A light scalar WIMP ?

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Identification of Dark Matter 2010 (IDM2010)

Montpellier, 26-30 July 2010

There is some experimental (i.e. CoGeNT, DAMA, perhaps CRESST) indication of a light WIMP (i.e. M ~ few GeV).

Likely to have nothing to do with Dark Matter, but the concordance is intriguing.

Here I consider the simplest model that is (marginally) compatible with current experiments, including WMAP.

I also discuss some of the possible constraints/signatures.

Scalar singlet model (SM+3)

$$\mathcal{L} \ni \frac{1}{2}\partial^\mu S \partial_\mu S - \frac{1}{2}\mu_S^2 S^2 - \frac{\lambda_S}{4} S^4 - \lambda_L H^\dagger H S^2$$

Introduce an *ad hoc* parity (with SM dof even)

$$S \to -S$$

Also assume <S>=0

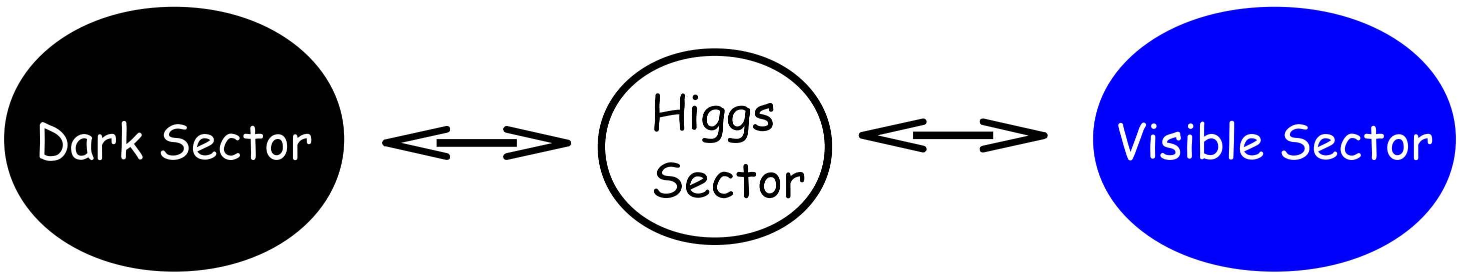
S is a dark matter candidate with mass

$$m_s^2 = \mu_s^2 + \lambda_s v^2$$

Silveira & Zee '85; McDonald '94; Burgess, Pospelov, ter Veldhuis '00; Patt,Wilczek '06; Barger et al '08;...

Motivation #1: an instance of Higgs portal

(Patt & Wilczek)



e.g. **Inert Doublet Model**

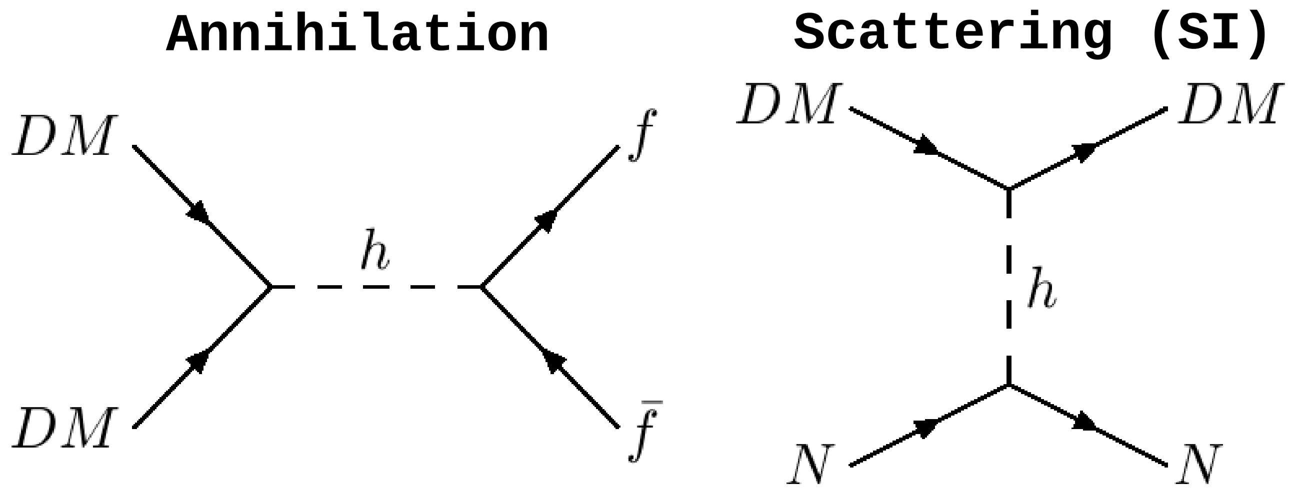
(Deshpande,Ma;Barbieri,Hall,Ryshkov)

WIMPless scalar (Feng et al; also Kumar's talk)

SO(10) framework (Kadastik,Kannike, Raidal)

...

Motivation #2: a one-to-one correspondence between annihilation and elastic scattering



$$\sigma(SS \to \bar{f}f)v_{rel} = n_c \frac{\lambda_L^2}{\pi} \frac{m_f^2}{m_h^4 m_S^3} (m_S^2 - m_f^2)^{3/2}$$

$$\sigma(SN \to SN) = \frac{\lambda_L^2}{\pi} \frac{\mu_r^2}{m_h^4 m_S^2} f^2 m_N^2$$

$$R \equiv \sum_f \frac{\sigma(SS \to \bar{f}f)v_{rel}}{\sigma(SN \to SN)} = \sum_f \frac{n_c m_f^2}{f^2 m_N^2 \mu_r^2} \frac{(m_S^2 - m_f^2)^{3/2}}{m_S}$$

Ratio depends only on M_S

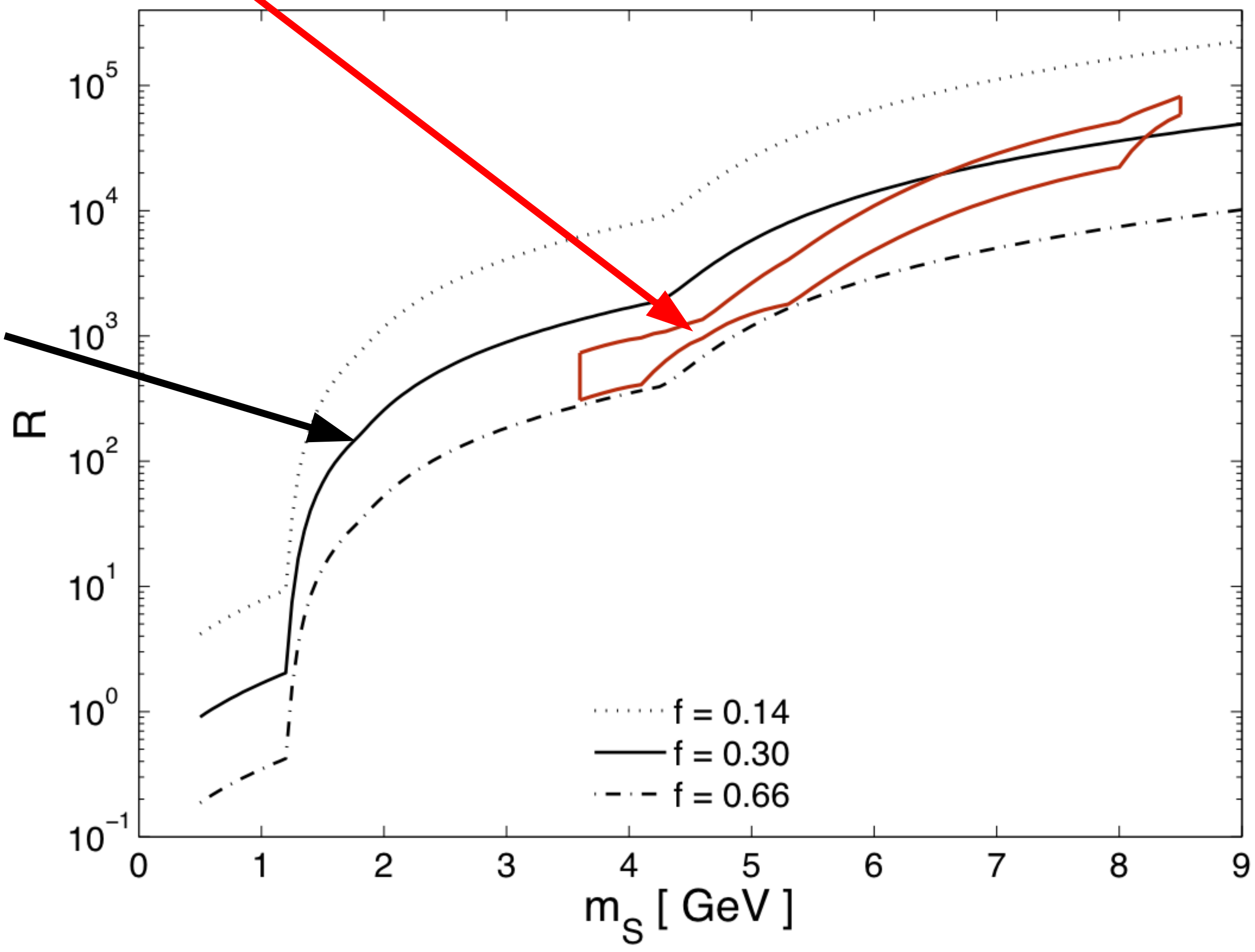
Higgs-Nucleus coupling... large uncertainty ($f \sim 0.1$-0.6 @ 2σ)

$$f\, m_N = \langle N | \Sigma\, m_q\, \bar{q}q | N \rangle = g_{hNN}\, v$$

WMAP / DAMA

DAMA region from Pietrello & Zurek '08
(with channelling & standard halo)

