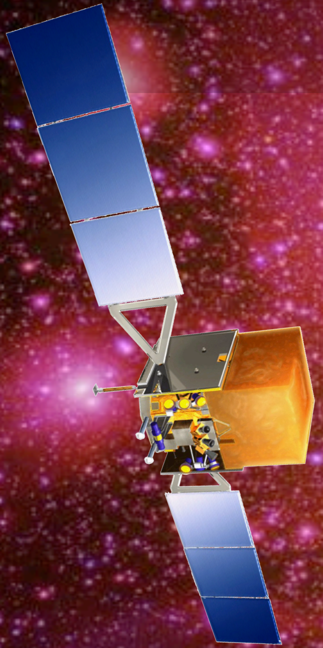
Current constraints on dark matter and future observational strategies with gamma-rays experiments



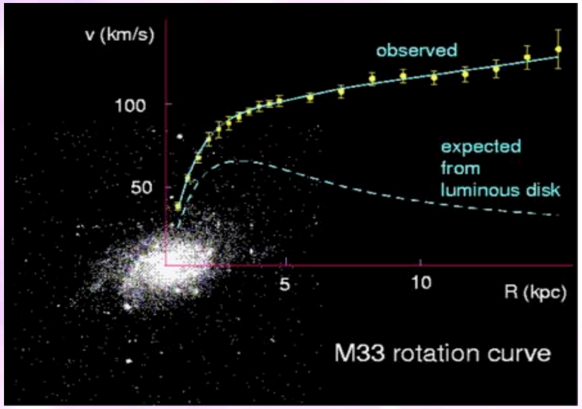
Aldo Morselli
INFN Roma Tor Vergata

5Th Workshop On Air Shower Detection At High Altitude
26-28 May, 2014, Paris, France

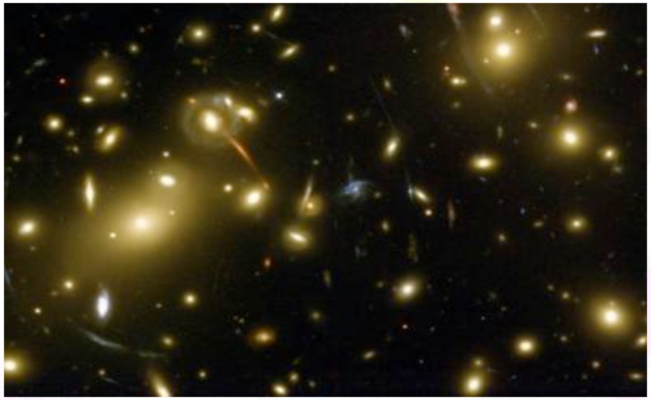
Dark Matter EVIDENCES

- In 1933, the astronomer Zwicky realized that the mass of the luminous matter in the Coma cluster was much smaller than its total mass implied by the motion of cluster member galaxies:
- Since then, many other evidences:

Rotation curves of galaxies

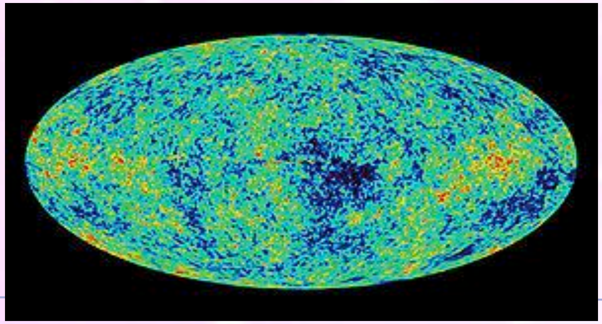


Gravitational lensing

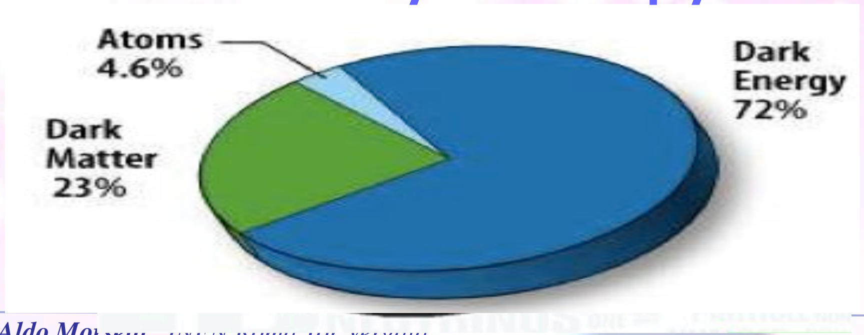


Bullet cluster

Structure formation as deduced from CMB



Data by WMAP imply:

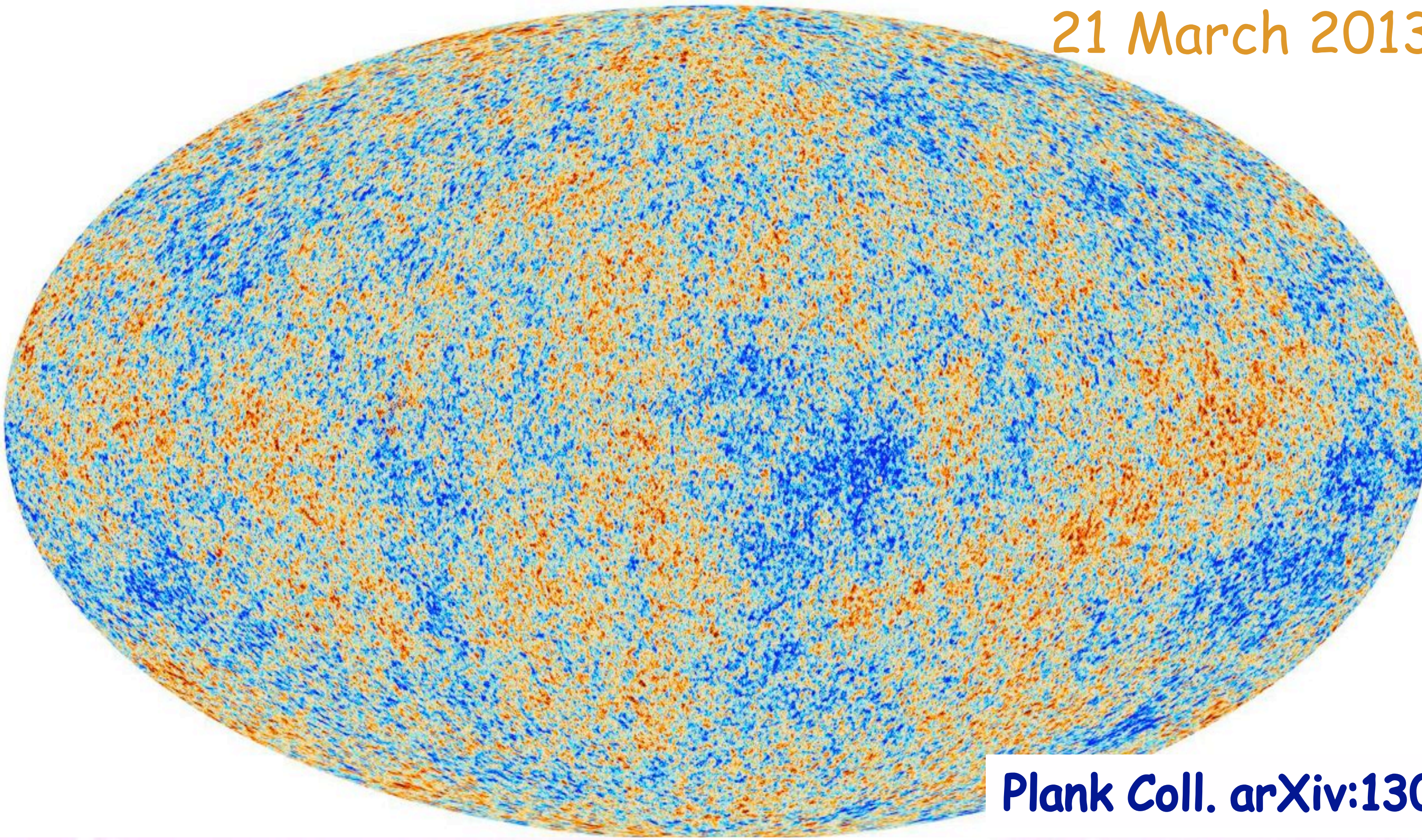


$\Omega_b h^2 \approx 0.02$

$\Omega_{DM} h^2 \approx 0.1$

The anisotropies of the Cosmic microwave background (CMB) as observed by Planck

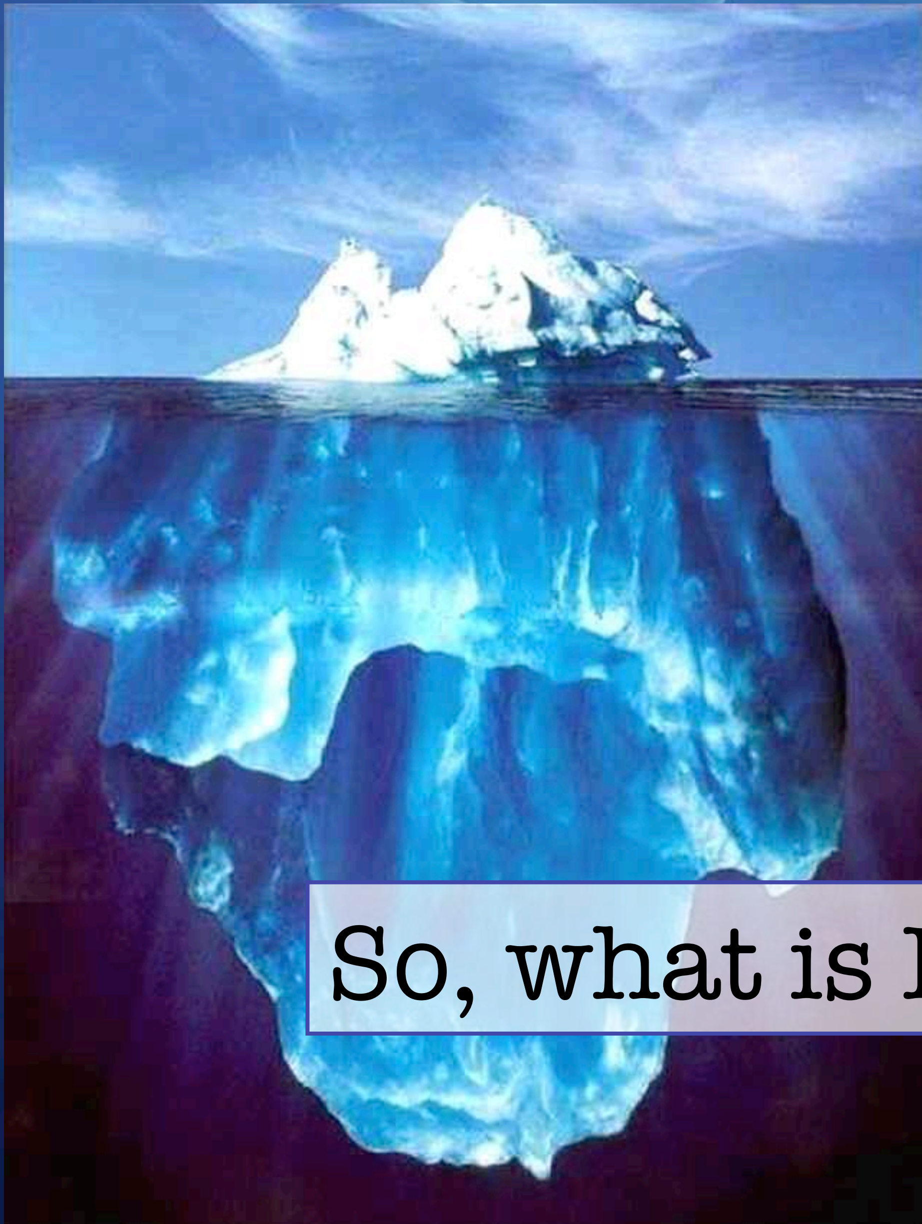
21 March 2013

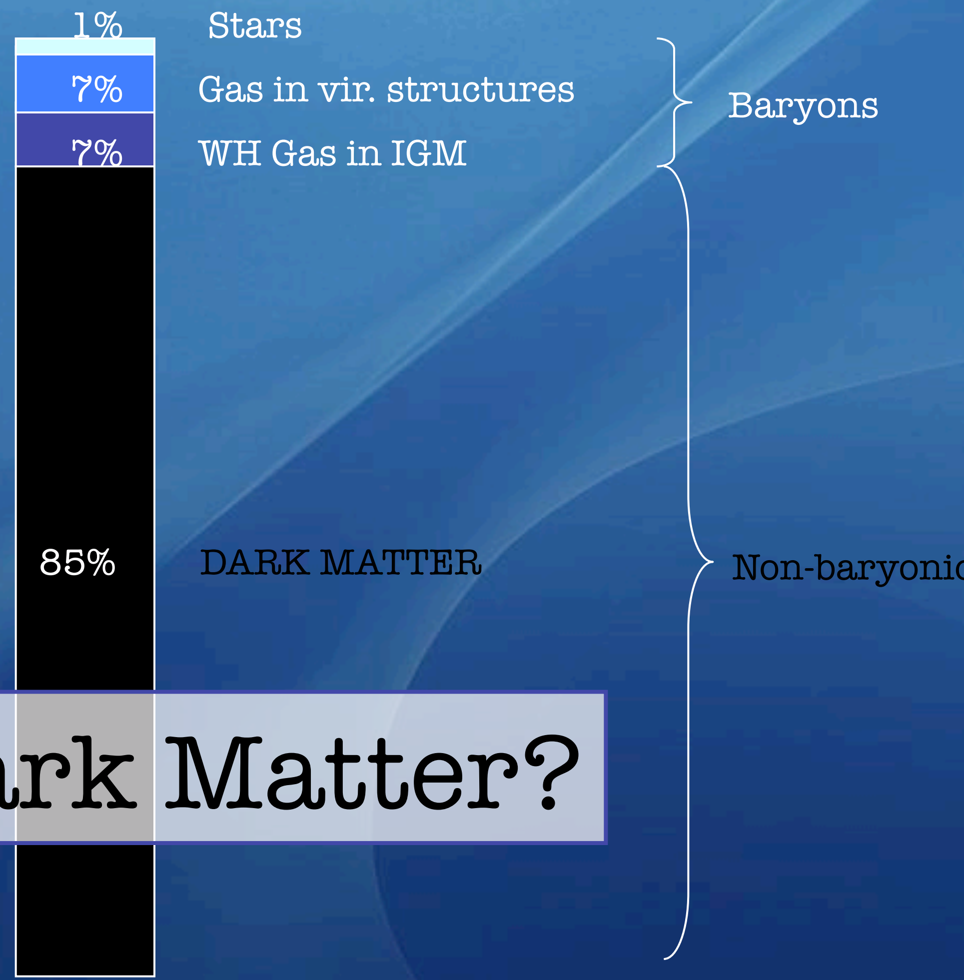


Plank Coll. arXiv:1303.5076

Dark Matter

An Inventory of Matter in the Universe

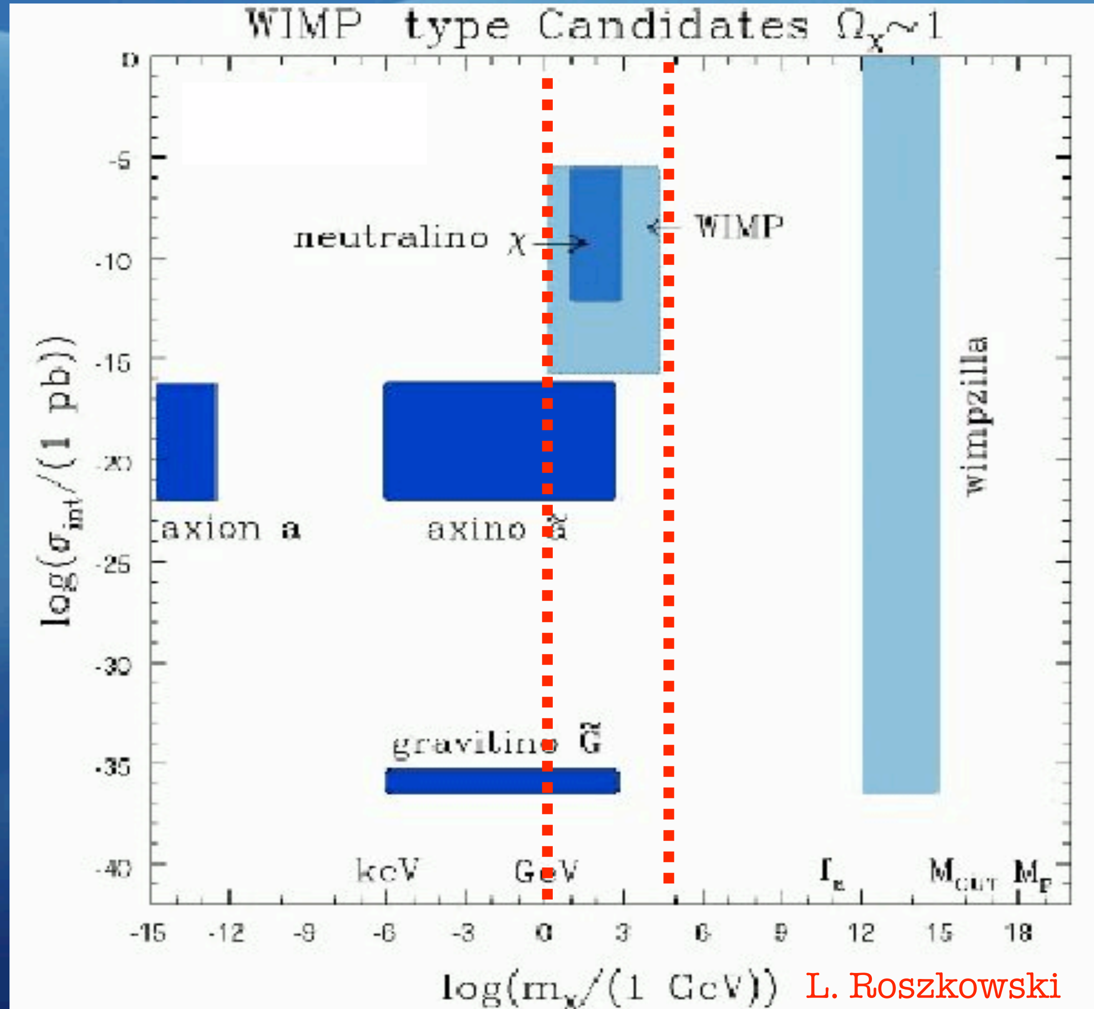




So, what is Dark Matter?

Dark Matter Candidates

- Kaluza-Klein DM in UED
- Kaluza-Klein DM in RS
- Axion
- Axino
- Gravitino
- Photino
- SM Neutrino
- Sterile Neutrino
- Sneutrino
- Light DM
- Little Higgs DM
- Wimpzillas
- Q-balls
- Mirror Matter
- Champs (charged DM)
- D-matter
- Cryptons
- Self-interacting
- Superweakly interacting
- Braneworld DM
- Heavy neutrino
- NEUTRALINO
- Messenger States in GMSB
- Branons
- Chaplygin Gas
- Split SUSY
- Primordial Black Holes



L. Roszkowski

Dark Matter Candidates

- Kaluza-Klein DM inUED
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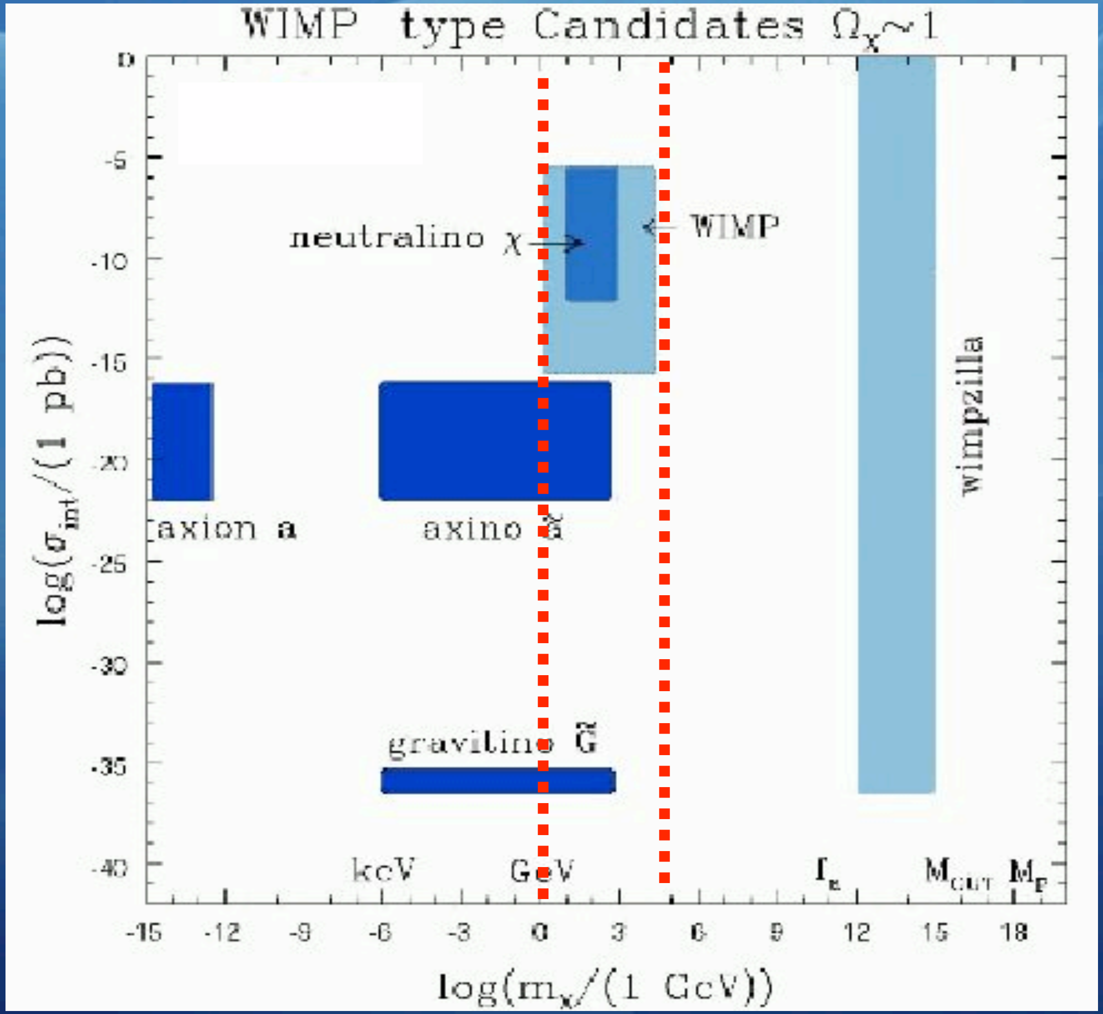
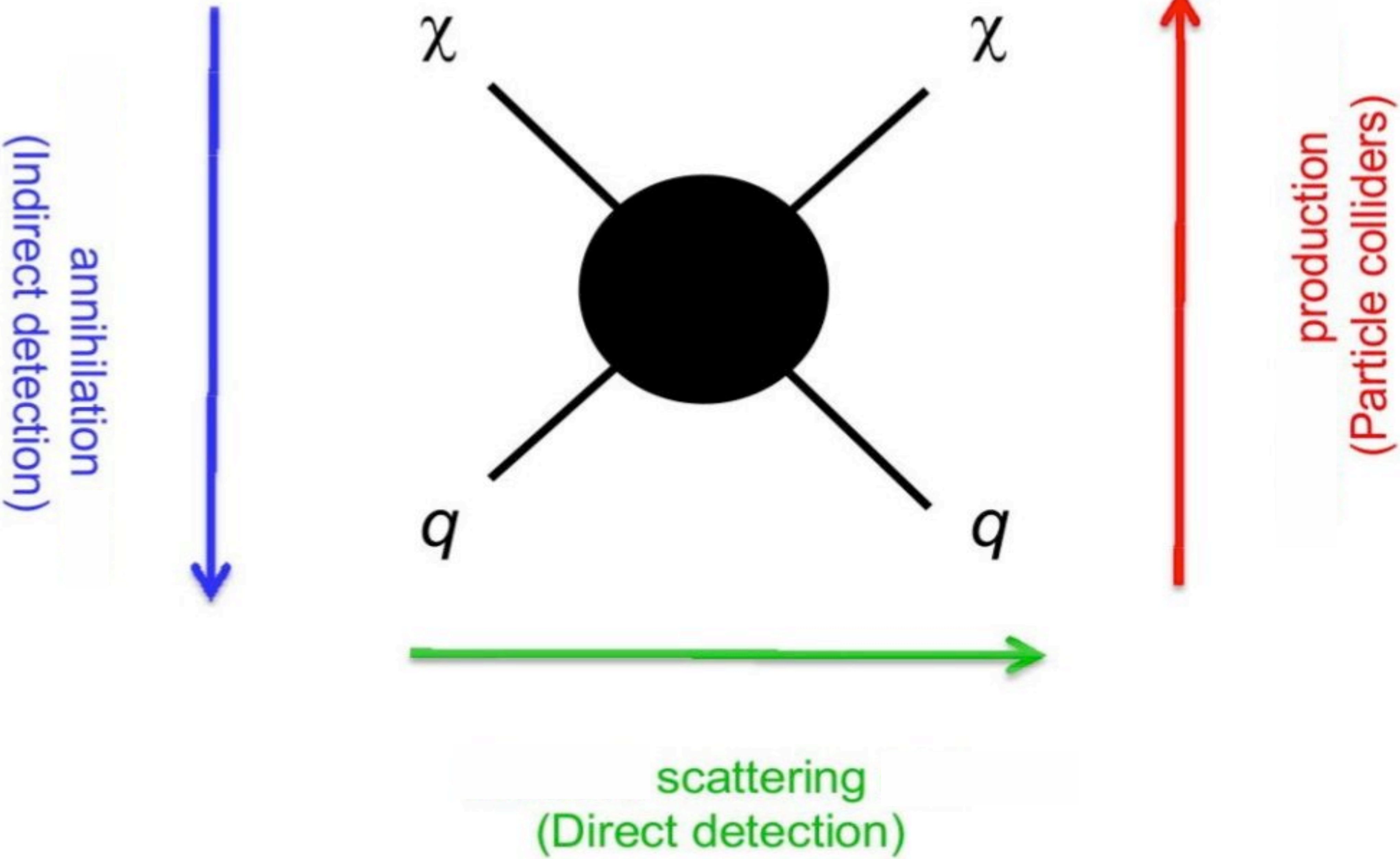
- Heavy neutrino
- **NEUTRALINO**
- Messenger States in GMSB
- Branons
- Chaplygin Gas
- Split SUSY
- Primordial Black Holes



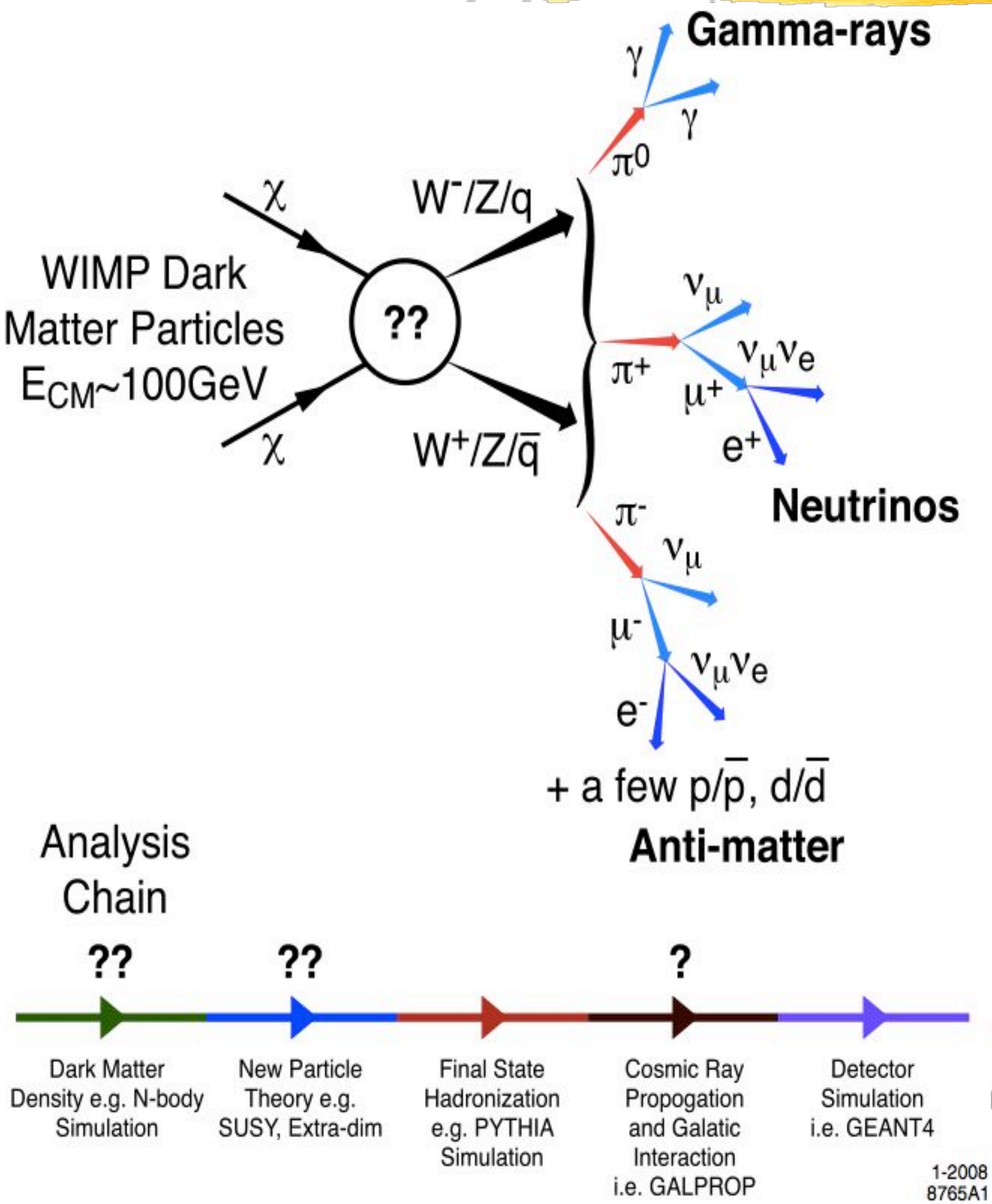

annihilation
(Indirect detection)
χ
χ
q
q
production
(Particle colliders)
scattering
(Direct detection)

