Constraints on Light WIMPs from Isotropic Diffuse γ-Ray Emission

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Rencontres de Moriond: EW Interactions and Unified Theories
March 2011

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Most likely to go away (see Steven Leman's talk), but the concordance is/was intriguing/stimulating.

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Here I discuss indirect constraints on light WIMPs based on the first-year Fermi-LAT data on the diffuse γ-ray background.

Based on work done in collaboration with Chiara Arina (RWTH Aachen).

ArXiv:1007.2765
JCAP 1101:011,2011

WIMP?

1. DM + DM $\longleftrightarrow$ SM + SM

2. Abundance from thermal freeze-out $\Omega \propto \langle \sigma v \rangle^{-1}$

If $\langle \sigma v \rangle \approx 3 \cdot 10^{-26}\,\mathrm{cm}^2 \cdot s^{-1}$ **WMAP OK!**

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particle physics

Astrophysics uncertainties

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particle physics

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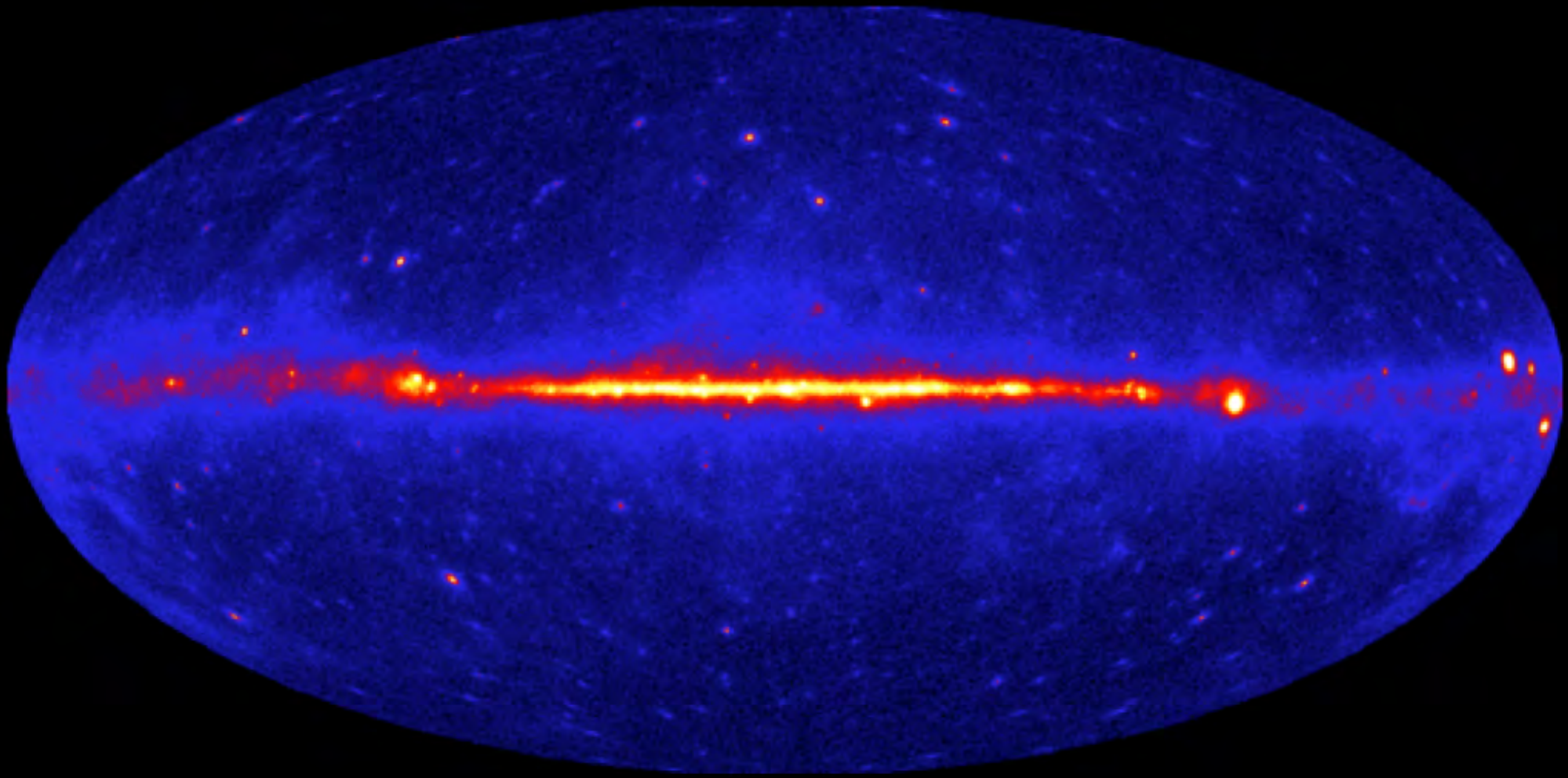
Astrophysics uncertainties

Where to look for DM in the Fermi-LAT gamma ray sky map?



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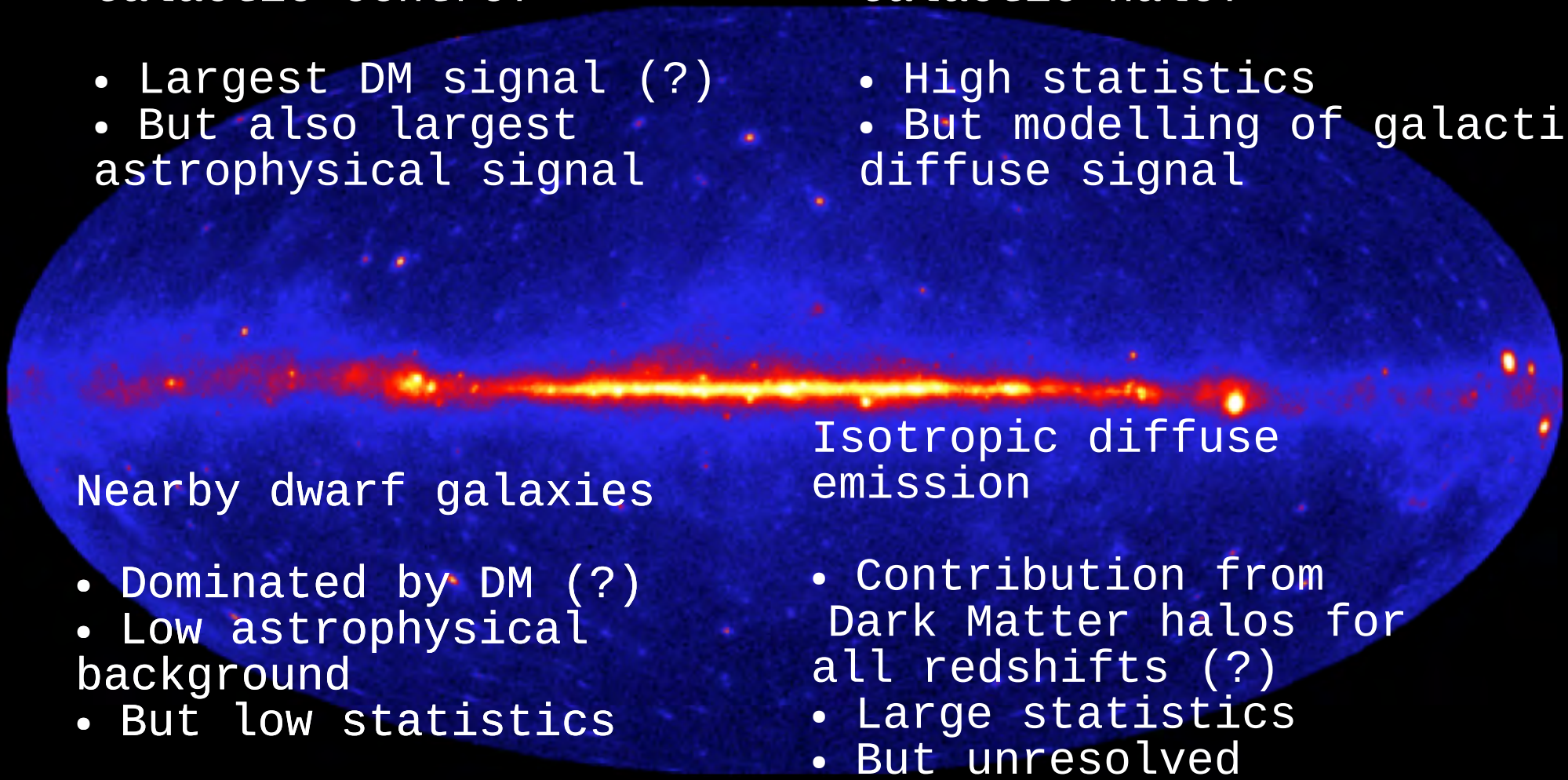

Galactic centre?

- Largest DM signal (?)
- But also largest astrophysical signal

Galactic halo?

- High statistics
- But modelling of galactic diffuse signal

Nearby dwarf galaxies

- Dominated by DM (?)
- Low astrophysical background
- But low statistics

Abdo et al
Astrophys.J. 712 (2010) 147-158
arXiv:1001.4531

Isotropic diffuse emission

- Contribution from Dark Matter halos for all redshifts (?)
- Large statistics
- But unresolved astrophysical sources

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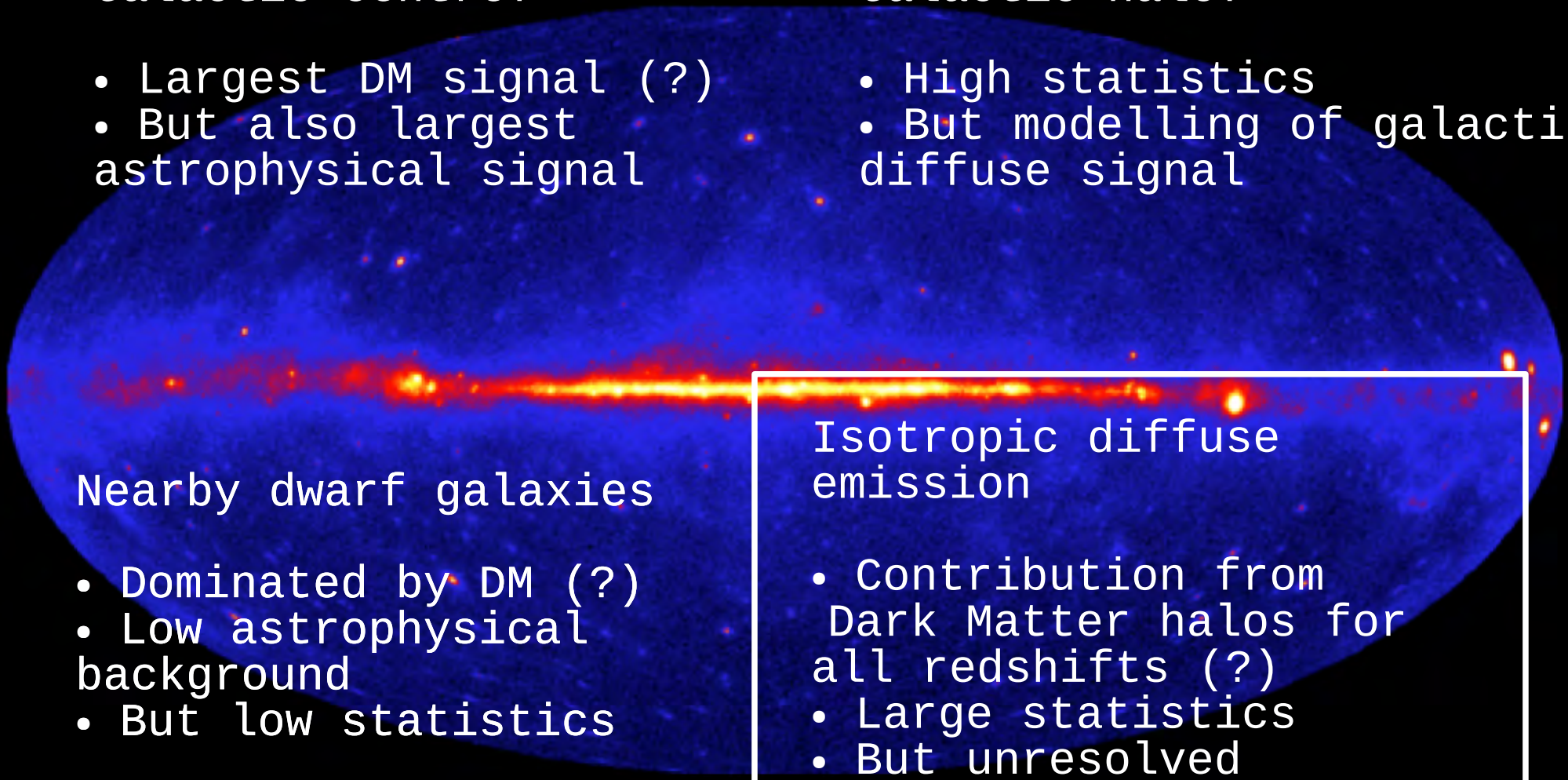

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AIM

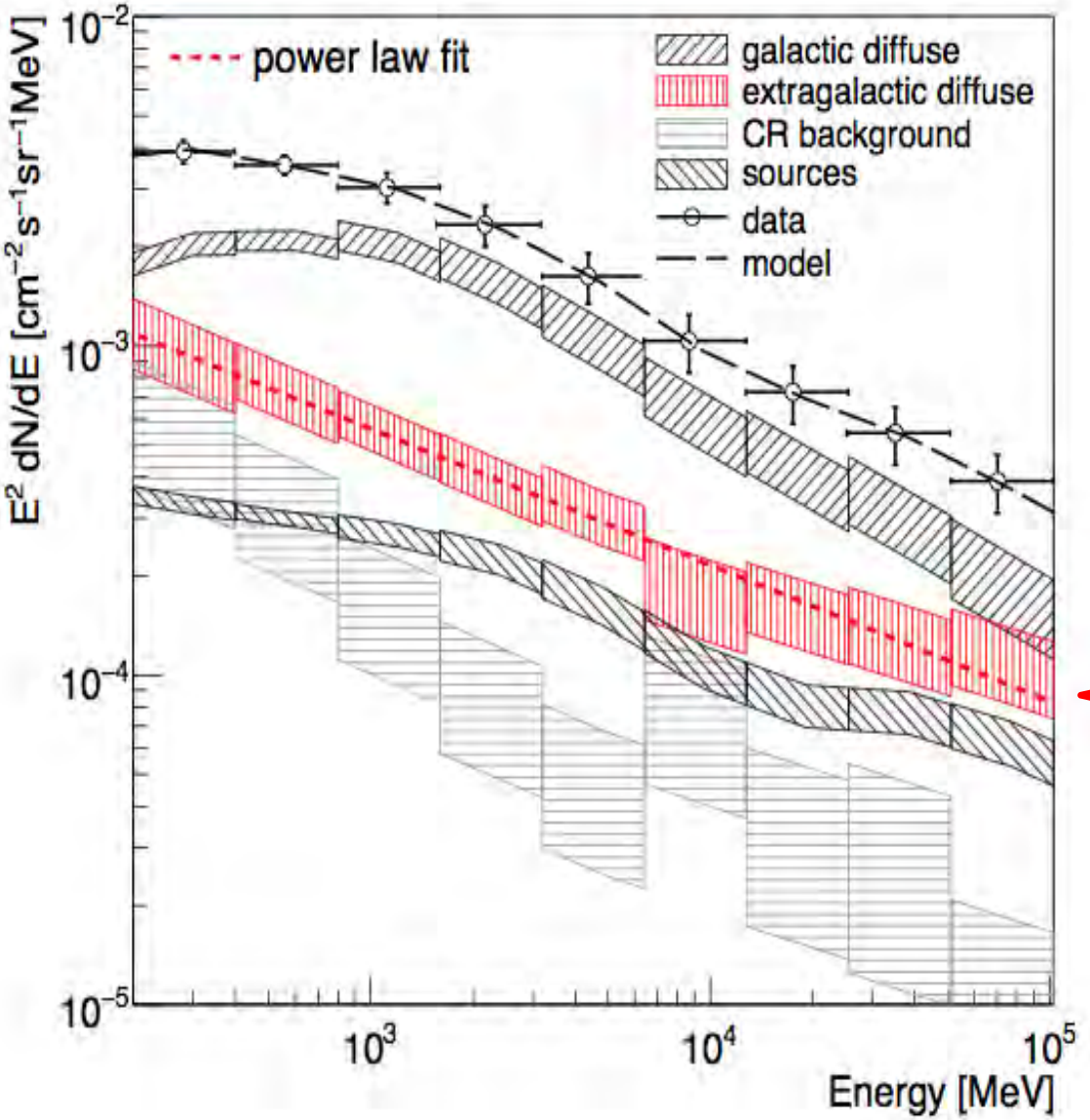
The Fermi-LAT spectrum (2010) is more constraining and has smaller error bars than the older analogous spectra from the EGRET experiment

Pre-launch analysis has shown that the Isotropic Diffuse Emission is potentially very constraining for DM.
(Baltz et al;...)

There are other analysis (2010).
Give limits on « standard » WIMPs (neutralino, KK-dm,...), or Pamela-motivated models.
(Abdo et al; Hutsi et al; Abazajian et al)

Here I specifically focus on constraints on light WIMPs, with mass in the few GeV range
(ie CoGeNT, DAMA).

