Characteristic Energy Dependence of Primary and Secondary Cosmic Rays measured with the AMS Detector on the Space Station

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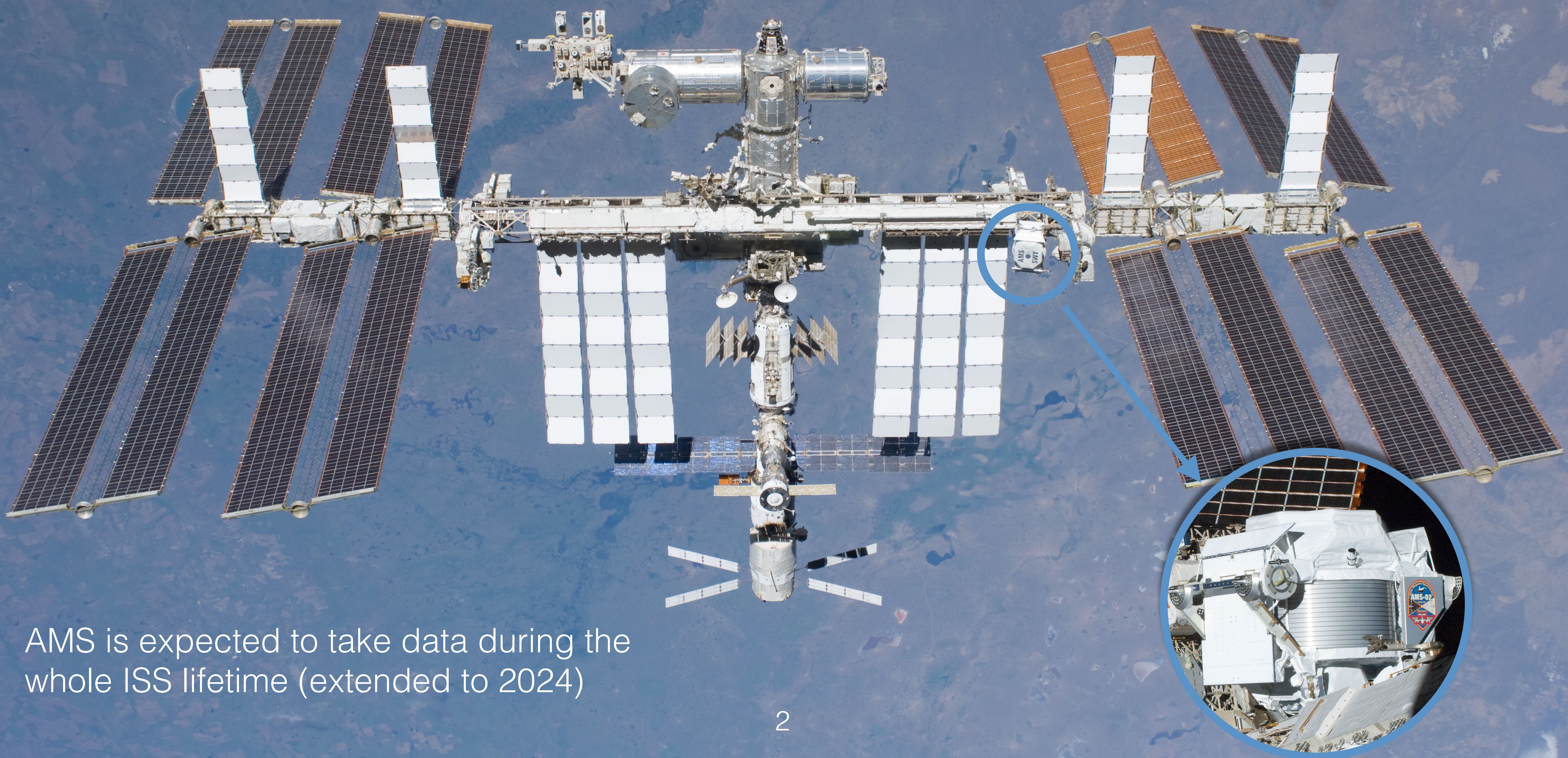
INFN - Sezione di Perugia

06/07/2017 - EPS - Venezia

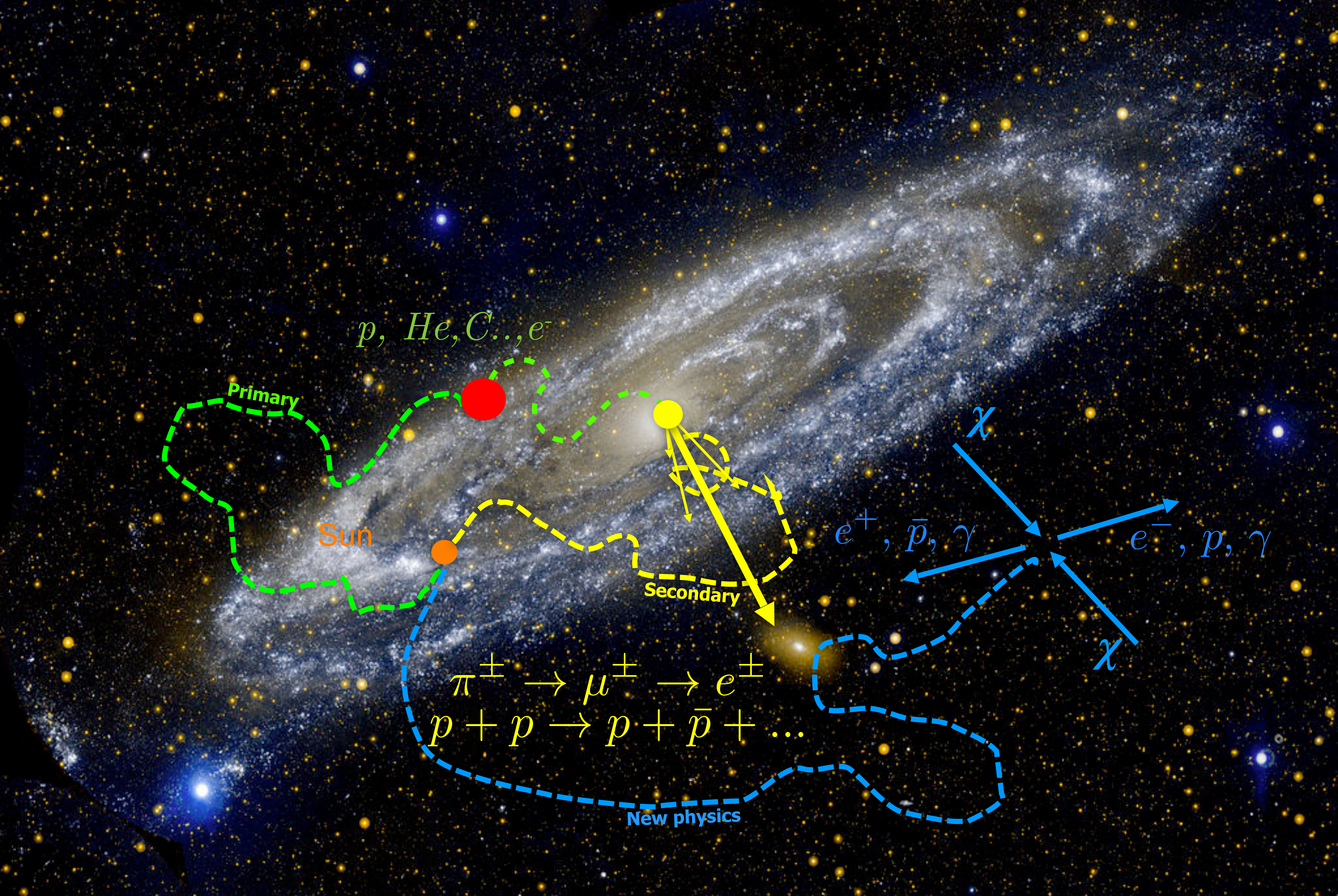
AMS-02 in orbit

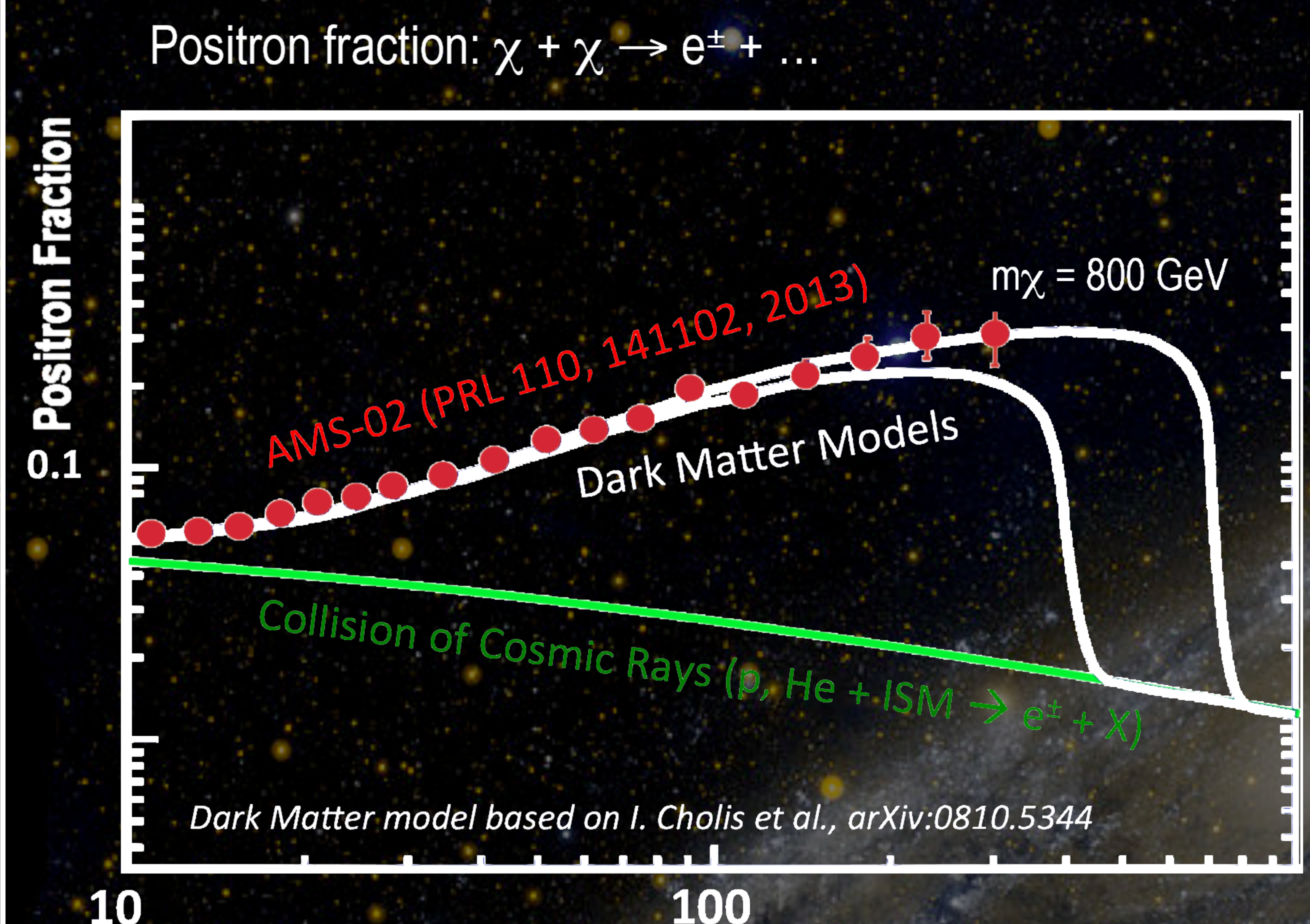
AMS-02 is a large-acceptance high-energy **magnetic spectrometer** capable of measure accurately particles in the **GeV-TeV** energy range.
Since **2011** May 19th AMS-02 has been operating on the International Space Station (ISS). AMS recorded **>100 billion CR triggers** in 6 years of operation.

