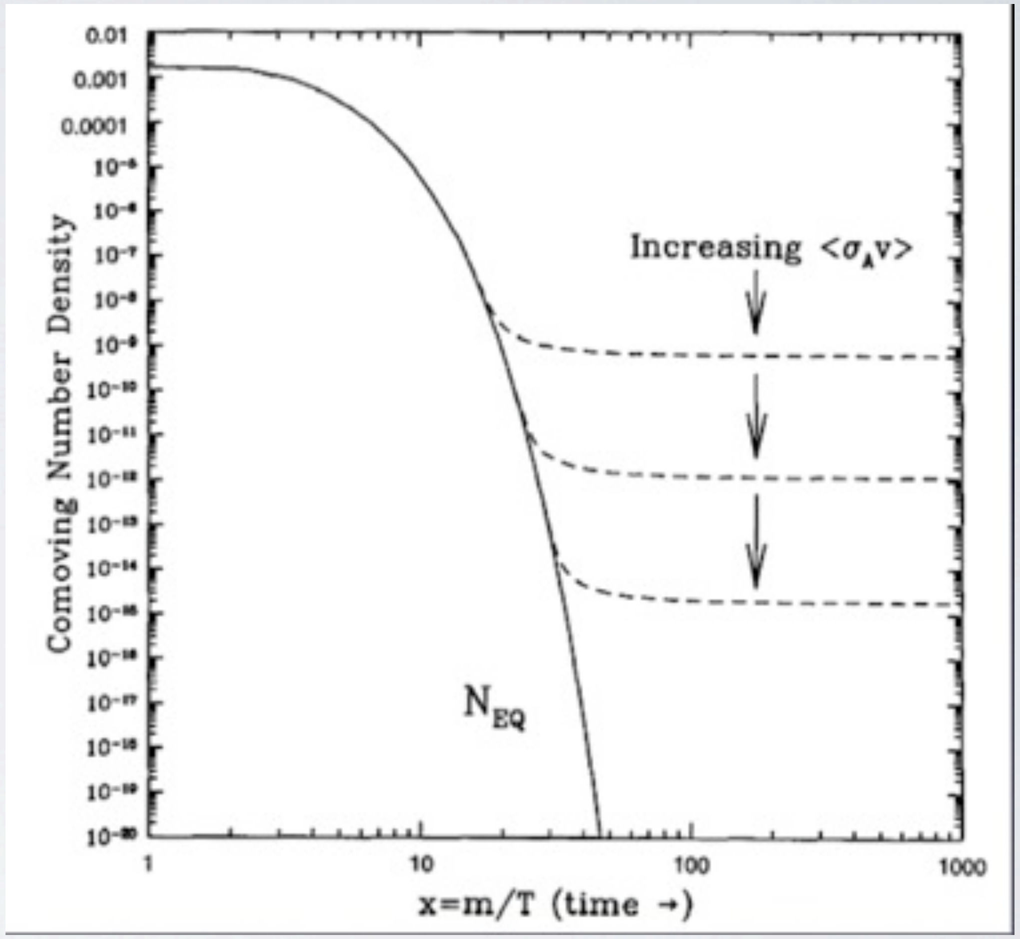
The WIMP "Miracle"

assume thermal equilibrium

When T<< MWIMP, number density falls as e-M/T



We want to know

$\rho_{now} = m\, n_{now}$

$\frac{n_\chi}{n_\gamma} \sim \text{constant}$

$\Longrightarrow$ calculate $\frac{n_\chi}{n_\gamma}$ at freezeout

$n \sigma v = H \sim T^2 / M_{pl}$

$n_\chi \sim e^{-m/T}$

$\hookrightarrow T << \infty$

$T \sim m$

$$\Longrightarrow n_\chi^f \sim \frac{T^2}{\langle \sigma v \rangle M_{pl}}$$

$$\frac{n_\chi^f}{n_\gamma^f} \sim \frac{1}{\langle \sigma v \rangle T M_{pl}} \sim \frac{1}{\langle \sigma v \rangle m_\chi M_{pl}}$$

We want to know

$$\rho_{now} = m\, n_{now}$$

$$\frac{n_\chi^f}{n_\gamma^f} \sim \frac{1}{\langle\sigma v\rangle T M_{pl}} \sim \frac{1}{\langle\sigma v\rangle m_\chi M_{pl}}$$

$$\frac{n_\chi^{now}}{n_\gamma^{now}} \sim \frac{n_\chi^f}{n_\gamma^f} \sim \frac{1}{\langle\sigma v\rangle m_\chi M_{pl}}$$

$$\Rightarrow n_\chi^{now} \sim \frac{n_\gamma^{now}}{\langle\sigma v\rangle m_\chi M_{pl}} \sim \frac{T_\gamma^3}{\langle\sigma v\rangle m_\chi M_{pl}}$$

$$\rho_\chi^{now} = m_\chi n_\chi^{now} \sim \frac{T_\gamma^3}{\langle\sigma v\rangle M_{pl}}$$

depends only on $\langle\sigma v\rangle$!

The WIMP not-miracle

$$\Omega h^2 \approx 0.1 \times \left(\frac{3 \times 10^{-26} cm^3 s^{-1}}{\langle \sigma v \rangle} \right)$$

$$\approx 0.1 \times \left(\frac{\alpha^2/(200\mathrm{GeV})^2}{\langle \sigma v \rangle} \right)$$

- Any weak- scale particle naturally freezes out within a few orders of magnitude of the correct cross section!

The WIMP miracle

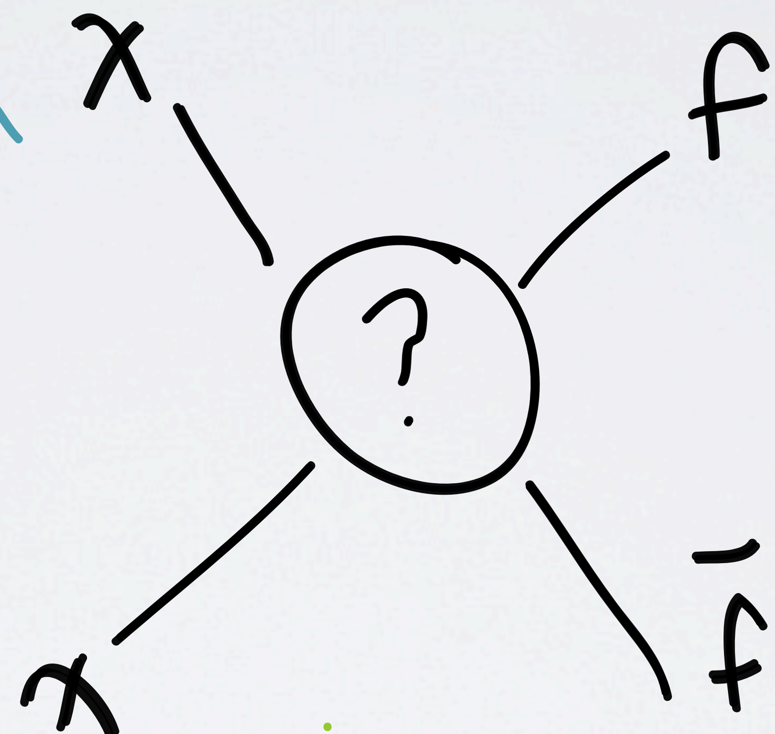
- So what good is this?

Tevatron, LHC, colliders

time

Direct Detection

DAMA, CoGeNT, XENON, CDMS, LUX, COUPP, PICASSO, SIMPLE, EDELWEISS, CRESST, KIMS, XMASS, ROSEBUD, NAIAD, ANAIS ...



time

INDIRECT detection

PAMELA, ATIC, Fermi, WMAP, PEBS, HESS, VERITAS, ...

OUTLINE

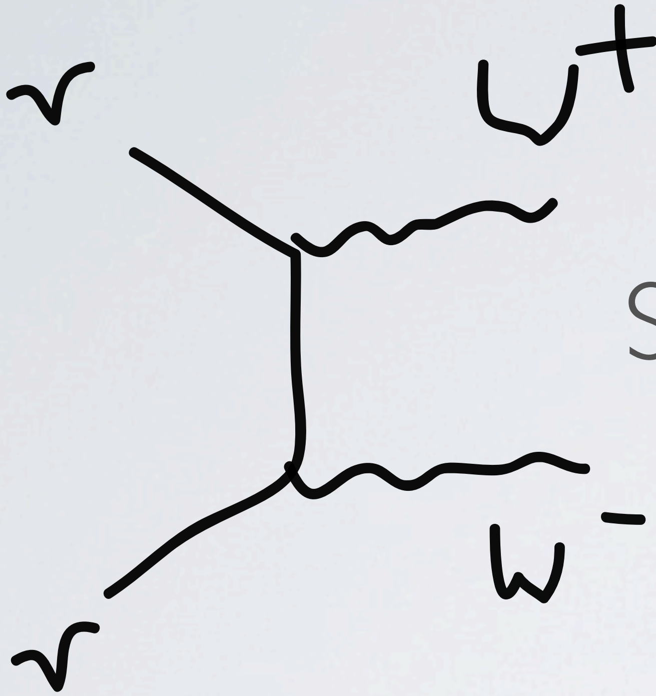
- The “neutralino” (whatever that is)
- The canonical WIMP: (2 ±1/2) Dirac fermion
  - (aka the “Higgsino” or 4th gen neutrino)
- Signals of thermal dark matter
  - direct detection
  - indirect detection
  - colliders

YOUR CANONICAL WIMP

- 4th generation Dirac neutrino is completely ruled out as a WIMP candidate*
- This makes it a very handy study

* unless you tweak some things

the Dirac neutrino



$$(\mathbf{2}, \pm\mathbf{1/2})$$

SU(2) U(1)

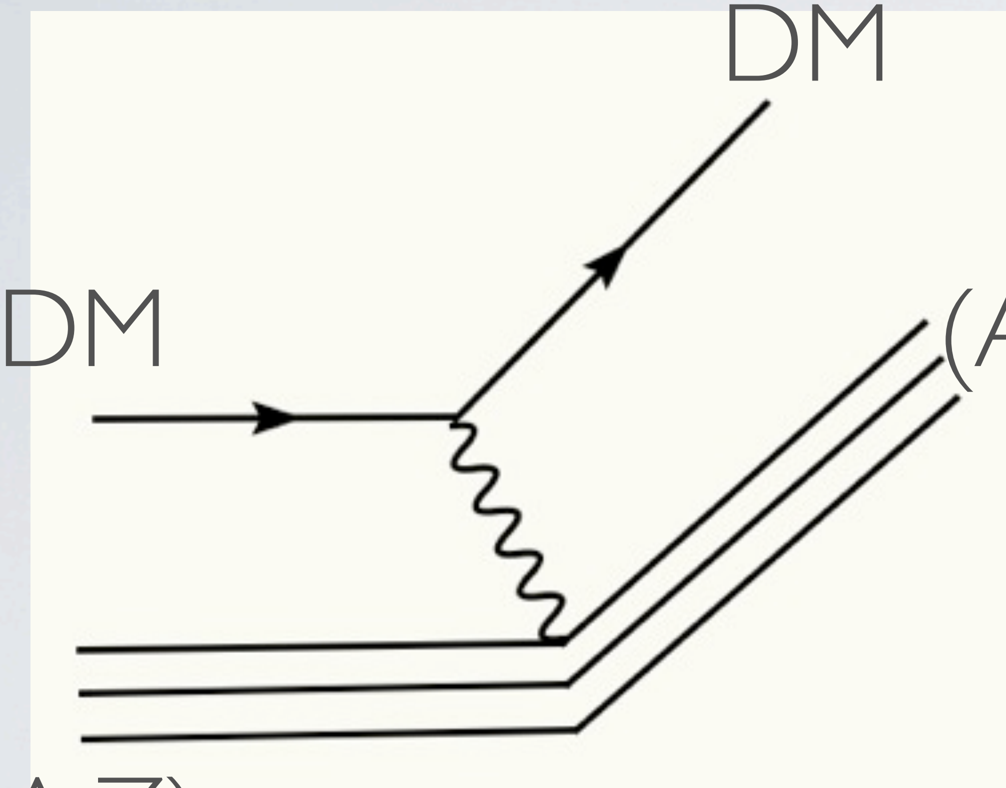
has same charges as Higgs left-handed lepton; "Higgsino"

$$\sigma v = \frac{g^4}{512\pi m_\nu^2}\left(21+3t_w^2+11t_w^4\right)$$

$$\Omega h^2 \simeq 0.1 \times \left(\frac{m_\nu}{\mathrm{TeV}}\right)^2$$

note: in reality weak scale particles are under-abundant. Want TeV or some suppression in cross section

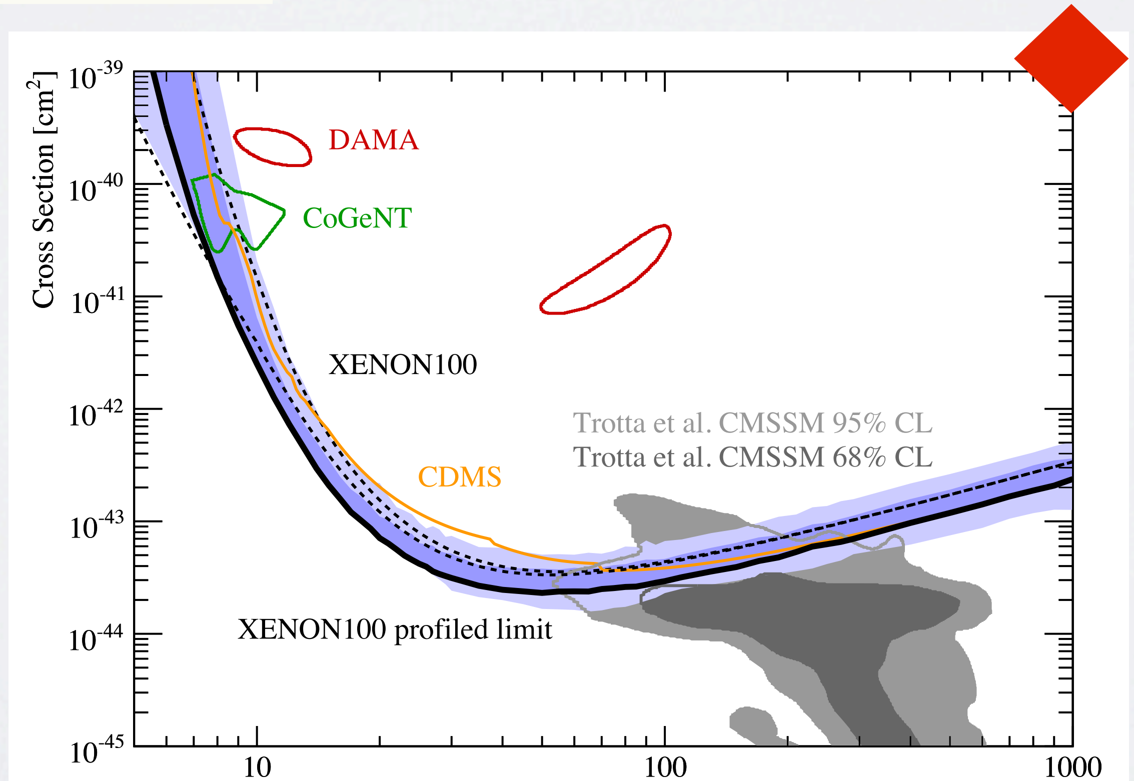
Direct detection



$$\sigma = \frac{G_f^2}{2\pi}\mu_{\chi N}((1-4s_W^2)Z-(A-Z))^2$$

$$\sigma_n = \frac{G_f^2}{2\pi}\mu_{\chi n}\frac{((1-4s_W^2)Z-(A-Z))^2}{A^2}$$

$$\sigma_n \approx 10^{-39}\mathrm{cm}^2$$



the neutralino

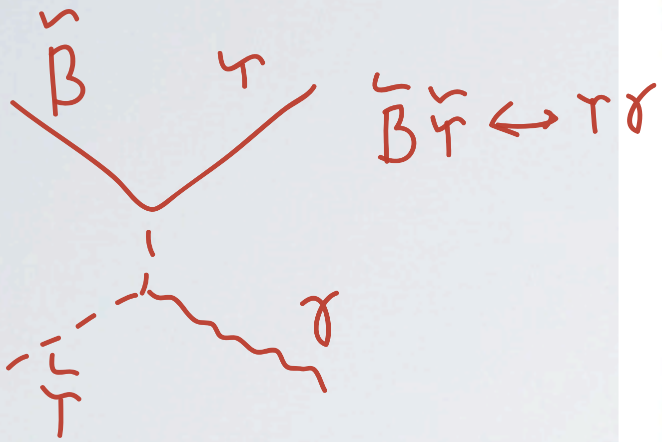
big $M_{1,2}$=> Higgsino-like

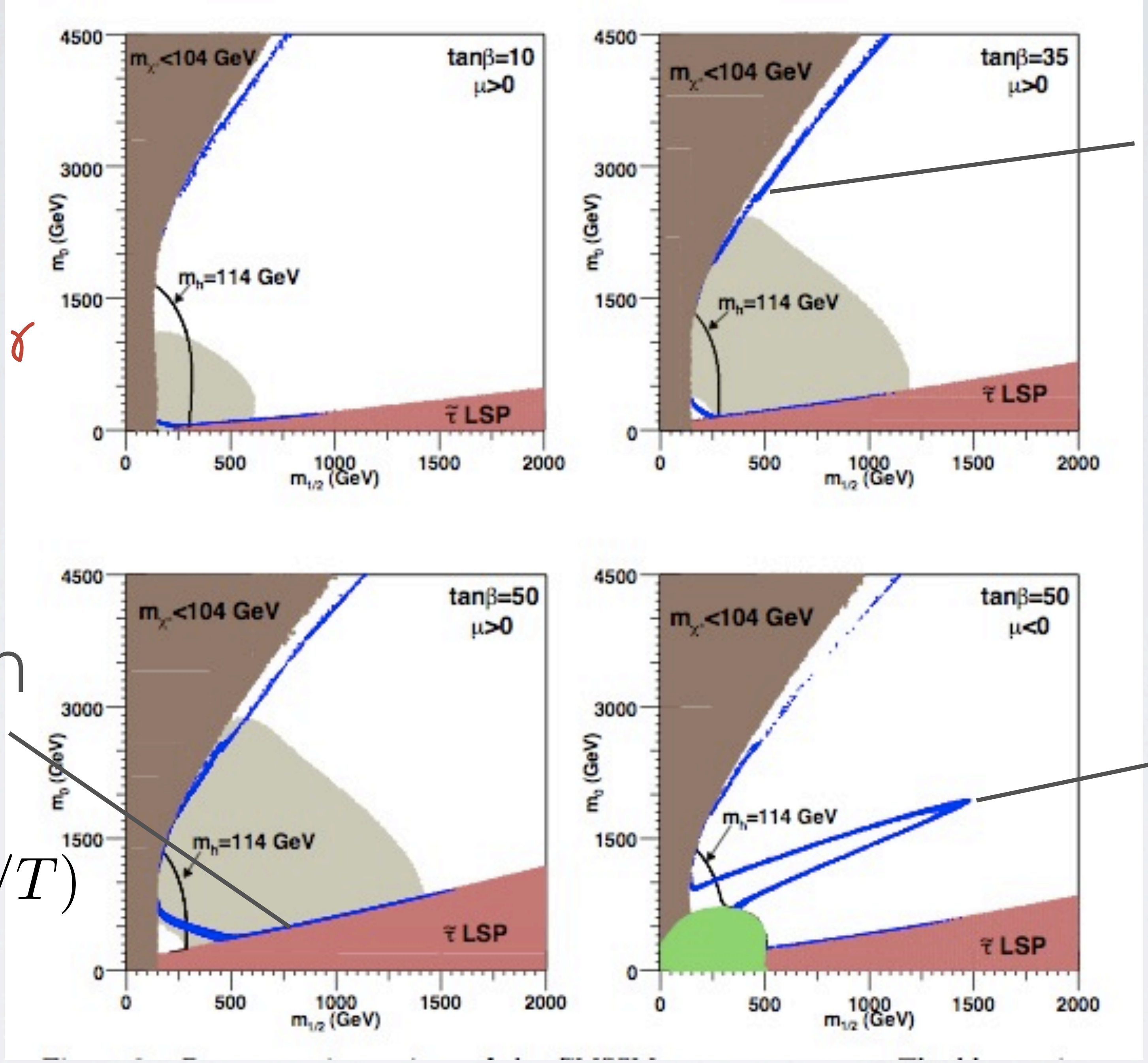
$$
\begin{array}{c}
B \\ W \\ Hu \\ Hd
\end{array}
\begin{pmatrix}
M_1 & 0 & -m_Z \cos\beta \sin\theta_W & m_Z \sin\beta \sin\theta_W \\
0 & M_2 & m_Z \cos\beta \cos\theta_W & -m_Z \sin\beta \cos\theta_W \\
-m_Z \cos\beta \sin\theta_W & m_Z \cos\beta \cos\theta_W & 0 & -\mu \\
m_Z \sin\beta \sin\theta_W & -m_Z \sin\beta \cos\theta_W & -\mu & 0
\end{pmatrix}
$$

big mu=> gaugino-like

$$\chi_{0,1,2,3} = \sum_{i=\tilde{B},\tilde{W}_3,\tilde{H}_u,\tilde{H}_d} U_{ij} f_i$$

mSUGRA





focus point

A funnel

coannihilation tail

$$\frac{n_{\tilde{\tau}}}{n_{\tilde{B}}} \sim \exp(-\Delta M/T)$$

need near-degenerarcy

NB: Over much of parameter space, the neutralino defies “WIMP” intuition

Be wary of correlations in CMSSM

- Common logical path in mSUGRA*

LEP Higgs mass limit m_h>114.4 GeV → SUSY predicts m_h<m_Z

↓

Need large radiative corrections to quartic to keep v=246 GeV

→ Large radiative corrections give contribution to Higgs mass

↓

Cancel those corrections with large μ term

→ μ term is Higgsino mass

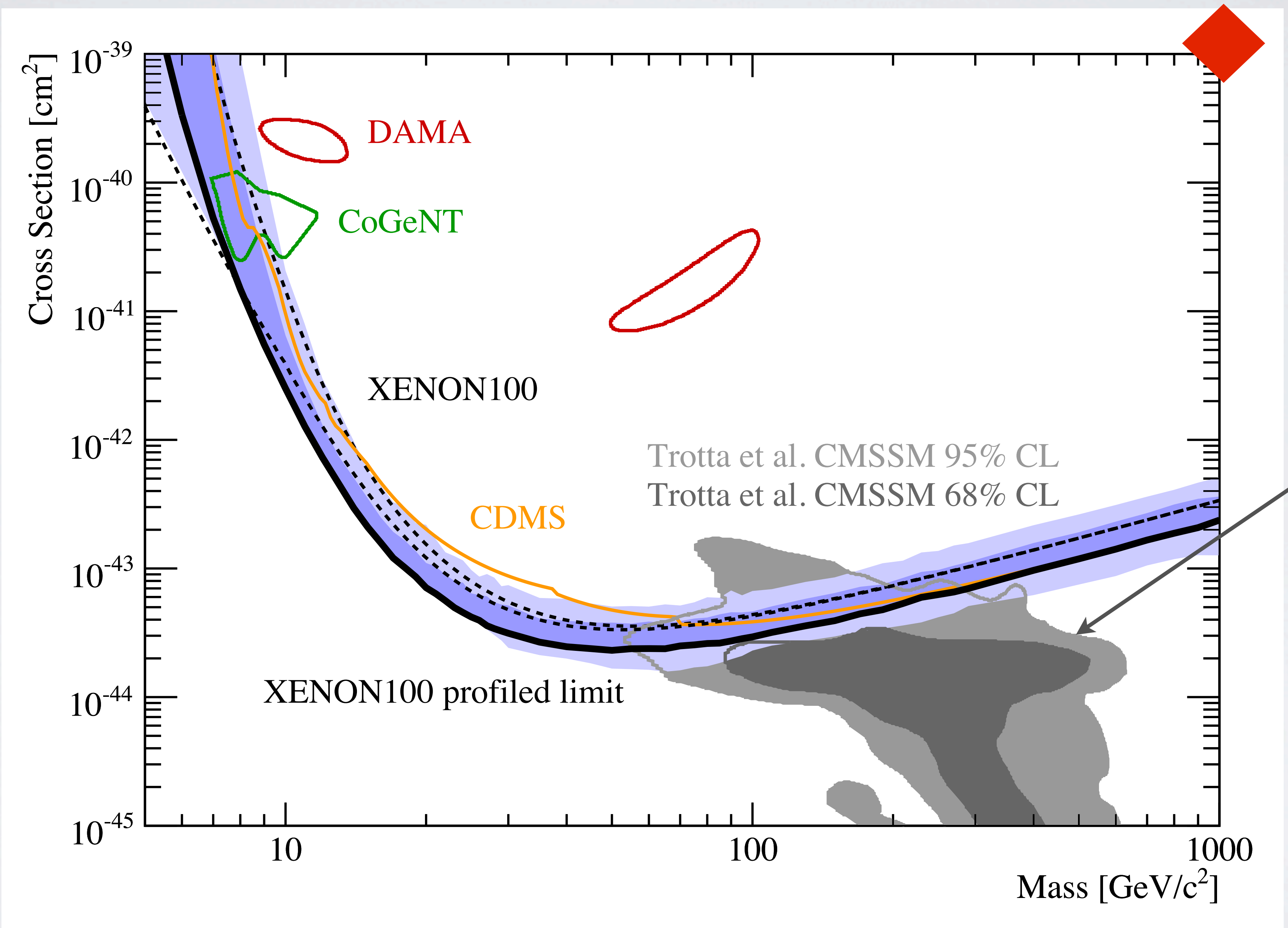
→ LSP is mostly Bino

→ Small elastic scattering cross sections

* No, not every point in mSUGRA, this is just an example,
NU models (non-unified) have different Higgs soft masses

the Dirac neutrino vs Higgsino

Wait! I thought the Dirac neutrino was like a Higgsino?



why is cross section so small?

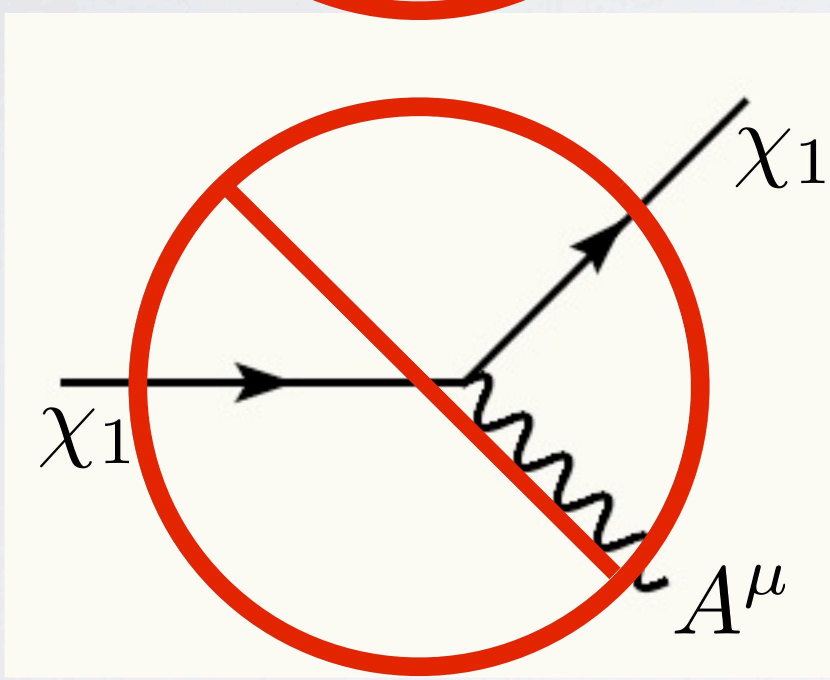
Is it just that the neutralino is only a little bit Higgsino?

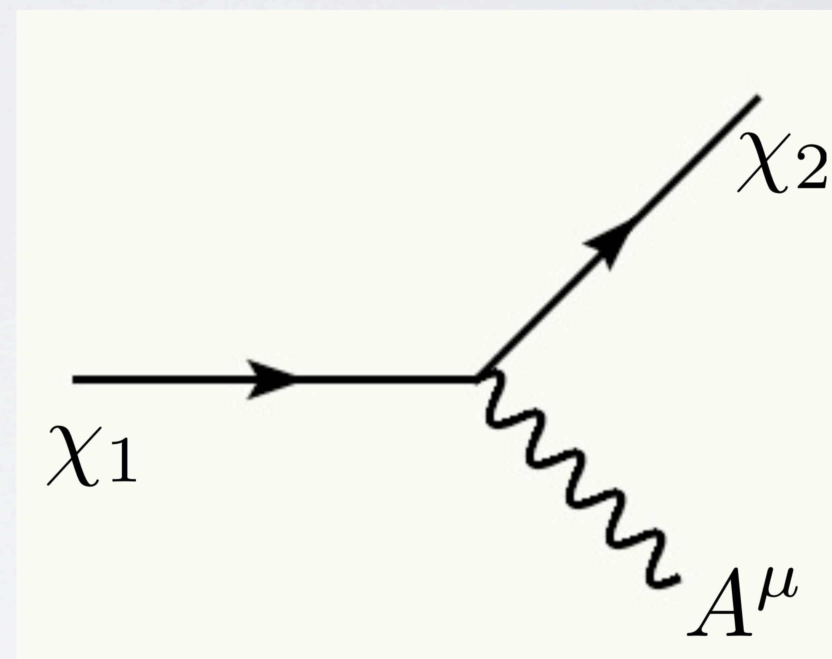
No! (I mean, it often is, but that's not what explains this)

Consider vector interaction

$\cancel{\chi_1 \sigma_\mu \chi_1 A^\mu}$

$\chi_1 \sigma_\mu \chi_2 A^\mu$



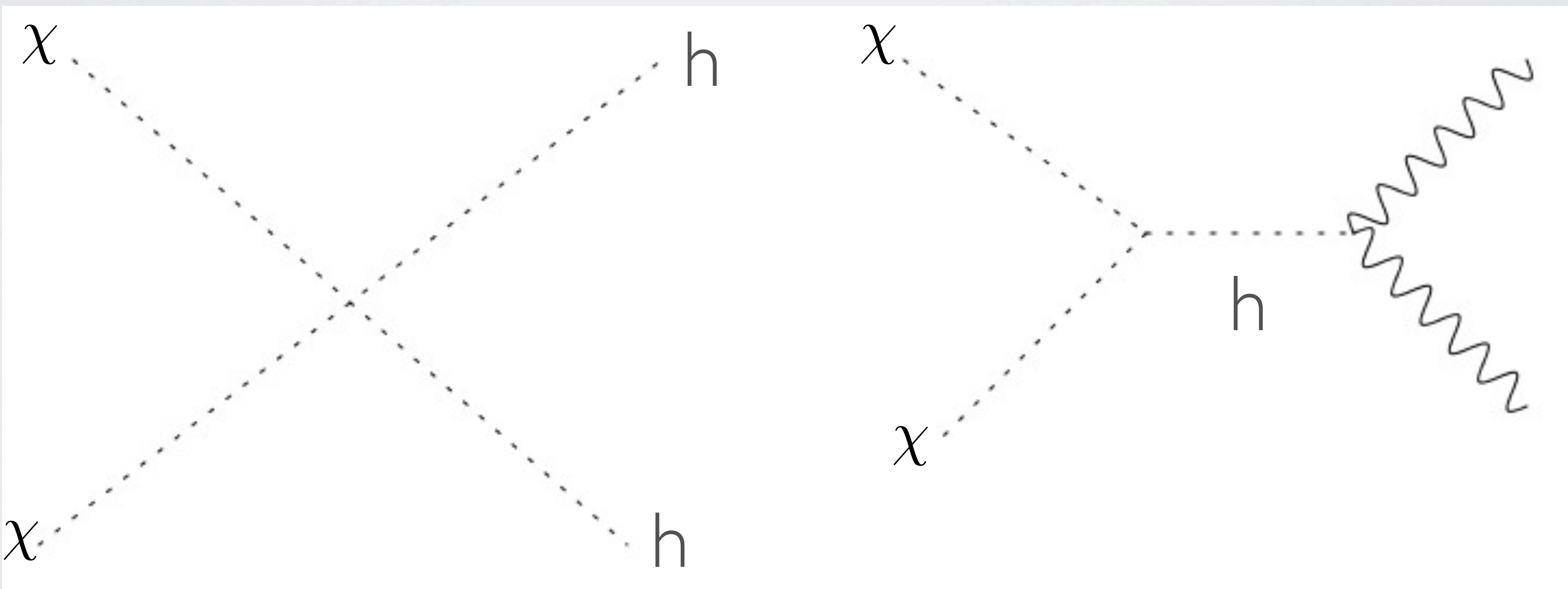


Vector interactions for massive Majorana fermions (or real scalars) always require multiple states interaction is off-diagonal (inter-neutralino scattering)

A "MINIMAL MODEL" OF DARK MATTER

Burgess, Pospelov, ter Veldhuis, '01

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



A "MINIMAL MODEL" OF DARK MATTER

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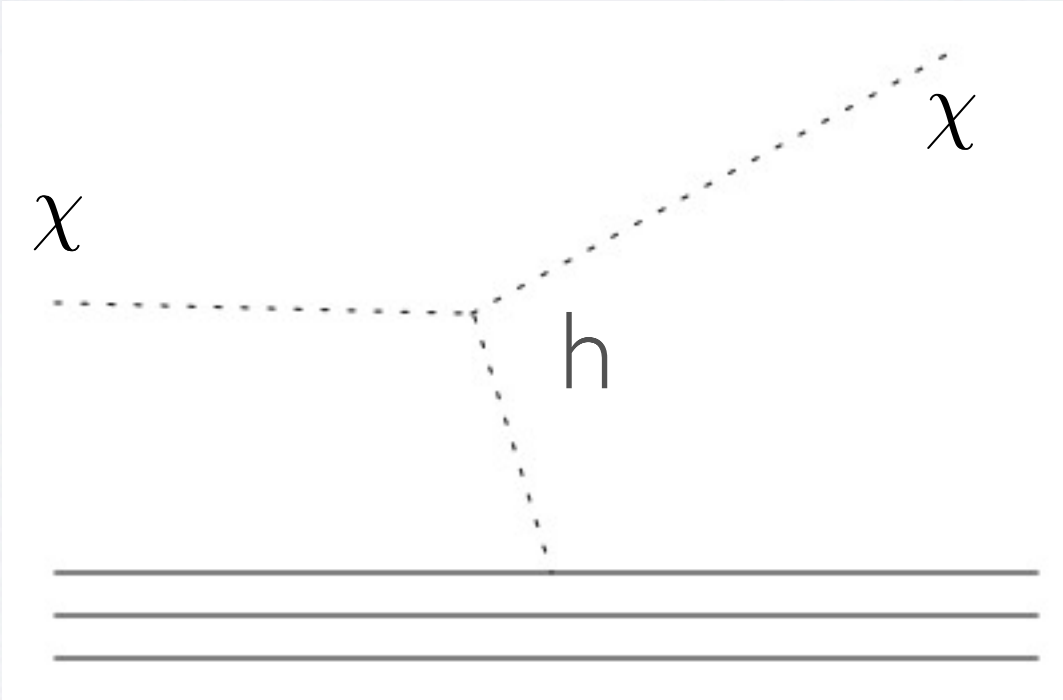
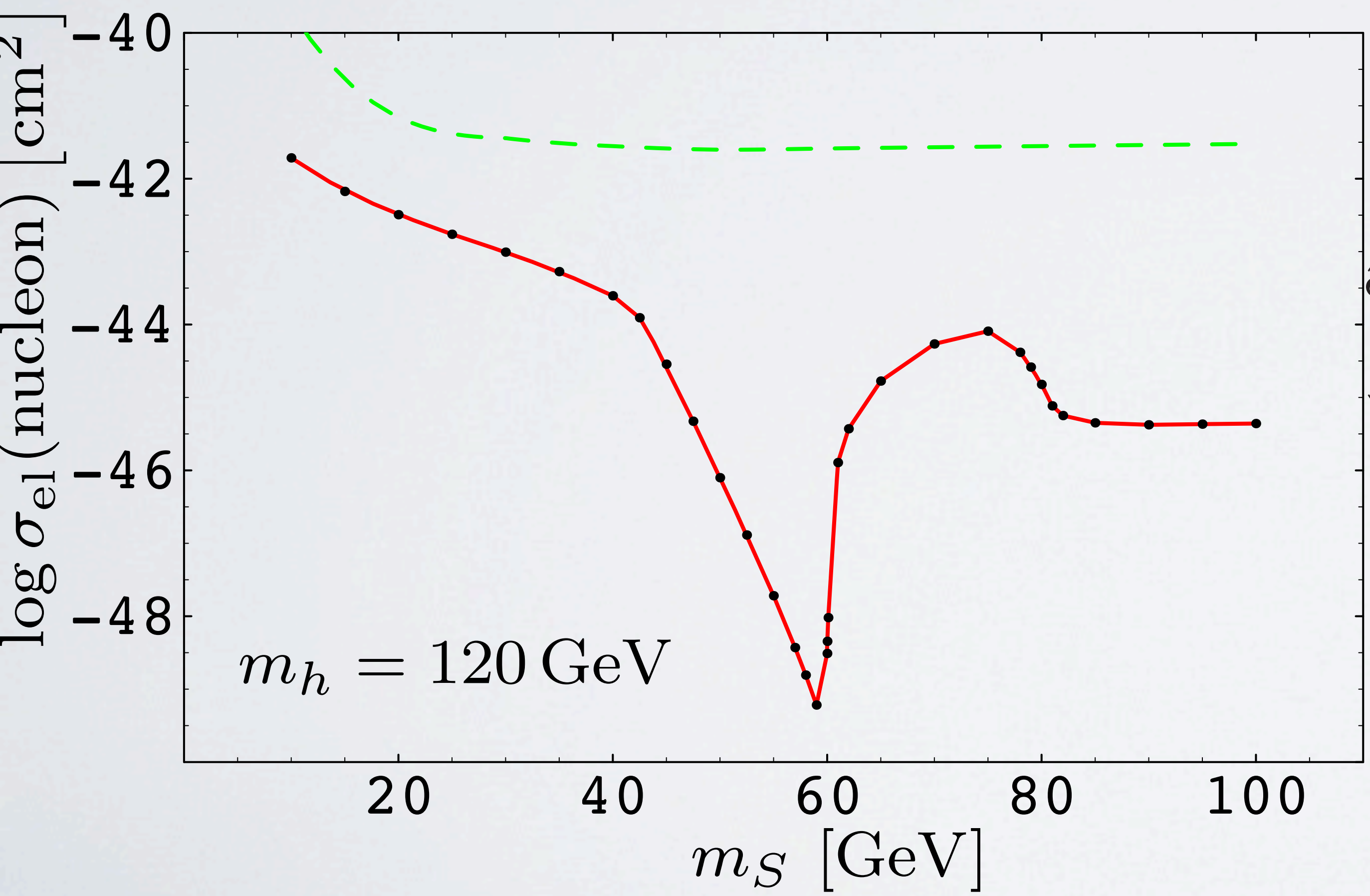
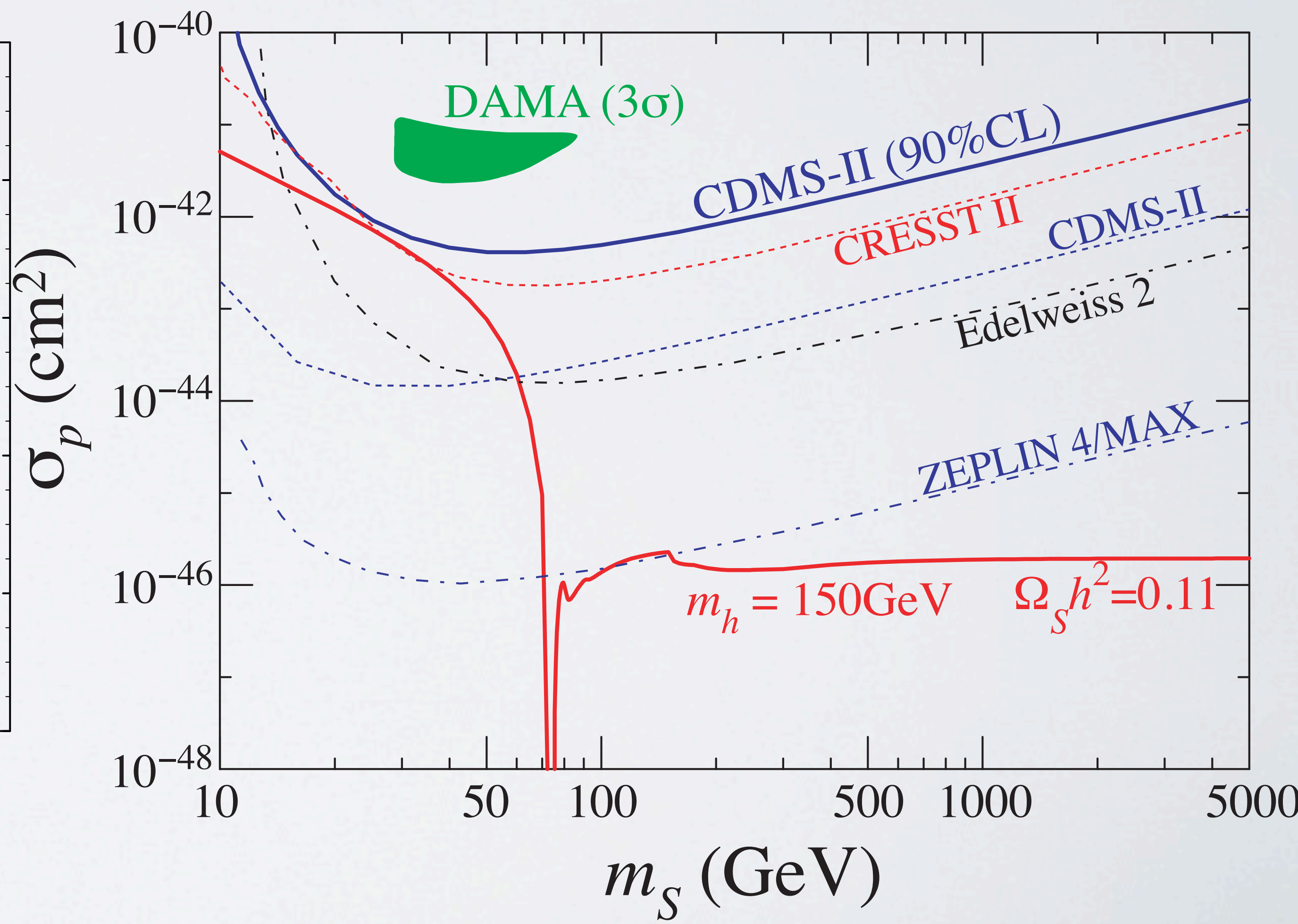


