Non-SUSY DM Candidates

by which I mean Scalar WIMPs

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The Higgs portal
Patt & Wilczek (2006)

Dark Sector ⟷ Higgs Sector ⟷ Visible Sector

The Higgs portal

Patt & Wilczek (2006)

$$\mathcal{L}_{SM} \supset -\mu^2 H^\dagger H + \lambda S^2 H^\dagger H$$

Simplest incarnation: S a singlet scalar

No <S> vacuum expectation
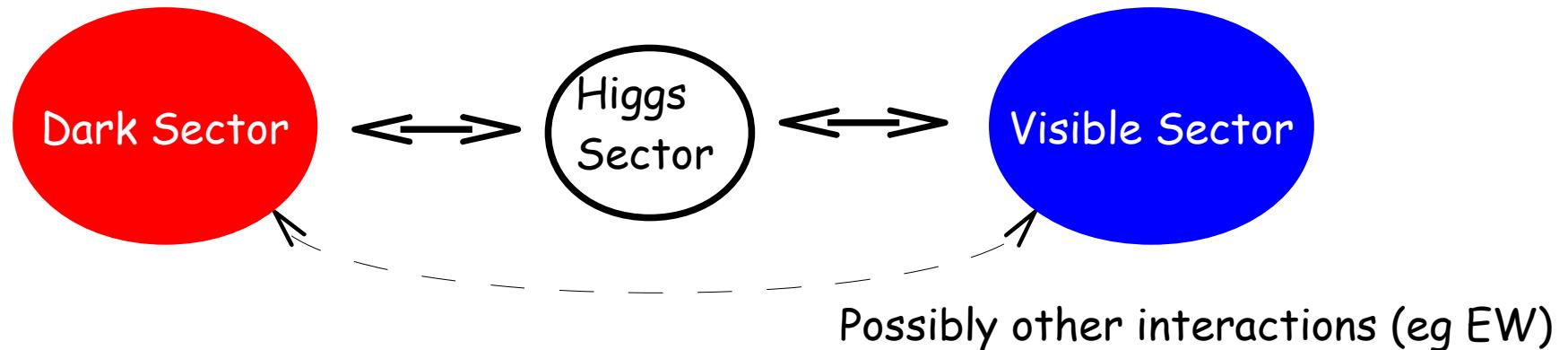
No linear, or cubic terms

-> S stable and neutral

Silveira & Zee '85; McDonald '94; Burgess, Pospelov, ter Veldhuis '00; Patt,Wilczek '06; Barger et al '08; Andreas, Hambye, M.T. '08

The Higgs portal   *Patt & Wilczek (2006)*

e.g. The Inert Doublet Model (IDM)

Higgs —> Higgs   Inert Higgs —> − Inert Higgs (*)

(*) Easy way to prevent FCNC: all SM fermions with same
parity

Deshpande, Ma (1978); Barbieri,Hall,Rychkov (2006);
Ma (2006; Lopez Honorez, Nezri, M.T. (2006)

The Inert Doublet candidates

|	
Heavy H0	$500 \text{ GeV} < M < \text{few TeV}$
Medium H0	$50 \text{ GeV} < M < 80 \text{ GeV}$
Light H0	$5 \text{ GeV} < M < 10 \text{ GeV}$

Natural extensions, among others
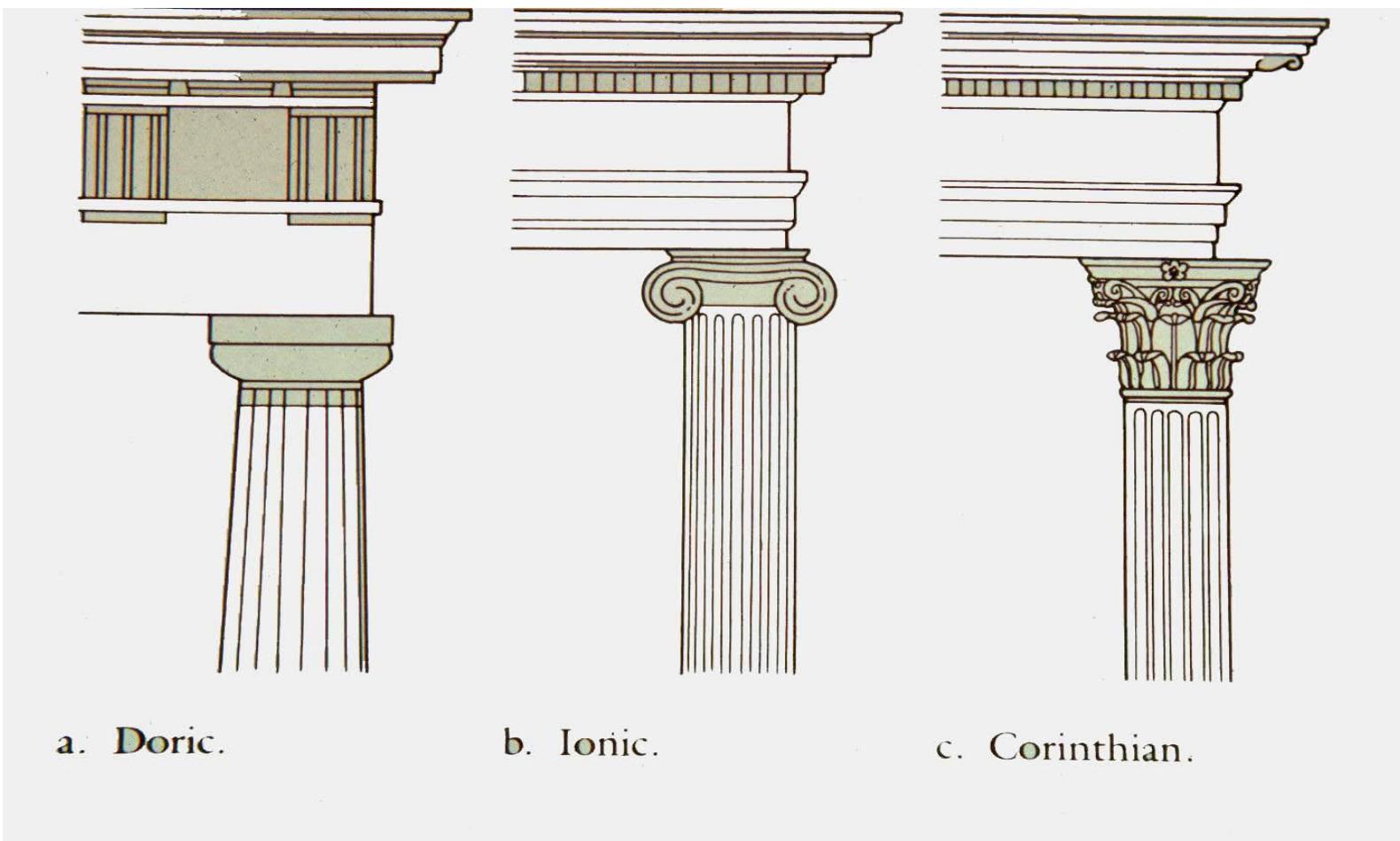
Radiative neutrino masses   Ma (2006)

Higher multiplets   Hambye, Ling, Lopez
Honorez, Rocher (2009)

WIMP archetypes

a. Doric.   b. Ionic.   c. Corinthian.

Spin 0
Inert Doublet

Spin ½
Neutralino

Spin 1
Heavy photon

Motivation?

There are some experimental indications(*) of the existence of light dark matter, M ~ few GeV.
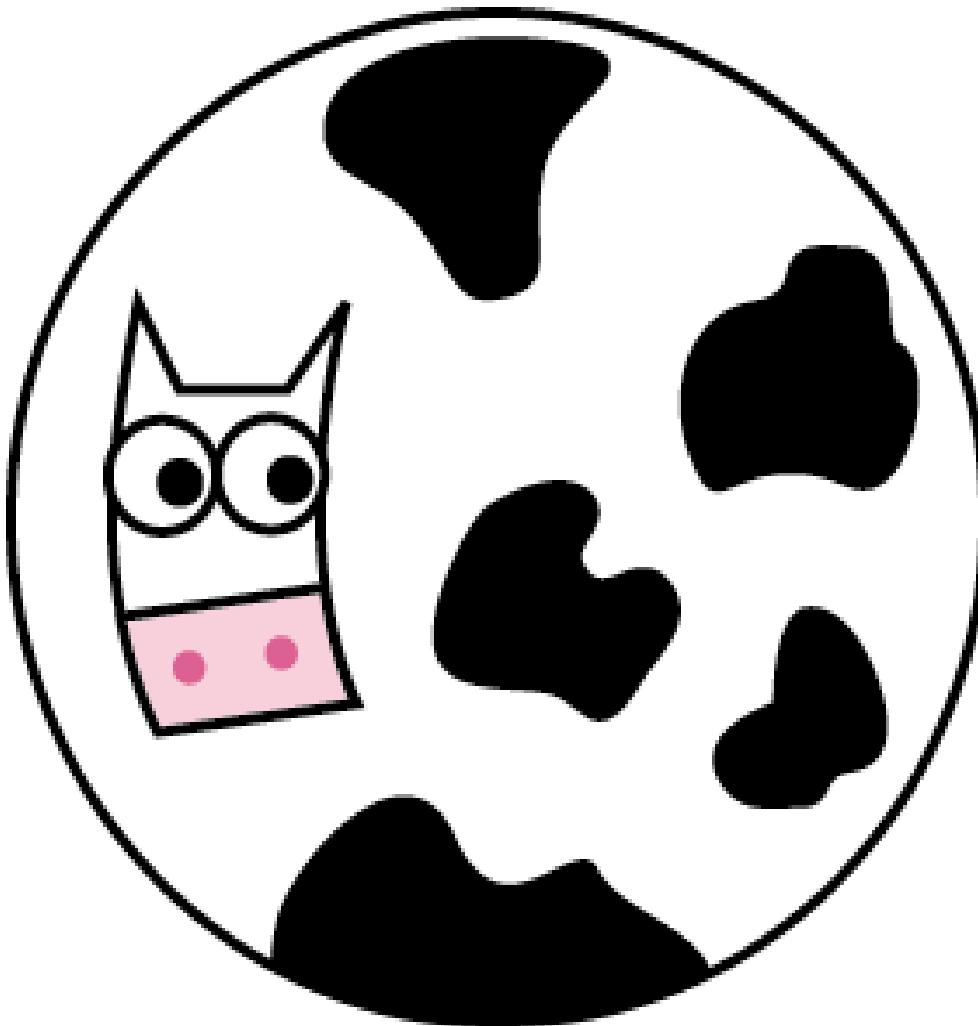
      (*) DAMA/LIBRA, CoGeNT, CRESST

Most likely nothing (*), but
the concordance is/was intriguing/stimulating.

   (*) Xenon10/100, CDMS-II

        A light WIMP scalar ?
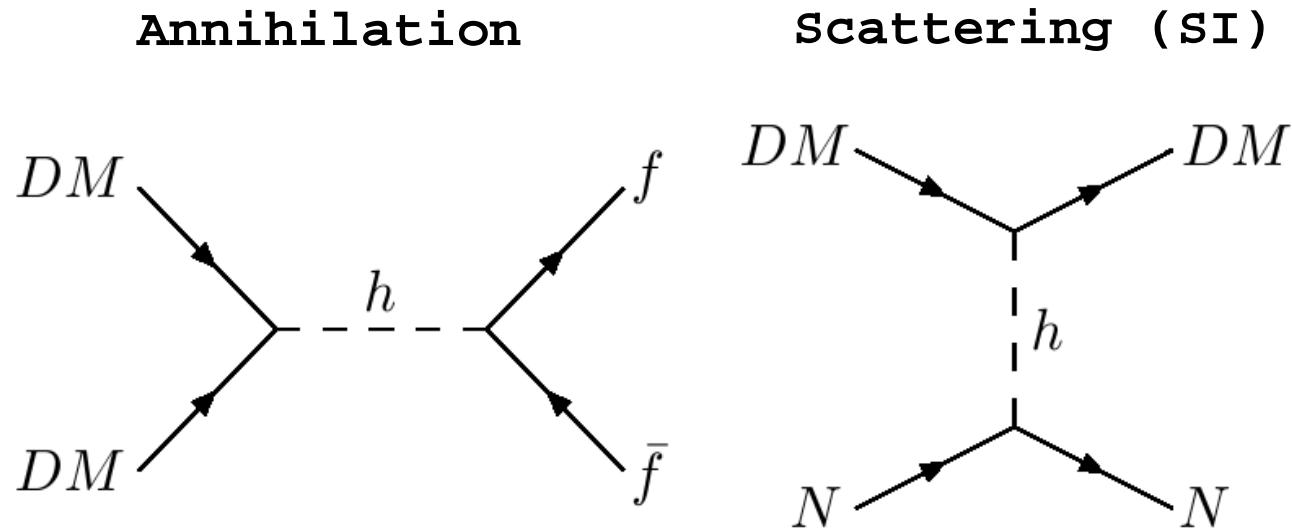
A light WIMP scalar ?

