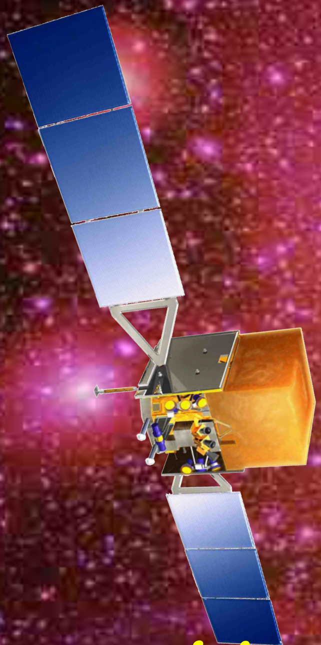
Search for dark matter in the Sky with ongoing and planned experiments



Aldo Morselli
INFN Roma Tor Vergata

SIXTEENTH LOMONOSOV CONFERENCE ON ELEMENTARY PARTICLE PHYSICS

Moscow State University, Moscow, 22 - 28 August, 2013

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

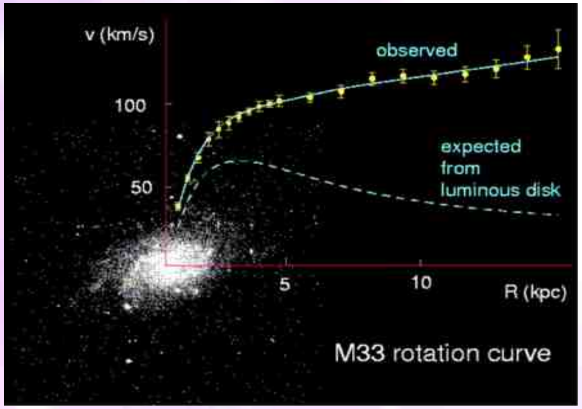
R.-D. Heuer, CERN General Director 36th International Conference on High Energy Physics ICHEP2012, Closing Talk

ICHEP2012 Melbourne

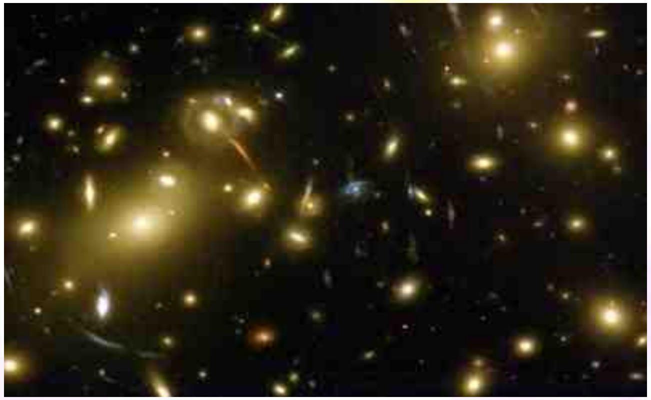
Dark Matter EVIDENCES

- 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:

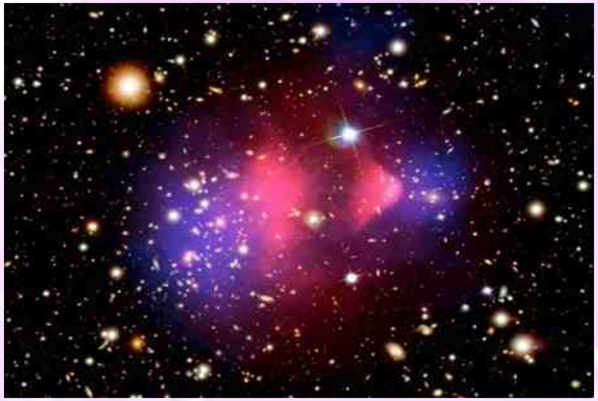
Rotation curves of galaxies



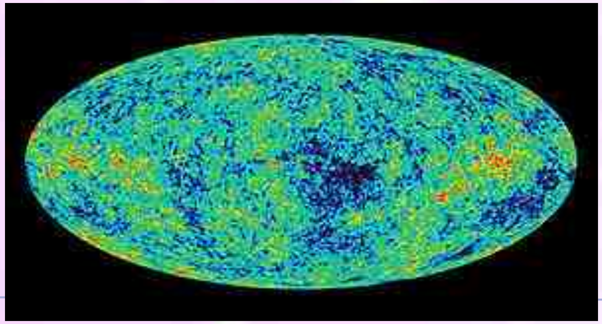
Gravitational lensing



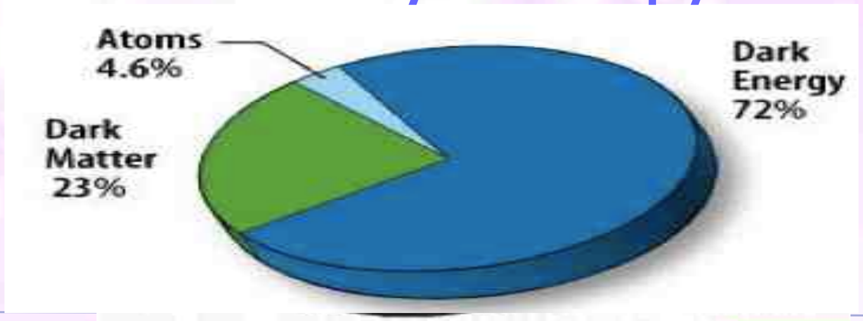
Bullet cluster



Structure formation as deduced from CMB



Data by WMAP imply:

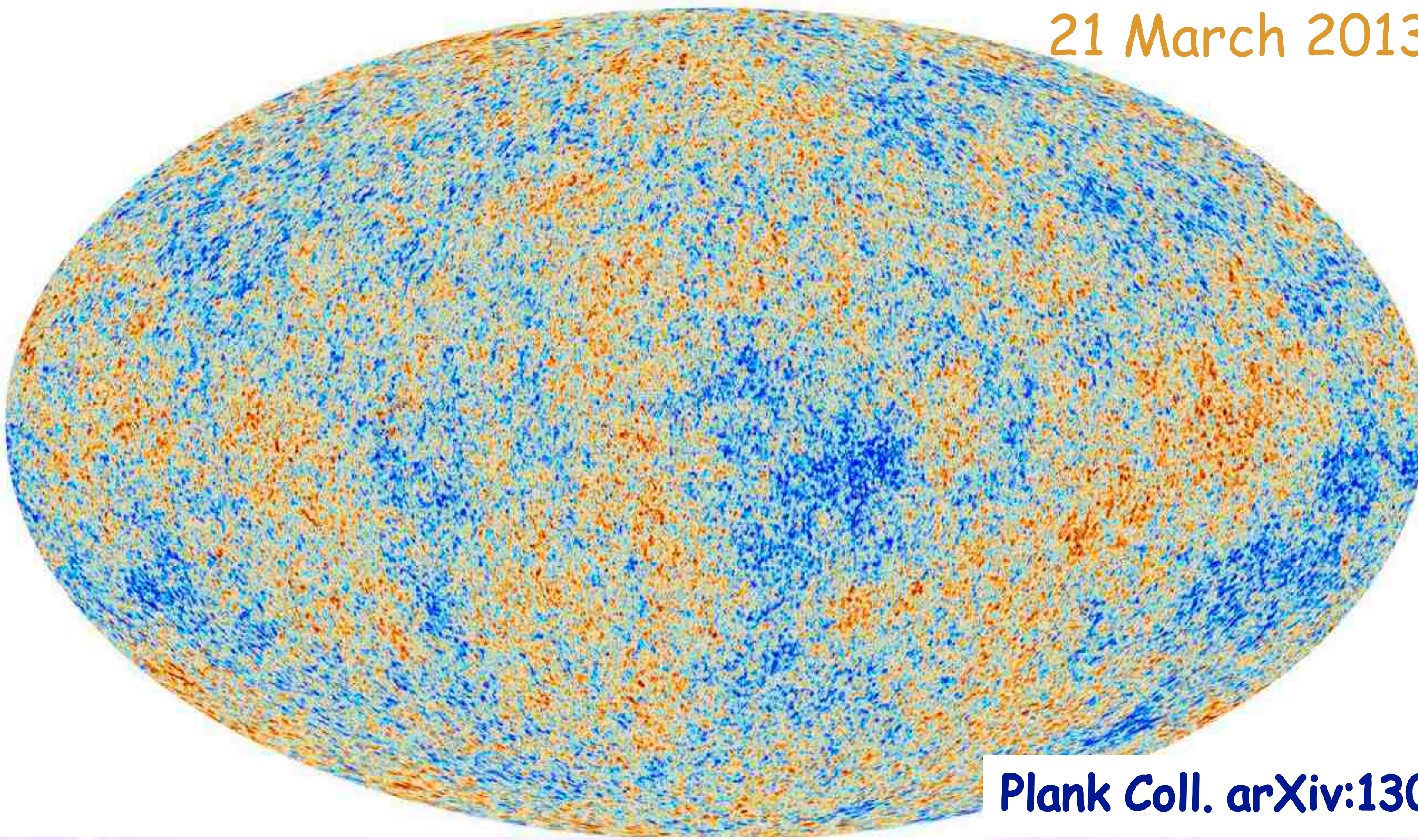


$\Omega_b h^2 \approx 0.02$

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

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

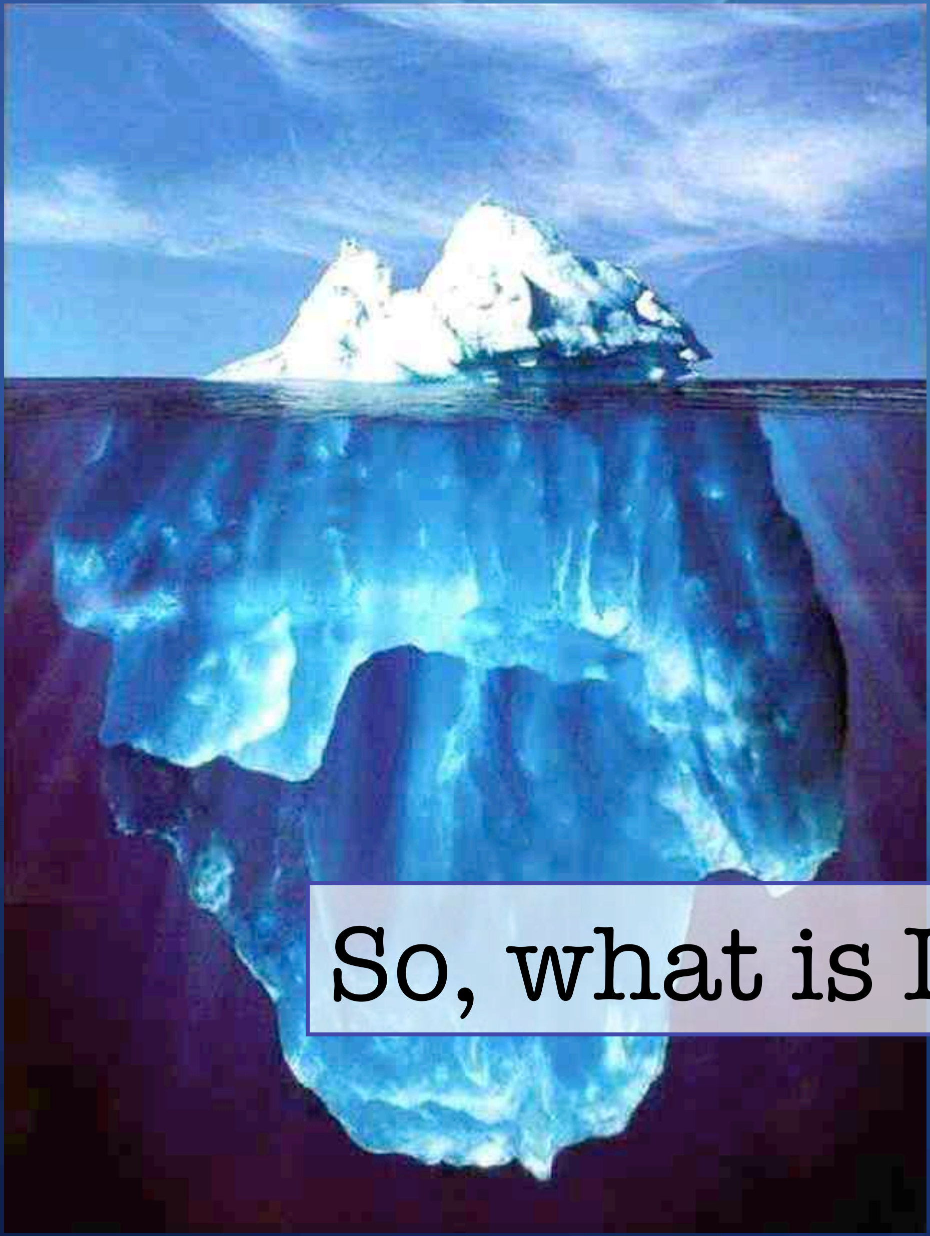
21 March 2013

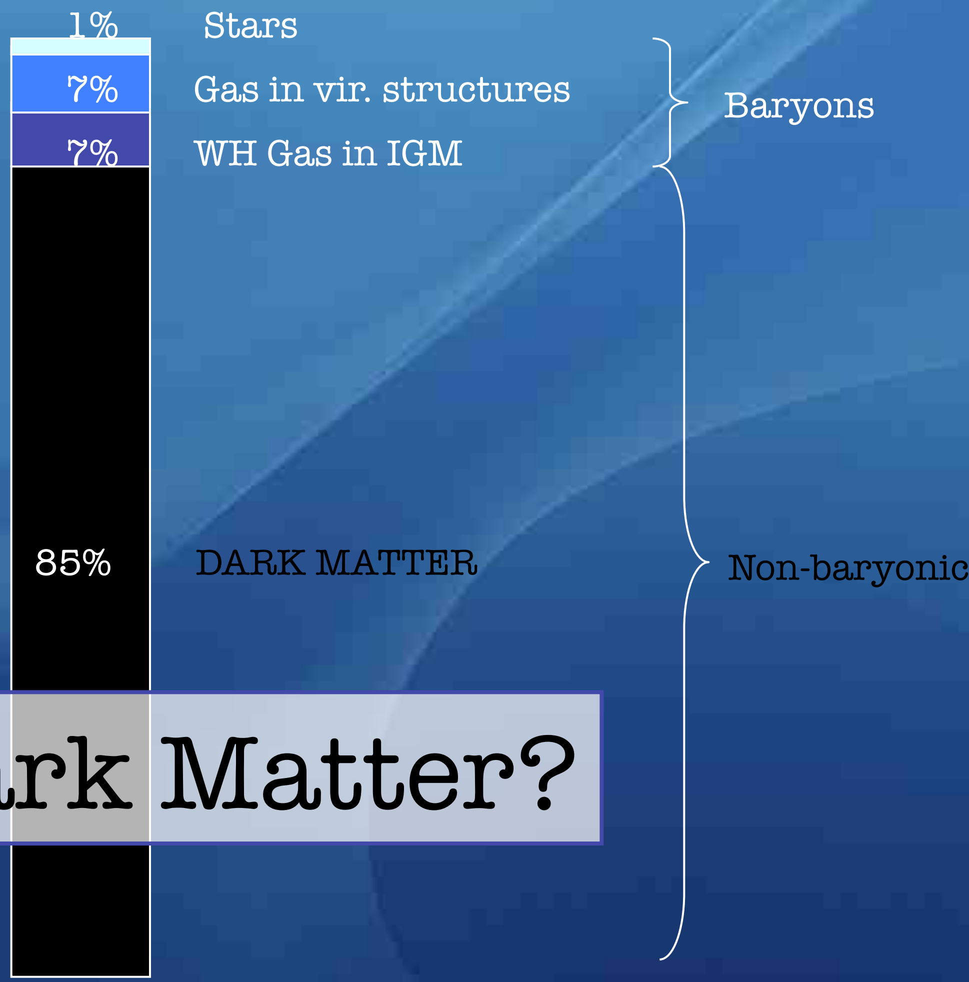


Plank Coll. arXiv:1303.5076

Dark Matter

An Inventory of Matter in the Universe

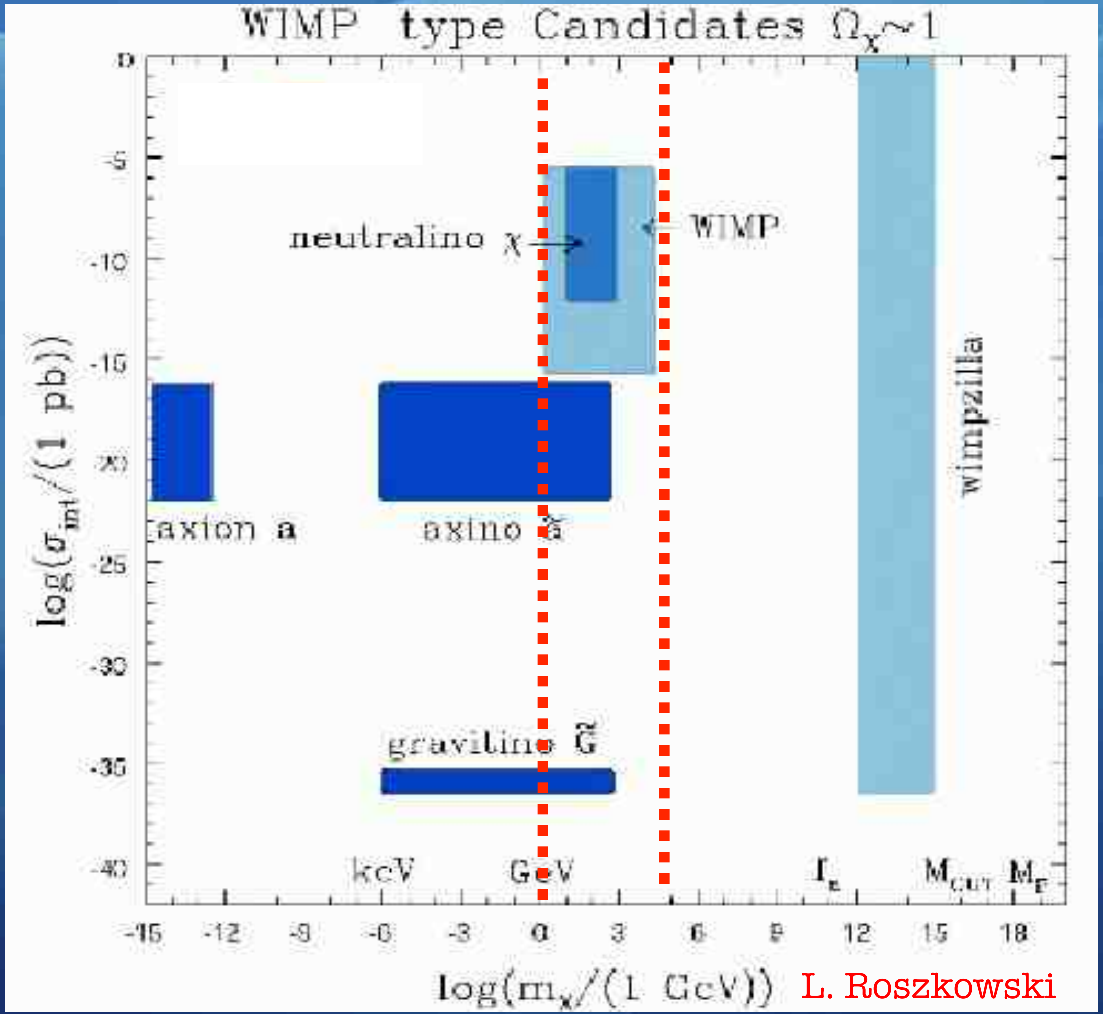




So, what is Dark Matter?

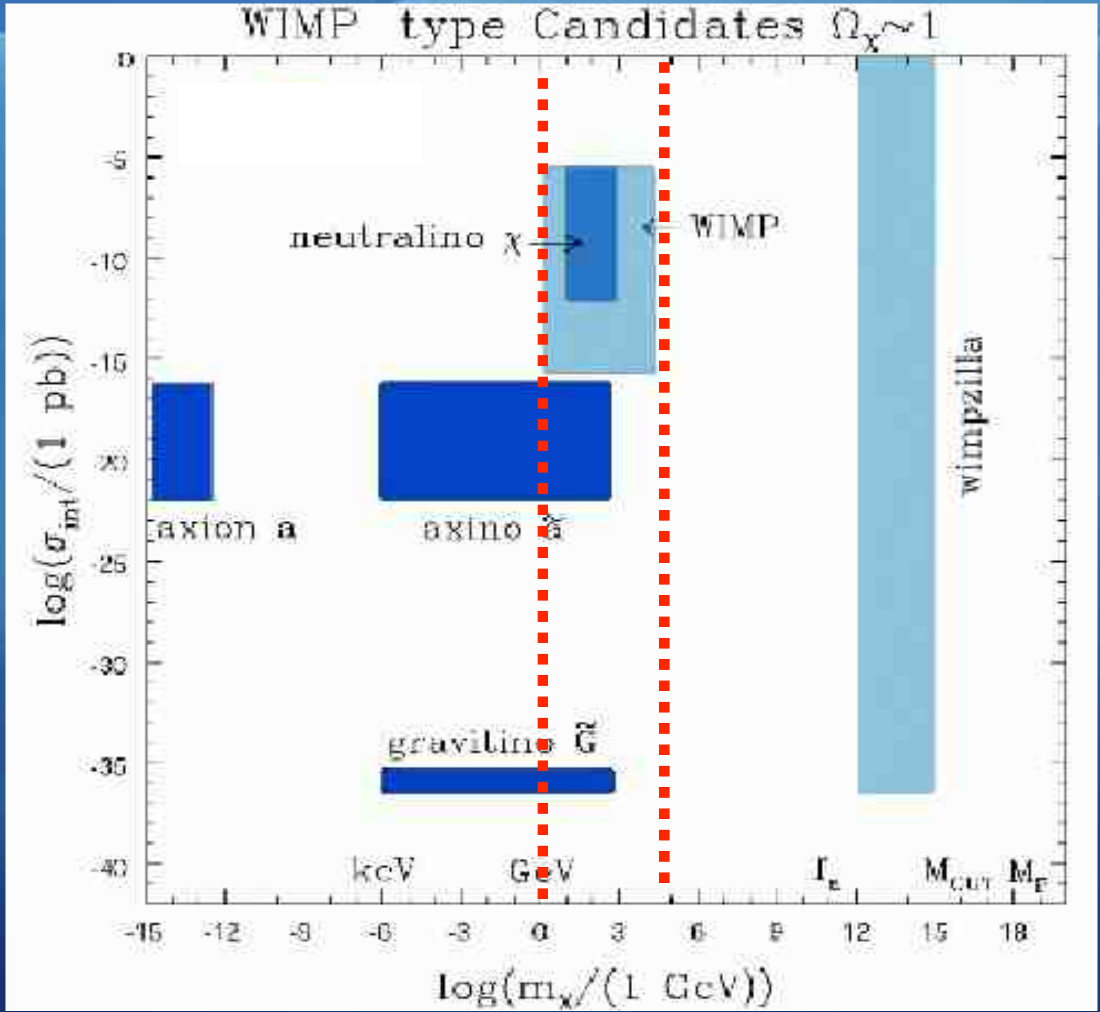
Dark Matter Candidates

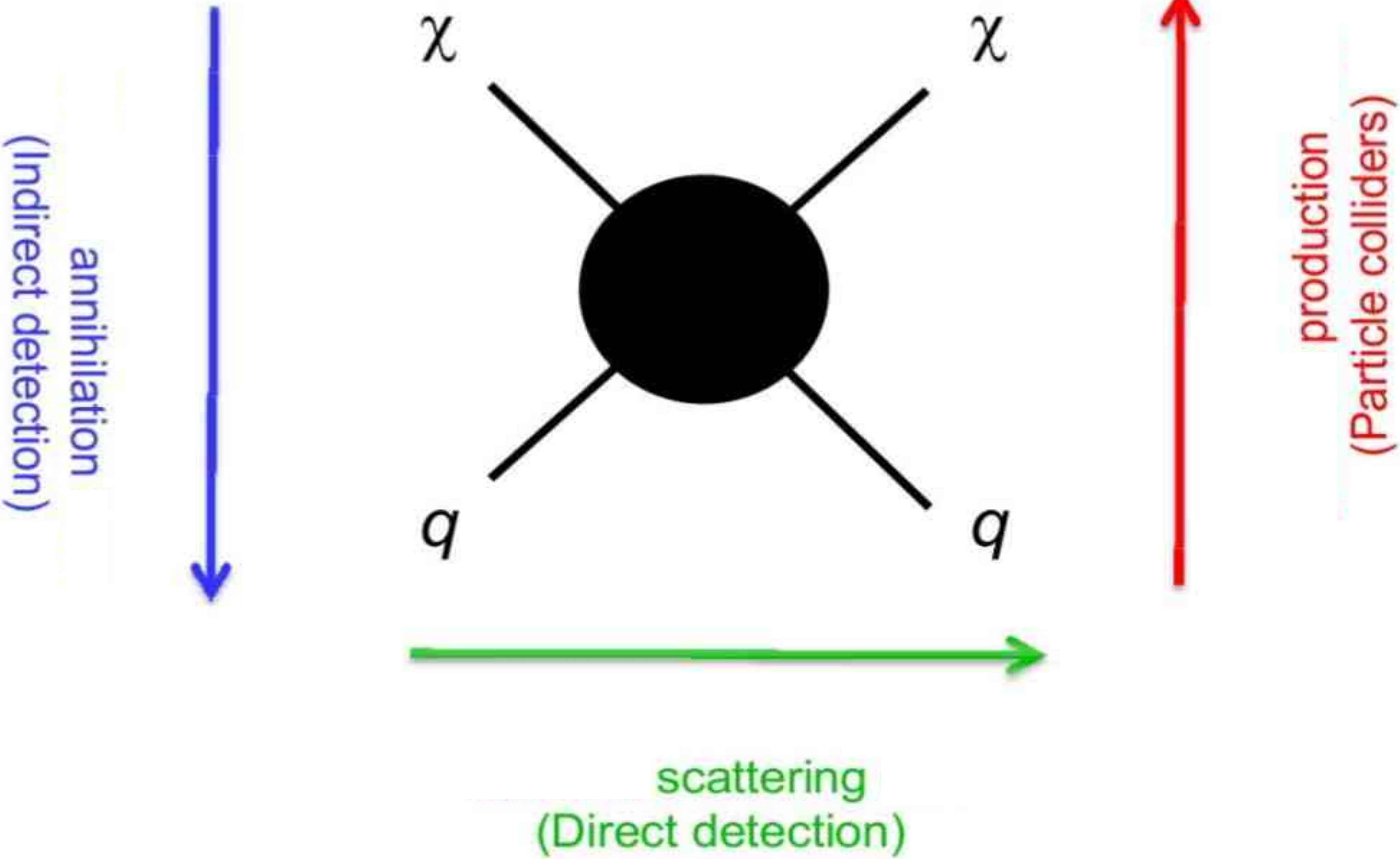
- Kaluza-Klein DM in UED
- Kaluza-Klein DM in RS
- Axion
- Axino
- Gravitino
- Photino
- SM Neutrino
- Sterile Neutrino
- Sneutrino
- Light DM
- Little Higgs DM
- Wimpzillas
- Q-balls
- Mirror Matter
- Champs (charged DM)
- D-matter
- Cryptons
- Self-interacting
- Superweakly interacting
- Braneworld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

