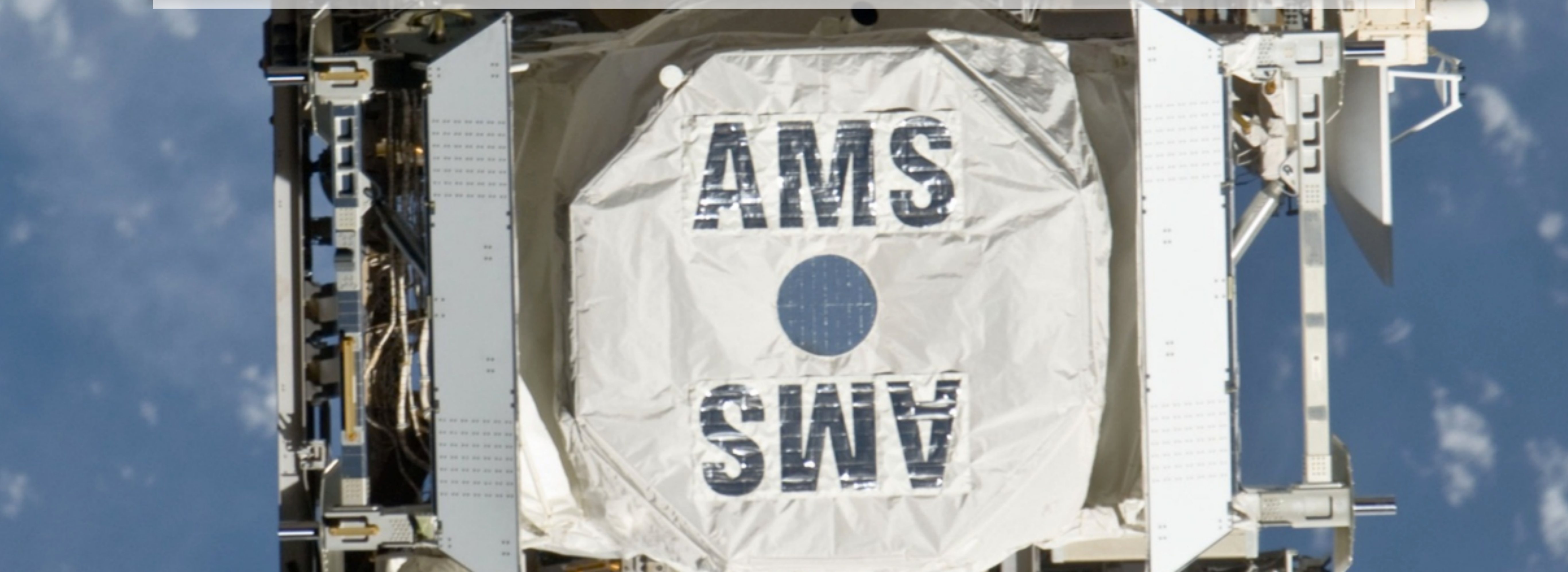
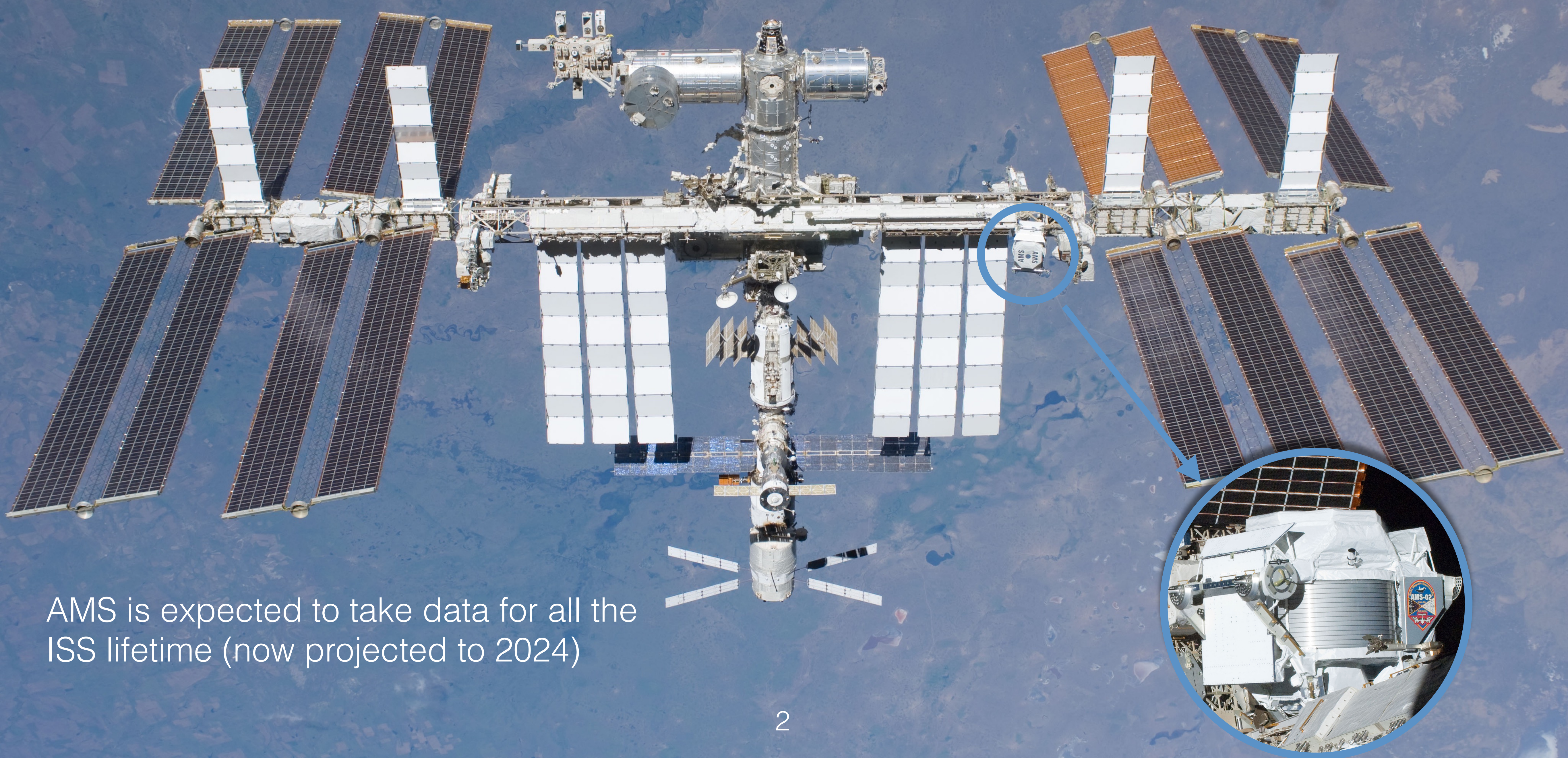
Precision Measurement of Nuclei Fluxes and their Ratios in Primary Cosmic Rays with the Alpha Magnetic Spectrometer on the International Space Station

V. Formato on behalf of the AMS collaboration
CERN and INFN - Sezione di Perugia
28/11/2016 - COSPA - Sydney



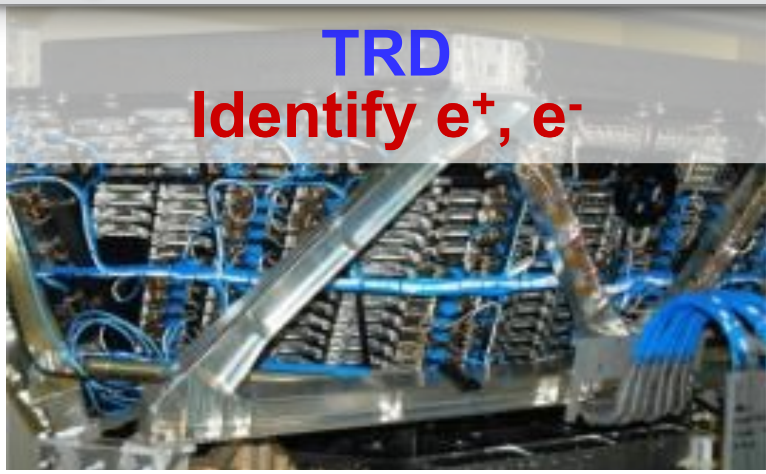
AMS-02 in orbit

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.**

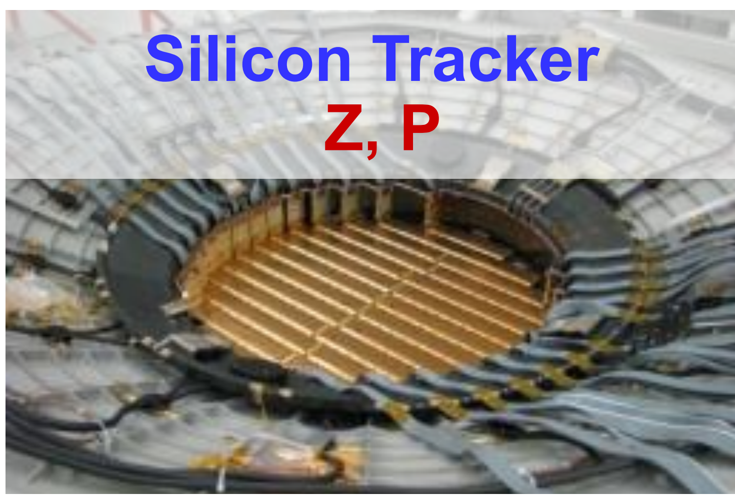


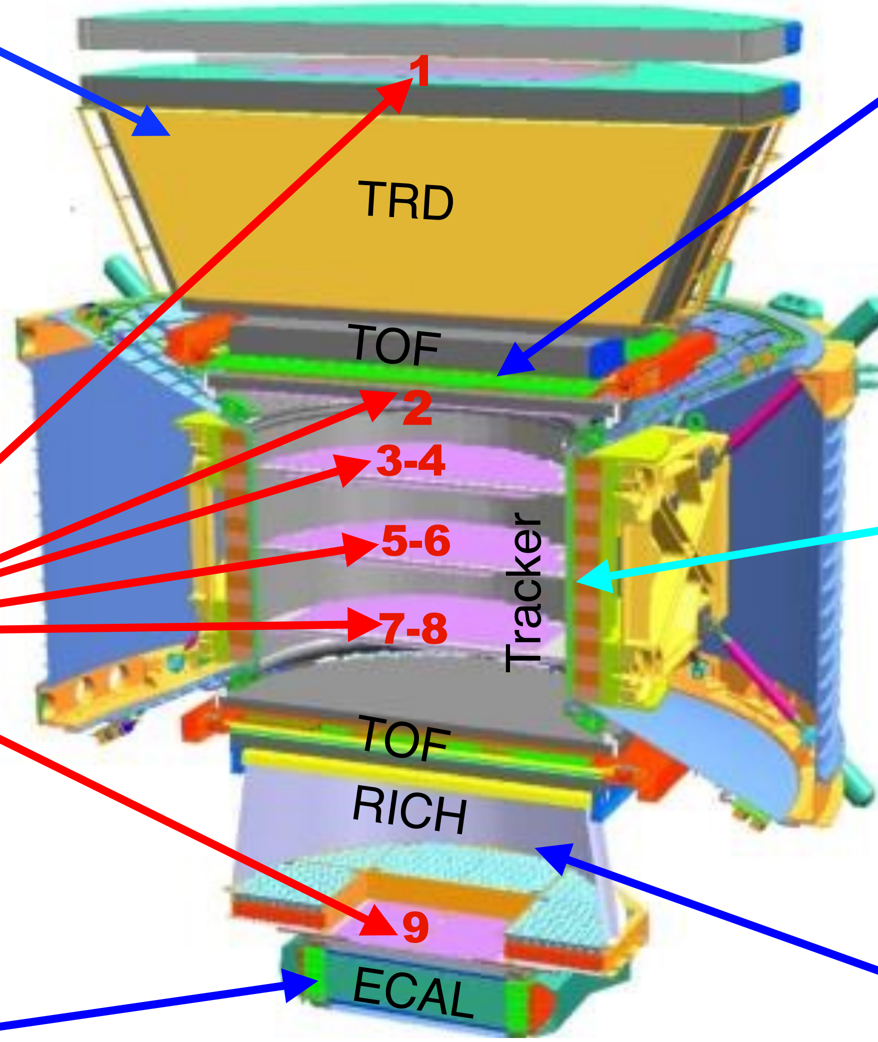
AMS is expected to take data for all the ISS lifetime (now projected to 2024)

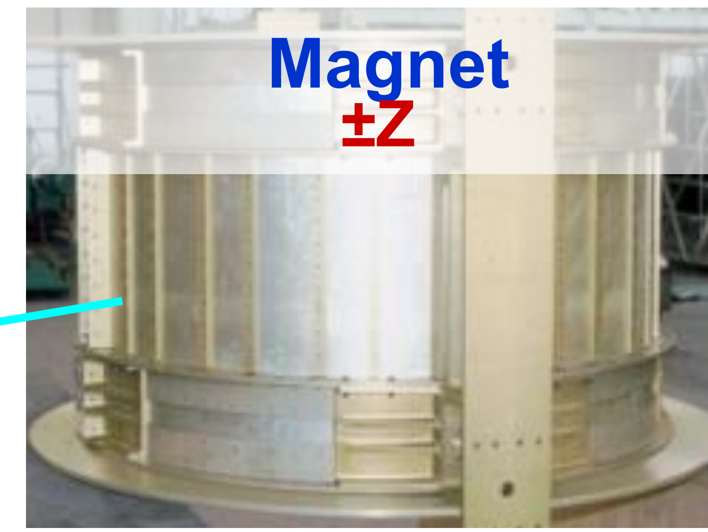
AMS in a nutshell



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







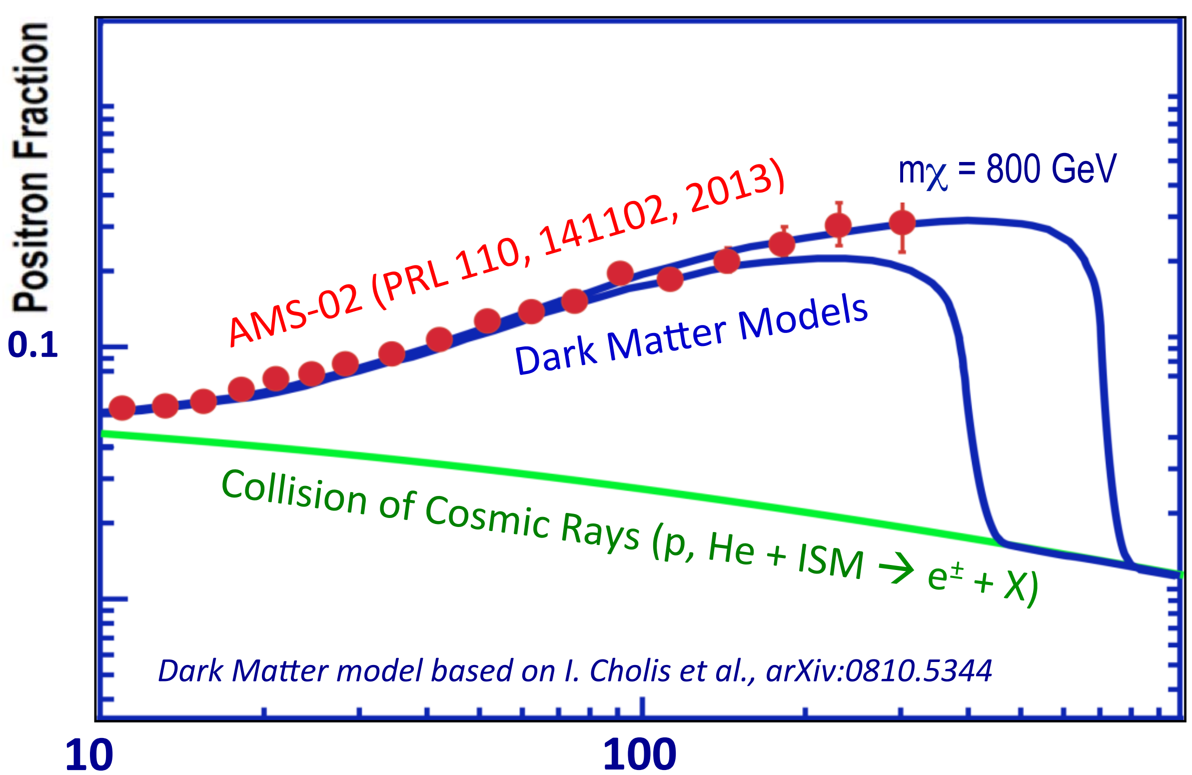
***Z, P** are measured independently by the Tracker, RICH, TOF and ECAL*

