RAPPORTEUR'S REPORT: SEARCHES FOR **DARK** PHOTONS AT JEFFERSON LAB

Neal Weiner
NYU

January 12, 2011

PROSPECTS

PROSPECTS

- The Dark Sector doesn't want to be found (P Fox)

PROSPECTS

- The Dark Sector doesn't want to be found (P Fox)
  - It's dark

PROSPECTS

- The Dark Sector doesn't want to be found (P Fox)
  - It's dark
  - XENON only ran in the winter, no attention to summer data

PROSPECTS

- The Dark Sector doesn't want to be found (P Fox)
  - It's dark
  - XENON only ran in the winter, no attention to summer data
  - KIMS funding problem

PROSPECTS

- The Dark Sector doesn't want to be found (P Fox)
  - It's dark
  - XENON only ran in the winter, no attention to summer data
  - KIMS funding problem
  - Other mystery issues

PROSPECTS

- The Dark Sector doesn't want to be found (P Fox)
  - It's dark
  - XENON only ran in the winter, no attention to summer data
  - KIMS funding problem
  - Other mystery issues
- 4 total itineraries to get here

PROSPECTS

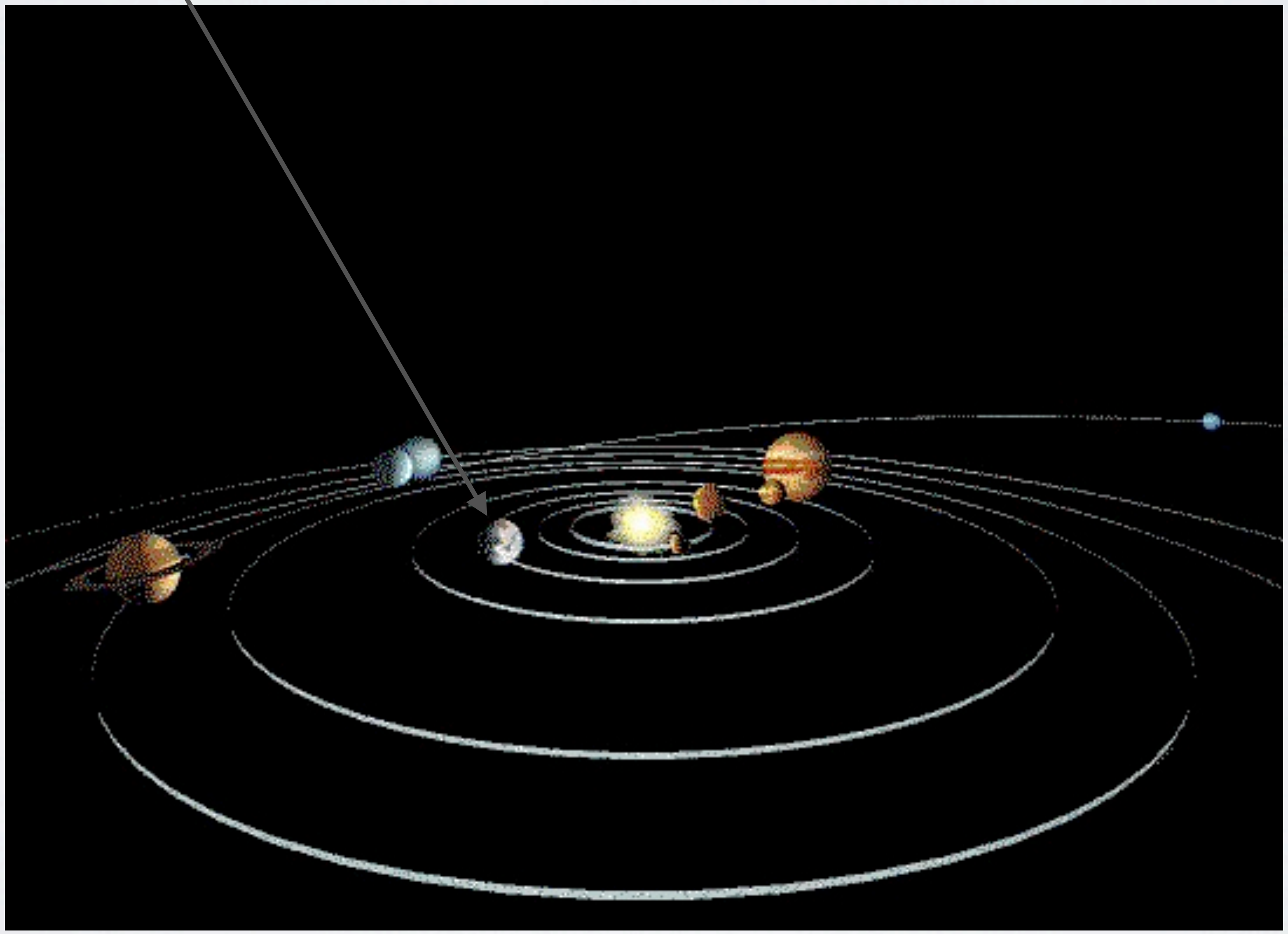
- The Dark Sector doesn't want to be found (P Fox)
  - It's dark
  - XENON only ran in the winter, no attention to summer data
  - KIMS funding problem
  - Other mystery issues
- 4 total itineraries to get here
  - Suggests that the impact could be high!

THE COPERNICAN EVOLUTION

You are here

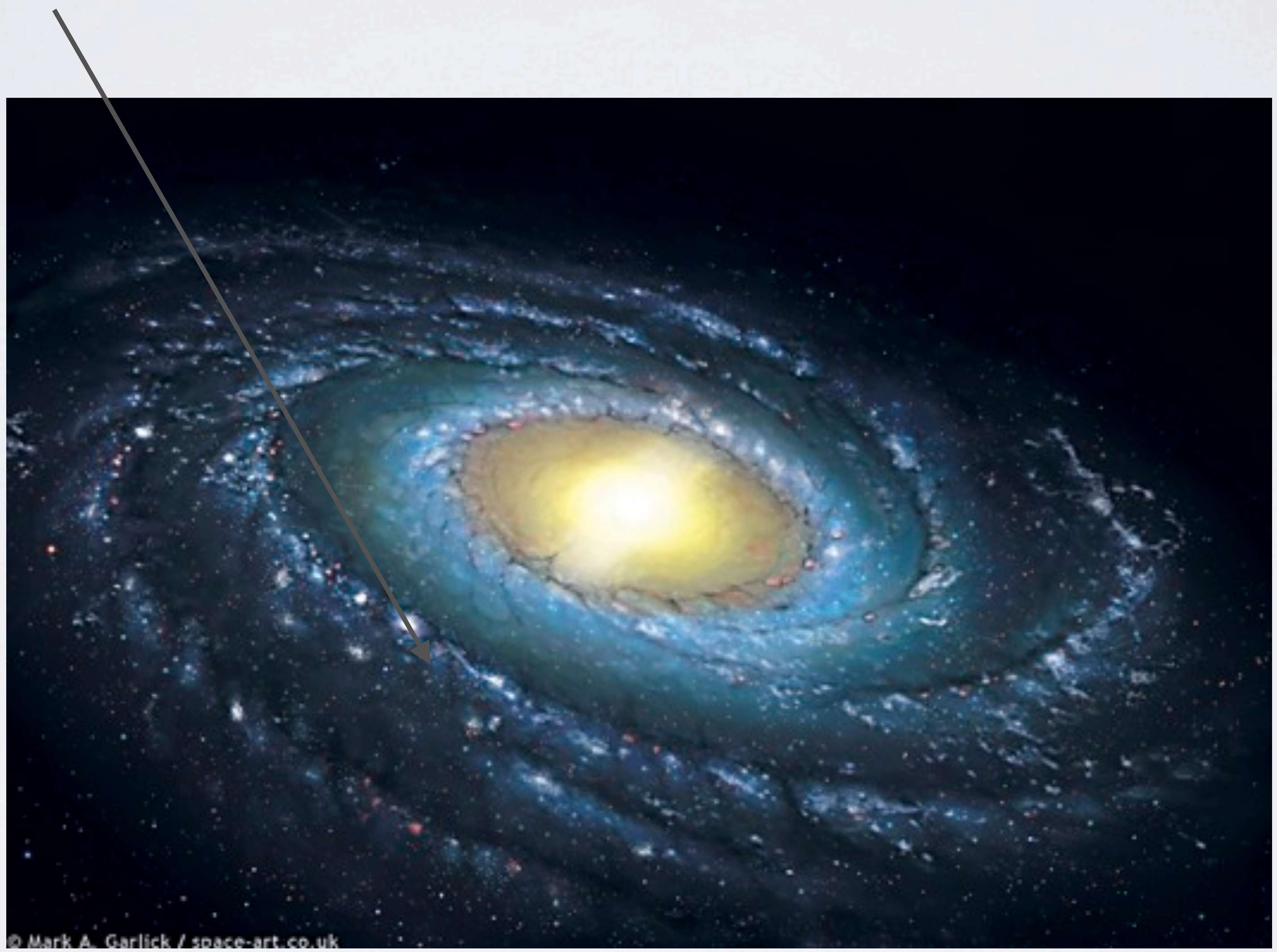
THE COPERNICAN EVOLUTION

You are here



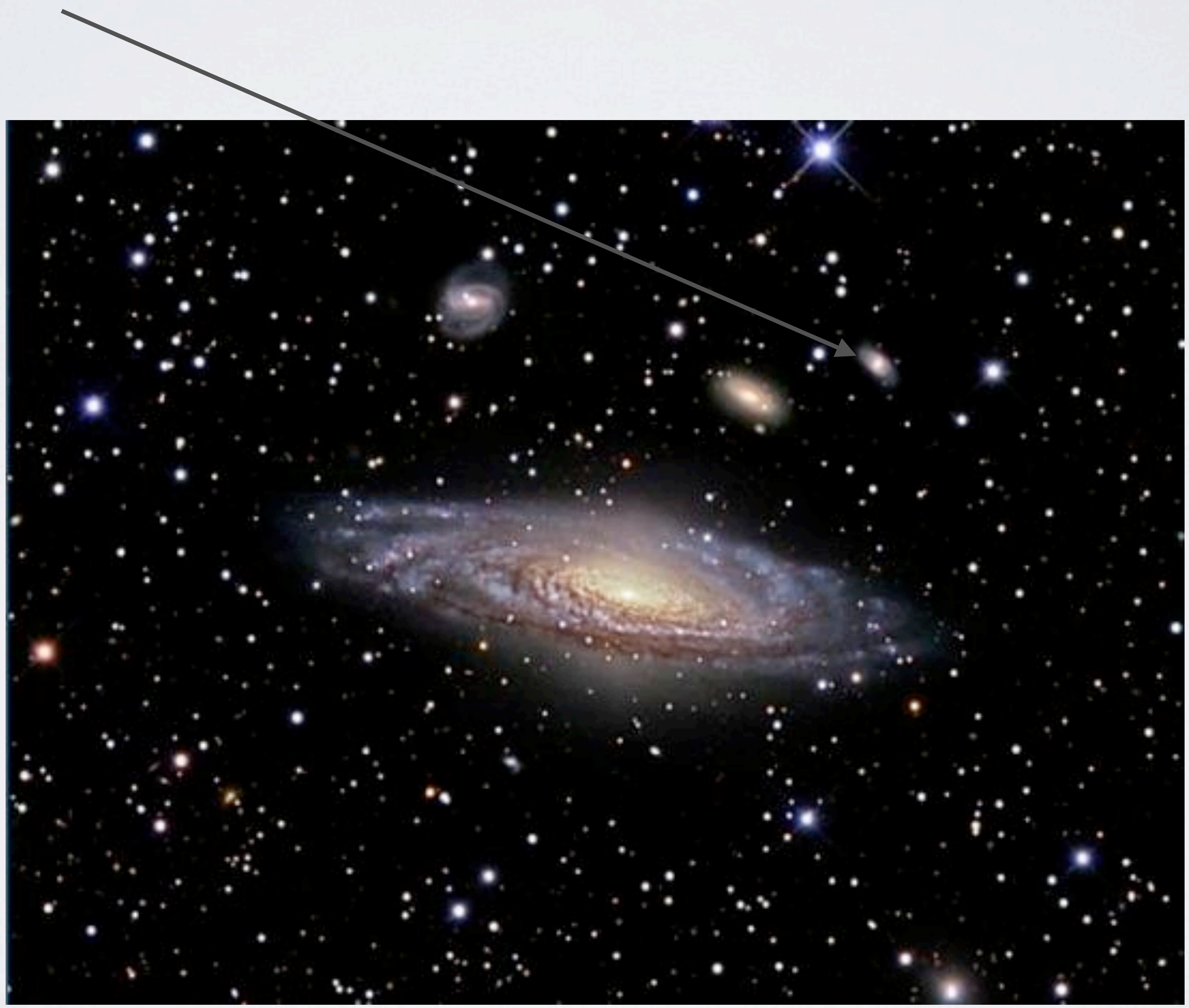
THE COPERNICAN EVOLUTION

You are here

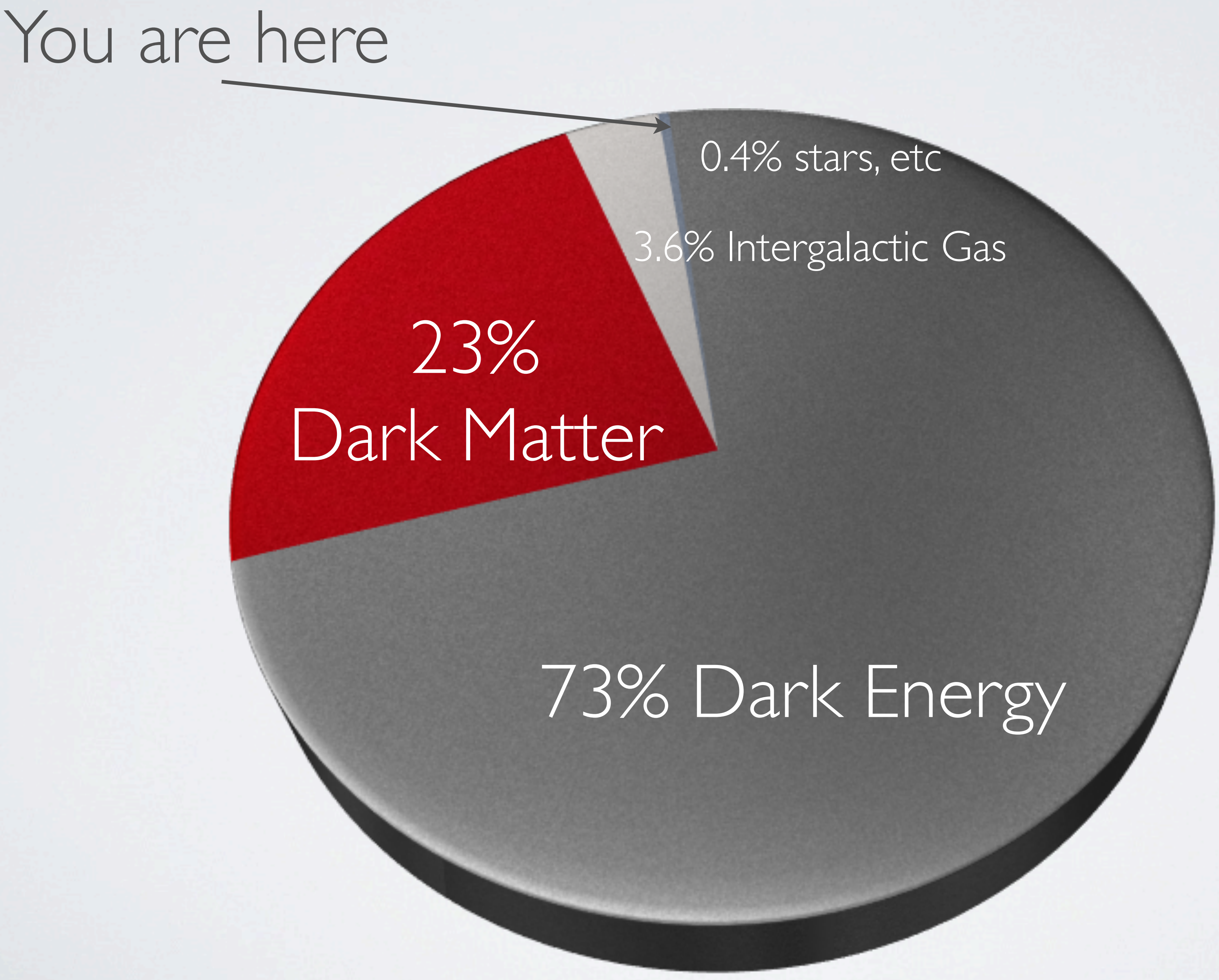


THE COPERNICAN EVOLUTION

You are here

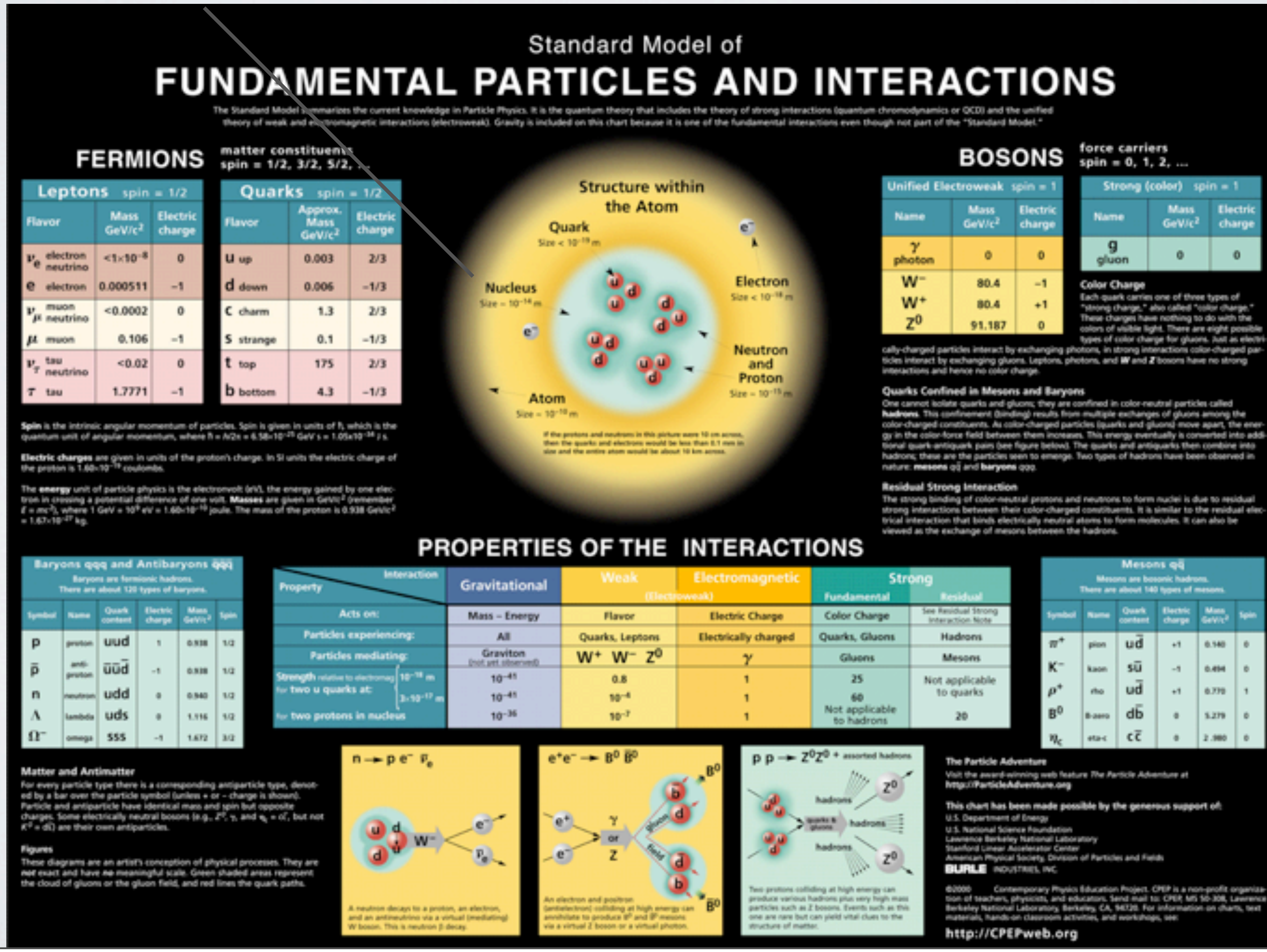


THE COPERNICAN EVOLUTION



THE COPERNICAN EVOLUTION

You are here



THE COPERNICAN EVOLUTION

You are here?

SU(7)xU(1)

Sp(6)xSU(2)

SU(15)

U(1)

U(1)xU(1)xU(1)

SU(3)xSU(2)xU(1)

Neutral matter

PORTALS TO A HIDDEN SECTOR

- Suppose there is matter uncharged under the SM
- How do we couple to it?

PORTALS TO A HIDDEN SECTOR

$$\underbrace{(\bar{L}H)}_{\text{Standard Model}} \times \underbrace{(N)}_{\text{Hidden Sector}}$$

Neutrino Portal

$$\underbrace{(F_{\mu\nu})}_{\text{Standard Model}} \times \underbrace{(F_d^{\mu\nu})}_{\text{Hidden Sector}}$$

Vector (photon) Portal

$$\underbrace{(h^\dagger h)}_{\text{Standard Model}} \times \underbrace{(a\phi)}_{\text{Hidden Sector}} + \text{h.c.}$$

Scalar (Higgs) Portal

*NB: Non-renormalizeable portals, e.g., axion portal also can be important

Neutrino Portal

$$\underbrace{(\bar{L}H)}_{\text{Standard Model}} \times \underbrace{(N)}_{\text{Hidden Sector}}$$

- Requires complete gauge singlet N
- Would naturally be heavy
- If charged, has coupling $\frac{\phi_d}{\Lambda}$ ~ small
- Dominant signal ⇒ neutrino mass

Scalar (Higgs) Portal

$$\underbrace{(h^\dagger h)}_{\text{Standard Model}} \times \underbrace{(a\phi)}_{\text{Hidden Sector}} + \text{h.c.}$$

- Requires complete gauge singlet φ, or $\langle\varphi\rangle = a$
- Would naturally have mass $m_\varphi = a$
- Has mixing with the Higgs ~ m_φ/m_W ~ small
- Dominant effect: rare meson decays, non-standard Higgs decays

Vector (photon) Portal

$$\epsilon \times \underbrace{(F_{\mu\nu})}_{\text{Standard Model}} \times \underbrace{(F_d^{\mu\nu})}_{\text{Hidden Sector}}$$

- Requires Hidden sector has an effective U(1) (can arise from breaking of non-Abelian sector)
- Natural mass scales/couplings shortly
- Mixes with the photon (if < GeV) or Z boson (if ~ M_W)
- Dominant effect is to give coupling of charged matter to new, dark photon, q=**ε** e

Vector (photon) Portal

$$\epsilon \times \underbrace{(F_{\mu\nu})}_{\text{Standard Model}} \times \underbrace{(F_d^{\mu\nu})}_{\text{Hidden Sector}}$$

$$\alpha, \alpha_{EM}$$

Fine structure constant

$$\epsilon, \alpha' = \epsilon^2 \alpha$$

Coupliing of dark photon to EM

$$\alpha_D$$

dark sector coupling

WHAT IS A NATURAL ε?