Singlet scalar

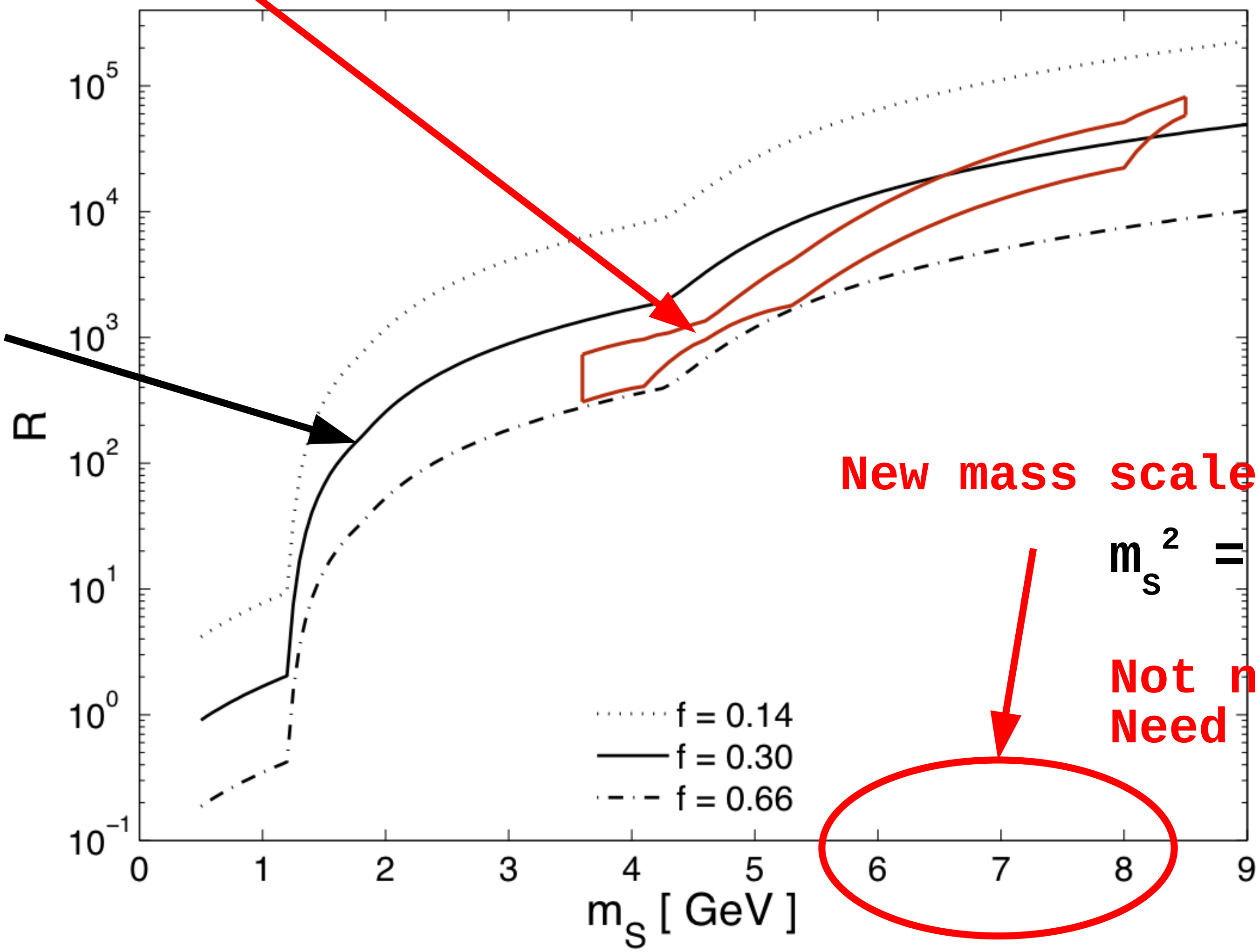


S.Andreas, Th.Hambye, MT '08

$\frac{\text{WMAP}}{\text{DAMA}}$

DAMA region from Pietrello & Zurek '08
(with channelling & standard halo)

Singlet scalar



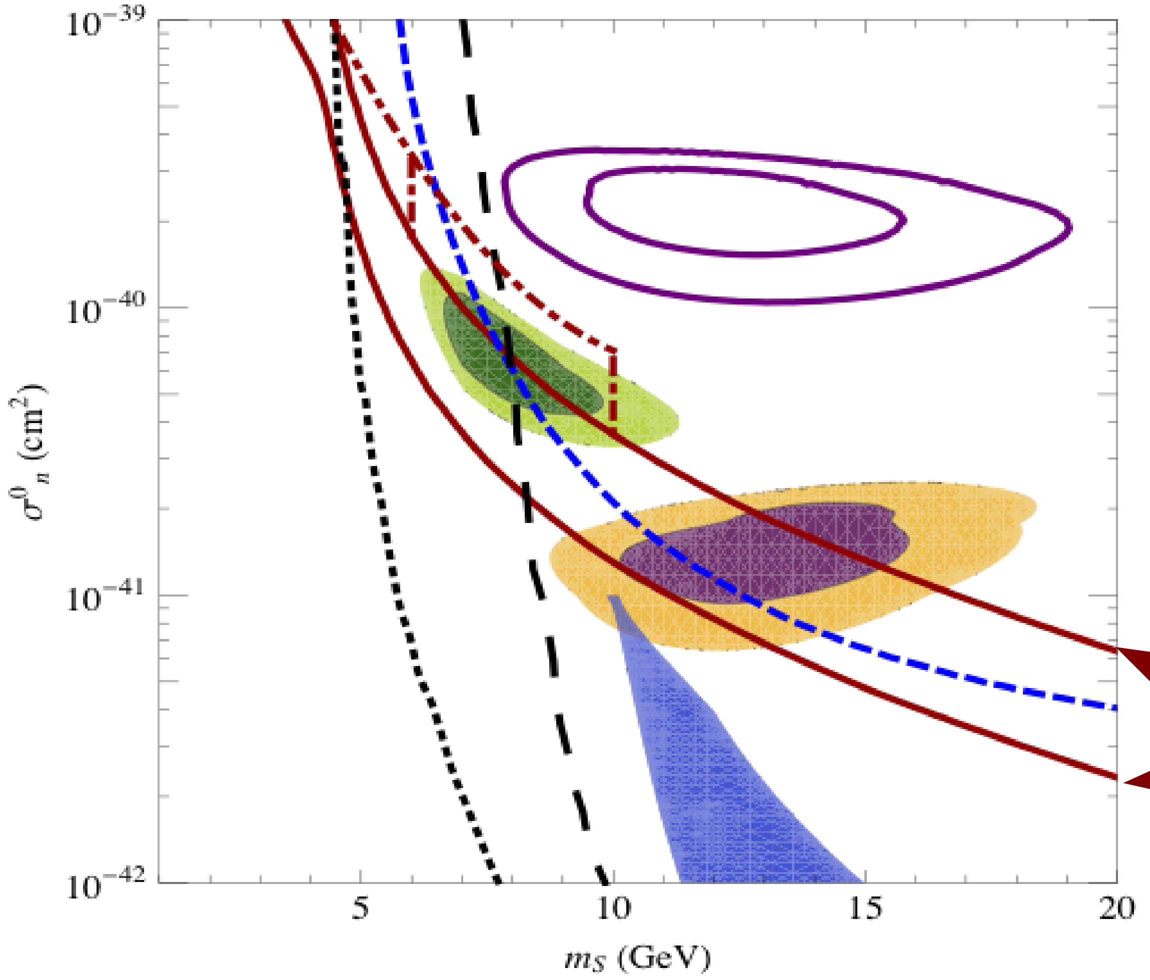
New mass scale?

