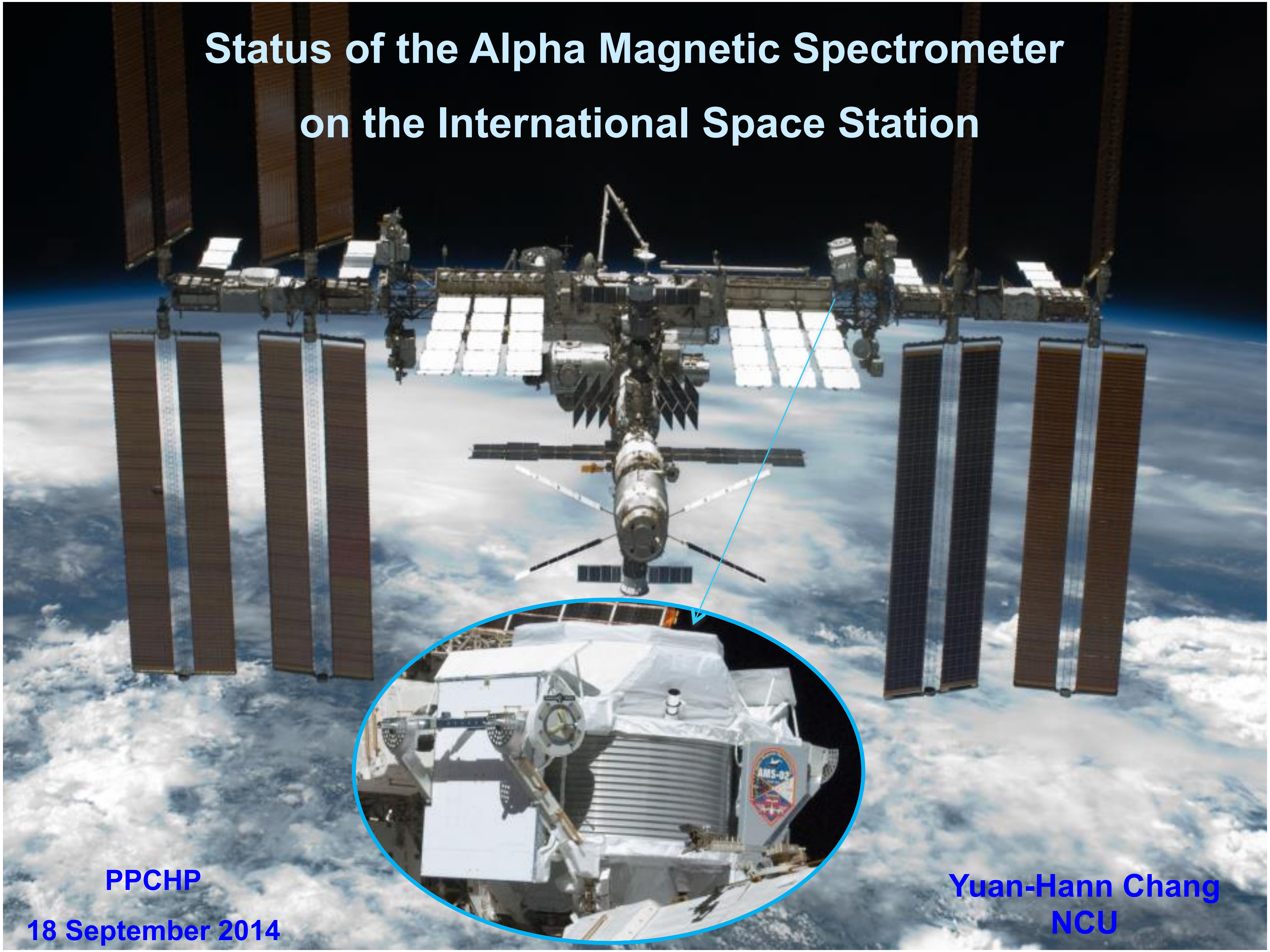
Status of the Alpha Magnetic Spectrometer on the International Space Station



PPCHP

18 September 2014

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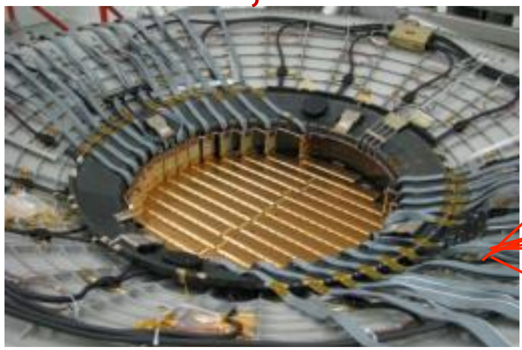
NCU

AMS: A TeV precision, multipurpose spectrometer

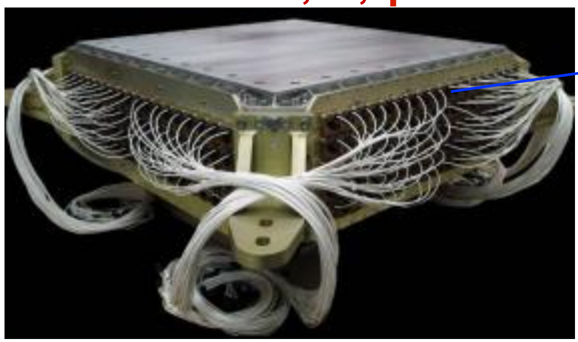
Particles and nuclei are defined by their charge (Z) and energy (E ~ P)

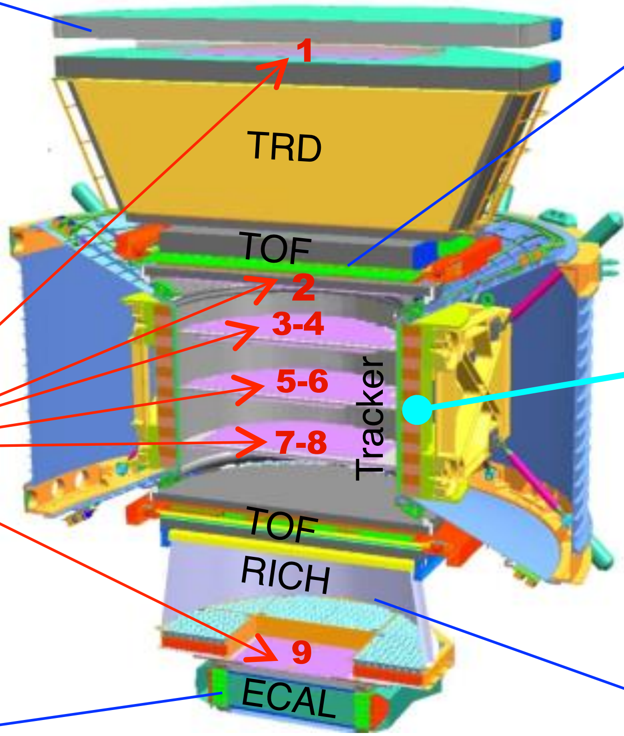
TRD
Identify e^+, e^-

Silicon Tracker
Z, P



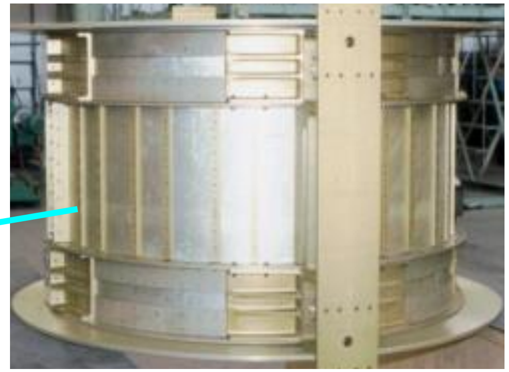
ECAL
E of e^+, e^-, γ



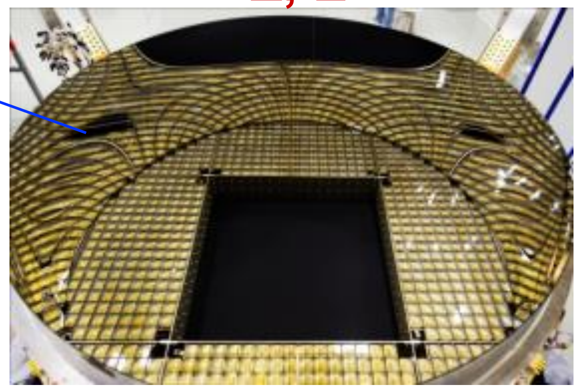


TOF
Z, E

Magnet
±Z



RICH
Z, E



***Z, P** are measured independently by the Tracker, RICH, TOF and ECAL*

Summary of the current status:

- AMS has been operational on the ISS for 40 months.
- All hardware are functioning smoothly
- 56 billion events collected.
- The results in this talk are based on 41 billion events, with ~10 million electrons and positrons.
- Data taking continues at ~16 billion events per year, expected for at least 10 more years.

AMS measurement of the e^+ and e^- spectrum (with > 10M events)

1. "First Result from the AMS on the ISS: Precision Measurement of the Positron Fraction in Primary Cosmic Rays of 0.5-350 GeV", PRL 110, 141102 (2013)
   - Measure $e^+/(e^+ + e^-)$ ratio

2. "High Statistics Measurement of the Positron Fraction in Primary Cosmic Rays of 0.5 – 500 GeV with the AMS on the ISS", PRL 113, 121101 (2014)
   - Update $e^+/(e^+ + e^-)$ ratio with high statistics

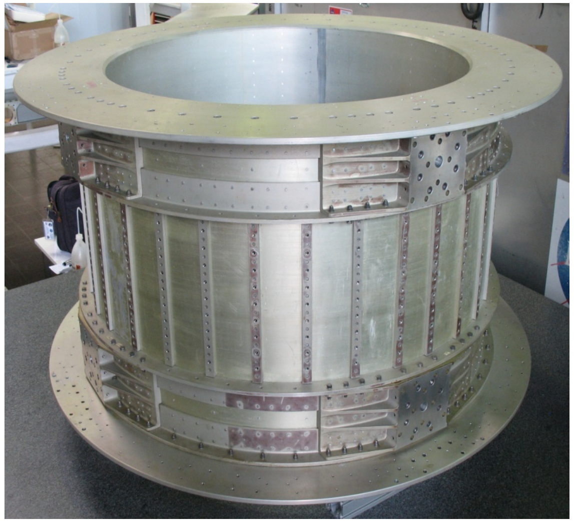
Acceptance effects are cancelled in $e^+/(e^+ + e^-)$ ratio – reduce systematic errors.

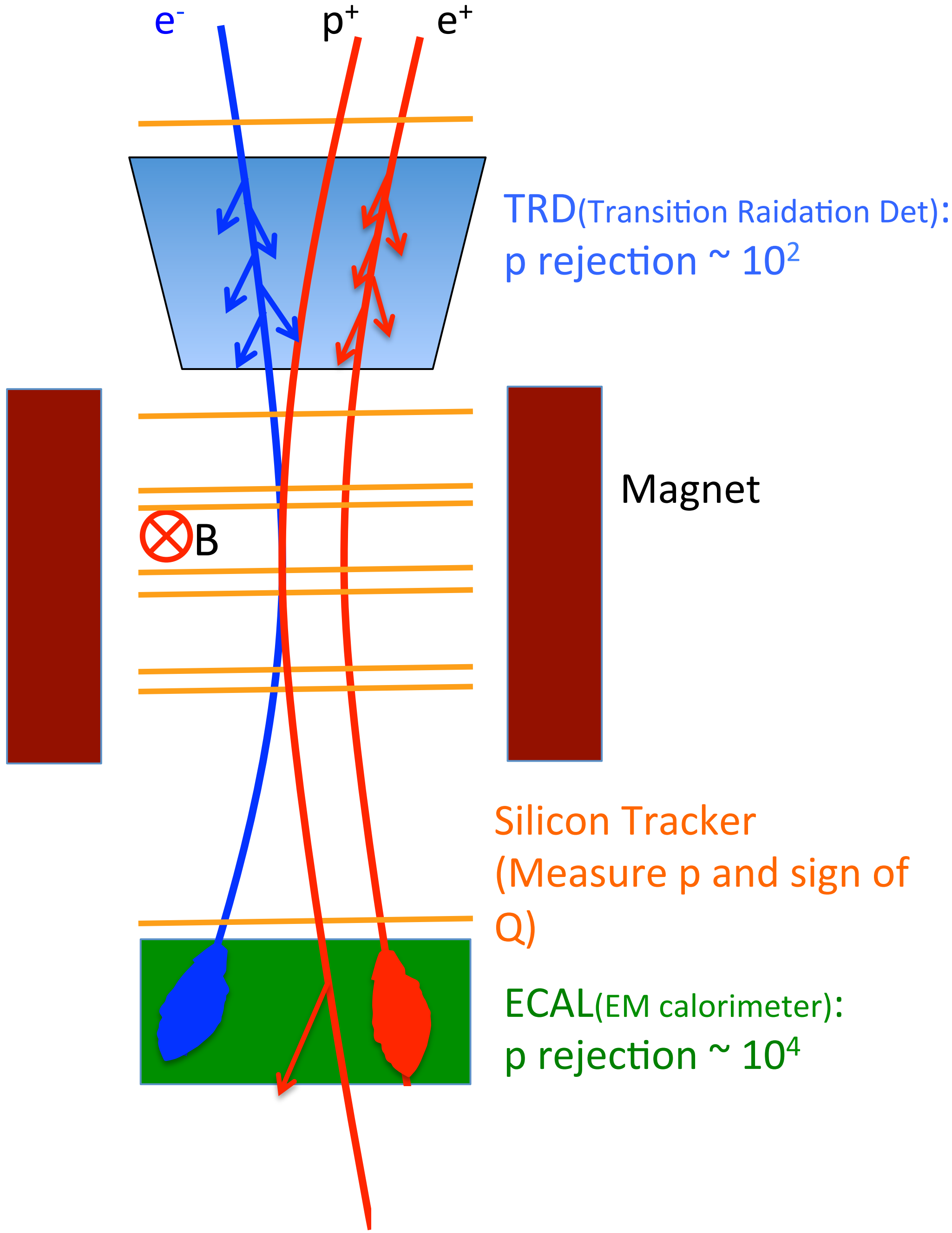
3. "Electron and Positron Fluxes in Primary Cosmic Rays Measured with the AMS on the ISS", PRL 113, 121102 (2014)
   - Measurement of separate e^+ and e^- flux

4. "A precision Measurement of the $(e^+ + e^-)$ Flux in Primary Cosmic Rays from 0.5 GeV to 1 TeV with the AMS on the ISS", submitted to PRL
   - Measurement of the total $(e^+ + e^-)$ flux

Independent from charge sign determination – smaller systematic, higher statistics, higher energy range.

