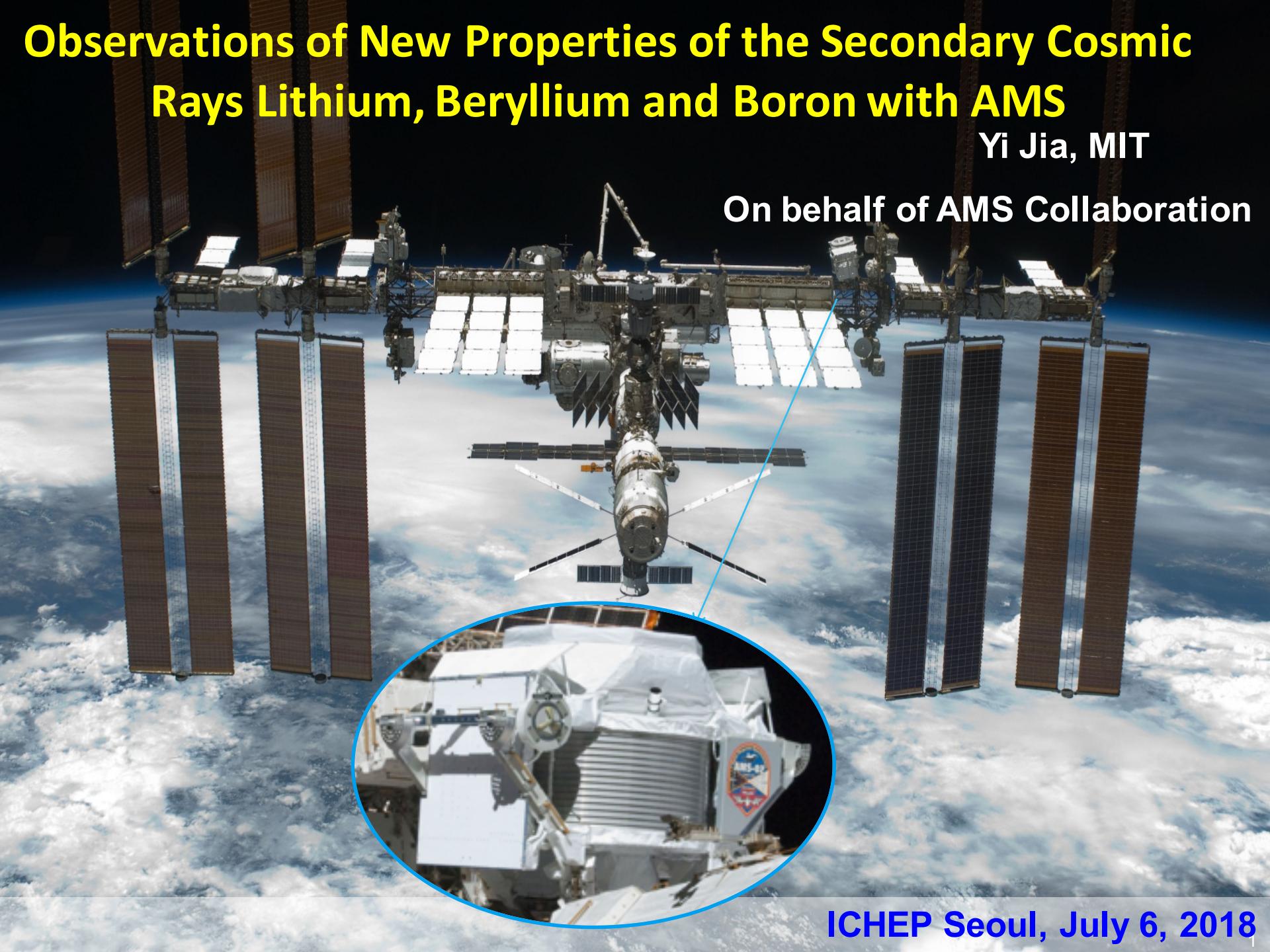


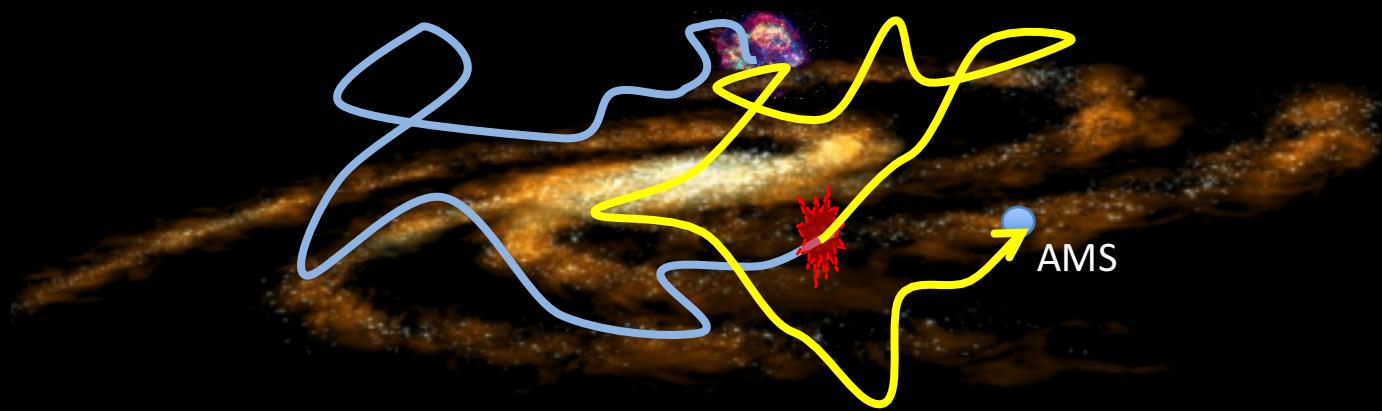
Observations of New Properties of the Secondary Cosmic Rays Lithium, Beryllium and Boron with AMS

