Light Dark Matter in the Lepton-Specific two-Higgs-Doublet Model.

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SB,S.Profumo Phys.Rev. D84 (2011) 055011 [arXiv:1106.3368]

|May 30th|PLANCK'12| Warsaw.

Evidence for DM is consistently growing since the 30's..

.. but we still don't know what it is !

However, we know it must be :

- Non-relativistic @ onset of galaxy formation
- Very Weakly interacting with photons (dark!)
- Able to reproduce the non-baryonic matter density

The DM "Landscape"

- Axions
- Sterile Neutrinos
- FIMPs
- WIMPs
- Primordial Black holes
- Q-Balls
- ...

- Known and well tested physics
- Thermal Production
- "Miraculous"
- Testable !

$$\Omega_{\rm CDM} h^2 \simeq 0.1 \, \frac{3 \times 10^{-26} \ {\rm cm}^3 {\rm s}^{-1}}{\langle \sigma v \rangle_{\rm f.o.}}$$

WIMPy Signals

- **Direct Detection**
  - XENON, CDMS, CRESST, COGENT, DAMA/LIBRA..
- **Indirect Detection** (FERMI, EGRET, HESS, PAMELA,...)
  - Cosmic-Rays: electrons, protons, anti-deuterons
  - Neutrinos
  - Gamma rays : (extra-) Galactic , lines, diffuse
  - Radio
  - ...

WIMPy Hints

- **Direct Detection**
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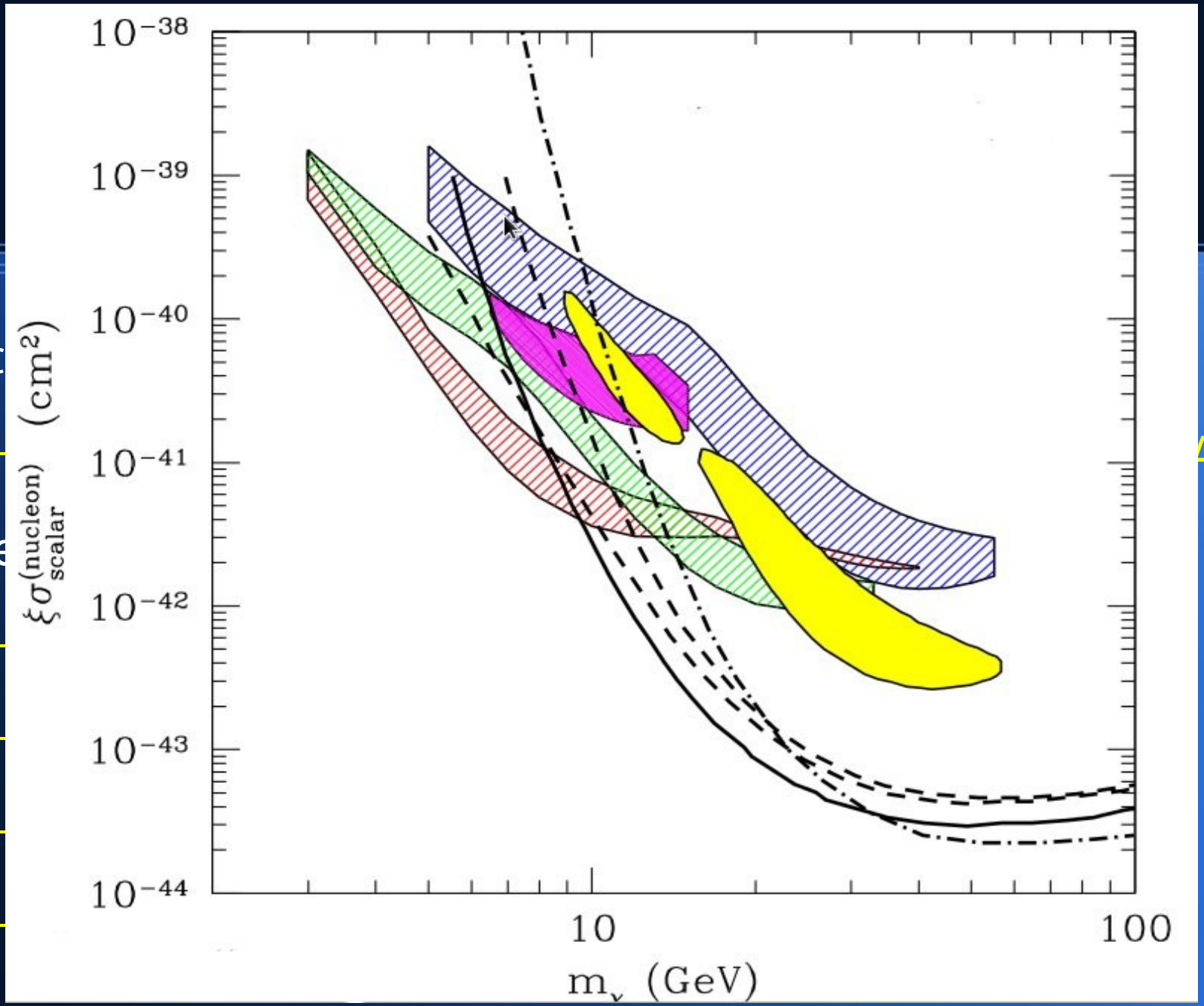
  - ...