Principle of AMS Detector for e+/e- measurement





Major issues for positron Measurement:

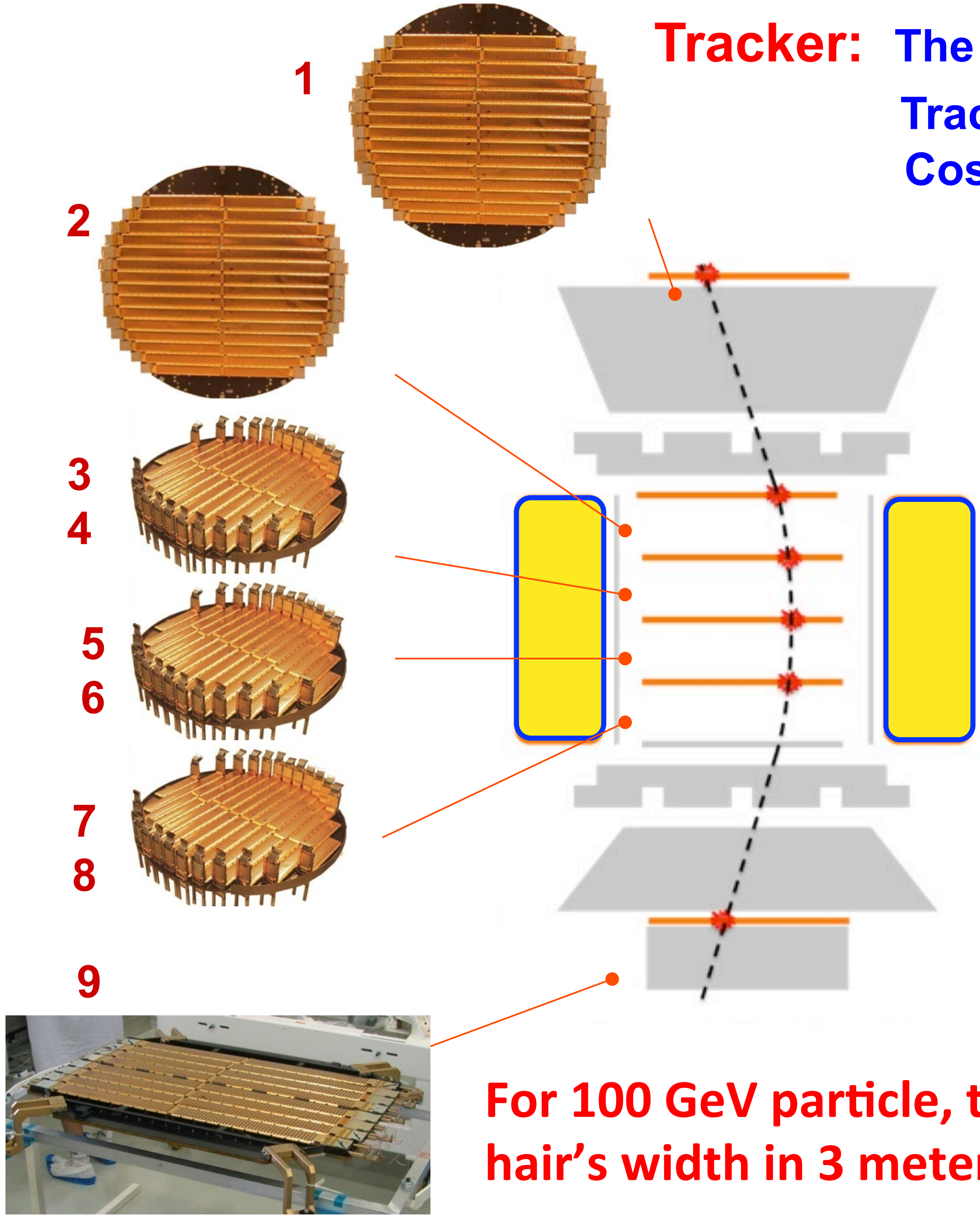
$p/e^+ \sim 10^4$: proton rejection

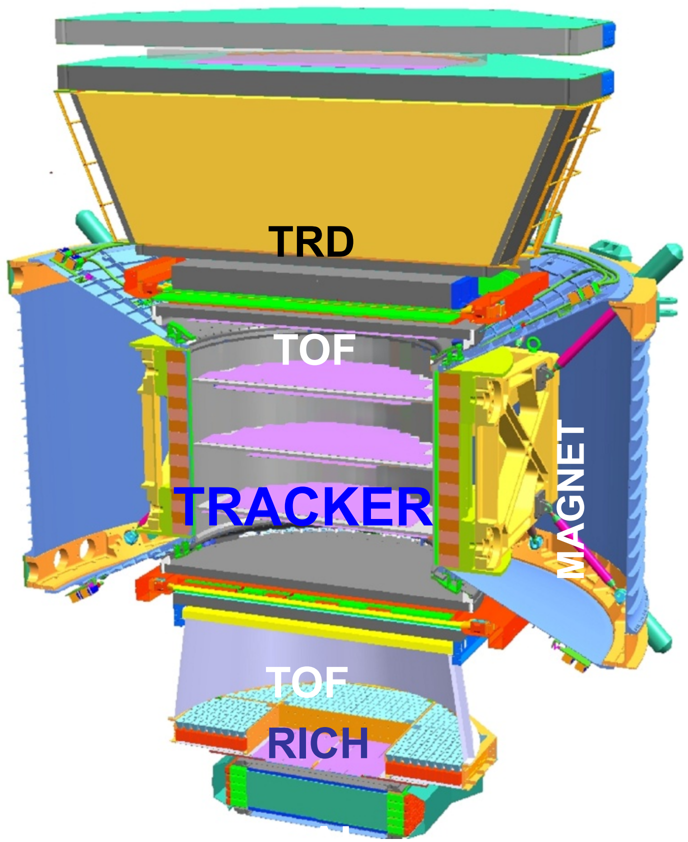
$e^-/e^+ \sim 10$: charge confusion

Performance of AMS in Space

Tracker: **The coordinate resolution is 10 μ**

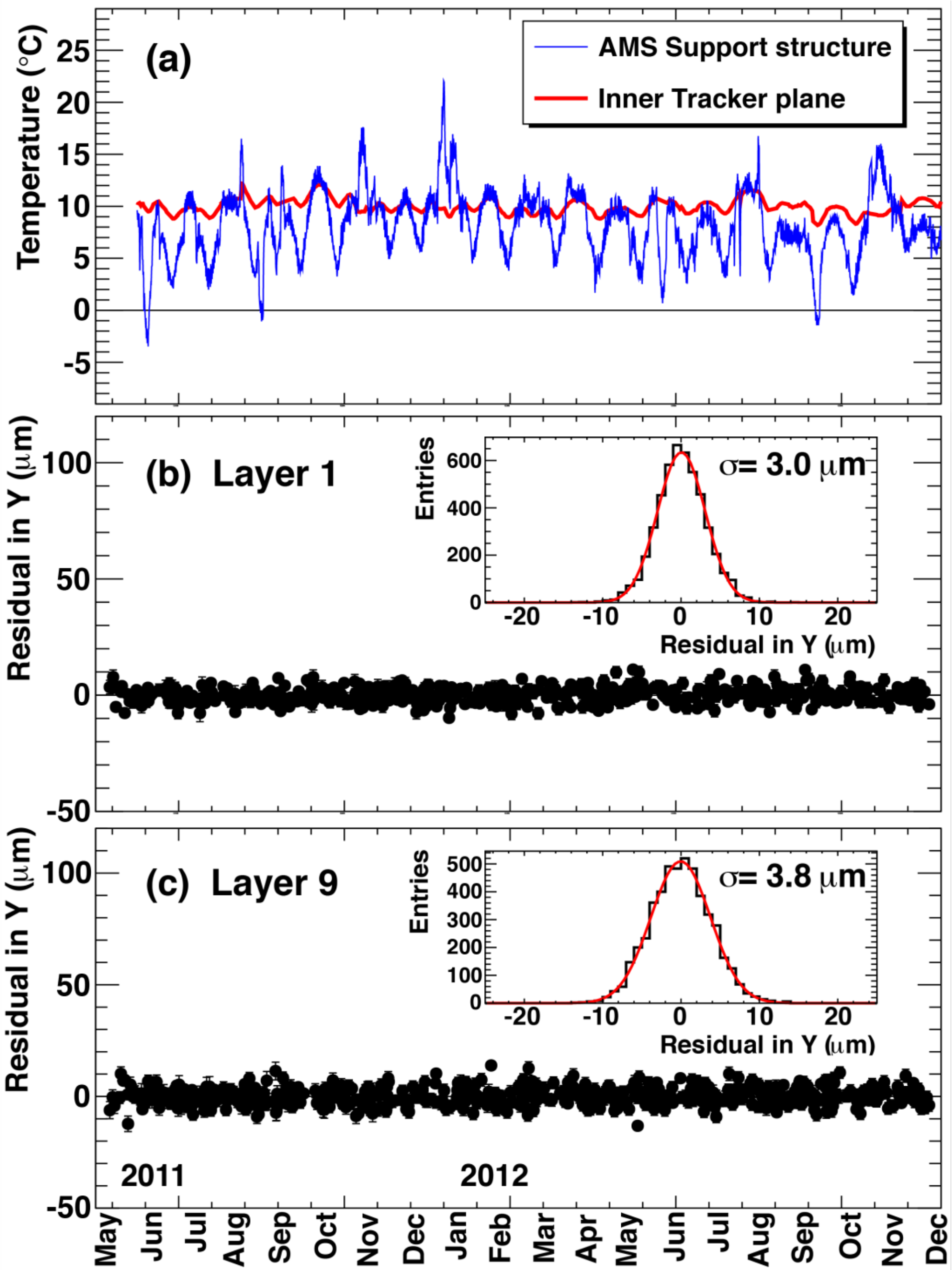
Tracker Alignment via Cosmic rays



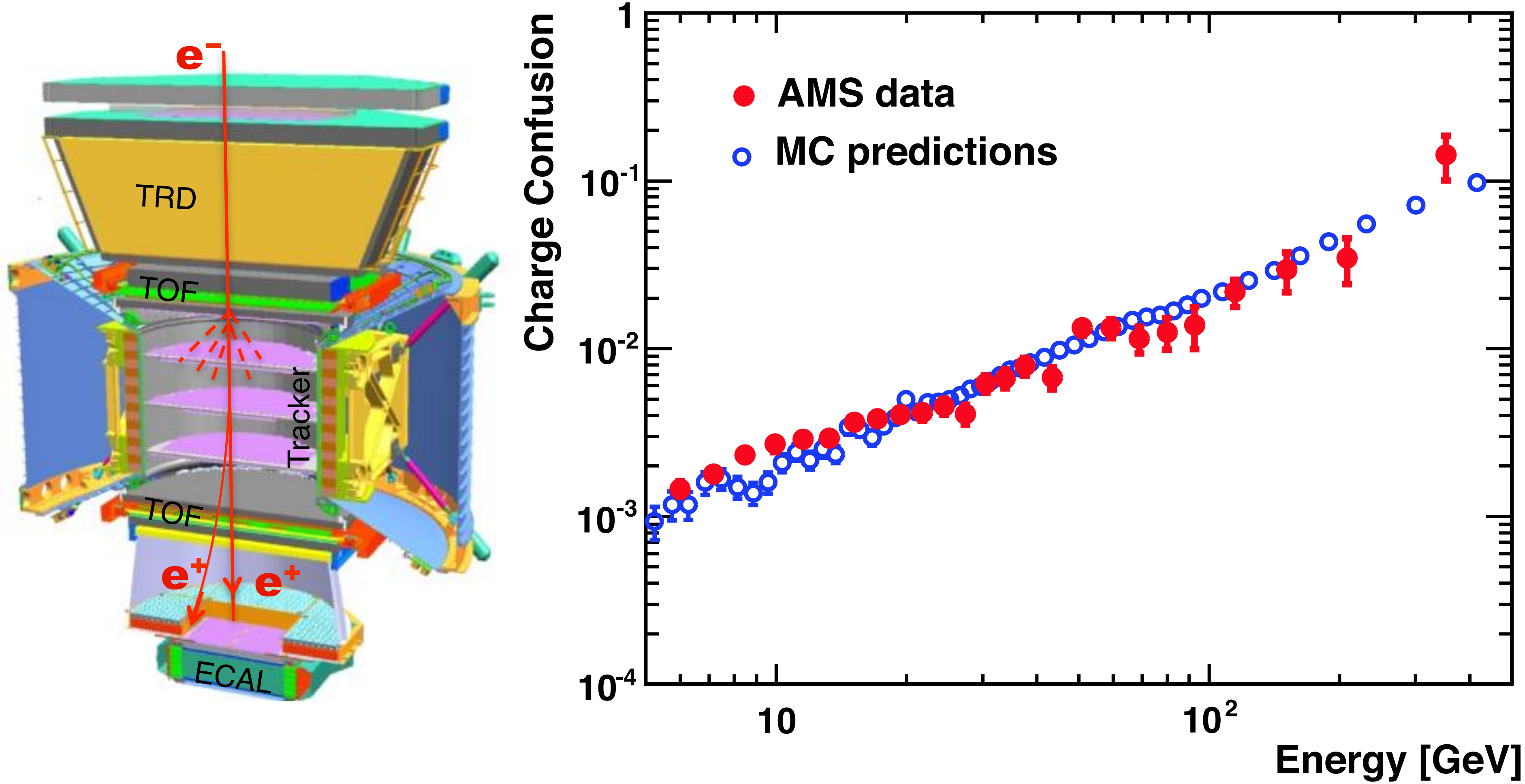


For 100 GeV particle, the bending is about 1 hair's width in 3 meter track length.