WHAT IS A NATURAL ε?

- Renormalizeable operator - could naturally be order 1

WHAT IS A NATURAL ε?

- Renormalizeable operator - could naturally be order 1
- If $U(1)_Y$ or $U(1)_D$ is part of a non-Abelian group, $\boldsymbol{\varepsilon}$=0 at tree level, arises at 1-loop

WHAT IS A NATURAL ε?

- Renormalizeable operator - could naturally be order 1
- If $U(1)_Y$ or $U(1)_D$ is part of a non-Abelian group, **ε**=0 at tree level, arises at 1-loop
- If matter in loop have masses split by radiative effects, naturally at 2-loop

WHAT IS A NATURAL ε?

- Renormalizeable operator - could naturally be order 1
- If $U(1)_Y$ or $U(1)_D$ is part of a non-Abelian group, $\varepsilon=0$ at tree level, arises at 1-loop
- If matter in loop have masses split by radiative effects, naturally at 2-loop
- If both $U(1)_Y$ ***and*** $U(1)_D$ are in non-Abelian group, with masses split radiatively, is naturally 3-loop

WHAT IS A NATURAL ε?

- Renormalizeable operator - could naturally be order 1
- If $U(1)_Y$ or $U(1)_D$ is part of a non-Abelian group, $\varepsilon=0$ at tree level, arises at 1-loop
- If matter in loop have masses split by radiative effects, naturally at 2-loop
- If both $U(1)_Y$ ***and*** $U(1)_D$ are in non-Abelian group, with masses split radiatively, is naturally 3-loop
- Natural range of $1>\varepsilon>10^{-8}$ (approximately)

WHAT IS A NATURAL MASS FOR A'?

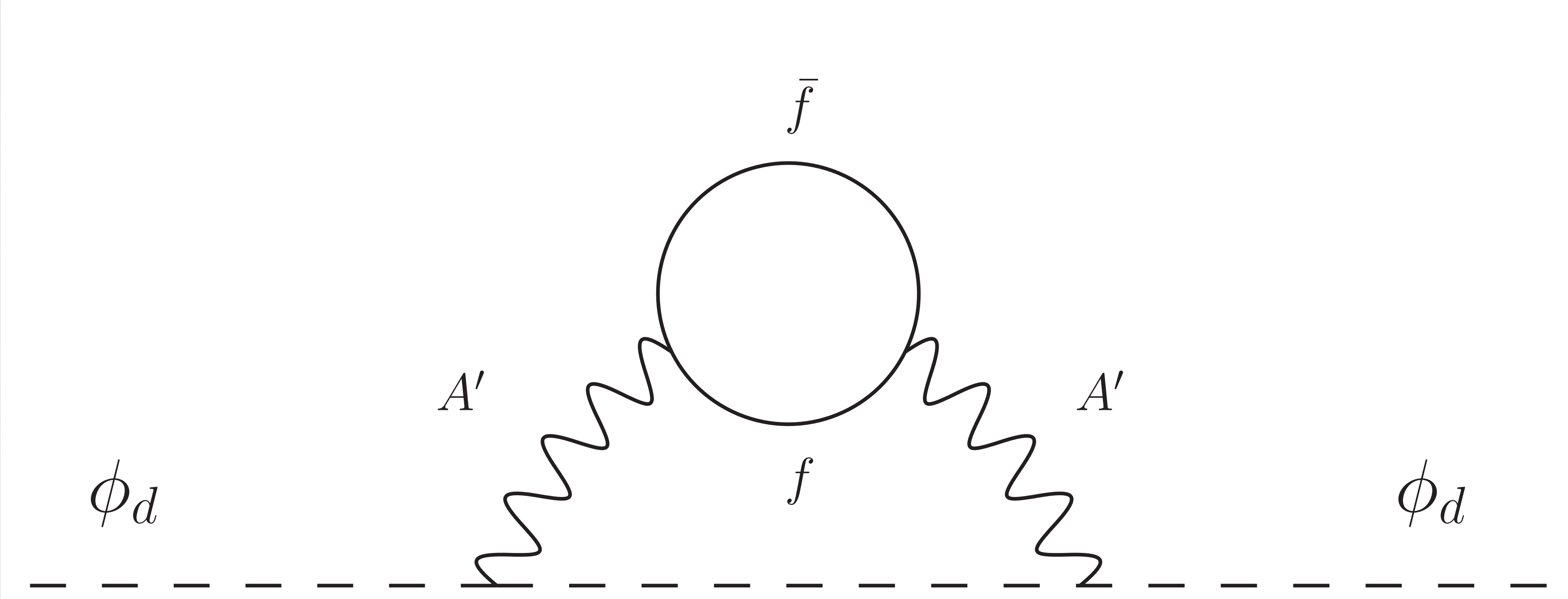
- SM Fields should not couple to a new, massless A'
  - (NB: If entirety of new physics is A', mixing is not a physical effect)
- What is natural mass scale?

WHAT IS A NATURAL MASS FOR A'?

- If strong dynamics (similar to QCD) drive $U(1)_d$ breaking, mass scale can be anything (theoretically)

WHAT IS A NATURAL MASS FOR A'?

- If $U(1)_d$ breaking is driven by a scalar, there is a *lower* bound on the mass from two-loop effects



$$m_\phi^2 \approx \epsilon^2 \left(\frac{\alpha_d}{4\pi}\right)^2 m_W^2$$

WHAT IS A NATURAL MASS FOR A'?

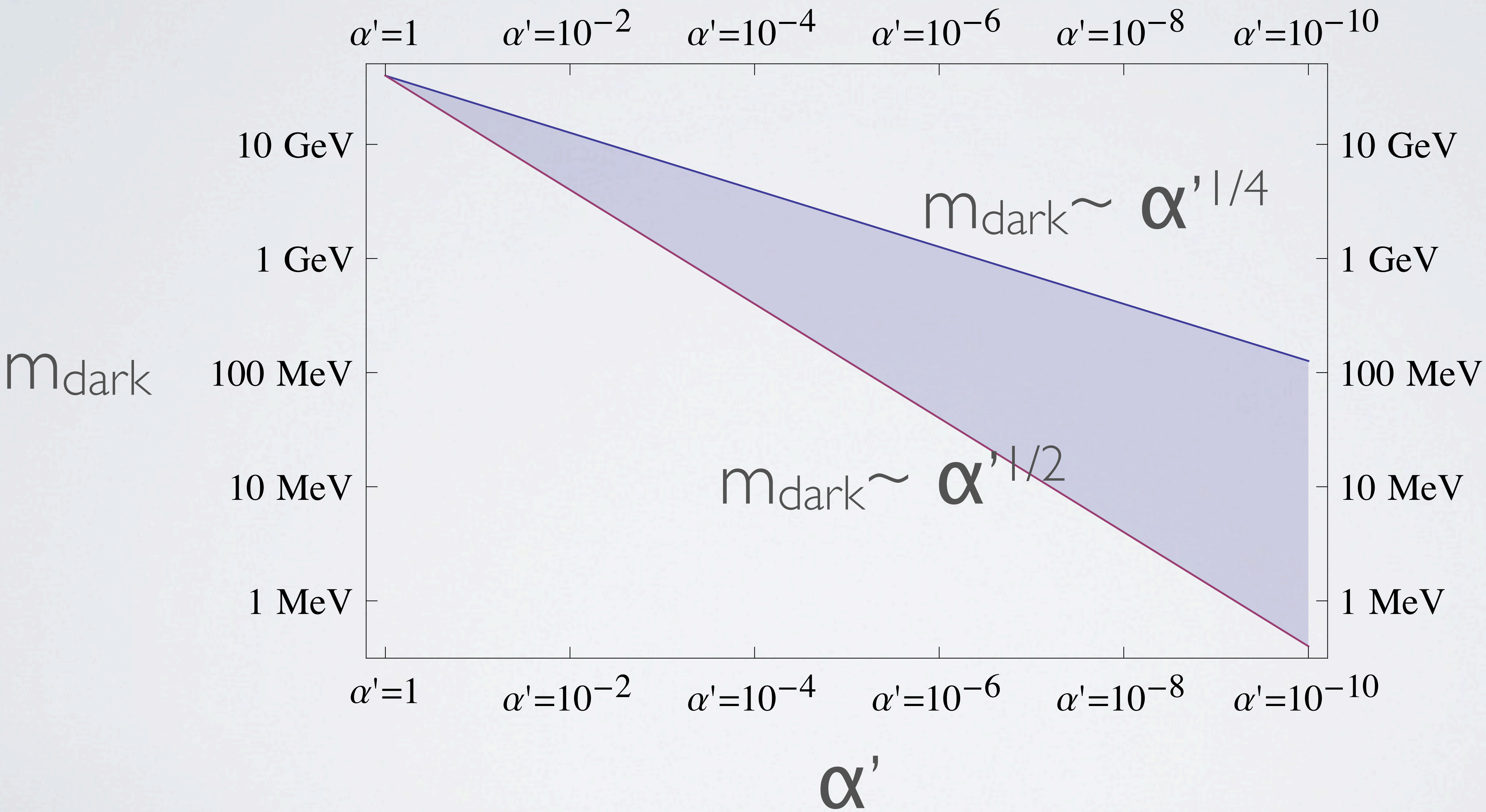
- In supersymmetric theories, there is an additional effect

$$\epsilon F_{\mu\nu} F_d^{\mu\nu} \Rightarrow \epsilon \int d^2\theta \, W_\alpha W_d^\alpha$$

$$V \supset \epsilon D_Y D_d = \epsilon \, g_Y \frac{v^2}{4} \cos(2\beta) \times (\phi_d^2 - \tilde{\phi}_d^2)$$

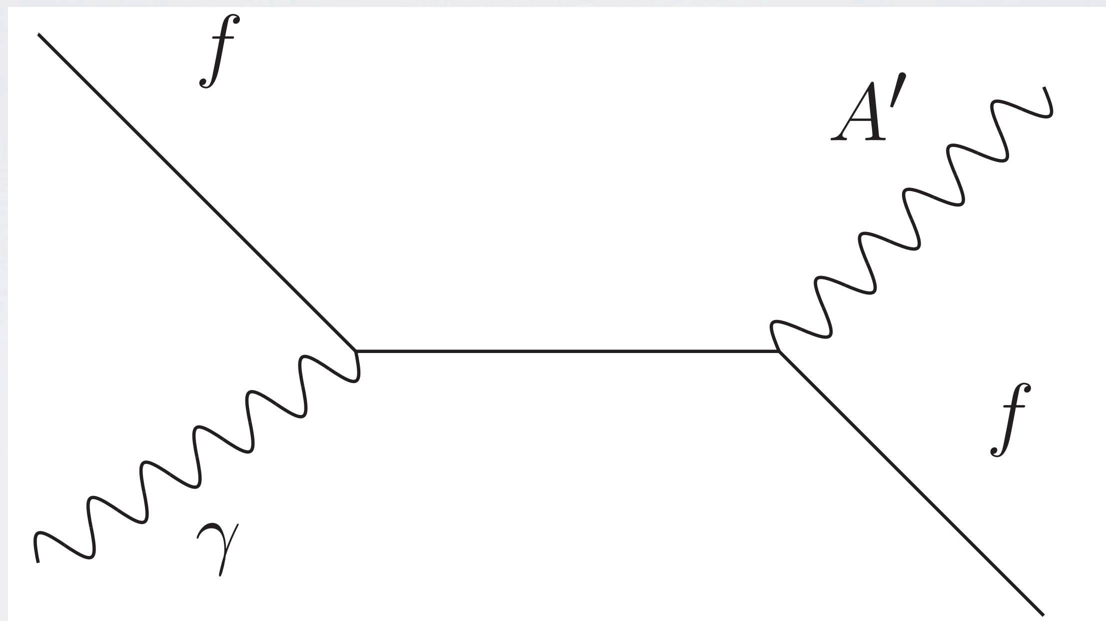
$$m_\phi^2 \approx \epsilon \alpha_Y m_W^2 \sim \sqrt{\alpha' \alpha_d} m_W^2$$

WHAT IS A NATURAL MASS FOR A'?



(Note: boundaries are approximate)

A BRIEF COSMIC HISTORY



Depending on mass, A' will generally thermalize for $\varepsilon > 10^{-9 \div -8}$ (i.e., $\alpha' > 10^{-18 \div -20}$)

Should be > 1 MeV to avoid problems with BBN

STILL A BROAD PARAMETER SPACE

STILL A BROAD PARAMETER SPACE

- $m_\chi > 1$ MeV, $\alpha' > 10^{-12}$ would be a natural part of particle physics landscape

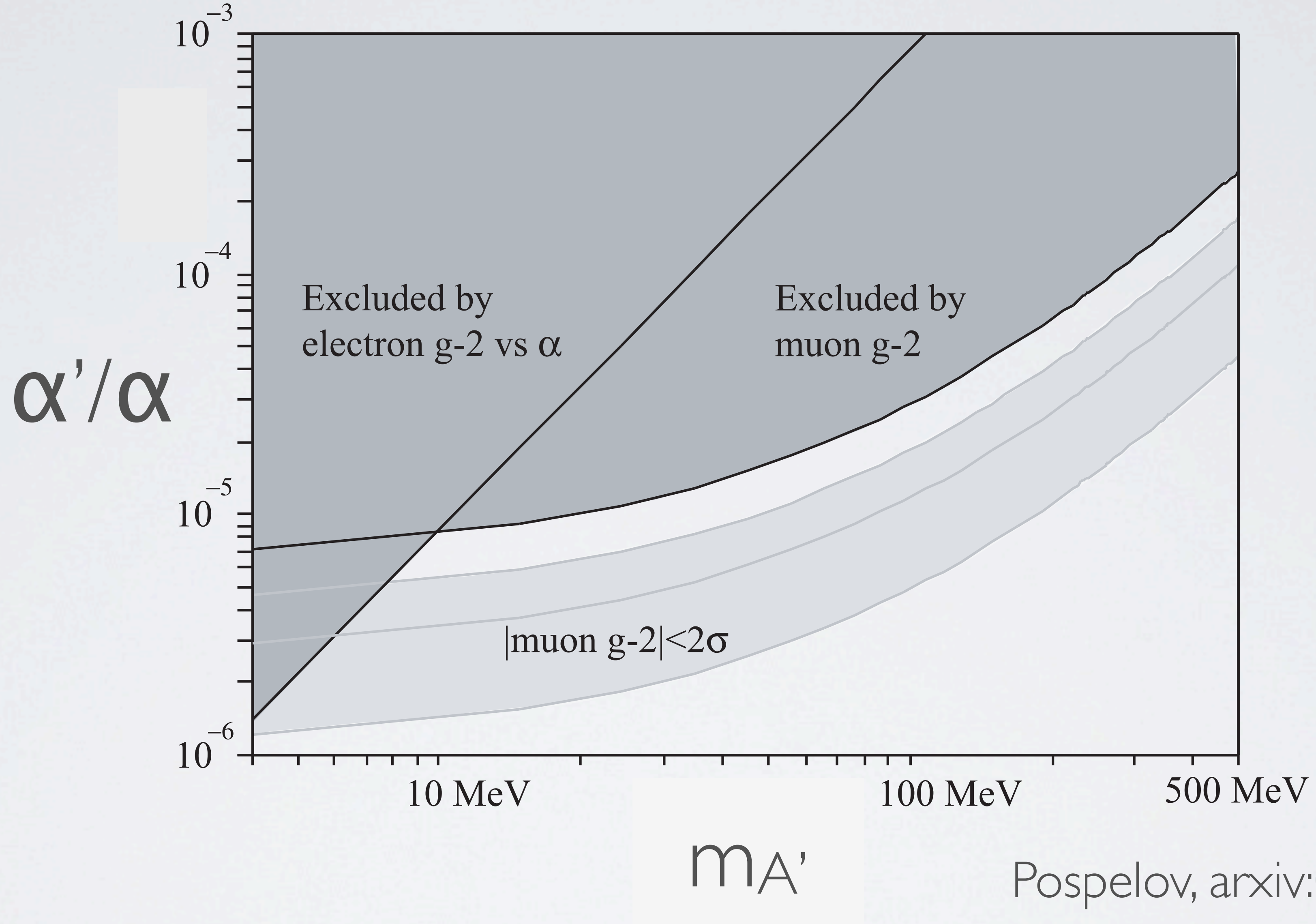
STILL A BROAD PARAMETER SPACE

- $m_\chi > 1$ MeV, $\alpha' > 10^{-12}$ would be a natural part of particle physics landscape
- Are any regions particularly motivated?

STILL A BROAD PARAMETER SPACE

- $m_\chi > 1$ MeV, $\alpha' > 10^{-12}$ would be a natural part of particle physics landscape
- Are any regions particularly motivated?
- A dark photon would influence particle physics at the GeV scale

g_μ-2



Pospelov, arxiv:0811.1030

g-2 for the muon 3.6**σ** deviation from SM prediction

STILL A BROAD PARAMETER SPACE

- $m_\chi > 1$ MeV, $\alpha' > 10^{-12}$ would be a natural part of particle physics landscape
- Are any regions particularly motivated?
- Dark matter charged under a dark force has been motivated by a variety of DM anomalies

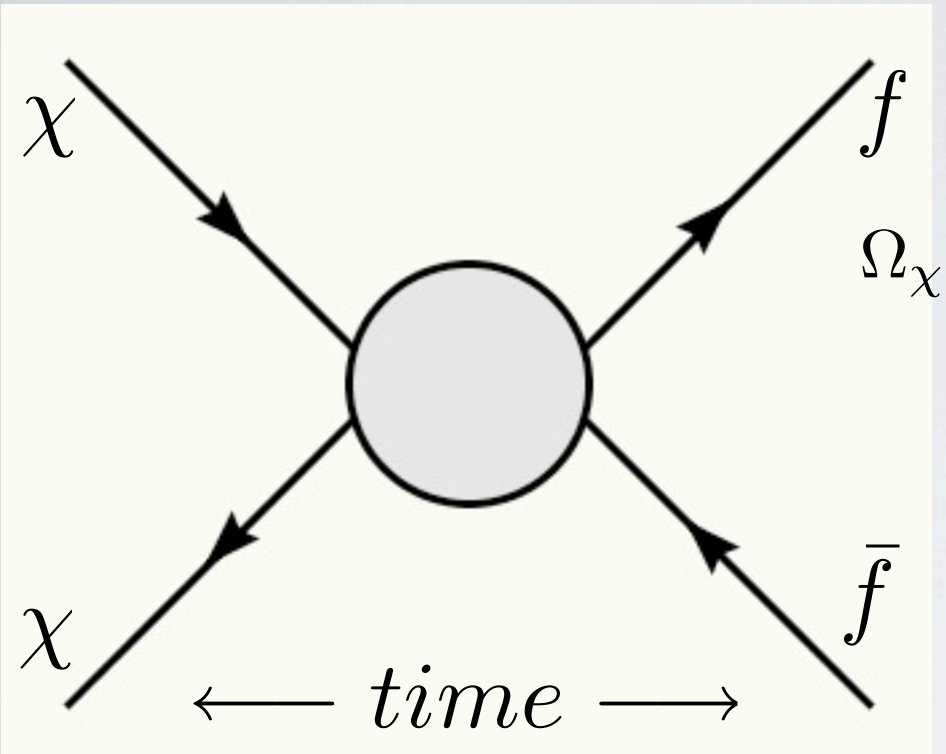
DM WITH A DARK U(1)

DM WITH A DARK U(1)

- The presence of a dark U(1) would very likely be accompanied by stable particles
- Thus dark matter would naturally be charged millicharged for a massless force [Holdom, '84]
- Dark matter can annihilate into the dark photon
- Dark matter can scatter via the dark photon

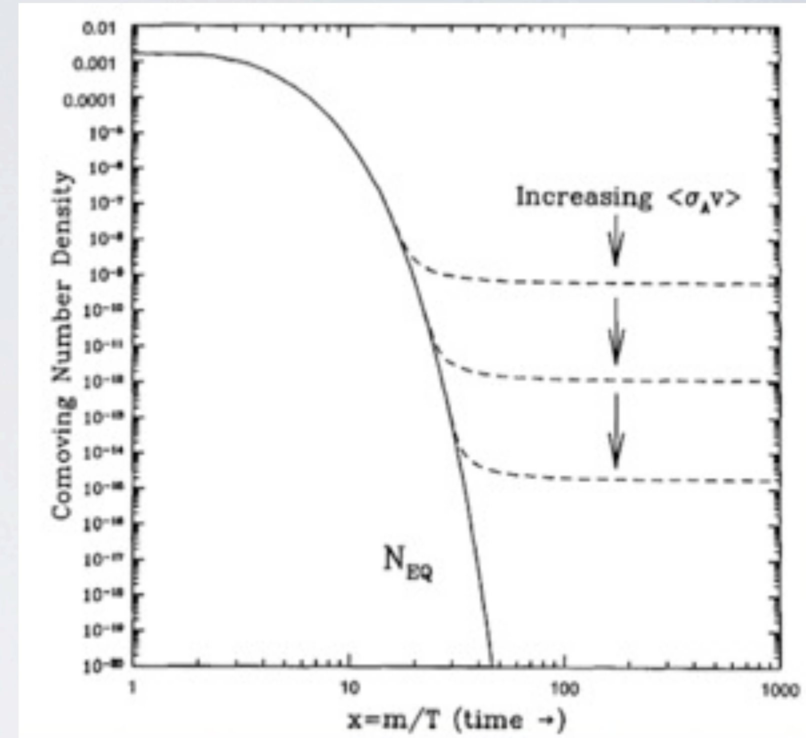
FREEZEOUT INTO A DARK PHOTON

"Classic" WIMP



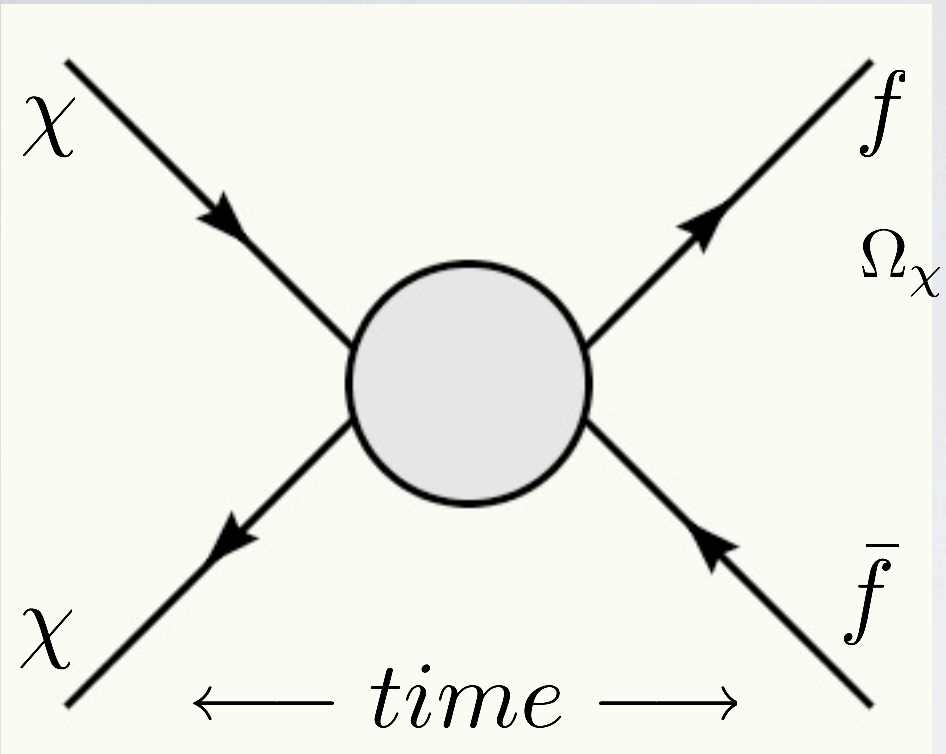
$$\Omega_\chi h^2 \approx 0.1 \times \frac{3 \times 10^{-26}\mathrm{cm}^3\mathrm{s}^{-1}}{\langle \sigma v \rangle}$$

