Indirect detection of WIMP dark matter

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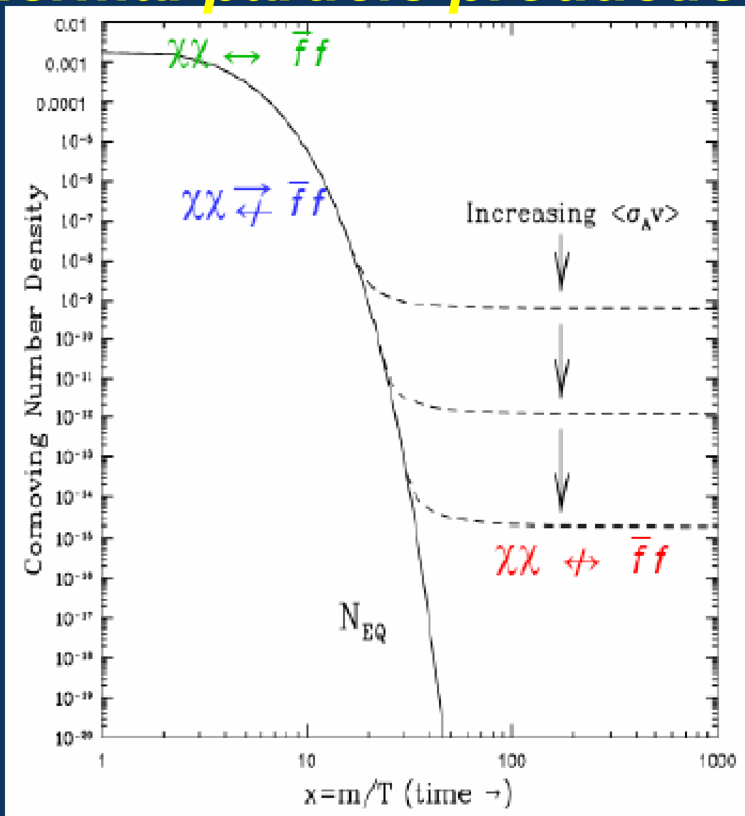
WHY WIMPS: THE COINCIDENCE

Thermal particle production in the Early Universe

~abundance (~ Ω)



~ time , 1/T

$$\Omega_{Wimp} \approx \frac{10^{-26} cm^{-3} s^{-1}}{\langle \sigma v \rangle} \approx 0.27$$

$$\langle \sigma v \rangle_{\sim weak} \sim \frac{\alpha^2}{m^2_{WIMP}} \sim 10^{-25} cm^{-3} s^{-1}$$

Provides a benchmark for indirect detection

Jungman+, Phys. Rept. (1996)

Two a priori unrelated quantities are similar within a factor of a few,

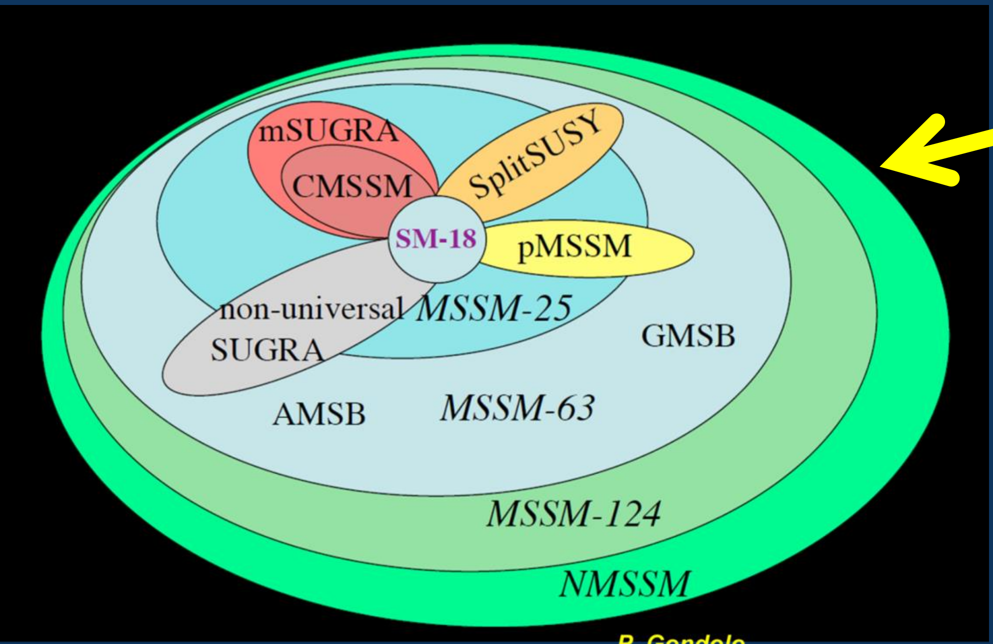
A

PRELIMINARIES

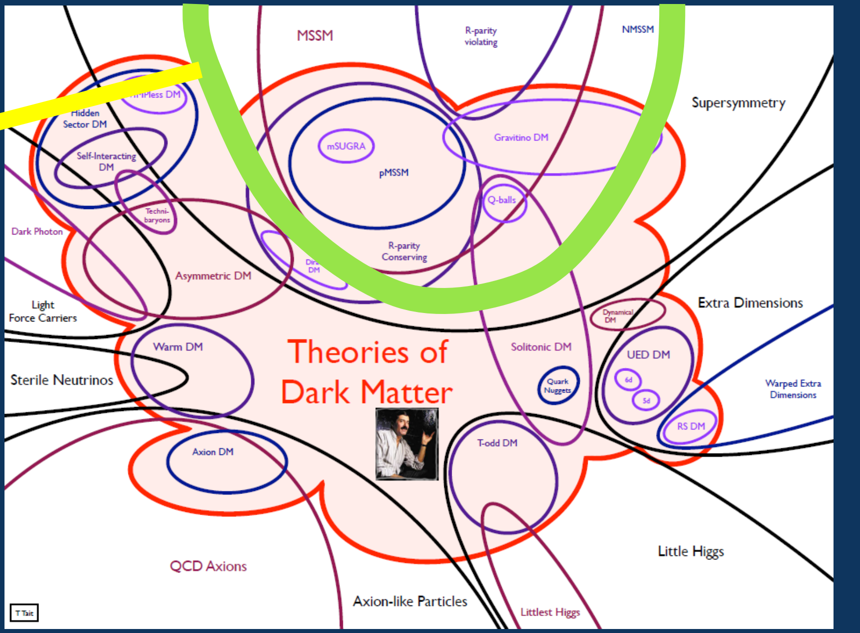
- Thermally produced WIMPs can have masses from a few GeV to upto ~100 TeV.

- The most studied WIMP candidate is realized within Supersymmetry. By naturalness arguments, WIMP masses above about ~TeV are disfavoured in Supersymmetry.

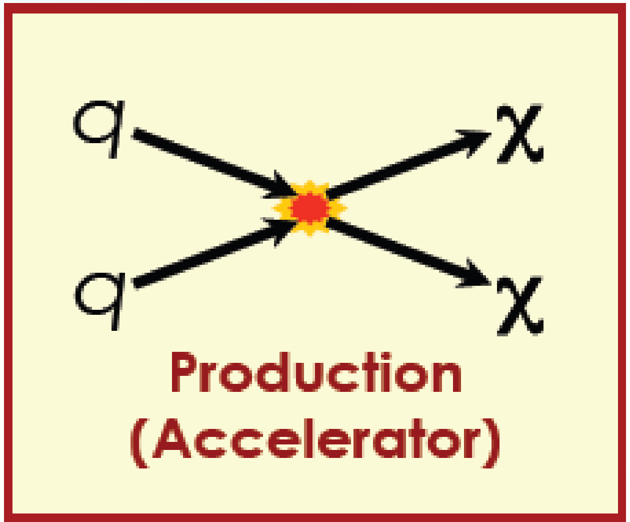
See however e.g, Dine (2015),
"Naturalness under stress"

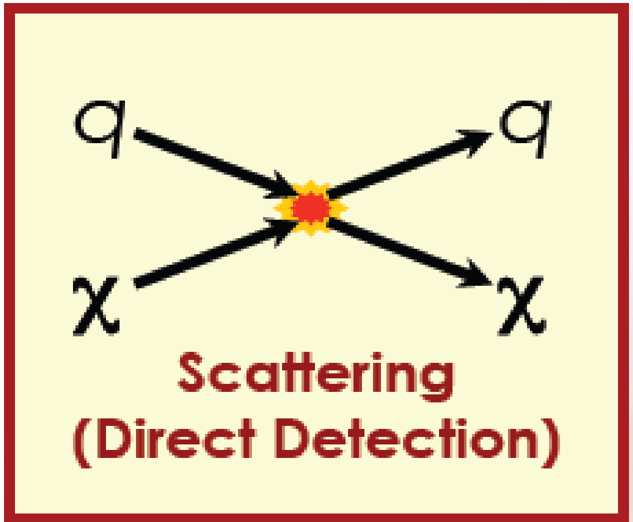


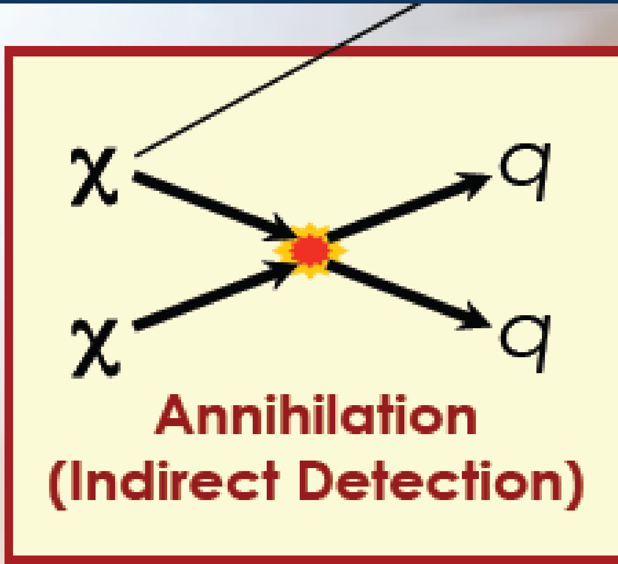
P. Gondolo

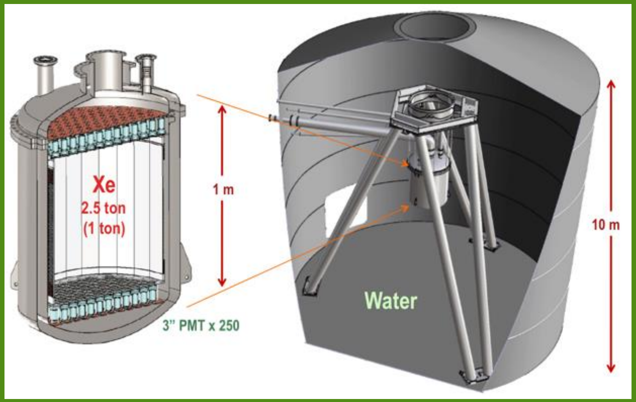


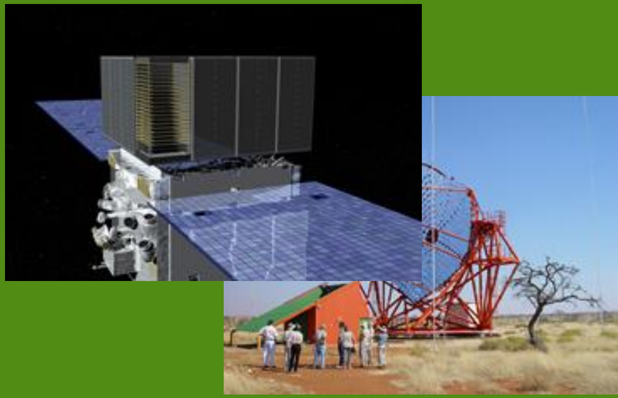
DETECTION OF WIMPS









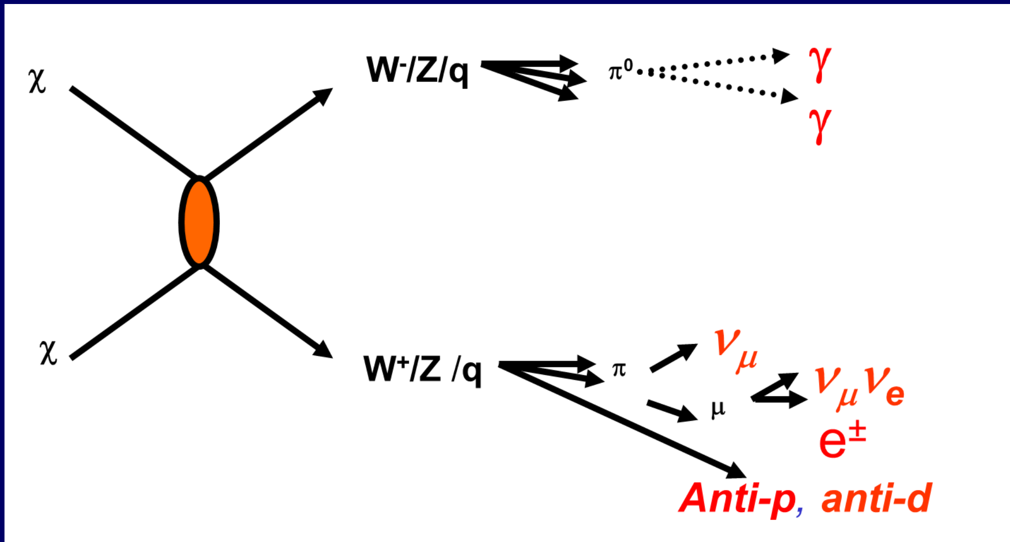


Large Hadron Collider

Deep underground (e.g based on Xenon), see Arneodo,Garbini talks

Gamma ray telescopes, neutrino telescopes, Charged cosmic ray detectors

Indirect detection of Dark Matter



Particle Physics

$$\frac{1}{4\pi}\frac{\langle\sigma_A v\rangle}{2m_\chi^2}\Sigma_f \frac{dN}{dE}B_f$$