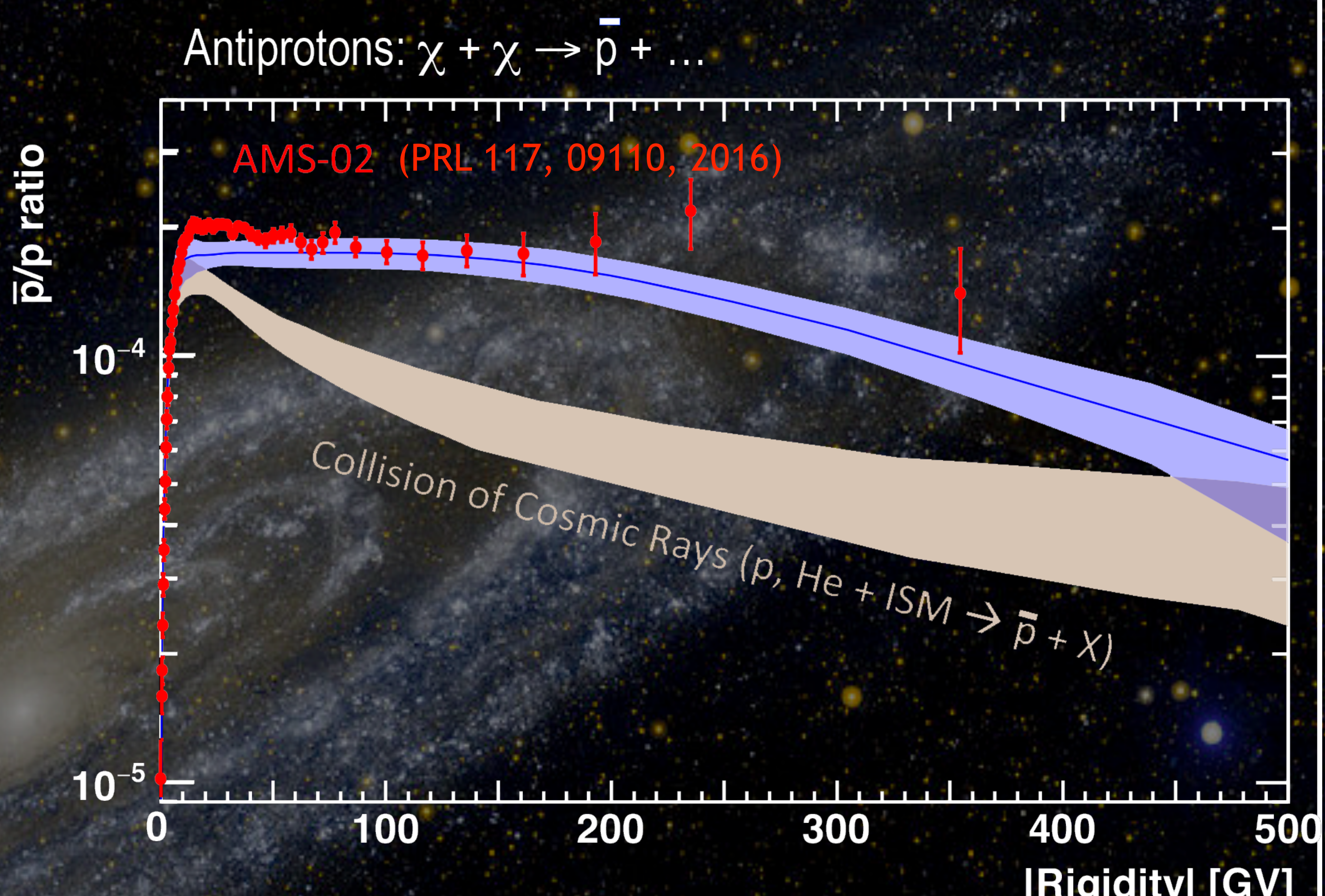


AMS is expected to take data during the whole ISS lifetime (extended to 2024)

Cosmic rays in the Galaxy





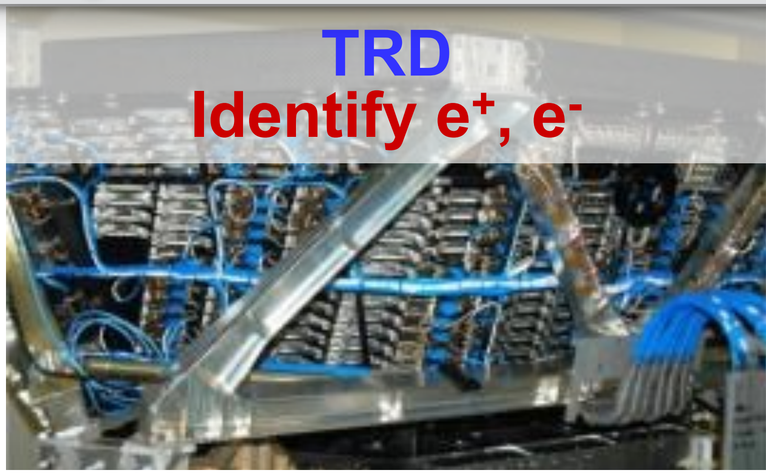


Collisions of Dark Matter particles (ex. neutralinos) may produce a signal of e+, p-bar, …
detected on top of the background from the collisions of CRs on interstellar medium (ISM)

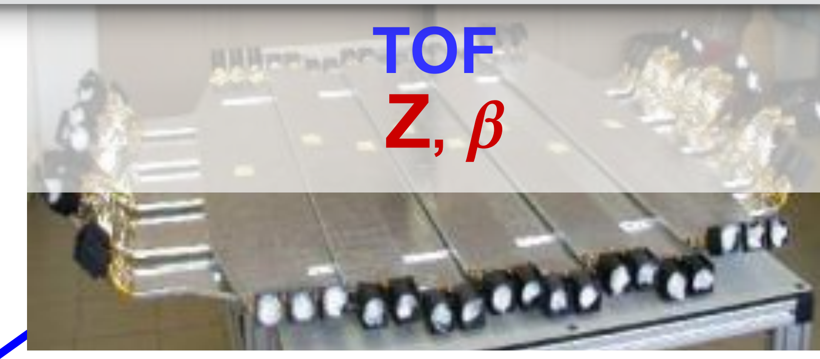
A detailed understanding of the **background** is mandatory. This needs precise knowledge of:

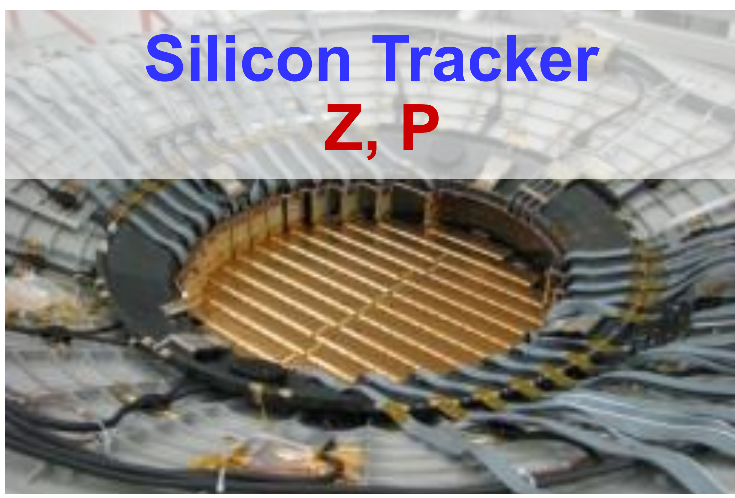
- The flux of primary (progenitors) Cosmic Rays **(p, He, …)**
- Behaviour of the CRs propagation in the Galaxy **(B/C, …)**

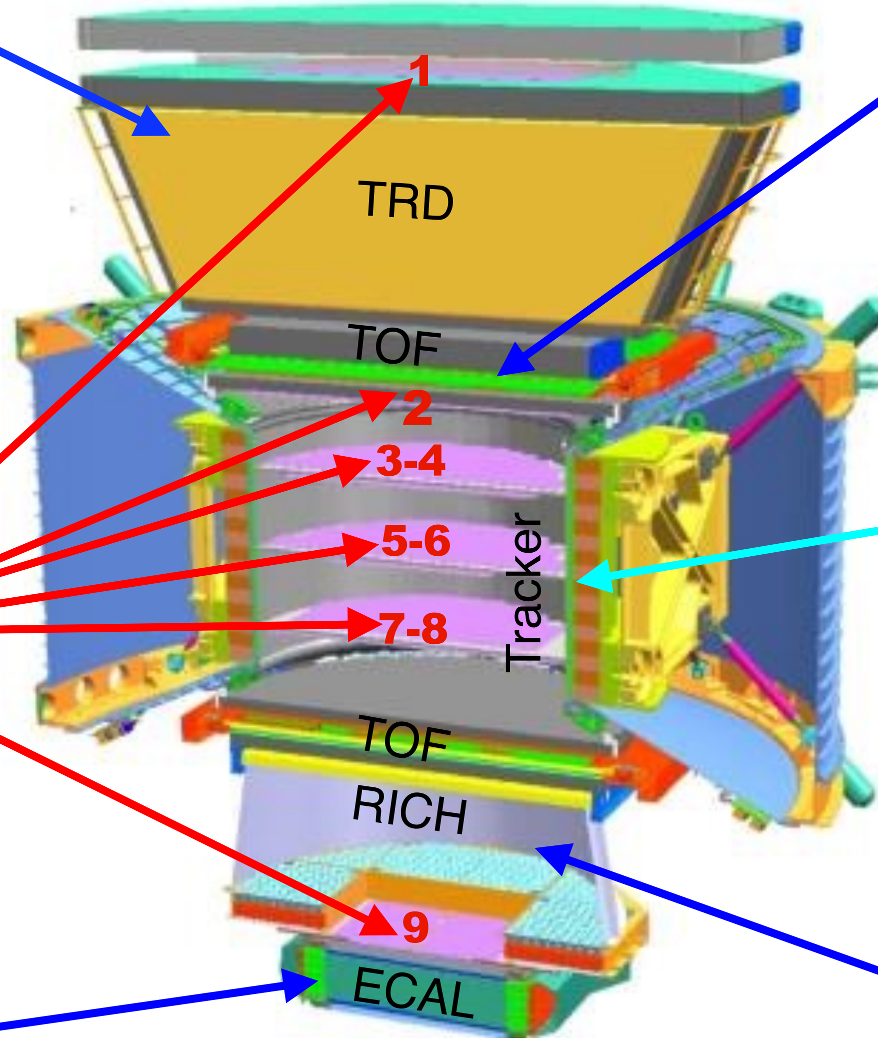
AMS-02

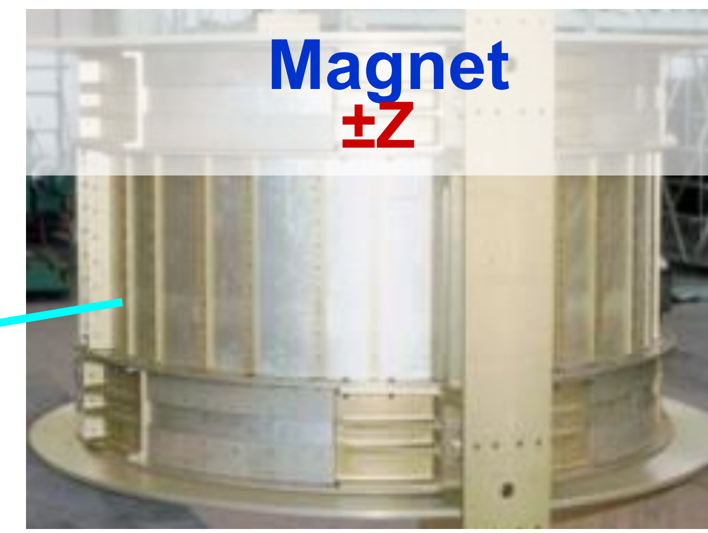


Particles and nuclei are defined by their charge (**Z**) and energy (**E ~ P**)