ORNITHORHYNCHUS ANATINUS.

The simplest model - scalar singlet DM

Annihilation **Scattering (SI)**

Relic abundance **Direct detection**

**Two parameters model:**

M_{dm} and coupling to
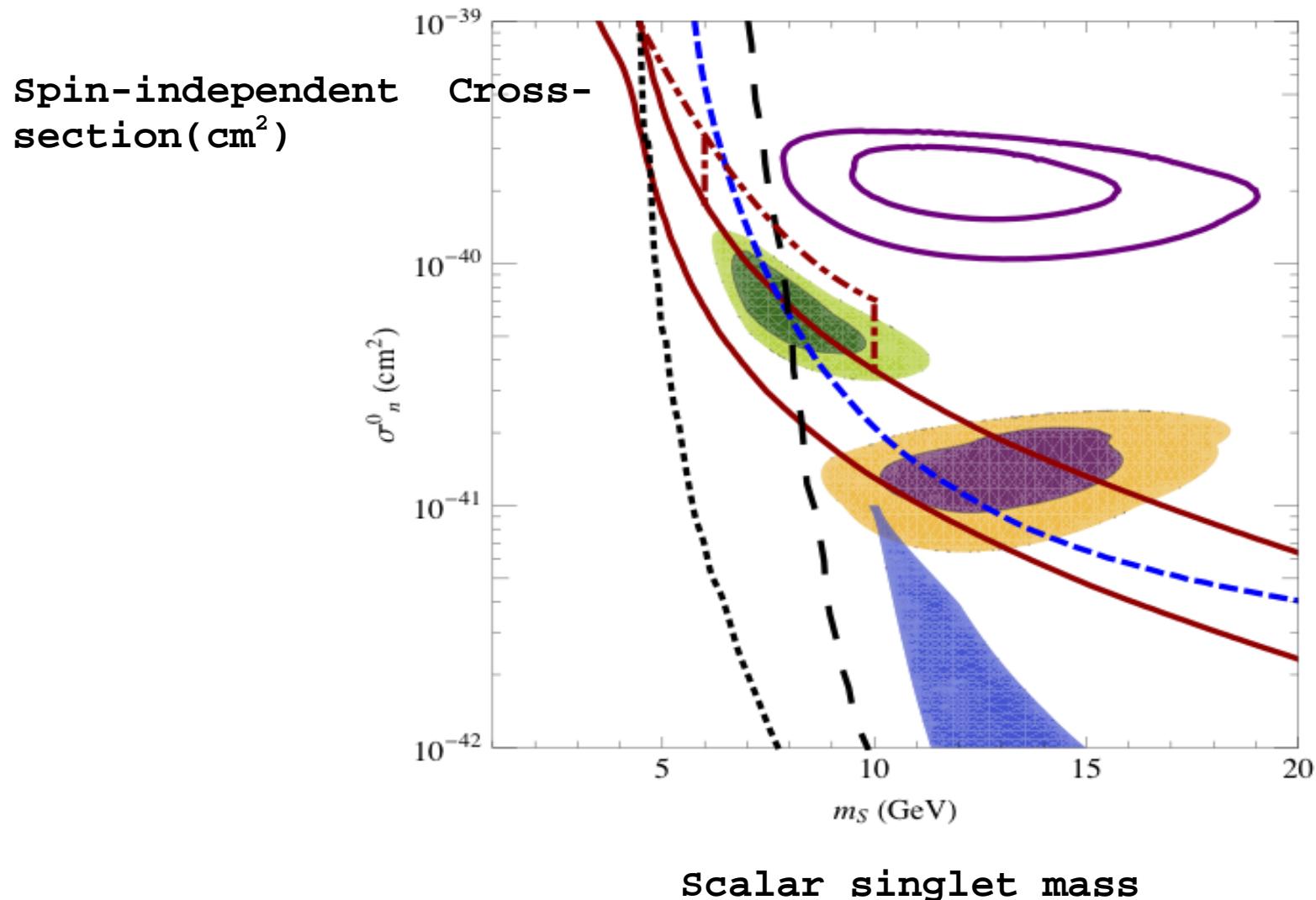
Higgs boson

$\longrightarrow$
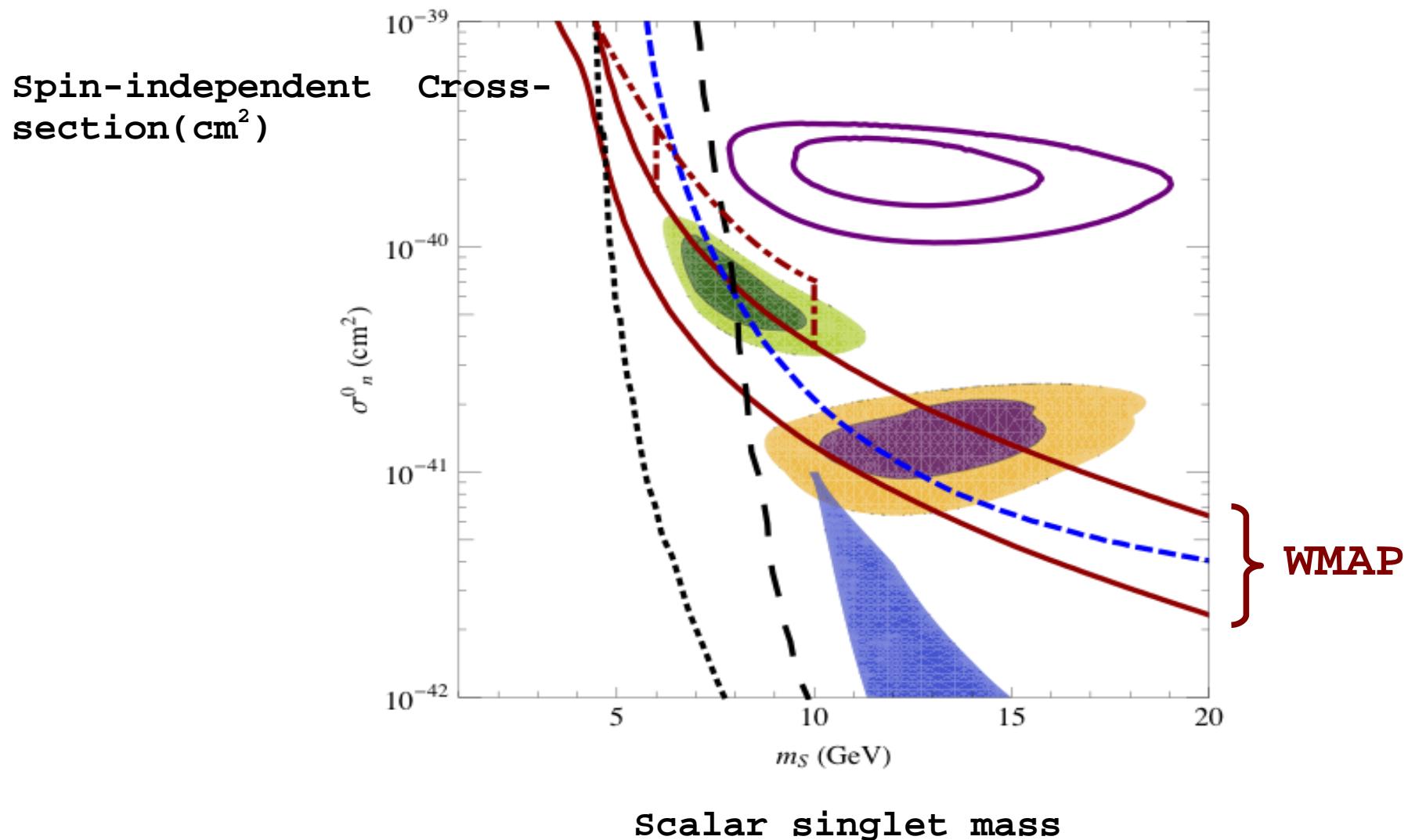
$$\Omega_{dm} - M_{dm}$$

or

$$\sigma_n^0 - M_{dm}$$

(Silveira & Zee; Mc Donald; Burgess et al;...
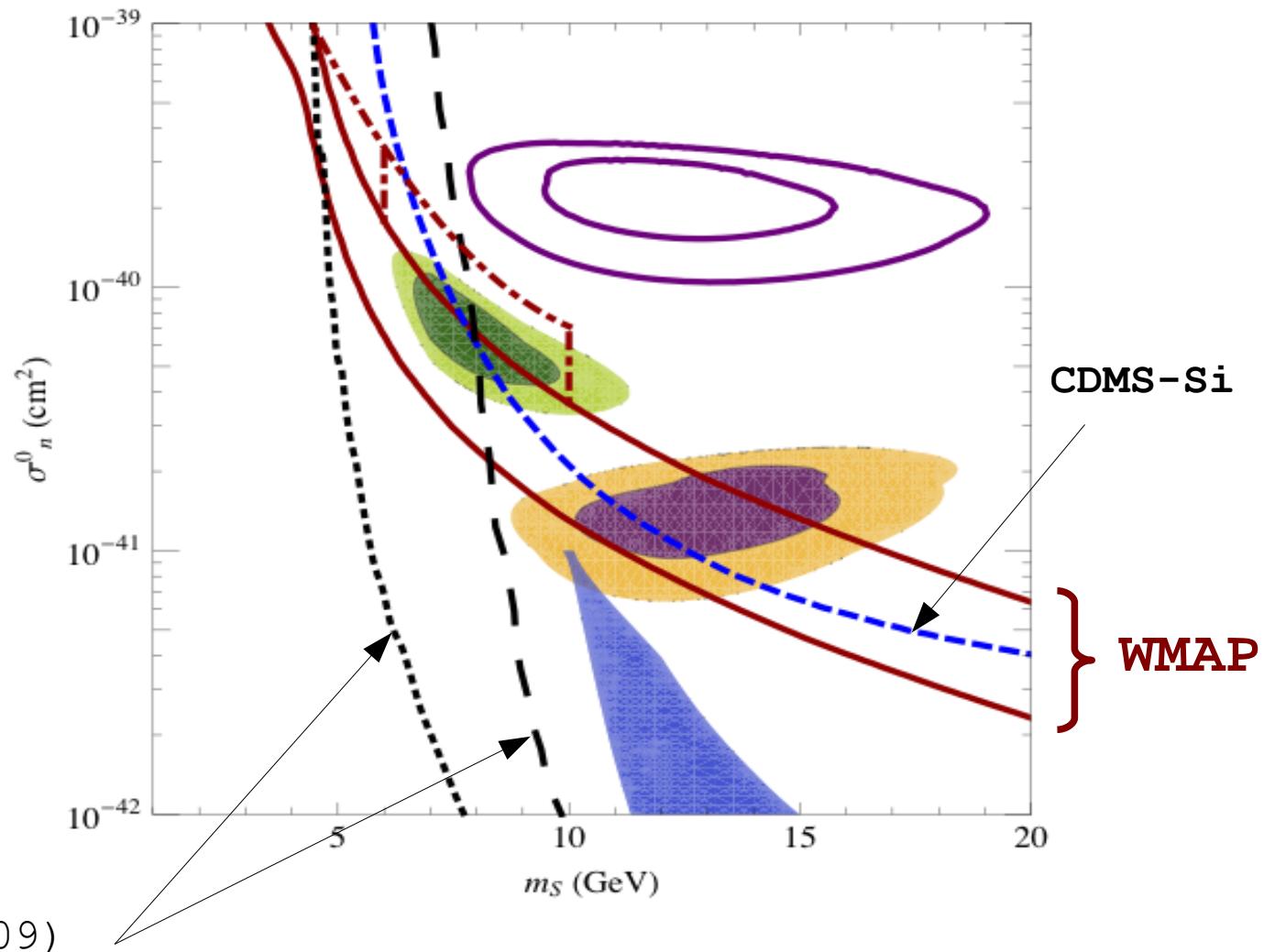
The simplest model - scalar singlet DM
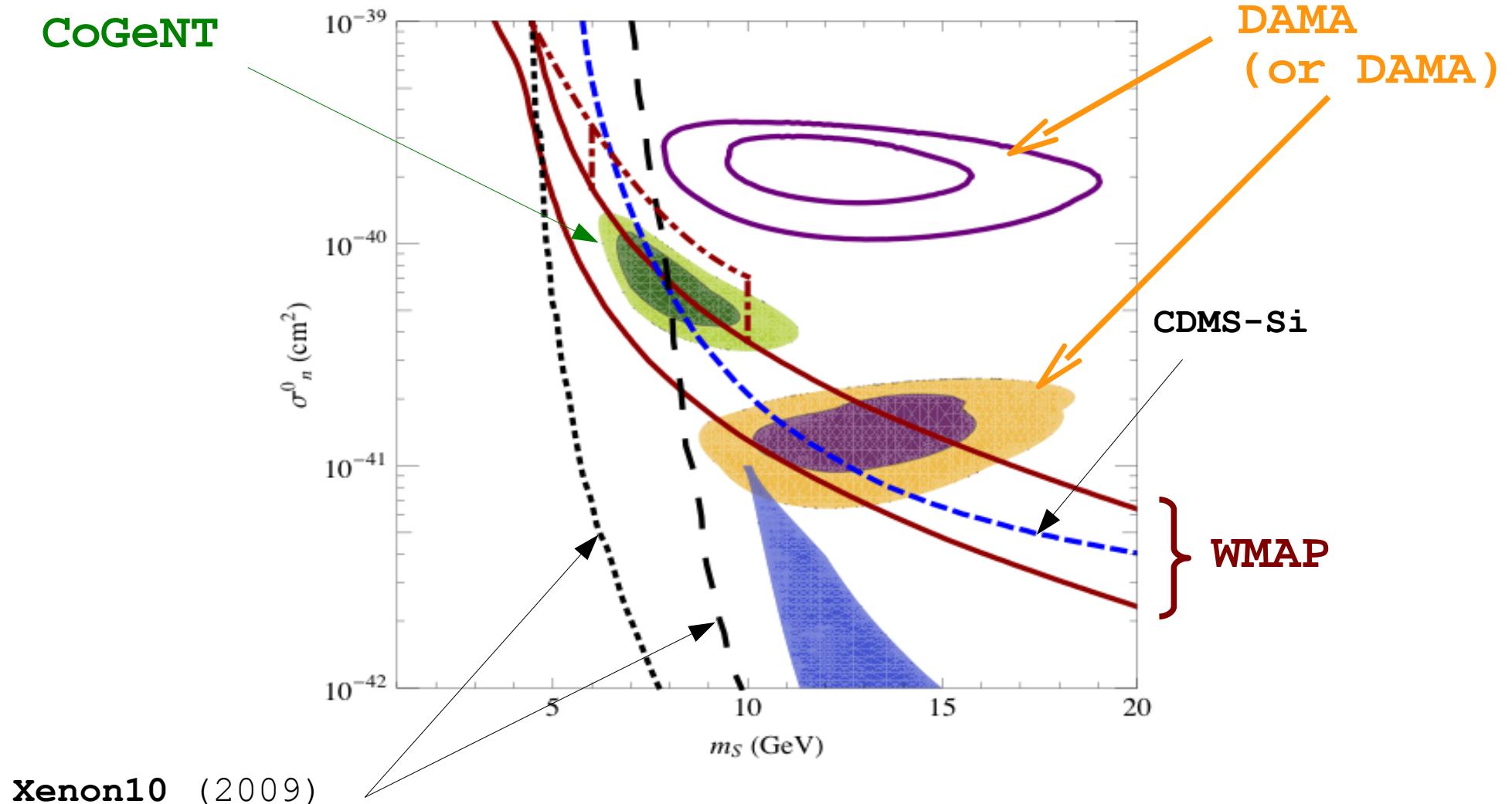
Spin-independent Cross-section(cm^2)