ν,γ: rate = PPP ´ Astrophysical part (APP)

$$APP = "J - factor" = \iint d\Omega\, dl\, \rho^2(l)$$

cosmic rays PPP = q(r,p,t)

$$\frac{\partial F(\mathbf{r},p,t)}{\partial t} - \nabla(\mathbf{D}_{xx}\nabla F) + \nabla(\mathbf{u}F) - \frac{\partial}{\partial p}\left(p^2 D_{pp}\frac{\partial}{\partial p}\frac{F}{p^2}\right) + \frac{\partial}{\partial p}\left[\dot{p}F - \frac{p}{3}(\nabla\mathbf{u})F\right] + \frac{F}{\tau_f} + \frac{F}{\tau_d} = q(\mathbf{r},p,t),$$

B-field, radiation field, gas, E-field:

Diffusion

re-acceleration

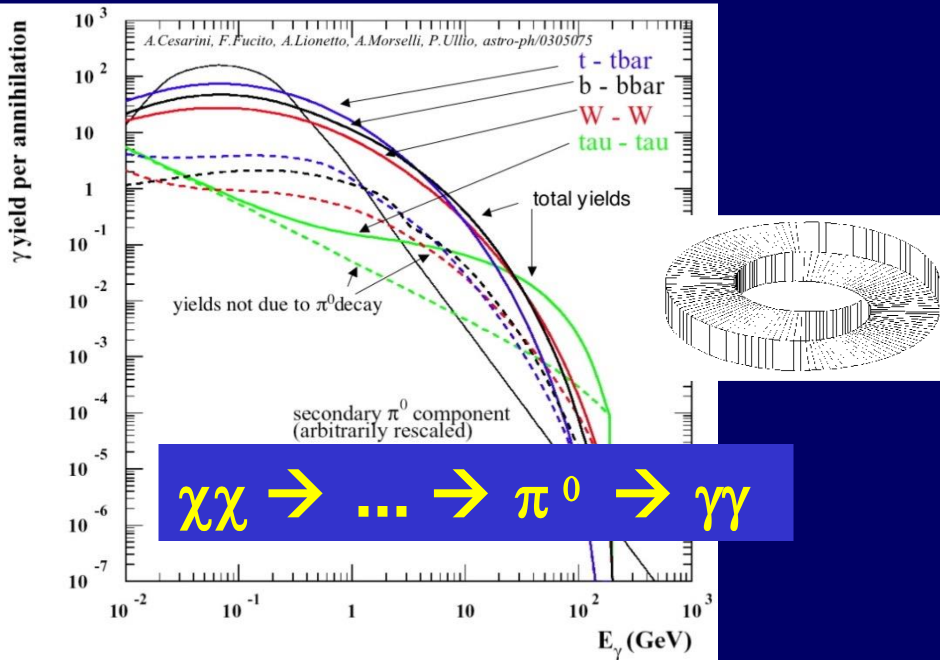
convection

energy loss

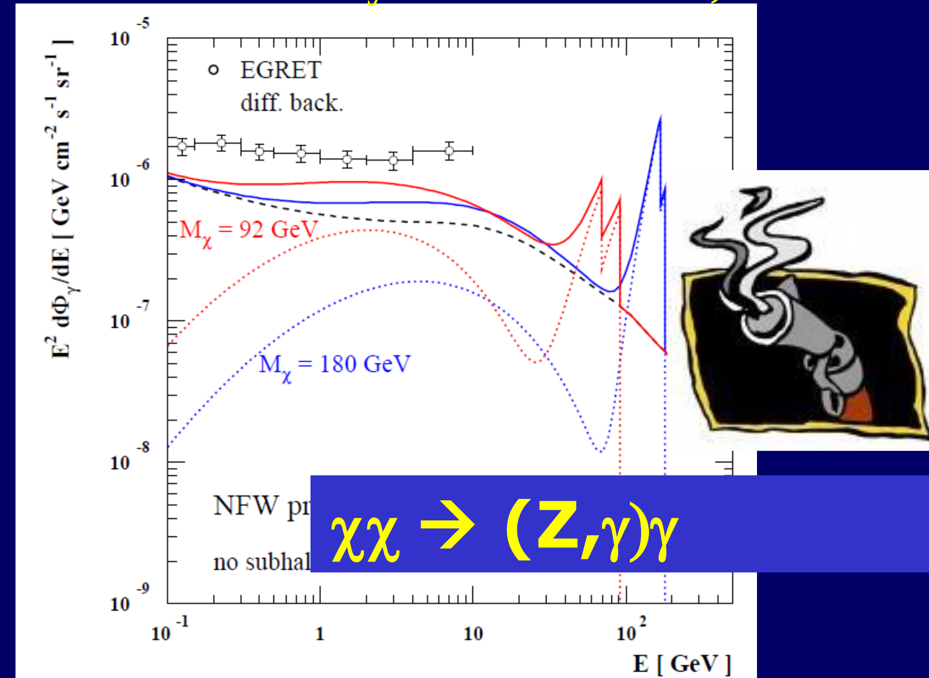
Spallation, decay

gamma rays: the golden channel

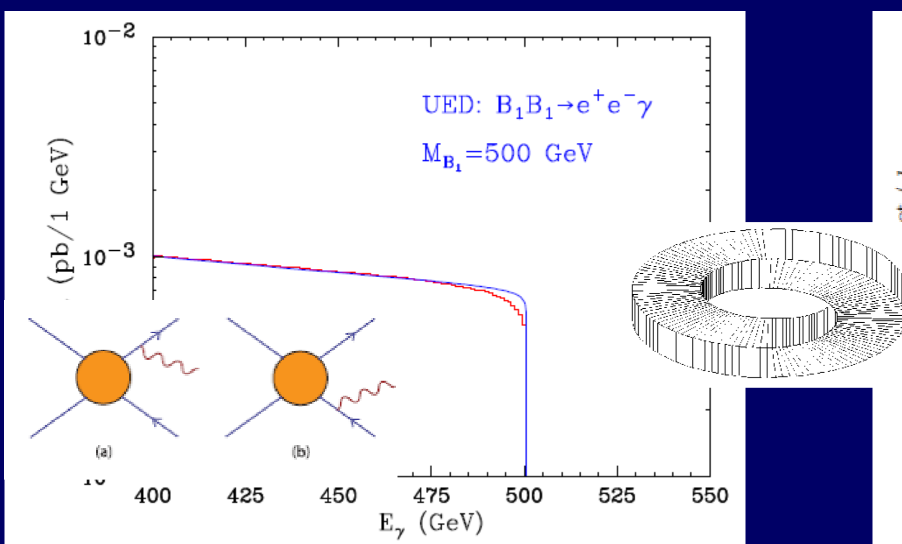
Universal spectral signatures



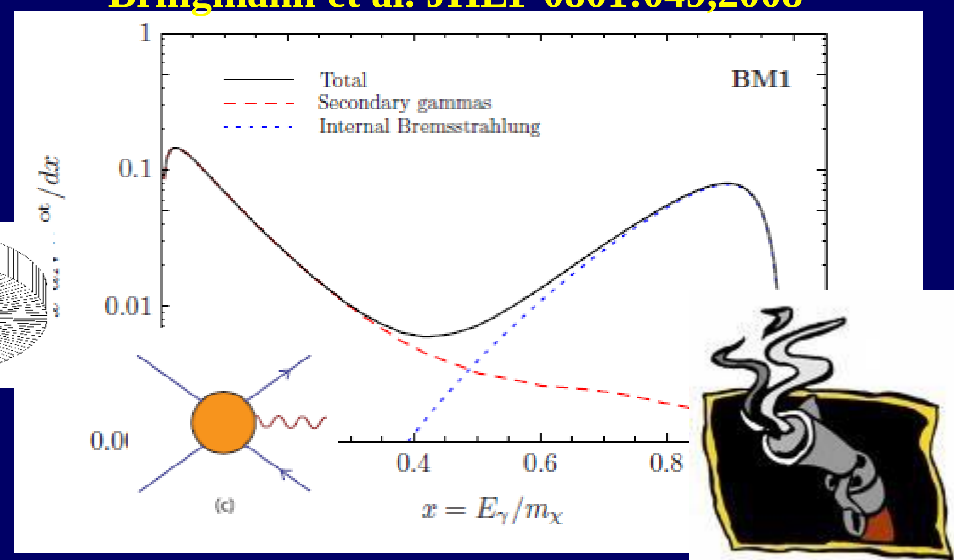
Ullio et al. Phys.Rev.D66:123502,2002



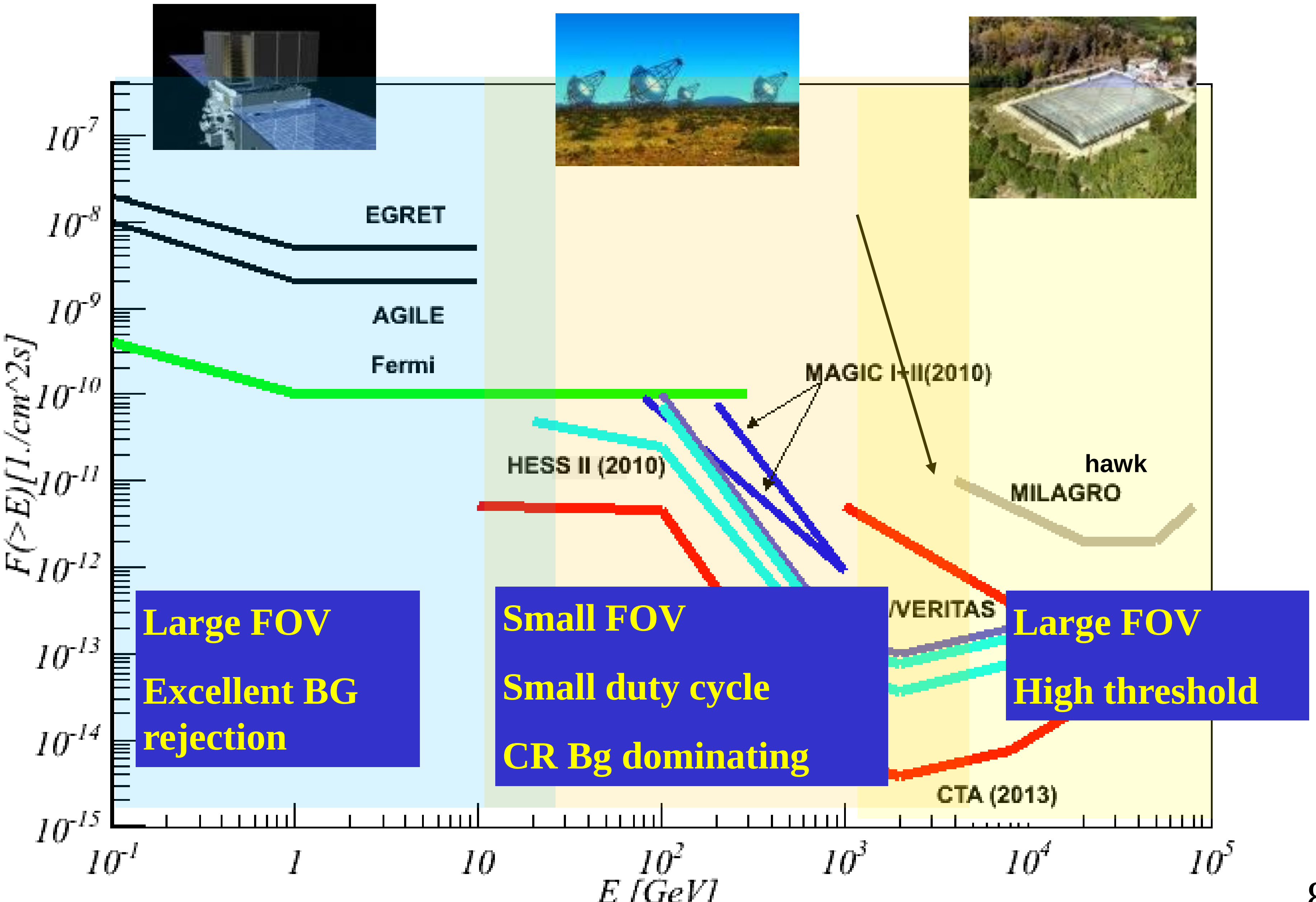
Birkedal et al.



