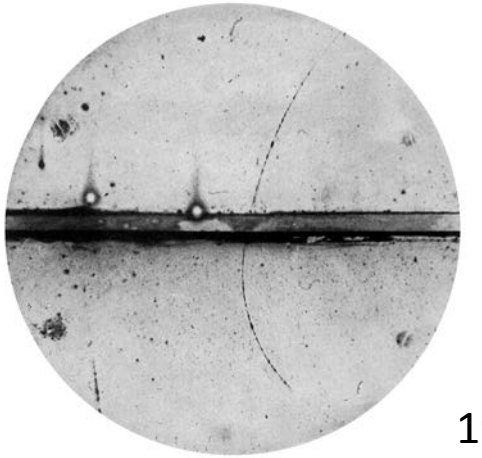
Positron fraction and lepton fluxes in cosmic rays.

Laboratoire d'Annecy-le-Vieux de Physique des Particules

Corinne Goy – LAPP (IN2P3/CNRS)

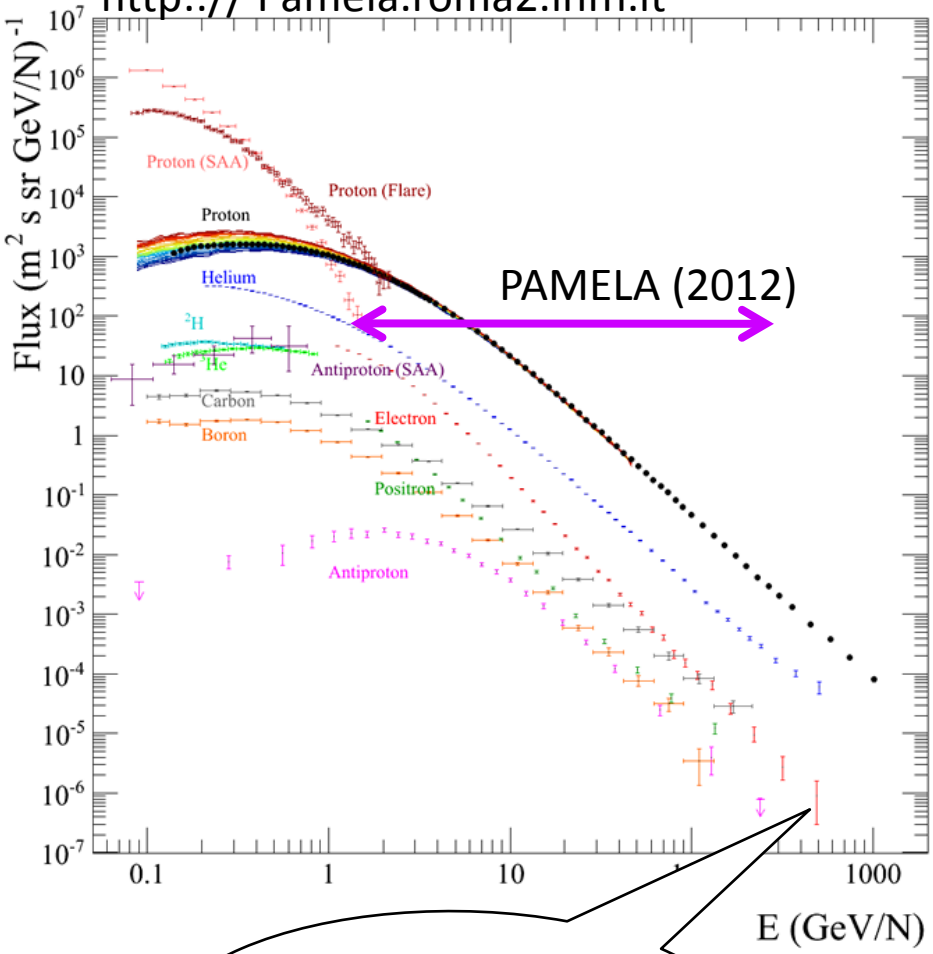
1912

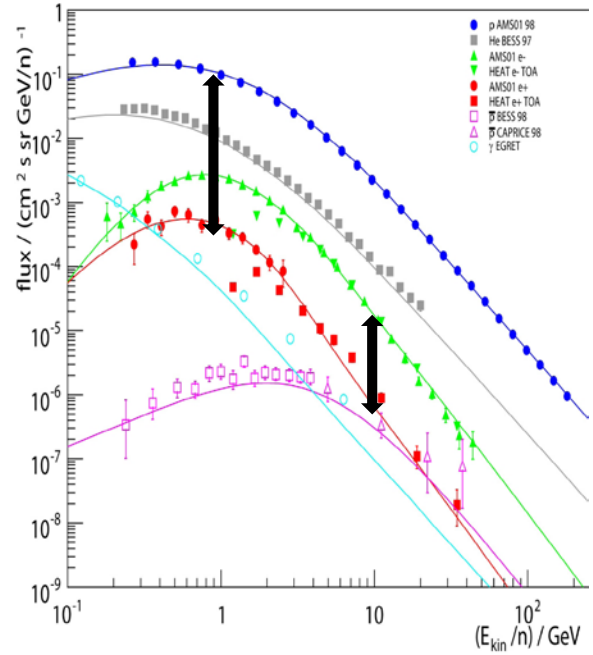


1932

Cosmic Ray panorama

http:// Pamela.roma2.infn.it





Pamela :
< 0.1 evt year/GeV

Experimental challenges :

- e^+/p ~ 10^{-3}
- e^+/e^- ~ 10^{-1}
- Flux $\propto E^{-\alpha}$
  - $\alpha \approx 2.7 / 3.3$
  - Statistical precision

Origin of Electrons

Primary particles ejected from SN/SNR … :

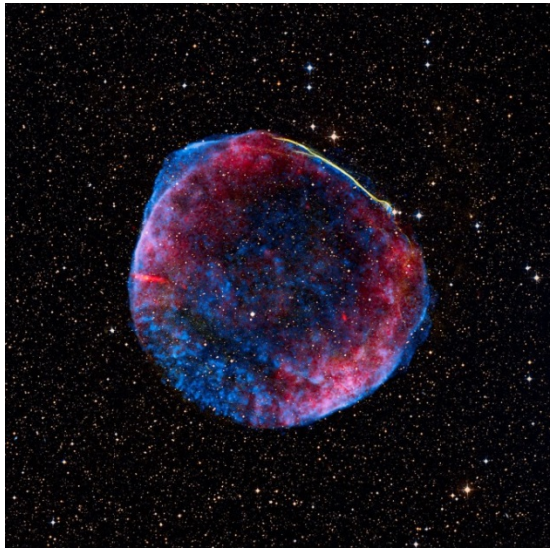
- Injection → **E** $^{-\gamma e}$
- Energy loss (IC,Sync) → ~**E** $^{-\gamma e-1}$

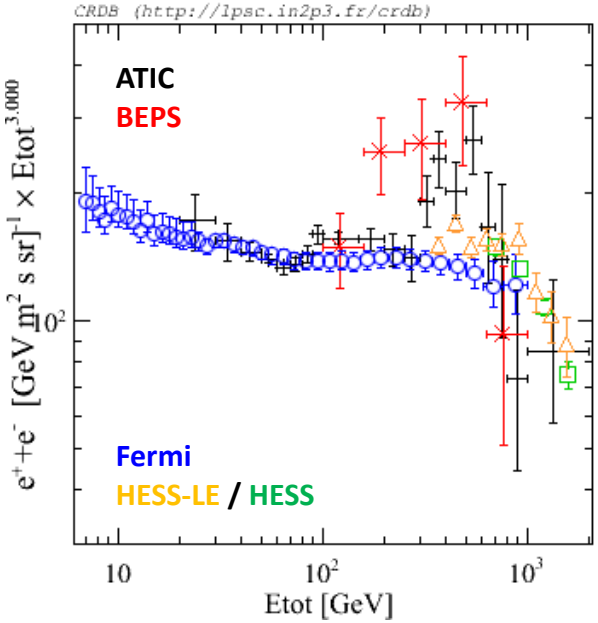
TeV electrons :

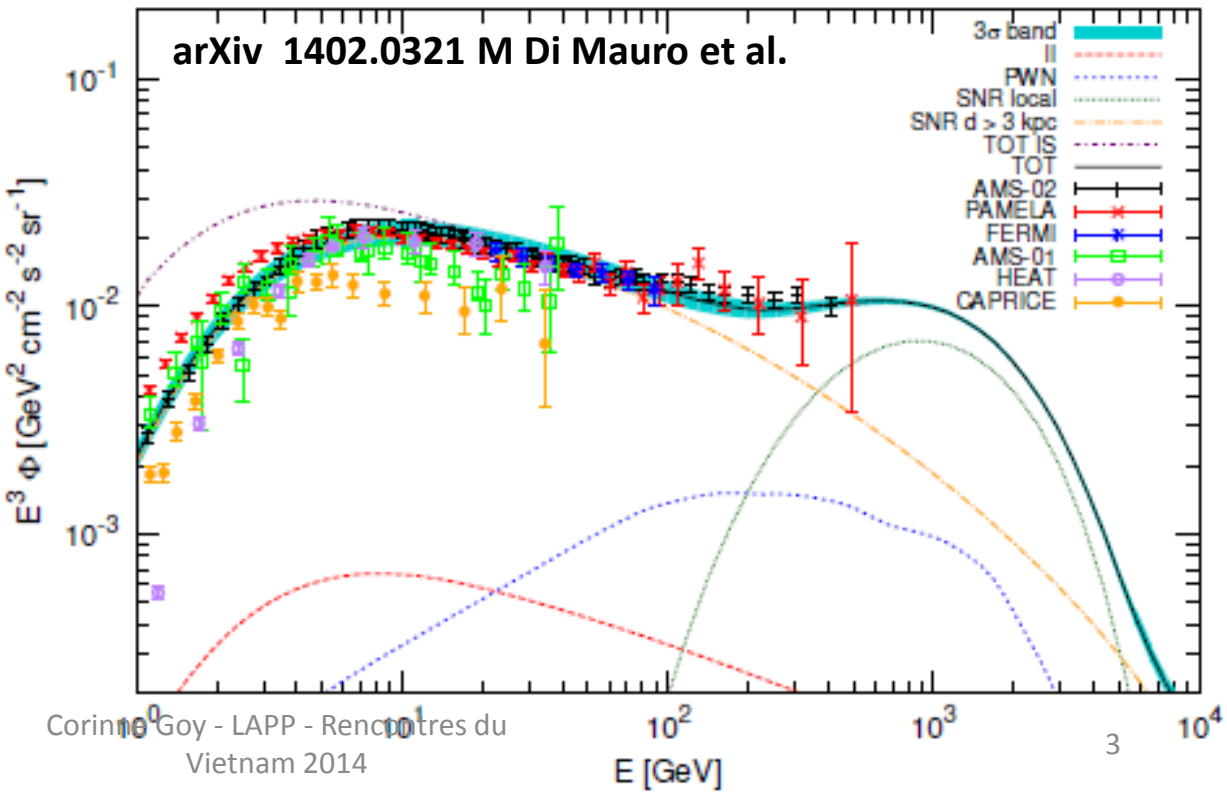
- Local < 1kpc
- Individual sources visible ?
  - ATIC
- Energy cut-off

Requirements :

- Statistics
- Energy resolution







Origin of positrons
Predictions & Uncertainties

Secondary particles from e.g

- p/He + ISM → p + n + π^+ ,…

Injection (proton spectrum) :

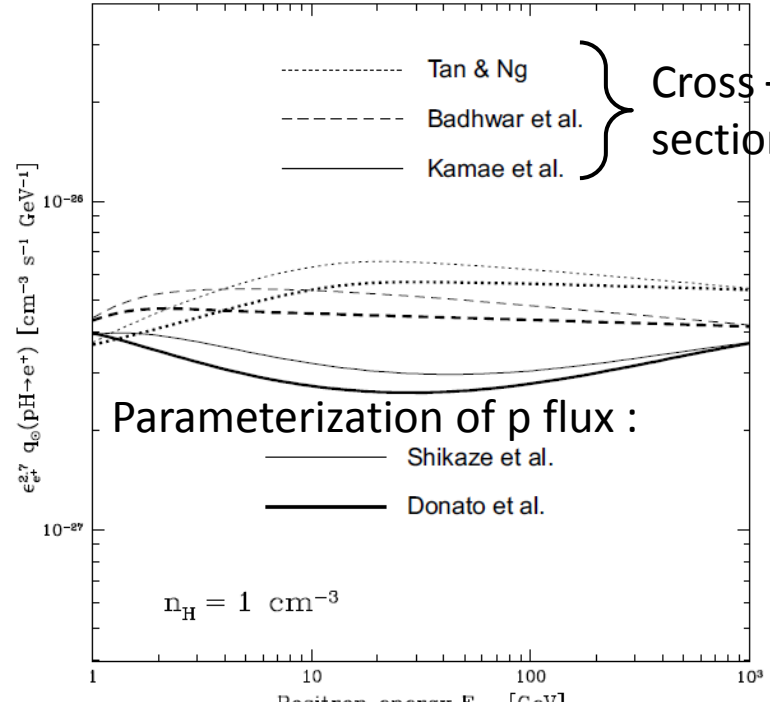
$E^{-\gamma p-\delta} \approx E^{-2.7}$

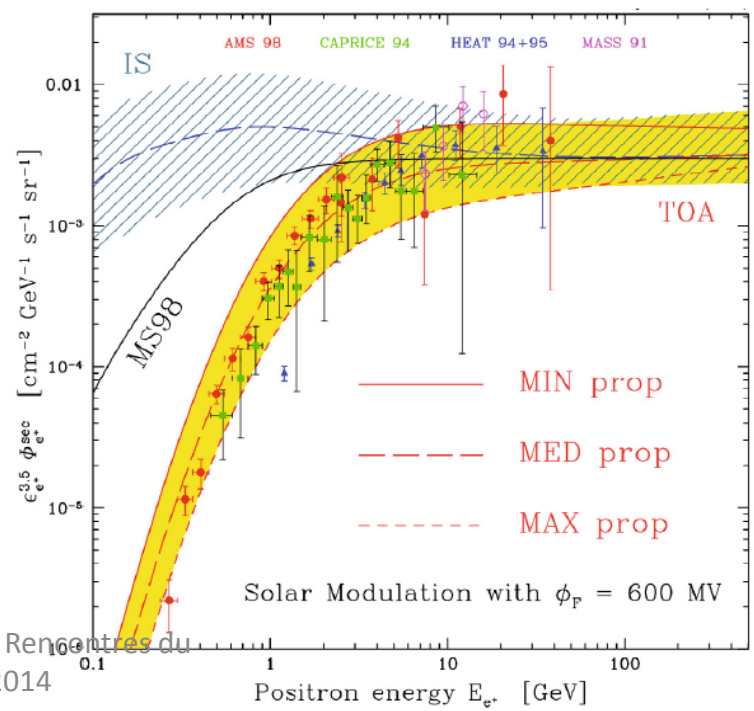
- γp ~ 2 (Fermi mechanism)
- δ = 0.3 - 0.8 (Diffusion : B/C, ….)

Energy loss (IC, Sync) : **$E^{-\gamma p-\delta-1}$**

Uncertainties arise from

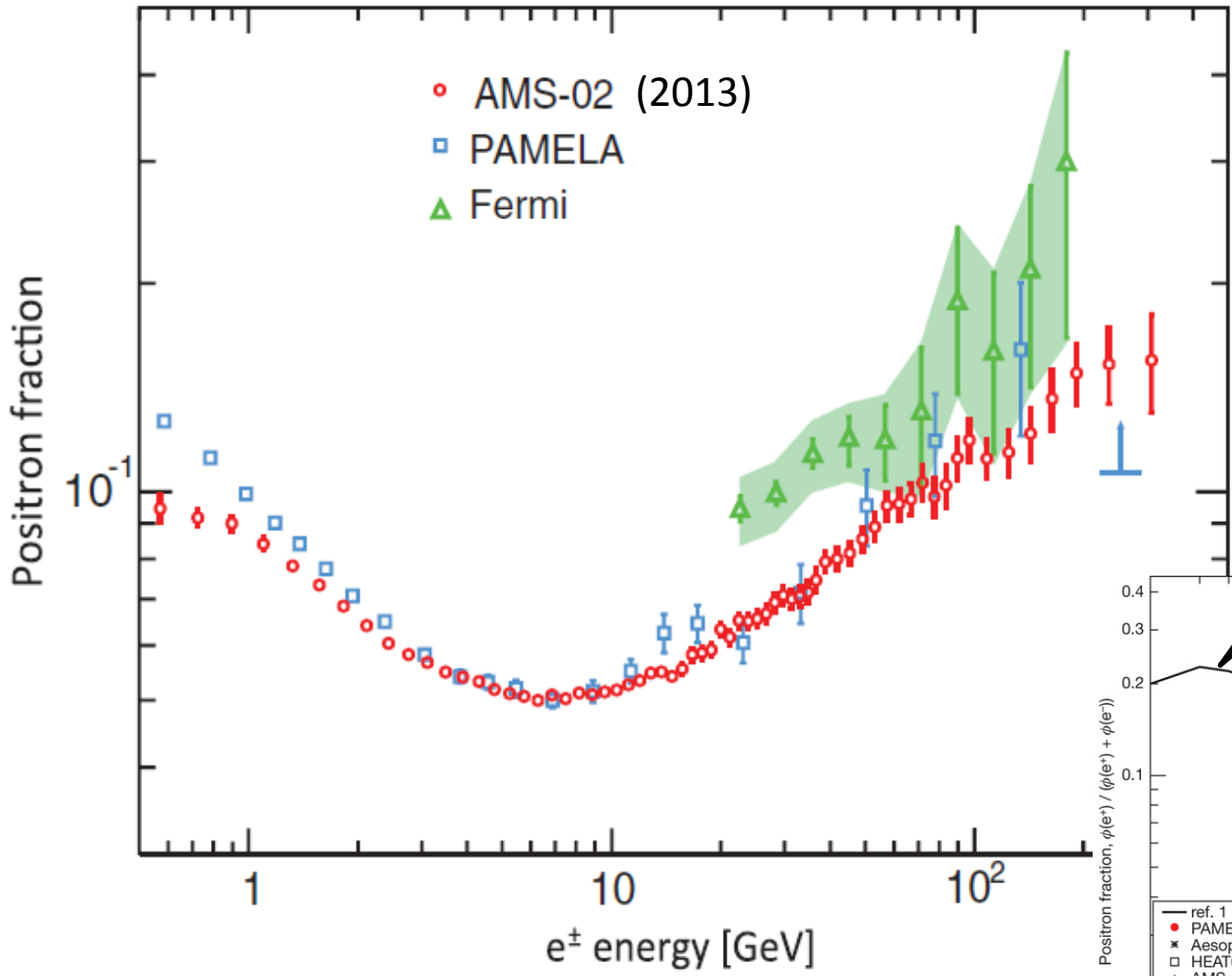
- Proton spectrum : extrapolation to higher energy
- **Cross-Section** :
- **Parameters of the propagation** (Halo, diffusion, winds …)





A&A 501 821-833 (2009)

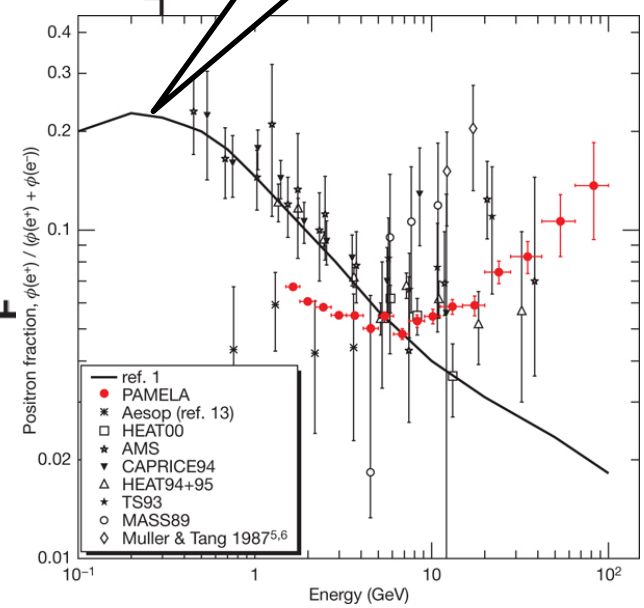
Primary source of positrons : nature ?