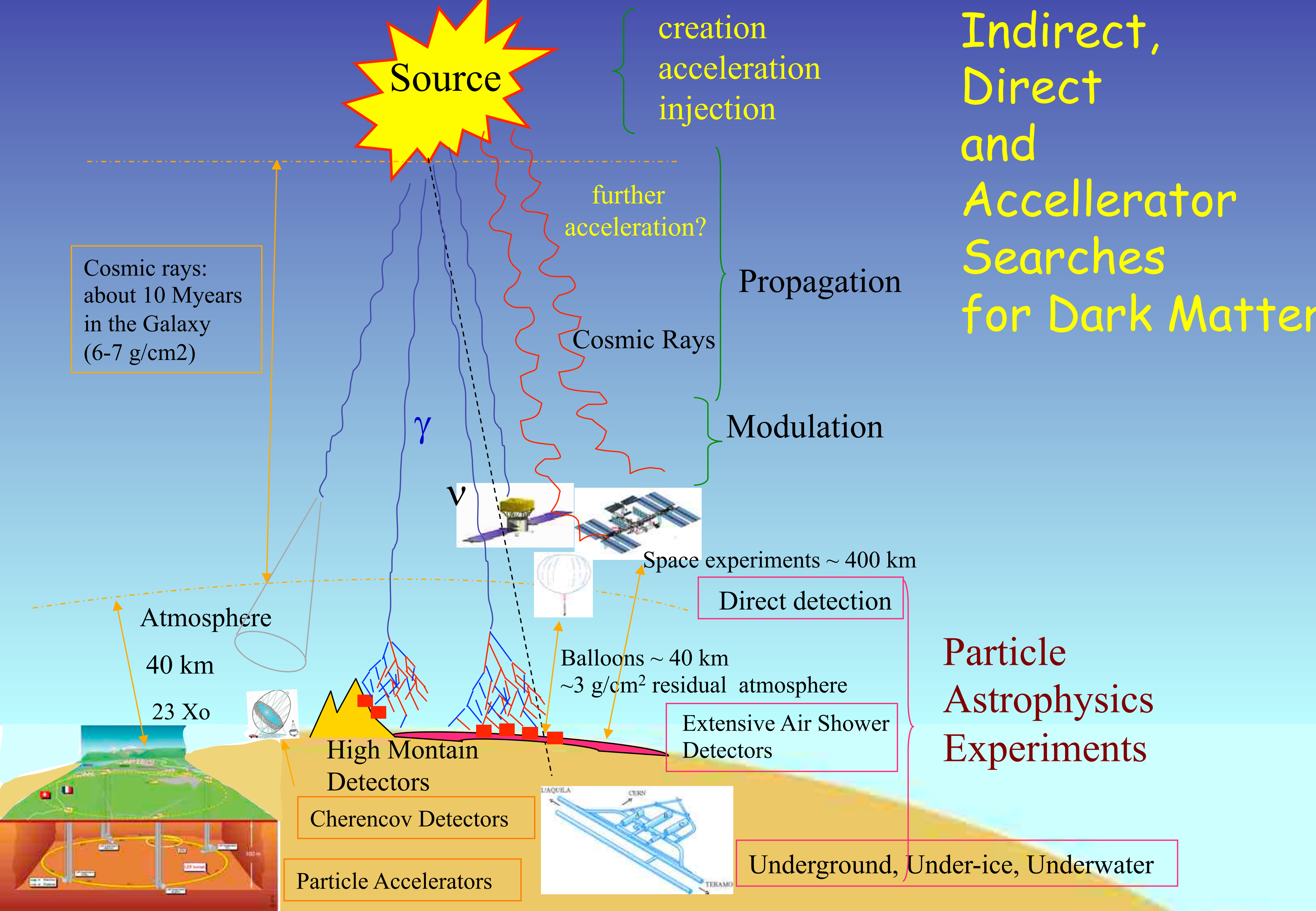


Dark Matter Candidates

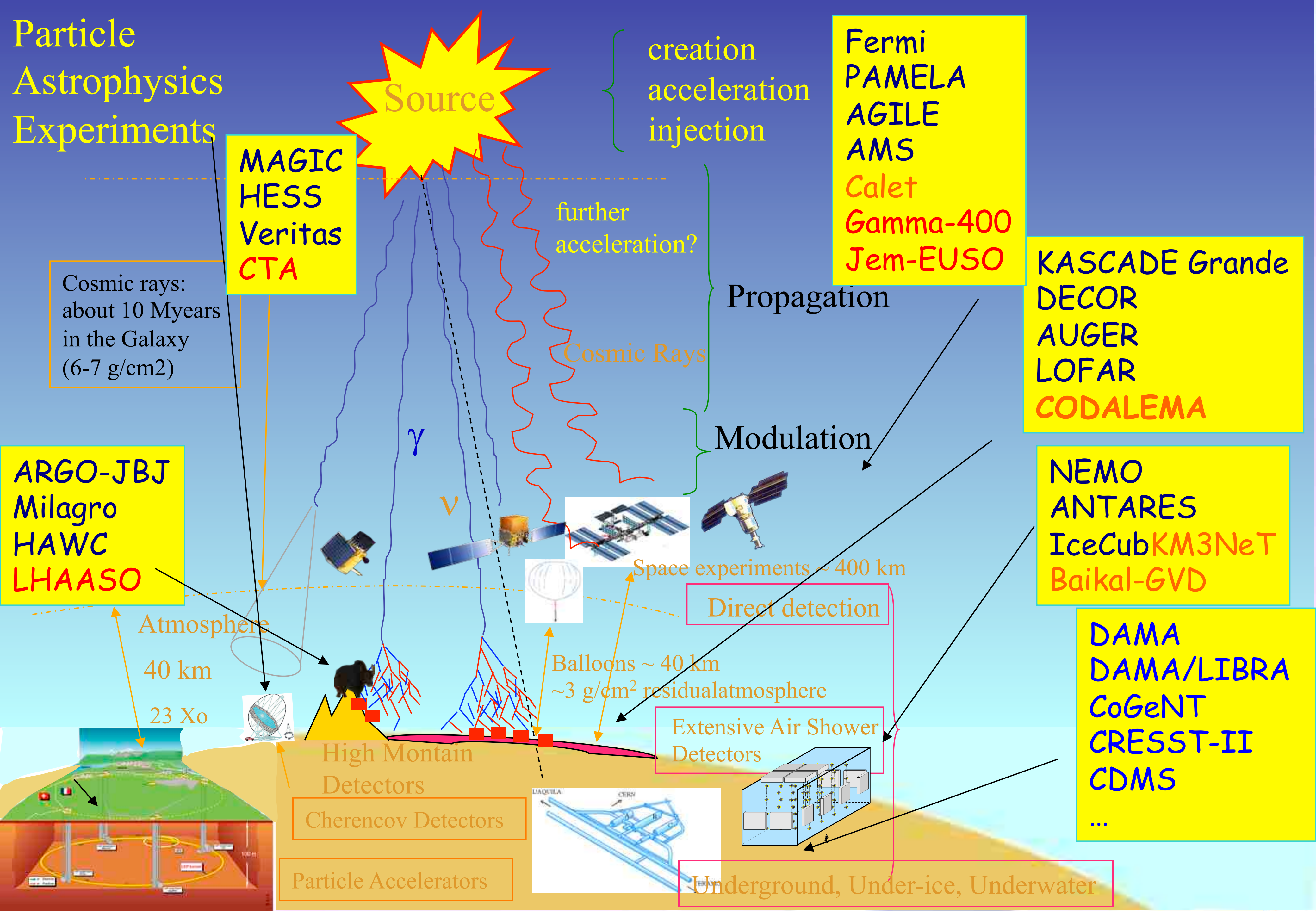
- Kaluza-Klein DM inUED
- Kaluza-Klein DM in RS
- Axion
- Axino
- Gravitino
- Photino
- SM Neutrino
- Sterile Neutrino
- Sneutrino
- Light DM
- Little Higgs DM
- Wimpzillas
- Q-balls
- Mirror Matter
- Champs (charged DM)
- D-matter
- Cryptons
- Self-interacting
- Superweakly interacting
- Braneworls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




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



Indirect, Direct and Accellerator Searches for Dark Matter
Source
creation
acceleration
injection
further acceleration?
Propagation
Cosmic Rays
Modulation
Cosmic rays: about 10 Myears in the Galaxy (6-7 g/cm2)
γ
ν
Space experiments ~ 400 km
Direct detection
Atmosphere
40 km
23 Xo
Balloons ~ 40 km
~3 g/cm² residual atmosphere
Extensive Air Shower Detectors
High Montain Detectors
Cherencov Detectors
Particle Accelerators
L'AQUILA
CERN
TERAMO
Particle Astrophysics Experiments
Underground, Under-ice, Underwater



Particle
Astrophysics
Experiments
Source
creation
acceleration
injection
Fermi
PAMELA
AGILE
AMS
Calet
Gamma-400
Jem-EUSO
MAGIC
HESS
Veritas
CTA
further
acceleration?
Propagation
Cosmic Rays
Cosmic rays:
about 10 Myears
in the Galaxy
(6-7 g/cm2)
KASCADE Grande
DECOR
AUGER
LOFAR
CODALEMA
Modulation
γ
ν
ARGO-JBJ
Milagro
HAWC
LHAASO
NEMO
ANTARES
IceCub KM3NeT
Baikal-GVD
Space experiments ~ 400 km
Direct detection
Atmosphere
40 km
23 Xo
Balloons ~ 40 km
~3 g/cm² residualatmosphere
DAMA
DAMA/LIBRA
CoGeNT
CRESST-II
CDMS
...
Extensive Air Shower
Detectors
High Montain
Detectors
Cherencov Detectors
Particle Accelerators
Underground, Under-ice, Underwater

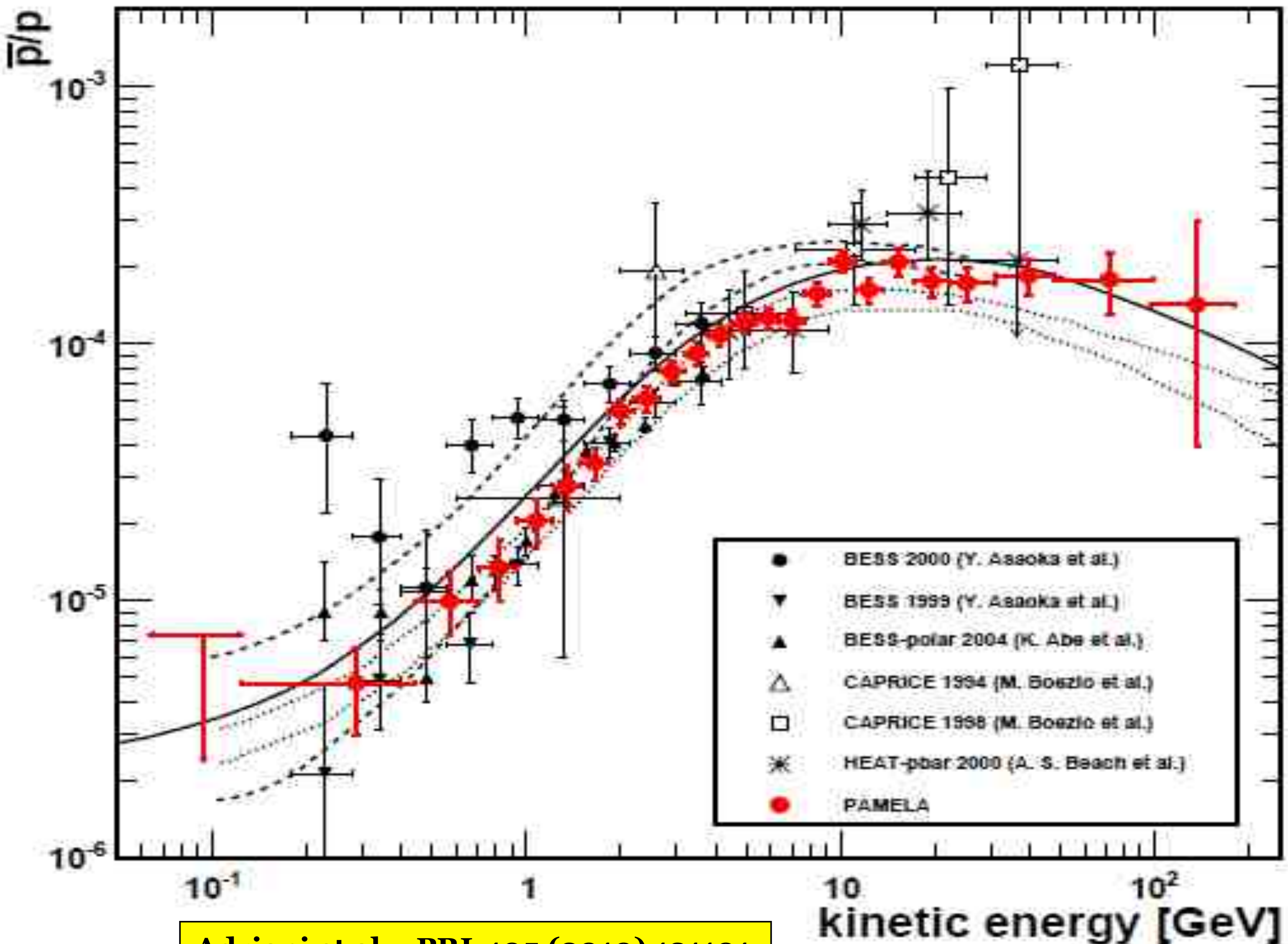
Neutralino WIMPs

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.

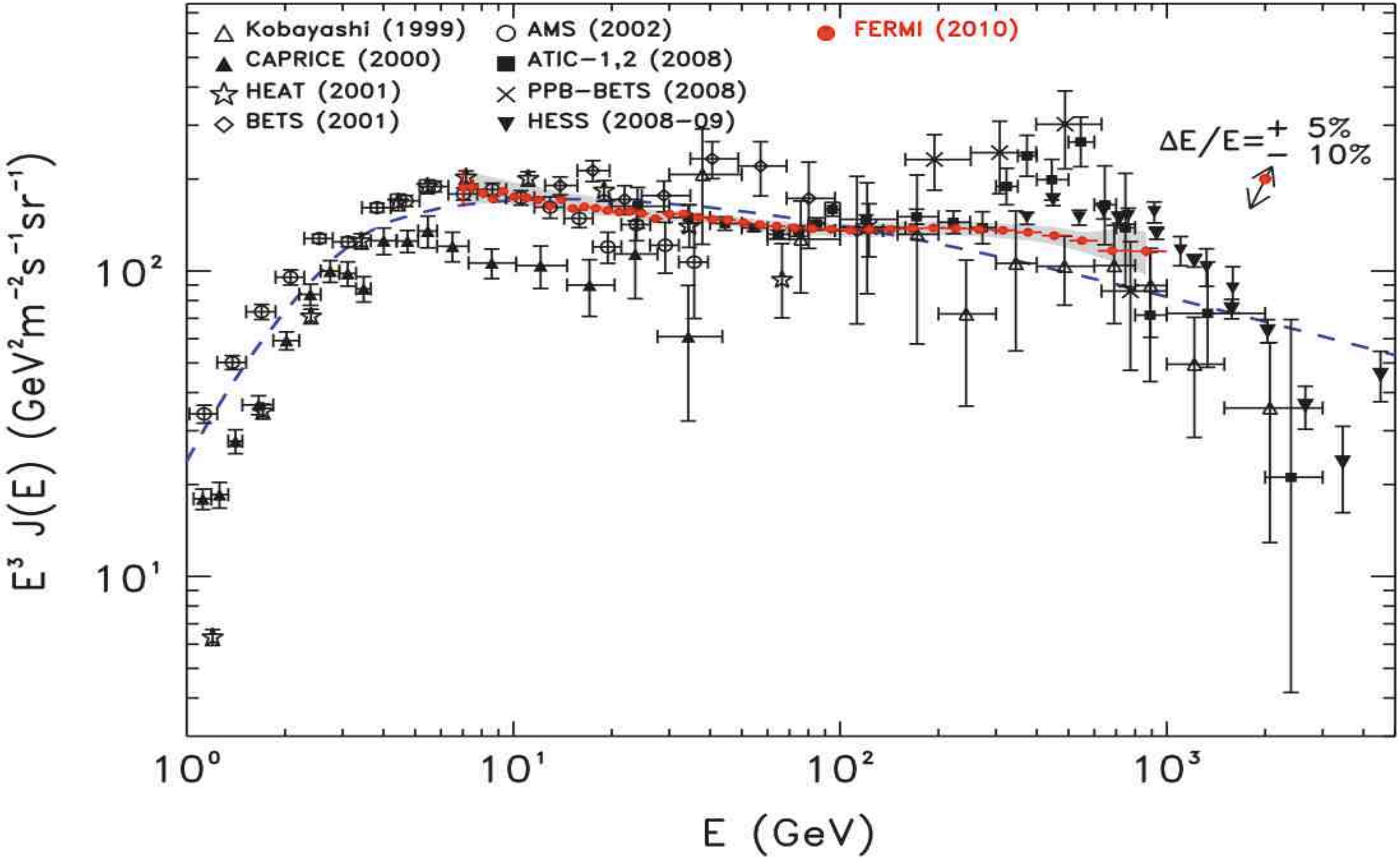
Antiproton-to-proton ratio

- Overall agreement with pure secondary calculation



Adriani et al. - PRL 105 (2010) 121101

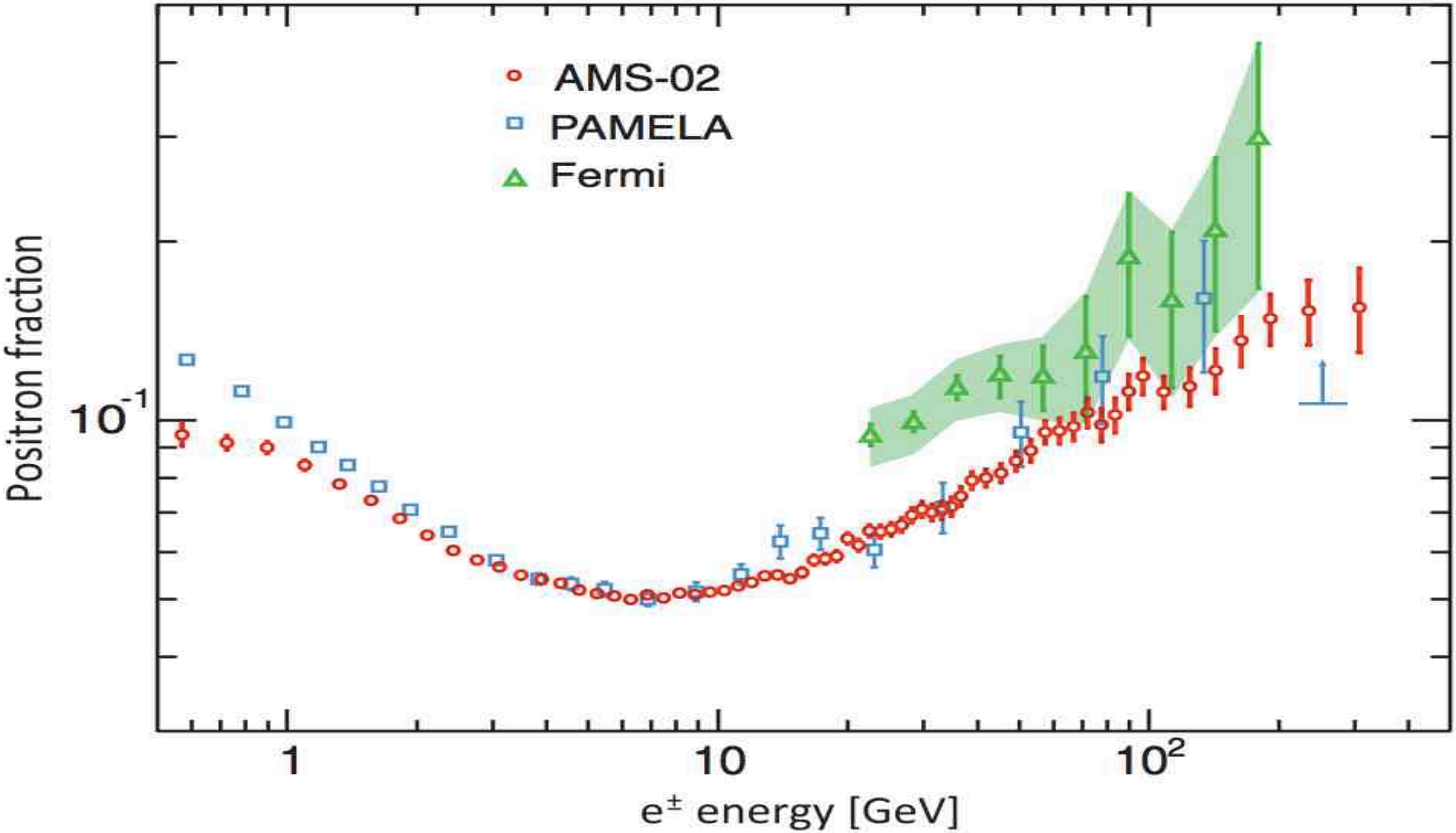
Fermi Electron + Positron spectrum



Extended Energy Range (7 GeV – 1 TeV) One year statistics (8M evts)

Fermi LAT Coll. Physical Review D, 82 092004 (2010) [arXiv:1008.3999]

Positron Fraction

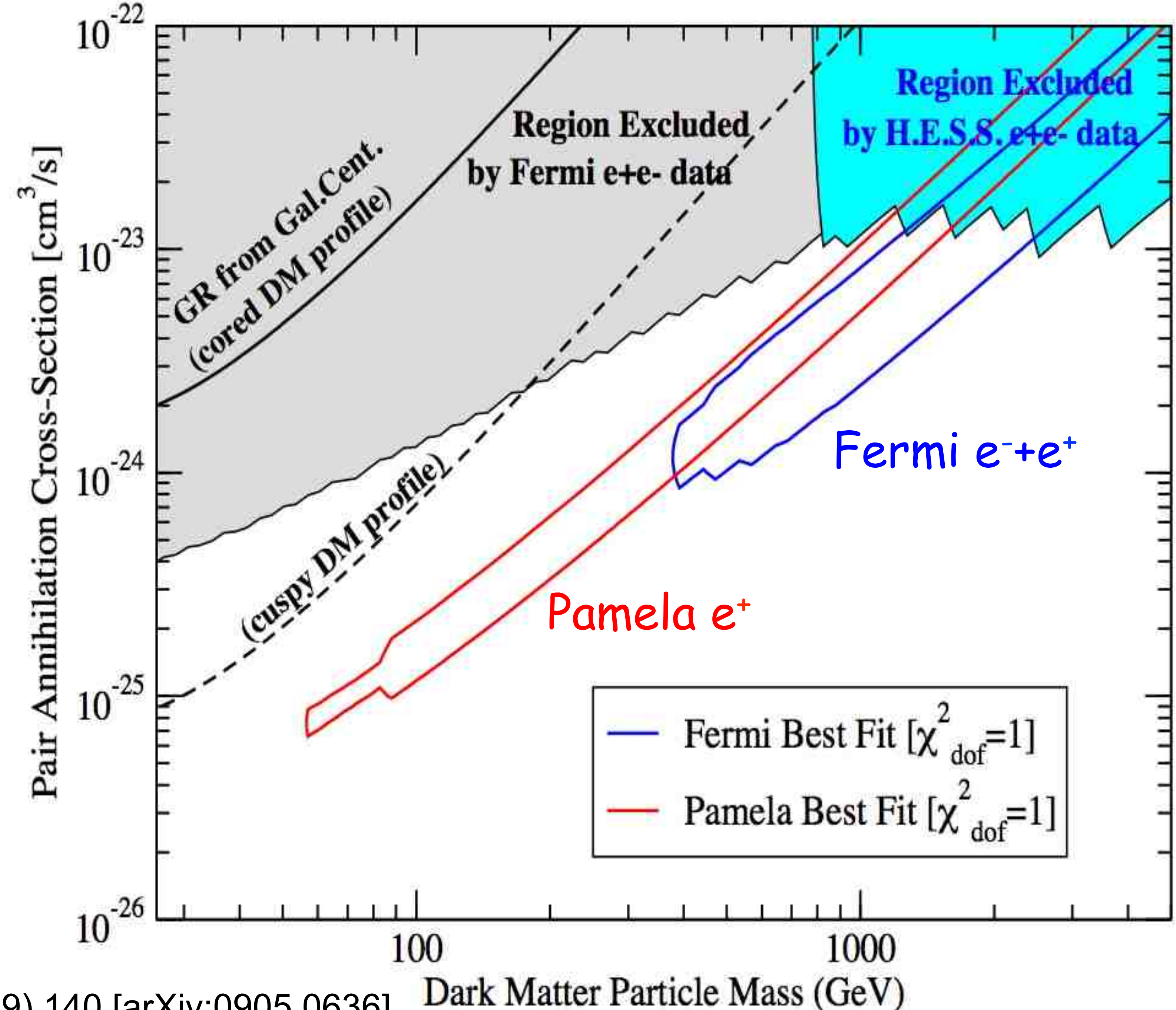


Pamela, Astropart. Phys. 34, 1 (2010) and arXiv:1308.0133

Fermi Coll., PRL, 108 (2012) 011103 arXiv:1109.0521 AMS: PRL 110, 141102 (2013)