A "MINIMAL MODEL" OF DARK MATTER

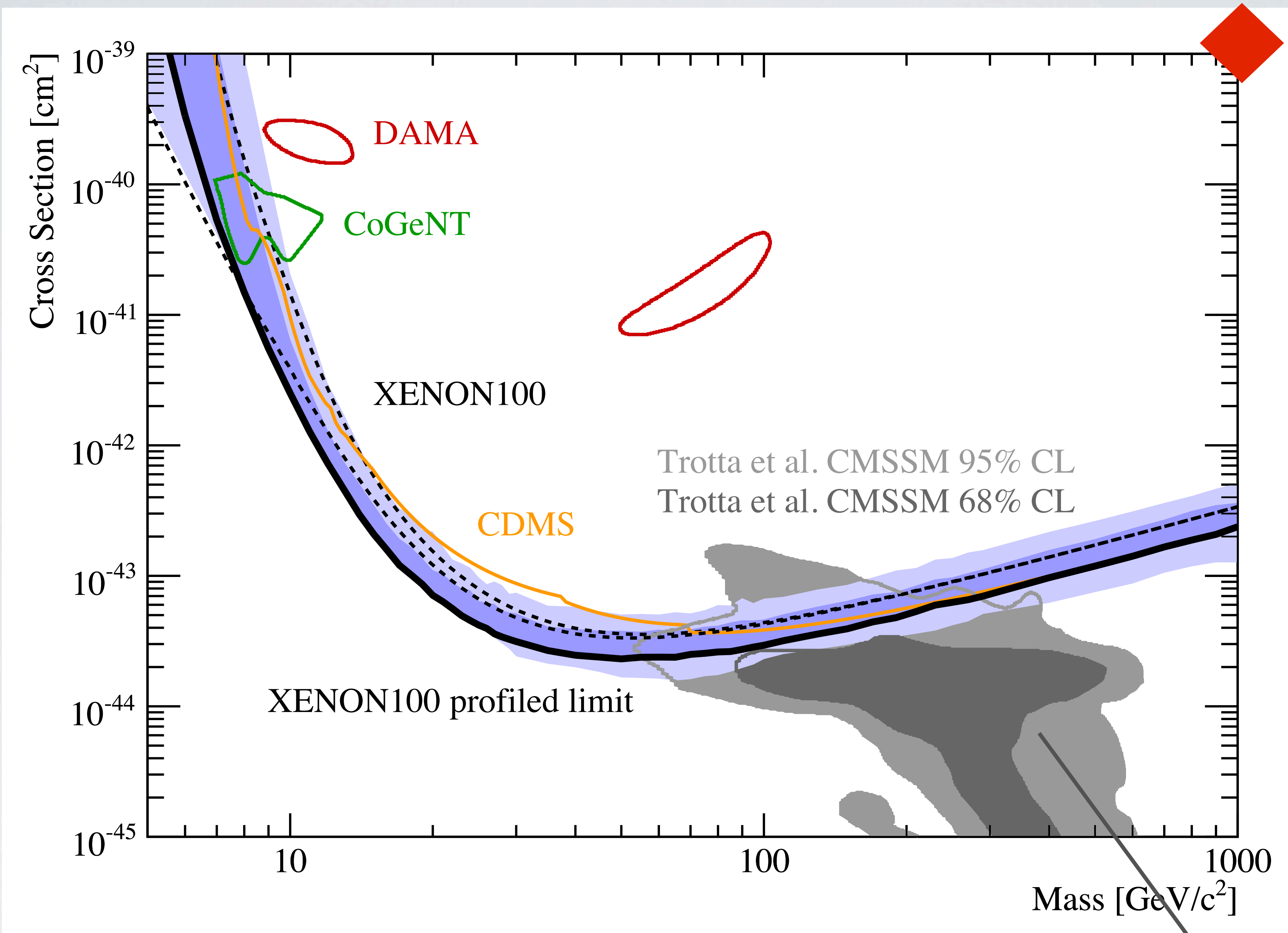
Burgess, Pospelov, ter Veldhuis, '01;
Davoudiasl, Kitano, Li, Murayama '04

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



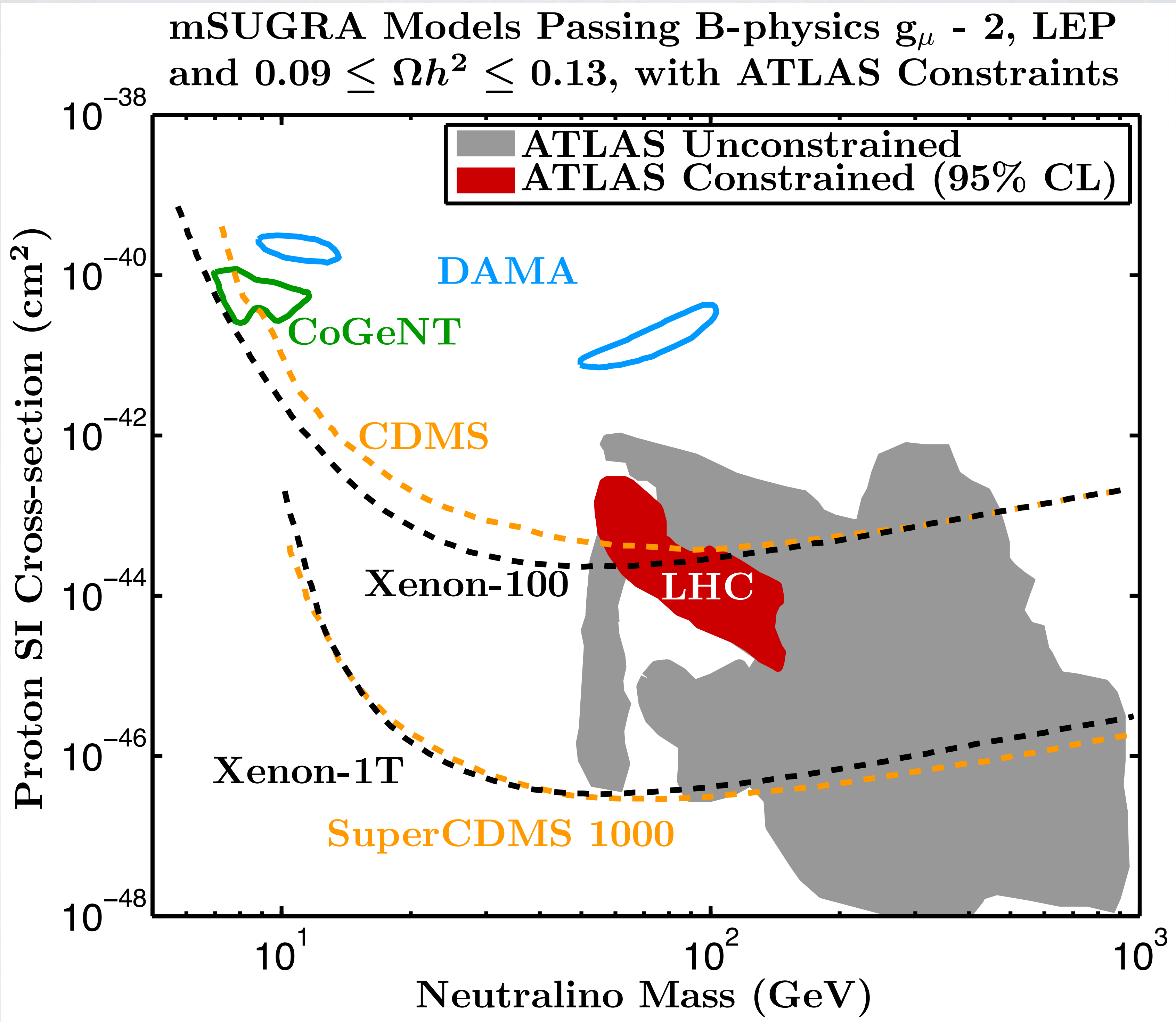


Davoudiasl, Kitano, Li, Murayama '04



much of this scattering is mediated by Higgs
not by Z boson

THE LHC BEGINS TO PROBE...



direct detection

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

nuclear physics

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

particle physics **astrophysics**

PP: Type of interaction, mediator

NP: Form factor - when de Broglie wavelength of interaction is comparable to nuclear size - resolve that it is not a point particle

~~spin independent~~ "nuclear charge" scattering

nuclear physics

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

particle physics **astrophysics**

PP: Type of interaction, mediator

NP: Form factor - when de Broglie wavelength of interaction is comparable to nuclear size - resolve that it is not a point particle ($q^2 \sim 2 M_N E_R$ => $E_R \sim 100$ keV) (Duda, Gondolo+Kemper 0608035)

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

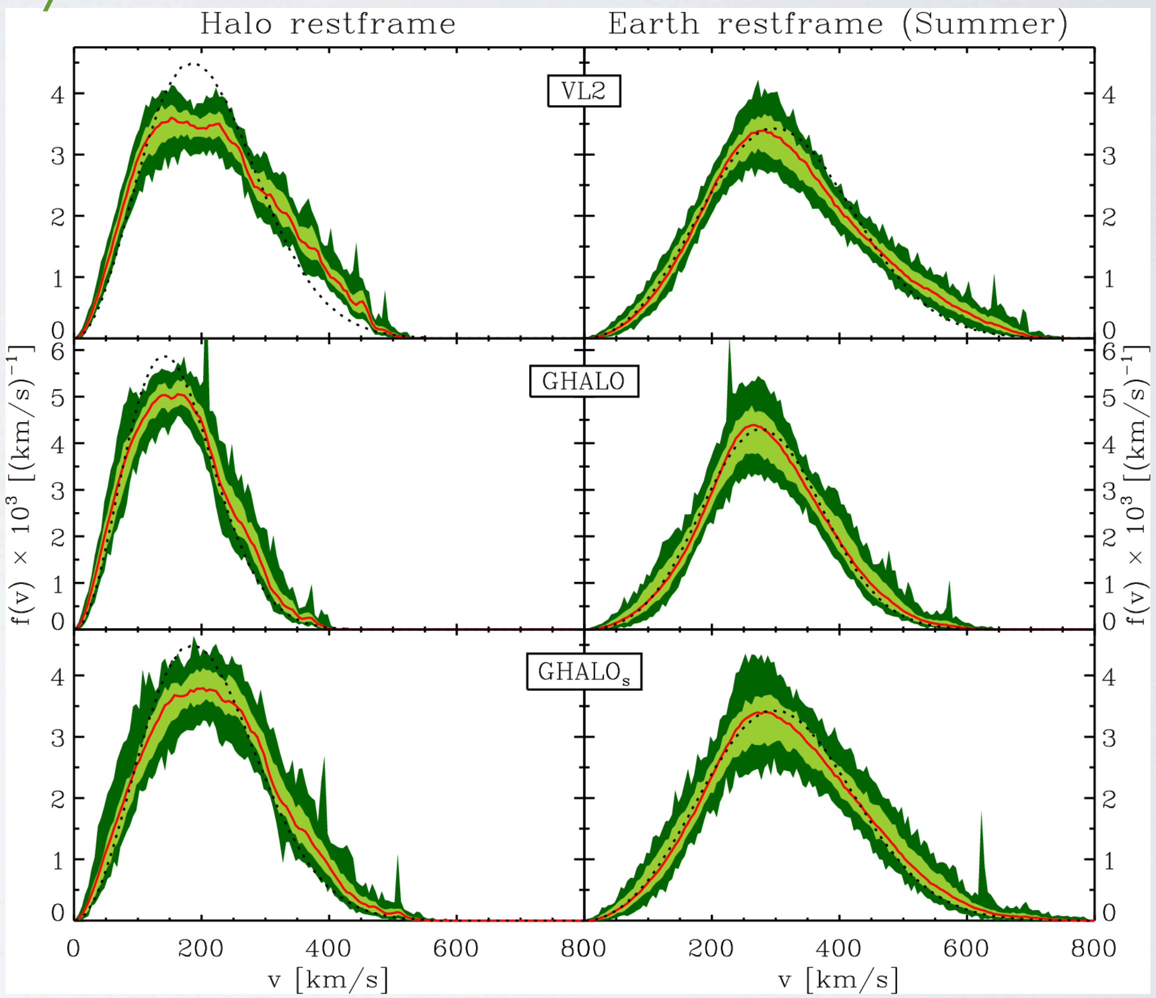
$$\frac{dR}{dE_R} = N_T M_N \frac{\rho_\chi \sigma_n}{2m_\chi \mu_{ne}^2} \frac{(f_p Z + f_n(A-Z))^2}{f_n^2} F^2[E_R] \int_{\beta_{min}}^{\infty} \frac{f(v)}{v} dv.$$

f(v) is the *speed* distribution of WIMPs

pseudo-Maxwellian, characterized by
v_0 (velocity dispersion)
v_{esc} (escape velocity)

Many errors in the literature!

Good reference: Freese, Gondolo, Savage 0607121

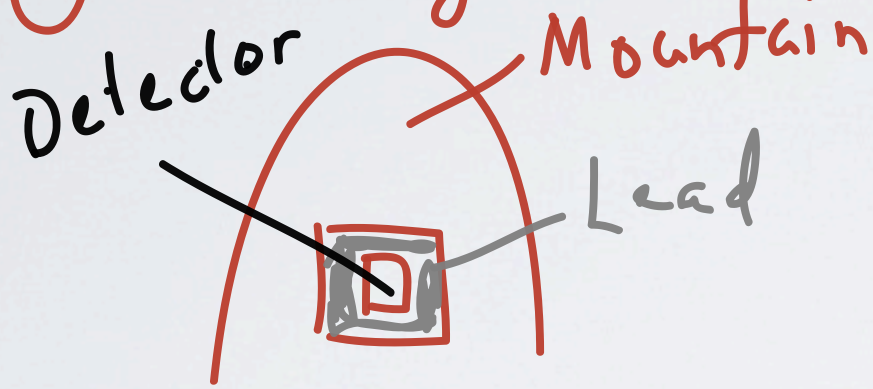


direct detection

σ, not σ_0

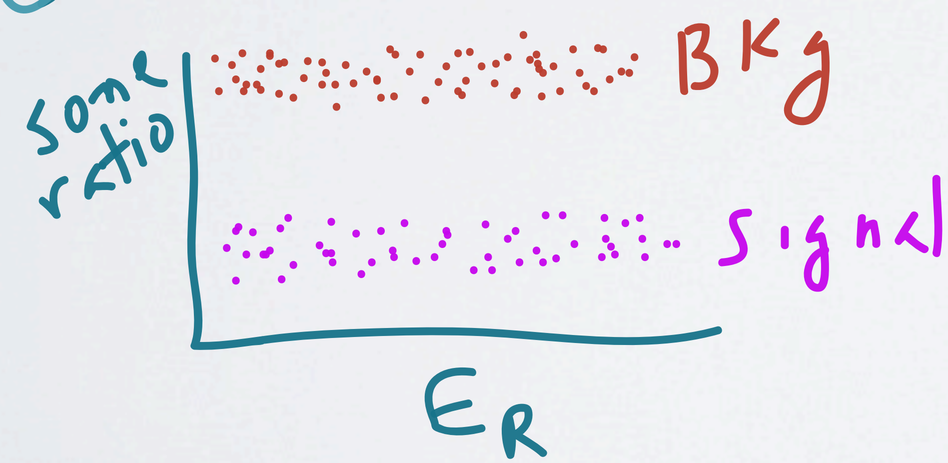
$$\text{rate} \approx \frac{\text{few events}}{\text{kg}\cdot\text{year}} \times \frac{\sigma}{10^{-36}\,\text{cm}^2} \times \frac{v}{300\,\text{km/s}}$$

① Shielding

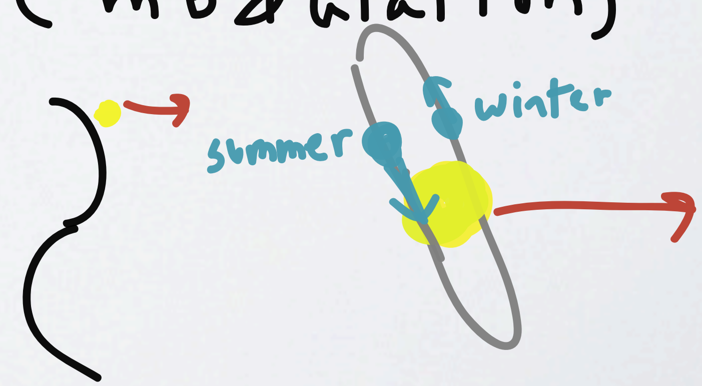


② Self-shielding/ fiducialization

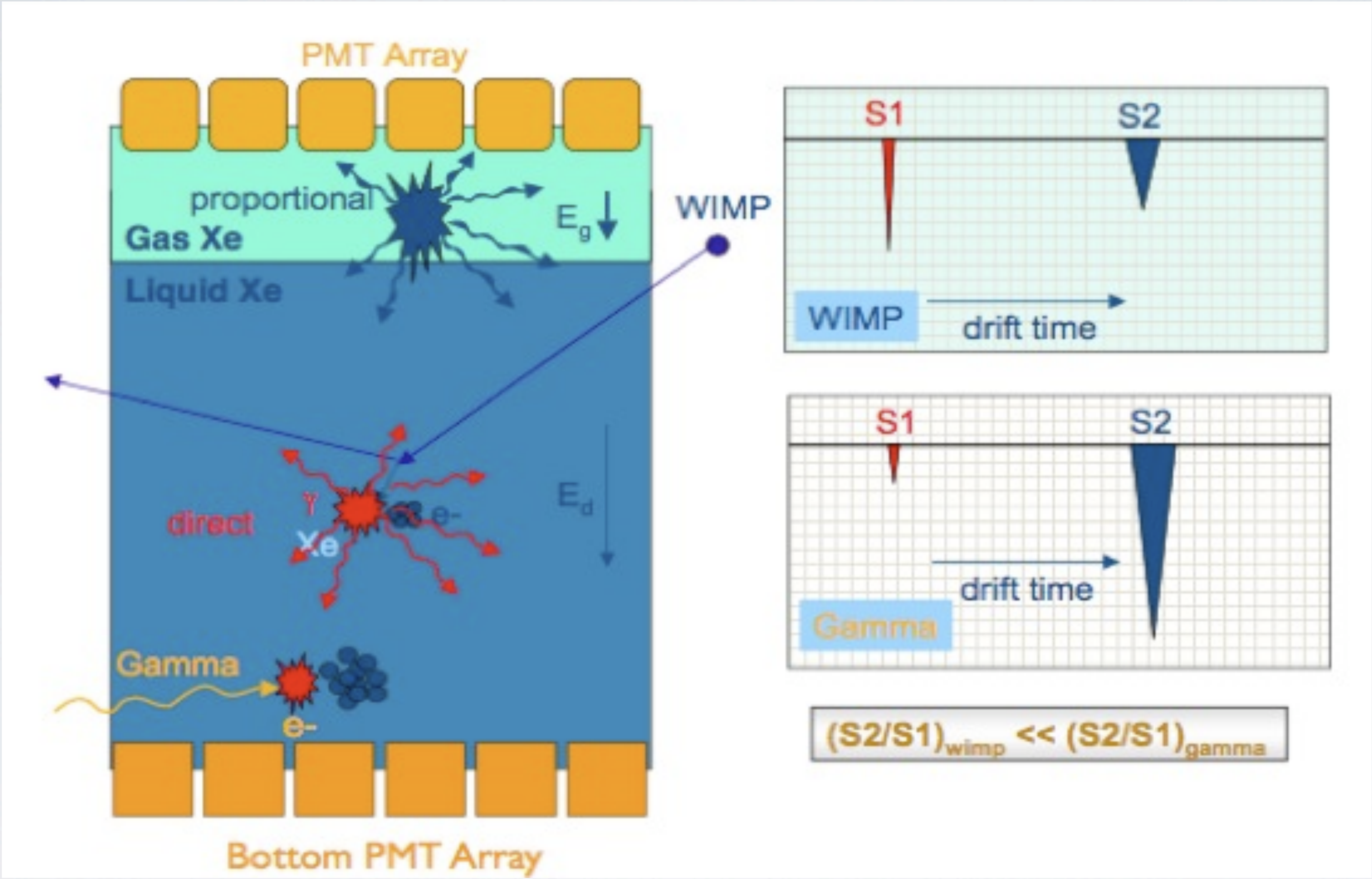
③ Discrimination



④ Other features (modulation)

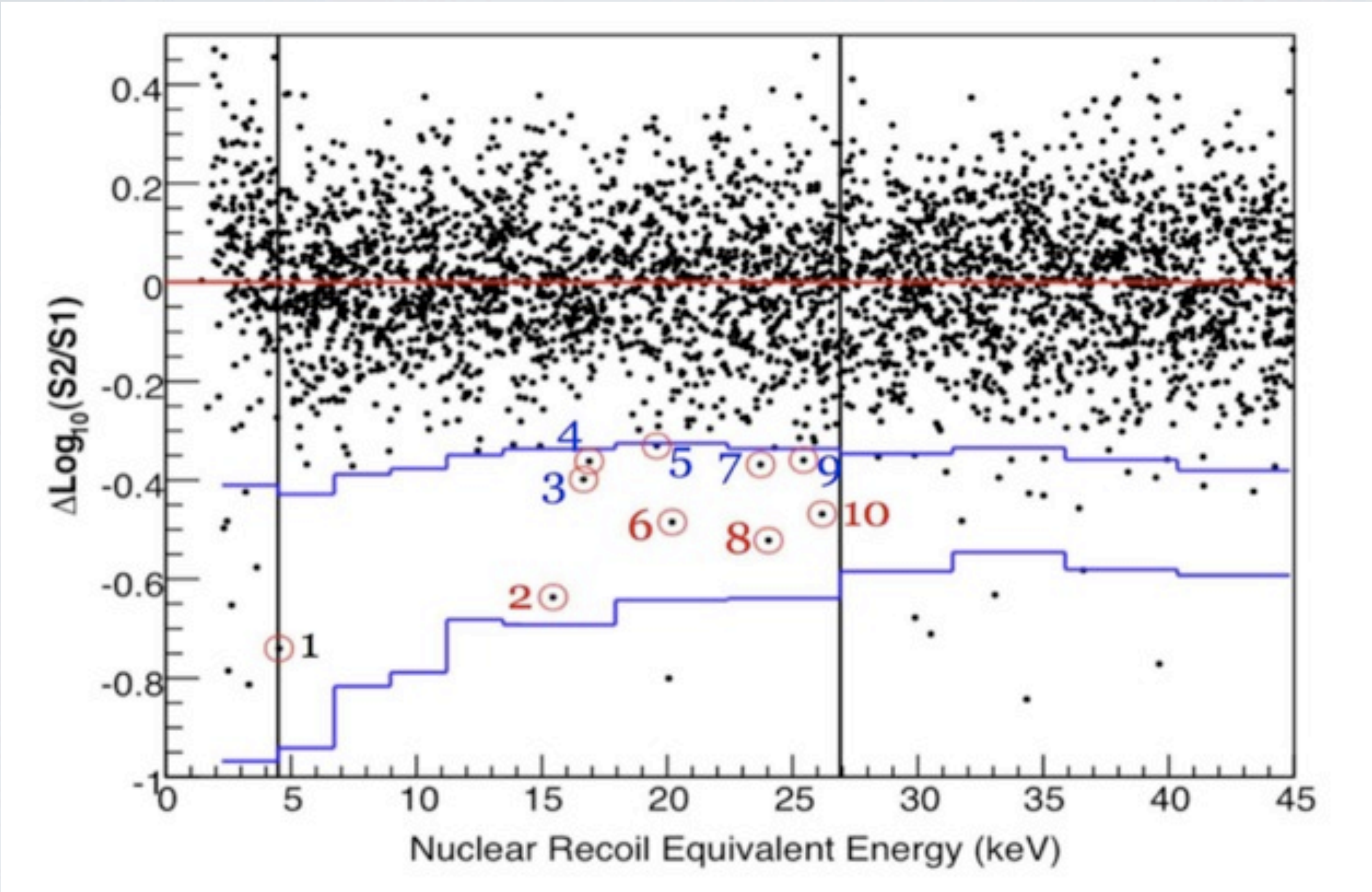


XENON



- Distinguish events by ratio of scintillation light compared with ionization (bowling ball vs ping pong ball)

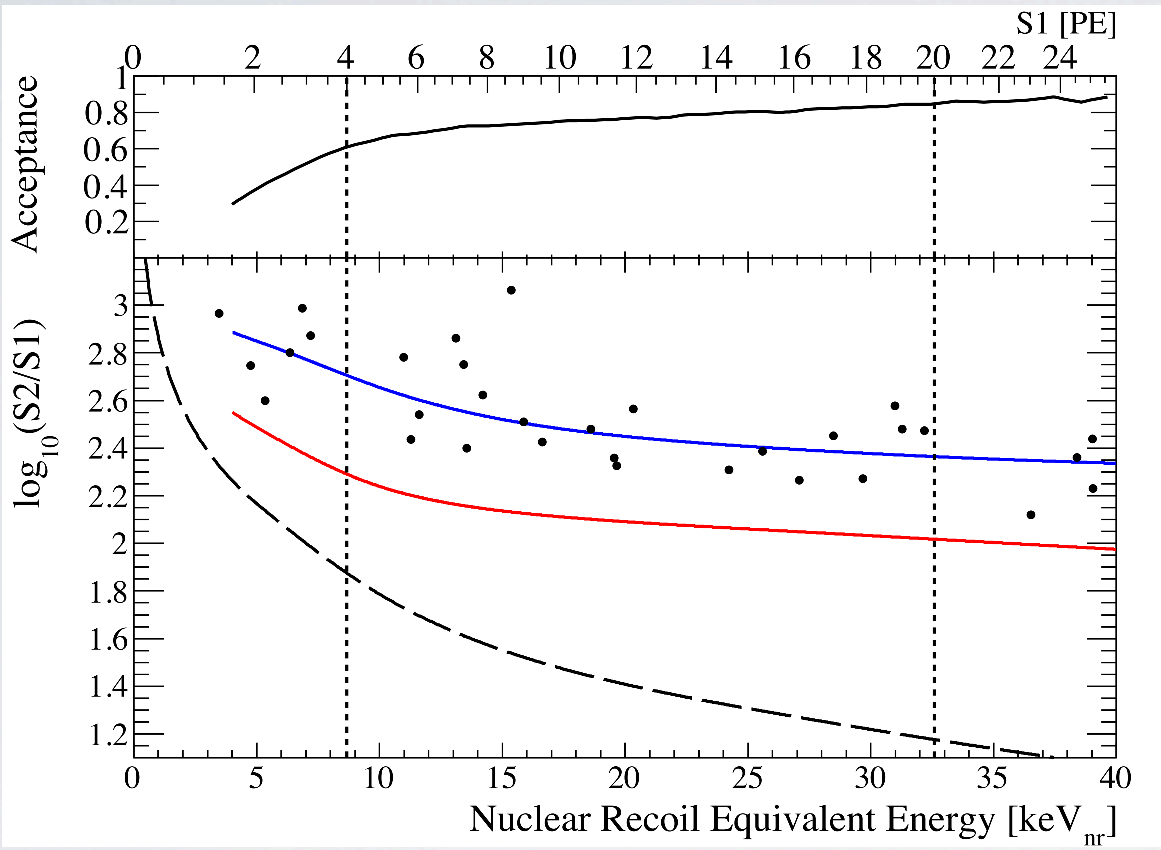
XENON10

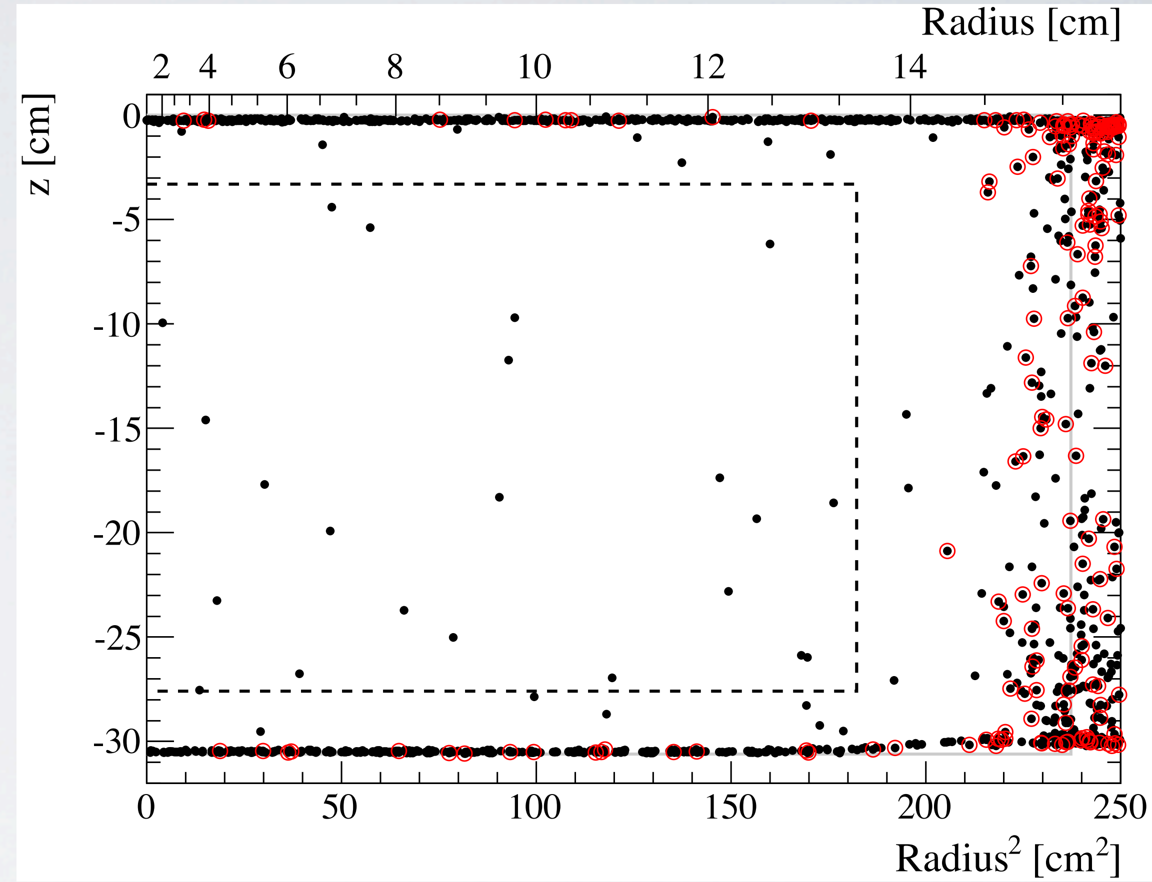


Angle et al, Phys.Rev.Lett.100:021303,2008

- Distinguish events by ratio of scintillation light compared with ionization (bowling ball vs ping pong ball)

XENON100

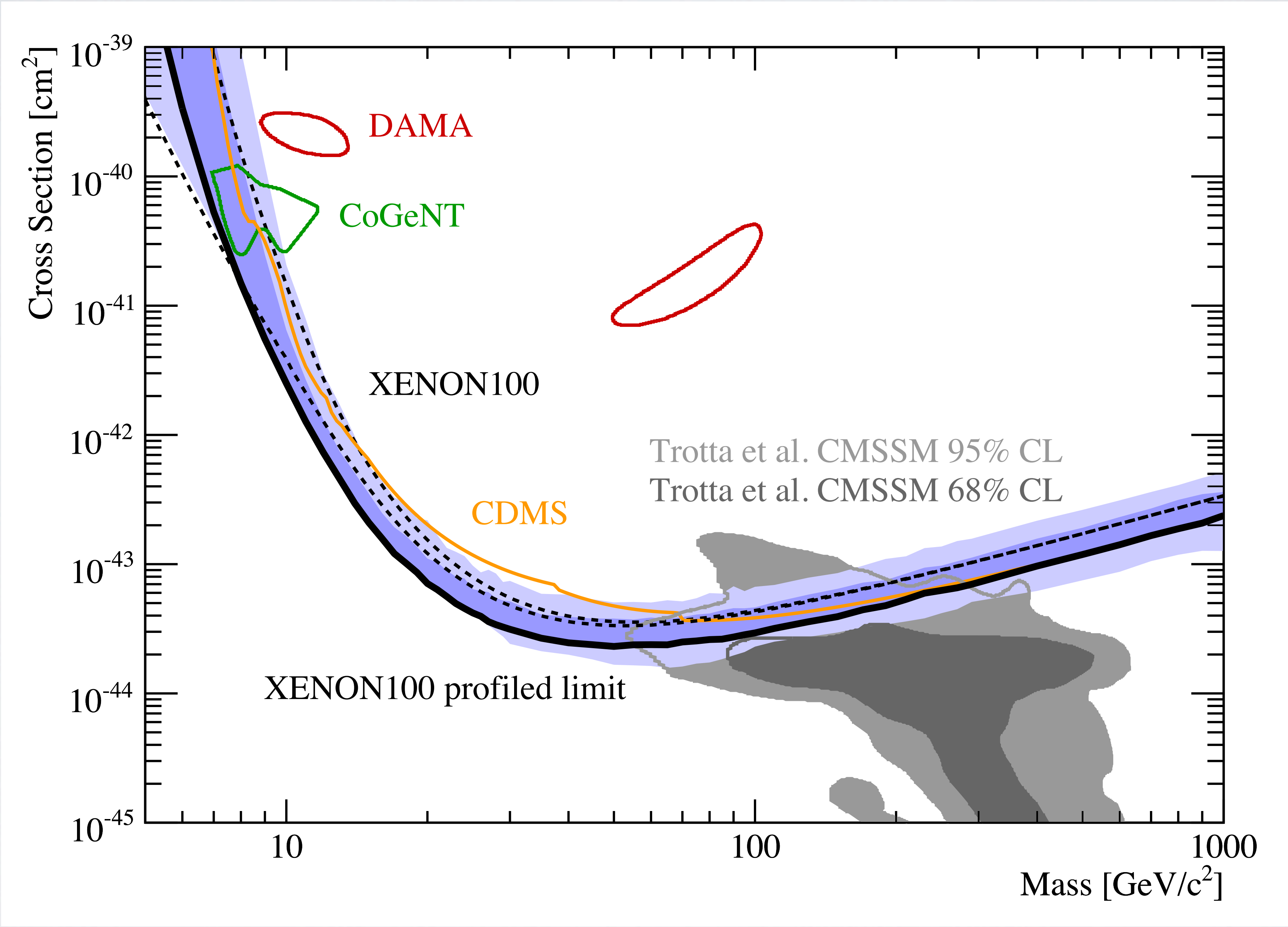




Major improvement in sensitivity - factor of 10 in exposure expected within ~ month (where month < year)

Upgrades: LUX, XENON1T, LZ; Also CDMS, Eureca, XMASS (for SI interactions)

where we are right now



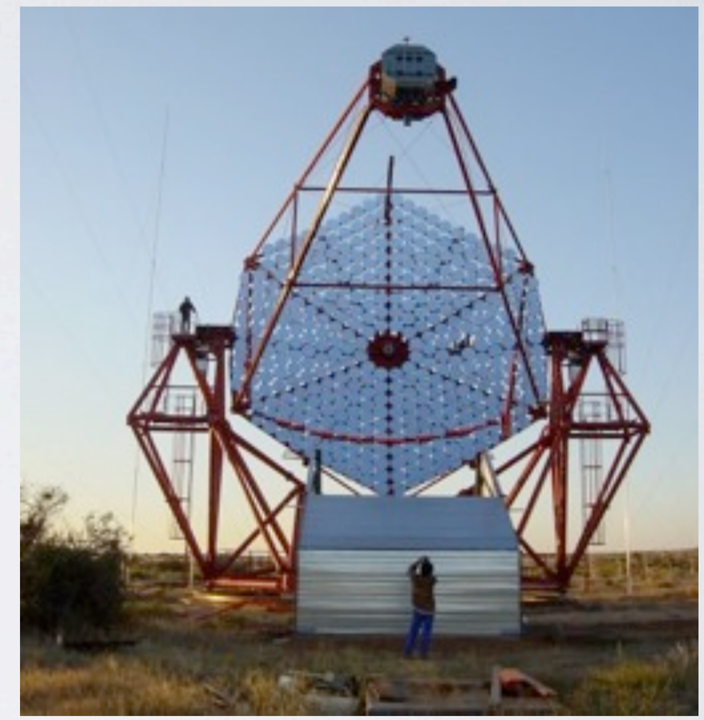
indirect detection

- dark matter in the halo right now could be producing cosmic rays

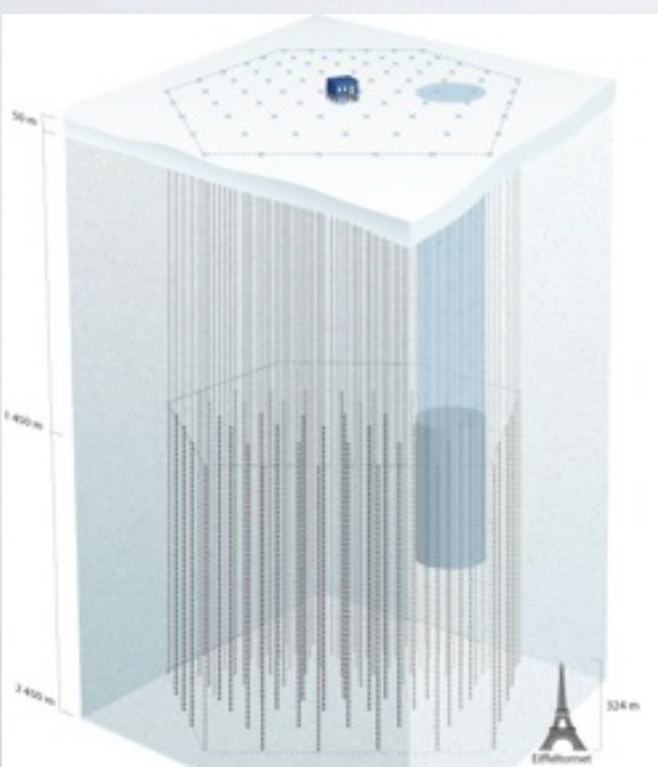
gamma rays (Fermi)

charged cosmic rays (PAMELA, ATIC)