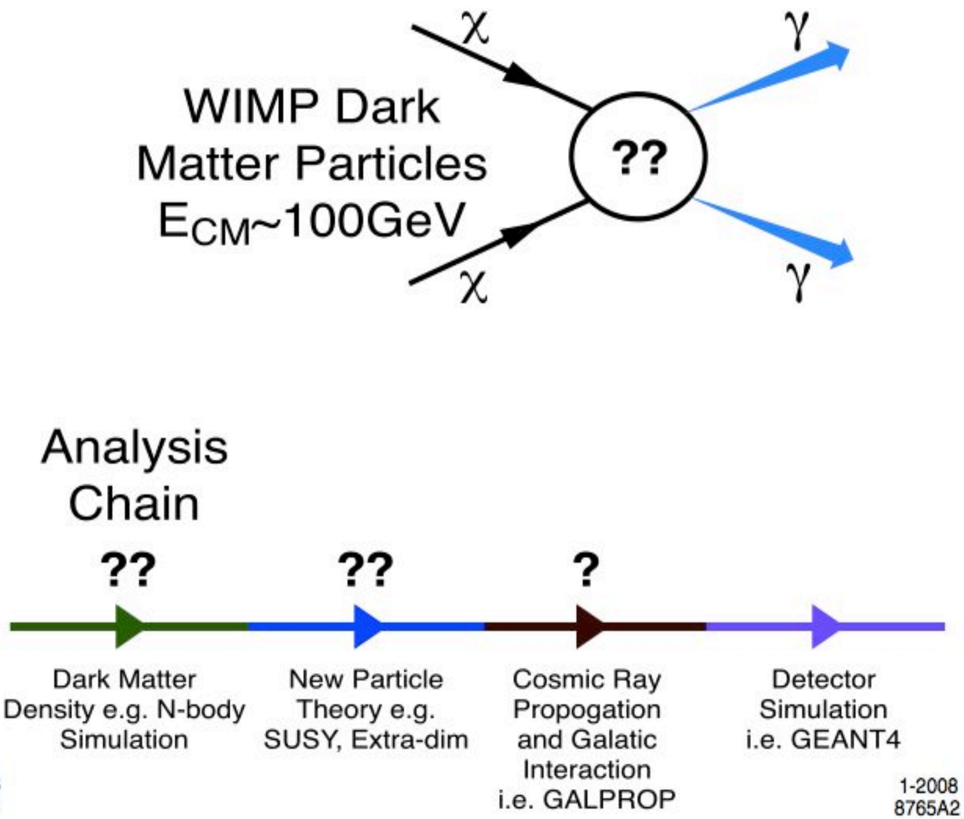
Neutralino WIMPs

Assume χ present in the galactic halo

- χ is its own antiparticle **=>** can annihilate in galactic halo producing gamma-rays, antiprotons, positrons….
- Antimatter not produced in large quantities through standard processes (secondary production through p + p **-->** anti p + X)
- So, any extra contribution from exotic sources (χ χ annihilation) is an interesting signature
- ie: χ χ --> anti p + X
- Produced from (e. g.) χ χ **-->** q / g / gauge boson / Higgs boson and subsequent decay and/ or hadronisation.

Annihilation channels

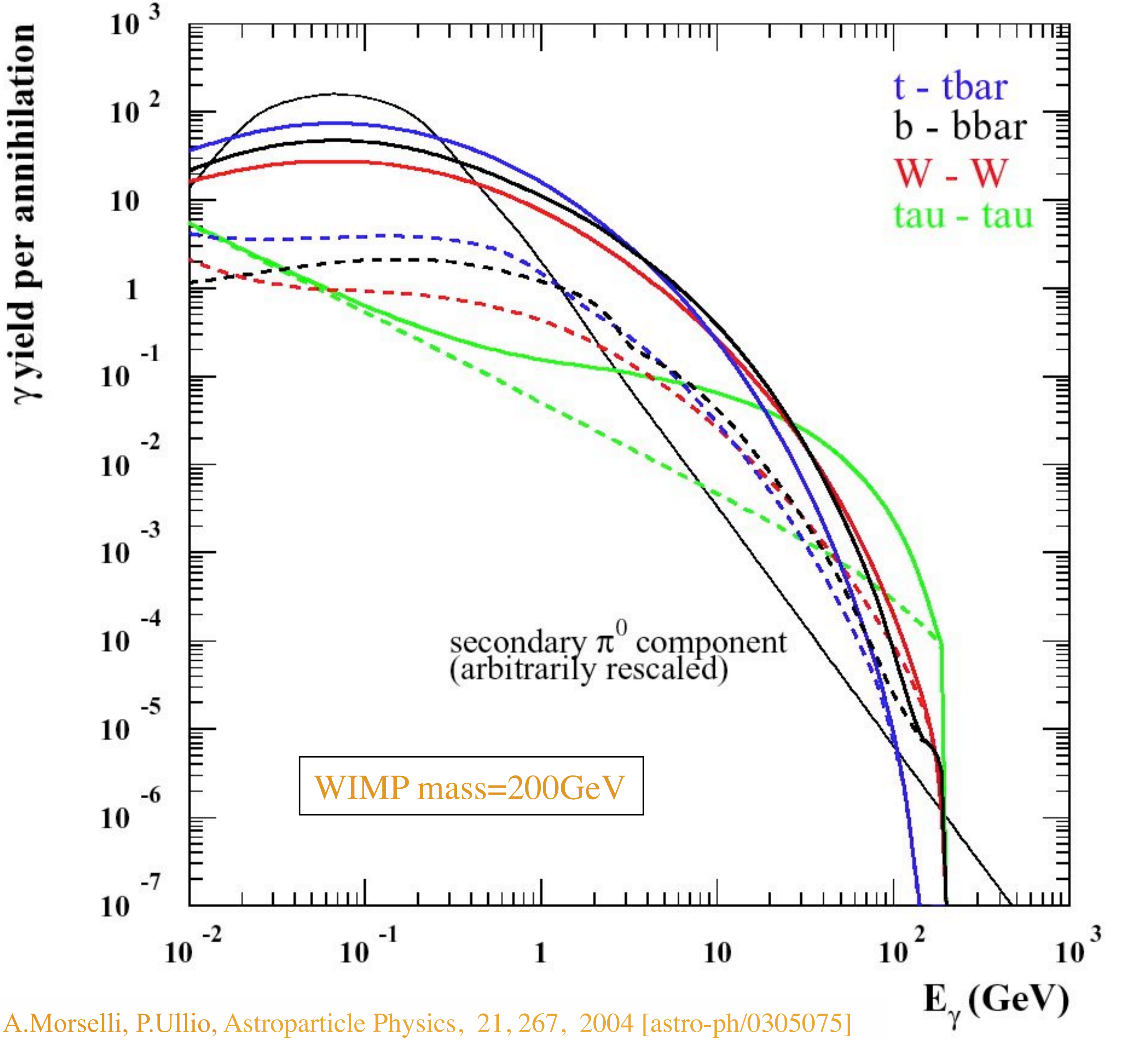




Differential yield for each annihilation channel

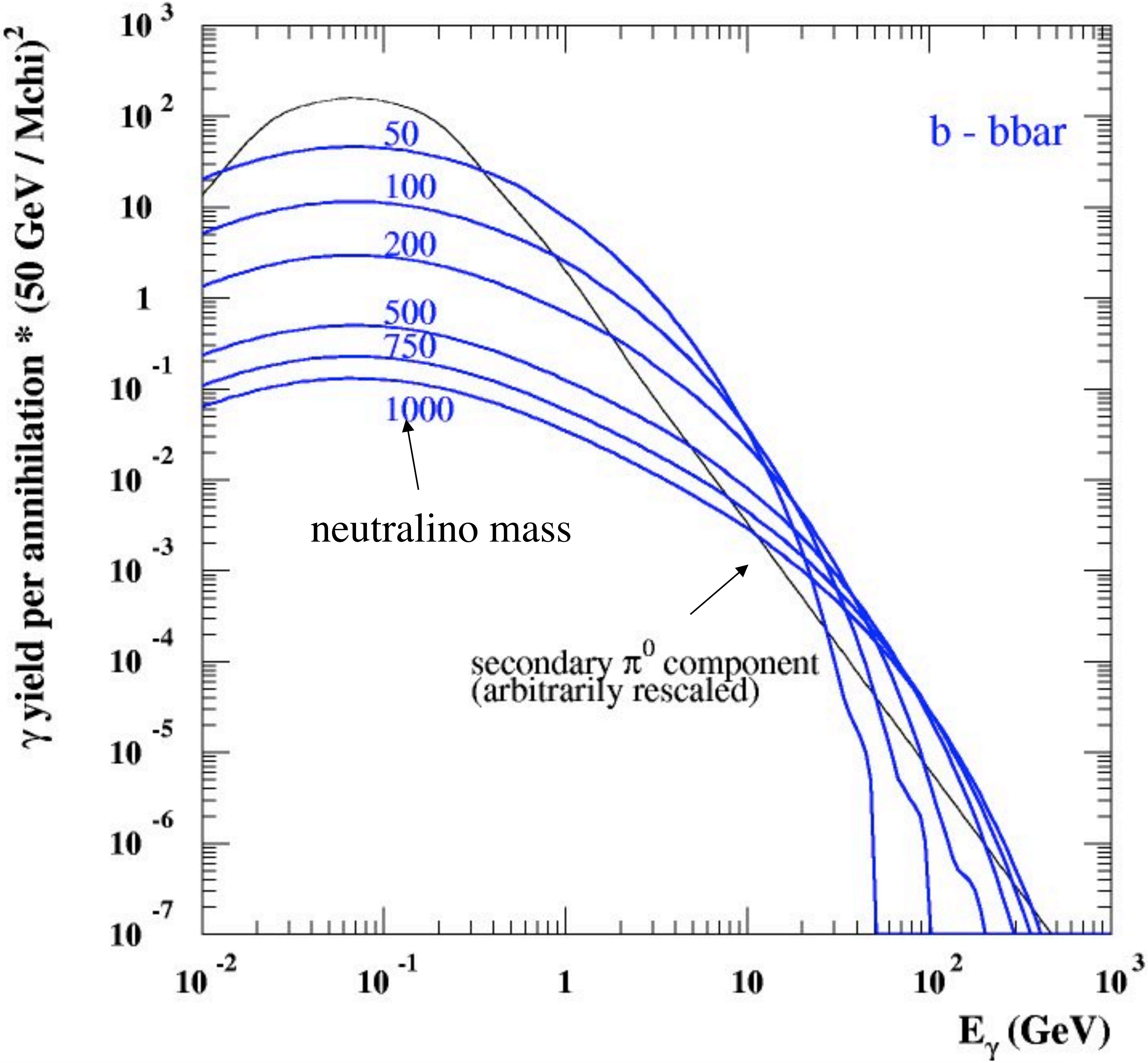
•Quite distinctive spectrum
(no power-law)

•solid lines are the total yields, while the dashed lines are components not due to π^0 decays



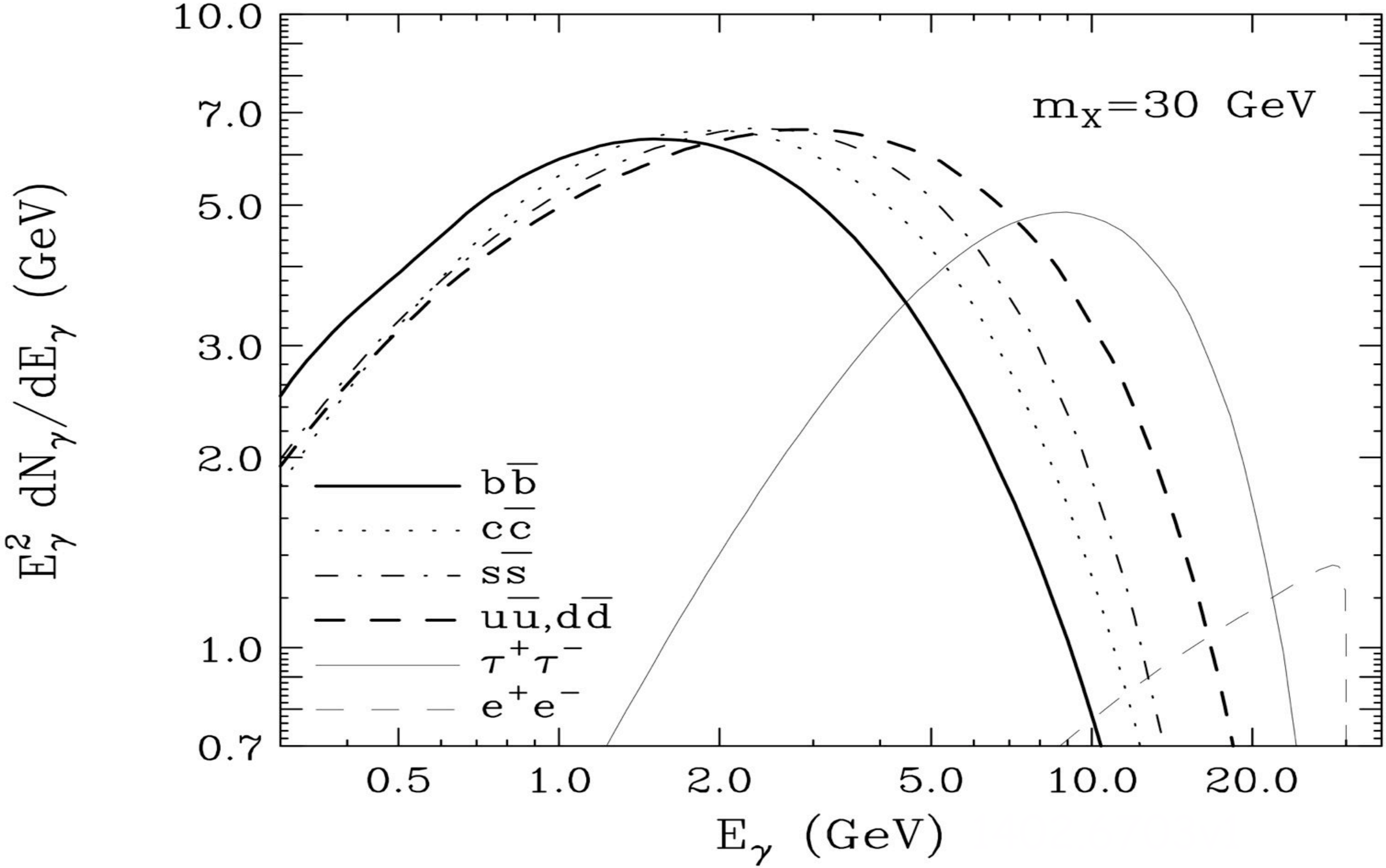
A.Cesarini, F.Fucito, A.Lionetto, A.Morselli, P.Ullio, Astroparticle Physics, 21, 267, 2004 [astro-ph/0305075]

Differential yield for b bar for different neutralino mass



A.Cesarini, F.Fucito, A.Lionetto, A.Morselli, P.Ullio, Astroparticle Physics, 21, 267-285, 2004 [astro-ph/0305075]

Gamma rays produced per dark matter annihilation

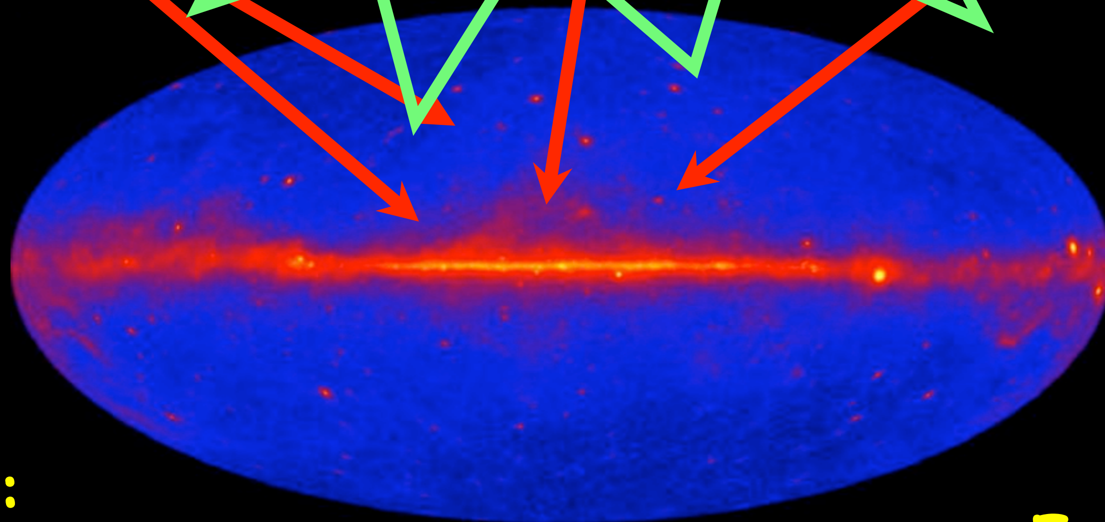


Search Strategies

Satellites:
Low background and good source id, but low statistics

Galactic center:
Good statistics but source confusion/diffuse background

Milky Way halo:
Large statistics but diffuse background



And electrons!
and
Anisotropies

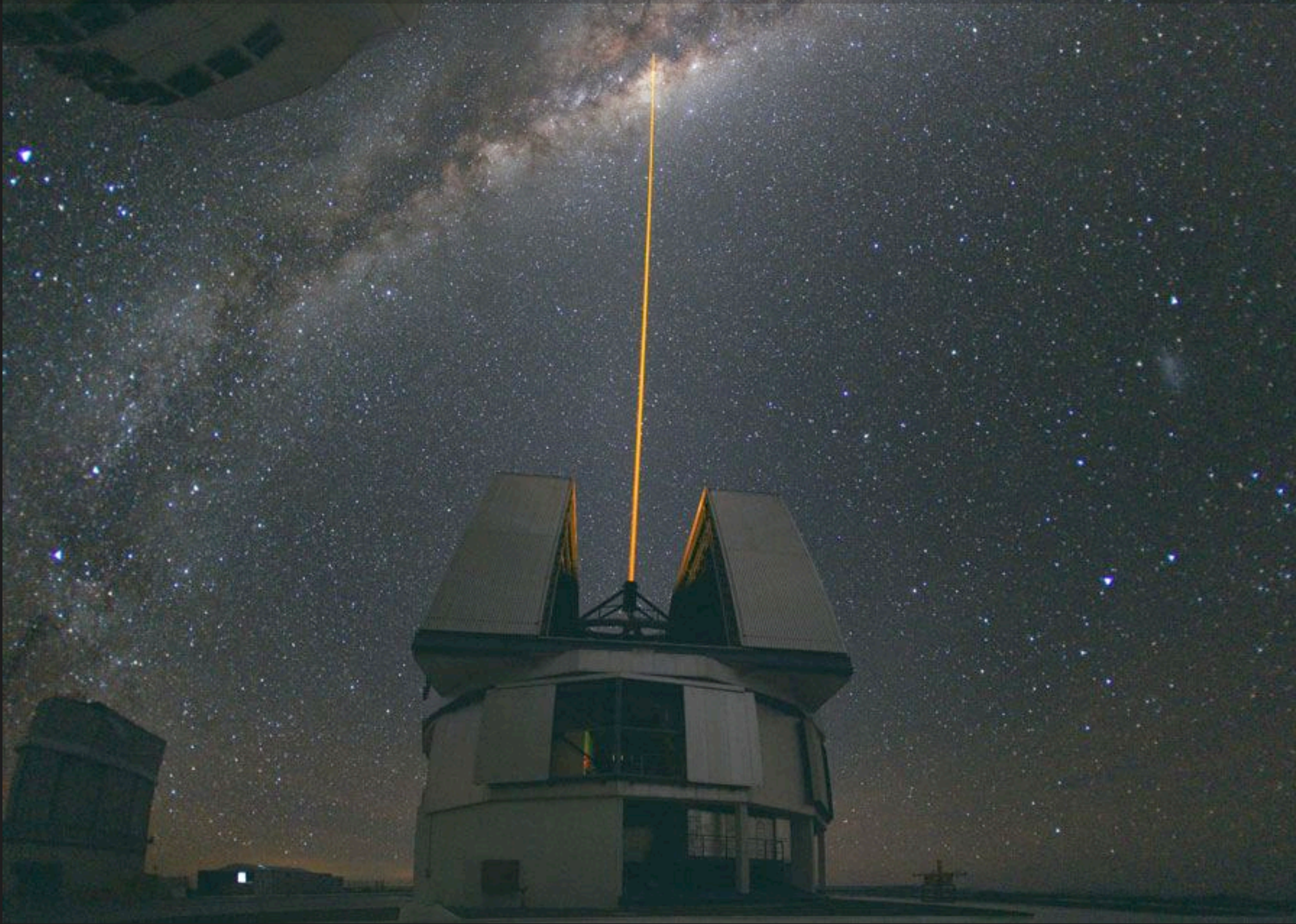
Spectral lines:
No astrophysical uncertainties, good source id, but low statistics

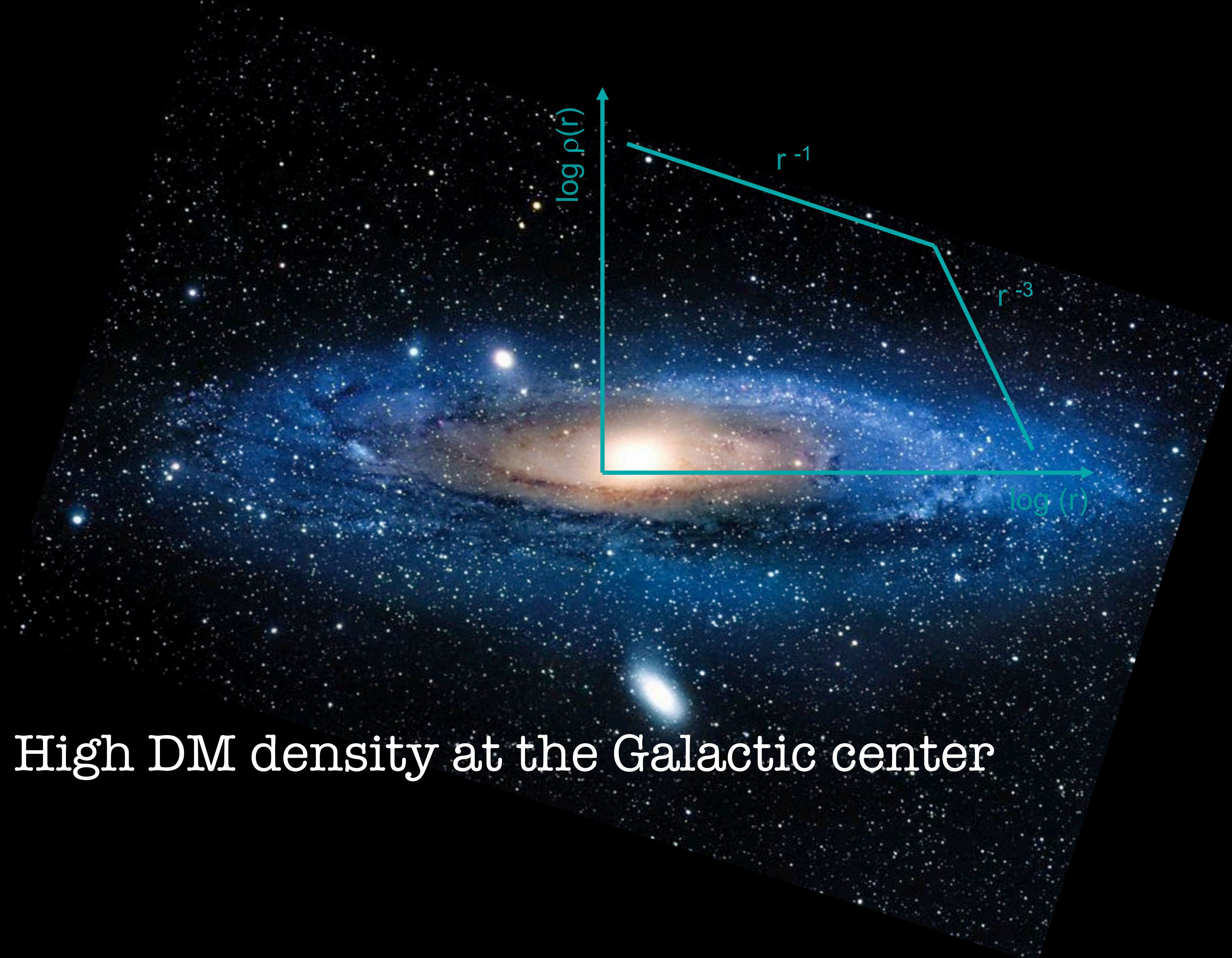
Galaxy clusters:
Low background but low statistics

Extra-galactic:
Large statistics, but astrophysics,galactic diffuse background

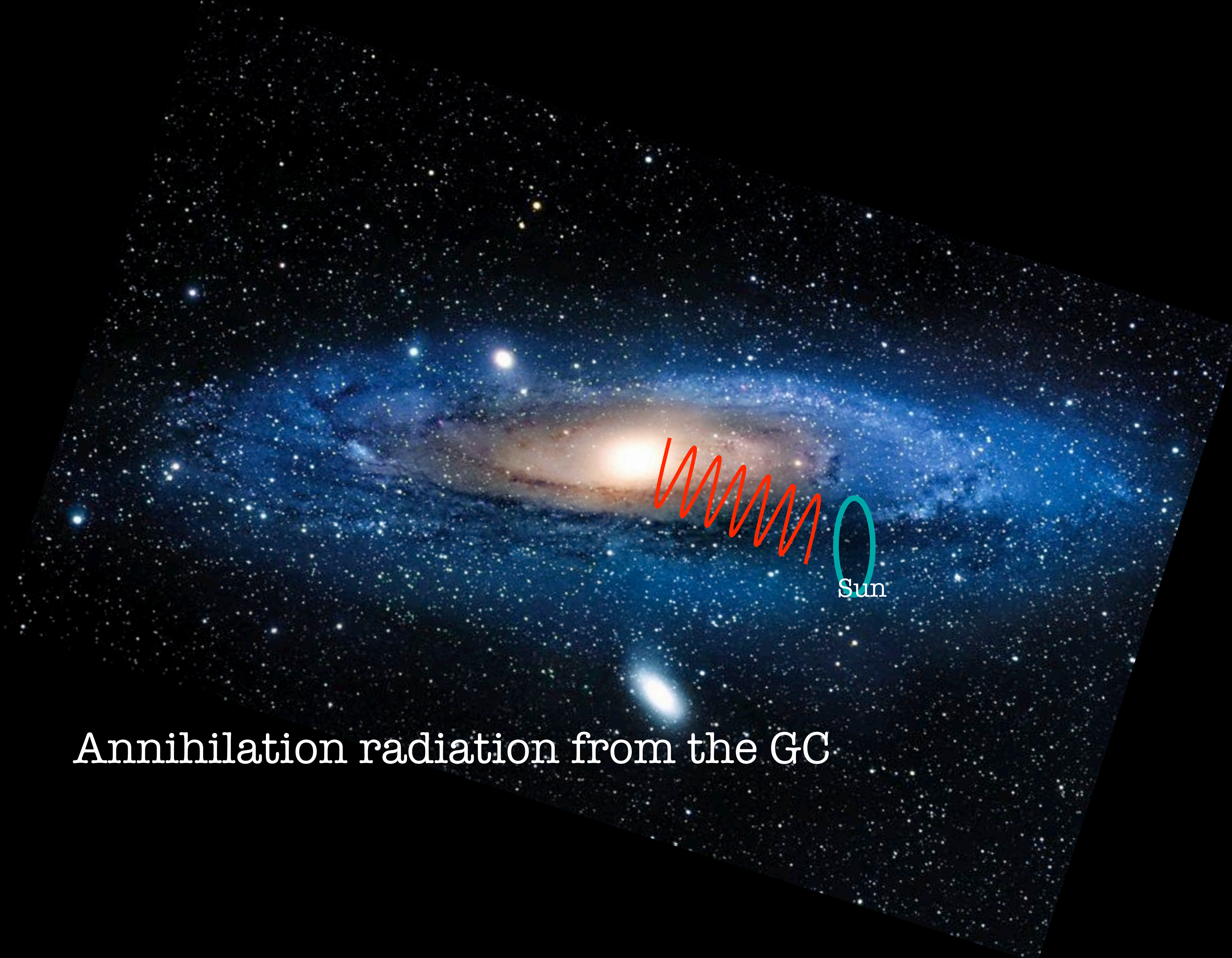
Pre-launch sensitivities published in Baltz et al., 2008, JCAP 0807:013 [astro-ph/0806.2911]

