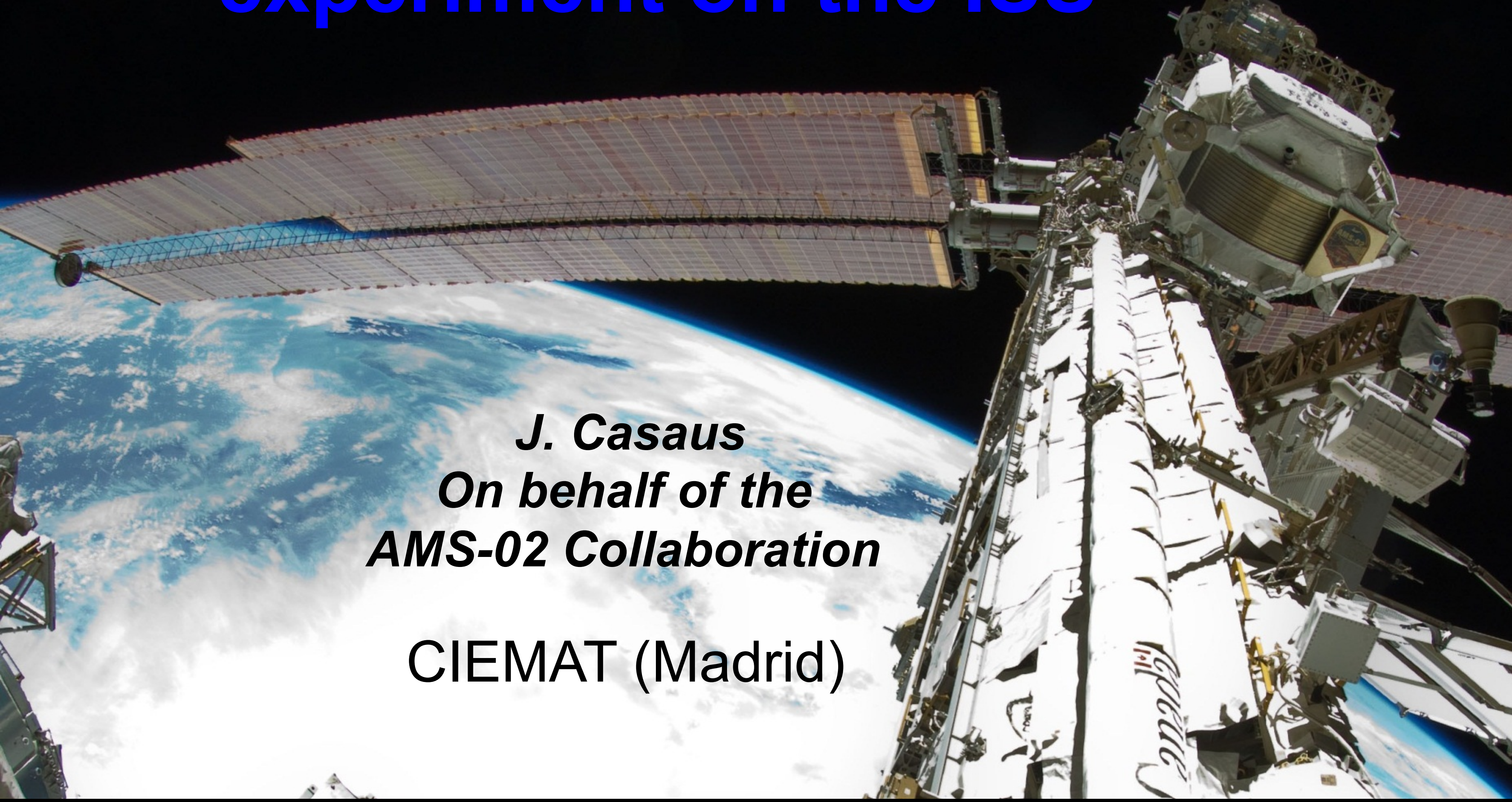
First results of the AMS-02 experiment on the ISS



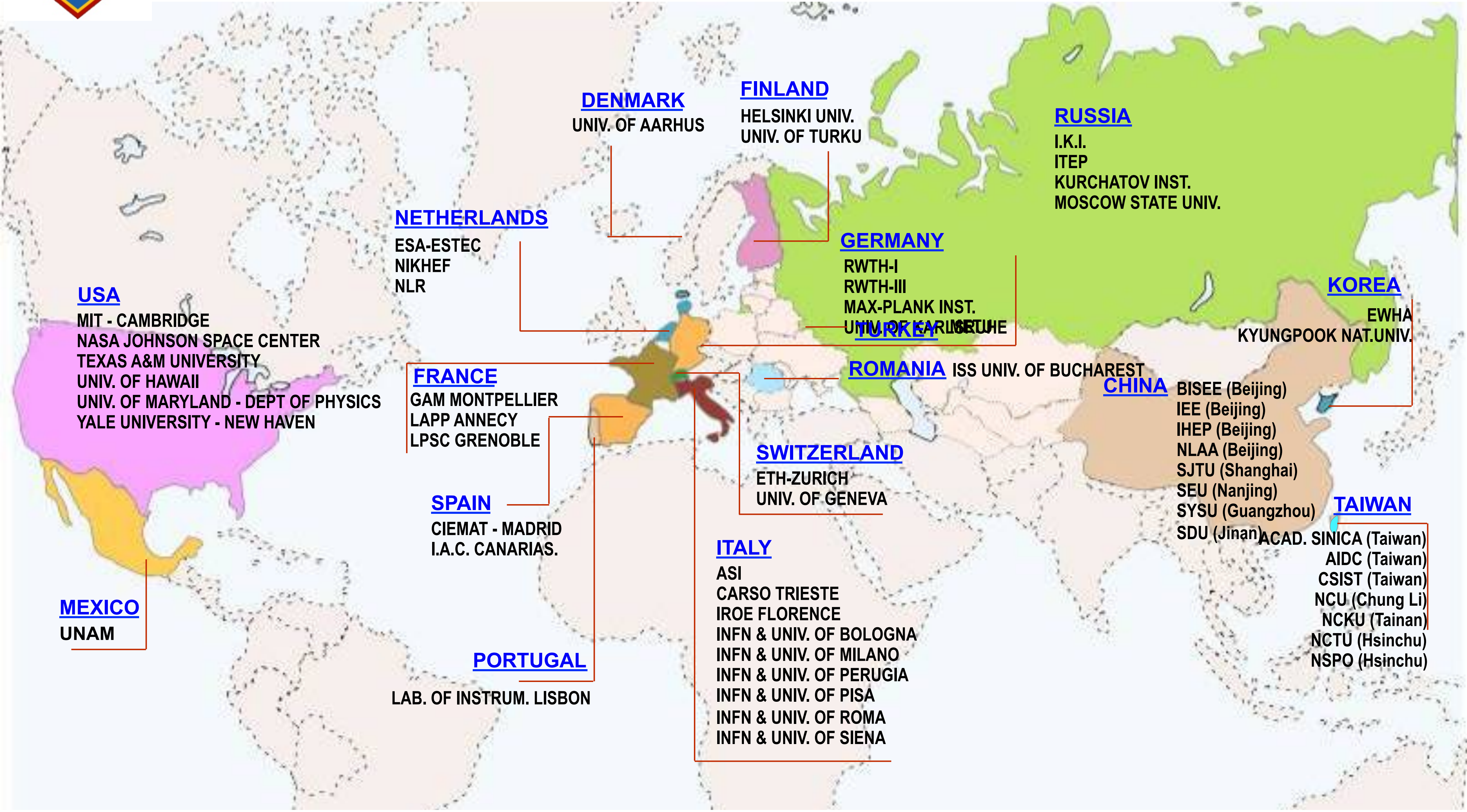
J. Casaus
On behalf of the
AMS-02 Collaboration

CIEMAT (Madrid)

CRA 2013, WIPAC, 26-28 Sep 2013

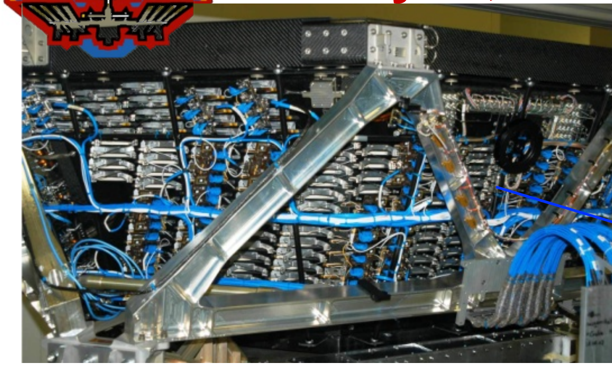
AMS International Collaboration

16 Countries, 60 Institutes
600 Physicists



AMS: A TeV precision, multipurpose spectrometer in space

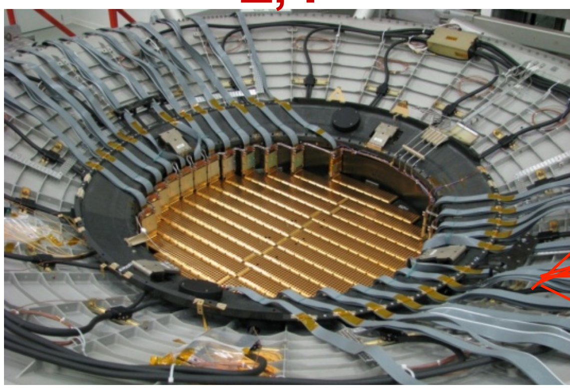
TRD
Identify e^+, e^-

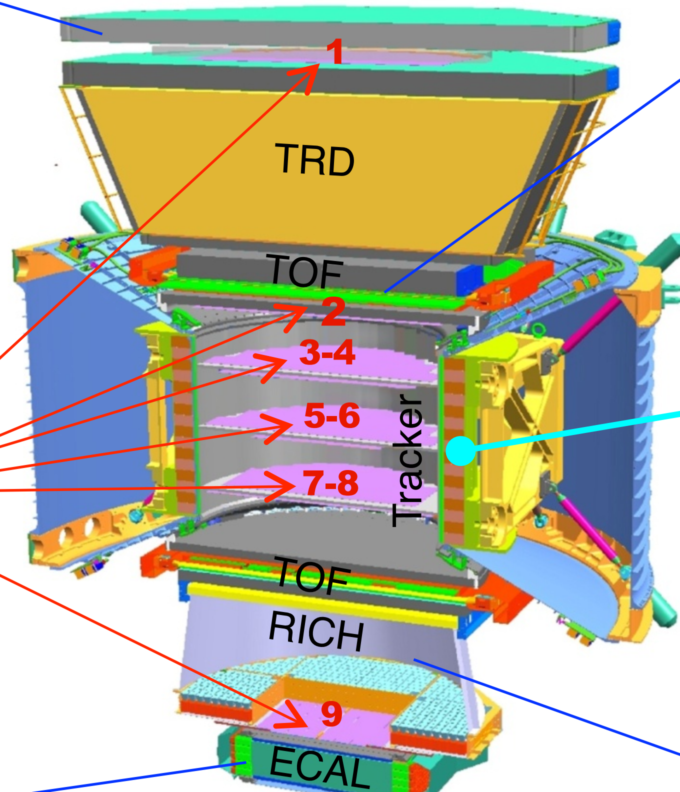


Particles and nuclei are defined by their charge (**Z**) and energy (**E ~ P**)

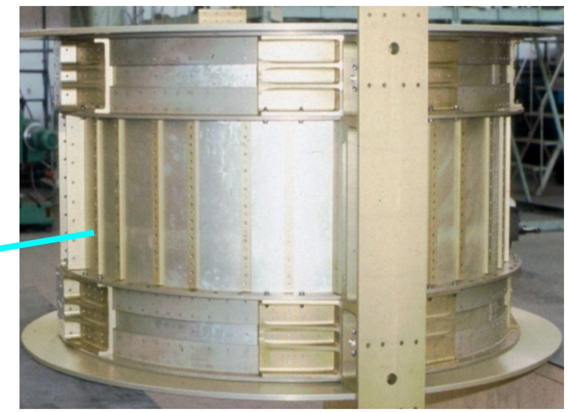
TOF
Z, E

Silicon Tracker
Z, P

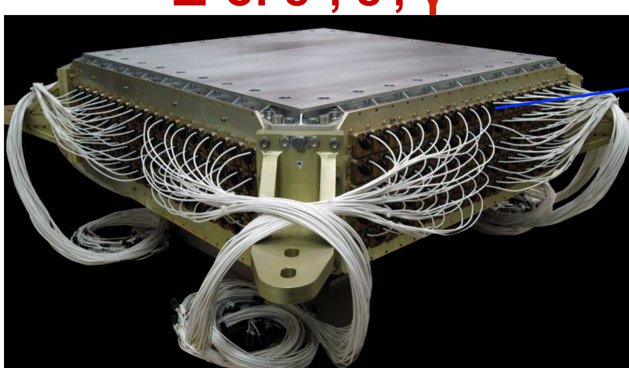




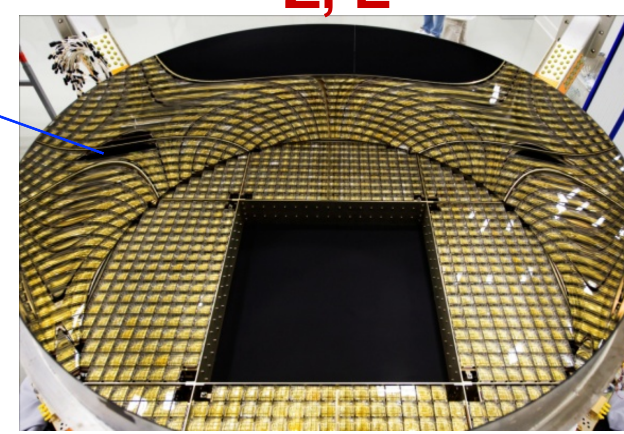
Magnet
±Z



ECAL
E of e^+, e^-, γ



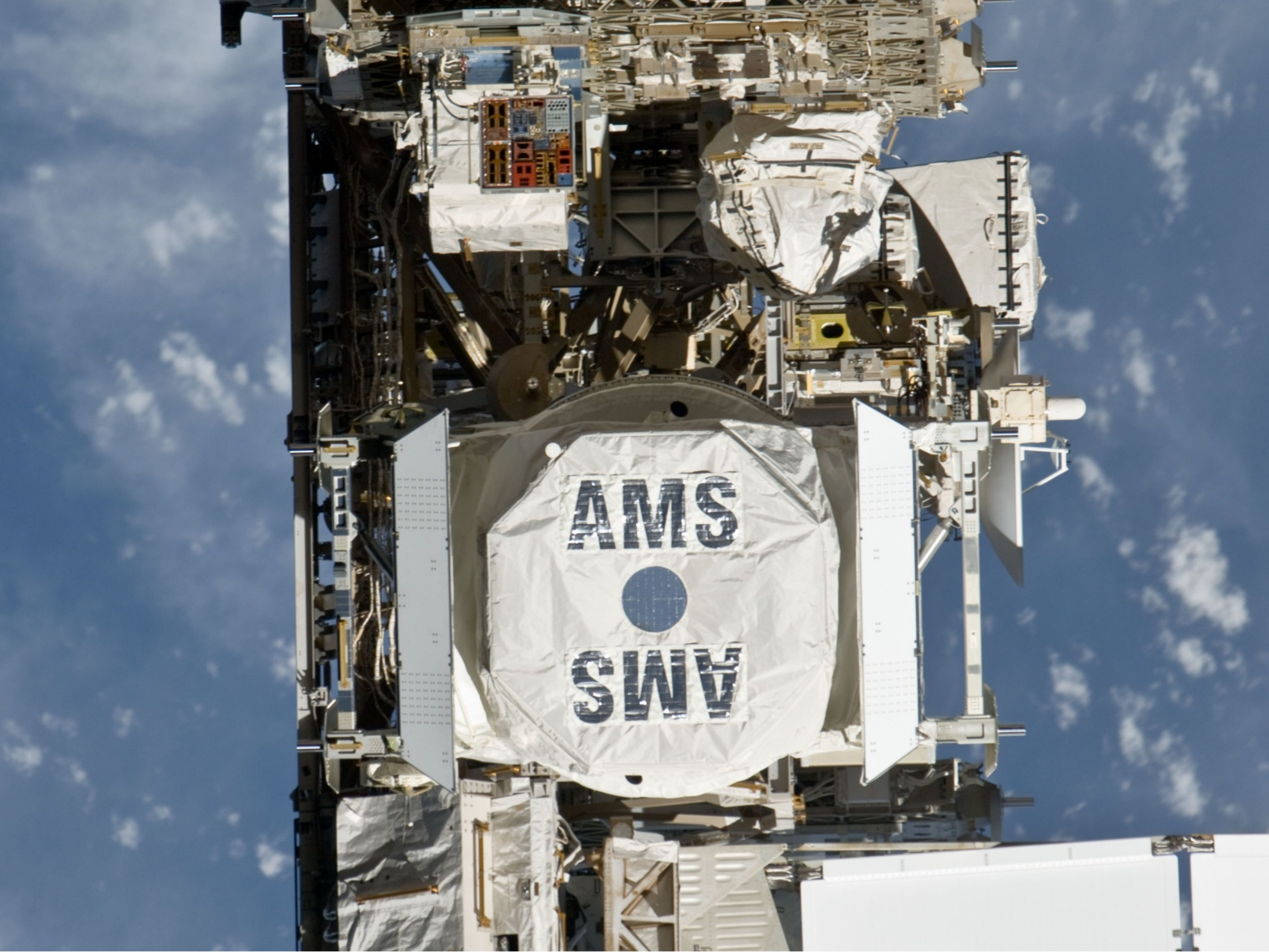
RICH
Z, E



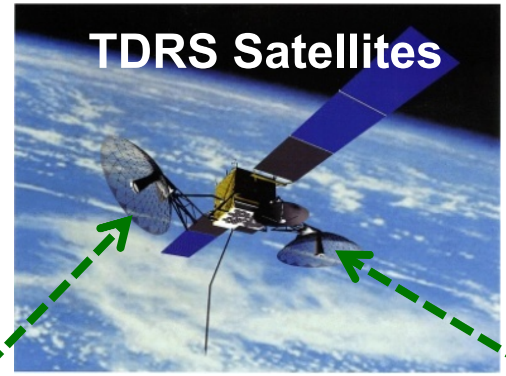
***Z, P** are measured independently by the Tracker, RICH, TOF and ECAL*

5m x 4m x 3m
7.5 tons


May 16, 2011



AMS
AMS

AMS Operations



White Sands, NM

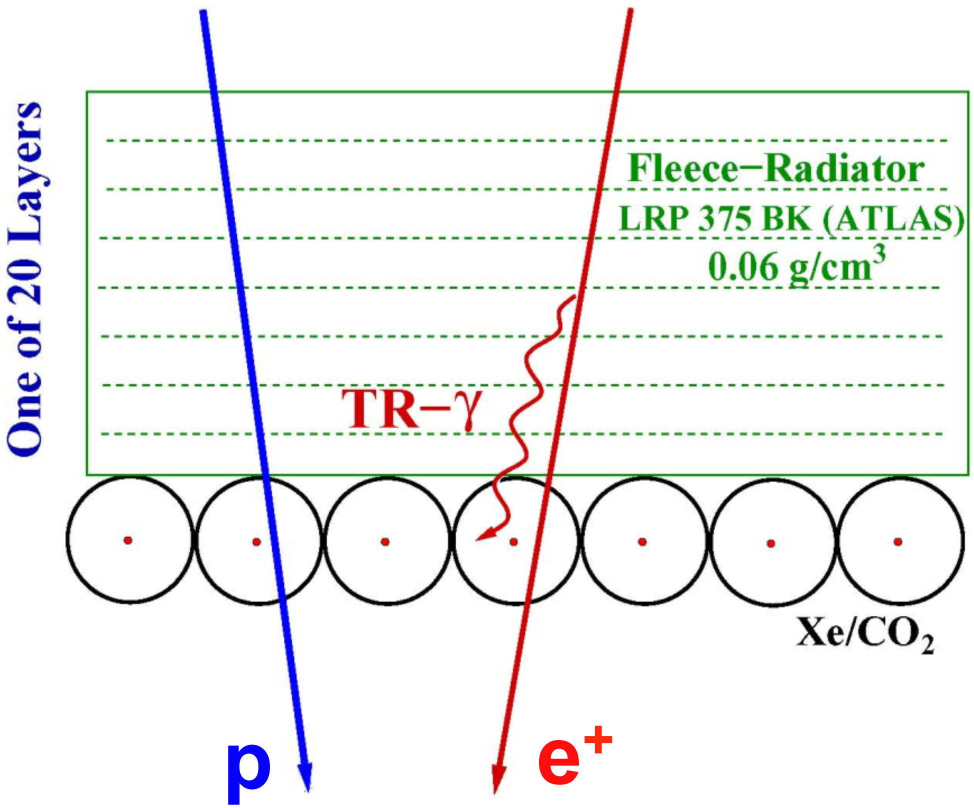
24 hours
x 365 days
x 10-20 years

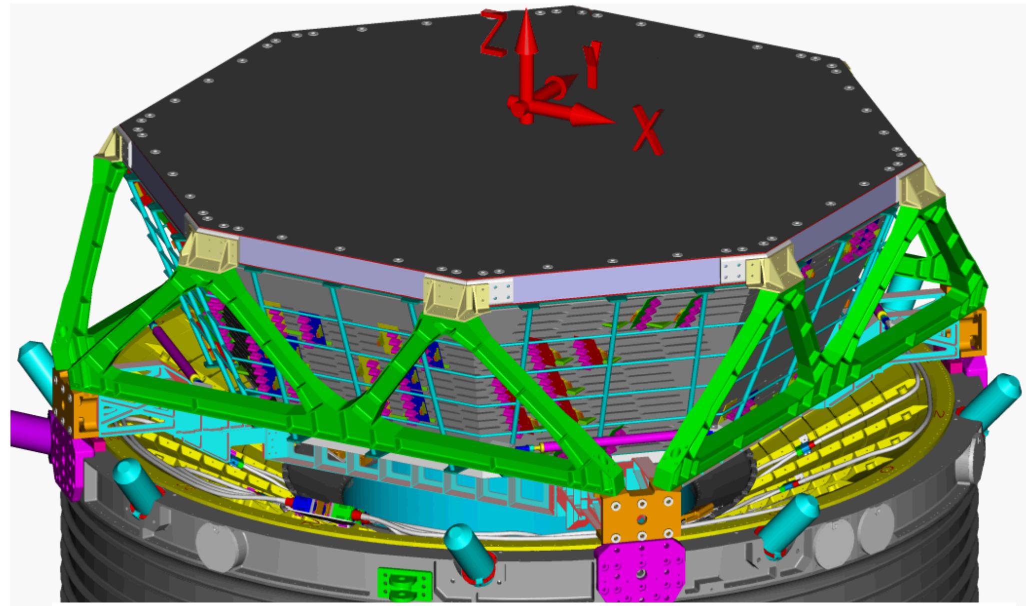
300,000 channels at 2 KHz,
650 onboard processors

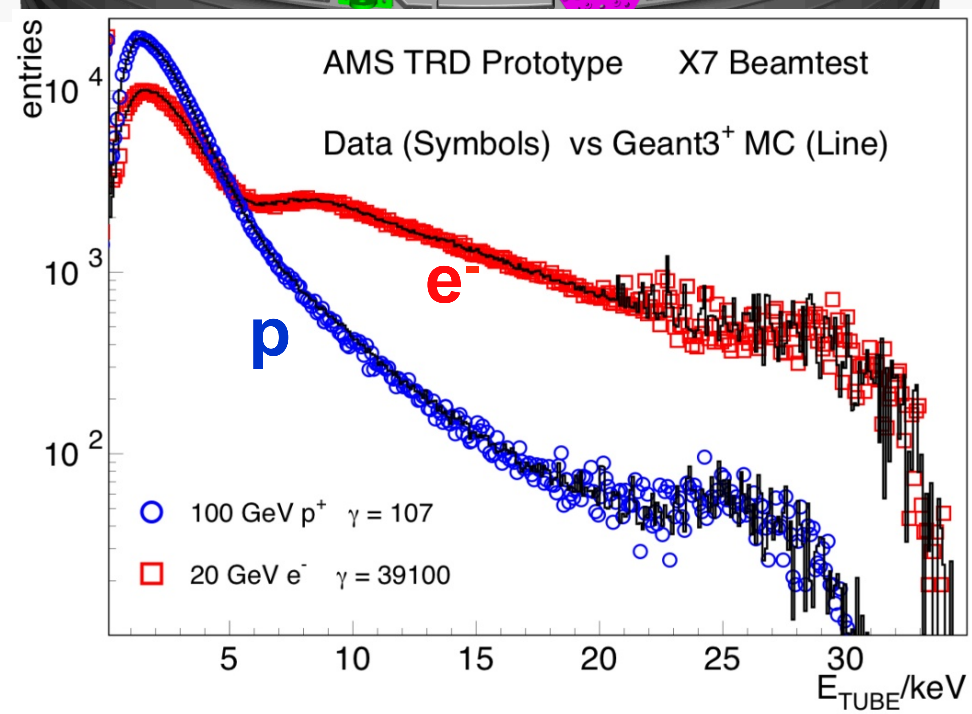
1118 temperature sensors,
298 heaters

Transition Radiation Detector.