Fermi-LAT data (& modelling) of Extragalactic diffuse emission



Actually the isotropic signal (galactic contribution expected)

Abdo *et al; Phys.Rev.Lett. 104 (2010) 101101;* arXiv:1002.3603

Extragalactic diffuse emission from DM annihilation

Particle physics

Astrophysical factors

$$\frac{d\Phi_\gamma}{dE} = \frac{c}{4\pi}\frac{\langle\sigma v\rangle}{2m_{\rm dm}^2}\int_0^\infty \frac{dz'}{H(z')(1+z')^4}\frac{dN_\gamma}{dE'} \times \overbrace{\mathcal{B}^2(z') \times \mathrm{e}^{-\tau(E',z')}}$$

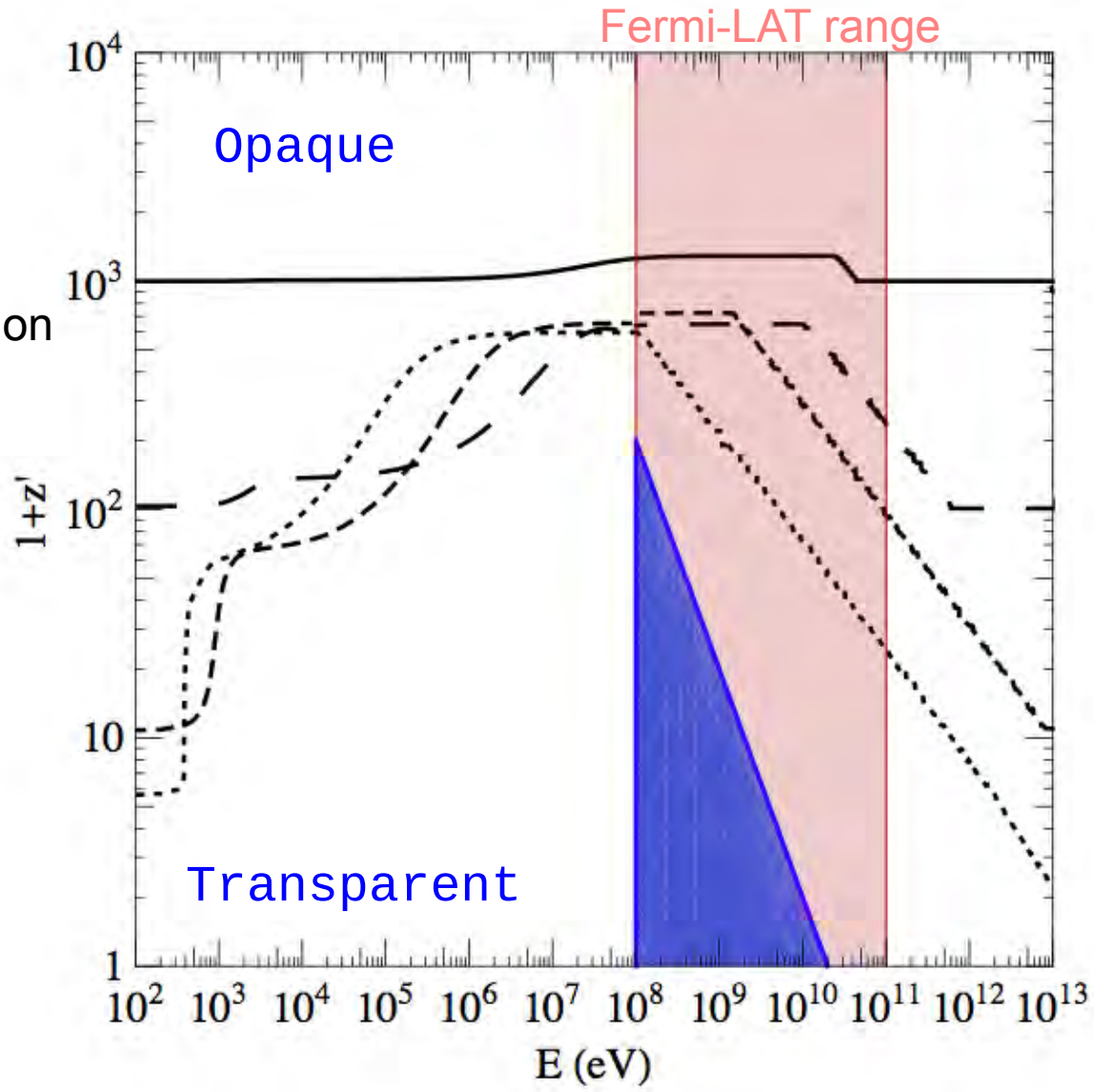
B. Boost factor:

Halos of DM matter
(of all sizes @ all redshift z)

A. Optical depth:

Absorption of due to Compton scattering, pair production,...

A. Optical depth



gamma-ray energy @ z=0

(C.Arina,M.T.)

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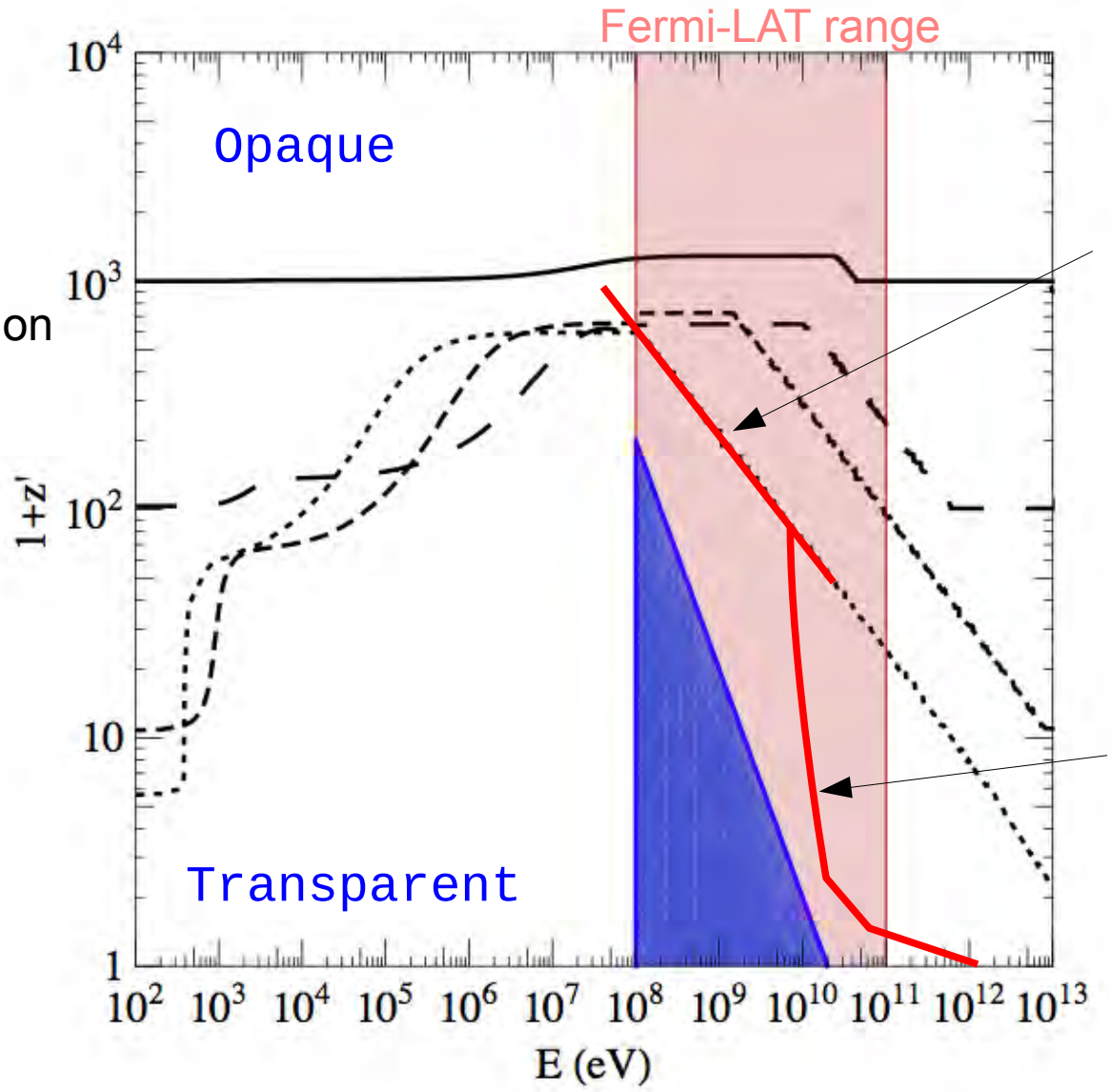

Redshift
@ emission

gamma-ray energy @ z=0

Absorption due to

$\gamma + \gamma_{CMB} \rightarrow e^+e^-$

Absorption due to

$\gamma + \gamma_{IR} \rightarrow e^+e^-$

(C.Arina,M.T.)

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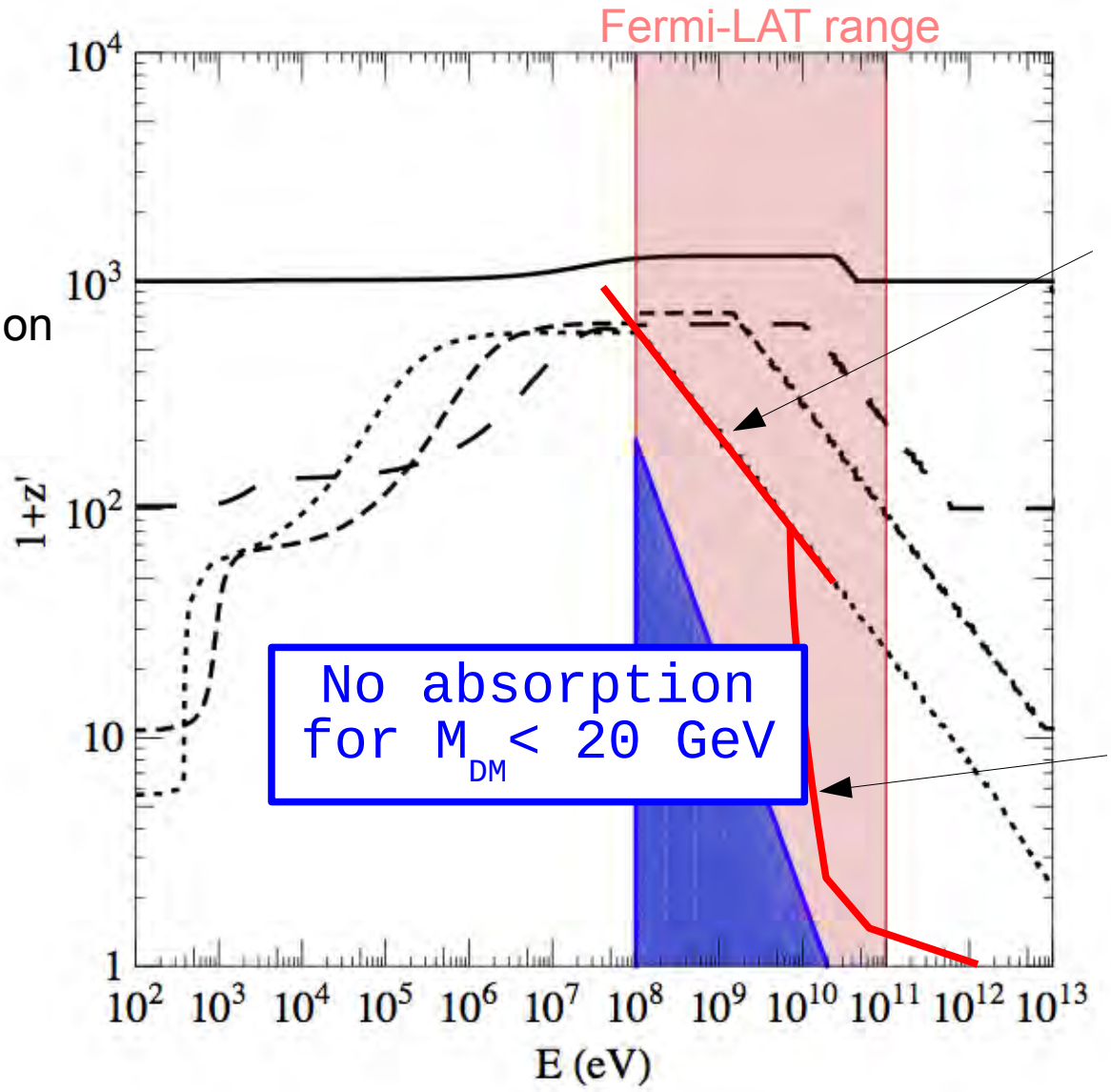

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(Hutsi et al)

(C.Arina,M.T.)

B. Boost from DM halos @ all redshifts?

$$\mathcal{B}^2(z) \propto \int dM \frac{dn}{dM}(z, M)(1+z)^3 \int dr\ 4\pi r^2 \rho^2(r, M)$$

Number of halos of mass M @ redshift z (here Press-Schechter)

Dark Matter profile (here NFW, but dependence mild)

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Dark Matter profile (here NFW, but dependence mild)

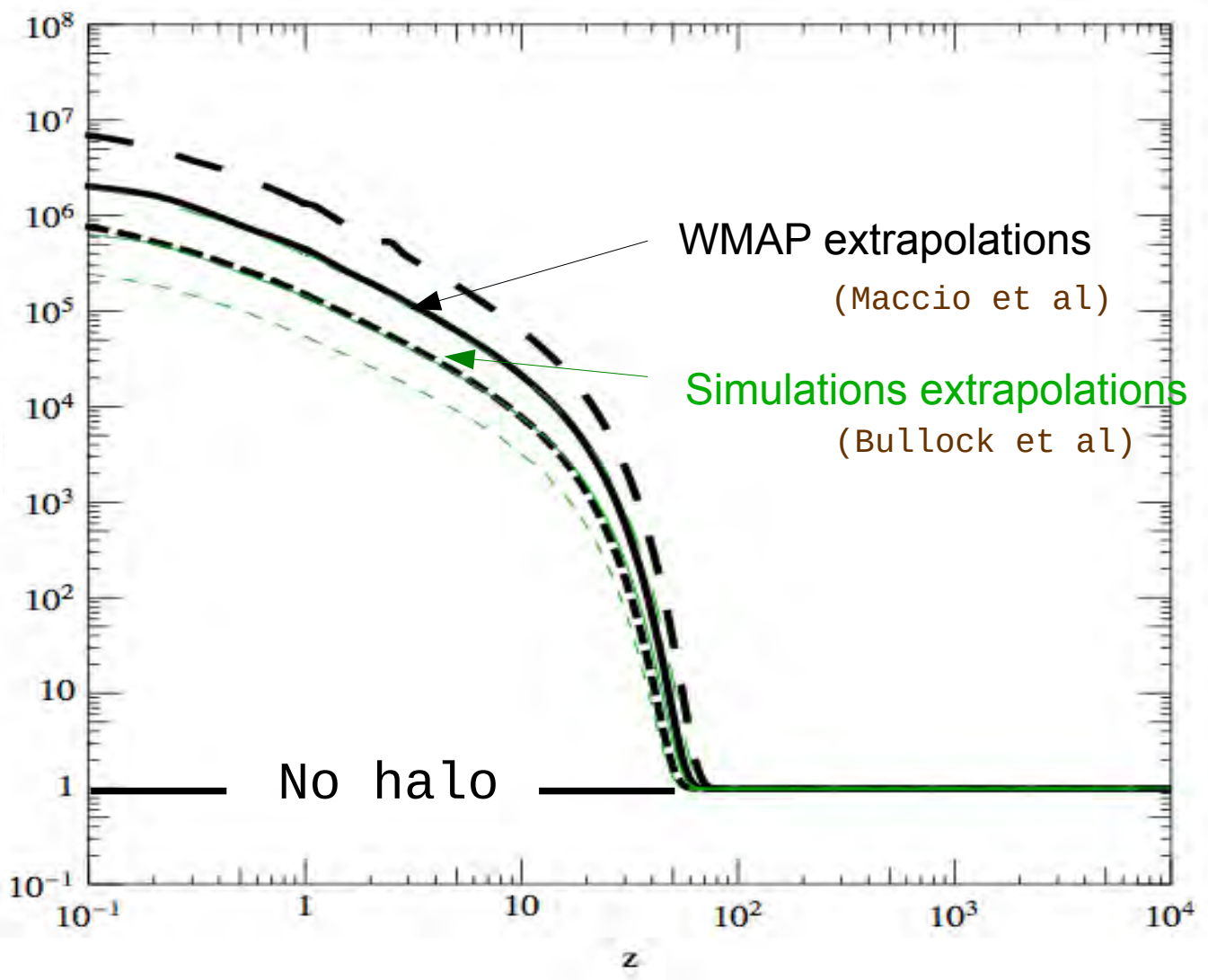
Depends on power spectrum of low mass halos

(potentially down to $M \sim 10^{-8} M_\odot$ ...)