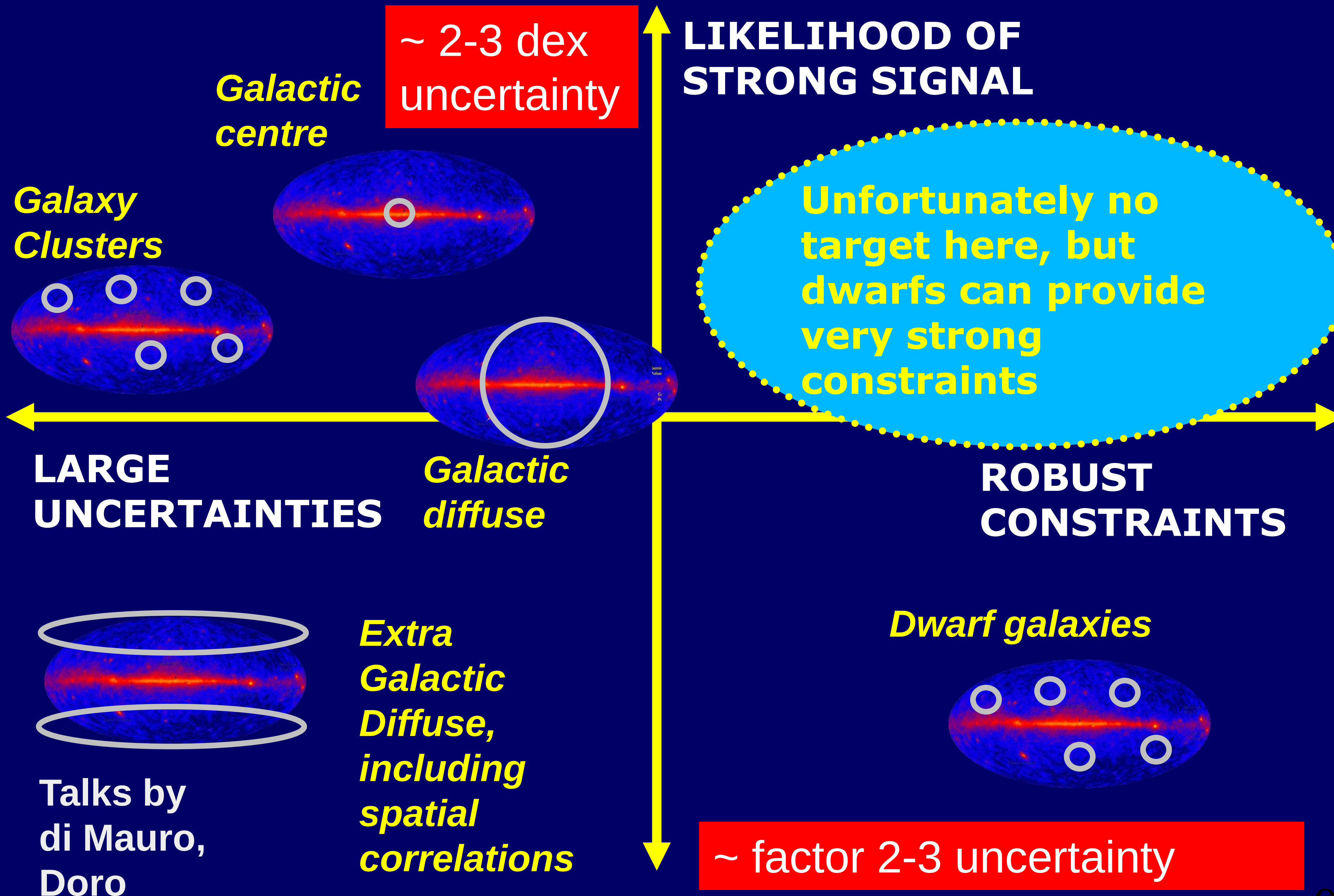
Bringmann et al. JHEP 0801:049,2008



Gamma-rays: sensitivity illustration



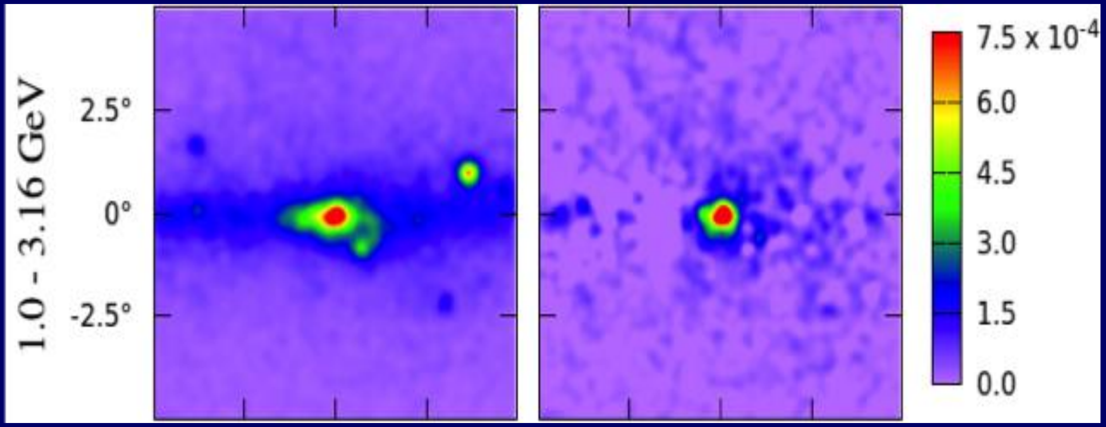
Targets and Challenges –satellites



Fermi-LAT Galactic center excess – history and status

- General agreement (e.g., Goodenough & Hooper 09, 11; Hooper & Slatyer 13; Daylan+14, Abazajian+14, Calore+14; Gordon & Macías 14) on the excess peaking at a few GeV above the ***standard*** diffuse emission models.
- Interpretation difficult due to complicated foreground/background modeling.
- DM annihilation a plausible and exciting possibility

Total flux **Residuals**

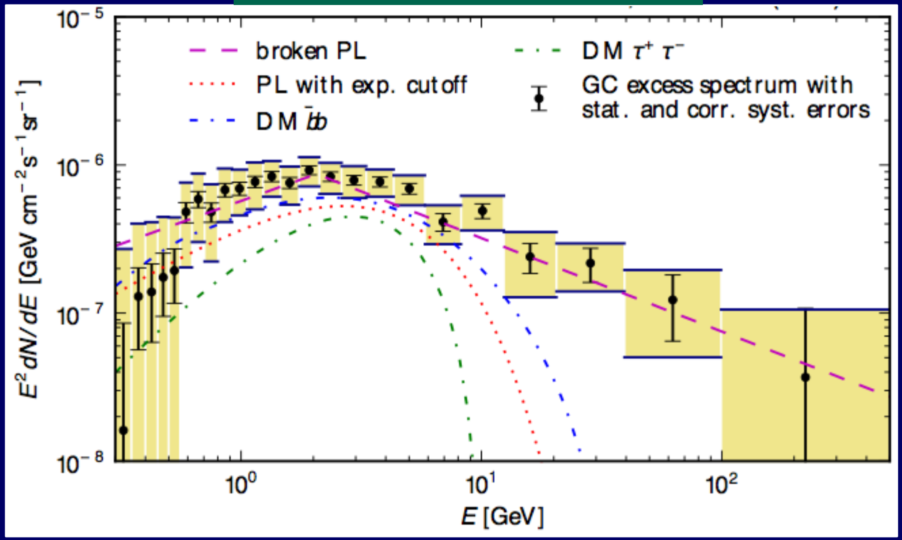


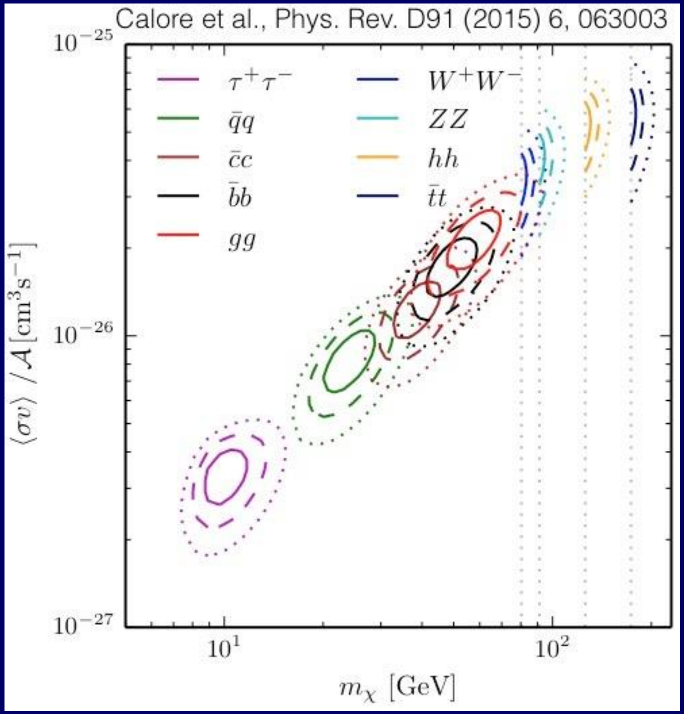
Daylan+14

What does the spectrum say?

- Spectral fit to DM models are good (broken power-law, PL with exp. Cut off also work …)
- Approx. half $<\sigma v>_{thermal}$
- DM mass:
  - ~50 GeV (b quarks)
  - ~40 GeV (c quarks)
  - ….

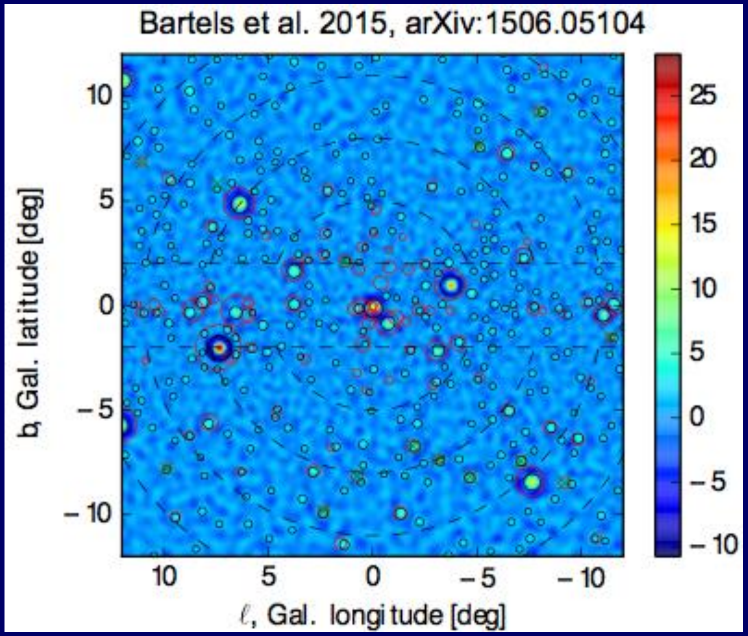
Calore + 2015

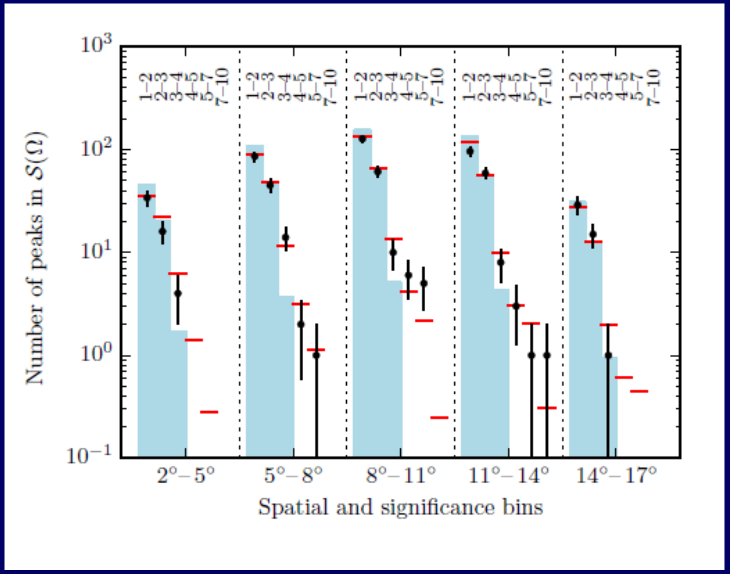




Is it really an extended source?

- Millisecond pulsars provide similar spectrum [Baltz+07], MSPs suggested [Abazaijan+14, O'Leary+15, Brandt+15]
- MSP wavelet decomposition of gamma-ray sky → 10σ exclusion of truly diffuse emission [Bartels+16, Lee+16] (see also Torino group work, Zechlin+ (2016))
- Requires extra bulge population of pulsars (~30 MLPs vs much less with MeerCAT survey)

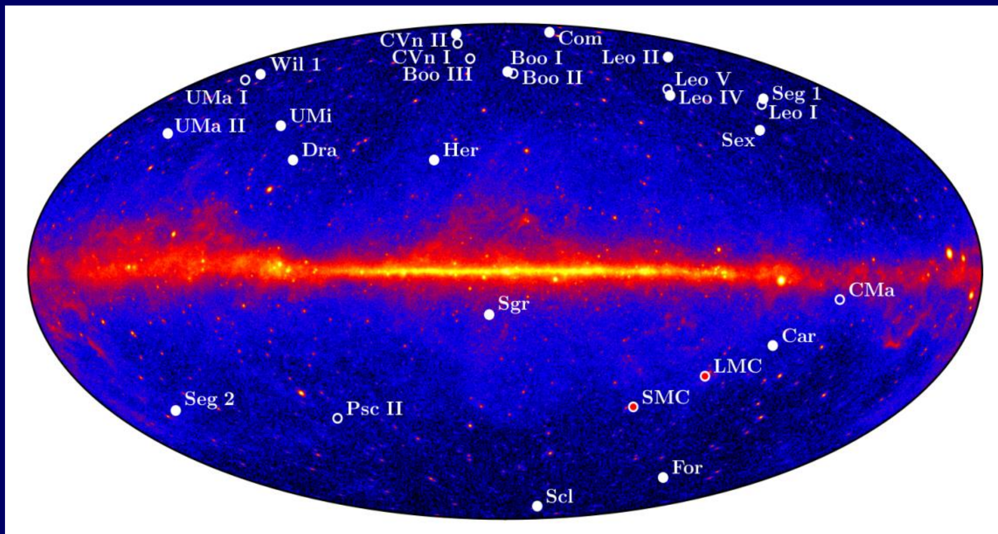


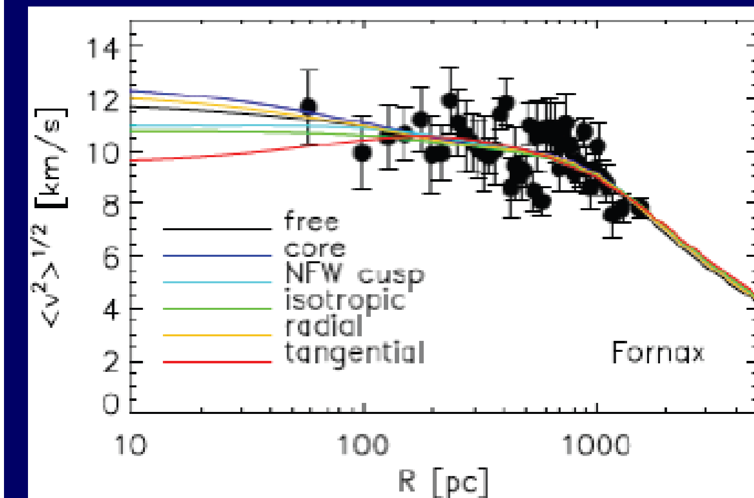


Weniger+ Calore talk at DSU

IS THERE ANY OTHER WAY TO CHECK THIS?