σ^0_n (cm^2)

m_S (GeV)

Scalar singlet mass

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

The simplest model - scalar singlet DM

Spin-independent Cross-section(cm^2)

σ^0_n (cm^2)

m_S (GeV)

WMAP

Scalar singlet mass

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

The simplest model – scalar singlet DM

CDMS-Si

WMAP

Xenon10 (2009)

σ^0_n (cm^2)

m_S (GeV)

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

The simplest model - scalar singlet DM

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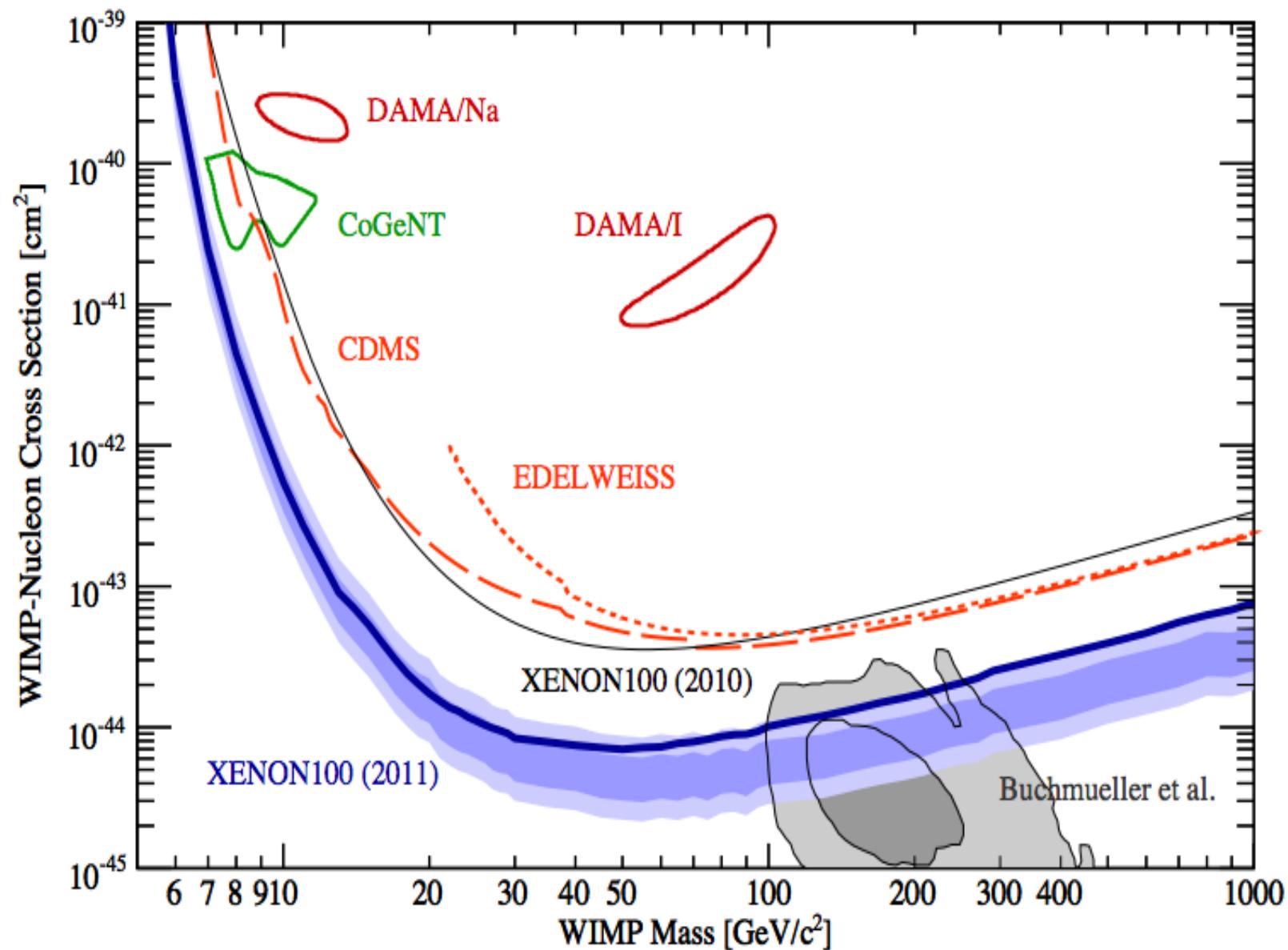
« Implications on Inelastic Dark Matter from 100 Live Days of XENON100 Data » (April 2011)

« A Bayesian view of the current status of dark matter direct searches »