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

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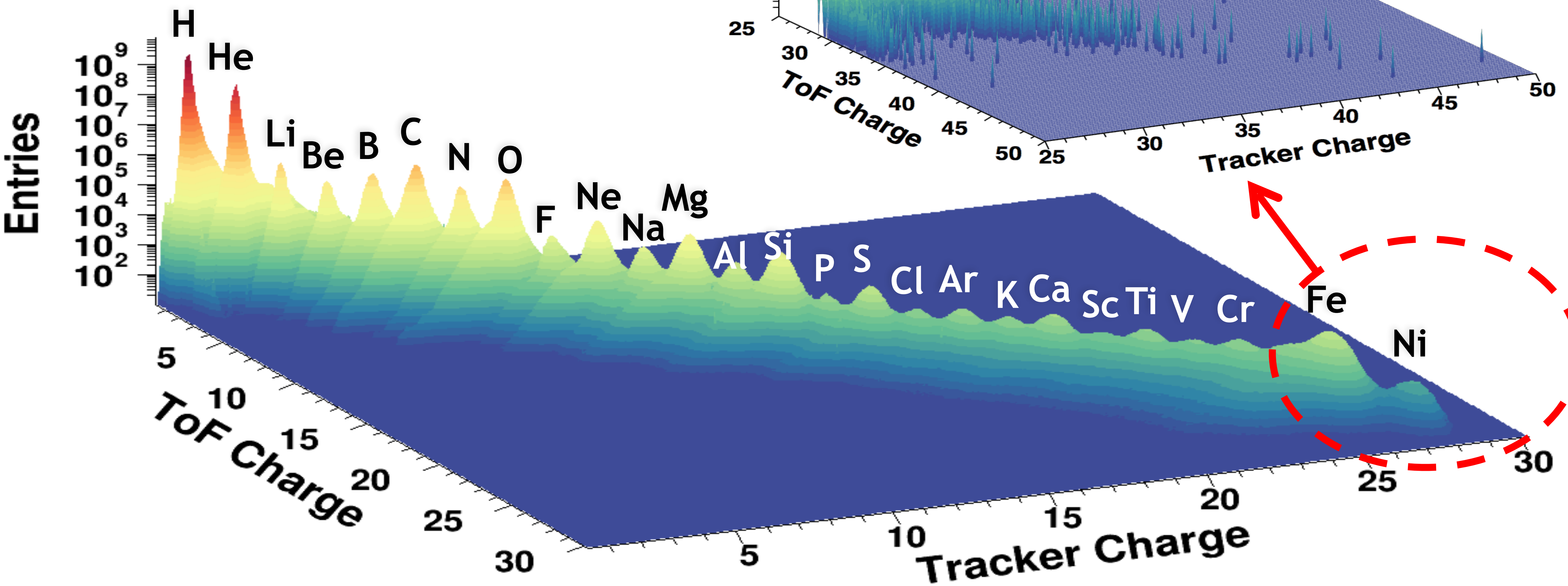
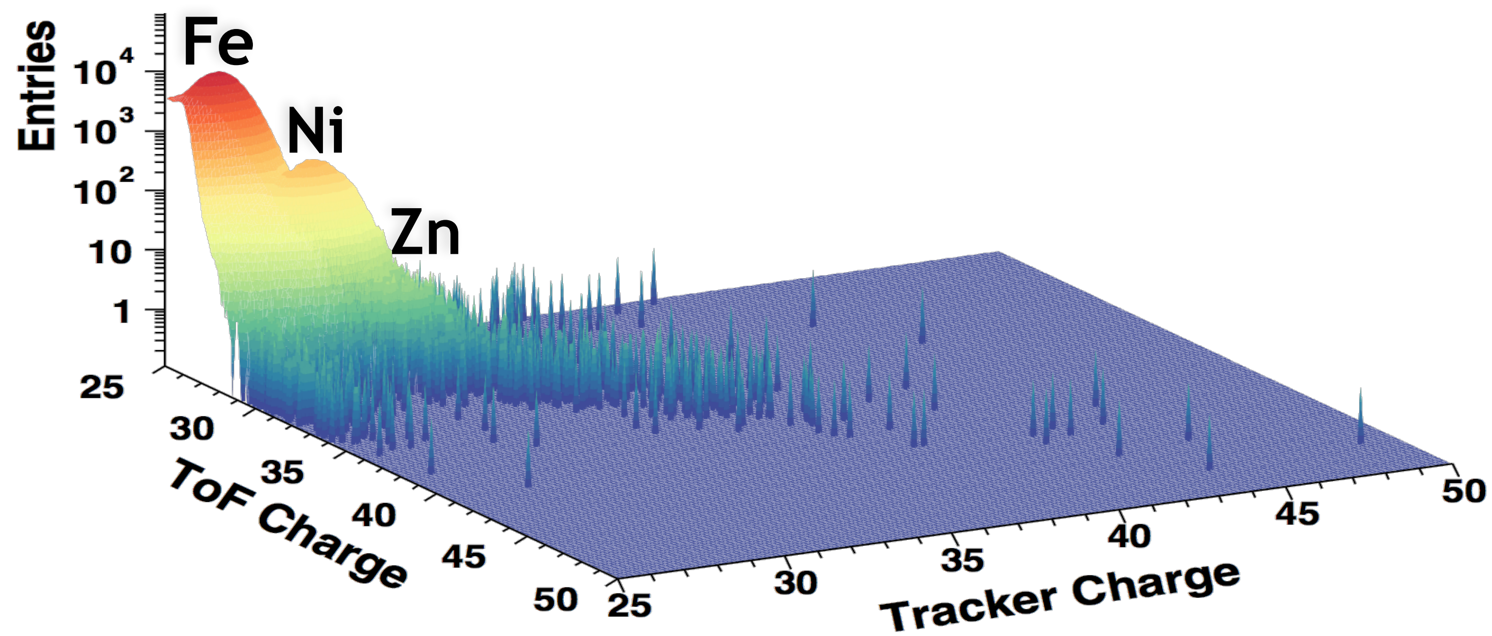
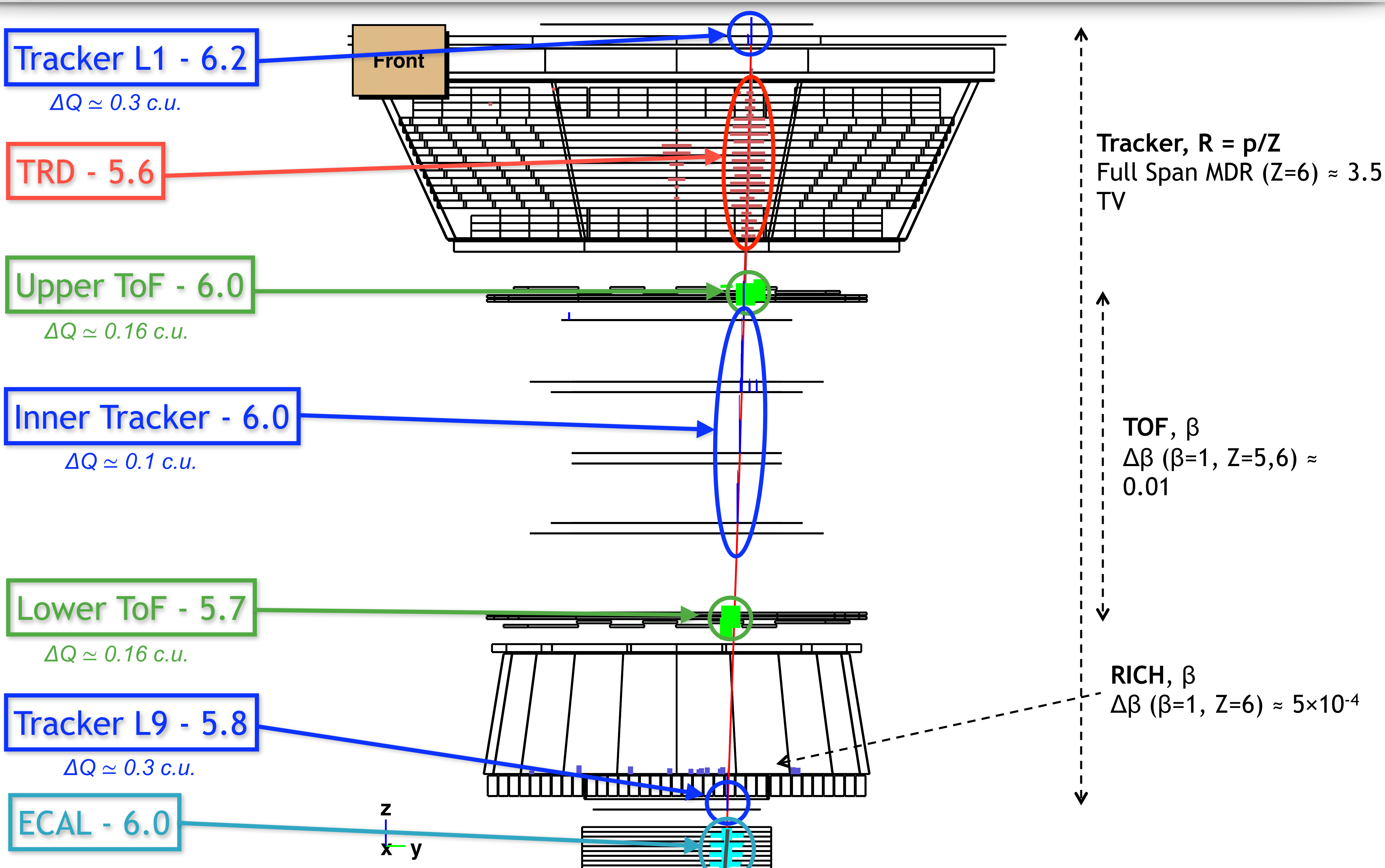
Nuclei identification in AMS





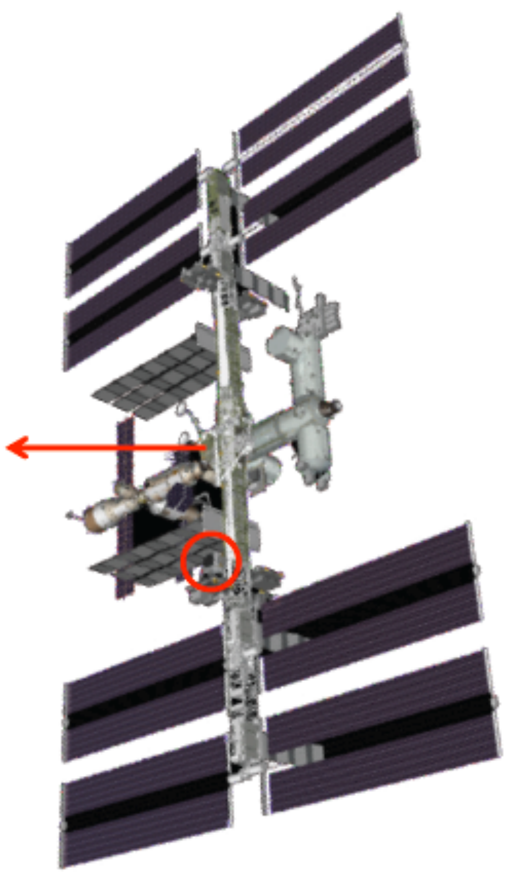
Charge measurements in AMS

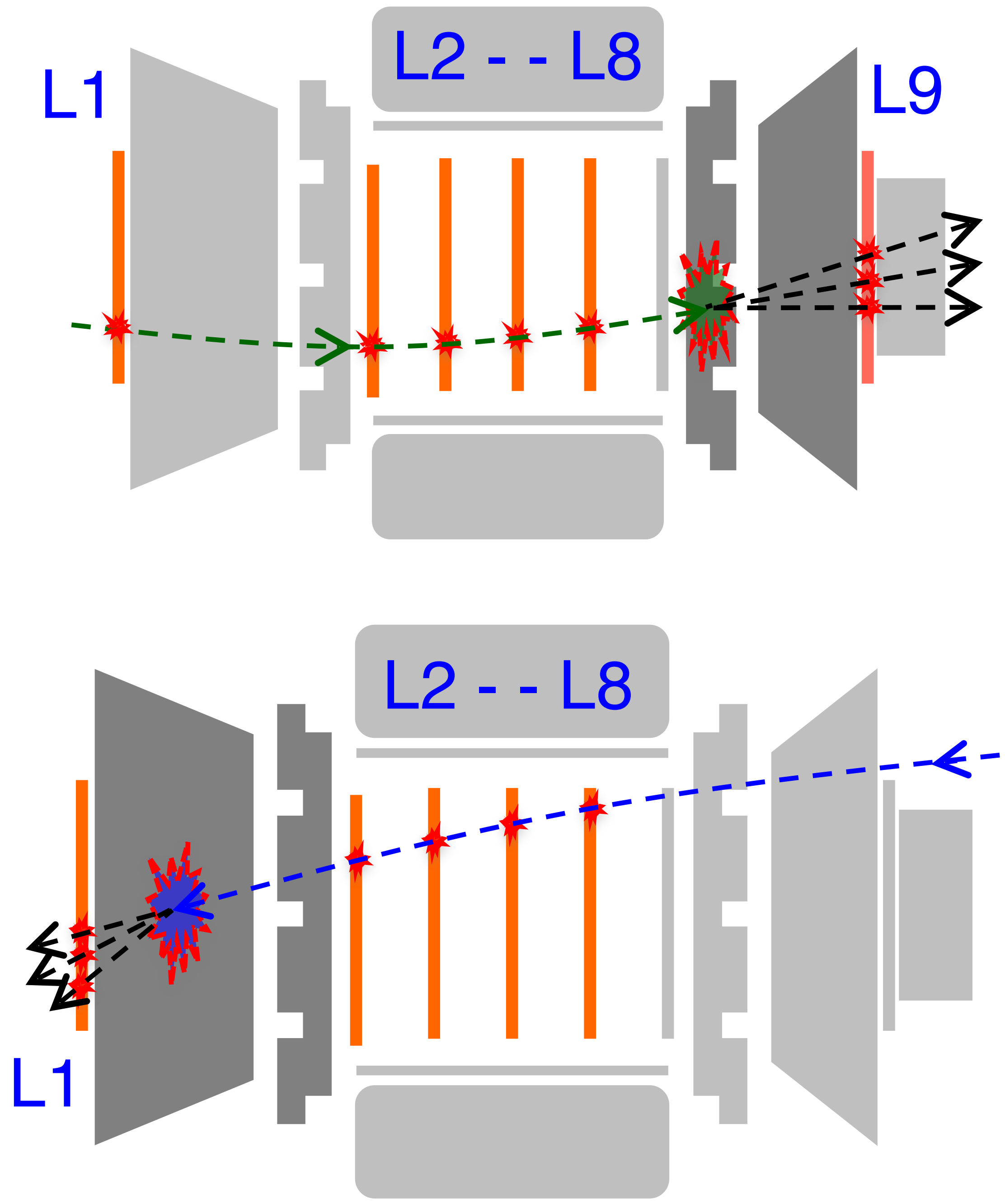
(e.g. Carbon nucleus: Z=6)



Cross-sections and materials

Measurement of nuclear cross sections / accurate check of the materials when AMS is flying in horizontal attitude





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.