4th generation of LAT Dwarf Search for Dark matter





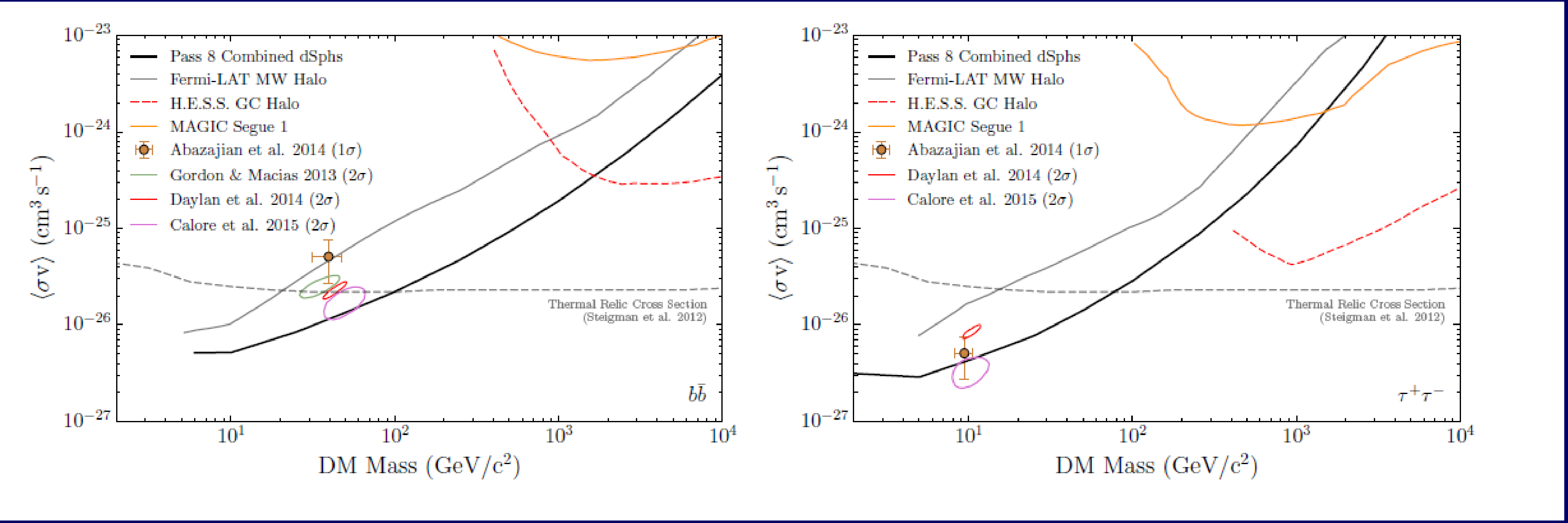
e.g:
Charbonnier+, MNRAS 418 (2011) 1526
Strigari+,Phys. Rev. D, 75, 083526
Evans+, Phys. Rev., D69, 123501, (2004)

arXiv	irf	time	targets	joint?
1001.4531	P6	11 mo.	10	no
1108.3546	P6	24 mo.	10	yes
1310.0828	P7	48 mo.	15	yes
1503.0264	P8	60 mo.	15	yes x2!

- 2011: first time “robust” thermal WIMP exclusion

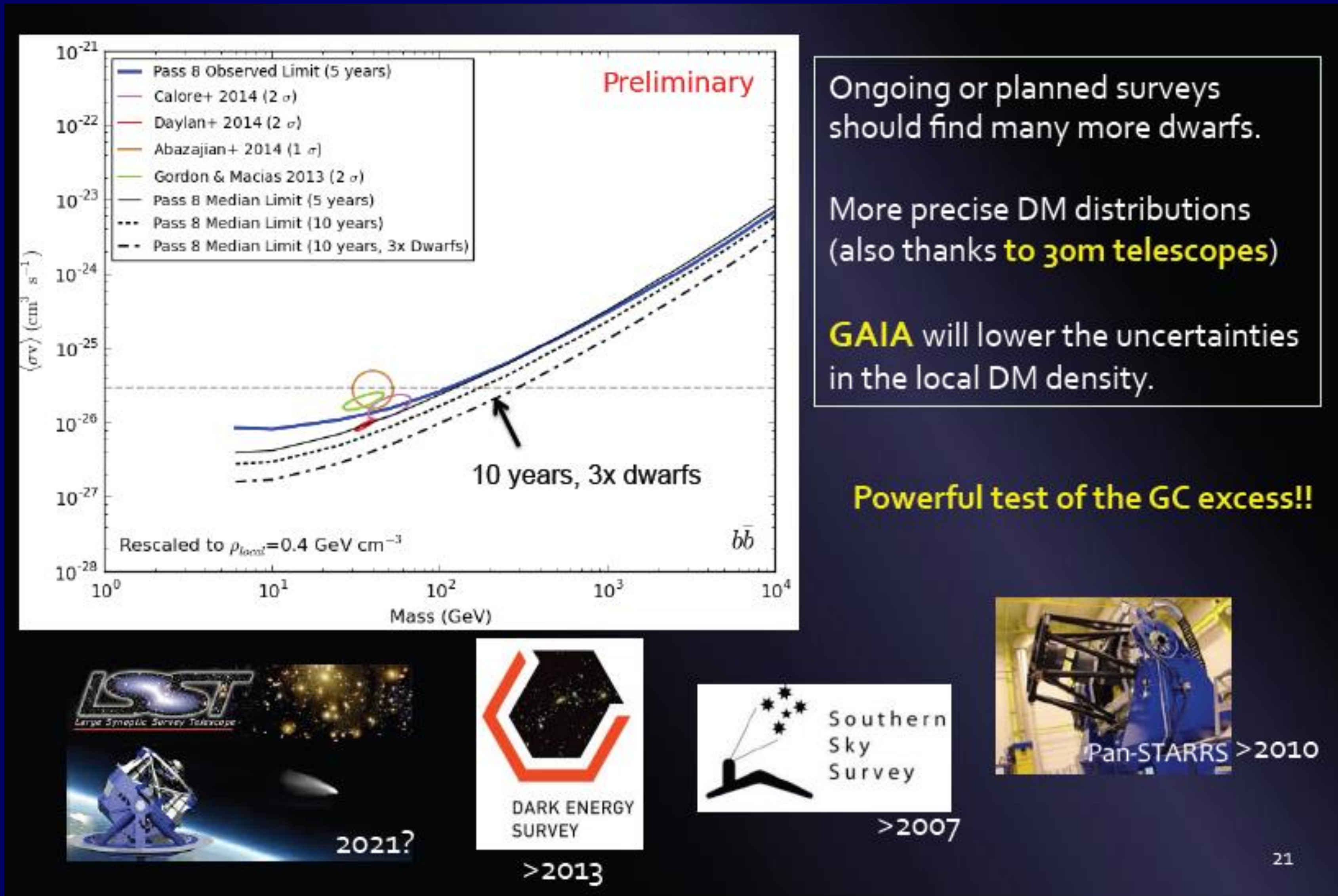
Dwarf-Galactic Center Compatibility

b-quark channel

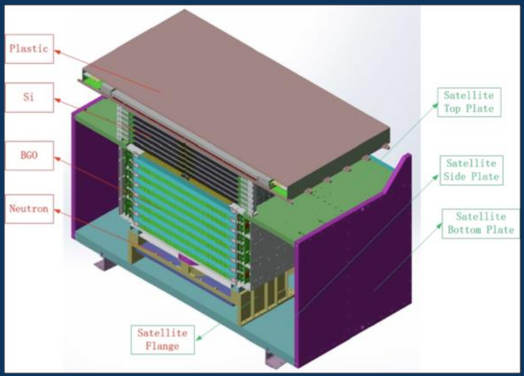


Phys. Rev. Letters (2015)
arXiv:1503.02641

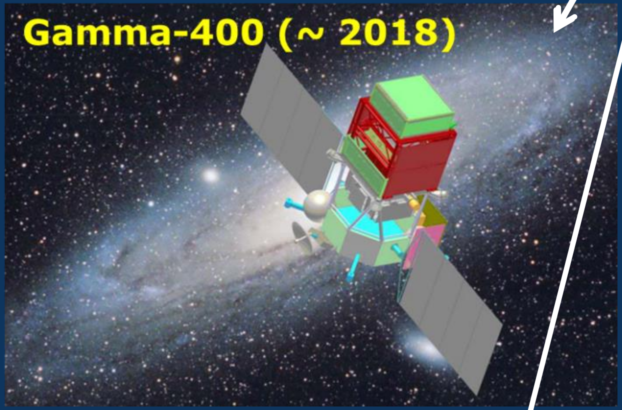
Future with more dwarfs

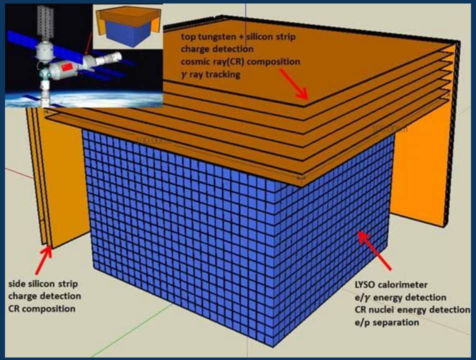


FUTURE SATELLITE MISSIONS



DAMPE launched!



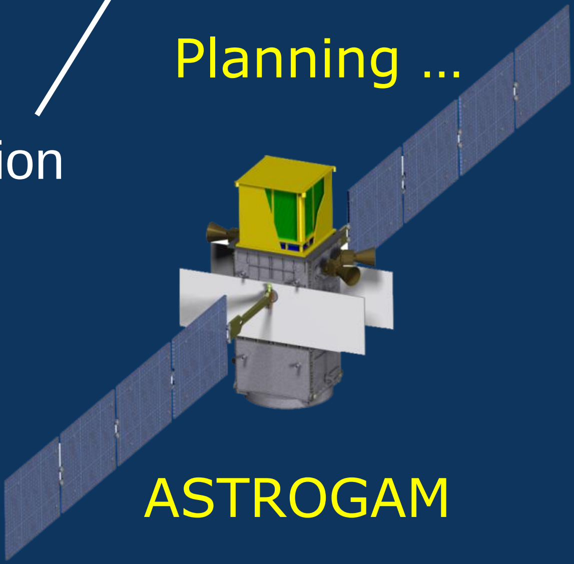


HERD (2020)

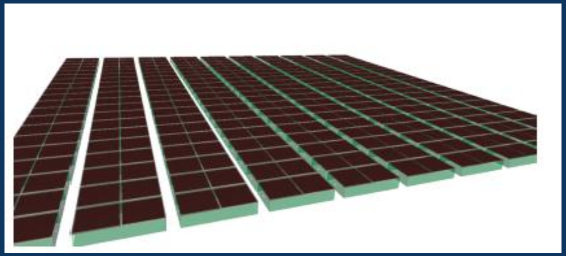
- Line features
- Low mass WIMPs, solution to the GC excess?
- For a generic ~100 GeV WIMP → nothing until 2025?

