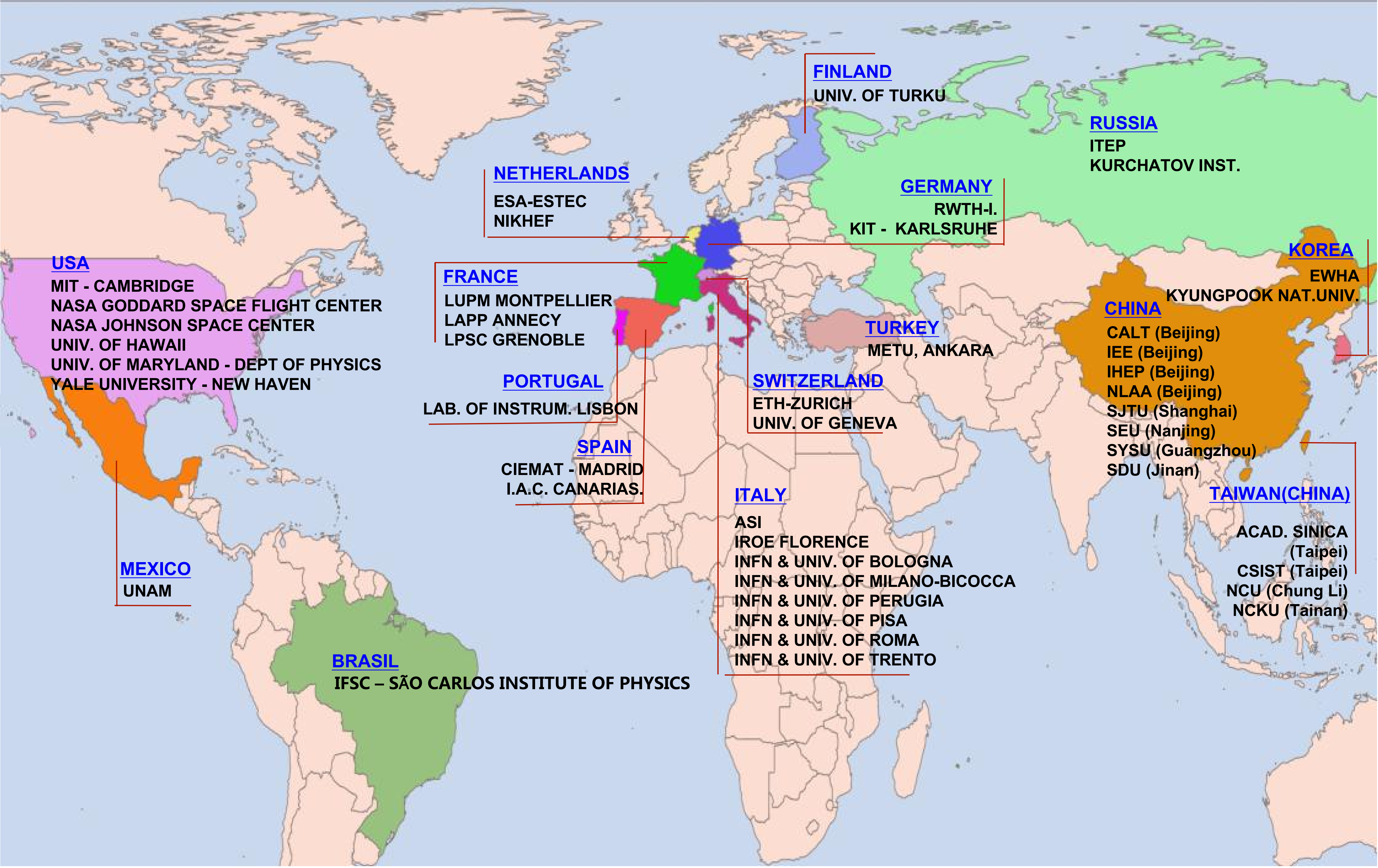
The Latest Results from AMS on the International Space Station

Zuhao LI IHEP, CAS

On behalf of the AMS Collaboration

Hefei, Aug 2016



AMS is a large international collaboration

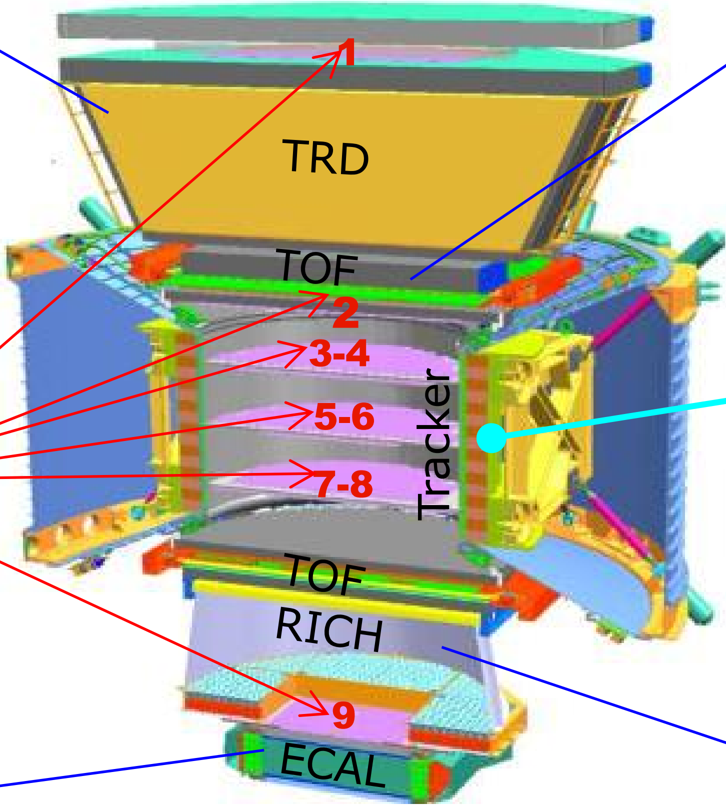
AMS: A TeV precision, multipurpose spectrometer

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

TRD
Identify e^+, e^-

Silicon Tracker
Z, P

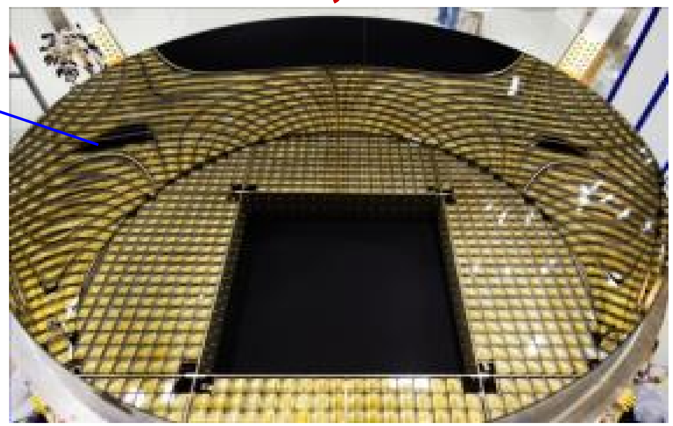
ECAL
E of e^+, e^-



TOF
Z, E

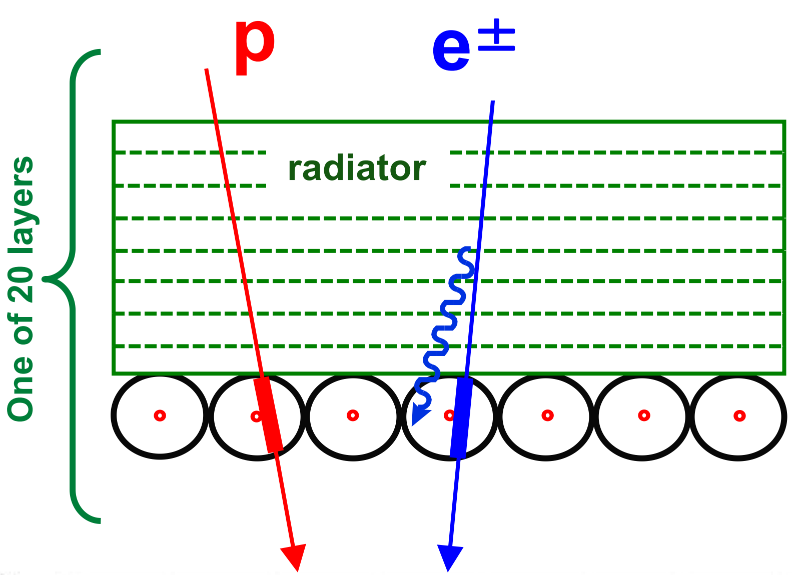
Magnet
±Z

RICH
Z, E

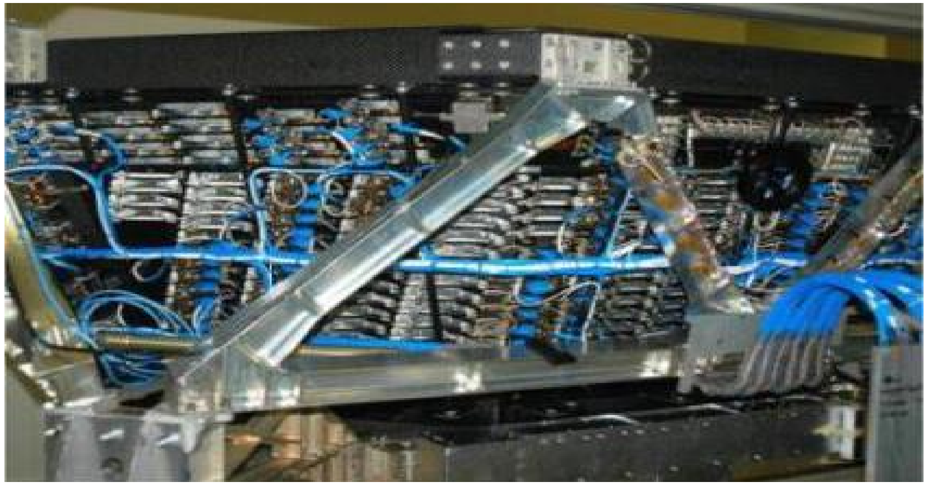


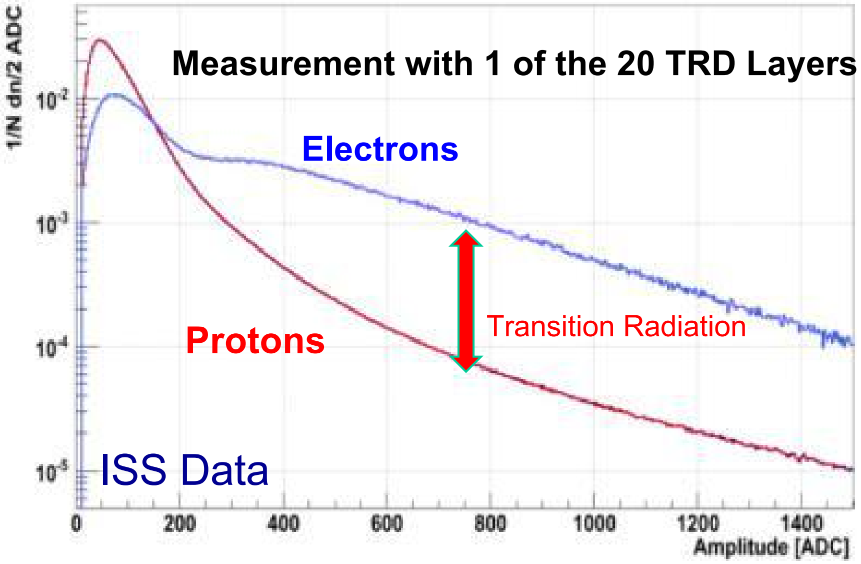
Z and P ~ E are measured independently by the Tracker, RICH, TOF and ECAL

Transition Radiation Detector



20 layers: fleece radiator and proportional tubes

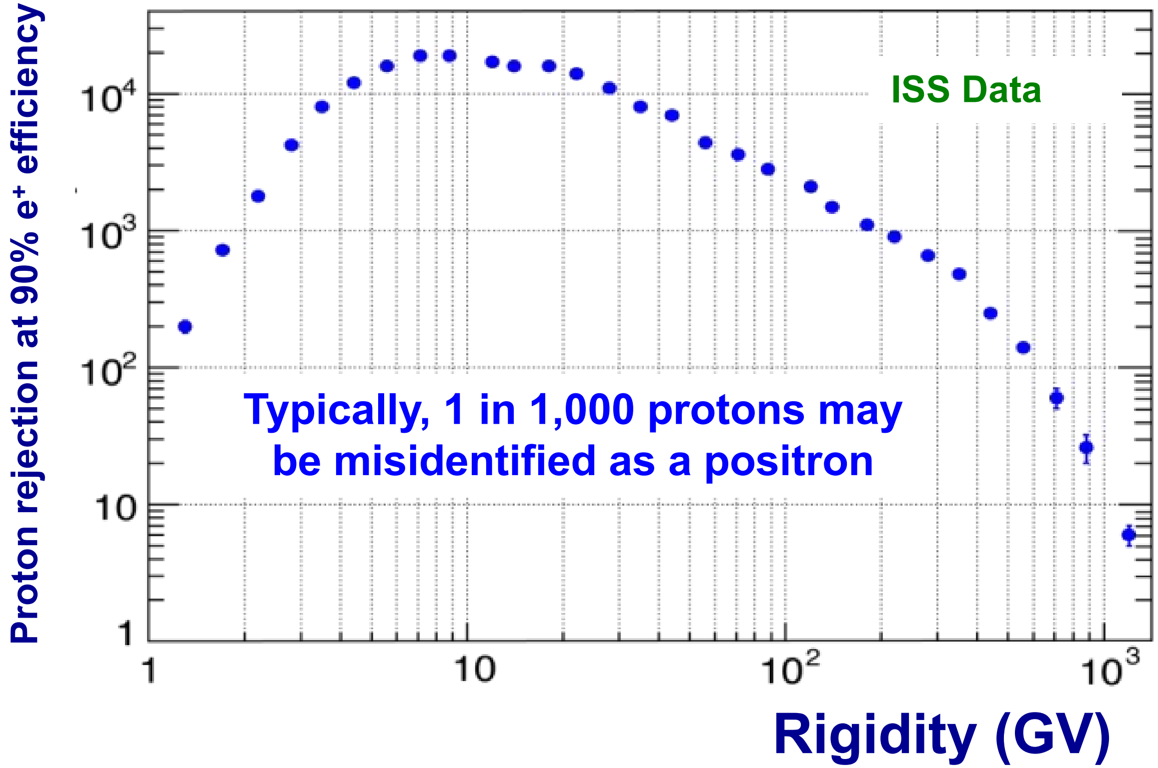




$$P_p = \sqrt[n]{\prod_i^n P_p^{(i)}(A)}$$

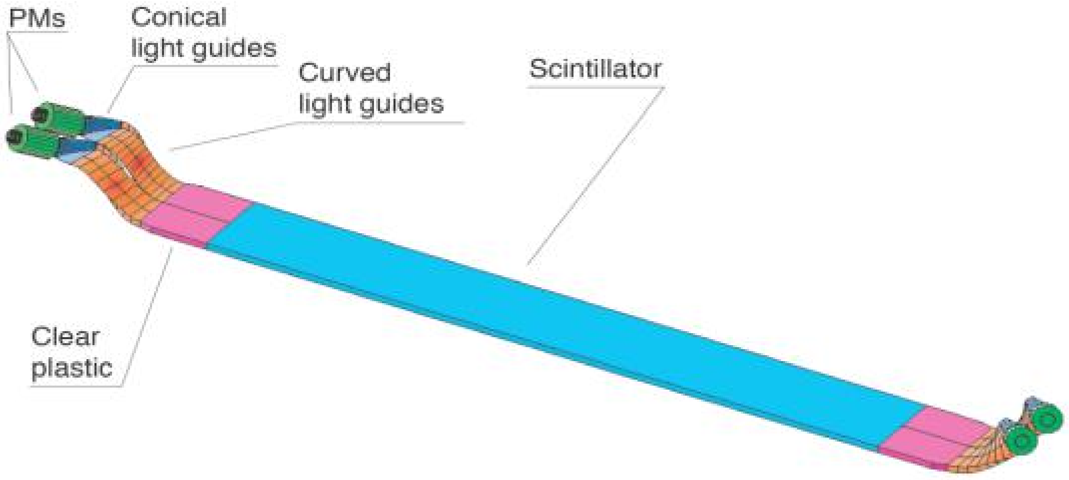
$$P_e = \sqrt[n]{\prod_i^n P_e^{(i)}(A)}$$

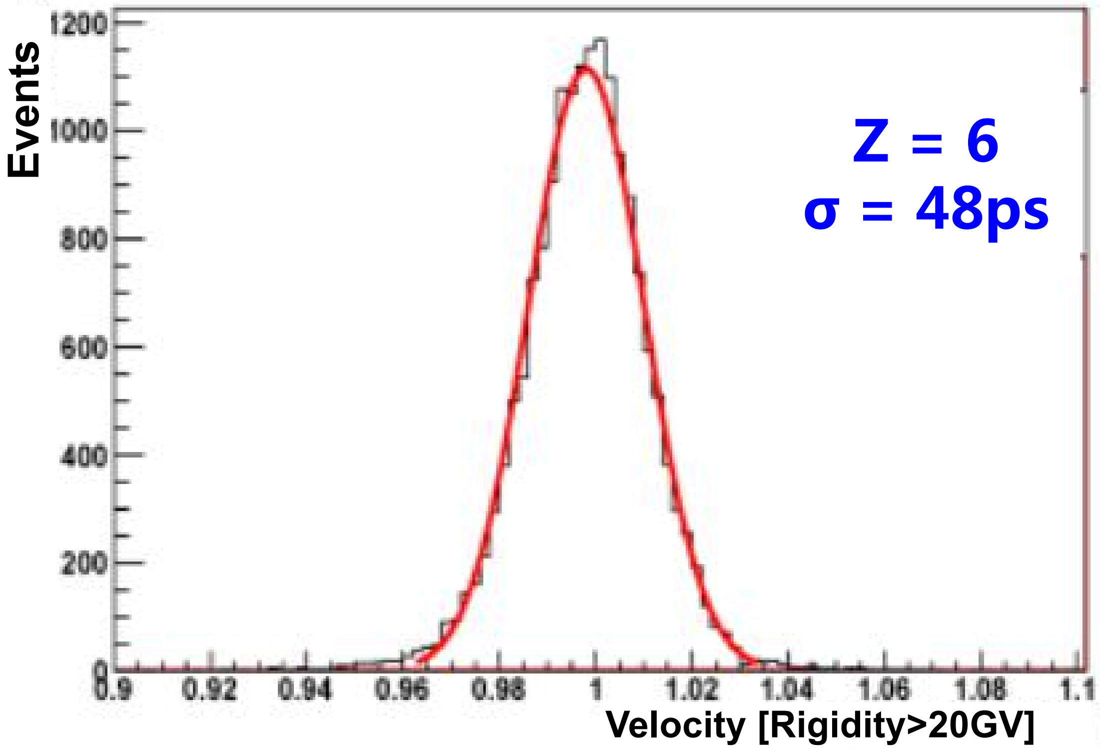
TRD estimator = $-\ln(P_e/(P_e+P_p))$



Time of Flight System

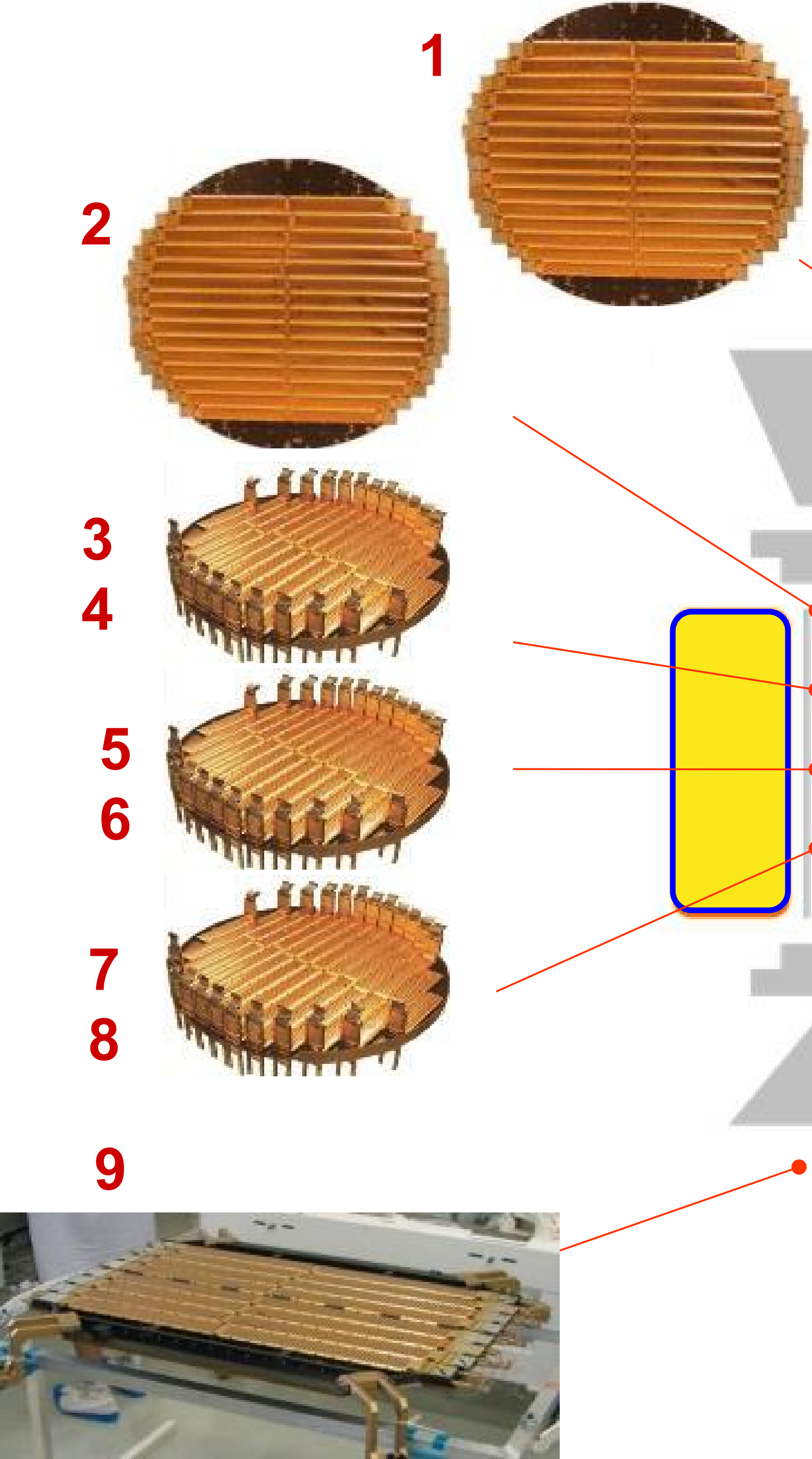
Measures Velocity and Charge of particles

