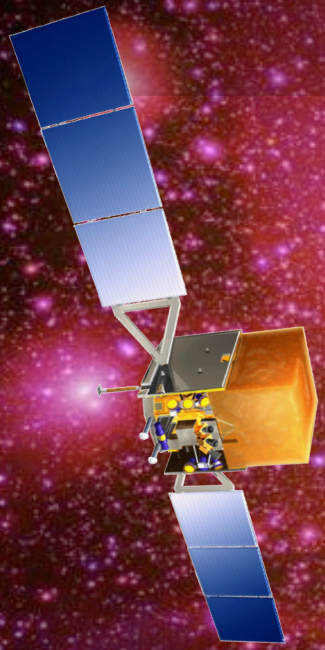
Constraints on WIMP annihilation for contracted Dark Matter in the inner Galaxy with gamma-rays



Aldo Morselli
INFN Roma Tor Vergata

SciNeGHE 2014
10th Workshop on Science with the New Generation of High Energy Gamma-ray Experiments
Fundamental physics with high energy cosmic gamma rays

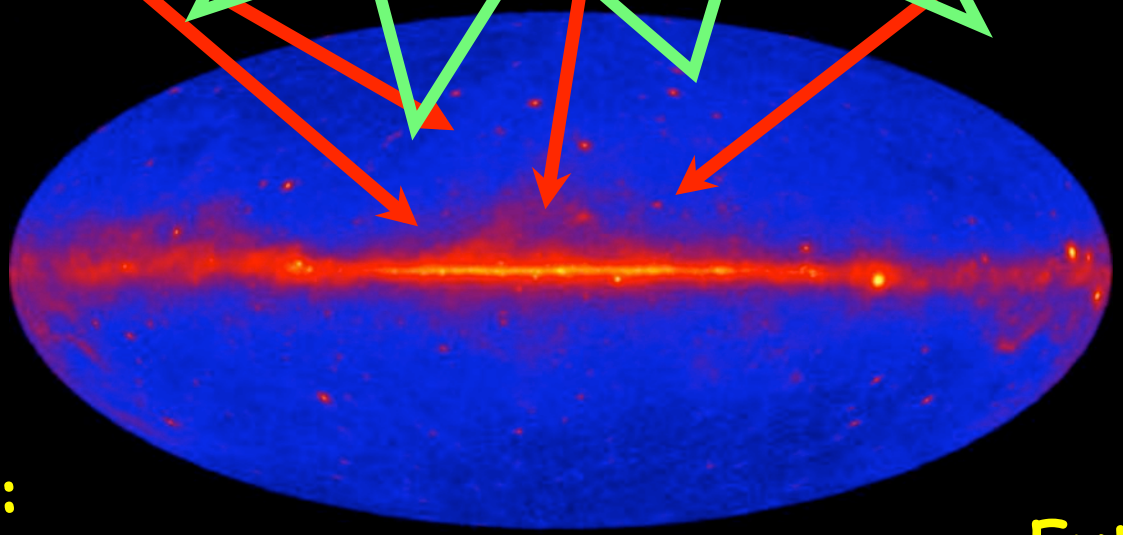
Lisboa June 4-6 2014

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

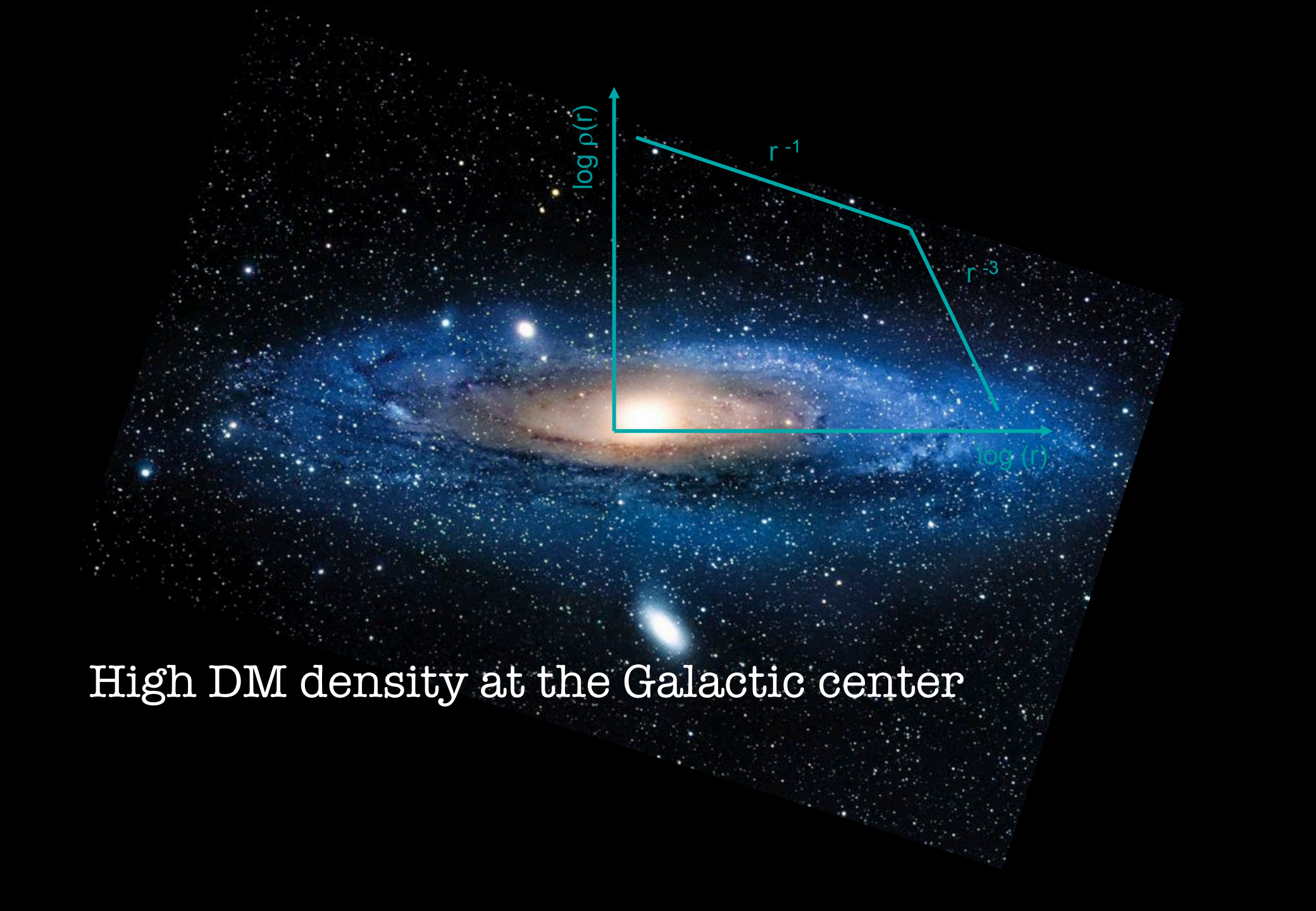
Spectral lines:
No astrophysical uncertainties, good source id, but low statistics

Galaxy clusters:
Low background but low statistics

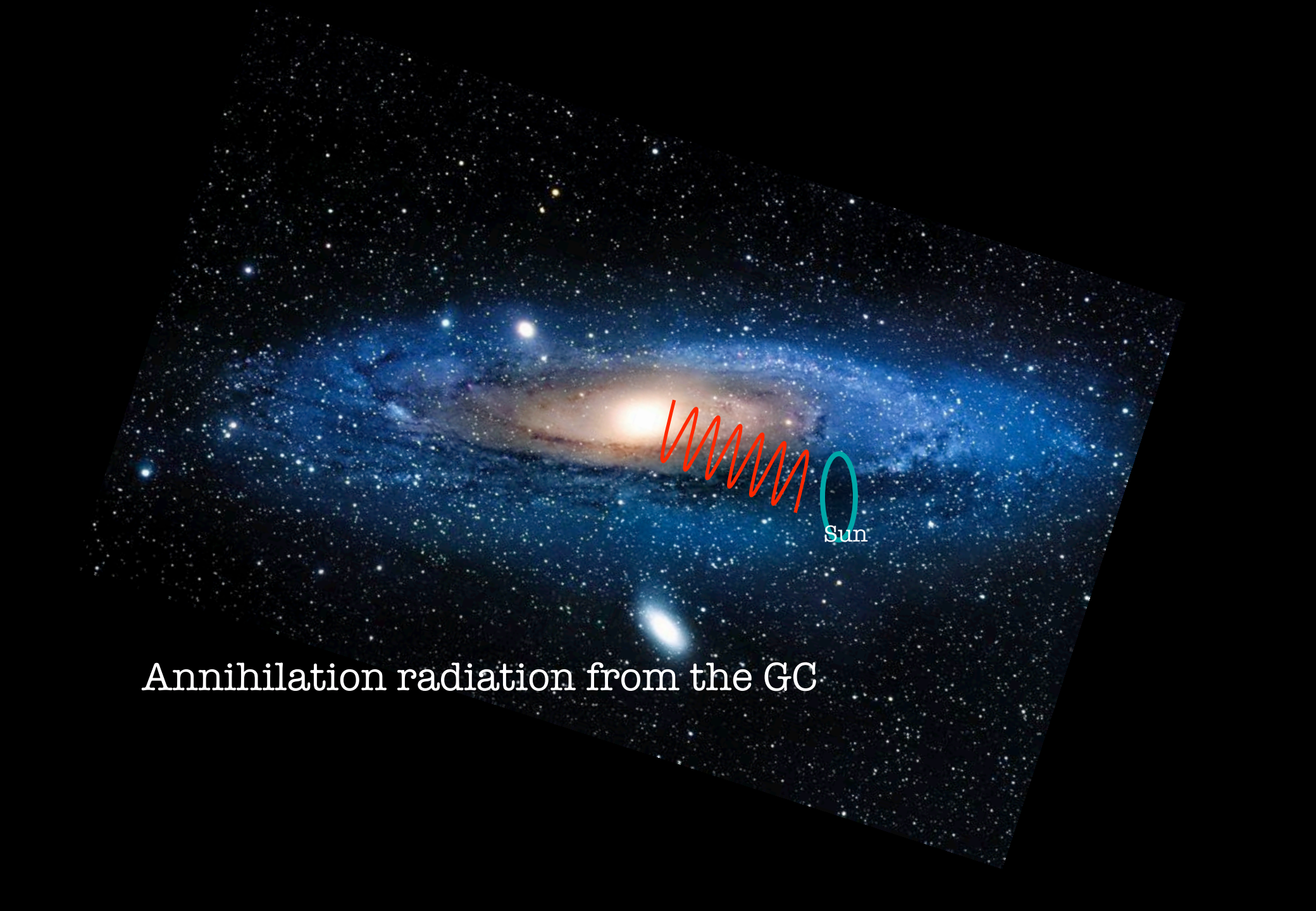
Extra-galactic:
Large statistics, but astrophysics,galactic diffuse background

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



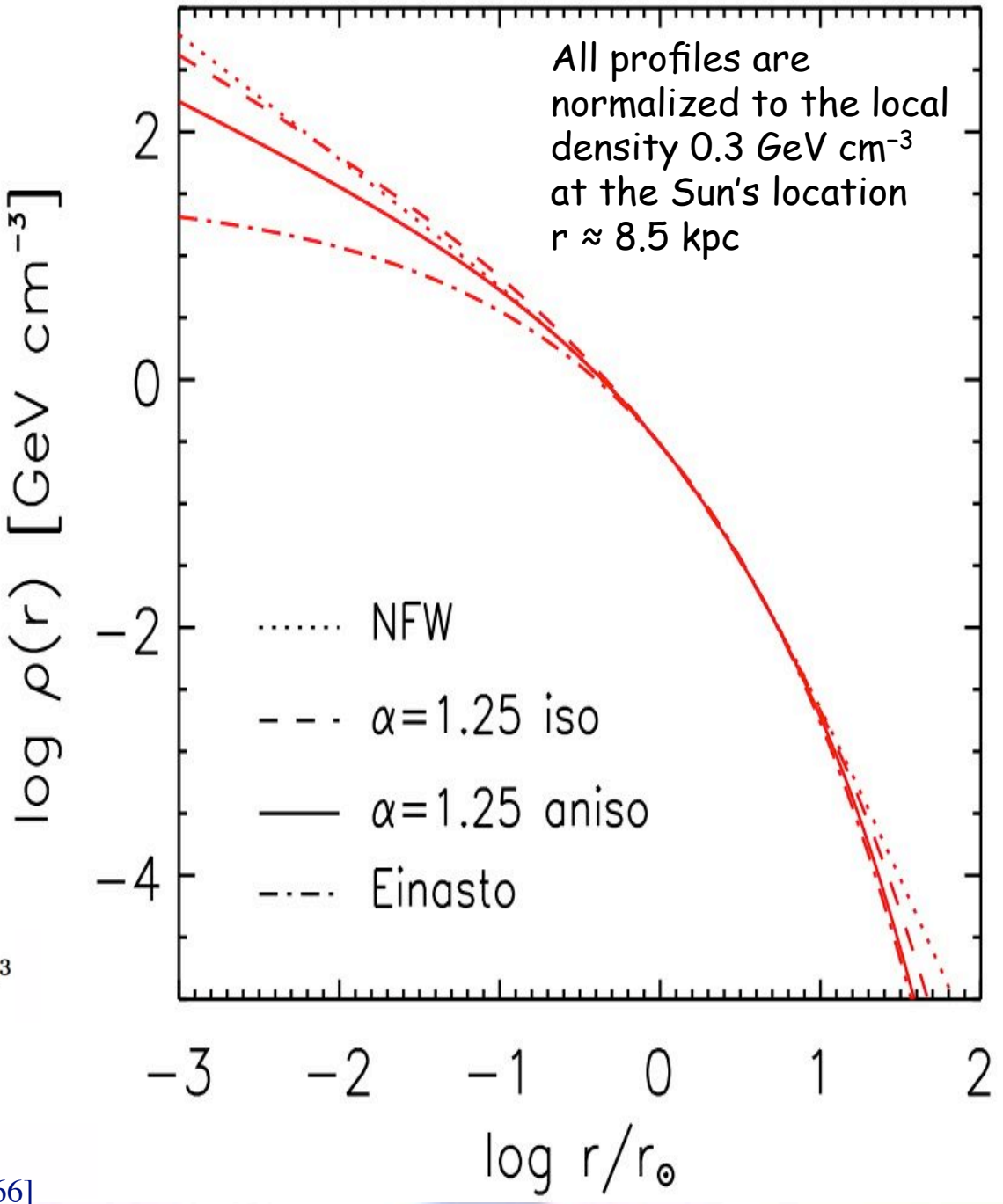
Annihilation radiation from the GC

Milky Way Dark Matter Profiles

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

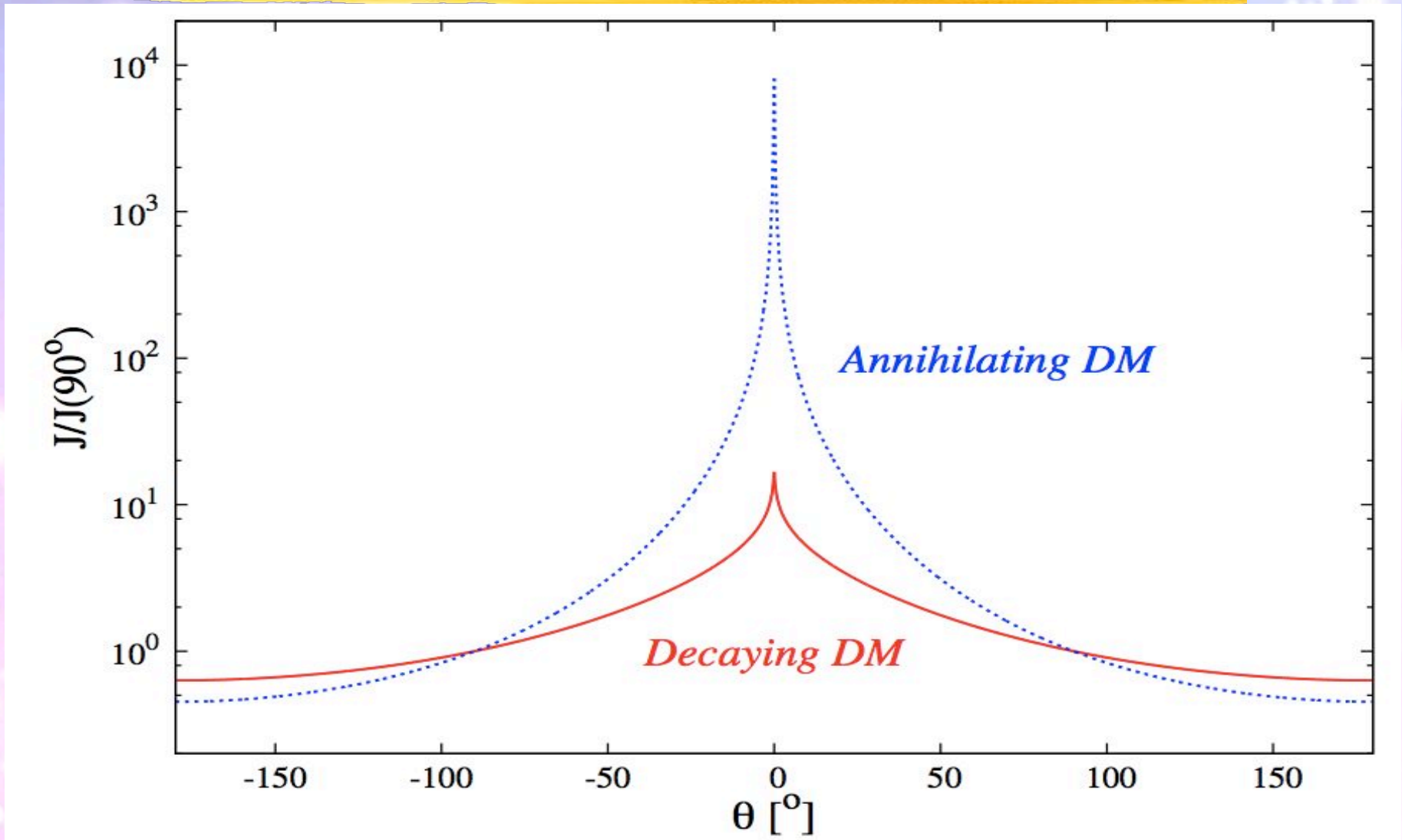
Halo model	α	β	γ	r_s in kpc
Cored isothermal	2	2	0	5
Navarro, Frenk, White	1	3	1	20
Moore	1	3	1.16	30

