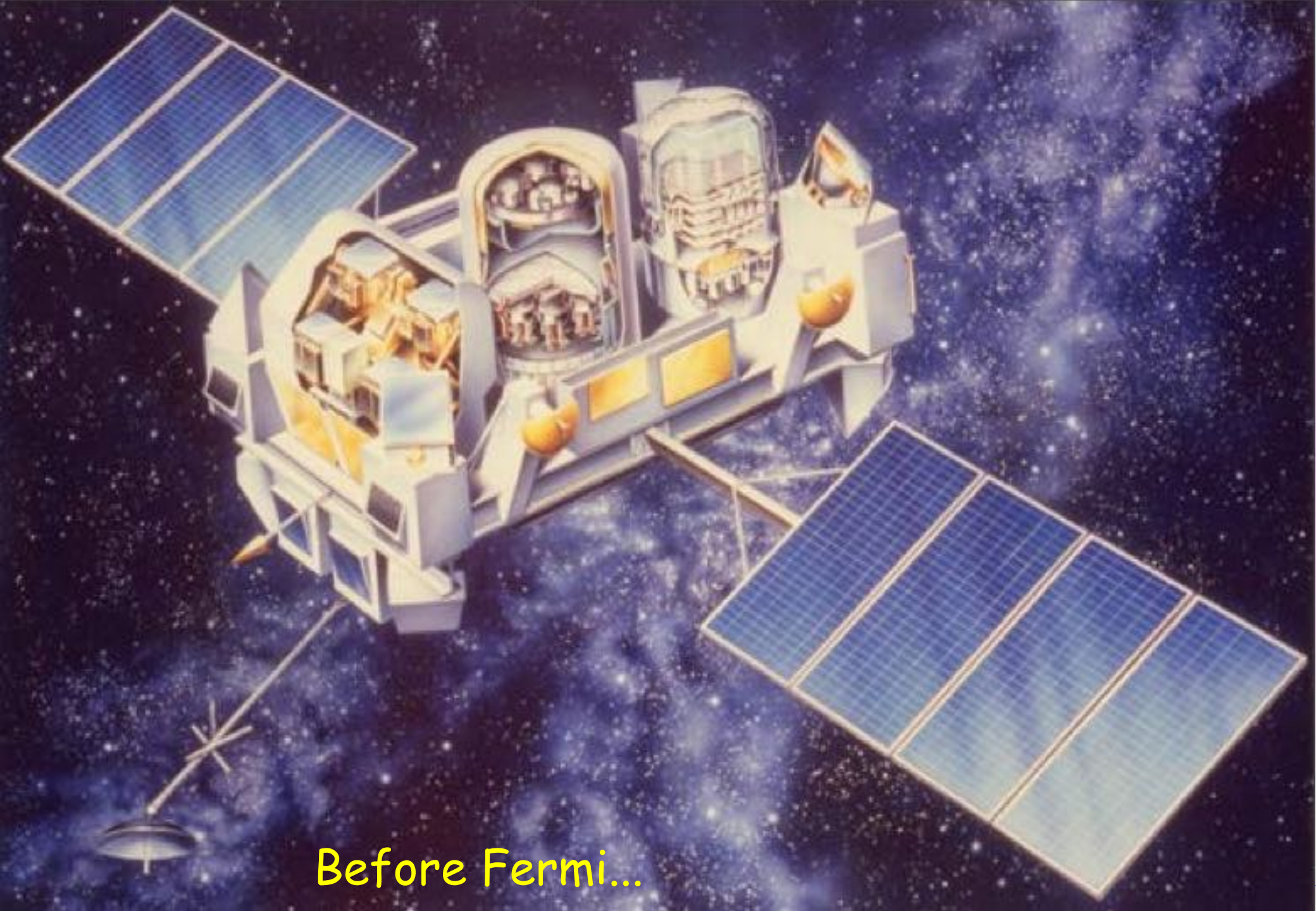
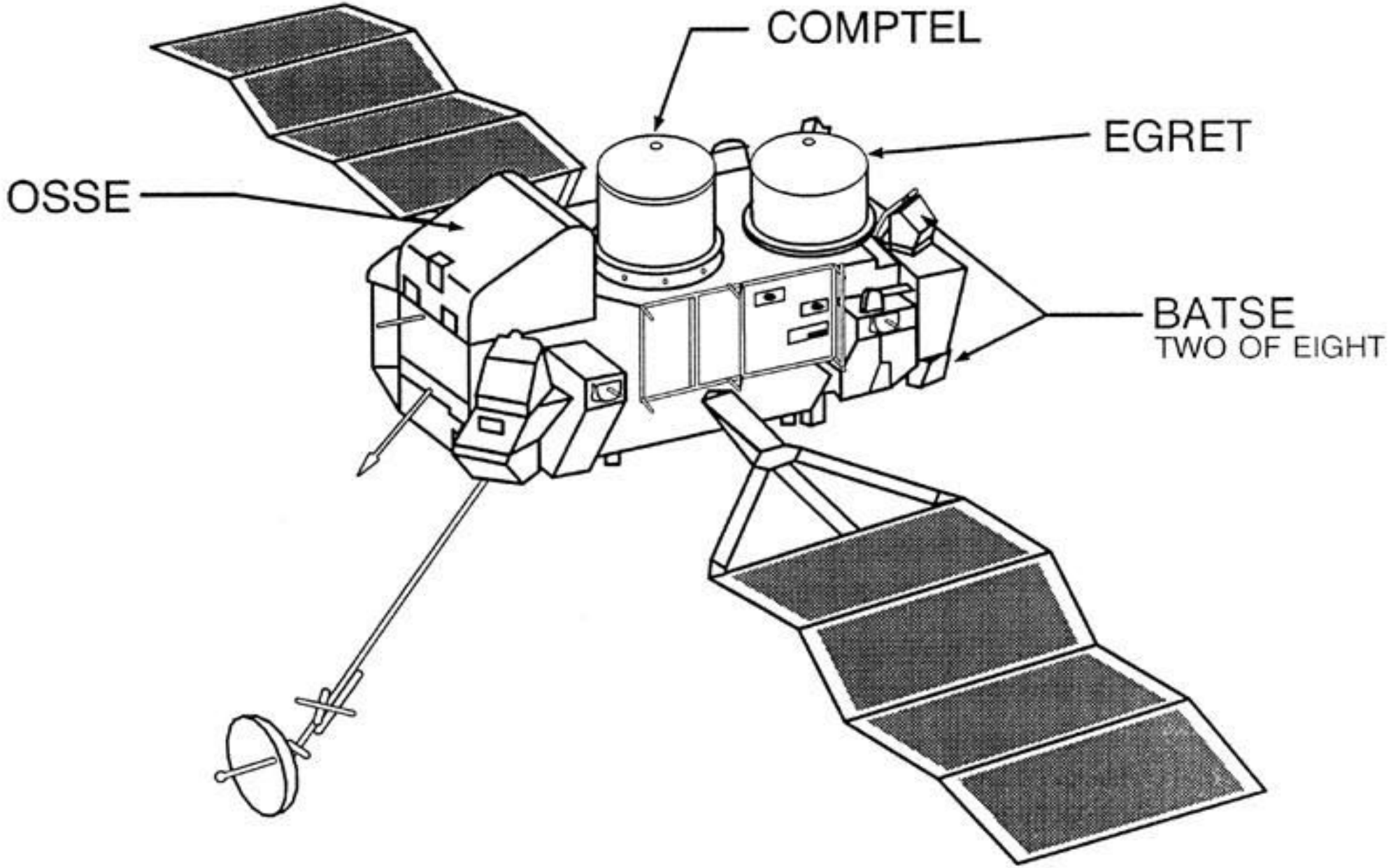
How Fermi has influenced the theory of dark matter

Aldo Morselli
INFN Roma Tor Vergata

Fermi Collaboration meeting Spring 2017
CERN Main Auditorium 29/03/17


Before Fermi...