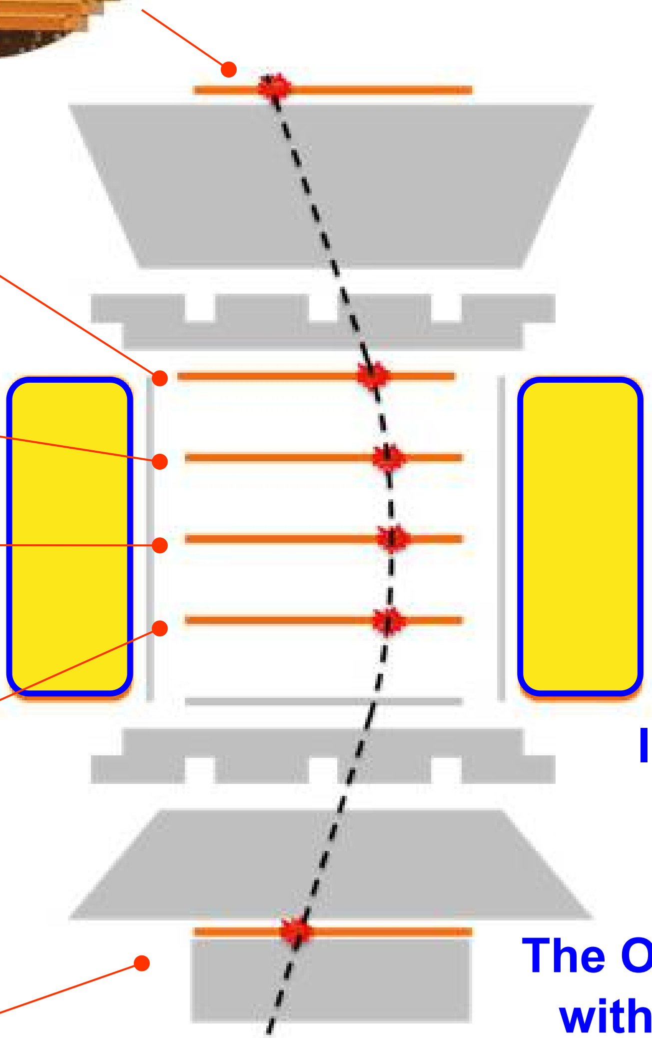


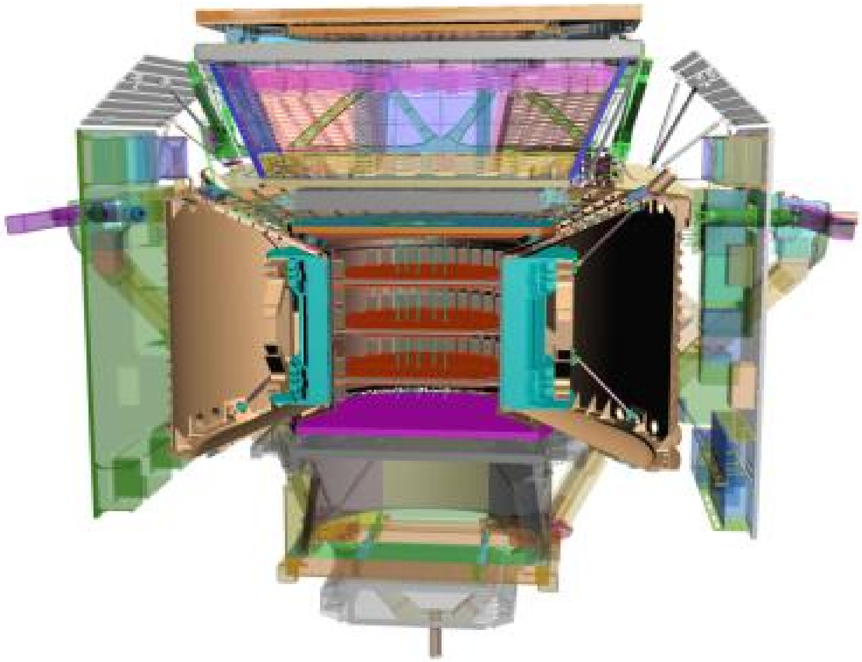


Tracker

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





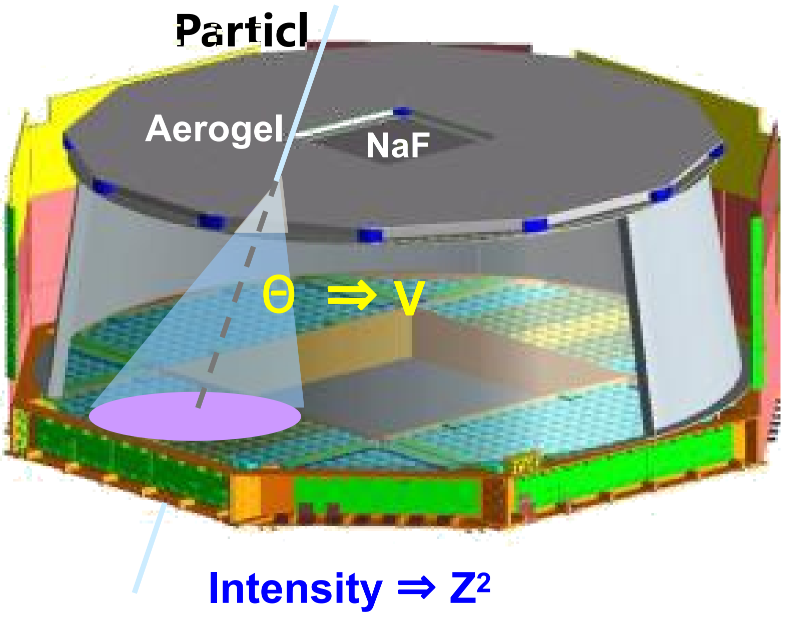


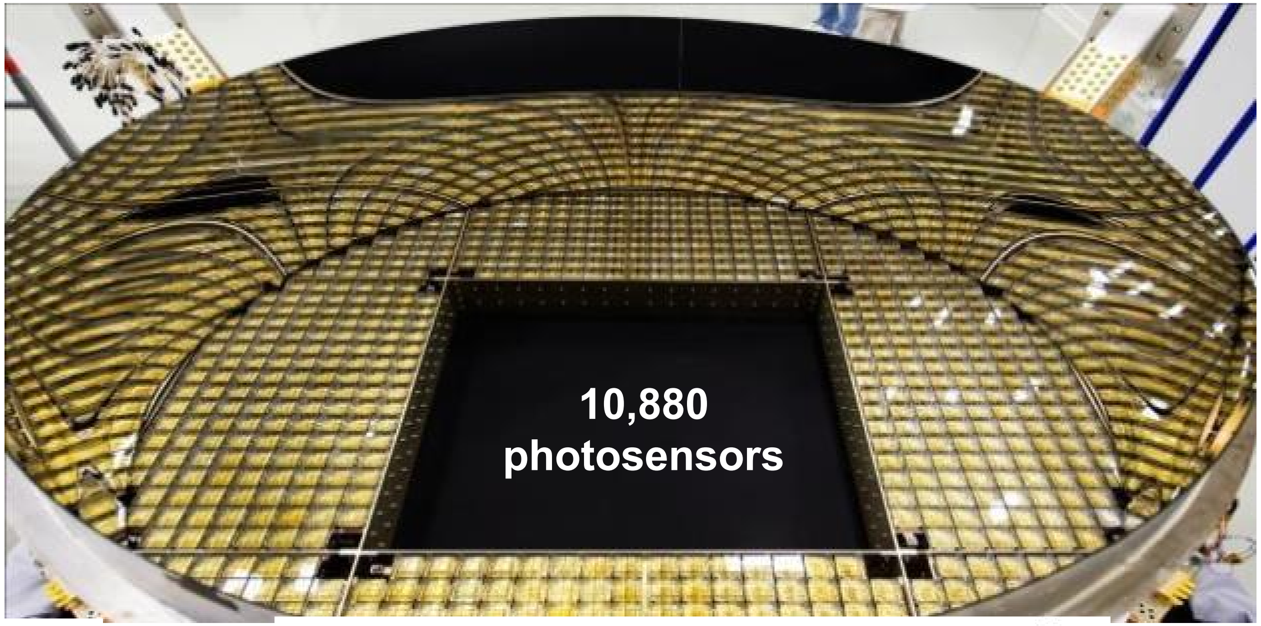
Inner tracker alignment stability monitored with IR Lasers.

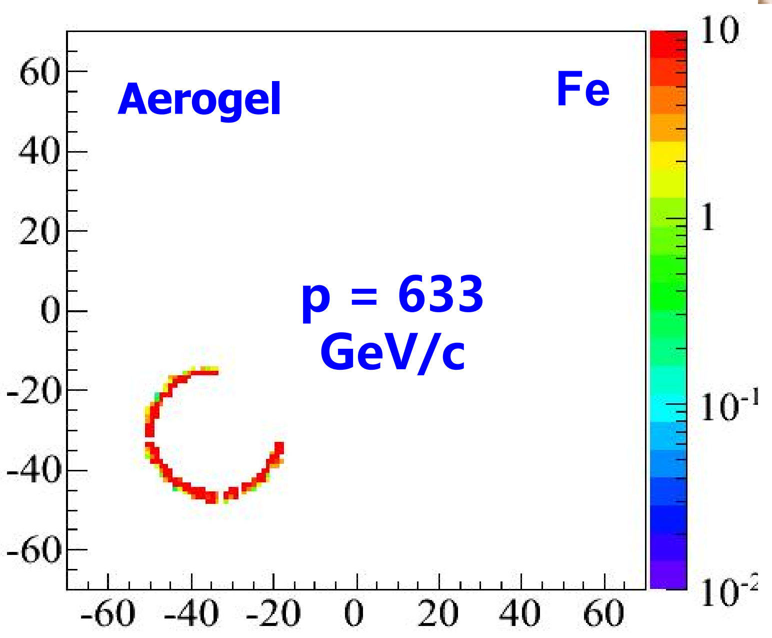
The Outer Tracker is continuously aligned with cosmic rays in a 2 minute window

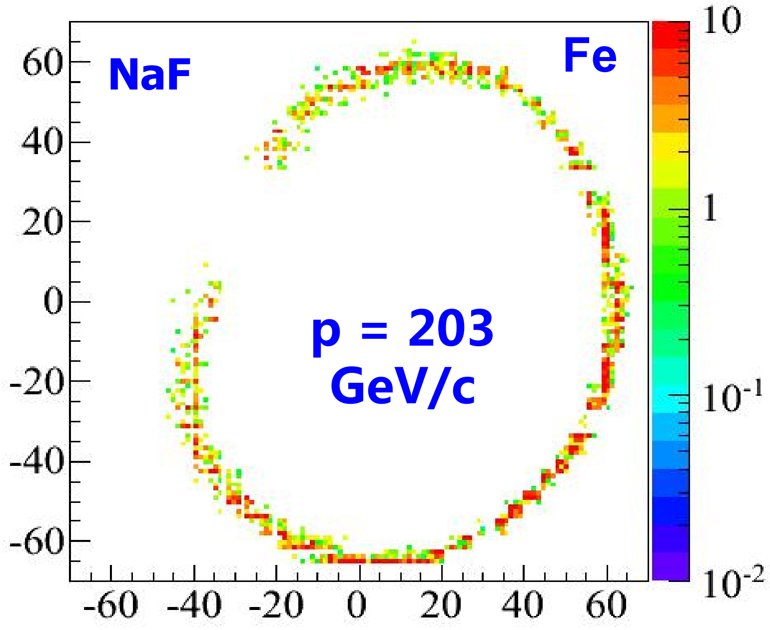
Ring Imaging CHerenkov (RICH)

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



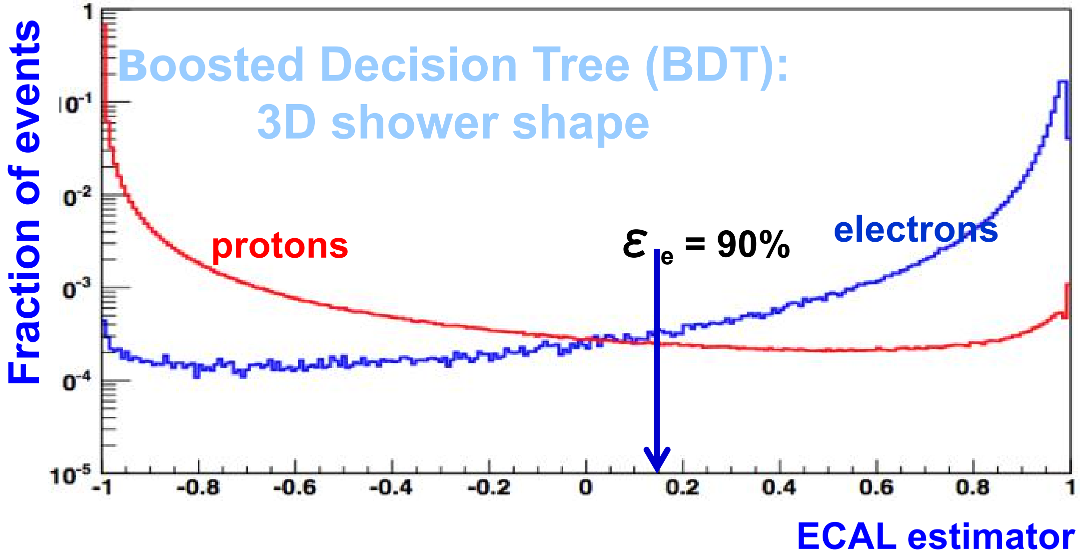


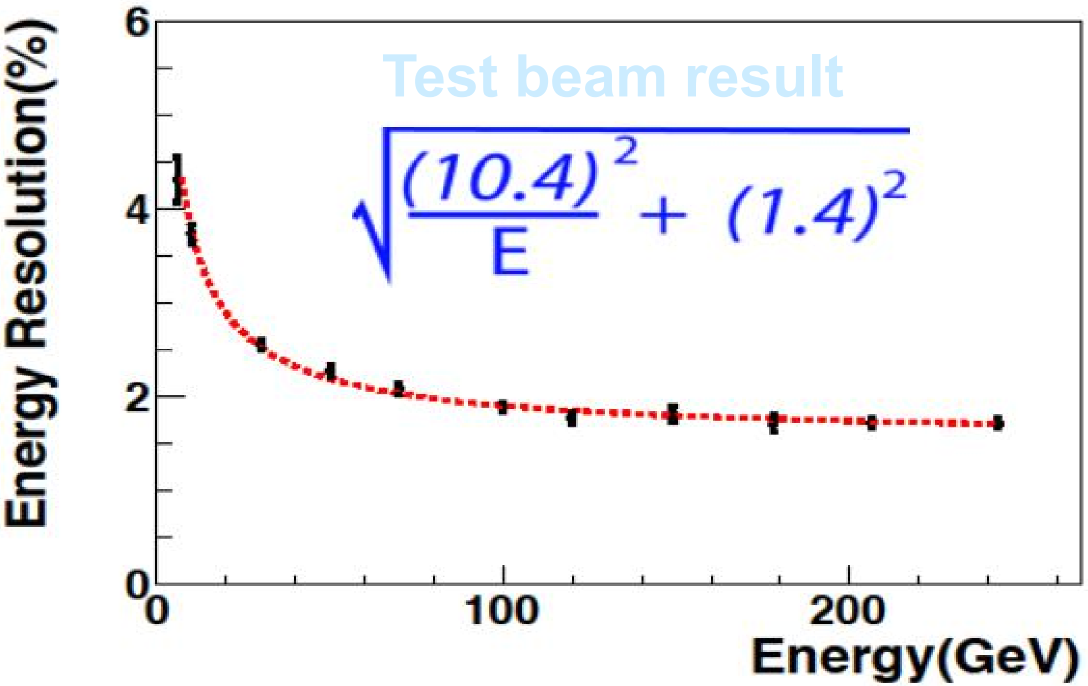




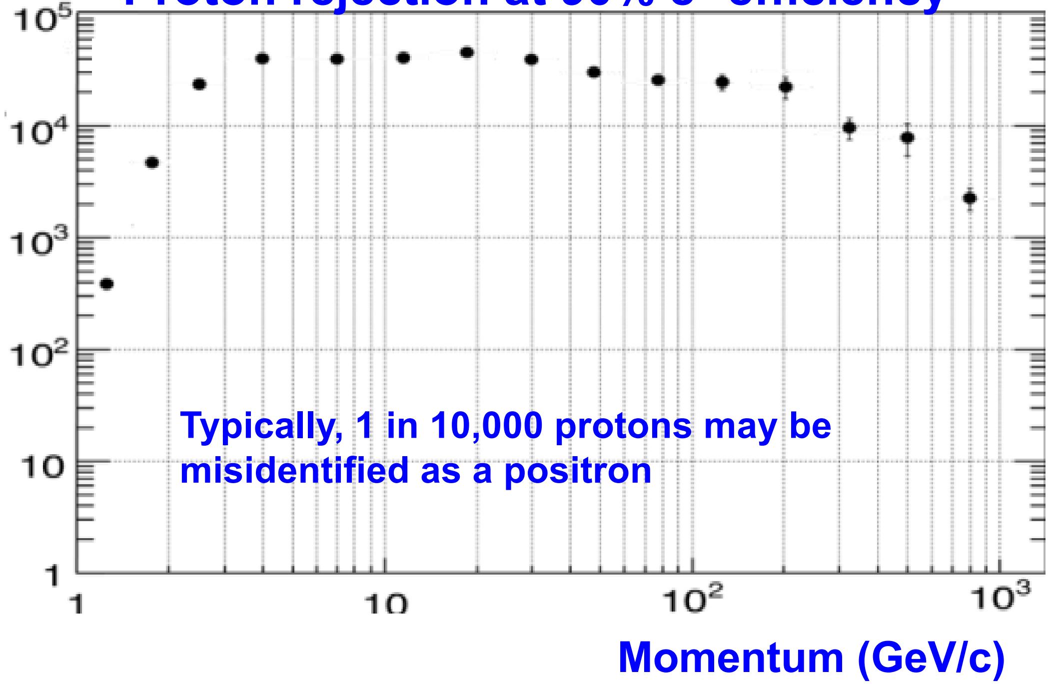
Electromagnetic Calorimeter

Provides a precision, 17 X_0, TeV, 3-dimensional measurement of the directions and energies of electrons and positrons, seperate $e^{\pm}$ from protons