The Galactic Center





High DM density at the Galactic center



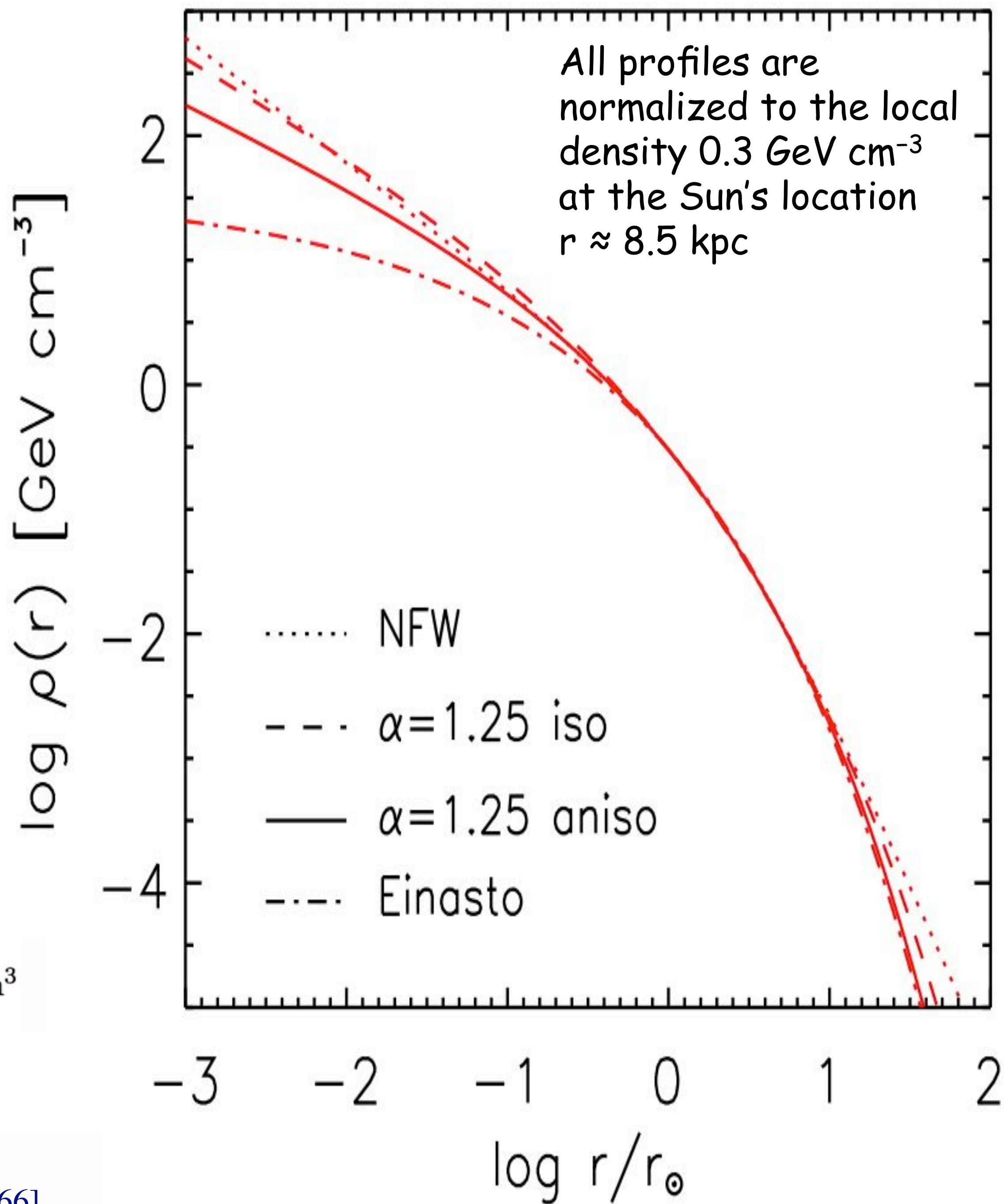
Annihilation radiation from the GC

Milky Way Dark Matter Profiles

$$\rho(r) = \rho_\odot \left[\frac{r_\odot}{r}\right]^\gamma \left[\frac{1+(r_\odot/r_s)^\alpha}{1+(r/r_s)^\alpha}\right]^{(\beta-\gamma)/\alpha}$$

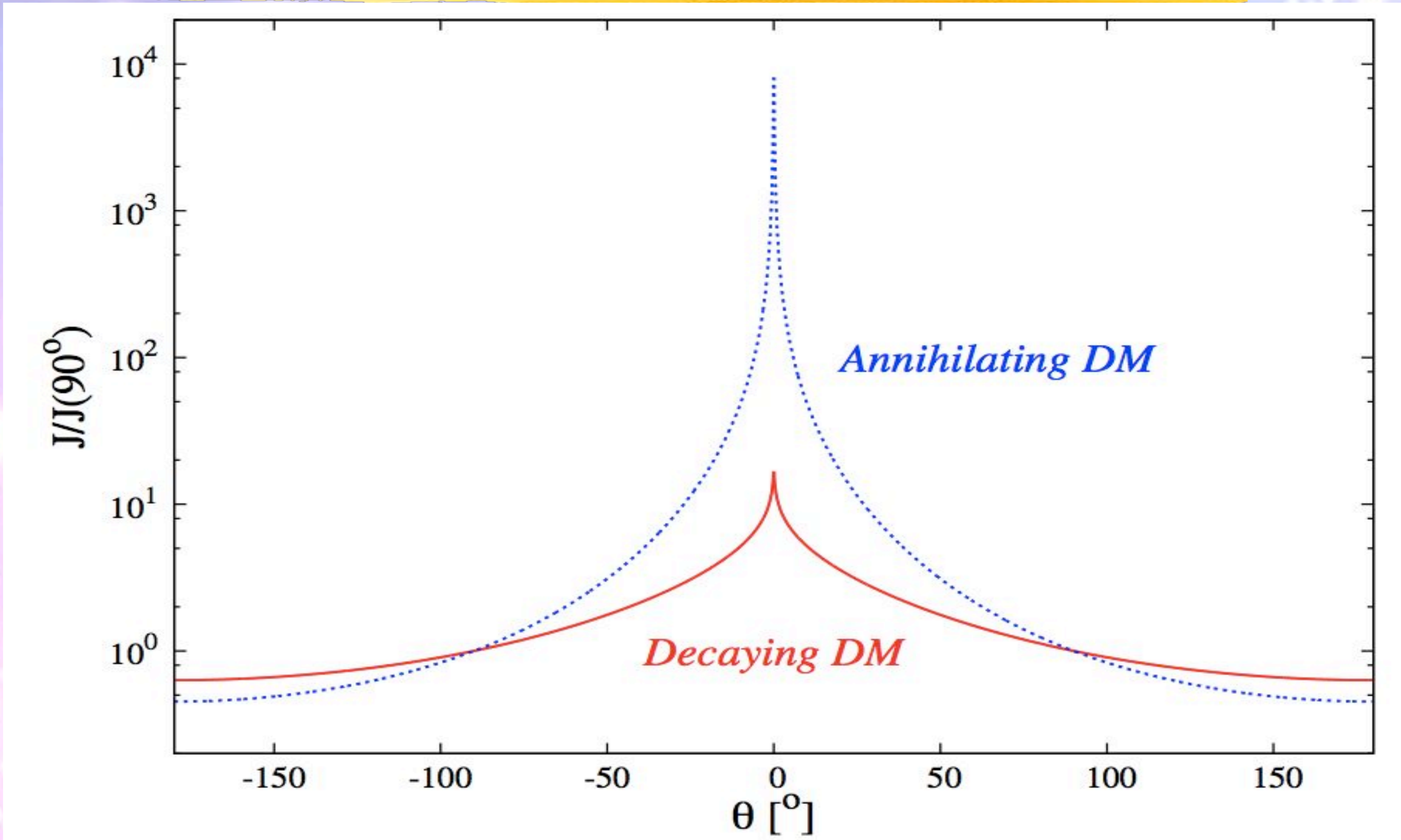
Halo model	α	β	γ	r_s in kpc
Cored isothermal	2	2	0	5
Navarro, Frenk, White	1	3	1	20
Moore	1	3	1.16	30

Einasto | $\alpha = 0.17$ $r_s = 20\,\mathrm{kpc}$ $\rho_s = 0.06\,\mathrm{GeV/cm^3}$



A.Lapi, A.Paggi, A.Cavaliere, A.Lionetto, A.Morselli, V.Vitale. A&A 510, A90 (2010) [arXiv:0912.1766]

Different spatial behaviour for decaying or annihilating dark matter

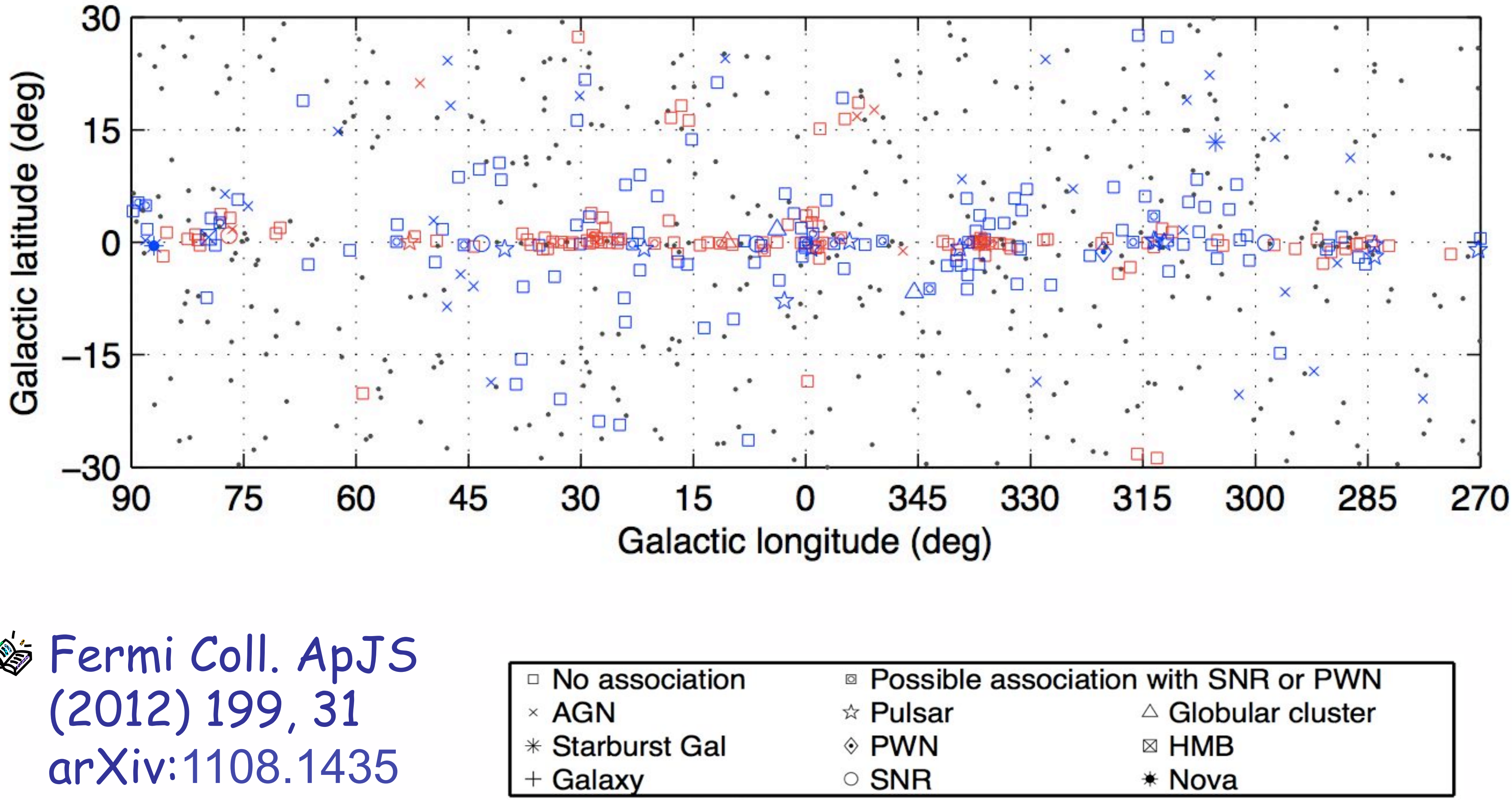


The angular profile of the gamma-ray signal is shown, as function of the angle θ to the centre of the galaxy for a Navarro-Frenk-White (NFW) halo distribution for decaying DM, solid (red) line, compared to the case of self-annihilating DM, dashed (blue) line

The Fermi LAT 2FGL Inner Galactic Region

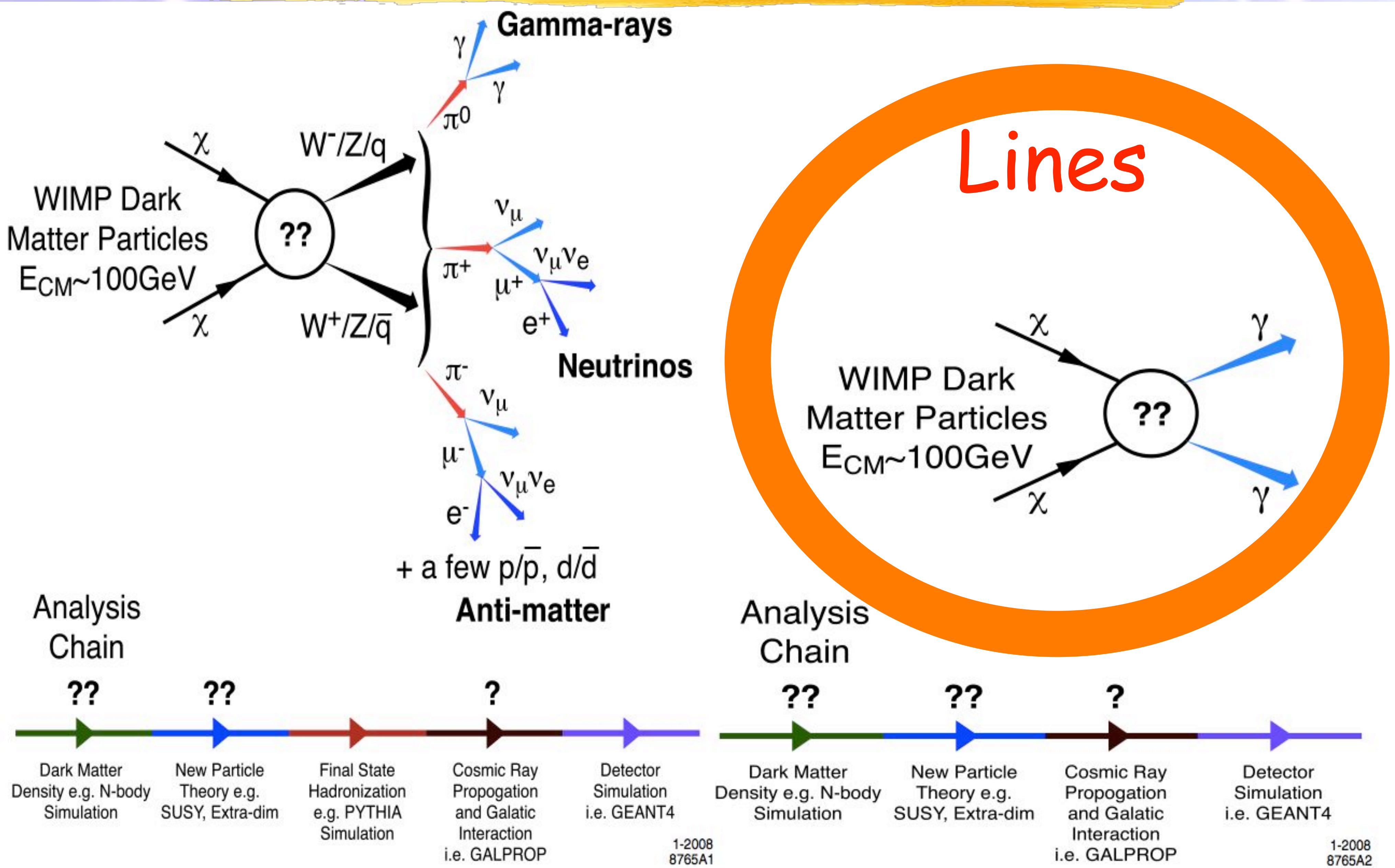
August 4, 2008, to July 31, 2010

100 MeV to 100 GeV energy range

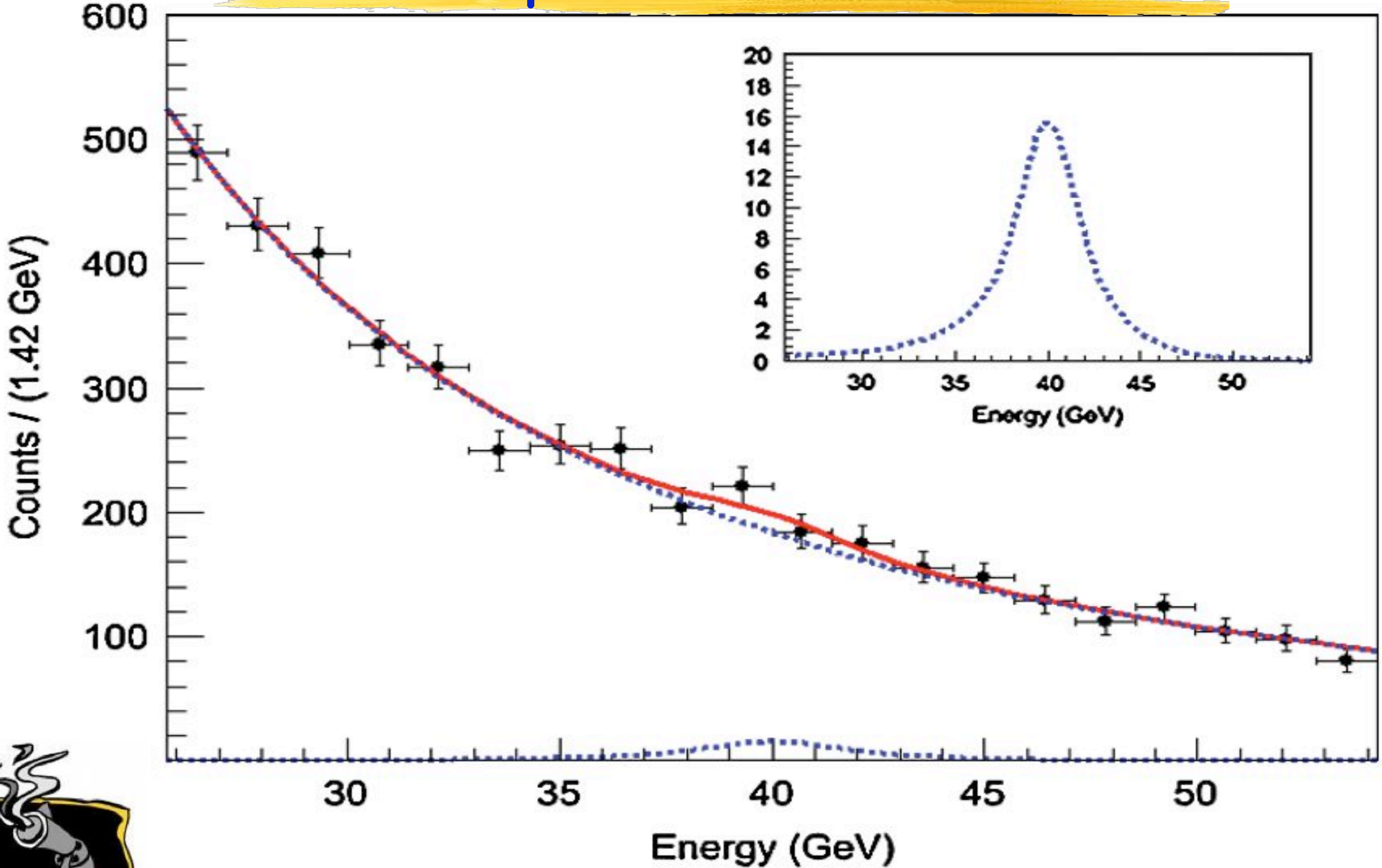


Fermi Coll. ApJS (2012) 199, 31
arXiv:1108.1435

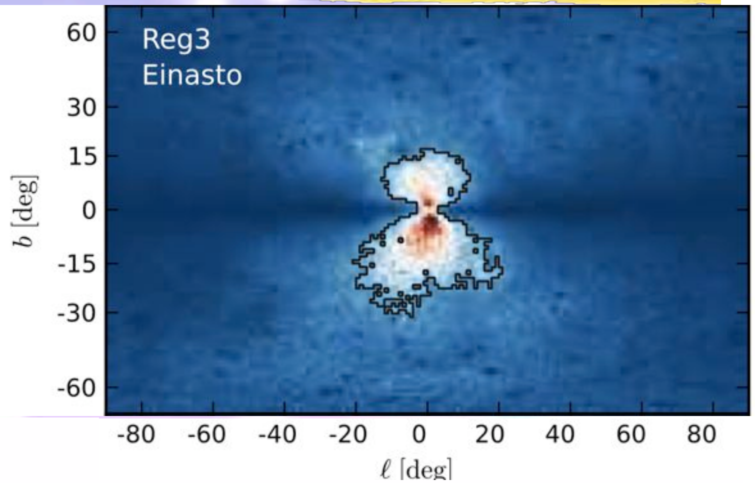
Annihilation channels

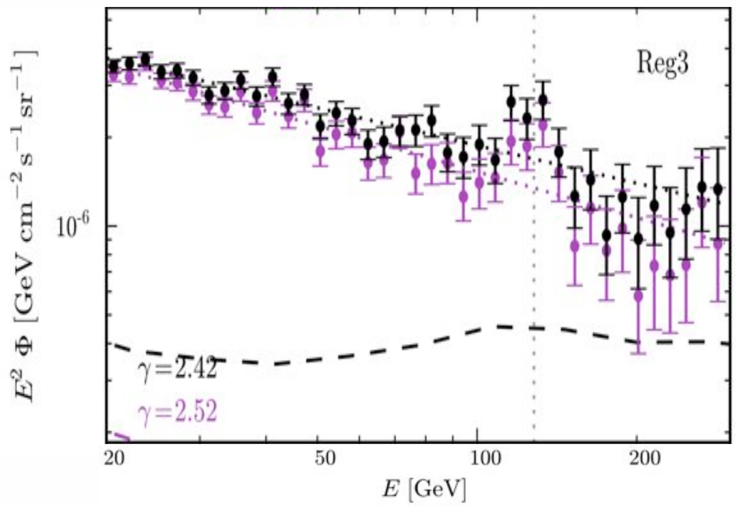


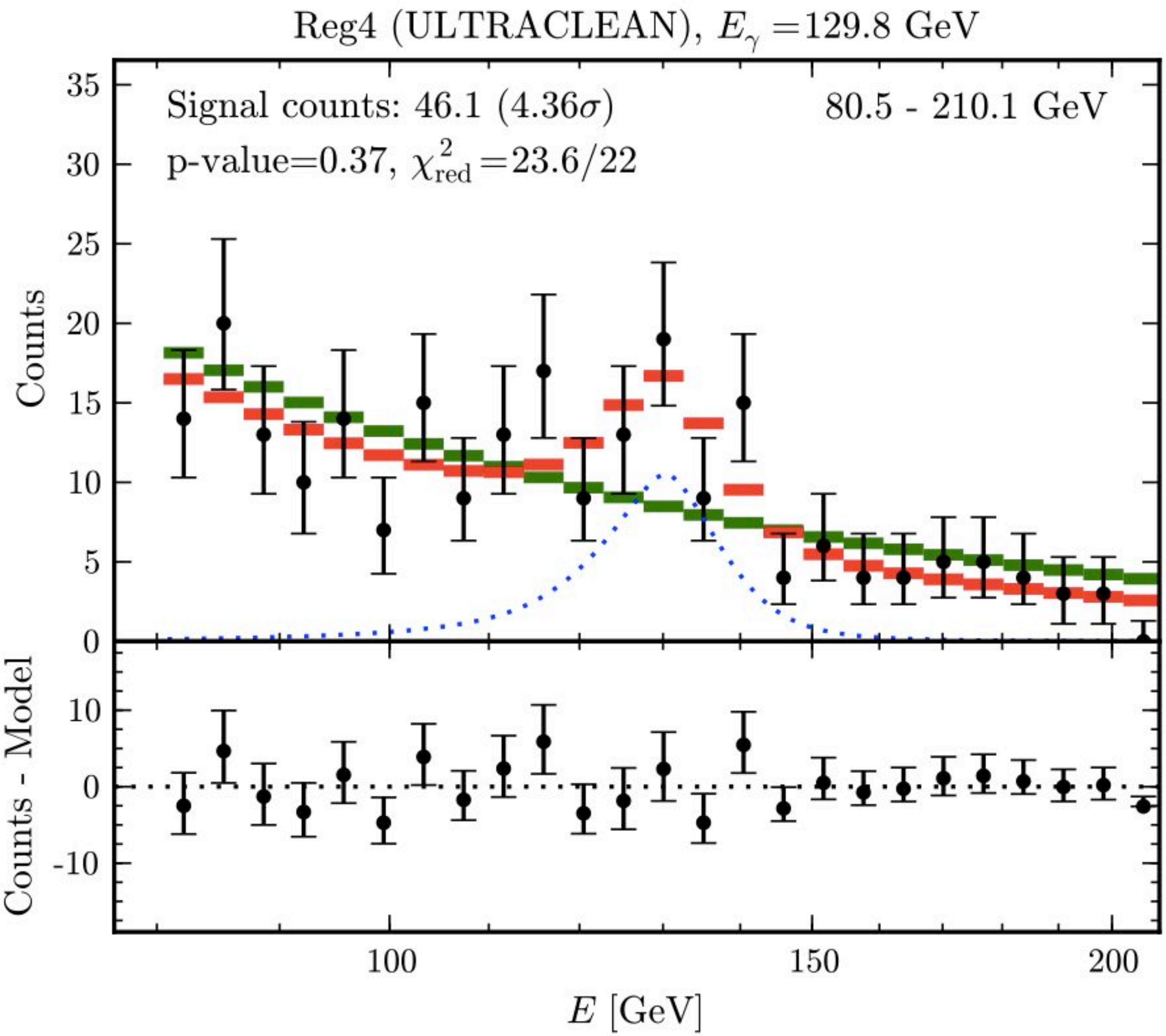
Wimp lines search



A line at ~ 130 GeV ?

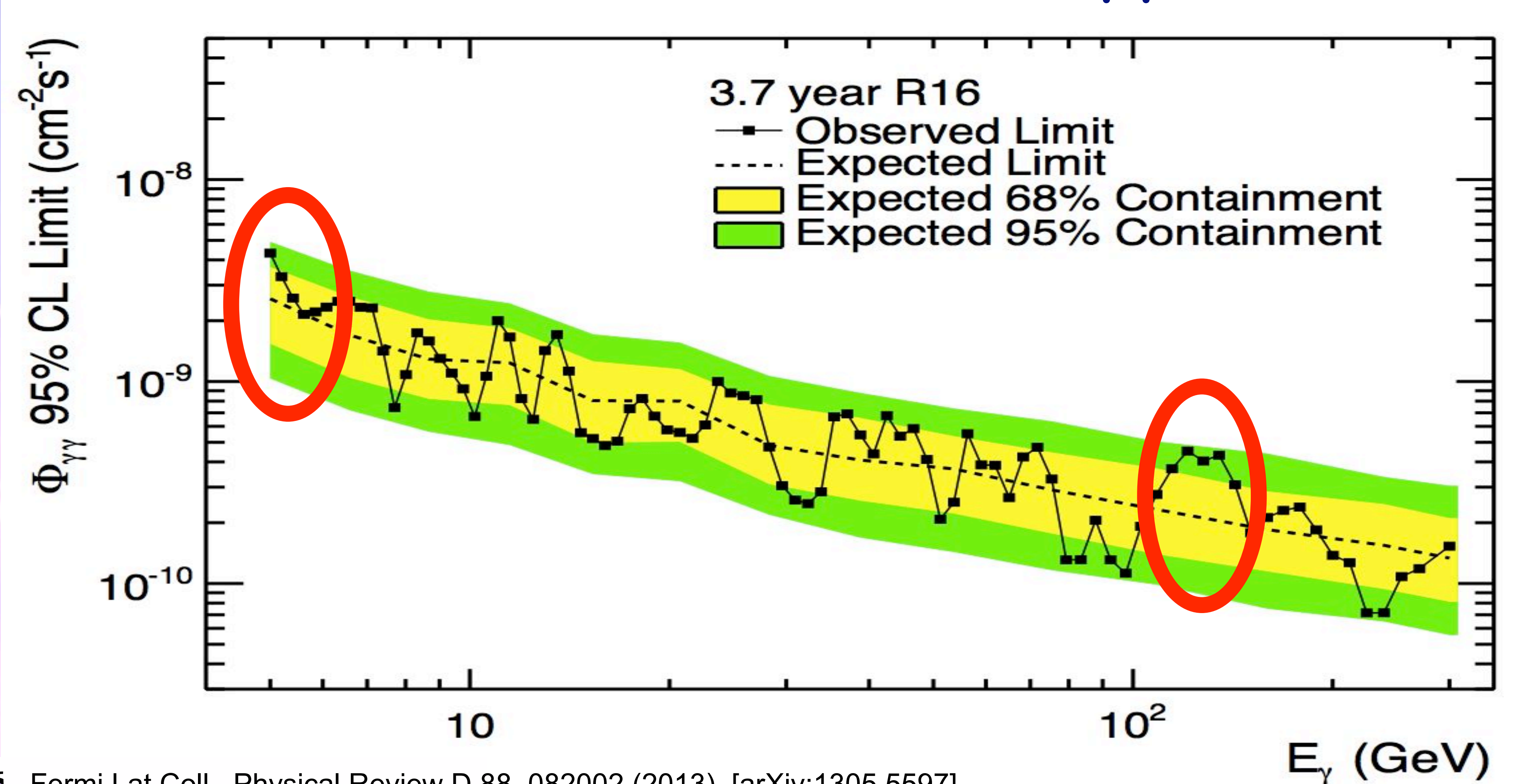






Weniger arXiv:1204.2797

Fermi-LAT Line Search Flux Upper Limits



Fermi Lat Coll., Physical Review D 88, 082002 (2013) [arXiv:1305.5597]

- Most of the limits fall within the expected bands.
- Near 135 GeV the limits are near the upper edge of the bands.
- The huge statistics at low energies mean small uncertainties in the collecting area can produce statistical significant spectral features.