Lepto-philic Models

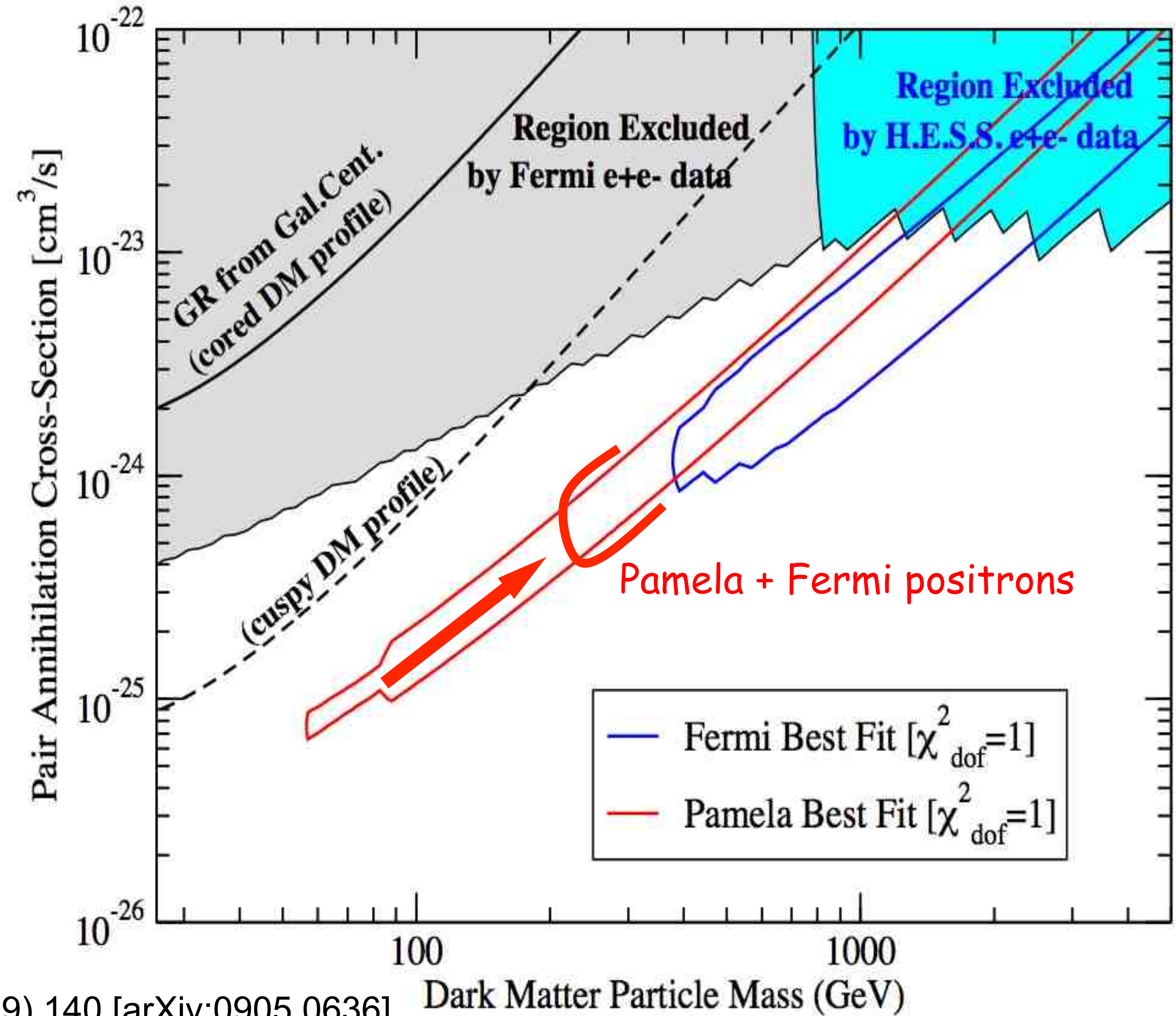
here we assume a democratic dark matter pair-annihilation branching ratio into each charged lepton species: 1/3 into e+e-, 1/3 into μ+ μ- and 1/3 into τ+ τ- Here too antiprotons are not produced in dark matter pair annihilation.



Astrp Phys.32 (2009) 140 [arXiv:0905.0636]

Lepto-philic Models

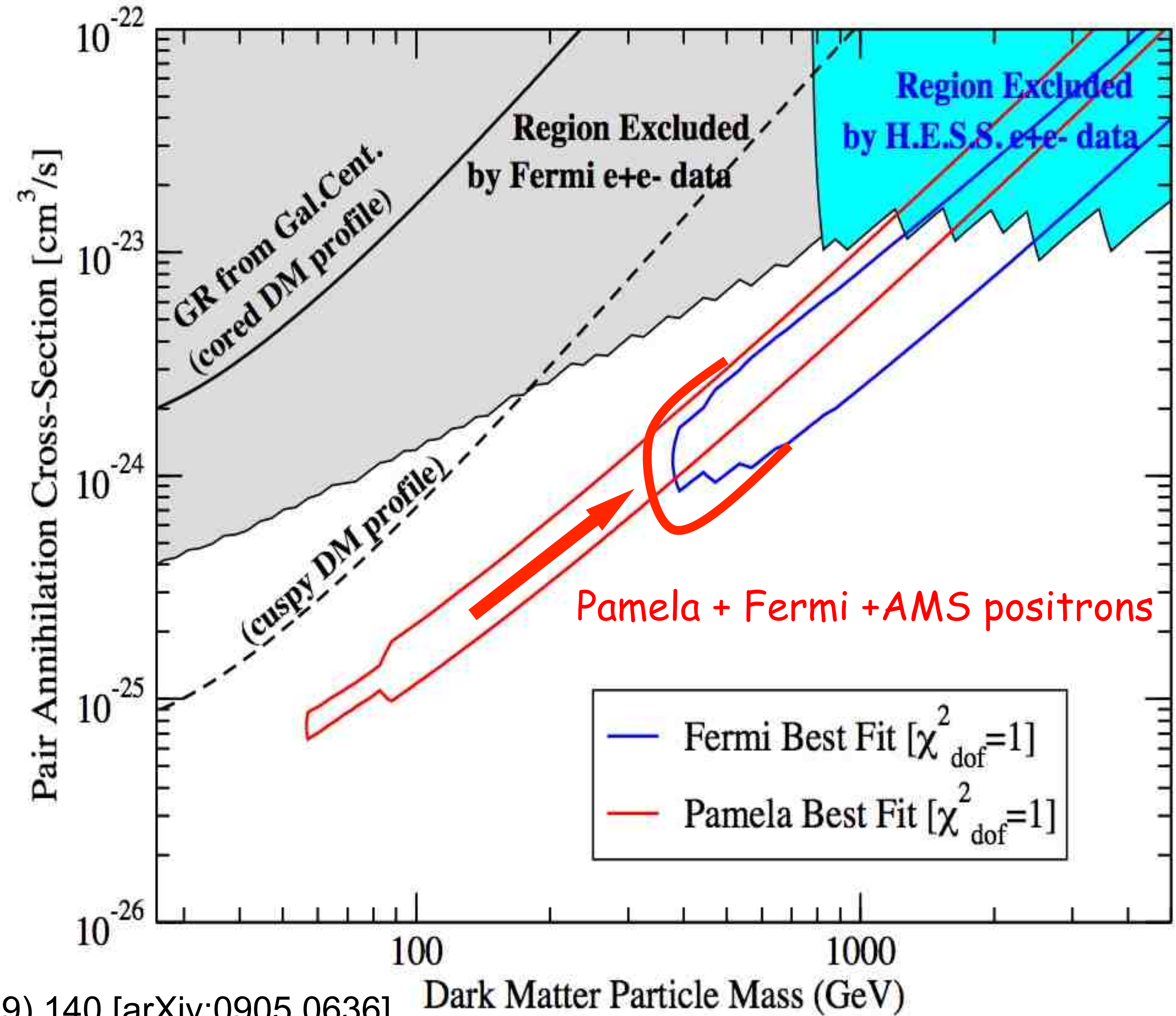
here we assume a democratic dark matter pair-annihilation branching ratio into each charged lepton species: 1/3 into e+e-, 1/3 into μ+ μ- and 1/3 into τ+ τ- Here too antiprotons are not produced in dark matter pair annihilation.



update of
Astrp Phys.32 (2009) 140 [arXiv:0905.0636]

Lepto-philic Models

here we assume a democratic dark matter pair-annihilation branching ratio into each charged lepton species: 1/3 into e+e-, 1/3 into μ+ μ- and 1/3 into τ+ τ- Here too antiprotons are not produced in dark matter pair annihilation.



update of
Astrp Phys.32 (2009) 140 [arXiv:0905.0636]

Pulsars

1. On purely energetic grounds they work (relatively large efficiency)

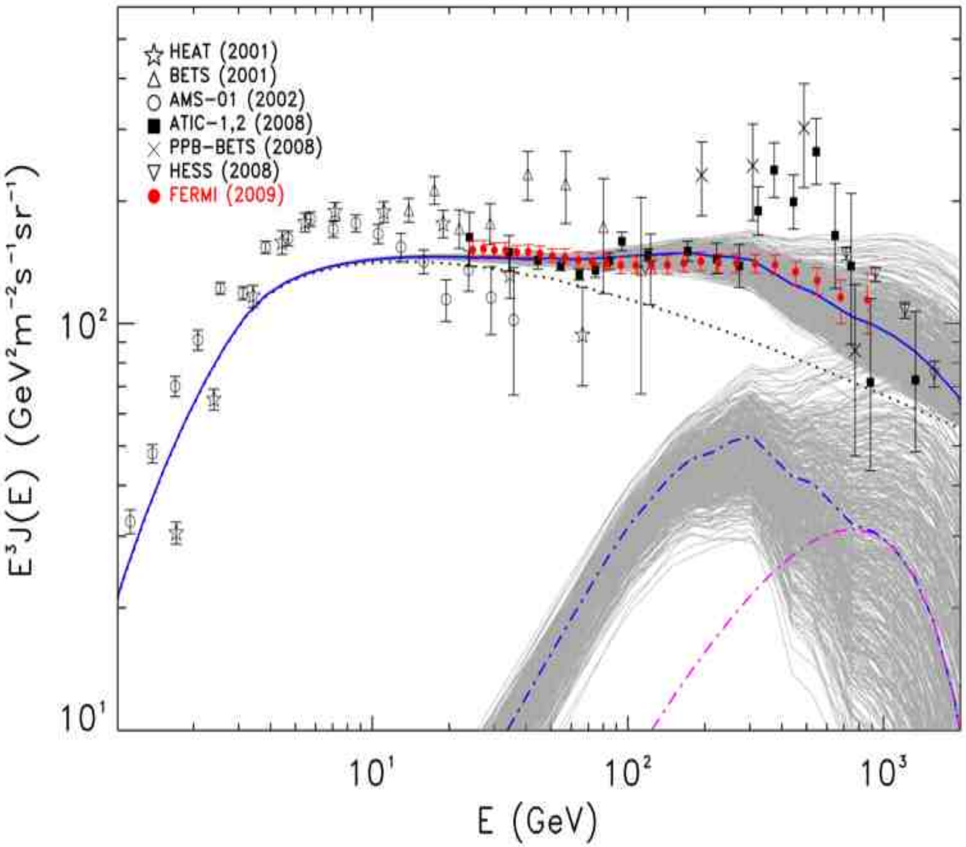
2. On the basis of the spectrum, it is not clear
   1. The spectra of PWN show relatively flat spectra of pairs at Low energies but we do not understand what it is
   2. The general spectra (acceleration at the termination shock) are too steep

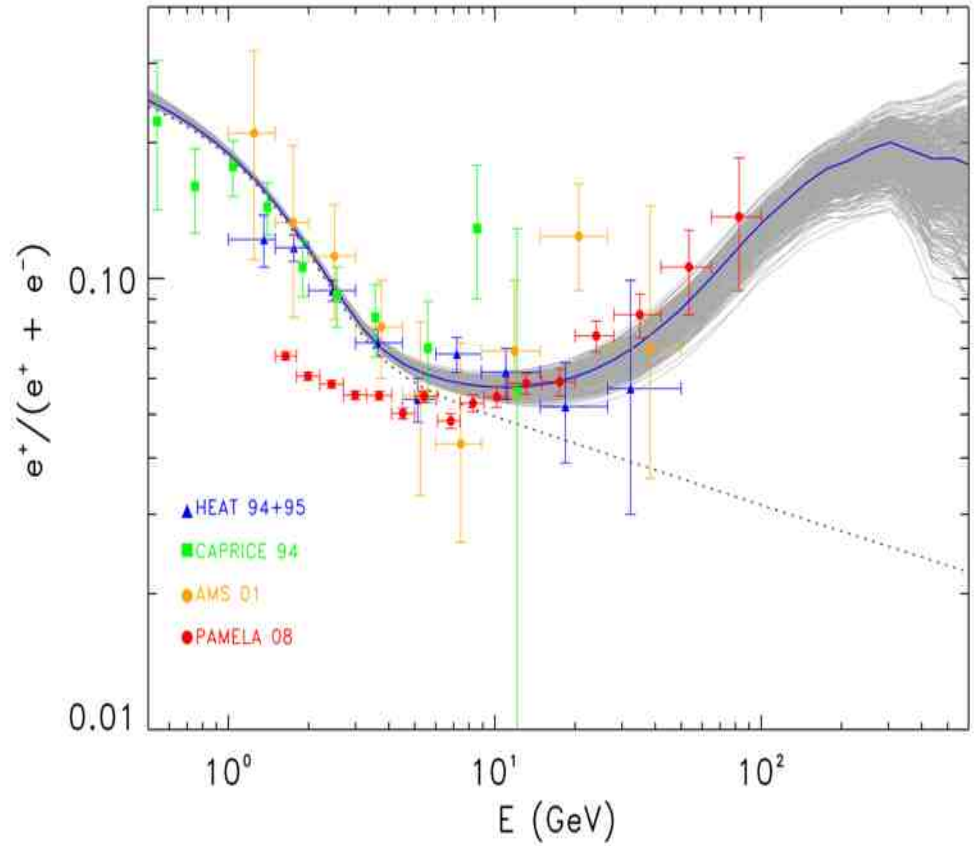
The biggest problem is that of escape of particles from the pulsar
   1. Even if acceleration works, pairs have to survive losses
   2. And in order to escape they have to cross other two shocks

New Fermi data on pulsars will help to constrain the pulsar models

What if we randomly vary the pulsar parameters relevant for e+e- production?

(injection spectrum, e+e- production efficiency, PWN "trapping" time)

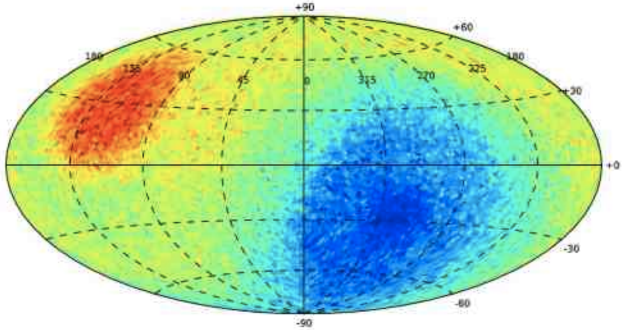




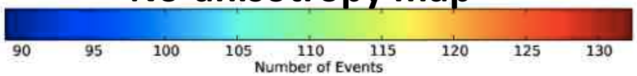
Under reasonable assumptions, electron/positron emission from pulsars offers a viable interpretation of Fermi CRE data which is also consistent with the HESS and Pamela results.

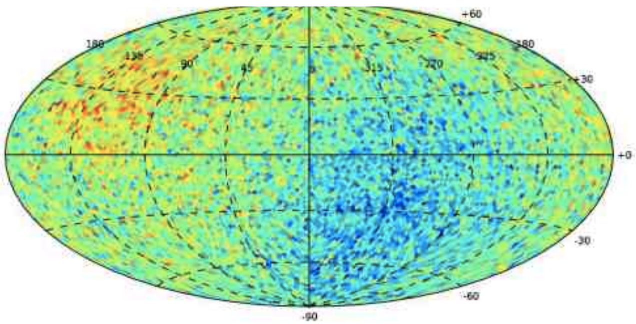
D.Grasso et al. Astropart. Phys. 32 (2009), pp.140 [arXiv:0905.0636]

Cosmic Ray Electrons Anisotropy

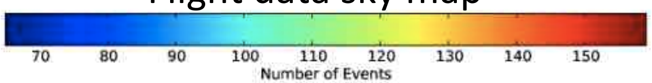


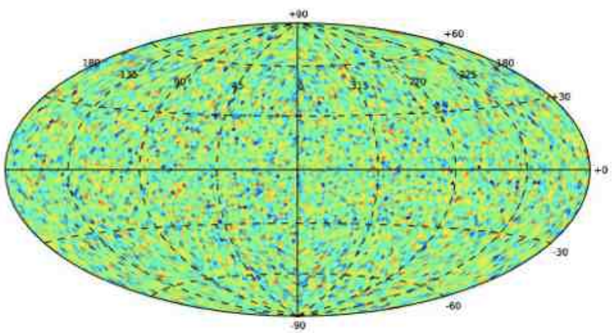
No-anisotropy map



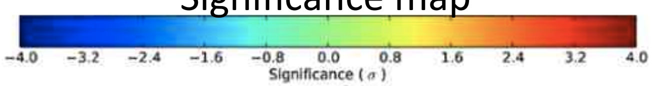


Flight data sky map



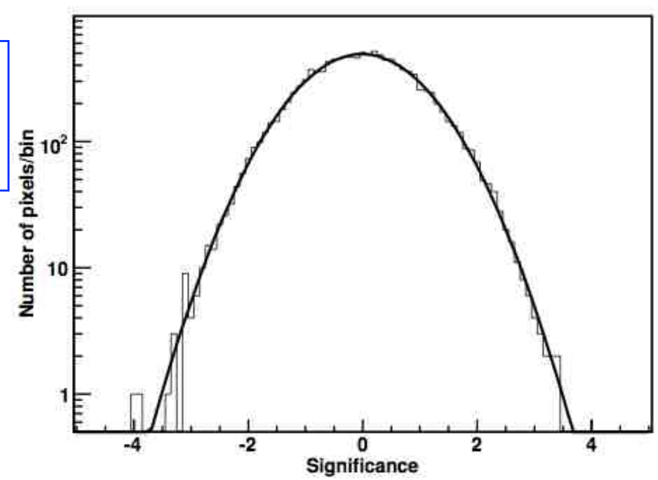


Significance map



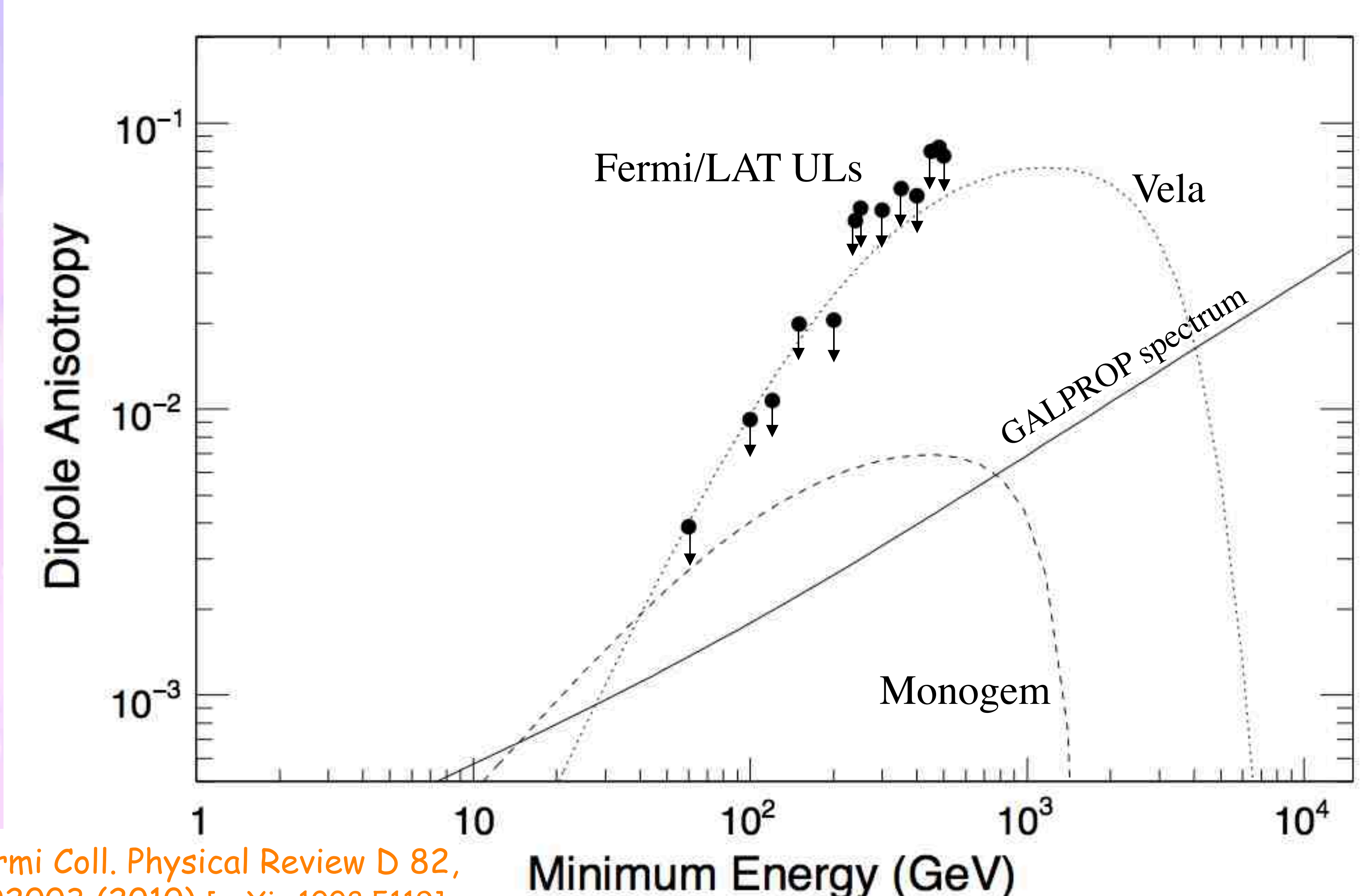
<u>the levels of anisotropy expected for Geminga-like and Monogem-like sources</u> (i.e. sources with similar distances and ages) <u>seem to be higher than the scale of anisotropies excluded by the results</u>
However, it is worth to point out that the model results are affected by large uncertainties related to the choice of the free parameters

Distribution of significance, fitted by a Gaussian →



Fermi Coll. Physical Review D 82, 092003 (2010) [arXiv:1008.5119]

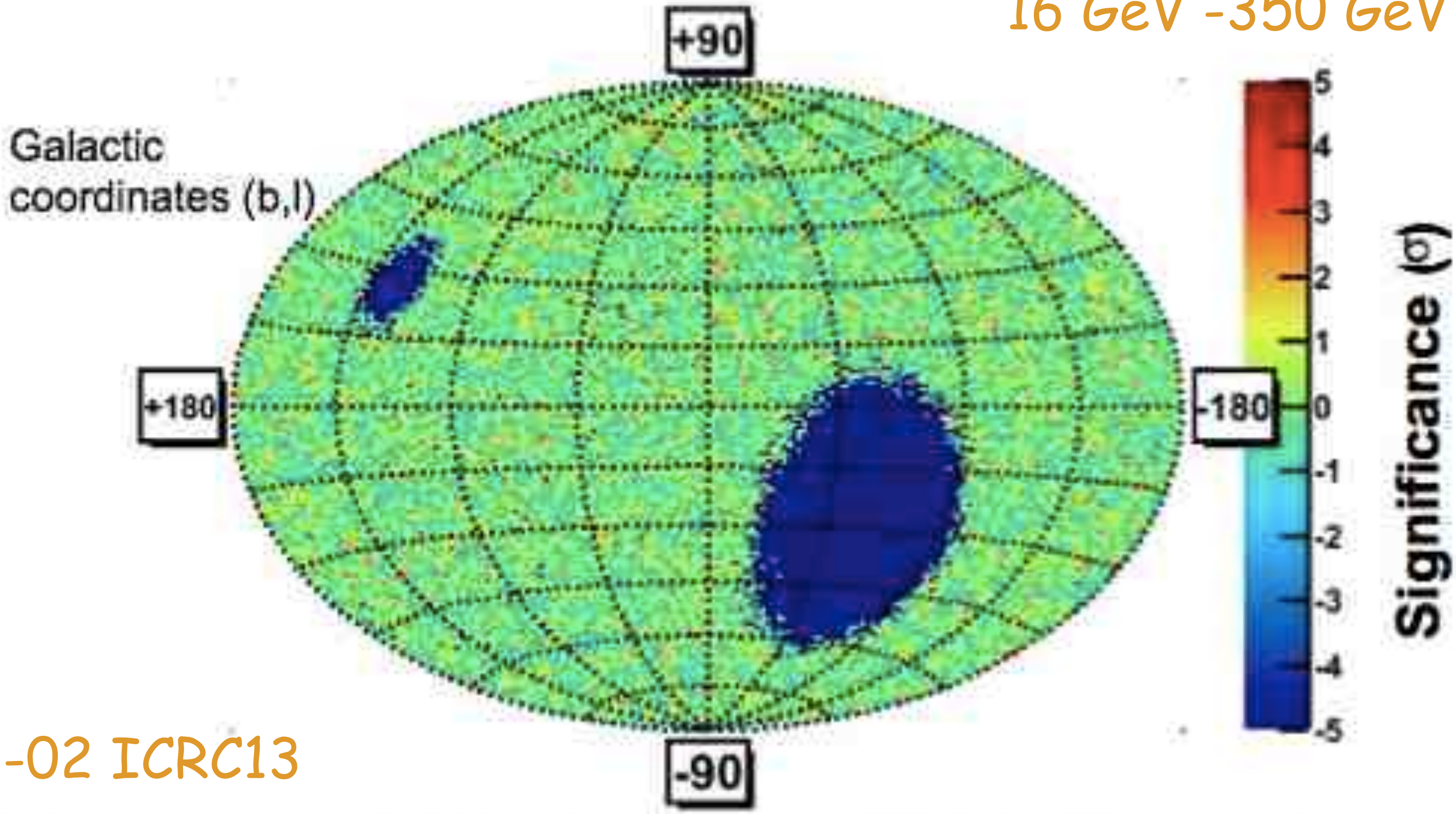
electron + positron expected anisotropy in the directions of Monogem and Vela