3

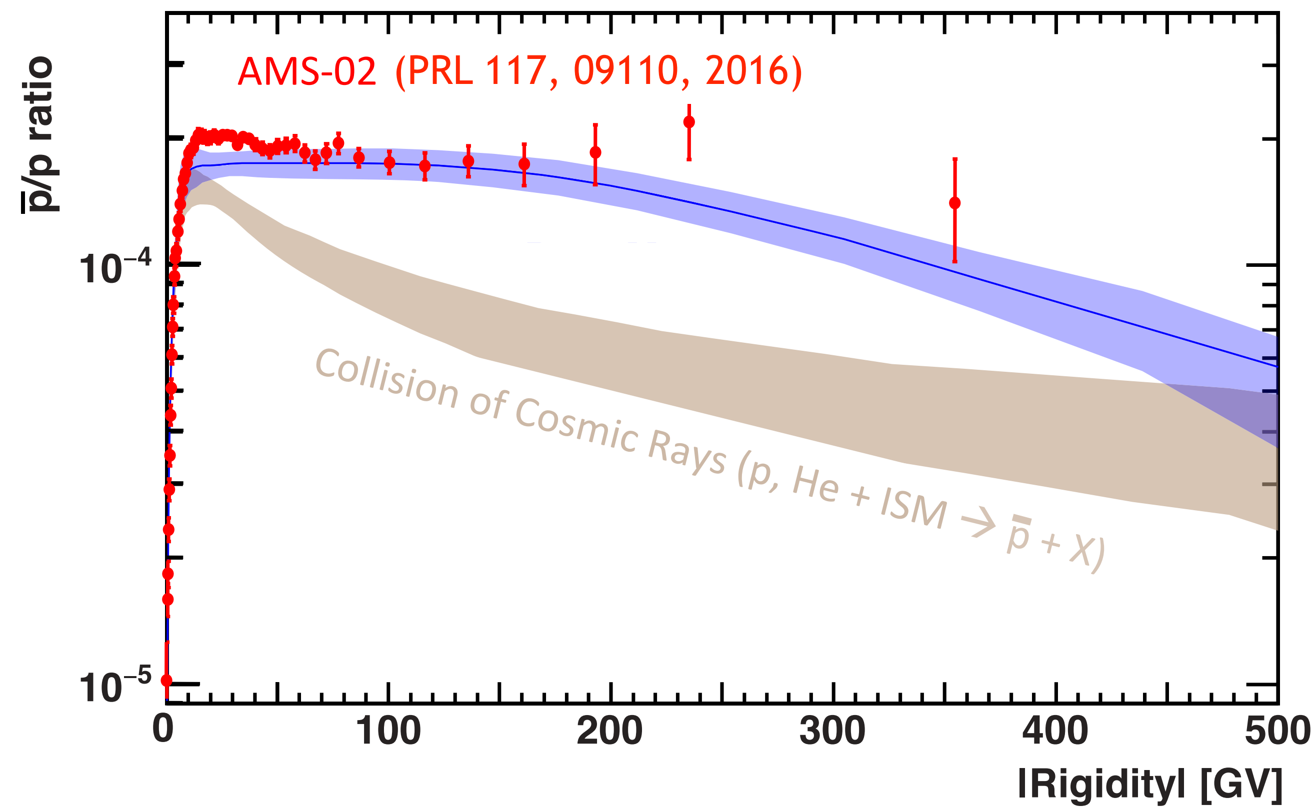
Dark Matter searches

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

Positron fraction: $\chi + \chi \rightarrow e^{\pm} + \ldots$



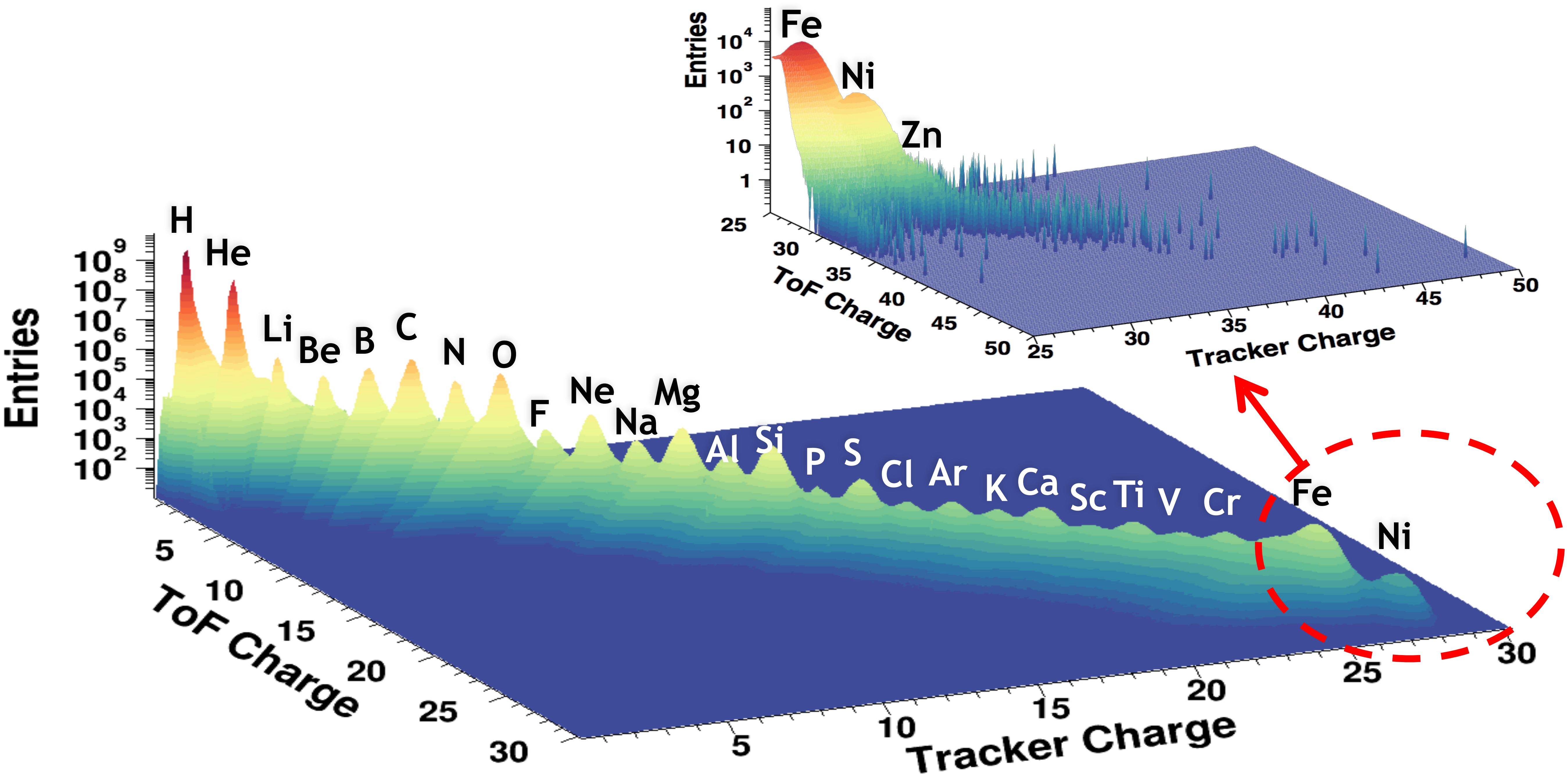
Antiprotons: $\chi + \chi \rightarrow \bar{p} + \ldots$



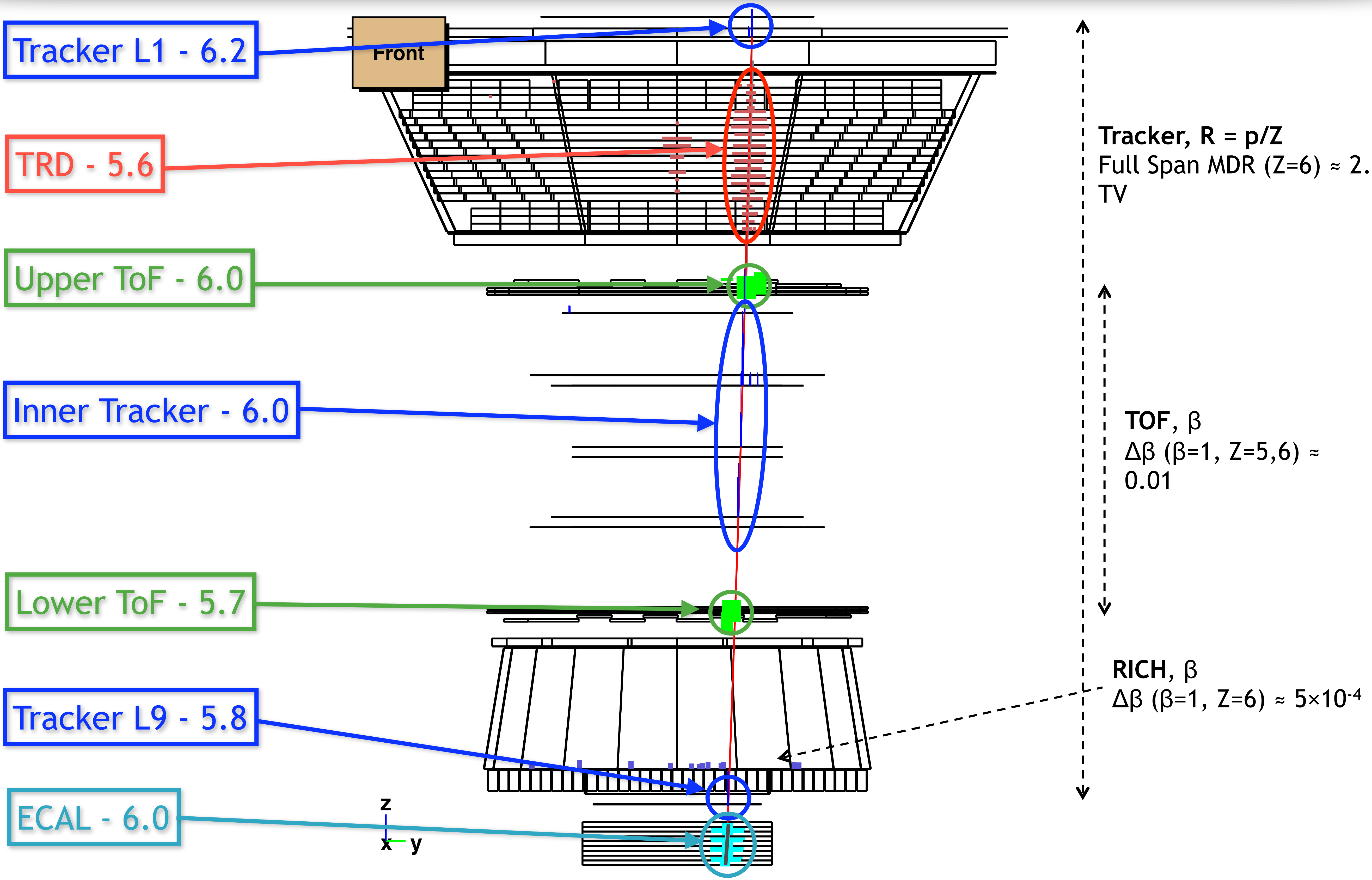
A detailed understanding of the **background** is mandatory. This needs precise knowledge of:

- The flux of primary (progenitors) Cosmic Rays **(p, He, …)**
- Behaviour of the CRs propagation in the Galaxy **(B/C, …)**

Nuclei identification in AMS



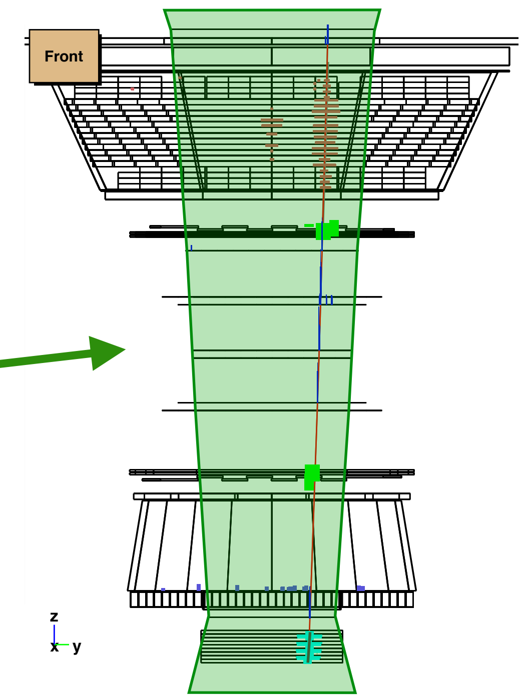
Charge measurements in AMS



Event selection

Selection

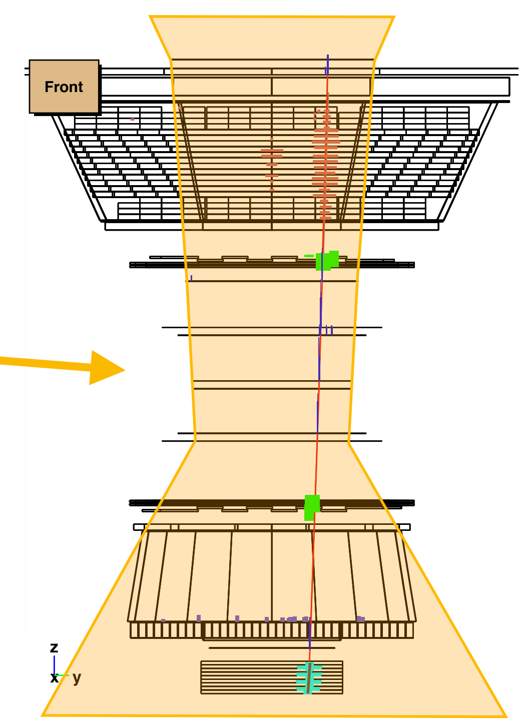
- Tracker and TOF Charge compatibility.
- Track passing through L1 with compatible charge.
- Tracks with at least 5 points and a good fit (χ^2_Y L2-L8 < 10).
- Rigidity above geomagnetic cutoff ($R > 1.2\ R_C$).



Long Lever Arm Analysis

- Tracker Layer 9 Charge compatible.
- Full Span Track with a good fit (χ^2_Y L1-L9 < 10).

→ *Highest possible MDR (2 TV for p, 3.0 TV for Li-B, 2.6 TV for C-O).*



Large Statistics Analysis

- No requirement on L9.
- Track with a good fit (χ^2_Y L1-L8 <10).