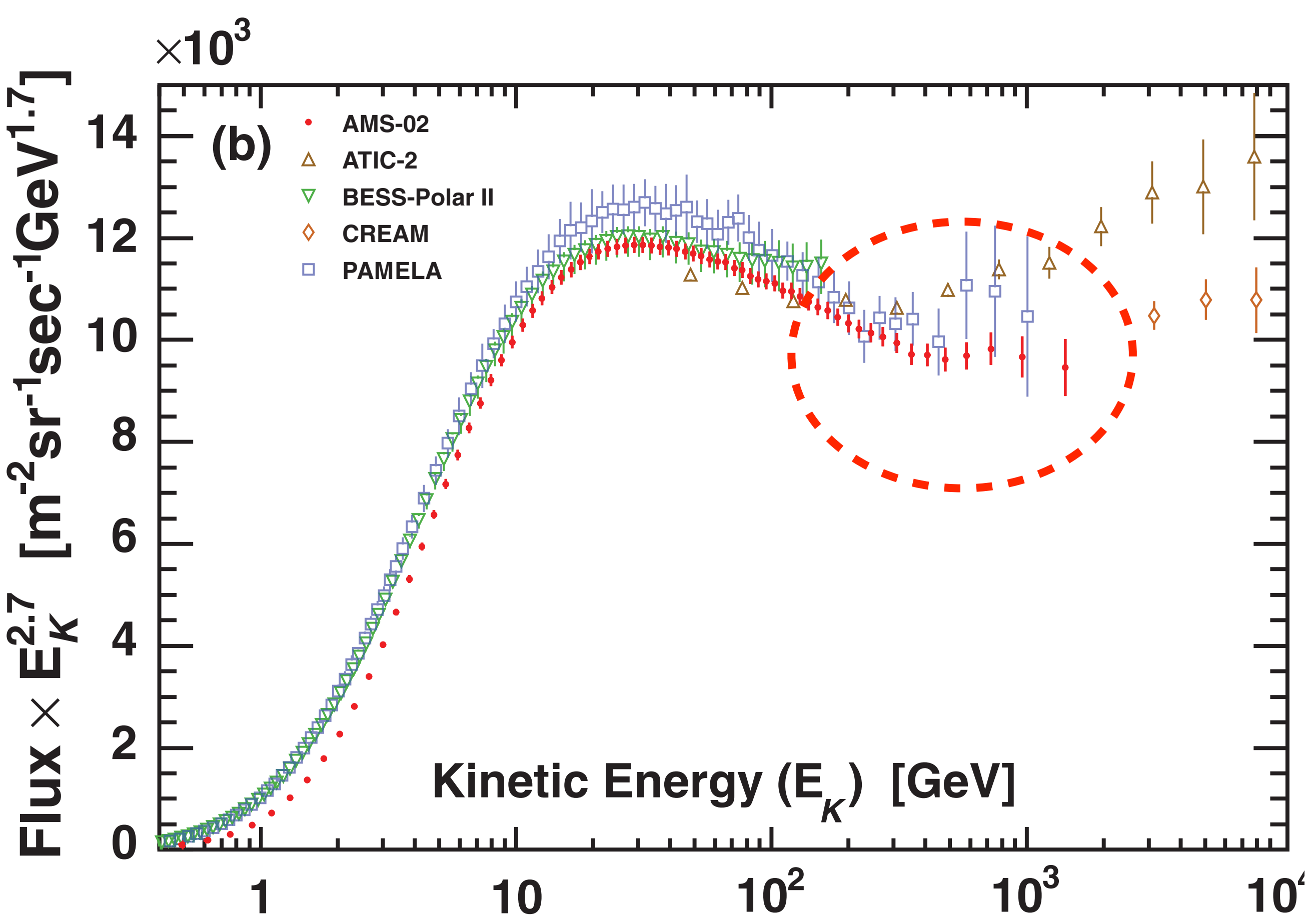
Third, we use right-to-left particles to measure the nuclear interactions in the upper part of detector.