$$\Rightarrow \langle \sigma v \rangle \approx \frac{\alpha^2}{M_W^2}$$



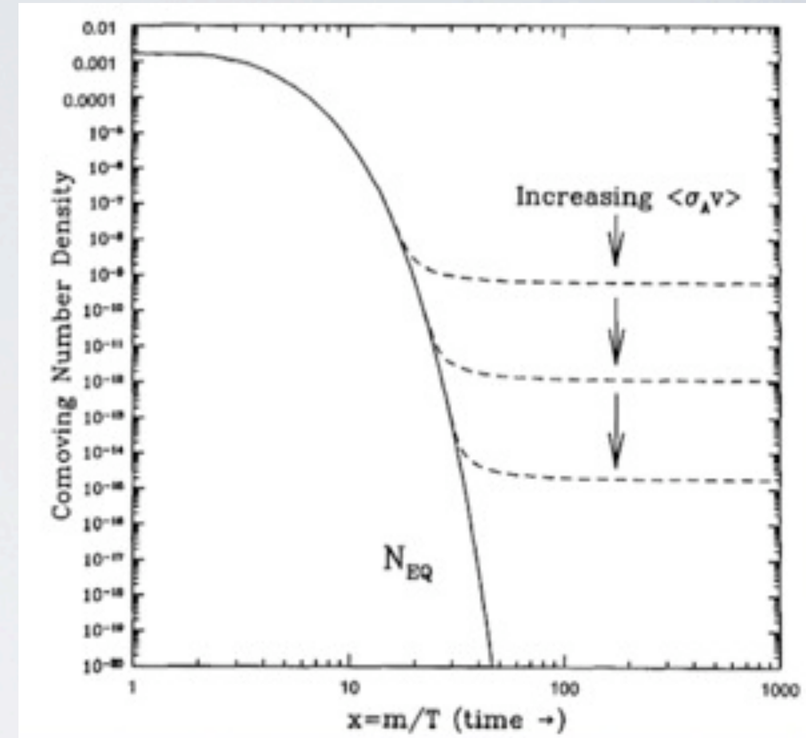
FREEZEOUT INTO A DARK PHOTON

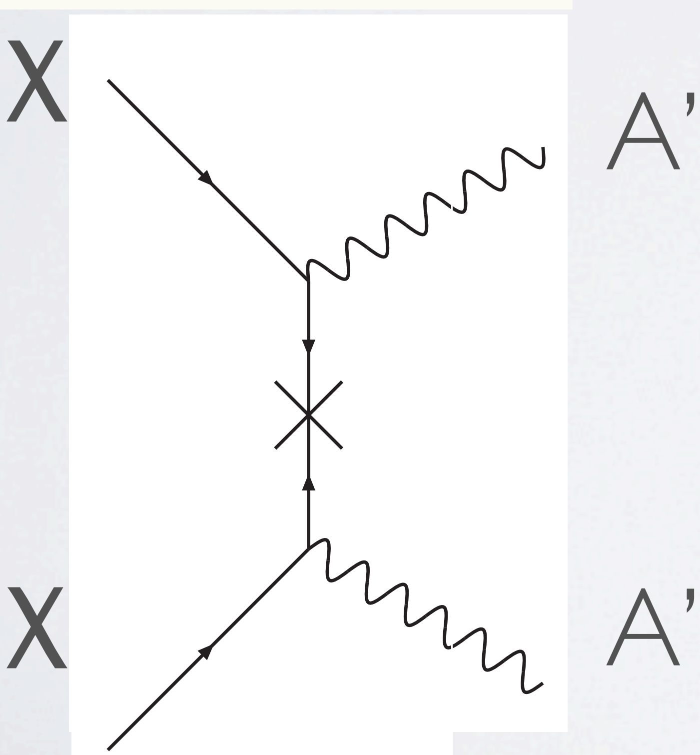
"Classic" WIMP

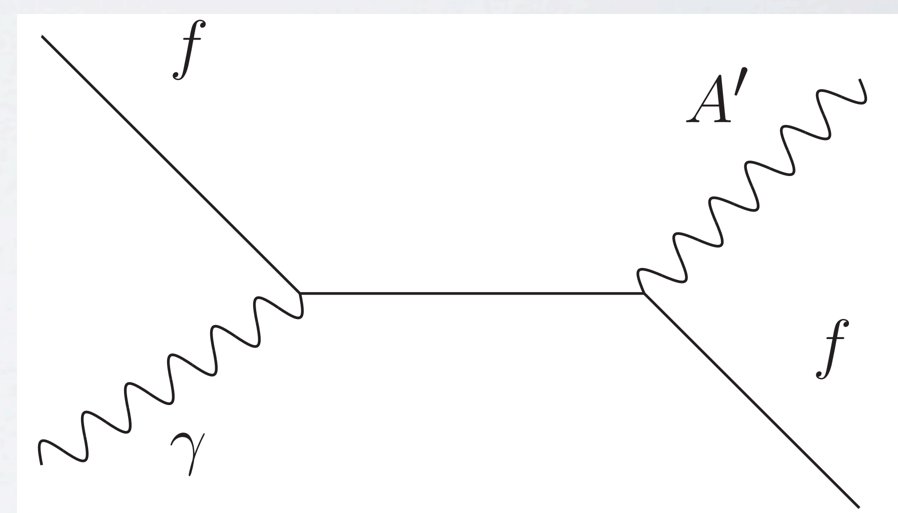


$$\Omega_\chi h^2 \approx 0.1 \times \frac{3\times 10^{-26}\mathrm{cm}^3\mathrm{s}^{-1}}{\langle \sigma v\rangle}$$

$$\Rightarrow \langle \sigma v\rangle \approx \frac{\alpha^2}{M_W^2}$$

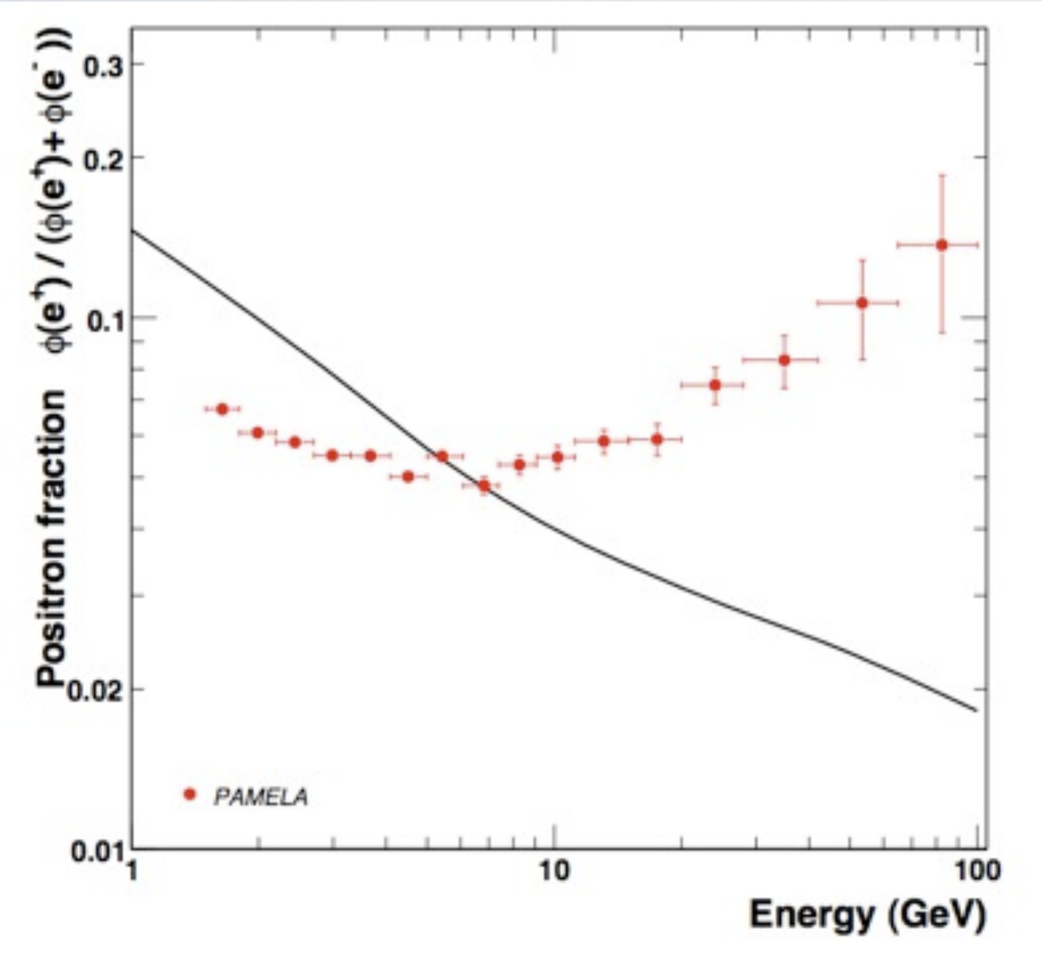


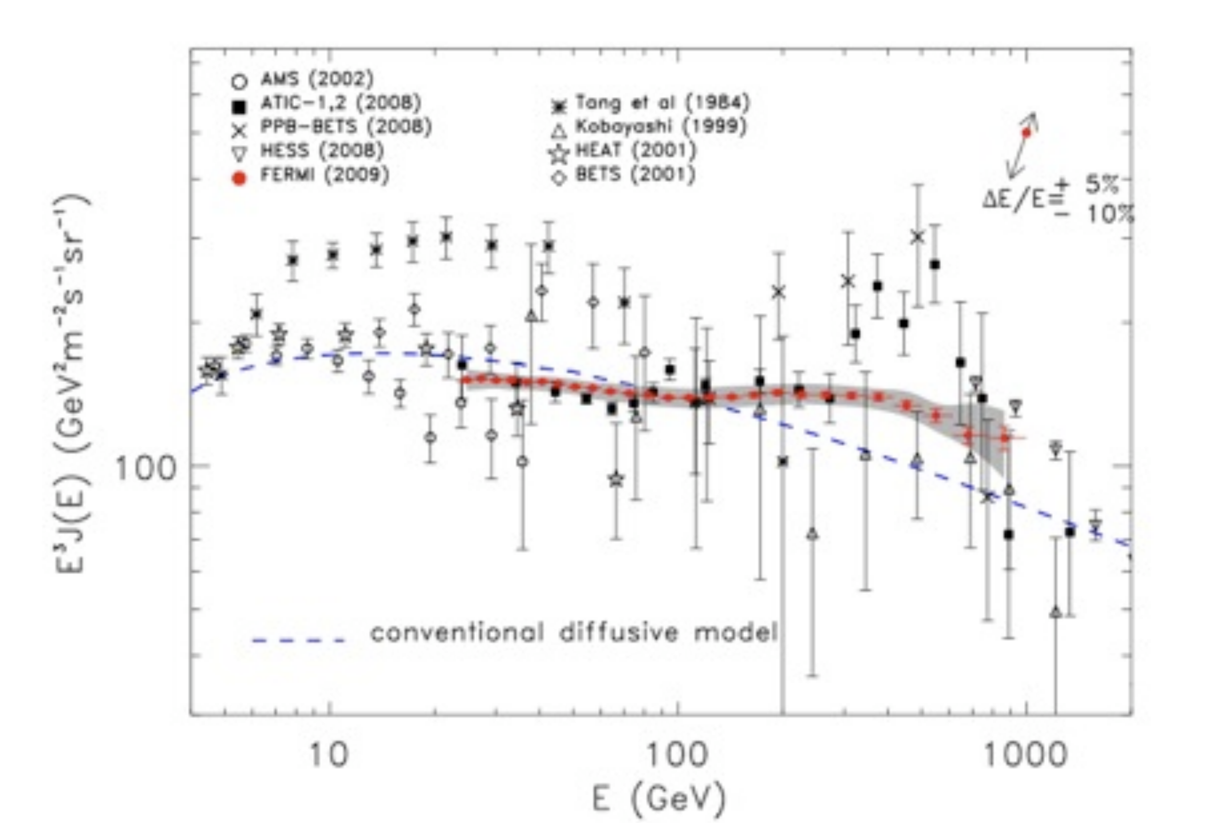




Finkbeiner, NW astro-ph 0702587v2; Pospelov,Ritz,Voloshin arxiv 0711.4866

COSMIC RAYS: PAMELA/FERMI





Fermi/LAT collaboration

DM?

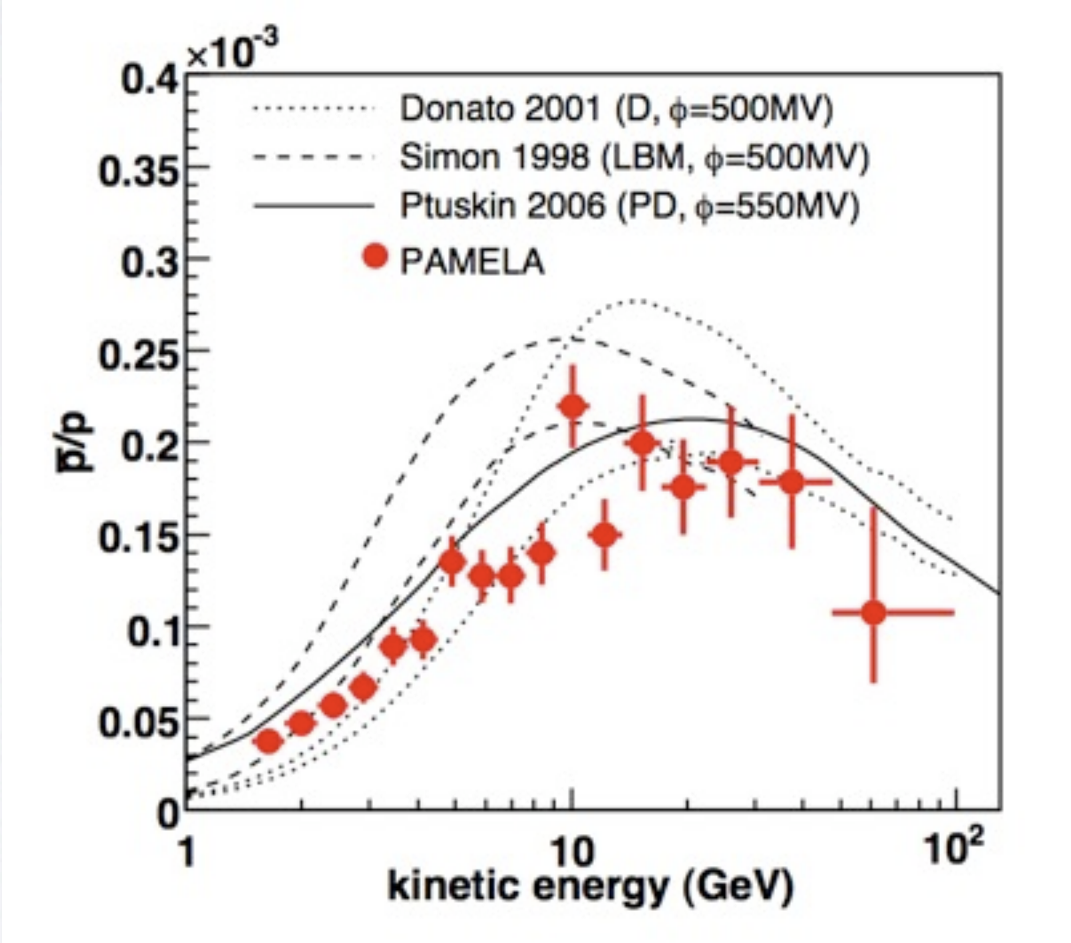
COSMIC RAYS: PAMELA/FERMI

COSMIC RAYS: PAMELA/FERMI

PAMELA sees no excess in antiprotons - excludes hadronic modes by order of magnitude (Cirelli et al, '08, Donato et al, '08)

COSMIC RAYS: PAMELA/FERMI

PAMELA sees no excess in antiprotons - excludes hadronic modes by order of magnitude (Cirelli et al, '08, Donato et al, '08)



COSMIC RAYS: PAMELA/FERMI

PAMELA sees no excess in antiprotons - excludes hadronic modes by order of magnitude (Cirelli et al, '08, Donato et al, '08)

COSMIC RAYS: PAMELA/FERMI

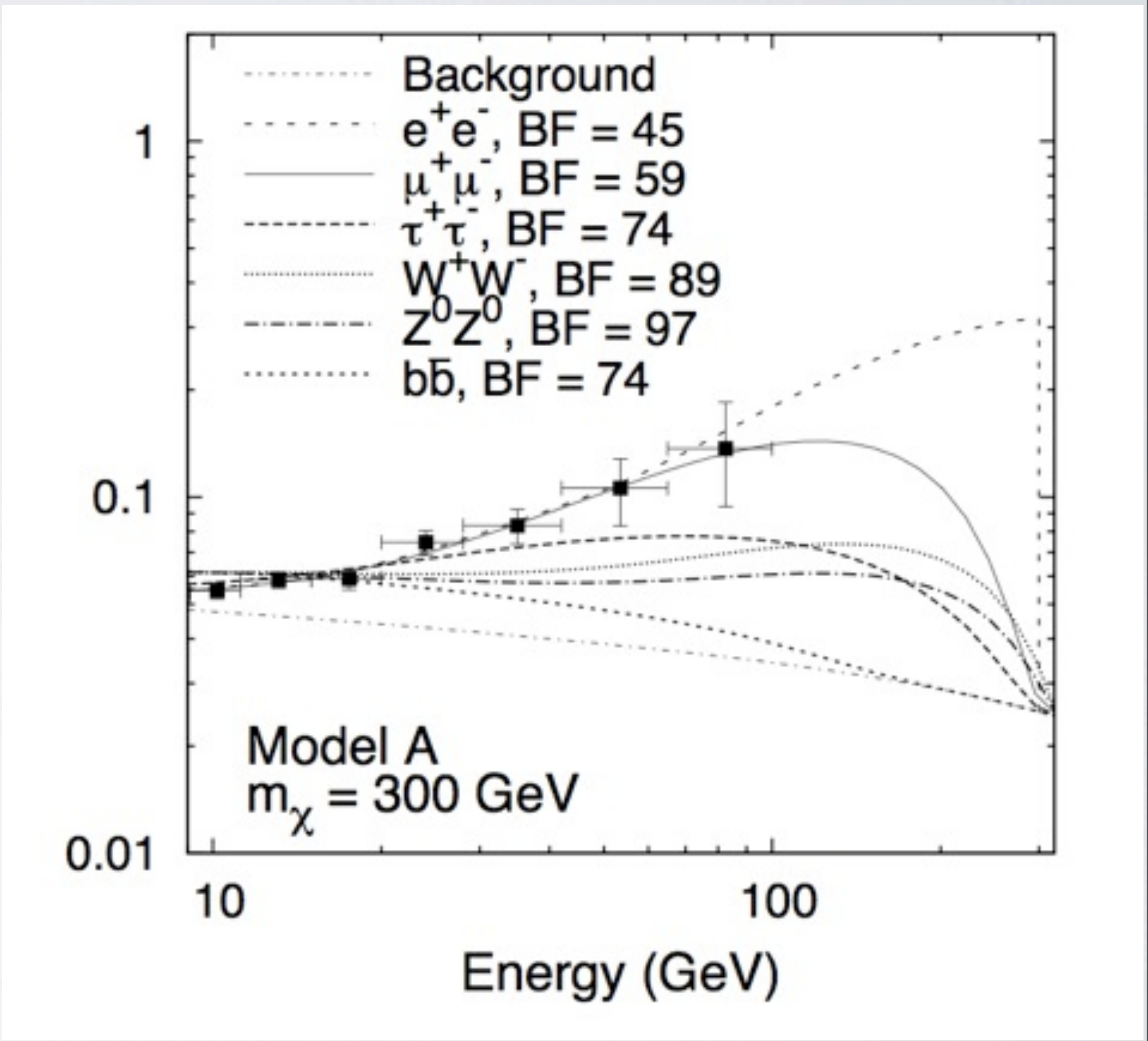
PAMELA sees no excess in antiprotons - excludes hadronic modes by order of magnitude (Cirelli et al, '08, Donato et al, '08)

The spectrum at PAMELA is very hard - not what you would expect from e.g., W's

COSMIC RAYS: PAMELA/FERMI

PAMELA sees no excess in antiprotons - excludes hadronic modes by order of magnitude (Cirelli et al, '08, Donato et al, '08)

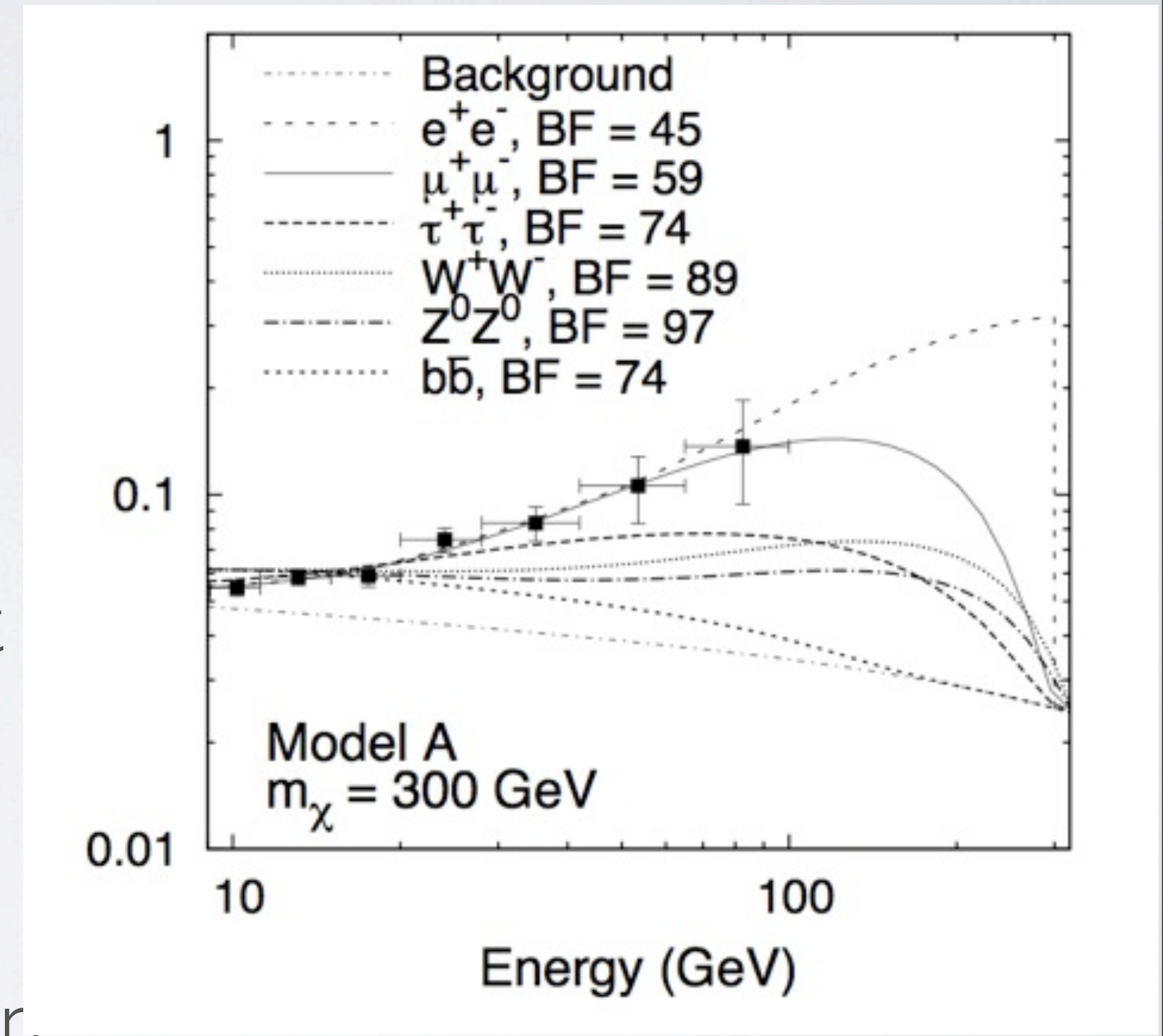
The spectrum at PAMELA is very hard - not what you would expect from e.g., W's