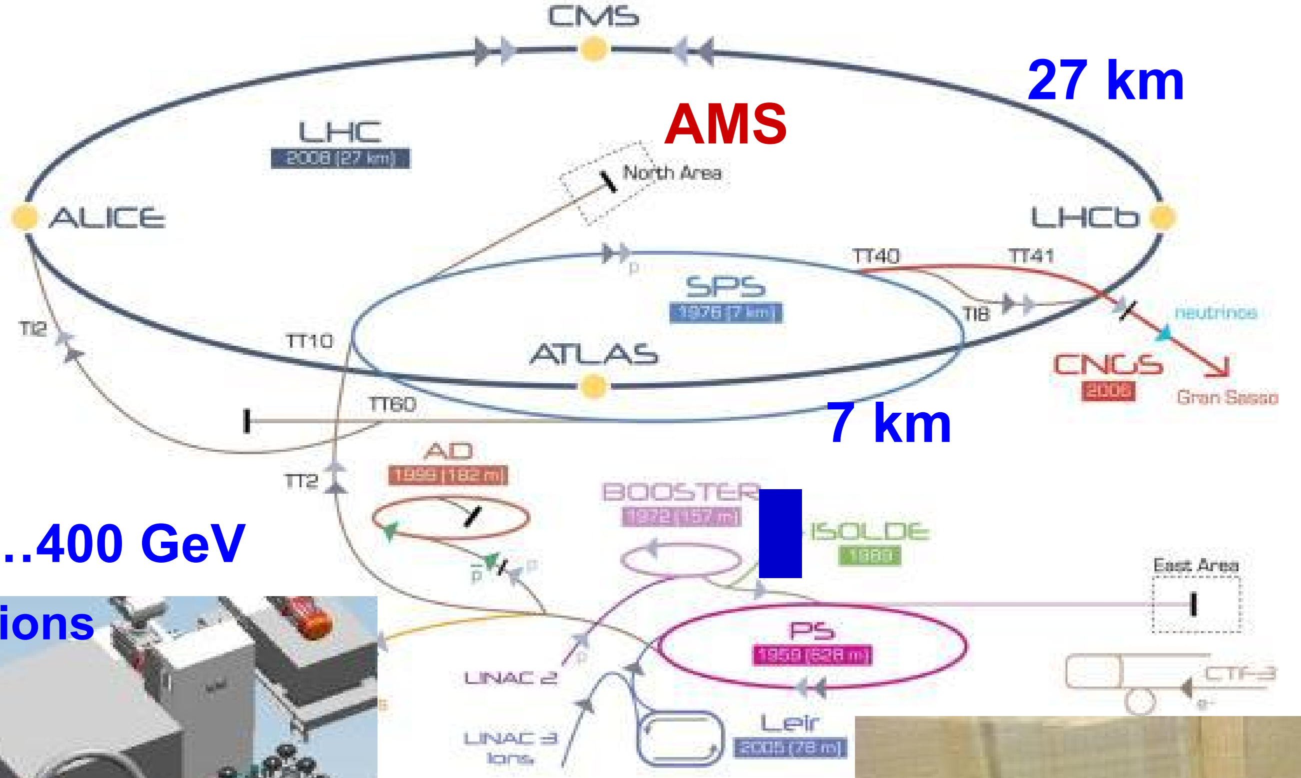




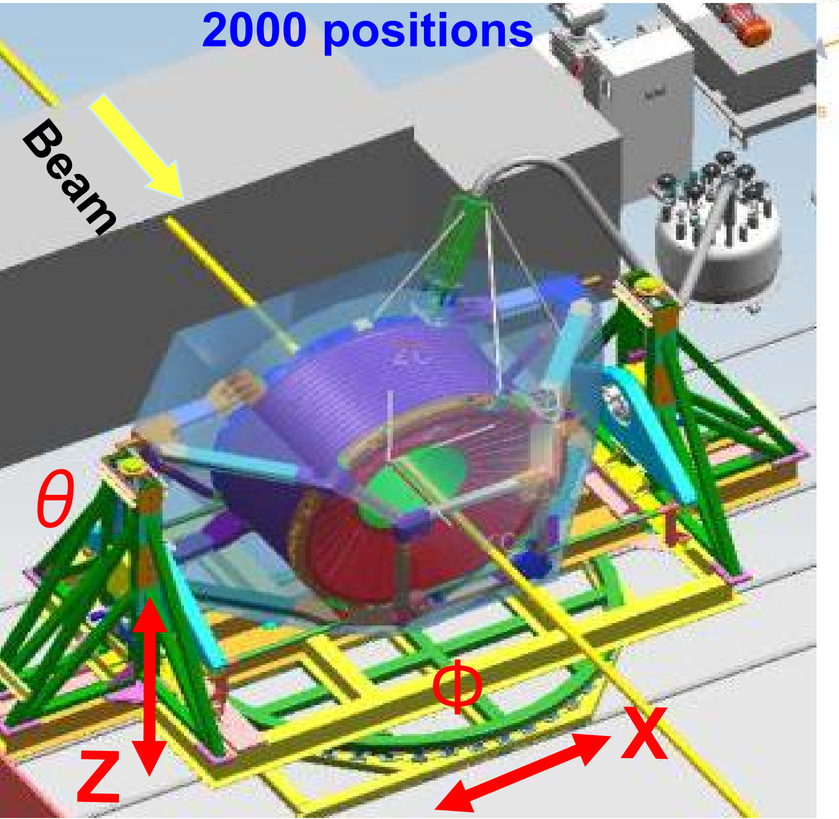
Proton rejection at 90% e^+ efficiency



Extensive tests and calibration at CERN



p, e$^+$, e$^-$, π 20…400 GeV



May 16, 2011

In >5 years on ISS,

AMS has collected ~90 billion cosmic rays.

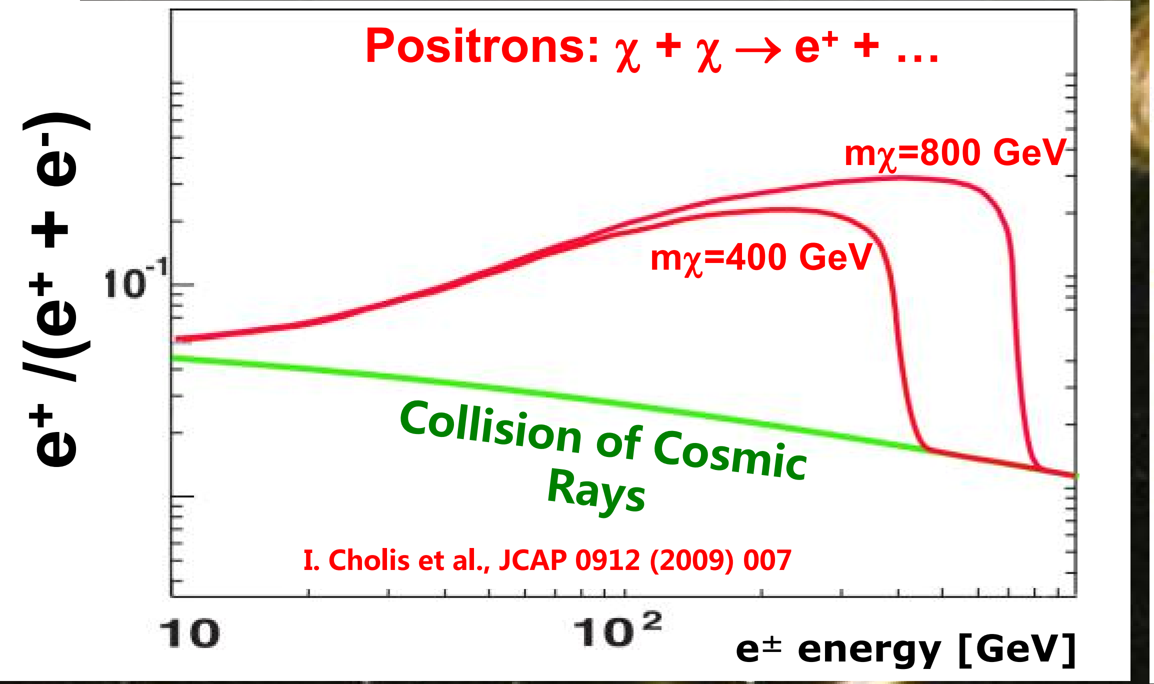
To match the statistics,

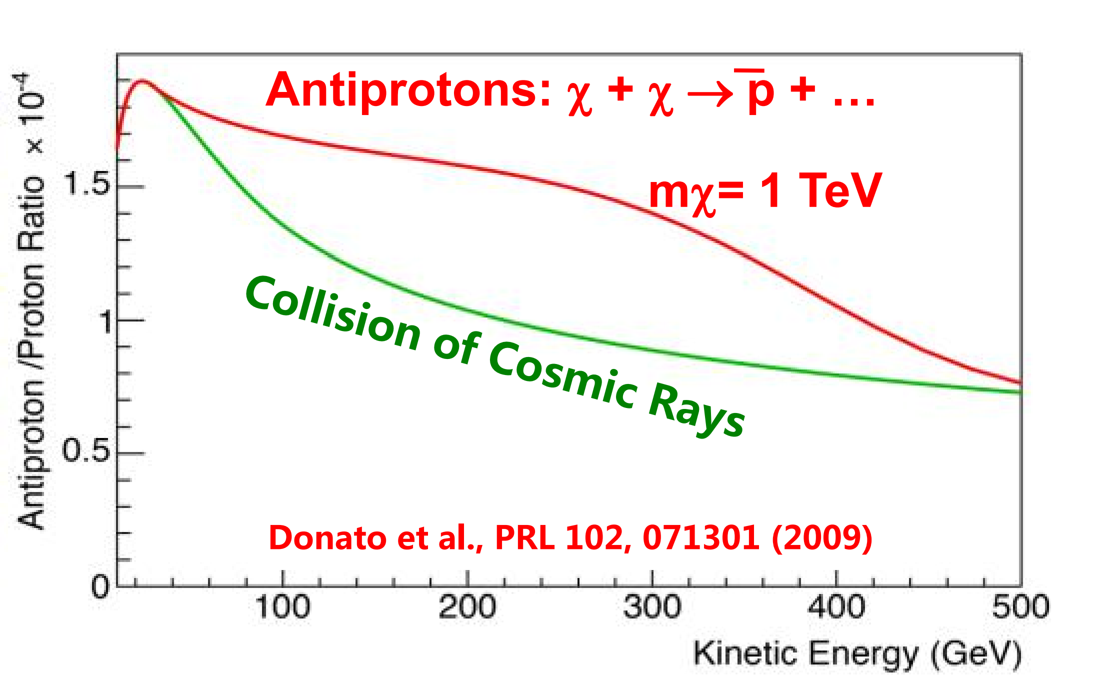
systematic error studies have become important.

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;
…………..

Selected for a Viewpoint in *Physics*

PRL **110**, 141102 (2013) PHYSICAL REVIEW LETTERS week ending 5 APRIL 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

M. Aguilar,[32,20] G. Alberti,[42,43] B. Alpat,[42] A. Alvino,[42,43] G. Ambrosi,[42] K. Andeen,[28] H. Anderhub,[54] L. Arruda,[30]

6.8 million events

Dear Sam,

this is just to let you know that your article the first AMS data has been selected in our 2013 APS Physics Highlights (http://physics.aps.org/articles/v6/139).

Congratulation on this work, which has generated a lot attention among our readers, the press and the scientific community.

Best regards,

Matteo

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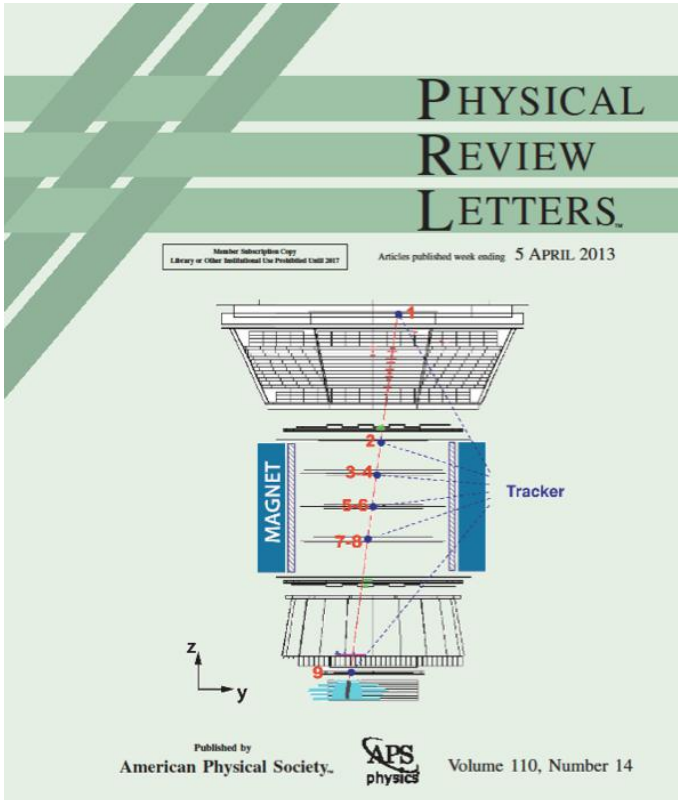
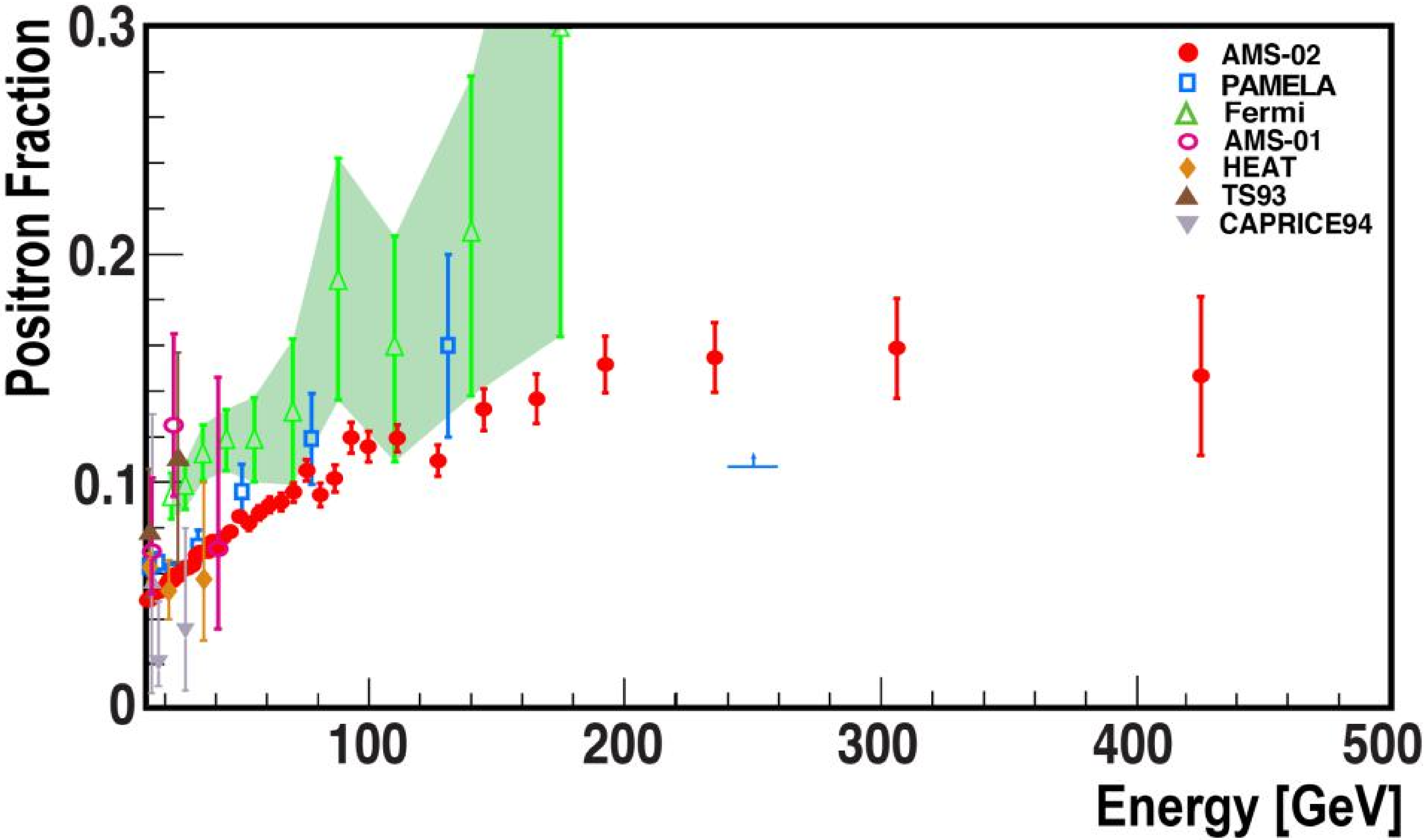
Matteo Rini, PhD
Deputy Editor, Physics
mrini@aps.org
http://physics.aps.org



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

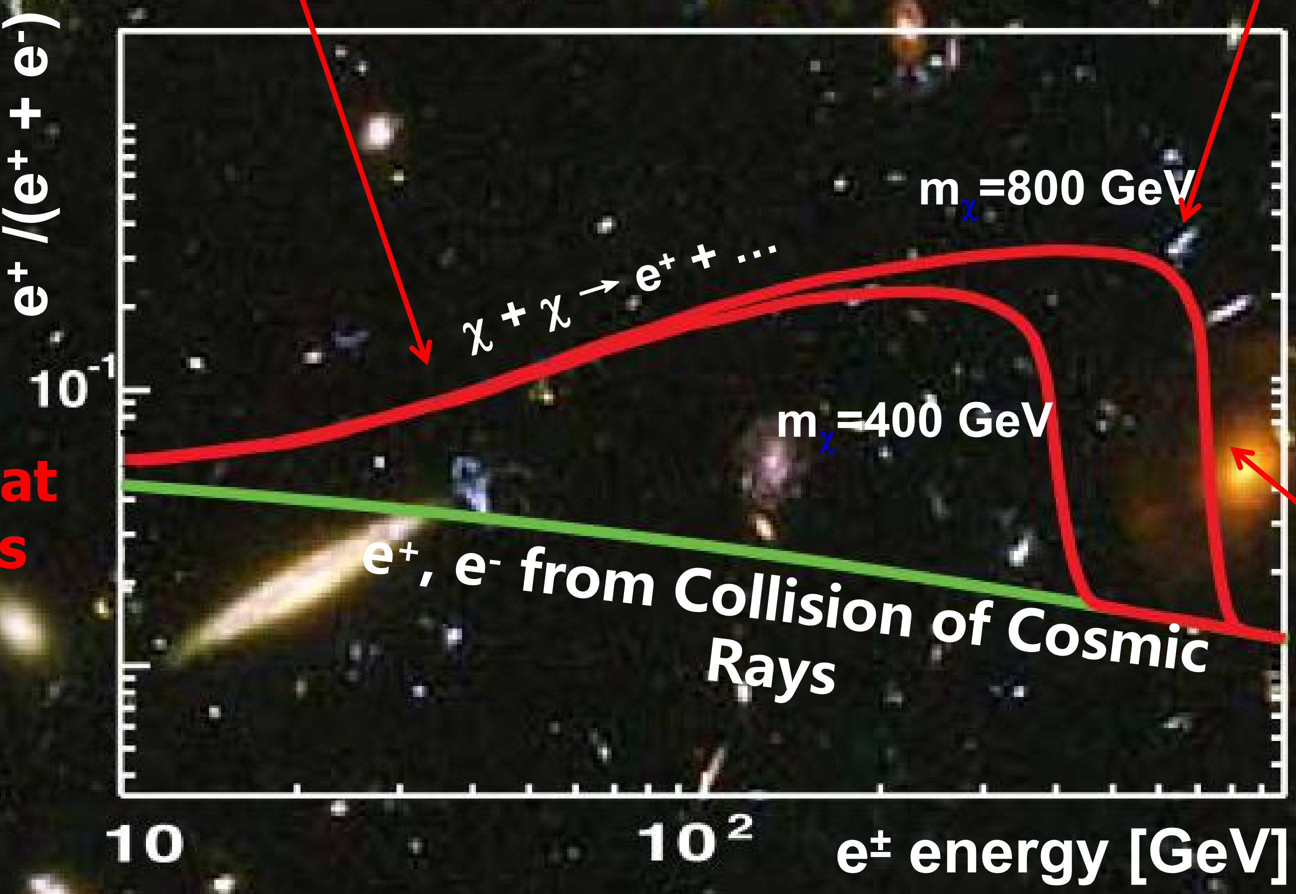


2. The rate of increase with energy

3. The existence of sharp structures.

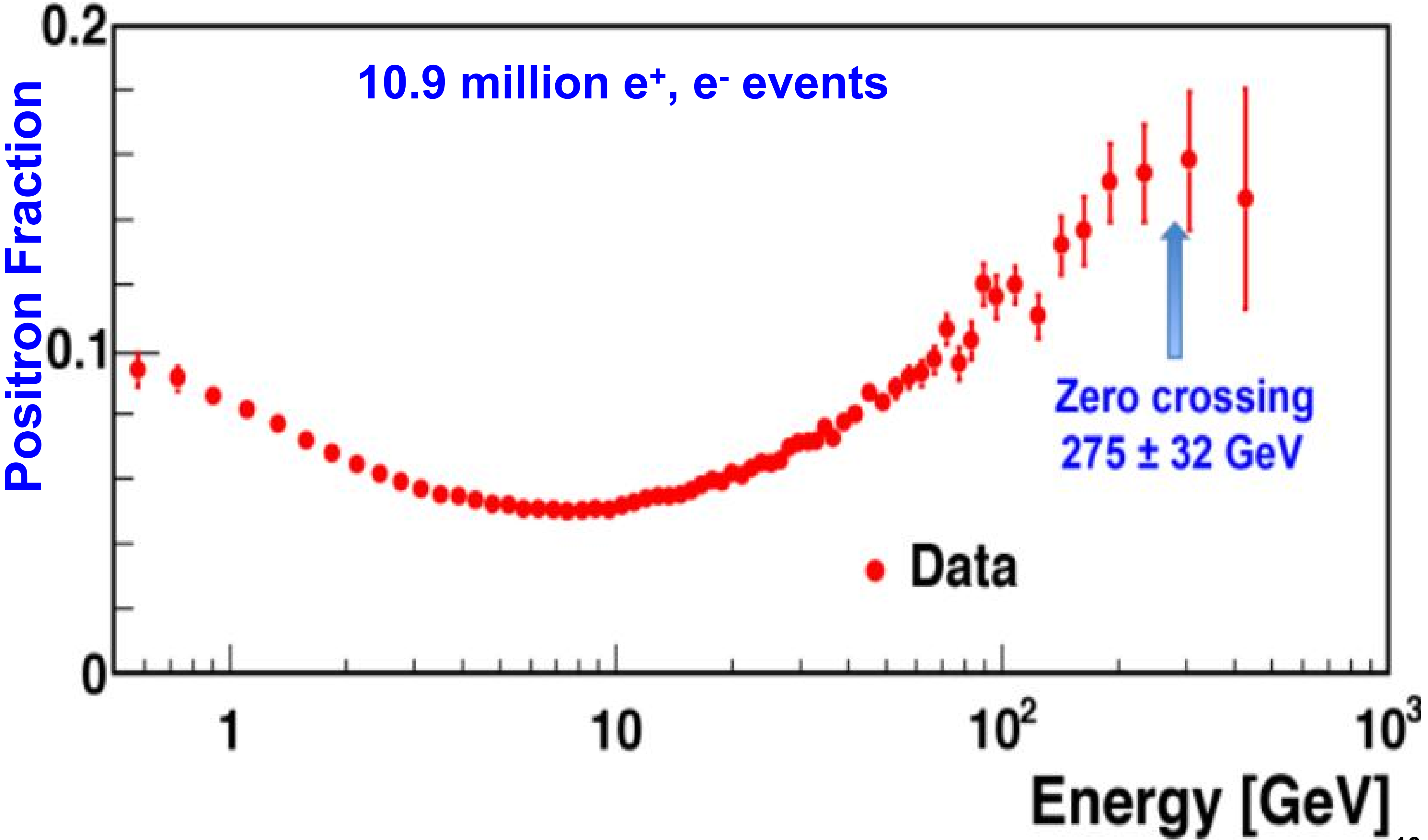
4. The energy beyond which it ceases to increase.