Yi Jia, MIT

On behalf of AMS Collaboration



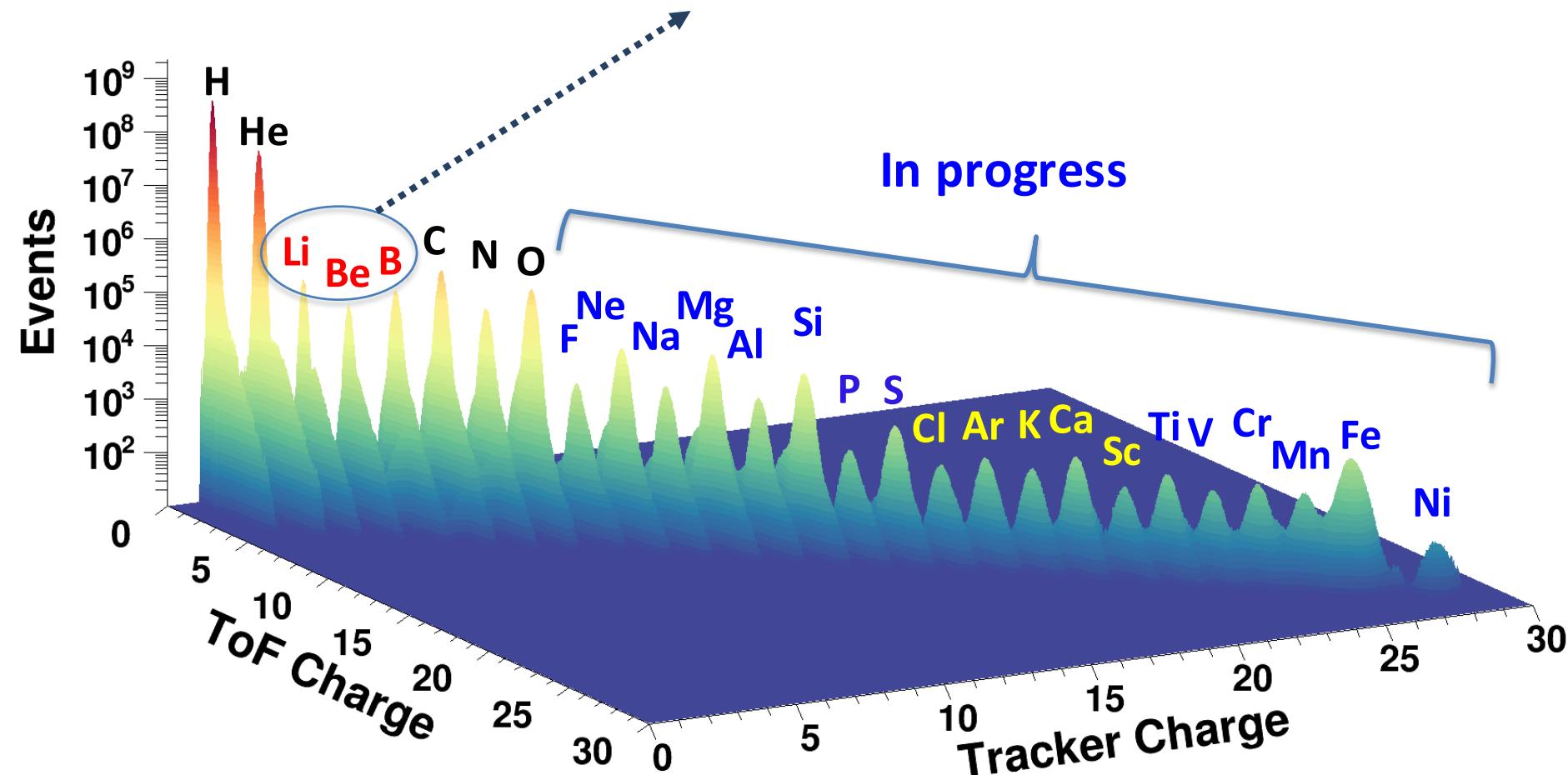
Secondary Cosmic Rays (Li, Be, B, ...)
are produced in the collisions of primary cosmic rays.
They carry information on the history of the travel and on
the properties of the interstellar medium.



The detailed knowledge of the secondary cosmic ray is important to study the origin and propagation of cosmic rays.

Periodic Table measured by AMS

Recent publication: Physical Review Letters 120, 0201101 (2018)



Precision Measurement of Cosmic Rays

AMS has seven instruments which
independently measure Cosmic Nuclei

Energy (E) or
Momentum (P)

Tracker and Magnet:

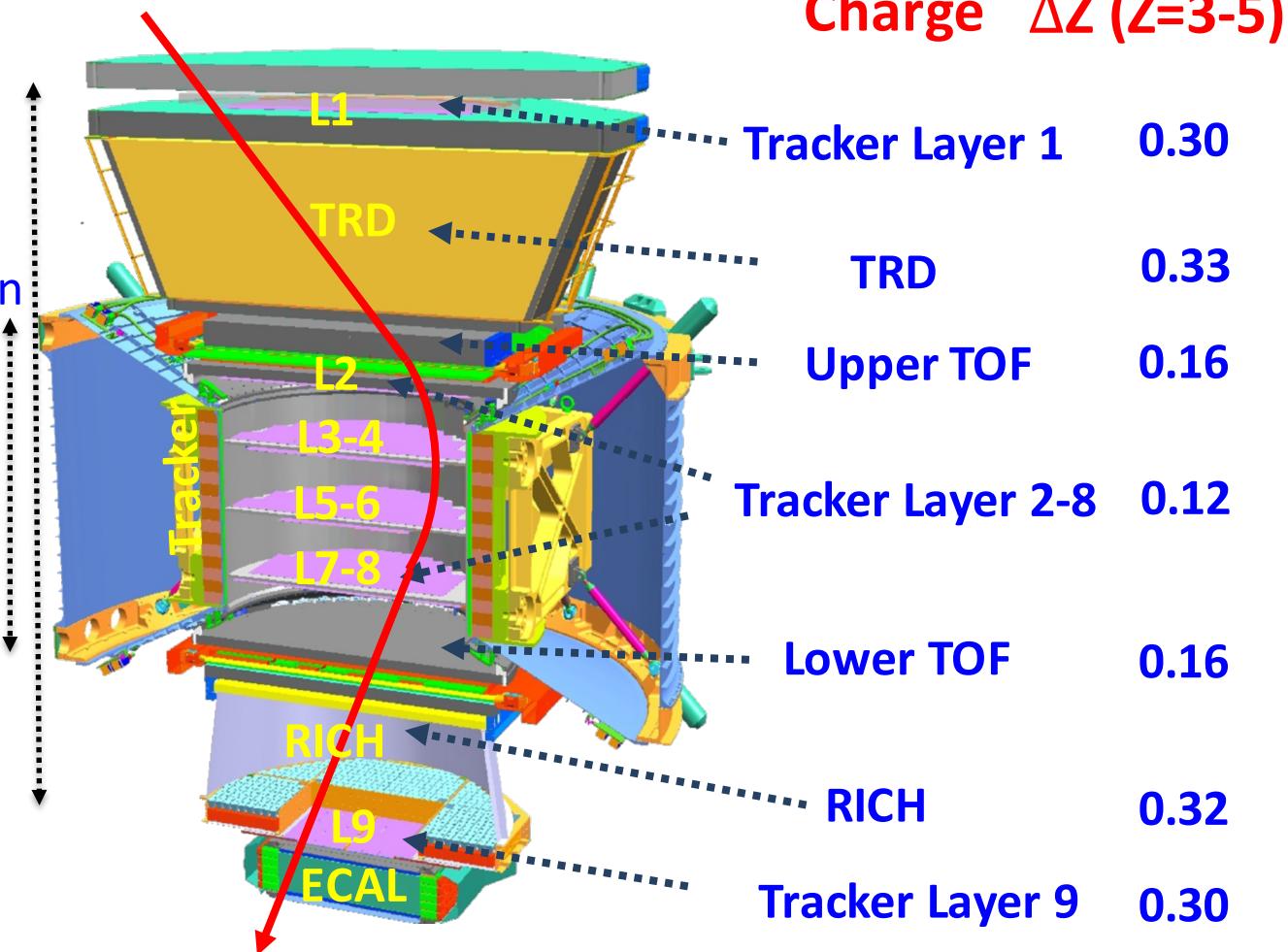
Rigidity $R = P/Z$

Bending Spatial Resolution
($Z=3-5$) $\approx 5.5 \mu m$

Full Span MDR
($Z=3-5$) ≈ 3.6 TV

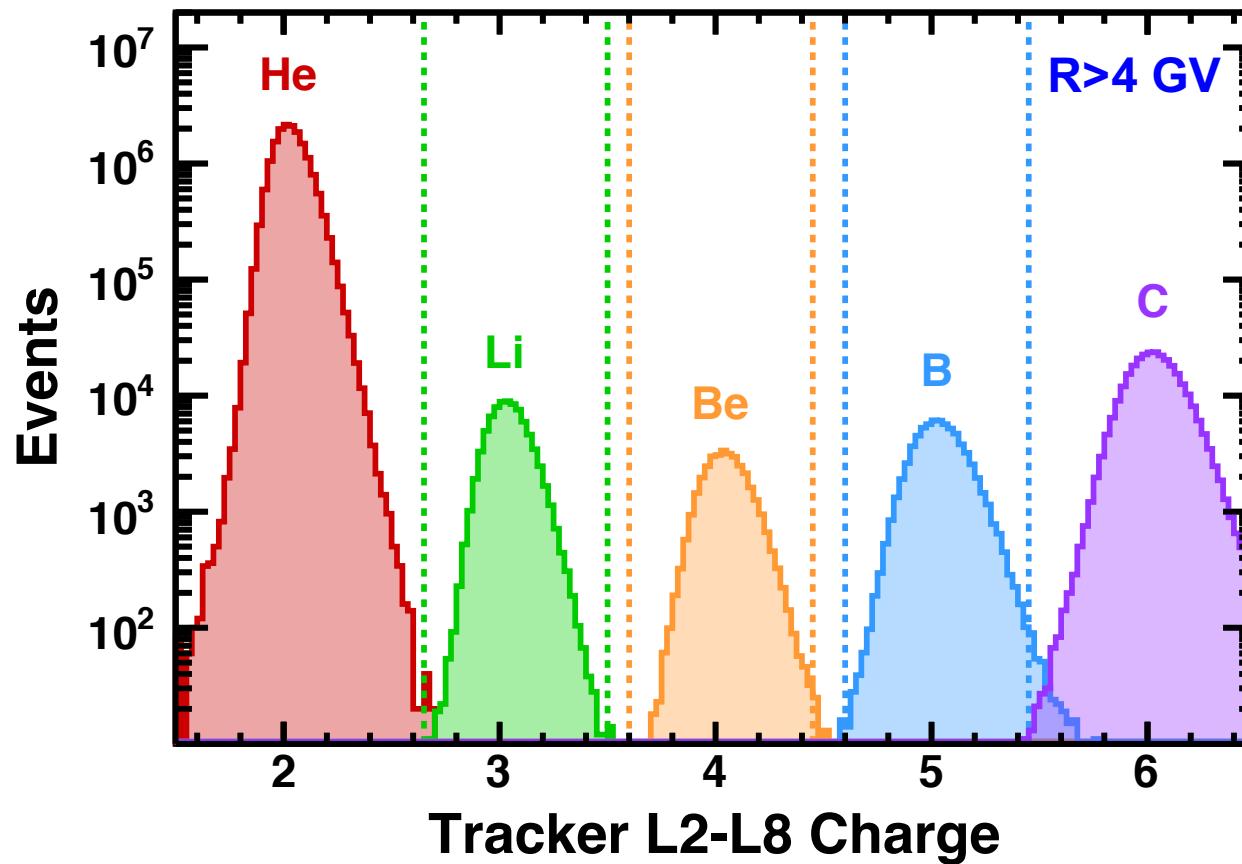
TOF: β

$\Delta\beta$ ($\beta=1, Z=3-5$) ≈ 0.01



Nuclei Selection

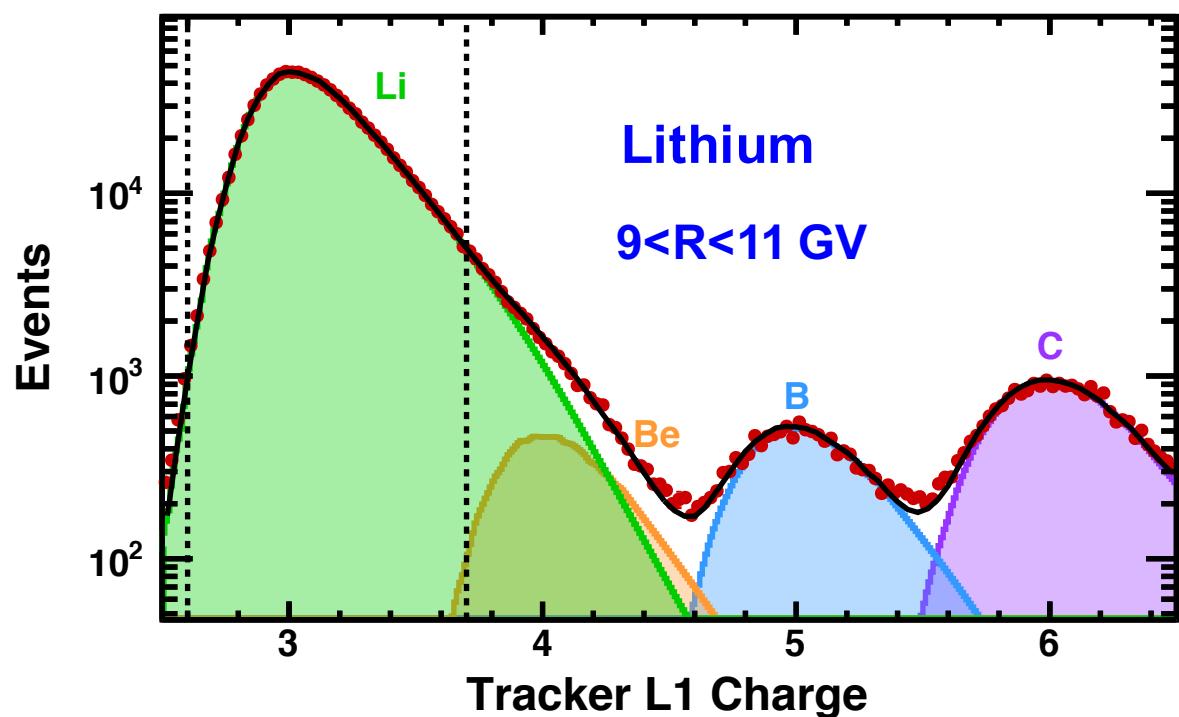
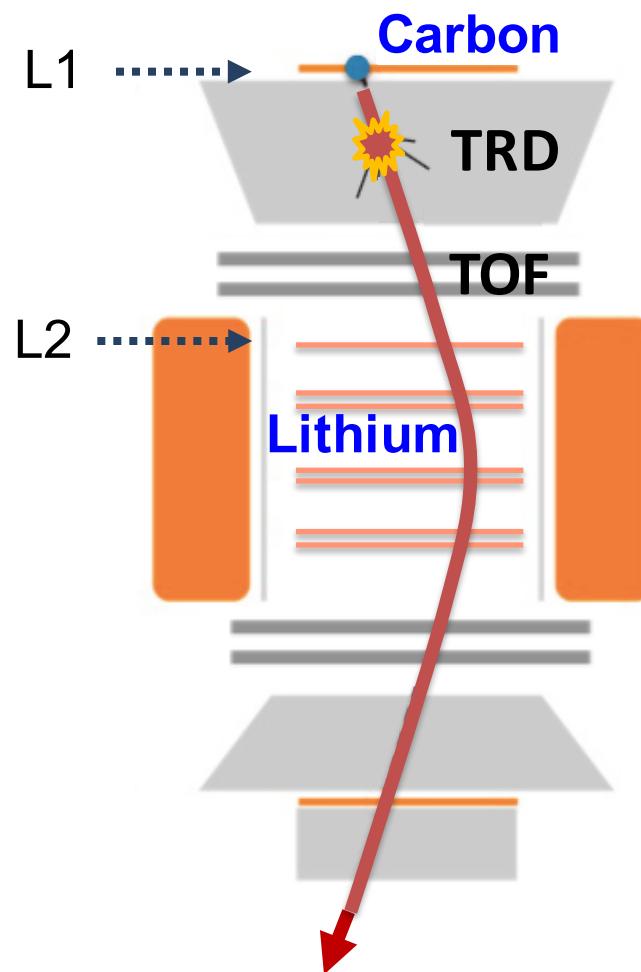