PANGU
盤古

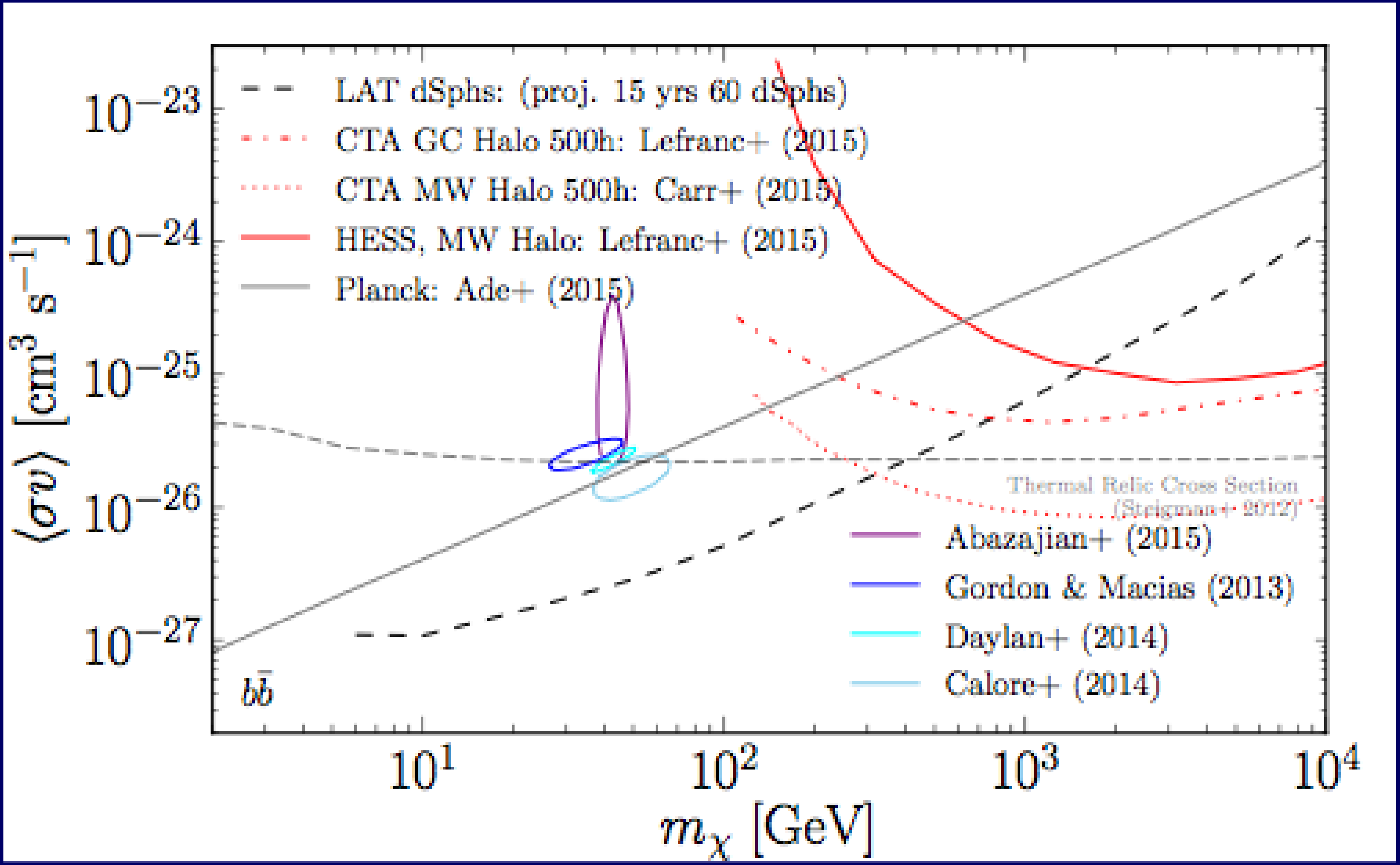
Planning …



ASTROGAM …

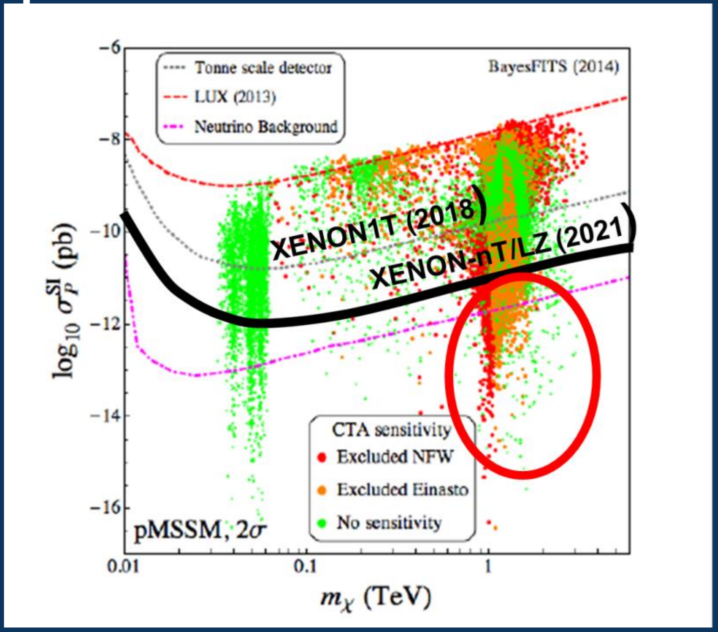


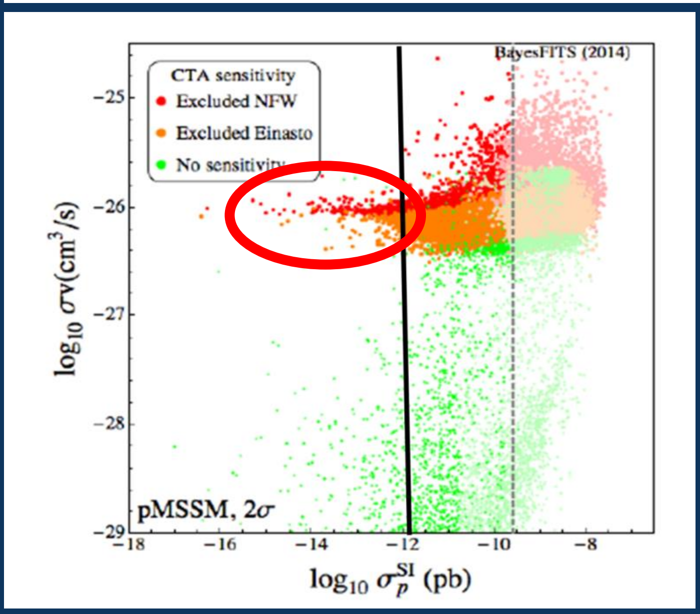
Most important gamma–ray constraints: summary



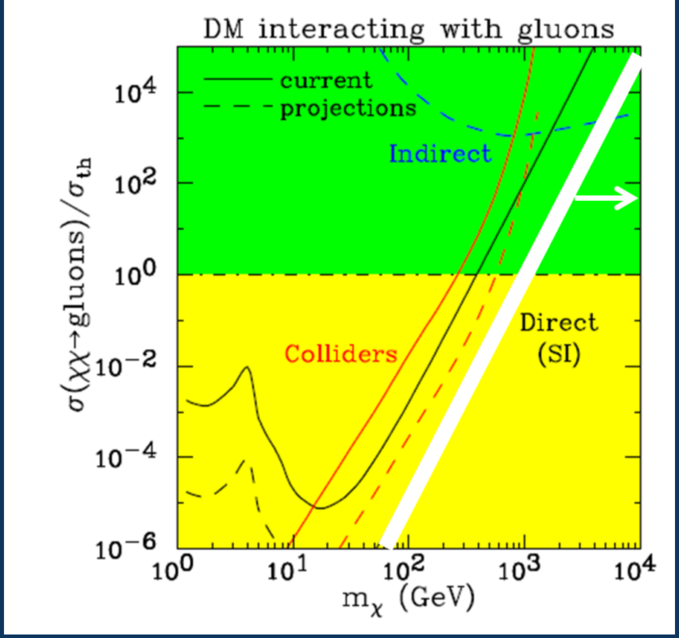
REACH

pMSSM19





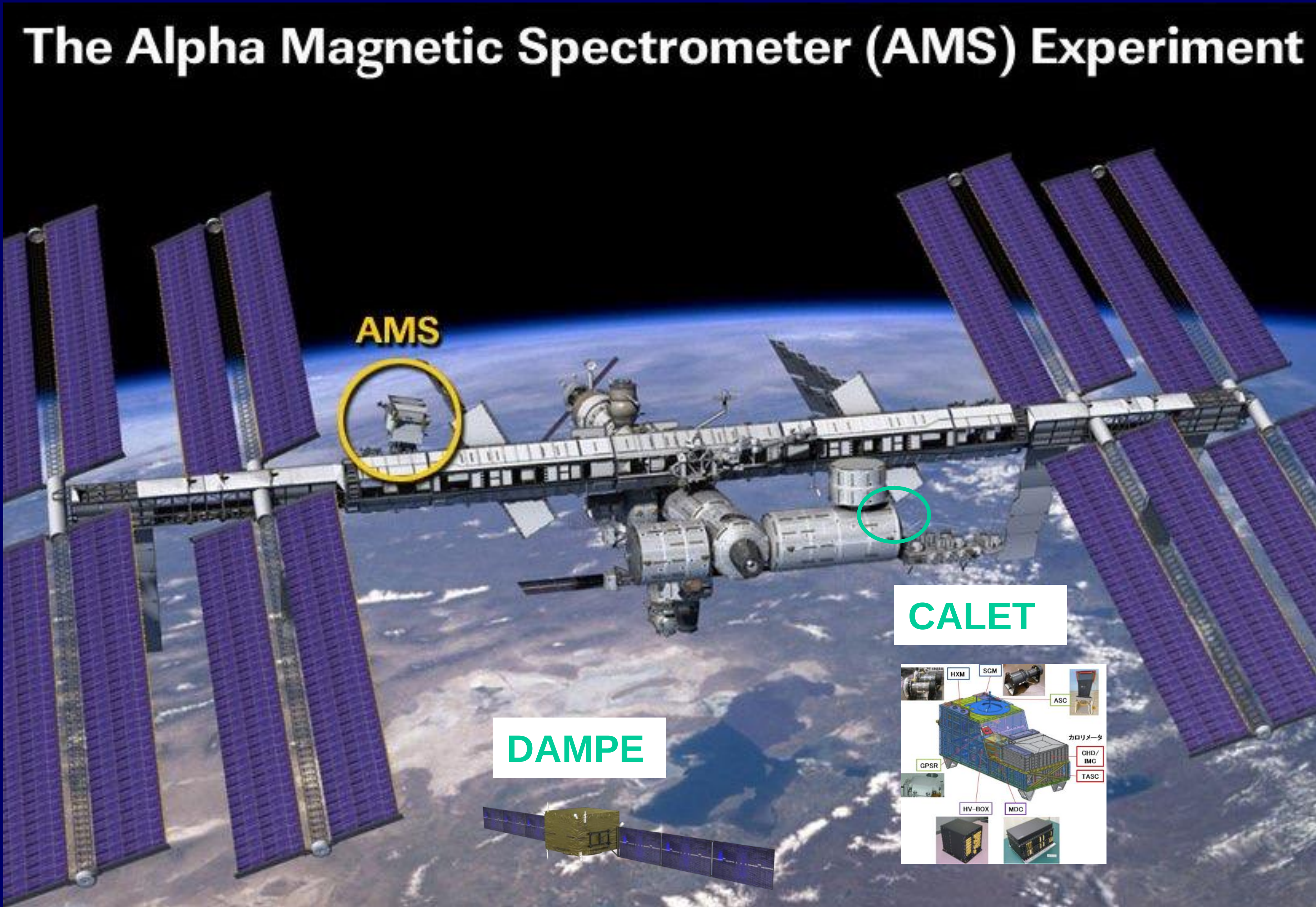
EFT



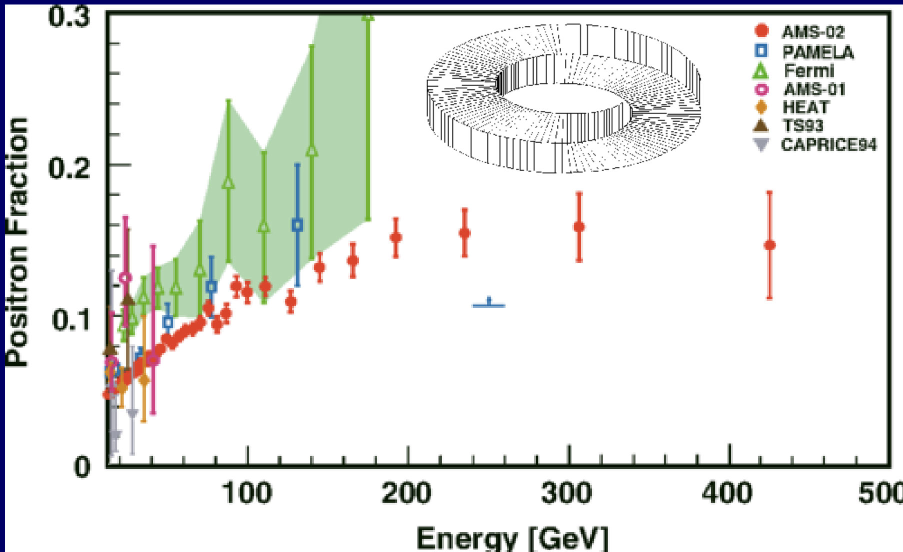
~ 1 TeV Higgsino

Direct detection reaches somewhat higher than LHC in mass, but ID takes over beyond a few TeV

Adapted from Roszkowski+ (2015)


The Alpha Magnetic Spectrometer (AMS) Experiment
AMS
CALET
DAMPE
HXM
SGM
ASC
カロリメータ
CHD/IMC
TASC
GPSR
HV-BOX
MDC

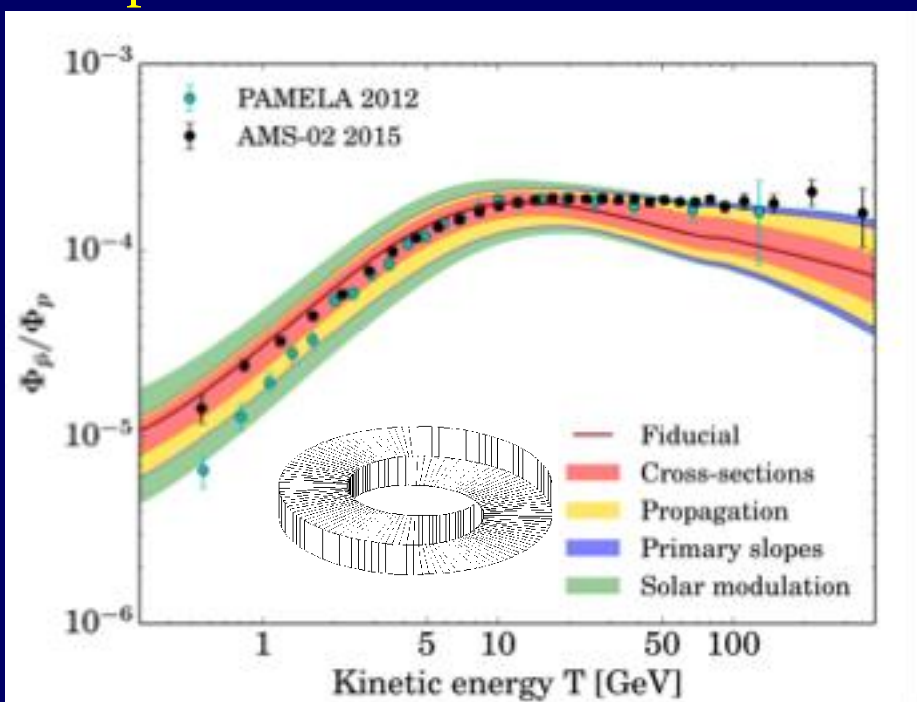
Cosmic rays: signatures



Positron fraction

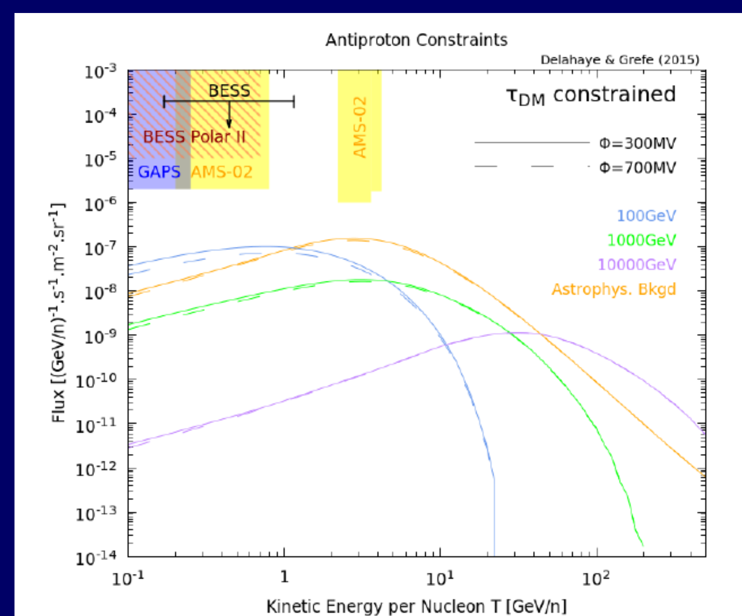
Talks by Caroff,Vecchi, Nozzoli, Mikhailov …