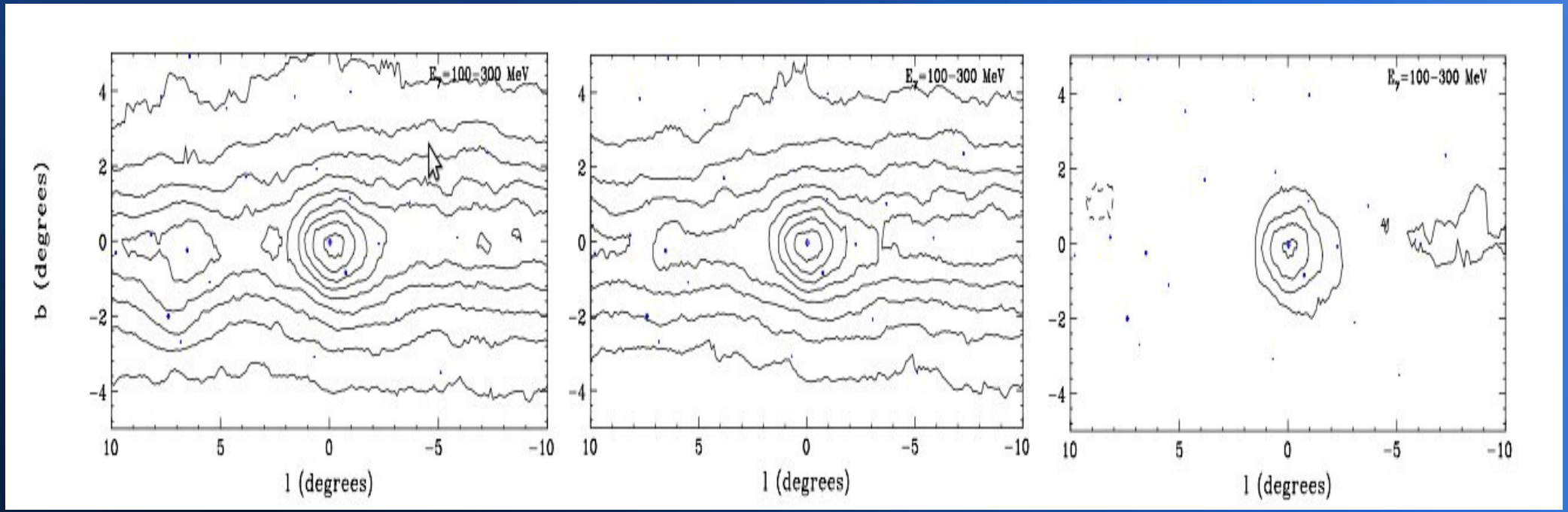
- Direc
- Indire



A..

From N.Fornengo's Talk.

A closer look at the GC



D.Hooper,L.Goodenough'11
D.Hooper,T.Linden'11
A.Boyarsky,D.Malyshev,O.Ruchayskiy'11

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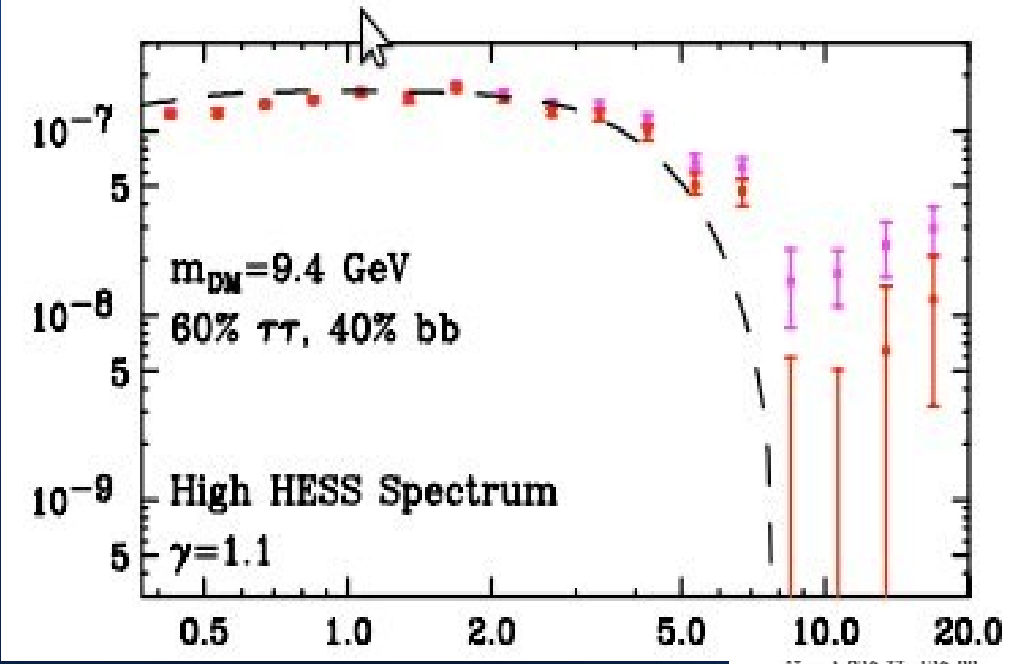

