Precision Measurements of the Nuclei Fluxes with the Alpha Magnetic Spectrometer on the International Space Station

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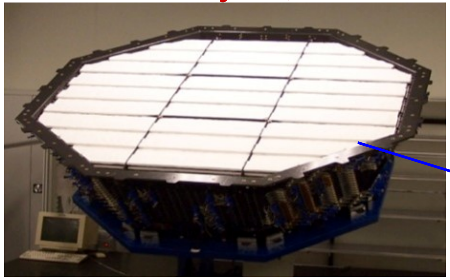
AMS Collaboration

TASK III, SPS Annual Meeting
Lugano, 24 August 2016

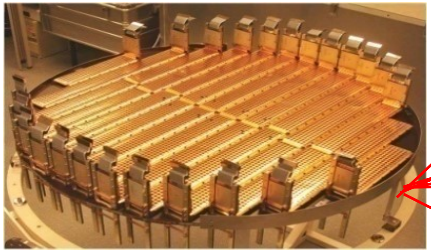
The Alpha Magnetic Spectrometer (AMS)

A TeV precision, multipurpose spectrometer

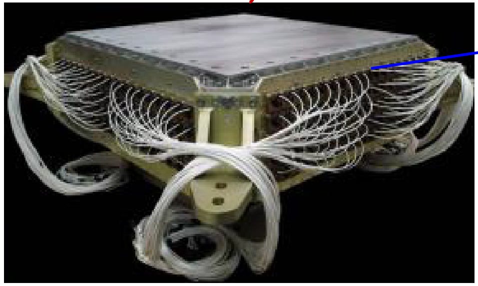
Transition Radiation Detector (TRD)
Identify e^+, e^-



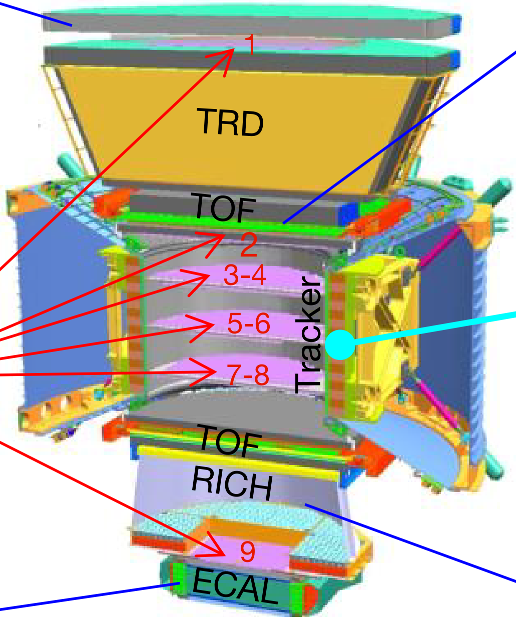
Silicon Tracker
Z, P



Electromagnetic Calorimeter (ECAL)
E of e^+, e^-



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

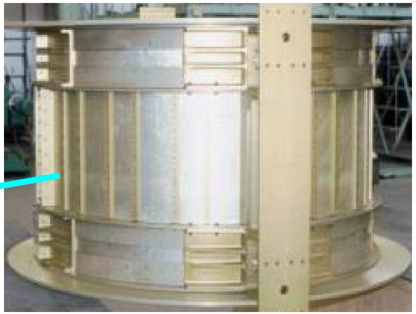


Z and P (E)

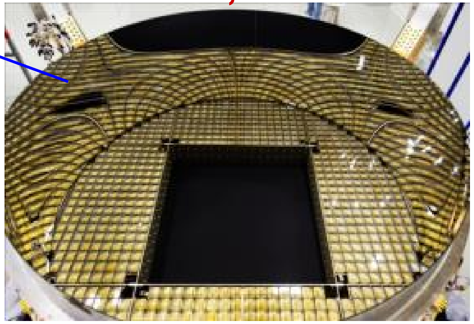
are measured independently by Tracker, RICH, TOF and ECAL

Time Of Flight (TOF)
Z, E

Magnet
±Z



Ring Imaging Čerenkov (RICH)
Z, E



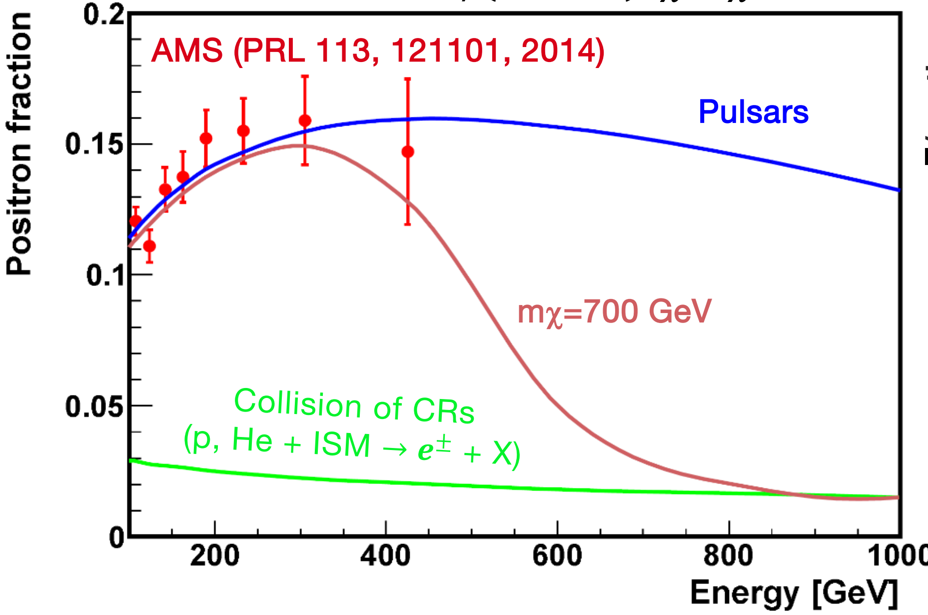
AMS in Space

In 5 years on ISS, AMS has collected > 80 billion cosmic rays.
To match the statistics, **systematic errors studies have become important.**

Search for Origin of Dark Matter: Background

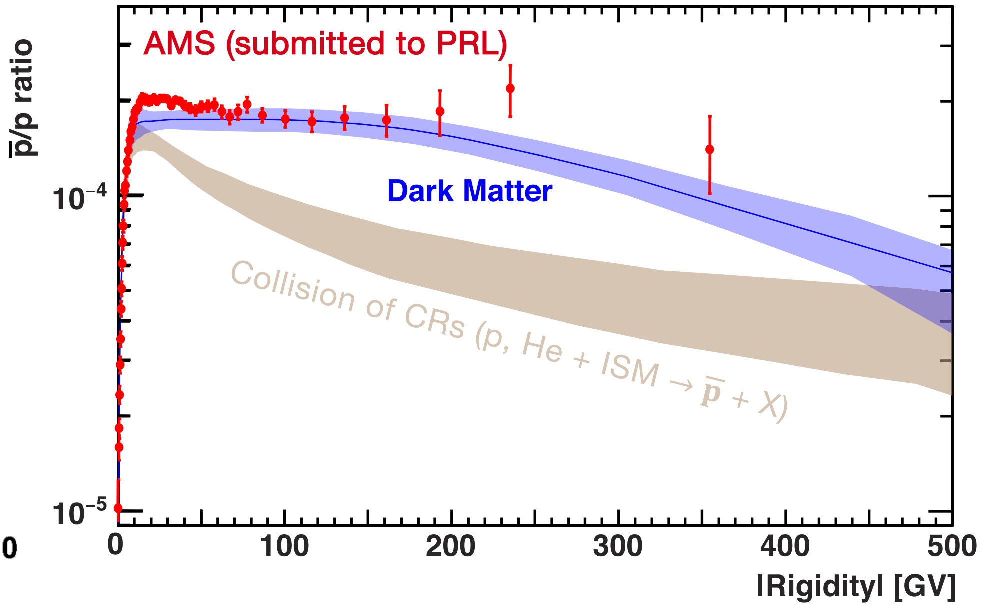
Annihilation of Dark Matter (neutralinos, χ) will produce additional e^+, $\overline{p}$, …, detected above the background from collisions of cosmic rays (CRs) on the interstellar medium (ISM).

Positron fraction $e^+/(e^+ + e^-)$: $\chi + \chi \rightarrow e^+ + \cdots$



I. Cholis and D. Hooper, Phys.Rev. D88 (2013) 023013
J. Kopp, Phys. Rev. D 88 (2013) 076013

Antiprotons: $\chi + \chi \rightarrow \overline{p} + \cdots$



Donato et al., PRL 102, 071301 (2009); m_χ = 1 TeV

To identify the Dark Matter signal, we need measurements of e^+, e^-, $\overline{p}$.

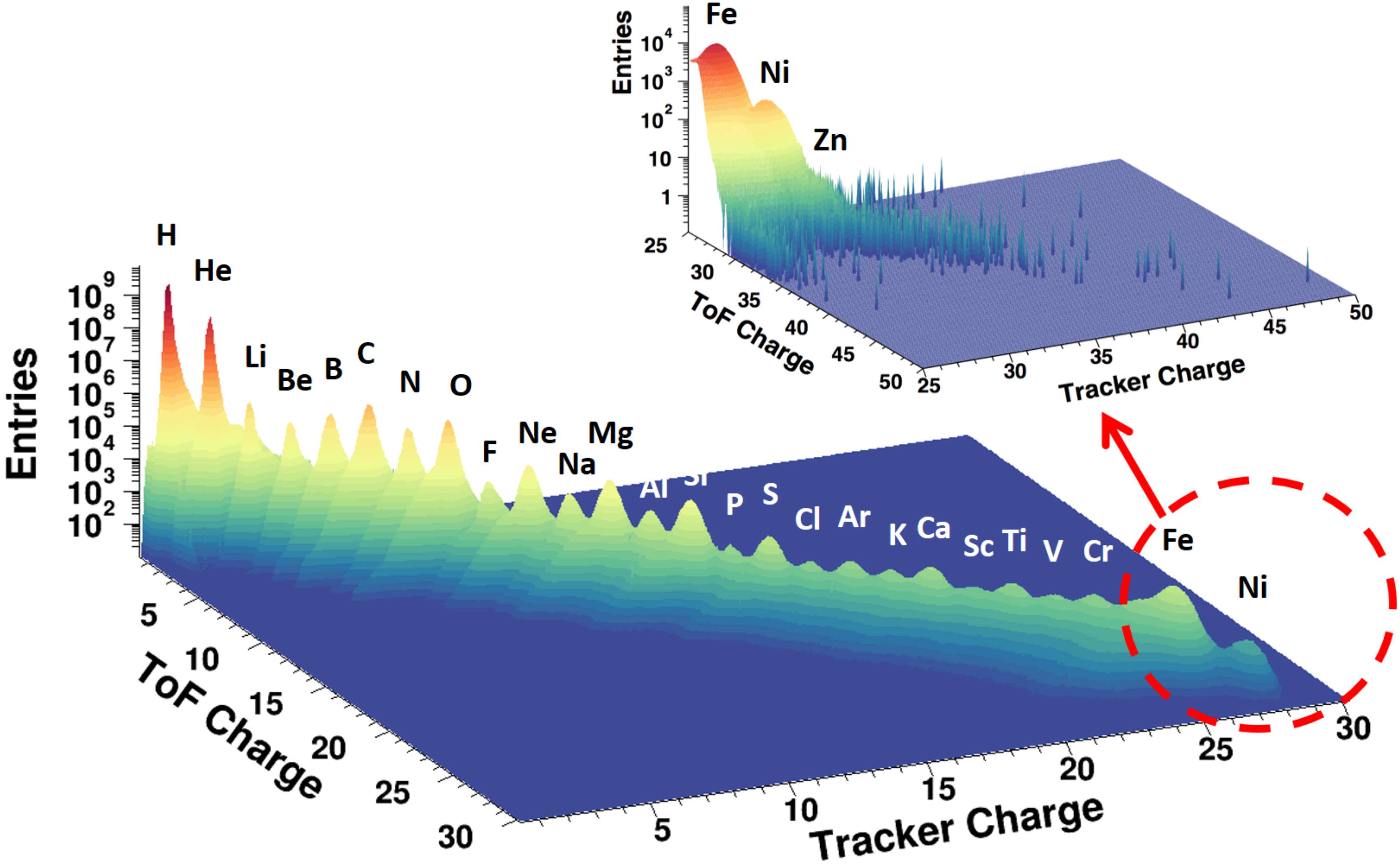
To understand the background, we need precise knowledge of

I. The CRs fluxes of e^+ and $\overline{p}$ “parents” (p, He, C, …),

II. CRs propagation and acceleration in the Milky Way (B/C, Li, …).

AMS Nuclei Fluxes Measurements

AMS will measure fluxes of all cosmic nuclei from Z=1 to 28 and beyond, such as H, He, Li, Be, B, C ,N ,O, Al, Si, Fe, Co, as well as flux ratios with unprecedented precision.