Antiproton fraction



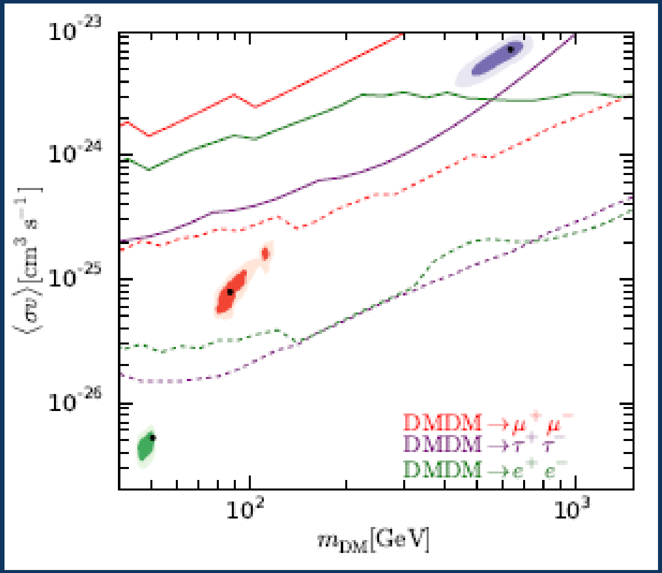
Anti-deuteron spectrum

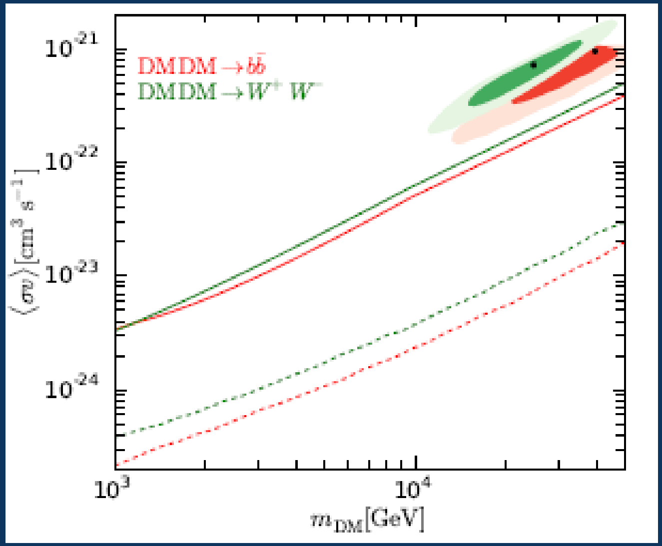
Seminal work by Donato,Fornengo+ (2000)
Delahaye+Grefe (2015)



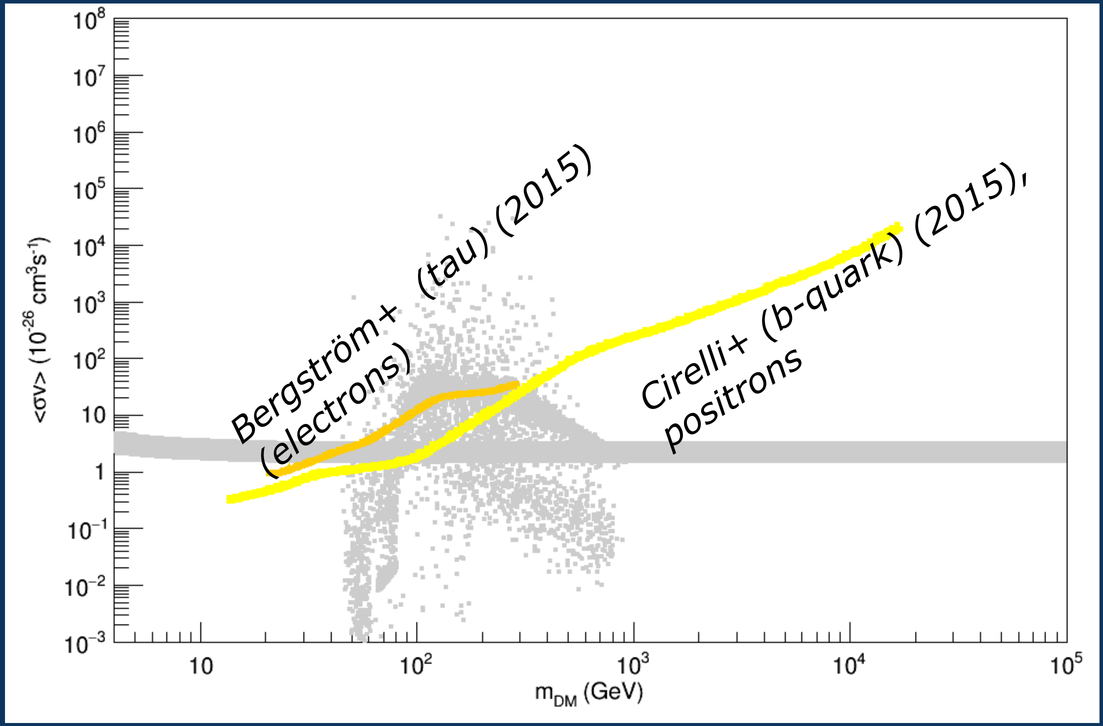
What does AMS tell us about dark matter?

Di Mauro+, 2016 (electrons)



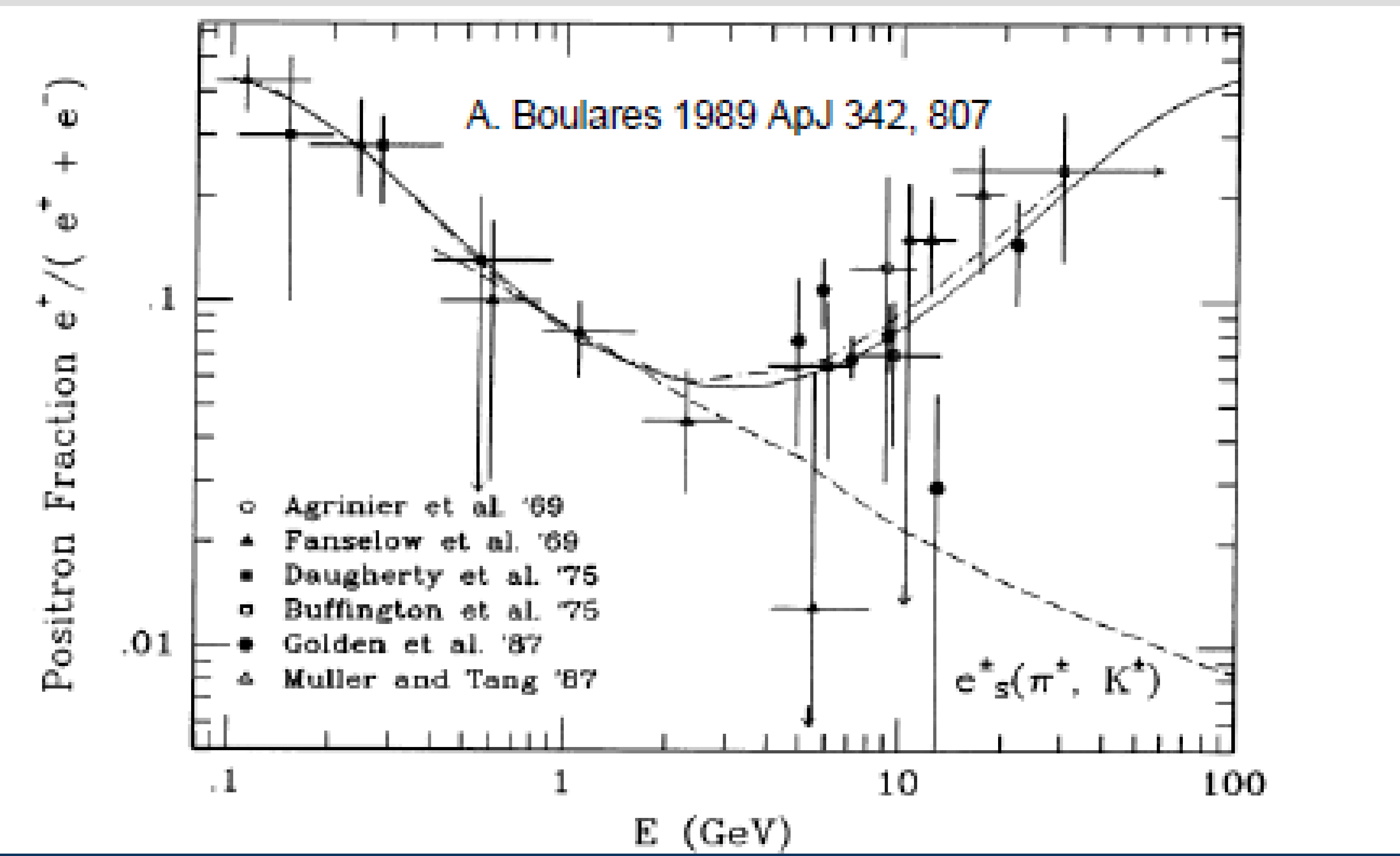


… using the excellent statistics to place constraints



… under Dark Matter assumption

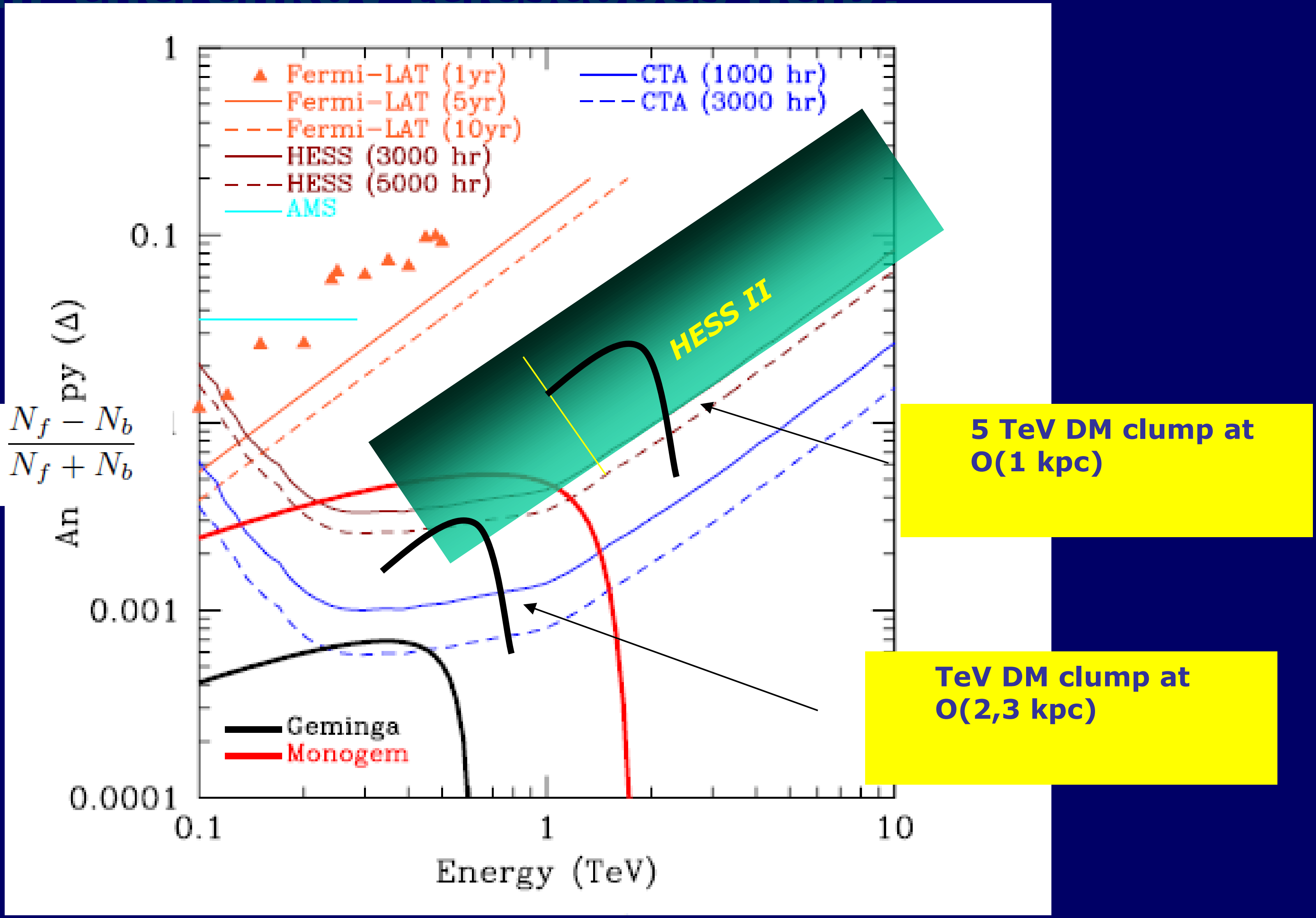
PULSARS



A. Boulares 1989 ApJ 342, 807
Positron Fraction e+/(e+ + e-)
.1
.01
.1
1
10
100
E (GeV)
Agrinier et al. '69
Fanselow et al. '69
Daugherty et al. '75
Buffington et al. '75
Golden et al. '87
Muller and Tang '87
e+s(π±, K±)

Can air cherenkov telescopes help?