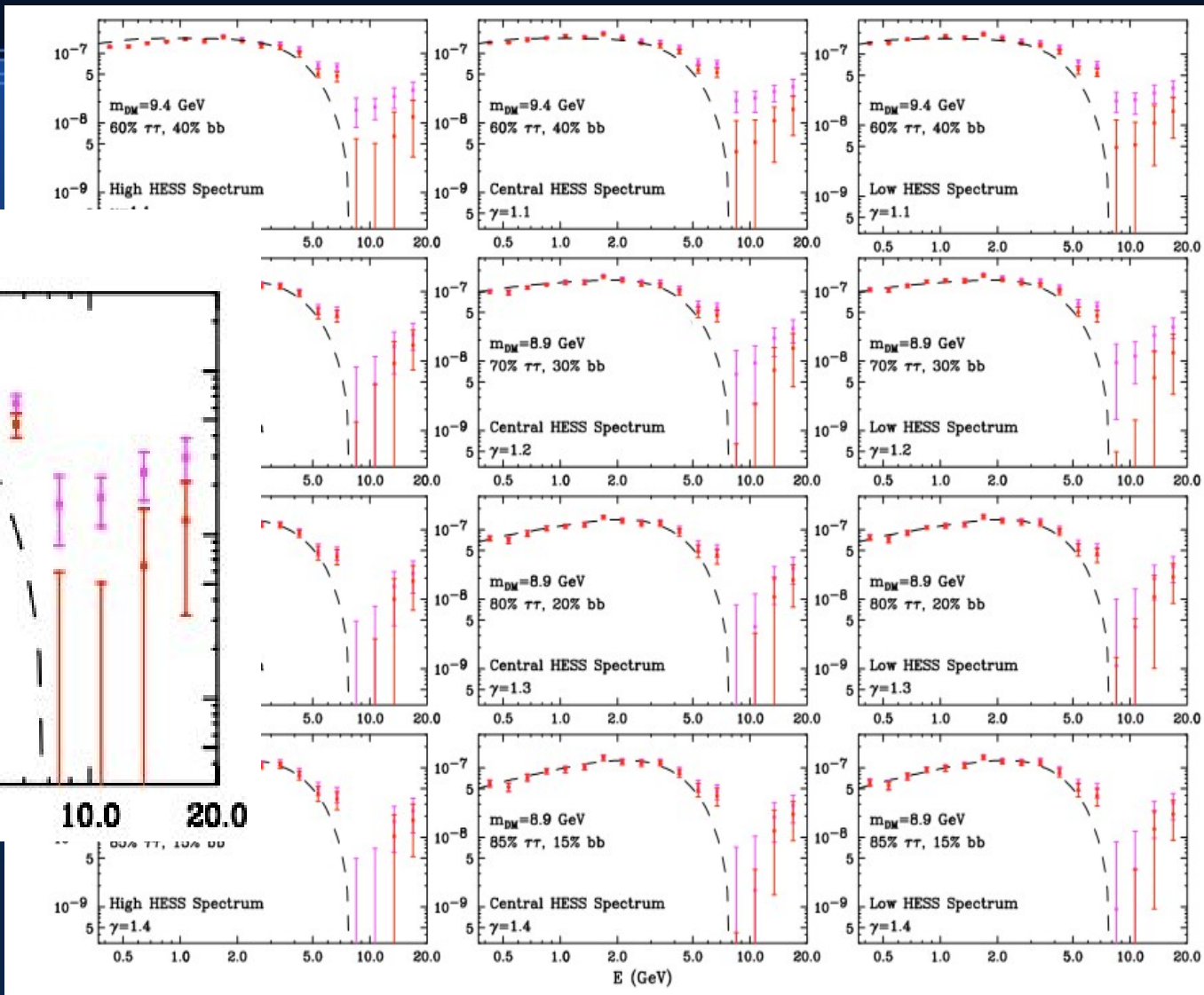

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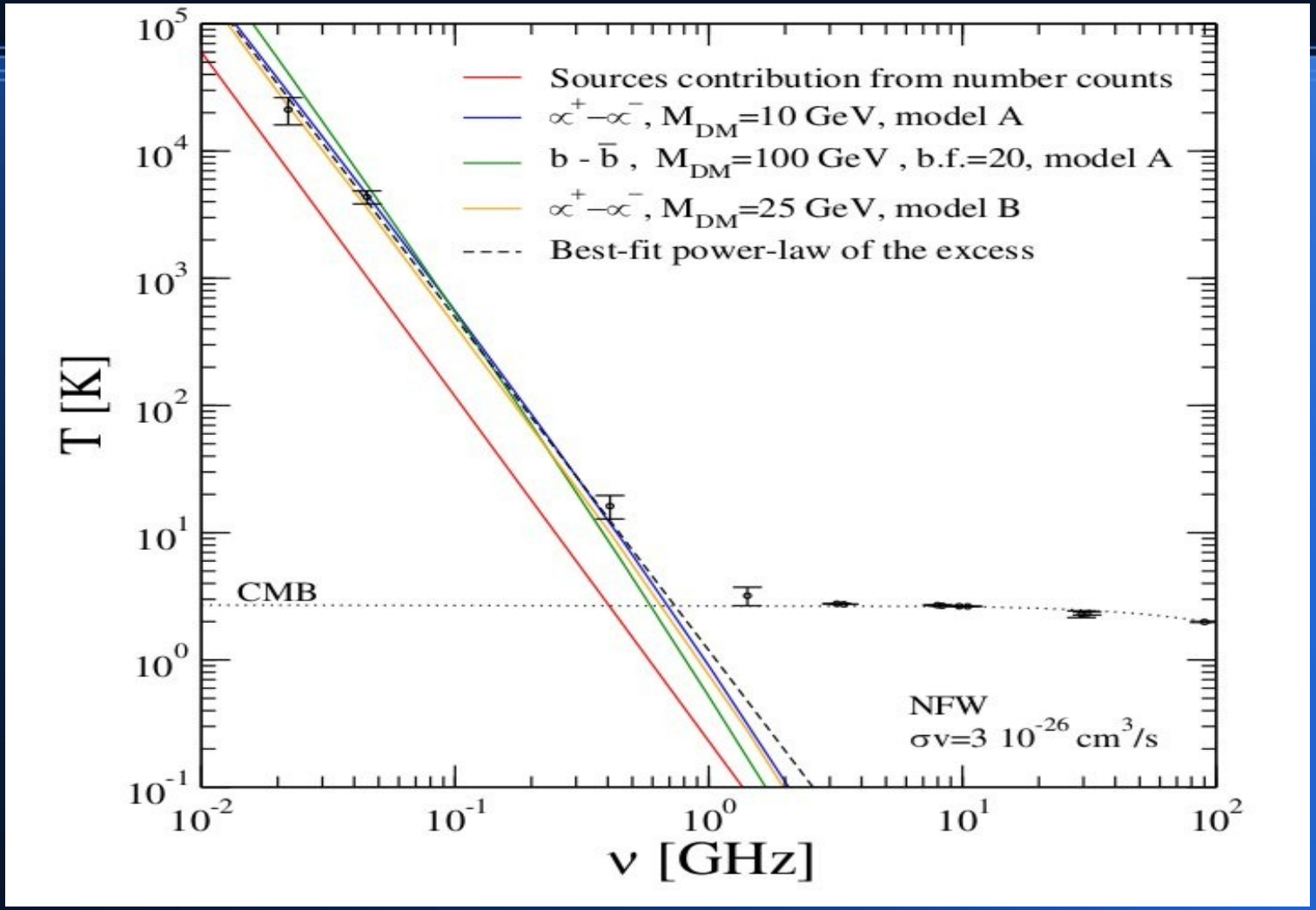
ARCADE Excess



N.Fornengo,R.Lineros,M.Regis,M.Taoso'11

WIMPy Conspiracy

- Very Different signals and experiments pointing to the same mass range !
- Mass ~ 10 GeV
- Thermal cross-section comes out naturally.
- Leptophilic nature of DM is favored.

The Model : 2HDM-L

- SM with two SU(2) doublets : Hl & Hq
- Dark Matter is a Scalar singlet

$$
\begin{aligned}
V &= \mu_1 H_Q^\dagger H_Q + \mu_2 H_L^\dagger H_L + \frac{m_3}{2} S^2 + \lambda_Q S^2 H_Q^\dagger H_Q + \lambda_L S^2 H_L^\dagger H_L \\
&+ \lambda_s S^4 + \lambda_1 (H_L^\dagger H_L)^2 + \lambda_2 (H_Q^\dagger H_Q)^2 + \lambda_3 (H_Q^\dagger H_Q)(H_L^\dagger H_L) \\
&+ \frac{\lambda_4}{2}((H_Q^\dagger H_L)^2 + h.c.) + \lambda_5 (H_Q^\dagger H_L \, H_L^\dagger H_Q).