$$m_s^2 = \mu_s^2 + \lambda_s v^2$$

Not natural
Need tuning :(

S.Andreas, Th.Hambye, MT '08

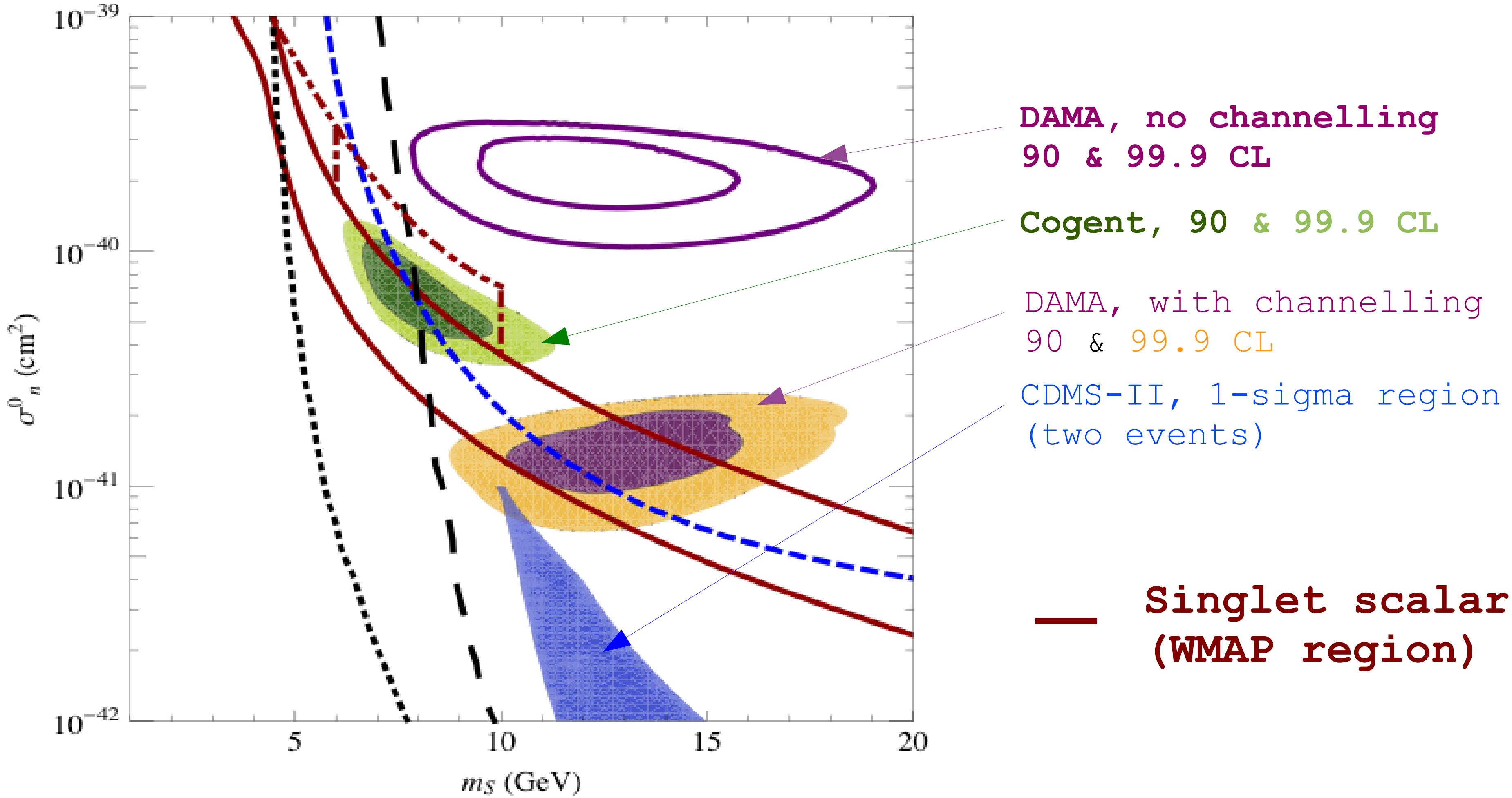
Concordance with CoGeNT and/or DAMA



Singlet scalar WMAP region

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

Concordance with CoGeNT and/or DAMA



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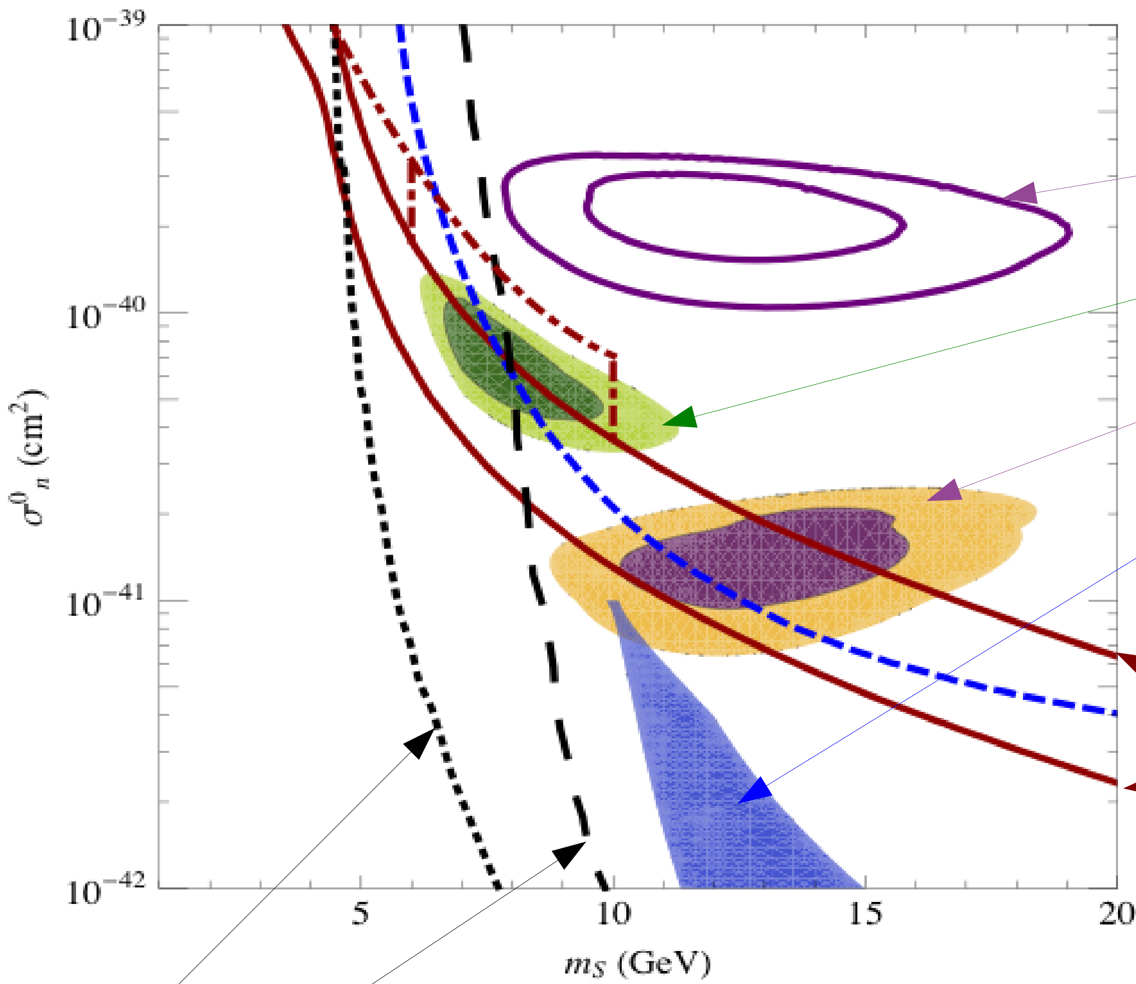


DAMA, no channelling 90 & 99.9 CL

Cogent, 90 & 99.9 CL

DAMA, with channelling 90 & 99.9 CL

CDMS-II, 1-sigma region (two events)

Singlet scalar (WMAP region)

- - - - Xenon10 (2009), constant Leff

— — Xenon10, conservative Leff (mean value)

— — CDMS-Si, 90 CL

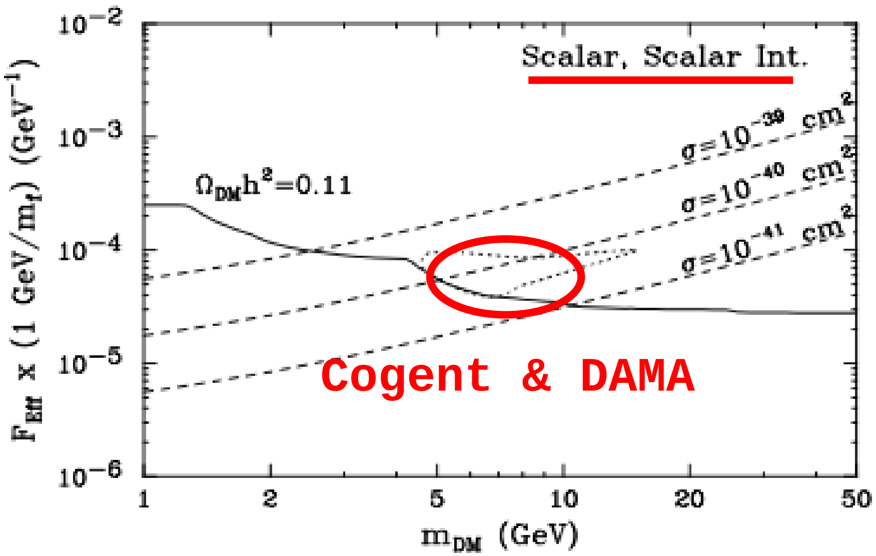
Andreas, Arina, Hambye, Ling & M.T.
arXiv:1003.2595

This is consistent with other recent works

Fitzpatrick, Hooper & Zurek

ArXiv:1003.0014

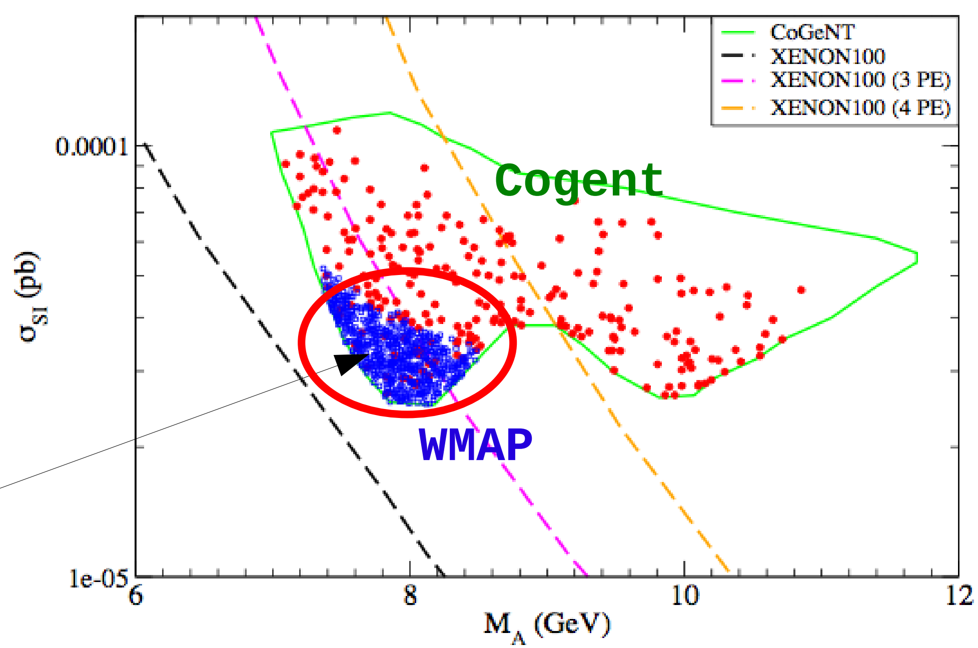
Effective operators approach



Barger, McCaskey, Shaughnessy

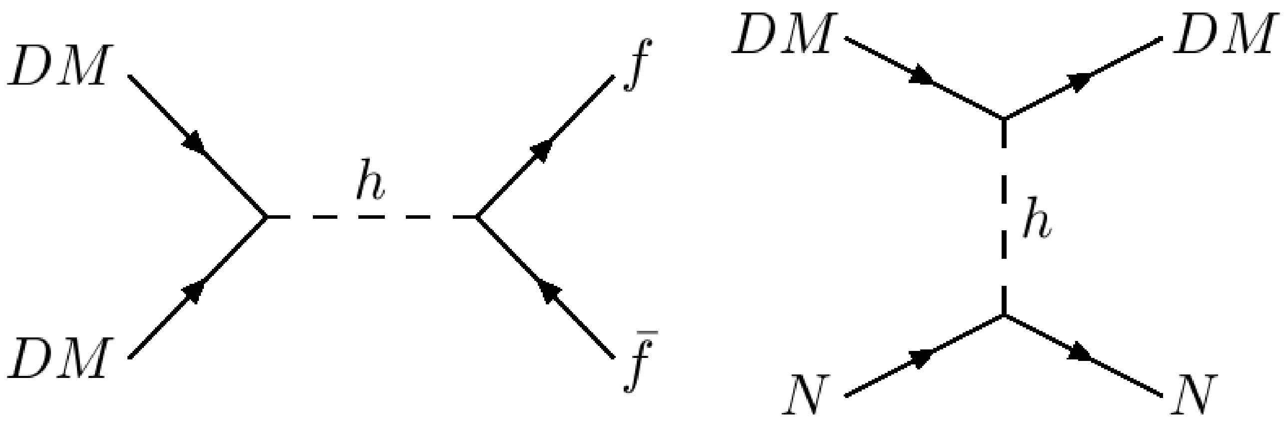
ArXiv:1005.3328

Complex singlet scalar



Effectively a **real** singlet scalar

Remark : A Majorana fermion singlet with Higgs does not work



$$\sigma(\bar{\psi}\psi \to \bar{f} f) v_{rel} \;=\; n_c \frac{Y_\psi^2}{16\pi} \frac{m_f^2 v_{rel}^2}{\mathrm{v}^2 m_h^4} \frac{(m_\psi^2 - m_f^2)^{3/2}}{m_\psi}$$

→ p-wave and helicity suppressed

Thus larger abundance

Typically needs other channels

e.g. light neutralino
(Bottino, Donato, Fornengo & Scopel)

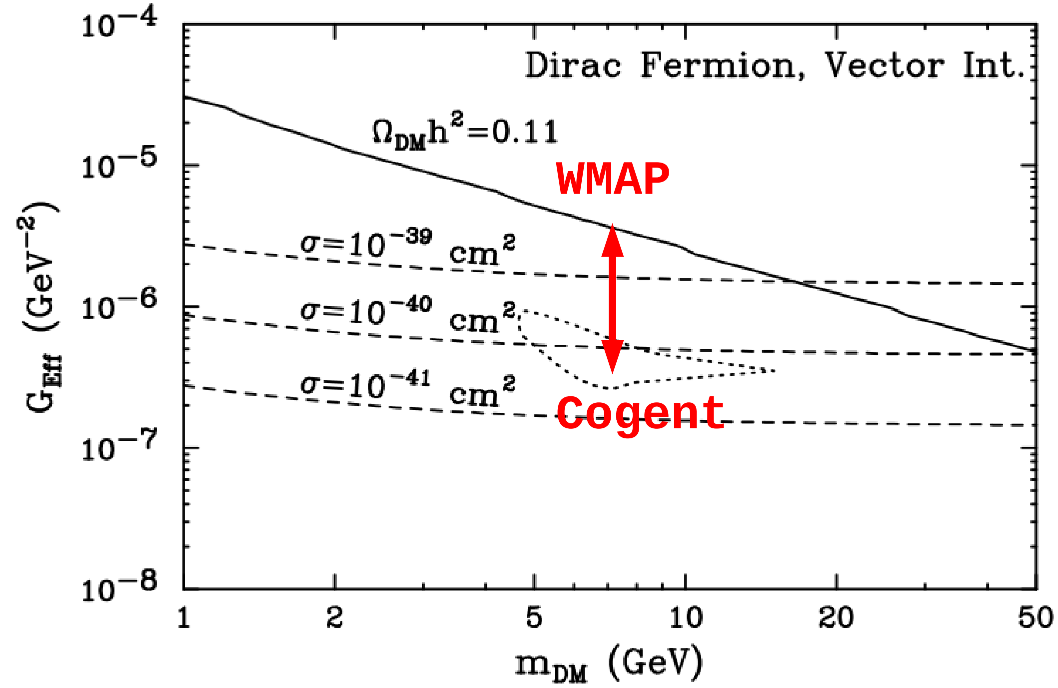
Andreas, Hambye, M.T.