→ extrapolations from WMAP measurements and/or numerical simu's

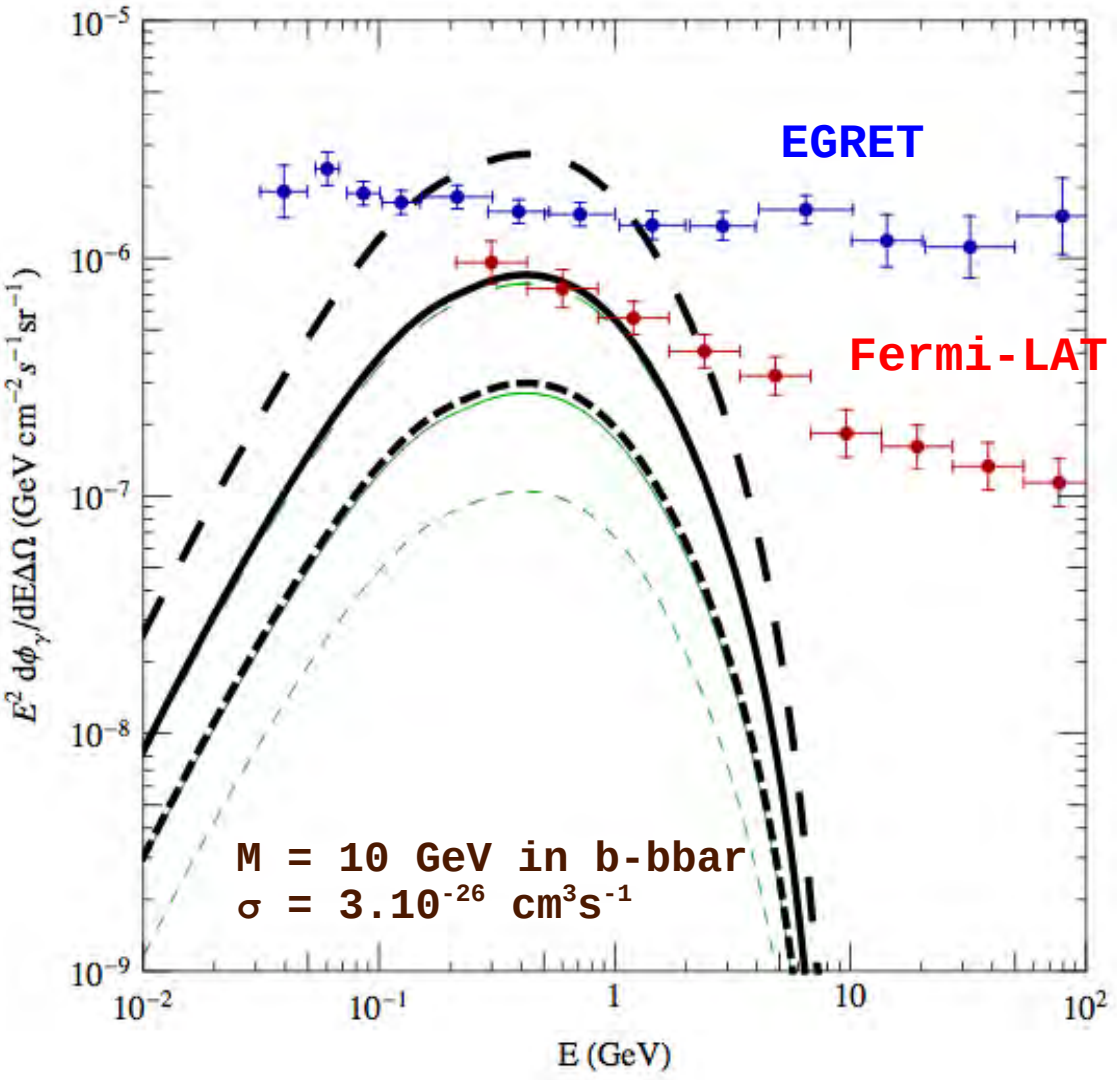
B. Boost from DM halos @ all redshifts?

$$\frac{\text{Boost}}{(1+z)^6}$$



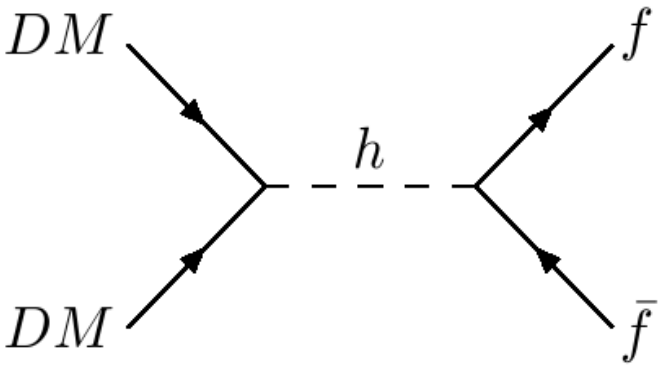
Redshift

Results: model independent spectral energy density

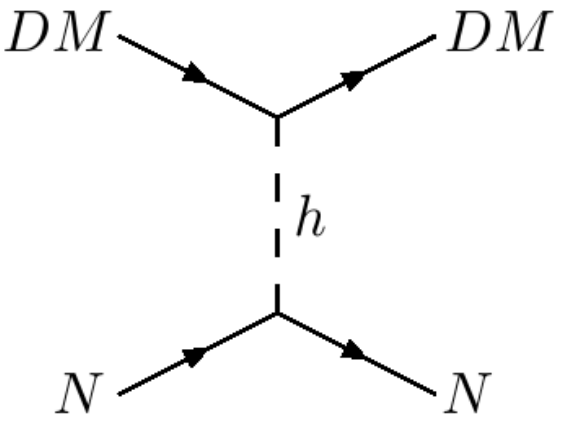


A simple model – scalar singlet DM

Annihilation



Scattering (SI)



Relic abundance **Direct detection**

Two parameters model:

M_{dm} and coupling to brout-englert-higgs boson

(λ/M_h^2)

(Silveira & Zee; Mc Donald; Burgess et al;...

A simple model – scalar singlet DM

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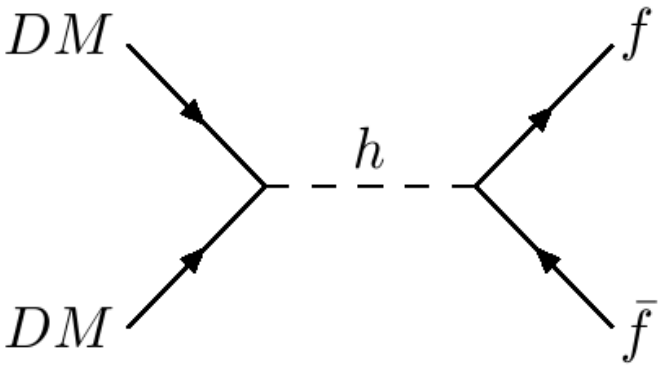

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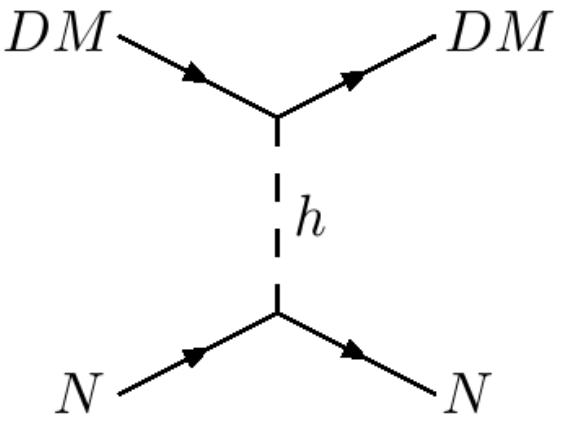


Relic abundance

Direct detection

Two parameters model:

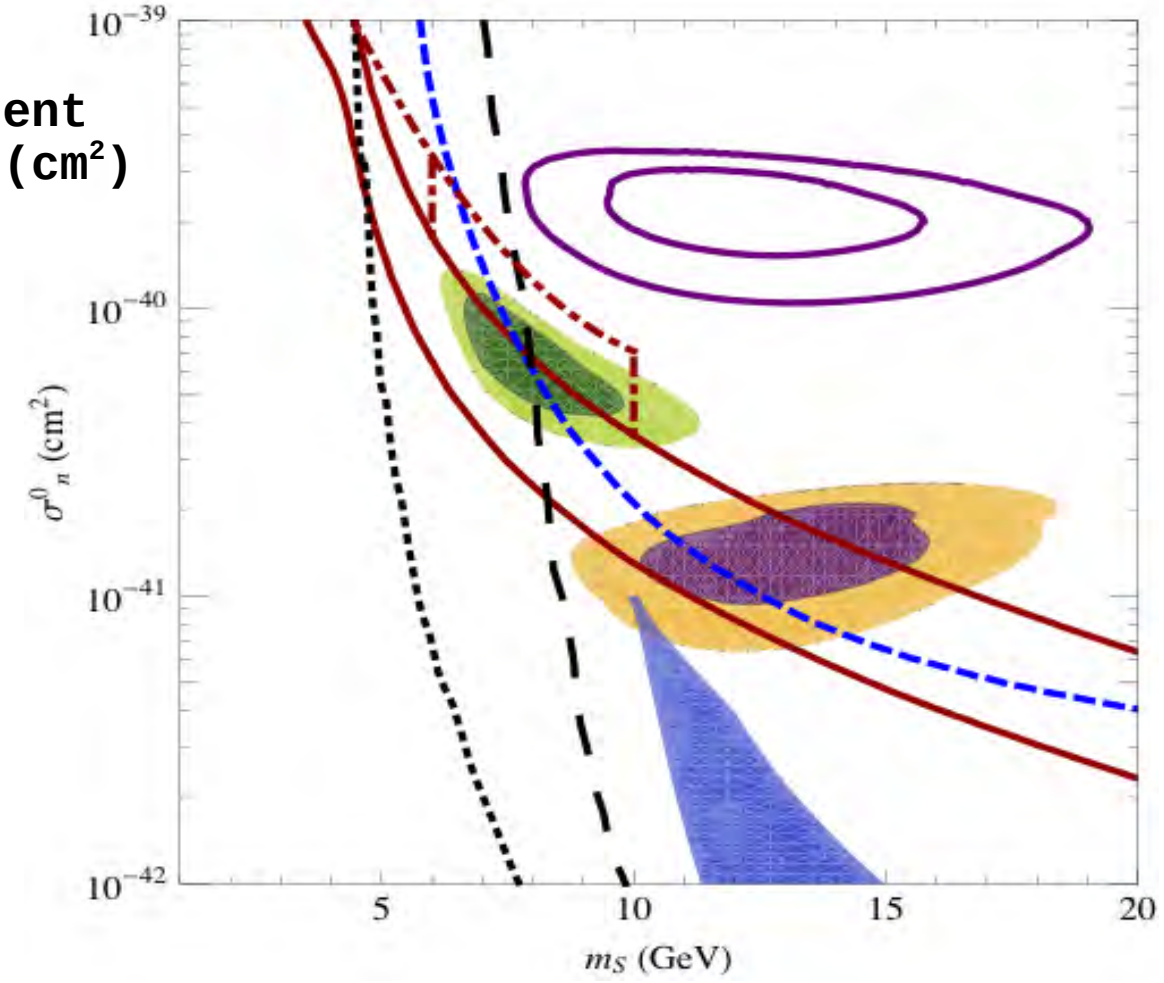
M_{dm} and coupling to brout-englert-higgs boson

$$\longrightarrow \begin{cases} \lambda - M_{\rm dm} \\ \Omega_{\rm dm} - M_{\rm dm} \\ \sigma_n - M_{\rm dm} \end{cases}$$

(Silveira & Zee; Mc Donald; Burgess et al;...

A simple model – scalar singlet DM

Spin-independent Cross-section(cm^2)



Scalar singlet mass

Andreas, Arina, Hambye, Ling & M.T. arXiv:1003.2595

A simple model – scalar singlet DM

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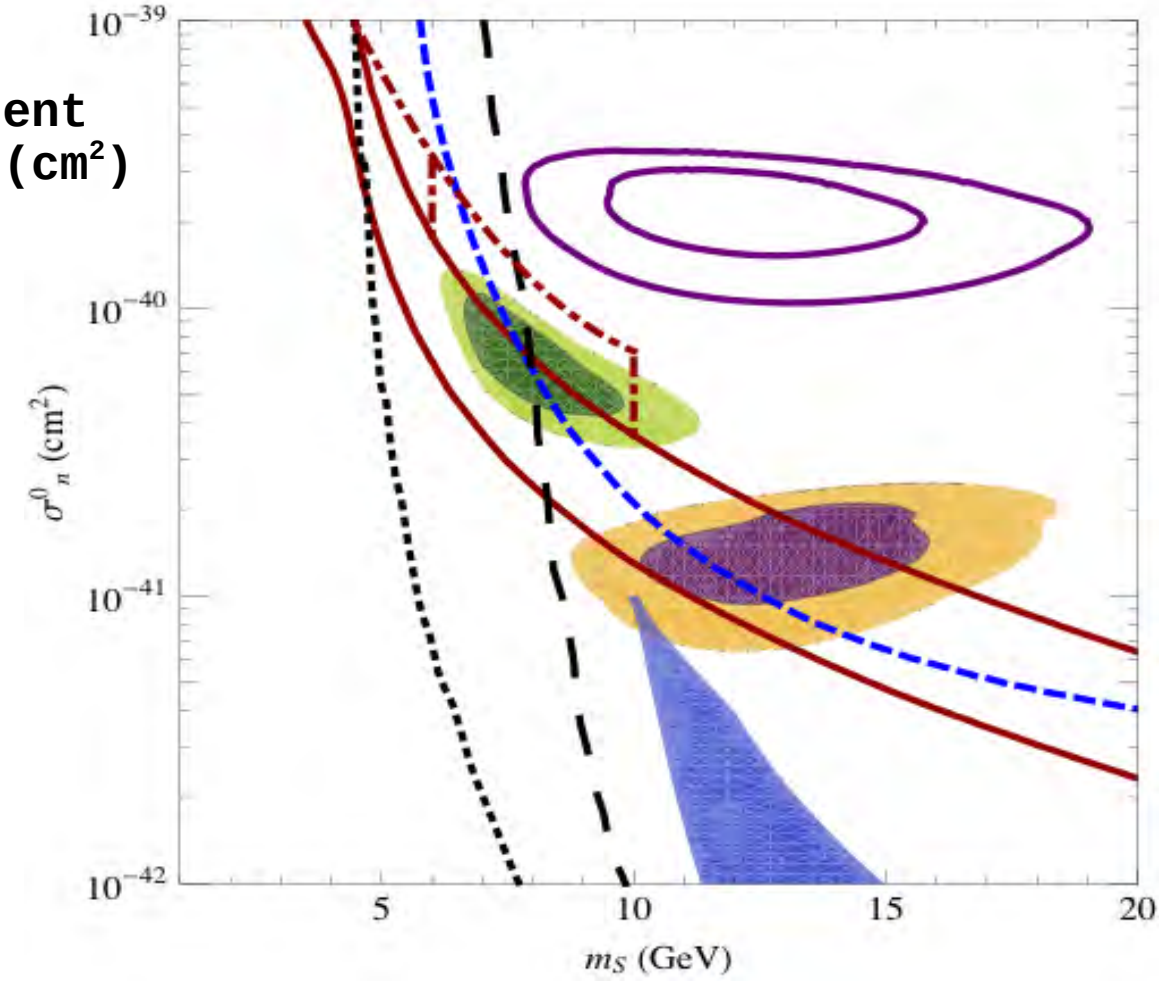

WMAP

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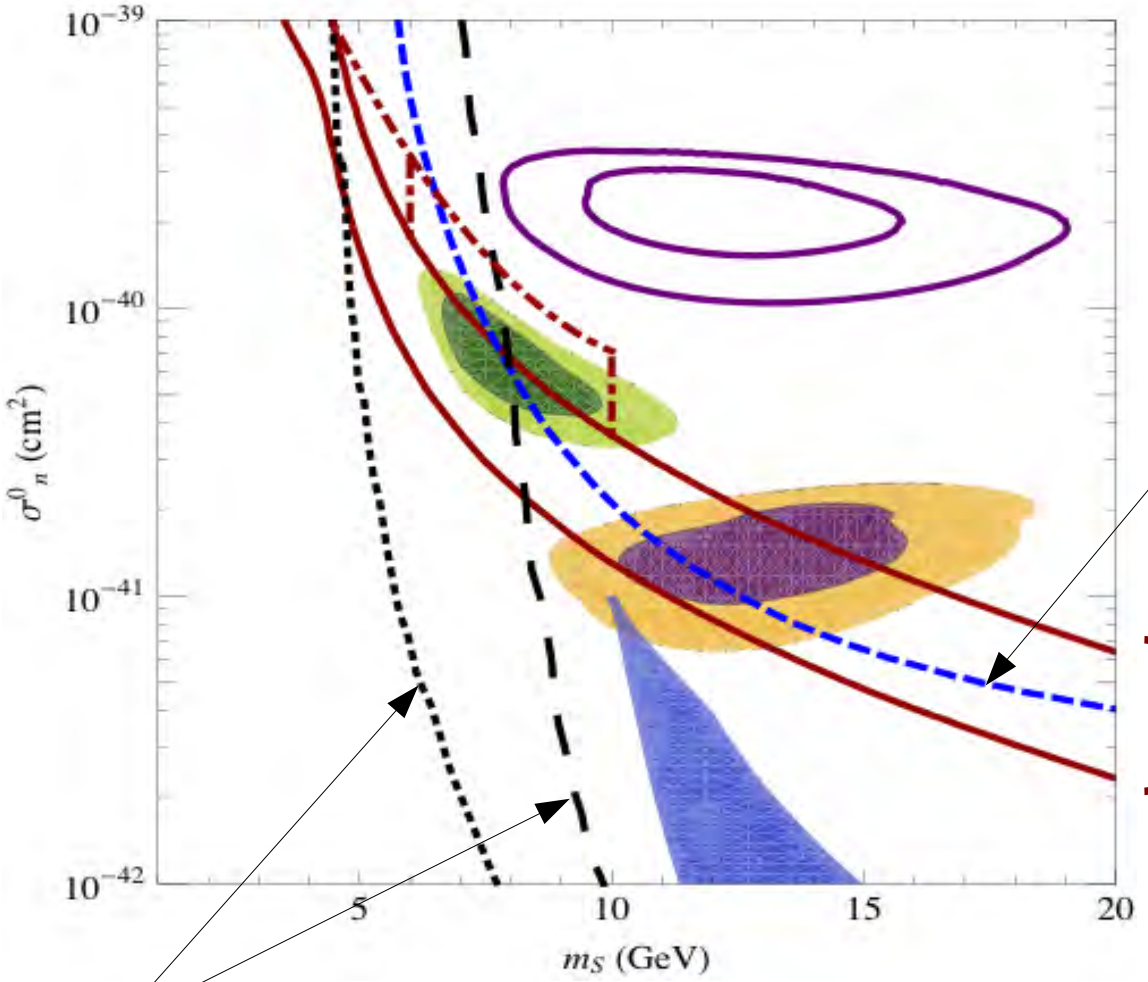

CDMS-Si

WMAP

Xenon10 (2009)

