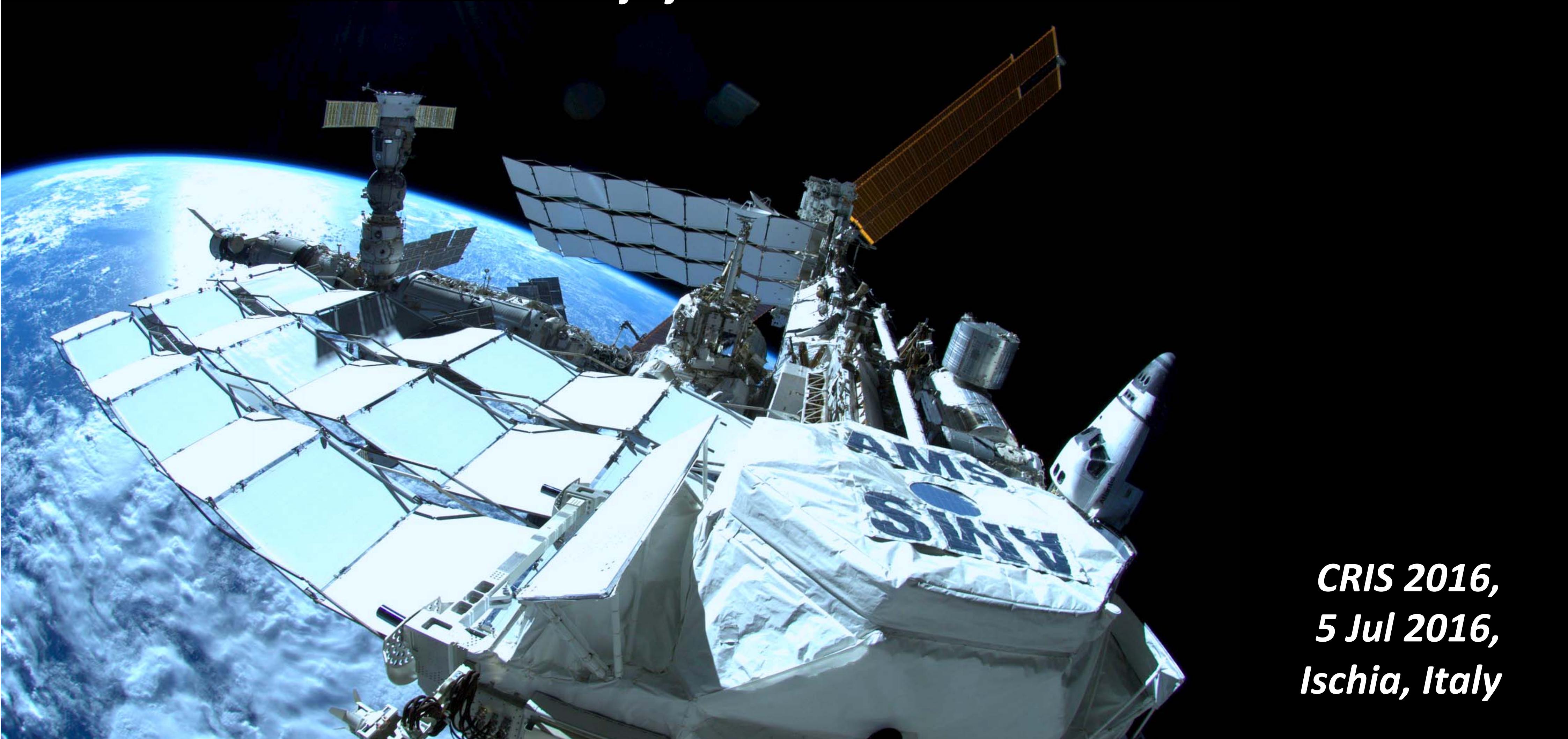
Recent Results of the Alpha Magnetic Spectrometer on the International Space Station

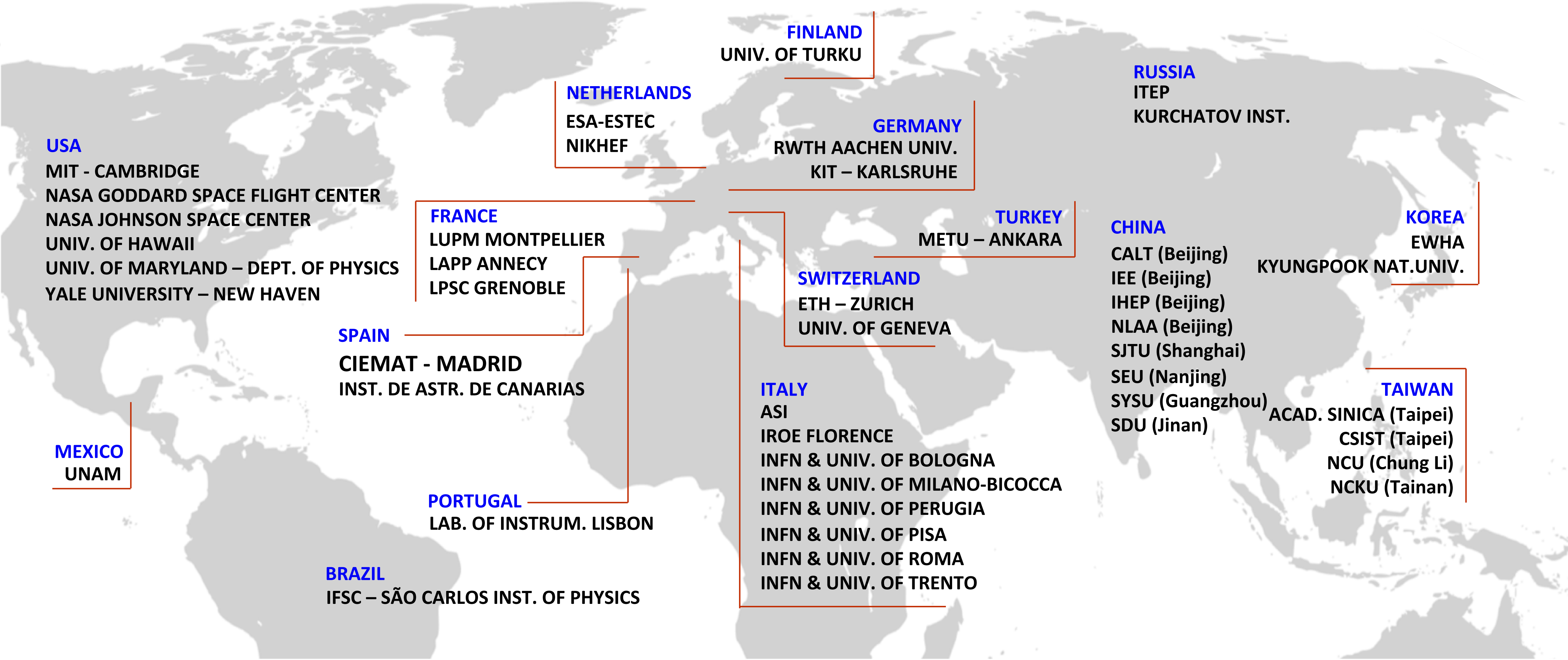
A. Oliva, CIEMAT, Spain
On behalf of the AMS Collaboration



CRIS 2016,
5 Jul 2016,
Ischia, Italy

AMS-02 Collaboration

16 Countries, 46 Institutes and about 600 Physicists



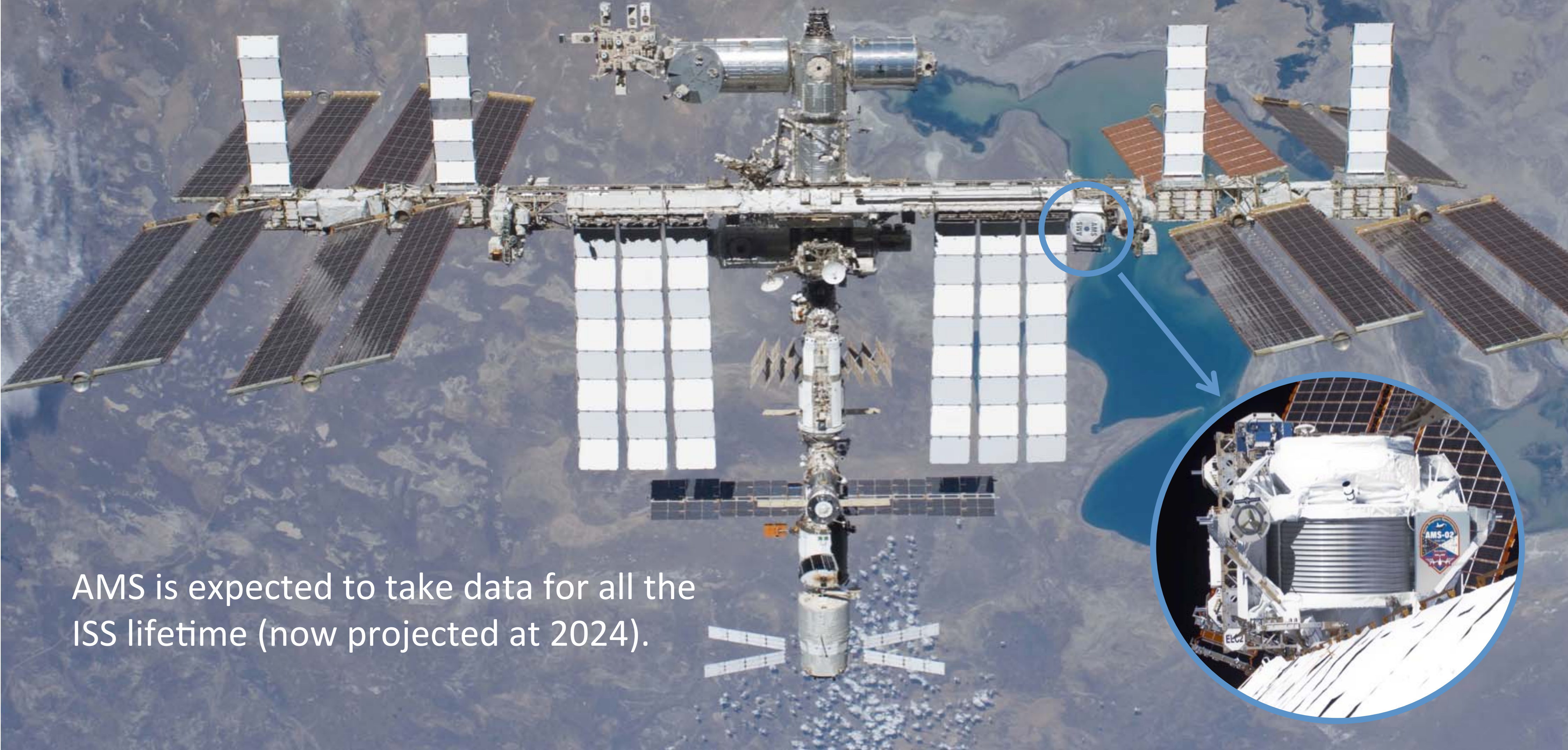
AMS-02 On Orbit

From May 19th **2011** active on ISS, operating continuously since then.

AMS has collected **>80 billion cosmic rays** in 5 years.

With such a statistics the **most rare components** of the cosmic rays are visible.

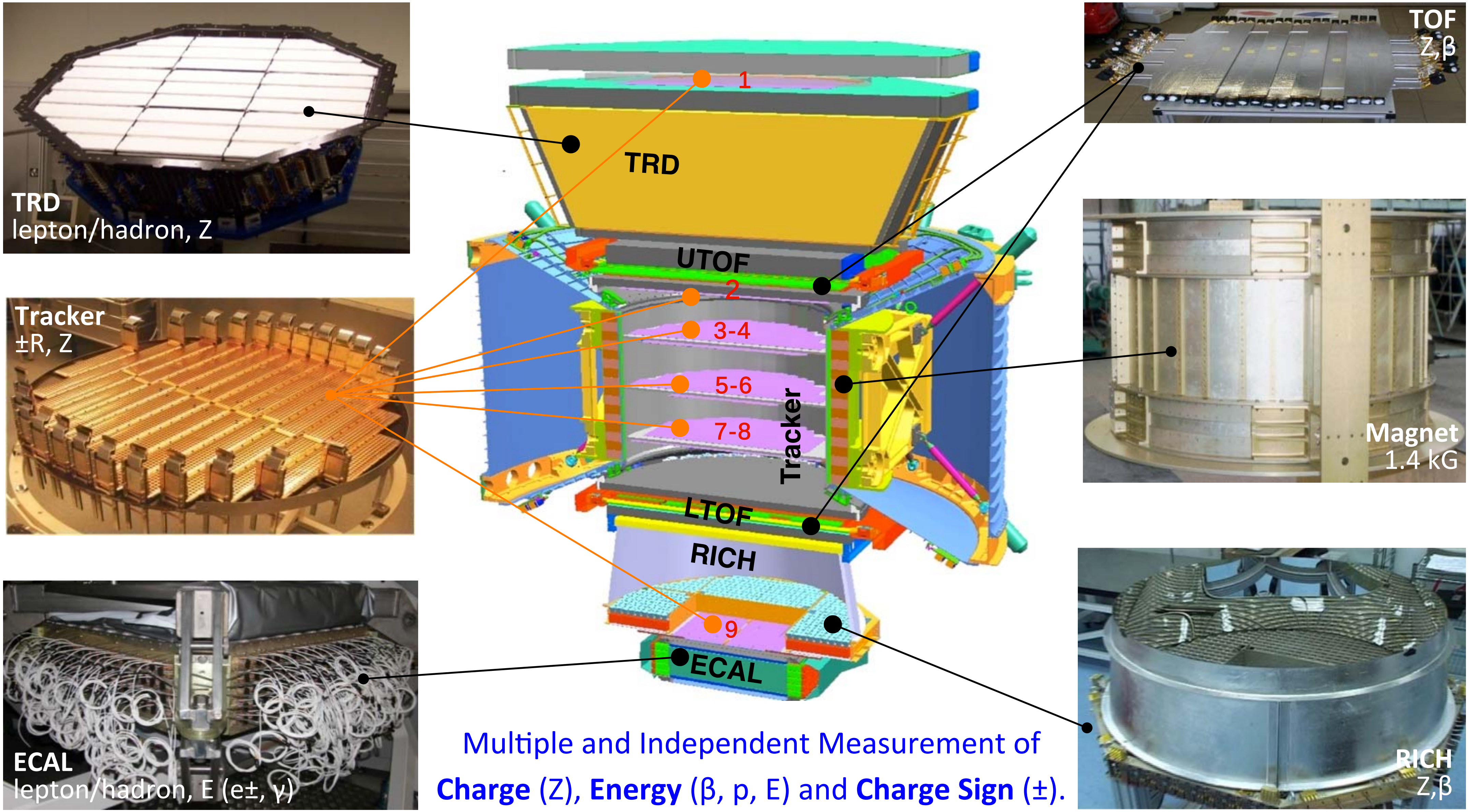
To match the statistics, **systematic errors studies have become important.**



AMS is expected to take data for all the ISS lifetime (now projected at 2024).

AMS-02: A TeV Multi-purpose Spectrometer

Separates **hadrons** from **leptons**, **matter** from **anti-matter** and able to do CRs **chemical** and **isotopic composition** in **GeV to TeV** range.

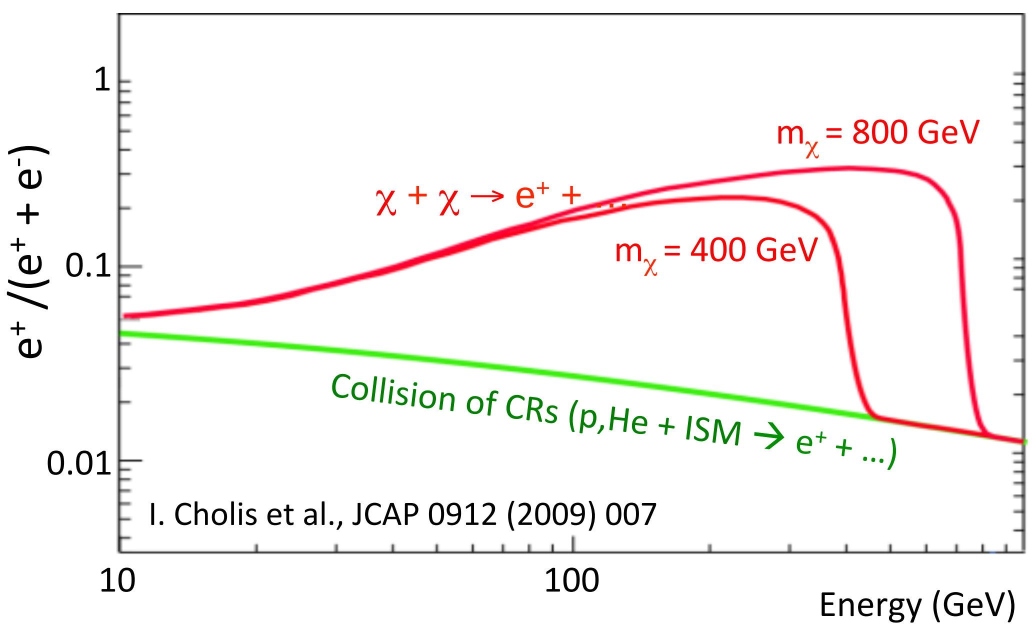


Multiple and Independent Measurement of **Charge** (Z), **Energy** (β, p, E) and **Charge Sign** (±).

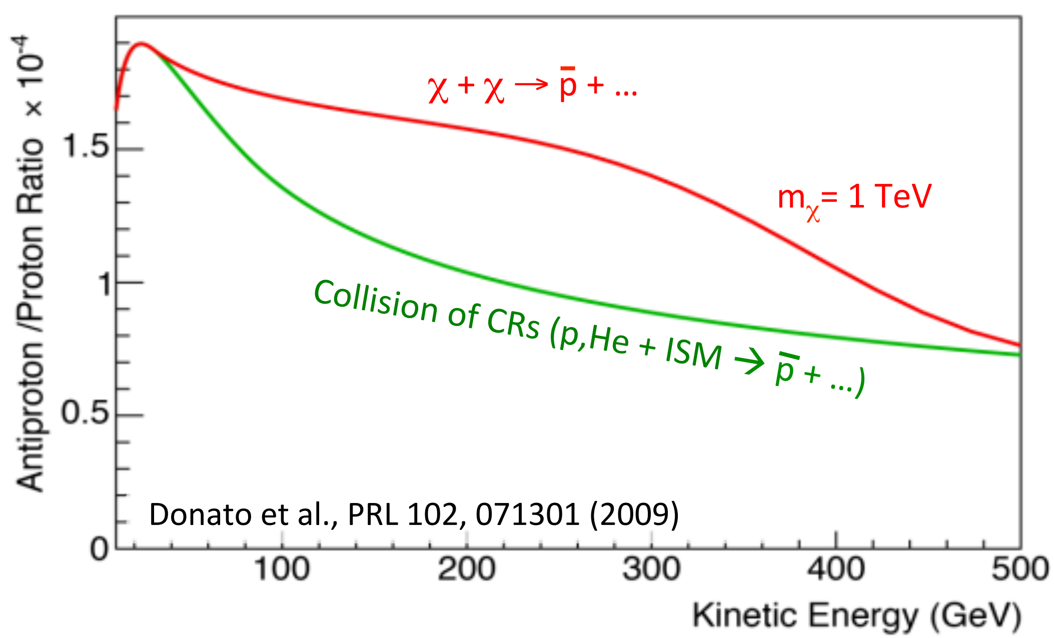
Search for Origin of Dark Matter: Signal

collisions of Dark Matter particles (ex. neutralinos) may produce a signal of e^+, p-bar, …
detected above the background from the collisions of CRs on interstellar medium (ISM)

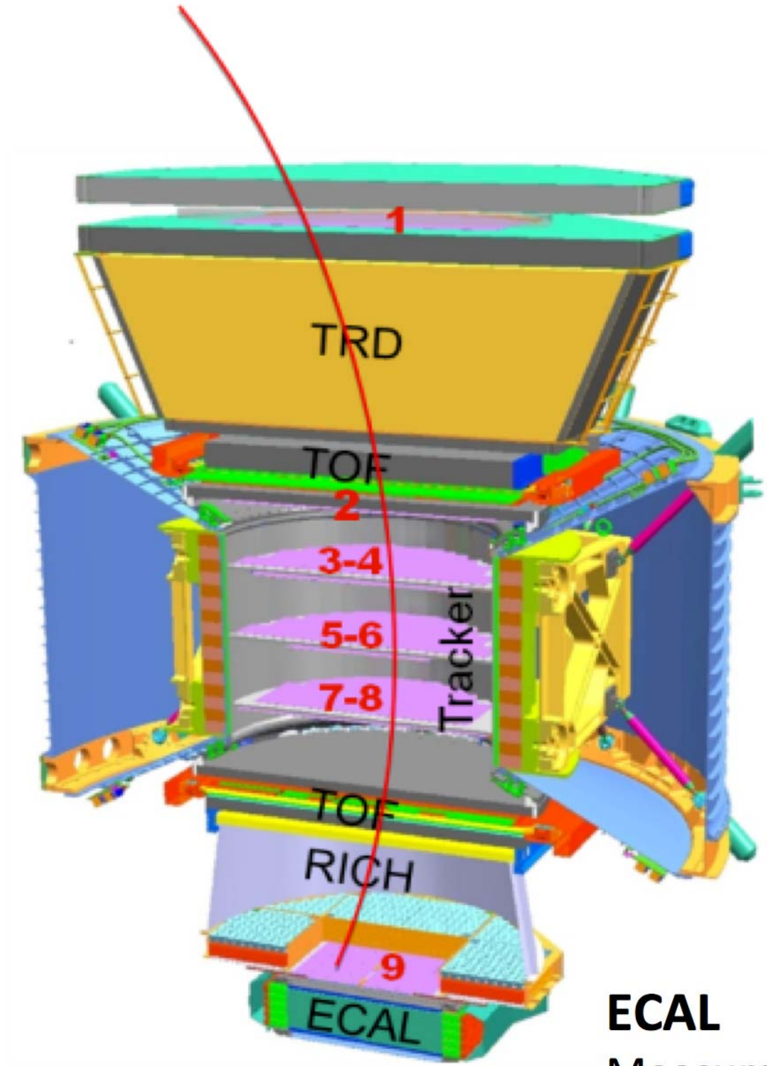
positron fraction



p-bar/p ratio



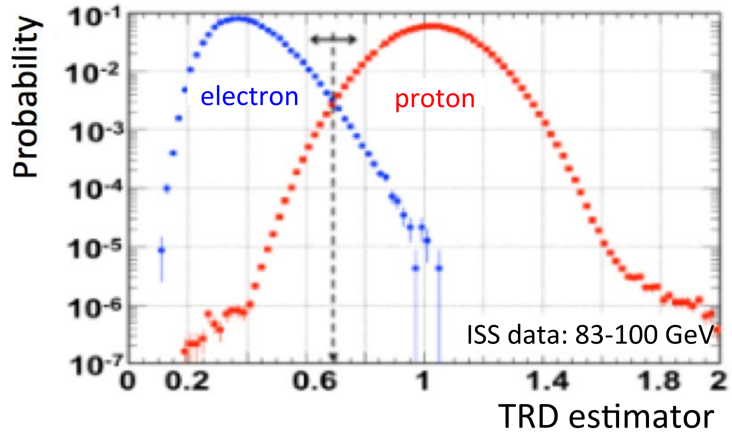
Identification of Electrons and Positrons with AMS

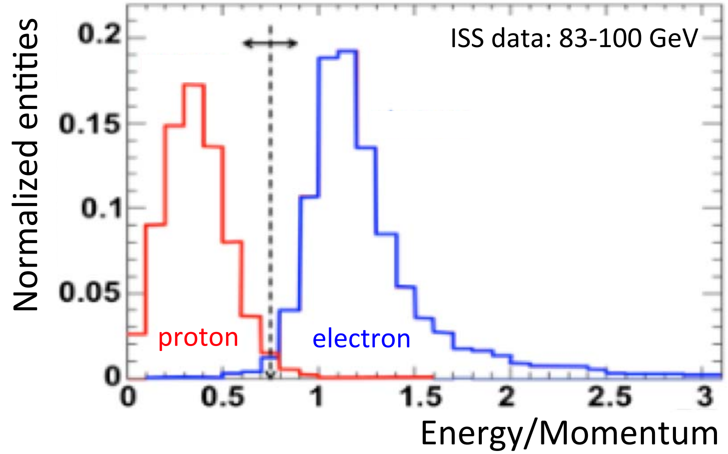


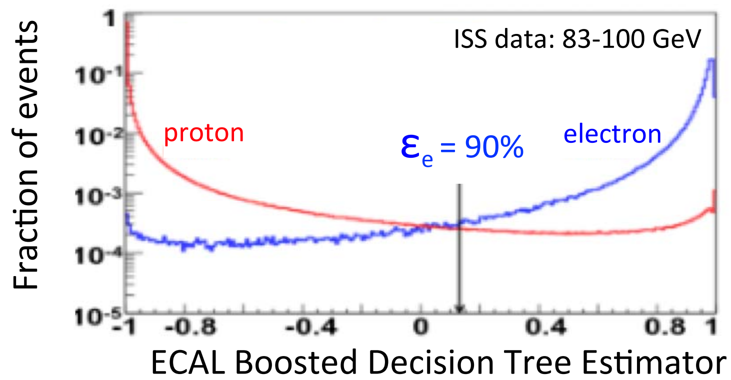
TRD
Z=1
Separate $e^{\pm}$ from p, anti-p

TRACKER
Z=1
Measures Momentum
Energy/Momentum match
($e^{\pm}$: E = P, p: E < P)