UH cosmics (ACTs like Hess/Veritas)

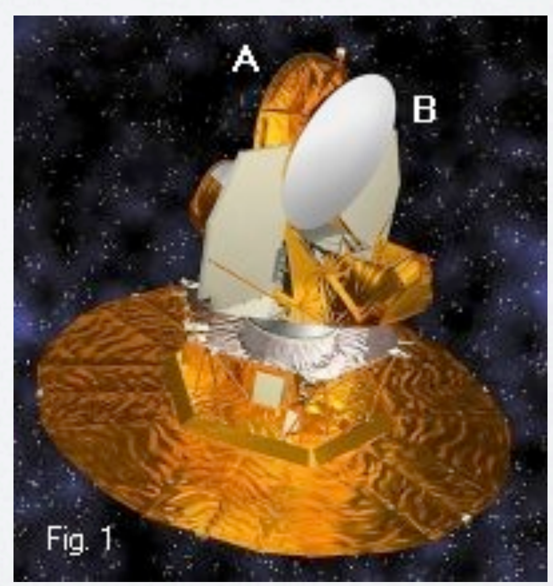


neutrinos (ICECUBE, ANTARES)

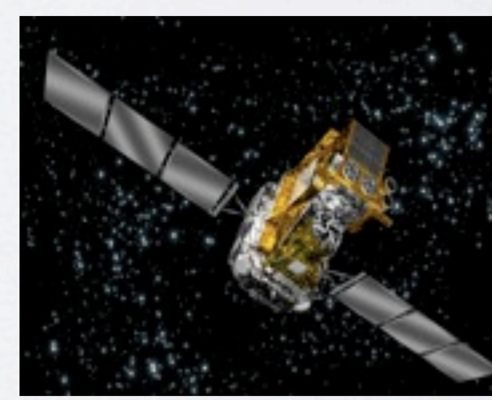


indirect indirect

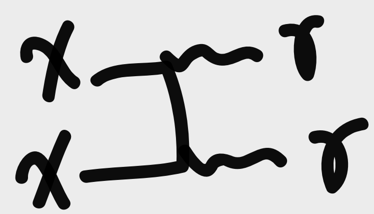
WMAP (microwave signals from HE electrons **or** corrections to the CMB)



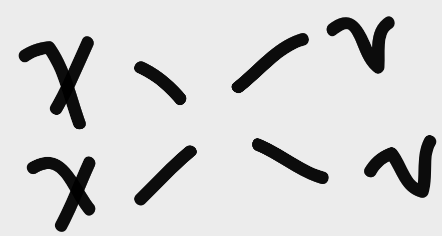
INTEGRAL produce LE positrons that then produce X-rays (511 keV)



indirect detection



rare (because DM is neutral)



happens

n_χ^2

volume element ($d\psi\, r^2$)

$$\phi(E,\psi) = \frac{1}{2}\langle \sigma v\rangle \sum_f \frac{dN_f}{dE} B_f \int_{los} dl(\psi)\, \frac{\rho_\chi(l)^2}{m_\chi^2} \times \frac{r^2}{4\pi r^2}$$

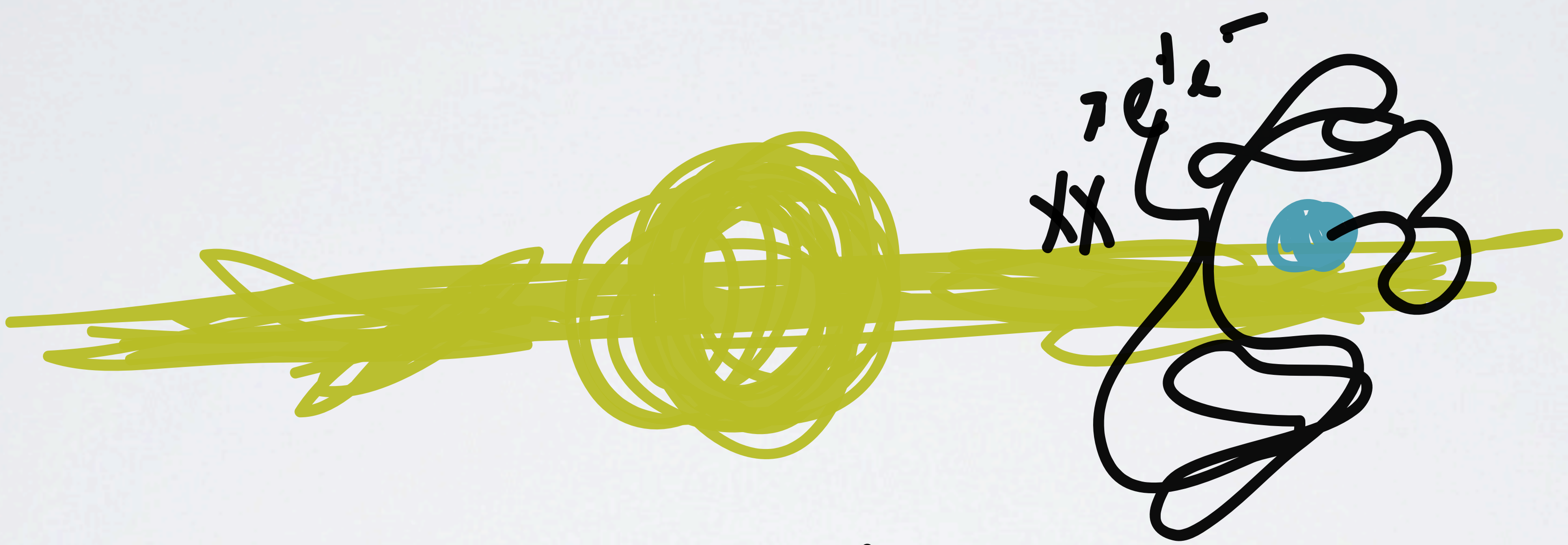
Gauss' law flux suppression

flux is high in galactic center, so are backgrounds

flux *may* be high in dwarfs

indirect detection: charged

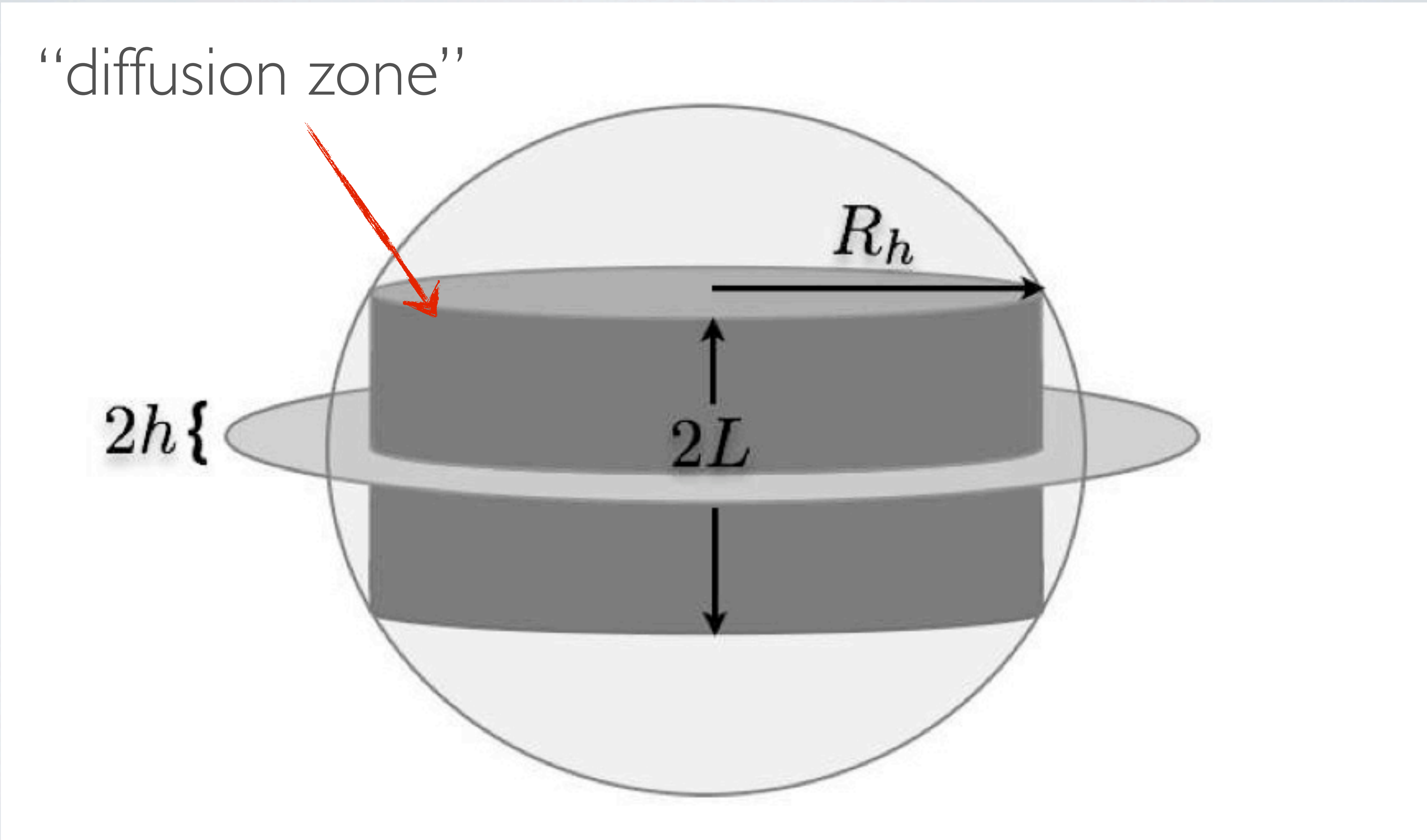
Milky Way



e range ~ kpc

p range ~ several kpc

indirect detection: charged



indirect detection: charged

energy loss mechanisms:
pretty well known

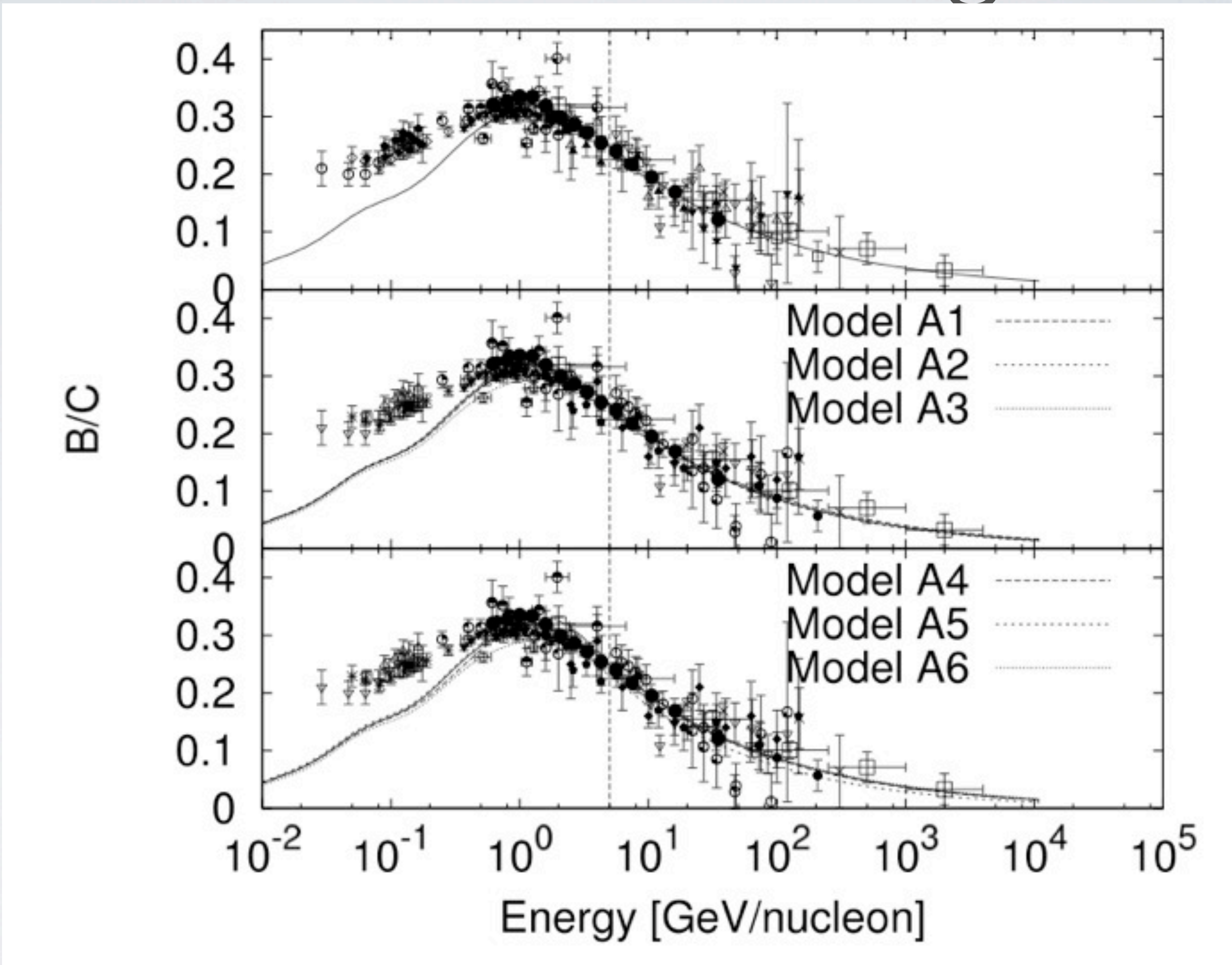
steady state
=0

$$\cancel{\frac{\partial}{\partial t}\frac{dN}{dE}} = \vec{\nabla}\cdot\left[K(E)\vec{\nabla}\frac{dn}{dE}\right] + \frac{\partial}{\partial E}\left[b(E,x)\frac{dn}{dE}\right] + Q[E,x]$$

diffusion constant
(not a constant)
unknown

source:
what we want
to know

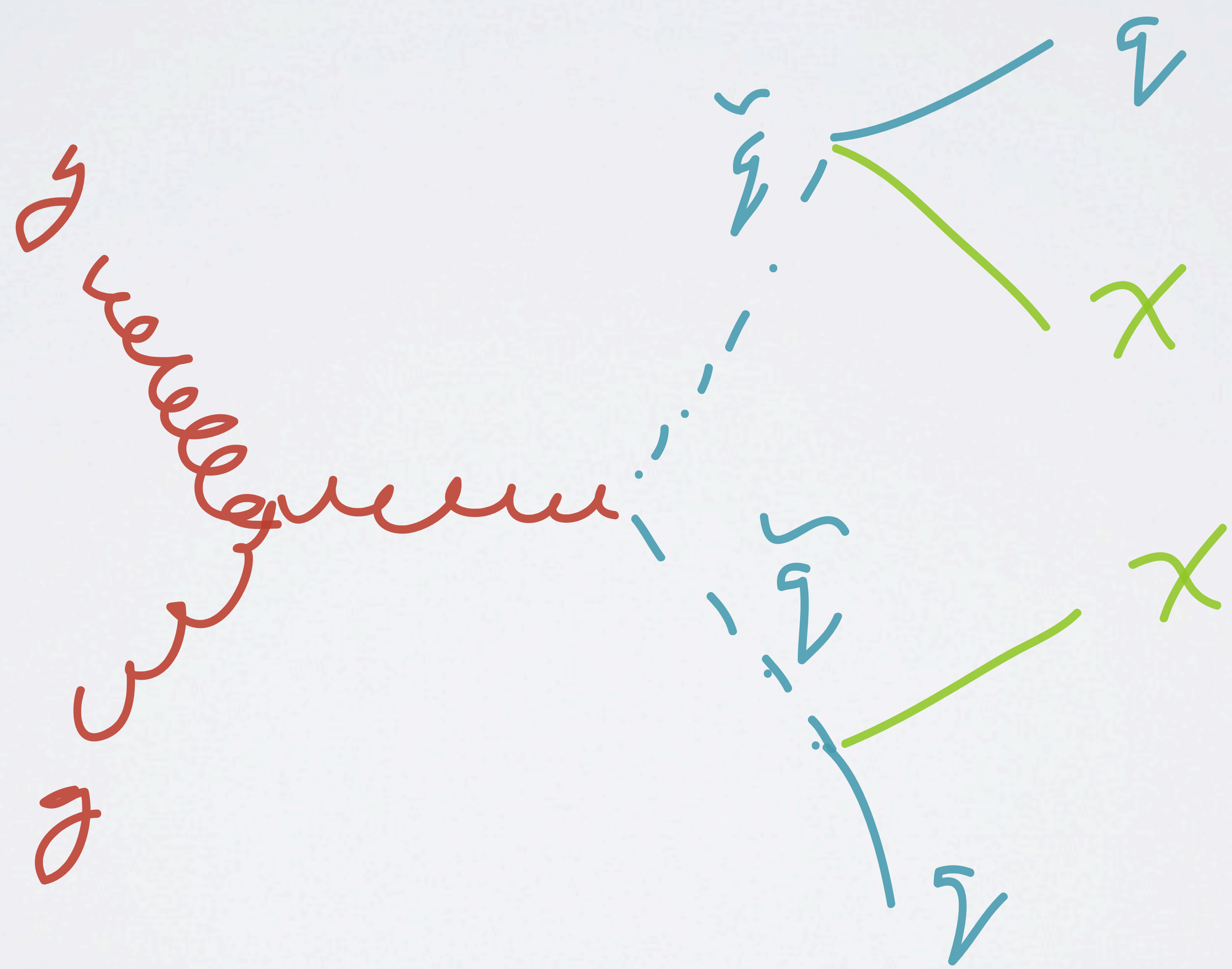
indirect detection: charged



Hooper + Simet '09

collider signals

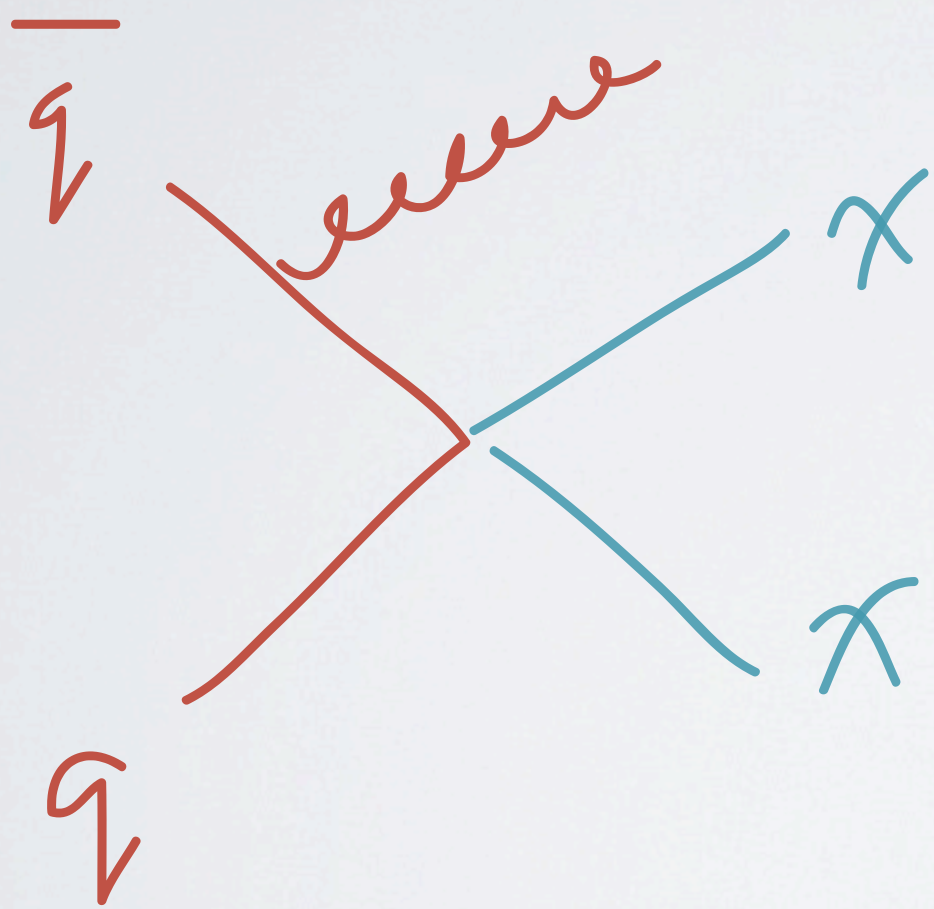
Unbalanced visible energy leads to MET
(missing transverse energy)

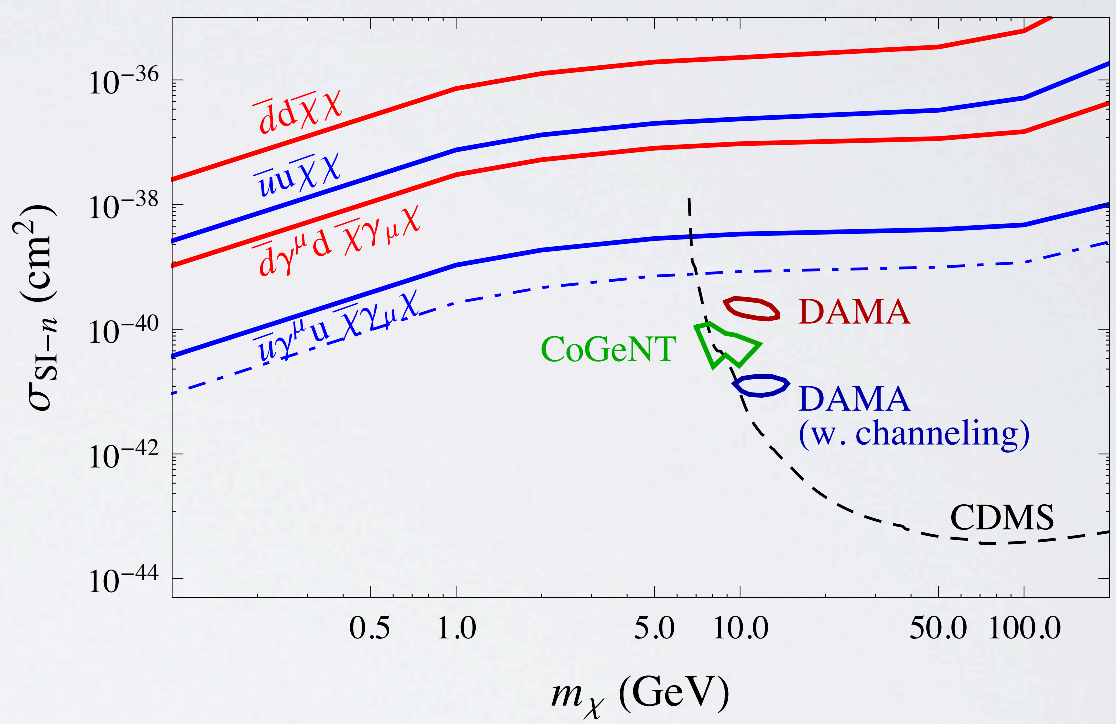


collider signals

Goodman, Ibe, Rajaraman, Shepherd, Tait, Yu, '10; Bai, Fox, Harnik '10; Bai, Fox, Harnik, Kopp, Tsai '11

Can you directly compare to direct detection? Almost



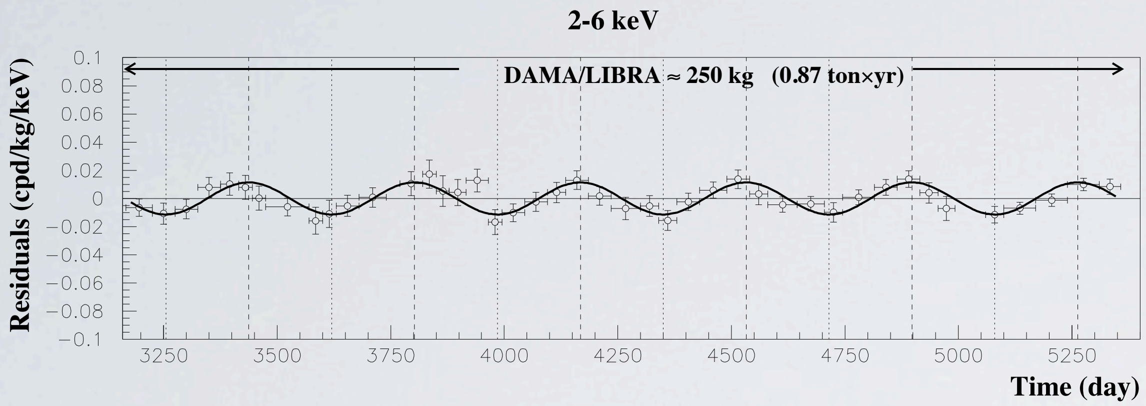


monojet (originally studied for large extra dimensions)

OUTLINE

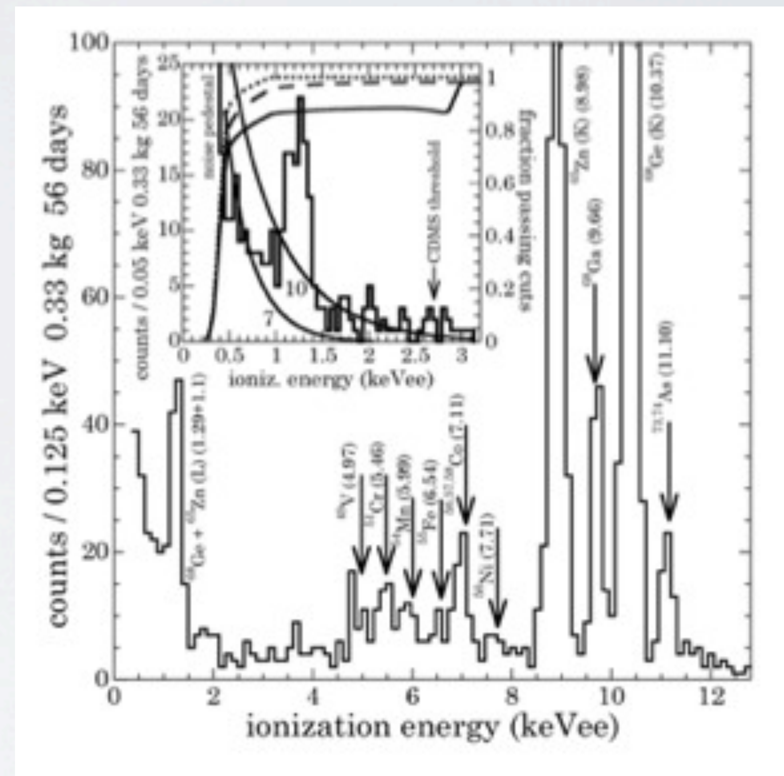
- Anomalies in direct detection
  - DAMA
  - CoGeNT
  - CRESST
- Scenarios: light WIMPs, spin-dependent, inelastic WIMPs, other exotica

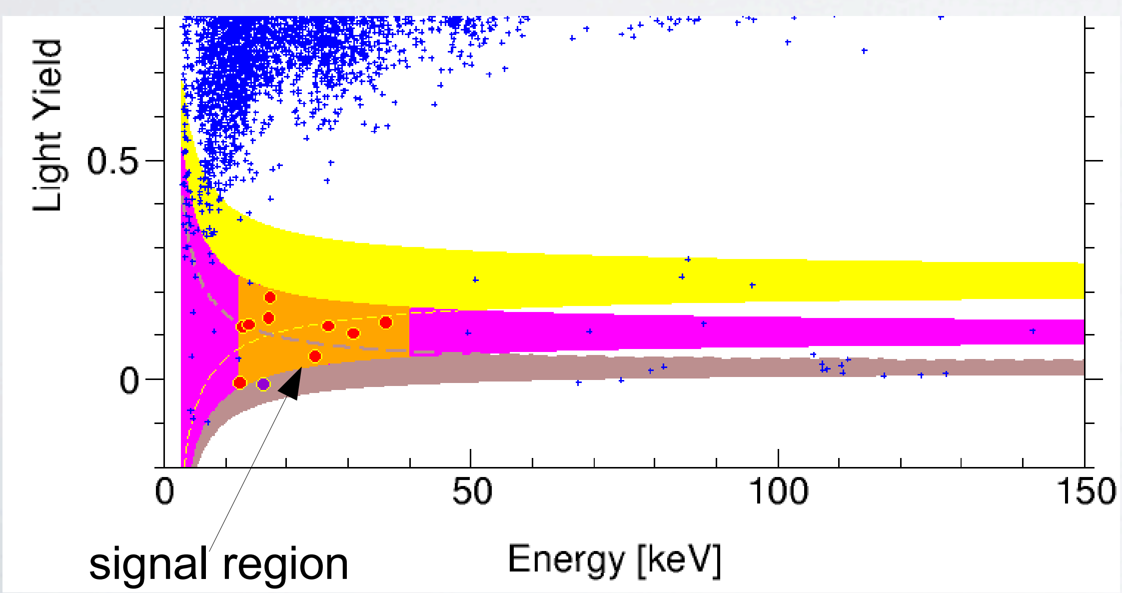
HINTS?



DAMA

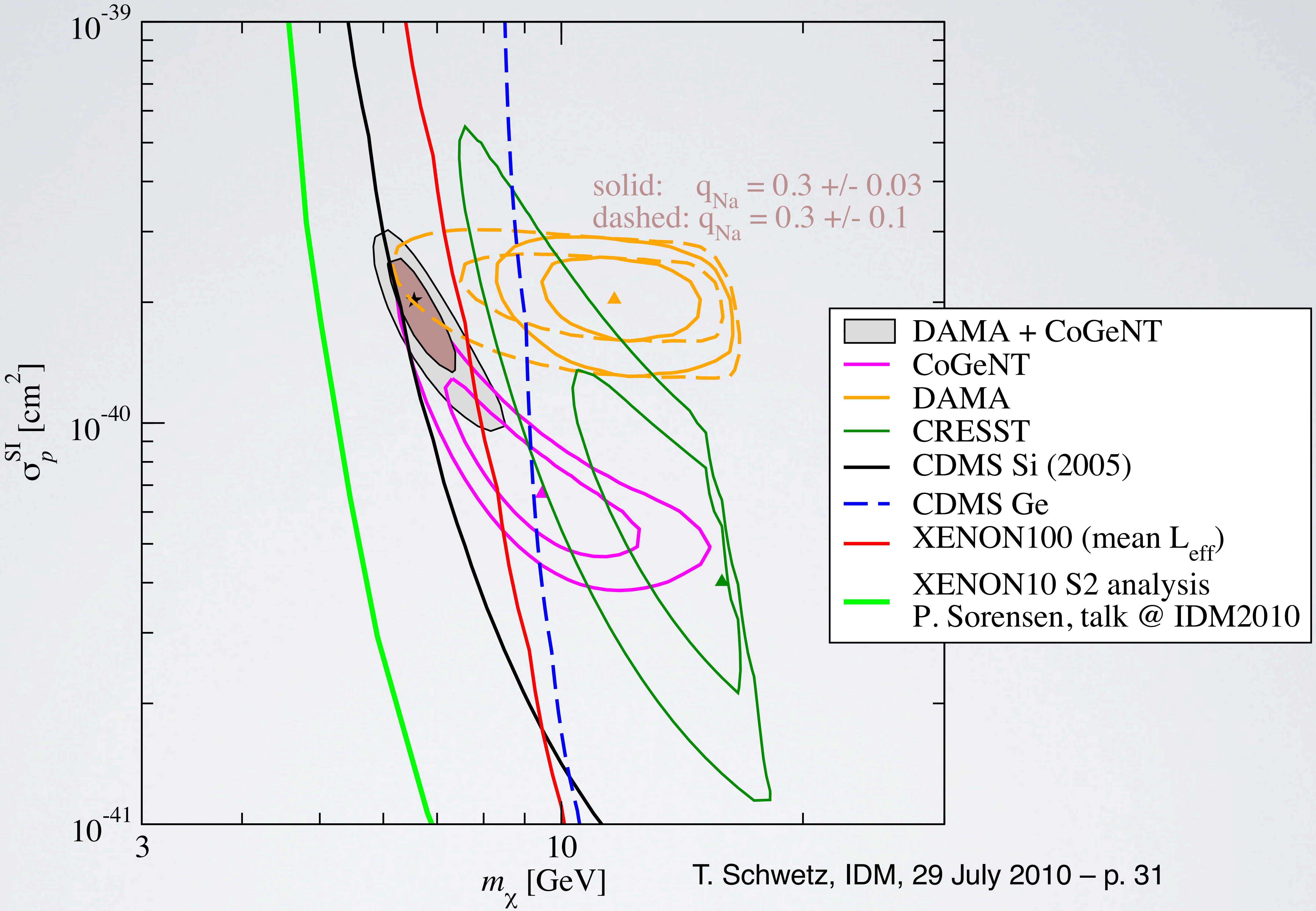
CoGeNT





CRESST

• The same beast?

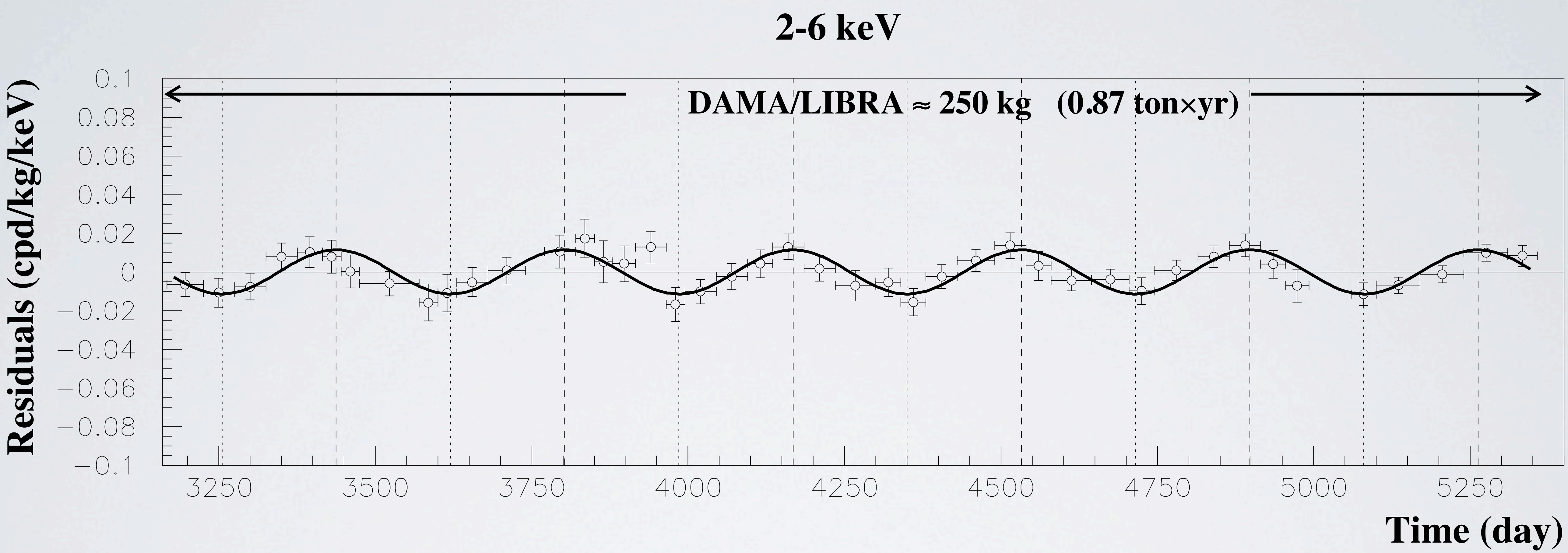


T. Schwetz, IDM, 29 July 2010 – p. 31

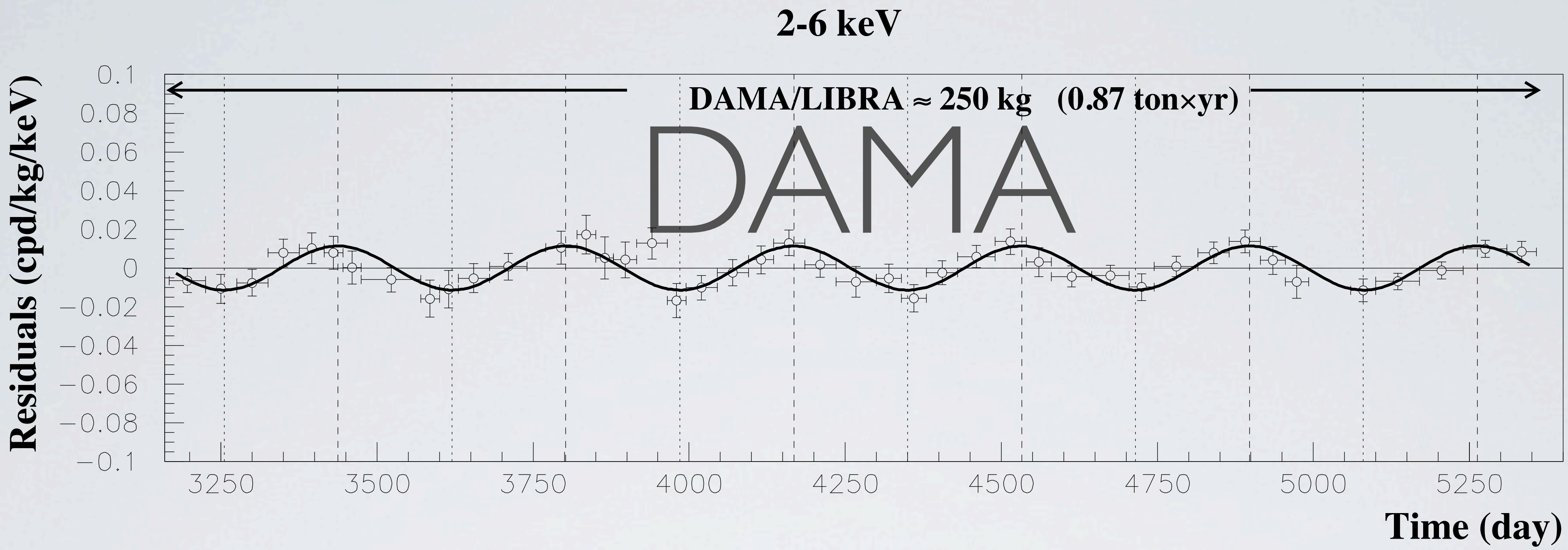
don't *really* line up, but within spitting distance

NB: *Not* MSSM (Kuflick, Pierce, Zurek '10)

DAMA


2-6 keV
DAMA/LIBRA ≈ 250 kg (0.87 ton×yr)
Residuals (cpd/kg/keV)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
3250
3500
3750
4000
4250
4500
4750
5000
5250
Time (day)

DAMA

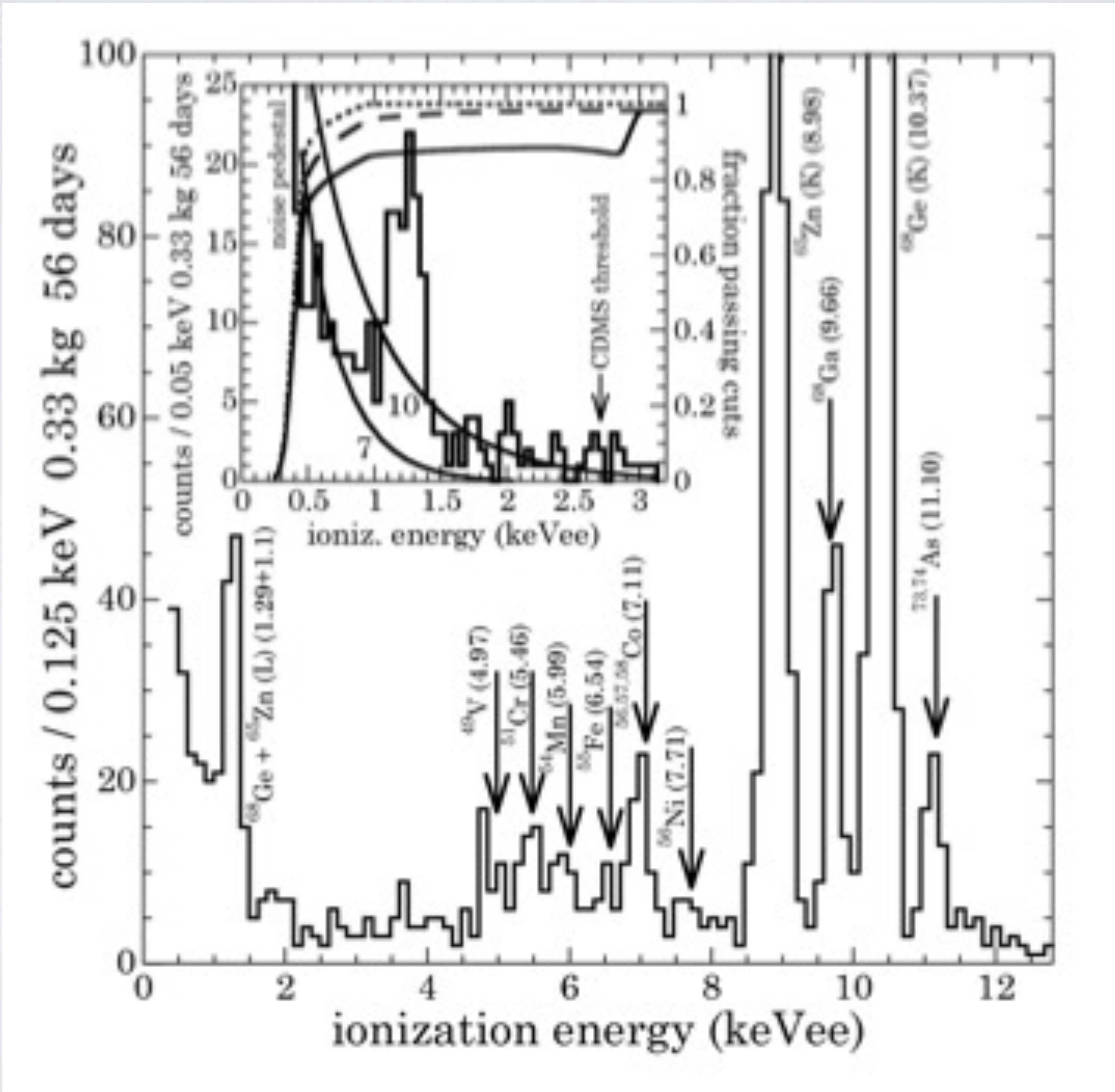


- What is it: annual modulation in scintillation events in 100/250 kg NaI(Tl) crystal - DM?