Charge measurements on tracker L1, the inner tracker, the upper TOF, and, for $R \geq 1.3\text{TV}$, tracker L9 are required to be compatible with charge $Z=3,4,\text{and } 5$.



The charge confusion from noninteracting nuclei is negligible.

a) Background Subtraction between L1 and L2

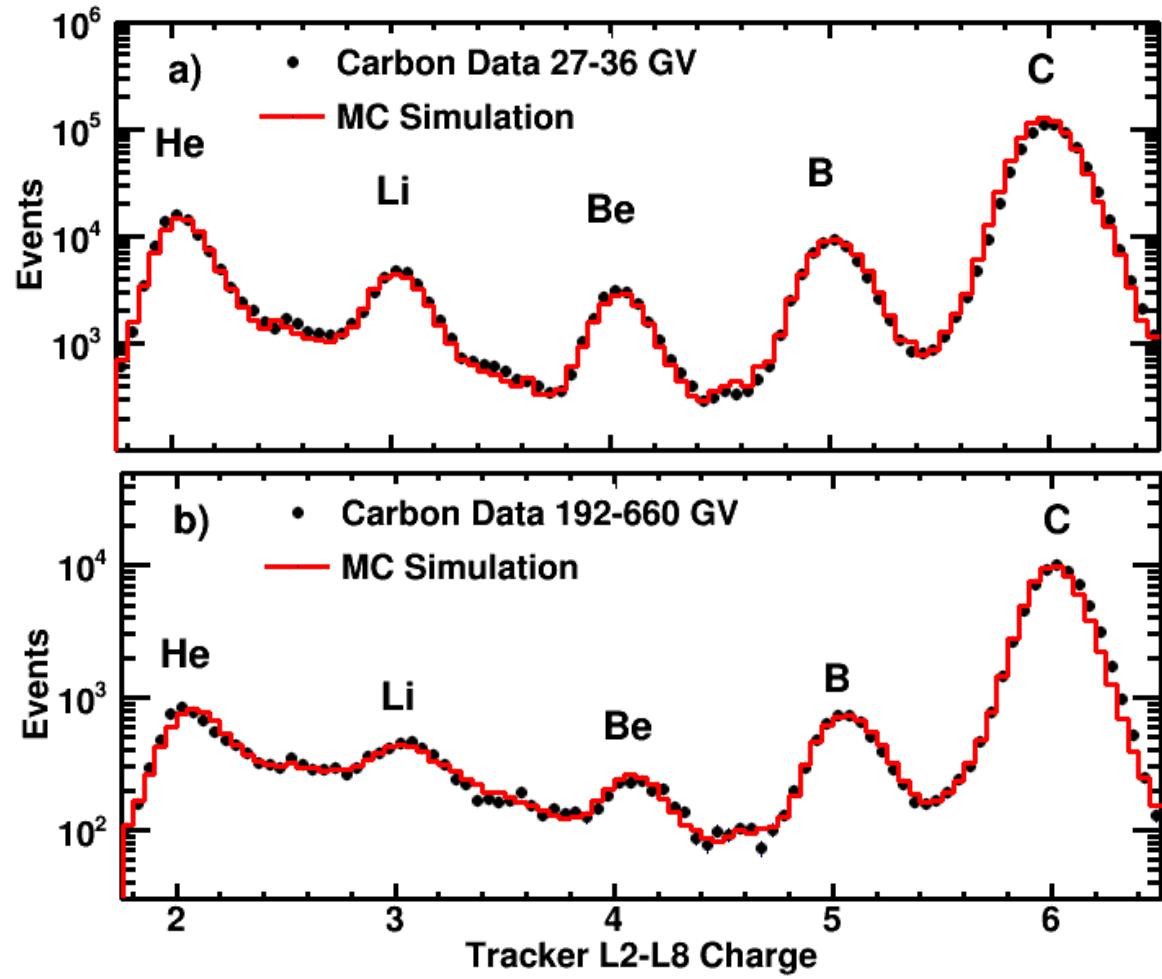
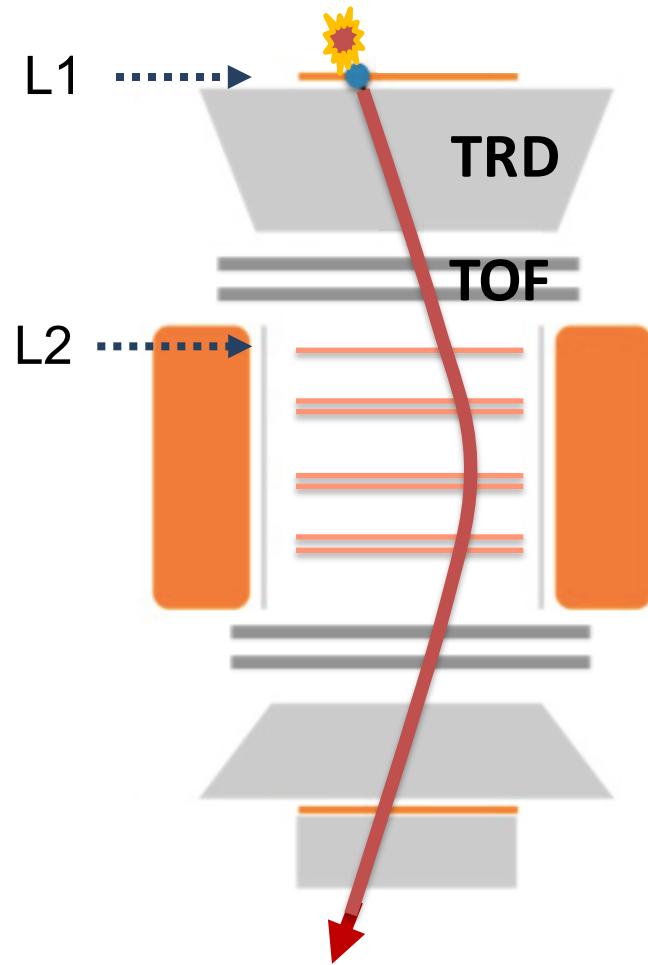
evaluated by fitting the charge distribution of tracker L1