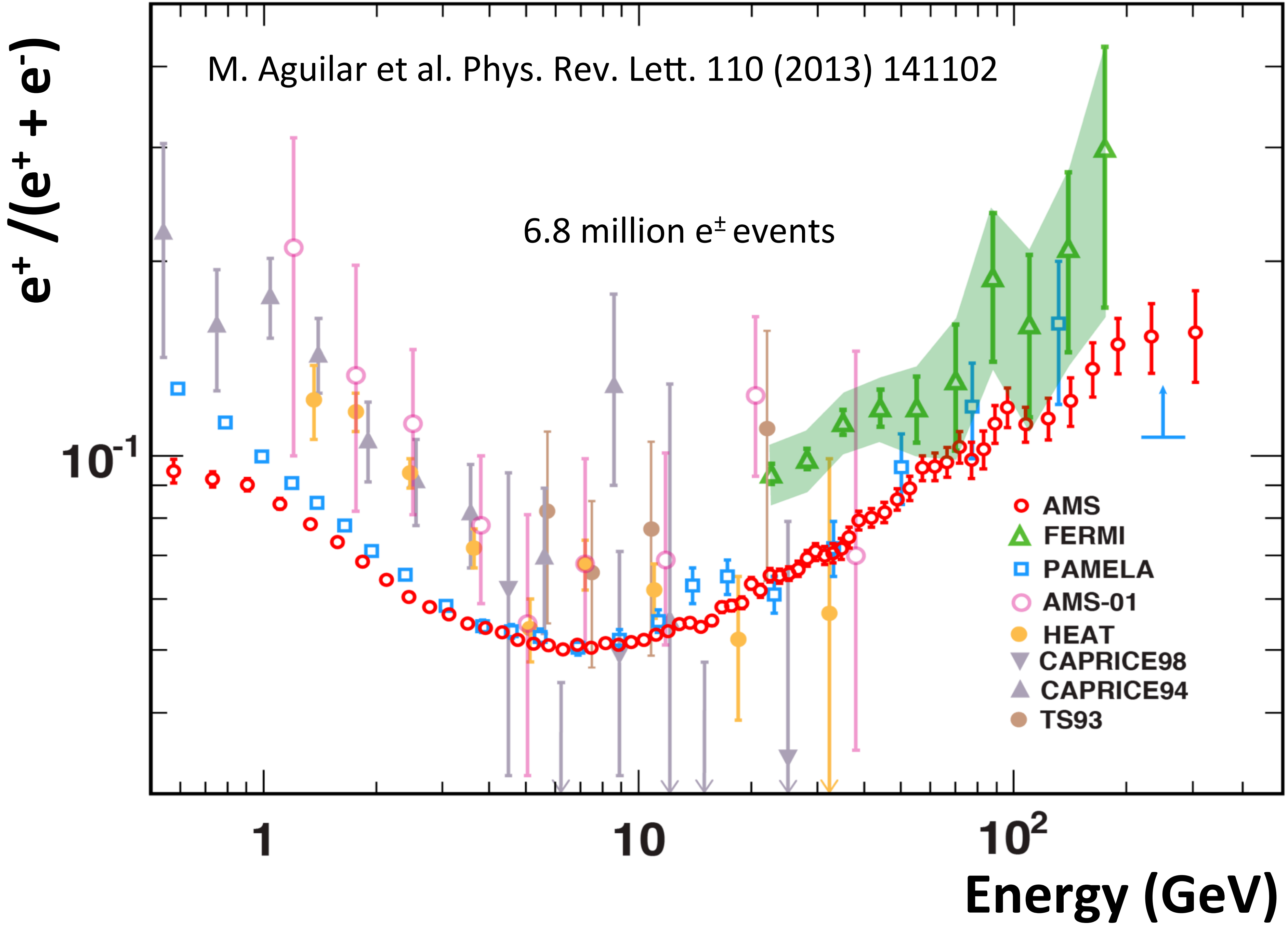
ECAL
Measures Energy of $e^{\pm}$
Shower shape separates $e^{\pm}$ from p, anti-p





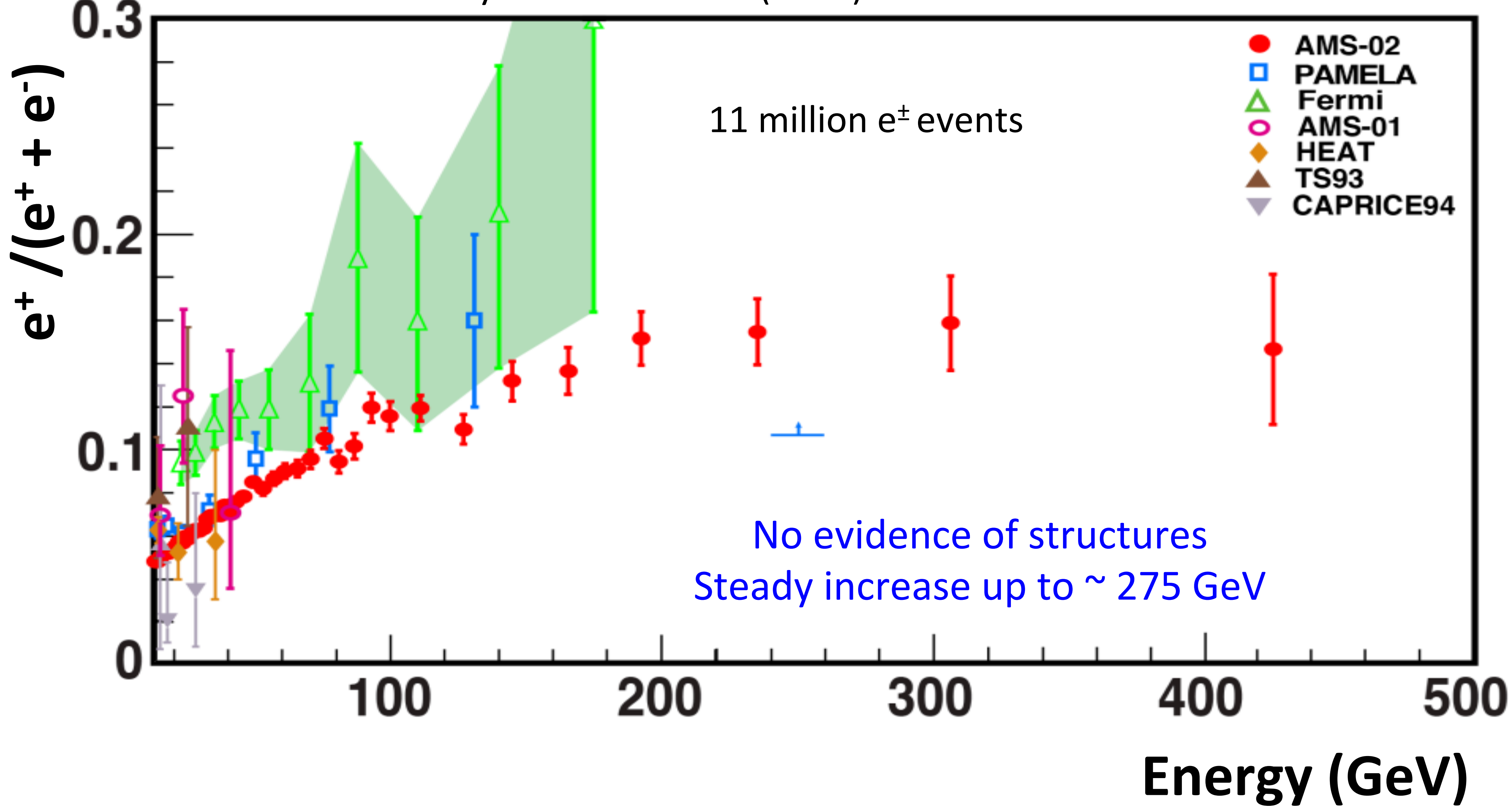


AMS Positron Fraction (2013)

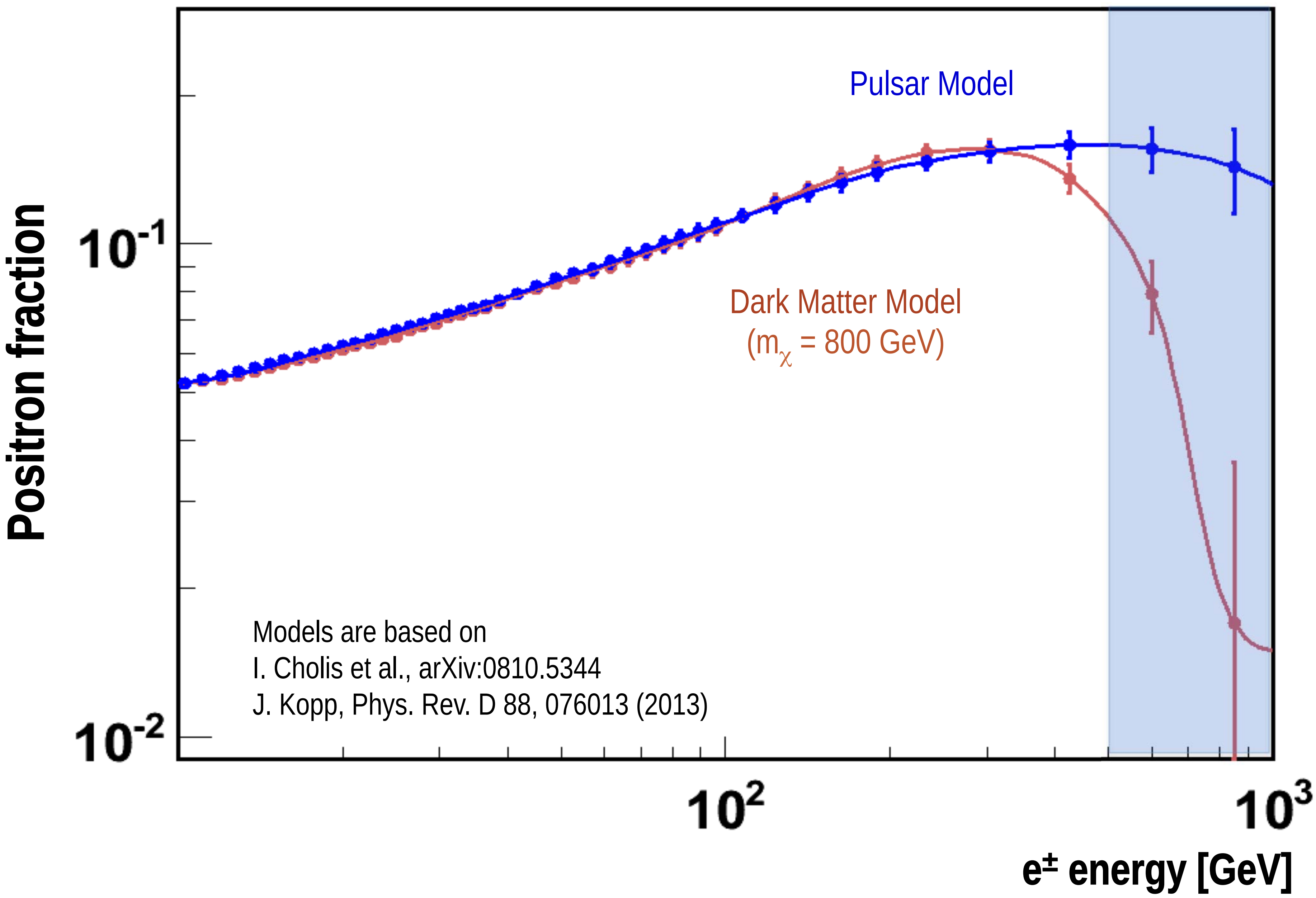


AMS Positron Fraction (2014): **Extending Range**

L. Accardo et al. Phys. Rev. Lett. 113 (2014) 121101

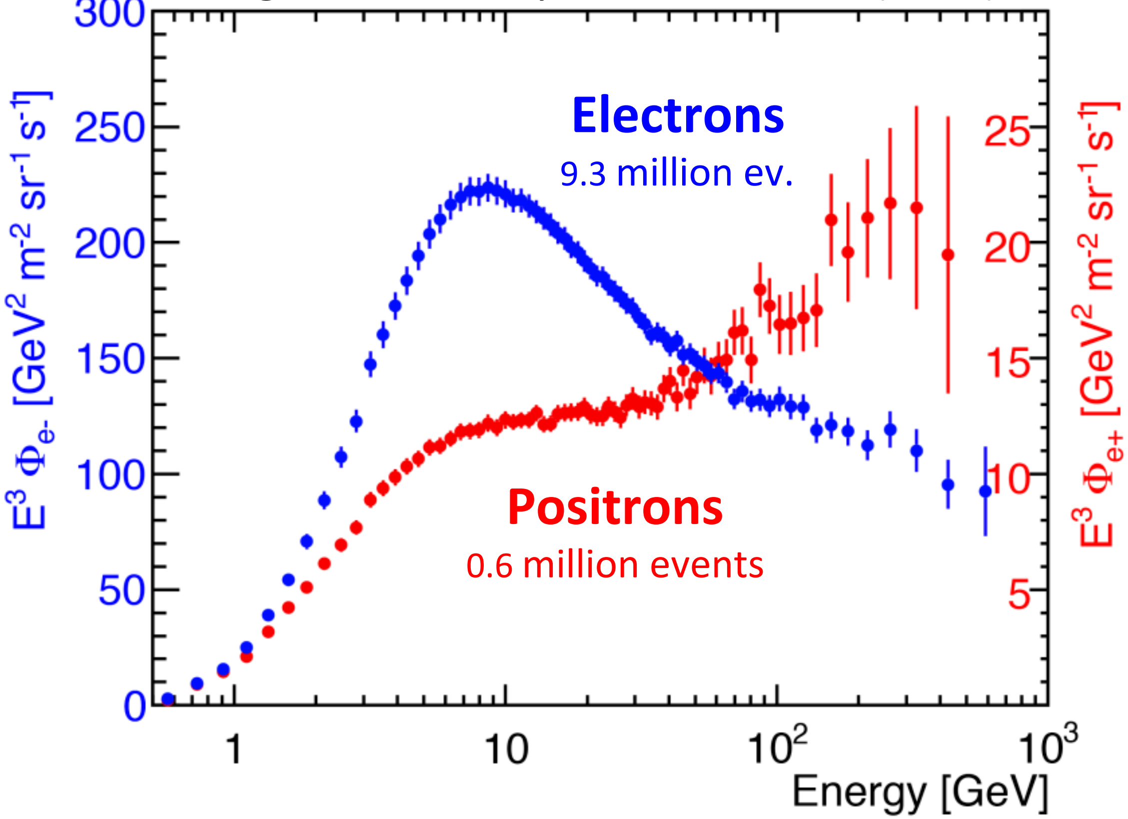


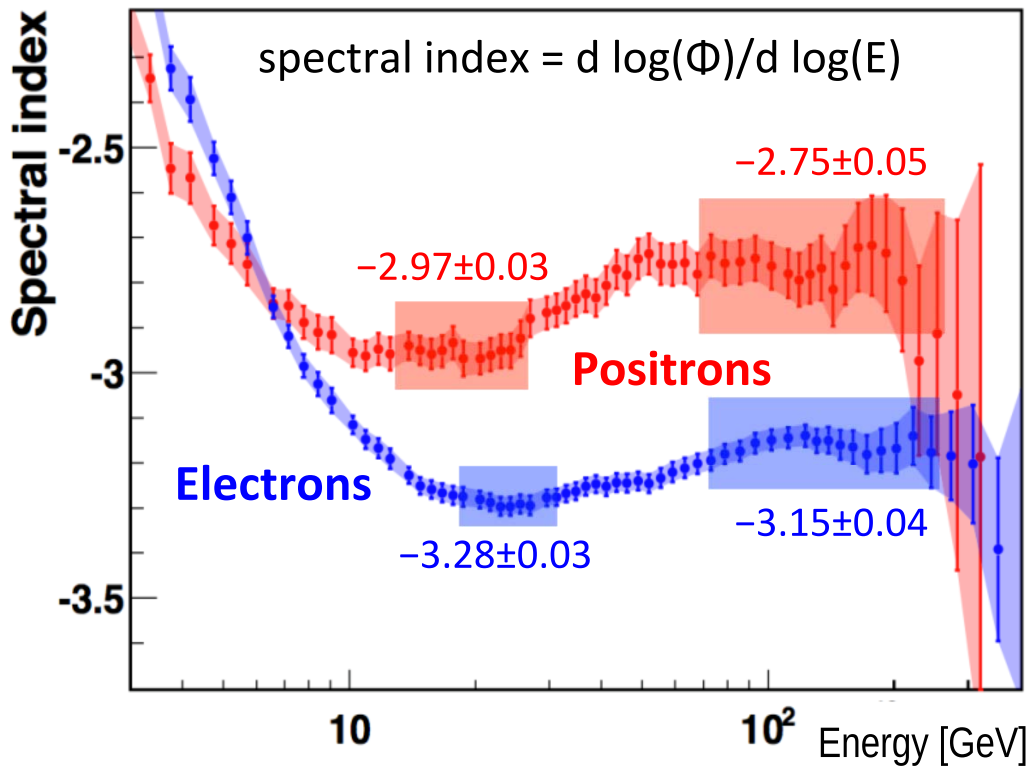
AMS Positron Fraction: **Projection to 2024**



AMS Electrons and Positron Fluxes

M. Aguilar et al. Phys. Rev. Lett. 113 (2014) 1211012



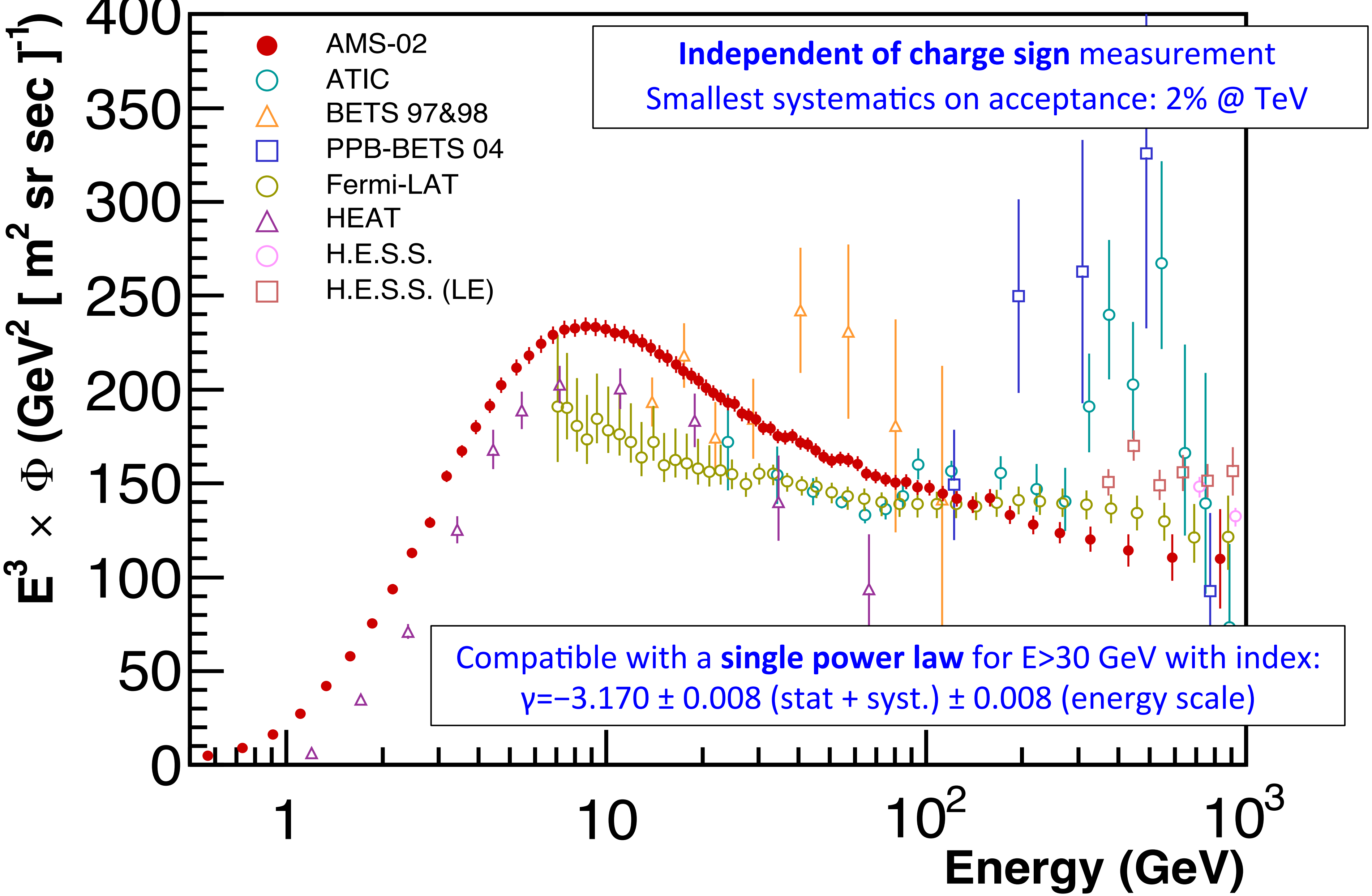


Positron flux above 20 GV is significantly harder than electrons one.

The rising in the positron fraction is due to a positron excess.

AMS ($e^+ + e^-$) Flux: **Extended Energy Range**

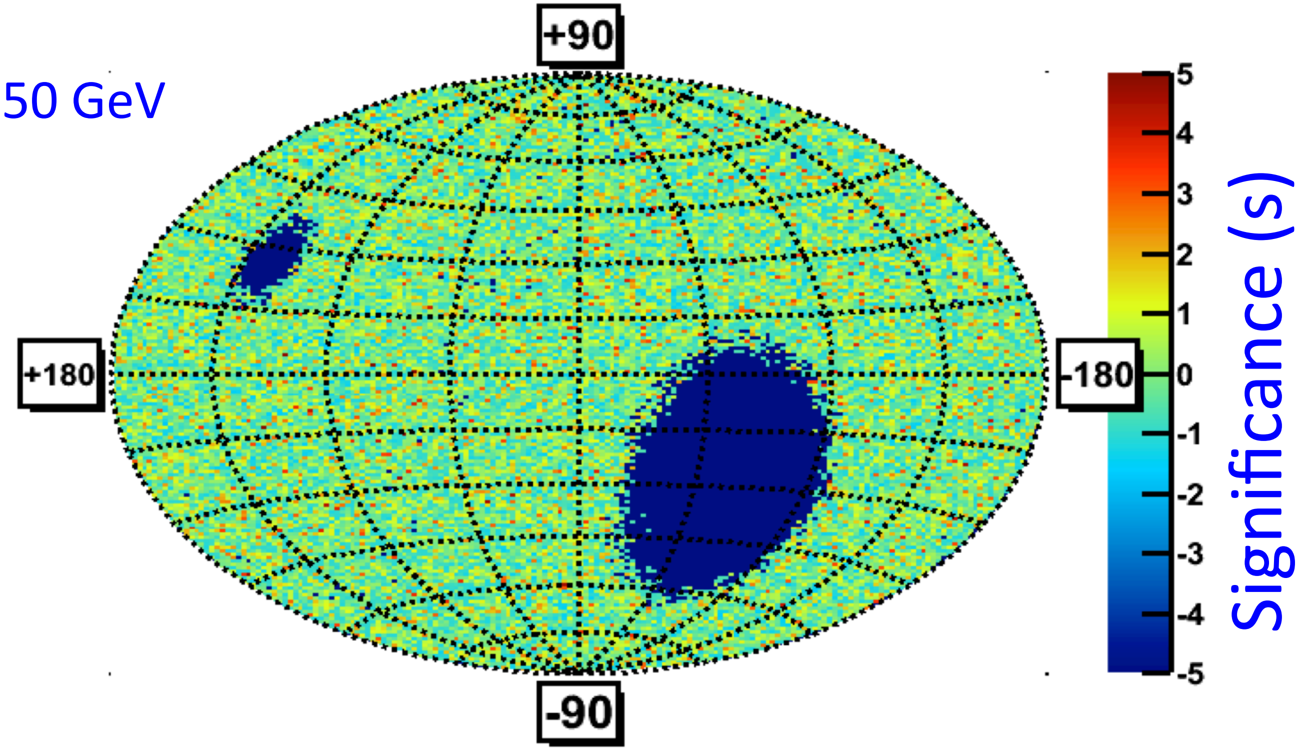
M. Aguilar et al. Phys. Rev. Lett. 113 (2014) 221102



AMS e^+/e^- Fraction **Anisotropy**

Primary sources of cosmic ray positrons and electrons
may induce some degree of anisotropy on the measured e^+/e^- ratio.

