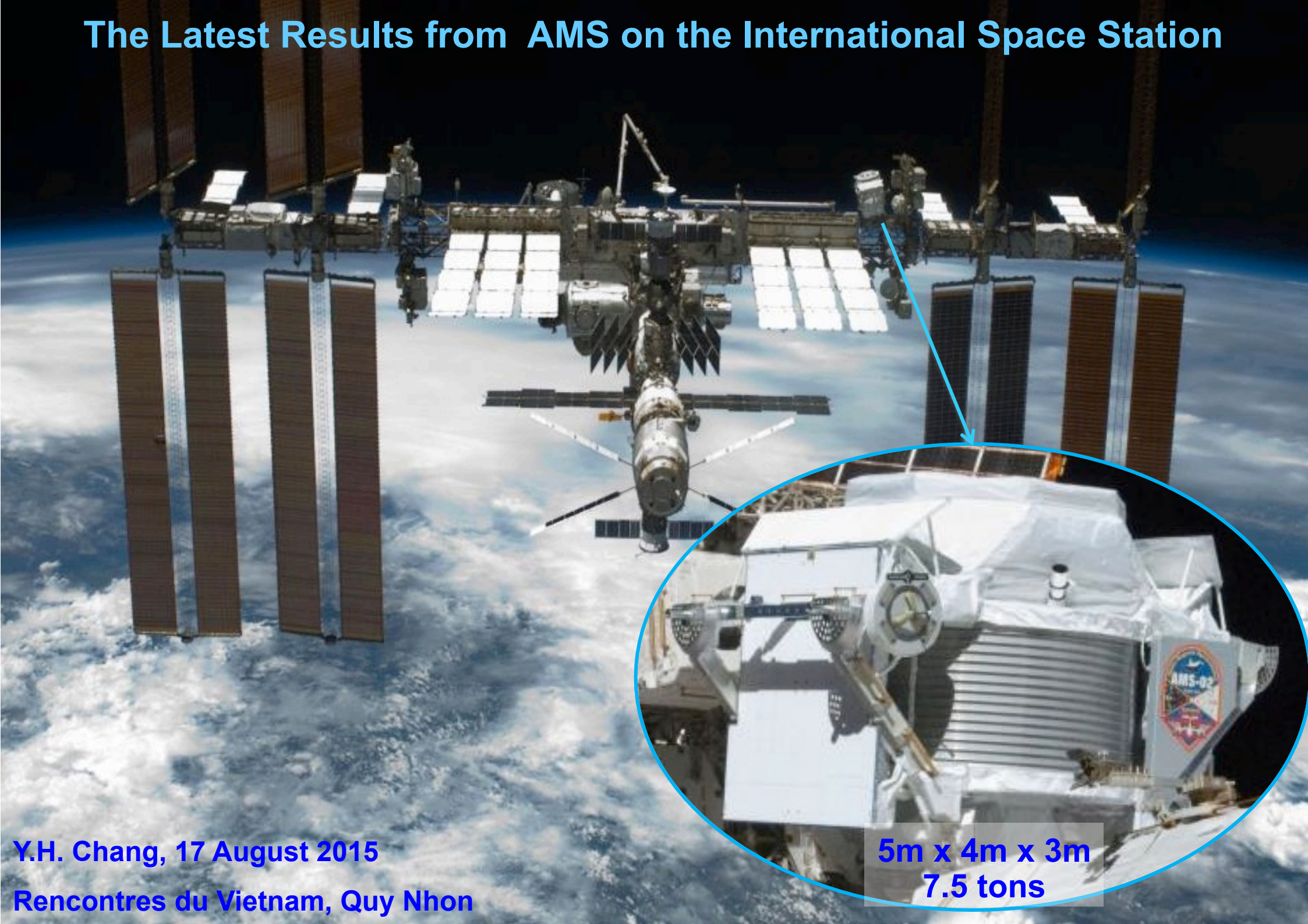
The Latest Results from AMS on the International Space Station



Y.H. Chang, 17 August 2015

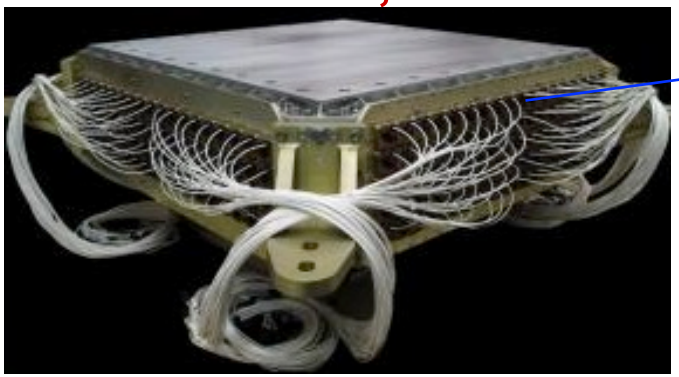
Rencontres du Vietnam, Quy Nhon

AMS: A TeV precision, multipurpose spectrometer

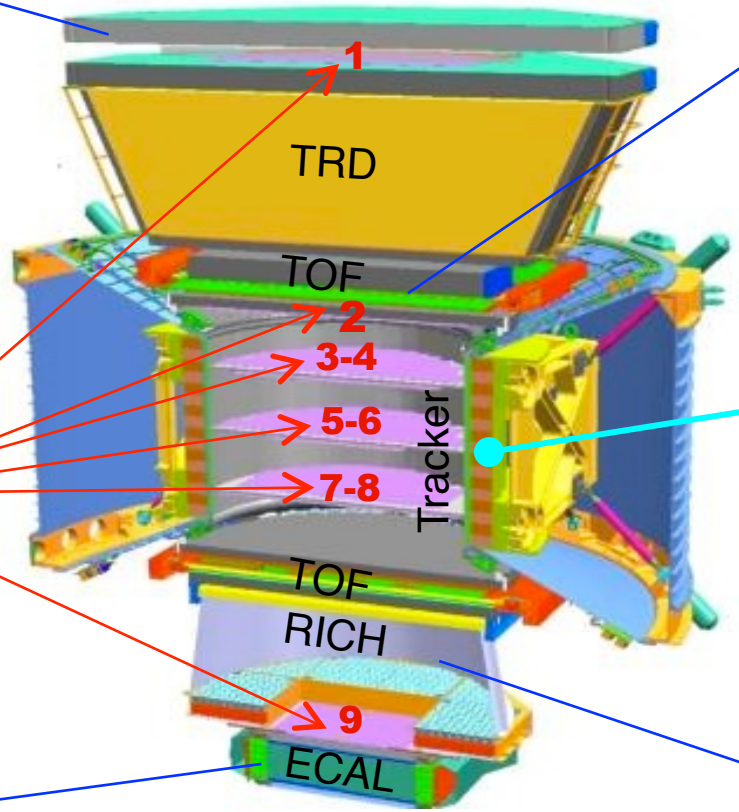
TRD
Identify e^+, e^-

Silicon Tracker
Z, P

ECAL
E of e^+, e^-



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



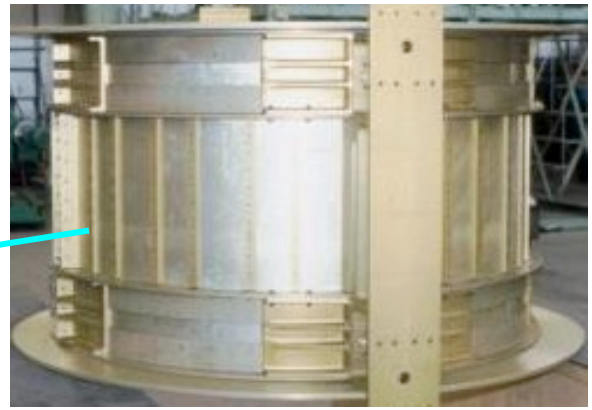
Z and P ~ E

are measured independently by the

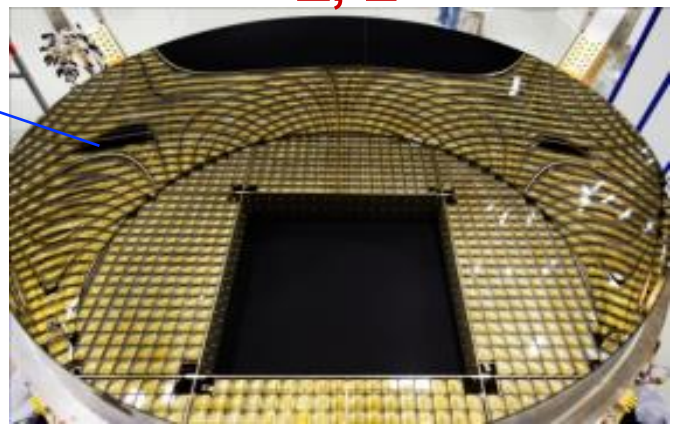
Tracker, RICH, TOF and ECAL

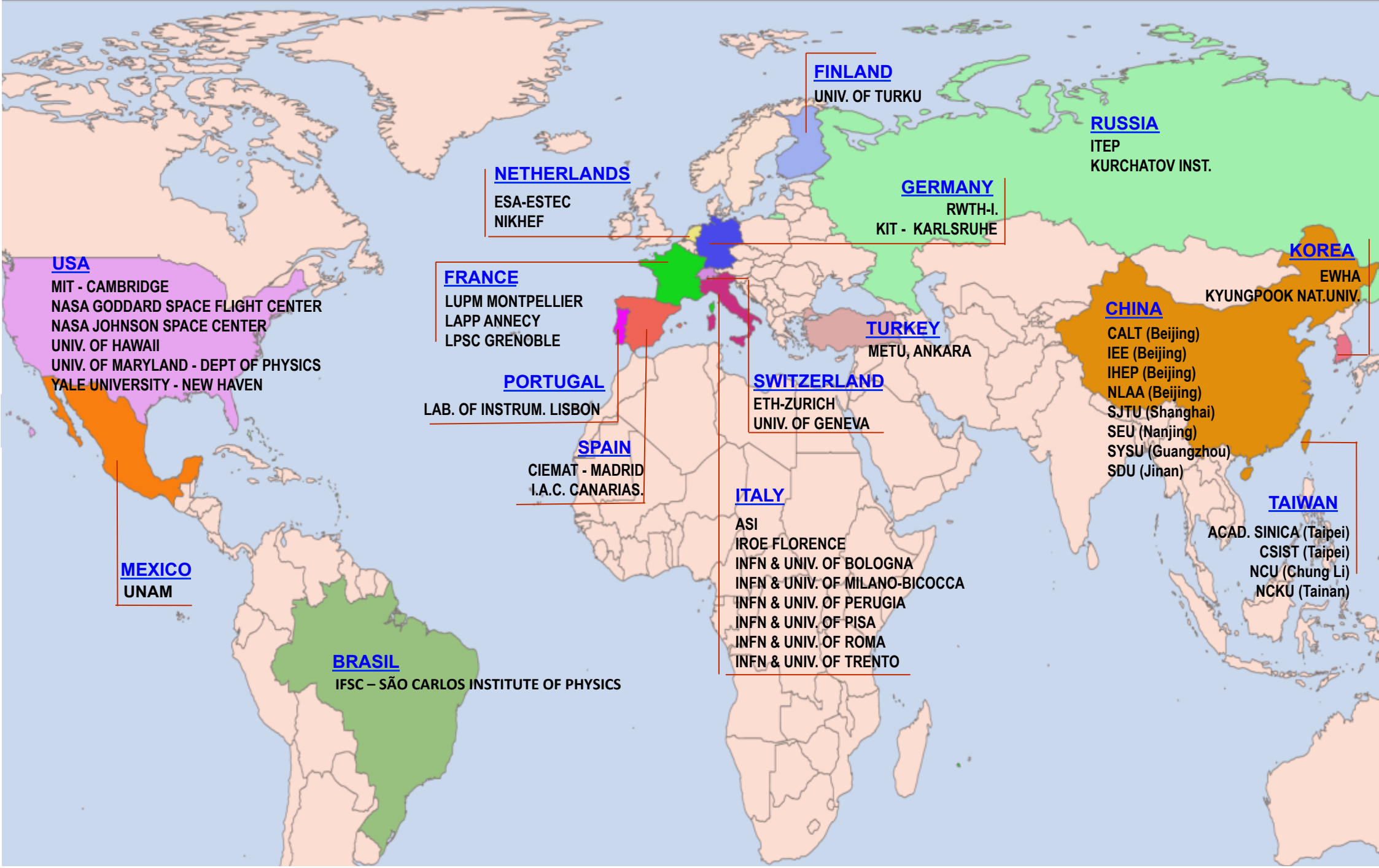
TOF
Z, E

Magnet
±Z



RICH
Z, E

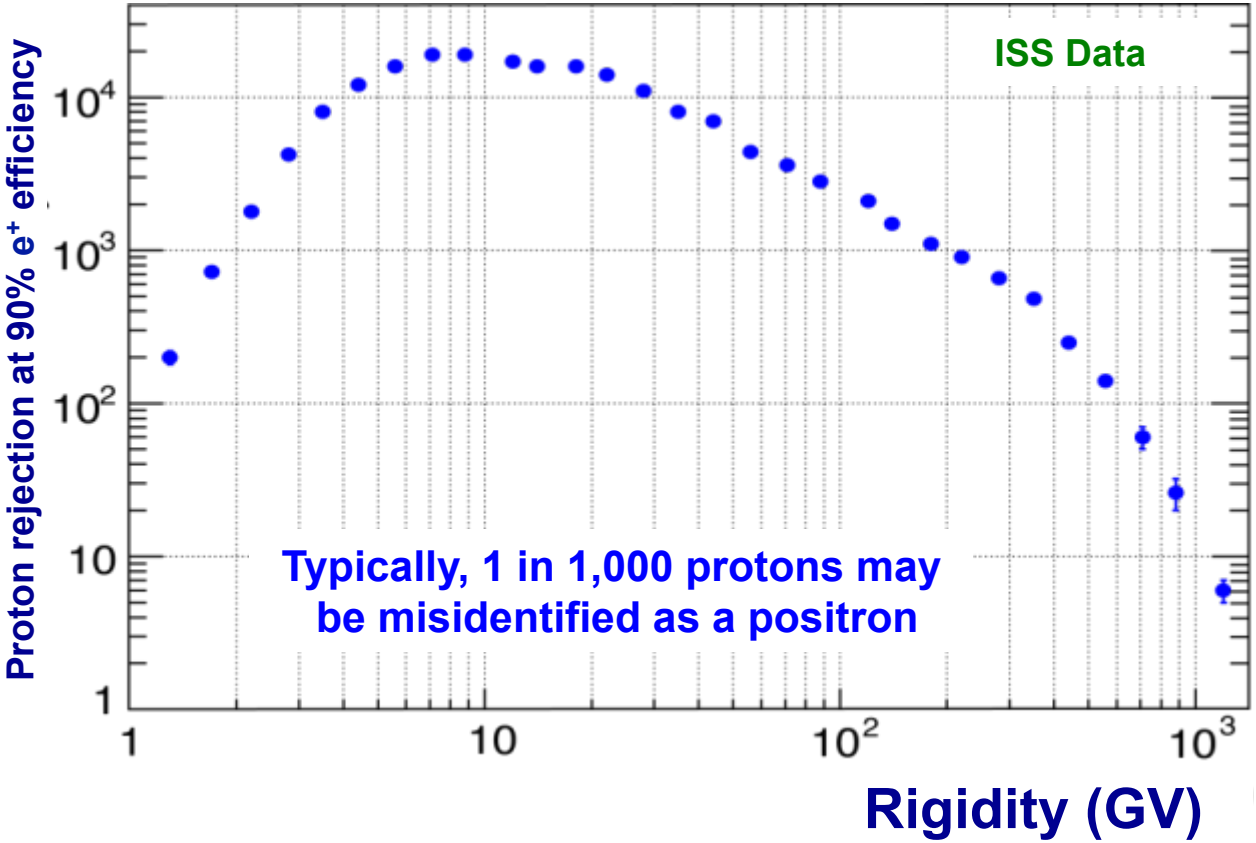


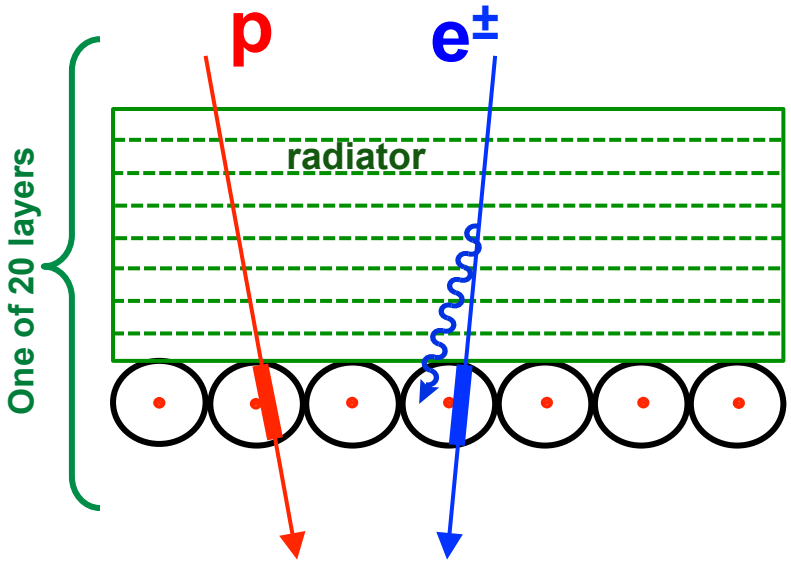


AMS is a U.S. DOE sponsored international collaboration

Transition Radiation Detector

20 layers: fleece radiator and proportional tubes





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

Normalized Probabilities

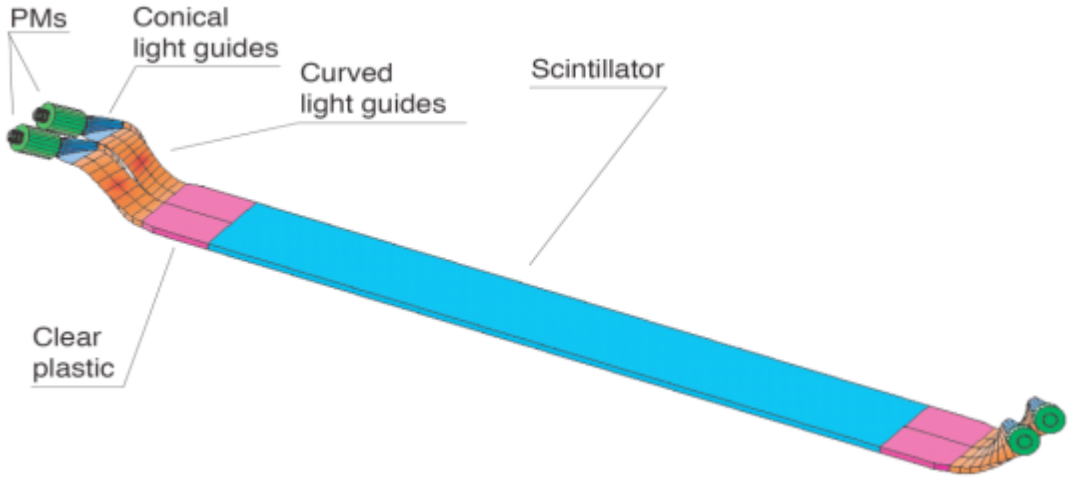
TRD estimator = $-\ln(P_e/(P_e+P_p))$

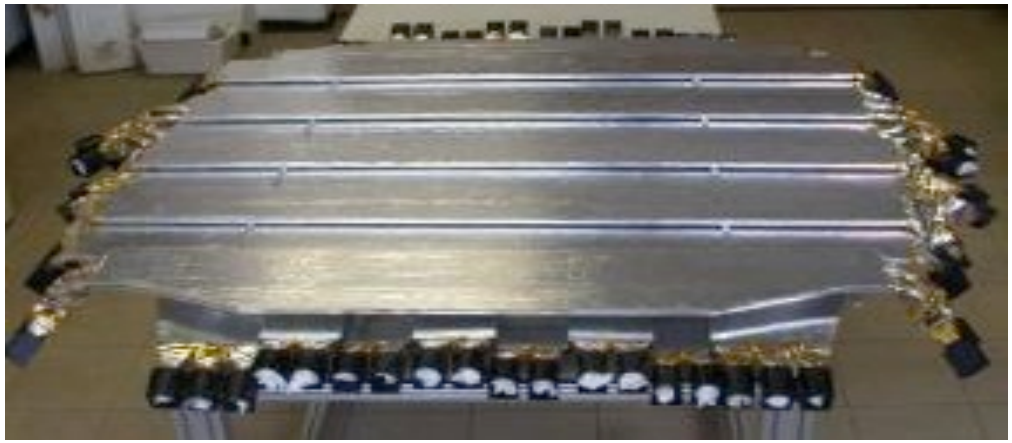
TRD likelihood = $-\mathrm{Log}_{10}(P_e)$

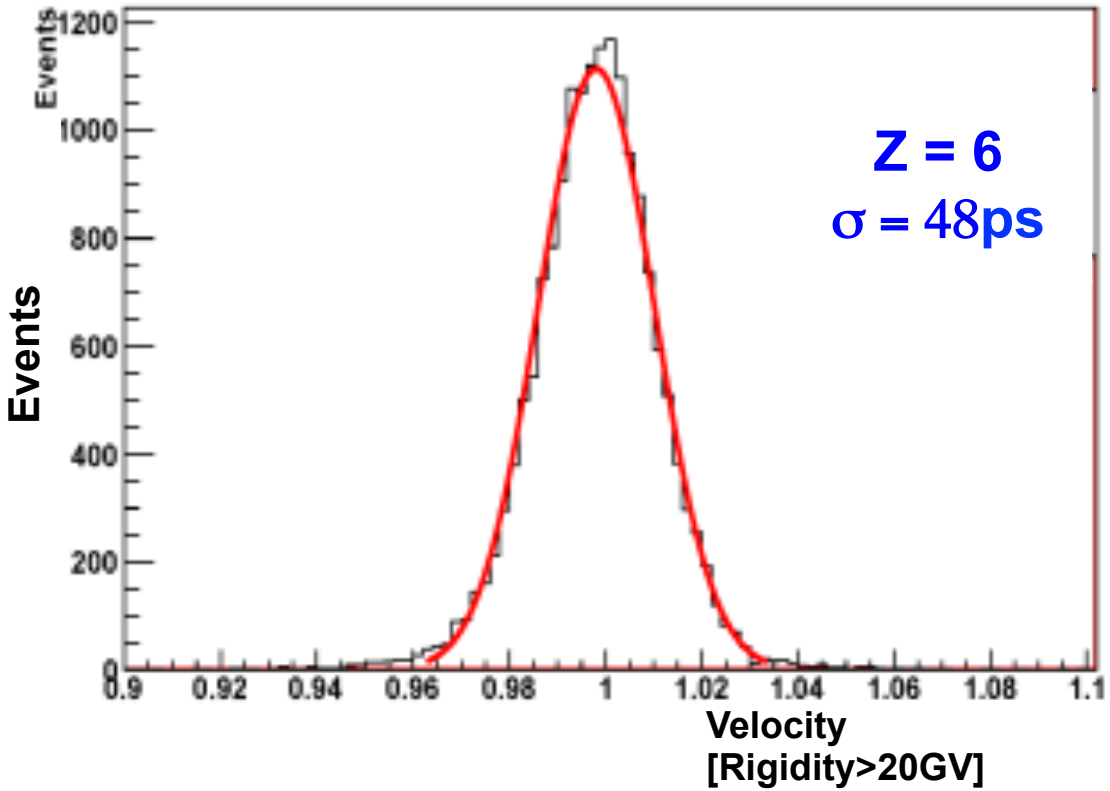
TRD classifier = $-\mathrm{Log}_{10}(P_e)-2$