This background is <0.5% for lithium and beryllium and <3% for boron over the entire rigidity range.

b) Background Subtraction above L1

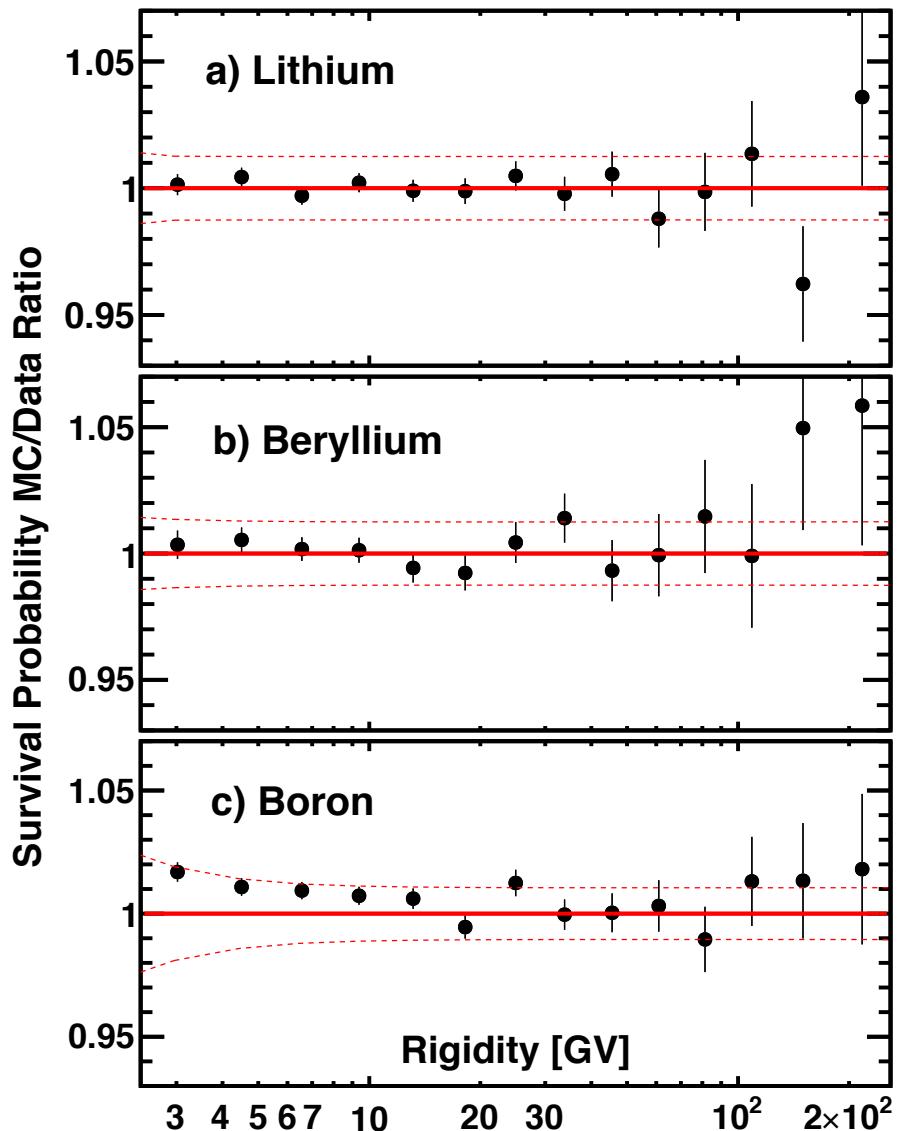
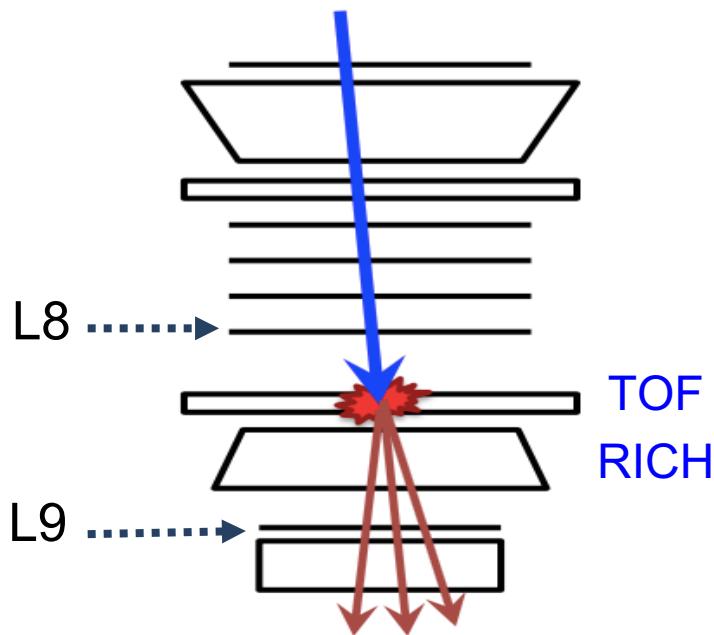
estimated from simulation using MC samples generated according to AMS flux measurements.