16 < E < 350 GeV

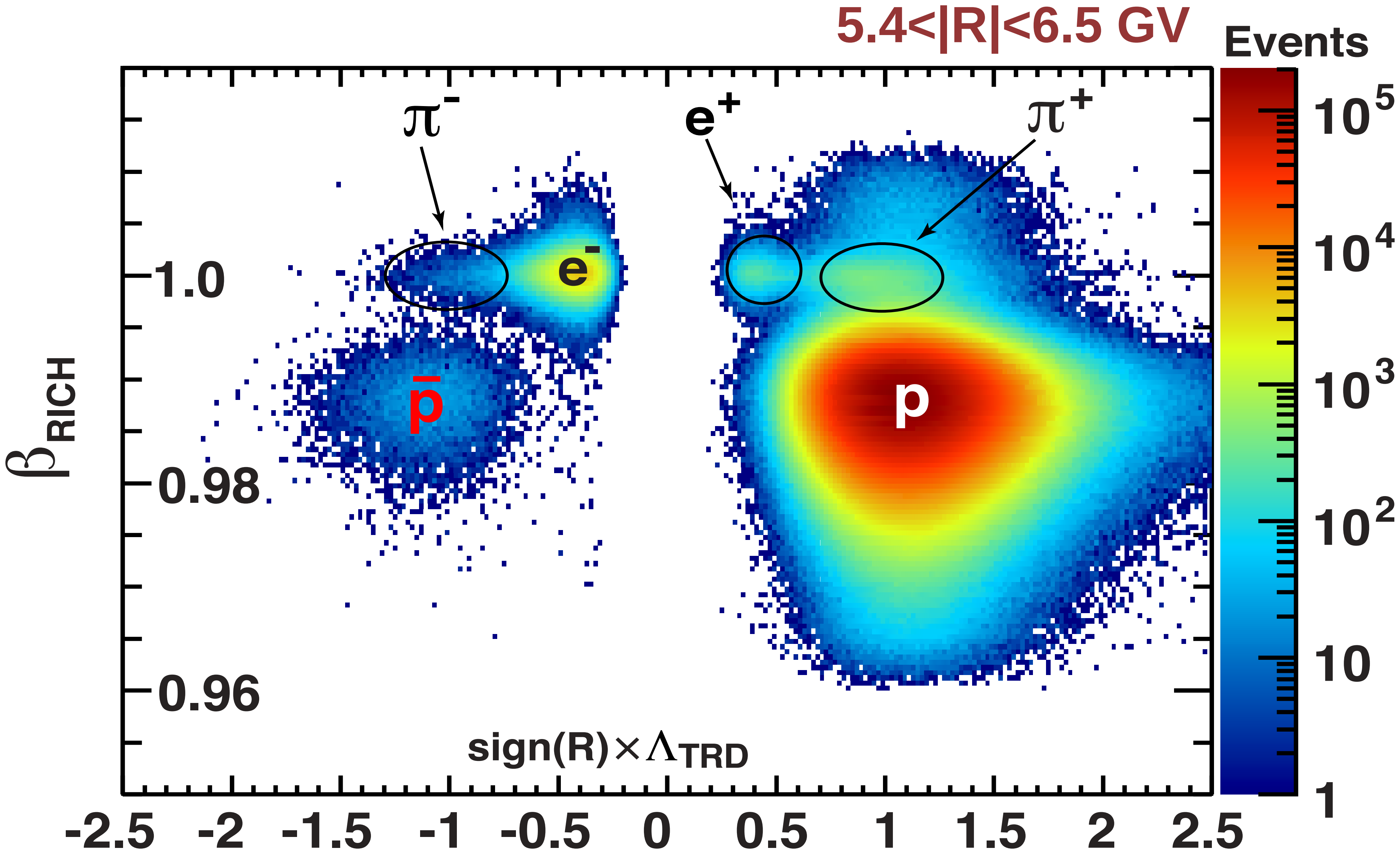


The fluctuations of the observed are described by using a spherical harmonic expansion
The observed limit on the amplitude of a dipole anisotropy is:

$\delta \leq 0.030$ at the 95% CL for 16 < E < 350 GeV

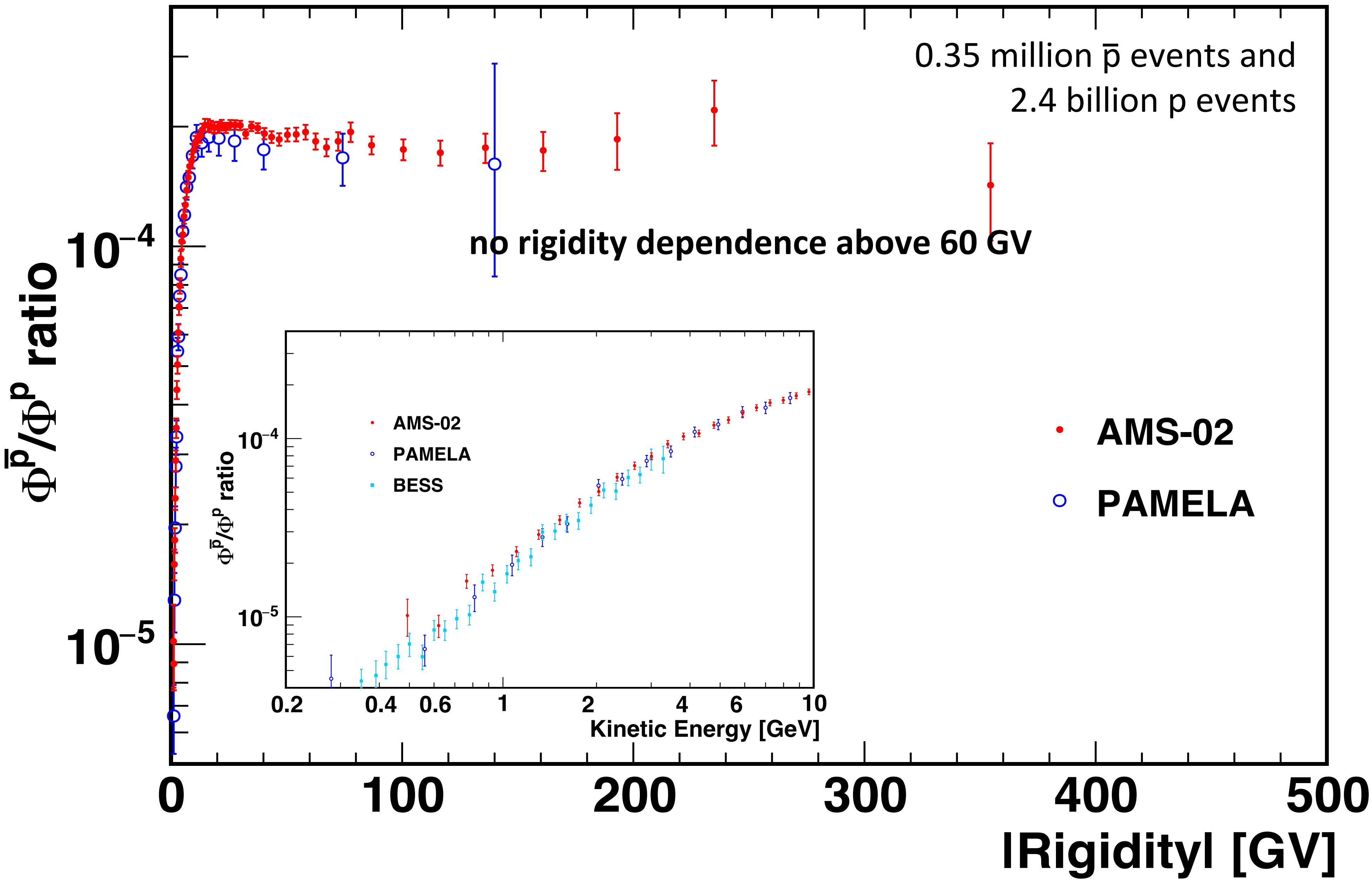
L. Accardo et al. Phys. Rev. Lett. 113 (2014) 121101

$\bar{p}$ Identification



AMS p̄/p Flux Ratio

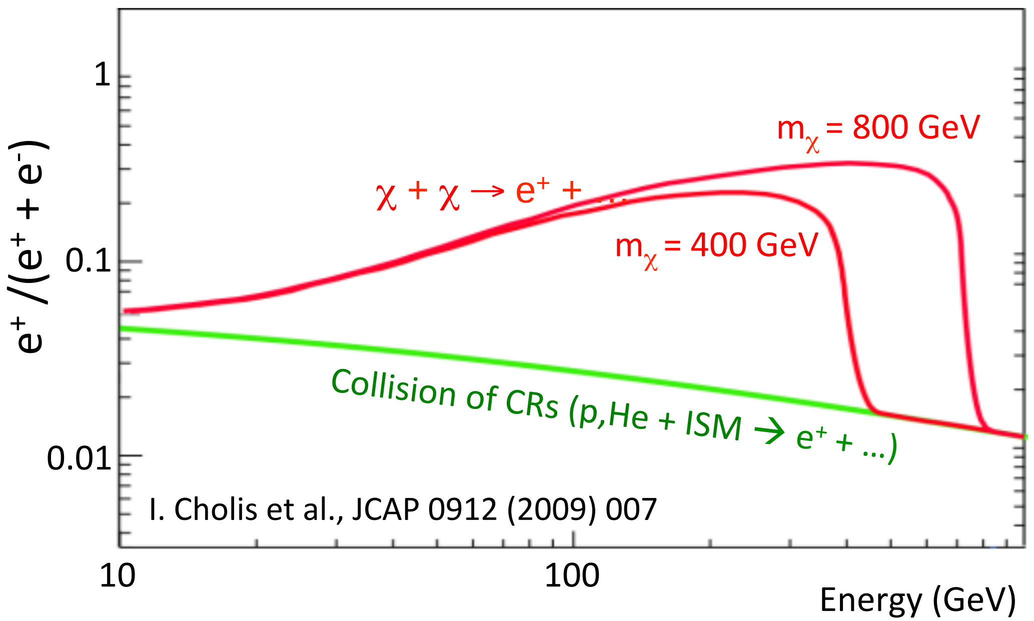
M. Aguilar et al., Submitted to PRL



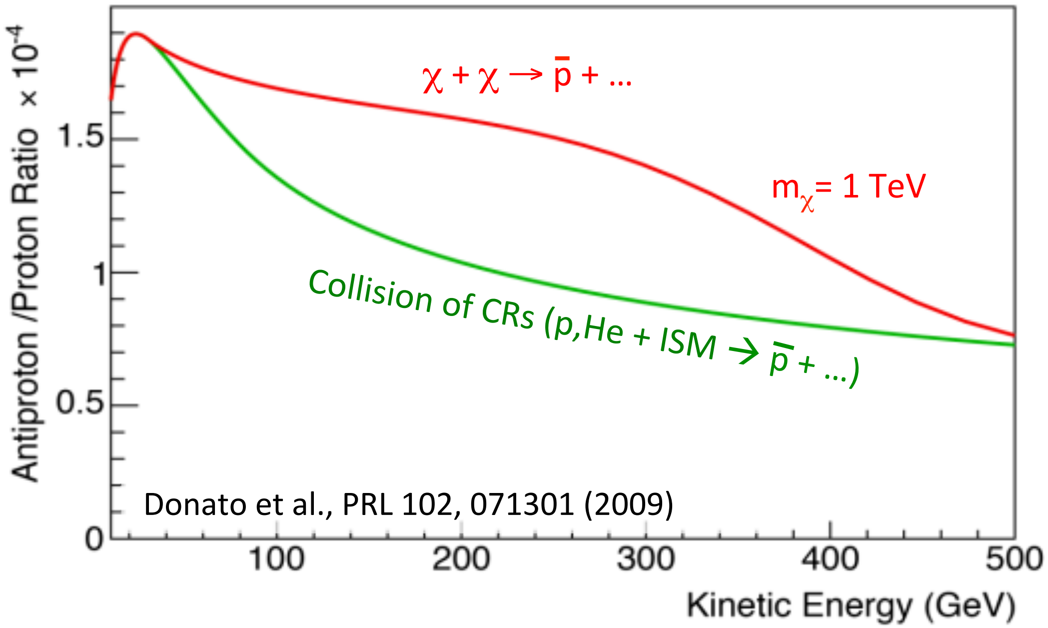
Search for Origin of Dark Matter: Background

collisions of Dark Matter particles (ex. neutralinos) may produce a signal of e^+, p-bar, …
detected above the background from the collisions of CRs on interstellar medium (ISM)

positron fraction

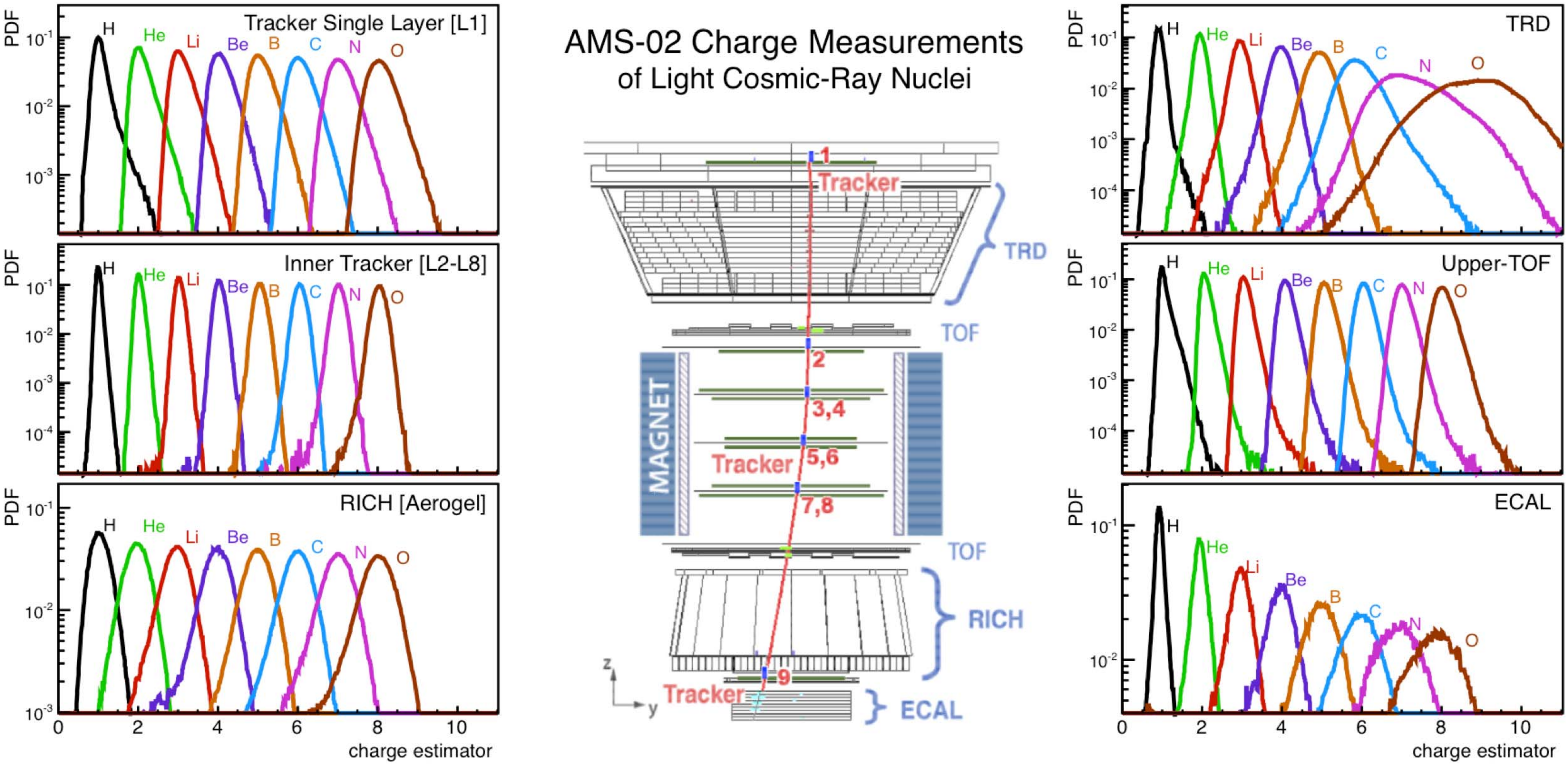


p-bar/p ratio

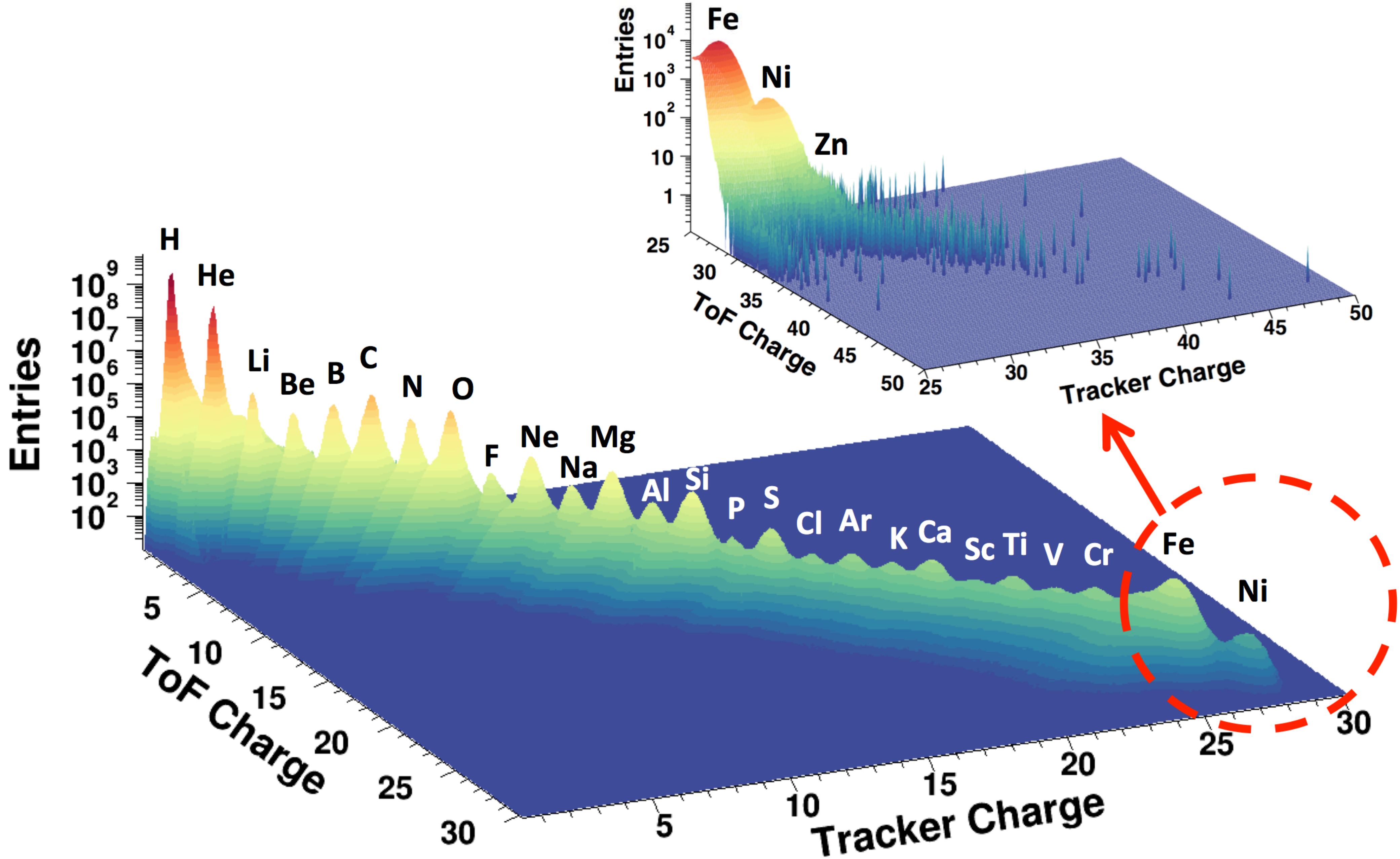


To understand **background**, we need precise knowledge of
- The cosmic ray fluxes of e^+ and p-bar "parents" (**p, He,** …)
- Behaviour of the CRs propagation in the Milky Way (**B/C**, …)

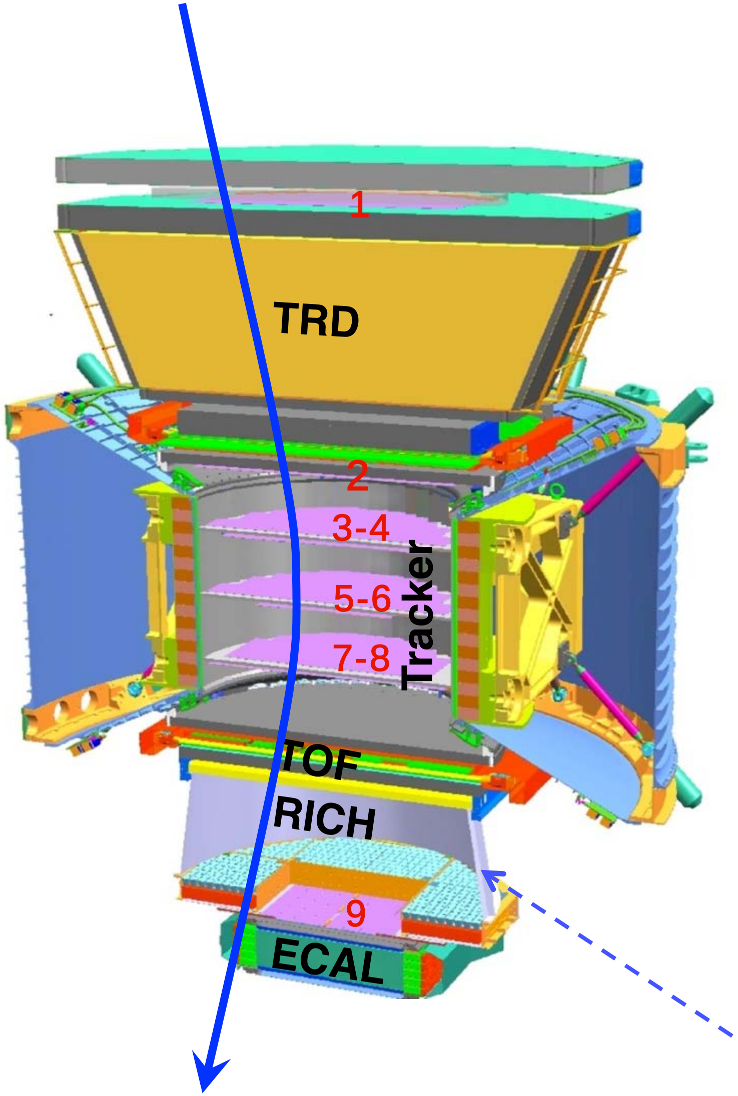
Multiple Charge Measurement with AMS-02



Cosmic Rays Chemical Composition with AMS



Multiple Measurement of Energy



Tracker, R = p/Z
Full Span MDR ≈ 2÷3 TV

TOF, β
$\Delta\beta$ (β=1) ≈ 0.01÷0.04

RICH, β
$\Delta\beta$ (β=1) ≈ $1 \div 5\times10^{-4}$

Proton Flux Determination

Isotropic Differential Flux
$(m^2\ sr\ s\ GV)^{-1}$

Number of protons

$$\Phi(R_i, R_i + \Delta R_i) = \frac{N(R_i, R_i + \Delta R_i)}{A_i\, \epsilon_i\, T_i\, \Delta R_i}$$

Effective geometric factor (acceptance)
estimated with MC and checked with data

Trigger efficiency
estimated from data

Exposure time
Duty cicle + Geomegnetic cutoff

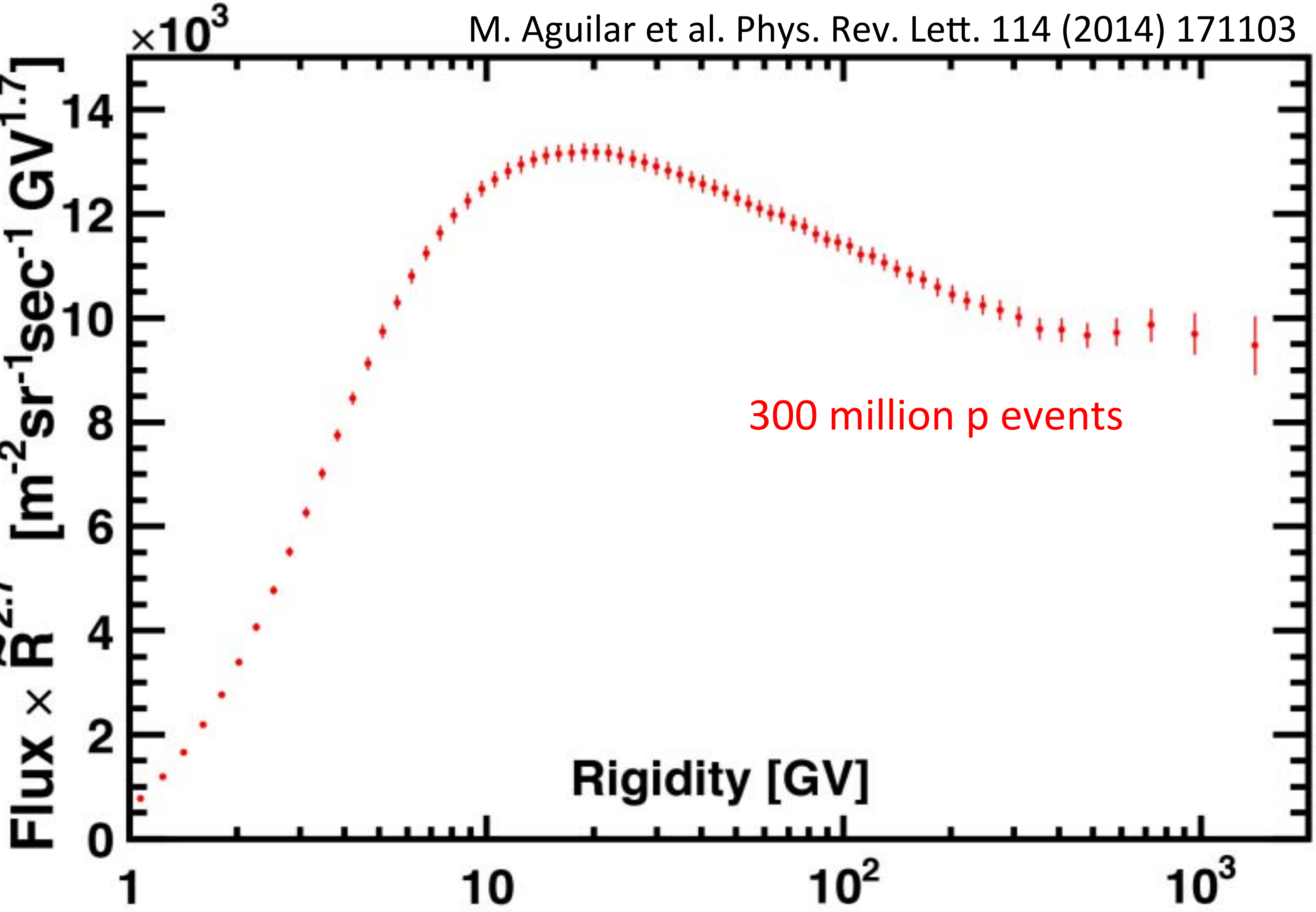
To match the statistics of 300 million events,
extensive systematic errors studies have been made.