Time of Flight System

Measures Velocity and Charge of particles



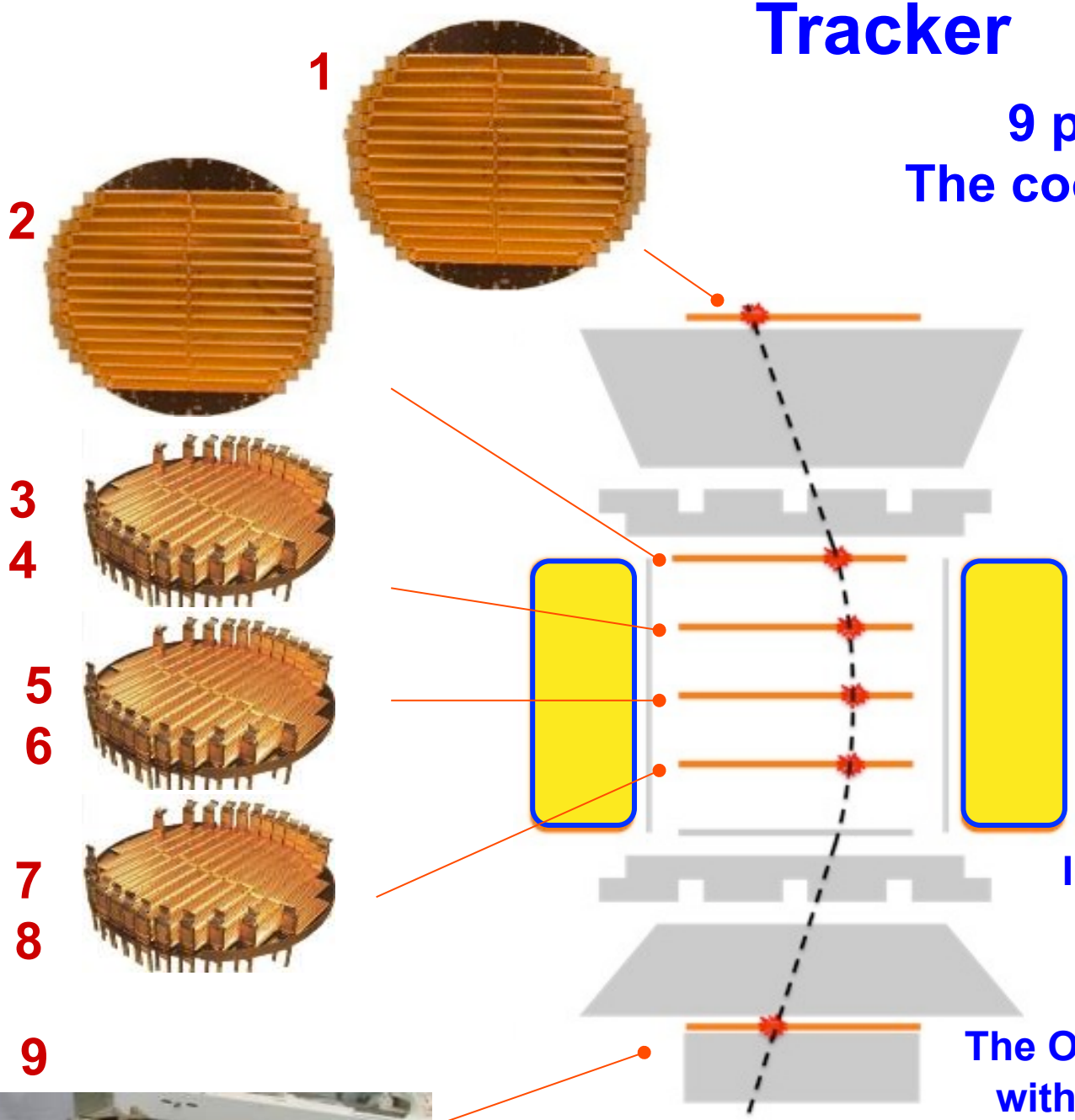


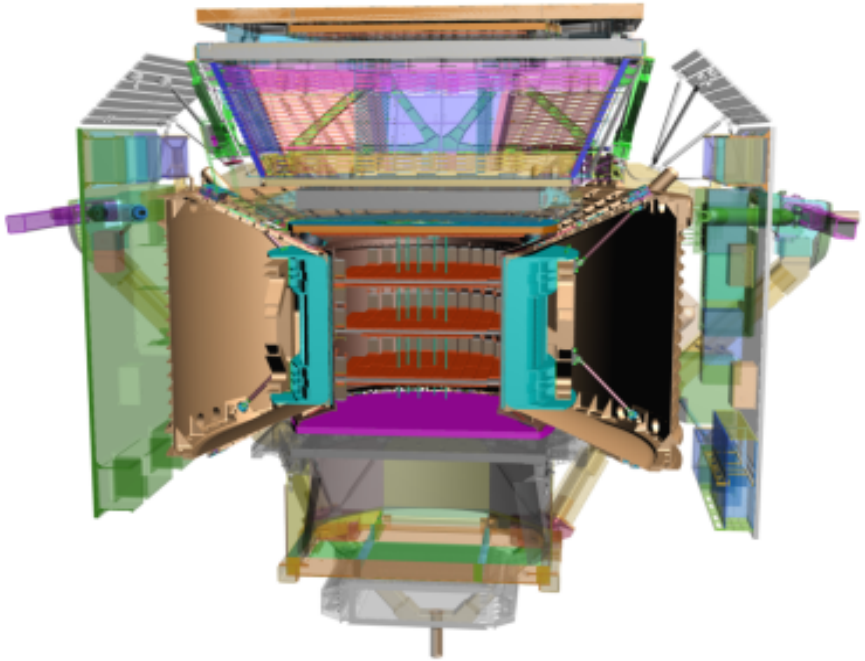


A. Contin, G. Laurenti, F. Palmonari

Tracker

9 planes, 200,000 channels
The coordinate resolution is 10 μm.





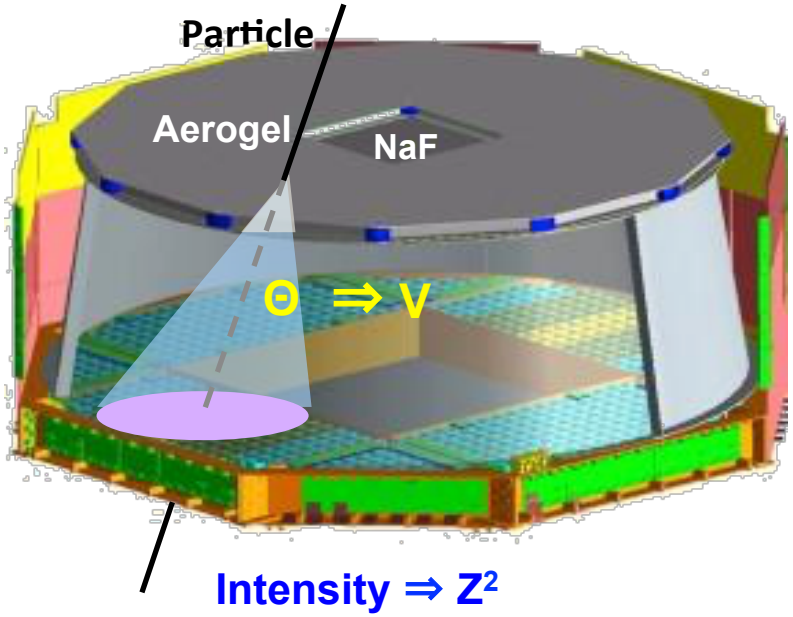
Inner tracker alignment stability monitored with IR Lasers.

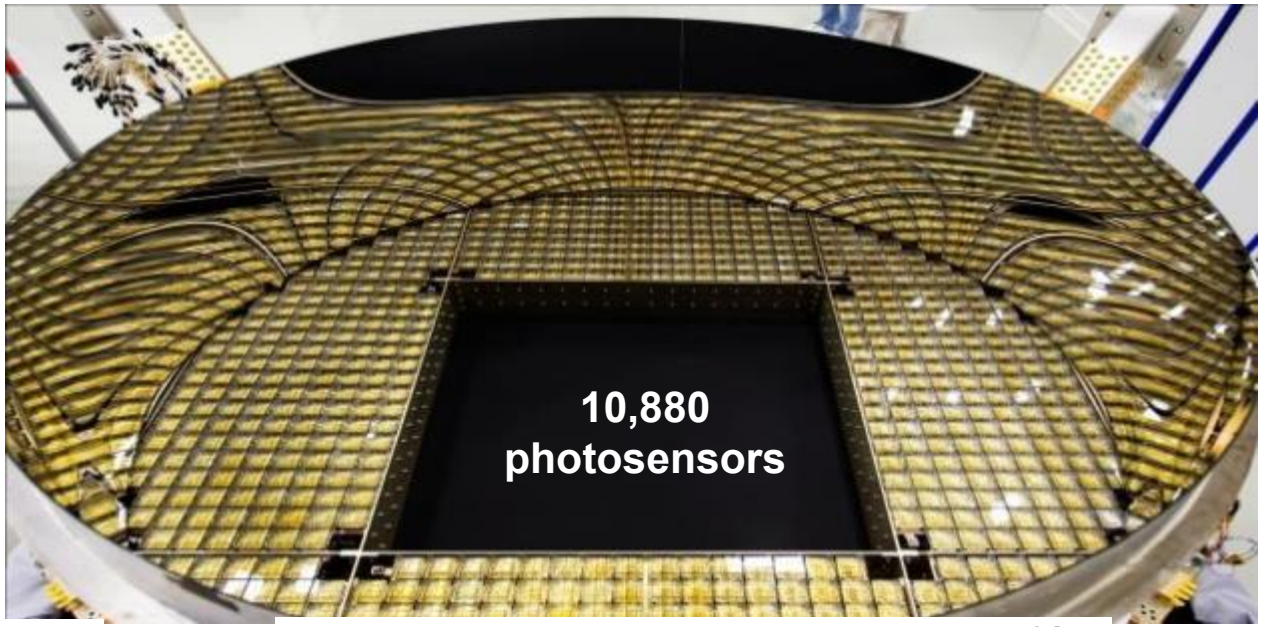
The Outer Tracker is continuously aligned with cosmic rays in a 2 minute window

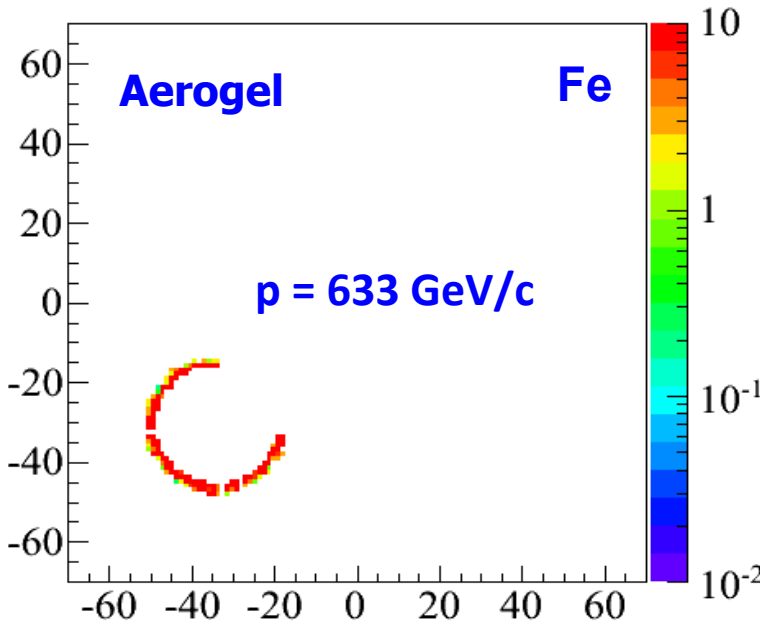
R. Battiston, G. Ambrosi, B. Bertucci

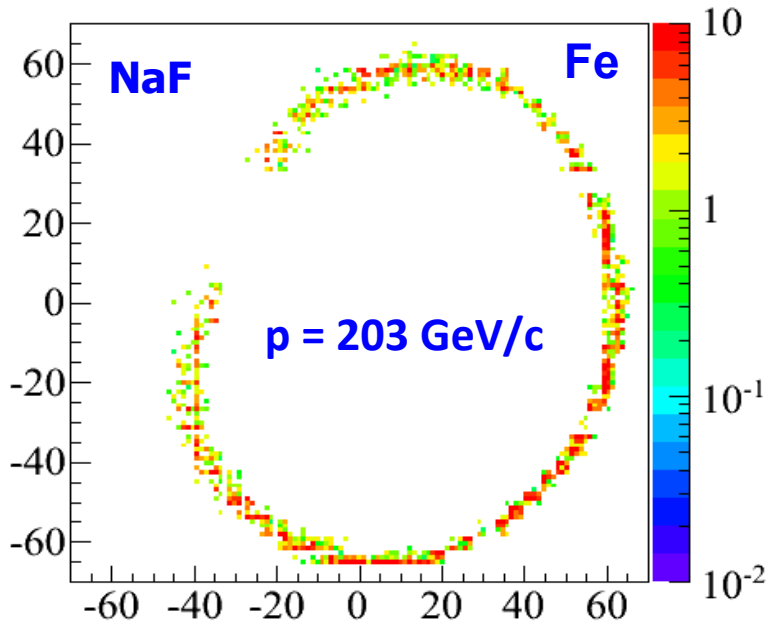
Ring Imaging CHerenkov (RICH)

Measurement of Nuclear Charge (Z^2) and its Velocity to 1/1000





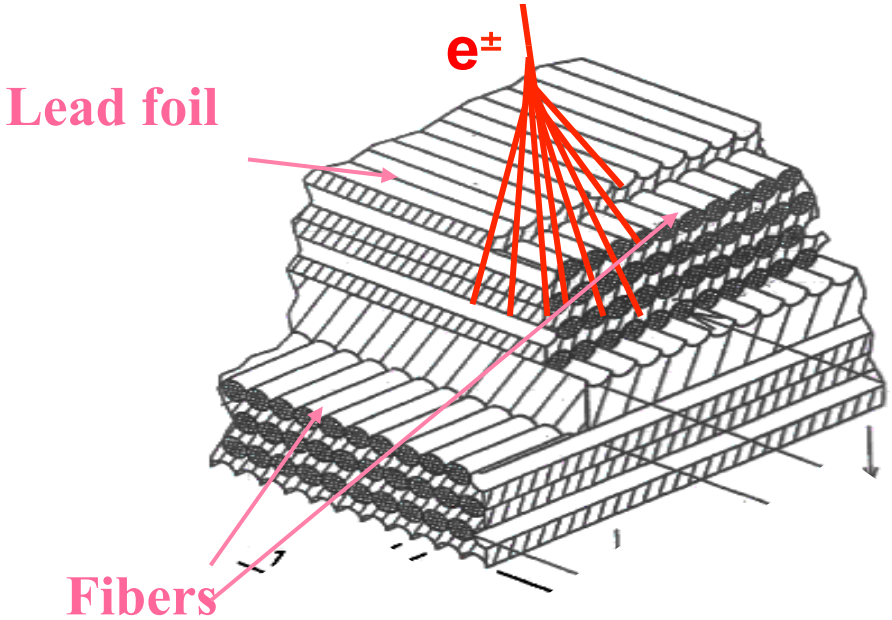


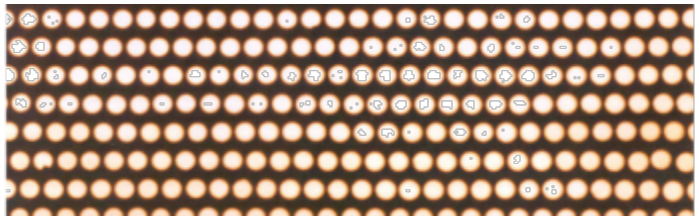


J. Berdugo, G. Laurenti

Electromagnetic Calorimeter

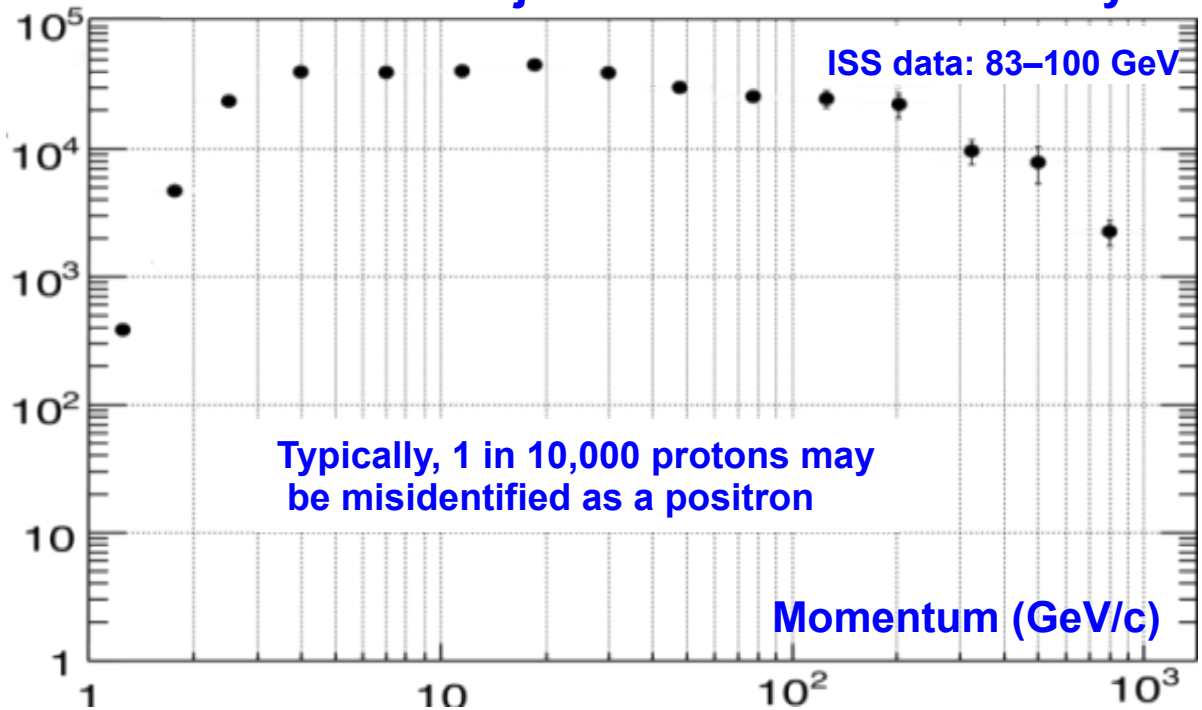
provides a precision, 17 X_0, TeV, 3-dimensional measurement of the directions and energies of electrons and positrons





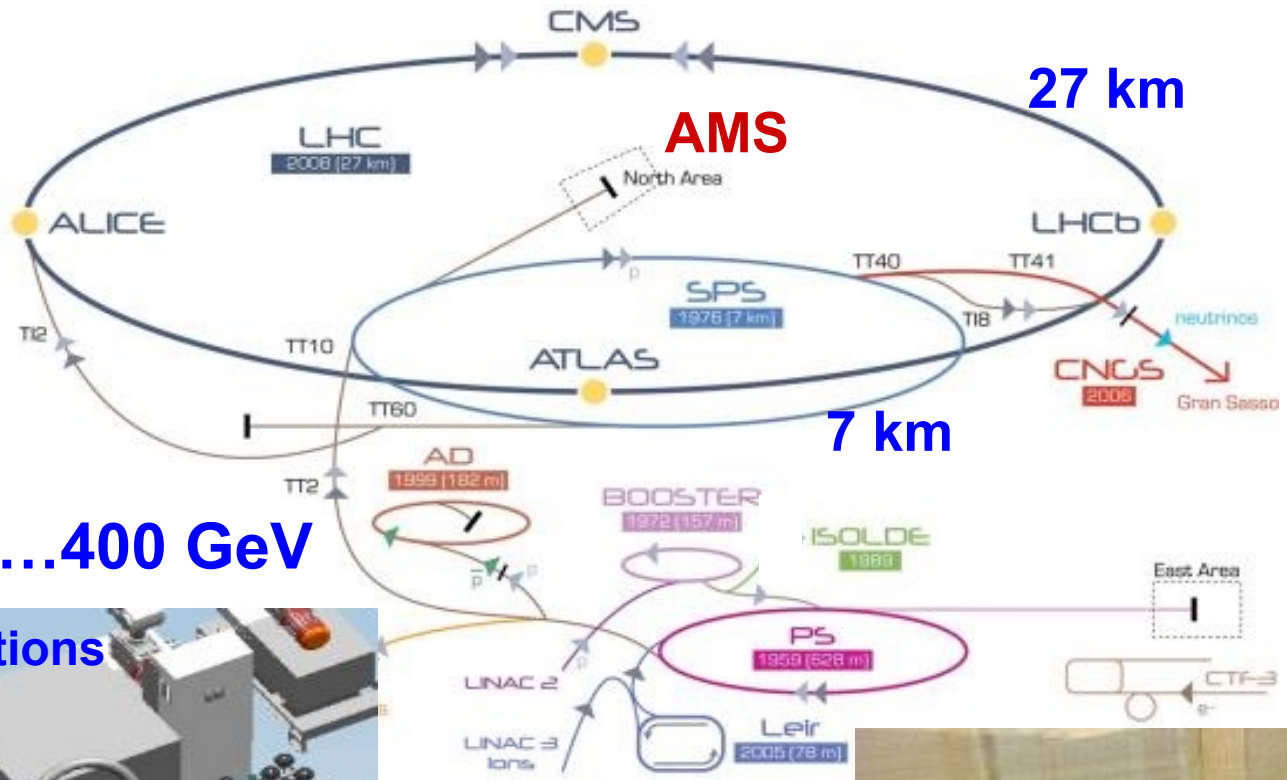
50 000 fibers, $\phi = 1$ mm distributed uniformly inside 600 Kg of lead

Proton rejection at 90% e^+ efficiency

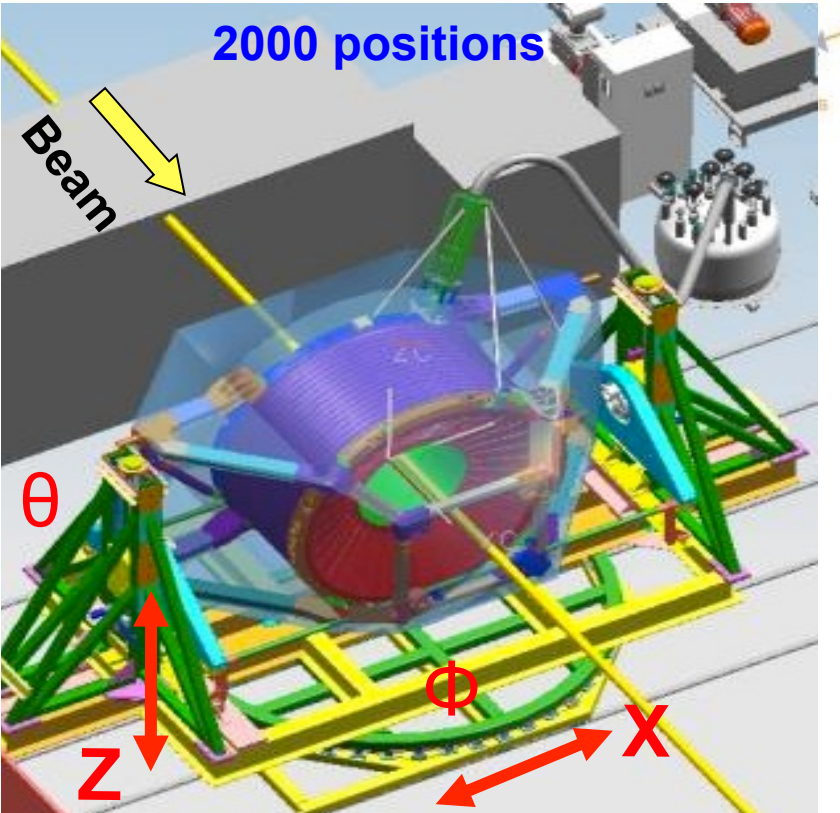


F. Cervelli, S. Rosier-Lees, H.S. Chen

Extensive tests and calibration at CERN



p, e^+, e^-, π 20…400 GeV



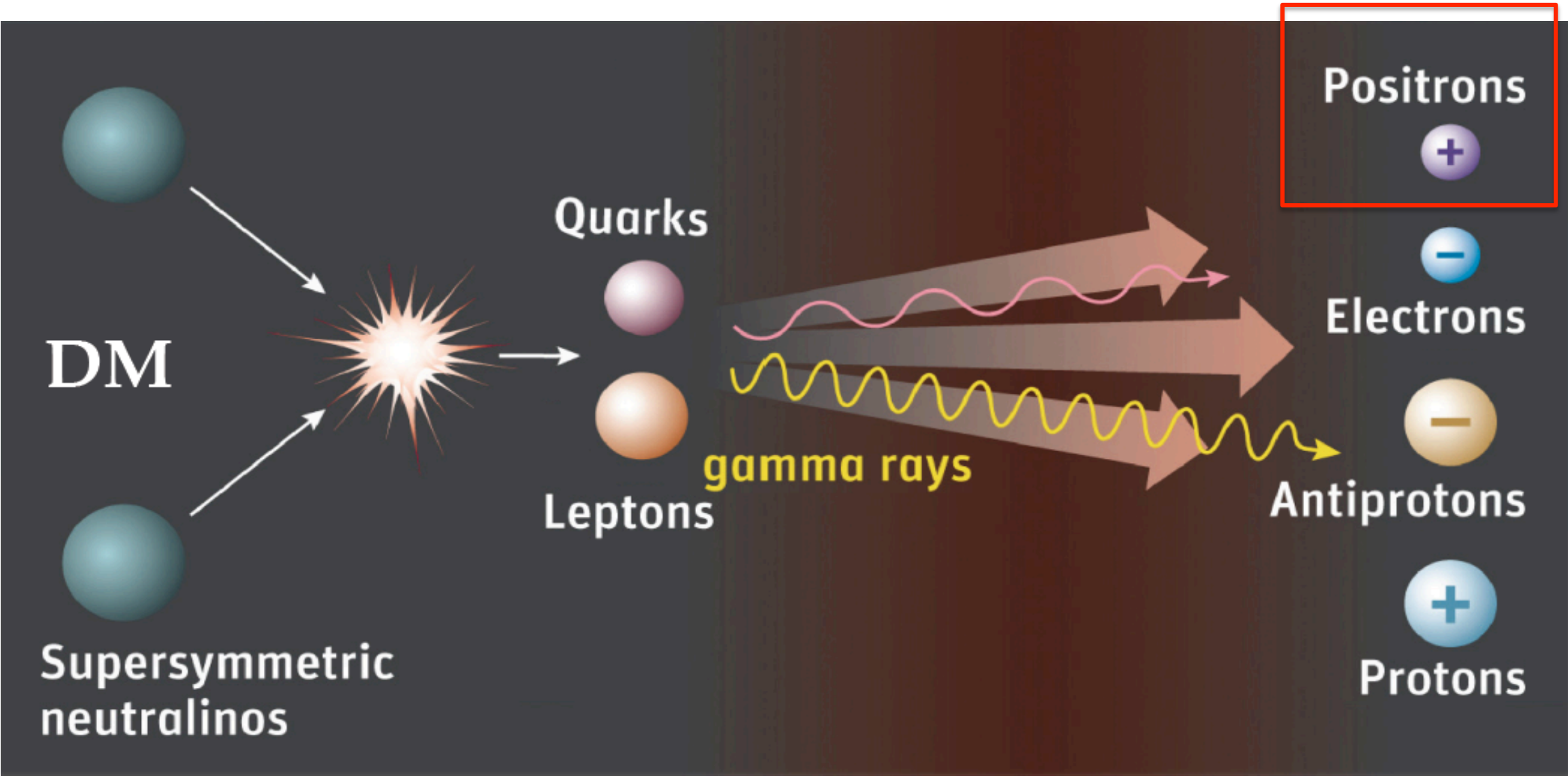
In 4 years on ISS,

AMS has collected >68 billion cosmic rays.