5. Isotropy.



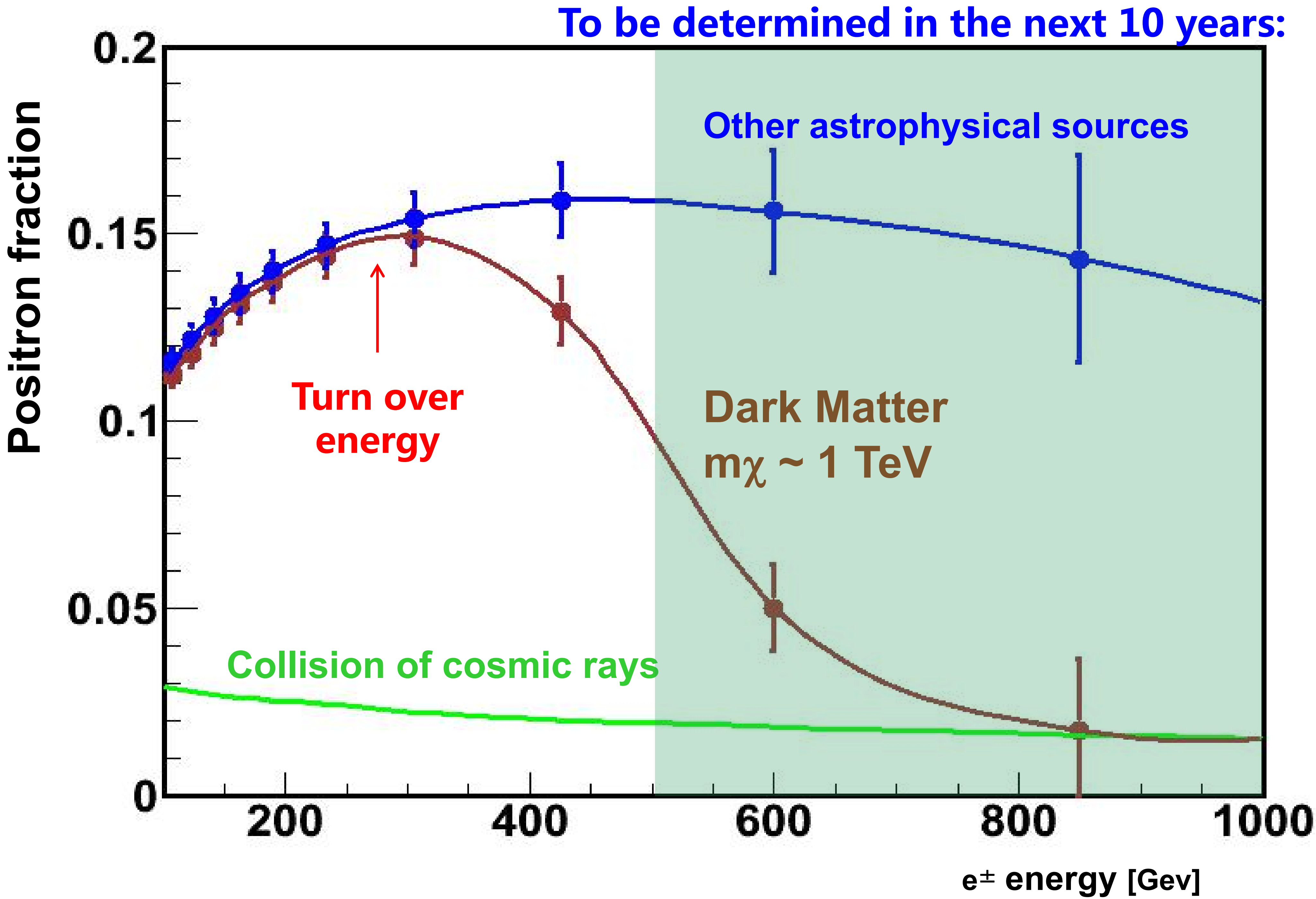
1. The energy at which it begins to increase.

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

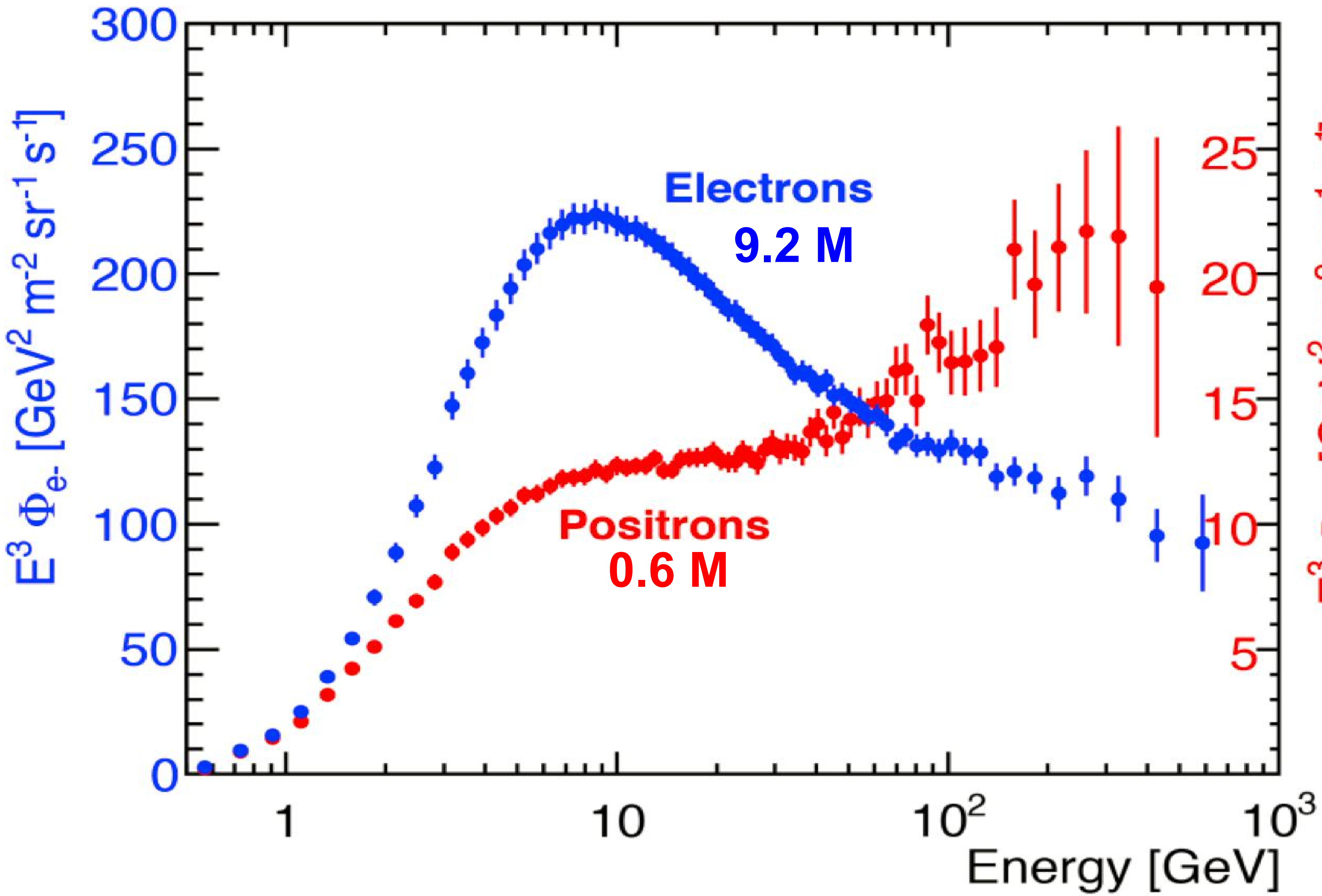


10.9 million e+, e- events
Positron Fraction
0.2
0.1
0
1
10
10^2
10^3
Energy [GeV]
Zero crossing
275 ± 32 GeV
Data

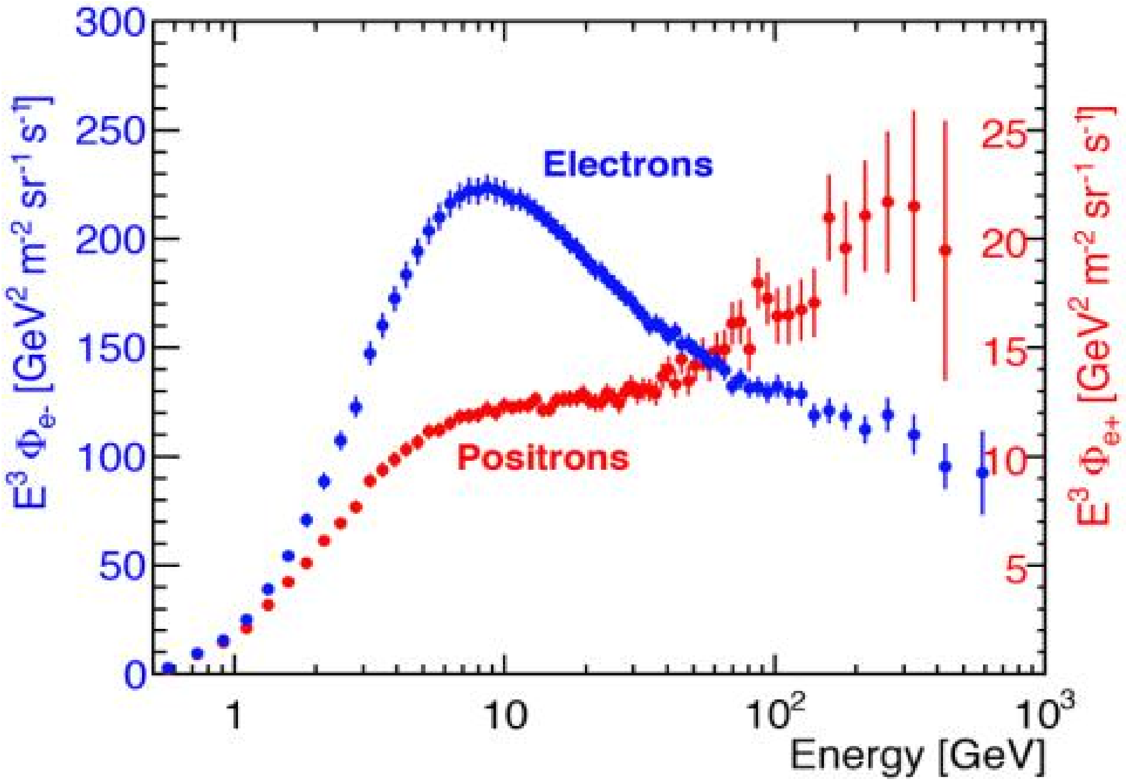
6. The expected rate at which it falls beyond the turning point.

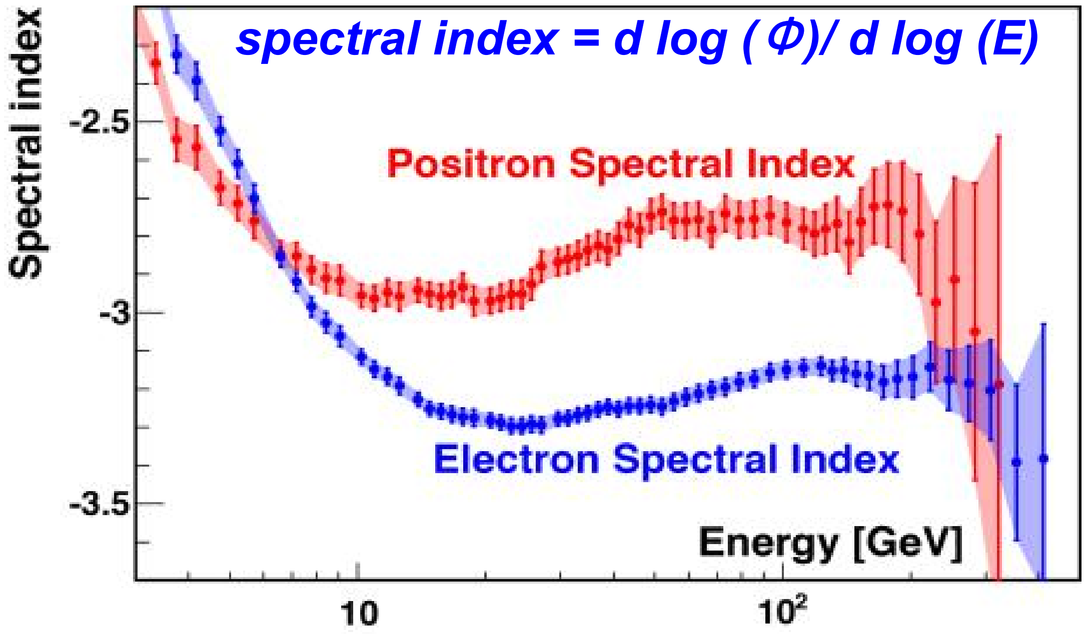


AMS, Electron Flux and the Positron Flux



The Electron Flux and the Positron Flux

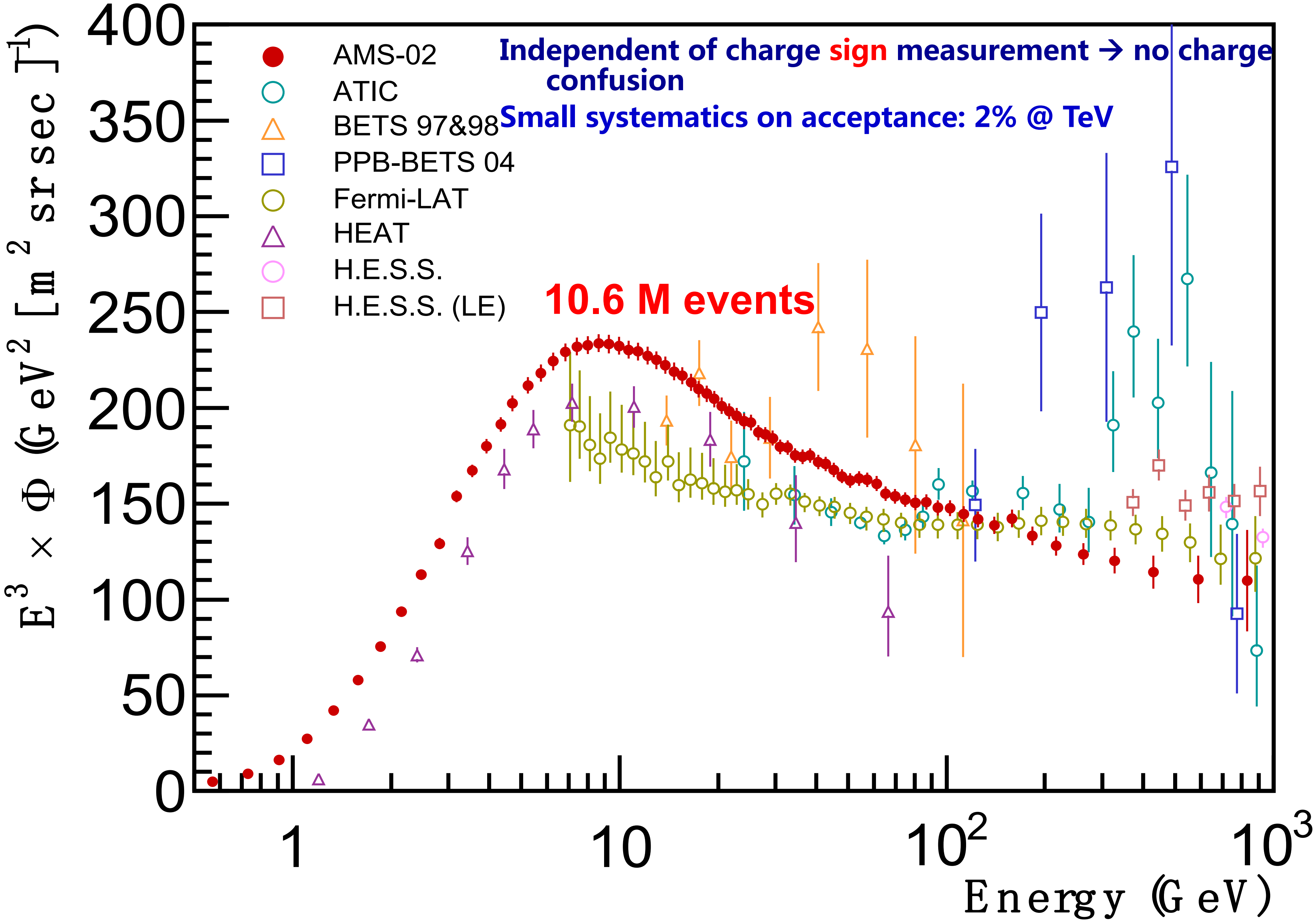




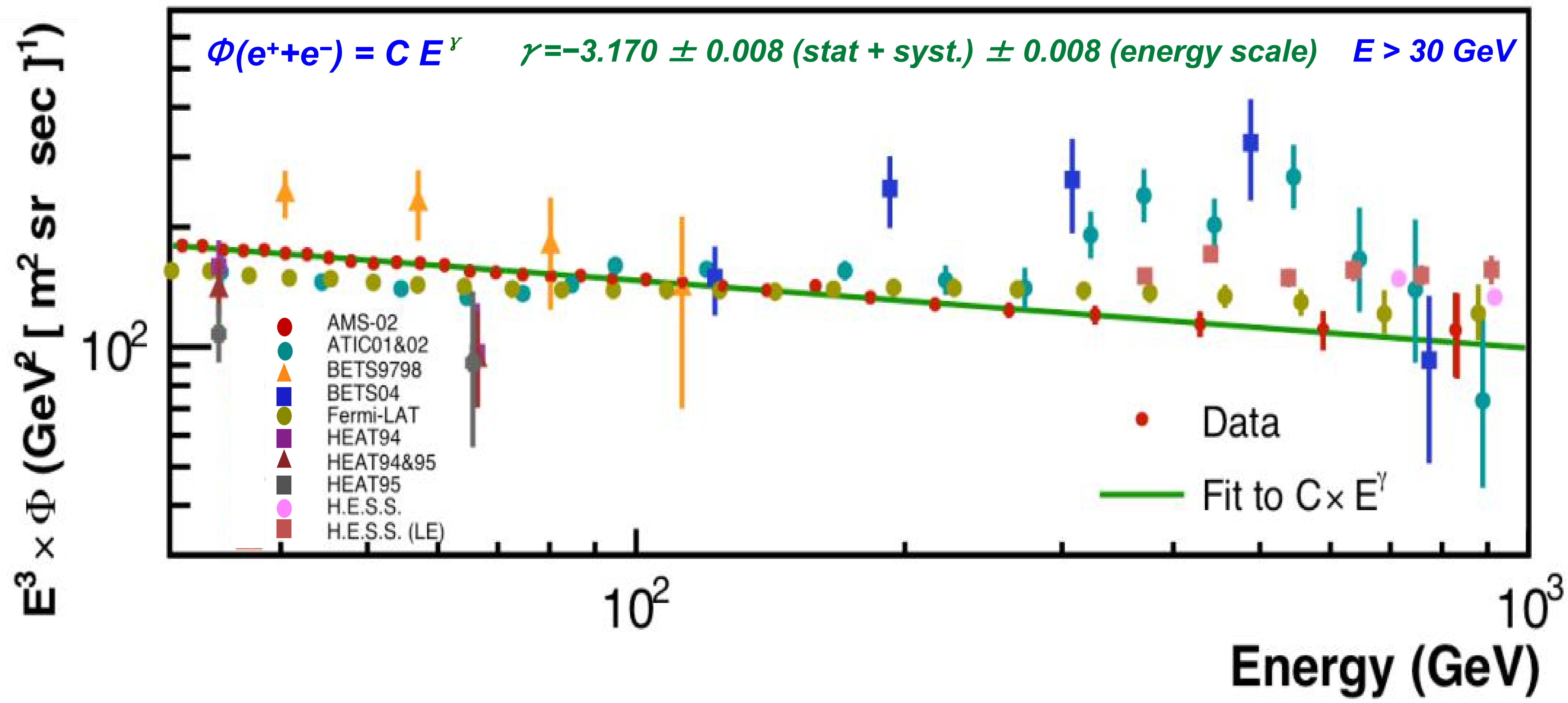
Observations:

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



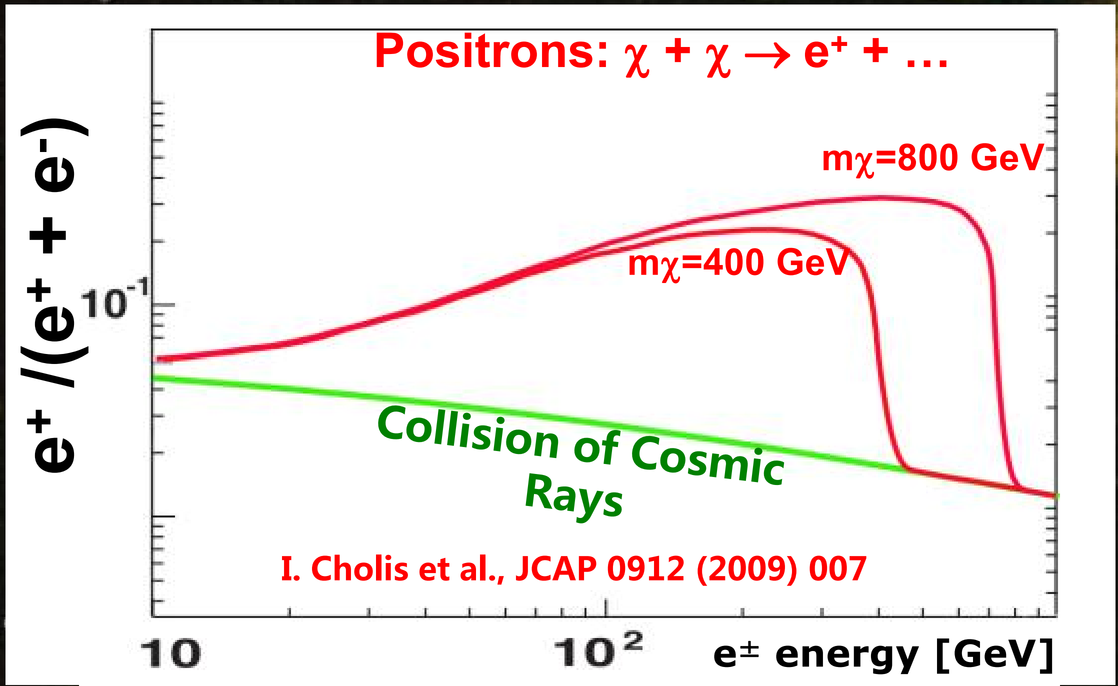
Spectral Indices of electrons+positrons

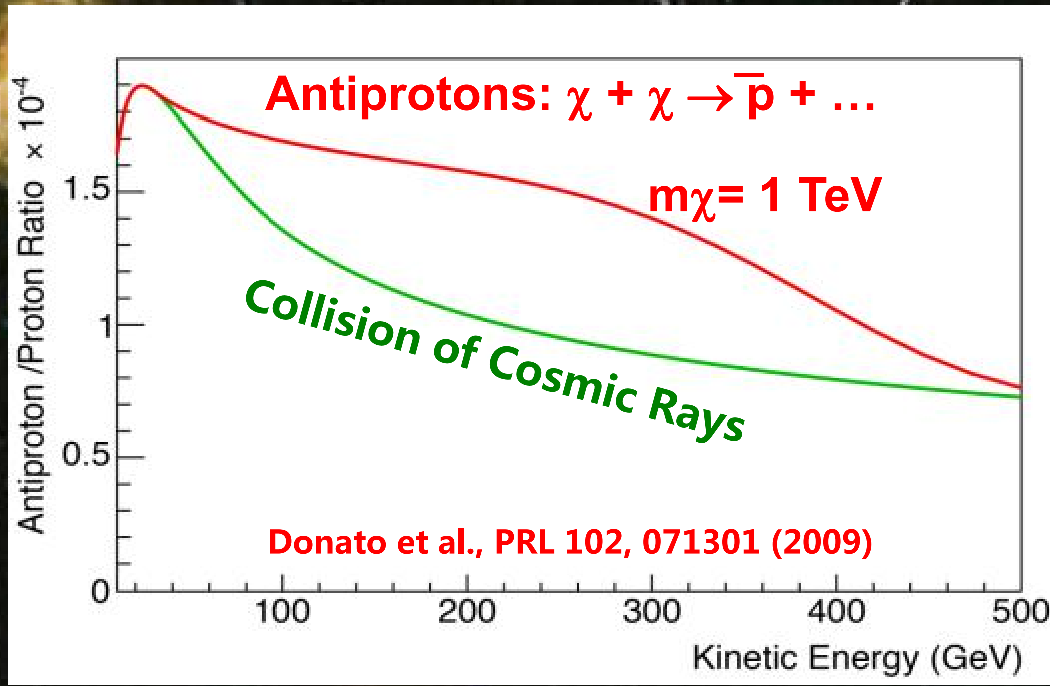


The Search for the Origin of Dark Matter

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

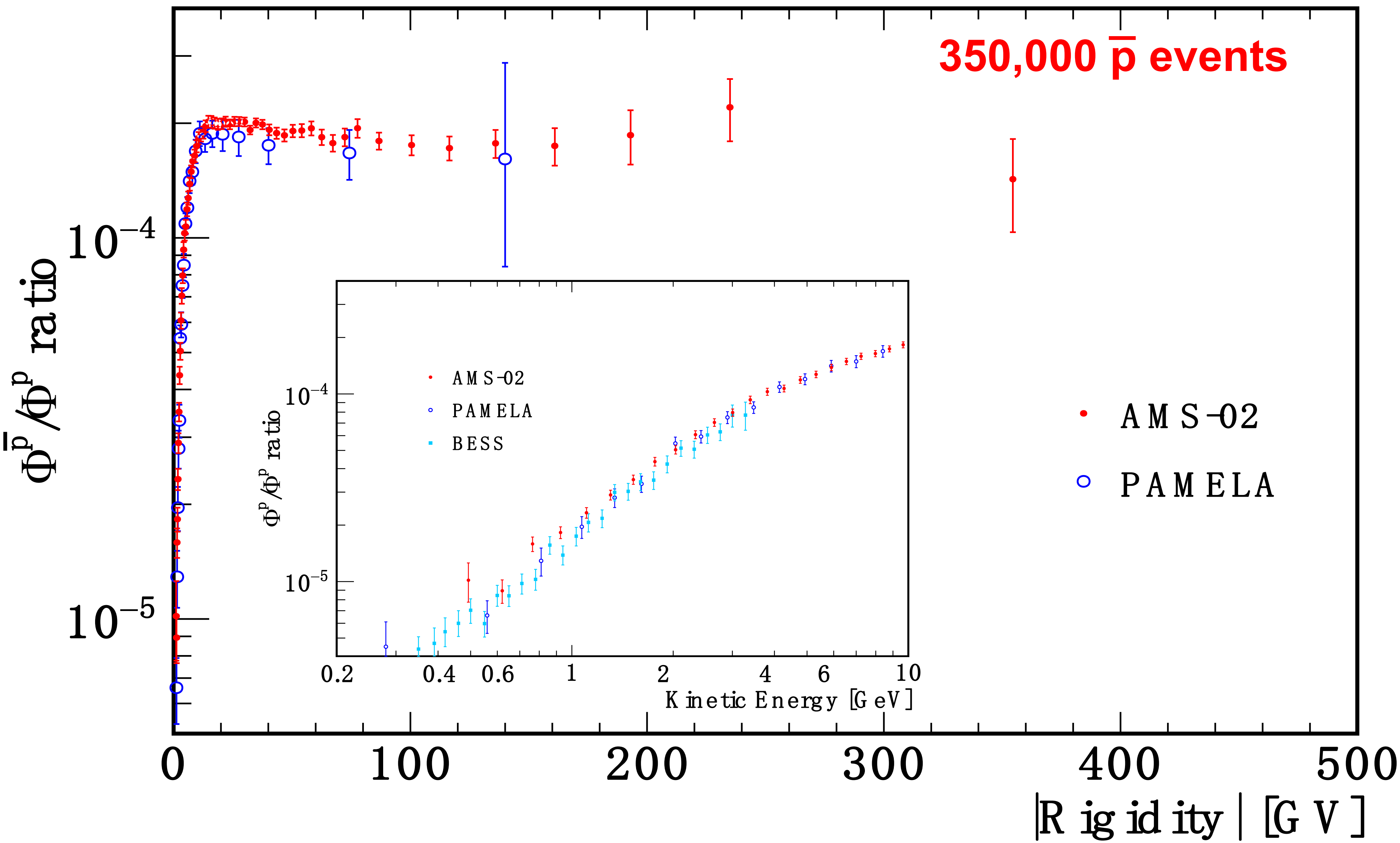
above the background from the collisions of “ordinary” cosmic rays





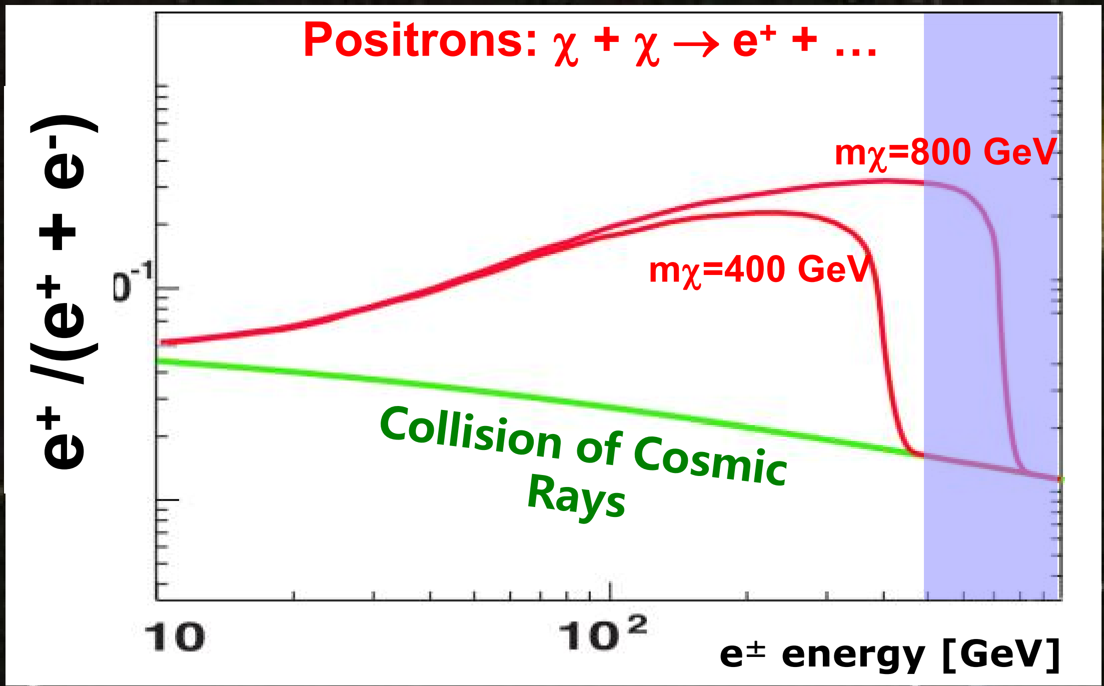
M. Turner and F. Wilczek, Phys. Rev. D42 (1990) 1001;
J. Ellis, 26th ICRC Salt Lake City (1999) astro-ph/9911440;
…………

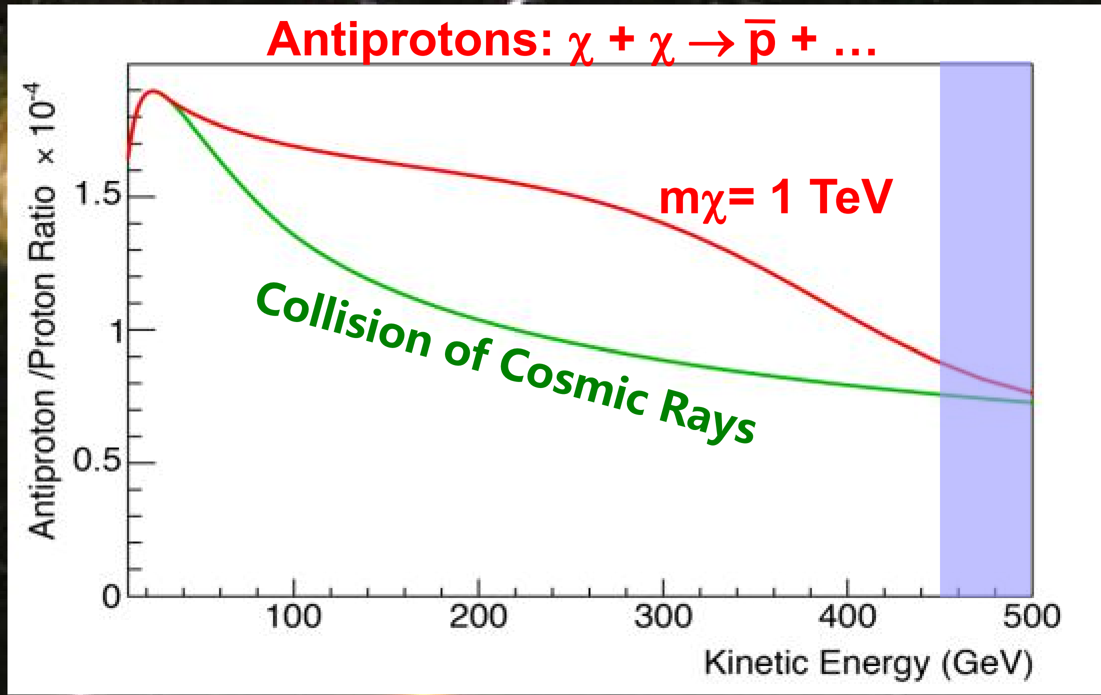
AMS $\bar{p}/p$ results



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.

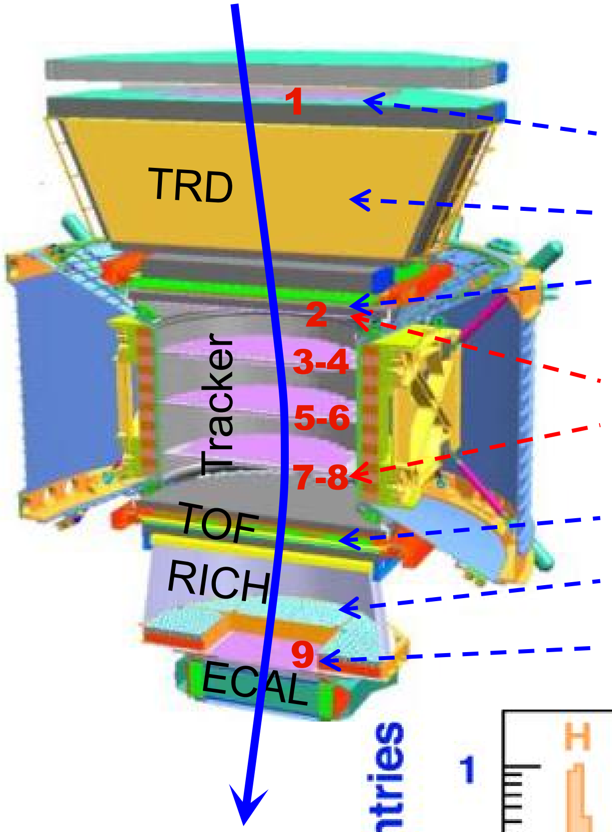




To understand background, we need precise knowledge of:

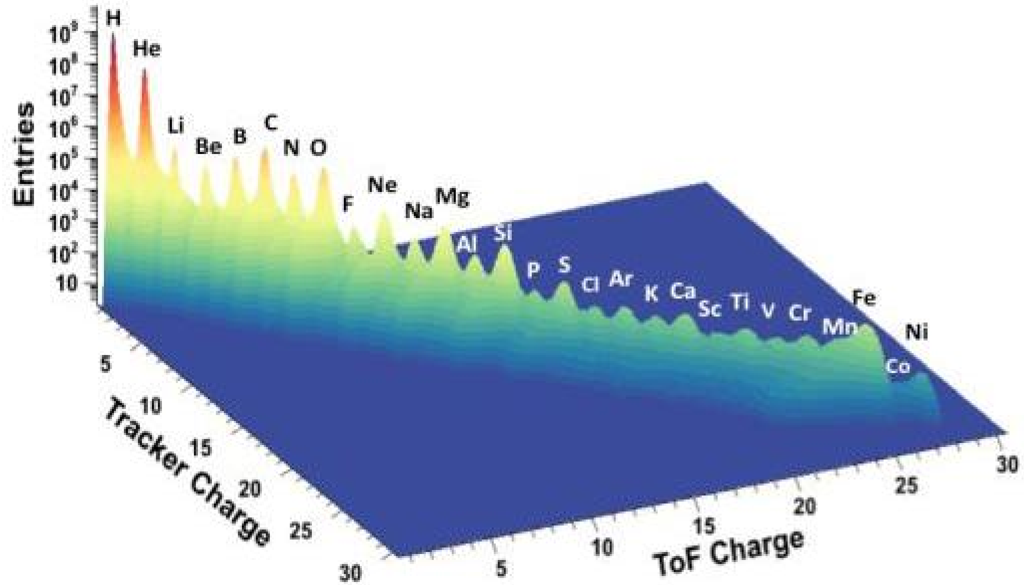
1. The cosmic ray fluxes (p, He, C, …)
2. Propagation and Acceleration (Li, B/C, …)

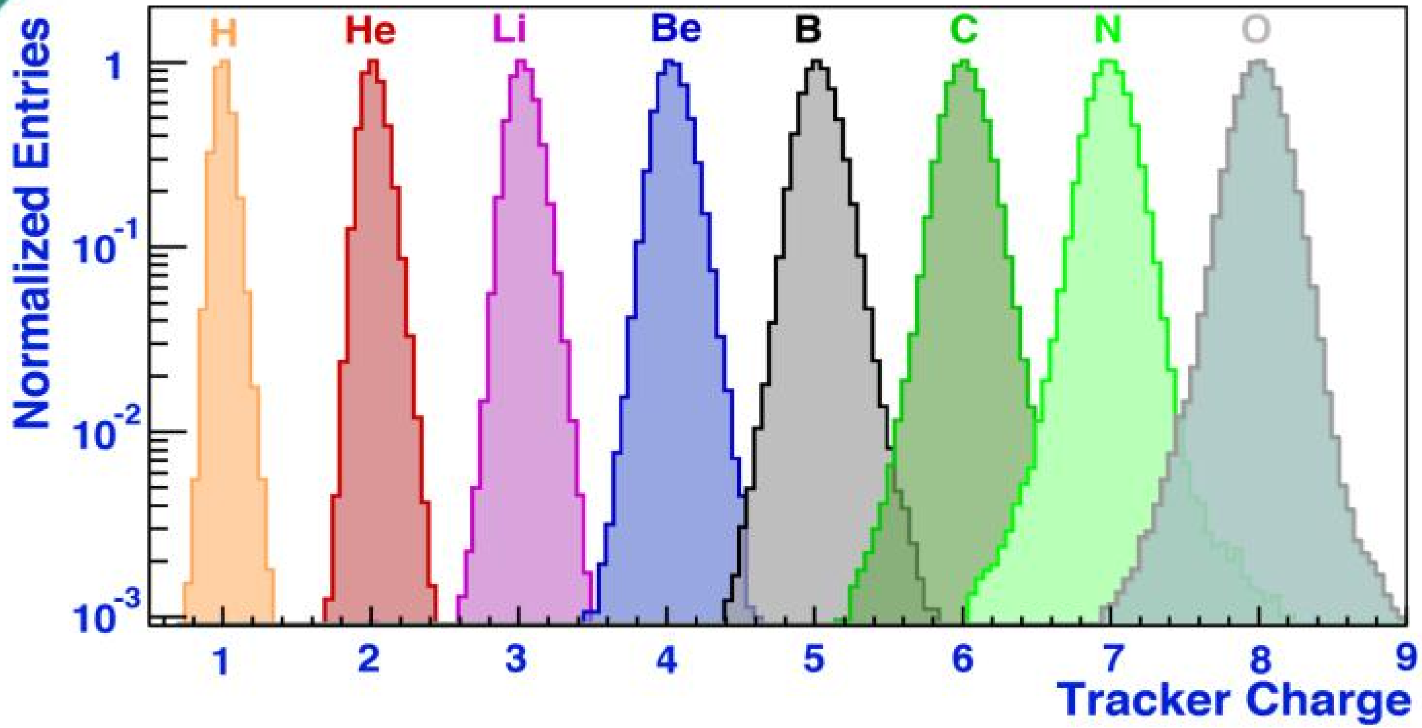
AMS: Multiple Measurements of Nuclear Charge



Charge Resolution (Z=6)

Detector	Resolution
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





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 protonflux Φ_i for the i th 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