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

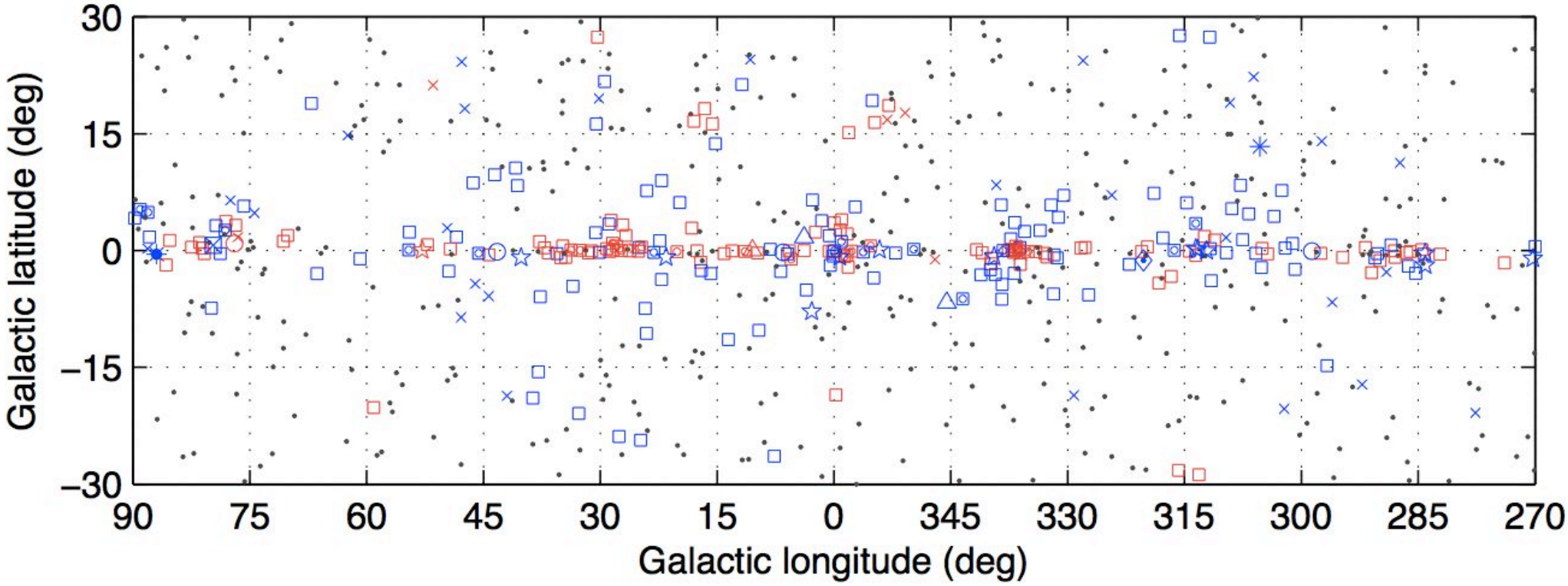


The angular profile of the gamma-ray signal is shown, as function of the angle θ to the centre of the galaxy for a Navarro-Frenk-White (NFW) halo distribution for decaying DM, solid (red) line, compared to the case of self-annihilating DM, dashed (blue) line

The Fermi LAT 2FGL Inner Galactic Region

August 4, 2008, to July 31, 2010

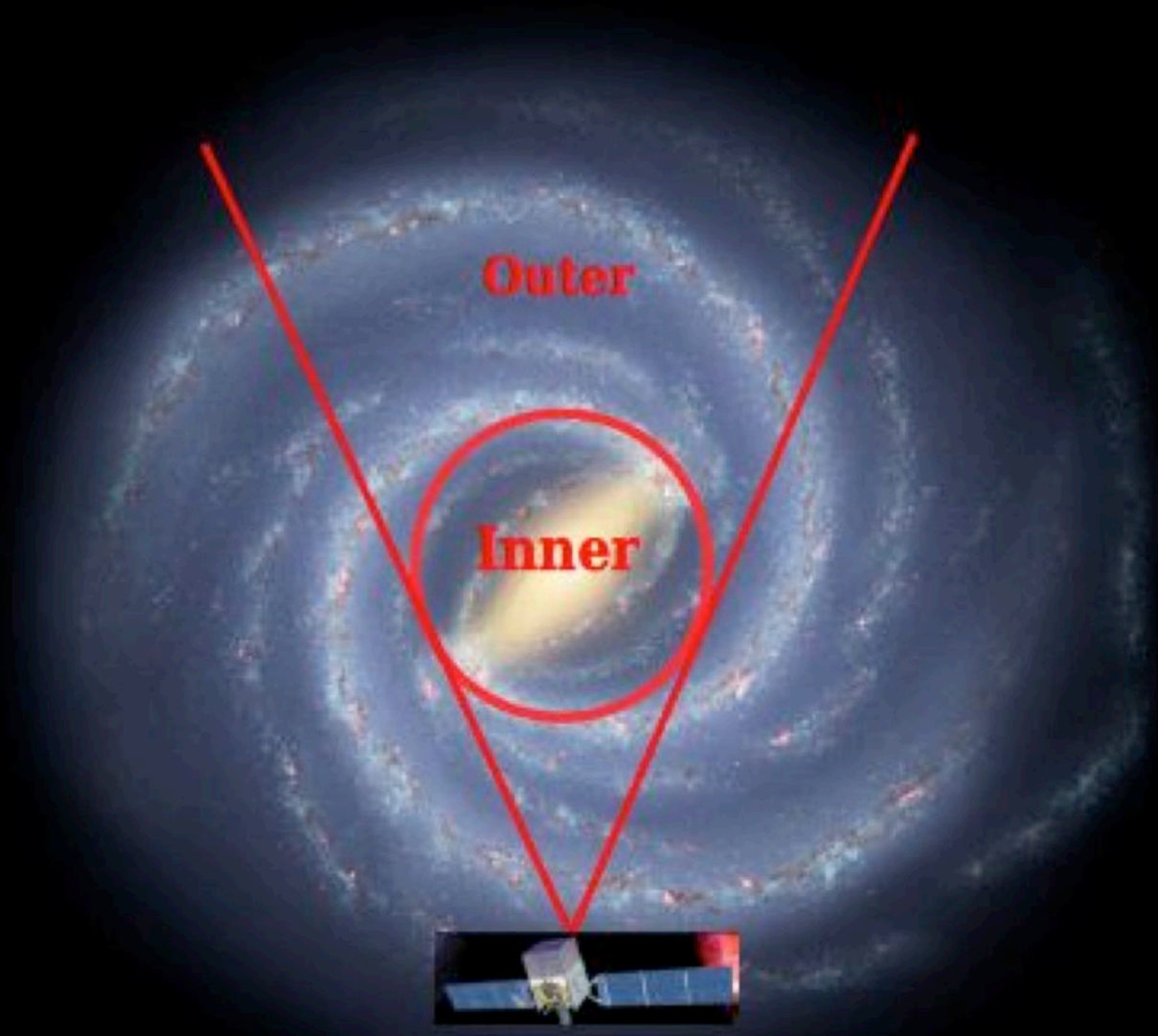
100 MeV to 100 GeV energy range



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

□ No association	⧈ Possible association with SNR or PWN	
× AGN	☆ Pulsar	△ Globular cluster
✳ Starburst Gal	◈ PWN	⊠ HMB
+ Galaxy	○ SNR	✷ Nova

FERMI-LAT VIEW OF THE GALACTIC CENTER

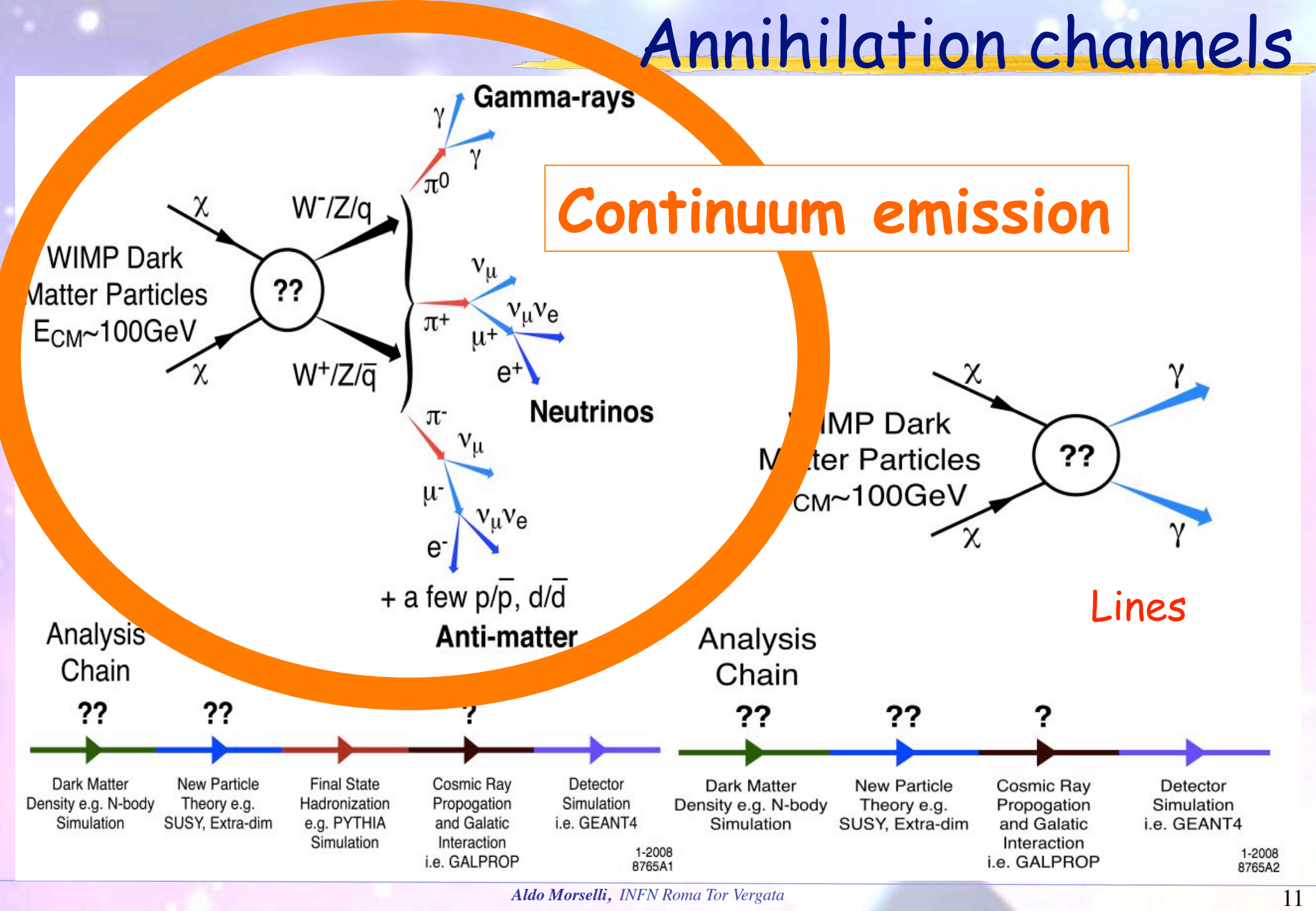


DISENTANGLING A DM SIGNAL FROM THE GALACTIC CENTER

You are here

Trying to figure out what is here

Annihilation channels

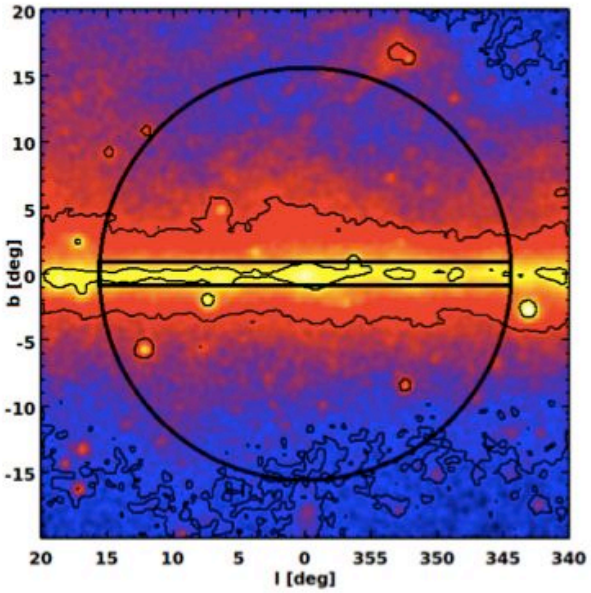


DISENTANGLING A Dark Matter SIGNAL FROM THE GALACTIC CENTER

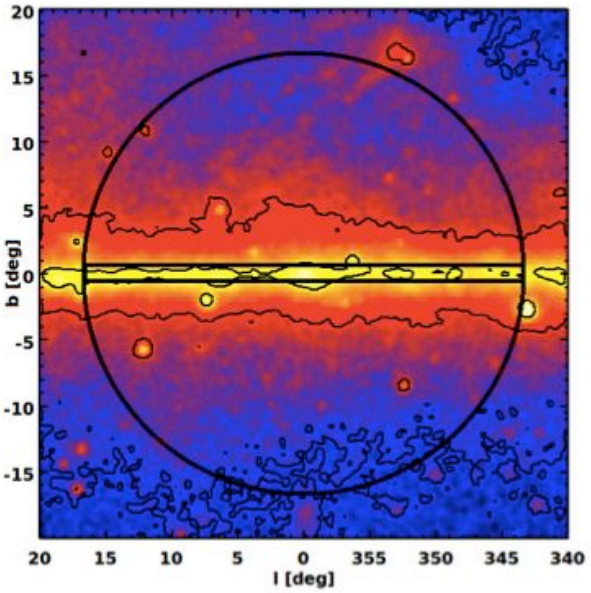
- Dark Matter-induced γ rays would appear as an exotic contribution in Fermi-LAT data of the Galactic Center!
- We need to understand the non-exotic contributions, i.e. the background, in order to disentangle the possible DM-induced γ rays!
- To set conservative constraints we don't need to understand the background, we can simply requiere that the expected DM signal does not exceed the measurement  (JCAP 10(2013)029)

