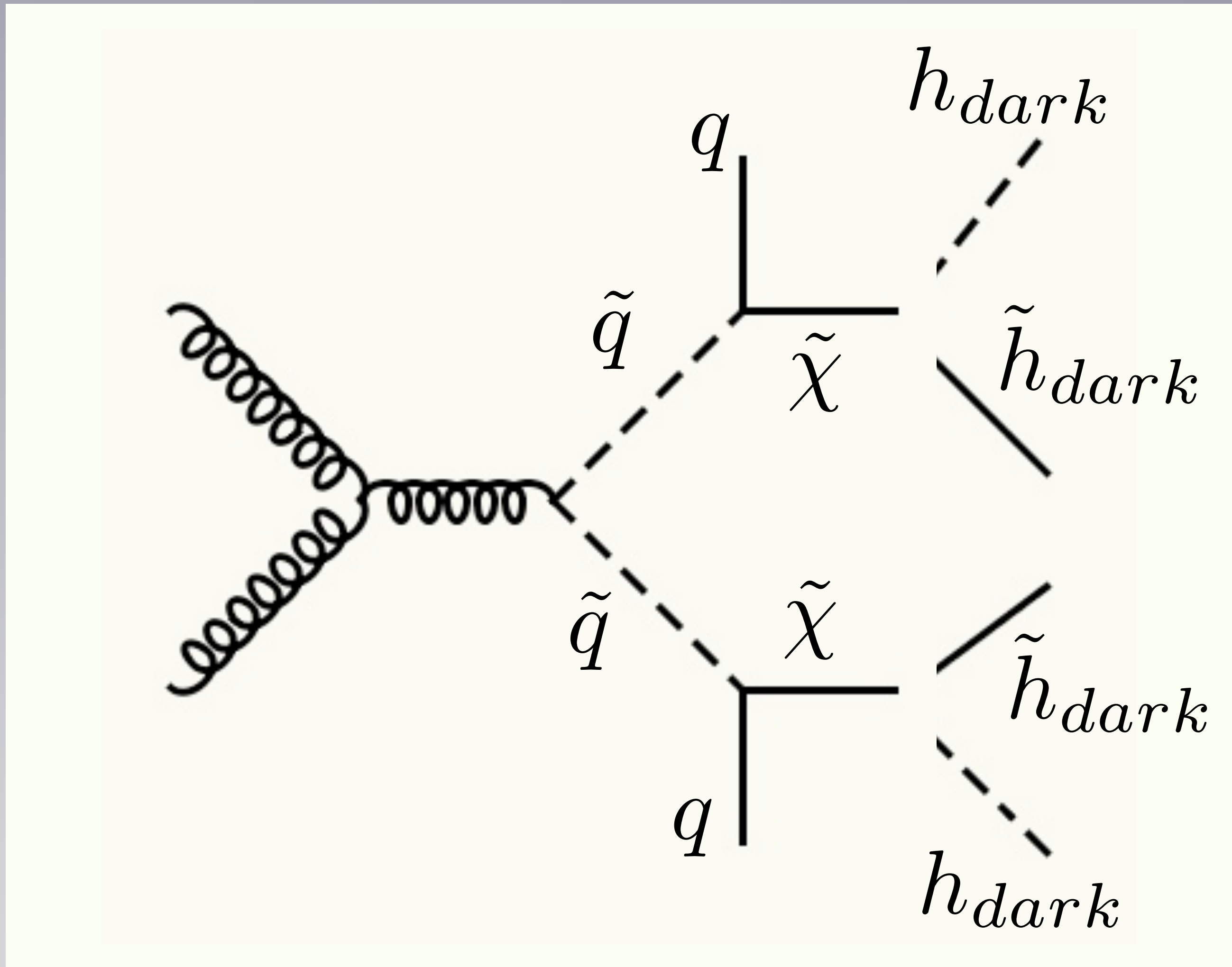

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