Indirect Search for Dark Matter in Cosmic Rays

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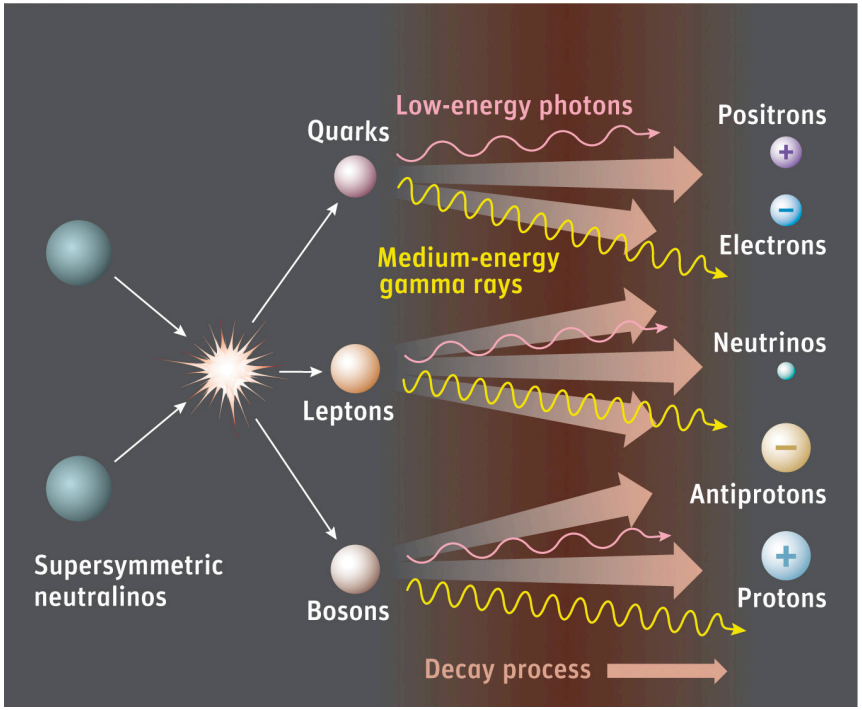
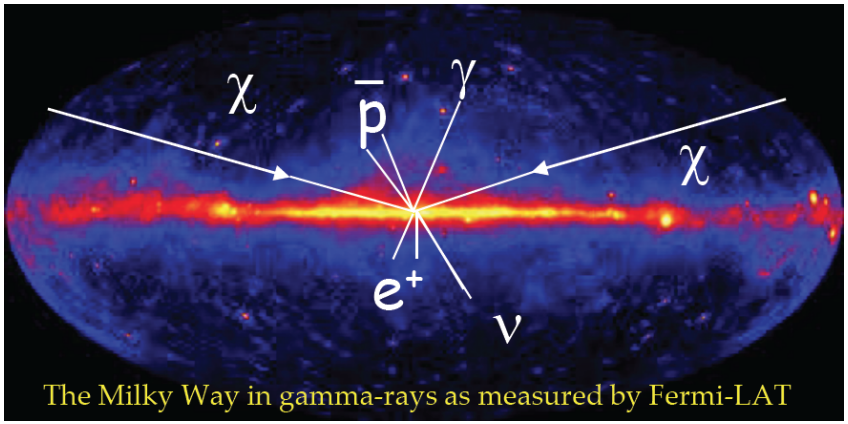
Dark Matter indirect search

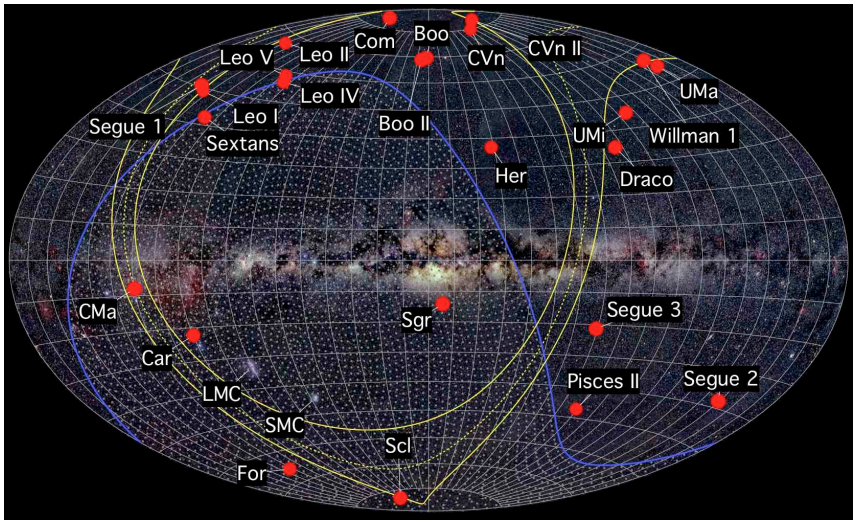


Annihilation rate $\propto n^2 \langle\sigma v\rangle$

Galactic Center

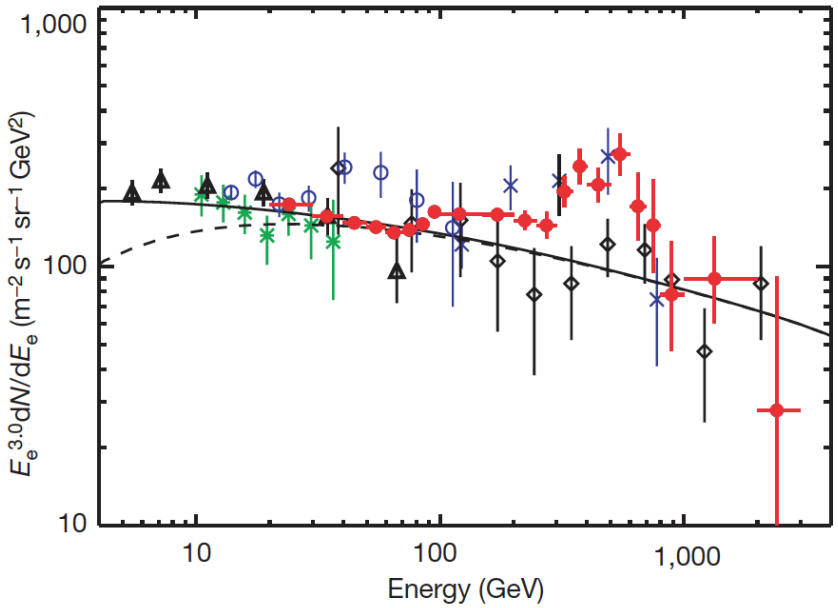


Dwarf Sph. Galaxies
High M/L ration
D= a few 10s kpc-100kpc



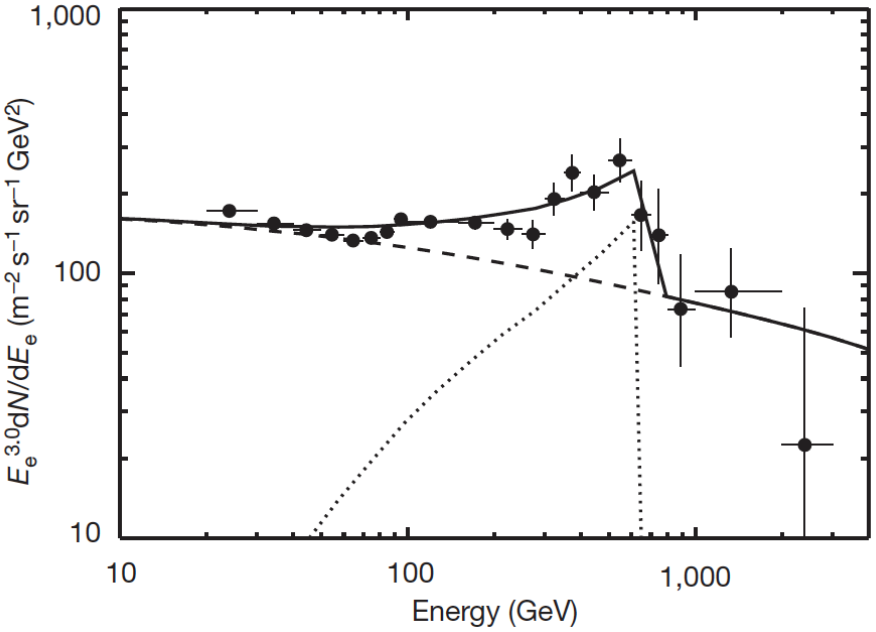
Observations of
High energy cosmic electrons

Electron Anomaly observed ATIC
An excess of cosmic ray electrons at energies of 300-800GeV