Systematics error included:
Trigger efficiency
Data/MC corrections
Inelastic interaction model uncertainty
Background contamination
Geomagnetic cutoff effect
Unfolding (unfolding procedure, use of 2 different methods)
Rigidity resolution function (checked with test beam data)
Absolute rigidity scale (misalignment, magnetic field)

Verification performed:
No dependence from AMS zenith angle
No dependence from position on the top of AMS
No dependence of flux > 45 GV from time
Same flux obtained using the upper part of AMS only

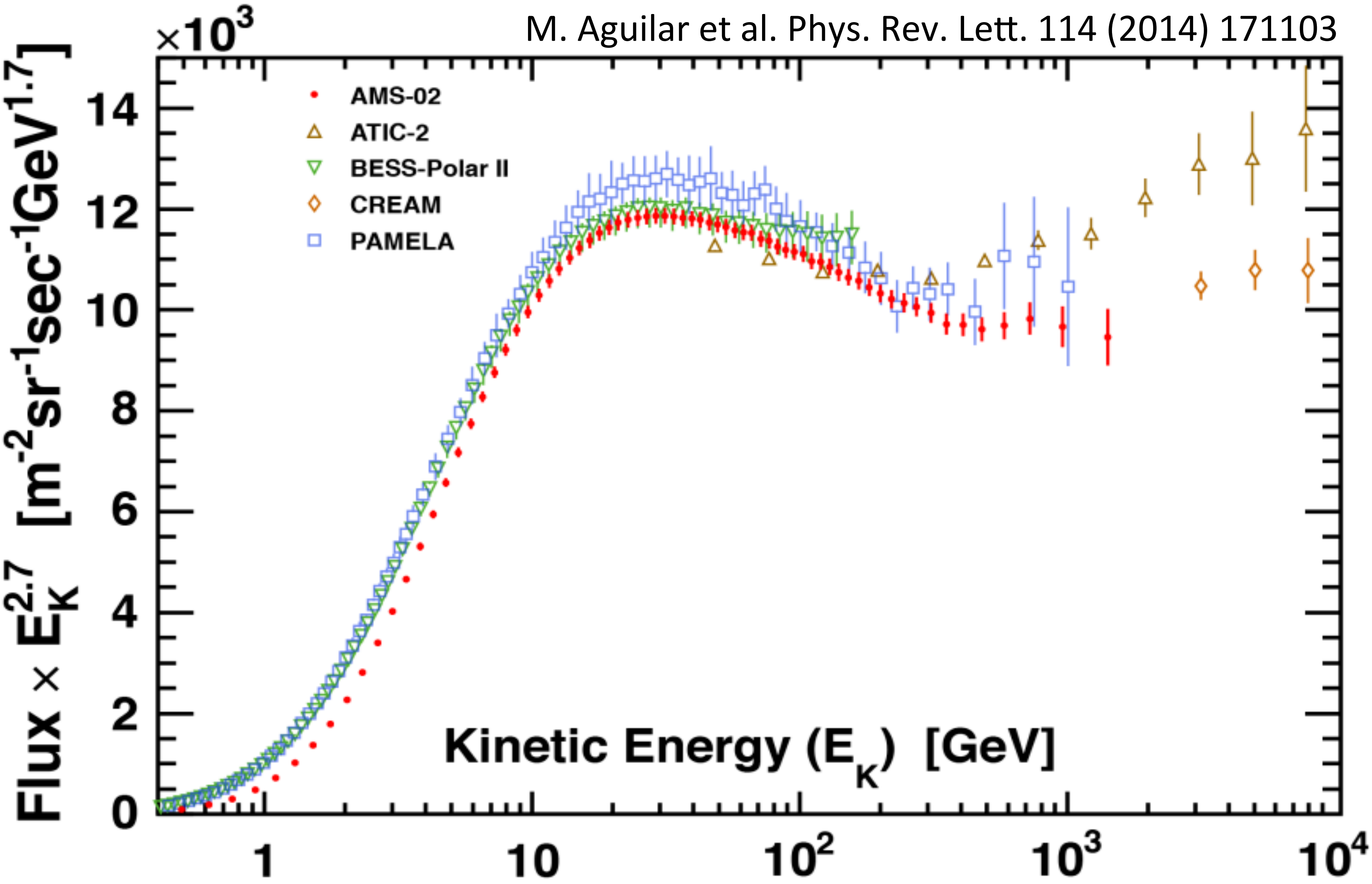
M. Aguilar et al. Phys. Rev. Lett. 114 (2014) 171103

AMS Proton Flux

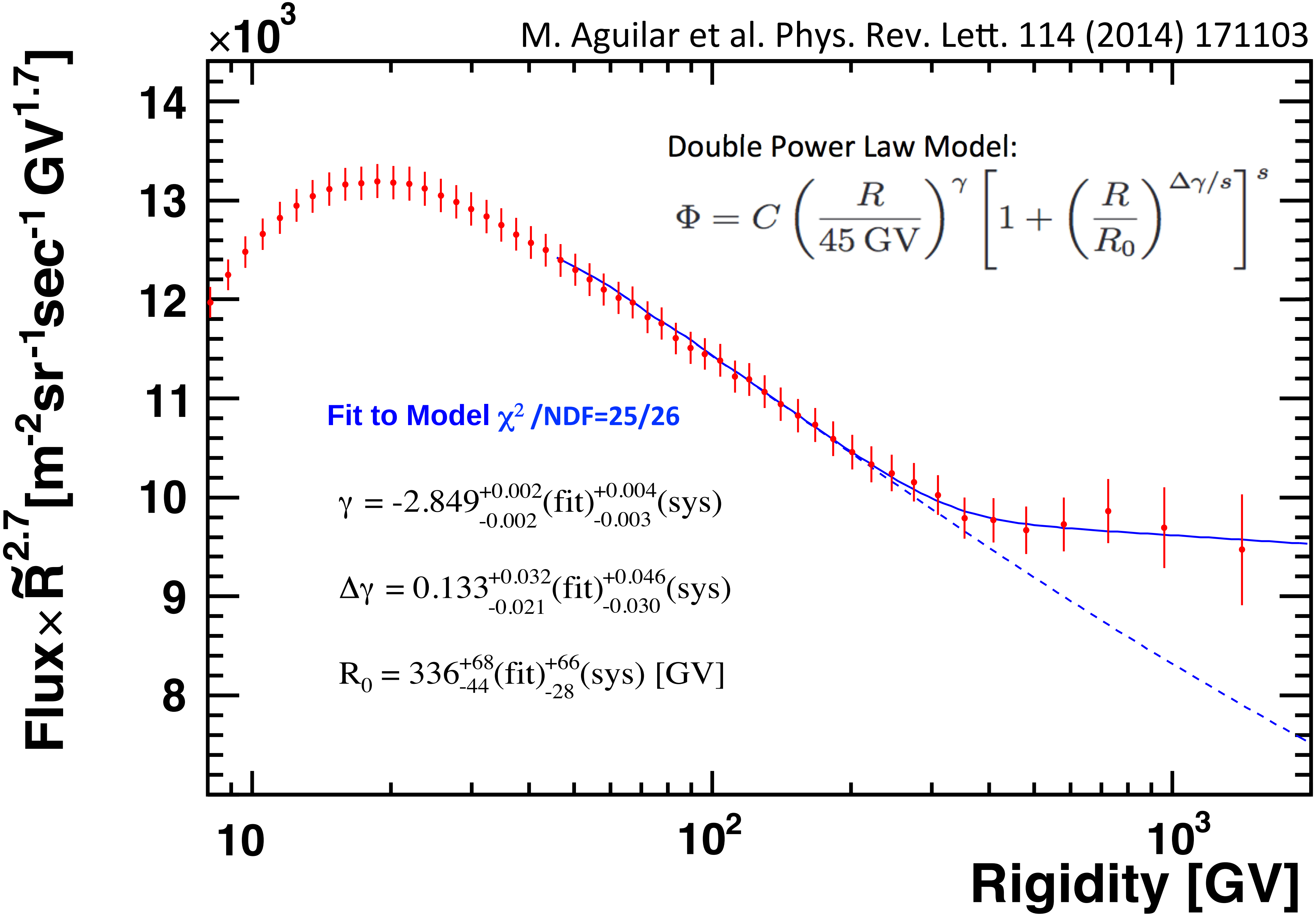


AMS Proton Flux Comparison

M. Aguilar et al. Phys. Rev. Lett. 114 (2014) 171103



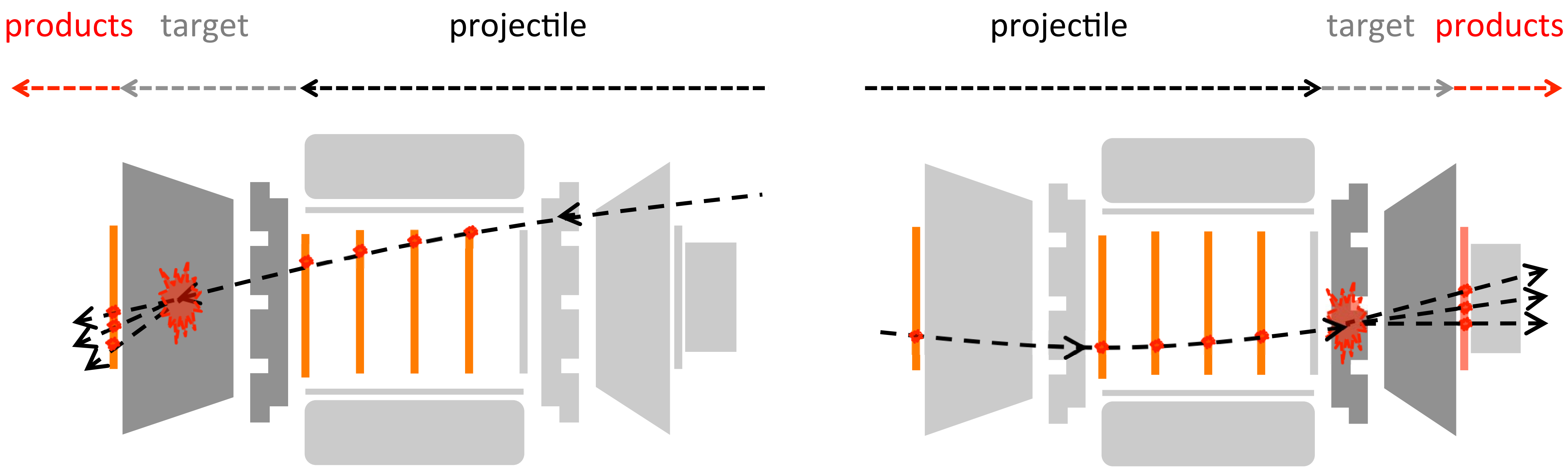
AMS Proton Flux **Is Not** a Single Power Law



Acceptance Verification for He and Light Nuclei

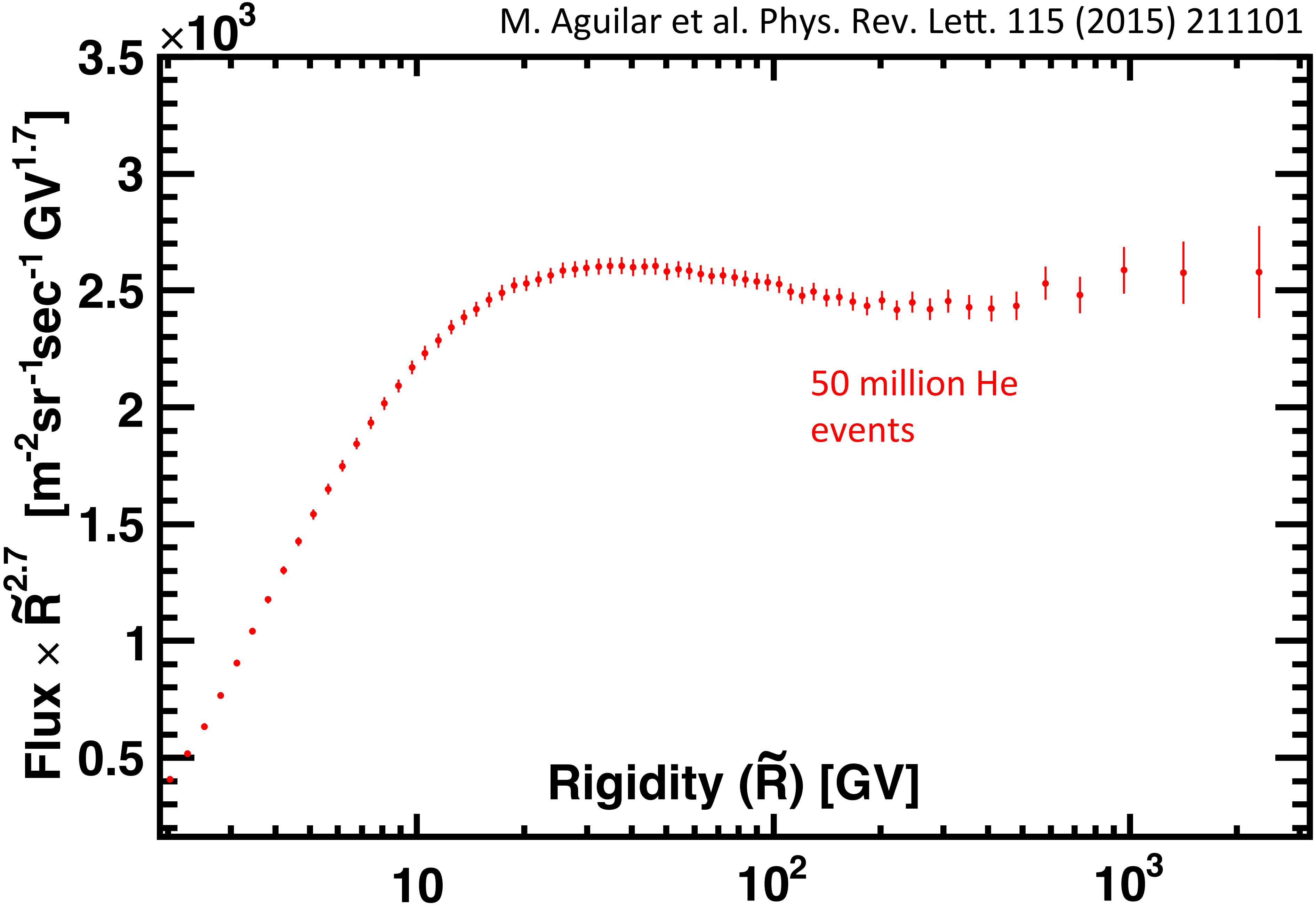
Inelastic XS of Light Nuclei on C and Al (that represent AMS materials for 73% and 17% in weight respectively) are known with large uncertainties only below 10 GV and represent a large source of errors for the flux determination.

We developed a method to verify the effect of interactions on AMS acceptance using ISS data using with data acquired when AMS pointing in horizontal direction (2 days up to now)



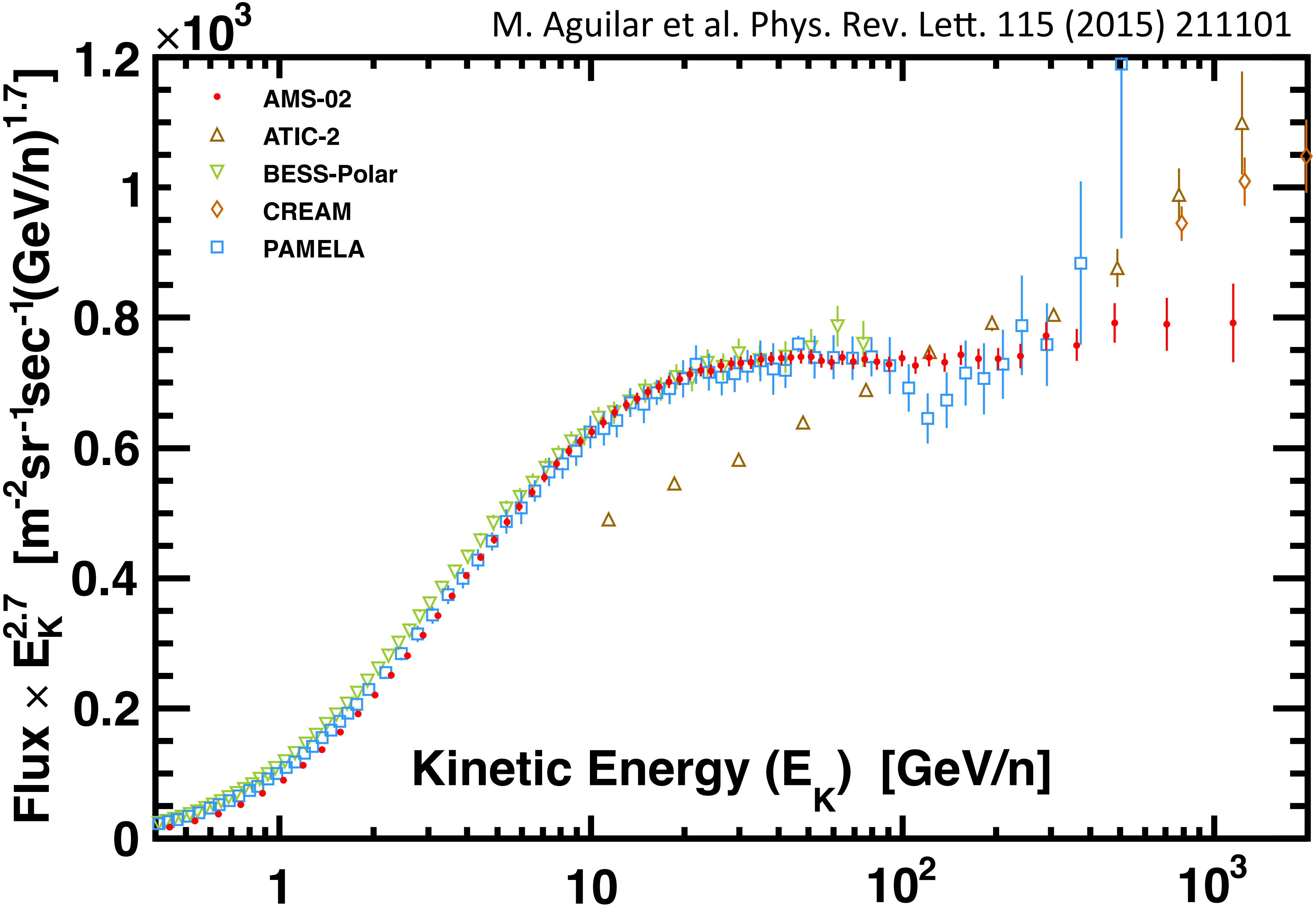
AMS Helium Flux

M. Aguilar et al. Phys. Rev. Lett. 115 (2015) 211101



AMS Helium Flux Comparison

M. Aguilar et al. Phys. Rev. Lett. 115 (2015) 211101



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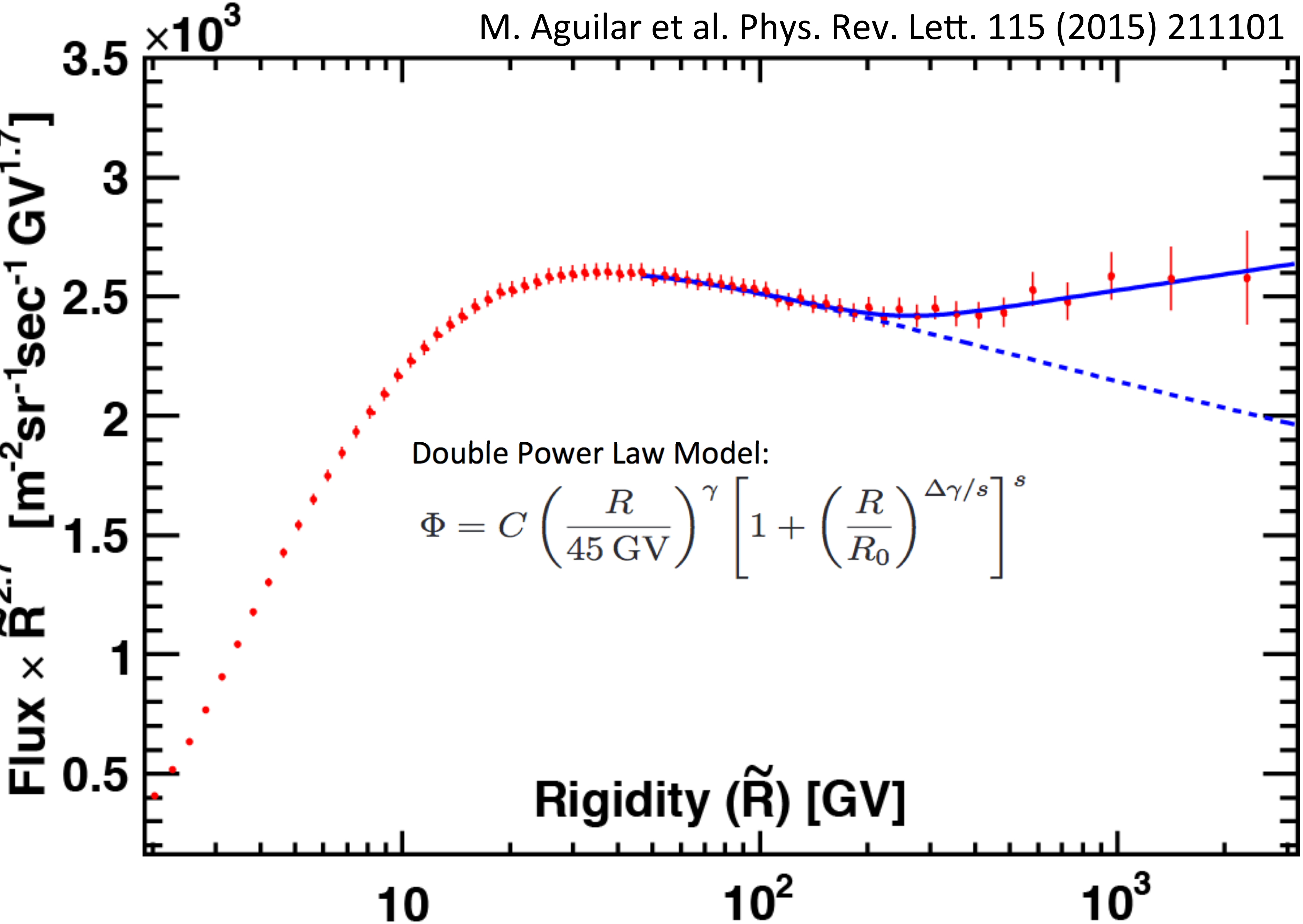
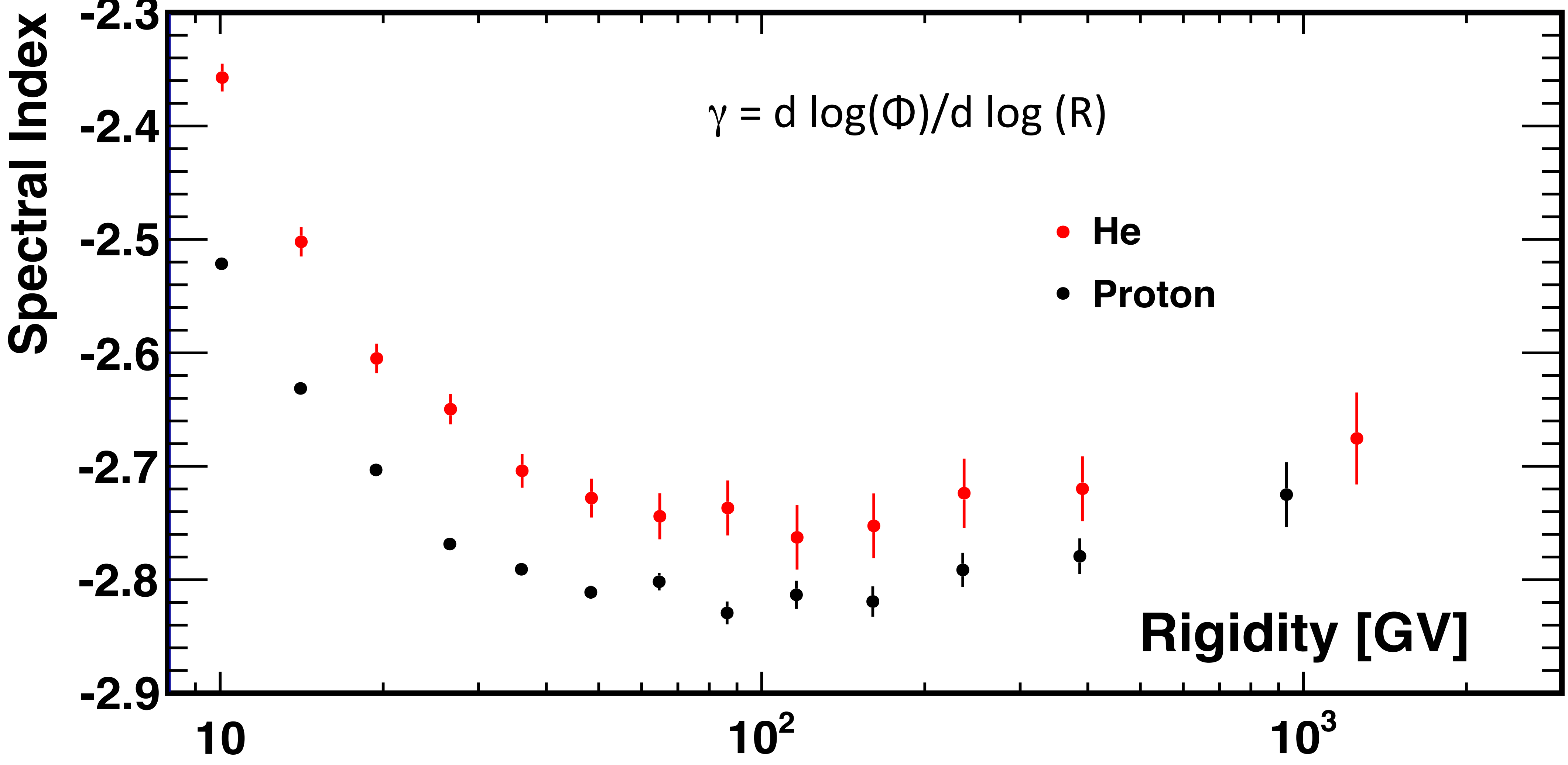
M. Aguilar et al. Phys. Rev. Lett. 115 (2015) 211101



$$\Phi = C\left(\frac{R}{45\,\mathrm{GV}}\right)^{\gamma}\left[1+\left(\frac{R}{R_0}\right)^{\Delta\gamma/s}\right]^{s}$$