Dirac DM candidate?

Fitzpatrick, Hooper & Zurek

ArXiv:1003.0014

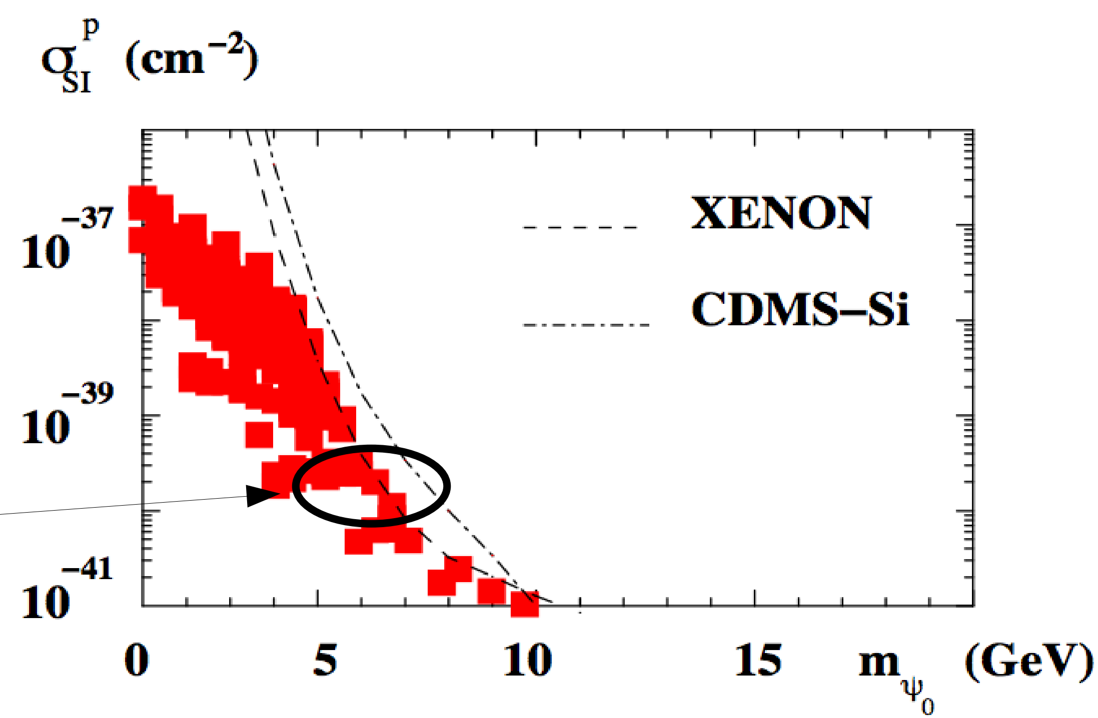
Effective operators approach



Mambrini ArXiv:1006.3318

Dirac fermion with a

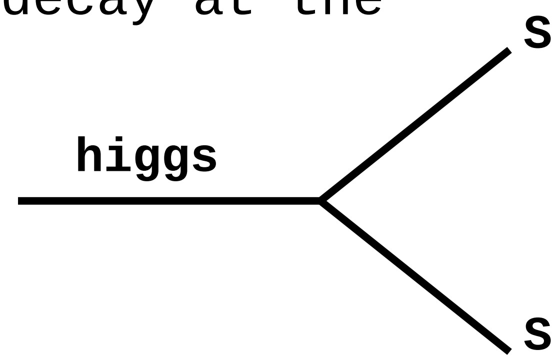
light Z'



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

Motivation 3: affects Higgs physics

Invisible Higgs decay at the LHC



For instance M_S = 7 GeV :

For λ_S = 0.2 and m_{higgs} = 120 GeV

BR(h-> SS) = 99.5%

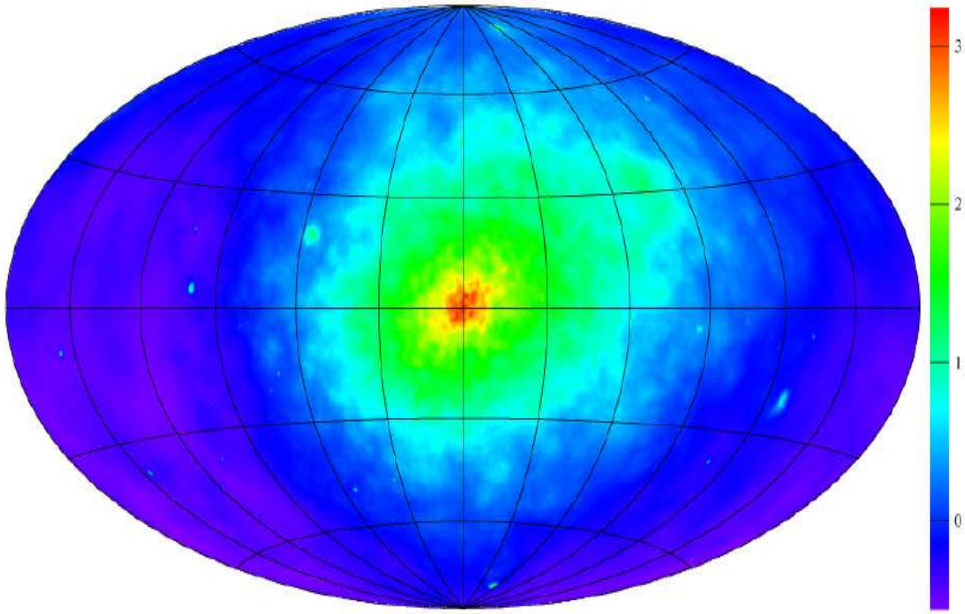
For λ_S = 0.55 and m_{higgs} = 200 GeV

BR(h-> SS) = 70%

Andreas, Hambye, M.T.

See also Burgess, Pospelov & ter Veldhuis; Barger et al;

Motivation 4: potentially « large » indirect signals



HORIZON simulation
Athanassoula et al

$$\frac{d\Phi_{\gamma,\nu}}{d\Omega} = \frac{1}{4\pi} \underbrace{\frac{1}{\delta}\frac{\langle\sigma v\rangle}{m_{DM}^2} \int_{E_{min}^{\gamma,\nu}}^{E_{max}^{\gamma,\nu}} \sum_i \frac{dN_{\gamma,\nu}^i}{dE_{\gamma,\nu}} BR_i}_{\doteq HEP_{\gamma,\nu}} \underbrace{\int_{l(\vec{\Omega})} \rho_{DM}^2 \, dl}_{\doteq ASTRO},$$

Annihilation rate ~ n_{dm}^2 ~ $1/m_{dm}^2$

Flux of gammas, neutrinos, positrons ↗↗

Constraint # 1: gammas rays from dwarf galaxies

Largest galactic subhalos

Low background, but low stastics

→ **analysis by Fermi-LAT collaboration, 11 months of data, with 95% CL on gamma flux from Milky Way dwarf galaxies (dSph)**

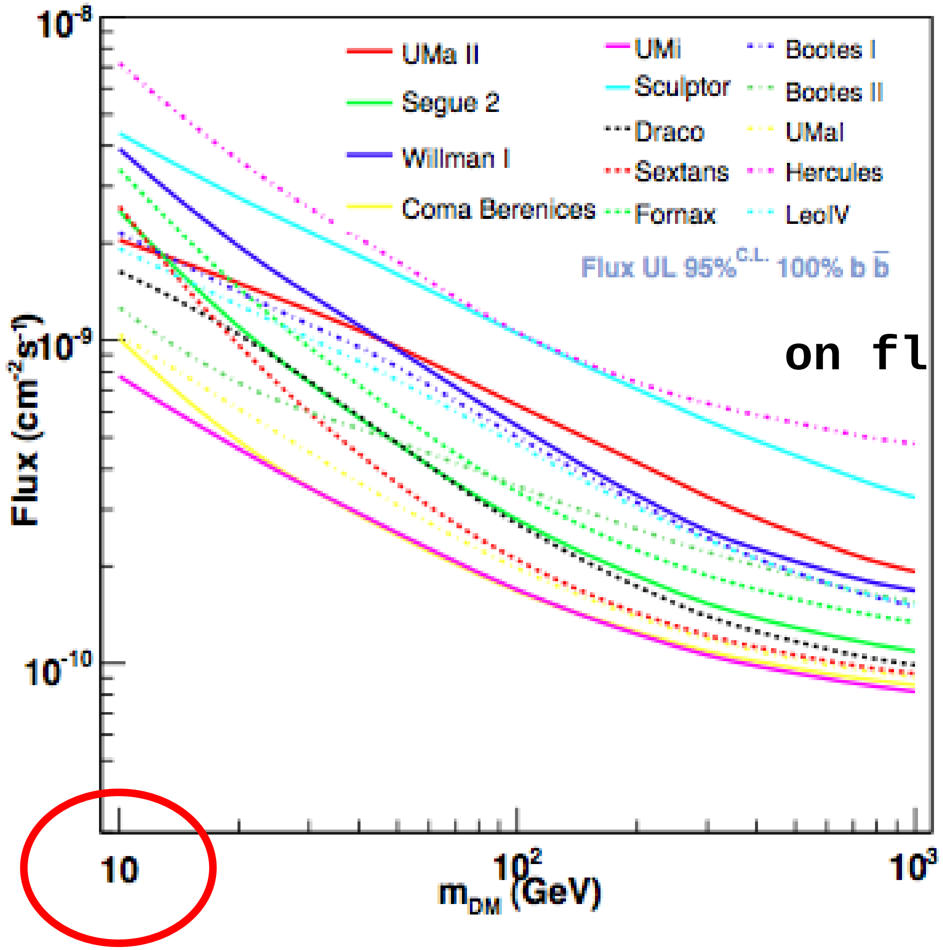
- **14 best candidates dSph, short distances (< 150 kpc), high latitudes for low background (-30° < b < 30°)**
- **dSph modelled as point sources**
- **No observation of gamma from dSph**

95% CL limits on DM based on NFW profile, and astrophysical background (point sources from Fermi catalog + galactic and isotropic diffuse emission)