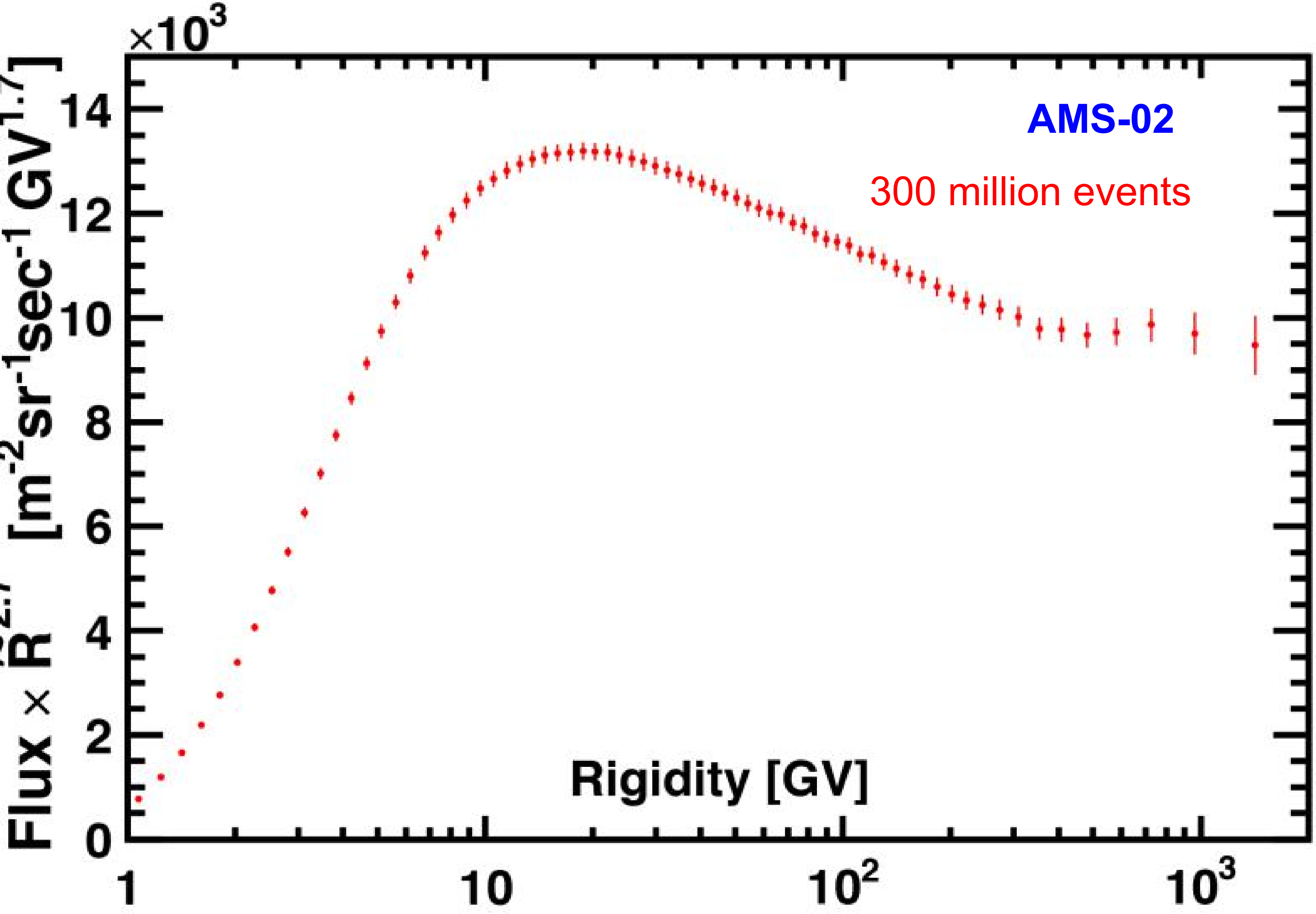
3) σ_{unf}:
   a. unfolding
   b. the rigidity resolution

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

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

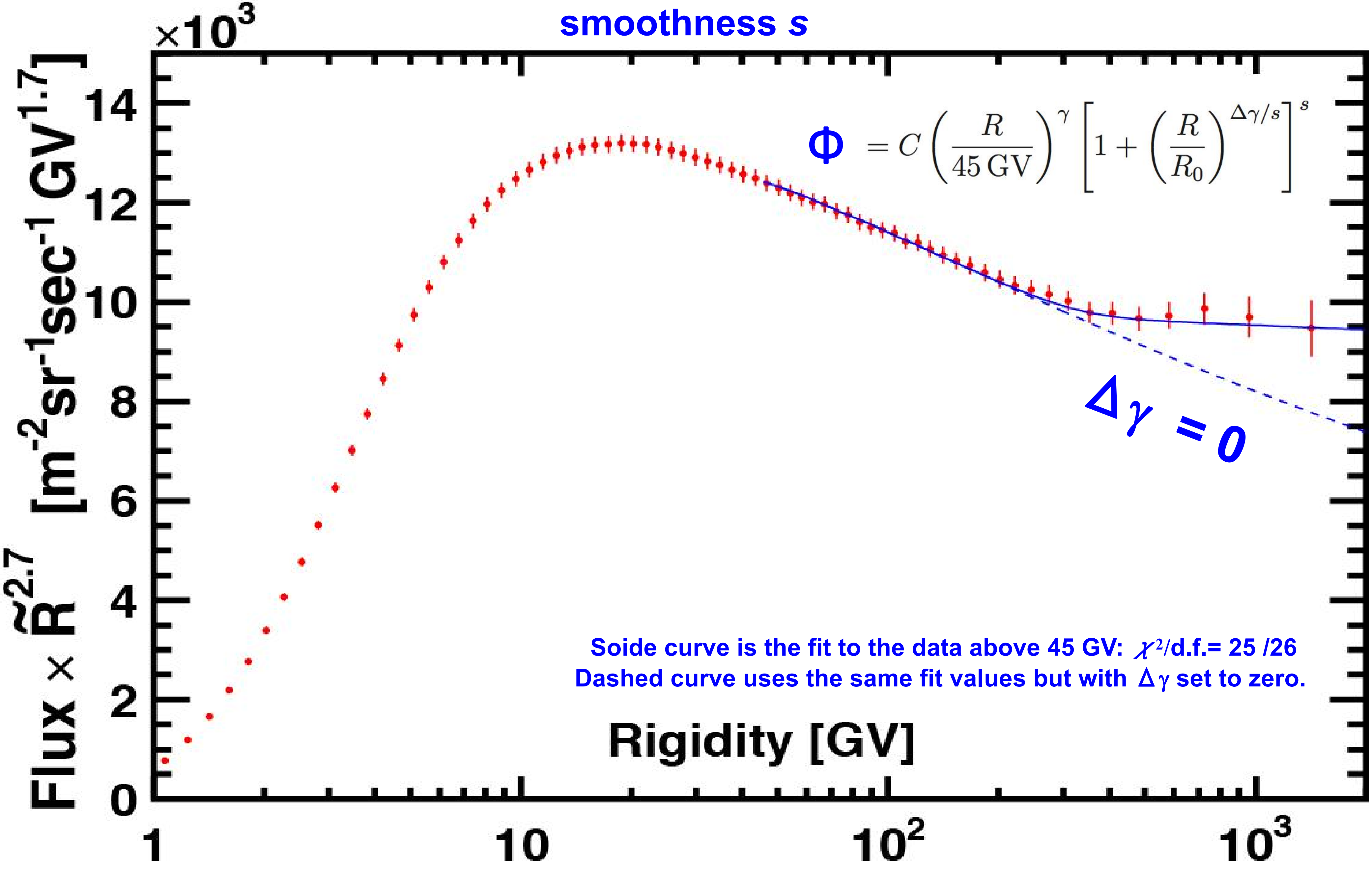
Rigidity [GV]	Φ	$\sigma_{stat.}$	$\sigma_{trig.}$	$\sigma_{acc.}$	$\sigma_{unf.}$	σ_{scale}	$\sigma_{syst.}$
100 – 108	(4.085	0.007	0.006	0.040	0.035	0.022	0.058)×10^{-2}
108 – 116	(3.294	0.007	0.005	0.033	0.028	0.018	0.047)×10^{-2}
116 – 125	(2.698	0.006	0.004	0.027	0.023	0.016	0.039)×10^{-2}
125 – 135	(2.174	0.005	0.004	0.022	0.019	0.013	0.032)×10^{-2}

AMS proton flux



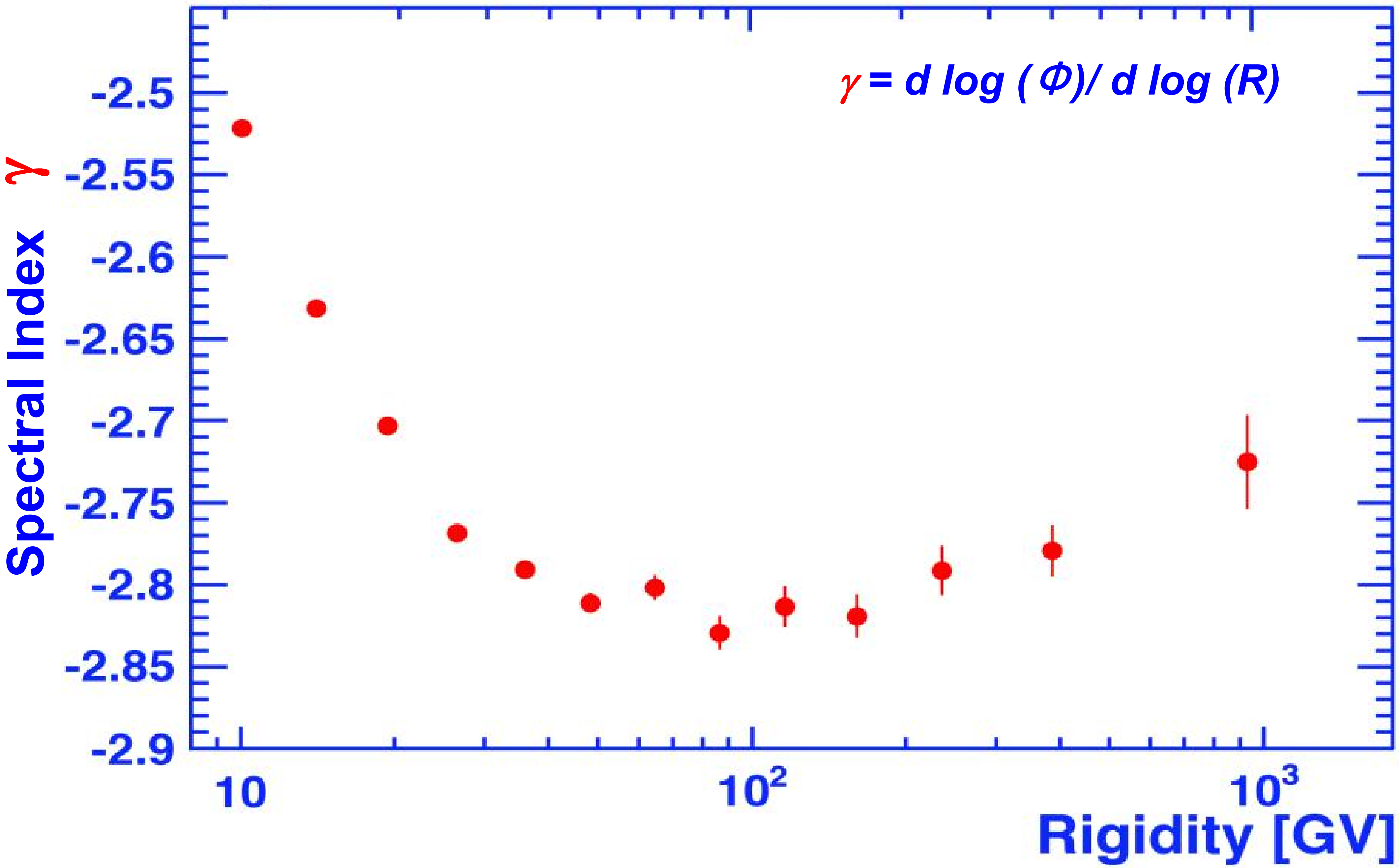
AMS proton flux

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

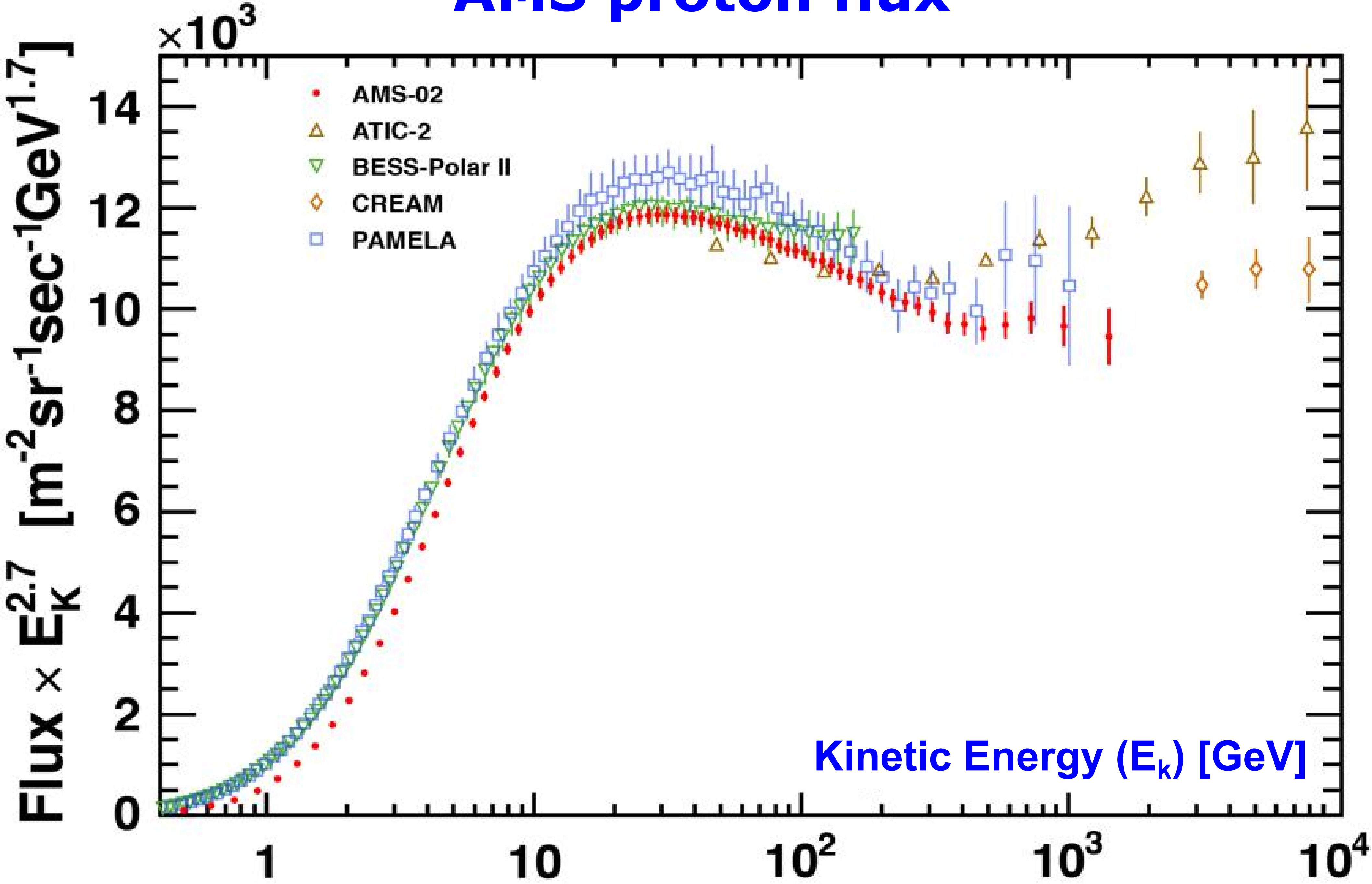


AMS proton spectral index variation:

Model independent measurement of spectral index

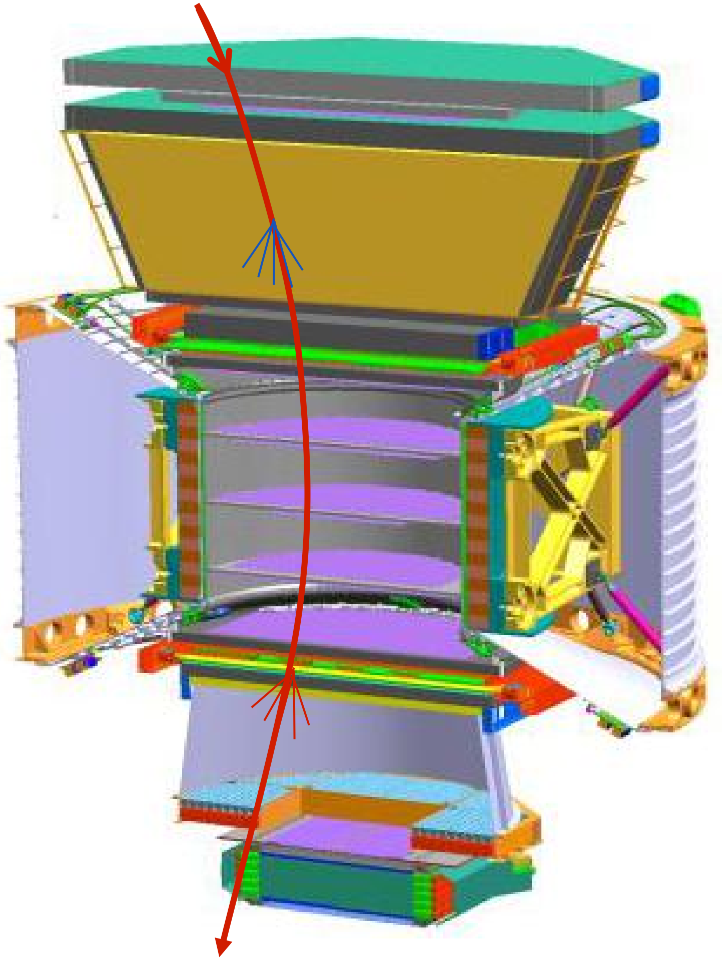


AMS proton flux



Accurate measurement of the flux of nuclei on the ISS

A new method:

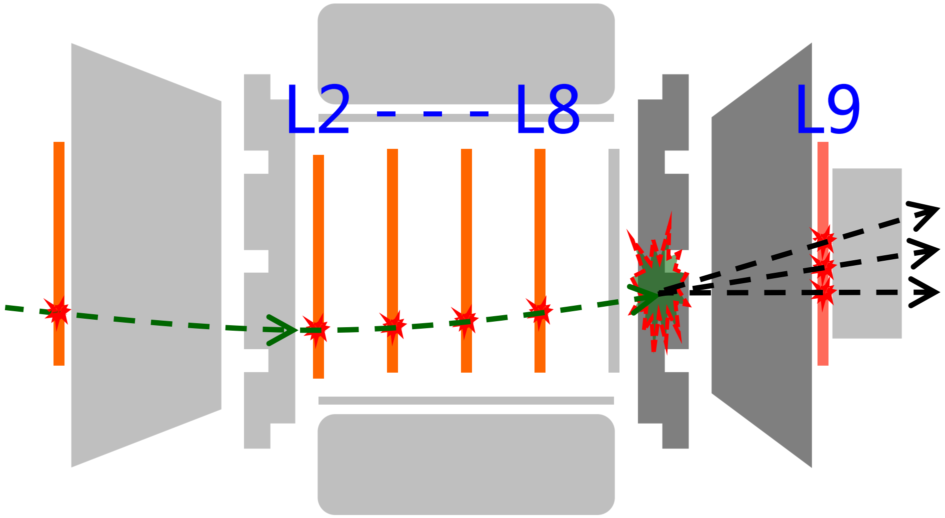


To measure the flux of nuclei (He, Li, Be, B, C, O, …) accurately, we need to know the interaction cross section of these nuclei with the materials in AMS.

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.

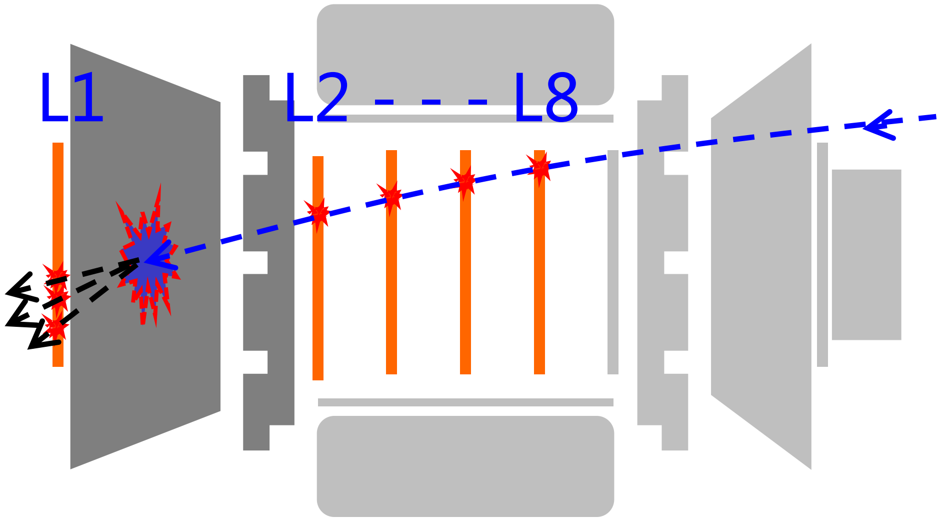
On ISS we have now a method to measure these interactions in space accurately.

