HEP 2013
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Indirect Searches for Dark Matter

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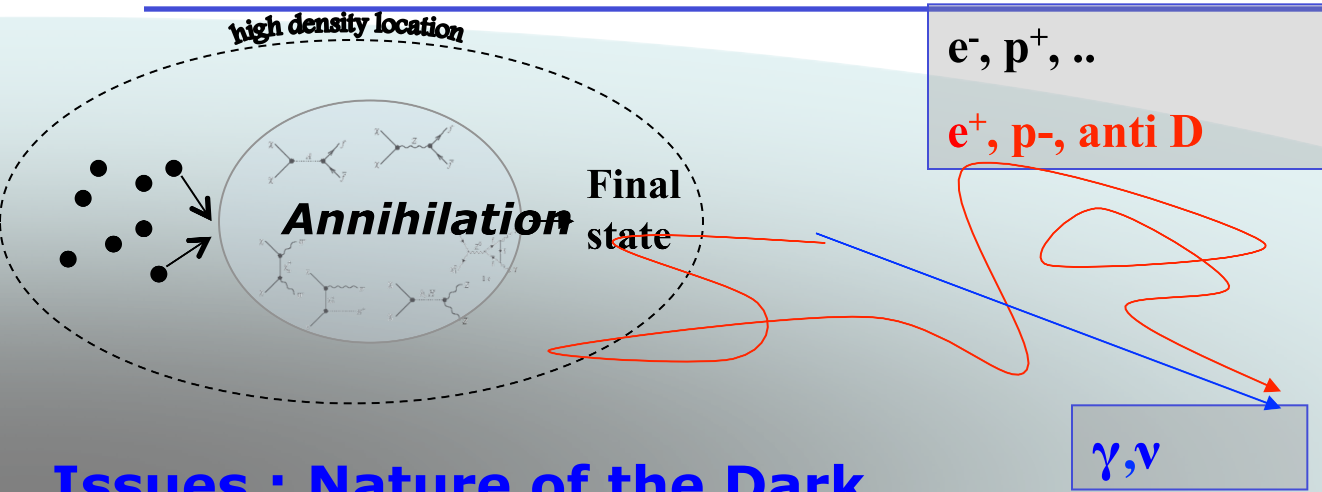
Outline

- Introduction
- Gamma rays
- Positron fraction
- Summary

Review of last results from
MAGIC, HESS, CTA, VERITAS, FERMI, AMS, PAMELA collaborations

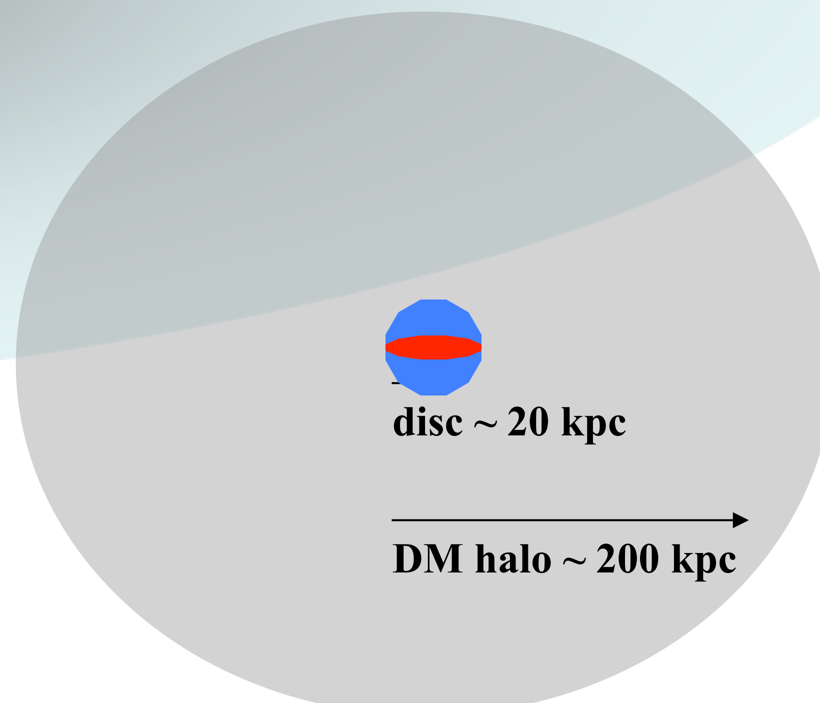
Ingredients



Issues : Nature of the Dark Matter and density profile of the dark halo

⇒ Consider only Wimp candidates

⇒ Most recent results : Gamma Rays and positron fraction

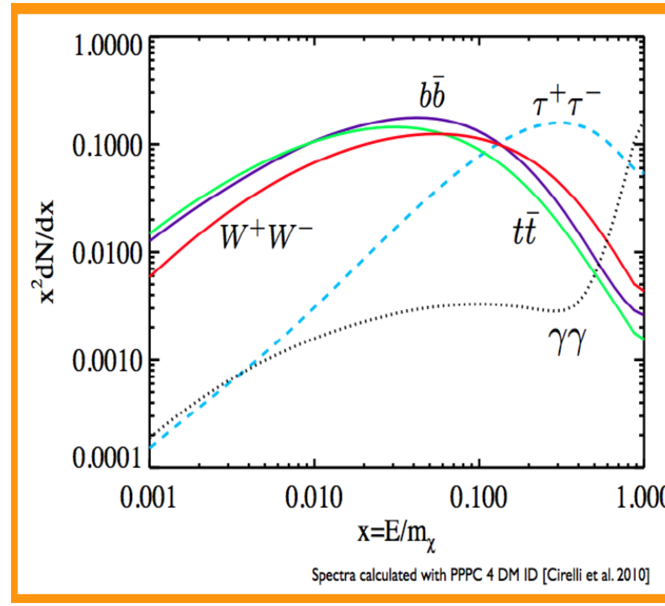


Not reported Axion Like Particle, see M.Meyer EPS-HEP parallel session

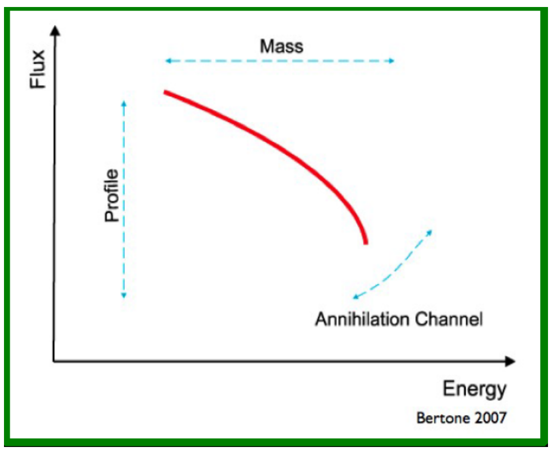
Gamma ray mode : features and strategy

Particle Physics
(annihilation modes)

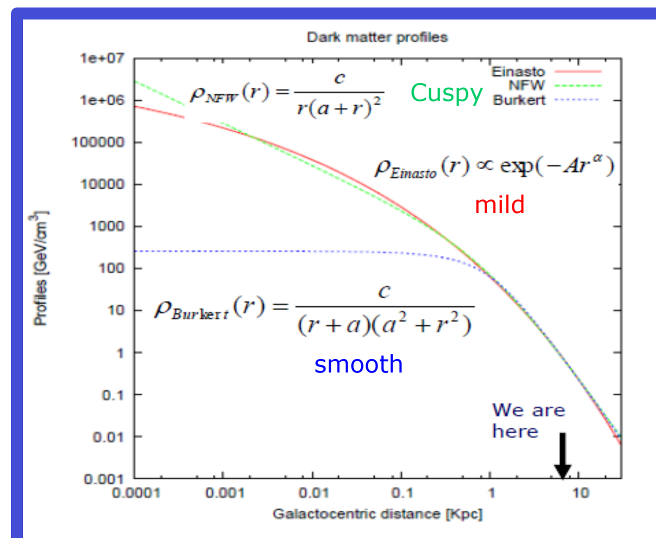
$$\frac{d\Phi_\gamma}{dE_\gamma}(E_\gamma,\phi,\theta) = \frac{1}{4\pi}\frac{<\sigma_{ann}v>}{2m^2_{WIMP}}\sum_f \frac{dN^f_\gamma}{dE_\gamma}B_f \times \int_{\Delta\Omega(\phi,\theta)} d\Omega' \int_{los} \rho^2(r)dl$$



Gamma Ray flux
(Signal in data)

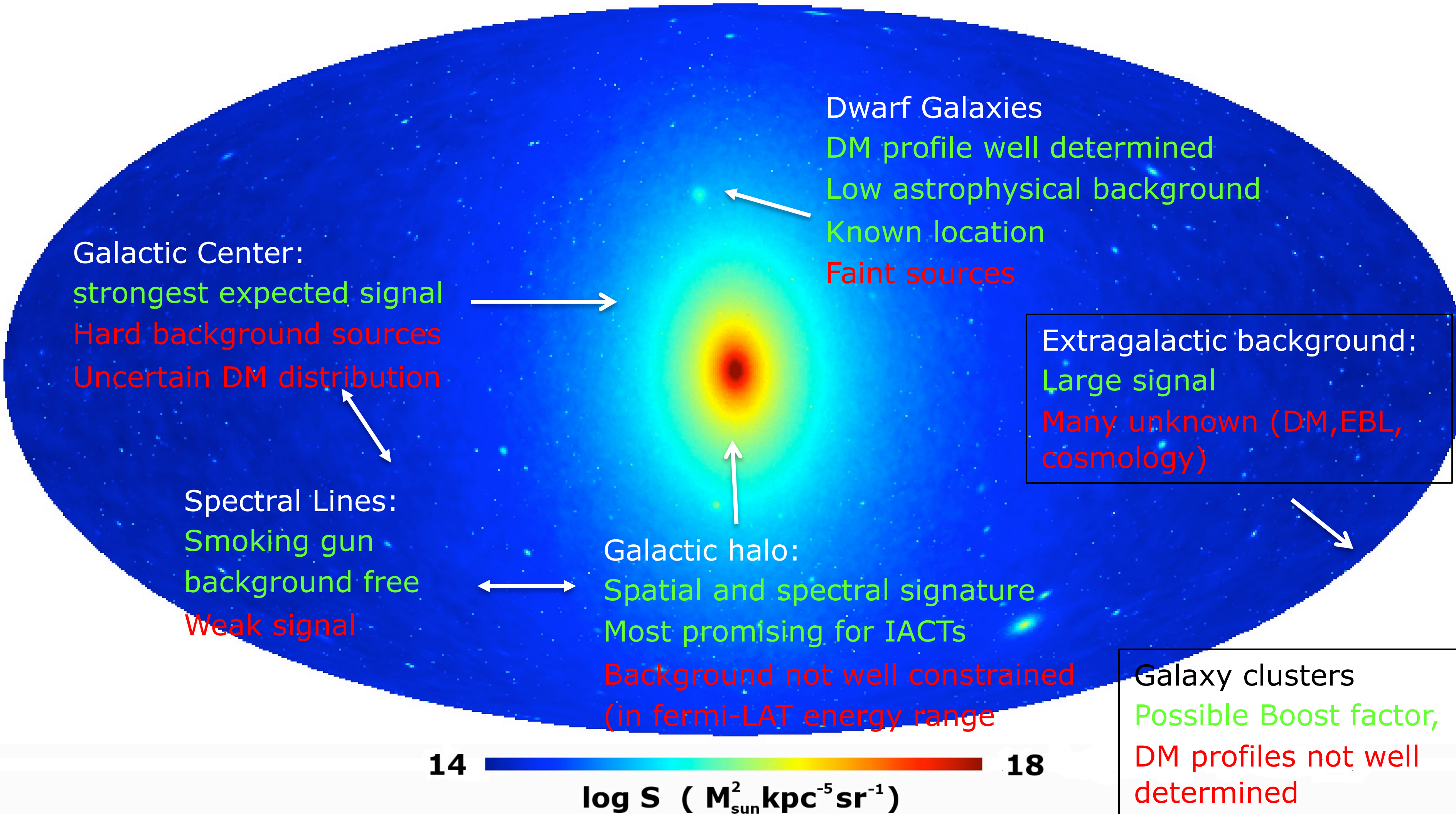


Dark Matter Distribution
(Line of Sight integral)
J-Factor



Ground based and Space Based detectors , complementary searches

Dark Matter Targets in Gamma rays



Galaxy clusters
Possible Boost factor,
DM profiles not well determined
Large astrophysical background

Not discussed in this presentation

Optimizing the Signal/background

Gamma rays on ground: **I**maging **A**ir **C**erenkov **T**elescopes

Energy range 50 GeV- 50 TeV

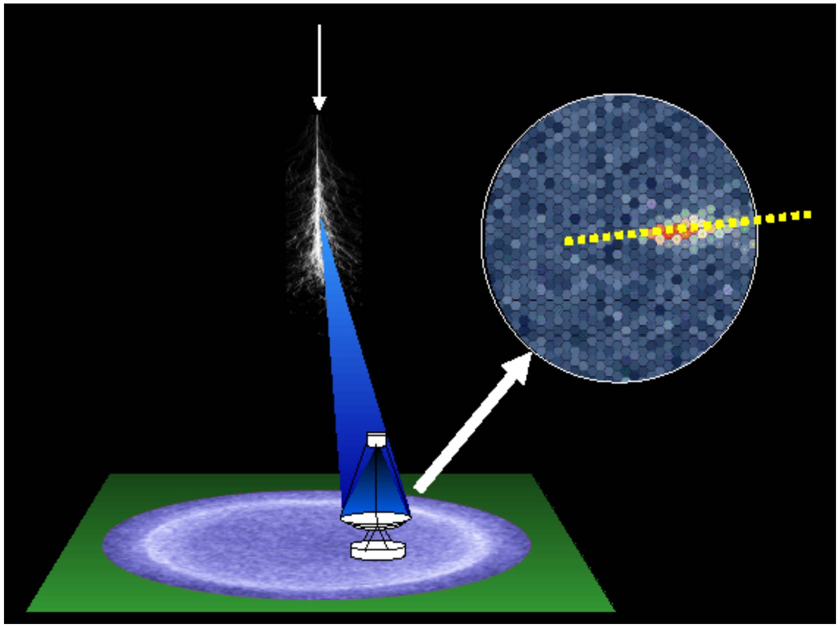
MAGIC 2 :
2 telescopes Ø17(3.5˚)
Threshold ~ 60 GeV
Operating since 2004
(stereo) 2009

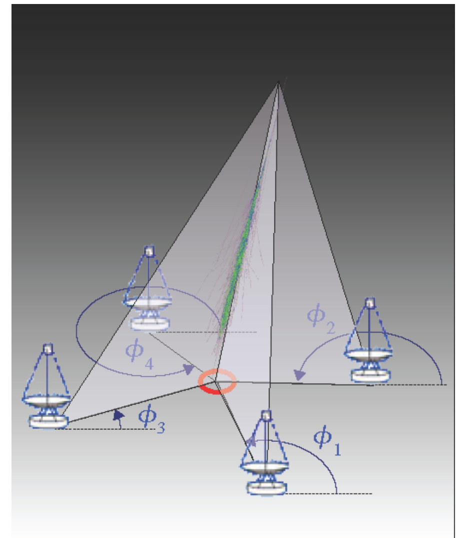
Veritas:
4 télescopes
Ø 12m (3.5˚)
Threshold ~ 100 GeV
Operating since 2007

H.E.S.S. :
4 telescopes Ø 13m(5˚)(2004)
1 telescope Ø 28 (09/2012)
Threshold ~ 150 GeV-30 GeV

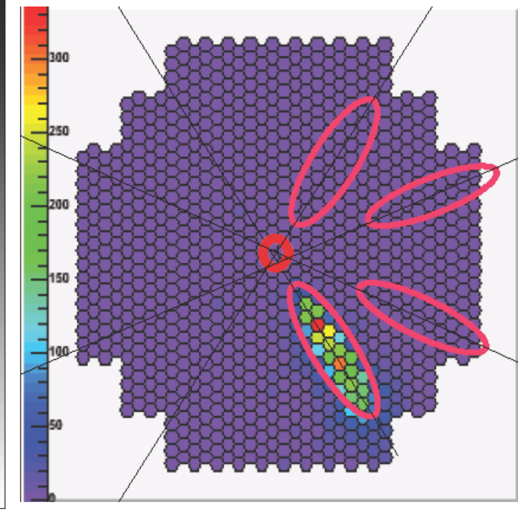
Complete coverage of the sky: galactic and extragalactic sources

IACT: Principle and performance



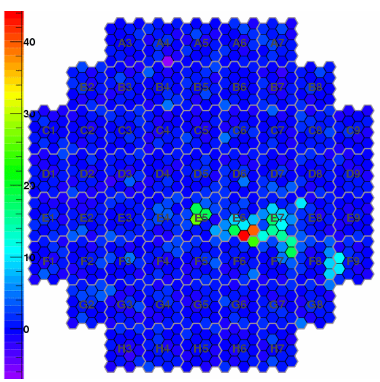


Stereoscopic reconstruction

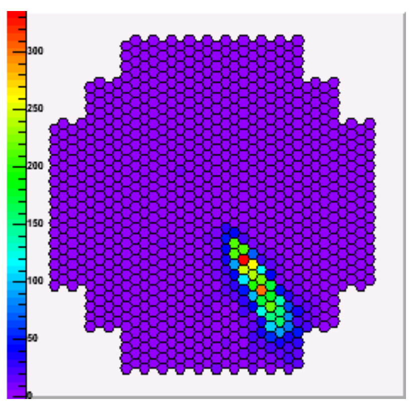


Shower direction given by the ellipse main axis intersections

Proton



Photon

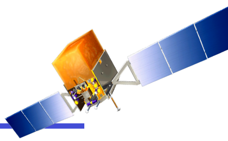


Main challenge: CR background rejection (1/10000)

Proven and highly performing detection technology

- Effective area = 2 10^5 m^2 at 1 TeV
- Field of View :5º
- Angular Resolution 0.1º
- Energy resolution : 10%-20%
- 1000h per year (night without moon)

Gamma rays in space: FERMI LAT observatory



Large Area Telescope (LAT)

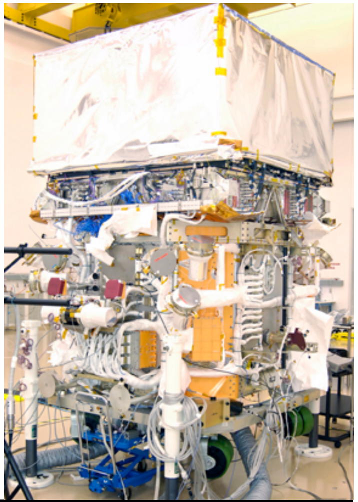
20 MeV – 300 GeV

Gamma-ray Burst Monitor (GBM)