Stability of the alignment on Tracker plane 1 & 9

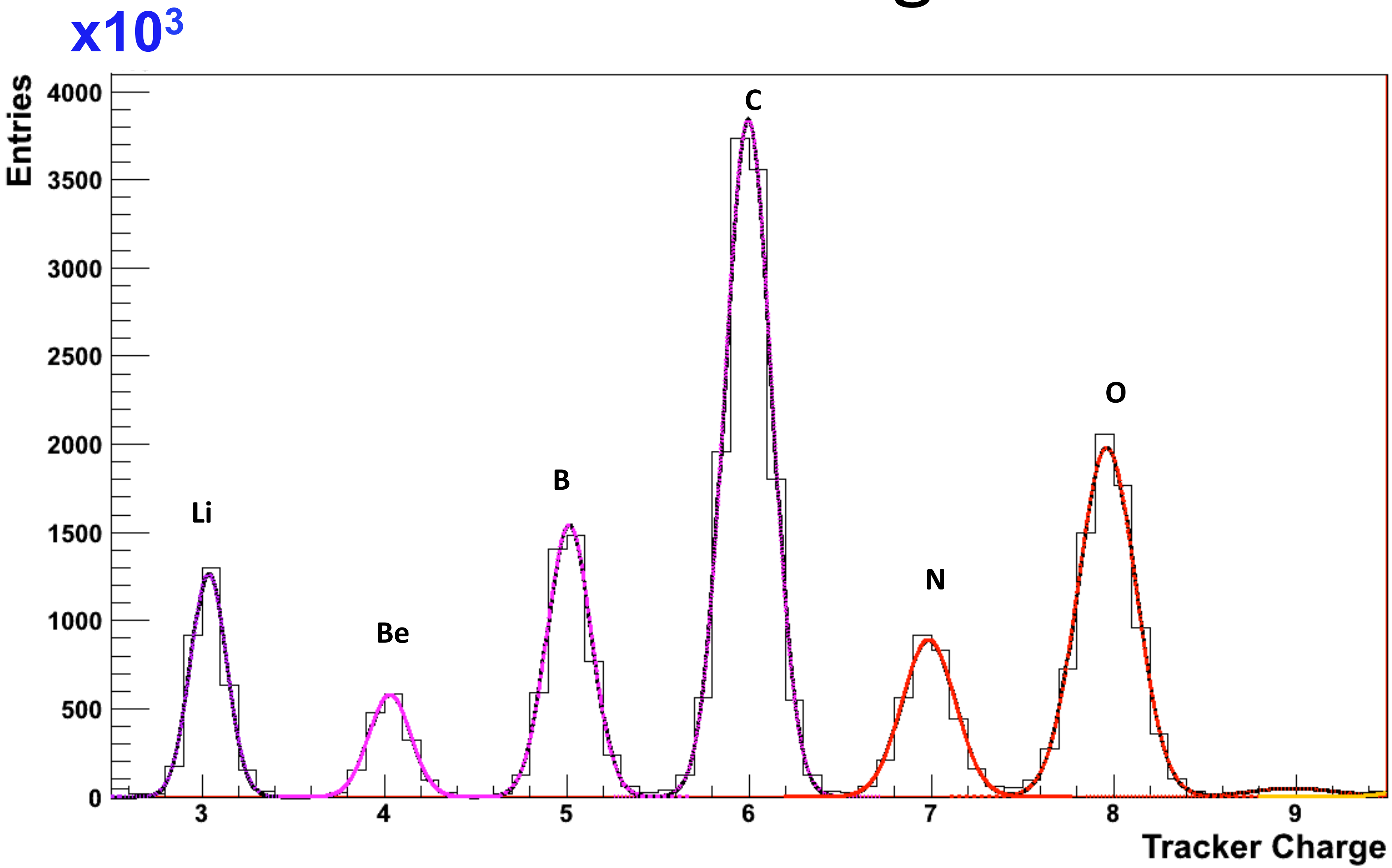


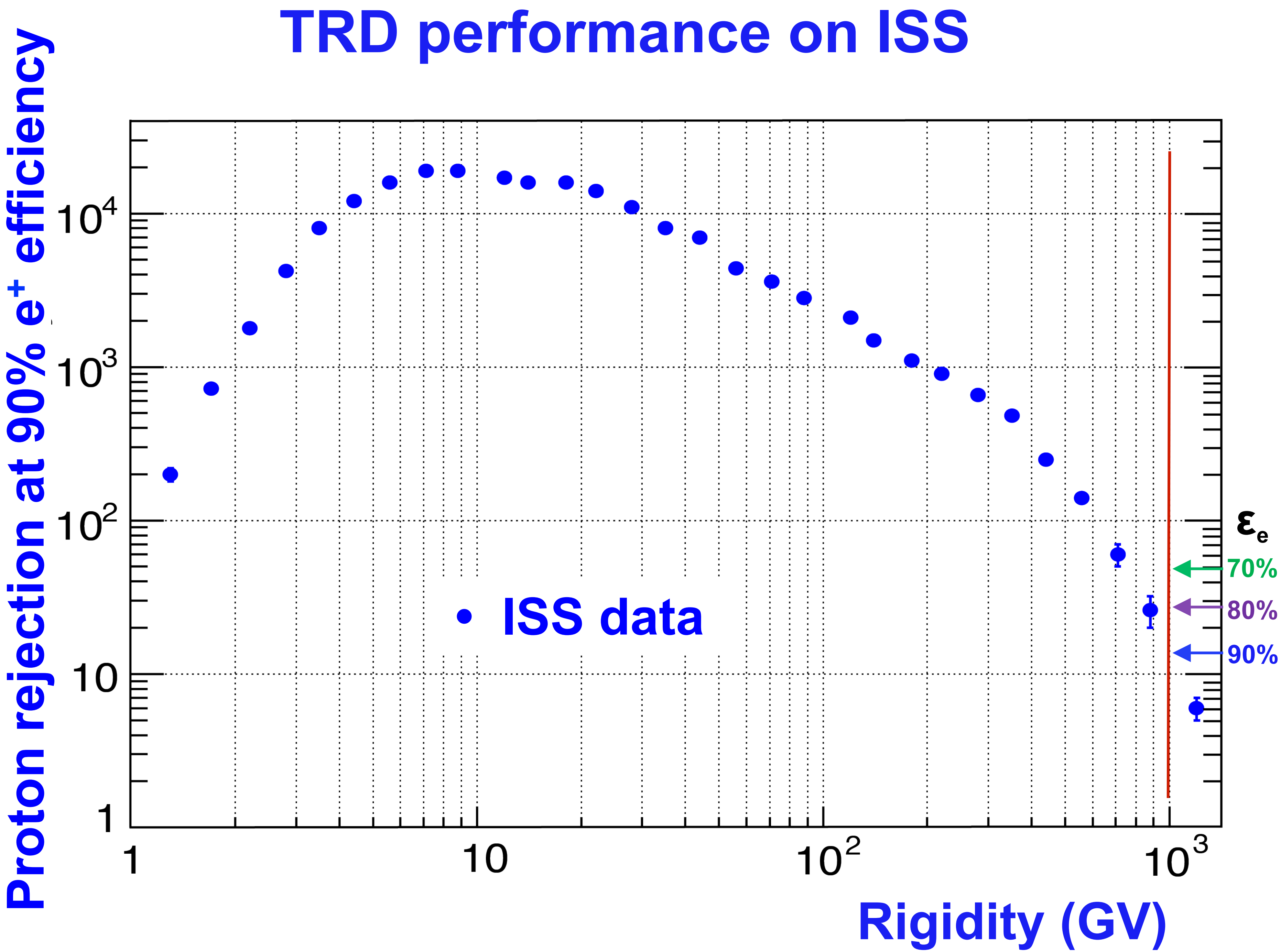
Charge confusion



Two sources: 1) large angle scattering and 2) production of secondary tracks along the path of the primary track. Both are well reproduced by MC. Systematic errors correspond to variations of these effects within their statistical limits and comparing the results with the Monte Carlo simulation

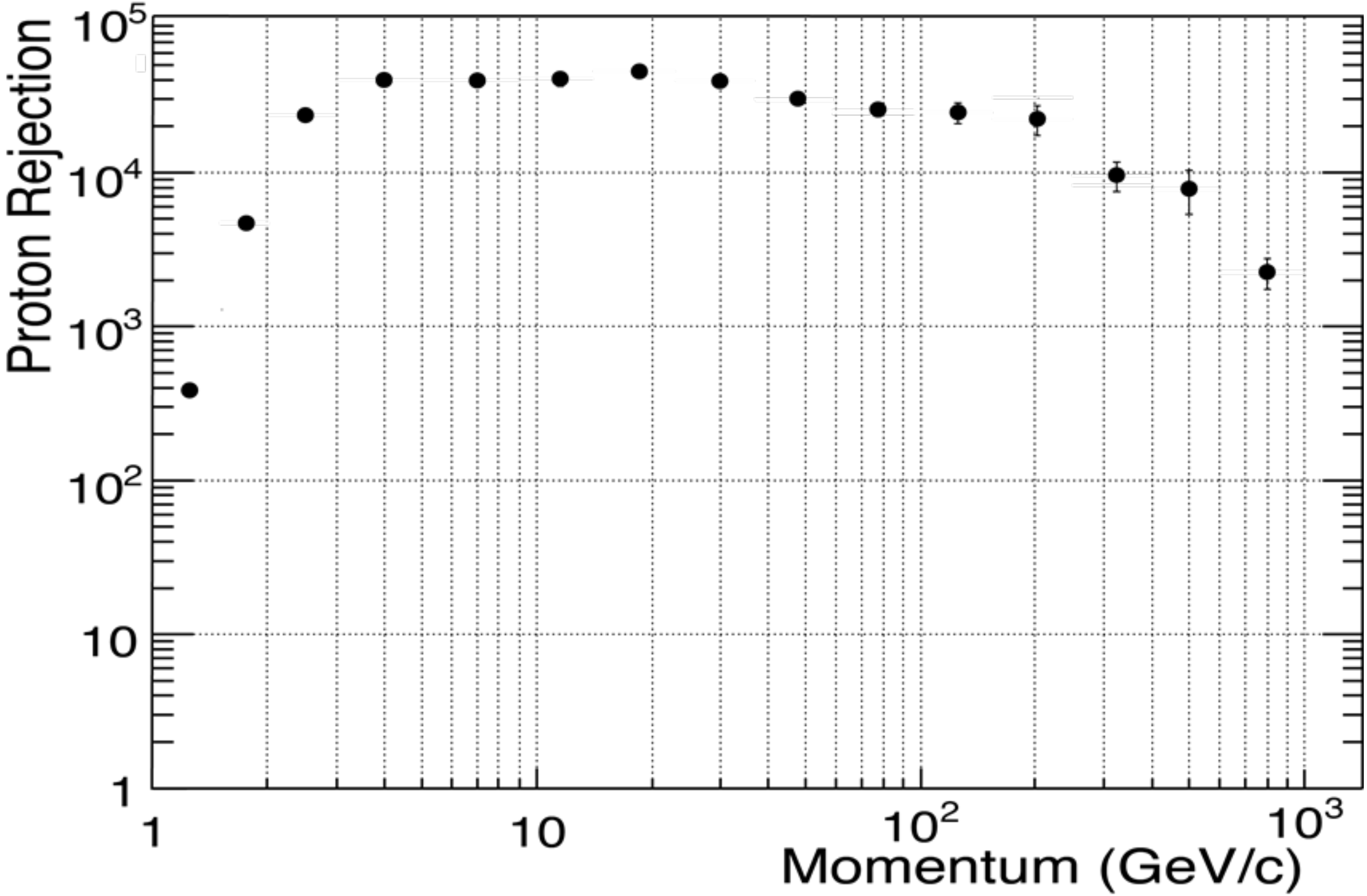
Tracker Charge





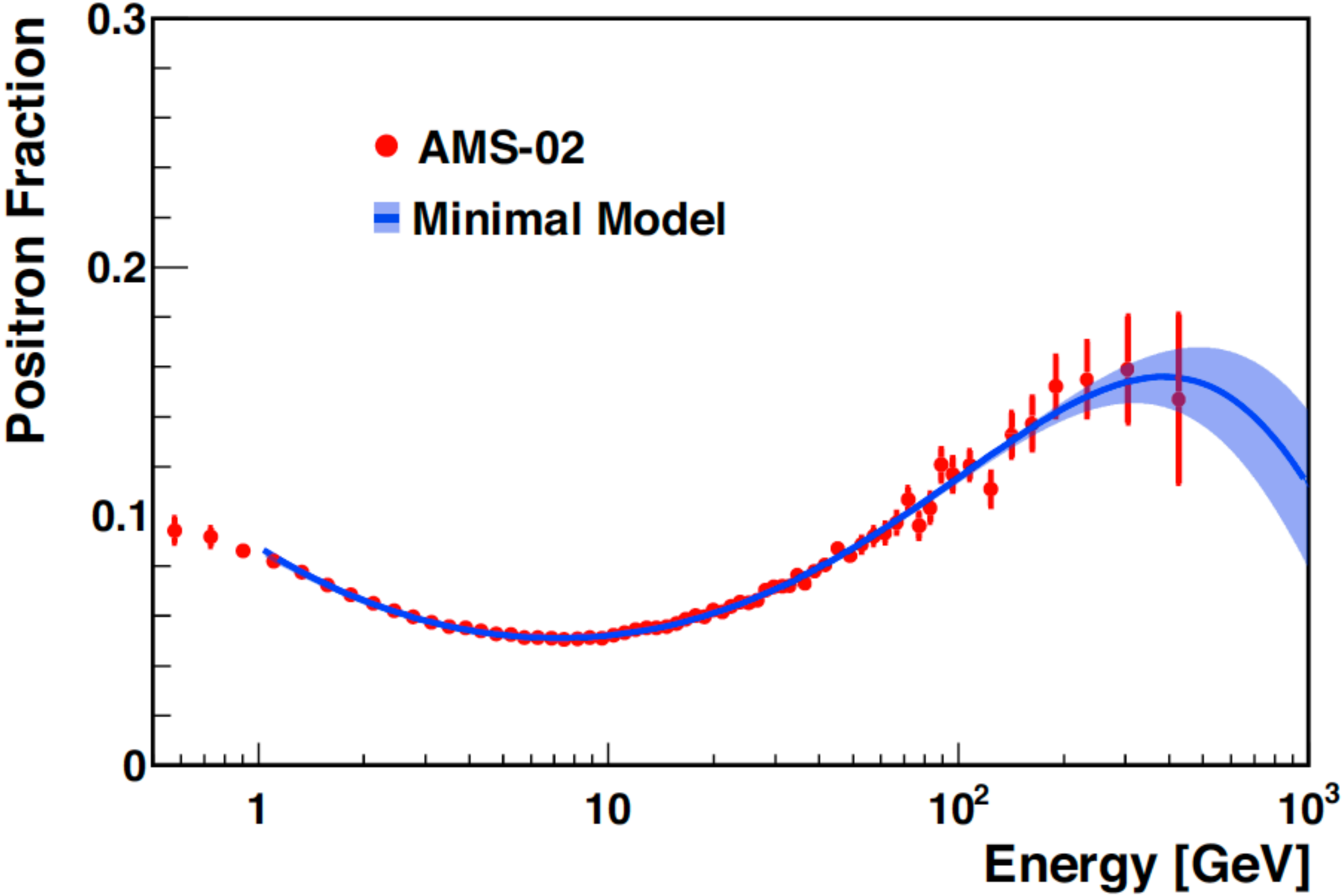
TRD performance on ISS
Proton rejection at 90% e+ efficiency
Rigidity (GV)
ISS data
εe
70%
80%
90%
1
10
10^2
10^3
10^4