To match the statistics,

systematic error studies have become important.

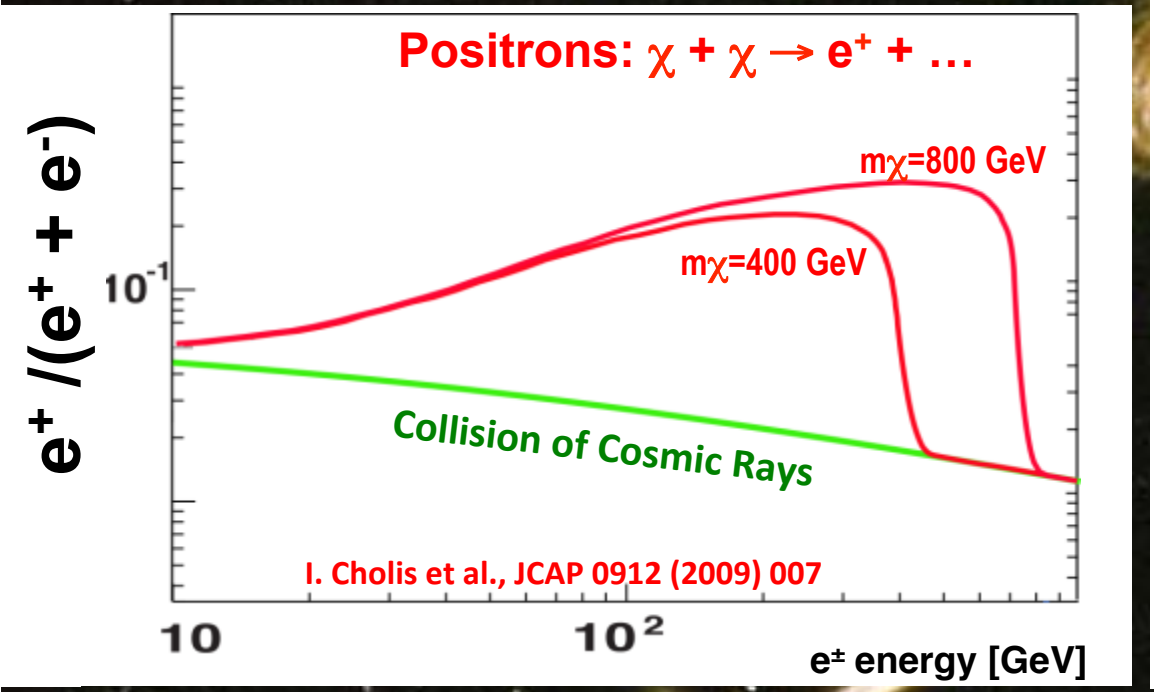
Search for the Dark Matter through its annihilation product: Positrons and Antiprotons in the cosmic rays.

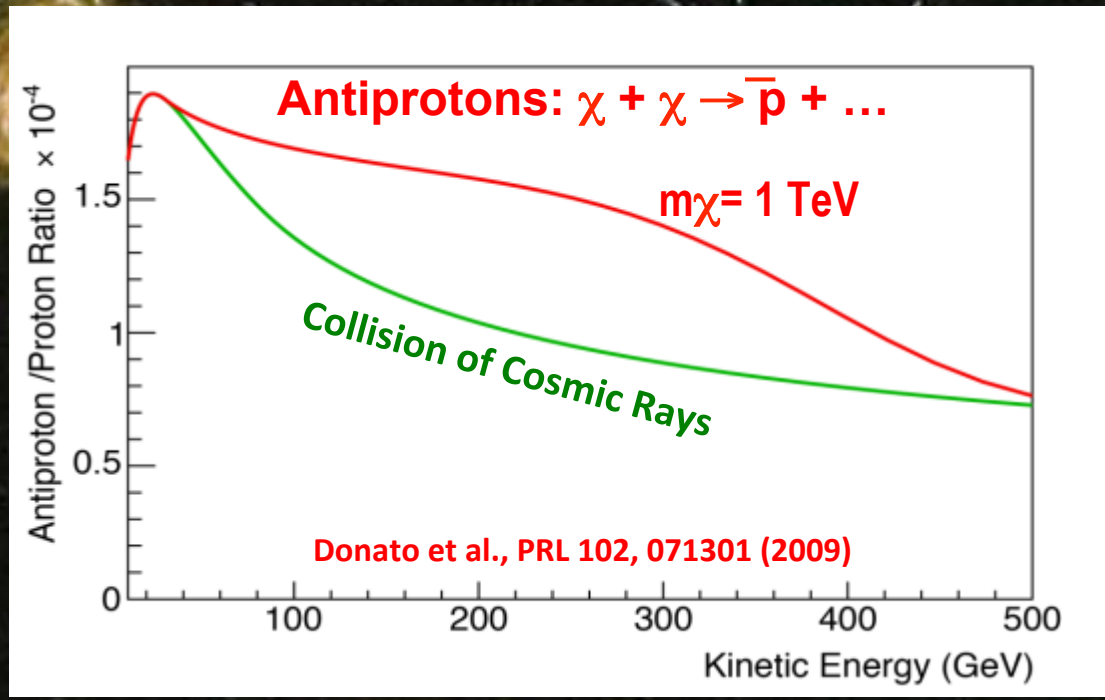


The Search for the Origin of Dark Matter

Collisions of Dark Matter (neutralinos, χ) will produce a signal of e+, $\bar{p}$, …

above the background from the collisions of "ordinary" cosmic rays

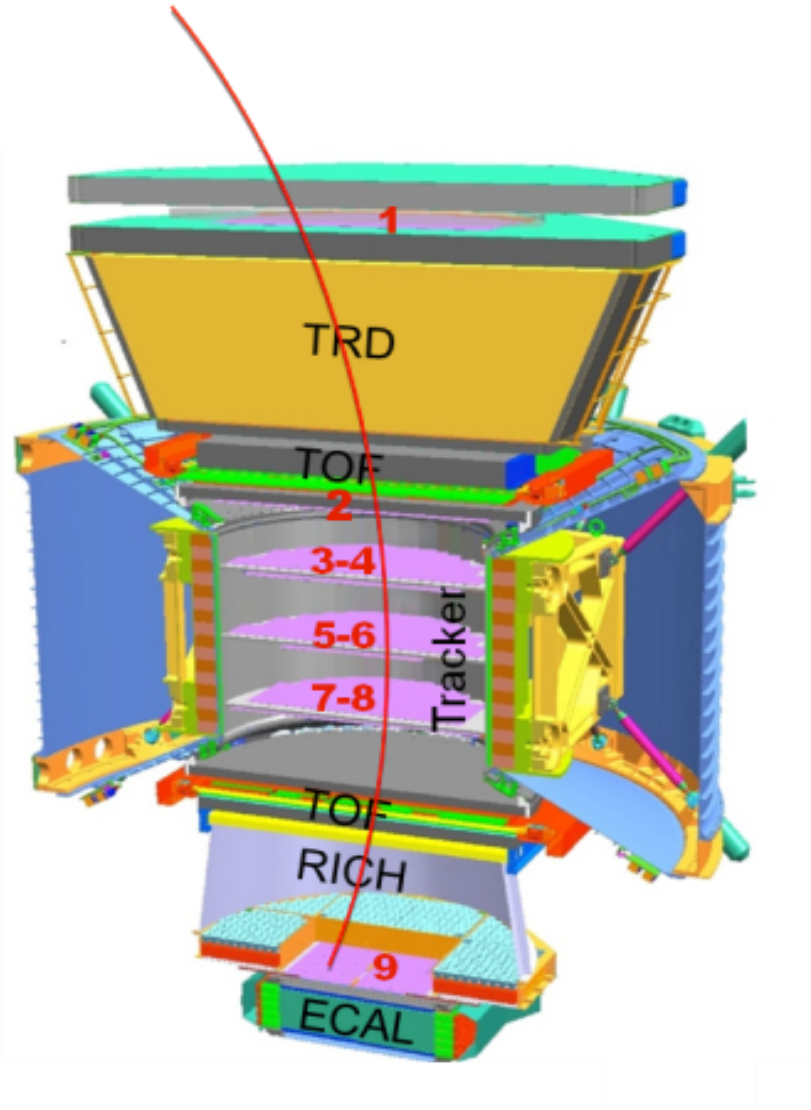




M. Turner and F. Wilczek, Phys. Rev. D42 (1990) 1001;
J. Ellis, 26th ICRC Salt Lake City (1999) astro-ph/9911440;
……..

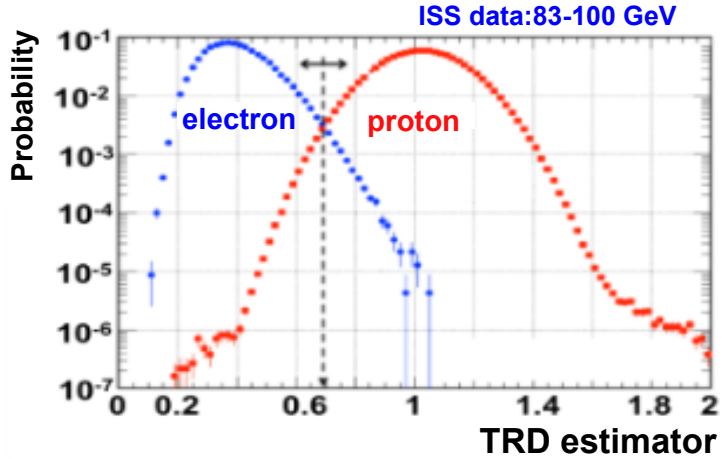
Physics of 11 million e^+, e^- events

Measuring electrons and positrons



TRD

identify $e^{\pm}$



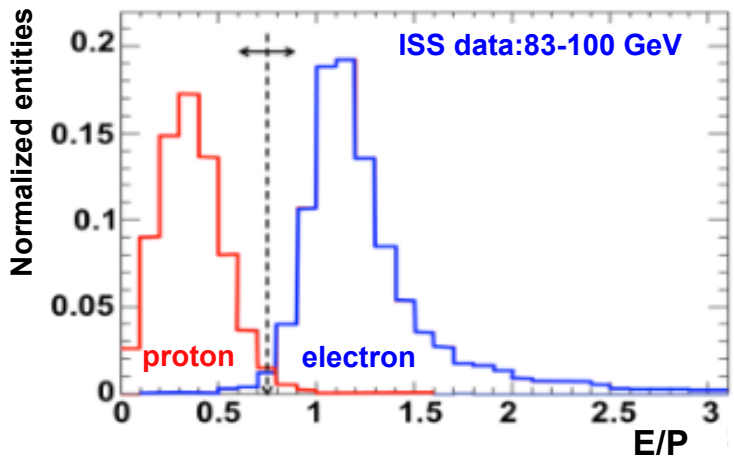
TRACKER

measures P

ECAL measures E

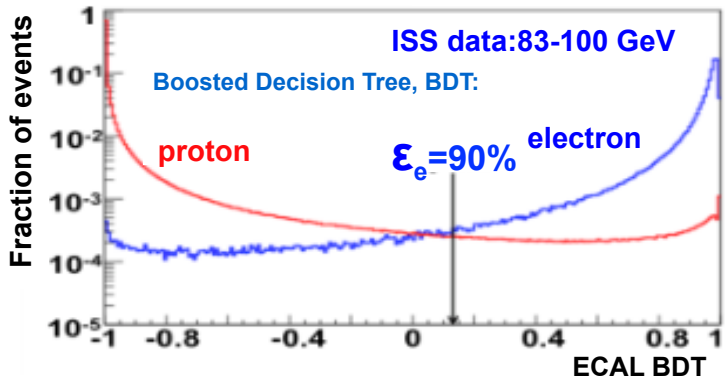
$e^{\pm}$: E=P

proton: E<P

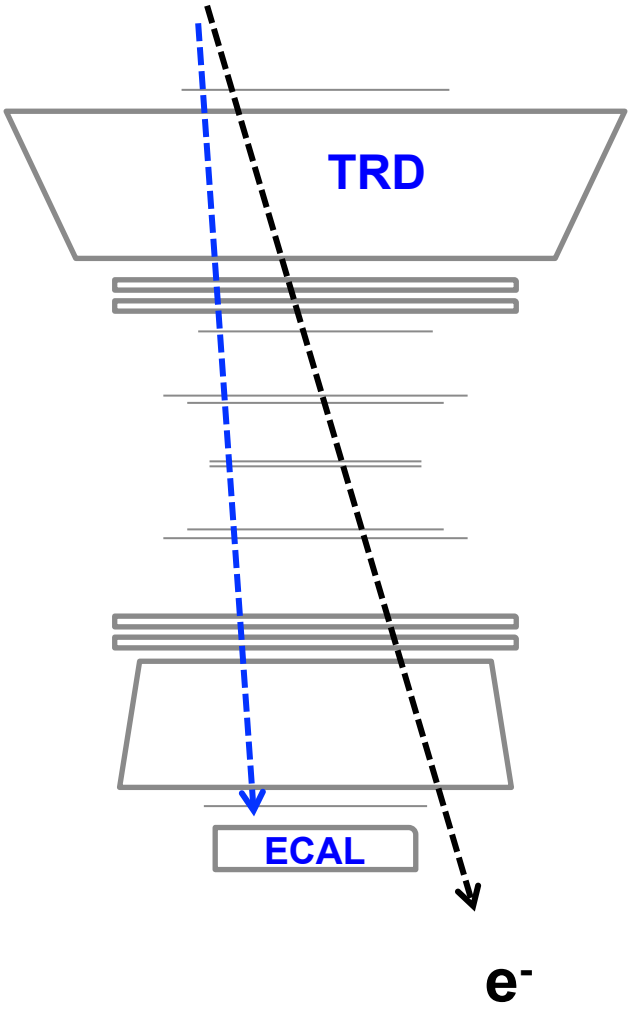


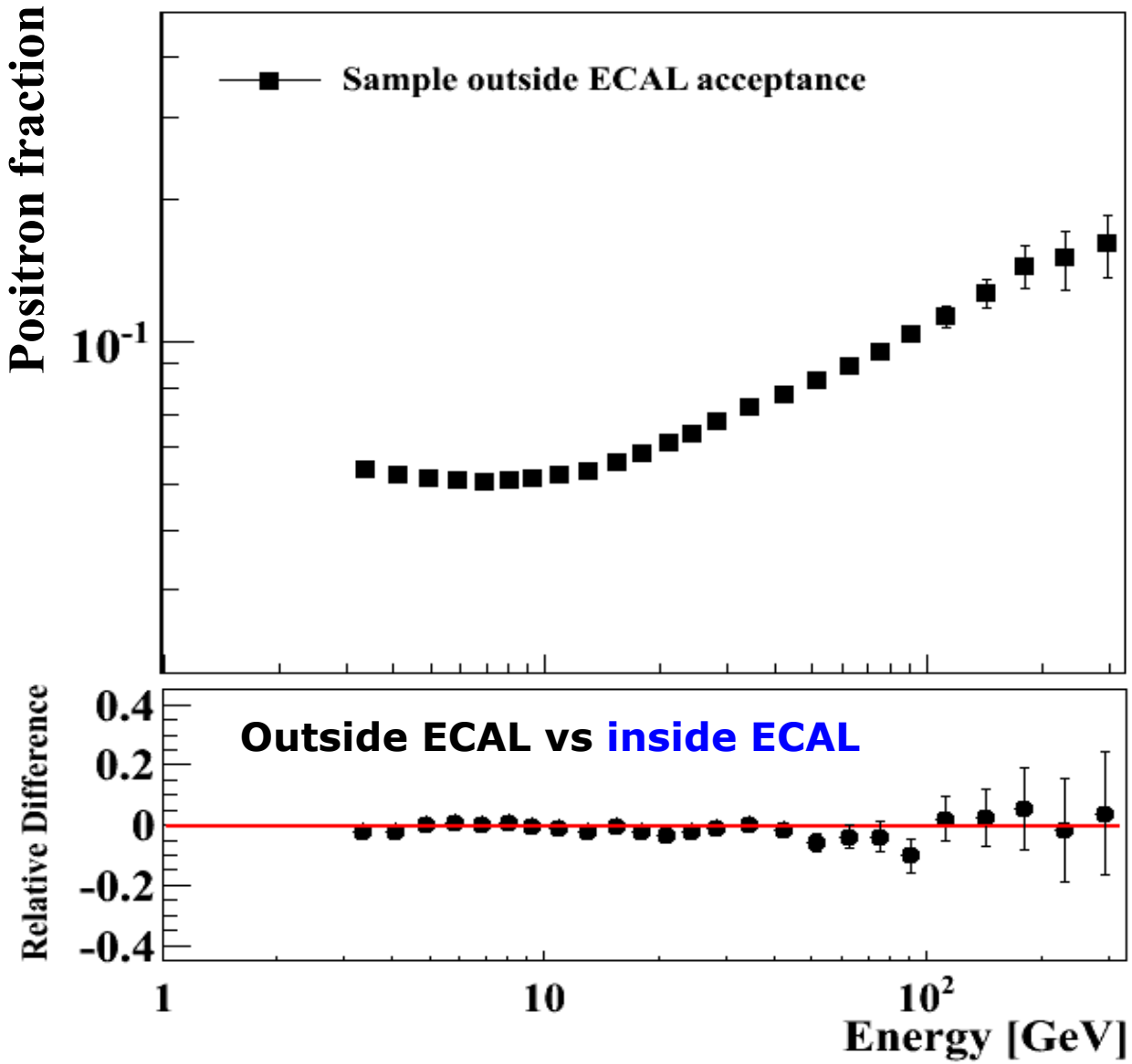
ECAL

measures E and shower shape to separate $e^{\pm}$ from protons



Verification of Positron Fraction
with two independent samples
Positron fraction analysis with TRD and ECAL versus TRD only





Good agreement between two independent samples

2. The rate of increase with energy

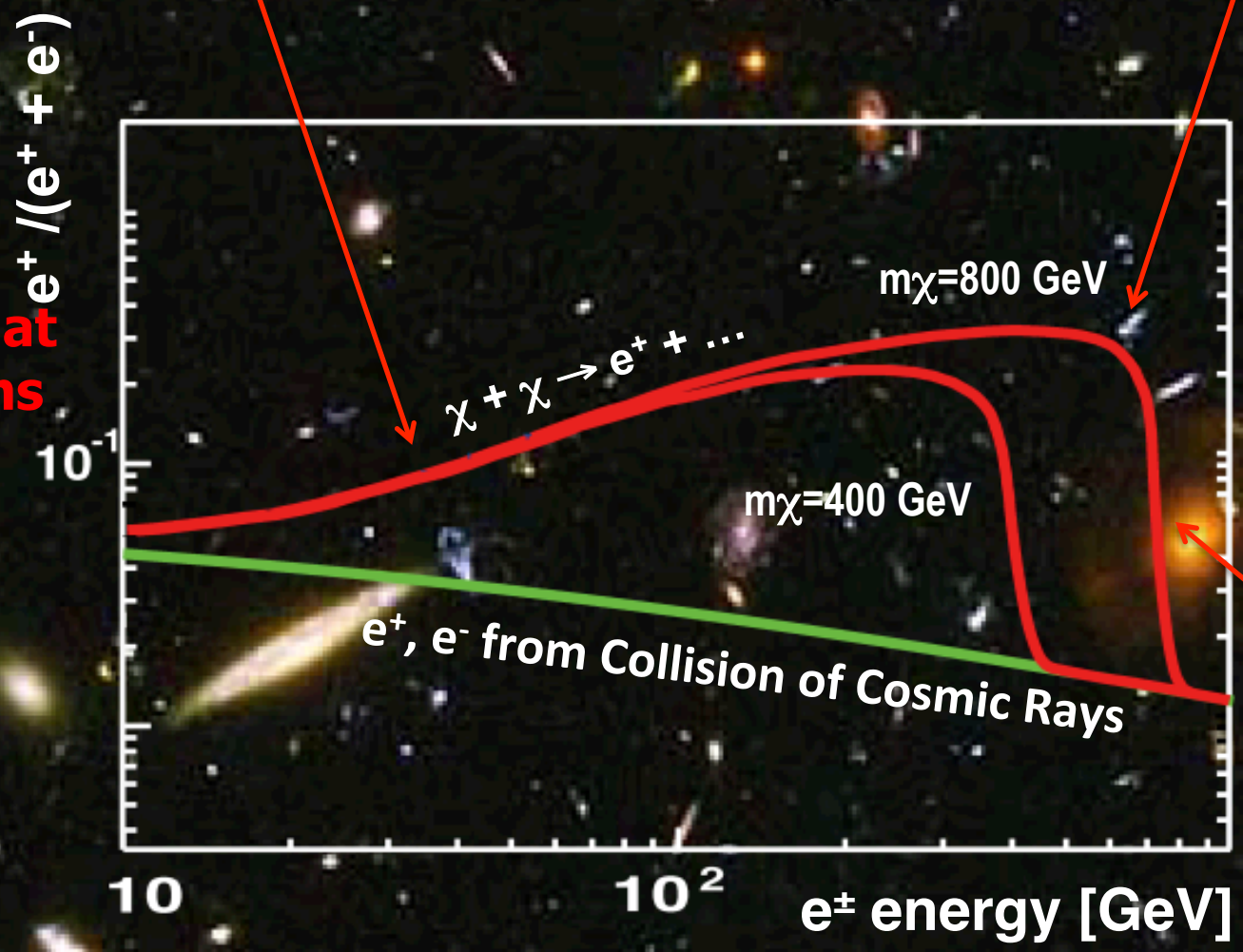
3. The existence of sharp structures.