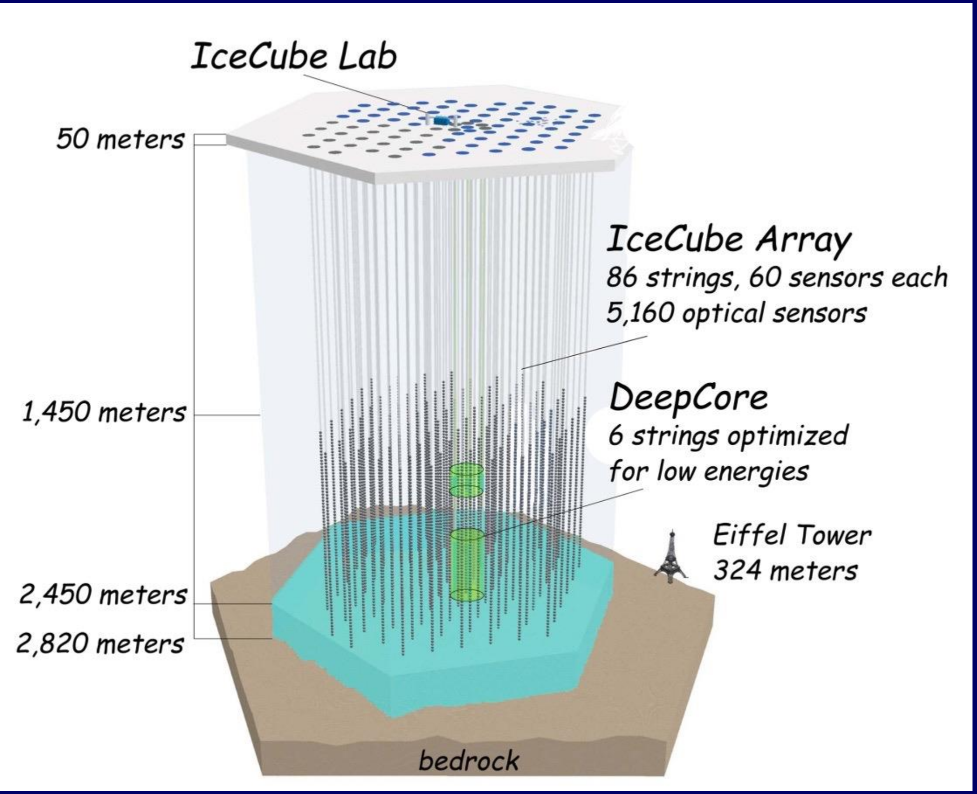
$$\Delta = \frac{N_f - N_b}{N_f + N_b}$$

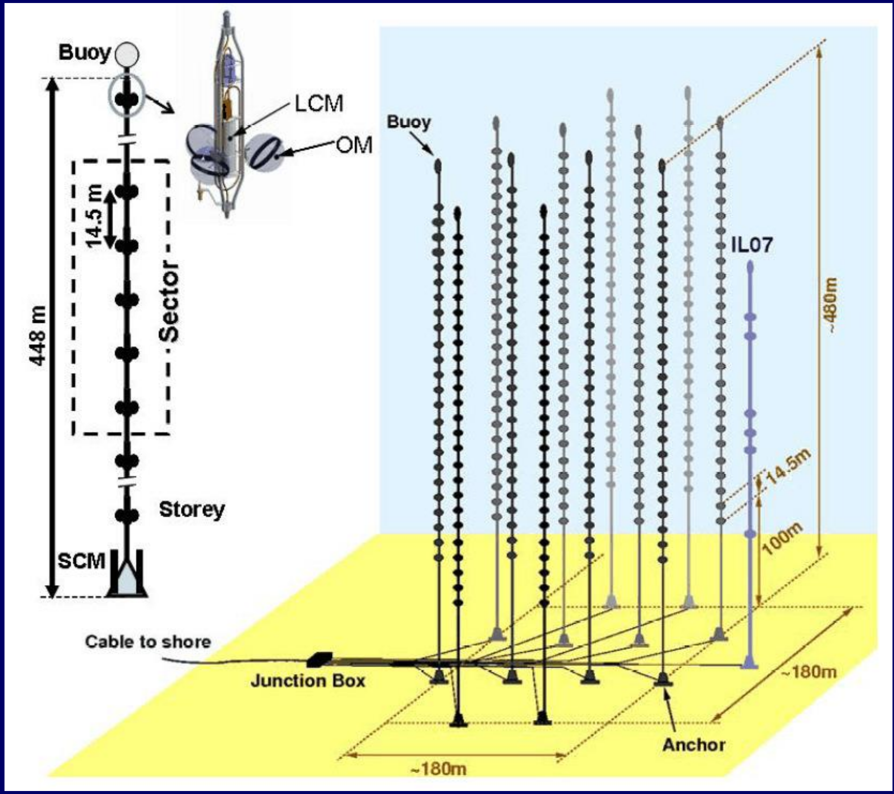


Linden,Profumo (2013)

See also Regis, Ullio (2009)

IceCube and ANTARES



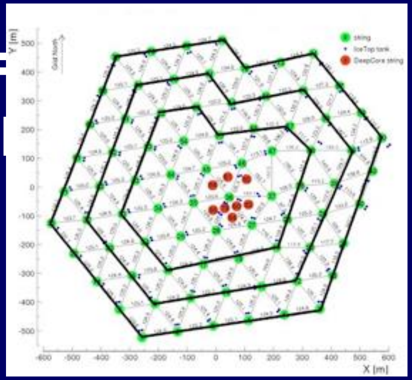


- Mainly northern hemisphere
- ~5000 channels
- Good calorimetry

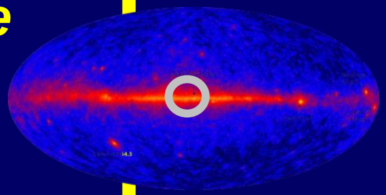
- Mainly southern hemisphere
- ~900 channels
- High resolving power

Targets and Challenges – neutrino telescopes

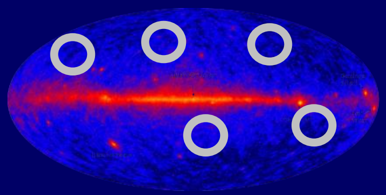
LIKELIHOOD OF
STRONG SIGNA

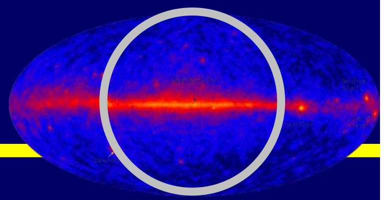


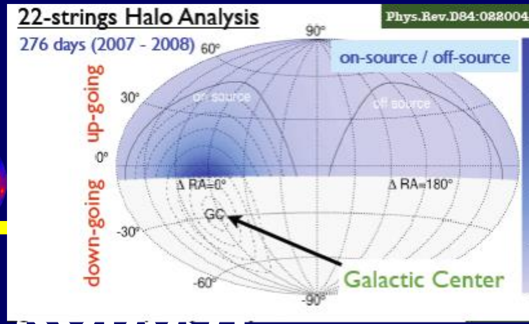
Galactic centre



Galaxy Clusters





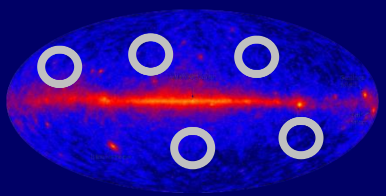


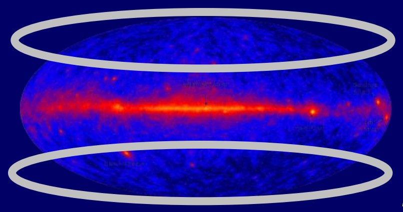
Galactic diffuse

LARGE UNCERTAINTIES

CONSTRAINTS

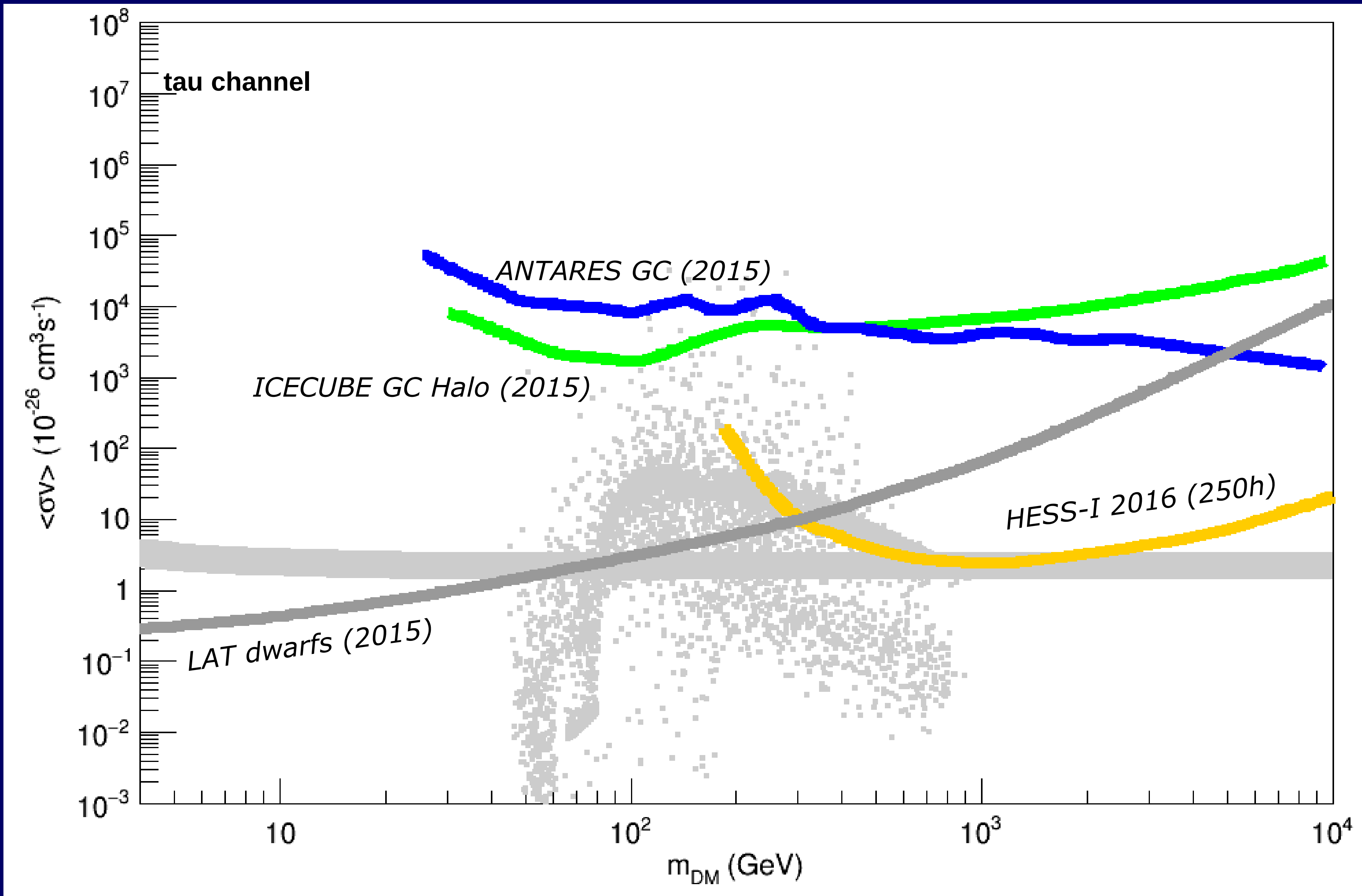
Dwarf galaxies



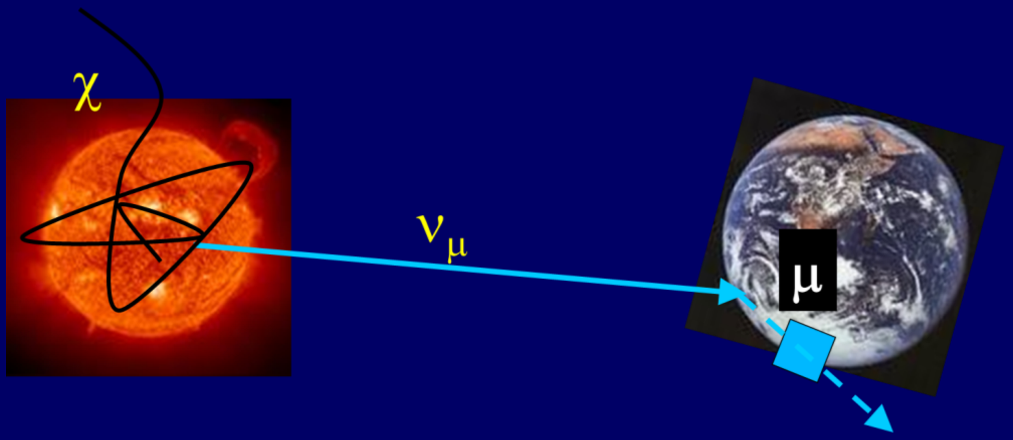


Extra Galactic Diffuse

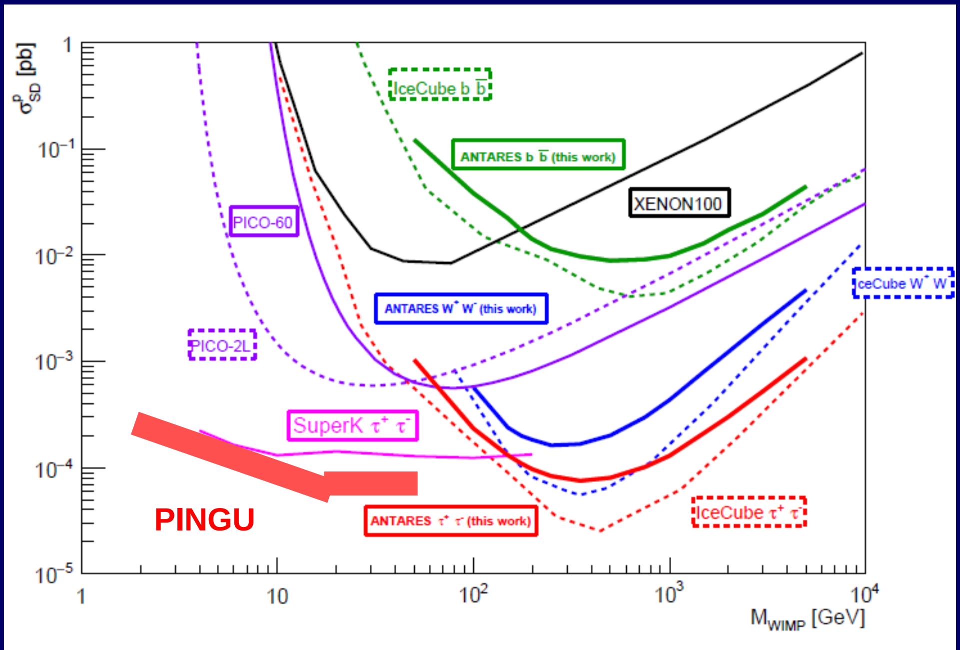
tau channel


tau channel
ANTARES GC (2015)
ICECUBE GC Halo (2015)
HESS-I 2016 (250h)
LAT dwarfs (2015)
<σv> (10^-26 cm^3s^-1)
m_DM (GeV)
10^8
10^7
10^6
10^5
10^4
10^3
10^2
10
1
10^-1
10^-2
10^-3
10
10^2
10^3
10^4