ATIC Electron Spectrum
Chang et al. in Nature 2008

ATIC, PPB-BETS



K-K particles annihilation
No suppression of e+e- pairs

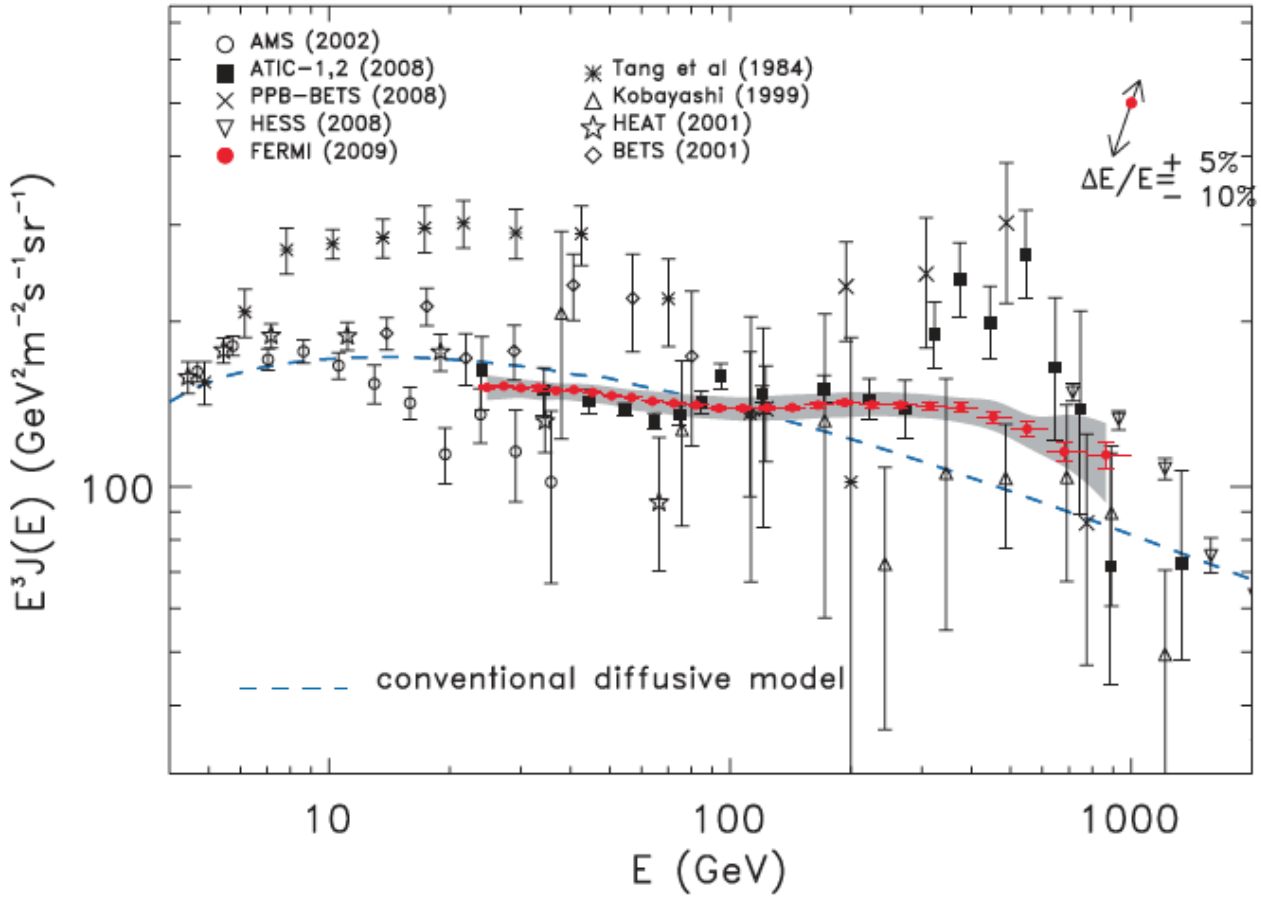
~0.4GeV/cm^3
Mass of KK particles 620GeV

$\langle\sigma v\rangle$ ~10^{-23} cm^{3}s^{-1}
~300 times higher than
canonical annihilation rate

IC peak at GeV in gamma

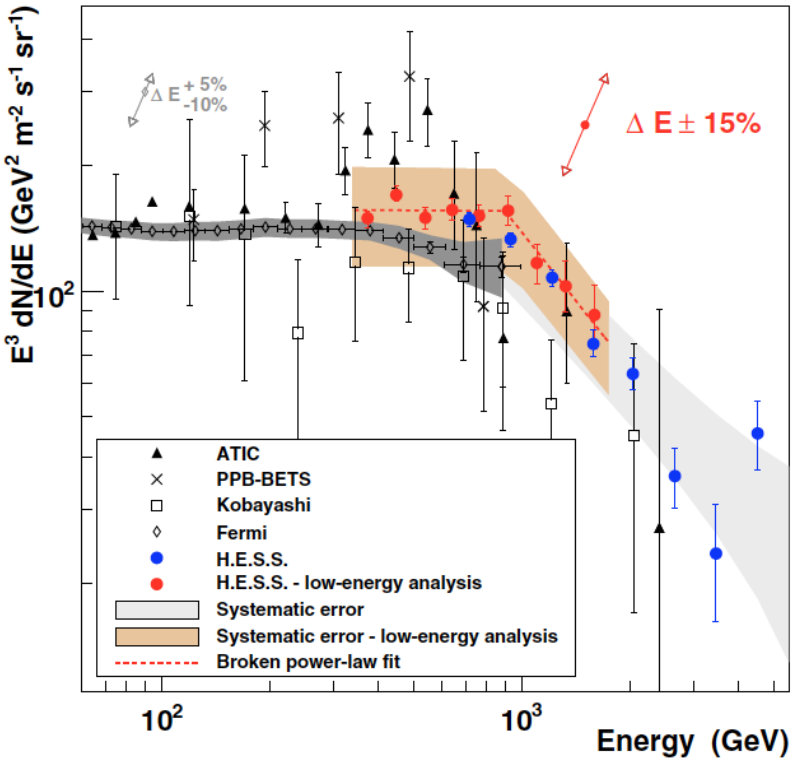
Electron Energy Spectrum observed by Fermi PRL 2009

Sharp bump in the electron energy spectrum disappeared
But anomalous broad excess was found/confirmed.