4. The energy beyond which it ceases to increase.

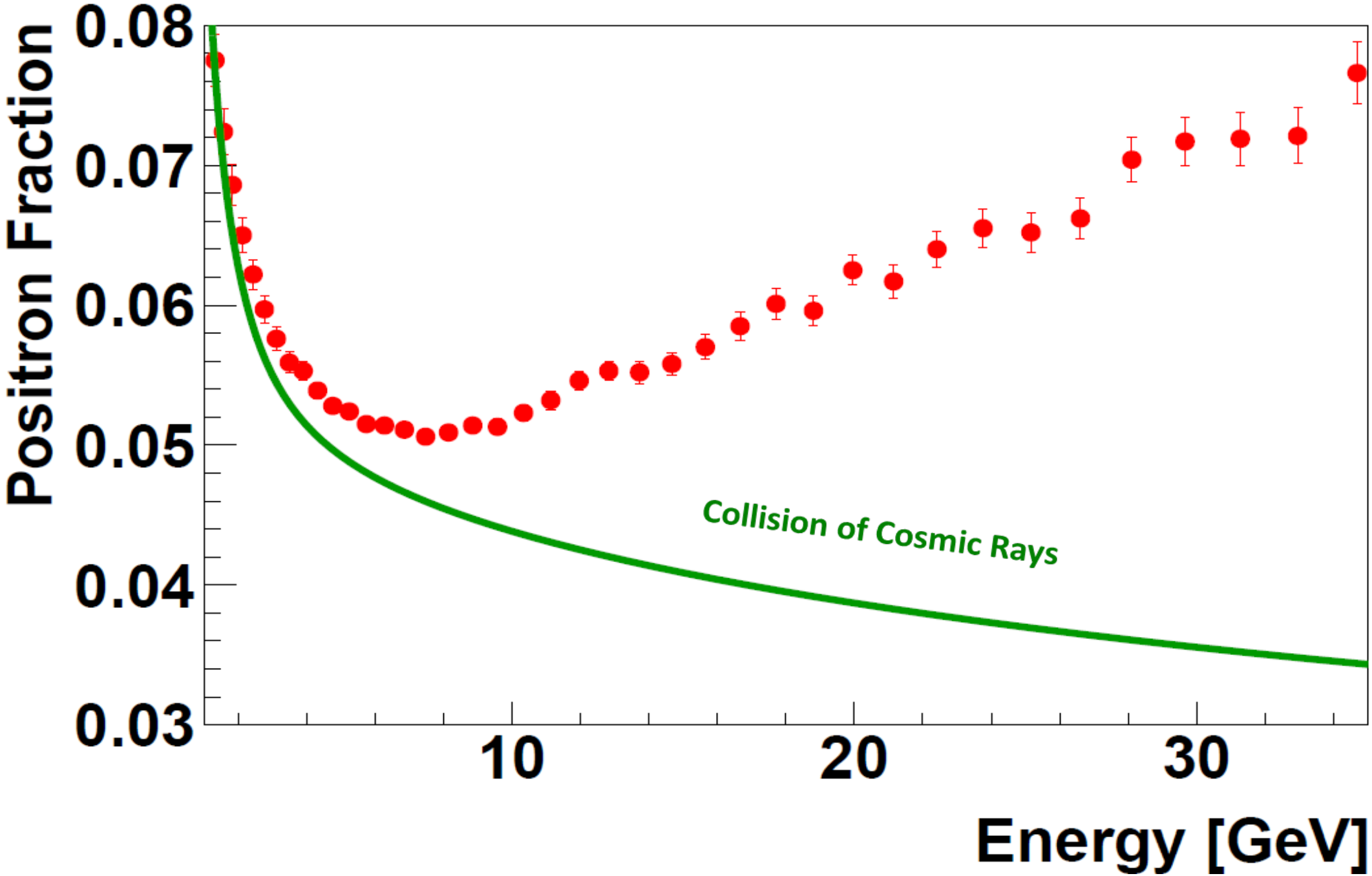
5. Isotropy.

1. The energy at which it begins to increase.

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



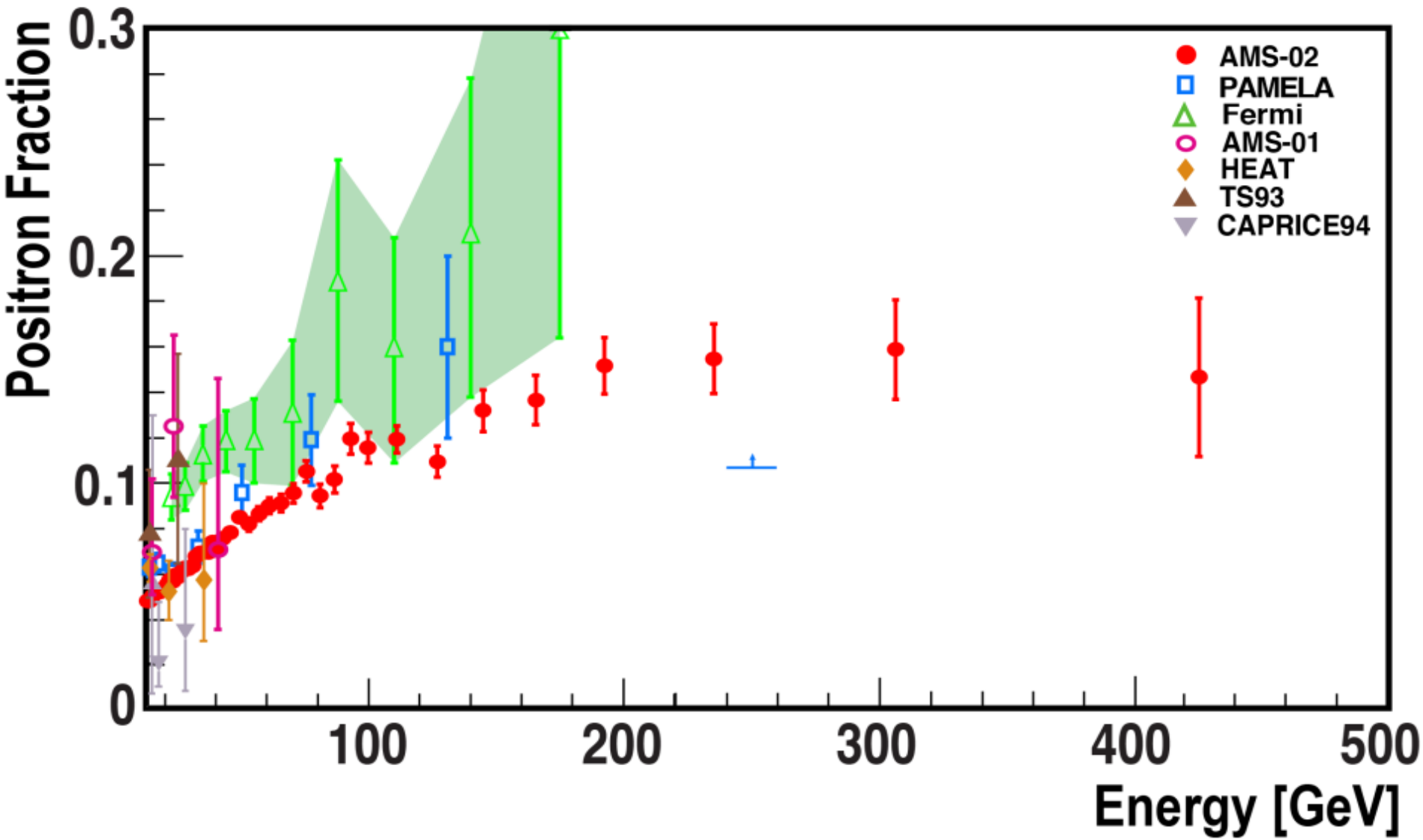
1. The energy at which it begins to increase.



PRL 113, 121101 (2014) PHYSICAL REVIEW LETTERS week ending 19 SEPTEMBER 2014

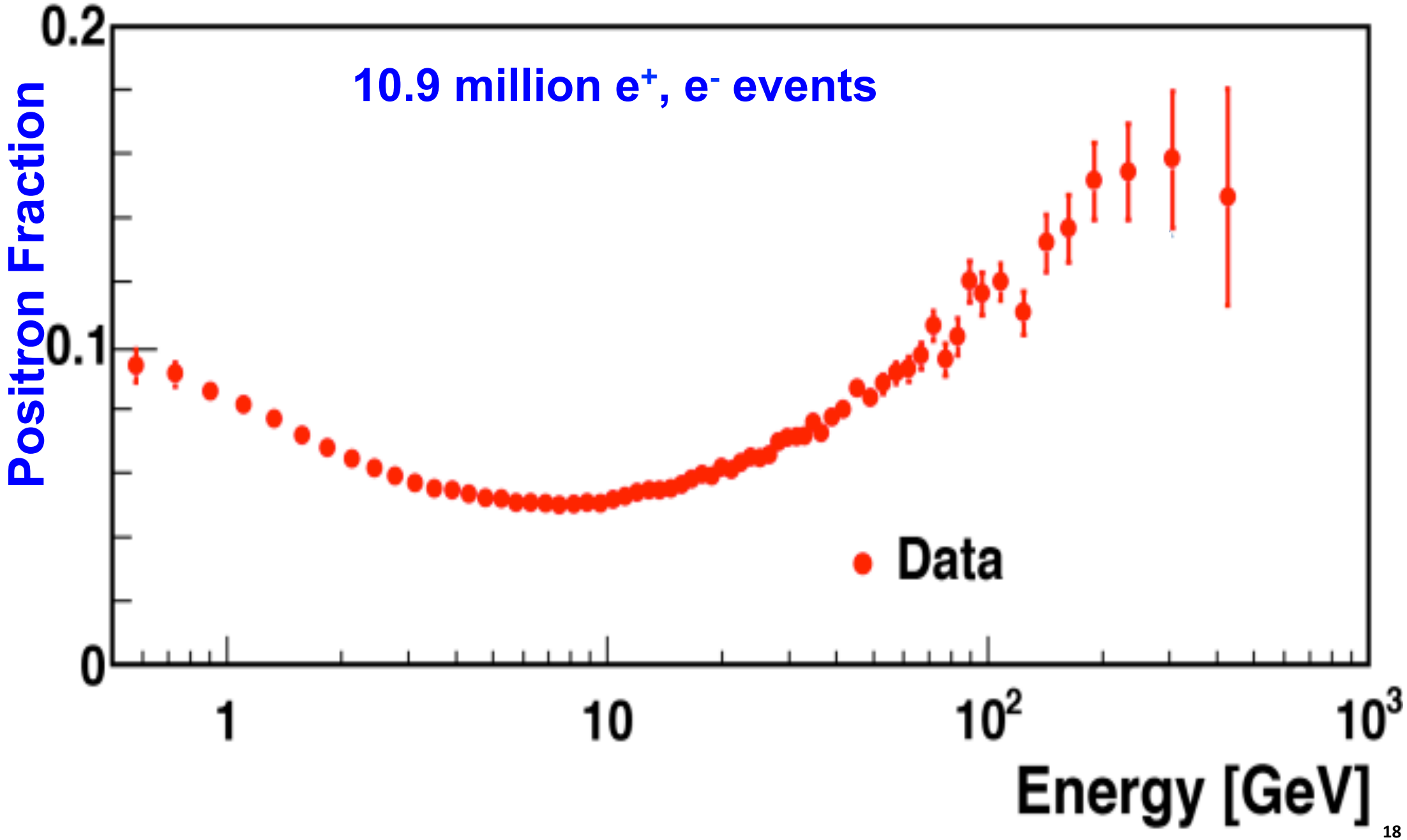
High Statistics Measurement of the Positron Fraction in Primary Cosmic Rays of 0.5–500 GeV with the Alpha Magnetic Spectrometer on the International Space Station

10.9 million e+ and e- events

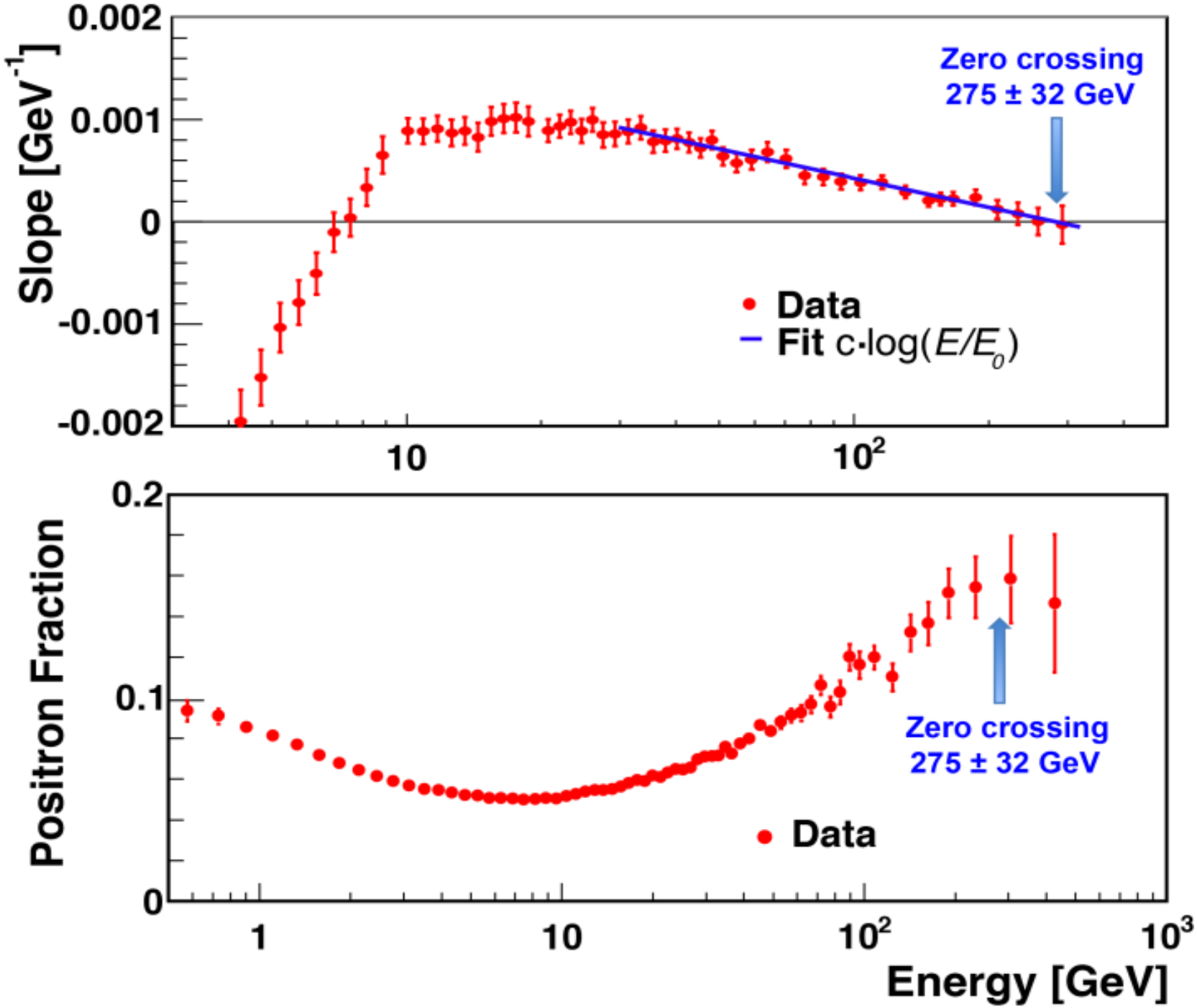


2. The rate of increase with energy.

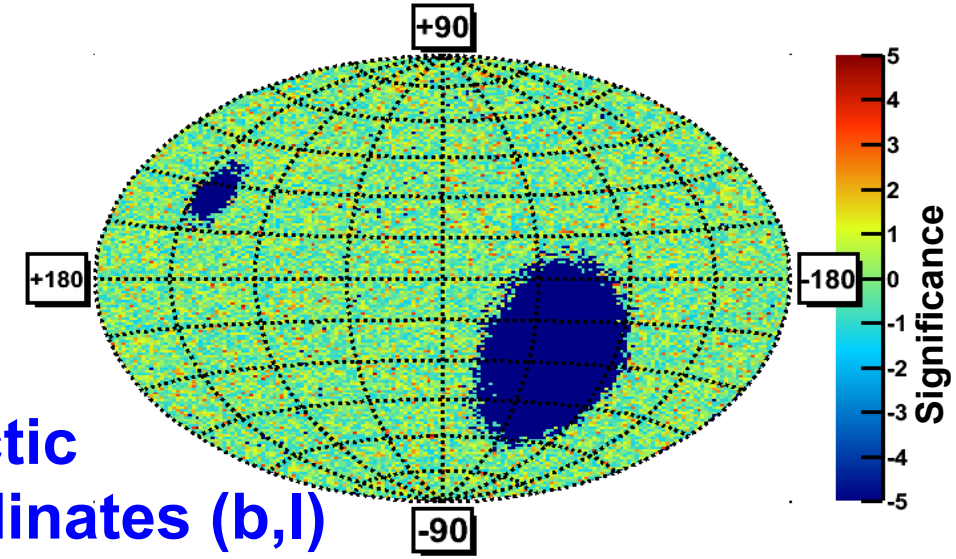
3. The non-existence of sharp structures.



4. The energy beyond which it ceases to increase.



5. The isotropy.



Galactic coordinates (b,l)

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

The anisotropy in galactic coordinates: $\delta \leq 0.030$ at the 95% confidence level

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

***C_1* is the dipole moment**

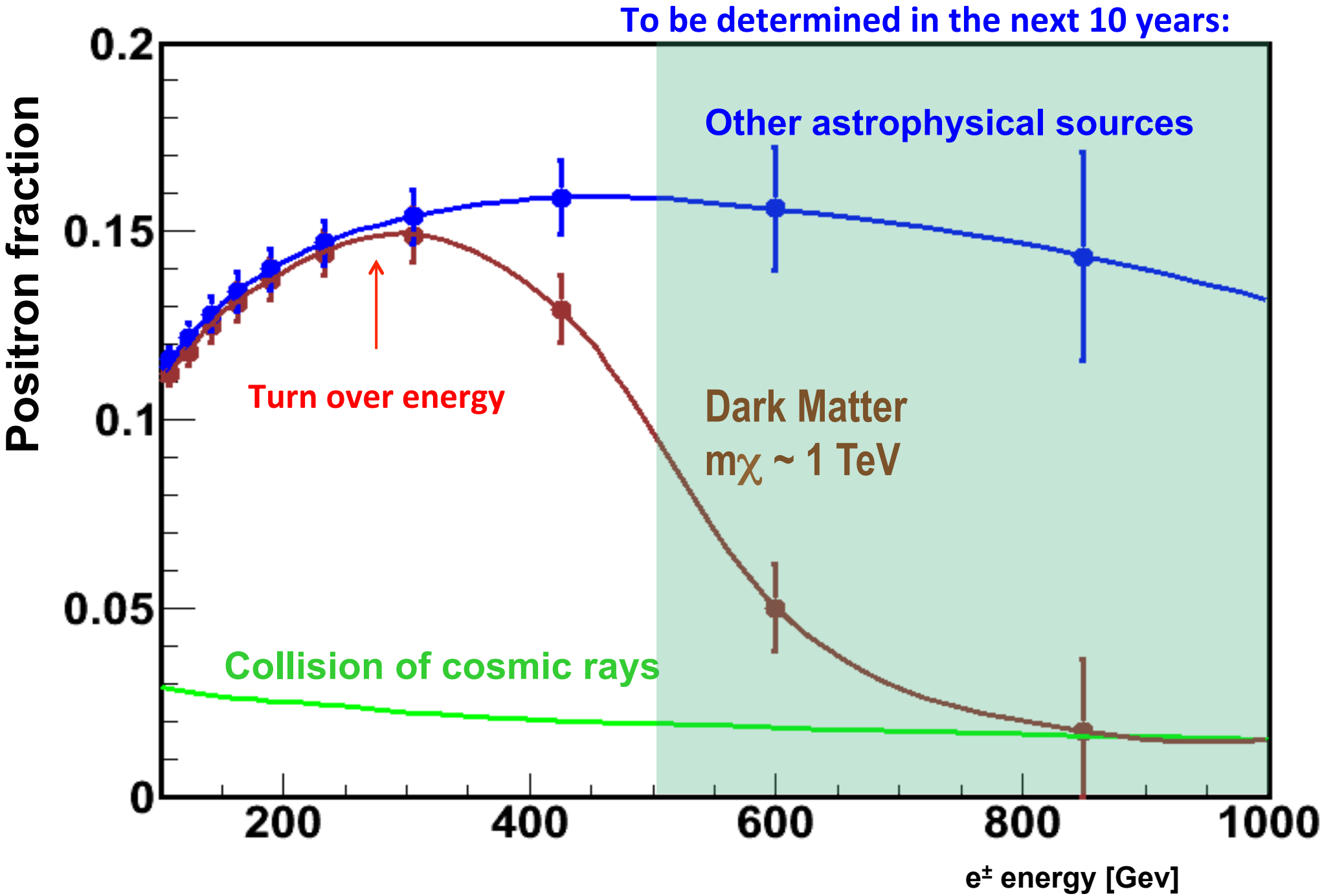
Arrival directions of electrons and positrons are used to build a sky map in galactic coordinates, (b, l), containing the number of observed positrons and electrons. The fluctuations of the observed positron ratio are described using a spherical harmonic expansion

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

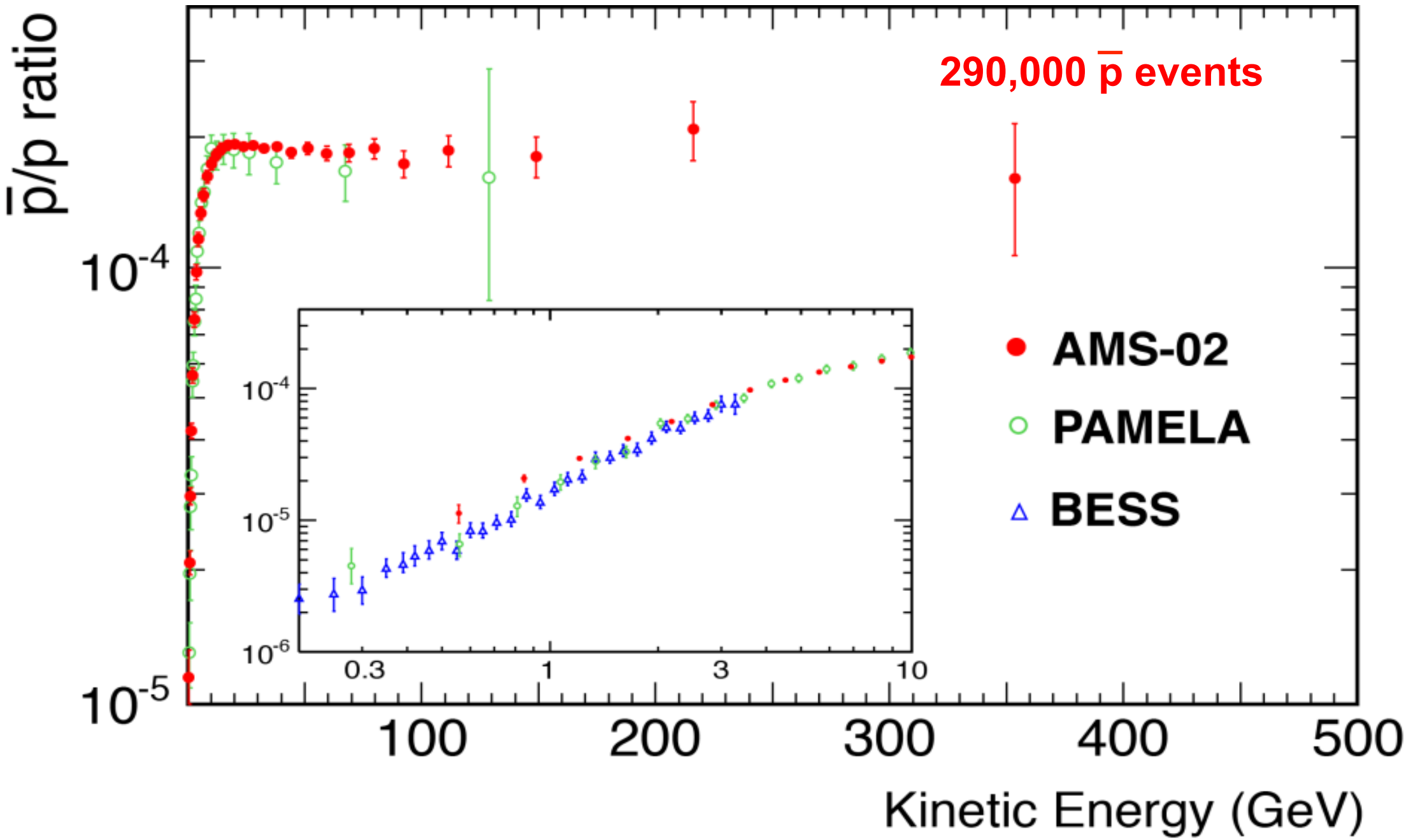
where $r_e(b,l)$ denotes the positron ratio at (b,l); $< r_e >$ is the average ratio over the sky map; $Y_{\ell m}$ are spherical harmonic functions and $a_{\ell m}$ are the corresponding weights. The coefficients of the angular power spectrum of the fluctuations are defined as

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

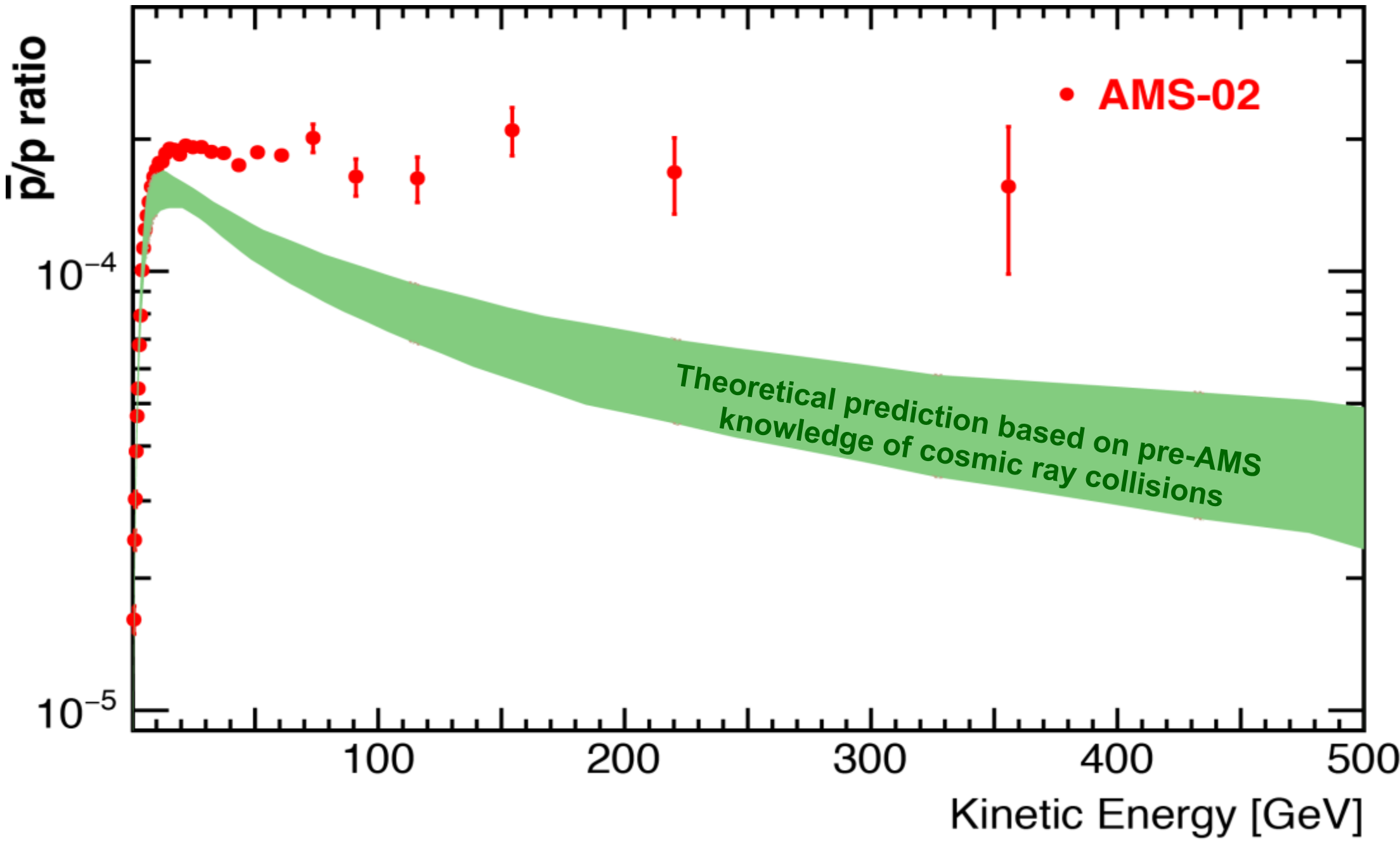
6. The expected rate at which it falls beyond the turning point.