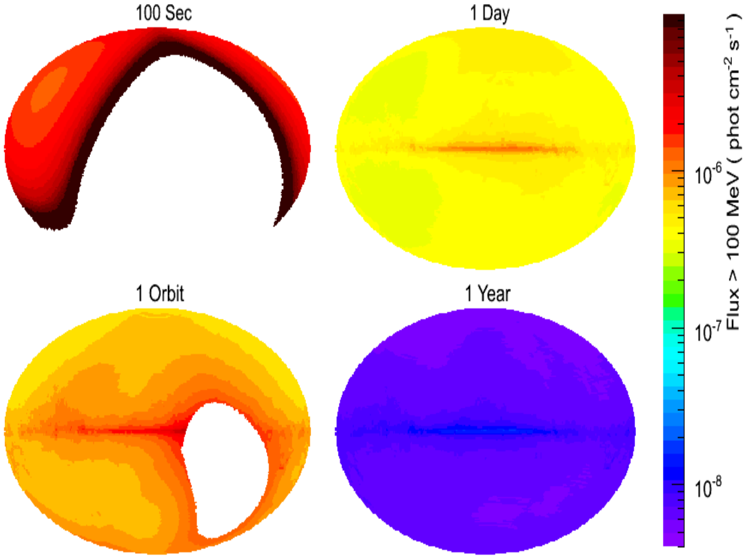
8 keV – 30 MeV

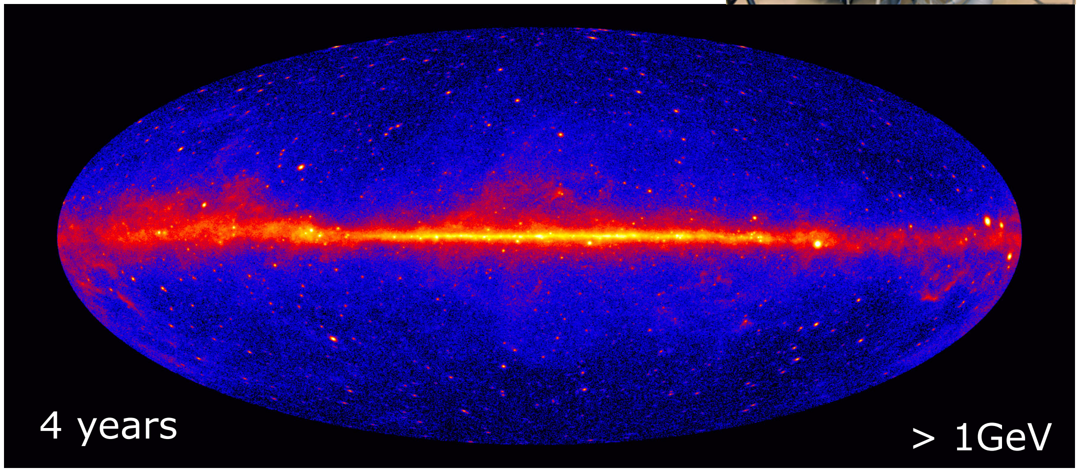
launch June 2008

lifetime: 5 + 5 years



LAT source sensitivity for exposures on various time scales





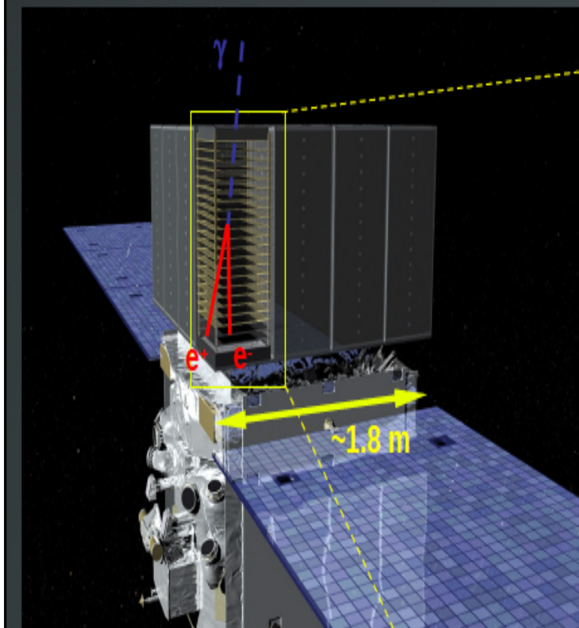
Every region viewed for 30 min every 3 hours

Recent Fermi-LAT all-sky catalogs

- 2FGL (Nolan et al 2012, ApJS 199, 31): 2 years, 100 MeV to 100 GeV, 1873 sources
- 1FHL (ArXiv 1306.6772): 3 years, > 10 GeV 514 sources

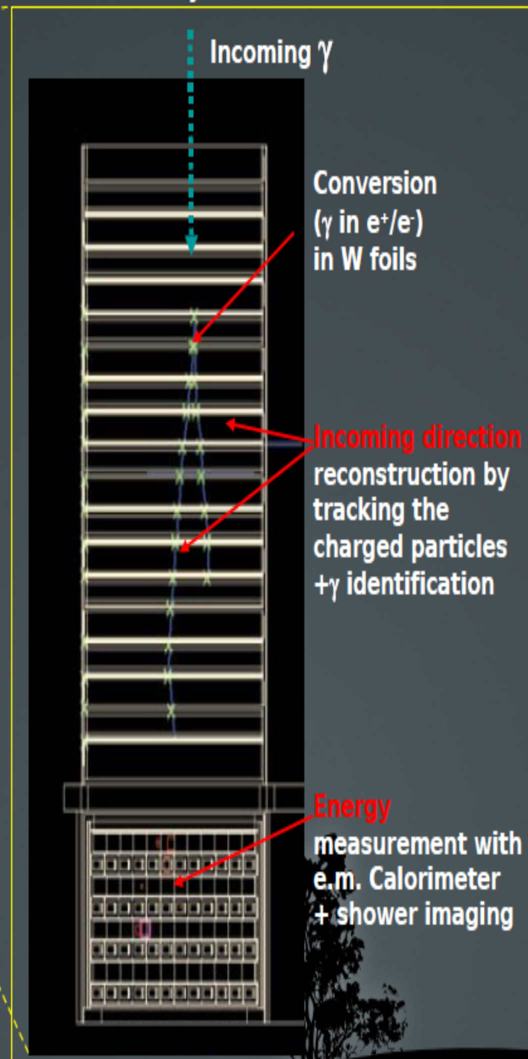
Fermi LAT: principle and Performanc

The LAT

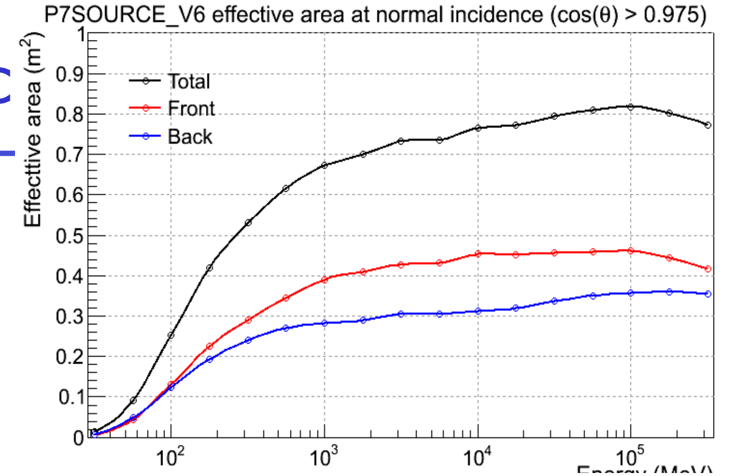


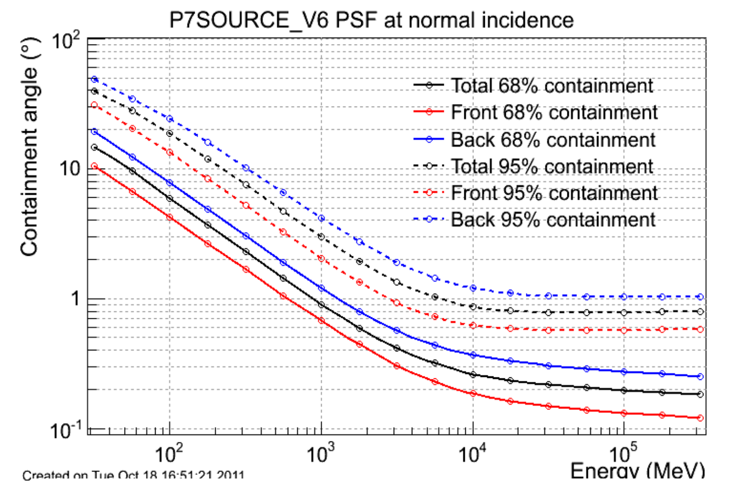
- **Precision Si-strip tracker :**
  Si-strip detector, W converter foils, 80 m^2 of Si active area,
  1.5 radiation lengths on-axis.
- **Hodoscopic CsI calorimeter :**
  array of 1536 CsI(Tl) crystals in 8 layers.
  8.6 radiation lengths on-axis.
- **Segmented Anti-Coincidence Detector :**
  89 plastic scintillator tiles and 8 ribbons.
  charged particles veto (0.9997 average detection efficiency).

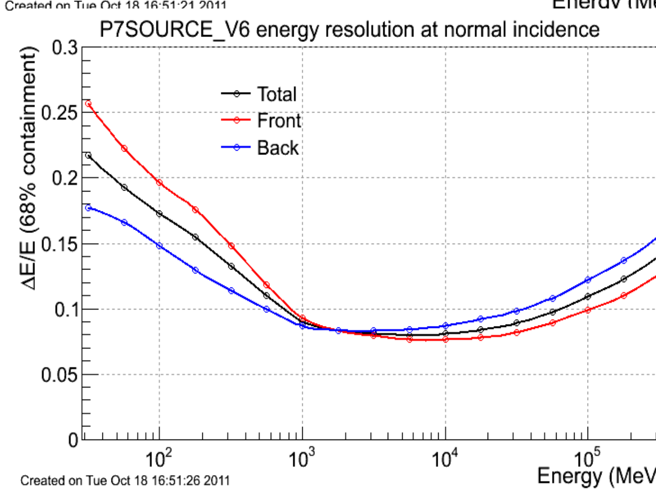
Modular pair-conversion telescope
4 x 4 array of identical towers



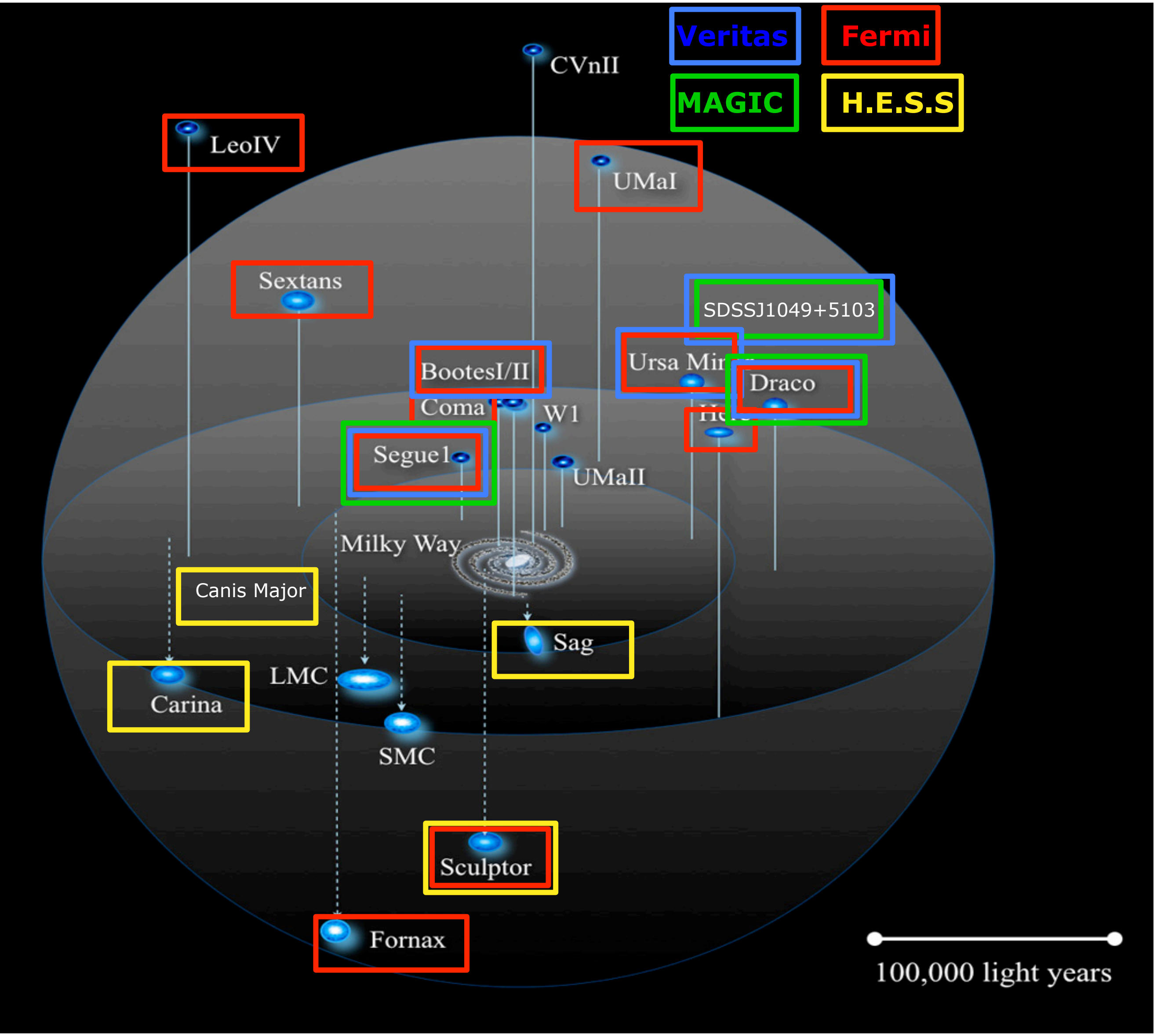
Fermi LAT Collaboration, APJ 697, 1071 (2009)







Dwarf Spheroidal galaxies probed with gamma-rays

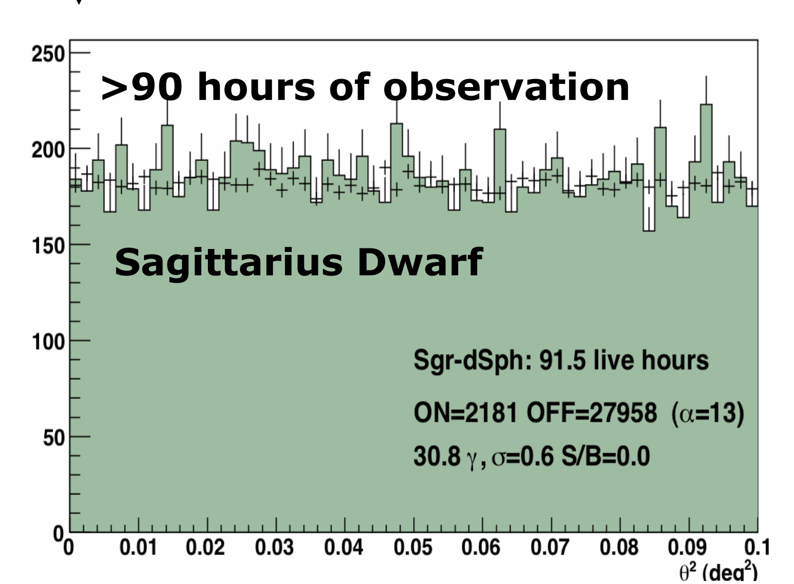


Cleanest Targets

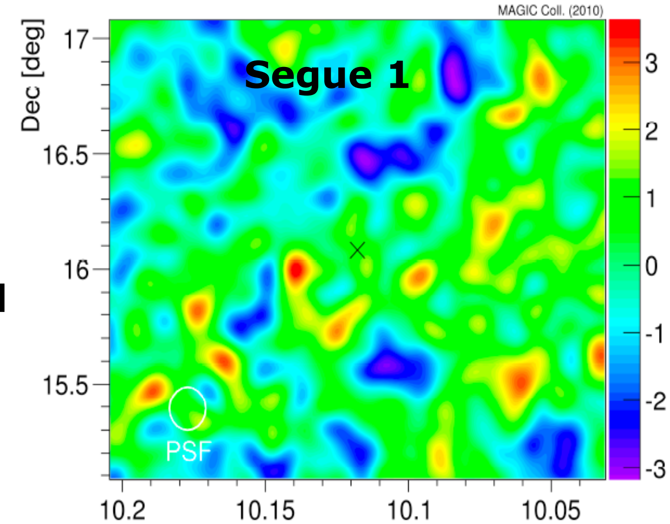
- High Mass/luminosity Ratio
- Low Astrophysical background
- Position known d<100kpc
- Dark Matter density predictions (J-factor) from stellar dynamics or n-body simulation

Sagittarius Dwarf (H.E.S.S) – Segue 1 (MAGIC&Veritas)