- What's to like: single hit, stable phase, low energy, no candidate "conventional" explanations

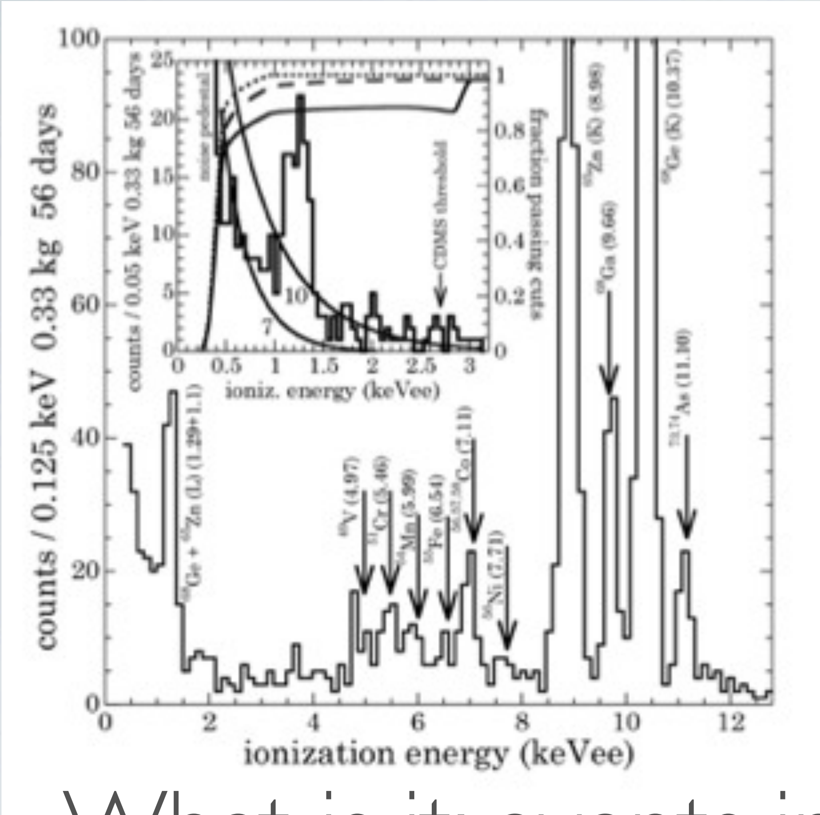
- What's not to like: null results from other exps, data are still unavailable, no event discrimination

COGENT



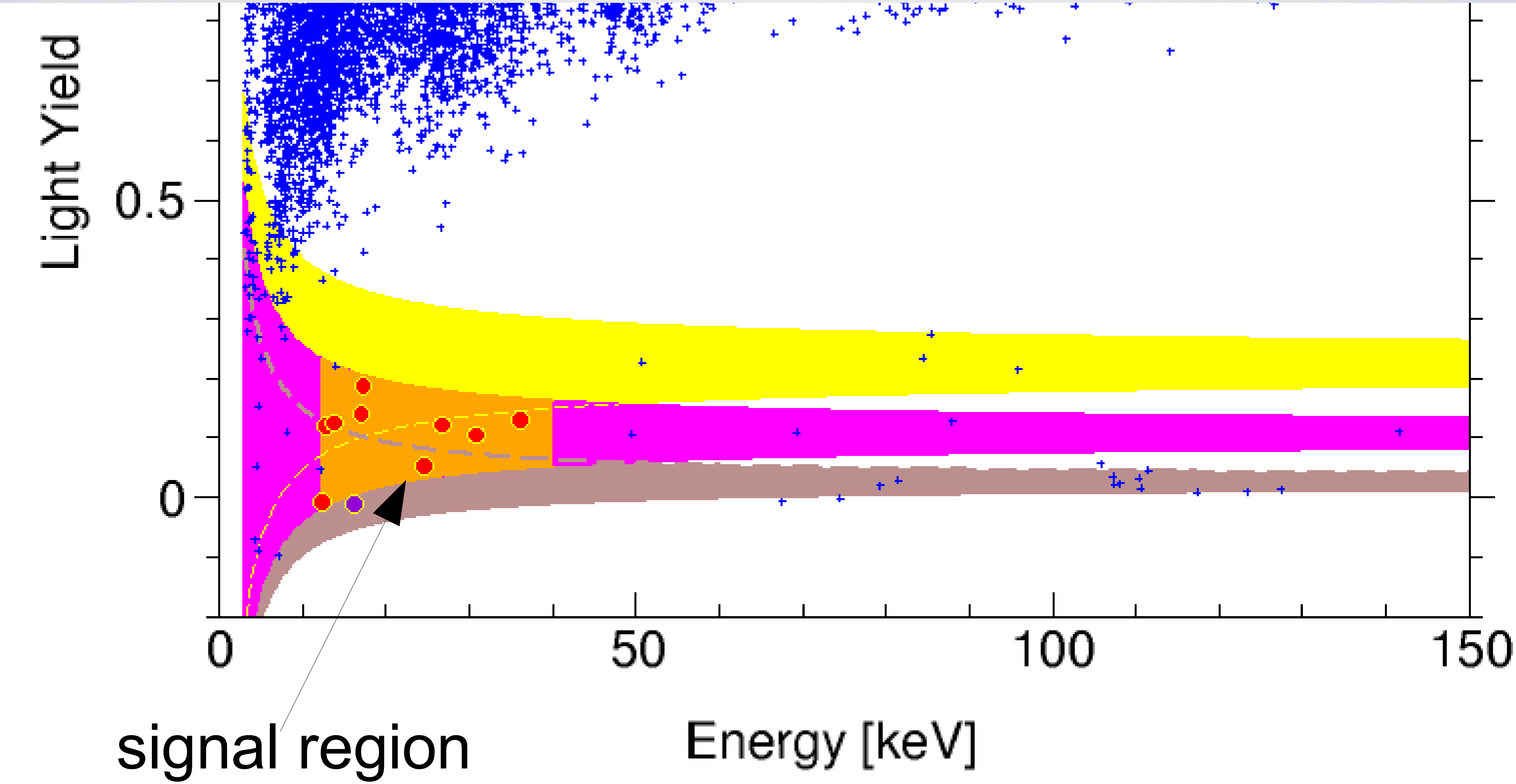
counts / 0.125 keV 0.33 kg 56 days
ionization energy (keVee)
^{68}Ge + ^{65}Zn (L) (1.29+1.1)
^{49}V (4.97)
^{51}Cr (5.46)
^{54}Mn (5.99)
^{55}Fe (6.54)
^{56,57,58}Co (7.11)
^{56}Ni (7.71)
^{65}Zn (K) (8.98)
^{68}Ga (9.66)
^{68}Ge (K) (10.37)
^{73,74}As (11.10)
counts / 0.05 keV 0.33 kg 56 days
fraction passing cuts
ioniz. energy (keVee)
noise pedestal
CDMS threshold

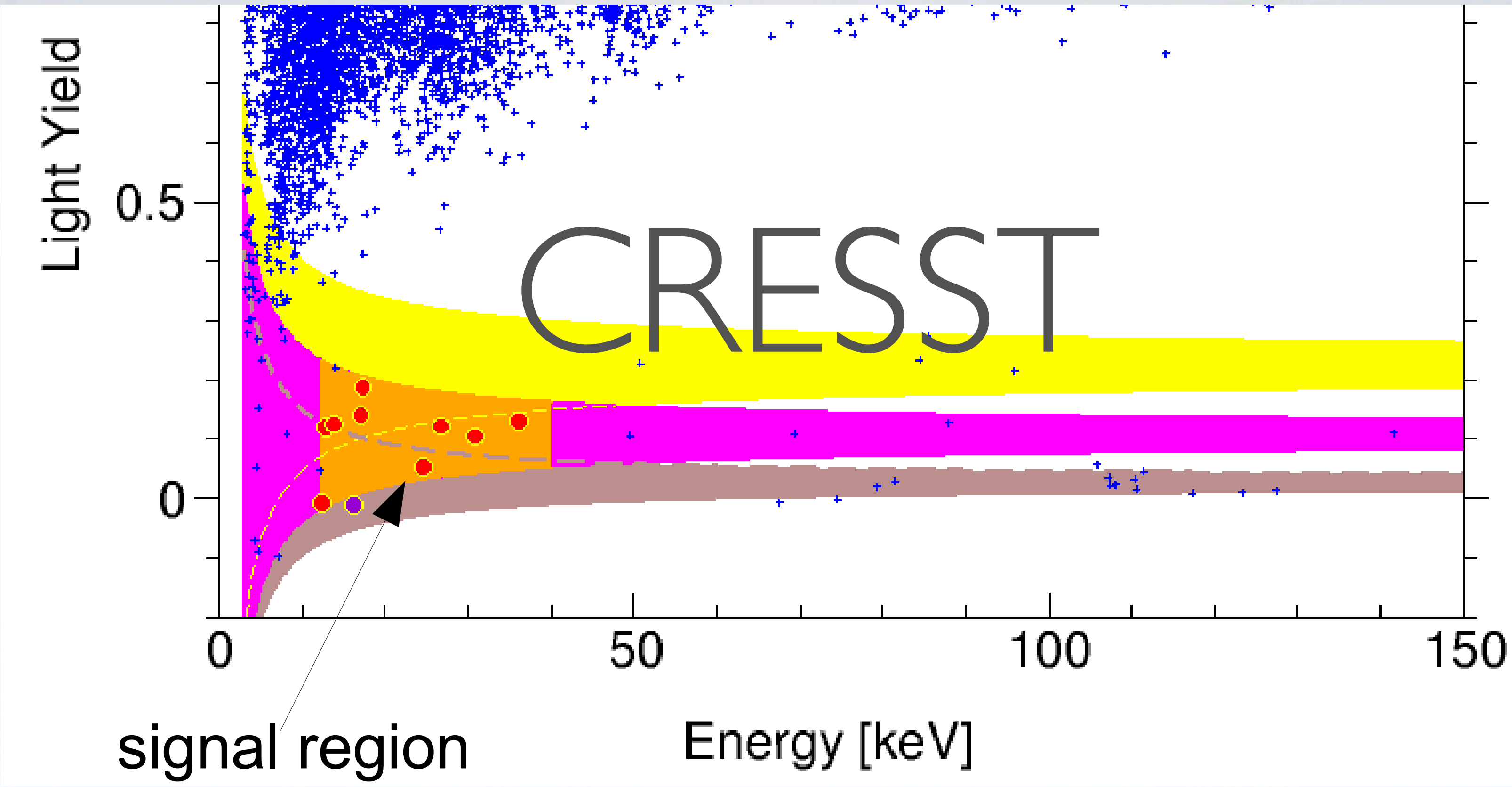
COGENT



- What is it: events in an ionization experiment, x10 larger than expected background - DM?
- What's to like: excellent energy resolution/calibration, good statistics
- What's not to like: no discrimination, hasn't been mercilessly beaten for a decade, no corroborating features [yet] (e.g. modulation), null results from other exps

CRESST





- What is it: an excess of events in a $CaWO_4$ detector, consistent with Oxygen scattering (~10-40 keV)

- What's to like: good discrimination vs electron recoil, not muon induced neutrons

- What's not to like: lots of events at high (15 keV+ energy, should have been seen elsewhere), signal lies left, right, above and below clear background sources, still have only seen 2 of 9 detectors, naively low energy looks too clean to be WIMP

The controversy

3) **Comments on arXiv:1006.0972 'XENON10/100 dark matter constraints in comparison with CoGeNT and DAMA: examining th**
J.I. Collar, . Jun 2010. 2pp. Temporary entry
e-Print: **arXiv:1006.2031** [astro-ph.CO]

References | LaTeX(US) | LaTeX(EU) | Harvmac | BibTeX | Keywords | Cited 10 times
Abstract and Postscript and PDF from arXiv.org (mirrors: au br cn de es fr il in it jp kr ru tw uk za aps lanl)
Bookmarkable link to this information

4) **Response to arXiv:1005.2615.**
J.I. Collar, D.N. McKinsey, . May 2010. Temporary entry
e-Print: **arXiv:1005.3723** [astro-ph.CO]

References | LaTeX(US) | LaTeX(EU) | Harvmac | BibTeX | Cited 15 times
Abstract and Postscript and PDF from arXiv.org (mirrors: au br cn de es fr il in it jp kr ru tw uk za aps lanl)
Bookmarkable link to this information

5) **Reply to the Comments on the XENON100 First Dark Matter Results.**
The XENON100 Collaboration, . May 2010. Temporary entry
e-Print: **arXiv:1005.2615** [astro-ph.CO]

References | LaTeX(US) | LaTeX(EU) | Harvmac | BibTeX | Keywords | Cited 14 times
Abstract and Postscript and PDF from arXiv.org (mirrors: au br cn de es fr il in it jp kr ru tw uk za aps lanl)
Bookmarkable link to this information

6) **Comments on 'First Dark Matter Results from the XENON100 Experiment'.**
J.I. Collar, D.N. McKinsey, . May 2010. Temporary entry
e-Print: **arXiv:1005.0838** [astro-ph.CO]

References | LaTeX(US) | LaTeX(EU) | Harvmac | BibTeX | Keywords | Cited 22 times
Abstract and Postscript and PDF from arXiv.org (mirrors: au br cn de es fr il in it jp kr ru tw uk za aps lanl)
Bookmarkable link to this information

7) **First Dark Matter Results from the XENON100 Experiment.**
By XENON100 Collaboration (E. Aprile *et al.*). May 2010. (Published Sep 24, 2010). 4pp.
Published in **Phys.Rev.Lett.105:131302,2010**.
e-Print: **arXiv:1005.0380** [astro-ph.CO]

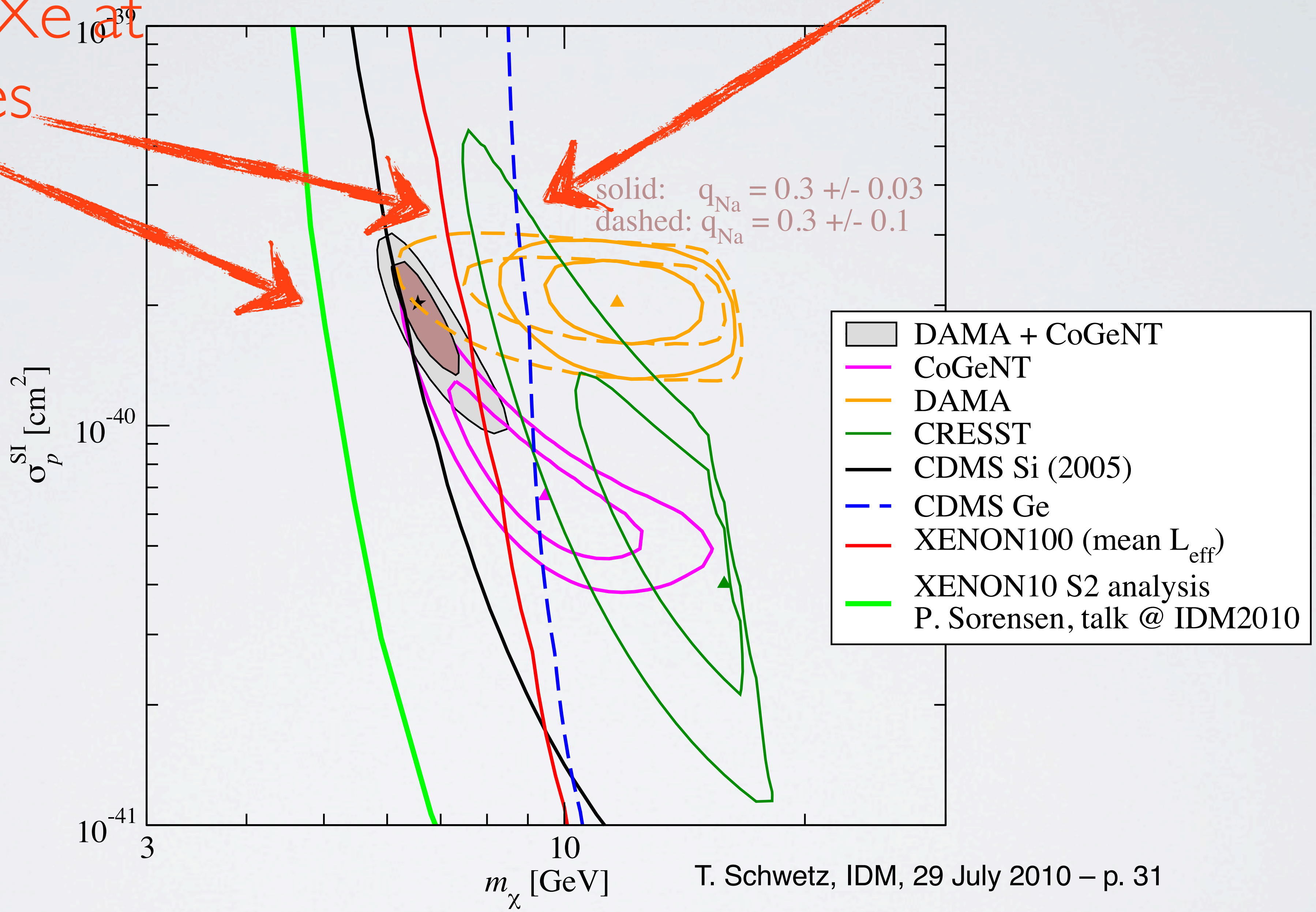
TOPCITE = 50+
References | LaTeX(US) | LaTeX(EU) | Harvmac | BibTeX | Keywords | Cited 103 times
Abstract and Postscript and PDF from arXiv.org (mirrors: au br cn de es fr il in it jp kr ru tw uk za aps lanl)
Journal Server [doi:10.1103/PhysRevLett.105.131302]
EXP XENON
Bookmarkable link to this information

FIND KEYWORD BIG TIZZY

The controversy

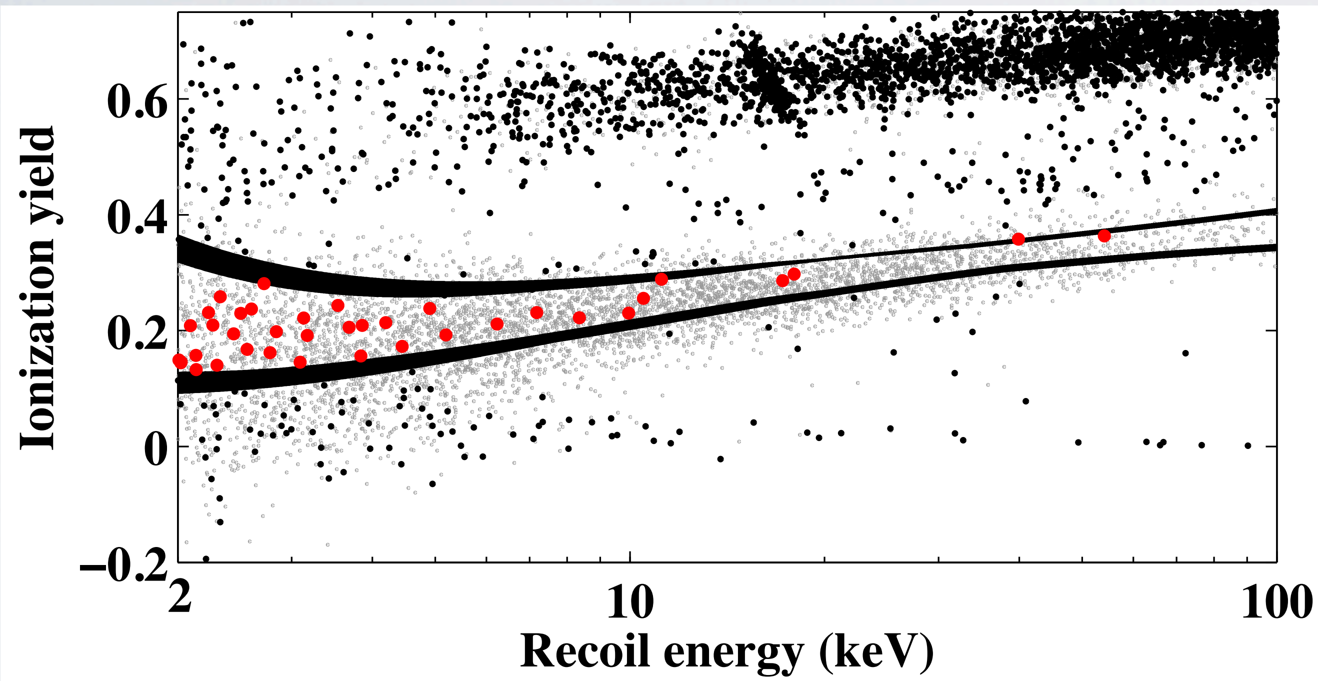
Limits from XENON invoke unmeasured properties of LXe at low energies

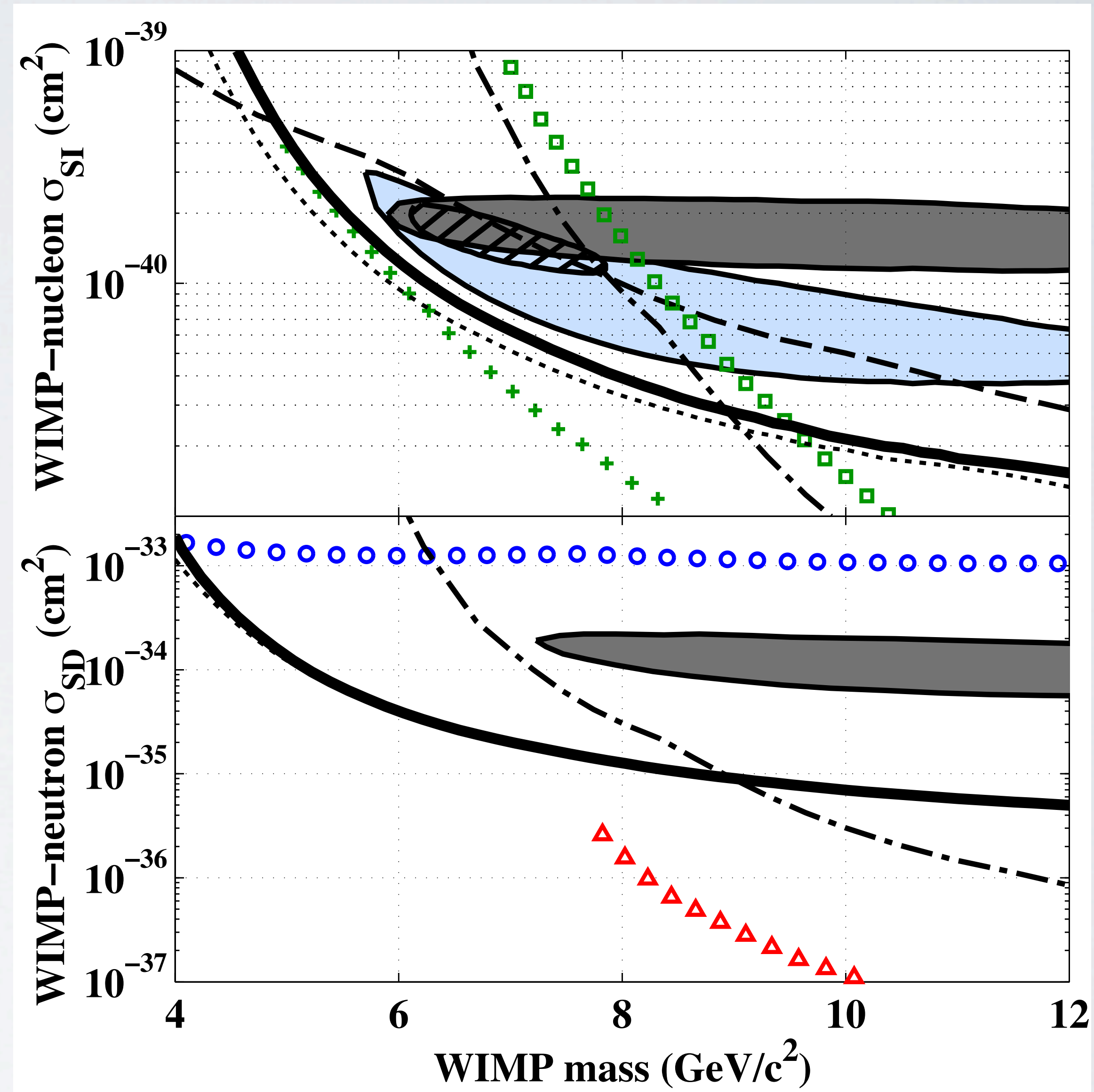
DAMA/CoGeNT agreement requires generous assumptions about QNa



T. Schwetz, IDM, 29 July 2010 – p. 31

A resolution?





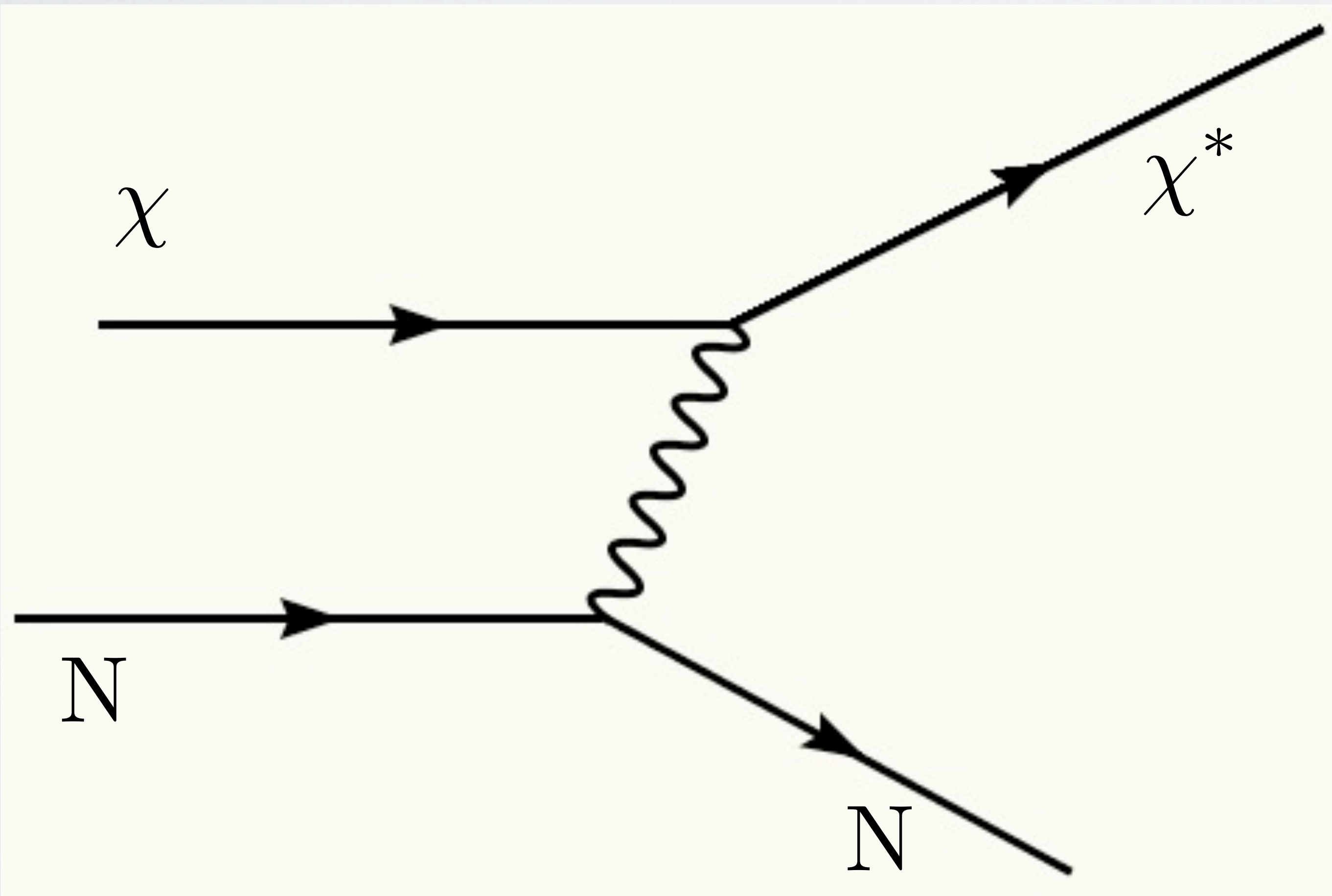
CDMS: Same target, same energy, should be comparable

inelastic dark matter

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

- DM-nucleus scattering must be inelastic

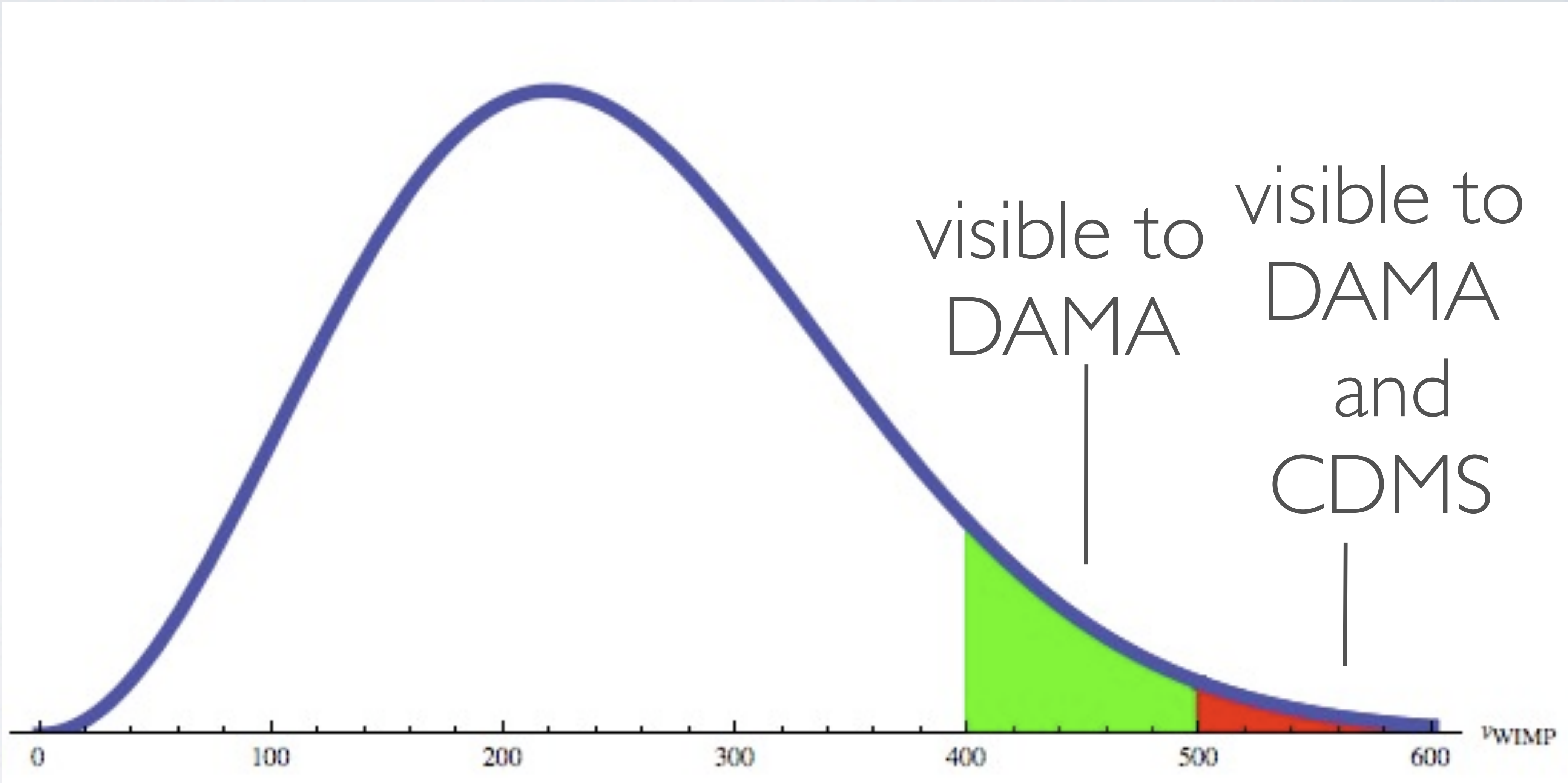
- If dark matter can only scatter off of a nucleus by transitioning to an excited state (100 keV), the kinematics are changed dramatically



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

Favors heavier targets

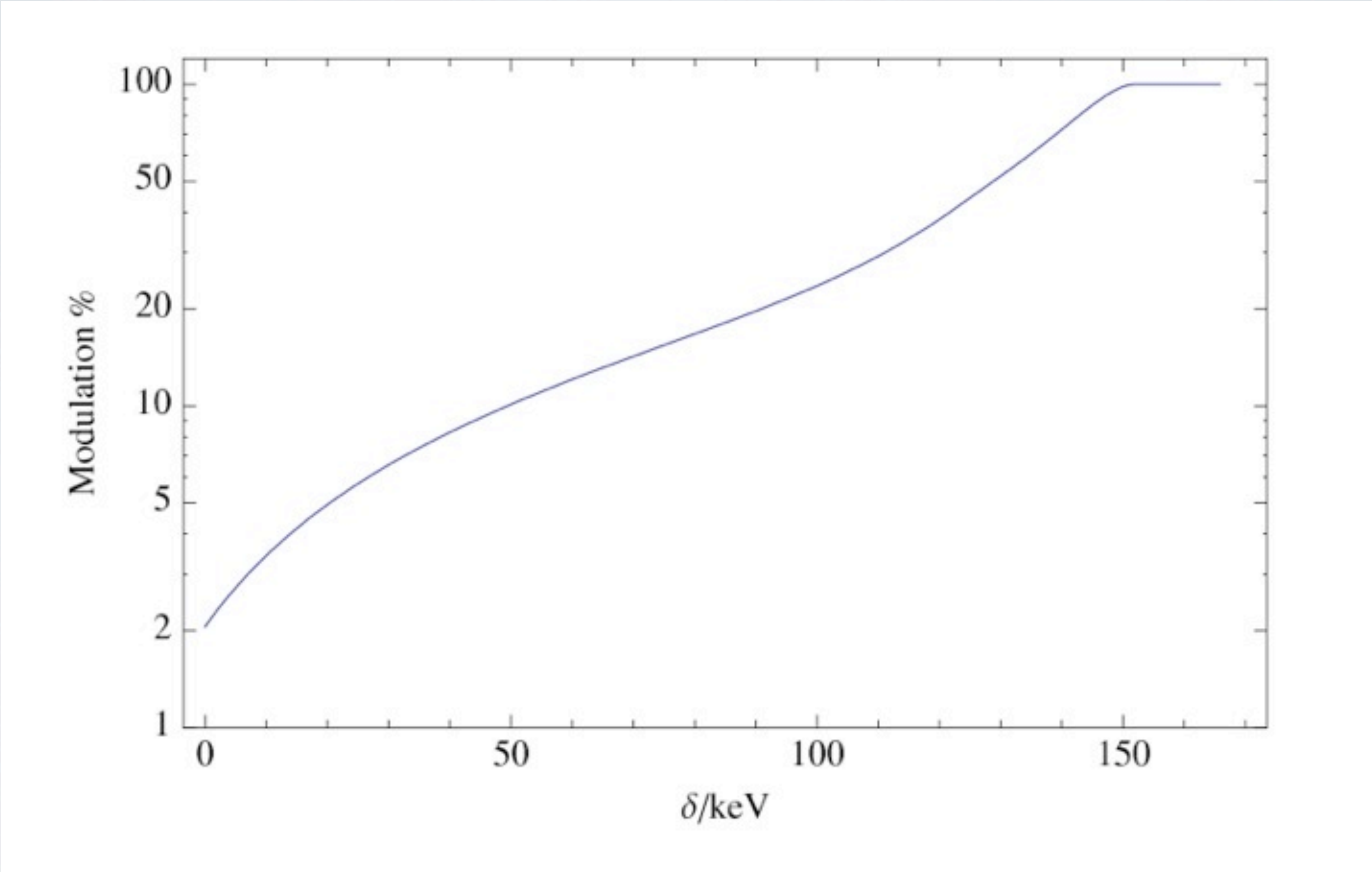
n(v): velocity distribution of WIMPs



WIMP velocity in km/s

Disfavors CDMS

Enhanced modulation



Favors modulation experiments

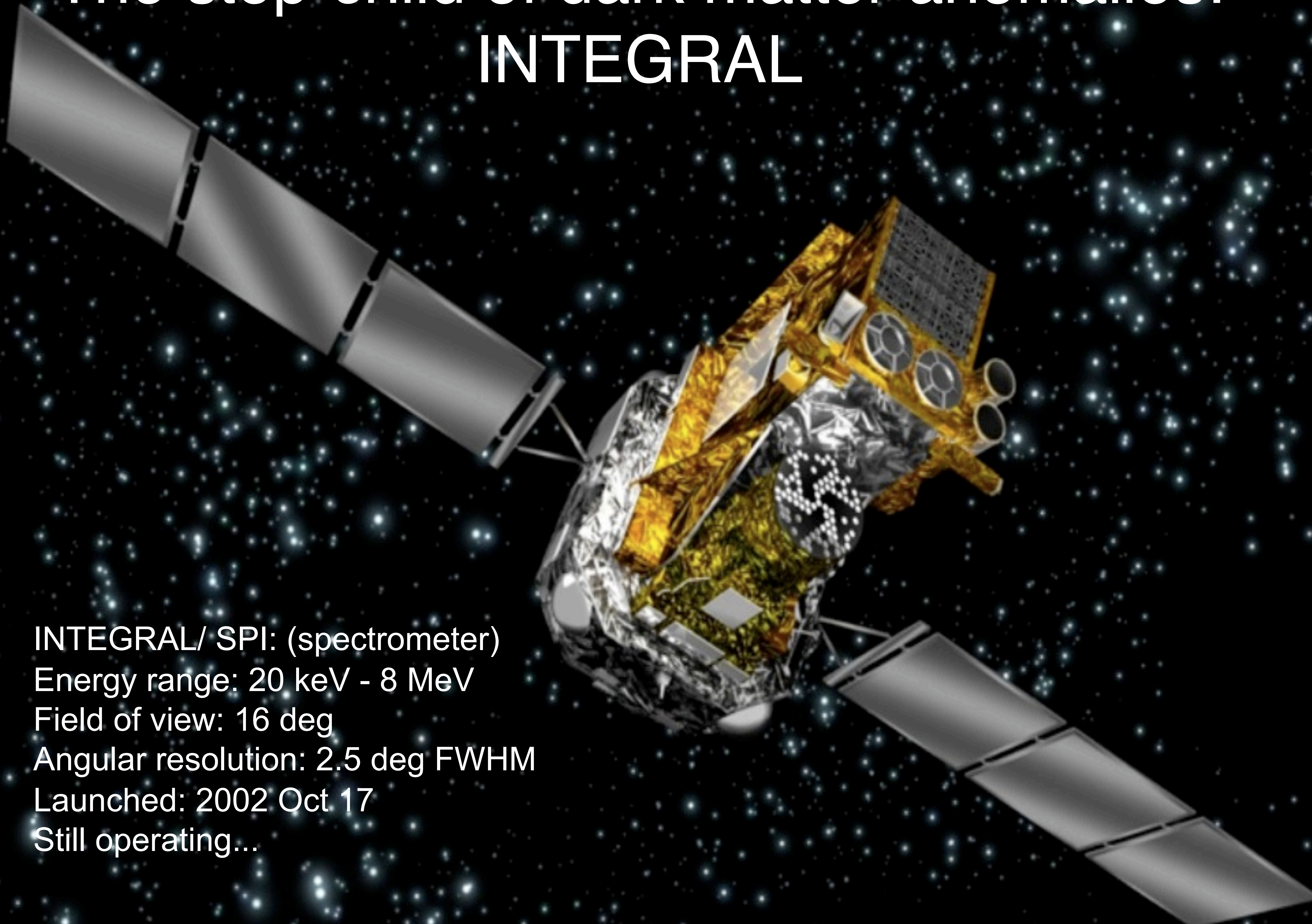
inelastic dark matter

- Favors heavy targets (Iodine) over light ones (Germanium)
- Enhances modulation (typically 50%, but up to 100% - sensitive to the non-Maxwellian features of the halo)
- Depletes low energy events
- Together these effects can allow a positive DAMA signal consistent with other results (CDMS, XENON10, ZEPLIN, CRESST, KIMS) - although increasingly tense