Flux Measurement

The isotropic flux Φ_i for the ith rigidity (≡momentum/charge) bin $(R_i,\ R_i + \Delta R_i)$ is

Number of events
corrected for bin-to-bin migration
due to tracker rigidity resolution

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

Bin width

Exposure Time

Trigger efficiency from data

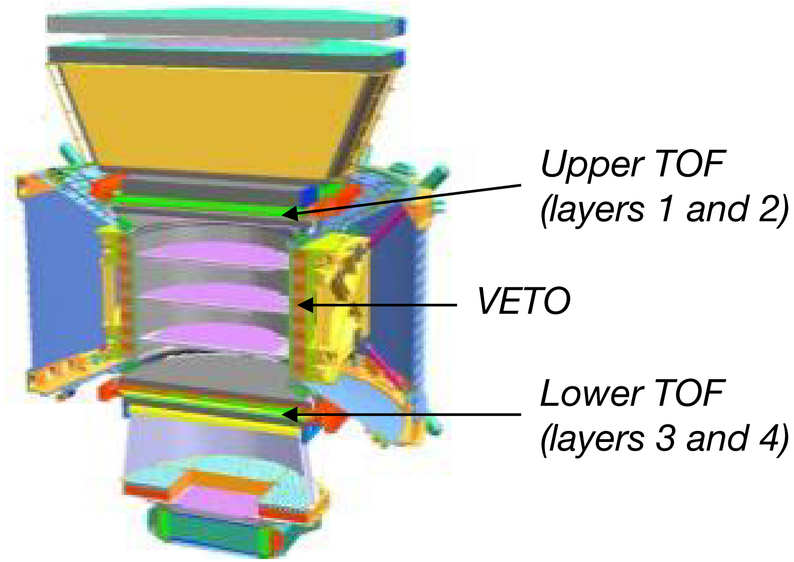
Effective acceptance from MC
verified with data

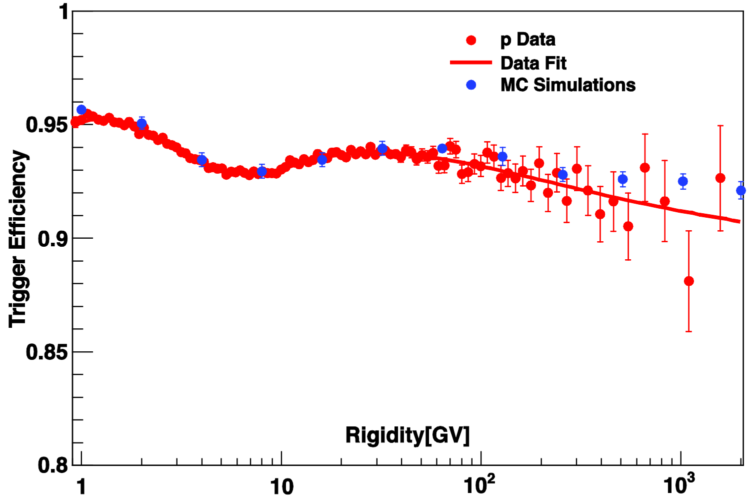
To match the statistics of 300 million events for protons and 50 million for helium nuclei, extensive systematic errors studies have been made.

Systematic Error on 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: 90-95% for protons, 95-99% for helium. The error is dominated by the statistics available from the unbiased trigger.

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



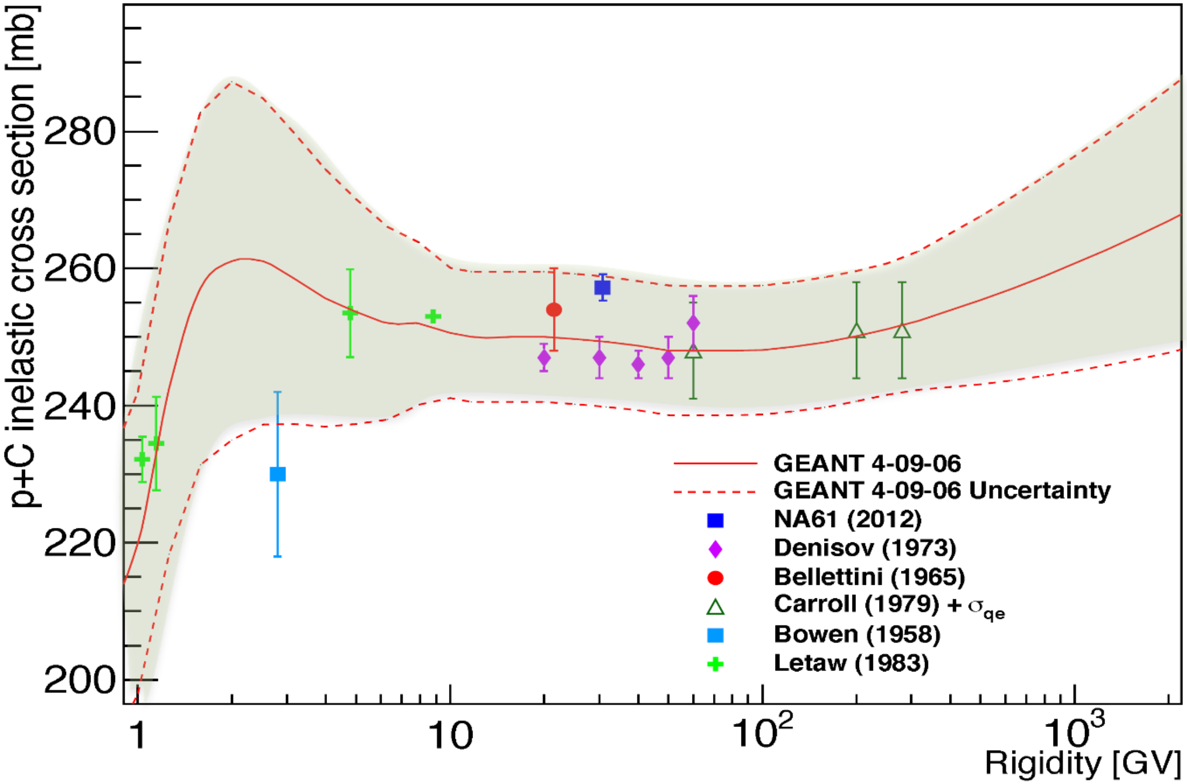


This systematic error is negligible (less than 0.1%) below 100GV and reaches 1.5% at highest rigidities.

Systematic Error on Acceptance due to Interactions

Acceptance for Proton

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



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

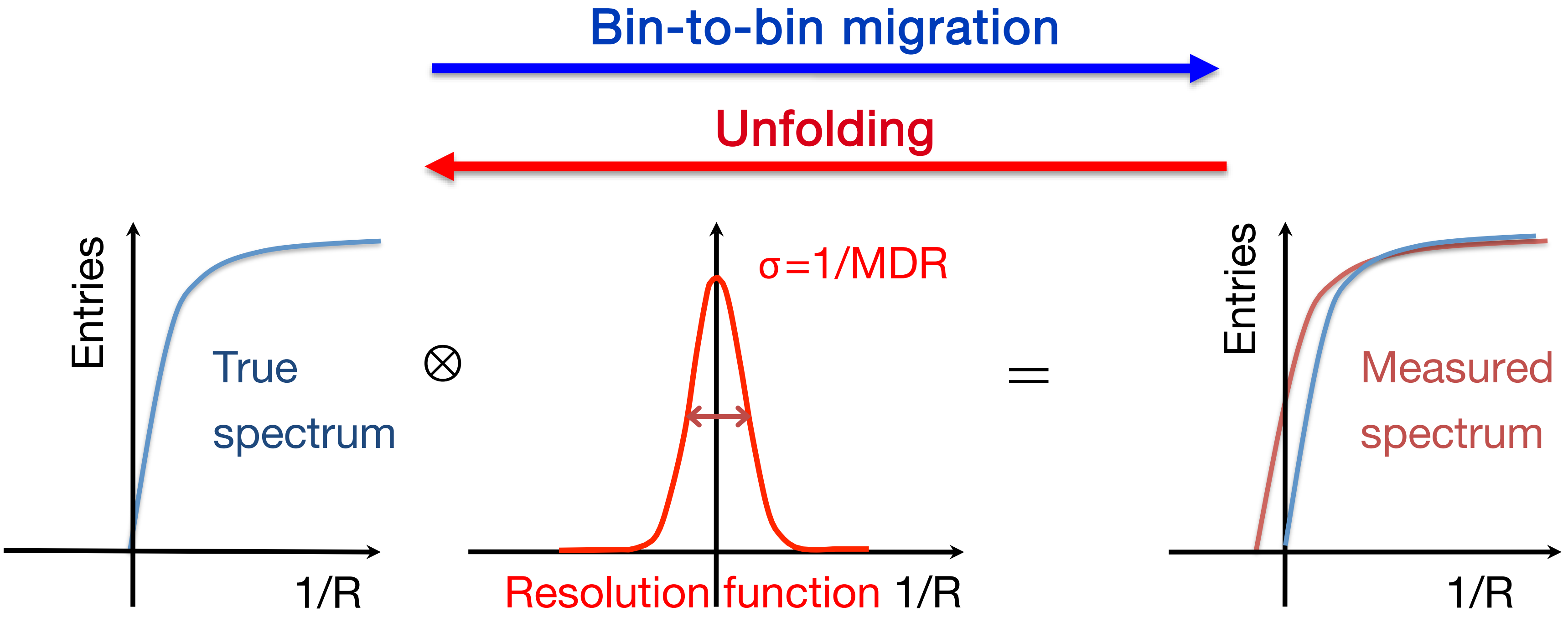
Using MC samples with cross sections scaled by ±10%, we found the errors on the proton flux due to uncertainty in inelastic cross sections are

1% [1GV] 0.6% [10-300 GV] 0.8% [1.8 TV]

Unfolding

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

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



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

Systematic Error on Rigidity Resolution Function

Protons

Resolution function from MC simulation

Verified with:

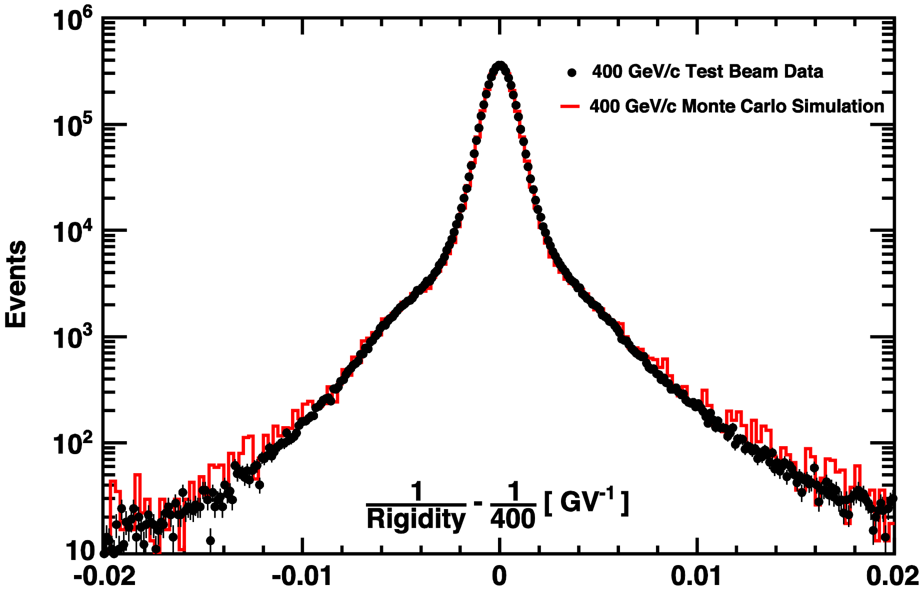
- 400 GeV/*c* proton beam data
- ISS data: tracker residuals, rigidity reconstruction (L1-L8) vs. (L2-L9)

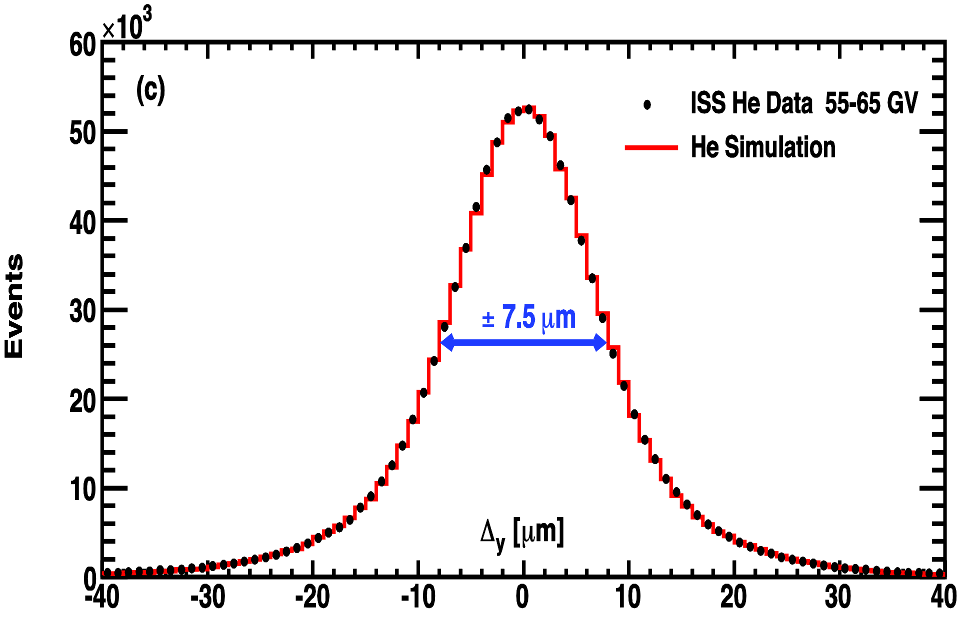
Helium

Resolution function from MC simulation

Verified with ISS data:

- Tracker residuals
- Rigidity reconstruction (L1-L8) vs. (L2-L9)



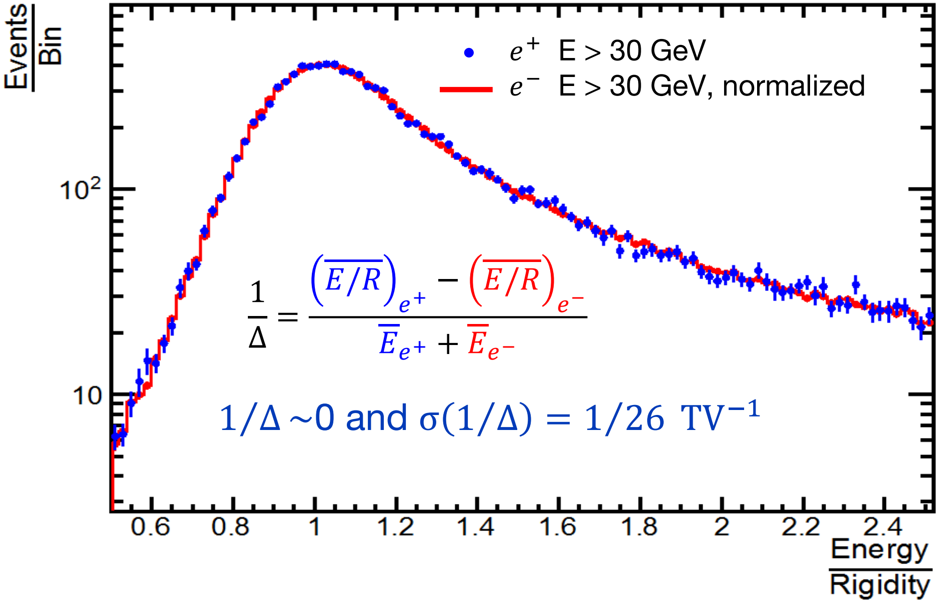


Systematic error on the flux < 1% below 300 GV, rising to 3% at 2 TV

Systematic Error on Absolute Rigidity Scale

(1) Residual tracker misalignment

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



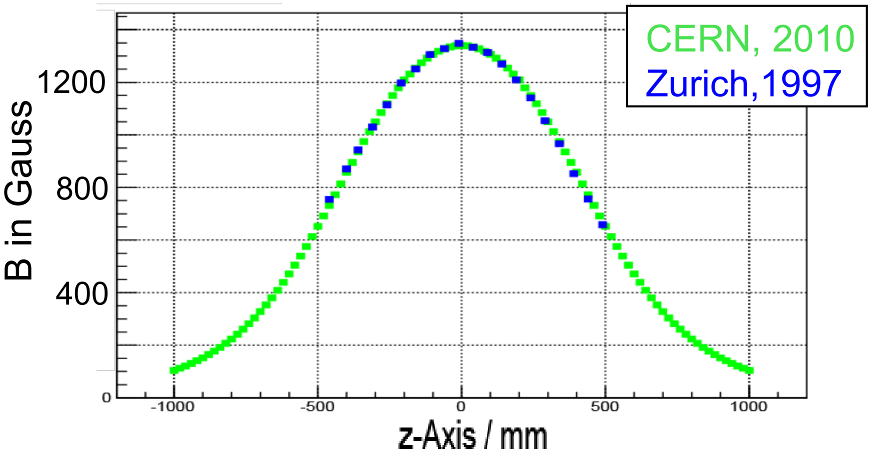
$$\frac{1}{\Delta} = \frac{\left(\overline{E/R}\right)_{e^+} - \left(\overline{E/R}\right)_{e^-}}{\overline{E}_{e^+} + \overline{E}_{e^-}}$$

$1/\Delta \sim 0$ and $\sigma(1/\Delta) = 1/26\ \mathrm{TV}^{-1}$

(2) Magnetic field

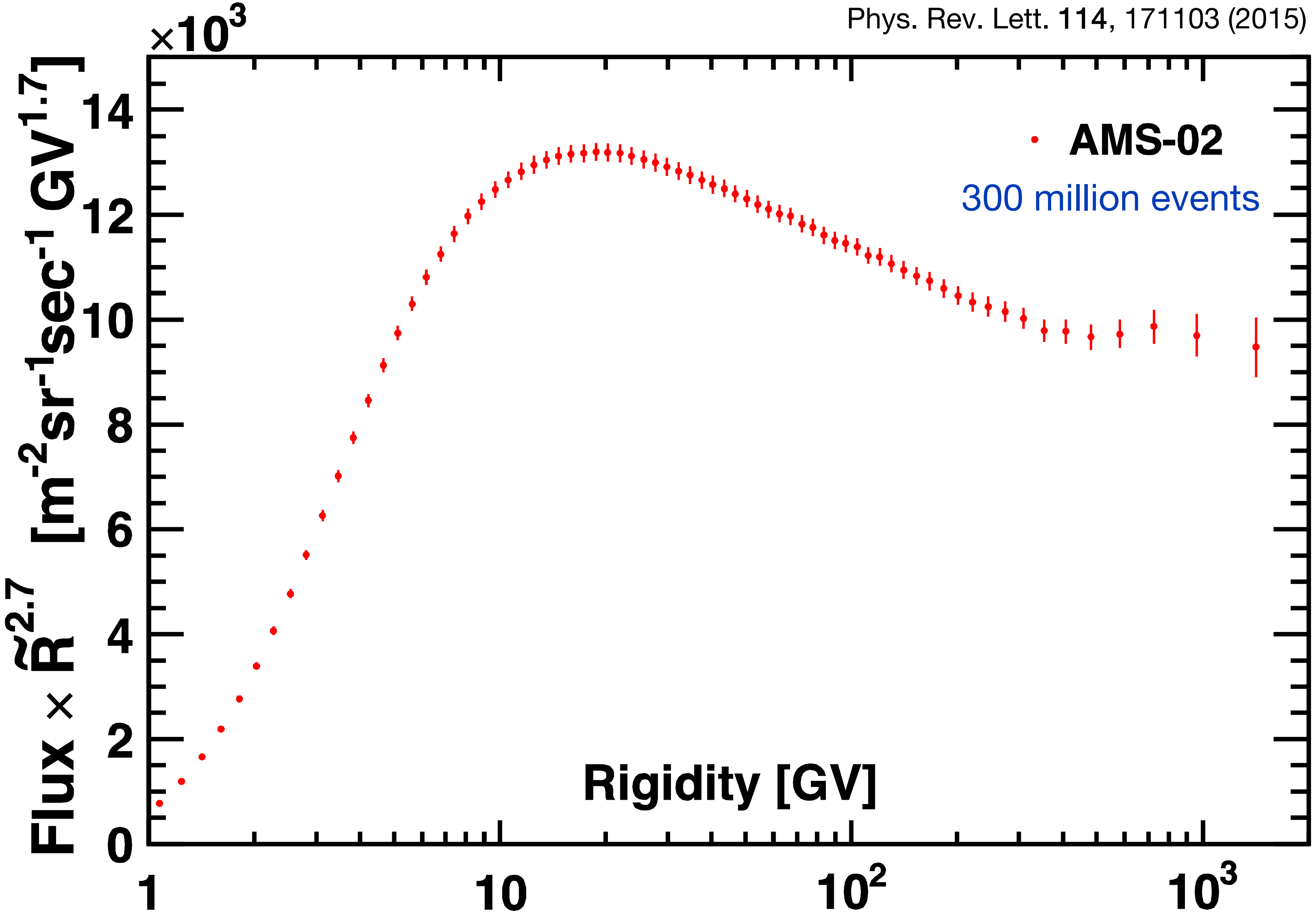
Mapping measurement (0.25%) and temperature corrections (0.1%).

This amounts to less than 0.5% systematic error on the flux.



