Status of dark matter searches and implications for A′s

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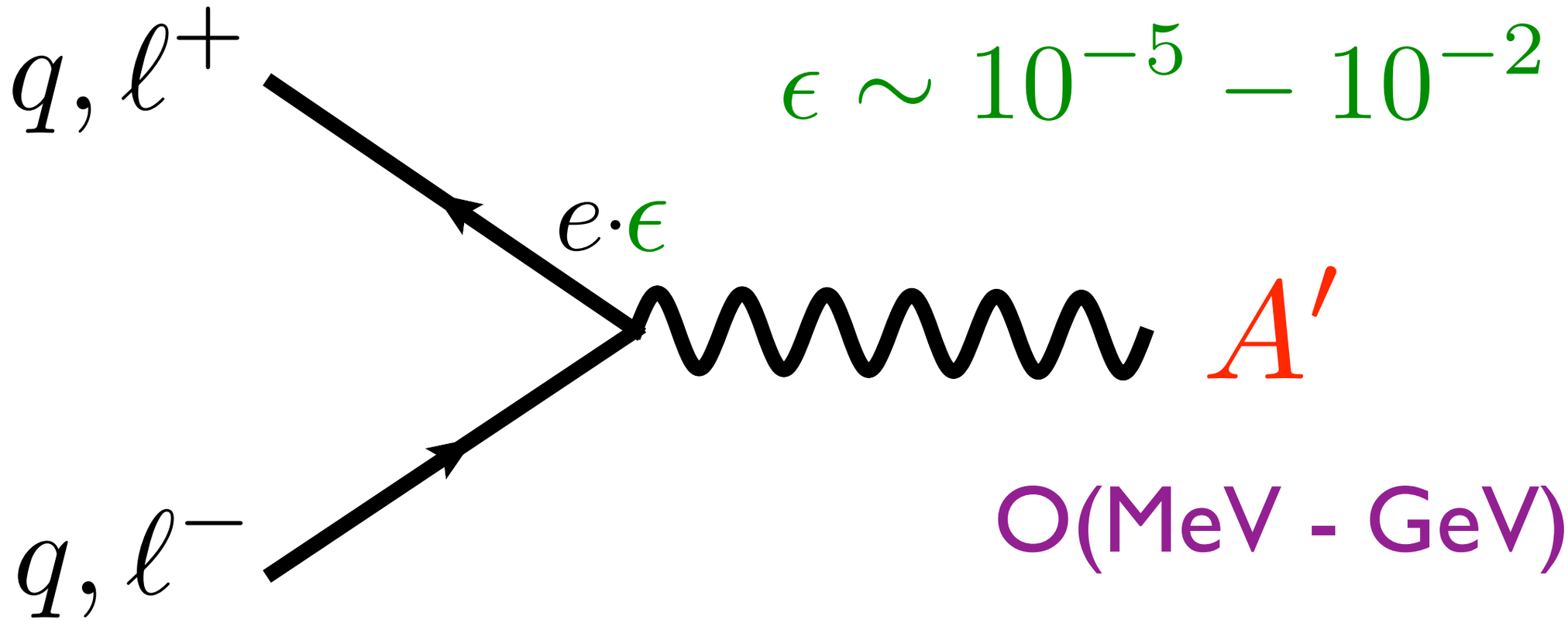
Theory Group, SLAC National Accelerator Laboratory

HPS collaboration meeting

May 26, 2011

A′ mediates a new force

couples to quarks & charged leptons



Theoretically natural + hints from (g_s-2), dark matter anomalies, ...

HPS, APEX, DarkLight, HIPS, Mainz etc. are systematically looking for a new particle weakly coupled to electrons

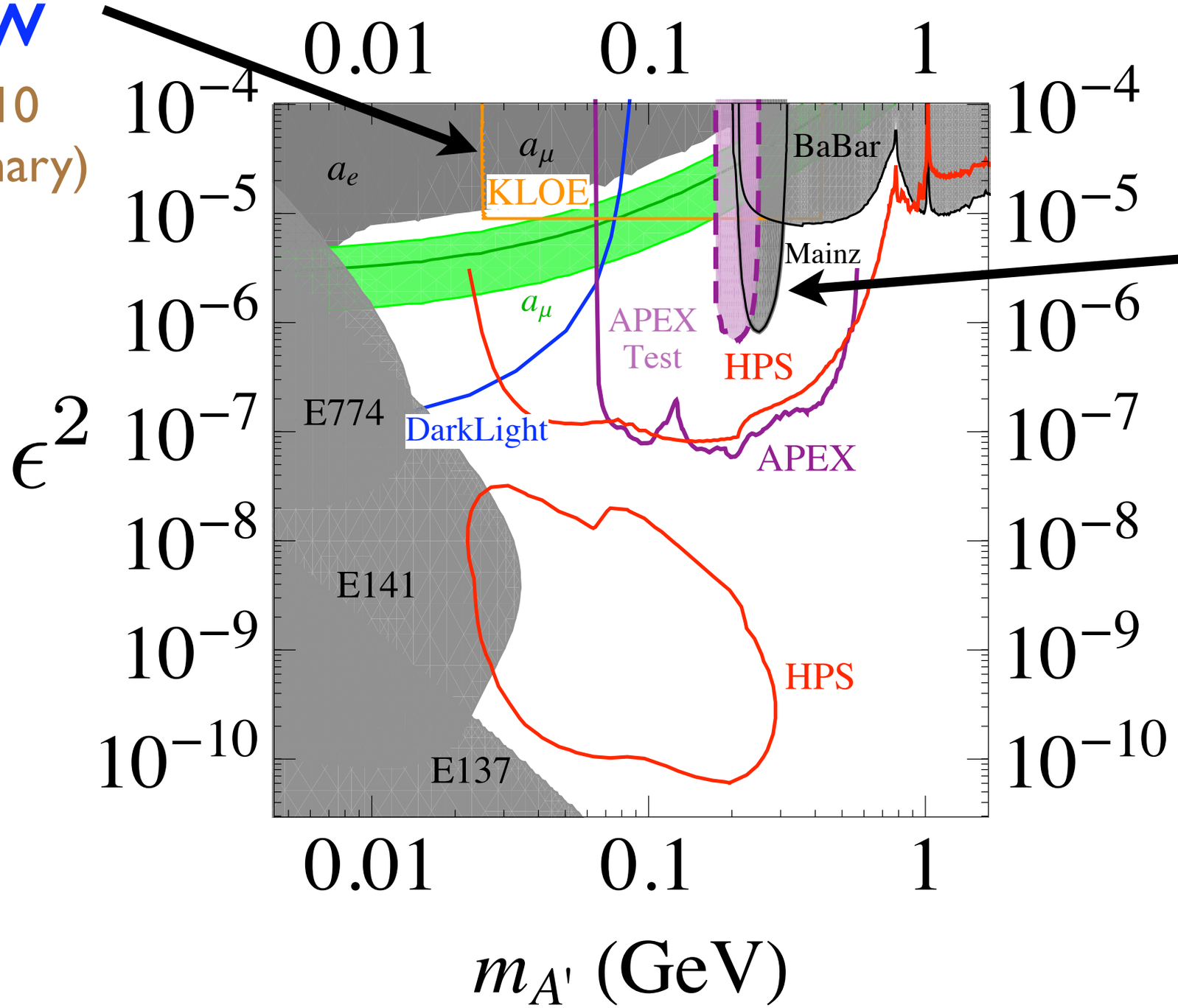
Constraints + Prospects

$$\phi \to \eta A' \to \eta e^+ e^-$$

New

12/2010

(preliminary)



New

1101.4091

This Talk: what's new?

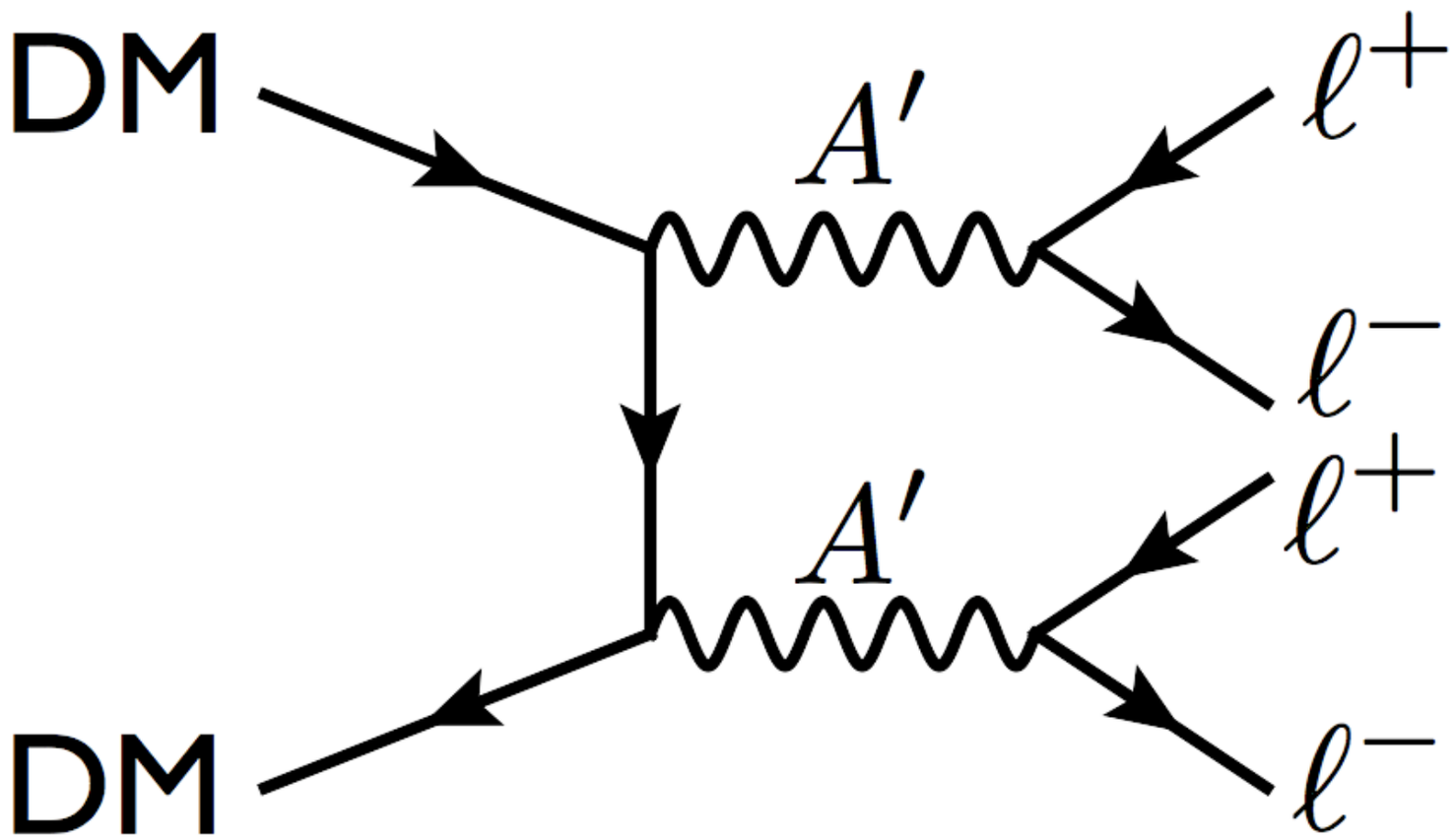
Is Dark Matter still motivating the search for new GeV-scale forces?

- DM indirect detection
  - cosmic-rays
  - gamma-rays, neutrinos (very brief)
  - Cosmic Microwave Background
  - WMAP haze, Fermi haze
- DM direct detection
  - DAMA, CoGeNT, XENON-100, CDMS-02, …

Answer: Yes! But it's complicated…

Dark matter can annihilate to A′s...

Arkani-Hamed, Finkbeiner, Slatyer, Weiner
Pospelov & Ritz

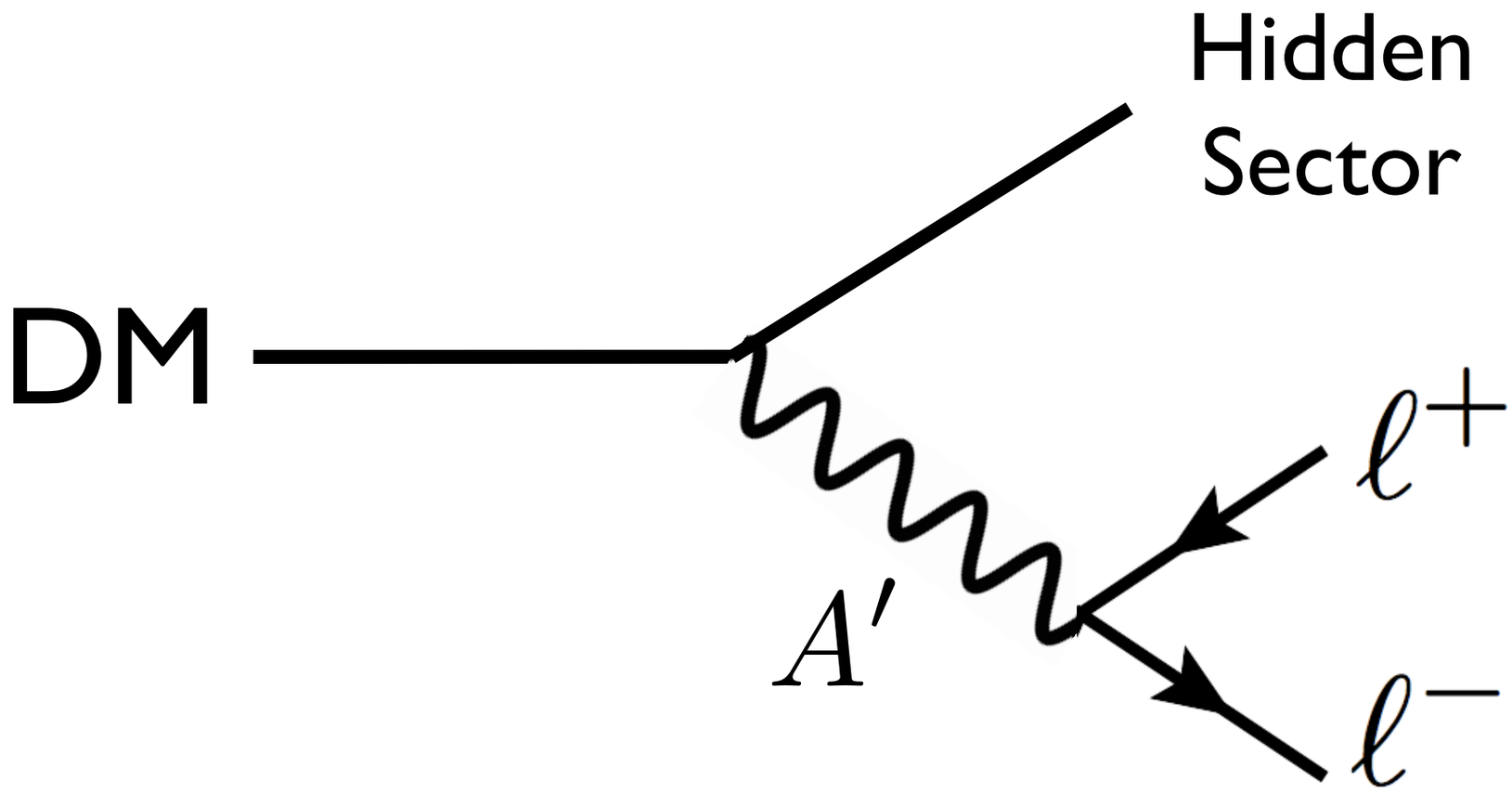


$m_{DM} \sim$ TeV $\qquad$ $m_{A'} \sim$ GeV

Or dark matter can decay to A′s…

[Ruderman, Volansky]

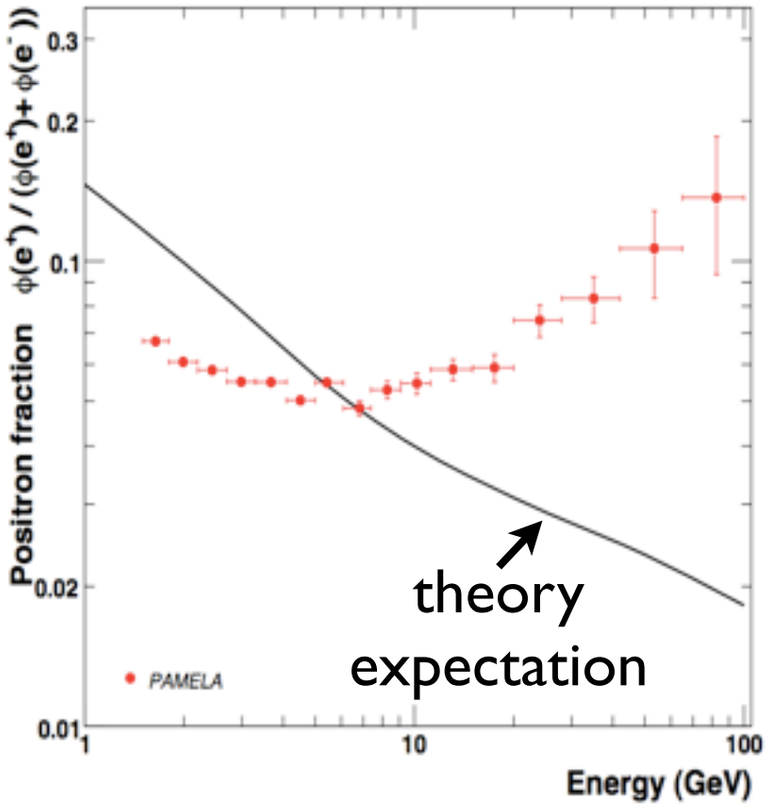
[RE, Kaplan, Schuster, Toro]



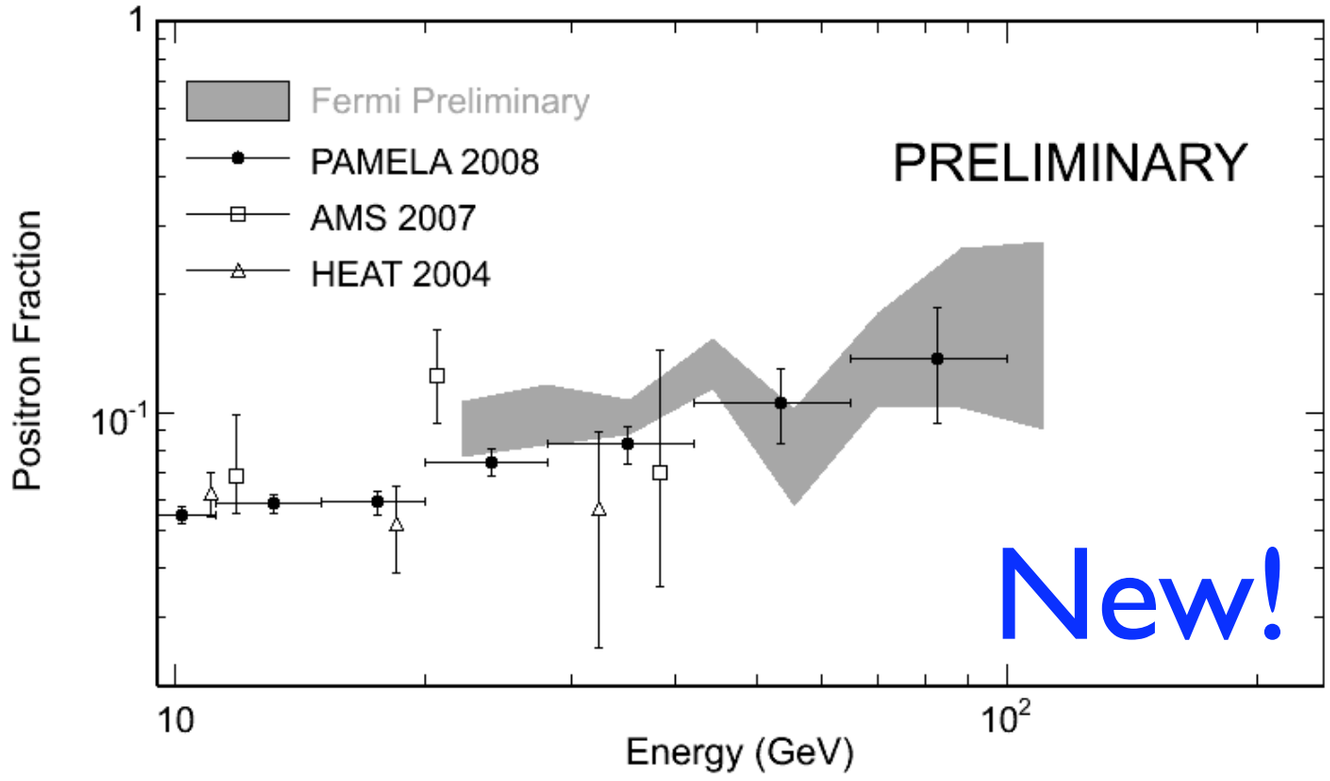
$m_{DM} \sim$ TeV $\qquad$ $m_{A'} \sim$ GeV

Can get observed cosmic-ray excesses

PAMELA: e^+ fraction



Fermi: e^+ fraction



New from PAMELA: e^+ fraction continues to rise

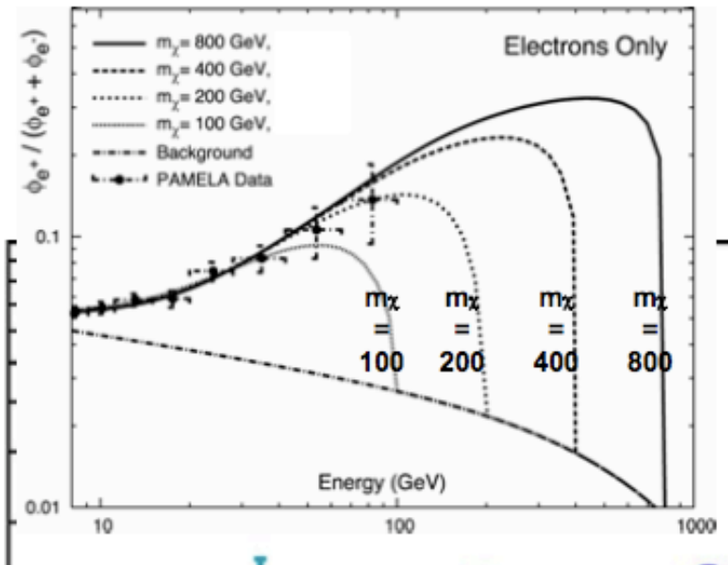
data point at ~0.2 (w/ large error bars) for the 100-200 GeV energy bin was shown publicly in Feb 2011 (still unpublished)

Origin of excess still unknown!