OUTLINE

- Anomalies in indirect detection
  - INTEGRAL
  - PAMELA/Fermi (electrons)
  - WMAP/Fermi (photons)
- Scenarios: MeV DM, “eXciting” DM, decaying DM
- Dark forces and signals

The step-child of dark matter anomalies: INTEGRAL



INTEGRAL/ SPI: (spectrometer)
Energy range: 20 keV - 8 MeV
Field of view: 16 deg
Angular resolution: 2.5 deg FWHM
Launched: 2002 Oct 17
Still operating...

the step child of dark matter anomalies

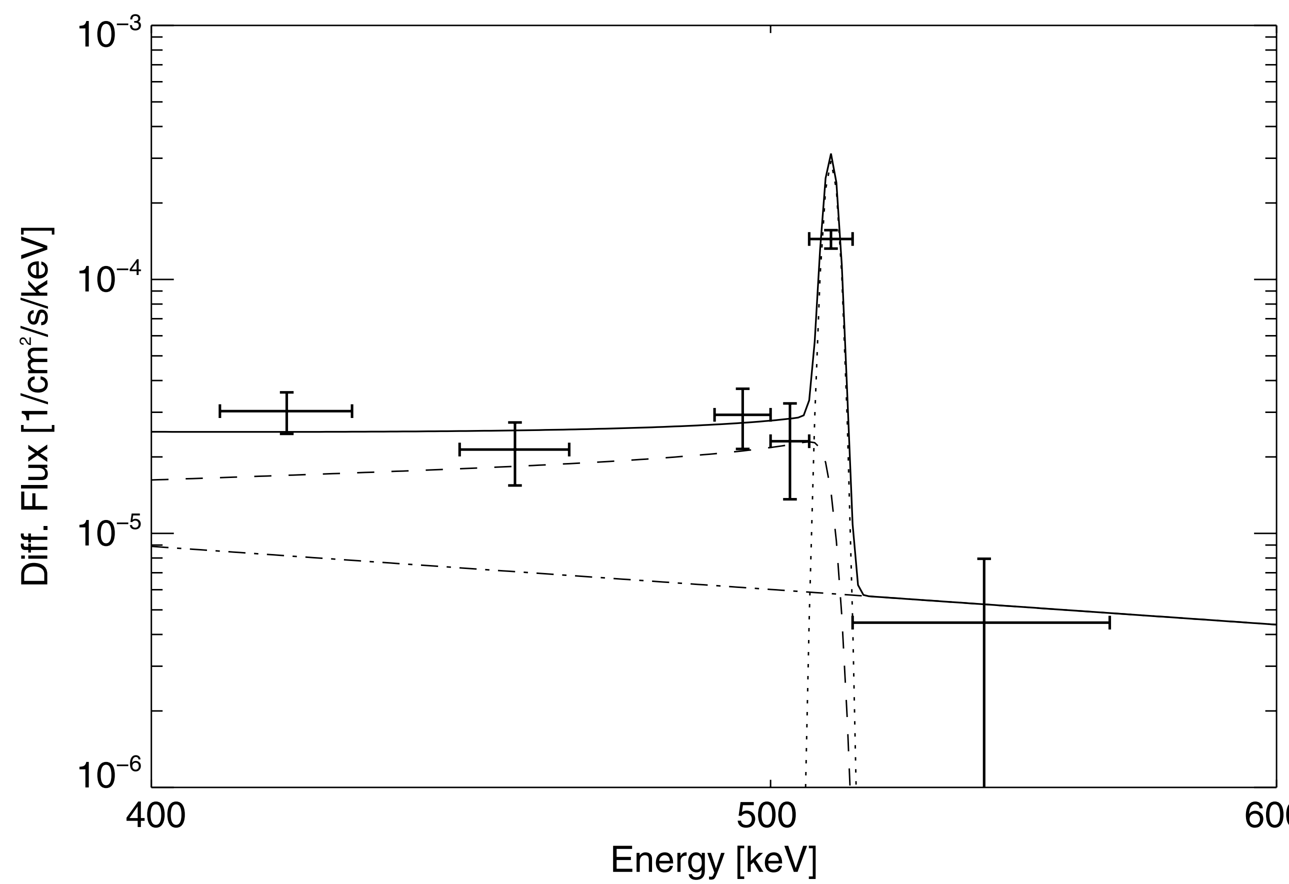
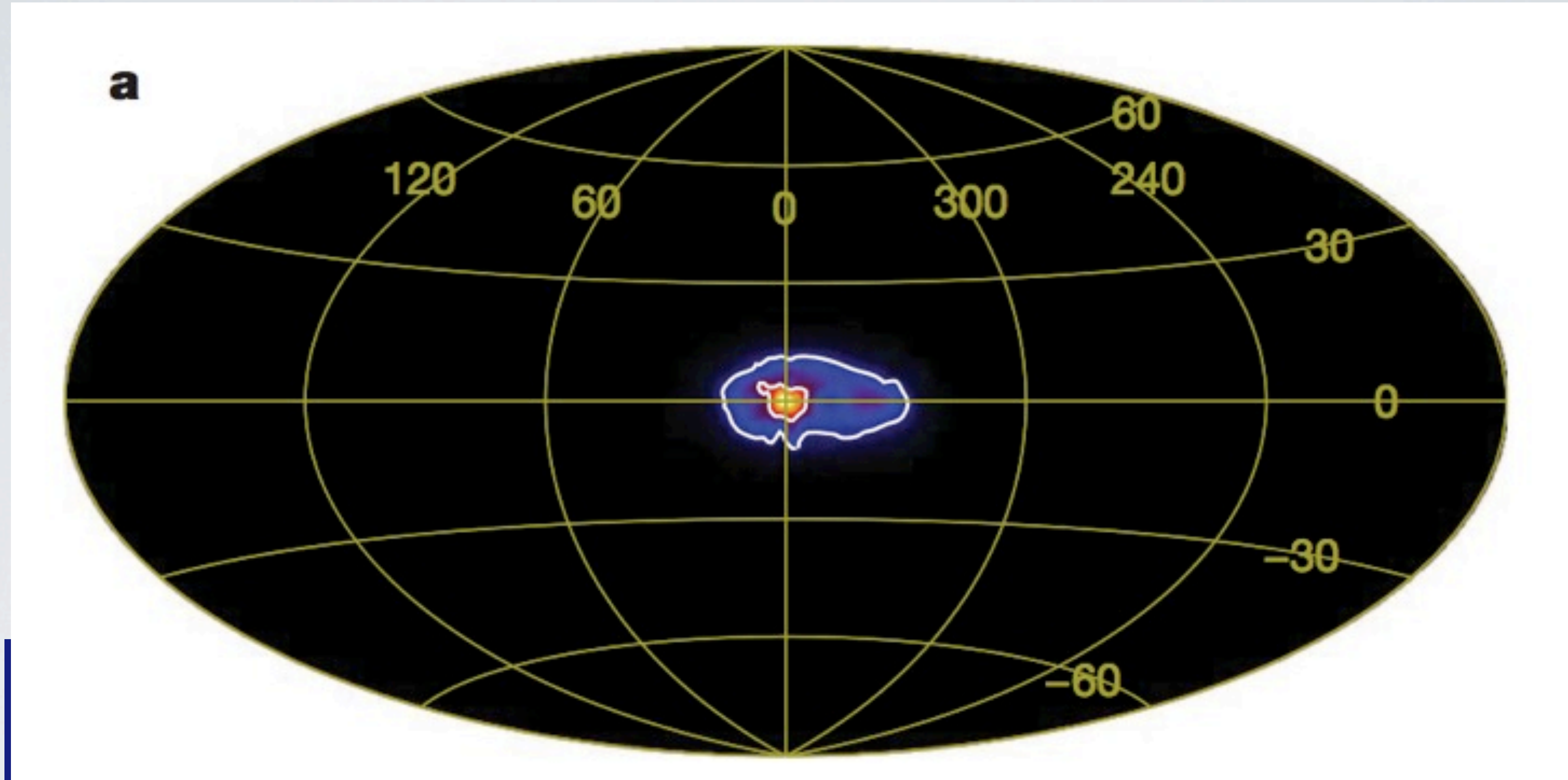
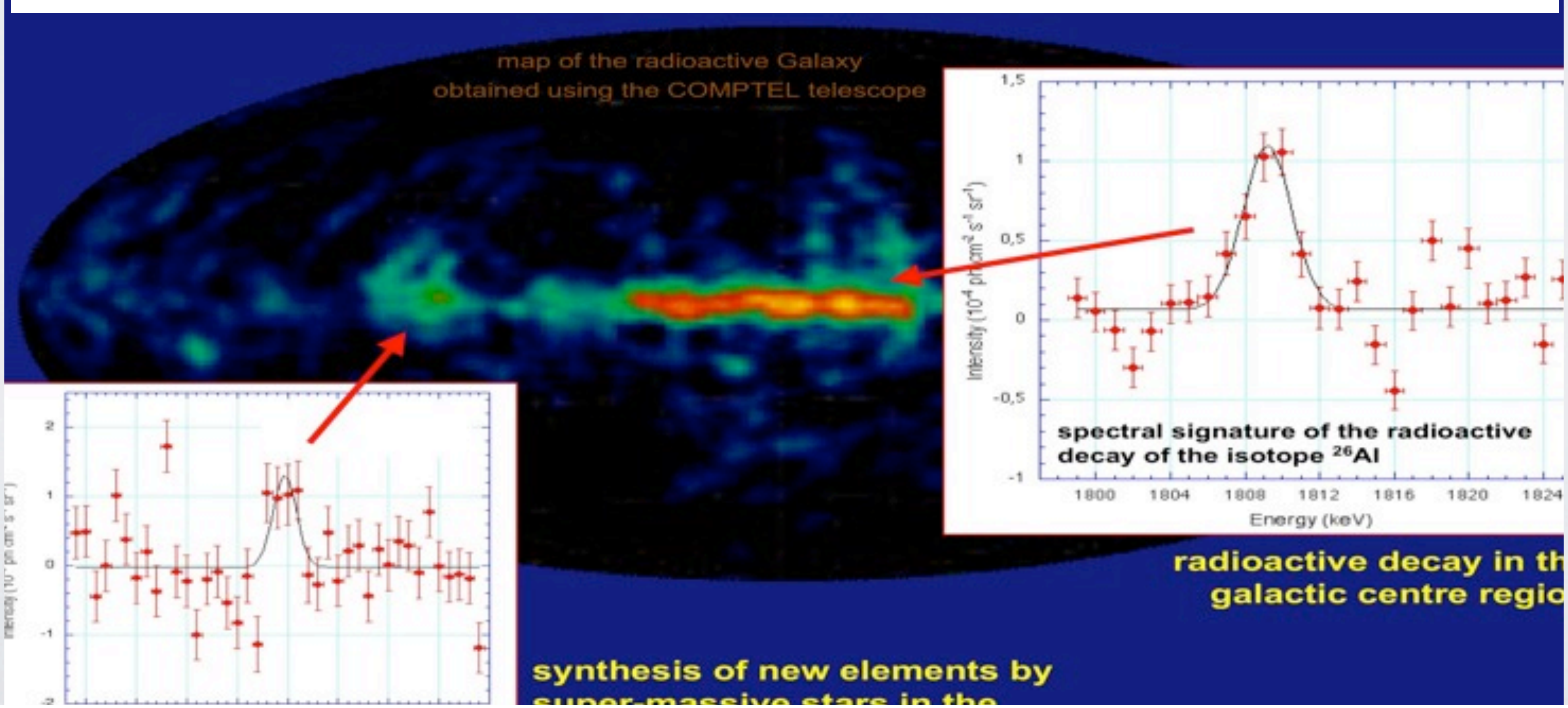


Fig. 2. A fit of the SPI result for the diffuse emission from the GC region ($|l|, |b| \leq 16°$) obtained with a spatial model consisting of an 8° *FWHM* Gaussian bulge and a CO disk. In the fit a diagonal response was assumed. The spectral components are: 511 keV line (dotted), Ps continuum (dashes), 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.

distribution of the INTEGRAL 511 keV line





Light (MeV) DM

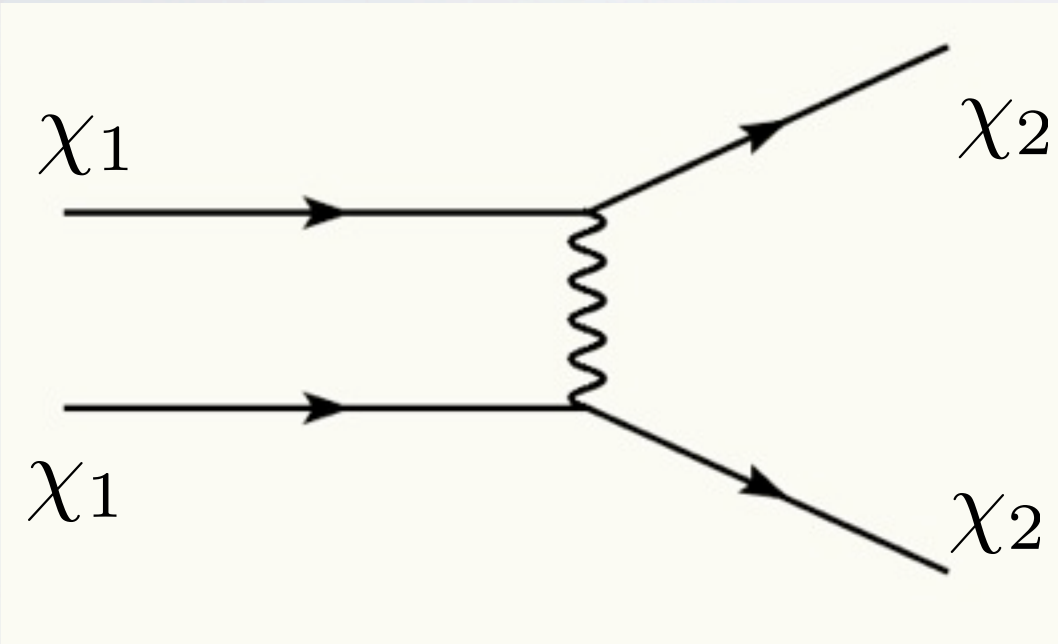
Boehm & Fayet '03; Boehm, Hooper, Silk, Casse, Paul '03

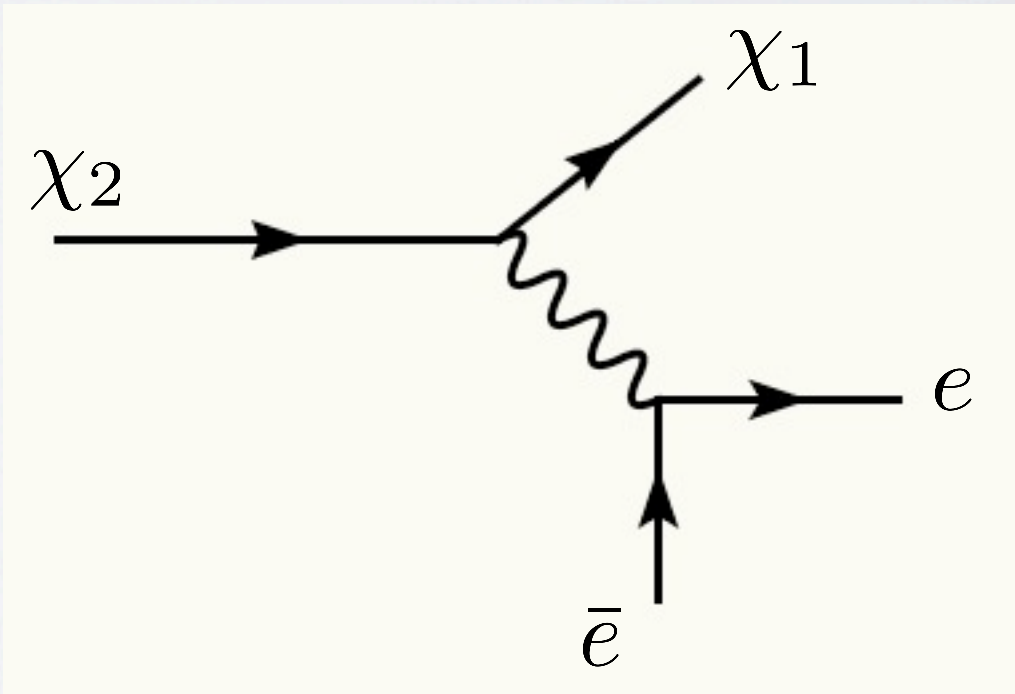
- Want an MeV WIMP to annihilate to e+e-
- How does such a stable particle interact with us?
- Need MeV mass boson (precision g-2? tough, but OK)

eXciting DM (XDM)

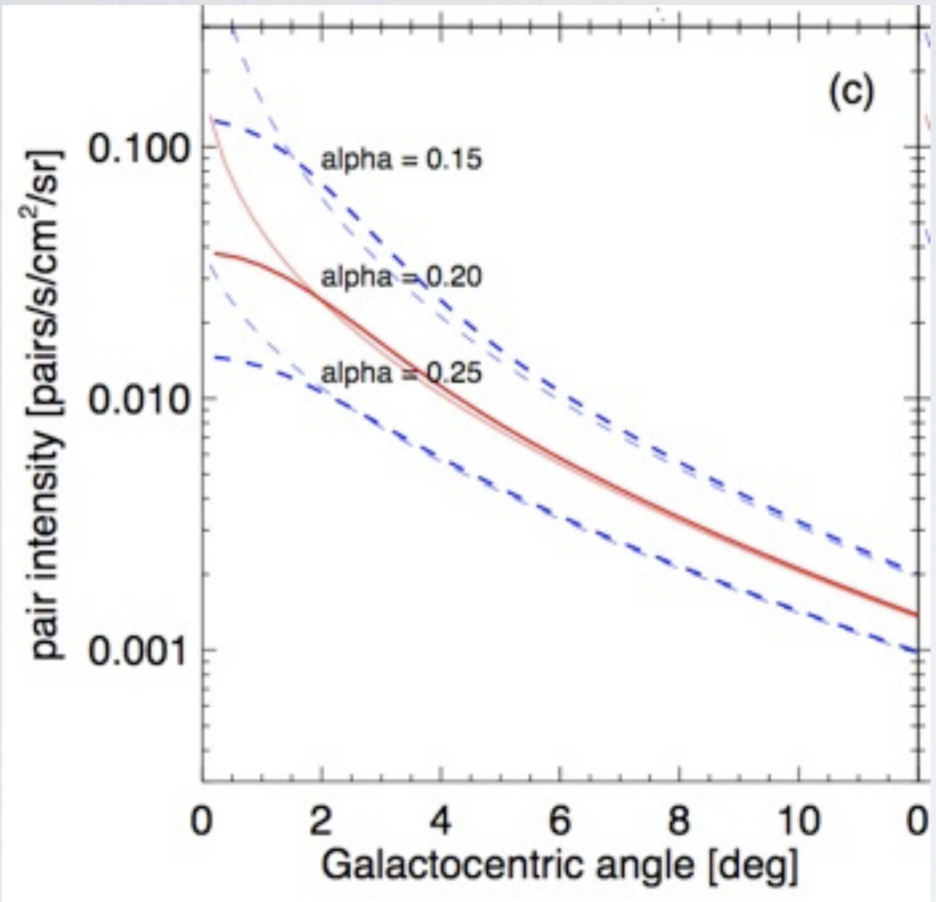
D.Finkbeiner, NW,
Phys.Rev.D76:083519,2007

- Suppose TeV mass dark matter has an excited state ~ MeV above the ground state and can scatter off itself into the excited state, then decay back by emitting e+e-





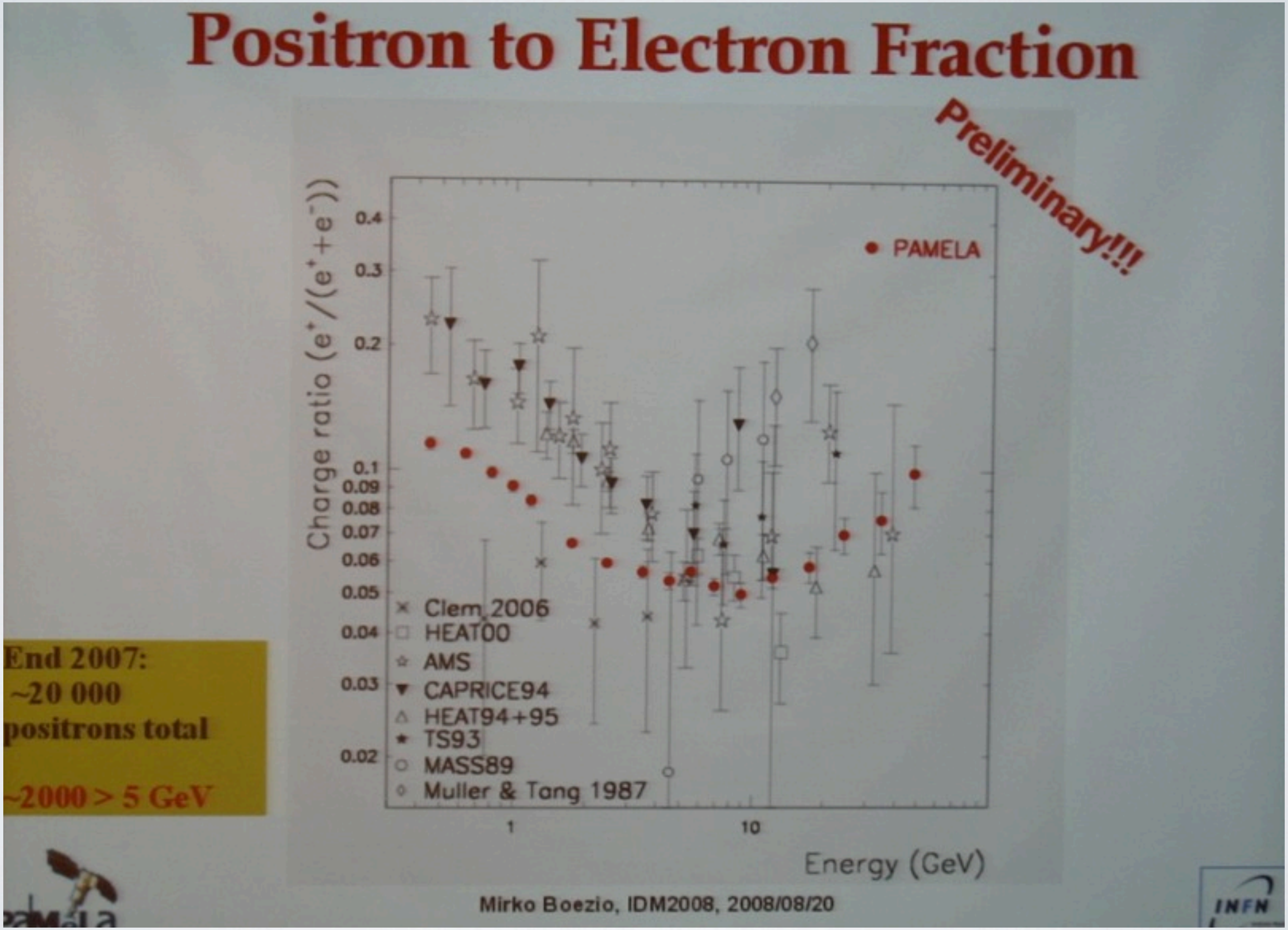
Need cross section near the geometric cross section, i.e.



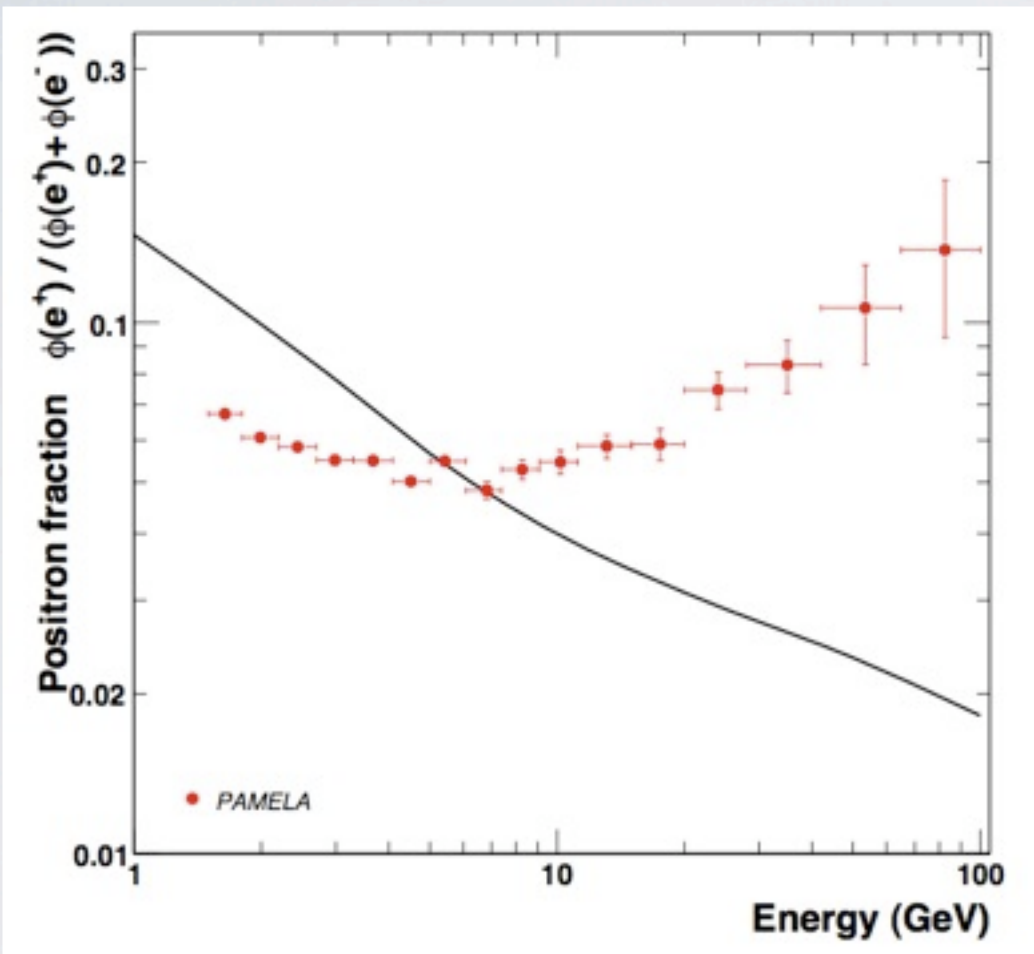
sigma ~ 1/q^2

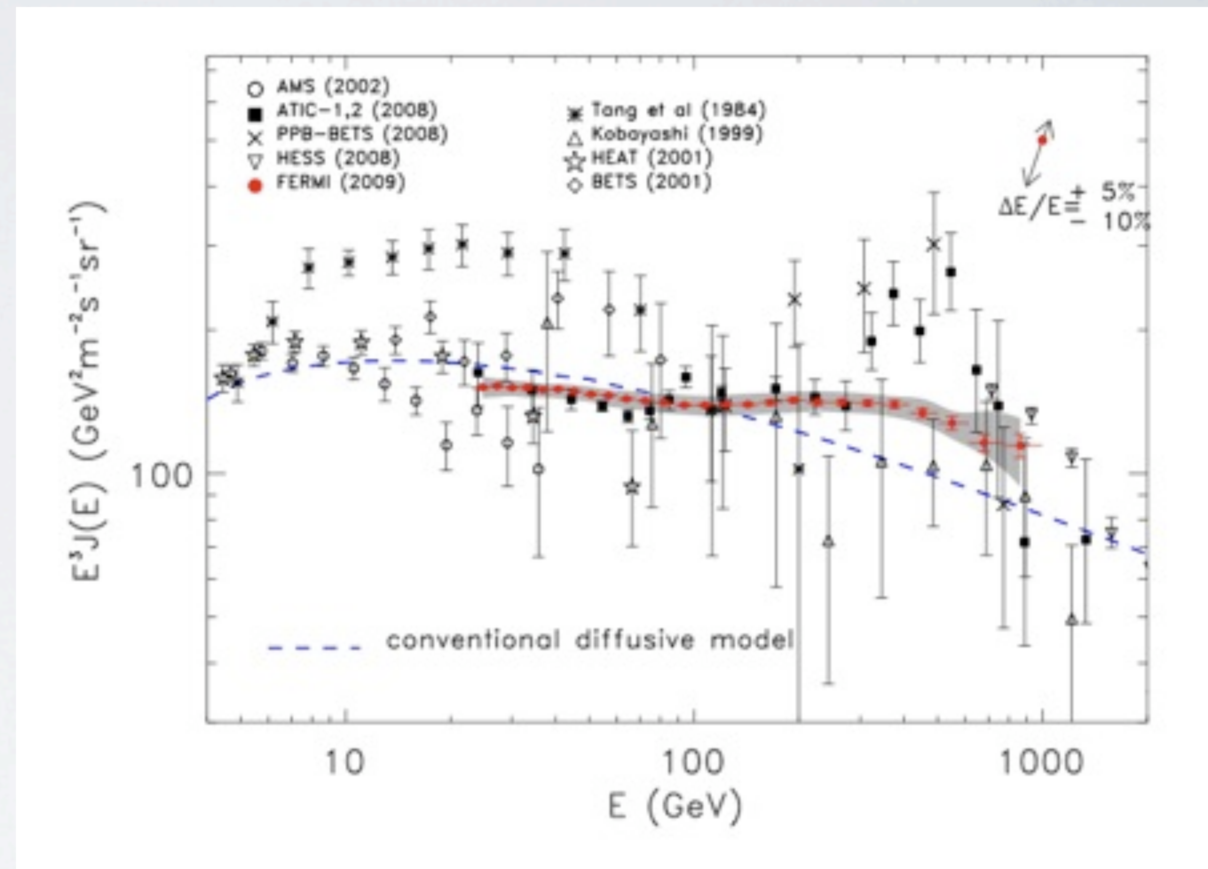
Only possible if new force with mass less than q^2~ GeV^2 is in the theory

PAMELA


Positron to Electron Fraction
Preliminary!!!
PAMELA
Charge ratio (e+/(e++e-))
Energy (GeV)
Clem 2006
HEAT00
AMS
CAPRICE94
HEAT94+95
TS93
MASS89
Muller & Tang 1987
End 2007:
~20 000
positrons total
~2000 > 5 GeV
Mirko Boezio, IDM2008, 2008/08/20
INFN

PAMELA/Fermi





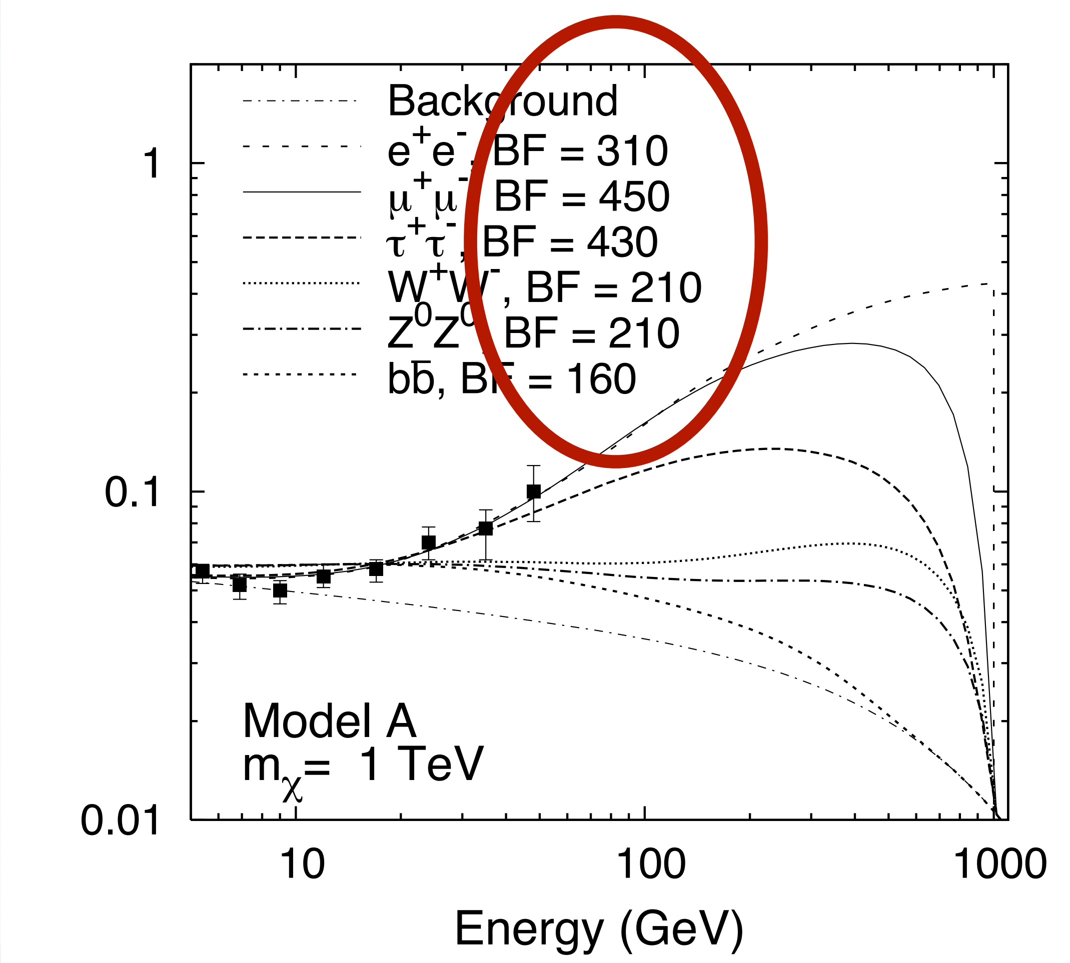
DM?