Secondary origin only :

$$\frac{\varphi_{e+}}{\varphi_{e-}+\varphi_{e+}} \sim E^{-\delta}$$

($\gamma p/\gamma e \sim 1$, $\delta = 0.3 - 0.8$)

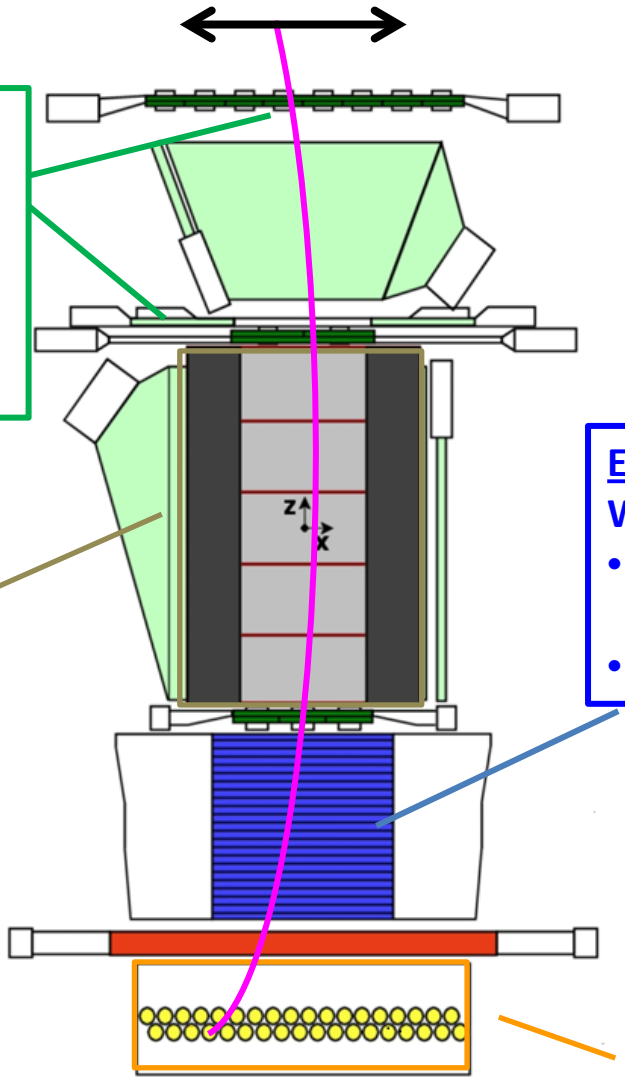


PAMELA – 2006 – 2014

Acceptance limited to ~ 21 cm^2.sr

NEW : all leptons analysis using Calorimeter + Neutron Detector

Set of Time-Of-Flight (TOF)
plastic scintillators + PMT:
- Trigger
- Albedo rejection
- Mass identification up to 1 GeV
- dE/dx

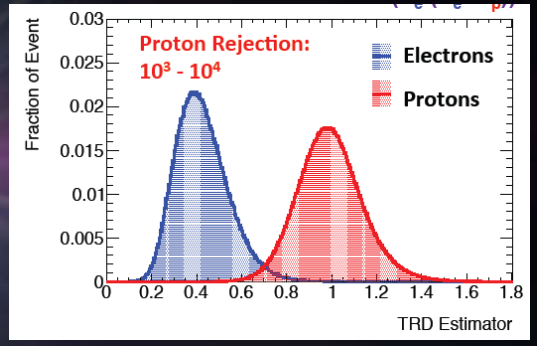


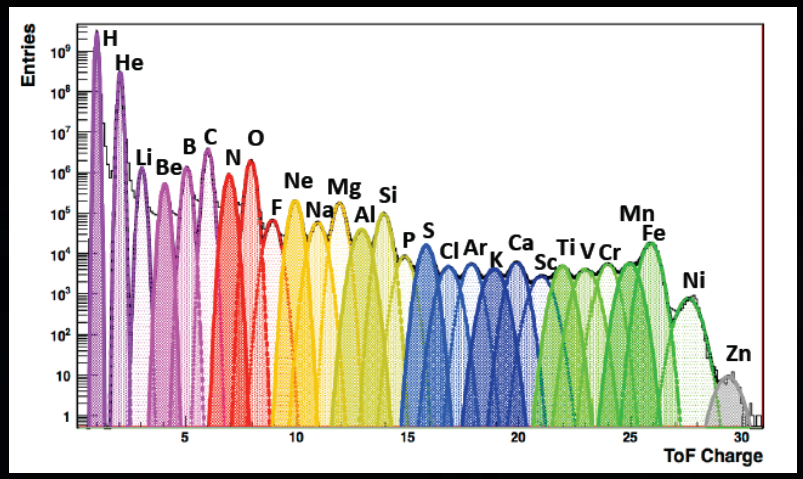
Electromagnetic calorimeter
W/Si sampling (16.3 X_0, 0.6 λ_I)
- Discrimination e^+ / p, p-bar / e^- (shower topology)
- Direct E measurement for e^-/e^+

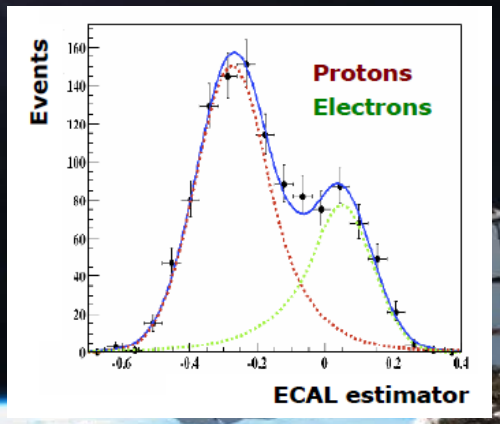
Spectrometer
microstrip Si tracking system (TRK) + permanent magnet 0.43 T
- Charge sign, momentum
- dE/dx

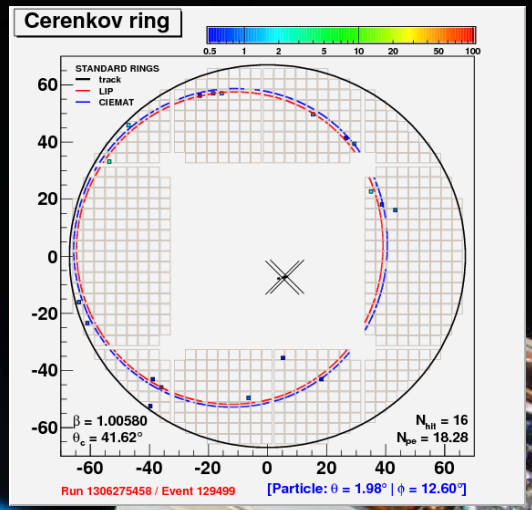
Neutron Detector
polyethylene + ^{3}He counters:
High-energy e/h discrimination

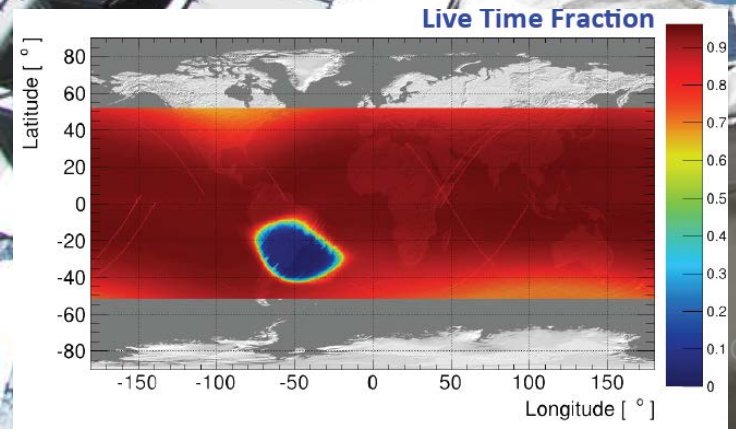
19 Mai 2011

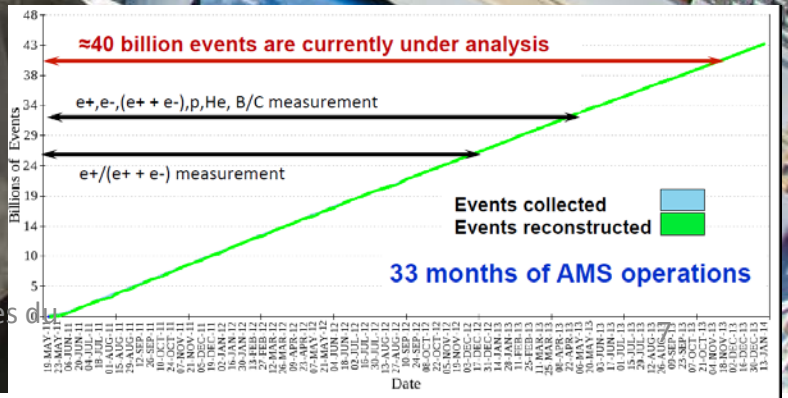

Proton Rejection:
10^3 - 10^4
Electrons
Protons
Fraction of Event
TRD Estimator

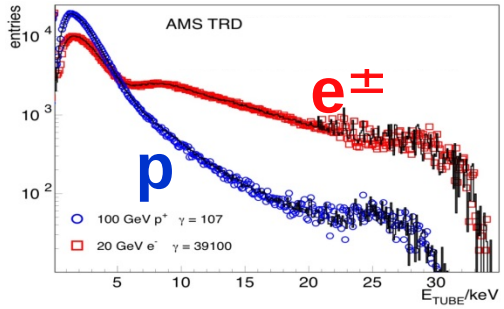

Entries
H He Li Be B C N O F Ne Na Mg Al Si P S Cl Ar K Ca Sc Ti V Cr Mn Fe Ni Zn
ToF Charge


Events
Protons
Electrons
ECAL estimator


Cerenkov ring
STANDARD RINGS
track
LIP
CIEMAT
β = 1.00580
θ_c = 41.62°
N_{hit} = 16
N_{pe} = 18.28
Run 1306275458 / Event 129499
[Particle: θ = 1.98° | ϕ = 12.60°]

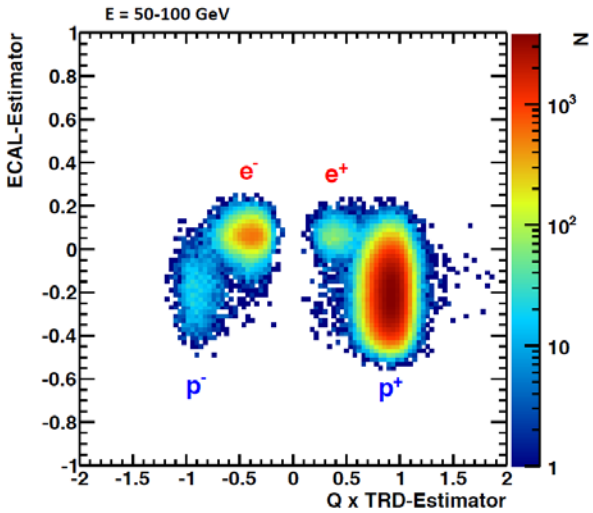

Live Time Fraction
Latitude [°]
Longitude [°]

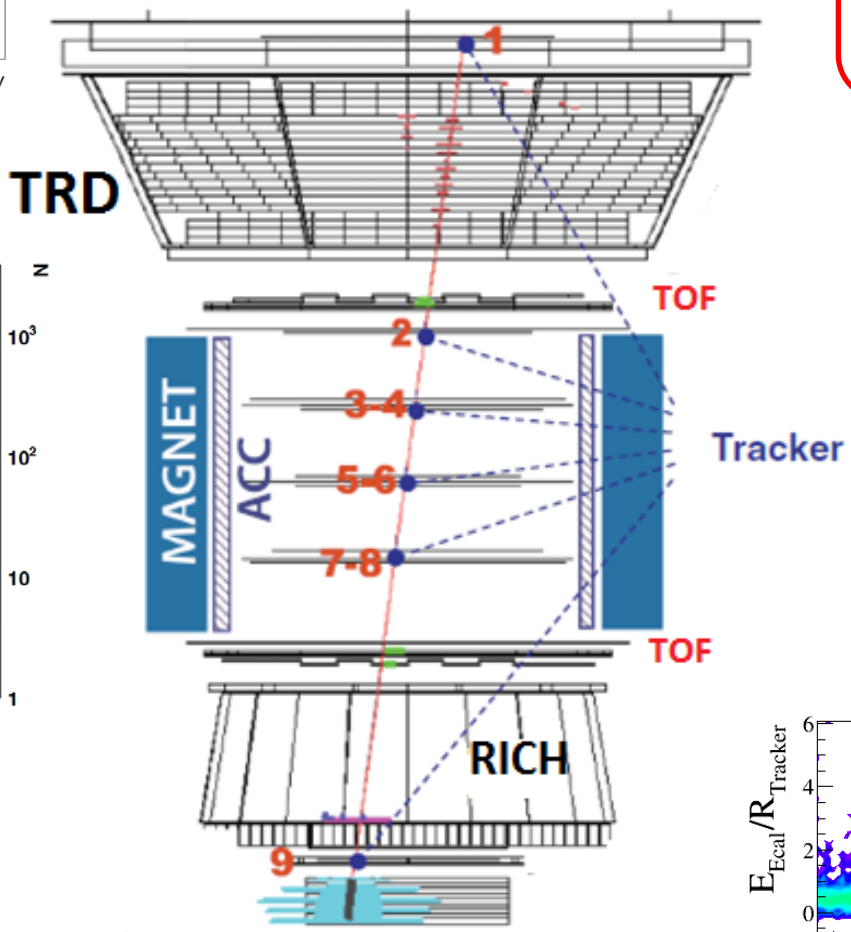

≈40 billion events are currently under analysis
e+,e-,(e+ + e-),p,He, B/C measurement
e+/(e+ + e-) measurement
Events collected
Events reconstructed
33 months of AMS operations
Billions of Events
Date



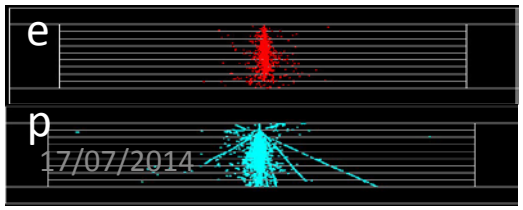
ACC(p) : 0.5 m².sr
ACC(e) : 0.04 m².sr

TOF :
Main trigger
Up/Down
direction

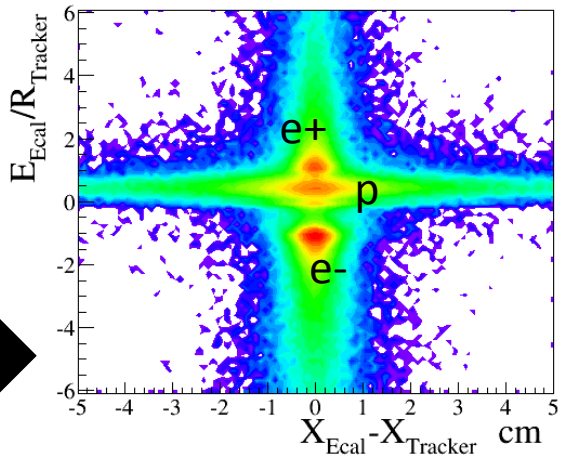




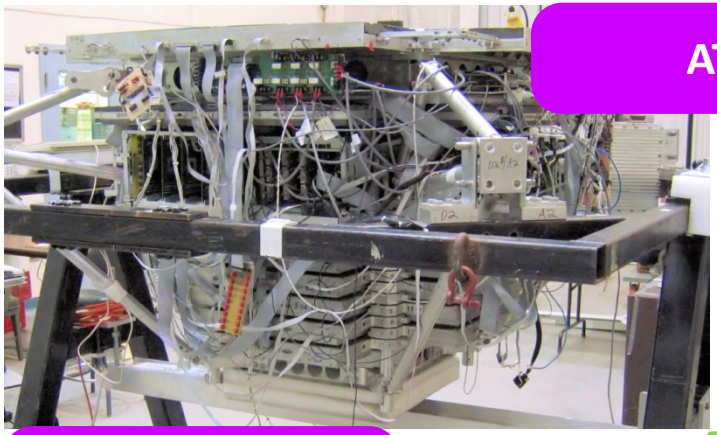
TRACKER :
8 layers Si – 10 µm
0.14 T
MDR ~ 2 TeV