Constraints from the inner Galaxy

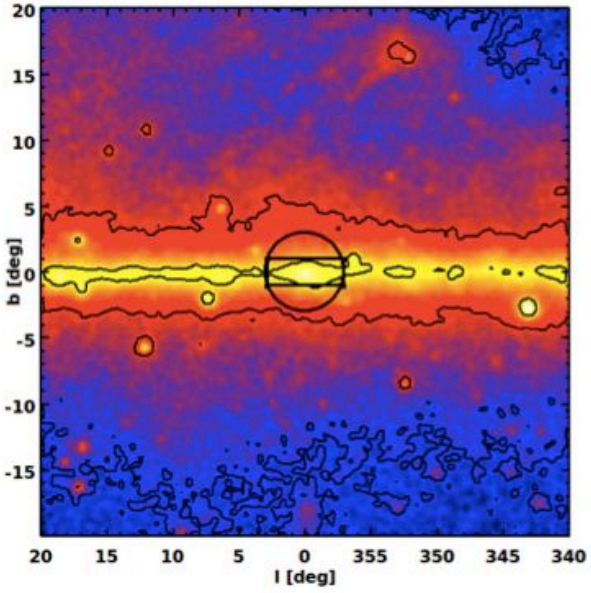
Optimized ROI for each profile



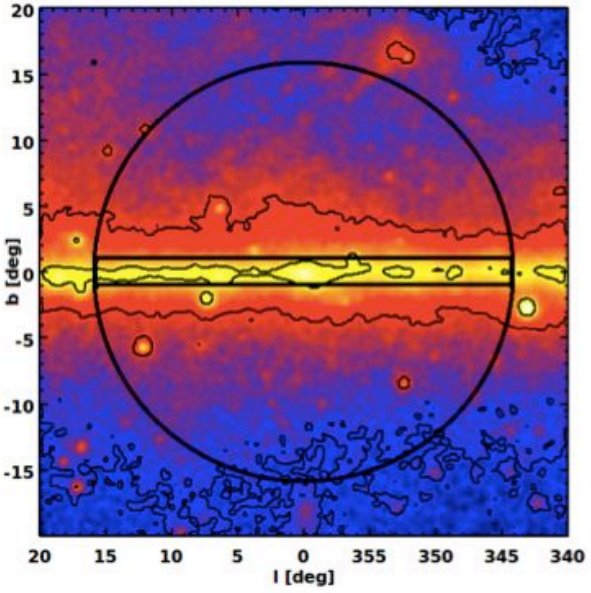
Einasto



NFW



NFWc

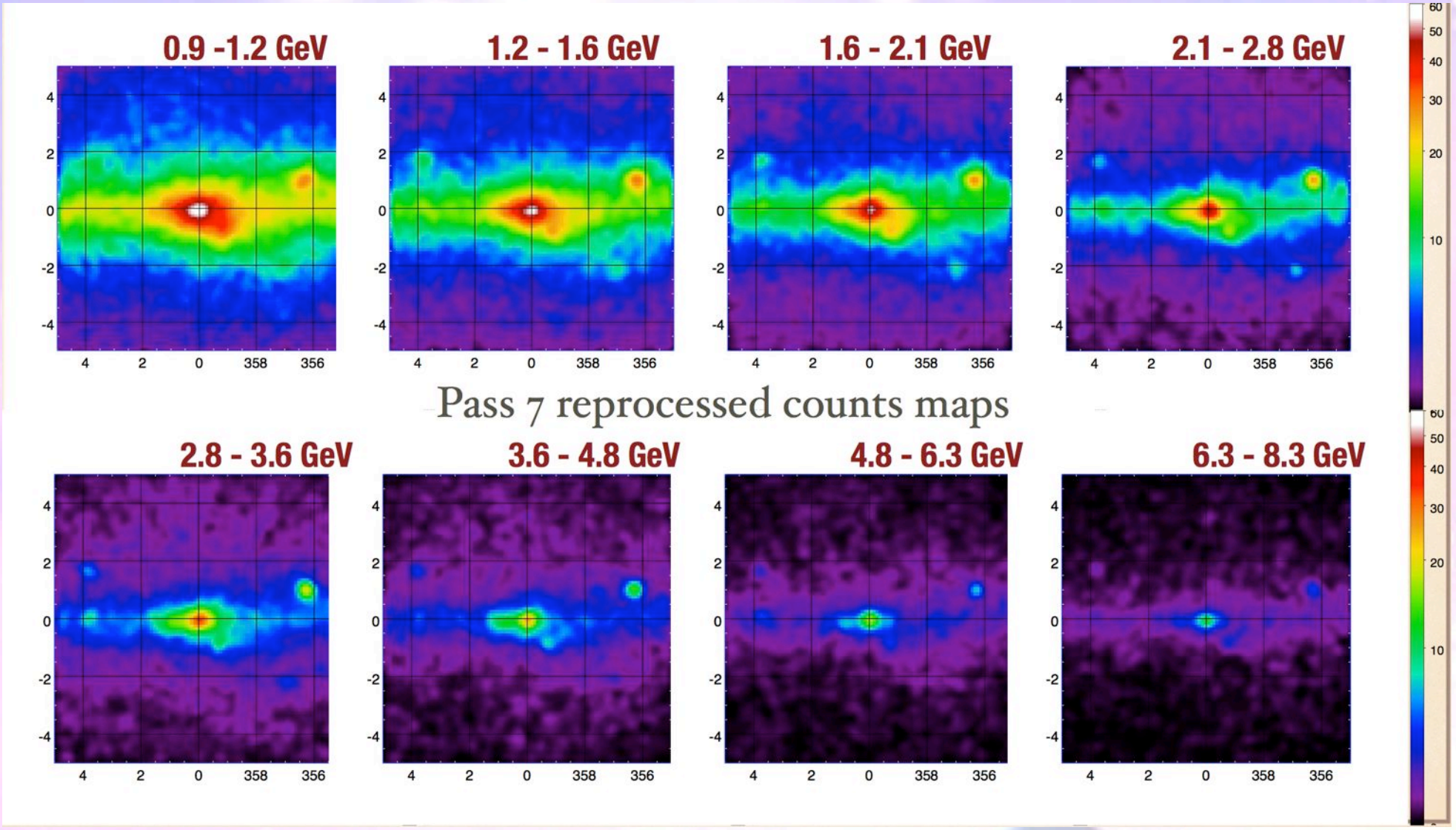


Burkert

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

FERMI-LAT VIEW OF THE GALACTIC CENTER

5.5 years, energies > 1 GeV



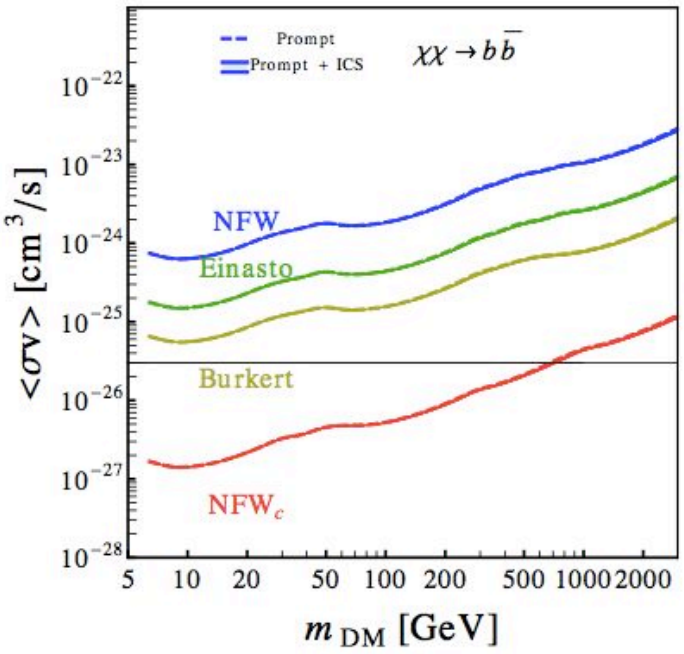
Constraints from the inner Galaxy

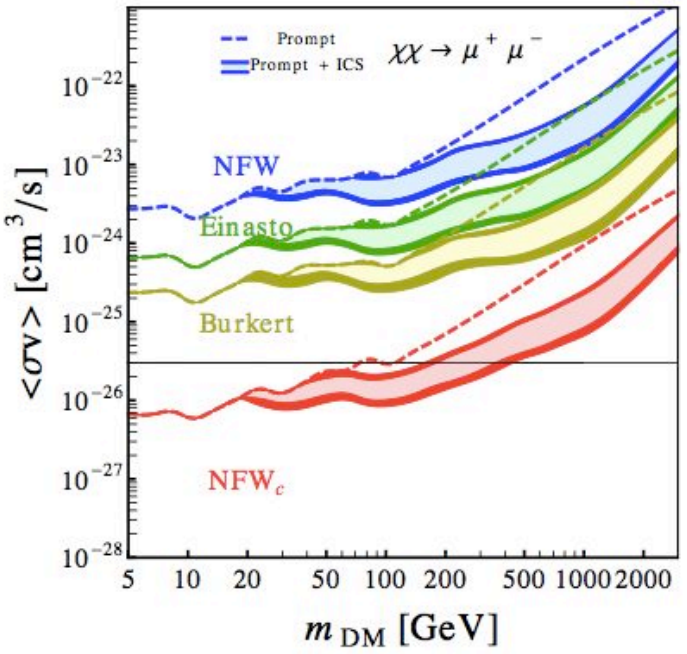
3 σ upper limits on the annihilation cross-section for different channels and halo profiles

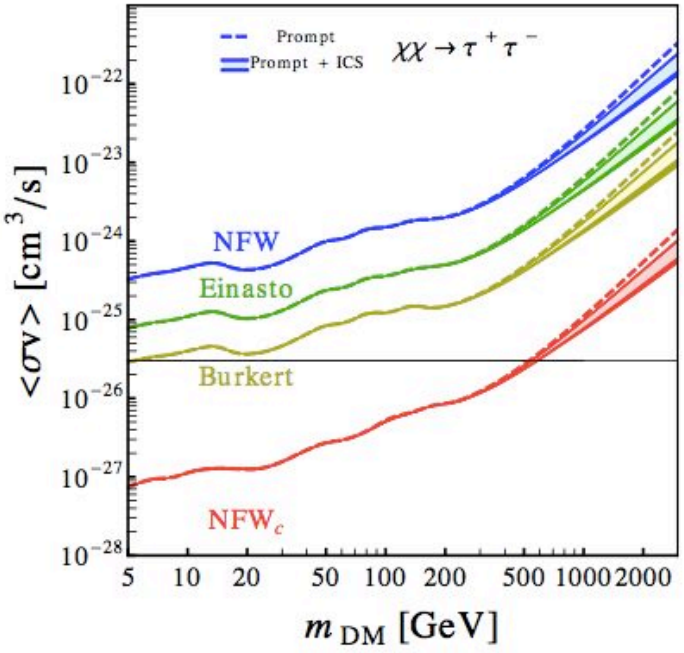
No assumption on background

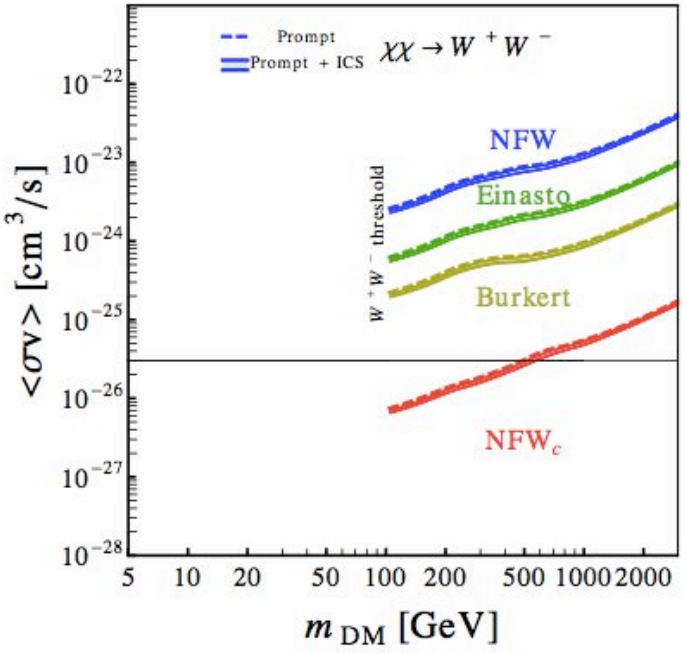
very robust result

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









History of GALACTIC CENTER observations

Indirect Search for Dark Matter from the center of the Milky Way with the Fermi-Large Area Telescope
Vincenzo Vitale, Aldo Morselli, the Fermi/LAT Collaboration
Proceedings of the 2009 Fermi Symposium, 6 pages, eConf Proceedings C091122 **arXiv:0912.3828**

Search for Dark Matter with Fermi Large Area Telescope: the Galactic Center
V.Vitale, A.Morselli, the Fermi/LAT Collaboration
Nuclear Instruments and Methods in Physics Research A 630 (2011) 147–150 (Available online 23 June 2010)

Dark Matter Annihilation in The Galactic Center As Seen by the Fermi Gamma Ray Space Telescope
Dan Hooper , Lisa Goodenough . (Available21 March 2011). 21 pp. Published in **Phys.Lett. B697 (2011) 412-428**

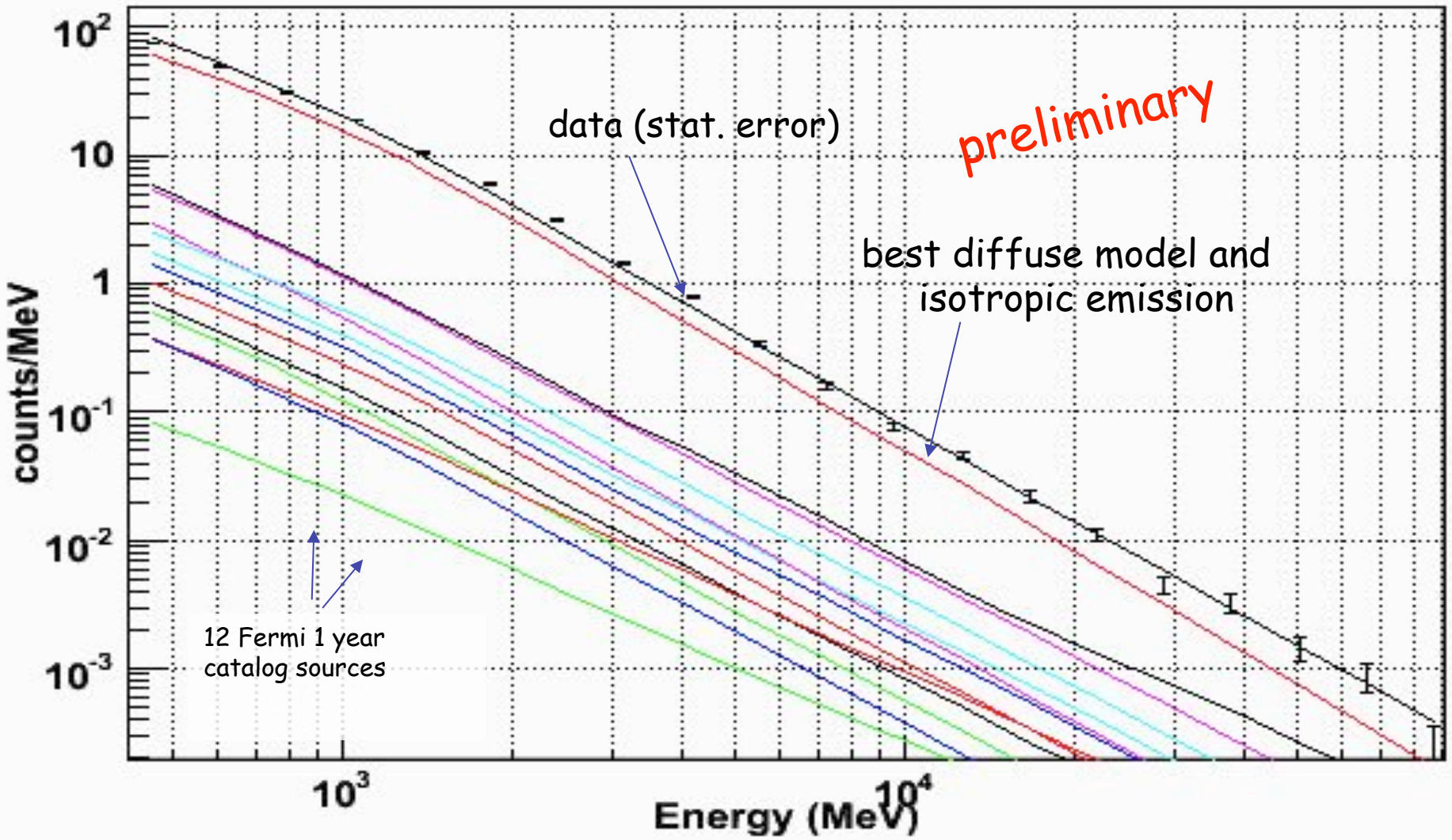
On The Origin Of The Gamma Rays From The Galactic Center
Dan Hooper , Tim Linden. Oct 2011. 13 pp. Published in **Phys.Rev. D84 (2011) 123005**

Detection of a Gamma-Ray Source in the Galactic Center Consistent with Extended Emission from Dark Matter Annihilation and Concentrated Astrophysical Emission
Kevork N. Abazajian, Manoj Kaplinghat (UC, Irvine). Jul 2012. 13 pp. Published in **Phys.Rev. D86 (2012) 083511**

Dark Matter and Pulsar Model Constraints from Galactic Center Fermi-LAT Gamma Ray Observations
Chris Gordon, Oscar Macías (Canterbury U.). Jun 24, 2013. 20 pp.
Published in **Phys.Rev. D88 (2013) 083521**

The Characterization of the Gamma-Ray Signal from the Central Milky Way: A Compelling Case for Annihilating Dark Matter
Tansu Daylan, Douglas P. Finkbeiner, Dan Hooper, Tim Linden, Stephen K. N. Portillo, Nicholas L. Rodd , Tracy R. Slatyer . Feb 26, 2014. 26 pp. e-Print: **arXiv:1402.6703 [astro-ph.HE]**

Spectrum (E> 400 MeV, 7°x7° region centered on the Galactic Center analyzed with binned likelihood analysis)



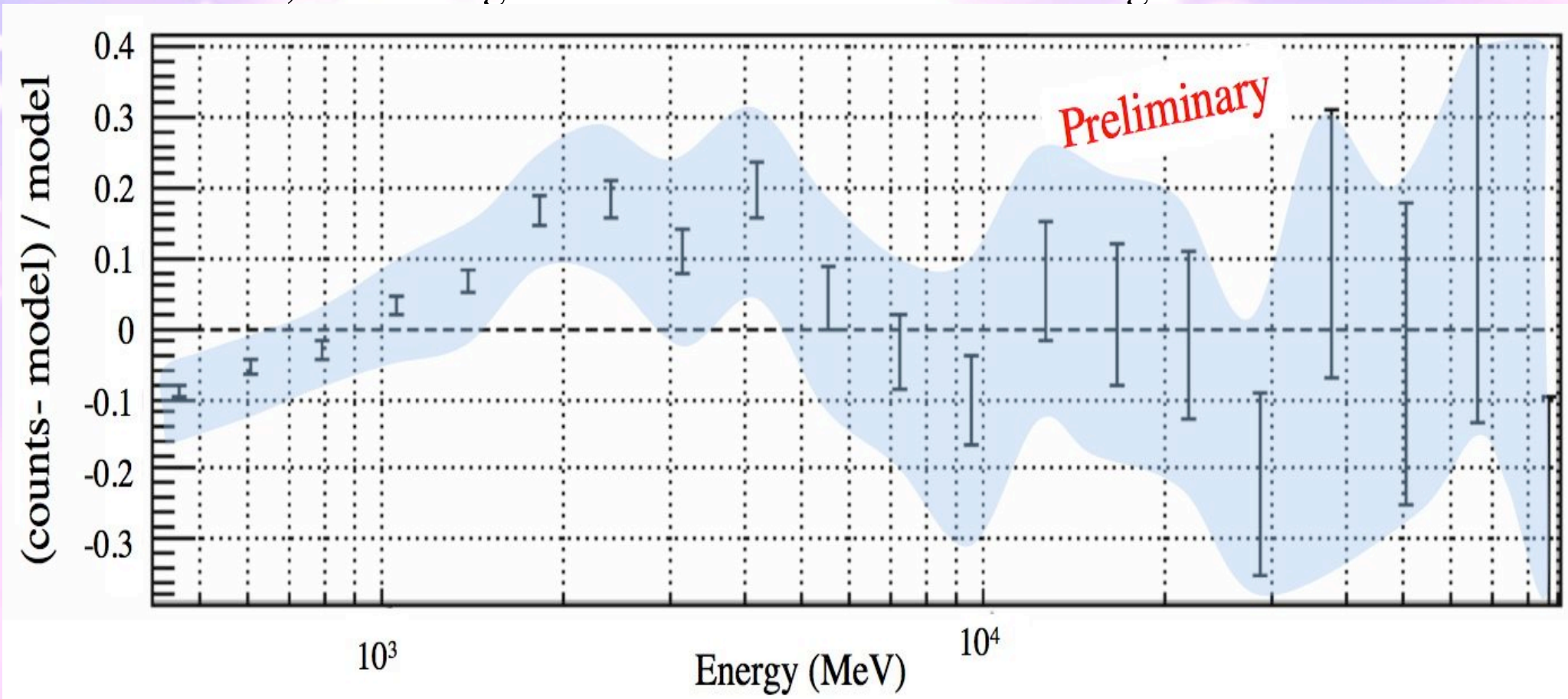
V.Vitale, A.Morselli, Fermi Coll. NIM A630 (2011) 147, arXiv:0912.3828