COSMIC RAYS: PAMELA/FERMI

PAMELA sees no excess in antiprotons - excludes hadronic modes by order of magnitude (Cirelli et al, '08, Donato et al, '08)

The spectrum at PAMELA is very hard - not what you would expect from e.g., W's



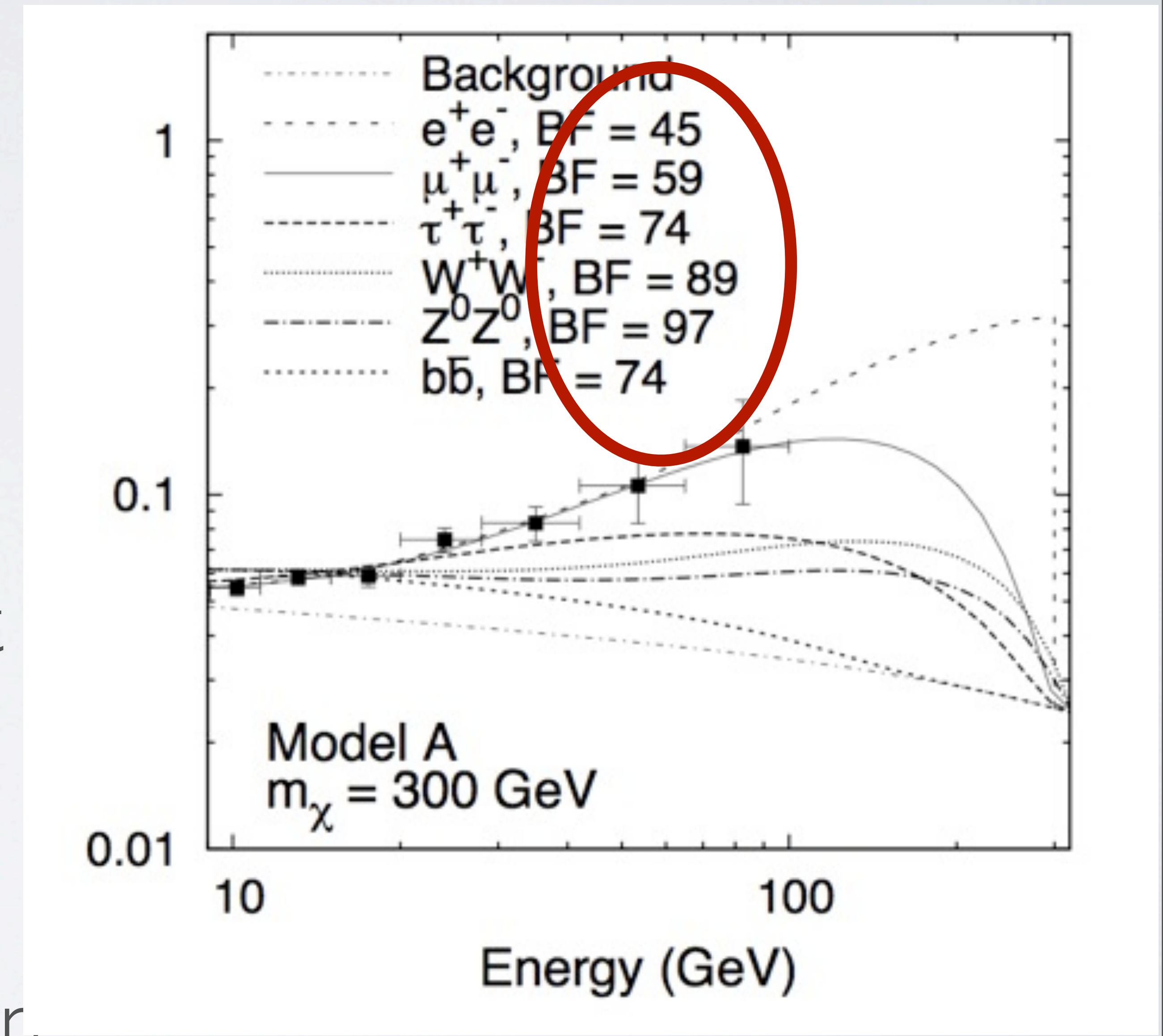
The cross sections needed are 10-1000x the thermal cross section

COSMIC RAYS: PAMELA/FERMI

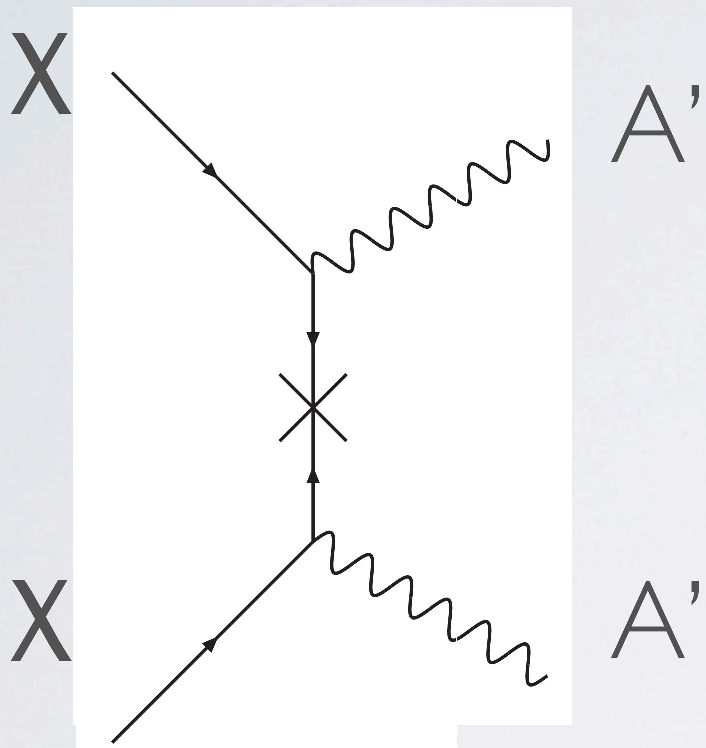
PAMELA sees no excess in antiprotons - excludes hadronic modes by order of magnitude (Cirelli et al, '08, Donato et al, '08)

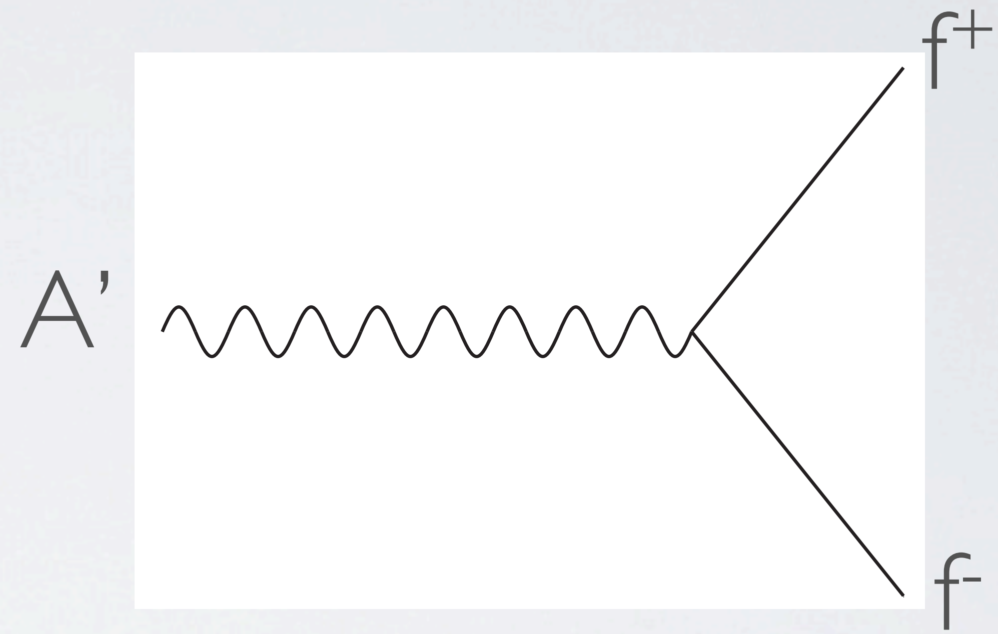
The spectrum at PAMELA is very hard - not what you would expect from e.g., W's

The cross sections needed are 10-1000x the thermal cross section



COSMIC RAYS: PAMELA/FERMI

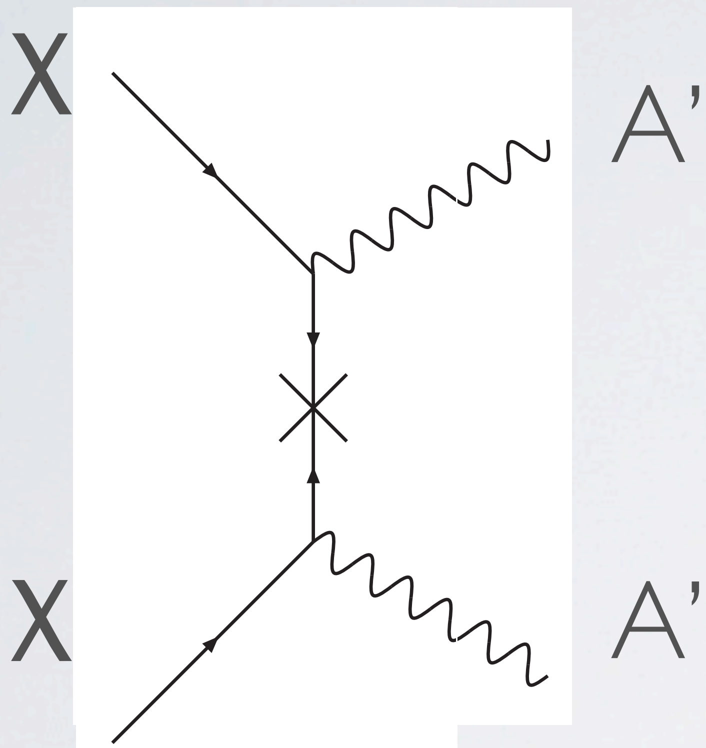


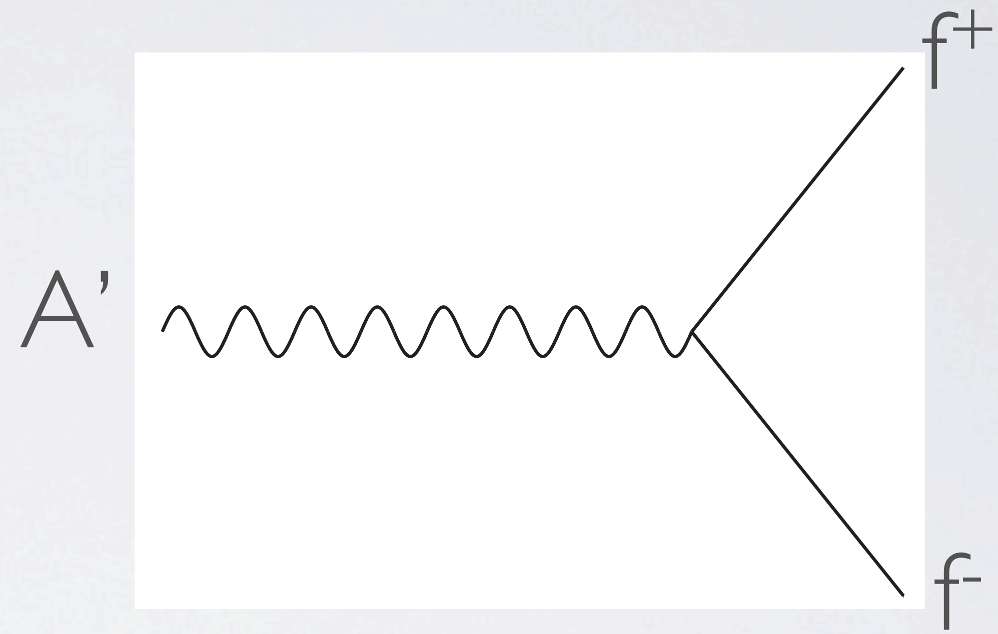


$m_{A'}$<GeV (no antiprotons, hard leptons)

(Finkbeiner, NW, arxiv 0702587v2; Cholis, Goodenough, NW arxiv 0802.2922)

COSMIC RAYS: PAMELA/FERMI



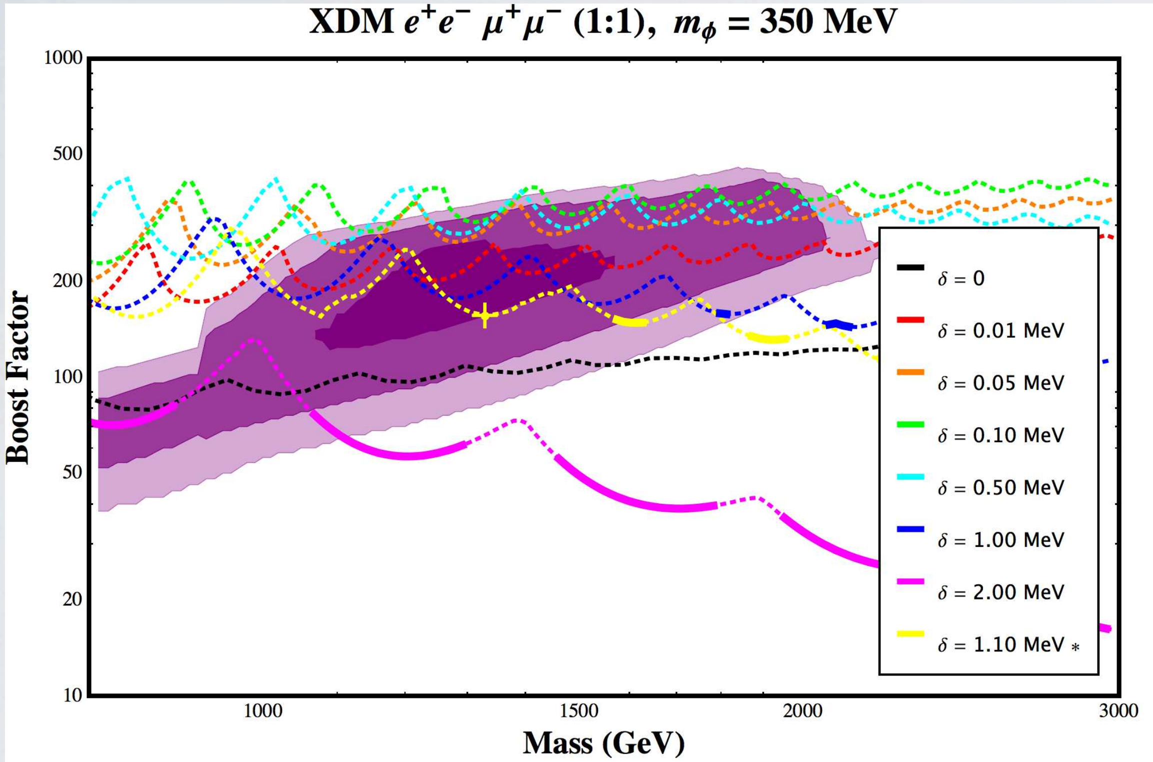


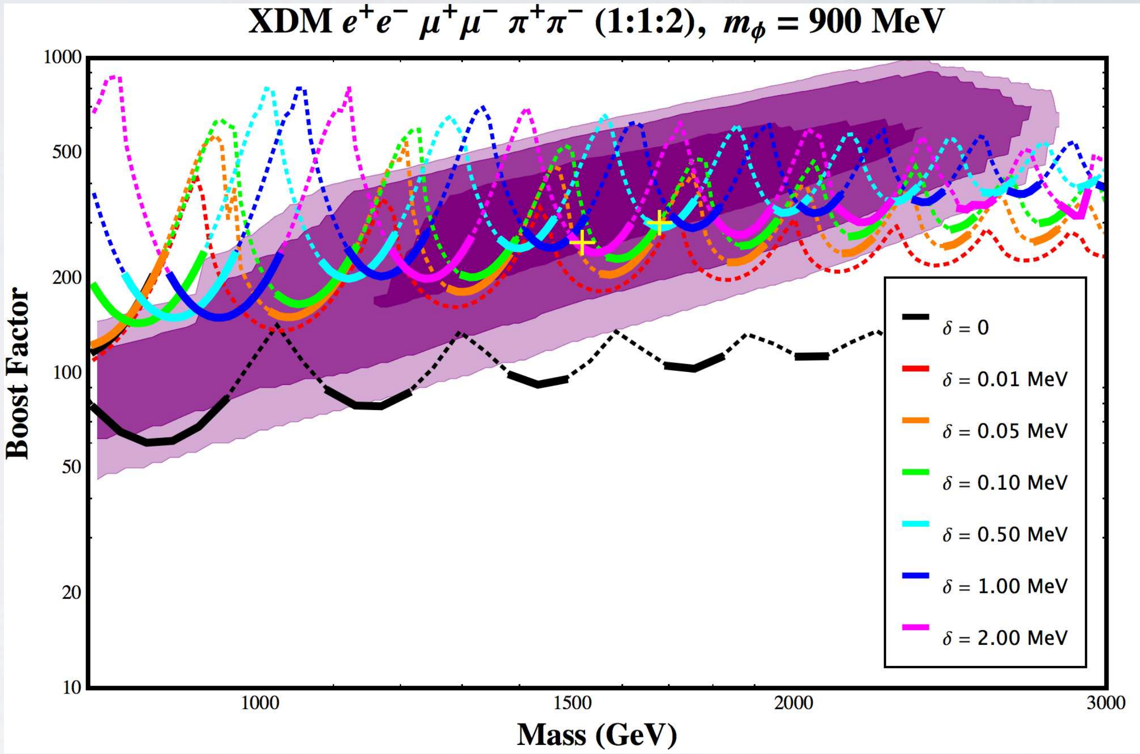
$m_{A'}$<GeV (no antiprotons, hard leptons)

(Finkbeiner, NW, arxiv 0702587v2; Cholis, Goodenough, NW arxiv 0802.2922)

Large cross section from Sommerfeld enhancement

COSMIC RAYS: PAMELA/FERMI



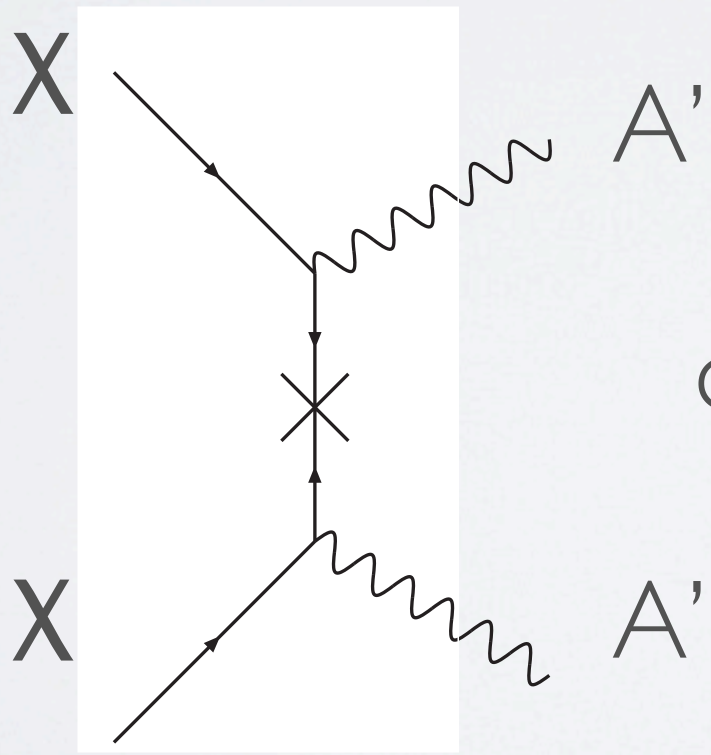


Finkbeiner et al, arxiv1011.3082

- Provides a consistent and testable DM intepretation

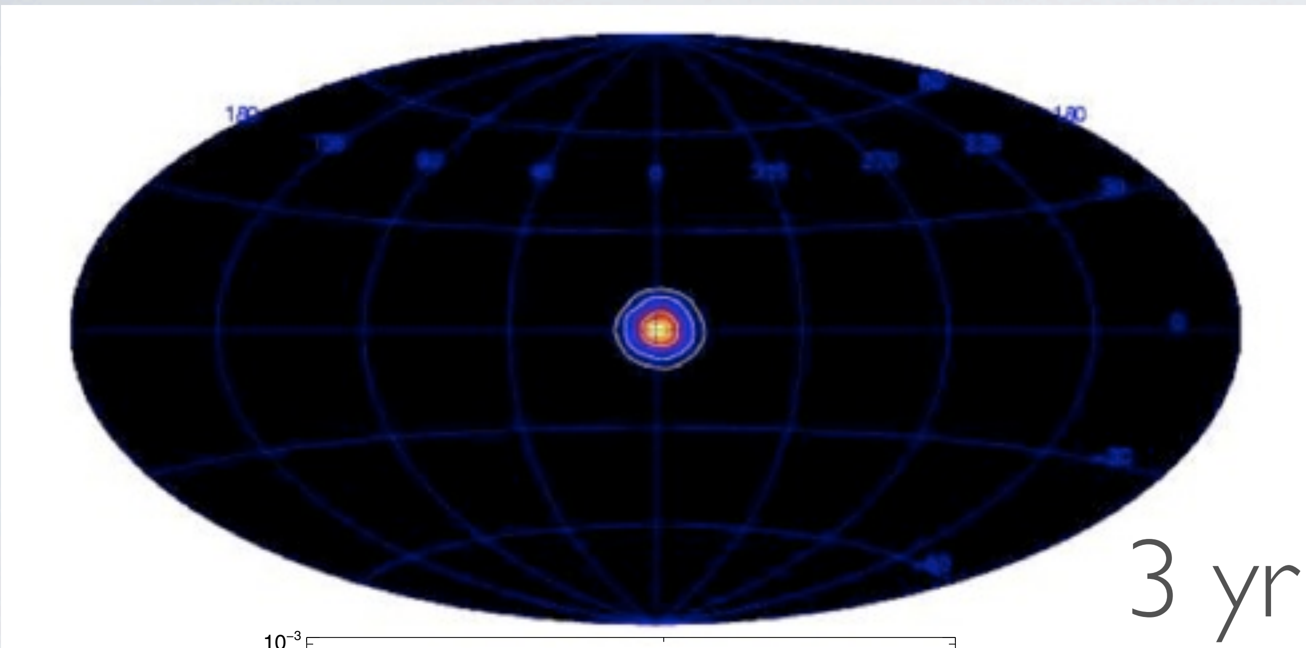
COSMIC RAYS: PAMELA/FERMI

- Motivates sub-GeV dark photon (determined by spectrum of positrons); typically 210 MeV < $m_{A'}$ < ~GeV