Fermi Coll. Physical Review D 82, 092003 (2010) [arXiv:1008.5119]

Dipole anisotropy in the positron ratio

16 GeV -350 GeV

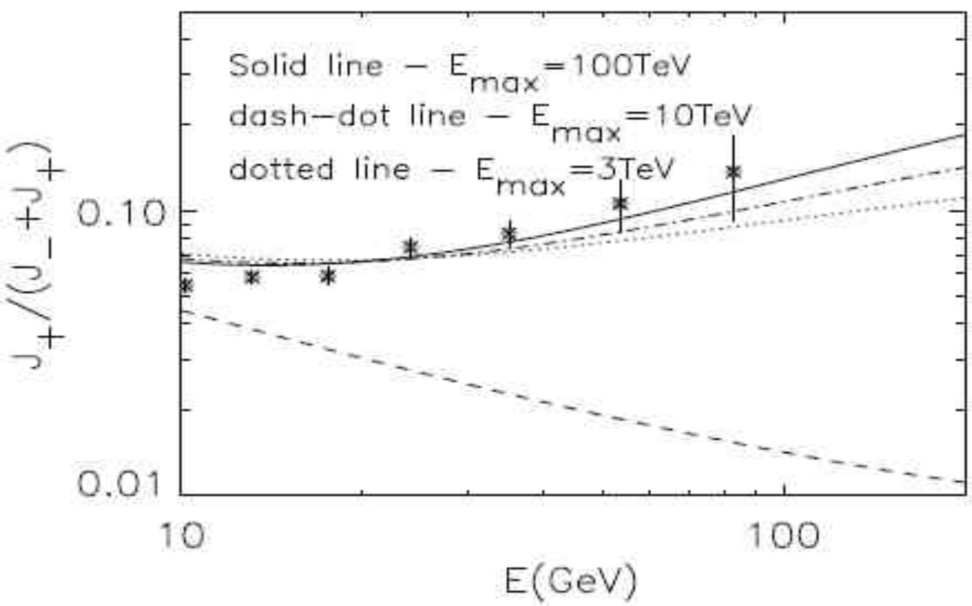


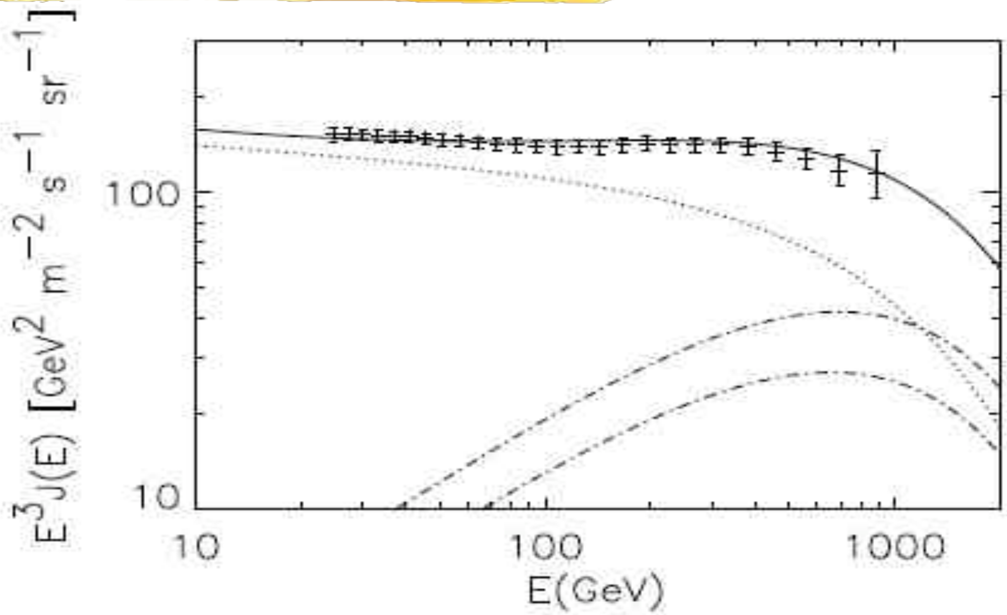
AMS-02 ICRC13

The fluctuations of the positron ratio e^+/e^- are isotropic

$\delta \leq 0.030$ at the 95% confidence level

other Astrophysical solution



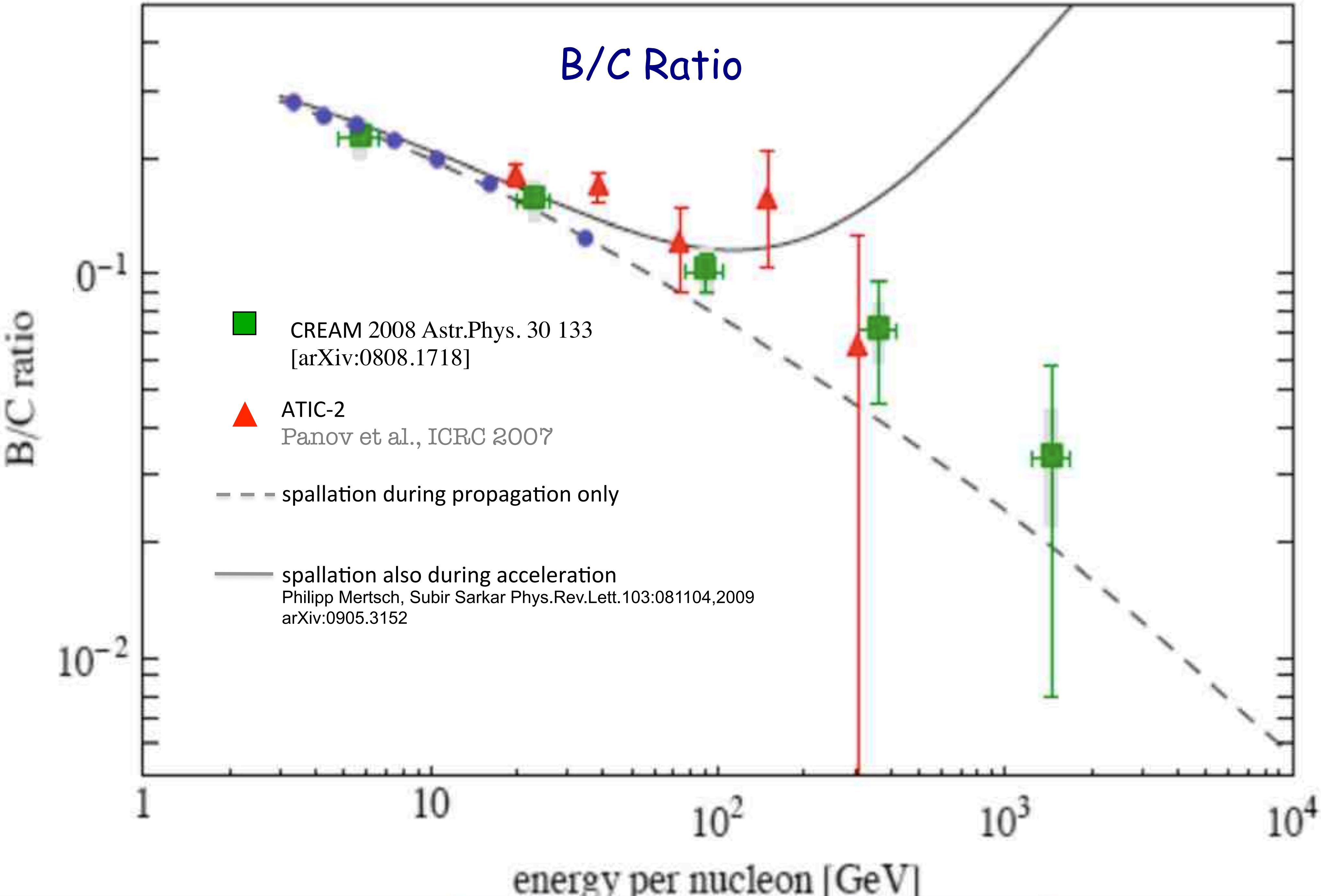


- Positrons created as secondary products of hadronic interactions inside the sources
- Secondary production takes place in the same region where cosmic rays are being accelerated

-> Therefore secondary positron have a very flat spectrum, which is responsible, after propagation in the Galaxy, for the observed positron excess

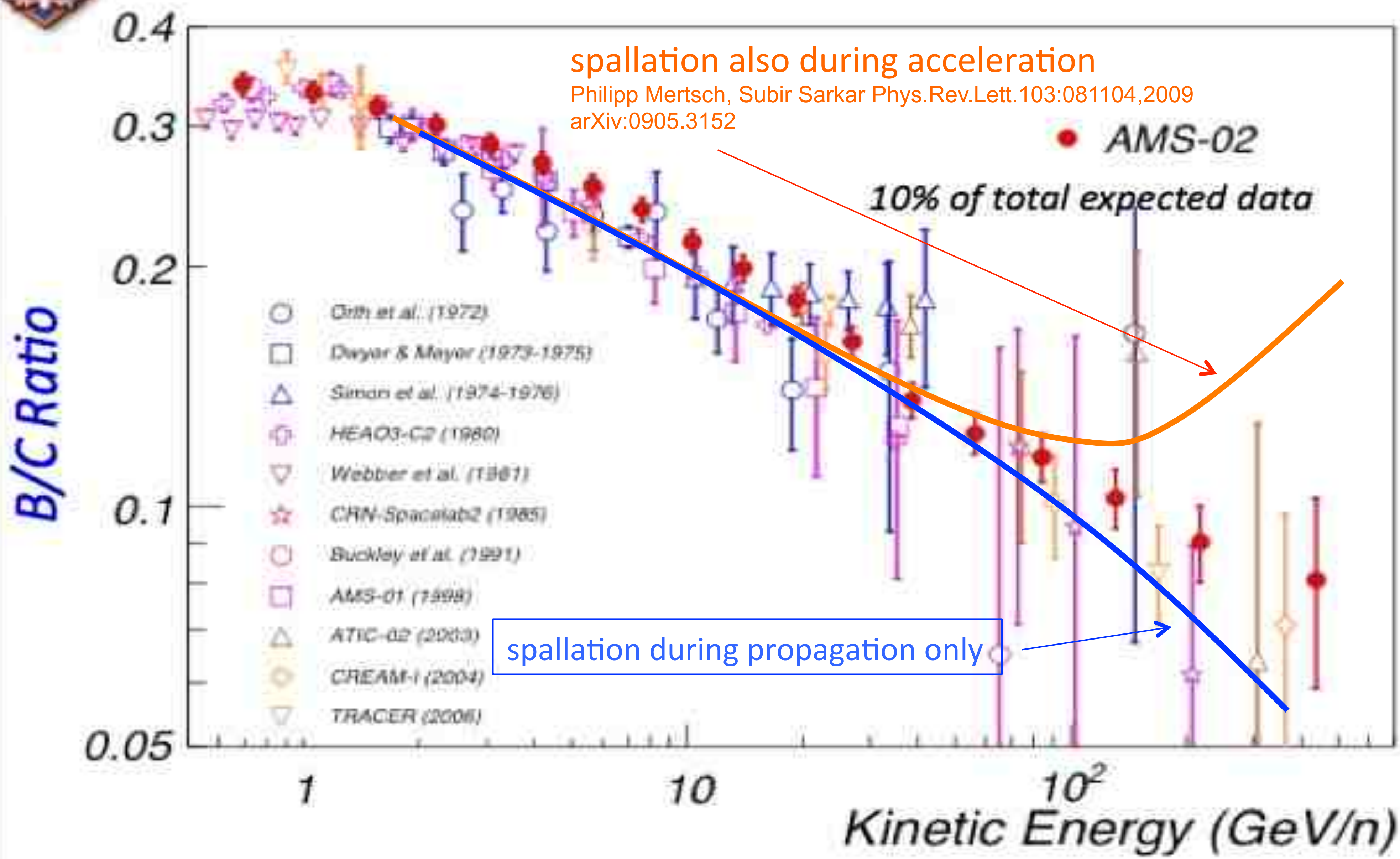
Blasi, arXiv:0903.2794

B/C Ratio

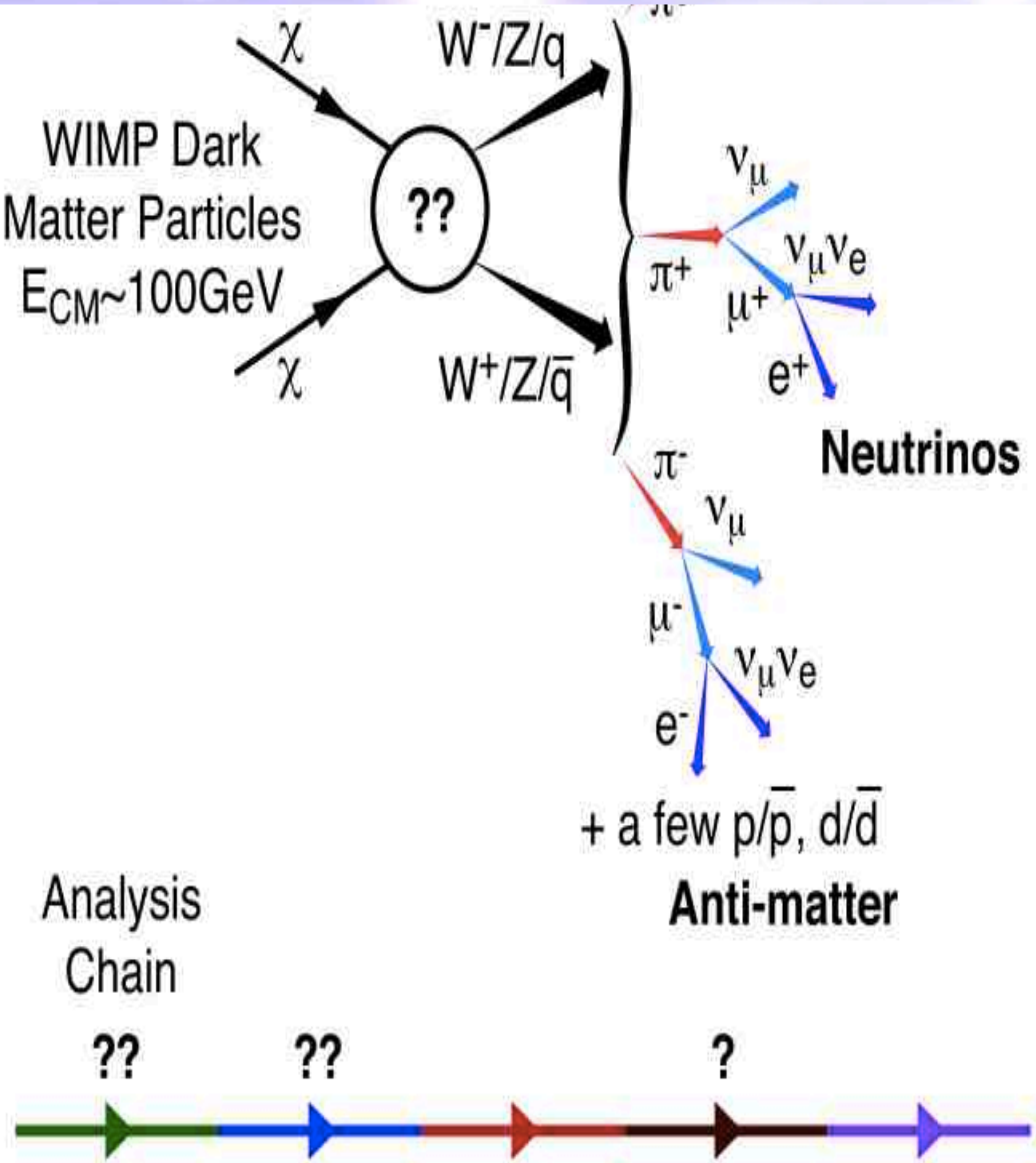


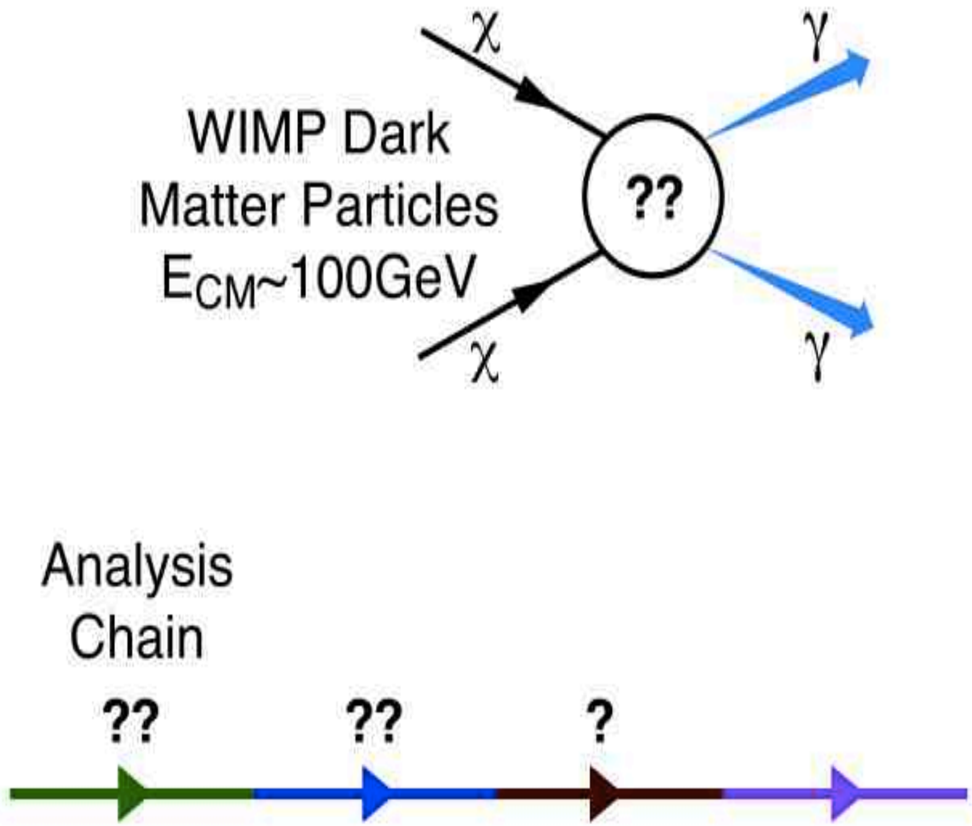
B/C ratio
CREAM 2008 Astr.Phys. 30 133
[arXiv:0808.1718]
ATIC-2
Panov et al., ICRC 2007
spallation during propagation only
spallation also during acceleration
Philipp Mertsch, Subir Sarkar Phys.Rev.Lett.103:081104,2009
arXiv:0905.3152
energy per nucleon [GeV]

Boron-to-Carbon ratio compared with previous data



Annihilation channels



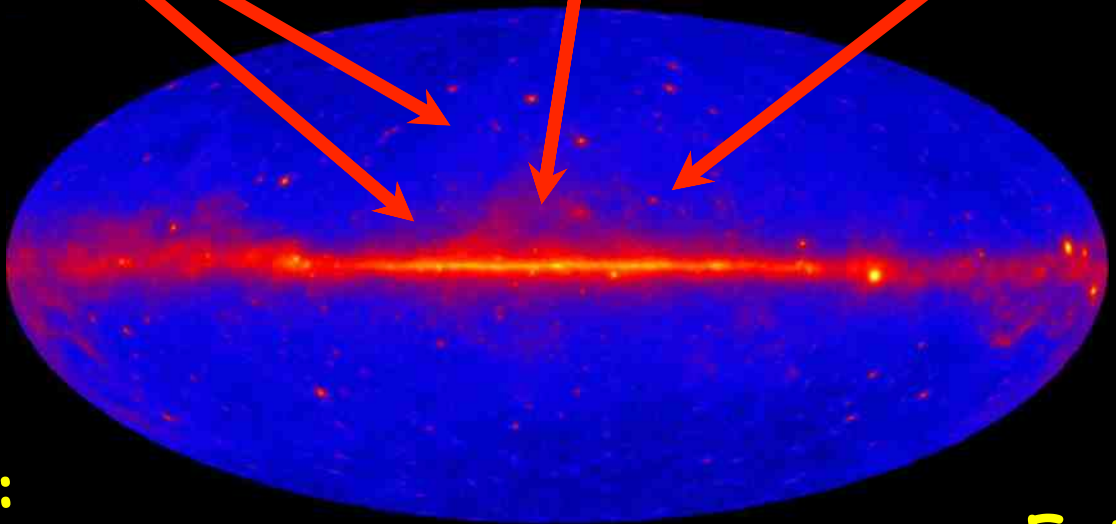


Search Strategies

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

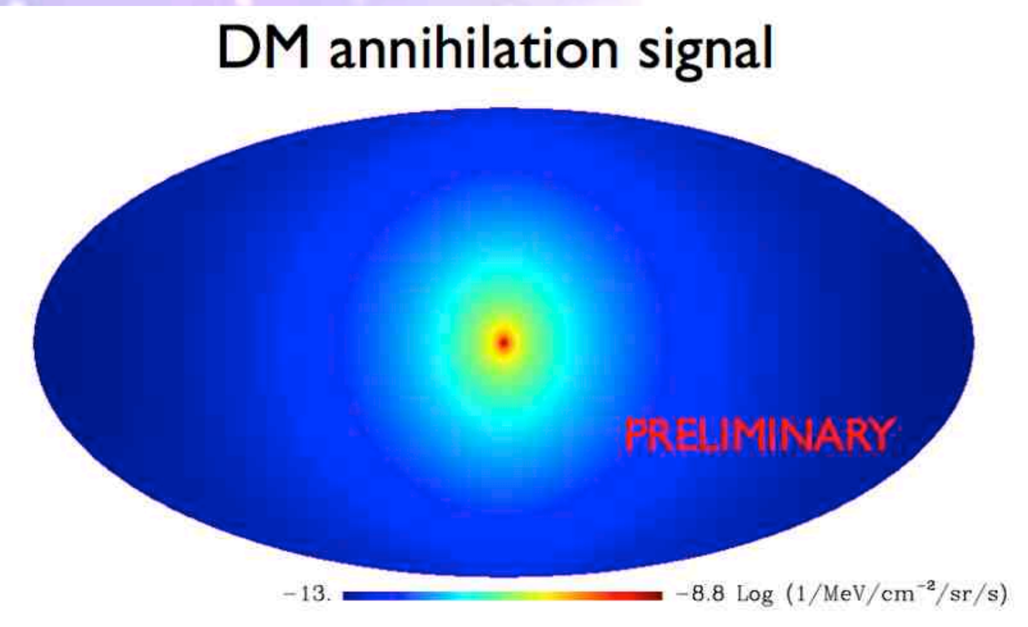
Galaxy clusters:
Low background but low statistics

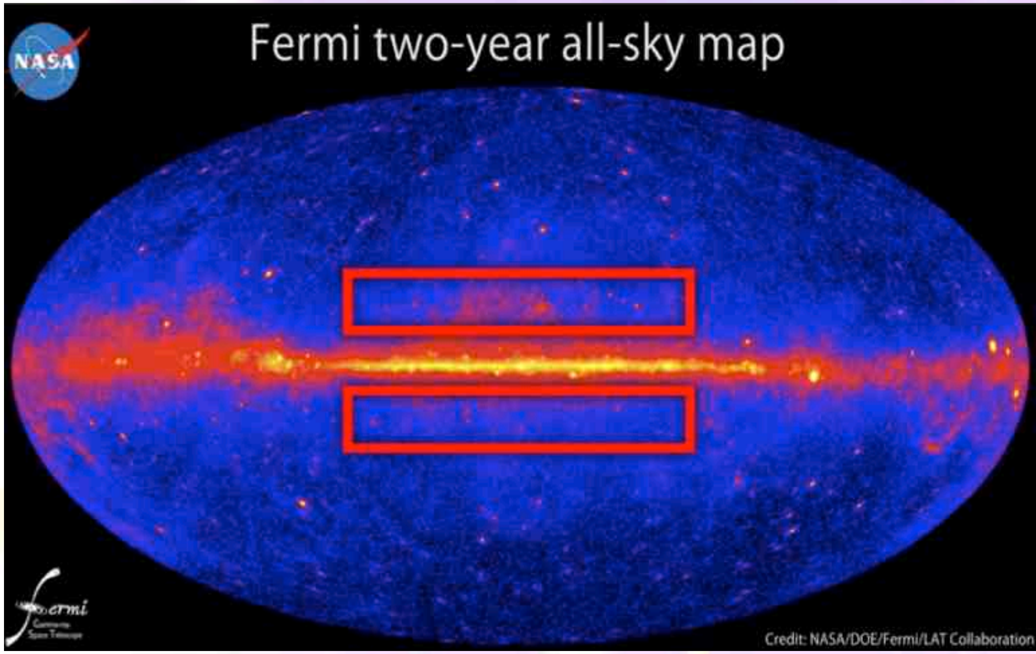
Extra-galactic:
Large statistics, but astrophysics,galactic diffuse background