GC Residuals

7°x7° region centered on the Galactic Center

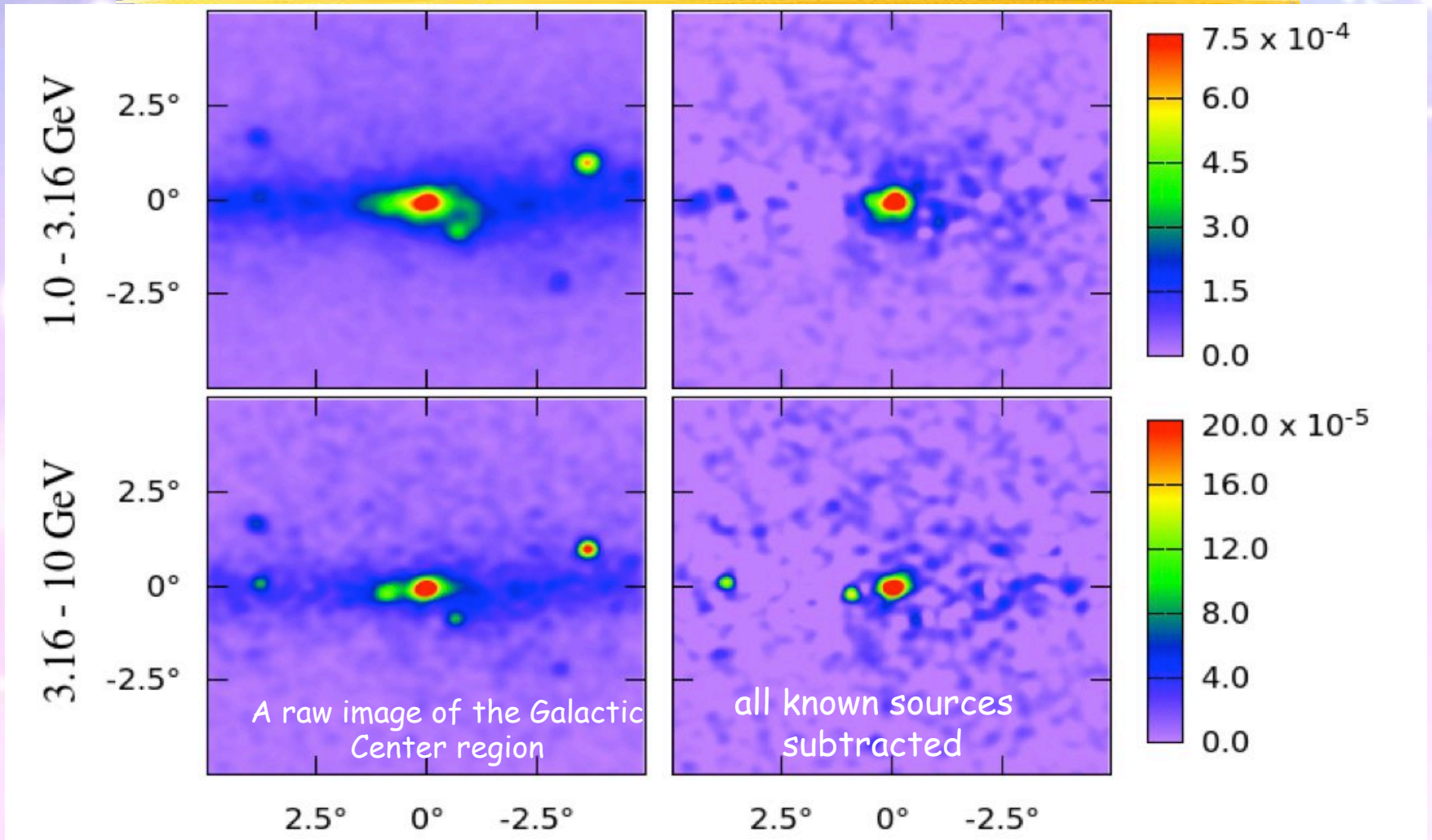
11 months of data, E >400 MeV, front-converting events analyzed with binned likelihood analysis)

- 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, Fermi Coll. NIM A630 (2011) 147, arXiv:0912.3828

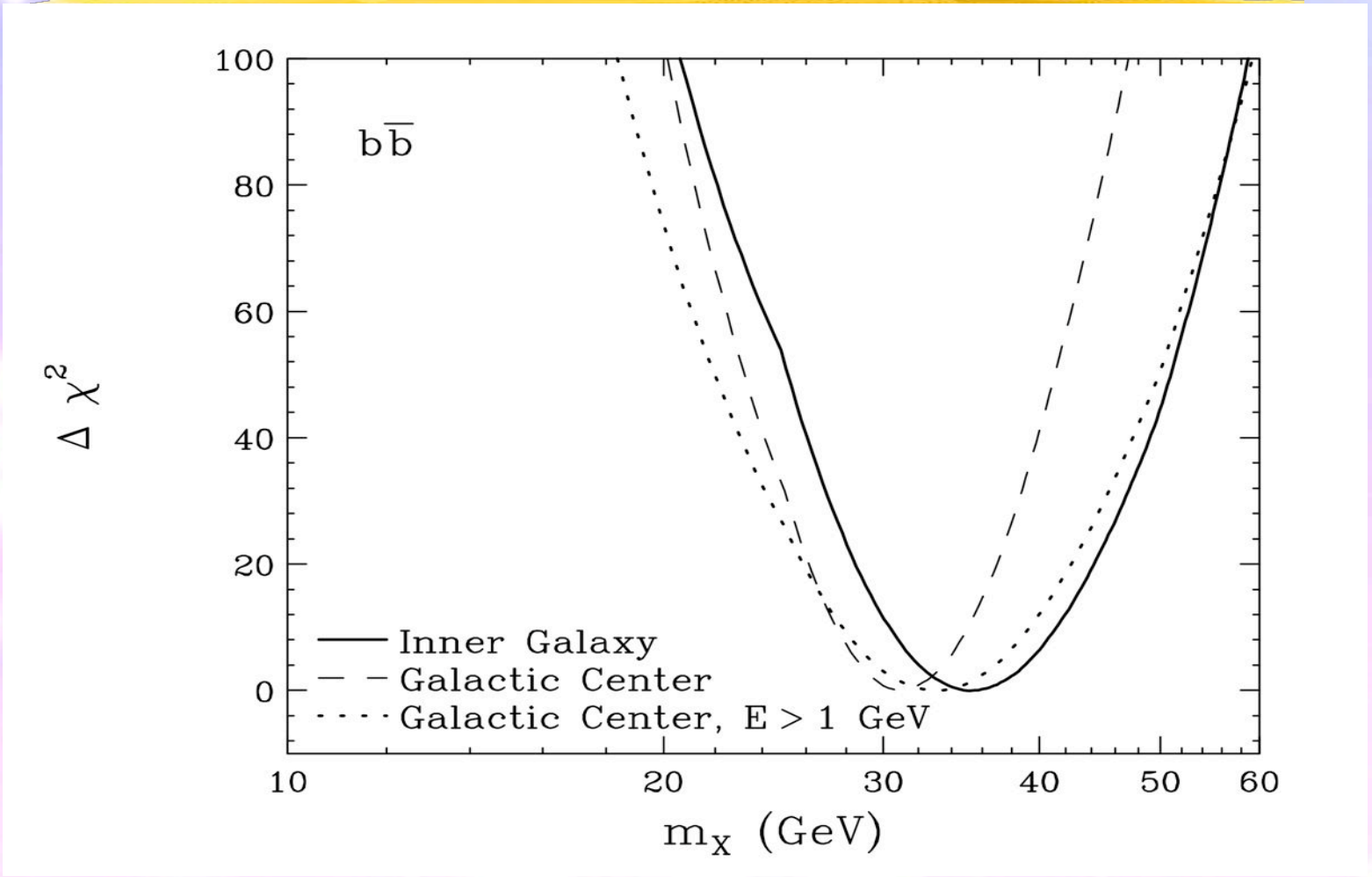
Galactic Center and Dark Matter



- 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

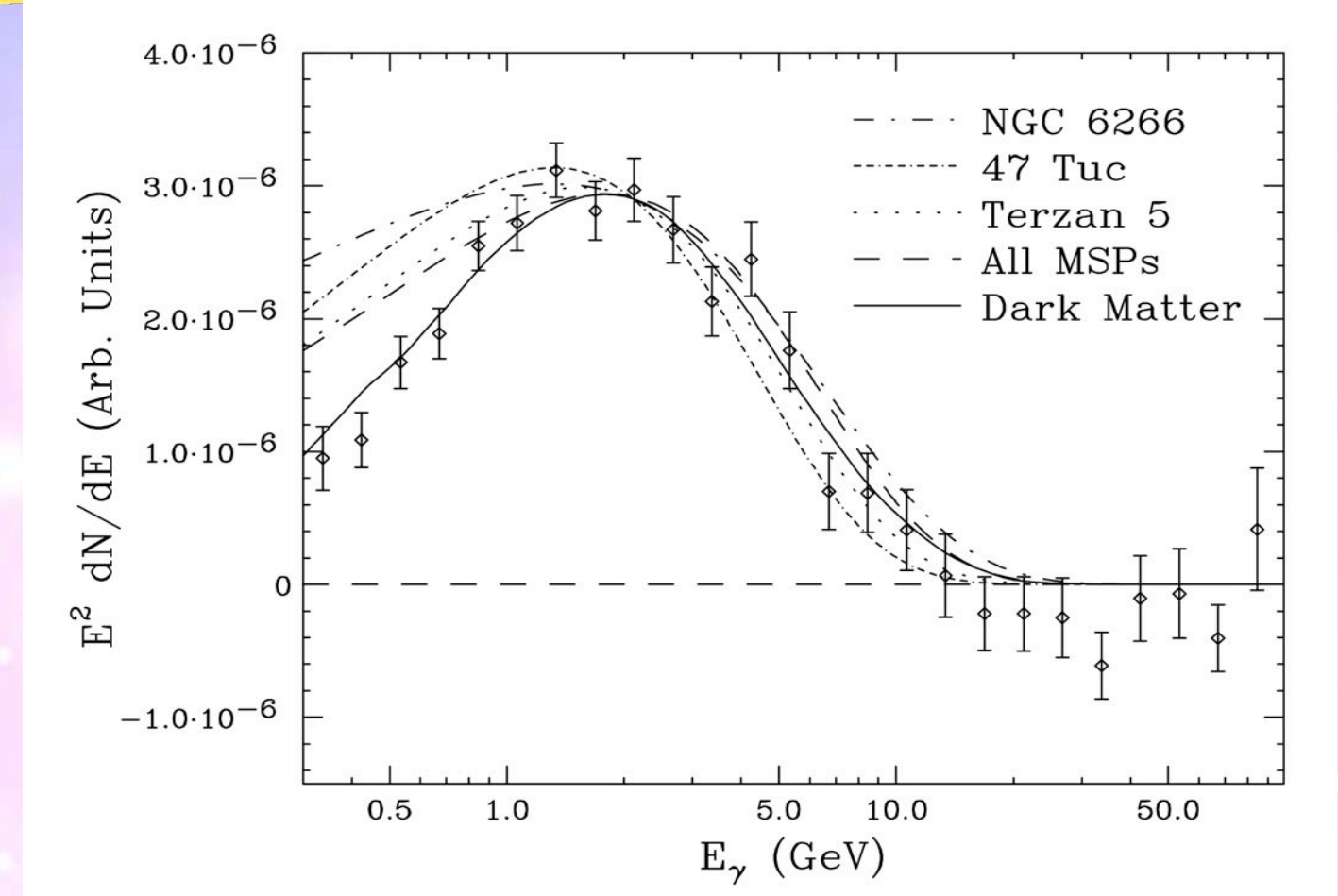
Galactic Center and Dark Matter



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

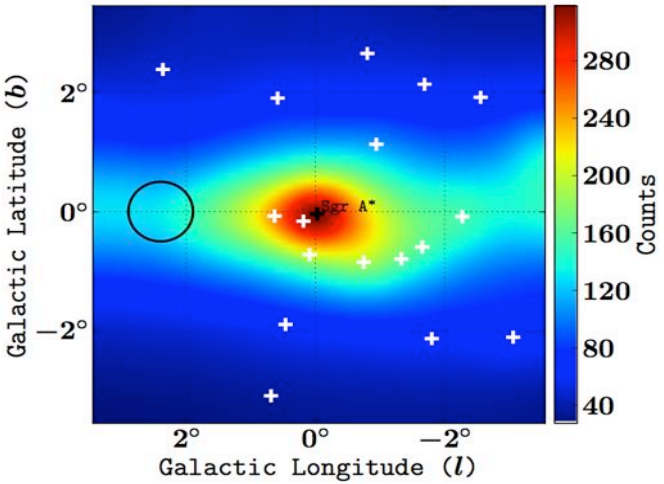
Galactic Center and Dark Matter

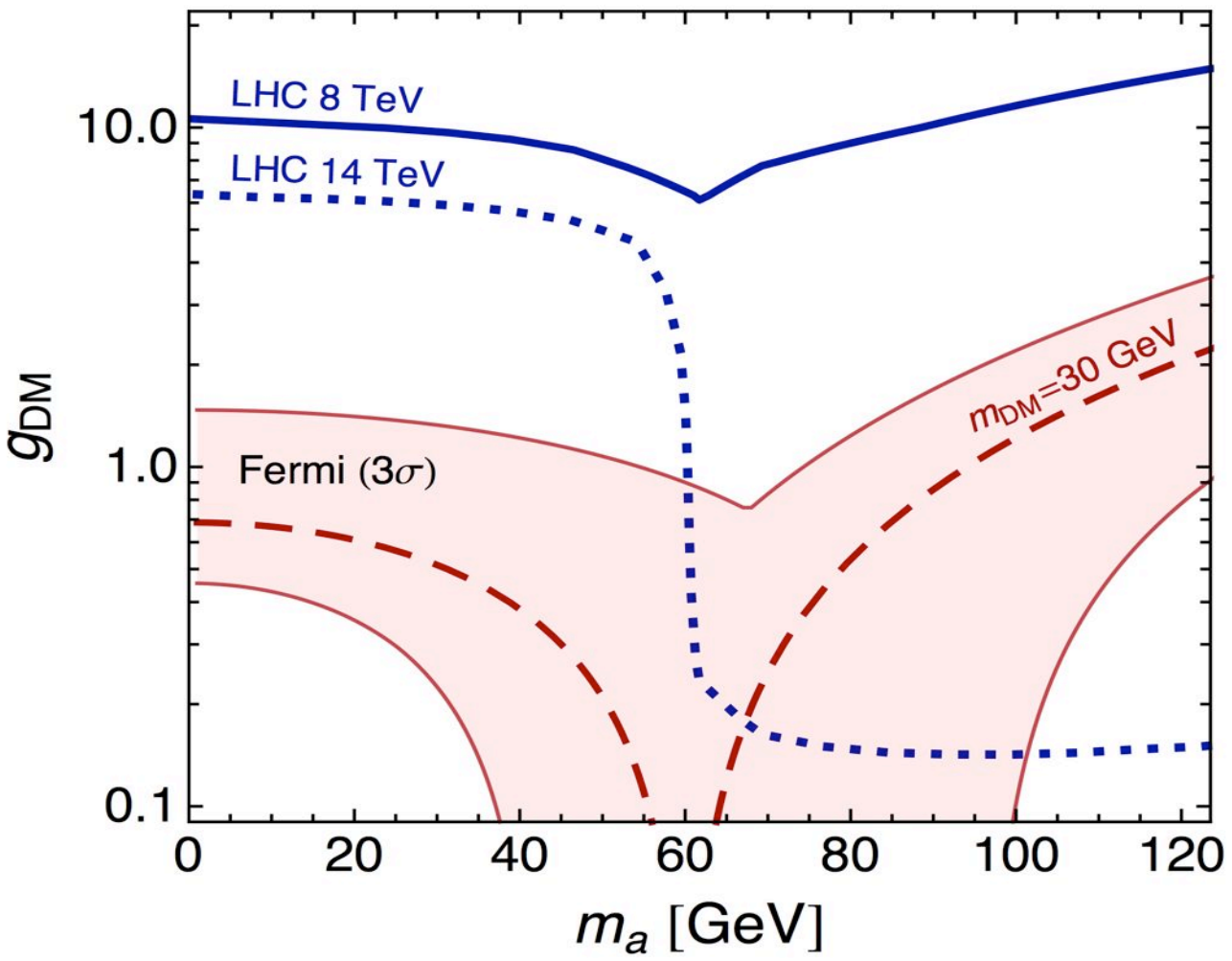


A comparison of the spectral shape of the gamma- ray excess from the sum of all millisecond pulsars detected as individual point sources by Fermi.The gamma-ray spectrum measured from millisecond pulsars and from globular clusters (whose emission is believed to be dominated by millisecond pulsars) is 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

ARE WE SEEING DARK MATTER WITH THE FERMI-LAT IN A REGION AROUND THE MILKY WAY CENTER?