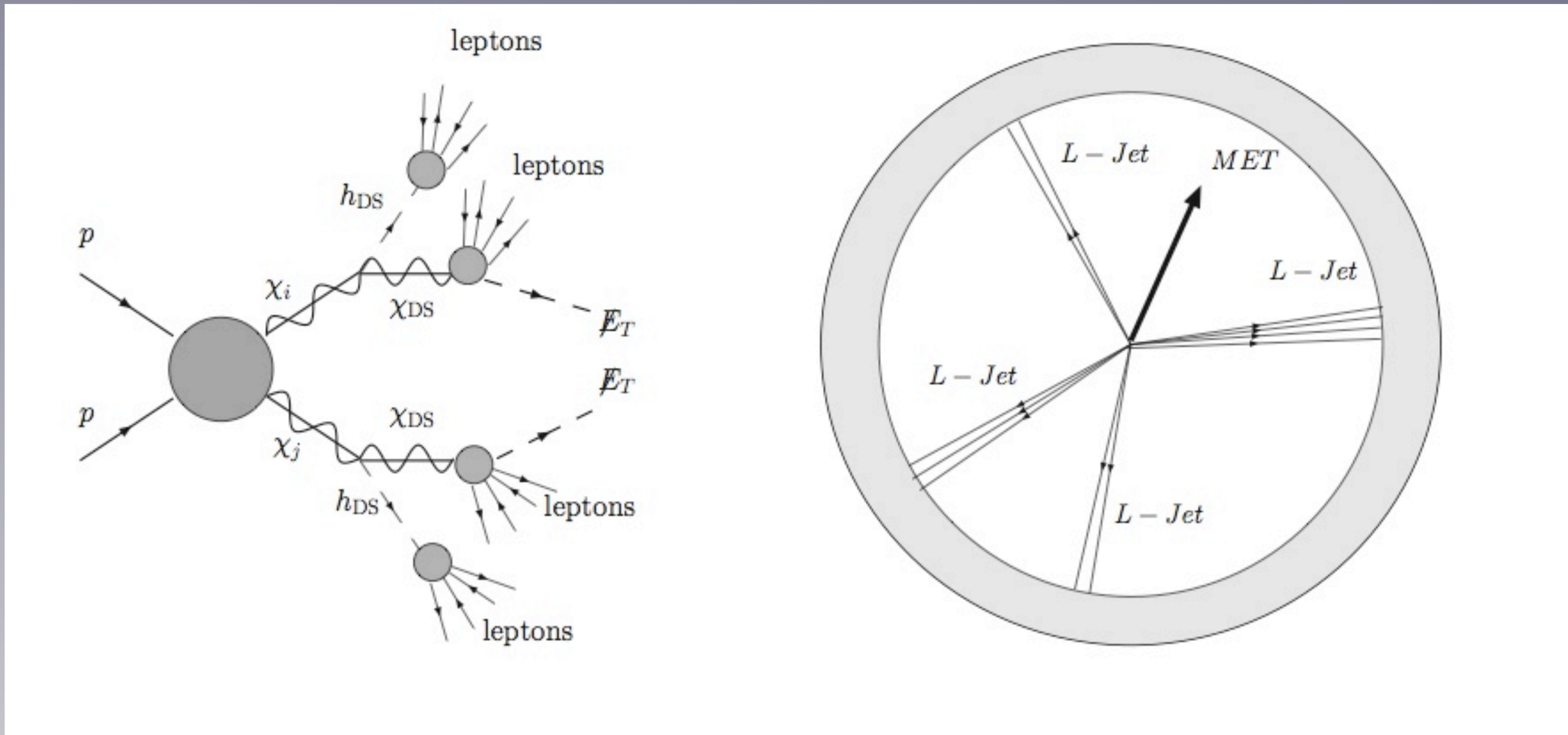
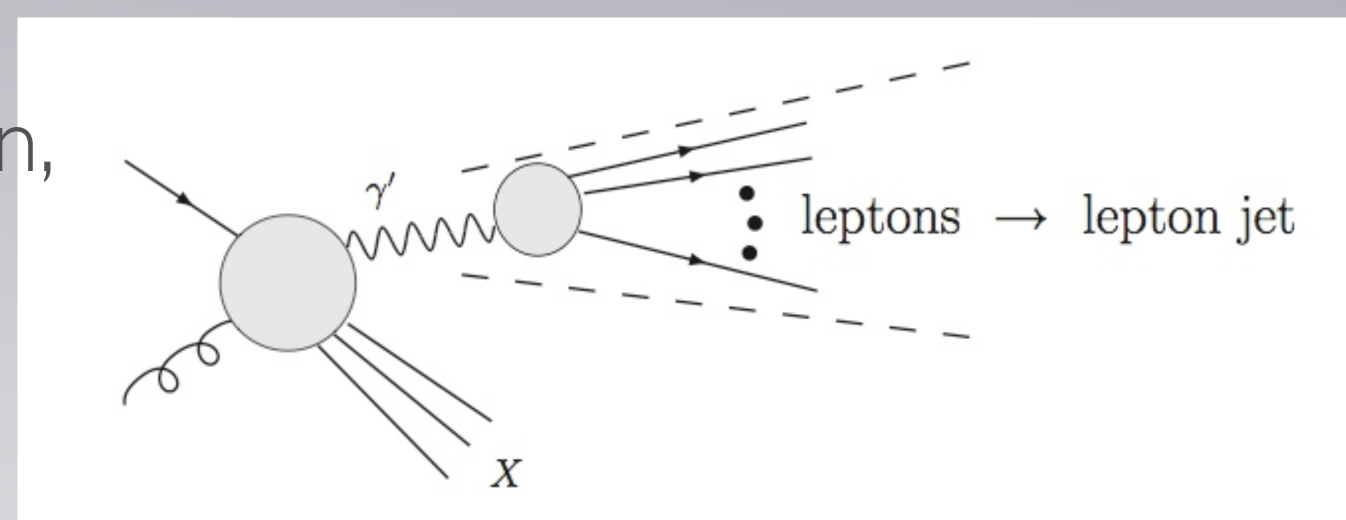