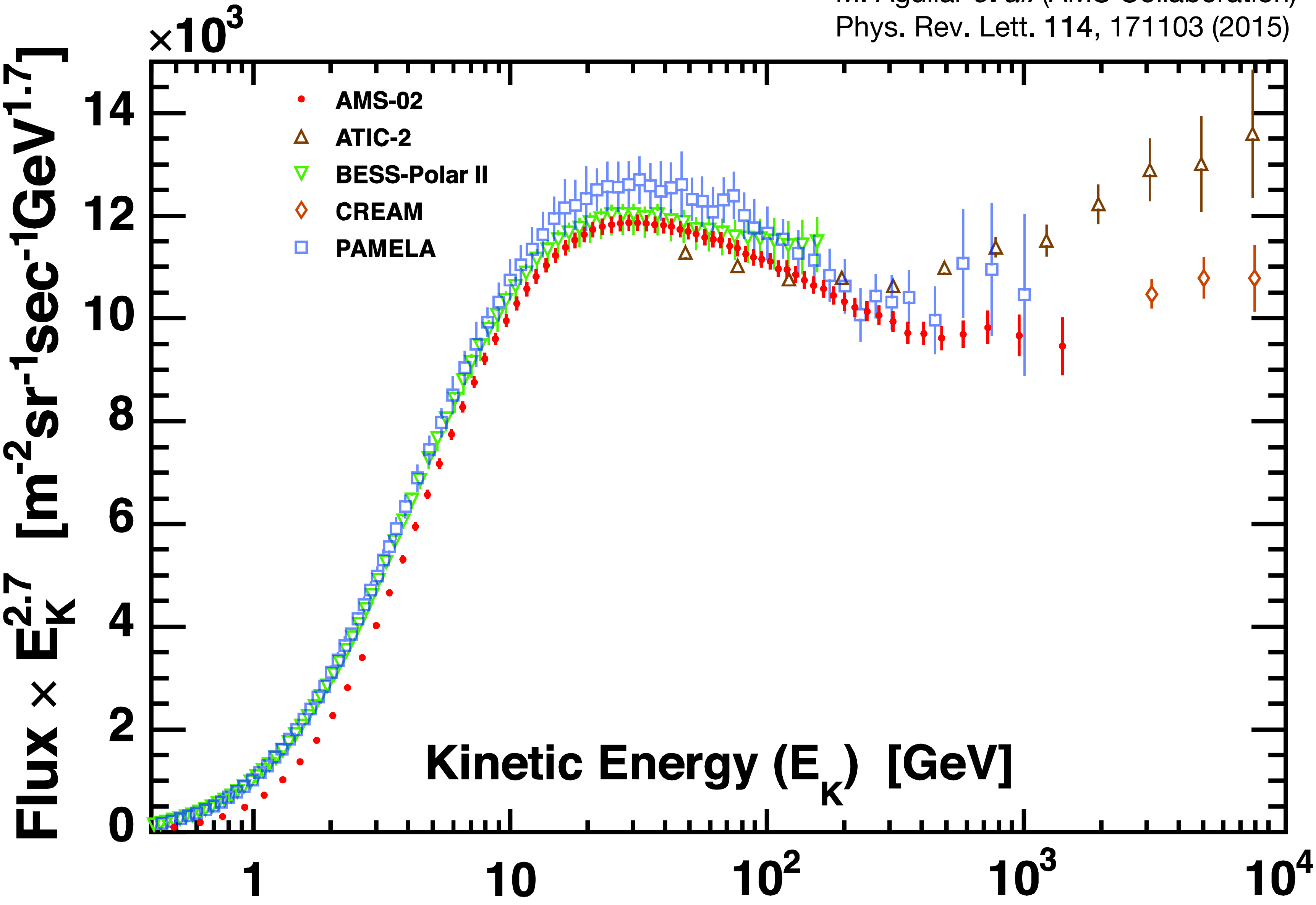
AMS Proton Flux

M. Aguilar *et al.* (AMS Collaboration)
Phys. Rev. Lett. **114**, 171103 (2015)



Proton Flux Comparison

M. Aguilar *et al.* (AMS Collaboration)
Phys. Rev. Lett. **114**, 171103 (2015)

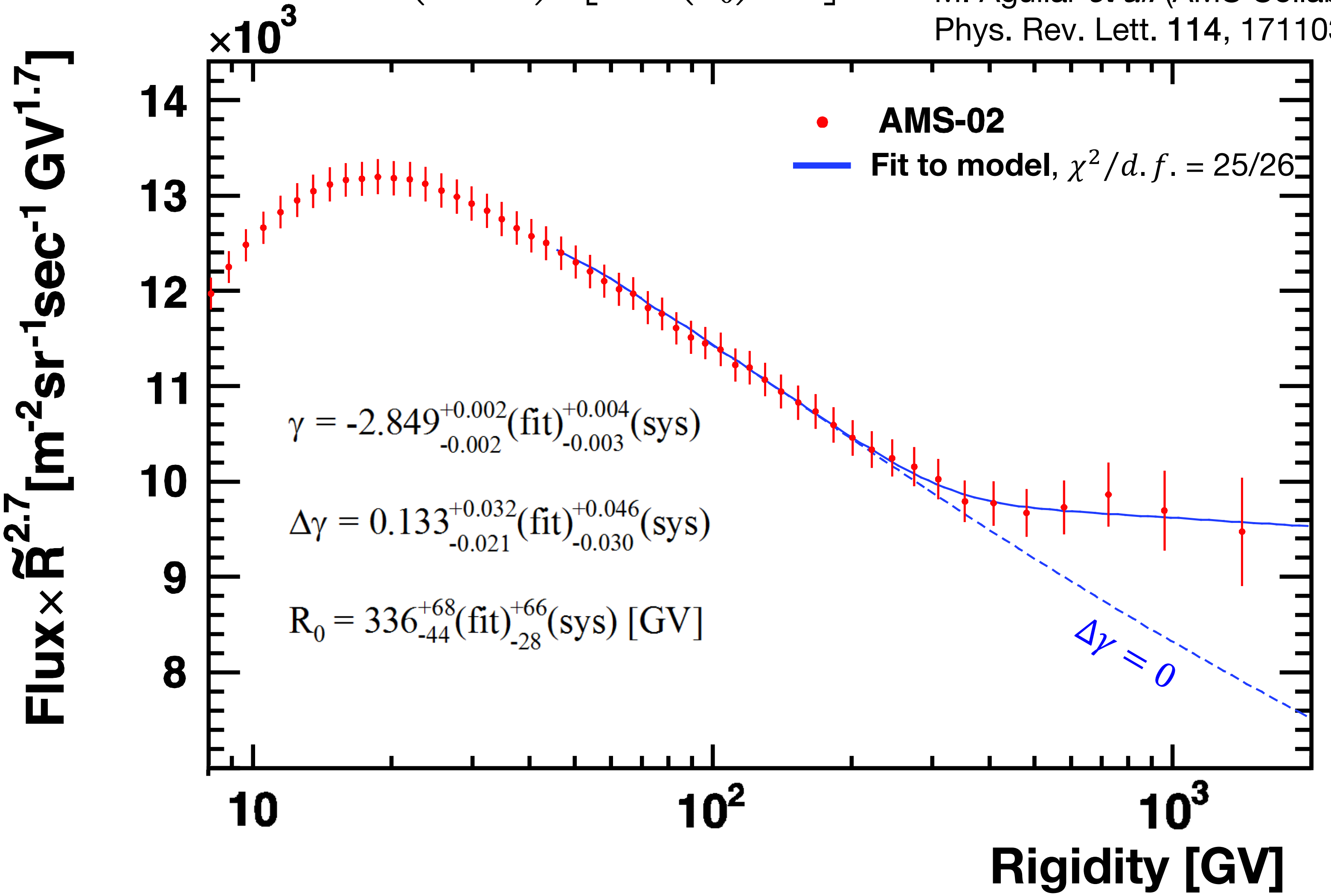


AMS Proton Flux

Not a Single Power Law

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

M. Aguilar *et al.* (AMS Collaboration)
Phys. Rev. Lett. **114**, 171103 (2015)

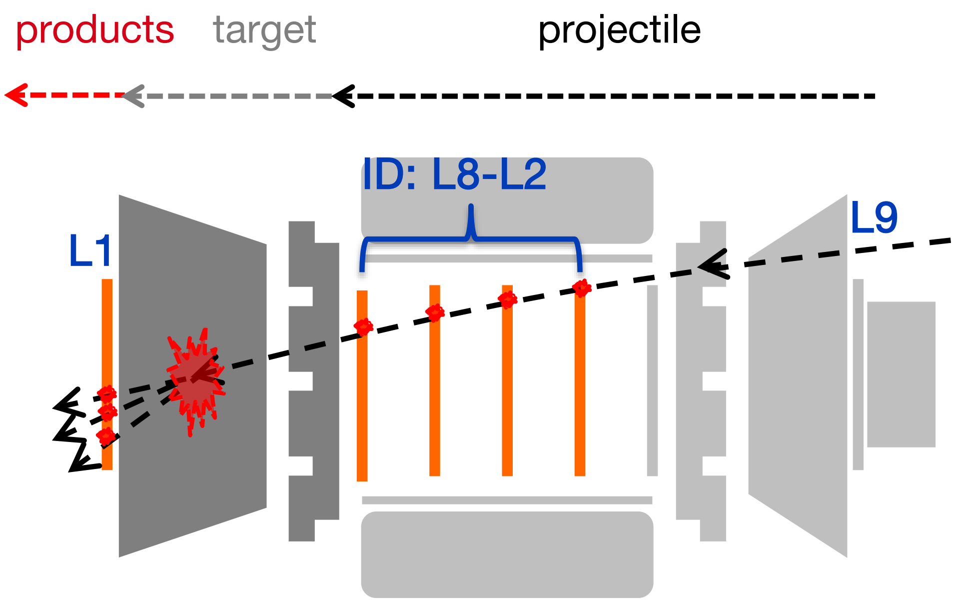


Nuclei Acceptance due to Interactions

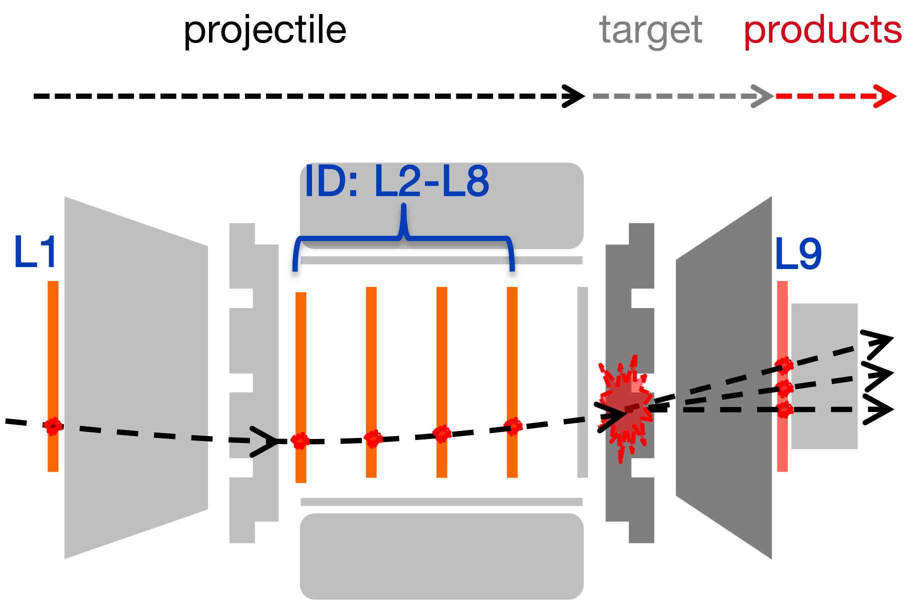
The inelastic cross sections of light nuclei + C, Al have only been measured below 10 GV (He, C, O), or not measured (Li, Be, B).

We have developed a method to determine the effect on the acceptance of interactions in the detector, with AMS pointing in horizontal direction (2 days in total).