Identify e^+, reject P





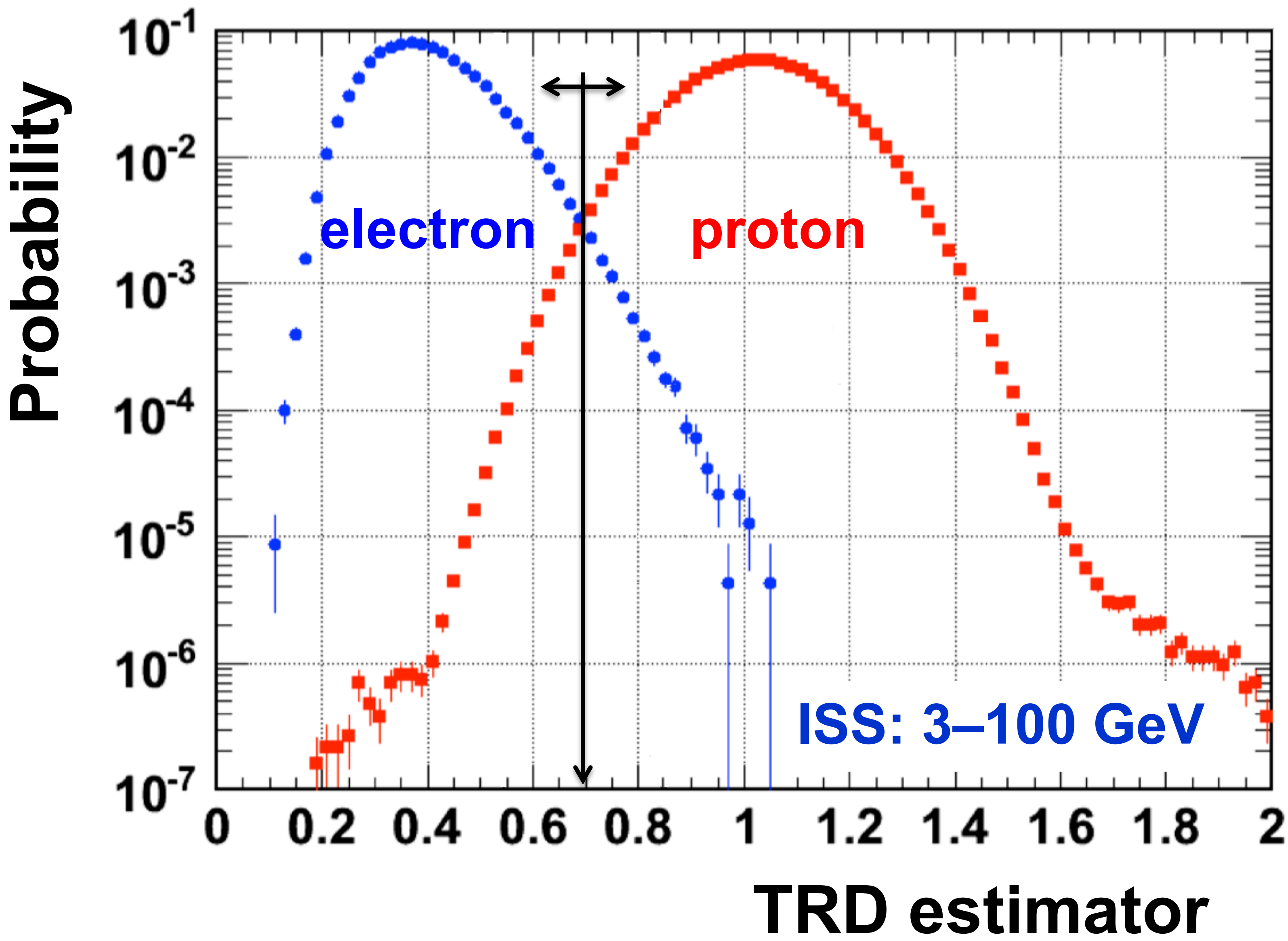


Leak rate: $CO_2 \approx 5\ \mu g/s$

Storage: 5 kg, >20 years lifetime

TRD performance on ISS

TRD estimator = $-\ln(P_e/(P_e+P_p))$

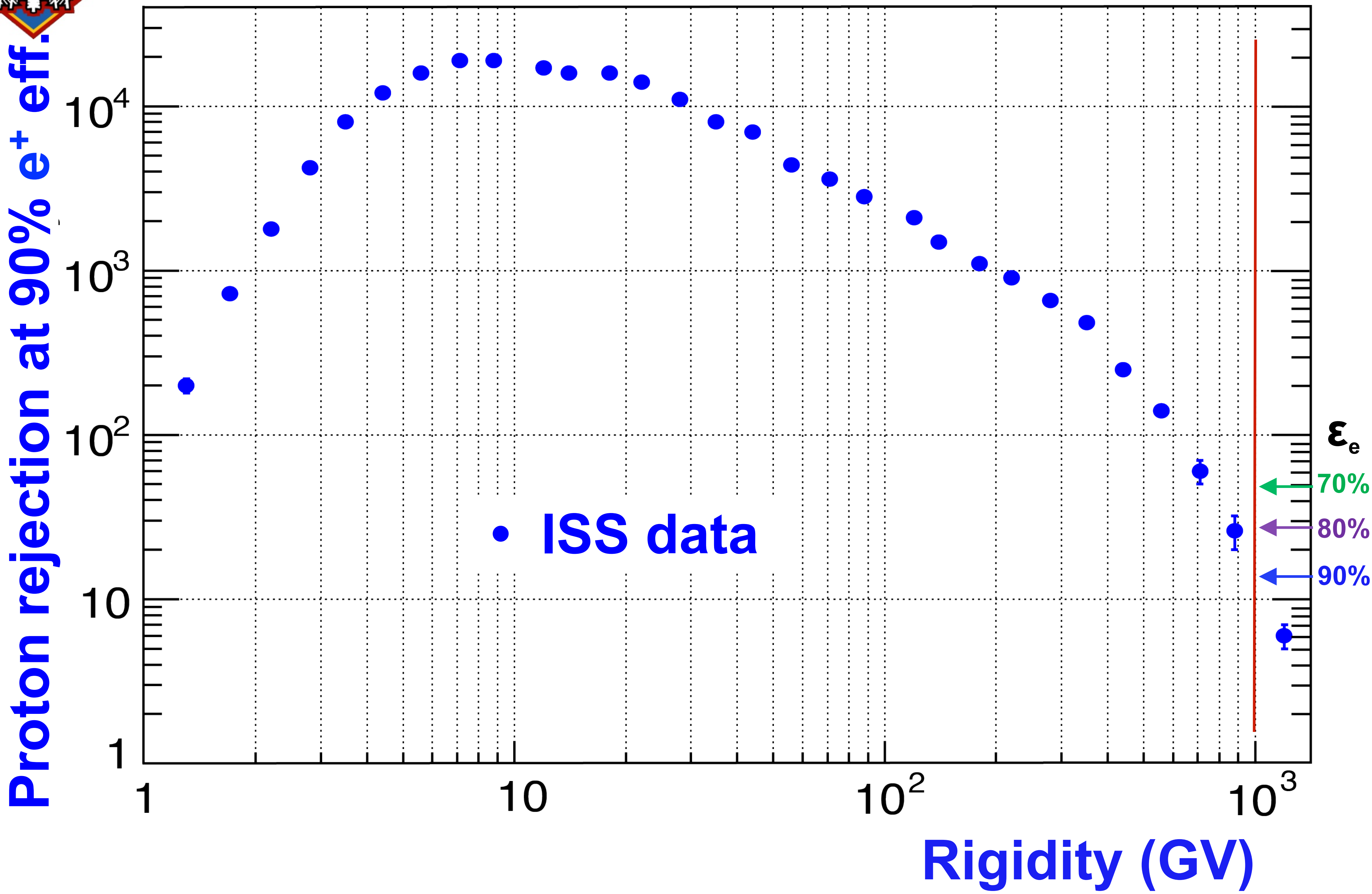


Normalized probabilities P_e and P_p

$$P_e = \sqrt[n]{\prod_i^n P_e^{(i)}(A)}$$

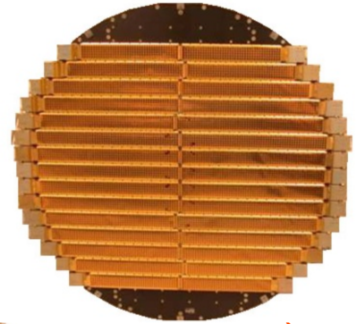
$$P_p = \sqrt[n]{\prod_i^n P_p^{(i)}(A)}$$

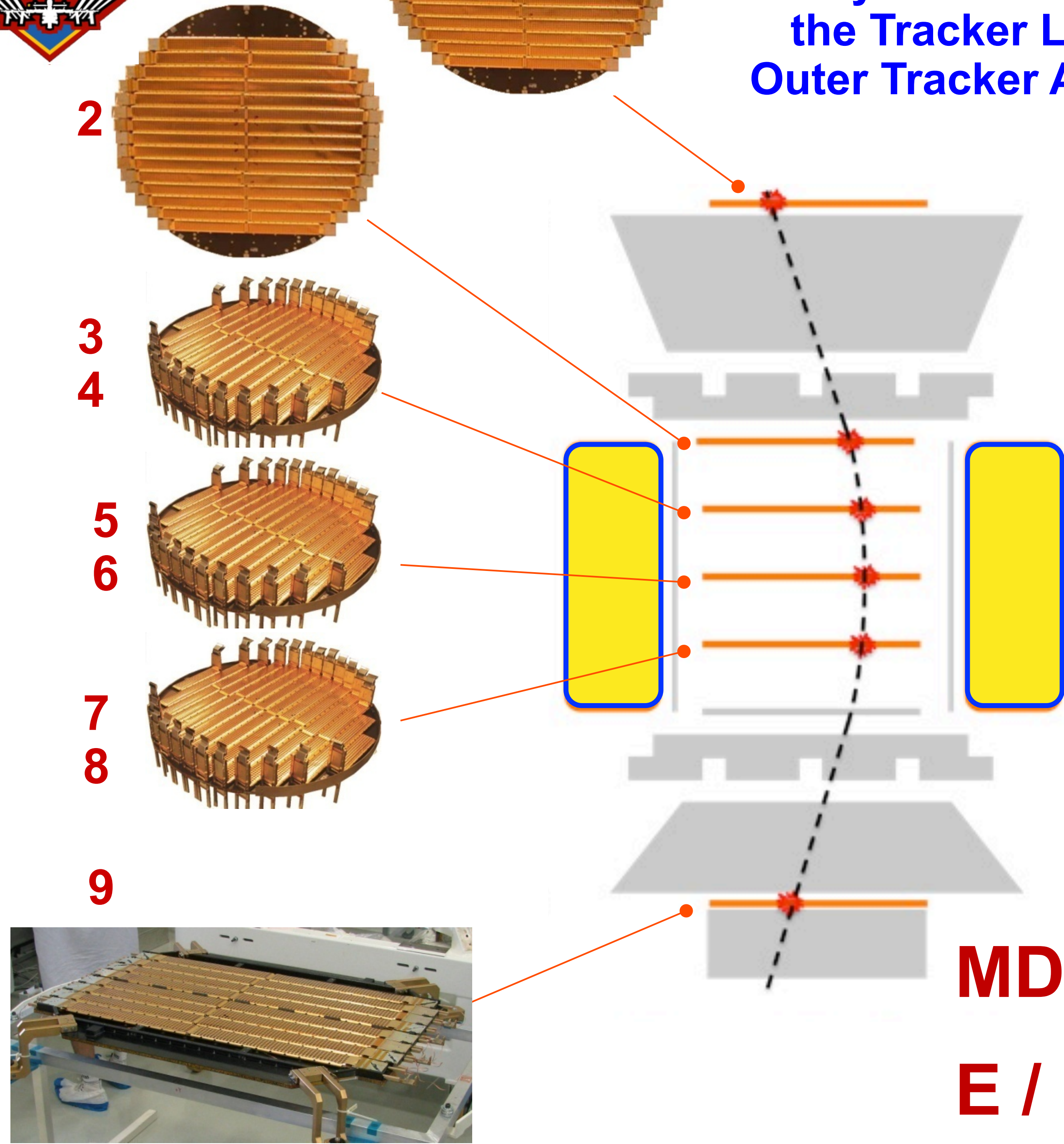
TRD performance on ISS

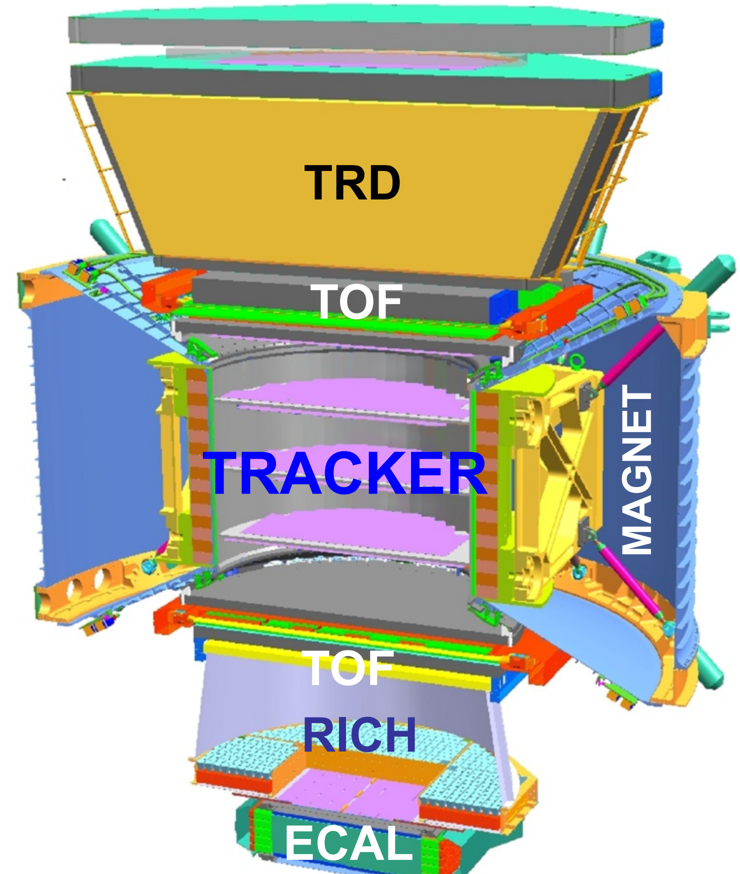


Tracker: The coordinate resolution is 10 μ

Stabilty of the Inner Tracker is monitored by the Tracker Laser Alignment System.
Outer Tracker Alignment via cosmic rays



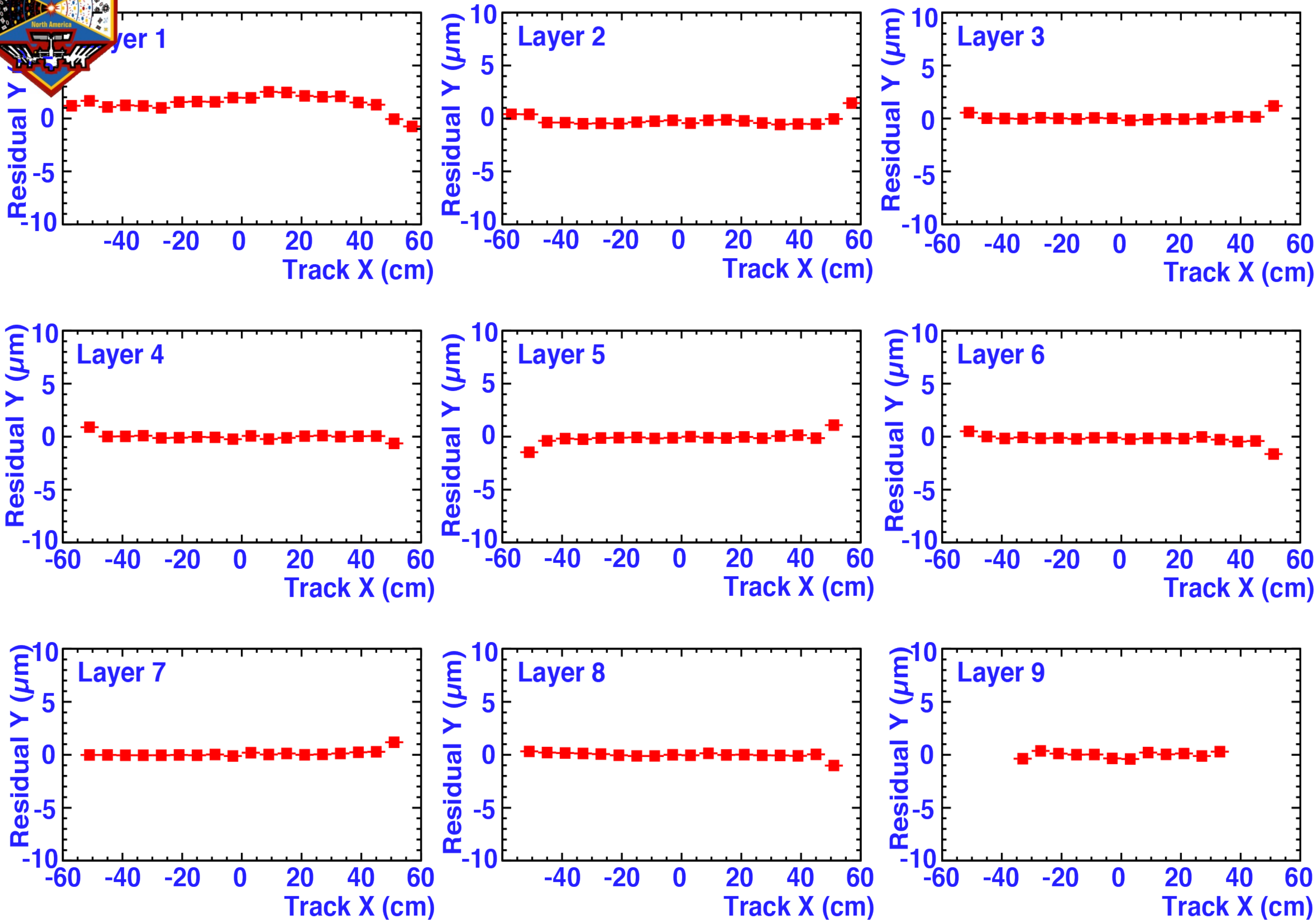




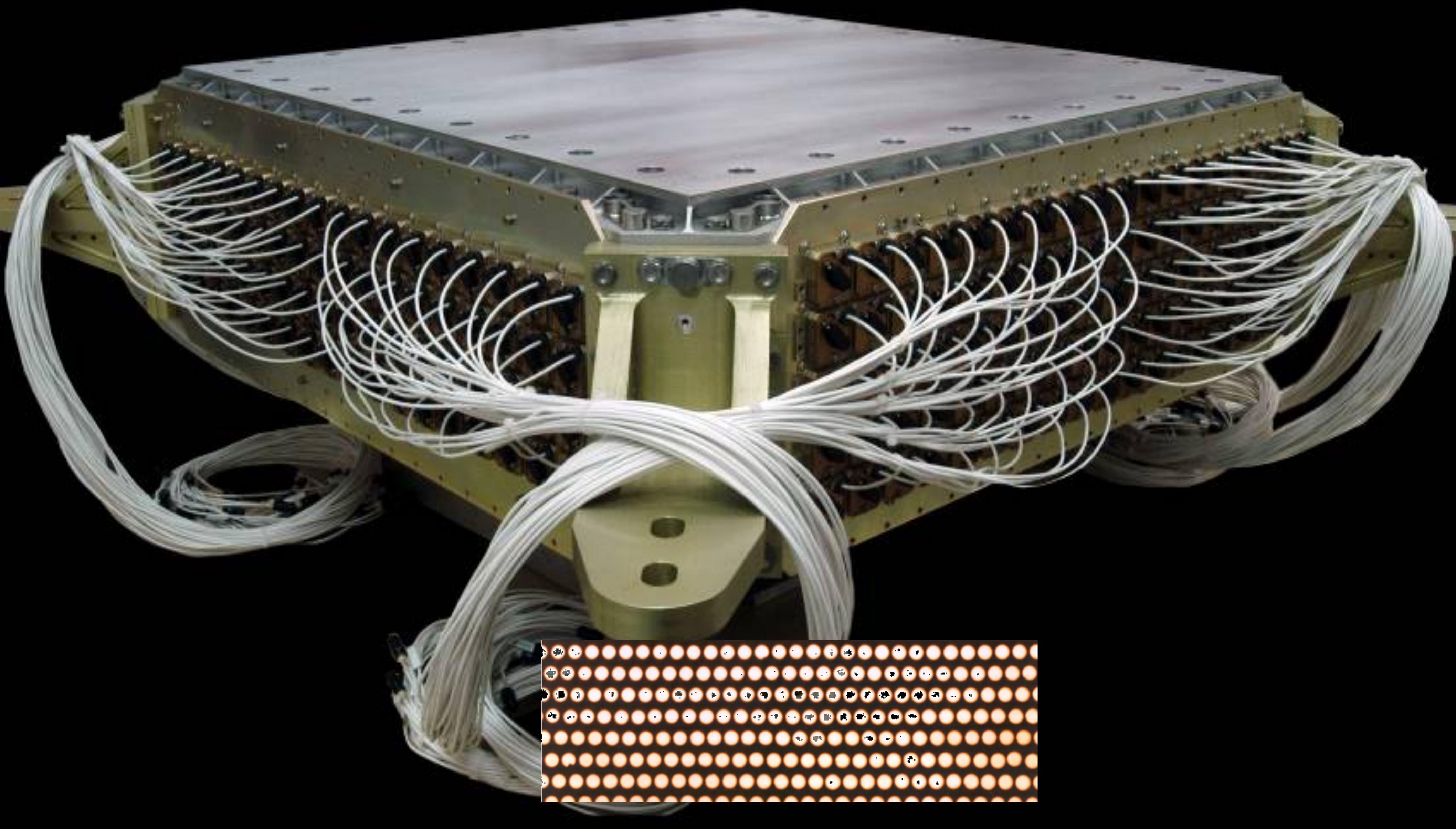
MDR ~2.0 TV

E / |p| matching

Alignment accuracy of the 9 Tracker layers over 18 months

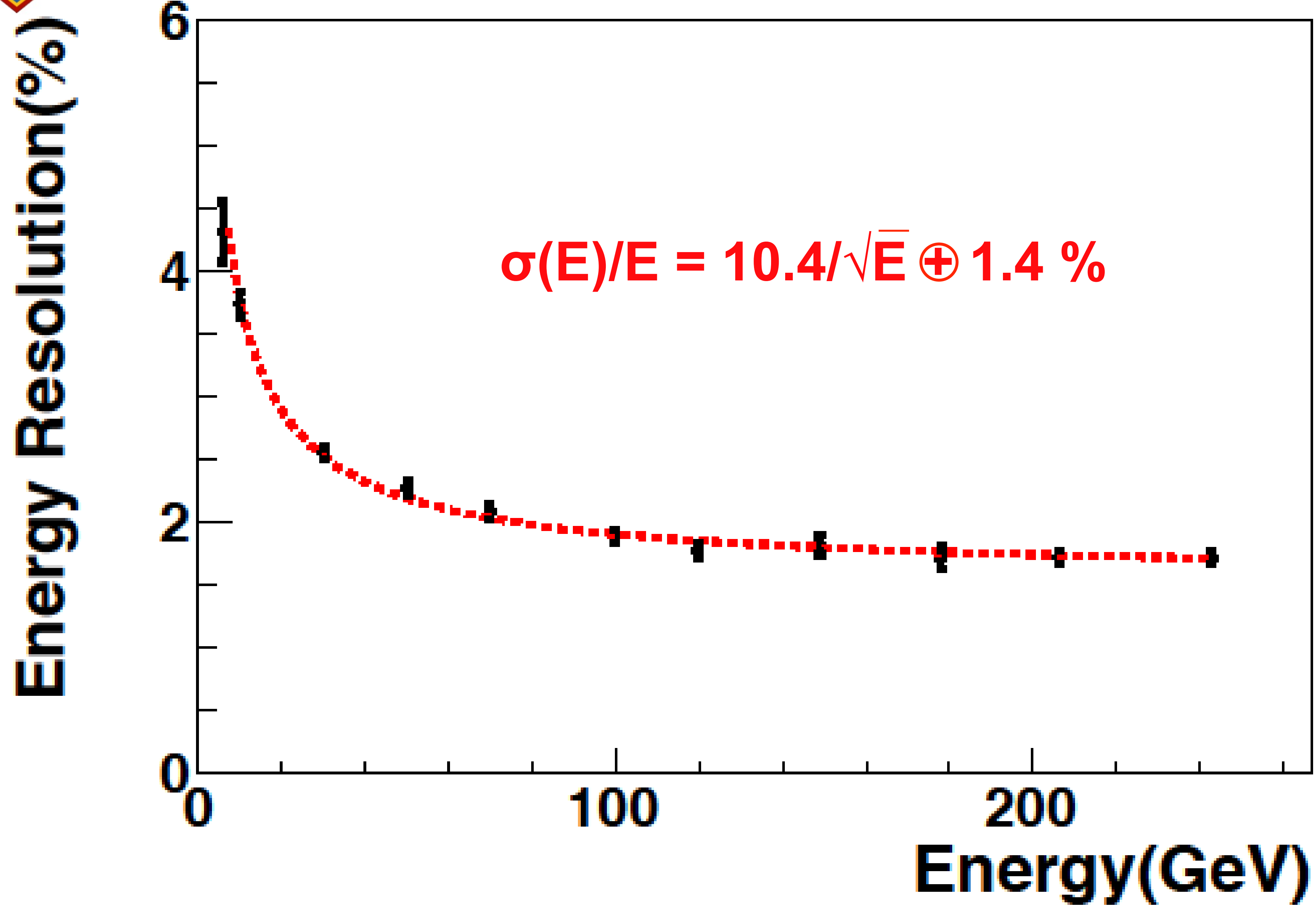


Calorimeter (ECAL)