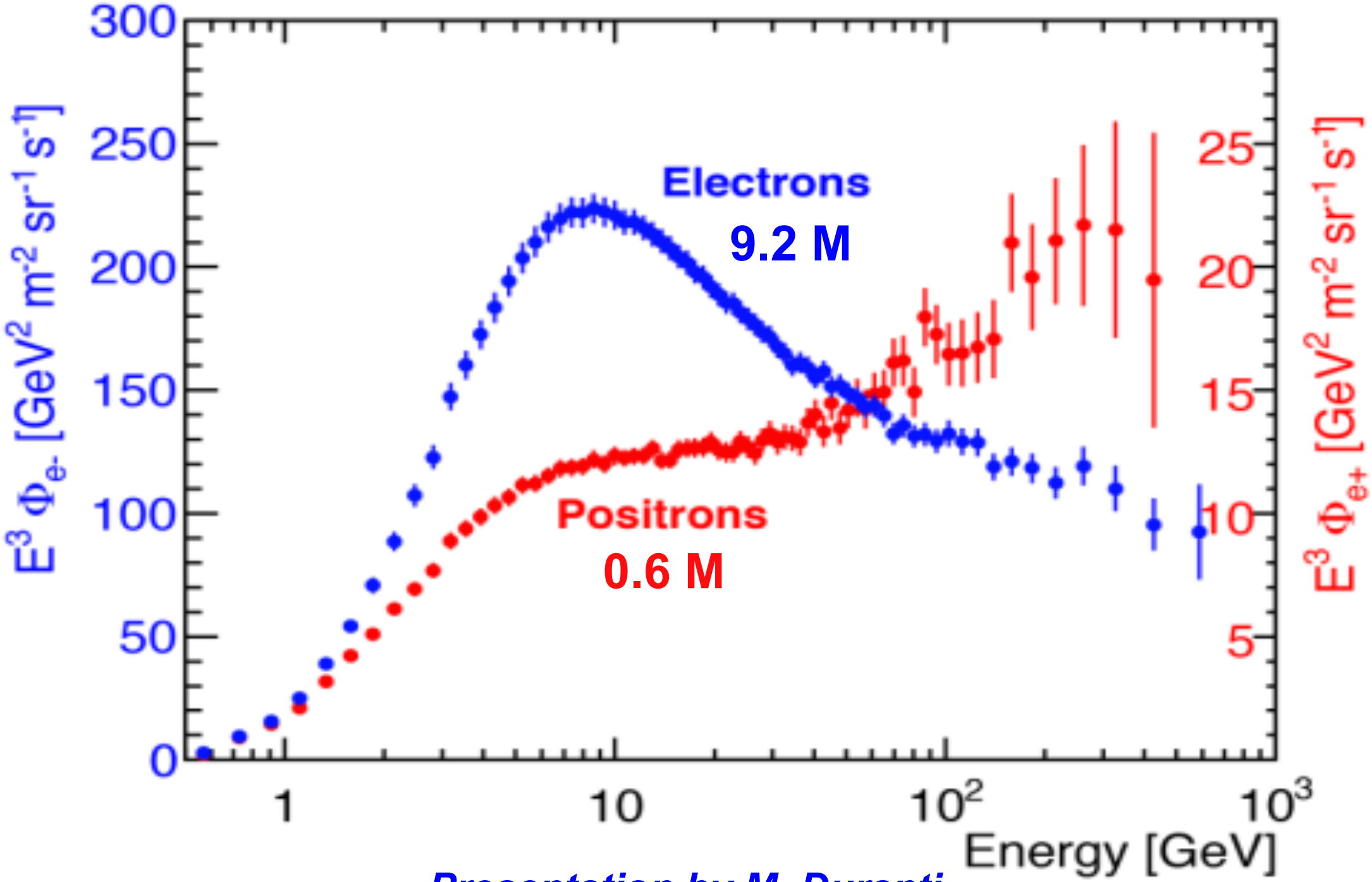
AMS $\bar{p}/p$ results



AMS $\bar{p}/p$ results

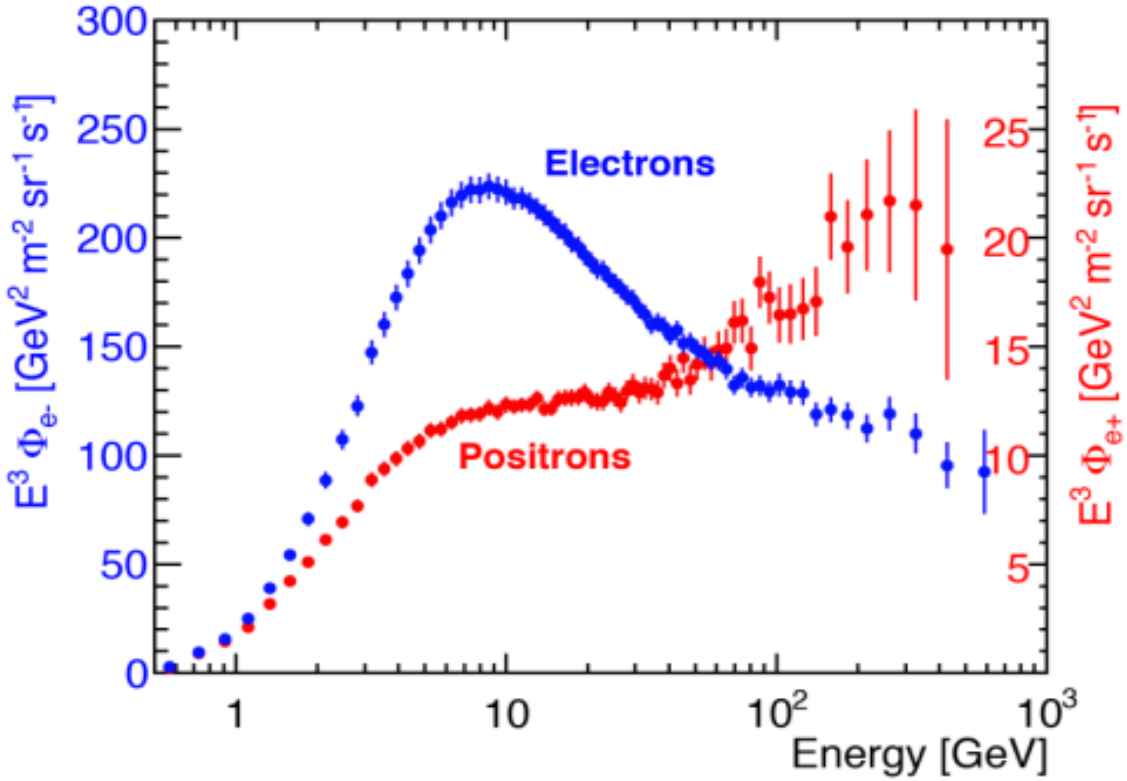


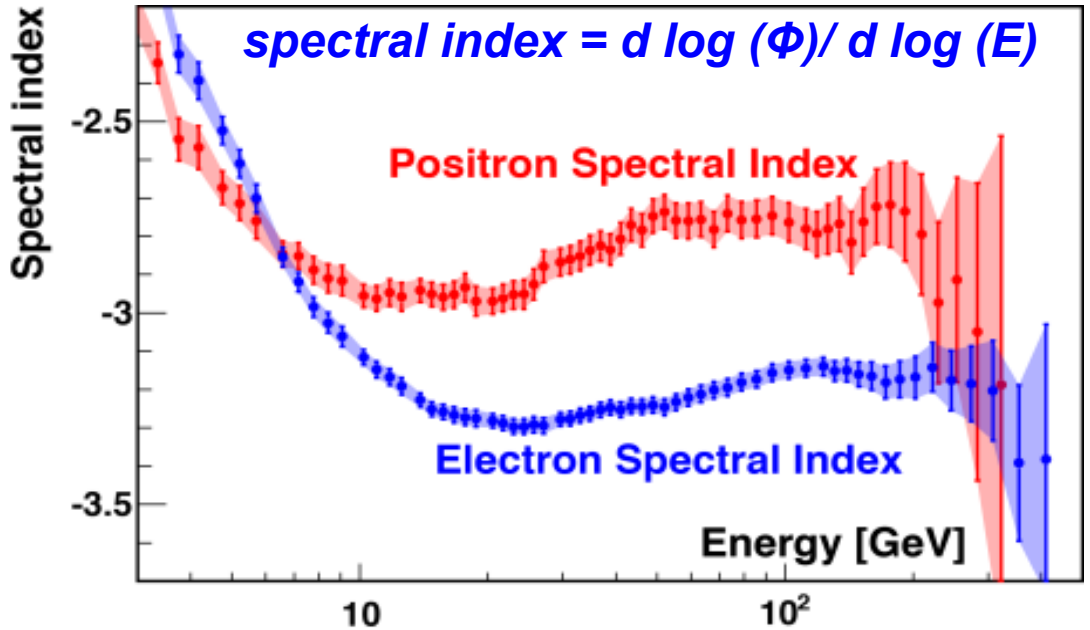
AMS, Electron Flux and the Positron Flux



Presentation by M. Duranti

The Electron Flux and the Positron Flux

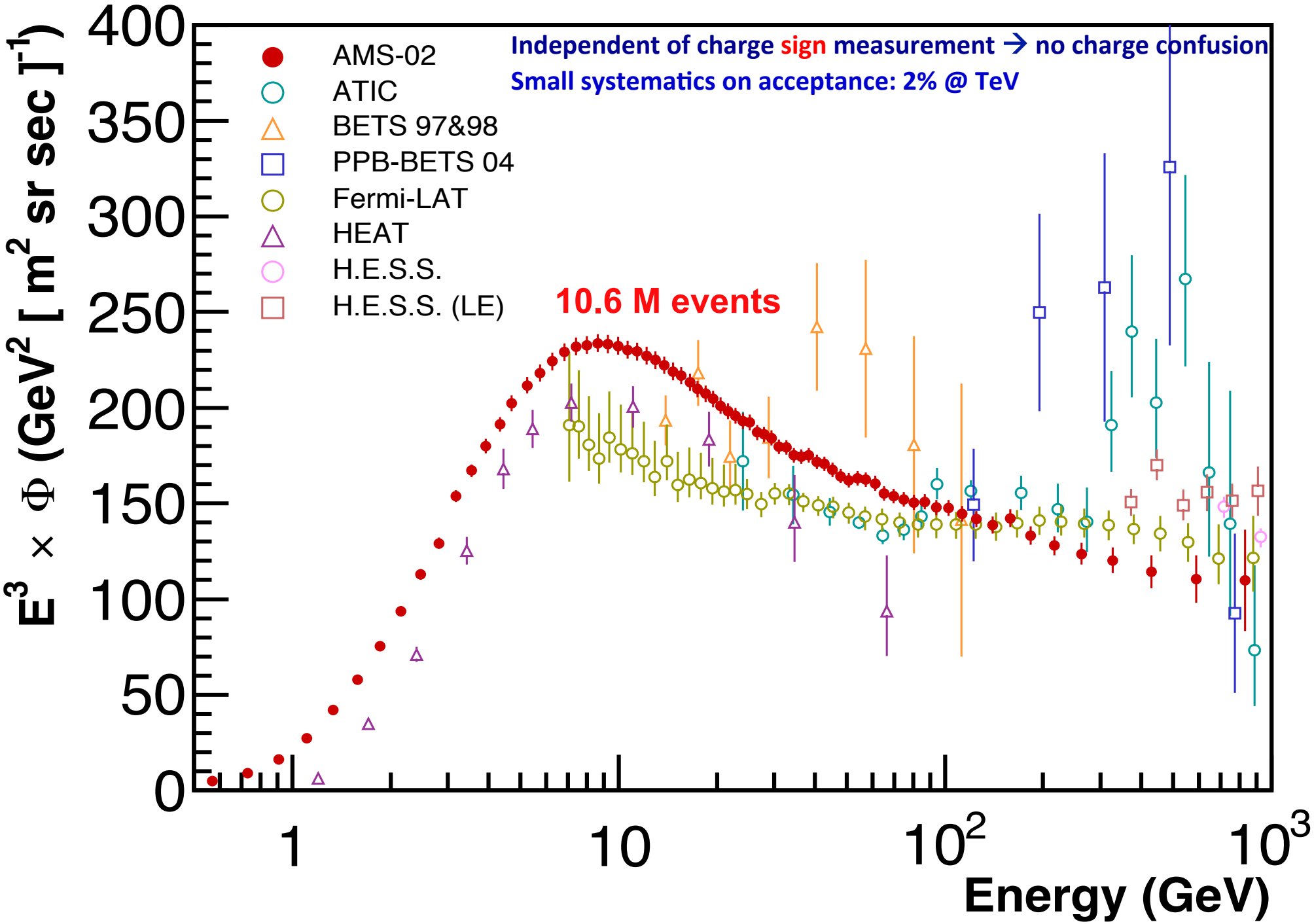




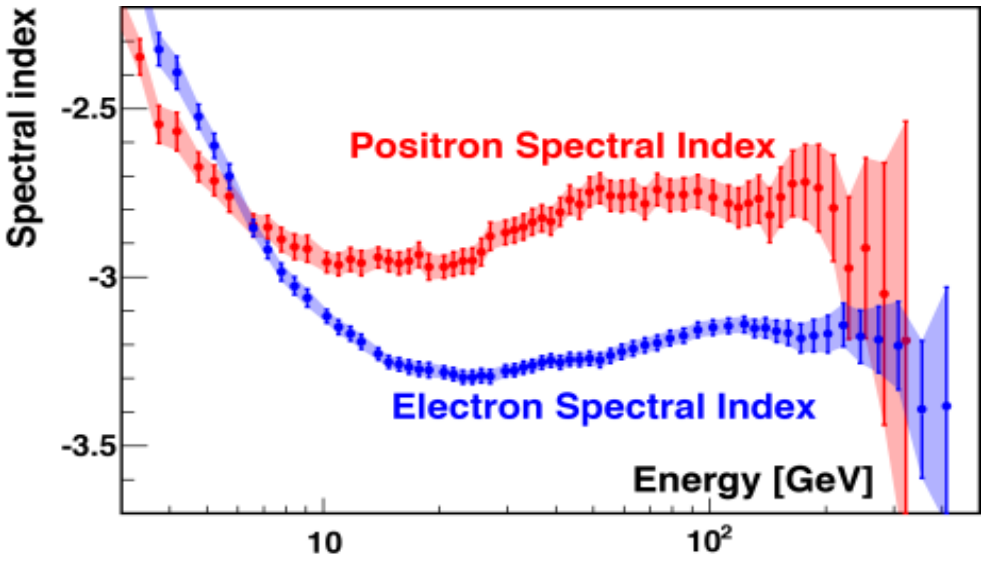
Observations:

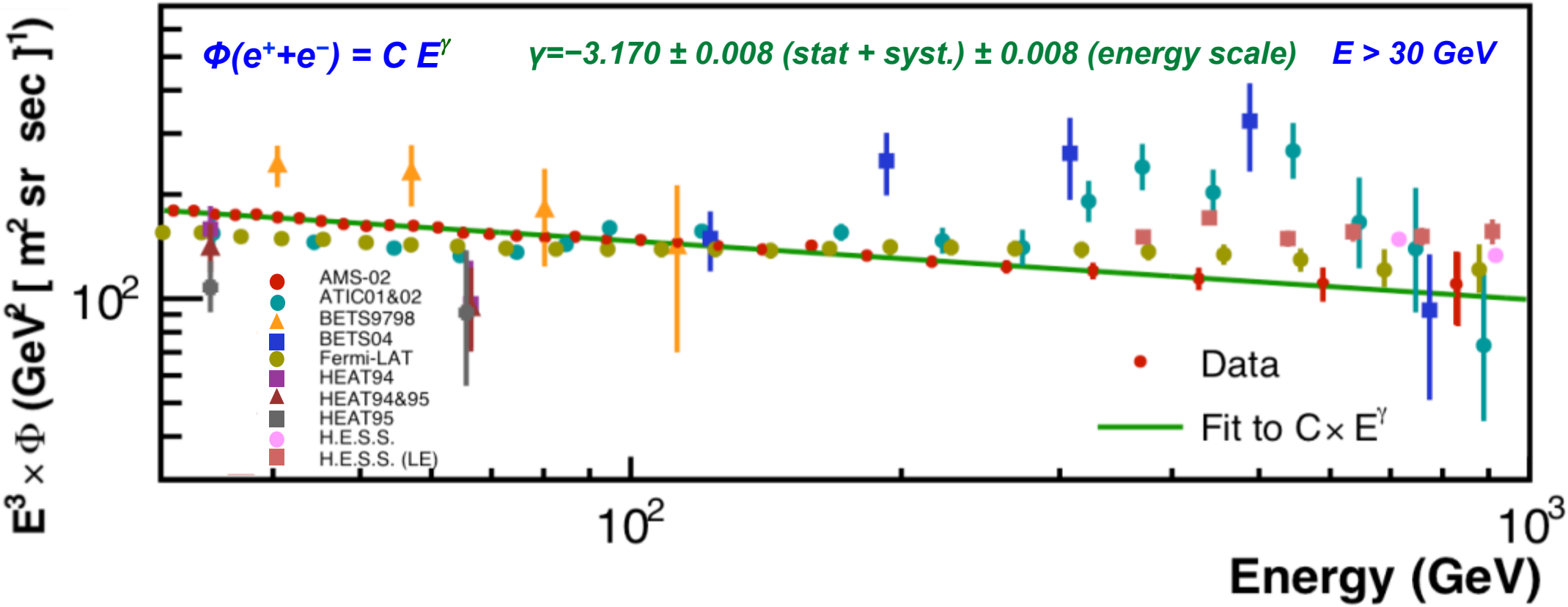
1. The electron flux and the positron flux are different in their magnitude and energy dependence.
2. Both spectra cannot be described by single power laws.
3. The spectral indices of electrons and positrons are different.
4. Both change their behavior at ~30GeV.
5. The rise in the positron fraction from 20 GeV is due to an excess of positrons, not the loss of electrons (the positron flux is harder).

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



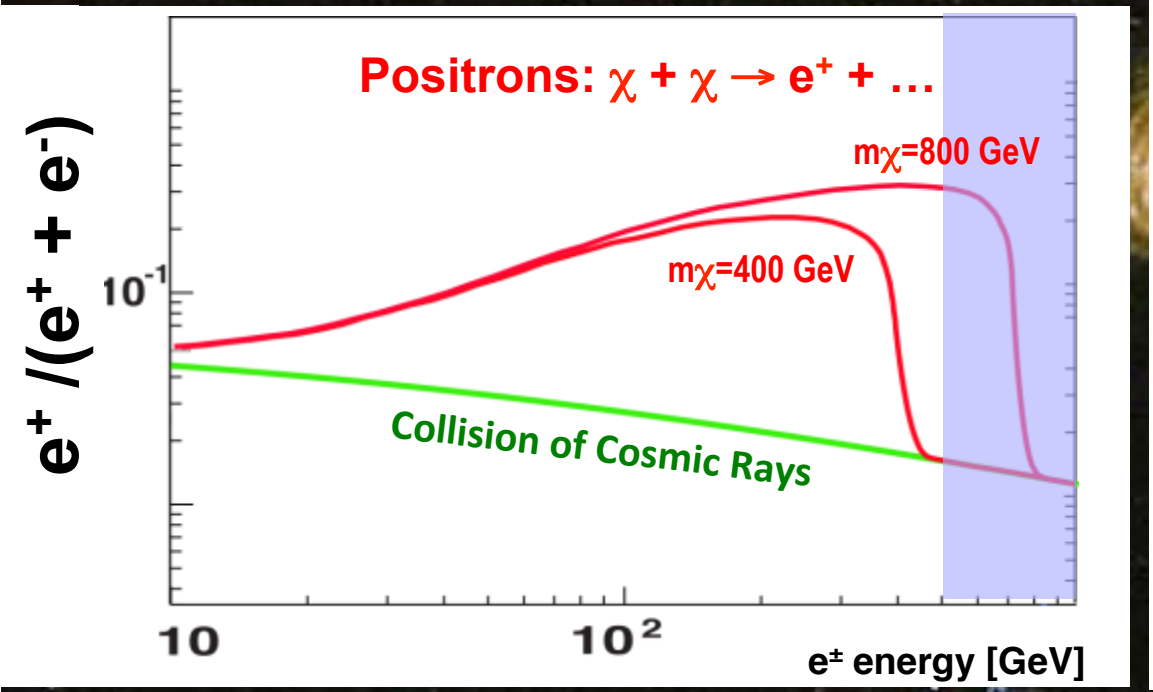
Spectral Indices of electrons, positrons, and (electrons + positrons)

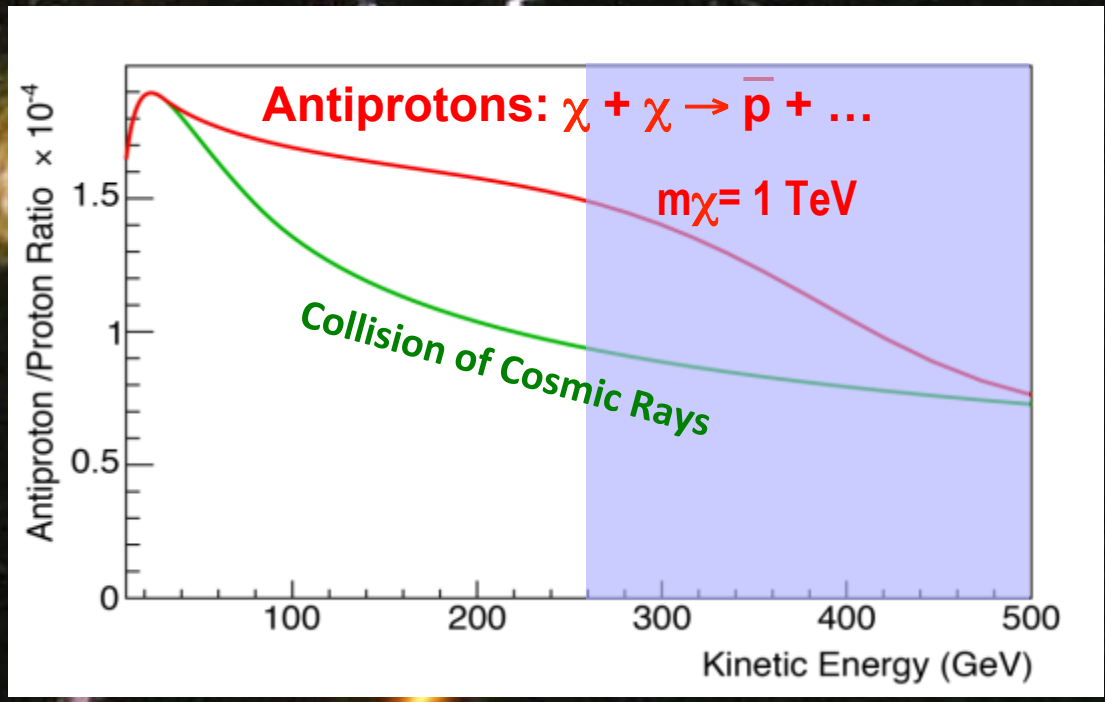




The Search for the Origin of Dark Matter

To identify the Dark Matter signal we need to measure the e^+, e^- and $\bar{p}$ signal accurately until 2024.