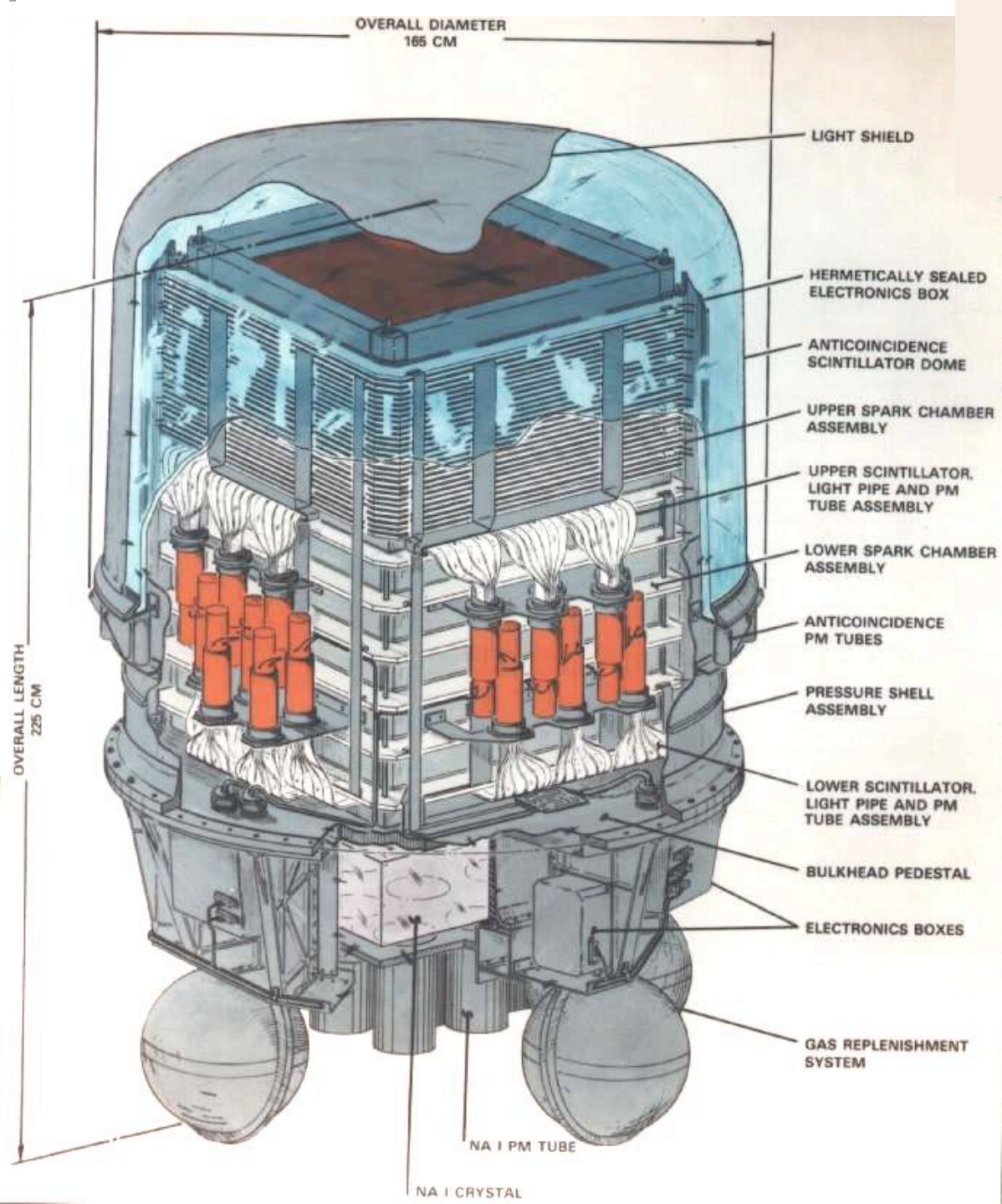
COMPTON OBSERVATORY INSTRUMENTS



EGRET:the detector

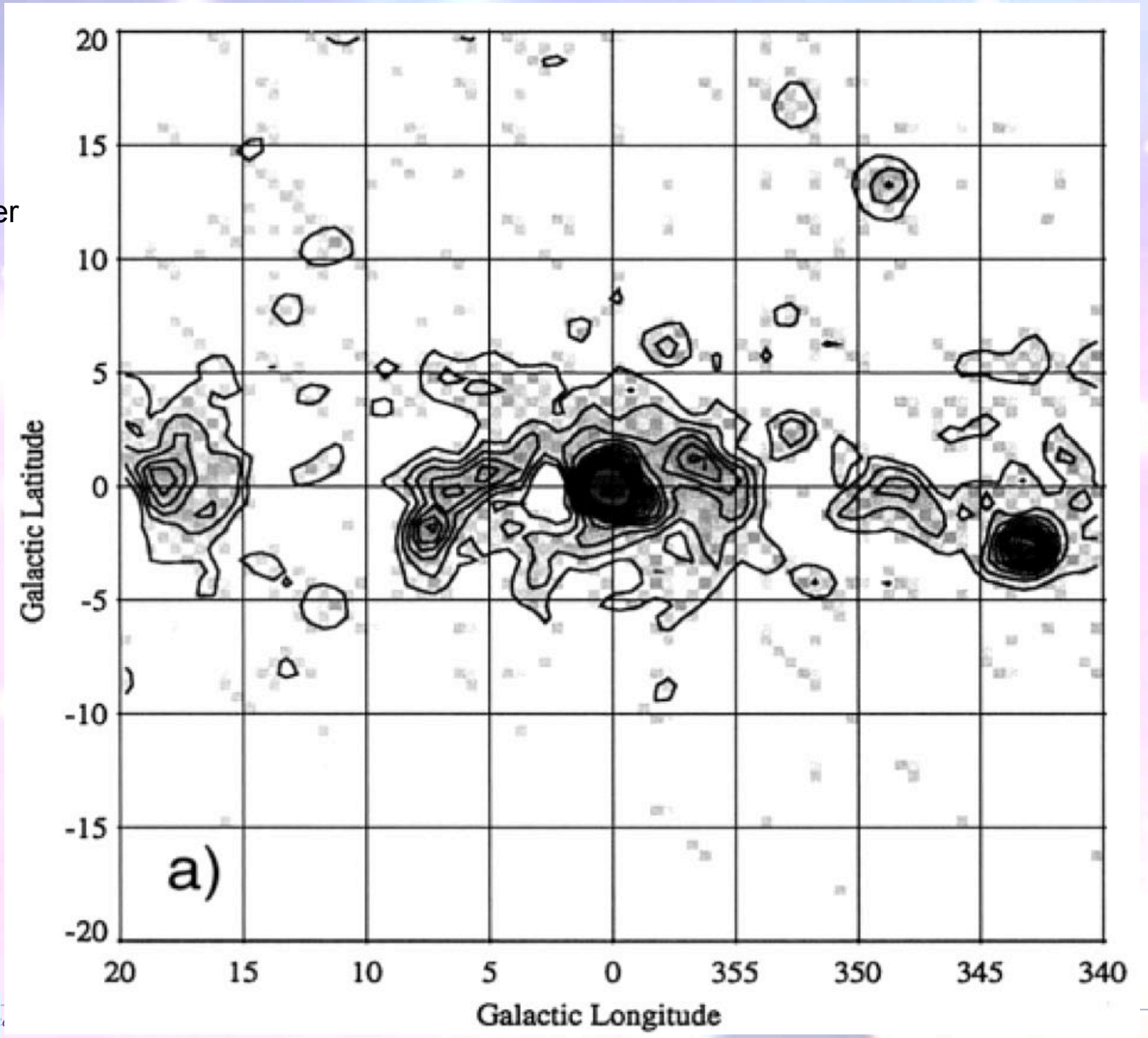
Energy range:	20 MeV - 30 GeV
Weight:	1820 Kg
Power:	160 W
Field of view:	0. 5 sr
Dead Time:	100 ms
Effective Area (@1GeV)	1200 cm^2
Angular resolution (@100MeV)	5.8°

Sensitivity	0.1 GeV	$5x10^{-8}$
for point	1 GeV	$1x10^{-8}$
sources	10 GeV	$2x10^{-8}$
(ph cm^{-2} s^{-1})*		

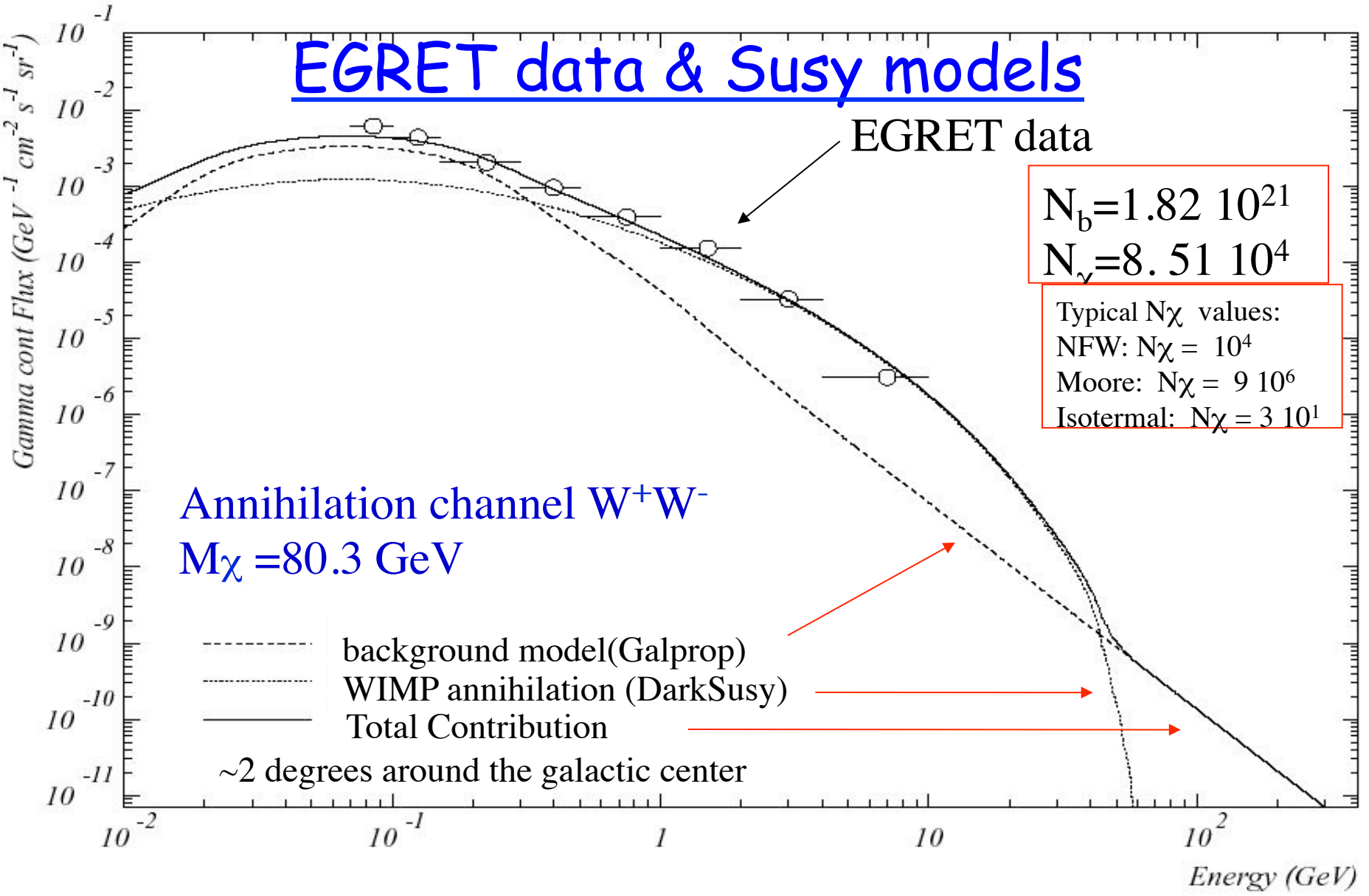


EGRET,
E > 1GeV

Mayer-Hasselwander et al, 1998



EGRET data & Susy models



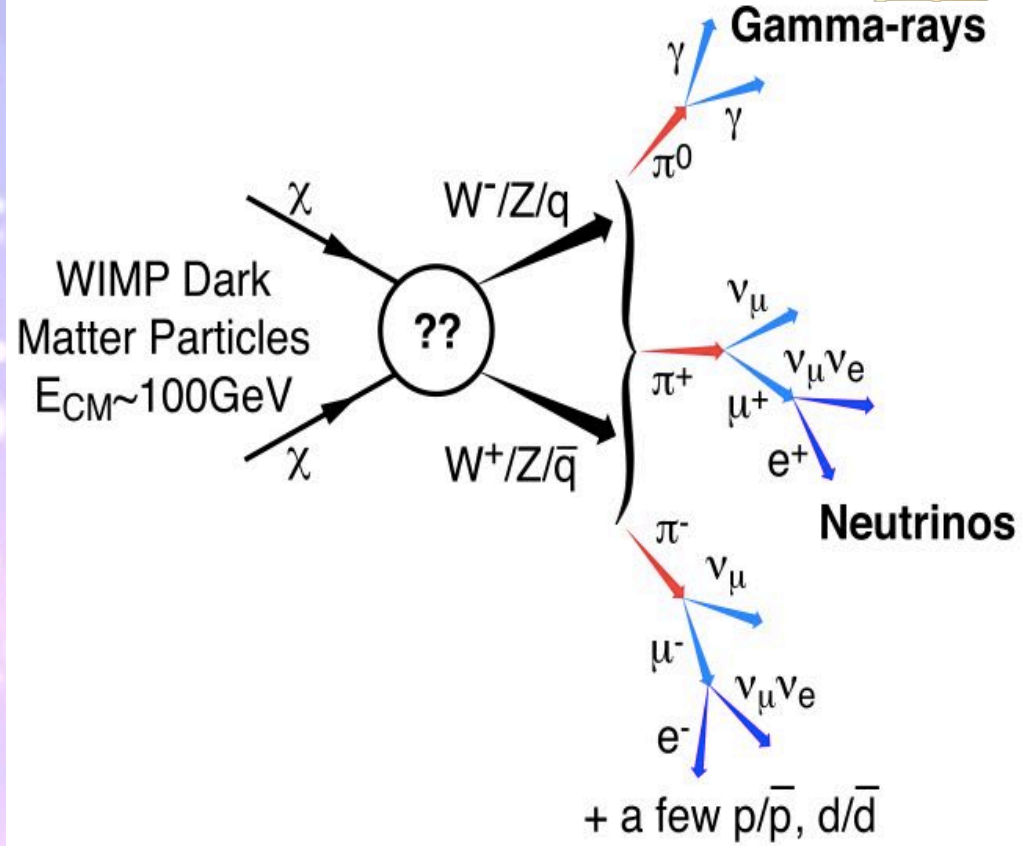
A.Morselli, A. Lionetto, A. Cesarini, F. Fucito, P. Ullio, Nucl. Phys. B 113B (2002) 213-220 [astro-ph/0211327]