AMS Proton and Helium **Spectral Index**

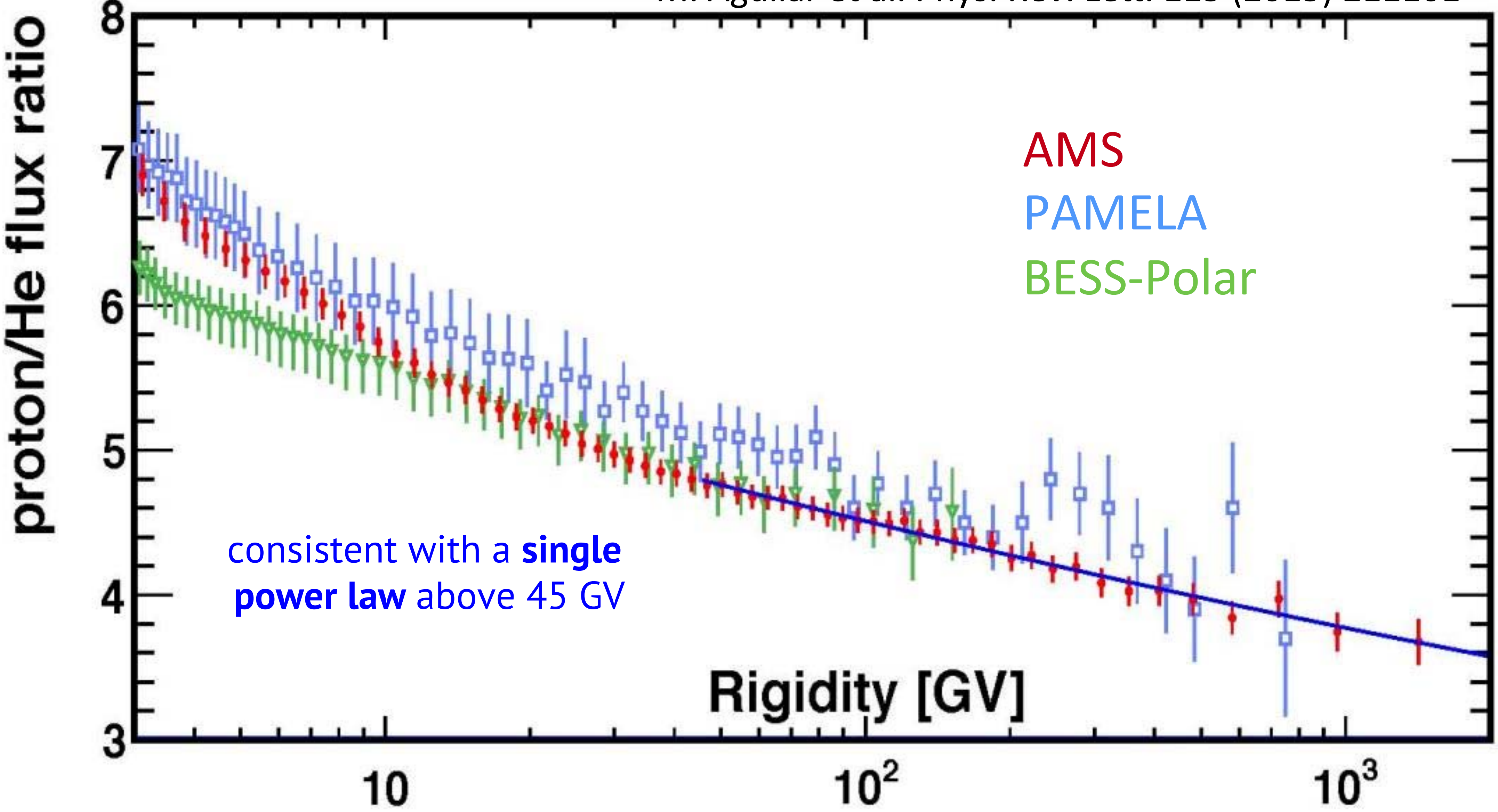
M. Aguilar et al. Phys. Rev. Lett. 115 (2015) 211101



Different magnitude, similar behavior.

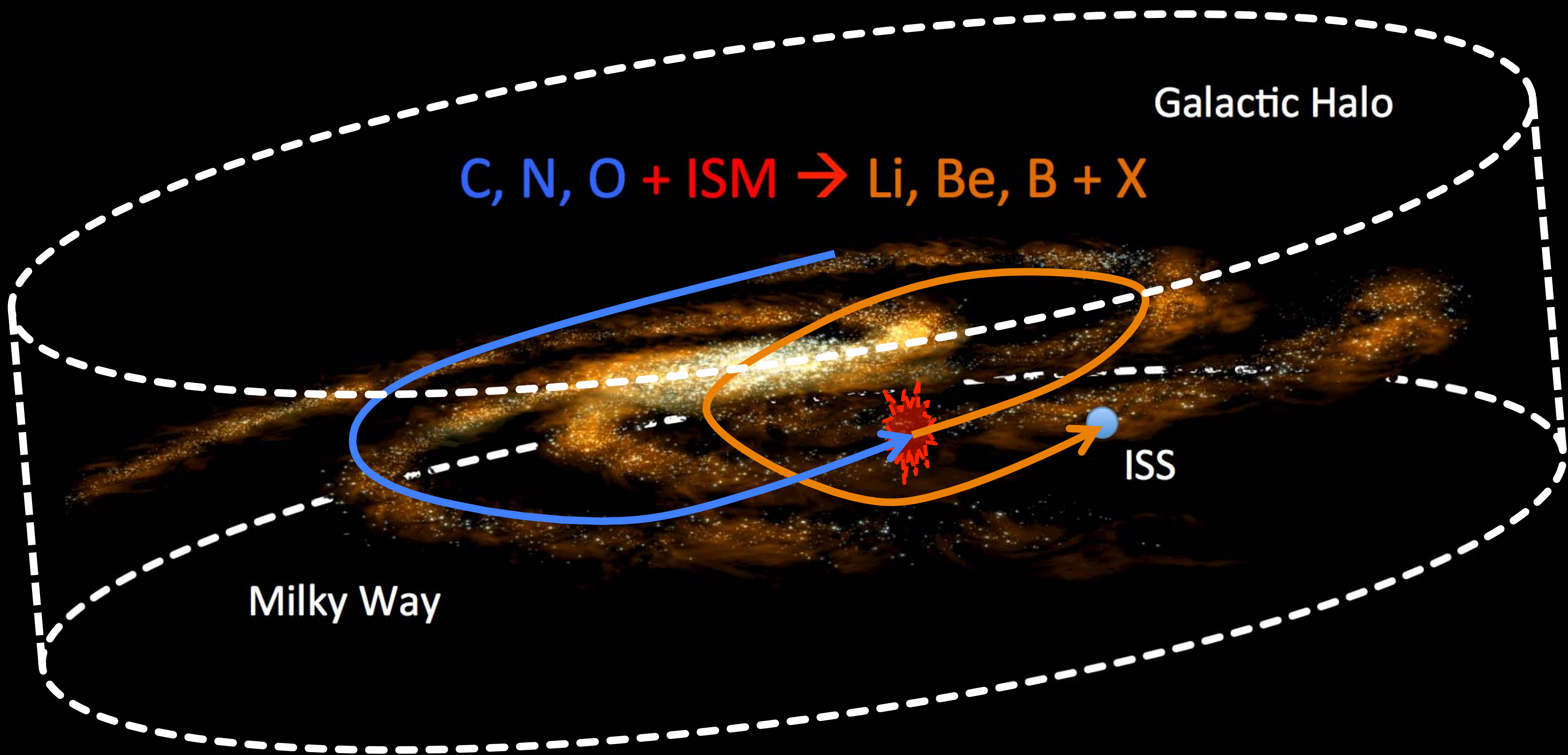
AMS p/He Flux Ratio Behaviour

M. Aguilar et al. Phys. Rev. Lett. 115 (2015) 211101

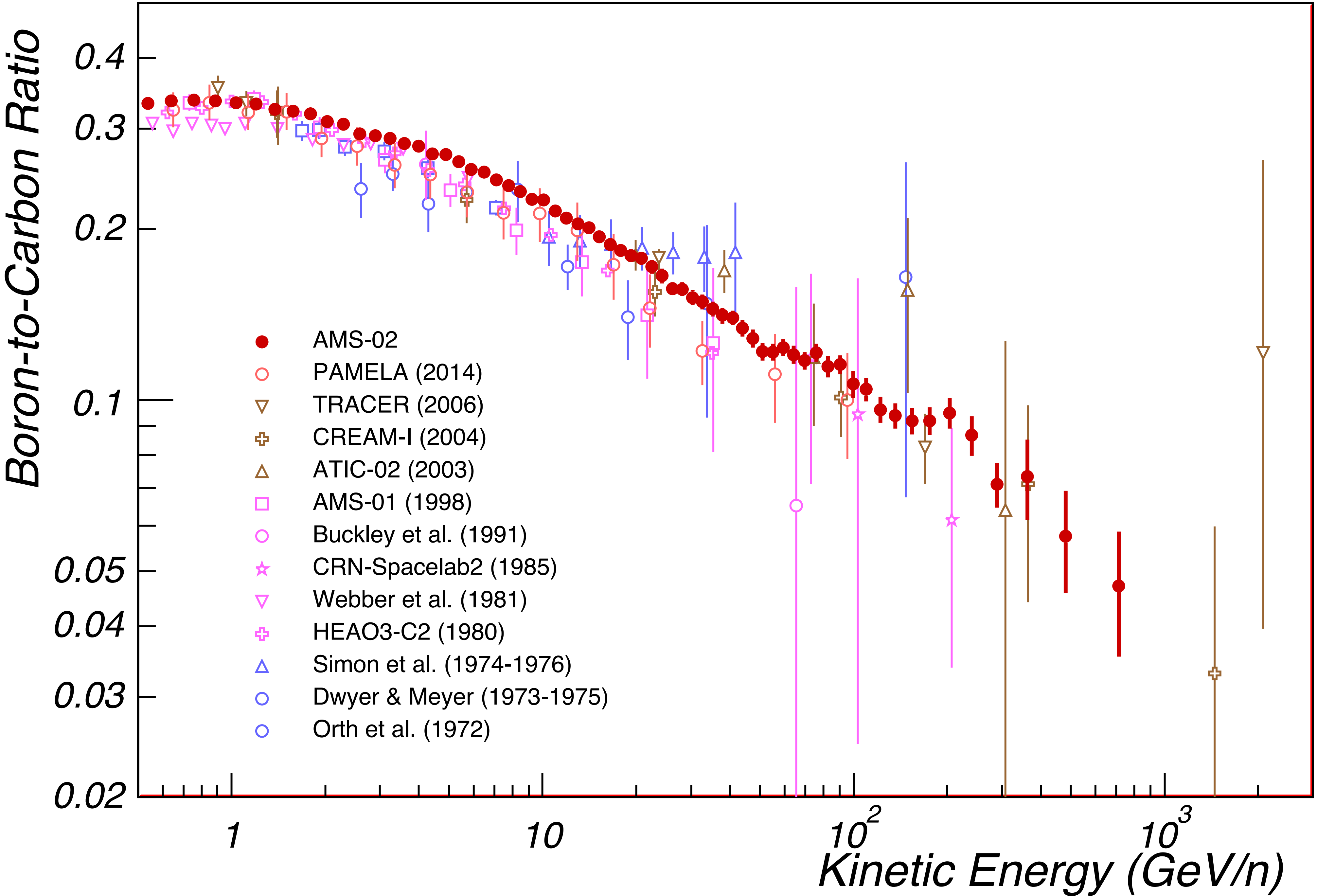


Search for Origin of Dark Matter: Background (II)

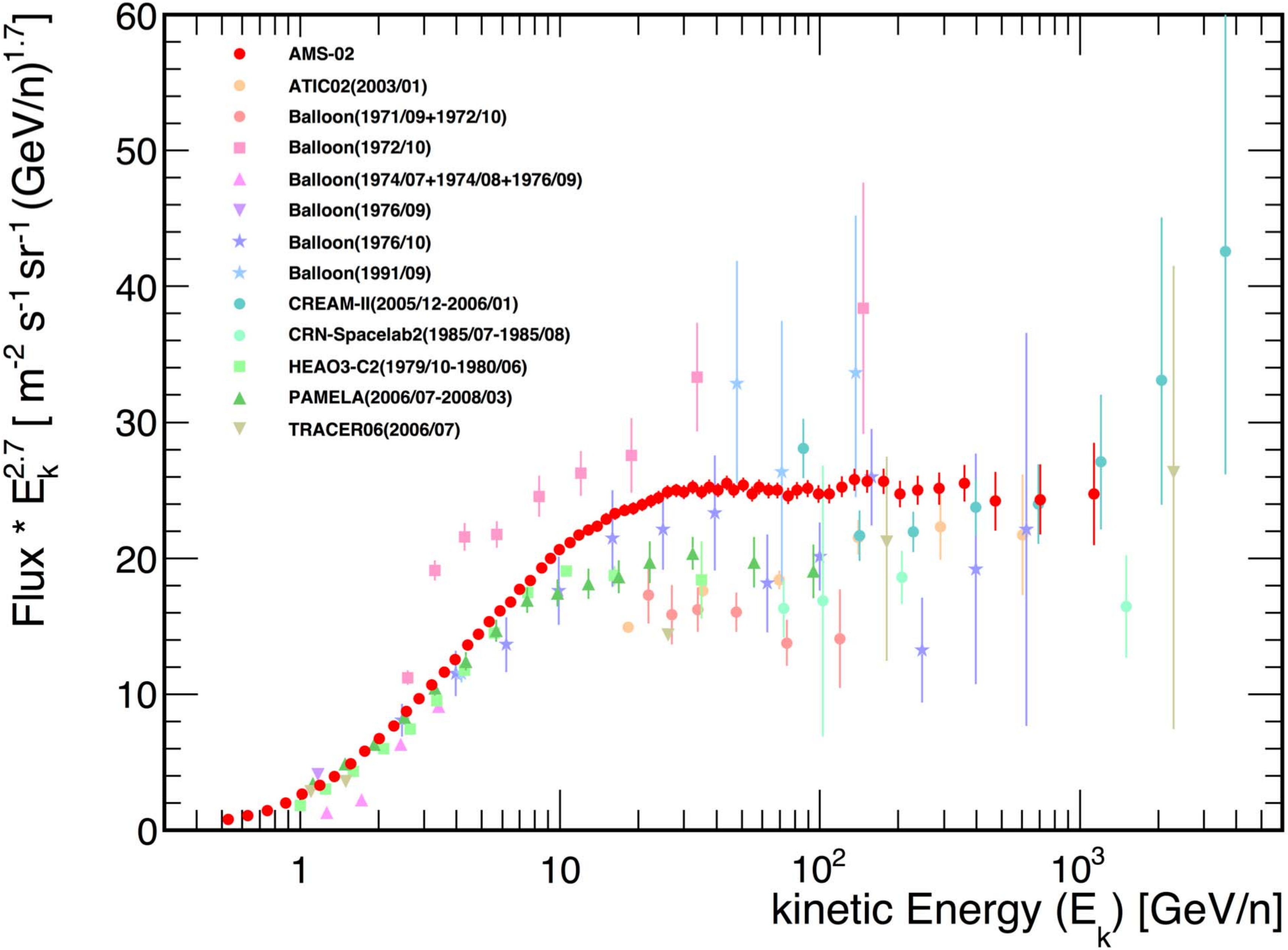
Precise measurement of the rigidity spectra of CRs produced by the spallation of heavier nuclei during their propagation provides information on the **CRs propagation** in the Milky Way.



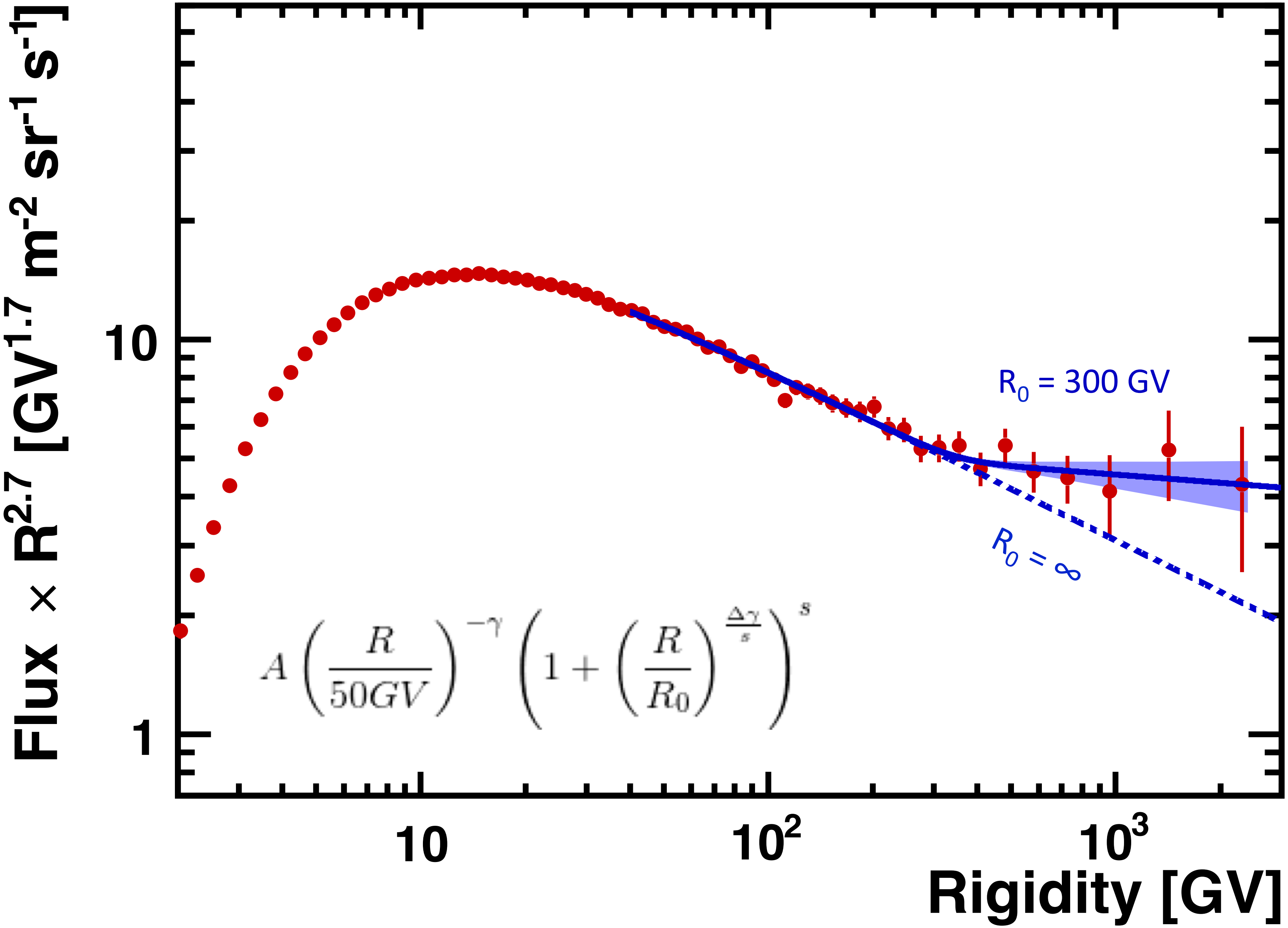
Boron/Carbon: Next Publication



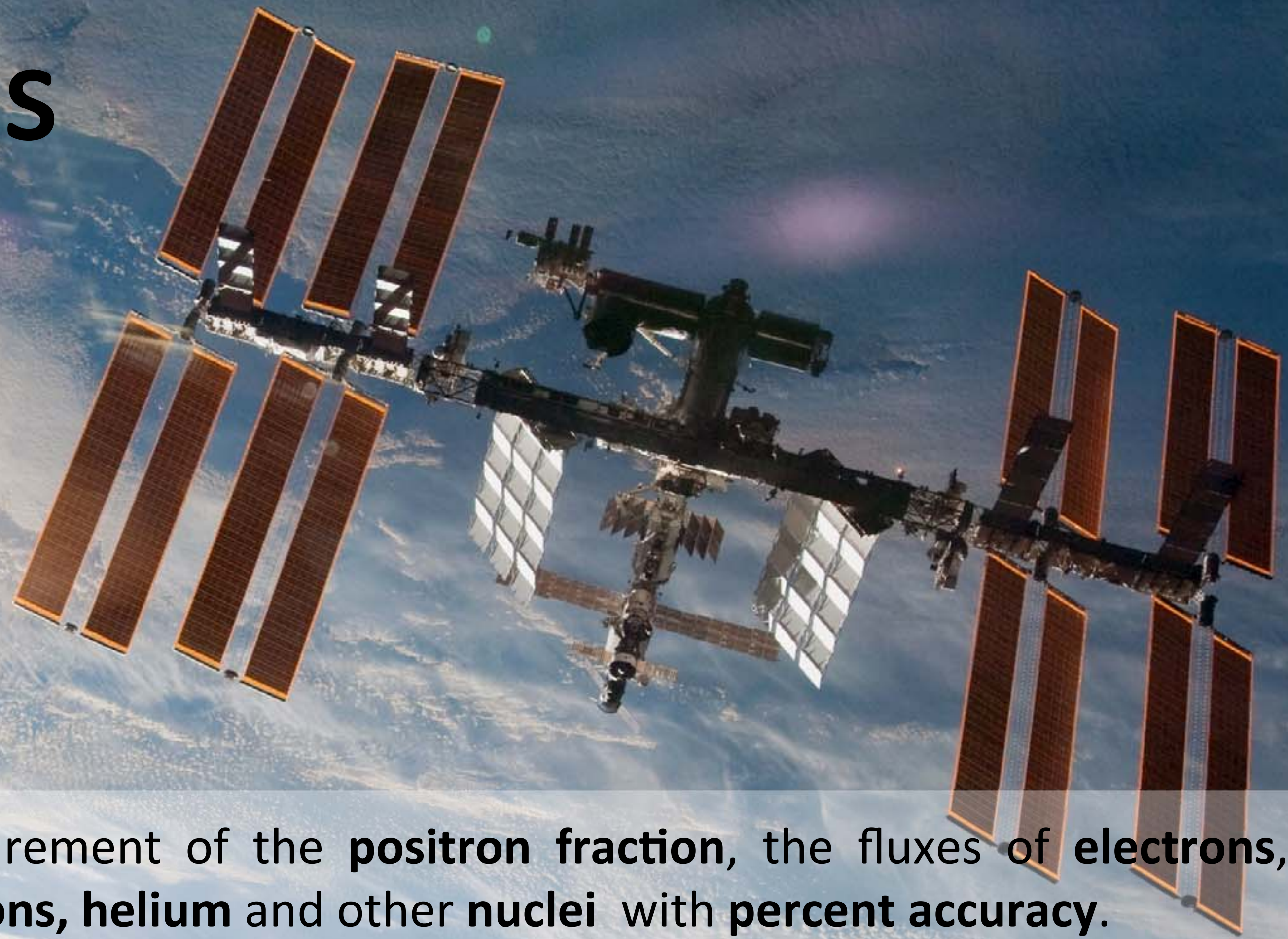
AMS Carbon Flux (Current Status)



AMS Lithium Flux (Current Status)



Conclusions



AMS is providing CRs measurement of the **positron fraction**, the fluxes of **electrons**, **positrons**, **protons, anti-protons, helium** and other **nuclei** with **percent accuracy**.

The **simultaneous** precise determination of different CRs species is a powerful tool for the understanding of the **CRs physics** and for the determination of **new phenomena**.

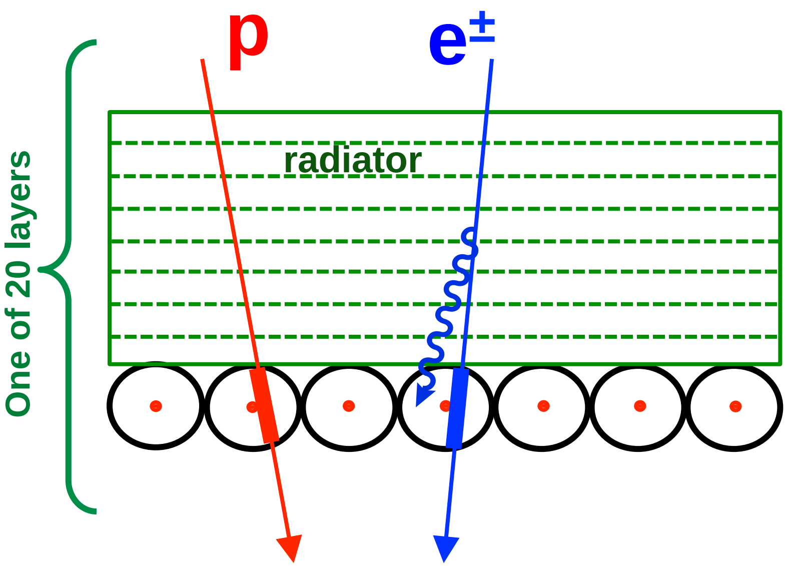
AMS will continue to take data for all the **ISS lifetime**, providing new information about **dark matter**, presence of primordial **anti-matter** and more detailed **CRs fluxes** description.