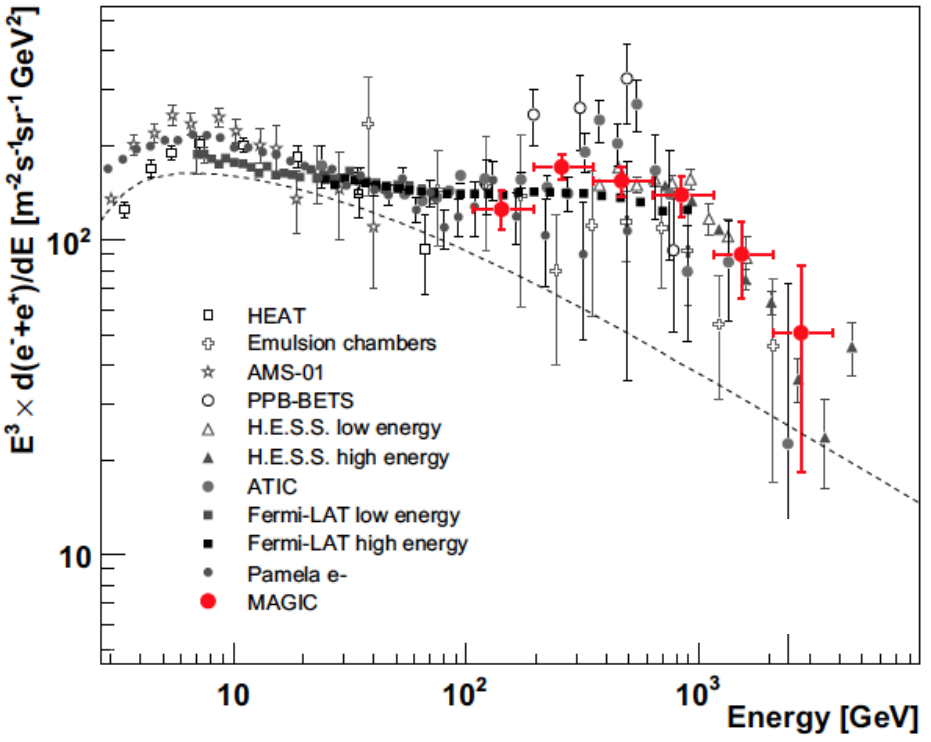


High energy electron measurements with IACTs

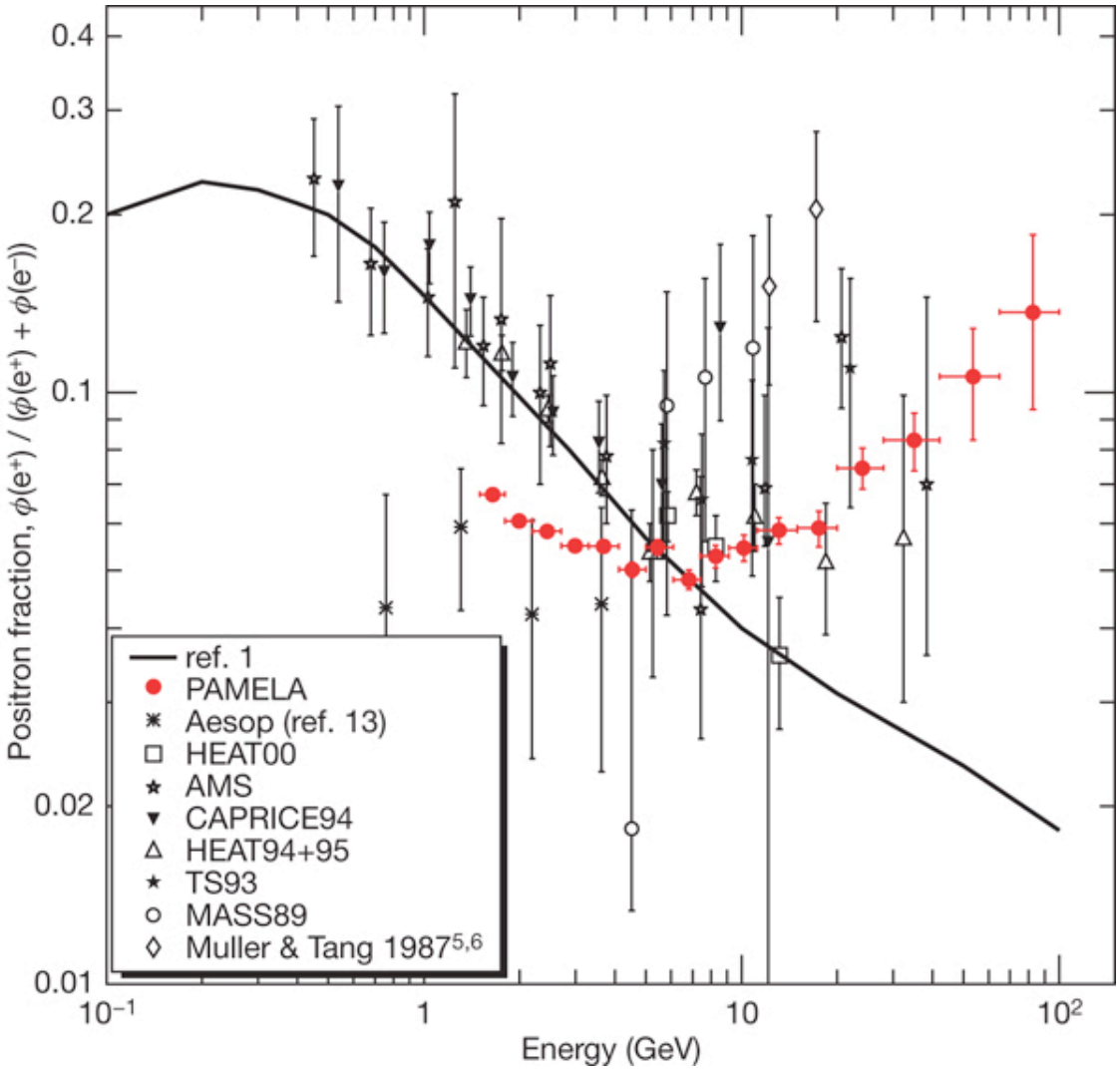
HESS A&A 2009



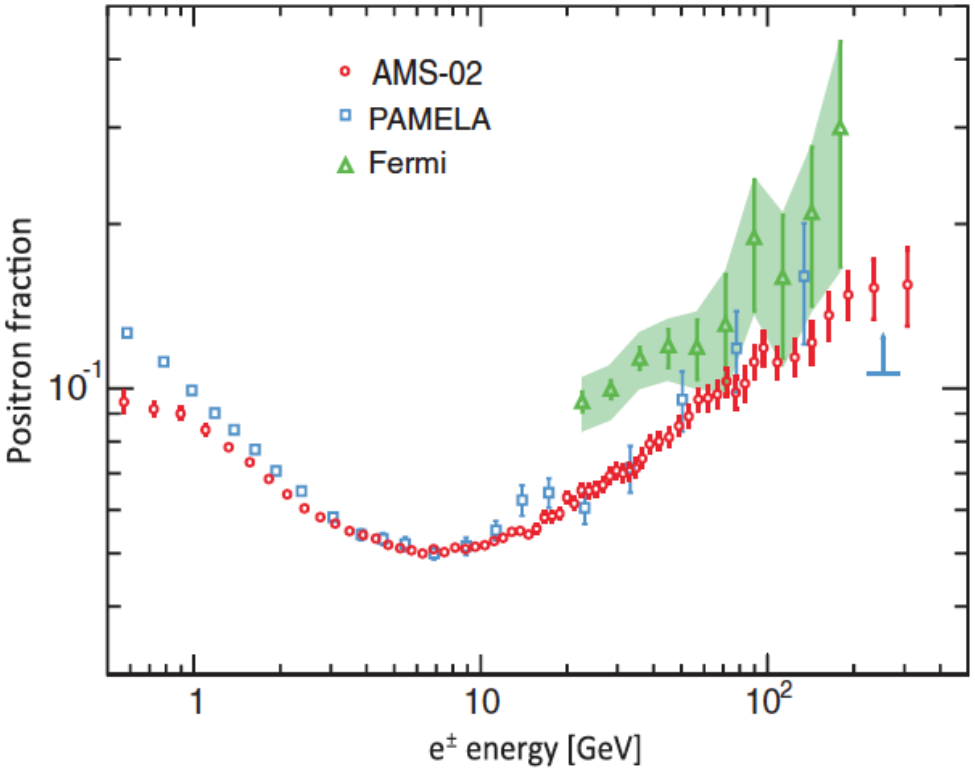
MAGIC 2011



Anomalous positron fraction observed by Pamela in Nature 2008



Anomalous positron fraction observed by AMS-02 in PRL 2013

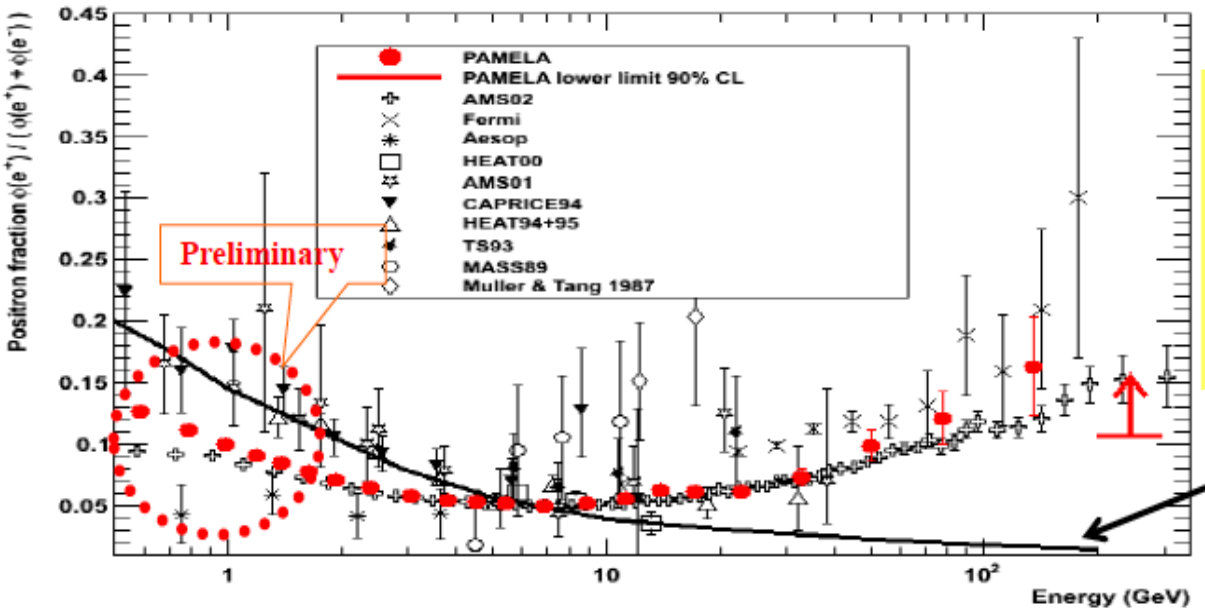


$$\Phi_{e^+} = C_{e^+} E^{-\gamma_{e^+}} + C_s E^{-\gamma_s} e^{-E/E_s}; \quad (1)$$