AMS-02

slide from Andrei Kounine
TeVPA 2010

I.Cholis et al, arXiv:0810.5344v3

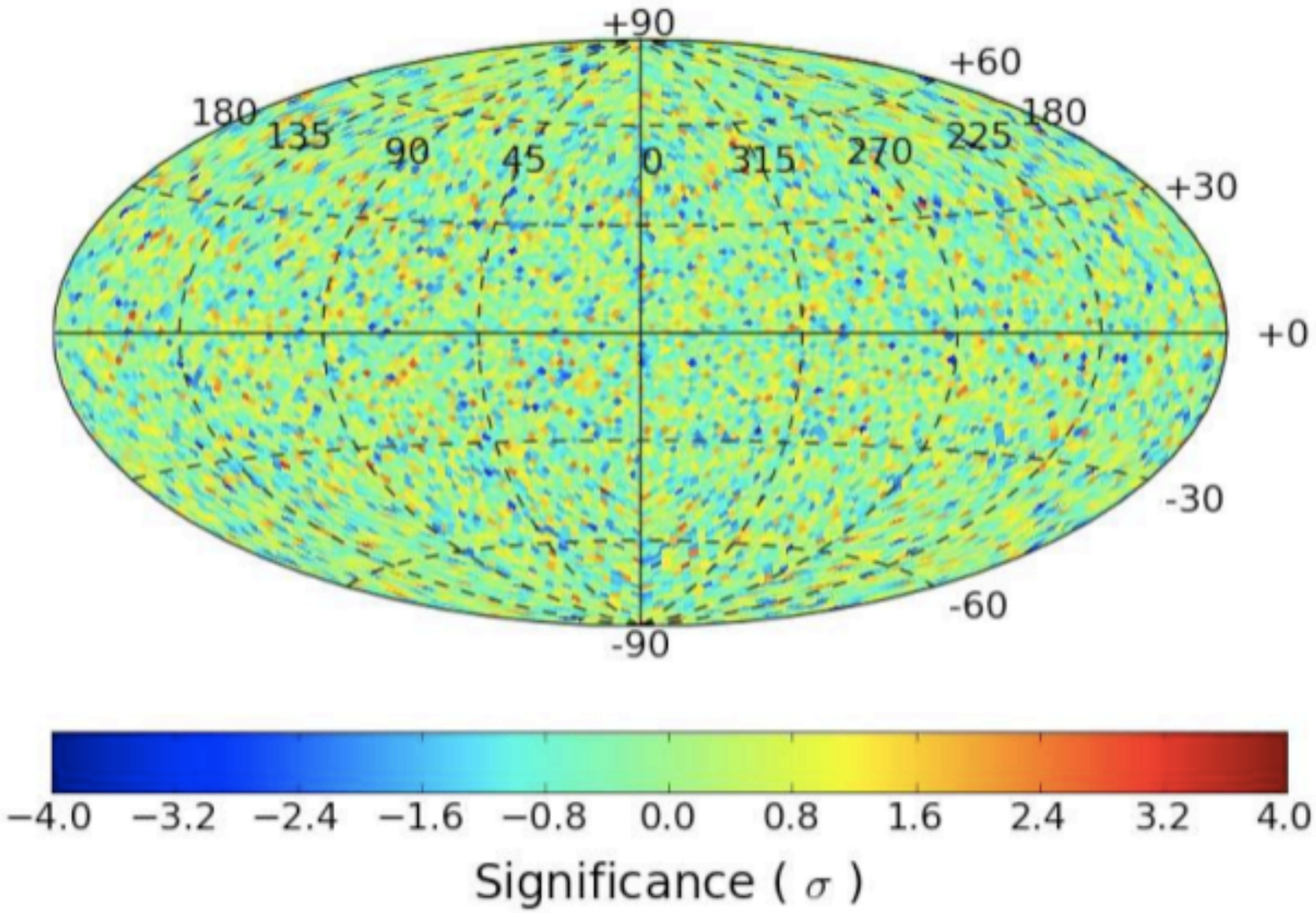


1. Large acceptance and long duration
2. e+/p ~ 10^{-6}

Launched May 16, 2011

Are there anisotropies in cosmic-ray data?

e.g. from a nearby pulsar?

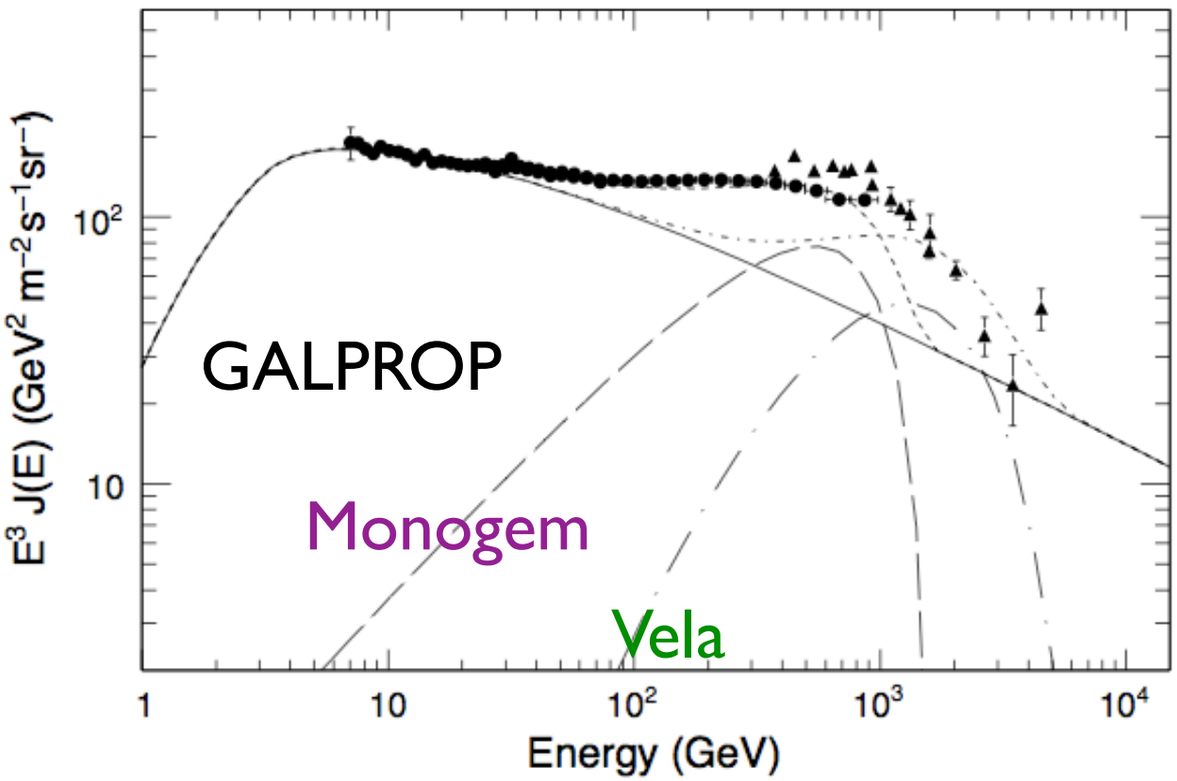


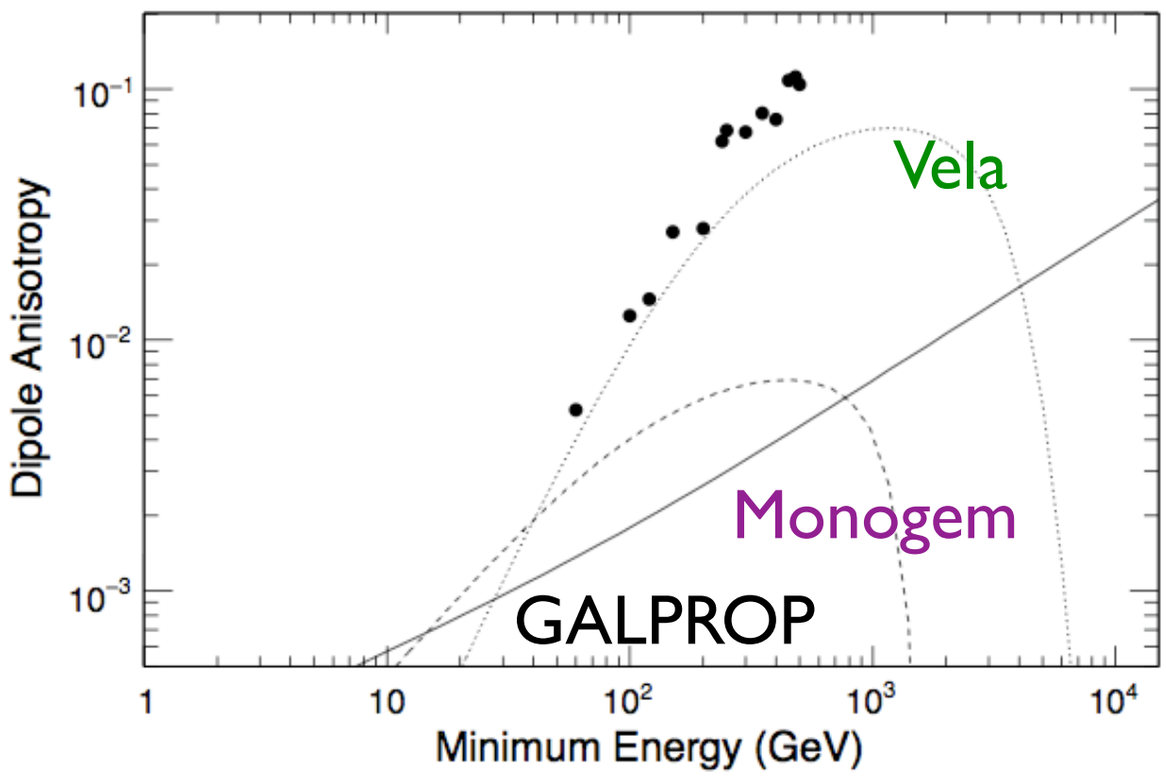
Fermi anisotropy

1008.5119

no significant anisotropy detected

Dipole anisotropy from pulsars





1008.5119

limit is consistent with expectation

so cannot distinguish between DM and pulsar explanation yet

Implications if cosmic-rays are from DM?

Many other signals possible!

- Gamma-rays
- Neutrinos
- Cosmic Microwave Background

} no signal with existing data

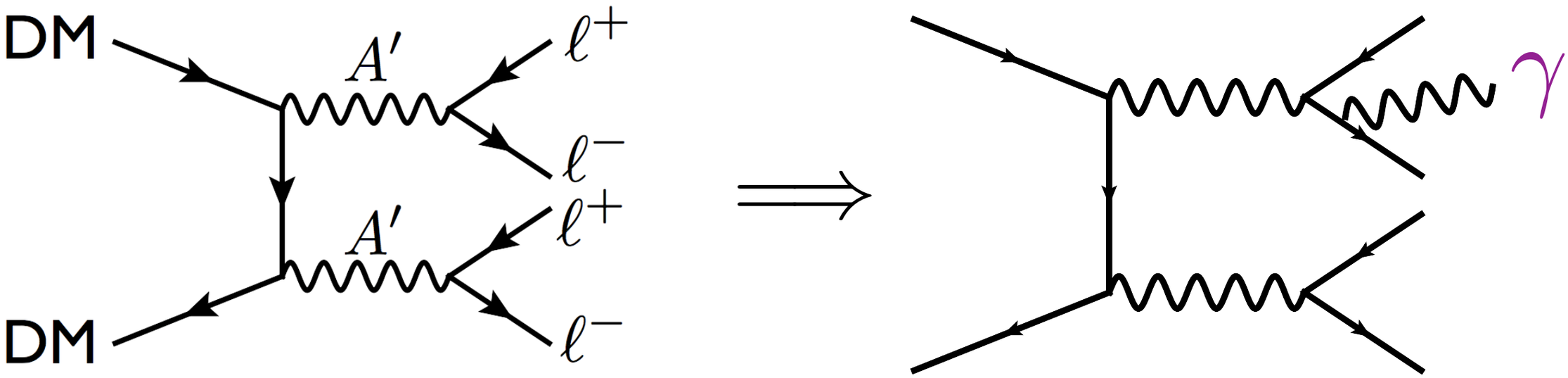
- WMAP and Fermi "haze"

signal seen, but interpretation unclear

in all cases, astrophysical uncertainties are large, so DM and A′ implications are unclear

Gamma-rays guaranteed

1. Final state radiation



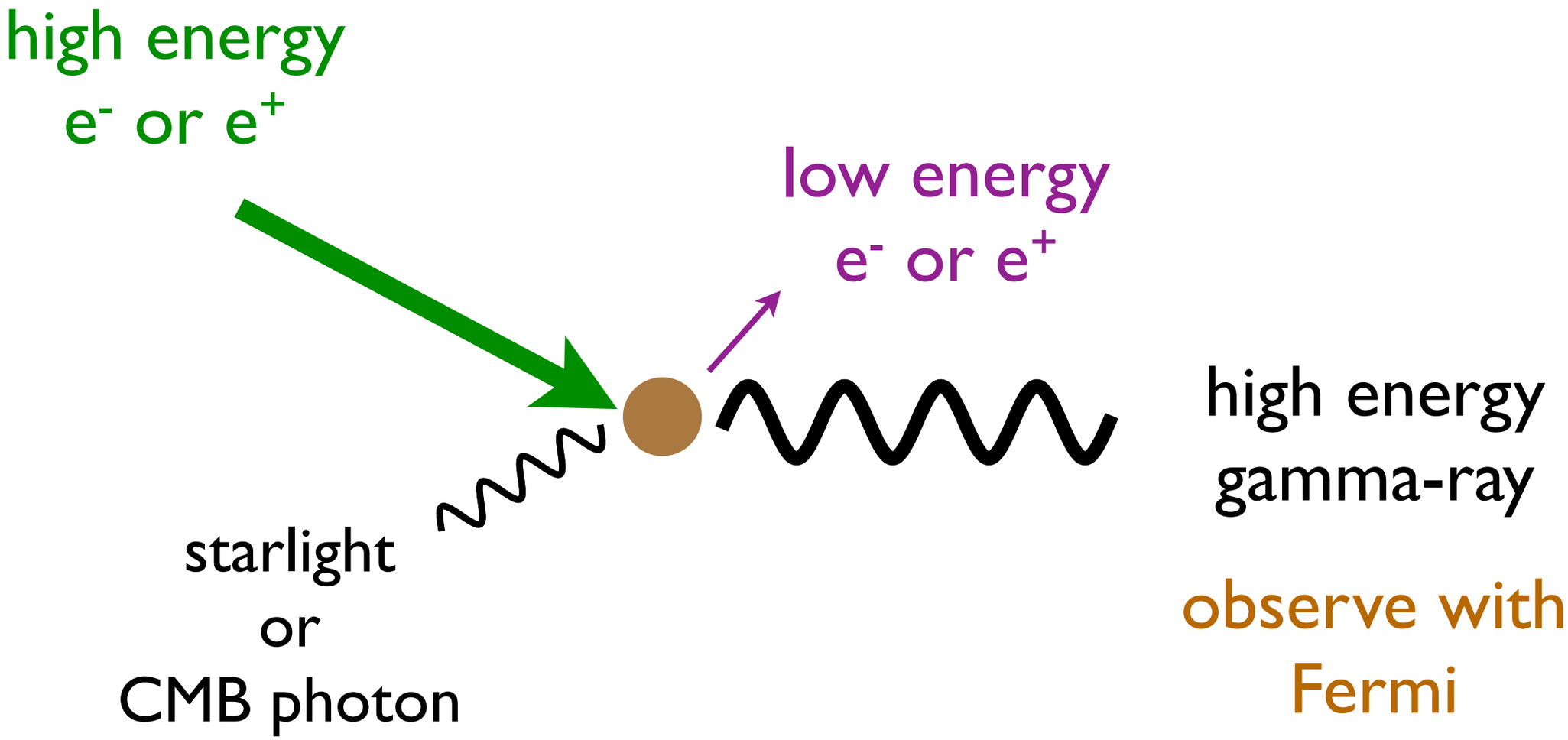
Observe with:

- Fermi
- Atmospheric Cherenkov Telescopes

  (VERITAS, HESS, MAGIC...)

Gamma-rays guaranteed

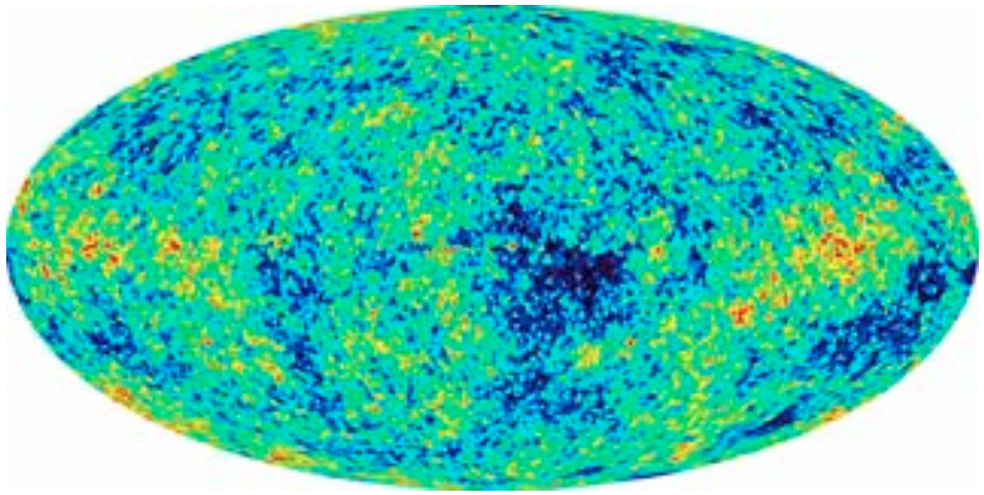
2. Inverse Compton Scattering



no γ-ray signal from DM seen with existing data

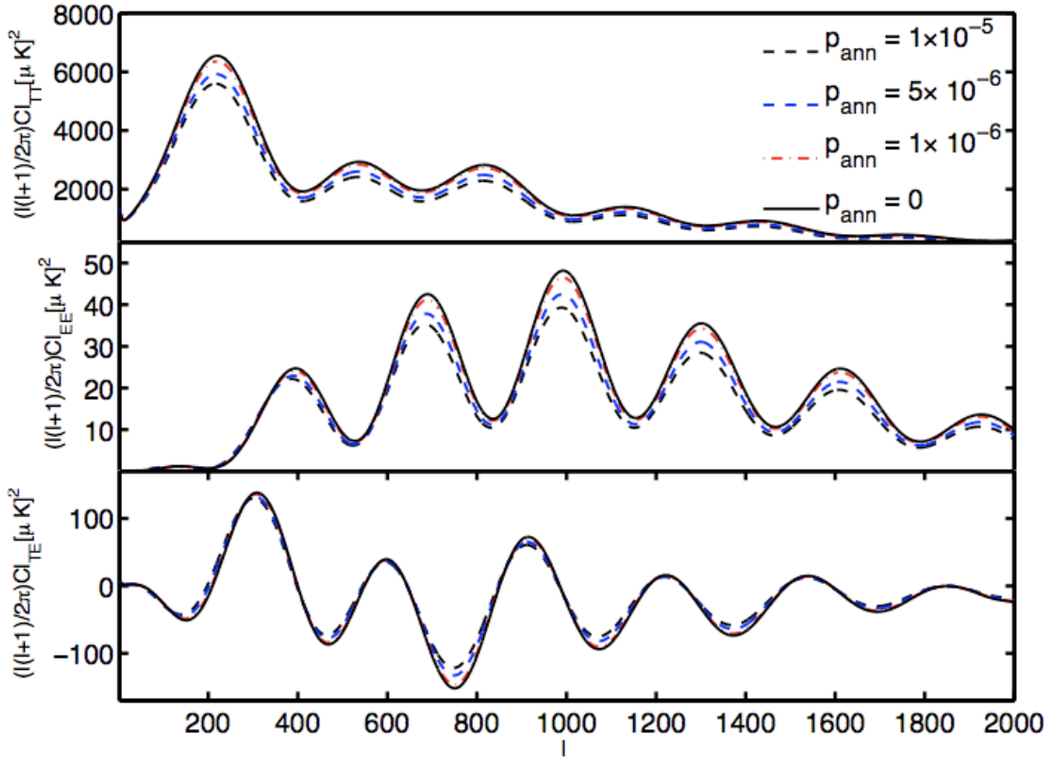
resulting constraints unclear due to astro uncertainties

Cosmic Microwave Background (CMB)



DM annihilation to high-energy e^+ and e^- in early Universe affects CMB formation

Power Spectrum

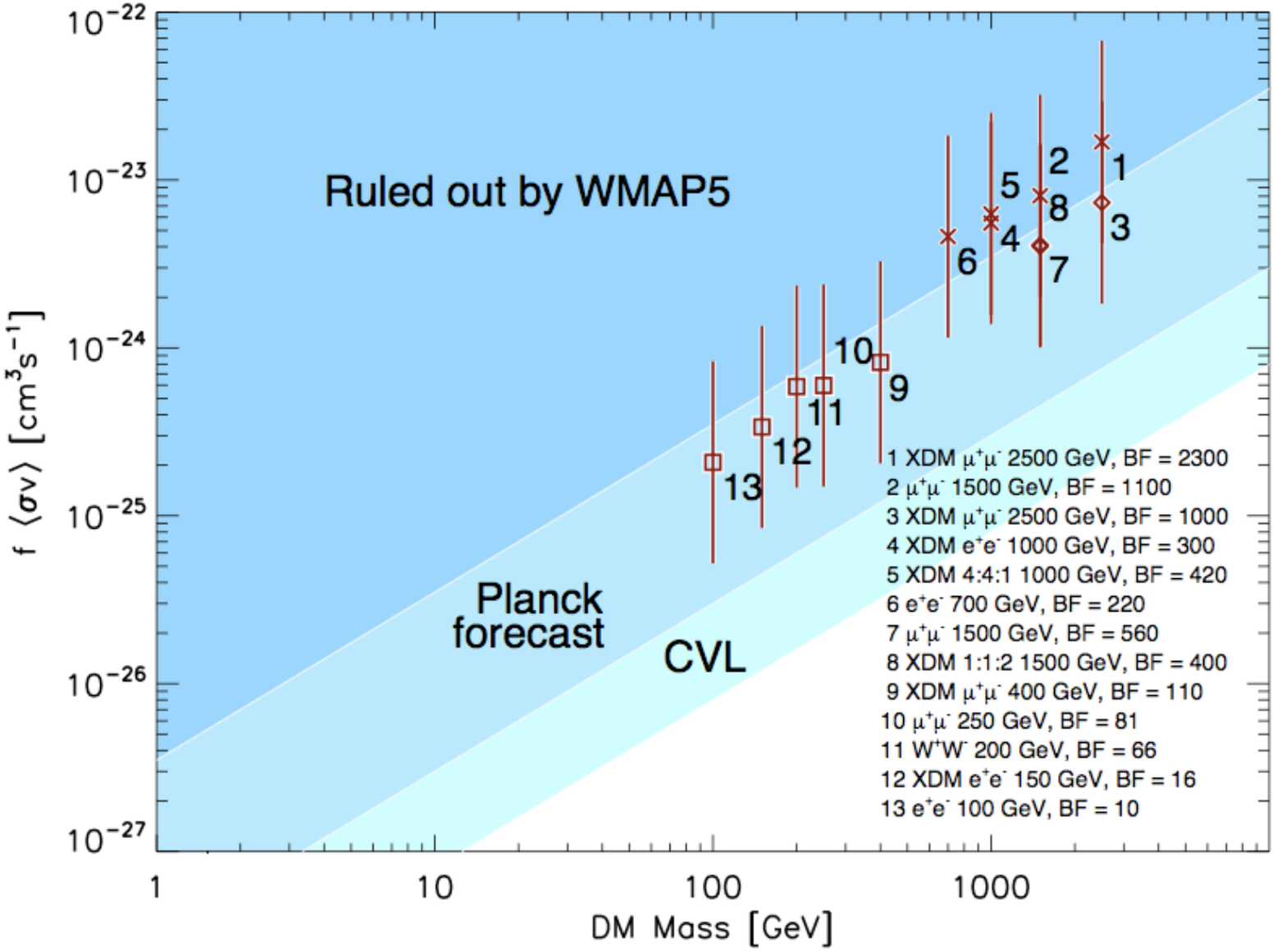


0906.0003

CMB photons scatter off e^- and e^+ and change power spectrum

Also: DM velocity very small, so large Sommerfeld enhancement!