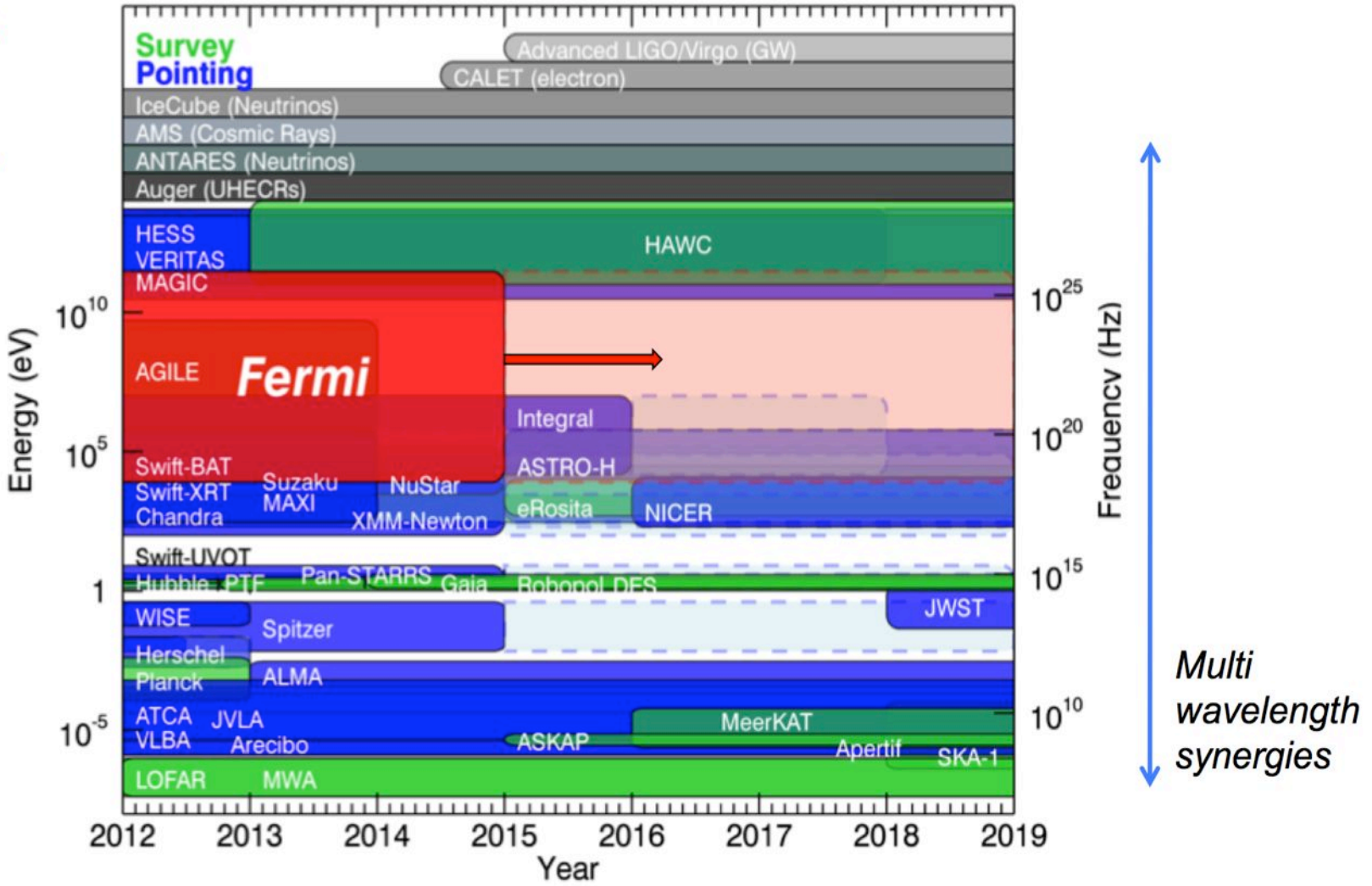
- Maybe yes, but we can't be sure as far as we don't understand the background at the level needed for disentangle a DM-induced γ-ray flux in this interesting region.
-
- New molecular and atomic gas, CR and γ-ray data is around the corner, keep tune!

What's next ?

Fermi mission status

http://science.nasa.gov/astrophysics/2014-senior-review-operating-missions/

Multi Messenger synergies



Multi wavelength synergies

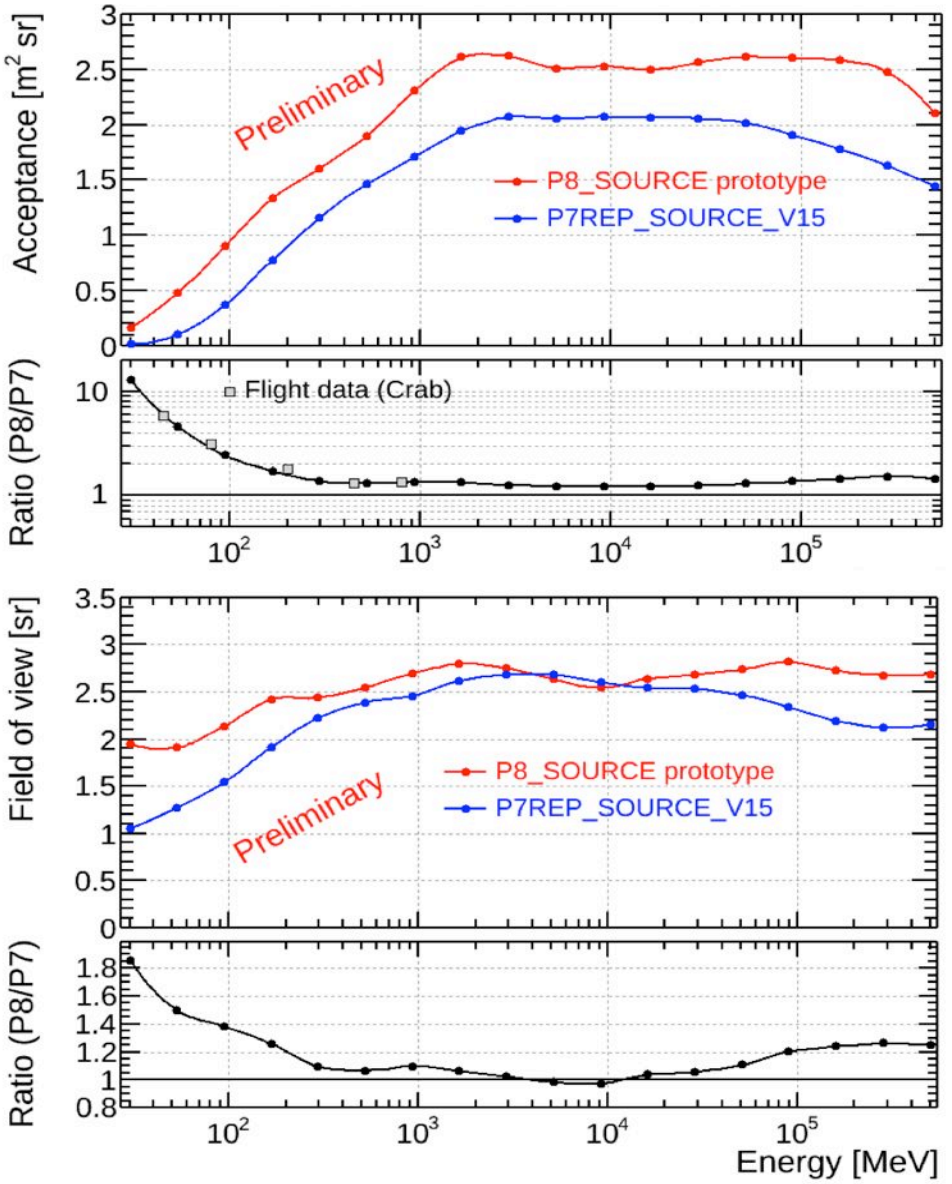
Latronico's talk

- **Now into extended operations, since 2013**
- **NASA 2014 Senior Review just approved operations through 2016**

Pass8 preliminary performance

- **Larger acceptance**
  - **Dramatic increase < 100 MeV**
- **Larger field of view**
  - **more off-axis effective area**
- **Similar E dispersion and PSF**
  - **Narrower PSF at highest energies, reduced tails**
  - **Can improve PSF by tightening event selection**

Latronico's talk



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 2020

100 MeV – 3 TeV, an approved Russian γ-ray satellite. Energy resolution (100 GeV) ~ 1 %. Effective area ~ 0.4 m^2. Angular resolution (100 GeV) ~ 0.01°.

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

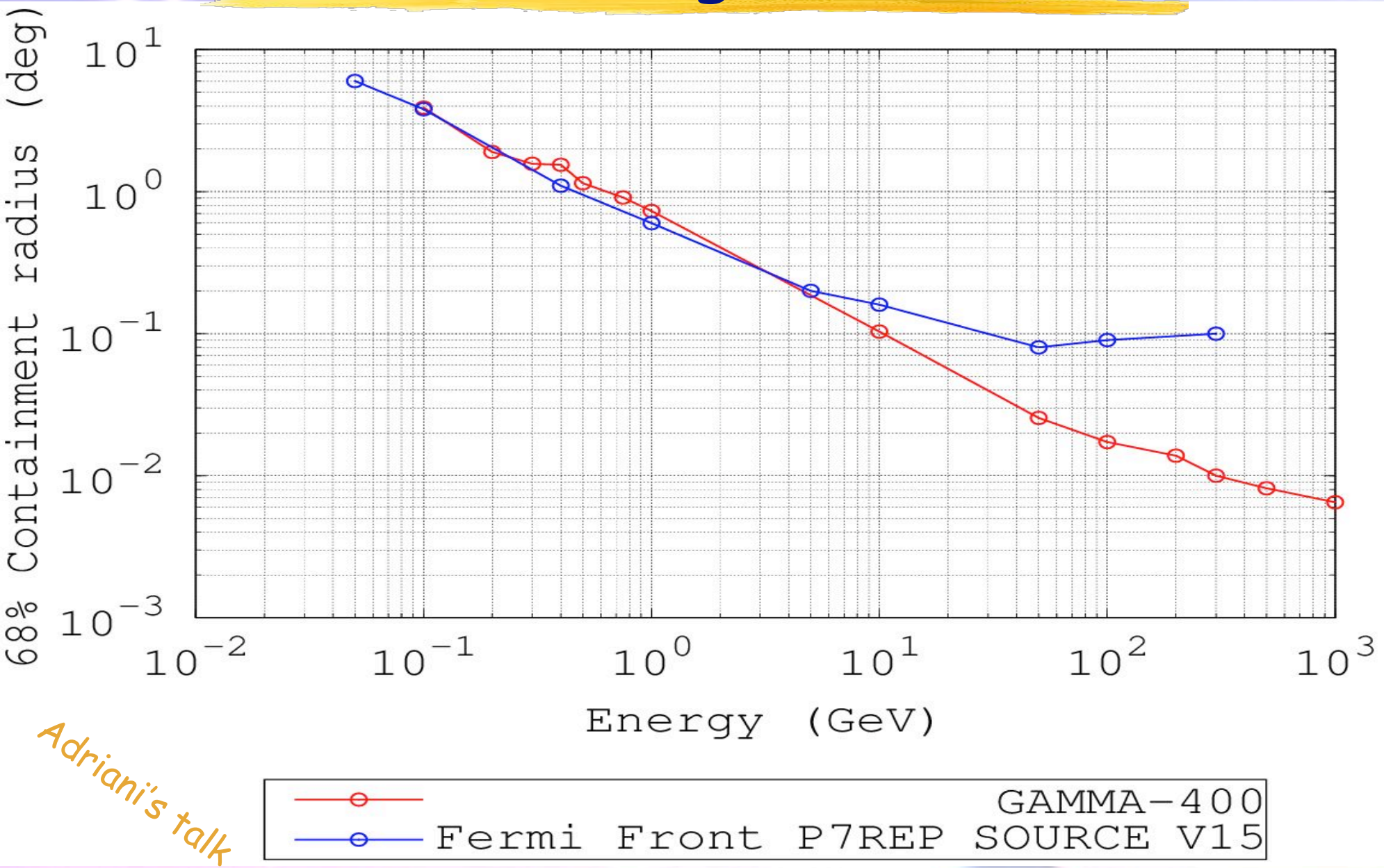
- DAMPE: Satellite of similar performance as Gamma-400.

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

- HERD: Instrument on the planned Chinese Space Station.

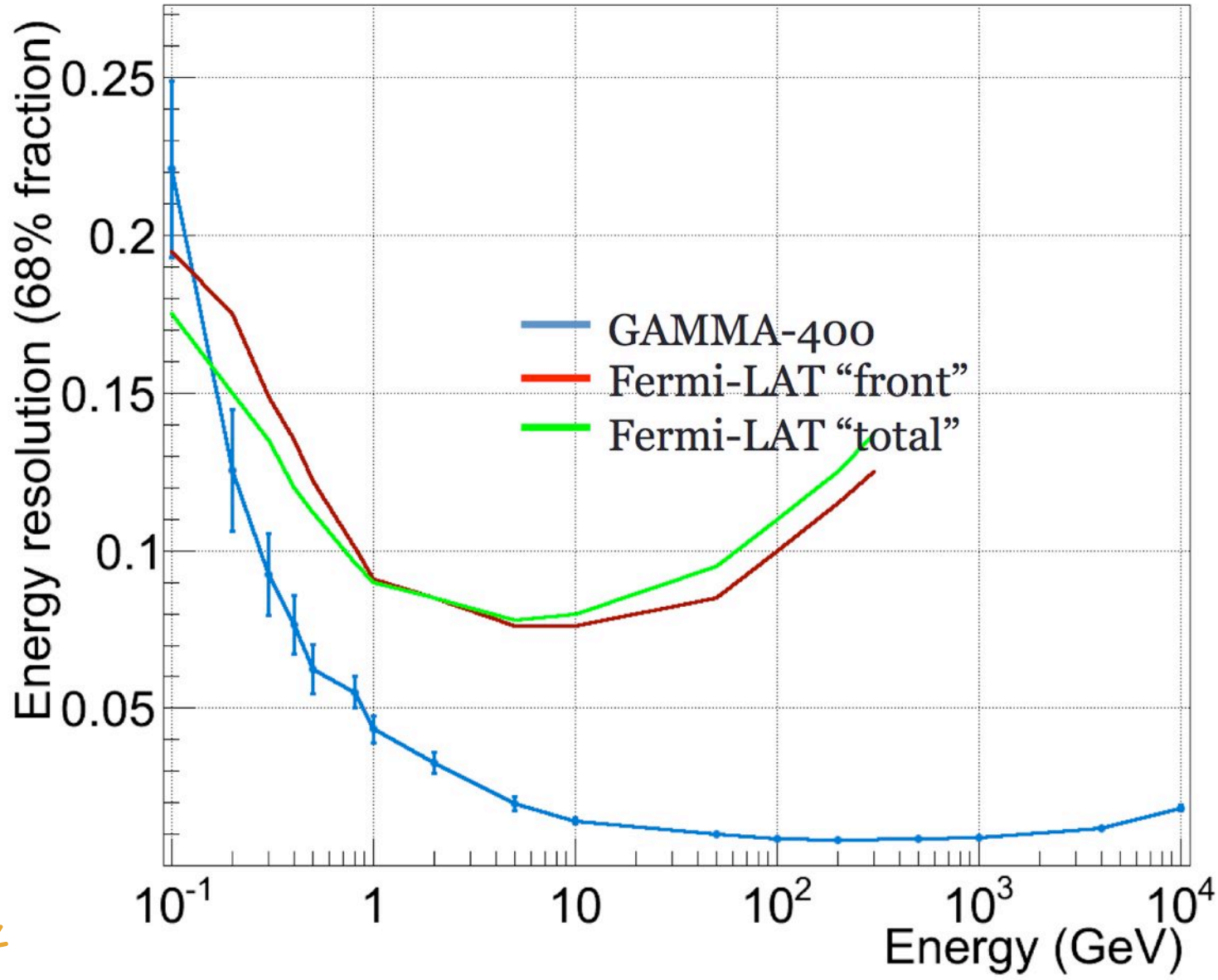
Energy resolution (100 GeV) ~ 1 %. Effective area ~ 1 - 2 m2. Angular resolution (100 GeV) ~ 0.01°. Planned launch around 2020.