The **ISS** has become an important platform for **fundamental physics research**.

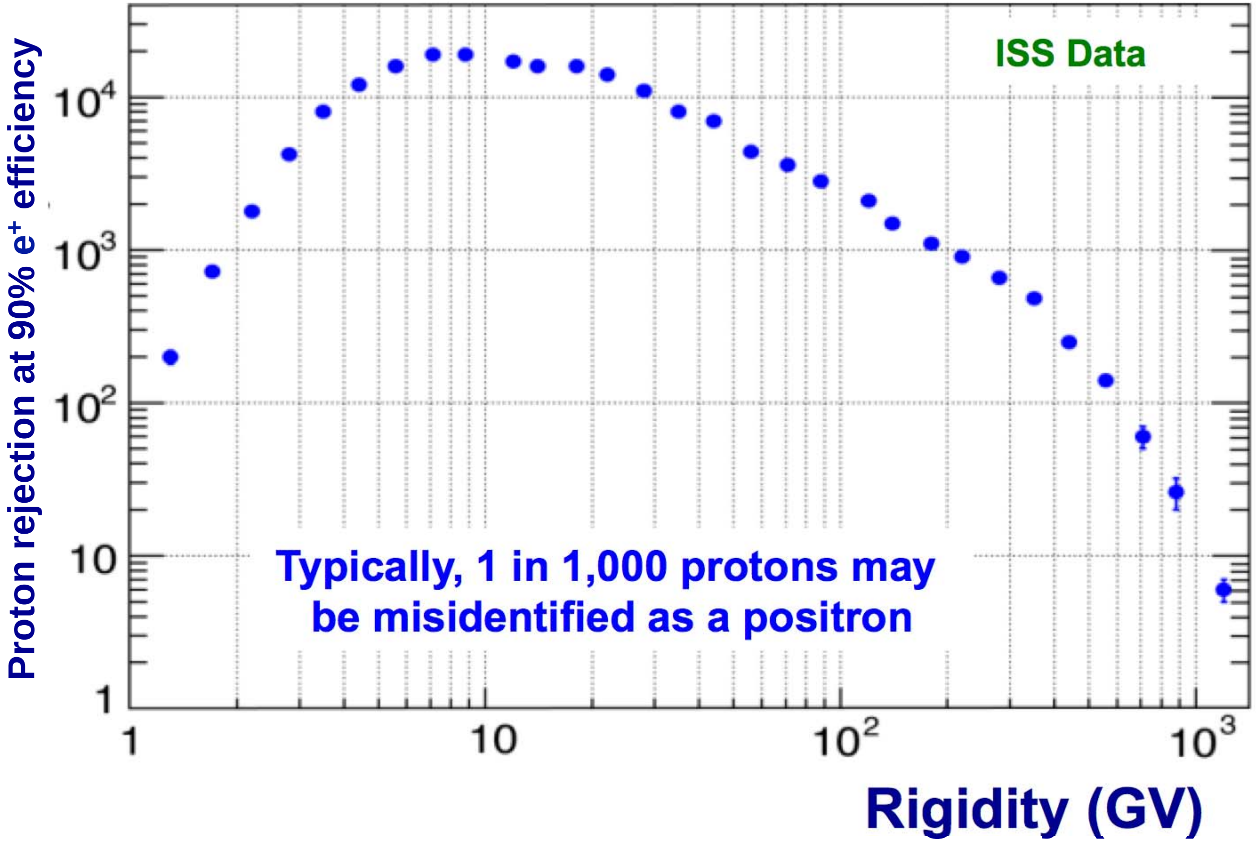
Backup

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

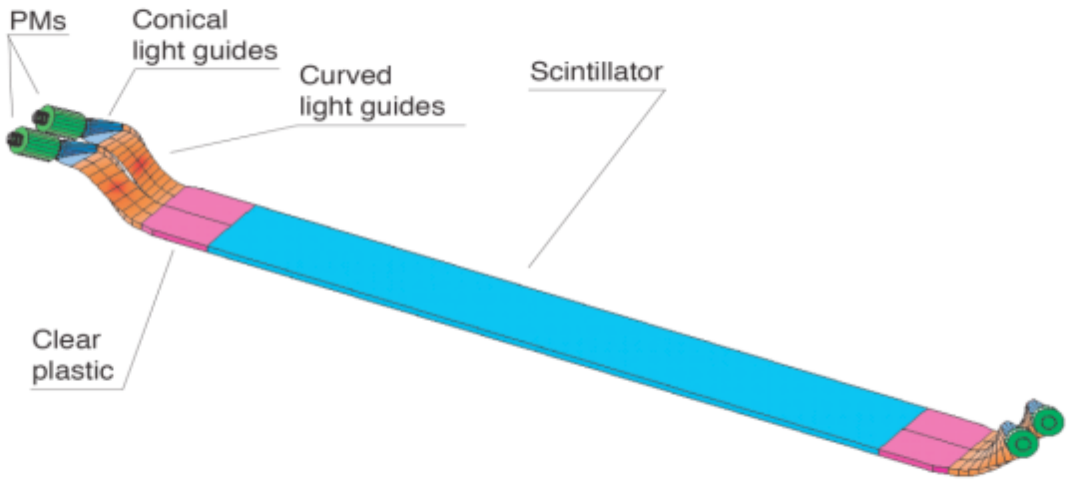
TRD likelihood = $-\text{Log}_{10}(P_e)$

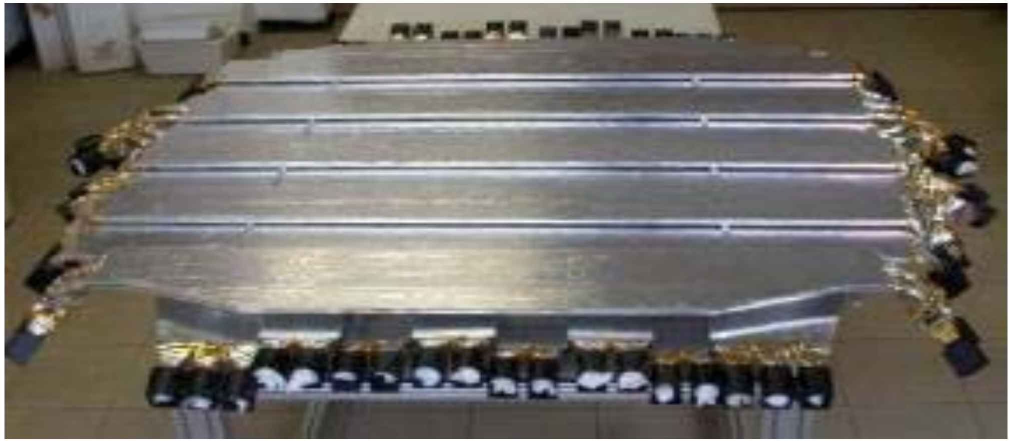
TRD classifier = $-\text{Log}_{10}(P_e)-2$

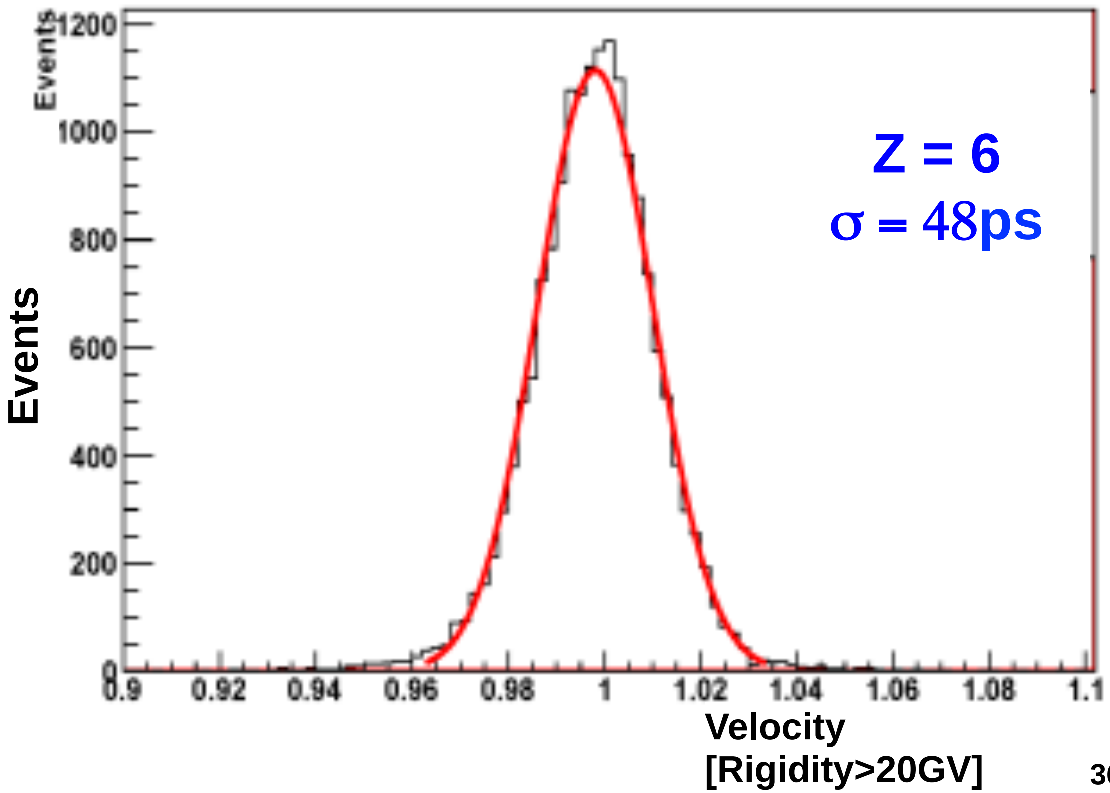
K. Luebelsmeyer, S. Schael

Time of Flight System

Measures Velocity and Charge of particles

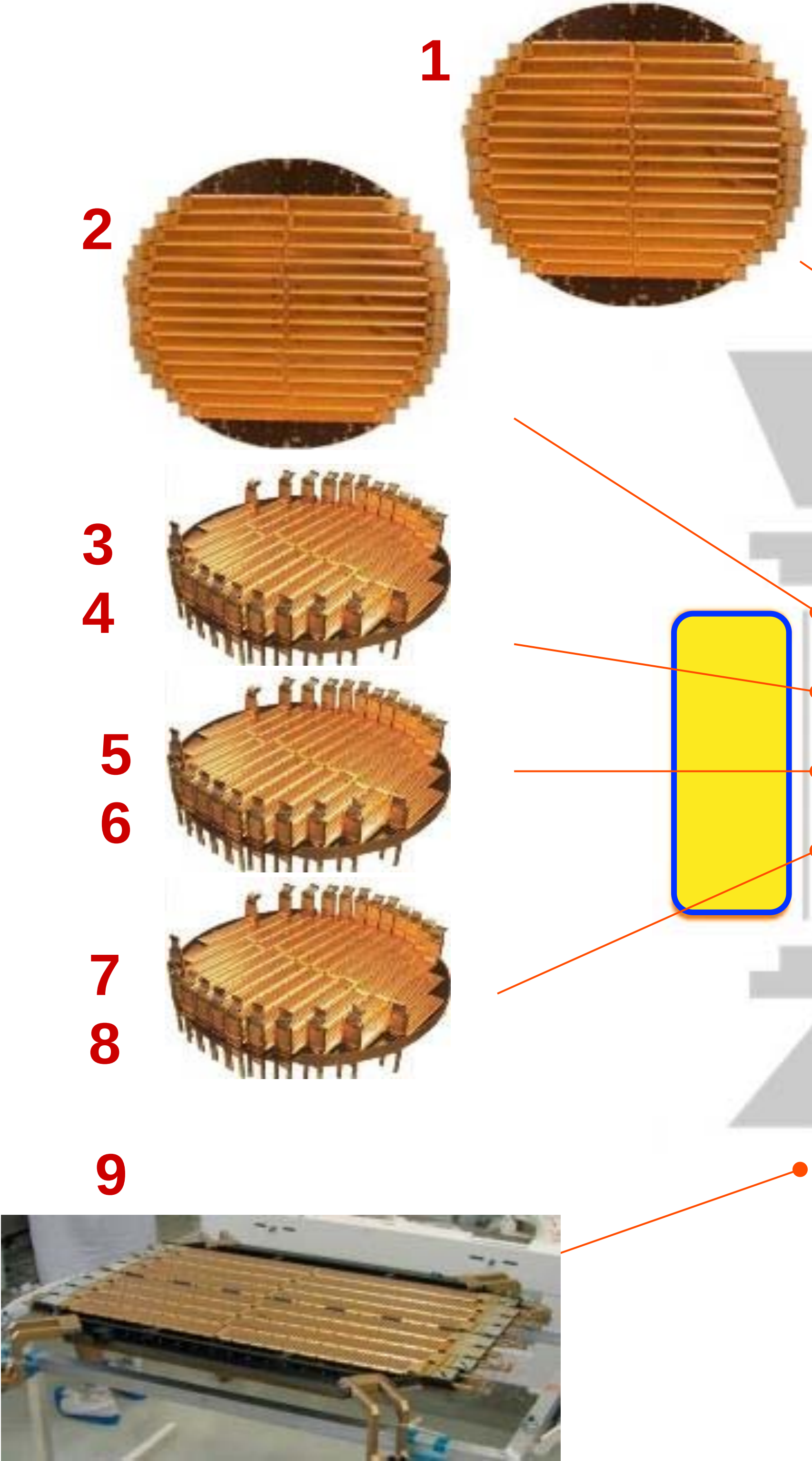


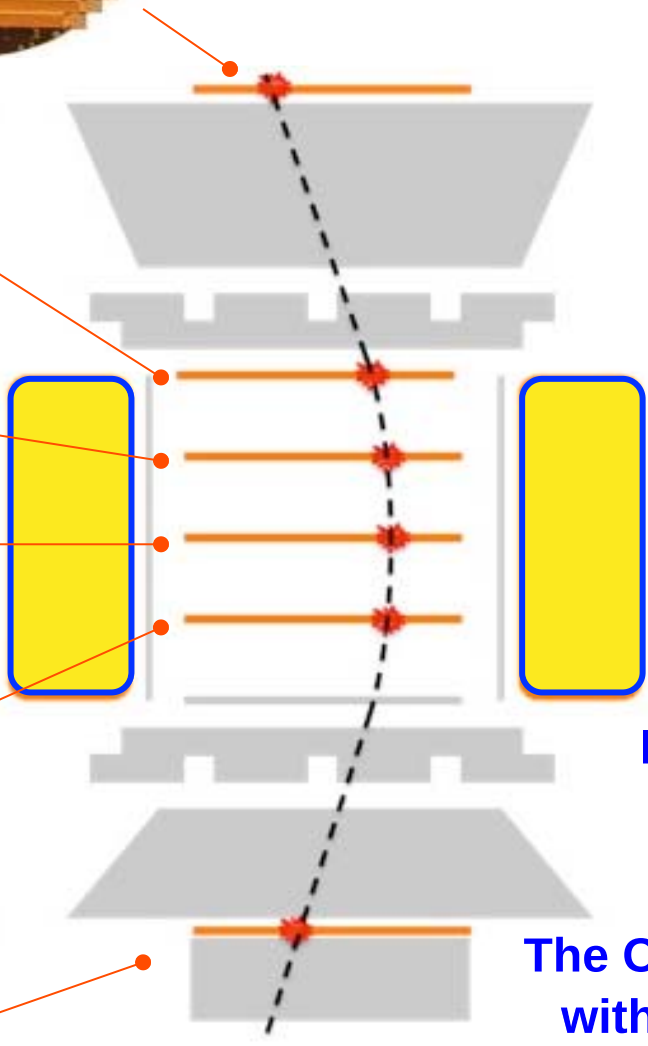




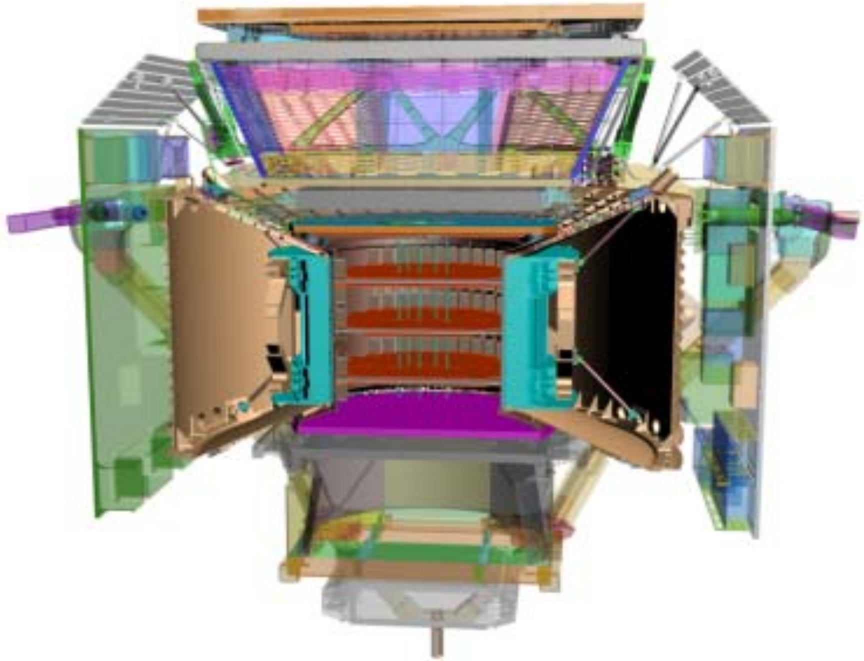
A. Contin, G. Laurenti, F. Palmonari

Tracker





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



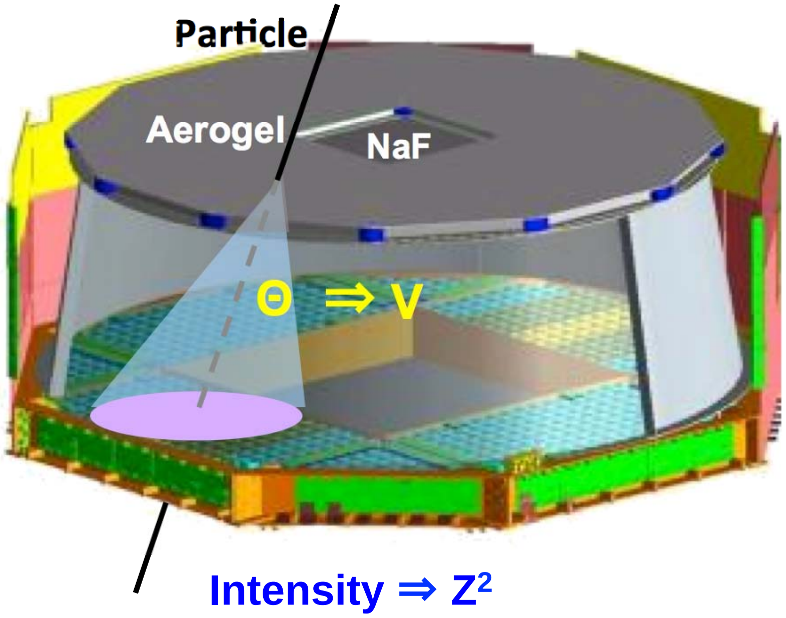
Inner tracker alignment stability monitored with IR Lasers.

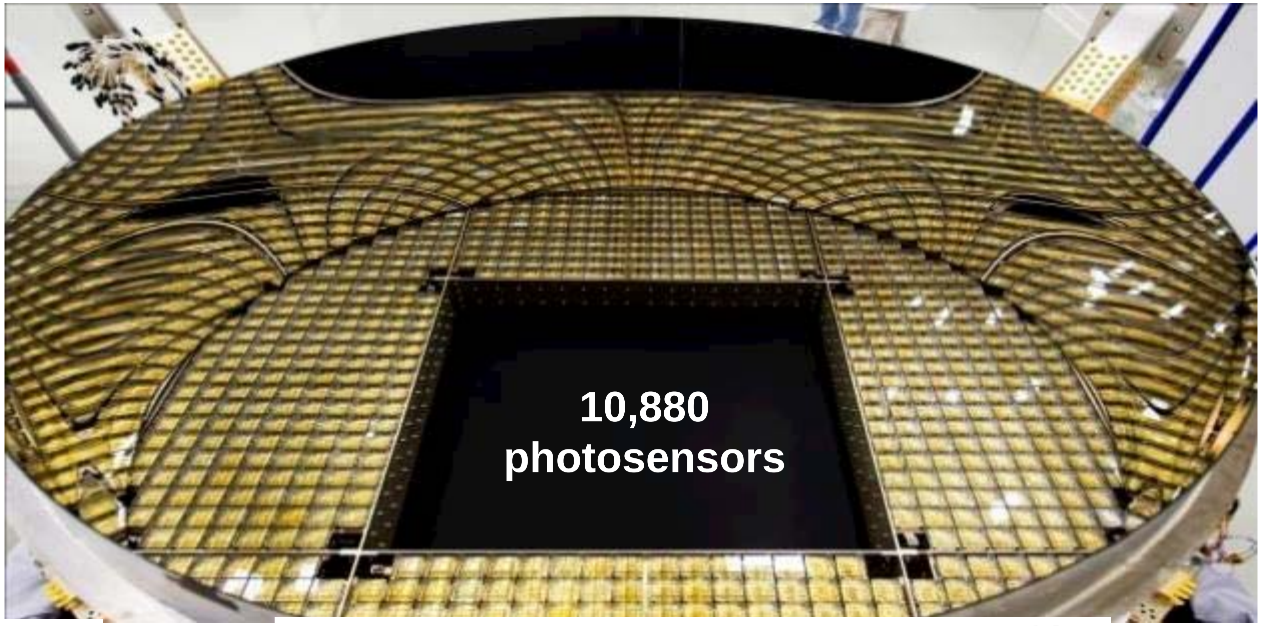
The Outer Tracker is continuously aligned with cosmic rays in a 2 minute window

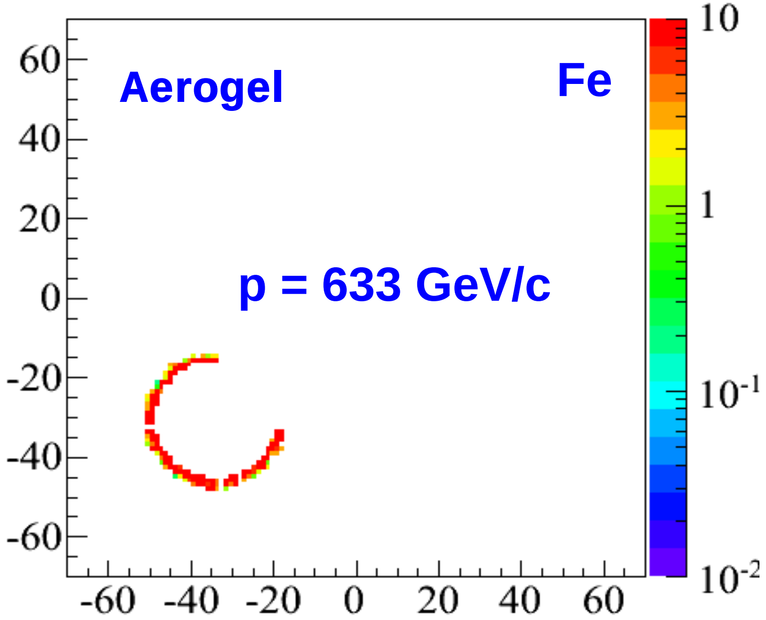
R. Battiston, G. Ambrosi, B. Bertucci

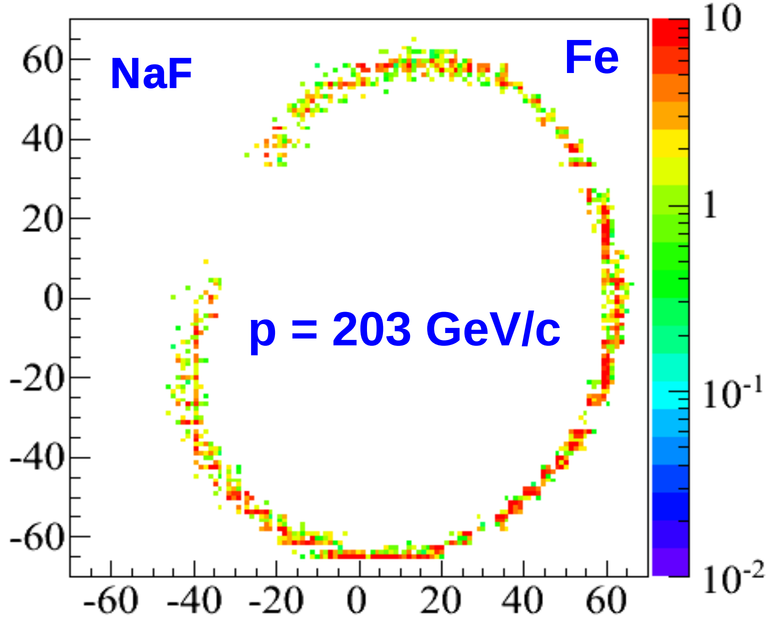
Ring Imaging CHerenkov (RICH)