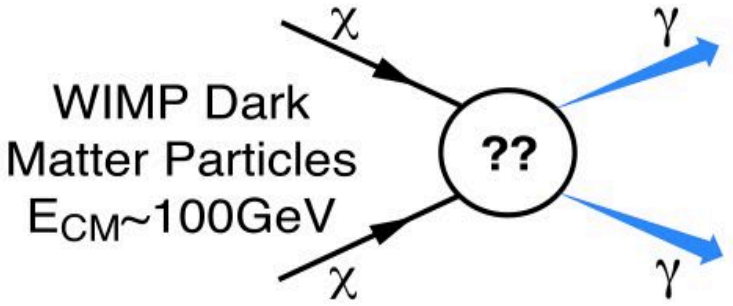
Neutralino WIMPs

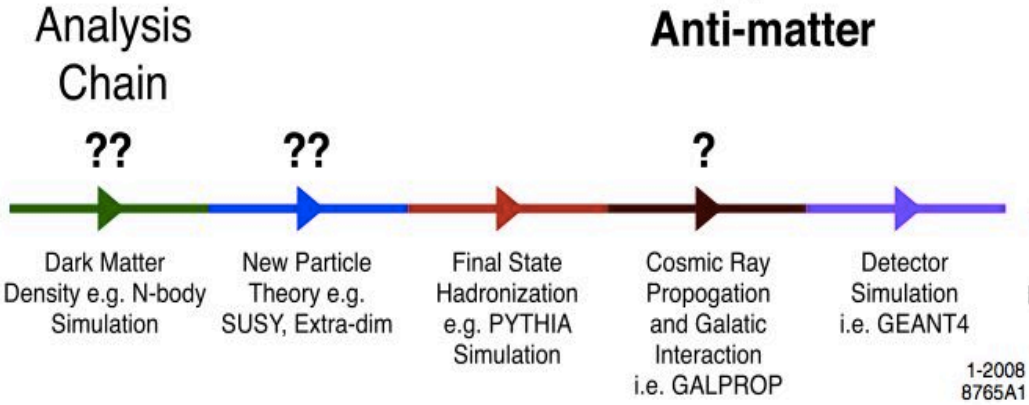
Assume χ present in the Galactic halo

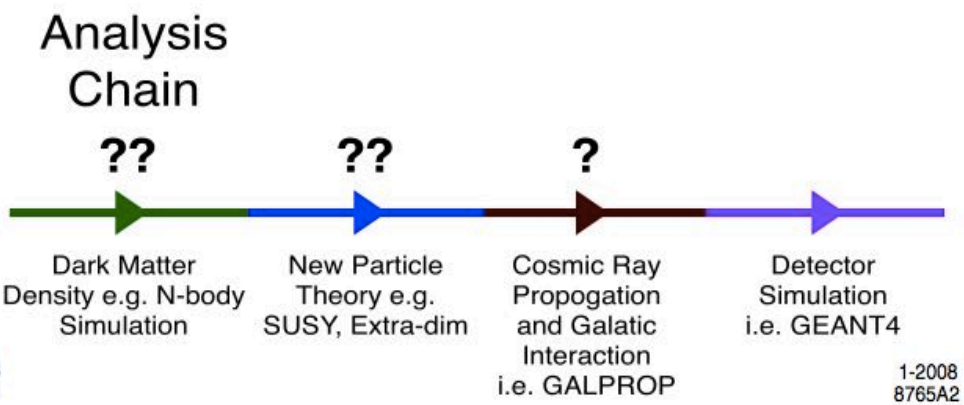
- χ is its own antiparticle => can annihilate in galactic halo producing gamma-rays, antiprotons, positrons….
- Antimatter not produced in large quantities through standard processes (secondary production through p + p --> anti p + X)
- So, any extra contribution from exotic sources (χ χ annihilation) 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





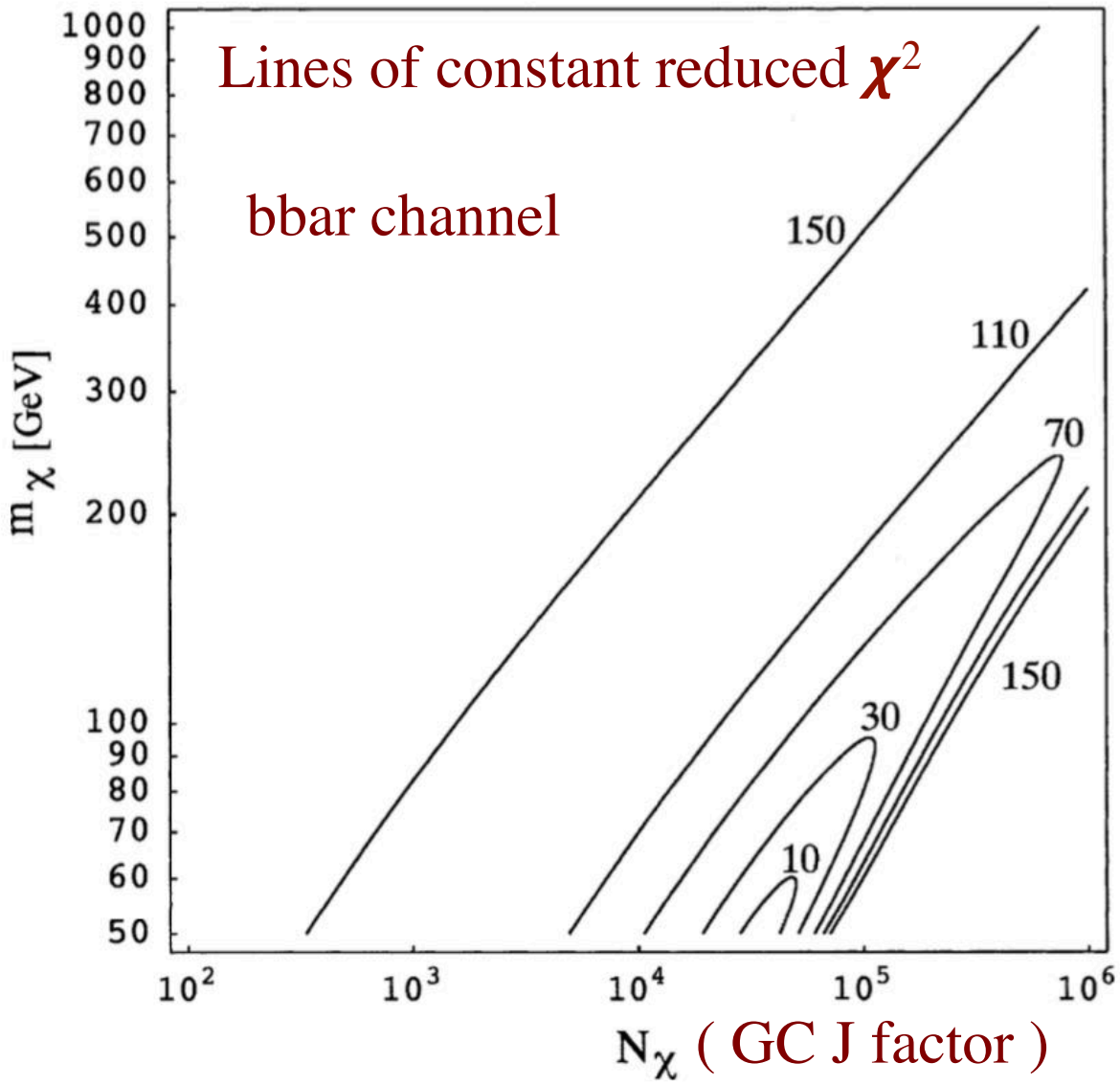




Lines of constant reduced χ^2 corresponding to best fits of the EGRET GC excess

mass ~ 50- 80 GeV

Very similar to the mass range found with Fermi LAT



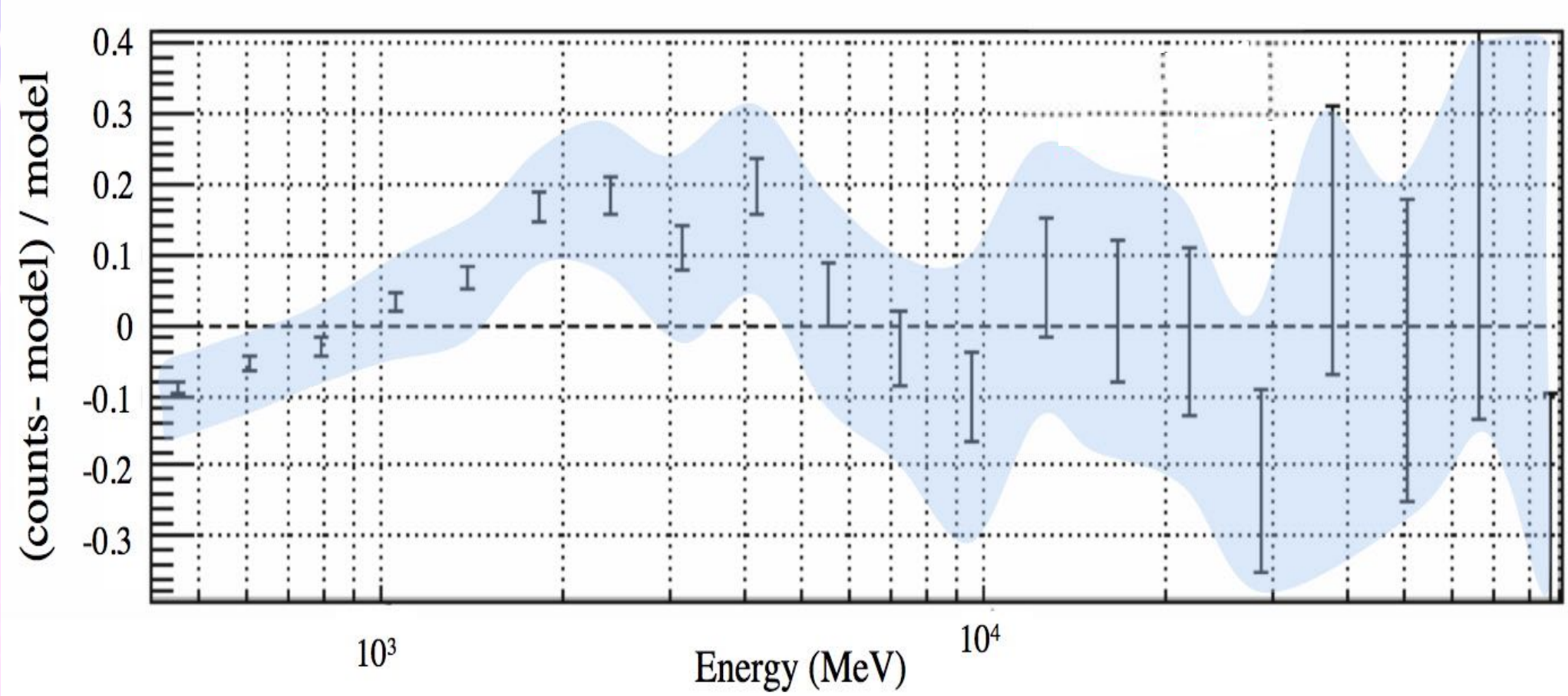
A.Cesarini, F.Fucito, A.Lionetto, A.Morselli, P.Ullio, Astroparticle Physics, 21, 267, 2004 [astro-ph/0305075]

The GeV excess

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



the GALACTIC CENTER : any hints of Dark Matter?

the beginning of the history :

The Galactic Center as a Dark Matter Gamma-Ray Source
A.Morselli, A. Lionetto, A. Cesarini, F. Fucito, P. Ullio, Nuclear Physics B 113B (2002) 213-220 [astro-ph/0211327]
A.Cesarini, F.Fucito, A.Lionetto, A.Morselli, P.Ullio Astroparticle Physics 21, 267-285, 2004 [astro-ph/0305075]