Gamma-400 Angular resolution



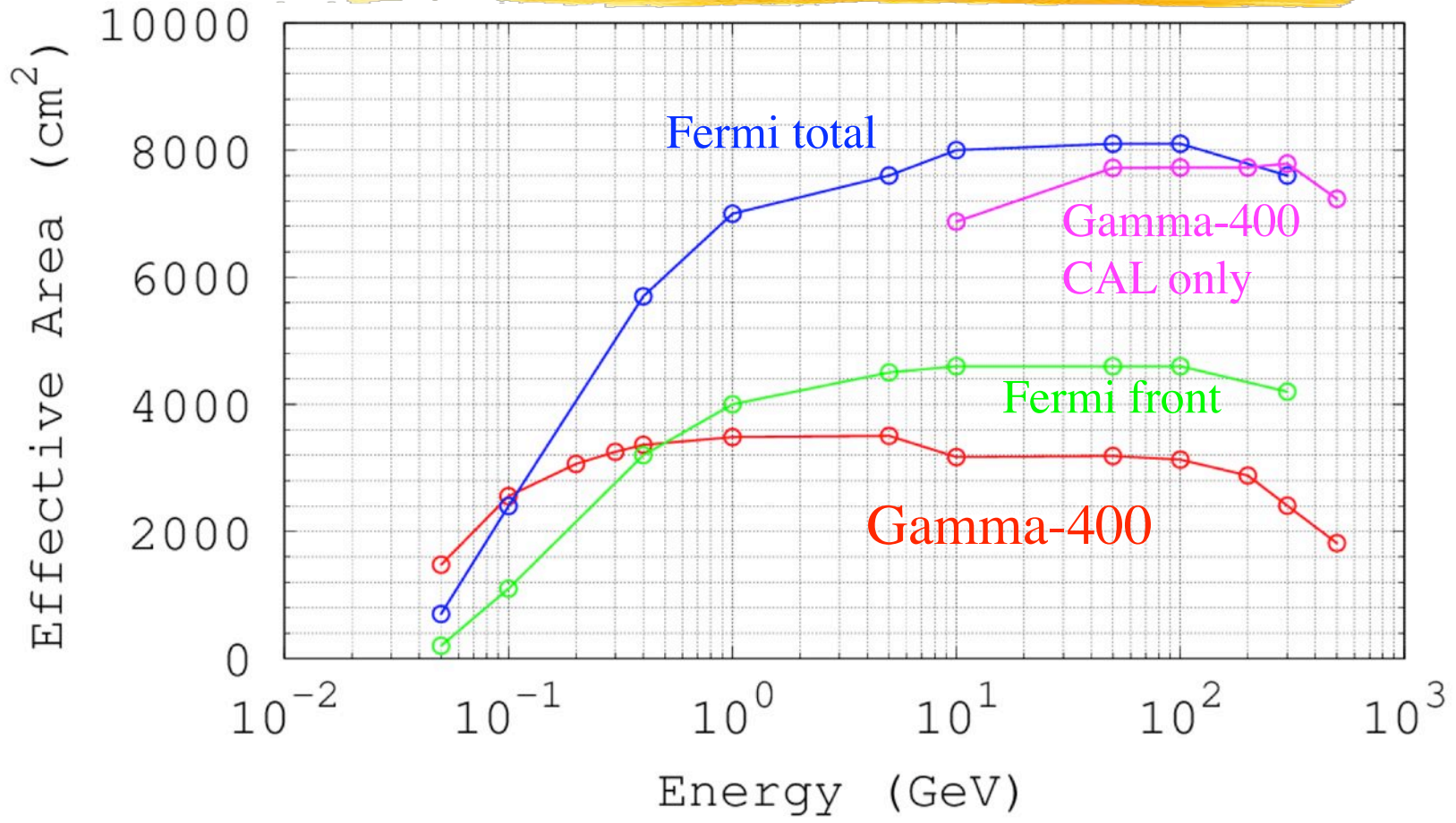
Adriani's talk

Gamma-400 Energy resolution for γ



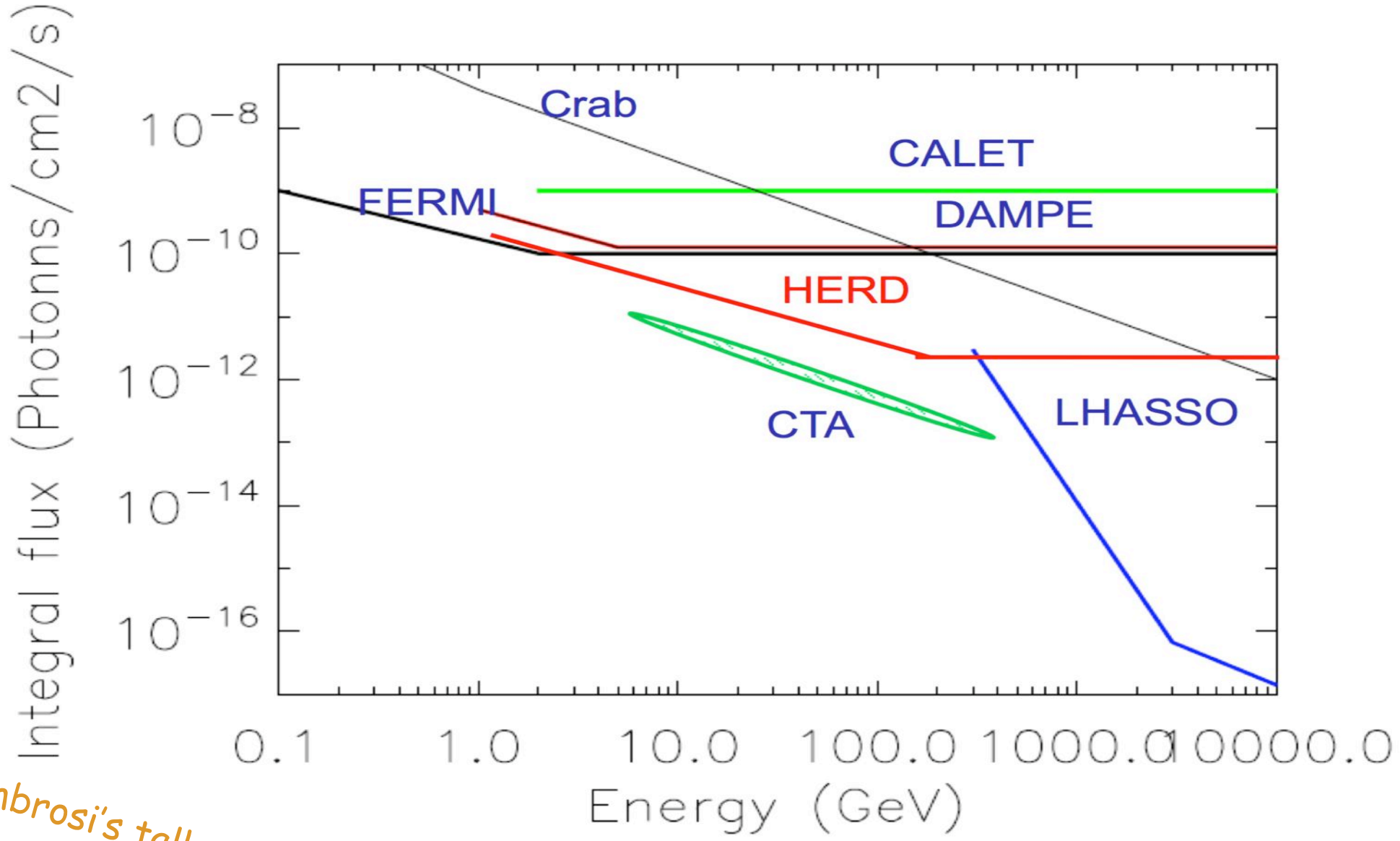
Adriani's talk

Gamma-400 Effective area for γ

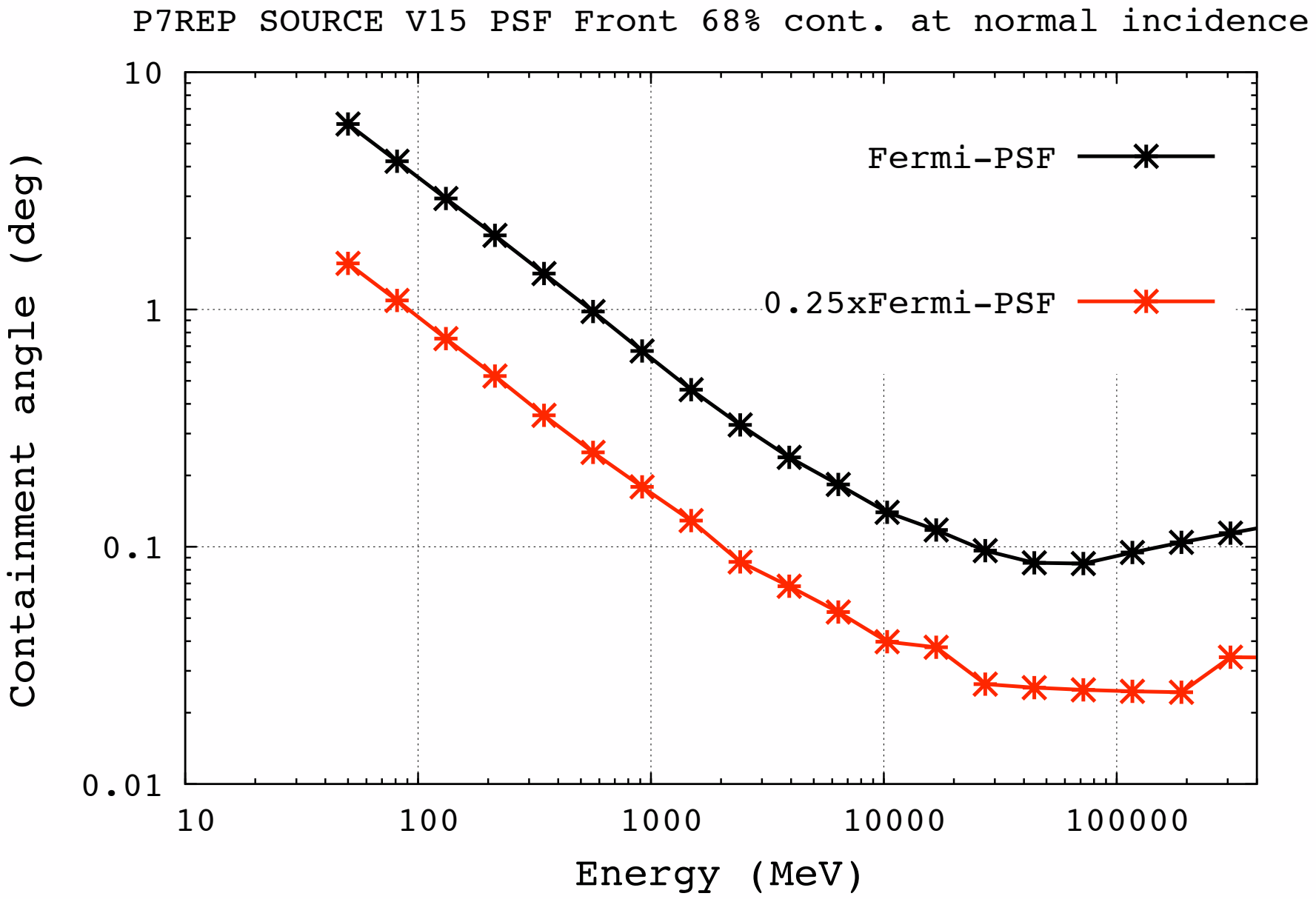


Adriani's talk

DAMPE and HERD Gamma-ray Sensitivity

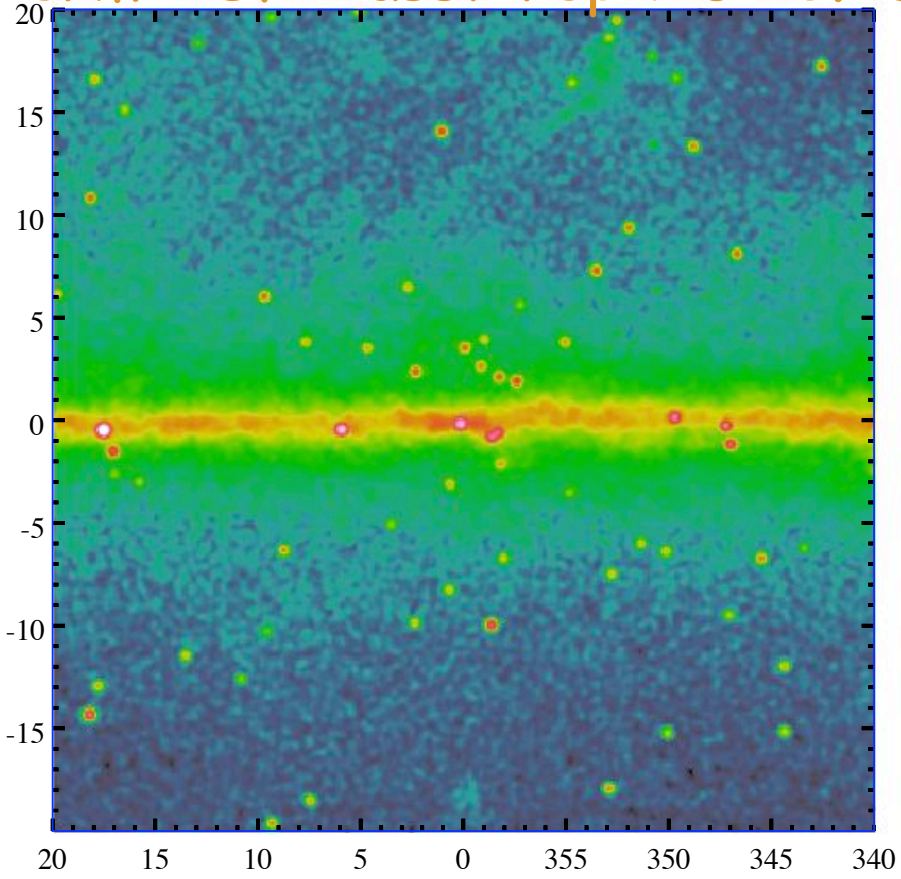


Ambrosi's talk

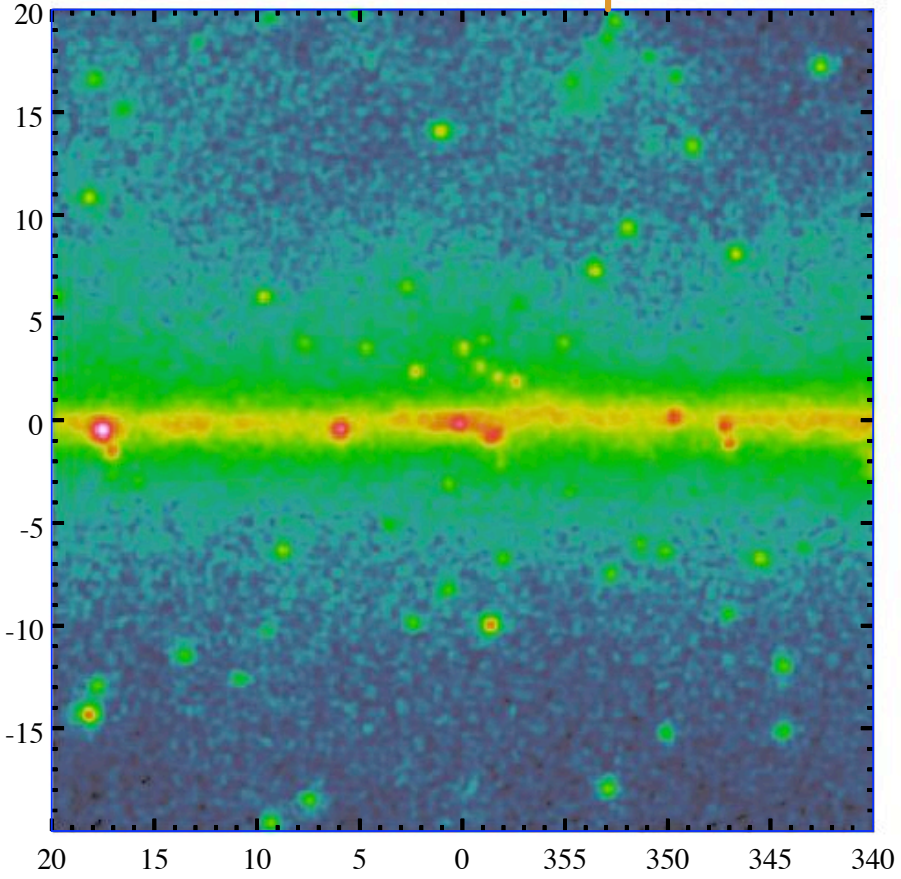

P7REP SOURCE V15 PSF Front 68% cont. at normal incidence
Containment angle (deg)
10
1
0.1
0.01
10
100
1000
10000
100000
Energy (MeV)
Fermi-PSF
0.25xFermi-PSF

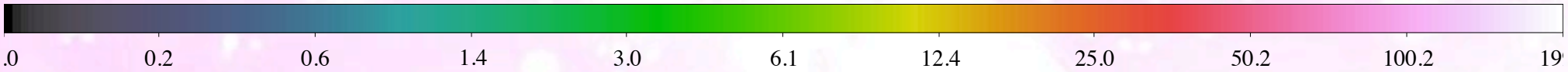
Galactic Center Region 1-5 GeV

Fermi PSF Pass7 rep v15 *0.25



Fermi PSF Pass7 rep v15 source



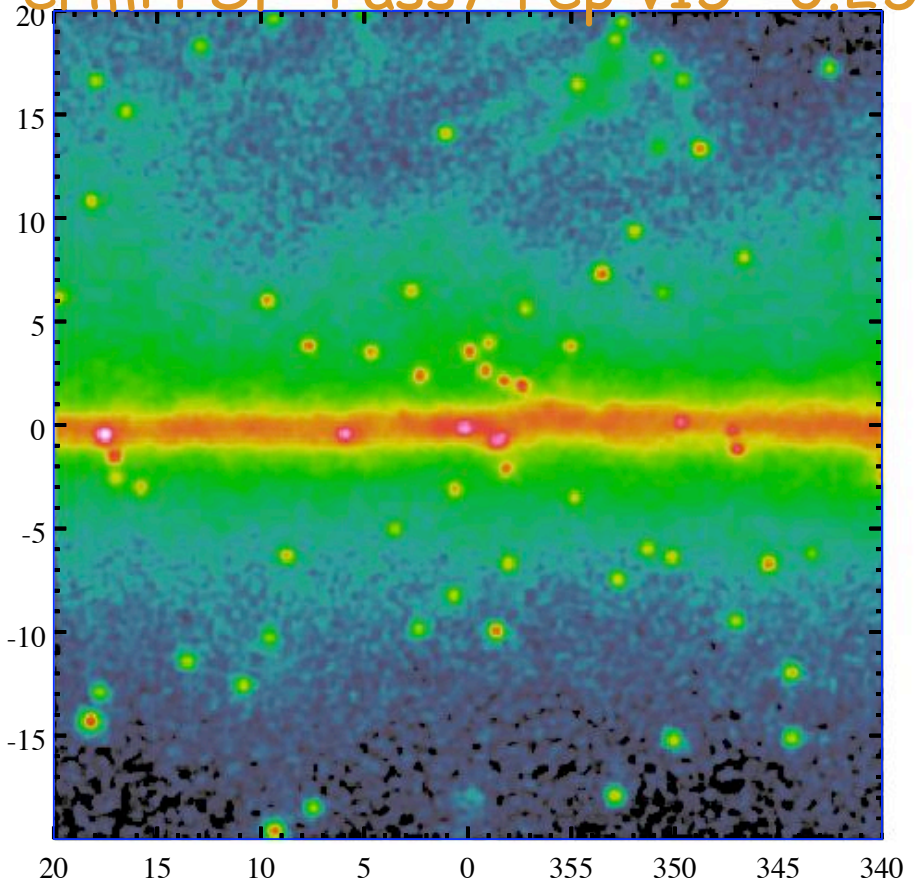


Sources from two years Fermi catalog , template ring model for diffuse

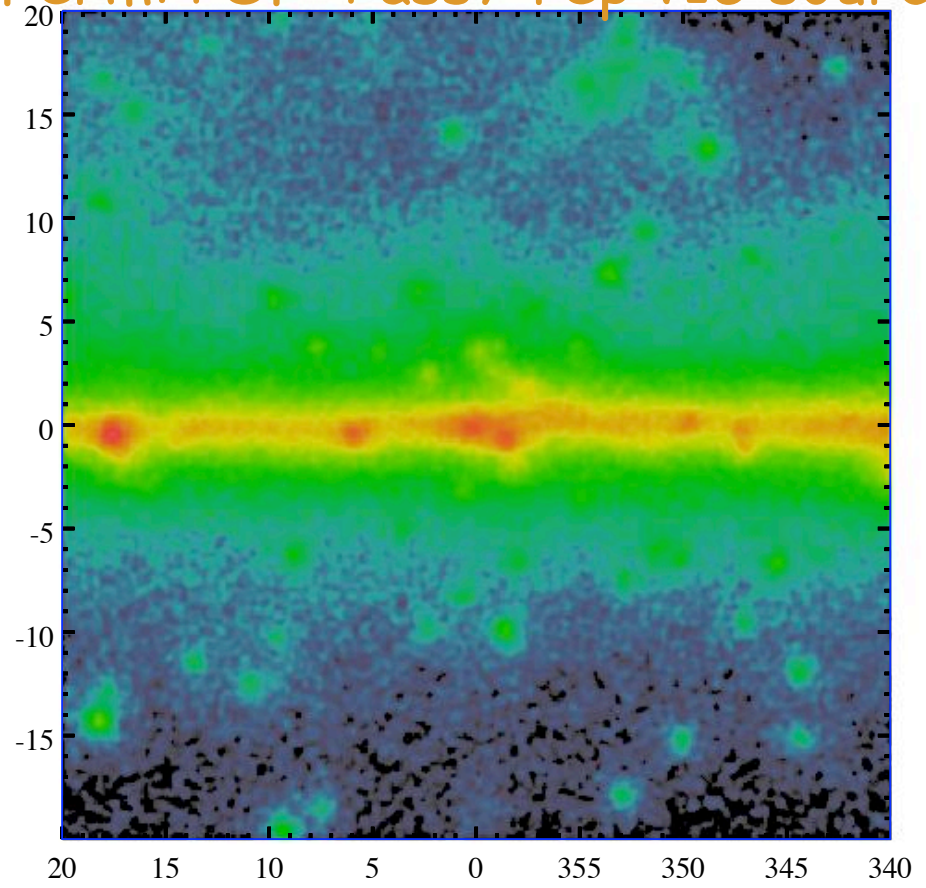
ApJ S 2012 199,31 [arXiv:1108.1435]