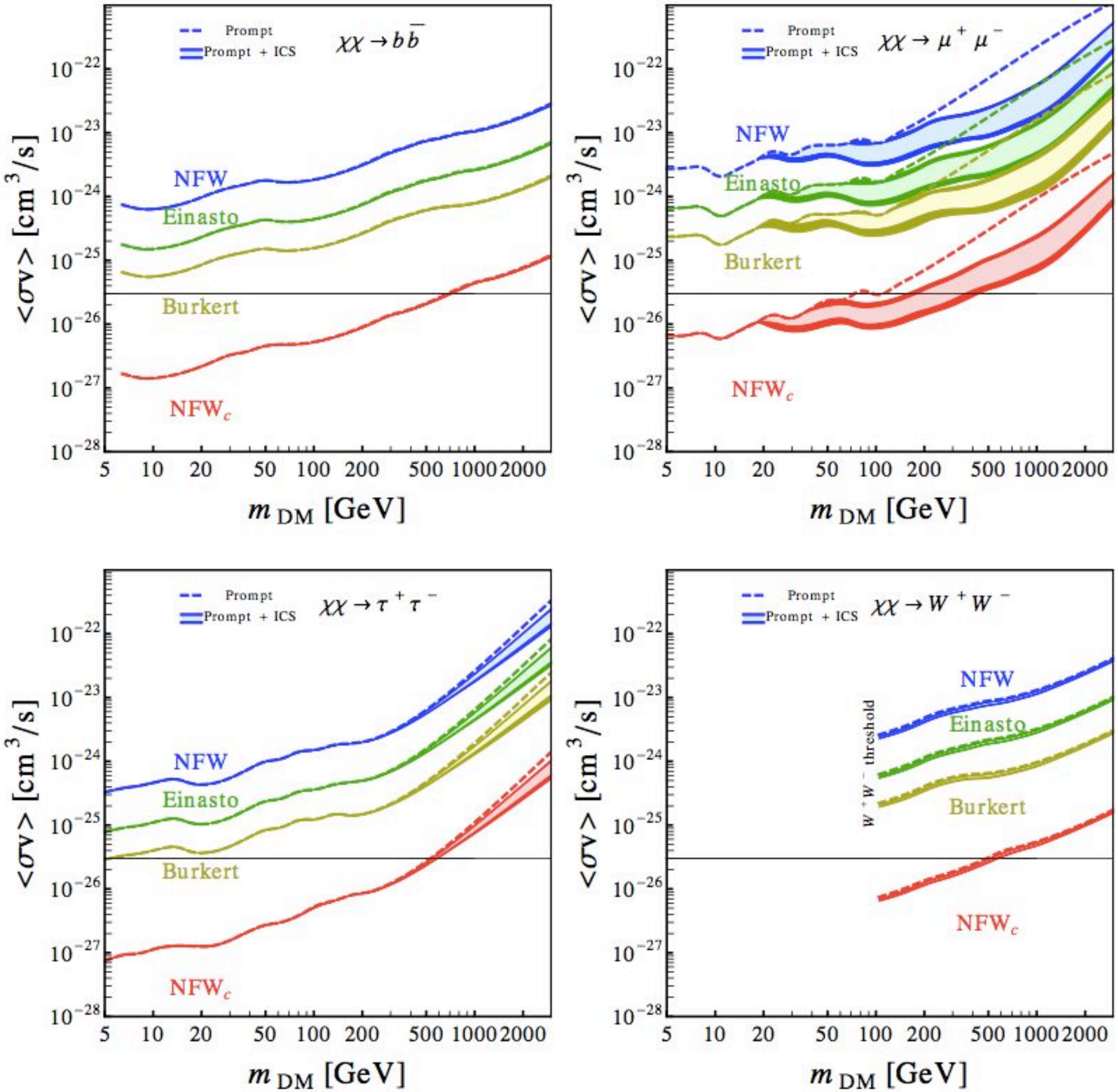
Constraints from the inner Galaxy

3 σ upper limits on the annihilation cross-section for different channels and halo profiles

No assumption on background

very robust result

Gomez-Vargas et al.
JCAP 10 (2013) 029
arXiv:1308.3515



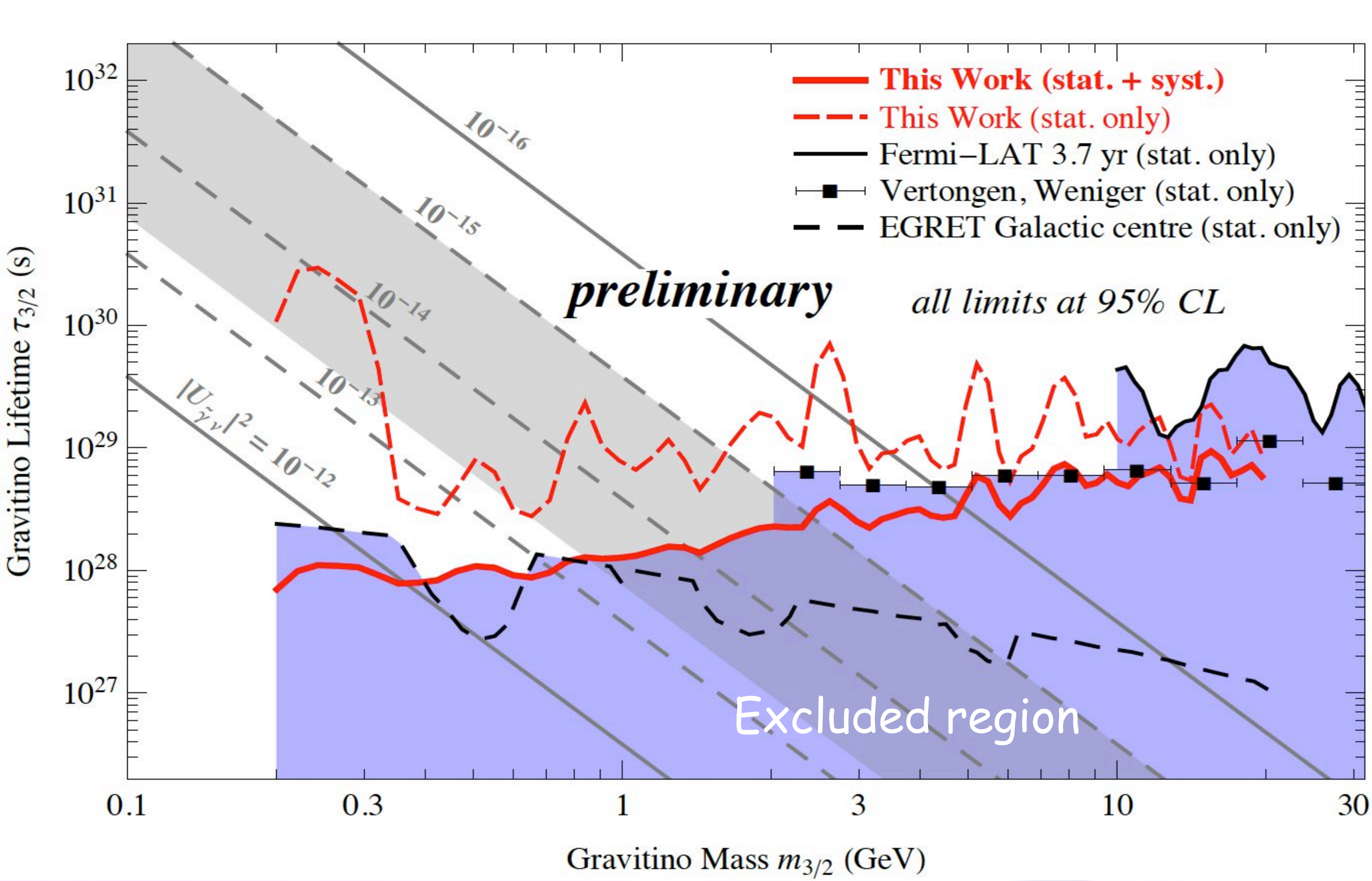
New Low Energy Line Search

Purpose:
To perform a spectral search for gamma-ray lines from 100 MeV to 10 GeV with the Fermi-LAT data
This would constrain models of gravitino decay, focus on the μνSSM (Lopez-Fogliani & C. Muñoz PRL 97(2006)041801)

People:
Andrea Albert (SLAC), Elliott Bloom (SLAC), Eric Charles (SLAC), German Gomez Vargas (PUC-Santiago/INFN-Roma2), Aldo Morselli (INFN Roma2) Carlos Muñoz (UAM/IFT Madrid), Michael Grefe (Hamburg), & Christoph Weniger (GRAPPA Amsterdam).

Data:
5.2 years of Pass 7 Reprocessed data
Fit for lines from 100 MeV to 10 GeV

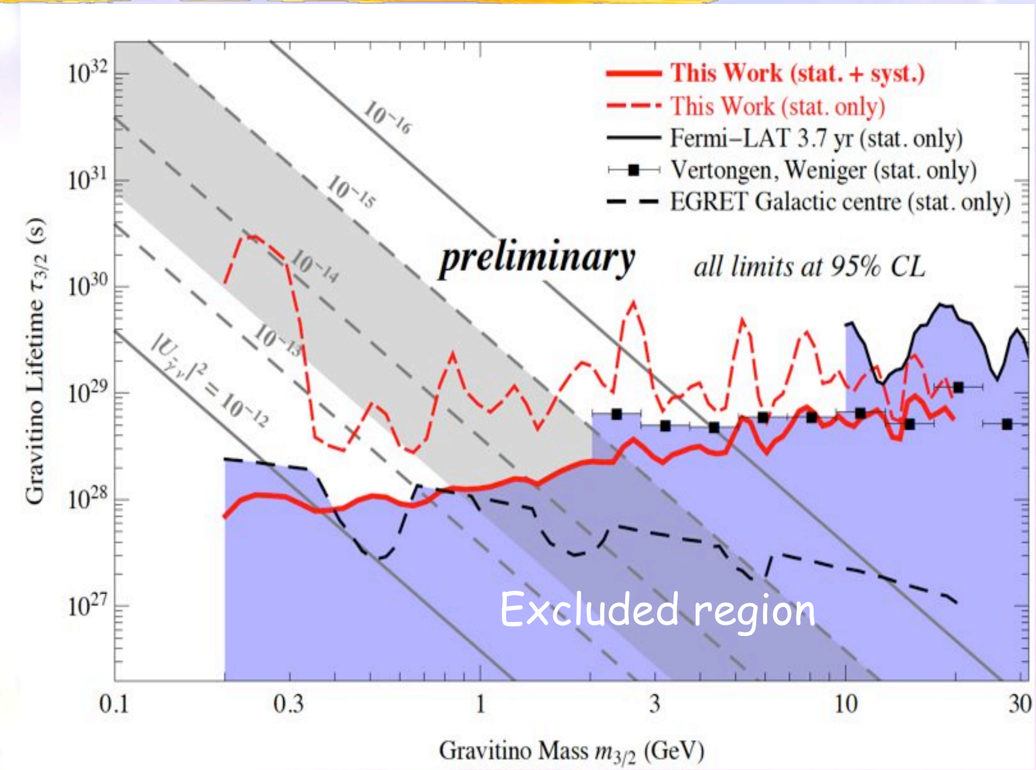
Preliminary Limits for |b|>60° RoI



New Low Energy Line Search

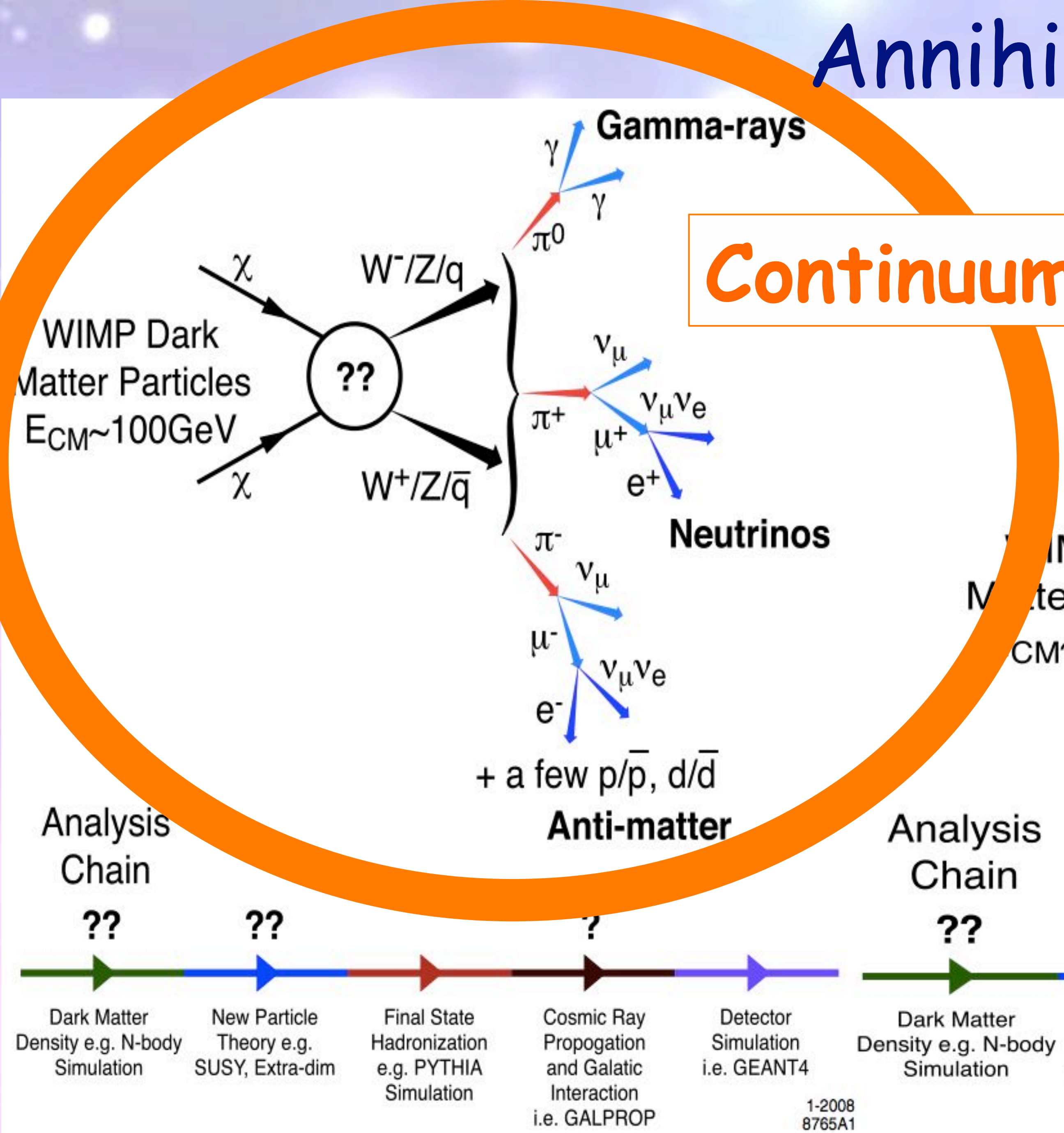
But this Analysis is Systematics Limited

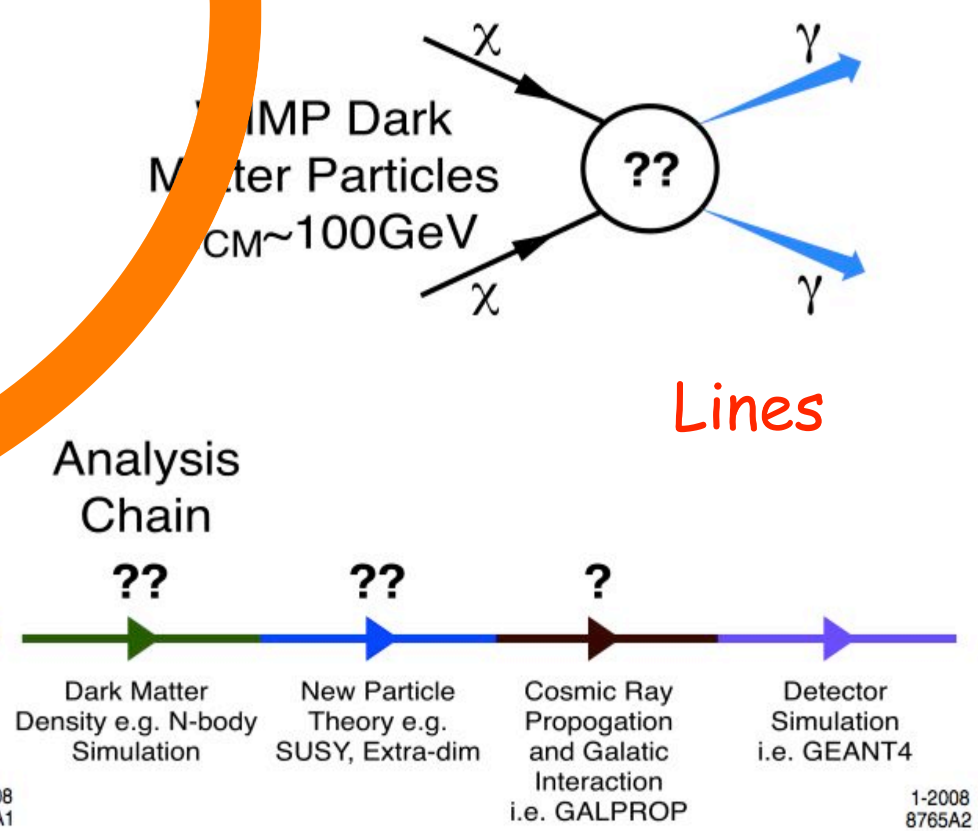
- *Modeling effective area*
- *background emission*
- *not masking known point sources*: because the broad PSF of the LAT at low energies.



To improve the search a better energy and angular resolution at low energies is needed

Annihilation channels

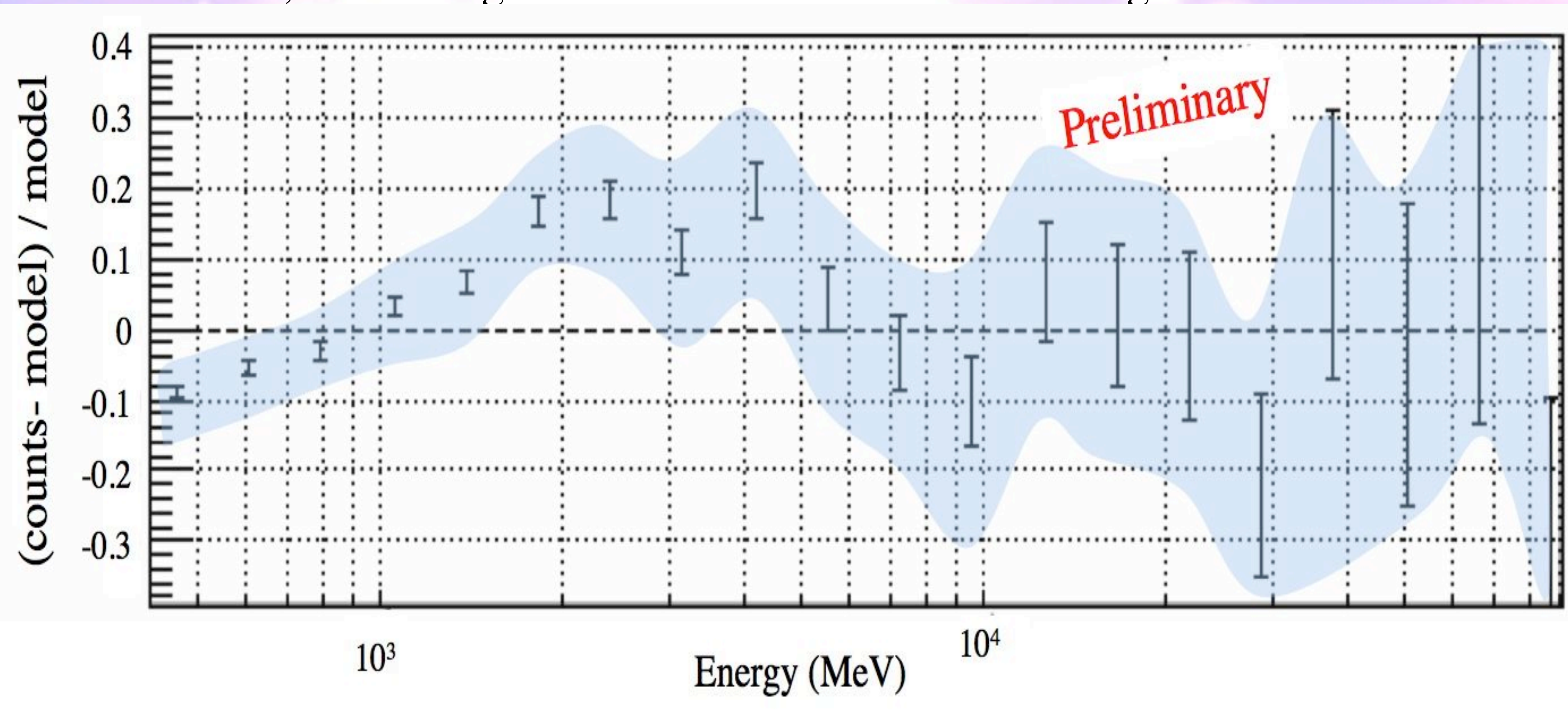




GC Residuals 7°x7° region centered on the Galactic Center

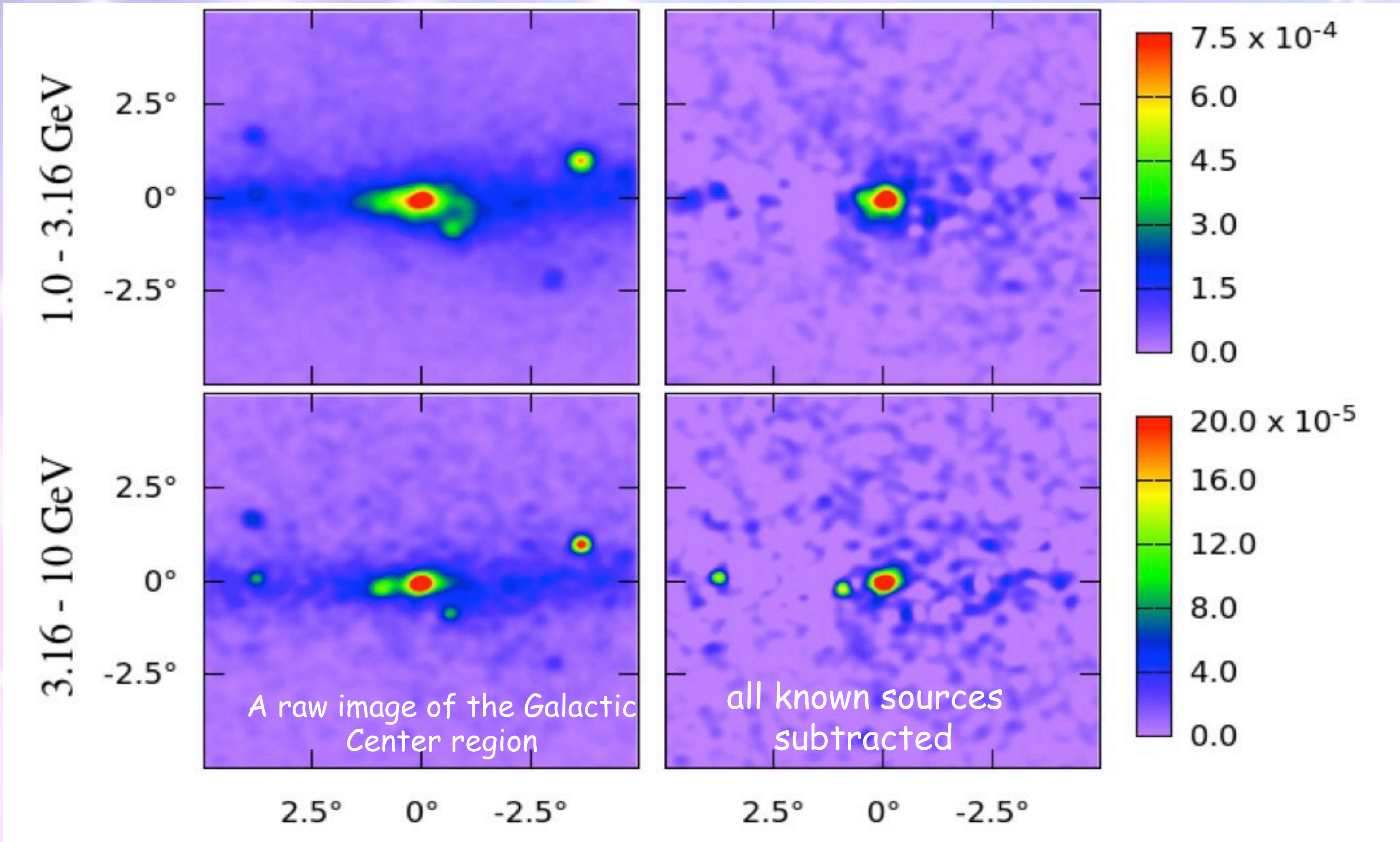
11 months of data, E >400 MeV, front-converting events analyzed with binned likelihood analysis)

- The systematic uncertainty of the effective area (blue area) of the LAT is ~10% at 100 MeV, decreasing to 5% at 560 MeV and increasing to 20% at 10 GeV