→ *Factor 5 more events, and less interacting events (for charge Z>2).*

Flux measurement

$$\Phi_j = \frac{N_j}{A_j \, \varepsilon_j \, T_j \, \Delta R_j}$$

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

Number of events
(in rigidity bin j, corrected for bin-to-bin migrations)

Acceptance (Effective geometrical factor) estimated with MC and validated with data

Trigger Efficiency
Estimated from data

Exposure Time
Duty cycle + Geomagnetic cutoff

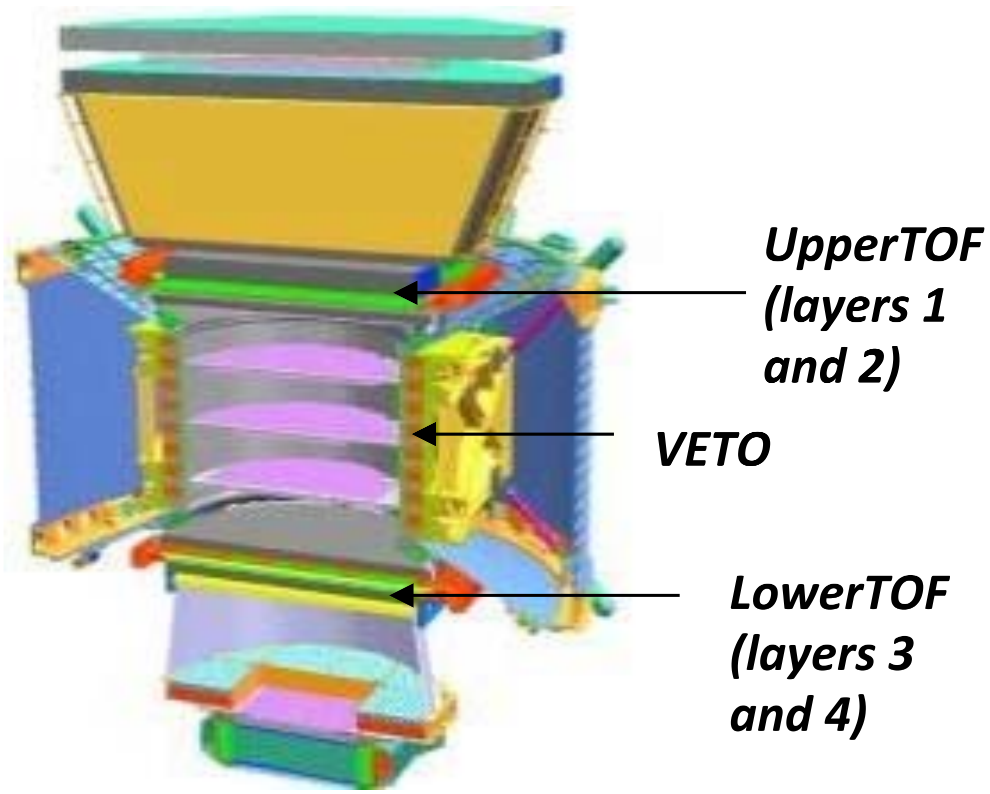
Bin width

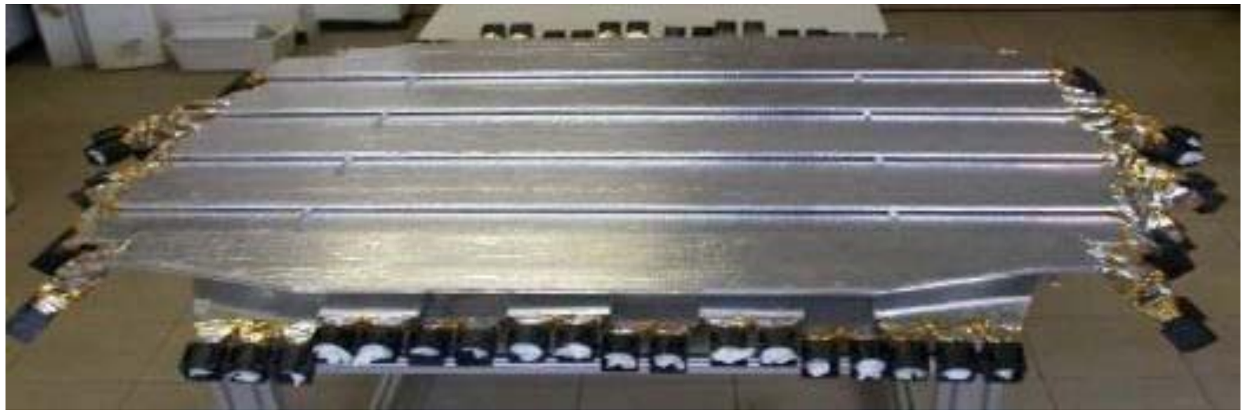
To match the high statistics (300 million protons and 50 million helium nuclei collected), extensive studies have been made of systematic errors

Trigger Efficiency

Trigger efficiency [4/4 TOF (+VETO)] was measured using 1% pre-scaled event sample obtained with unbiased 3/4 TOF coincidence trigger:
90-95% (protons) - 95-99% (helium)

$$\Phi_j = \frac{N_j}{A_j \, \varepsilon_j \, T_j \, \Delta R_j}$$





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

Trigger Efficiency

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No ACC VETO for Z>2

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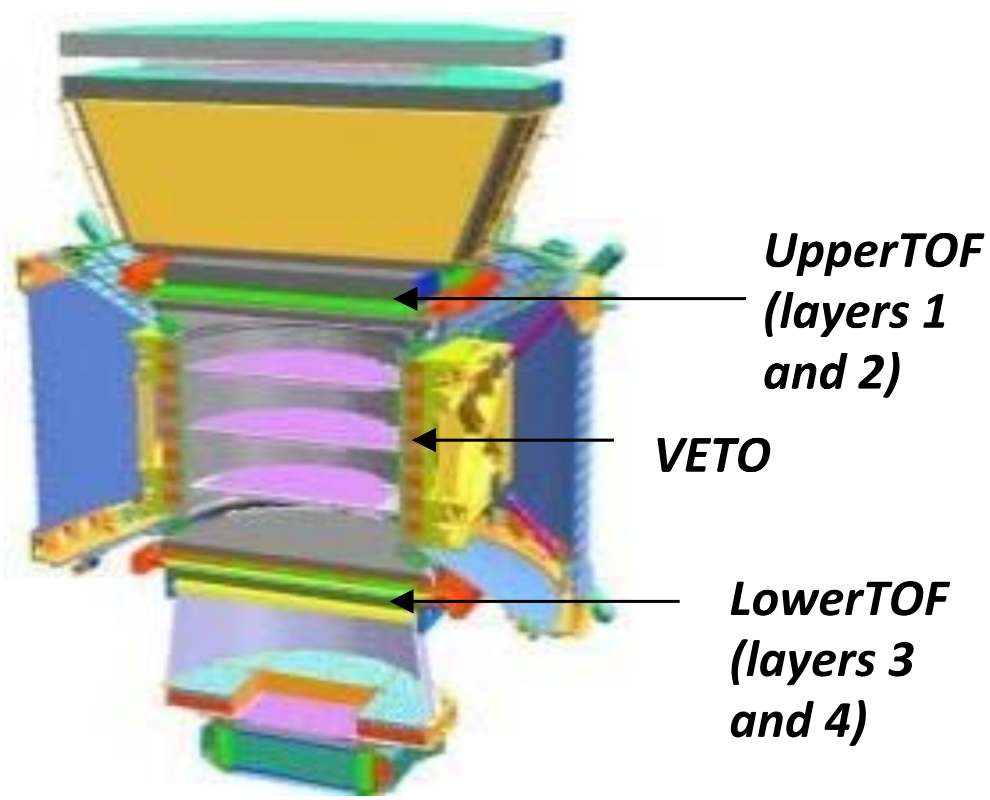

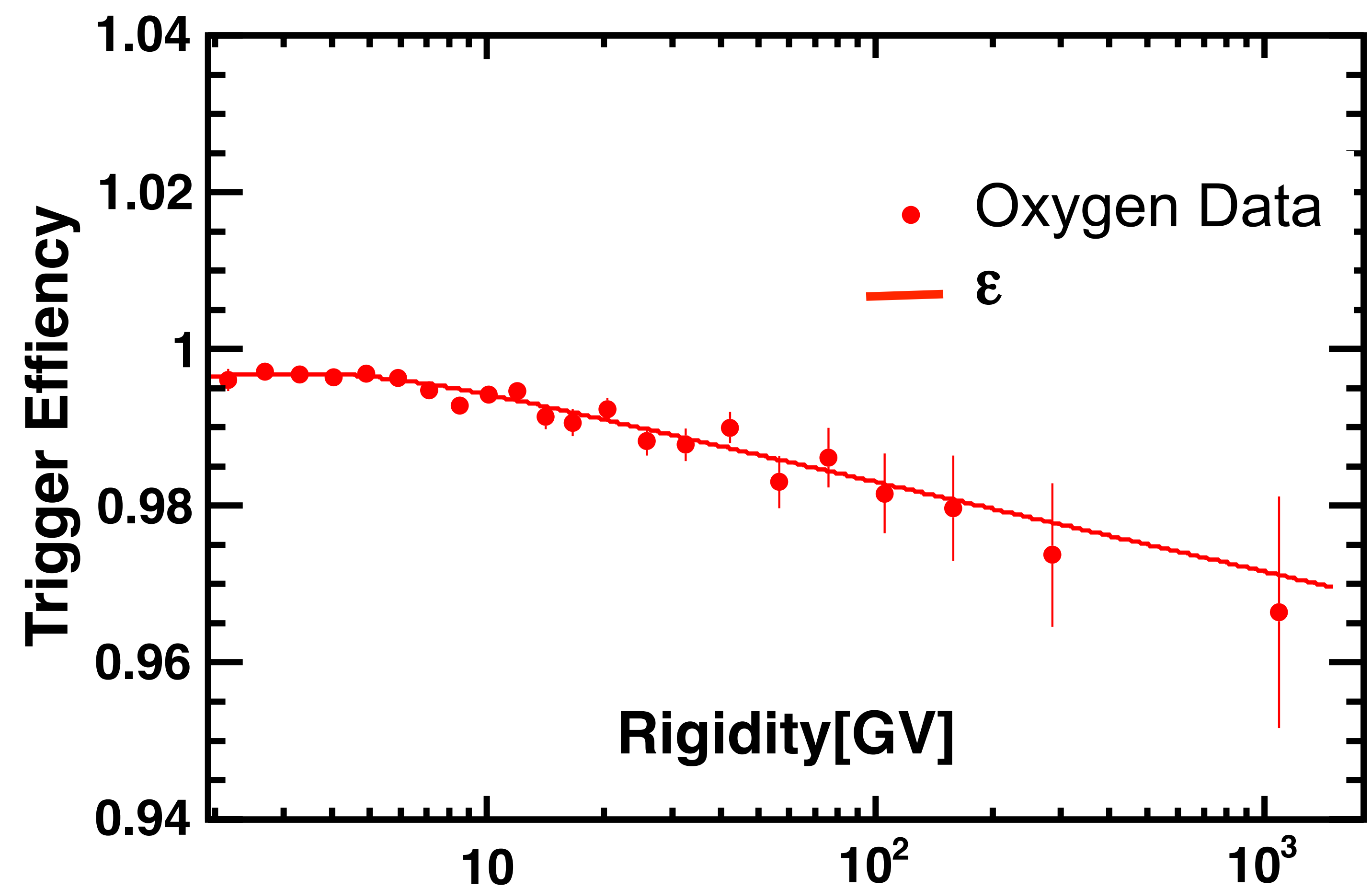

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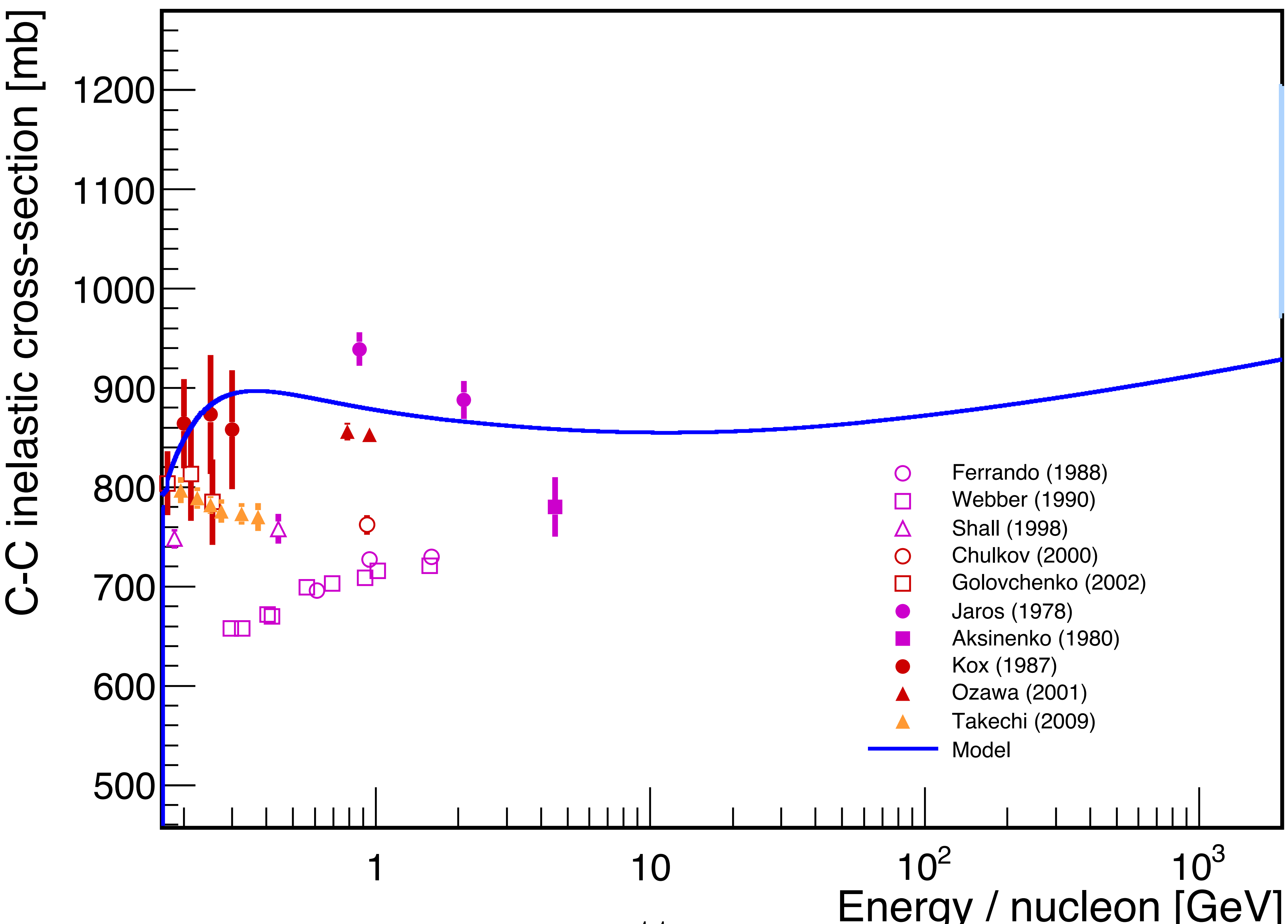
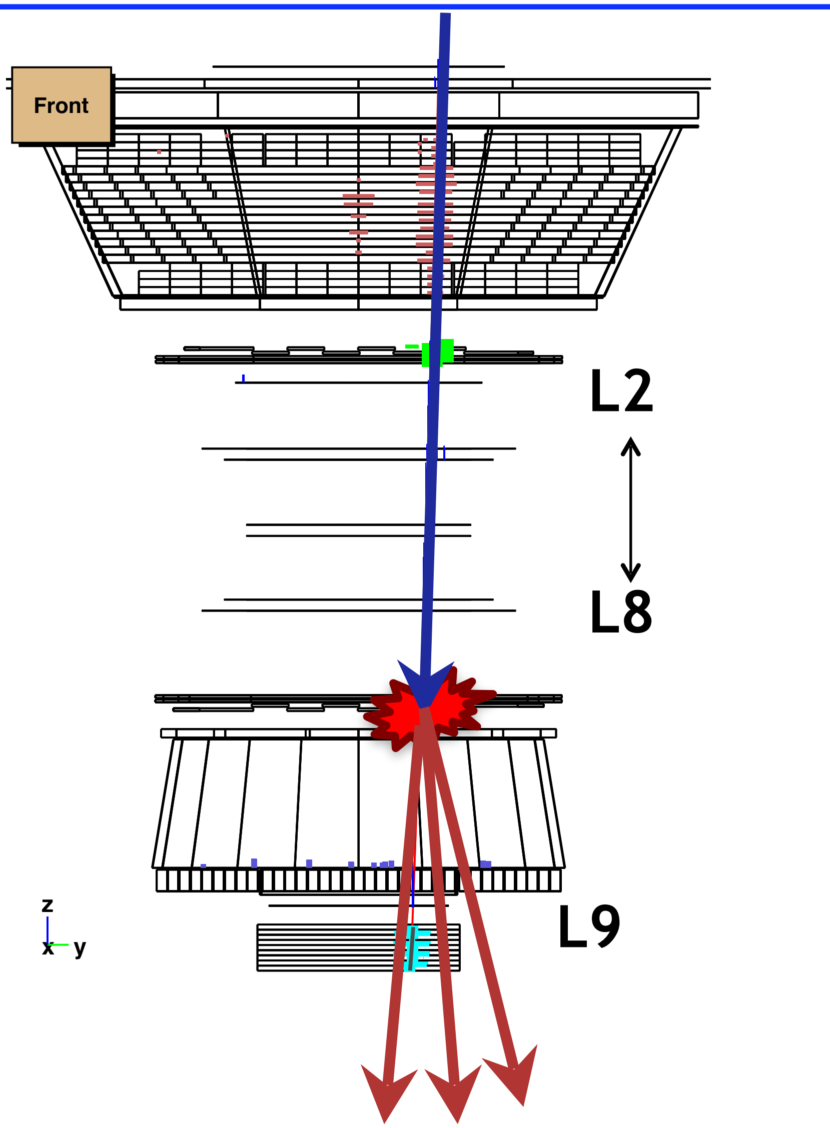
Systematics on Acceptance

The AMS-02 detector is mostly made of Carbon (73%) and Aluminium (17%). The inelastic cross-sections N+C and N+Al are only measured at very low energies (if there are measurements at all). AMS-02 can provide help with these cross-sections.