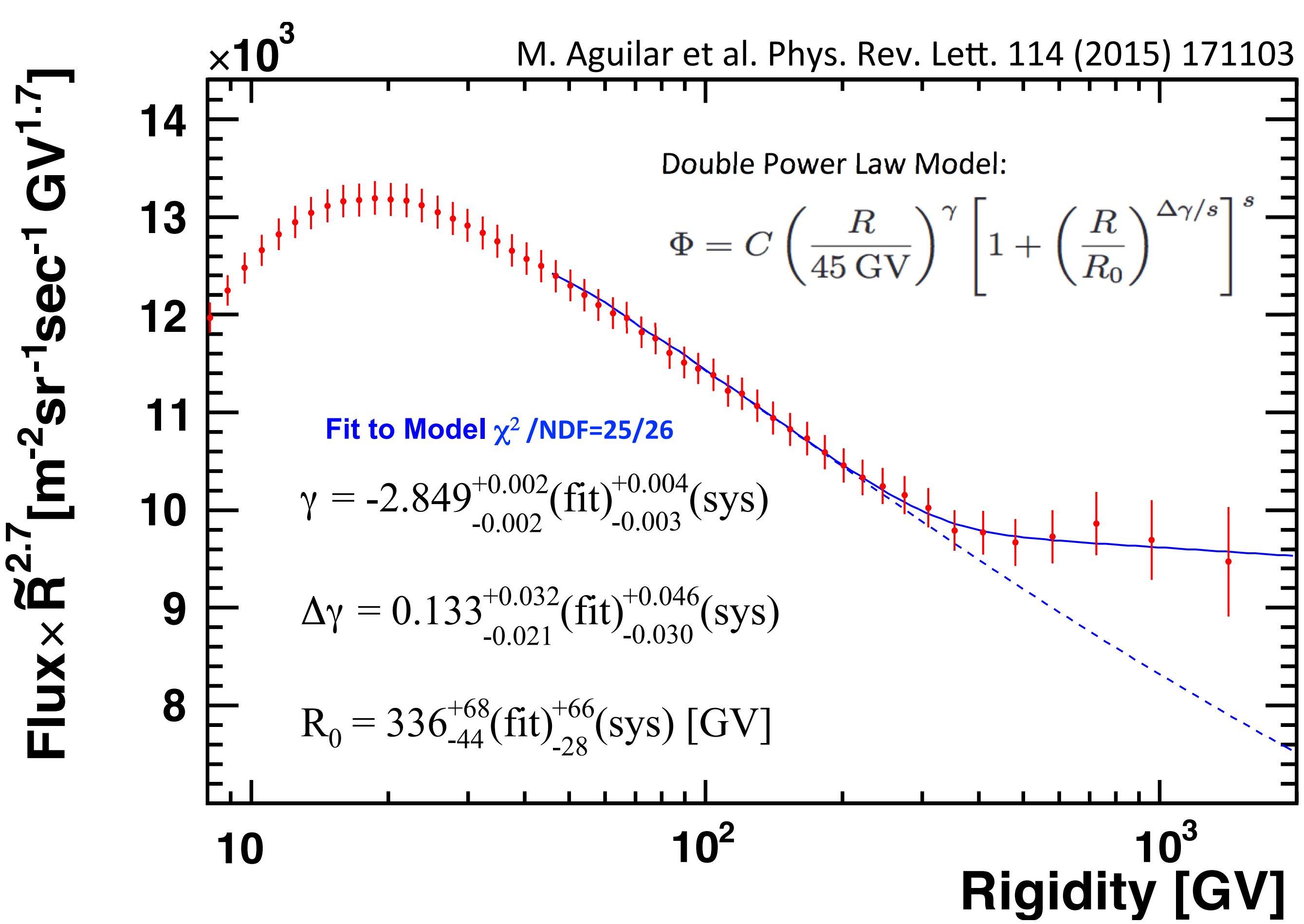
Proton and Helium fluxes

<u>*Interesting features:*</u>

1) Both proton and helium fluxes show a hardening

H flux measurement:
300 million events





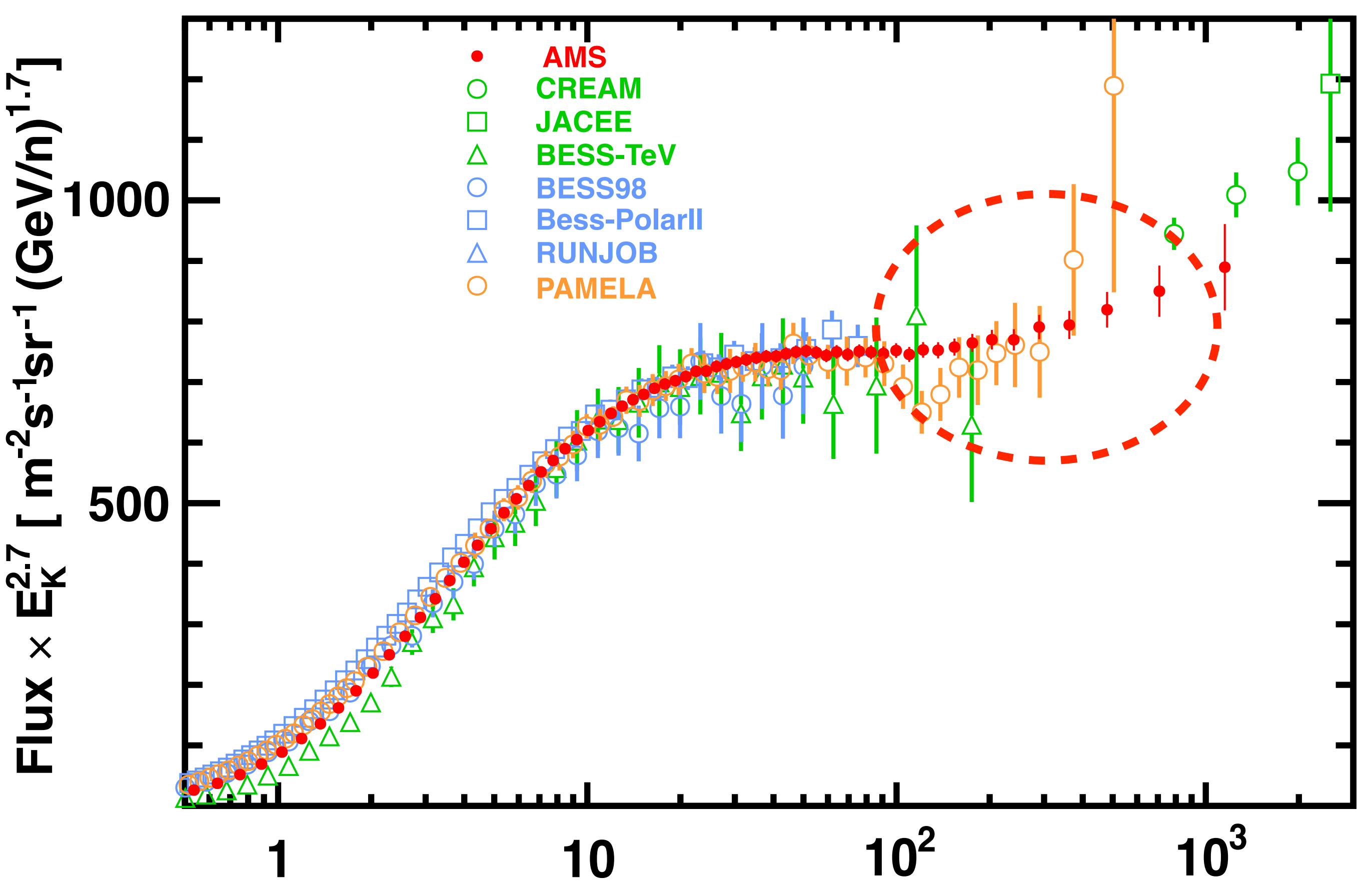
Proton and Helium fluxes

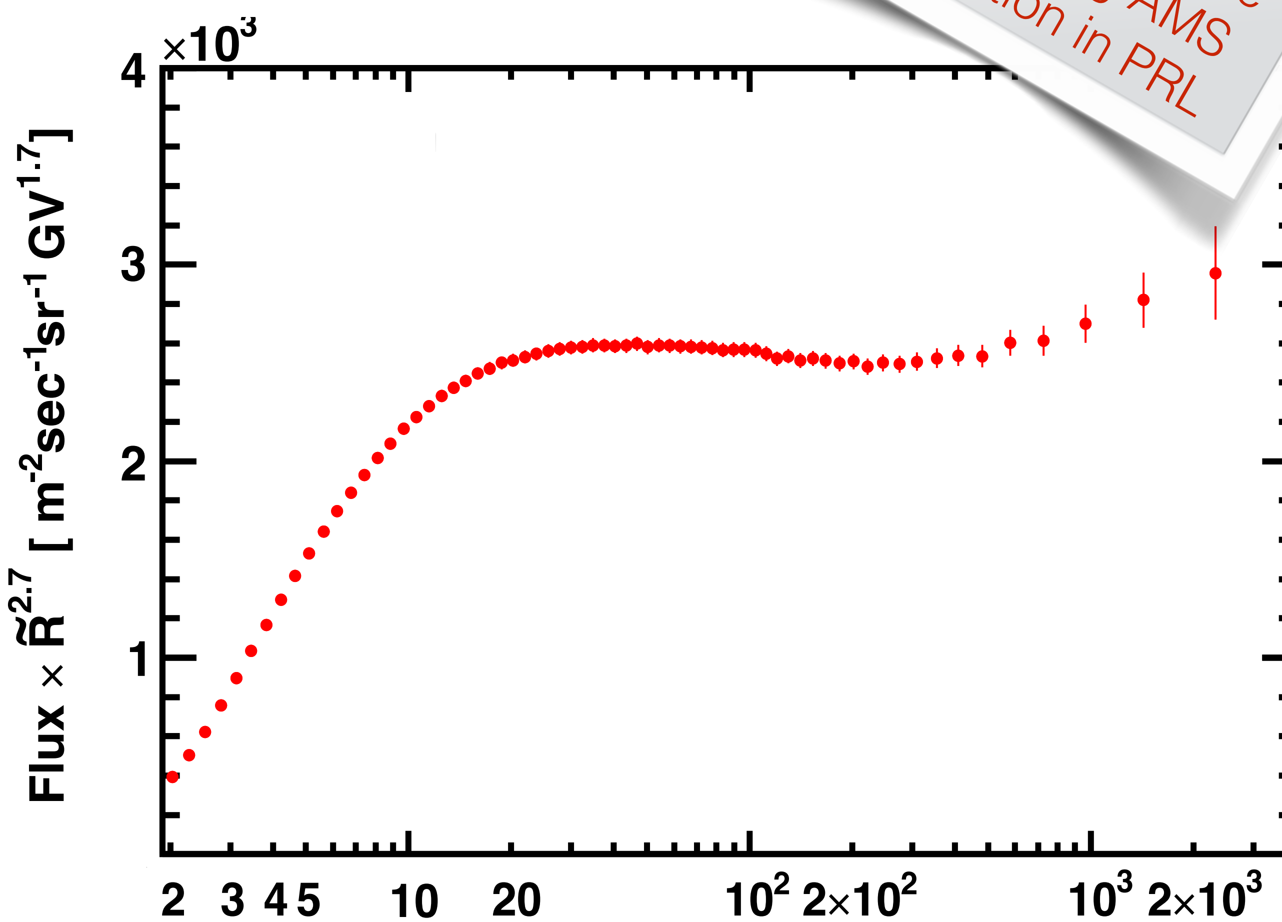
__Interesting features:__

1) Both proton and helium fluxes show a hardening

new He flux measurement:
90 million events

Preliminary data
Please refer to the forthcoming AMS publication in PRL





Higher charge: Primaries

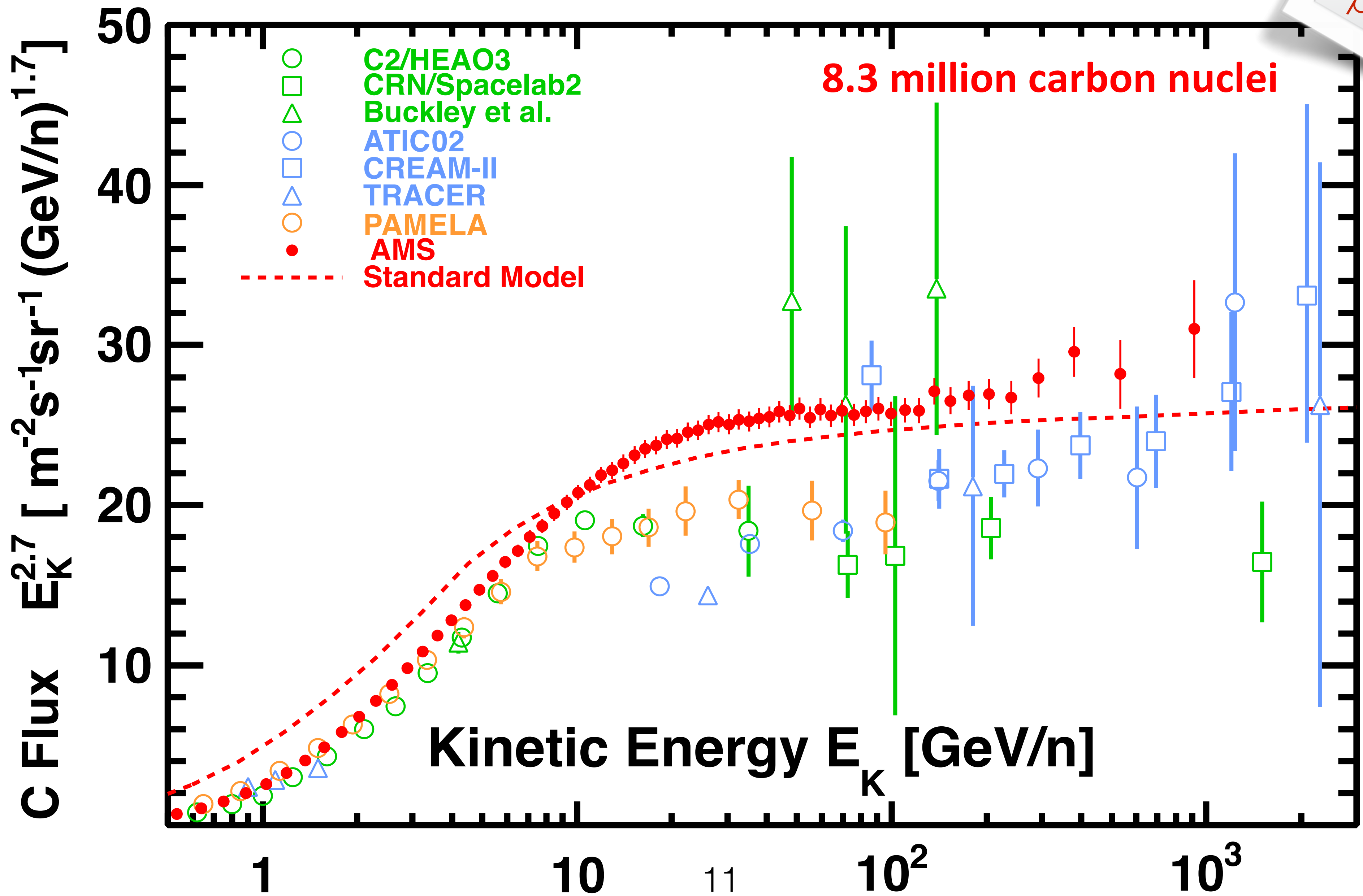
Primaries:

AMS-02 measures Carbon, Nitrogen, Oxygen fluxes in an extended energy range and unprecedented precision.

Ongoing analyses based on ~ 5 years data (2011-2016):

- Standard model: GALPROP with best fit parameters from *Trotta et al, 2011*

Preliminary data
Please refer to the forthcoming AMS publication in PRL

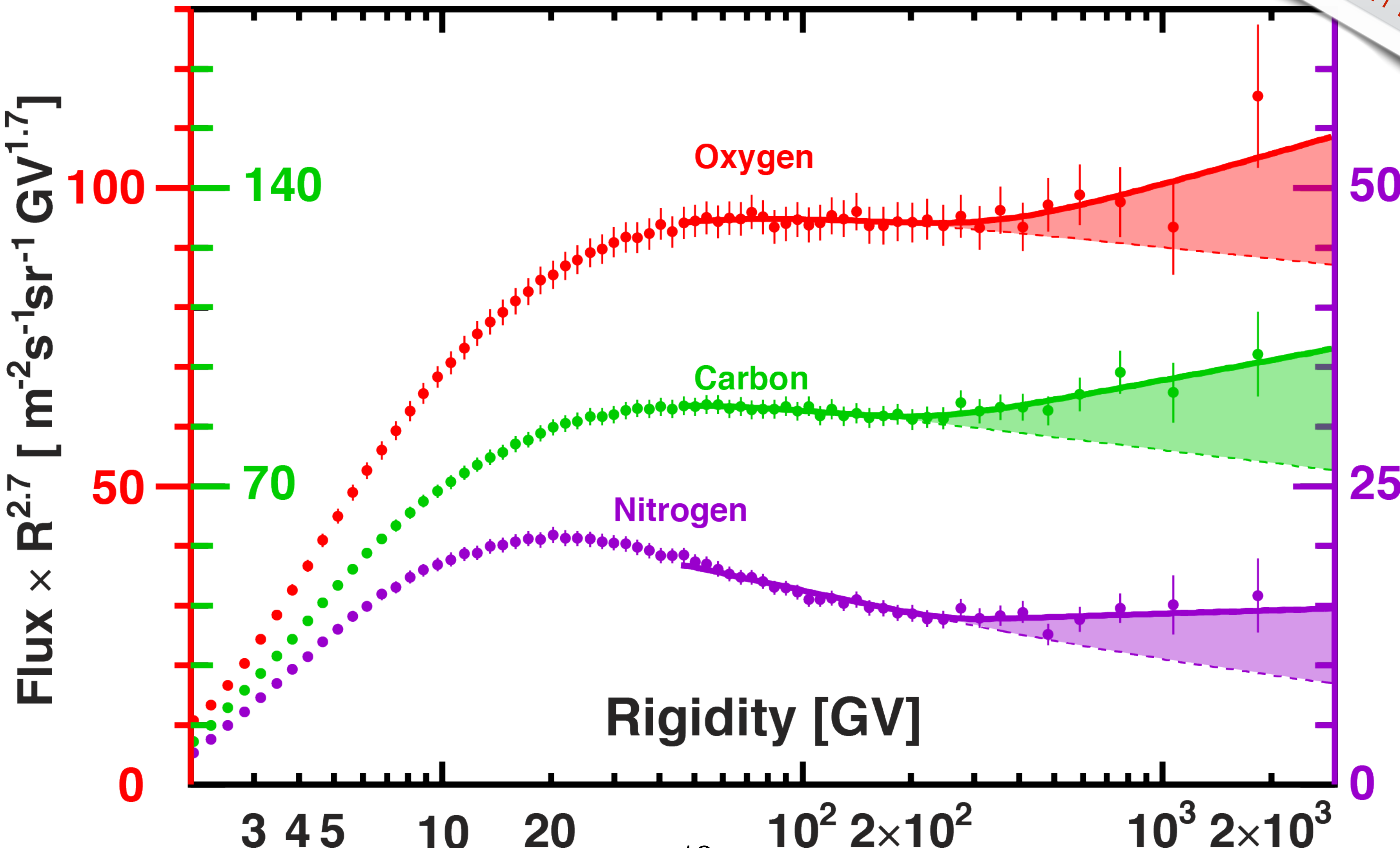


Higher charge: Primaries

Interesting features:

2) Also for Carbon, Nitrogen and Oxygen the single-power law behaviour is excluded by AMS-02 data: a change of spectral index is observed at ≈ the same rigidity.

Preliminary data
Please refer to the forthcoming AMS publication in PRL



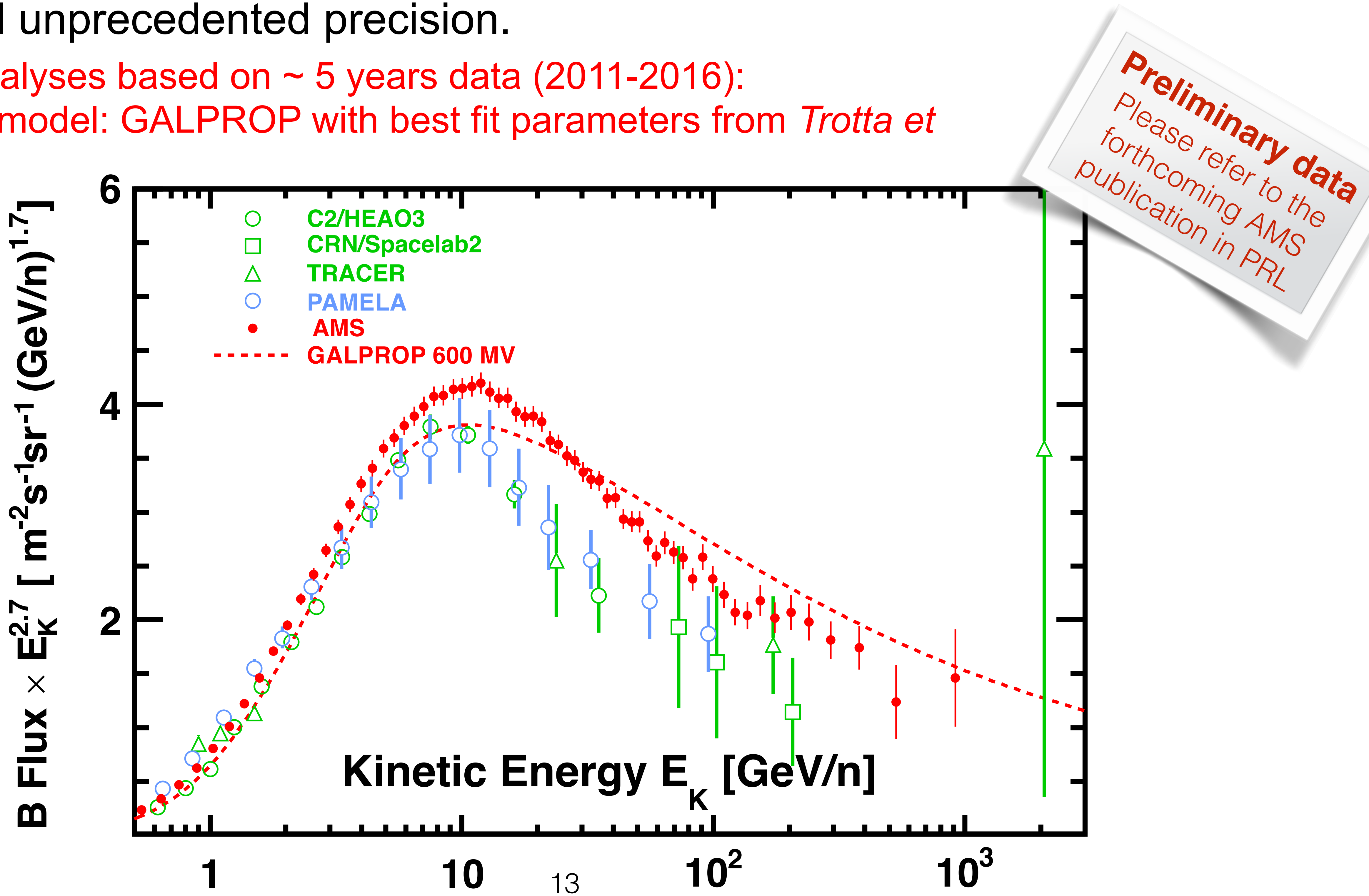
Higher charge: Secondaries

Secondaries:

AMS-02 measures Lithium, Beryllium and Boron fluxes in an extended energy range and unprecedented precision.