Source position

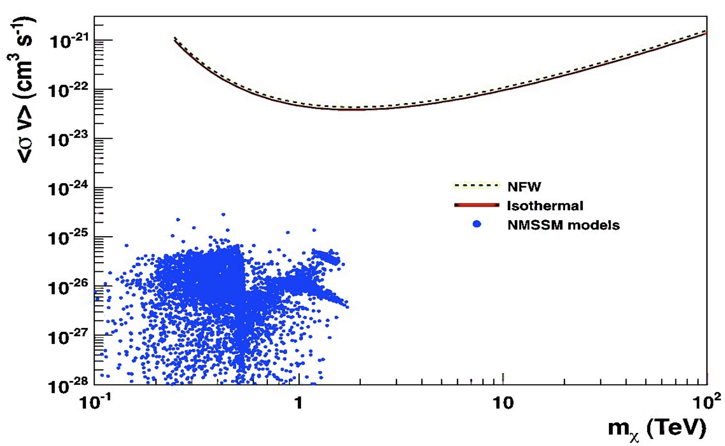


Significance sky map after ~30 h

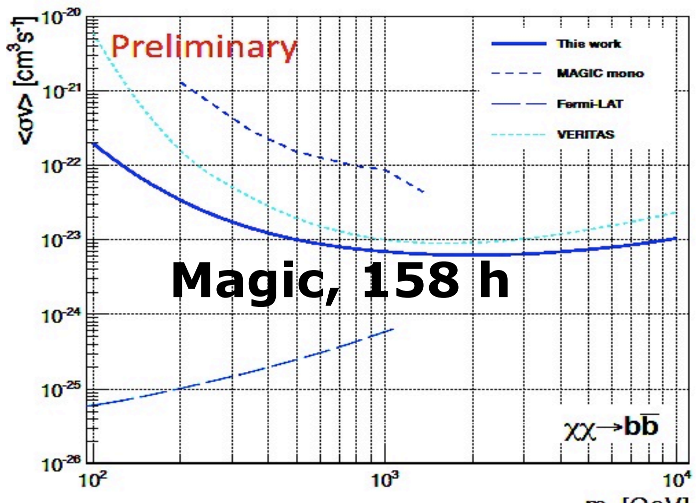


No signal detected

Upper limits on <σv> Assuming J factors

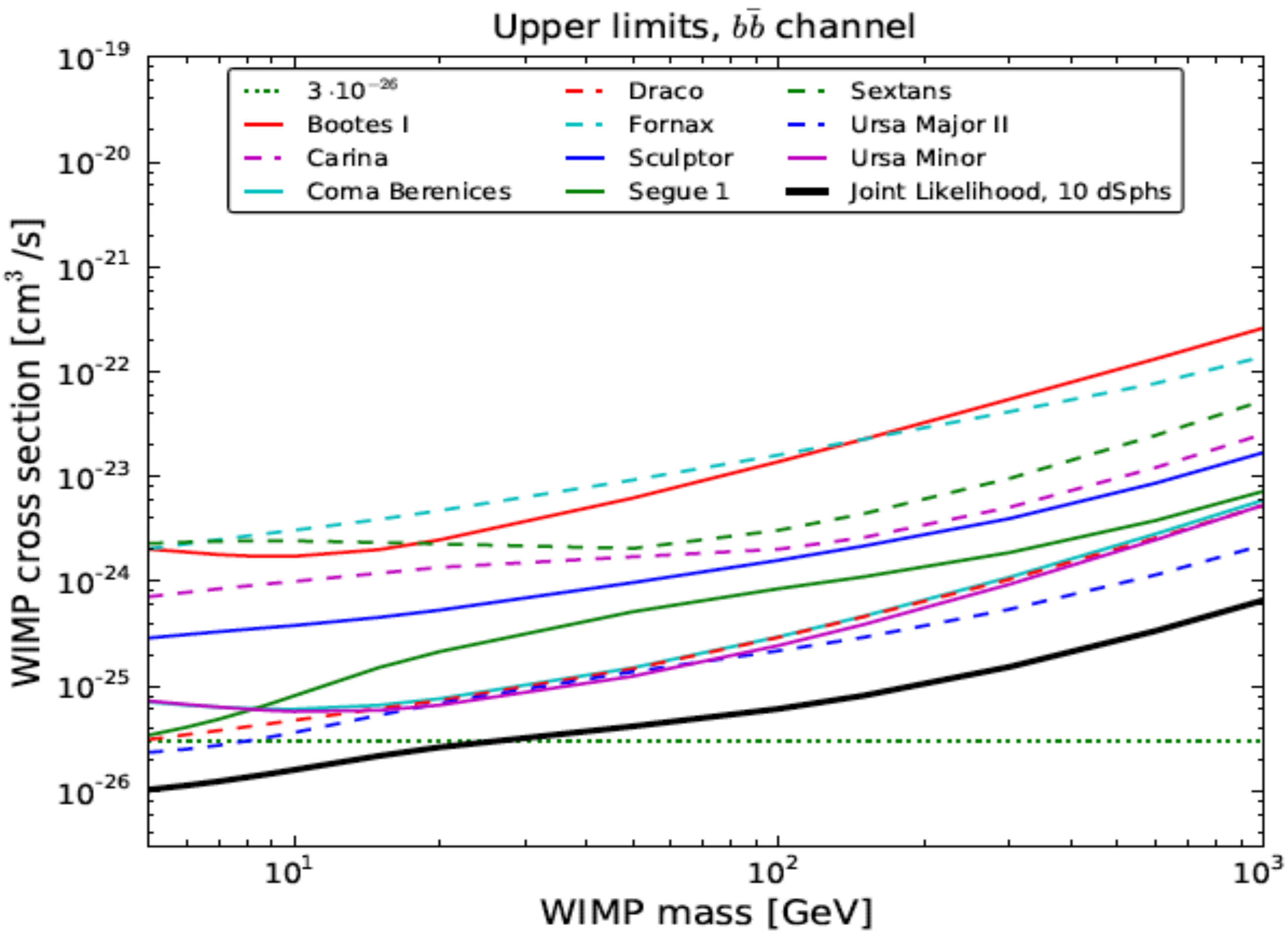


HESS Coll.ICRC2013_956



Magic Coll. J.Aleksic, EPS-HEP parallel session

Dwarf Spheroidal galaxies Fermi LAT

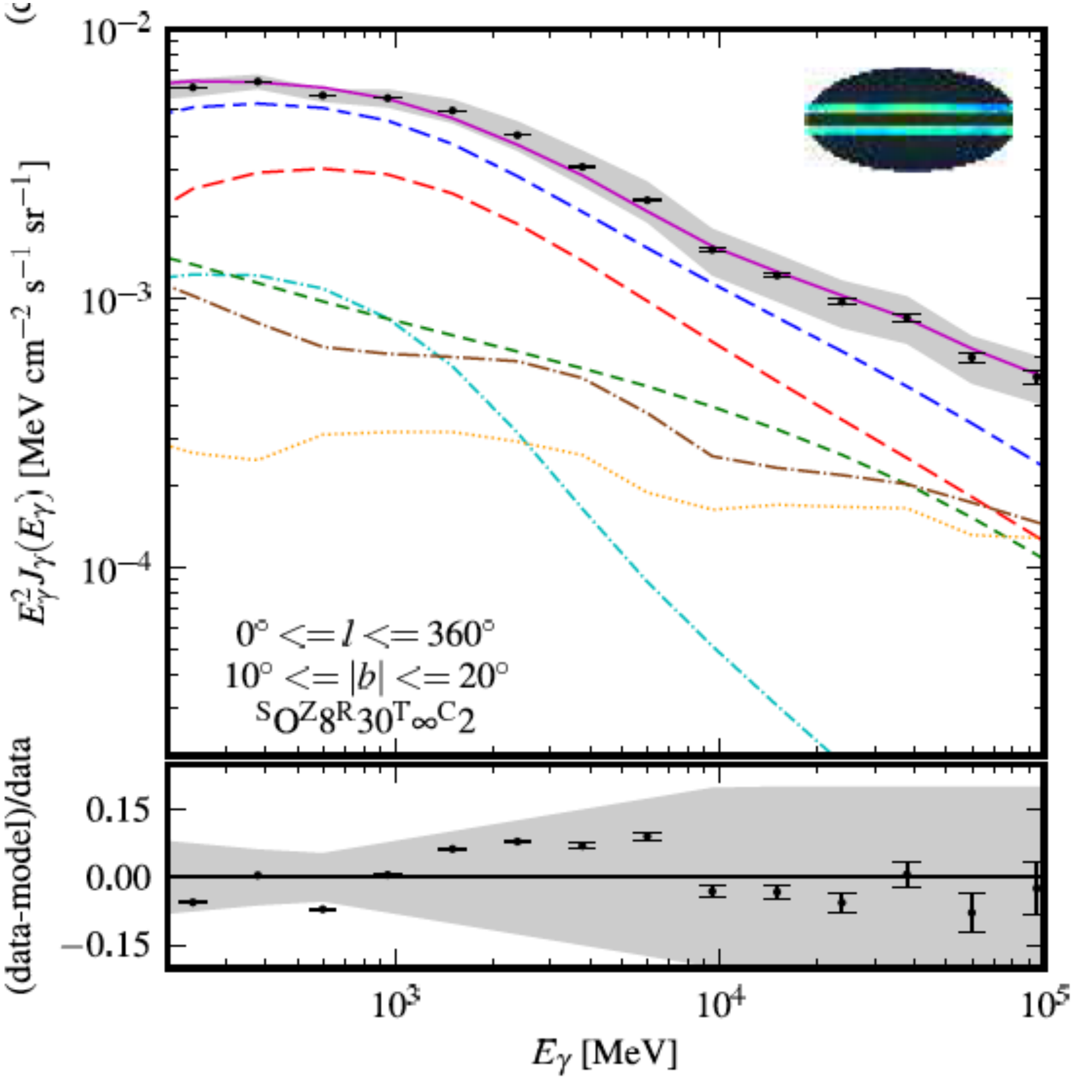


- **10 DSphs analysed and combined**
- **0.2-100 GeV**
- **Background is fitted independently (galactic diffuse emission and isotropic background)**
- **No signal detected of over 24 months of data**

Fermi-LAT collaboration, PRL 107.241302 (2011)

Galactic Halo Fermi LAT

Fermi LAT Collaboration, arXiv:1202.4039



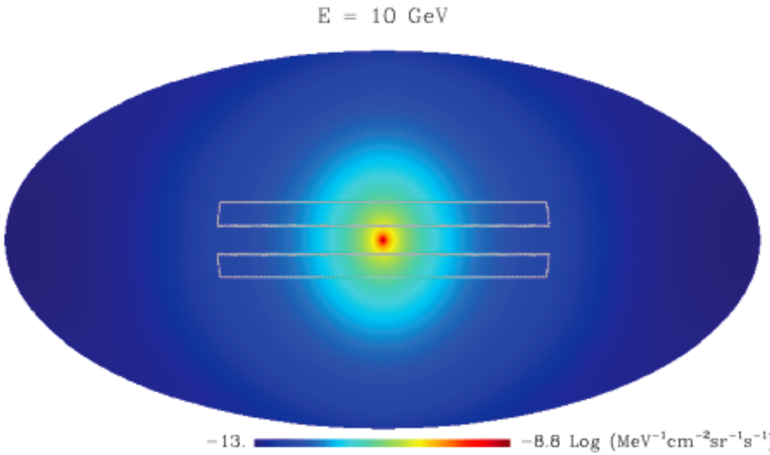
Intermediate latitudes

- 21 months .2-100 GeV
- Different Galactic Diffusive Emission components, parameterized using CR propagation models (GALPROP) and properties of the interstellar models
  - Galactic diffuse emission
    - Π^0 decay
    - Inverse Compton
    - Bremsstrahlung
  - Isotropic background
  - Sources

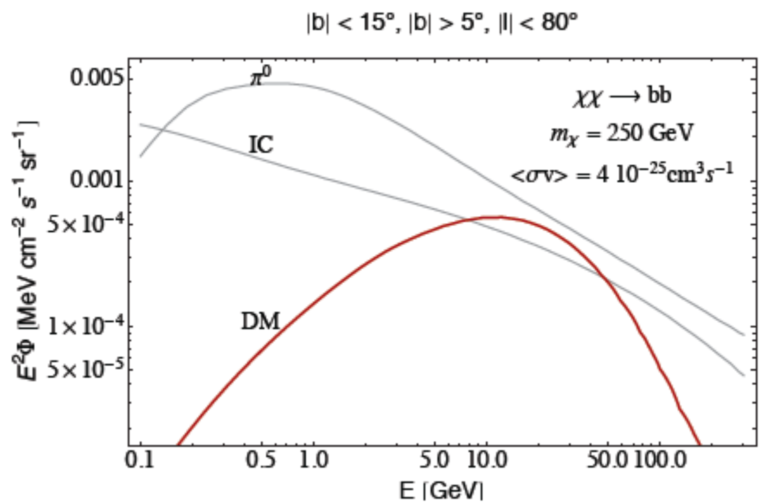
Systematics uncertainties are dominant

Galactic Halo Fermi LAT Interpretation

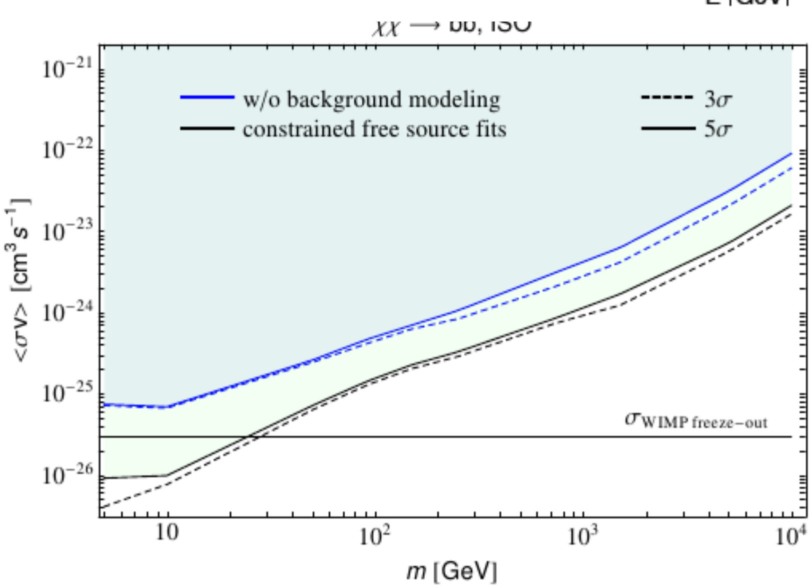
Dark Matter density distribution (NFW profile)



Gamma spectrum – M_{wimp}=250 GeV



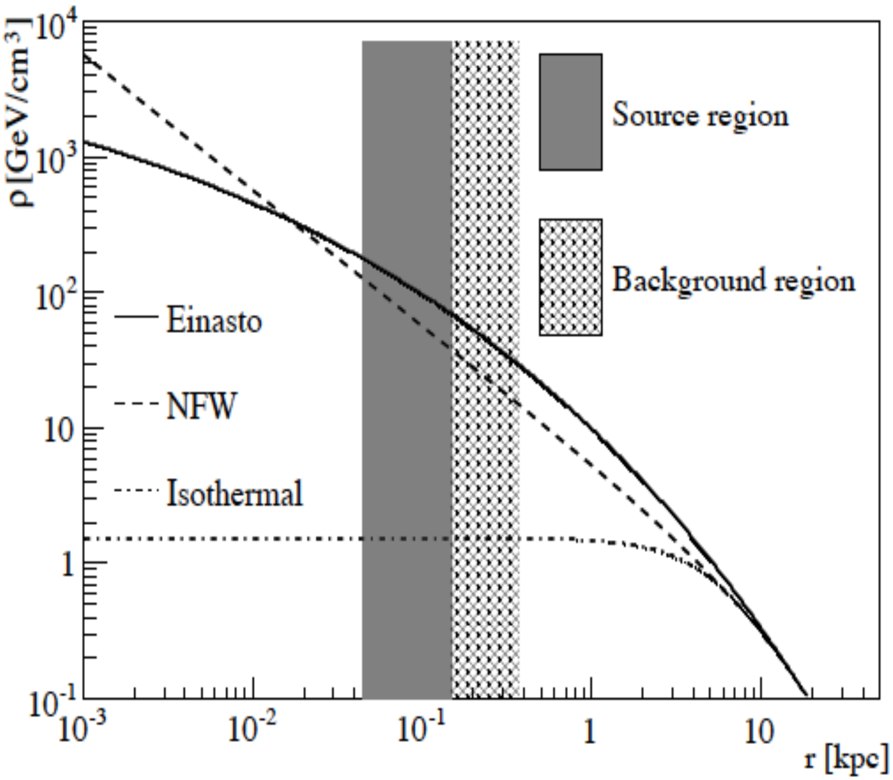
-> Upper limits on <σv>
with or without background subtraction



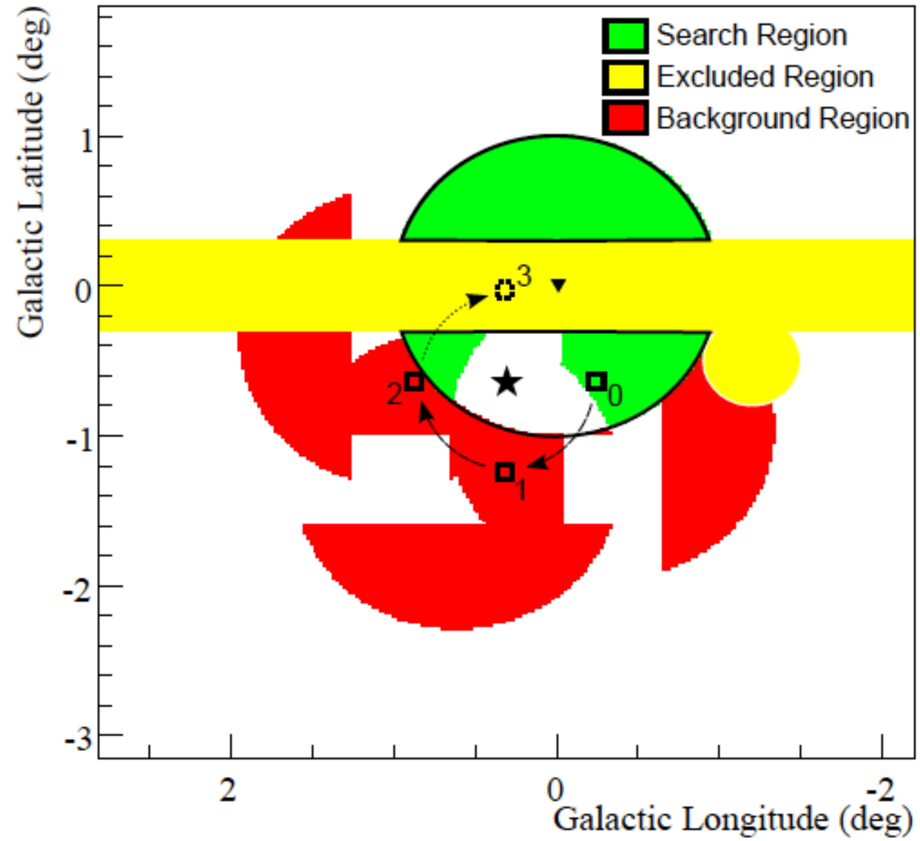
Fermi Coll., 2012, ApJ, 761, 91

Galactic Center Halo H.E.S.S

Dark Matter profiles comparison



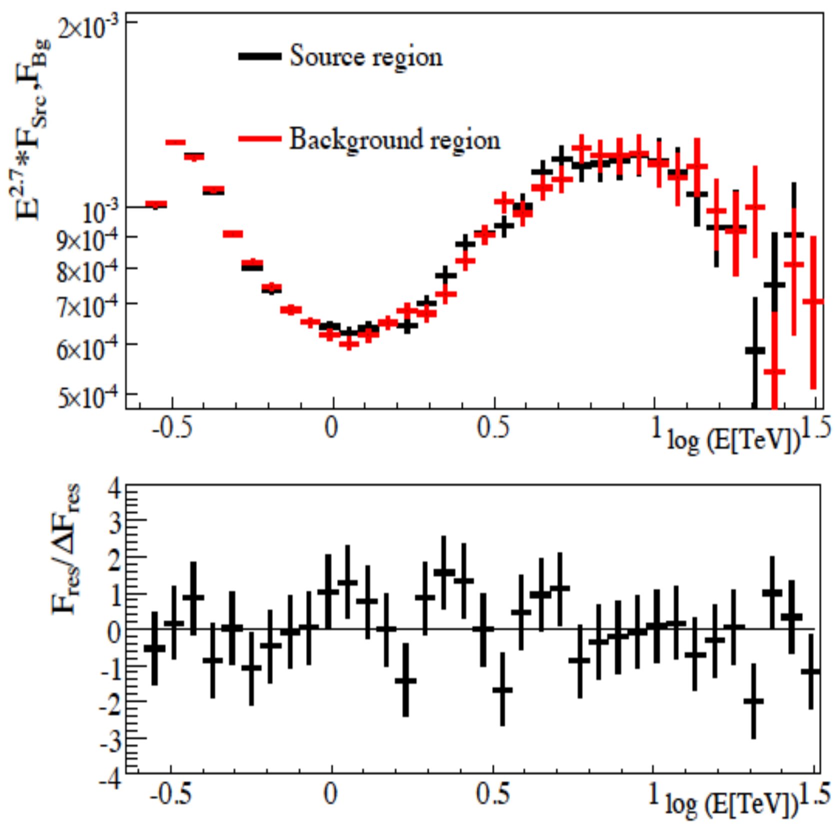
Phys.Rev.Lett. 106 (2011) 161301

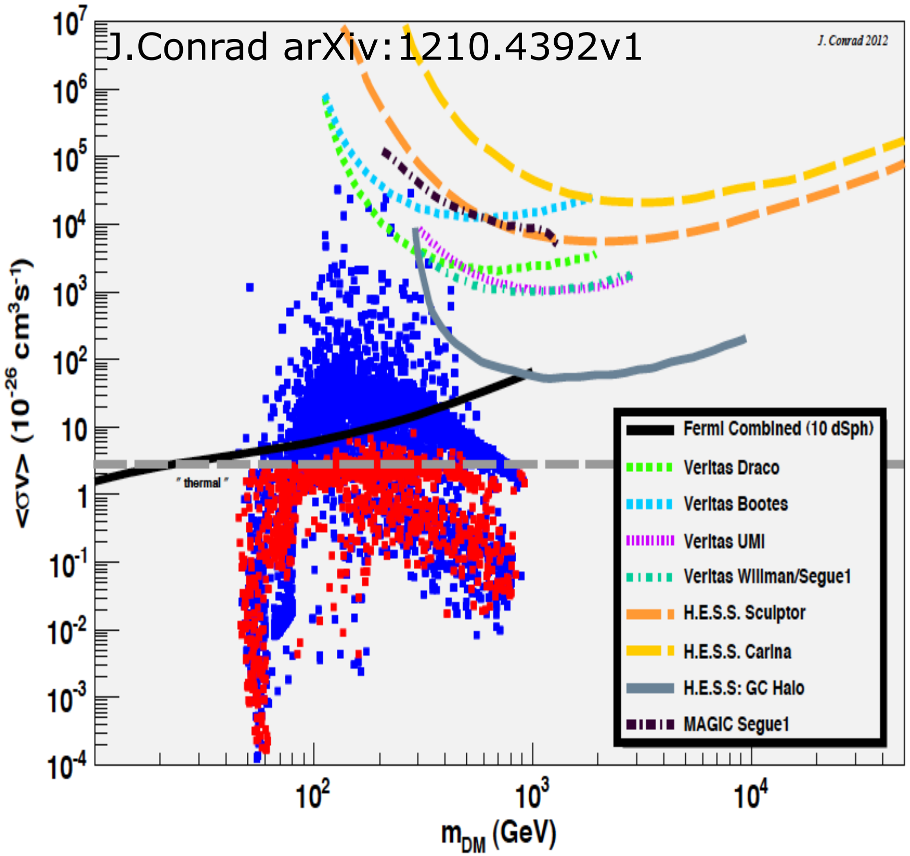


- **The Cosmic ray background is directly measured**
- Search regions near the Galactic Center
- 100 hours of observation