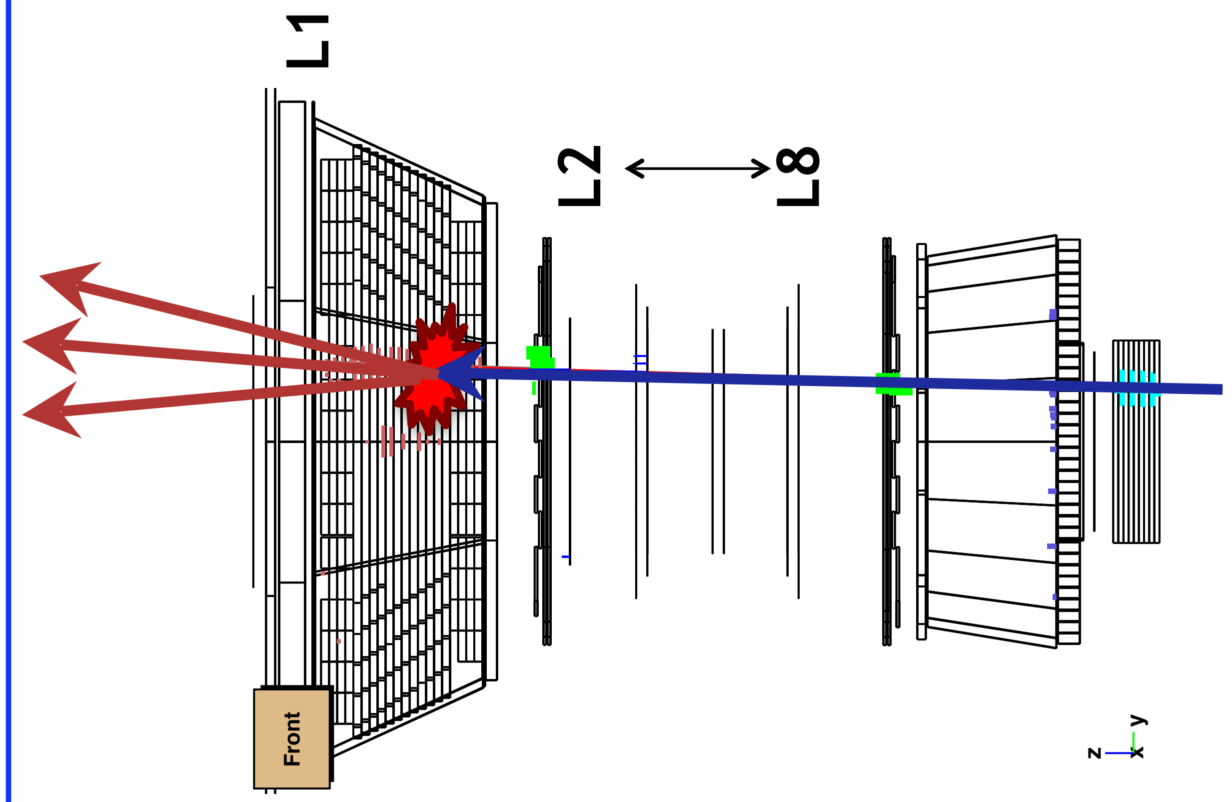
$$\Phi_j = \frac{N_j}{A_j \, \varepsilon_j \, T_j \, \Delta R_j}$$



Systematics on Acceptance



With ISS nominal orientation
Particles coming from top,
interacting on lower part of AMS



With ISS flying at 90° w.r.t. zenith
Particles coming from bottom,
interacting on upper part of AMS
(only ~2 days of data available)

Performing this measurement on both orientations cancels any bias in the material budget of AMS MC simulation. In this way, varying the cross-sections in the MC, the one with the best agreement with data is chosen.

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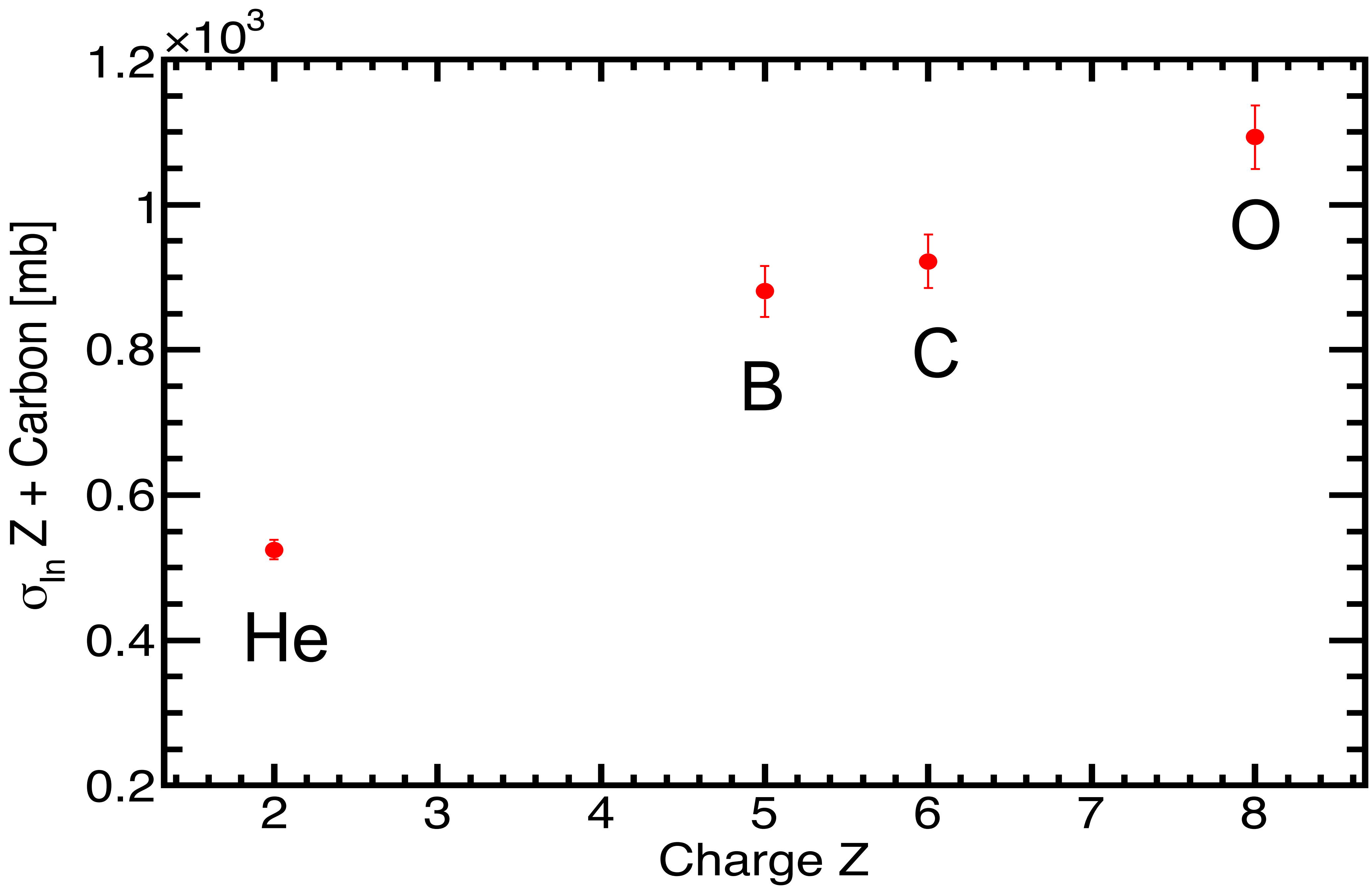
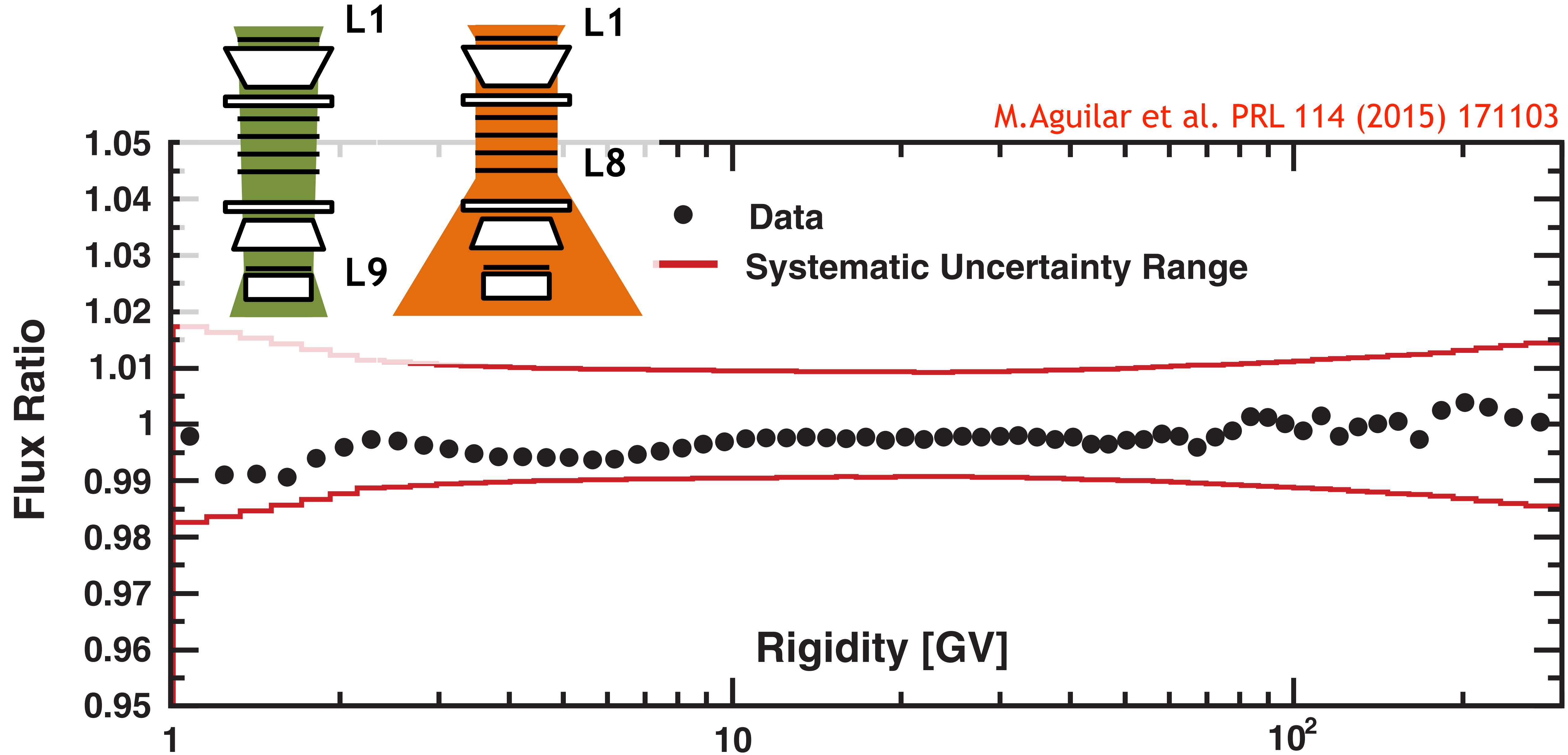


Measurement verification

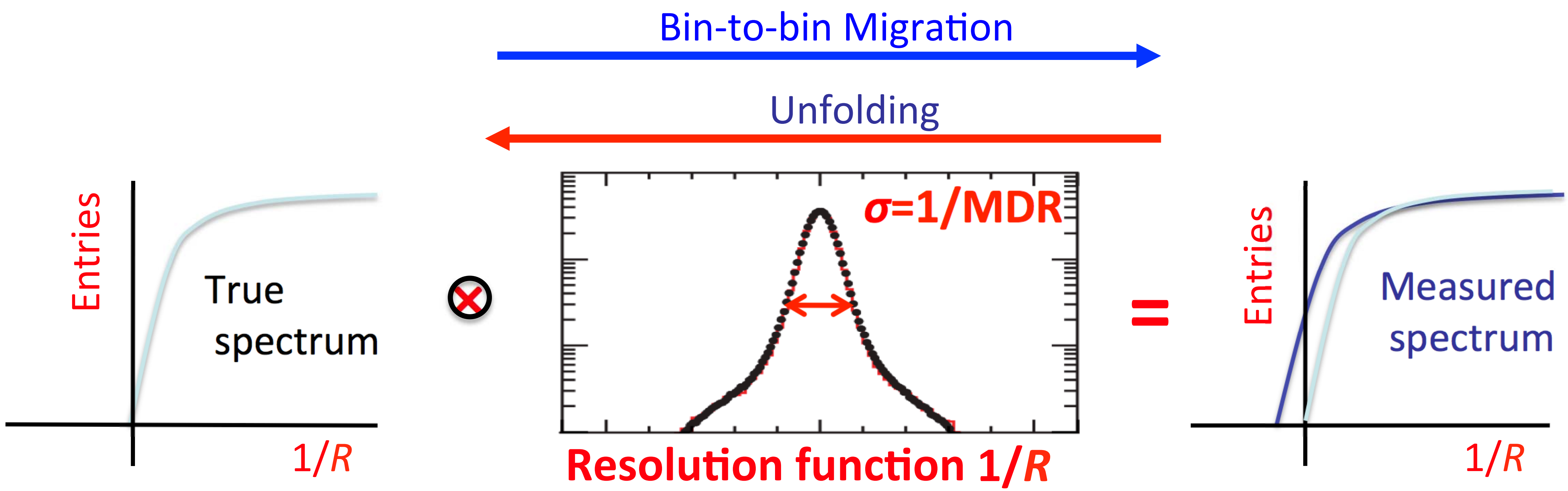
Fluxes measured using events passing through L1-L9
divided by the ones measured using events passing through L1-L8 (or L2-L8).
The observed agreement verifies:
(i) **acceptance**: the amount of material traversed is different
(ii) **unfolding**: bin-to-bin migration is different due to different resolution



Unfolding

Due to the finite resolution of the Tracker events can be measured in a rigidity bin they don't belong to. This, combined with the steep power-law nature of the CR spectrum leads to a distortion in the measured flux. Many different procedures to correct for this effect, all relying on a precise knowledge of the resolution function.