Data from ISS: Proton rejection using the ECAL



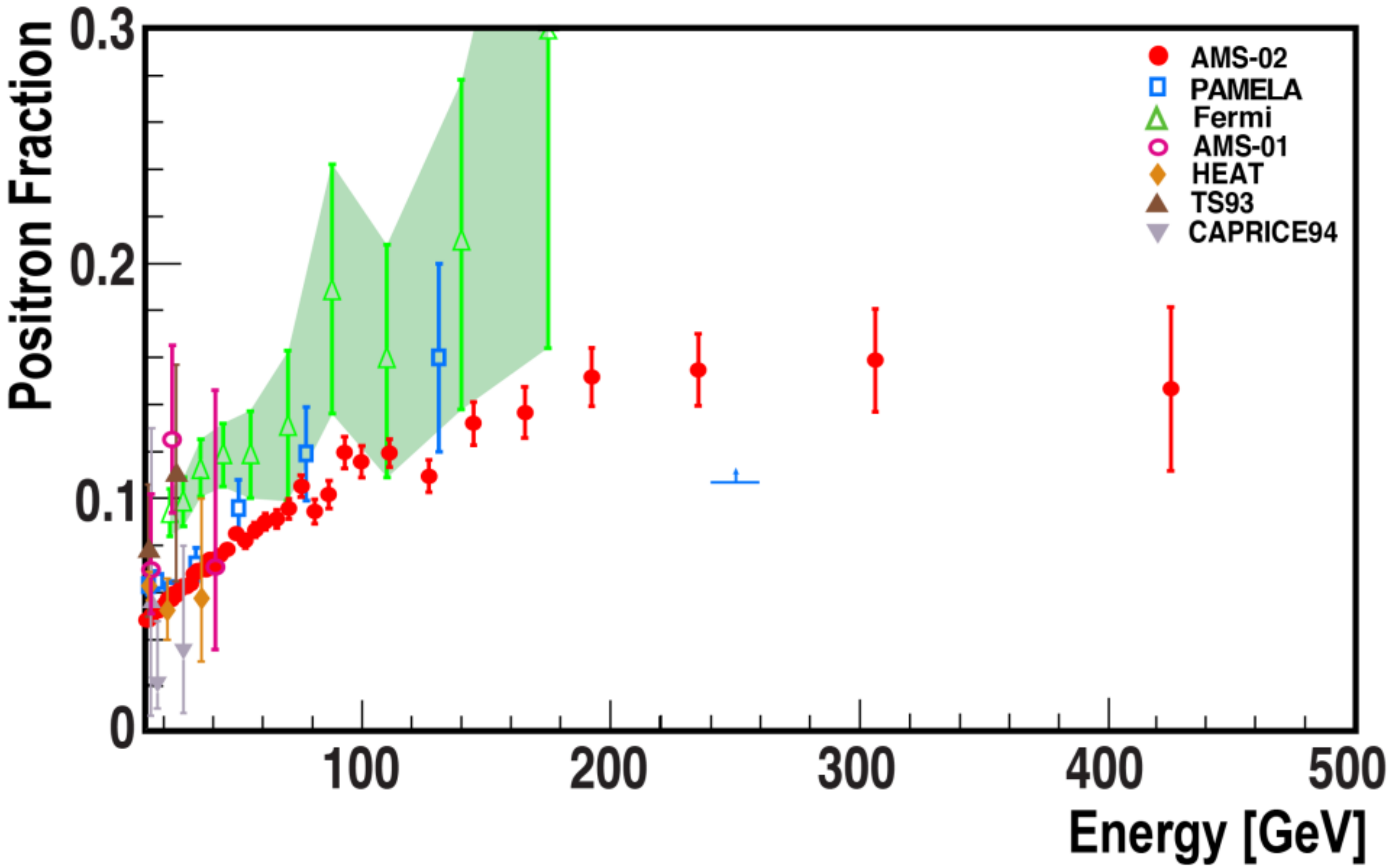
Results from $e^+/(e^++e^-)$ ratio measurements

AMS measurement of the $e^+/(e^++e^-)$ ratio

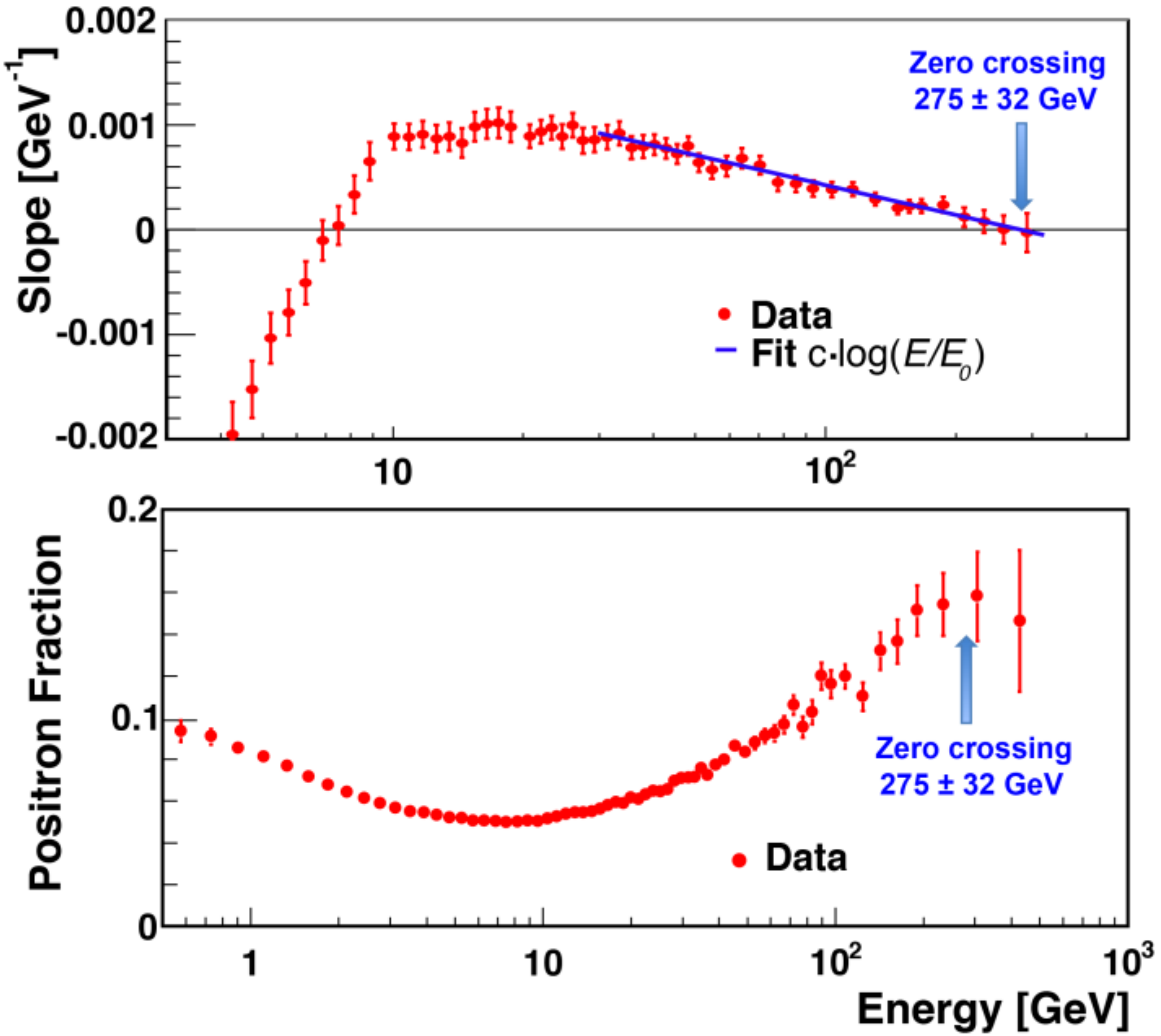


(ii) The rate of increase with energy.

(iii) The non-existence of sharp structures.

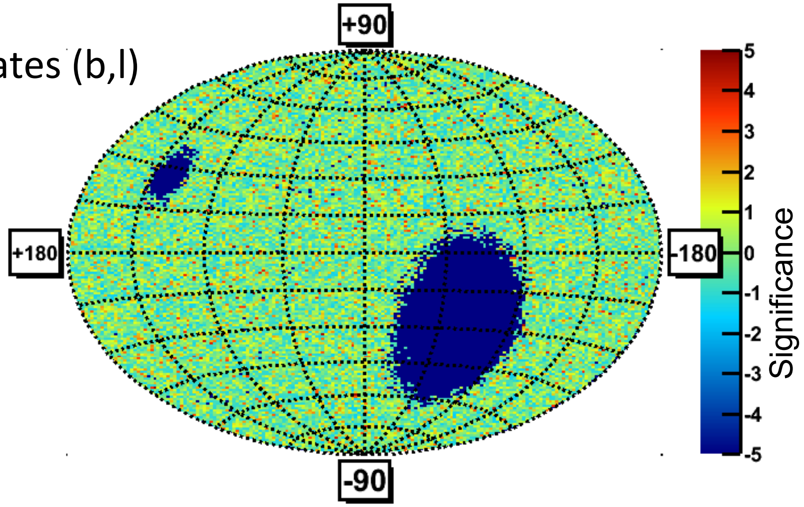


The energy beyond which it ceases to increase.



(v) The isotropy.

Galactic coordinates (b,l)



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

The anisotropy in galactic coordinates:
δ ≤ 0.030 at the 95% confidence level

$\delta = 3\sqrt{C_1/4\pi}$ C_1 is the dipole moment

Arrival directions of electrons and positrons are used to build a sky map in galactic coordinates, (b, l), containing the number of observed positrons and electrons. The fluctuations of the observed positron ratio are described using a spherical harmonic expansion

$$\frac{r_e(b,l)}{< r_e >} - 1 = \sum_{\ell=0}^{\infty} \sum_{m=-\ell}^{\ell} a_{\ell m}\, Y_{\ell m}(\pi/2 - b, l),$$

where $r_e(b,l)$ denotes the positron ratio at (b,l); $< r_e >$ is the average ratio over the sky map; $Y_{\ell m}$ are spherical harmonic functions and $a_{\ell m}$ are the corresponding weights. The coefficients of the angular power spectrum of the fluctuations are defined as

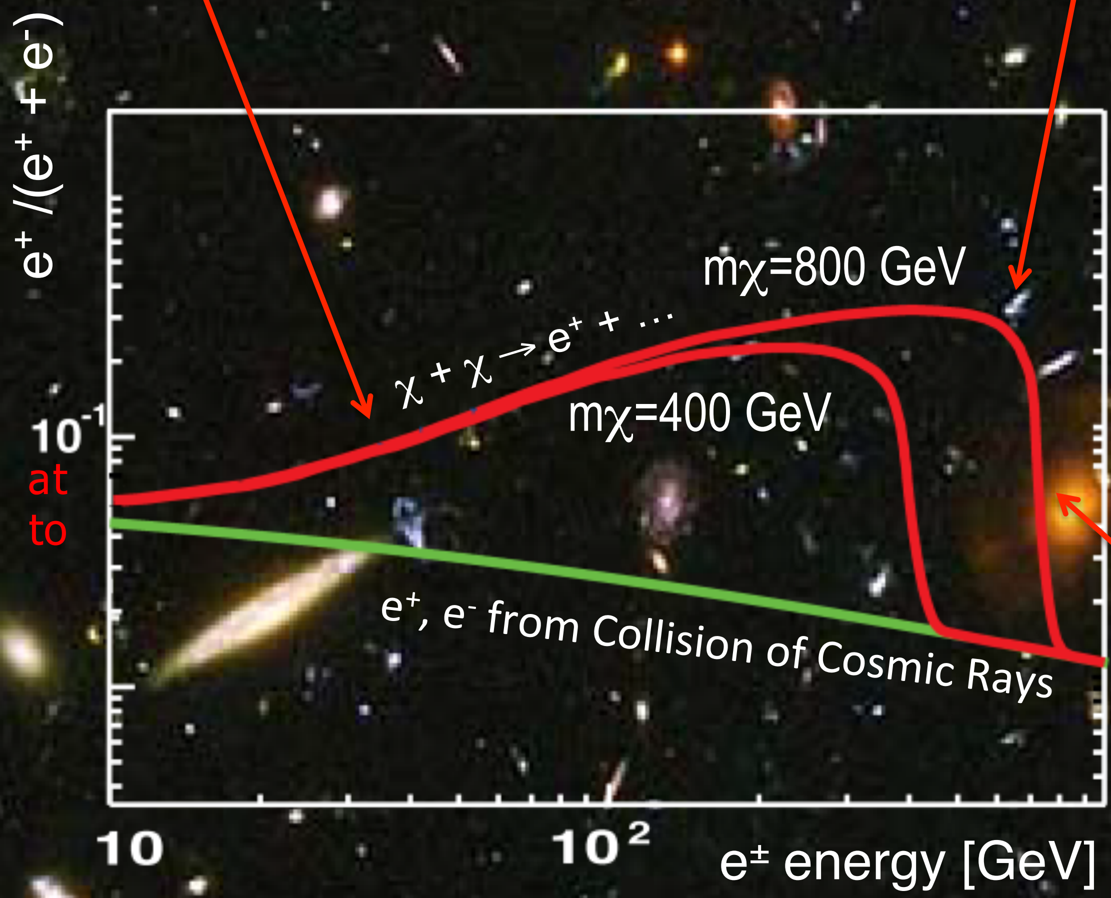
$$C_\ell = \frac{1}{2\ell+1} \sum_{m=-\ell}^{\ell} |a_{\ell m}|^2. \qquad \delta = 3\sqrt{C_1/4\pi}$$