Ongoing analyses based on ~ 5 years data (2011-2016):

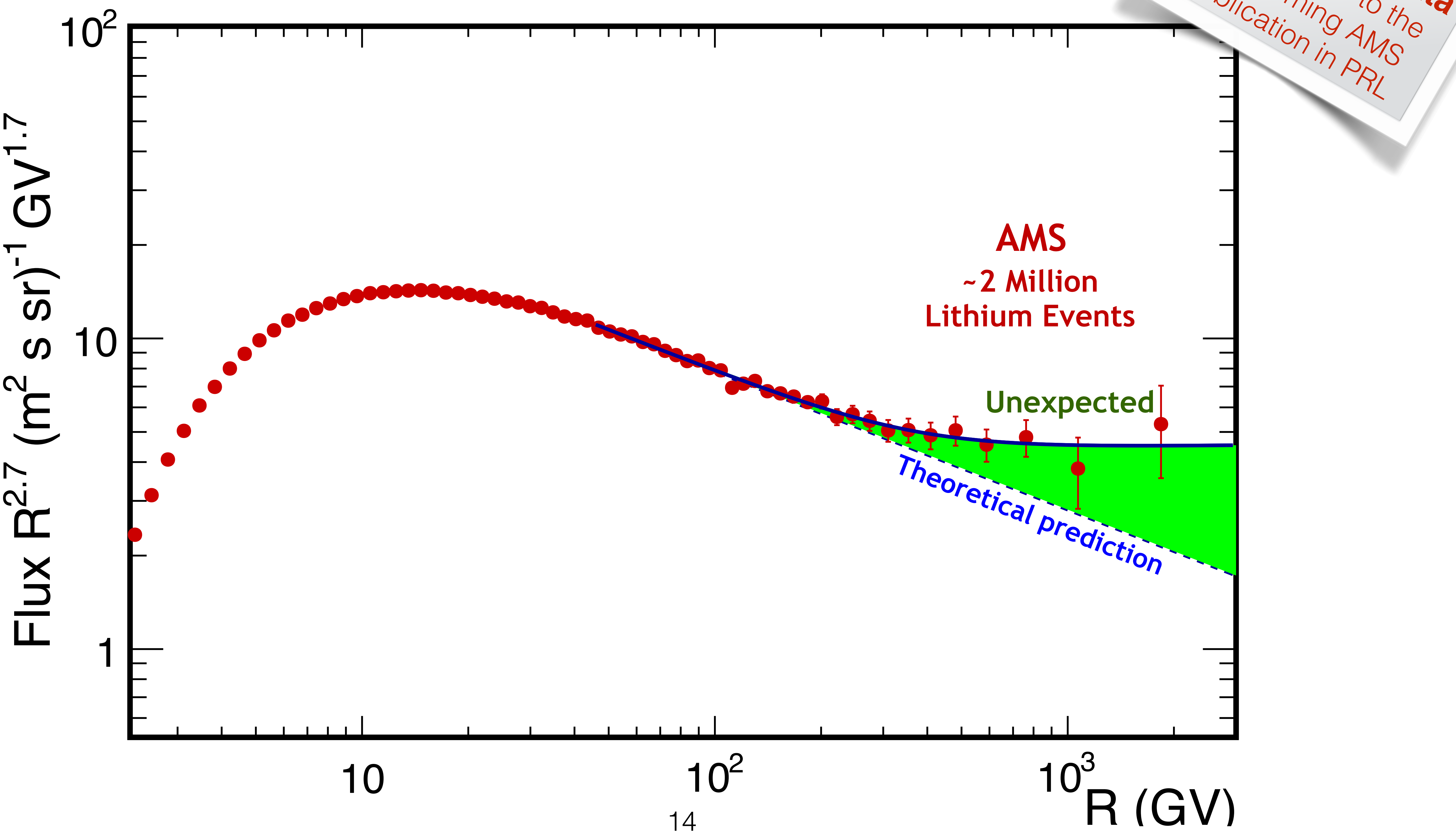
- Standard model: GALPROP with best fit parameters from *Trotta et al, 2011*



Lithium flux

Interesting features:

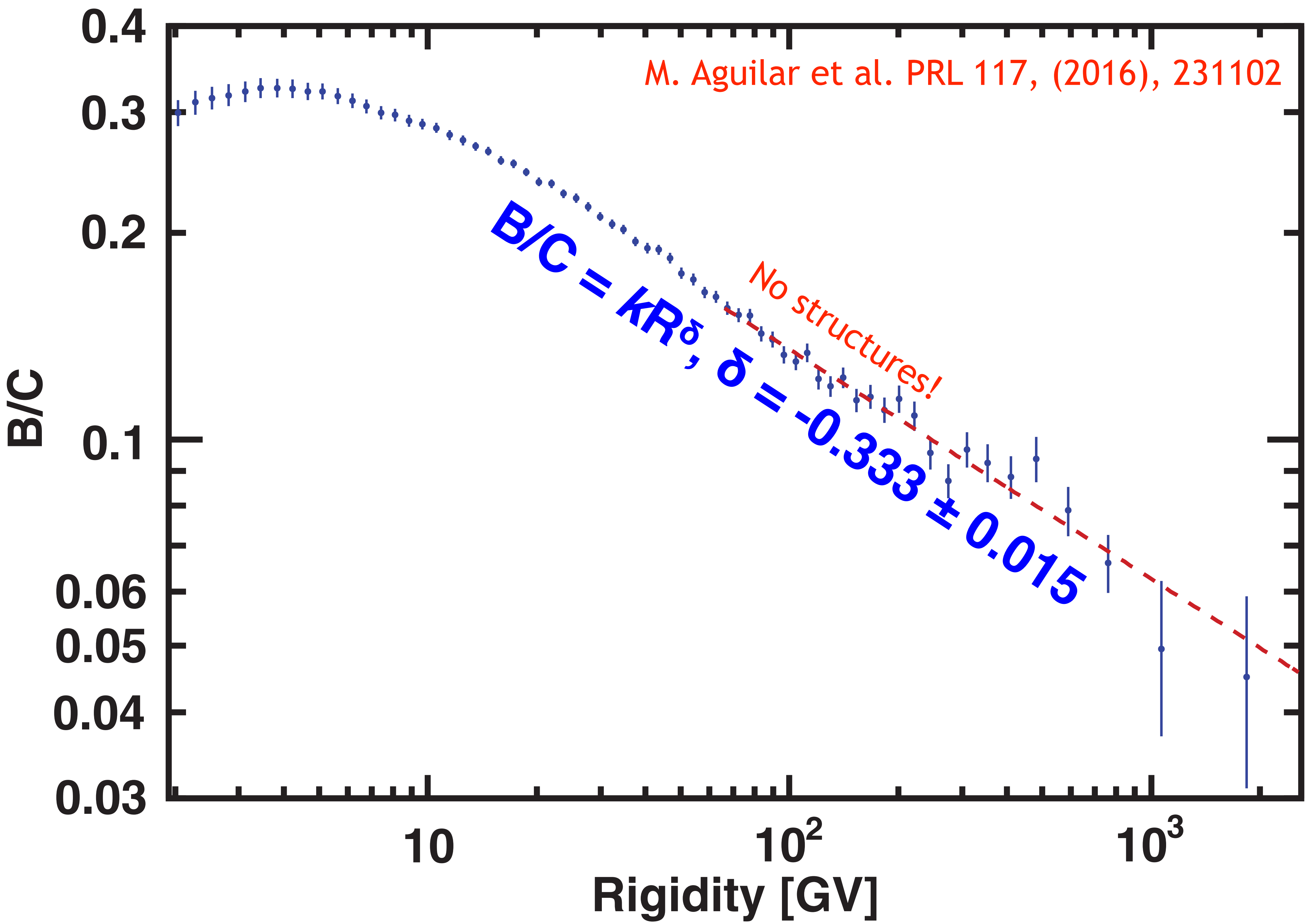
3) The Lithium flux shows a hardening as well



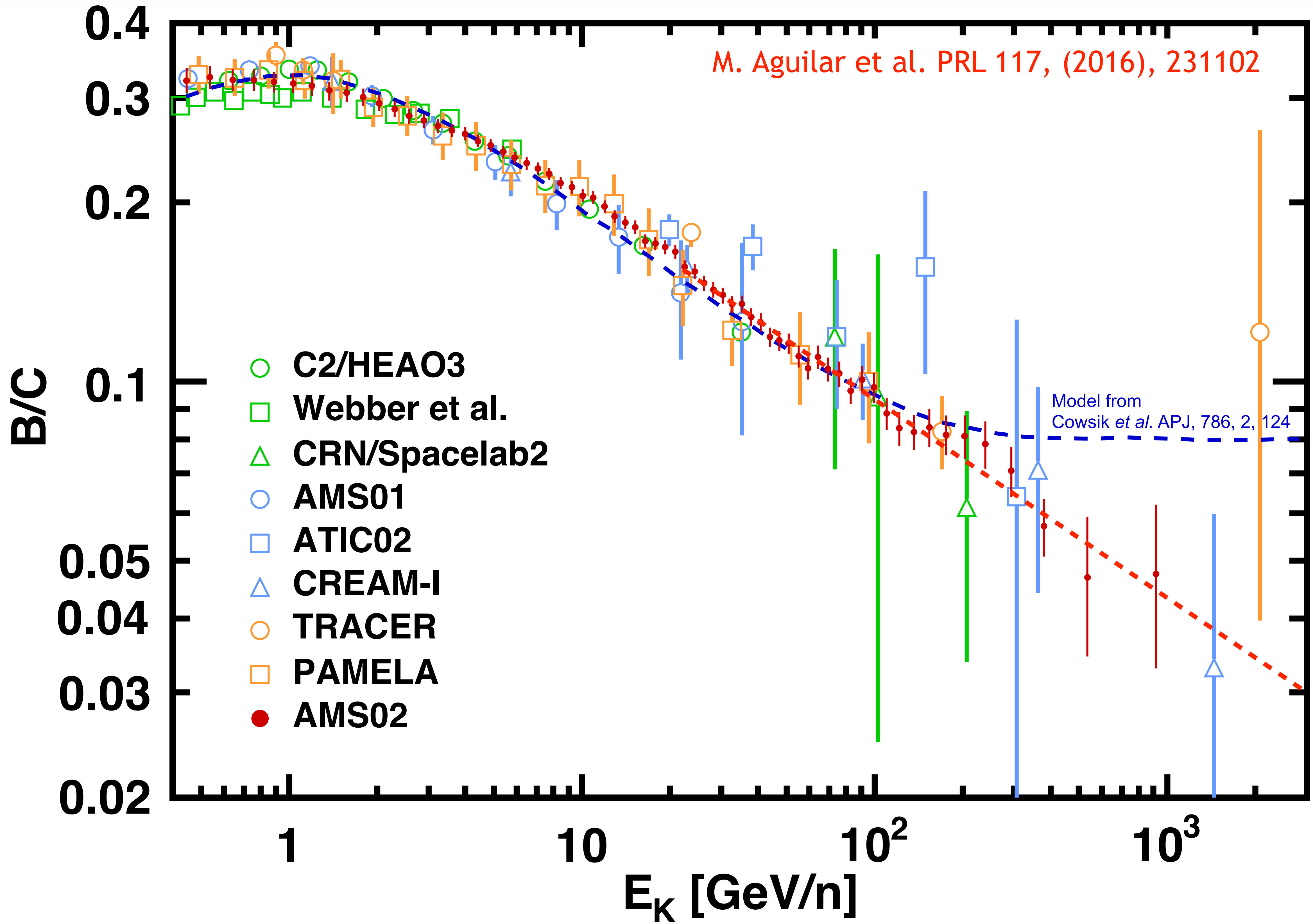
B/C

Interesting features:

4) The flux ratio between primaries (C) and secondaries (B) provides information on propagation and the ISM: AMS data supports Kolmogorov turbulence model



B/C


M. Aguilar et al. PRL 117, (2016), 231102
B/C
0.4
0.3
0.2
0.1
0.05
0.04
0.03
0.02
1
10
10^2
10^3
E_K [GeV/n]
C2/HEAO3
Webber et al.
CRN/Spacelab2
AMS01
ATIC02
CREAM-I
TRACER
PAMELA
AMS02
Model from
Cowsik *et al.* APJ, 786, 2, 124

Conclusions

- AMS keeps providing precision measurements of CRs (**positron fraction**, electron, **positrons, protons, anti-protons, helium** and **nuclei** fluxes) with a **few percent** precision.

- **Simultaneous** measurement of many CR species is a key instrument for acquiring knowledge of **cosmic ray physics** and for the discovery of **new phenomena**.

- AMS will continue gathering data for the entire duration of the **ISS**, continuing the search for **dark matter**, **primordial antimatter** and a more detailed description of **cosmic rays fluxes**.

- Unexpected **patterns** are emerging from the **hadronic** component of cosmic rays as well. **Spectral features** are emerging on almost every species and are **challenging** our current view of CR propagation.

Backup

KEEP
CALM
AND
CHECK
BACKUP SLIDES

Backgrounds

Background from heavier eleme
between Tracker L1 and L2 can
Data by fitting the Charge D
typical systematic error <0.