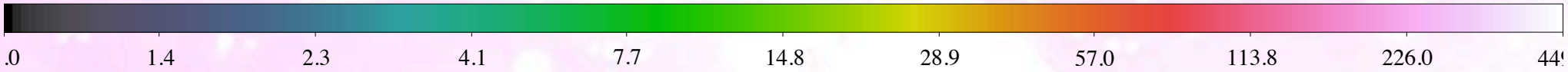
Galactic Center Region 0.2-1 GeV

Fermi PSF Pass7 rep v15 *0.25



Fermi PSF Pass7 rep v15 source

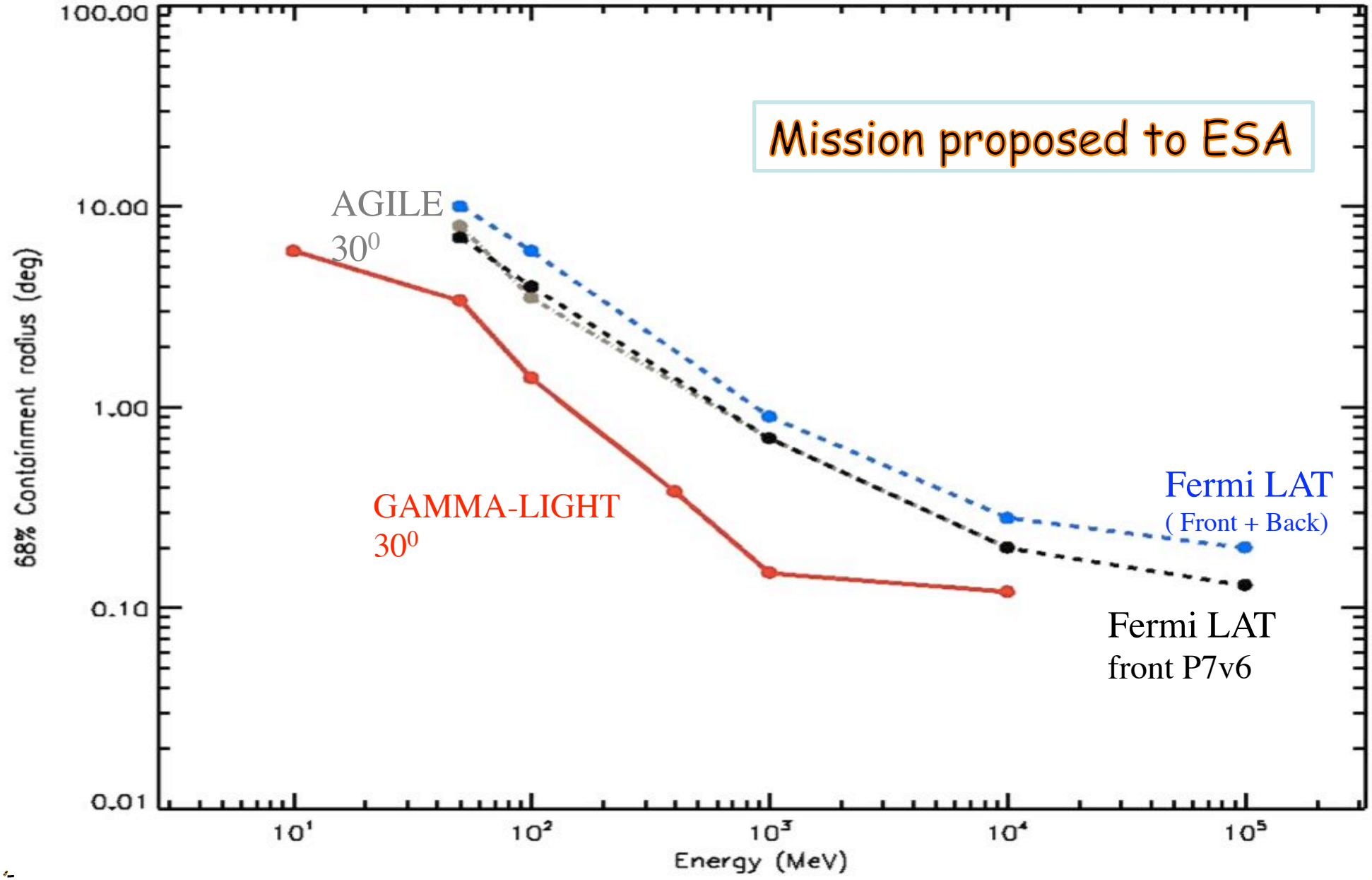




Sources from two years Fermi catalog , template ring model for diffuse,

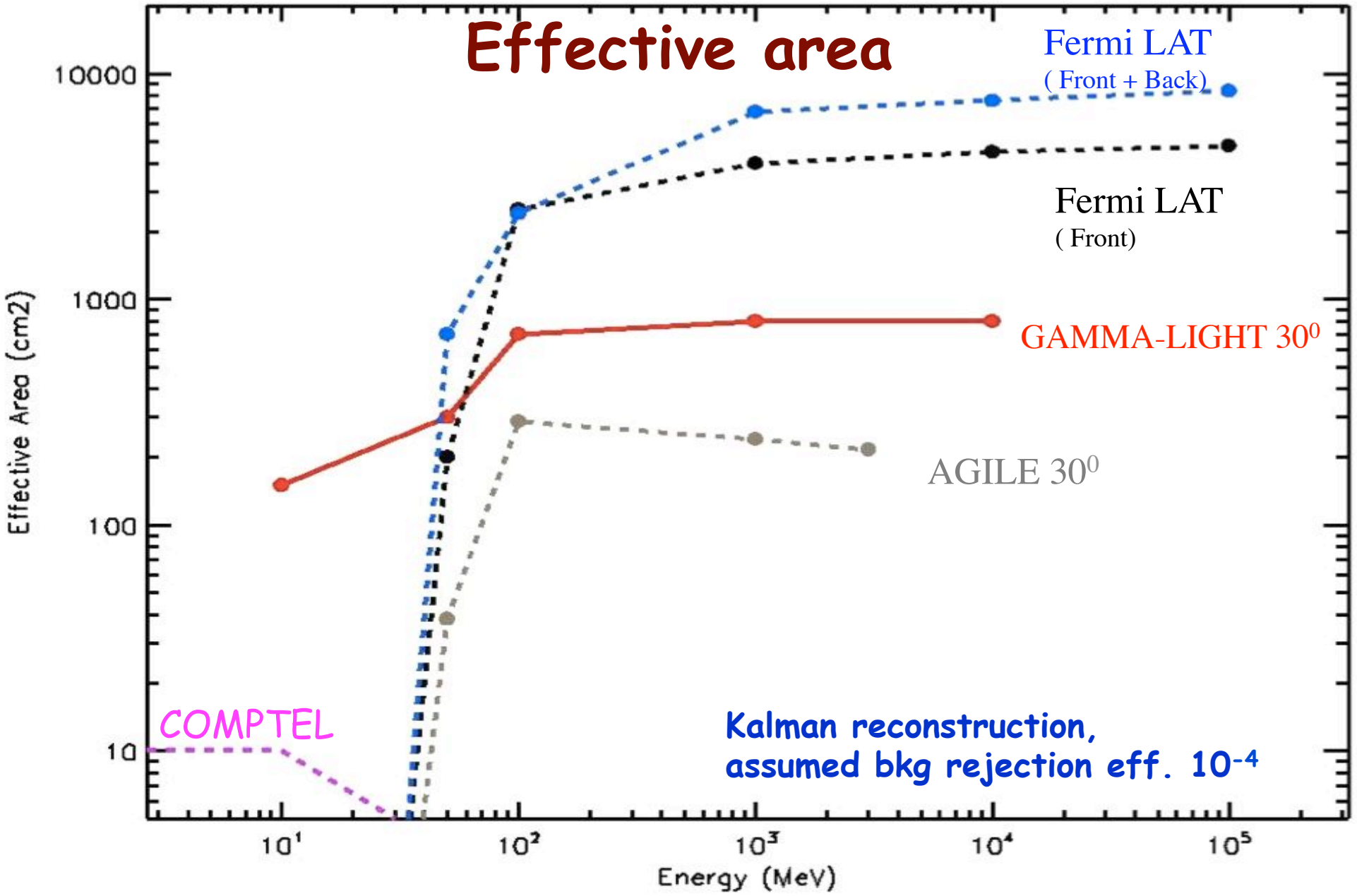
ApJ S 2012 199,31 [arXiv:1108.1435]

Gamma-Light Point Spread Function (angular resolution)

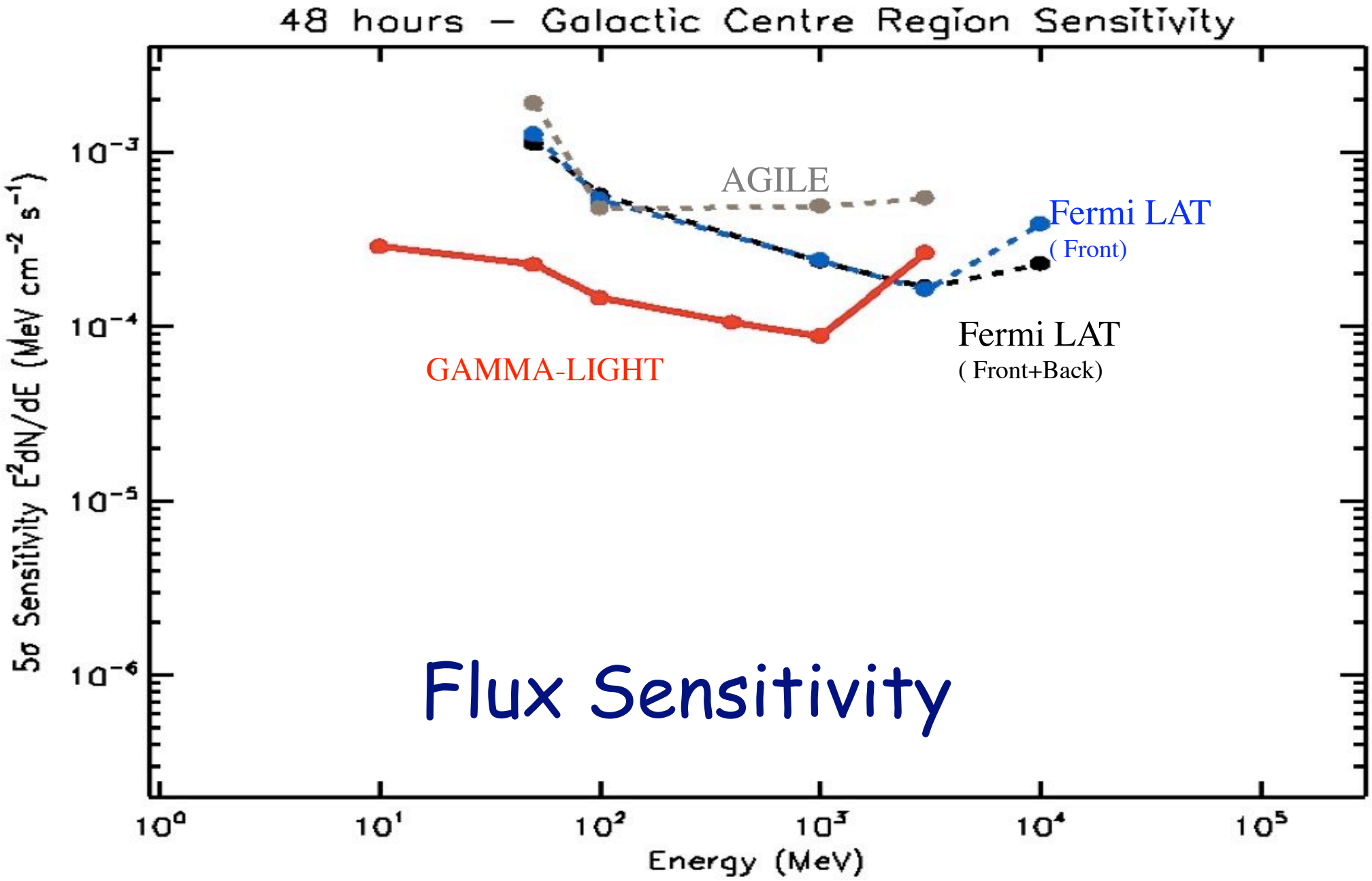


A.Morselli et al. , Nuclear Physics B Proc. Supp. 239–240 (2013) 193-198 [arXiv:1406.1071]

Effective area



A.Morselli et al. , Nuclear Physics B Proc. Supp. 239–240 (2013) 193-198 [arXiv:1406.1071]



A.Morselli et al. , Nuclear Physics B Proc. Supp. 239–240 (2013) 193-198 [arXiv:1406.1071]

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).

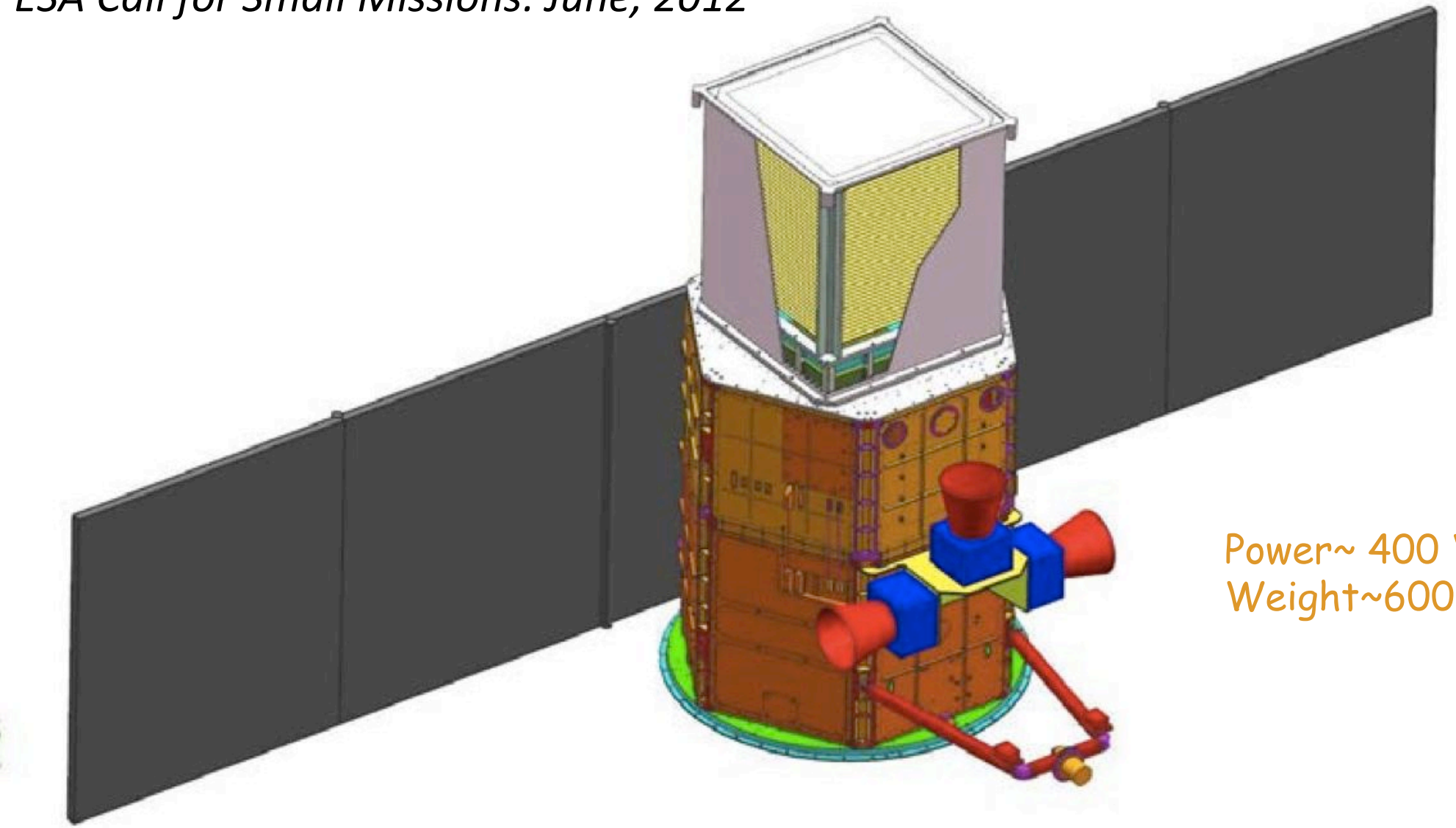
In the future it would be extremely important to extend the energy range of experiments at lower energies (compared to the Fermi energies) (eg. Gamma-Light) and higher energies (HAWC, Dampe, HERD, Gamma-400, CTA, LHAASO)

Additional slides

- Thank you for the attention !