Features of a Neutralino Darkmatter model

2. The rate of increase with energy
3. The existence of sharp structures.

4. The energy beyond which it ceases to increase.

5. Isotropy.



1. The energy at which it begins to increase.

6. The rate at which it falls beyond the turning point.

Results from separate e^+ and e^- flux measurements

Measurement of the flux of electrons and positrons

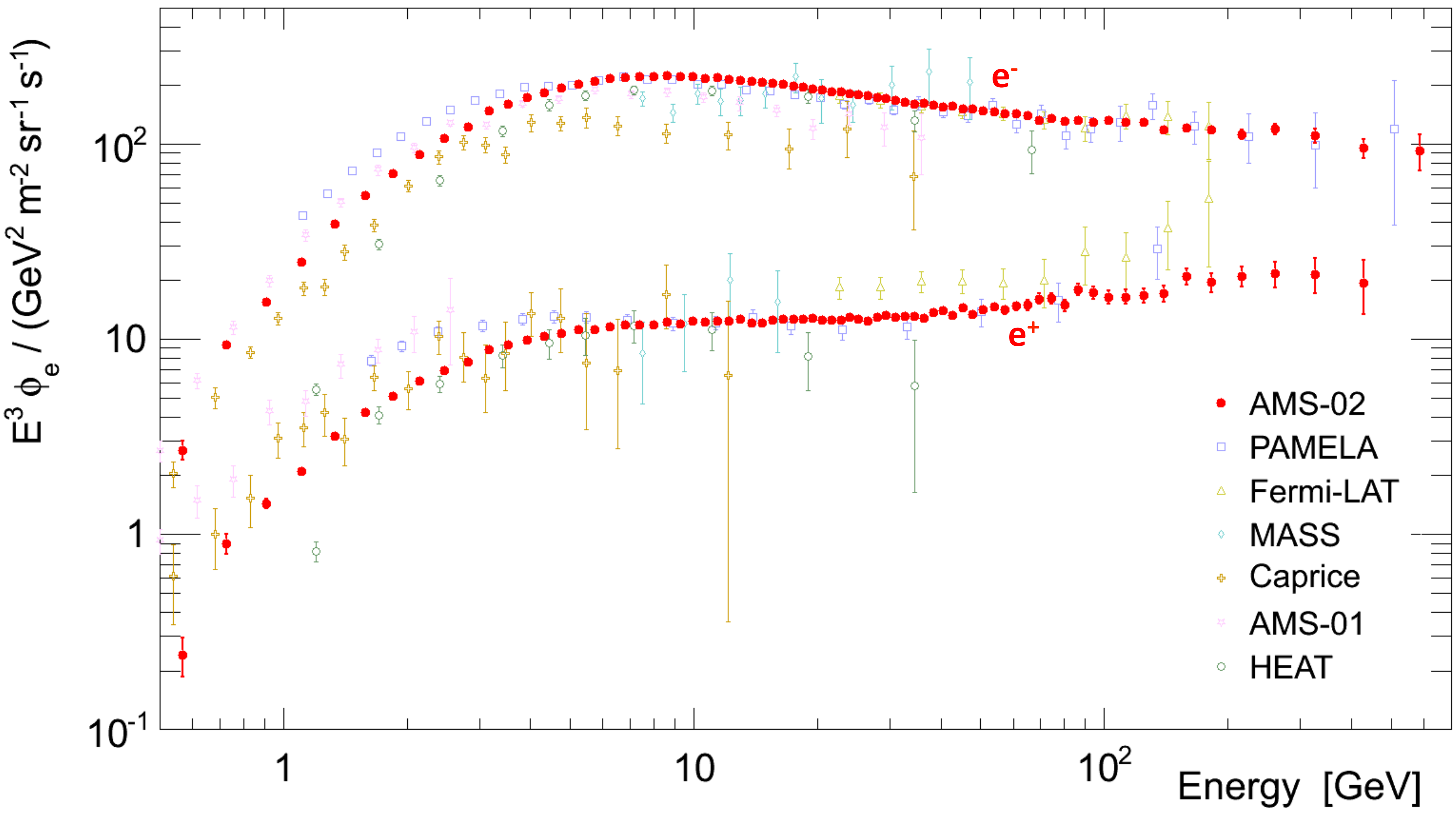
$$\Phi_{e^\pm}(E) = \frac{N_{e^\pm}(E)}{A_{eff}(E) \cdot \varepsilon_{trig}(E) \cdot T(E) \cdot \Delta E}$$

$N_{e\pm}$ is the number of electron or positron events
ε_{trig} is the trigger efficiency
T is the exposure time

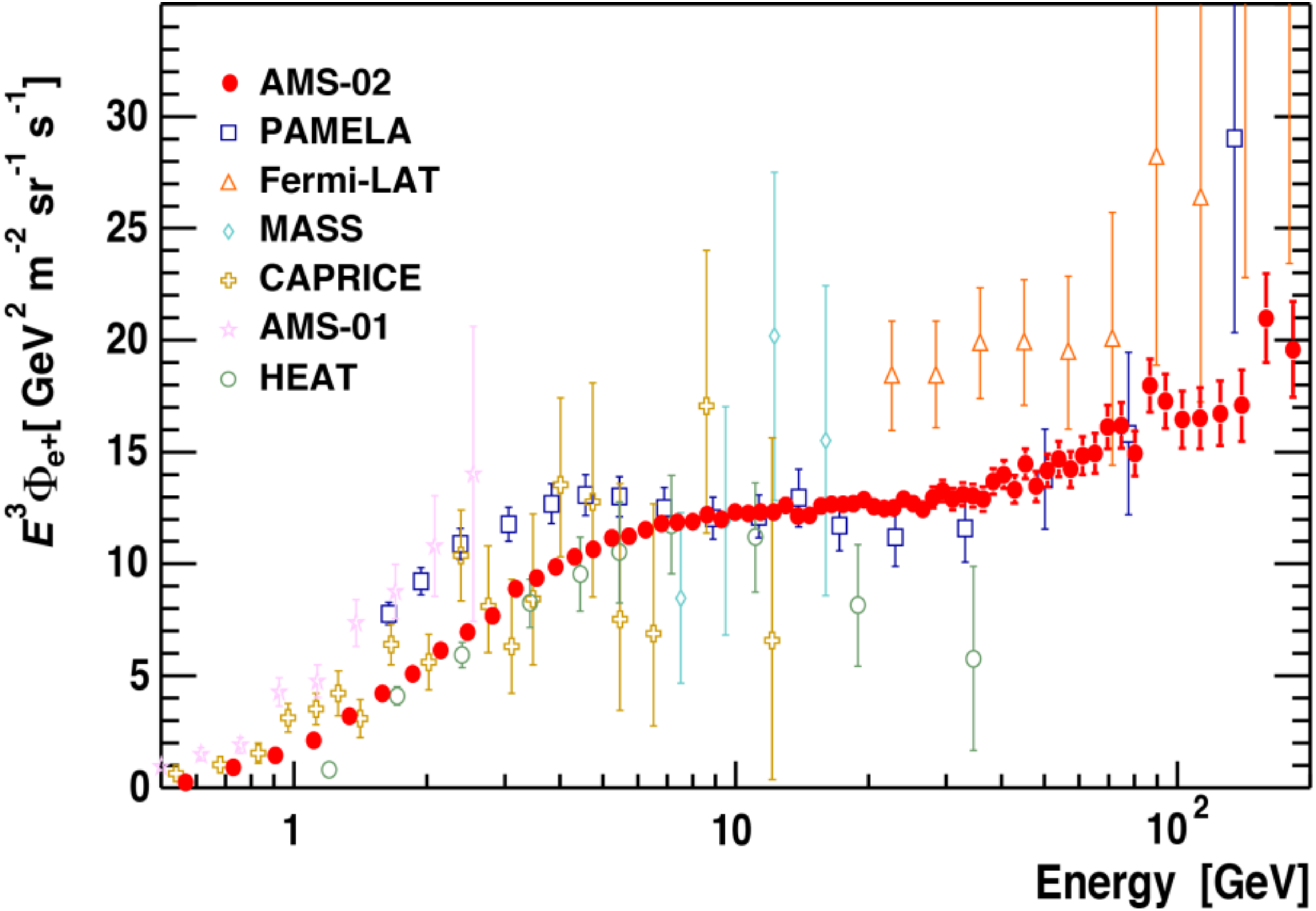
A_{eff} is the effective acceptance $A_{eff} = A_{geom} \cdot \varepsilon_{sel} \cdot \varepsilon_{id} \cdot (1+\delta)$

A_{geom} is the geometrical acceptance, ≃ 550 cm^2sr
ε_{sel} is the event selection efficiency
ε_{id} is the $e^\pm$ identification efficiency
δ is a minor correction from the comparison between data and Monte Carlo (-2% at 10Gev to -6% at 700 GeV). The error on $(1+\delta)$ is ~2.5%.