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





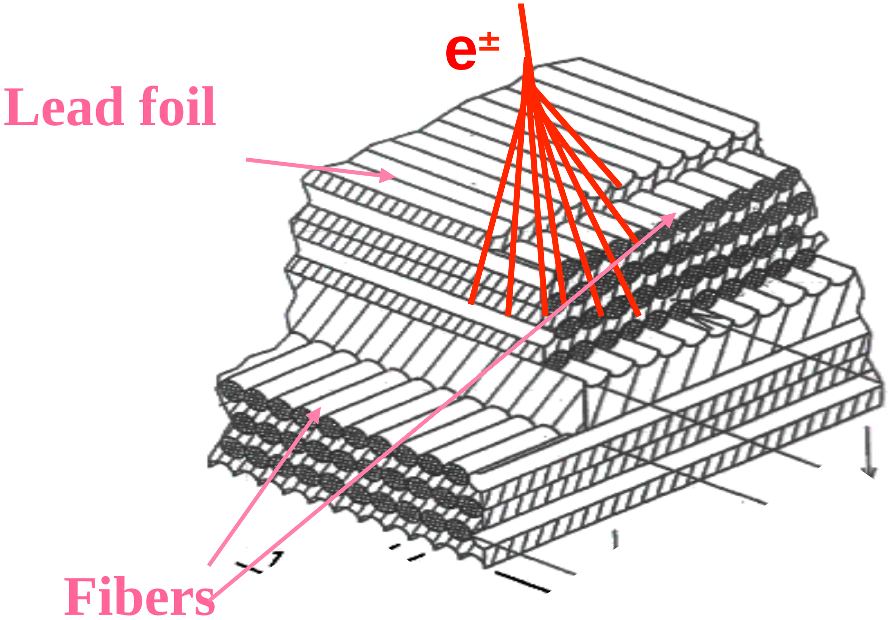


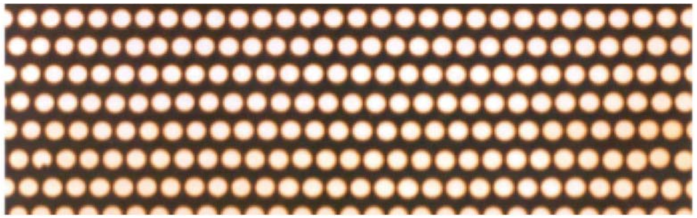


J. Berdugo, G. Laurenti

Electromagnetic Calorimeter

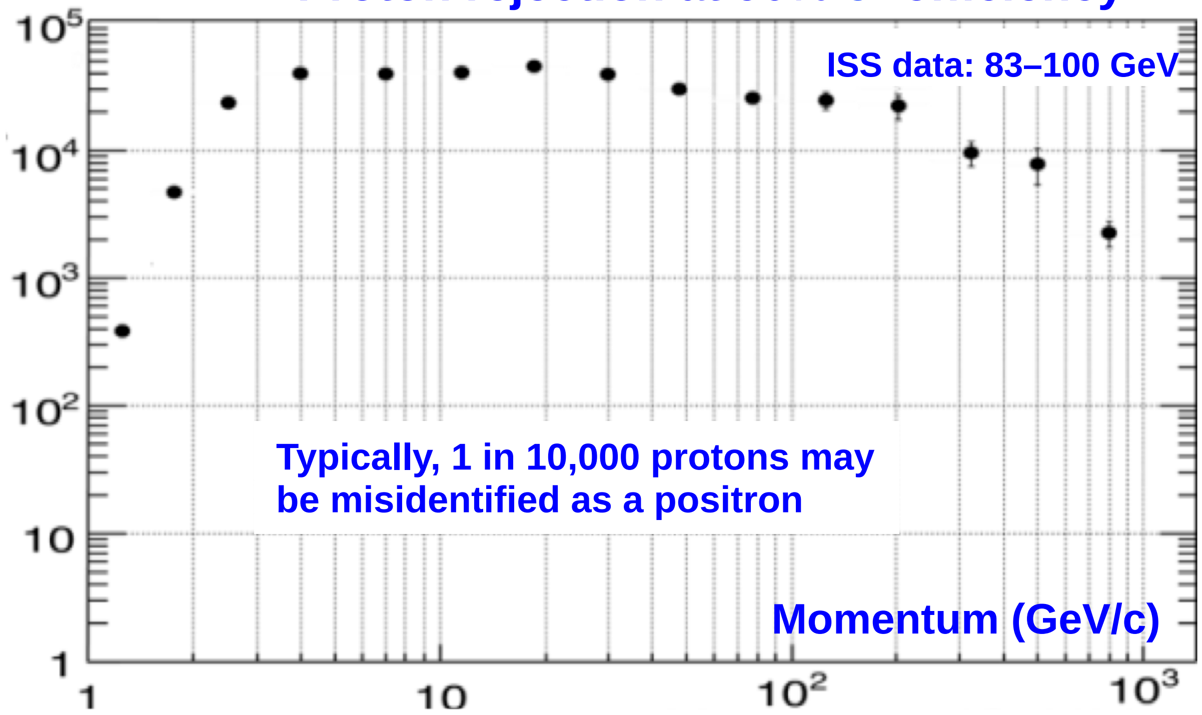
provides a precision, 17 X_0, TeV, 3-dimensional measurement of the directions and energies of electrons and positrons





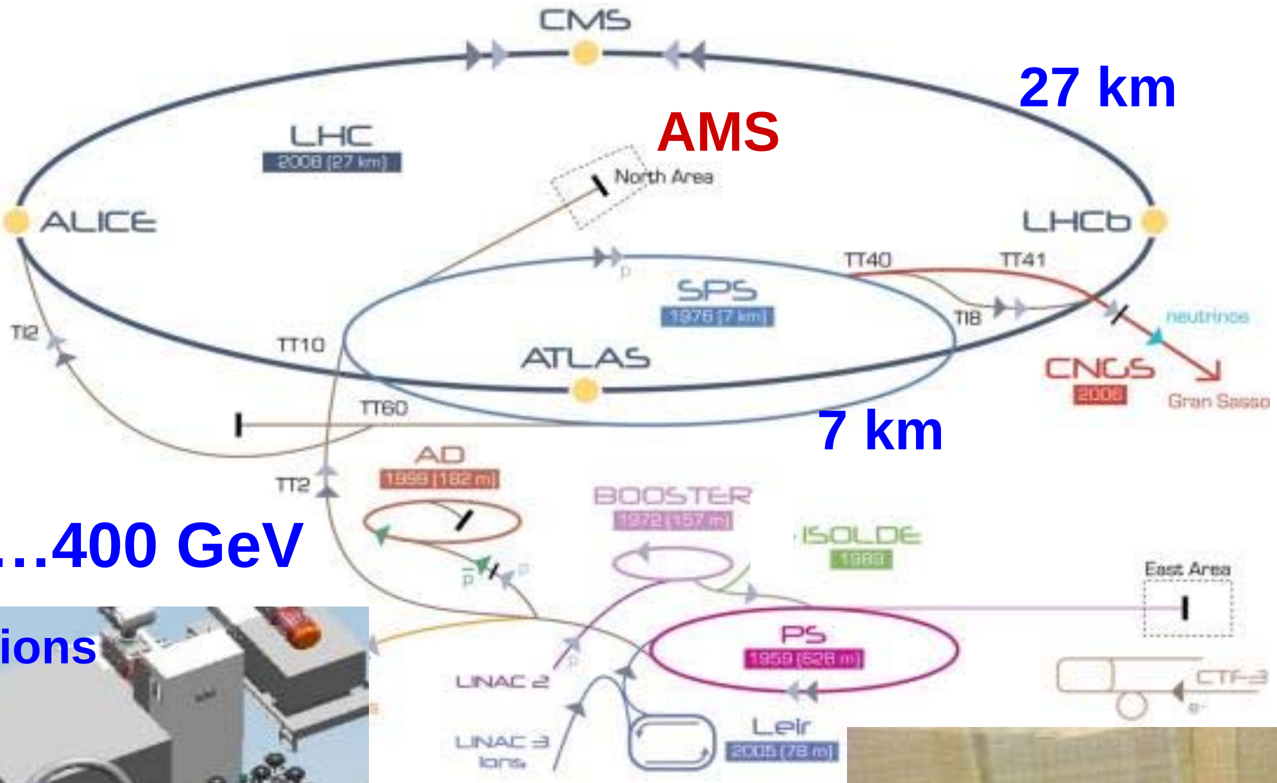
50 000 fibers, $\phi = 1$ mm distributed uniformly inside 600 Kg of lead

Proton rejection at 90% e^+ efficiency

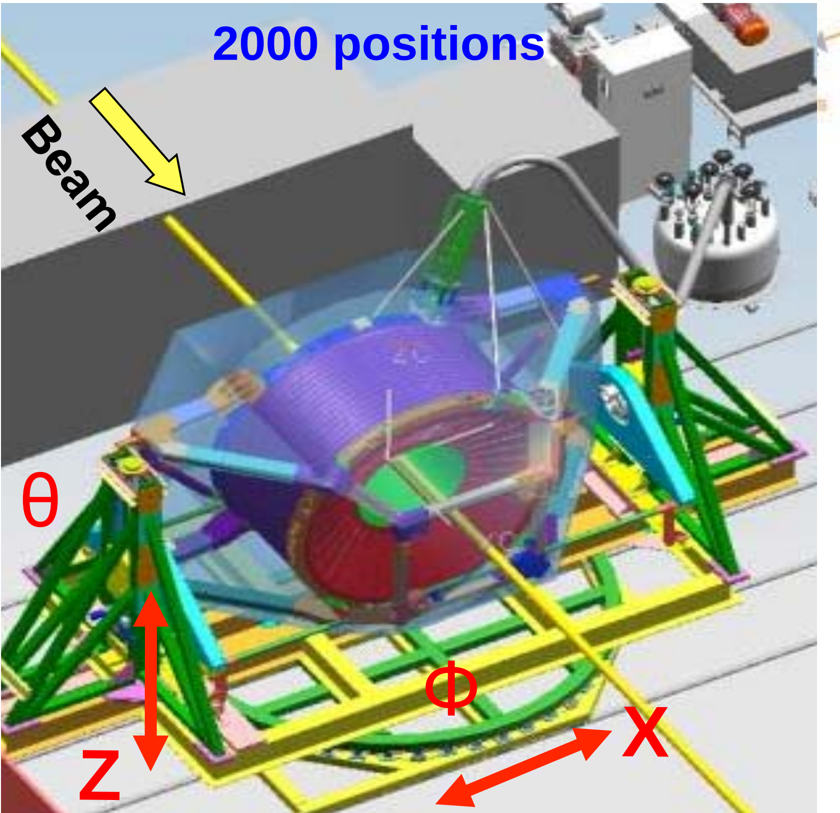


F. Cervelli, S. Rosier-Lees, H.S. Chen

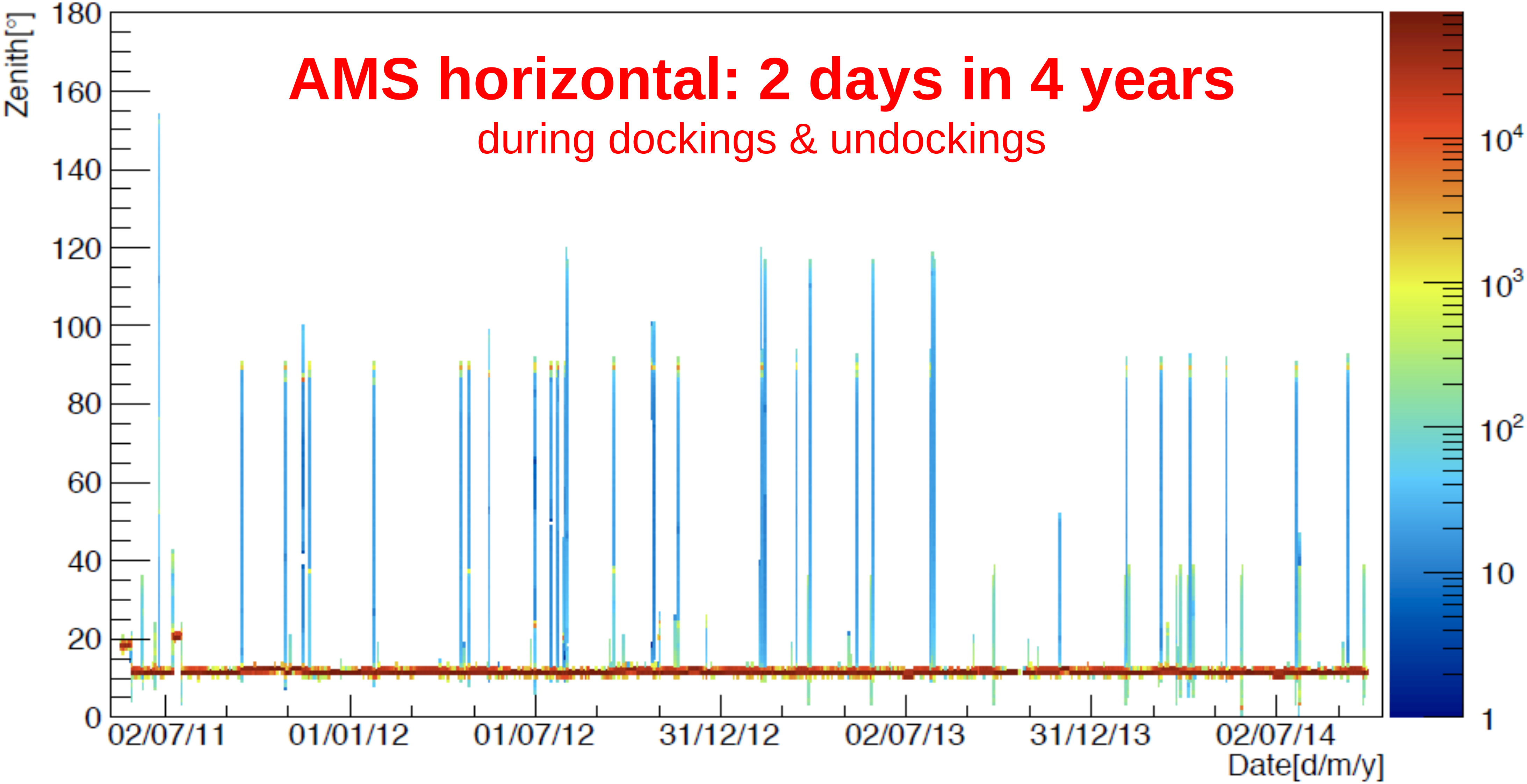
Extensive tests and calibration at CERN



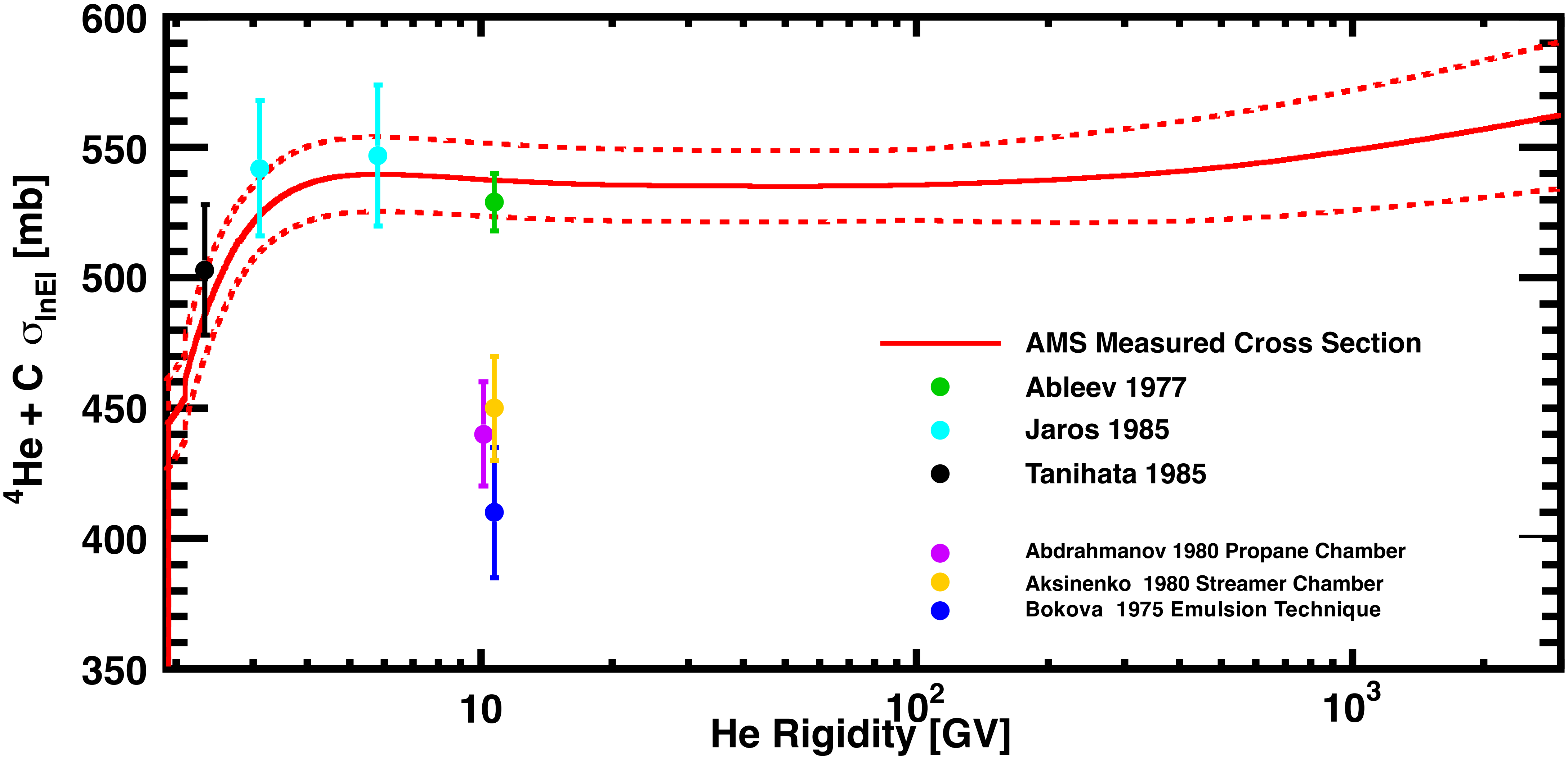
p, e^+, e^-, π 20…400 GeV



Measuring the interactions of nuclei within AMS requires horizontal particles, which are detected when the ISS flies with AMS horizontal



AMS Measurement of He+C Cross Section

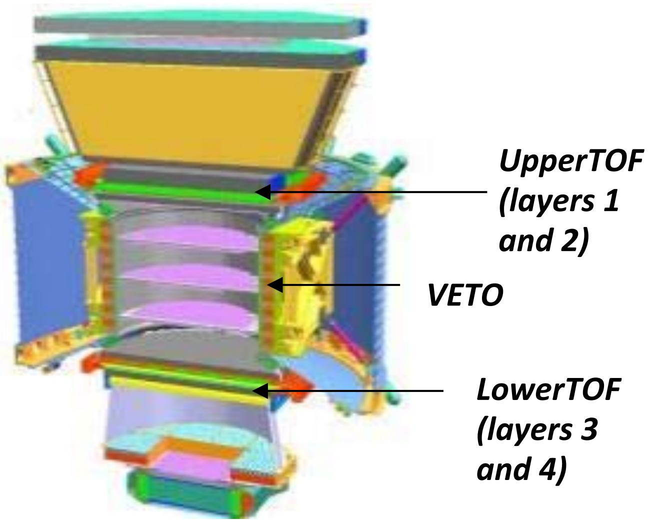


Trigger Efficiency

Trigger efficiency [4/4 TOF (+ VETO)] was measured using 1% prescaled event sample obtained with unbiased 3 out of 4 ToF coincidence trigger:

ε_T= 90-95% for protons, 95-99% for helium

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

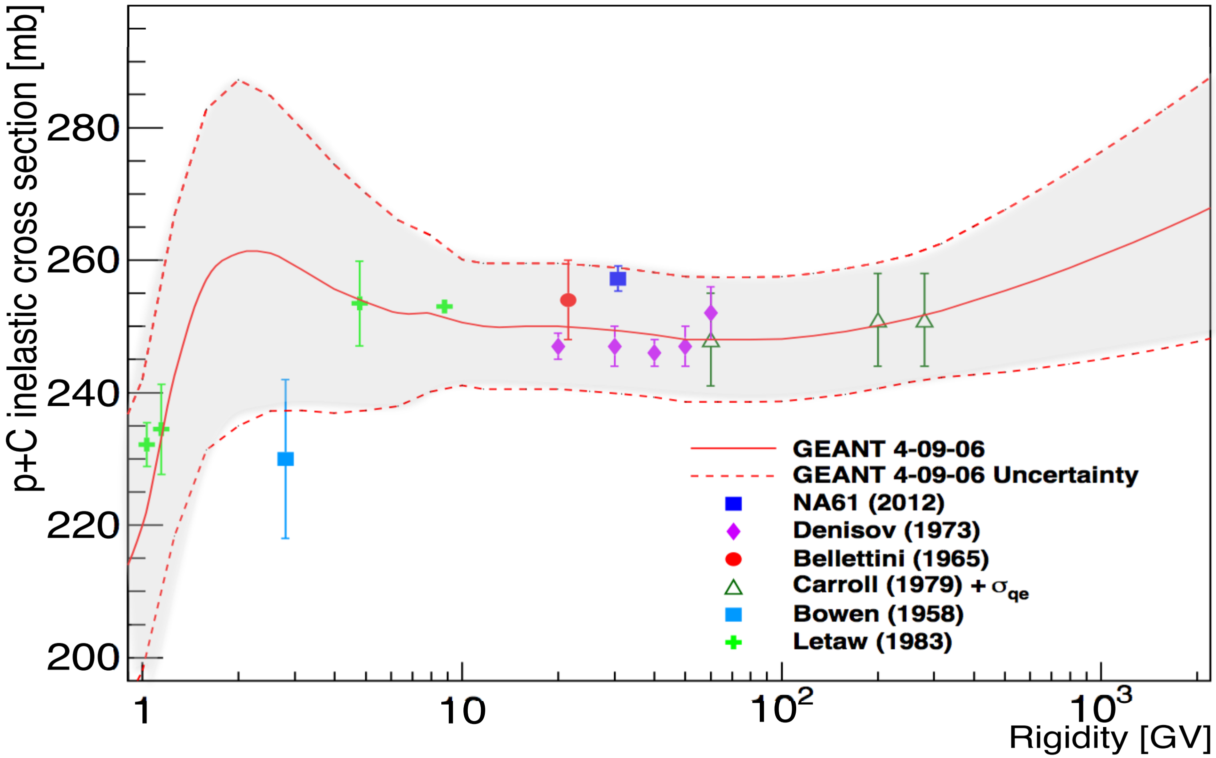


This systematic error is negligible (less than 0.1%) below 100GV and increasing ~1.5% at highest rigidities

Proton Acceptance

The detector is mostly made of C(73% by weight) and Al(17 %). The inelastic cross sections of p + C and p + Al are known to few percent between 1 GV and 1.8 TV.