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

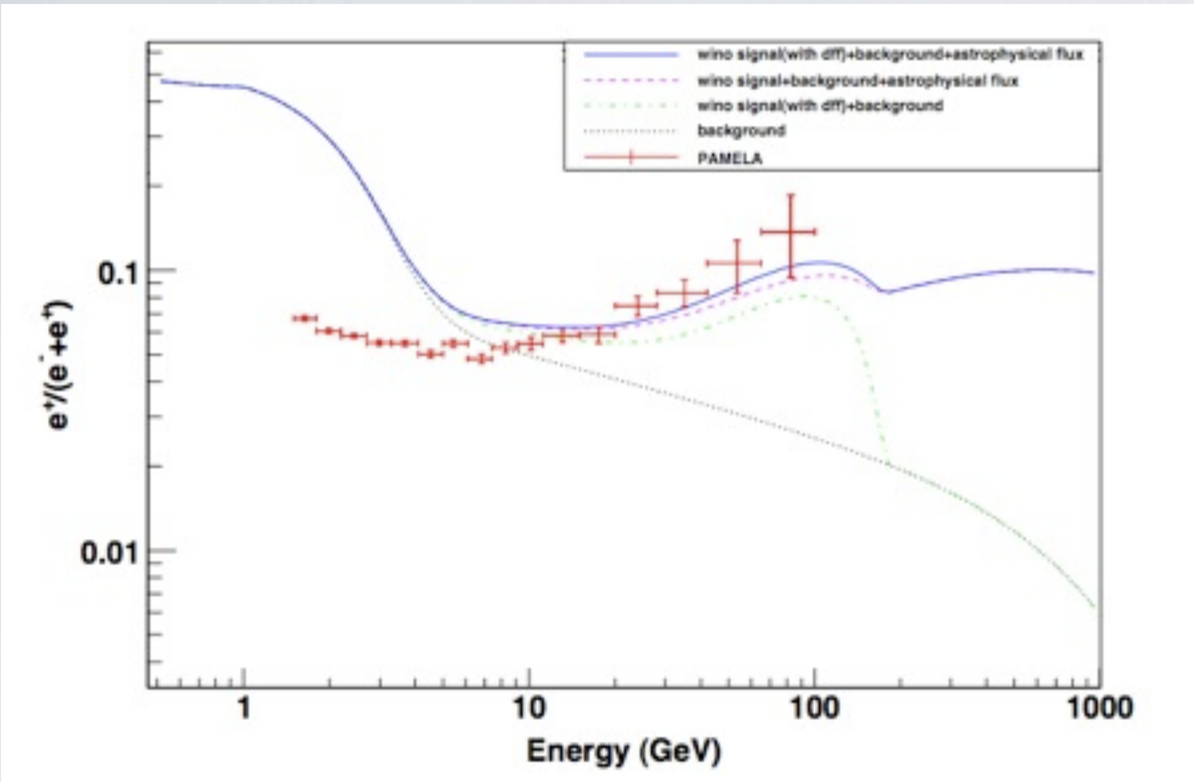


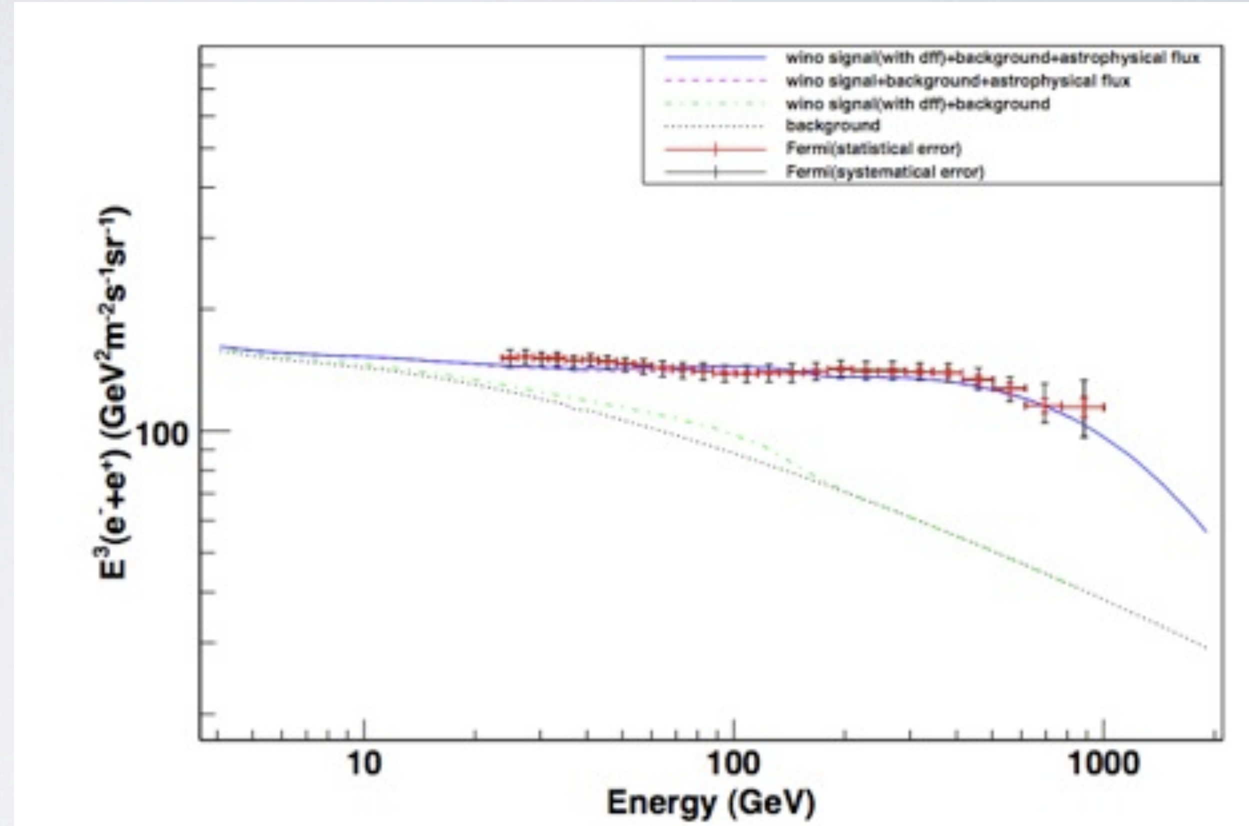
Explaining PAMELA/Fermi

- Issues to address
- (1) Size of signal
- (2) Hard positrons
- (3) No antiprotons
- Dark matter could be produced non-thermally (gets 1, model build for 2/3)
- Dark matter could decay (gets 1, model build 2/3)
- Dark matter could interact through new, GeV scale force (gets 1,2,3, model build GeV scale)

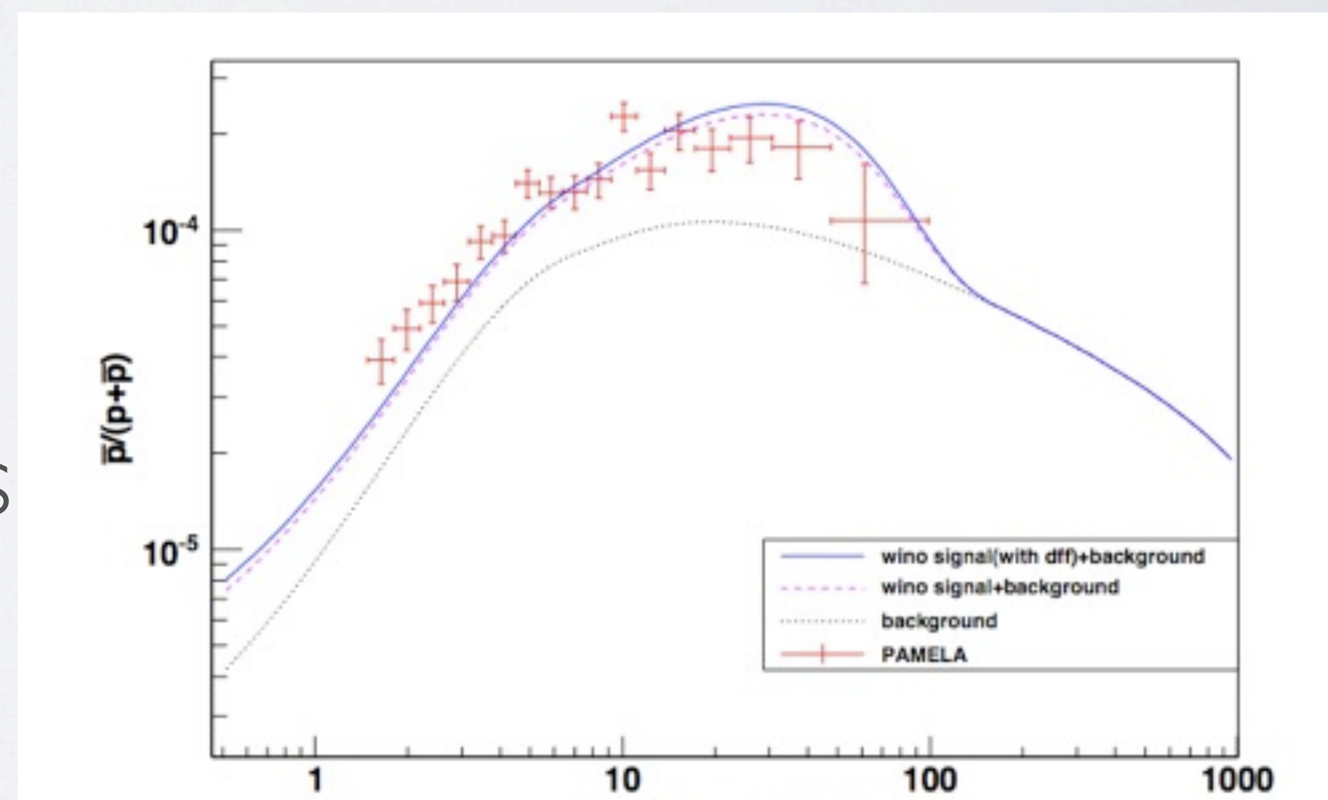
Non-thermal Winos

(Grajek, Kane, Phalen, Pierce, Watson, ’08; Kane, Lu, Watson ‘09)





Requires new source of electrons; constrained by recent Fermi measurements



Decaying DM

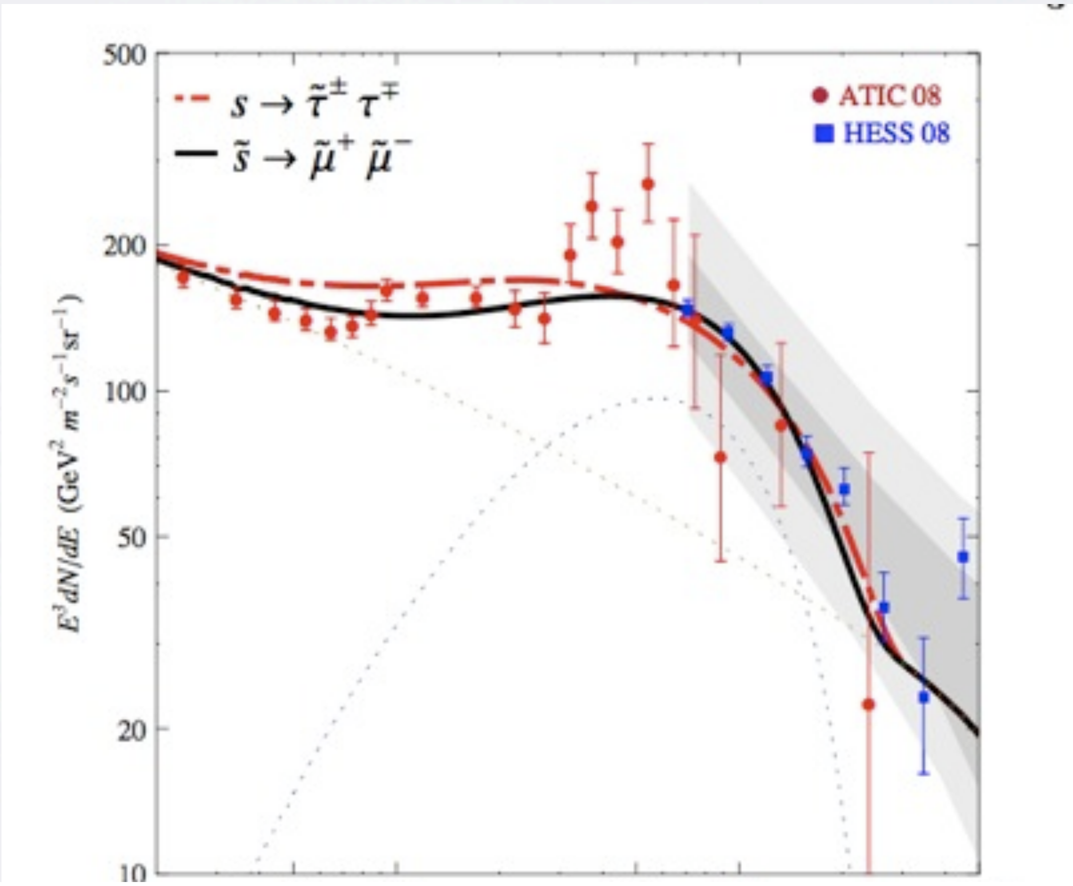
Eichler '89; Chen, Takahashi, Yanagida '08; Yin, Yuan, Liu, Zhang, Bi, Zhu '08; Ibarra, Tran '09; Arvanitaki, Dimopoulos, Dubovsky, Graham, Harnik, Rajendran '09...

Why is lifetime 10^27 s?

$$\frac{TeV^5}{M_{GUT}^4} \sim (10^{26}\mathrm{sec})^{-1}$$

Why is dominantly going to leptons?

Some SUSY ideas, or decaying into light bosons



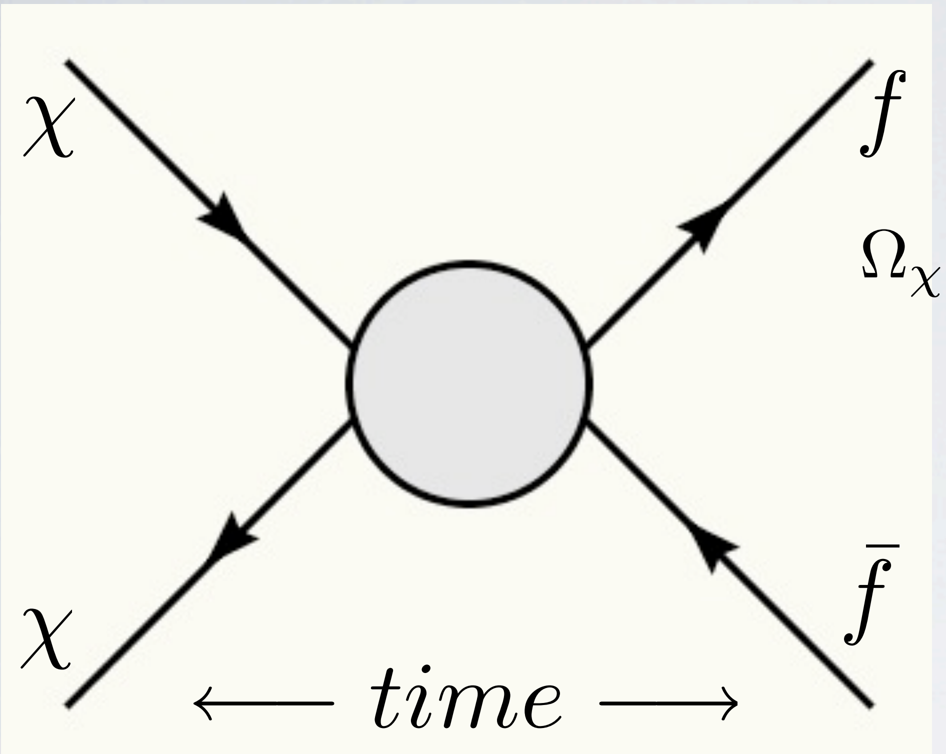
Arvanitaki, et al '09

New Dark Forces

- Revisit XDM setup: theory has light mediator Φ
- Mass must be below ~ GeV, what are consequences?

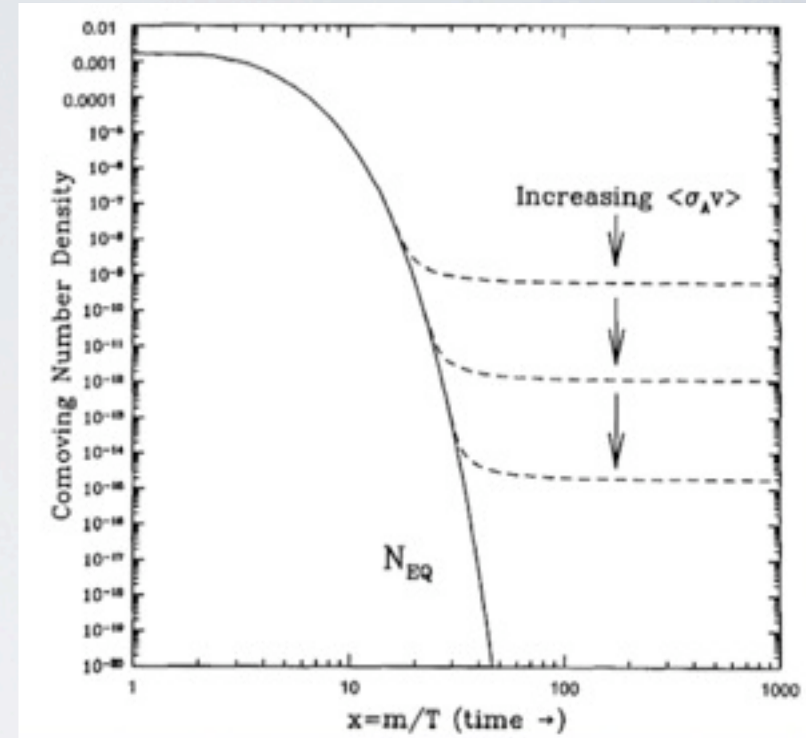
freezeout into a dark photon

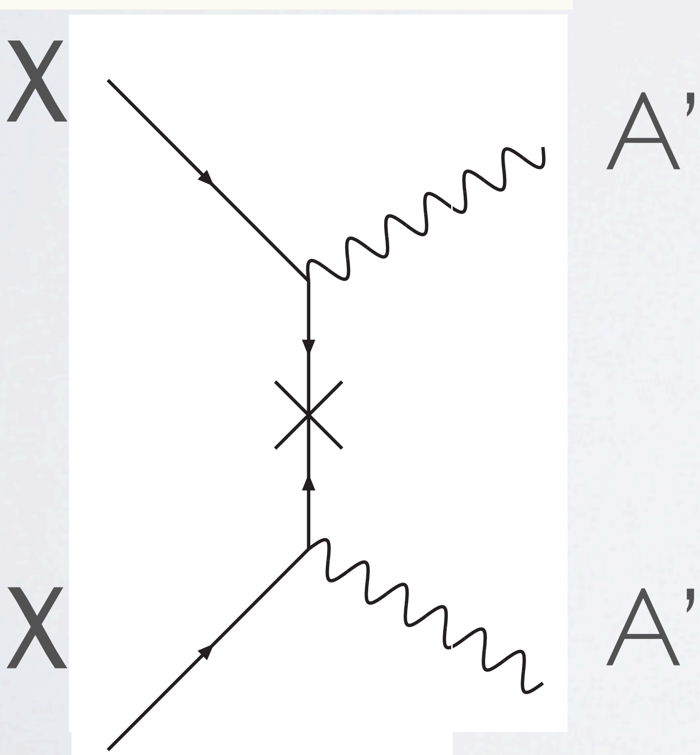
"Classic" WIMP

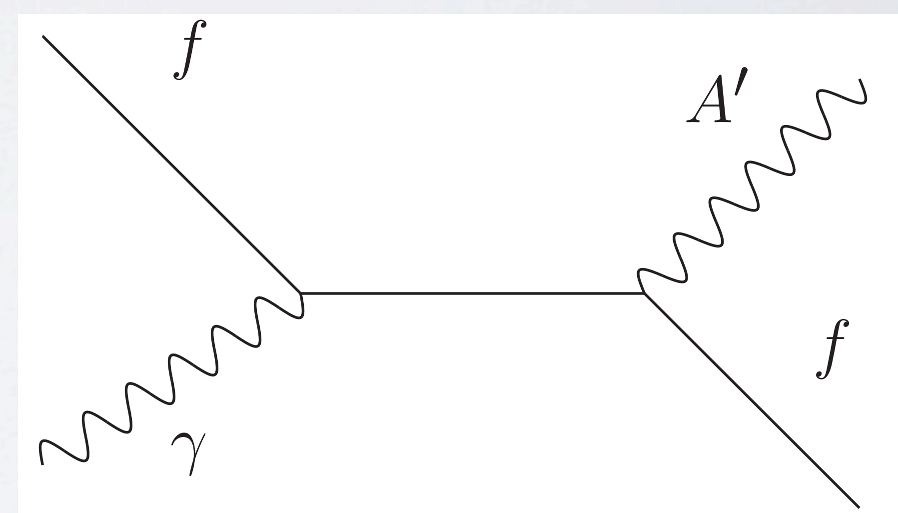


$$\Omega_\chi h^2 \approx 0.1 \times \frac{3 \times 10^{-26}\mathrm{cm}^3\mathrm{s}^{-1}}{\langle \sigma v \rangle}$$

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

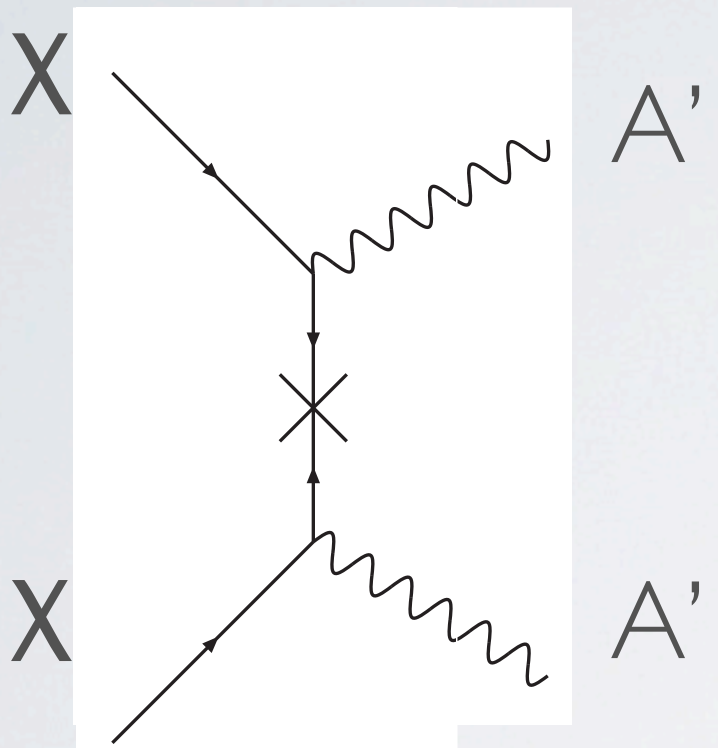


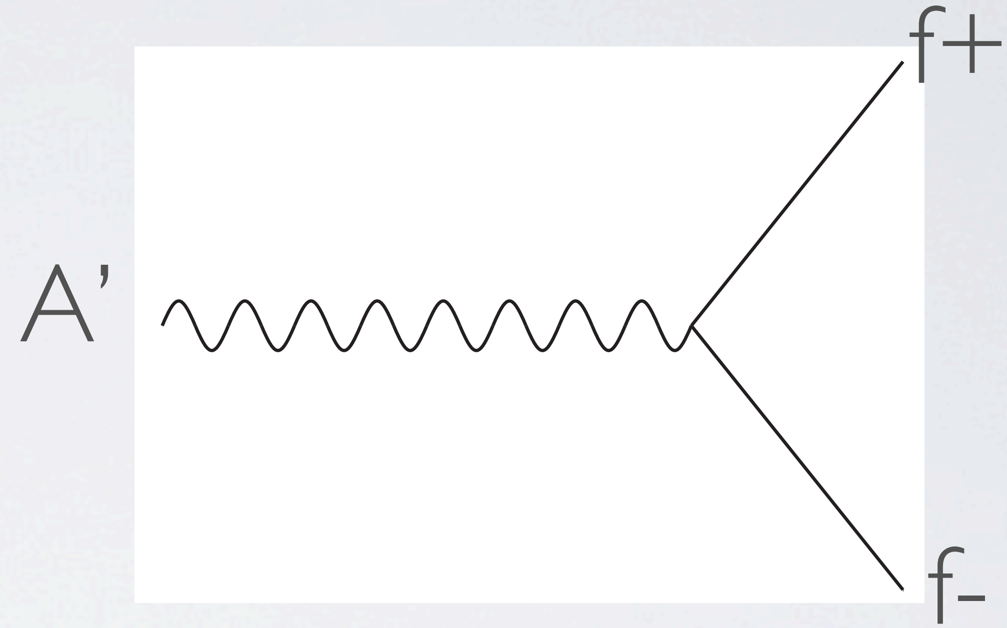




Finkbeiner, NW astro-ph 0702587v2; Pospelov,Ritz,Voloshin arxiv 0711.4866

cosmic rays: PAMELA/Fermi

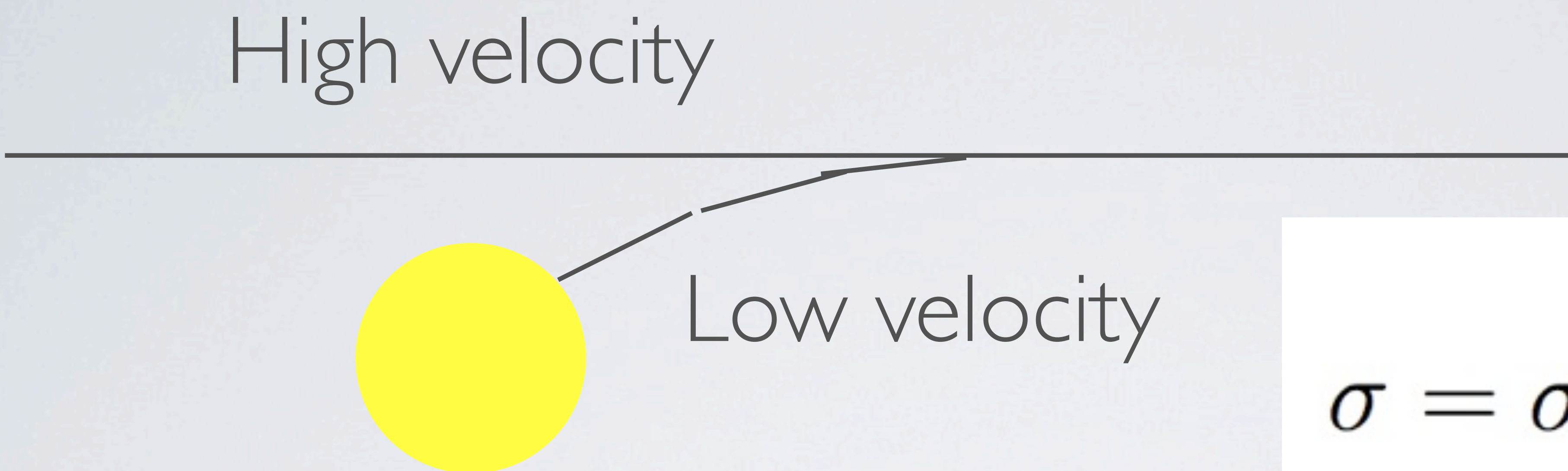




mA'<GeV (no antiprotons, hard leptons)

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

Sommerfeld Enhancement



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

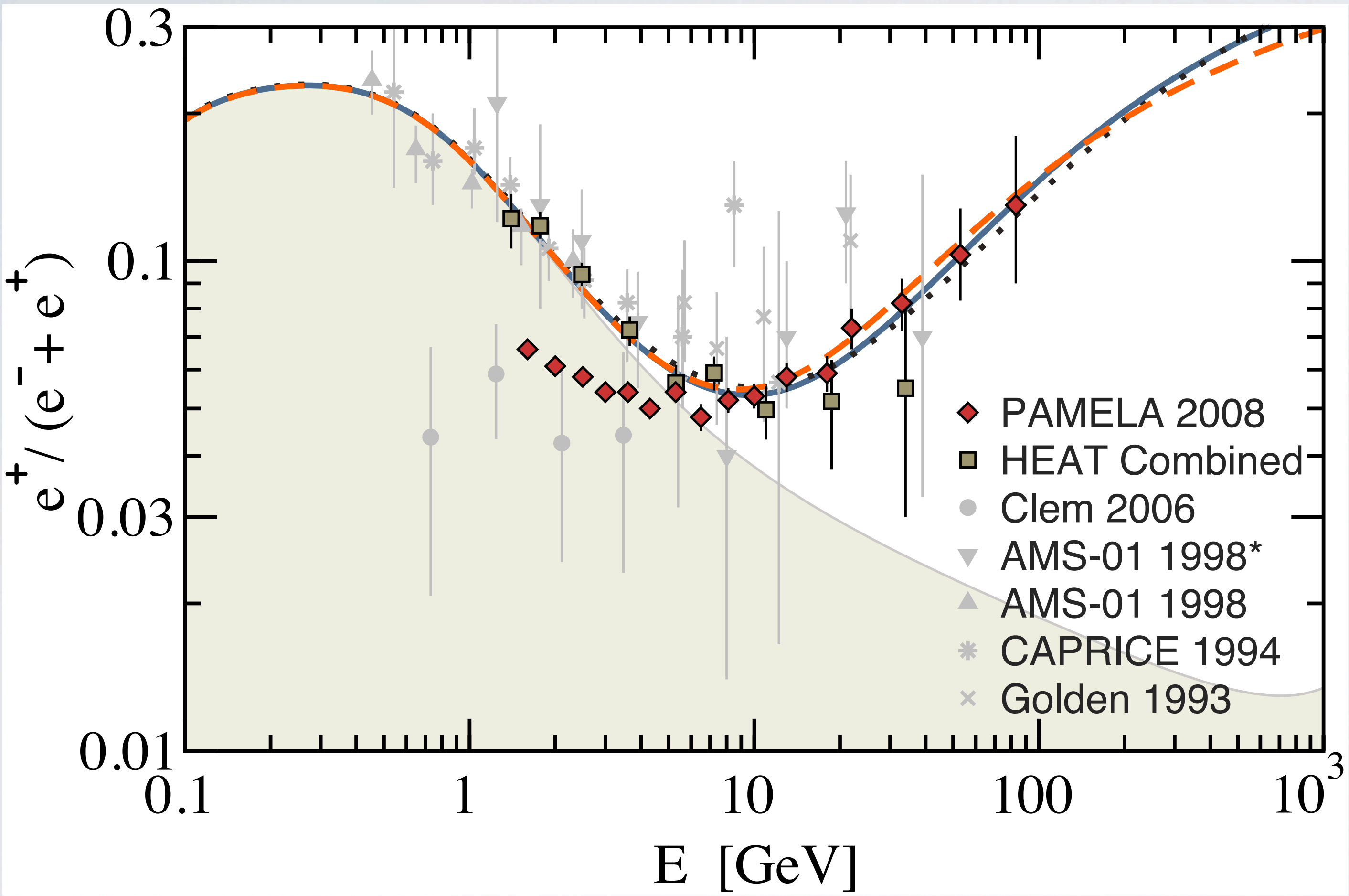
If particles interact via a "long range" force, cross sections can be much larger than the perturbative cross section

If these signals arise from thermal dark matter, dark matter must have a long range force

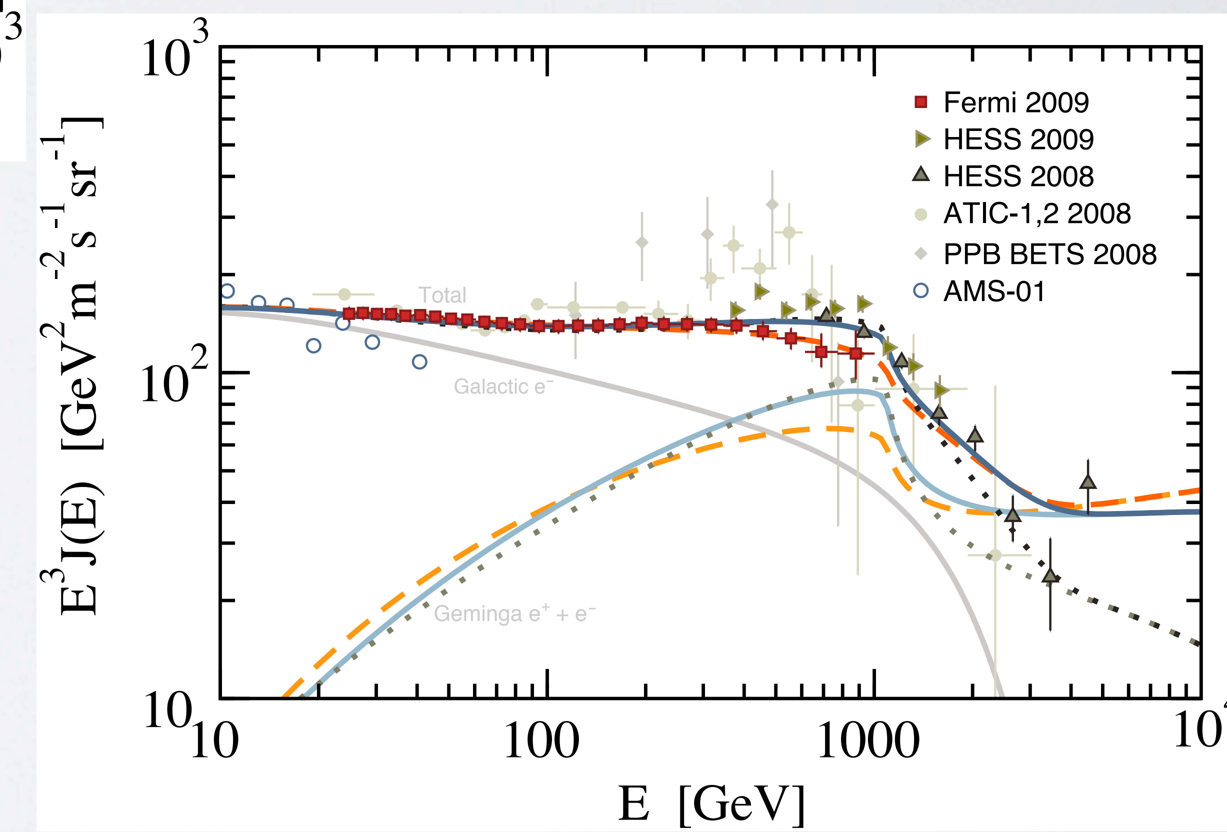
$$\mathrm{range} \sim \mathrm{fm} \sim (200\,\mathrm{MeV})^{-1}$$

Hisano, Nojiri, Matsumoto, '04; Cirelli, Strumia, Tamburini, '07; Arkani-Hamed, Finkbeiner, Slatyer, NW, '08; Pospelov, Ritz, '08

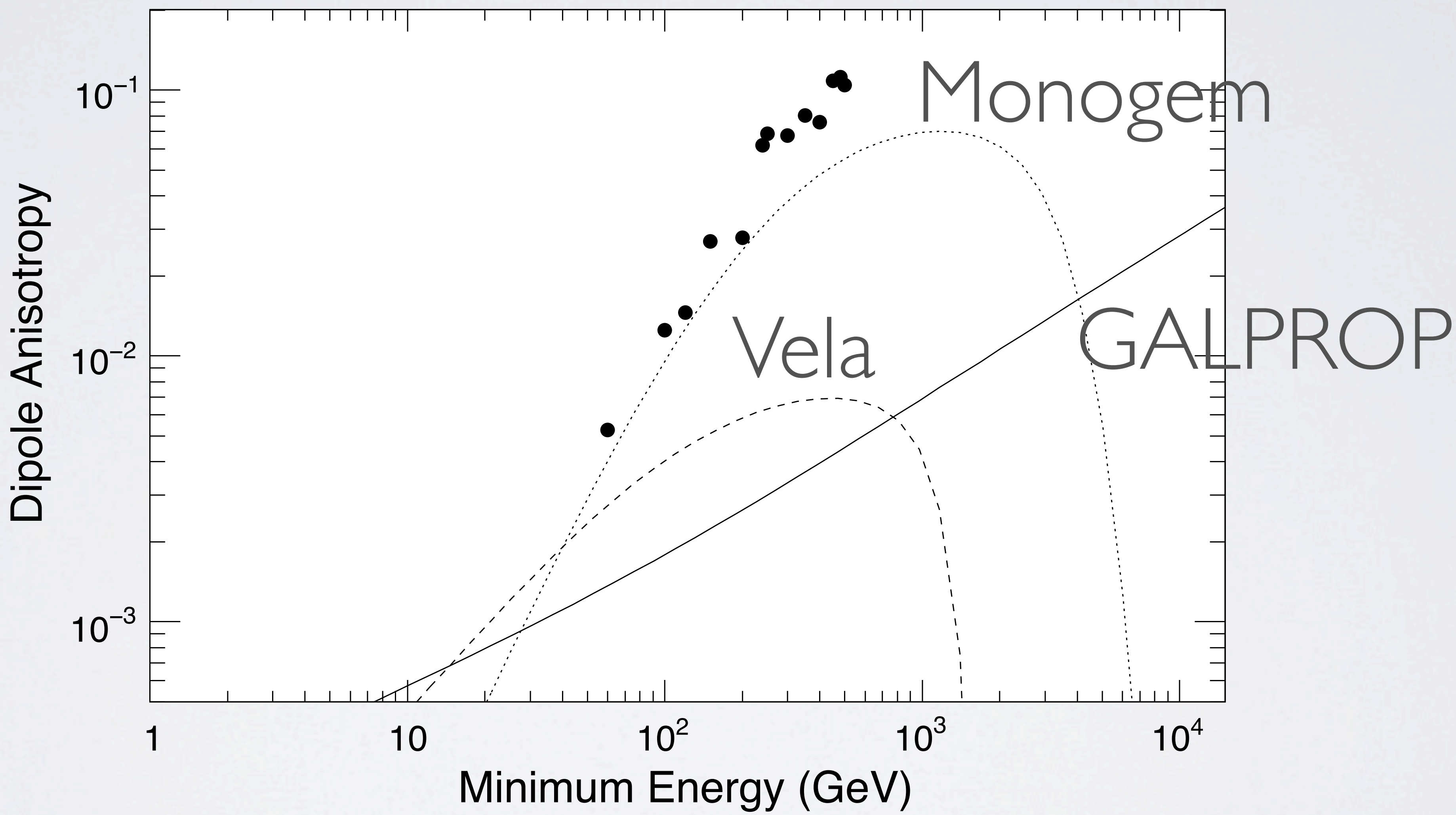
pulsars



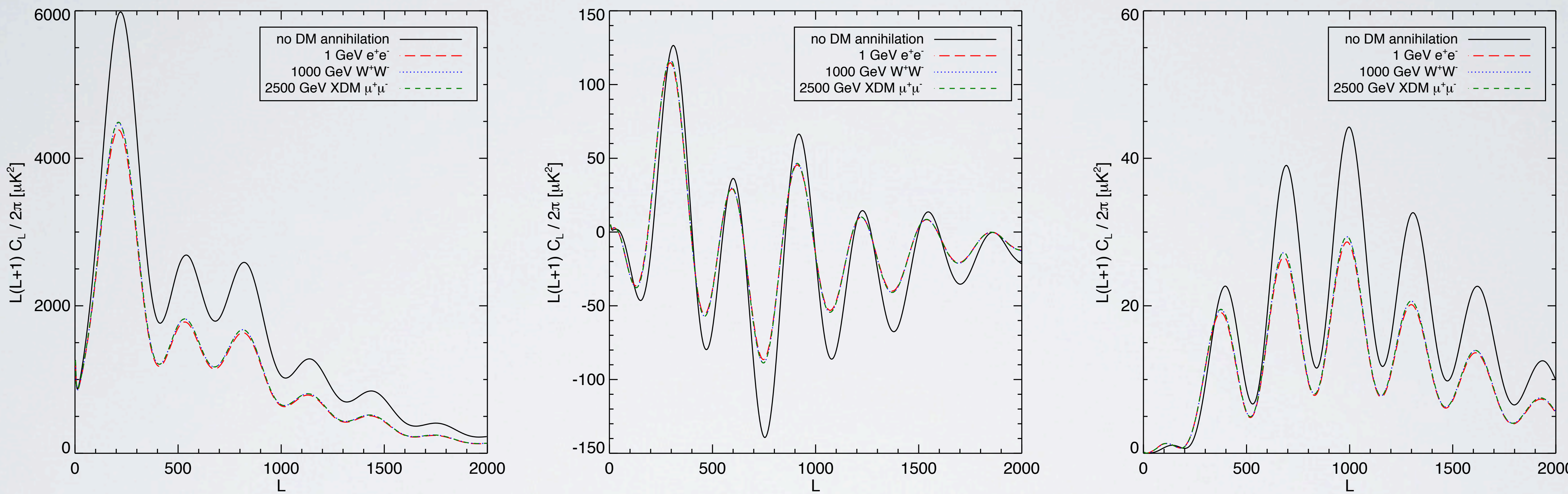
e.g. Yüksel, Kistler, Stanev '09



no anisotropy (yet)



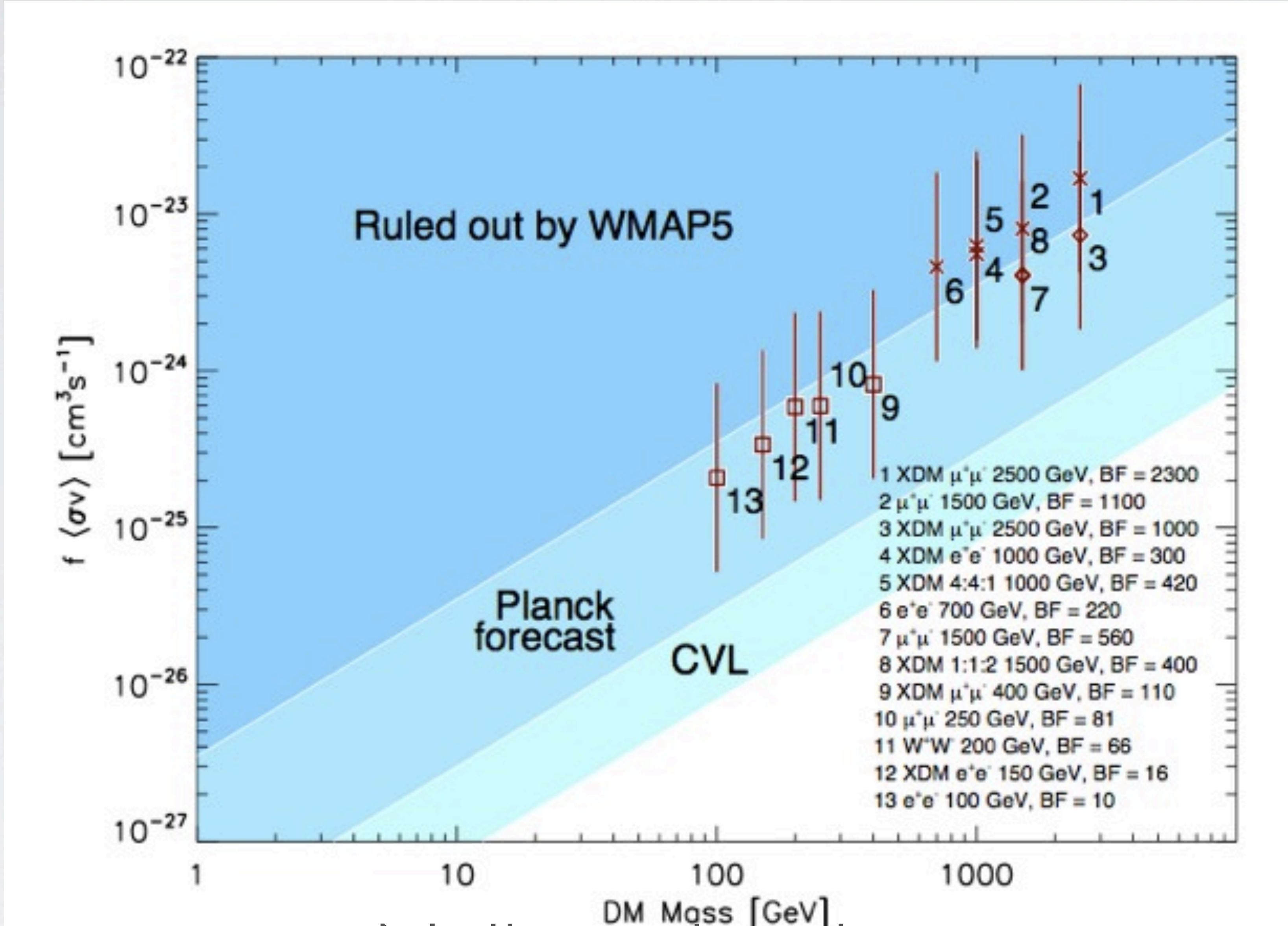
A resolution in 2013?