AMS result on electron and positron flux in the Cosmic Rays



Positron Flux

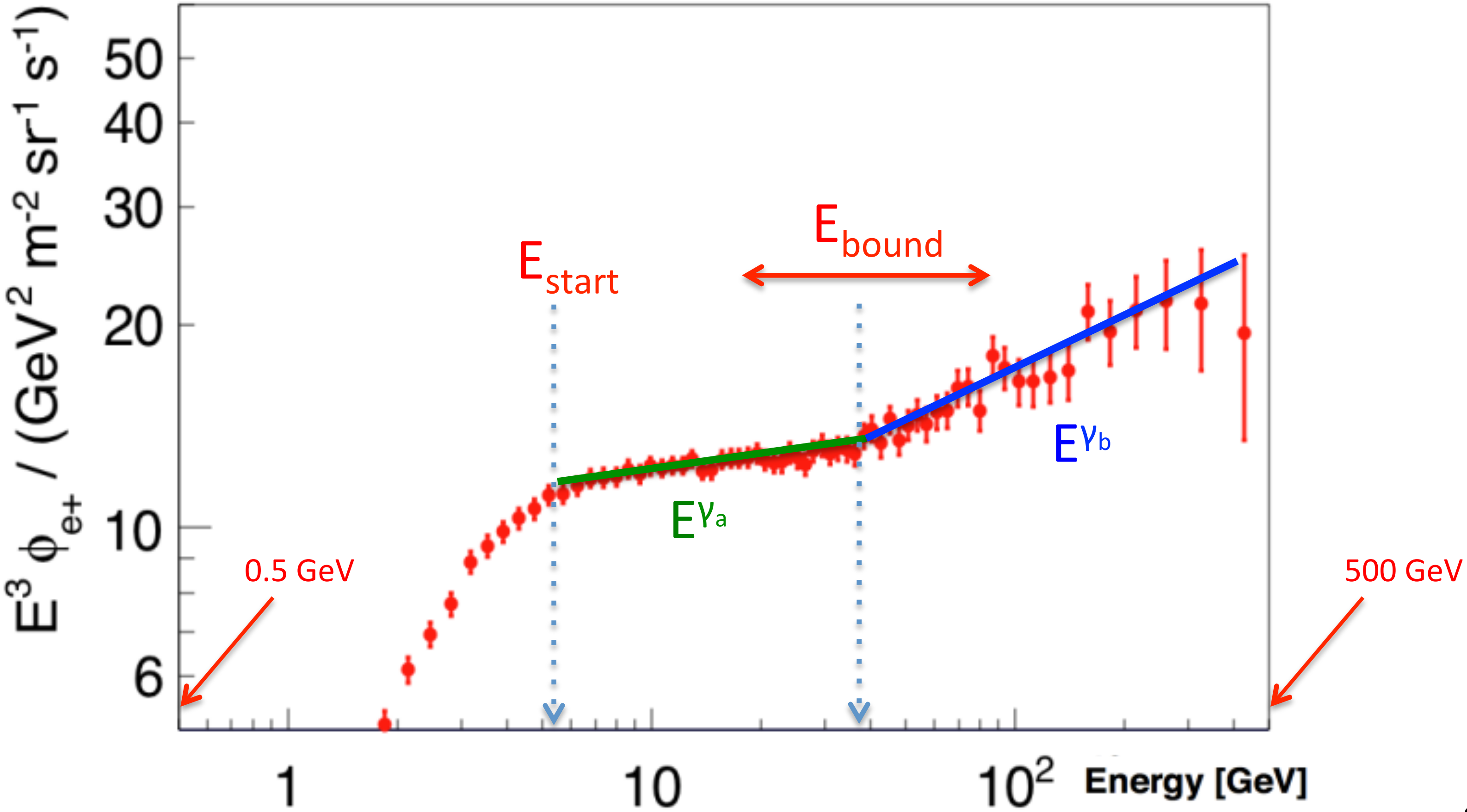


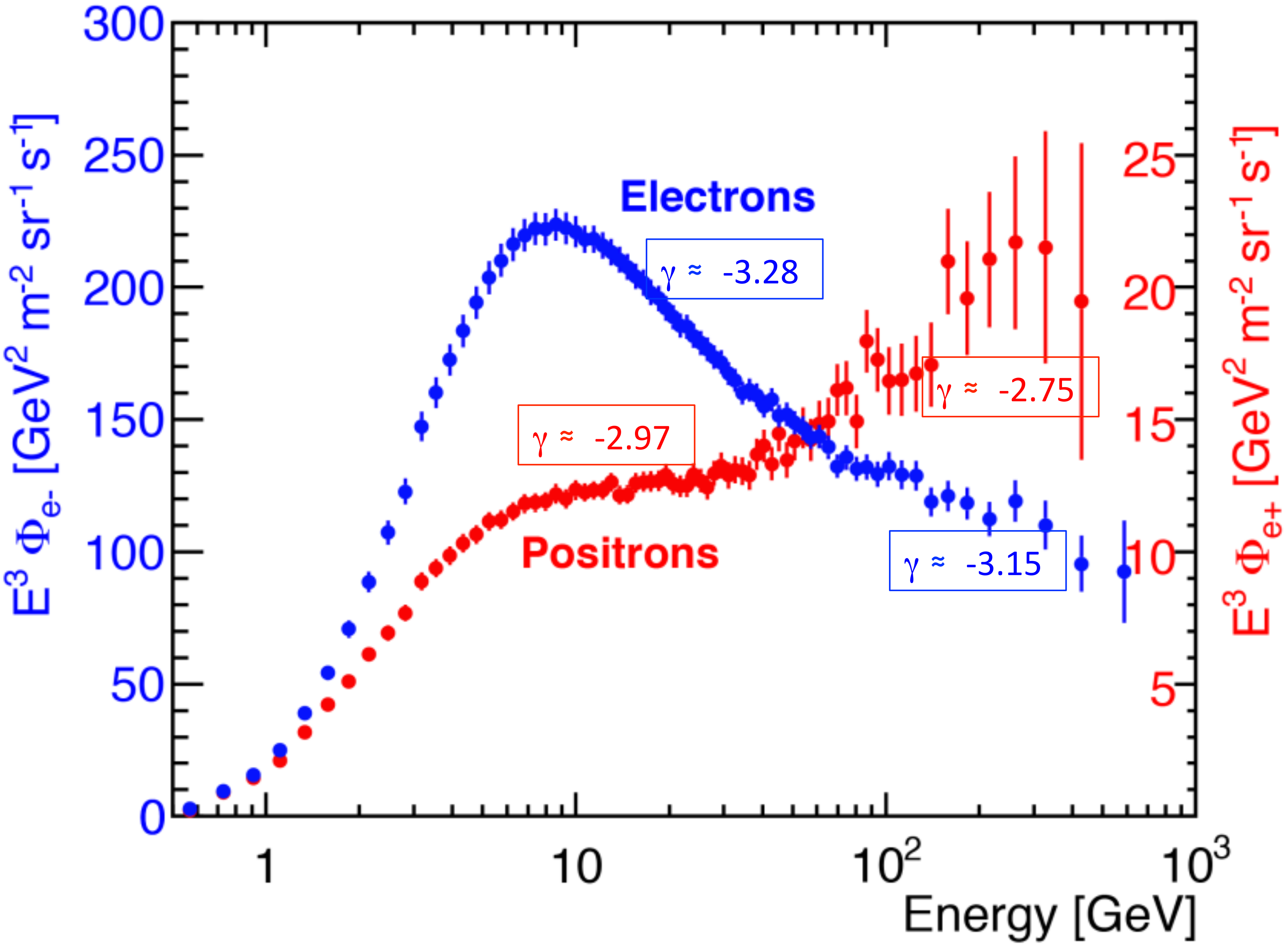
Lower energy limit for single power law (E^{γ}) description

Study intervals with starting energies E_{start}, and ending at the highest energy.

Split a interval into two sections by any boundary E_{bound}, fit with single power law for each section. Determine the significance between the difference of γ_a and γ_b

The limit is defined by the lowest E_{start} that gives consistent spectral indices at the 90% C.L. for any boundary yields Positrons: 27.2 GeV and Electron: 52.3 GeV

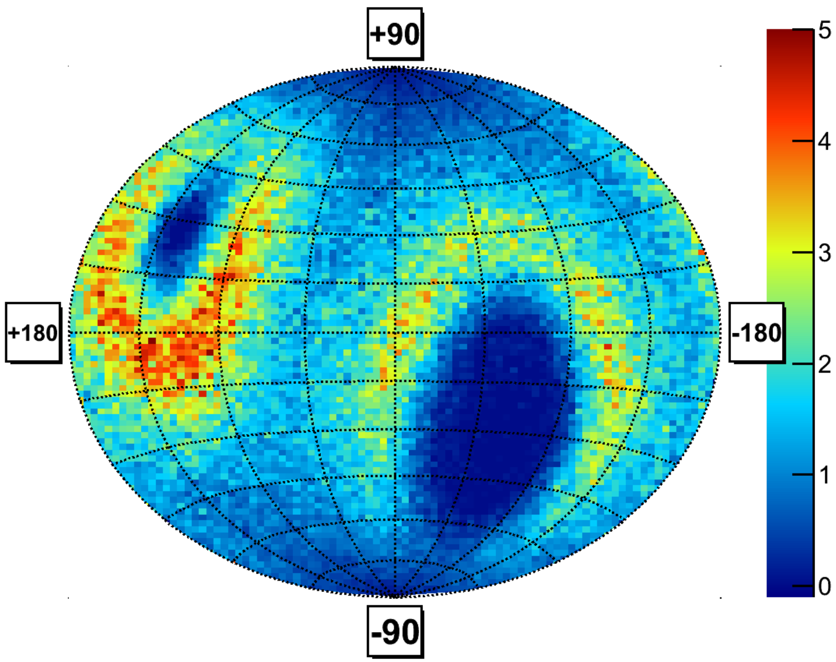




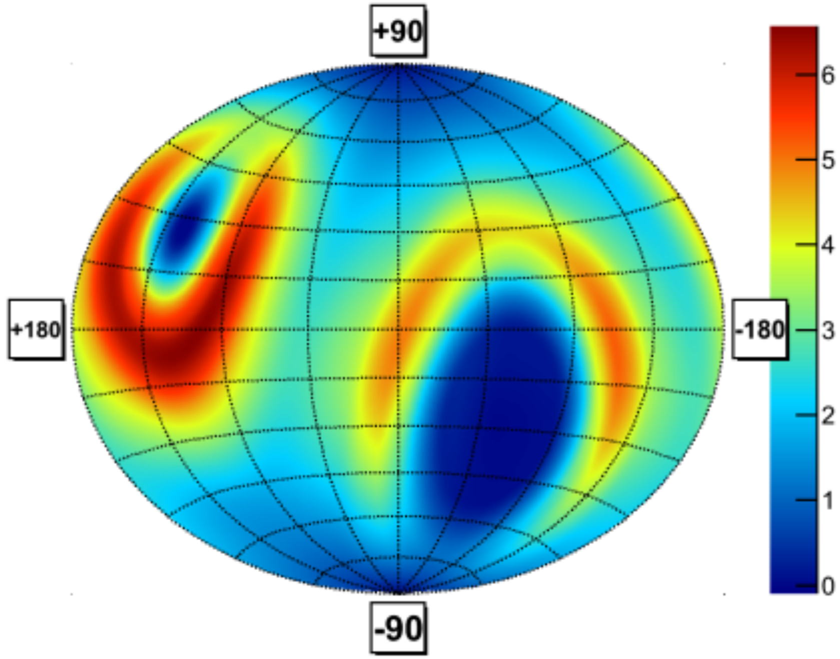
Conclusion: The electron flux and the positron flux are different in their magnitude and energy dependence.

Electron Anisotropy

Measured Distribution



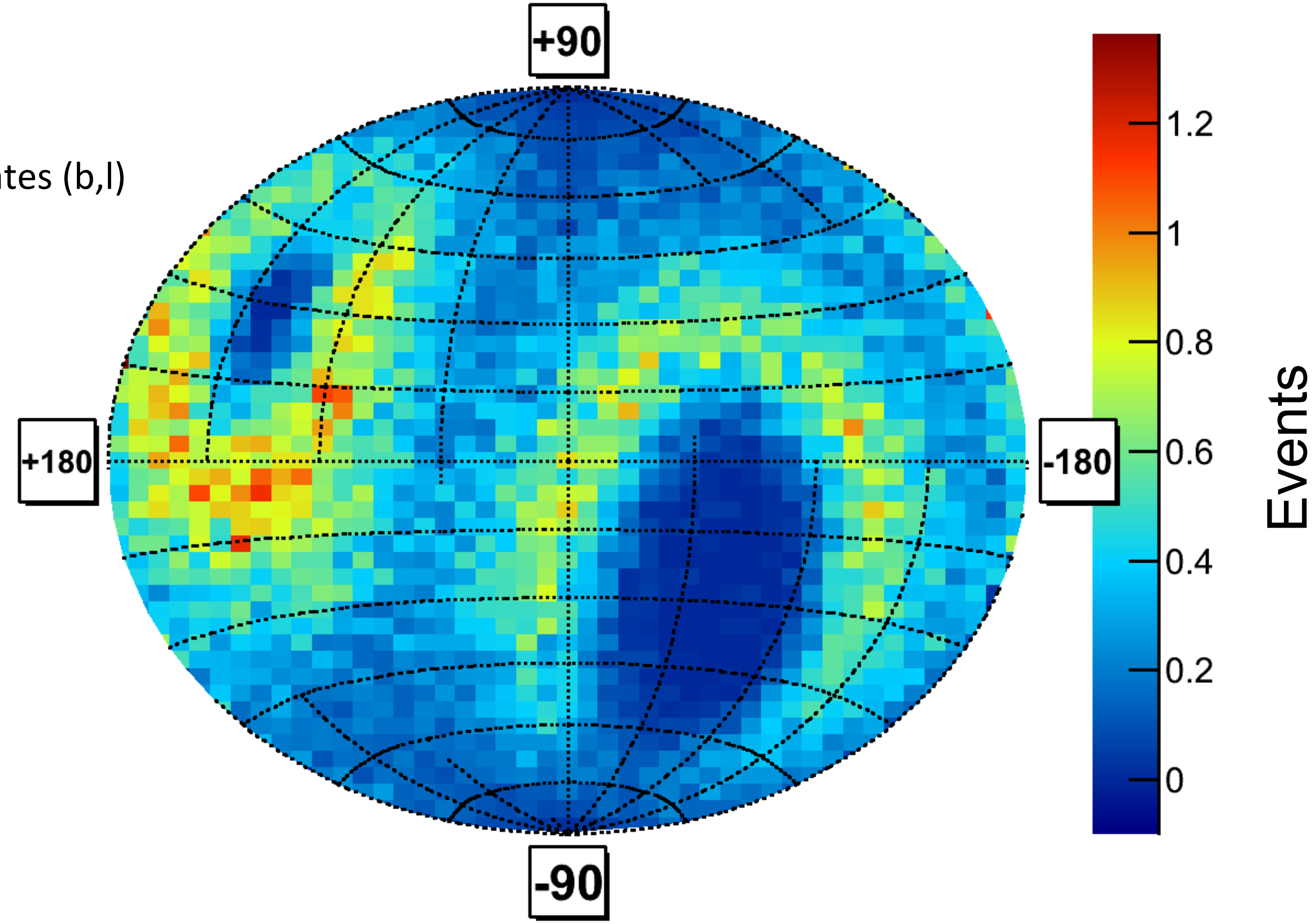
Expected Isotropic Distribution



The incoming direction of electrons above 16 GeV in galactic coordinates yields **$\delta \leq 0.01$ at the 95% confidence level**

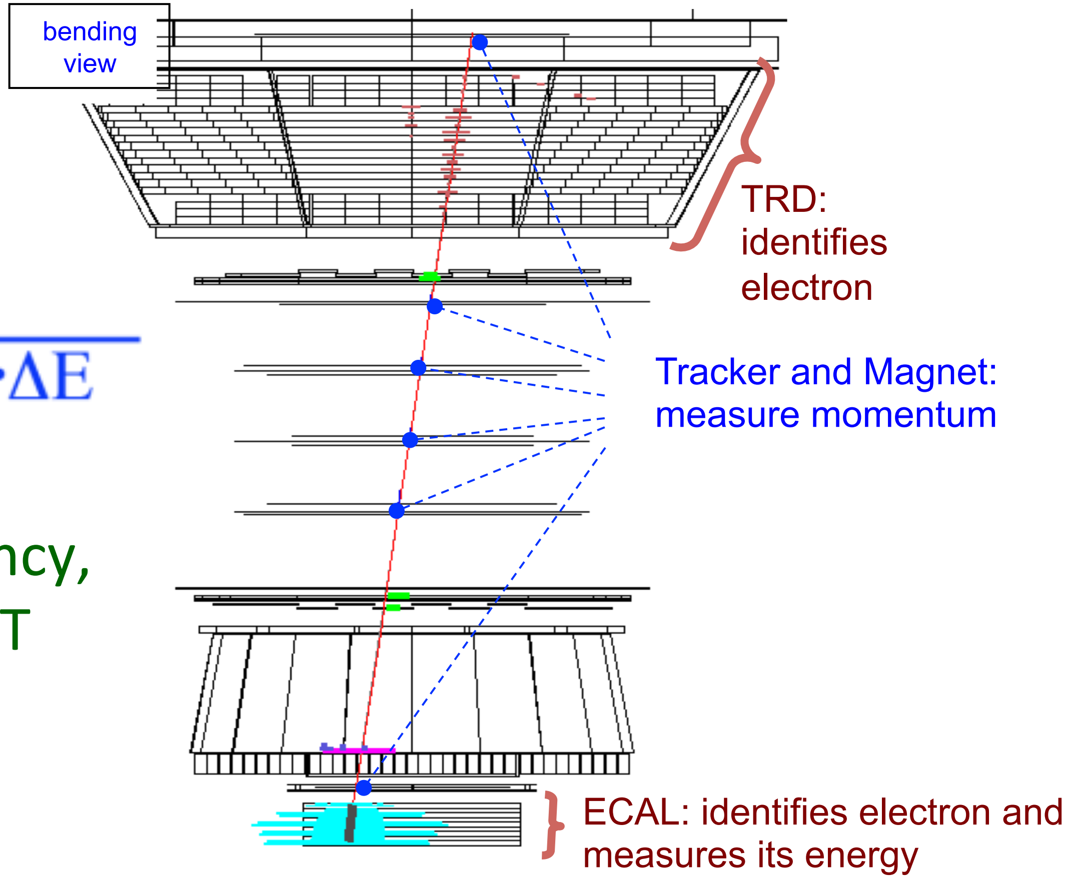
Positron Anisotropy

Galactic
coordinates (b,l)



The incoming direction of positrons above 16 GeV in galactic coordinates yields **δ ≤ 0.03** at the 95% confidence level

Combined ($e^+ + e^-$) Flux: event selection



$$\Phi(E) = \frac{N(E)}{A_{eff}(E) \cdot \varepsilon_{ECAL}(E) \cdot T(E) \cdot \Delta E}$$