Differential flux measurements for the source and background regions

Upper limits on <σv>





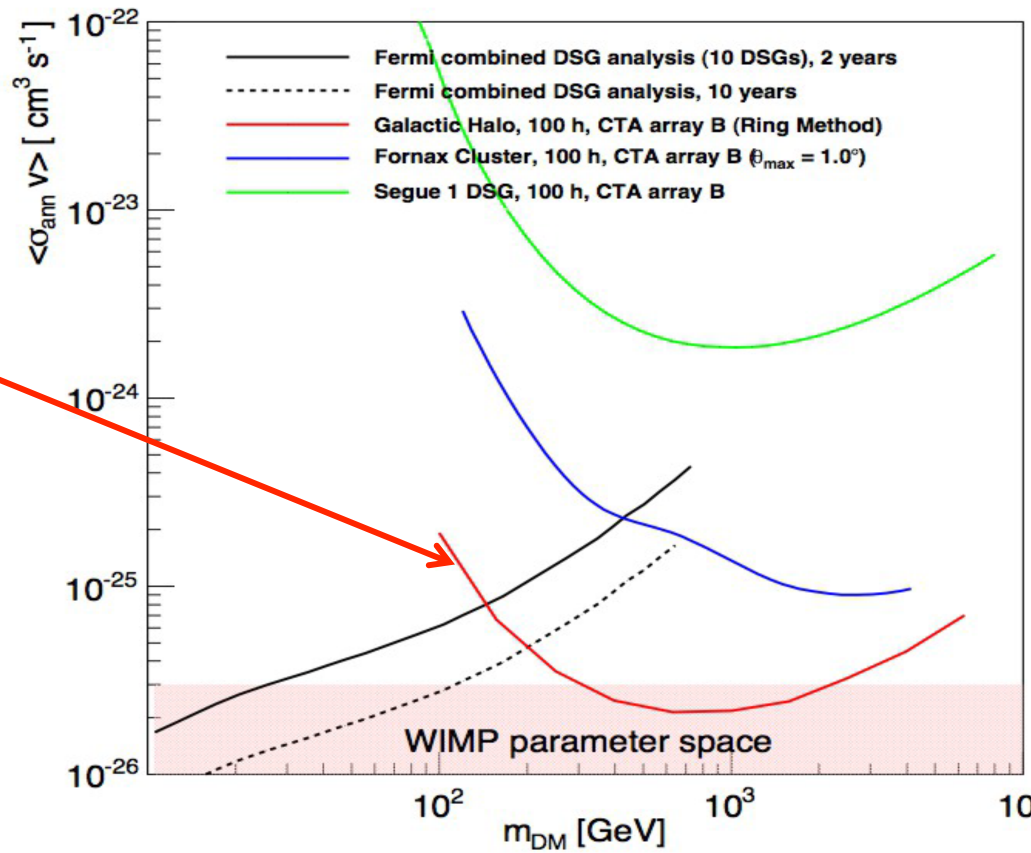
Phys.Rev.Lett. 106 (2011) 161301

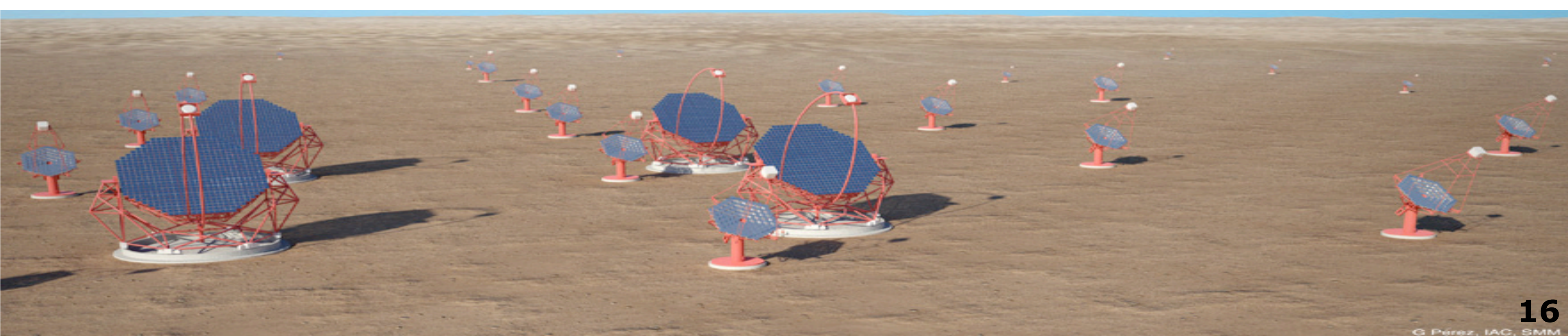
Highest sensitivity from ACT observations

CTA : 100 hours

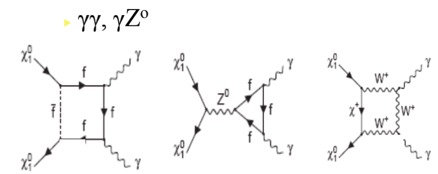
Galactic Halo : most sensitive method

M. Doro et al., arXiv:1208:5356 [astro-ph.IM]



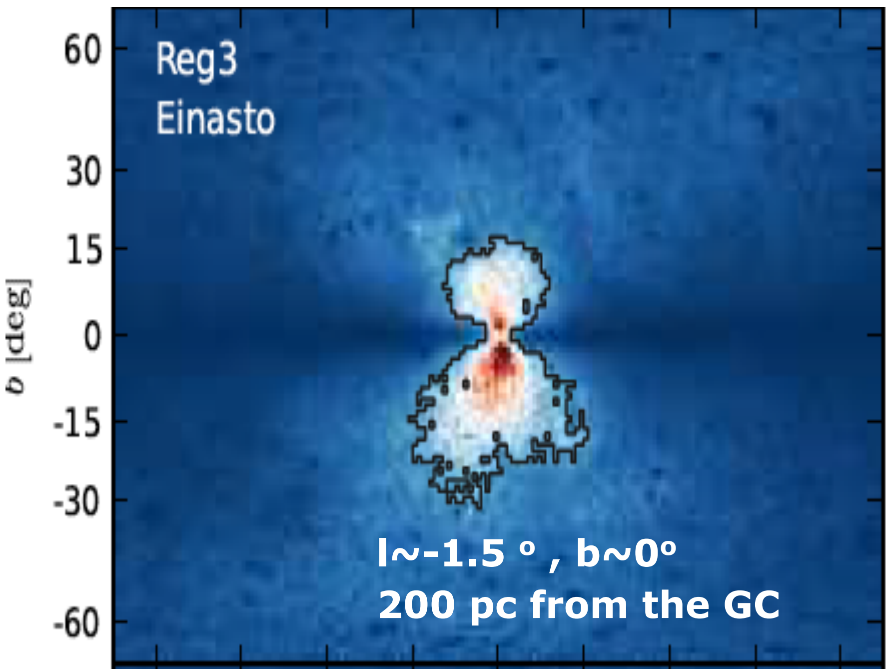


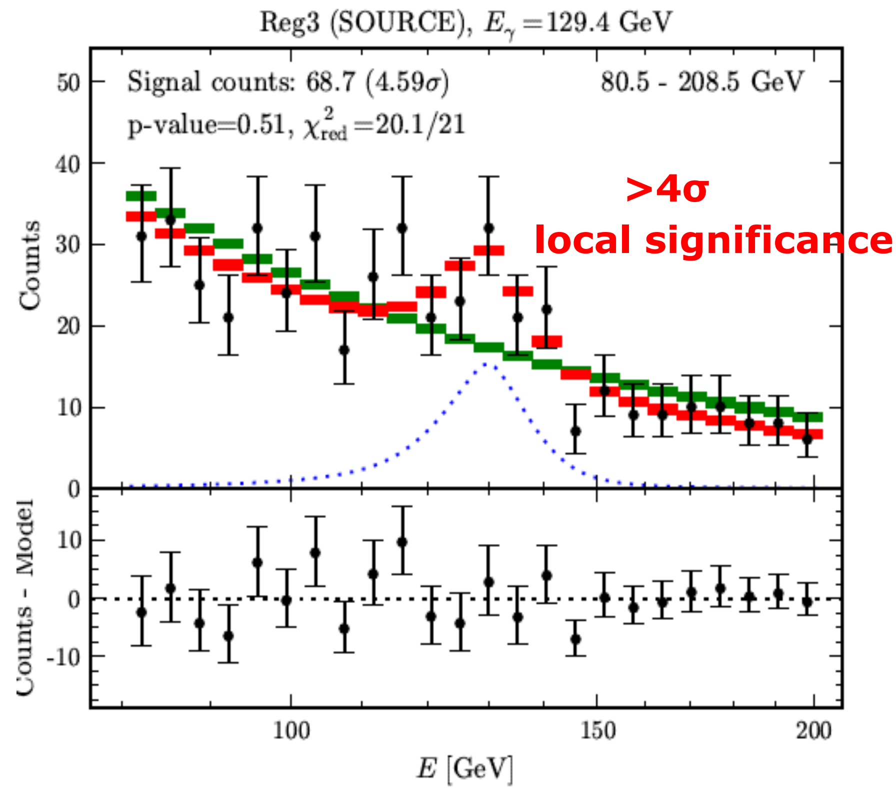
γ-ray lines Fermi LAT data



43 Months of Fermi public data

T.Bringmann et al [arXiv:1203.1312] C. Weniger arXiv:1204.2797v2





Target region : reg3 surrounding the Galactic center

Optimizing s/b in the energy 1-20 GeV , for variety DM profiles

If Dark Matter=> Br(γγ)≈3-4%

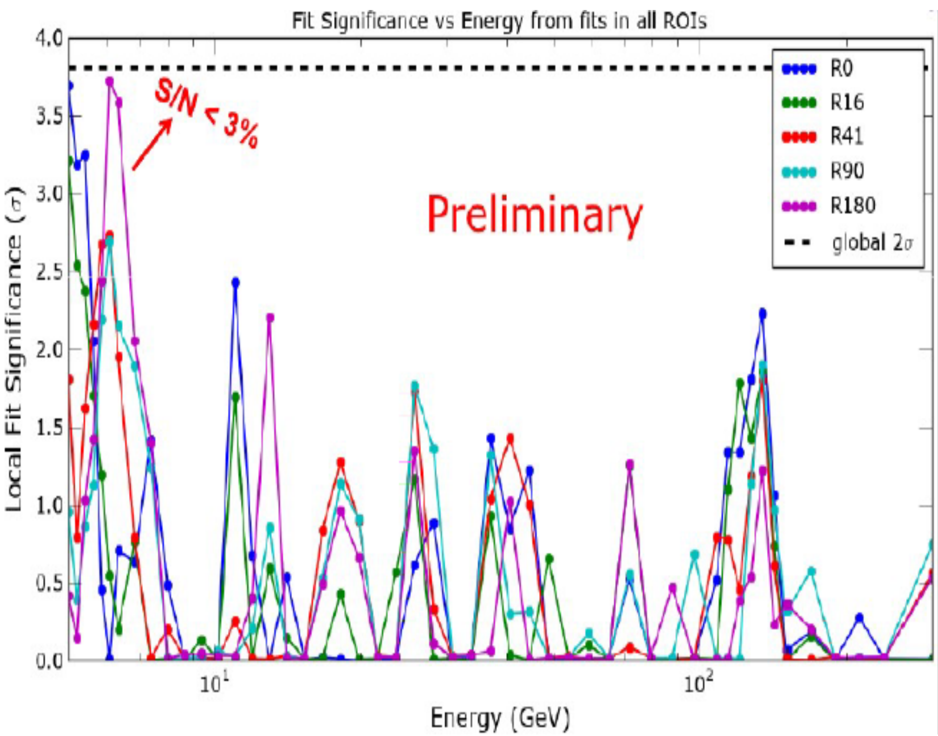
$$\chi\chi \to \gamma\gamma(\gamma Z) : M_\chi = 130(144)\ GeV$$

$$<\sigma v>= 1.3(3.1)\ 10^{-27} cm^3 s^{-1}$$

γ-ray lines - Fermi LAT ou slide suivant

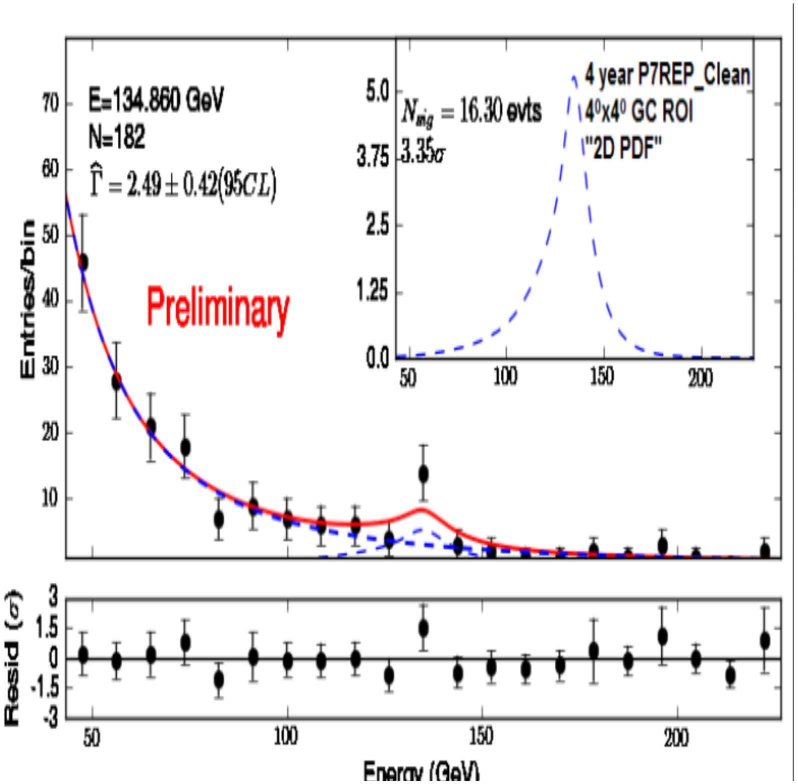
Fermi LAT, 4 years
- **new processing,**
- **new Regions of Interests (including Galactic Plane)**

No significant line structure found



Fermi LAT, 4 years
- **new processing, new analysis**
- **In the Galactic Center (4°×4°)**

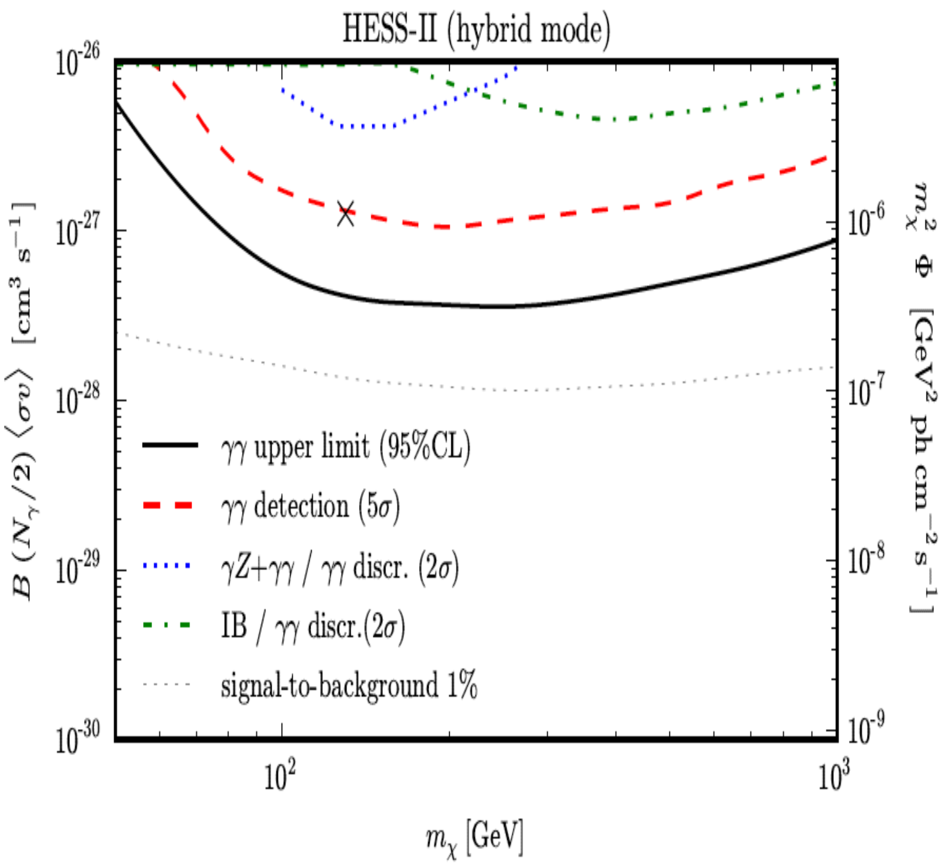
Line-like feature near 135 GeV (3.35 σ)