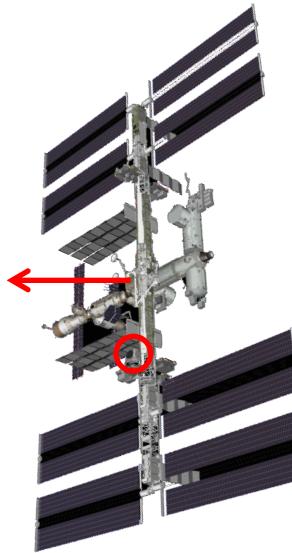
For Li, Be, and B these backgrounds are estimated to be 5%, 8%, and 5% at 2 GV and 2%, 13%, and 8% at 3.3 TV, respectively.

Inelastic Interactions of Nuclei in the AMS Materials.

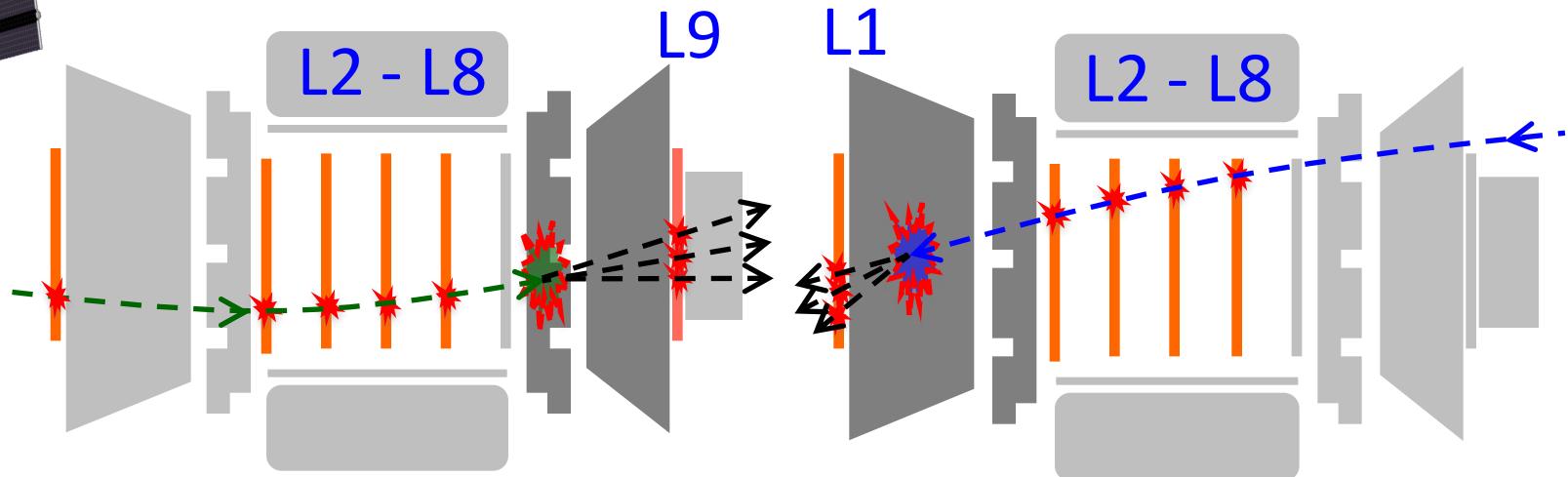
The probability of detecting survival nuclei after traversing the material between L8 and L9 can be used to verify the inelastic cross section



Inelastic Interactions of Nuclei in the AMS Materials.



The survival probability between L1 and L2 is measured using data acquired when AMS pointing in horizontal direction ($\sim 10^5$ sec exposure), in which cosmic rays can enter AMS both **right to left** and **left to right**.

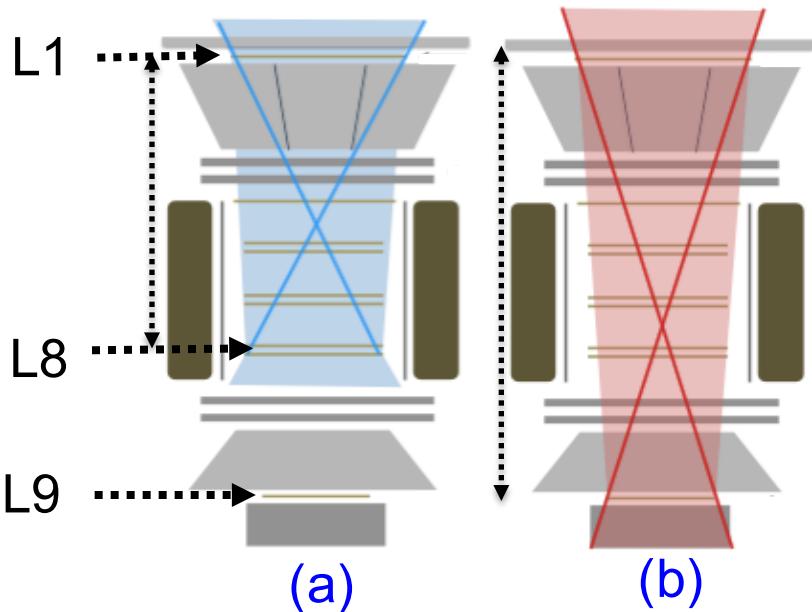


The systematic errors due to uncertainties of inelastic cross sections are < 2%–3% up to 100 GV and <3%-4% at 3.3 TV.