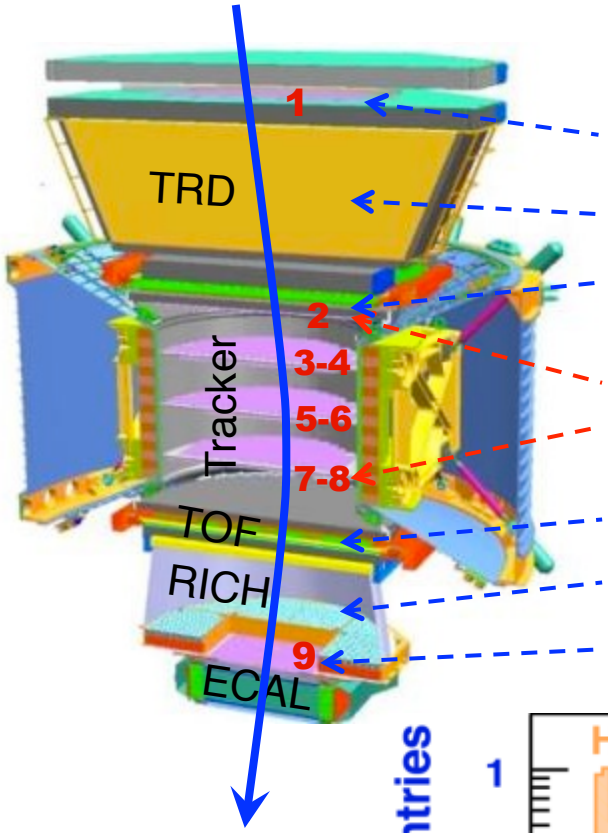




To understand background, we need precise knowledge of:

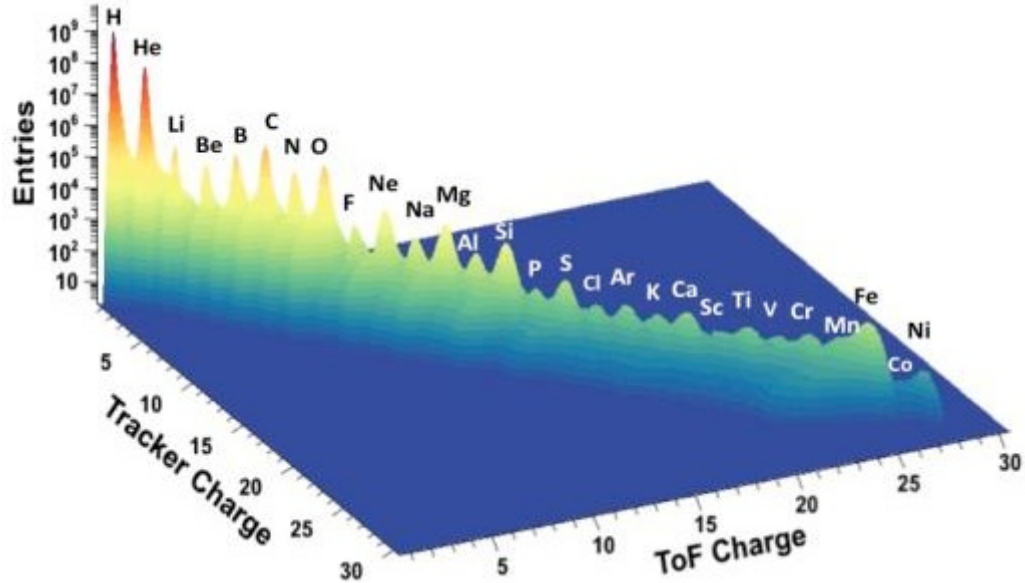
1. **The cosmic ray fluxes (p, He, C, …)**
2. **Propagation and Acceleration (Li, B/C, …)**

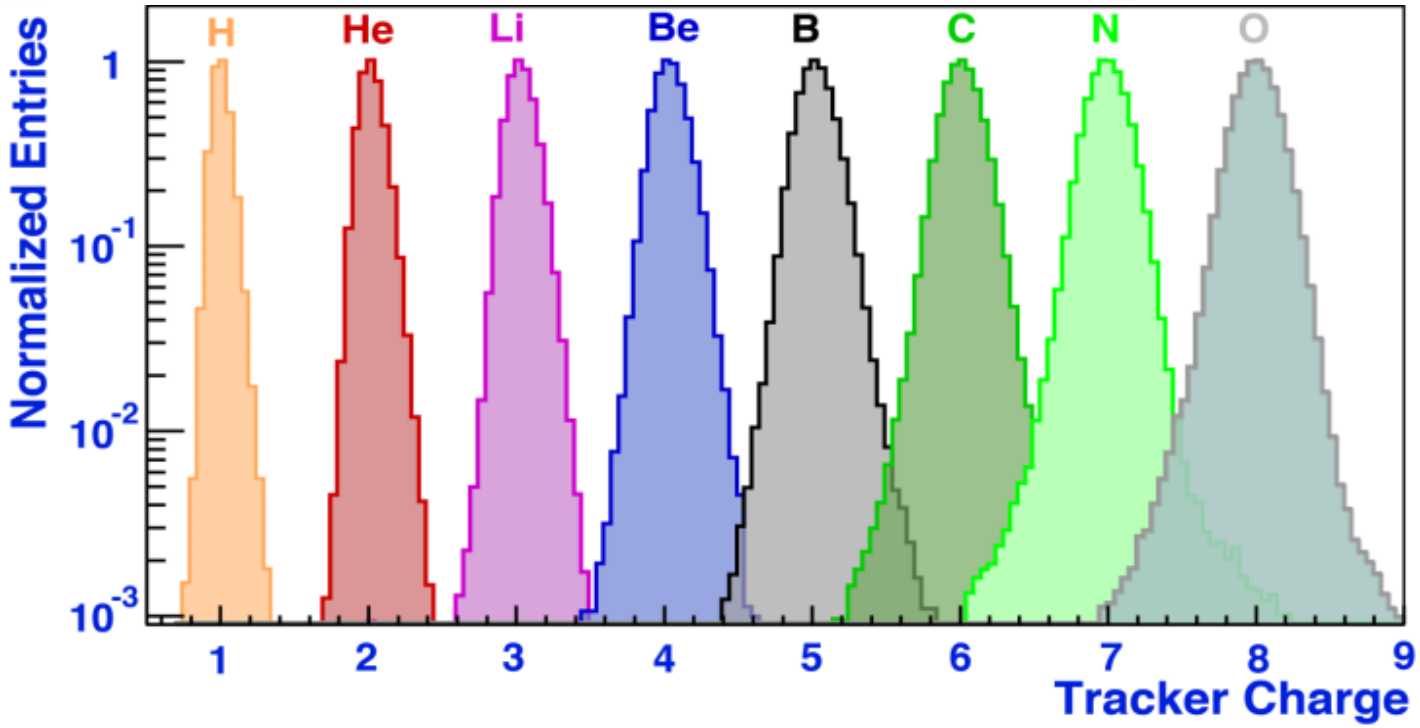
AMS: Multiple Measurements of Nuclear Charge



Charge Resolution (Z=6)

Tracker Plane 1	0.30
TRD	0.33
Upper TOF	0.16
Inner Tracker 2-8	0.12
Lower TOF	0.16
RICH	0.32
Tracker Plane 9	0.30





PRL 114, 171103 (2015) PHYSICAL REVIEW LETTERS week ending 1 MAY 2015

Precision Measurement of the Proton Flux in Primary Cosmic Rays from Rigidity 1 GV to 1.8 TV with the Alpha Magnetic Spectrometer on the International Space Station

The isotropic proton flux Φ_i for the ith rigidity bin (R_i , $R_i + \Delta R_i$) is:

$$\Phi_i = \frac{N_i}{A_i \varepsilon_i T_i \Delta R_i}$$

To match the statistics of 300 million events, extensive systematic errors studies have been made.

1) $\sigma_{trig.}$:trigger efficiency

2) $\sigma_{acc.}$:
   a. the acceptance and event selection
   b. background contamination
   c. geomagnetic cutoff

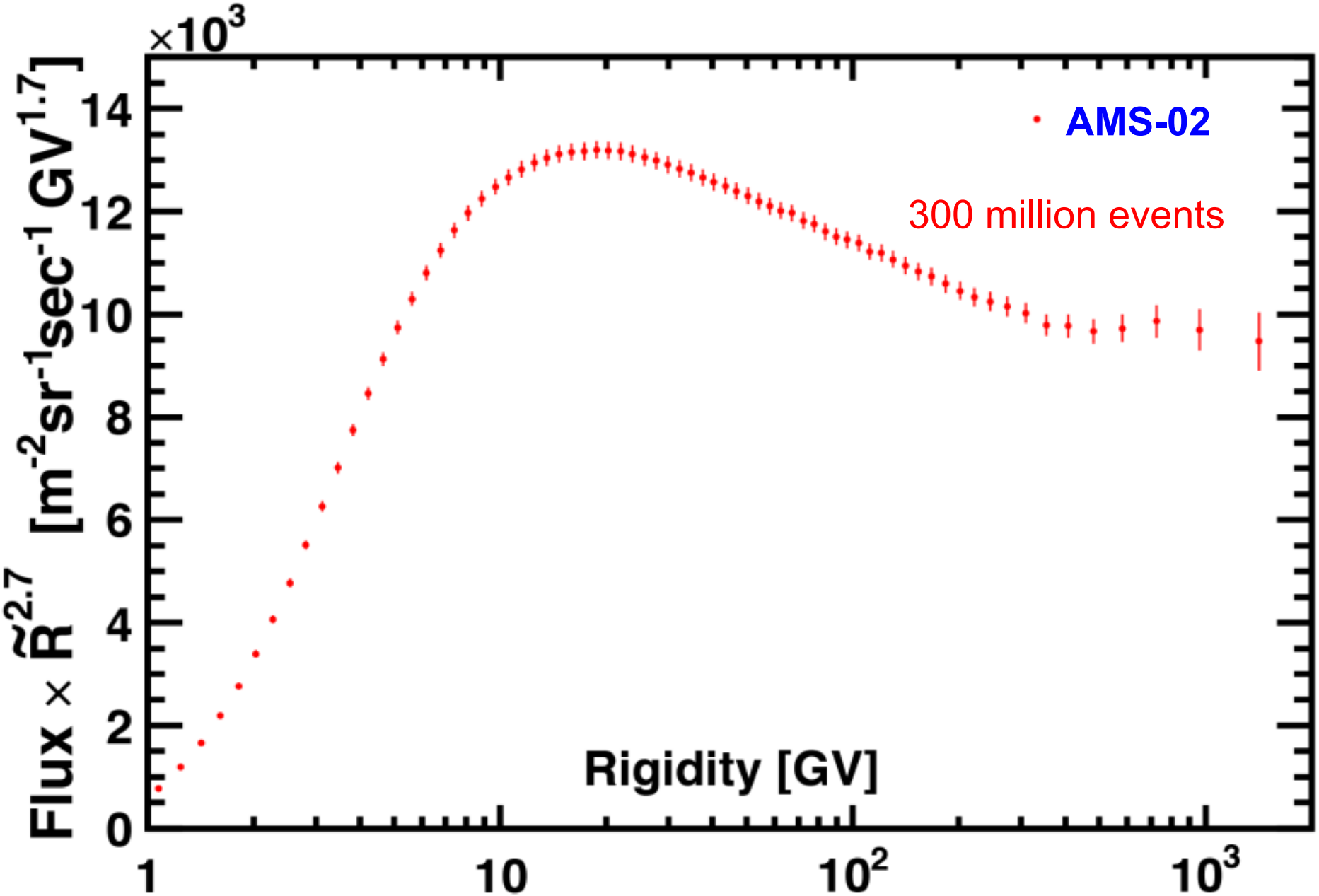
3) $\sigma_{unf.}$
   a. unfolding
   b. the rigidity resolution function

4) $\sigma_{scale.}$: the absolute rigidity scale

TABLE I: The proton flux Φ as a function of rigidity

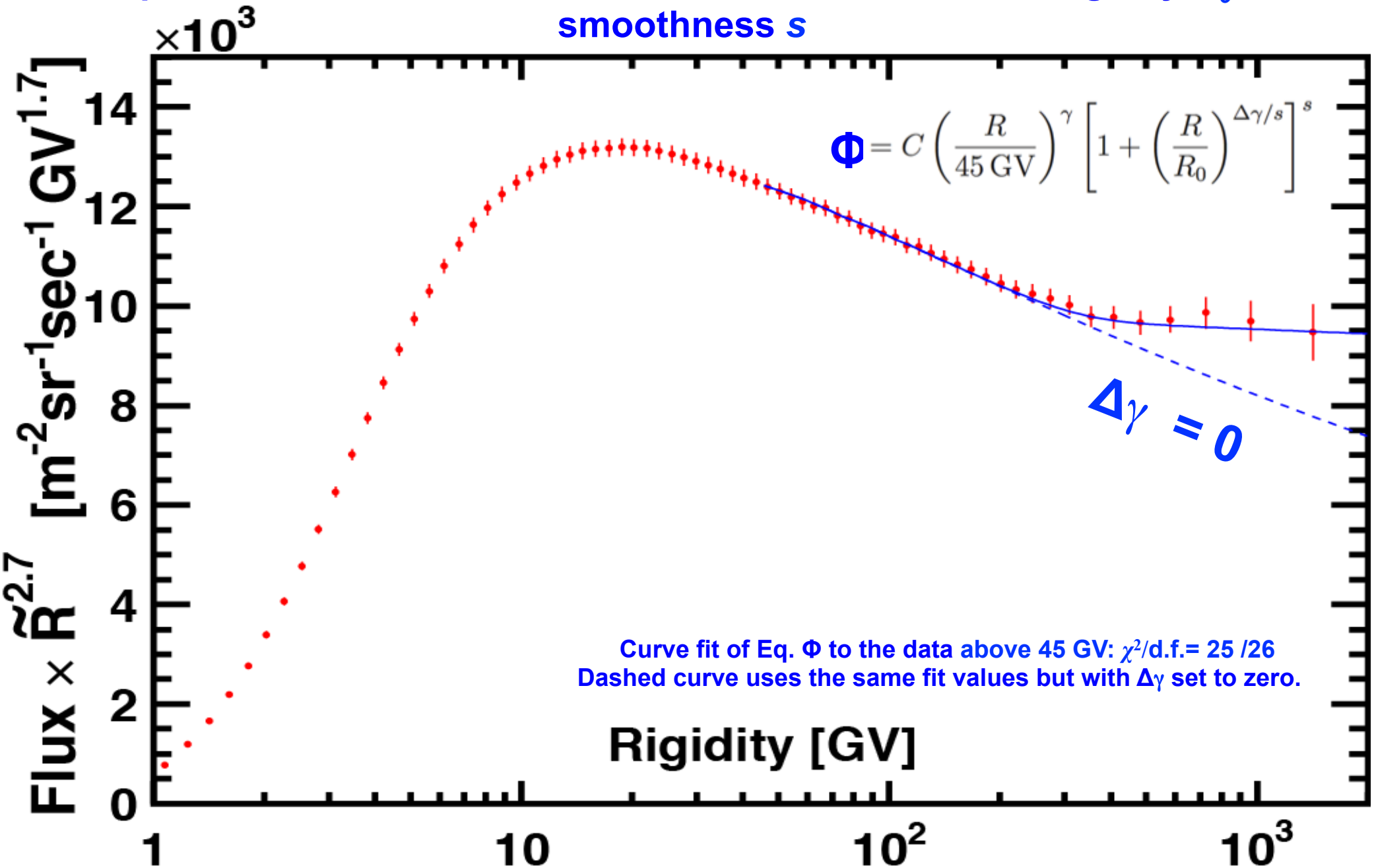
Rigidity [GV]	Φ	$\sigma_{stat.}$	$\sigma_{trig.}$	$\sigma_{acc.}$	$\sigma_{unf.}$	σ_{scale}	$\sigma_{syst.}$
100 – 108	(4.085	0.007	0.006	0.040	0.035	0.022	$0.058)\times10^{-2}$
108 – 116	(3.294	0.007	0.005	0.033	0.028	0.018	$0.047)\times10^{-2}$
116 – 125	(2.698	0.006	0.004	0.027	0.023	0.016	$0.039)\times10^{-2}$
125 – 135	(2.174	0.005	0.004	0.022	0.019	0.013	$0.032)\times10^{-2}$

AMS proton flux



AMS proton flux

two power laws: R^{γ}, $R^{\gamma+\Delta\gamma}$ with a characteristic transition rigidity R_0 and smoothness s



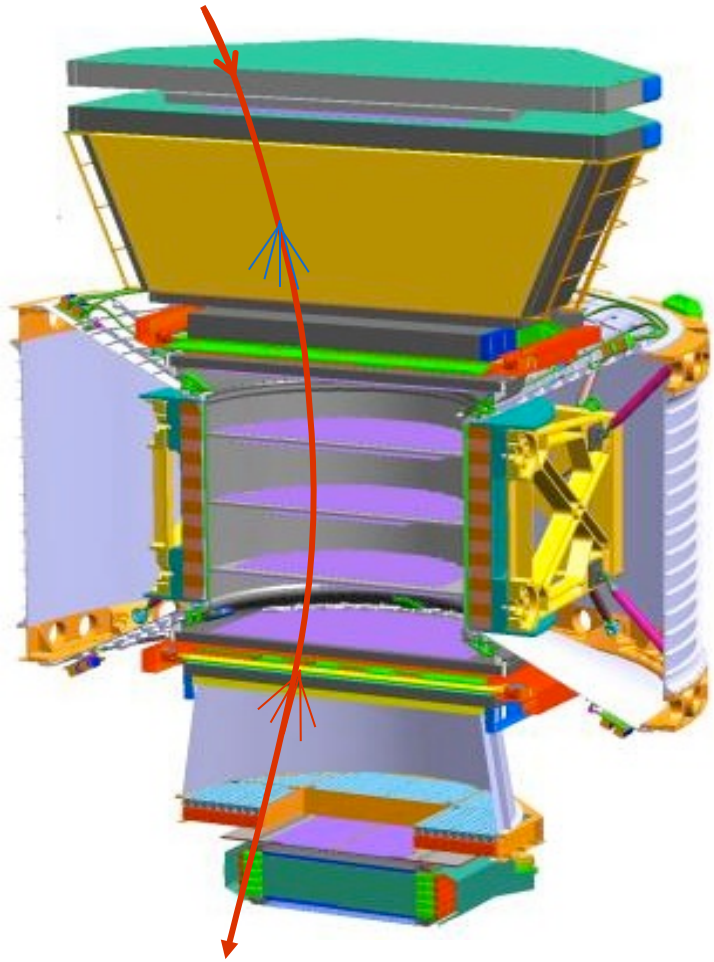
Accurate measurement of the flux of nuclei on the ISS.

A new method:

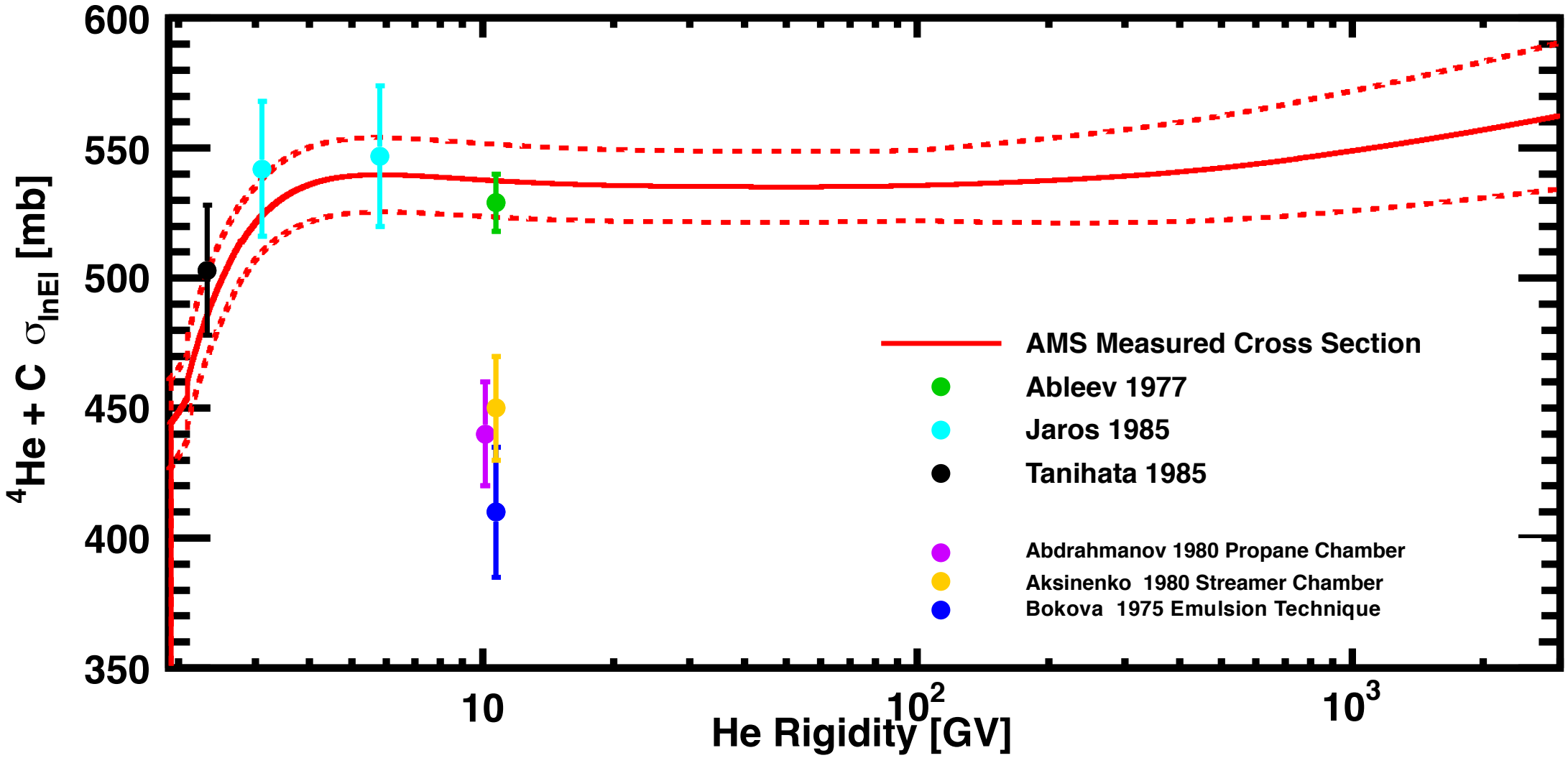
To measure the flux of nuclei (He, Li, Be, B, C, O, …) accurately, we need to know the interaction cross section of these nuclei with the materials in AMS.

Unfortunately, the interactions of nuclei with the materials in AMS could not be measured on the ground. This limits the accuracy to which we could measure the fluxes.