CoGeNT

Xenon100
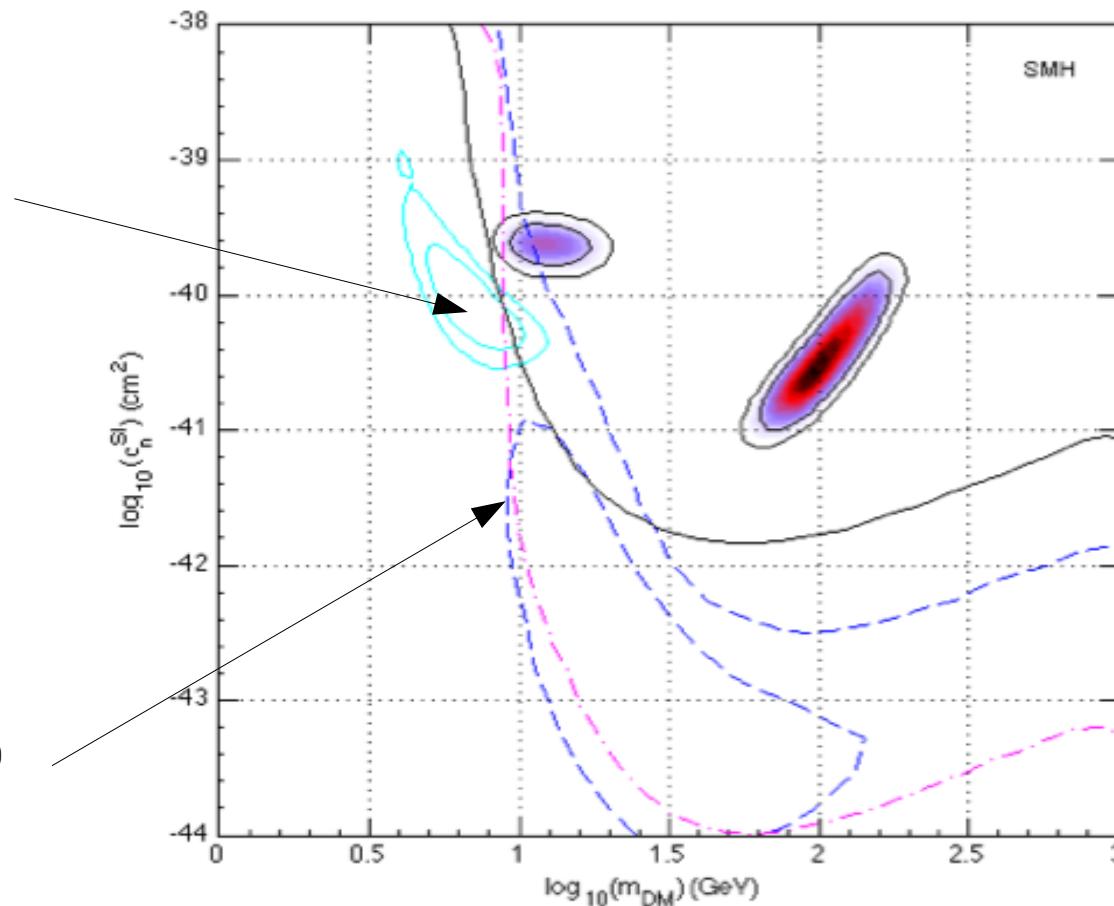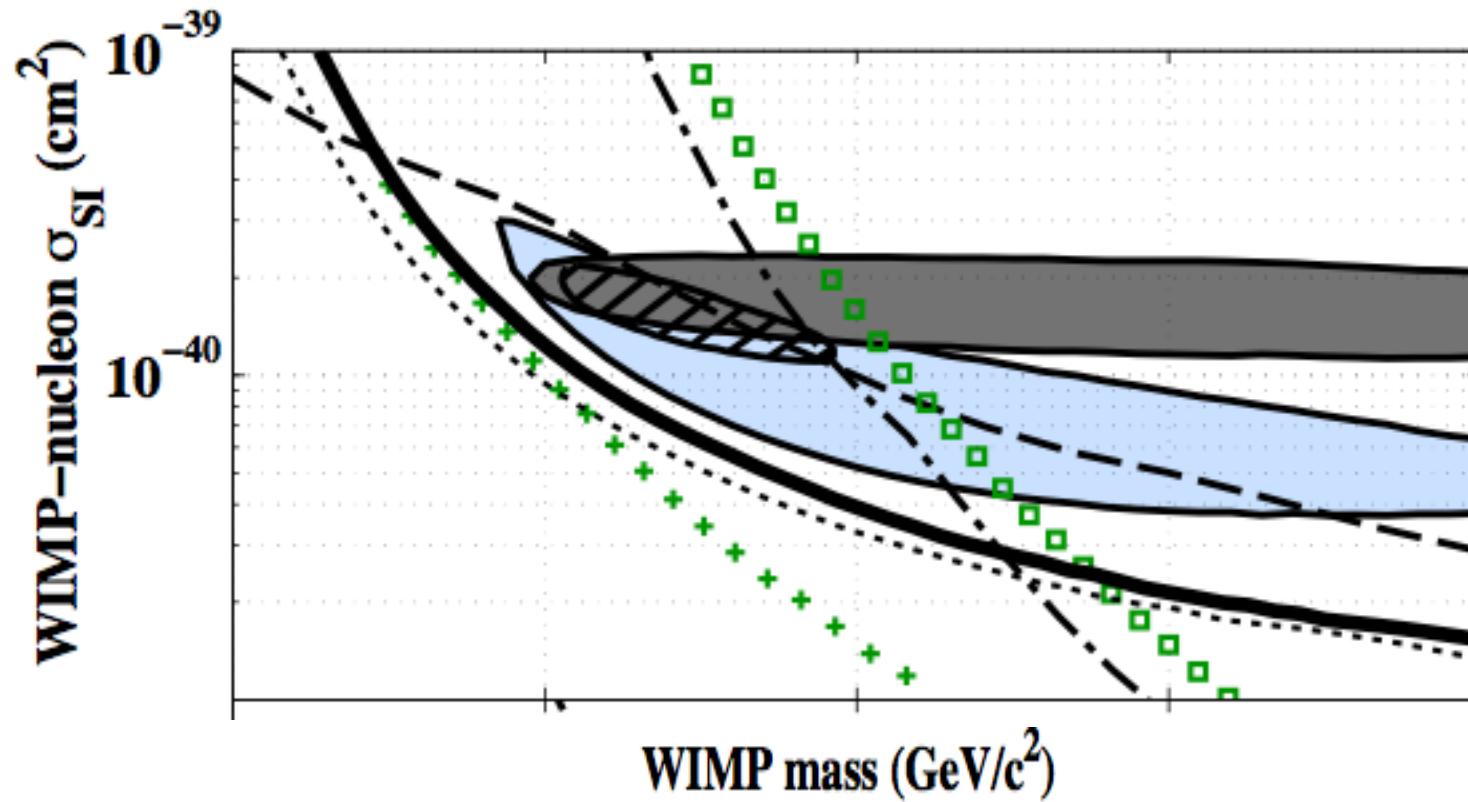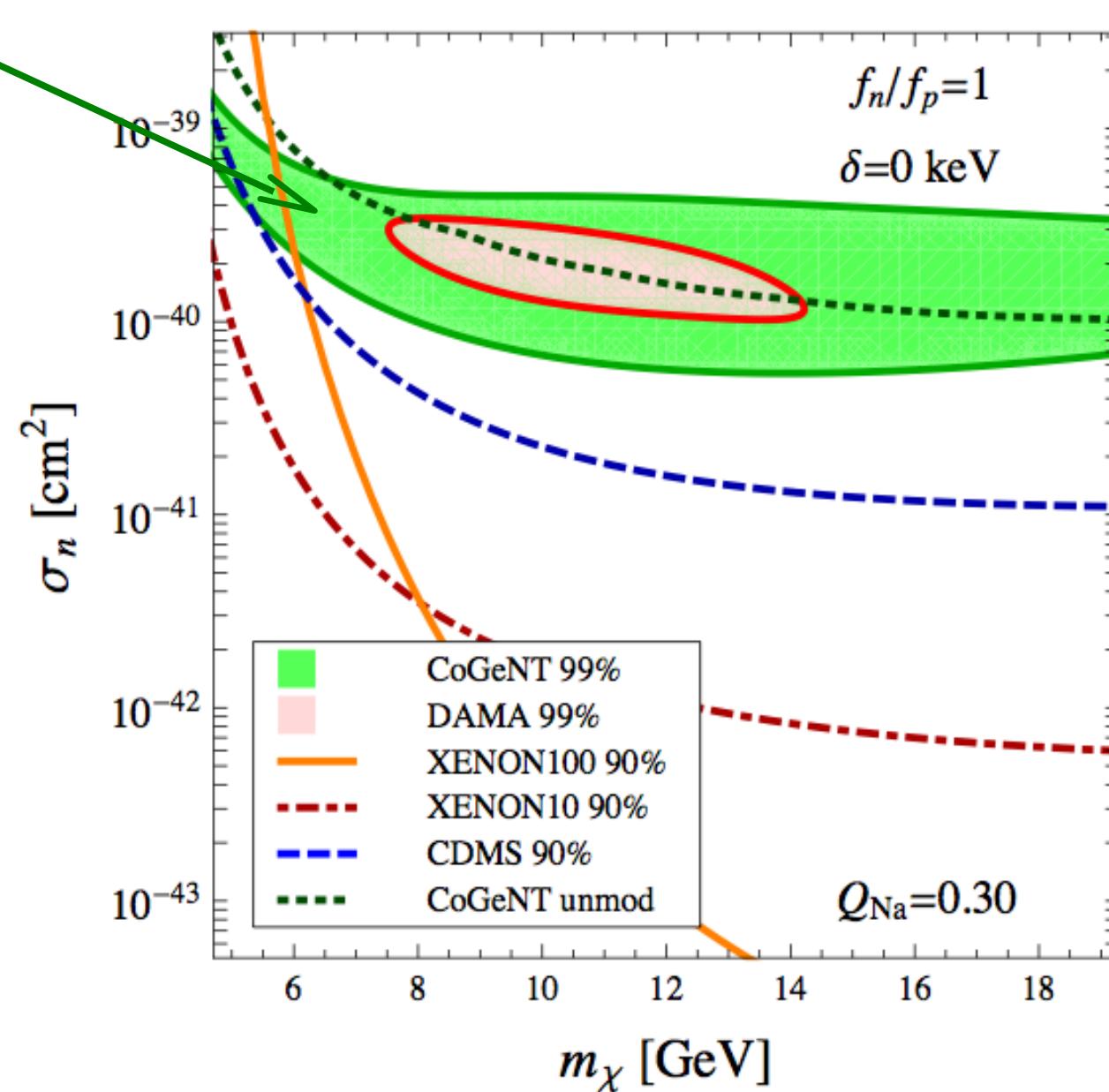
Figure 8. 2D credible regions for all experiments assuming the SMH. For DAMA (shaded) and CoGeNT (cyan) we show the 90% and 99% contours. The black solid line represents the $90_S\%$ bound for CDMSSi, and the pink dot-dash curve for Xenon100. For CDMSGe we show both the $90_S\%$ and $99_S\%$ contours in blue dashed lines.

« **Results from a Low-Energy Analysis of the CDMS II Germanium Data** »
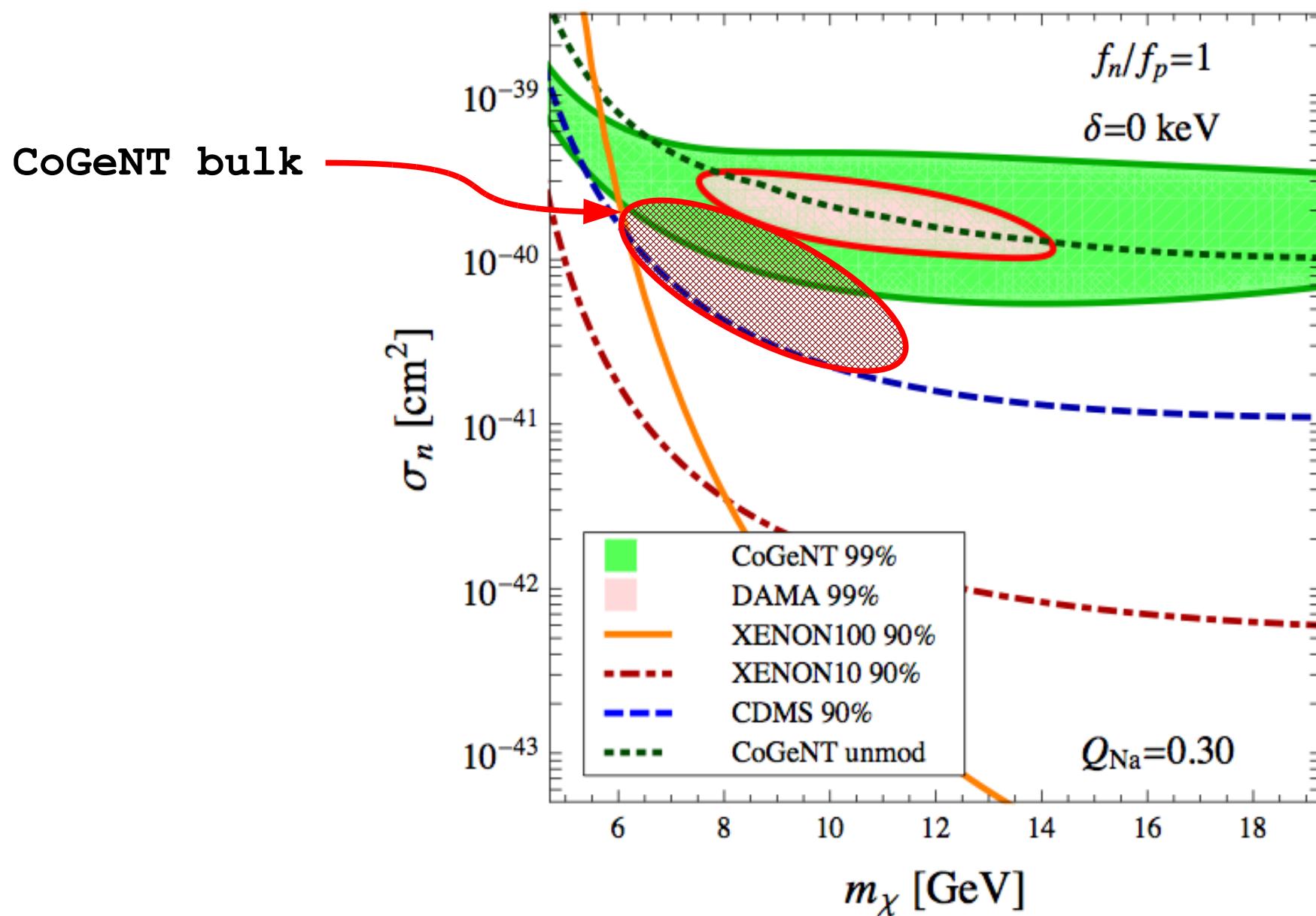
And more to come from a low-energy analysis of Xenon10/100 (even more constraining (?) but unpublished yet)

More confusion: CoGeNT Modulation (?)