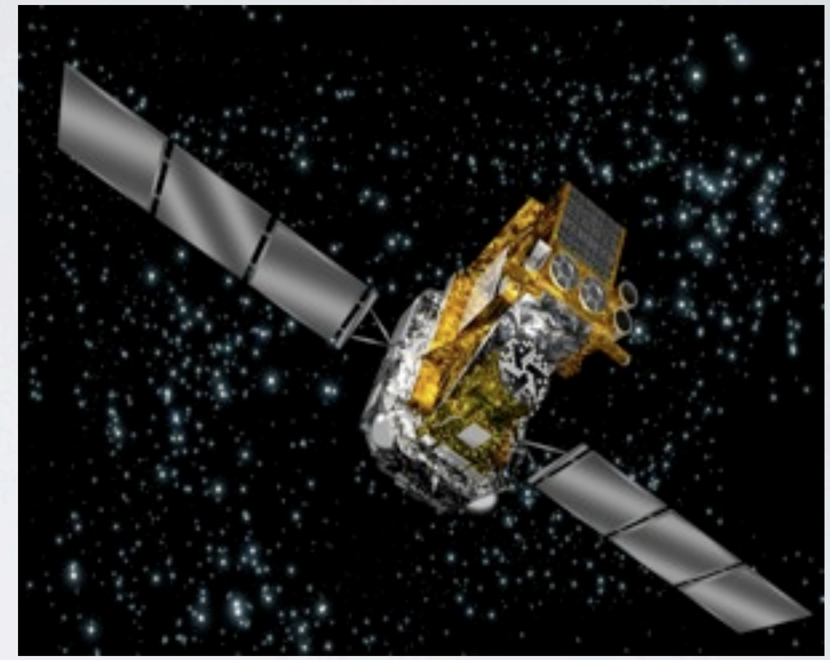


doesn't depend on α'

COSMIC RAYS: INTEGRAL



3 yr



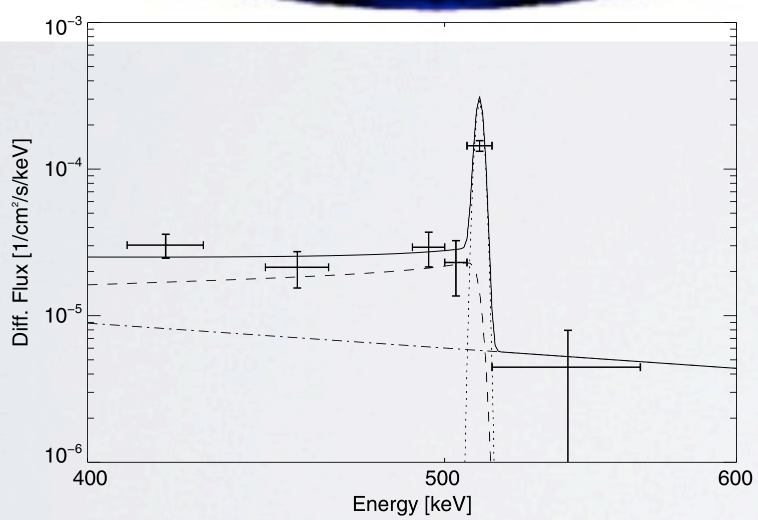
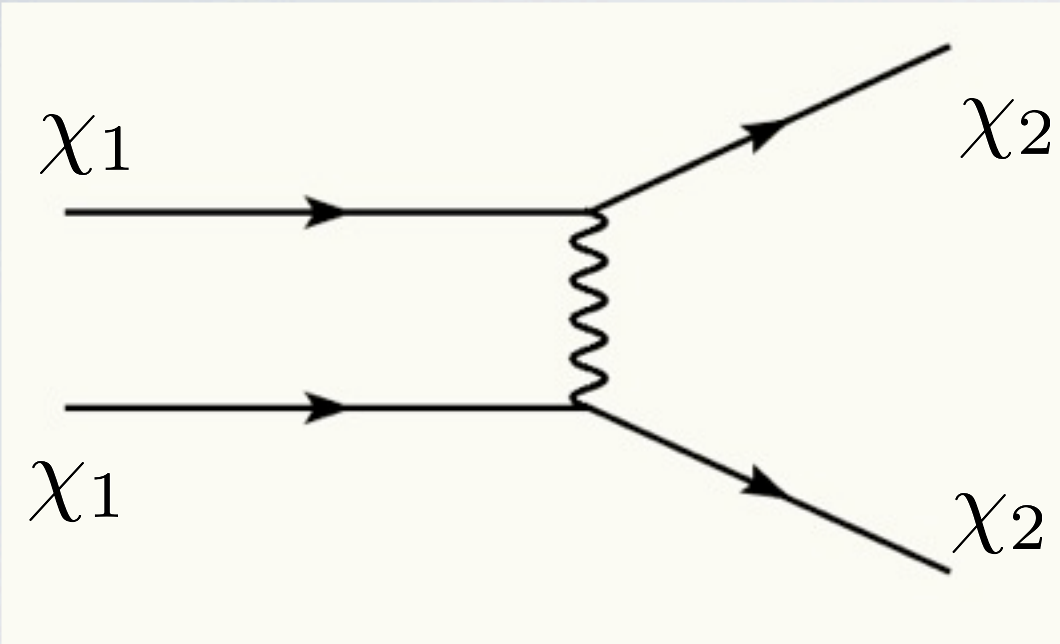


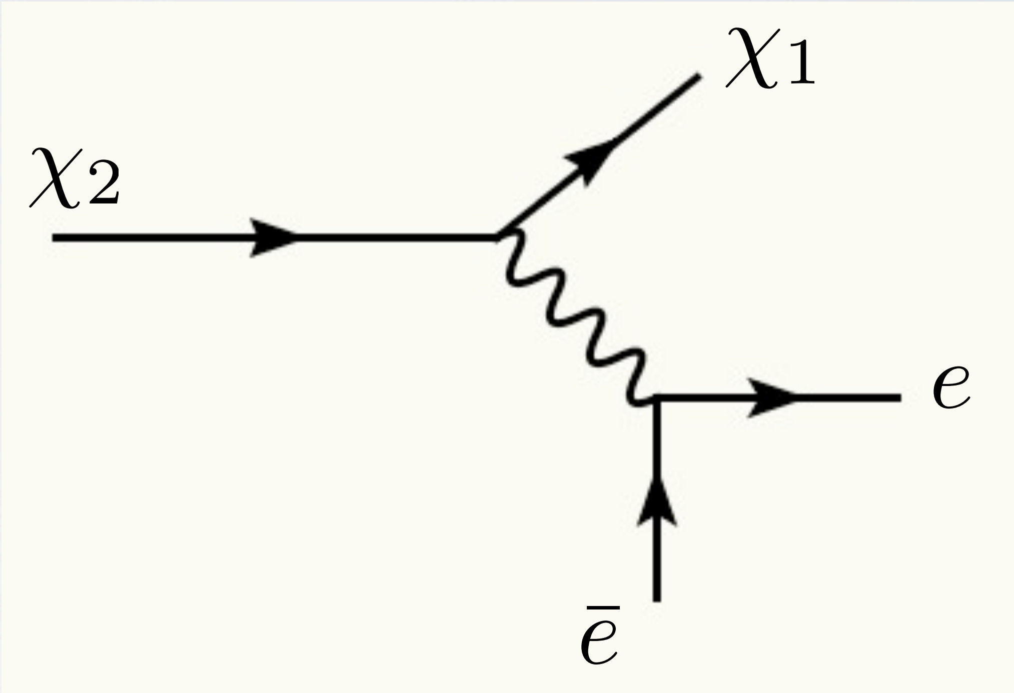
Fig. 2. A fit of the SPI result for the diffuse emission from the GC region ($|l|, |b| \leq 16°$) obtained with a spatial model consisting of an 8° *FWHM* Gaussian bulge and a CO disk. In the fit a diagonal response was assumed. The spectral components are: 511 keV line (dotted), Ps continuum (dashes), and power-law continuum (dash-dots). The summed models are indicated by the solid line. Details of the fitting procedure are given in the text.

Large excess of cosmic ray positrons (low energy)

COSMIC RAYS: INTEGRAL



subsequent decays should produce e+e- pairs



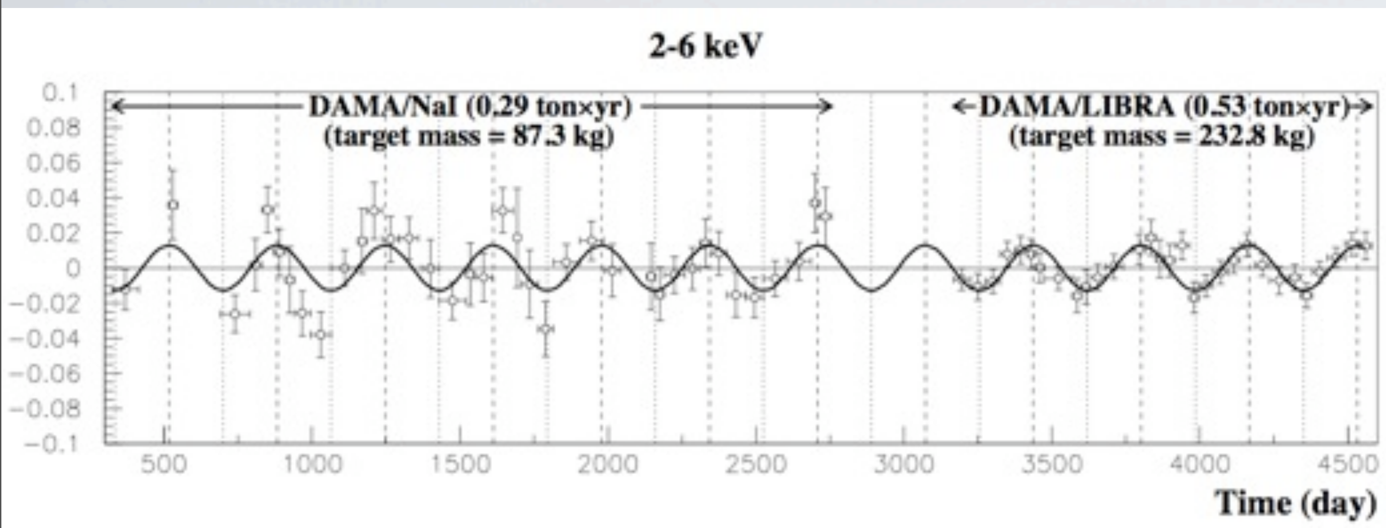
WIMP-WIMP should induce WIMP excitations

Possible origin for INTEGRAL positron excess

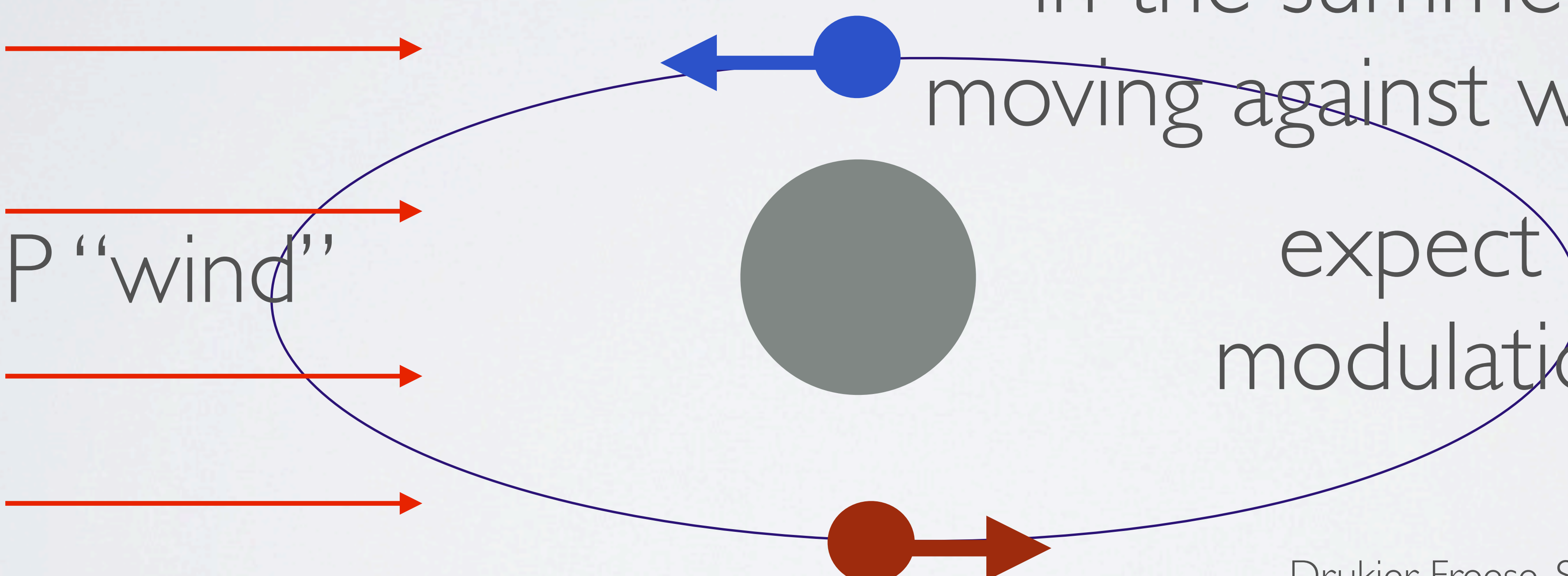
D.Finkbeiner, NW, 0702587v2

Also no dependence on α'

DIRECT DETECTION: DAMA



in the summer, moving against wind



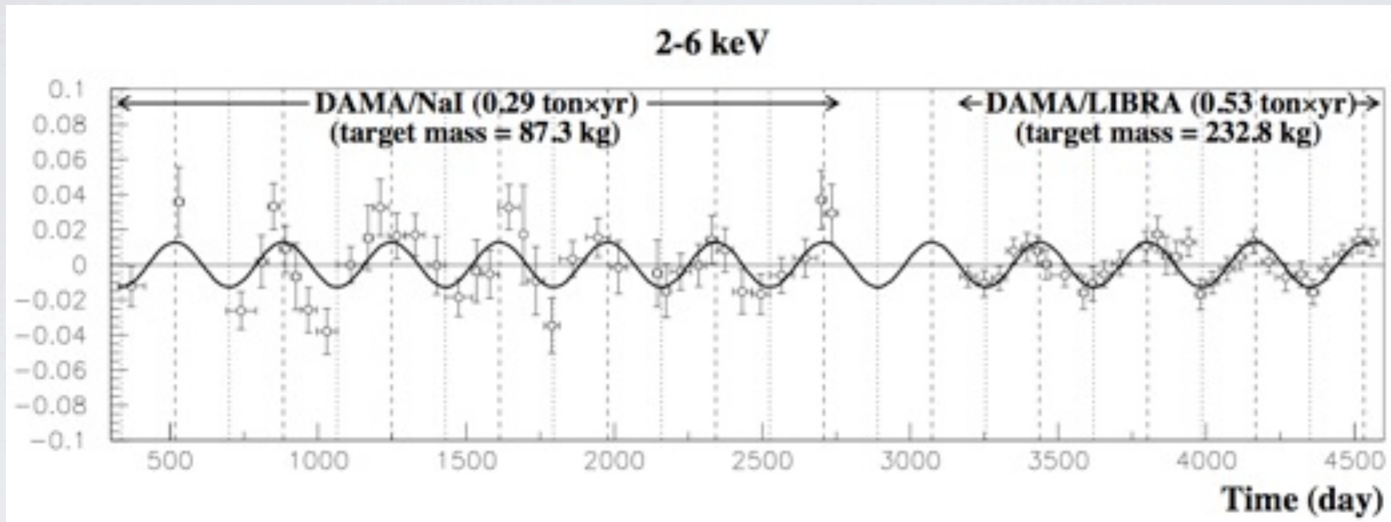
WIMP "wind"

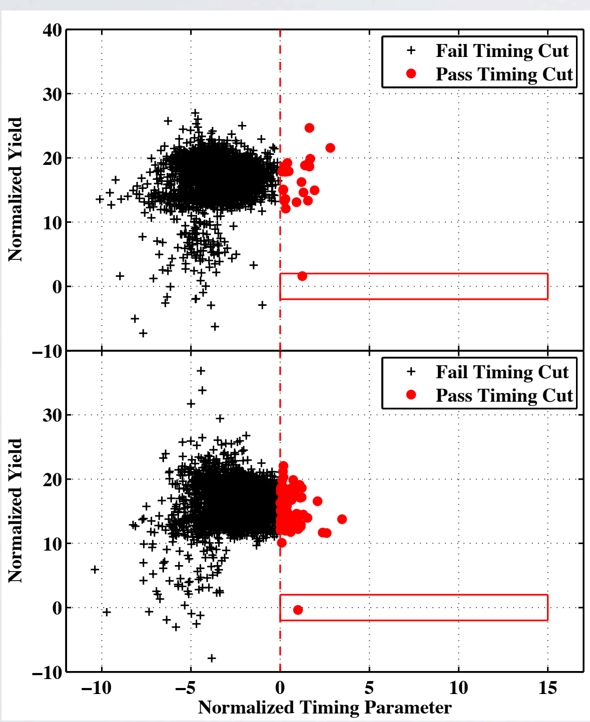
expect an annual modulation in signal!