Baumgart, Cheung, Ruderman, Wang, Yavin, ' 09



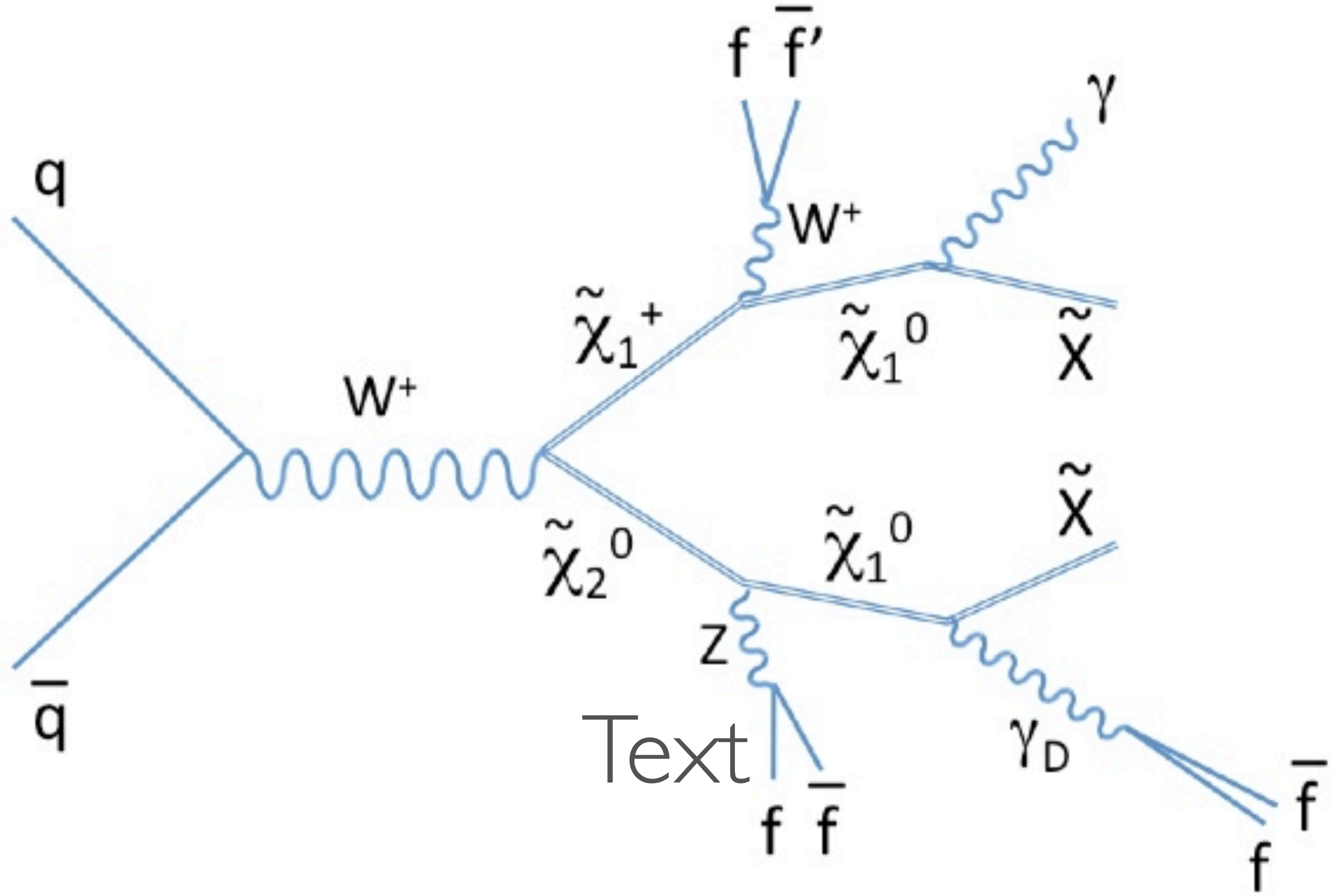


FIG. 1: One of the diagrams giving rise to the events with a photon, dark photon (γ_D), and large missing energy due to escaping darkinos ($\tilde{X}$) at the Fermilab Tevatron Collider.