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

Constraints from the Milky Way halo

testing the LAT diffuse data for a contribution from a Milky Way DM annihilation/decay signal





2 years of data 1-100 GeV energy range

ROI: 5° <|b|<15° and |l|<80°, chosen to:

• minimize DM profile uncertainty (highest in the Galactic Center region)

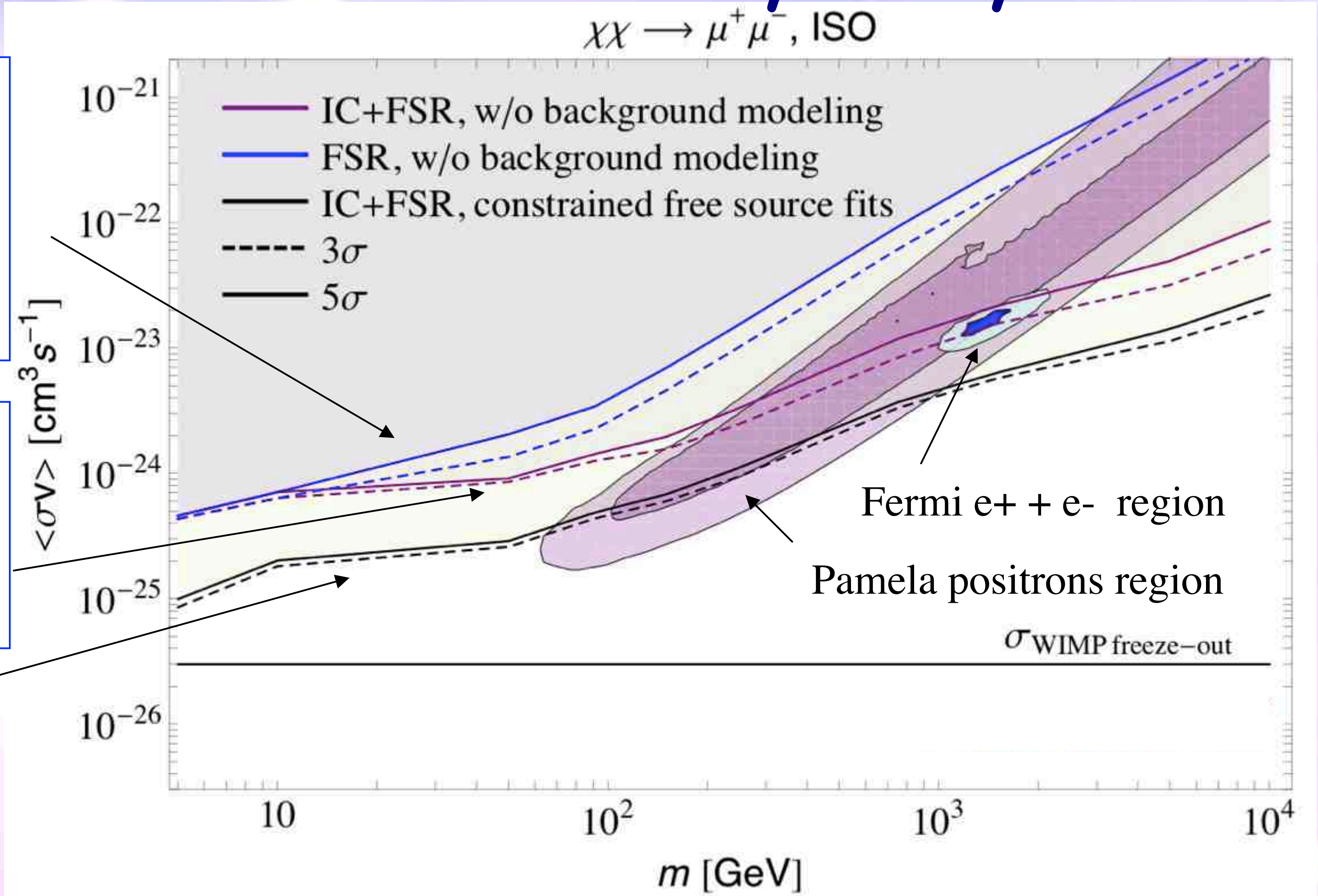
• limit astrophysical uncertainty by masking out the Galactic plane and cutting-out high- latitude emission from the Fermi lobes and Loop I

Constraints from the Milky Way halo

only photons produced by muons (no electrons) to set "no-background limits"

"no-background limits" including FSR +IC from dark matter

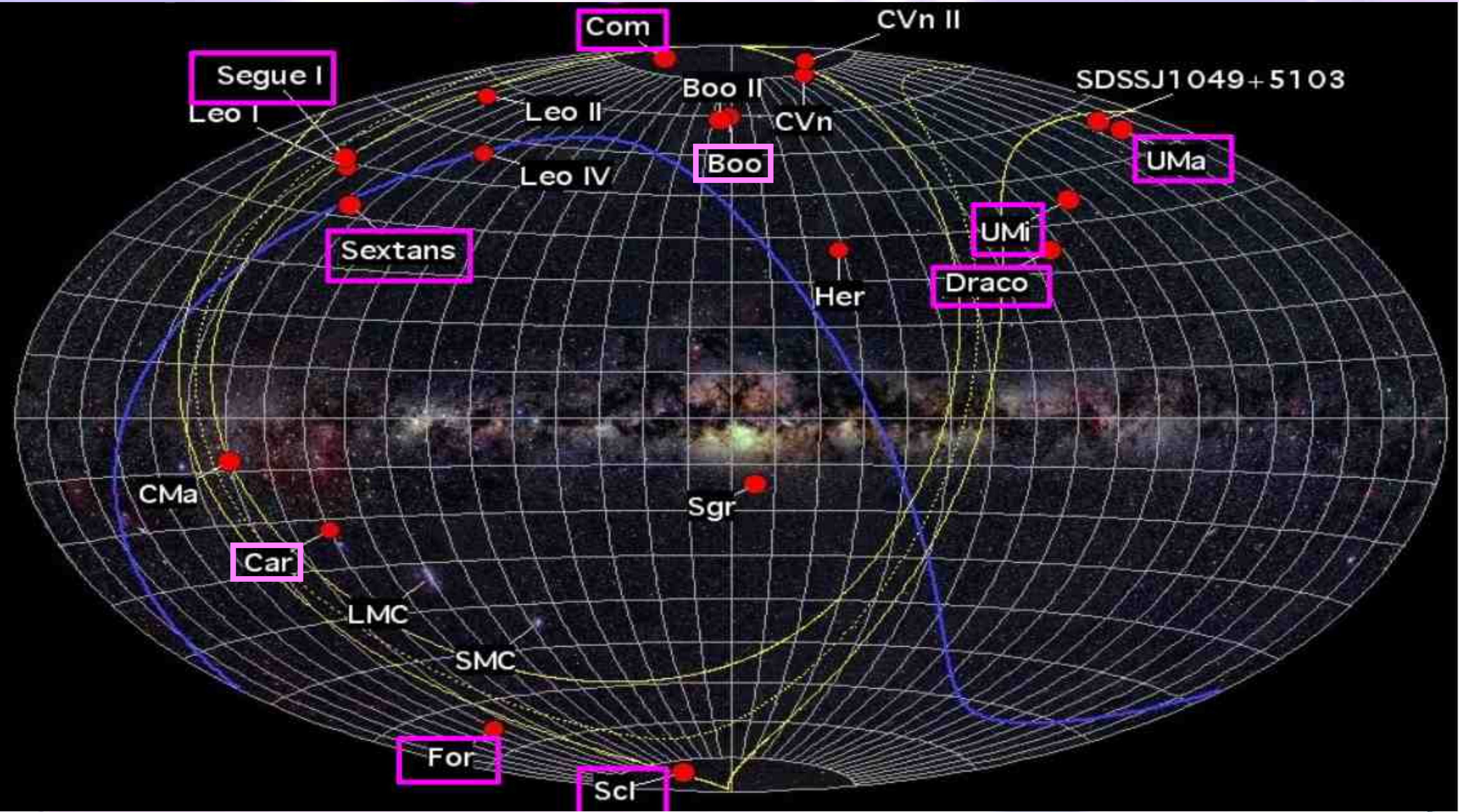
limits from profile likelihood and CR sources set to zero in the inner 3 kpc



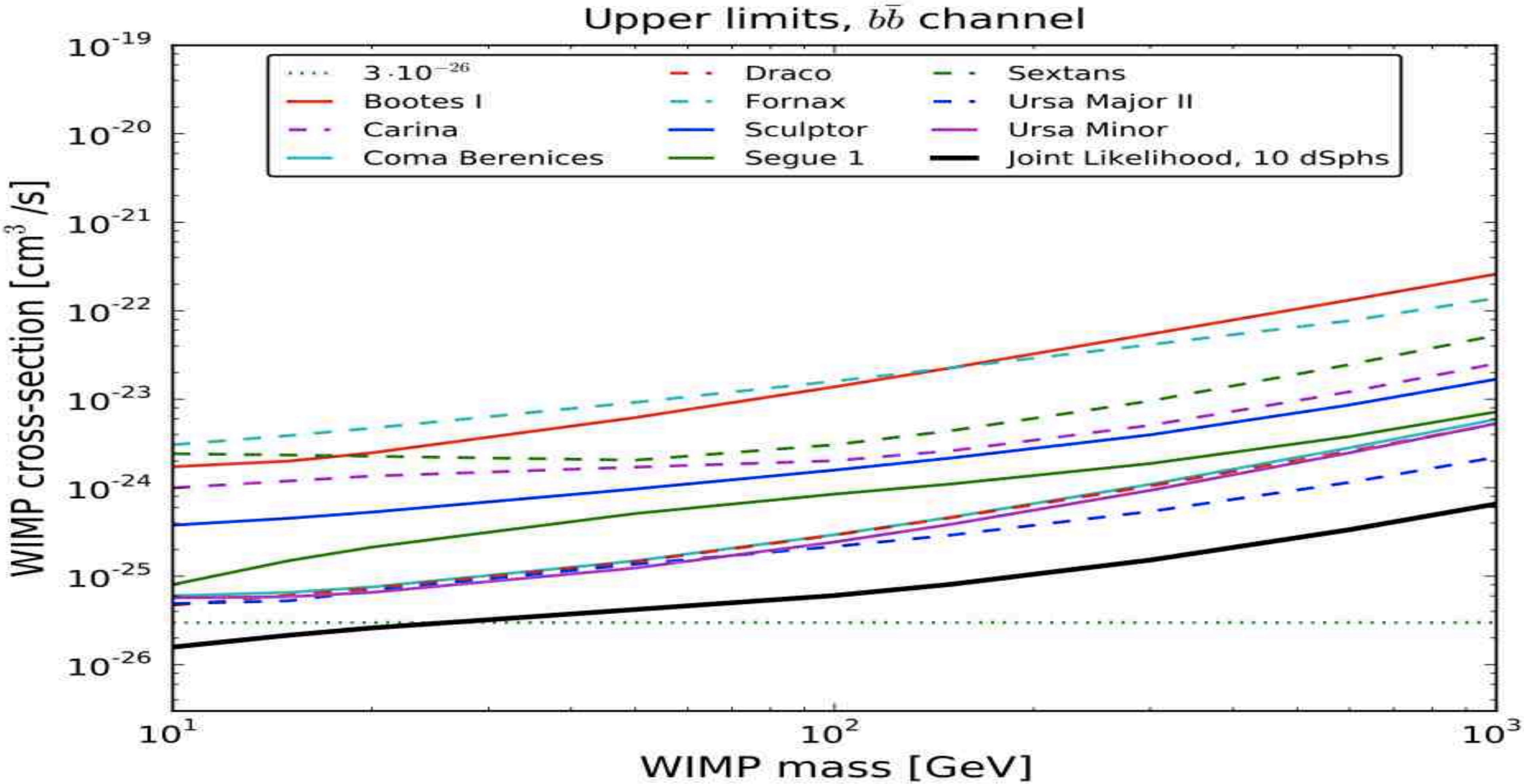
DM interpretation of PAMELA/Fermi CR anomalies disfavored

Fermi Coll.ApJ 761 (2012) 91 [arXiv:1205.6474]

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



Dwarf Spheroidal Galaxies combined analysis

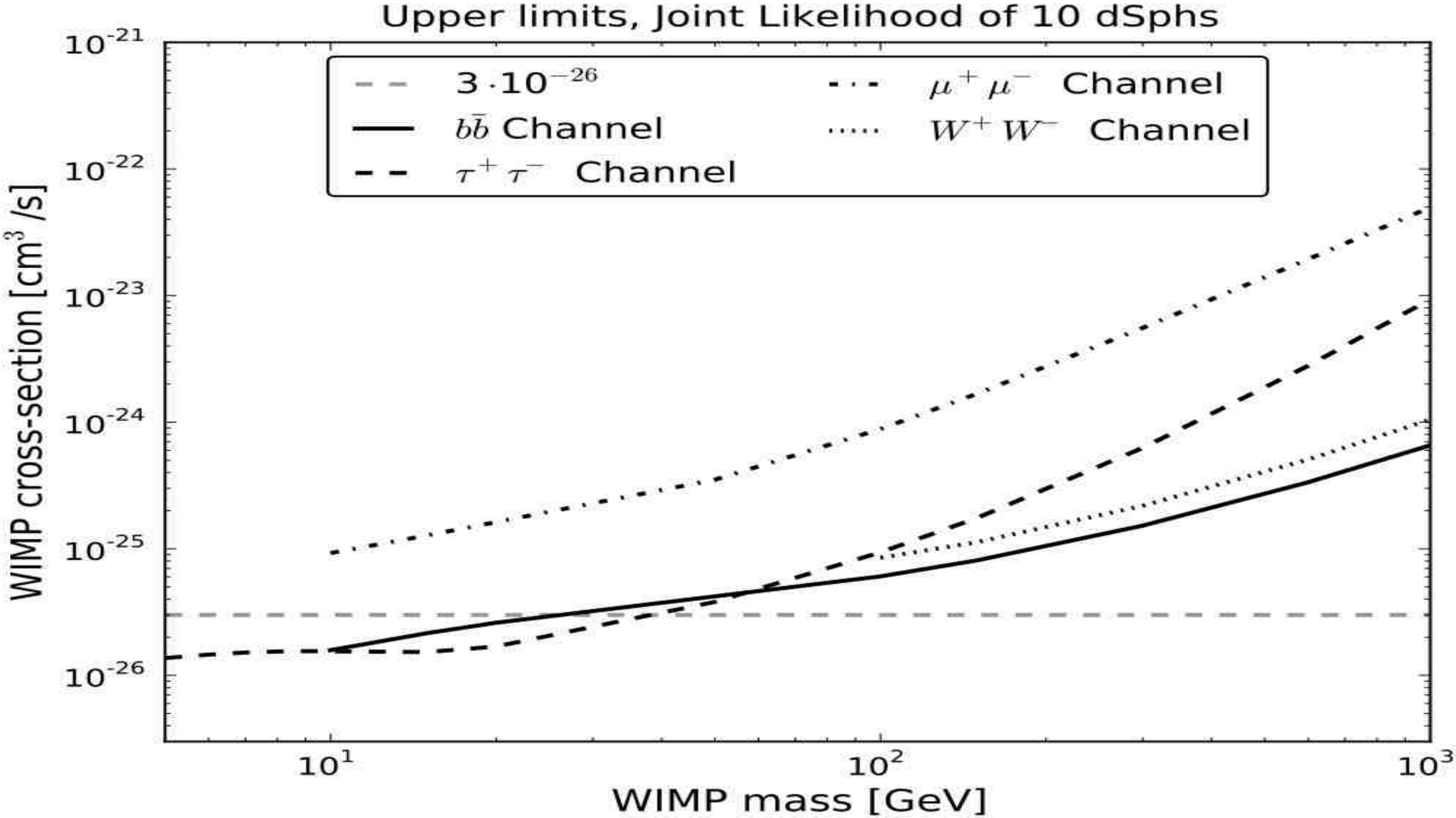


robust constraints including J-factor uncertainties from the stellar data statistical analysis

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

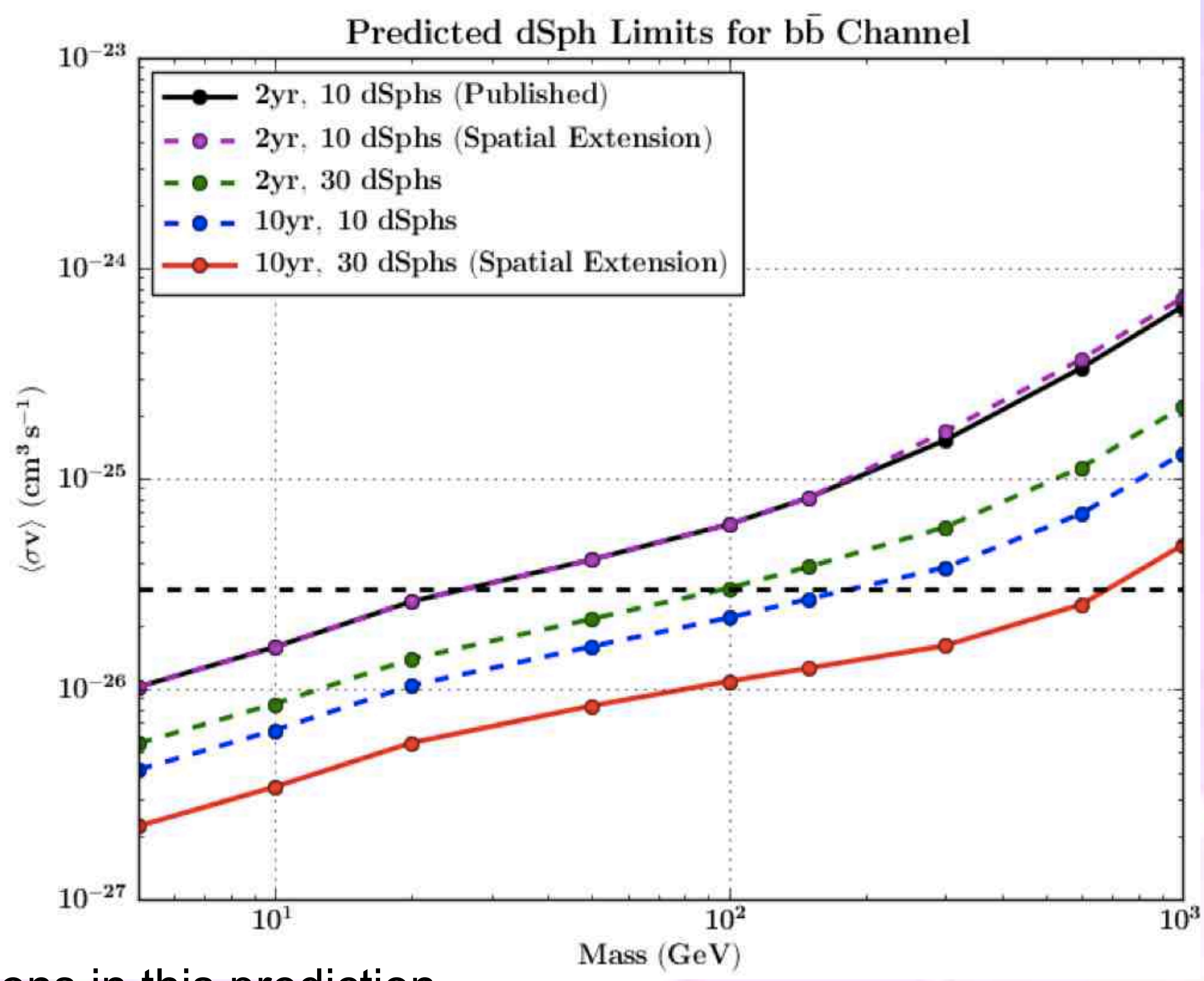


robust constraints including J-factor uncertainties from the stellar data statistical analysis

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

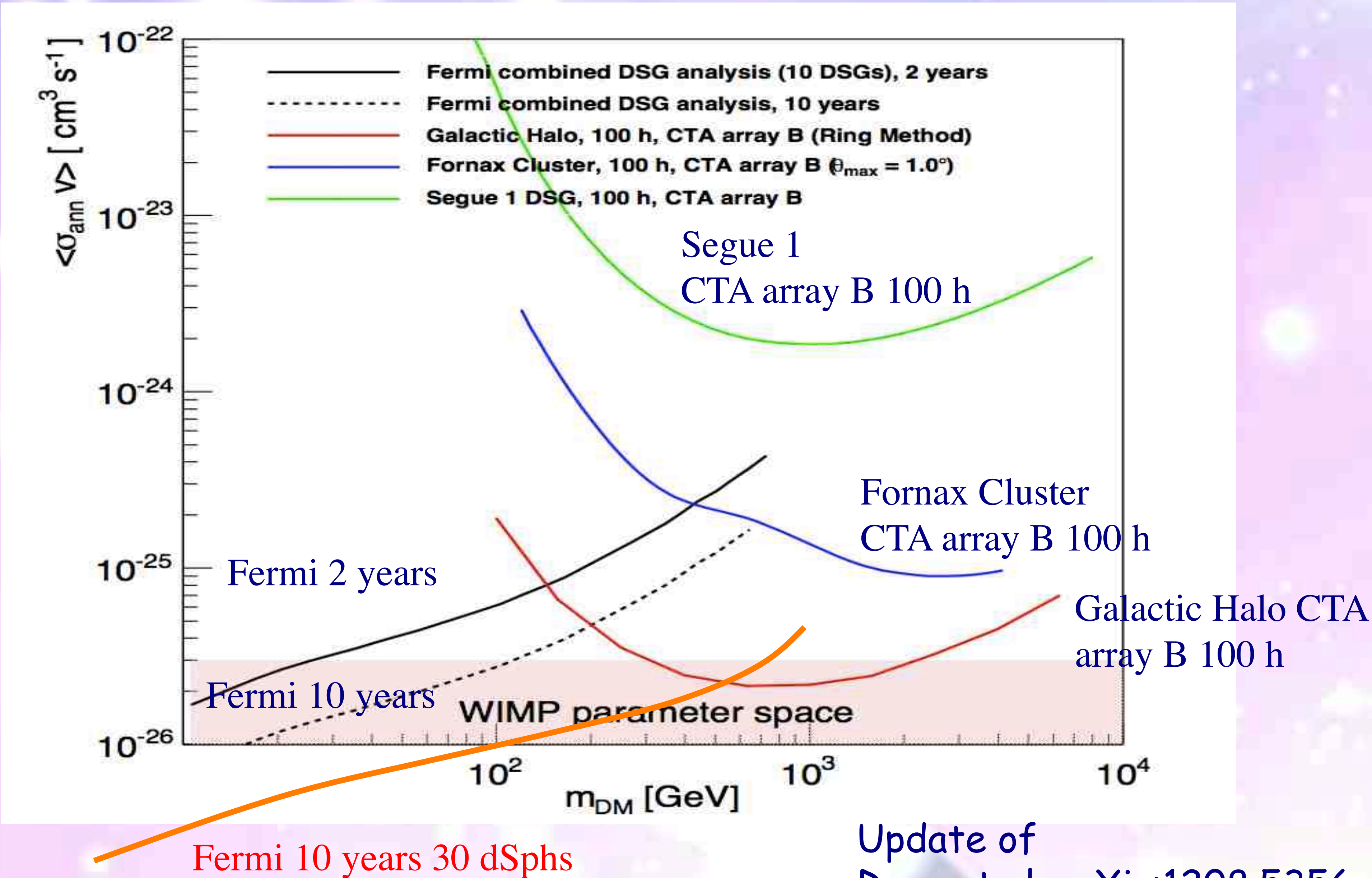
DM limit improvement estimate in 10 years with the composite likelihood approach (2008- 2018)

- 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)



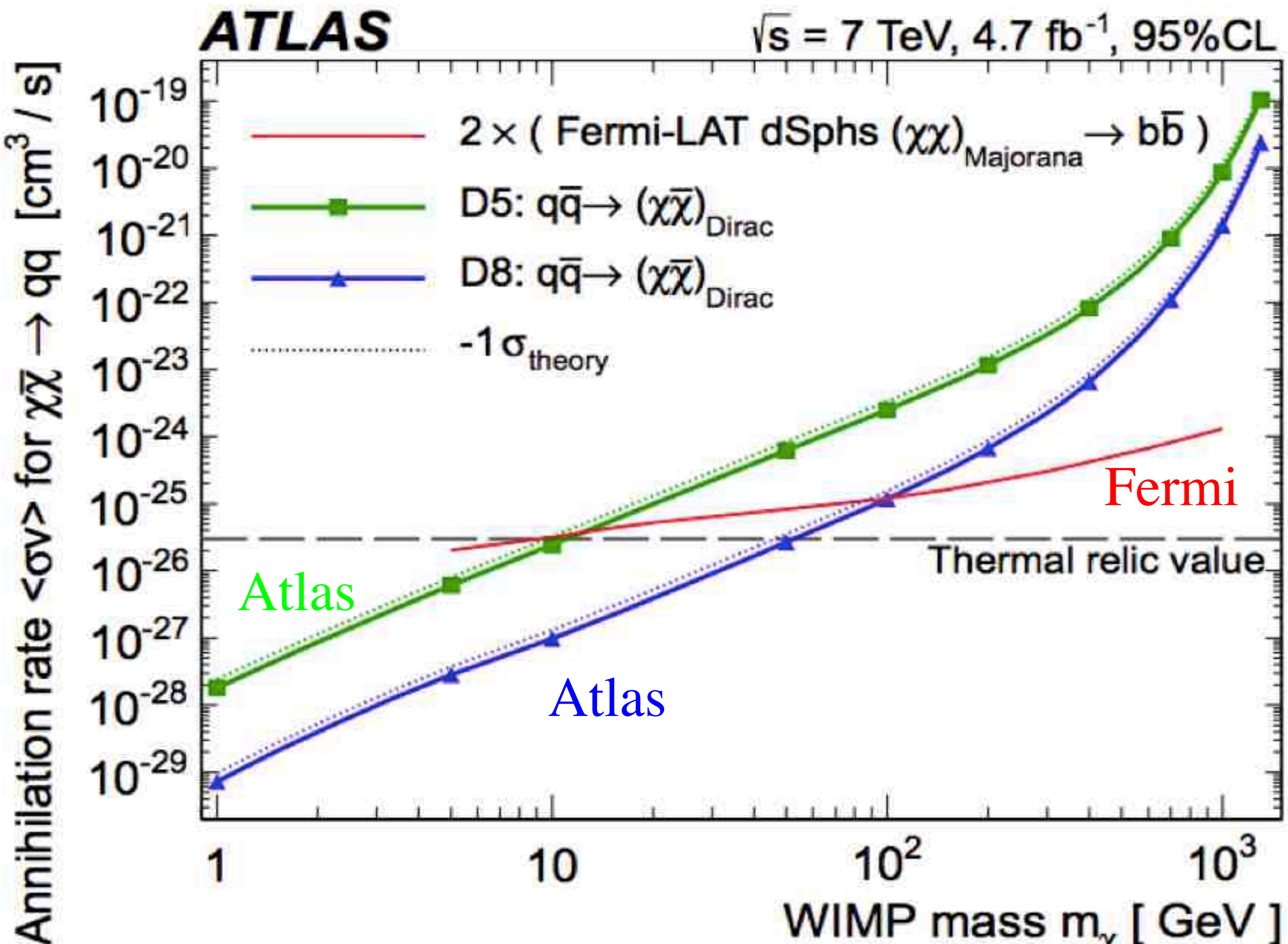
- There are many assumptions in this prediction
- Doesn't deal with a possible detections.