Drukier, Freese, Spergel Phys.Rev.D33:3495-3508,198

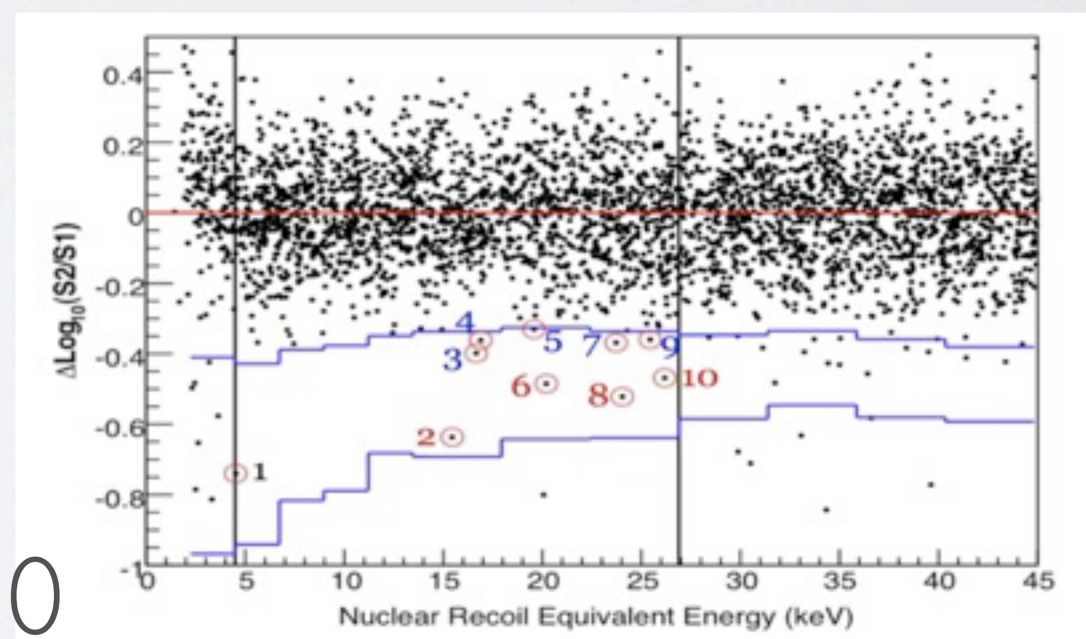
in the winter, moving against wind

DIRECT DETECTION: DAMA



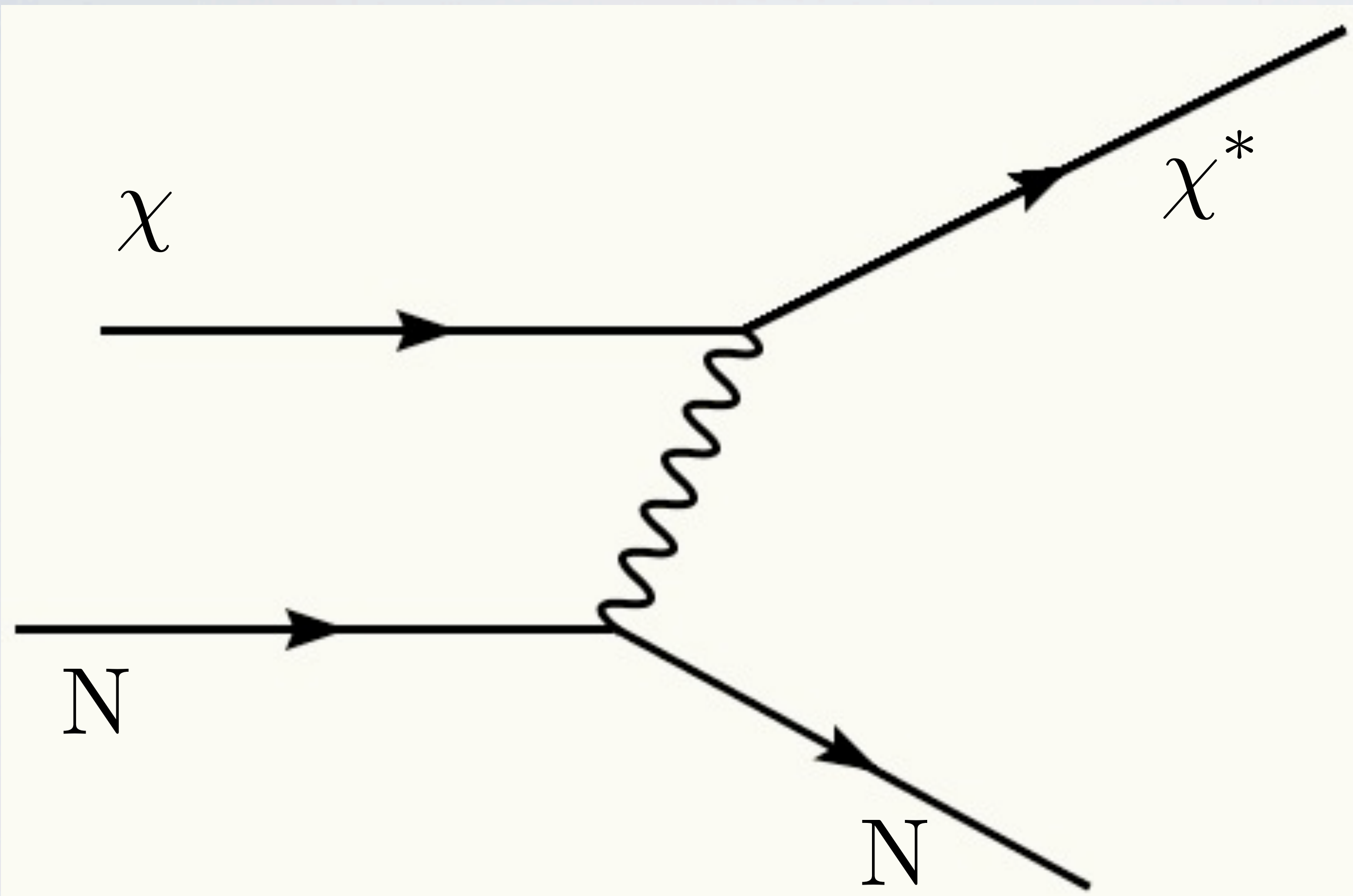


CDMS



XENON10

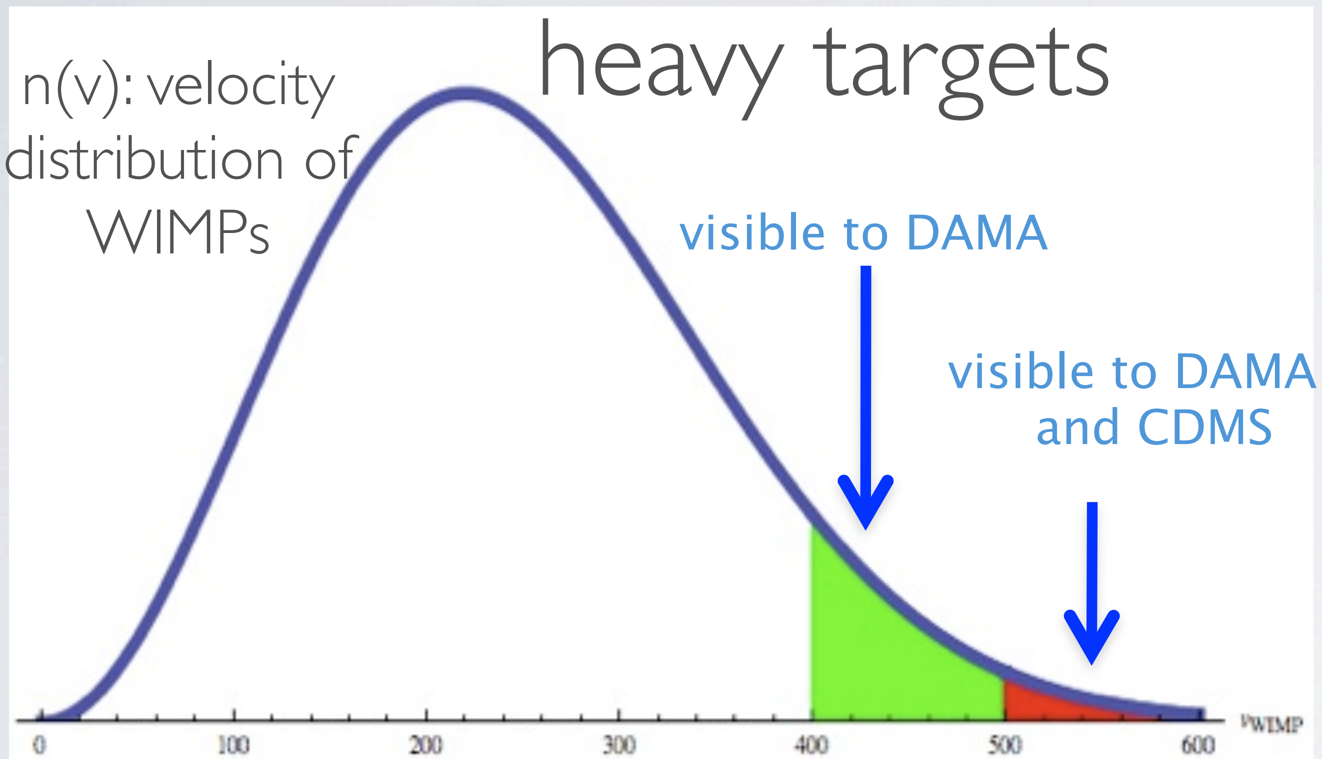
DIRECT DETECTION: DAMA

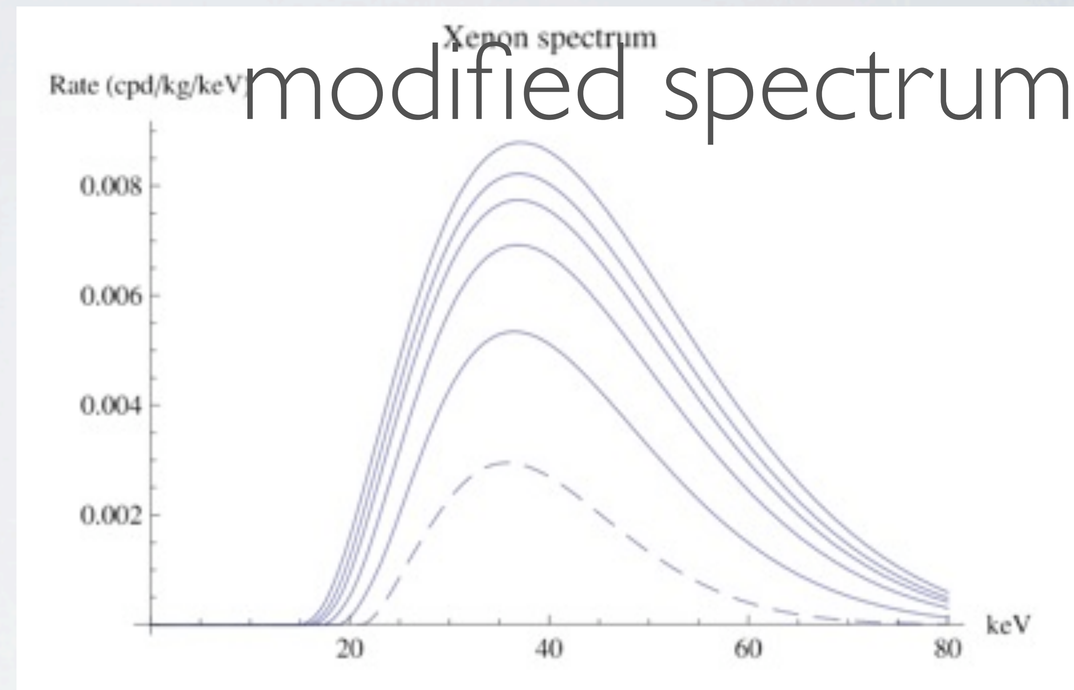


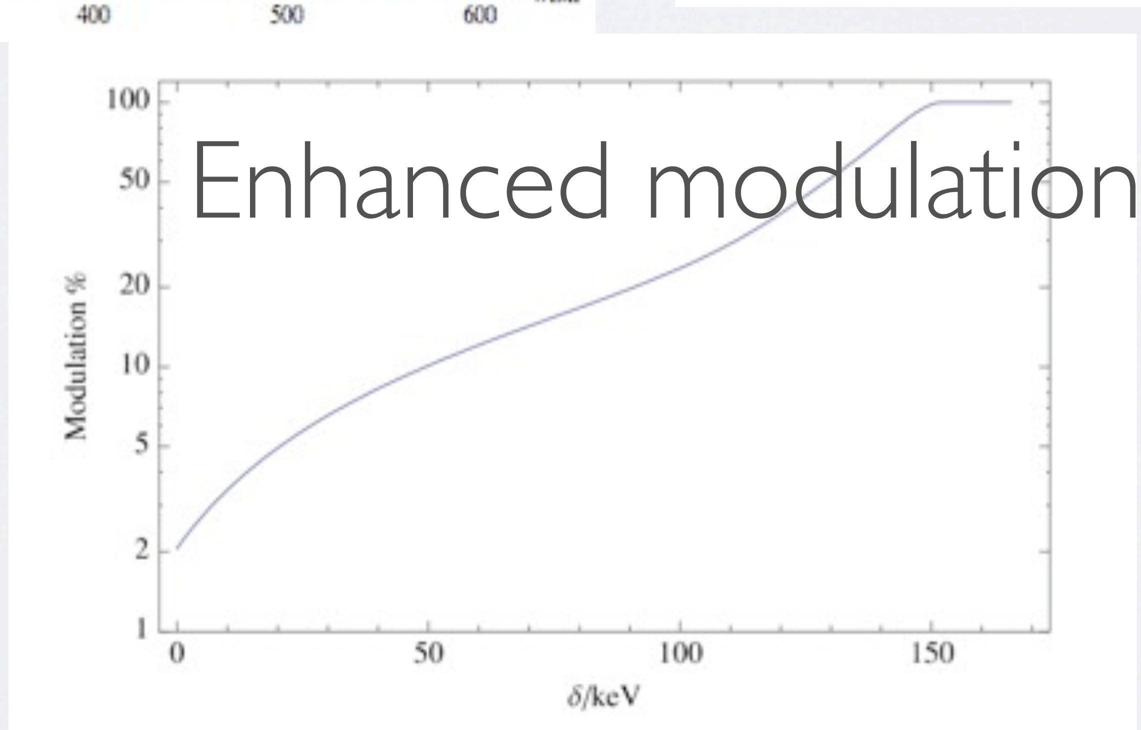
$$\frac{\mu_{\chi N} v^2}{2} > \delta$$

Scattering via dark photon naturally off-diagonal - realization of "inelastic dark matter"

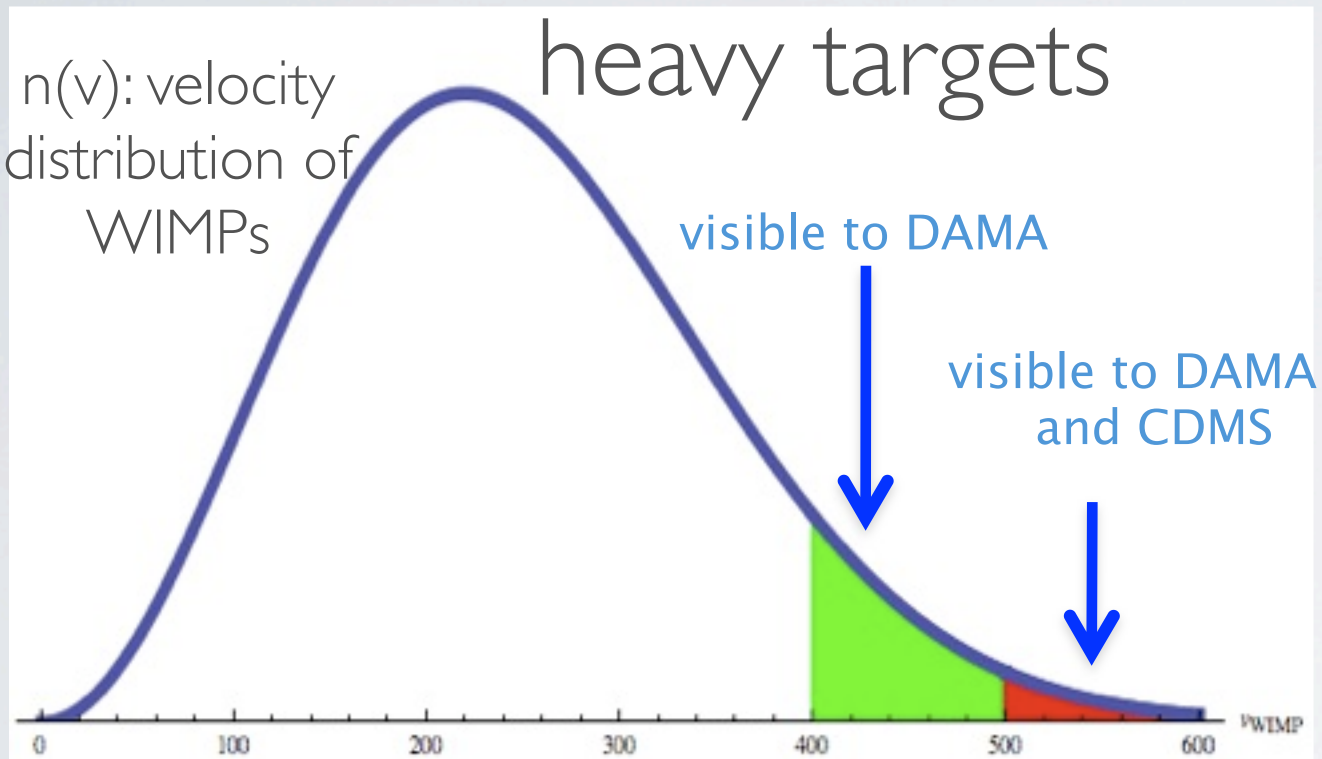
DIRECT DETECTION: DAMA

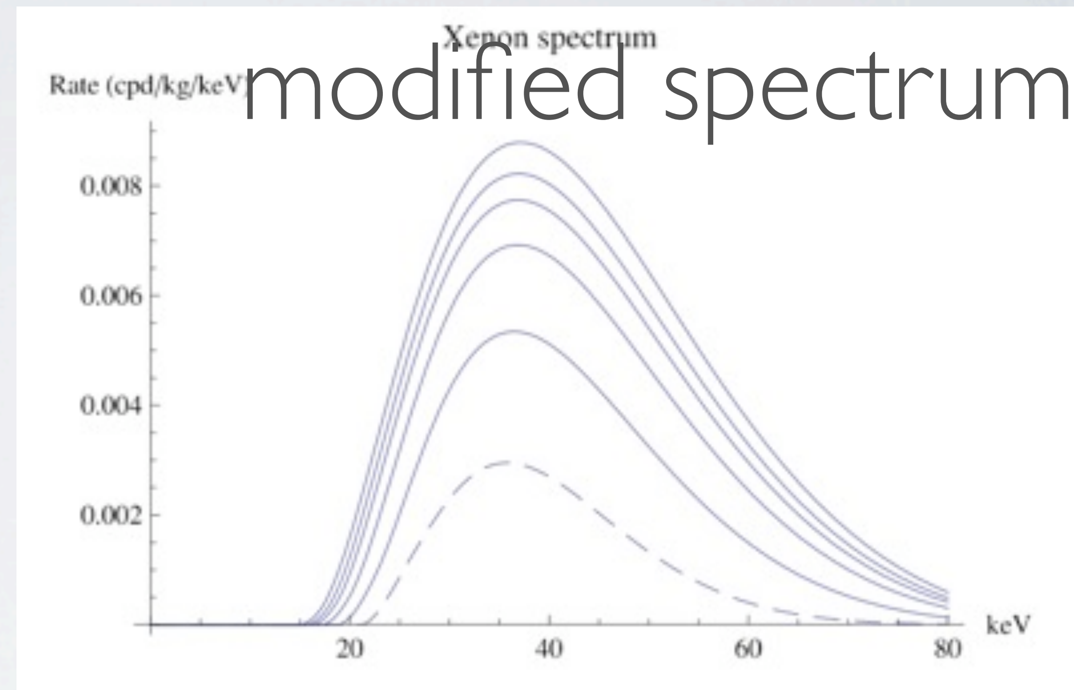


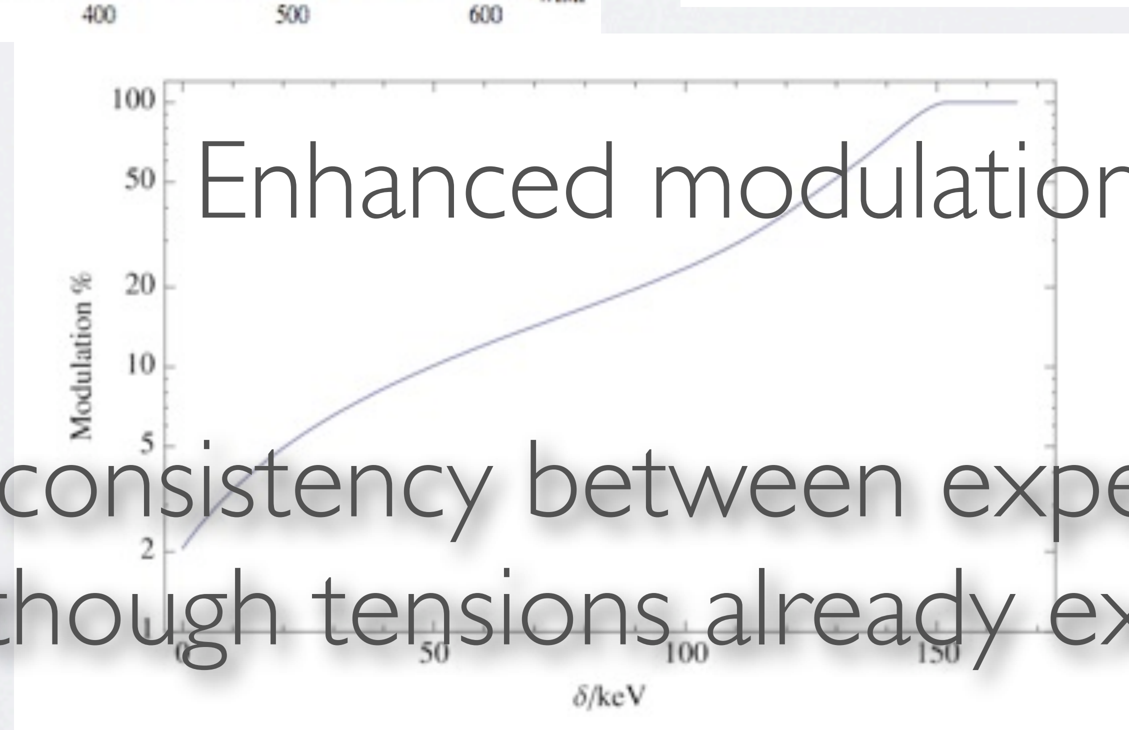




DIRECT DETECTION: DAMA

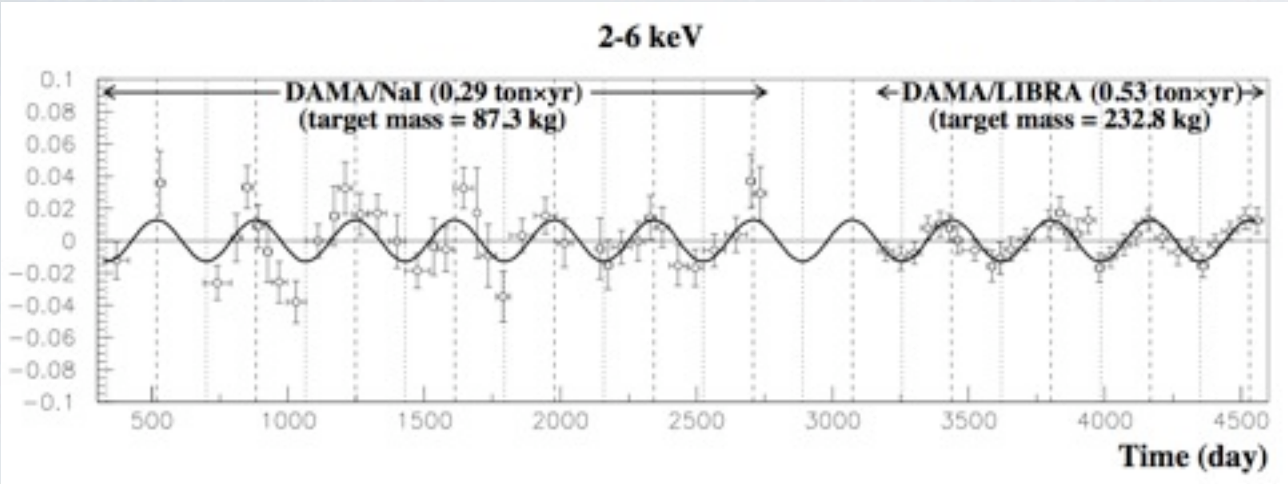




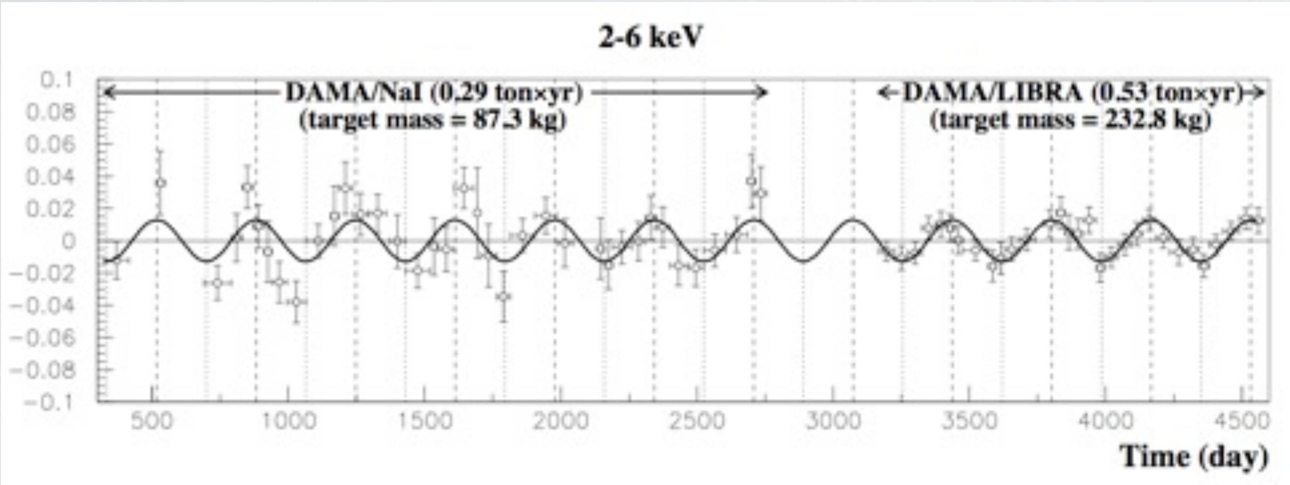


Allows consistency between experiments
(although tensions already exist)