CMB constraints on DM annihilation



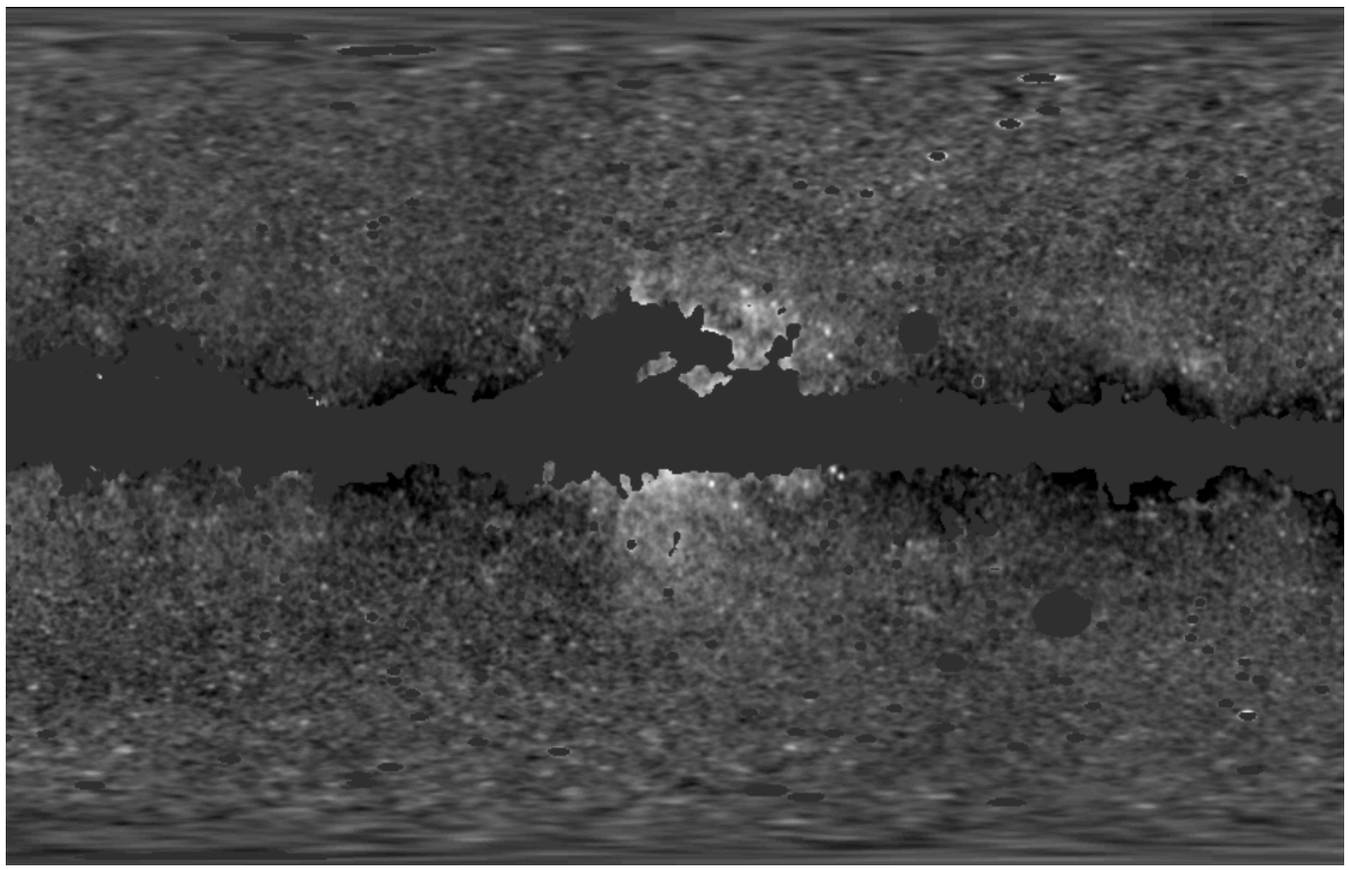
interesting constraints from WMAP

Planck expected to be decisive if cosmic-ray excesses are DM

Padmanabhan, Finkbeiner
Slatyer, Padmanabhan, Finkbeiner
Galli, Iocco, Bertone, Melchiorri

WMAP "haze"

Finkbeiner (2004)

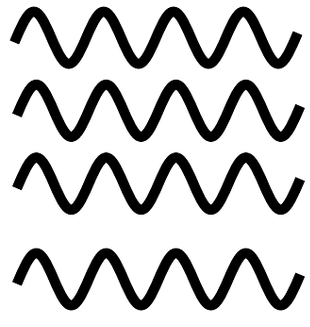


Microwave excess
near Galactic center

Origin?

high energy
e^- & e^+

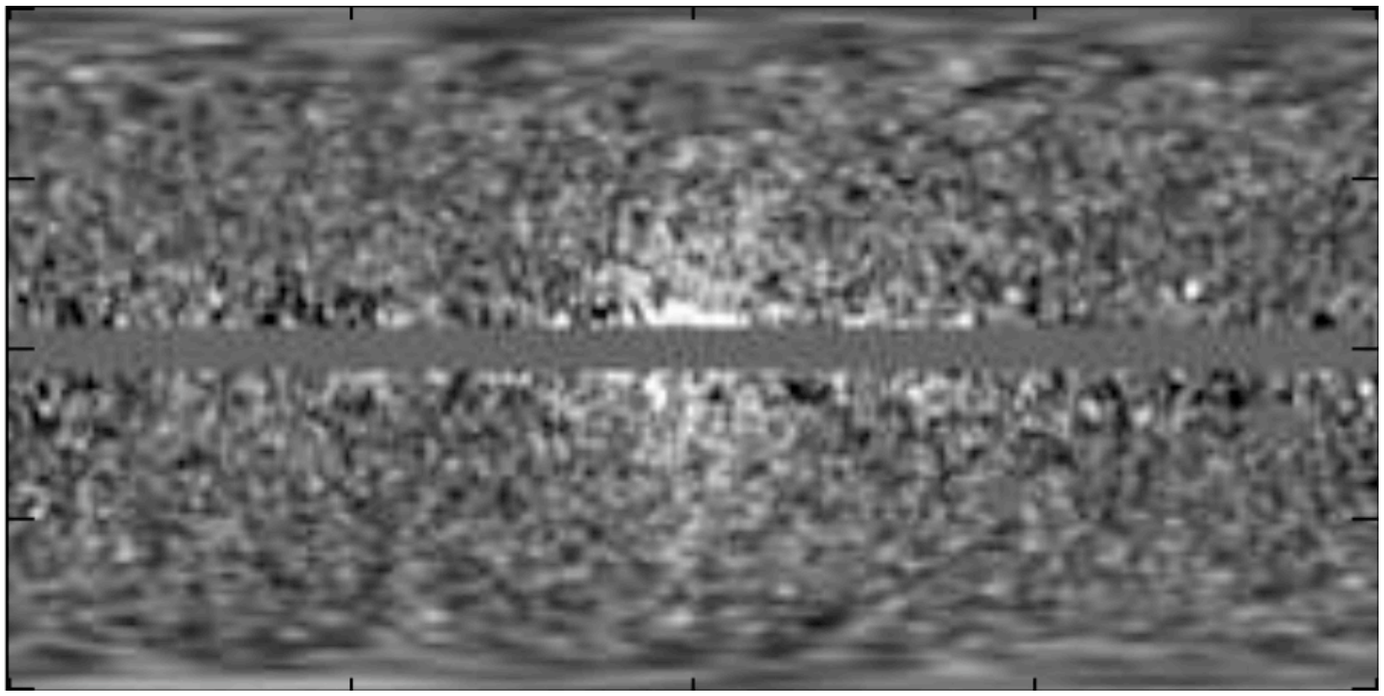
from DM?



produces synchrotron radiation
in Galactic magnetic field

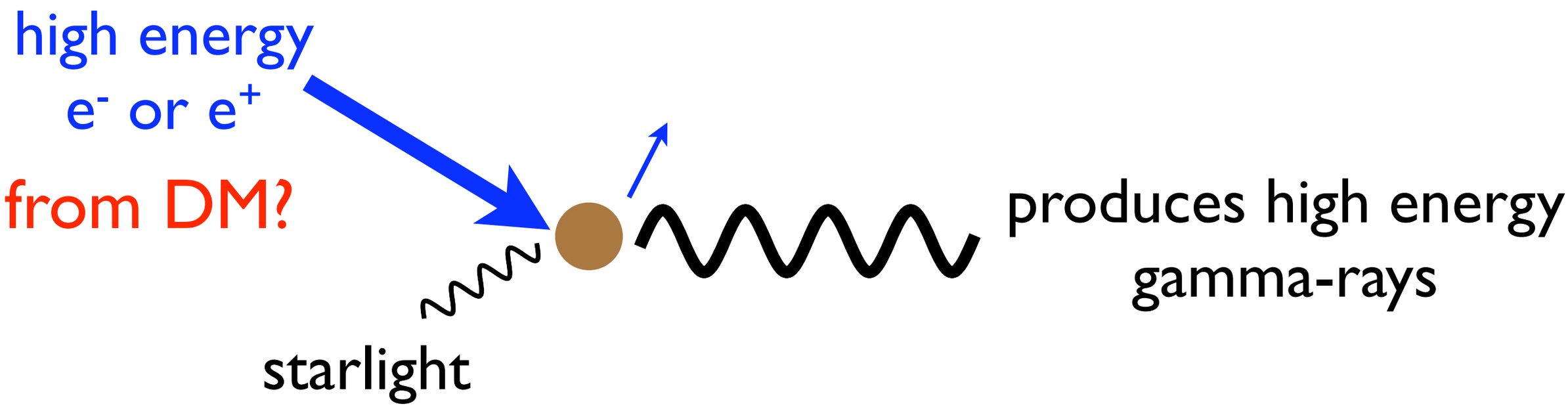
Fermi "haze"

Dobler et. al. (2009) (1 year of data)



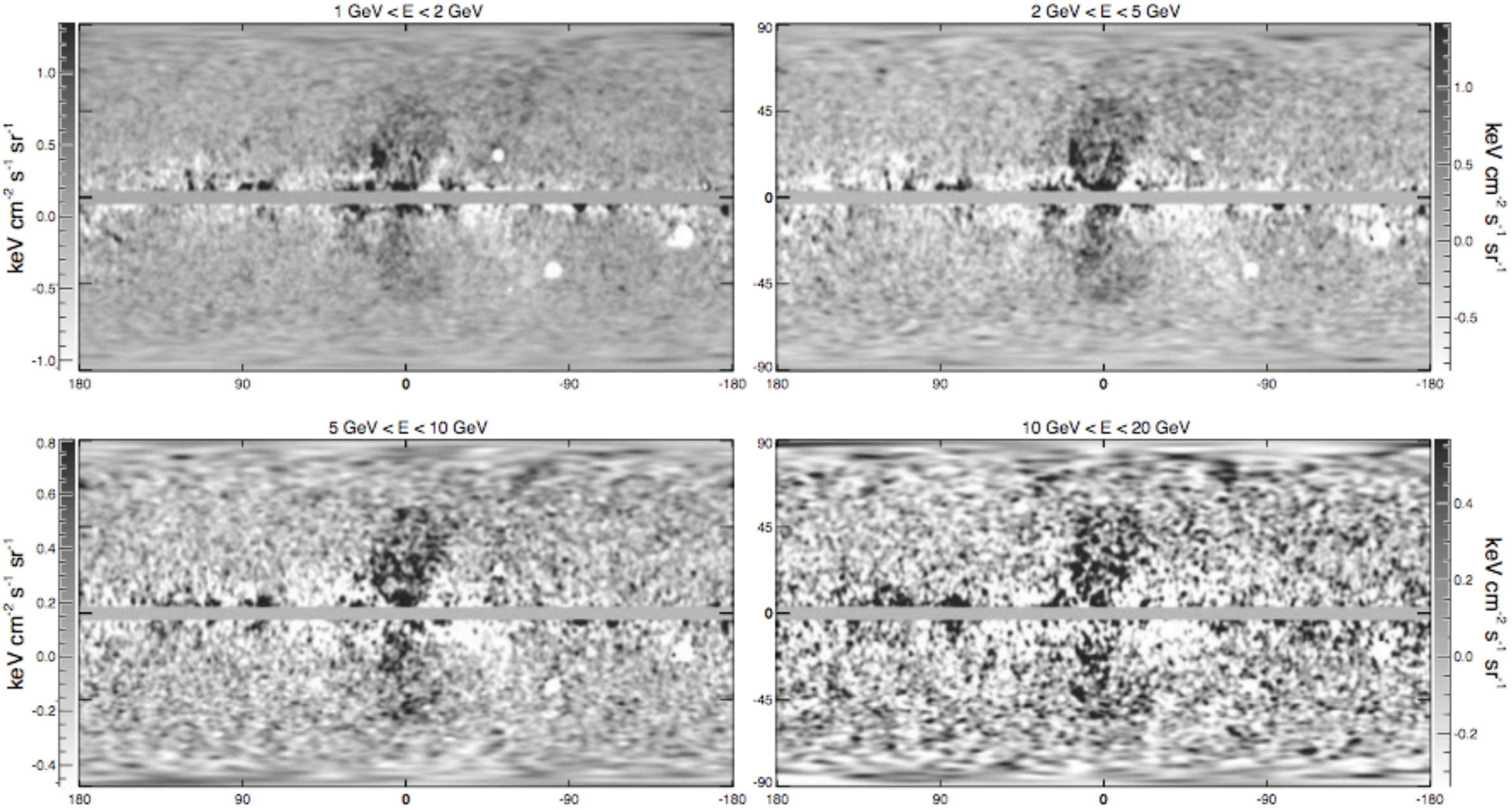
Gamma-ray excess
near Galactic center

Origin?



Fermi "haze" $\Longrightarrow$ Fermi "bubbles"?

Su et. al. (2010) (1.6 years of data)



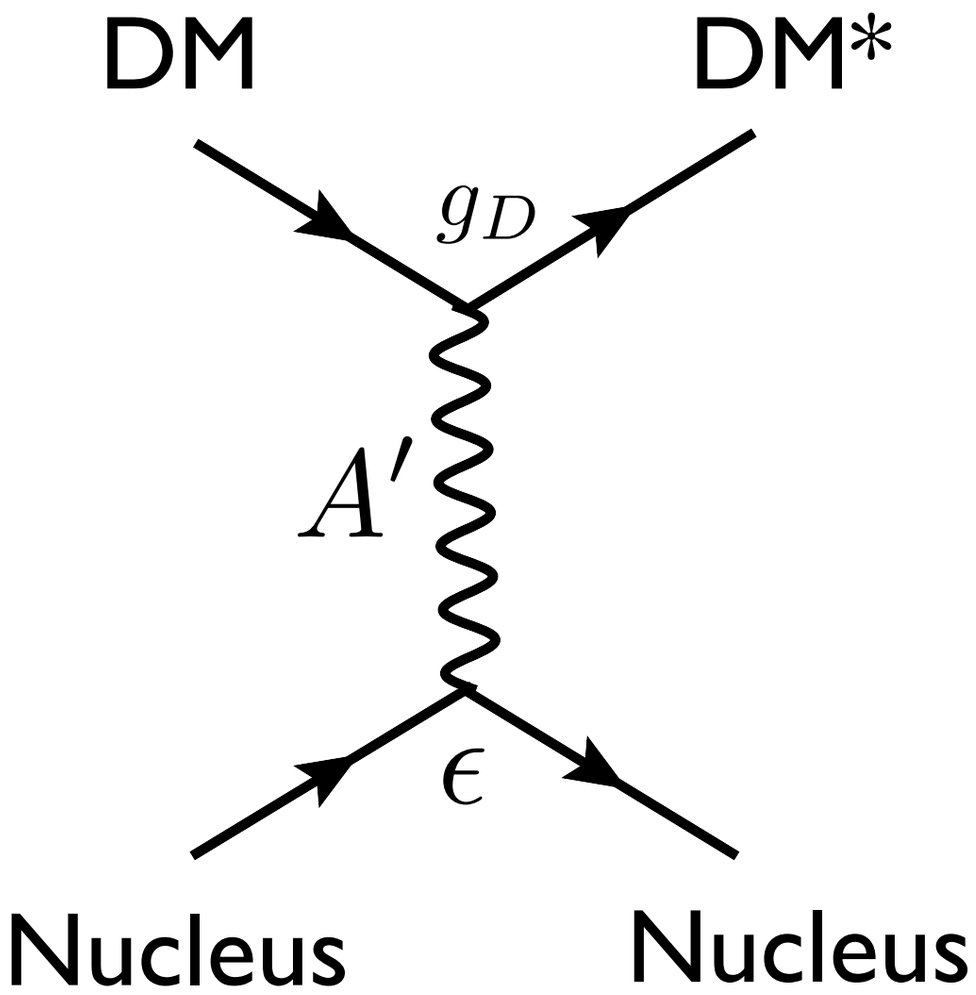
DM shouldn't cause sharp edges…

interpretation still unclear

Outline

- DM indirect detection
  - cosmic-rays
  - gamma-rays, neutrinos (very brief)
    - Cosmic Microwave Background
    - WMAP haze, Fermi haze
- DM direct detection
  - DAMA, CoGeNT, XENON-100, CDMS-02, …

DM can scatter off nuclei via A′ exchange

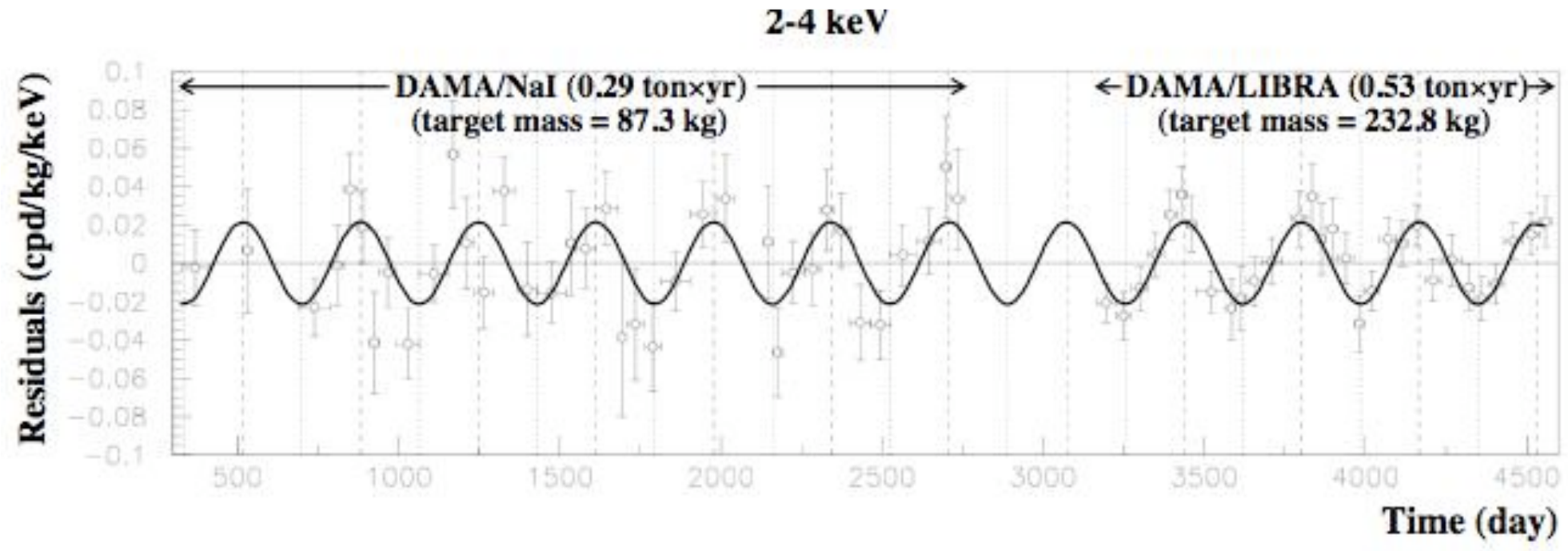


DM can scatter *elastically*,
or
if it has excited states, it
can scatter *inelastically*

look for recoiling
detector nuclei

Is DAMA seeing DM?