Dwarf Spheroidal Galaxies upper-limits



Update of
Doro et al. arXiv:1208.5356

ATLAS-Fermi Results

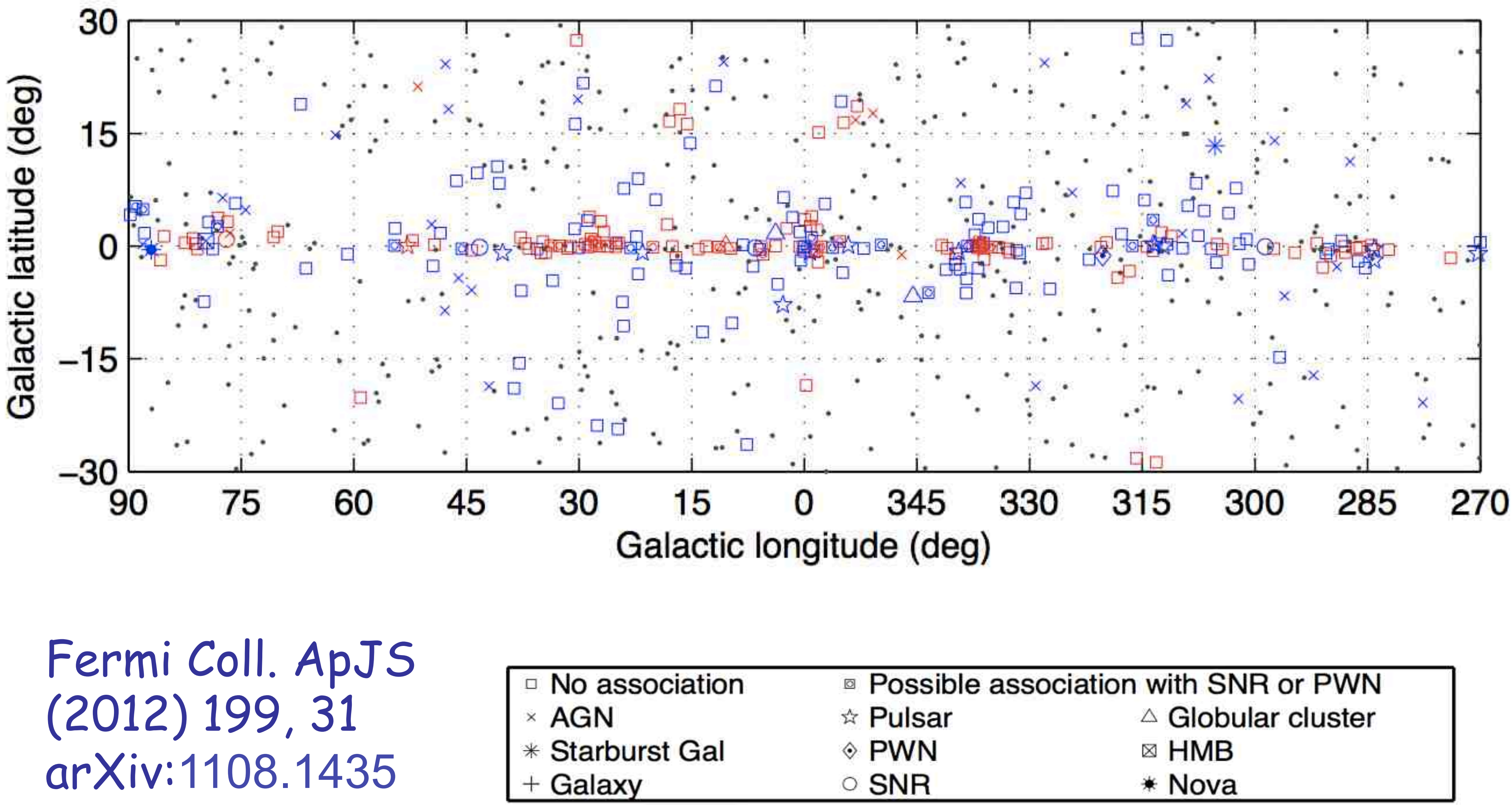


Atlas Coll. arXiv:1210.4491

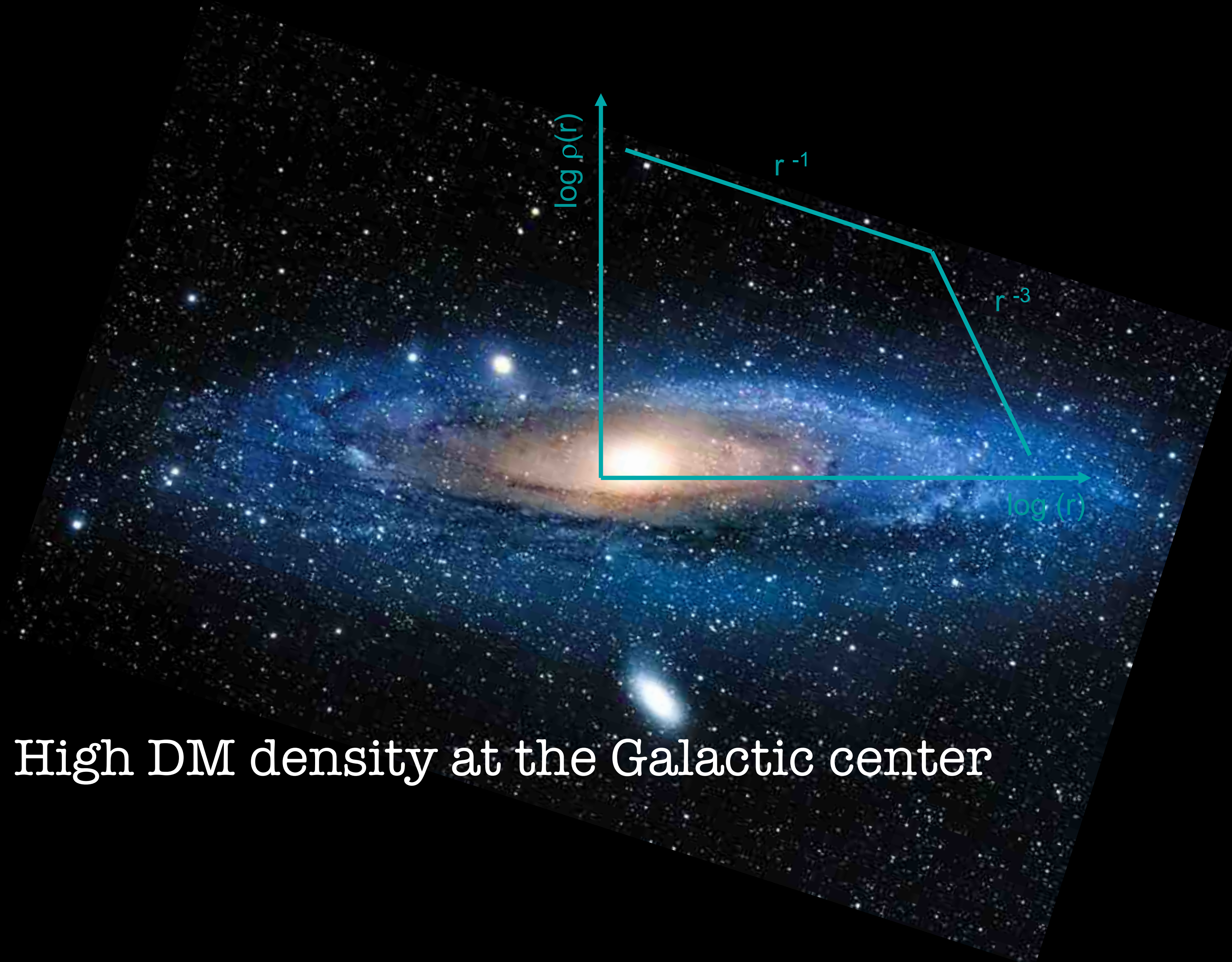
The Fermi LAT 2FGL Inner Galactic Region

August 4, 2008, to July 31, 2010

100 MeV to 100 GeV energy range



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



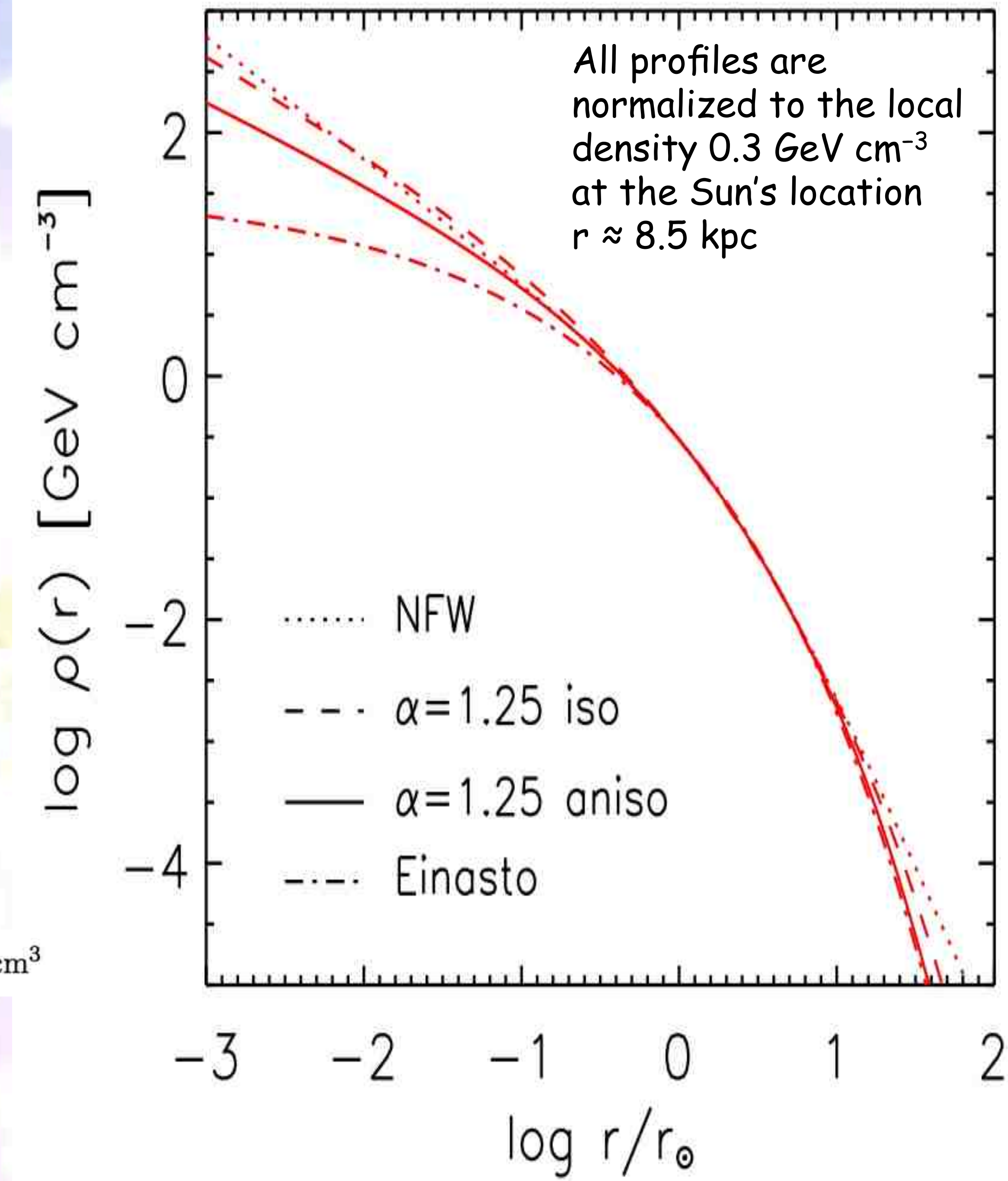
High DM density at the Galactic center

Milky Way Dark Matter Profiles

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

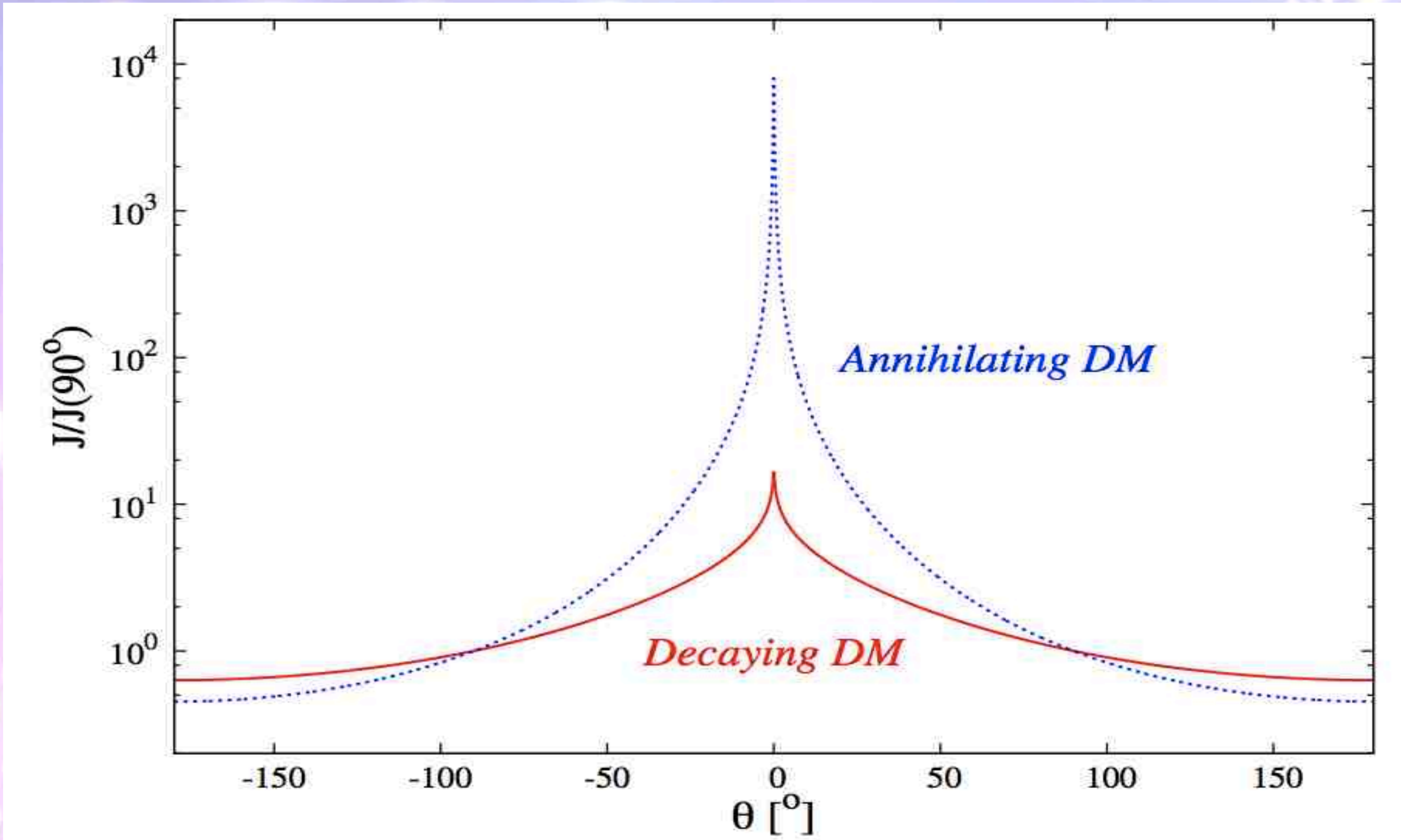
Halo model	α	β	γ	r_s in kpc
Cored isothermal	2	2	0	5
Navarro, Frenk, White	1	3	1	20
Moore	1	3	1.16	30

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



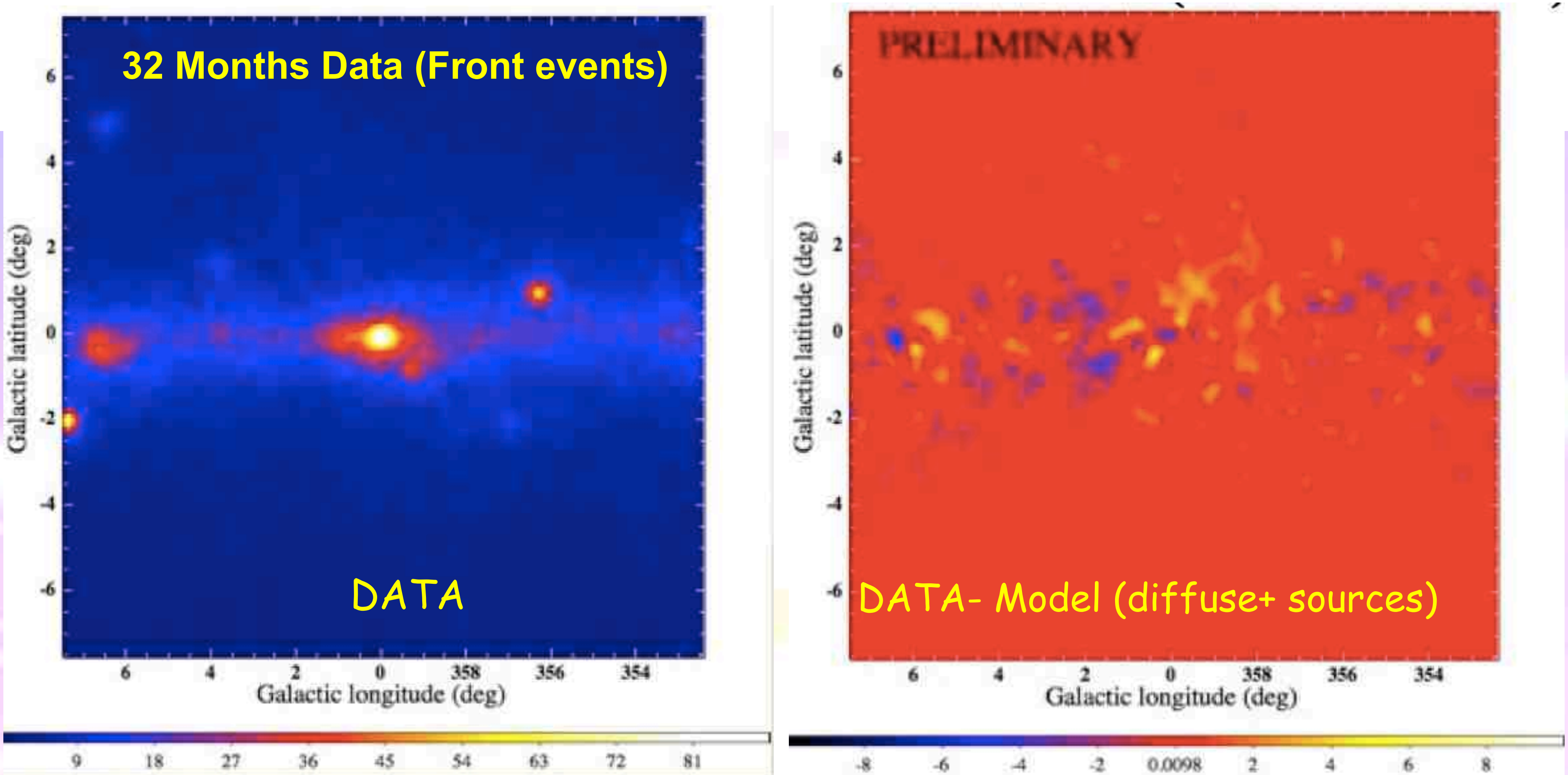
A.Lapi et al. arXiv:0912.1766

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

Residual Emission for 15 * 15 degrees around the Galactic center

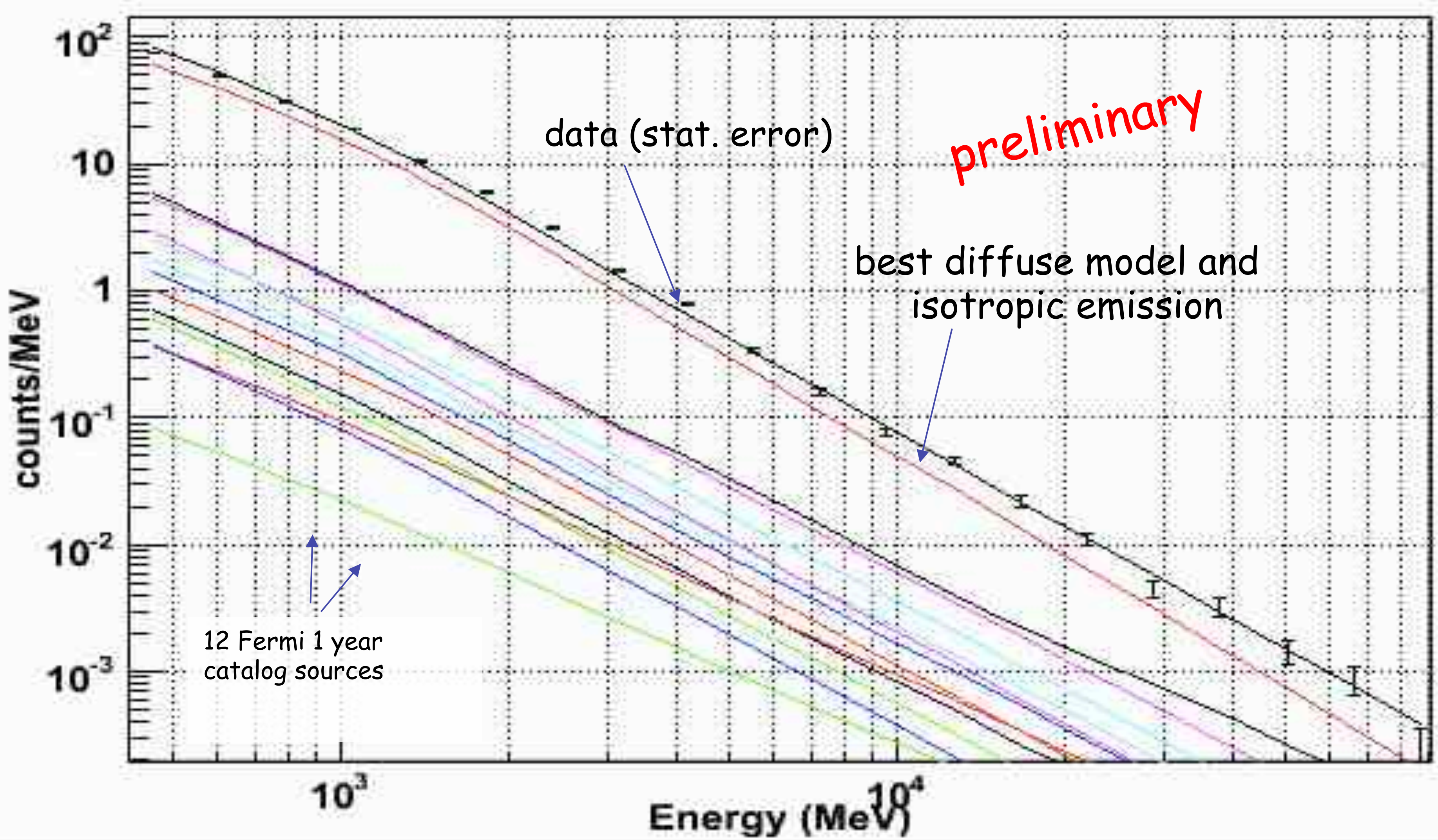


Diffuse emission and point sources account for most of the emission observed in the region.