Null results: clear
Positive results?

Finkbeiner, Padmanabhan '05; Galli, Iocco, Bertone, Melchiorri '09;
Slatyer, Padmanabhan, Finkbeiner, '09

A resolution in 2013?



Null results: clear

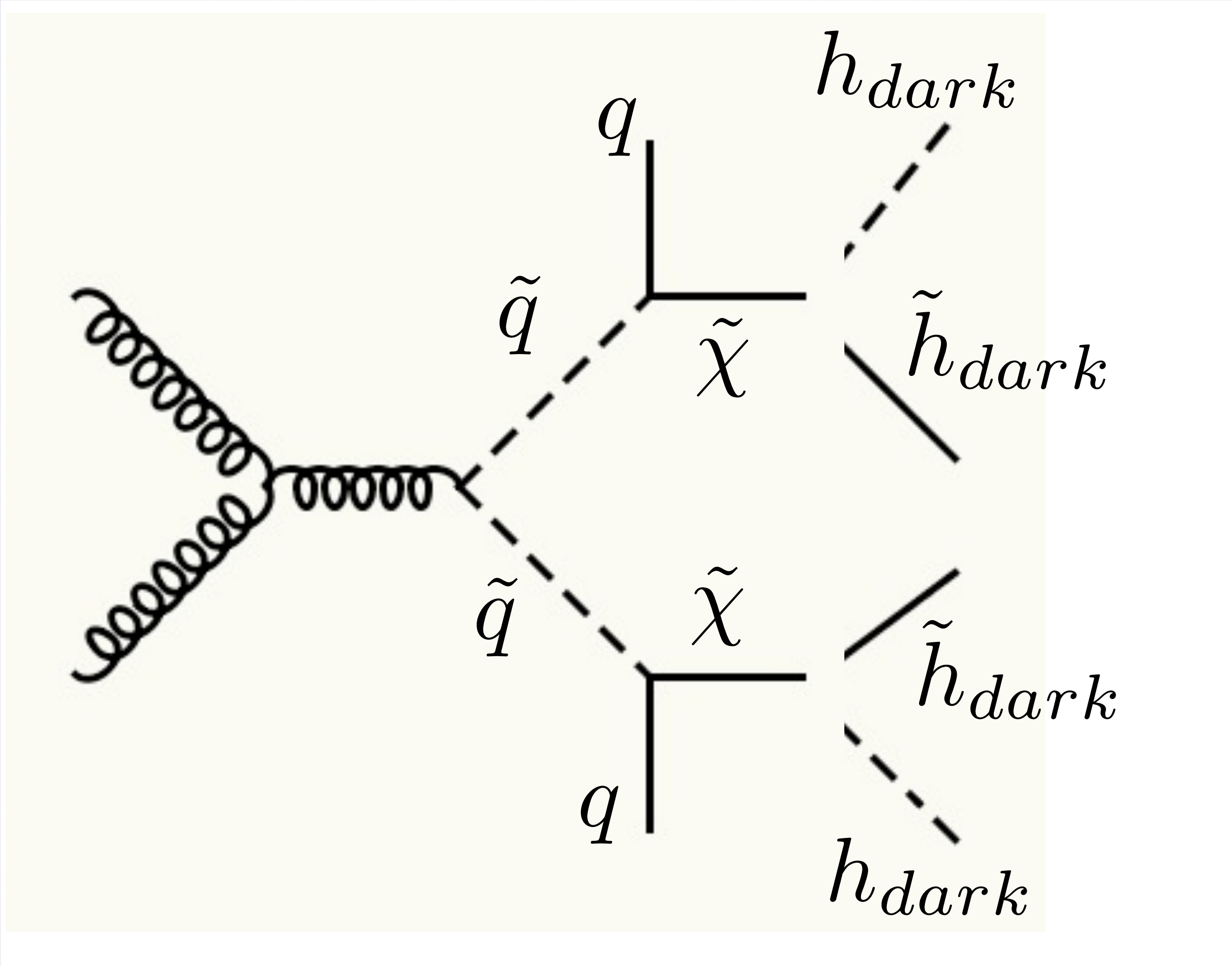
Positive results?

Finkbeiner, Padmanabhan ’05; Galli, Iocco, Bertone, Melchiorri ’09;
Slatyer, Padmanabhan, Finkbeiner, ’09

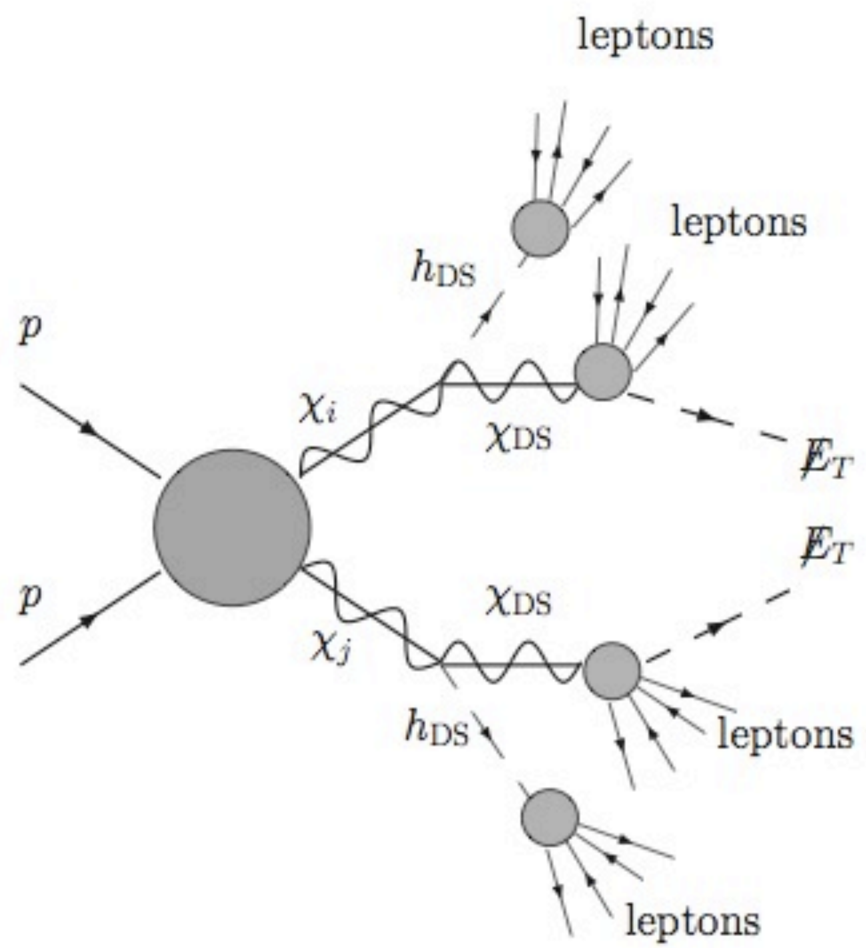
New Collider Pheno: Lepton Jets

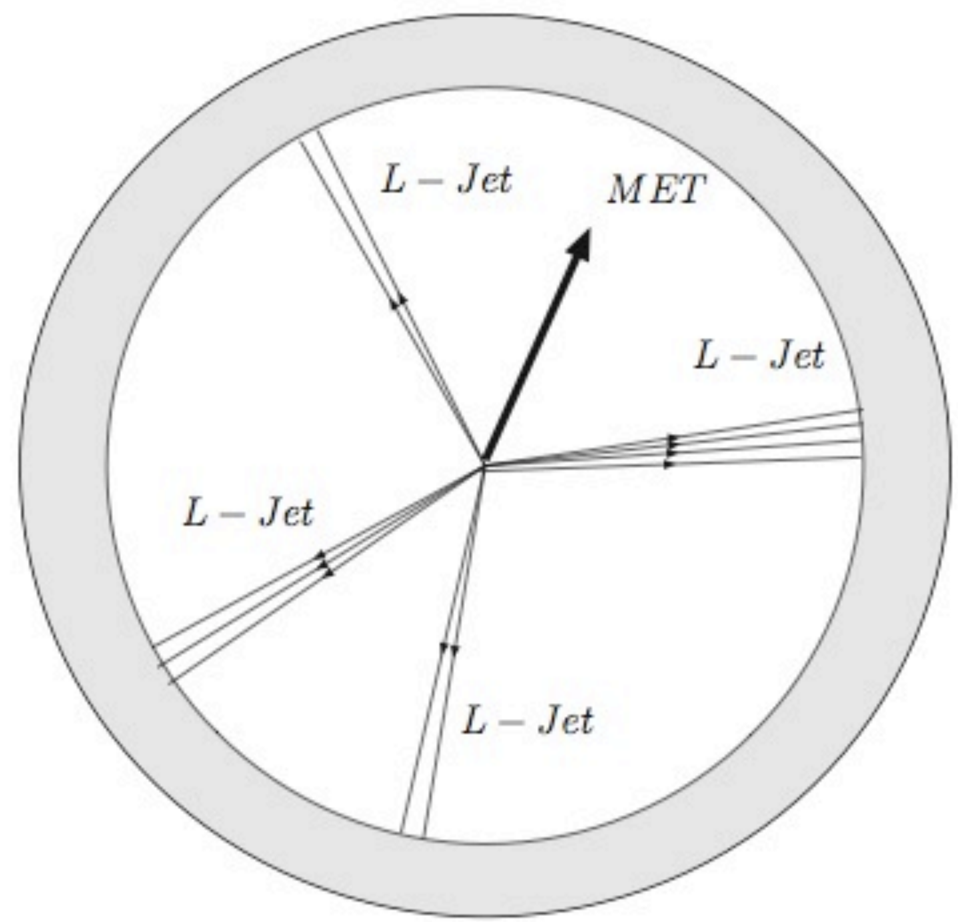
- Production of Gdark states, yield boosted, highly collimated leptons ("lepton jets")

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

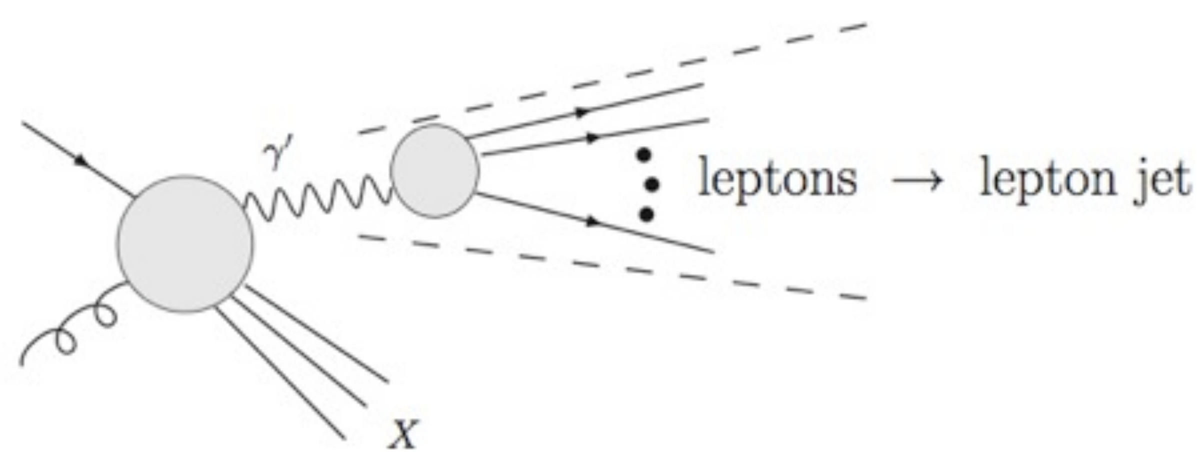


cf "Hidden Valley" models, Strassler and Zurek '06





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



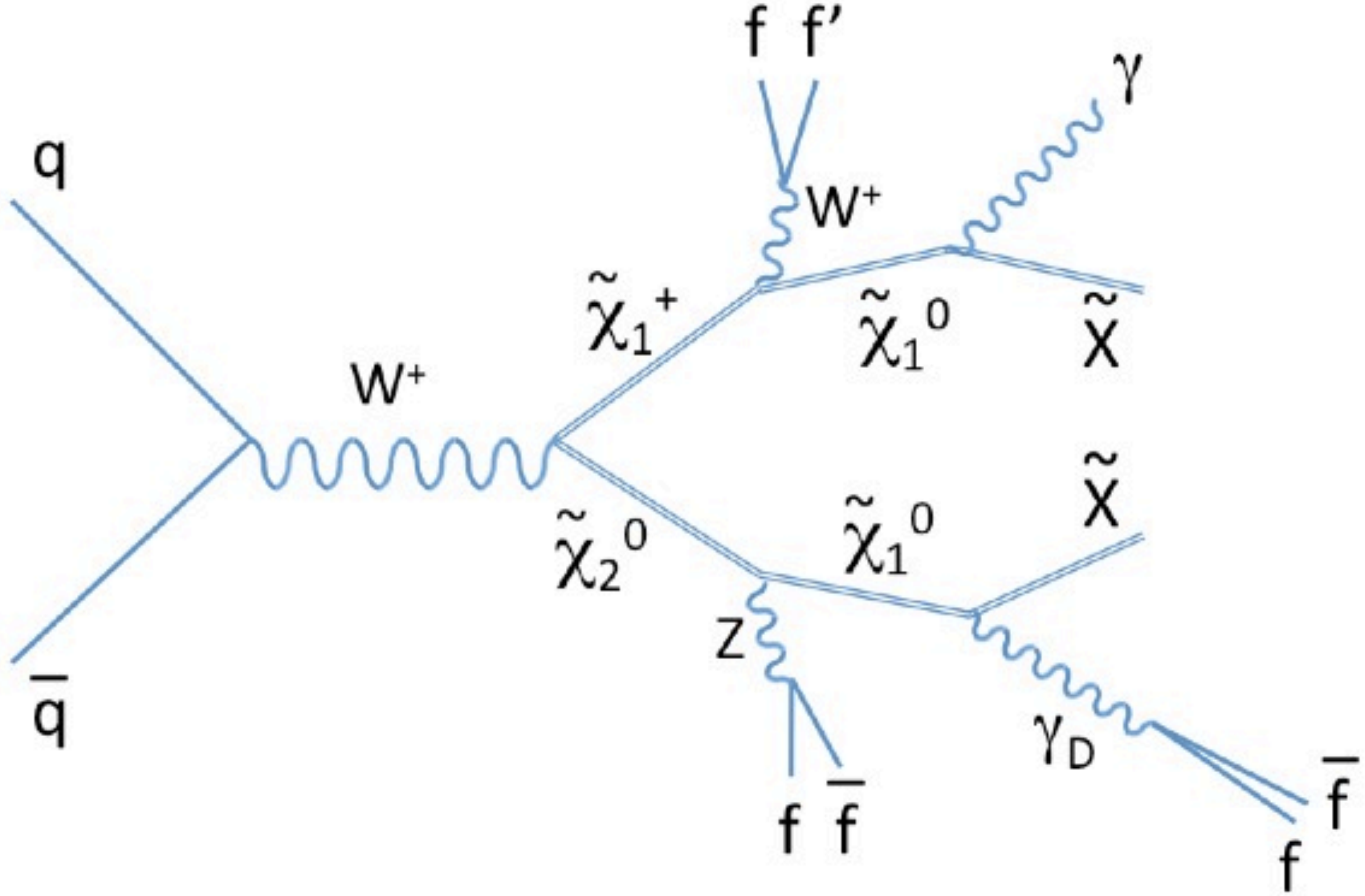


FIG. 1: One of the diagrams giving rise to the events with a photon, dark photon (γ_D), and large missing energy due to escaping darkinos ($\tilde{X}$) at the Fermilab Tevatron Collider.

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

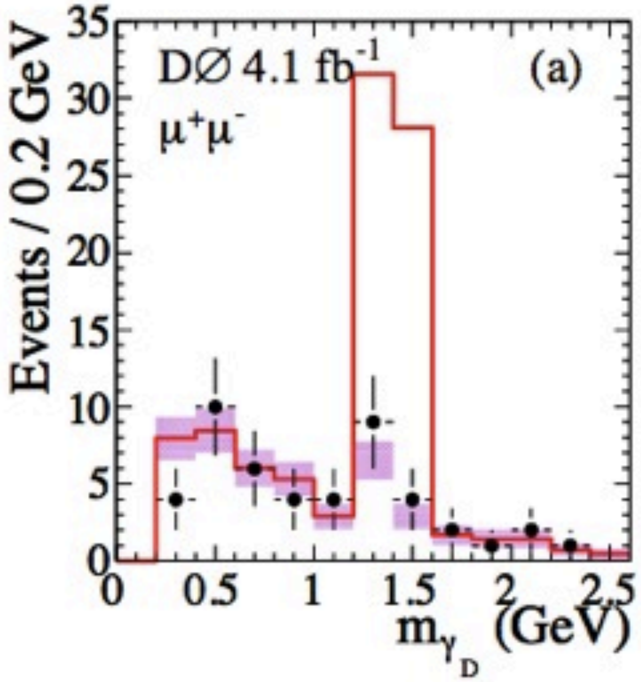


FIG. 2: Observed mass distributions in the signal region are represented as points with error bars, the background estimation is shown as filled band, and an example signal for $m_{\gamma_D} = 1.4$ GeV plus background is shown as the solid histogram for the dimuon channel (a) and the dielectron channel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

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

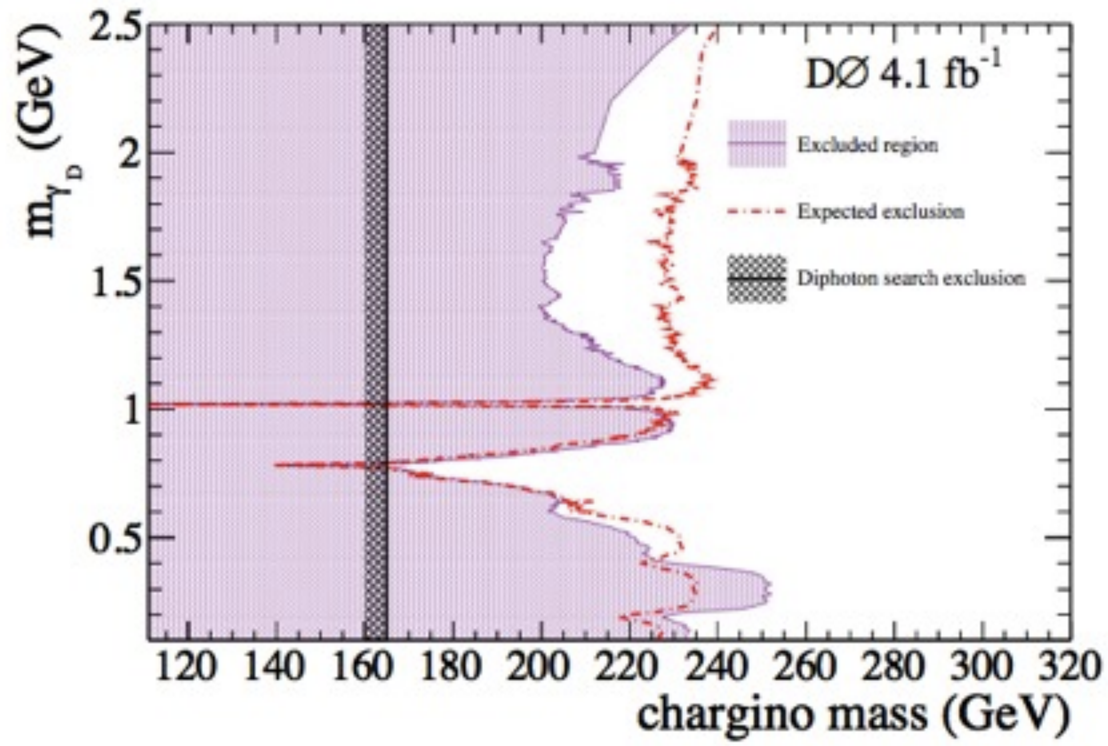
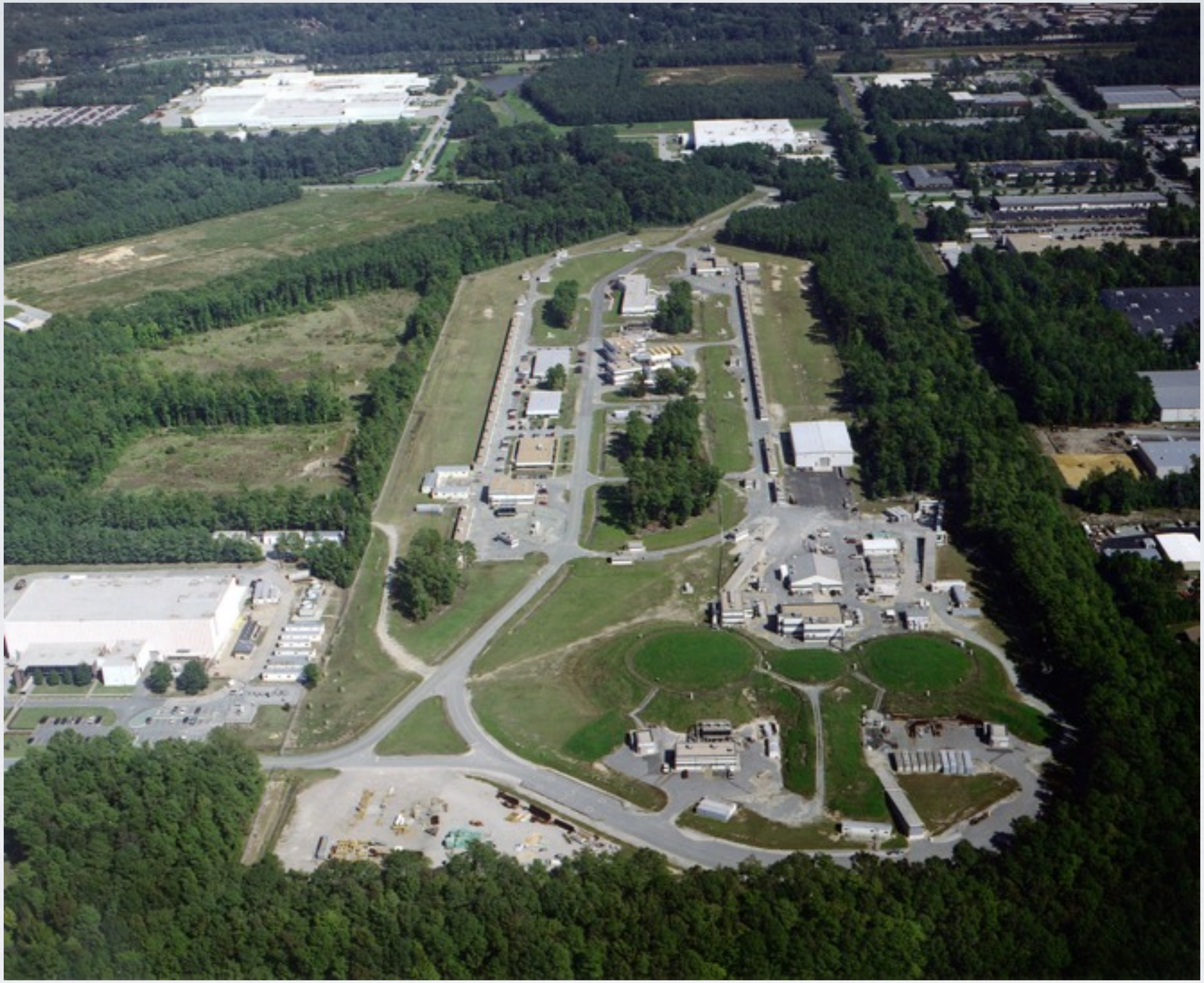


FIG. 3: The excluded region of possible masses of the lightest chargino and the dark photon for $\mathcal{B} = 0.5$ are shown as the shaded region. The expected limit is illustrated as the dash-dotted line. The vertical black line corresponds to the exclusion from the diphoton search [21].

SEARCHES AT LOW ENERGY

- Very weakly coupled, ~ GeV mass state
- LHC/Tevatron not the best place to make it



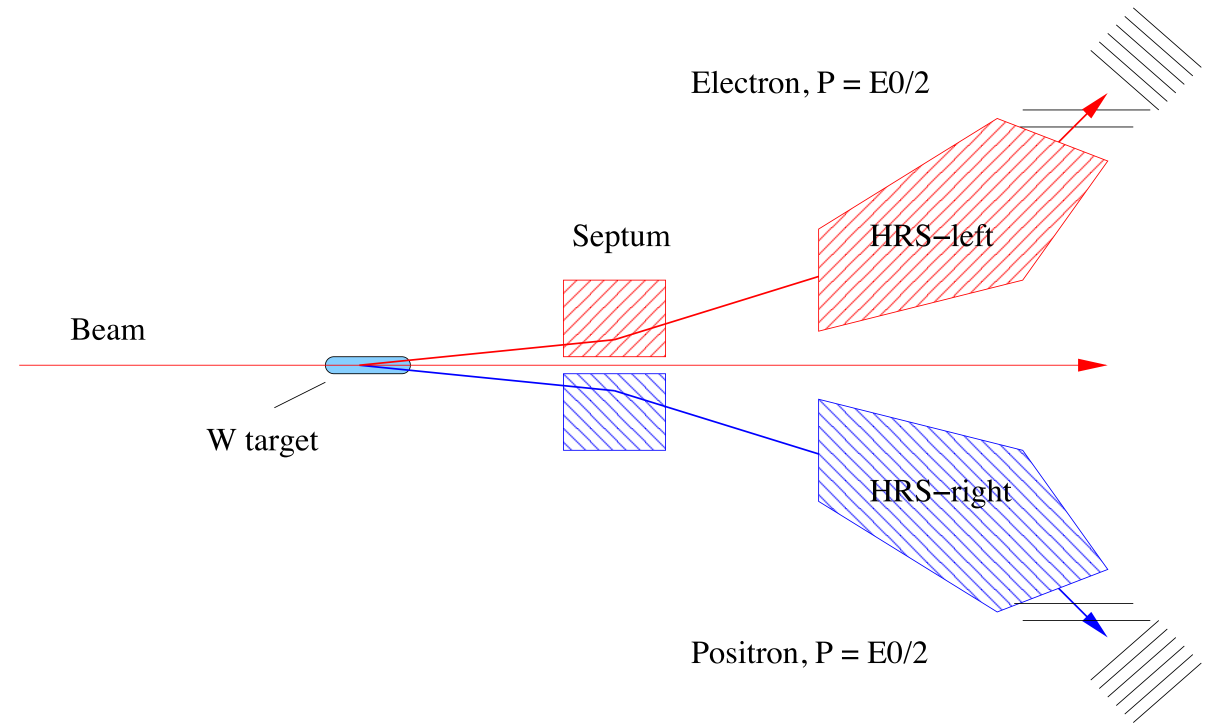
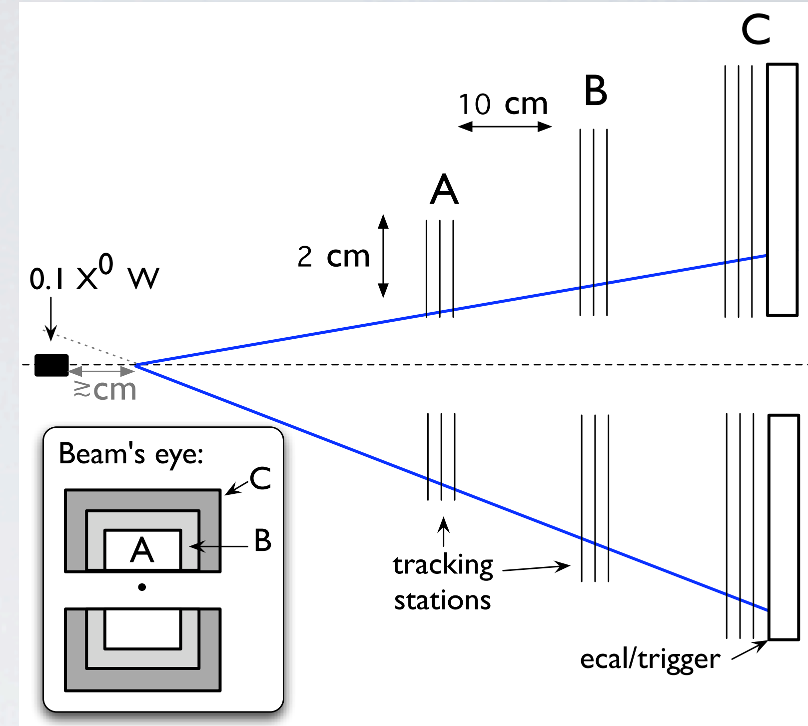
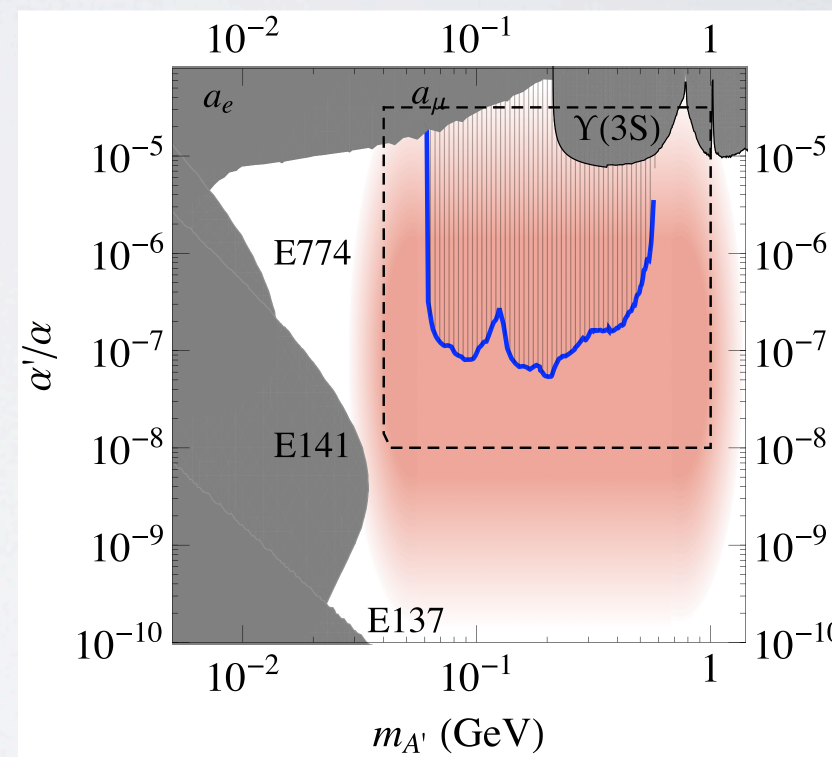


FIG. 5: The layout of the experimental setup — see text for details.