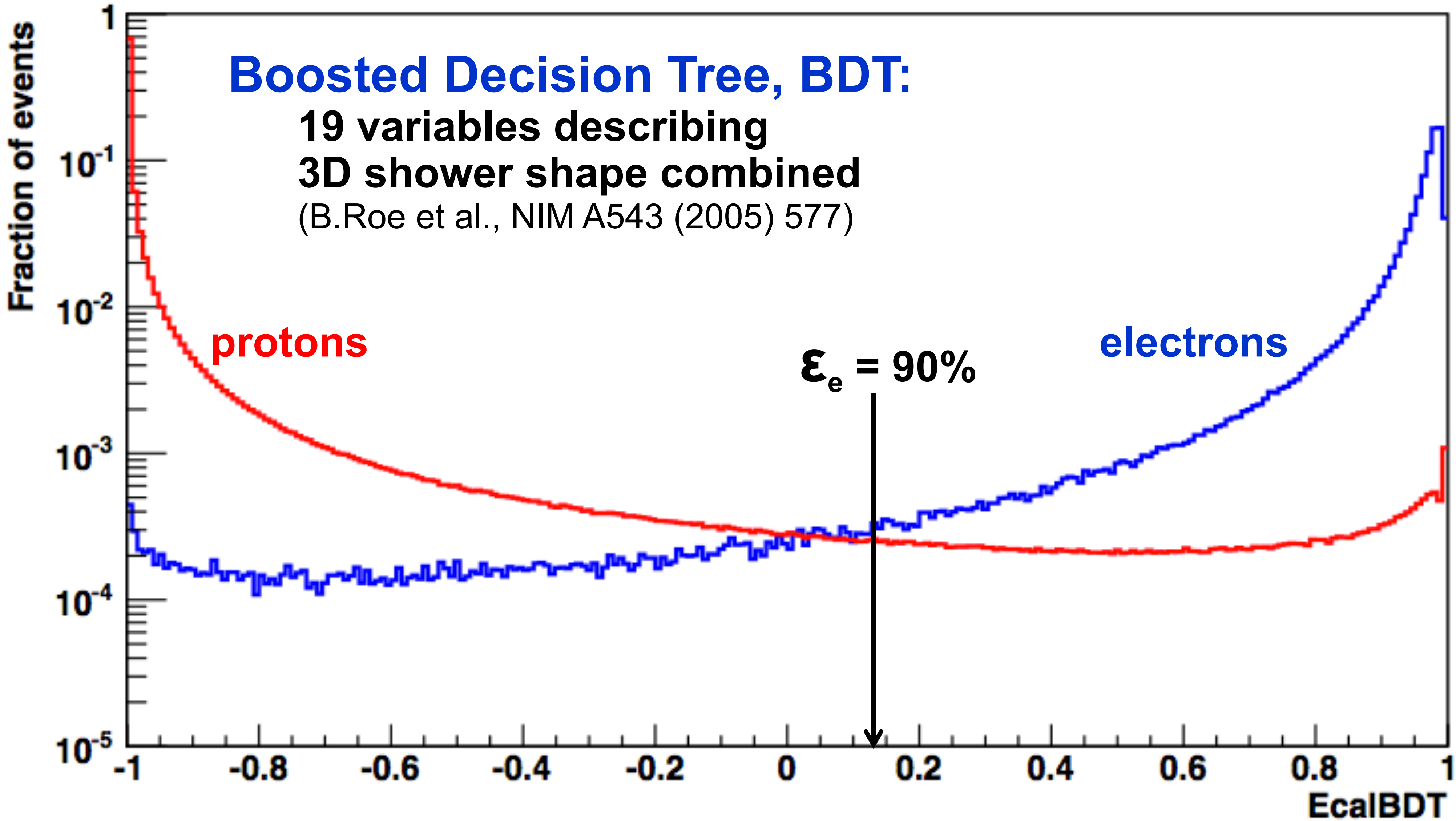
50,000 fibers, $\phi = 1$mm, distributed uniformly inside 600 kg of lead which provides a precision, 3-dimensional, $17X_0$ measurement of the directions and energies of light rays and electrons up to 1 TeV

ECAL Performance

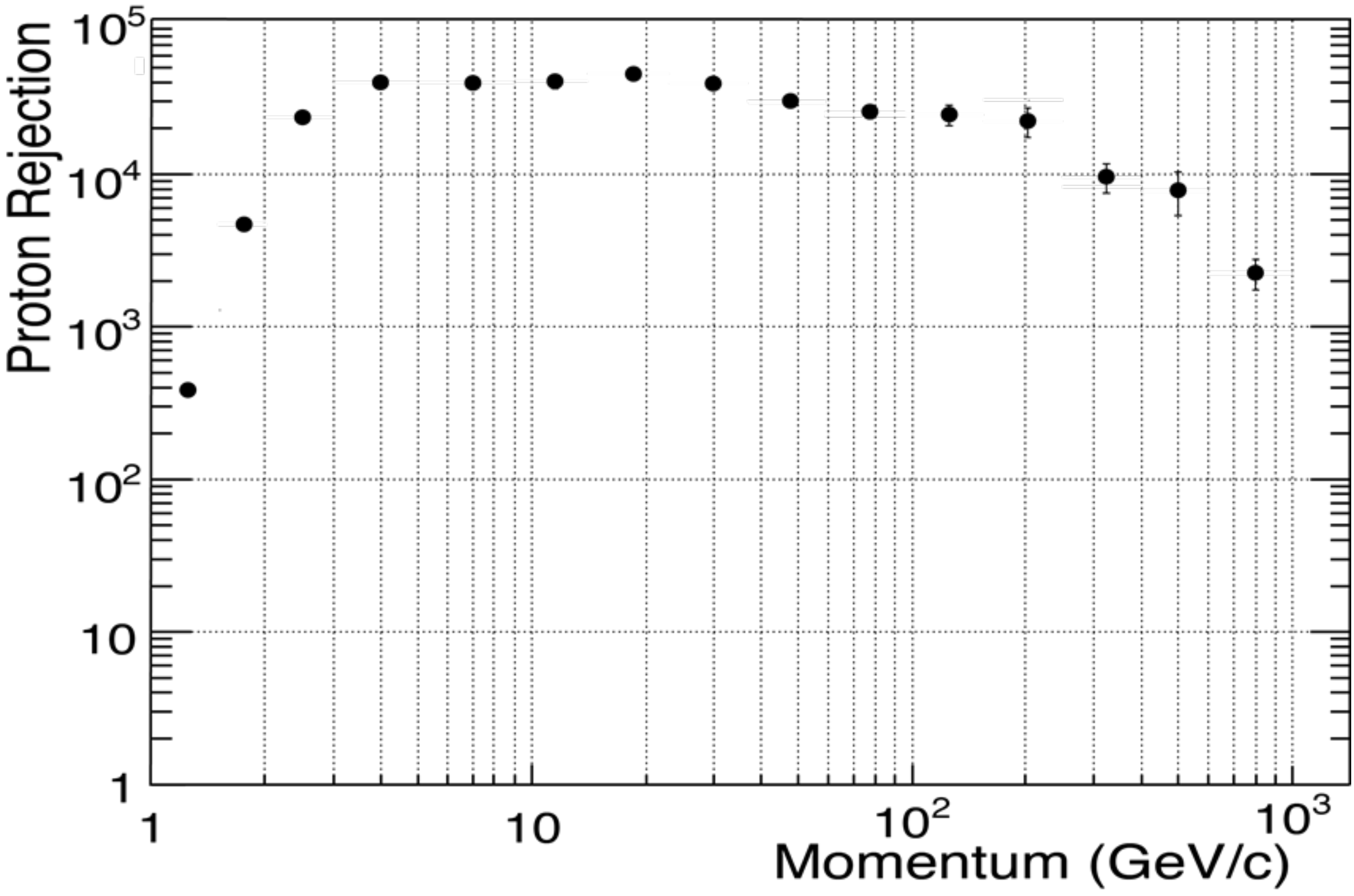


Separation of protons and electrons with ECAL

ISS data: 83–100 GeV



Data from ISS: Proton rejection using the ECAL



Results from the first 2 years of AMS

- Individual flux measurements:
    - Proton flux 1 GV - 1.8 TV
    - Helium flux 2 GV - 3 TV
    - Electron flux 1 - 500 GeV
    - Positron flux 1 - 350 GeV
    - Electron plus positron flux 0.5 - 700 GeV

- Flux Ratios:
    - Boron to carbon ratio 0.5 - 670 GeV/n
    - Positron fraction 0.5 - 350 GeV

- Anisotropy Searches
    - Positron to electron and positron to proton ratio

Presented at ICRC2013, Rio de Janeiro

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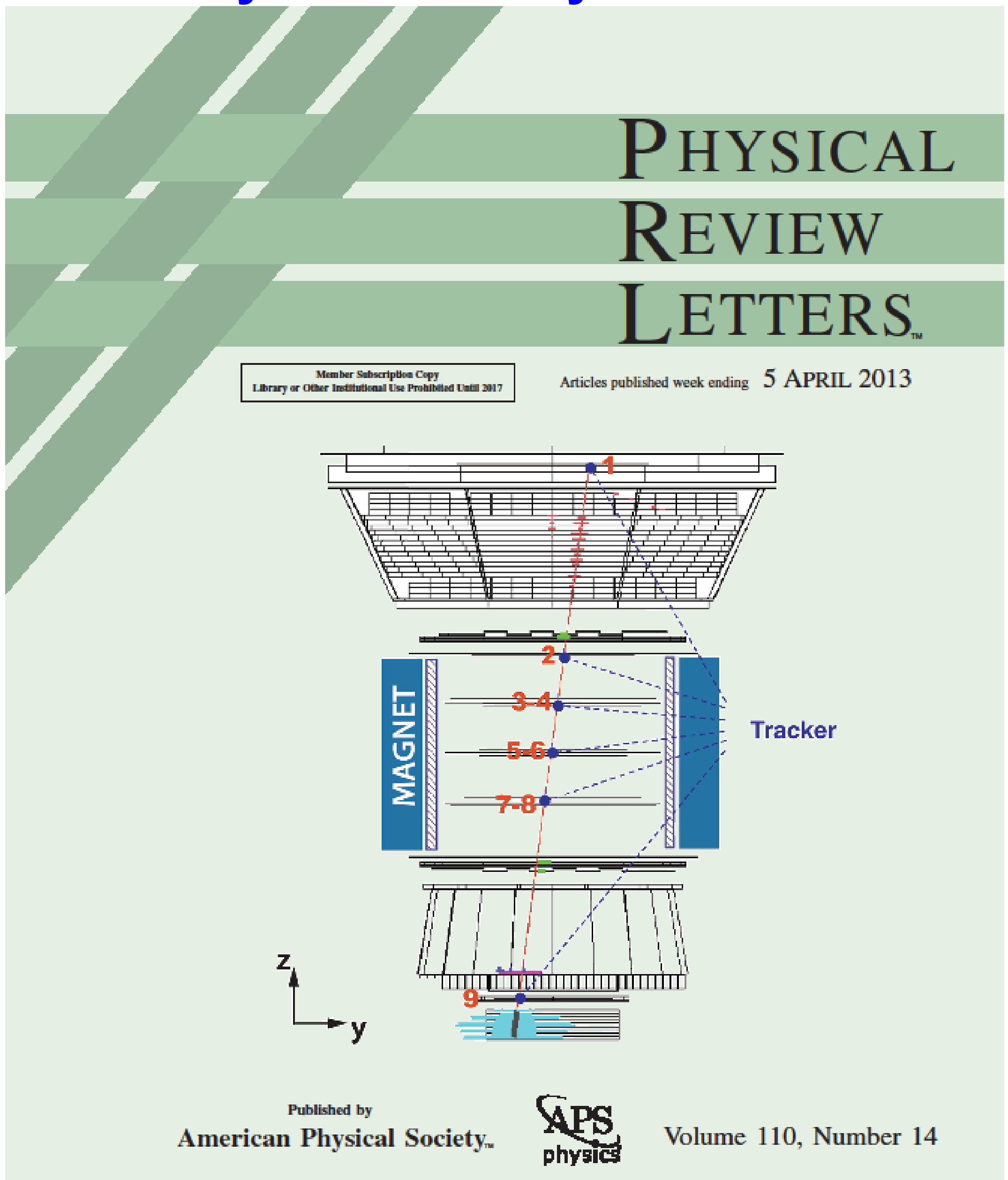
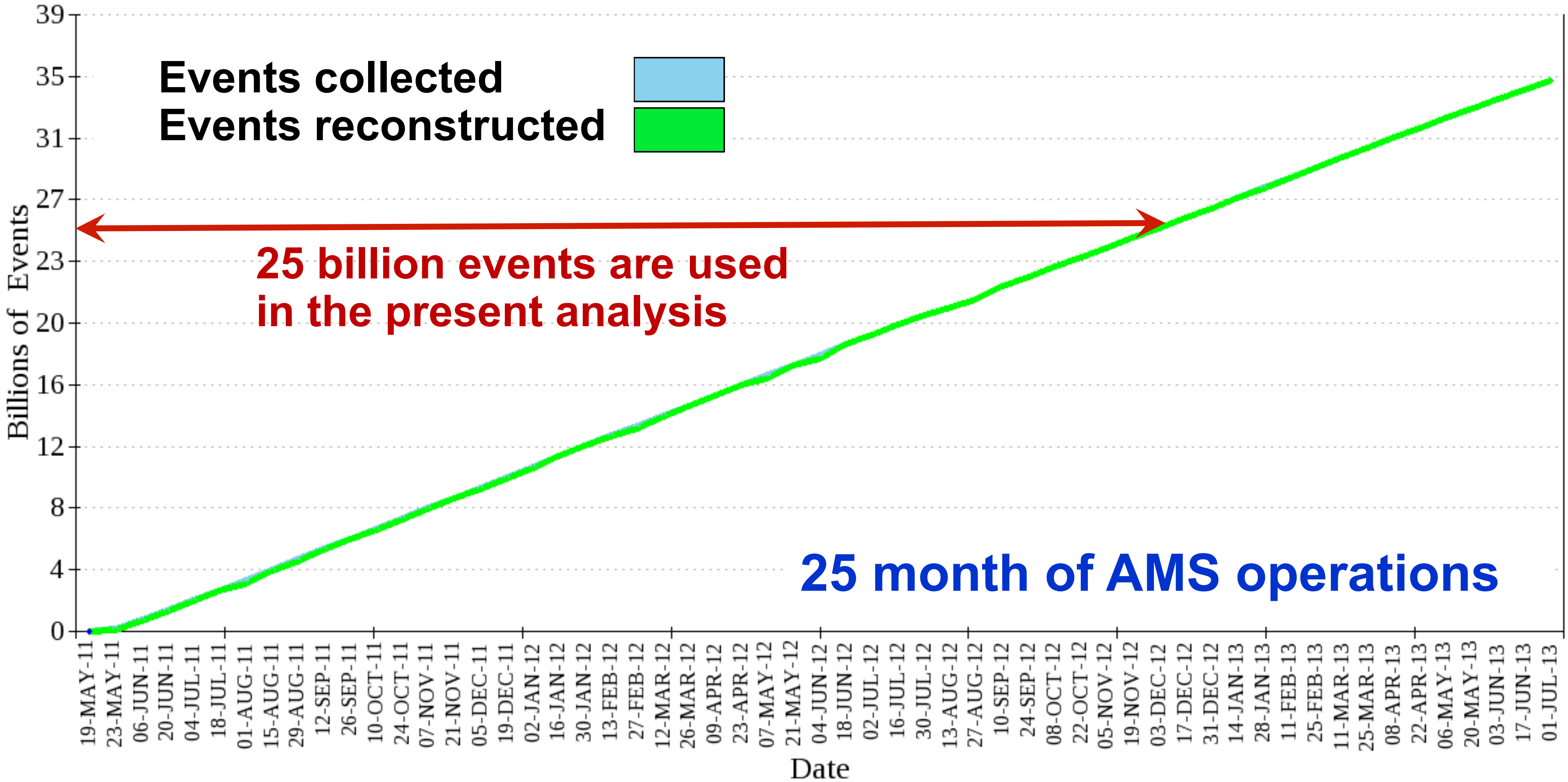
PRL 110, 141102 (2013)

First Result from the Alpha Magnetic Spectrometer on the International Space Station: Precision Measurement of the Positron Fraction in Primary Cosmic Rays of 0.5–350 GeV



To date AMS collected over 35 billion events



Event selection

-**DAQ:** efficiency > 50% (no SAA)

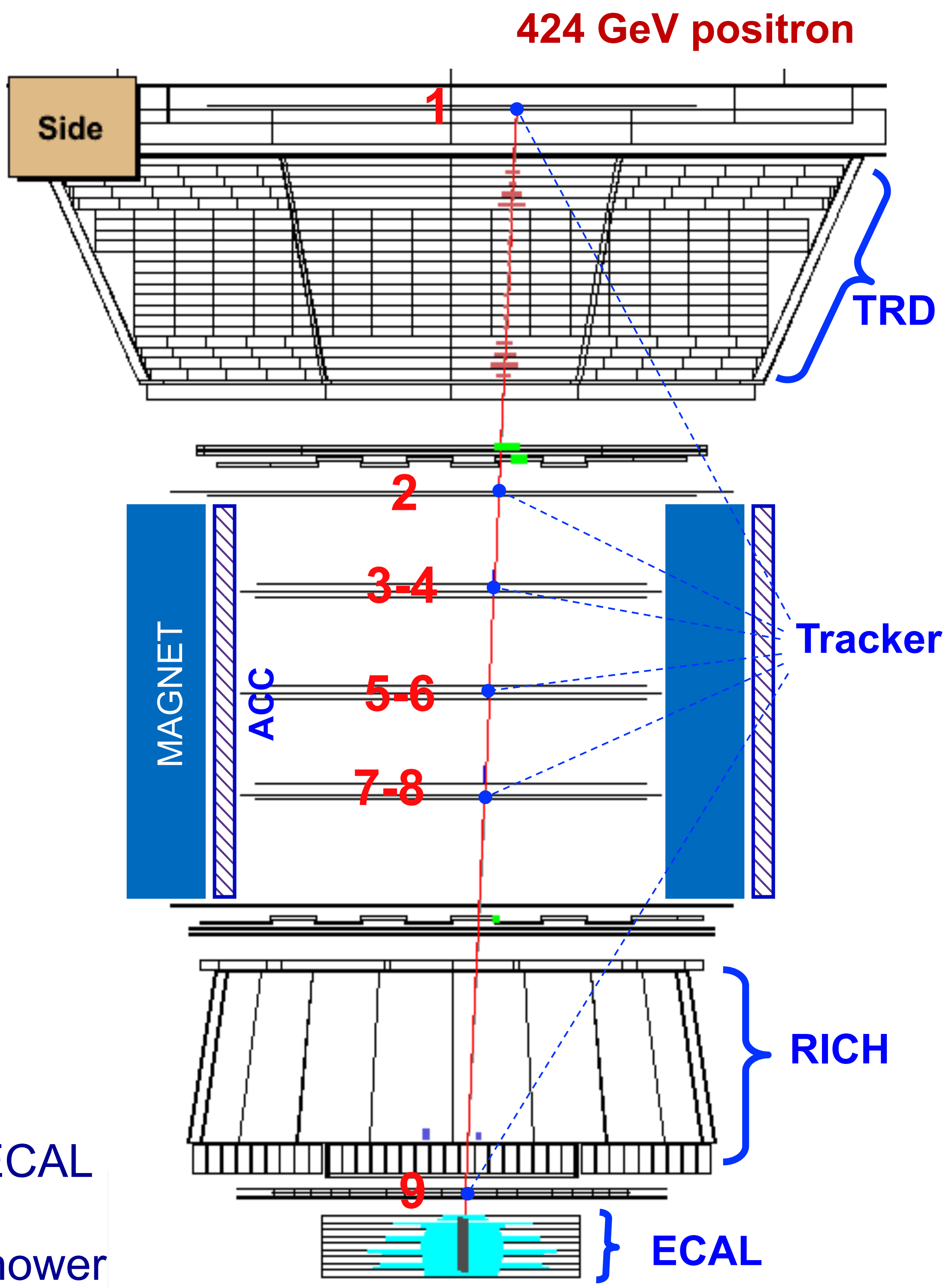
-**Geomagnetic cutoff:**
E>1.2·max cutoff

-**TRACKER:**
- Track quality
- geometrical match with ECAL shower

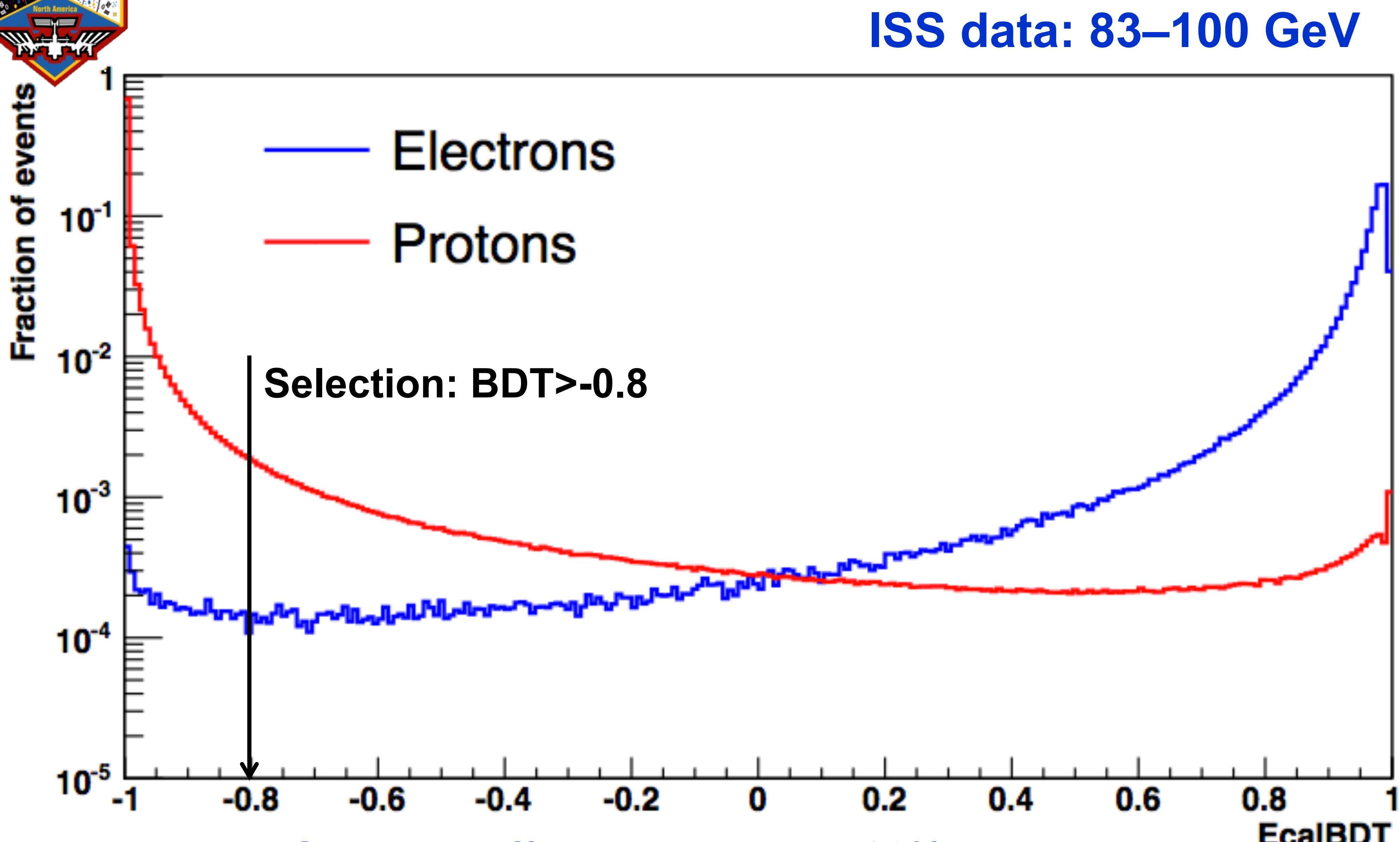
-**TRD:** at least 15 hits

-**TOF:** downgoing particle,
β>0.8, 0.8<Z<1.4

-**ECAL:**
- shower axis within the fiducial ECAL volume
- electromagnetic shape of the shower



Event selection: ECAL BDT



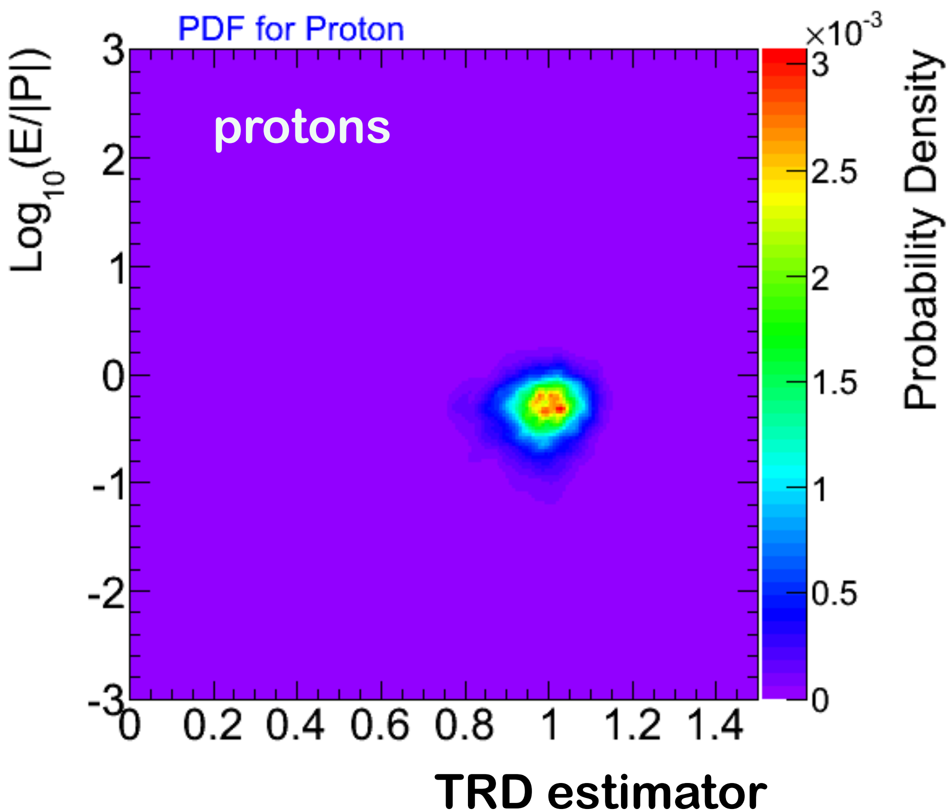
Selection efficiency is high, ≳90%, and uniform in a wide energy range, 2–400 GeV

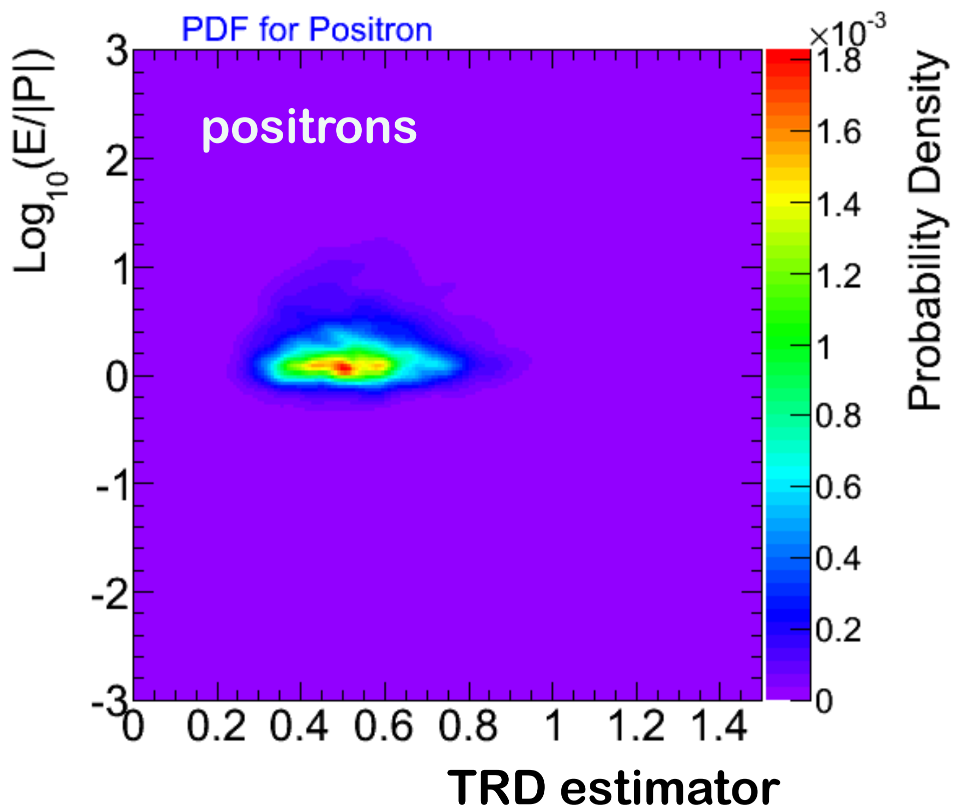
$N_{e^\pm} \approx$ 6,800,000 $N_p \approx$ 700,000

Analysis: 2D fit to measure $Ne^{\pm}$ and Np

2D reference spectra for the signal and the background are fitted to data in the [TRD estimator- log(E/|P|] plane.