DAMA (NaI) sees annual modulation



Two popular possibilities to explain this with DM and A′s:

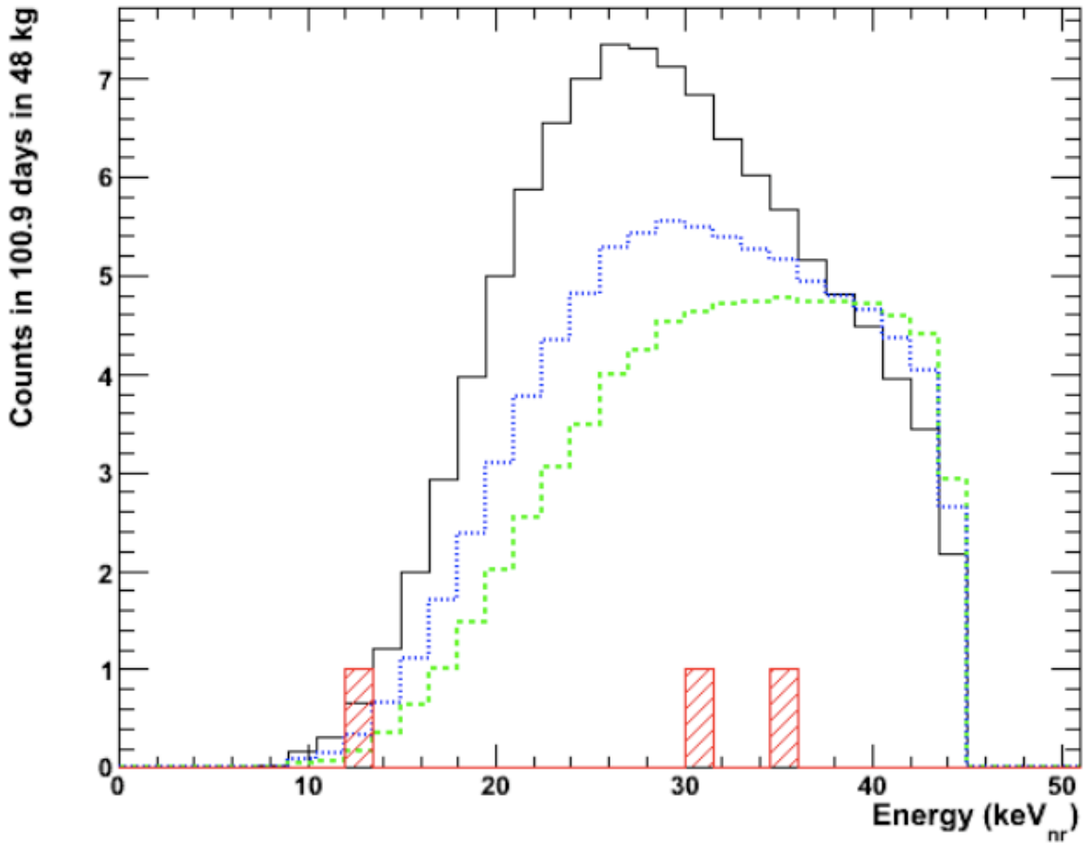
- ~100 GeV DM with ~100 keV splittings scattering *inelastically* off Iodine

- 5-10 GeV DM scattering *elastically* off Na

} focus first on this

New Results from XENON-100: inelastic DM

Expected spectra from DM versus data



$m_\chi \sim 50$ GeV, $\delta \sim 110$ keV

$m_\chi \sim 55$ GeV, $\delta \sim 115$ keV

$m_\chi \sim 60$ GeV, $\delta \sim 120$ keV

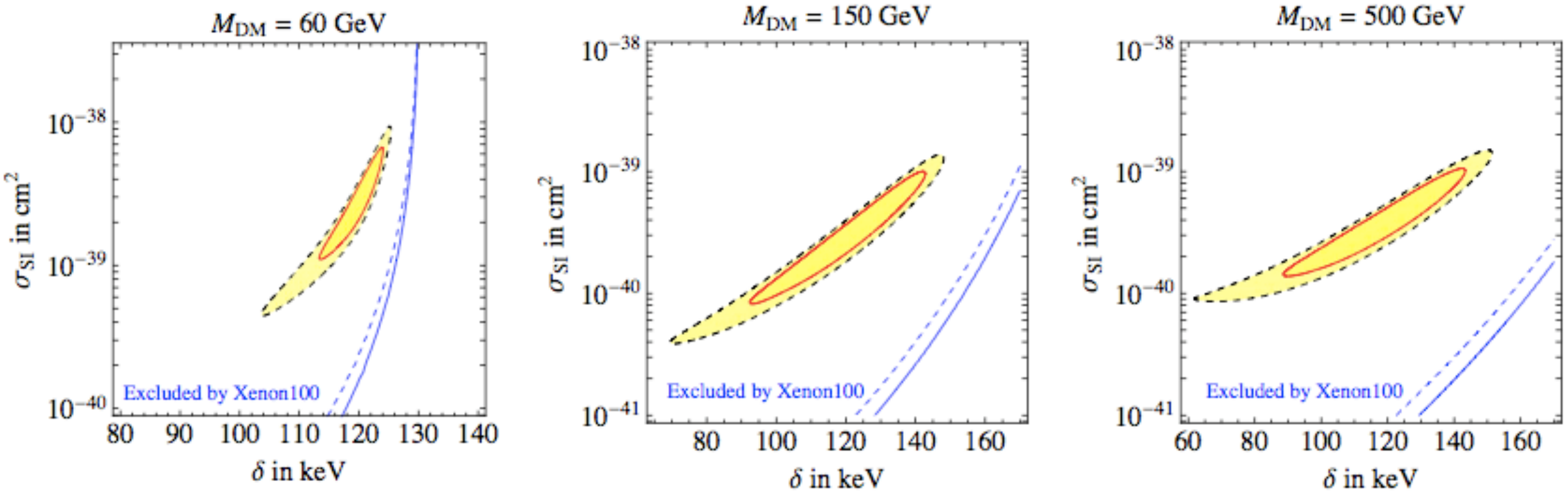
observed spectrum in red

1104.3121

$$\text{data} \ll \text{expected}$$

New Results from XENON-100: inelastic DM

Constraints

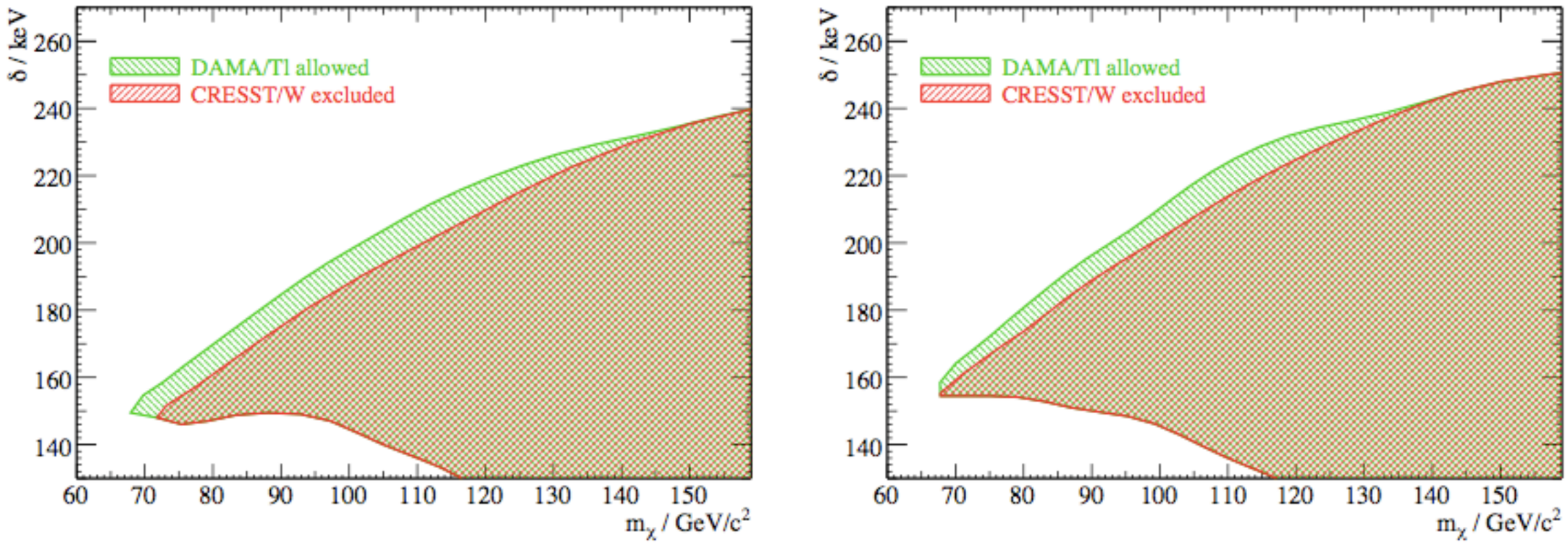


1104.3572

inelastic DM as an explanation of DAMA seems very disfavored...

But inelastic DM isn't completely dead...

DAMA has Thallium impurities (A~205) 10^{-3},
which allows large DM splittings



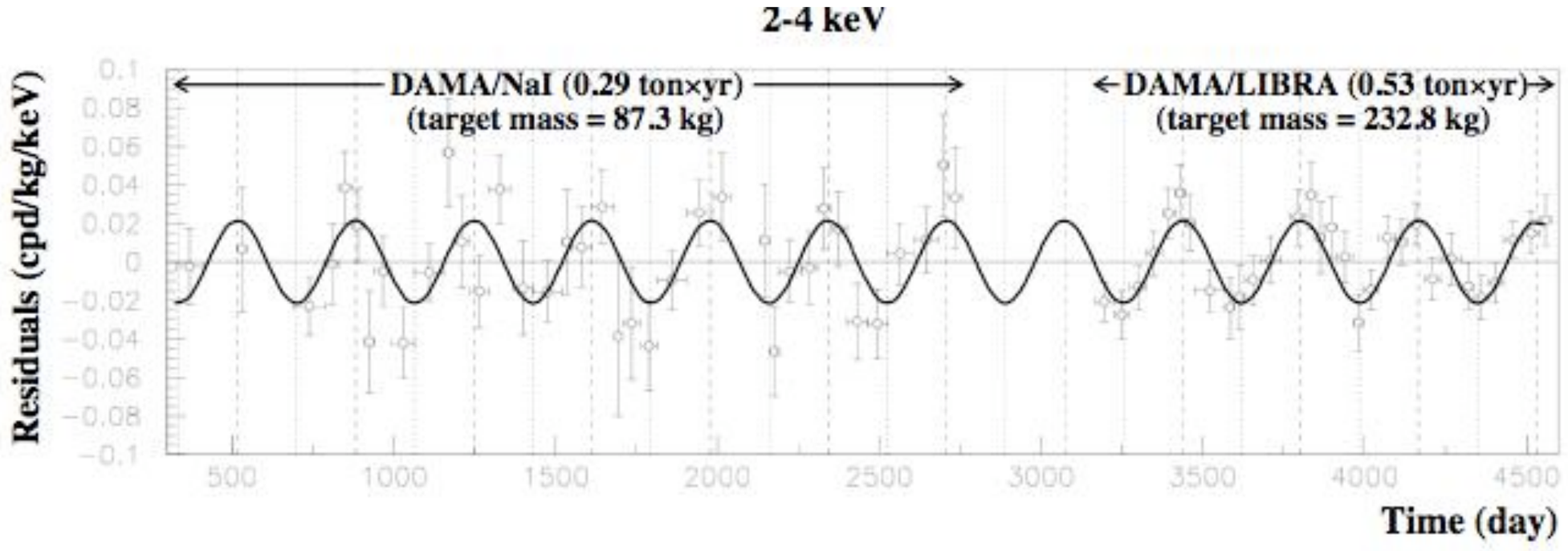
1007.2688

in this case, XENON-100 isn't sensitive

(there is also "isospin violating" and "magnetic" inelastic DM)

Is DAMA seeing DM?

DAMA (NaI) sees annual modulation

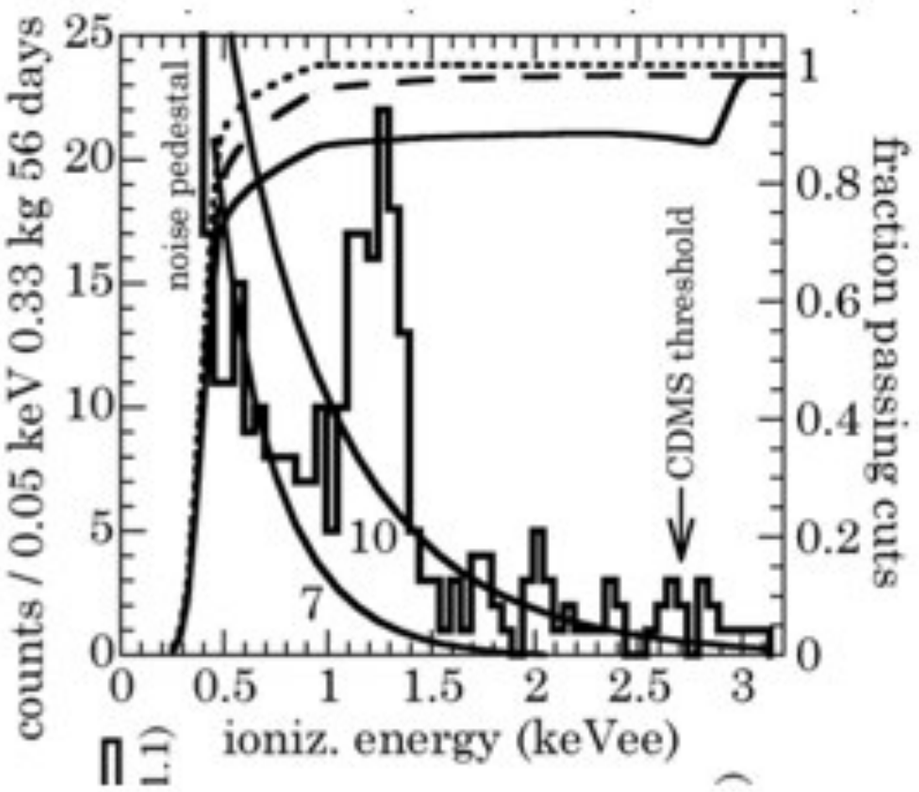


Two popular possibilities to explain this with DM and A's:

- ~100 GeV DM with ~100 keV splittings scattering *inelastically* off Iodine

- 5-10 GeV DM scattering e*lastically* off Na } focus now on this

Light DM scenario is motivated also by CoGeNT!



CoGeNT (Germanium)
sees excess of
O(100) events

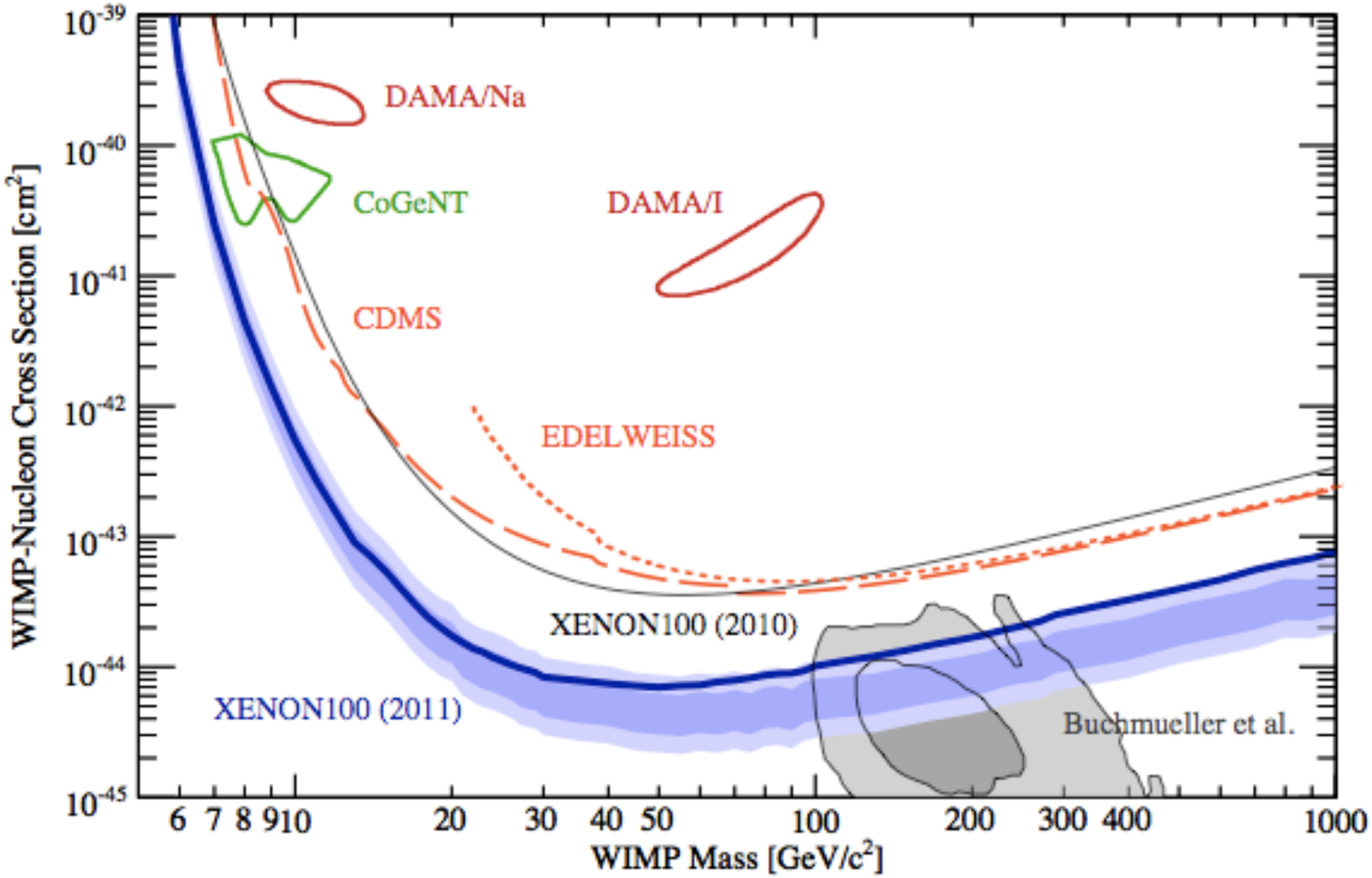
Can be explained by:

- 5-10 GeV DM scattering *elastically* (like DAMA!?)

known force carriers cannot give such a
large cross-section without being ruled out!

New results from XENON-100 disfavors light DM

(100 days of data)

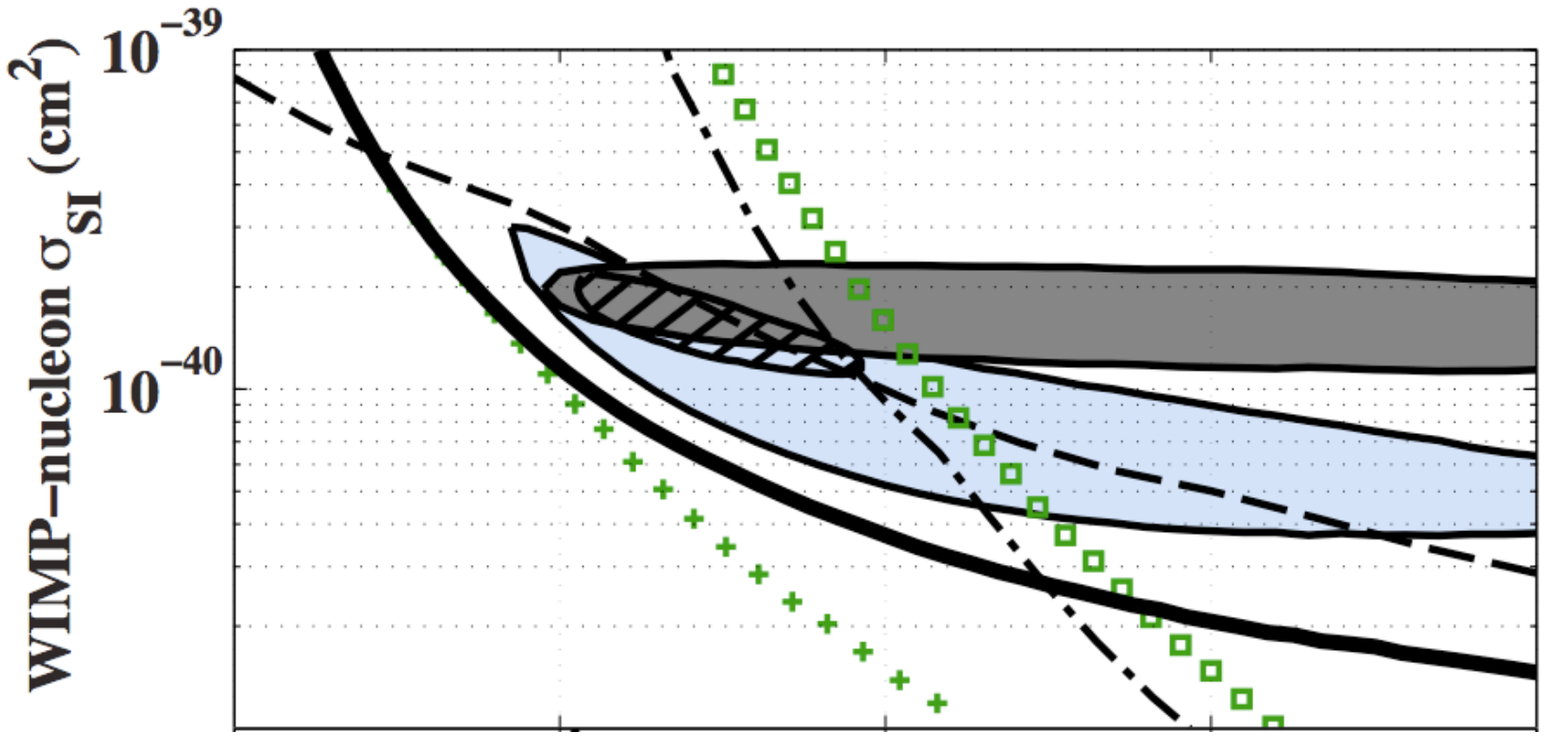


1104.2549

- light DM produces small recoil energies, where detector response is less well known
- some have questioned resulting limits

Recent low energy analysis from CDMS-02

also appears to disfavor light DM scenario explaining DAMA/CoGeNT...



in green:
XENON-100 with different assumptions about energy threshold

in black:
CDMS-02
1011.2482

but there are reservations about this analysis in the literature by J. Collar (on CoGeNT), see e.g. 1103.3481

To summarize...