Limits on flux between 100 MeV < E < 50 GeV

100% in b-bbar

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



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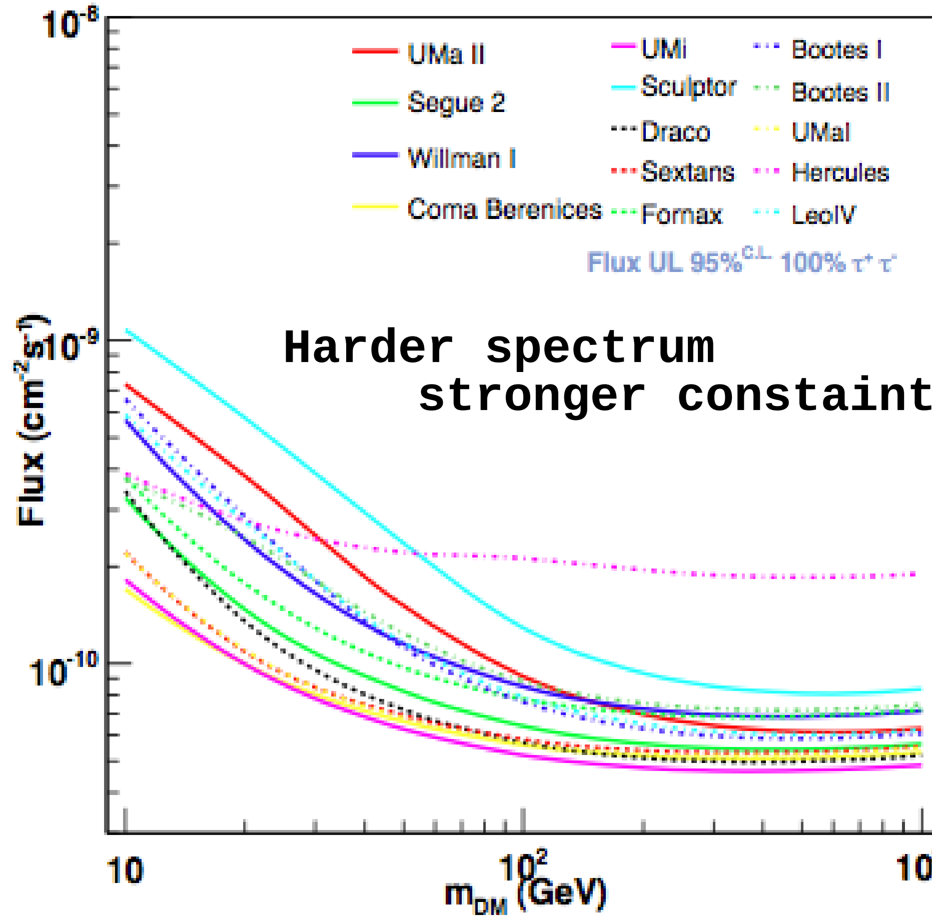


Harder spectrum
stronger constaints

Fermi-LAT; Abdo et al, arXiv:1001.4531

Limits on gamma ray flux from dPhs from a scalar singlet with WMAP cross section

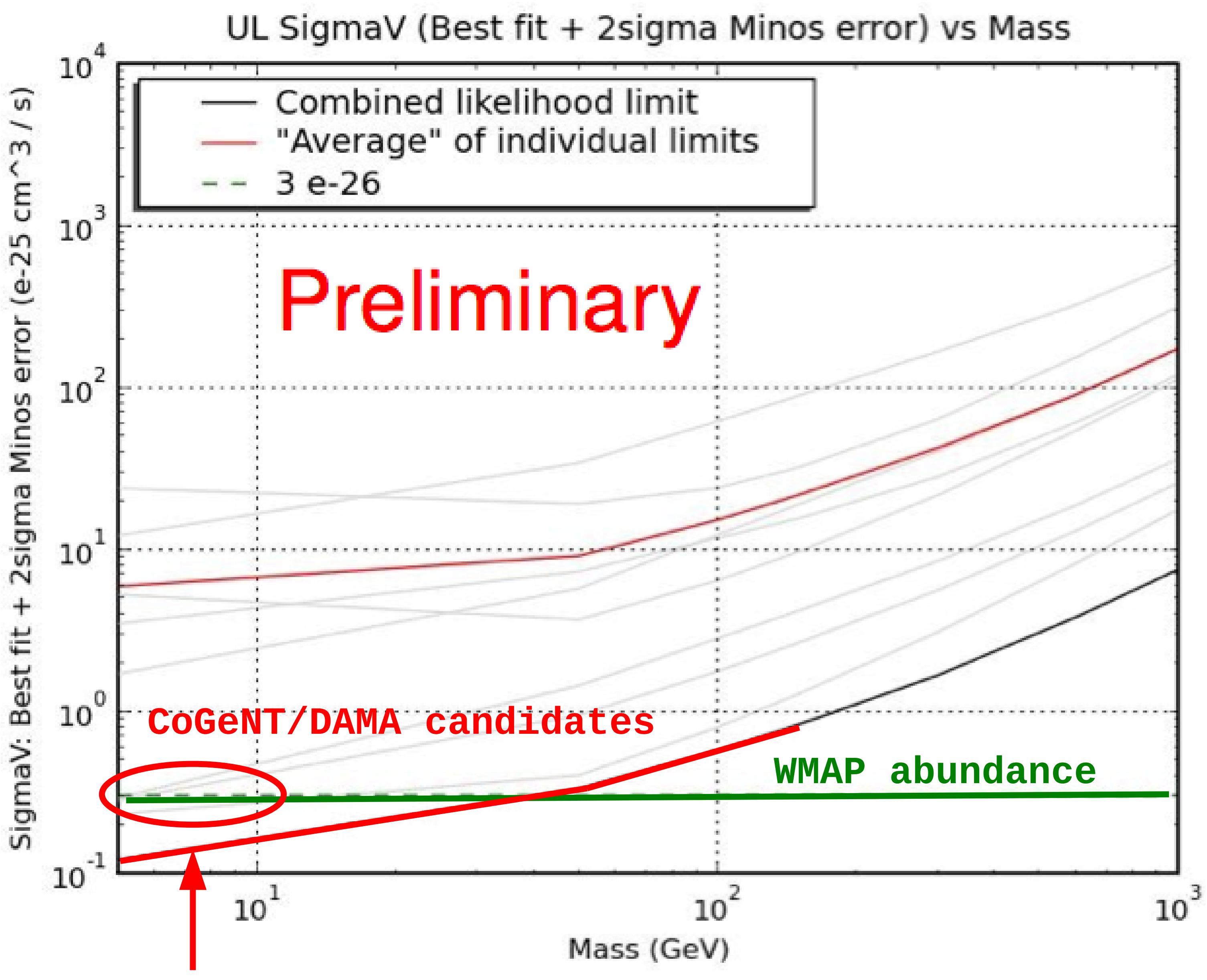
	Ursa Minor		Draco	
m_S and BR	$\Phi_{\rm pred}({\rm cm}^{-2}{\rm s}^{-1})$	$\Phi^{95\%{\rm CL}}_{\rm lim}({\rm cm}^{-2}{\rm s}^{-1})$	$\Phi_{\rm pred}({\rm cm}^{-2}{\rm s}^{-1})$	$\Phi^{95\%{\rm CL}}_{\rm lim}({\rm cm}^{-2}{\rm s}^{-1})$
10 GeV ${\rm BR}(SS \to \tau^+\tau^-) \simeq 10\%$ ${\rm BR}(SS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

Predictions but tentative (e.g. energy resolution,acceptance, not taken into account,...)

Our (naive) extrapolations based on Fermi-LAT analysis

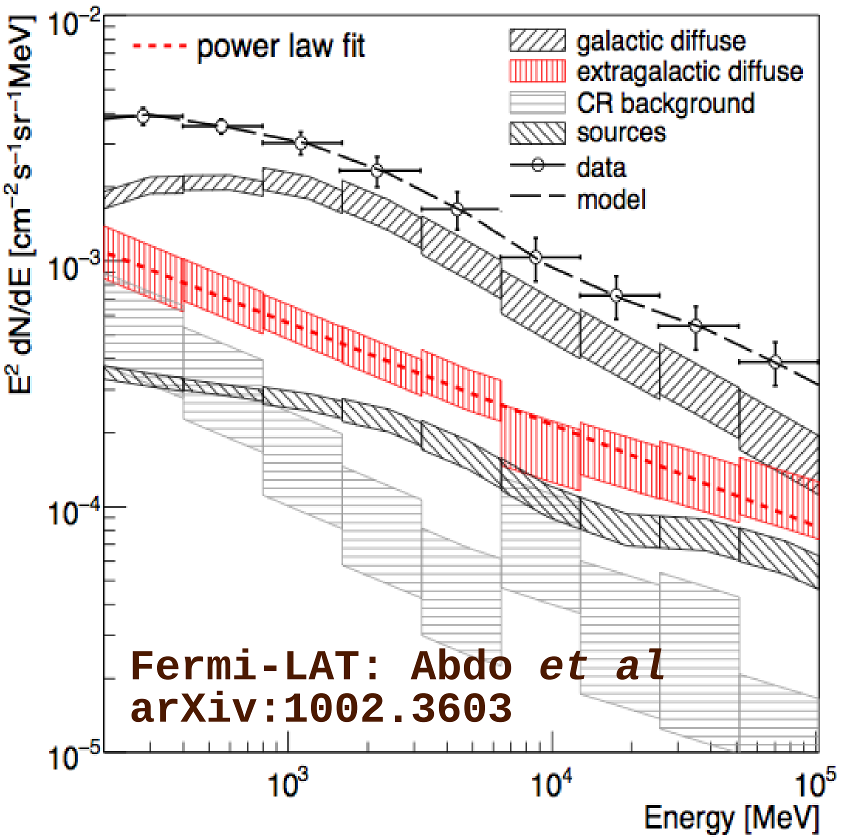
Andreas, Arina, Hambye, Ling, M.T. (arXiv:1003.2595)
See also Fitzpatrick, Hooper & Zurek

From the talk by Maja LLENA GARDE (Fermi)



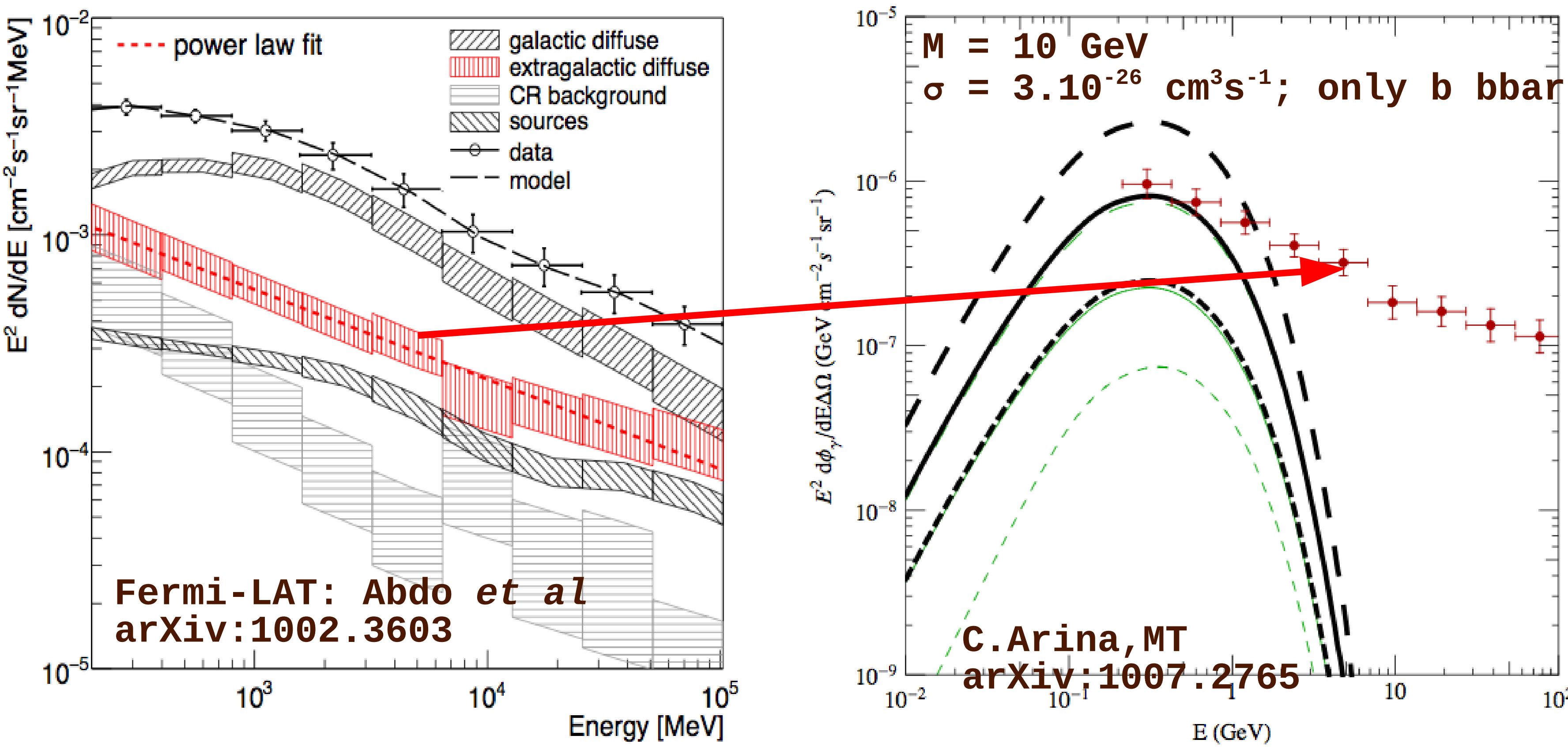
Stacked analysis: low candidates excluded @ 95% C.L.