\end{aligned}
$$

The Model : 2HDM-L

- Essentially 6 parameters.

$$
\begin{aligned}
M^2_{H_1} &= v_1^2\lambda_1 + v_2^2\lambda_2 - \sqrt{L^2\, v_1^2 v_2^2 + (v_1^2\lambda_1 - v_2^2\lambda_2)^2};\\
M^2_{H_2} &= v_1^2\lambda_1 + v_2^2\lambda_2 + \sqrt{L^2\, v_1^2 v_2^2 + (v_1^2\lambda_1 - v_2^2\lambda_2)^2};\\
M^2_{A_2} &= -v^2\lambda_4;\\
M^2_{H_2^\pm} &= -\frac{1}{2}v^2(\lambda_4+\lambda_5);\\
M^2_S &= \frac{1}{2}(2\,m_3 + v_1^2\lambda_L + v_2^2\lambda_Q),
\end{aligned}
\qquad L = \lambda_3 + \lambda_4 + \lambda_5
$$

$$
M_{H_1},\ M_{H_2},\ M_{A_2},\ M_{H_2^\pm},\ M_S,\ \lambda_L,\ \lambda_Q,\ \tan\beta = v_2/v_1,\ \alpha.
$$

The Model : 2HDM-L

- The following constraints are imposed :
  - Perturbativity
  - Vacuum stability
  - Electroweak precision tests (T-parameter)
  - Flavor physics