Survival probability L2→L1

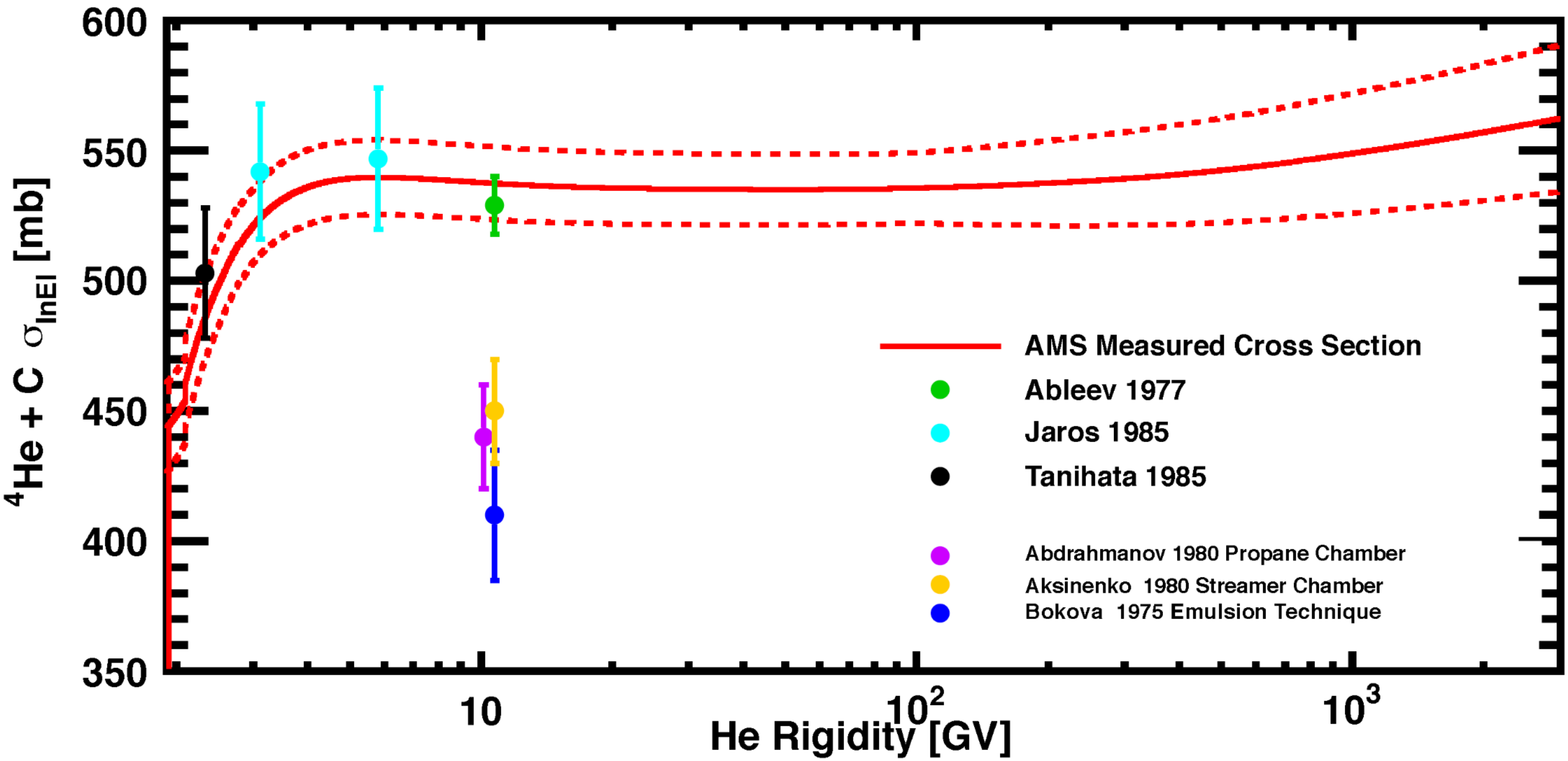


Survival probability L8→L9



This method was verified by comparing this L8→L9 survival probability to the one using the data collected when AMS was in normal data taking conditions.

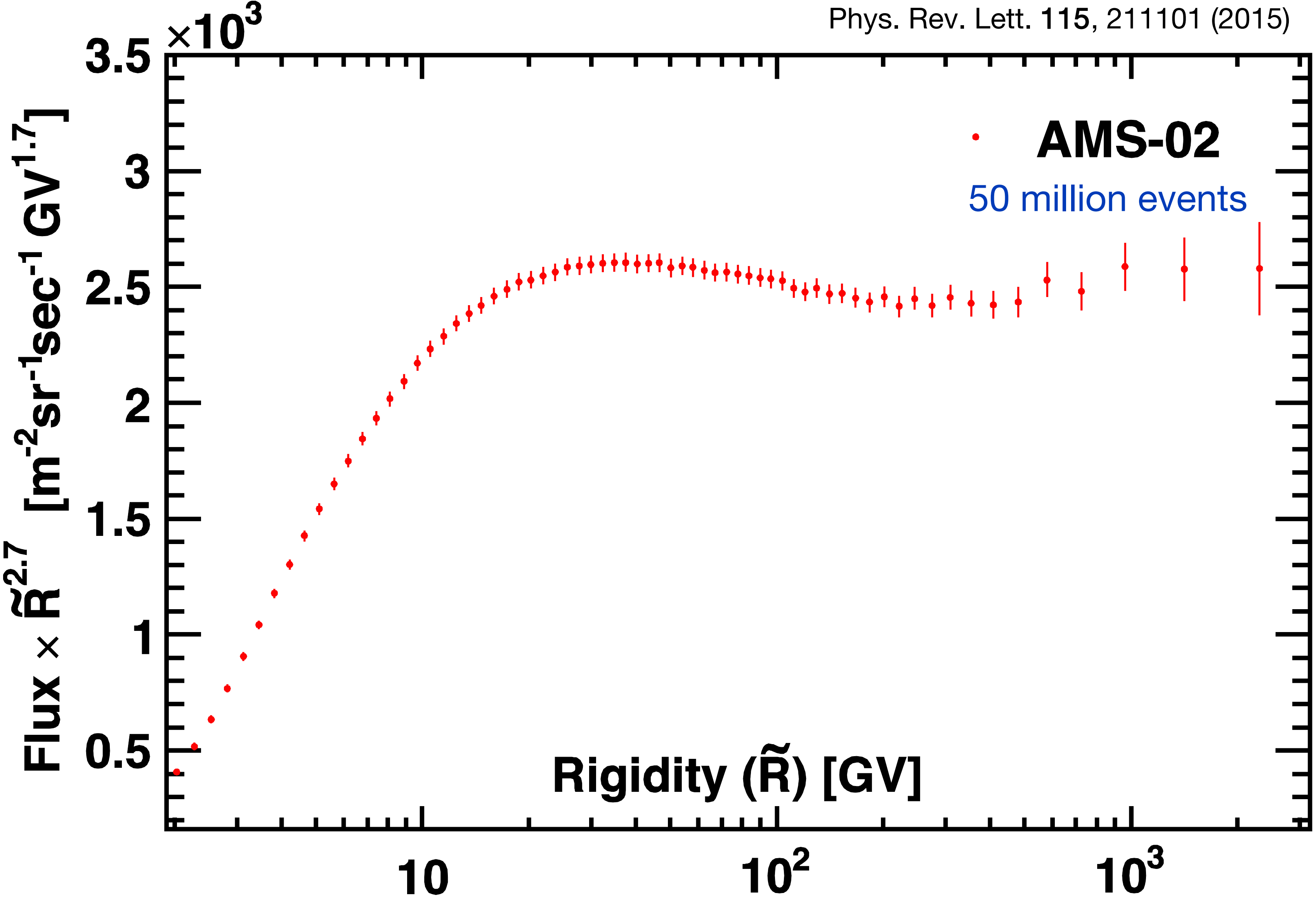
^{4}He + C Inelastic Cross Section Measurement



The systematic error on the He flux due to uncertainties of He inelastic cross sections: ~1% below 200 GV, increasing to ~2% at 3 TV

AMS Helium Flux

M. Aguilar *et al.* (AMS Collaboration)
Phys. Rev. Lett. **115**, 211101 (2015)



Helium Flux Comparison

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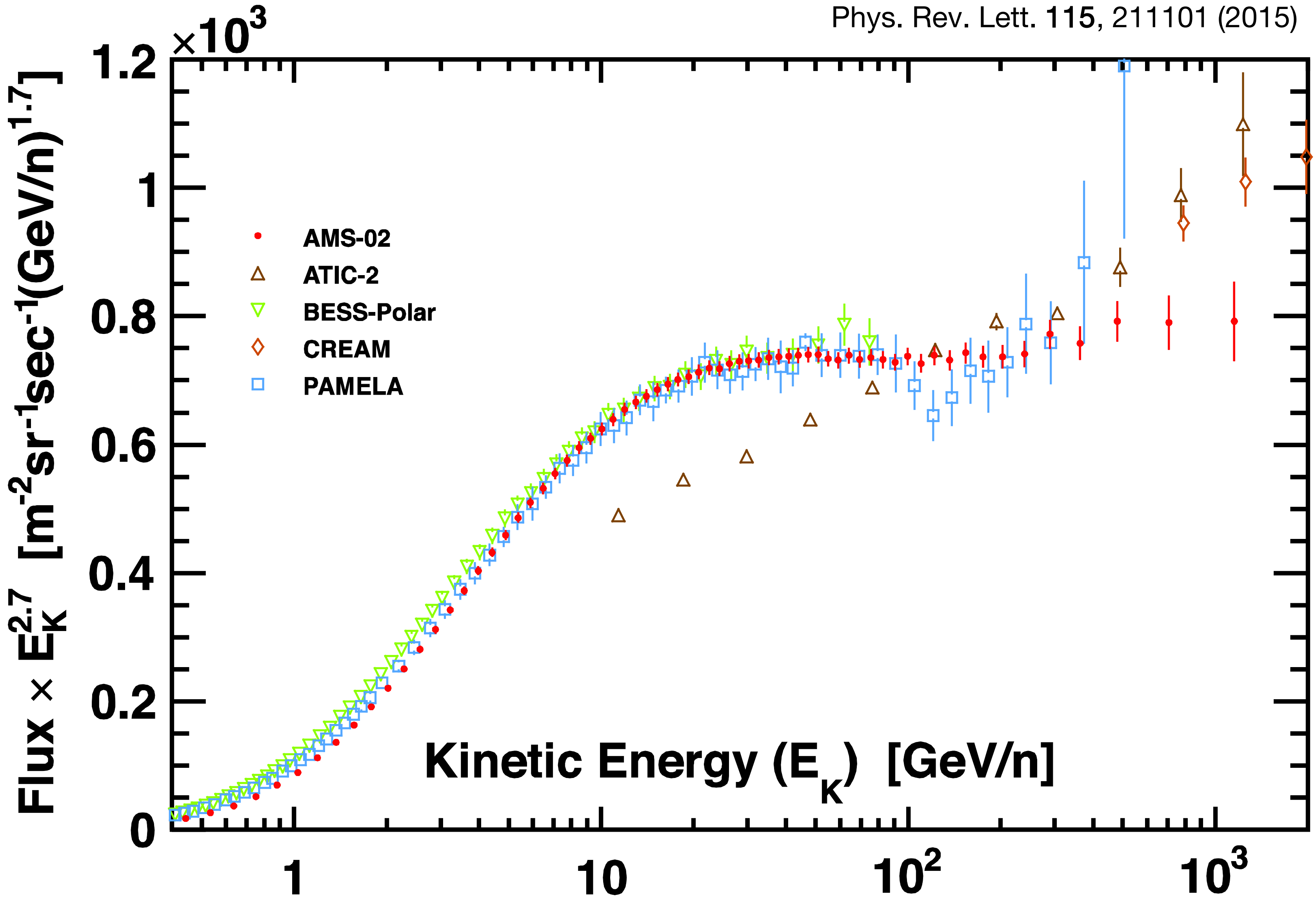
Phys. Rev. Lett. **115**, 211101 (2015)