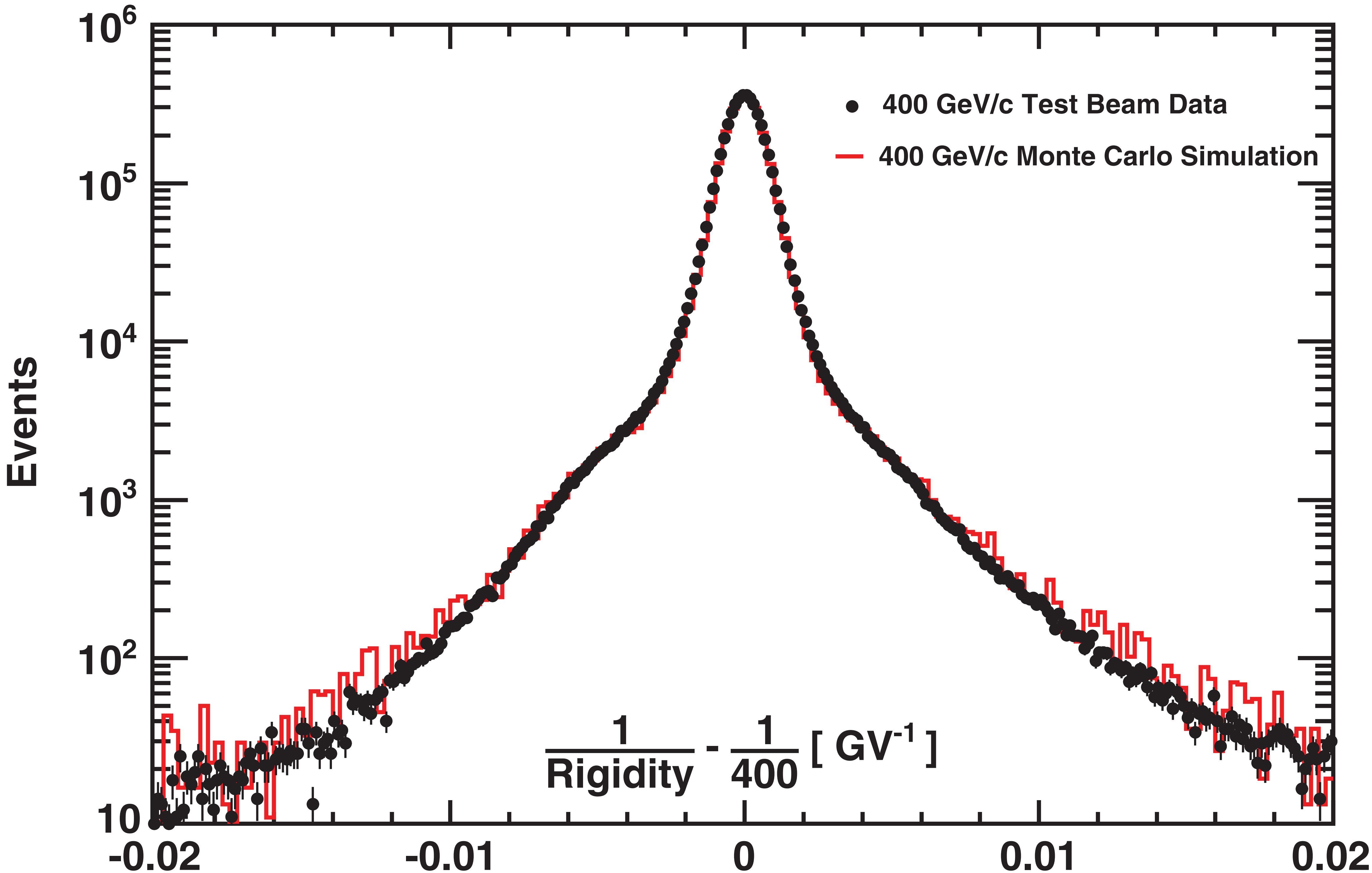
$$\Phi_j = \frac{N_j}{A_j \, \varepsilon_j \, T_j \, \Delta R_j}$$



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

Unfolding

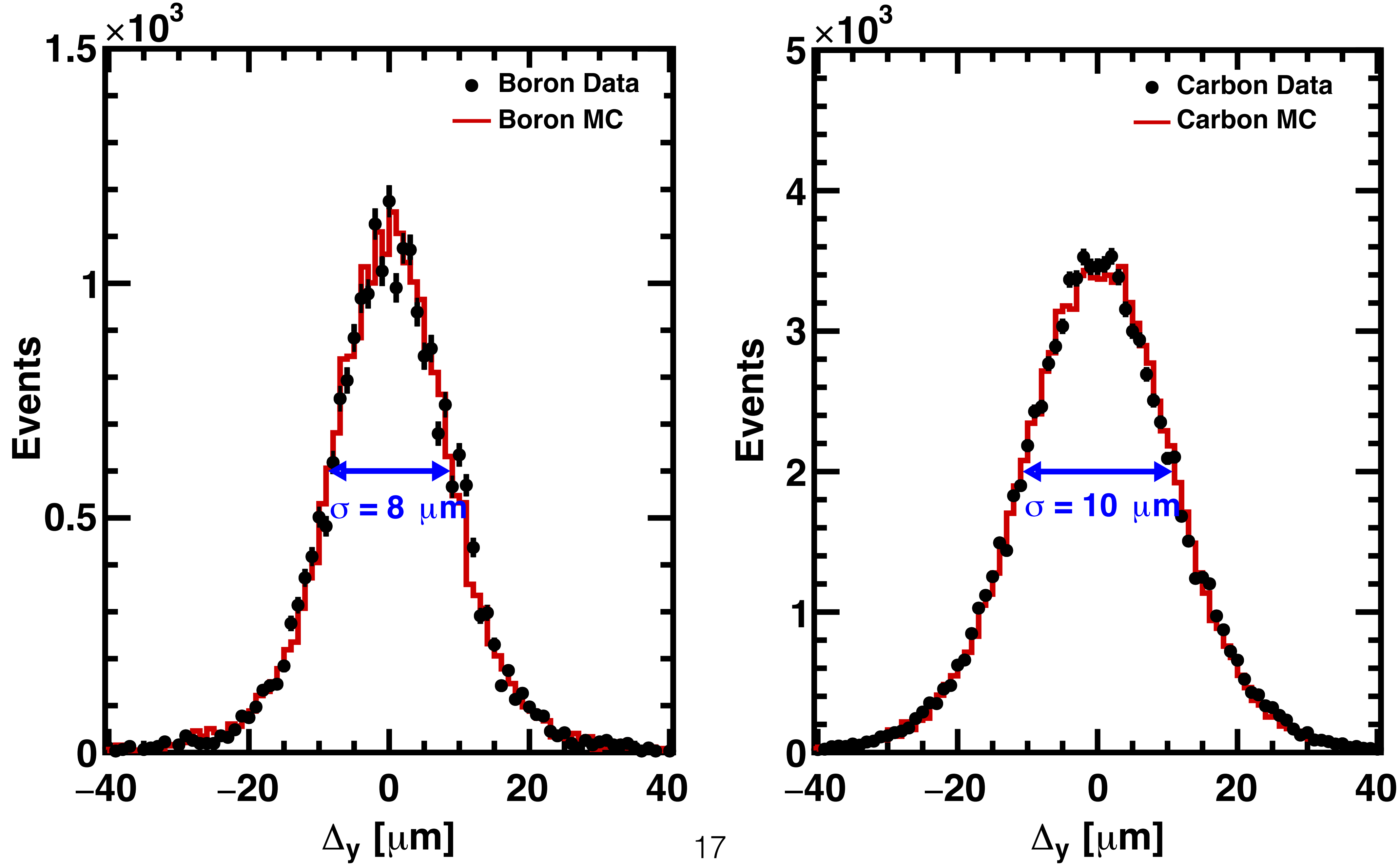
The resolution function for protons was measured on a 400 GV proton beam from the CERN SPS and the result was used to validate the MC simulation.



Systematics on Rigidity Resolution

The MC rigidity resolution functions for Z>2 were verified with the ISS data in multiple ways. One of the comparison is the validation of the spatial resolution of the inner tracker.

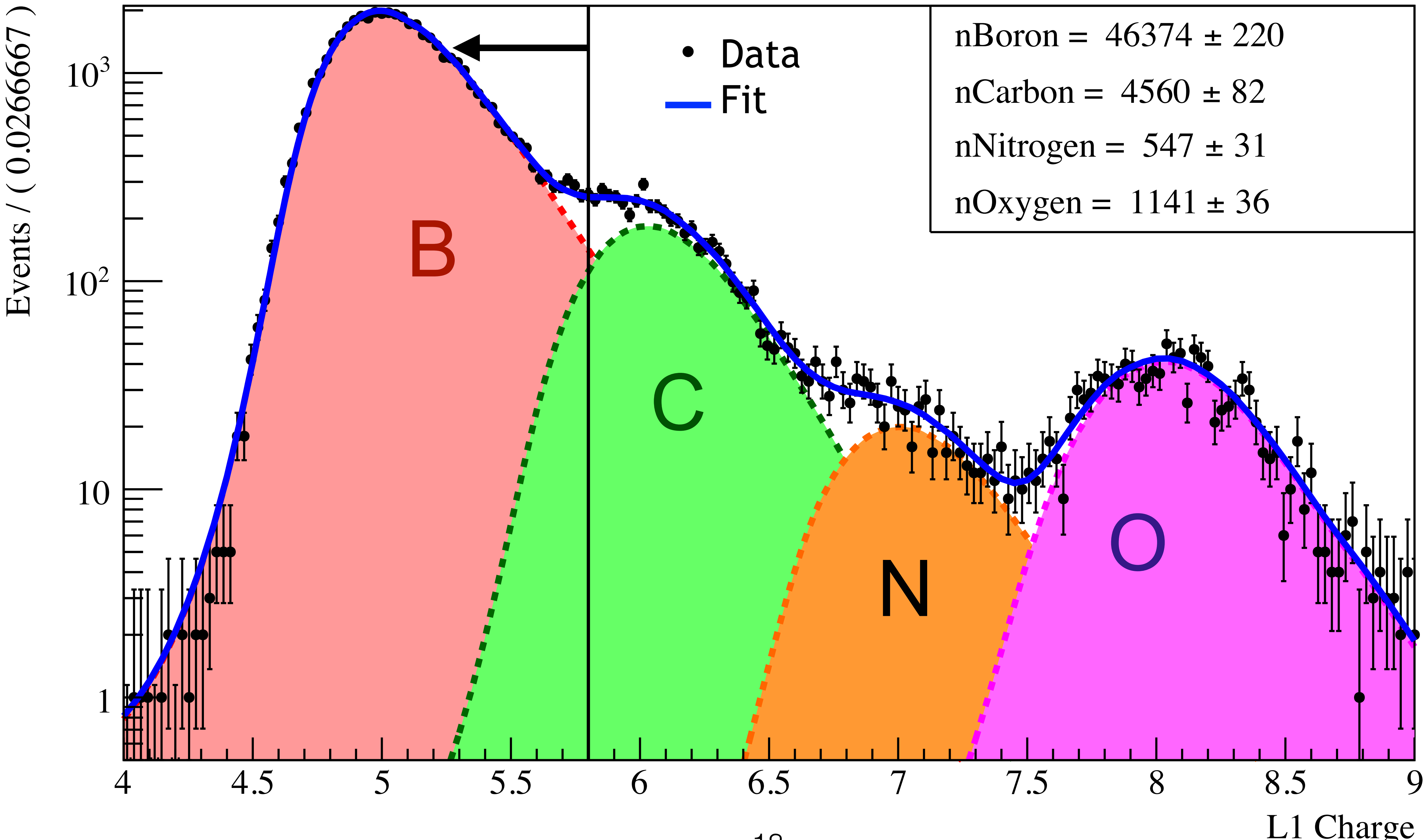
Systematic errors arising from the understanding of the resolution matrix and the bin-to-bin migration unfolding procedures account for 1% below 200GV and from 3% to 6% at 2.5 TV.



Backgrounds

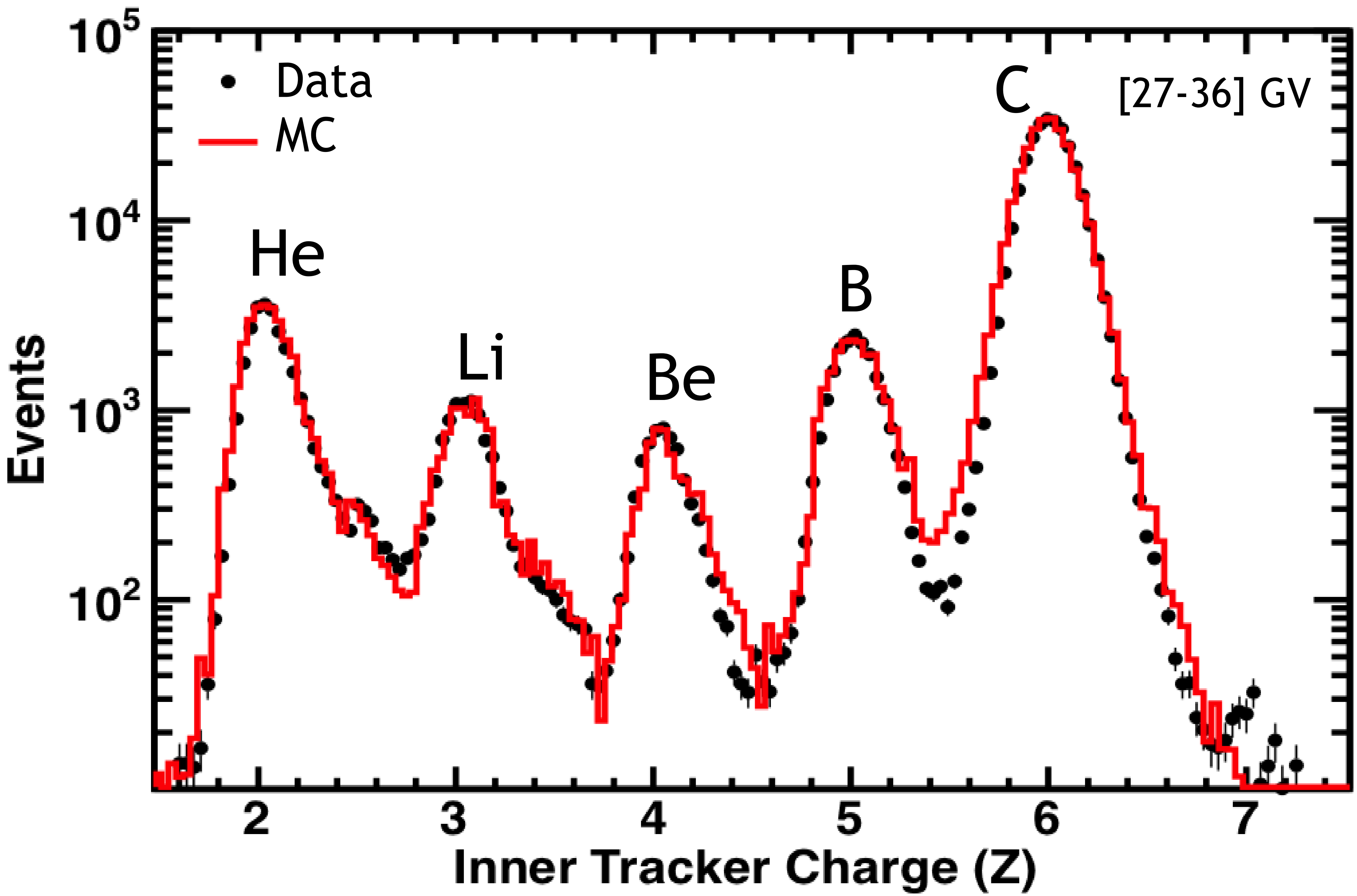
Background from heavier elements, which interact between Tracker L1 and L2 can be measured from Data by fitting the Charge Distribution in L1. This typical systematic error <0.5%

Contamination < 3%
Selection efficiency > 96%
Systematics on the knowledge of the charge spectra are included in final error.