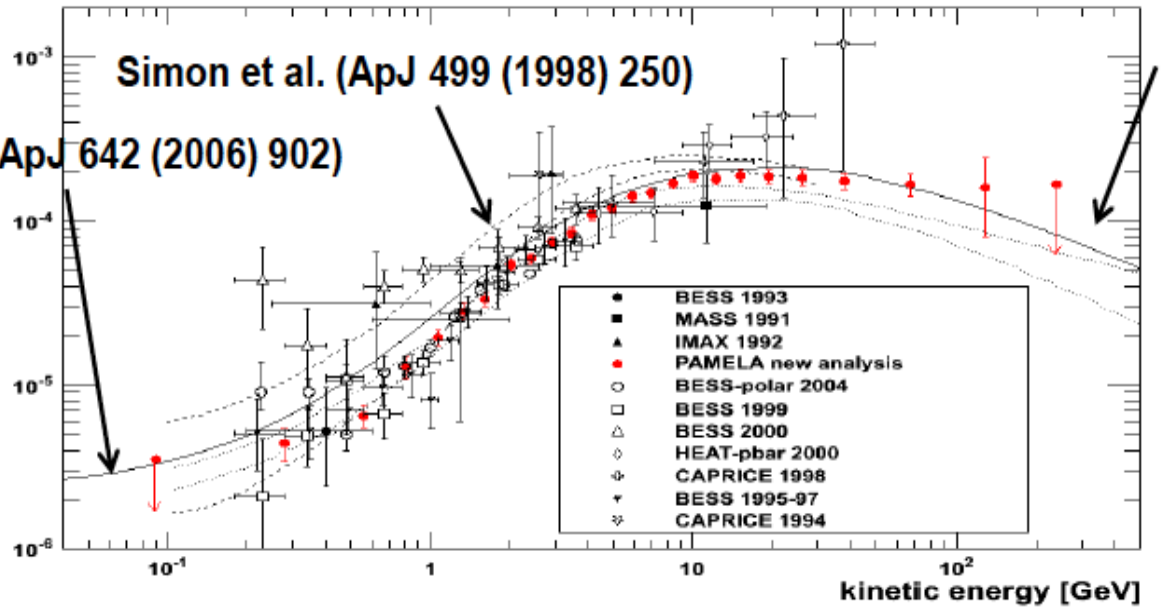
$$\Phi_{e^-} = C_{e^-} E^{-\gamma_{e^-}} + C_s E^{-\gamma_s} e^{-E/E_s} \quad (2)$$

C_{e+}, C_{e-}: Diffuse components of e+ and e-

Cs: some new source (single source)



CR Positron spectrum significantly harder than expectations from secondary production Moskalenko & Strong 98



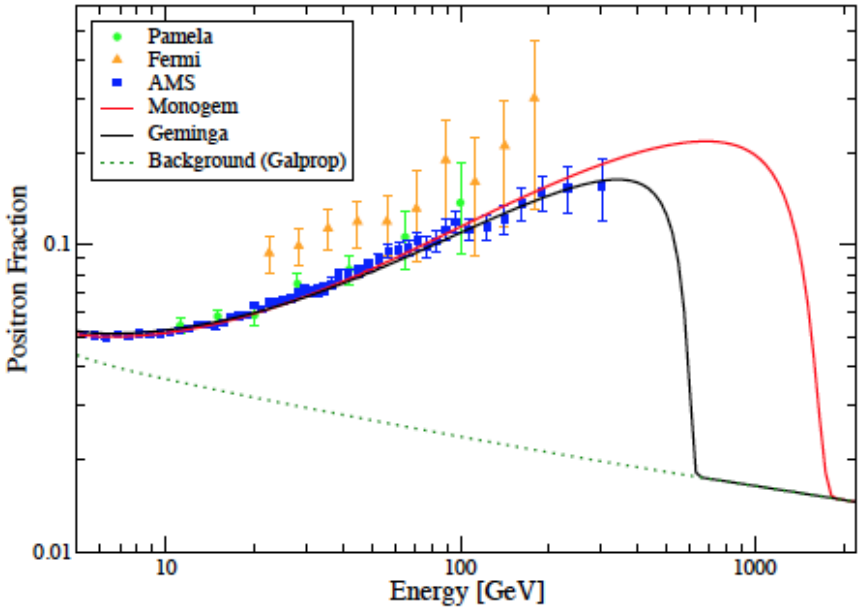
Donato et al. (PRL 102 (2009) 071301)

But antiprotons in CRs are in agreement with secondary production

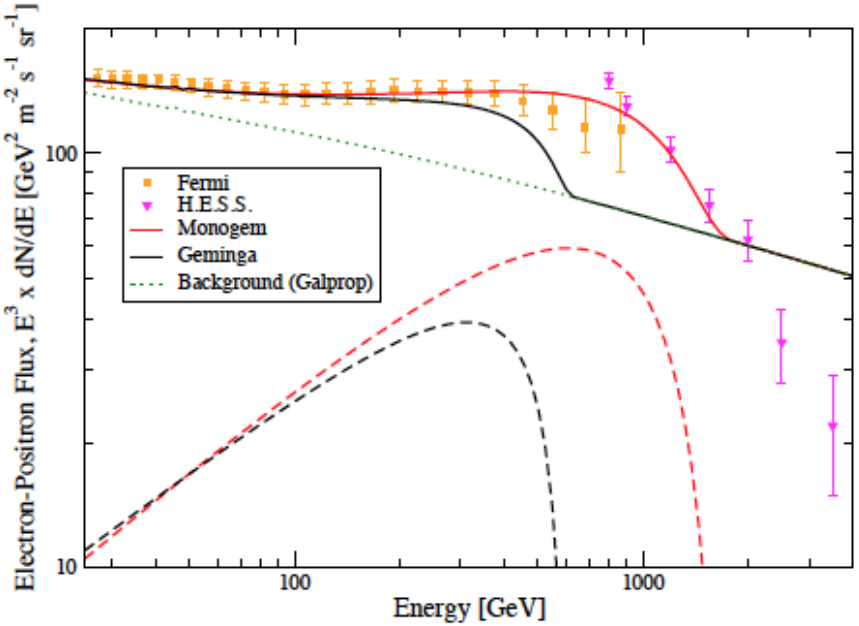
Courtesy of M.Boezio

An example of the modeling with the local sources Geminga and Monogem by Linden and Profumo 2013

e+ fraction anomaly



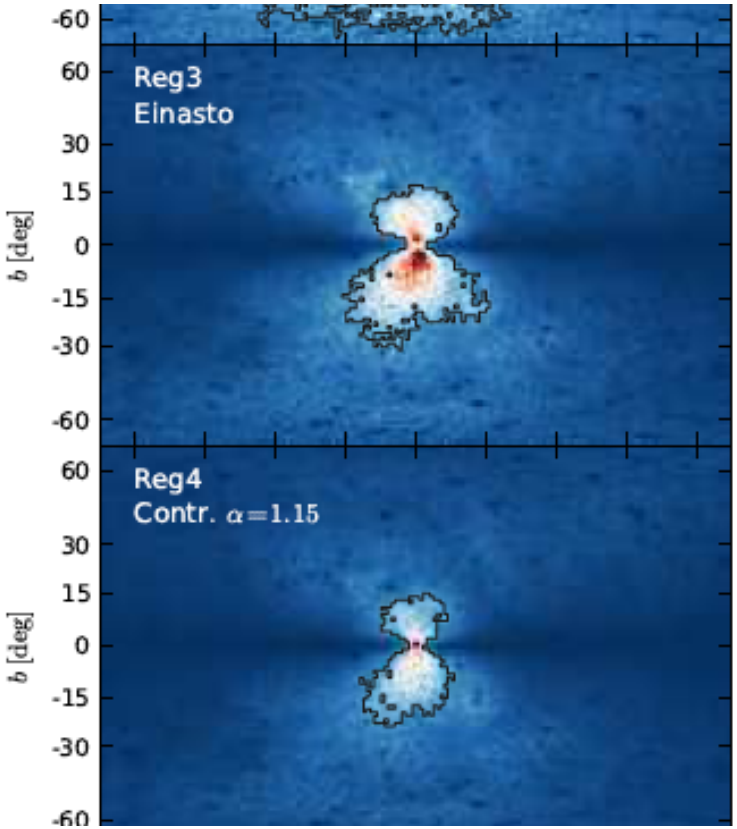
Electron (e+, e-) spectrum

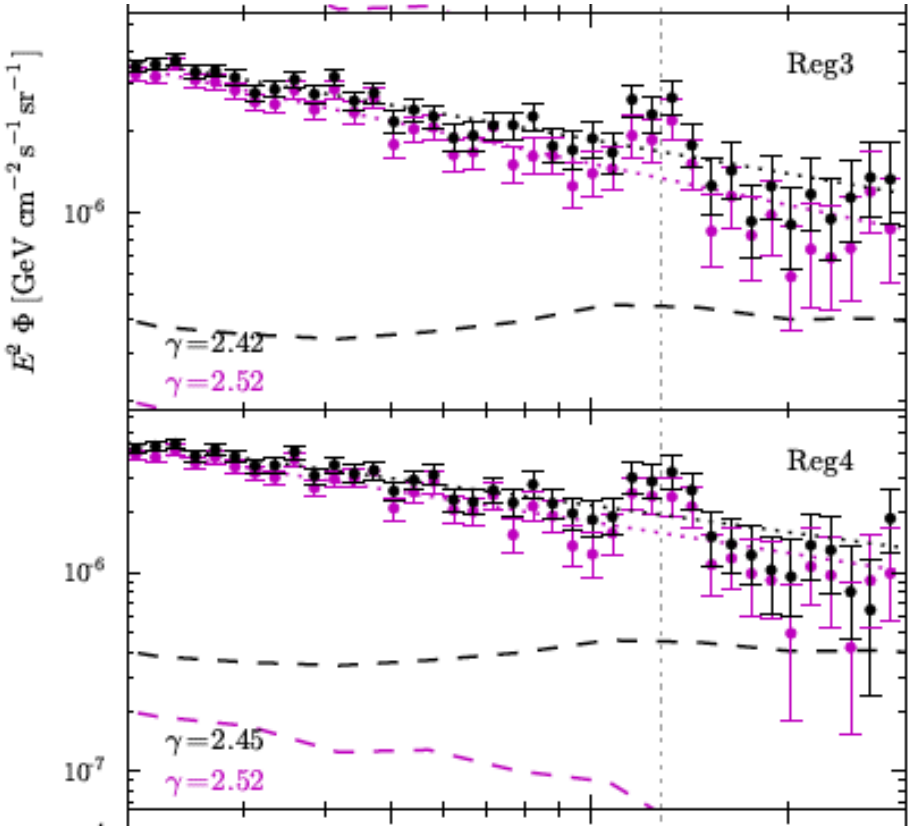


Observations of
High Energy Gamma Rays

130GeV Line feature in gamma rays from Galactic Center in Fermi-LAT data (43 months), C. Weniger in 2012