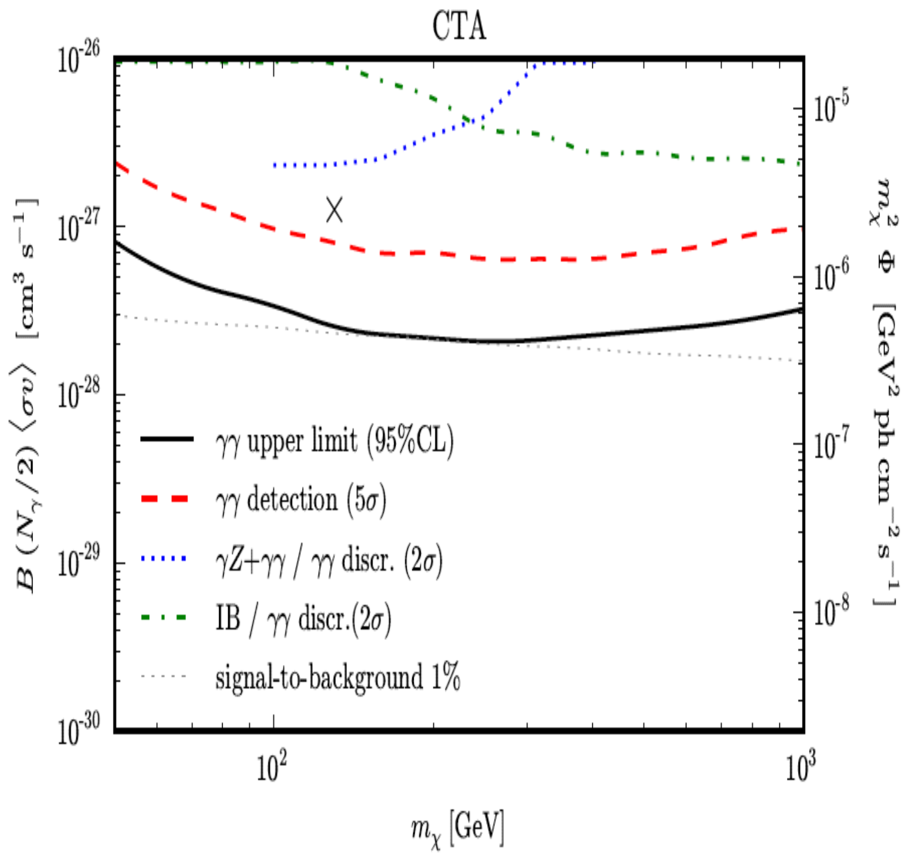
=> systematics studies on going (limb earth control)
A publication expected in one year

γ-ray lines (Galactic Center) Prospects

Lars Bergström et al, arXiv:1207.6773v1



50h of observation with Hess II



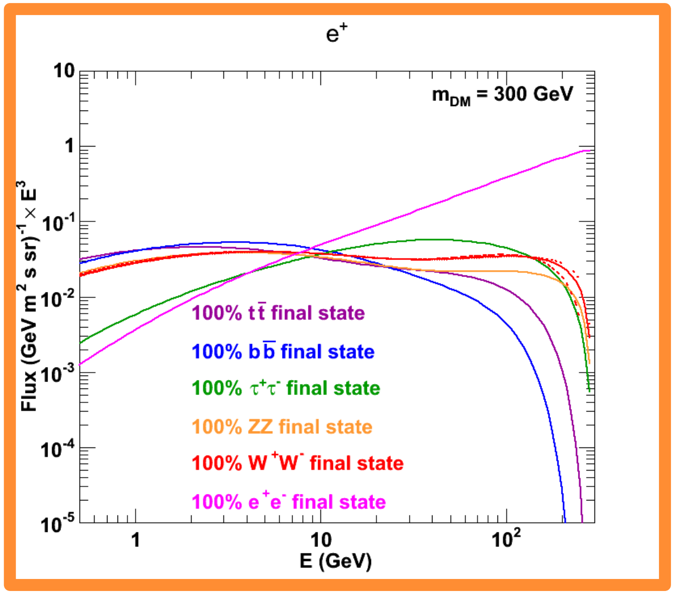
5h of observation with CTA

Positron mode : features and strategy

Particle Physics

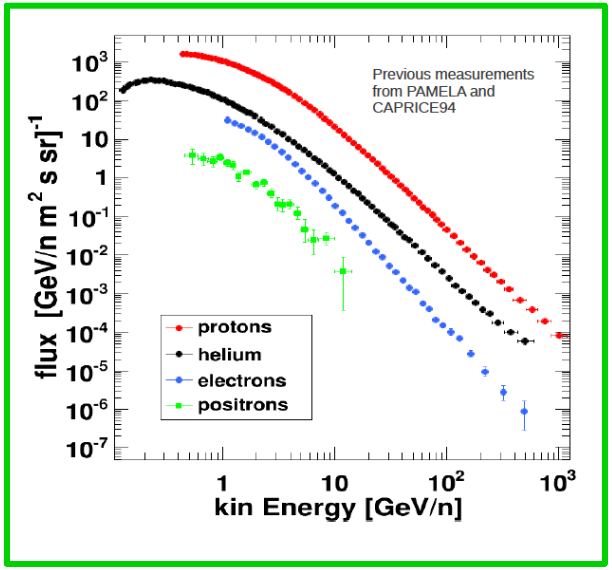
(annihilation modes)

$$\frac{d\Phi_{e+}}{dE_{e+}}(E_{e+}) = \frac{<\sigma_{ann}v>}{2m^2_{WIMP}}\sum_f \frac{dN^f_{e+}}{dE_{e+}}B_f \times B \times \rho^2_\chi$$



Positron flux

(Signal in data)



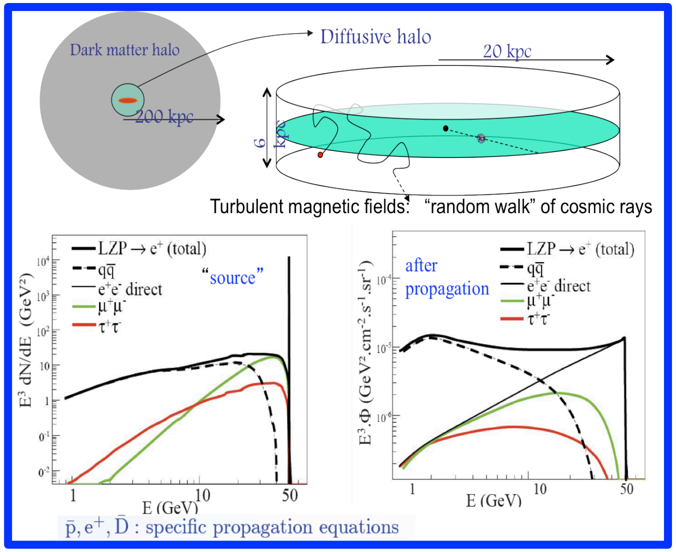
- **Propagation effect**: probed zones for e+,e- within 1-4 kpc
- Boost factor: over densities (clumps)

$$B \propto \frac{\langle\rho^2\rangle}{\langle\rho\rangle^2}$$

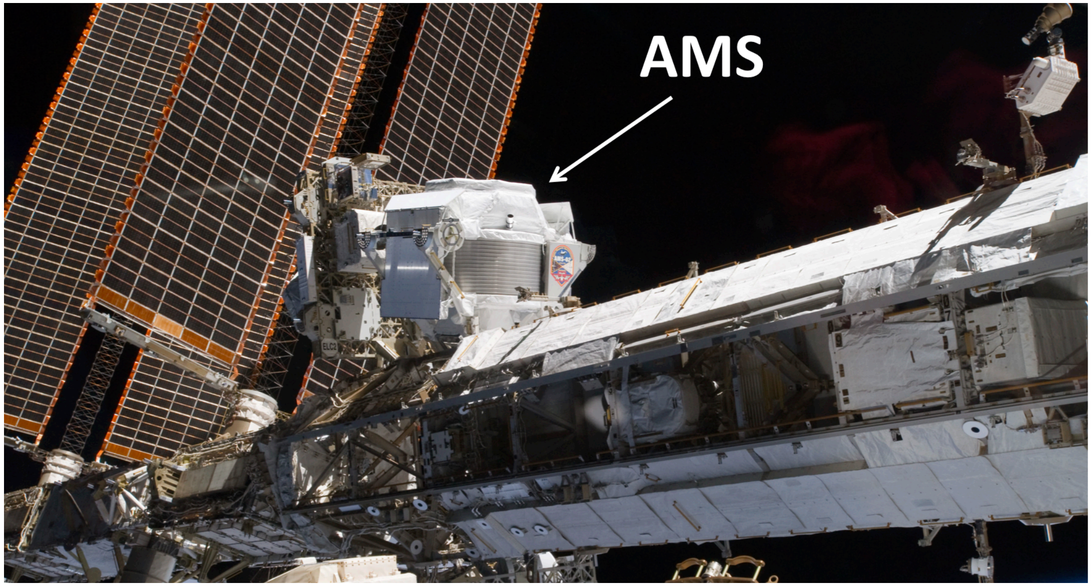
Background

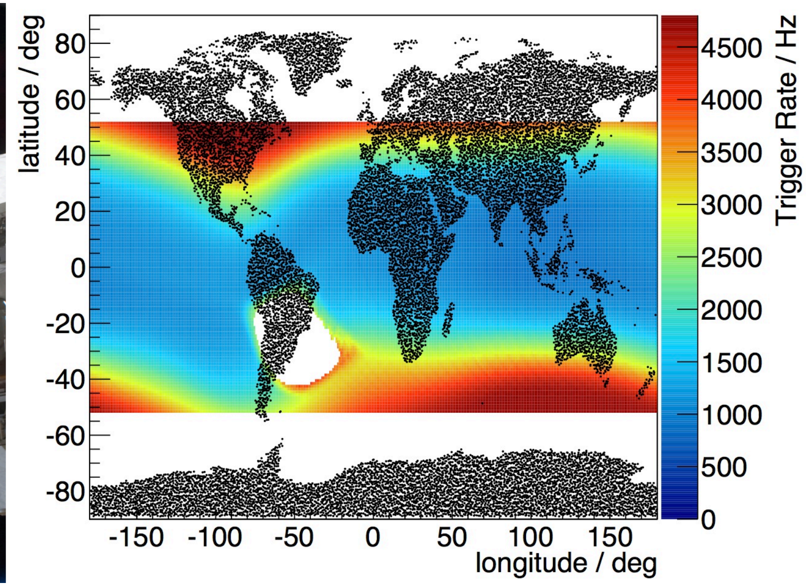
protons : $\Phi_p \sim 10^{3\text{-}4} * \Phi_{e+}$

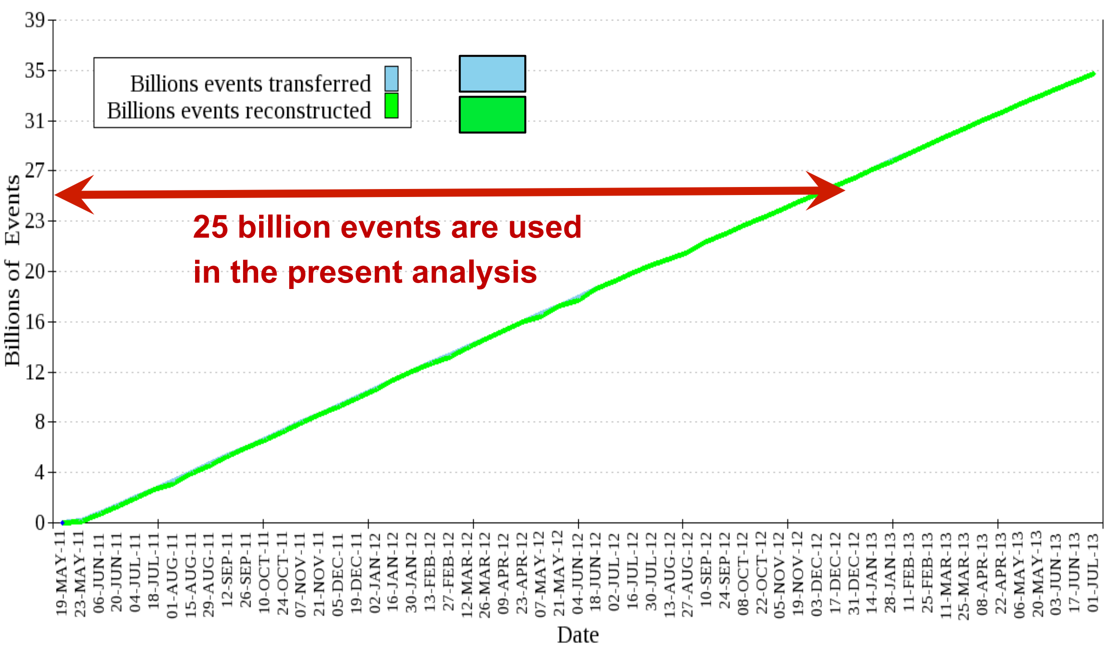
electrons : $\Phi_{e-} \sim 10 * \Phi_{e+}$



The **A**lpha **M**agnetic **S**pectrometer on the **I**nternational **S**pace **S**tation







Launch May 2011

Payload Operations Control Center at Cern since June 2011

26 Months of operation:

More than 35 billions of data

20 years of operation foreseen

Ref:

S.Ting Cern Seminar, April 2013

Phys.Rev.Lett. 110 (2013) 14,

M.Heil parallel sessions EPS

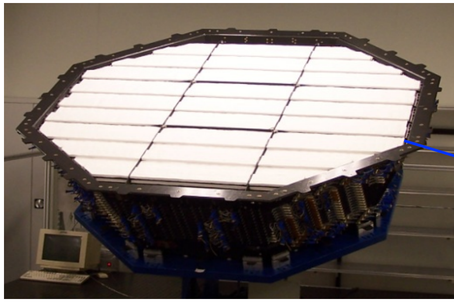
ICRC2013_ 1257,1261,1264,1267

AMS: A TeV precision, multipurpose spectrometer in space

Particles and nuclei are identified by their charge (Z) and energy (E ~ P)