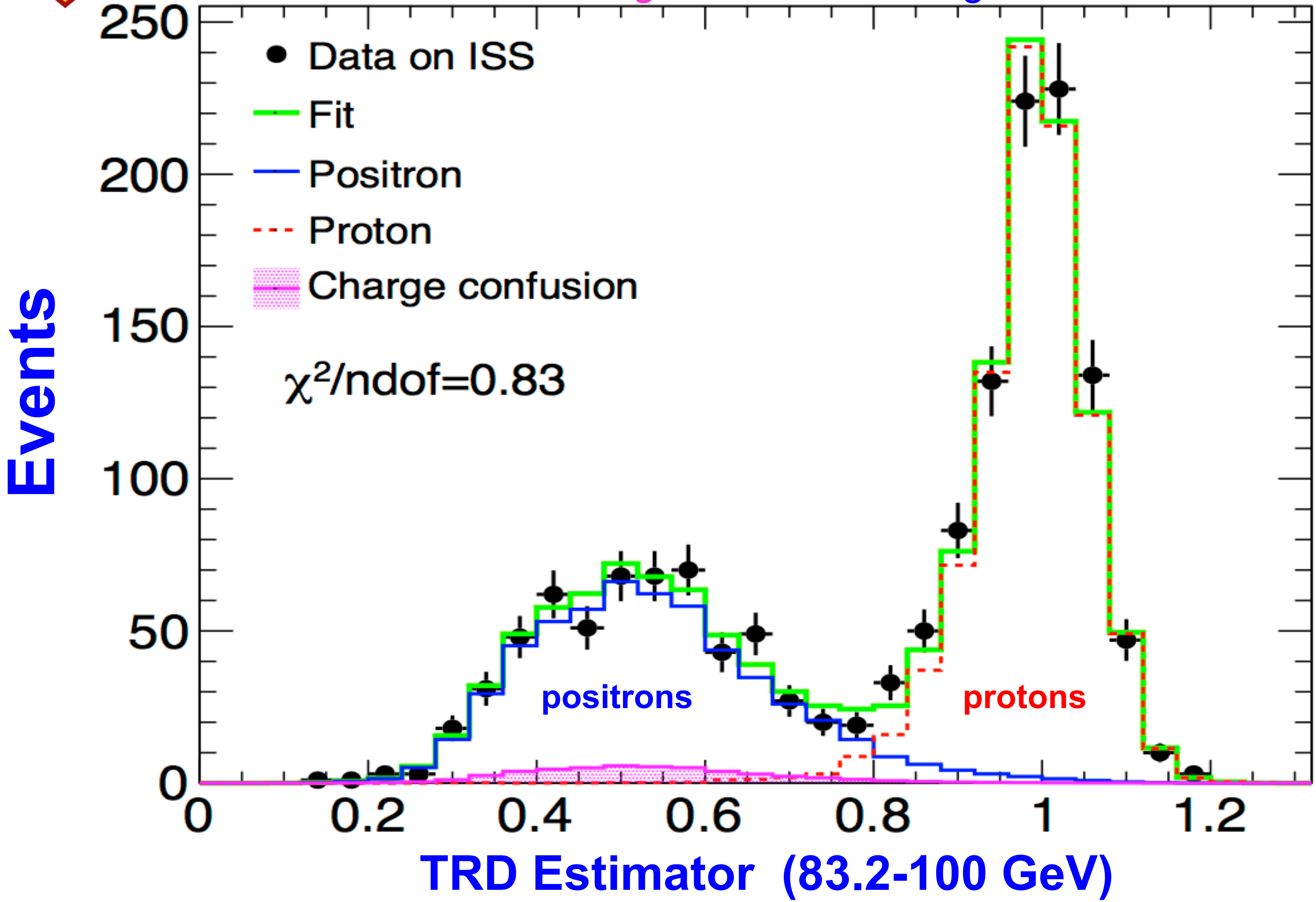
The method combines redundant information from TRD, ECAL, and Tracker; and provides much better statistical accuracy compared to cut-based analysis.





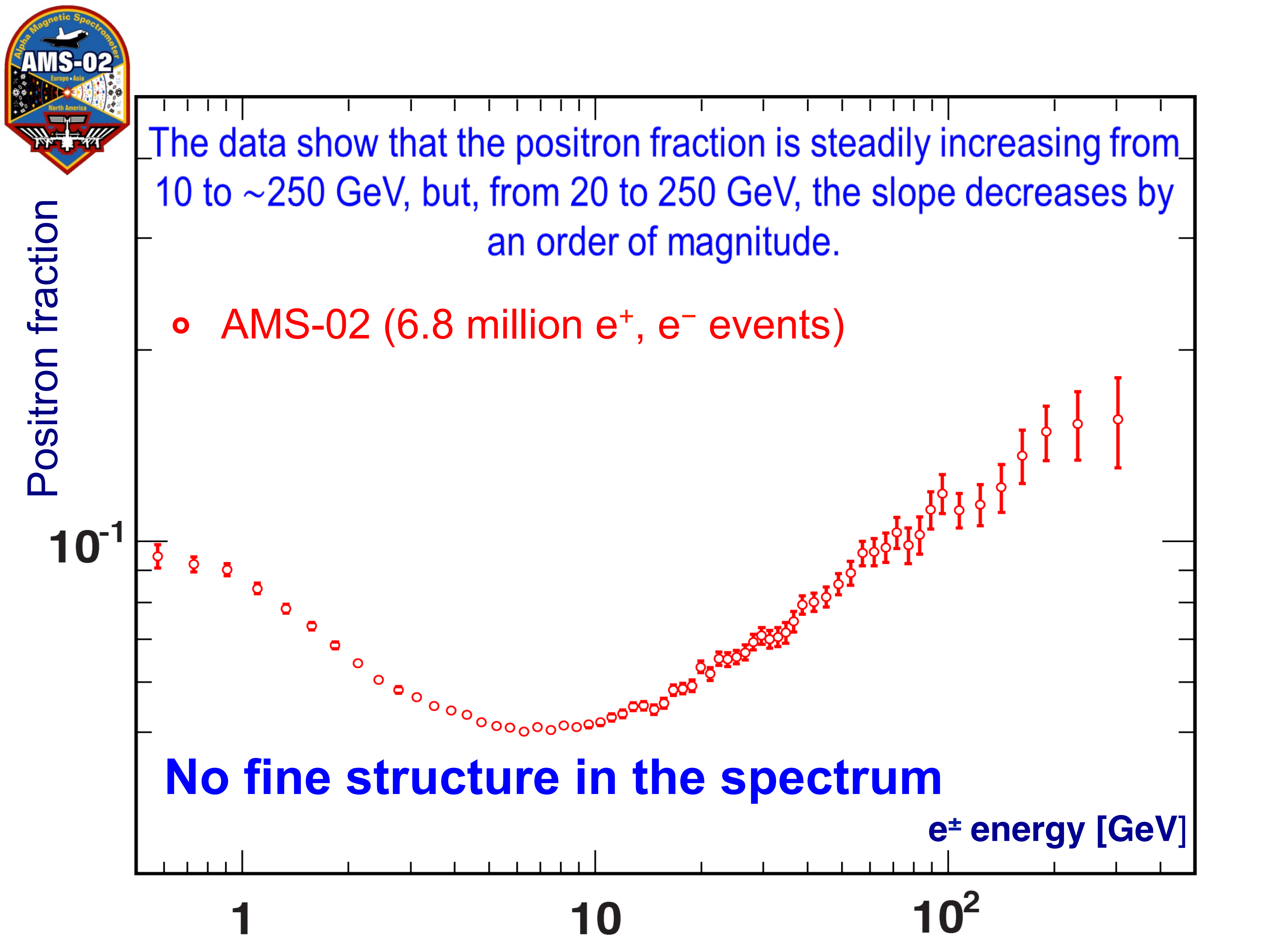
Results of the fit:

The TRD Estimator shows clear separation between protons and positrons with a small charge confusion background



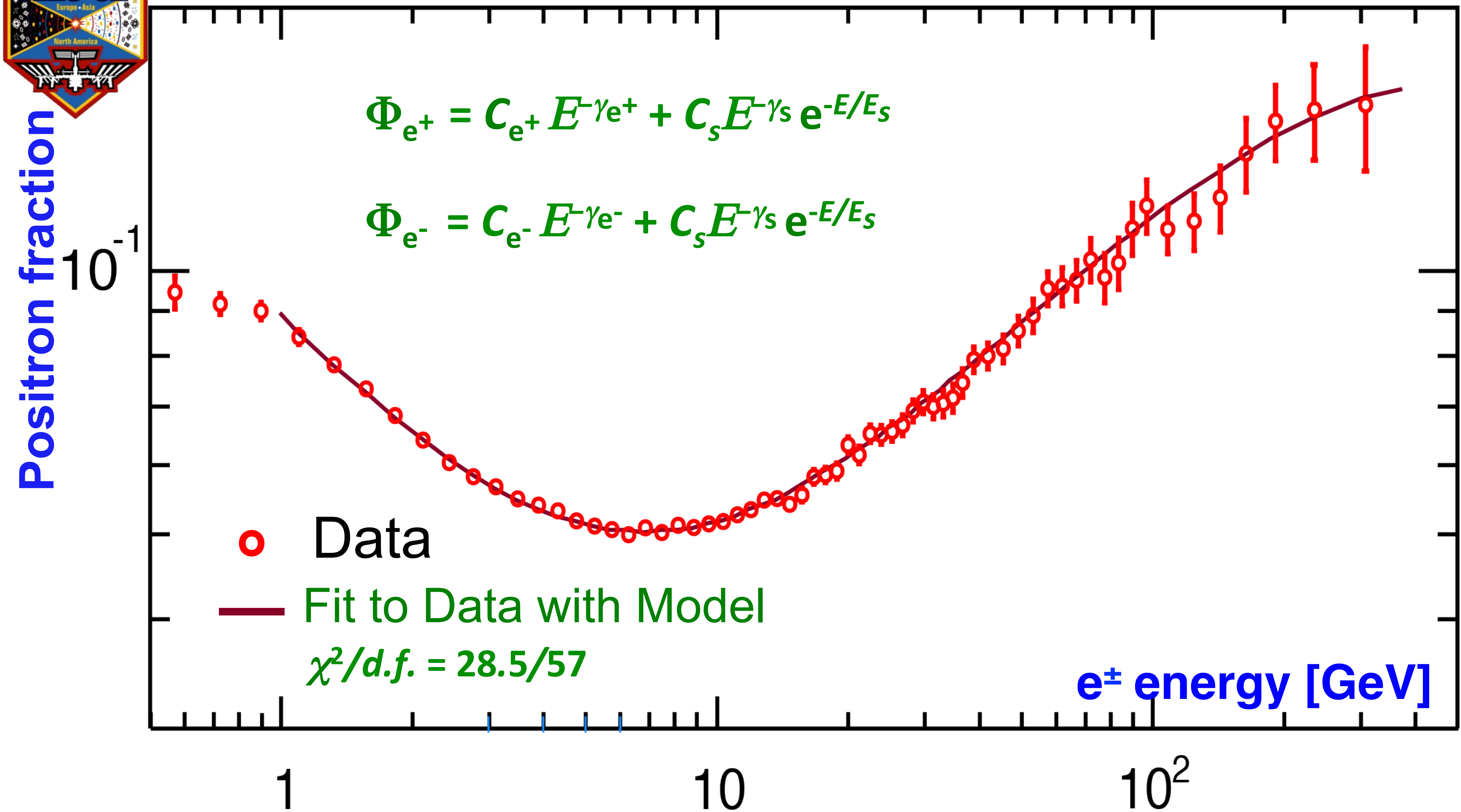
AMS Result: Measurement of the positron fraction

Positron events, positron fraction in each energy bin				Systematic Errors					
Energy [GeV]	N_{e+}	Fraction	statistical error	acceptance asymmetry	event selection	bin-to-bin migration	reference spectra	charge confusion	total systematic uncertainty
Energy[GeV]	N_{e+}	Fraction	$\sigma_{stat.}$	$\sigma_{acc.}$	$\sigma_{sel.}$	$\sigma_{mig.}$	$\sigma_{ref.}$	$\sigma_{c.c.}$	$\sigma_{syst.}$
1.00-1.21	9335	0.0842	0.0008	0.0005	0.0009	0.0008	0.0001	0.0005	0.0014
1.97-2.28	23893	0.0642	0.0004	0.0002	0.0005	0.0002	0.0001	0.0002	0.0006
3.30-3.70	20707	0.0550	0.0004	0.0001	0.0003	0.0000	0.0001	0.0002	0.0004
6.56-7.16	13153	0.0510	0.0004	0.0001	0.0000	0.0000	0.0001	0.0002	0.0002
09.95-10.73	7161	0.0519	0.0006	0.0001	0.0000	0.0000	0.0001	0.0002	0.0002
19.37-20.54	2322	0.0634	0.0013	0.0001	0.0001	0.0000	0.0001	0.0002	0.0003
30.45-32.10	1094	0.0701	0.0022	0.0001	0.0002	0.0000	0.0001	0.0003	0.0004
40.00-43.39	976	0.0802	0.0026	0.0002	0.0005	0.0000	0.0001	0.0004	0.0007
50.87-54.98	605	0.0891	0.0038	0.0002	0.0006	0.0000	0.0001	0.0004	0.0008
64.03-69.00	392	0.0978	0.0050	0.0002	0.0010	0.0000	0.0002	0.0007	0.0013
74.30-80.00	276	0.0985	0.0062	0.0002	0.0010	0.0000	0.0002	0.0010	0.0014
86.00-92.50	240	0.1120	0.0075	0.0002	0.0010	0.0000	0.0003	0.0011	0.0015
100.0-115.1	304	0.1118	0.0066	0.0002	0.0015	0.0000	0.0003	0.0015	0.0022
115.1-132.1	223	0.1142	0.0080	0.0002	0.0019	0.0000	0.0004	0.0019	0.0027
132.1-151.5	156	0.1215	0.0100	0.0002	0.0021	0.0000	0.0005	0.0024	0.0032
151.5-173.5	144	0.1364	0.0121	0.0002	0.0026	0.0000	0.0006	0.0045	0.0052
173.5-206.0	134	0.1485	0.0133	0.0002	0.0031	0.0000	0.0009	0.0050	0.0060
206.0-260.0	101	0.1530	0.0160	0.0003	0.0031	0.0000	0.0013	0.0095	0.0101
260.0-350.0	72	0.1550	0.0200	0.0003	0.0056	0.0000	0.0018	0.0140	0.0152



The data show that the positron fraction is steadily increasing from 10 to ~250 GeV, but, from 20 to 250 GeV, the slope decreases by an order of magnitude.
AMS-02 (6.8 million e+, e− events)
No fine structure in the spectrum
Positron fraction
e± energy [GeV]
10-1
1
10
102

Comparing data with a minimal model



The agreement between the data and the model shows that the positron fraction spectrum is consistent with e± fluxes each of which is the sum of its diffuse spectrum and a single common power law source.

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

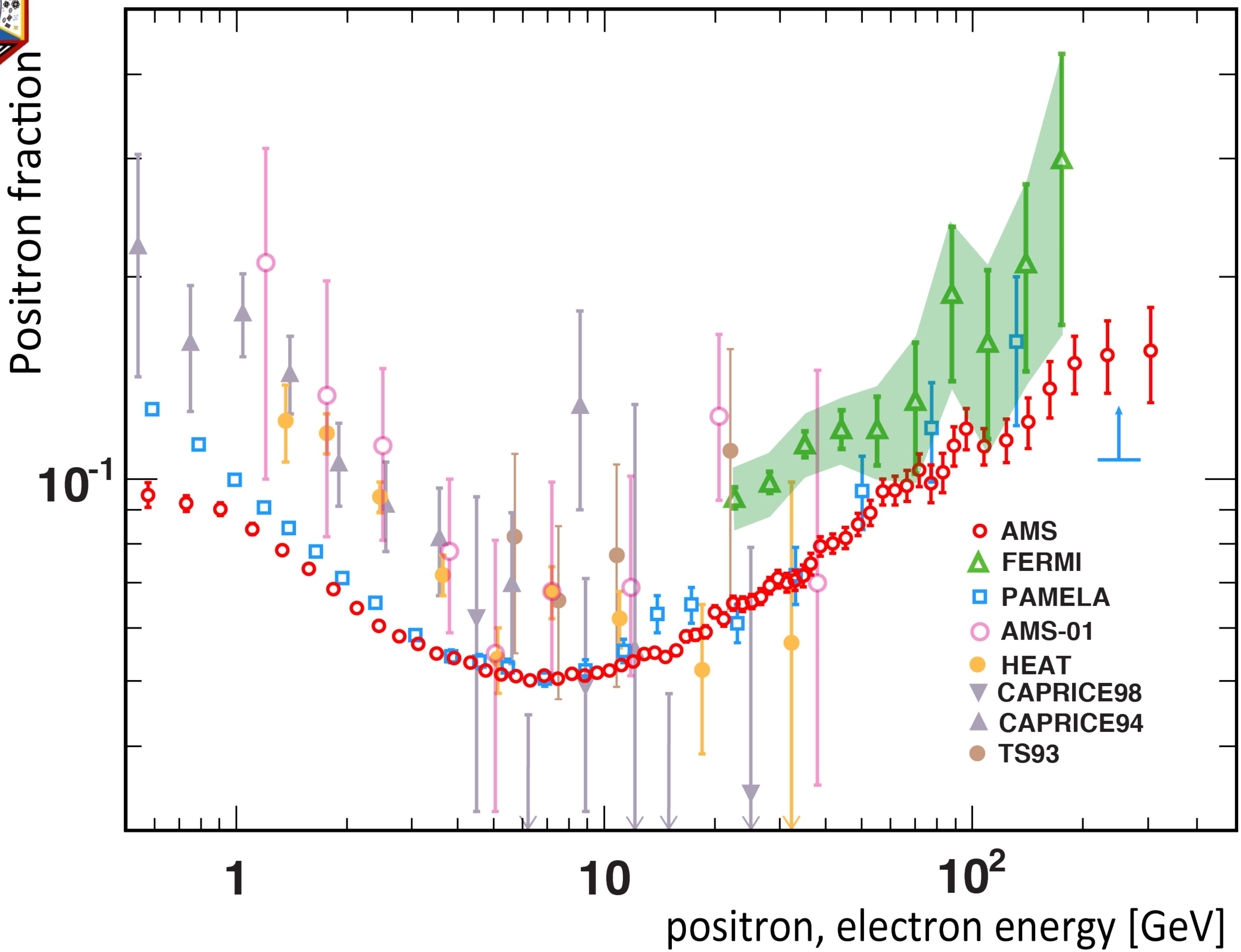
$\gamma_{e-} - \gamma_{e+}$ **= −0.63 ± 0.03**, *i.e.*, the diffuse positron spectrum is less energetic than the diffuse electron spectrum;

$\gamma_{e-} - \gamma_{s}$ **= 0.66±0.05**, *i.e.*, the source spectrum is more energetic than the diffuse electron spectrum;

C_{e+}/C_{e-} **= 0.091 ± 0.001**, *i.e.*, the weight of the diffuse positron flux amounts to ~10% of that of the diffuse electron flux;

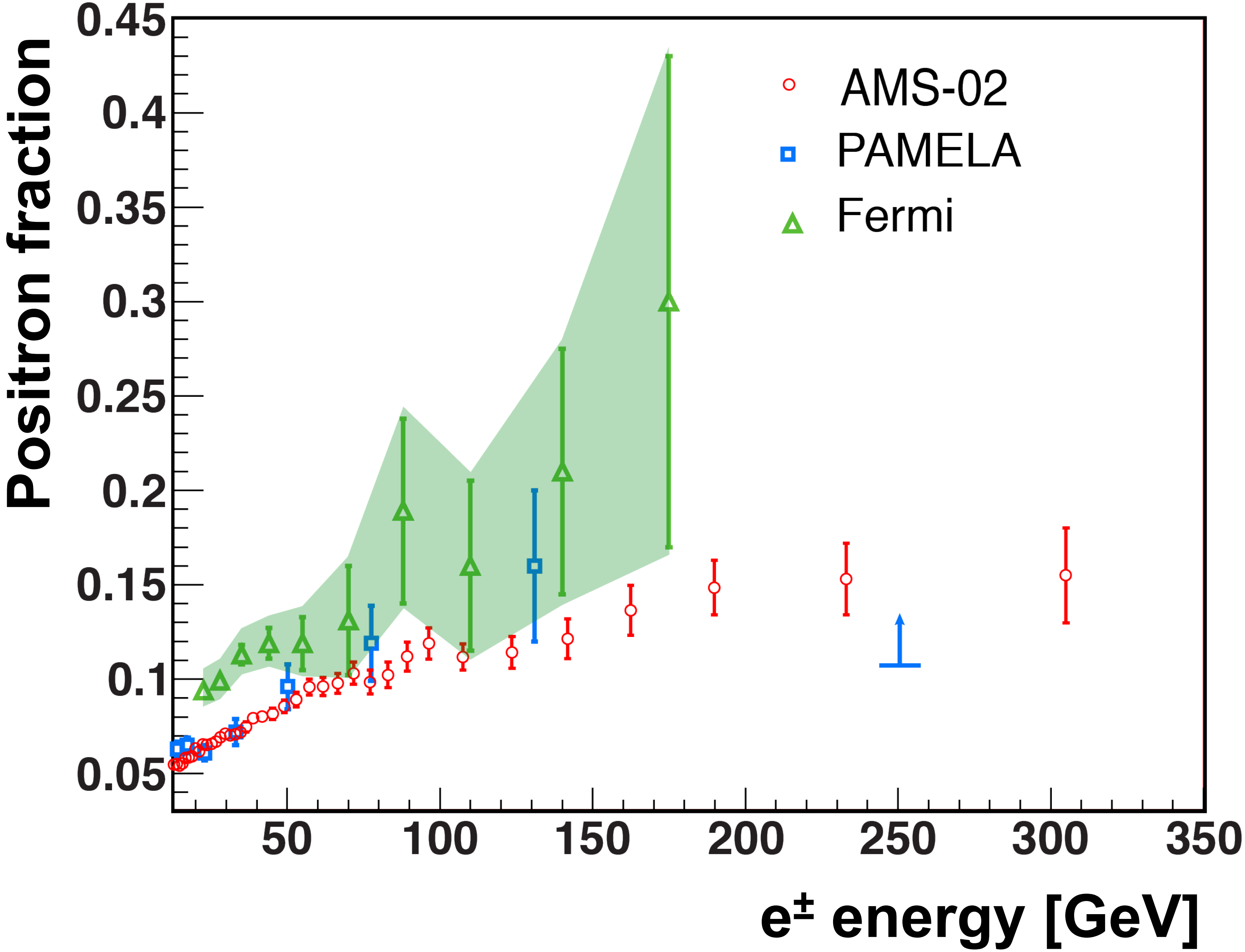
C_{s}/C_{e-} **= 0.0078 ± 0.0012**, *i.e.*, the weight of the common source constitutes only ~1% of that of the diffuse electron flux;

$1/E_s$ **= 0.0013 ± 0.0007 GeV**$^{-1}$,
corresponding to a cutoff energy of 760^{+1000}_{-280} **GeV**.