Contamination < 3%
Selection efficiency > 96%
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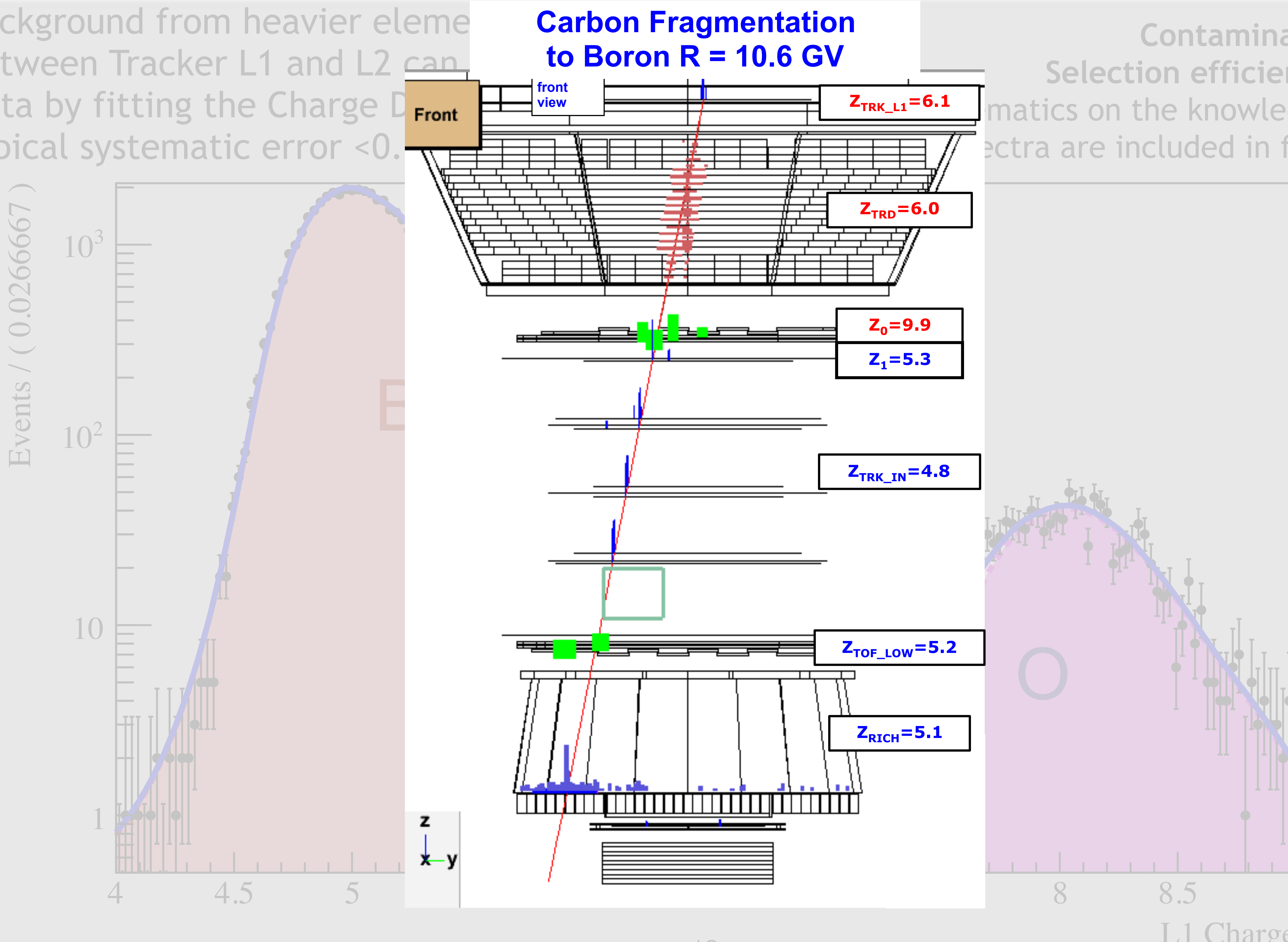
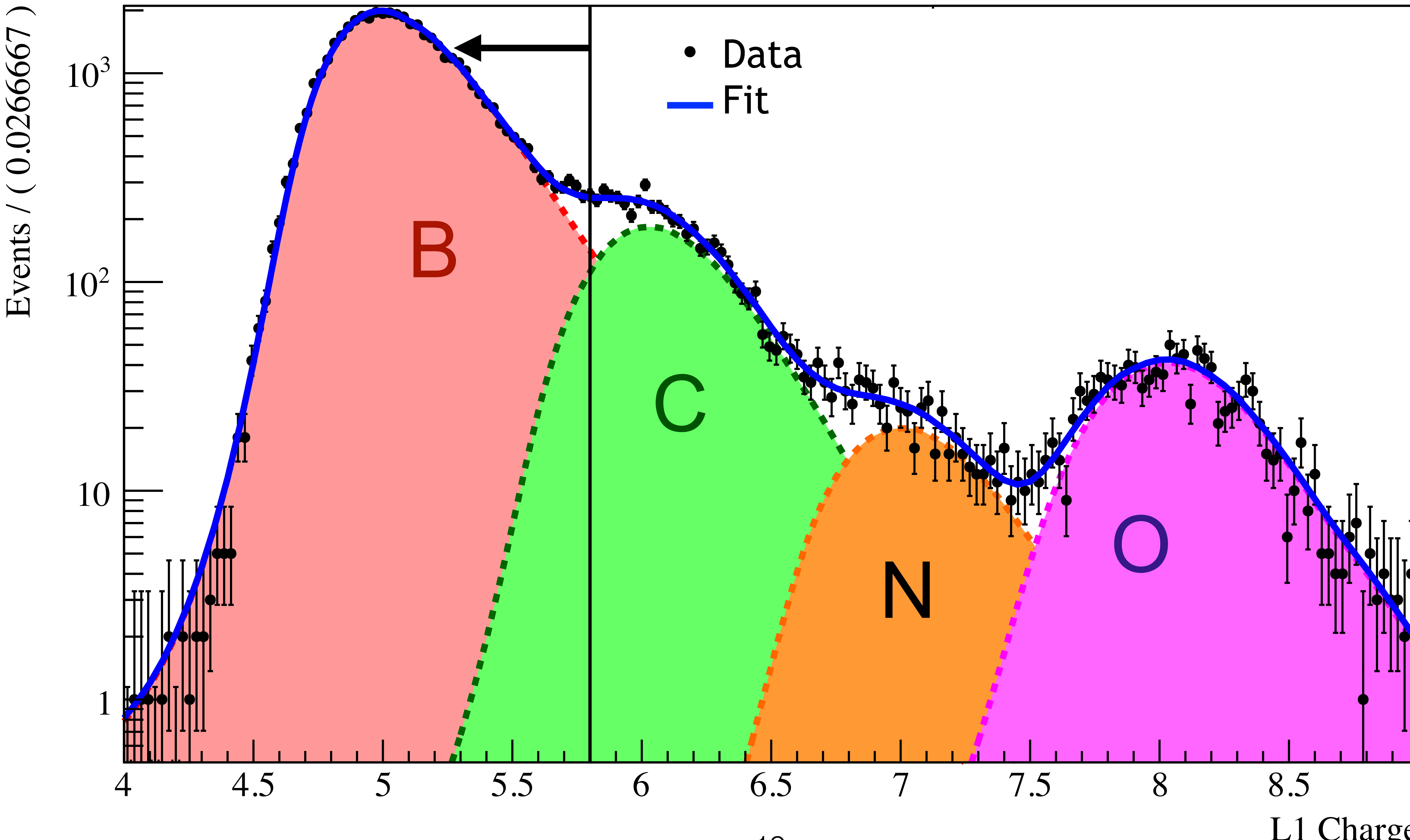


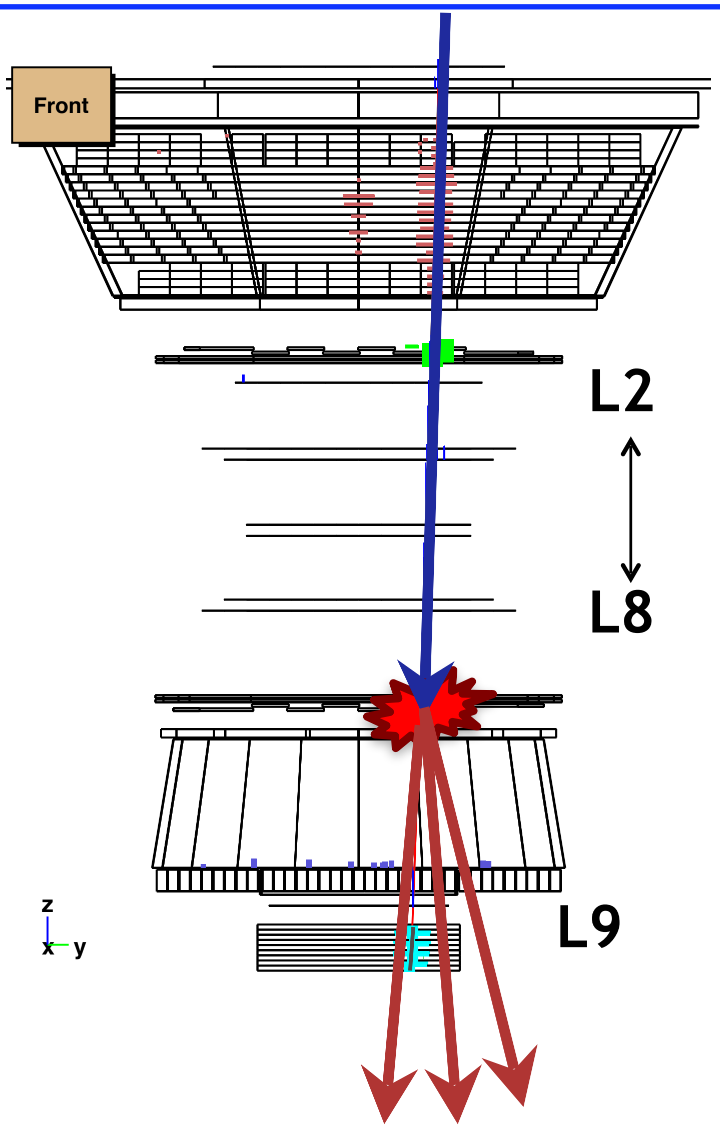
Backgrounds

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%

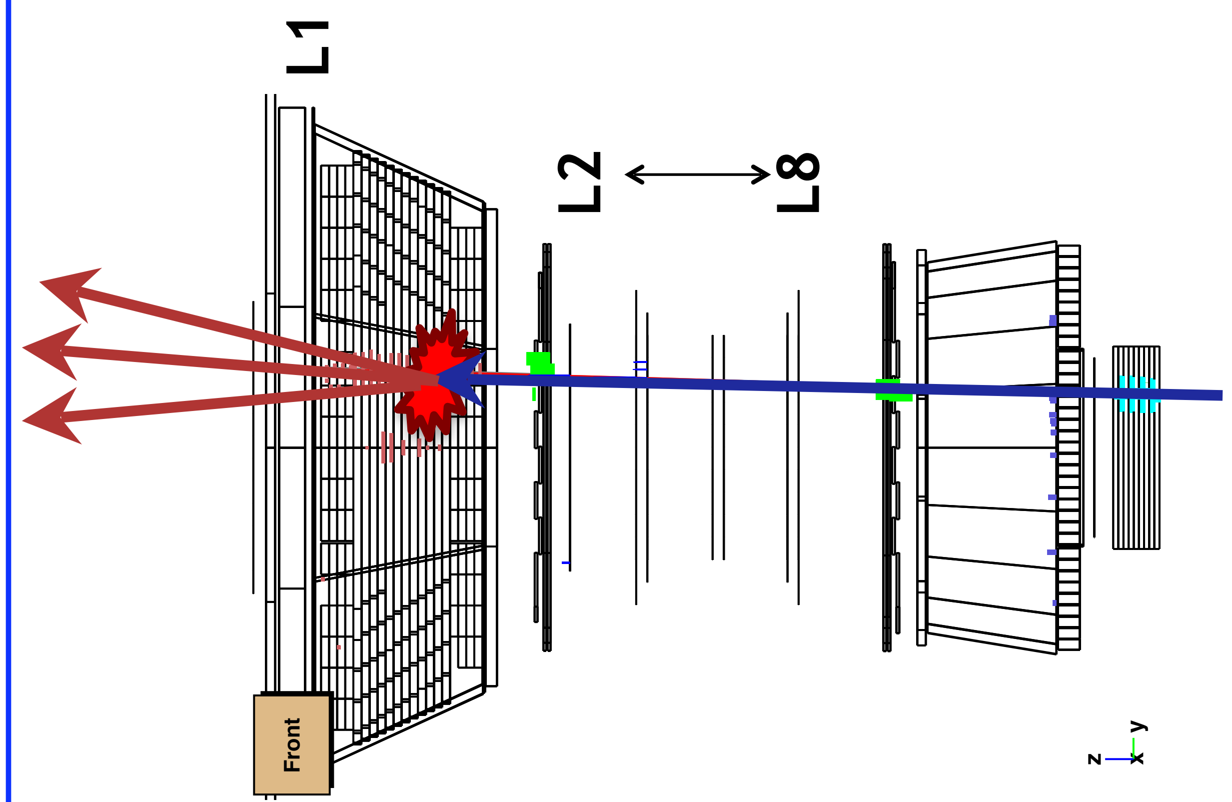
Contamination < 3%
Selection efficiency > 96%
Systematics on the knowledge of the charge spectra are included in final error.