Mads T. Frandsen, Felix Kahlhoefer, John March-Russell, Christopher McCabe, Matthew McCullough, Kai Schmidt-Hoberg

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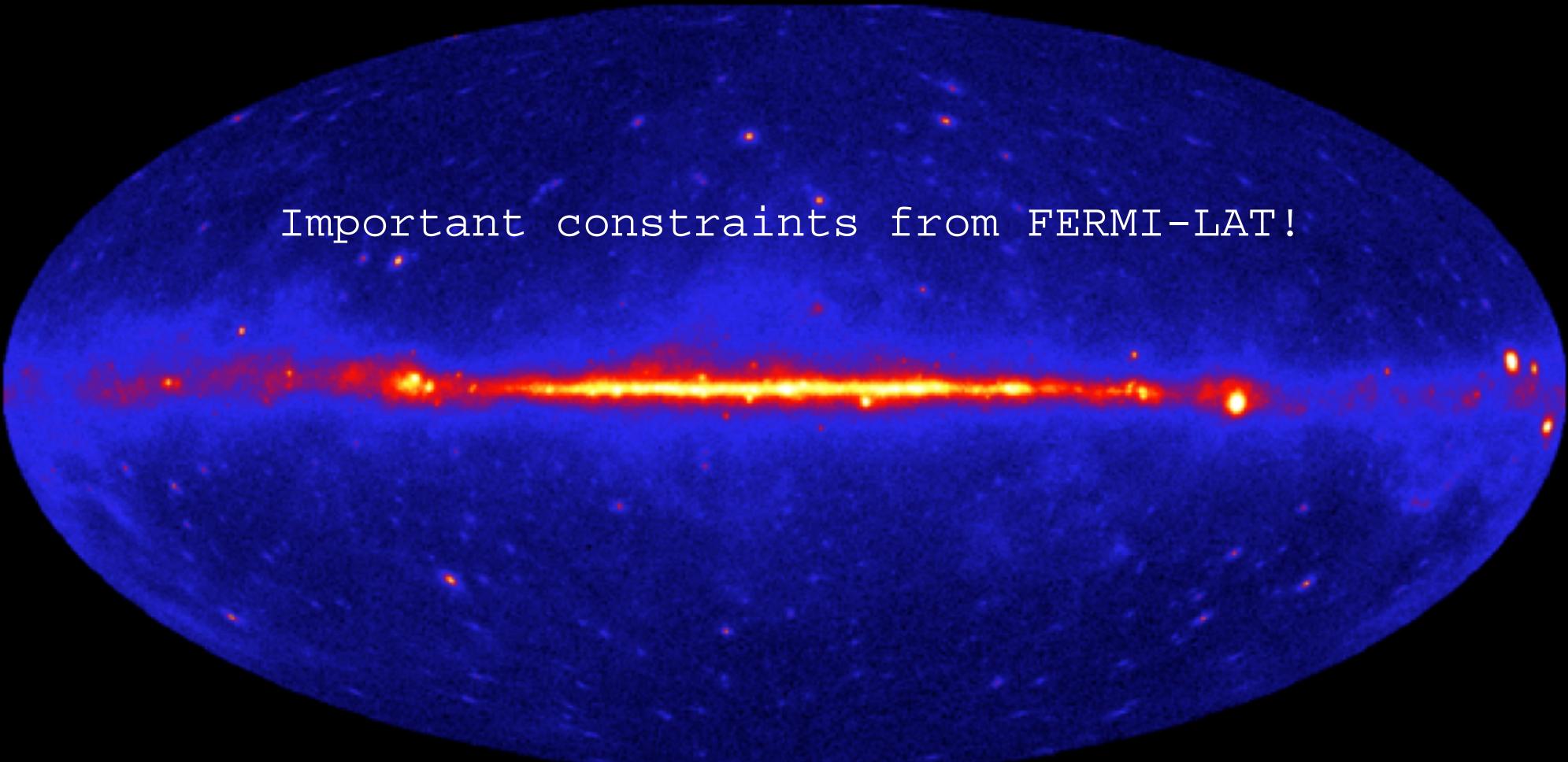
What a year!

CDMS-II 2 events...   November 2009

CoGeNT   Excess?   March 2010

Xenon100 (first results)   May 2010

CDMS-II (low recoil analysis)   December 2010

Xenon100 (100 days exp.)   May 2011

CRESST   Excess (?)

Xenon10 Low recoil analysis   July 2010

CoGeNT   Modulation?   May 2011

What a year!

Important constraints from FERMI-LAT!

WIMP

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

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

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

Indirect dectection

DM + DM $\longrightarrow q/\bar{q}\,,\,\tau^+\tau^-\,,\ldots$

$\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad \longrightarrow \pi^{0\prime}s \longrightarrow \gamma's$

WMAP

$$\phi_\gamma \propto \langle \sigma v \rangle \times \frac{dN_\gamma}{dE} \times \int_{los} dl\, \frac{\rho_{\mathrm{dm}}^2(l)}{m_{\mathrm{dm}}^2}$$

particle physics

Light WIMPs

Astrophysics uncertainties

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

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 not-resolved astrophysical sources

Abdo et al   JCAP 1004 (2010) 014 arXiv:1002.4415

1: Limits on light WIMPS from Fermi-LAT data (11 months) on dSPhs
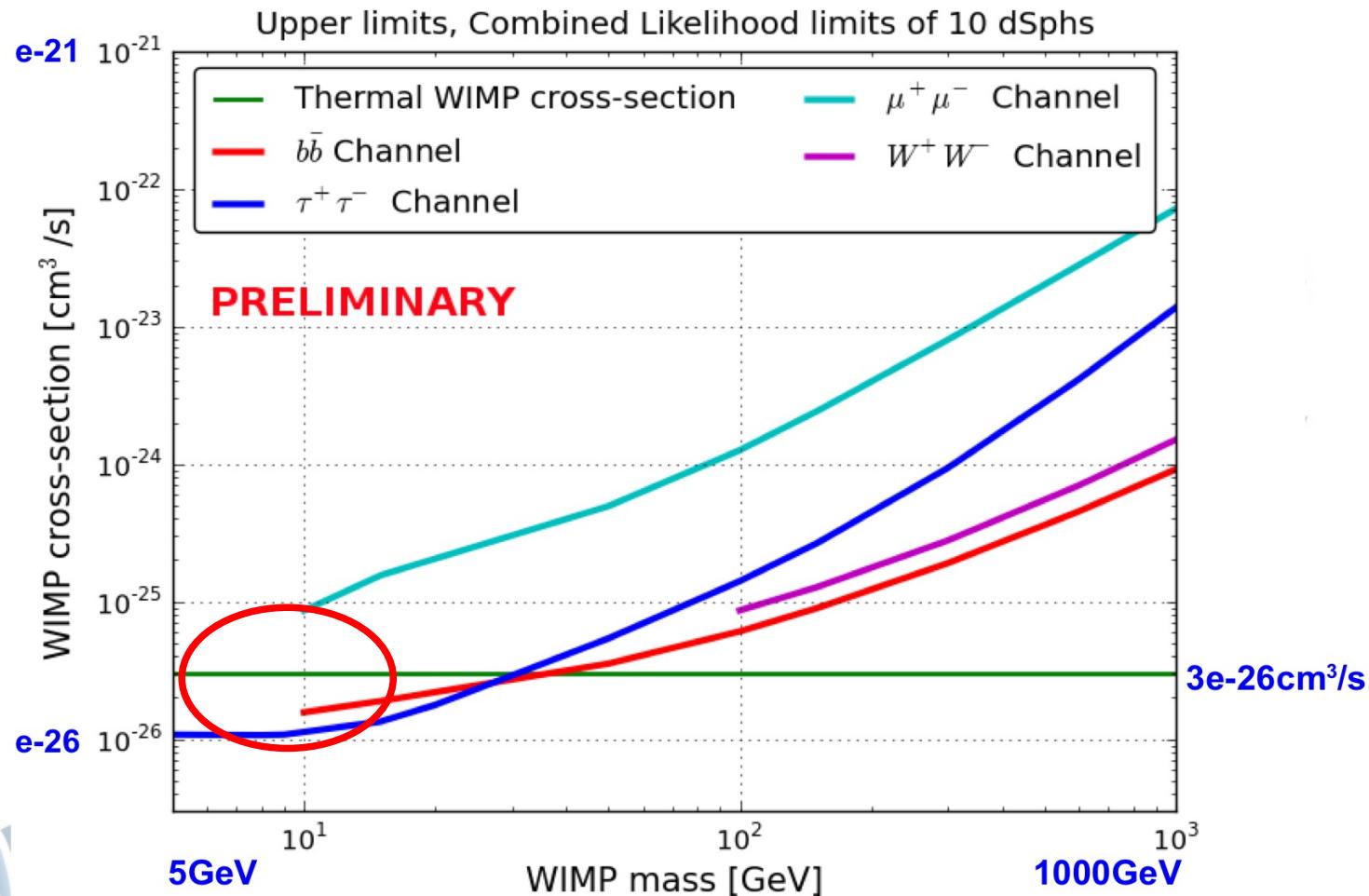
M_{DM}	BR	$\dfrac{\langle \sigma v \rangle}{10^{-26} cm^2 \cdot s^{-1}}$	
		Ursa Minor	Draco
10 GeV	$BR(SS \to \tau^- \tau^+) \simeq 10\%$ $BR(SS \to b\bar{b} + c\bar{c}) \simeq 90\%$	≤ 2.6	≤ 2.9
6 GeV	$BR(SS \to \tau^- \tau^+) \simeq 20\%$ $BR(SS \to b\bar{b} + c\bar{c}) \simeq 80\%$	$\lesssim 2$	$\lesssim 2$
8 GeV	$BR(XX \to \tau^+ \tau^-) = 100\%$	$\lesssim 2.4$	$\lesssim 2.5$

To be compared to $\langle \sigma v \rangle \approx 3 \cdot 10{-26} cm^2 \cdot s^{-1}$ from WMAP
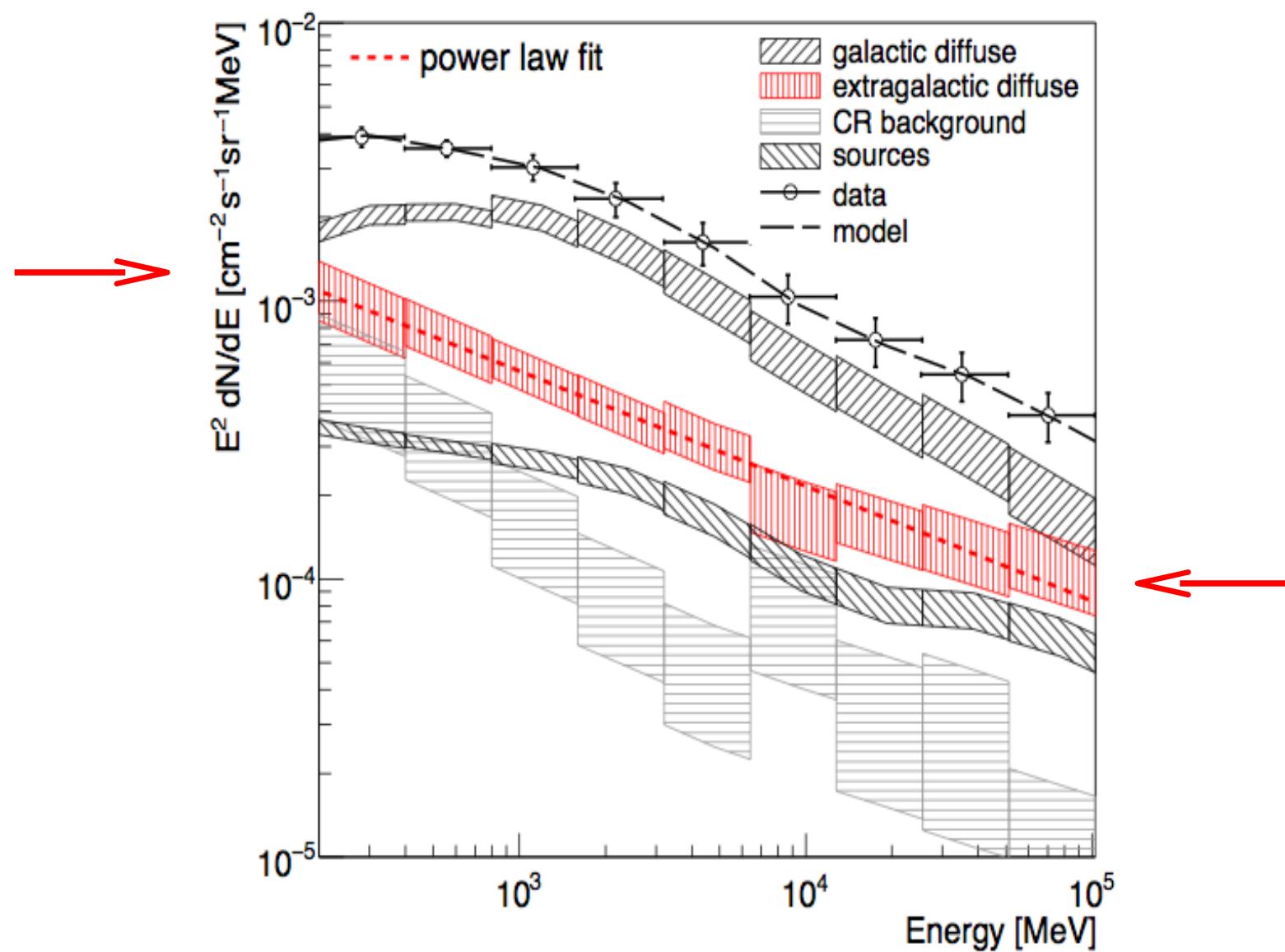
Andreas, Arina, Hambye, Ling, M.T. (arXiv:1003.2595)
See also Fitzpatrick, Hooper & Zurek