Two popular scenarios (light DM scattering elastically and heavy DM scattering inelastically) are very constrained

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So what are we to make of the DAMA annual modulation signal?

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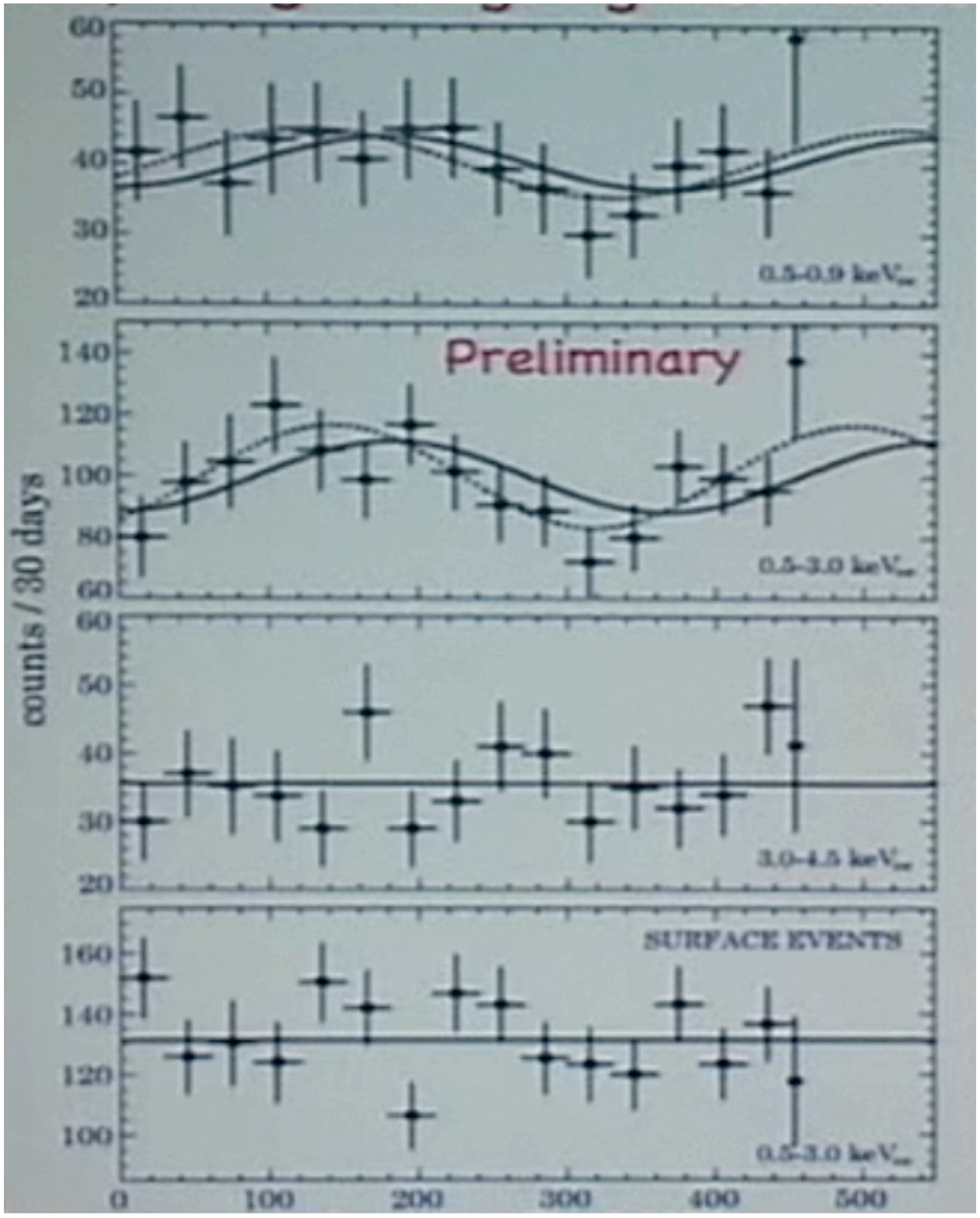
Two popular scenarios (light DM scattering elastically and heavy DM scattering inelastically) are very constrained

So what are we to make of the DAMA annual modulation signal?

and now there is this…

Whoa!? Is CoGeNT seeing annual modulation??



~2.8 sigma

Very preliminary…
(no paper yet)

Choices:

- CoGeNT is wrong
- XENON-100, CDMS, etc. are wrong
- DM is more complicated

So the intrigue isn't finished yet…

04/2011

Summary

- DM annihilation or decay to A′s can produce various signals (gamma-rays, neutrinos, CMB)
  - large astrophysical uncertainties
  - Planck is likely to be decisive
  - DM *decays to A′s* are much less constraining
  - Origin of e^+ excess still unknown!

Summary

- DM annihilation or decay to A′s can produce various signals (gamma-rays, neutrinos, CMB)
  - large astrophysical uncertainties
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  - DM *decays to A′s* are much less constraining
  - Origin of e^+ excess still unknown!

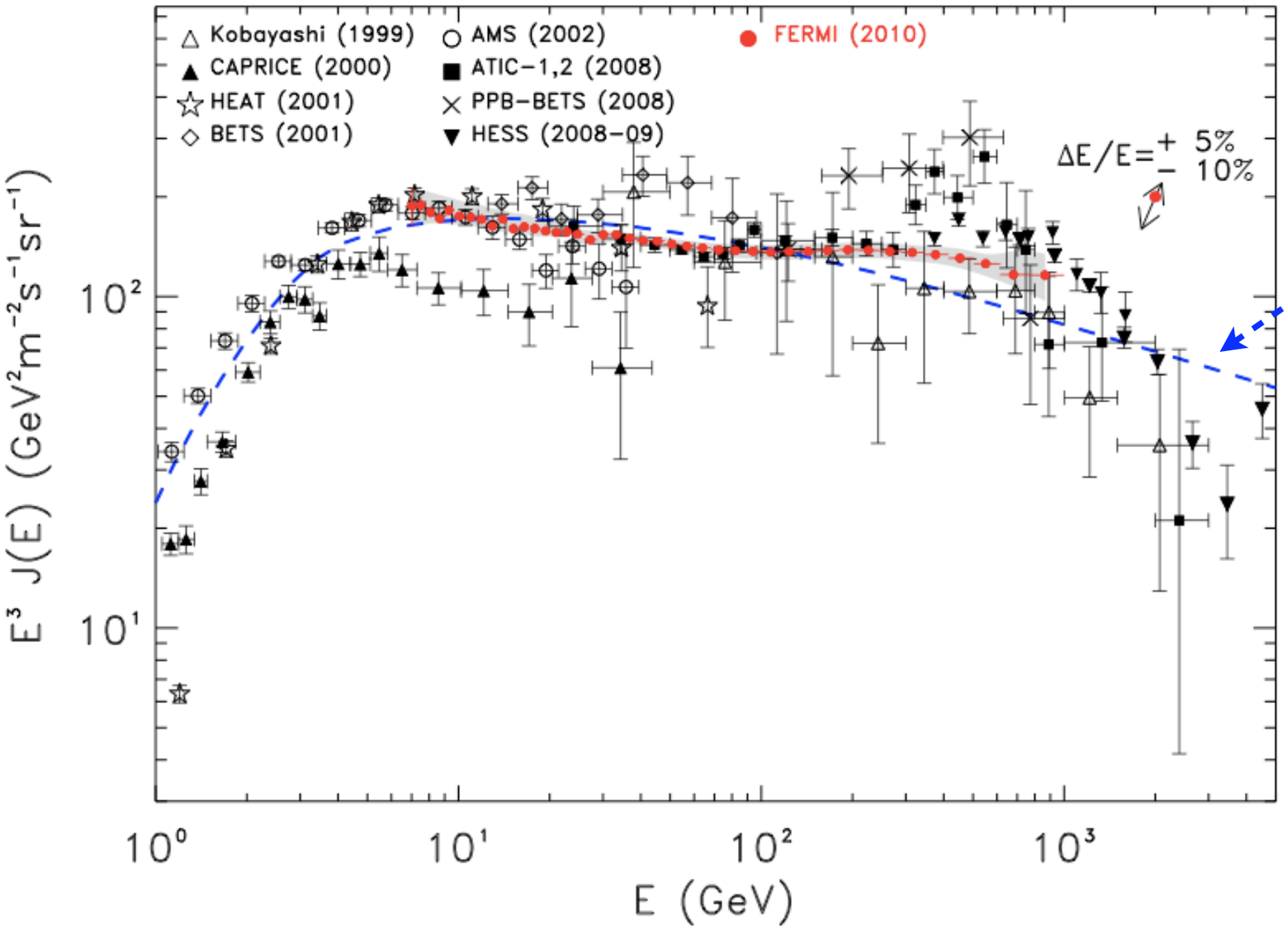
- Signals at DAMA and/or CoGeNT suggest *light elastic* or *heavy inelastic* DM
  - standard picture severely constrained from XENON-100, CDMS-02, … (bounds on light DM somewhat controversial)
  - situation very unclear, but DAMA's (and CoGeNT's!?) annual modulation signal still needs an explanation!

If signals are DM, then likely need a new force carrier

Backup

Observed cosmic-ray excesses

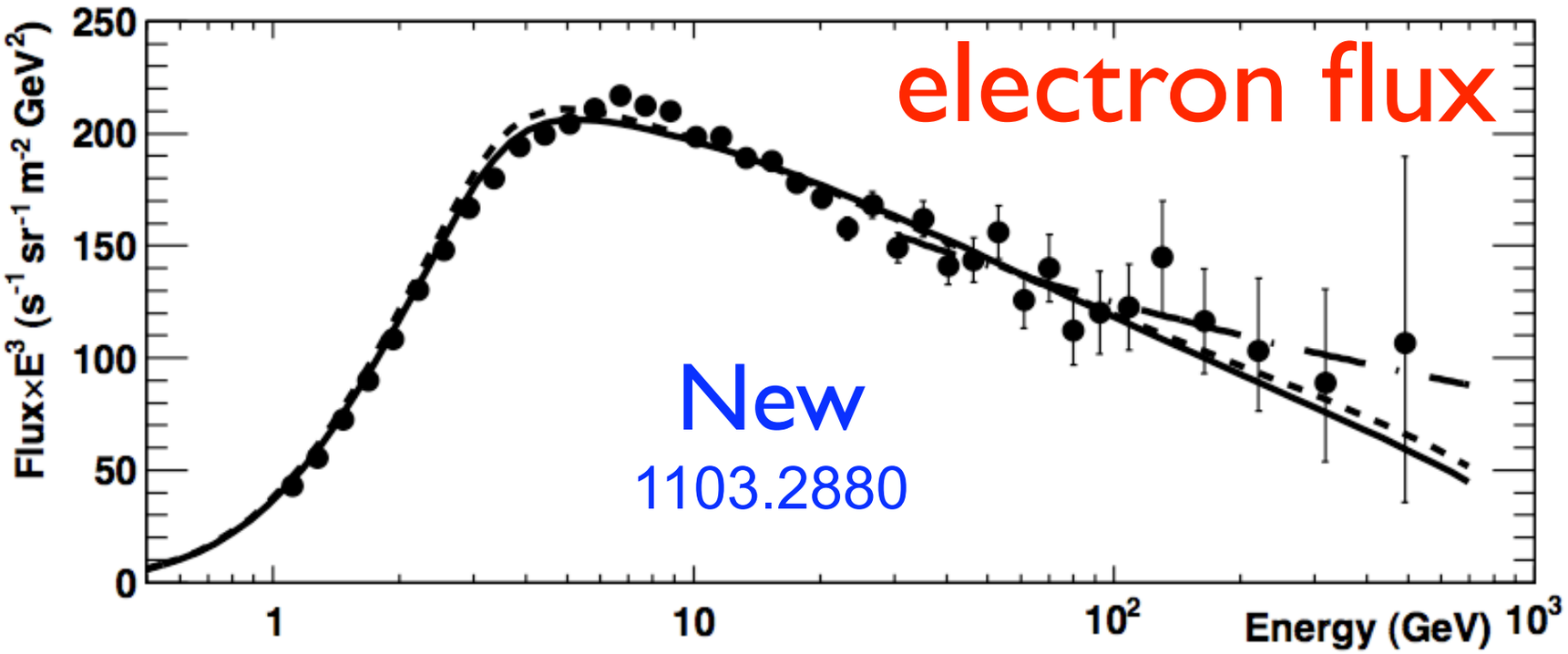
Fermi: $e^+ + e^-$ flux



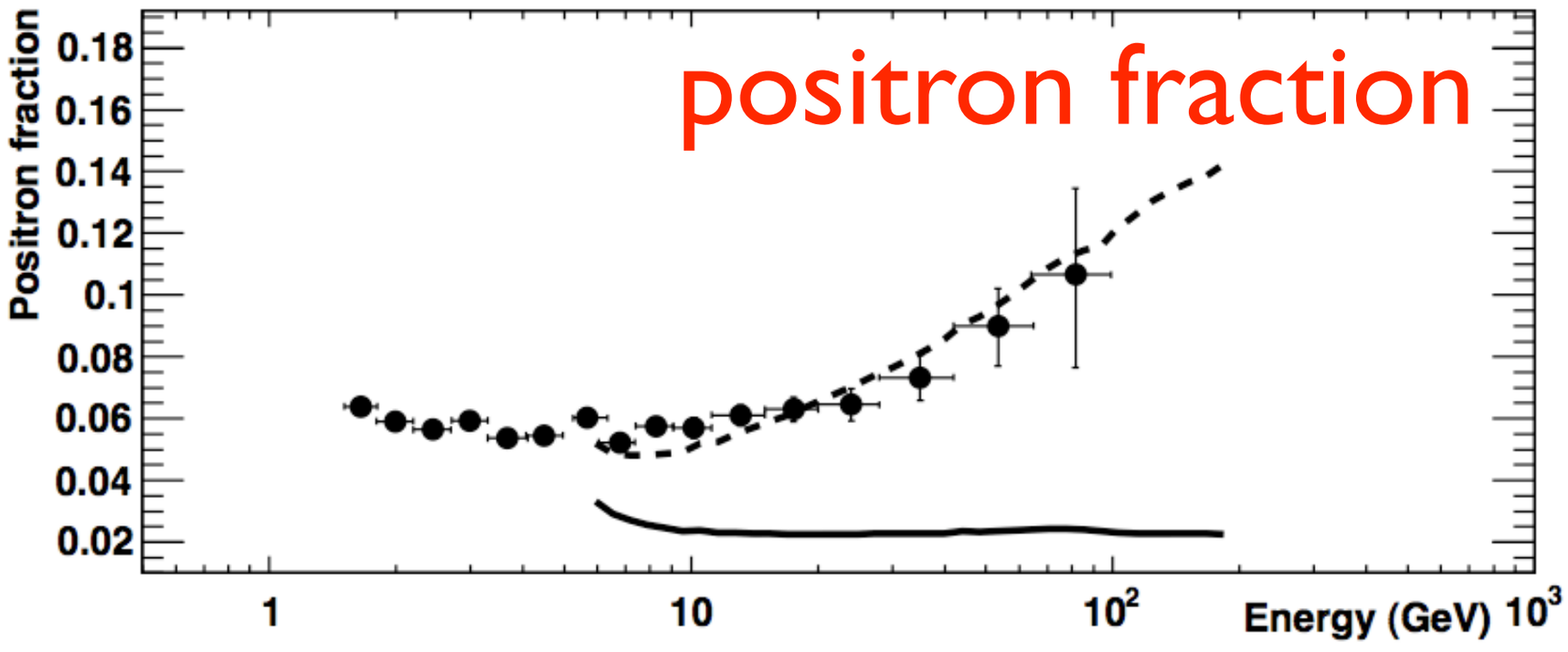
theory expectation

Fermi updated their $e^+ + e^-$ measurement in 2010

PAMELA electron and positron spectrum



long dashed: power-law fit to data above 30 GeV

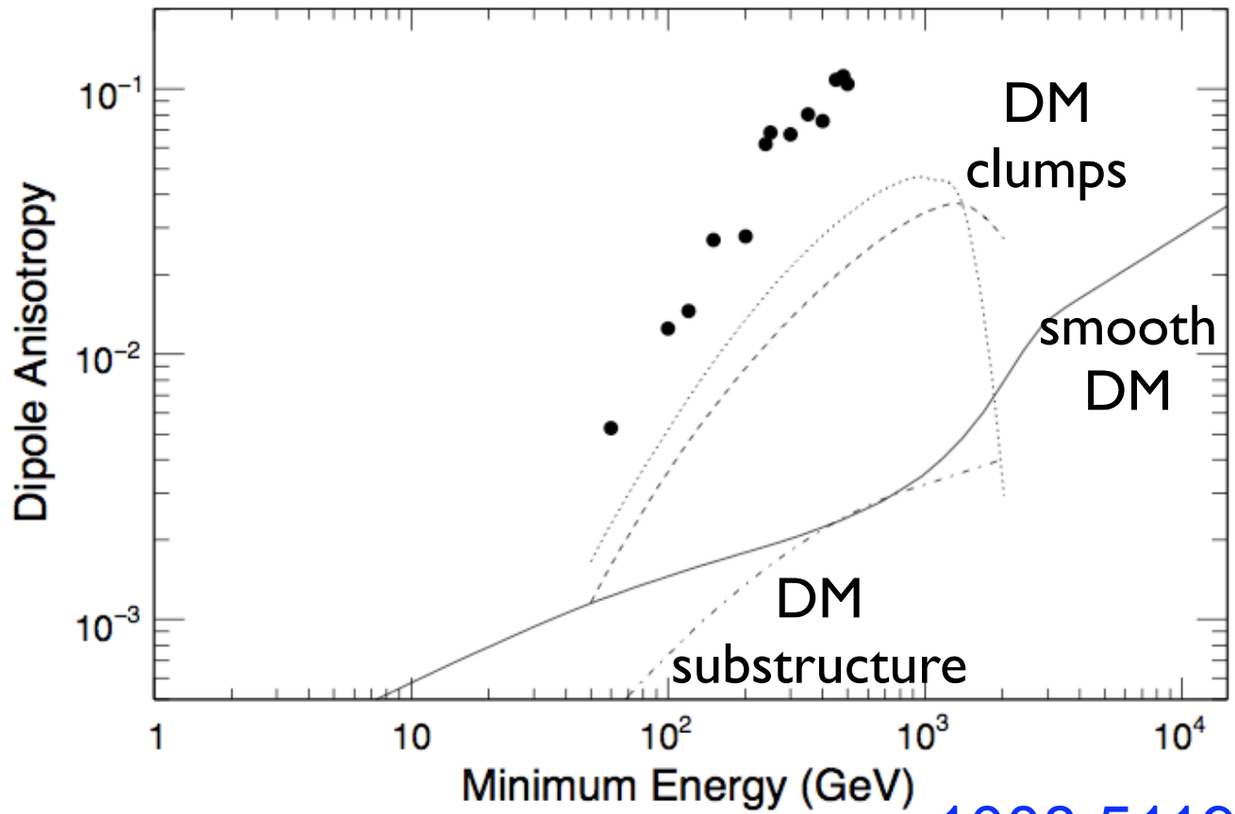


short dashed: incl. additional e^+ & e^- component

solid: "theory"

Cosmic-ray anisotropies from a pulsar or DM

Dipole anisotropy from DM



1008.5119

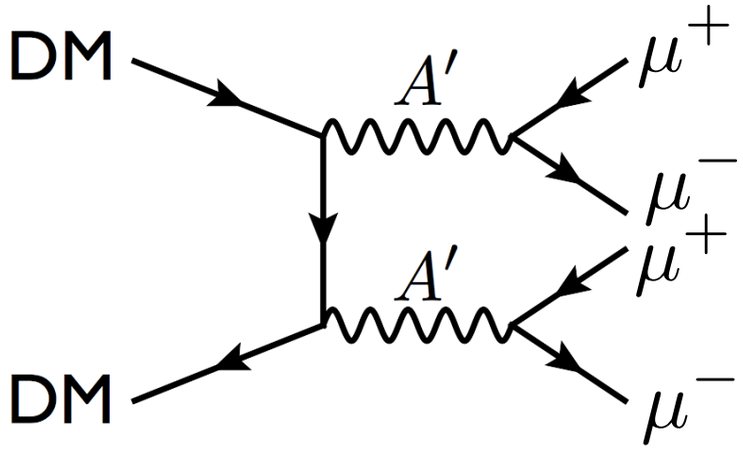
FIG. 10: Dipole anisotropy δ versus the minimum energy for some DM scenarios. Solid line: DM distributed in the Milky Way Halo; dashed and dotted lines: two dark matter benchmark models taken from [41]; dot-dashed line: DM from the population of Galactic substructures [42] (see text). The 95 % CL upper limits on the dipole anisotropy from the data are also shown with circles.