V.Vitale, A.Morselli for the Fermi Coll. NIM A630 (2011) 147, arXiv:0912.3828

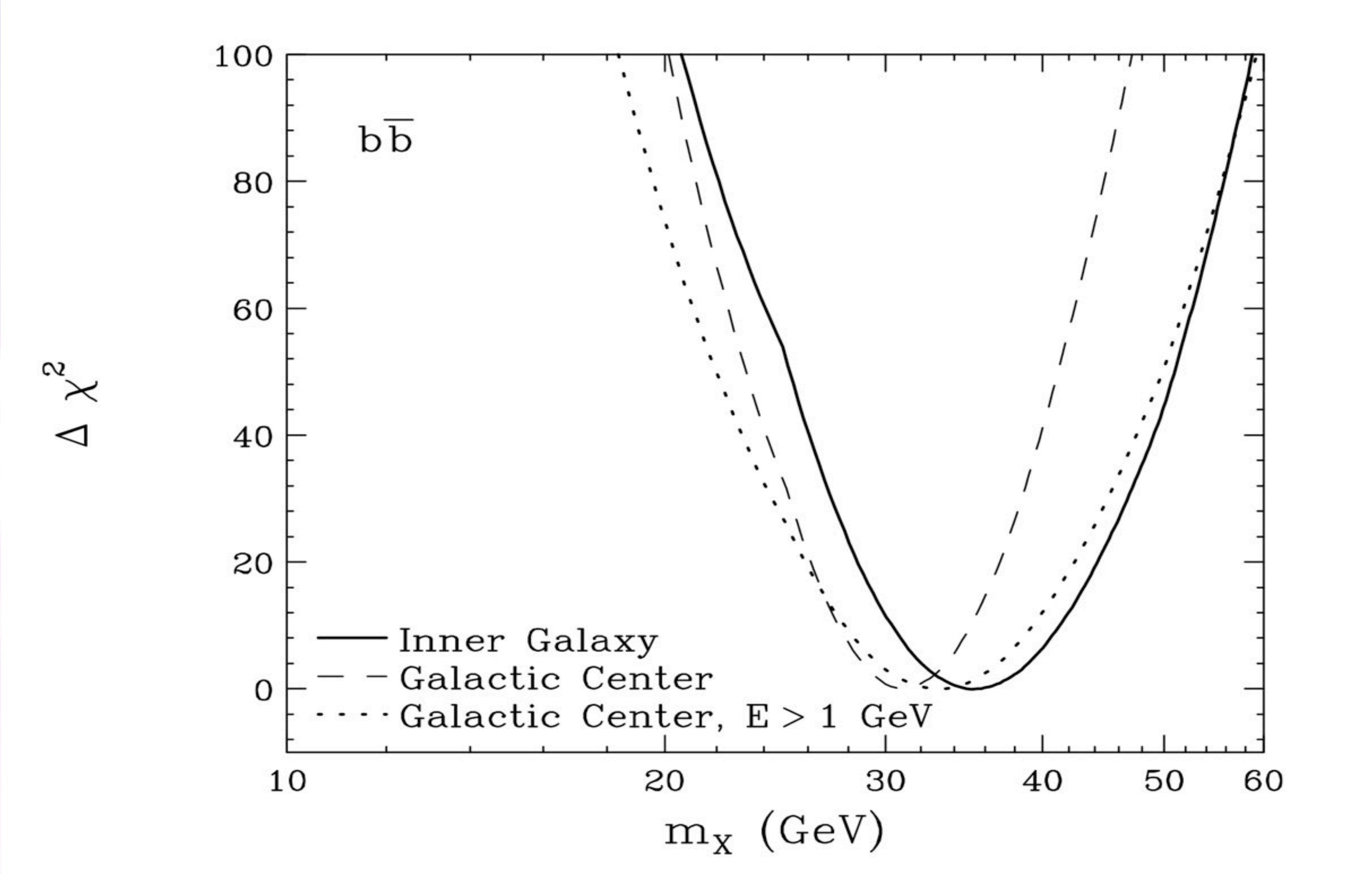
Galactic Center and Dark Matter



- Spatially extended excess of 1-3 GeV γ rays with a spectrum, angular distribution, and overall normalization that is in good agreement with that predicted by simple annihilating dark matter models"
- Well fit by a 31-40 GeV WIMP with $\langle\sigma v\rangle = (1.4 - 2.0) \times 10^{-26}$ cm^3/s
- approximately spherically symmetric and centered around the dynamical center of the Milky Way

A Compelling Case for Annihilating Dark Matter arXiv:1402.6703

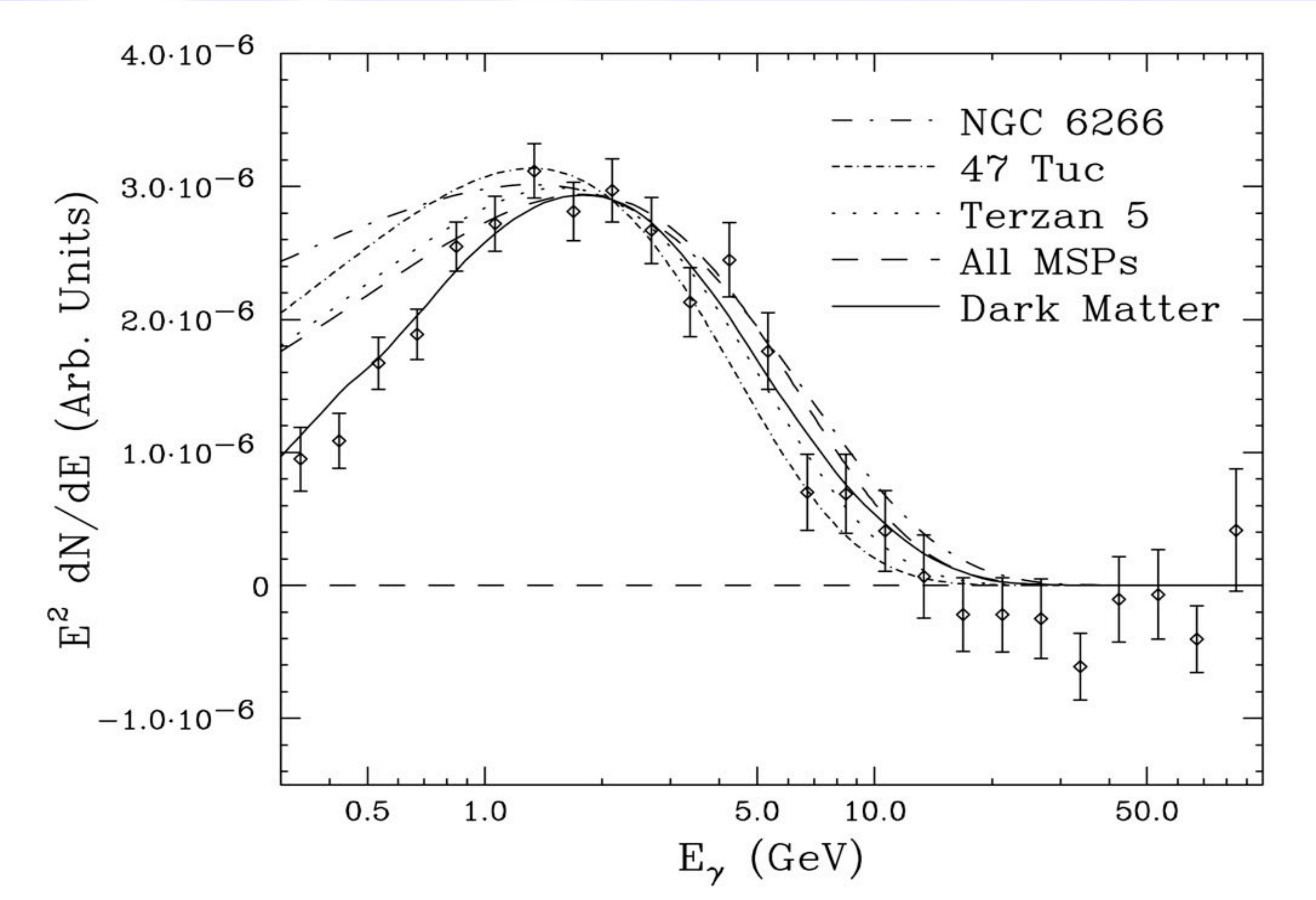
Galactic Center and Dark Matter



A comparison of the dark matter mass determination using the spectrum derived from our Inner Galaxy analysis (solid line) and using the spectrum derived from our Galactic Center analysis (dashed and dotted lines)

A Compelling Case for Annihilating Dark Matter arXiv:1402.6703

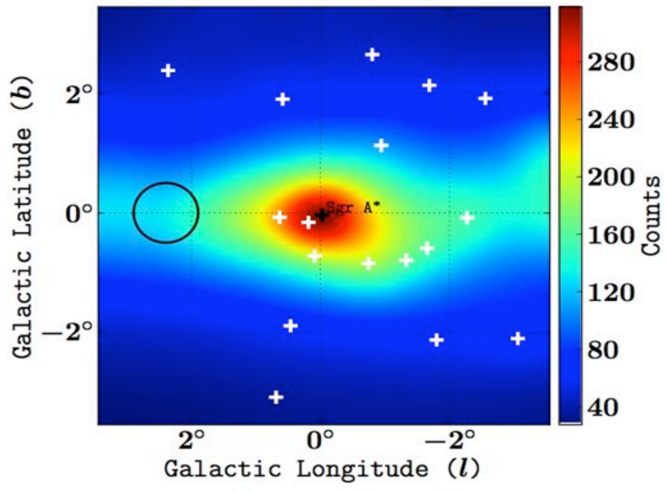
Galactic Center and Dark Matter



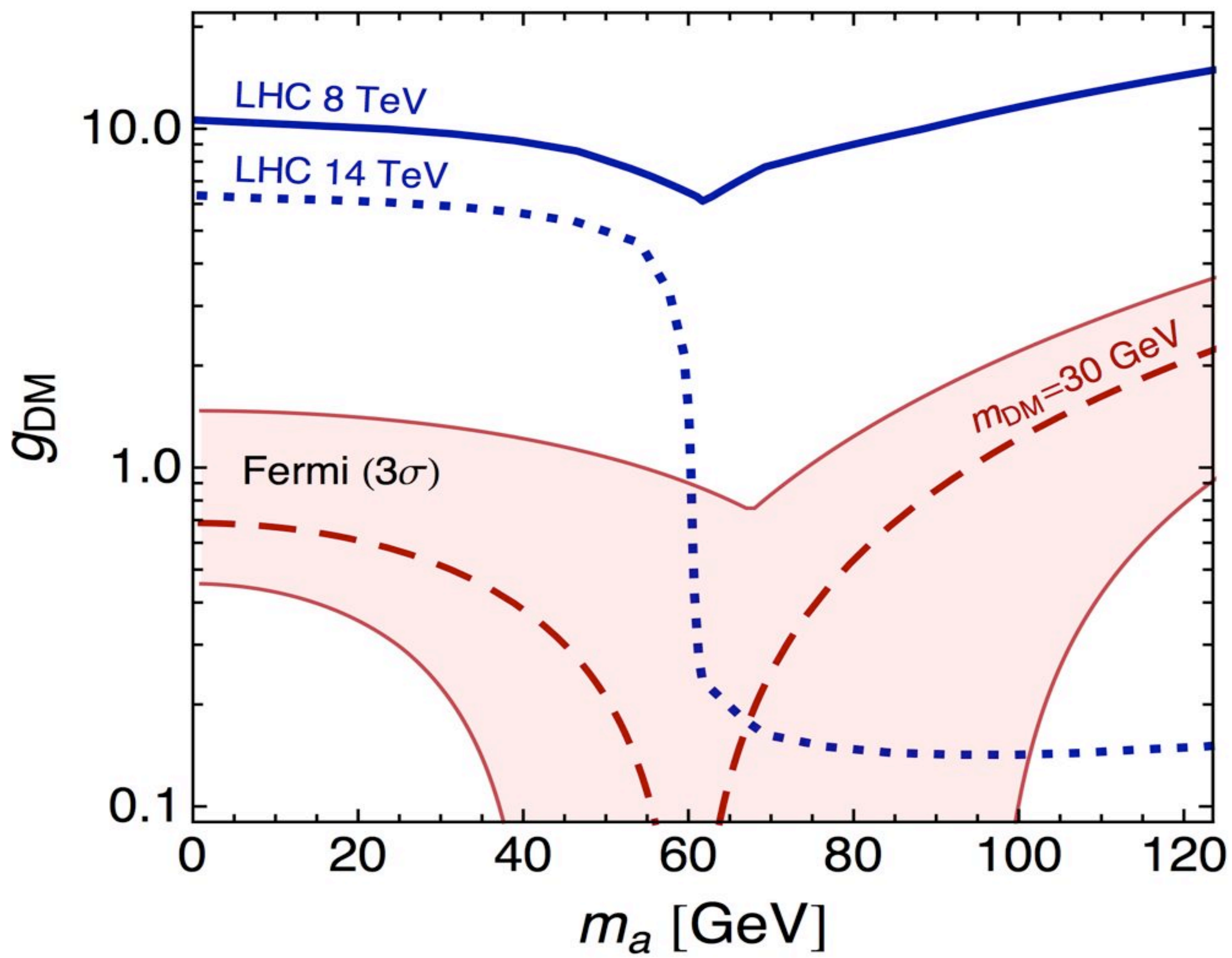
A comparison of the spectral shape of the gamma- ray excess from the sum of all millisecond pulsars detected as individual point sources by Fermi.The gamma-ray spectrum measured from millisecond pulsars and from globular clusters (whose emission is believed to be dominated by millisecond pulsars) is consistently softer than that of the observed excess at energies below ~1 GeV.

A Compelling Case for Annihilating Dark Matter arXiv:1402.6703

Galactic Center and Dark Matter



arXiv:1306.5725



Se non è vero è ben trovato

arXiv:1401.6458

New gamma projects in space

- **Gamma-light** (Proposed to ESA but not approved)

http://agenda.infn.it/getFile.py/access?contribId=67&resId=0&materialId=slides&confId=4267

- **Gamma-400** launch foreseen by end 2018

100 MeV – 3 TeV, an approved Russian γ-ray satellite. Energy resolution (100 GeV) ~ 1 %. Effective area ~ 0.4 m2. Angular resolution (100 GeV) ~ 0.01°.

Science with Gamma-400 Workshop http://cdsagenda5.ictp.it/full_display.php?ida=a1311

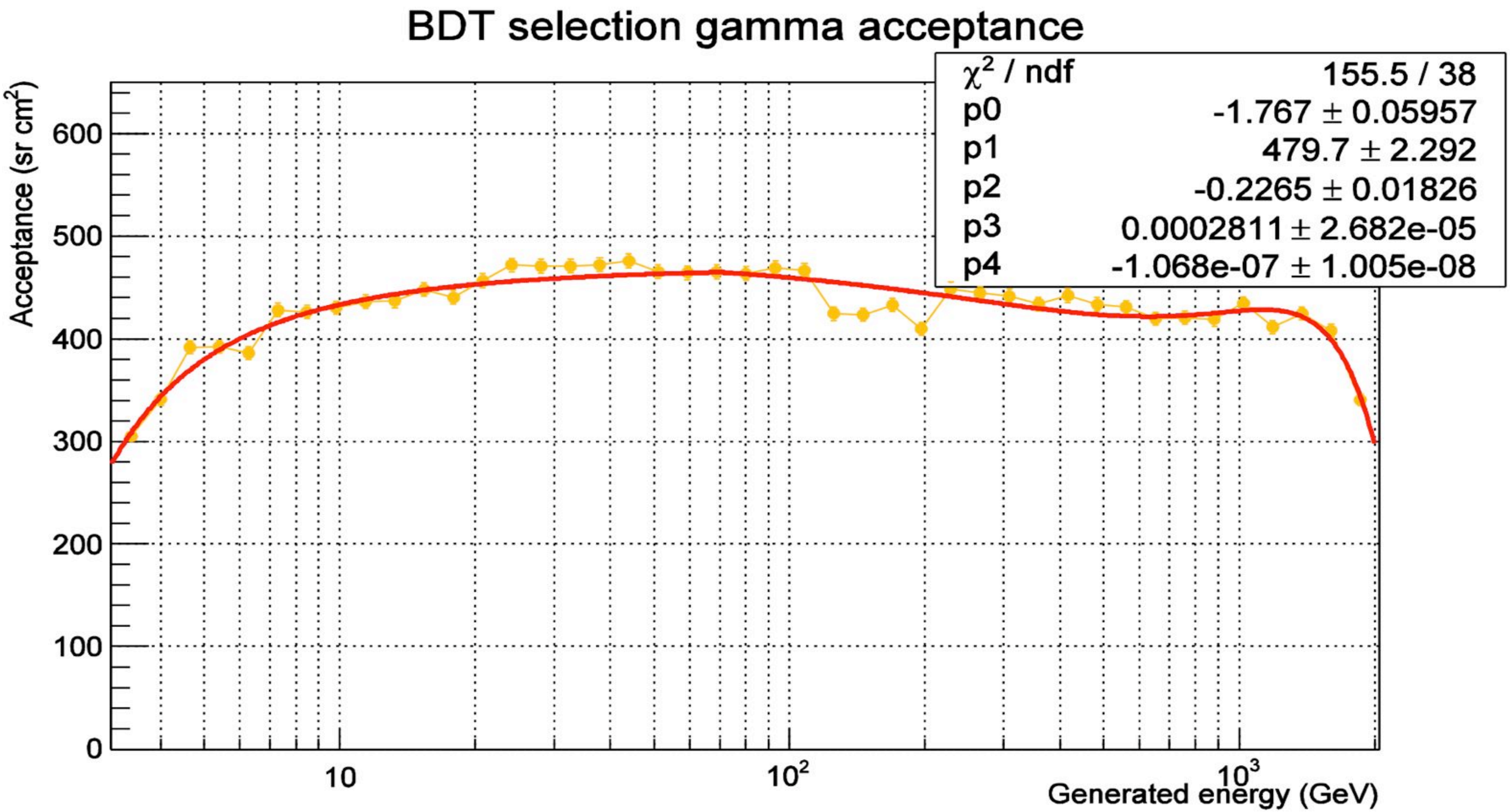
- **DAMPE**: Satellite of similar performance as Gamma-400.

An approved Chinese γ-ray satellite. Planned launch 2015-16.

- **HERD**: Instrument on the planned Chinese Space Station.

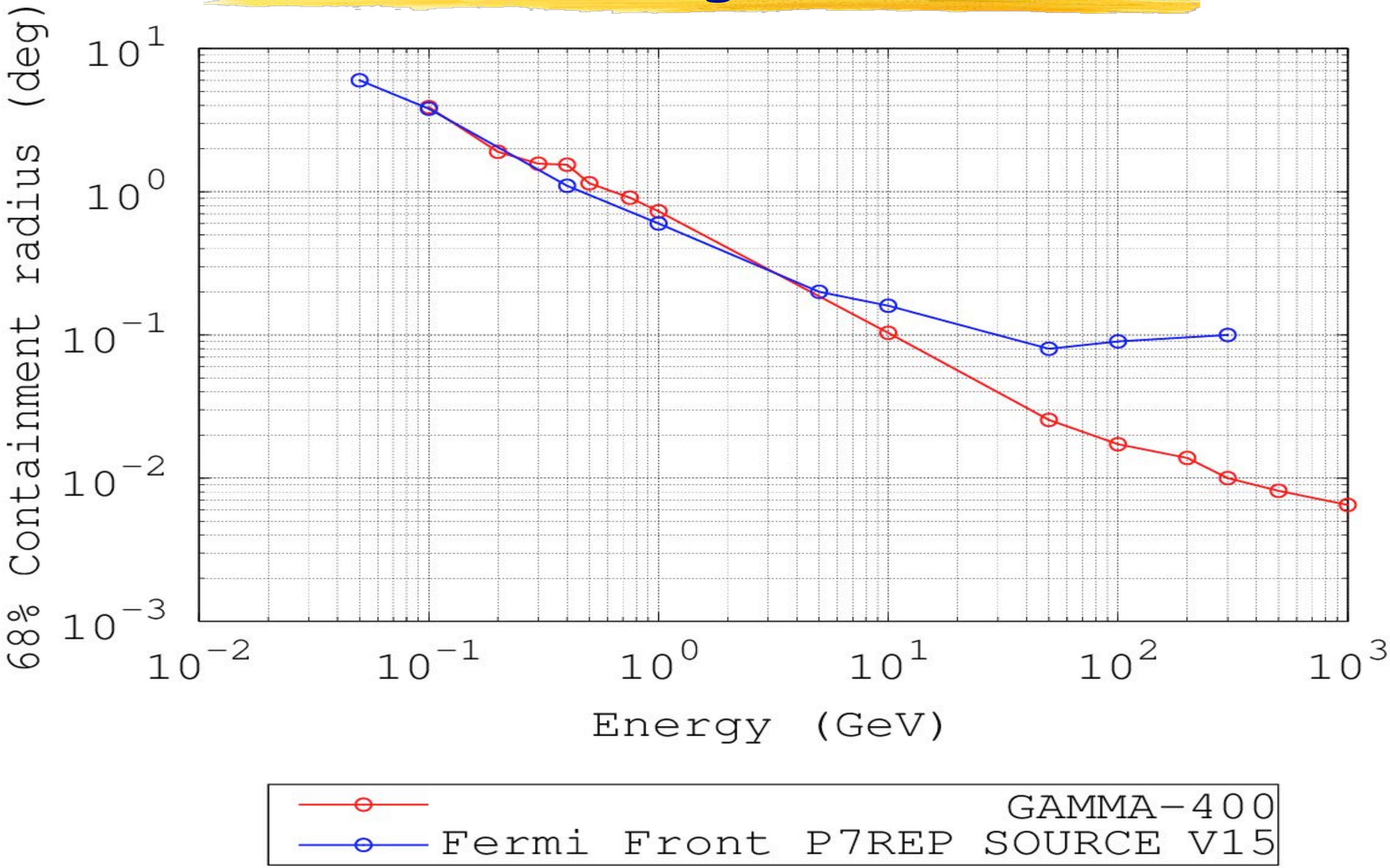
Energy resolution (100 GeV) ~ 1 %. Effective area ~ 1 - 2 m2. Angular resolution (100 GeV) ~ 0.01°. Planned launch around 2020.