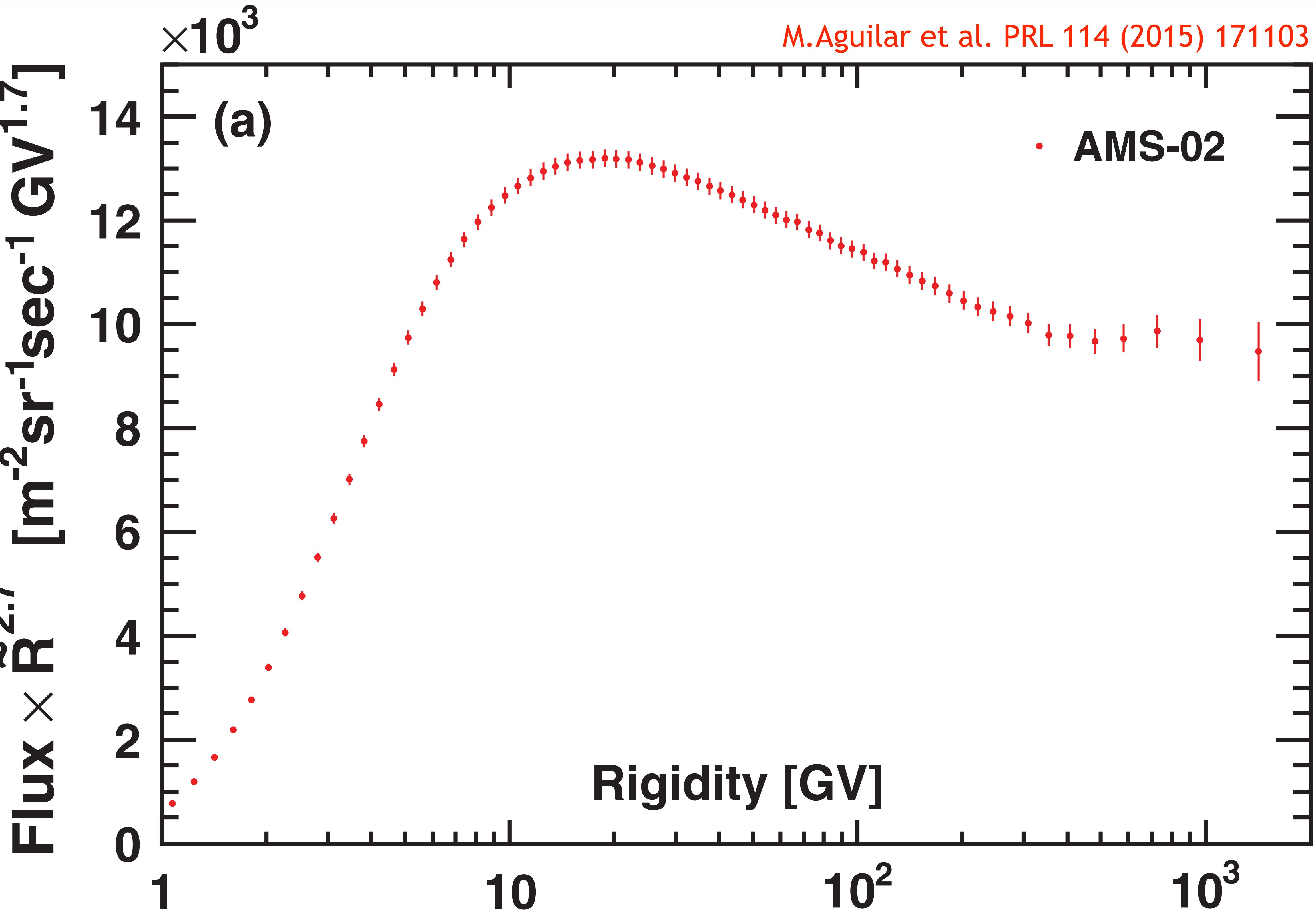
Interactions above L1

Background generated above L1 is calculated using MC and light nuclei fluxes measured by AMS.
MC interaction channels (ex. C + C, Al → B + X) have been verified with data (see below).
Background is up to 9% for secondary nuclei like Li, Be, B, N associated systematic error is below 1%.



AMS Proton Flux

M.Aguilar et al. PRL 114 (2015) 171103



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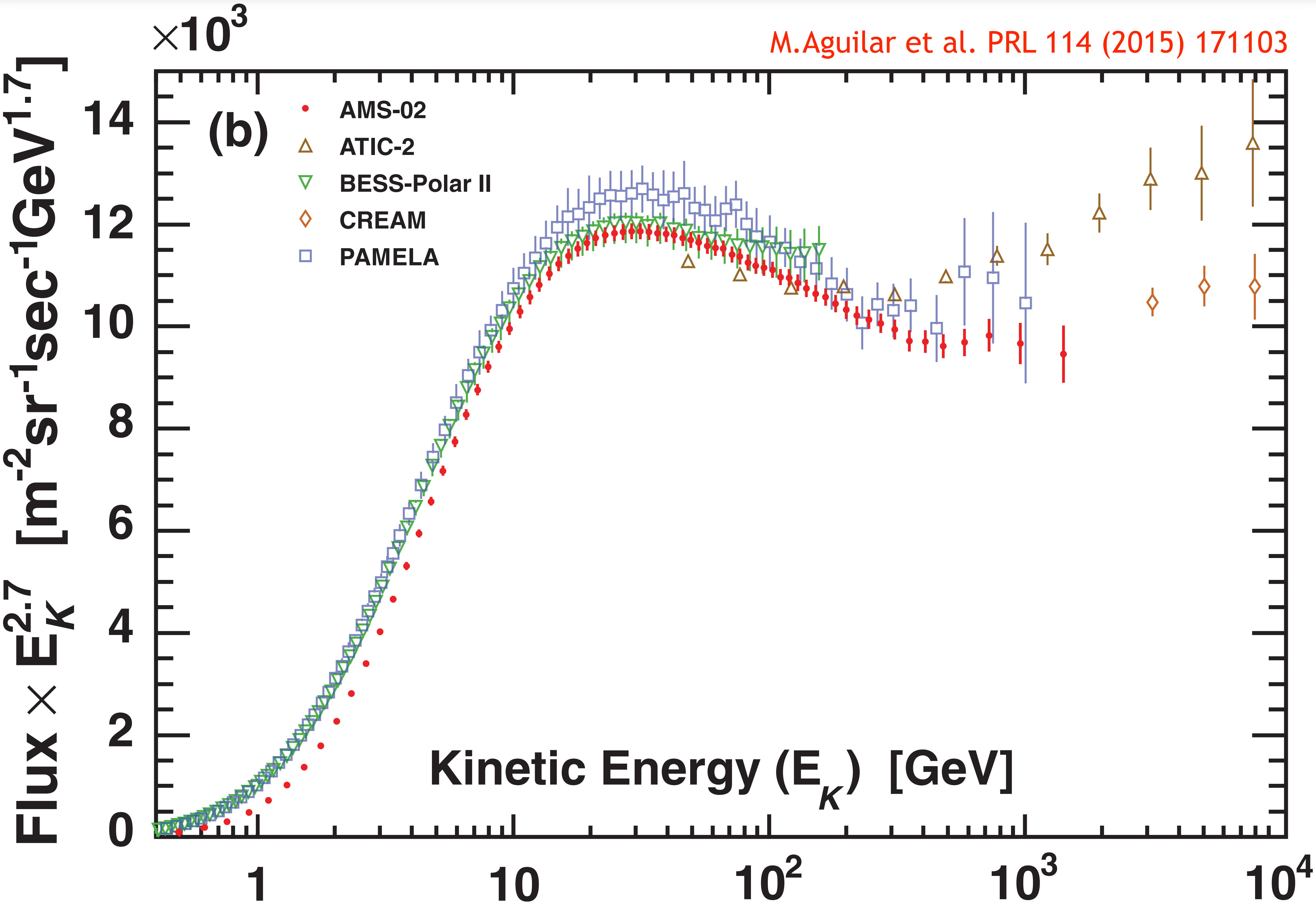
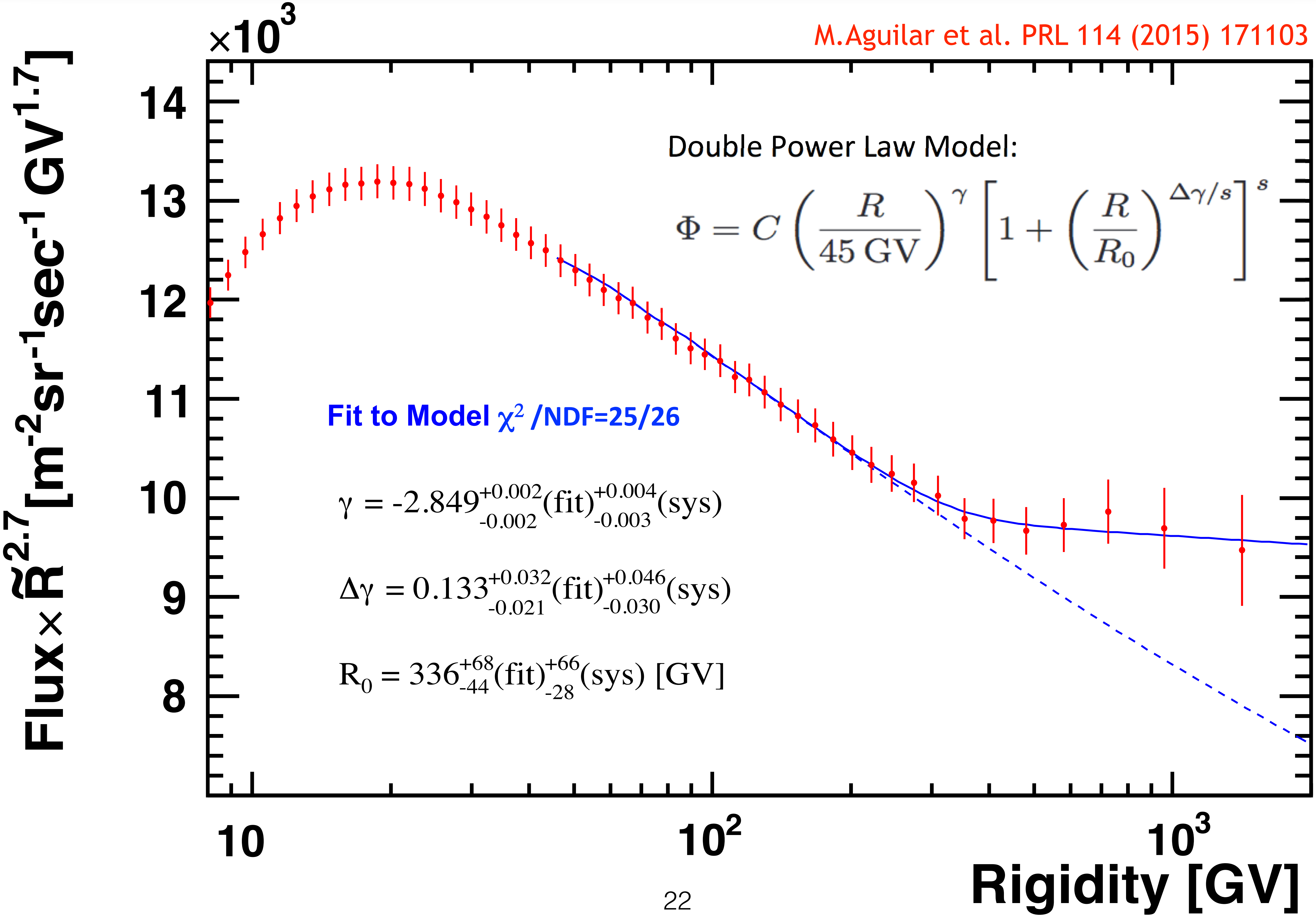