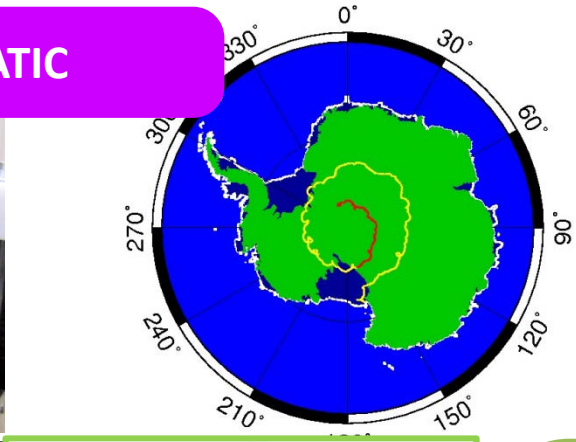


ECAL :
Imaging Calorimeter
17 x0 Lead/Sci - 2%



ATIC



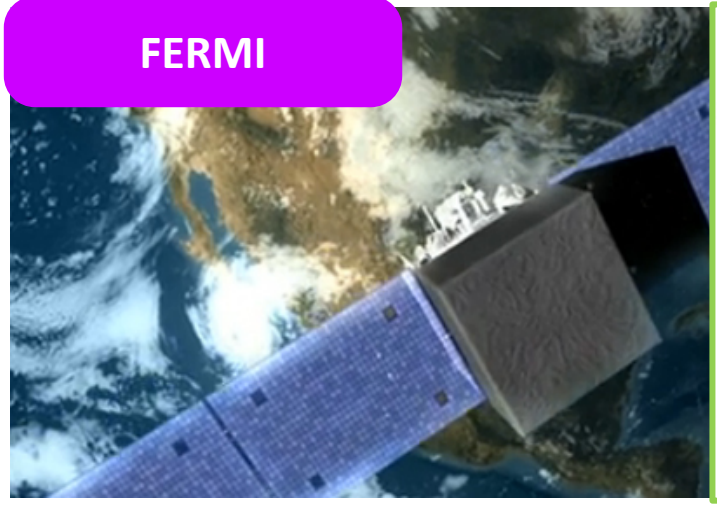


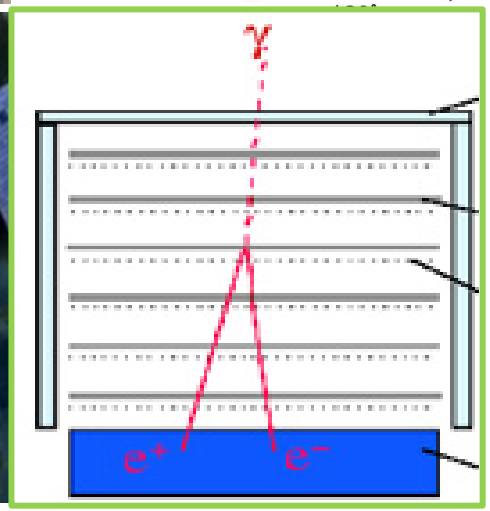
No magnet – 0.25 m^2.sr

e^+/p

Imaging calorimeter
22.5 X0 BGO / 2%

FERMI



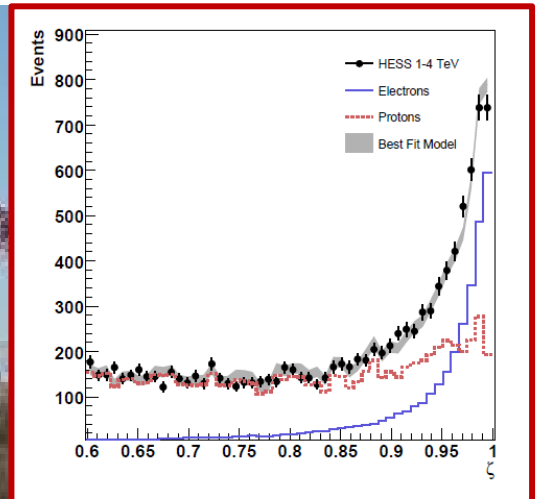


No magnet – ~2 m^2.sr

e^+/p Imaging Calorimeter
10 X0 CsI / 5-10%

e^+/e^- : Earth shadow

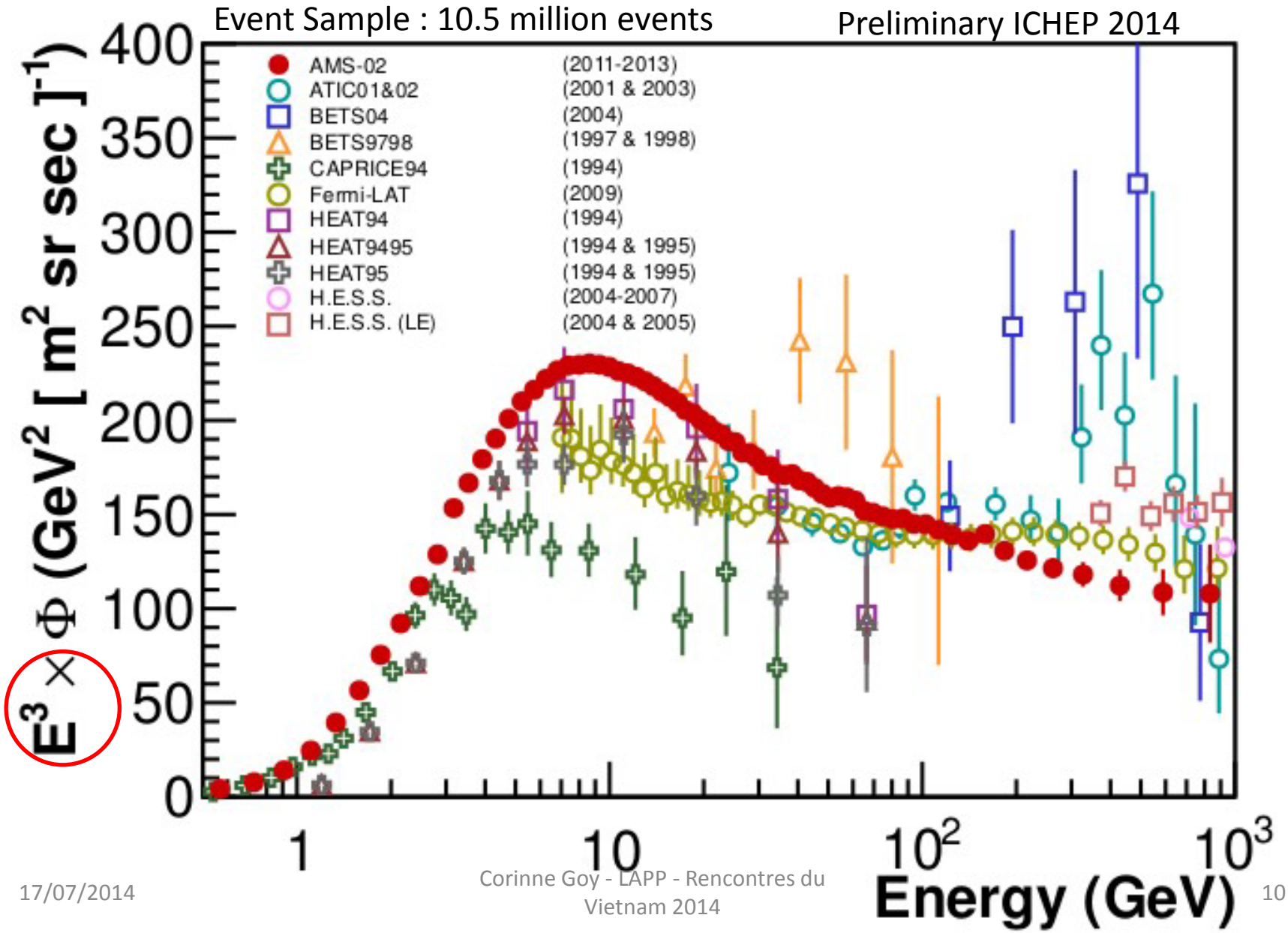
HESS



e^+/p

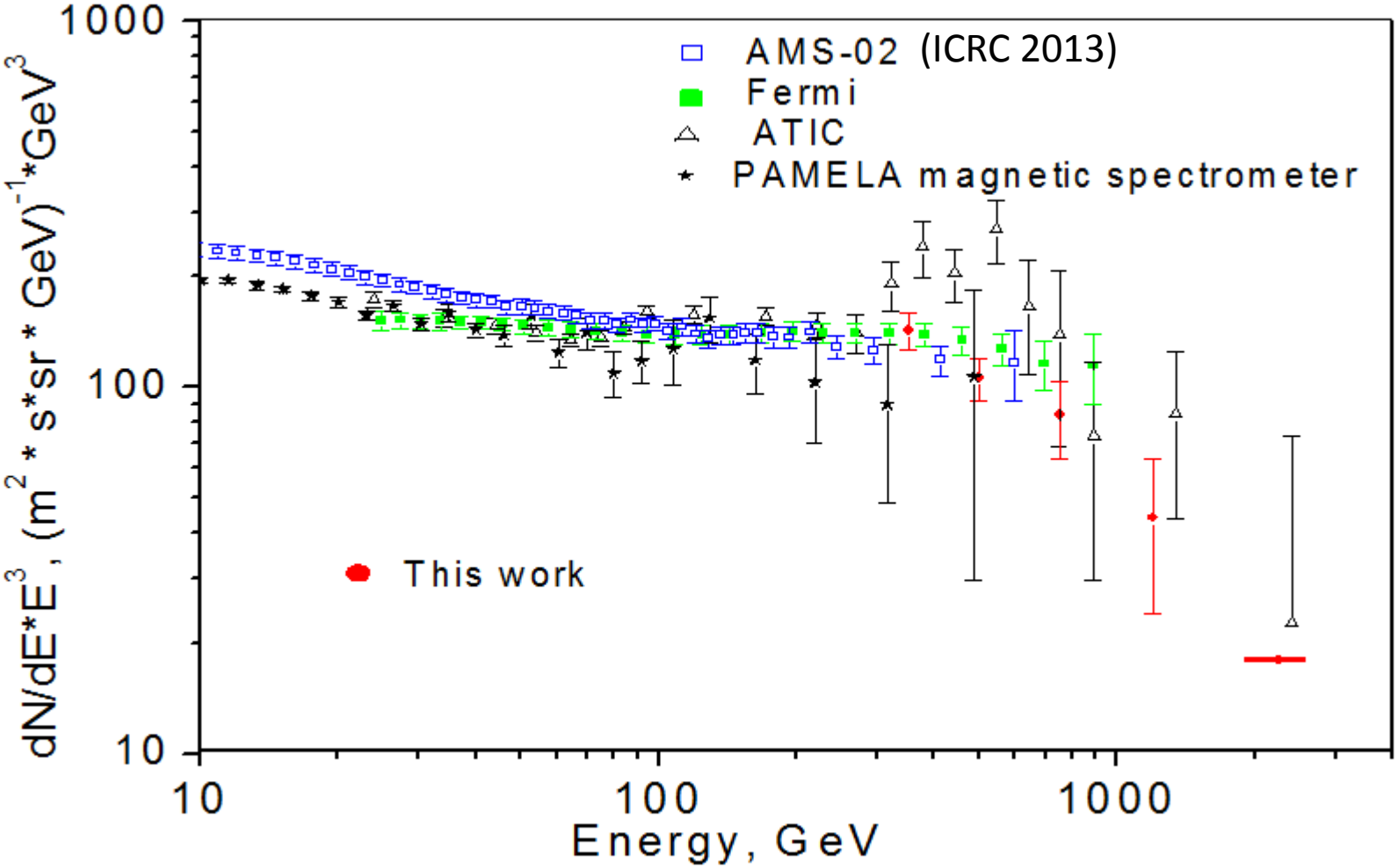
Shower shape in atmosphere
15 %
Large collection area
(80- 100 m^2.sr)

All electrons flux (1) : AMS 2014 – 1 TeV

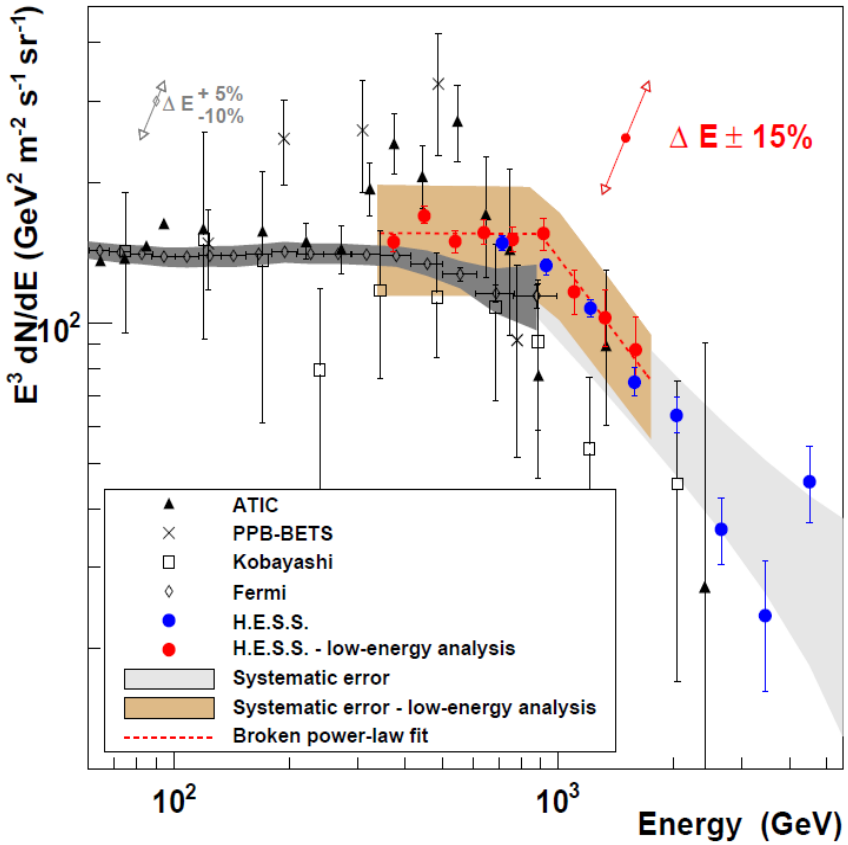


All electrons flux (2) : PAMELA 2014 -1 TeV

Preliminary ICHEP 2014



All electrons flux – HESS – several TeV



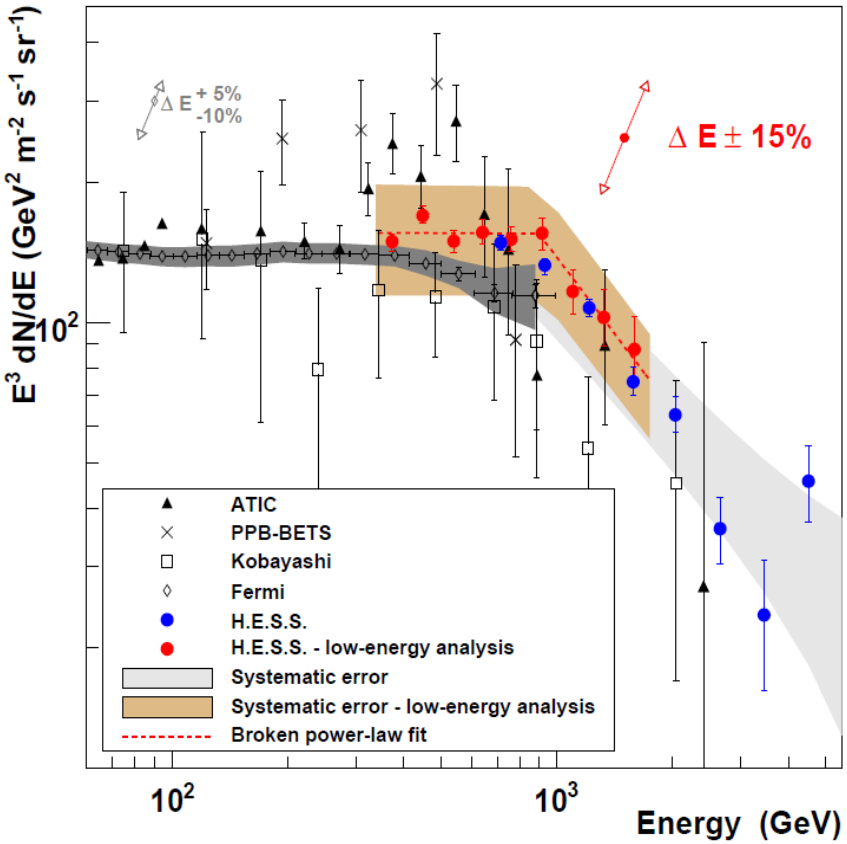
γ1 = 3.0 +/- 0.1
γ2 = 4.1 +/- 0.3

Systematic :

- Atmosphere modeling
- Proton shower modeling (π^0)
- Energy scale

Evidence for an energy cut-off at about 1-2 TeV

Energy Scale

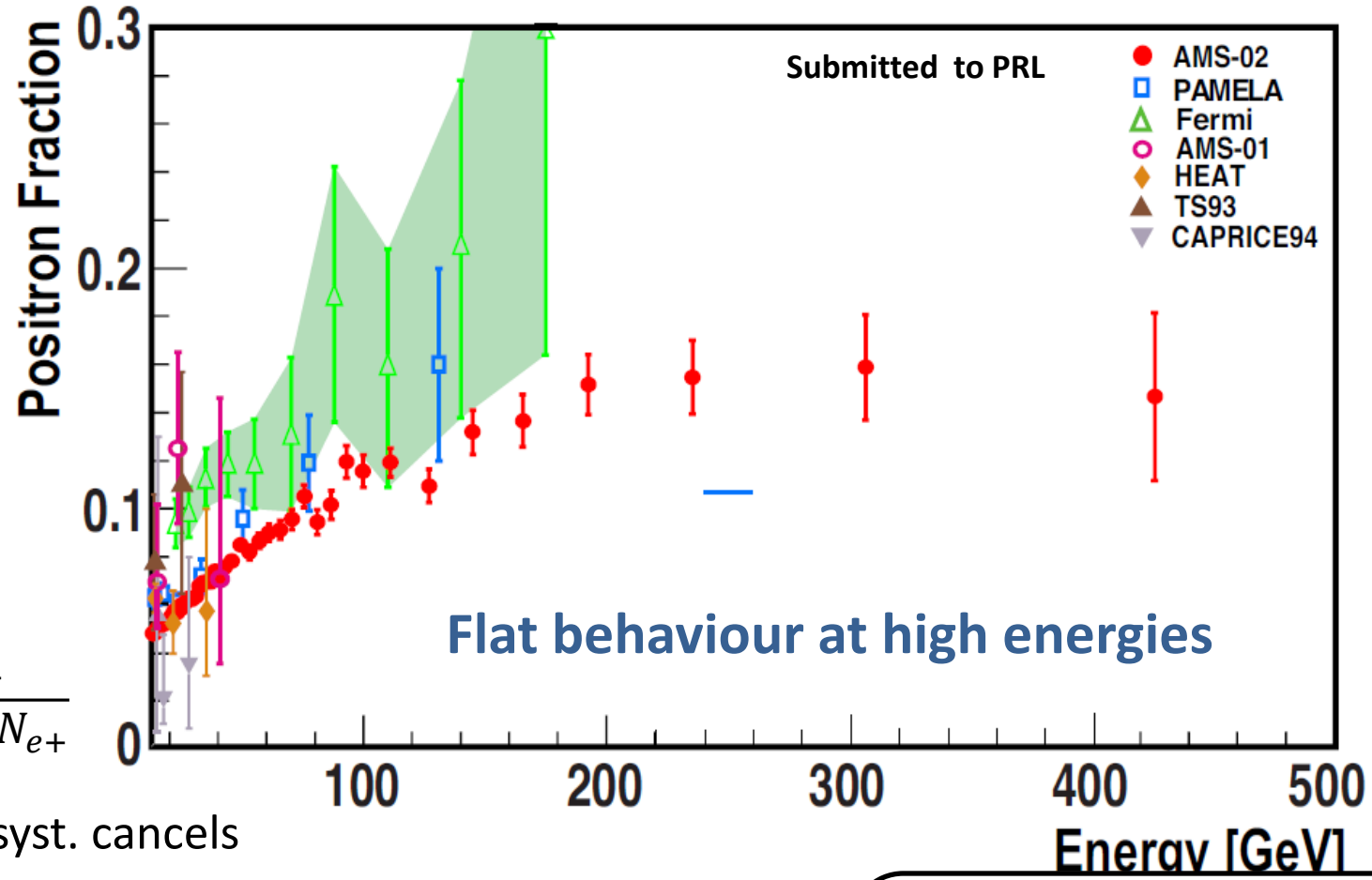


$$\varphi \propto \varphi_0 \times E^{-3}$$

- Lots of protons →homogeneity response , time stability
- Linearity : ions (dE/dx) , E/p
- Absolute E scale
  - No standard candles in space
  - Test beam
  - MC description ...
  - E/p (p ...)