LIGHT DARK MATTER

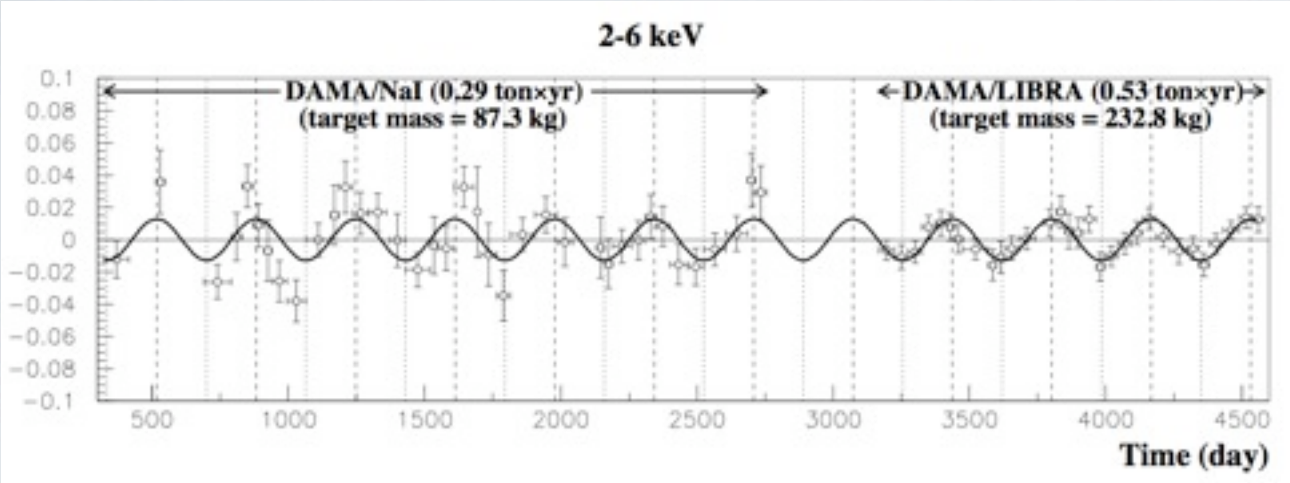


LIGHT DARK MATTER

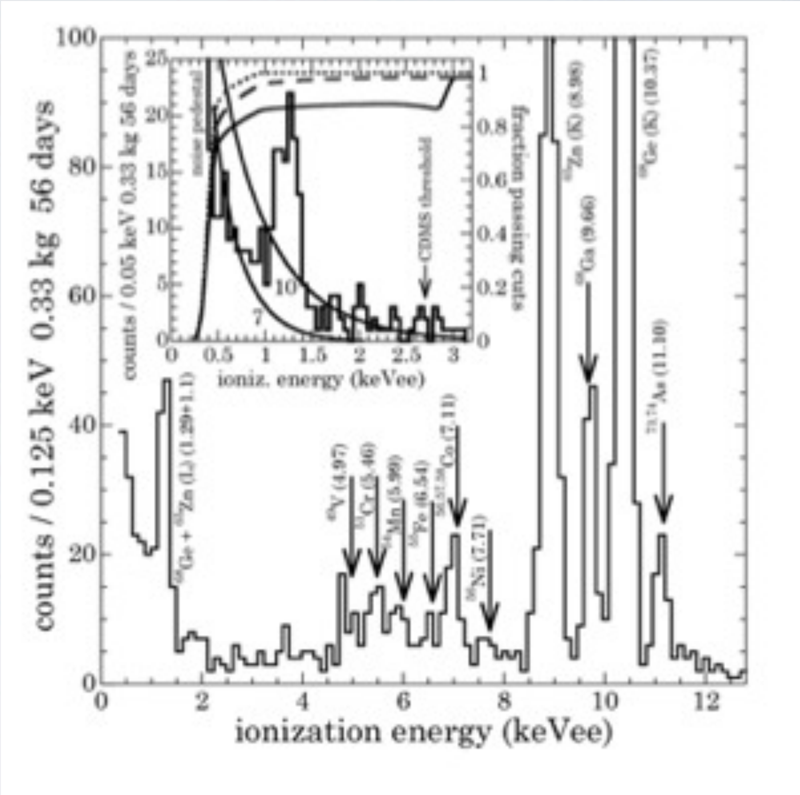


DM Interpretation: variation in WIMP scattering as Earth moves around sun (with and against galactic motion)

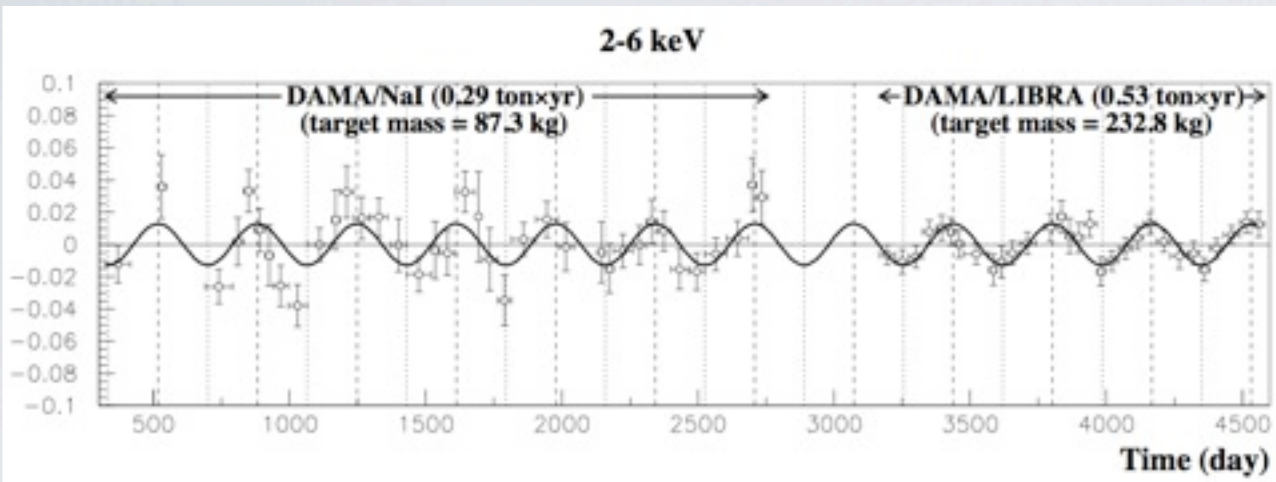
LIGHT DARK MATTER



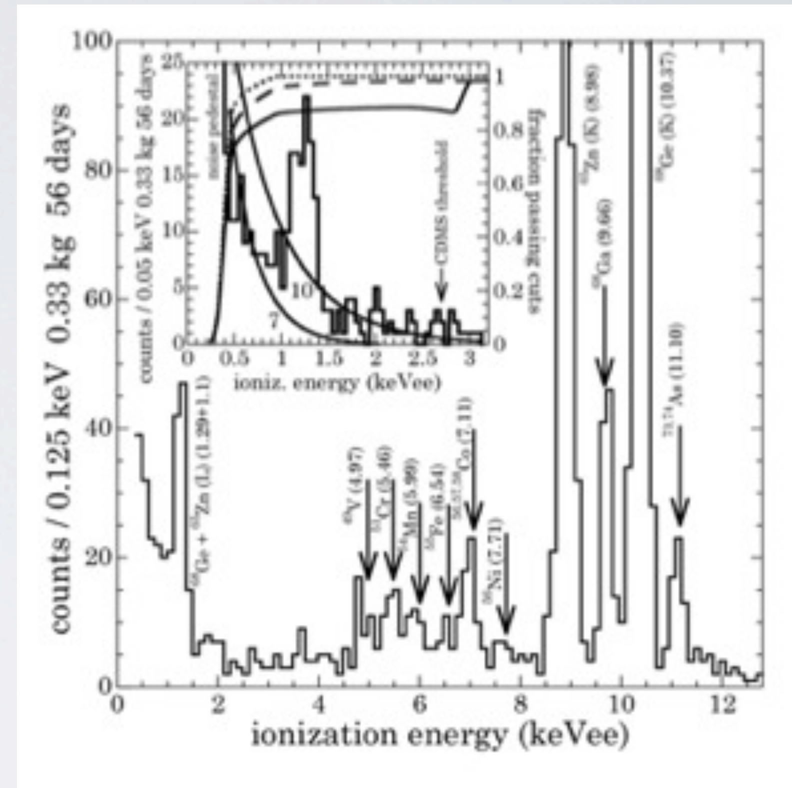
DM Interpretation: variation in WIMP scattering as Earth moves around sun (with and against galactic motion)



LIGHT DARK MATTER

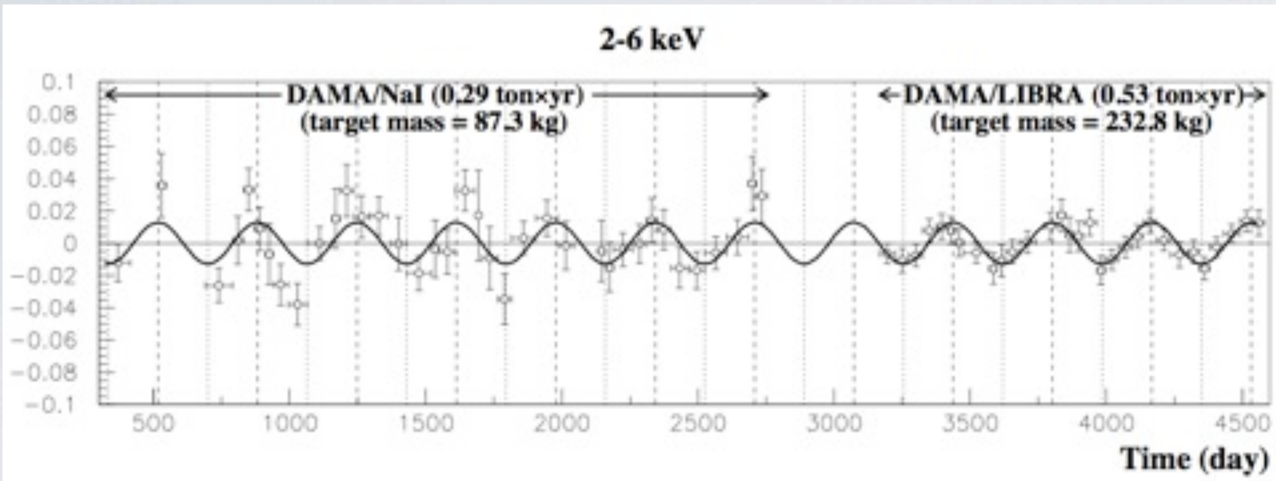


DM Interpretation: variation in WIMP scattering as Earth moves around sun (with and against galactic motion)

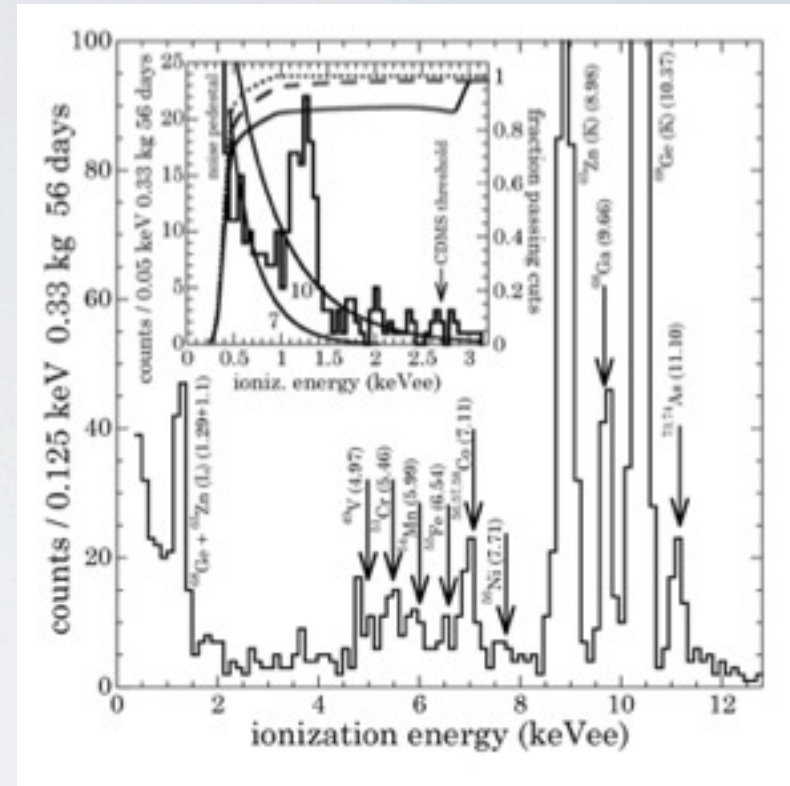


DM Interpretation: elastic scattering of ~7GeV WIMP

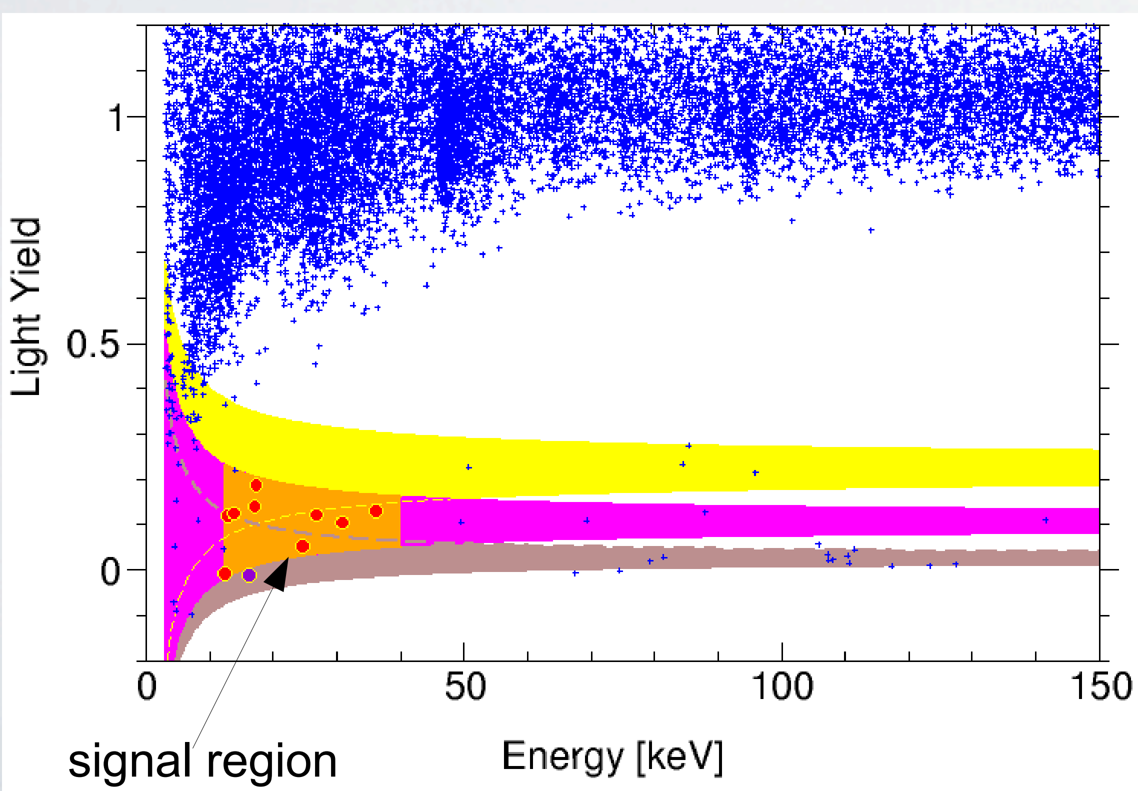
LIGHT DARK MATTER



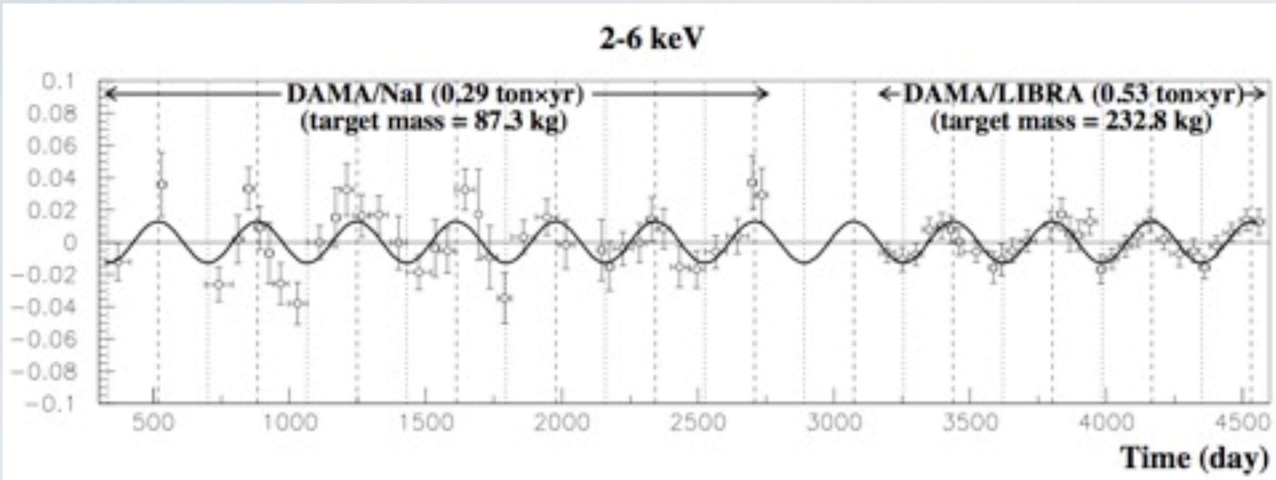
DM Interpretation: variation in WIMP scattering as Earth moves around sun (with and against galactic motion)



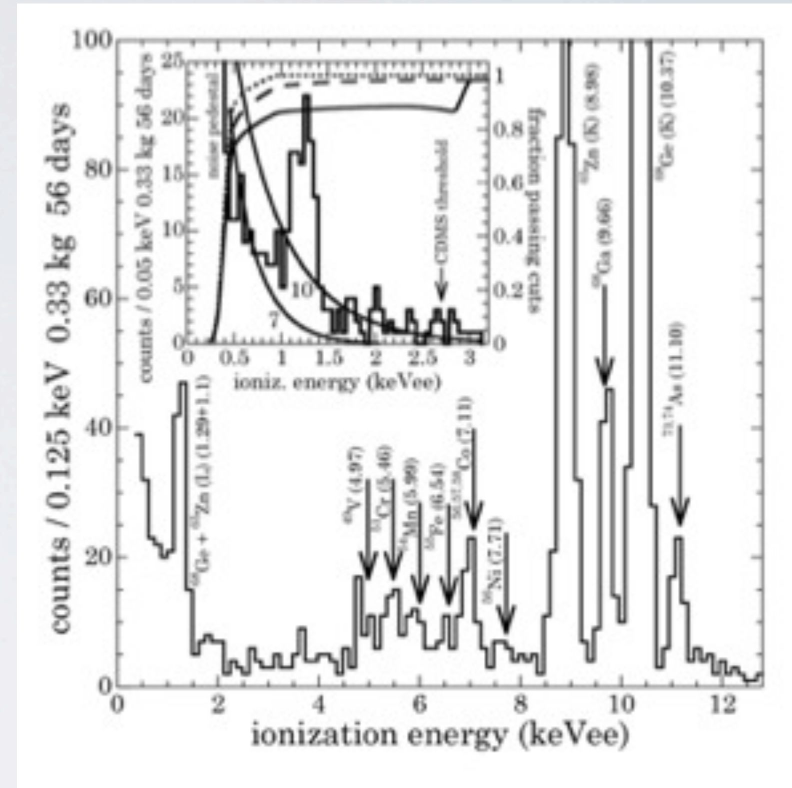
DM Interpretation: elastic scattering of ~7GeV WIMP

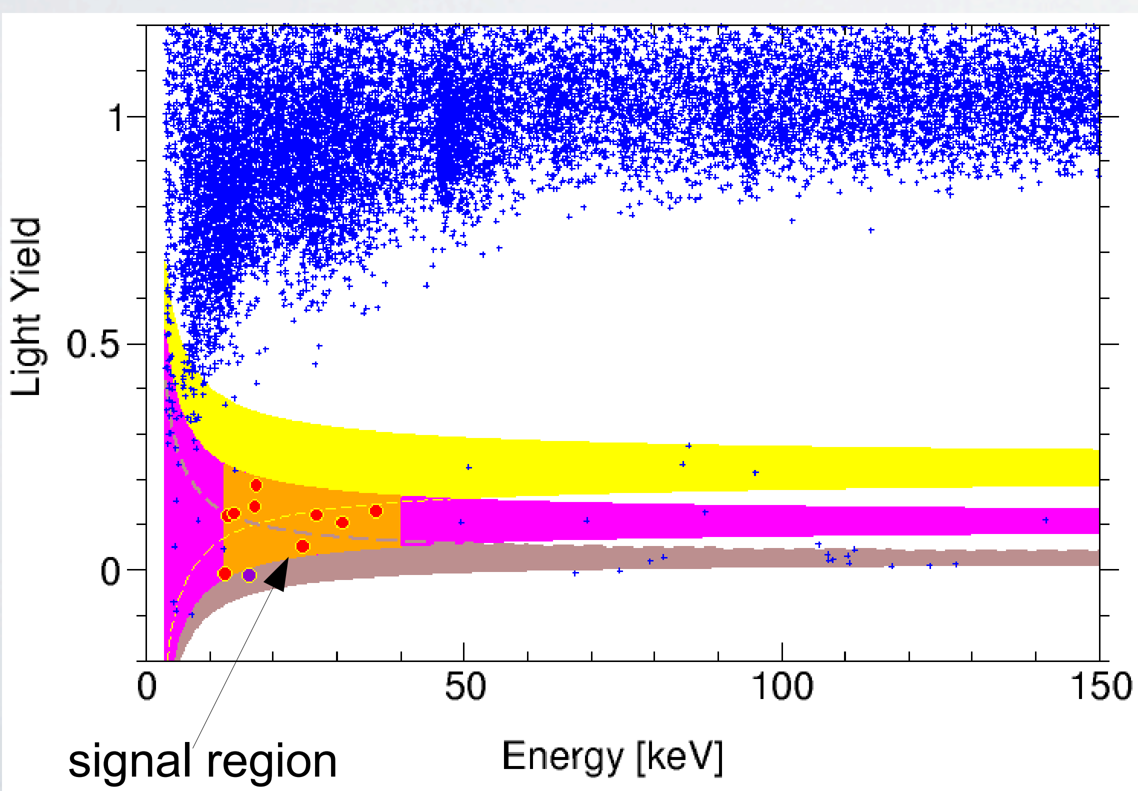


LIGHT DARK MATTER



DM Interpretation: variation in WIMP scattering as Earth moves around sun (with and against galactic motion)