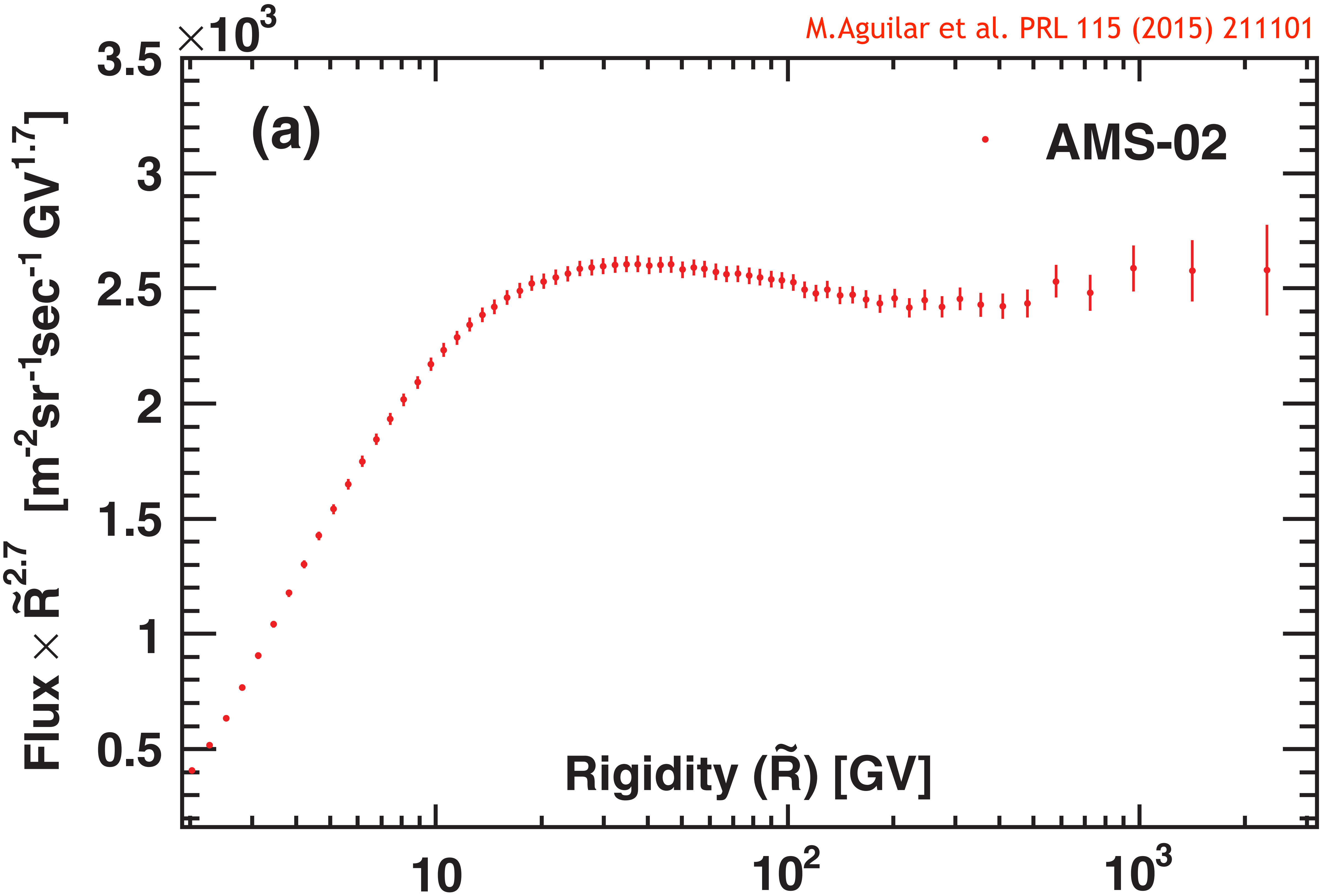
Not a single power-law

M.Aguilar et al. PRL 114 (2015) 171103

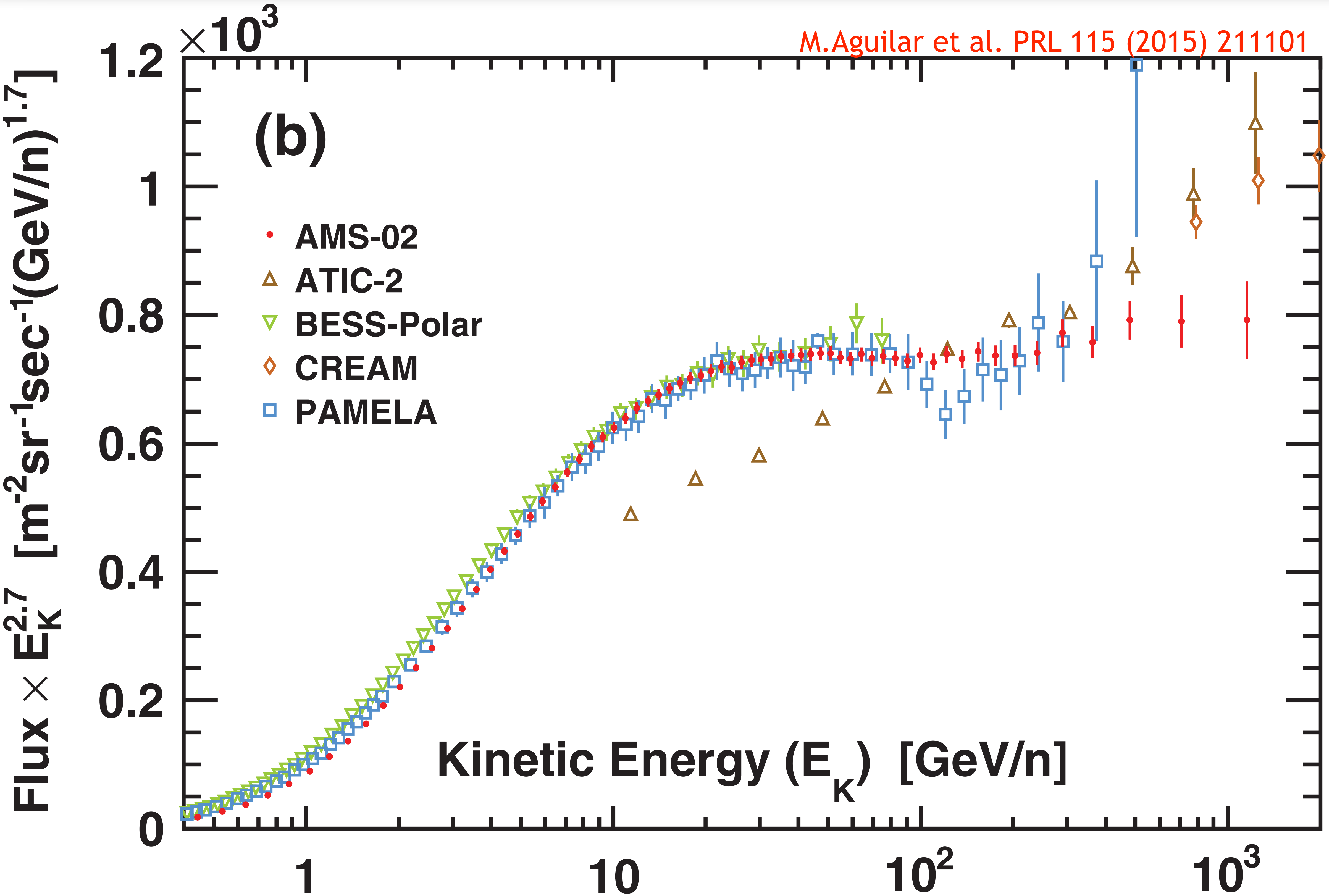


AMS Helium Flux

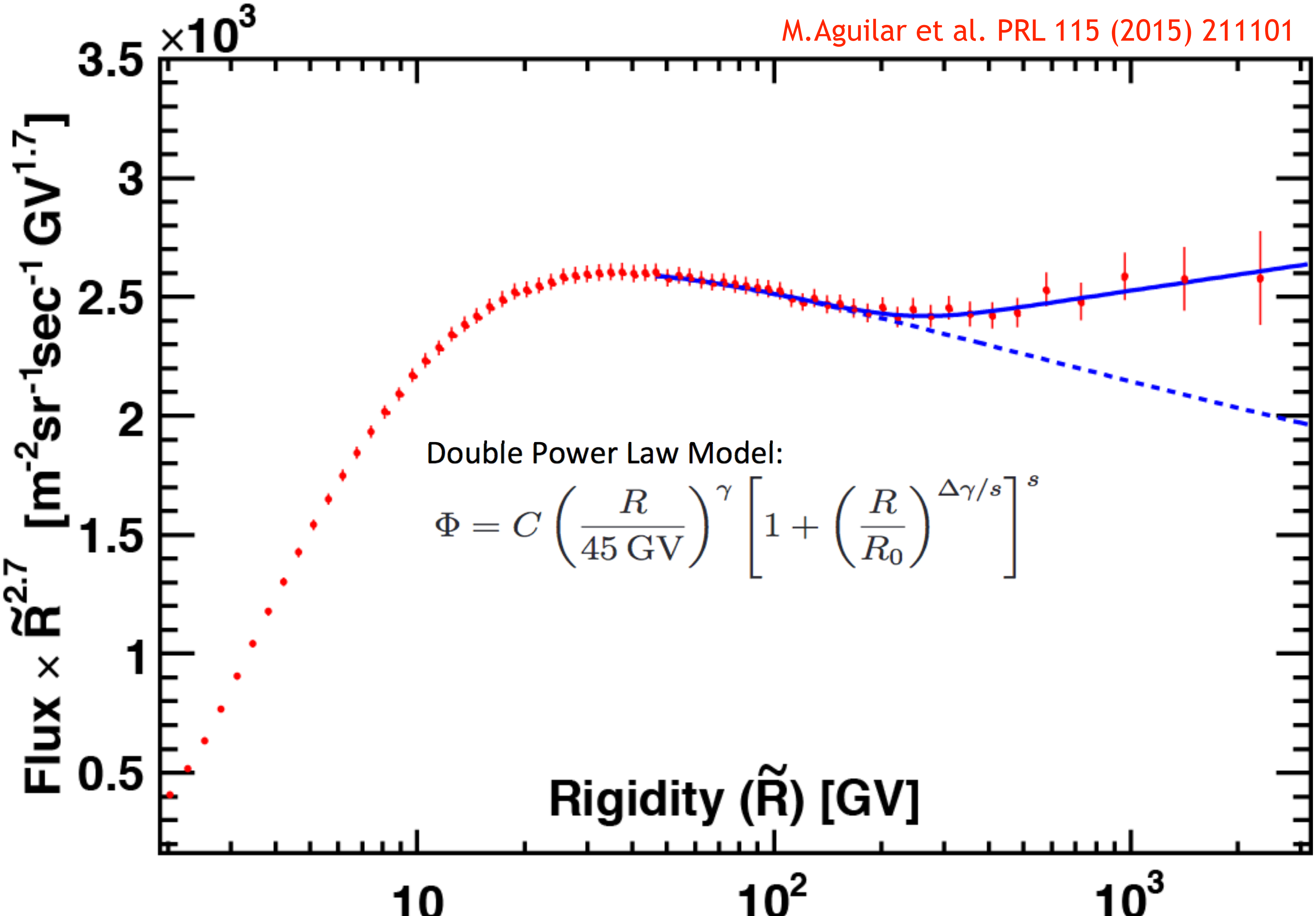
M.Aguilar et al. PRL 115 (2015) 211101



AMS Helium Flux



Not a single power-law



Spectral index

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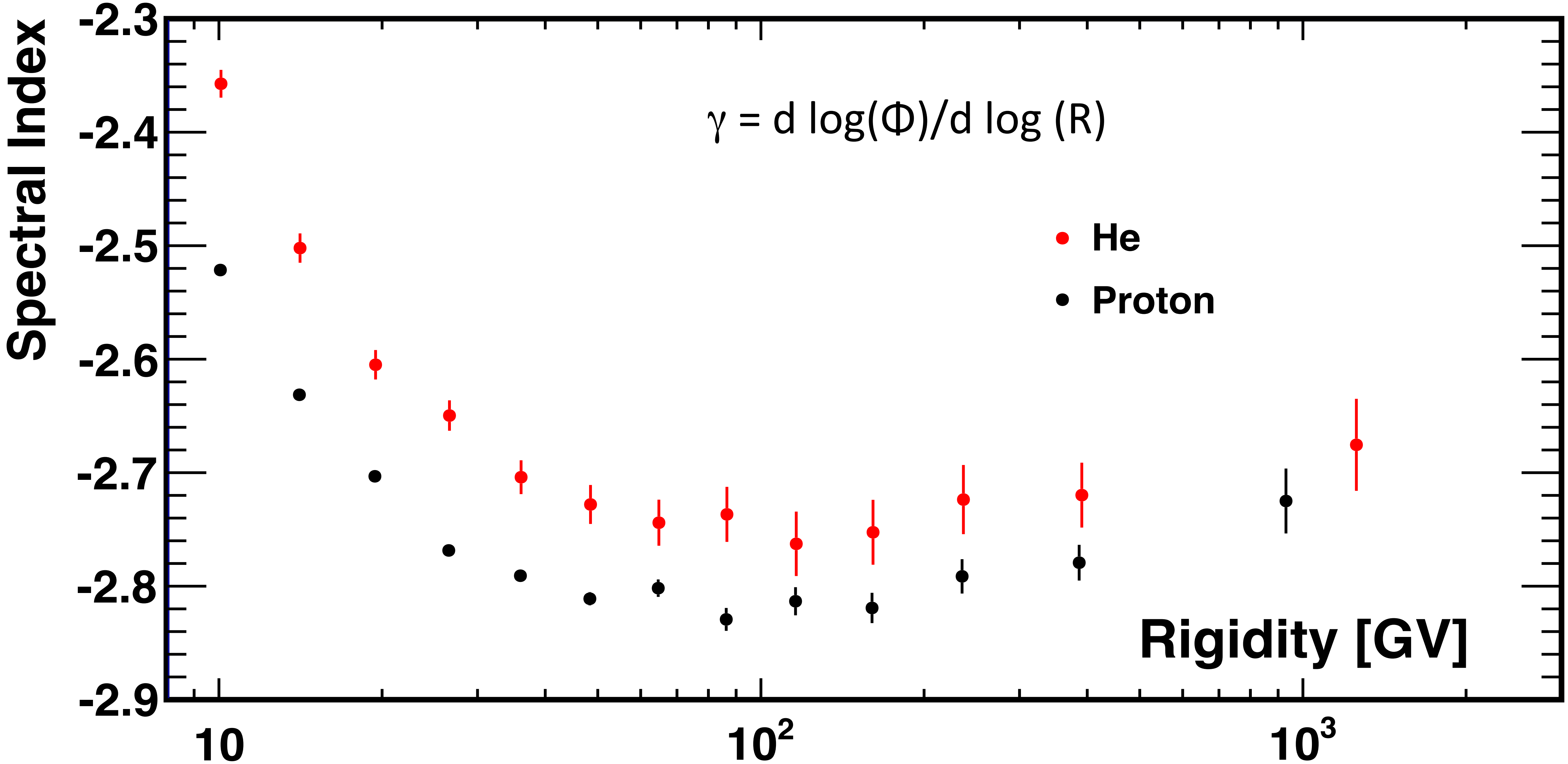
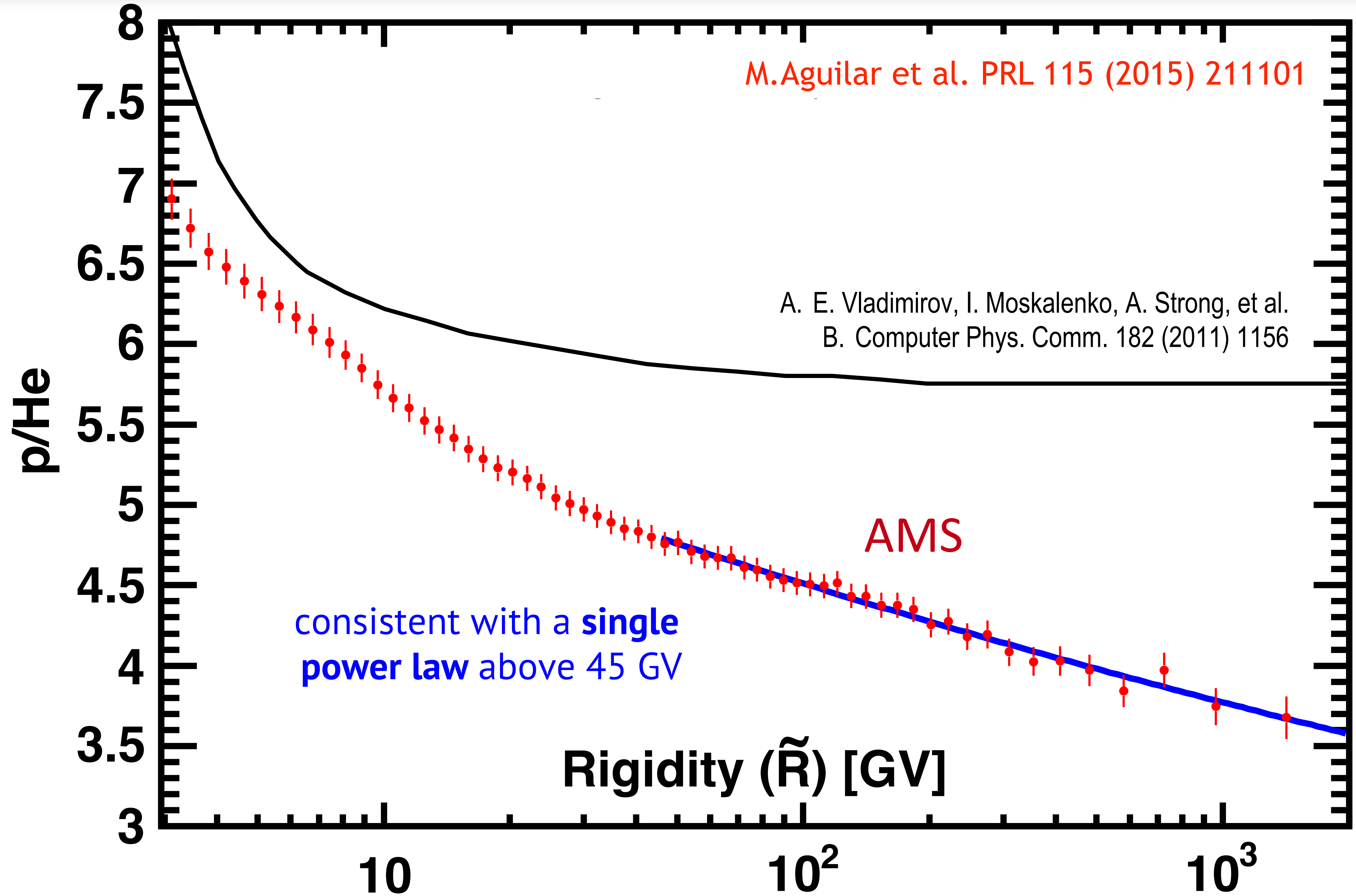


Even though the flux magnitude is different, they present similar energy dependence.