limit is consistent with expectation

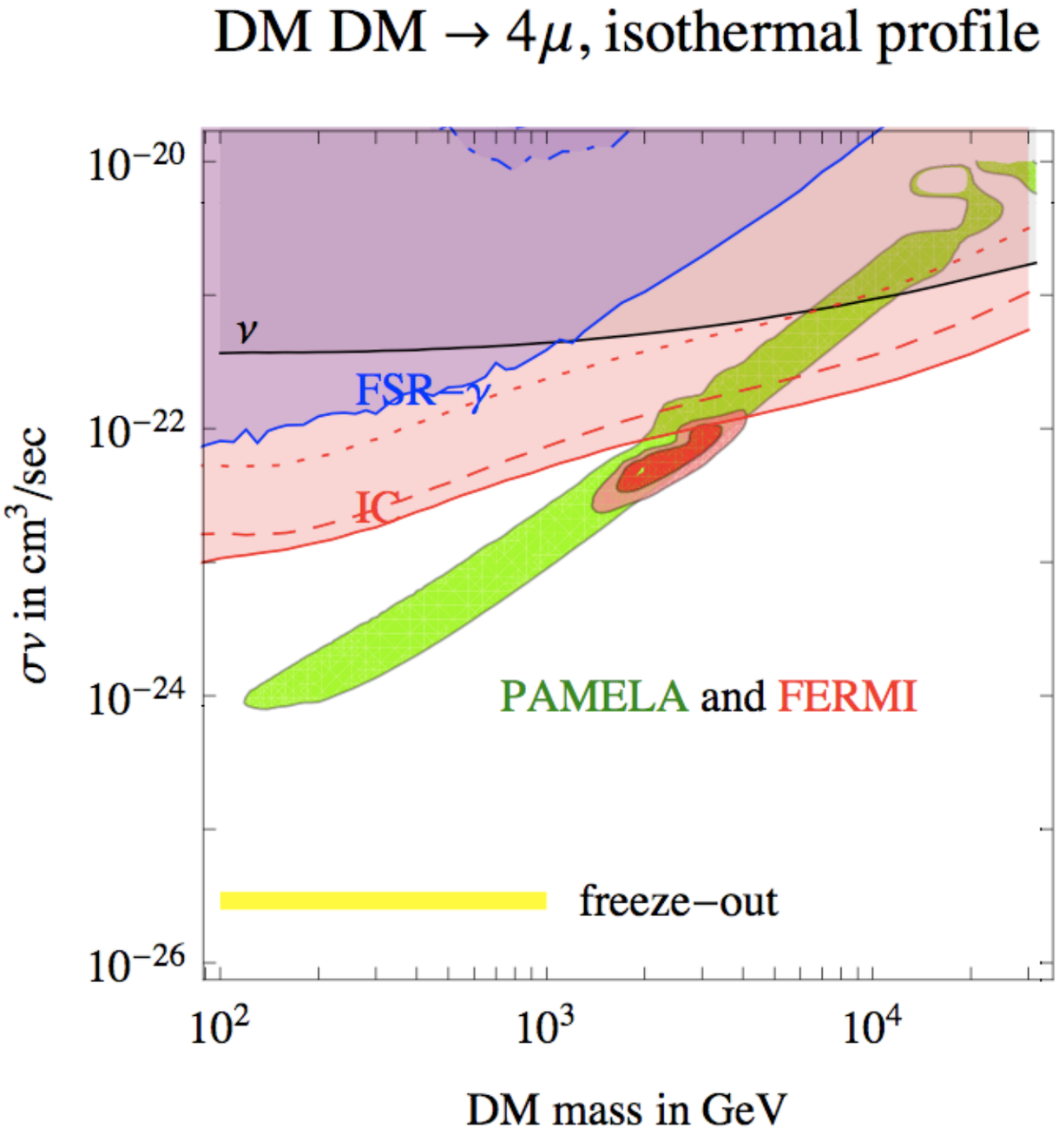
No γ-ray signal seen with existing data

Can set constraints

e.g. for:



constraints from Milky-Way halo

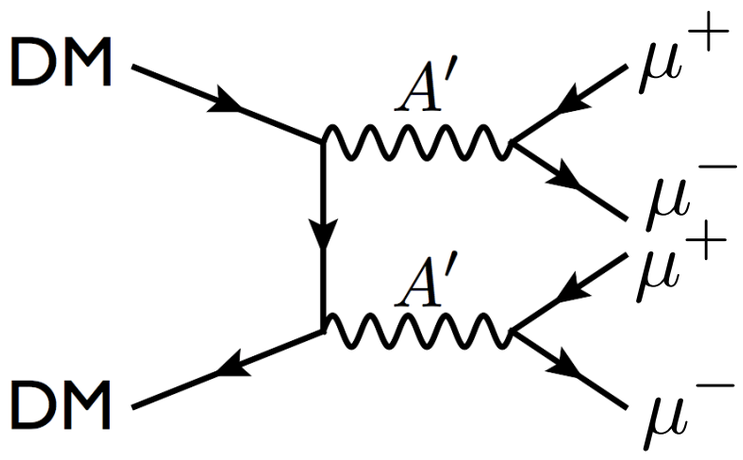


[Papucci, Strumia]

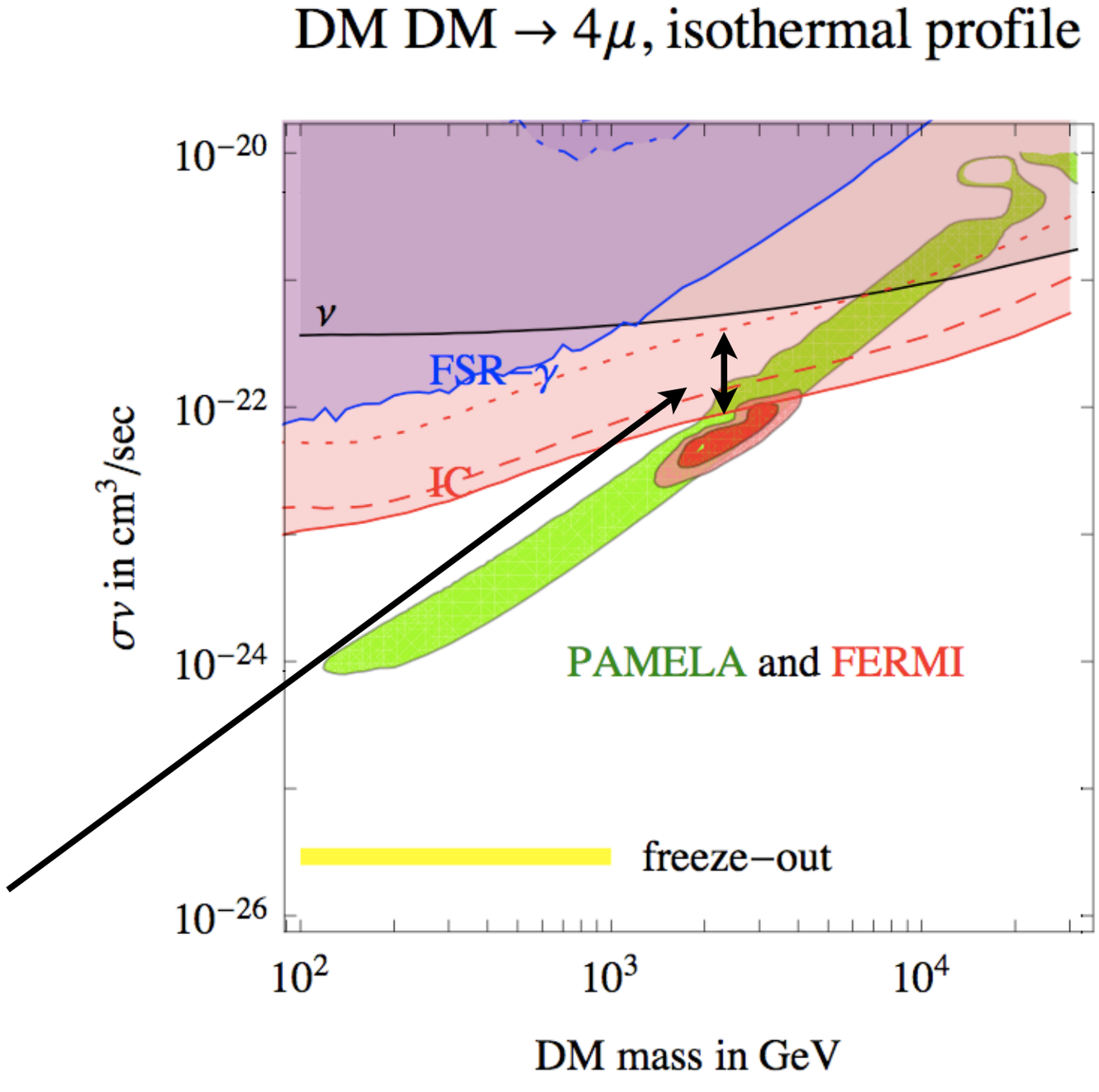
No γ-ray signal seen with existing data

Can set constraints

e.g. for:



constraints depend on diffusion of e^+, e^- in halo

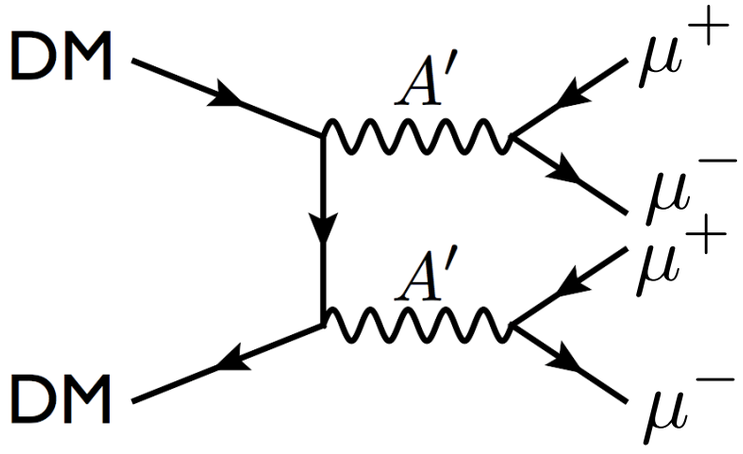


[Papucci, Strumia]

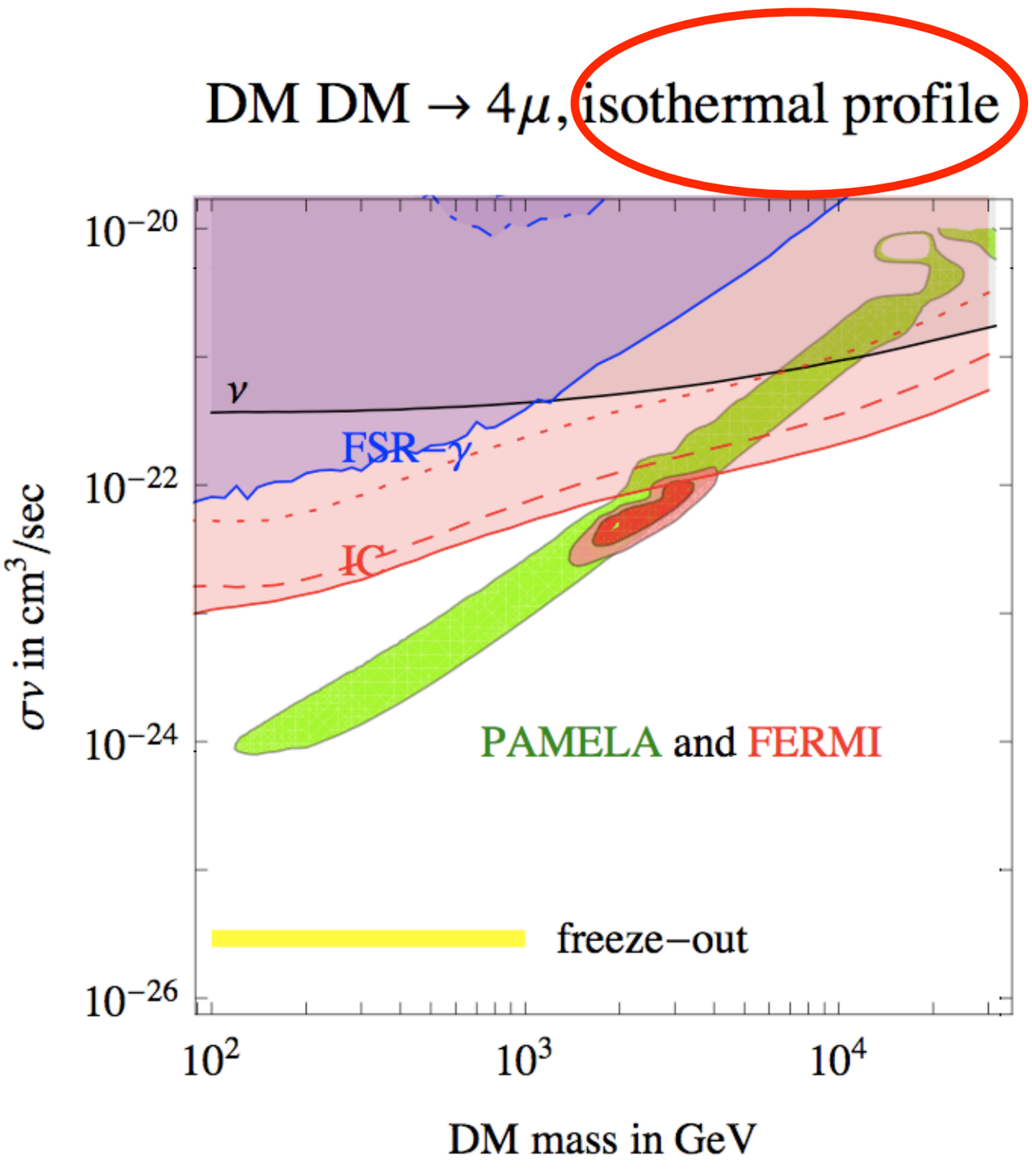
No γ-ray signal seen with existing data

Can set constraints

e.g. for:

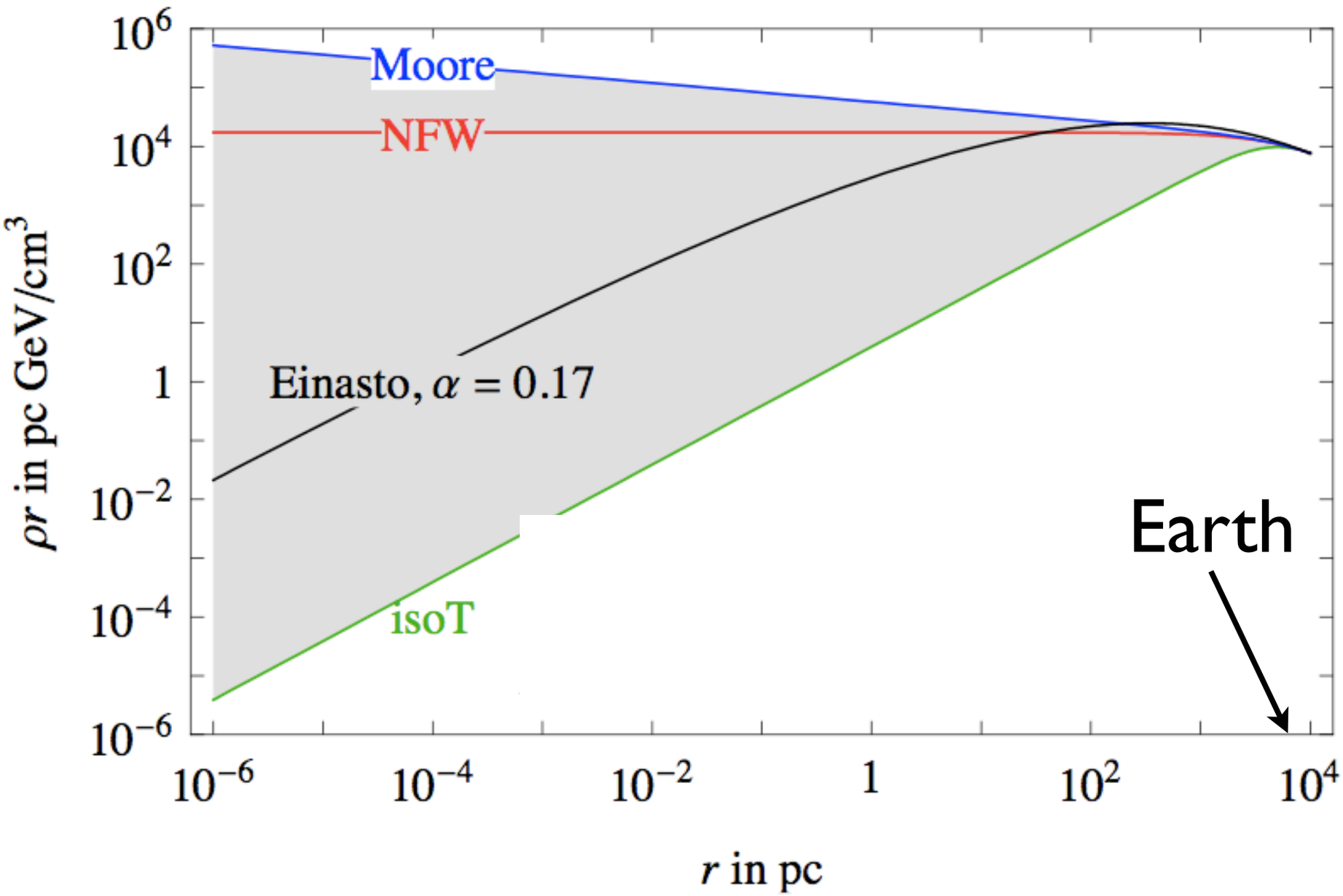


constraints depend on DM profile



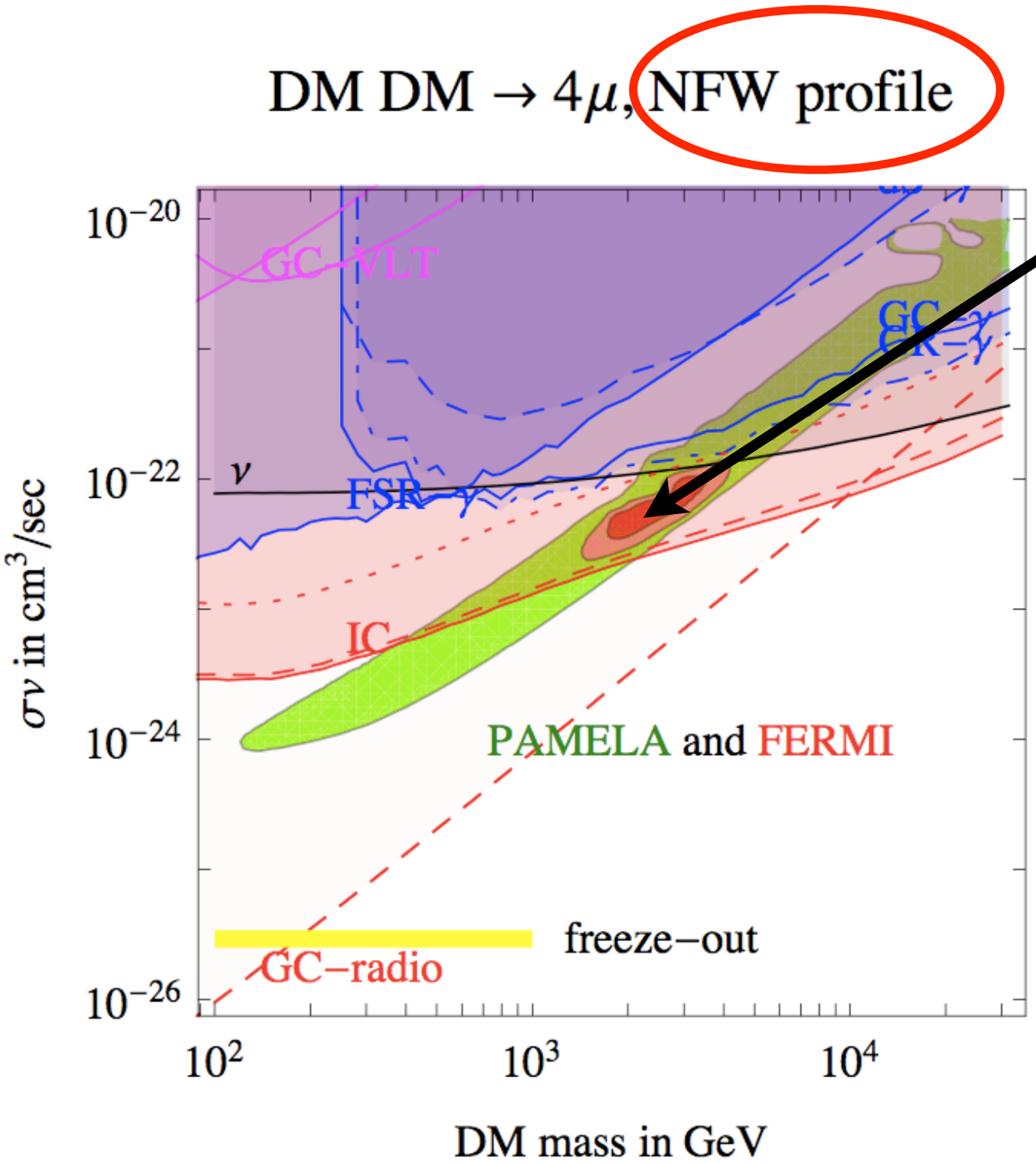
[Papucci, Strumia]

DM density profile?