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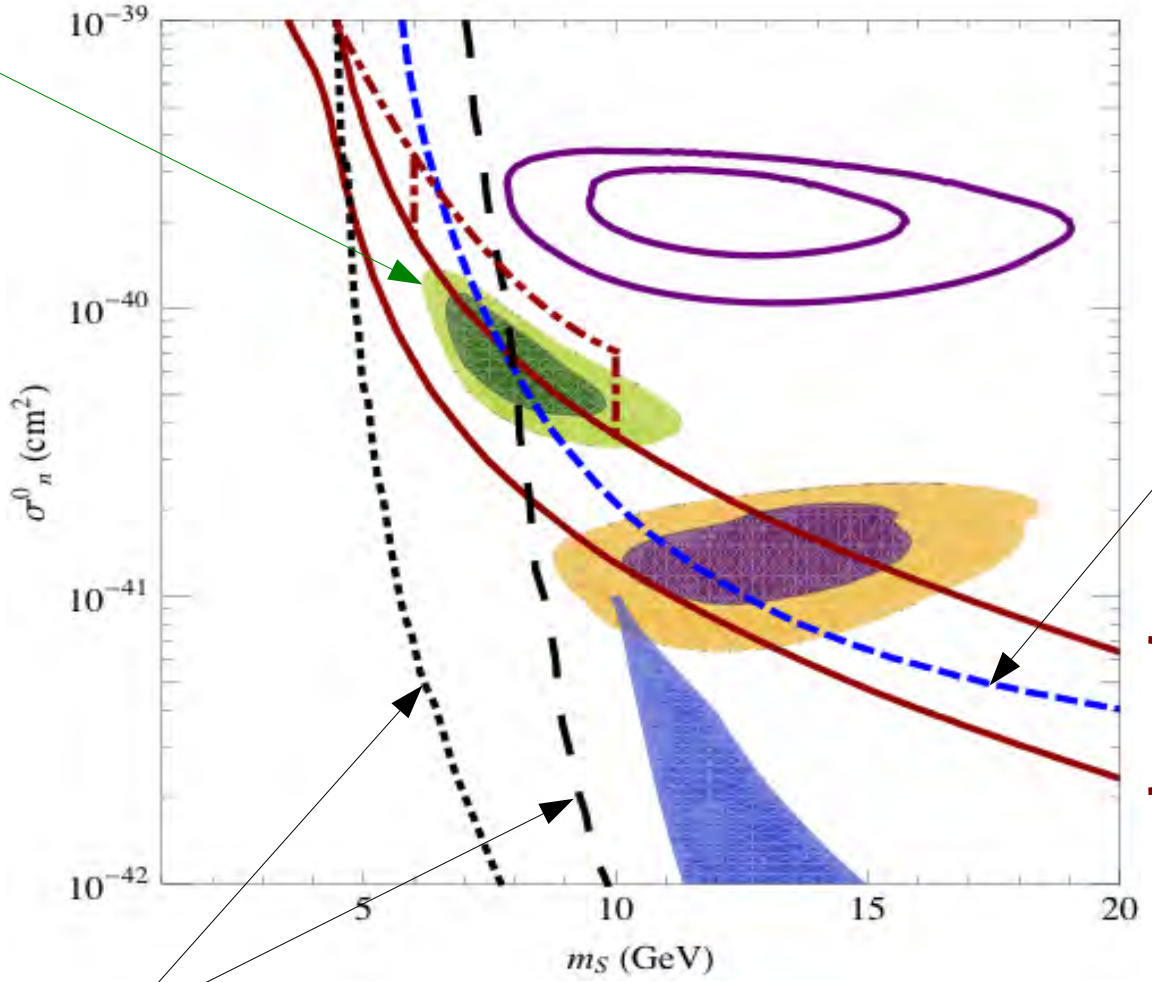

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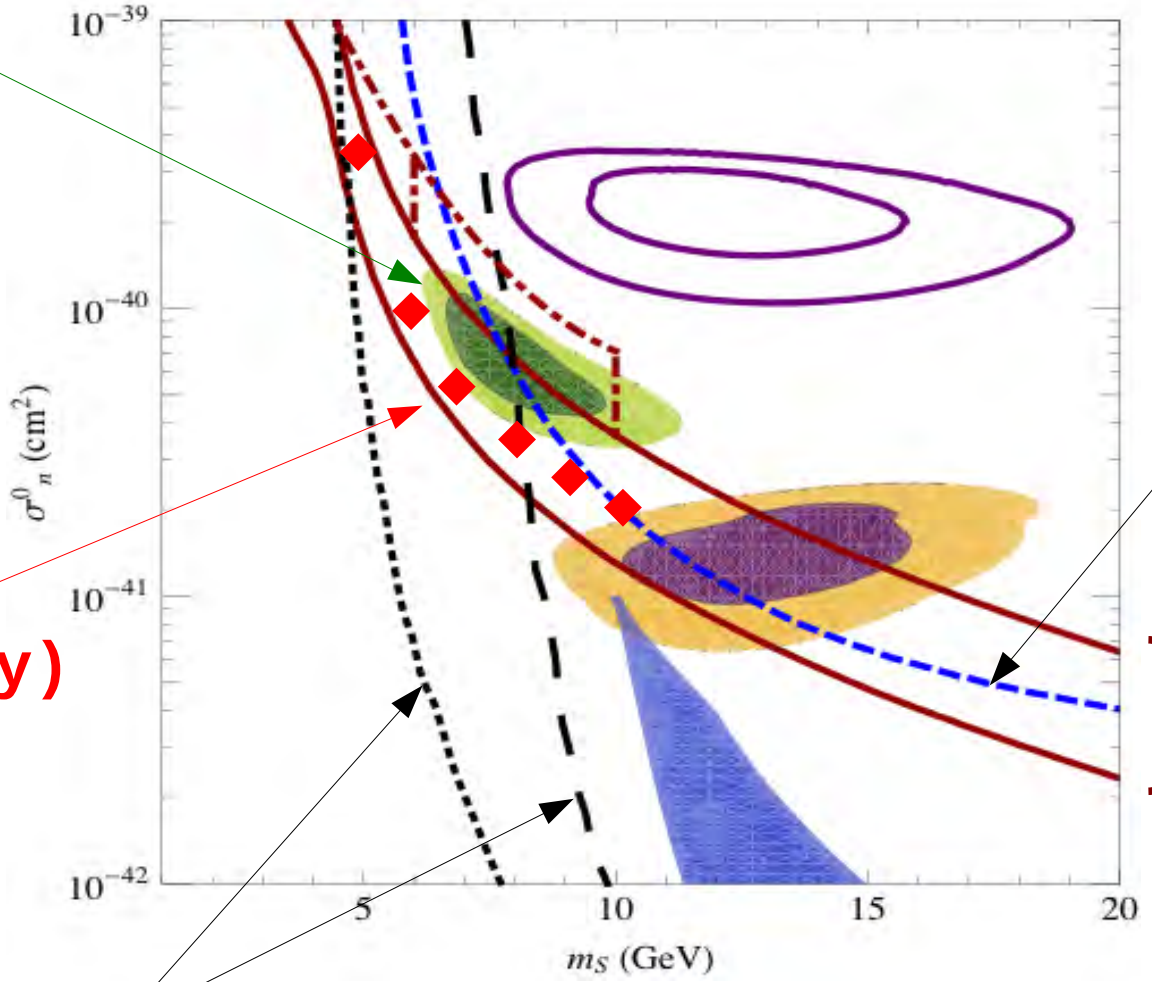


CoGeNT

CDMS-II (low-energy)

CDMS-Si

WMAP

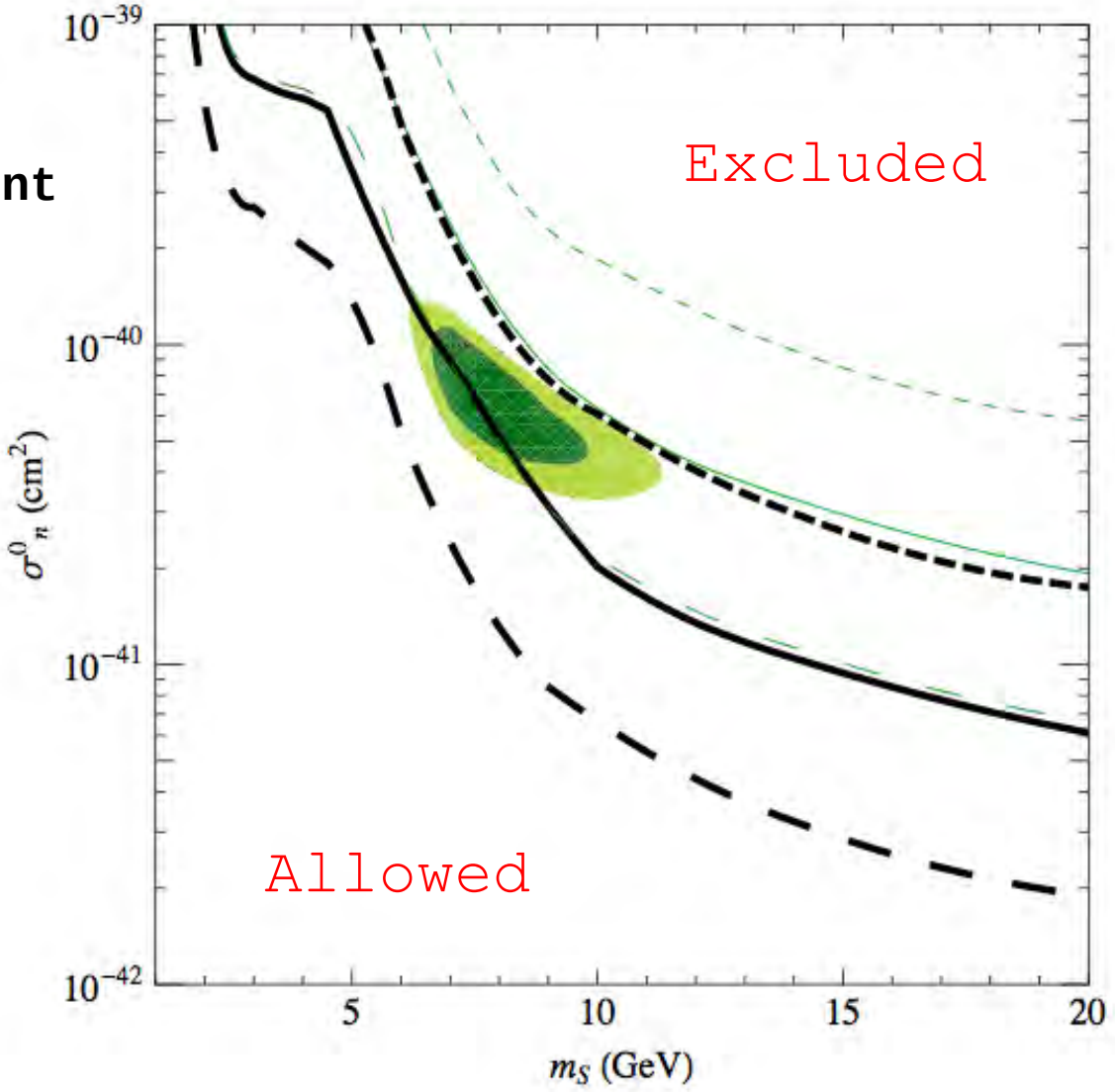
Xenon10 (2009)

Andreas, Arina, Hambye, Ling & M.T. arXiv:1003.2595

Results: scalar singlet DM

95% CL exclusion limits from Diffuse Isotropic Emission

Spin-independent cross-section

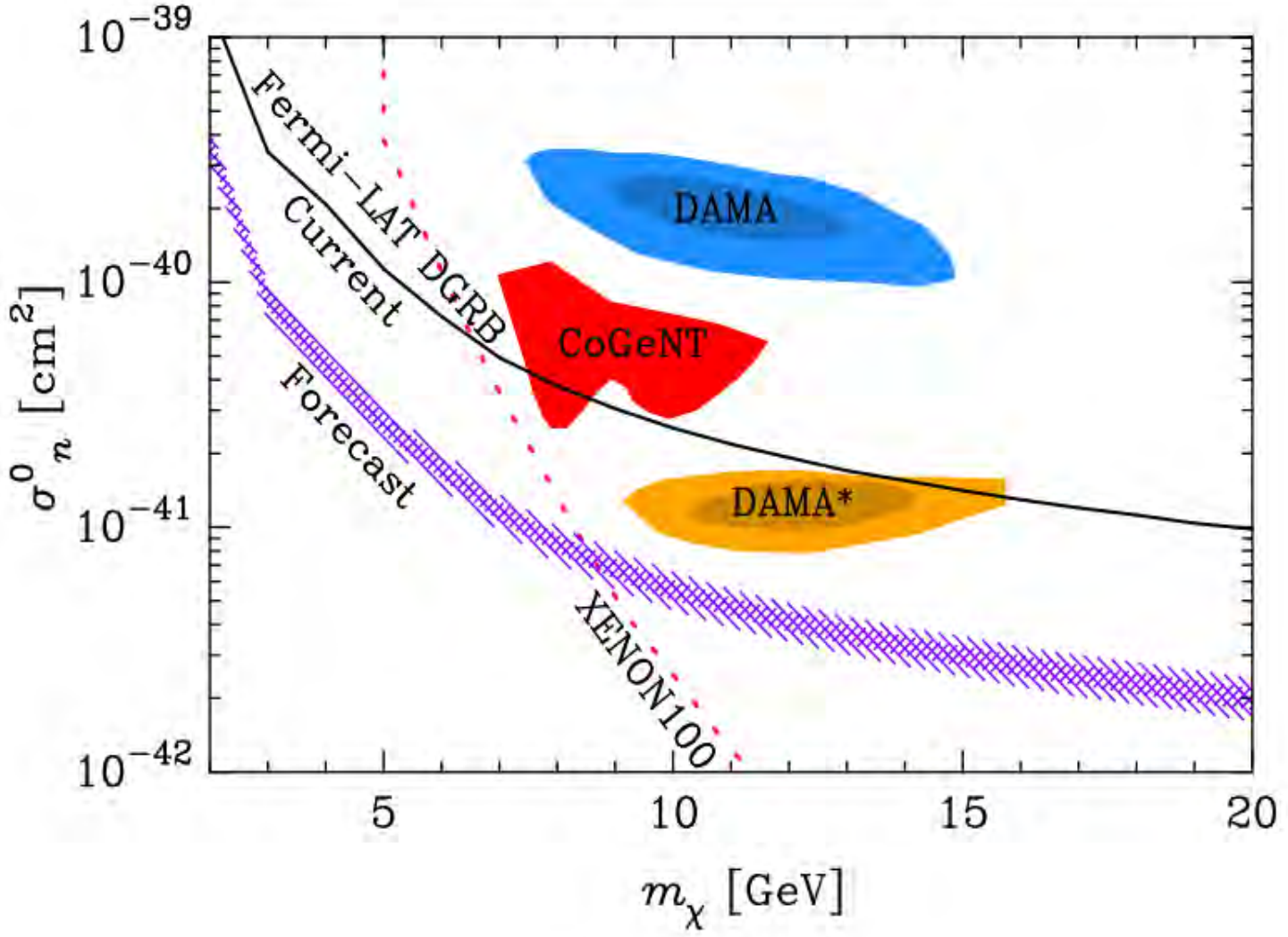


Scalar singlet mass

Arina & M.T. arXiv:1007.2765

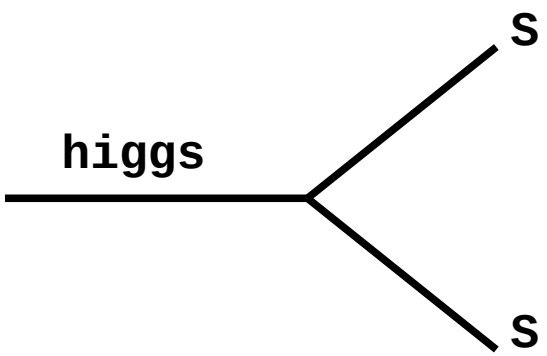
More results: scalar singlet DM

Forecast: Fermi-LAT resolving extra-galactic sources (AGN, Blazars,...)



Abazajian, Blanchet and Harding arXiv:1012.1247

BTW, this is an invisible Higgs scenario



For M_{DM} = 7 GeV :

m_{higgs} = 120 GeV **BR(h → SS) = 99.5%**

m_{higgs} = 200 GeV **BR(h → SS) = 70%**

LHC Discovery Potential

(14 TeV, L = 30 fb^{-1})

(M.Warsinsky, ATLAS, ICHEP2007)

$$\sigma_n^0 \approx 5 \cdot 10^{-44}\,\mathrm{cm}^2$$

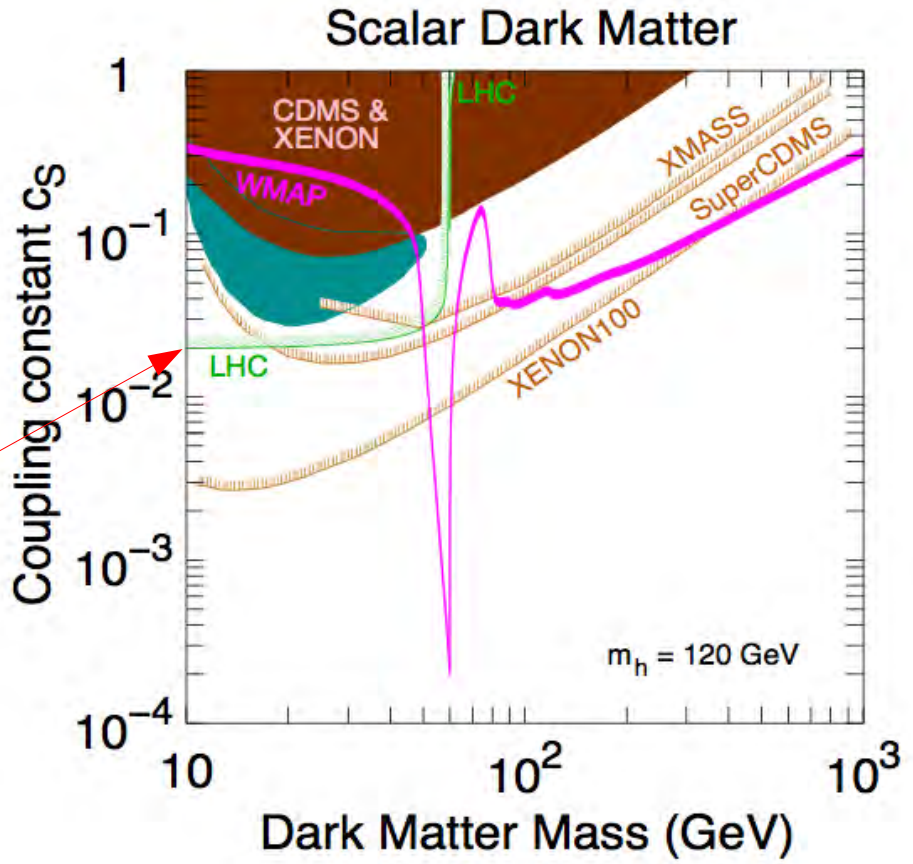


Fig. from Kanemura et al, 1005.5651

Conclusions

Recent Fermi-LAT data give interesting indirect constraints on Light Dark Matter candidates.

Not only Diffuse emission, also constraints from dwarf spheroidal galaxies (with different systematics, etc, not discussed here).