AMS Helium Flux

Not a Single Power Law

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

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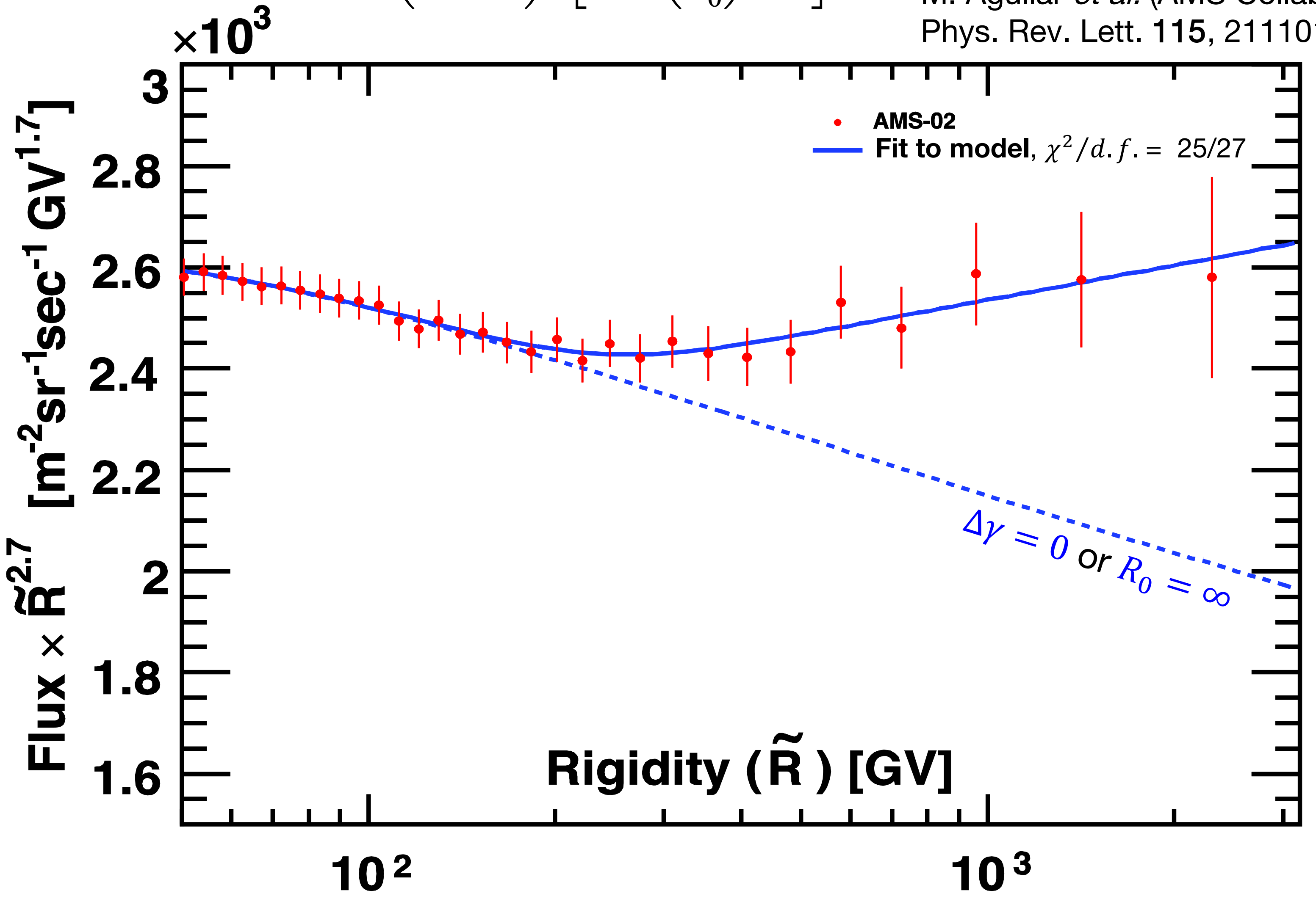
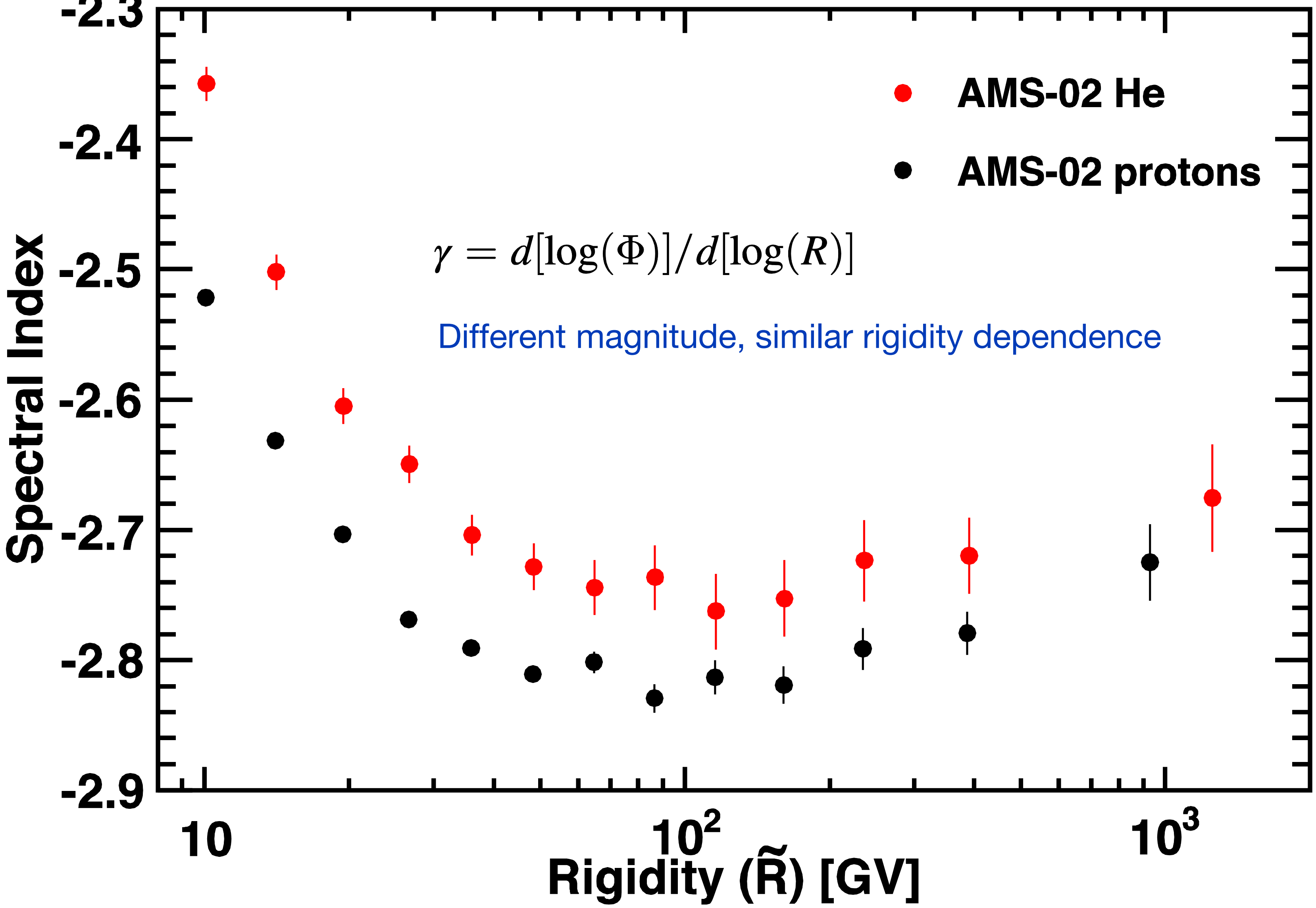


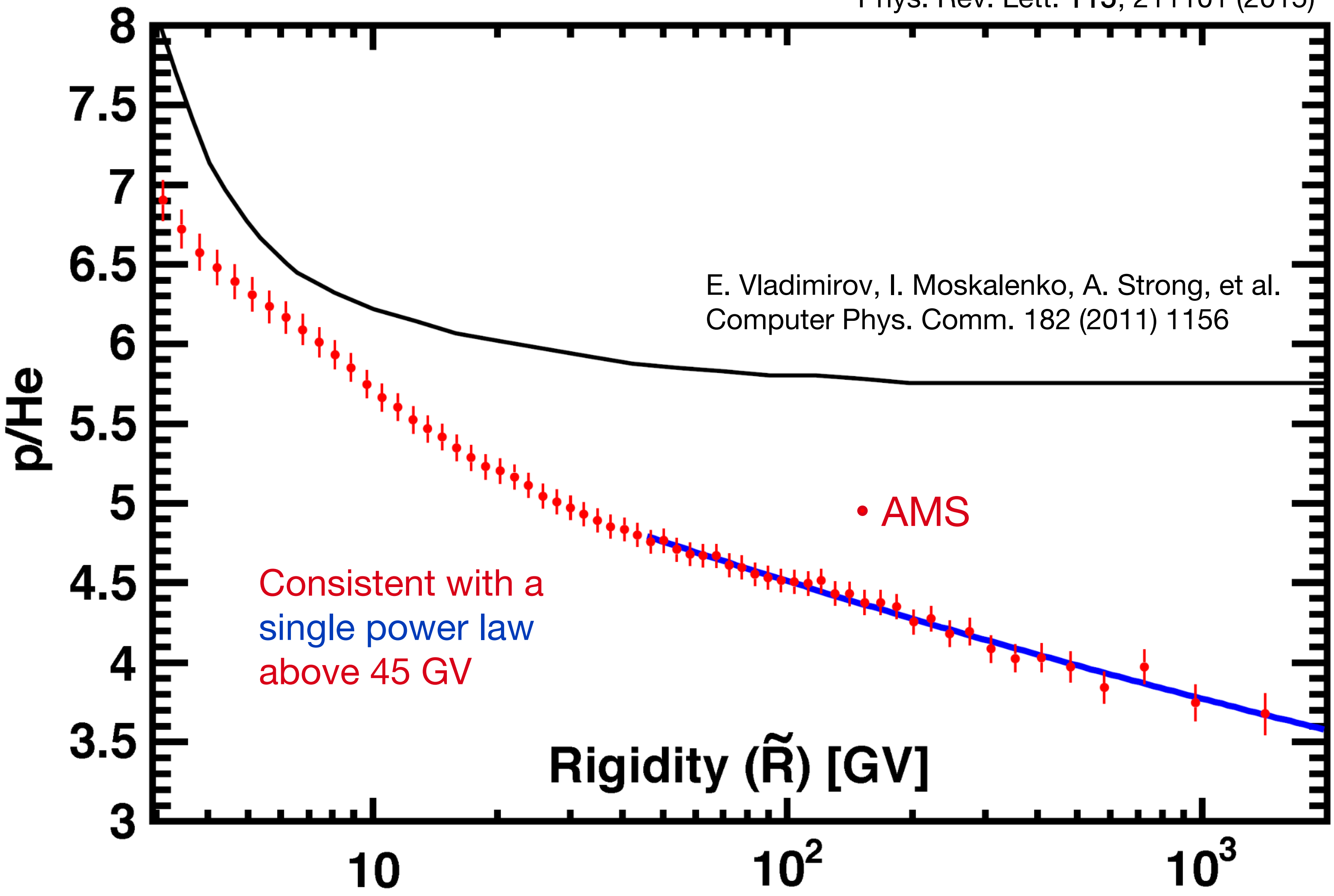
AMS Proton and Helium Spectral Index (γ) Variation