Measuring the interactions of nuclei within AMS
when AMS is flying horizontal



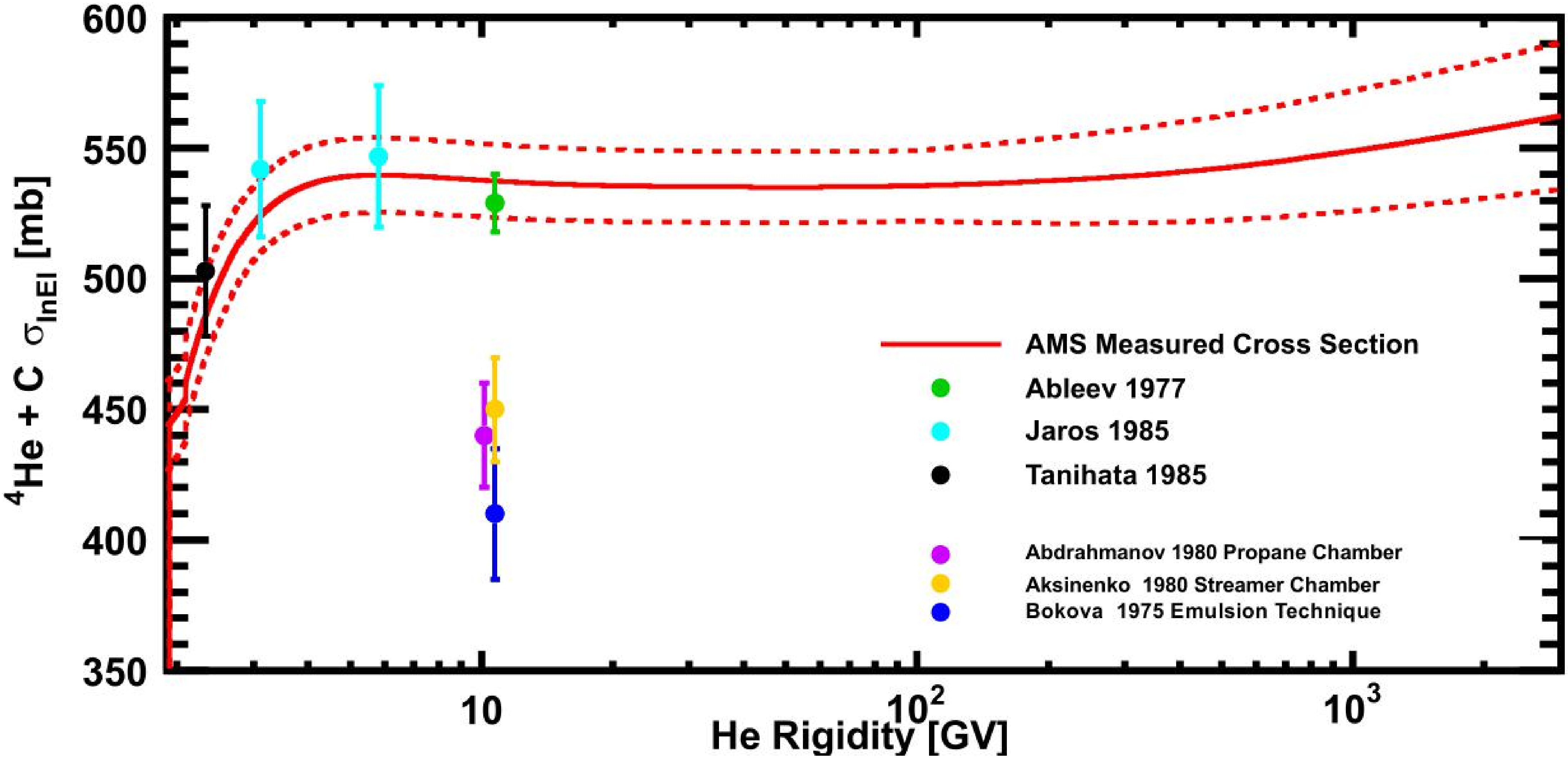
First, we use the seven inner tracker layers, L2-L8, to define beams of nuclei: He, Li, Be, B, …

Second, we use left-to-right particles to measure the nuclear interactions in the lower part of the detector.

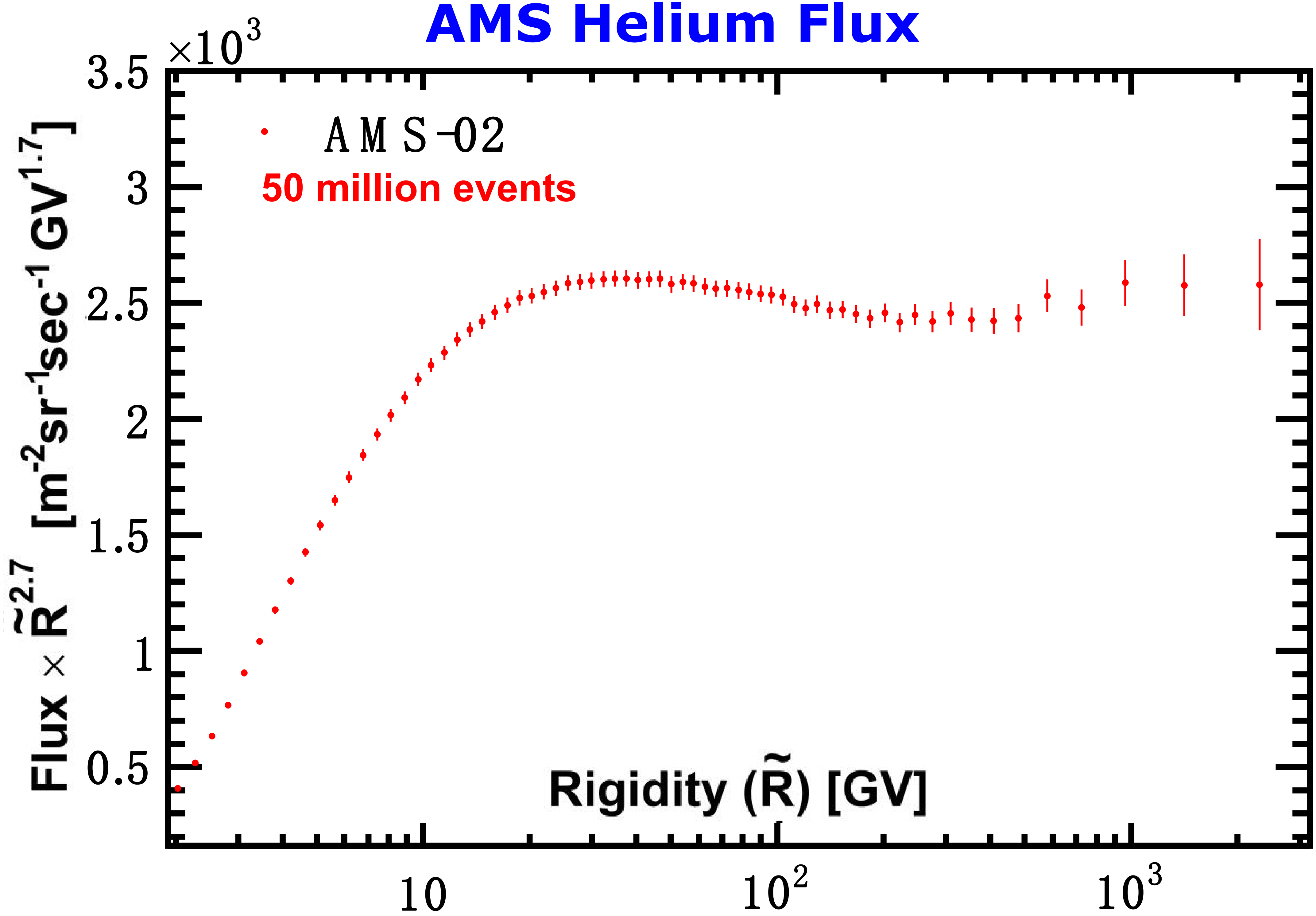


Third, we use right-to-left particles to measure the nuclear interactions in the upper part of detector.