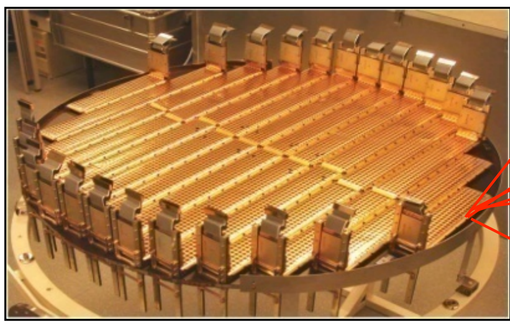
TRD

Identify e+, e-



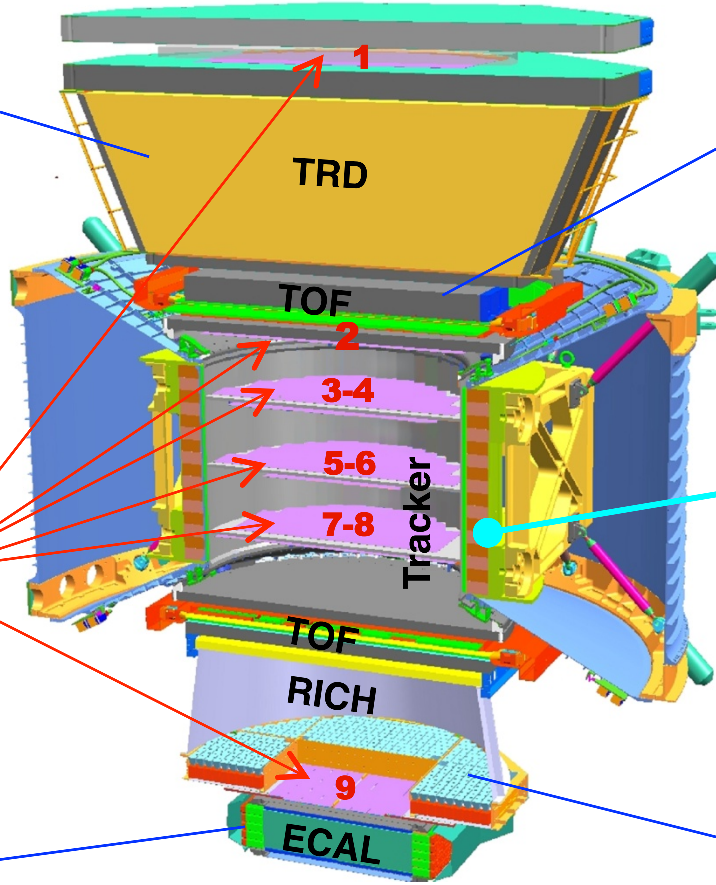
Silicon Tracker

Z, P



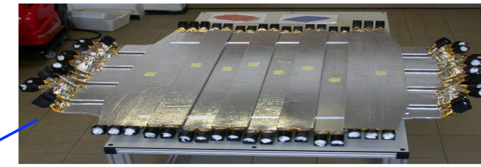
3D imaging ECAL

E of e+, e-, γ



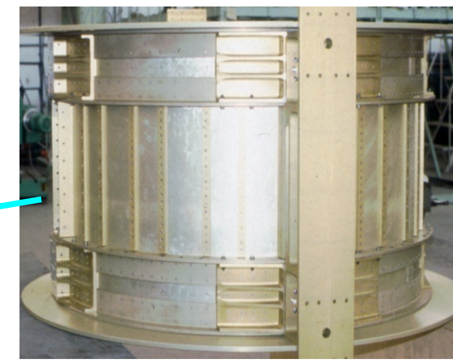
TOF

Z, E



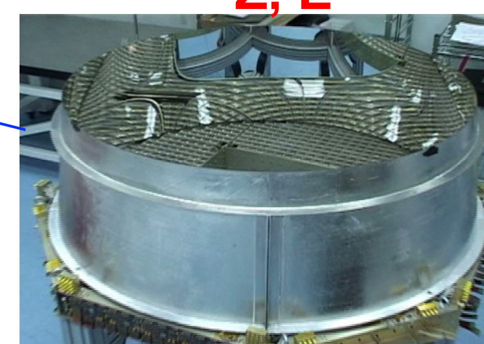
Magnet

±Z



RICH

Z, E



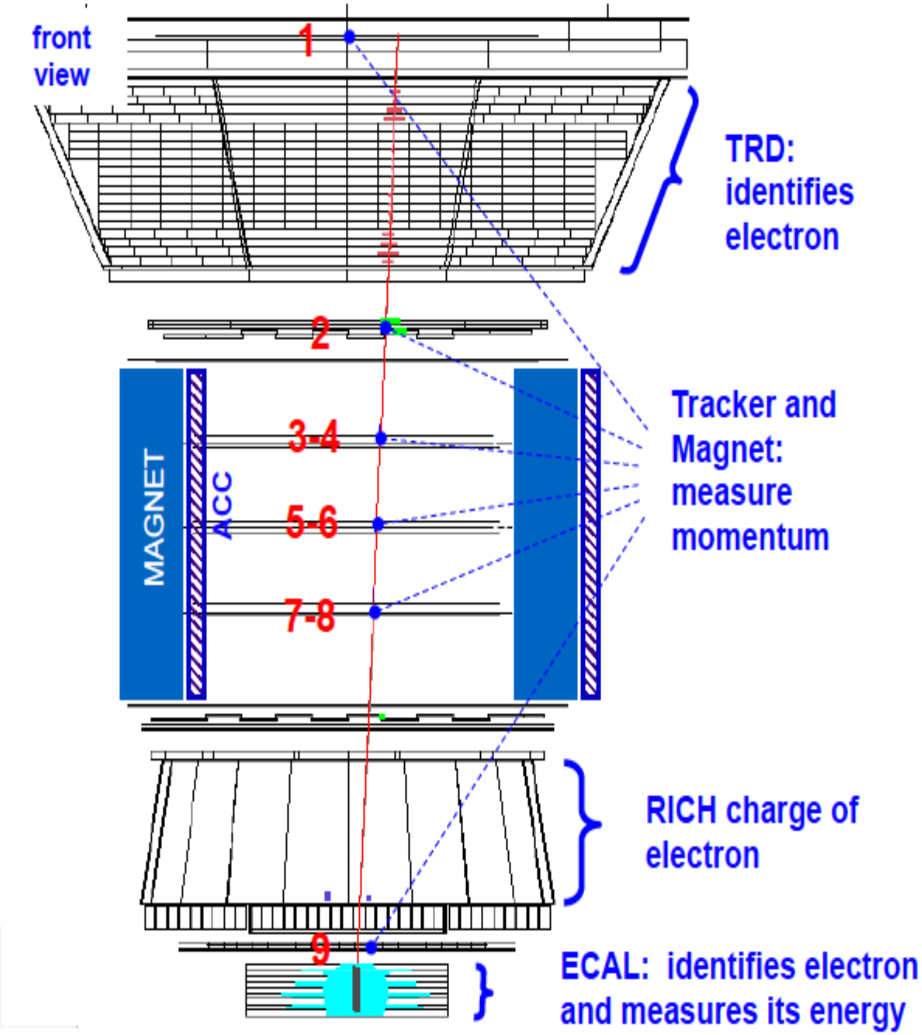
5m x 4m x 3m   7.5 tons

Z, P are measured independently from Tracker, RICH, TOF and ECAL

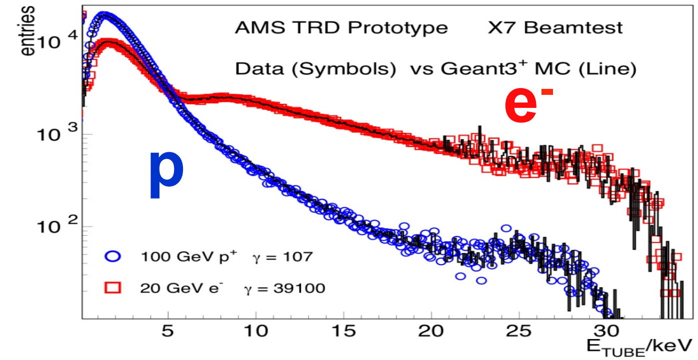
e+,e- Identification in AMS

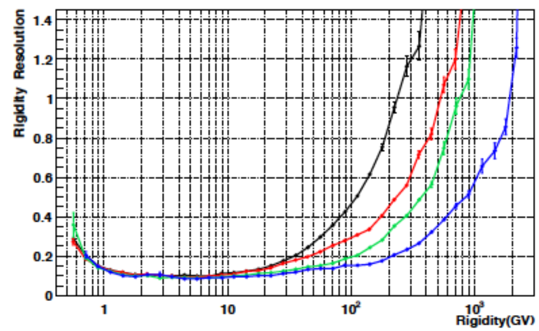
AMS

Proton rejection goal > 1/100000 => 3 independent detectors are used

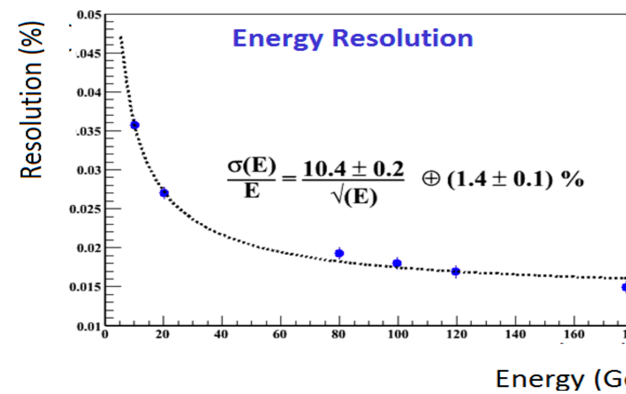


AMS data on ISS: 424 GeV positron





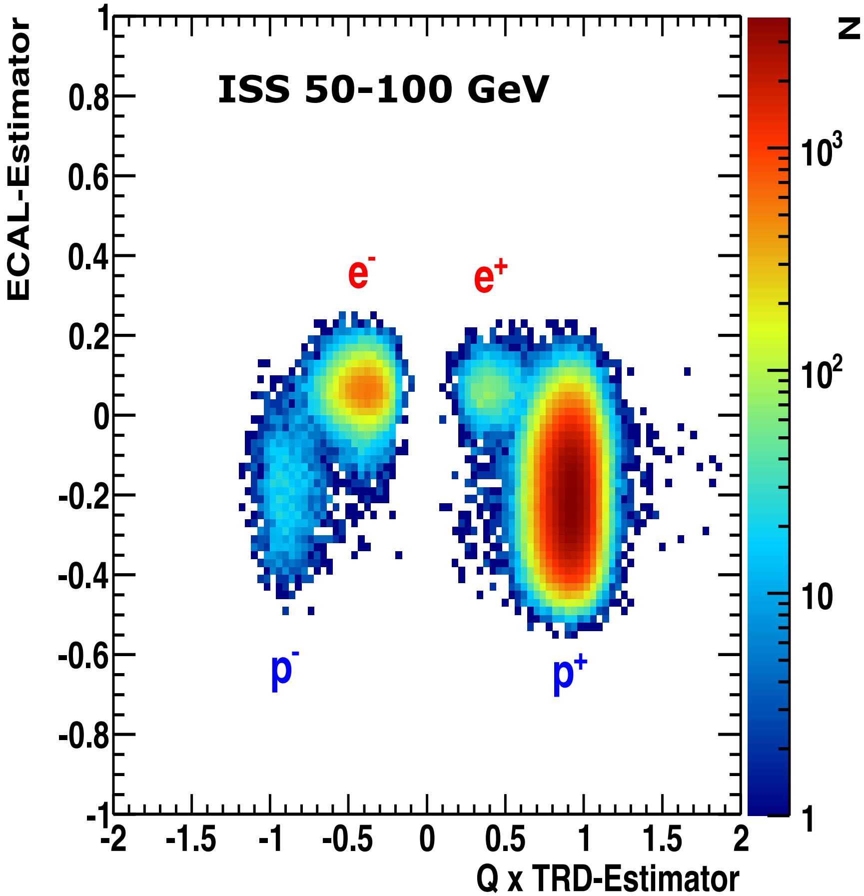
MDR=2 TV



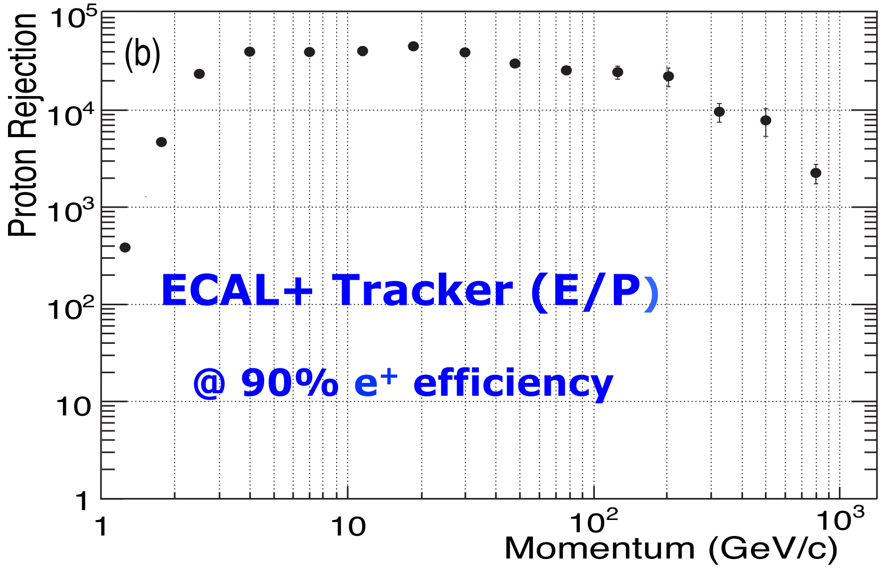
Proton rejection

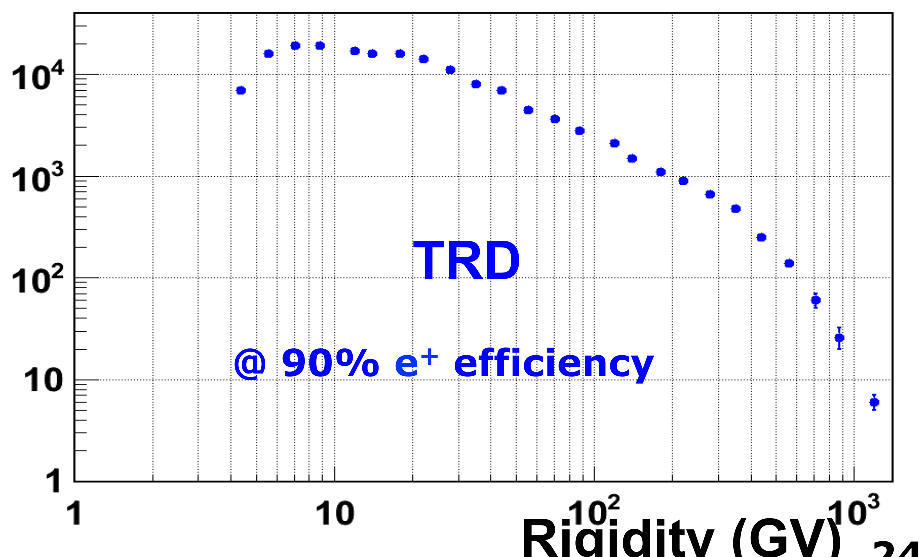
AMS

ECAL estimator : Boost Decision Tree
based on the 3D shower shape features



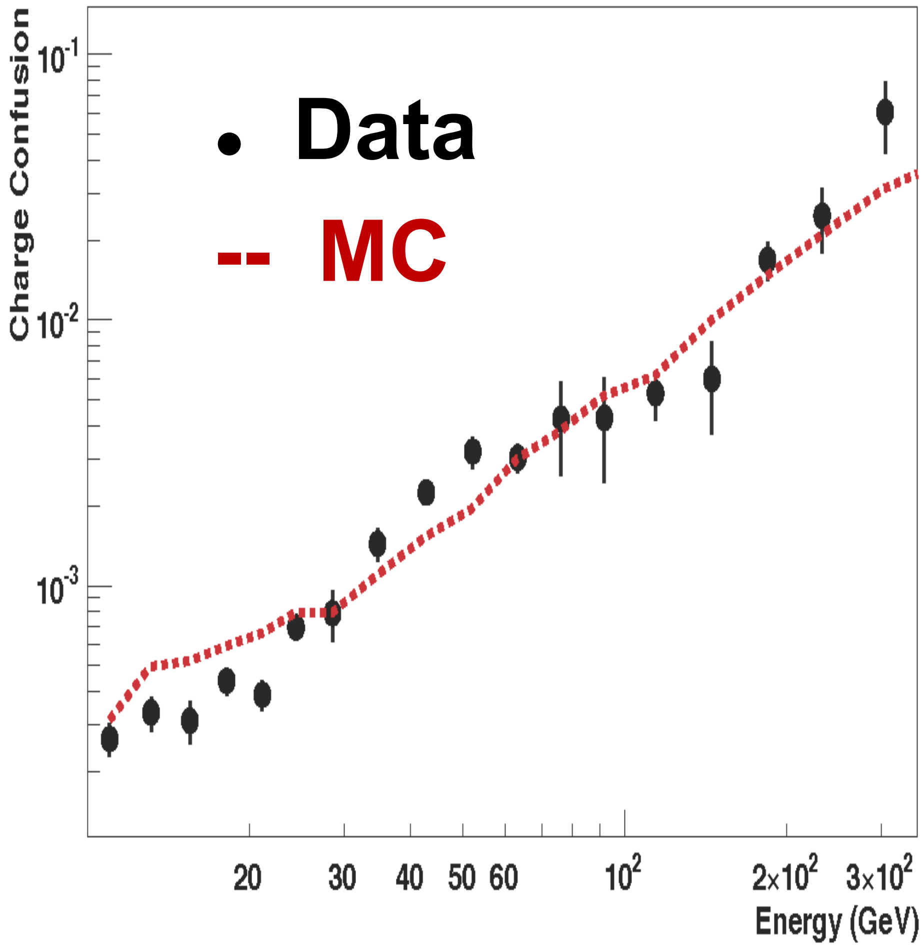
TRD estimator :likelihood based on
the signal amplitude in each layer (20 in total)





Electron rejection

Charge confusion



2 sources

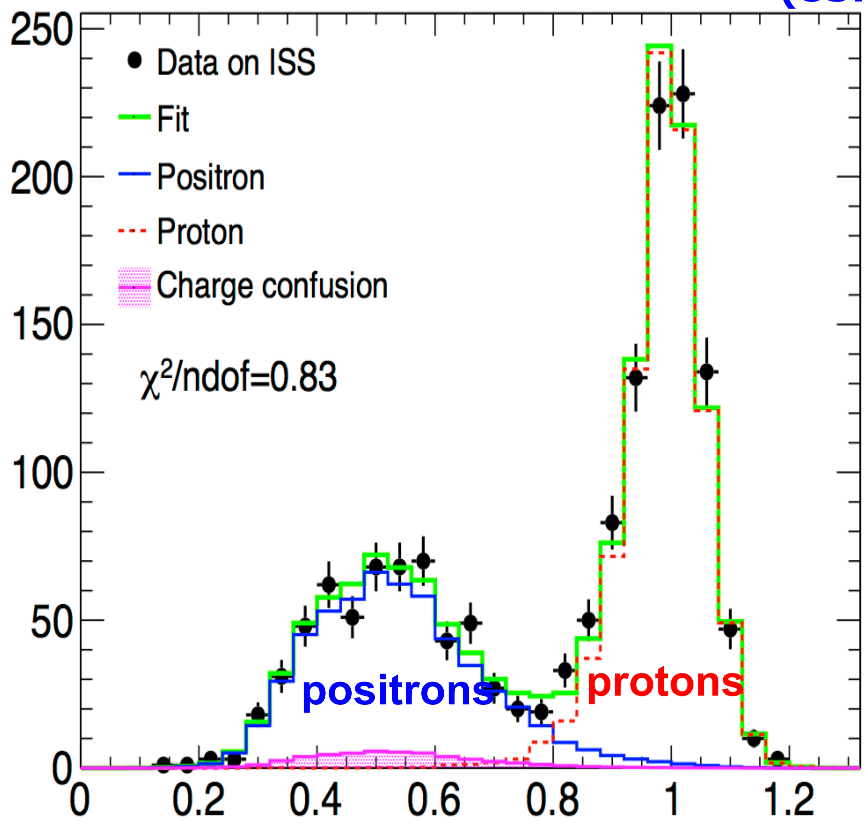
- Multiple scattering and finite resolution of the tracker
- Secondary tracks produced along the the path of primary e^{+-} (tagged and controlled with the lower TOF)

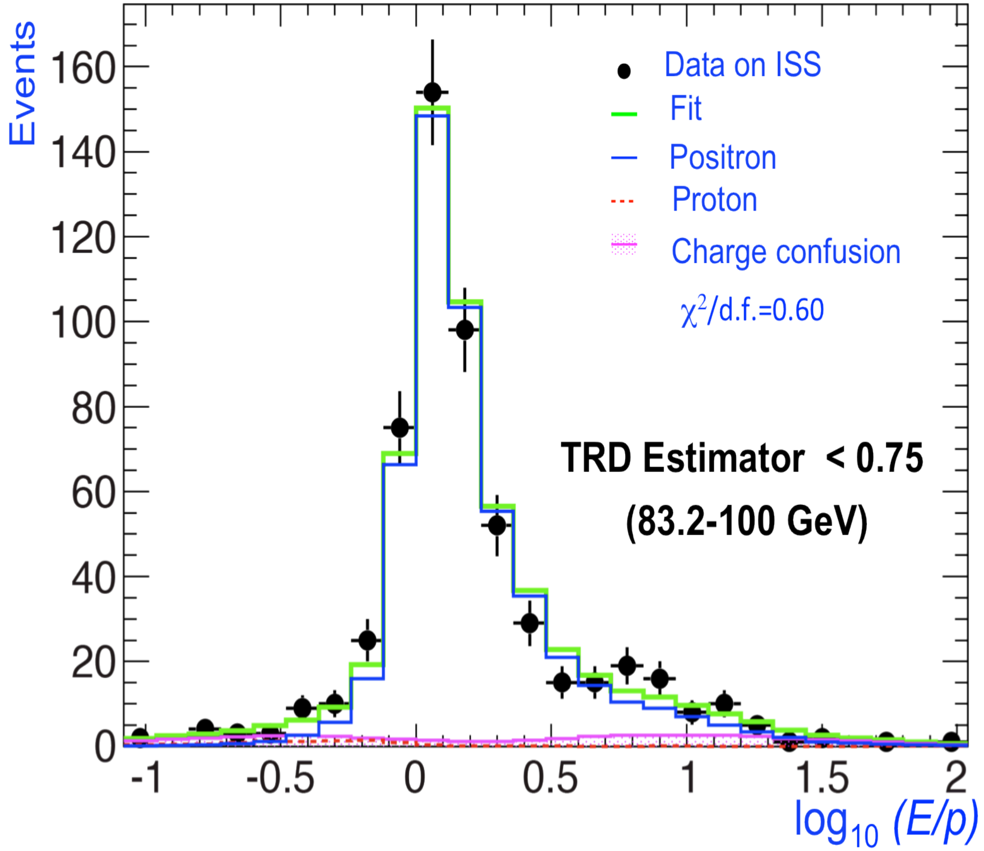
Good agreement Data/MC

Analysis: 2D fit to measure **Ne±** and Np

Large statistics: 2-D reference spectra for the signal and background are fitted in the (E/P –TRD estimator) plane for each energy bin, after a selection on the ECAL