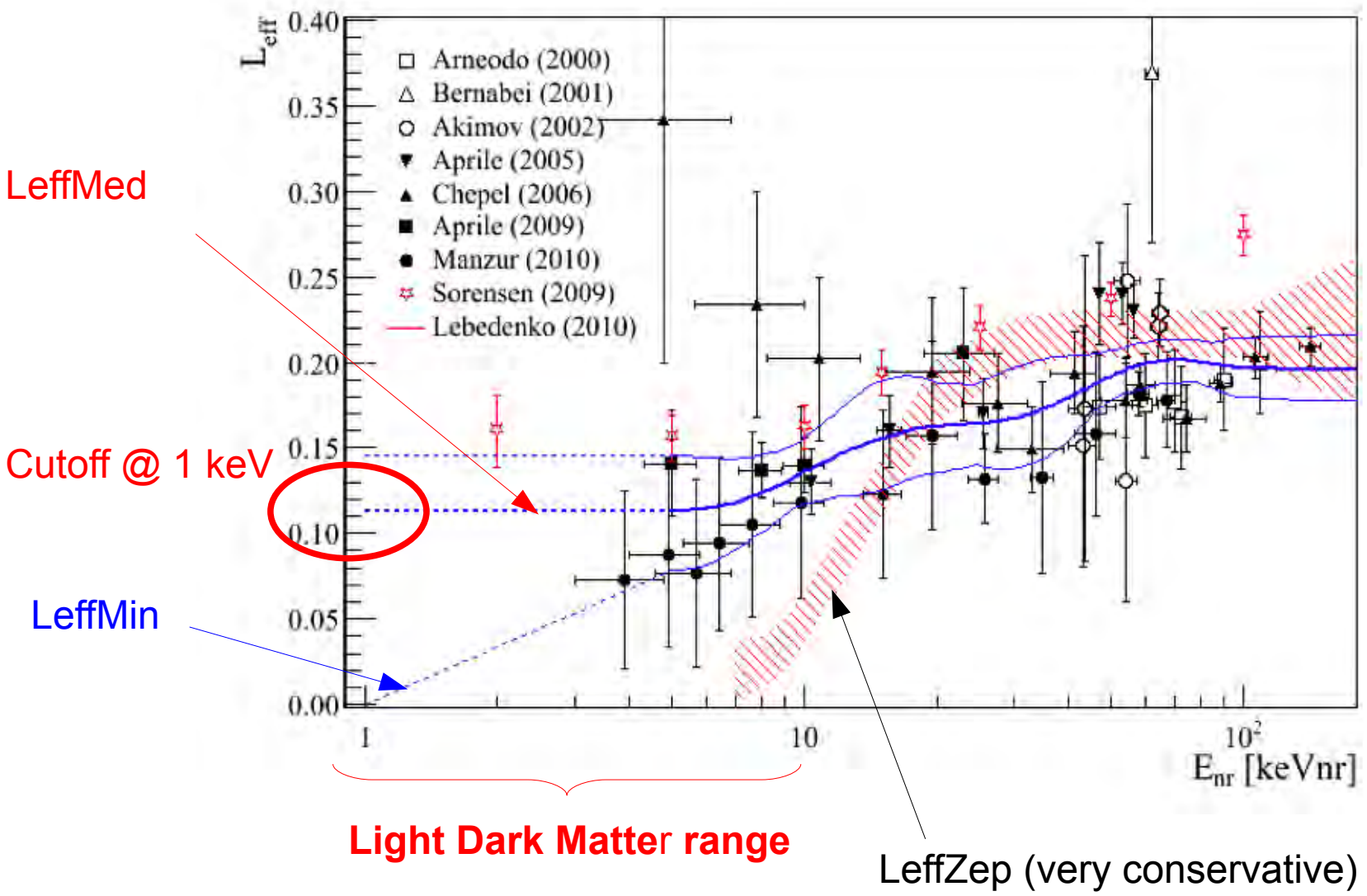
Nice interplay between direct and indirect detection.

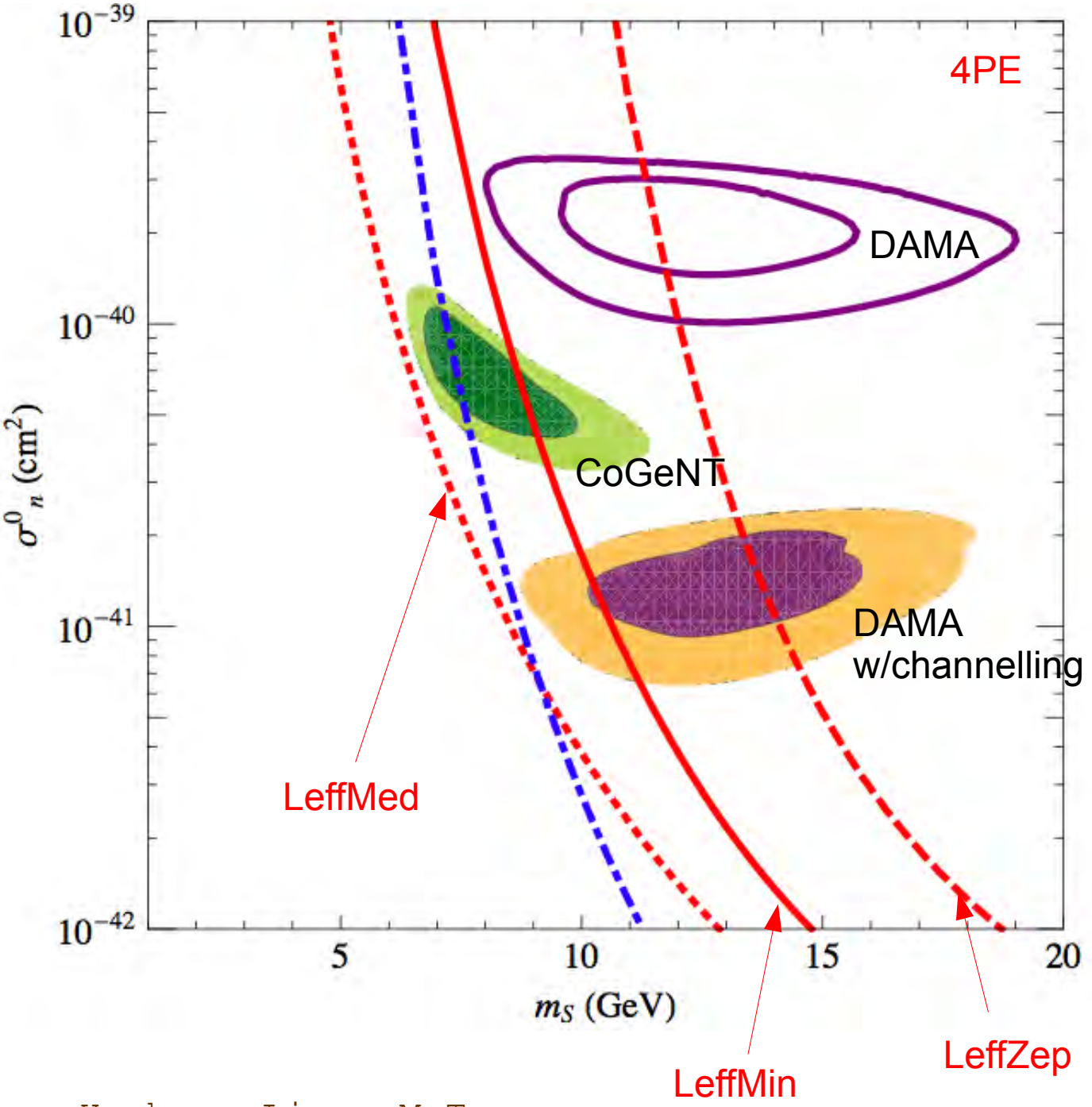
See also important rôle of collider constraints (see the talk by Joachim Kopp)

Backup slides

In LXe experiments, mapping of signal (ie photoelectrons PE) to E_{recoil} depends on the so-called Scintillation Efficiency (Leff)

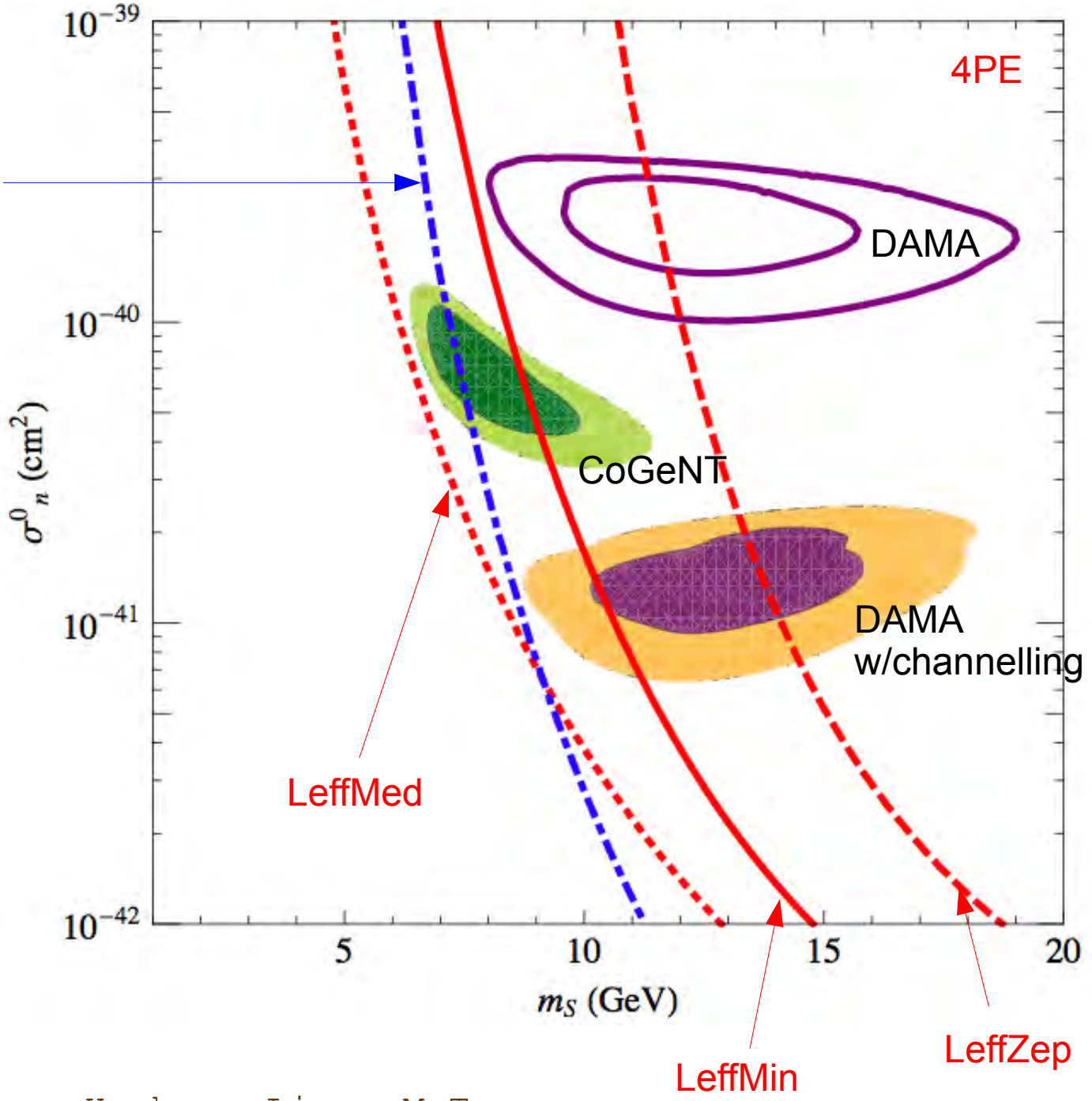
Problem: Leff poorly known at low recoil energies
See Collar & McKinsey vs Xenon100 debate





Andreas, Arina, Hambye, Ling, M.T.
(arXiv:1003.2595)

Prospect:
1 ton-days
exposure
(LeffMin)



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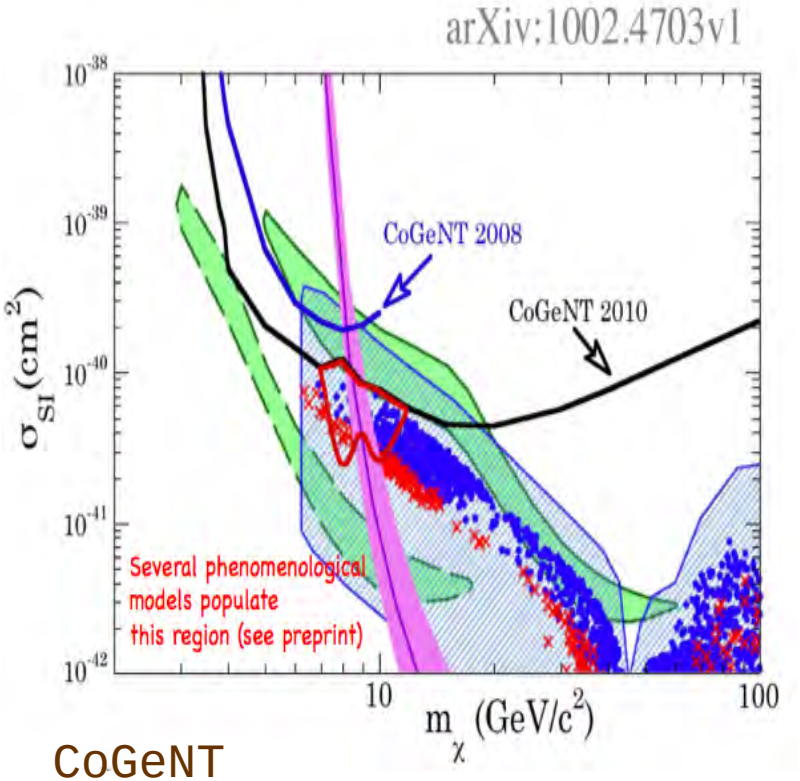
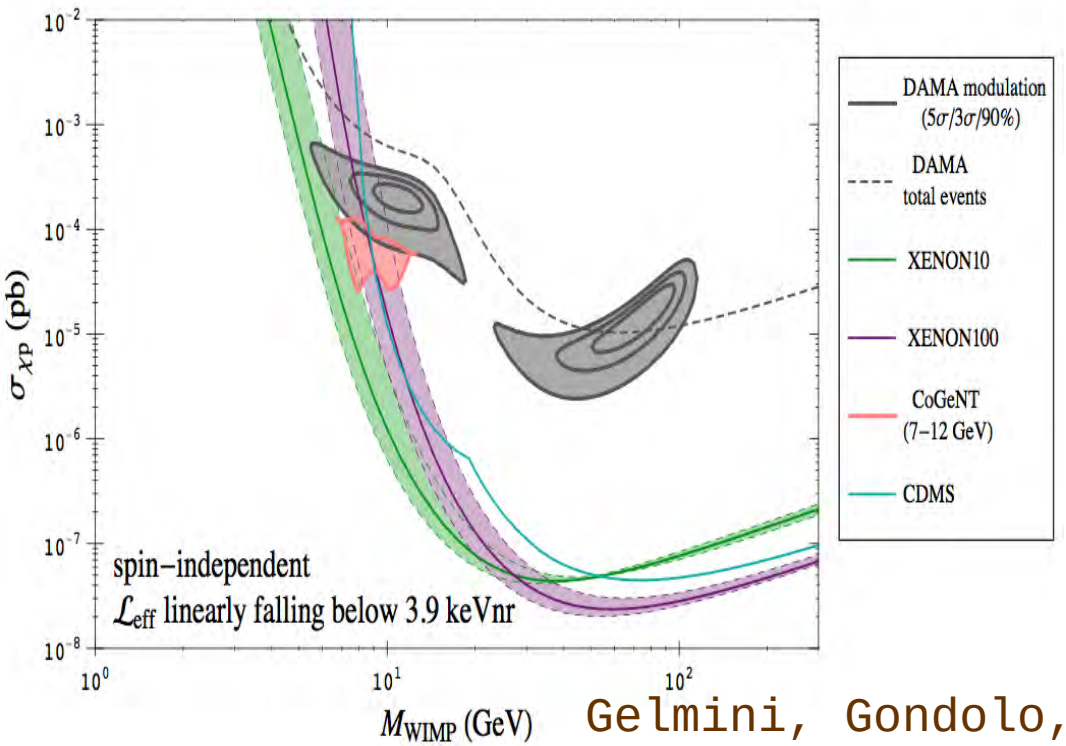
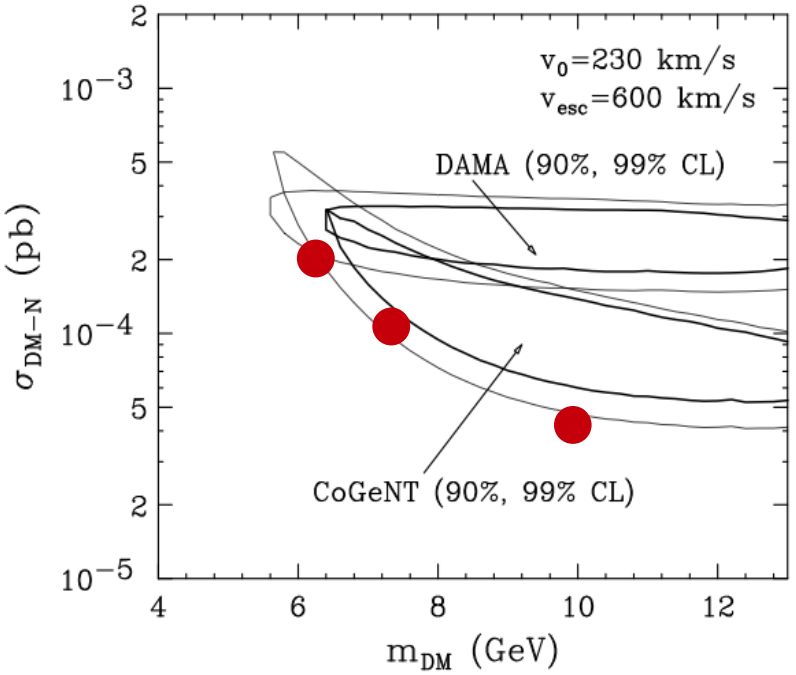