Low-level residuals remain, the interpretation of these is work in-progress

Papers are forthcoming and will include dark matter results.

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

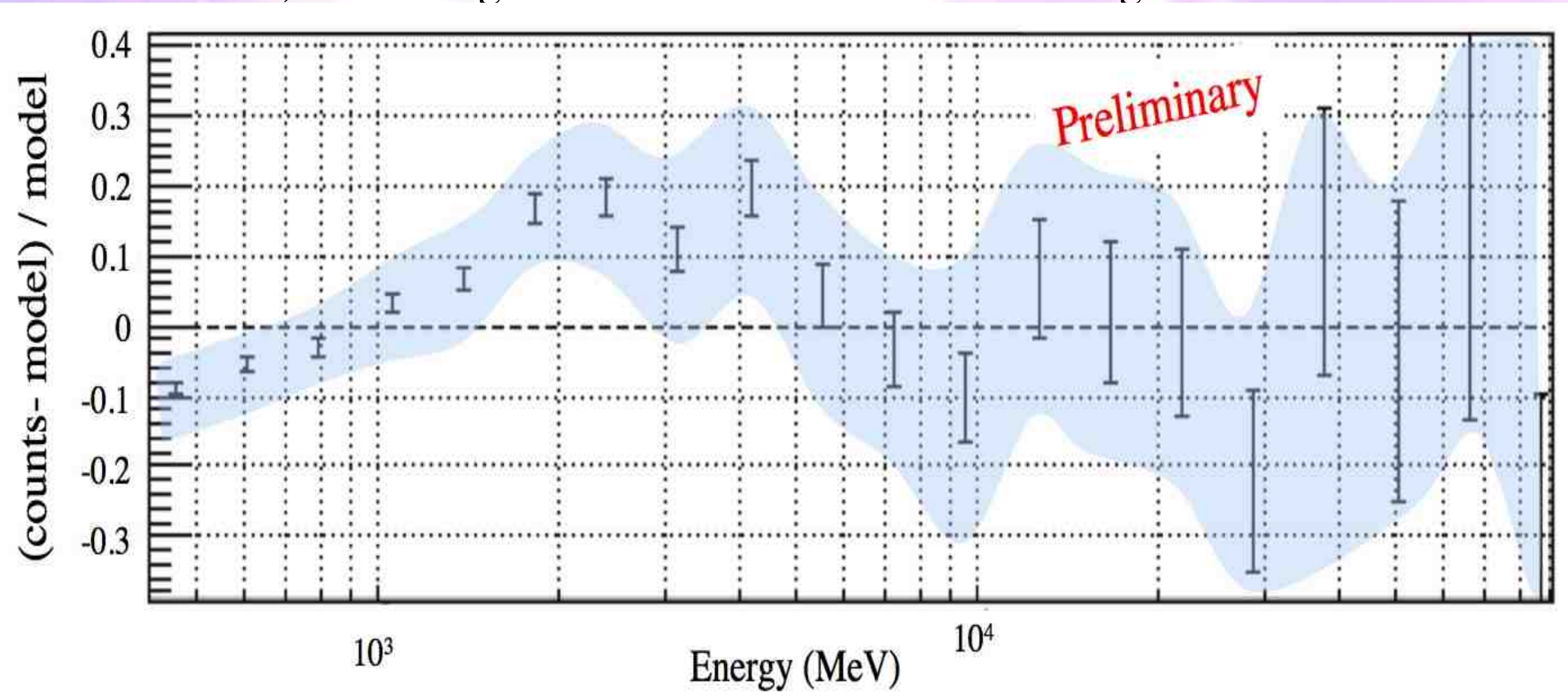


Fermi Coll. NIM A630 (2011) 147 [arXiv:0912.3828]

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



Fermi Coll. NIM A630 (2011) 147 [arXiv:0912.3828]

Galactic Center bump and LHC and direct detection results

- We revisit MSSM scenarios with light neutralino as a dark matter candidate in view of the latest LHC and dark matter direct and indirect detection experiments. We show that scenarios with a very light neutralino (~ 10 GeV) and a scalar bottom quark close in mass, can satisfy all the available constraints from LEP, Tevatron, LHC, flavour and low energy experiments and provide solutions in agreement with the bulk of dark matter direct detection experiments DAMA/LIBRA, CoGeNT and CRESST-II

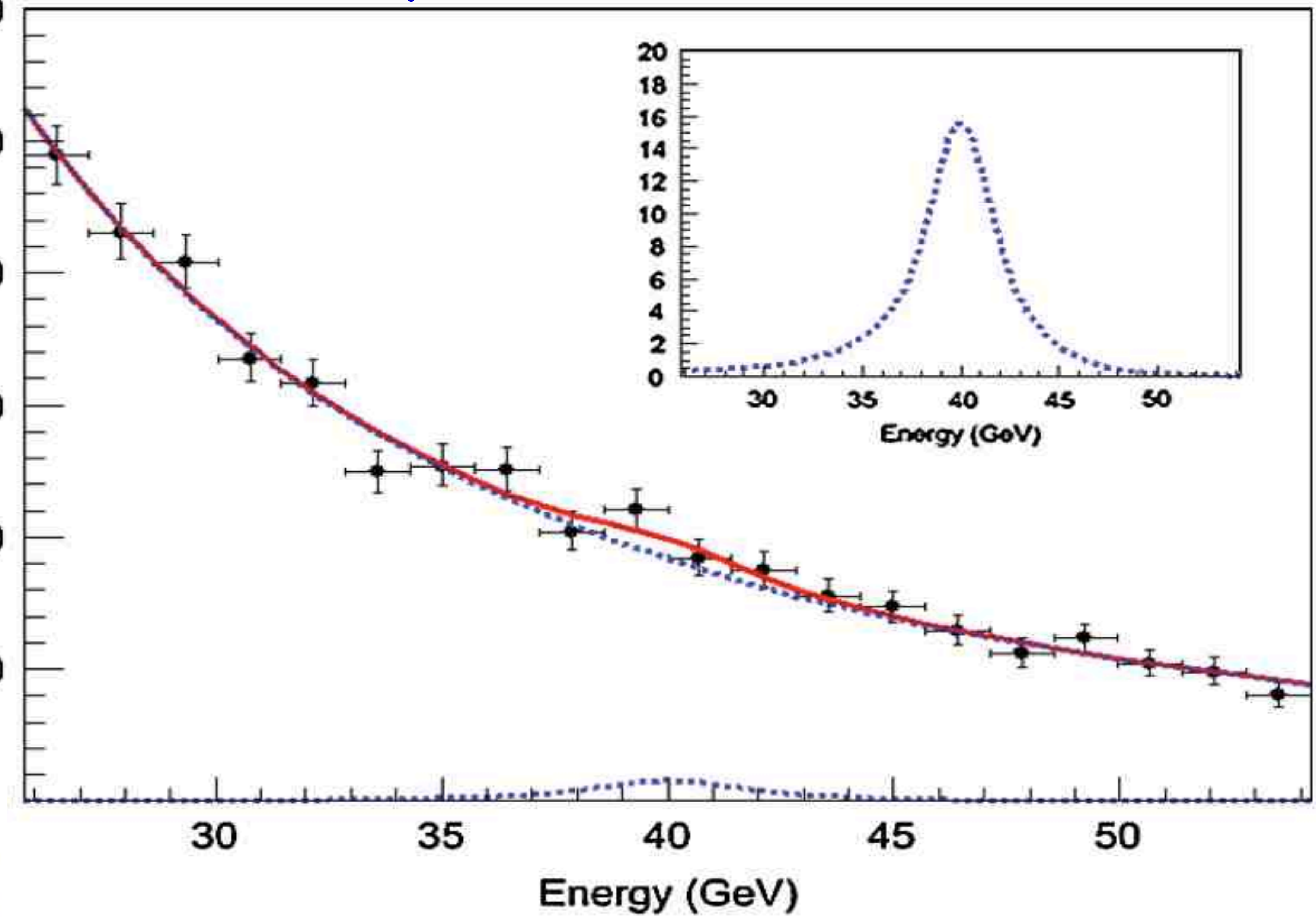
Alexandre Arbey, Marco Battaglia, Farvah Mahmoudi, arxiv:1308.2153

5-7 GeV bump produced by pulsar population ?

- we find that millisecond pulsars can account for no more than ~10% of the Inner Galaxy's GeV excess

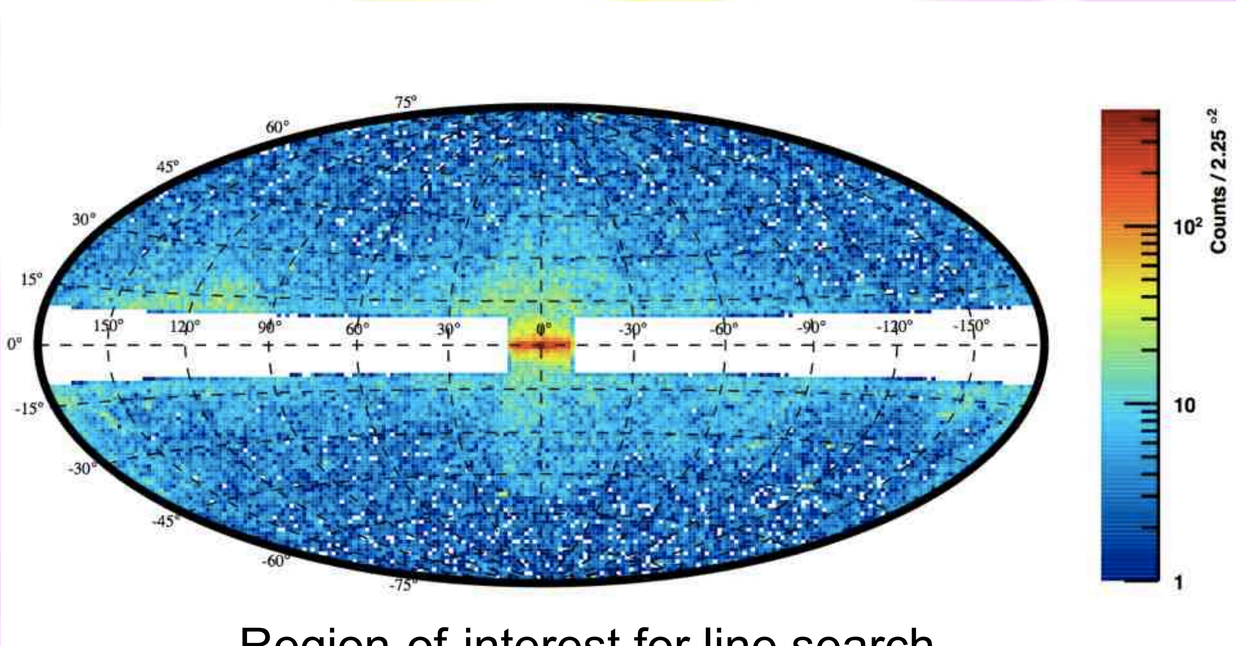
Dan Hooper, Ilias Cholis, Tim Linden, Jennifer Siegal-Gaskins, Tracy Slatyer arXiv:1305.0830v1

Wimp lines search



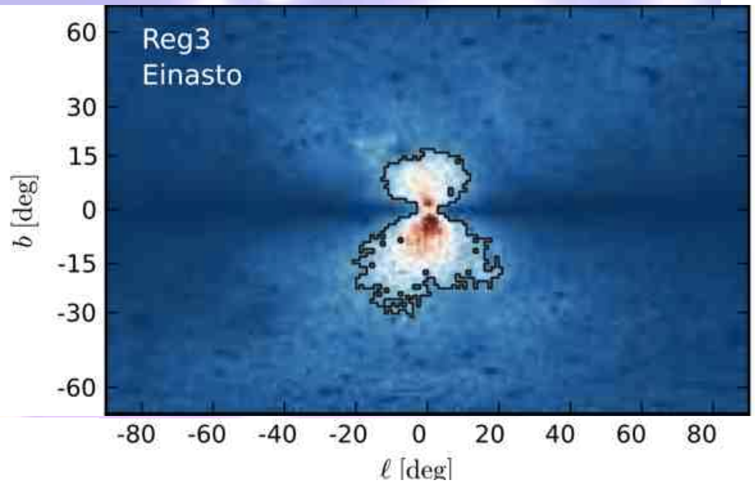
Search for Spectral Gamma Lines

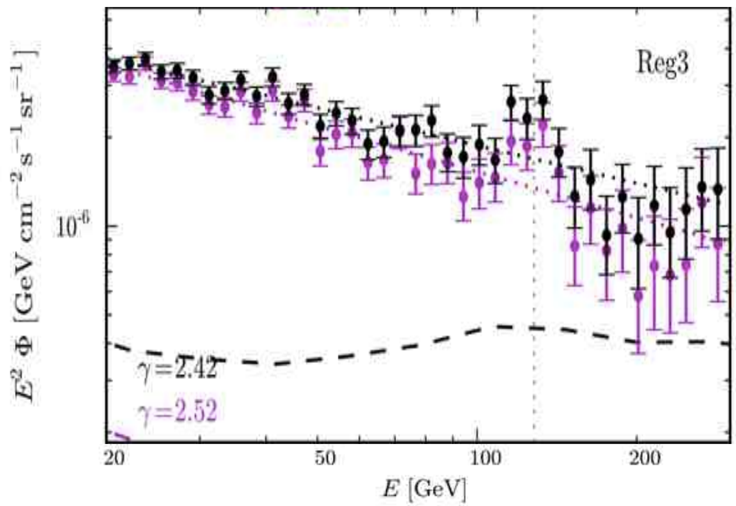
- Smoking gun signal of dark matter
- Search for lines in the first 23 months of Fermi data (7-200 GeV en.range)
- Search region |b|>10° plus a 20°x 20° square centered at the galactic center
- For the region within 1° of the GC, no point source removal was done as this would have removed the GC
- For the remaining part of the ROI, point sources were masked from the analysis using a circle of radius 0.2 deg
- The data selection includes additional cuts to remove residual charged particle contamination.

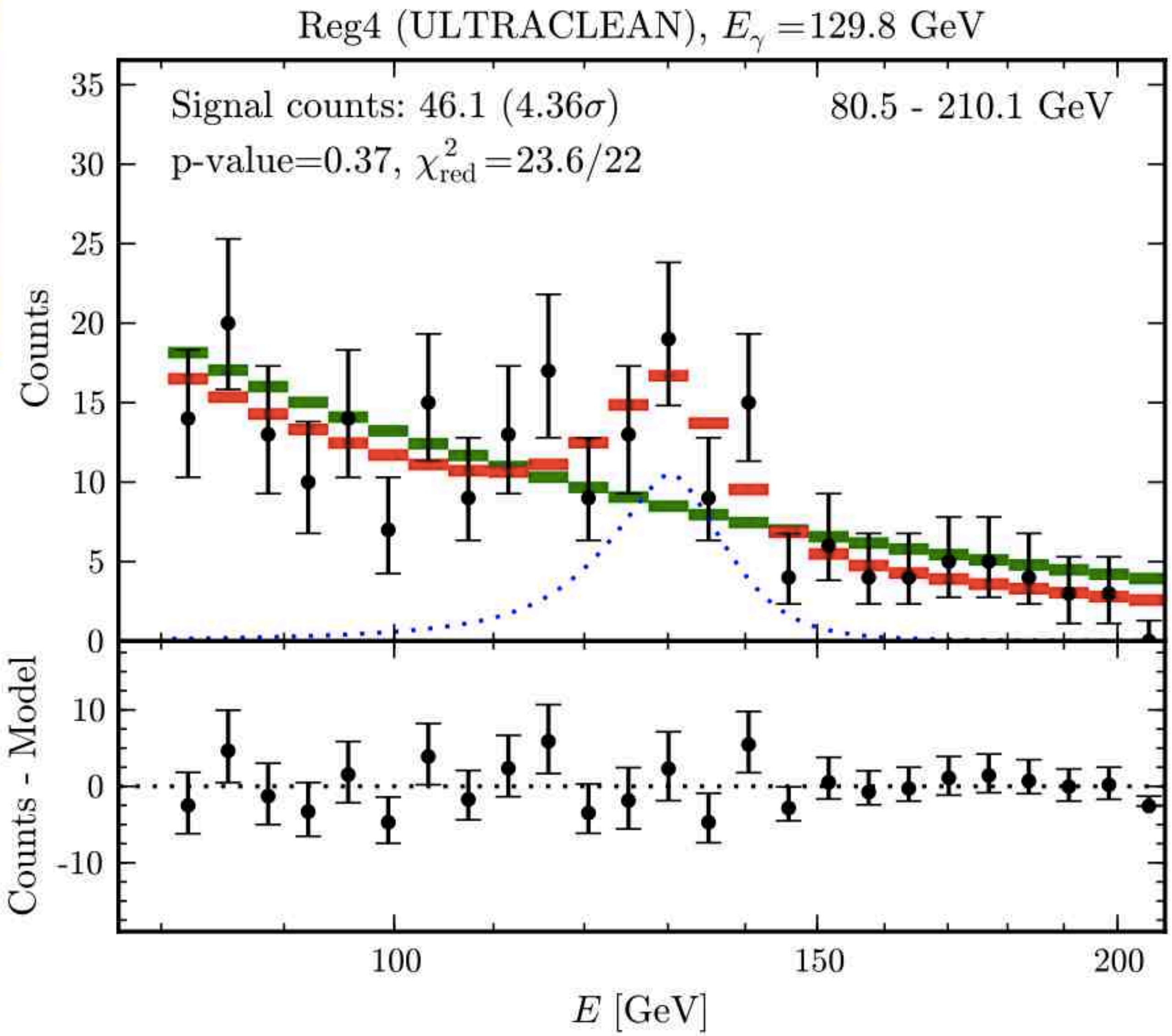


Region-of-interest for line search

A line at ~ 130 GeV ?







Weniger arXiv:1204.2797

A line at ~ 130 GeV ?

see also

Tempel et al. arXiv:1205.1045

Kyae & Park arXiv:1205.4151

Dudas Mambrini et al. arXiv:1205.1520

Boyarsky et al. arXiv:1205.4700

Lee et al. arXiv:1205.4700

Acharya, Kane et al. arXiv:1205.5789

Buckley, Hooper arXiv:1205.6811

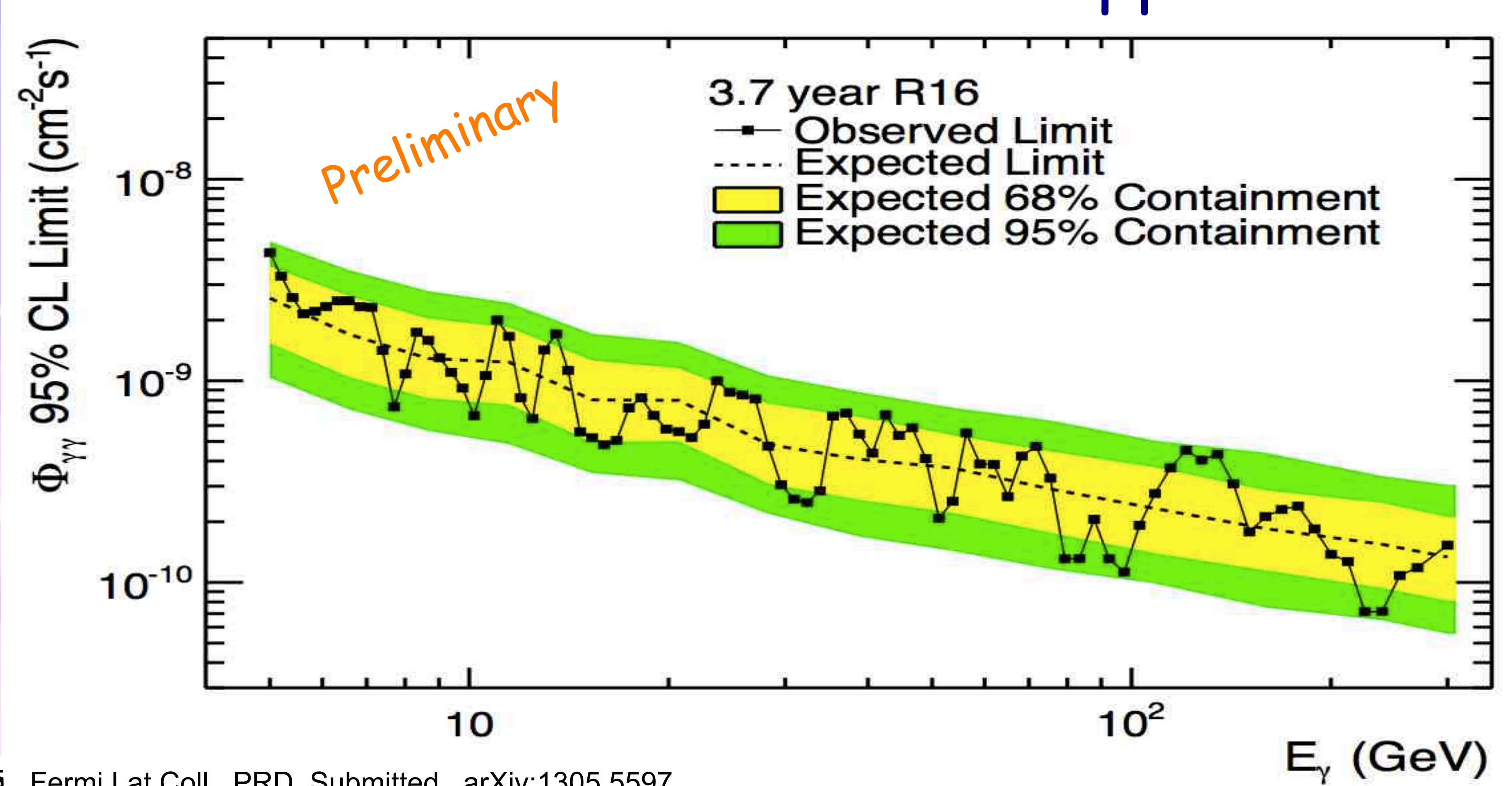
Su, Finkbeiner arXiv:1206.1616

Chu,Hambye et al. arXiv:1206.2279

Finkbeiner, Su, Weniger arXiv:1209.4562

.... Fermi-LAT analysis is in progress

Fermi-LAT Line Search Flux Upper Limits

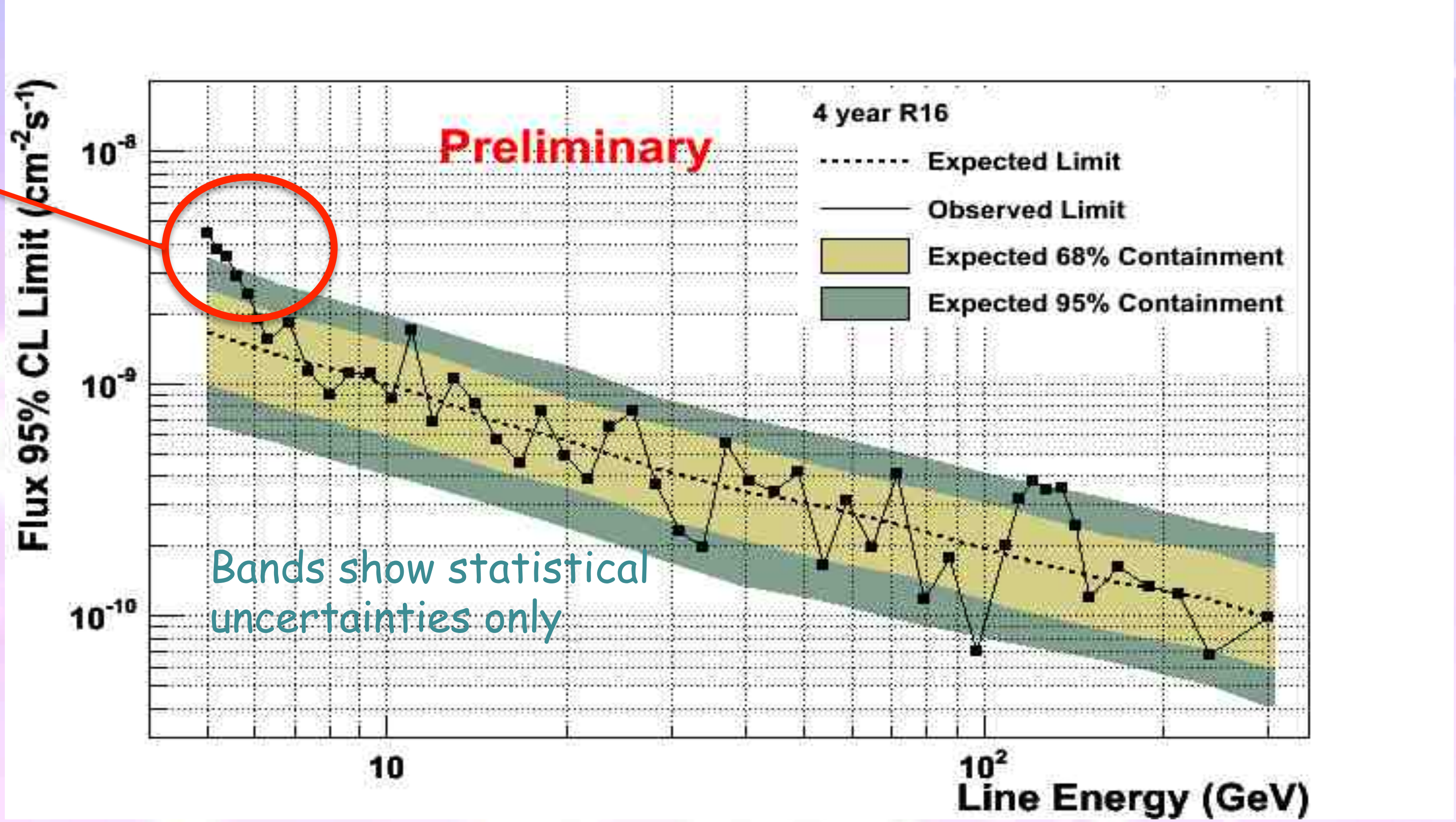


Fermi Lat Coll., PRD Submitted, arXiv:1305.5597

- 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.