Constraint # 2: Isotropic extragalactic gamma-ray flux



Fermi-LAT: Abdo *et al*
arXiv:1002.3603

Constraint # 2: Isotropic extragalactic gamma-ray flux



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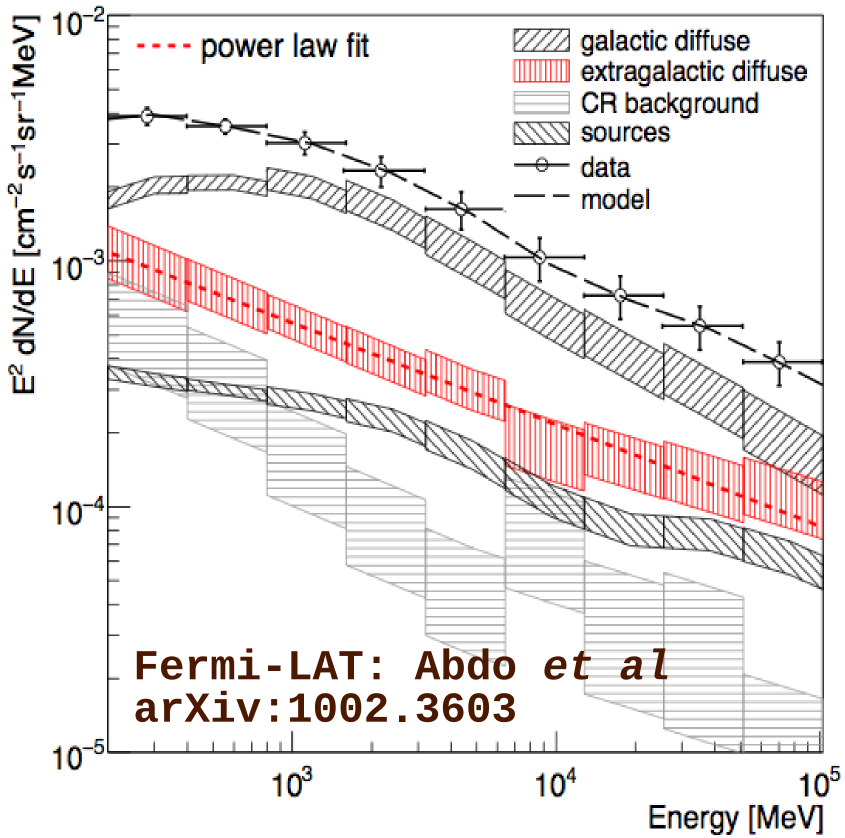
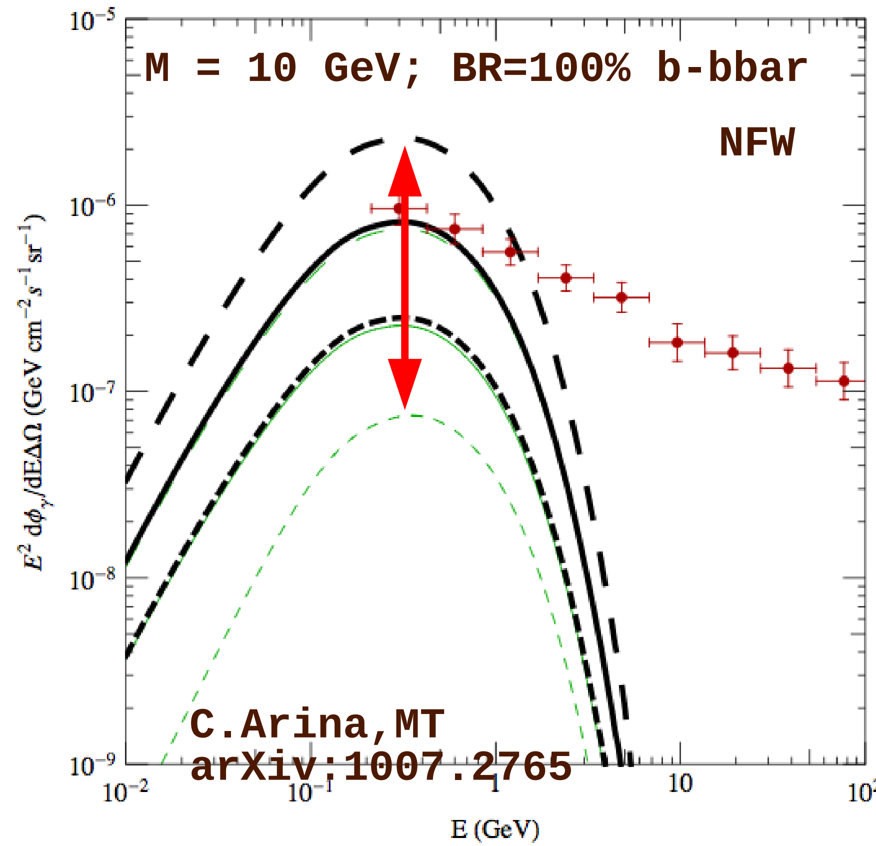
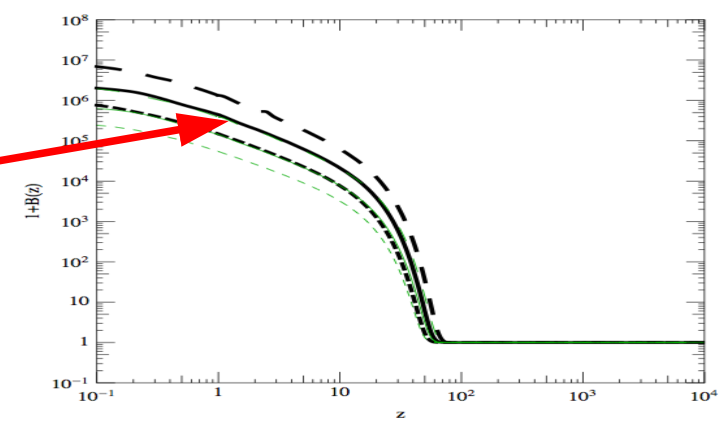




Boost factor

$$\frac{d\Phi_\gamma}{dE} = \frac{c}{4\pi}\frac{<\sigma v>_{ann}}{2M_{DM}^2}\int_0^\infty dz' \frac{1}{H(z')(1+z')^4}\frac{dN_\gamma}{dE'}\mathcal{B}^2(z')e^{-\tau(E',0,z')}$$



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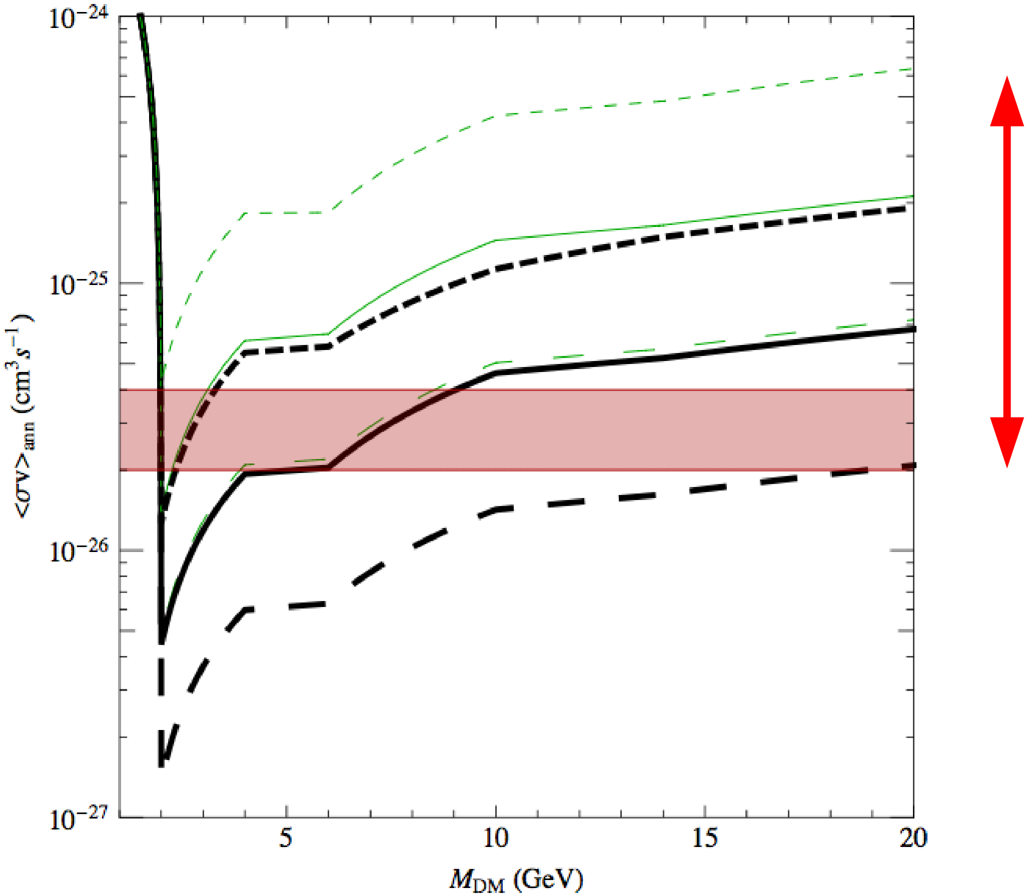


Astrophysics uncertainty on distribution of small mass dark matter halos (dn/dM)