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$$\frac{1}{2}\left(3(\lambda_1+\lambda_2)\pm\sqrt{9(\lambda_1-\lambda_2)^2+4(2\lambda_3+\lambda_4|)^2}\right)<8\pi \quad , \quad \lambda_3+2\lambda_4\pm|\lambda_5|<8\pi$$

$$\frac{1}{2}\left(\lambda_1+\lambda_2\pm\sqrt{(\lambda_1-\lambda_2)^2+4|\lambda_5|^2}\right)<8\pi \quad , \quad \lambda_3\pm\lambda_4<8\pi$$

$$\frac{1}{2}\left(\lambda_1+\lambda_2\pm\sqrt{(\lambda_1-\lambda_2)^2+4|\lambda_5|^2}\right)<8\pi \quad , \quad \lambda_3\pm|\lambda_5|<8\pi.$$

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$$\lambda_{1,2} > 0 \quad , \quad \lambda_3 > -2\sqrt{\lambda_1 \lambda_2} \quad , \quad \lambda_3 + \lambda_4 - |\lambda_5| > -2\sqrt{\lambda_1 \lambda_2}.$$

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$$-0.08 \leq T \leq 0.14.$$

$$\begin{aligned}\Delta\rho \;=\; & \frac{g^2}{64\pi^2 M_W^2}\Big[F(M_{H_2^\pm}, M_{A_2}) + 3(F(M_W, M_{H_1}) - F(M_Z, M_{H_1})) \\ & \cos(\alpha-\beta)^2(F(M_{H_2^+}, M_{H_2}) + F(M_{A_2}, M_{H_2}) + 3F(M_W, M_{H_1}) - 3F(M_Z, M_{H_1})) \\ & \sin(\alpha-\beta)^2(F(M_{H_2^+}, M_{H_1}) + F(M_{A_2}, M_{H_1}) + 3F(M_W, M_{H_2}) - 3F(M_Z, M_{H_2}))\Big] \\ & = \alpha_{em} T,\end{aligned}$$