**Stacking analysis (10 dSphs, 24 months of Fermi data)**

2011 Fermi Symposium (May 2011, Roma)

Results all channels

Upper limits, Combined Likelihood limits of 10 dSphs

PRELIMINARY

5GeV

1000GeV

3e-26cm³/s

#2: Fermi-LAT data of Extragalactic gamma-ray diffuse emission

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

Extragalactic diffuse emission from DM annihilation

Particle physics

Astrophysical factors

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

B. Boost factor:

Halos of DM matter
all sizes @ all redshift z)   (of
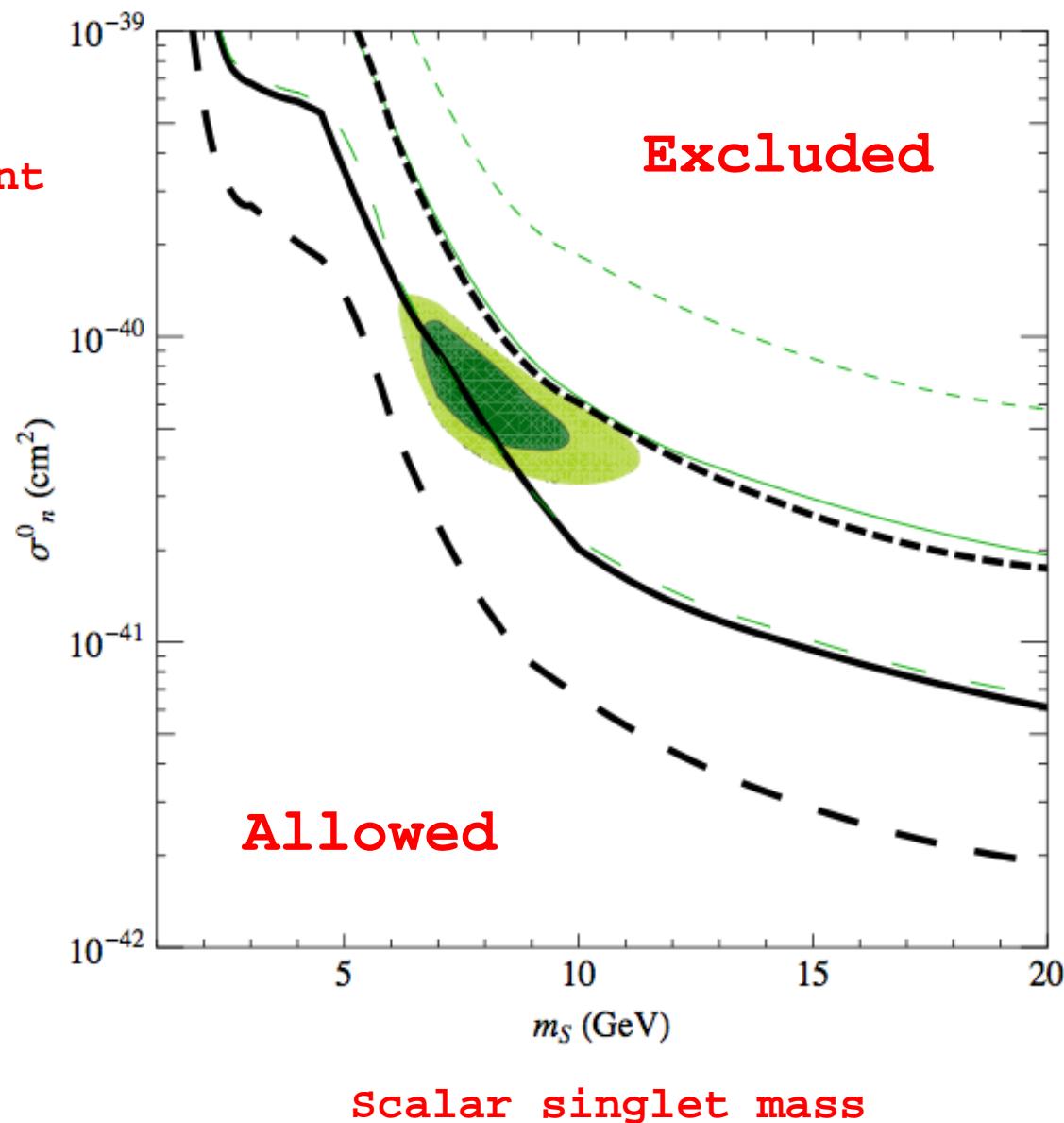
A. Optical depth:

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

Results: scalar singlet DM
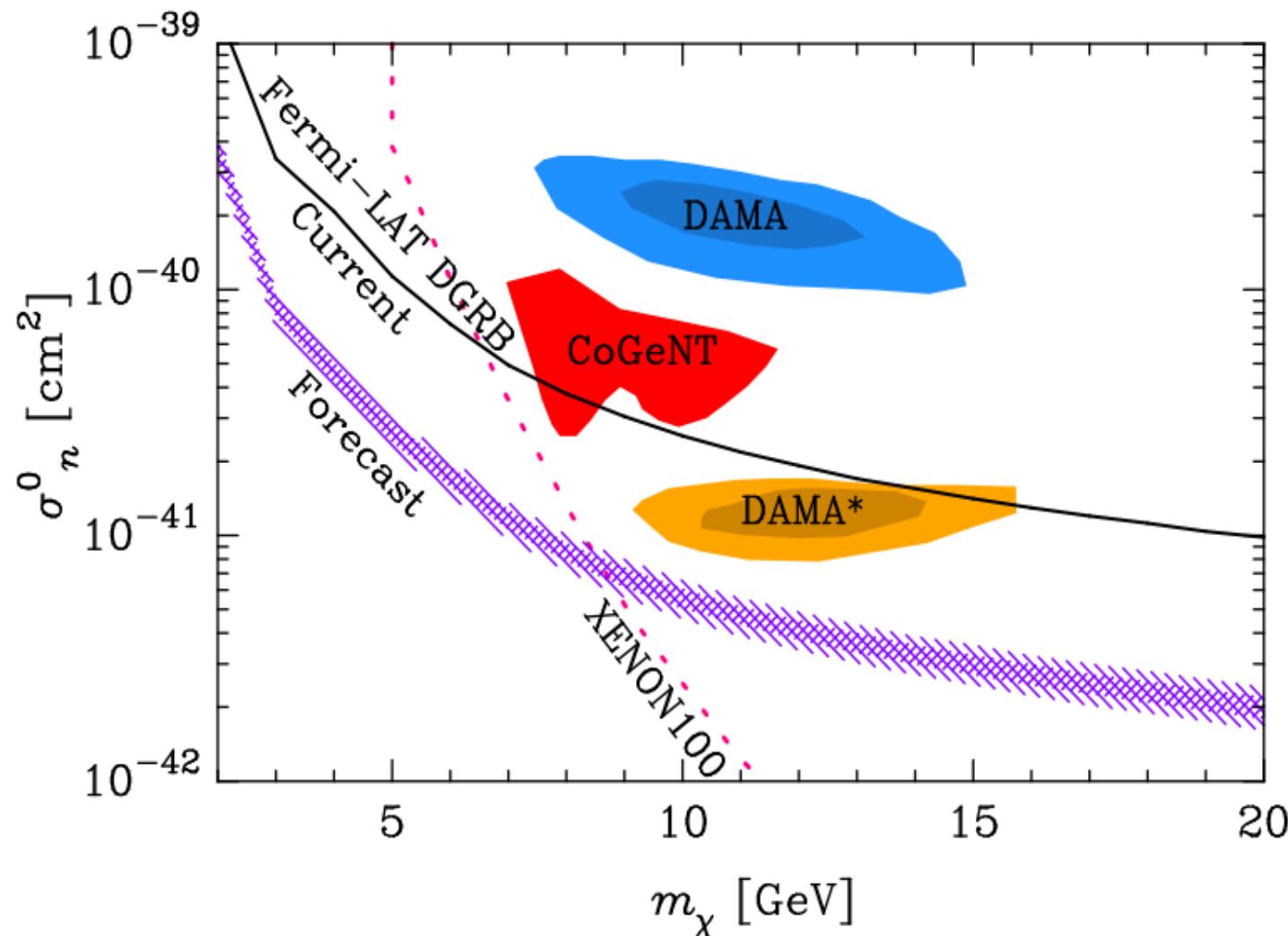
95% CL exclusion limits from Diffuse Isotropic Emission

Spin-independent

cross-section

Excluded

Allowed

σ_n^0 (cm^2)

m_S (GeV)

Scalar singlet mass
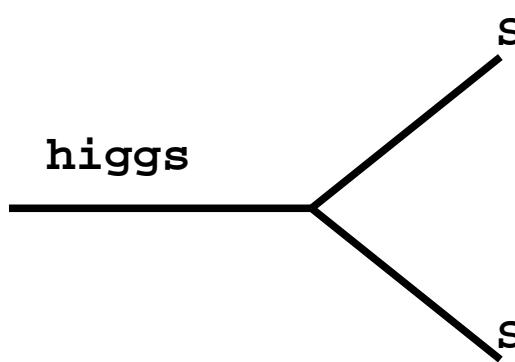
More results: scalar singlet DM

Forecast: identification of extra-galactic sources (AGN, Blazars,...)

Abazajian, Blanchet and Harding arXiv:1012.1247

BTW, this is an invisible Higgs scenario

higgs 〈 S / S

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)

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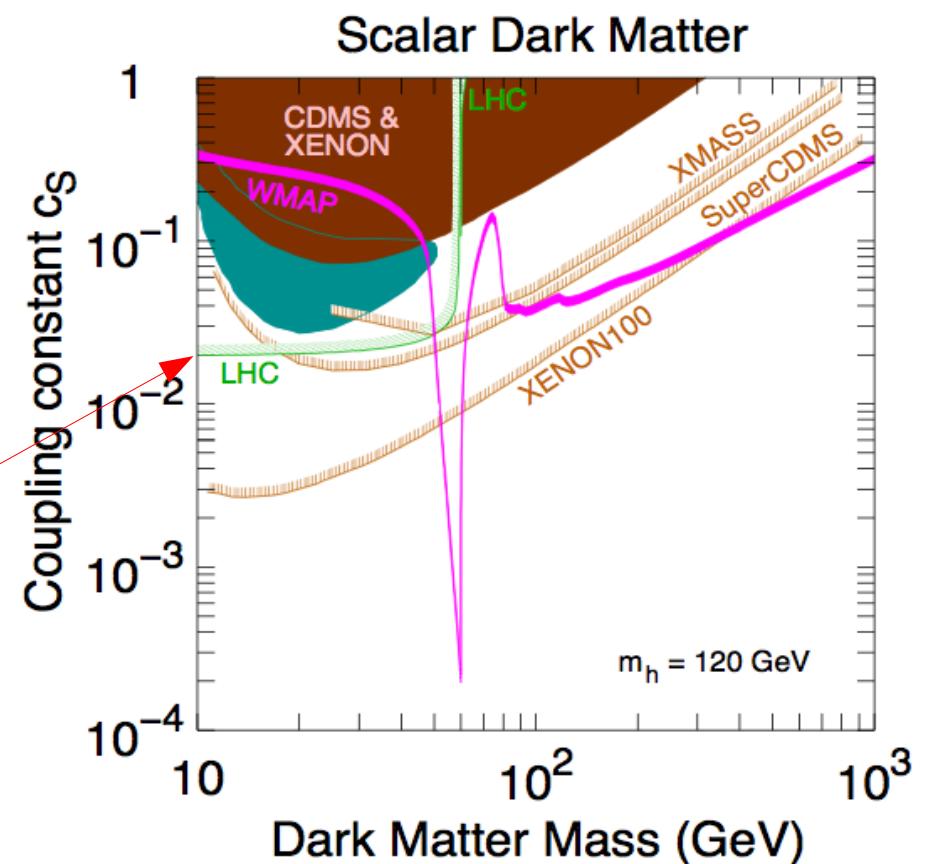

Scalar Dark Matter

Fig. from Kanemura et al, 1005.5651

Conclusions

Confusing hints of light dark matter

Not very natural in framework of MSSM (NMSSM?)

Scalar dark matter? Unlikely...

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

Beautiful interplay between direct and indirect detection.