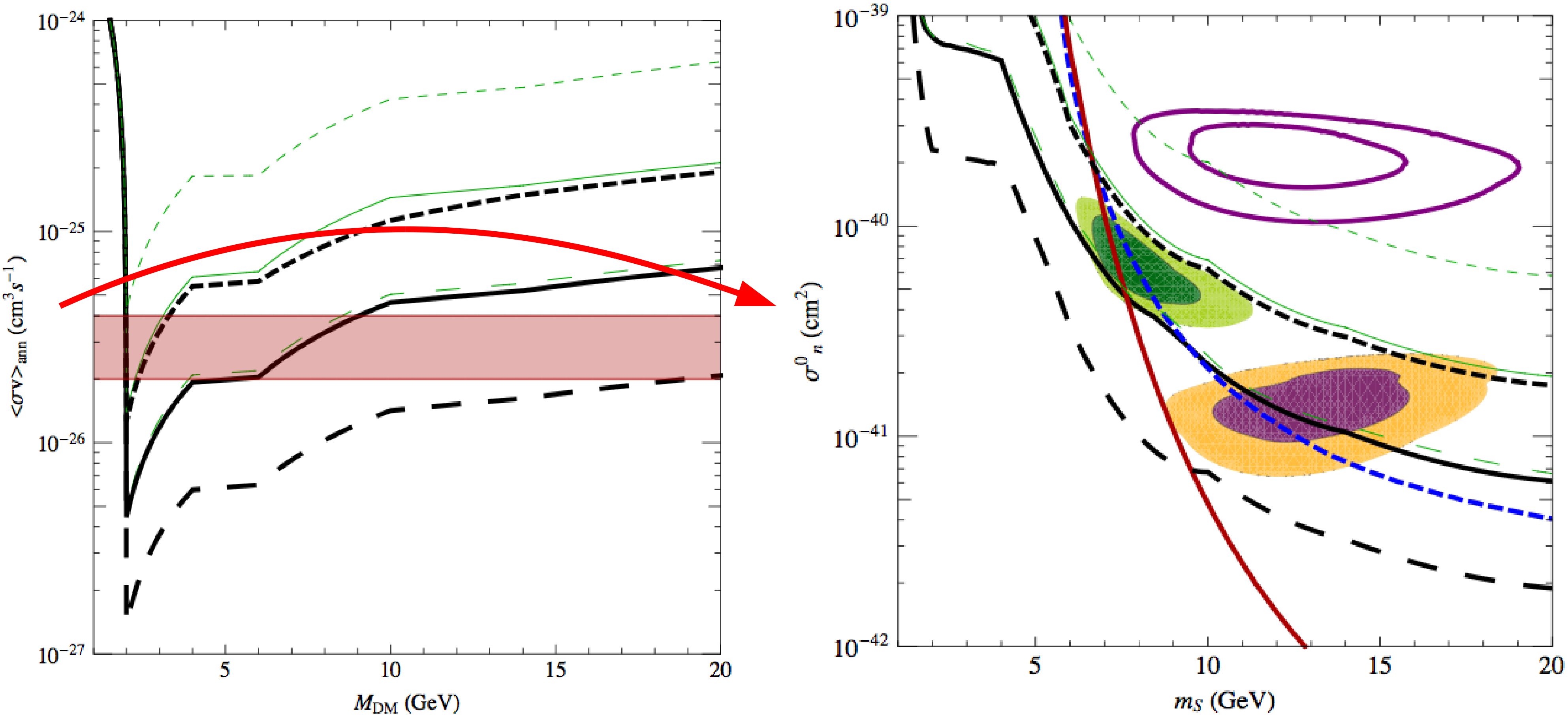
Further uncertainty from DM profile (here NFW)

95% CL (from no excess in any single bin)

Consistent with many other works, some pre-dating Fermi-LAT

Abdo et al; Profumo & Tesla; Beacon et al; Cirelli et al; Yuksel; etc

Constraint # 2: Isotropic extragalactic gamma-ray flux



Using the one-to-one correspondence between the annihilation and the scattering cross sections

$$\sum_f \frac{\sigma(SS \to \bar{f}f)v_{rel}}{\sigma(SN \to SN)} = \sum_f \frac{n_c m_f^2}{f^2 m_N^2 \mu_n^2} \frac{(m_S^2 - m_f^2)^{3/2}}{m_S}$$

Singlet scalar model, but quite generic results

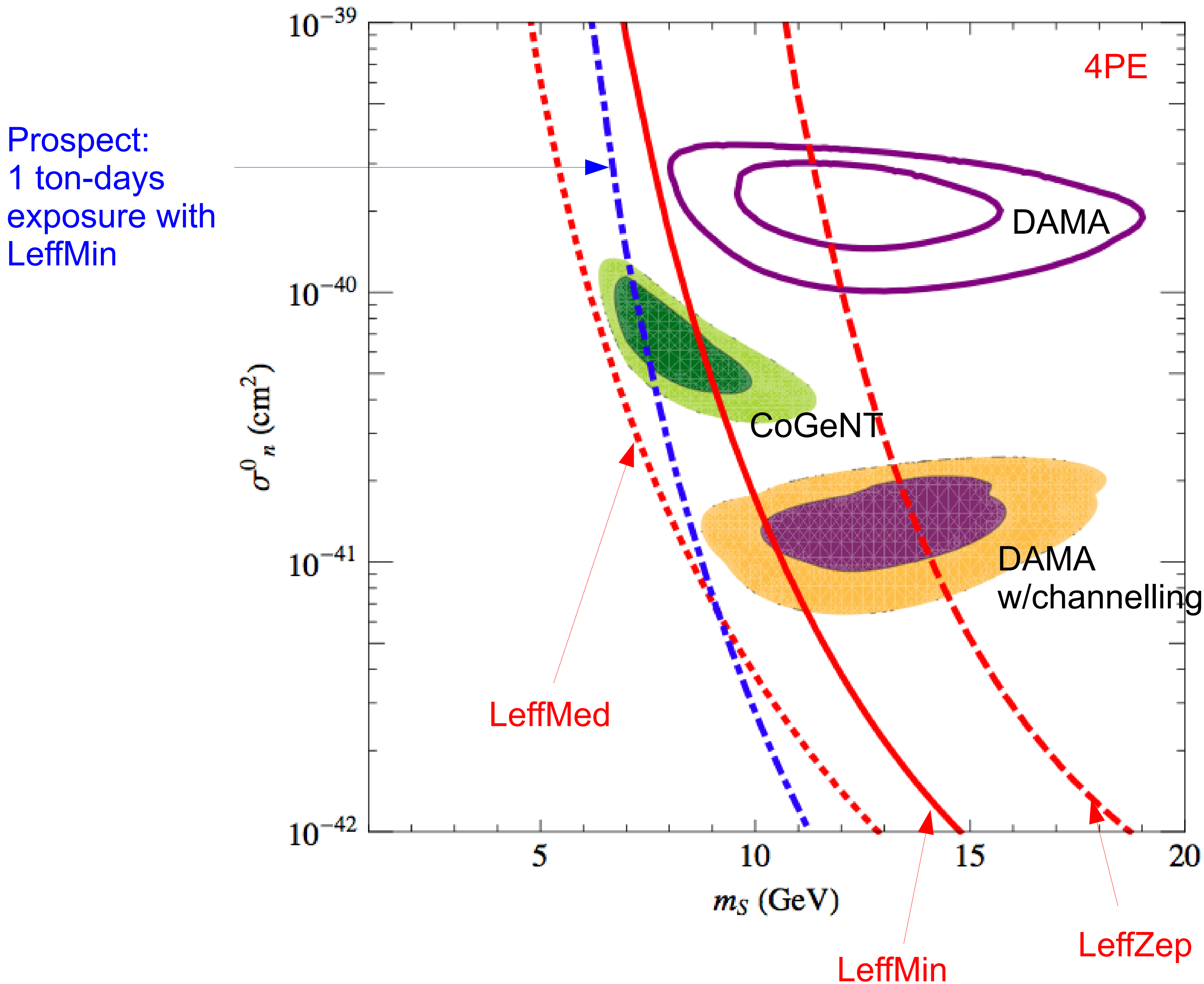
May be consistent with CoGeNT and/or DAMA (or CRESST for that matter) and WMAP thermal abundance

Challenged (to say the least) by other direct detection experiments

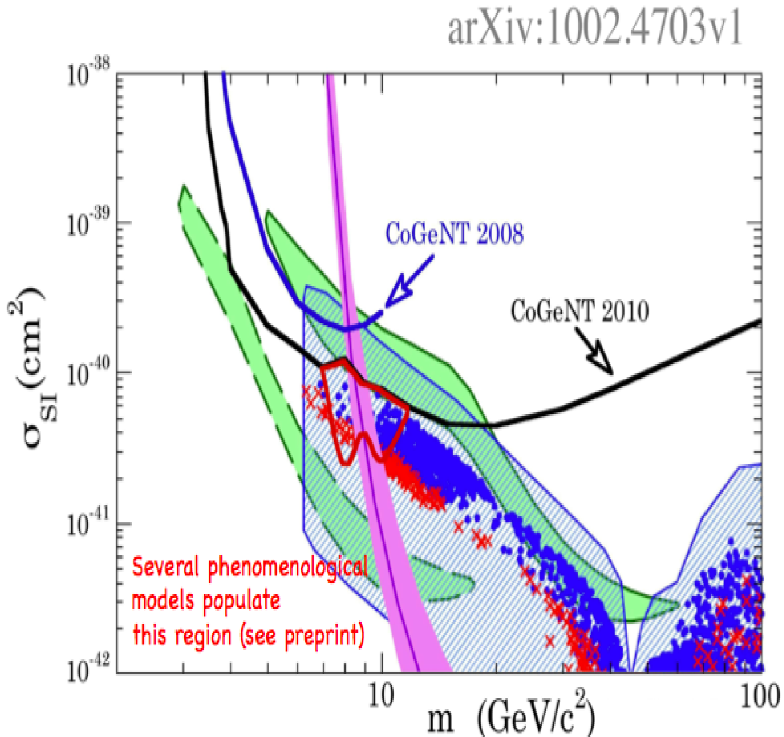
Interesting indirect constraints from Fermi-LAT data, possibly excluding this (category of) models

Still interesting implications for Higgs search (invisible decay)