~ 2- 5 % for Satellite /Balloon
~ 15 % for HESS

Positron fraction - AMS – 500 GeV

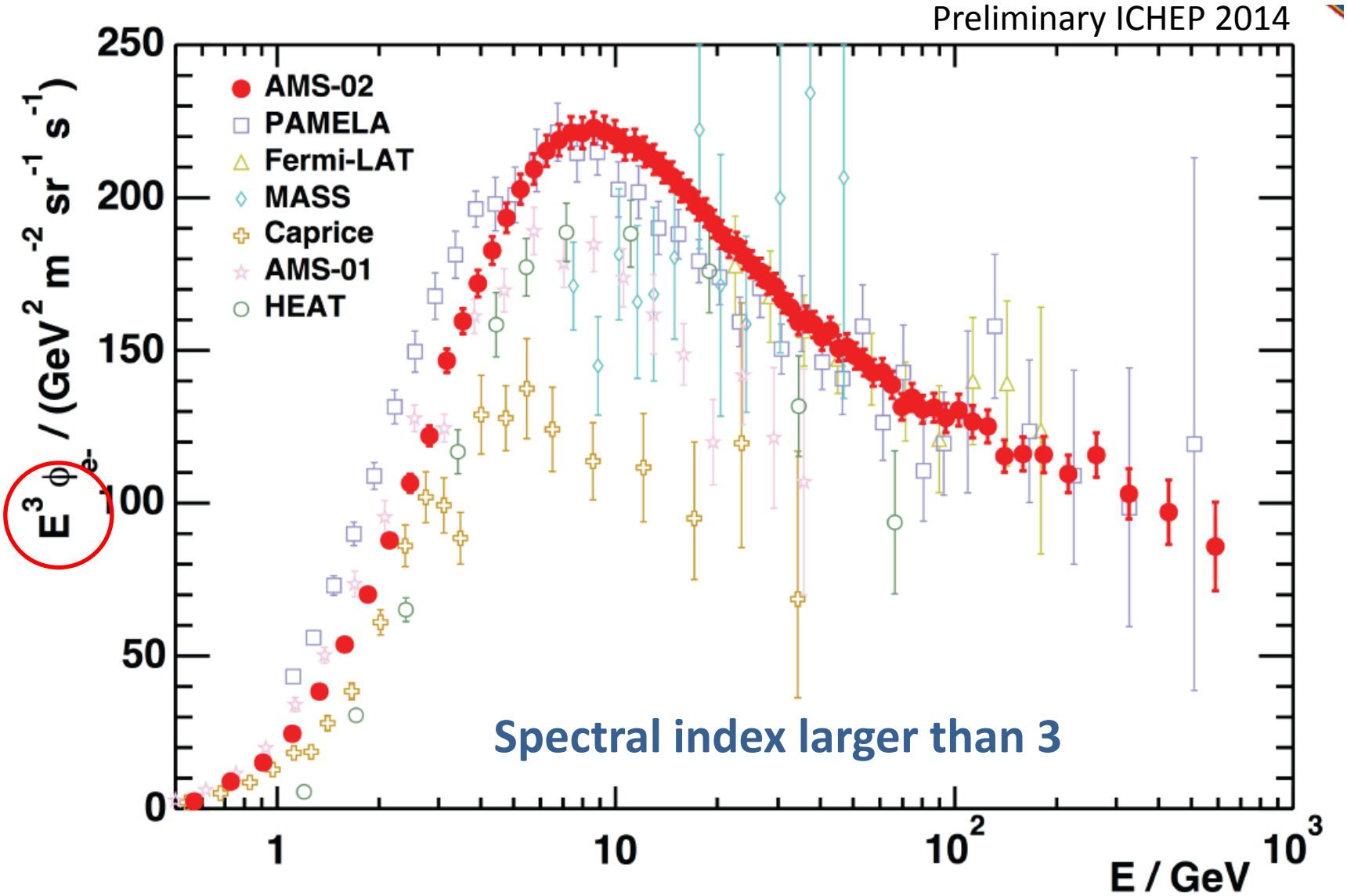


$$R_{ex} \sim \frac{N_{e+}}{N_{e-} + N_{e+}}$$

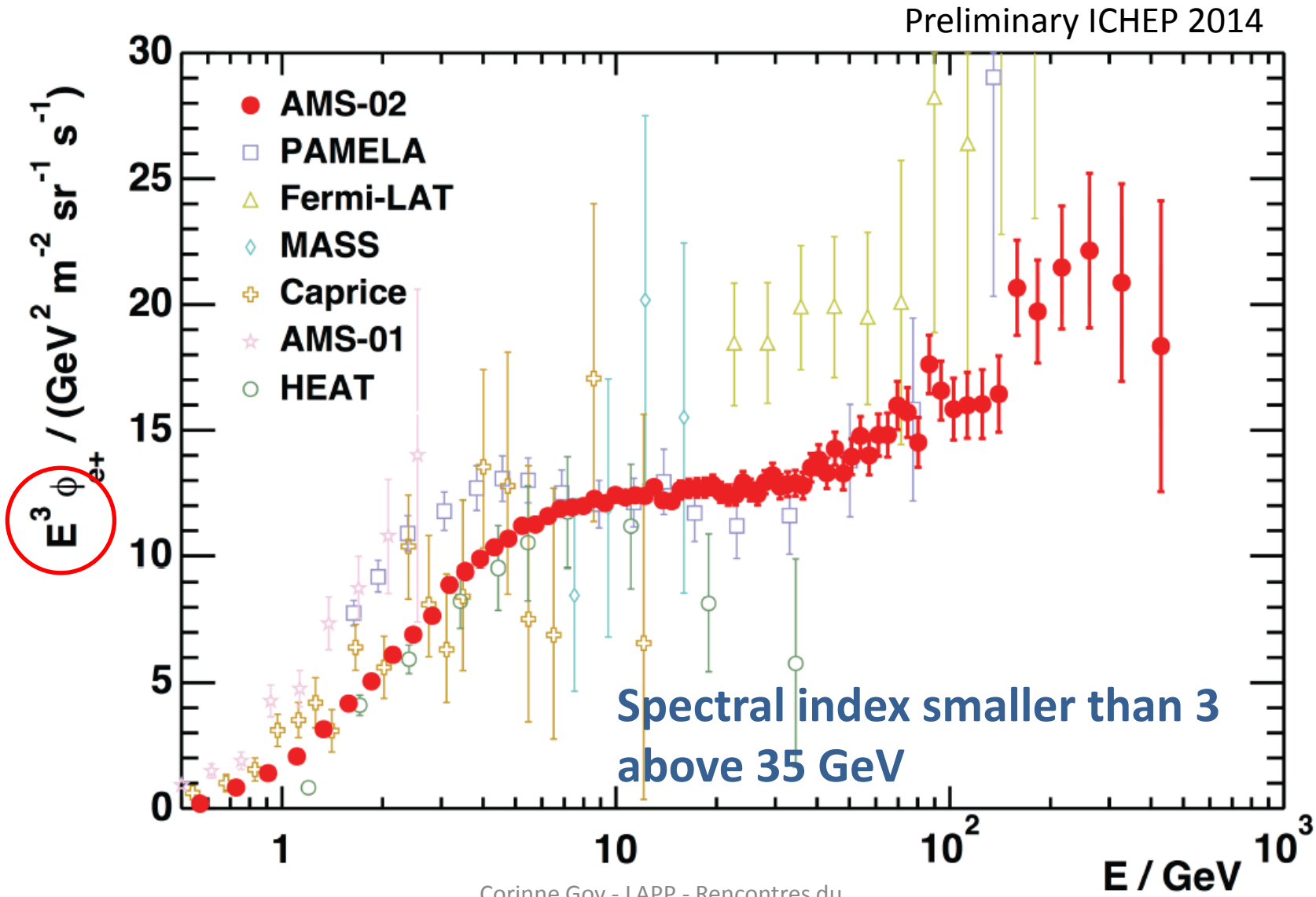
- Energy scale syst. cancels
- Acc/Eff syst. cancels
- Main issues :
  - Protons rejection
  - Charge confusion

AMS - 30 months
- 72 positrons (last bin)
- Stat : 18%
- Syst (cc) : 12%

Electron flux up to 700 GeV

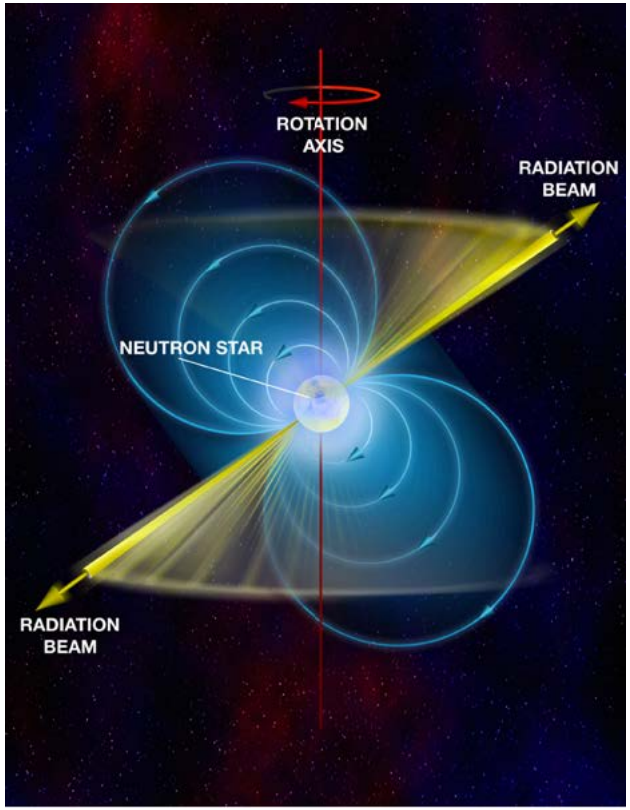


Positron flux up to 500 GeV

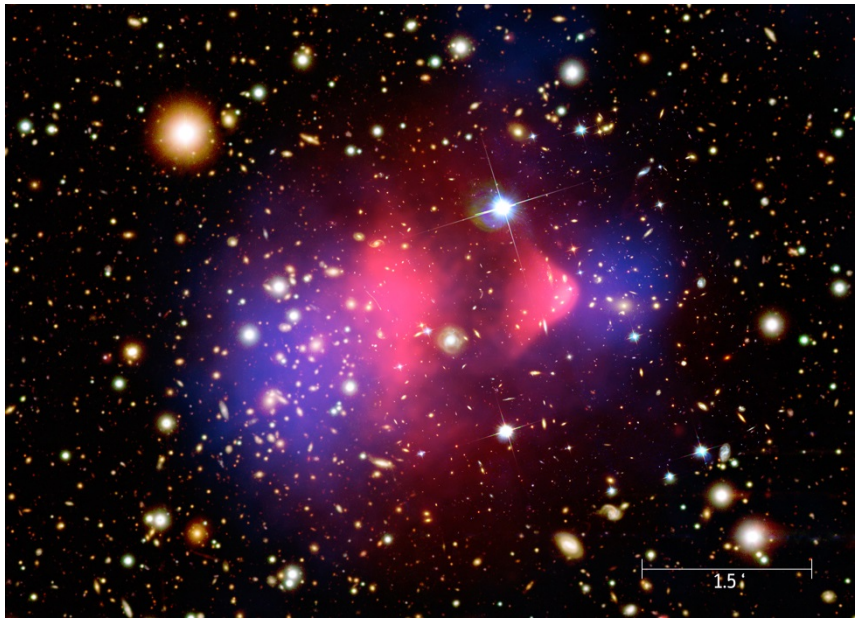


Interpretations (1)

Astrophysics : Pulsar Wind



Dark Matter :



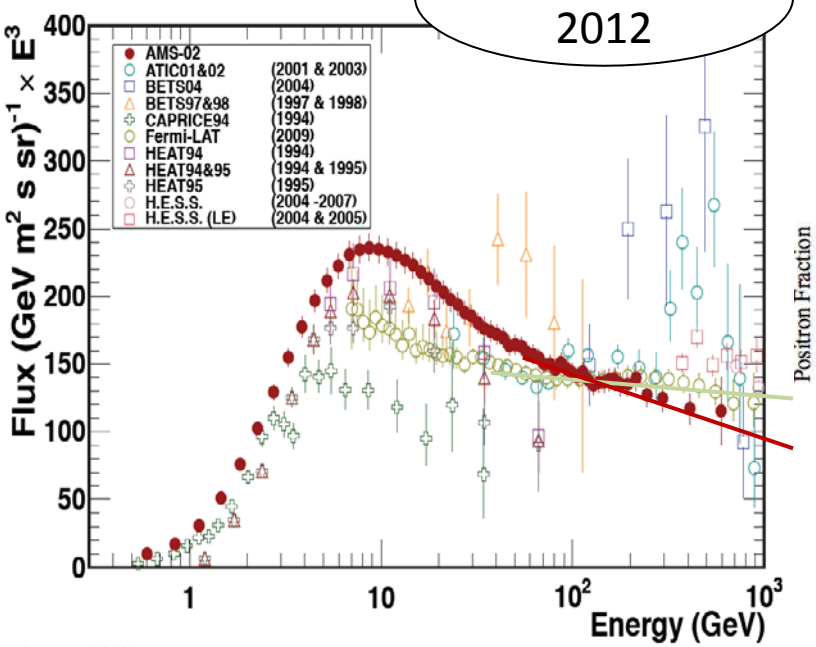
- Leptophilic : constraint from anti-proton
  - (or nearby clumps)
- Larger cross-sections than required by the relic density
  - Or Boost factors
  - Or Sommerfeld effect

Interpretations (2) – examples

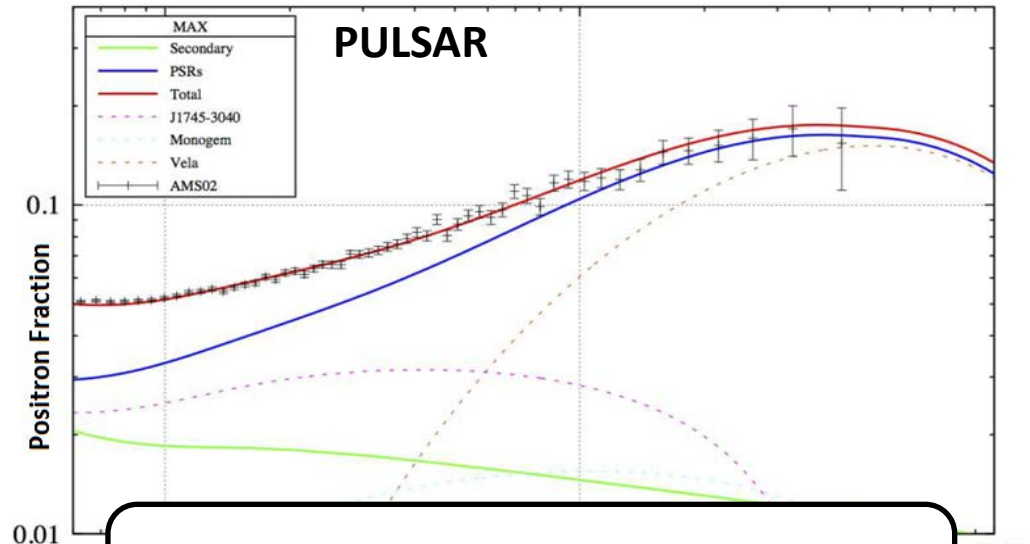
Secondary + Primary fluxes

$$R_{Th} = \frac{\varphi_{e+}}{\varphi_{Leptons}}$$

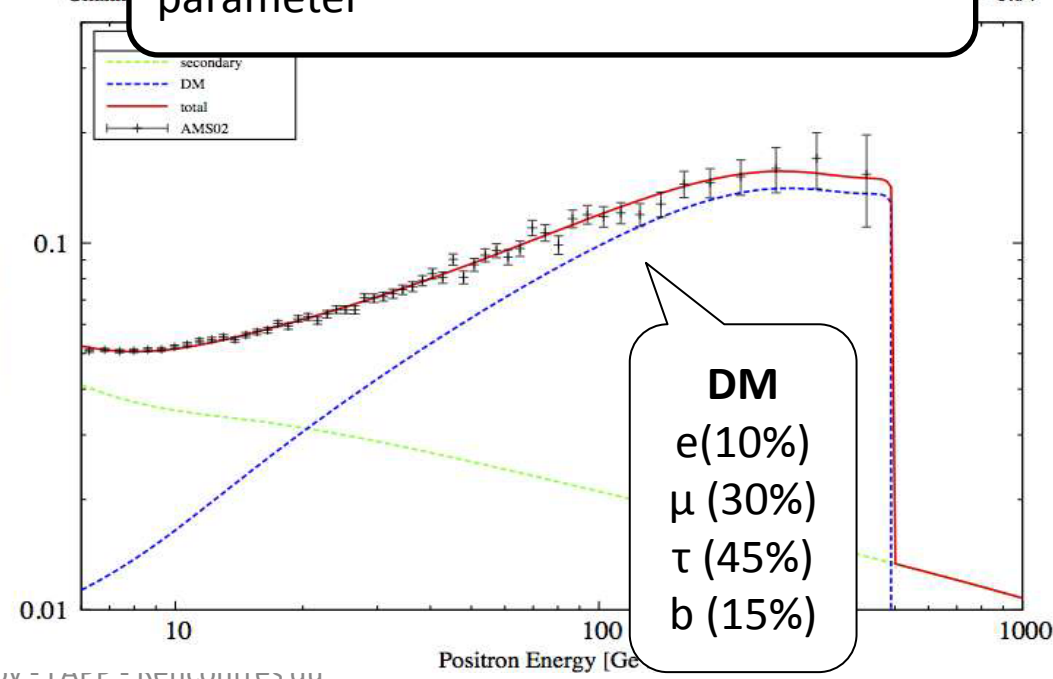
AMS – ICRC 2012



LAPTH & LAPP prelim.



Decrease of the signal is a discriminating parameter



DM
e(10%)
μ (30%)
τ (45%)
b (15%)

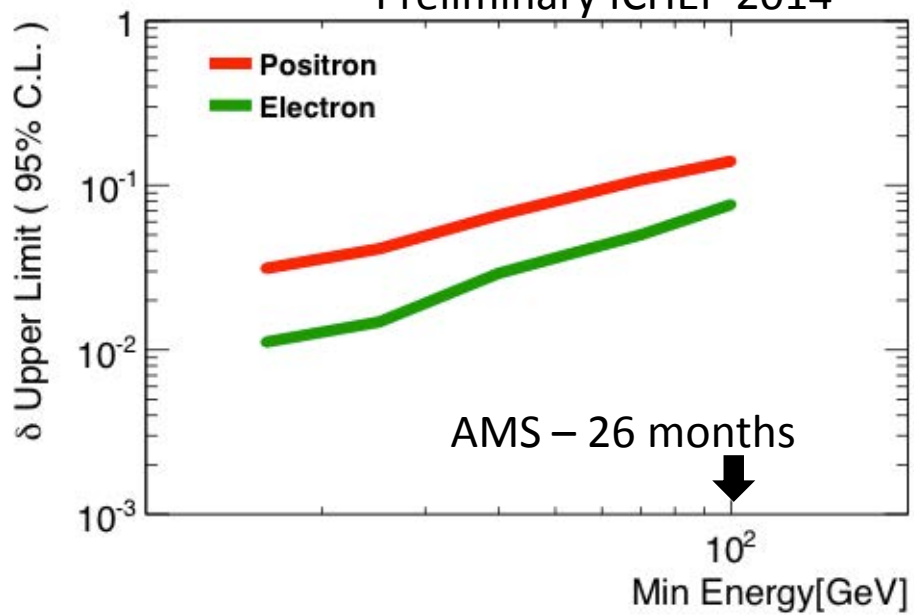
Anisotropy (1)

- In arrival direction of electrons and positrons.