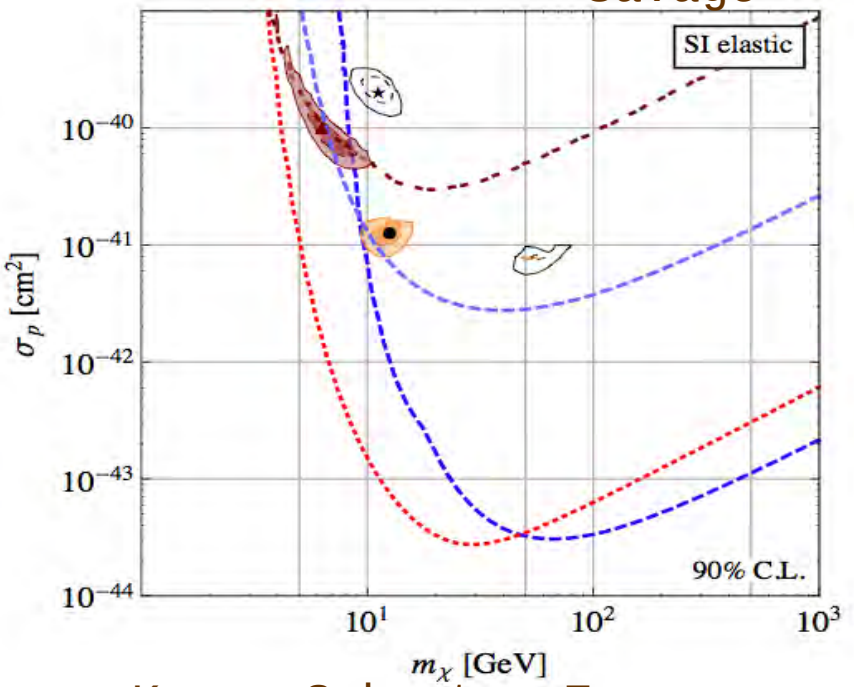
CoGeNT



Gelmini, Gondolo, Savage



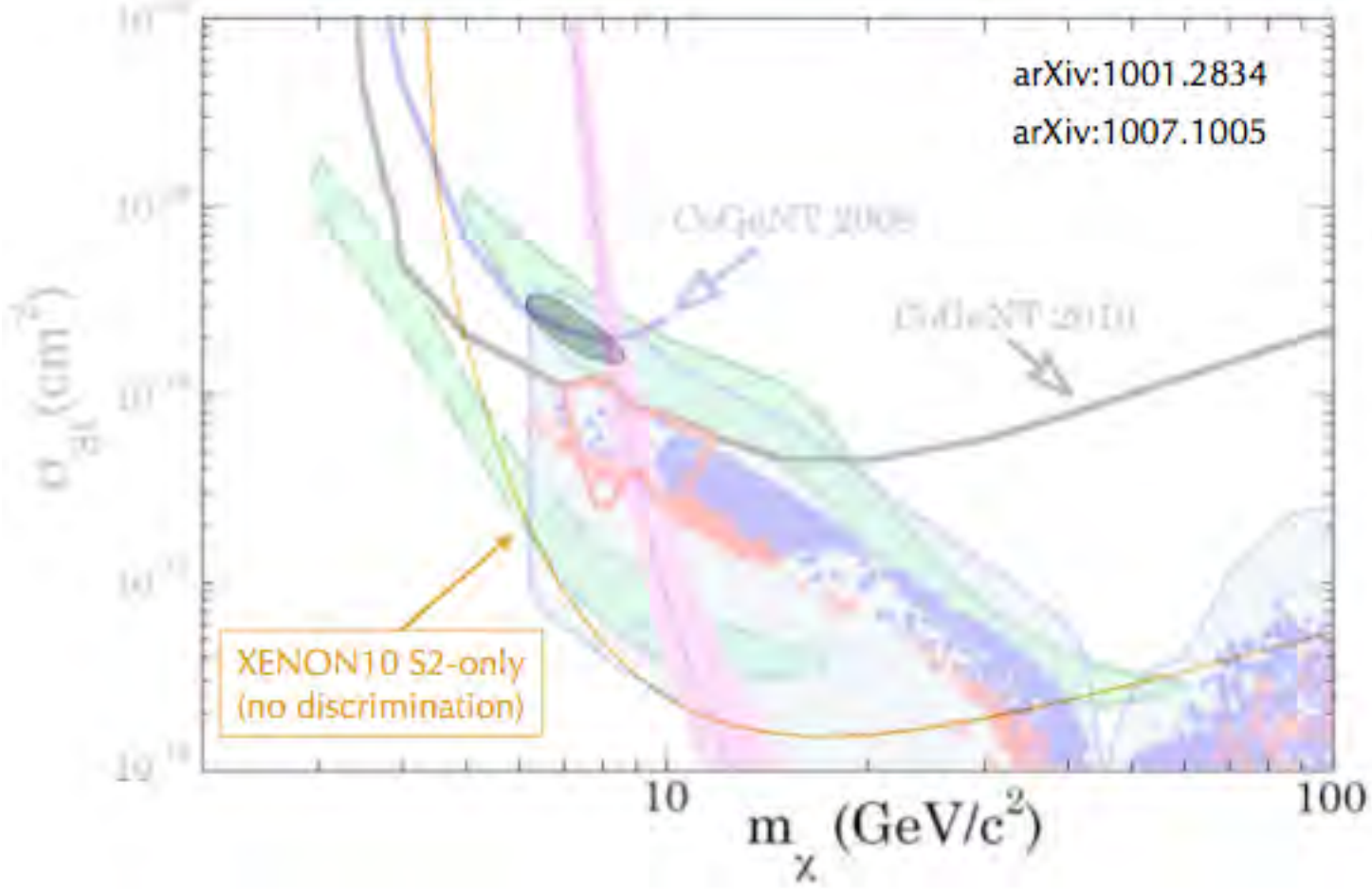
Hooper,Collar,Hall,McKinsey



Kopp, Schwetz, Zupan

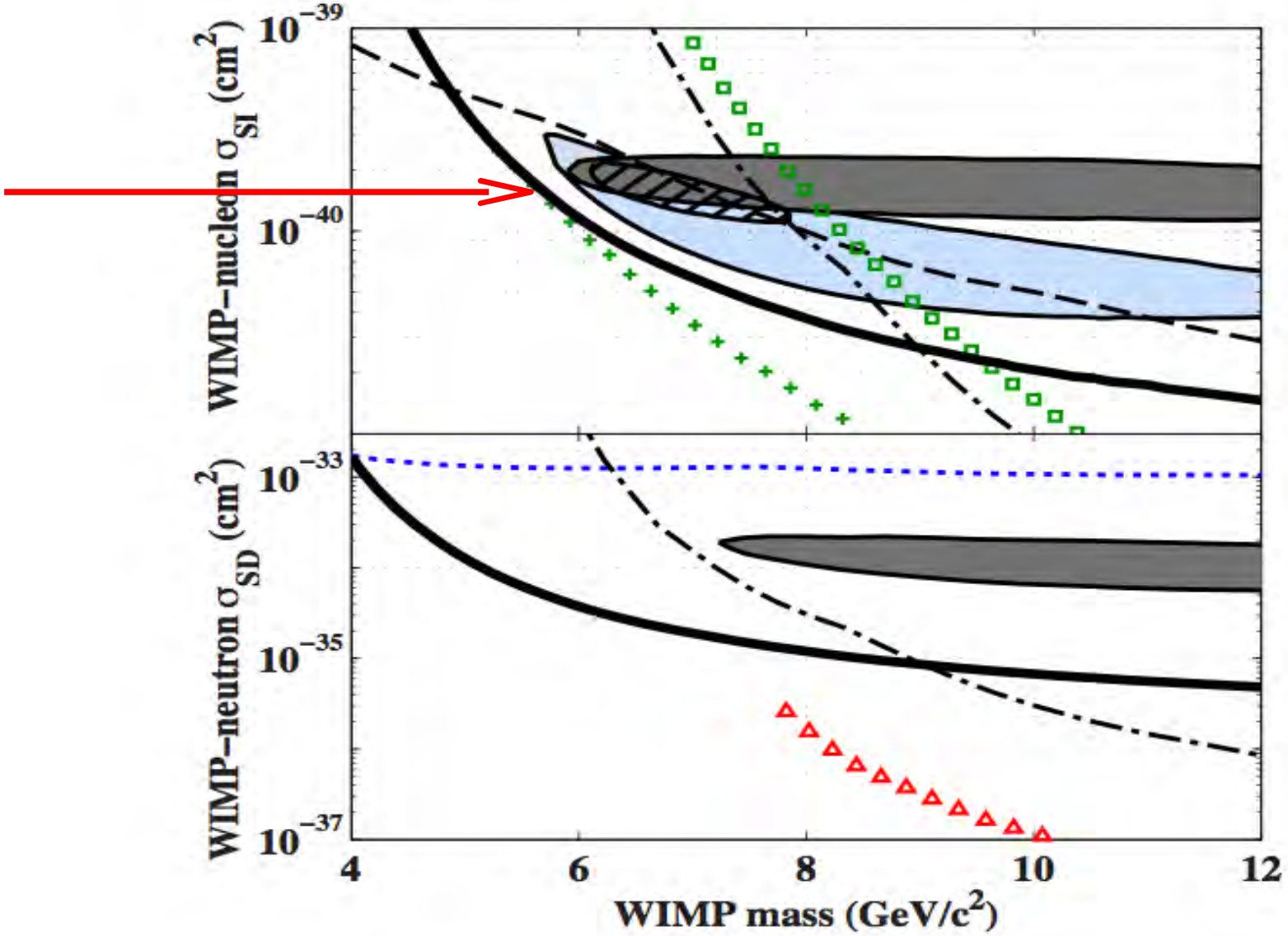
(preliminary) dark matter exclusion limits

Notice: this S2-only exclusion limit curve is preliminary, and has not been fully reviewed by the XENON10 collaboration. Pending review it is subject to change.



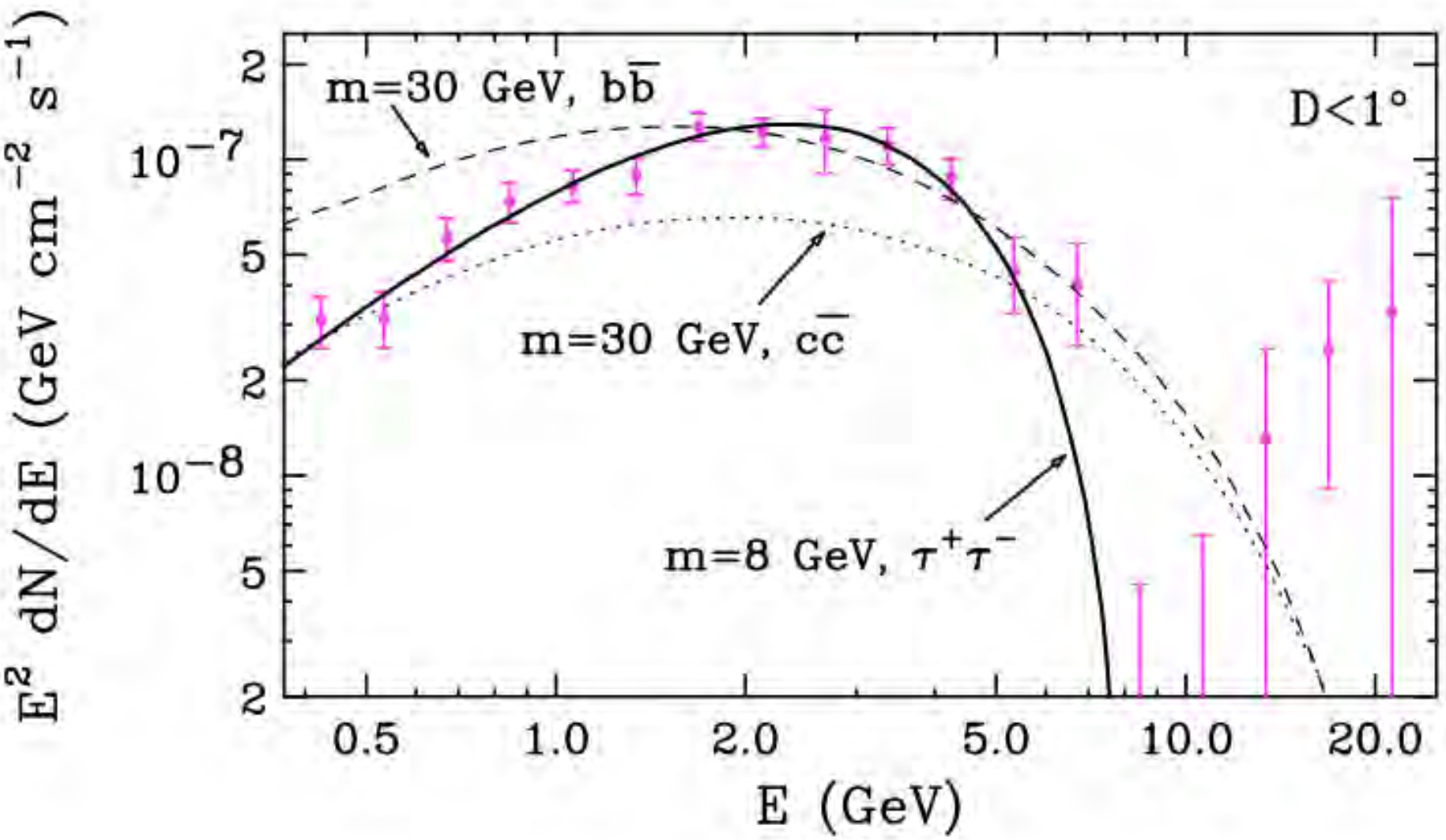
- Max Gap 90% C.L. upper limit between 1.6 keVr and 3.8 keVr
- 12.5 live days
- 1.2 kg target
- conservative -1σ Q_y energy calibration
- no account of resolution (this would improve limits)

Results from a Low-Energy Analysis of the CDMS II Germanium Data



CDMS collaboration arXiv:1011.2482

An 8 GeV candidate and the Fermi-LAT data from the Galactic Centre?



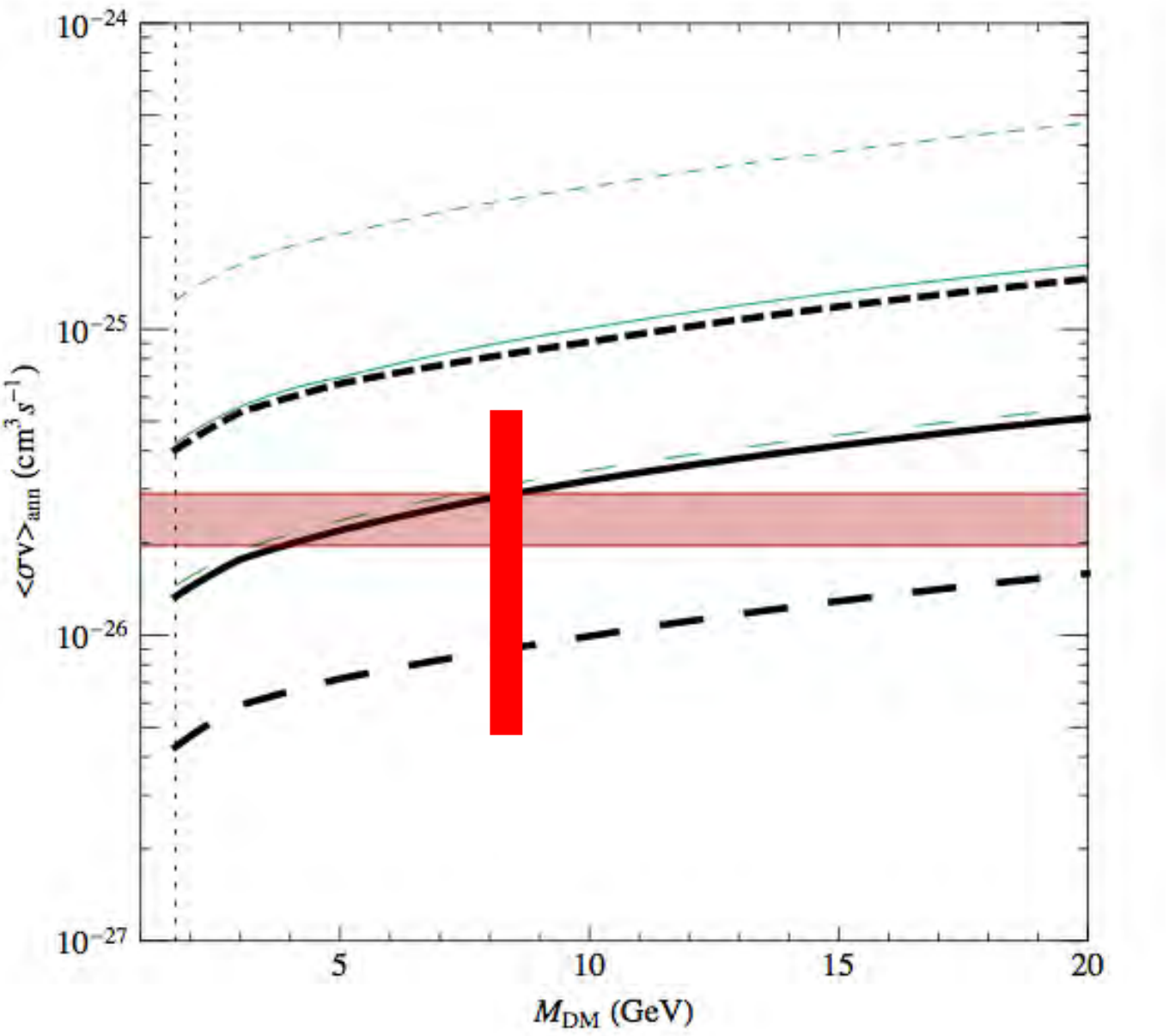
Hooper & Goodenough, arXiv:1010.2752

95% C.L. limits on annihilation cross sections from Milky Way dSphs

M_{DM}	BR	Ursa Minor	Draco
10 GeV	$\mathrm{BR}(SS \to \tau^-\tau^+) \simeq 10\%$ $\mathrm{BR}(SS \to b\bar{b} + c\bar{c}) \simeq 90\%$	≤ 2.6	≤ 2.9
6 GeV	$\mathrm{BR}(SS \to \tau^-\tau^+) \simeq 20\%$ $\mathrm{BR}(SS \to b\bar{b} + c\bar{c}) \simeq 80\%$	$\lesssim 2$	$\lesssim 2$
8 GeV	$\mathrm{BR}(XX \to \tau^+\tau^-) = 100\%$	$\lesssim 2.4$	$\lesssim 2.5$

Table 1: 95 C.L. exclusion limits on the annihilation cross-section (σv in units of 10^{26} cm$^3\cdot$s^{-1}) based on the limits on the flux of gamma-rays set by *Fermi*-LAT for two representative dSphs (Ursa Minor and Draco), using the median value of the J-factors [26]. The last line is relevant for the 8 GeV candidate of Ref.[28]