Possible Evidence For Dark Matter Annihilation In The Inner Milky Way From The Fermi Gamma Ray Space Telescope
Lisa Goodenough, Dan Hooper arXiv:0910.2998

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, 2-5 November 2009, eConf Proceedings C091122 **arXiv:0912.3828** **21 Dec 2009**

Search for Dark Matter with Fermi Large Area Telescope: the Galactic Center
V.Vitale, A.Morselli, the Fermi-LAT Collaboration NIM A 630 (2011) 147–150 (Available online 23 June 2010)

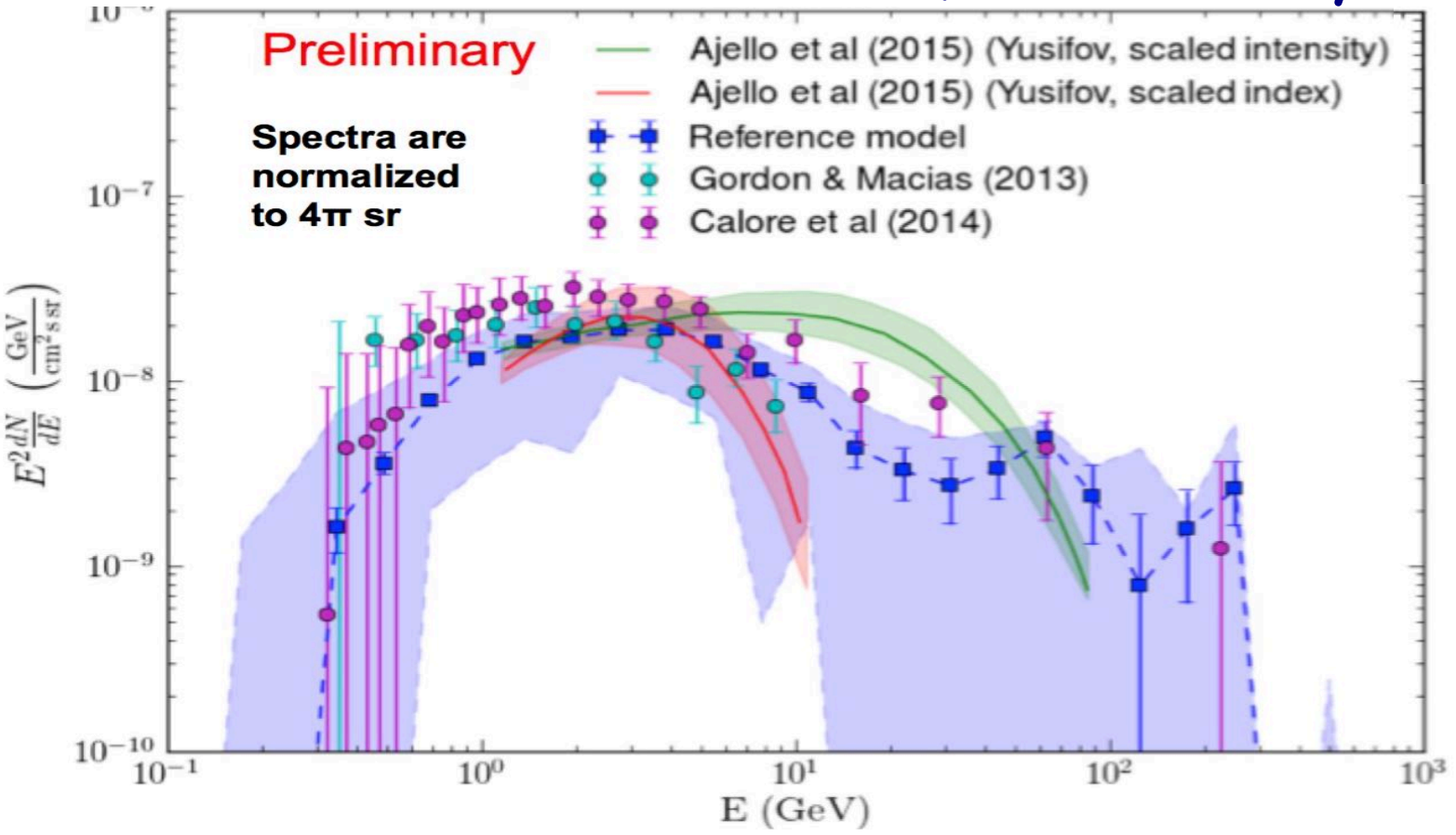
Dark Matter Annihilation in The Galactic Center As Seen by the Fermi Gamma Ray Space Telescope
Dan Hooper , Lisa Goodenough . (21 March 2011). 21 pp. **Phys.Lett. B697 (2011) 412-428**

..... **hundreds of articles ...**

Background model systematics for the Fermi GeV excess
F.Calore, I. Cholis, C. Weniger JCAP03(2015)038 **arXiv:1409.0042v1**

Fermi-LAT observations of high-energy γ-ray emission toward the galactic centre
M. Ajello et al.[Fermi-LAT Coll.] **Apj 819:44 2016 arXiv:1511.02938**
(using Pass7, Pass8 analysis in progress)

The GeV excess (Pass8 analysis)



following uncertainties have relatively small effect on the excess spectrum

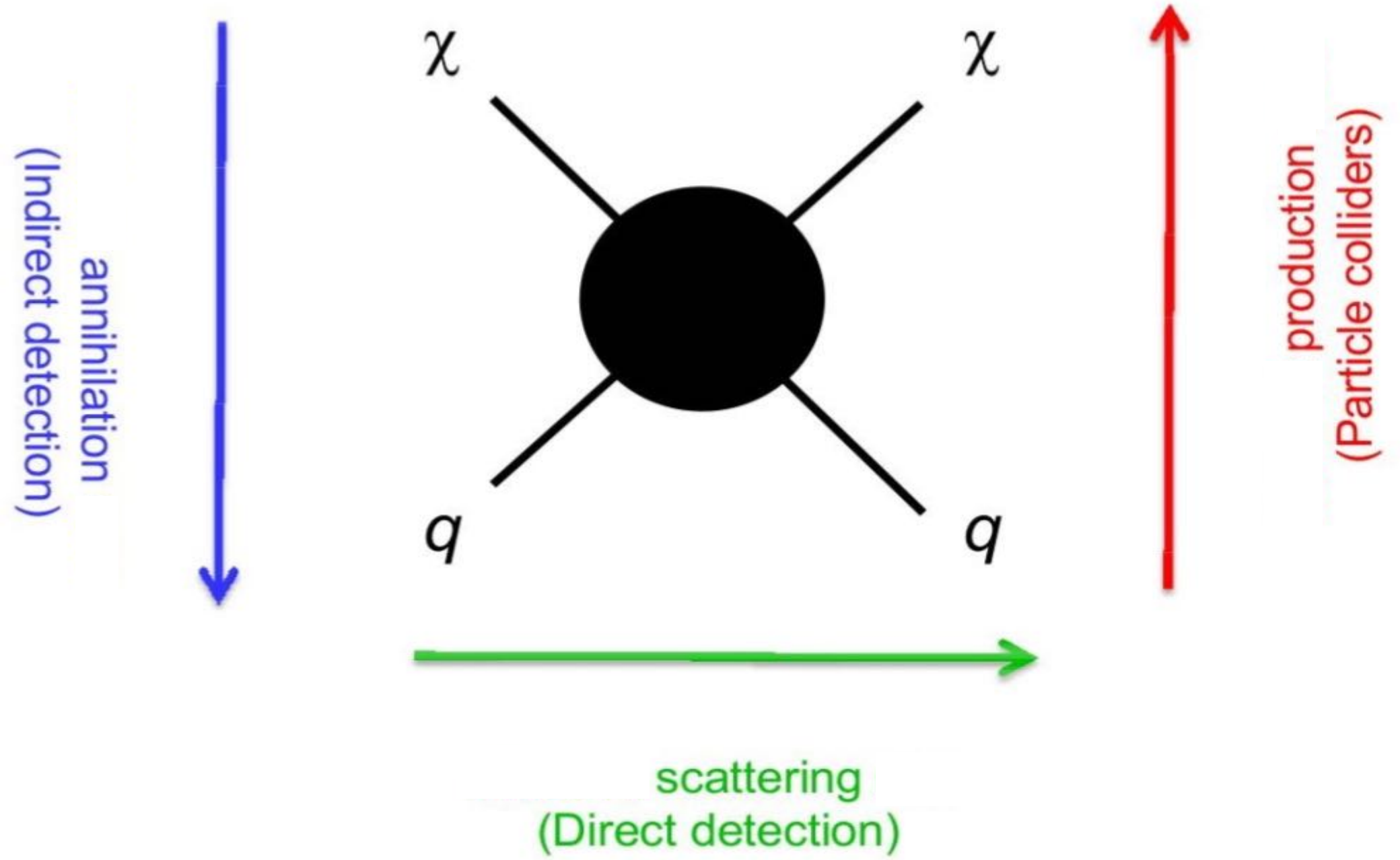
- Variation of GALPROP models
- Distribution of gas along the line of sight

- **Most significant sources of uncertainty are:**

- Fermi bubbles morphology at low latitude
- Sources of CR electrons near the GC

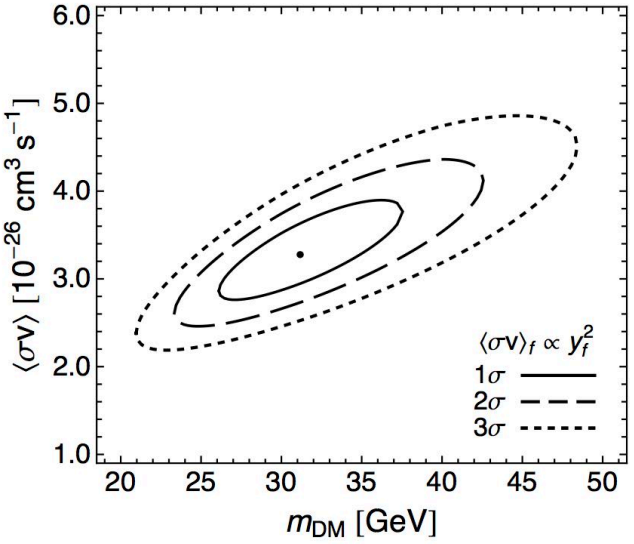
Fermi-LAT Collaboration **in preparation**