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



Using MC samples with cross sections scaled by ±10%, we found that the errors on the proton flux due to uncertainty in inelastic cross sections are:

1% [1GV]

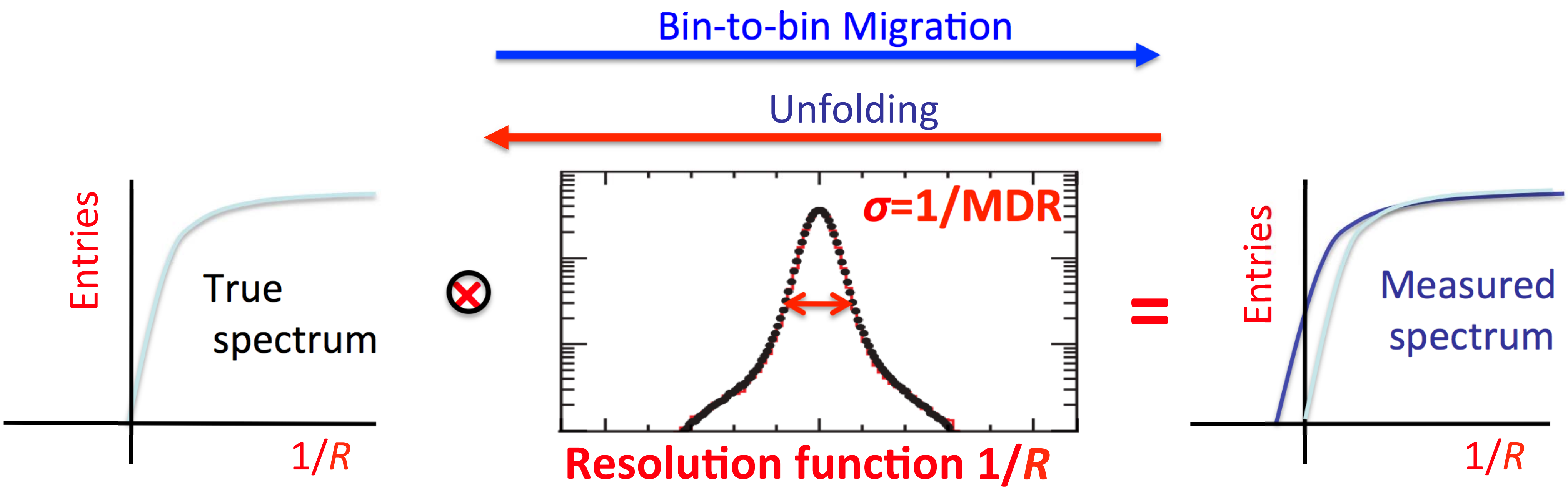
0.6% [10-300 GV]

0.8% [1.8 TV]

Unfolding

Correction of bin-to-bin migration is needed due to the finite tracker resolution

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

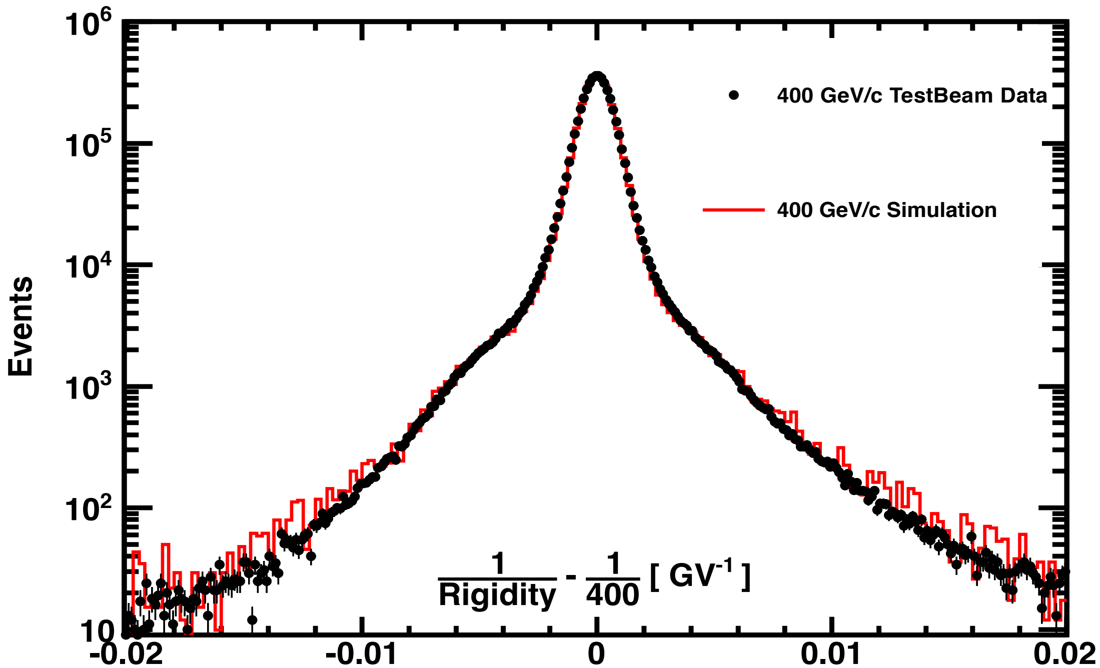


Difference between different unfolding algorithms gives a systematic error ~0.5%

Tracker resolution

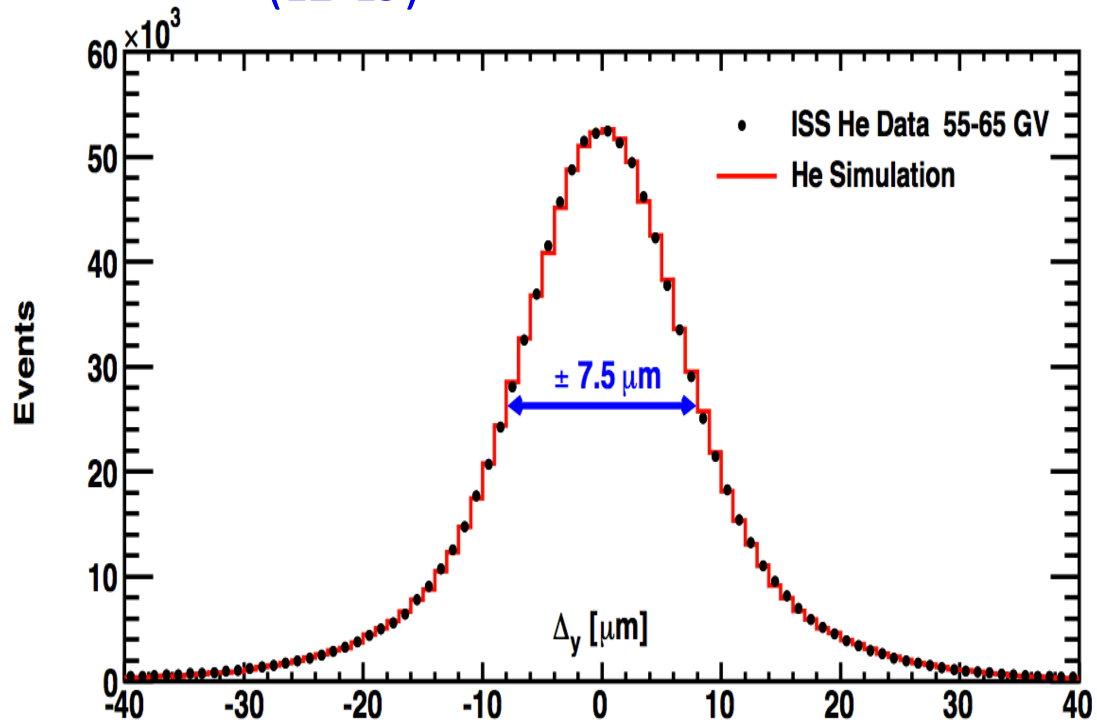
Protons

- Resolution function from MC simulation
- Verified with:
  - 400 GeV/c Test Beams data
  - ISS data: tracker residuals, rigidity reconstruction (L1-L8) vs. (L2-L9)



Helium

- Resolution function from MC simulation
- Verified with ISS data:
  - Tracker residuals
  - Rigidity reconstruction (L1-L8) vs. (L2-L9)

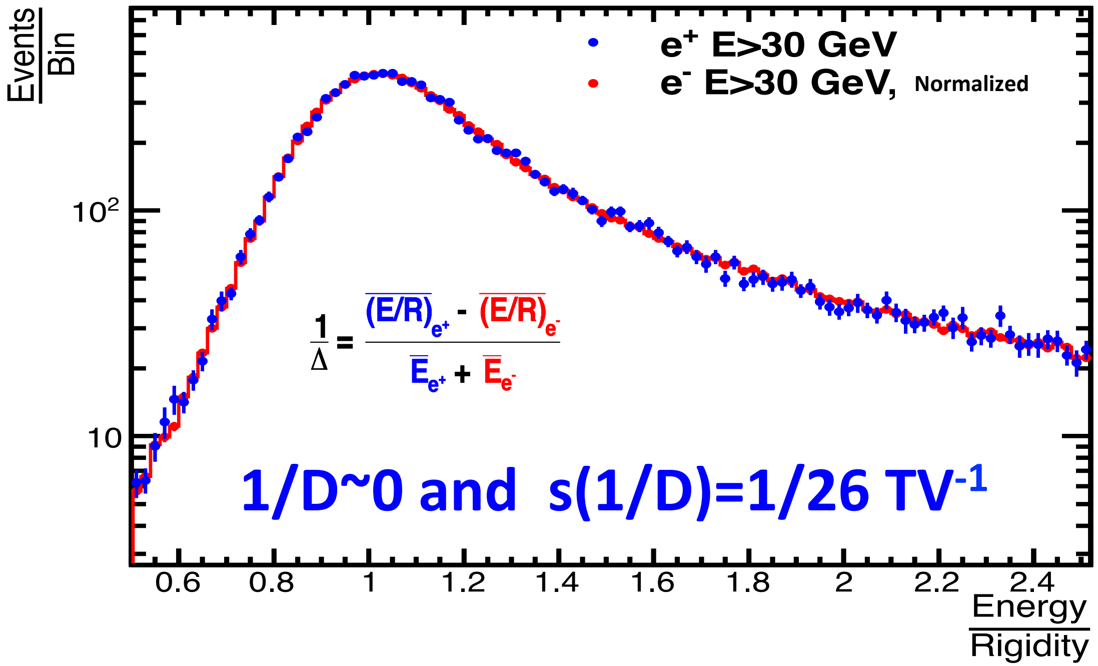


Uncertainty on the flux < 1% below 300 GV rising to 3% at 2 TV

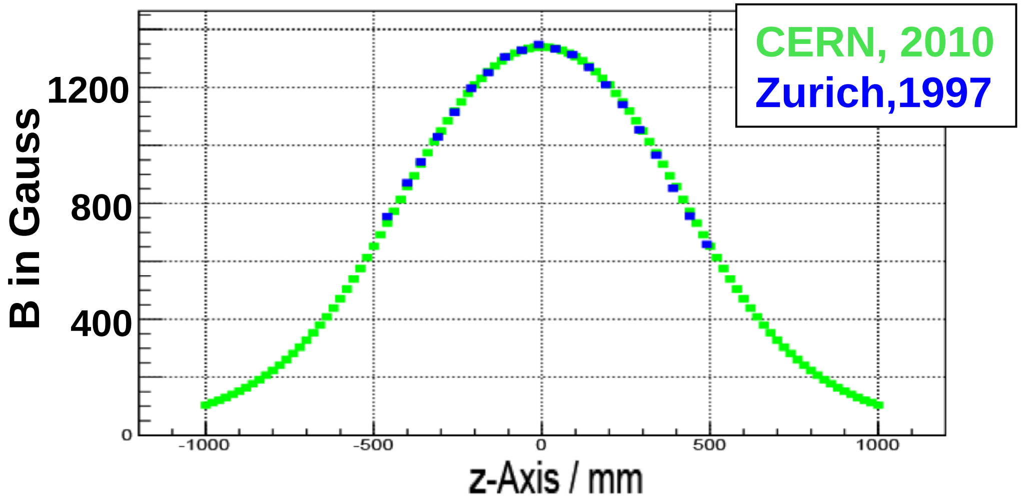
Rigidity Scale

Two contributions to the uncertainty:

Residual tracker misalignment:
checked with $E_{ECAL}/R_{Tracker}$ ratio for electrons and positrons, limited by the current high energy positron statistics.
The corresponding flux error is 2.5% @1 TV.

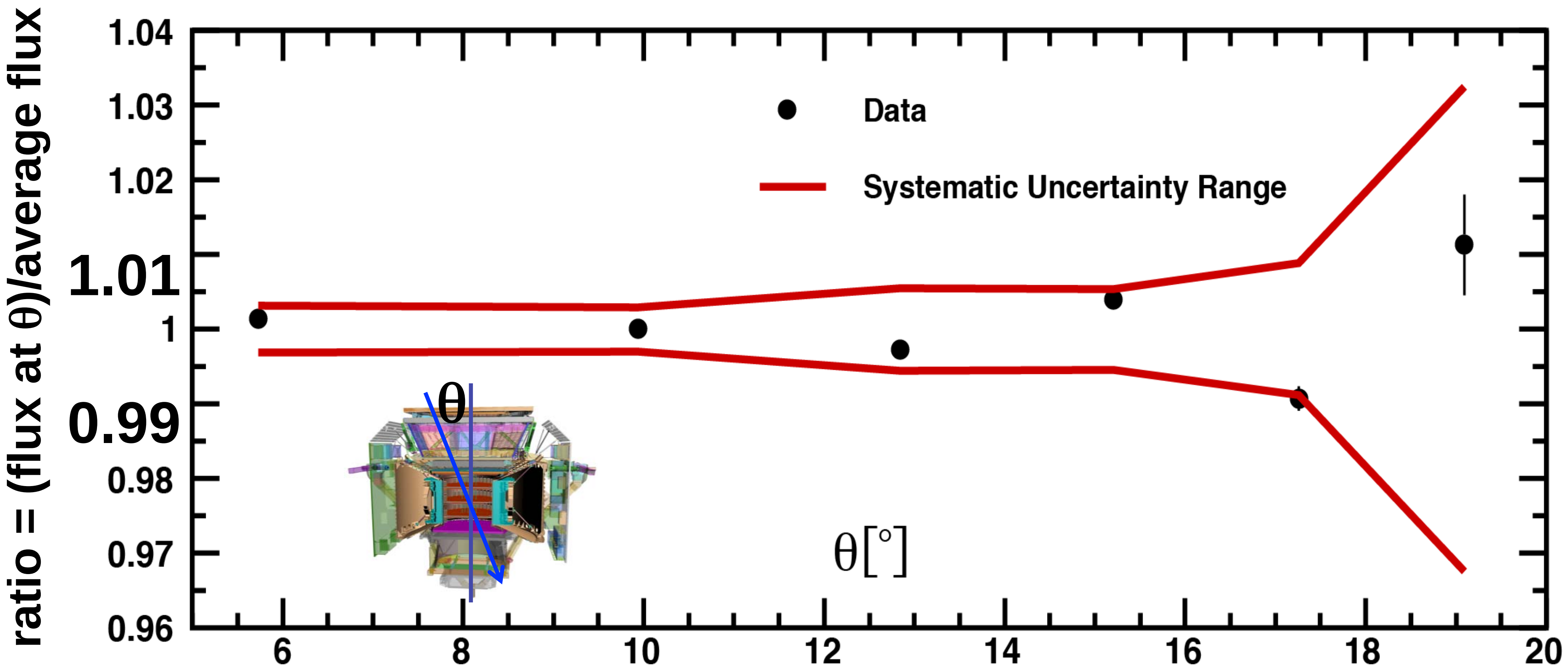


Magnetic field:
mapping measurement (0.25%) and temperature corrections (0.1%). Taken in quadrature and weighted by the measured flux rigidity dependence.
This amounts to less than 0.5% systematic error on the flux.



Verification (I)

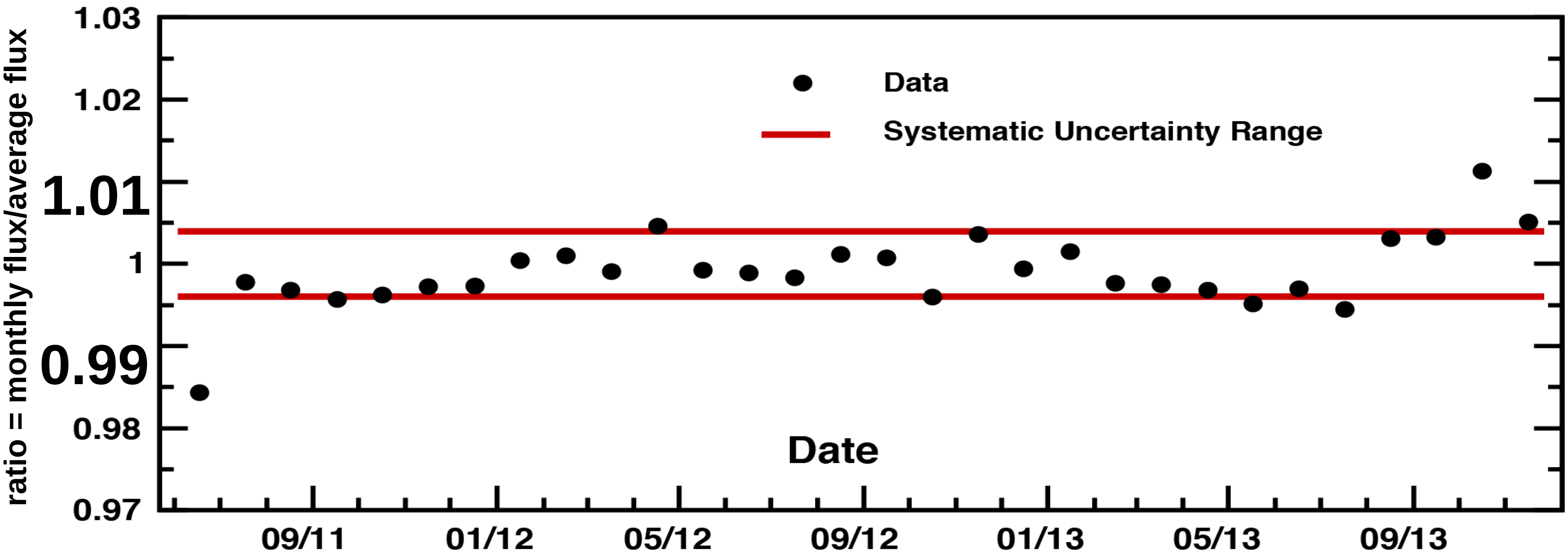
Study the dependence of the integral of the proton flux above 30 GV
on the angle Θ between the incoming proton direction and the AMS zenith axis.



This verifies the systematic error assigned to the acceptance.

Verification (II)

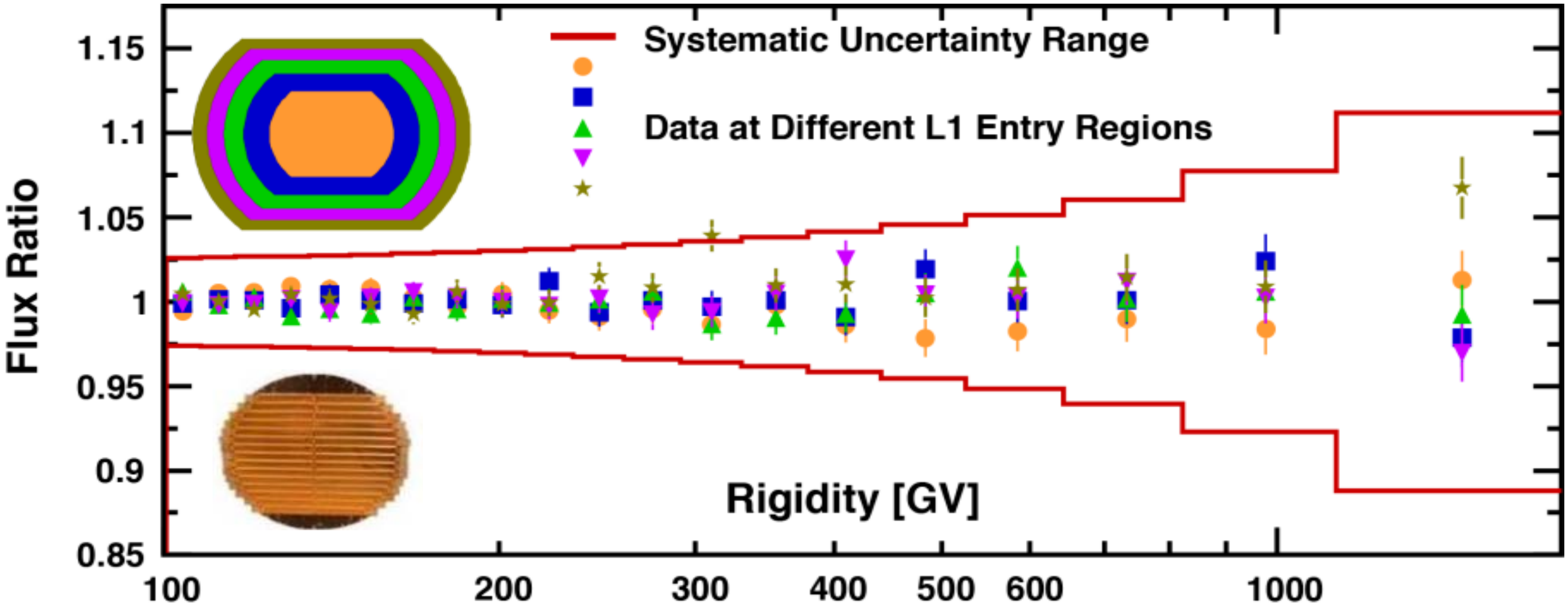
The monthly integral flux above 45GV is within the systematic error of 0.4%.



This verifies that the flux above 45GV shows no observable effect from solar modulation fluctuations and that the detector performance is stable.

Verification (III)

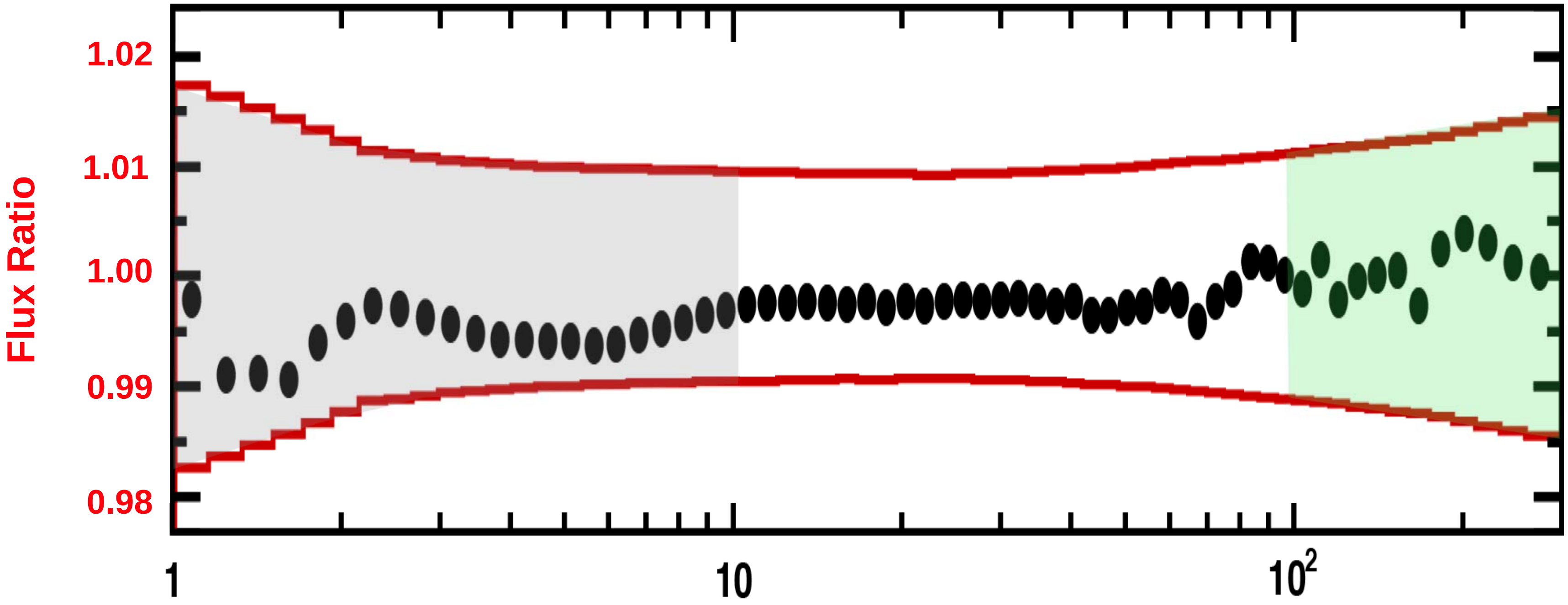
The ratios of fluxes obtained using events which pass through different sections of L1 to the average flux is in good agreement and within the assigned systematic errors.



This verifies the errors assigned to the tracker alignment.

Verification (IV)

The flux obtained with only the inner Tracker (L2-L8) is in good agreement to the one obtained with the full span Tracker (L1-L9)



This verifies the error on the rigidity resolution function and the unfolding

Verification (V)

Among many unfolding procedures, we selected two.
The small differences between the two procedures (< 0.5%) are accounted as a systematic error.

We have checked the sensitivity of the results to the binning by:

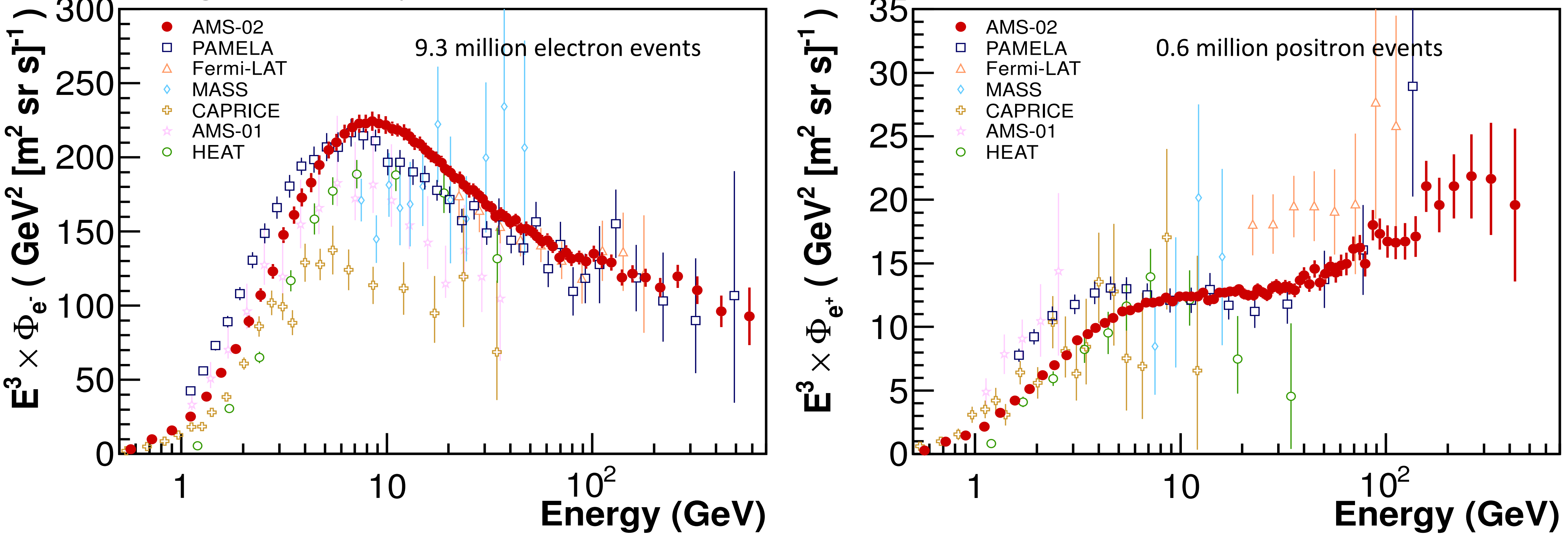
1. **increasing the bin width by factors of 2 and 4**

2. **reducing the bin width by factors of 2 and 4.**

The resulting uncertainty is well within the assigned systematic errors.

AMS Electrons and Positron Fluxes

M. Aguilar et al. Phys. Rev. Lett. 113 (2014) 1211012



AMS p/He Flux Ratio **Is a Single Power Law**

M. Aguilar et al. Phys. Rev. Lett. 115 (2015) 211101