4.6 sigma excess (50 photons)
Flux ~ 2x 10^{-10} cm^{-2} s^{-1}
$\langle\sigma v\rangle$ = 1.27 x 10^{-27} cm^3 s^{-1}





Upper limit obtained with the refined Analysis by Fermi team (43 months)

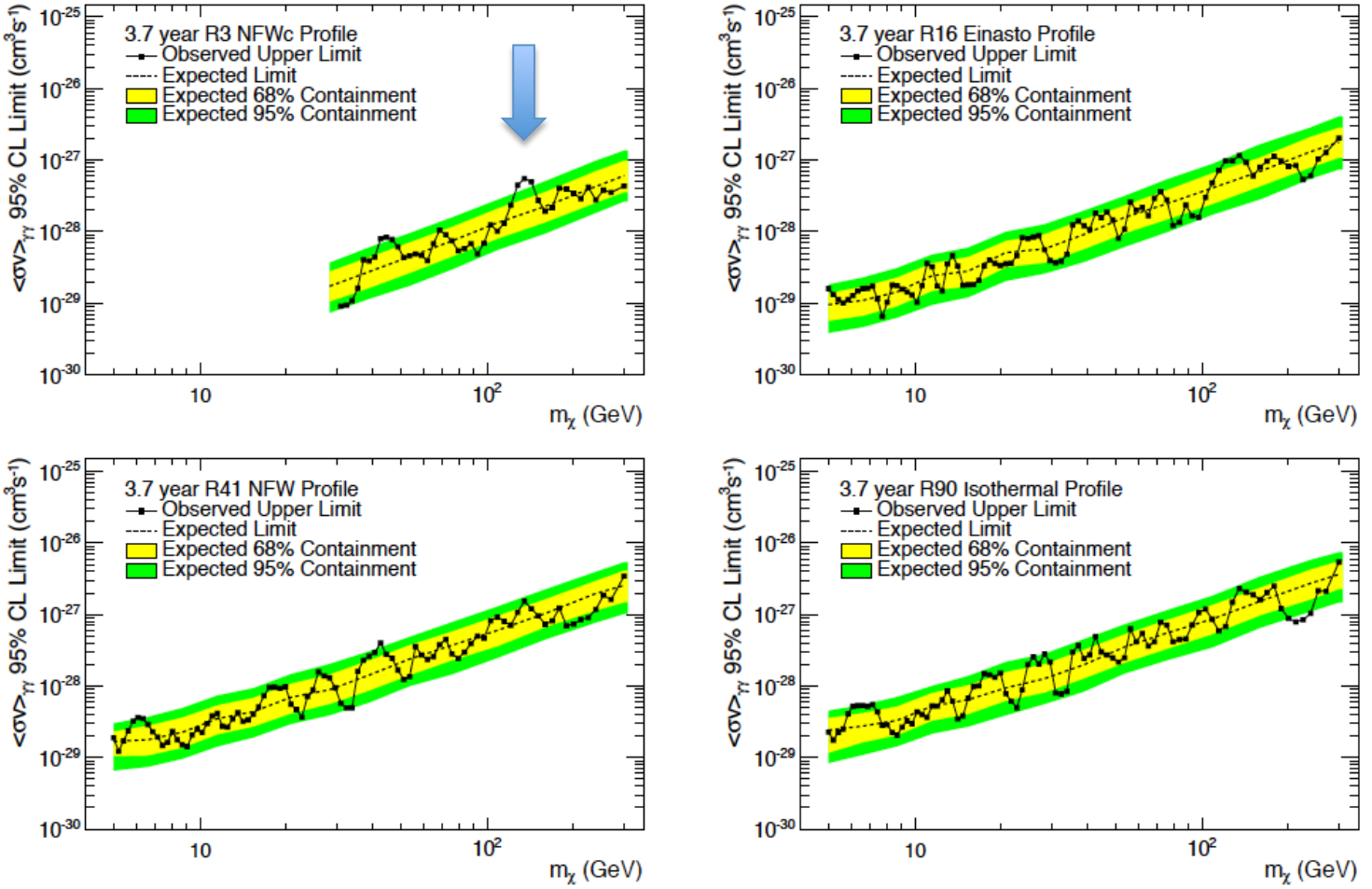
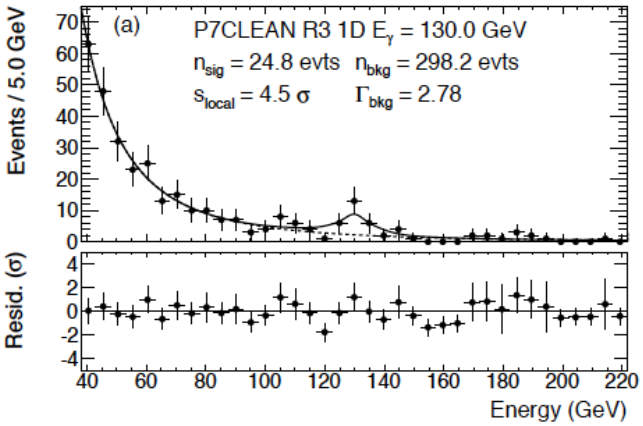
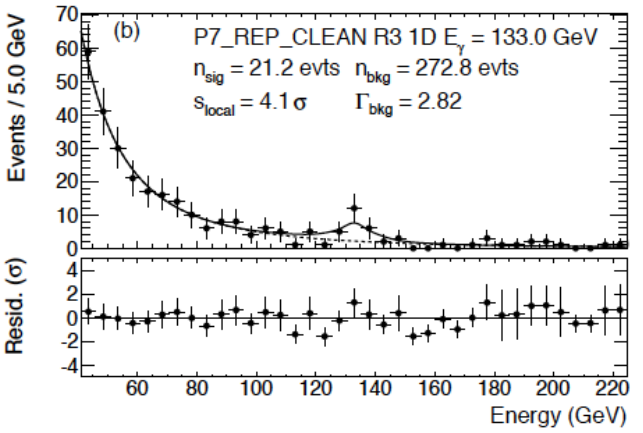


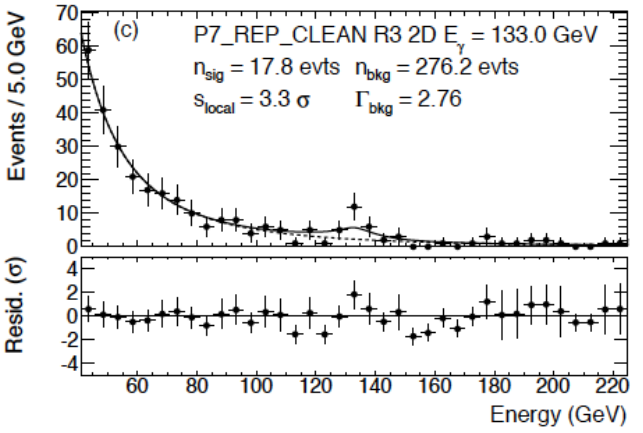
FIG. 9. 95% CL $\langle \sigma v \rangle_{\gamma\gamma}$ upper limits for each DM profile considered in the corresponding optimized ROI. Yellow (green) bands show the 68% (95%) expected containment derived from 1000 single-power-law (no DM) MC simulations. The dashed lines show the median expected limits from those simulations.