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
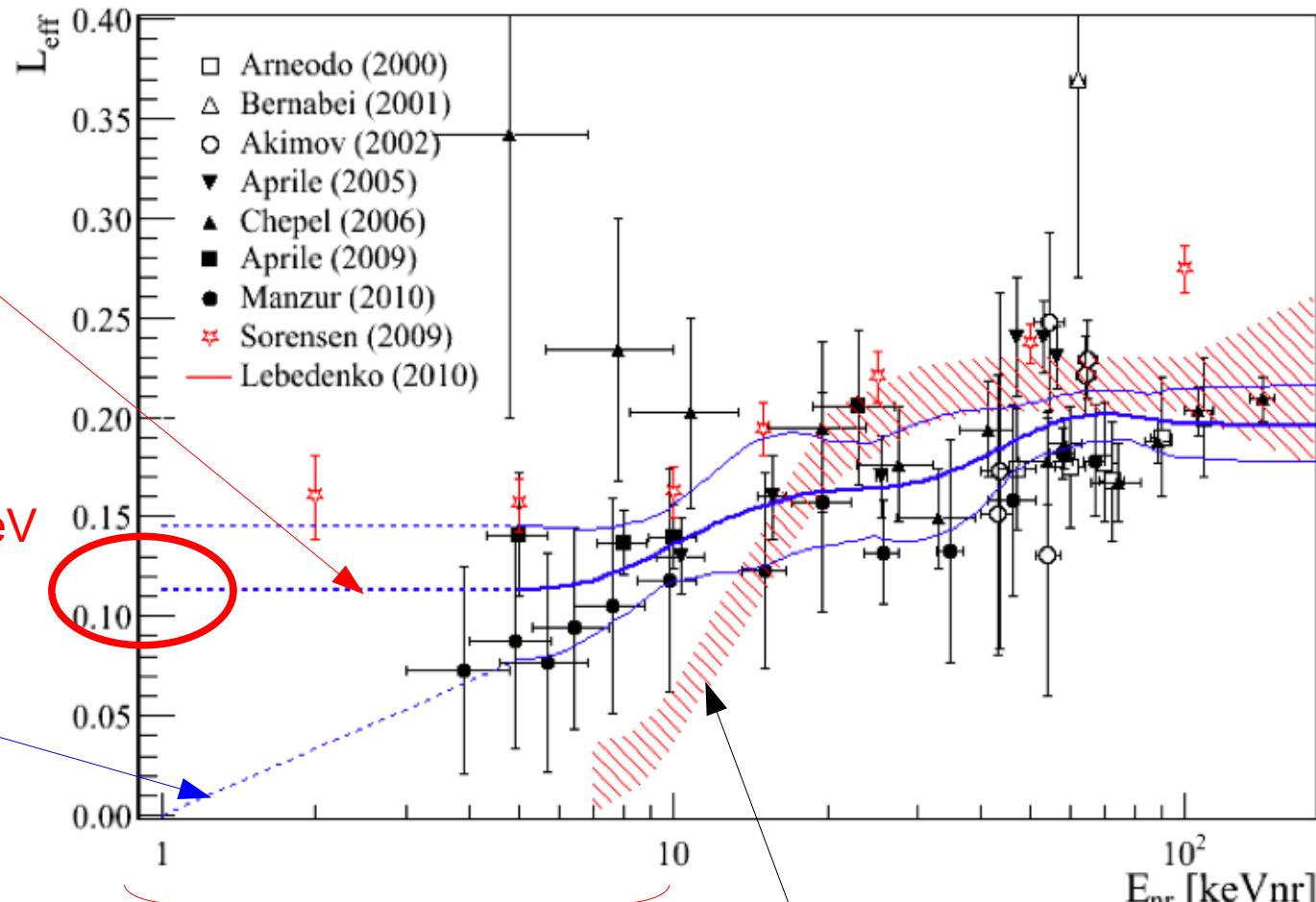
LeffMed
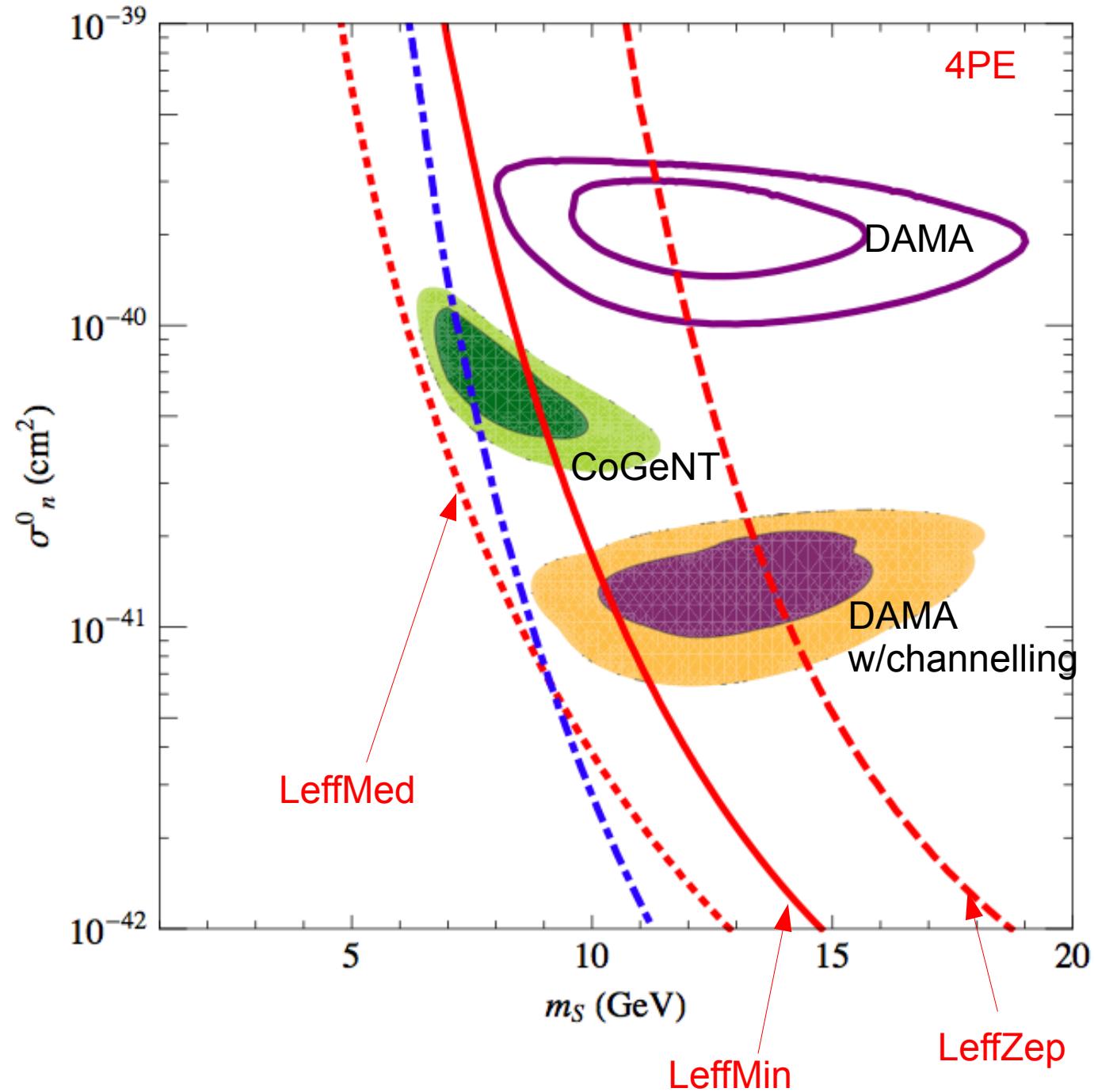
Cutoff @ 1 keV

LeffMin
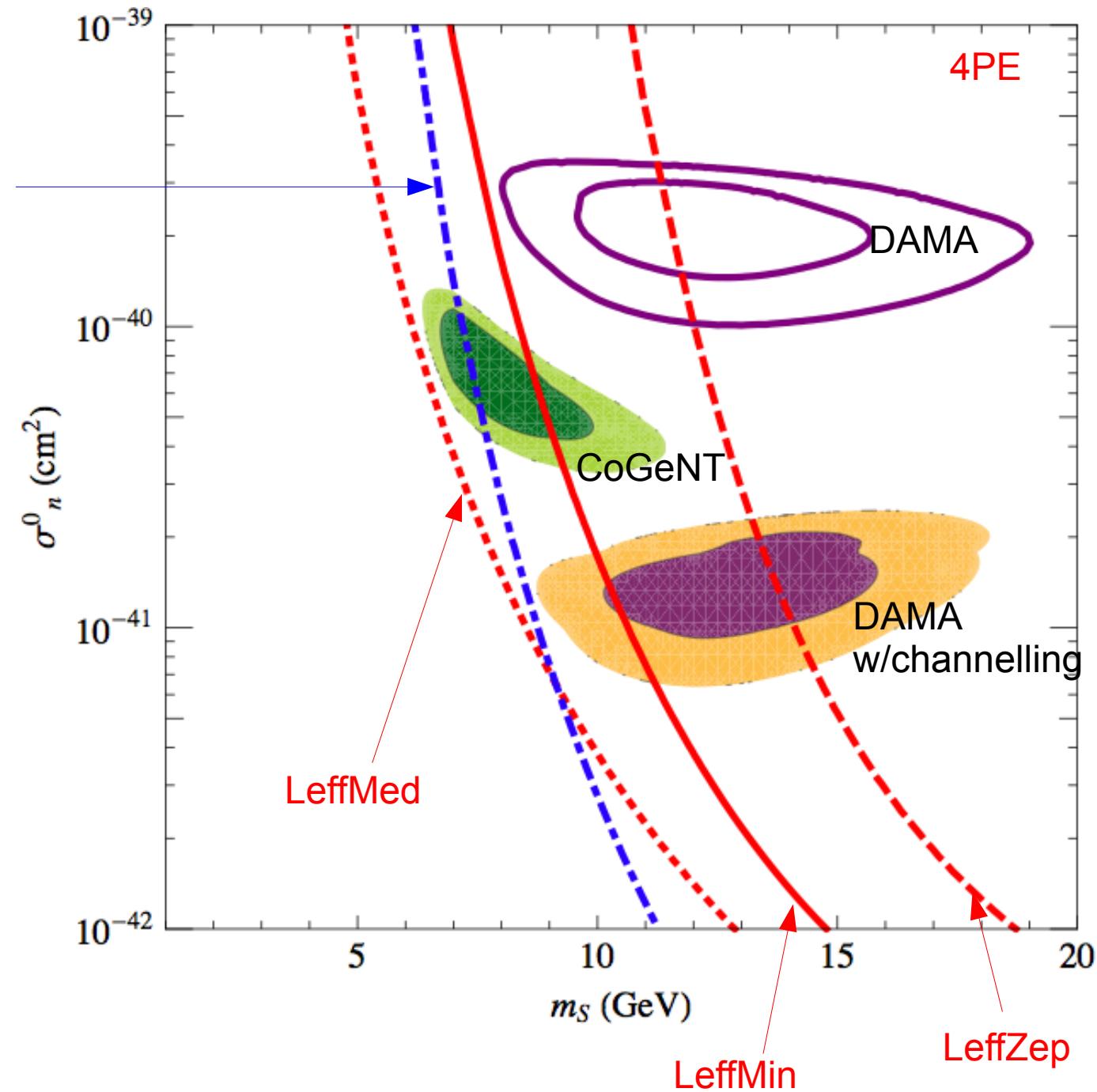
Light Dark Matter range

LeffZep (very conservative)

4PE

σ^0_n (cm^2)

m_S (GeV)