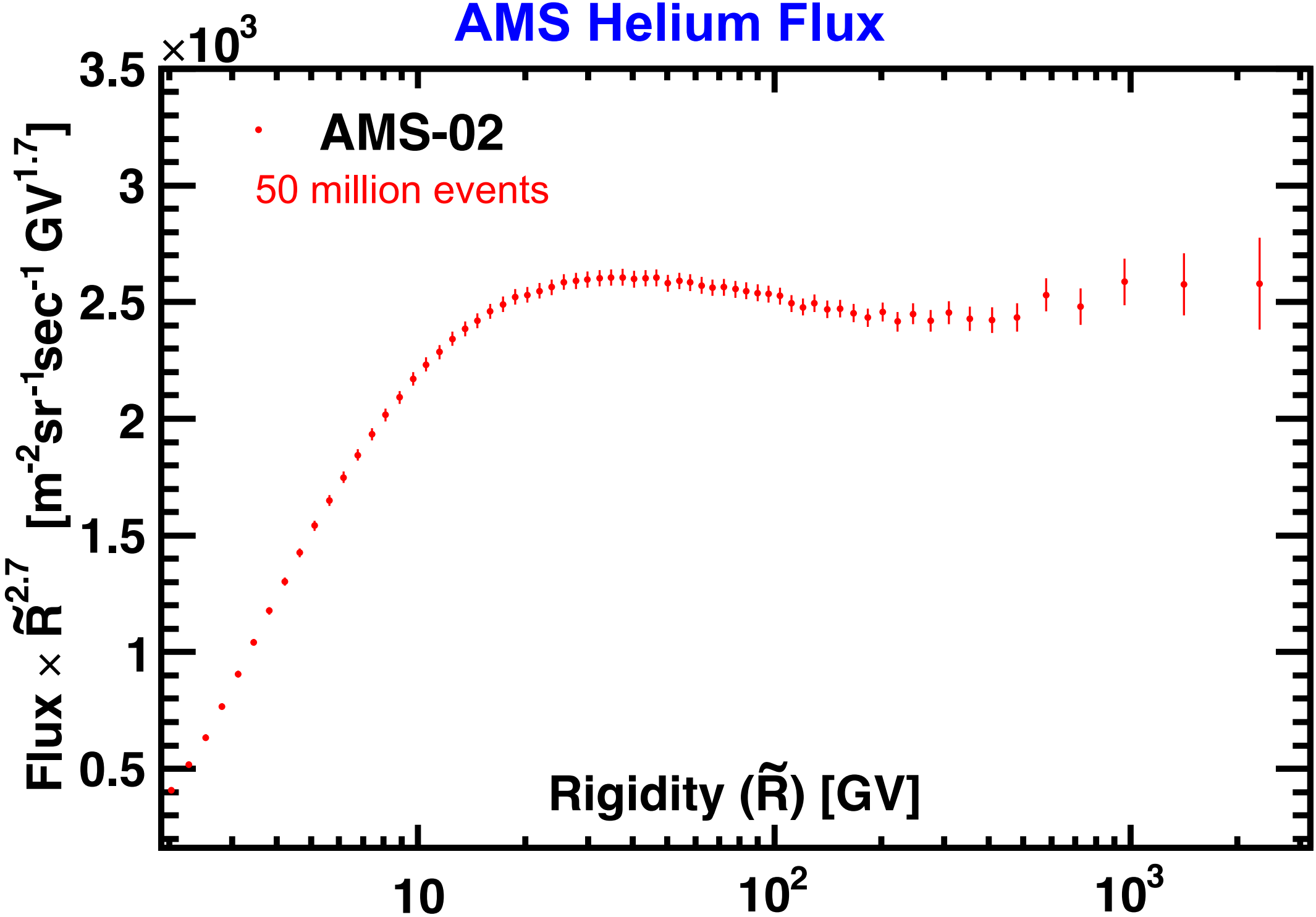
On ISS we have now a method to measure these interactions in space accurately.



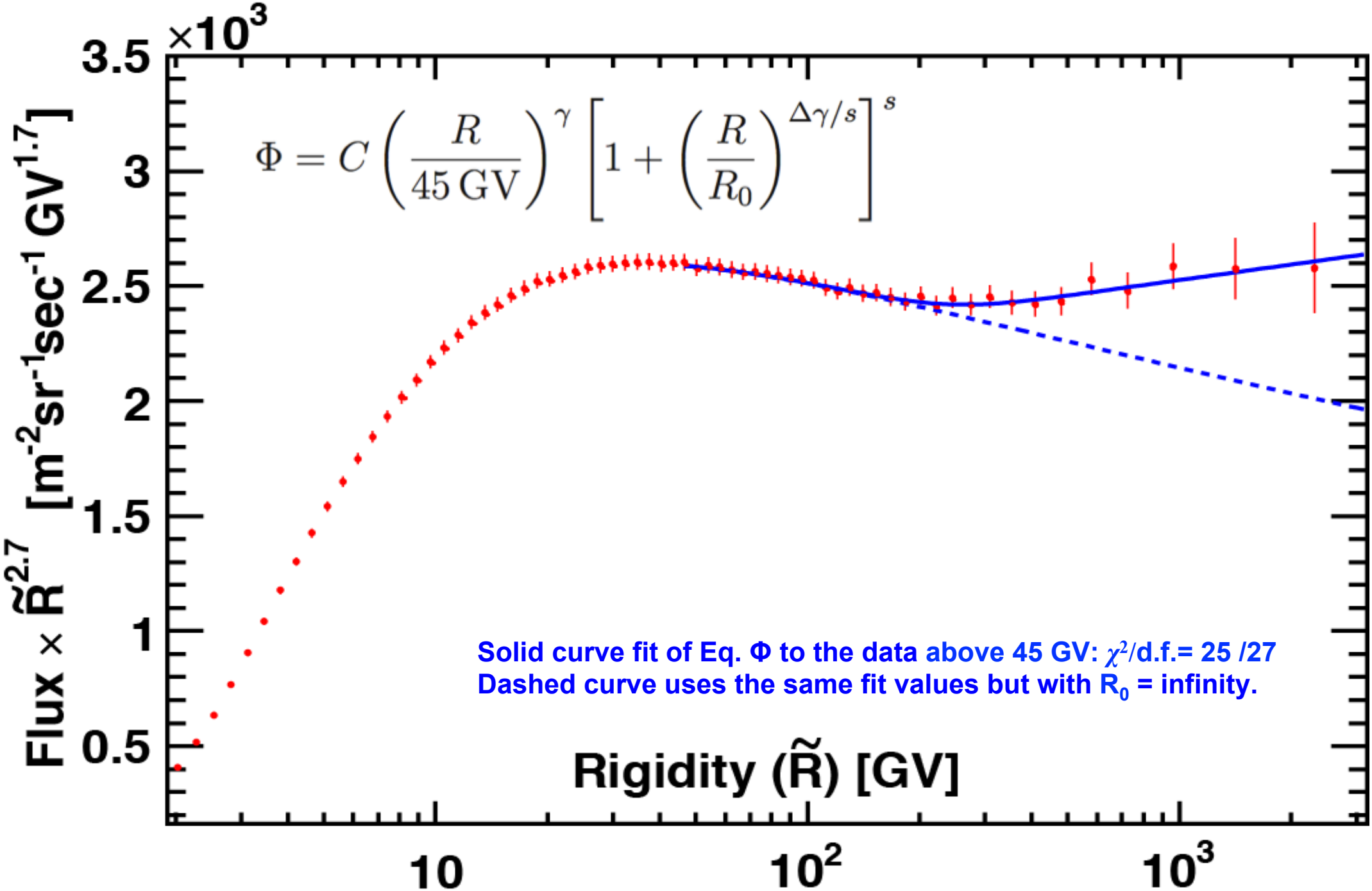
AMS Measurement of He+C Cross Section



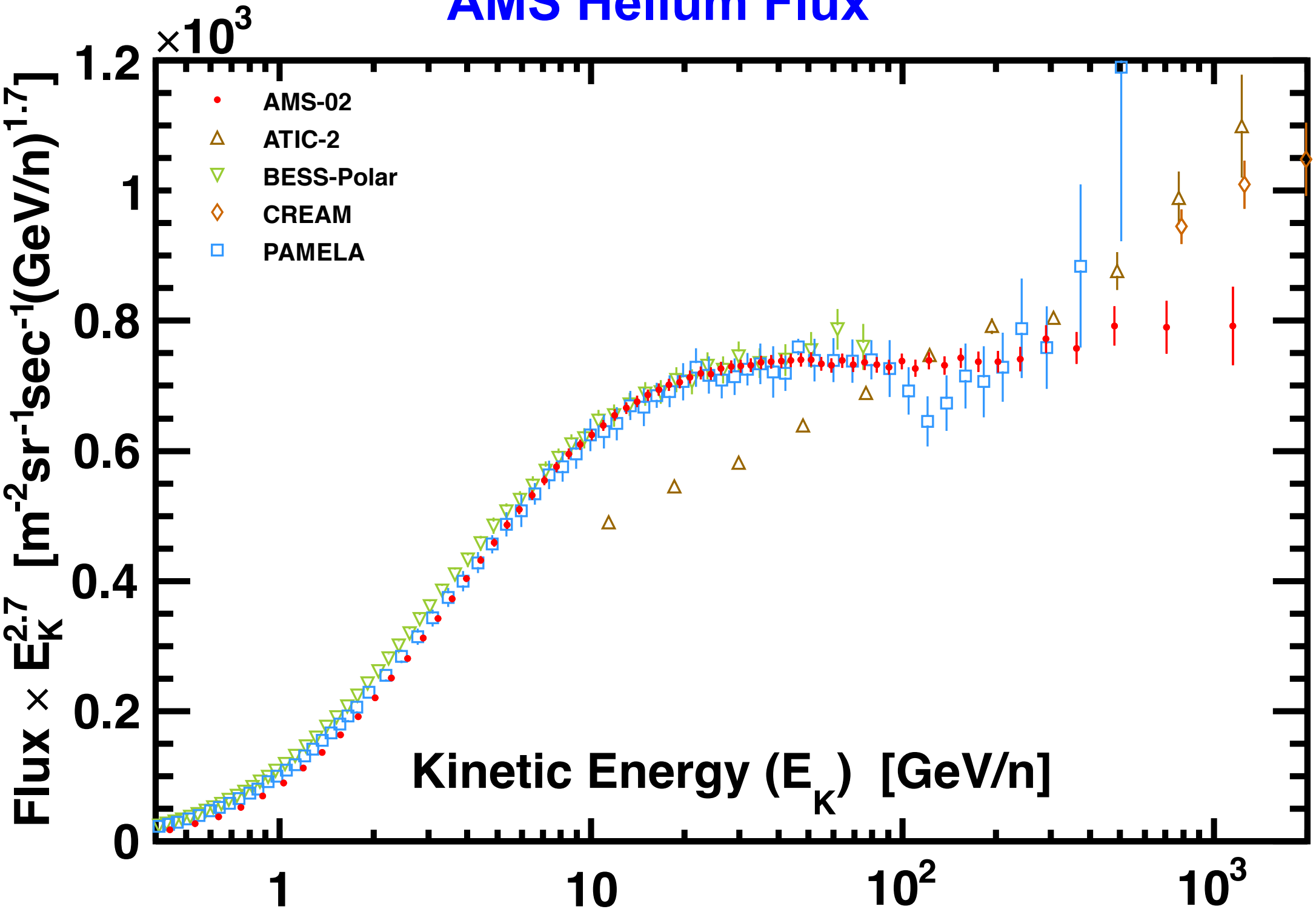
AMS Helium Flux



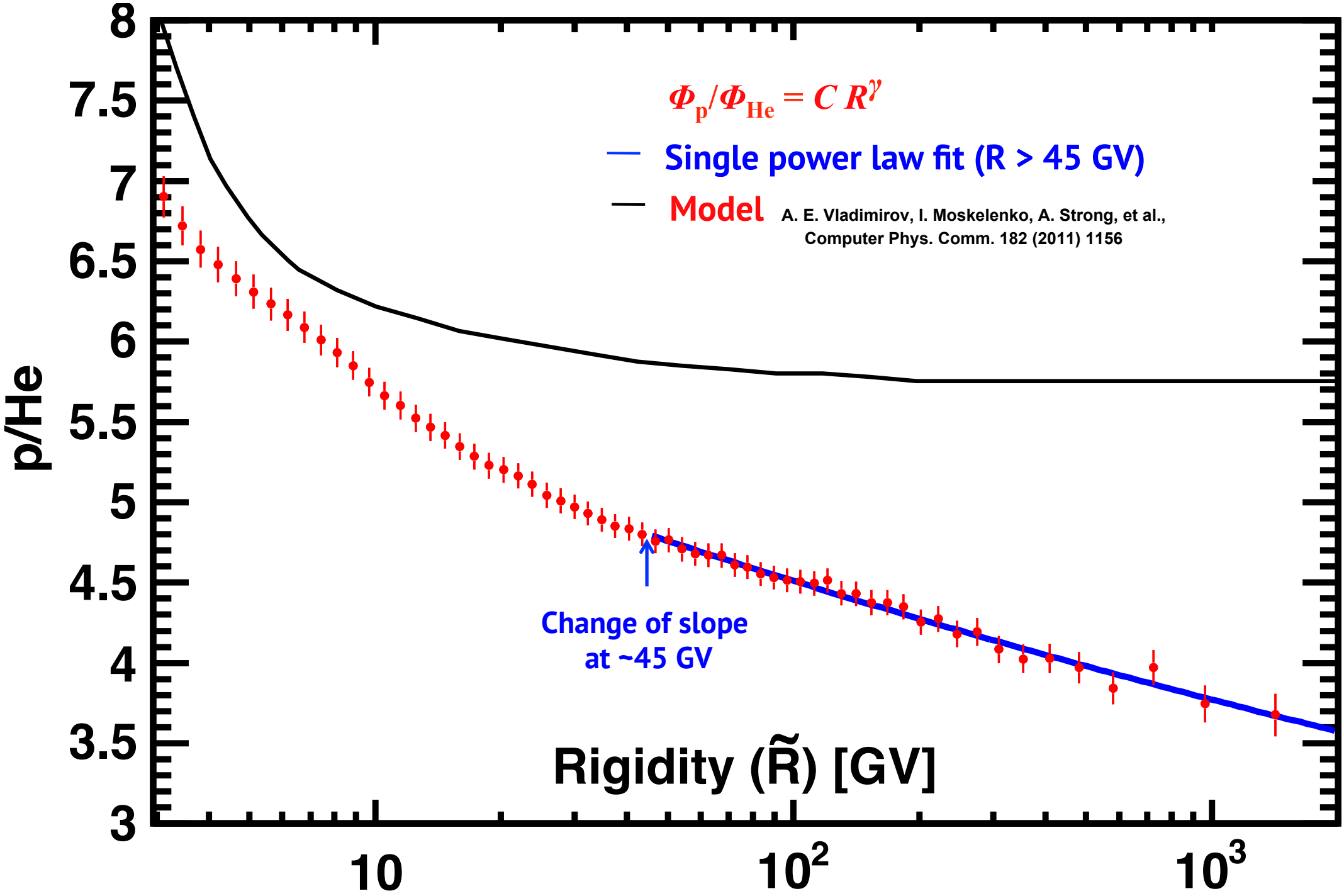
AMS Helium Flux



AMS Helium Flux



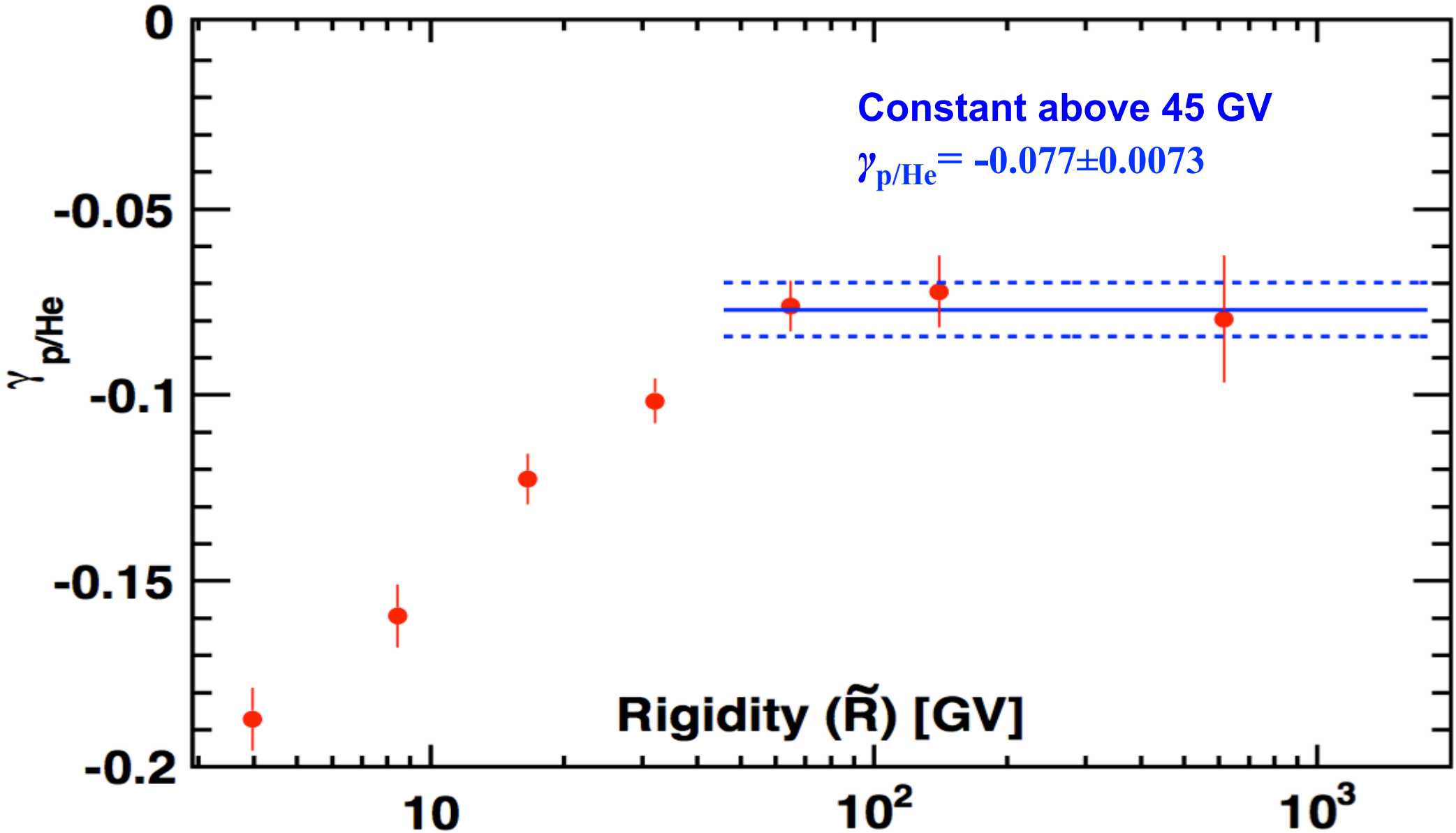
The AMS proton/helium ratio



Spectral index of p/He ratio

p/ He ratio = C R $^{\gamma}$

p/He spectral index (γ) = d log (p/He ratio)/ d log (R)

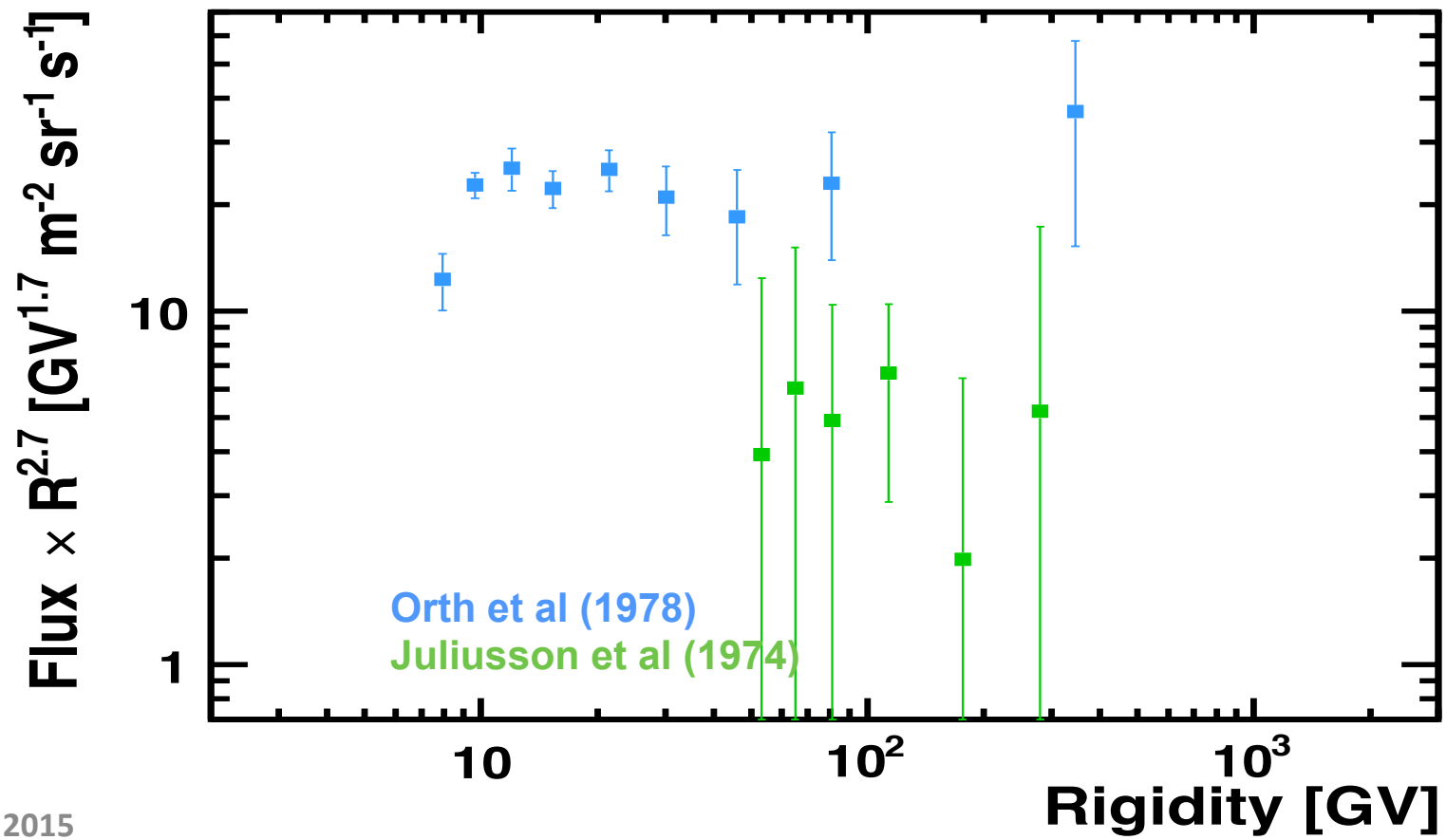


Lithium in Cosmic Rays

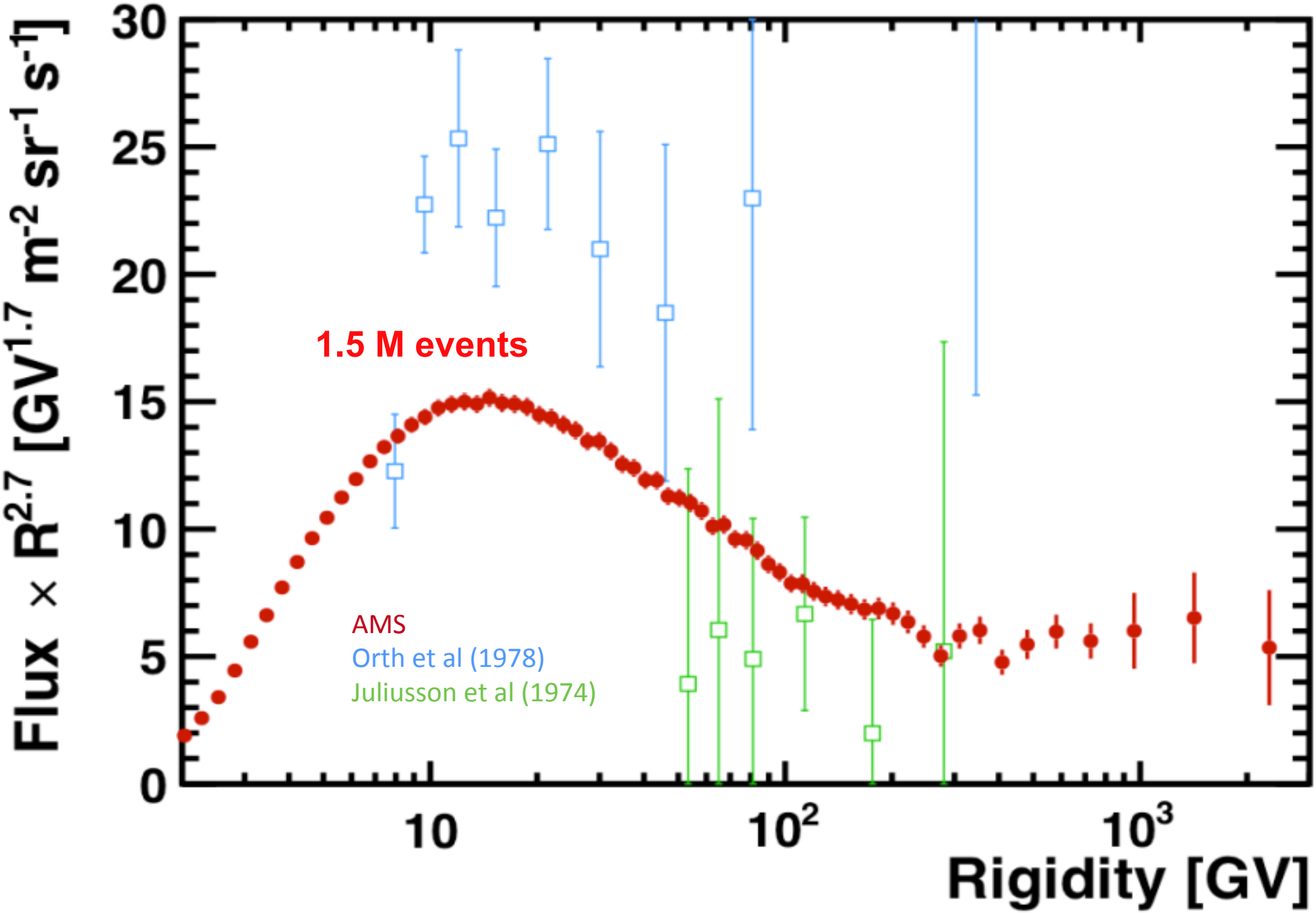
- Like B and Be, Li is produced by the spallation of heavier nuclei during their propagation.
- Sensitive to CR propagation parameters (diffusion, convection, reacceleration…).