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S.Su,B.Thomas'09

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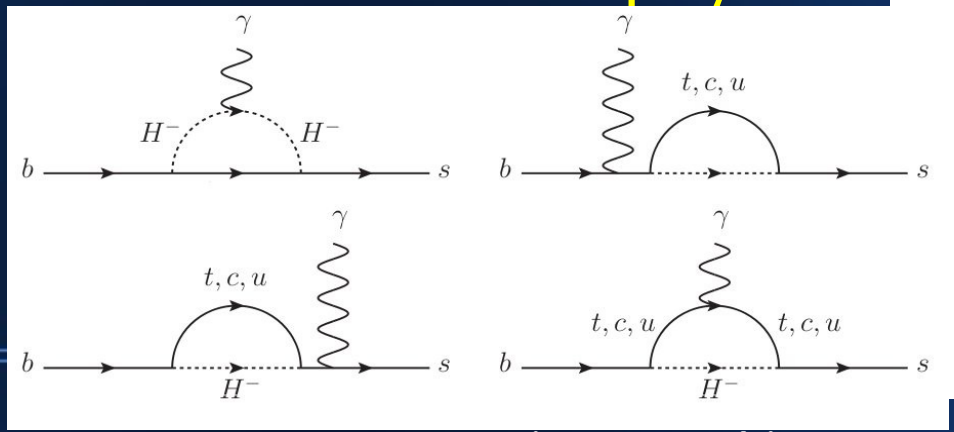
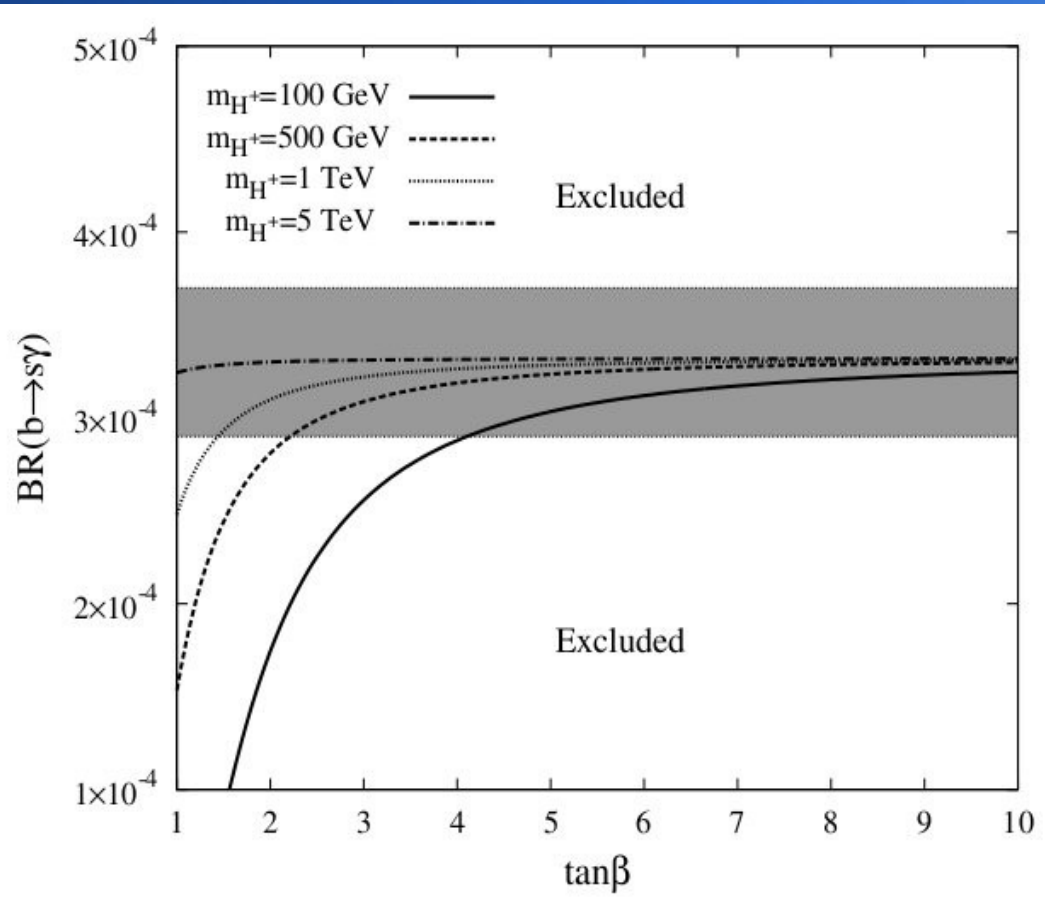
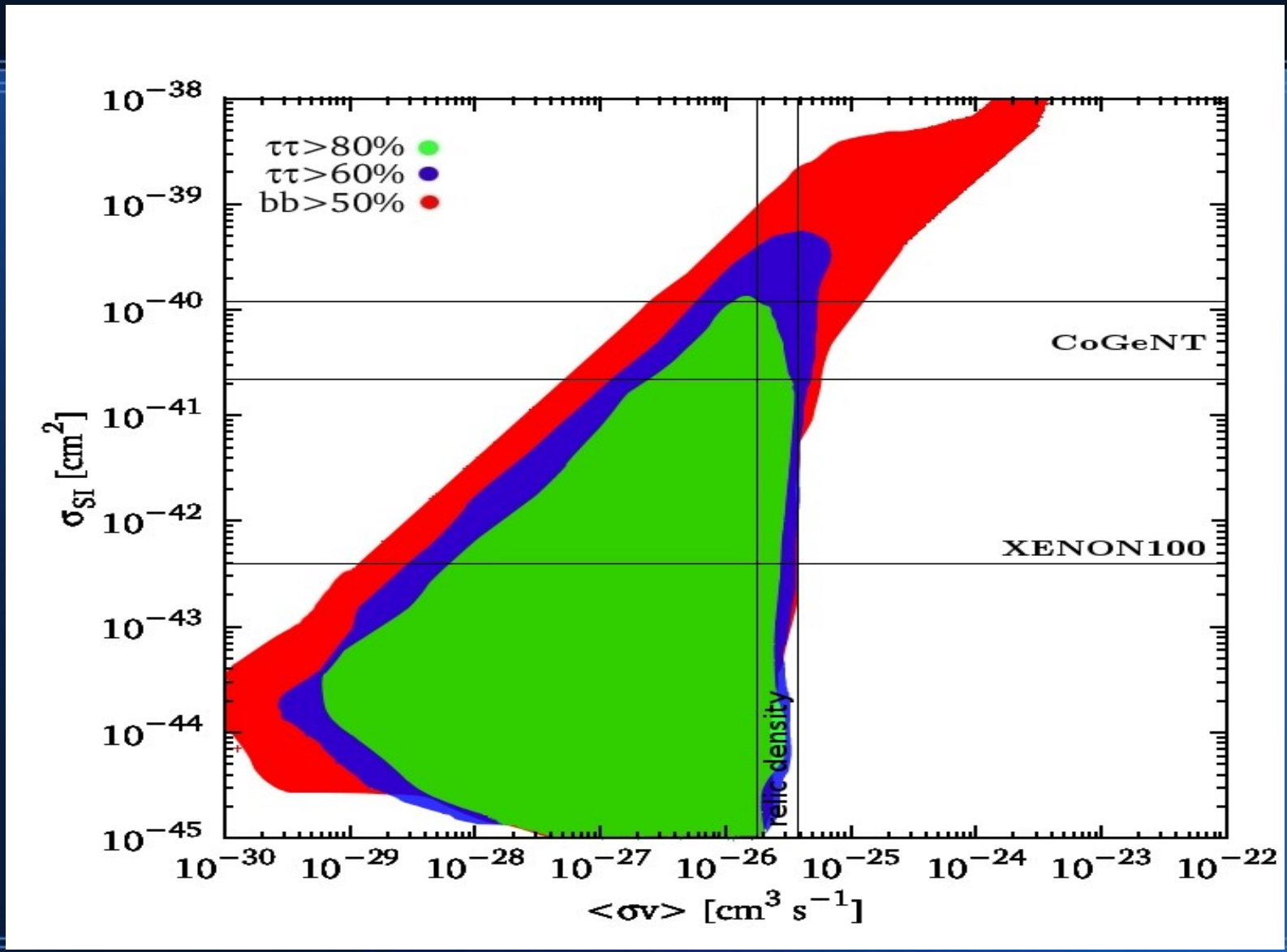




8GEV Benchmark



8GEV Benchmark

$$C_l = \frac{(\lambda_Q \tan\beta \cos\alpha - \lambda_L \sin\alpha)\sin\alpha}{s - M_{H_2}^2} - \frac{(\lambda_Q \tan\beta \sin\alpha + \lambda_L \cos\alpha)\cos\alpha}{s - M_{H_1}^2},$$

$$C_q = -\frac{(\lambda_Q \cos\alpha - \lambda_L \cot\beta \sin\alpha)\cos\alpha}{s - M_{H_2}^2} - \frac{(\lambda_Q \sin\alpha + \lambda_L \cot\beta \cos\alpha)\sin\alpha}{s - M_{H_1}^2}.$$