Positron fraction
10^{-1}
1
10
10^2
positron, electron energy [GeV]
AMS
FERMI
PAMELA
AMS-01
HEAT
CAPRICE98
CAPRICE94
TS93

AMS published results on the positron fraction show an increase above 10 GeV

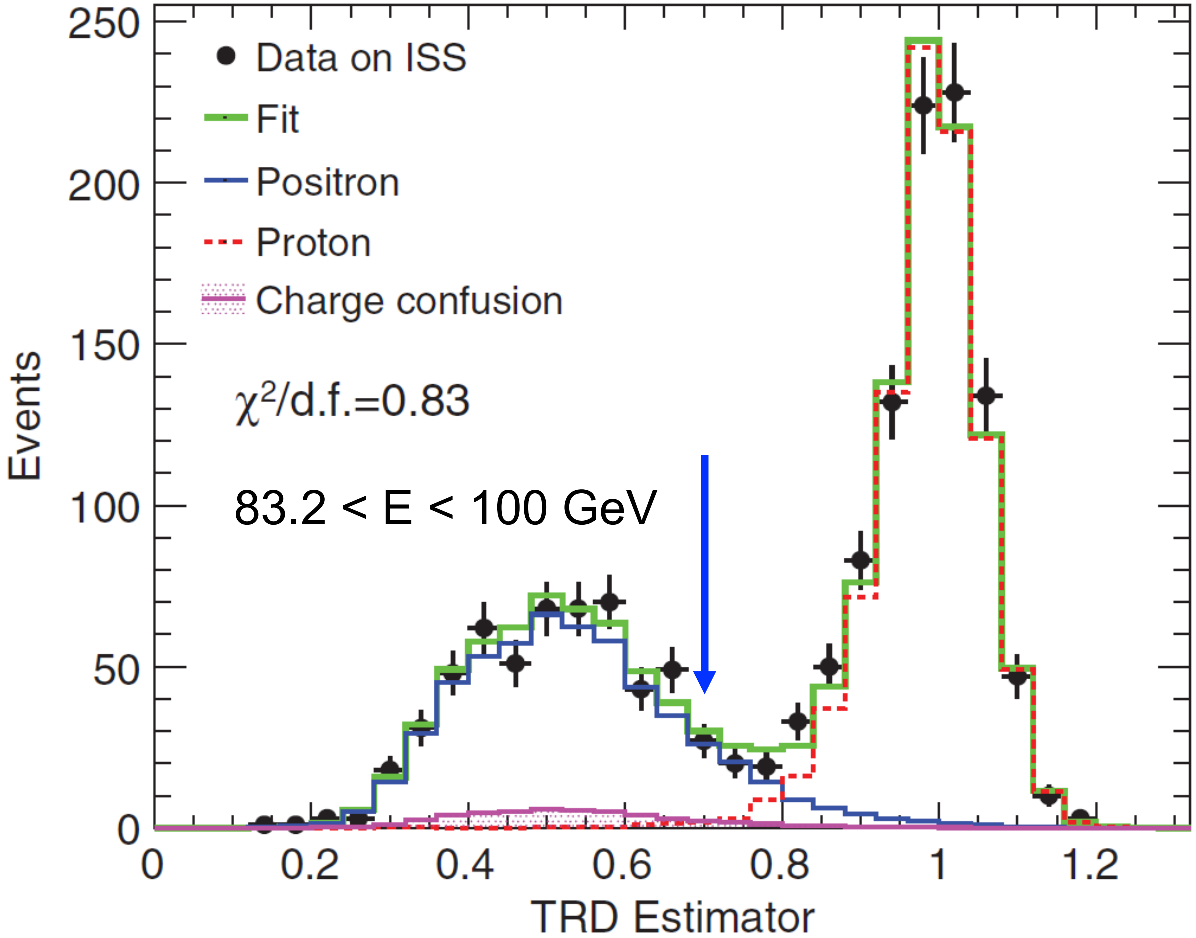


This observation shows the existence of new physical phenomena, whether from a particle physics or an astrophysical origin.

Primary sources of cosmic ray positrons and electrons may induce some degree of anisotropy on the measured positron to electron ratio, e^+/e^-, that is, the ratio of the positron flux to the electron flux.

A systematic search for anisotropies using the selected sample is performed from 16 to 350 GeV.

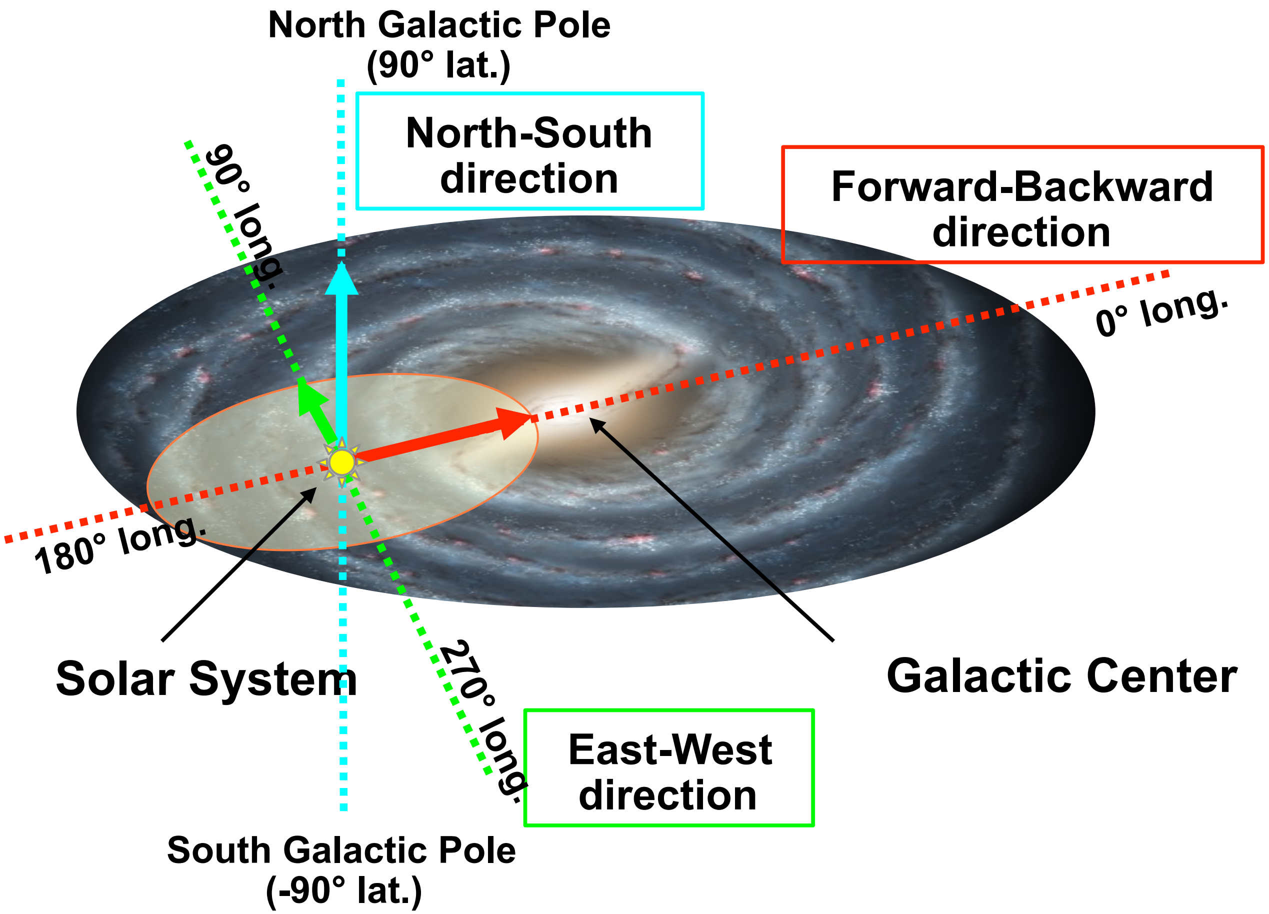
Proton background is reduced to the per mil level with a cut based selection on the TRD and ECAL estimators



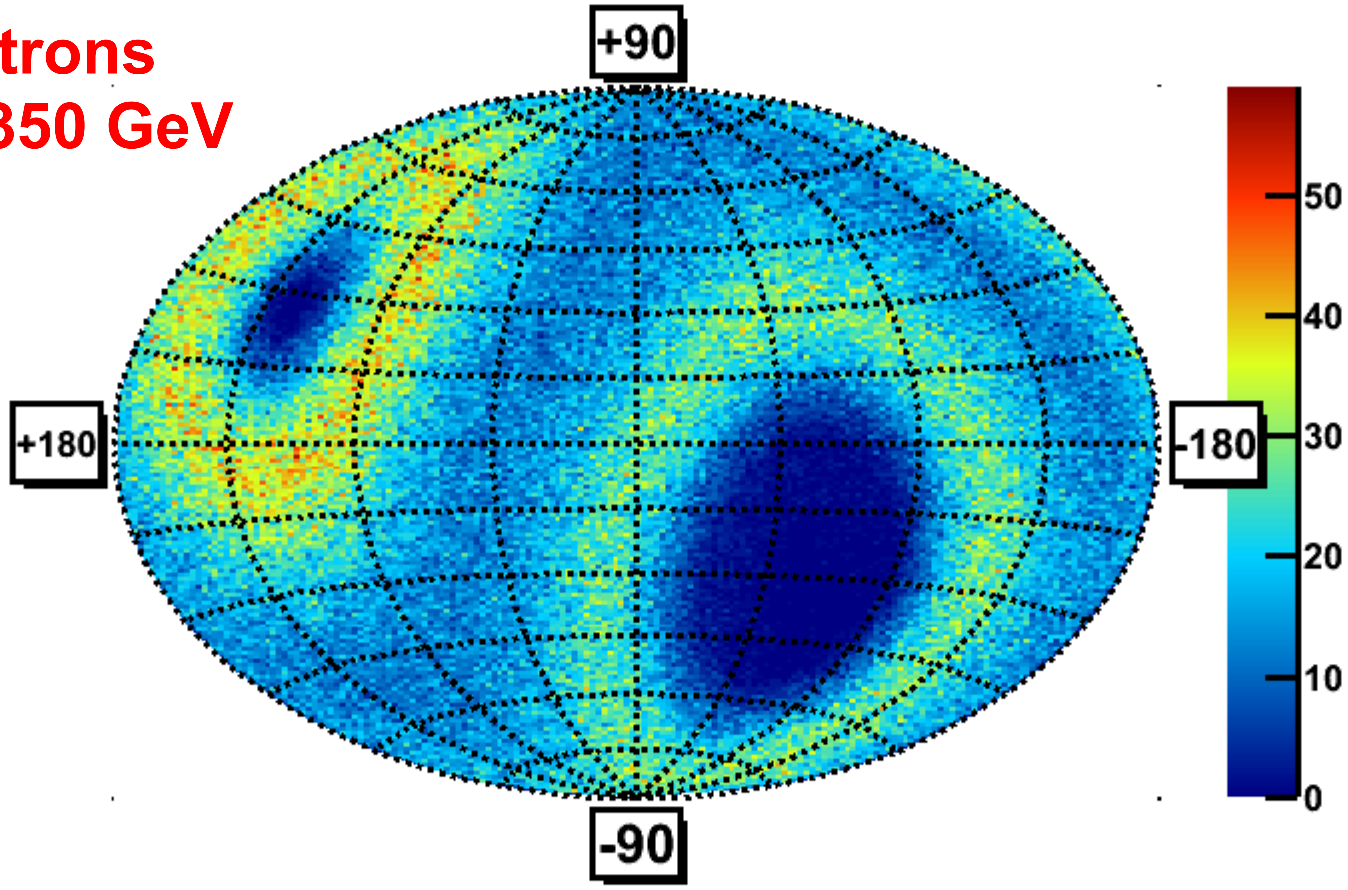
35,000 e^+ and 460,000 e^- are selected in the data collected from 19 May 2011 to 10 March 2013

Selected events are grouped into 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 galactic coordinates, (b,l), containing the number of observed positrons and electrons



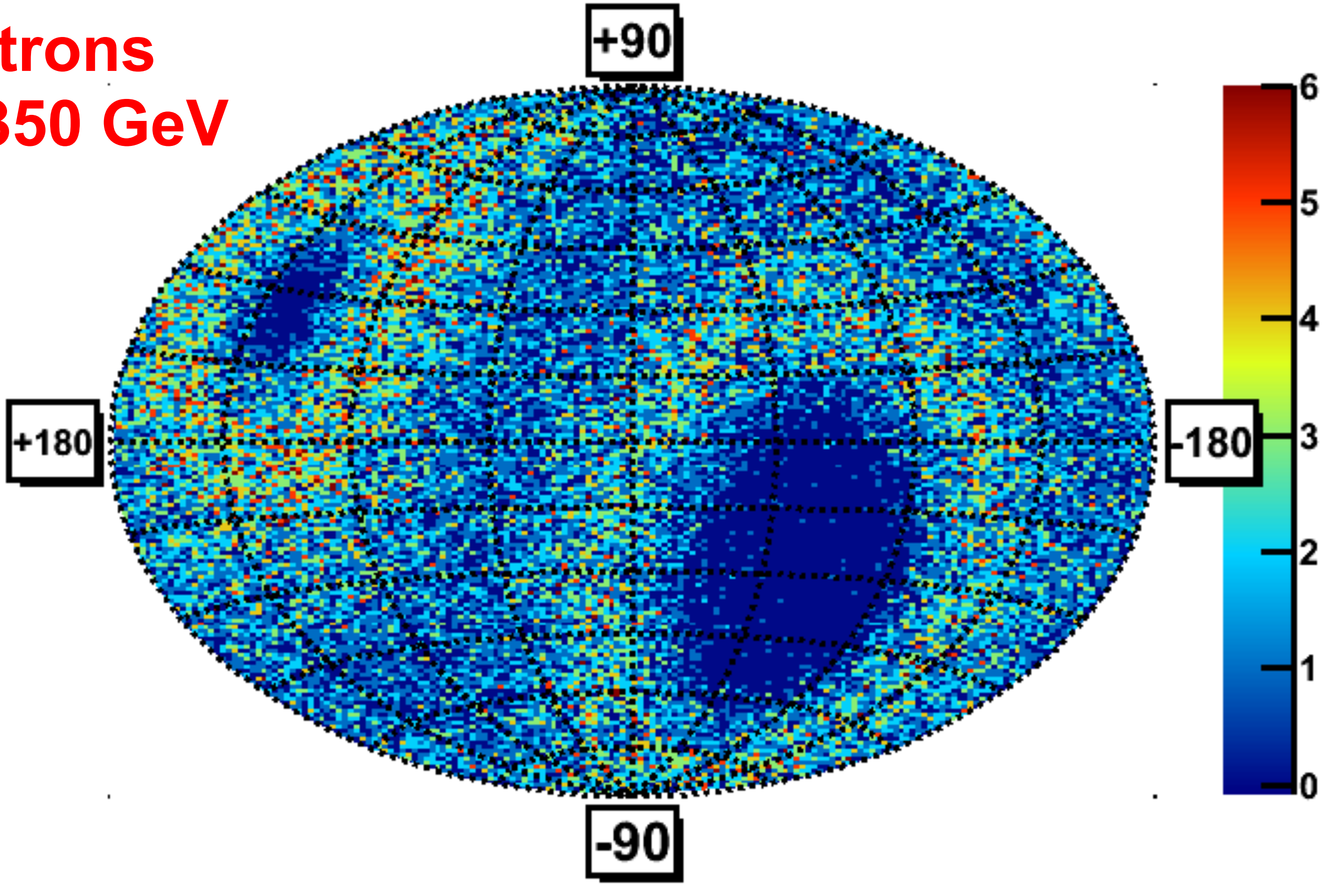
The maps show the exposure of AMS in Galactic coordinates.



Bins corresponding to directions with low exposure are masked in the subsequent analysis

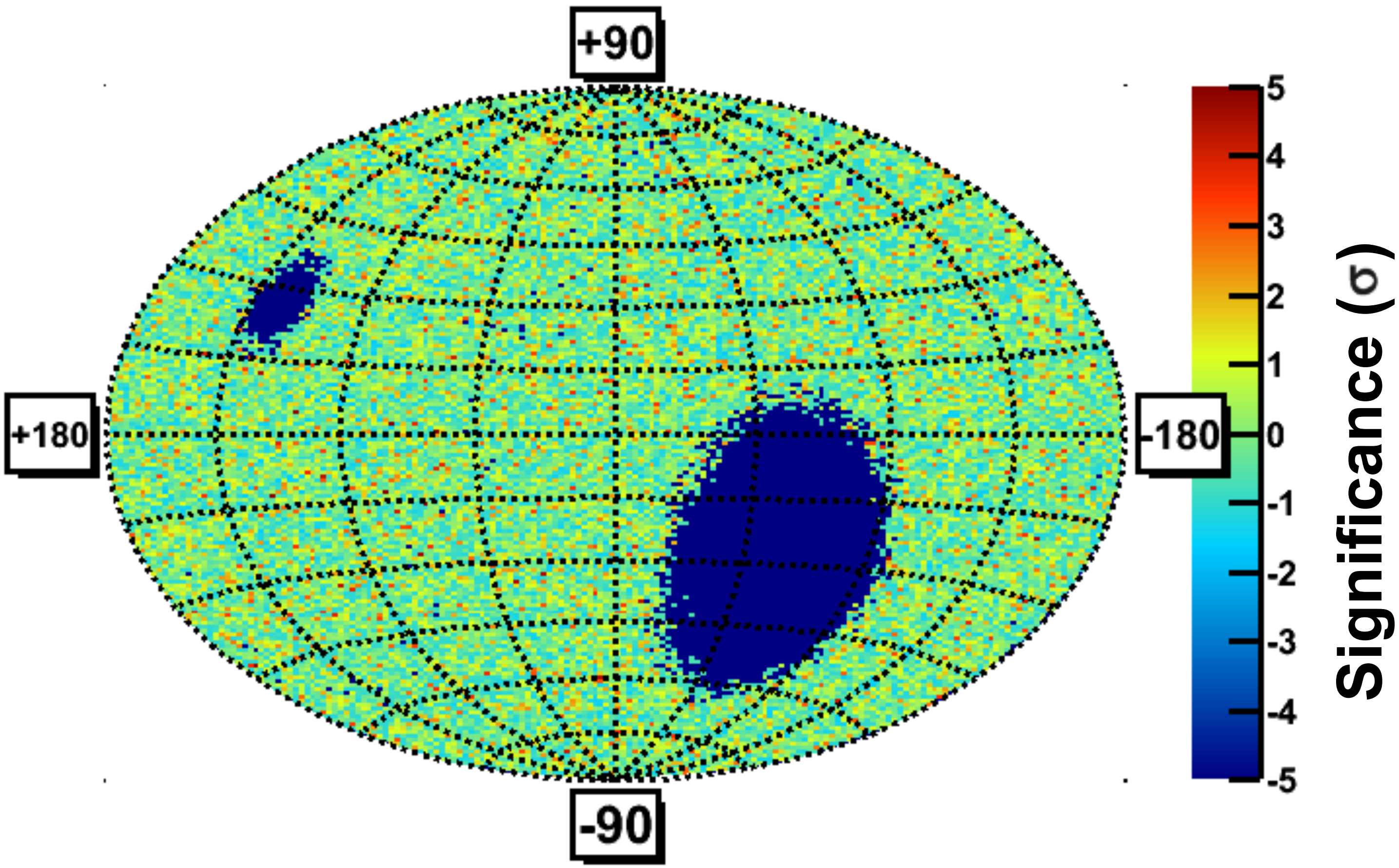
The maps show the exposure of AMS in Galactic coordinates.

positrons
16<E<350 GeV



Bins corresponding to directions with low exposure are masked in the subsequent analysis

The relative fluctuations of the positron ratio, e^+/e^-, across the observed sky map show no evident pattern



The relative fluctuations of the positron ratio, e^+/e^-, are described by means of a spherical harmonic expansion

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

Where

$r_e(b,l)$ **denotes the positron ratio at *(b,l)*,**

$\langle r_e \rangle$ **is the average ratio over the sky map,**

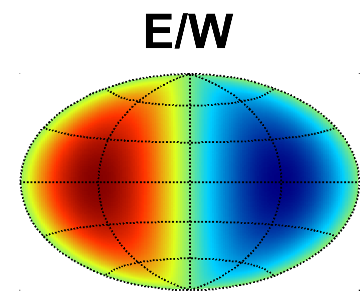
$Y_{\ell m}$ **are the real spherical harmonic functions,**

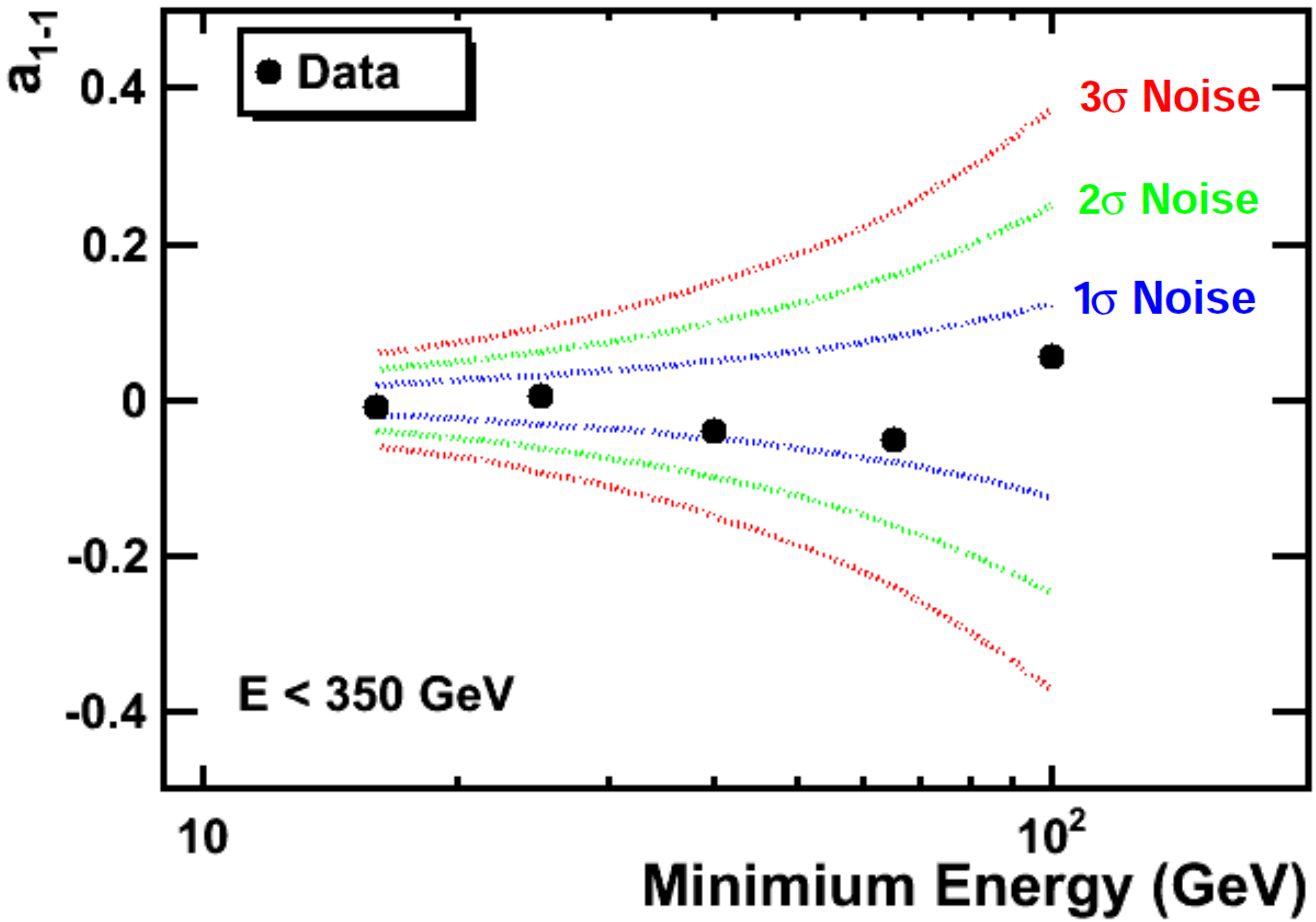
$a_{\ell m}$ **are their corresponding amplitudes**

The amplitudes of spherical harmonic contributions at fixed angular scale, ℓ are fit to data for dipole (ℓ=*1*), quadrupole (ℓ=*2*) and octopole (ℓ=*3*)

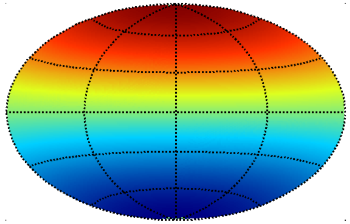
The fit amplitudes, $a_{\ell m}$ are found to be consistent with the hypothesis of isotropy at all energies and angular scales