Systematics on Acceptance



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

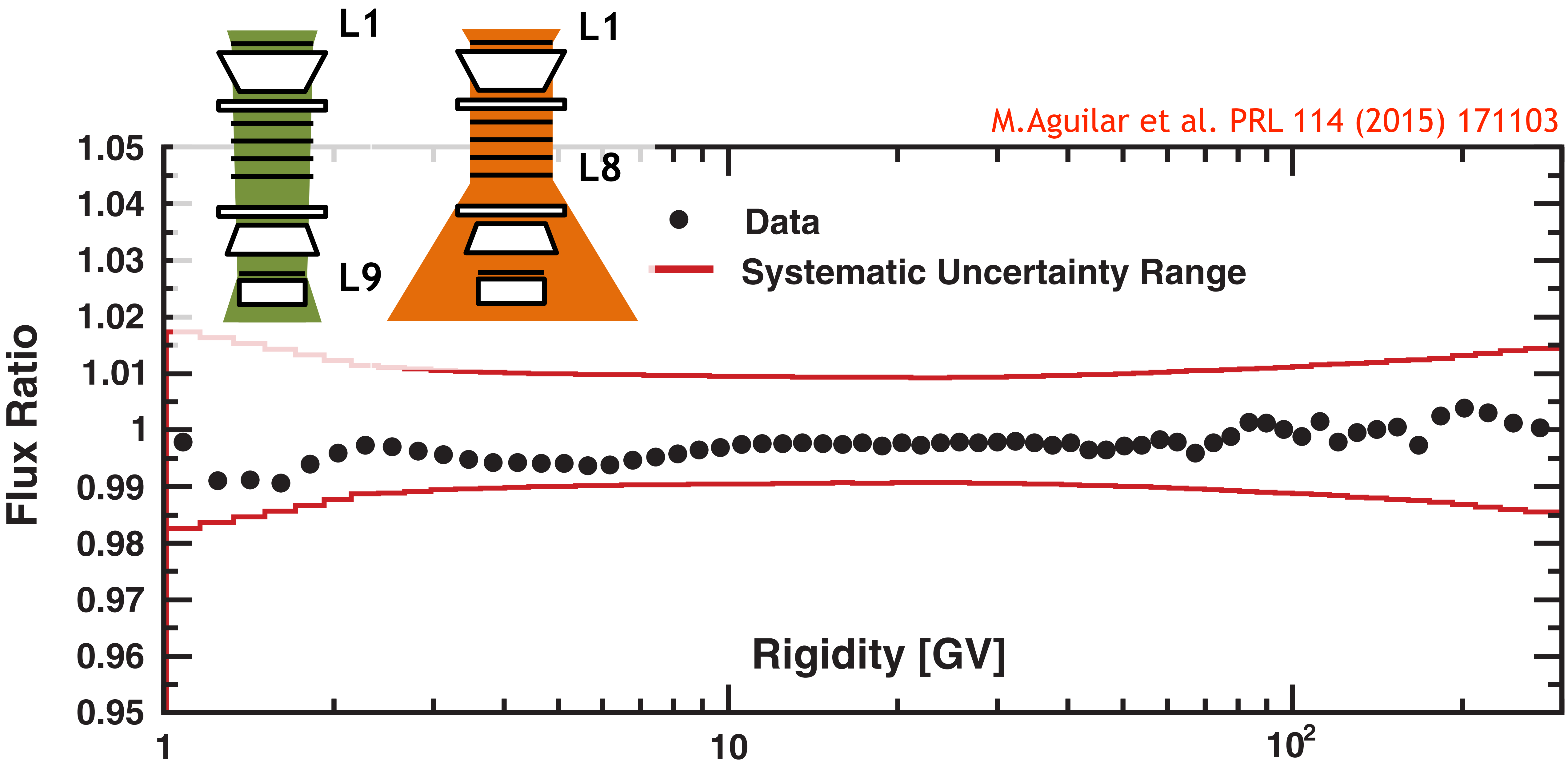


With ISS flying at 90° w.r.t. zenith
Particles coming from bottom,
interacting on upper part of AMS
(only ~2 days of data available)

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.

Measurement verification

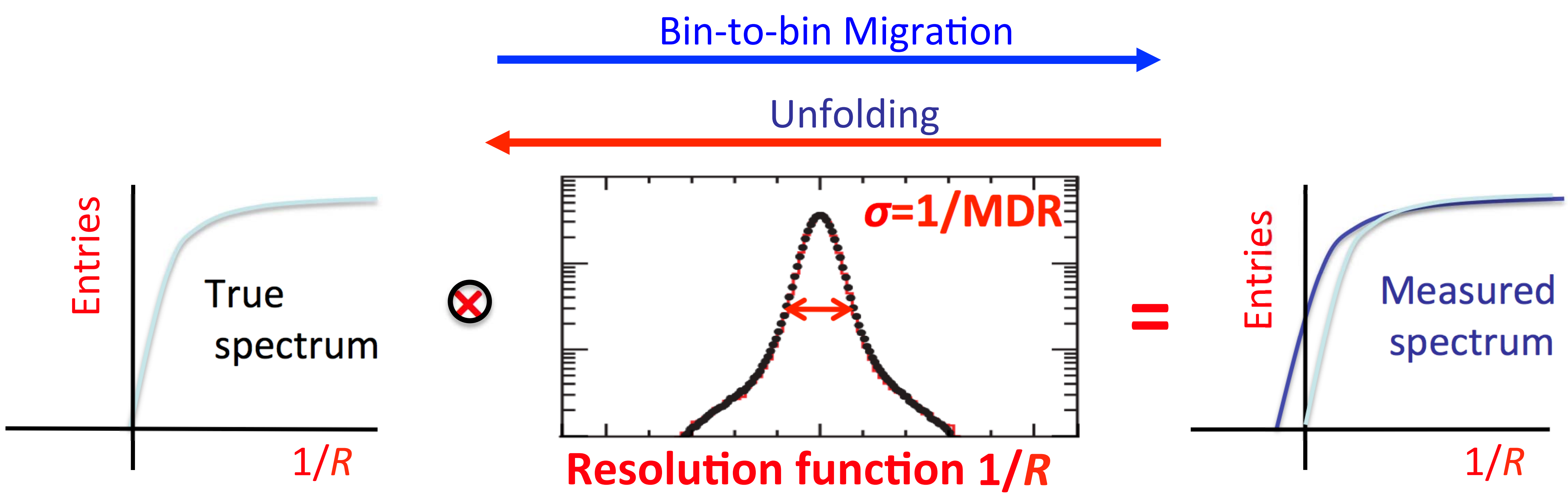
Fluxes measured using events passing through L1-L9
divided by the ones measured using events passing through L1-L8 (or L2-L8).
The observed agreement verifies:
(i) **acceptance**: the amount of material traversed is different
(ii) **unfolding**: bin-to-bin migration is different due to different resolution



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.

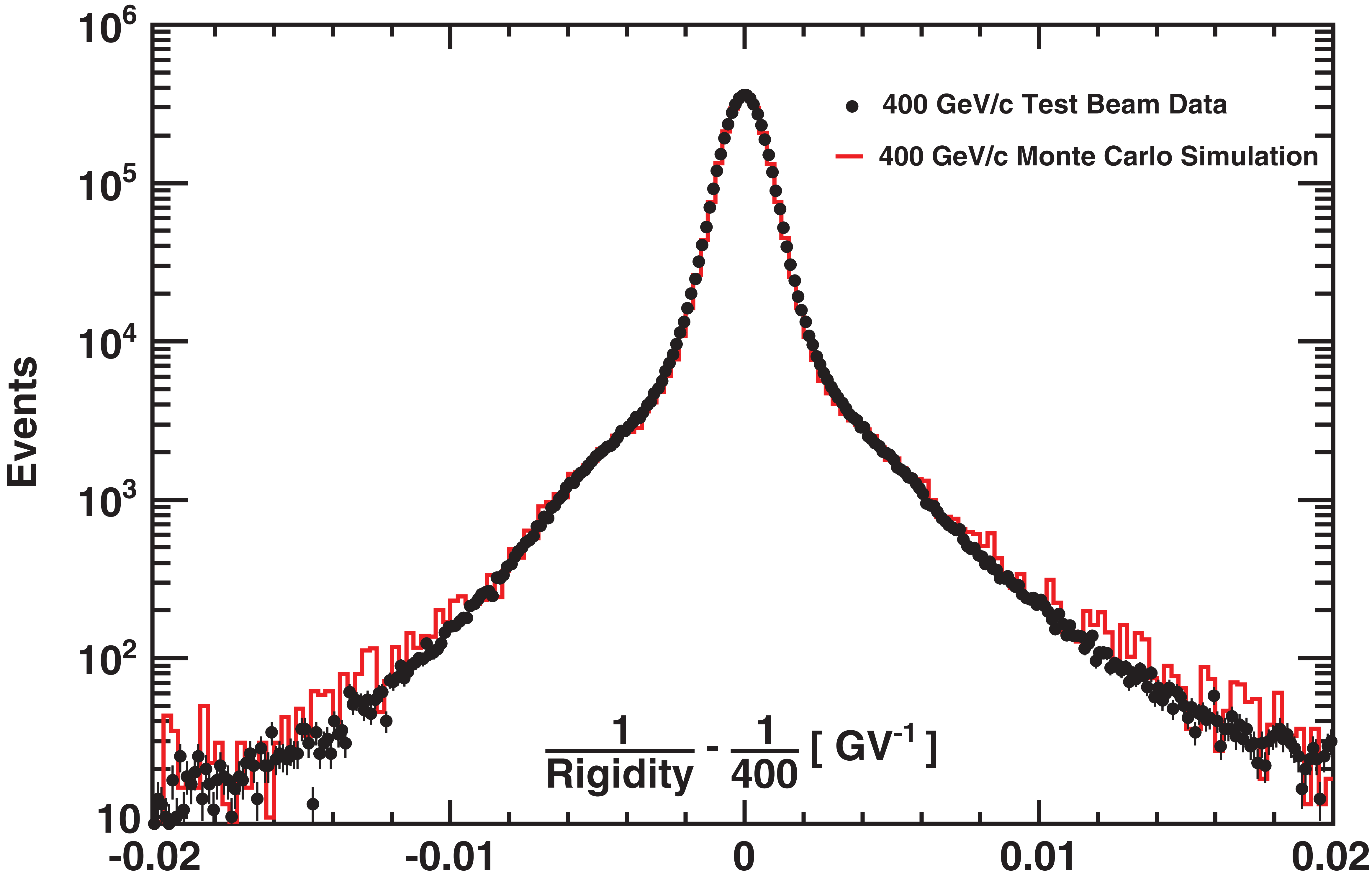
$$\Phi_j = \frac{N_j}{A_j\,\varepsilon_j\,T_j\,\Delta R_j}$$



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

Unfolding

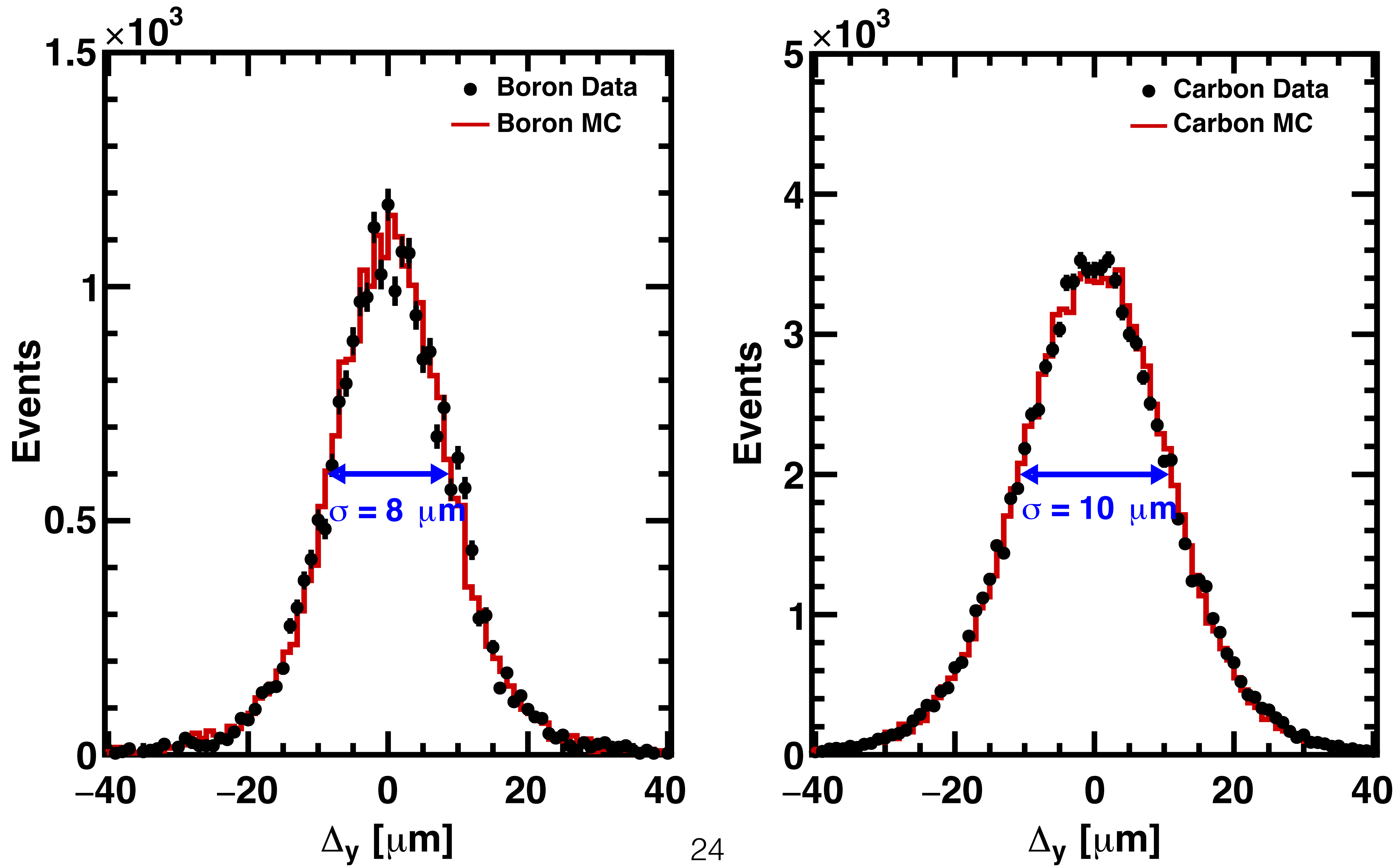
The resolution function for protons was measured on a 400 GV proton beam from the CERN SPS and the result was used to validate the MC simulation.



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.



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%.