$\Longrightarrow$ signal size difficult to predict

Stronger constraints for sharper profile



[Papucci, Strumia]

Preferred region also uncertain:

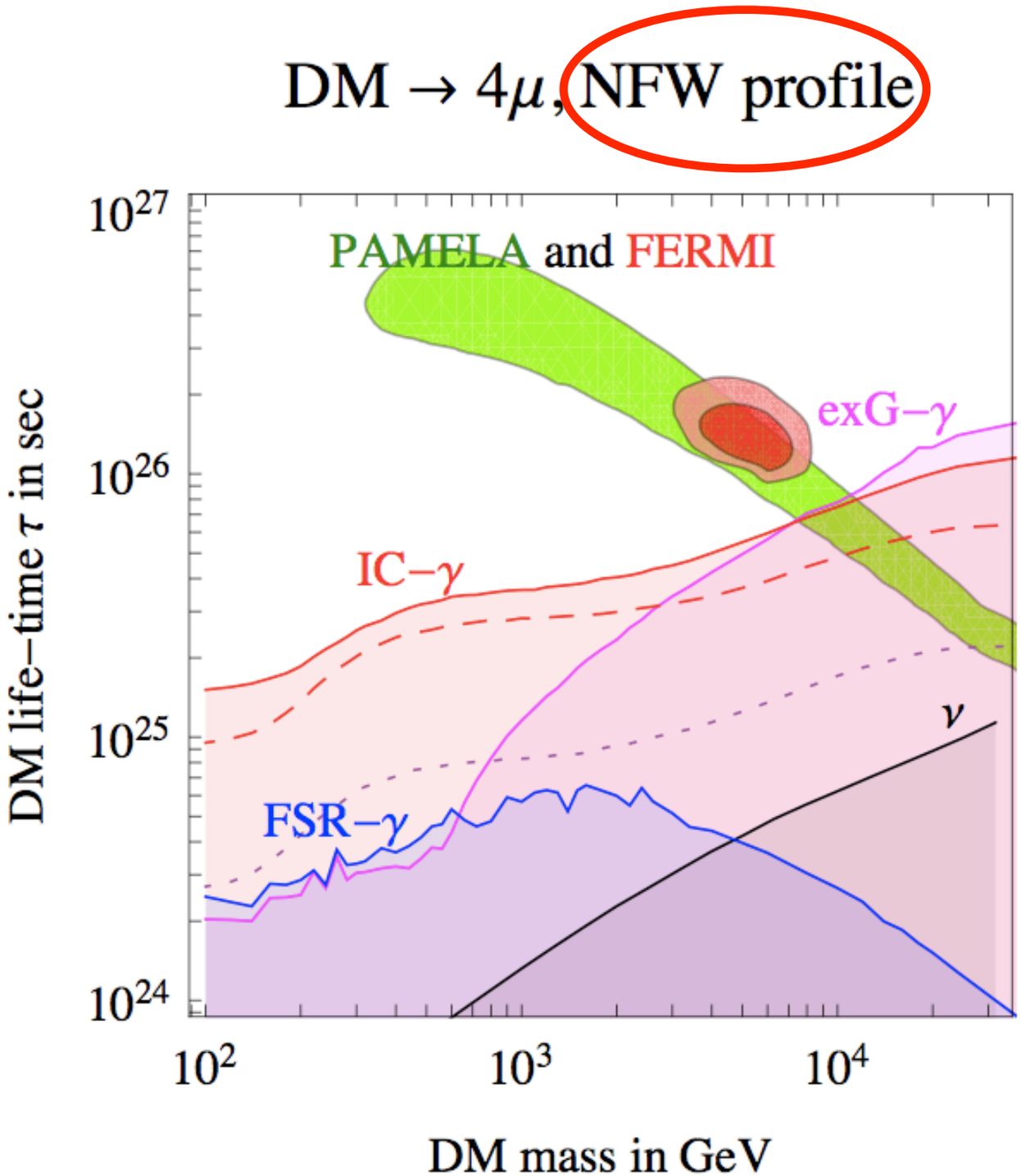
- Local DM density?
- astro backgrounds?
- e^+, e^- propagation?
- Contribution from substructure?

$\Longrightarrow$ can shift down σv of preferred regions

More recent (preliminary!) results from Fermi seem stronger

can expect more results soon...

Weaker constraints for dark matter decays

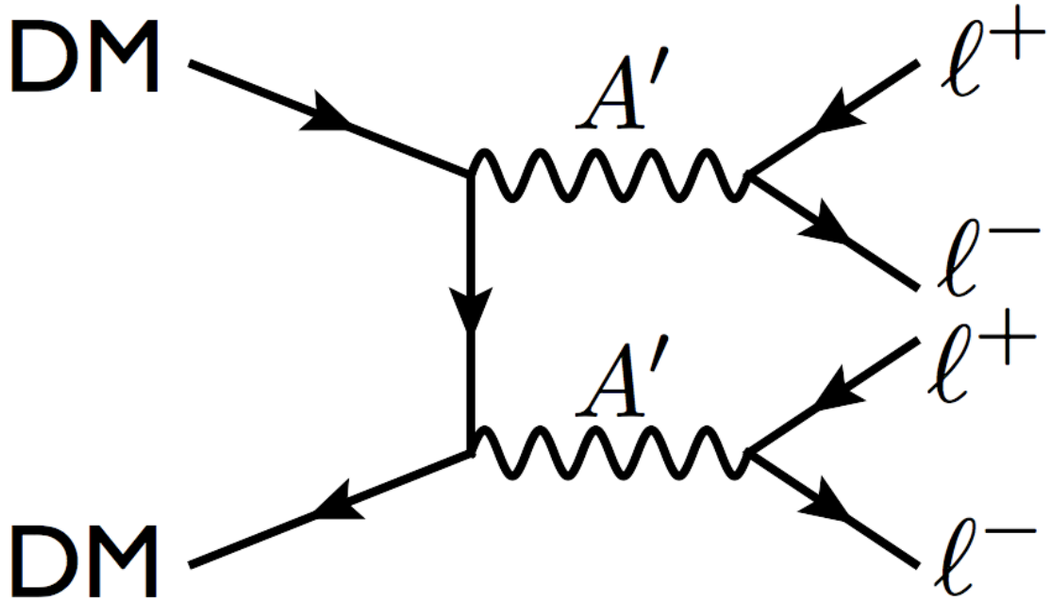


[Papucci, Strumia]

weaker constraints
even for sharper profile

Future observations
could see a signal

Neutrinos possible



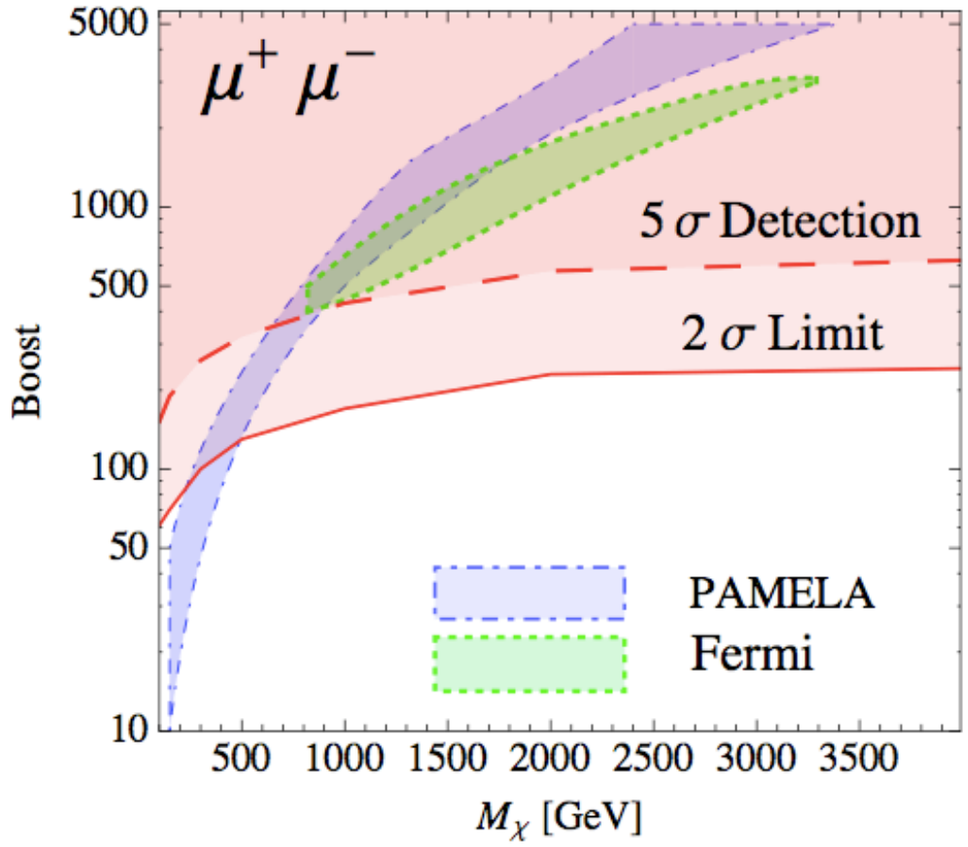
Neutrinos guaranteed if $\ell = \mu, \tau$

$$\tau \longrightarrow \mu \nu_\mu \nu_\tau \ , \ \mu \longrightarrow e \nu_e \nu_\mu$$

observe with IceCube, Super-K

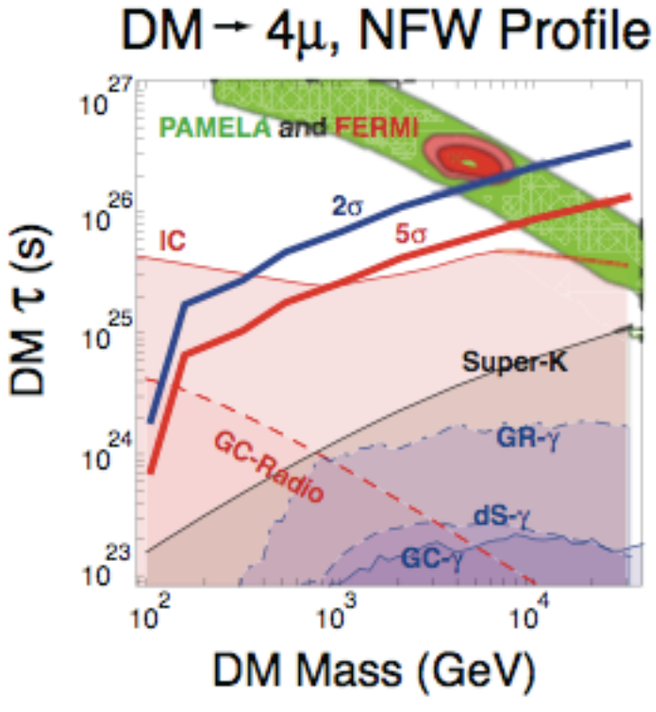
Neutrinos & IceCube

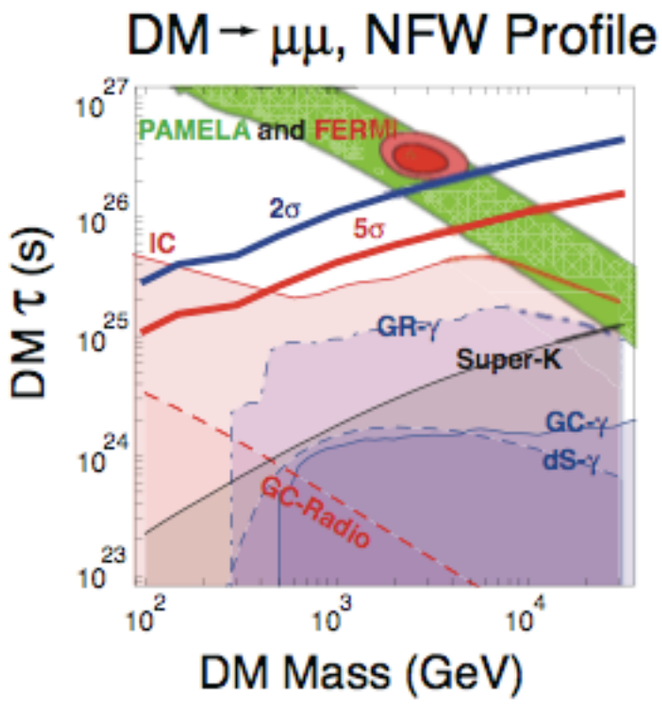
DM annihilation

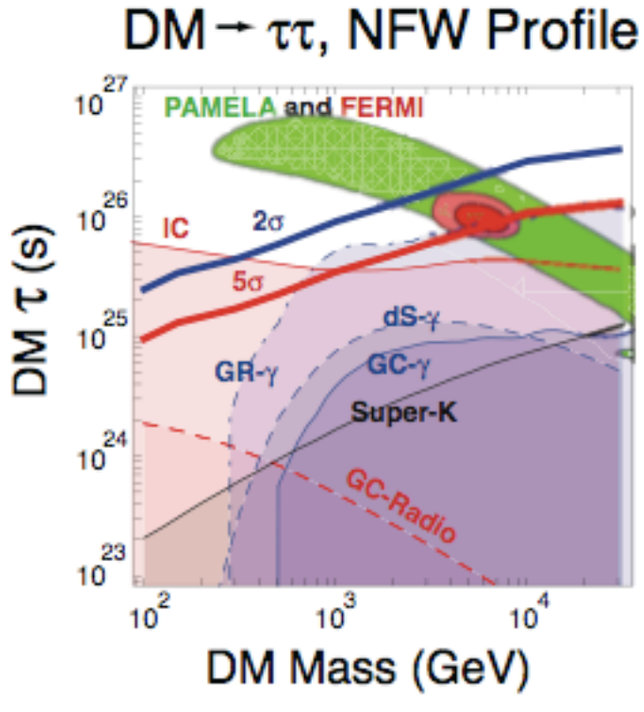


0905.4764

DM decay







0907.2385

Some benchmarks from 1011.3082

Finkbeiner, Goodenough, Slatyer, Vogelsberger, Weiner

explains CR-excesses + consistent with CMB data

Annihilation Channel	m_ϕ (MeV)	m_χ (TeV)	α_D	δ (MeV)	Local BF	Saturated BF	CMB limit
1:1:2 $e^\pm : \mu^\pm : \pi^\pm$	900	1.68	0.04067	0.15	300	530	600
1:1:2 $e^\pm : \mu^\pm : \pi^\pm$	900	1.52	0.03725	1.34	260	360	545
1:1:1 $e^\pm : \mu^\pm : \pi^\pm$	580	1.55	0.03523	1.49	250	437	490
1:1:1 $e^\pm : \mu^\pm : \pi^\pm$	580	1.20	0.03054	1.00	244	374	379
1:1 $e^\pm : \mu^\pm$	350	1.33	0.02643	1.10	156	339	340
$e^\pm$ only	200	1.00	0.01622	0.70	67	171	171

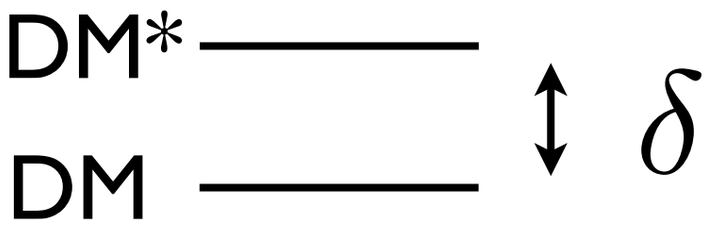
$m_{A'}$ ~ 200 - 900 MeV

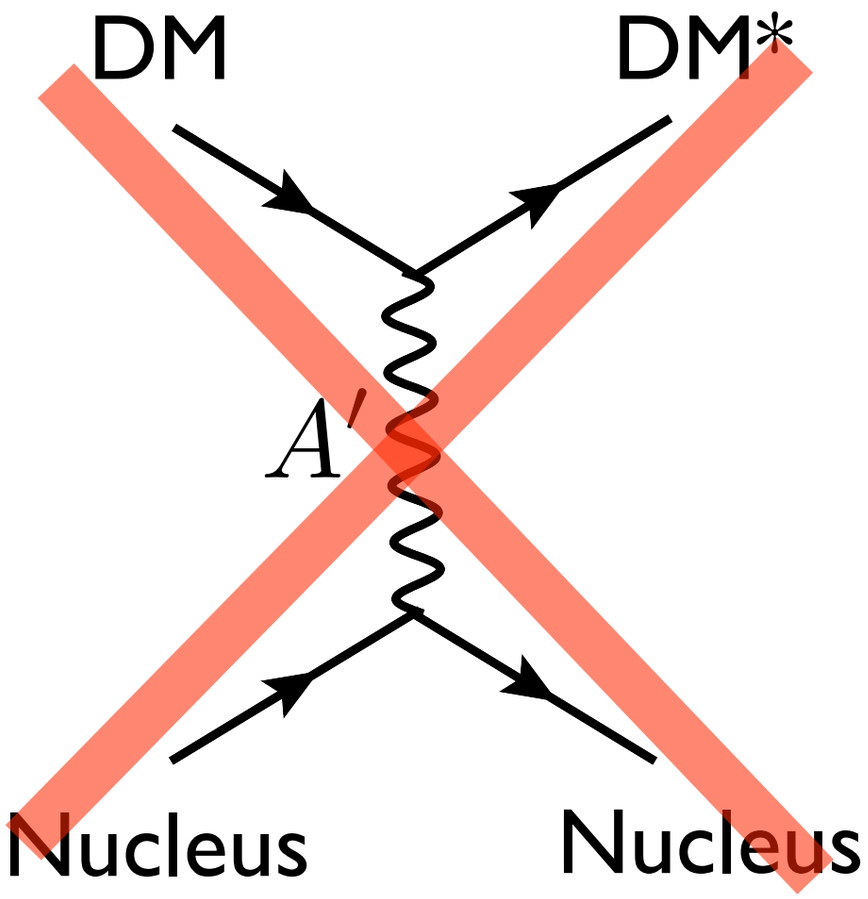
α_D fixed from requiring correct DM relic abundance

δ is splitting between two DM components

ϵ is *not* fixed by these indirect measurements!

A note on inelastic DM with large splittings





Note:

$$\delta > \text{a few } 100 \text{ keV}$$

$\Longrightarrow$ DM difficult to detect at direct detection experiments

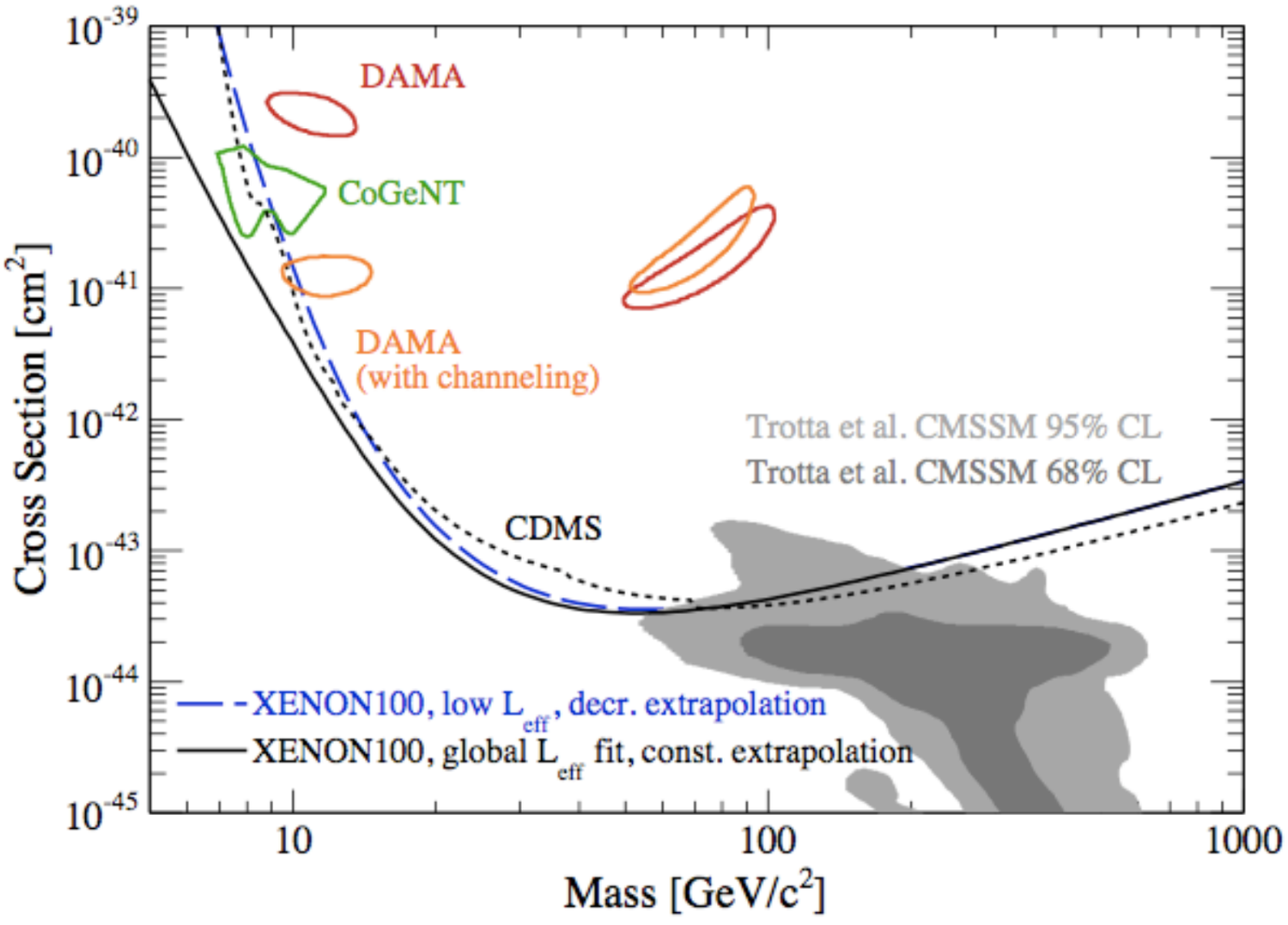
i.e. a model can explain the PAMELA/ Fermi cosmic-ray data, but be nearly invisible in direct detection experiments

Caveats: there will be an elastic scattering via A′ exchange through a *one-loop diagram* and also through Higgs exchange (these are small)