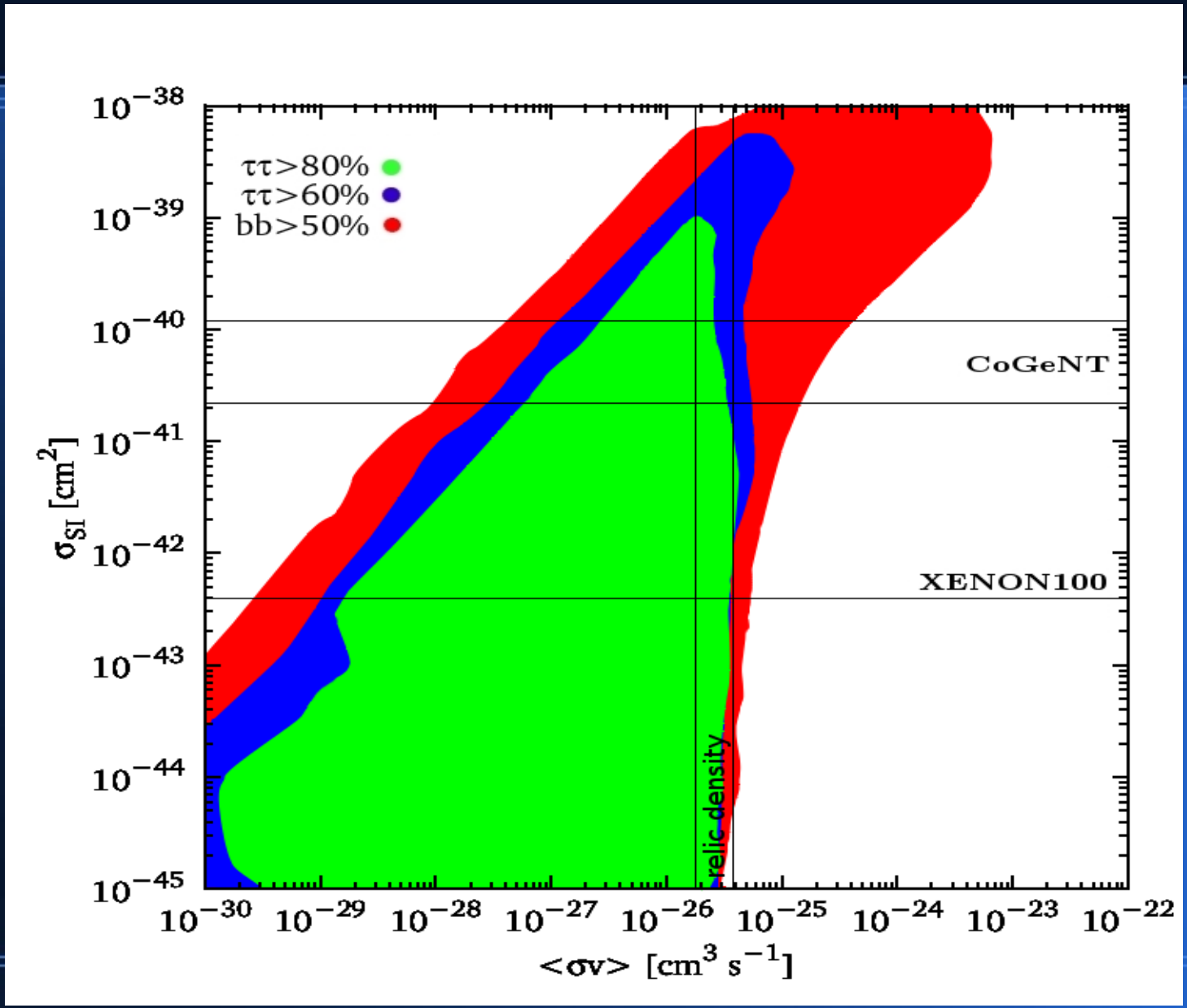
$$\langle \sigma v \rangle = \frac{N_c m_f^2}{4\pi}\left[1 - \frac{4m_f^2}{s}\right]^{3/2} C_f^2$$