C, N, O,…Fe + ISM → Li
→ B, Be + ISM → Li

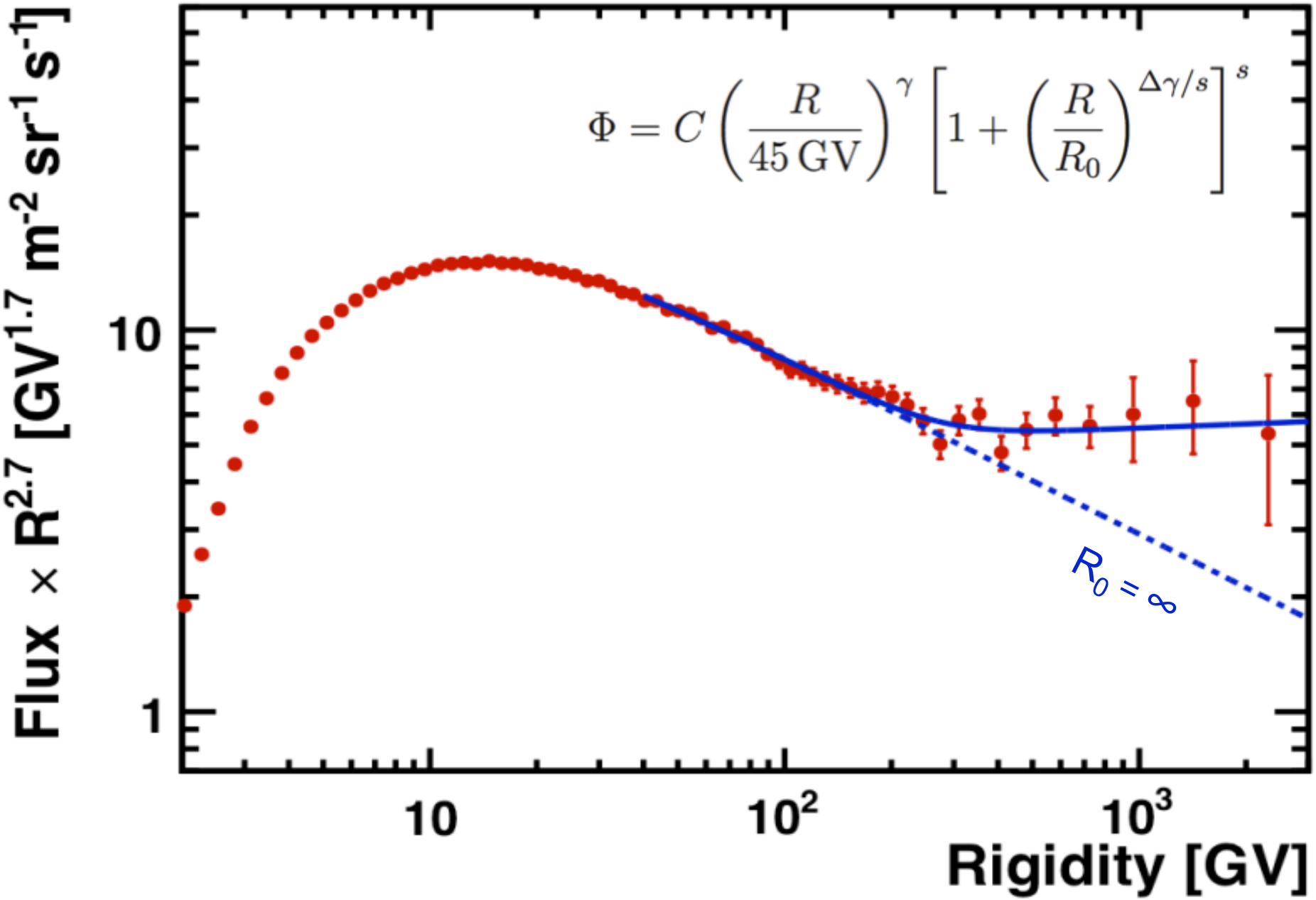
Current data from balloon experiments:



AMS Lithium flux – current status

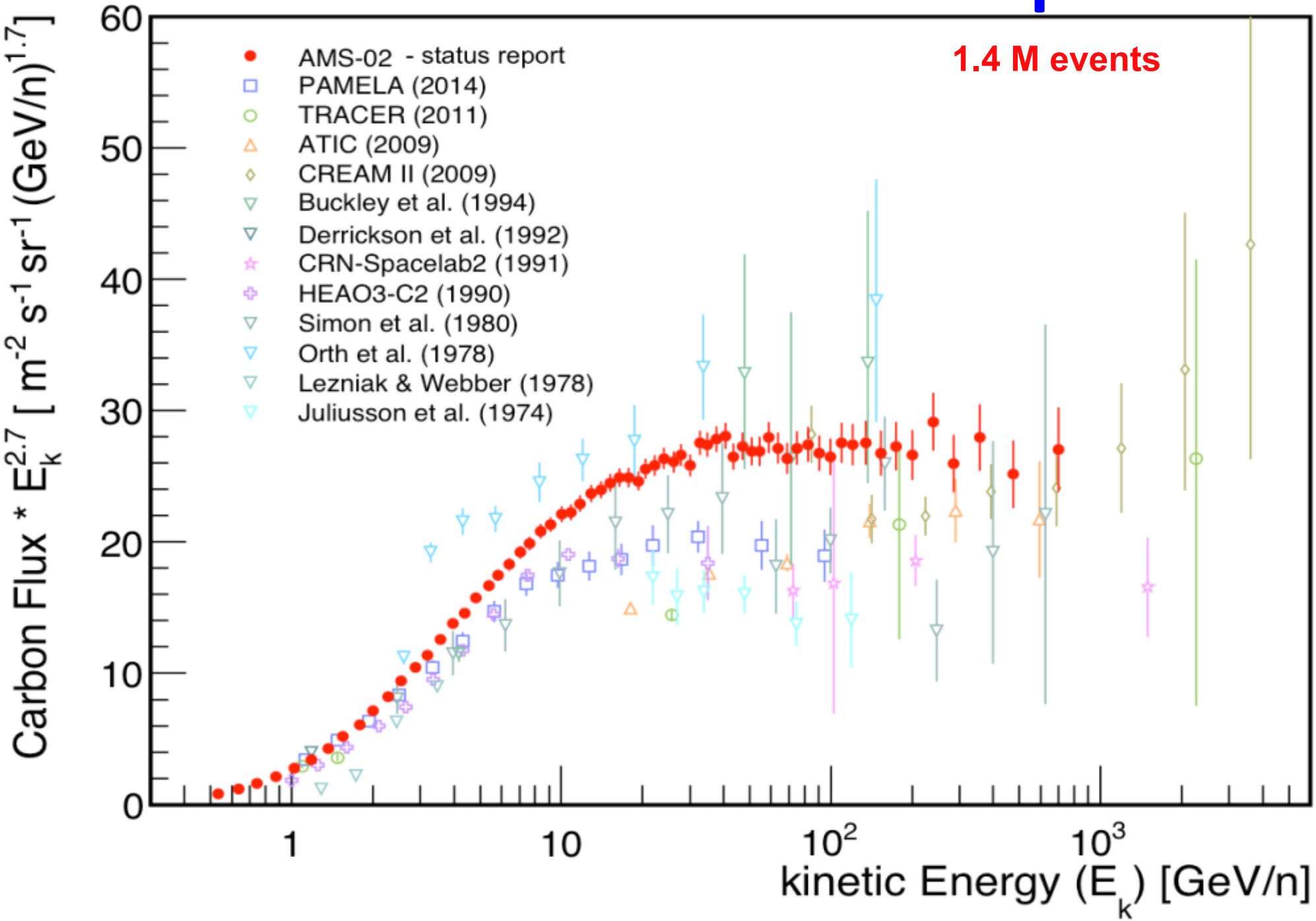


Lithium flux with two power law fit



Slope changes at about the same rigidity as for protons and helium

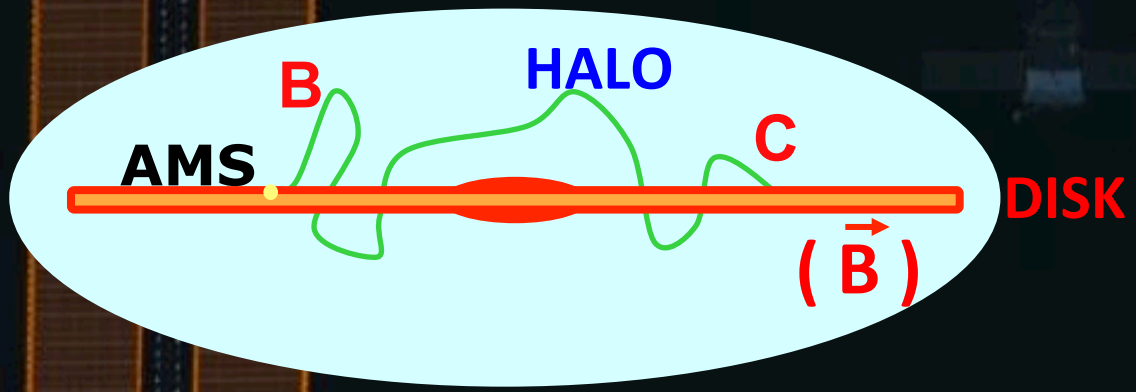
AMS Carbon Flux – status report

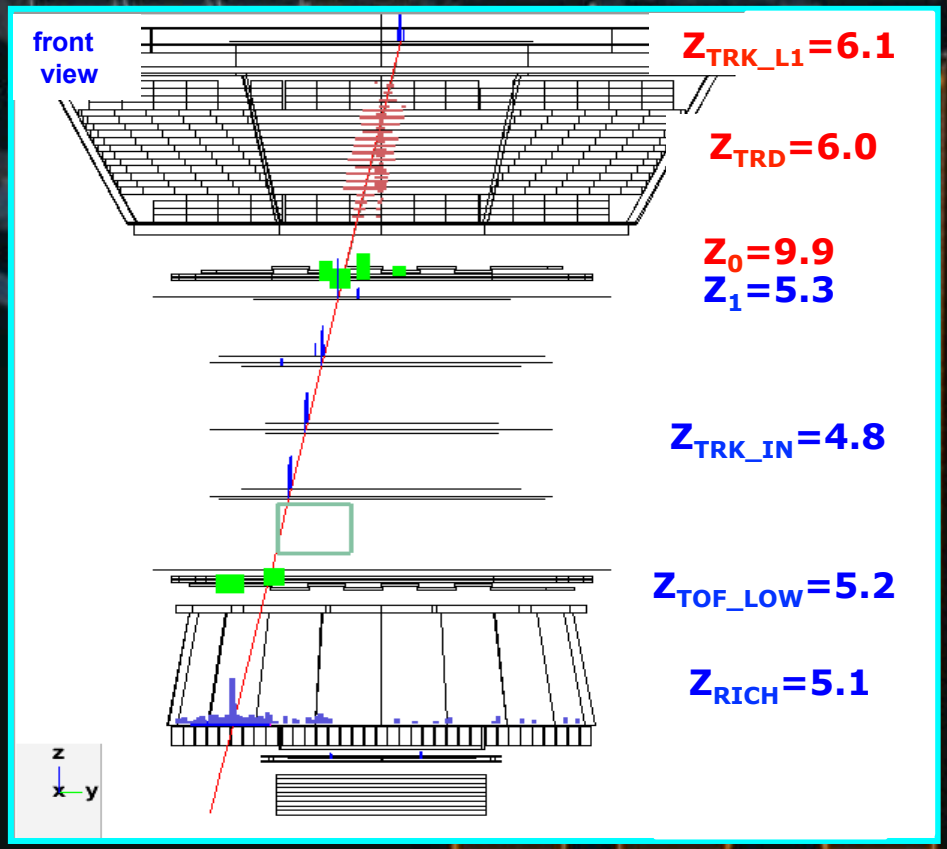


Precise measurement of the rigidity spectra of B/C provides information on Cosmic Ray Interactions and Propagation

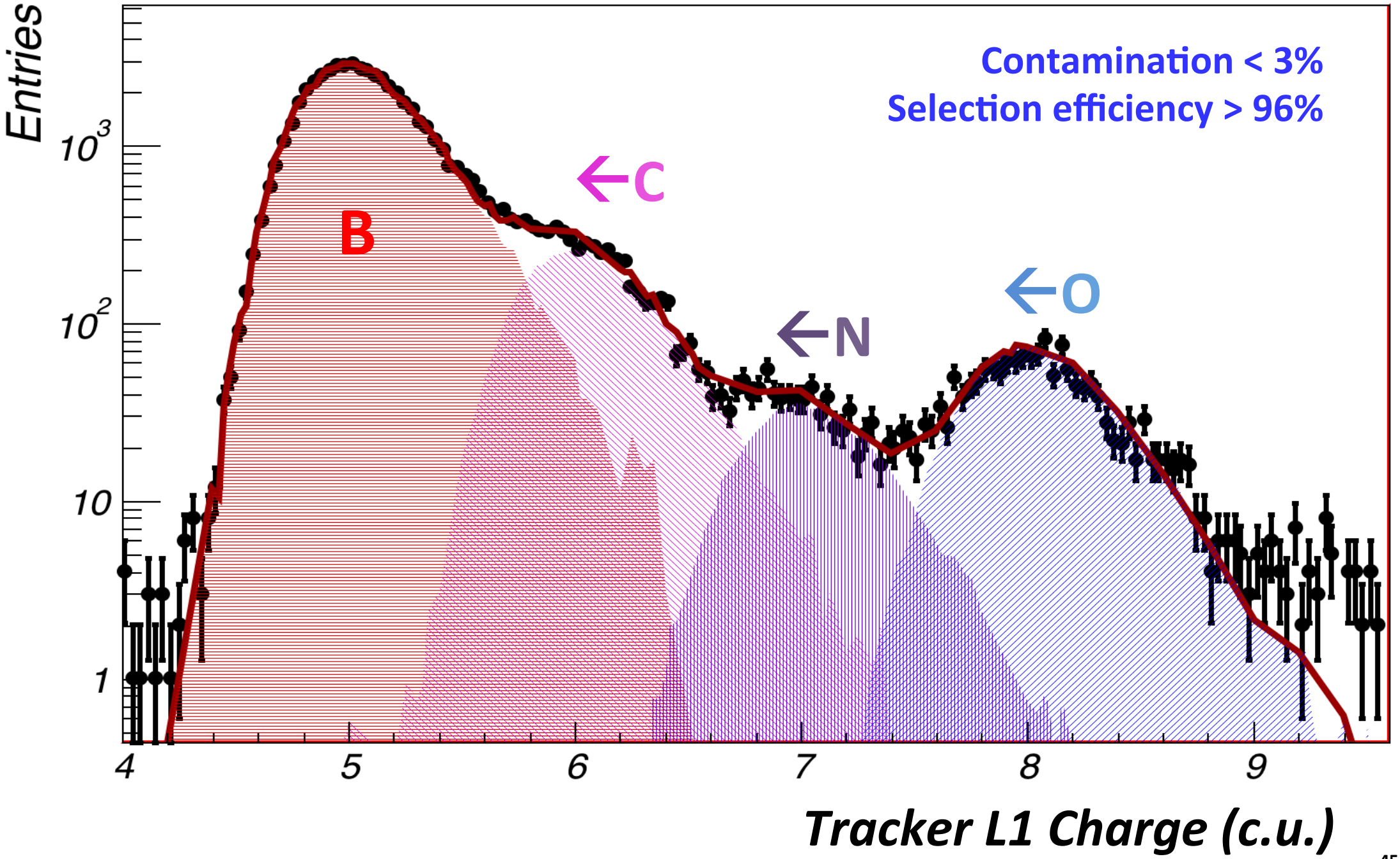
Carbon Fragmentation to Boron R = 10.6 GV

The propagation of cosmic rays and their interactions with the Interstellar Medium (ISM) is measured through the B/C ratio.

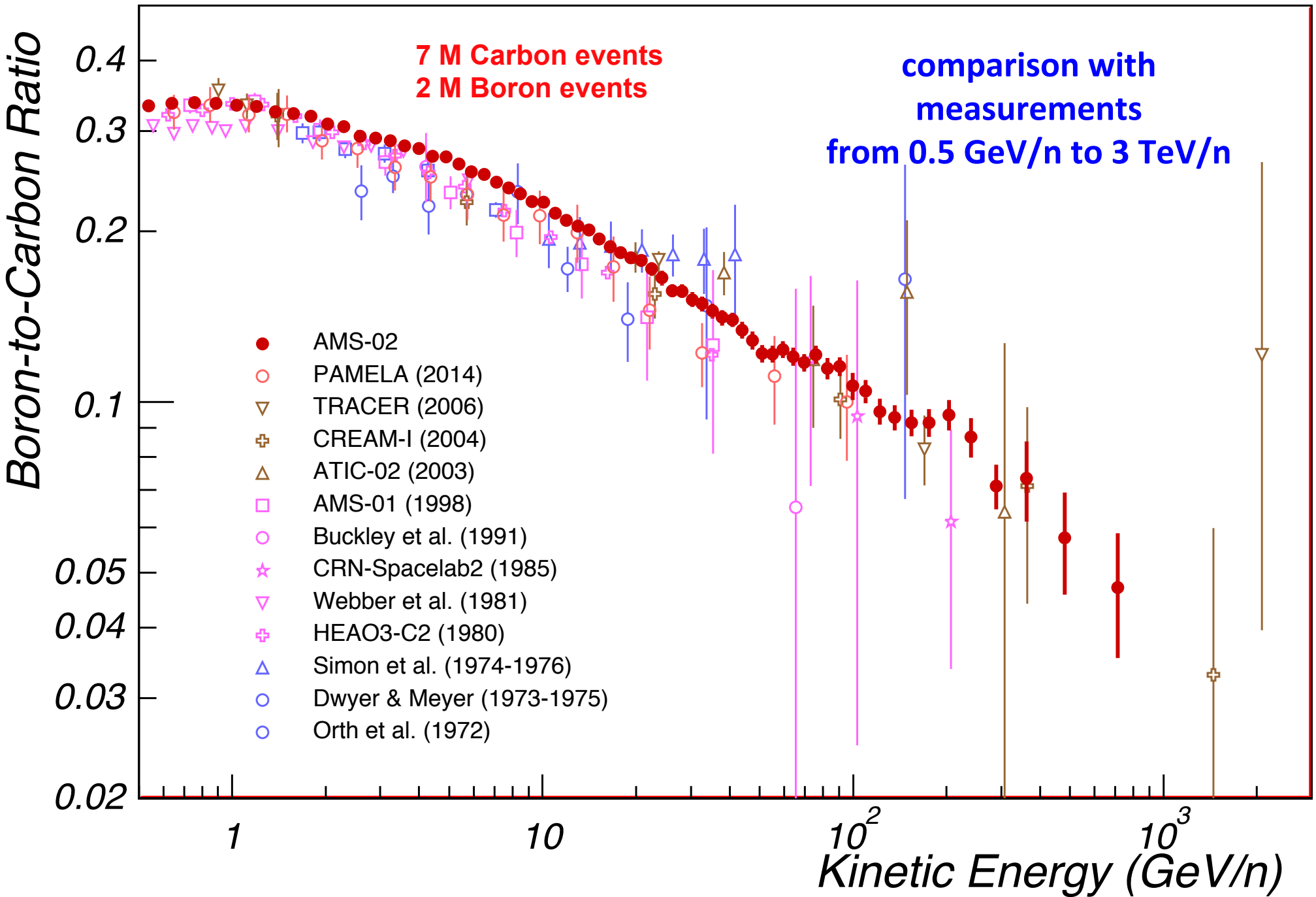




Boron and Carbon: Sample composition

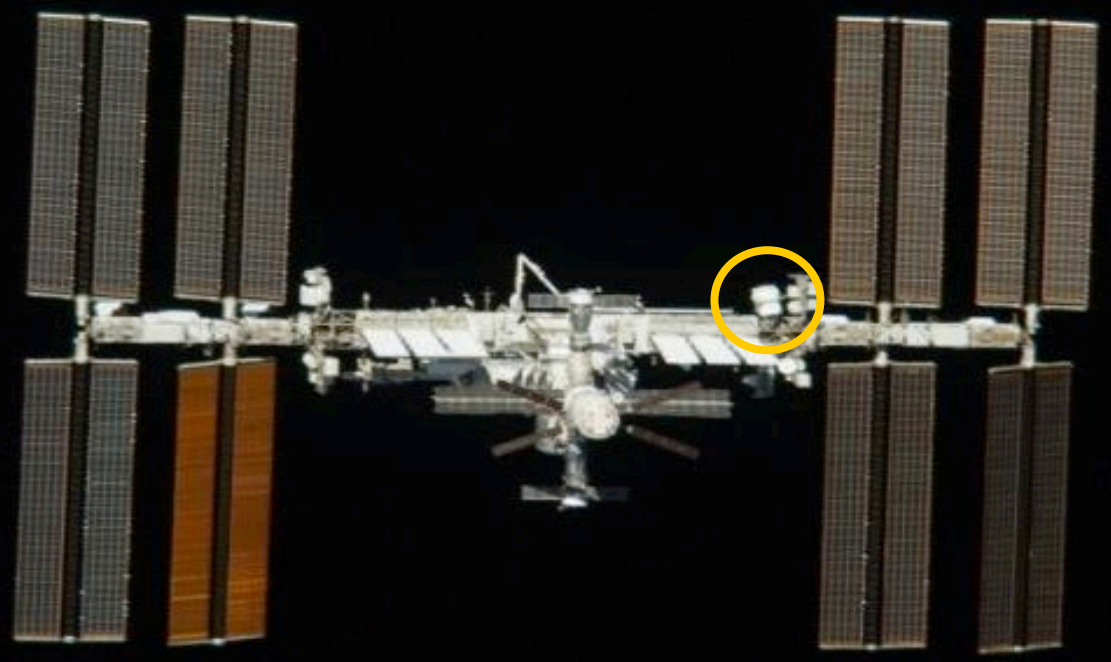


AMS B/C Ratio converted in Kinetic Energy



The latest AMS measurements of the positron fraction, the antiproton/proton ratio, the behavior of the fluxes of electrons, positrons, protons, helium, and other nuclei is providing new, precise, and unexpected information.

The accuracy and characteristics of the data, simultaneously from many different types of cosmic rays, will soon determine the true nature of the new phenomena we observe.



AMS physics for the lifetime of the Space Station

Accurate measurement (~1%) of Cosmic Rays to higher energies including:

a. Continue the study of Dark Matter

b. Search for the Existence of Antimatter

c. Search for New Phenomena, …