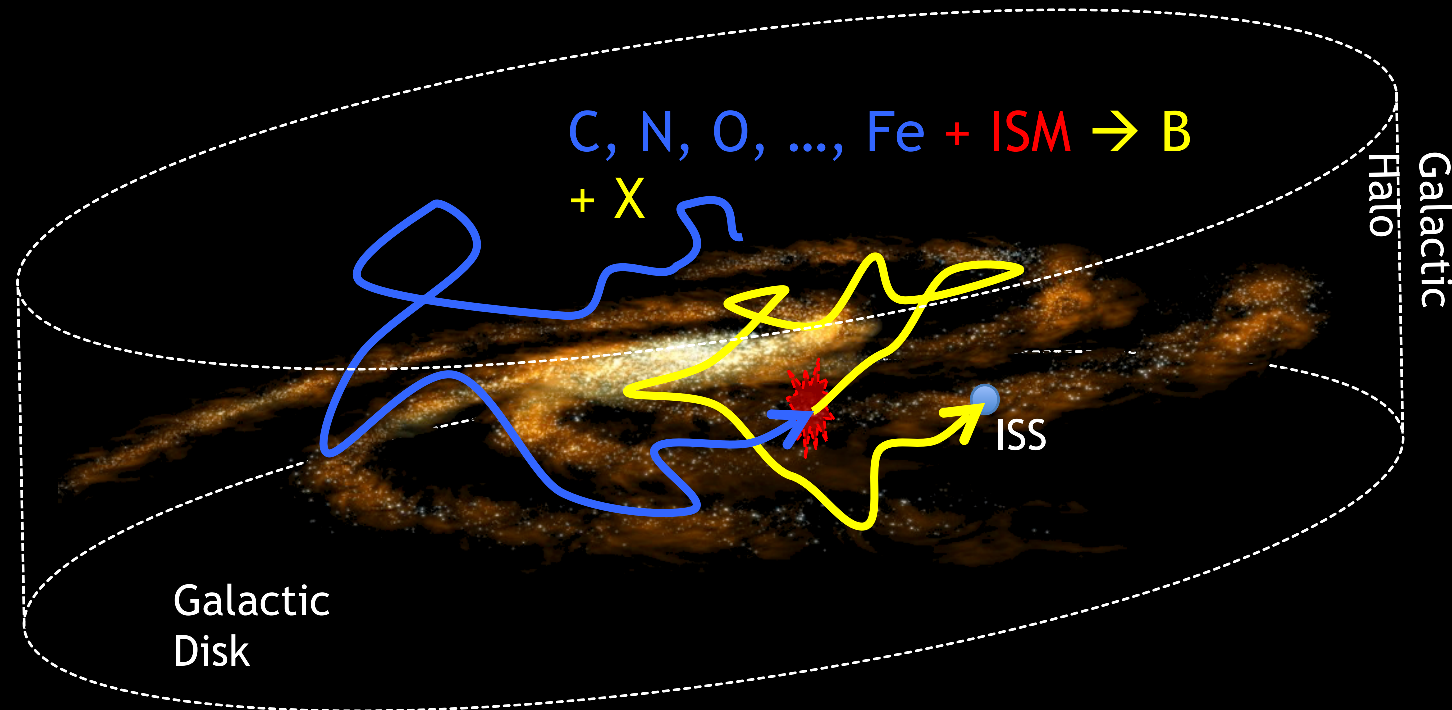
Spectral index



Even though the flux magnitude is different, they present similar energy dependence.
Also shown when examining the p/He flux ratio

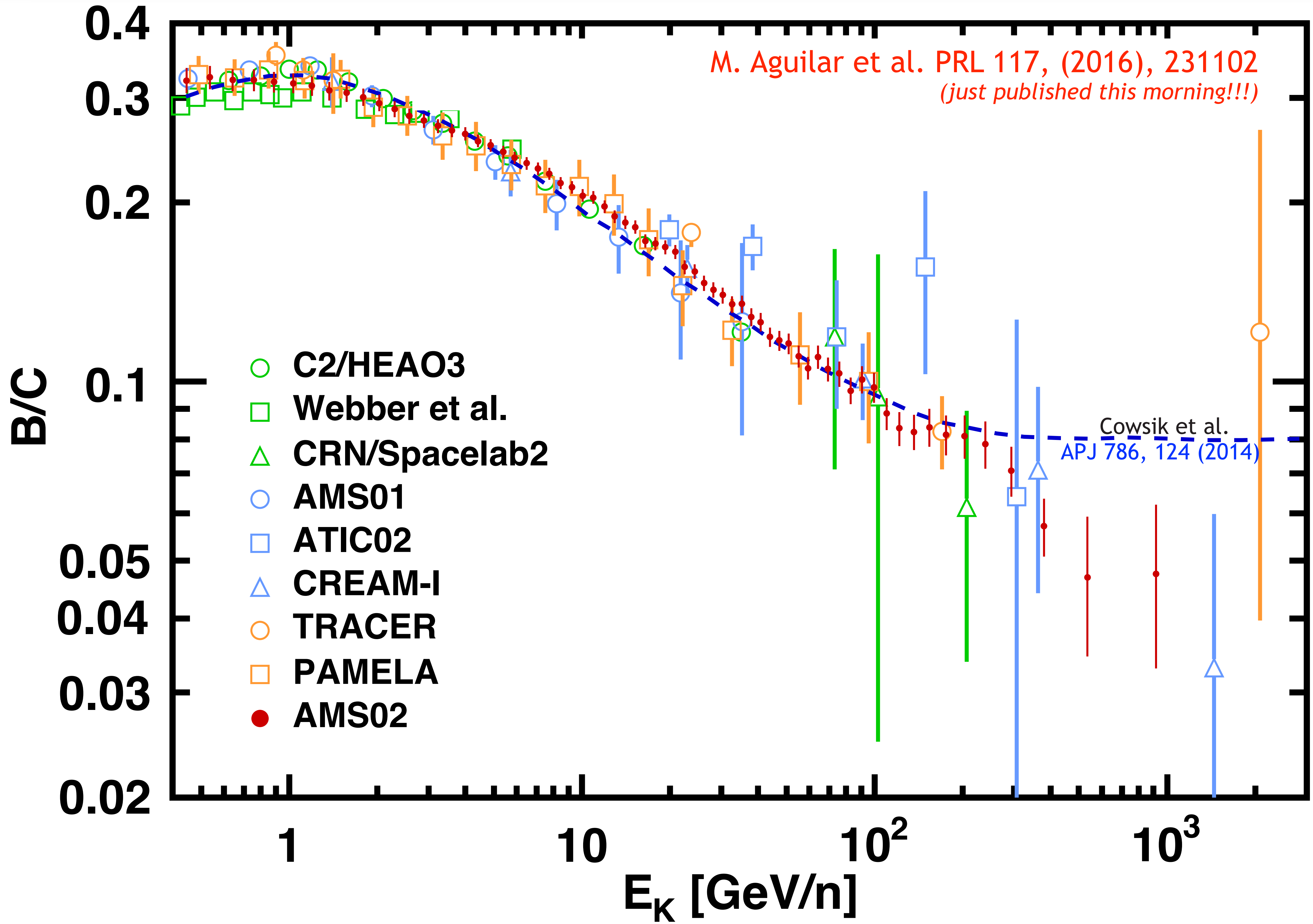
Secondary/primary cosmic rays

The B/C flux ratio and other secondary/primary ratios are powerful tools to study the properties of cosmic ray propagation as secondaries are assumed to be produced purely from collision of primary cosmic rays, such as Carbon and Oxygen, with the interstellar medium (ISM).

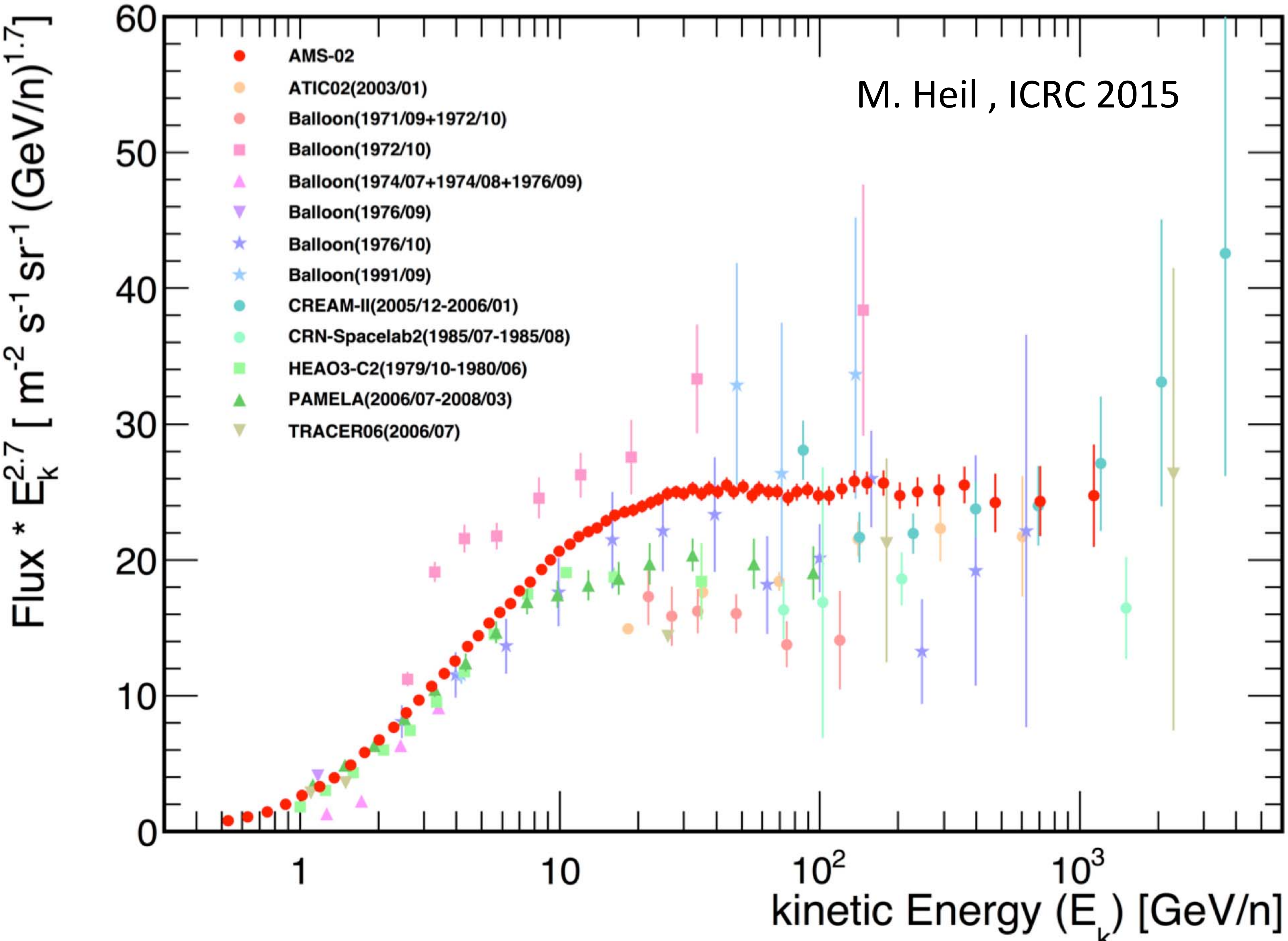


CRs are commonly modelled as a relativistic gas diffusing into a magnetised plasma. Diffusion models based on different assumptions predict different behaviour for B/C ~ R^{δ}. With Kolmogorov interstellar turbulence model a $\delta = -1/3$ is expected, while Kraichnan theory leads to $\delta = -1/2$.

B/C flux ratio

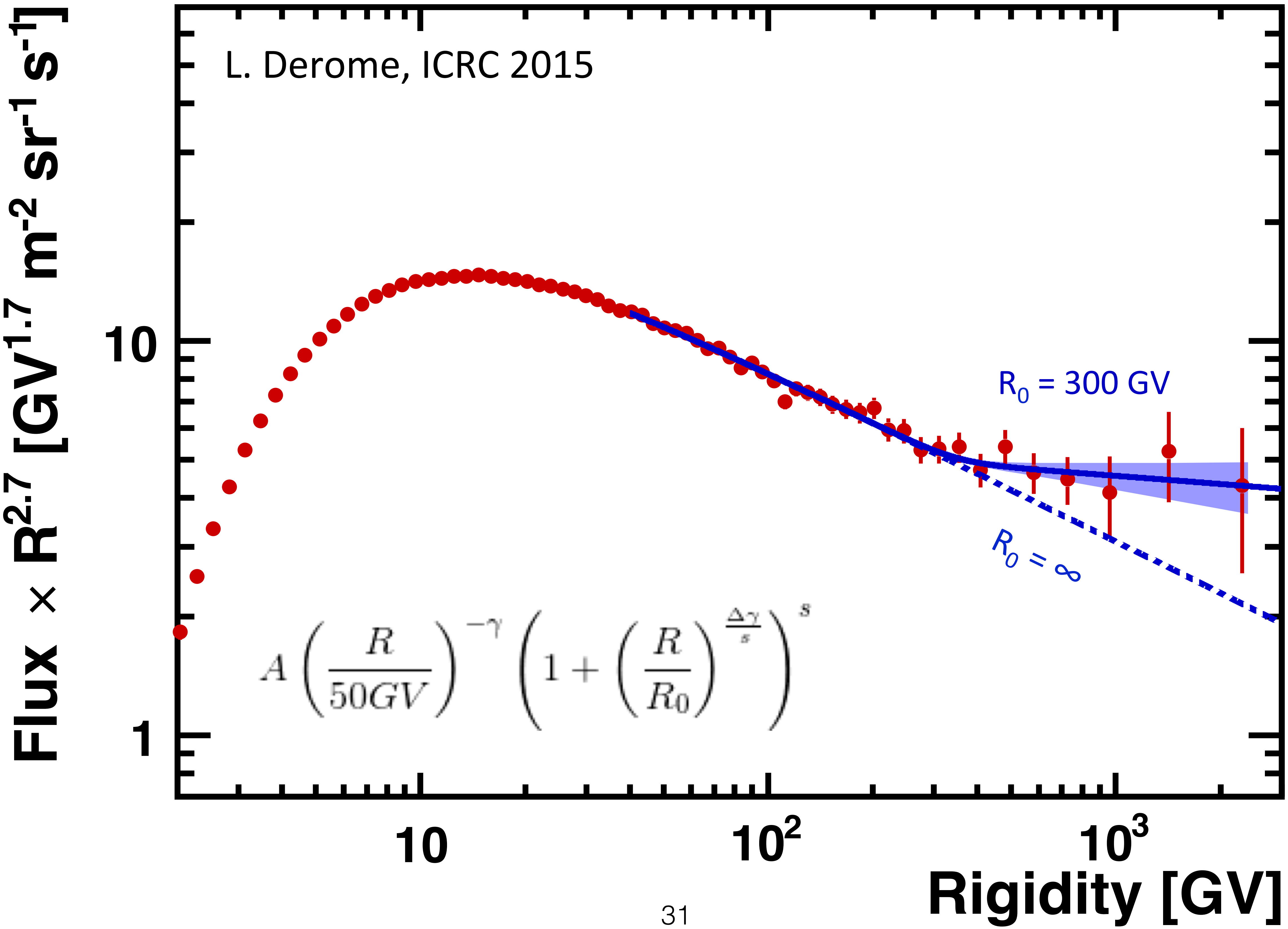


Carbon flux



M. Heil , ICRC 2015
AMS-02
ATIC02(2003/01)
Balloon(1971/09+1972/10)
Balloon(1972/10)
Balloon(1974/07+1974/08+1976/09)
Balloon(1976/09)
Balloon(1976/10)
Balloon(1991/09)
CREAM-II(2005/12-2006/01)
CRN-Spacelab2(1985/07-1985/08)
HEAO3-C2(1979/10-1980/06)
PAMELA(2006/07-2008/03)
TRACER06(2006/07)
Flux * $E_k^{2.7}$ [m^{-2} s^{-1} sr^{-1} $(GeV/n)^{1.7}$]
0
10
20
30
40
50
60
1
10
10^2
10^3
kinetic Energy (E_k) [GeV/n]

Lithium flux



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 the whole **ISS lifetime**, providing new information about **dark matter**, presence of primordial **antimatter** and more detailed **CRs fluxes** description.

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