$$\sigma_{SI} = \frac{m_p^4}{2\pi(m_p + M_S)^2} C_q^2 F_N^2$$

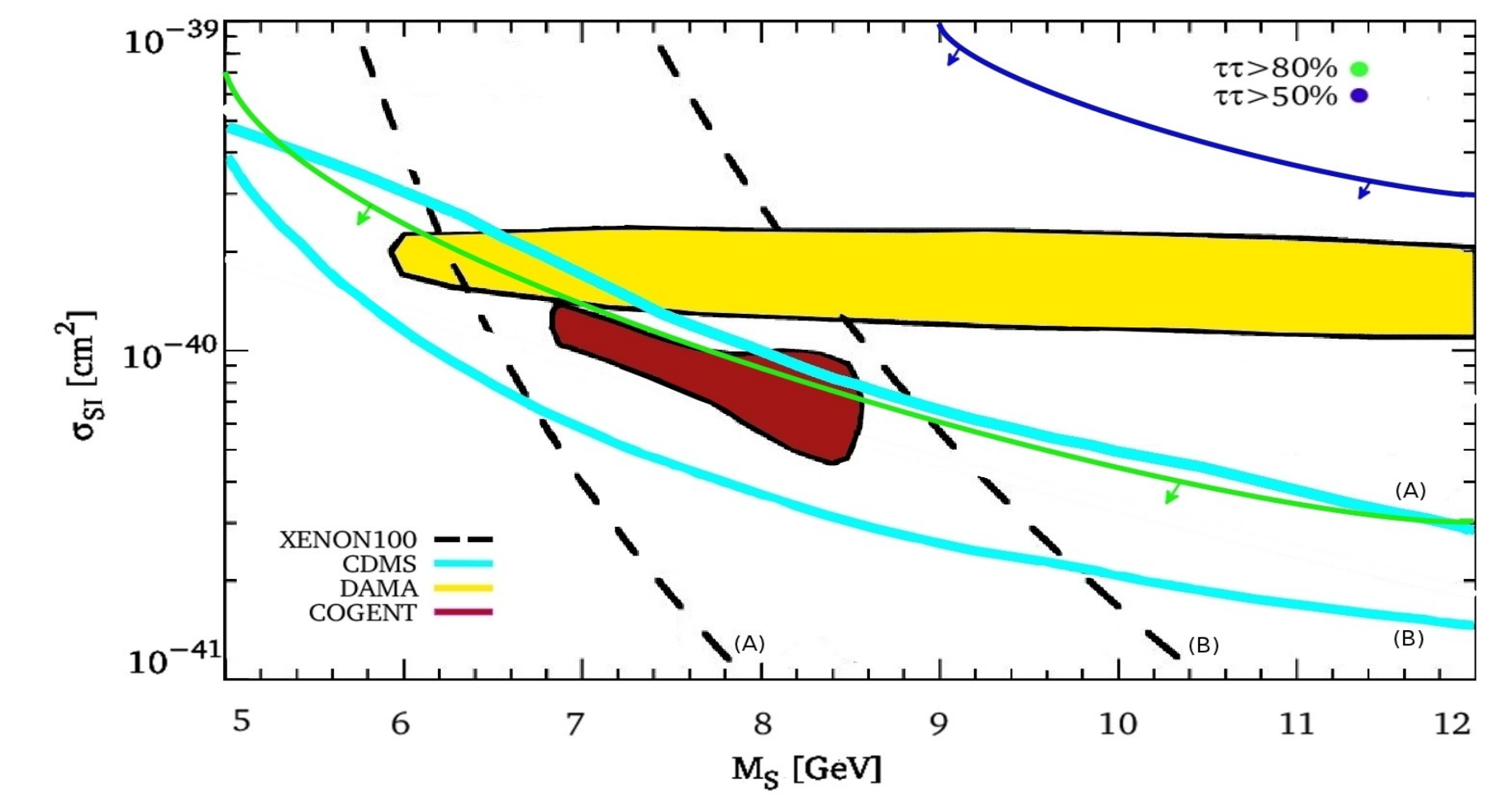
Full Scan

- Scan over the following variables :
  - Scalar masses : 114 GeV - ~600 GEV
  - TanBeta : 0 – 50
  - Couplings : within perturbative limits
  - DM : 5 – 15 GeV
- Apply constraints (tweak **H+** when necessary).
- Calculate relic density, (in)direct detection cross-sections.

Full Scan


ττ>80%
ττ>60%
bb>50%
CoGeNT
XENON100
relic density
σ_{SI} [cm^2]
<σv> [cm^3 s^{-1}]
10^{-38}
10^{-39}
10^{-40}
10^{-41}
10^{-42}
10^{-43}
10^{-44}
10^{-45}
10^{-30} 10^{-29} 10^{-28} 10^{-27} 10^{-26} 10^{-25} 10^{-24} 10^{-23} 10^{-22}

Full Scan


10^{-39}
10^{-40}
10^{-41}
σ_{SI} [cm^2]
ττ>80%
ττ>50%
XENON100
CDMS
DAMA
COGENT
(A)
(B)
(A)
(B)
5
6
7
8
9
10
11
12
M_S [GeV]

Conclusions

- We're living very interesting times for DM detection !
- Very different hints point to the same region of WIMP parameter space.
- We showed that the 2HDM-L can explain in a minimal way these “anomalies” !
- A strong interplay with LHC is possible !

Model	M_{H_1}	M_{H_2}	λ_L	λ_Q	$\sin\alpha$	$\tan\beta$	$\sigma_{SI}[\mathrm{cm}^2]$	Ωh^2	$\langle\sigma v\rangle$ $[10^{-26}$ cm^3/s]]
A	114.8	177.1	6.75	-0.55	0.638	5.67	6.79×10^{-45}	0.12	2.22
B	114.7	270.	6.87	-0.21	0.01	5.79	2.17×10^{-43}	0.12	2.24
C	117.	163.	-3.9	1.01	0.169	7.1	8.69×10^{-41}	0.12	2.14
D	114.6	162.3	-0.48	0.87	0.25	6.62	8.04×10^{-41}	0.091	2.96

TABLE I: Examples of set of parameters for the $M_S = 8$ GeV benchmark