DAMA

CoGeNT

DAMA w/channelling

LeffMed

LeffMin

LeffZep

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

Andreas, Arina, Hambye, Ling, M.T.
(arXiv:1003.2595)
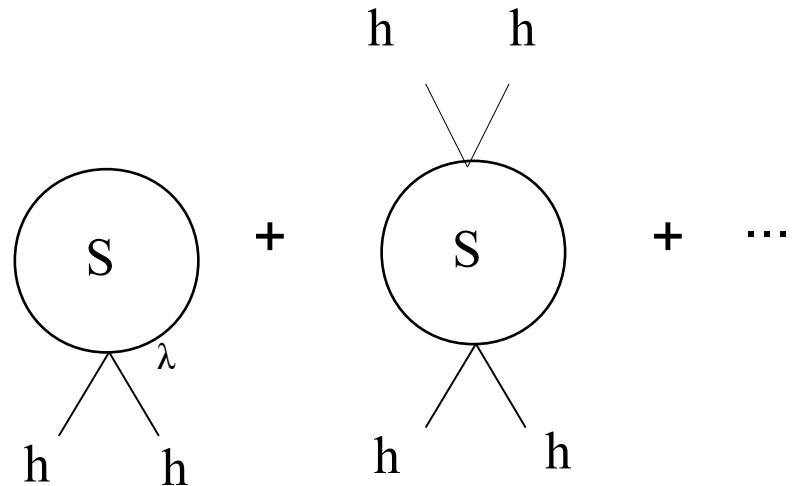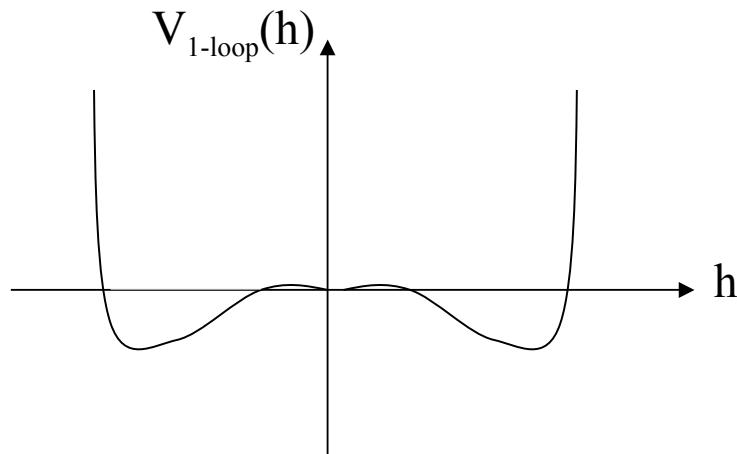
Hierarchy problem
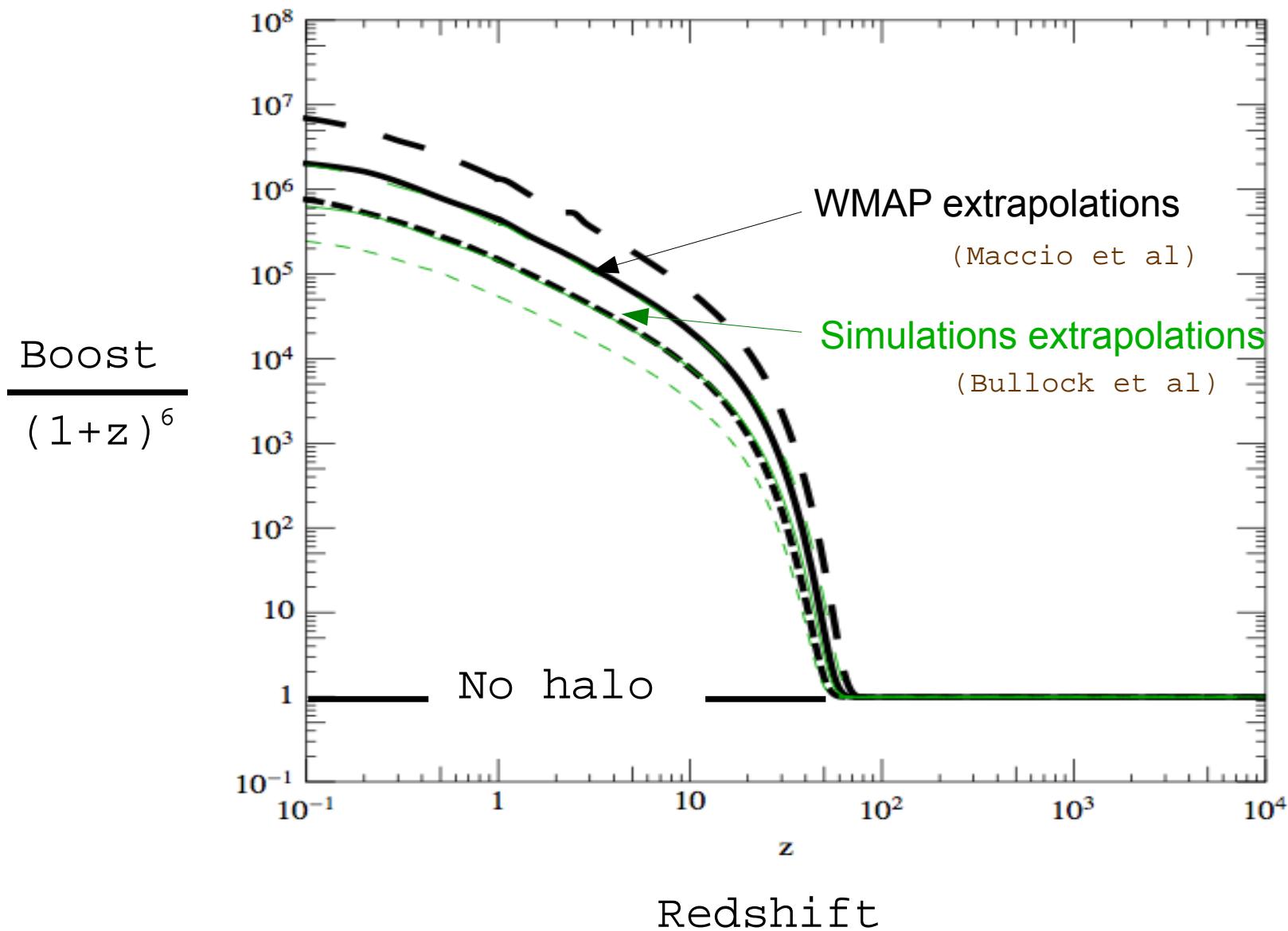
Electroweak Symmetry Breaking and Dark Matter?
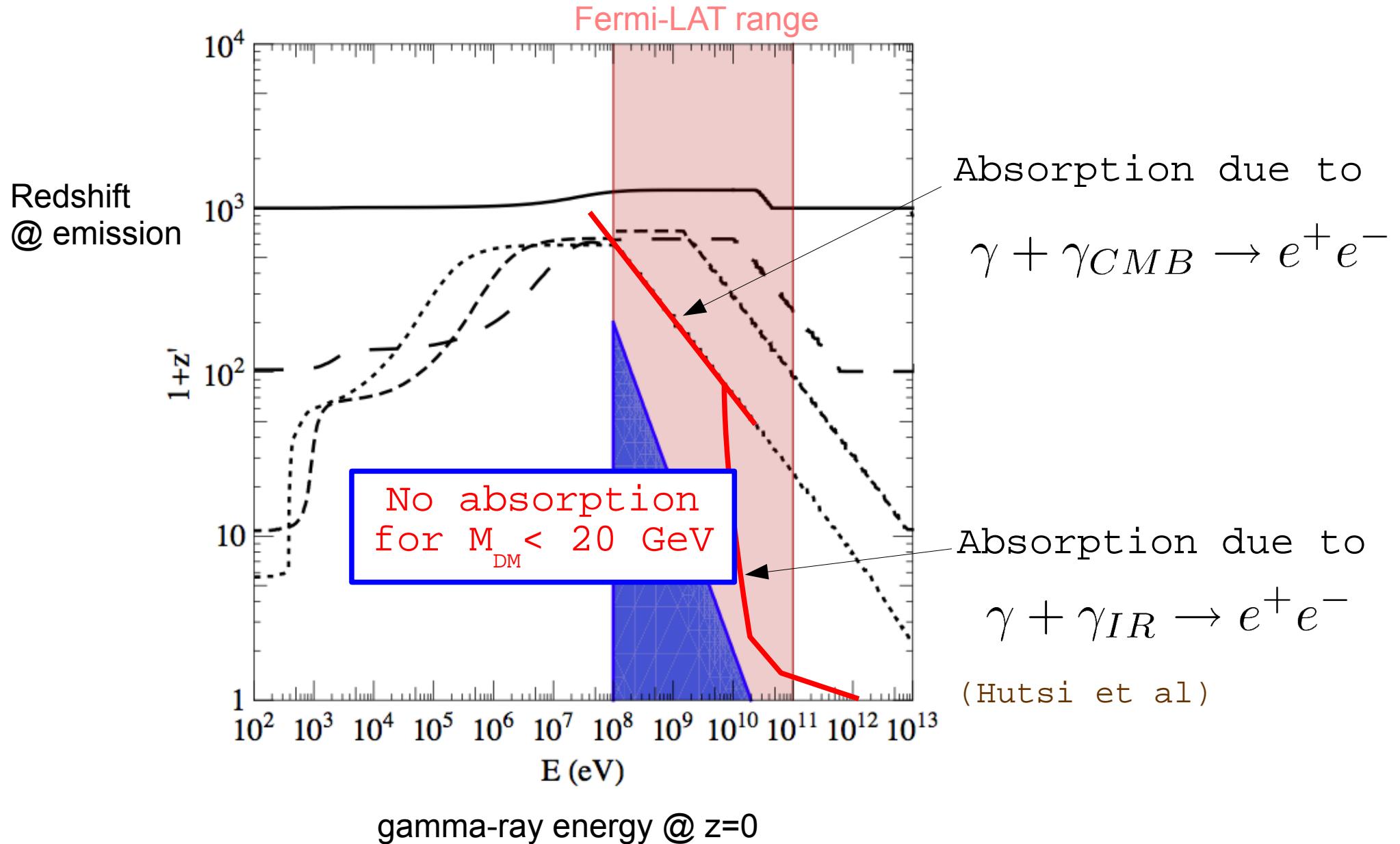

Scalar Dark matter loops have the right sign
to break the EW symmetry

Need relatively large quartics (λ~1)
or, argh, many scalars

Pratt & Wilczek; Espinosa & Quiros;
Hambye & Tytgat

B. Boost from DM halos @ all redshifts?

Boost / (1+z)^6 versus Redshift (z)

WMAP extrapolations (Maccio et al)

Simulations extrapolations (Bullock et al)

No halo

A. Optical depth

Fermi-LAT range

Redshift @ emission

$1+z'$

Absorption due to

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

No absorption for $M_{DM} < 20$ GeV

Absorption due to

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

(Hutsi et al)

E (eV)

gamma-ray energy @ z=0

(C.Arina,M.T.)

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

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

Dark Matter profile
(here NFW, but
dependence mild)

Depends on power spectrum of low mass halos
(potentially
down to $...M) \sim 10^{-8} M_\odot$
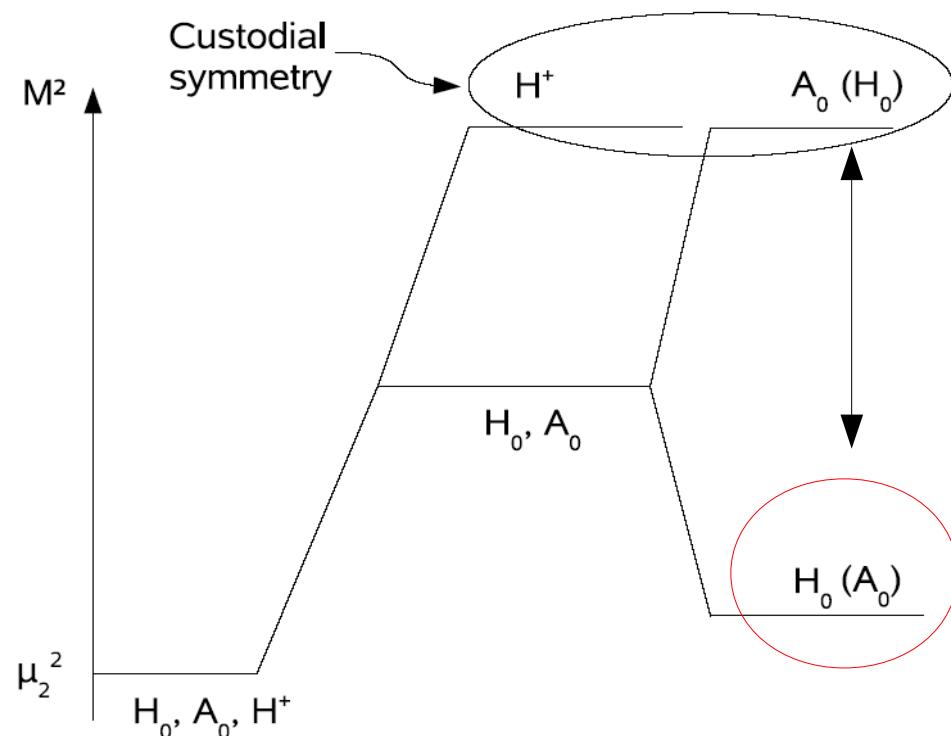
extrapolations from WMAP measurements
and/or numerical simu's

Focus on a Light H0?

Global custodial SU(2) symmetry if $M_{H+} = M_{H0}$ or
$M_{H+} = M_{A0}$

Effectively H_0 ~ scalar singlet S

(Gérard, Herquet; Andreas, Hambye, M.T.)