Constraints on light DM elastic scenario have been somewhat controversial

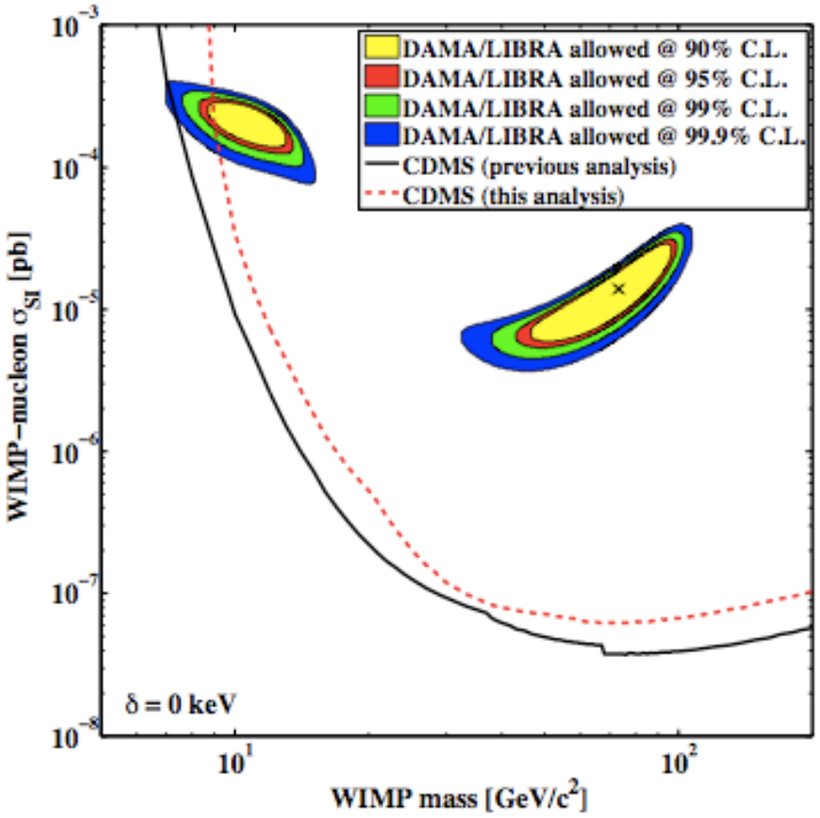
detector response for small recoil energies is less well known

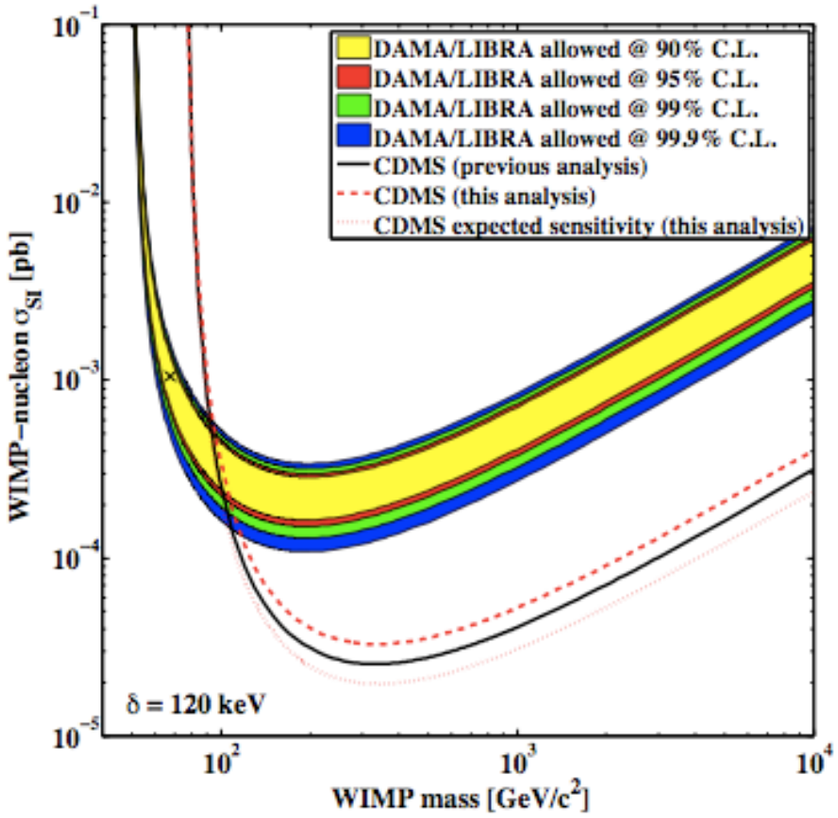
e.g. primary scintillation efficiency in Xenon is uncertain



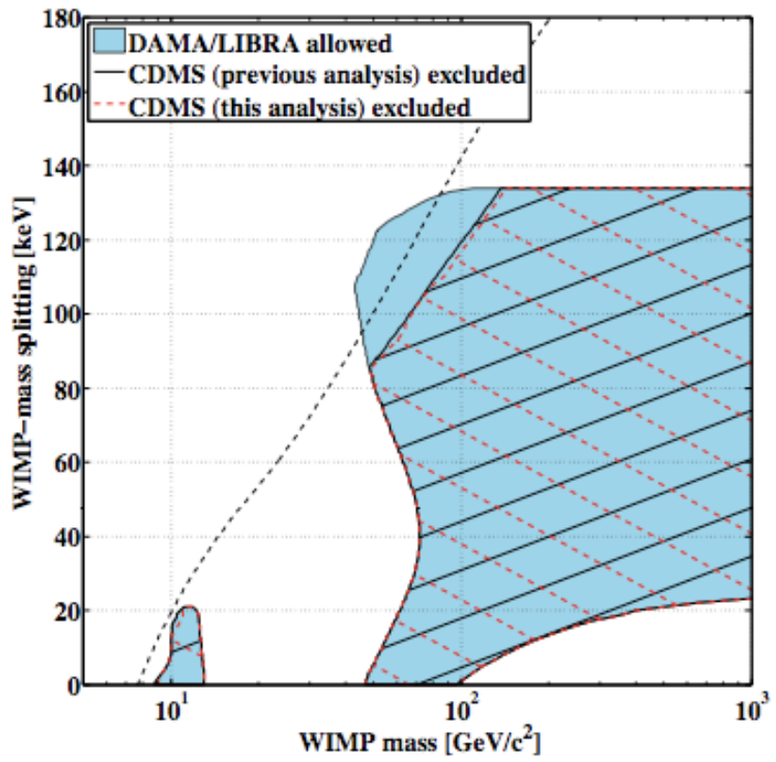
e.g. XENON-100
1005.0380
(10 days of data)

Both light elastic and heavy inelastic DM are constrained





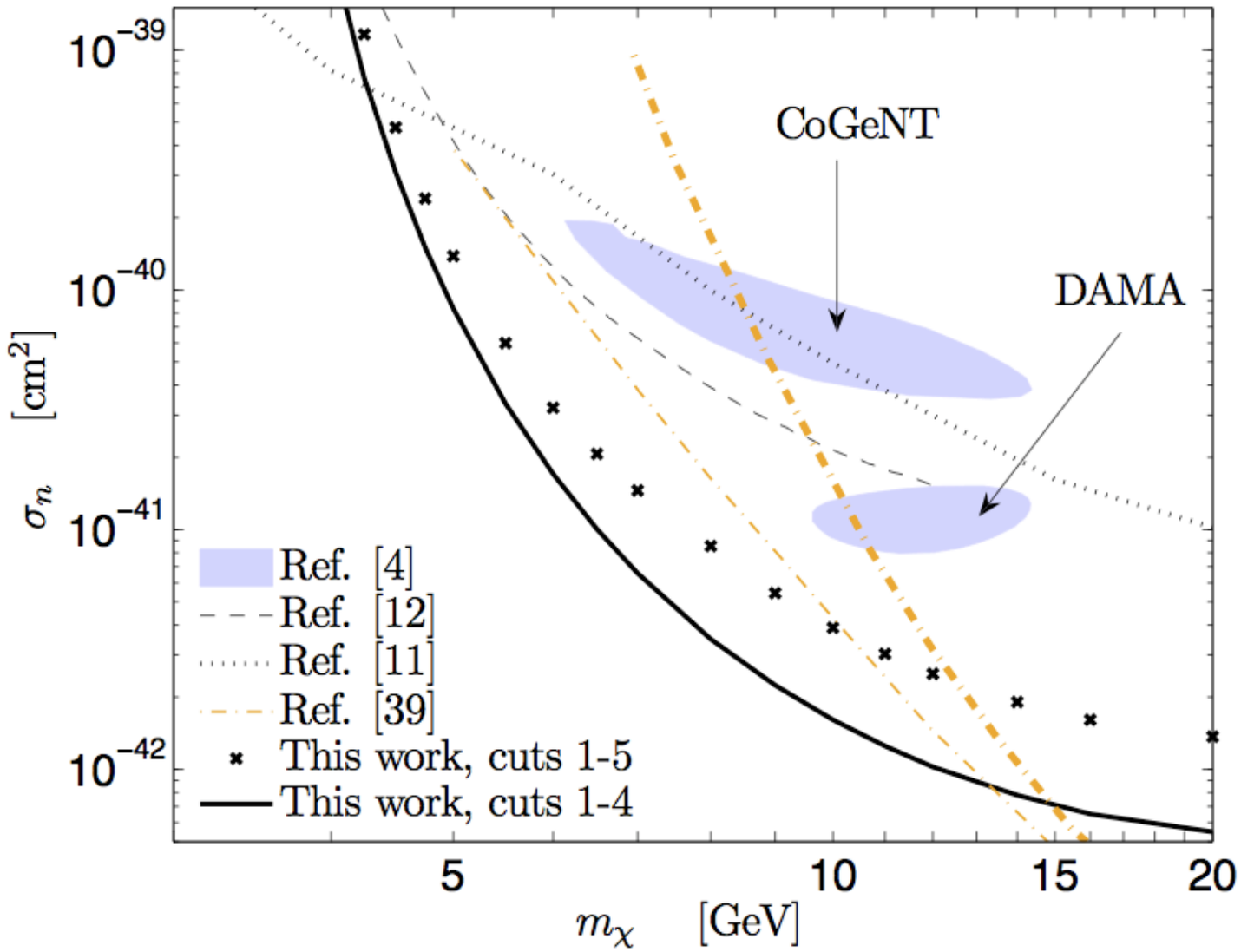
δ



e.g. CDMS-2
1012.5078

New paper from XENON-10 disfavors light DM

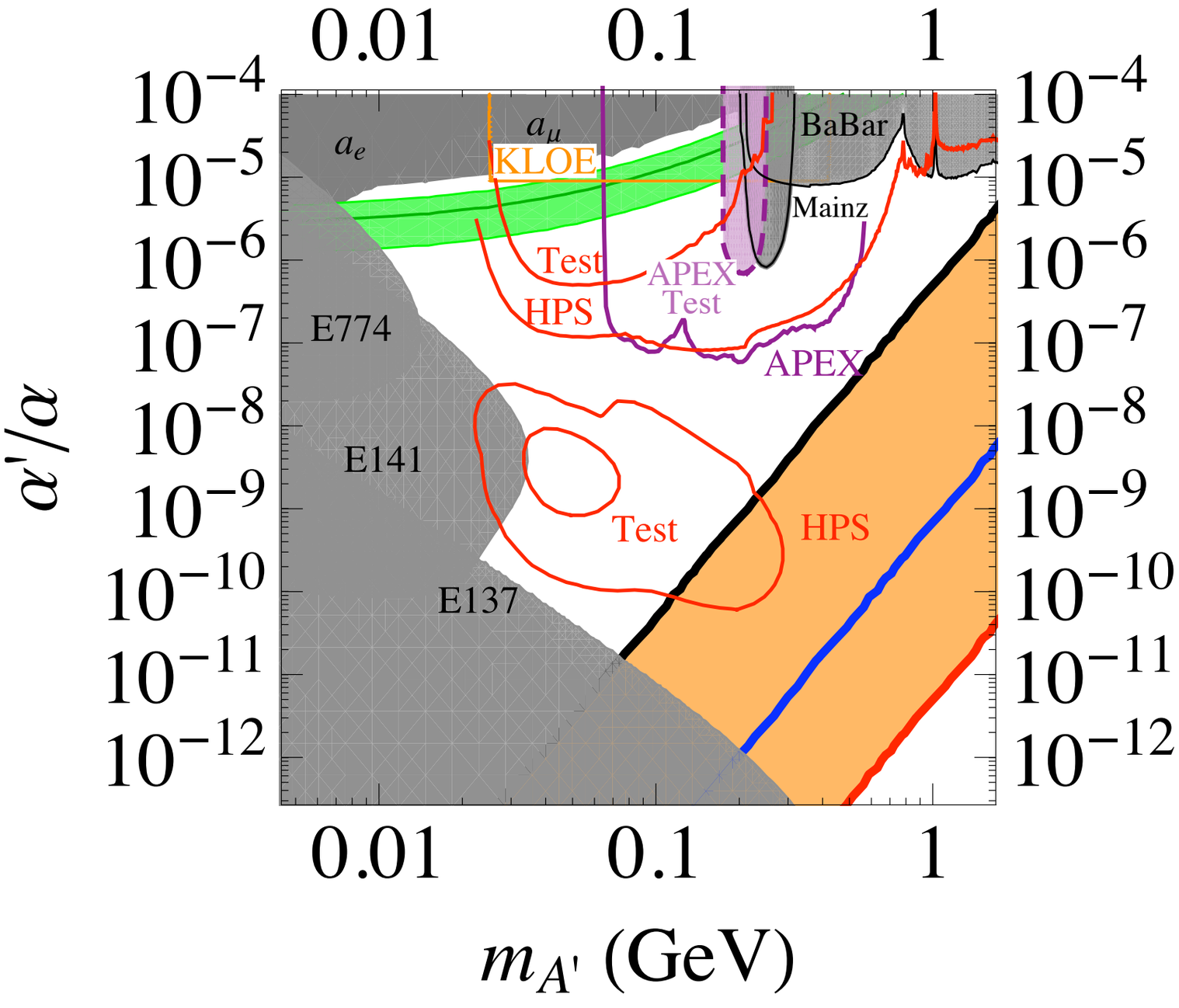
this analysis doesn't use primary scintillation efficiency



1104.3088

J. Collar (on CoGeNT) has reservations about this analysis, see e.g. 1103.3481

Preferred region for DAMA



$\alpha_D = 10^{-5}$

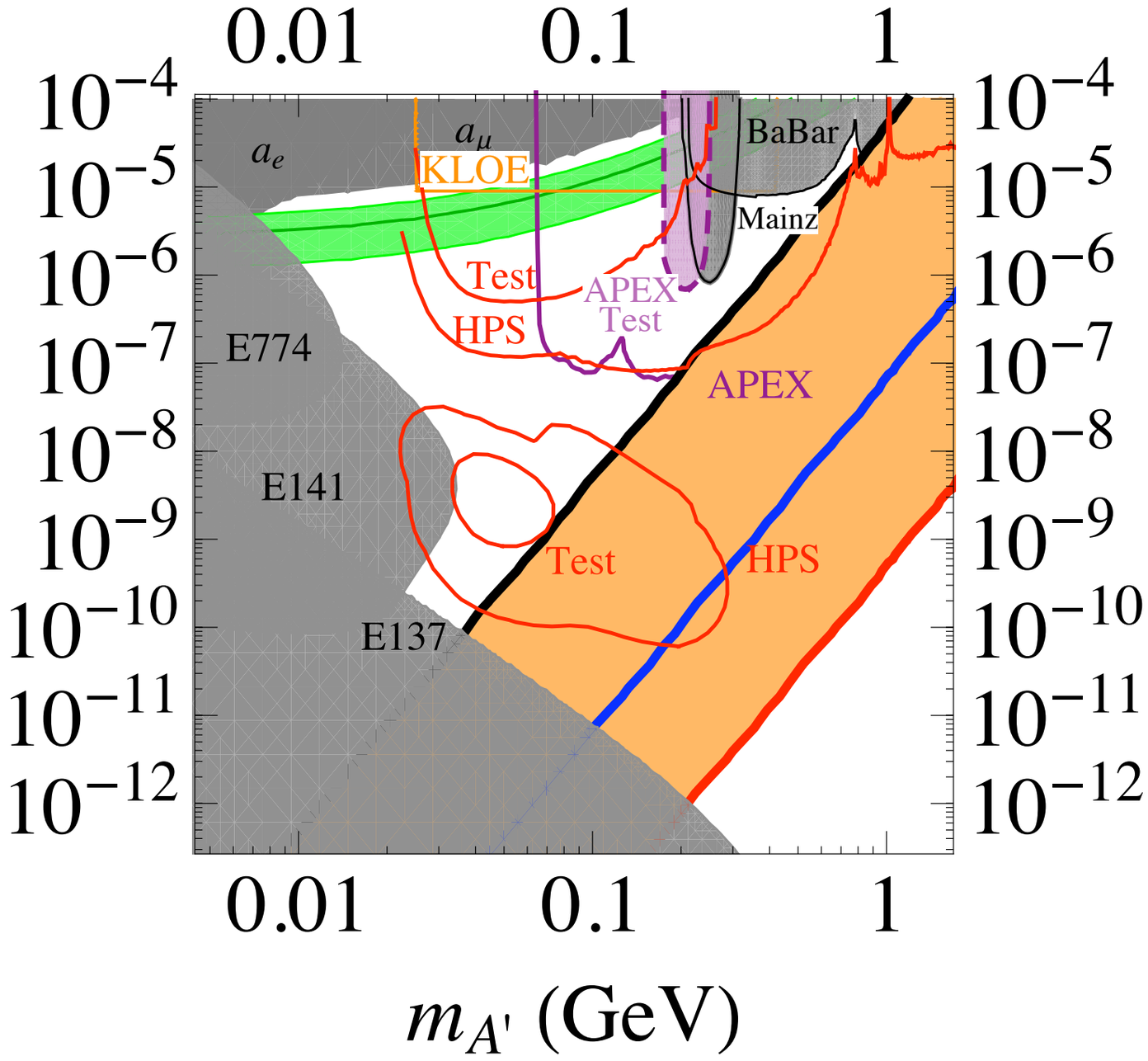
$\alpha_D = \dfrac{1}{137}$

$\alpha_D = 0.1$

assumes $\sigma = 5 \times 10^{-40}\,\mathrm{cm}^2$
consistent with DAMA

lower σ, would
shifts contours down

But if a subdominant component of dark matter scatters with a large cross-section…



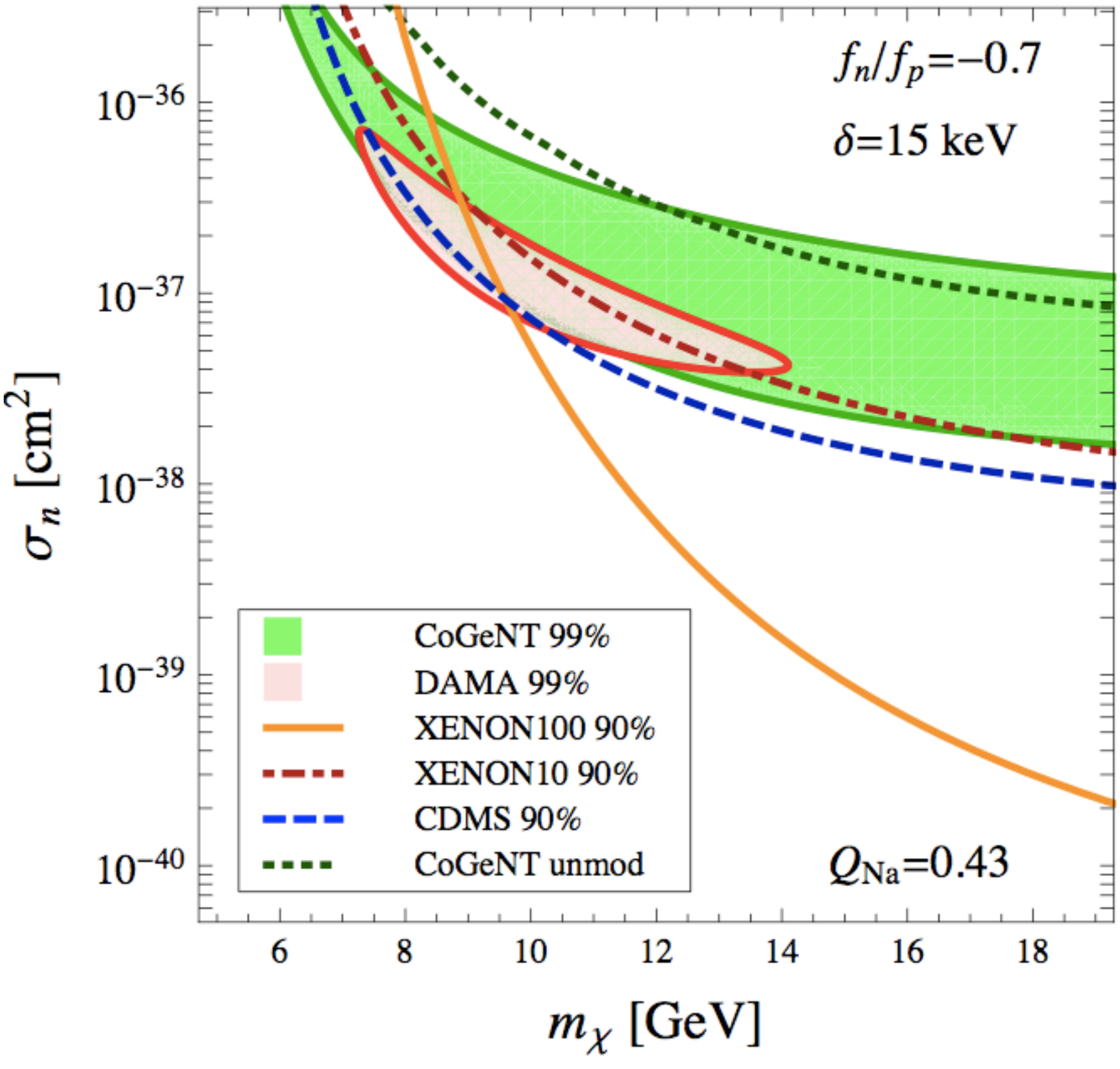
$\alpha_D = 10^{-5}$

$\alpha_D = \dfrac{1}{137}$

$\alpha_D = 0.1$

assumes $\sigma = 5 \times 10^{-38}\,\mathrm{cm}^2$ and subdominant component makes up 1% of total dark matter density

isospin violating, inelastic DM can explain DAMA and CoGeNT



1105.3734