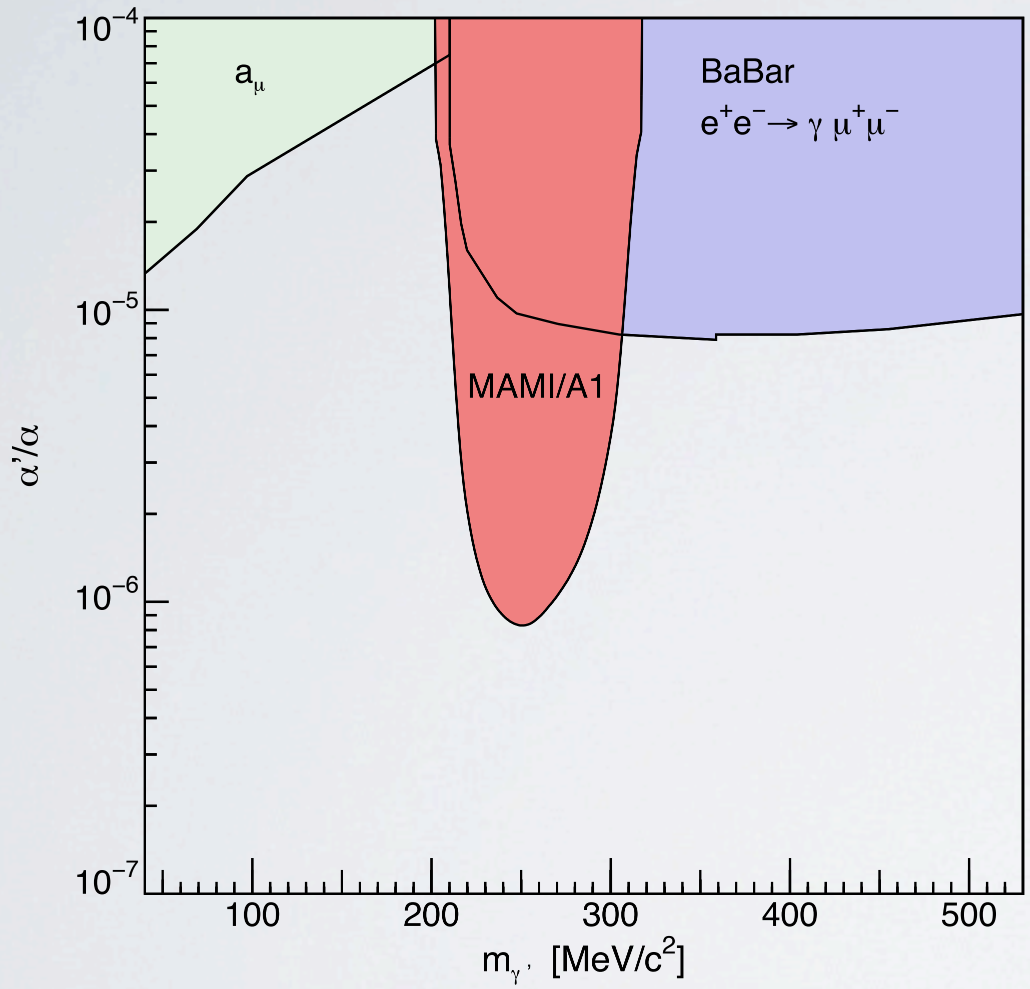


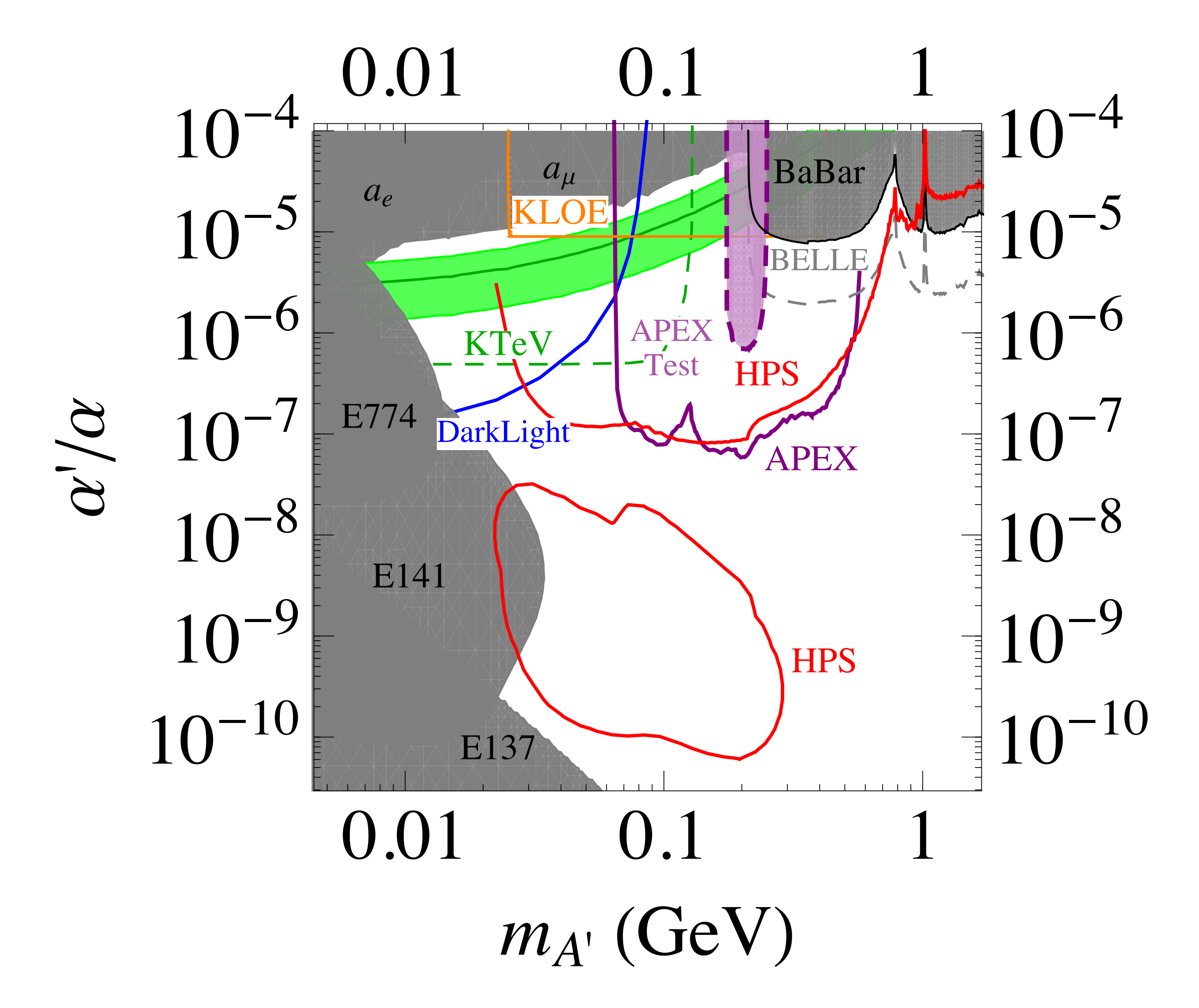


Bjorken, Essig, Schuster, Toro

APEX, HPS, Darklight... - searches for new physics at the **<GeV** scale

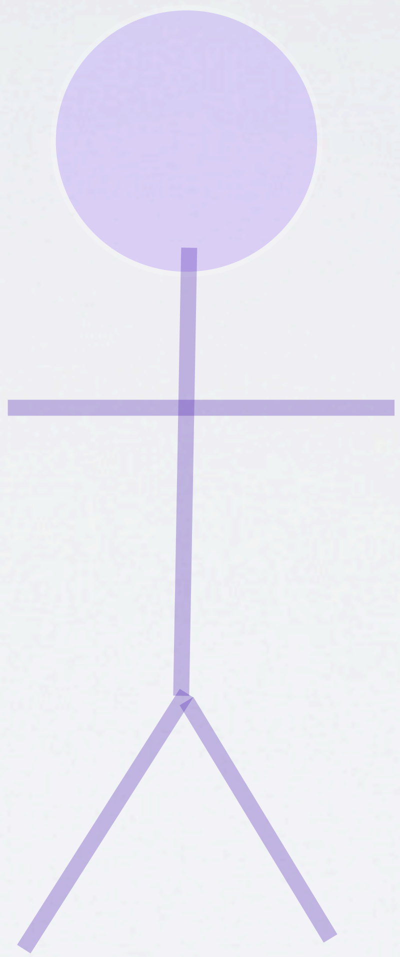
First results from MAMI





JLAB reach

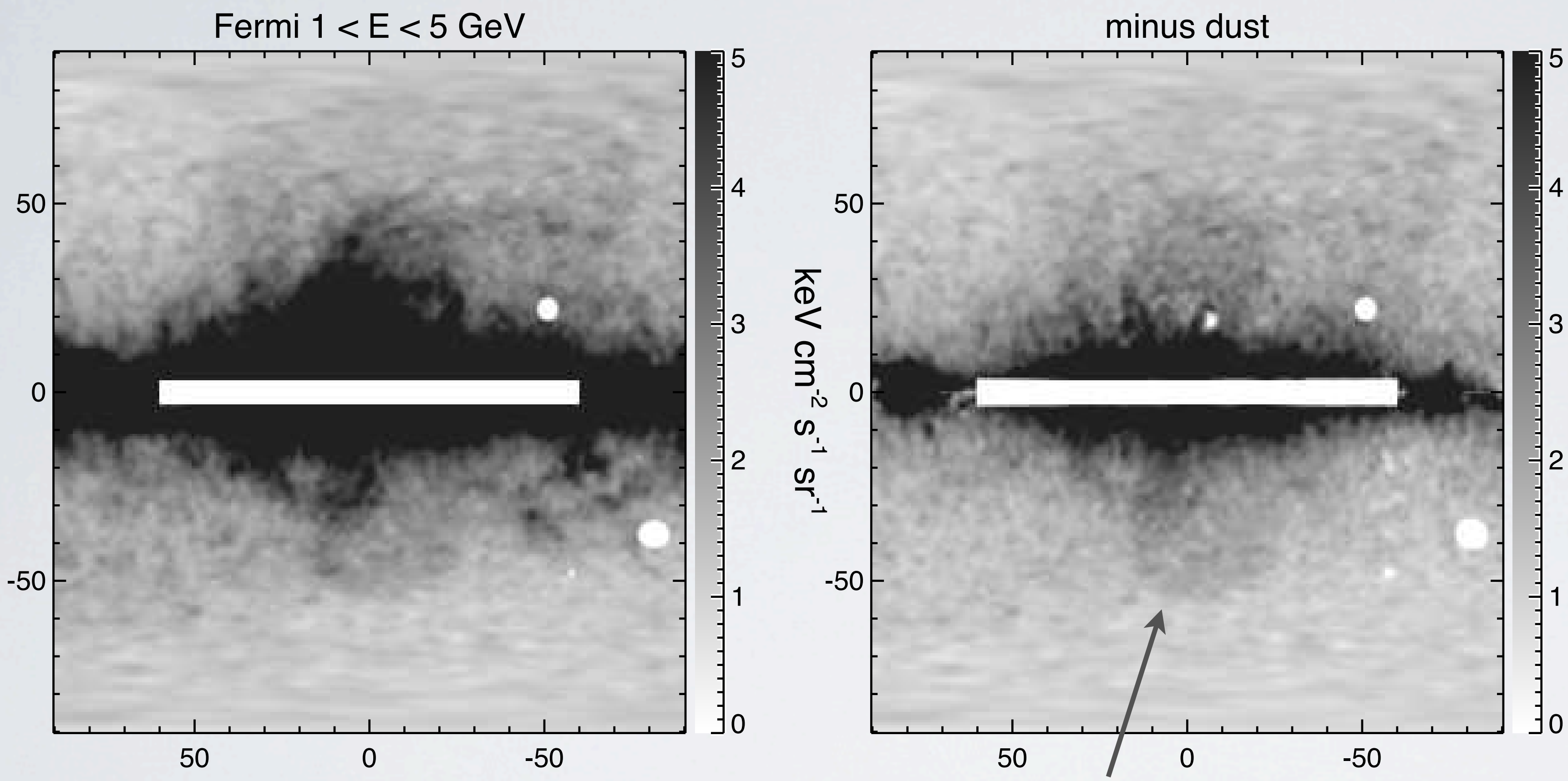
Prof. Dark Matter



DM 2011-2012

- Lots of new data
- Lots of new ideas
- Changes every month

Fermi haze/bubbles

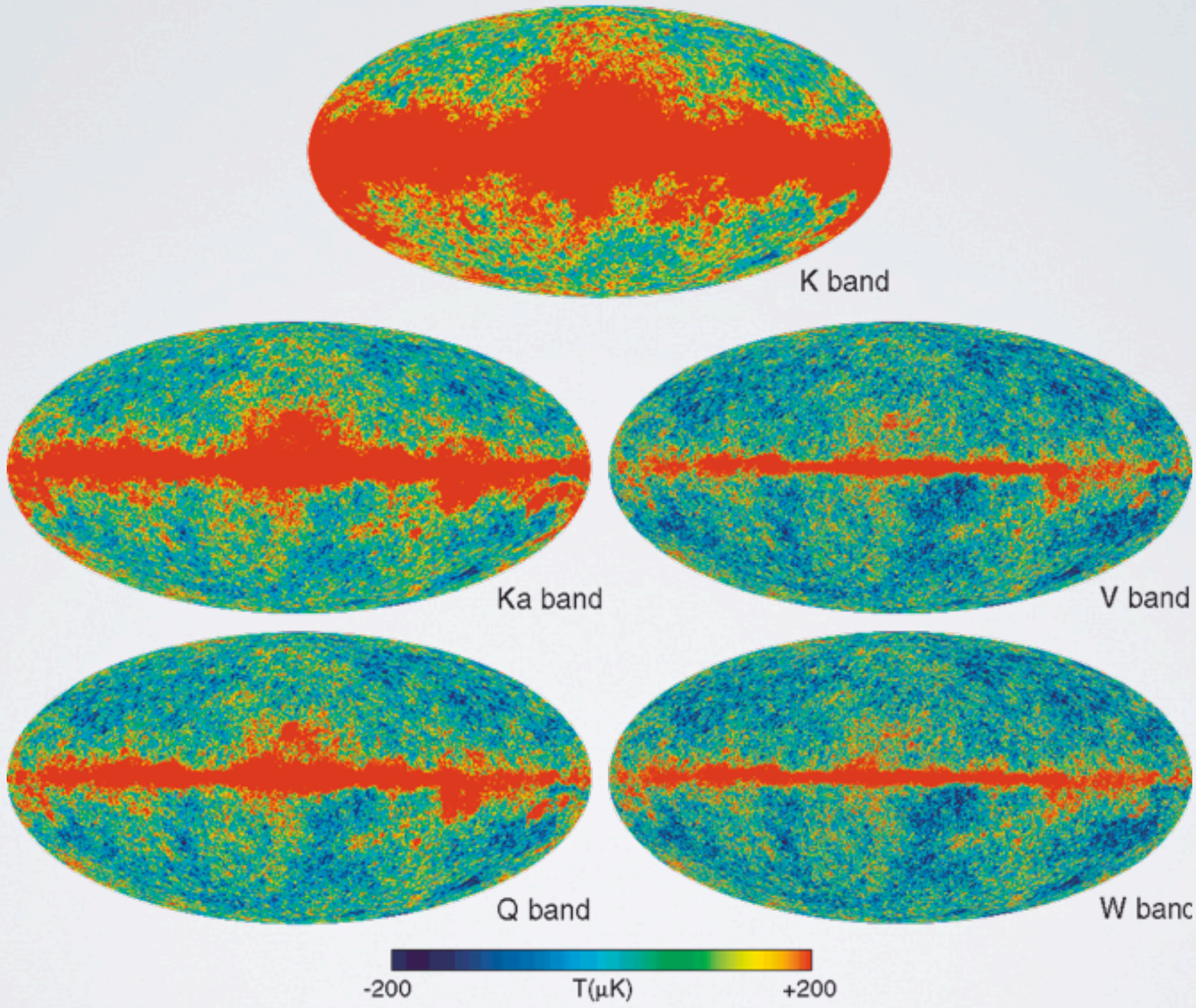


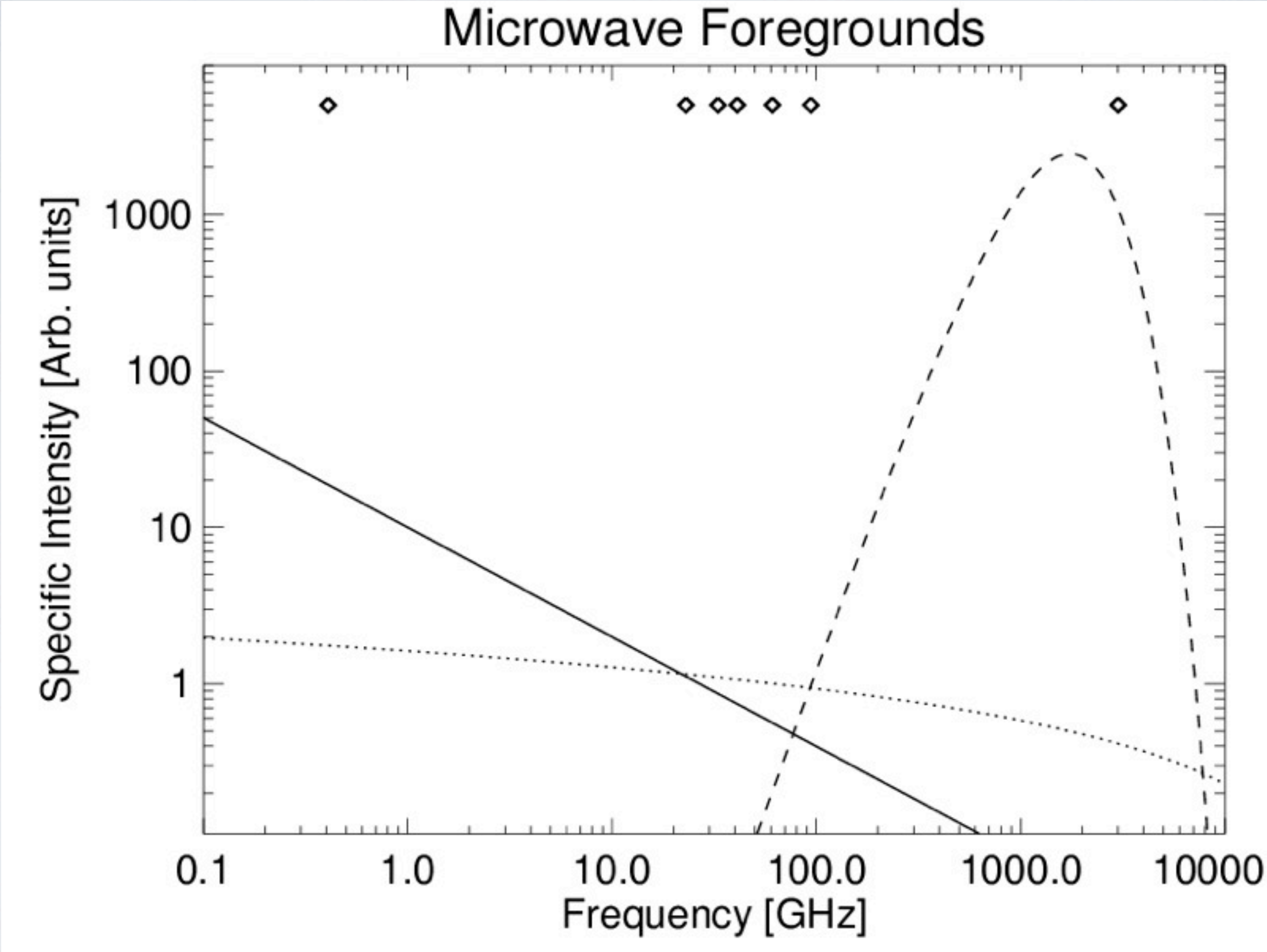
Su, Finkbeiner, Slatyer

sharp edges difficult to explain (for anyone)

Dobler, Cholis, NW

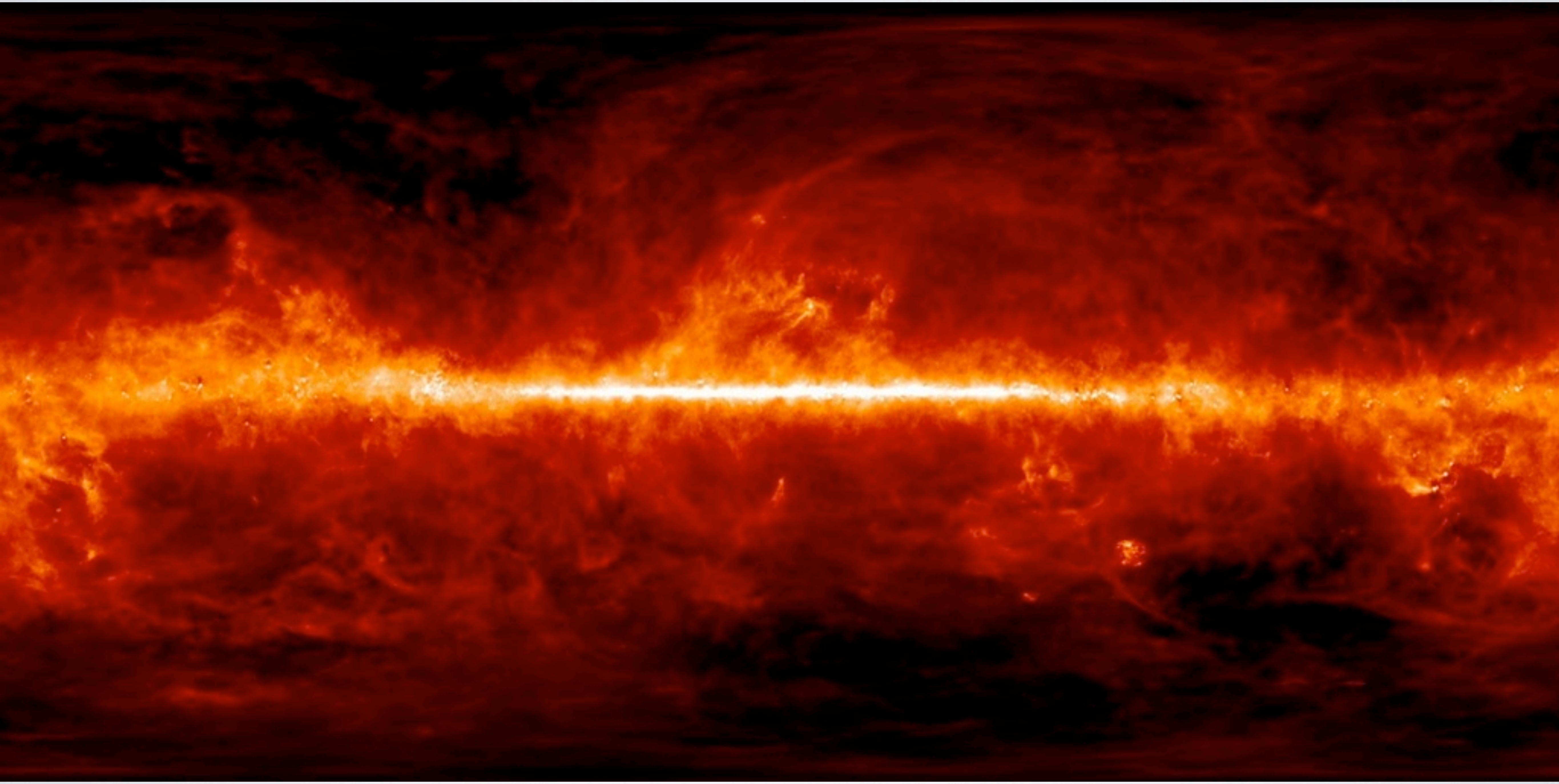
WMAP



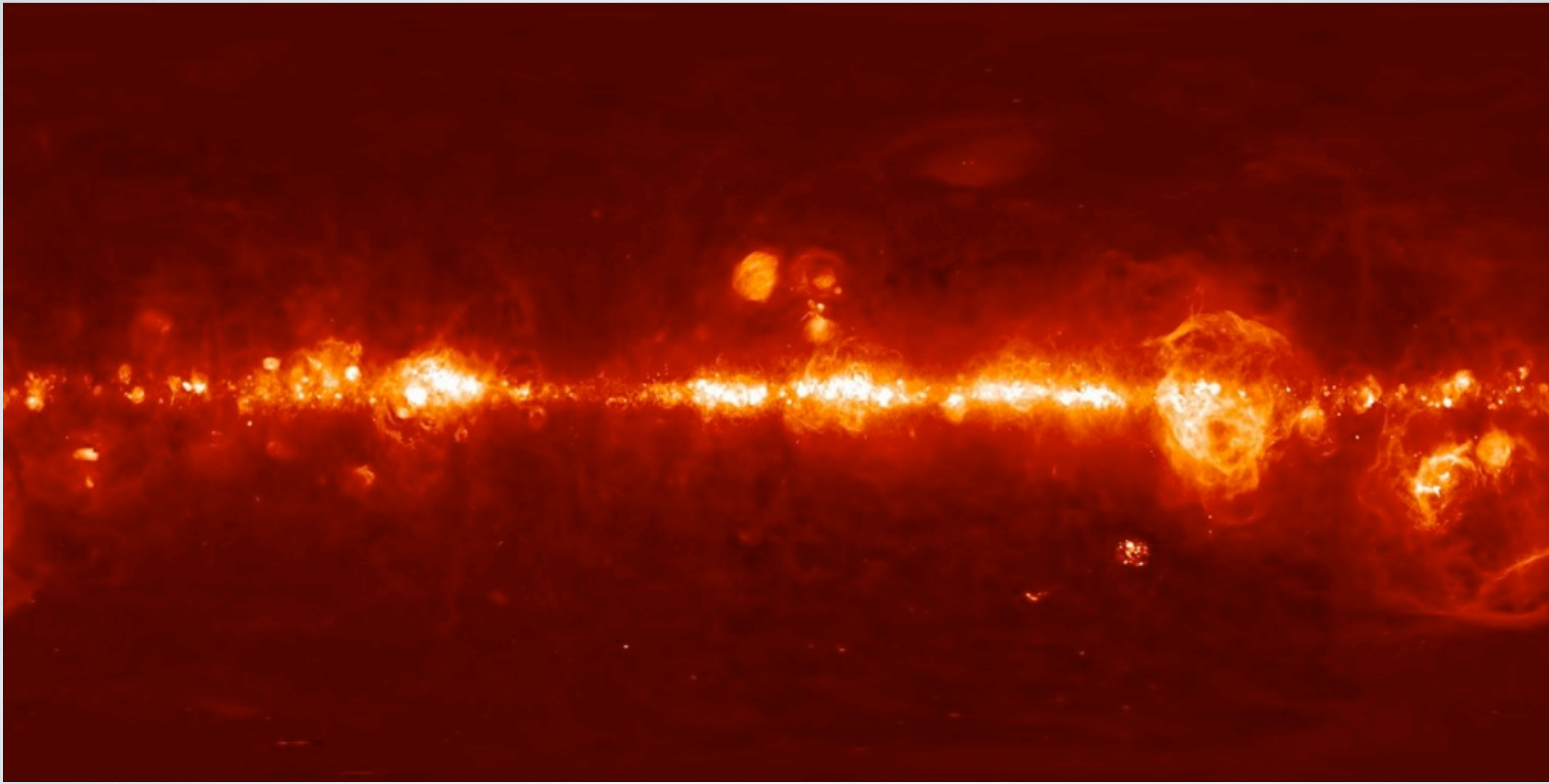


Microwave Foregrounds
Specific Intensity [Arb. units]
1000
100
10
1
0.1
1.0
10.0
100.0
1000.0
10000
Frequency [GHz]

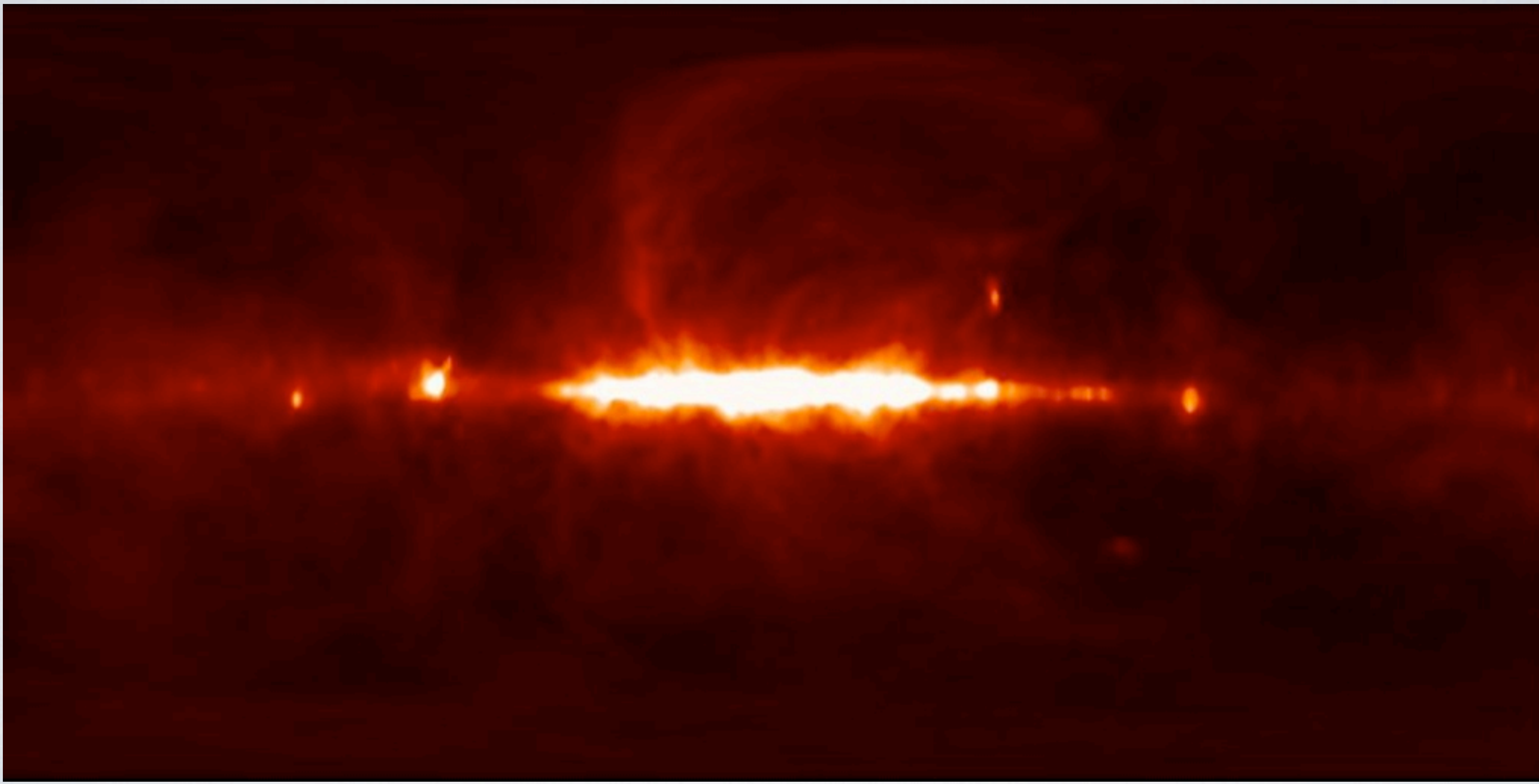
Interstellar Dust from IRAS, DIRBE (Finkbeiner et al. 1999) Map extrapolated from 3 THz (100 micron) with FIRAS.



Ionized Gas from WHAM, SHASSA, VTSS (Finkbeiner 2003)
H-alpha emission measure goes as thermal bremsstrahlung.



Synchrotron at 408 MHz (Haslam et al. 1982)



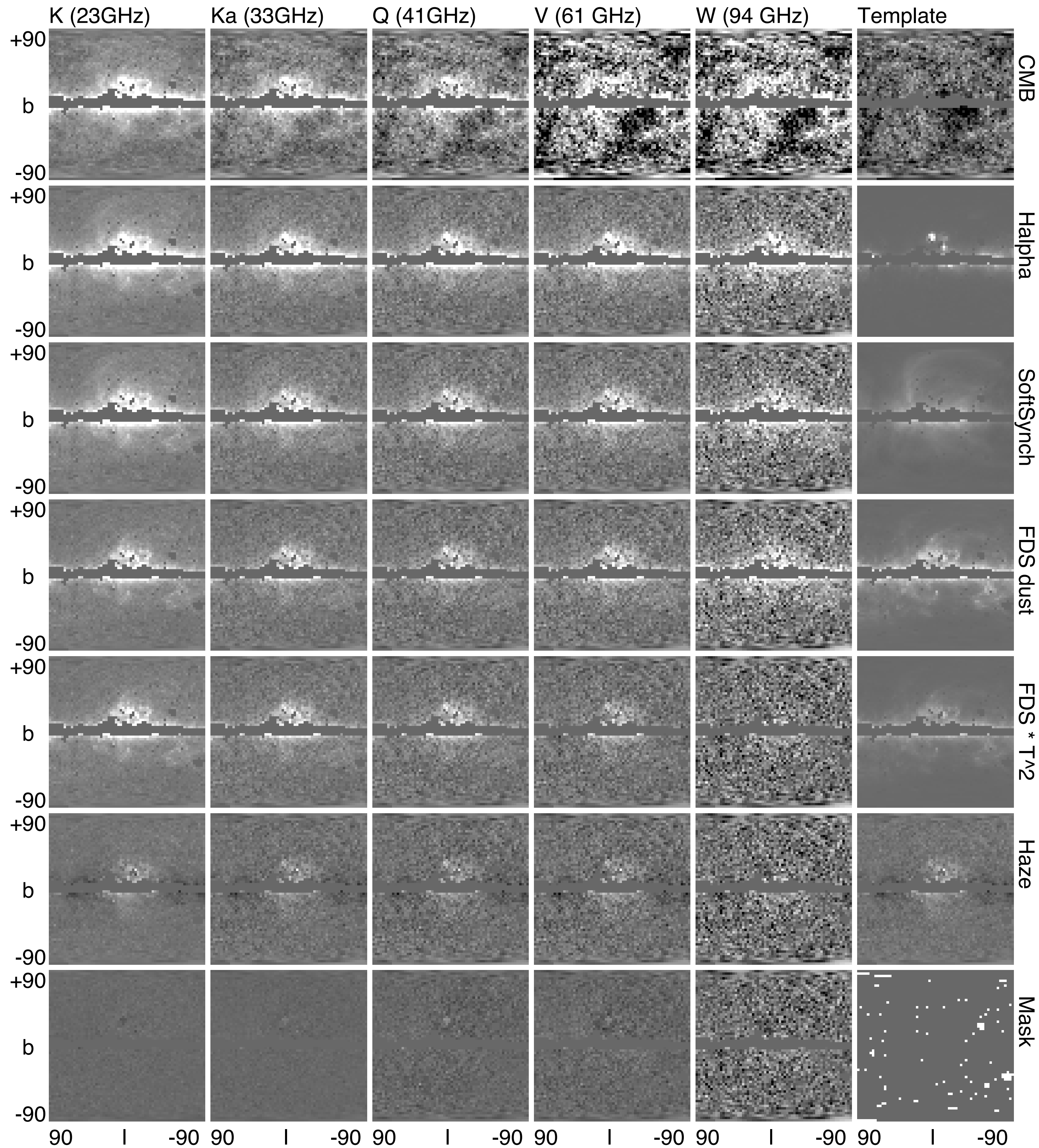
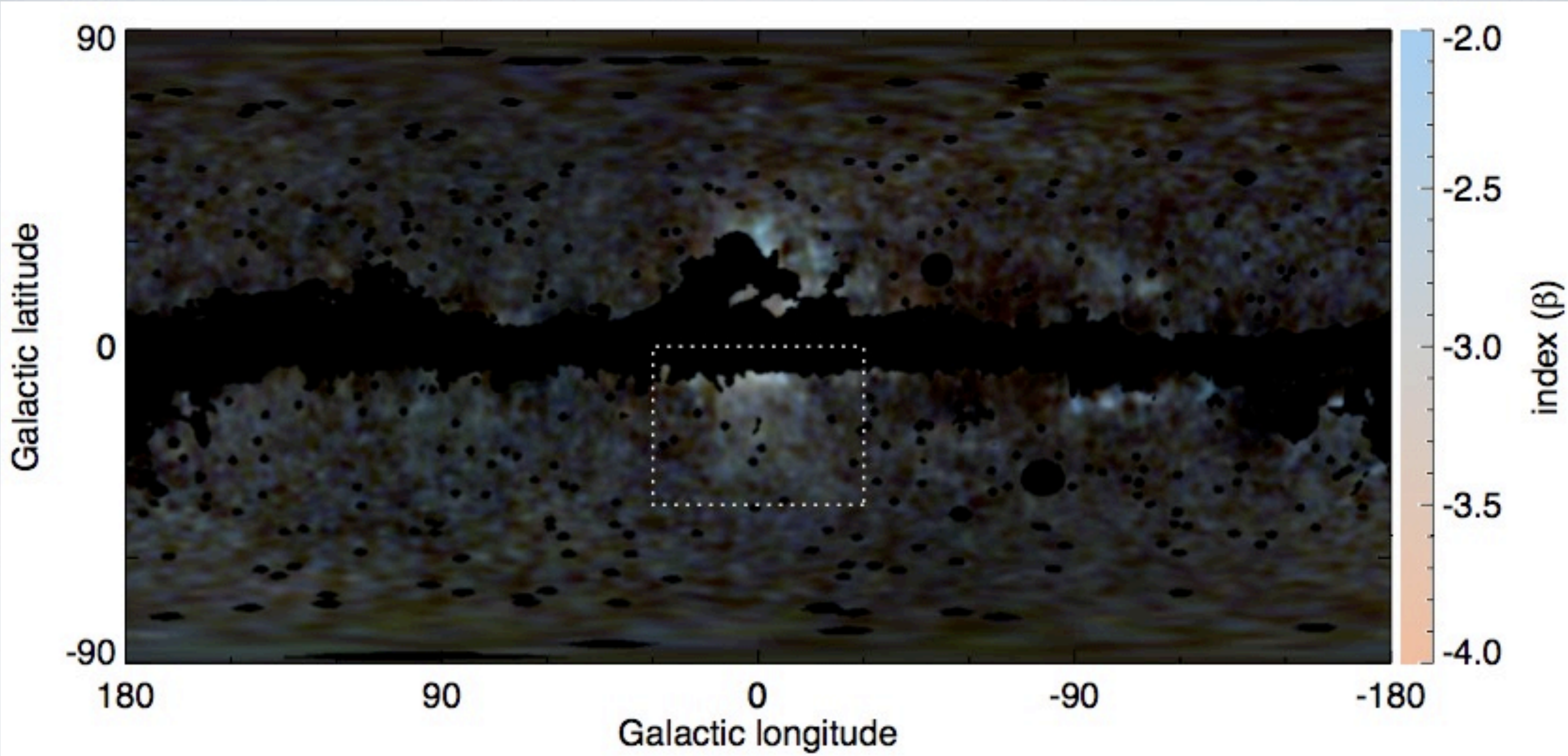
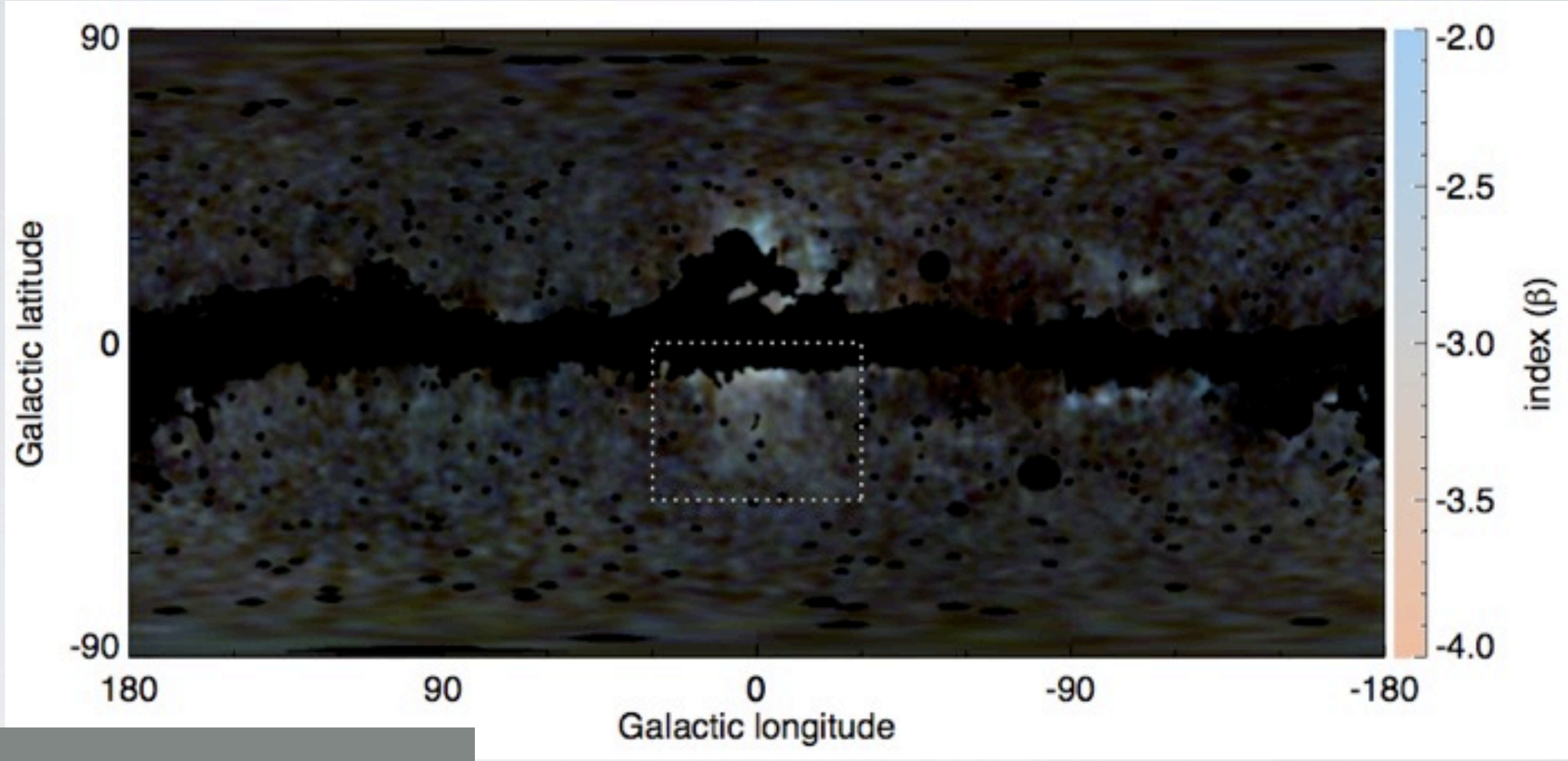


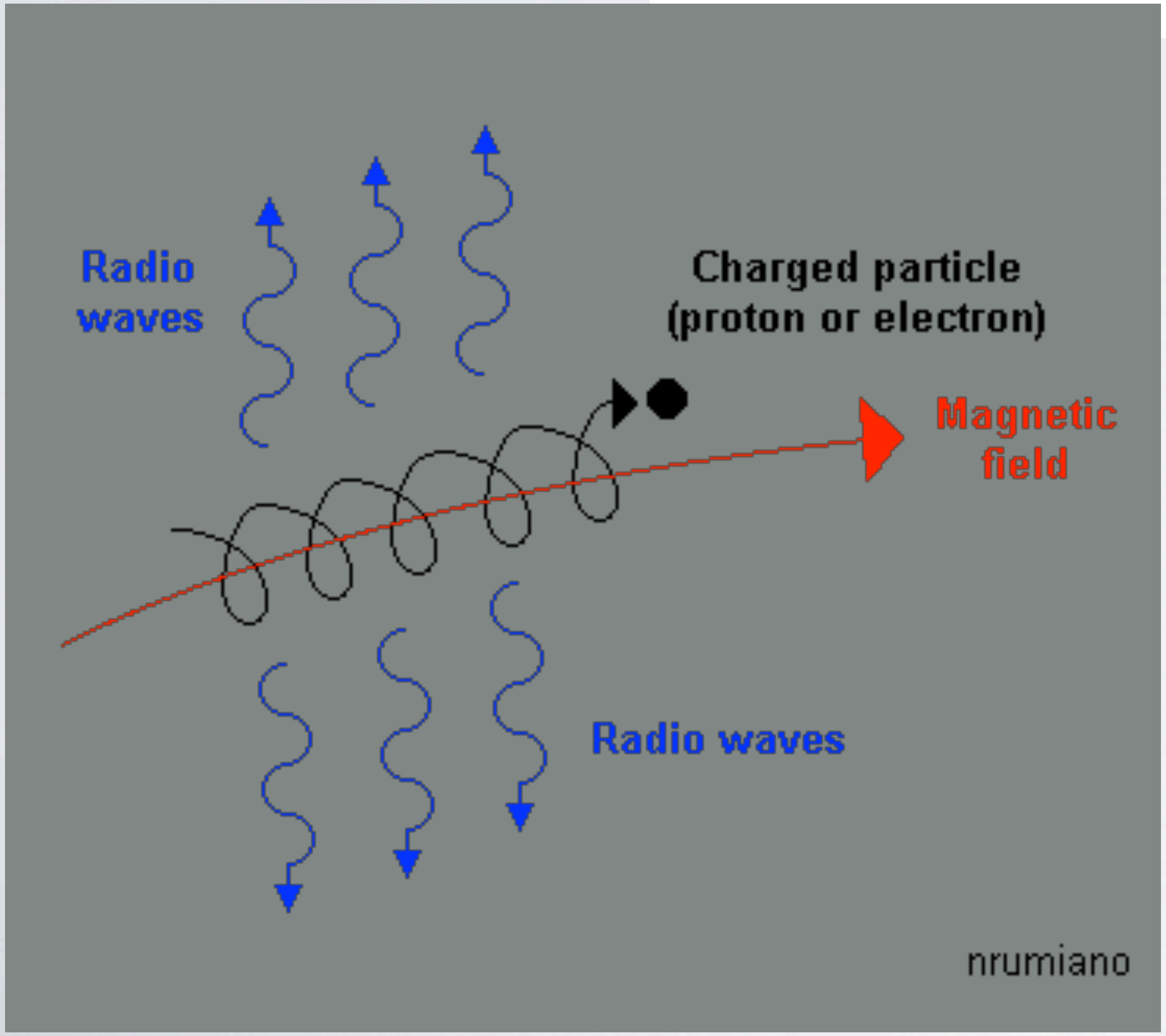
Fig. 1.— The WMAP foreground grid; see detailed discussion in §2.7.



Dobler and Finkbeiner '08

A "Haze"





Dobler and Finkbeiner '08

electrons spiraling in magnetic field create microwaves