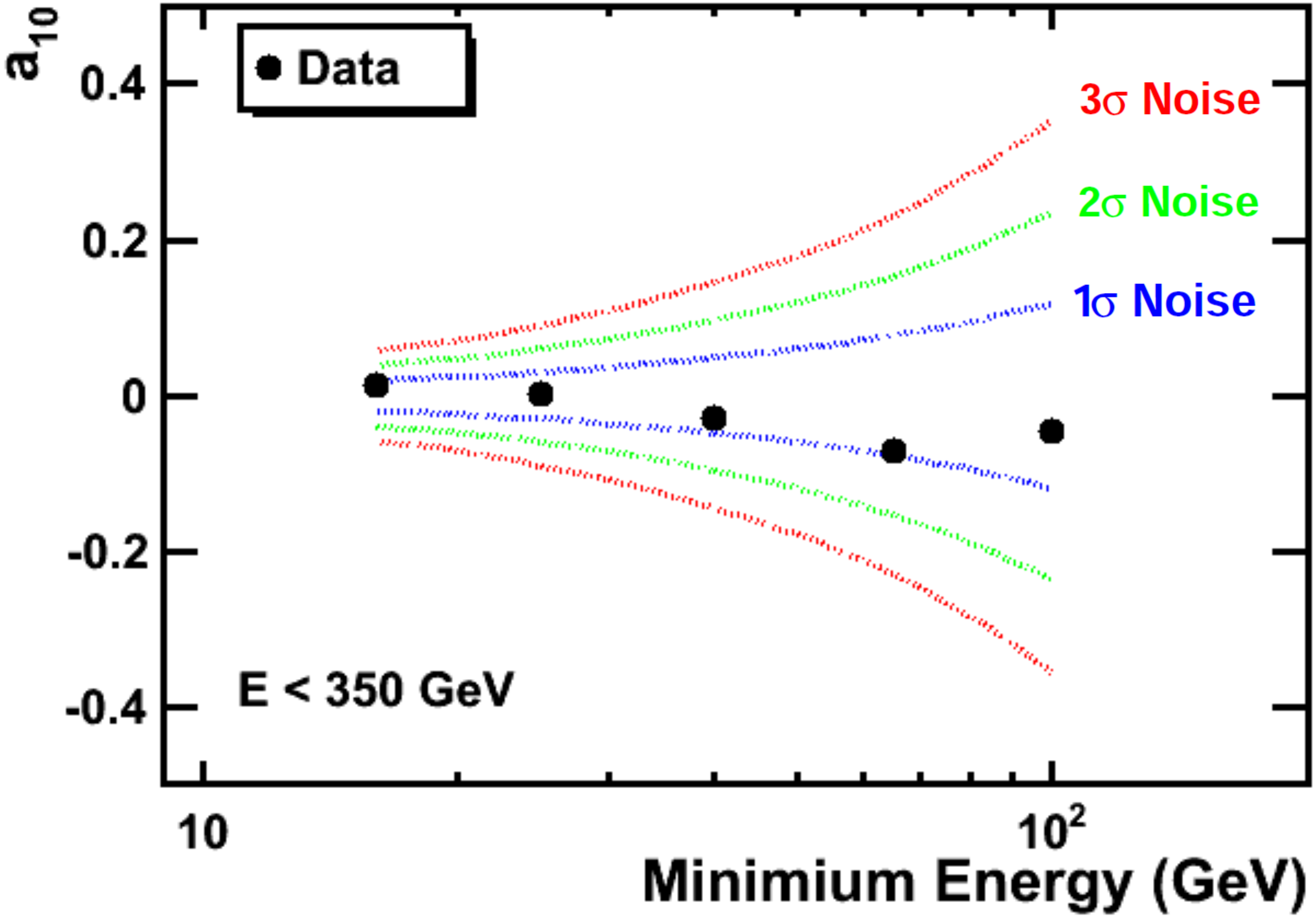
Dipole amplitude a_{1-1}

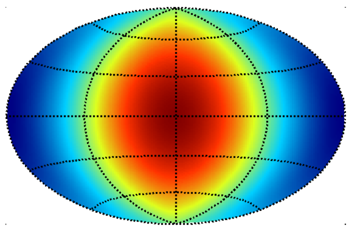




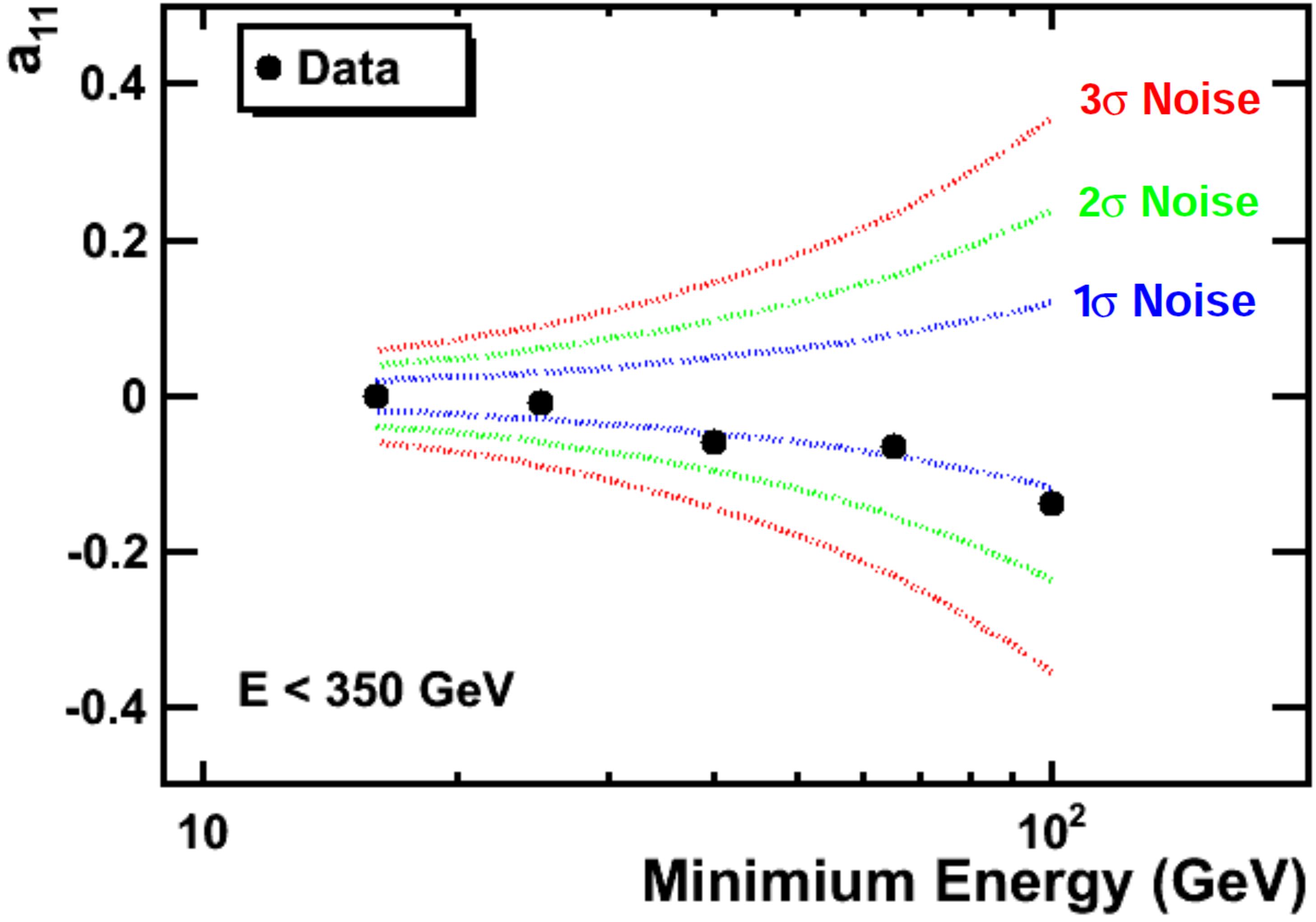
Dipole amplitude a_{10}







Dipole amplitude a_{11}

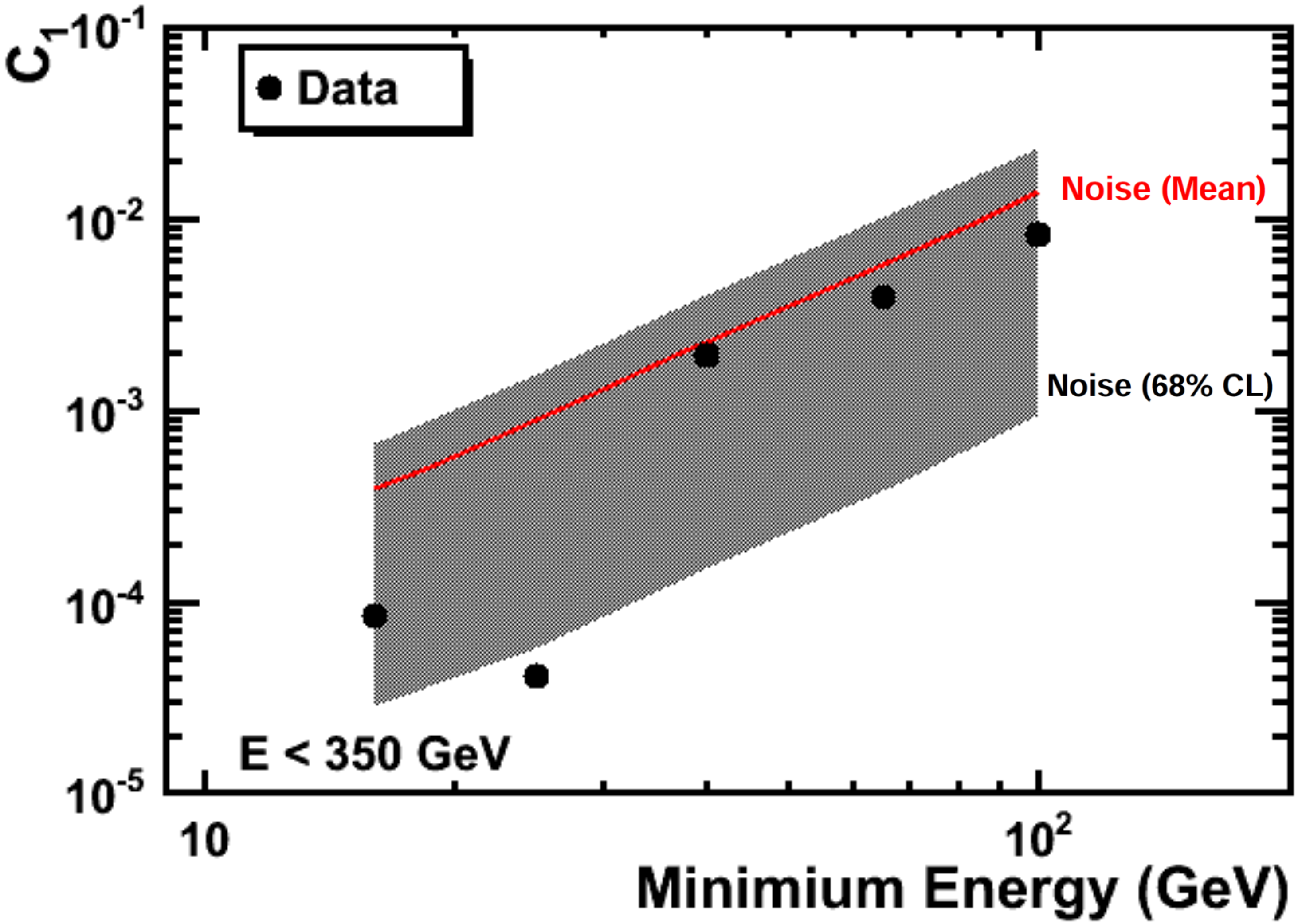


The coefficients of the angular power spectrum of the fluctuations, C_l are defined as

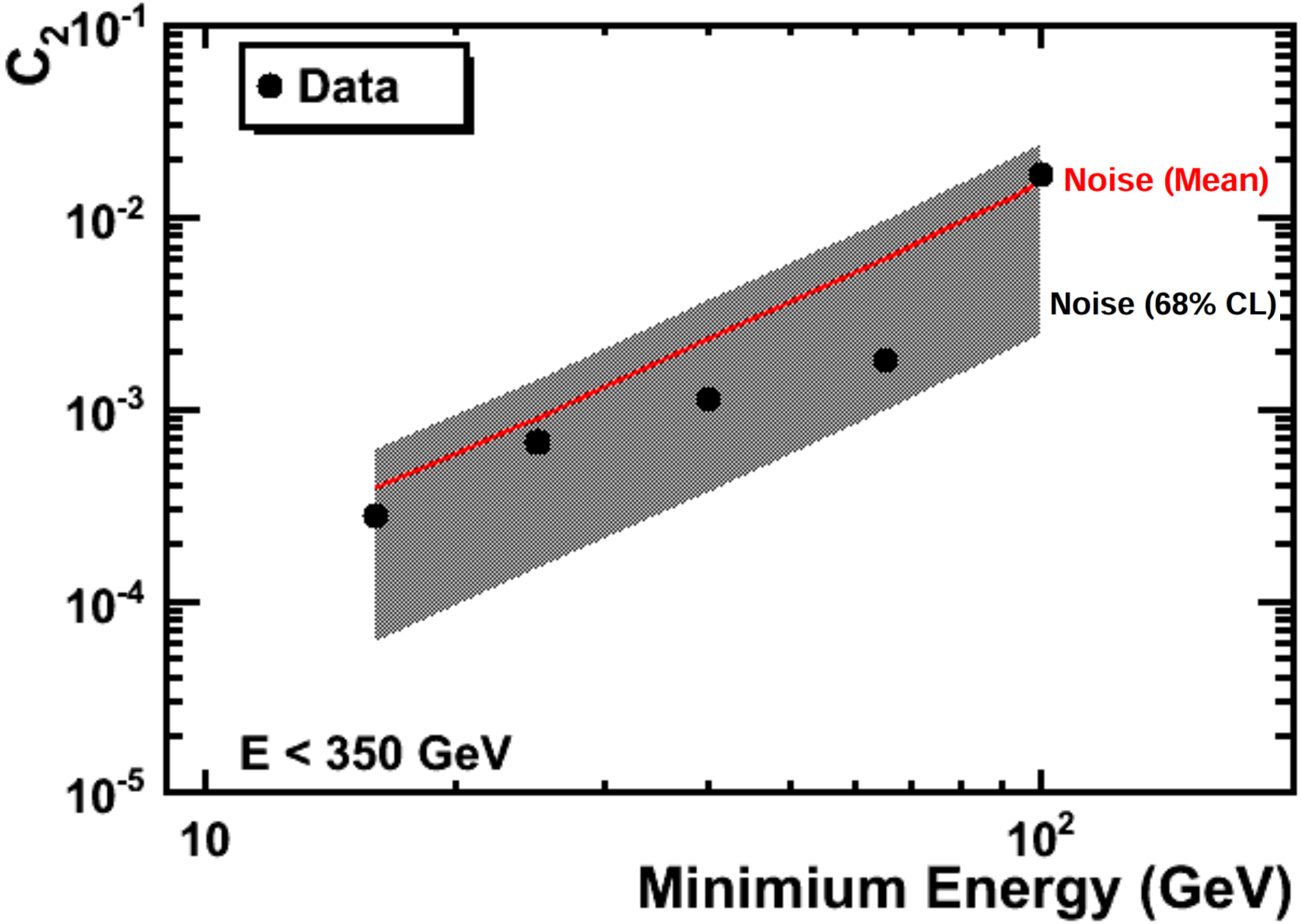
$$C_\ell = \frac{1}{2\ell + 1} \sum_{m=-\ell}^{\ell} a_{\ell m}^2$$

The values obtained from the fits to the data are compared to the expectations from isotropy

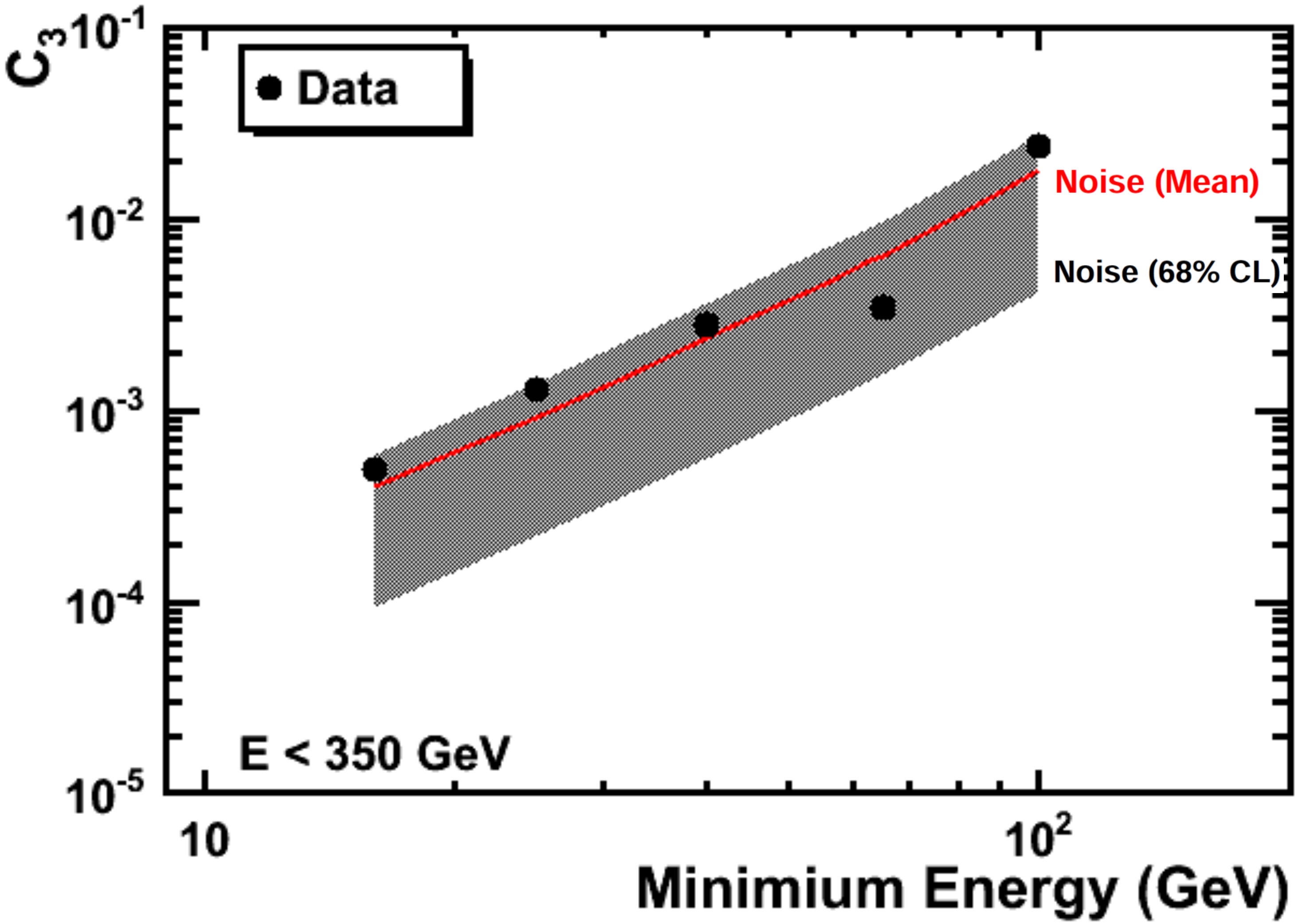
The dipole coefficient C_1



The quadrupole coefficient C_2



The octopole coefficient C_3

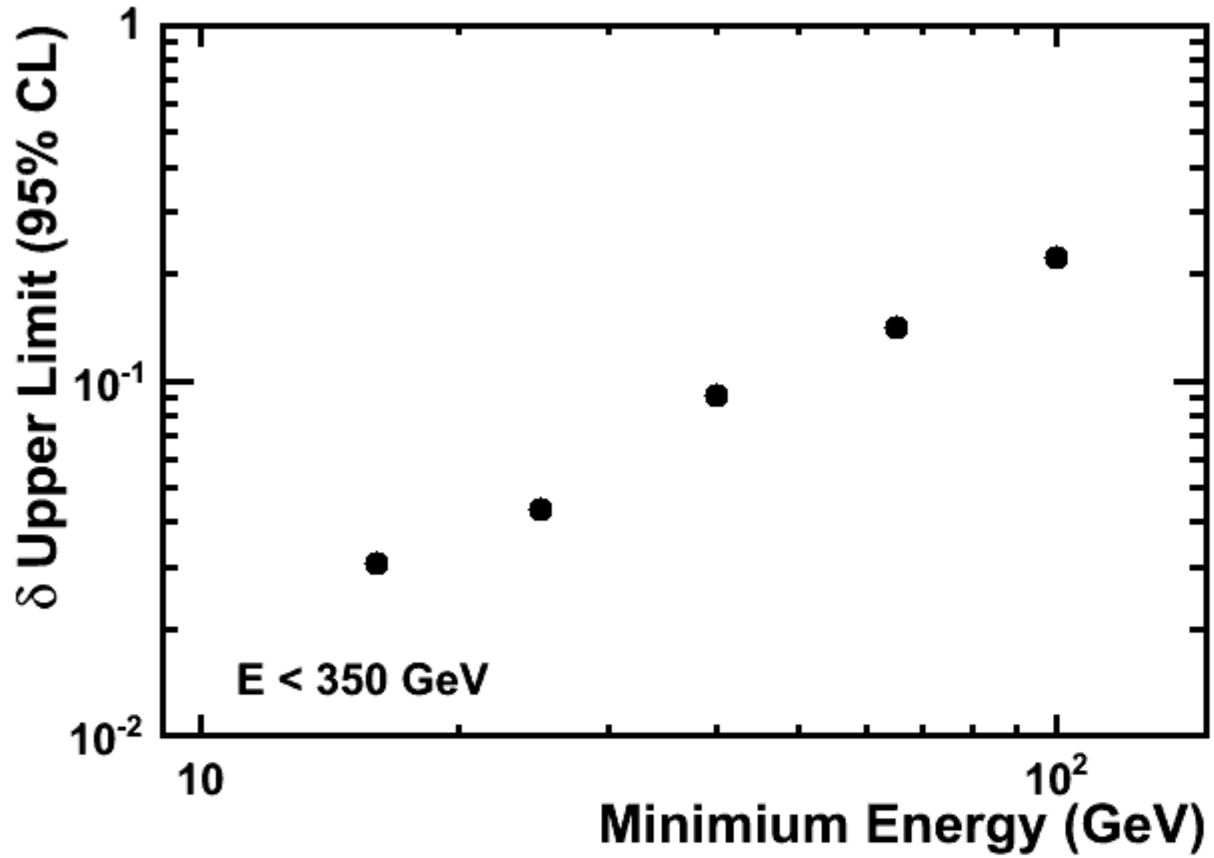


The coefficients of the multipole expansion are found consistent with the expectations from isotropy and upper limits are obtained.