M. Aguilar *et al.* (AMS Collaboration)
Phys. Rev. Lett. **115**, 211101 (2015)



AMS Proton/Helium Flux Ratio

M. Aguilar *et al.* (AMS Collaboration)
Phys. Rev. Lett. **115**, 211101 (2015)

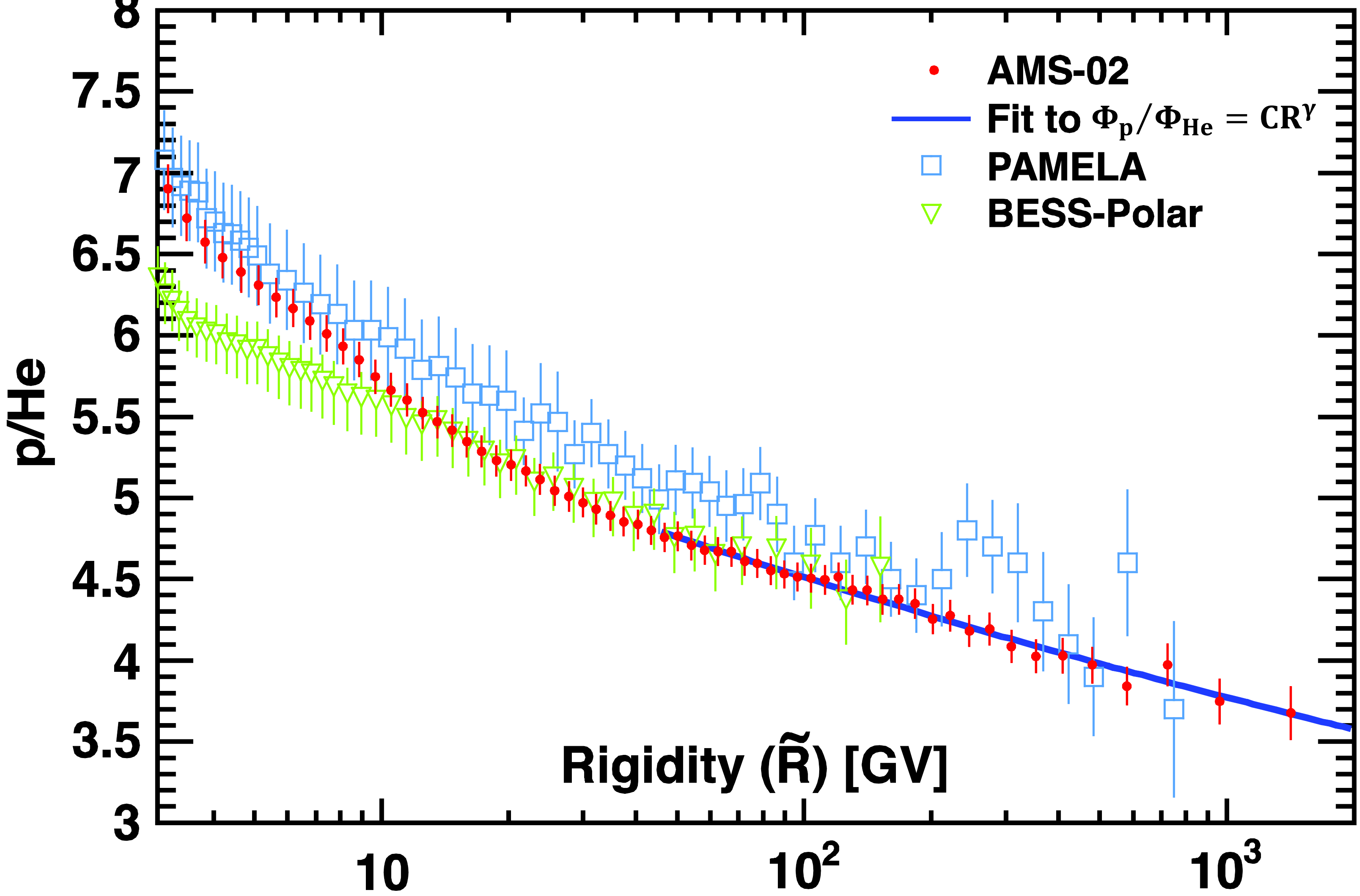


E. Vladimirov, I. Moskalenko, A. Strong, et al.
Computer Phys. Comm. 182 (2011) 1156

Consistent with a
single power law
above 45 GV

Proton/Helium Flux Ratio Comparison

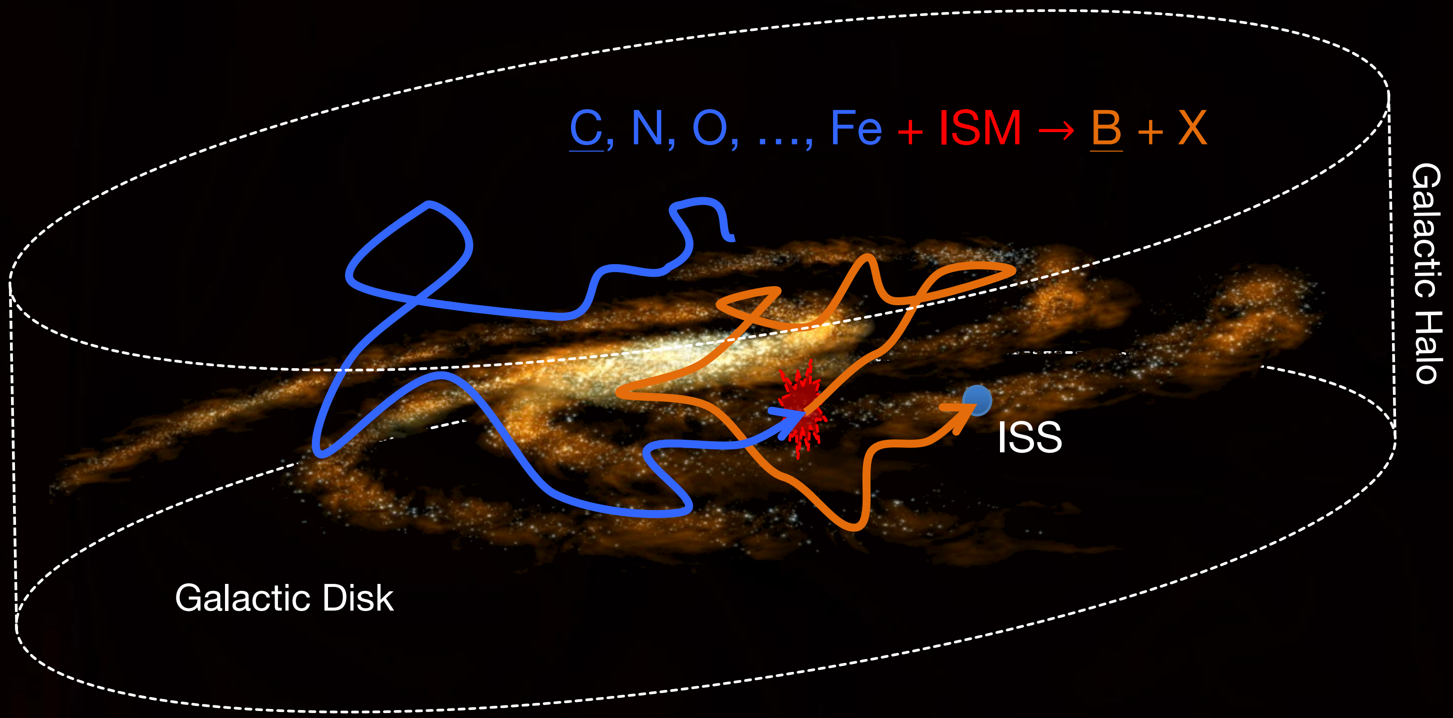
M. Aguilar *et al.* (AMS Collaboration)
Phys. Rev. Lett. **115**, 211101 (2015)



Search for Origin of Dark Matter: Background (Ⅱ)

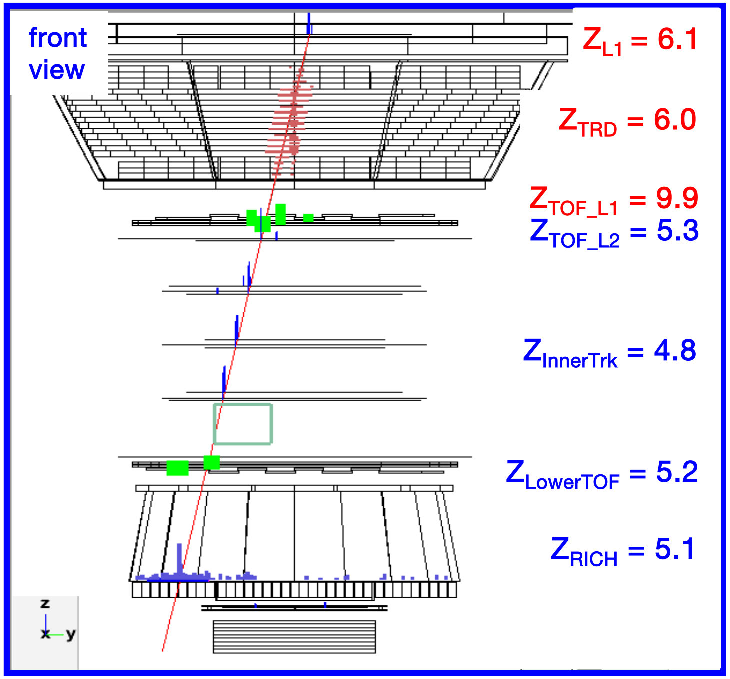
CRs Propagation

B nuclei in CRs are produced by collisions of heavier nuclei, such as C and O, with the ISM. Therefore the B/C measures directly the average amount of interstellar material traversed by CRs.

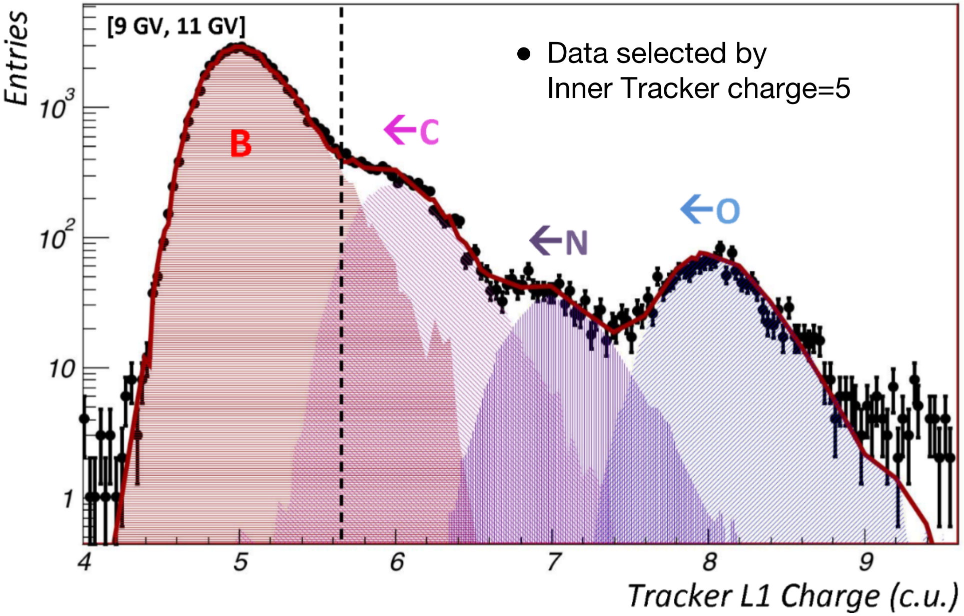


Systematics on Background from Interactions

- There is a small background from interactions of heavier nuclei between Tracker L1 and L2, such as Carbon → Boron, Carbon → Lithium, or Oxygen → Carbon.
- The amount of residual contamination after charge selection on L1 is calculated by fitting the data with B, C, N and O charge distributions derived from data.
- Contamination $< 3\%$ over the entire rigidity range for Boron and negligible for Carbon.