D0 Collaboration, [arXiv:0905.1478] Phys.Rev.Lett. 103 (2009) 081802

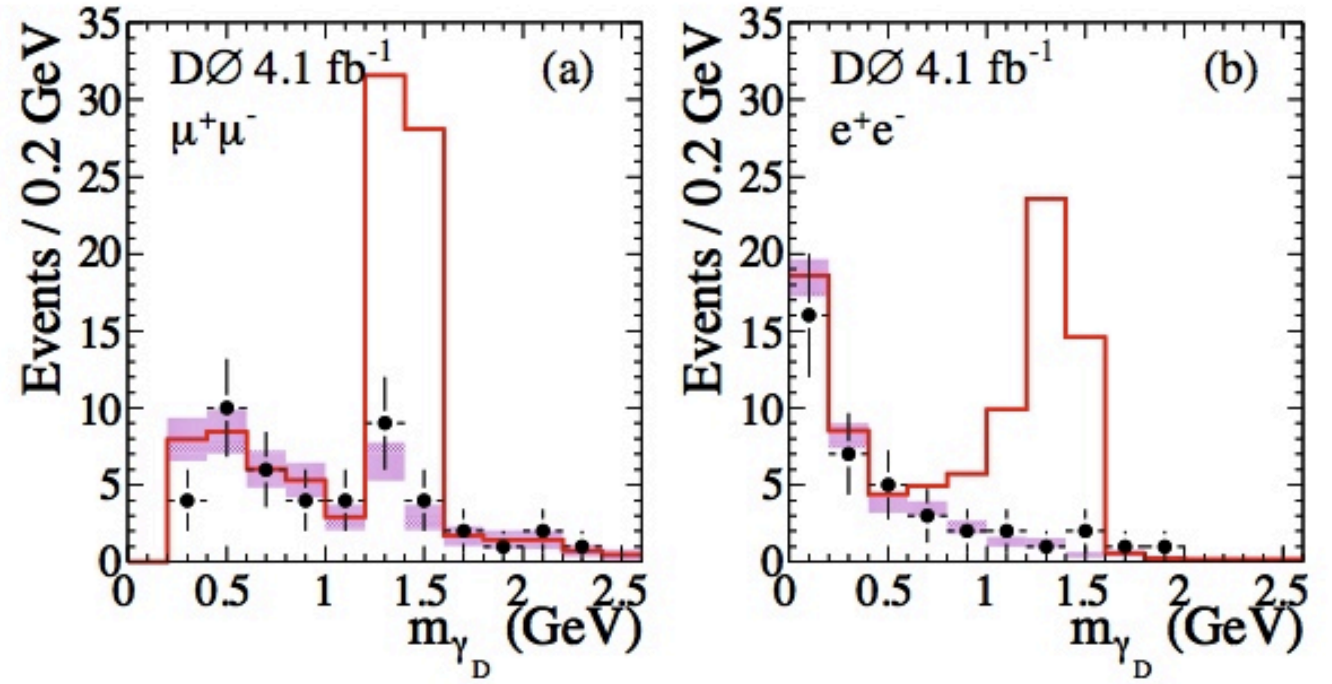


FIG. 2: Observed mass distributions in the signal region are represented as points with error bars, the background estimation is shown as filled band, and an example signal for $m_{\gamma_D} = 1.4$ GeV plus background is shown as the solid histogram for the dimuon channel (a) and the dielectron channel (b).