Galactic Center and Earth Limb Fermi Official

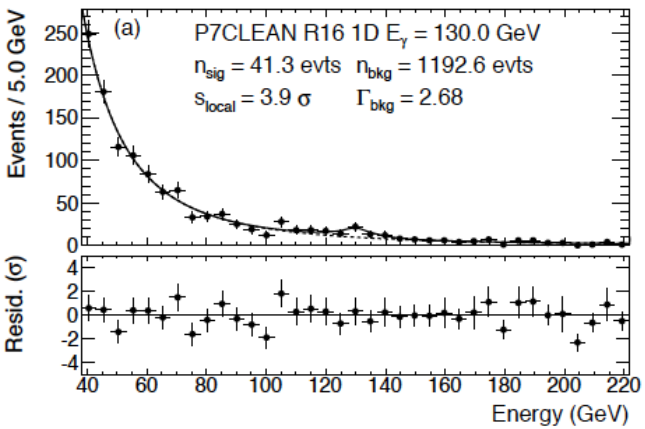
Galactic Center R3

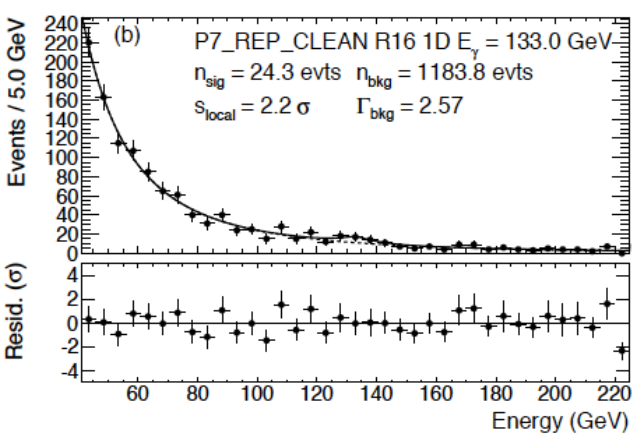


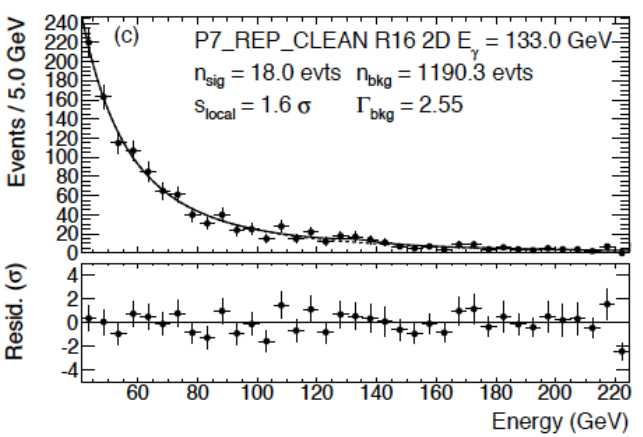




Earth Limb events

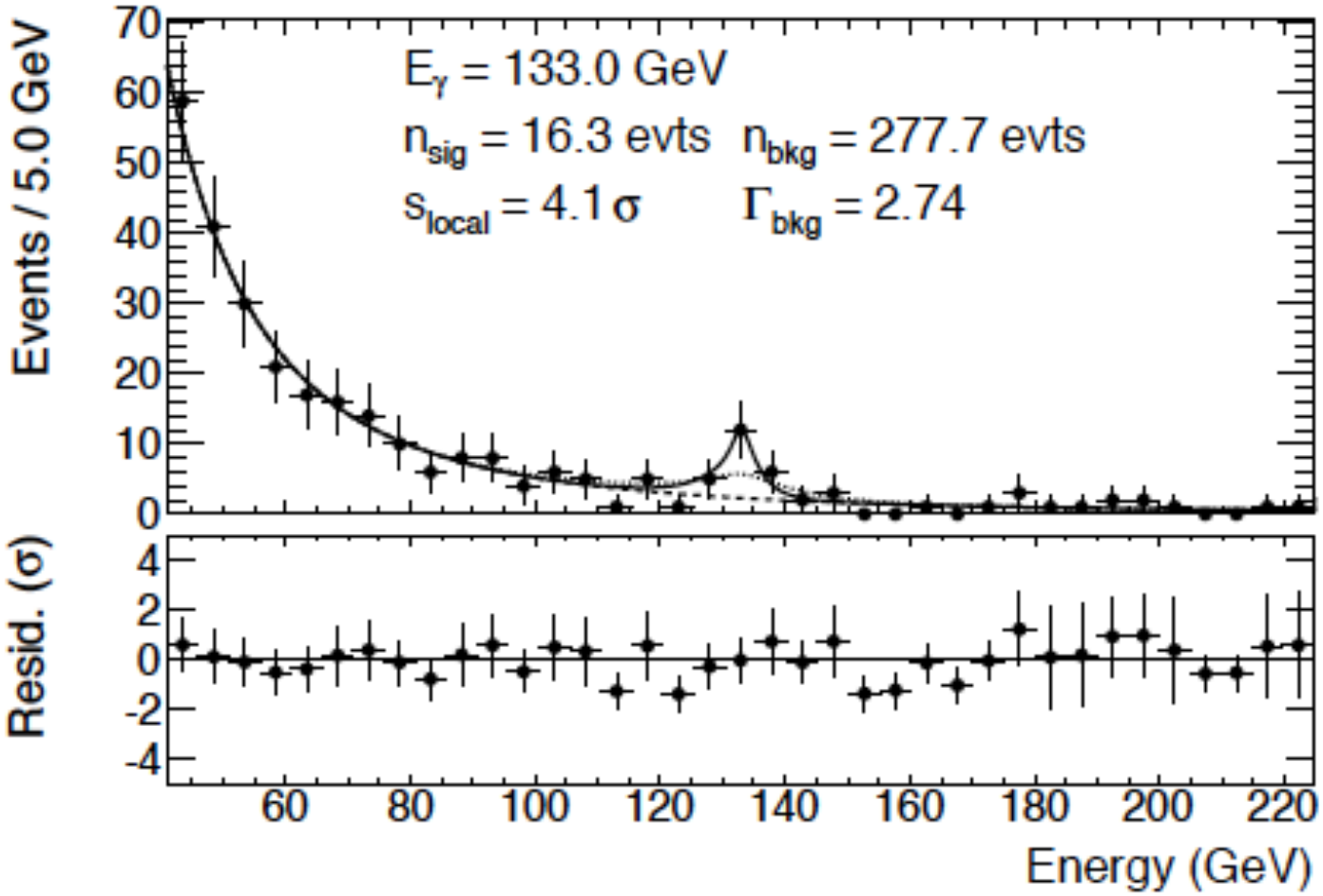






Analysis with 2D Energy Dispersion Model

Fit to a gamma-ray line at 133 GeV in the P7REP CLEAN R3 data using the 2D model including a scale factor for the width of the energy dispersion.



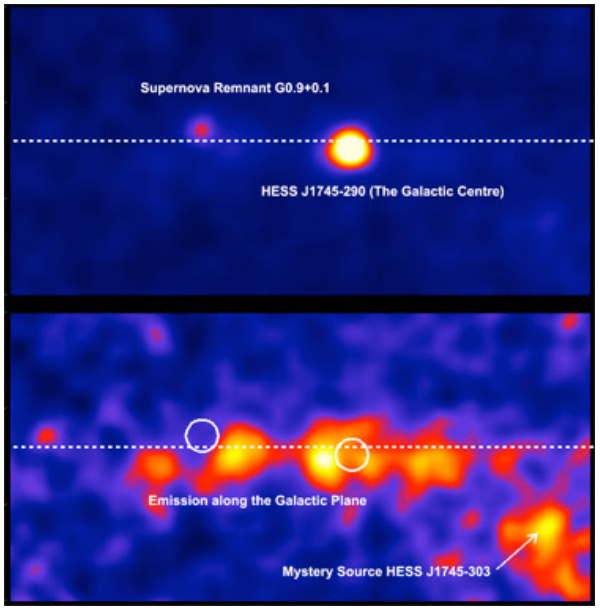
Conclusion and Summary in Fermi Paper (PRL 2013)

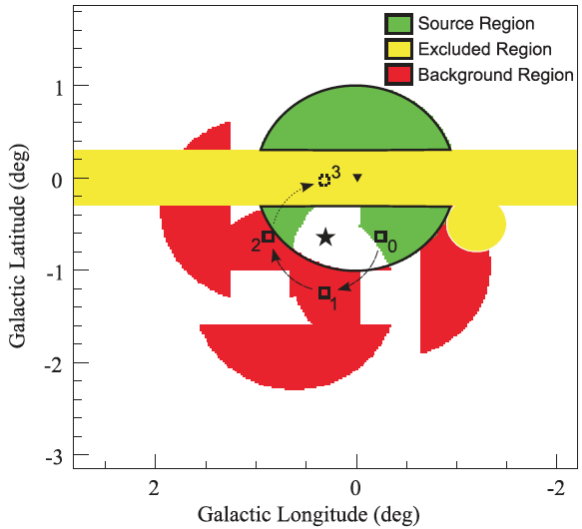
Reports of a line-like feature in the GC using the public data have appeared in the literature [25, 28, 30]. The authors calculated the flux of the source producing the line-like feature to be $\sim 2 \times 10^{-10}\text{cm}^{-2}\text{s}^{-1}$, which is not ruled out by our 95% CL $\Phi_{\gamma\gamma}$ limits in R3 ($3.4 \times 10^{-10}\text{cm}^{-2}\text{s}^{-1}$ for $E_\gamma = 135$ GeV, see Tab. IX). Additionally, these reported fluxes are similar to the mean value obtained from our fit at 133 GeV in R3 of $\Phi^{R3}_{\gamma\gamma}(E_\gamma = 133\text{ GeV}) = 1.9 \times 10^{-10}\text{cm}^{-2}\text{s}^{-1}$.