95% C.L. limits on tau pairs annihilation from Extra-galactic gamma

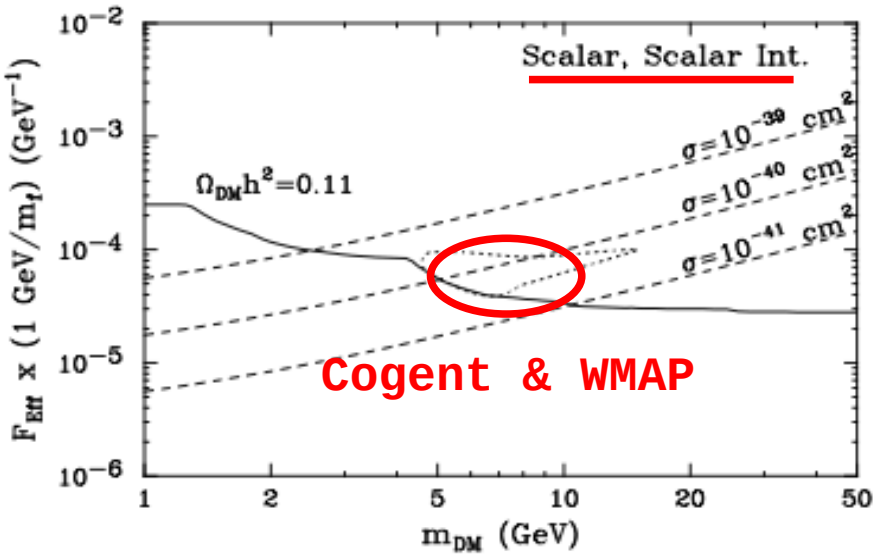


This is consistent with other recent works

Fitzpatrick, Hooper & Zurek

ArXiv:1003.0014

Effective operators approach

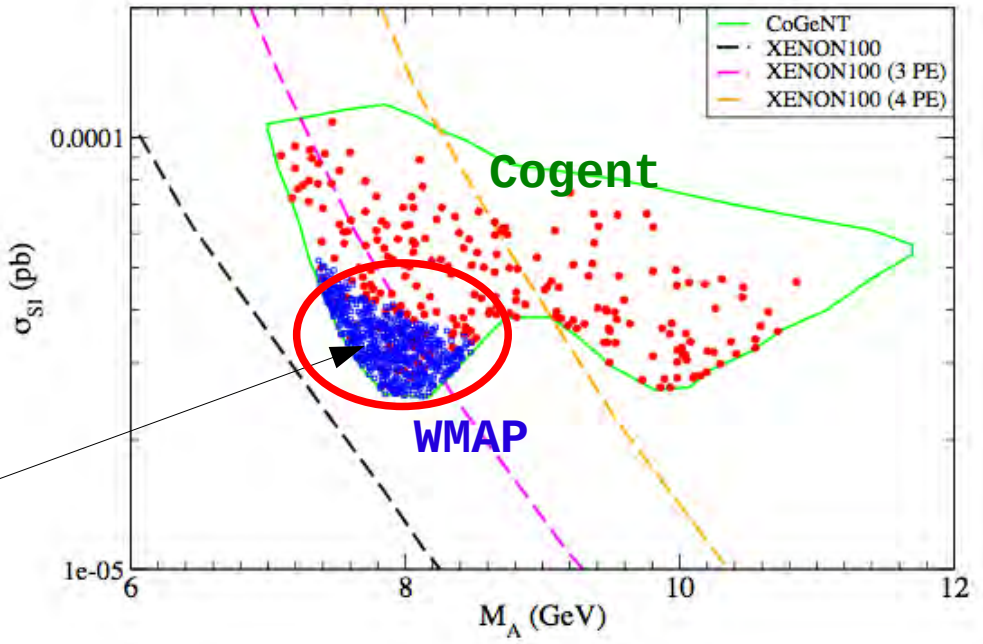


Barger, McCaskey, Shaughnessy

ArXiv:1005.3328

Complex singlet scalar

Effectively a **real** singlet scalar

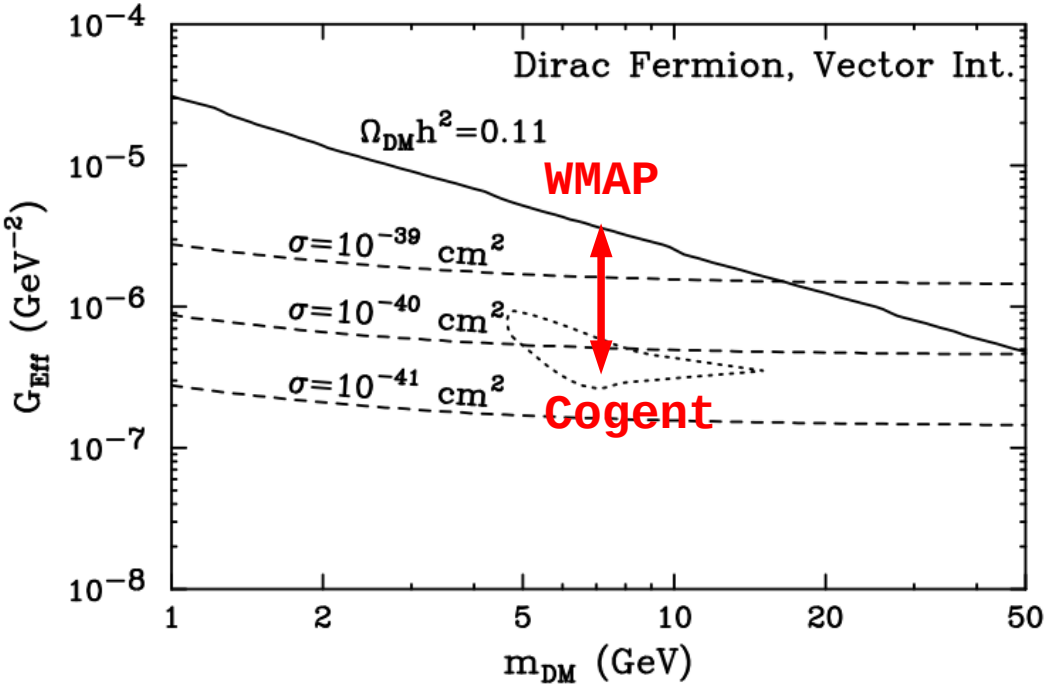


Dirac DM candidate, vector interaction ?

Fitzpatrick, Hooper & Zurek

ArXiv:1003.0014

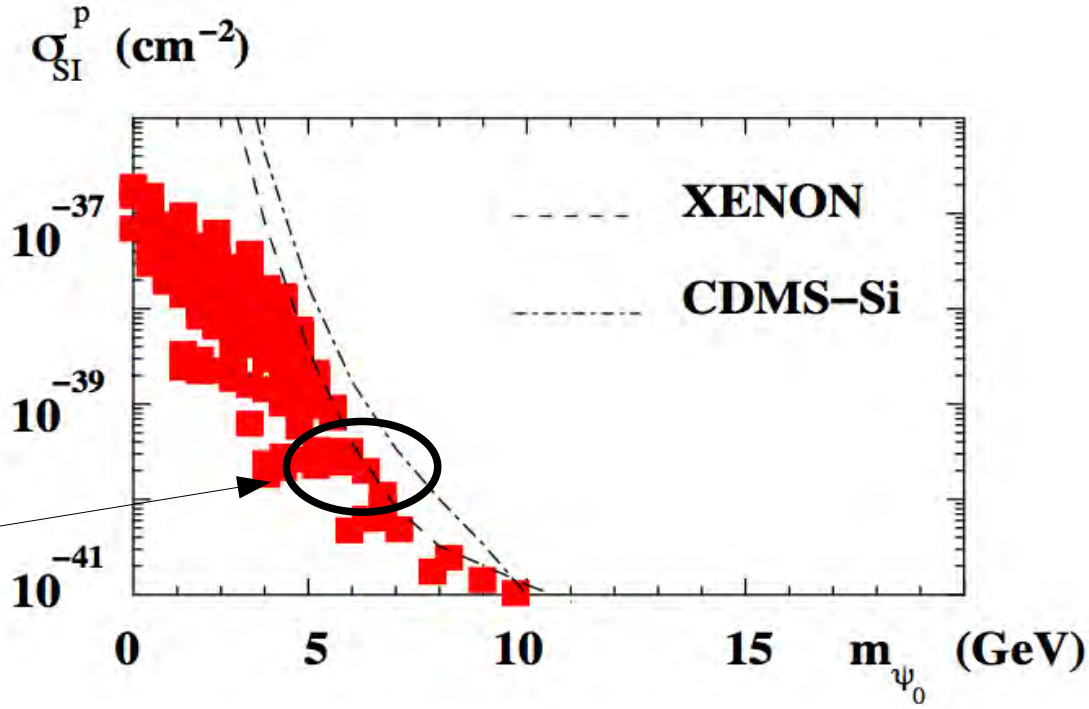
Effective operators approach



Mambrini ArXiv:1006.3318

Dirac fermion with a

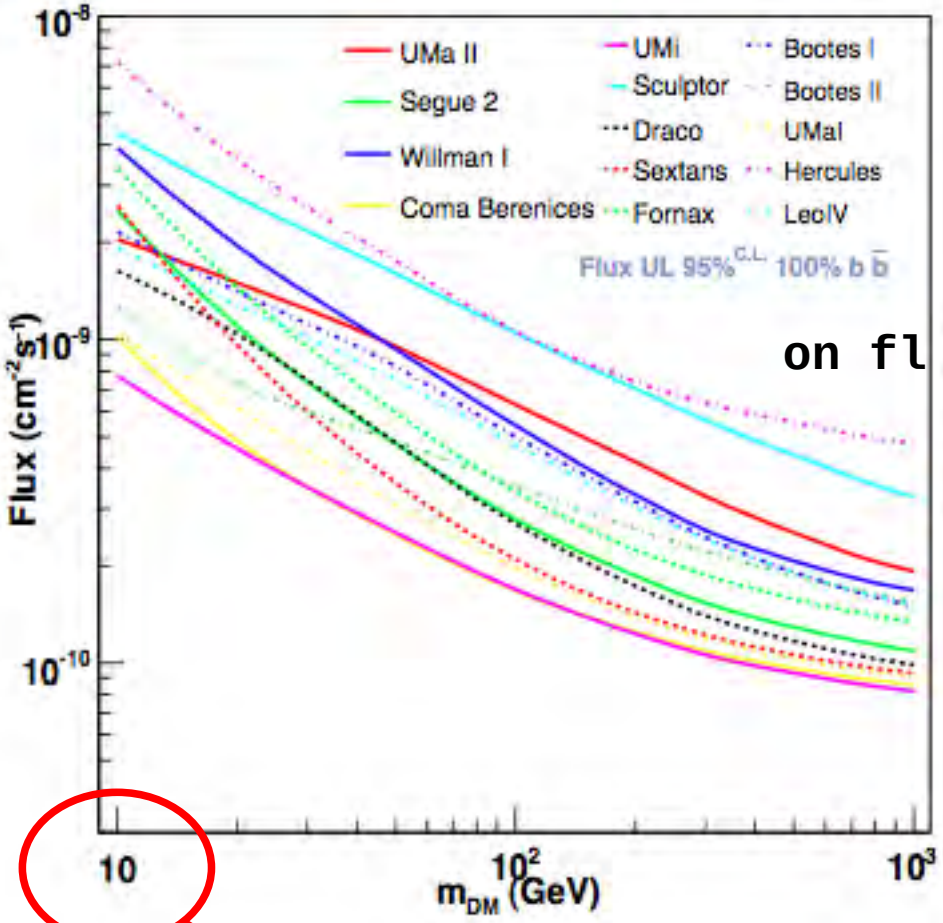
light Z'



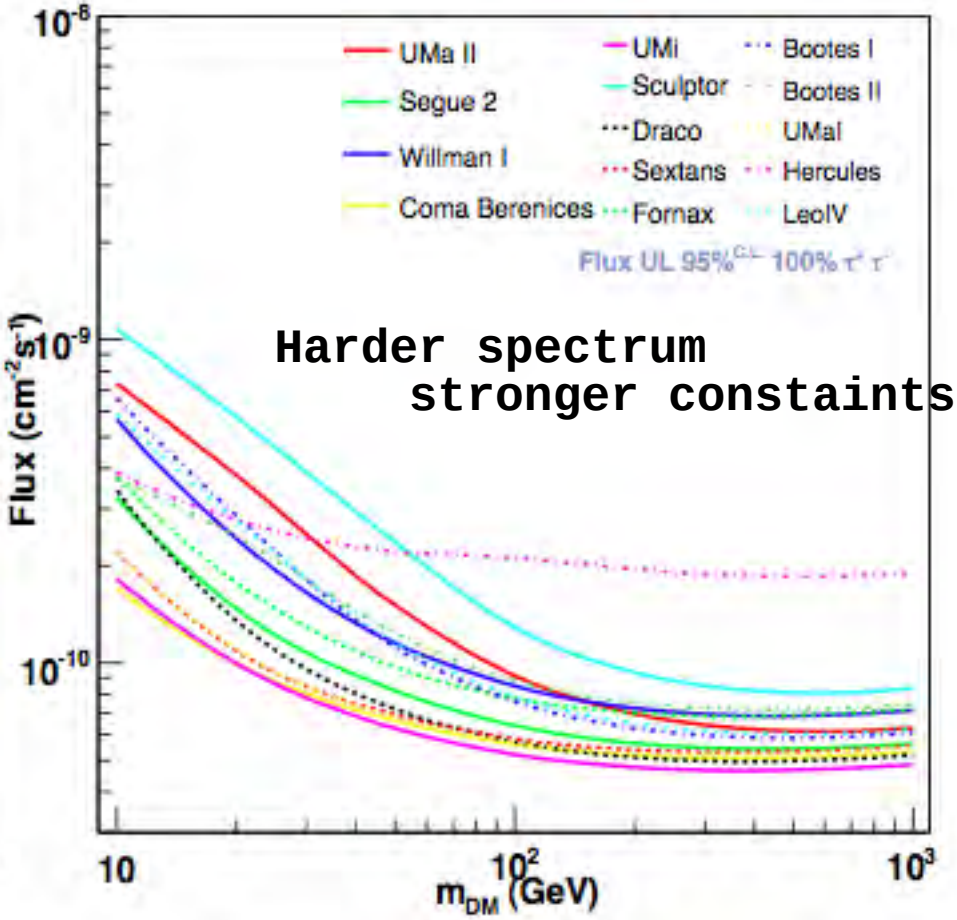
OK if use the Z' pole to enhance the annihilation cross section

95% C.L. limits on flux from dSphs between 100 MeV < E < 50 GeV

100% in b-bbar



100% in $\tau^+ \tau^-$



Harder spectrum
stronger constaints

But only published limits for M > 30 GeV neutralino and KK-dm candidates

Figures from Fermi-LAT; Abdo et al, arXiv:1001.4531

New limits on the gamma ray flux from dSphs from a light scalar singlet with WMAP cross section

	Ursa Minor L/M~75		Draco L/M~80	
m_S and BR	$\Phi_{\rm pred}({\rm cm}^{-2}{\rm s}^{-1})$	$\Phi_{\rm lim}^{95\%{\rm CL}}({\rm cm}^{-2}{\rm s}^{-1})$	$\Phi_{\rm pred}({\rm cm}^{-2}{\rm s}^{-1})$	$\Phi_{\rm lim}^{95\%{\rm CL}}({\rm cm}^{-2}{\rm s}^{-1})$
10 GeV $\mathrm{BR}(SS \to \tau^+\tau^-) \simeq 10\%$ $\mathrm{BR}(SS \to b\bar{b} + c\bar{c}) \simeq 90\%$	8.5×10^{-10}	$>$ 7.8×10^{-10}	1.6×10^{-9}	1.6×10^{-9}
6 GeV $\mathrm{BR}(SS \to \tau^+\tau^-) \simeq 20\%$ $\mathrm{BR}(SS \to b\bar{b} + c\bar{c}) \simeq 80\%$	1.5×10^{-9}	$>$ 1.0×10^{-9}	2.8×10^{-9}	$>$ 1.7×10^{-9}

Our predicted fluxes but tentative (e.g. energy resolution, acceptance,... not taken into account)

Our (naive) extrapolations based on Fermi-LAT data

Andreas, Arina, Hambye, Ling, M.T. (arXiv:1003.2595)

See also Fitzpatrick, Hooper & Zurek

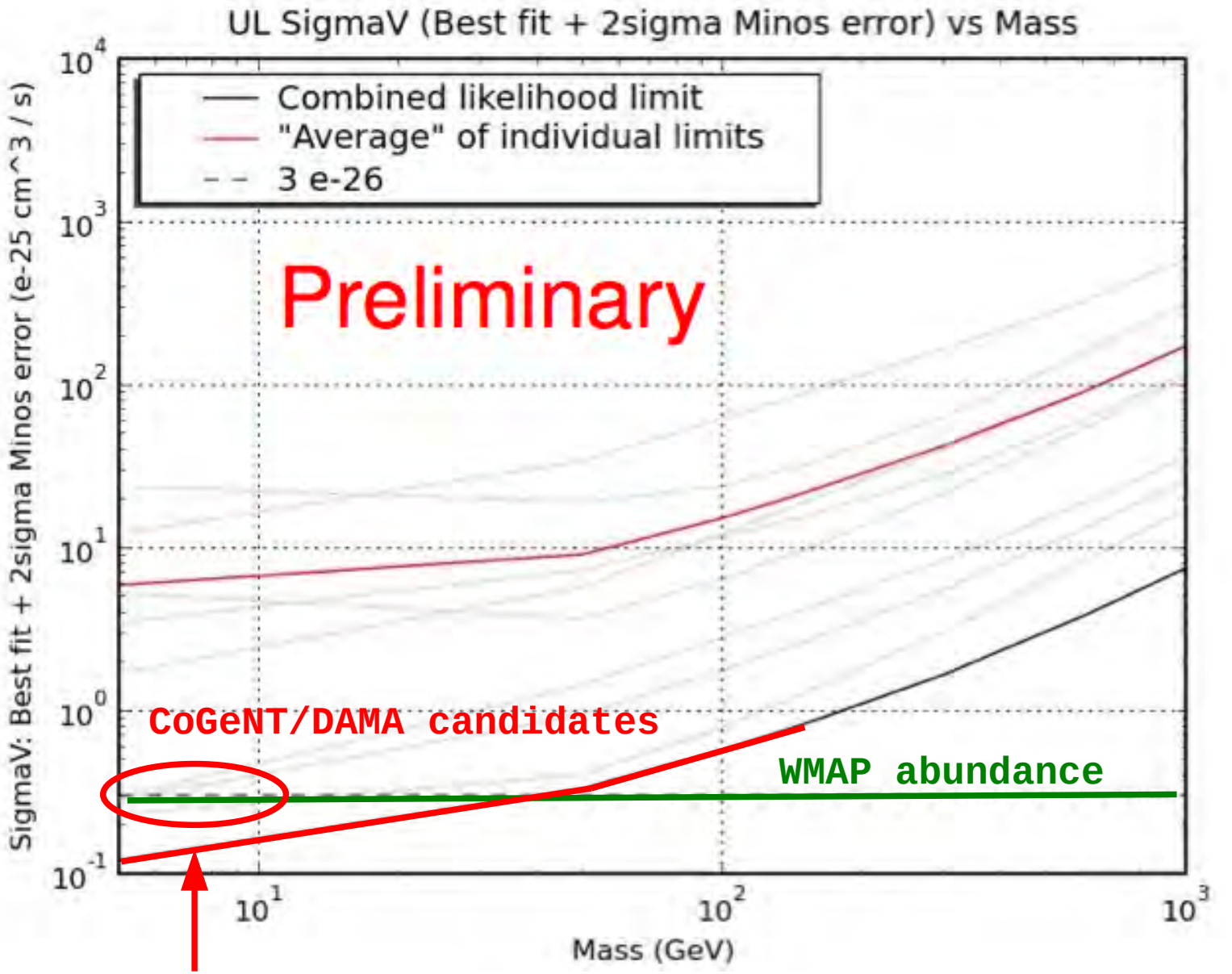
95% C.L. limits on annihilation cross sections from Milky Way dSphs