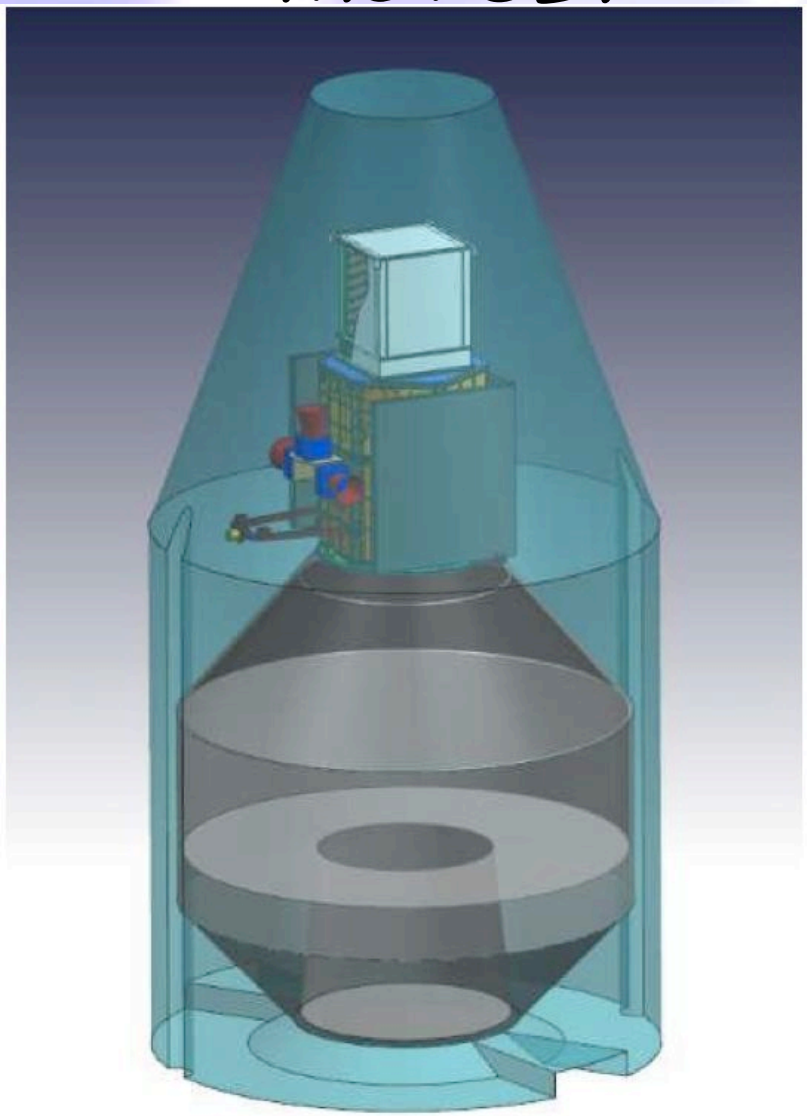
Gamma-light payload

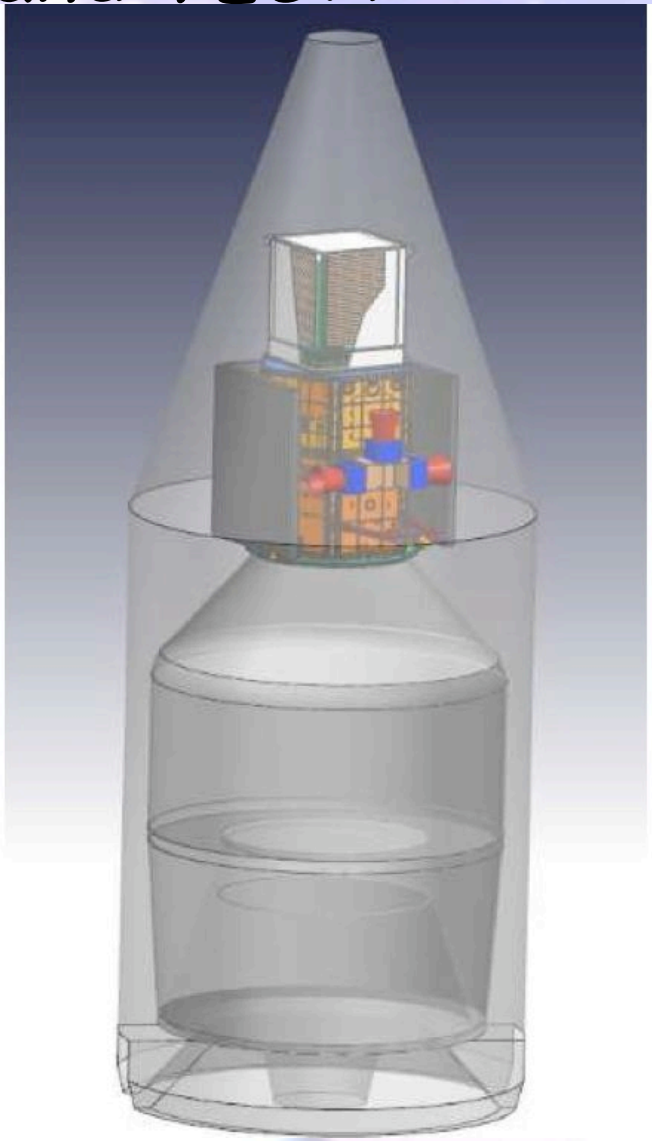
ESA Call for Small Missions: June, 2012



Power~ 400 W
Weight~600 Kg

GAMMA-LIGHT satellite launch configurations for the PSLV and VEGA



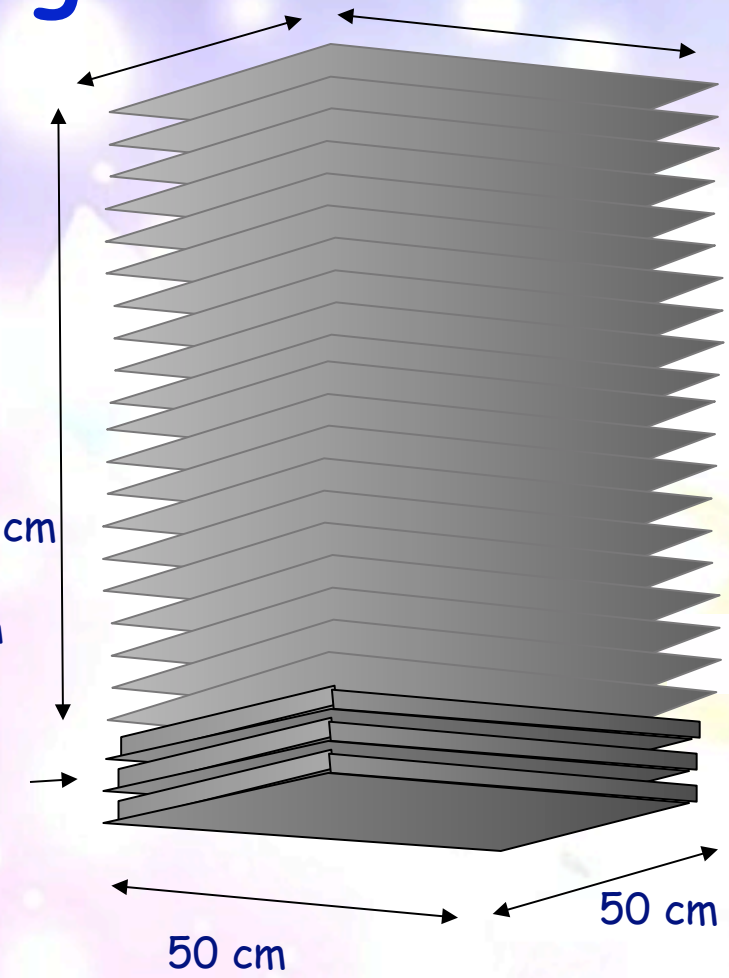


- a companion satellite similar to G-LIGHT can be accomodated.

Gamma-light scheme

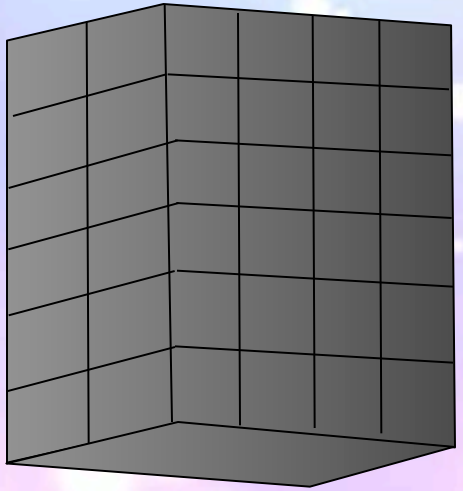
40+1 x-y planes
100 μm pitch
each
~0.025 X_0

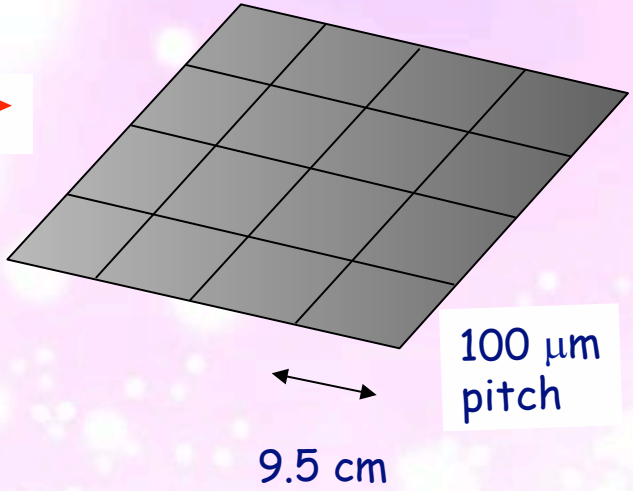
Tot~ 1 X_0



height of a plane 1.3 cm

2 Xo Calorimiter

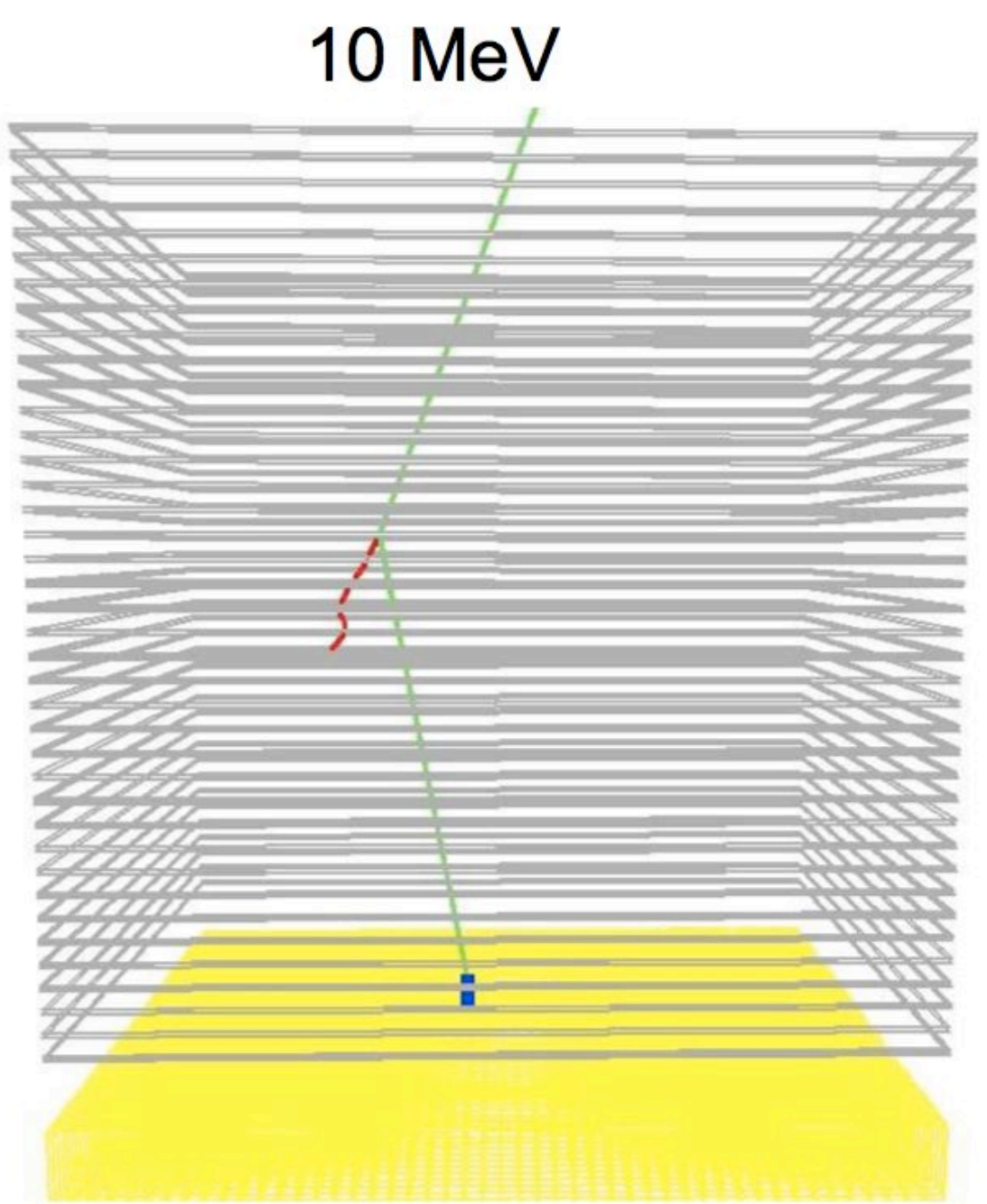




*Compton scattering **and** pair production telescope*

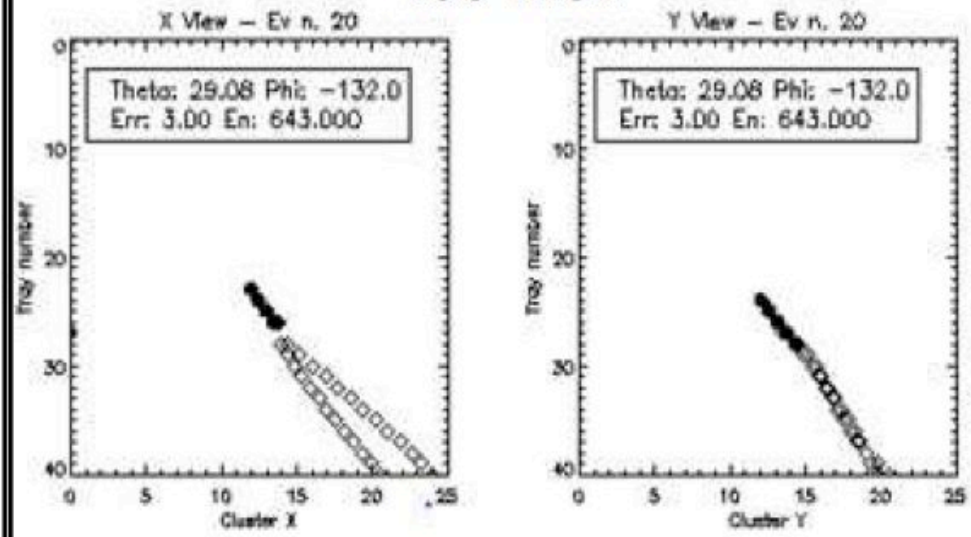
Gamma-LIGHT Simulation

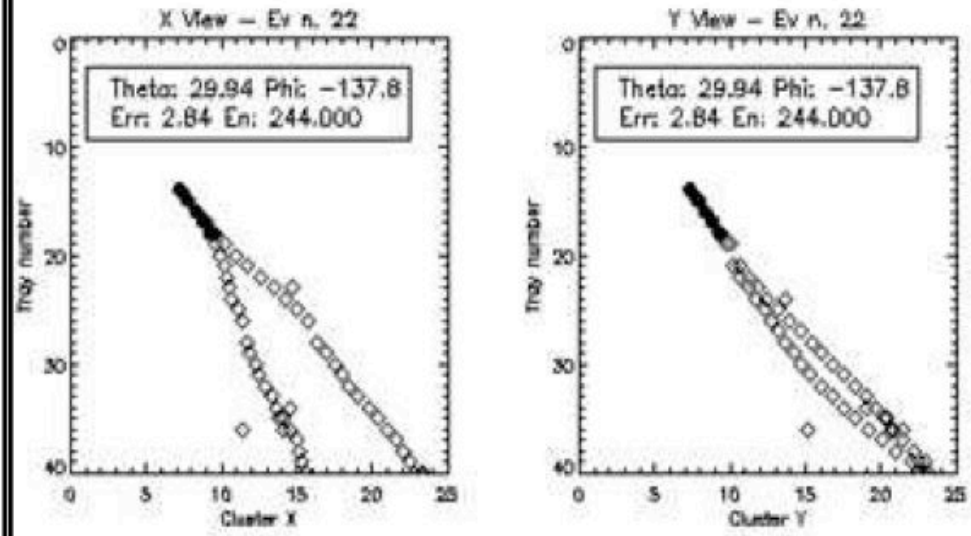
Compton interaction of a 10 MeV photon producing a low-energy single-track electron, and depositing energy in the Calorimeter for a 30° incidence



Gamma-light Simulation

100 MeV





1 GeV