Fermi-LAT Line Search Flux Upper Limits

S/N < 4%

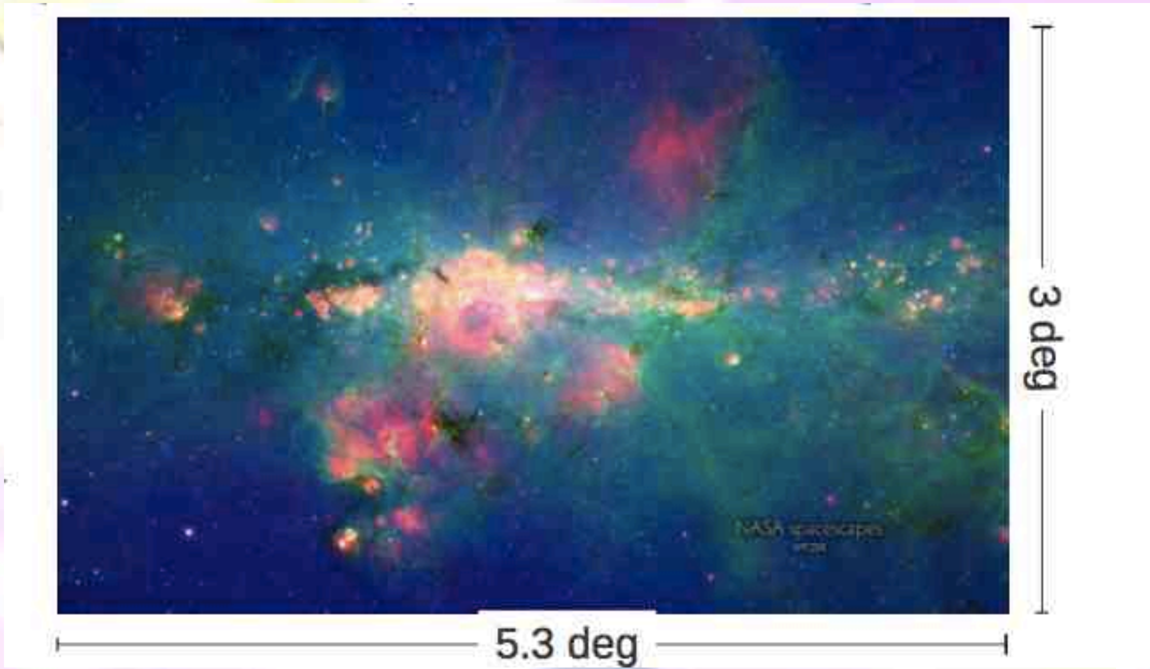


- Most of the limits fall within the expected bands.
- Near 135 GeV the limits are near the upper edge of the bands.
- The huge statistics at low energies mean small uncertainties in the collecting area can produce statistical significant spectral features.

Constraints from the inner Galaxy

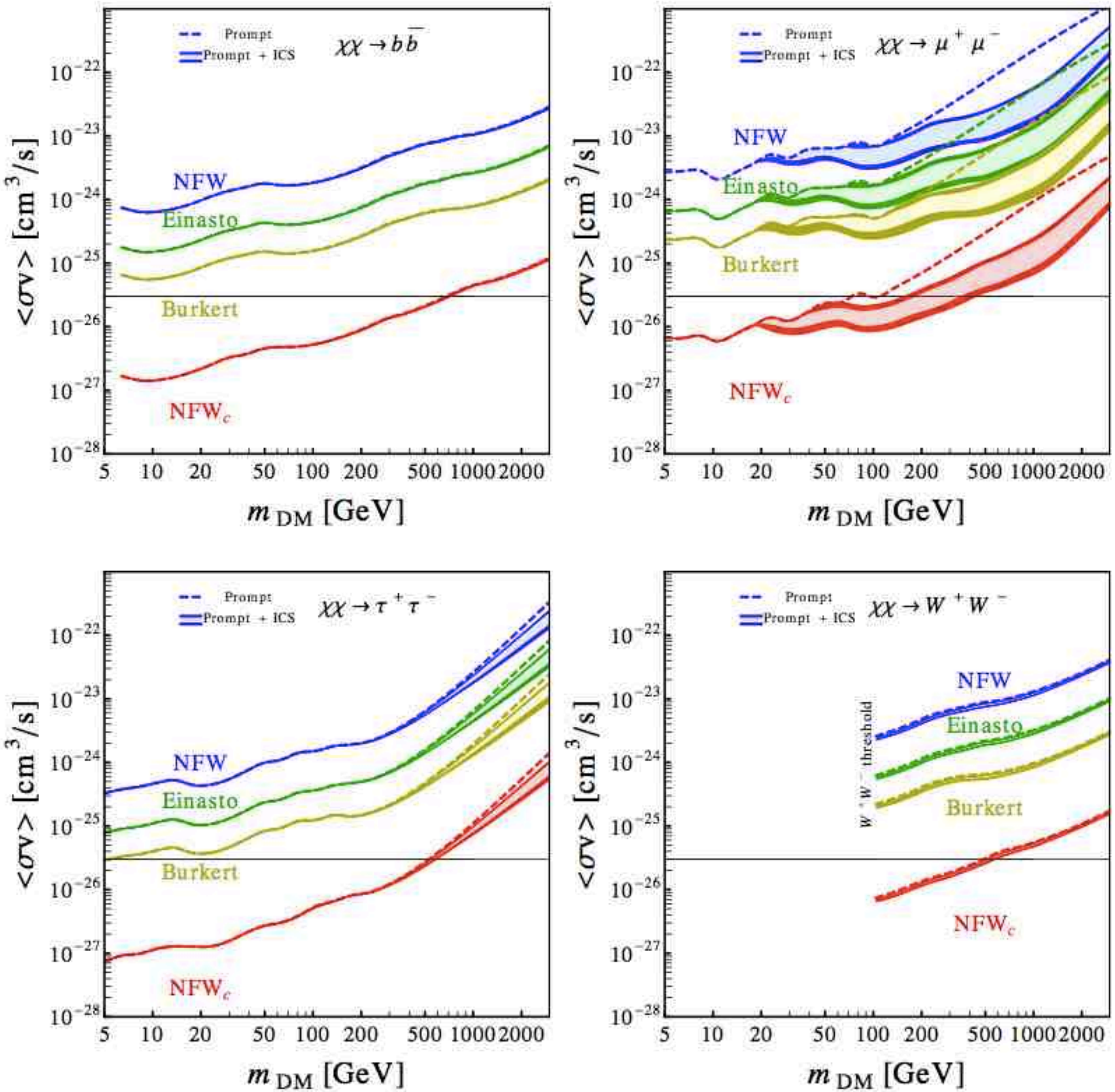
The gamma-ray flux produced by dark matter annihilation is expected to be maximized in the inner regions of the Milky Way.
The DM density in the GC may be larger than typically obtained in *N*-body cosmological simulations. Ordinary matter (baryons) dominates the central region of our Galaxy. Thus, baryons may significantly affect the DM.
As baryons collapse and move to the center they increase the graviational potential, which turn forces the DM to contract and increase its density.
If this is the only effect of baryons, then the expected annihilation signal will substantially increase.

Blue represents 3.6-micron light and green shows 8-micron light, both captured by Spitzer's infrared array camera. Red is 24- micron light detected by Spitzer's multiband imaging photometer.
http://www.spitzer.caltech.edu/ima ges/3560-sig11-003-Stars-Gather-in-Downtown-Milky-Way



Constraints from the inner Galaxy

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



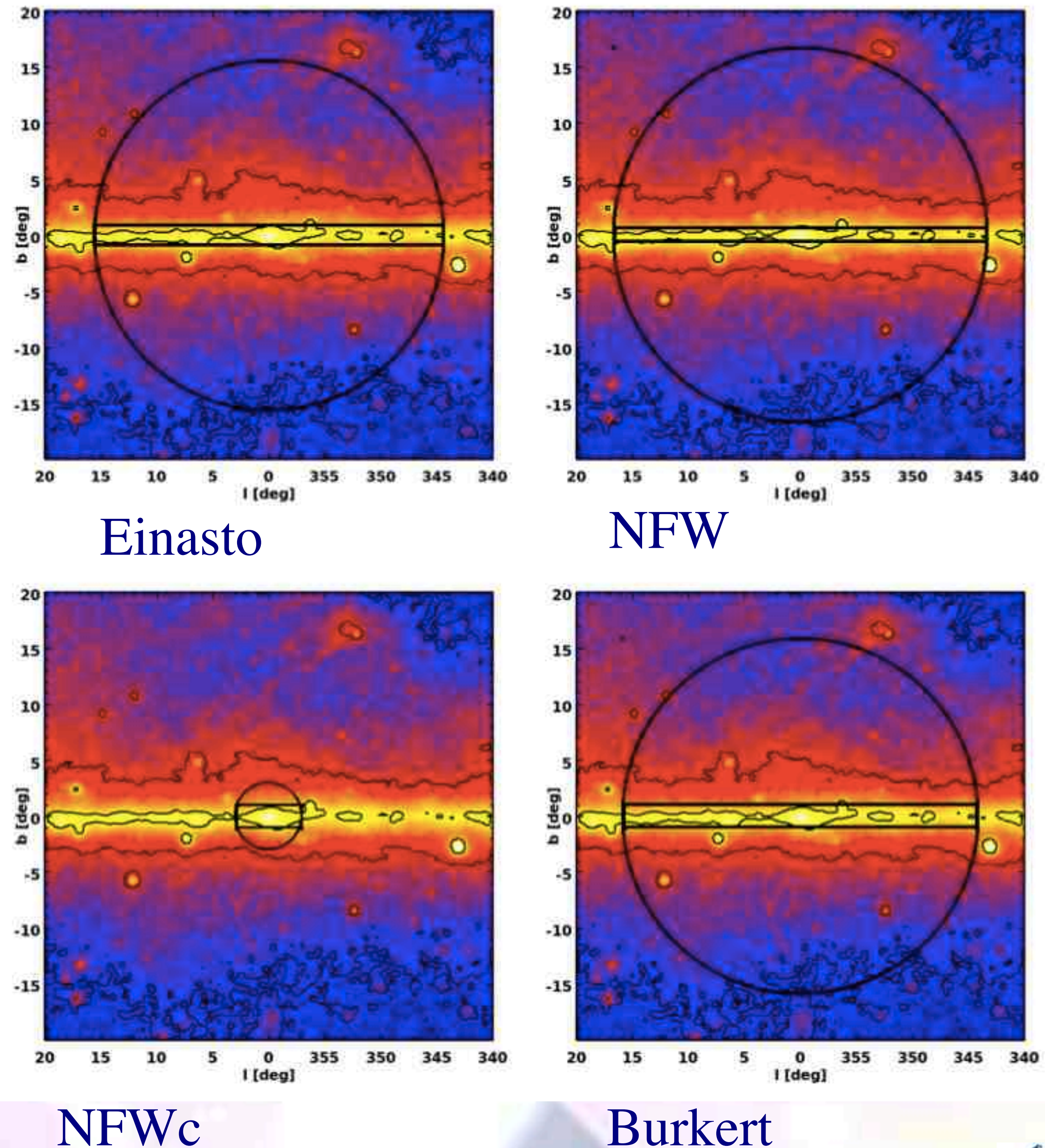
No assumption on background

very robust result

Gomez-Vargas et al. JCAP sub., arXiv:1308.3515

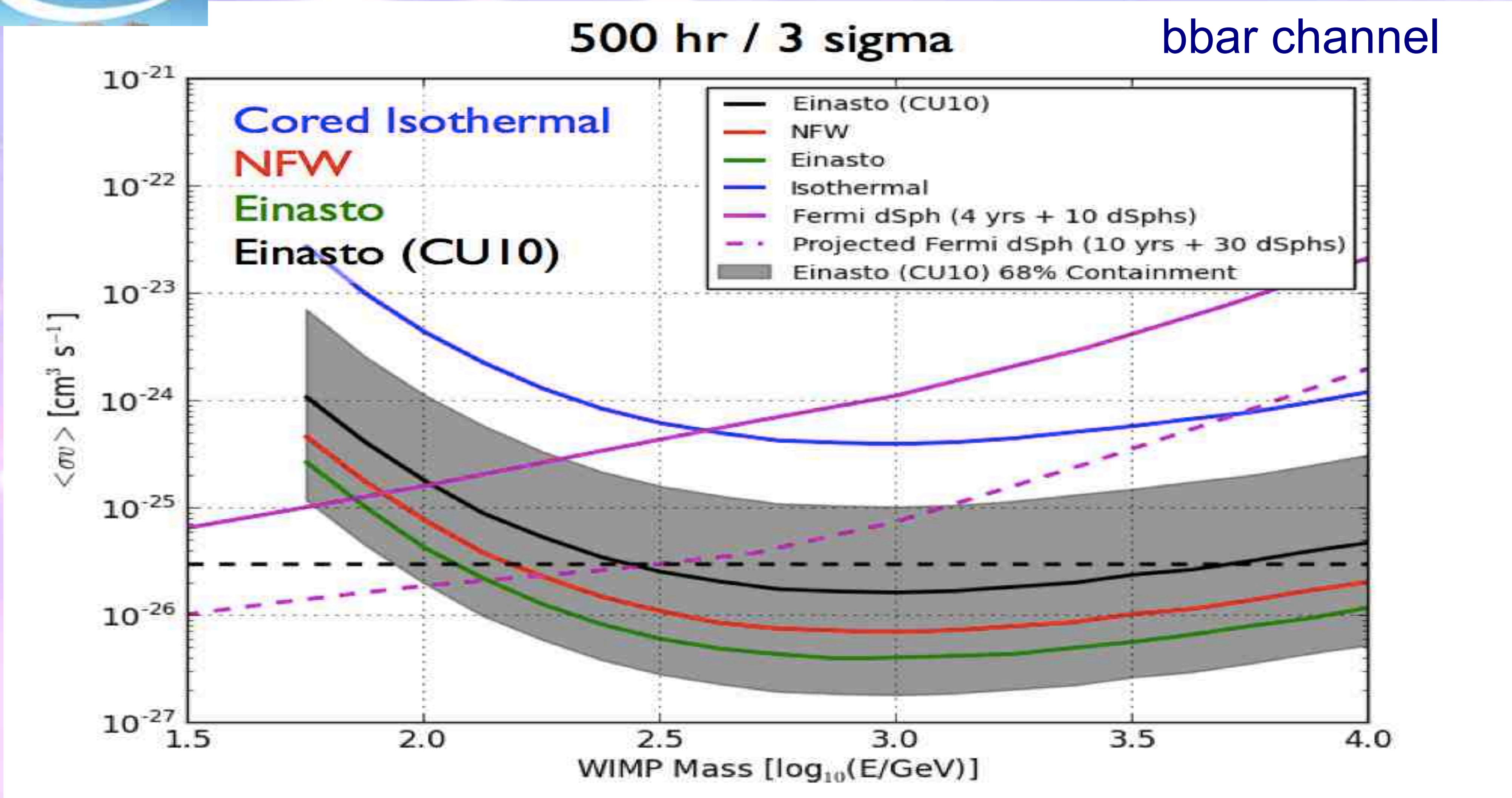
Constraints from the inner Galaxy

Optimized ROI for each profile



Gomez-Vargas et al. JCAP sub., arXiv:1308.3515

CTA and Galactic Center



Models with thermal relic cross section should be detectable assuming an extrapolation of the DM density profile consistent with CDM simulations

New projects in space

- CALET CALorimetric Electron Telescope launch planned for 2014

  arXiv:1302.1257

- Gamma-light

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

(Proposed to ESA but not approved)

- JEM EUSO launch tentatively planned for 2017

  P. Picozza Ricap13

- 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

New projects in space 2

- 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

Approved mission by ROSCOSMOS

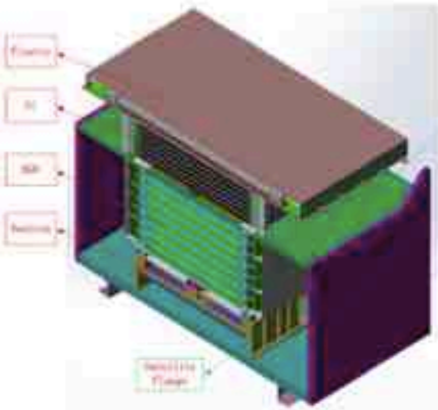
Originally devoted Gamma rays study (30 GeV – 1 TeV) & high-energy electrons and positrons.

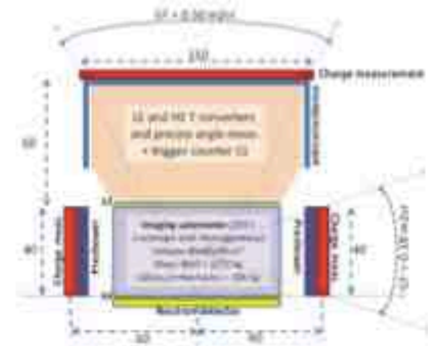
On going study for a revision of the project

- Launch foreseen by end 2018 unique opportunity to configure the apparatus for :

- gamma-rays from 100 MeV < up to 300 GeV
- proton & nuclei in cosmic-rays up to the "knee"
- electrons/positrons beyond TeV energy range

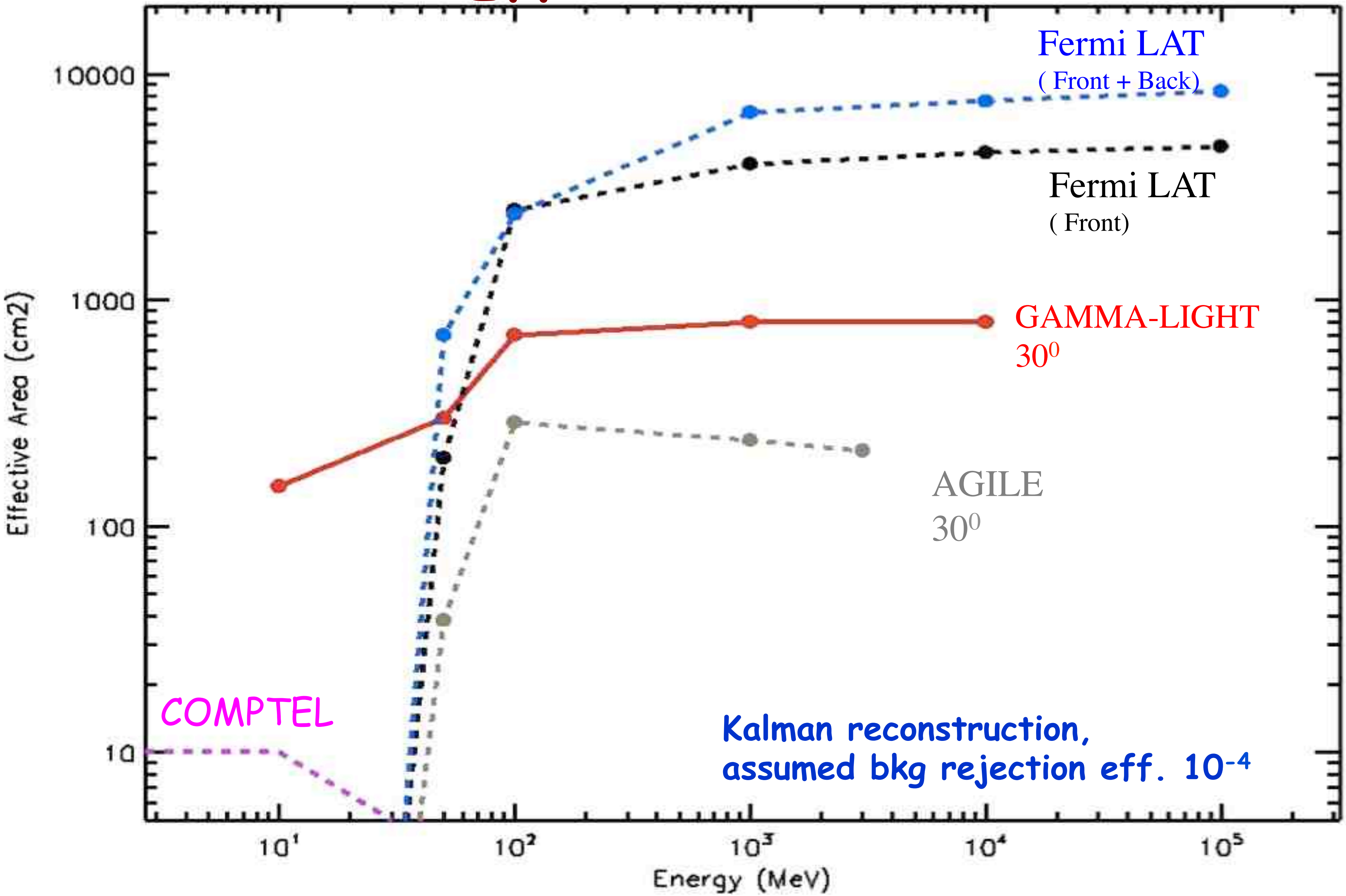
DAMPE and other detectors

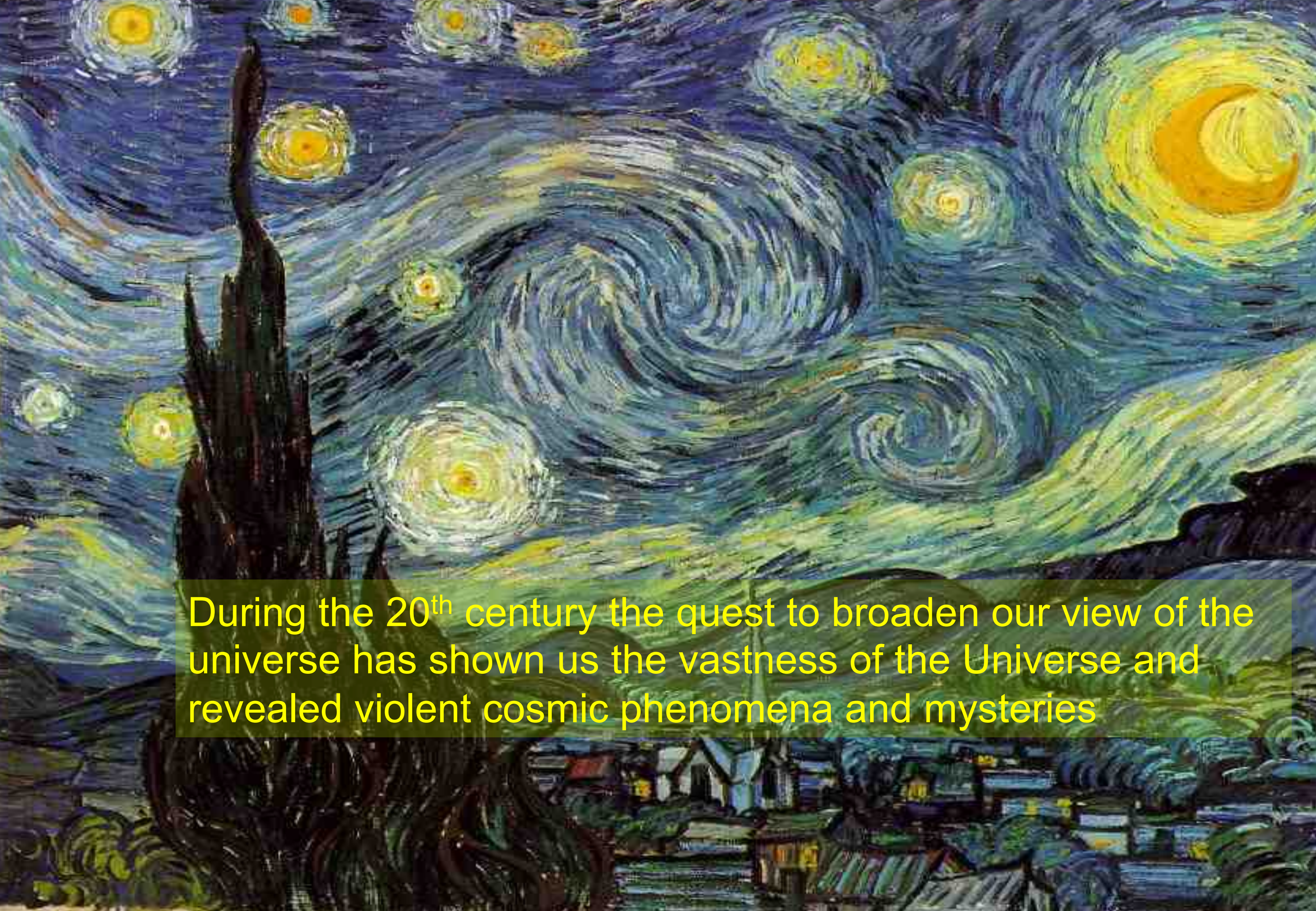




	DAMPE	AMS-02	Fermi LAT	CALET	GAMMA-400
Energy range (GeV)	5 - 10^4	0.1 - 10^3	0.02 - 300	1 - 10^3	0.1 – 3 10^3
e/γ Energy res.@100 GeV (%)	1.5	3	10	2	1
e/γ Angular res.@100 GeV (°)	0.1	0.3	0.1	0.1	0.01
e/p discrimination	10^5	10^5 - 10^6	10^3	10^5	10^6
Calorimeter thickness (X_0)	31	17	8.6	30	25
Geometrical accep. ($m^2 sr$)	0.4	0.09	1	0.12	0.5

Effective area





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?

Thank you for the attention !!