see the talk of Dmitry Malyshev this morning

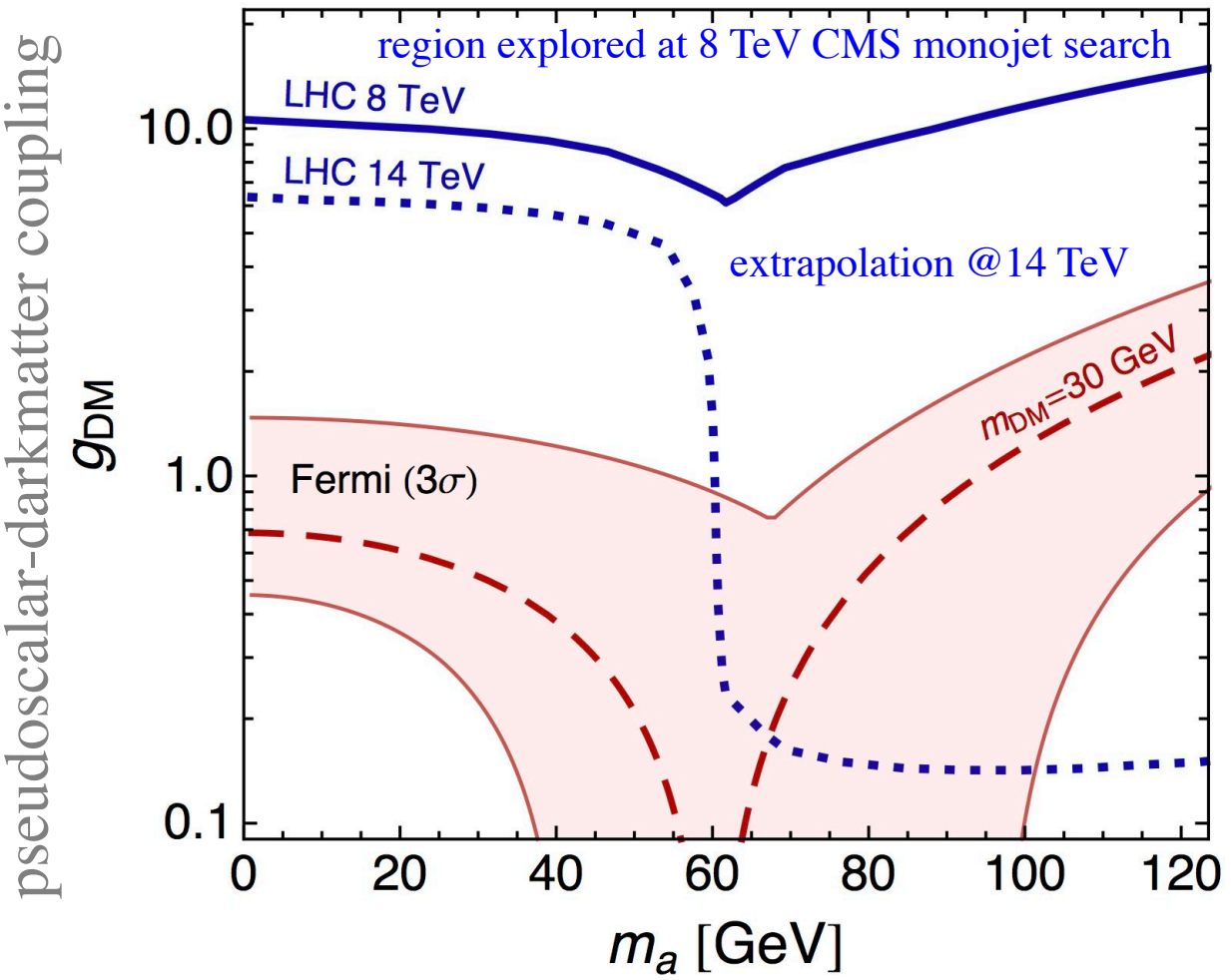

annihilation
(Indirect detection)
χ
χ
q
q
production
(Particle colliders)
scattering
(Direct detection)

Galactic Center and Dark Matter

GeV excess fit



note:this plot is valid only for a particular model of coy Dirac dark matter that annihilates primarily into b quarks via a pseudoscalar



Se non è vero è ben trovato

(If it is not true, it is well conceived)

Bœhm et al. JCAP05(2014)009

arXiv:1401.6458

The GeV excess : Other explanations exist

- past activity of the Galactic center

(e.g. Petrovic et al., arXiv:1405.7928, Carlson & Profumo arXiv:1405.7685)

- Population of millisecond Pulsars around the Galactic Center

(e.g. , Yuan and Zhang arXiv:1404.2318v1, Lee et al. arXiv:1506.05124
Bartels et.al. 1506.05104)

- Series of Leptonic Cosmic-Ray Outbursts

Cholis et al. arXiv:1506.05119

- Stellar population of the X-bulge and the nuclear bulge

Macias et al. arXiv:1611.06644

- Molecular Clouds in the disk

De Boer et al. arXiv:1610.08926

- Different diffusion coefficent in the GC region

.....

How to discriminate between different hypothesis ?

How to discriminate between different hypothesis ?

eROSITA

- Modeling of the Fermi bubbles
- Look for correlated features near the Galactic center

HESS, MAGIC, CTA

- Fermi bubbles near the GC are much brighter
- Possible to see with Cherenkov telescopes?

Radio observations, MeerKAT, SKA

- Search for individual pulsars in the halo around the GC

Radio surveys, Planck

- Look for correlated synchrotron emission near the GC

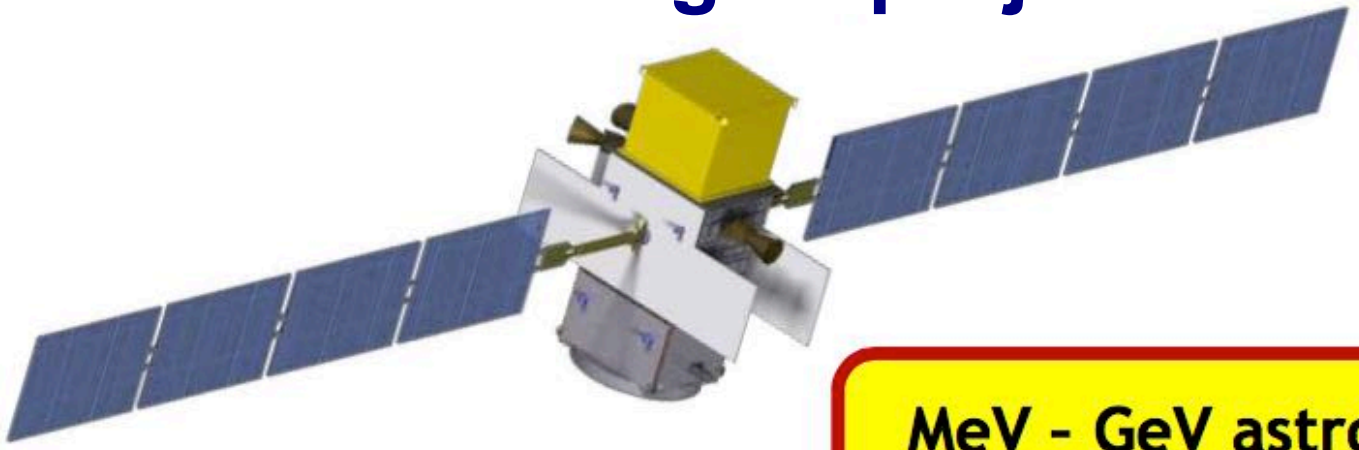
More Fermi LAT analysis

- Diffuse emission modeling
- Analysis of point sources near the GC

But ultimately We need a new experiment with better angular resolution below 100 MeV

The next gamma-ray MeV-GeV mission:

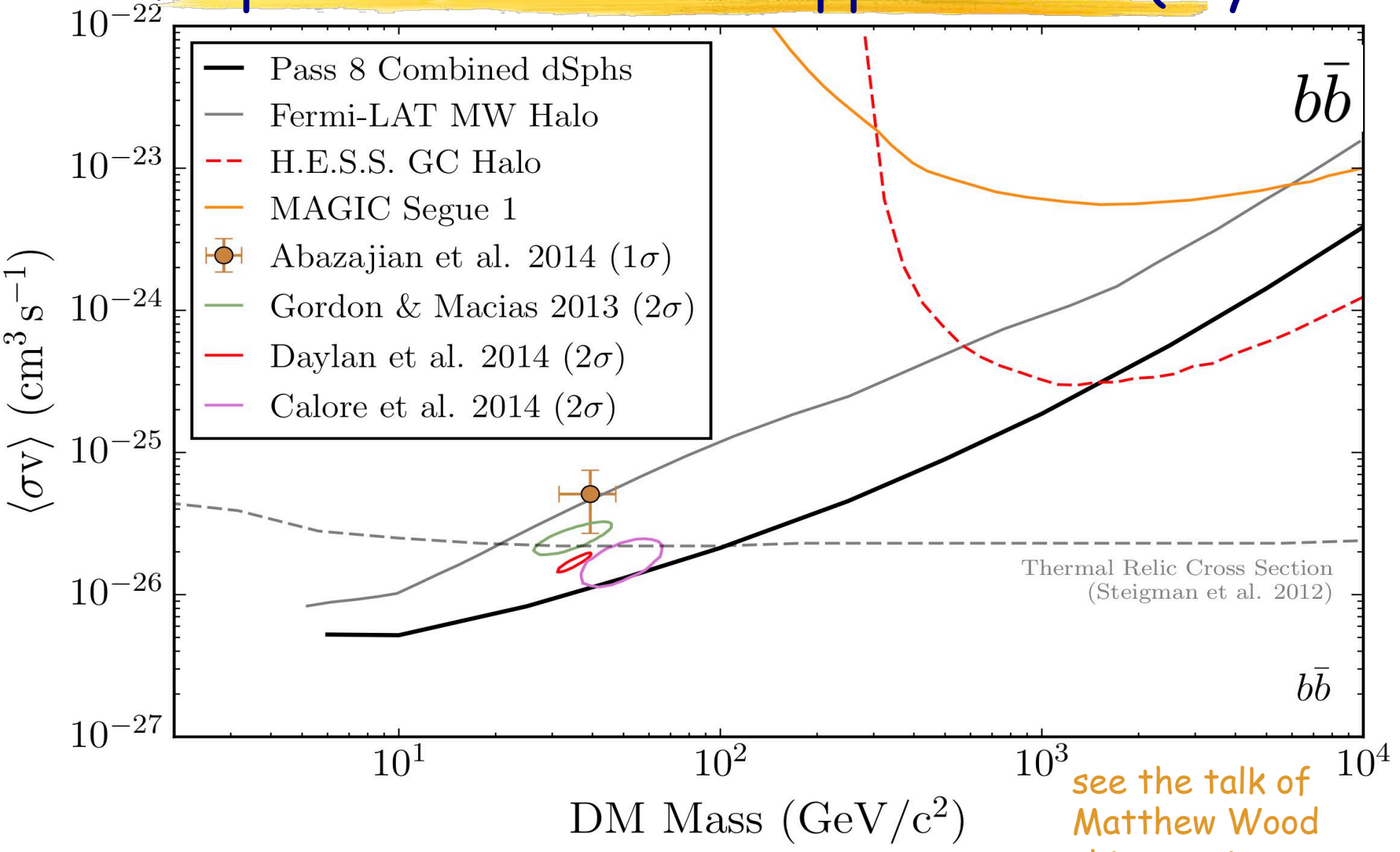
the e-Astrogam project



MeV - GeV astrophysics
MeV - GeV community

Proposed for the ESA M4 call; currently under study for enhancement and reconfiguration for the ESA M5 call. ASTROGAM is **focused on gamma-ray astrophysics in the range 0.3-100 MeV** with excellent capability also at GeV energies.