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

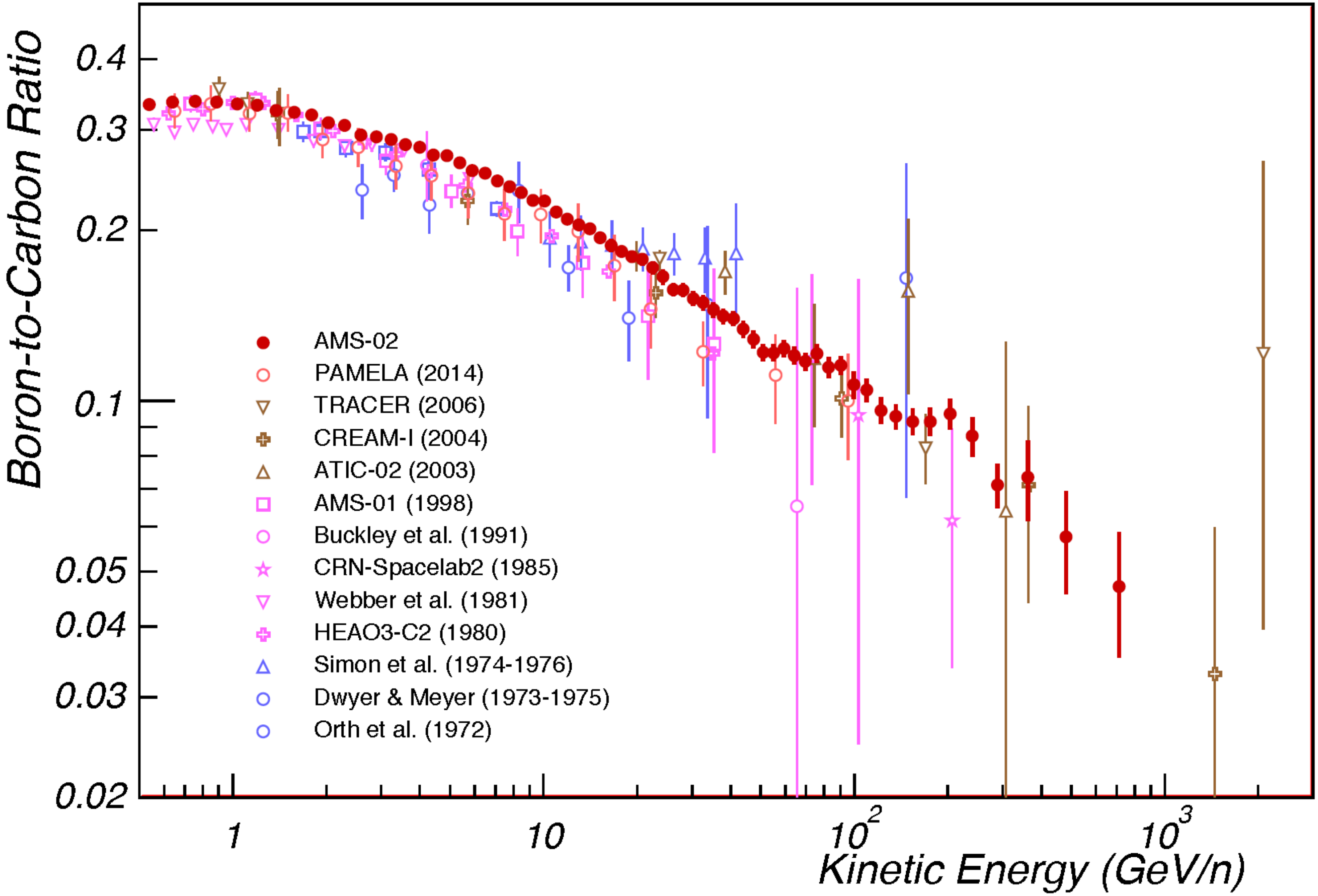


Systematic uncertainty on the knowledge of the charge templates are included in the final flux error ($< 1\%$).

AMS Boron/Carbon Flux Ratio

Current Status

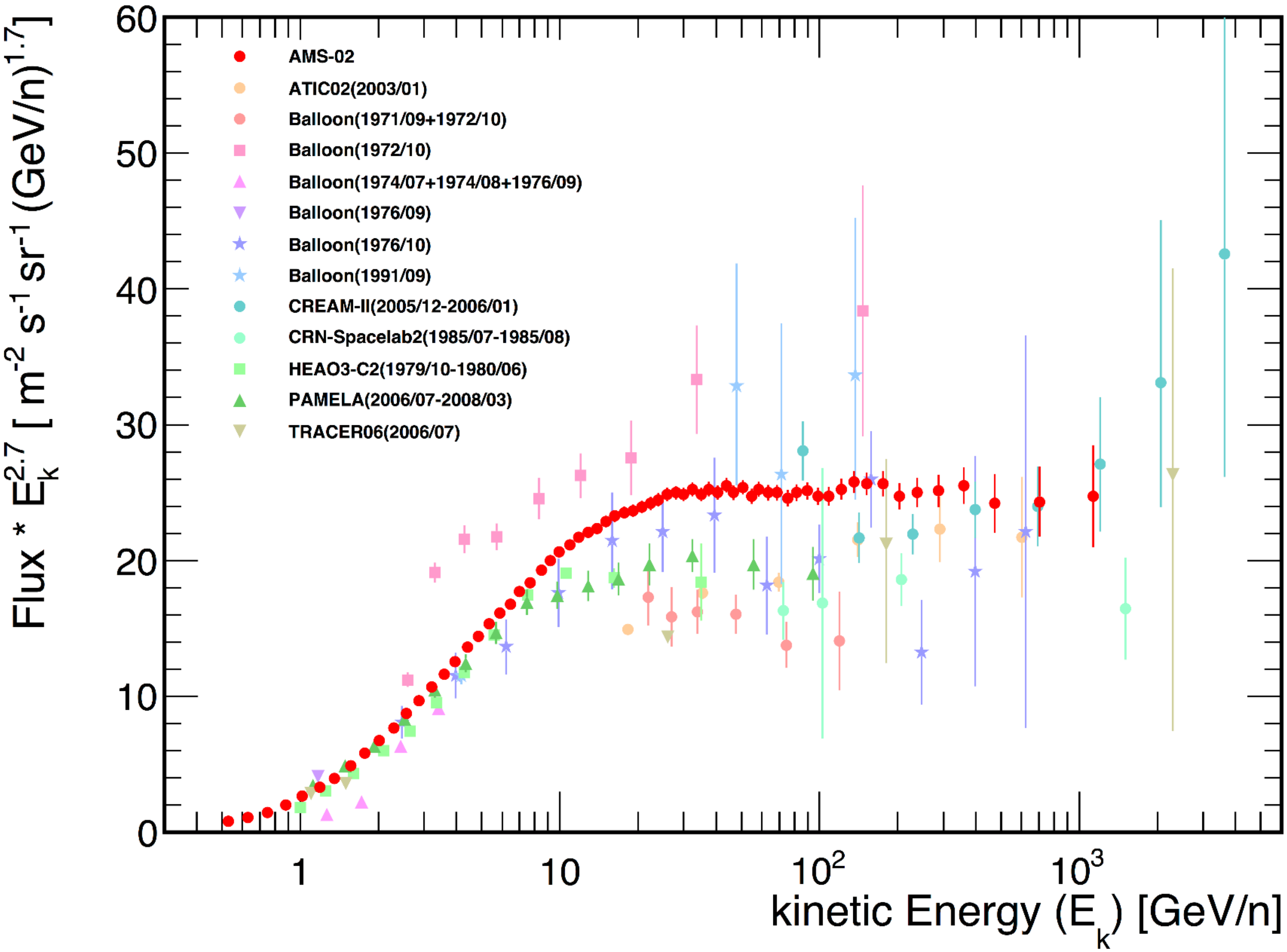
A. Oliva, ICHEP 2016



AMS Carbon Flux

Current Status

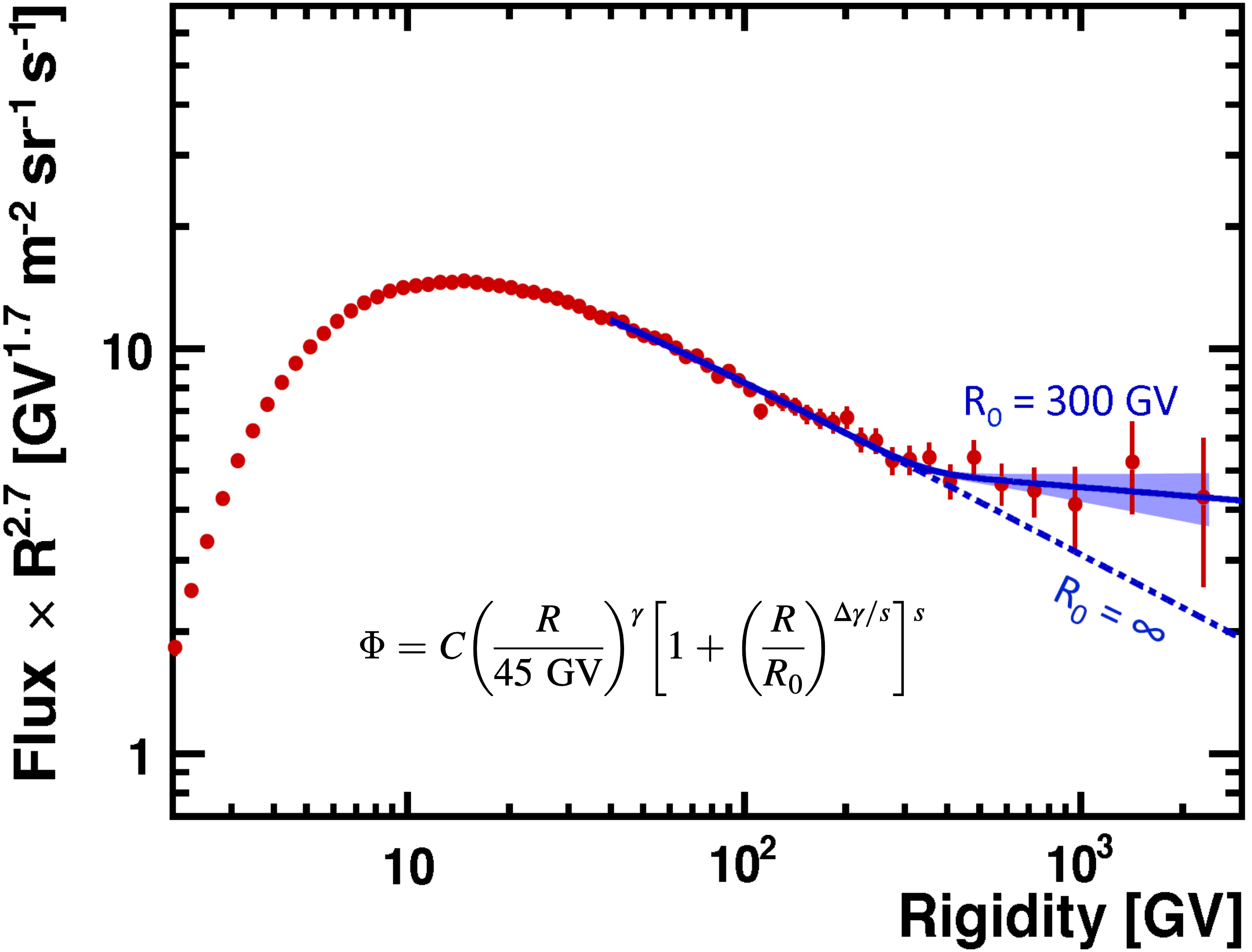
M. Heil, RICAP 2016



AMS Lithium Flux

Current Status

L. Derome, ICRC 2015



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

AMS is providing CRs information with **~1%** uncertainty.

The accuracy and characteristics of the data, **simultaneously** from many different types of CRs, will provide new insights into the source of CRs and their propagation through the galaxy.

The Space Station has become a unique platform for precision physics research.