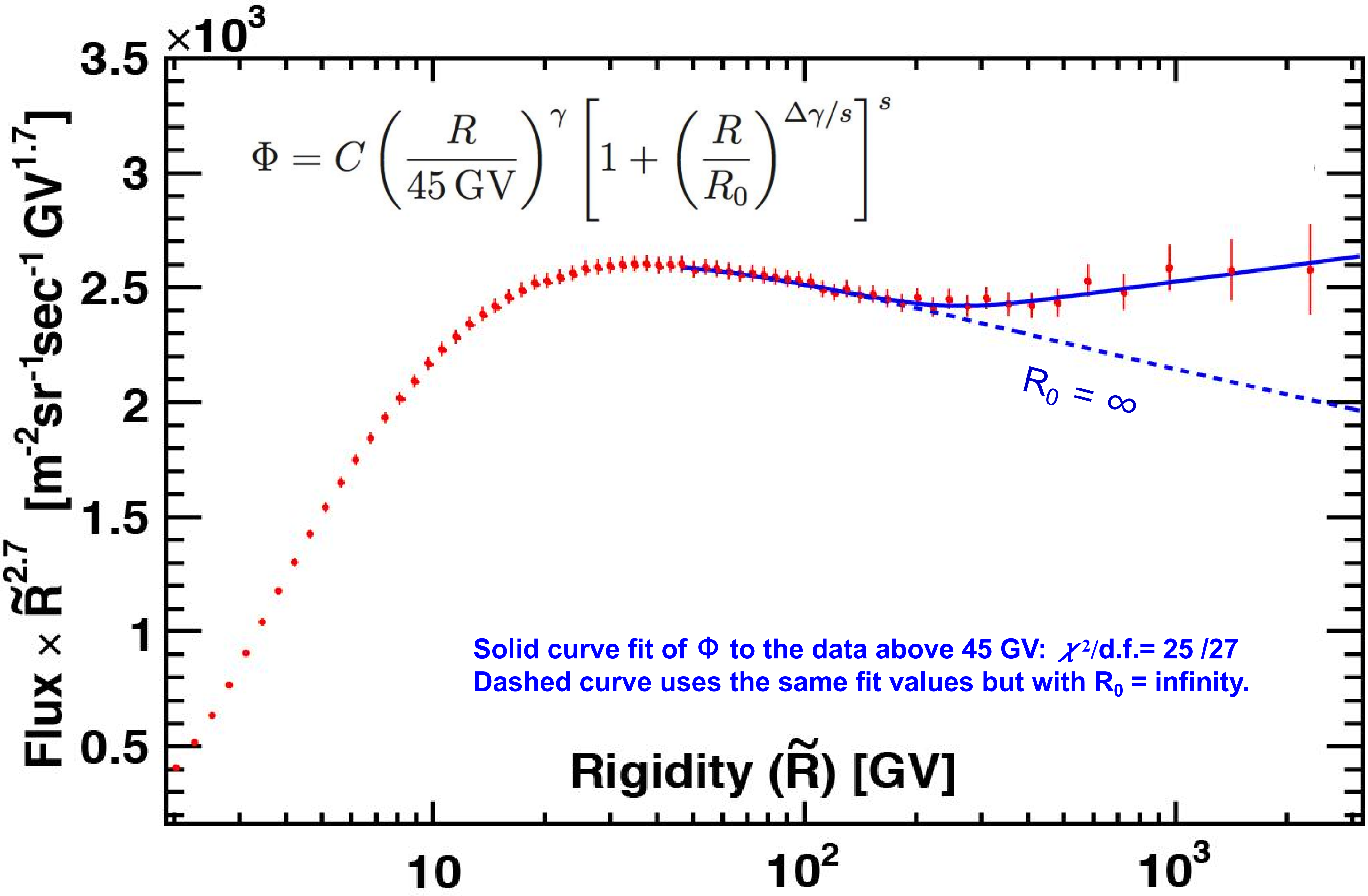
AMS Measurement of He+C Cross Section



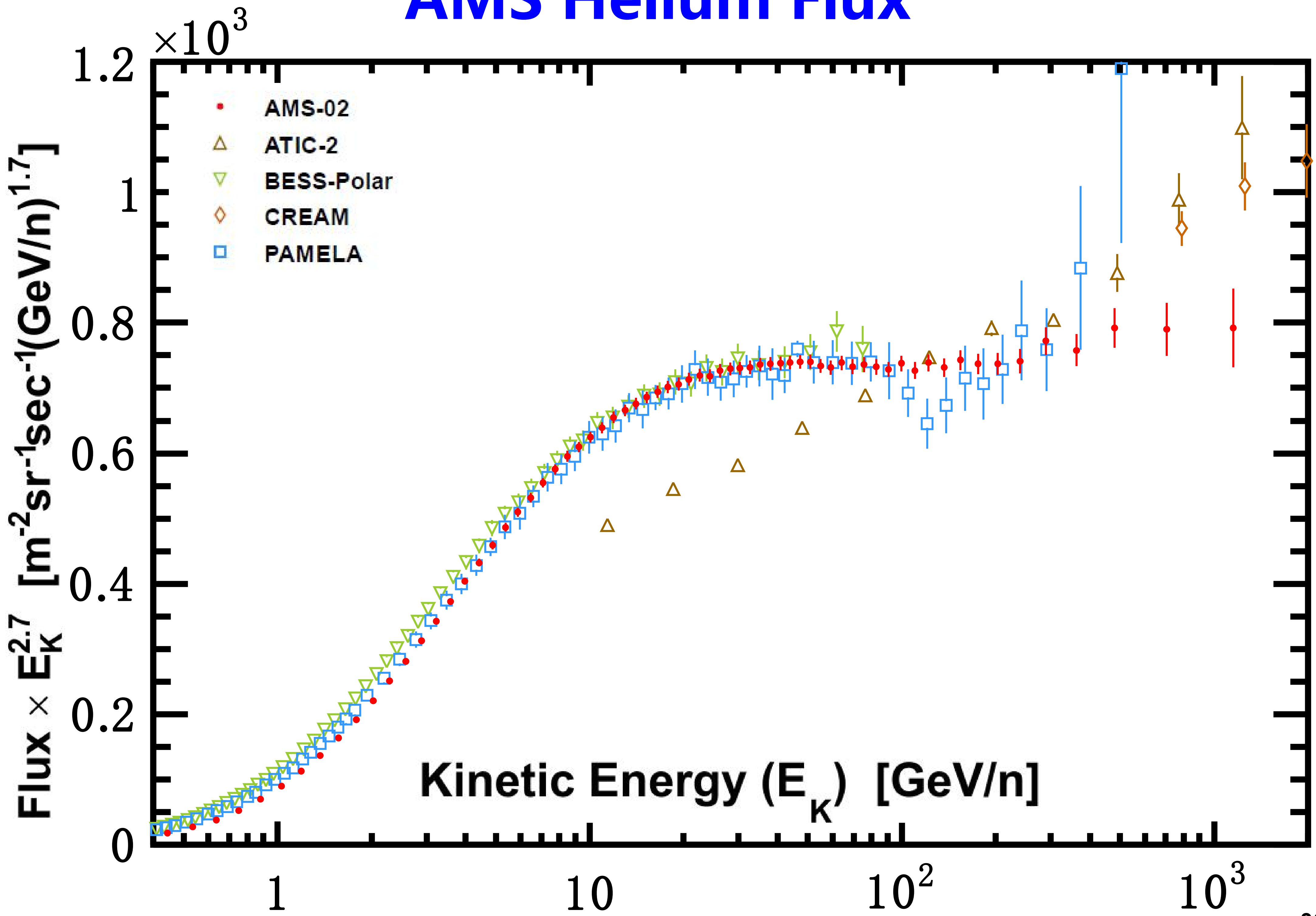
AMS Helium Flux



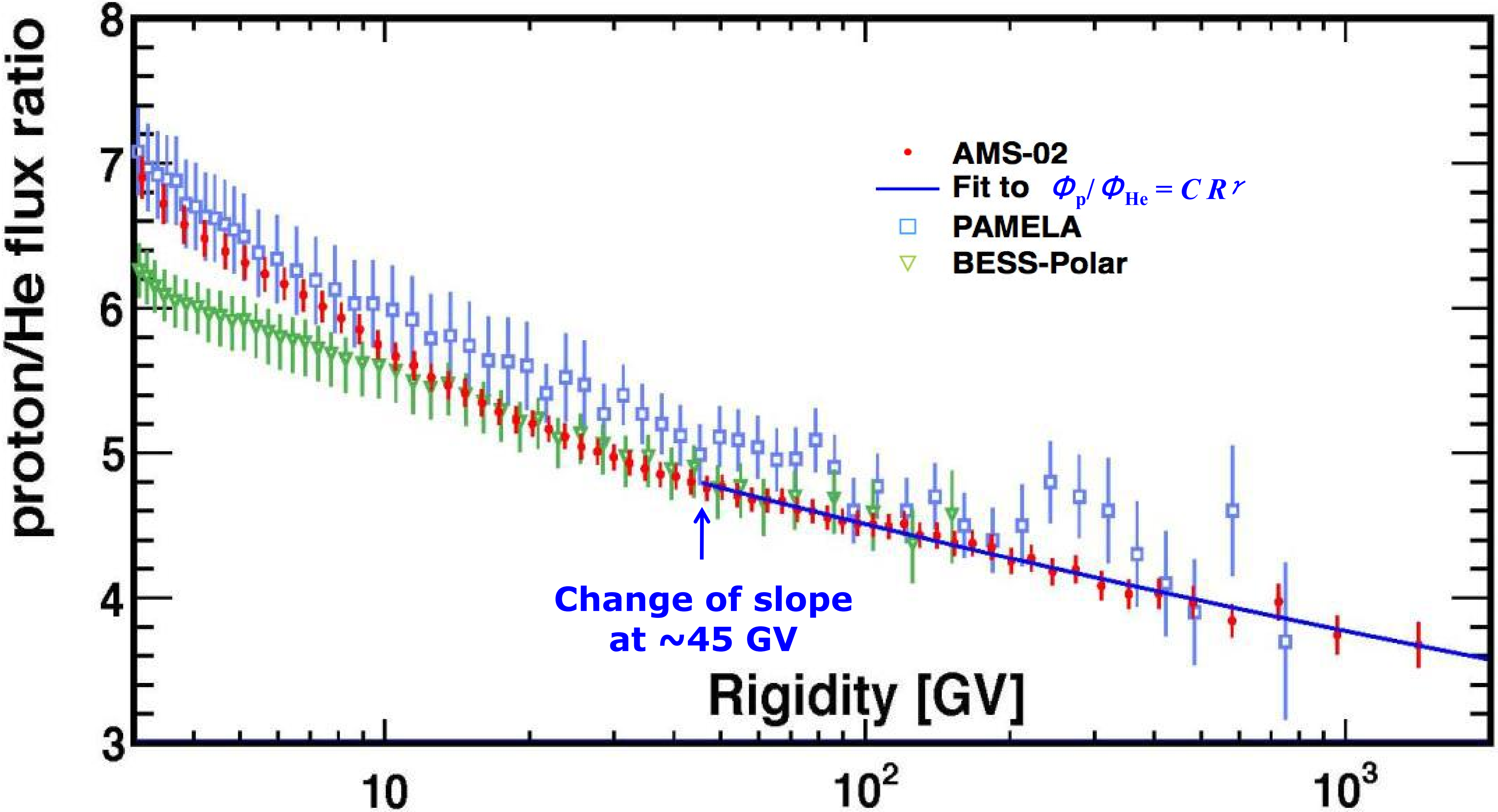
AMS Helium Flux



AMS Helium Flux



proton/He flux ratio

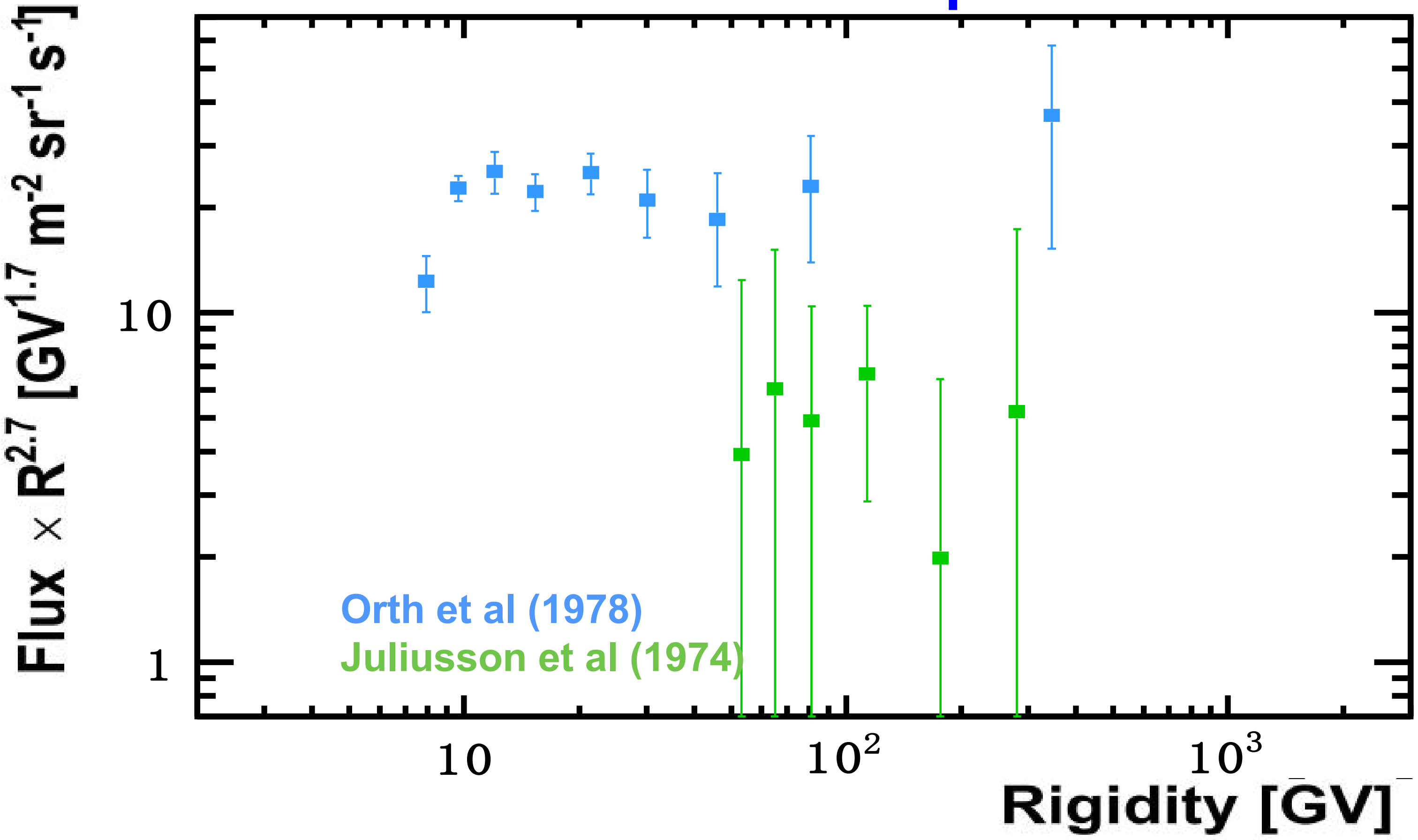


Lithium in Cosmic Rays

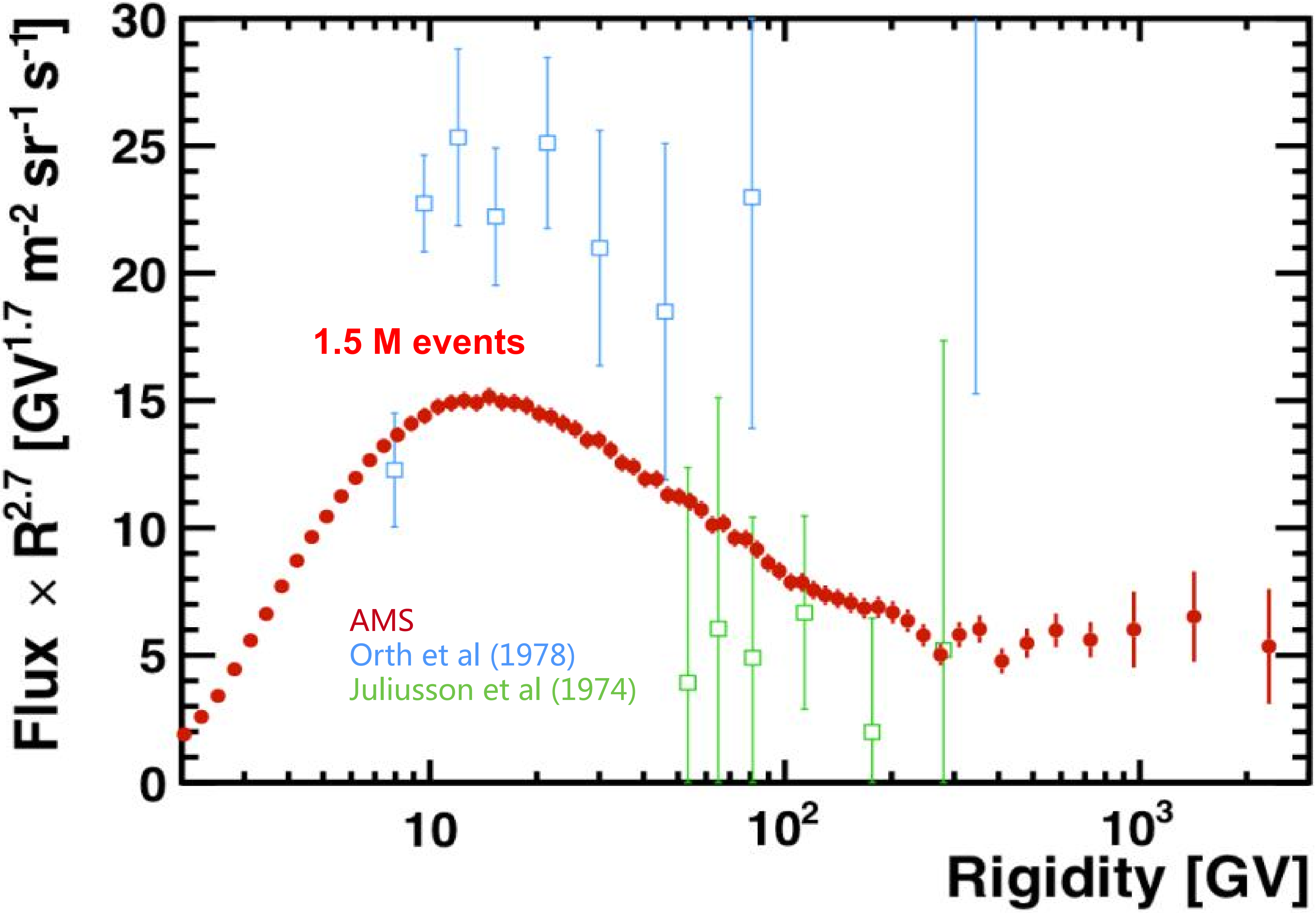
- Like B and Be, Li is produced by the spallation of heavier nuclei during their propagation.
- Sensitive to CR propagation parameters (diffusion, convection, reacceleration…).

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

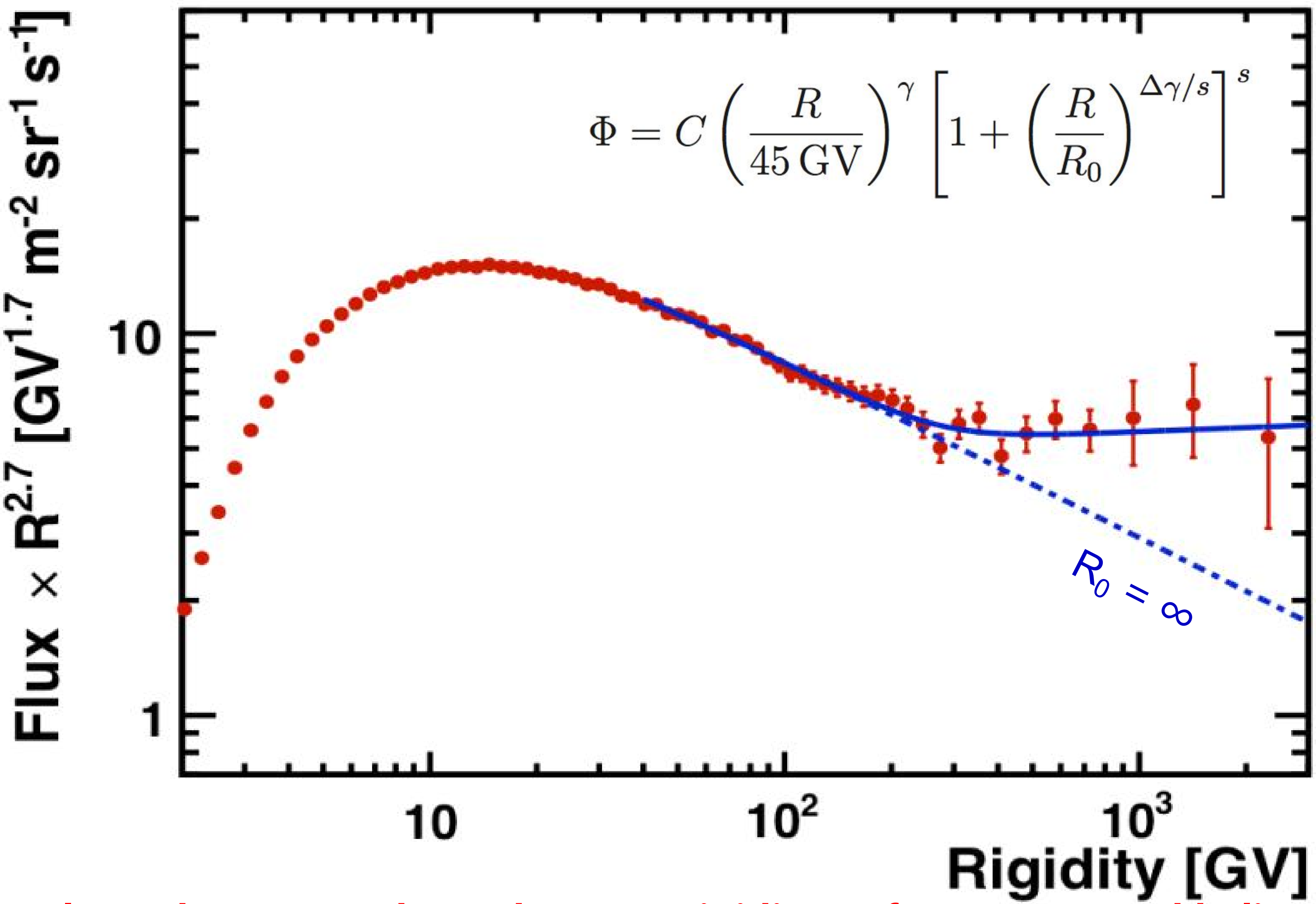
Current data from balloon experiments:



AMS Lithium flux – current status



Lithium flux with two power law fit

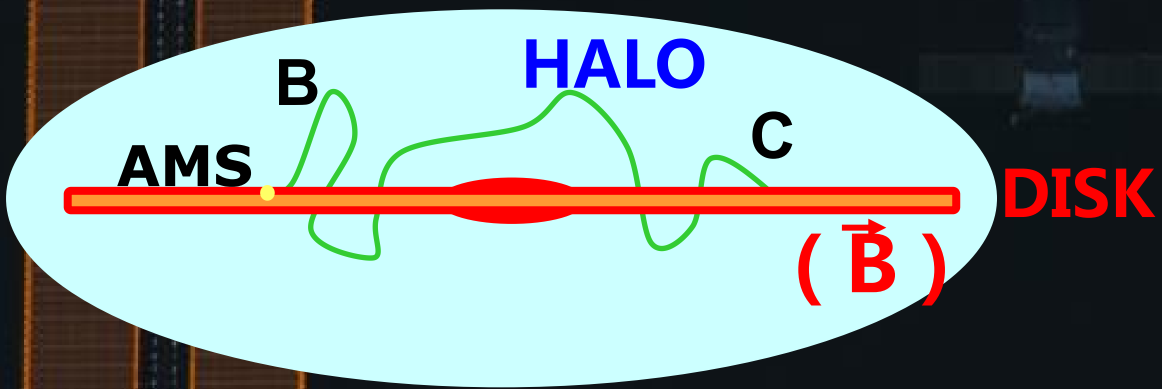


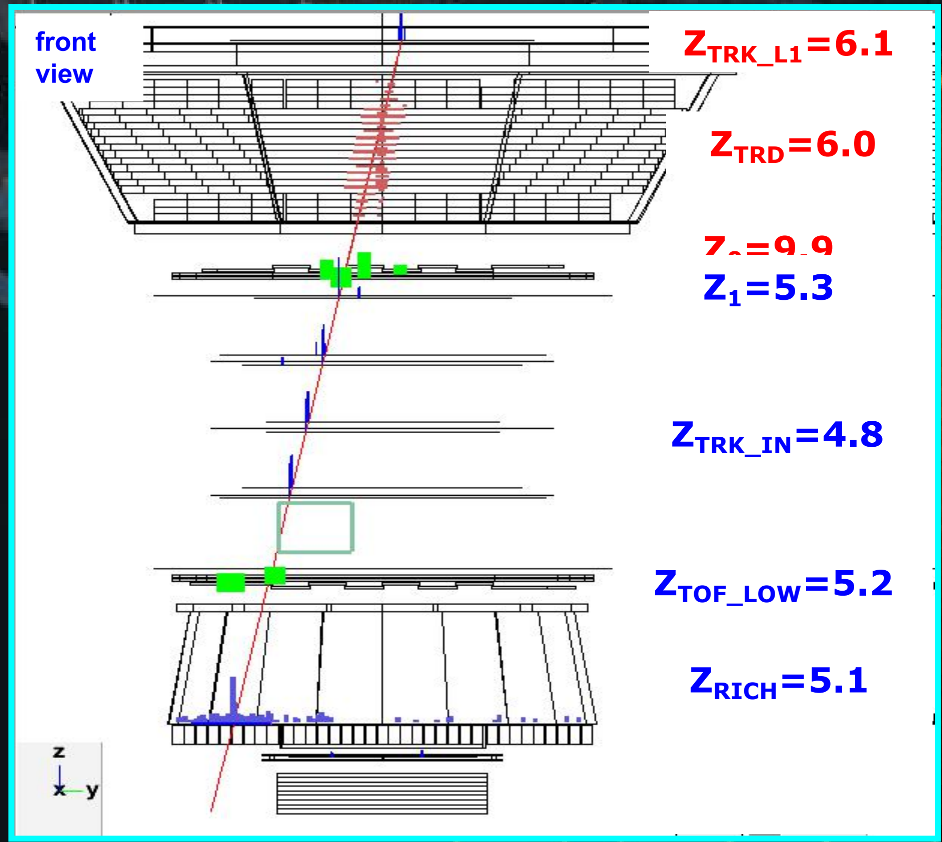
Slope changes at about the same rigidity as for protons and helium

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

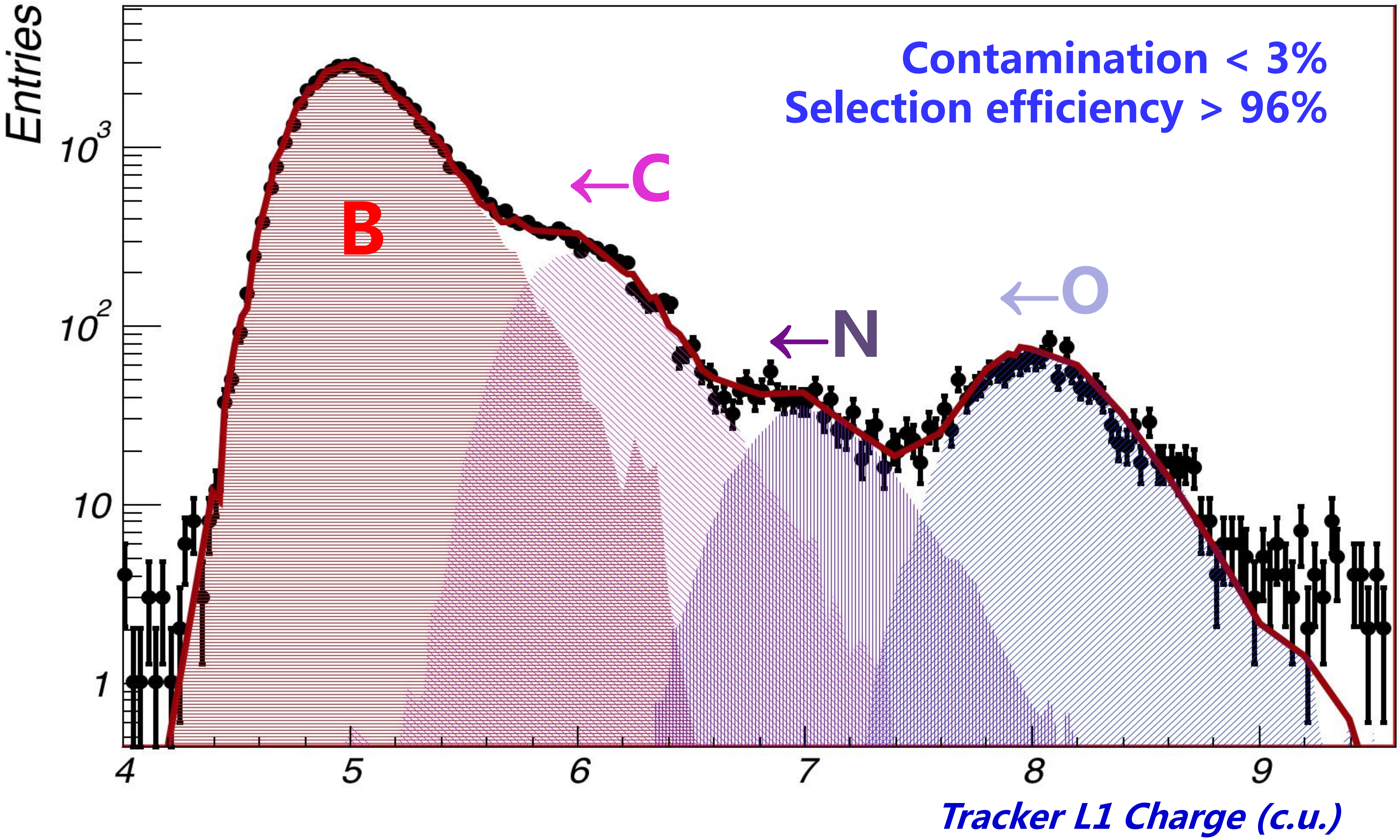
Carbon Fragmentation
to Boron R = 10.6 GV

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

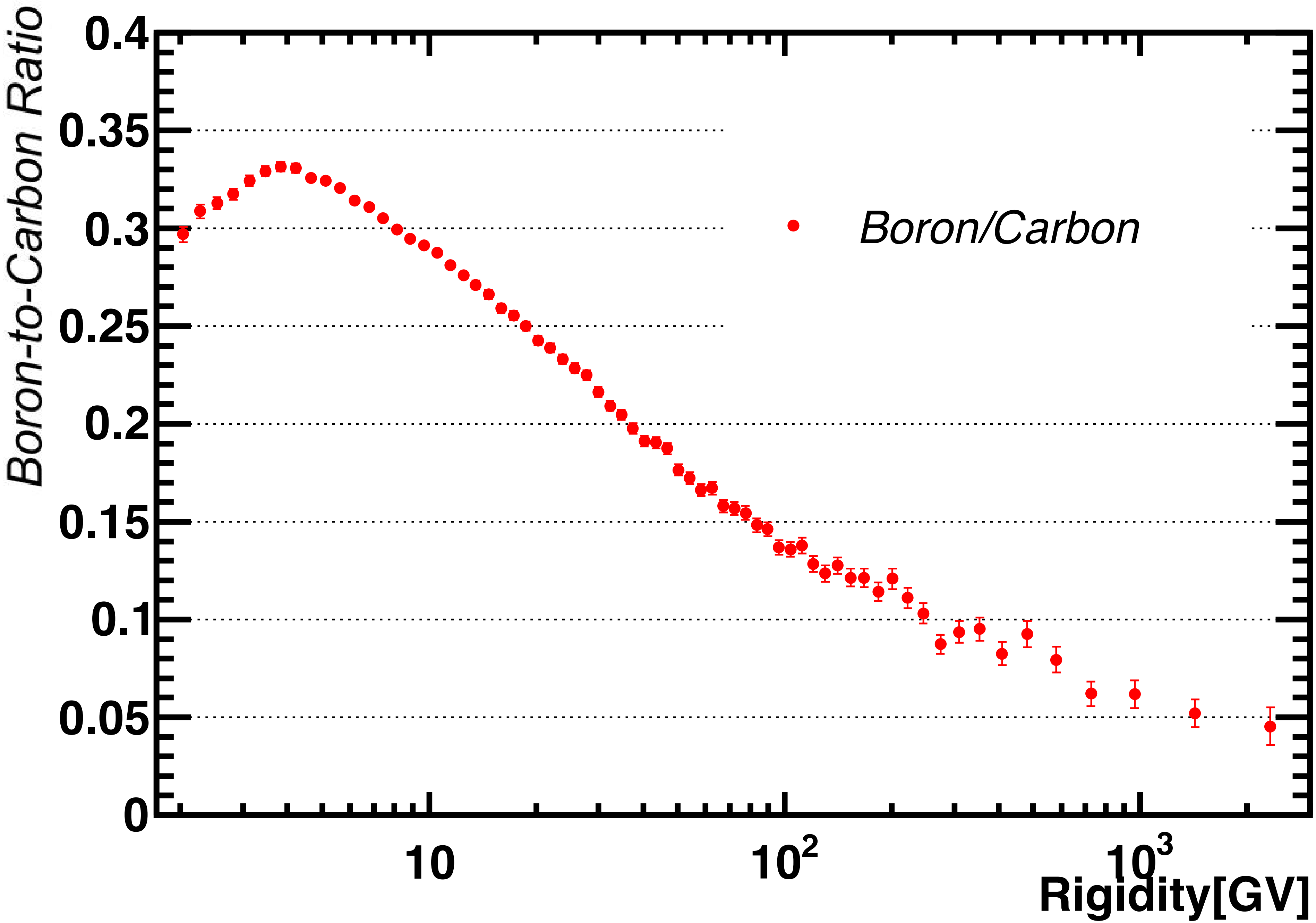




Boron and Carbon: Sample composition



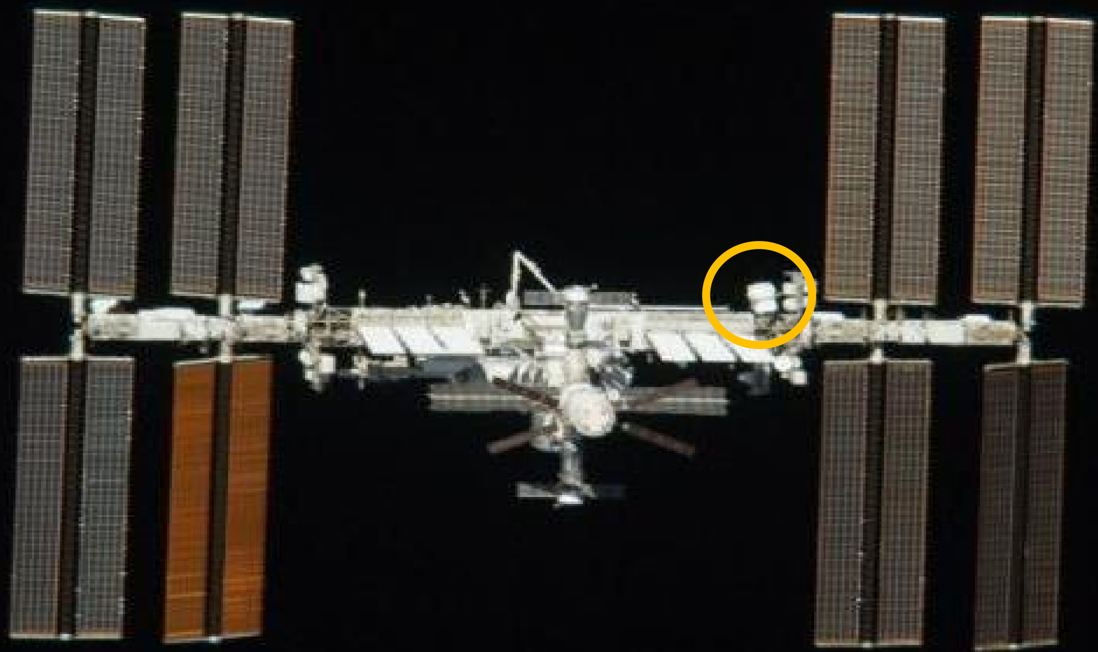
AMS B/C Ratio



Boron-to-Carbon Ratio
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Boron/Carbon
10
10^2
10^3
Rigidity[GV]

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, …

In the past hundred years, measurements of charged cosmic rays by balloons and satellites have typically contained ~30% accuracy.

AMS is providing cosmic ray information with ~1% accuracy.

The improvement in accuracy will provide new insights.

The Space Station is now a unique platform for fundamental physics research.