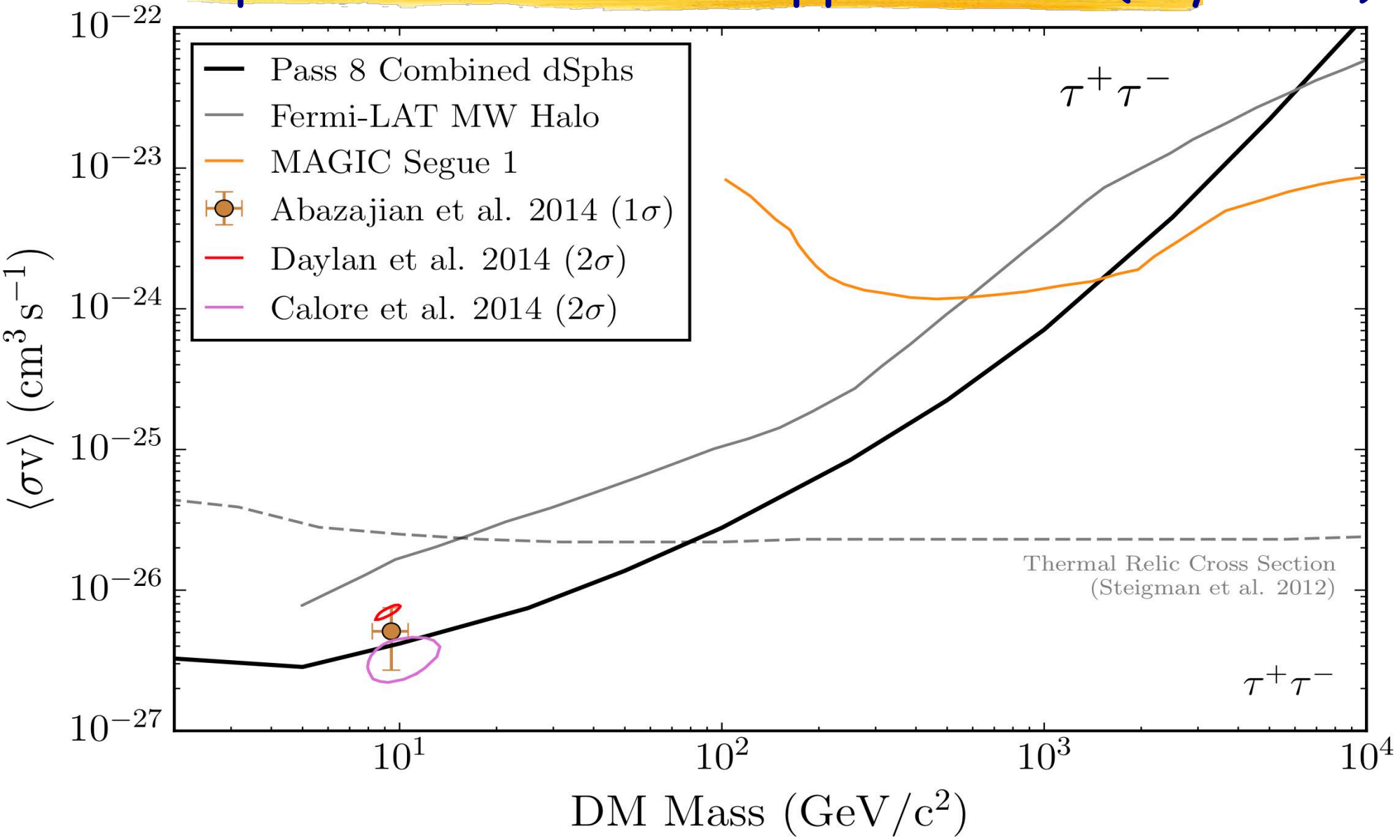
Dwarf Spheroidal Galaxies upper-limits (6 years)



see the talk of Matthew Wood this morning

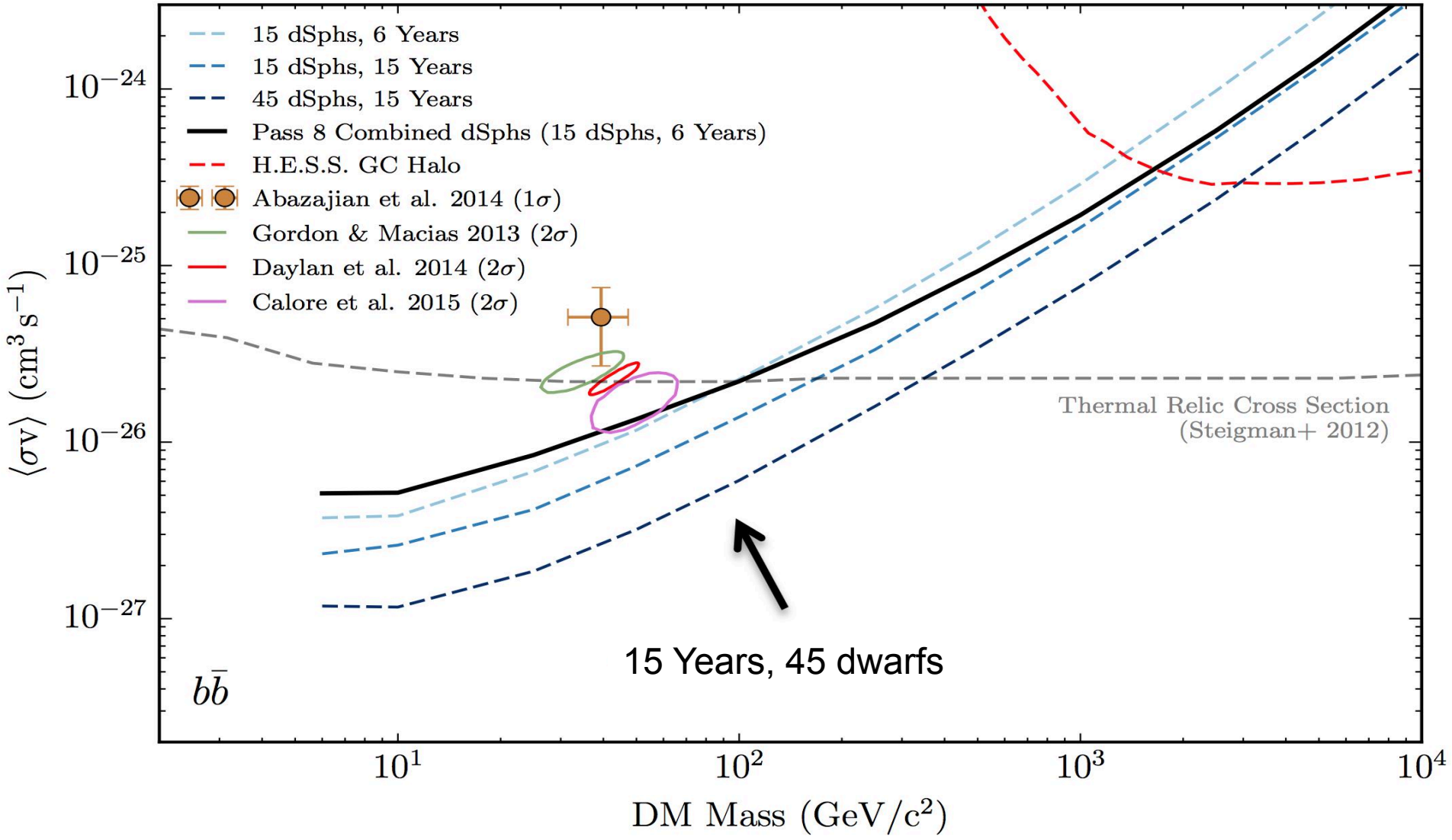
M.Ackermann et al., [Fermi Coll.] PRL 115, 231301 (2015) [arXiv:1503.02641]

Dwarf Spheroidal Galaxies upper-limits (6 years)

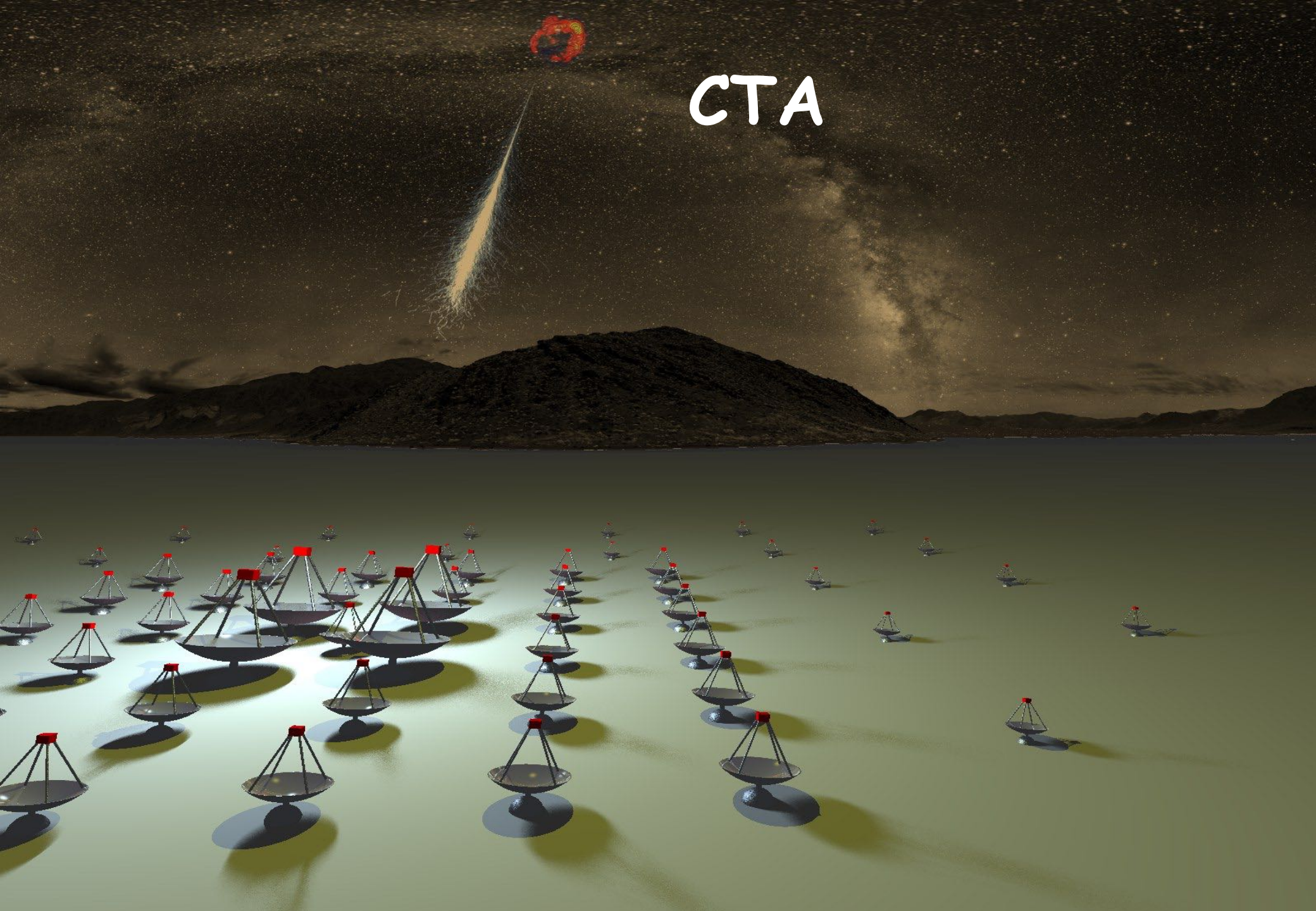


M.Ackermann et al., [Fermi Coll.] PRL 115, 231301 (2015) [arXiv:1503.02641]

DM limit improvement estimate in 15 years with the composite likelihood approach (2008- 2023)