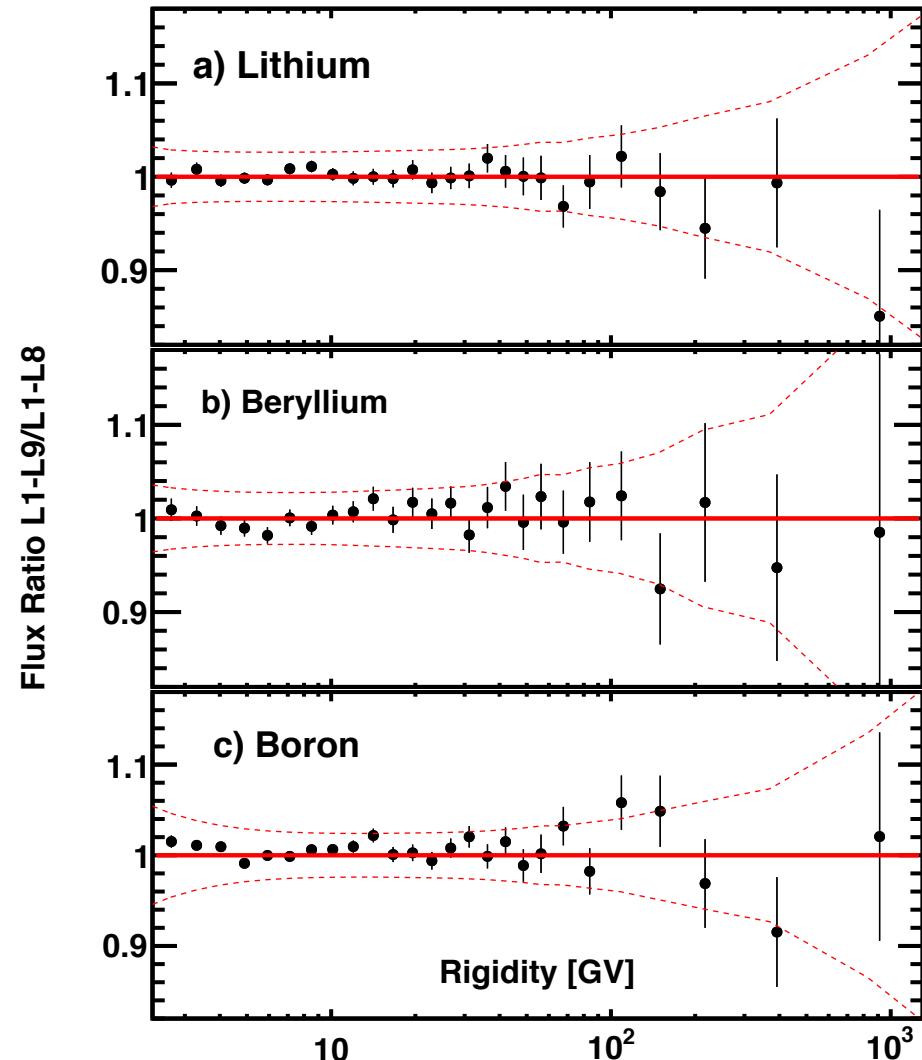
Flux Measurement Verification

The ratio of the measurements
using events

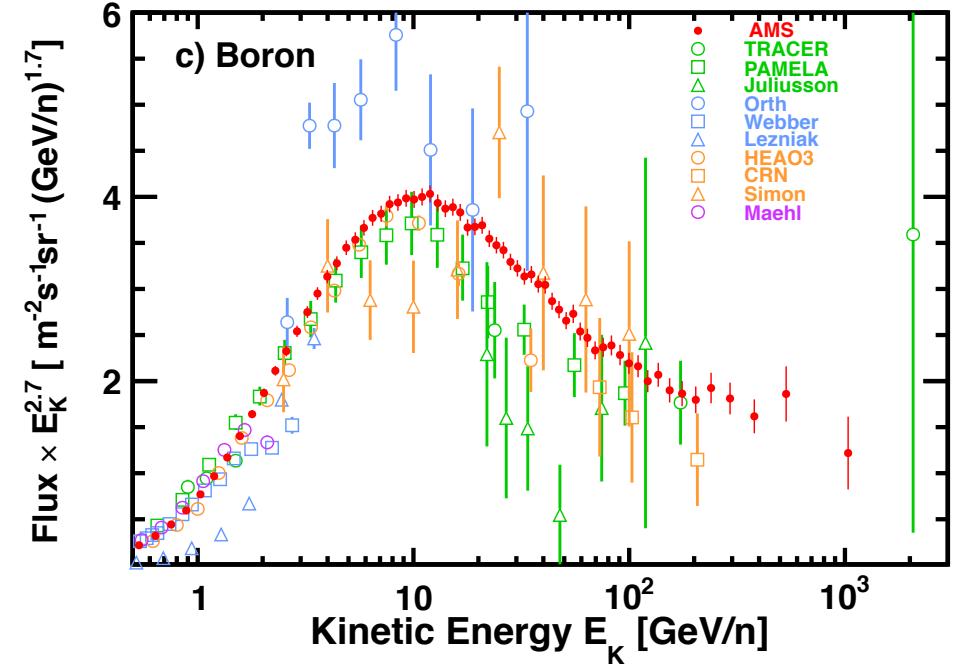
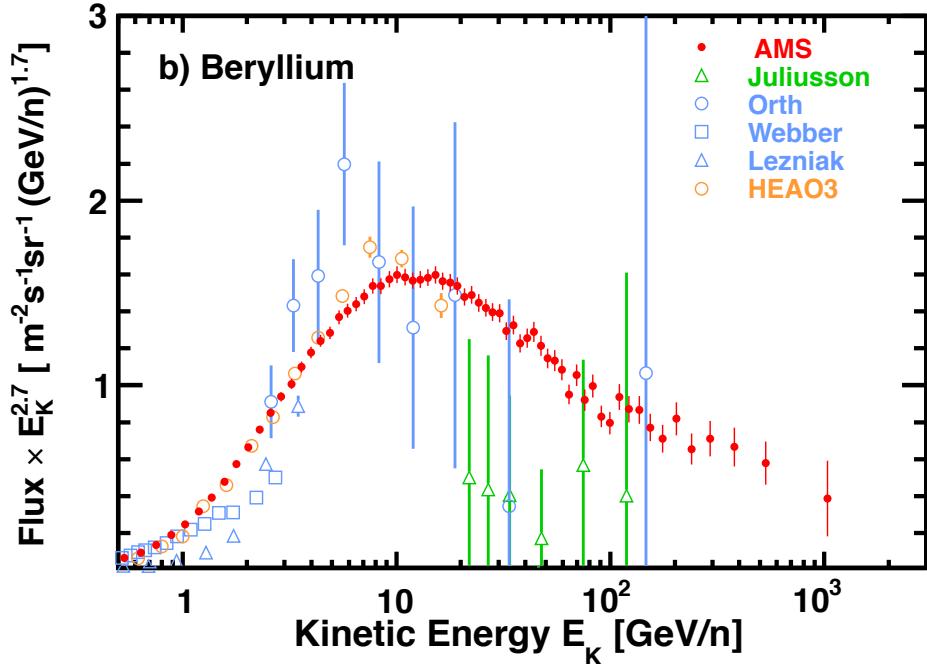
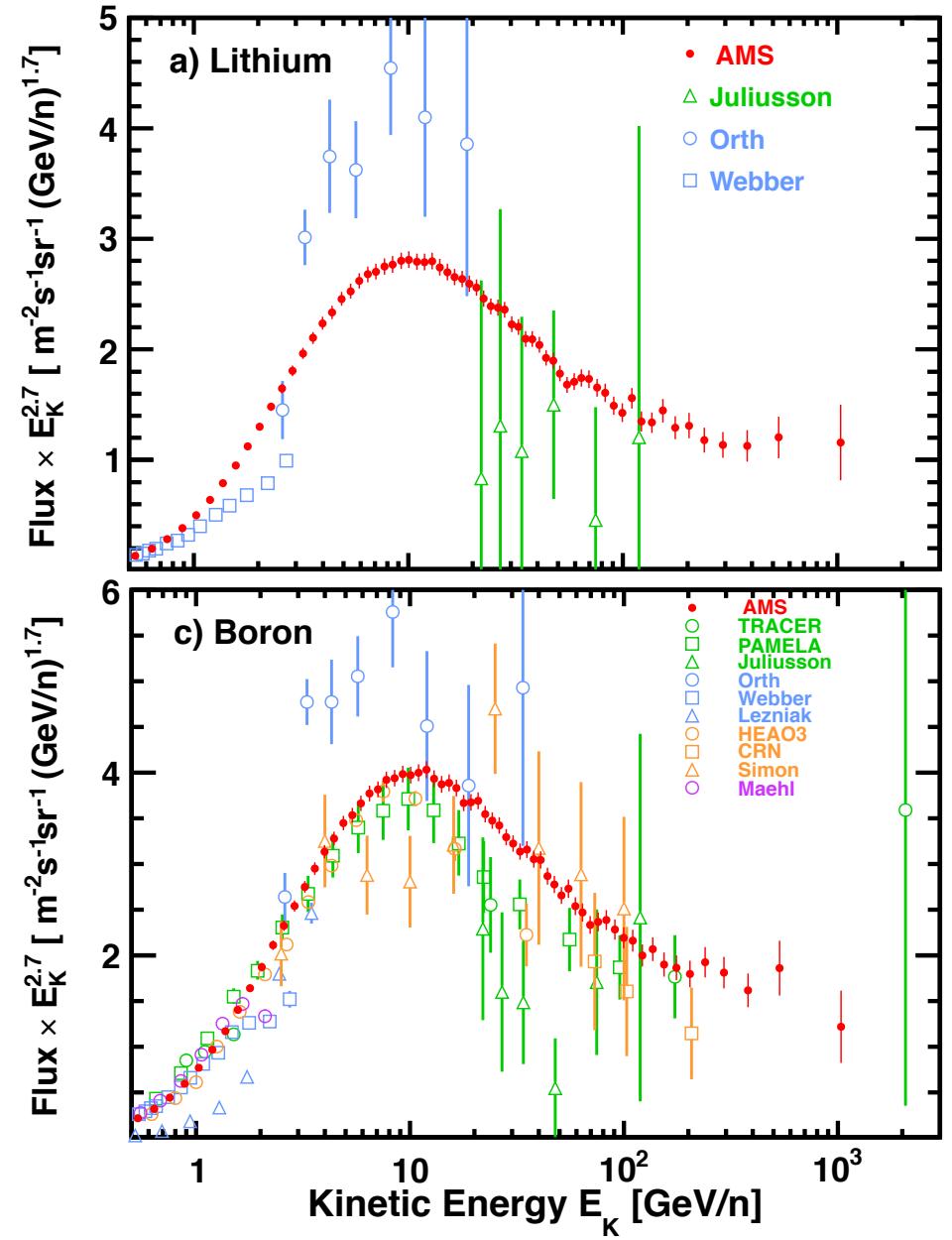
- (a) passing through L1 to L8
- (b) passing through L1 to L9