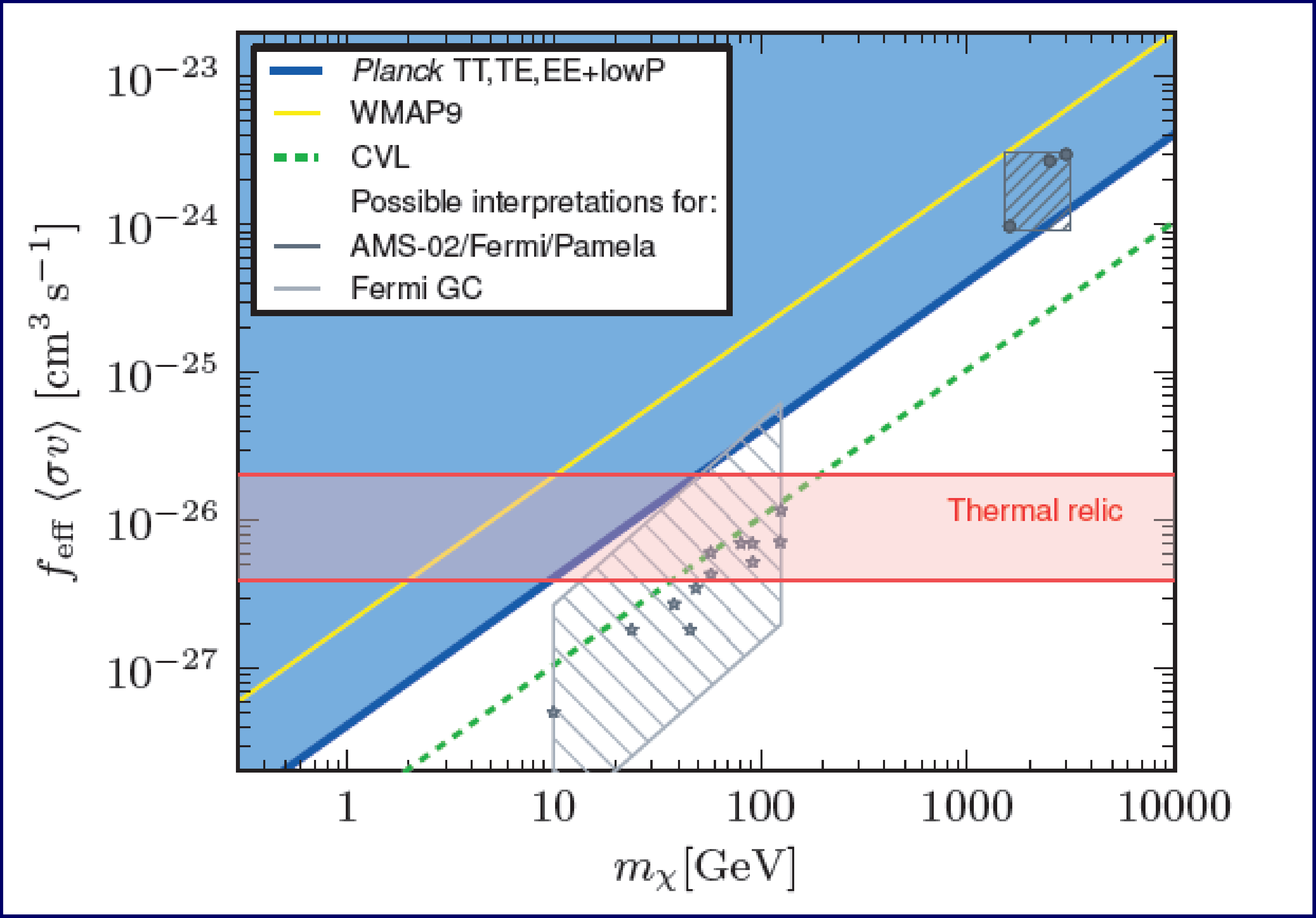
Competetive in direct detection observables



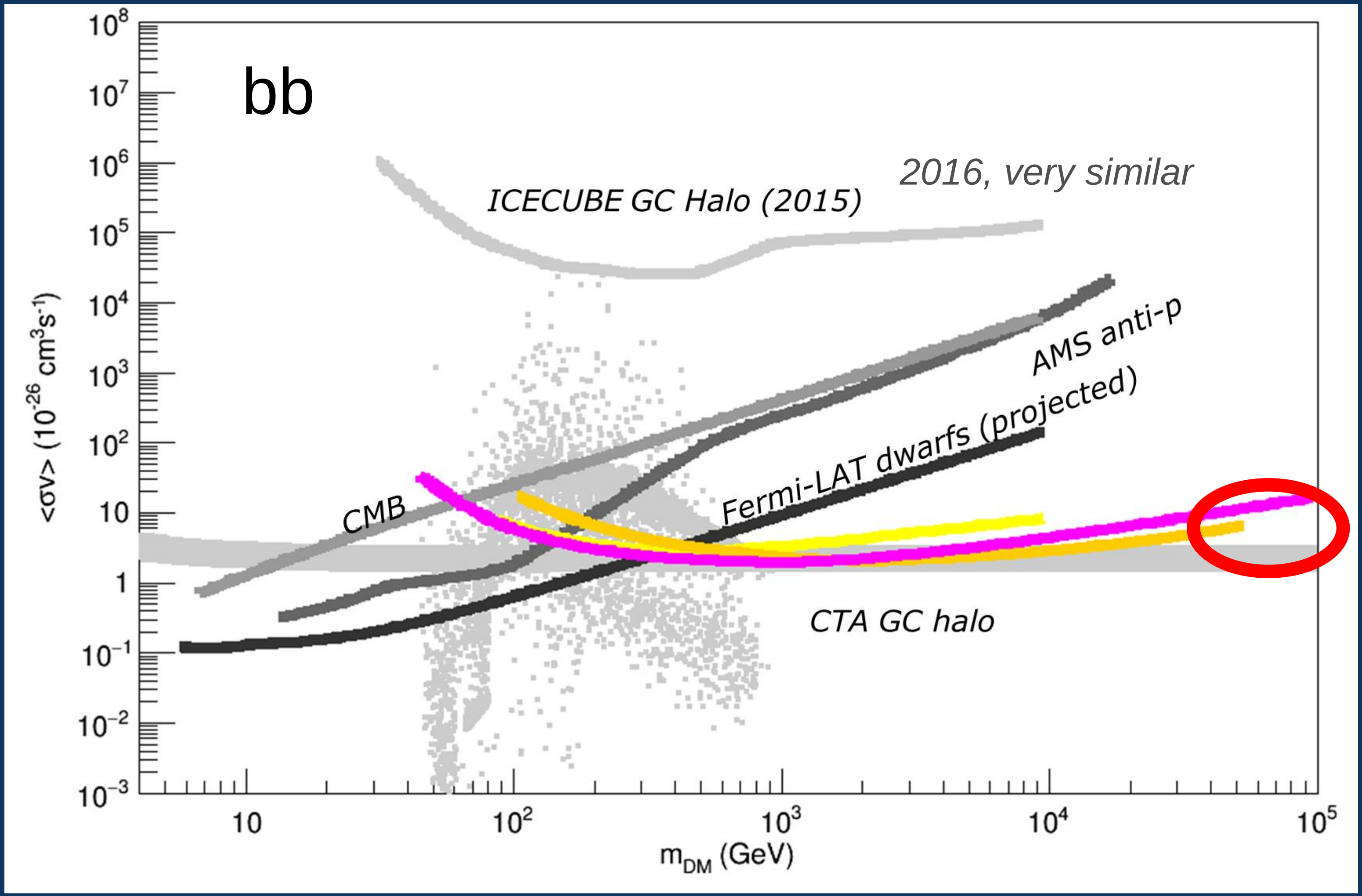
$\Gamma_{Capture}$ $(\propto \sigma_{SD})$ $= 2\, \Gamma_{annihilation}$



Cosmic Microwave background - PLANCK



INDIRECT OVERVIEW



AMS magnetic spectrometer see Schael Talk

If DM ~2-3TeV

CTA sensitivities:

Silverwood+(2015)
Doro+ (2013)
Carr+ (2015)

~1 dex @ 1 TeV,
~2-3 dex @ 10 TeV

~100 TeV!

Final remarks.

- We are in the middle of an exciting phase for indirect detection of WIMP dark matter.

- Gamma-rays yield the most promise, for the most generic WIMPs. The fiield is driven by Galacic Center and Dwarf Galaxy targets.

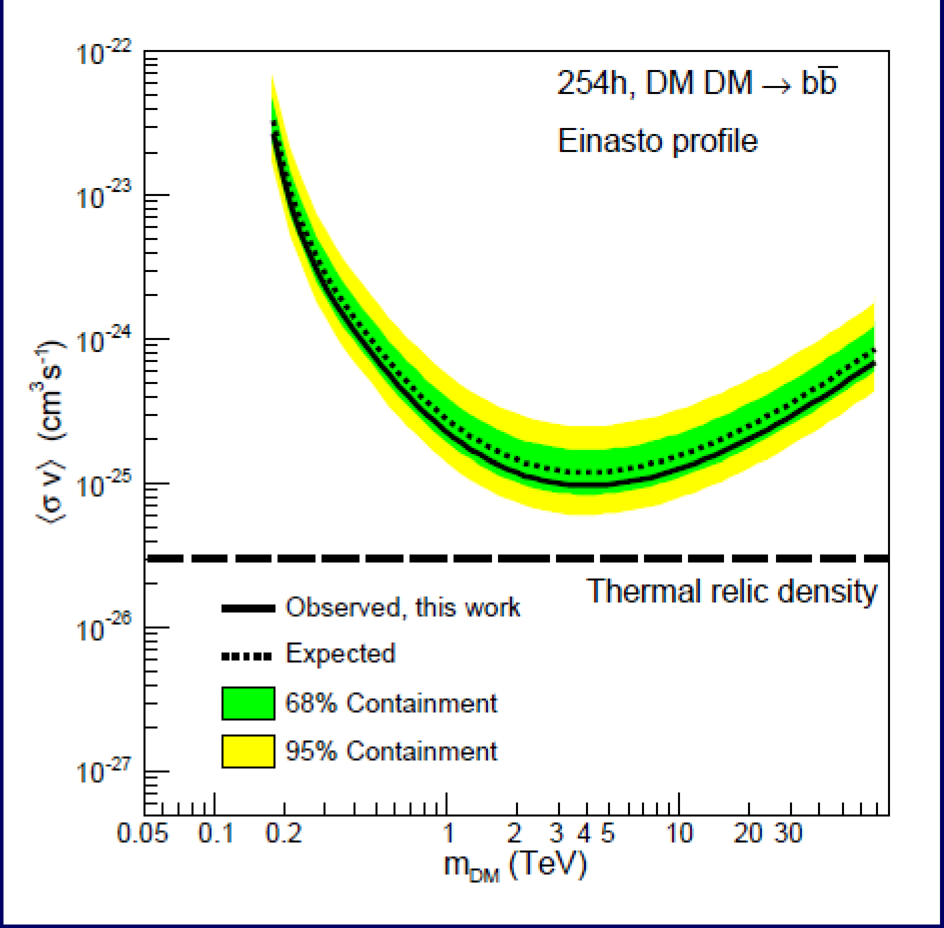
- Future: a lot of excitement is almost guaranteed: the next major step in sensitivity will happen in direct detection. LHC? If nothing is seen → CTA

"The train of Supersymmetry is late"

Guido Altarelli

- Cosmic-rays and neutrinos have their role to play for more specific models. Neutrinos have a niche when it comes to spin-dependent WIMP scattering.

HESS (2016)



254h, DM DM → $b\bar{b}$
Einasto profile
Thermal relic density
Observed, this work
Expected
68% Containment
95% Containment
$\langle\sigma v\rangle$ ($cm^3 s^{-1}$)
10^{-22}
10^{-23}
10^{-24}
10^{-25}
10^{-26}
10^{-27}
0.05 0.1 0.2 1 2 3 4 5 10 20 30
m_{DM} (TeV)