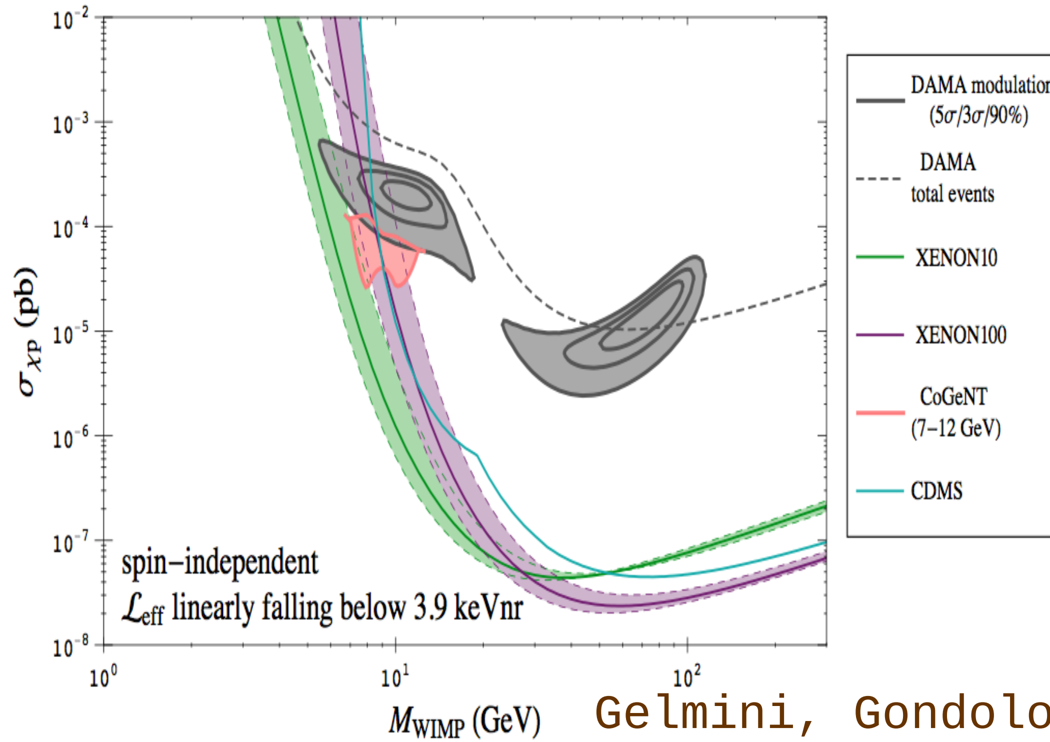
Backup slides



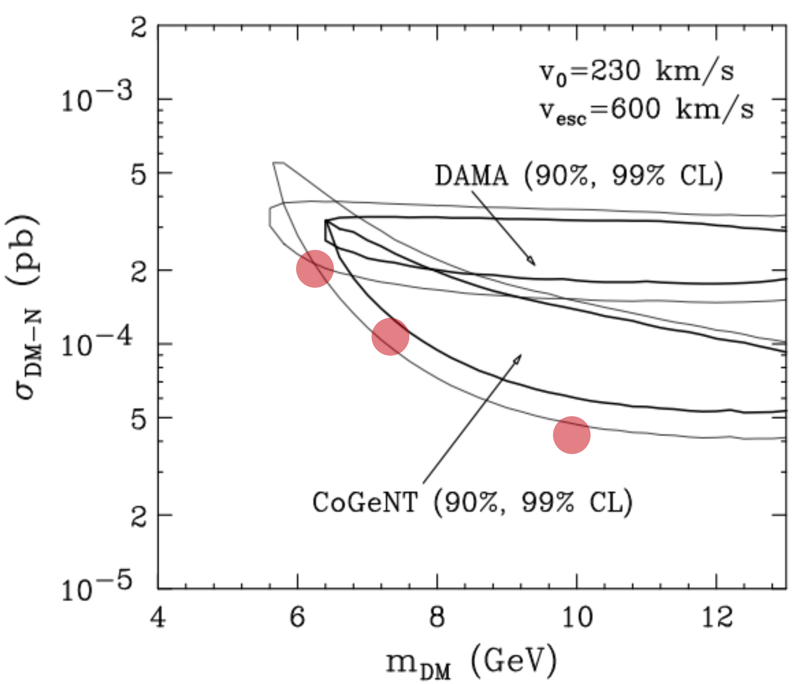
Andreas, Arina, Hambye, Ling, M.T.
(arXiv:1003.2595)



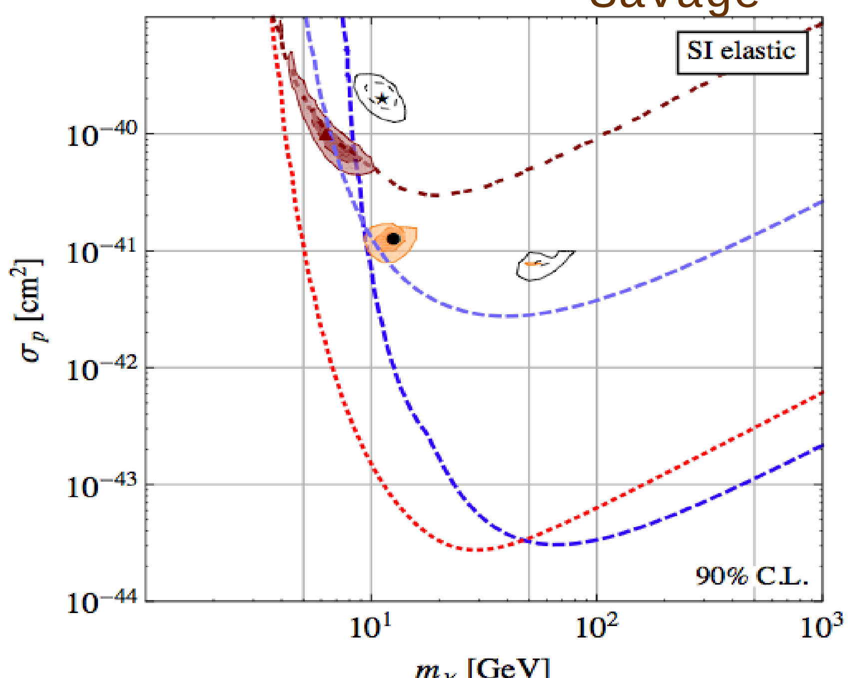
CoGeNT



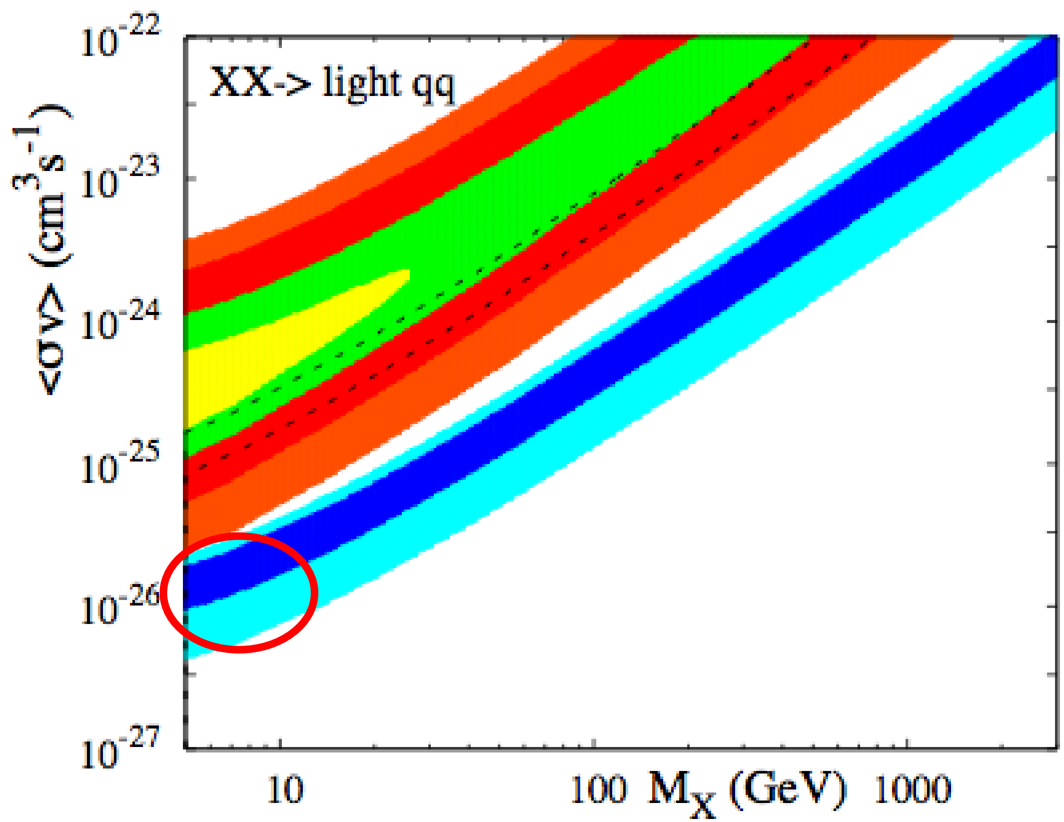
Gelmini, Gondolo, Savage



Hooper,Collar,Hall,McKinsey

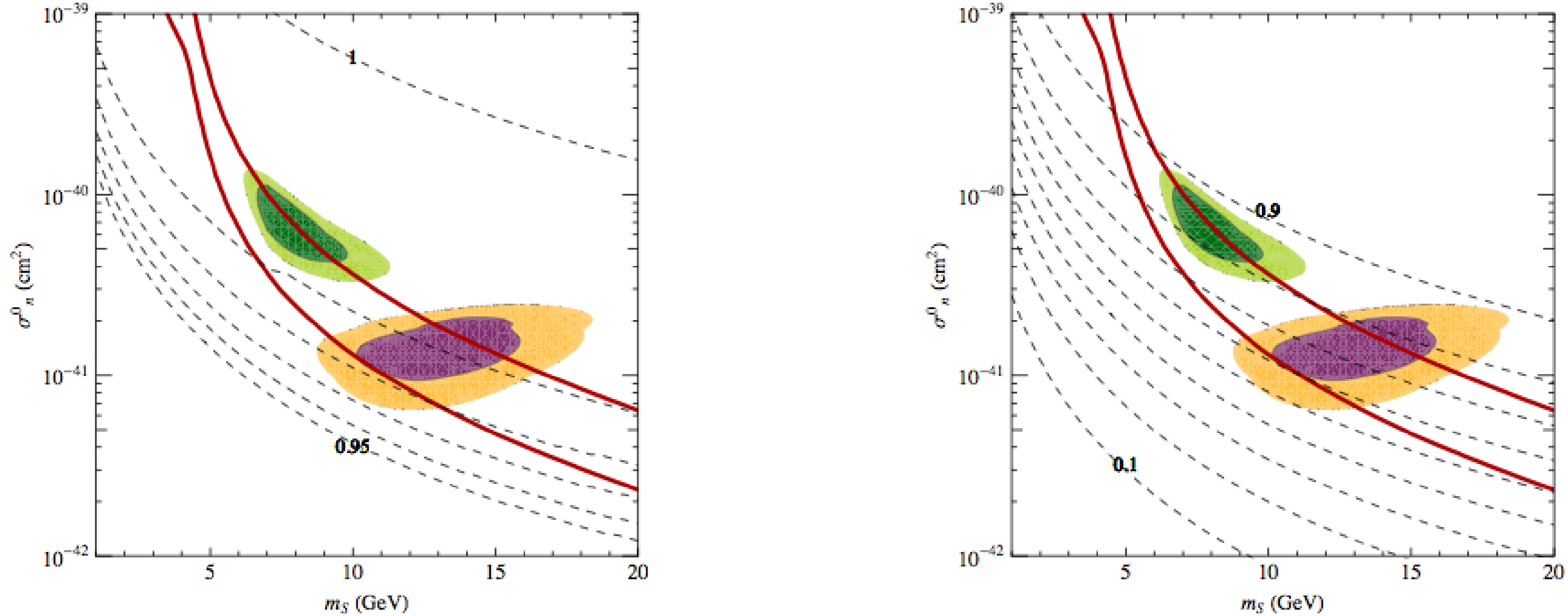


Kopp, Schwetz, Zupan



Jedamzik & Pospelov

Figure 3. Dark matter annihilation rate versus dark matter mass. The blue band shows parameters where ^{6}Li due to residual dark matter annihilation may account for the ^{6}Li abundance as inferred in HD84937 (^{6}Li/^{7}Li≈ 0.014 − 0.09 at 2-σ), whereas the orange-red-green-yellow region shows where ^{7}Li is efficiently destroyed i.e. ^{7}Li/H$< 1.5, 2, 3,$ and 4×10^{-10}, respectively. Above the lower (upper) dashed line D/H exceeds 4×10^{-5} (5.3×10^{-5}), such that parameter space above the upper dashed line is ruled out by D overproduction. Scenarios between this line and the



10^{-39}
10^{-40}
10^{-41}
10^{-42}
$\sigma^0{}_n$ (cm^2)
1
0.95
5
10
15
20
m_S (GeV)
10^{-39}
10^{-40}
10^{-41}
10^{-42}
$\sigma^0{}_n$ (cm^2)
0.9
0.1
5
10
15
20
m_S (GeV)