In particular, upper limits on the dipole anisotropy parameter δ

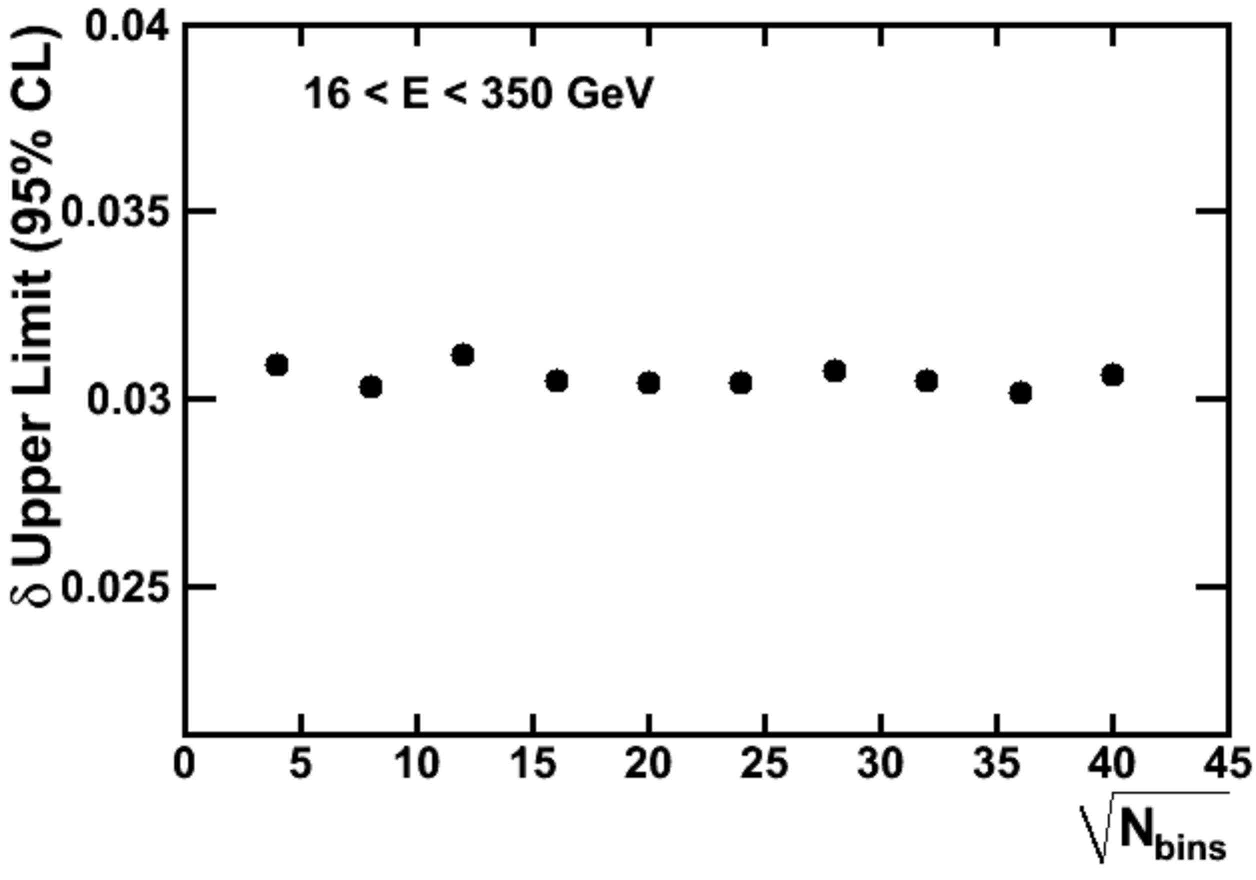
$$\delta = 3\sqrt{\frac{C_1}{4\pi}}$$

AMS upper limits on δ at the 95% CL

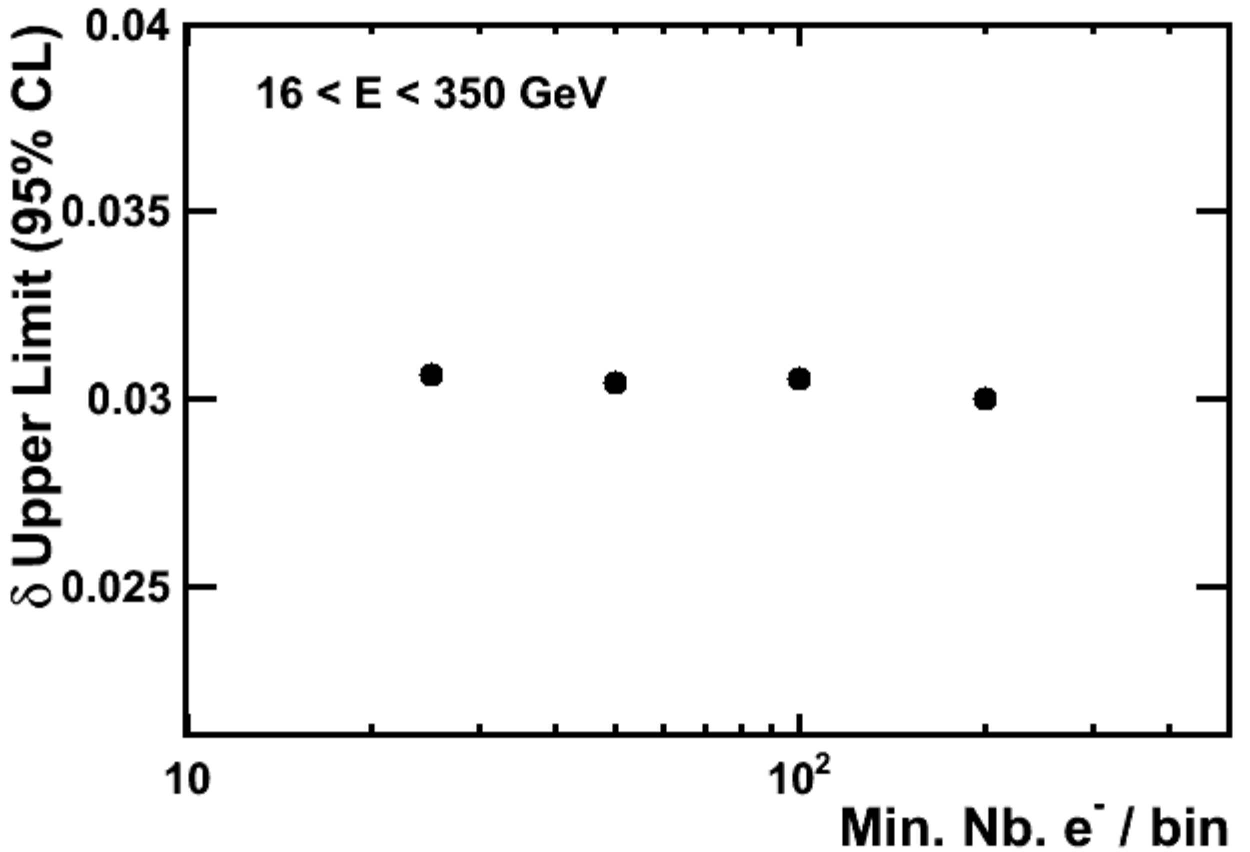


δ<0.030 for 16<E<350GeV

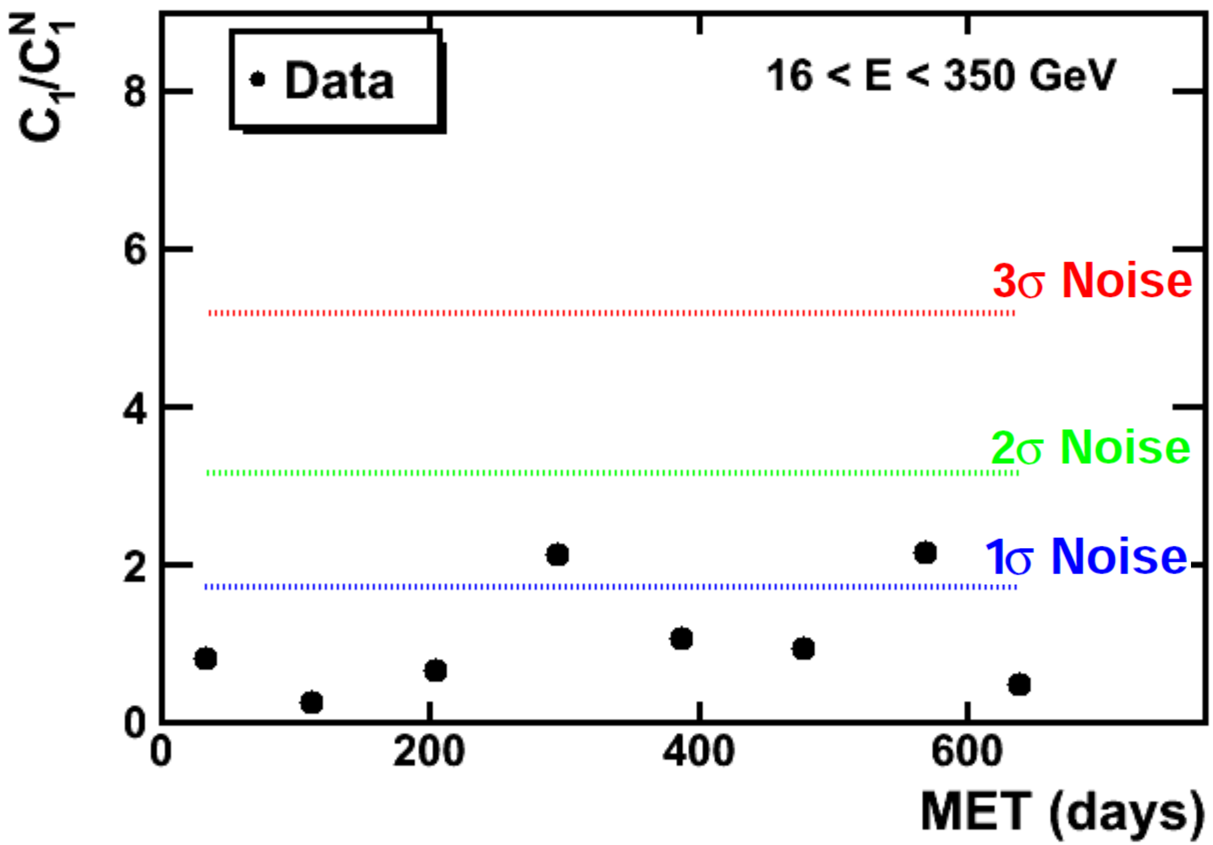
Checks including changes on pixelation scheme, on the angular bin size and the number of masked pixels show no indication of significant systematics



Checks including changes on pixelation scheme, on the angular bin size and the number of masked pixels show no indication of significant systematics



Search for seasonal excess which could reveal a signal of solar origin



No seasonal excess is found

Complete analysis repeated using sky maps in Geocentric Solar Ecliptic Coordinates yields consistent results

Analysis of the positron to proton ratio

Protons provide a high statistics same signed reference for positrons, complementary to electrons.

Same analysis performed using the arrival directions as well as on the asymptotic directions after backtracing their trajectories in the geomagnetic field

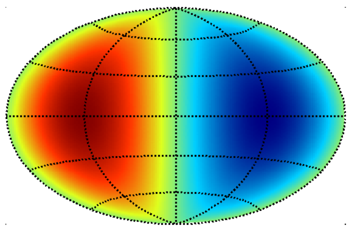
The geomagnetic field model includes IGRF-11 for the internal field and Tsyganenko 1996 and 2005 for the external field

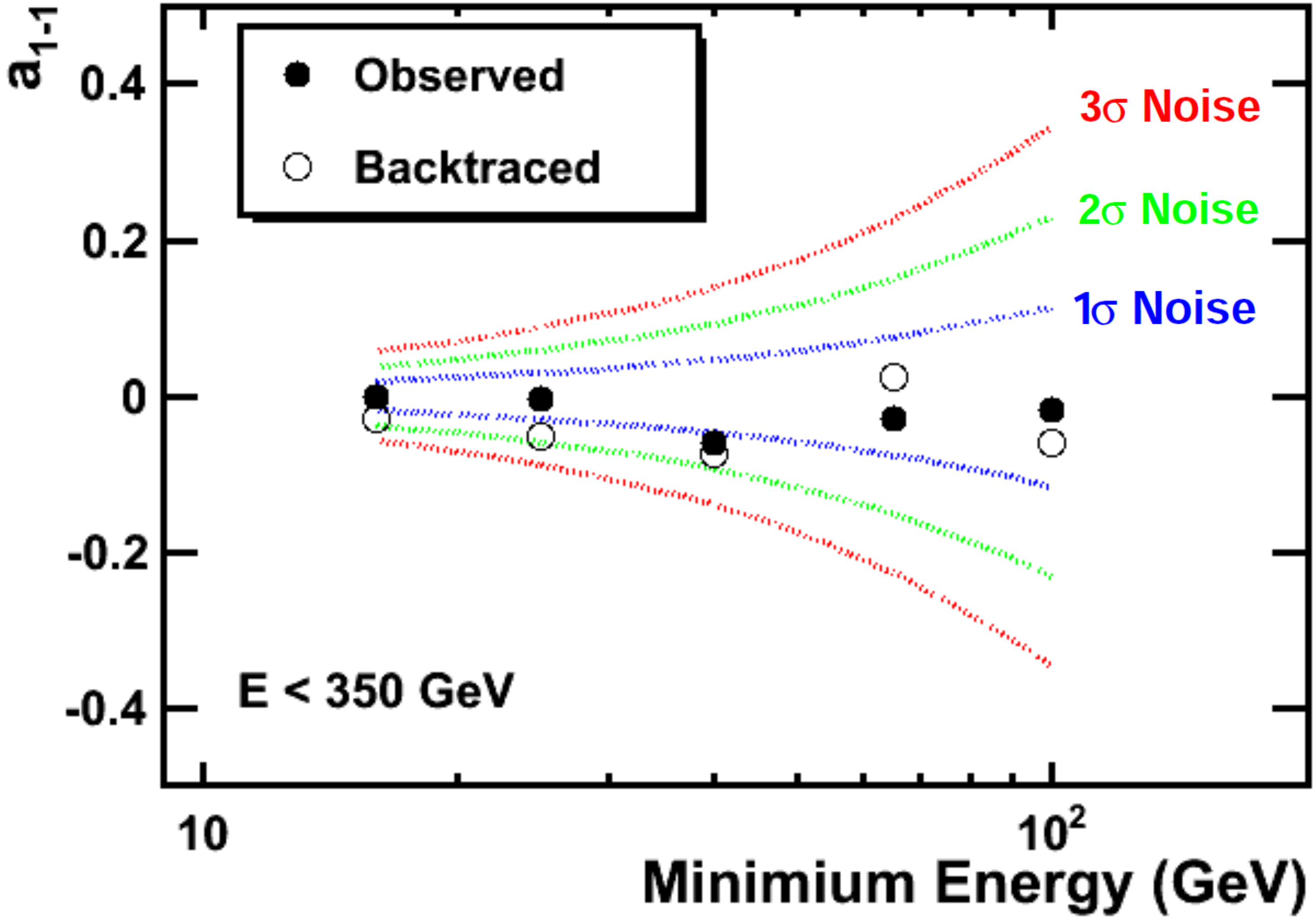
The sensitivity to a dipole anisotropy using the positron to proton ratio is consistent with that obtained on the positron to electron analysis.

Similar sensitivity to a dipole anisotropy is obtained after backtracing their trajectories in the geomagnetic field to the border of the magnetosphere.

No significant anisotropy is observed at any angular scale and energy range and limits to a dipole consistent with those of the e^+/e^- analysis are obtained

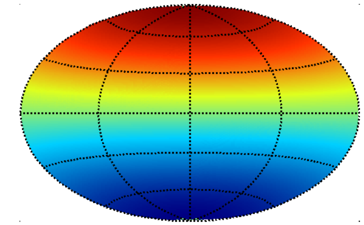
Dipole amplitude a_{1-1}

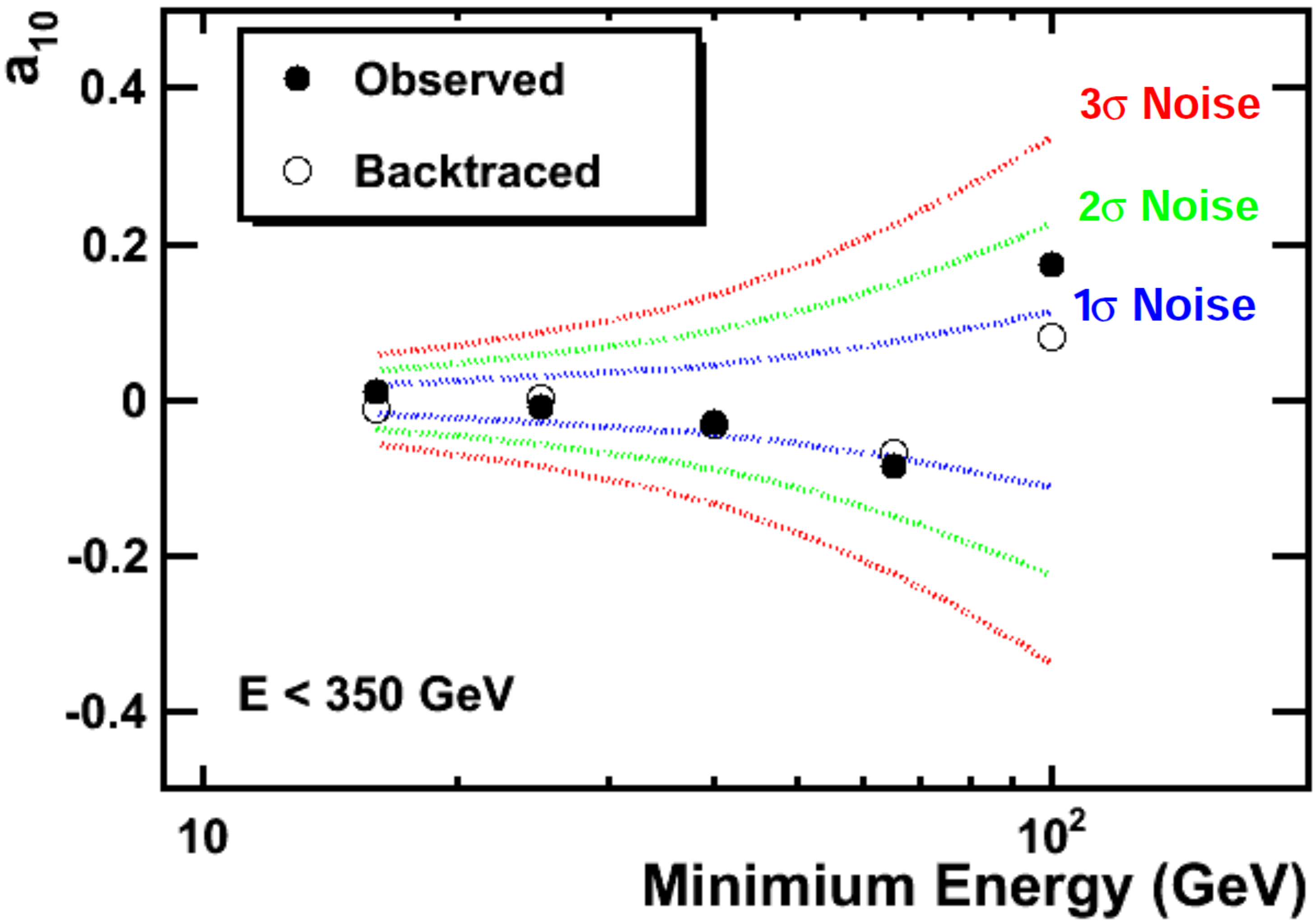




Dipole amplitude a_{10}

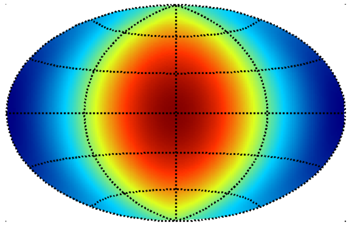
N/S

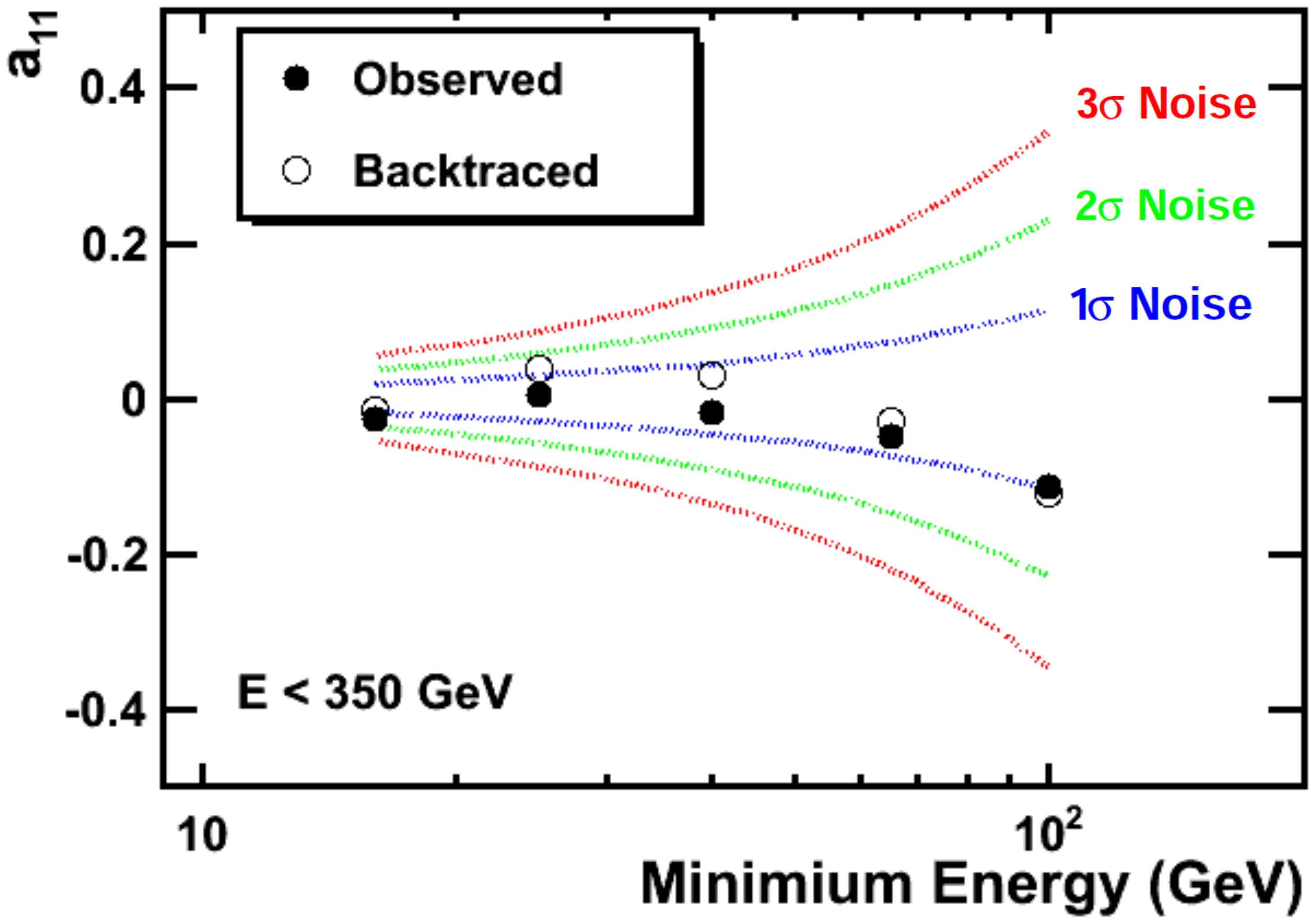




Dipole amplitude a_{11}

F/B





In conclusion, the first 6.8 million primary positron and electron events collected with AMS on the ISS show:

I. At energies <10GeV, a decrease in the positron fraction with increasing energy.

II. A steady increase in the positron fraction from 10 to ~250 GeV.

III. The determination of the behavior of the positron fraction from 250 to 350 GeV and beyond requires more statistics.

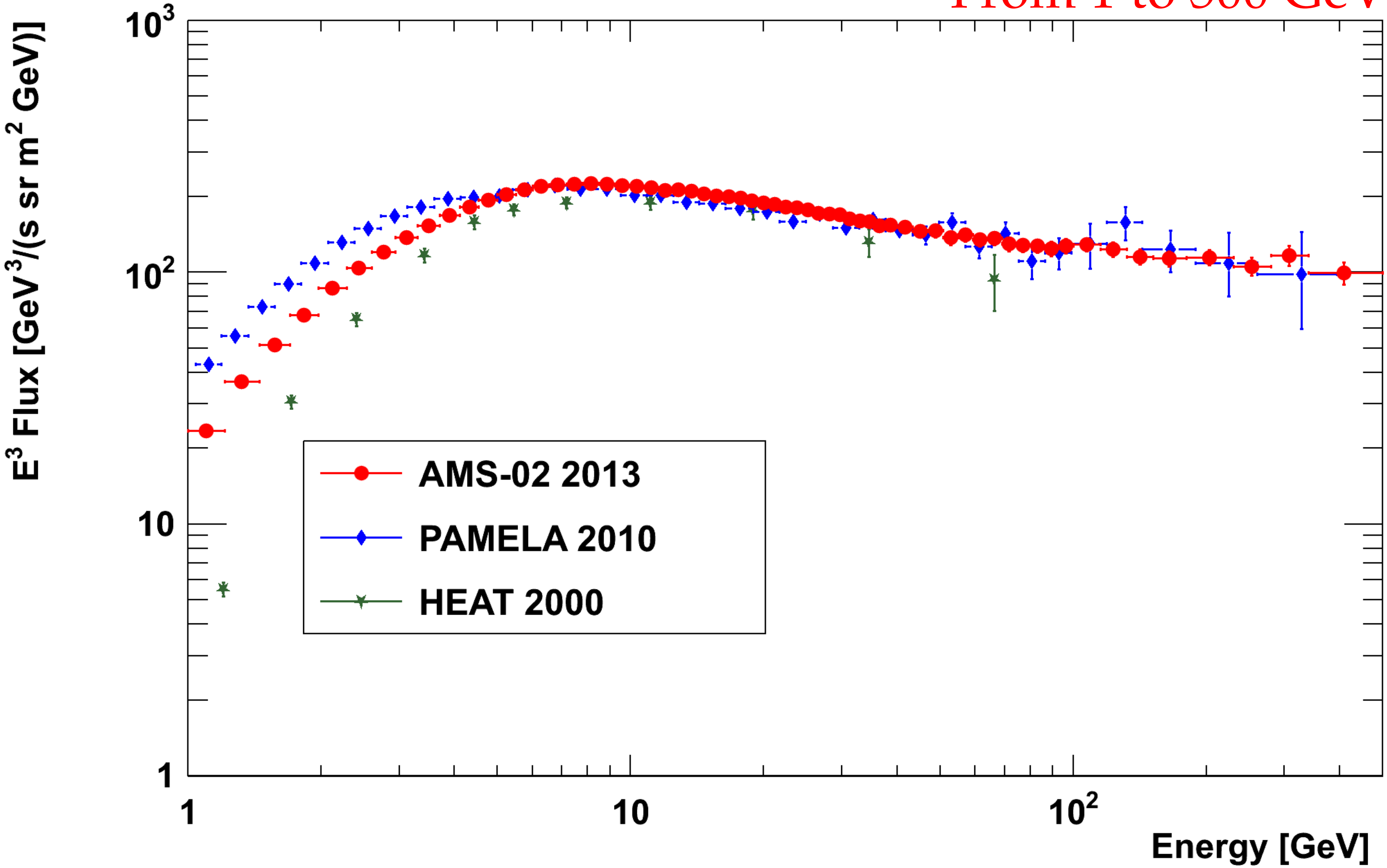
IV. The slope of the positron fraction versus energy decreases by an order of magnitude from 20 to 250 GeV and no fine structure is observed. The positron fraction spectrum is consistent with $e^{\pm}$ fluxes each of which is the sum of its diffuse spectrum and a single common power law source.

V. No anisotropy is found on the positron to electron ratio in the energy range from 16 to 350 GeV on sky maps built on their arrival directions in galactic or solar coordinates. A limit on the dipole component $\delta<0.030$ at the 95% CL is set.

VI. Consistent results are obtained on the positron to proton ratio, e^{+}/p, and equivalent limits are computed at the border of the magnetosphere.