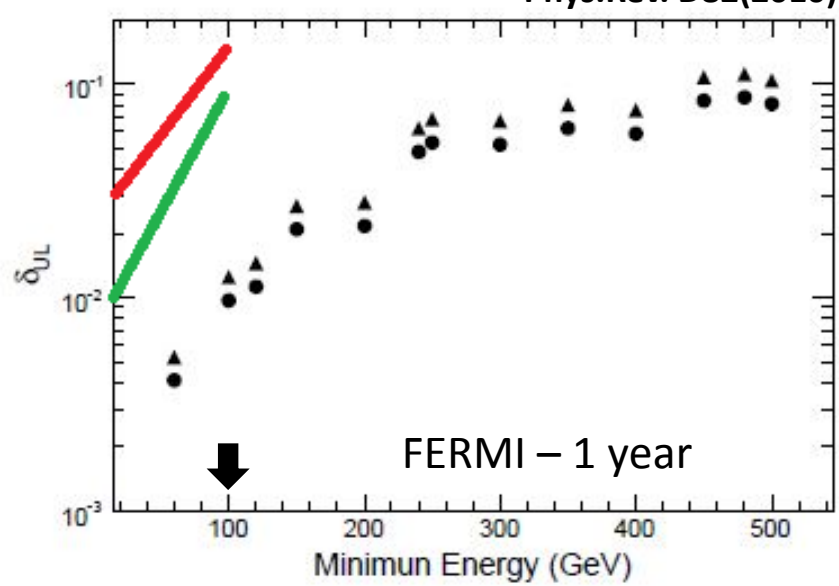
Indication of an astrophysical source
… but could be mimicked by a nearby clump …

- AMS : can distinguish between positrons and electrons.
- Fermi : large statistic – higher E range
- compatibility with isotropic distribution of arrival directions

Preliminary ICHEP 2014

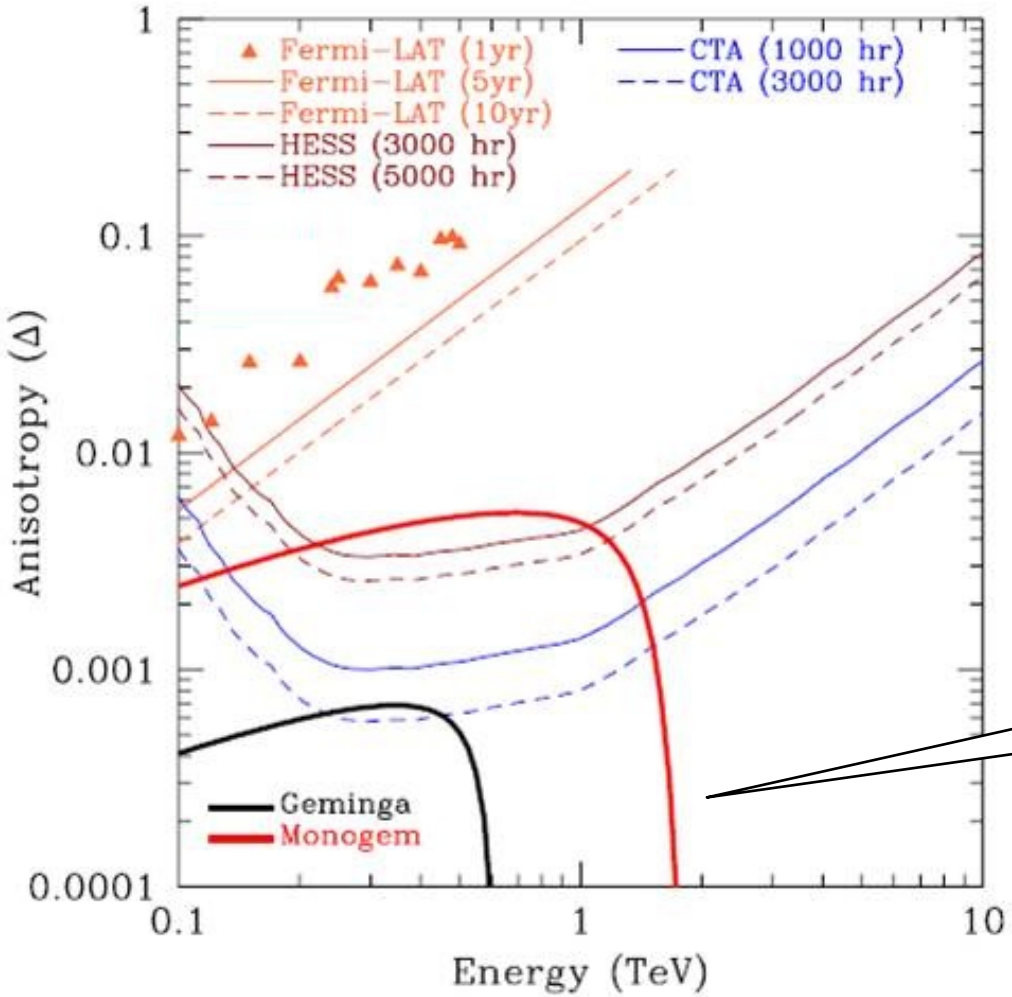


Phys.Rev. D82(2010)



Anisotropy (2) – prospects

arXiv:1304.1791

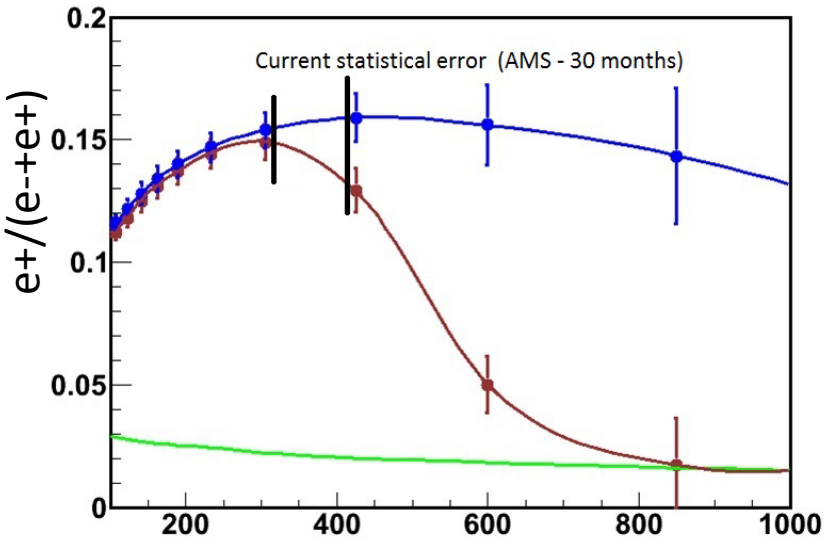


Subject to modelling

Outlook

- **½ TeV – TeV range is being explored**
  - But statistically limited
  - $N_{Leptons} \propto Acc(m^2.sr) \times T$

AMS - ~ 10 years projection



- **T comes for free ! But ….**
  - PAMELA ~ 8 to 9 years
    - → won't improve significantly stat
  - AMS : ~3 years
    - a factor 4 to expect in stat (10 years) → δ_{Stat} /2

- **Next step requires a significant increase in the geometrical acceptance :**

  CALET : 0.12 m^2.sr

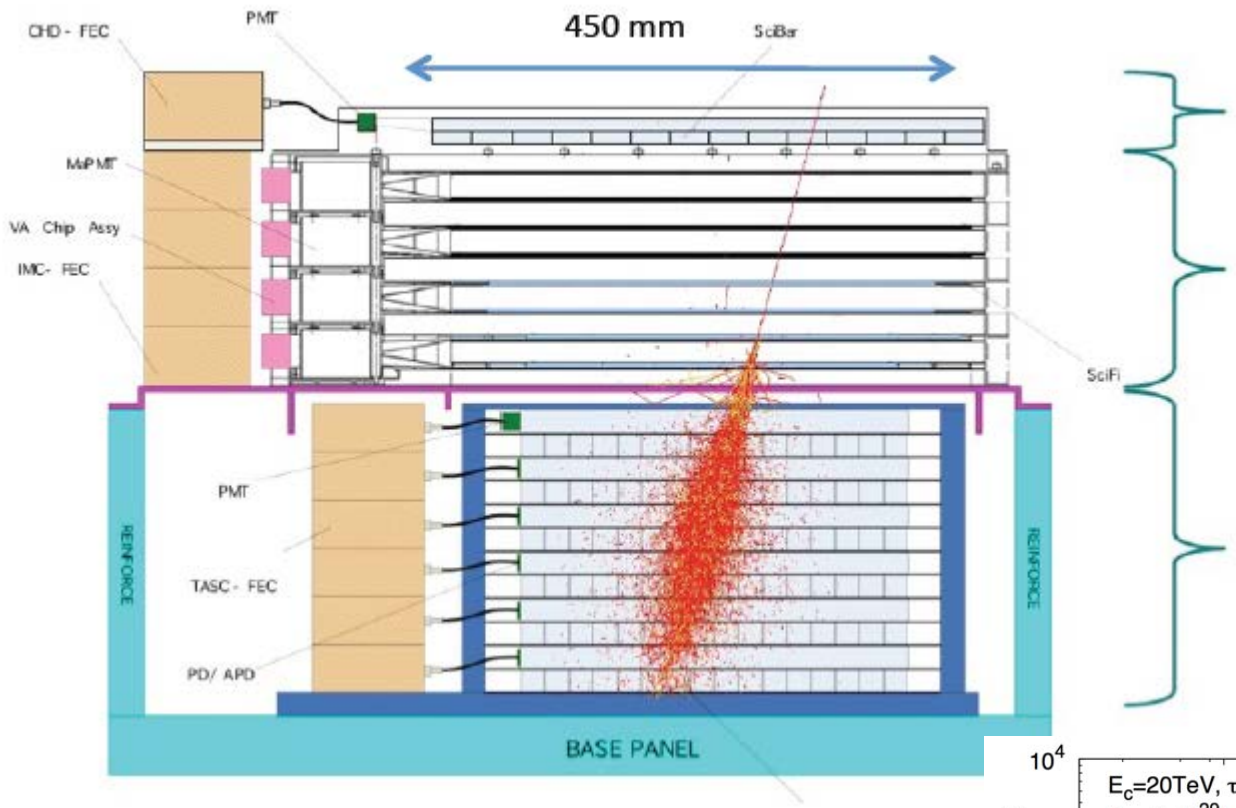
  GAMMA 400 : ~2.5 m^2.sr

  CTA

  } All electrons

CALET - launch 2015 on ISS (see next talk)

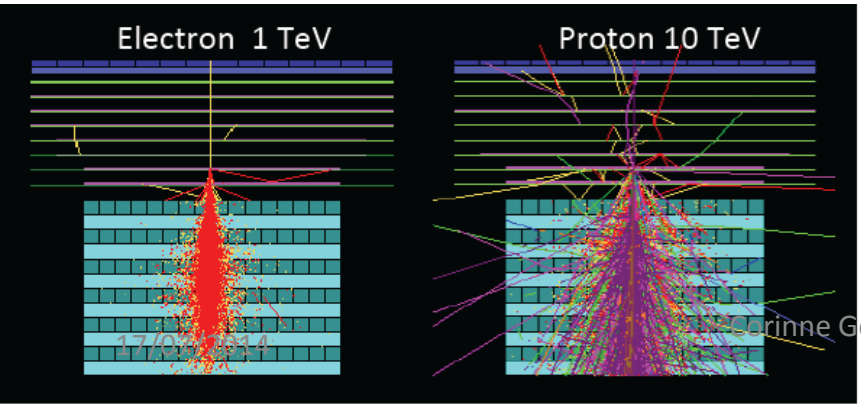
ACC :
0.12 m^2sr.
(~ AMS X 3)



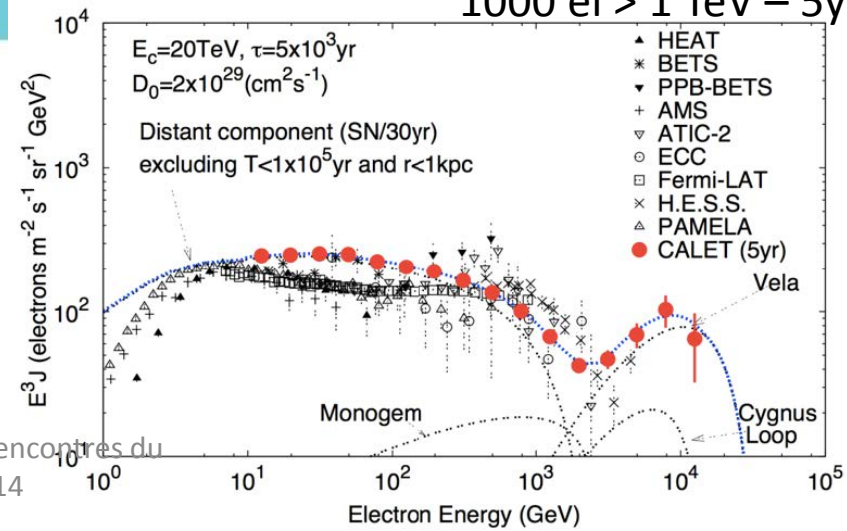
Z

Imaging Calorimeter
(W / Fiber)
3 X0

Absorption Calorimeter
(PWO)
27 X0
1.35 λ

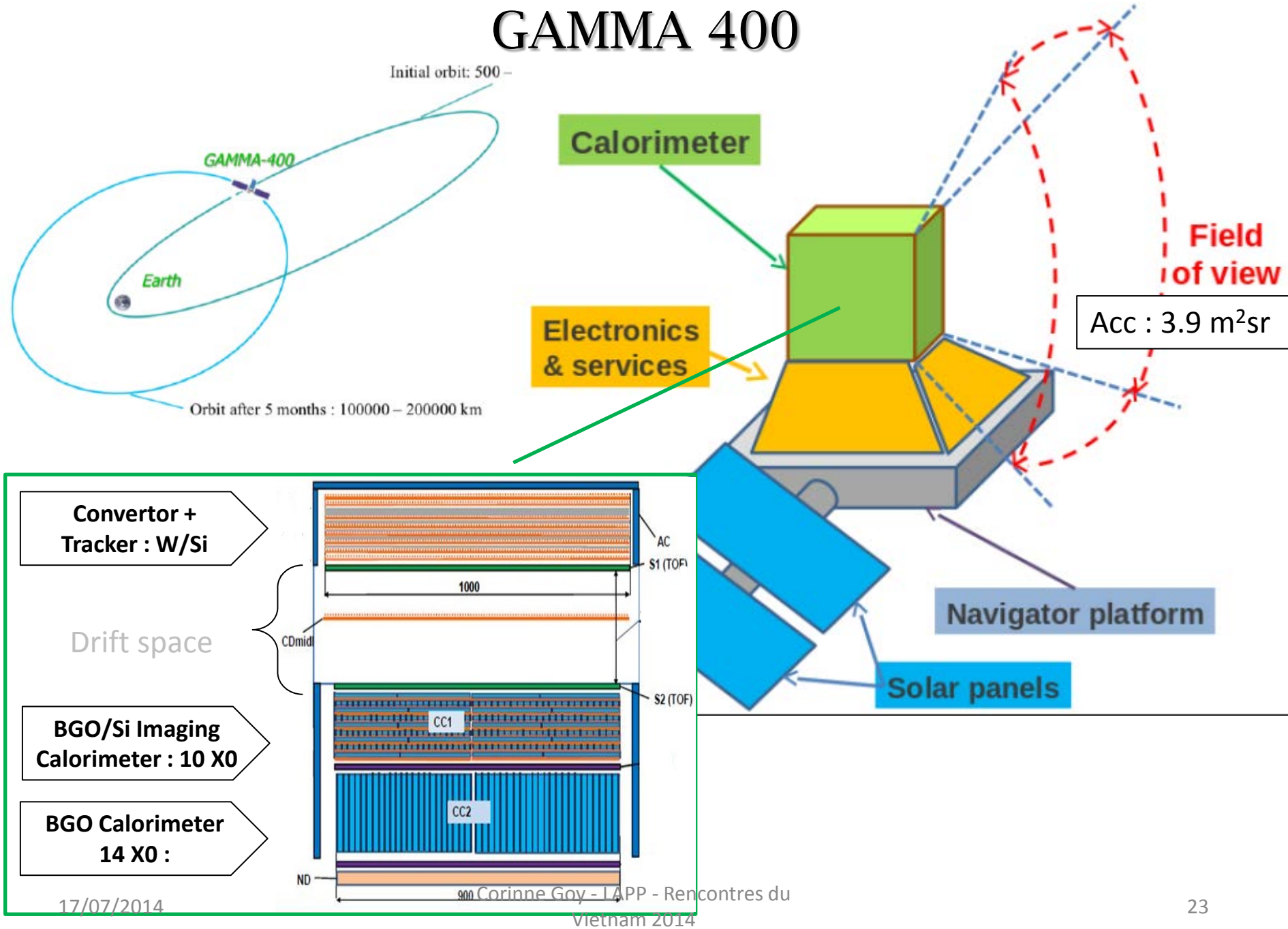


1000 el > 1 TeV – 5y



GAMMA 400

Initial orbit: 500 –
GAMMA-400
Earth
Orbit after 5 months : 100000 – 200000 km


Calorimeter
Electronics & services
Field of view
Acc : 3.9 m²sr
Navigator platform
Solar panels
Convertor + Tracker : W/Si
Drift space
BGO/Si Imaging Calorimeter : 10 X0
BGO Calorimeter 14 X0 :
AC
S1 (TOF)
1000
CDmid
S2 (TOF)
CC1
CC2
ND
900

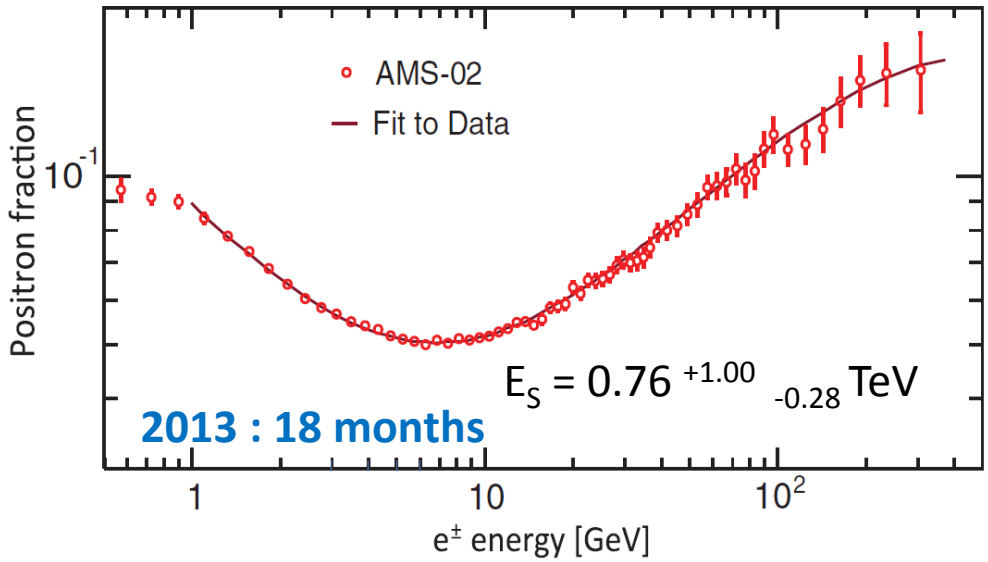
Positrons (Electrons)

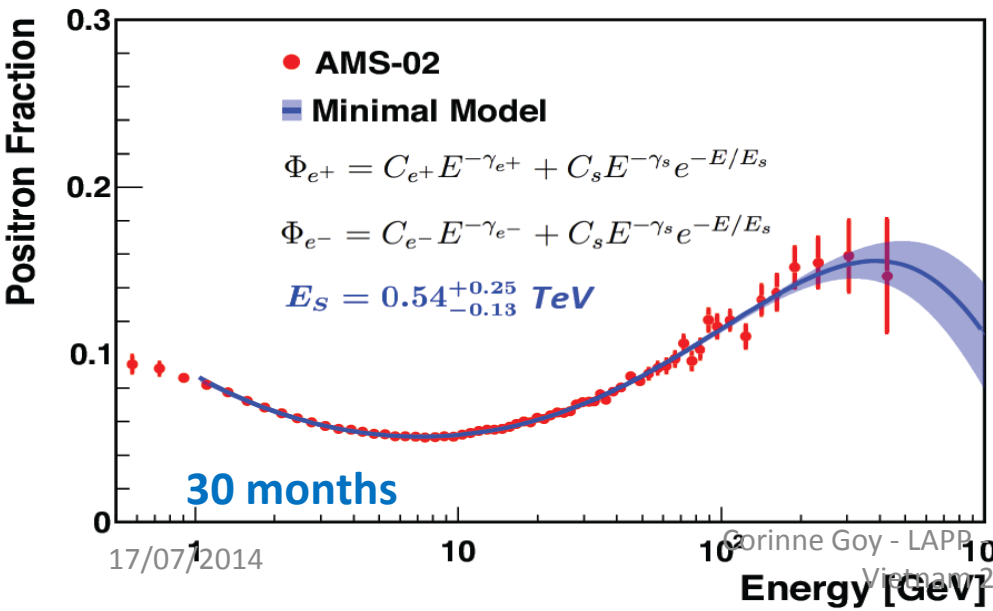
- Positrons of several TeV
  - 5 m^2.sr (AMS X 100)
- Calorimeter
  - W : 15 tons
- Issue is the magnet
  - Large permanent magnet :
    - Weight – B field limited
  - Superconducting
    - Lighter (1 tons) – larger B field – mitigate CC

AMS – 03 ?