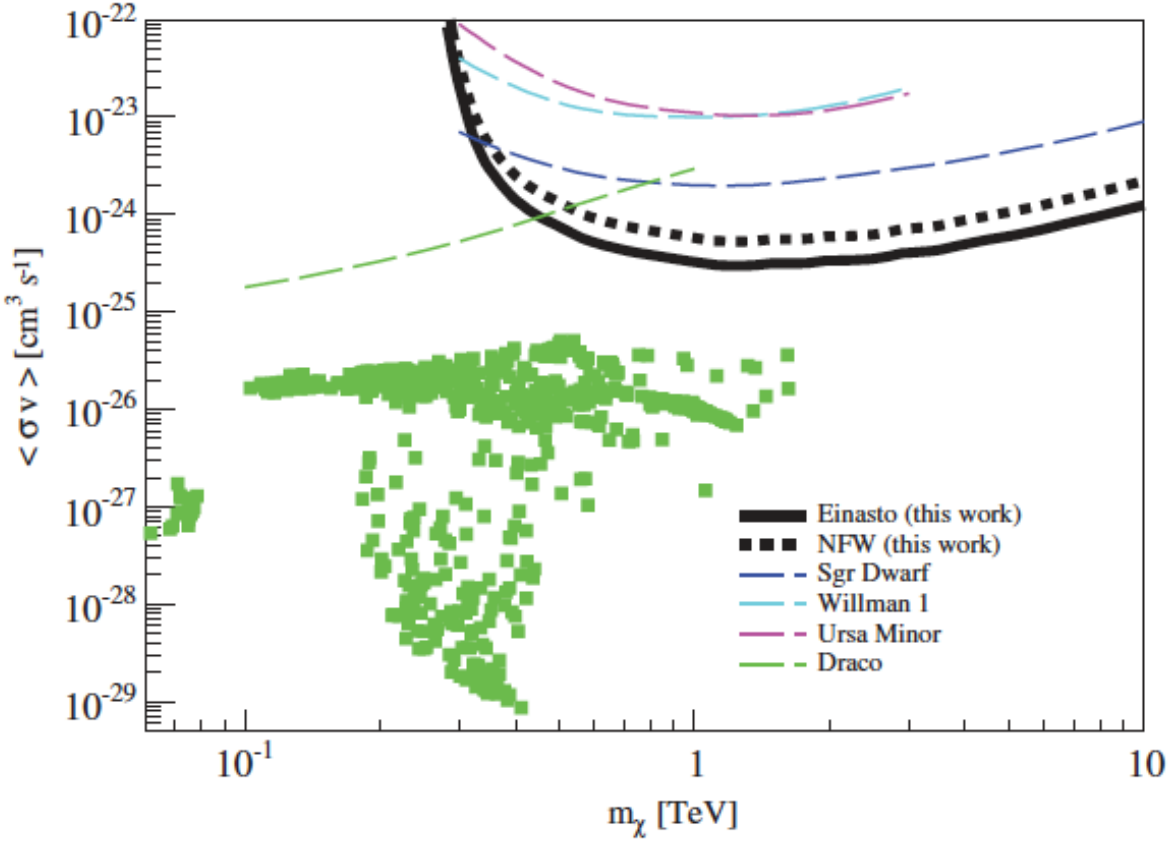
The fit at 133 GeV in R3 yields $s_{\text{local}} = 3.3\sigma$ with $f(133\text{ GeV})_{R3} = 0.61$, which is larger than any of the systematic effects summarized in Sec. VI (see Tab. III) and is larger than the feature seen at 133 GeV in the Limb: $f(133\text{ GeV})_{\text{Limb}} = 0.14$. Also, if the feature is due to an instrumental effect, one would have expected it to appear in the spectra of γ rays from the inverse ROI, which it does not. Therefore, the 133 GeV feature in R3 cannot be entirely explained in terms of known systematic effects. However, as discussed in Sec. VIII, the 133 GeV feature does have certain characteristics that disfavor interpreting it as a DM signal. The fit significance reduces when using the 2D energy dispersion model, making the global significance of the feature $s_{\text{global}} = 1.6\sigma$. This decrease in significance is in large part due to the 133 GeV feature being much narrower than the LAT energy resolution, and not being present in events with $\theta > 50°$. More data and study are needed to clarify the origin of this feature.

Observation of VHE gamma rays

Galactic Center observation by HESS in PRL 2011







Deep observation of Segue-1 by MAGIC

Segue 1: Dwarf Sph. Galaxy
Discovered by SDSS in 2006

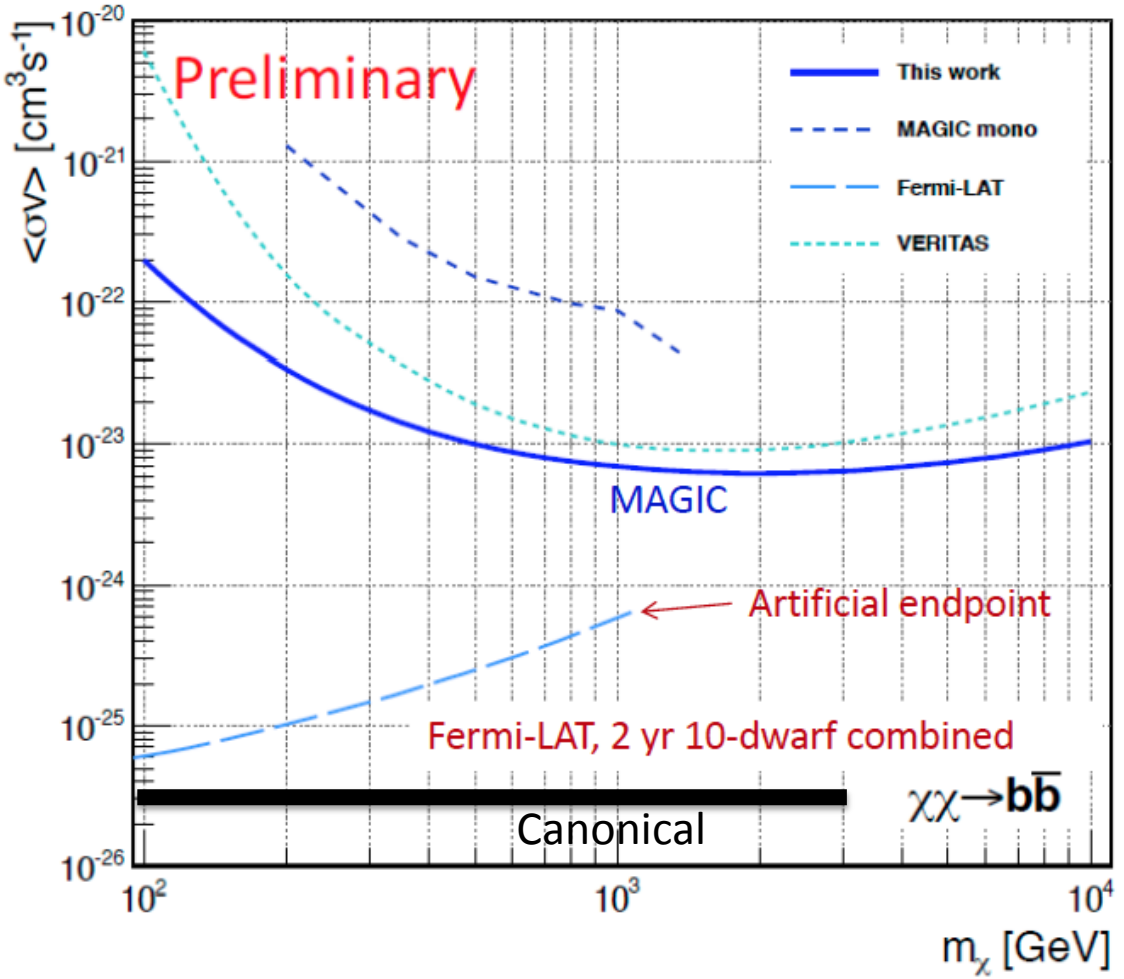
Distance = 23kpc
M/L = 3400 $M_\odot/L_\odot$
M = 600,000$M_\odot$

$$\frac{d\Phi_\gamma}{dE_\gamma} = \frac{1}{4\pi}\frac{\langle\sigma v\rangle}{2m_\chi^2}\frac{dN_\gamma}{dE_\gamma} \times J(\Delta\Omega),$$