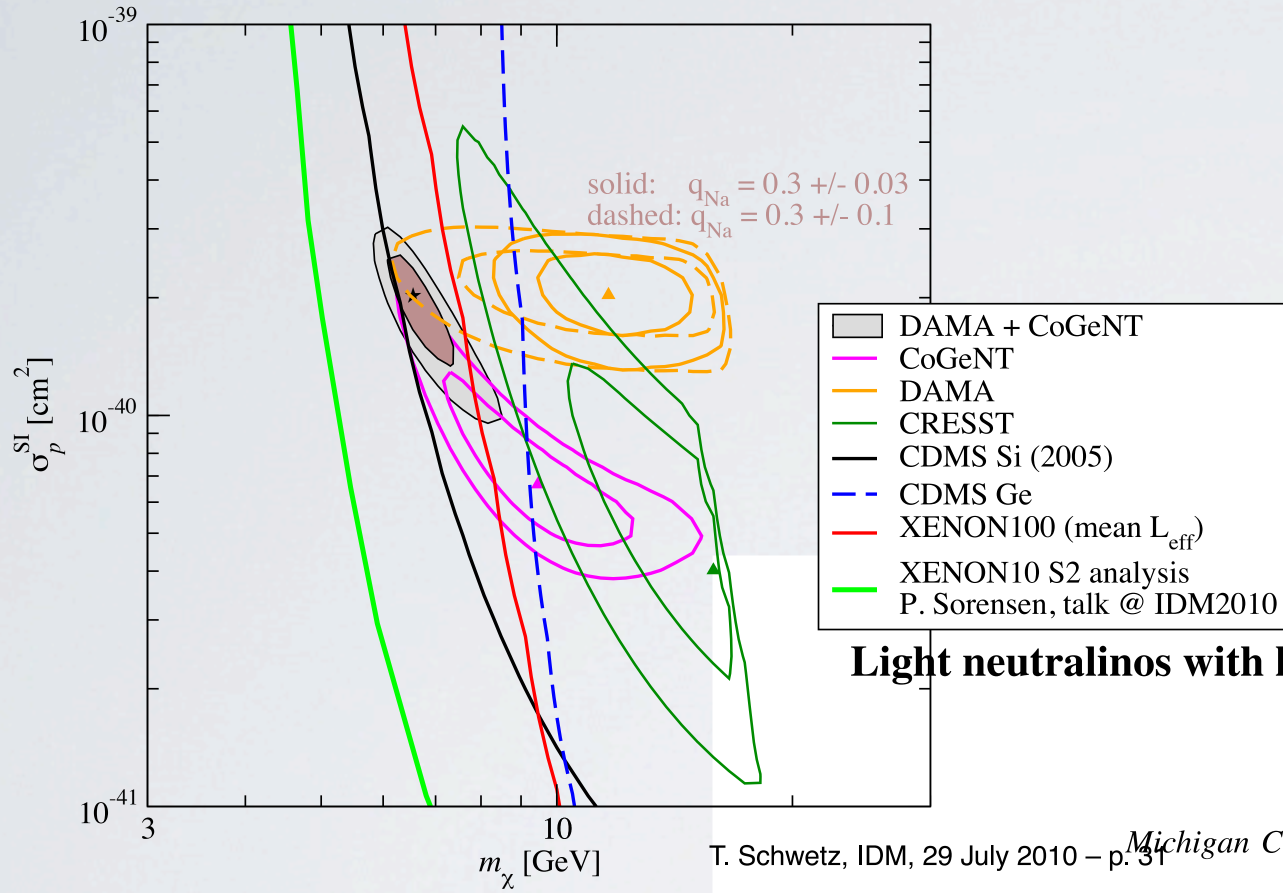




DM Interpretation: elastic scattering of ~7GeV WIMP

DM Interpretation: unquantified (**pre-announced March 2010**) "Light" WIMP

LIGHT DARK MATTER



T. Schwetz, IDM, 29 July 2010 – p. 31

Light neutralinos with large scattering cross sections in the minimal supersymmetric standard model

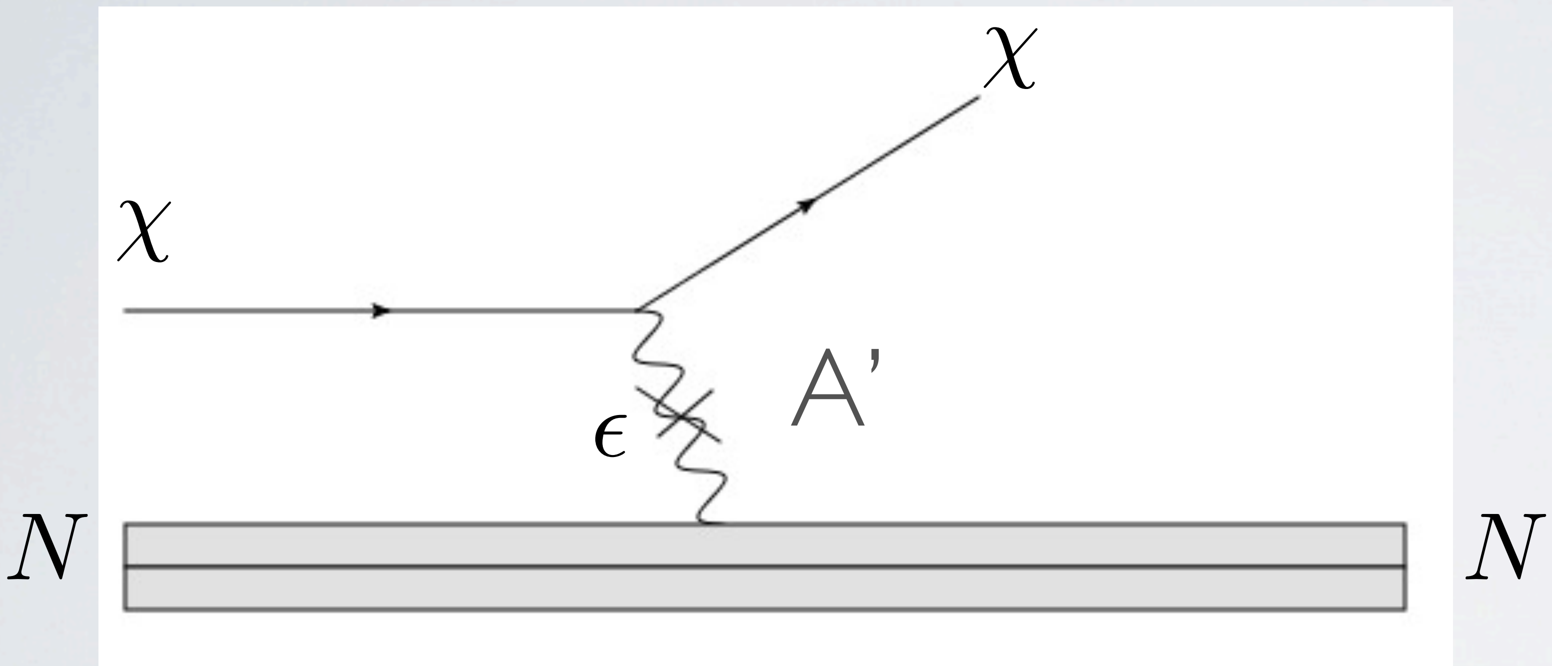
Eric Kuflik, Aaron Pierce, and Kathryn M. Zurek

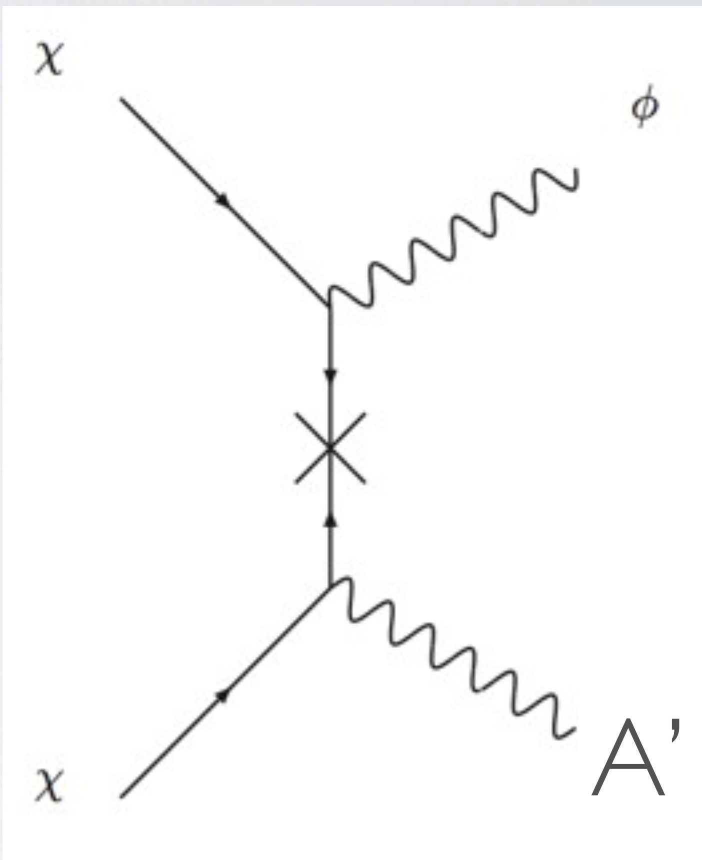
Michigan Center for Theoretical Physics, University of Michigan, Ann Arbor, MI 48109

(Dated: July 20, 2010)

Motivated by recent data from CoGeNT and the DAMA annual modulation signal, we discuss collider constraints on minimal supersymmetric standard model neutralino dark matter with mass in the 5-15 GeV range. The lightest superpartner (LSP) would be a bino with a small Higgsino admixture. Maximization of the dark matter-nucleon scattering cross section for such a weakly interacting massive particle requires a light Higgs boson with $\tan\beta$ enhanced couplings. Limits on the invisible width of the Z boson, combined with the rare decays $B^{\pm} \to \tau\nu$, and the ratio $B \to D\tau\nu / B \to D\ell\nu$, constrain cross sections to be below $\sigma_n \lesssim 5 \times 10^{-42}$ cm^2. This indicates a higher local Dark Matter density than is usually assumed by a factor of roughly six would be necessary to explain the CoGeNT excess. This scenario also requires a light charged Higgs boson, which can give substantial contributions to rare decays such as $b \to s\gamma$ and $t \to bH^{+}$. We also discuss the impact of Tevatron searches for Higgs bosons at large $\tan\beta$.

LIGHT DARK MATTER



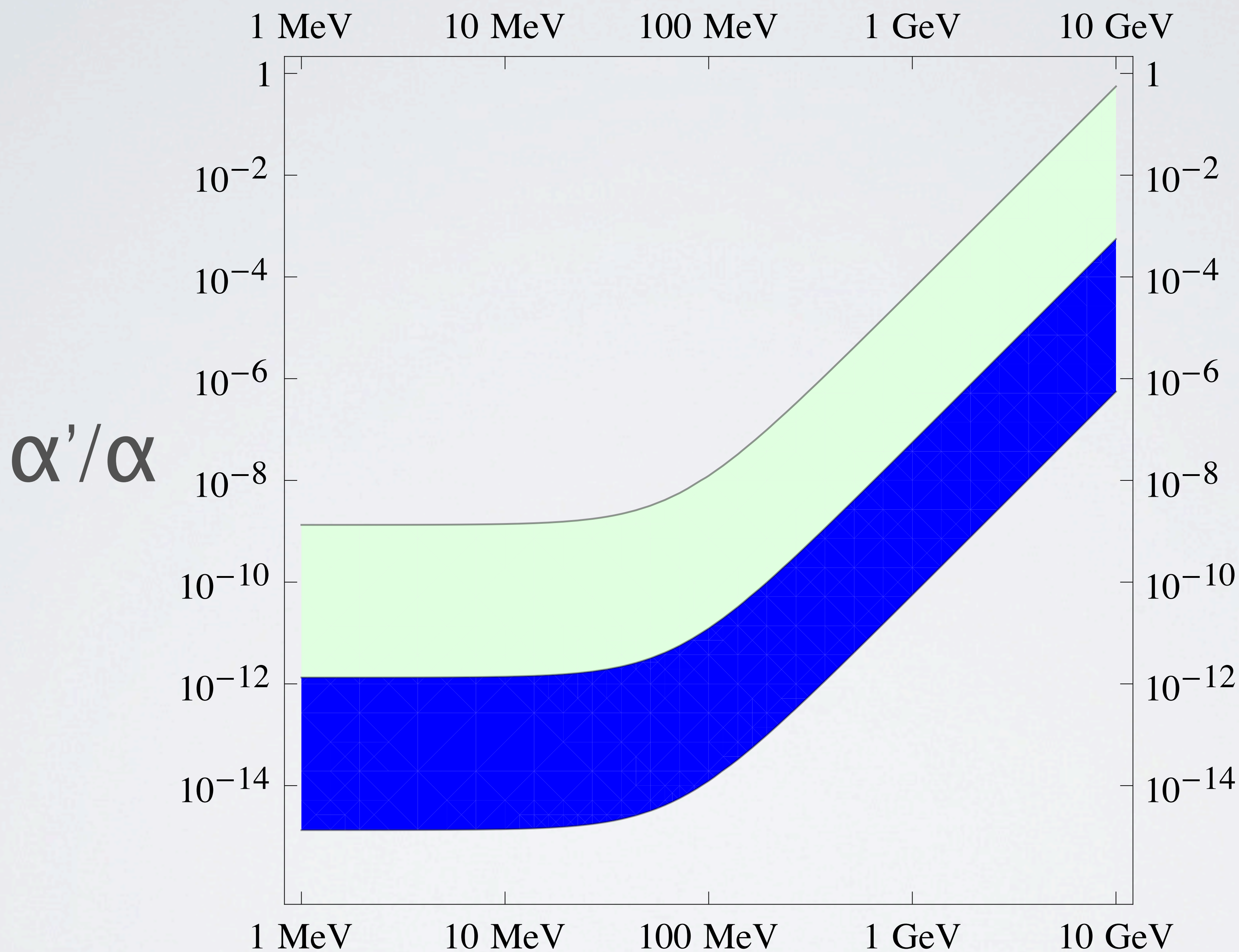


$$\sigma \approx \frac{\alpha_d \alpha_{EM} \epsilon^2}{m_\phi^4}$$

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

allows large cross section with reasonable relic abundance

DARK MATTER



NB: $\text{rate} \sim \frac{\rho}{m_\chi}\sigma \sim \frac{m_\chi}{\alpha_d^2} \times \frac{\alpha_d \alpha'}{m_{A'}^4}$

HOW TO FIND A DARK PHOTON

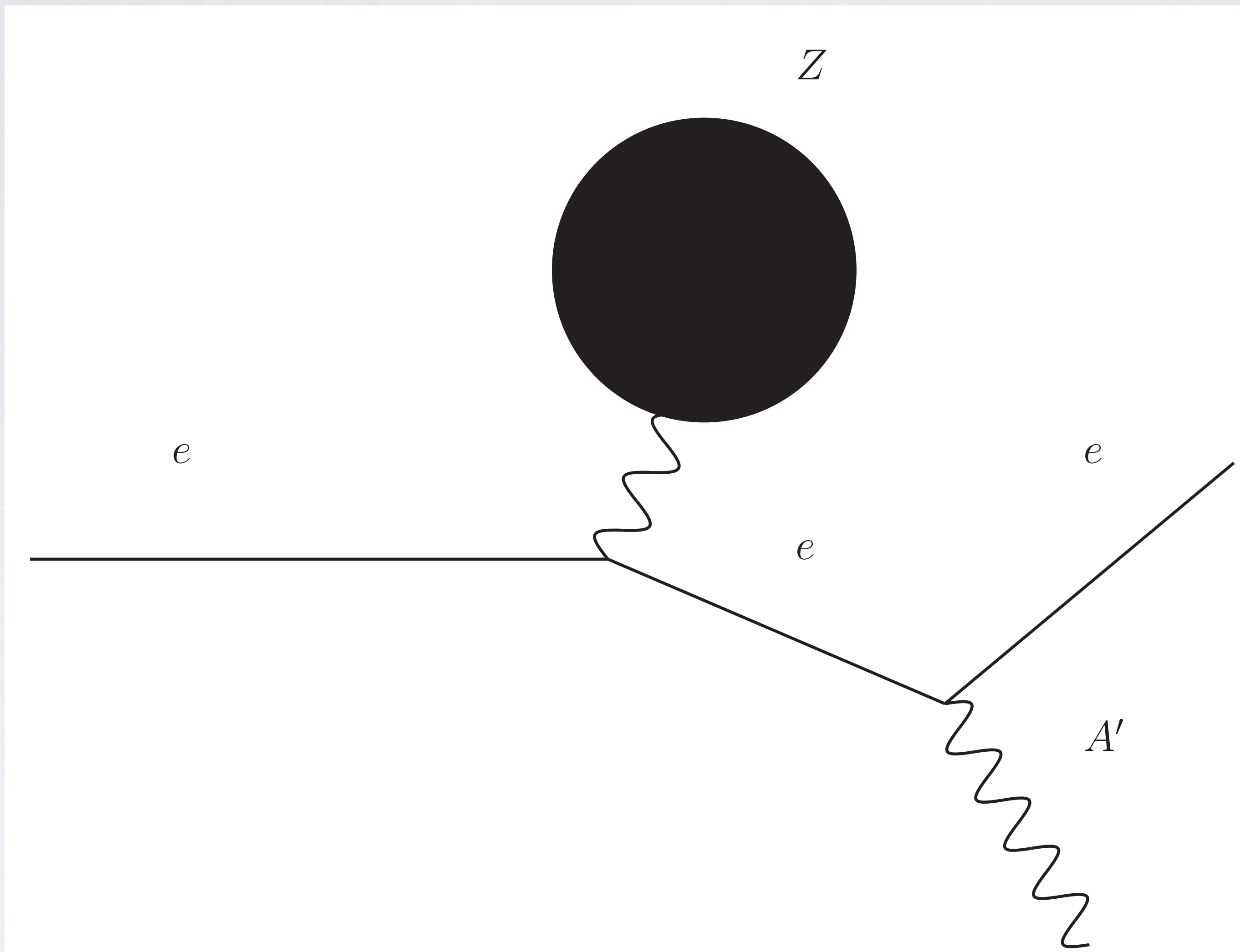
HOW TO FIND A DARK PHOTON

- Rare process
  - High luminosity
  - Extremely low backgrounds

HOW TO FIND A DARK PHOTON

- Rare process
  - High luminosity
  - Extremely low backgrounds
- LHC complementary as produceable in SUSY cascade decays
  - Cascades fairly unique to SUSY
  - Much harder to directly discover

HOW TO FIND A DARK PHOTON



Find A' via spectrometry, vertexing (A' decays), or "MET" (target recoil)

HOW TO FIND A DARK PHOTON

HOW TO FIND A DARK PHOTON

- Additional complications:

HOW TO FIND A DARK PHOTON

- Additional complications:
  - *decay modes*?

HOW TO FIND A DARK PHOTON

- Additional complications:
  - *decay modes*?
- Even when motivated by cosmic rays, don't know that strongest coupled A' decays to charged pairs

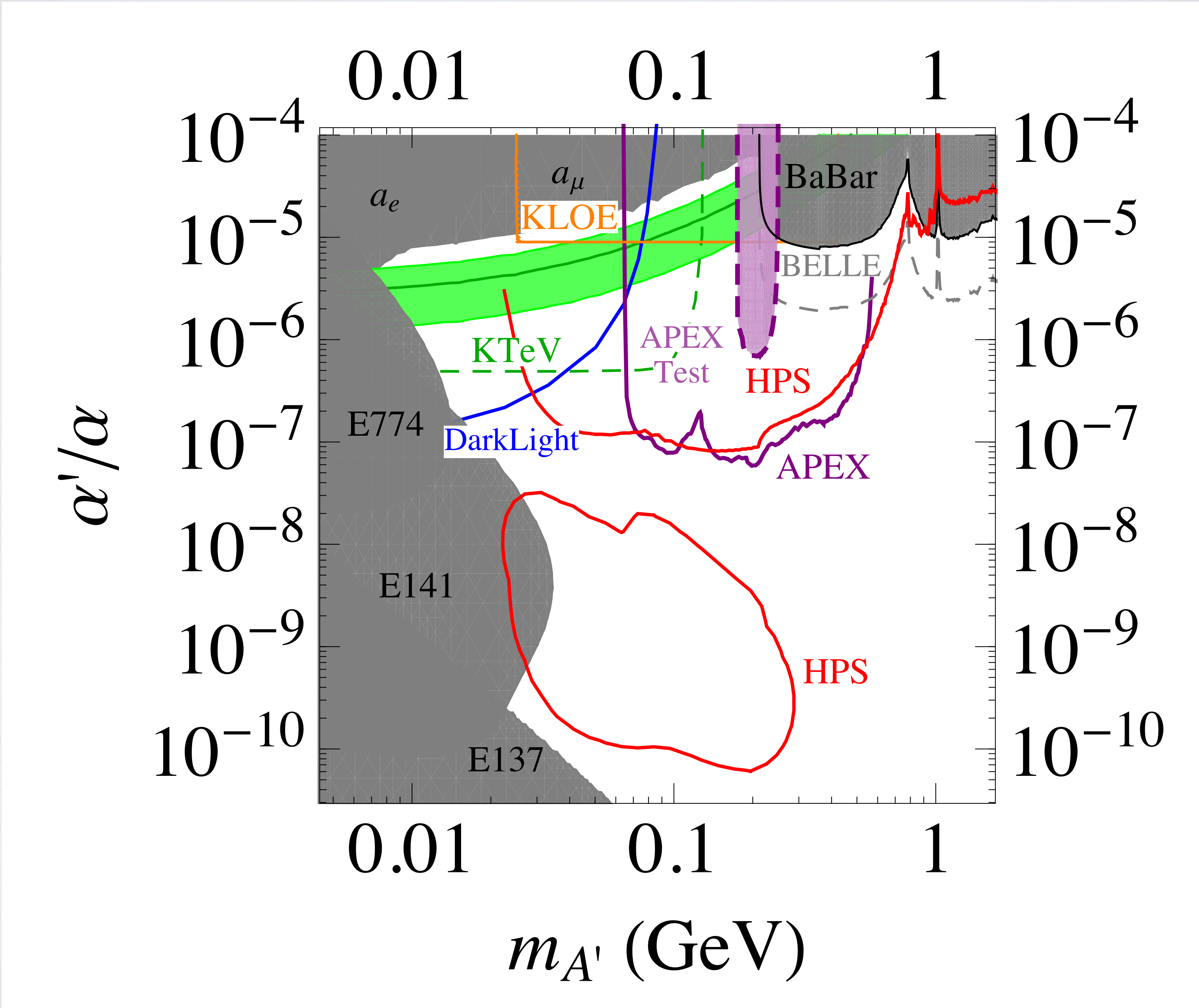
HOW TO FIND A DARK PHOTON

- Additional complications:
  - *decay modes*?
- Even when motivated by cosmic rays, don't know that strongest coupled A' decays to charged pairs
- Non-Abelian models can be very complicated

HOW TO FIND A DARK PHOTON

- Additional complications:
  - *decay modes*?
- Even when motivated by cosmic rays, don't know that strongest coupled A' decays to charged pairs
- Non-Abelian models can be very complicated
- Important to develop general approaches for the future

NEAR TERM REACH OF JLAB



WHAT WOULD HAPPEN IF IT WERE FOUND

- The discovery of the “Theory Space Landscape”
- immediate need for confirmation/redundancy

COPERNICUS 2011

COPERNICUS 2011

- Jefferson Lab has the opportunity to be the LHC of weakly coupled physics

COPERNICUS 2011

- Jefferson Lab has the opportunity to be the LHC of weakly coupled physics
- Accessible parameter space is motivated, but not converse

COPERNICUS 2011

- Jefferson Lab has the opportunity to be the LHC of weakly coupled physics
- Accessible parameter space is motivated, but not converse
- Need redundant experiments - multiple decay modes

COPERNICUS 2011

- Jefferson Lab has the opportunity to be the LHC of weakly coupled physics
- Accessible parameter space is motivated, but not converse
- Need redundant experiments - multiple decay modes
- This is only the beginning: need development of future techniques

COPERNICUS 2011

- Jefferson Lab has the opportunity to be the LHC of weakly coupled physics
- Accessible parameter space is motivated, but not converse
- Need redundant experiments - multiple decay modes
- This is only the beginning: need development of future techniques
- Potential impact - while speculative - to rival LHC