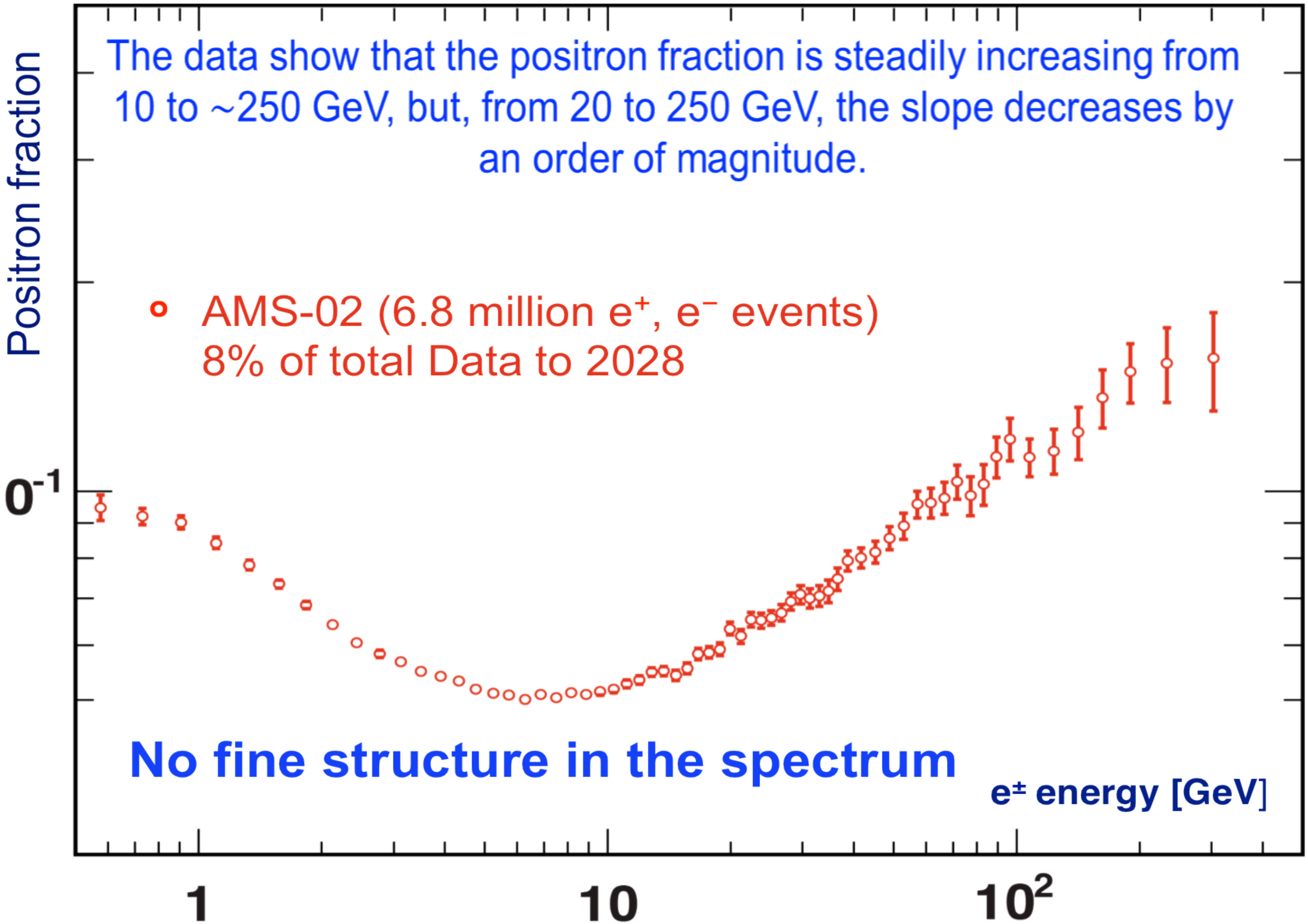
(83.2-100 GeV)



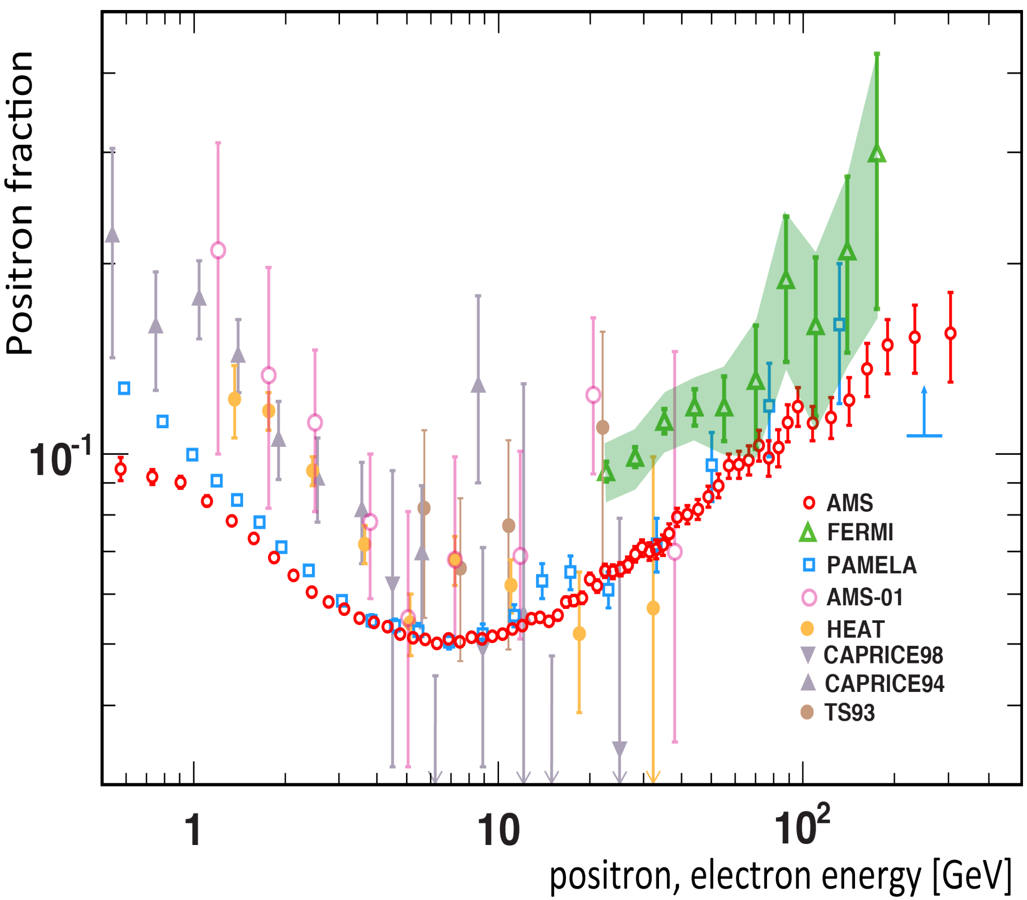


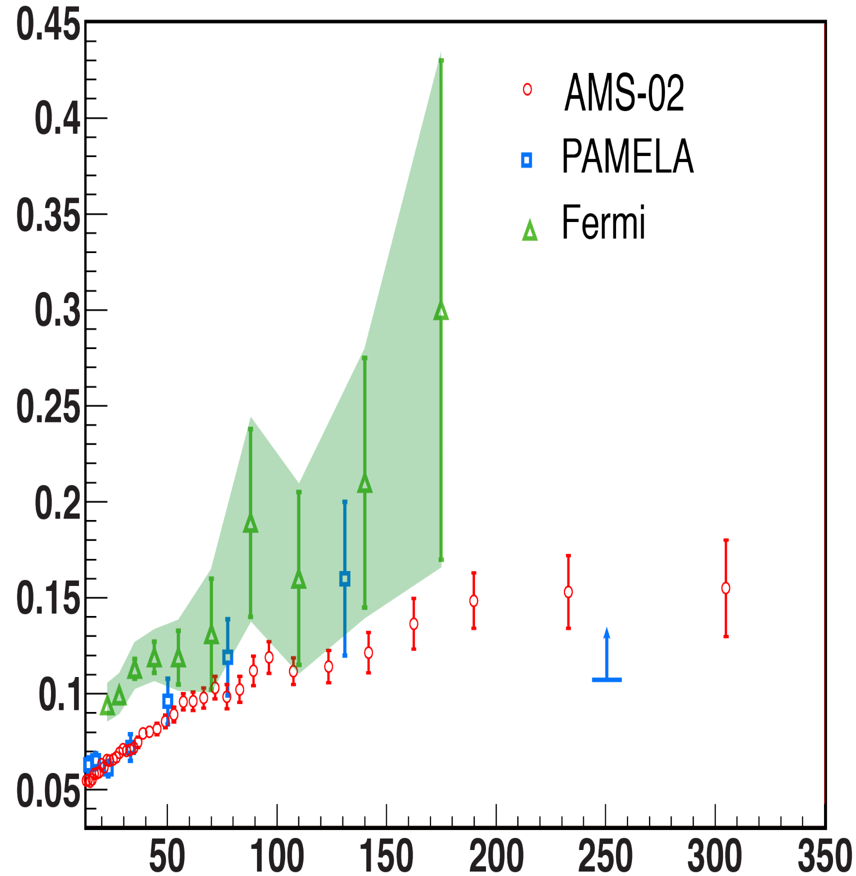
The large redundancy allows to control precisely the systematics uncertainties (M.Heil , parallel session)

Positron fraction AMS



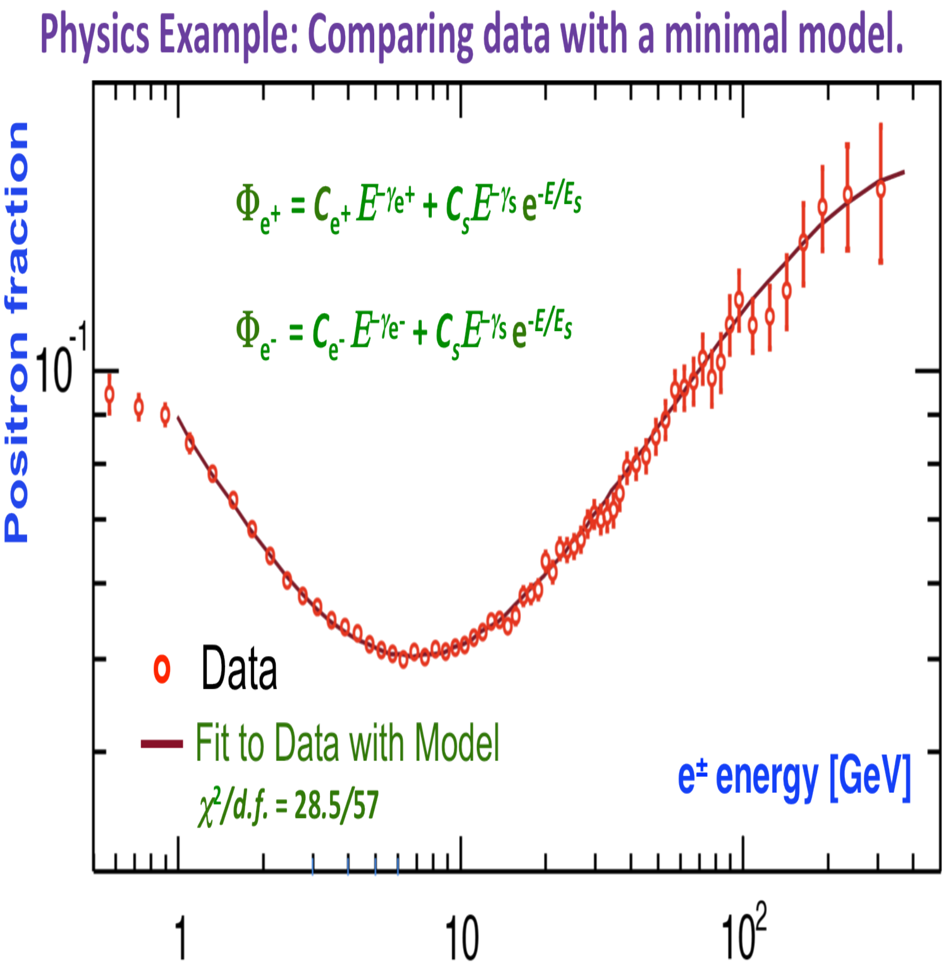
Positron fraction : measurement comparison





->e± Energy [GeV]

Positron fraction AMS



Positrons:

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

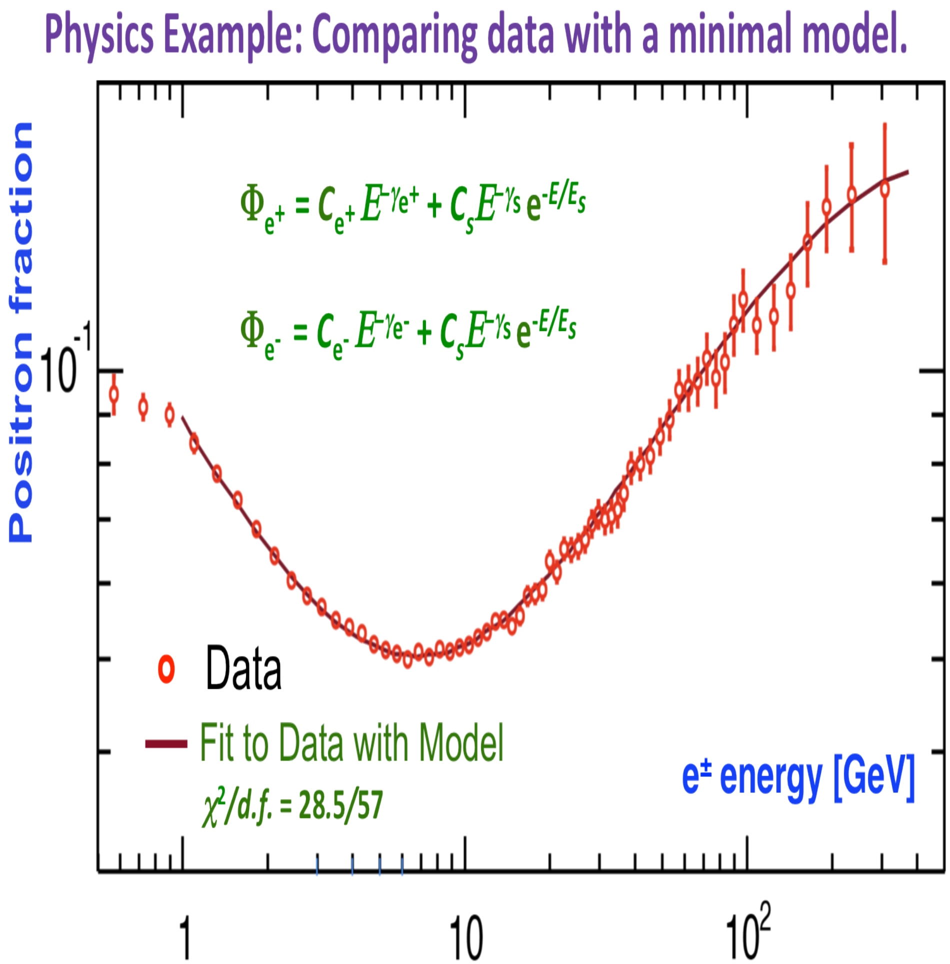
Secondaries plus source component

Electrons :

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

Secondaries+ Astrophysics primaries (SNR+..) plus the same source component

Positron fraction



Results of the fit to the data in the energy range 1 to 350 GeV yields:

- $\gamma_{e-} - \gamma_{e+} = -0.63 \pm 0.03$, *i.e.*, the diffuse positron spectrum is less
- energetic than the diffuse electron spectrum;
- $\gamma_{e-} - \gamma_s = 0.66 \pm 0.05$, *i.e.*, the source spectrum is more energetic than the diffuse electron spectrum;
- $C_{e+}/C_{e-} = 0.091 \pm 0.001$, *i.e.*, the weight of the diffuse positron flux amounts to ~10% of that of the diffuse electron flux;
- $C_s/C_{e-} = 0.0078 \pm 0.0012$, *i.e.*, the weight of the common source constitutes only ~1% of that of the diffuse electron flux;
- $1/E_s = 0.0013 \pm 0.0007\ \mathrm{GeV}^{-1}$, corresponding to a cutoff energy of 760^{+1000} GeV.

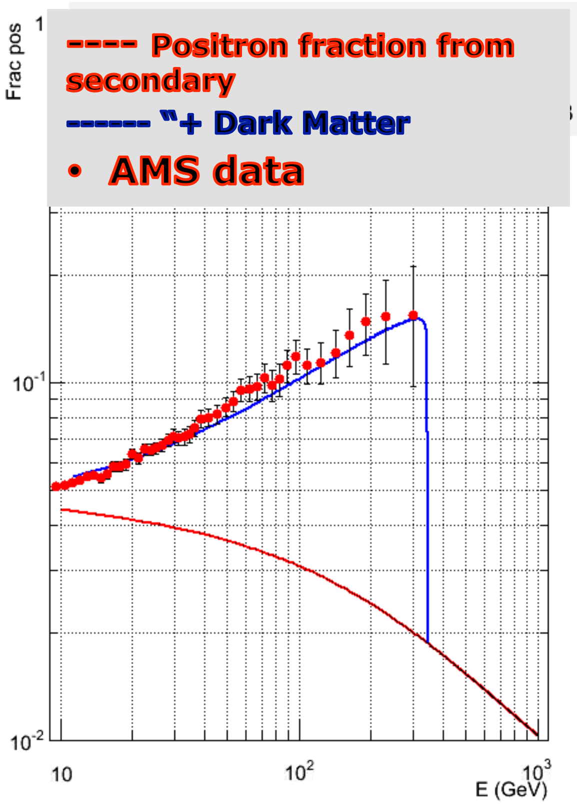
=> Primary positrons are needed

Propagation Model tests

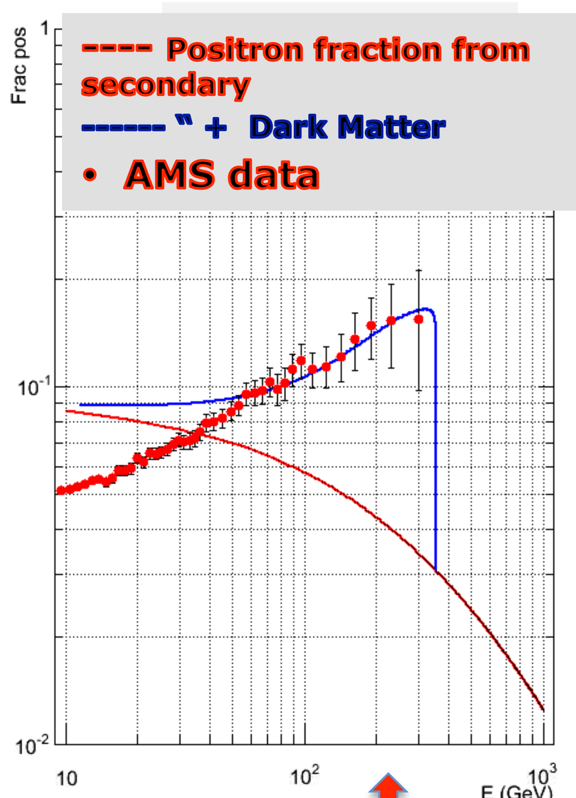
Modèle	δ	K_0 [kpc^2/Myr]	L [kpc]
min	0.85	0.0016	1
med	0.70	0.0112	4
max	0.46	0.0765	15

Independently of the origin of the Source

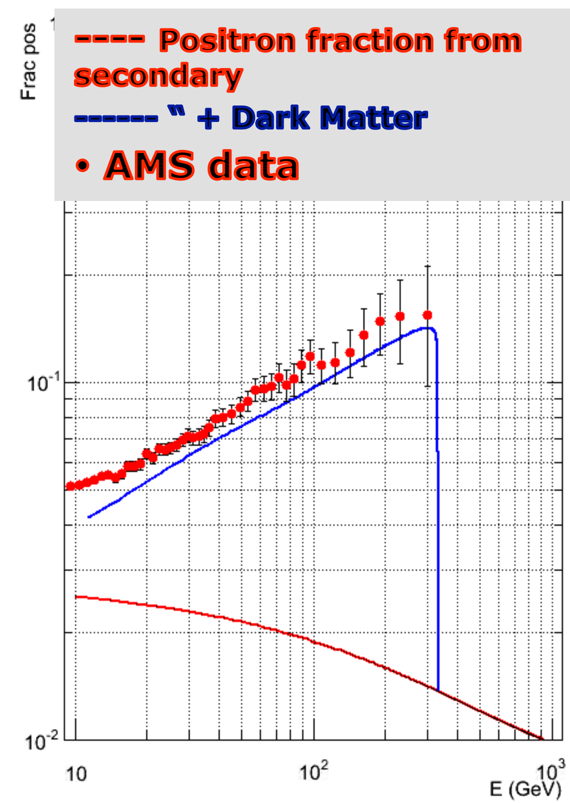
Medium Model



Minimal Model



Maximal Model



Excluded

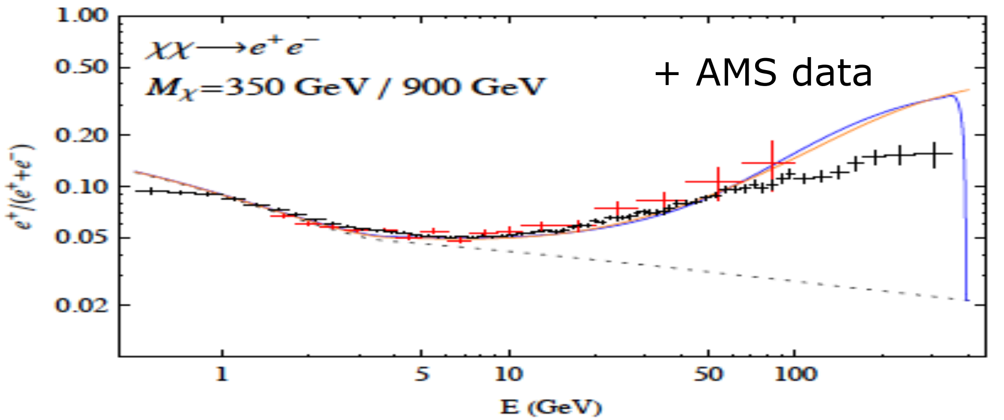
$\Rightarrow$ **Important to constraint the propagation model parameters to draw any interpretations (B/C measurements in Pamela, AMS and 2014 CALET or ISS Cream)**