D0 Collaboration, [arXiv: 0905.1478] Phys.Rev.Lett. 103 (2009) 081802

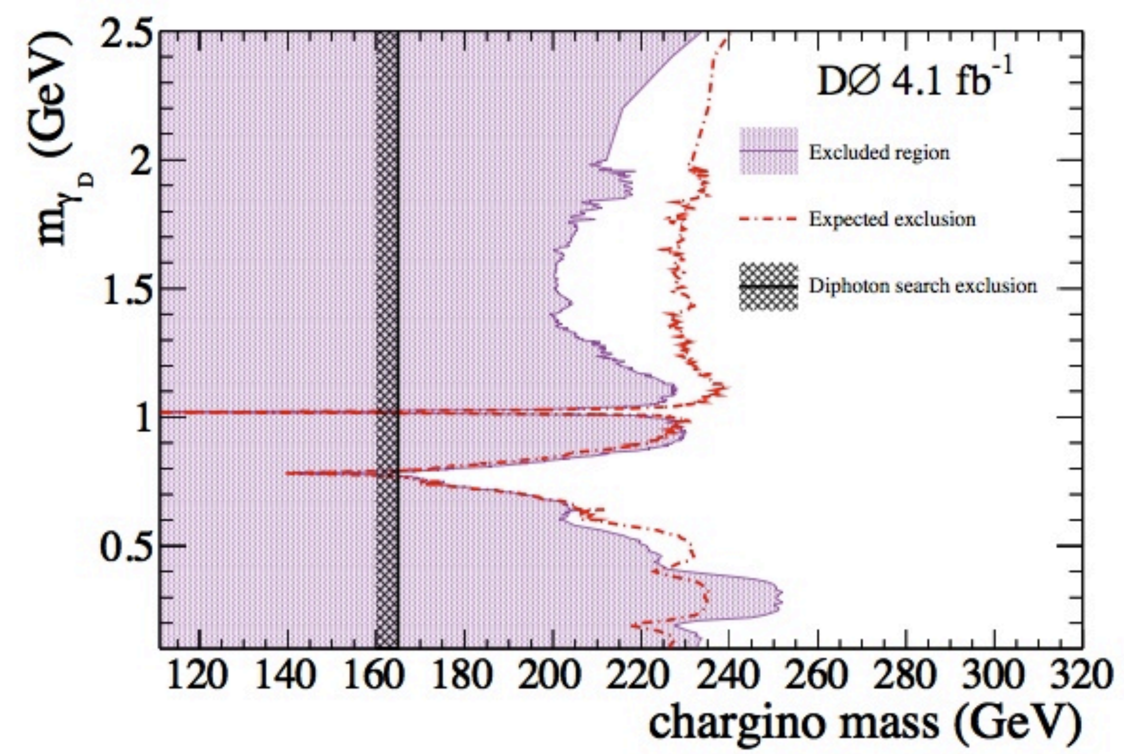
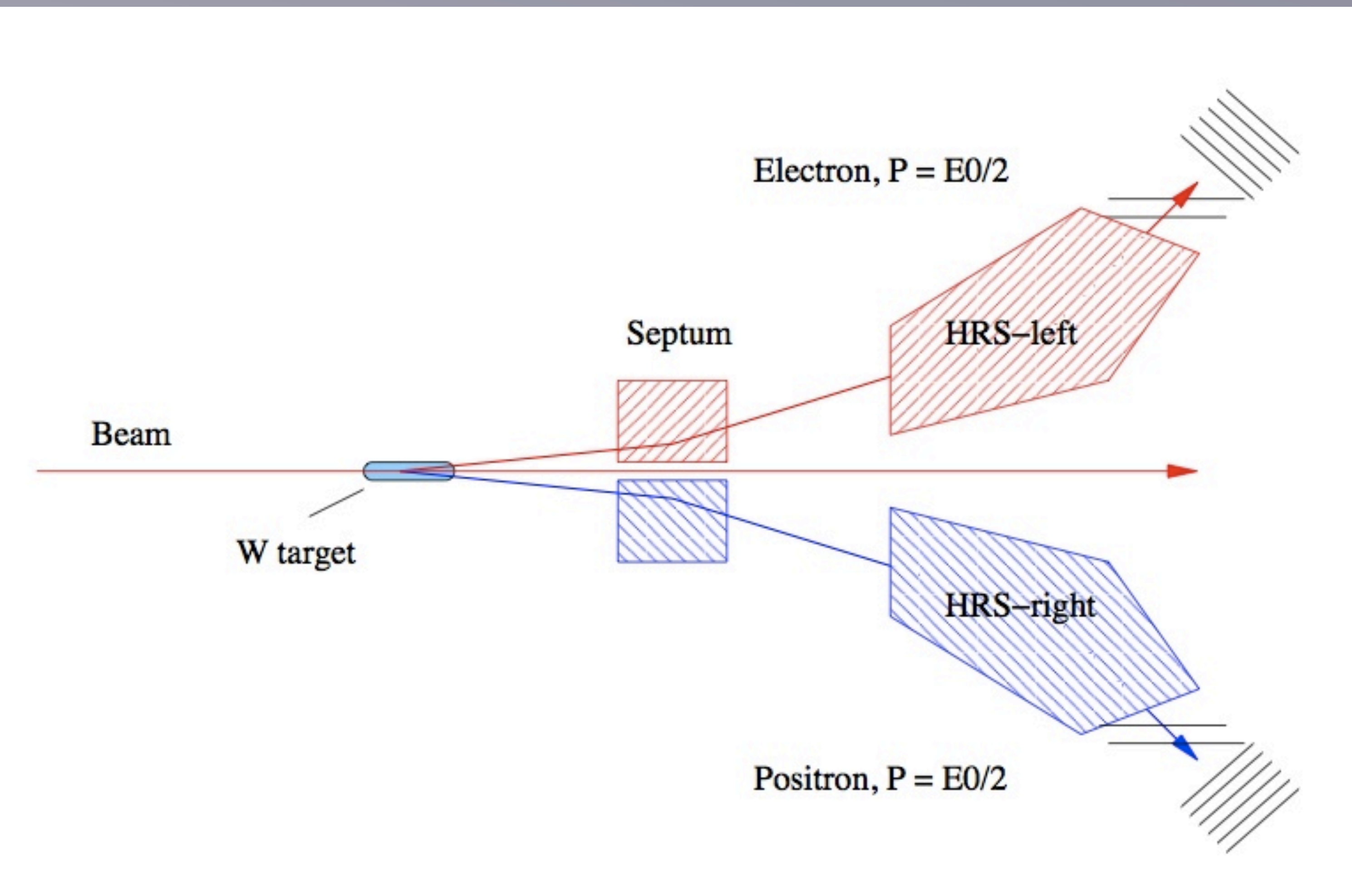
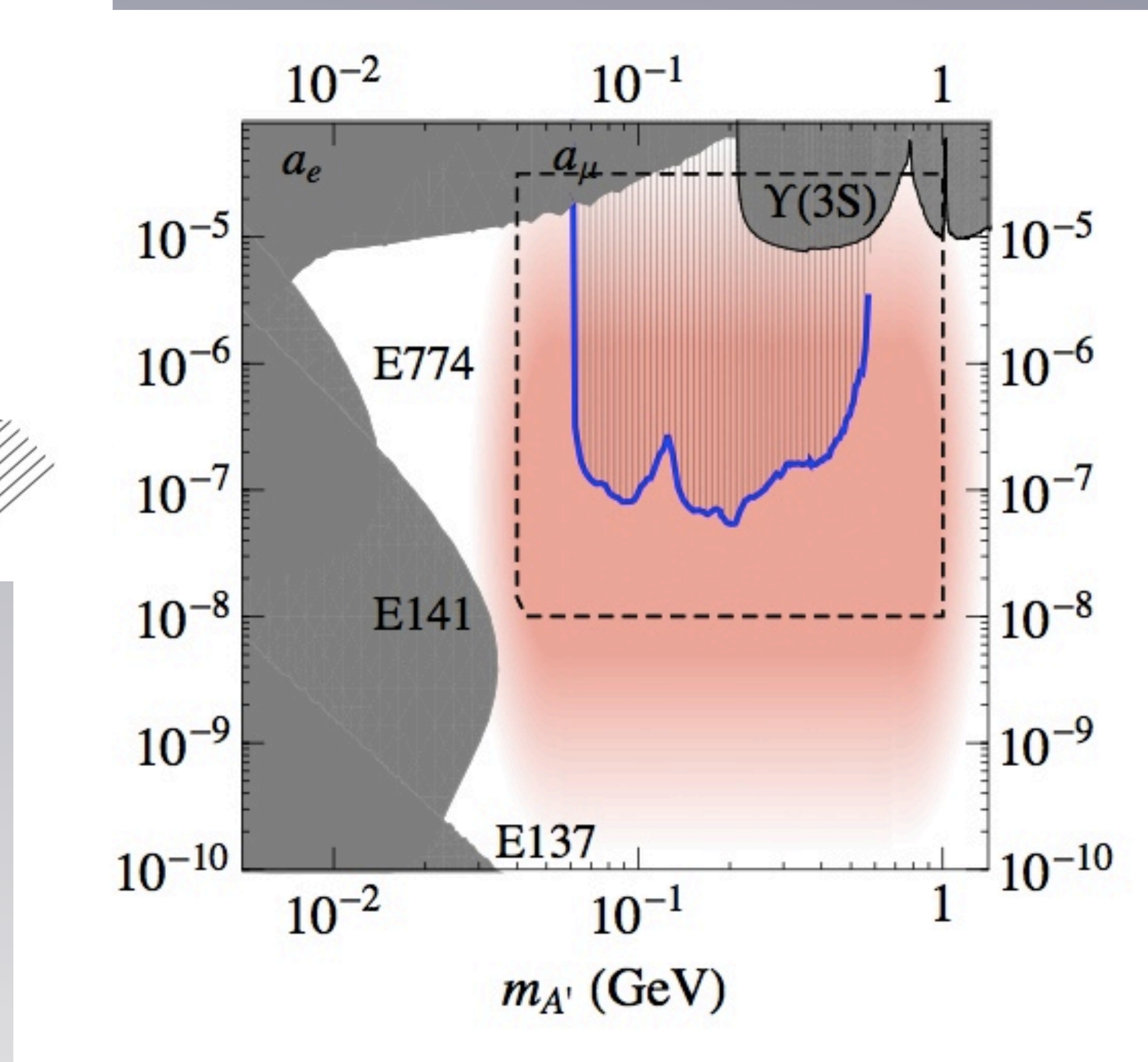


FIG. 3: The excluded region of possible masses of the lightest chargino and the dark photon for $\mathcal{B} = 0.5$ are shown as the shaded region. The expected limit is illustrated as the dash-dotted line. The vertical black line corresponds to the exclusion from the diphoton search [21].

APEX



Essig, Schuster, Toro, Wojtsekhowski,
arxiv:1001.2557



See talks today by
Kolomensky + Essig

FINDING HIDDEN SYMMETRIES IN DARK MATTER

- Hidden Symmetries for dark matter are natural in many models
  - Relevant for stability, number density (asymmetric DM), cosmic ray signals (annihilation modes and Sommerfeld) and direct detection (large cross sections and inelastic)

- Light WIMPs are MOTIVATED by current anomalies, but models are natural even if excluded
- Dark forces can generate cosmic ray excesses (Planck will definitively test)
- inelastic Dark Matter constrained, but alive (halo models, magnetic interactions); should be tested in 2011
- Dynamics of dwarfs galaxies can be affected by dark forces

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Any one may be pointing us to the next symmetry to be discovered!