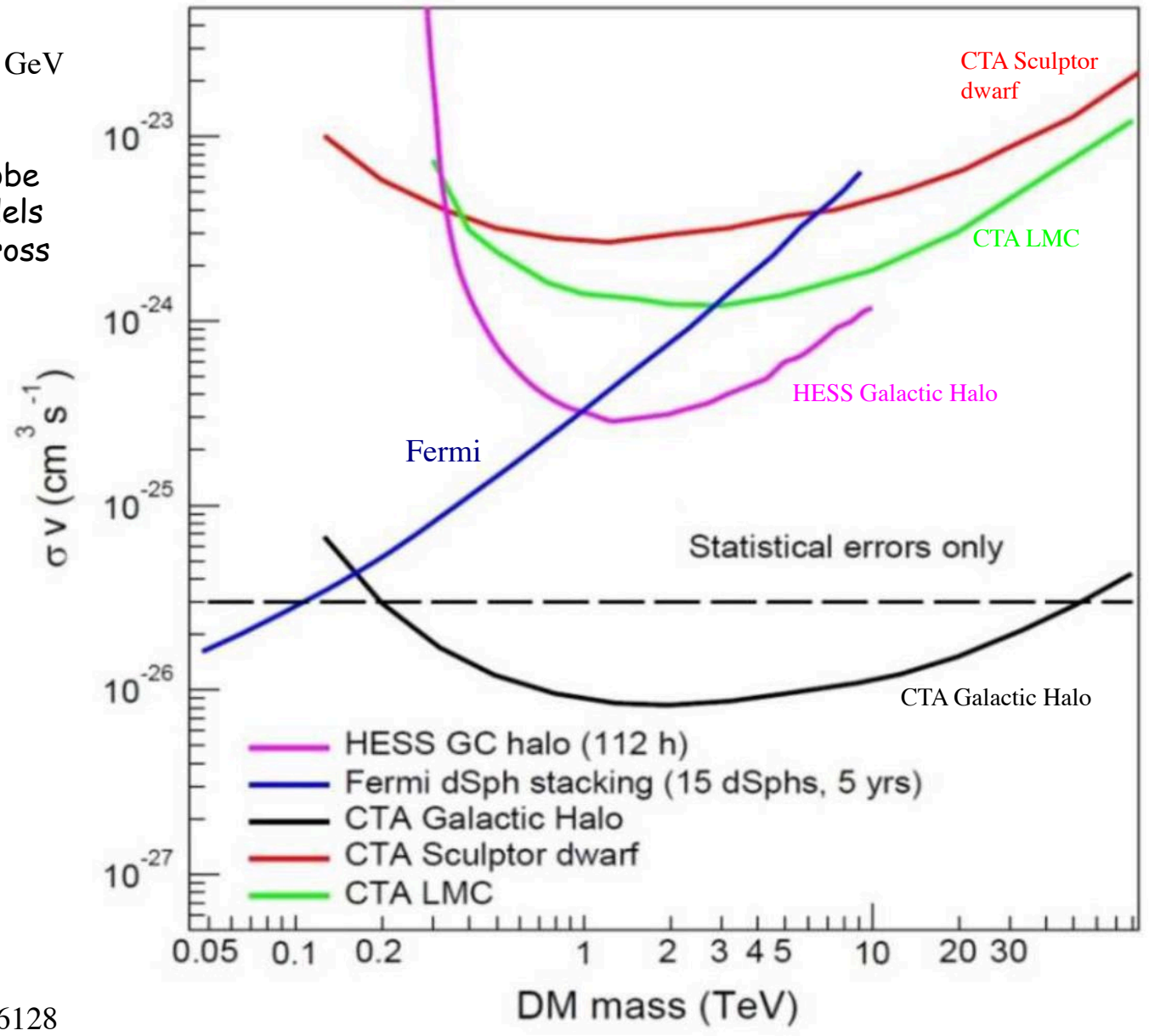
E. Charles et.al, Phy Rep. 636 2016, arXiv:1605.02016


CTA

HESS, FERMI, CTA DM upper-limits

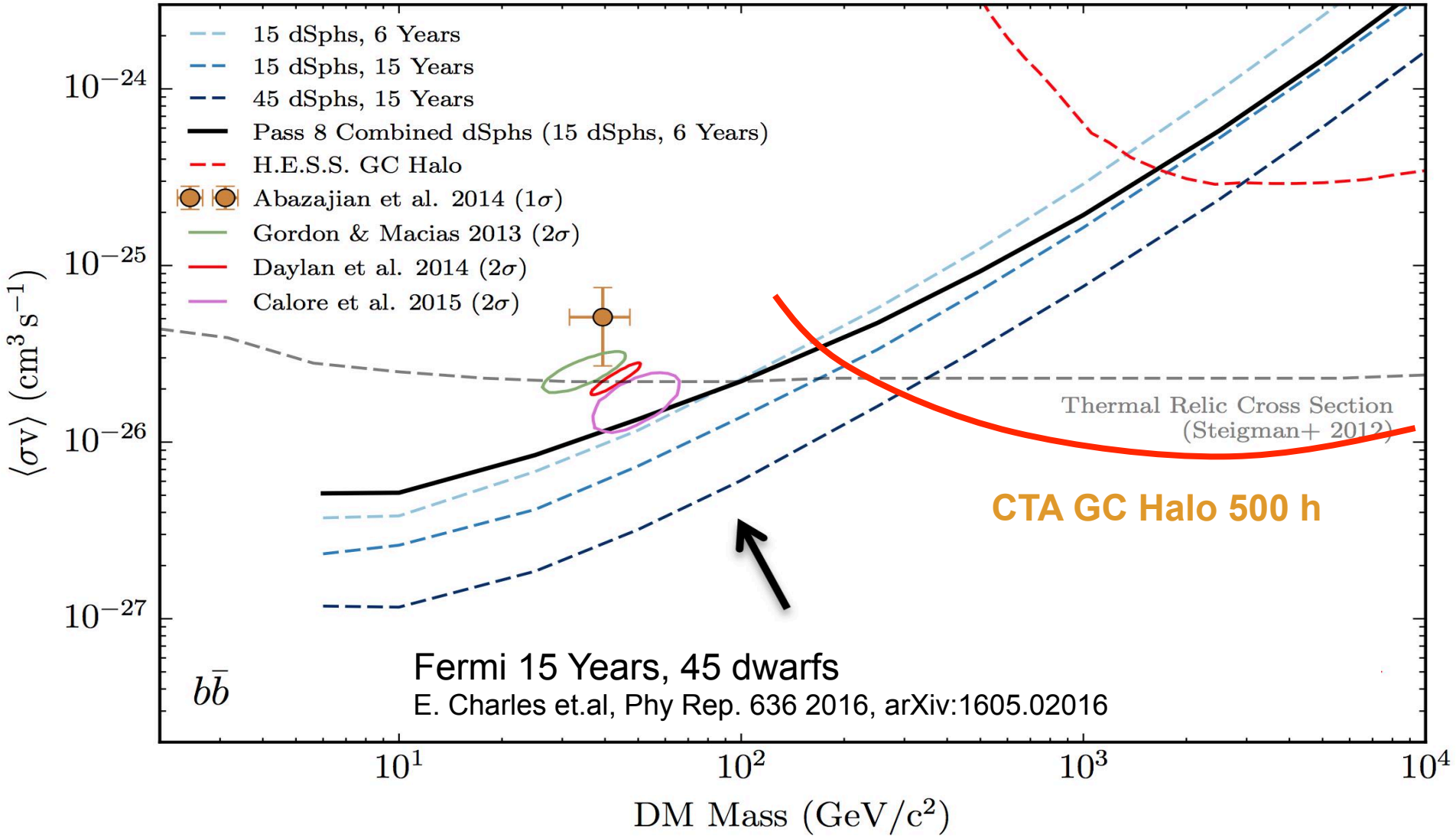
CTA 500 hr, statistical only, NFW, 30 GeV

Together Fermi and CTA will probe most of the space of WIMP models with thermal relic annihilation cross section



Carr et al. 2015 arXiv:1508.06128

DM limit improvement estimate in 15 years (2008- 2023)



CTA sensitivity curve from Carr et al. 2015 500 hr, statistical only, NFW, 30 GeV threshold arXiv:1508.06128

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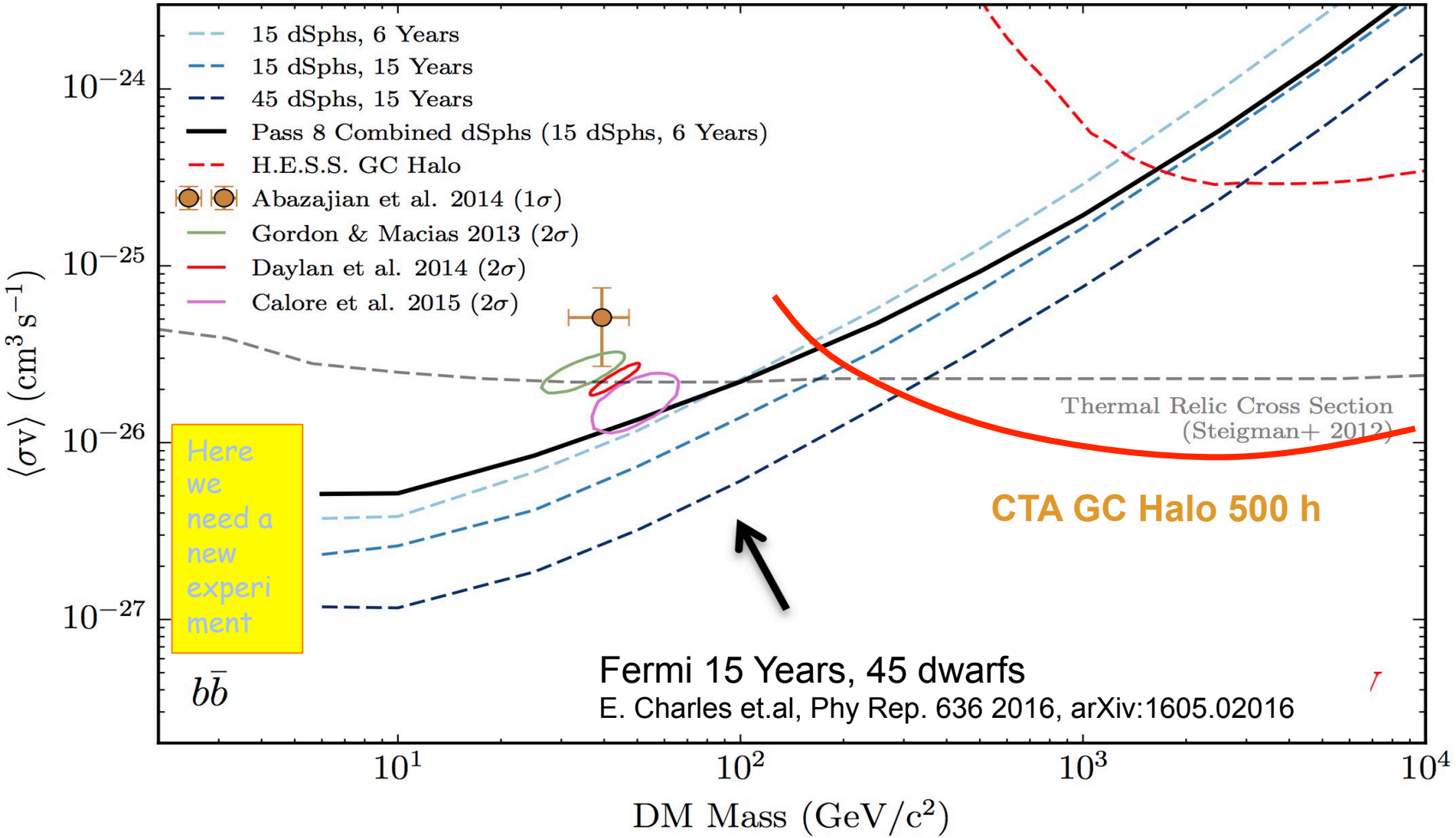

CTA sensitivity curve from Carr et al. 2015 500 hr, statistical only, NFW, 30 GeV threshold arXiv:1508.06128