AMS-02 Acceptance for gamma-rays

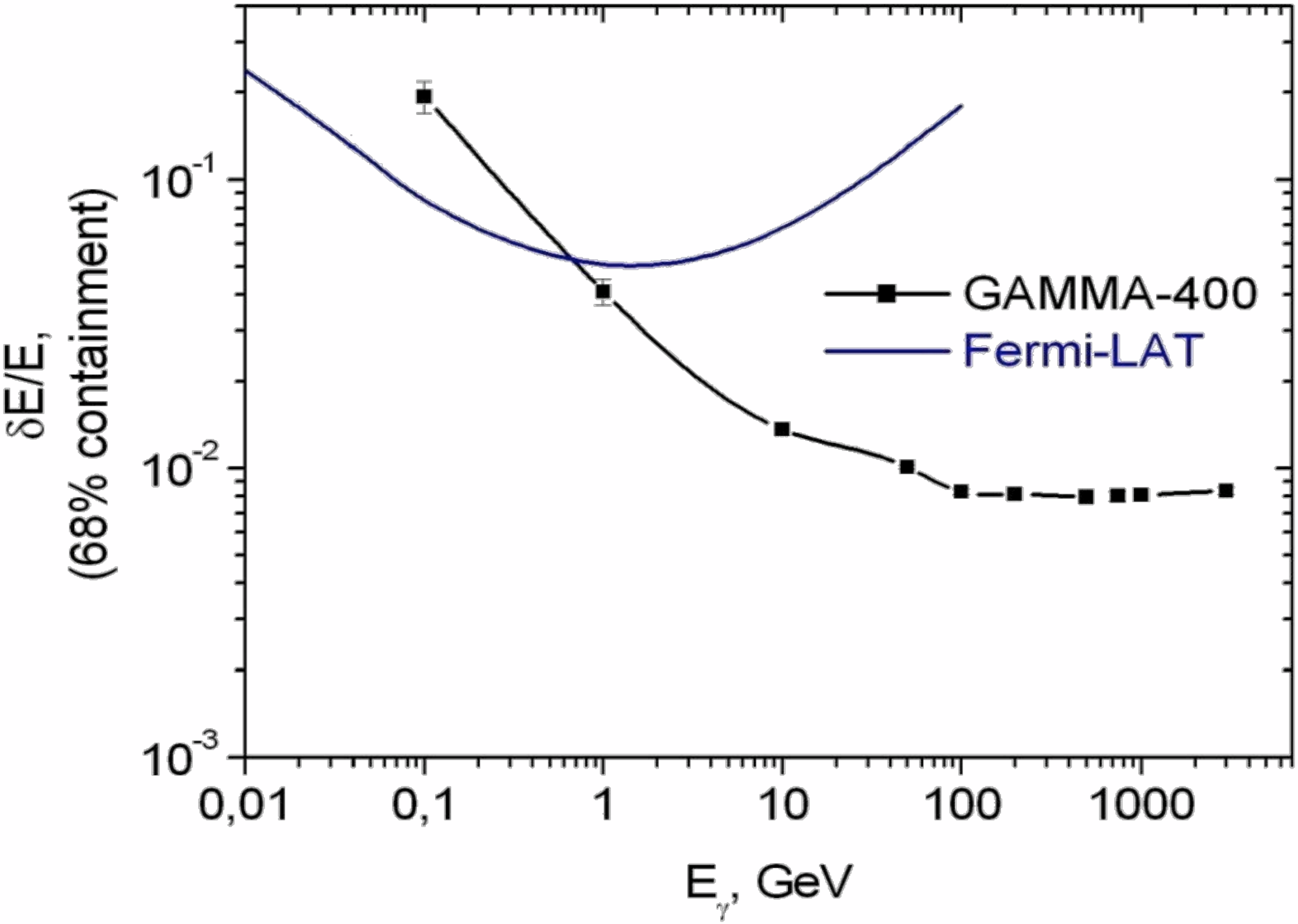


To be compared with Fermi-LAT 20000 sr cm3 @ 100 GeV

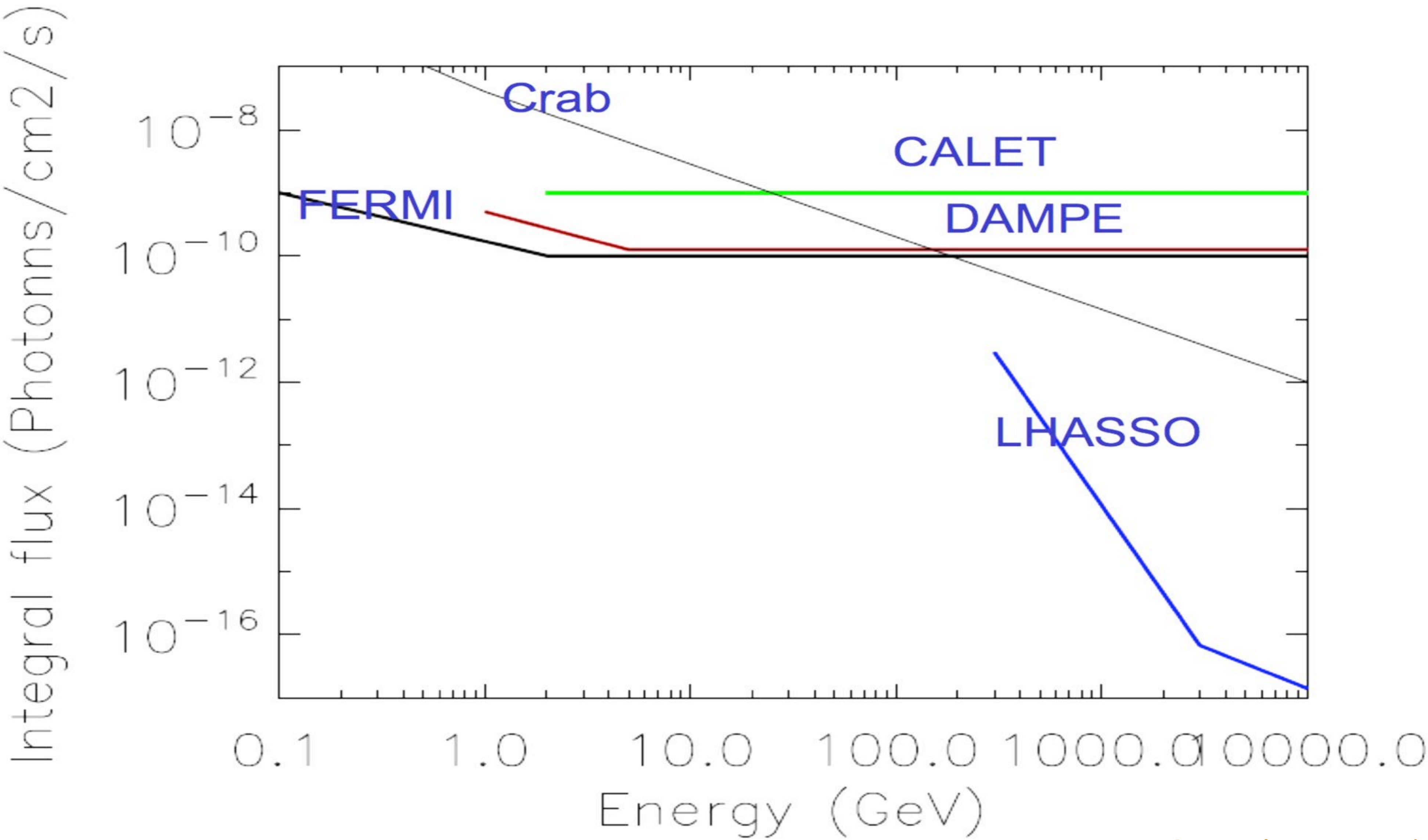
Gamma-400 Angular resolution



Gamma-400 Energy resolution for γ

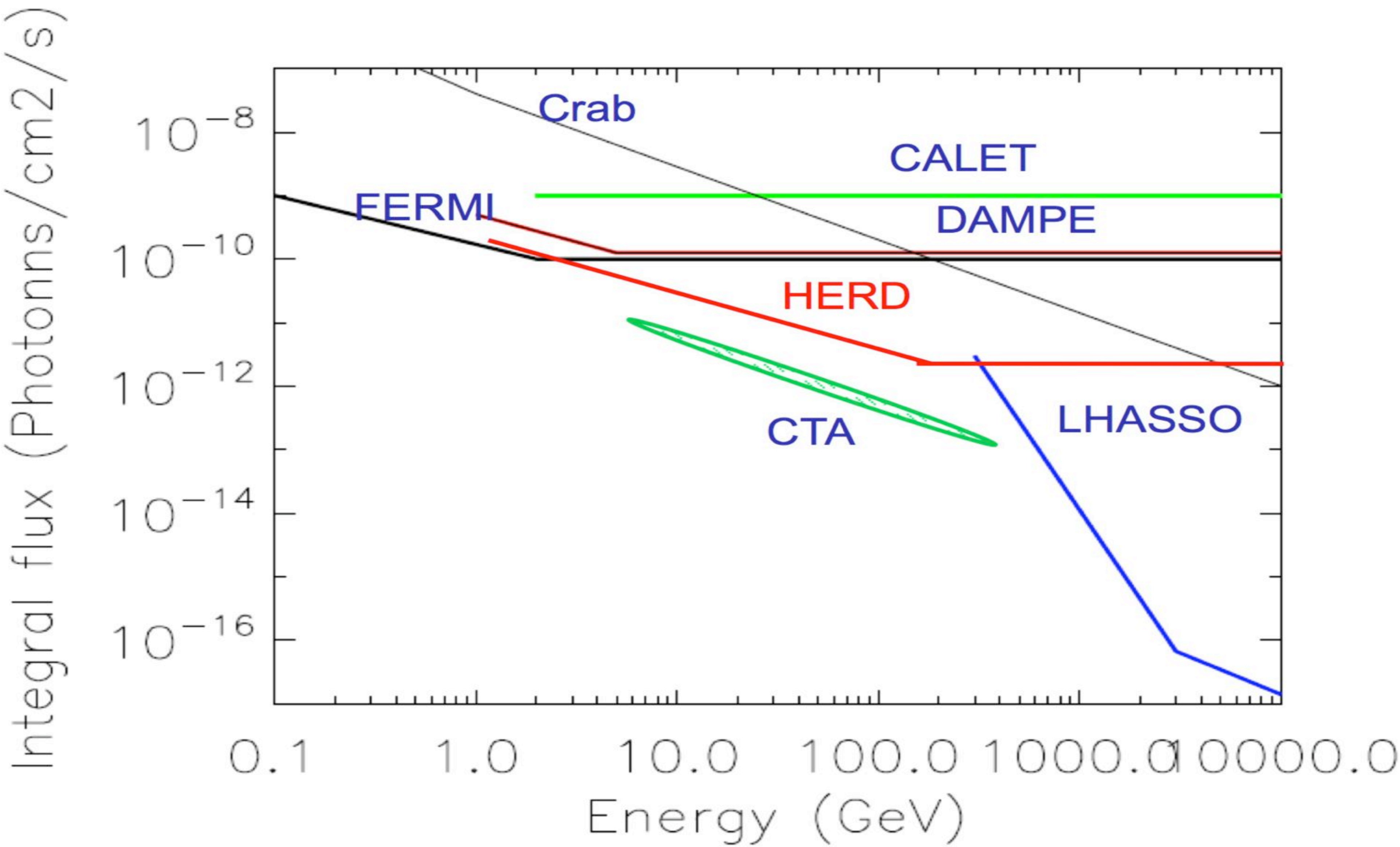


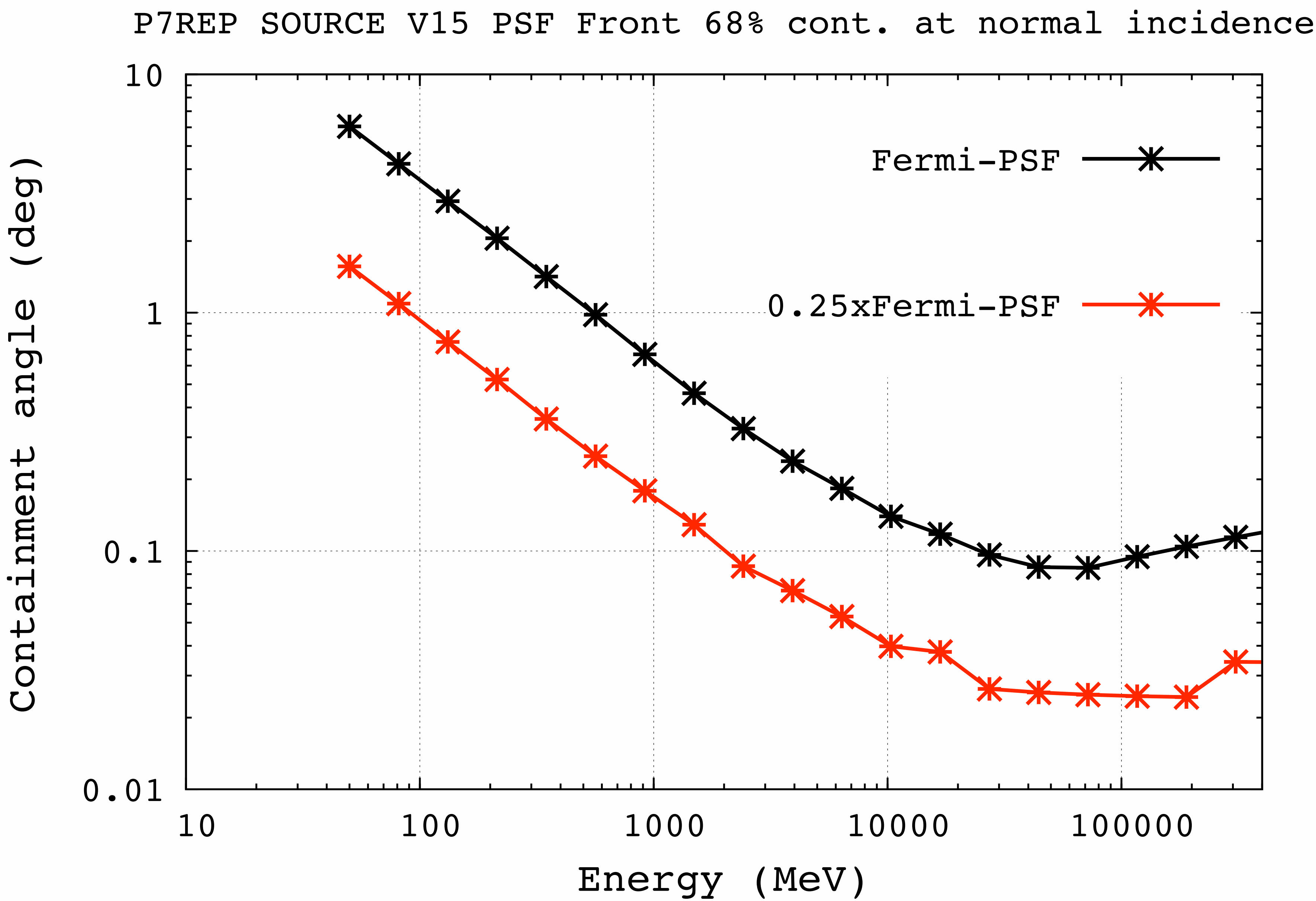
DAMPE Gamma-ray Sensitivity



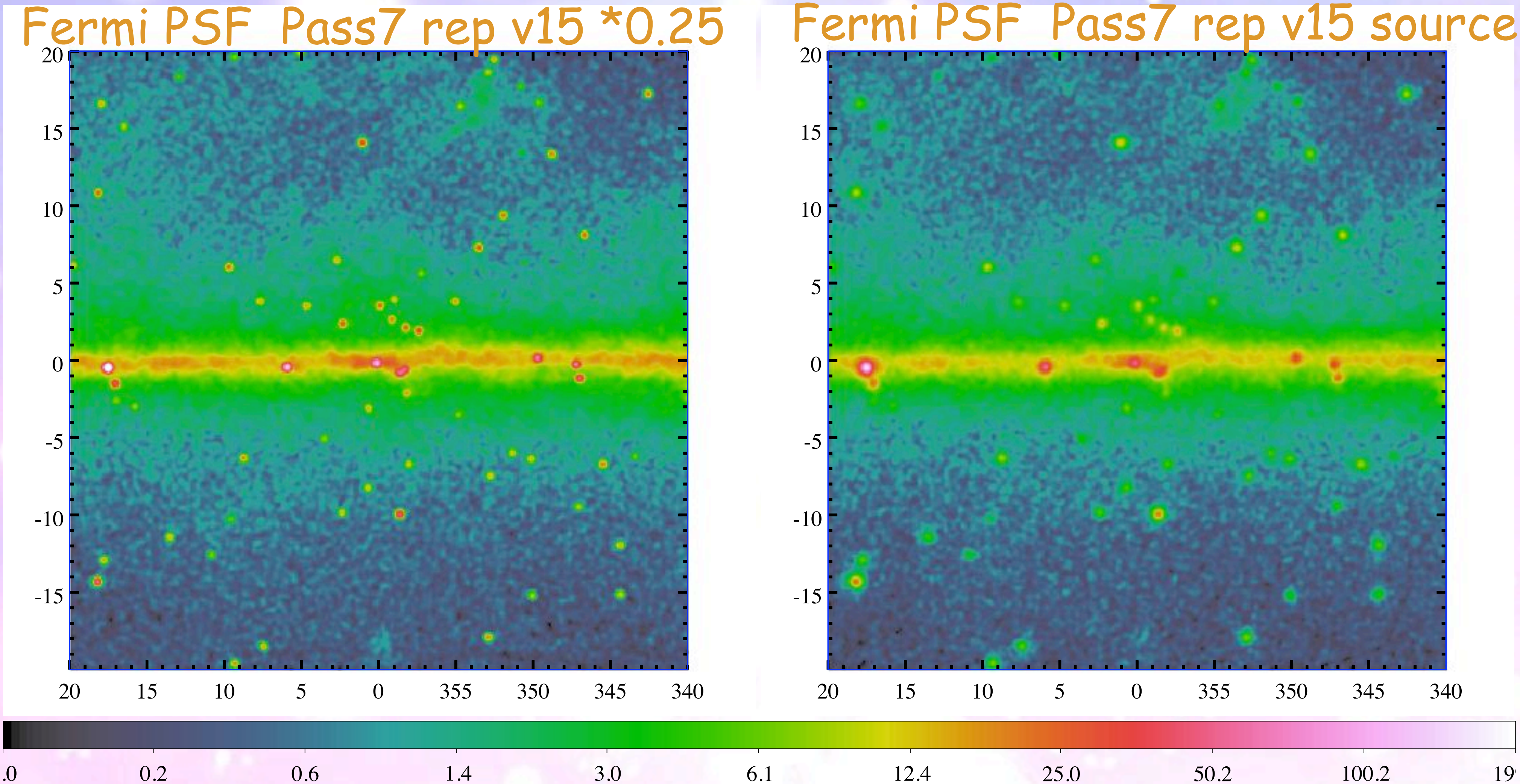
Wang YiFang last week

HERD Gamma-ray Sensitivity




P7REP SOURCE V15 PSF Front 68% cont. at normal incidence
Containment angle (deg)
10
1
0.1
0.01
10
100
1000
10000
100000
Energy (MeV)
Fermi-PSF
0.25xFermi-PSF

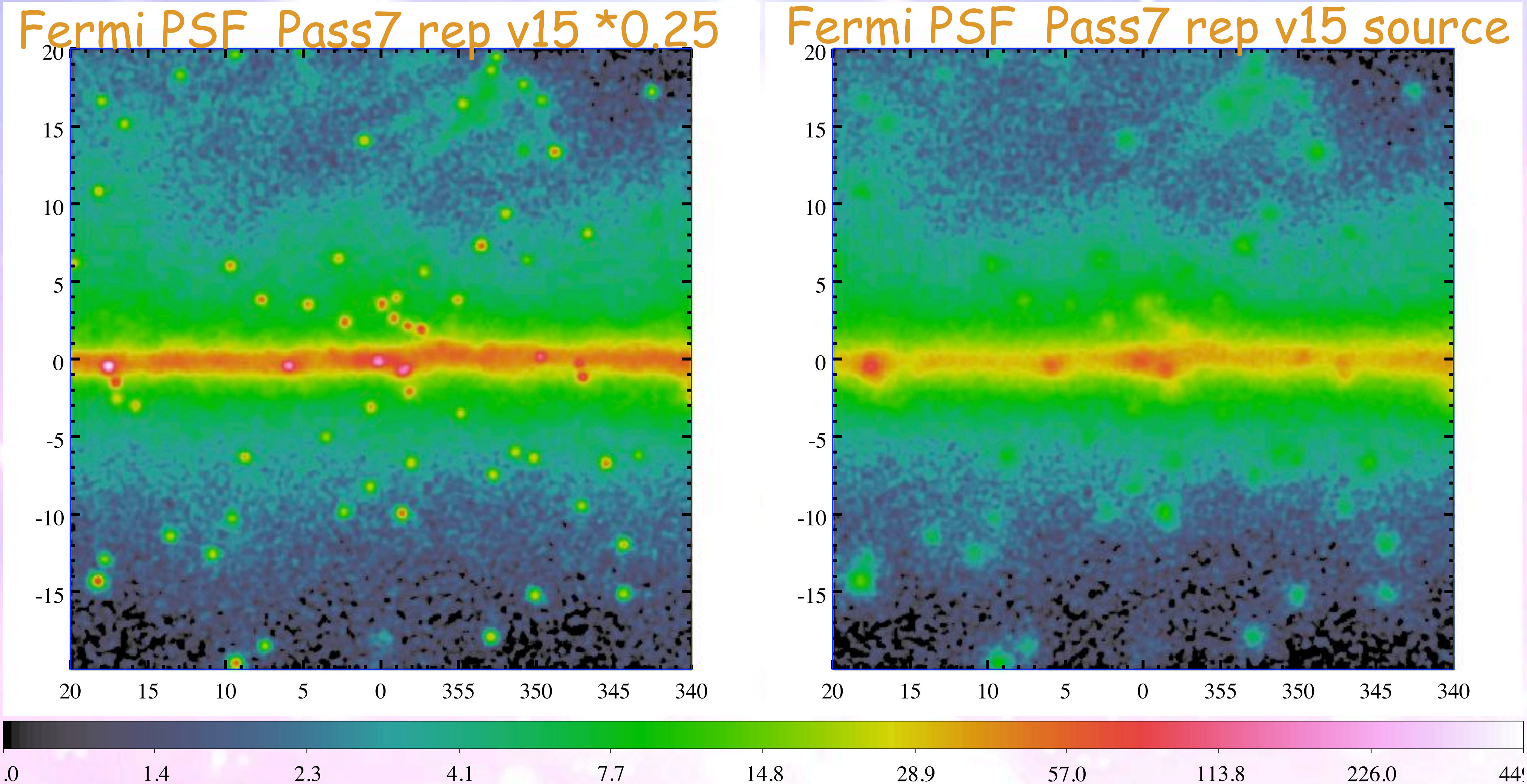
Galactic Center Region 1-5 GeV



Sources from two years Fermi catalog , template ring model for diffuse

ApJ S 2012 199,31 [arXiv:1108.1435]

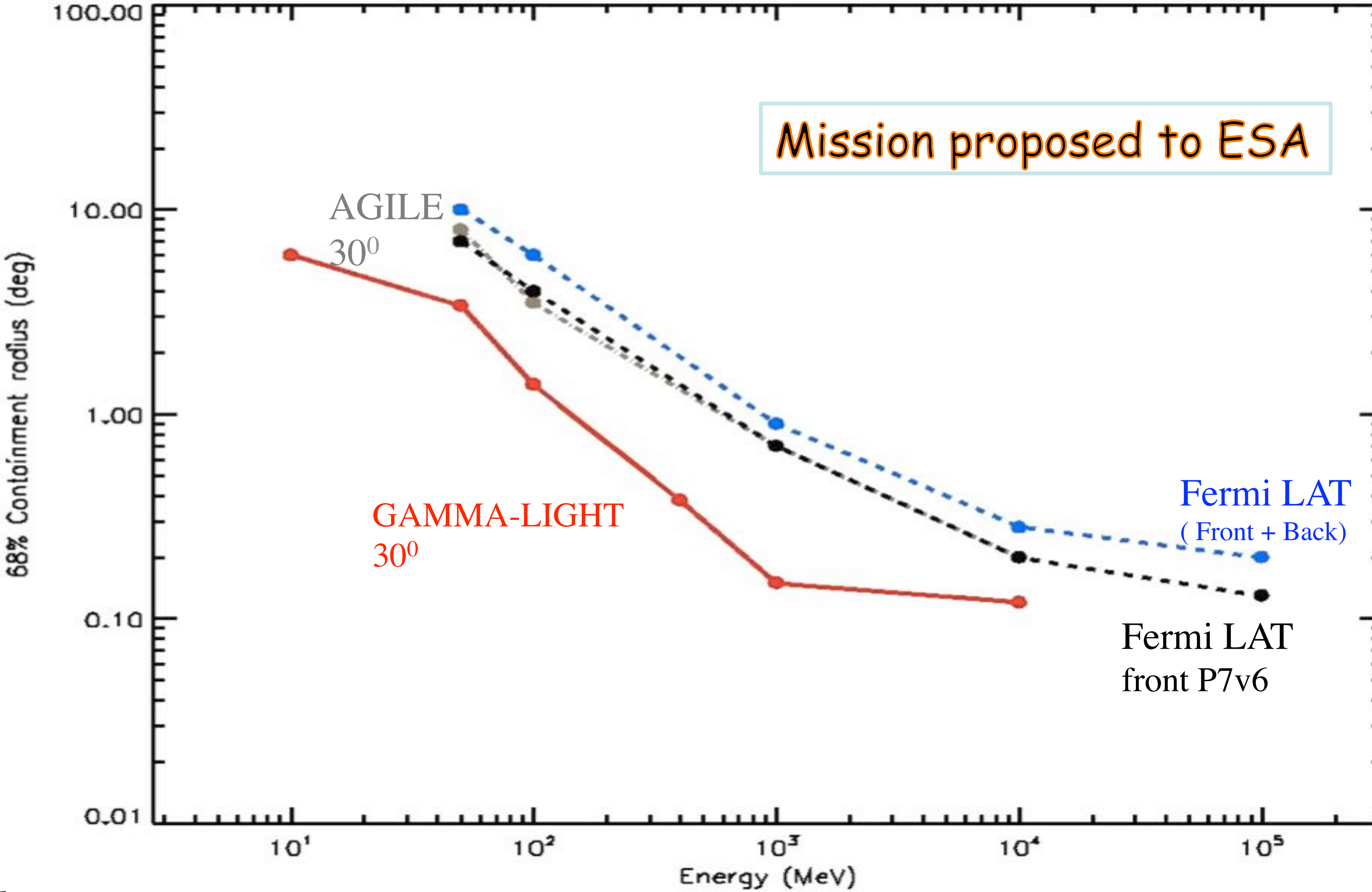
Galactic Center Region 0.2-1 GeV



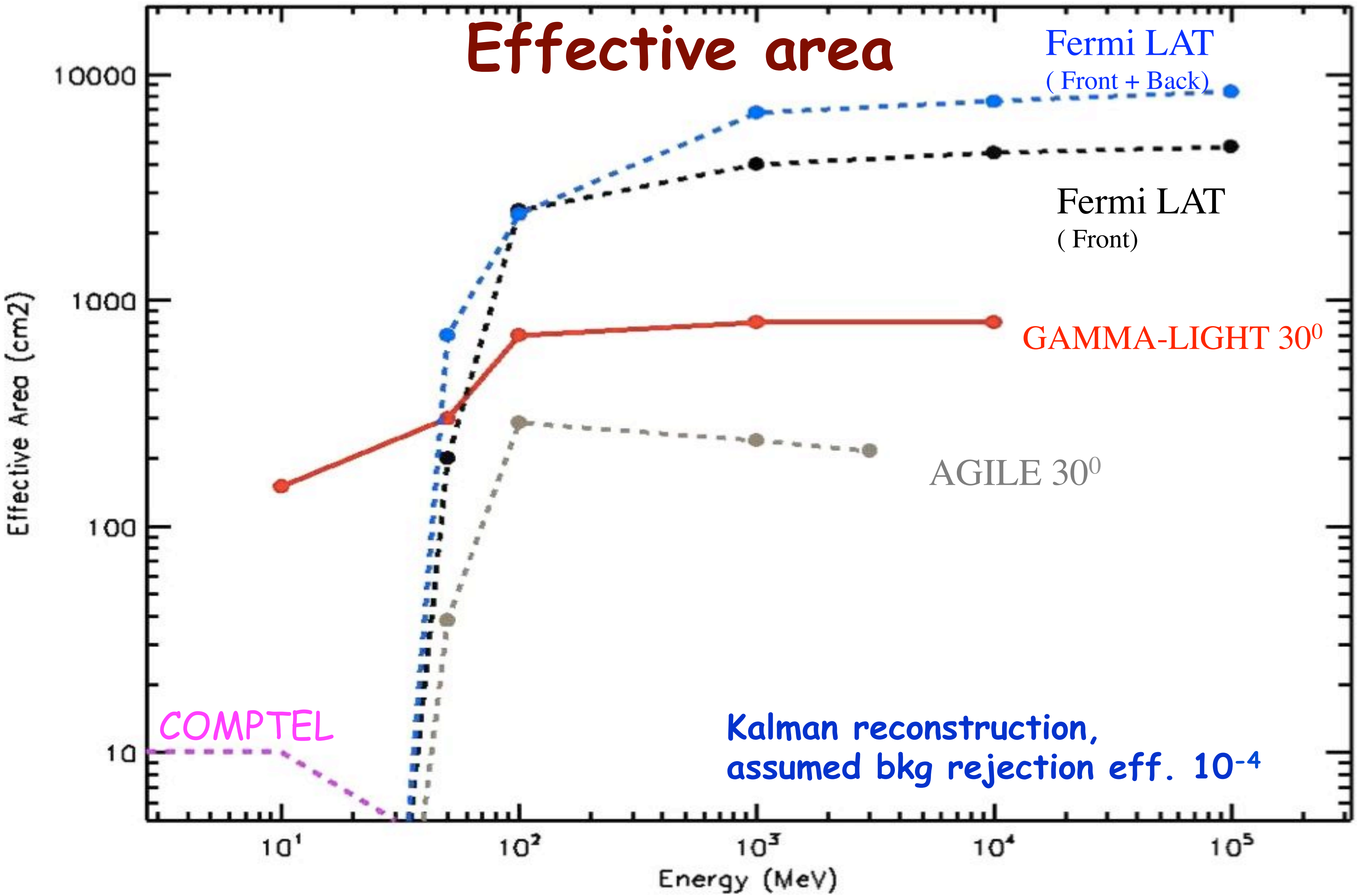
Sources from two years Fermi catalog , template ring model for diffuse,

ApJ S 2012 199,31 [arXiv:1108.1435]

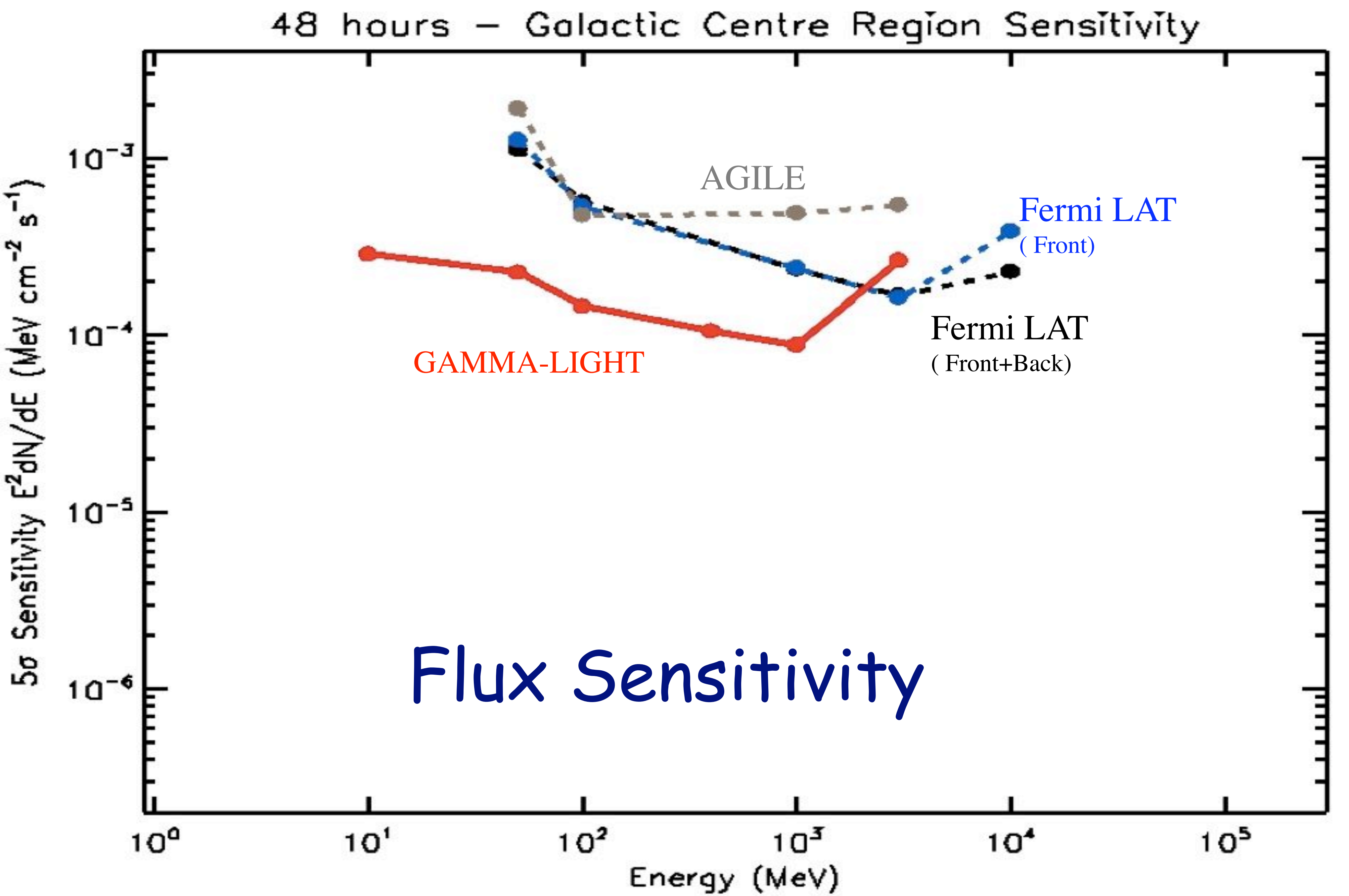
Gamma-Light Point Spread Function (angular resolution)



A.Morselli et al. , Nuclear Physics B Proc. Supp. 239–240 (2013) 193-198



A.Morselli et al. , Nuclear Physics B Proc. Supp. 239–240 (2013) 193-198



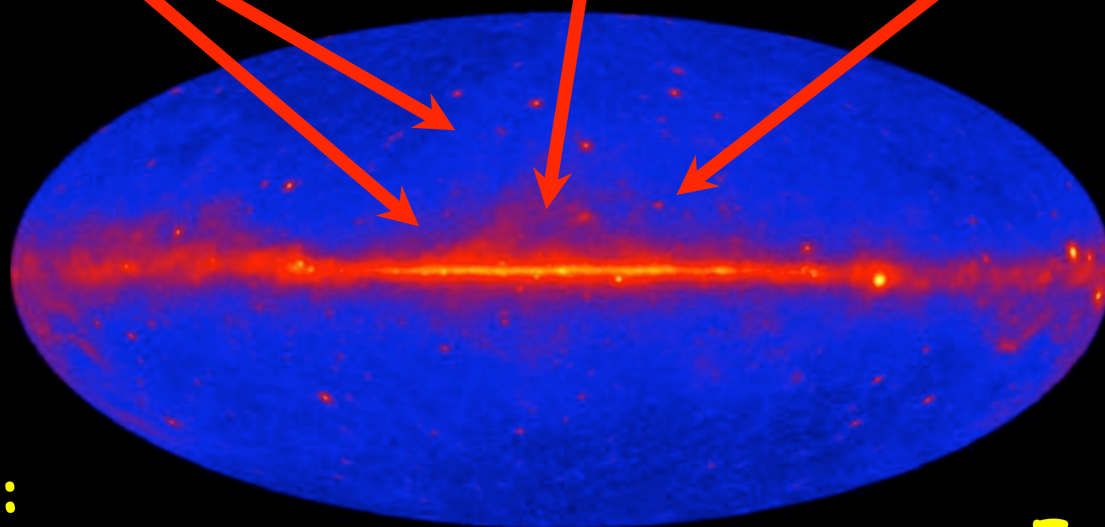
48 hours – Galactic Centre Region Sensitivity
AGILE
Fermi LAT
(Front)
Fermi LAT
(Front+Back)
GAMMA-LIGHT
Flux Sensitivity
5σ Sensitivity E²dN/dE (MeV cm⁻² s⁻¹)
Energy (MeV)