- TeV e+/e- → SRD

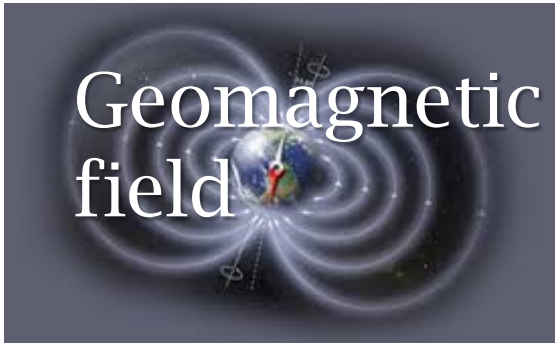
Conclusion

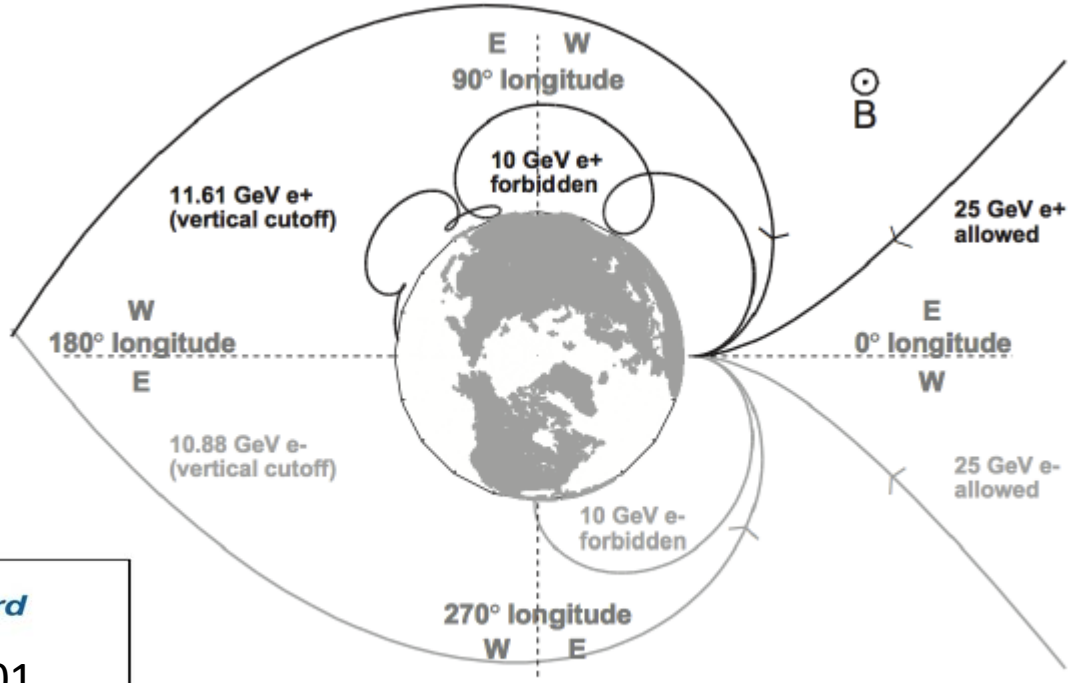


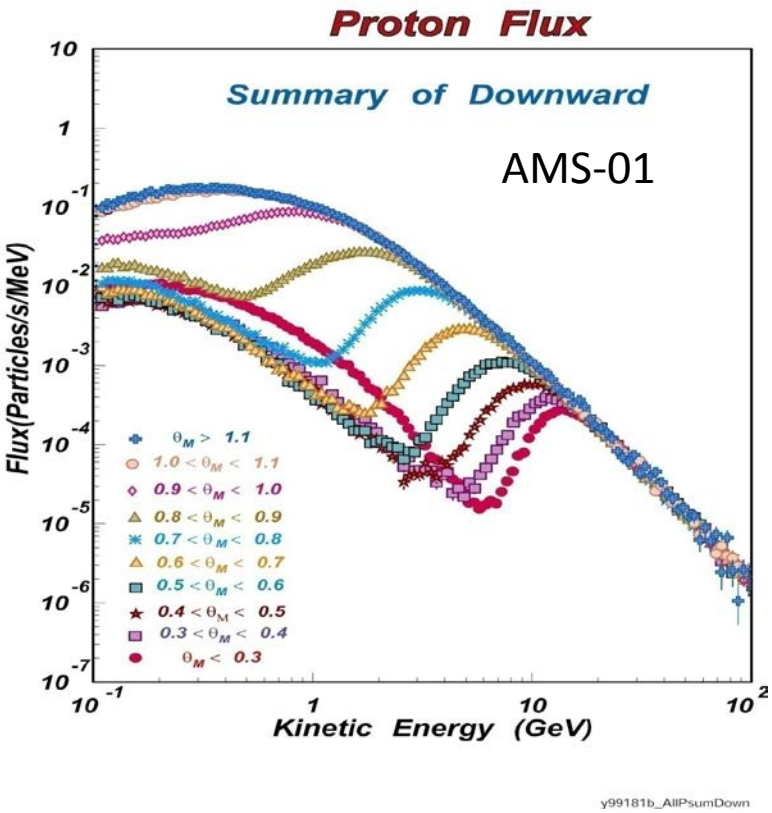


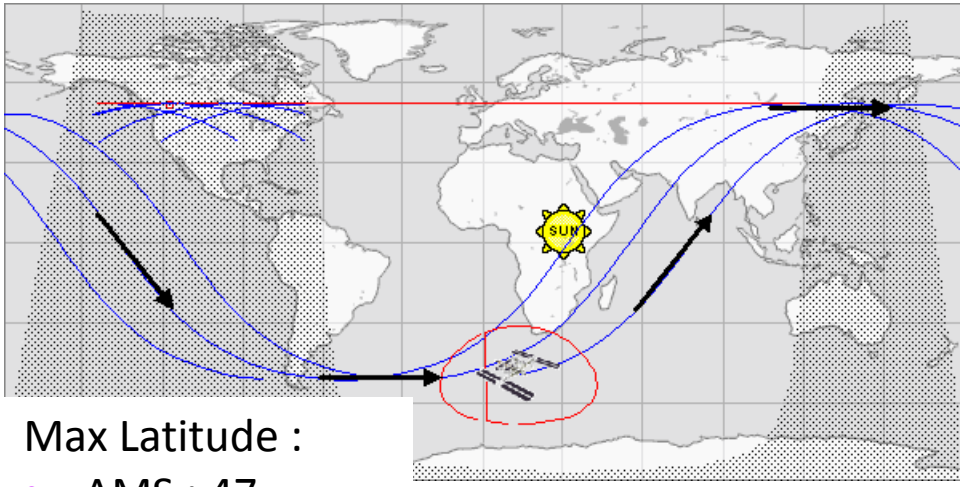
- Positrons :
  - Up to ½ TeV is being explored
  - AMS :
    - Pos fraction : sub PRL
    - All leptons + ind. Fluxes: end of 2014
  - 10 years :
    - few hundred e+ above 500 GeV
- Leptons :
  - Promising result with CALET
  - CTA with a large collection area will be able to observe change of slope

BACKUP SLIDES





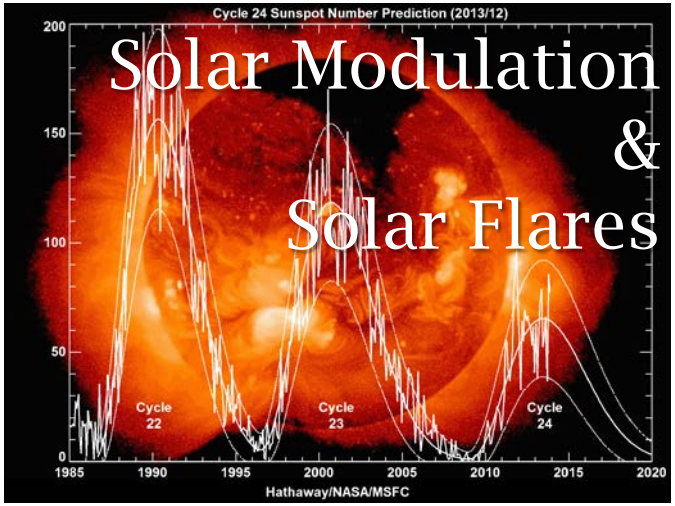




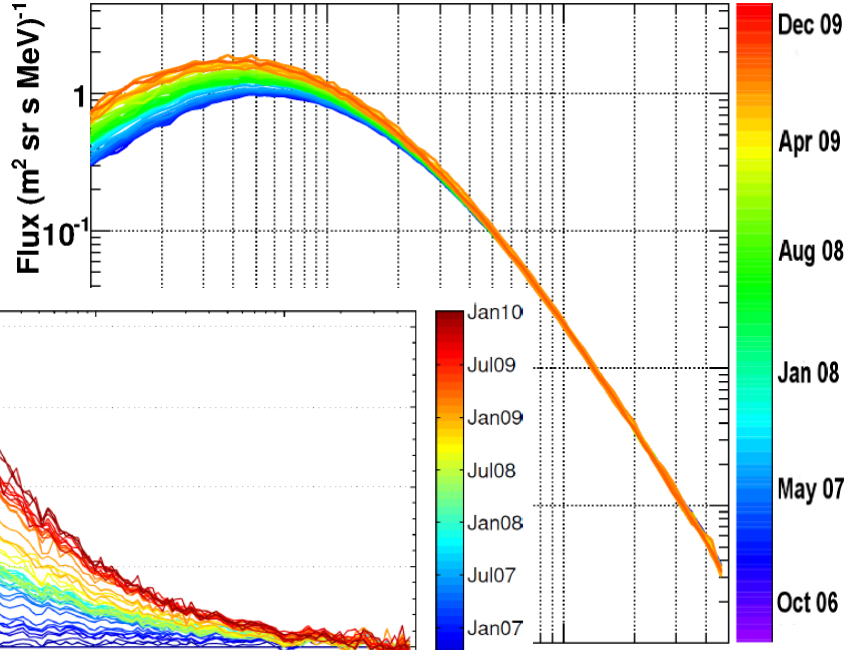
Max Latitude :

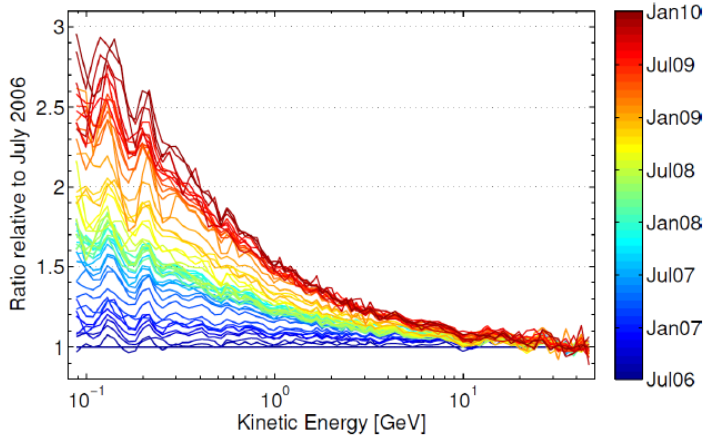
- AMS : 47
- Pamela : 70

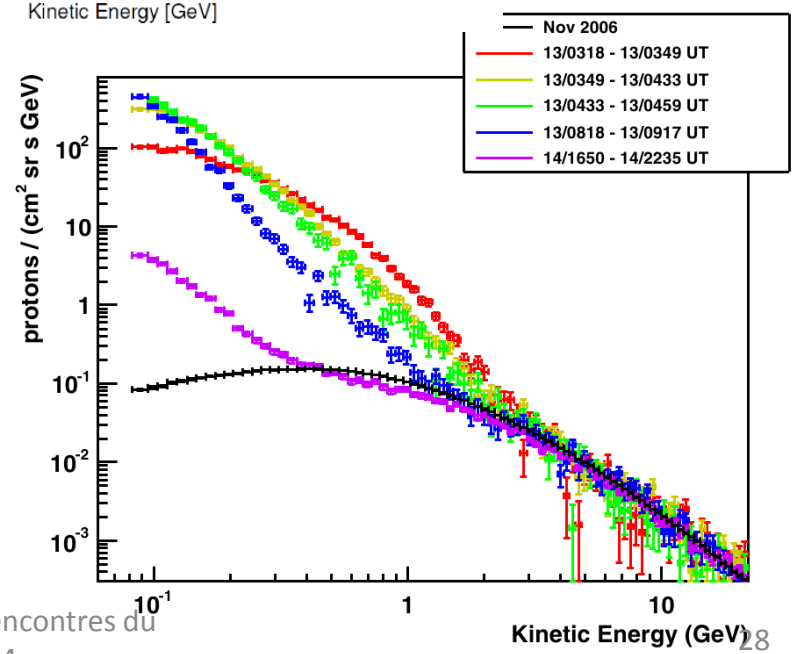
Solar Modulation & Solar Flares



$$\Phi_{e^+}^{\mathrm{TOA}}(E) = \frac{E^2}{(E+\phi_{e^+})^2}\Phi_{e^+}^{\mathrm{IS}}(E+\phi_{e^+})$$

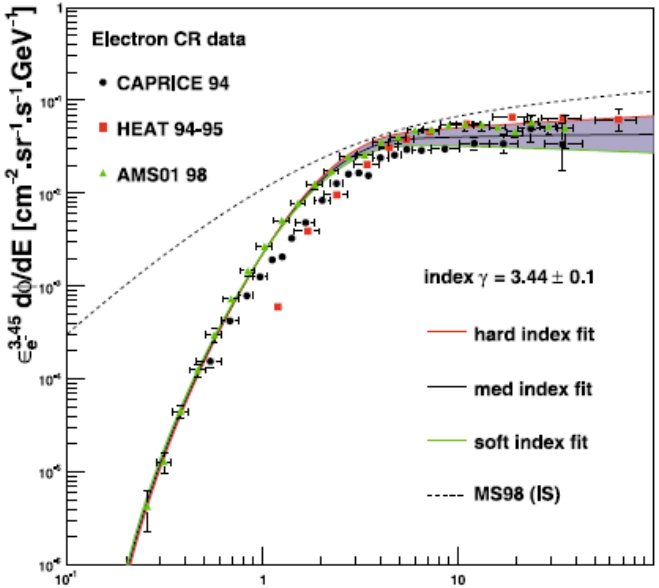




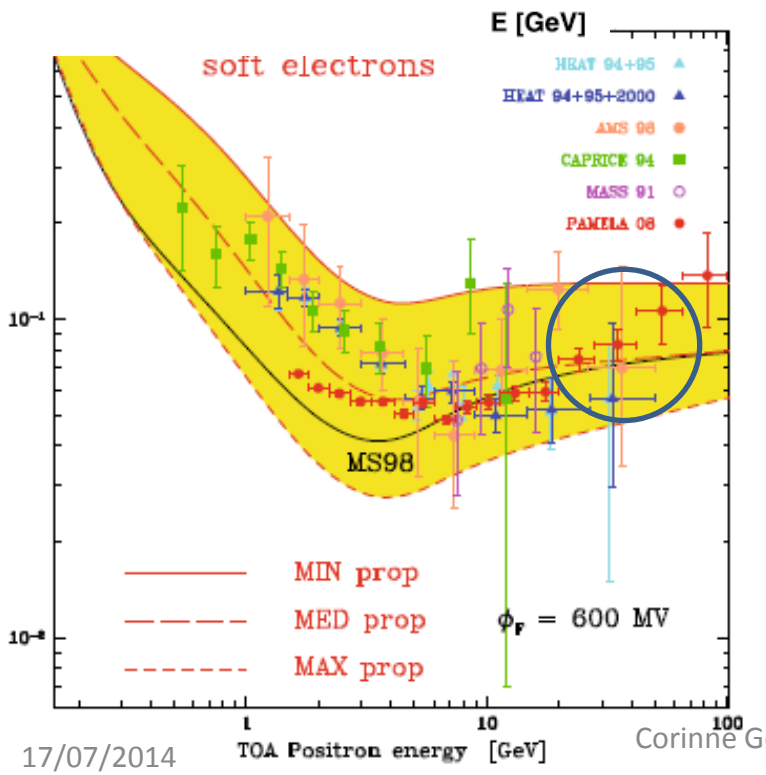


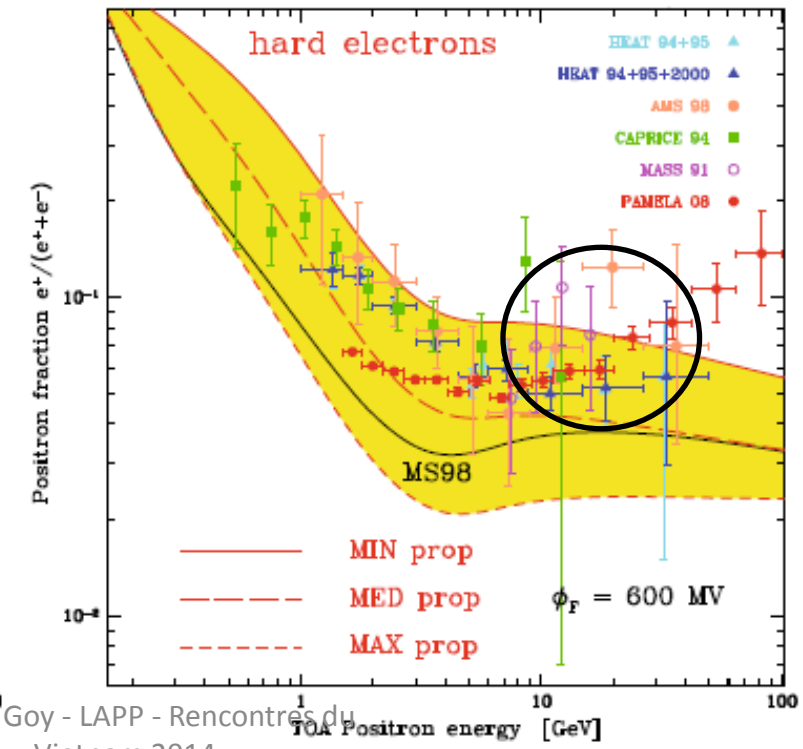
Below 10 GeV, the comparison between measurements and with predictions is not straightforward.