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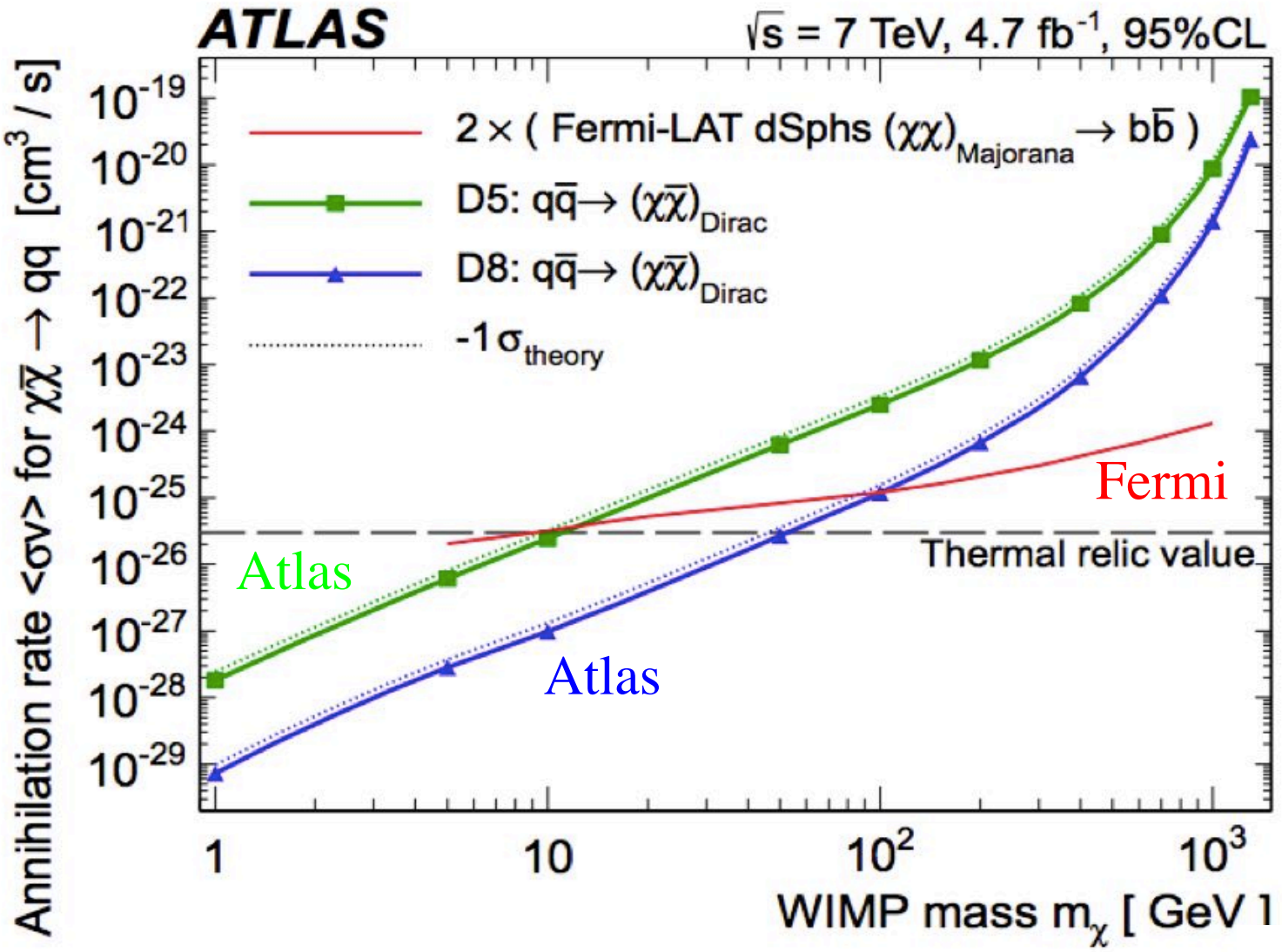
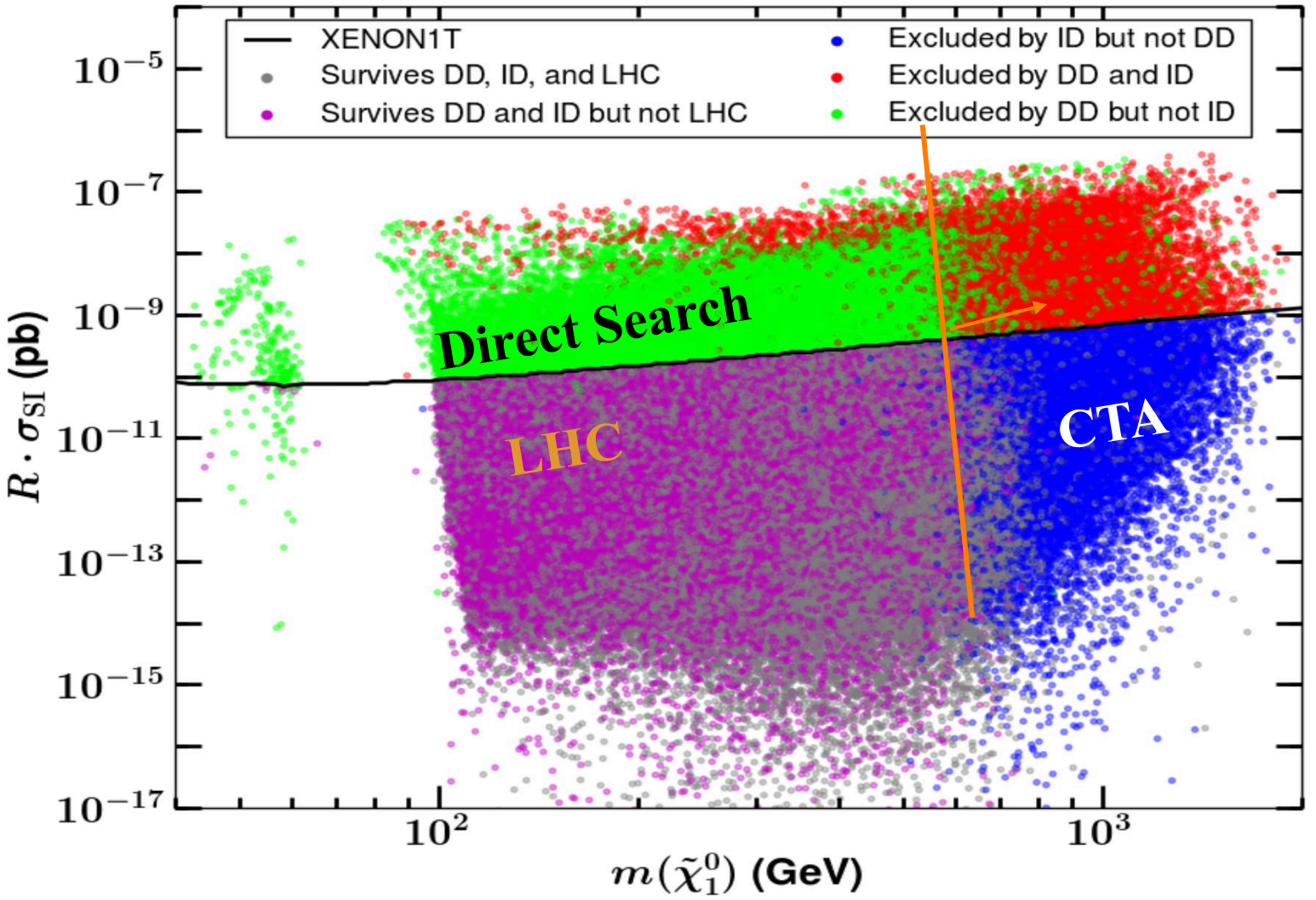
ATLAS-Fermi Results



note: ATLAS limits are for the four light quark flavours assuming equal coupling strengths for all quark flavours to the WIMPs

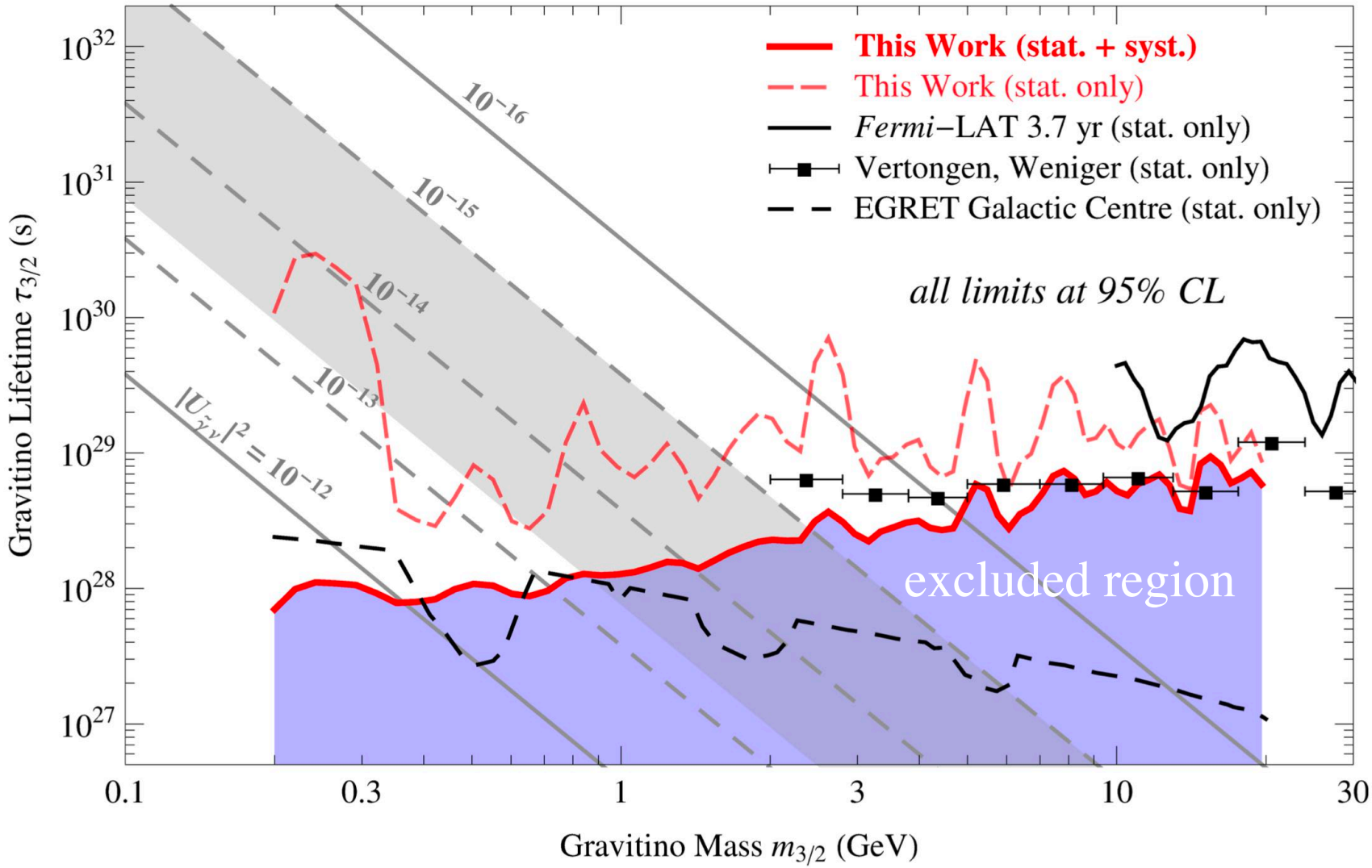
Atlas Coll. JHEP 1304 (2013) 075 arXiv:1210.4491

Complementarity and Searches for Dark Matter in the pMSSM



Cahill-Rowley et al. arXiv: 1305.6921

Low Energy Line Search



A.Albert et. al. JCAP 10(2014) 023,[arXiv:1406.3430]

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).
- A great number of dark matter theoretical model has been inspired by the Fermi data
- In the future it would be extremely important to extend the energy range of experiments at lower energies (compared to the Fermi energies)(e-AstroGAM, AMEGO) and higher energies (CTA)

Prospects in indirect detection of dark matter from 300 KeV to 100 TeV