Search Strategies

Satellites:
Low background and good source id, but low statistics

Galactic center:
Good statistics but source confusion/diffuse background

Milky Way halo:
Large statistics but diffuse background



And electrons!
and
Anisotropies

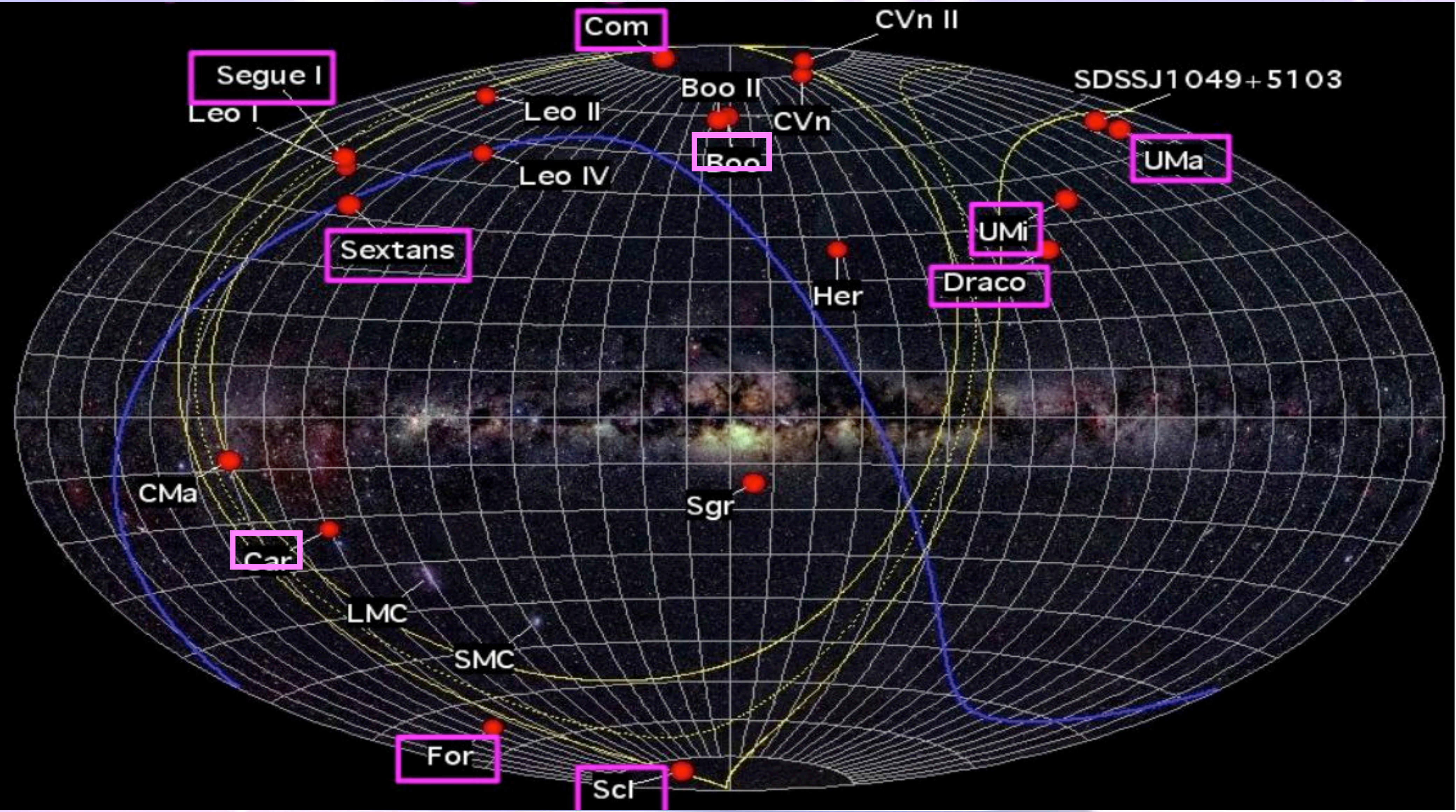
Spectral lines:
No astrophysical uncertainties, good source id, but low statistics

Galaxy clusters:
Low background but low statistics

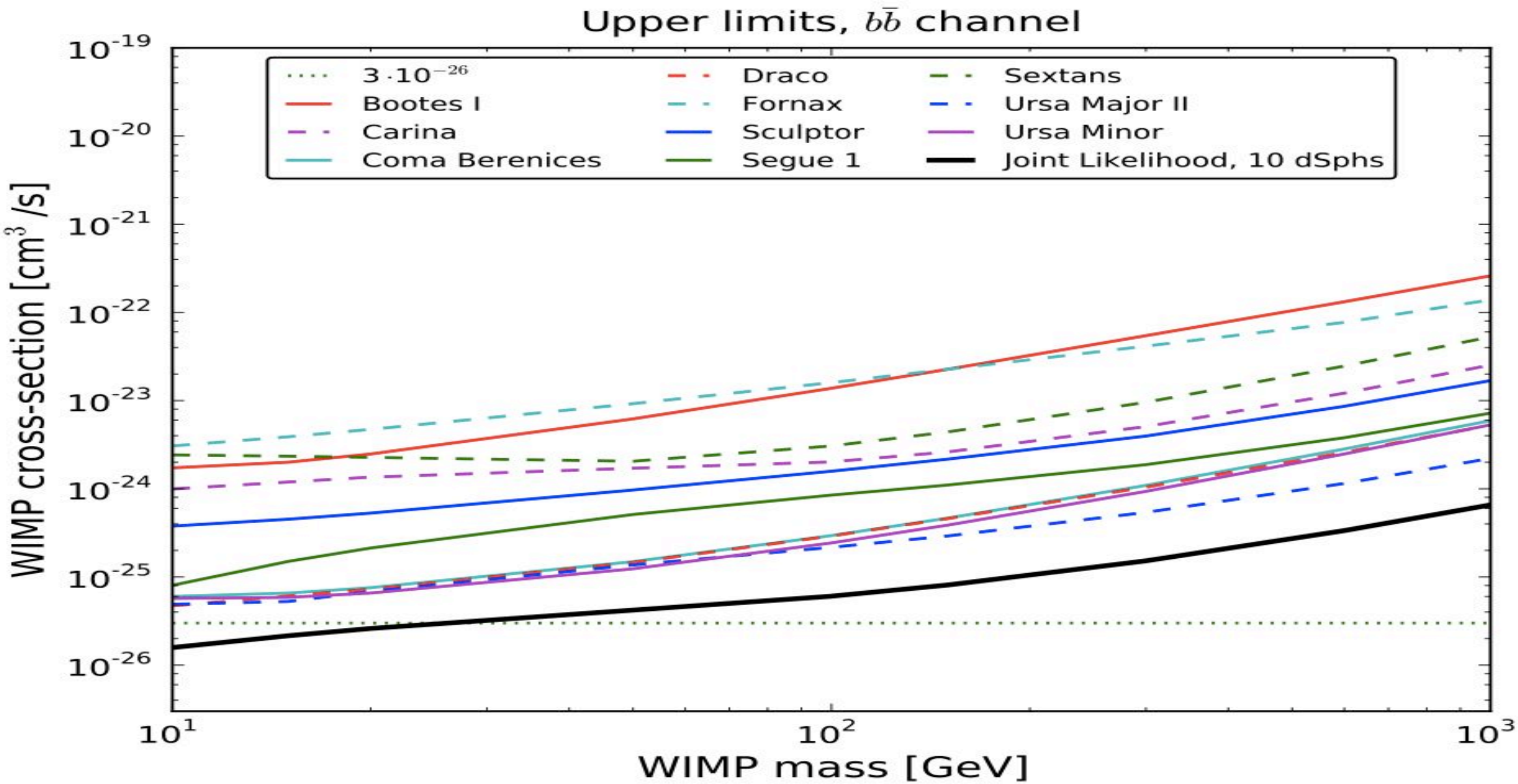
Extra-galactic:
Large statistics, but astrophysics,galactic diffuse background

Pre-launch sensitivities published in Baltz et al., 2008, JCAP 0807:013 [astro-ph/0806.2911]

Dwarf spheroidal galaxies (dSph) : promising targets for DM detection



Dwarf Spheroidal Galaxies combined analysis

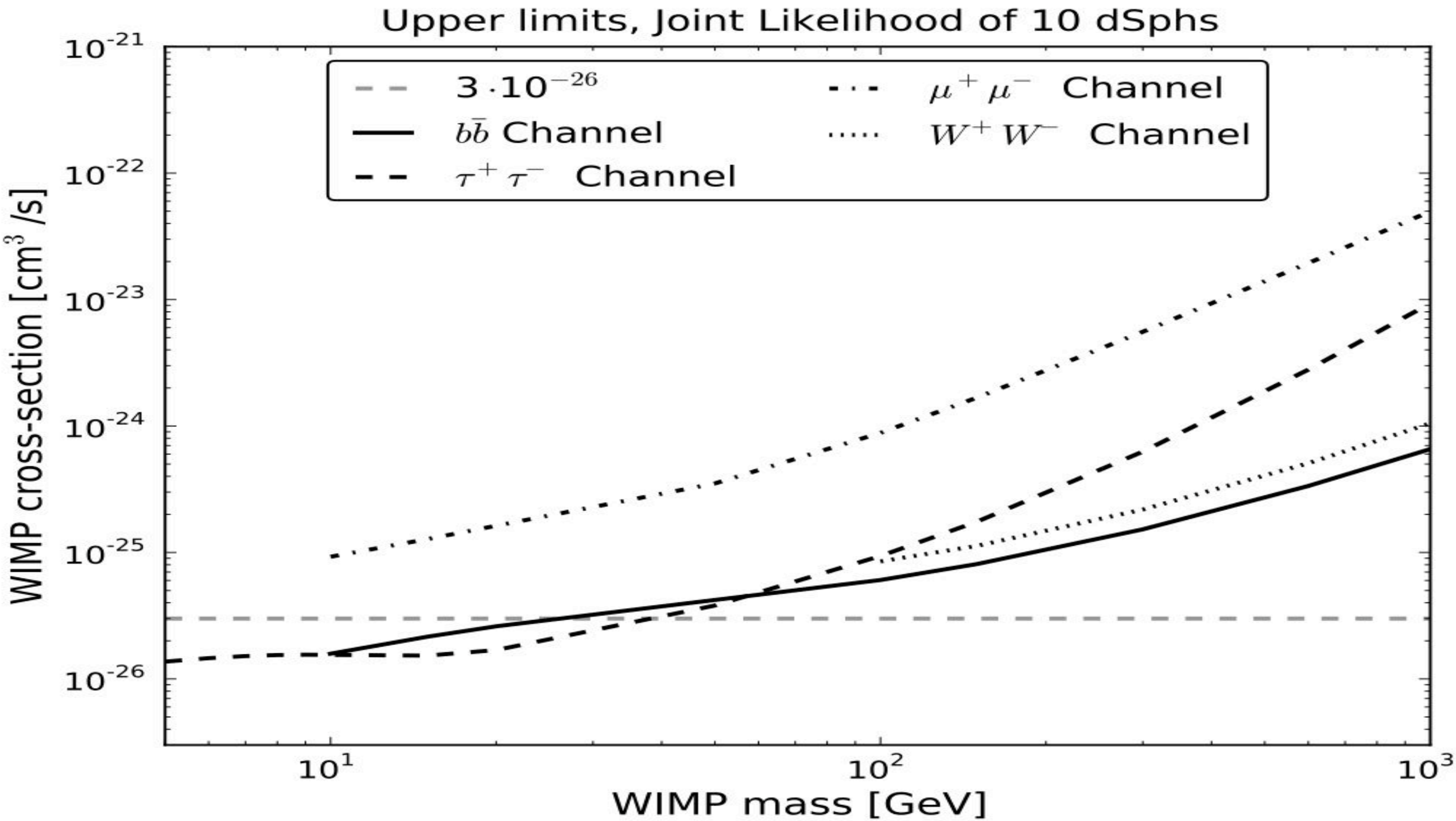


robust constraints including J-factor uncertainties from the stellar data statistical analysis

NFW. For cored dark matter profile, the J-factors for most of the dSphs would either increase or not change much

Fermi Lat Coll., PRL 107, 241302 (2011) [arXiv:1108.3546]

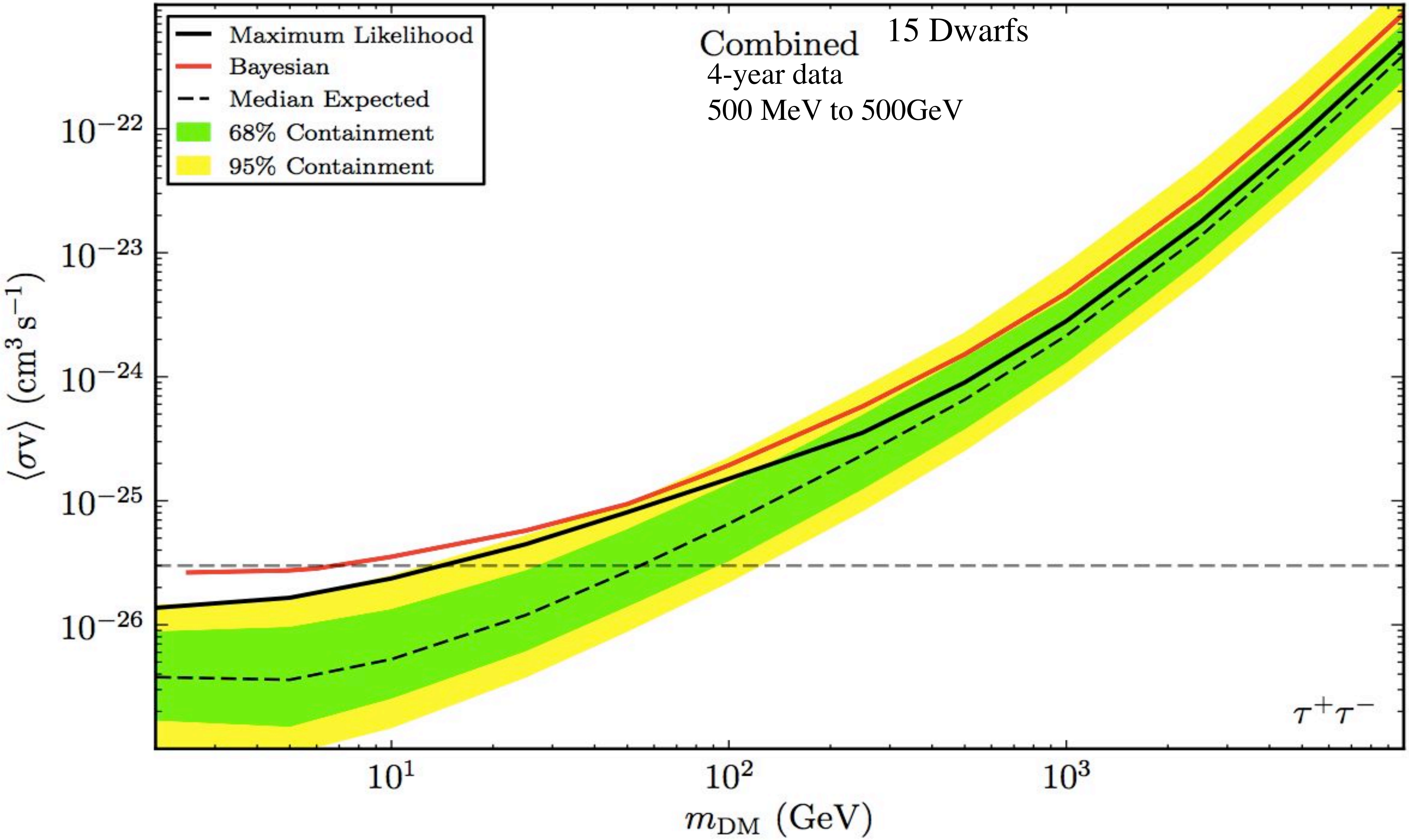
Dwarf Spheroidal Galaxies combined analysis



robust constraints including J-factor uncertainties from the stellar data statistical analysis

Fermi Lat Coll., PRL 107, 241302 (2011) [arXiv:1108.3546]

Dwarf Spheroidal Galaxies upper-limits

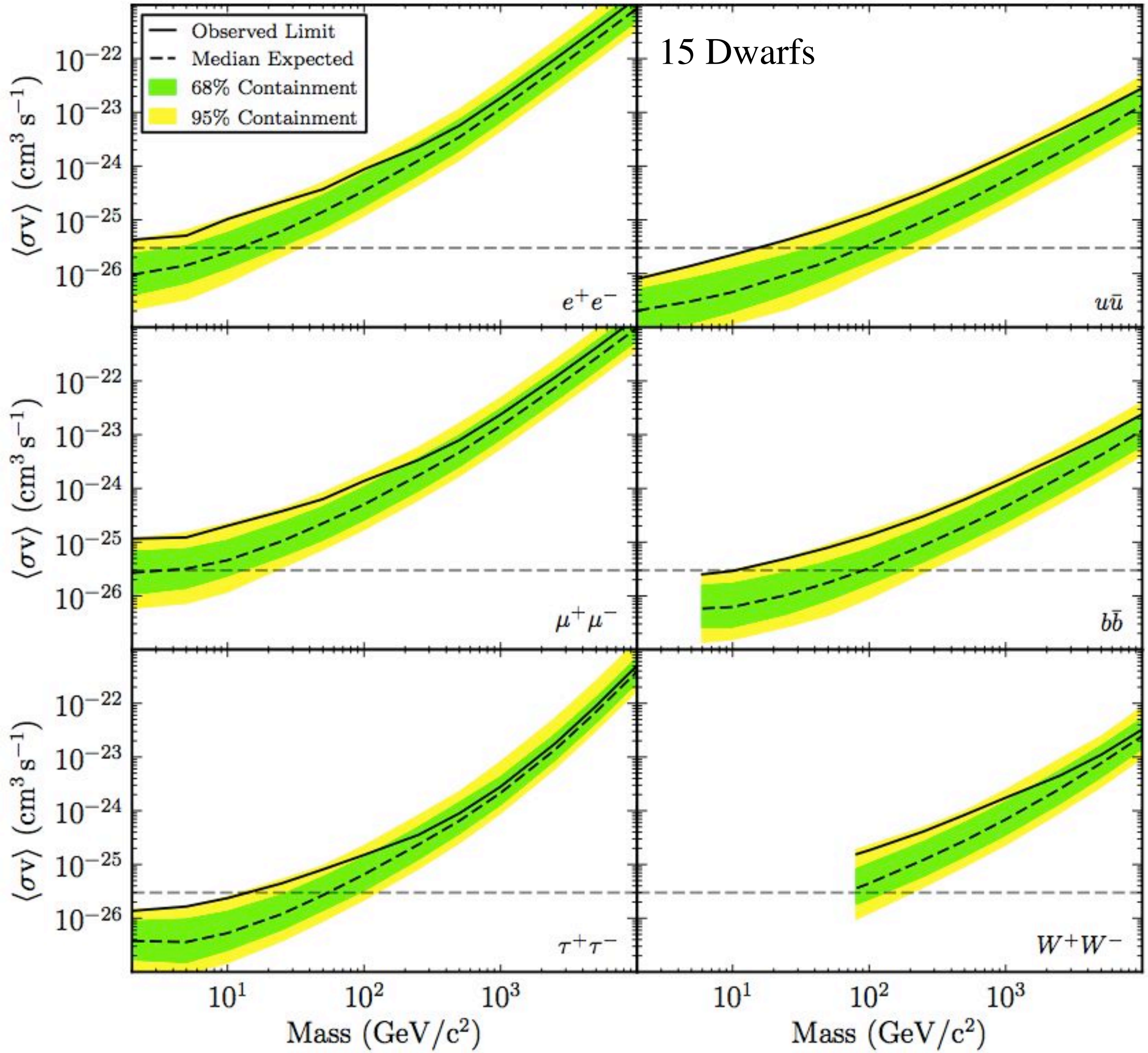


M.Ackermann et al., [Fermi Coll.] Phys.Rev.D 89, 042001 (2014)[arXiv:1310.0828]

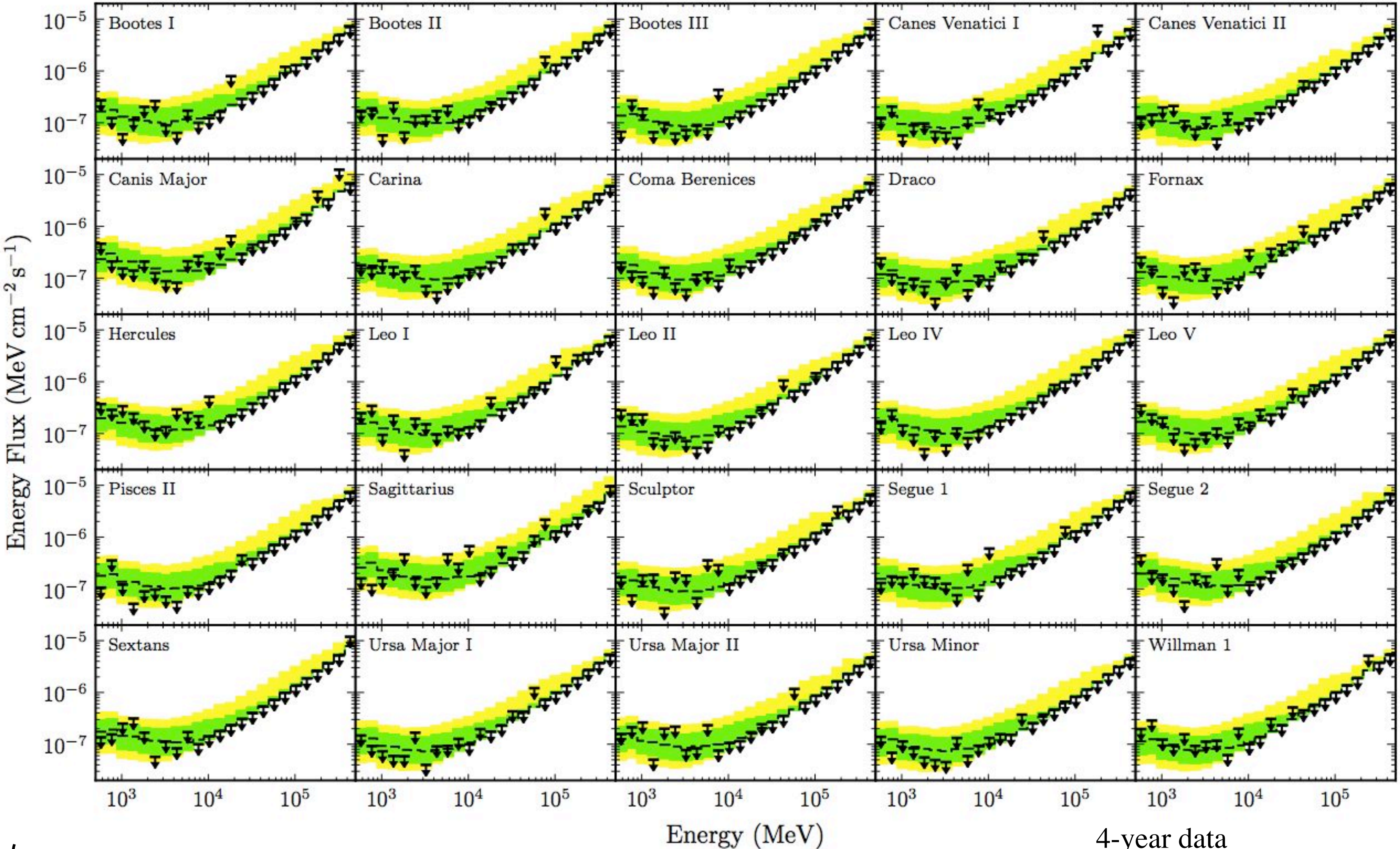
Dwarf Spheroidal Galaxies upper-limits

15 Dwarfs
4-year data
500 MeV to 500GeV

M.Ackermann et al., [Fermi Coll.] Phys.Rev.D 89, 042001 (2014) [arXiv:1310.0828]



25 Dwarf Spheroidal Galaxies upper-limits

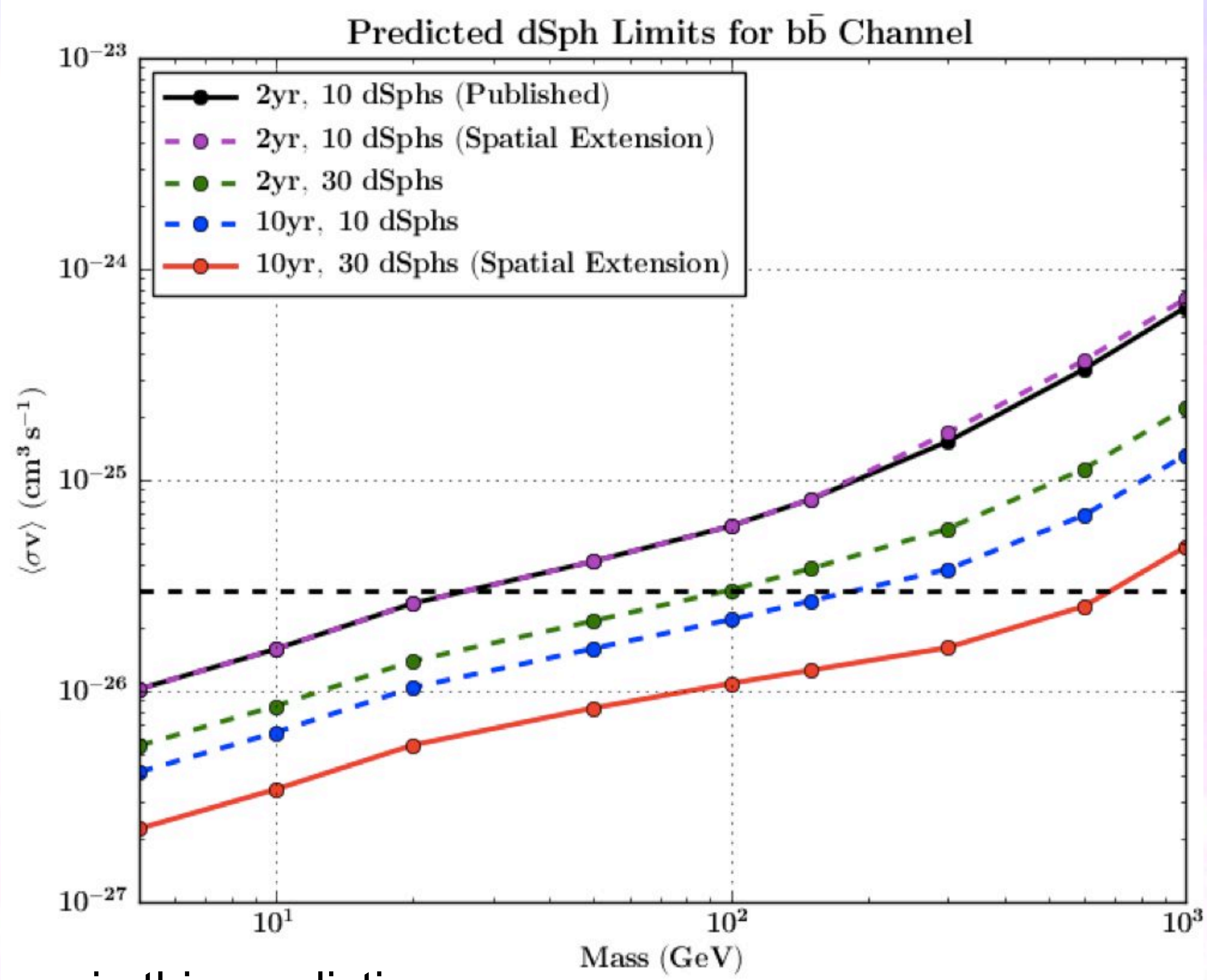


4-year data
500 MeV to 500GeV

M.Ackermann et al., [Fermi Coll.] PRD 89, 042001 (2014).[arXiv:1310.0828]

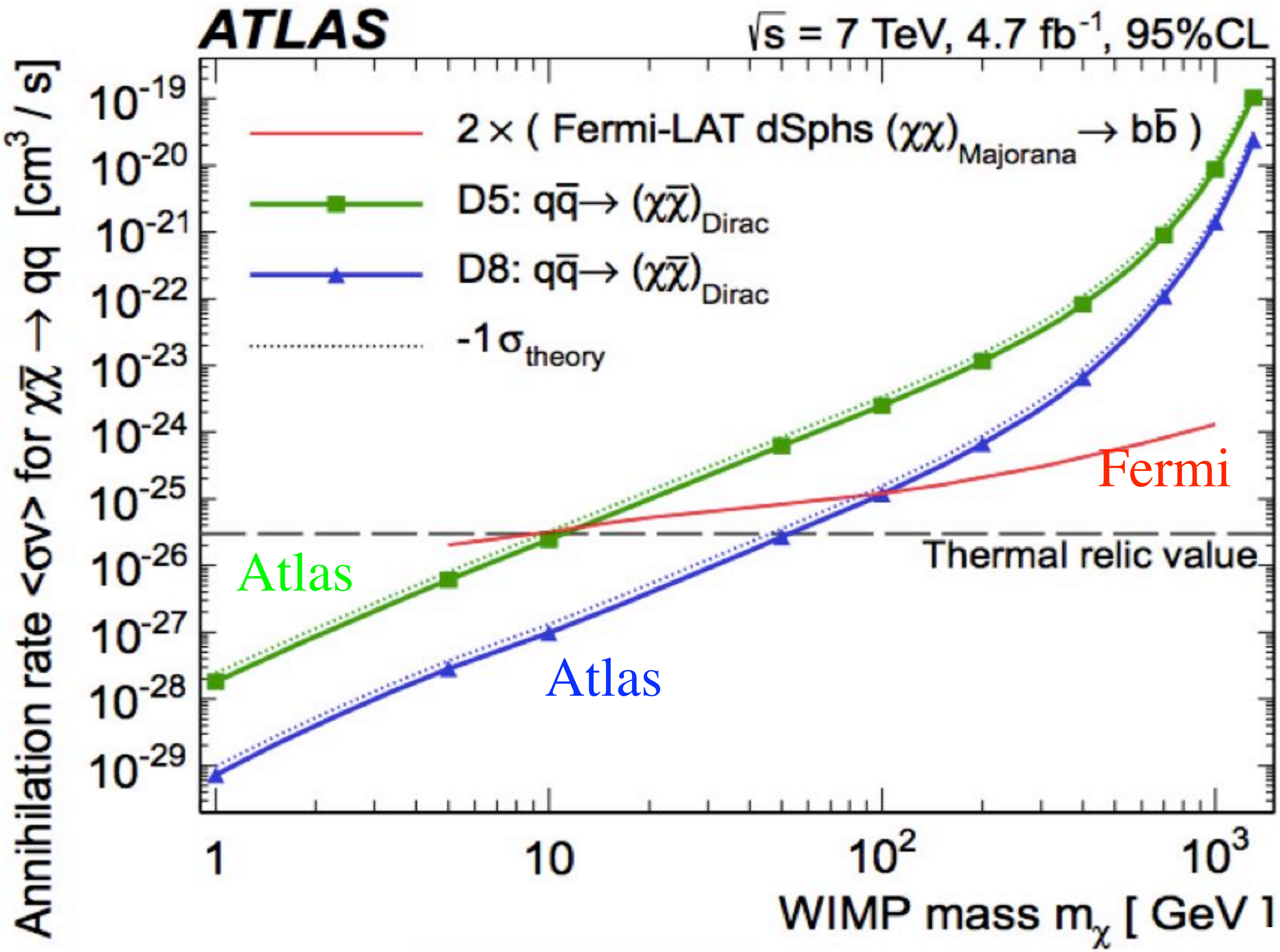
DM limit improvement estimate in 10 years with the composite likelihood approach (2008- 2018)