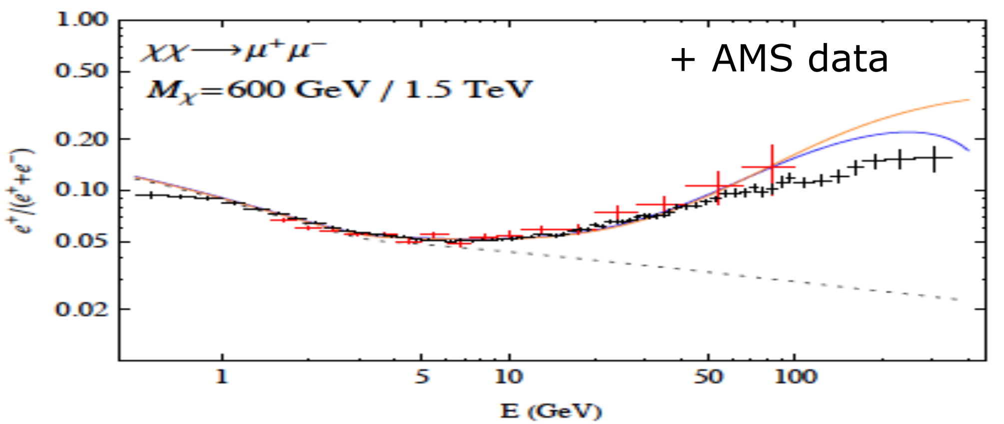
$\Rightarrow$ **Important also to look at the positron and electron fluxes separately (PAMELA,AMS)**

Impact of the precision of the measurement: shape

If 100% WIMP DM origin: different branching ratio scenarios can be tested

I.Colis et al arXiv:1304.1840 [astro-ph.HE]



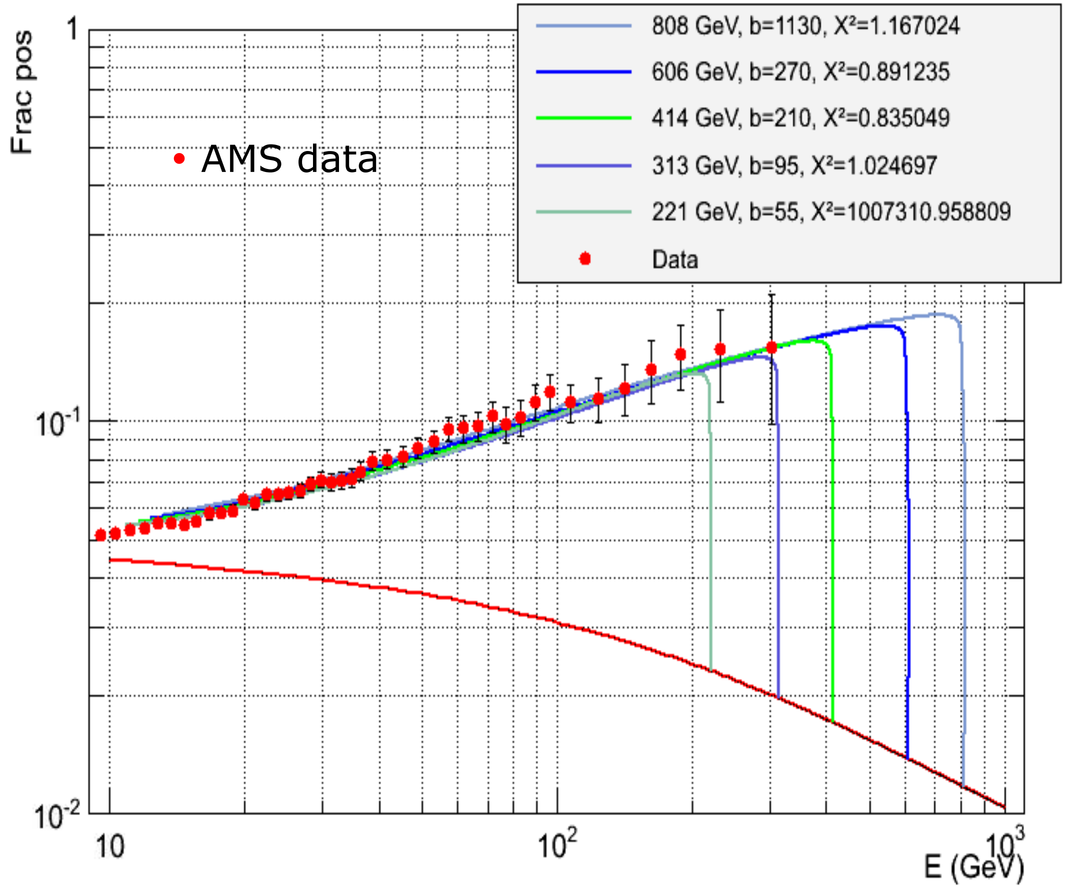


"Dark Matter models in which the WIMP annihilates 100% into e+e- are no longer of producing positron rise in the positron fraction"

Impact of the precision of the measurement: shape

If 100% WIMP DM origin: different masses are tested

- 50% branching ration into tau tau
- Low masses are disfavored (Energy cut off)
- Large masses are disfavored (very high boost factor)



Extended analysis (low mass exclusion <90 GeV) see: L.Bergstrom et al.arXiv: 1306.398 [astro-ph.HE]

Summary

- Extensive searches in Gamma Rays with improved sensitivities expected in the future.
  - The gamma line question is still open : new complementary measurements expected from FERMI but also HESS2, CTA (soon), **Da**rk **Ma**tter **Pa**rticle Explorer(2015), GAMMA-400 (2018) …
- Positron:
  - Positron fraction: very precise measurement from AMS confirming the rise observed by Pamela and Fermi. AMS can probe energies > 350 GeV
  - Positron fluxes expected soon from PAMELA and AMS(Energy > 350 GeV).
  - Background parameterization:
    - Secondary : need to constraint the propagation parameters with data **Boron/Carbon** ratio (PAMELA, AMS, CALET(2014, up to 8 TeV/n)): **Measurements with high precision are expected.**
    - Primary positrons **: How to disentangle Pulsar positrons from DM positrons?**
- Combination of the searches (anti-p, positron and gamma-rays)
  - Antiprotons (AMS),
  - Electrons+Positrons (AMS, PAMELA, HESS, Fermi, MAGIC, CTA, CALET)
  - Gamma (standard, FSR,..)

Pulsars: Possible sources of primary positrons

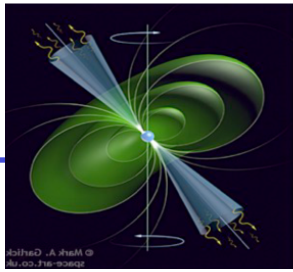
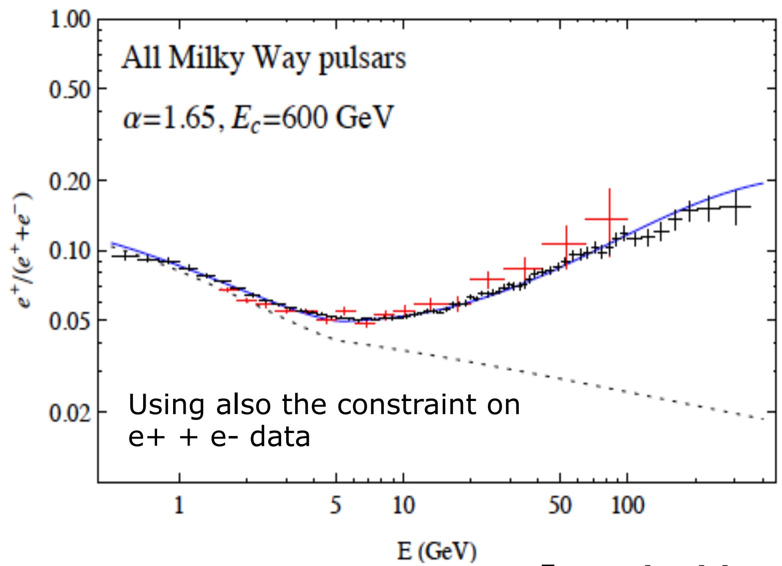


TABLE 1
LIST OF NEARBY SNRS

SNR	Distance (kpc)	Age (yr)	E_{max} [a] (TeV)
SN 185	0.95	1.8×10^3	1.7×10^2
S147	0.80	4.6×10^3	63
HB 21	0.80	1.9×10^4	14
G65.3+5.7	0.80	2.0×10^4	13
Cygnus Loop	0.44	2.0×10^4	13
Vela	0.30	1.1×10^4	25
Monogem	0.30	8.6×10^4	2.8
Loop1	0.17	2.0×10^5	1.2
Geminga	0.4	3.4×10^5	0.67

- Mechanism : the spinning B of the pulsar strips electrons that emit gamma => production of e+e- pair that are trapped in the cloud, further accelerated and later released
- The pulsar bust be young (< 10^5 years) and nearby (<1 kpc)
- Predicted Flux: $\Phi_{e\pm} = E^{-\alpha} exp(-\frac{E}{E_c})$ $alpha \sim 2$ $E_c = few\ TeV$

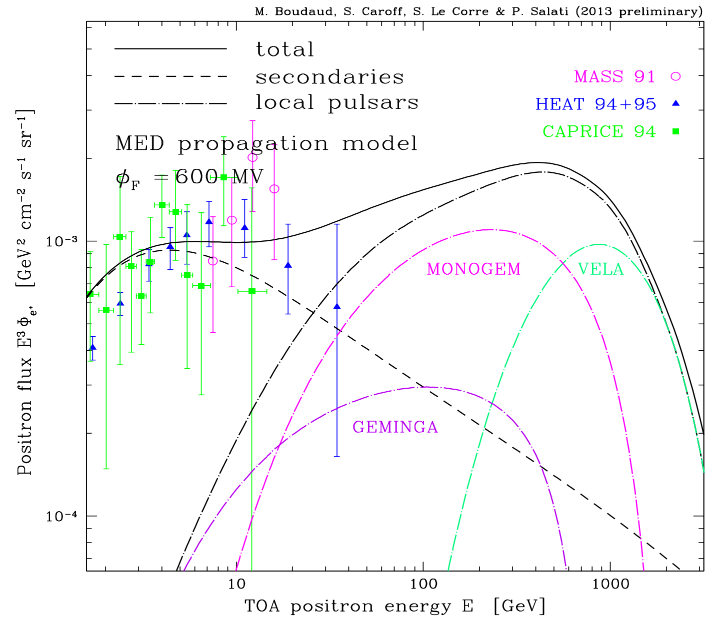
16% of the pulsar energy goes into e+e- pairs **for all the pulsars**



I.Colis et al arXiv:1304.1840 [astro-ph.HE]

Or

Positron Spectrum

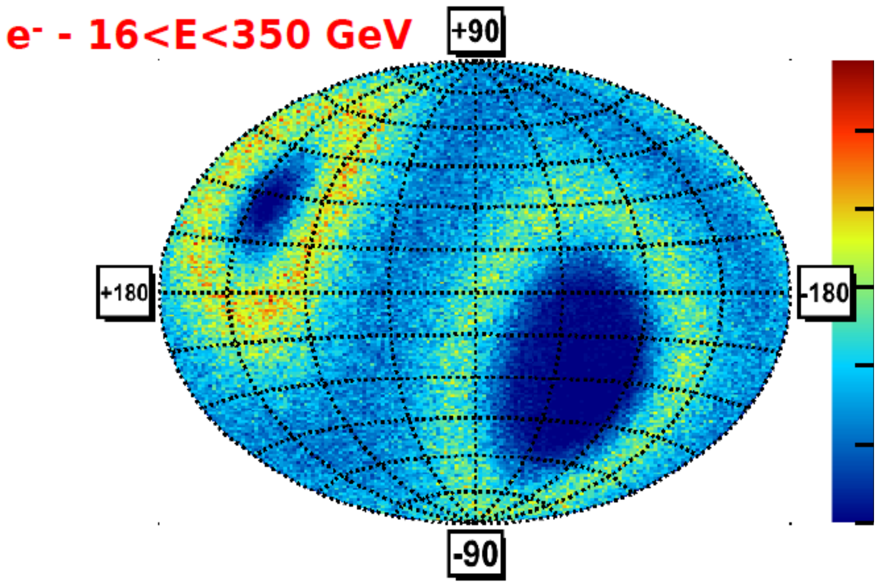


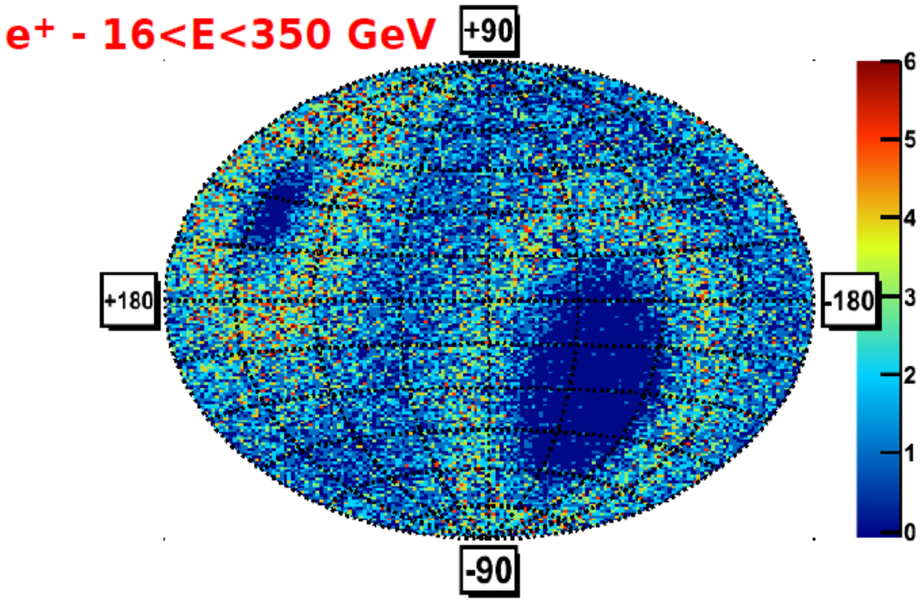
⇒ **Important to measure the positron and electron spectrum separately**

⇒ **Anisotropy for both electrons and positrons (r:distance, t=age** $\delta_{max} = \frac{3}{2c}\frac{r}{t}$

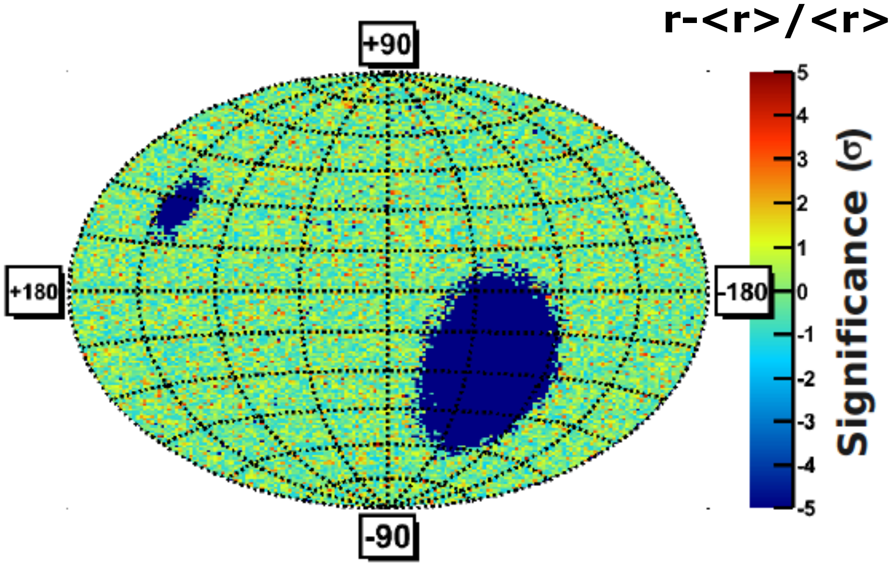
Anisotropy Measurements

- Selected events are grouped in 5 cumulative energy bins:
  16-350, 25-350, 40-350, 65-350 and 100-350 GeV
- Their arrival directions are used to build sky maps in the galactic coordinate(b,l)

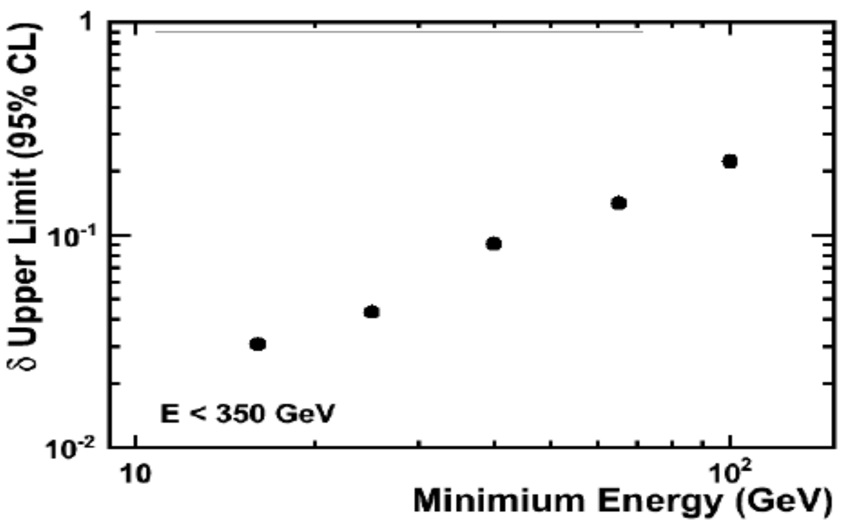




Anisotropy Measurements AMS



The relative fluctuations of the ratio across the observed sky map show no evident pattern



δ<0.030 for 16<E<350GeV

- The coefficients of the multiple expansion are found to be consistent with the expectations from isotropy.
- Upper limits on the dipole parameter δ are set.
- \- After 20 years a sensitivity of the order of 0.014 is expecteds