For illustration only

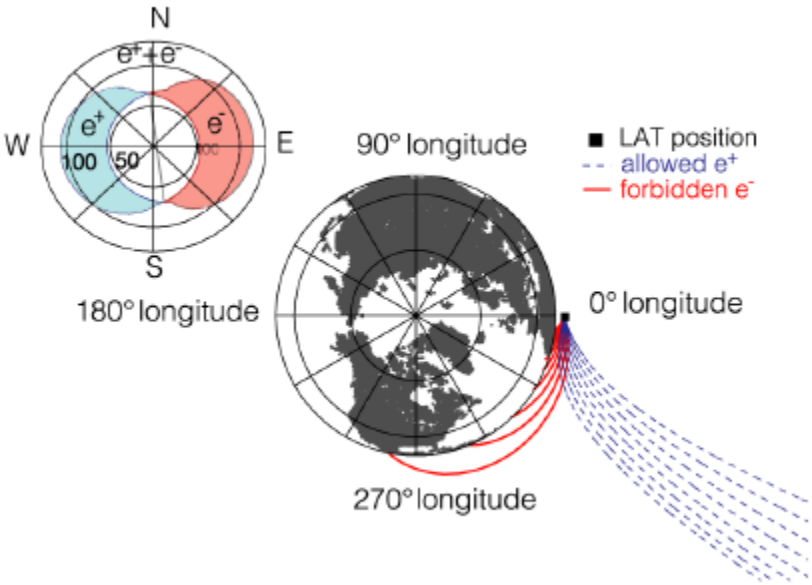


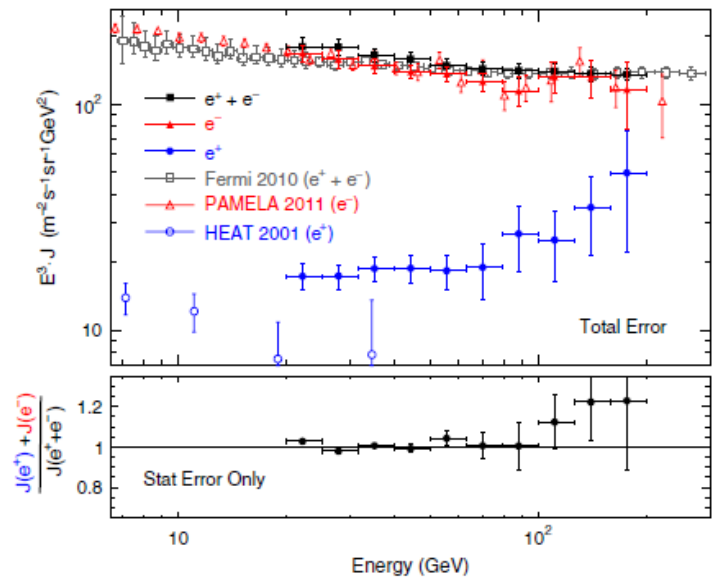
A&A 501 821-833 (2009)

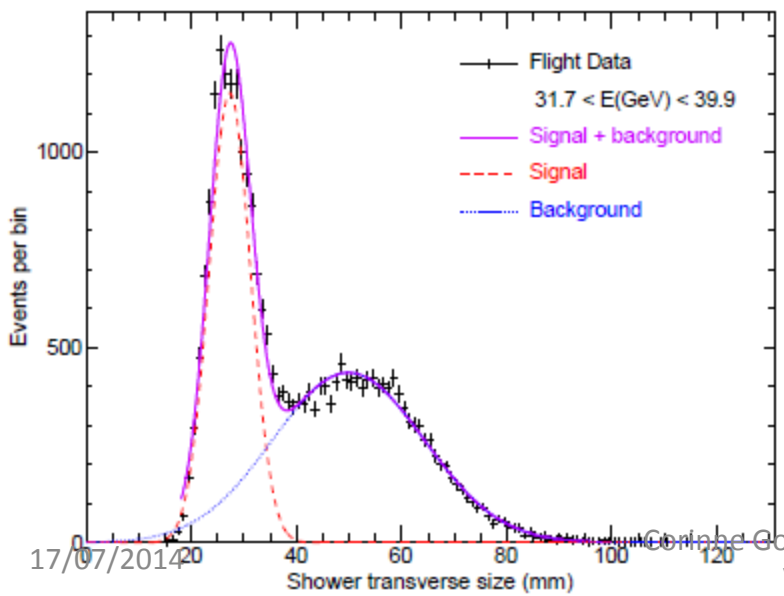


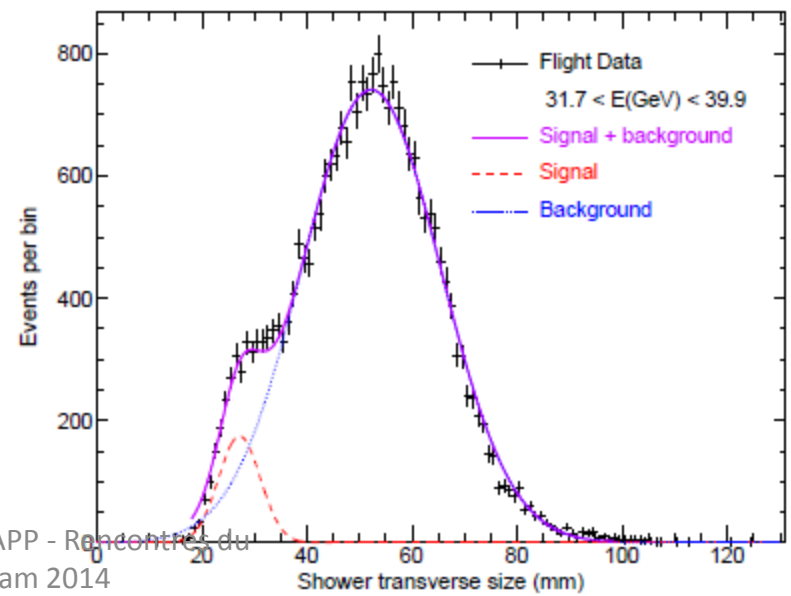


Fermi positron

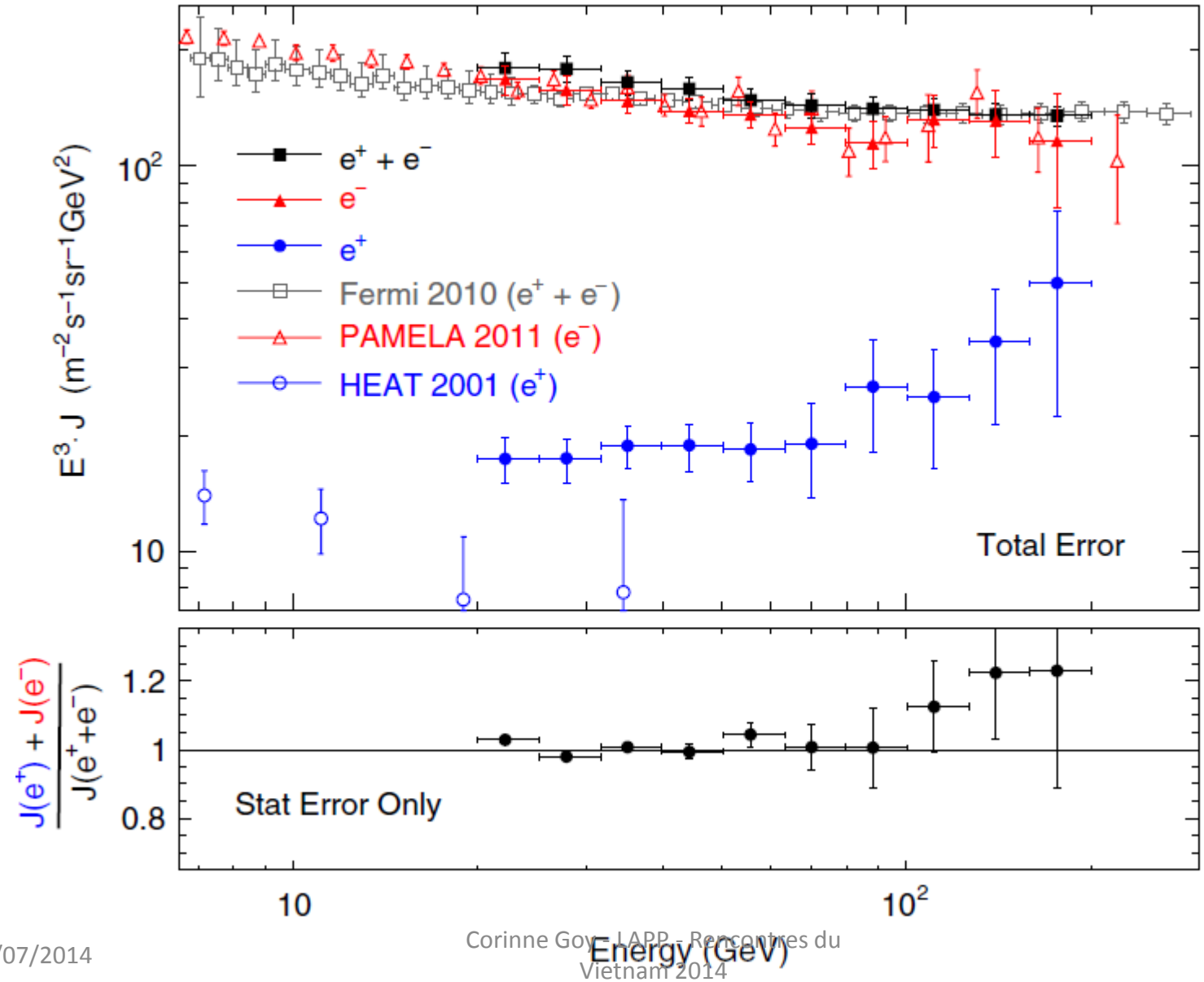




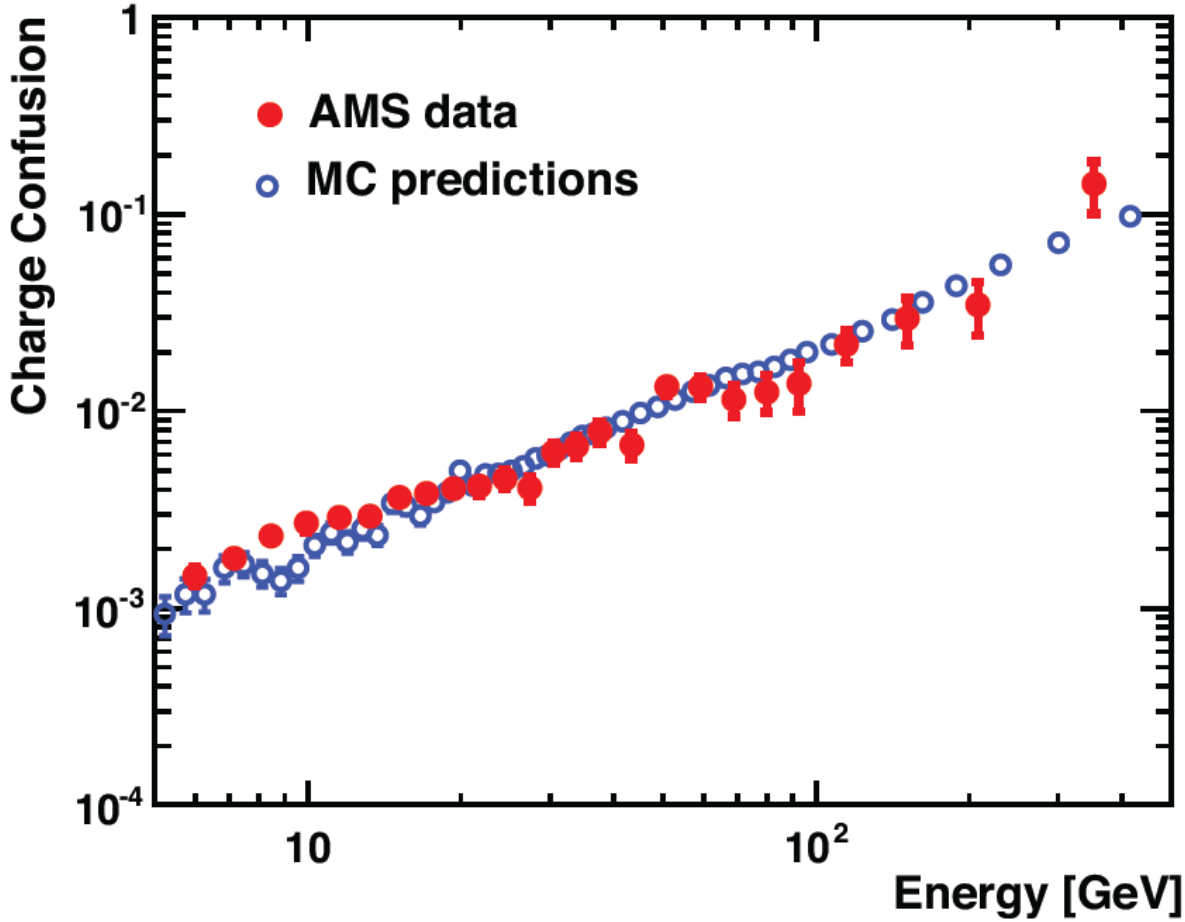




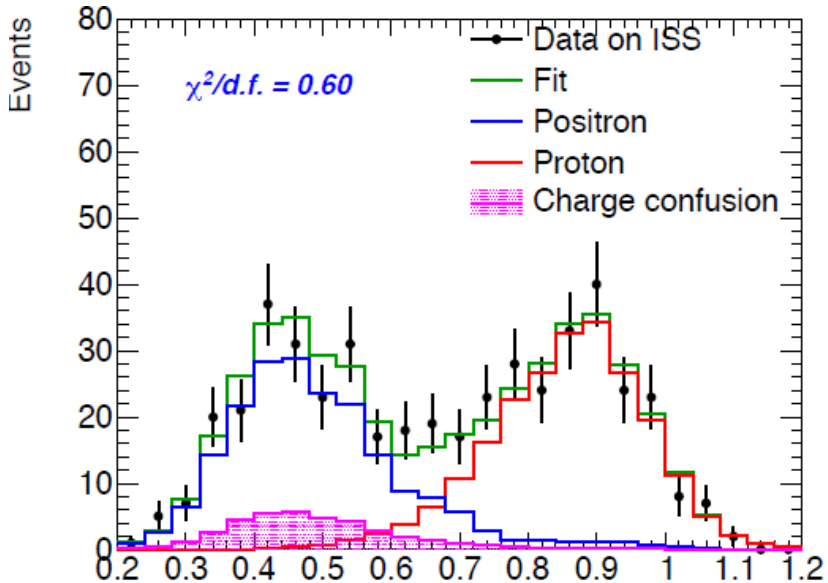
Self consistency



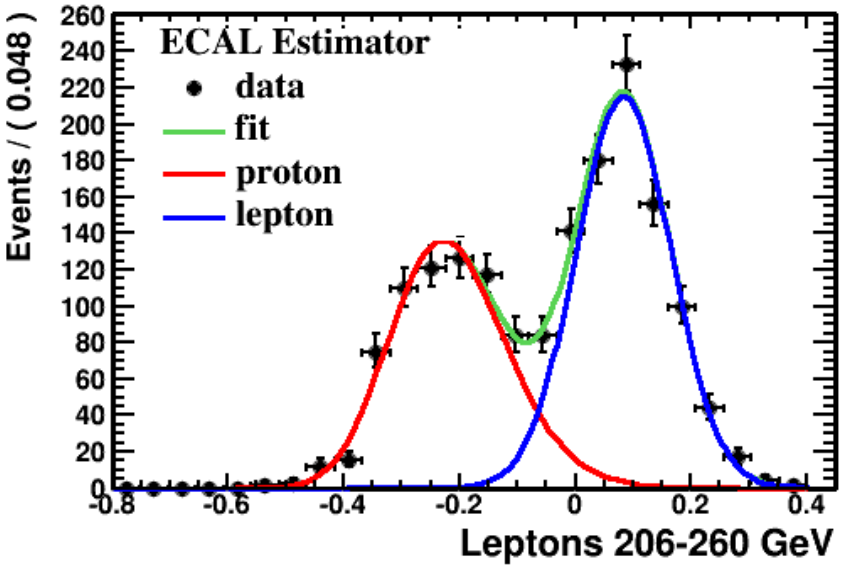
AMS : Charge confusion



Electron / Proton separation : method



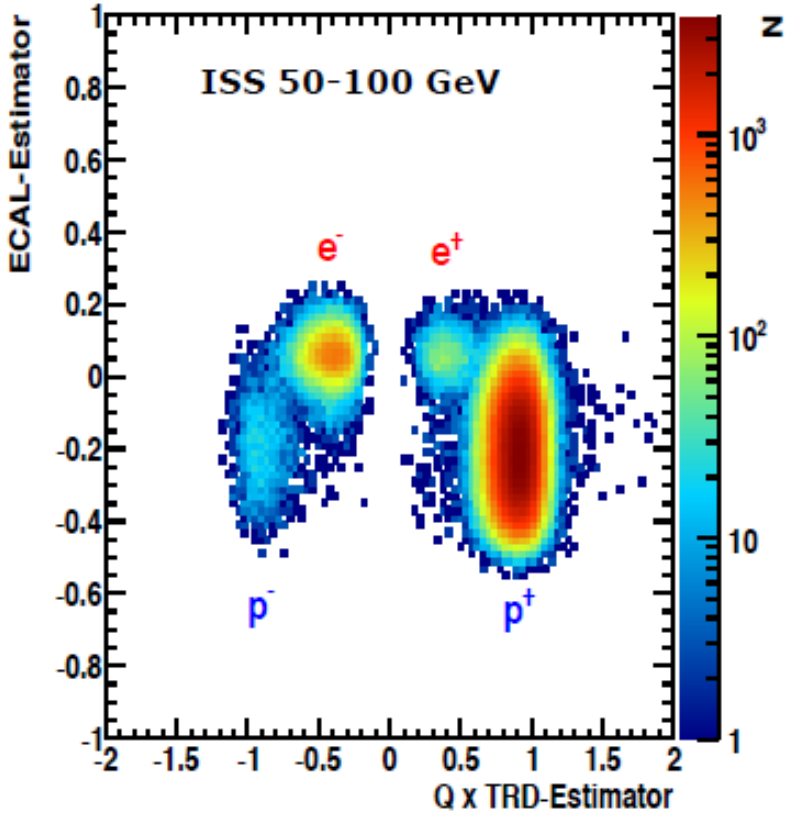
TRD

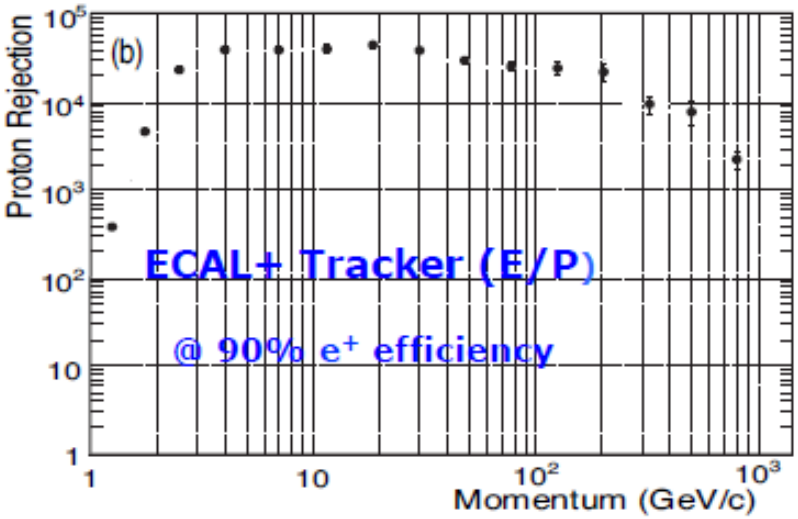


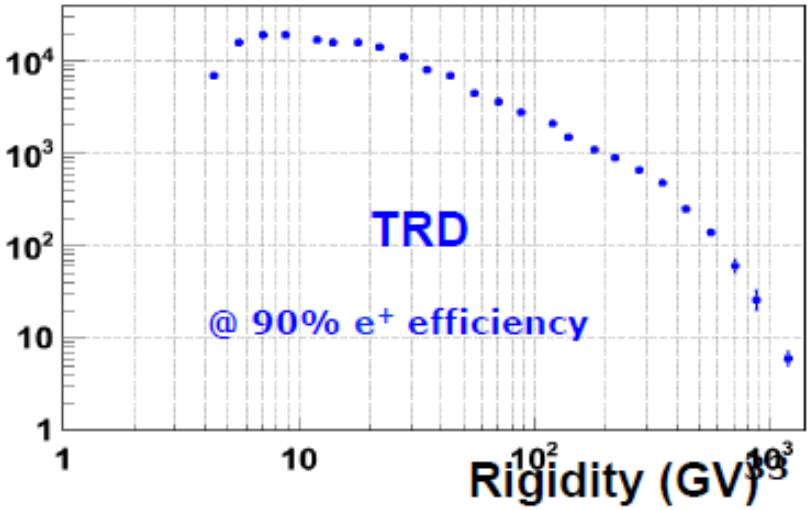
ECAL

Proton rejection

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



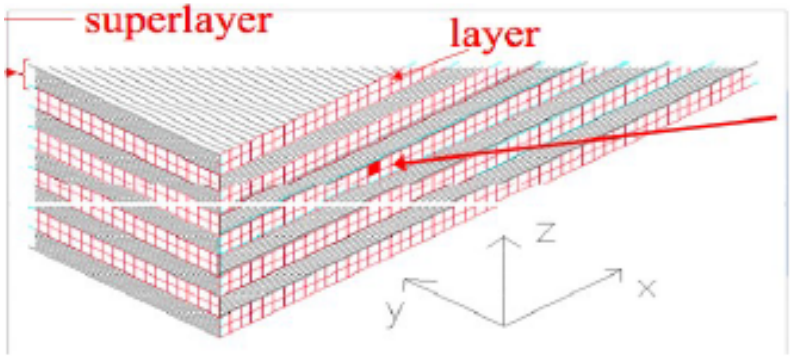


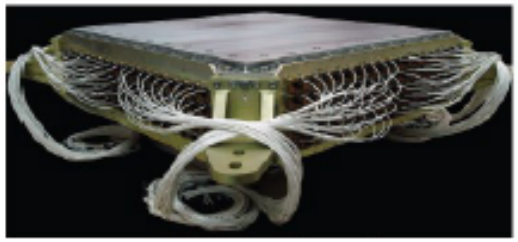


TRD estimator :likelihood based on the signal amplitude in each layer (20 in total)