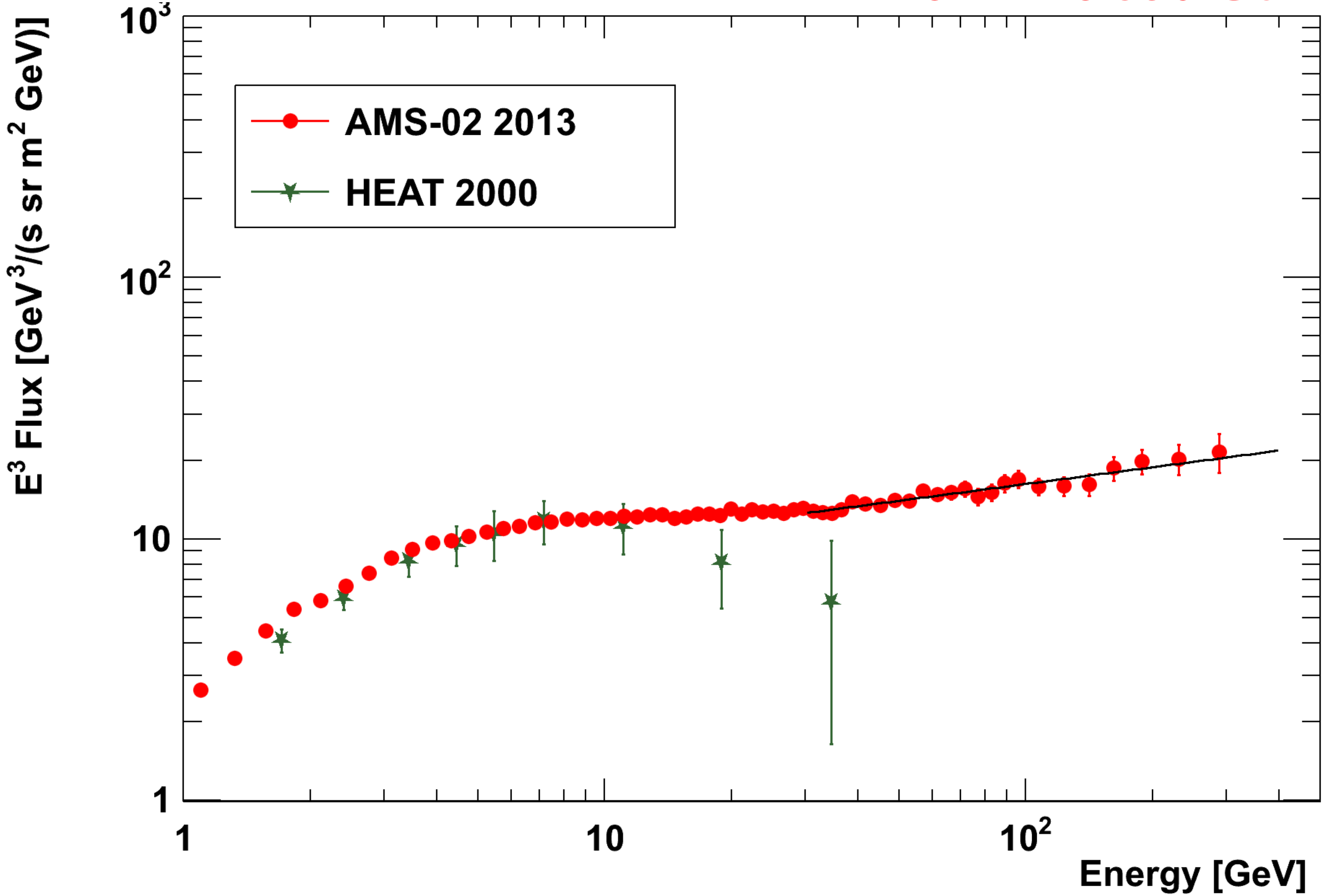
Electron Flux

From 1 to 500 GeV



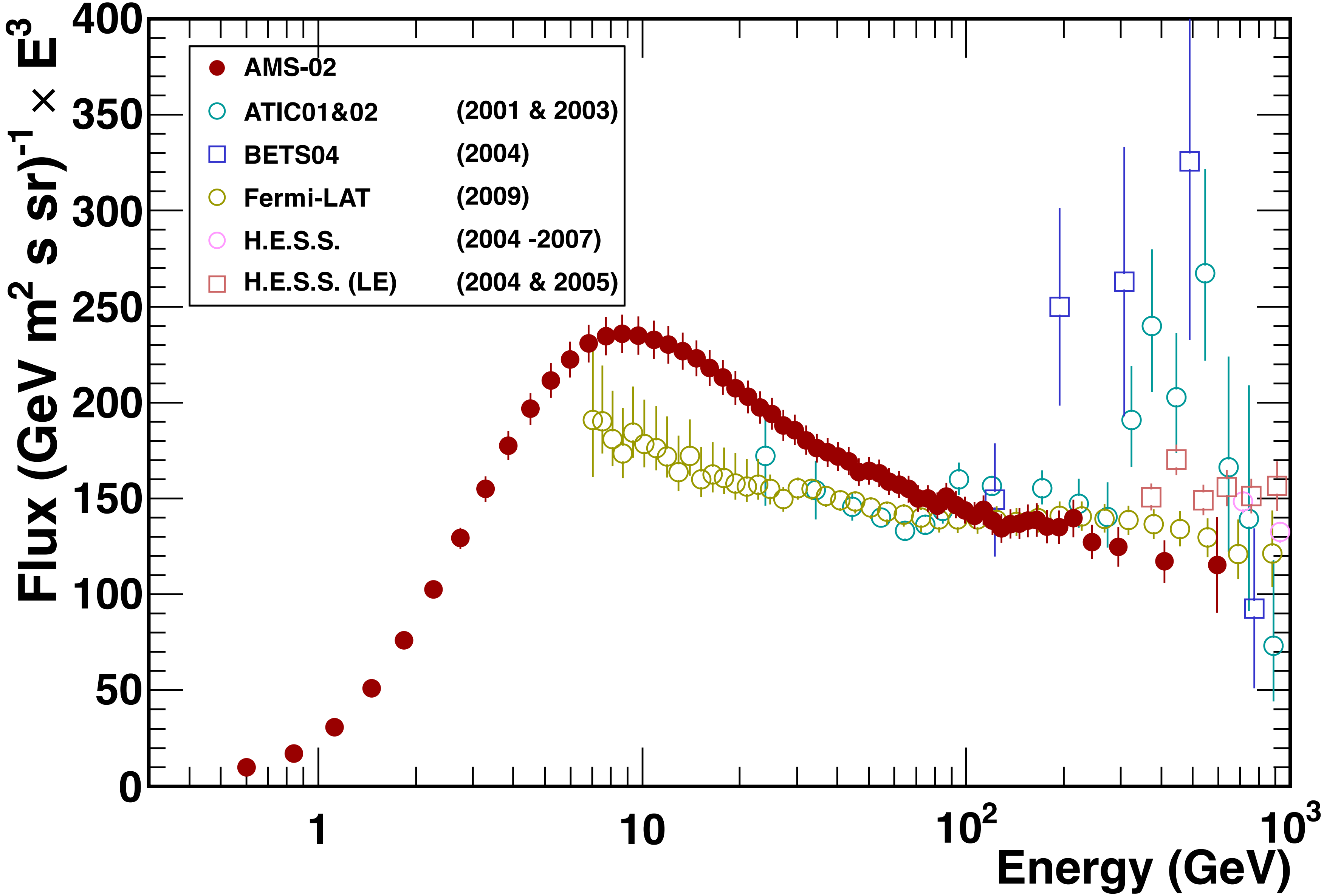
Positron Flux

From 1 to 350 GeV



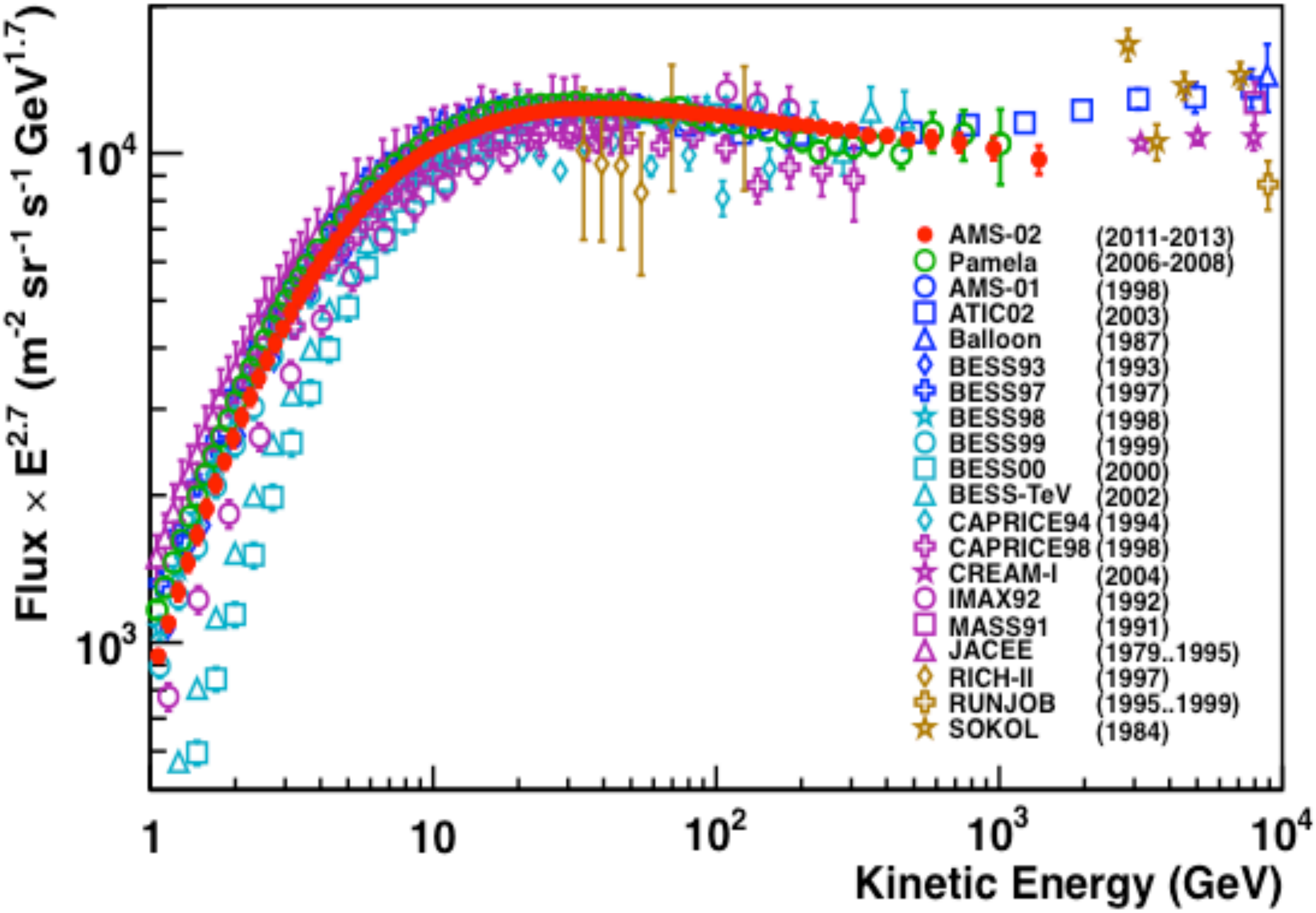
(Electron plus Positron) Flux

From 1 to 700 GeV

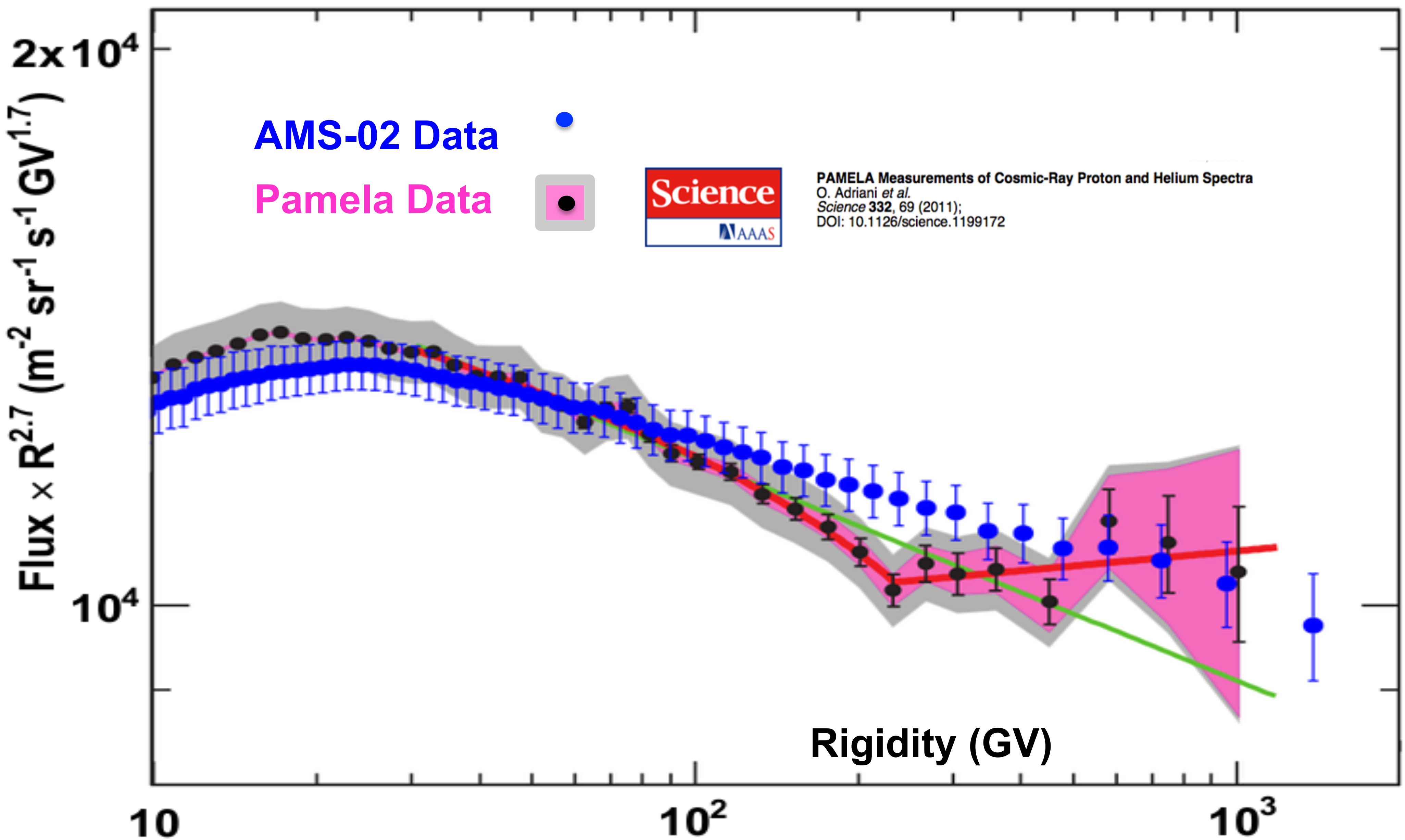


Proton Flux

From 1 GV to 1.8 TV



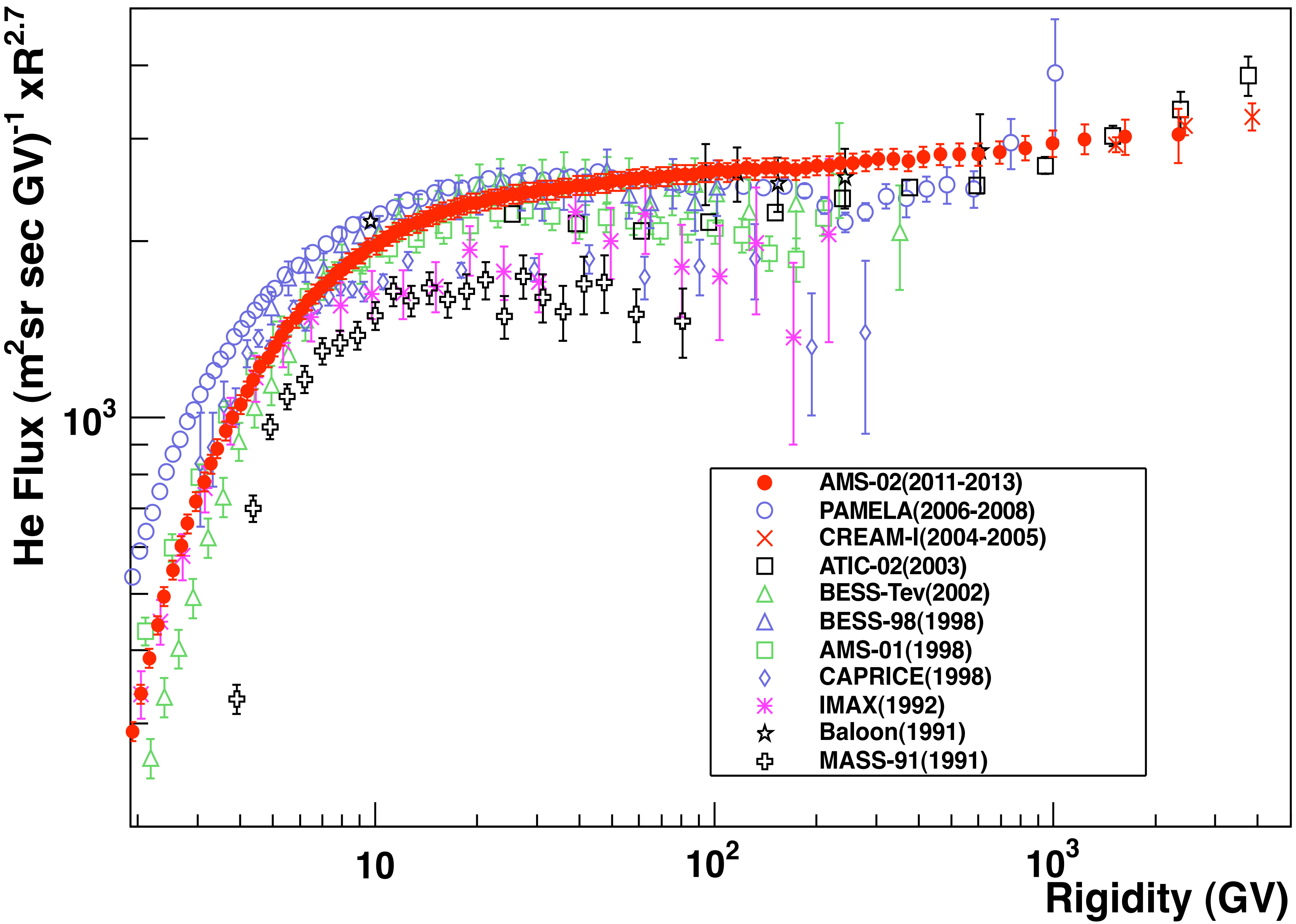
Proton Flux



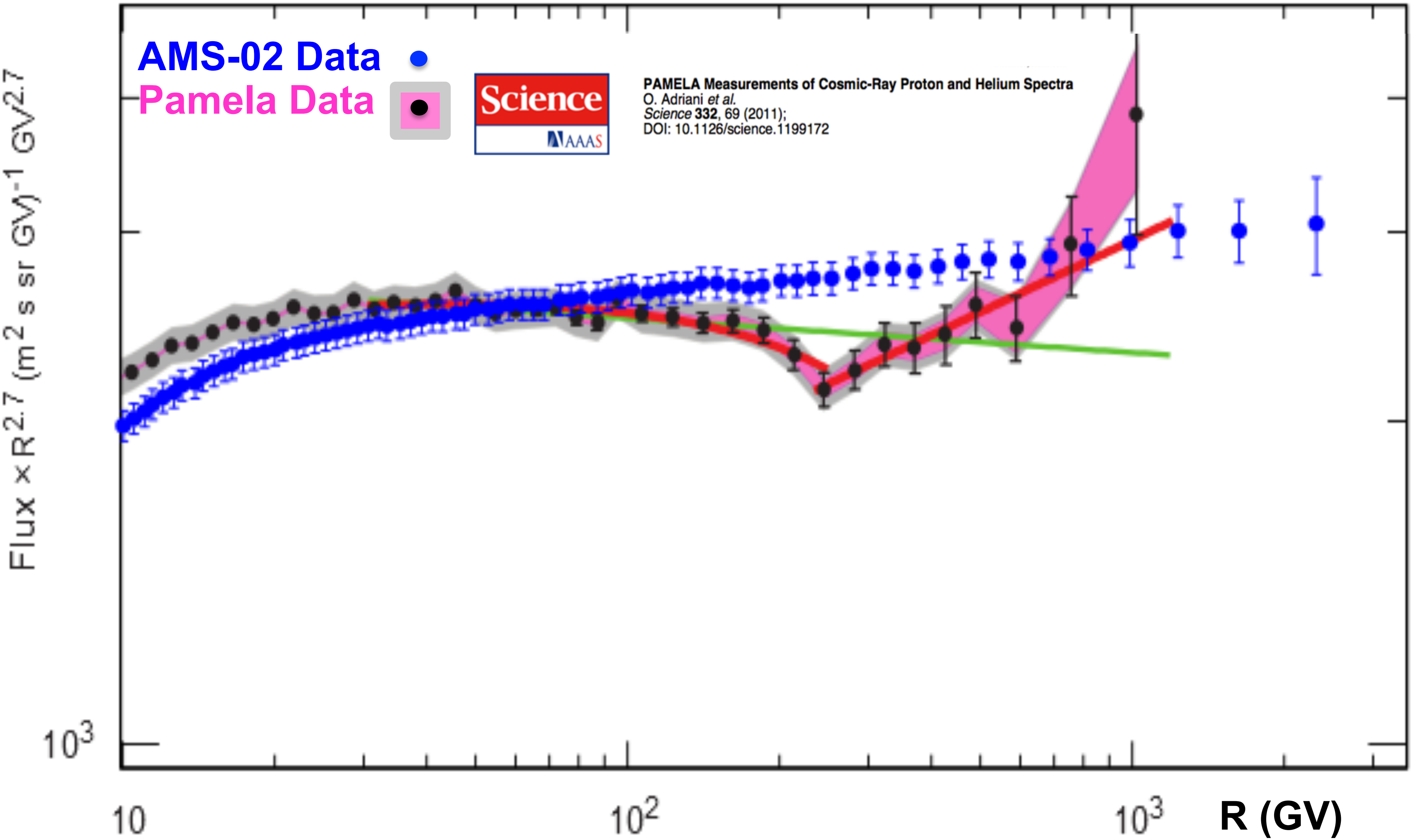
2x10^4
10^4
Flux × R^2.7 (m^-2 sr^-1 s^-1 GV^1.7)
AMS-02 Data
Pamela Data
Science
AAAS
PAMELA Measurements of Cosmic-Ray Proton and Helium Spectra
O. Adriani et al.
Science 332, 69 (2011);
DOI: 10.1126/science.1199172
Rigidity (GV)
10
10^2
10^3

Helium Flux

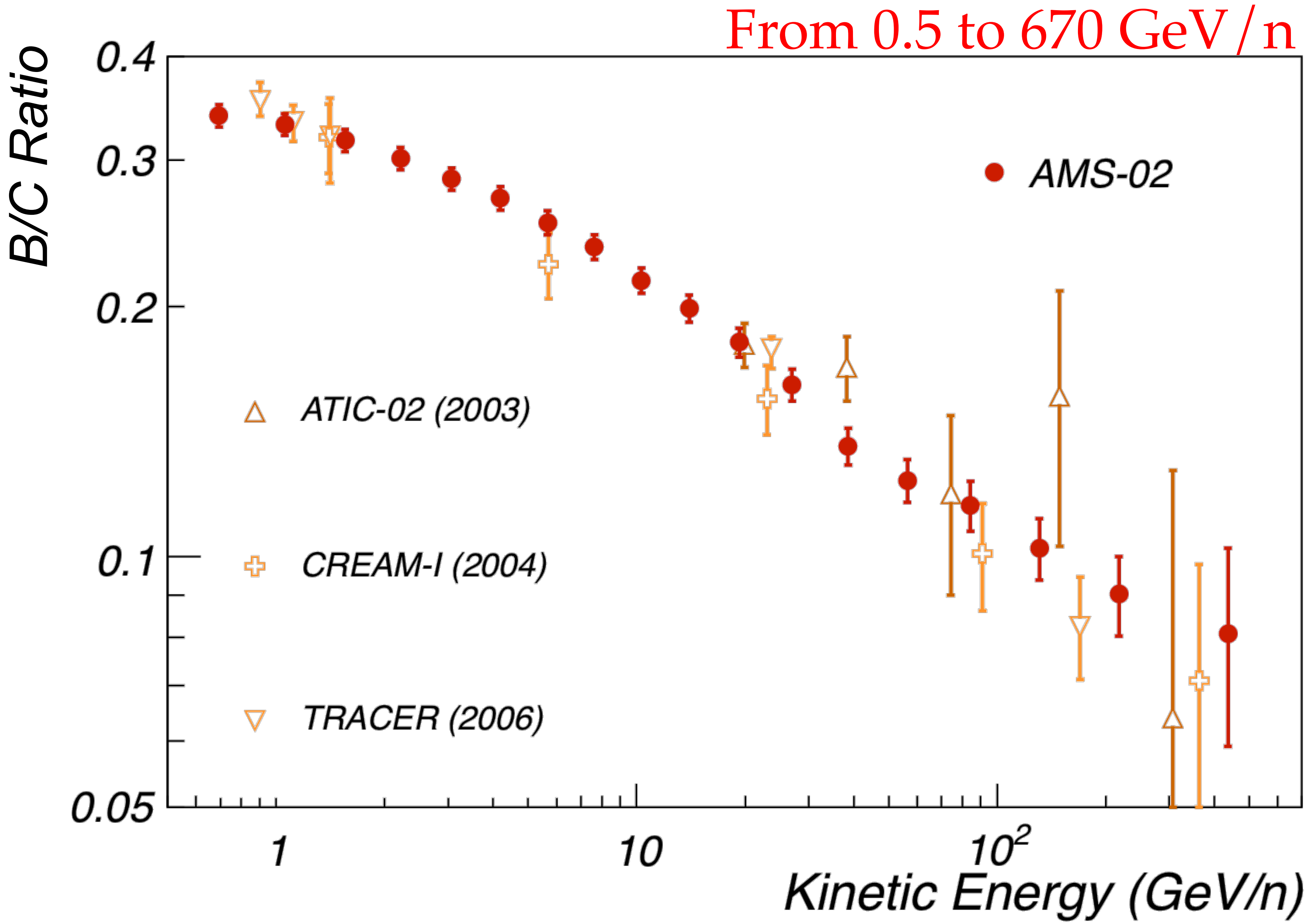
From 2 GV to 3 TV



Helium Flux


AMS-02 Data
Pamela Data
Science
AAAS
PAMELA Measurements of Cosmic-Ray Proton and Helium Spectra
O. Adriani et al.
Science 332, 69 (2011);
DOI: 10.1126/science.1199172
Flux × R^2.7 (m^2 s sr GV)^-1 GV^2.7
10^3
10
10^2
10^3
R (GV)

Boron to Carbon Ratio



Summary

- The positron fraction is determined in the energy range from 0.5 to 350GeV and its energy spectrum shows an steadily increasing fraction from 10 to ~250GeV with no fine structure. The positron to electron and positron to proton ratios are consistent with isotropy.
- Electron, positron and electon plus positron fluxes show a consistent picture, with a break in the positron spectrum at 30 GeV.
- Proton and helium fluxes show no break in their spectrum.
- Boron to carbon ratio is consistent with previous measurements.

Uncertainties at high energy come from limited statistics.

AMS-02 has collected 10% of its target data sample.