- 10 years of data instead of 2(5x)
- 30 dSphs (3x) (supposing that the new optical surveys will find new dSph)
- -10% from spatial extension (source extension increases the signal region at high energy E > 10 GeV, M > 200 GeV)



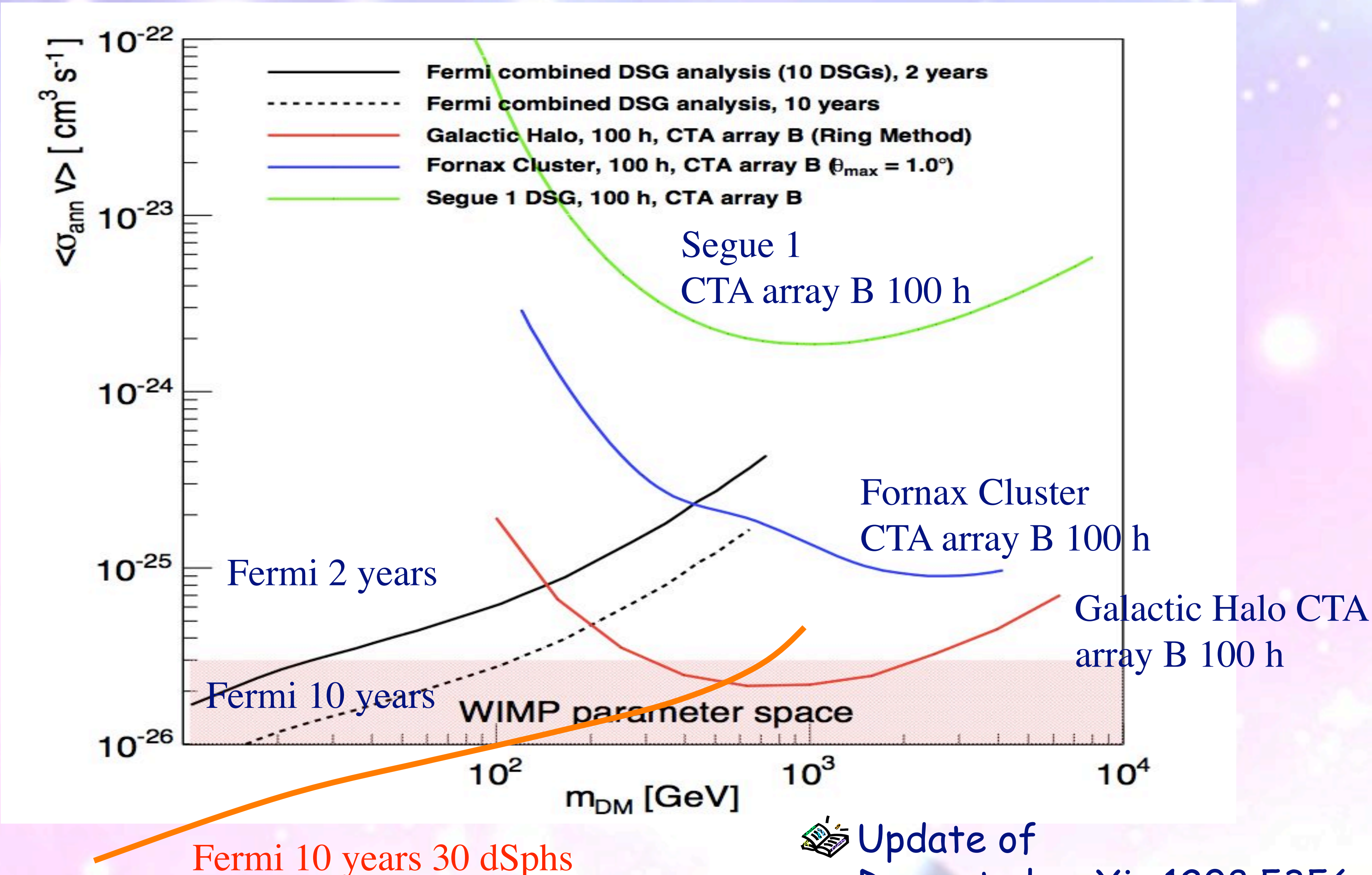
- There are many assumptions in this prediction
- Doesn't deal with a possible detections.

ATLAS-Fermi Results



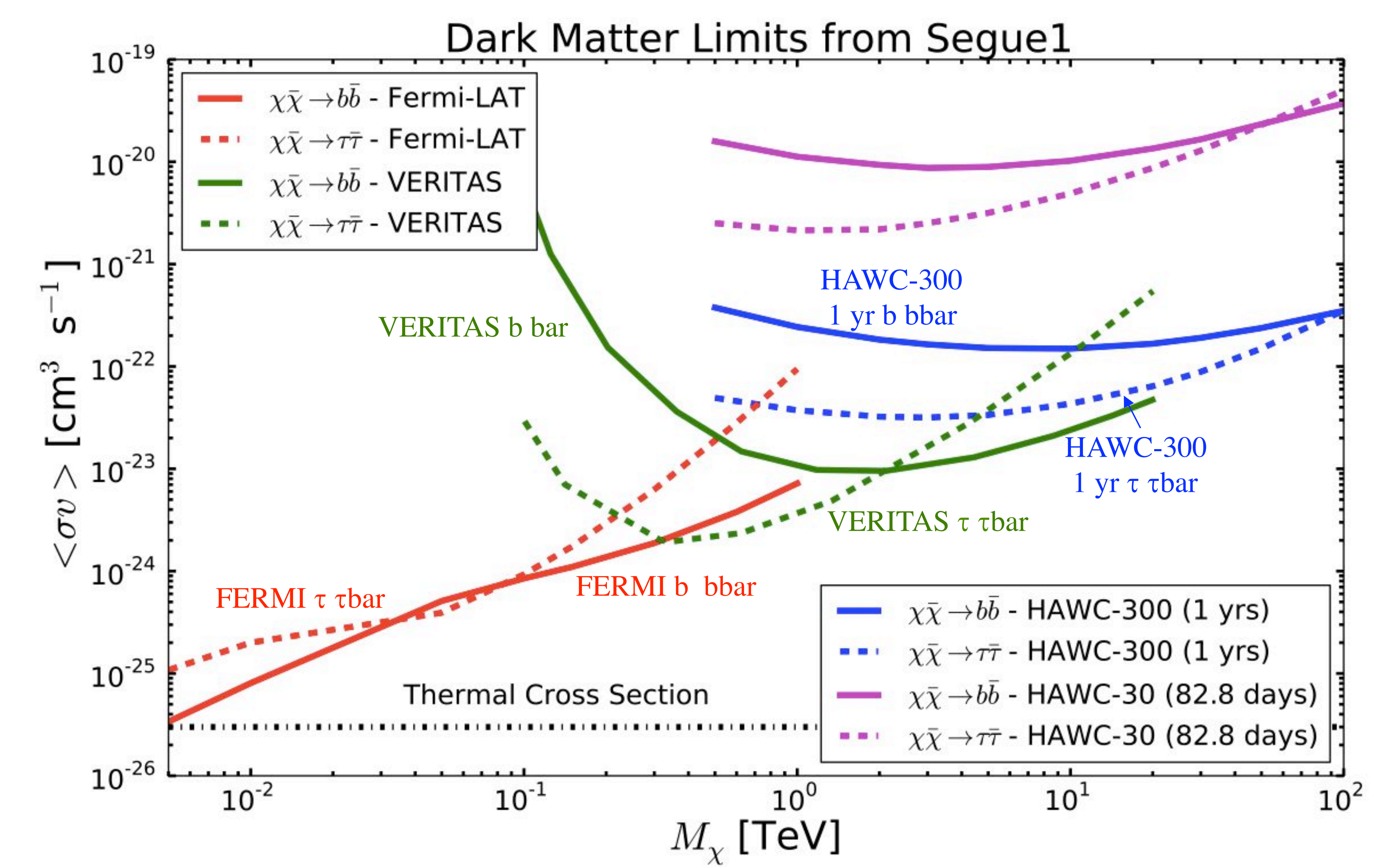
Atlas Coll. arXiv:1210.4491

Dwarf Spheroidal Galaxies upper-limits

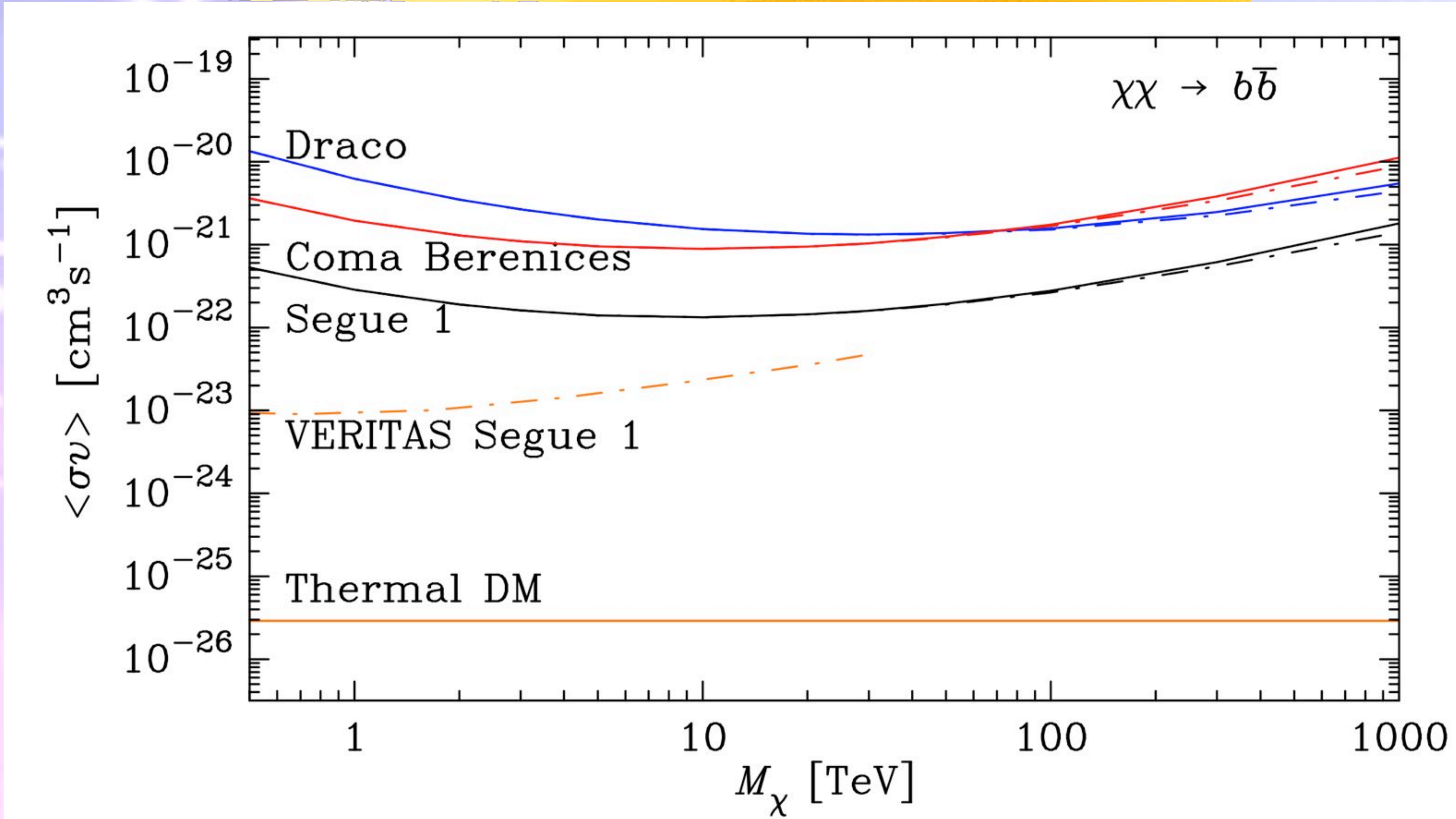


Update of
Doro et al. arXiv:1208.5356

HAWC and Dark Matter Search

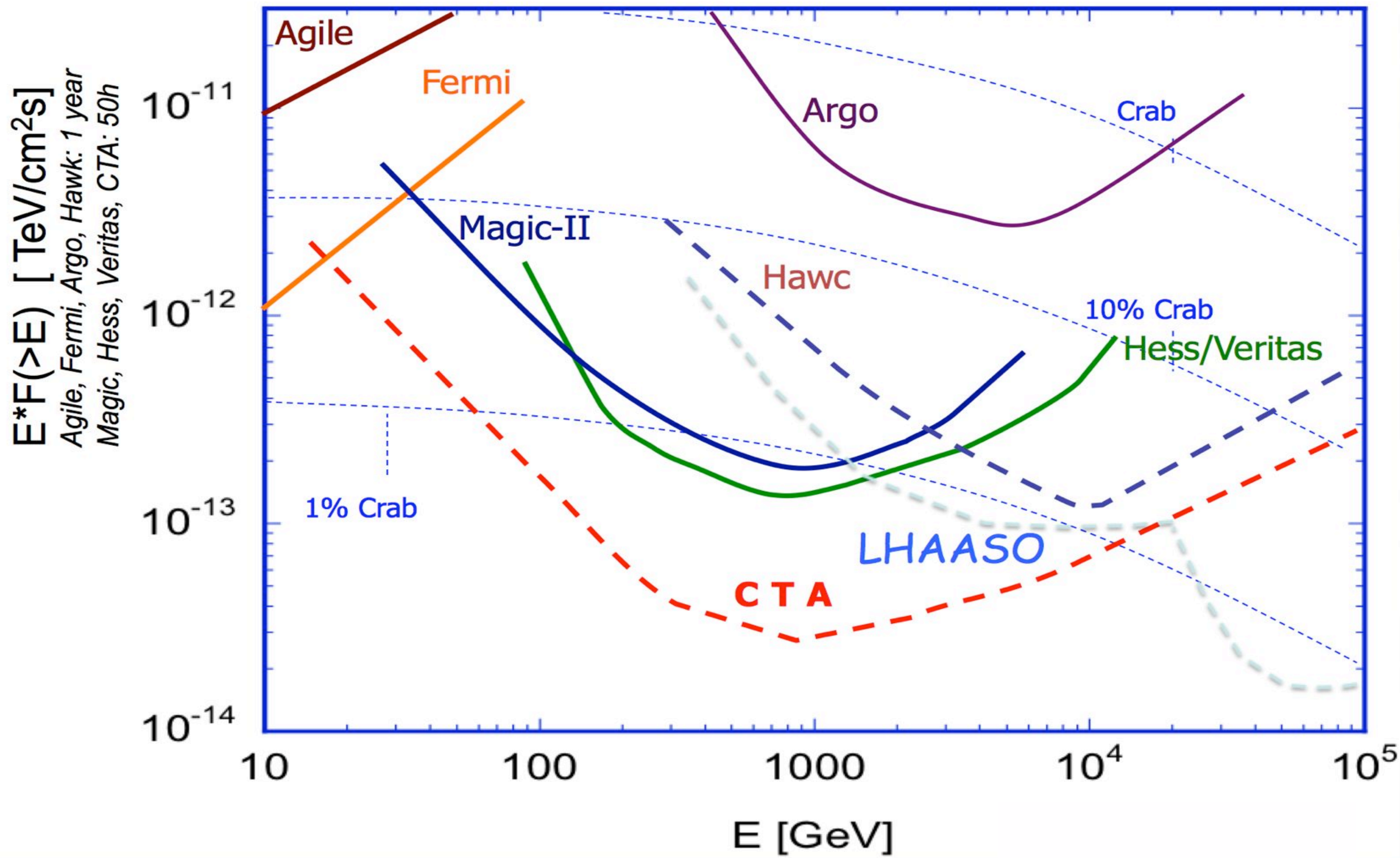


HAWC and Dark Matter Search

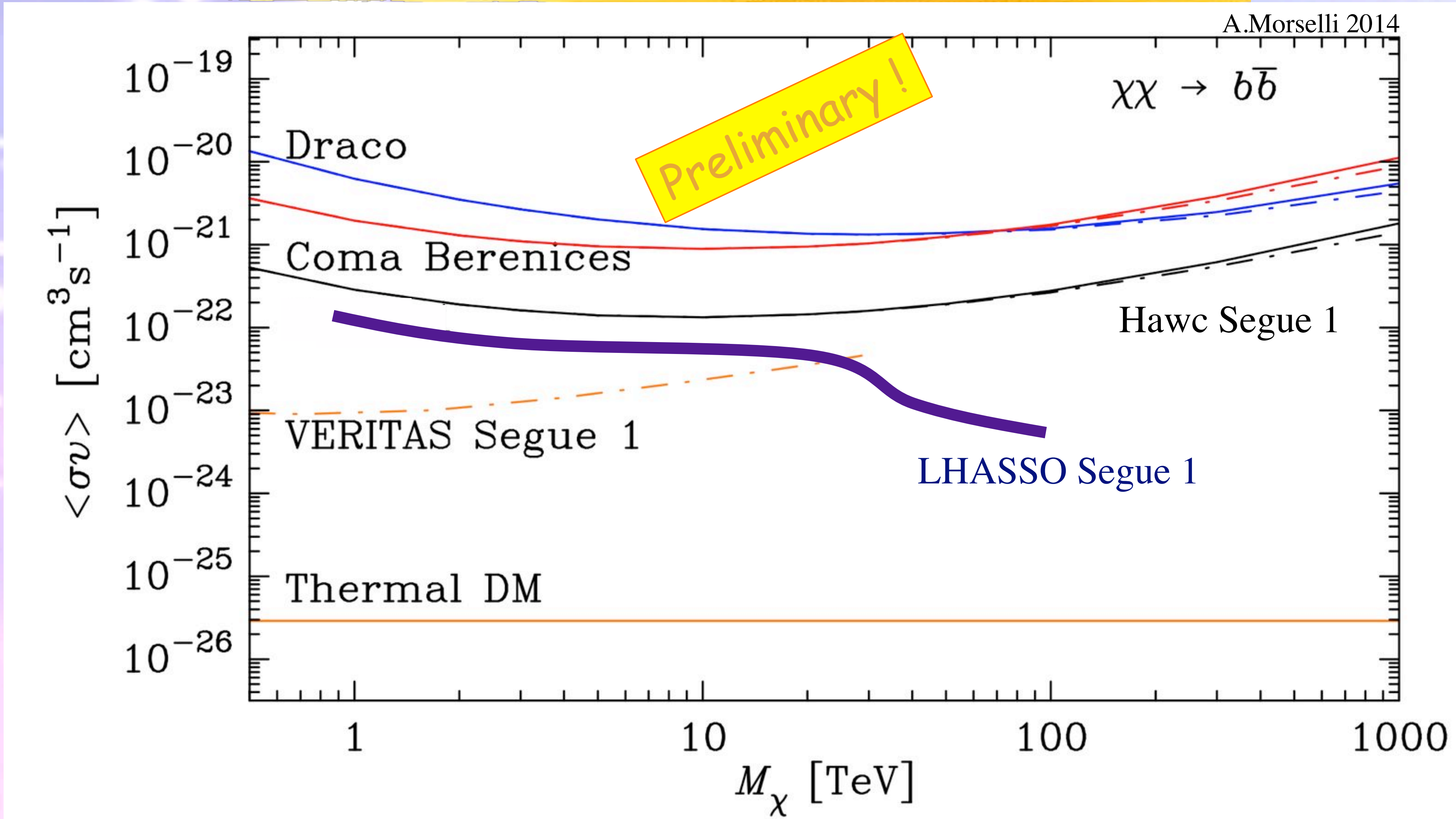


HAWC Coll. arXiv:1405.1730

Sensitivity of present and future experiments

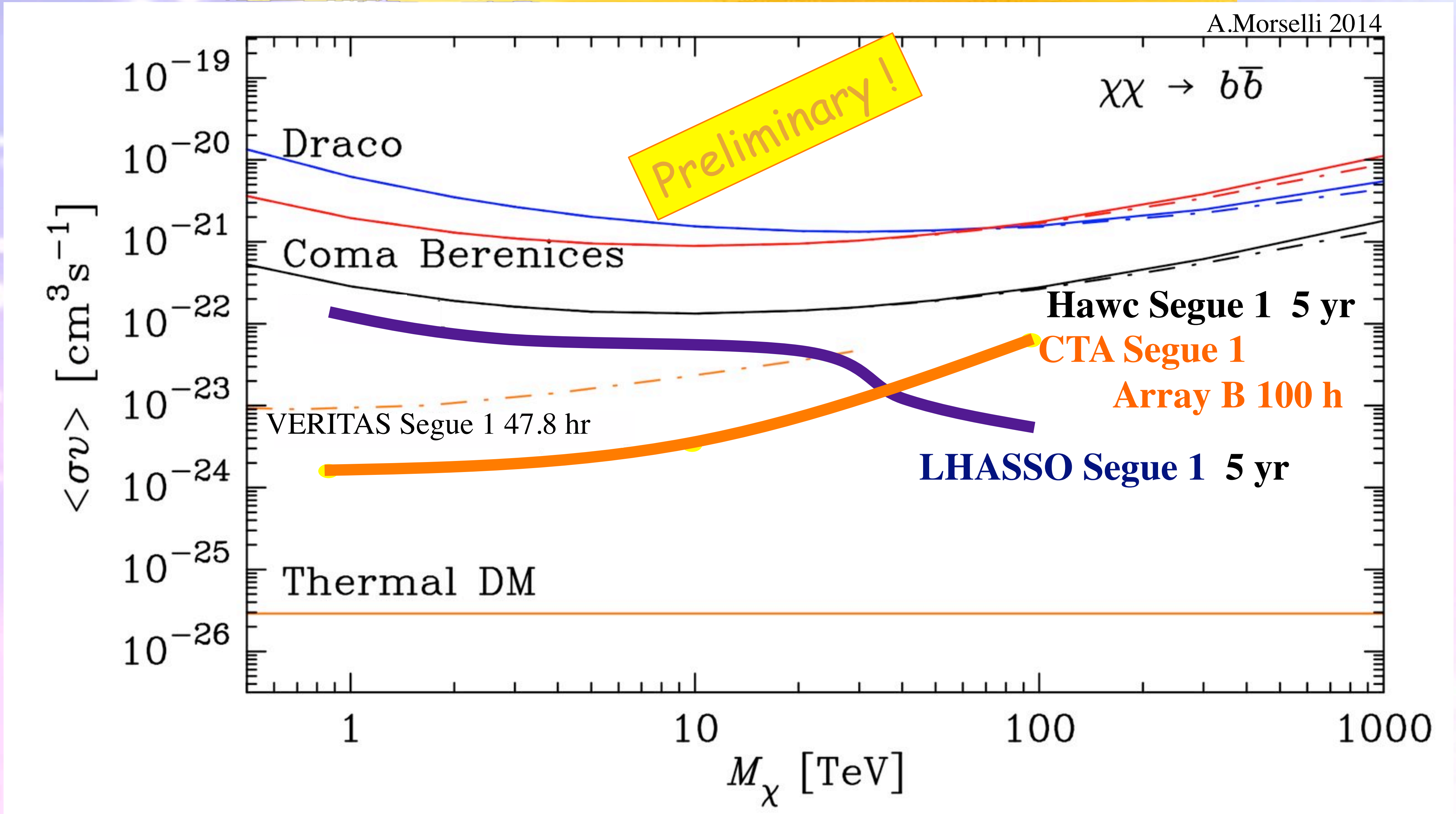


LHAASO and Dark Matter Search



update of arXiv:1405.1730

LHAASO CTA and HAWC and Dark Matter Search



update of arXiv:1405.1730, arXiv:1208.5356

Past decades saw precision studies of 5 % of our Universe -> Discovery of the Standard Model

The LHC is delivering data

We are just at the beginning of exploring 95 % of the Universe.

Exciting prospects

R.-D. Heuer, CERN General Director 36th International Conference on High Energy Physics ICHEP2012, Closing Talk

ICHEP2012 Melbourne

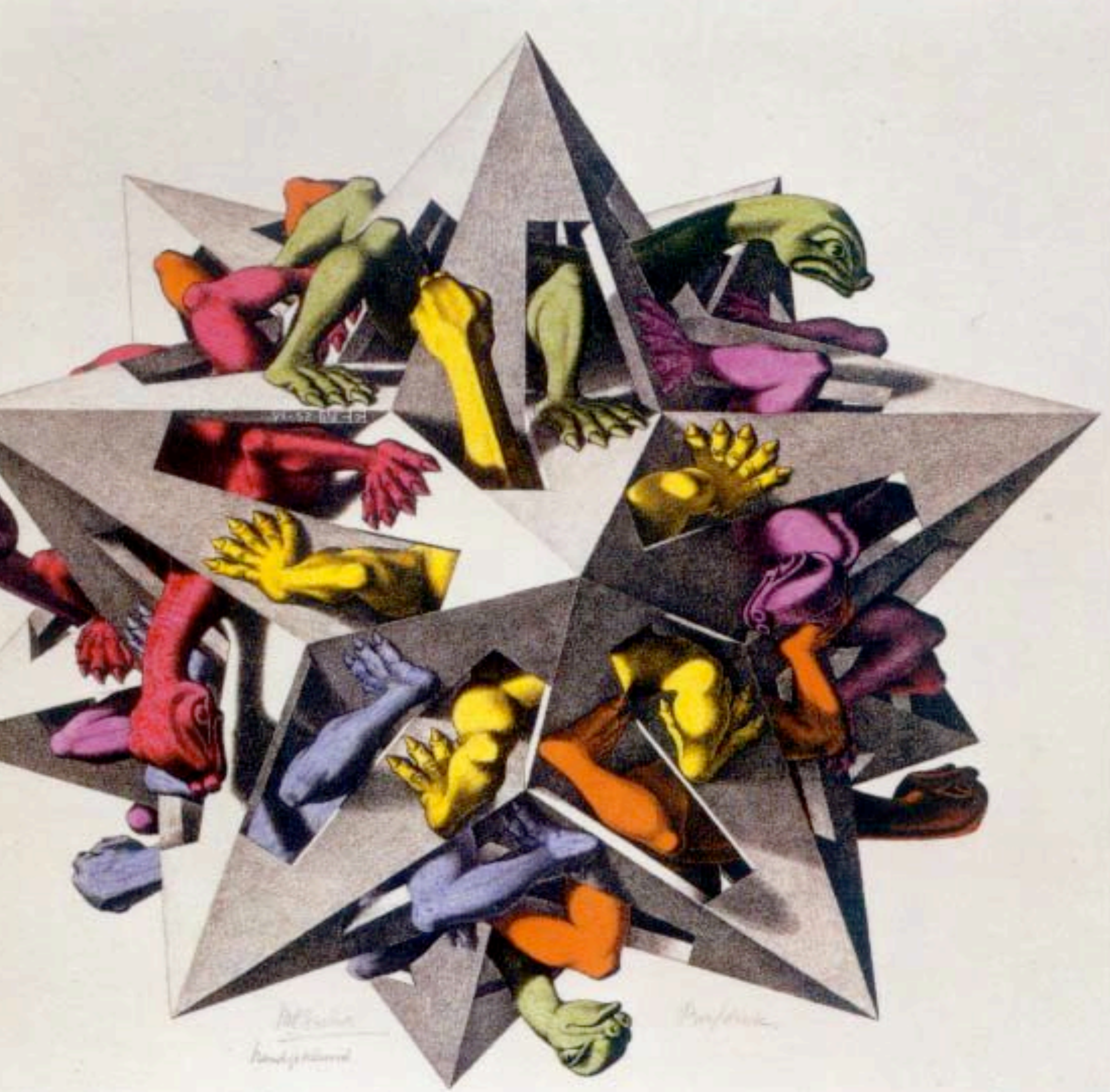
Conclusions

Detection of gamma rays from the annihilation or decay of dark matter particles is a promising method for identifying dark matter, understanding its intrinsic properties, and mapping its distribution in the universe (in synergy with the experiments at the LHC and in the underground laboratories).

In the future it would be extremely important to extend the energy range of experiments at lower energies (compared to the Fermi energies) (eg. Gamma-Light) and higher energies (HAWC, CTA, LHAASO)


For long time we saw the sky tranquil and calm


During the 20th century the quest to broaden our view of the universe has shown us the vastness of the Universe and revealed violent cosmic phenomena and mysteries




The future?