Energy Measurement

The AMS-02 electromagnetic calorimeter: a 3-D sampling calorimeter made out of lead and scintillating fibers



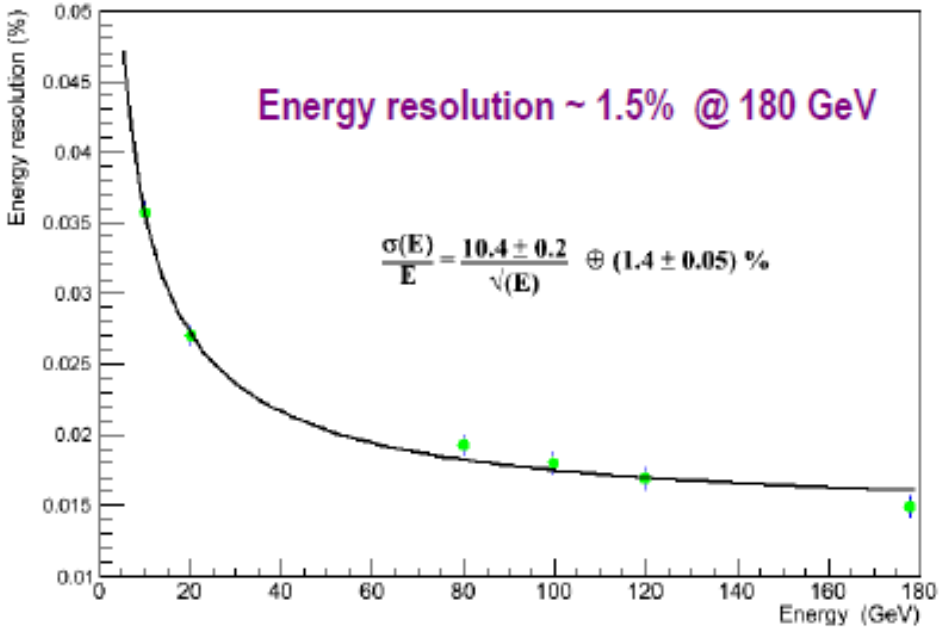


High granularity: ~ 0.9 x 0.9 cm

18 Longitudinal samplings

72 Lateral samplings

17 X_0, $\lambda_I / X_0 \sim 22$



Gamma-400

Russian conceptual scheme of the apparatus

AC - anticoincidence detectors

C1 - 2 layers x 2 single side Si 0.3mm (pitch 0.5 mm)

C2 - Converter - total 1 Xo

1 layer W 0.7 Xo (2.45 mm) +Si (x,y) 0.5mm (pitch 0.1mm)

2 layers W 0.1 Xo (0.35 mm) +Si (x,y) 0.5 mm (pitch 0.1 mm)

2 layers W 0.05 Xo (0.175 mm) +Si (x,y)0.5 mm (pitch 0.1 mm)

1 layer Si (x,y) 0.5 mm (pitch 0.1 mm)

CDmidl - Si (x,y) detectors (pitch 0.1 mm)

S1, S2 - TOF detectors

S3, S4 trigger detectors

CC1 - imaging calorimeter (10Xo)

10 layers BGO 1.12x2.24x23 + 1.12x2.24x22 cm

(20+20)x4x10 crystals

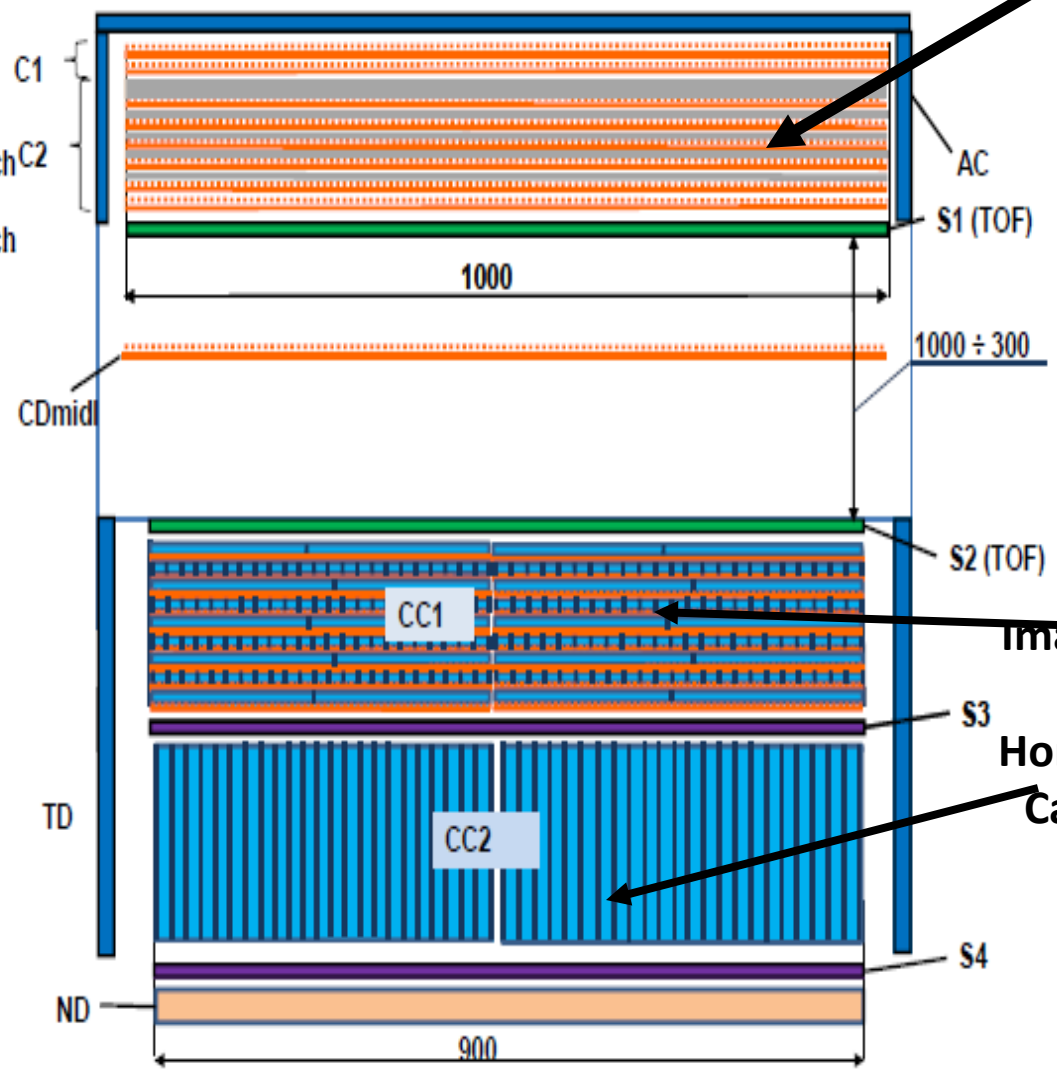
(WLS 1mm 2 layers x, 2layers y) Si (x,y)(pitch 1cm)

CC2 - electromagnetic calorimeter BGO (14Xo)

2.24x2.24x15.7cm - 400x4 crystals

ND - neutron detector

TD - 4 trigger detectors



Converter/Tracker (W+Si)

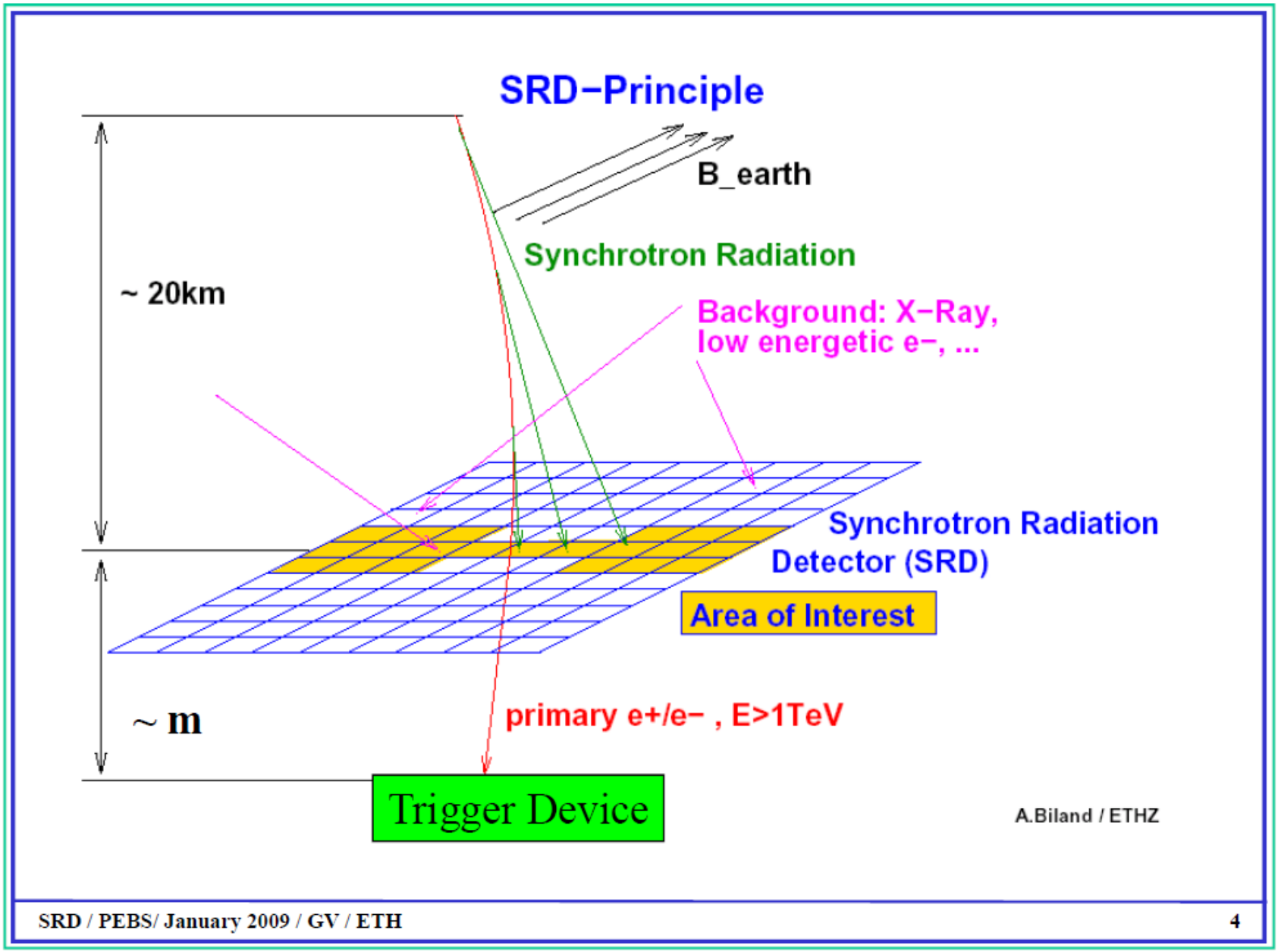
Imaging Calor. (CC1)

Homogeneous Calorimeter (BGO) (CC2)

Electron count estimation

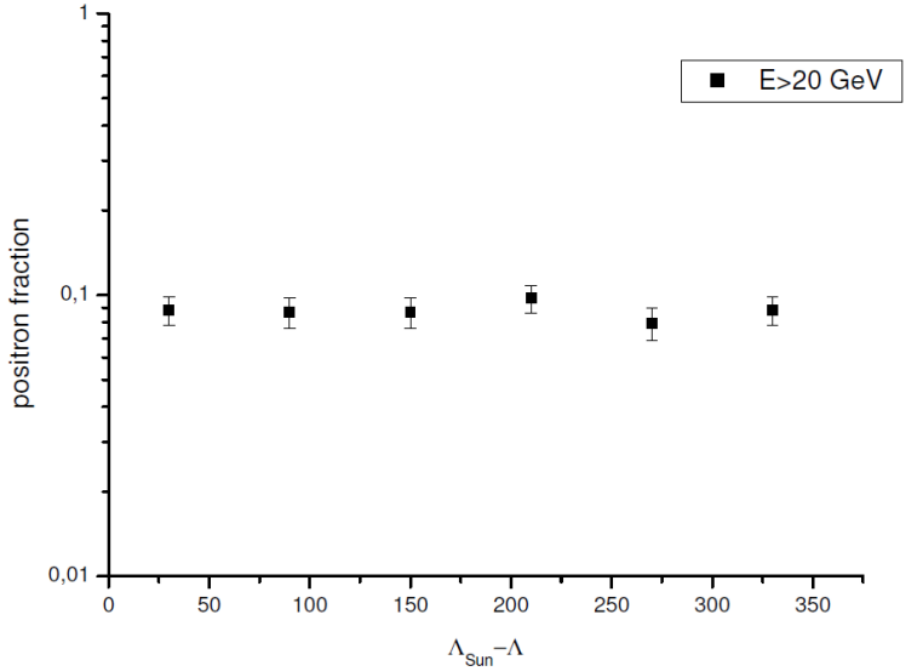
/12

Experiment	Duration	GF (m^2 sr)	Calo σ(E)/E	Calo depth	e/p rejection factor	E>0.5 TeV	E>1 TeV	E>2 TeV	E>4 TeV
CALET	5 y	0.12	~2%	30 X_0	10^5	7982	1527	238	25
AMS02	10 y	0.5	~2%	16 X_0	10^3	66515	12726	1986	211
ATIC	30 d	0.25	~2%	18 X_0	10^4	273	52	8	1
FERMI	10 y	1.6 @ 300 GeV 0.6@ 800 GeV	~15%	8.6 X_0	10^4	59864	6362	NA	NA
G400	10 y	3.9	~2%	25.4 X_0	10^5	518819	99266	15488	1647

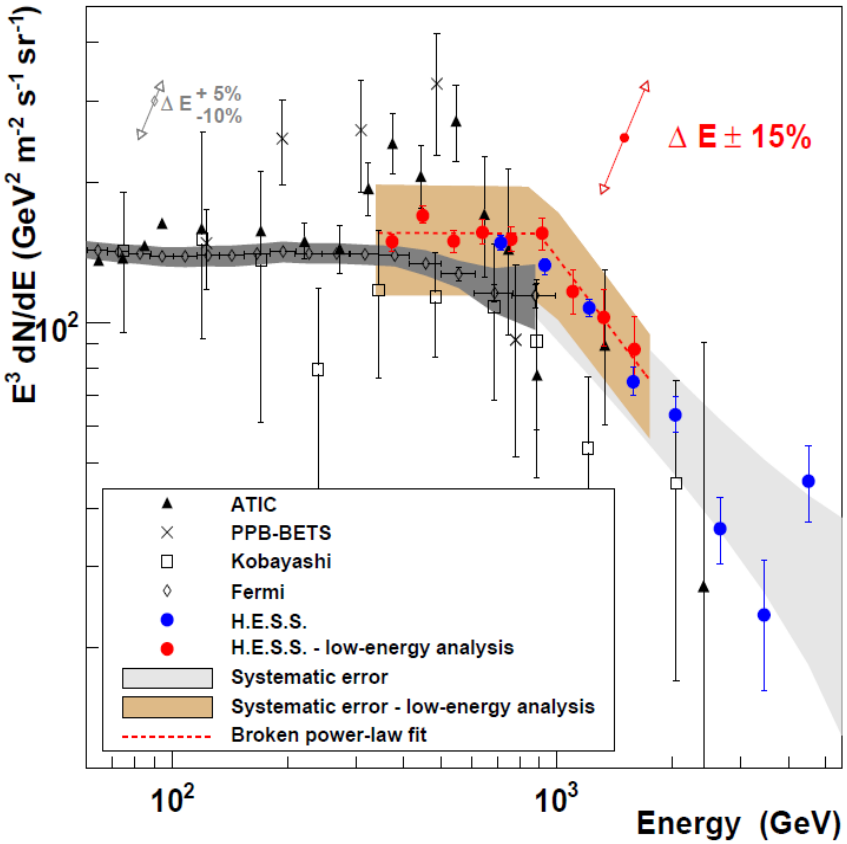

SRD−Principle
B_earth
Synchrotron Radiation
~ 20km
Background: X−Ray,
low energetic e−, ...
Synchrotron Radiation
Detector (SRD)
Area of Interest
~ m
primary e+/e− , E>1TeV
Trigger Device
A.Biland / ETHZ
SRD / PEBS/ January 2009 / GV / ETH
4

Anisotropy – Sun

PAMELA



Energy Scale



$$\varphi \propto \varphi_0 \times E^{-3}$$
$$\Delta\varphi/\varphi = -2\ \Delta E/E$$

- Lots of protons →homogeneity response , time stability
- Linearity : ions (dE/dx) , E/p
- Absolute E scale
  - No standard candles in space
  - Test beam
  - MC description ...
  - E/p (p ...)

~ 2- 5 % for Satellite /Balloon
~ 15 % for HESS