ECAL Identification efficiency, ε_{ECAL} for $e^{\pm}$ based on BDT

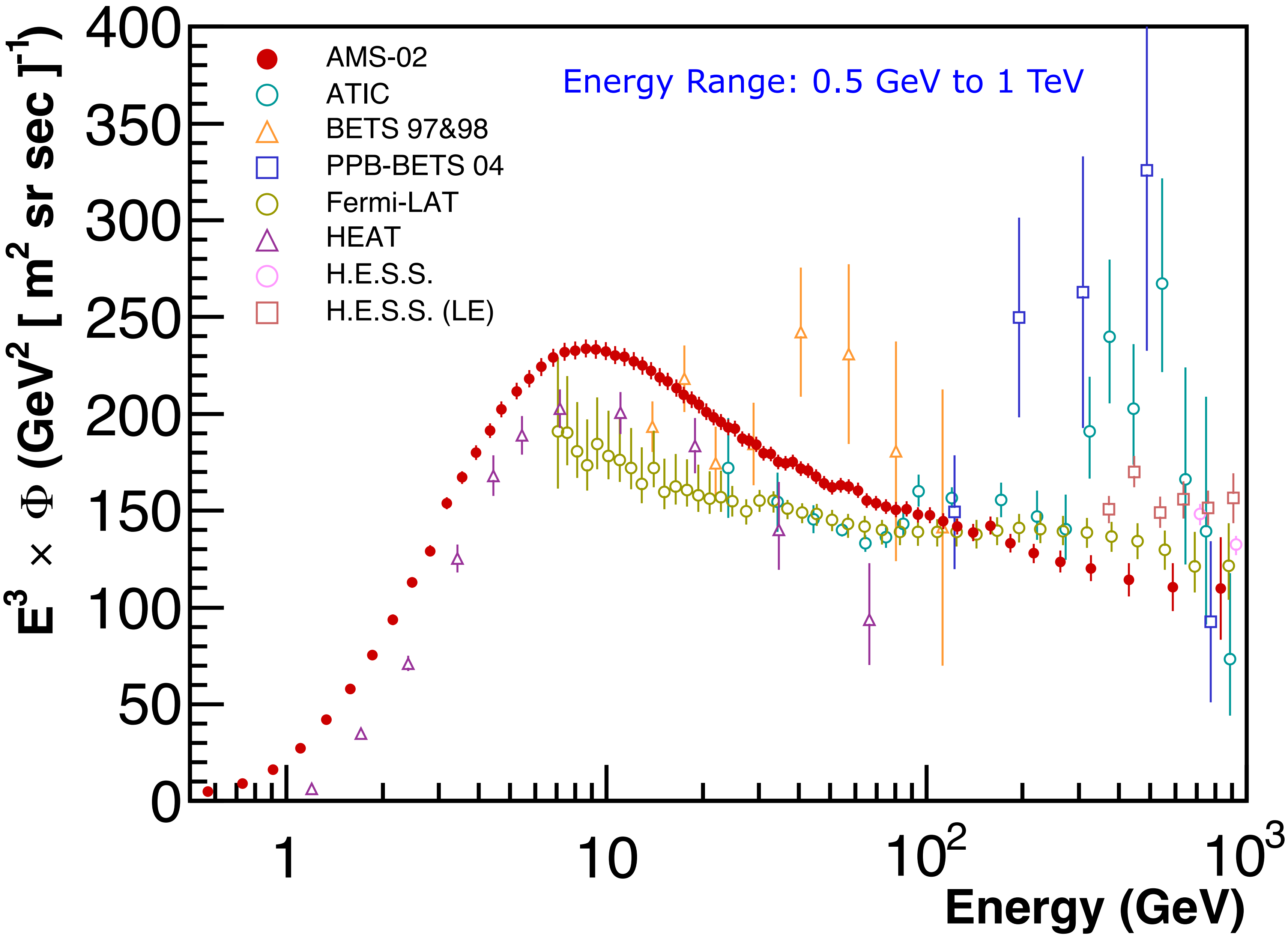
TRD and ECAL are the key detectors in the ($e^+ + e^-$) selection

Independent of charge sign measurement → no charge confusion

High selection efficiency : 70% @ TeV

Small systematics on acceptance: 2% @ TeV

AMS Results: (e^+ + e^-) flux

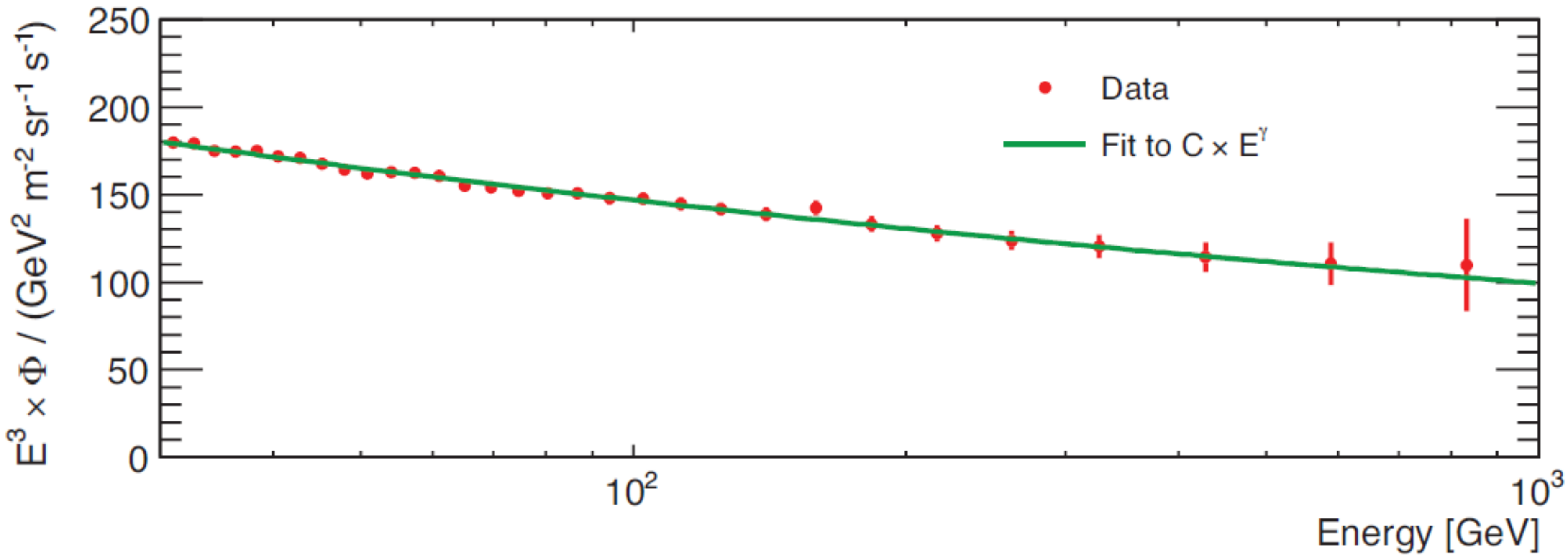


The flux is smooth and reveals new and distinct information.

$$\Phi(e^+ + e^-) = C\,E^{\gamma}$$

$\gamma = -3.170 \pm 0.008$ (stat + syst.) $\pm\ 0.008$ (energy scale)

$E > 30$ GeV



The flux is consistent with a single power law above 30 GeV.

EXAMPLE:

Minimal Model Fit to the data

Diffuse Flux — Source Flux

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

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

Simultaneous fit to

- **a) Positron Fraction from 2GeV**
- **b) Electron + Positron from 2GeV**

- **(γ_{e-} - γ_{e+}), (γ_{e-} - γ_s), C_{e+}, C_{e-}, C_s, E_s are constant**
- **γ_{e-} is energy dependent below ~15 GeV.**

Minimal Model:

Diffuse Flux **Source Flux**

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

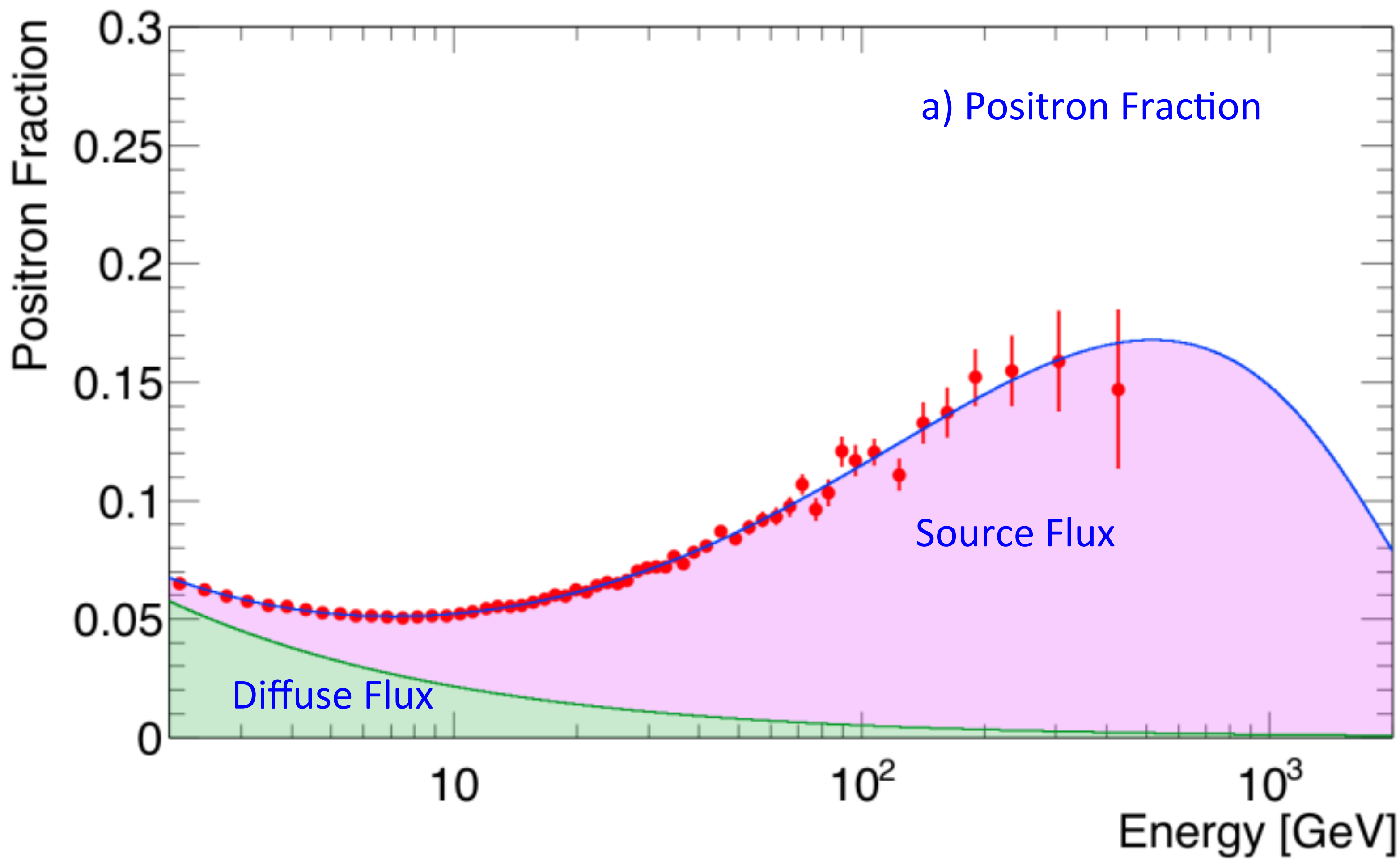
$$\Phi_{e^-} = C_{e^-} E^{-\gamma_{e^-}} + C_s E^{-\gamma_s} e^{-E/E_s}$$

Fit to a) Positron Fraction from 2 GeV determines the relations:

$\gamma_{e-} - \gamma_{e+} = -0.63 \pm 0.06$, $\gamma_{e-} - \gamma_s = 0.66 \pm 0.05$,

$C_{e+} / C_{e-} = 0.095 \pm 0.003$, $C_s / C_{e-} = 0.008 \pm 0.001$

$1/E_s = 1.3 \pm 0.6\ \mathrm{TeV}^{-1}$



Minimal Model:

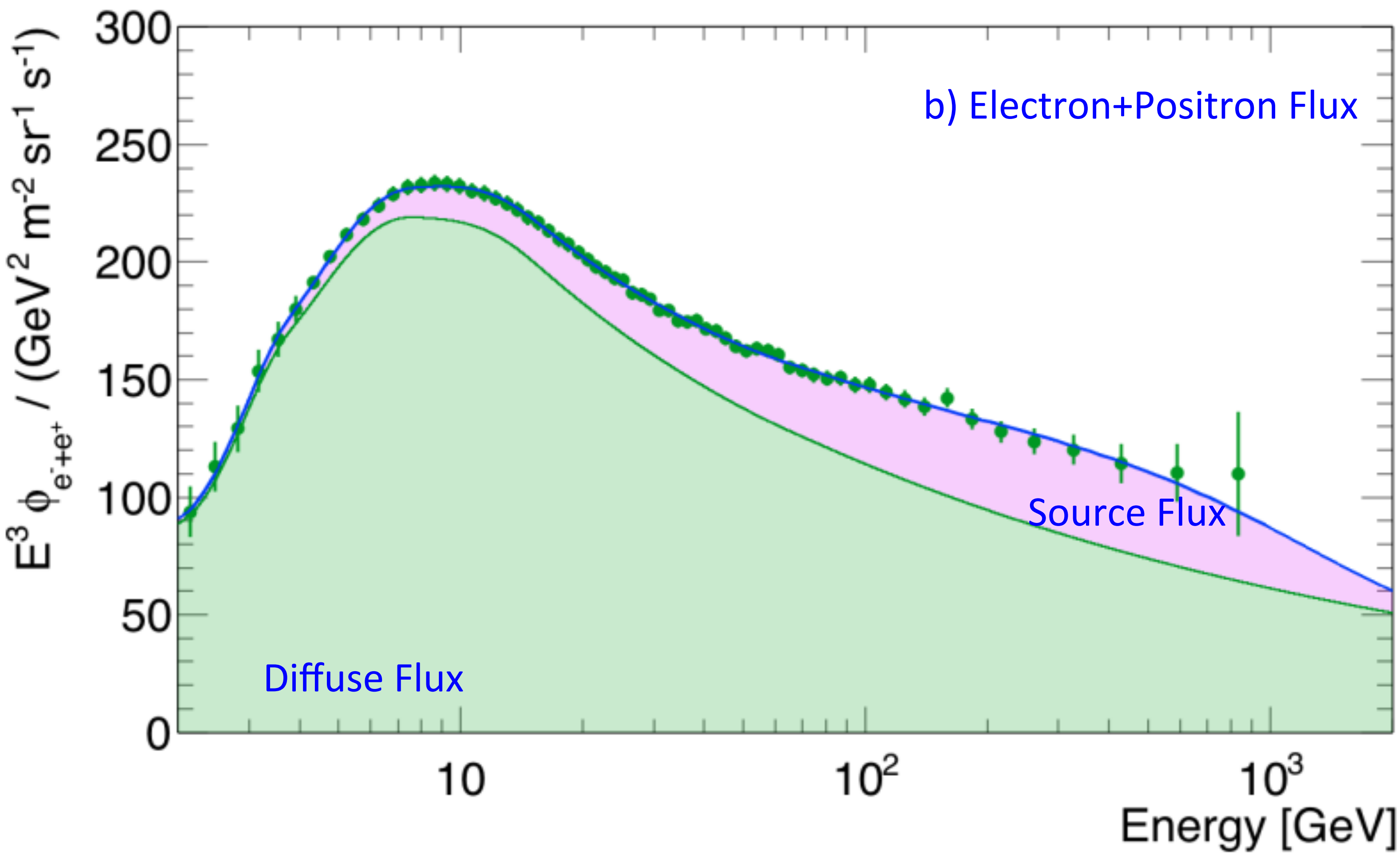
Diffuse Flux **Source Flux**

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

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

Fit to b) Electron + Positron Flux from 2 GeV determines γ_{e-} and C_{e-}

γ_{e-} is energy dependent below ~15 GeV



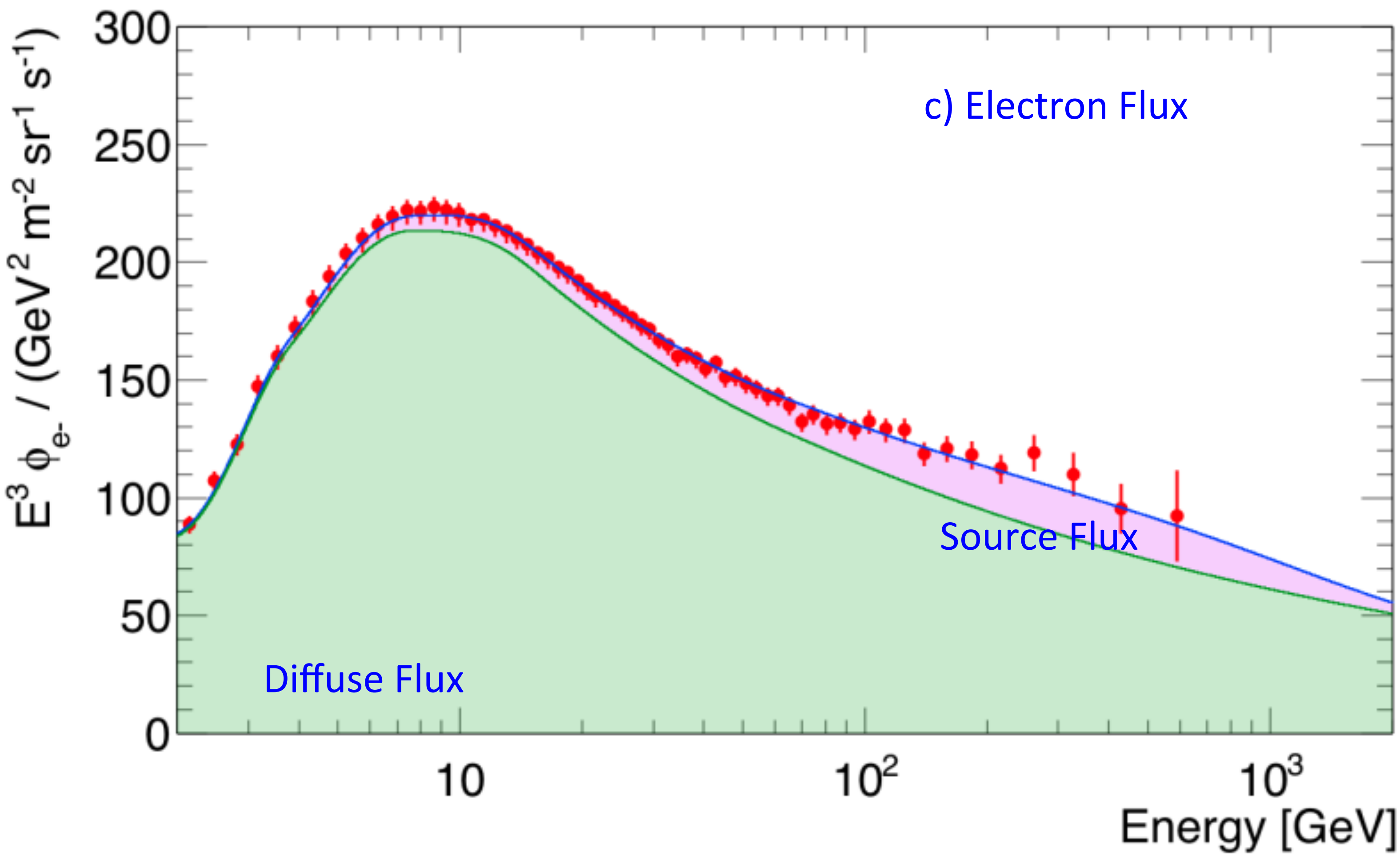
Minimal Model:

Diffuse Flux **Source Flux**

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

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

Prediction from fit it to a) Positron Fraction and b) Electron + Positron Flux



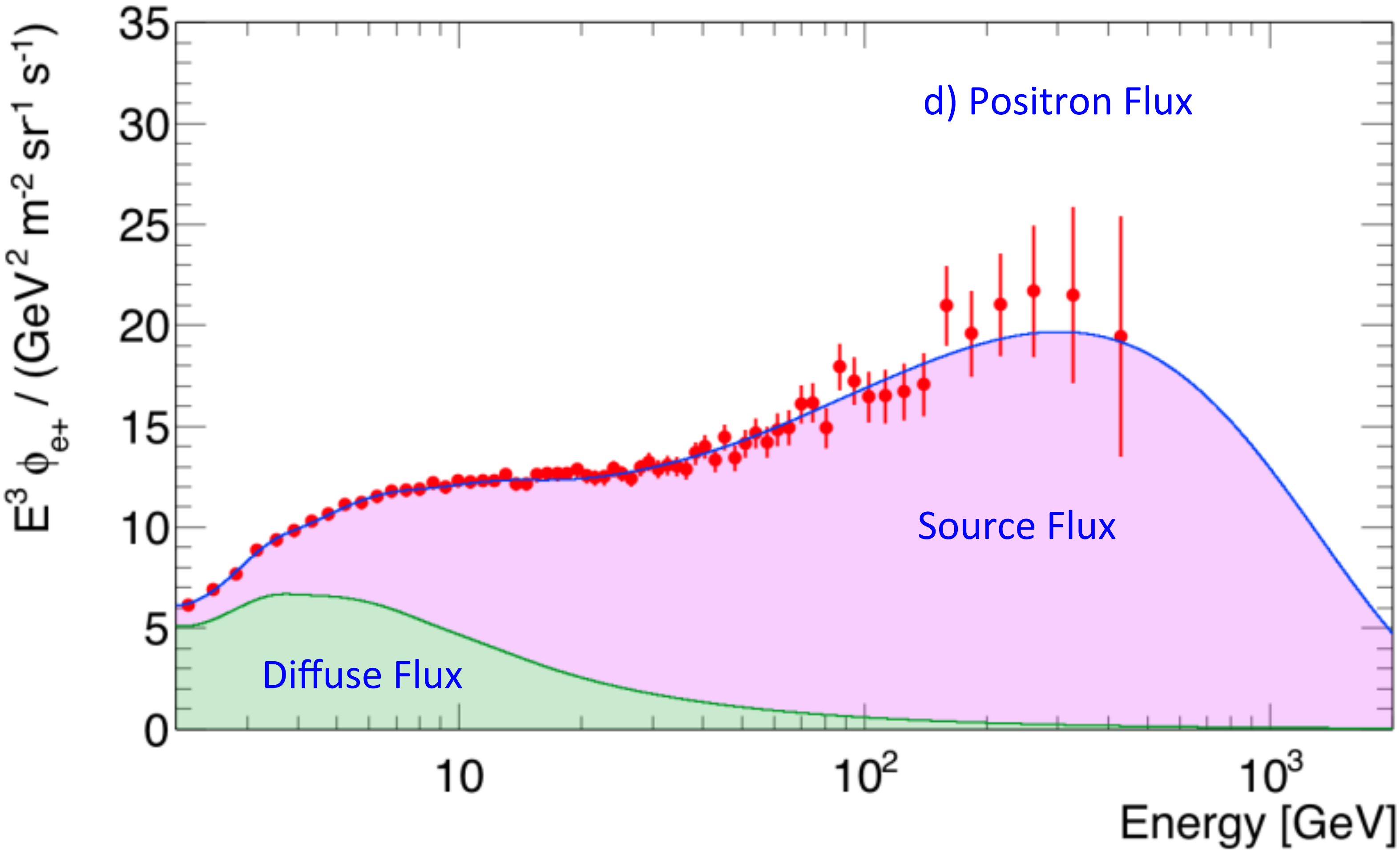
Minimal Model:

Diffuse Flux **Source Flux**

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

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

Prediction from fit it to a) Positron Fraction and b) Electron + Positron Flux



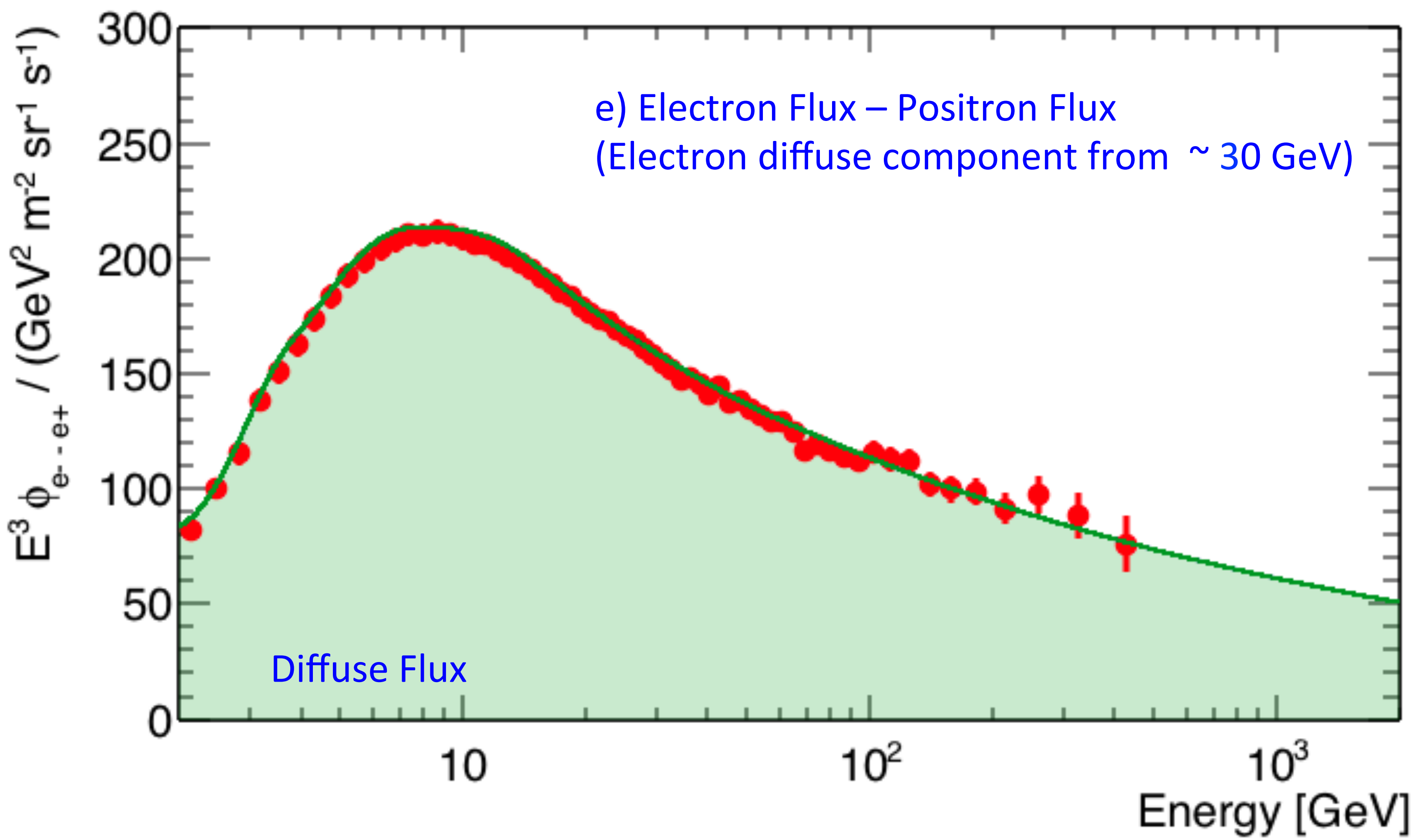
Minimal Model:

Diffuse Flux / **Source Flux**

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

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

Prediction from fit it to a) Positron Fraction and b) Electron + Positron Flux



Conclusions:

- AMS detector is working smoothly for 40 months. 56 billion events have been collected.
- Electron and positron flux are measured with few percent uncertainty up to 1 TeV.
- The positron fraction shows that the energy dependence come to a maximum at 275± 32 GeV, and is consistent with a source of ~1 TeV mass.
- Both electron and positron flux seems to have a break of the power law distribution at ~30 GeV.
- More data is needed to extend the positron fraction measurement to ~1 TeV energy, so that the exact nature of the source can be determined.

The $(e^+ + e^-)$ flux before AMS