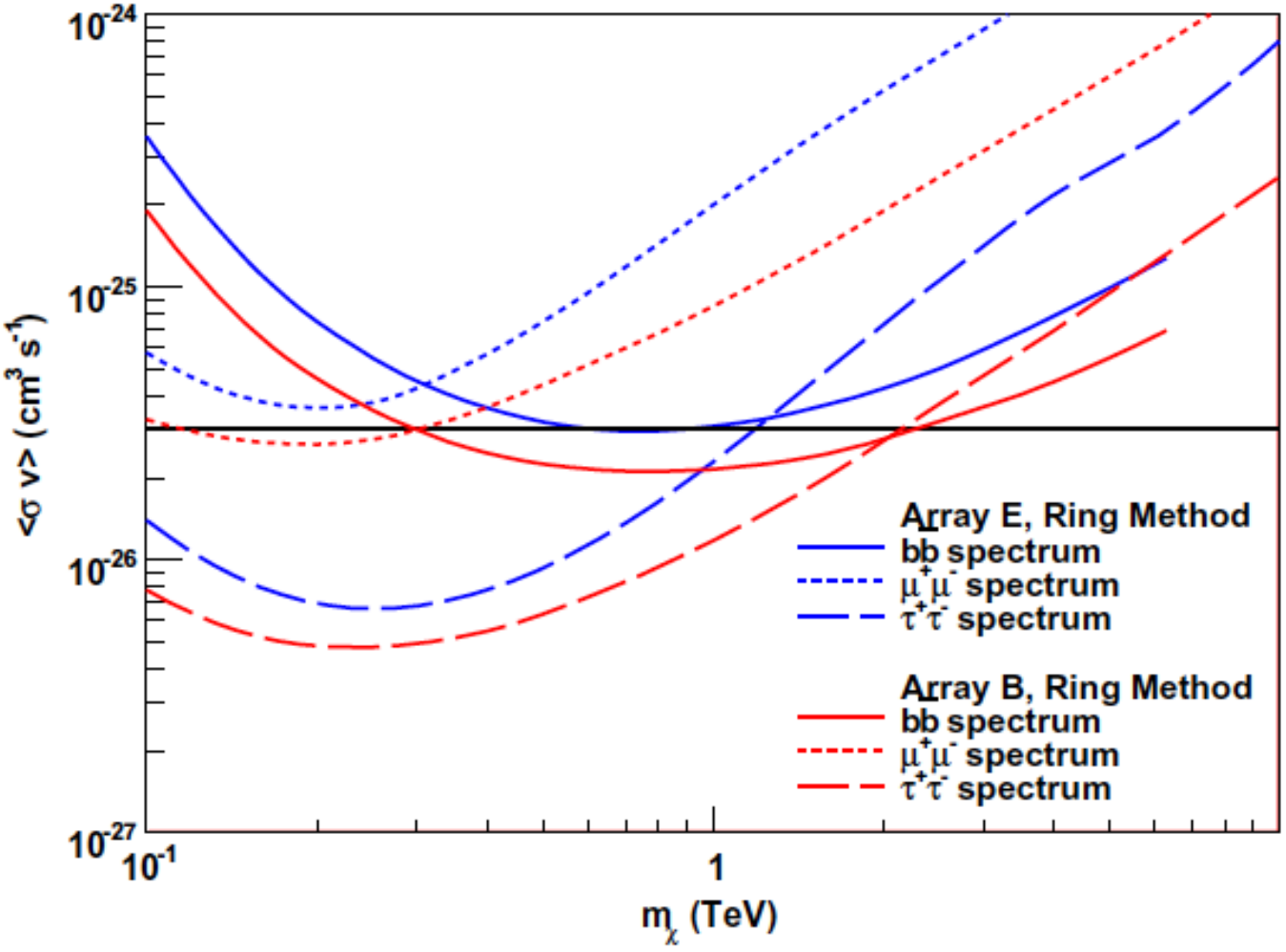
$$J(\Delta\Omega) = \int_{\Delta\Omega}\int \rho^2(l,\Omega)\, dl d\Omega\ .$$

Name	l deg.	b deg.	d kpc	$\overline{\log_{10}(J)}$ $\log_{10}[\mathrm{GeV^2cm^{-5}}]$	σ	ref.
Bootes I	358.08	69.62	60	17.7	0.34	[15]
Carina	260.11	−22.22	101	18.0	0.13	[16]
Coma Berenices	241.9	83.6	44	19.0	0.37	[17]
Draco	86.37	34.72	80	18.8	0.13	[16]
Fornax	237.1	−65.7	138	17.7	0.23	[16]
Sculptor	287.15	−83.16	80	18.4	0.13	[16]
Segue 1	220.48	50.42	23	19.6	0.53	[18]
Sextans	243.4	42.2	86	17.8	0.23	[16]
Ursa Major II	152.46	37.44	32	19.6	0.40	[17]
Ursa Minor	104.95	44.80	66	18.5	0.18	[16]

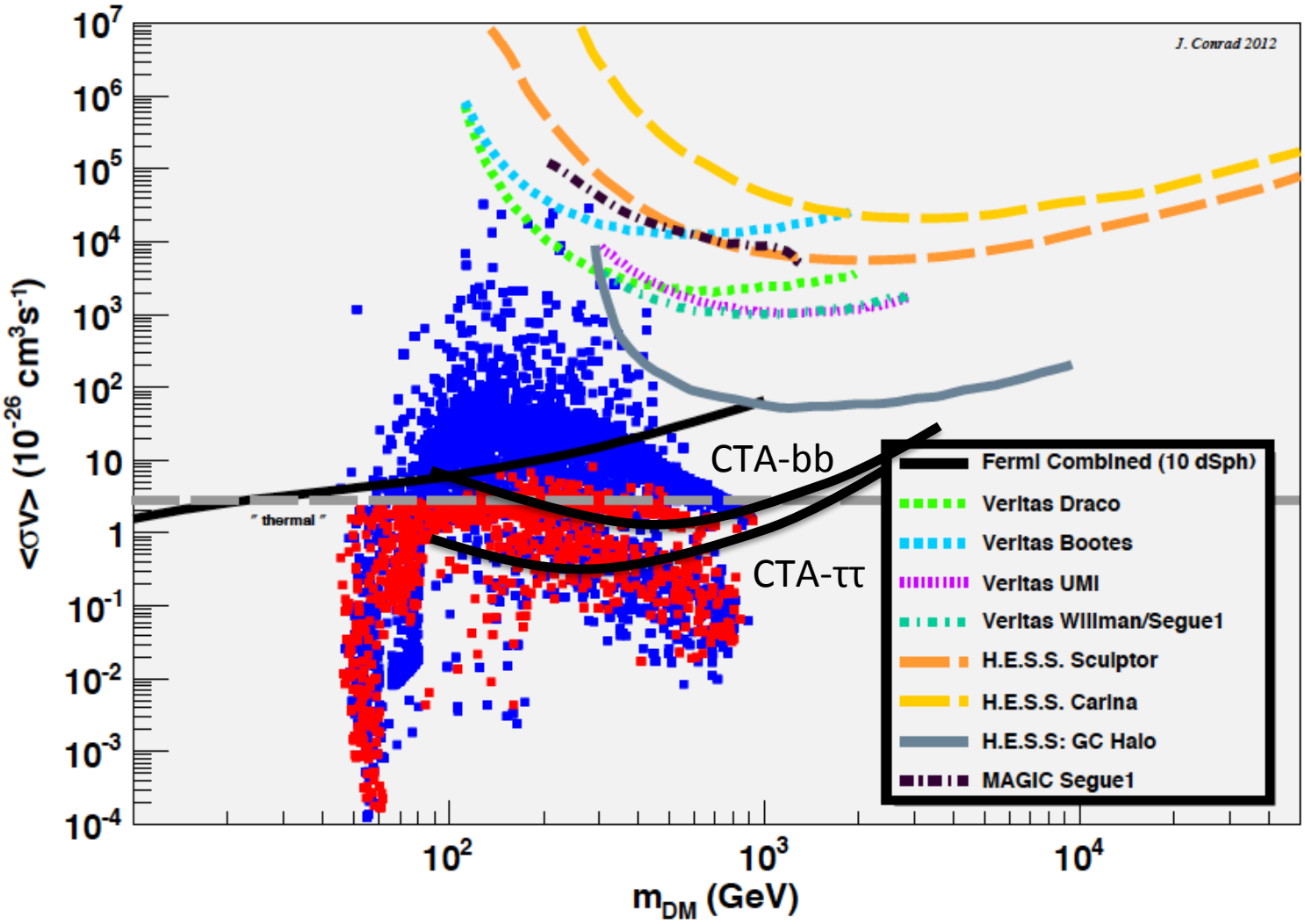
Jelena Aleksic, EPS HEP 2013



CTA sensitivity for G.C. Halo



CTA Sensitivities for G.C. Halo in 100 h



Summary

- Anomaly of the electron spectrum and the fraction of positron is observed.
  - too high $<\sigma v>$
  - well explained by nearby astronomical objects (maybe pulsars)

- Possible 133GeV line in gamma ray emission around G.C. is observed by Fermi
  - Local statistical significance is 3.3 sigma, but can not be explained by systematics of the instrument
  - More data is necessary

- Search for Dark Matter in VHE energy region is getting active.
  - In CTA era, the sensitivity will reach the canonical annihilation cross section.
  - G.C. (133GeV) line will be explored with much higher sensitivity by CTA south