M_{DM}	BR	Ursa Minor	Draco
10 GeV	$\mathrm{BR}(SS \to \tau^-\tau^+) \simeq 10\%$ $\mathrm{BR}(SS \to b\bar{b} + c\bar{c}) \simeq 90\%$	≤ 2.6	≤ 2.9
6 GeV	$\mathrm{BR}(SS \to \tau^-\tau^+) \simeq 20\%$ $\mathrm{BR}(SS \to b\bar{b} + c\bar{c}) \simeq 80\%$	$\lesssim 2$	$\lesssim 2$
8 GeV	$\mathrm{BR}(XX \to \tau^+\tau^-) = 100\%$	$\lesssim 2.4$	$\lesssim 2.5$

Table 1: 95 C.L. exclusion limits on the annihilation cross-section (σv in units of 10^{26} cm$^3\cdot$s^{-1}) based on the limits on the flux of gamma-rays set by *Fermi*-LAT for two representative dSphs (Ursa Minor and Draco), using the median value of the J-factors [26]. The last line is relevant for the 8 GeV candidate of Ref.[28]

WMAP → σ v 3 10^{-26} cm^3 s^{-1}

From the talk by Maja LLENA GARDE (Fermi-LAT) @ IDM2010



Stacked analysis → stronger limits: light candidates in b-bbar excluded @ 95% CL

95% C.L. limits on annihilation cross sections from Milky Way dSphs

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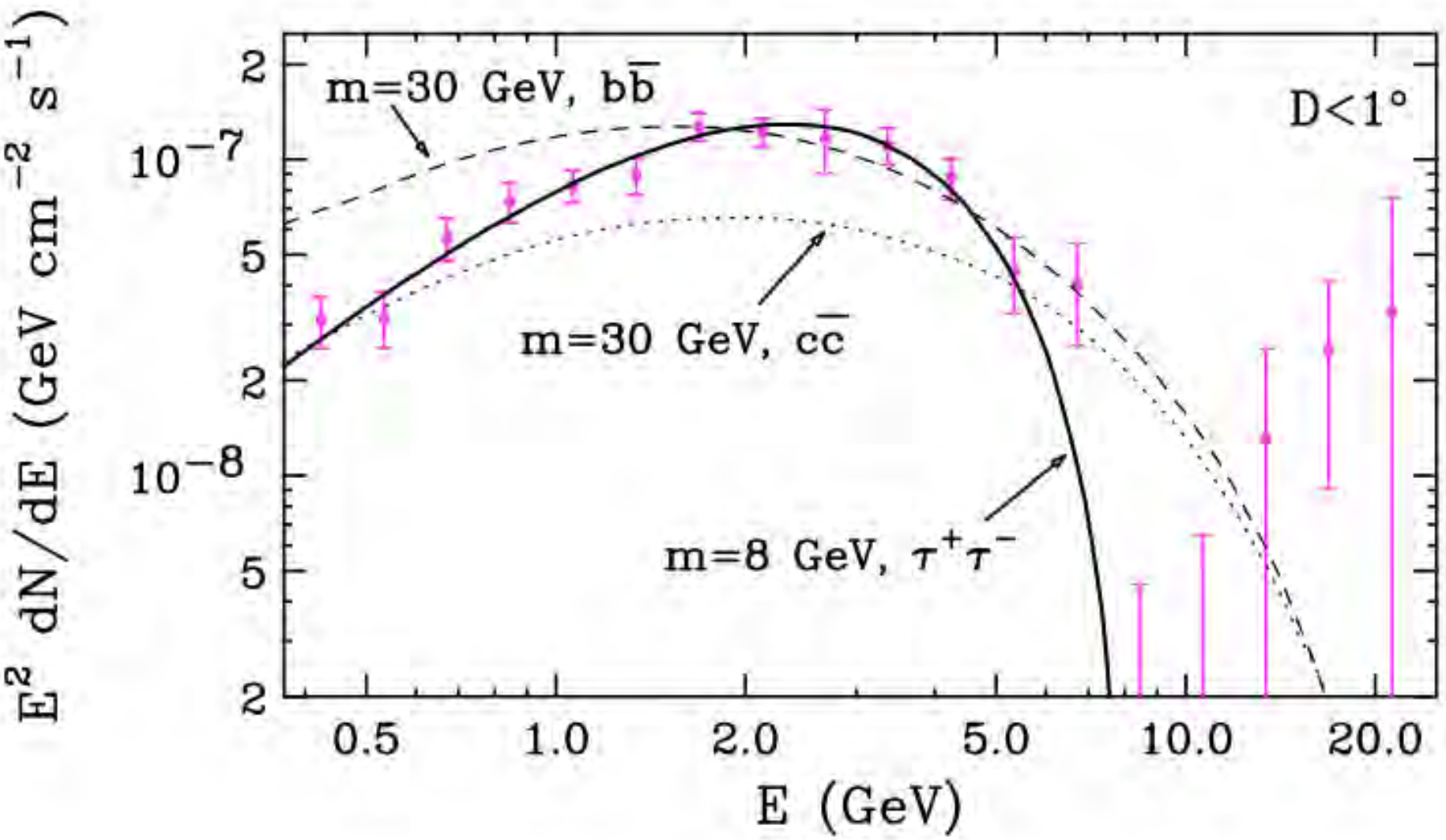
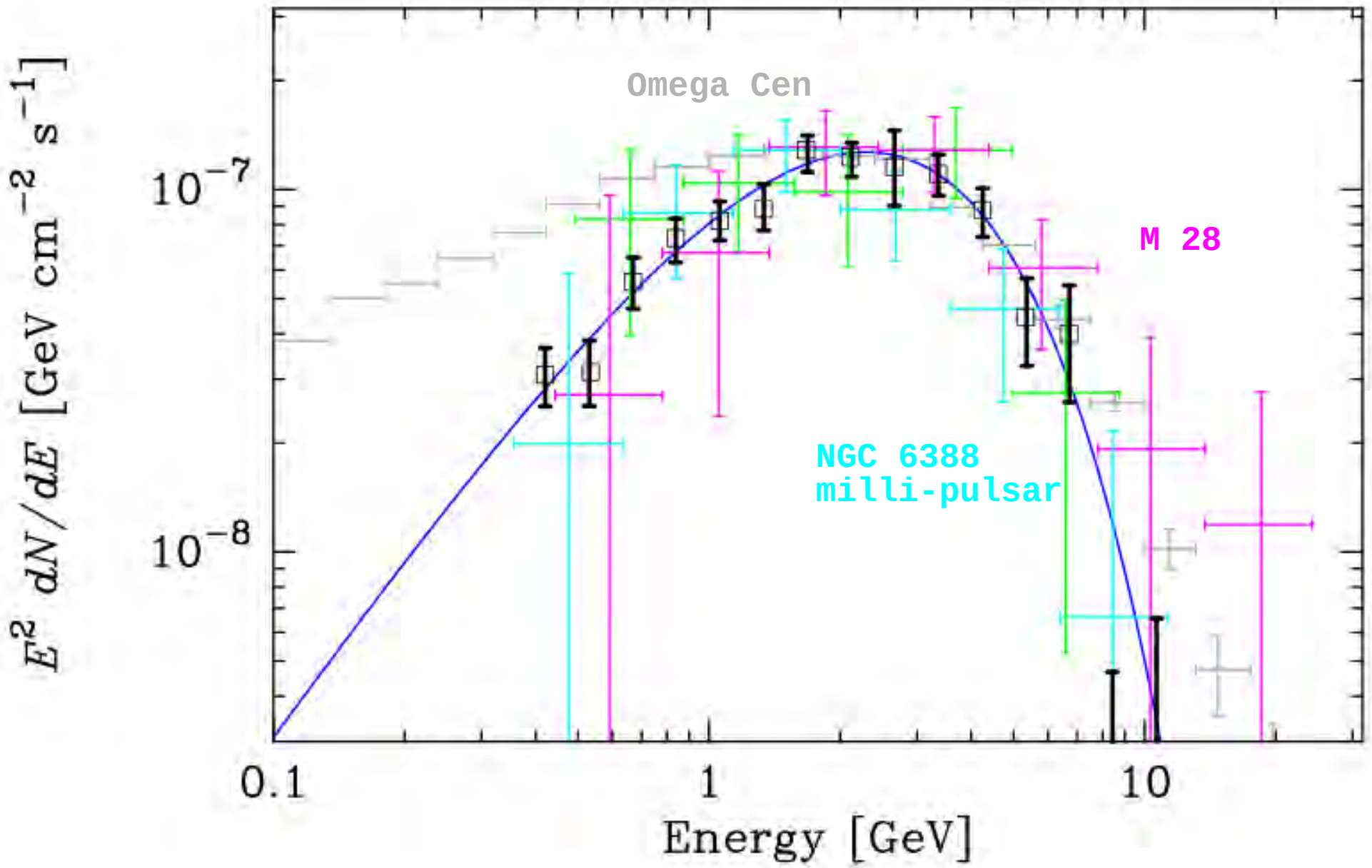
An 8 GeV candidate and the Fermi-LAT data from the Galactic Centre?



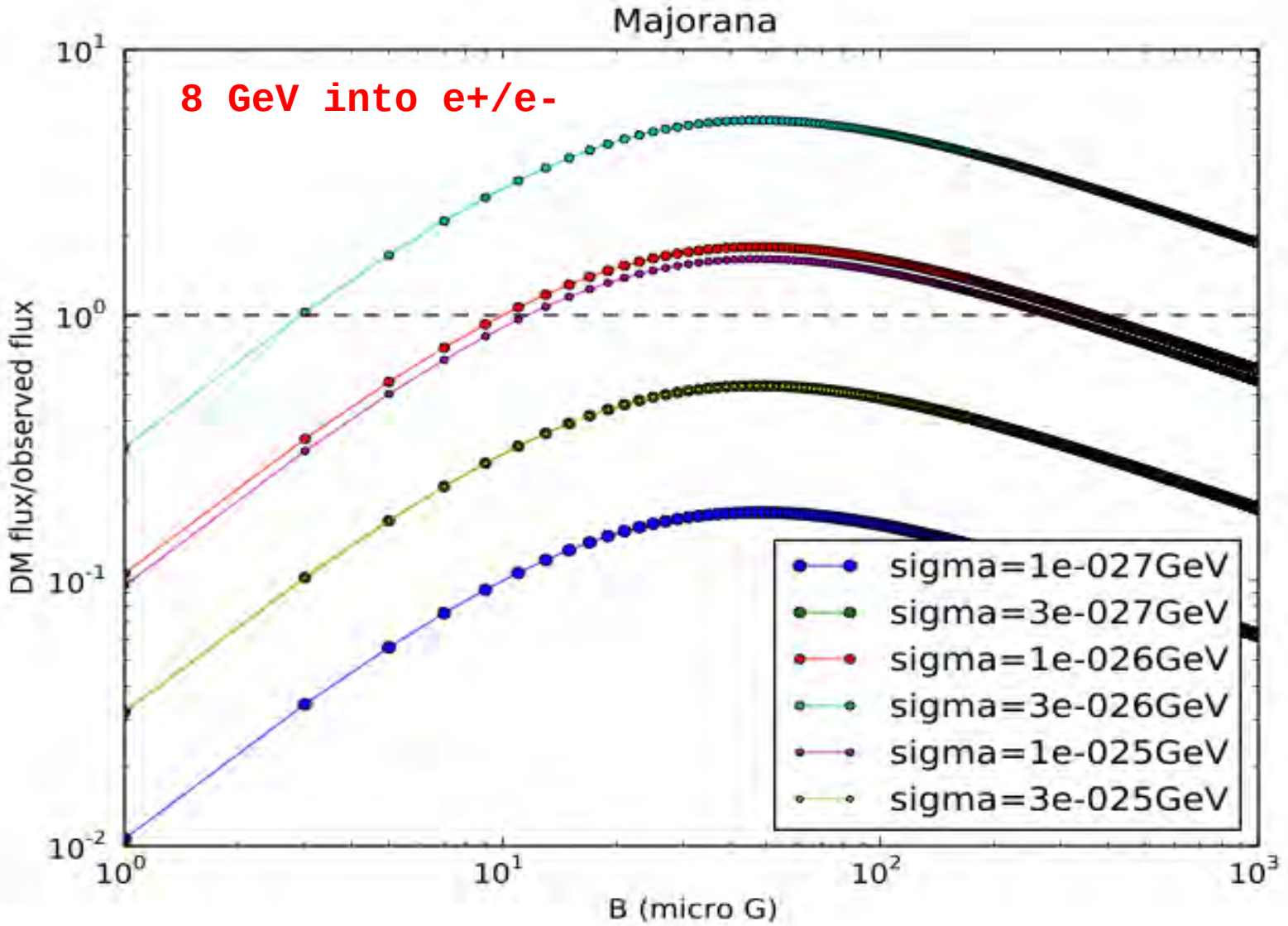
Hooper & Goodenough, arXiv:1010.2752

Could be (again, remember PAMELA?) pulsars...



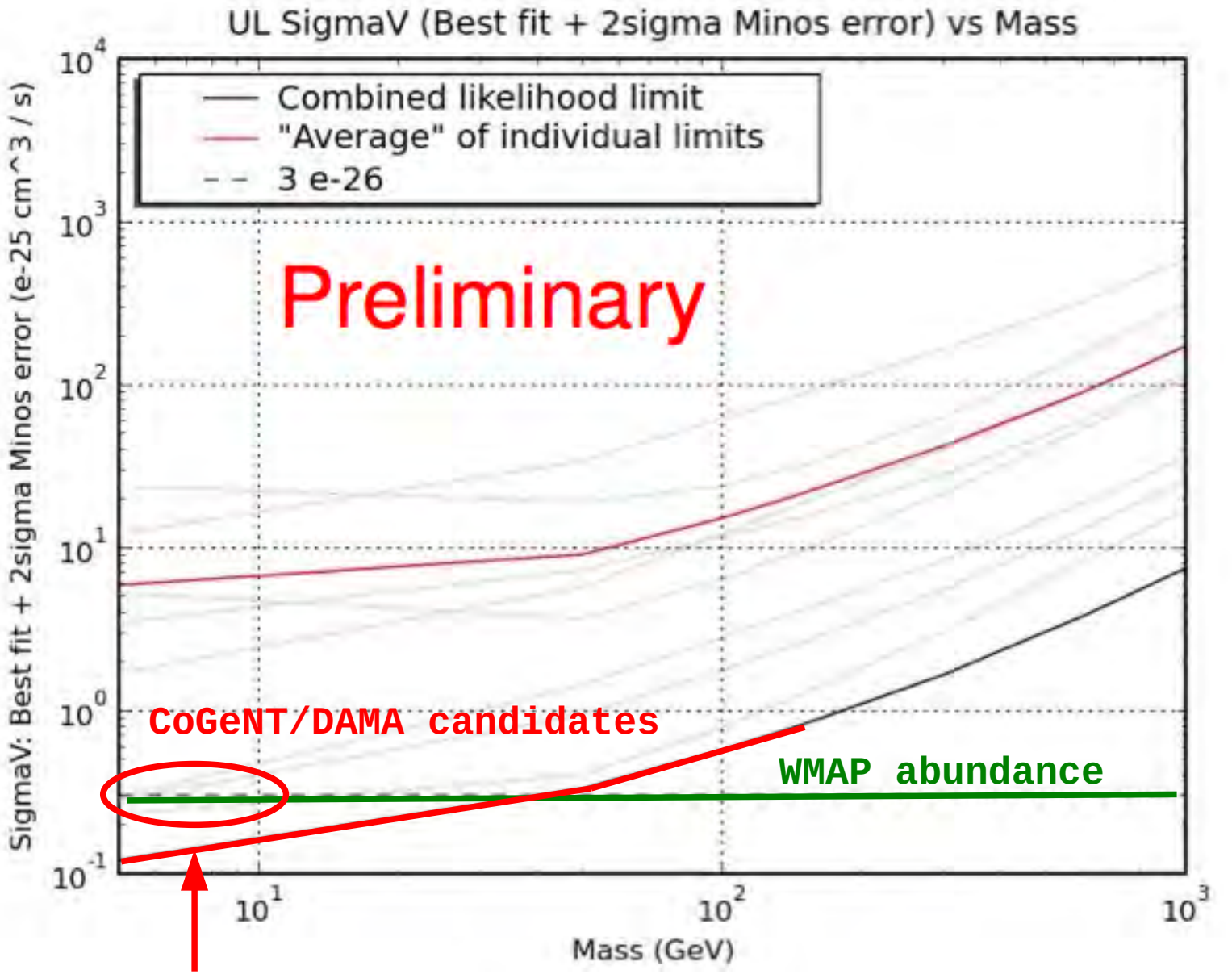
Abazajian arXiv:1011.4275

Constraints on 8 GeV DM from synchrotron radiation (radio) @ GC !



Boehm, Silk and Enslin, arXiv:1008.5175

From the talk by Maja LLENA GARDE (Fermi-LAT) @ IDM2010



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