The good agreement verifies
the systematic errors on
unfolding and acceptance.



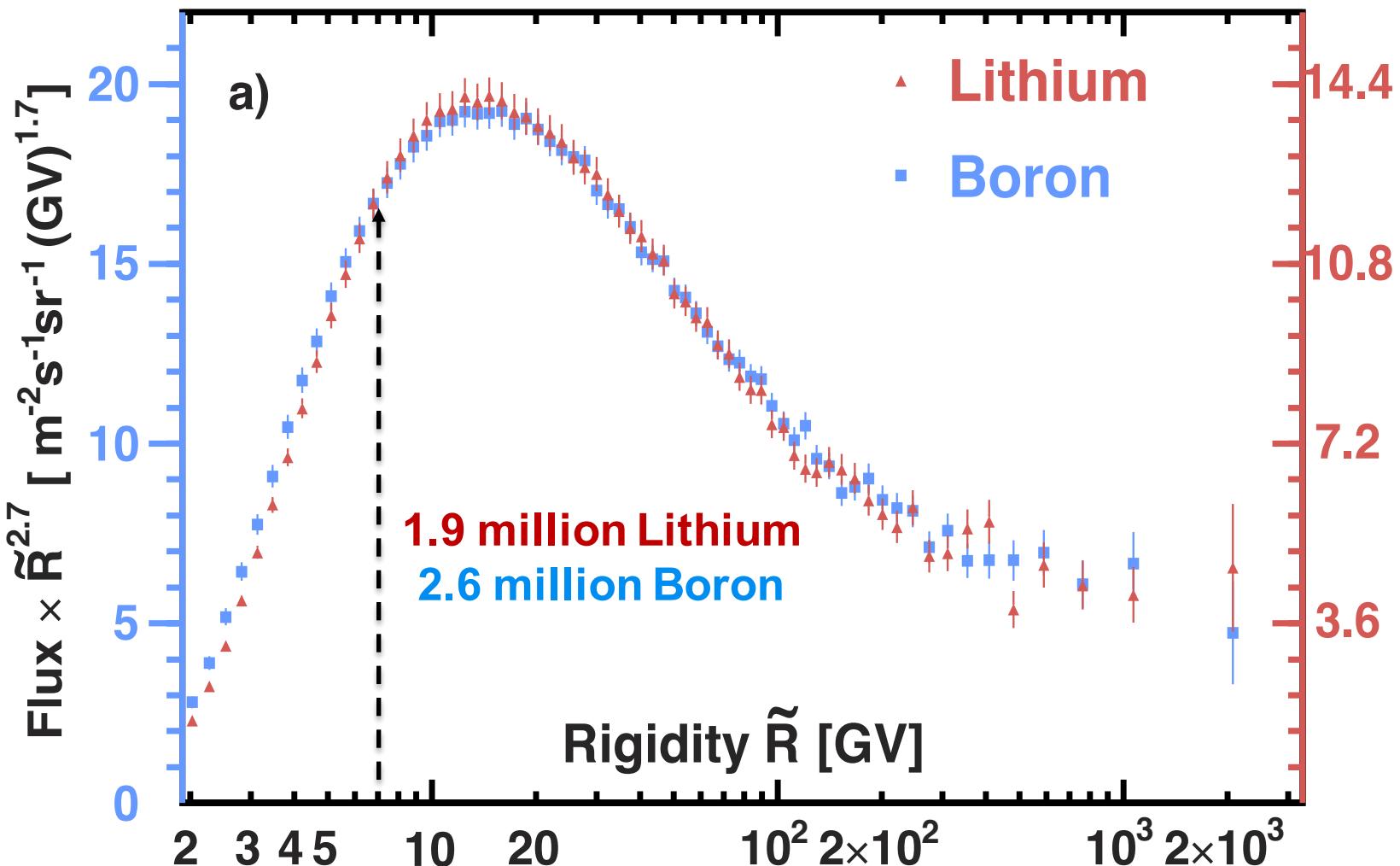
Fluxes Results with Previous Measurements



With precise (**total error is 3%-4%** at **100 GV**) measurements from 1.9 GV to 3.3 TV by AMS, we are able to study the properties of secondary cosmic rays in details.

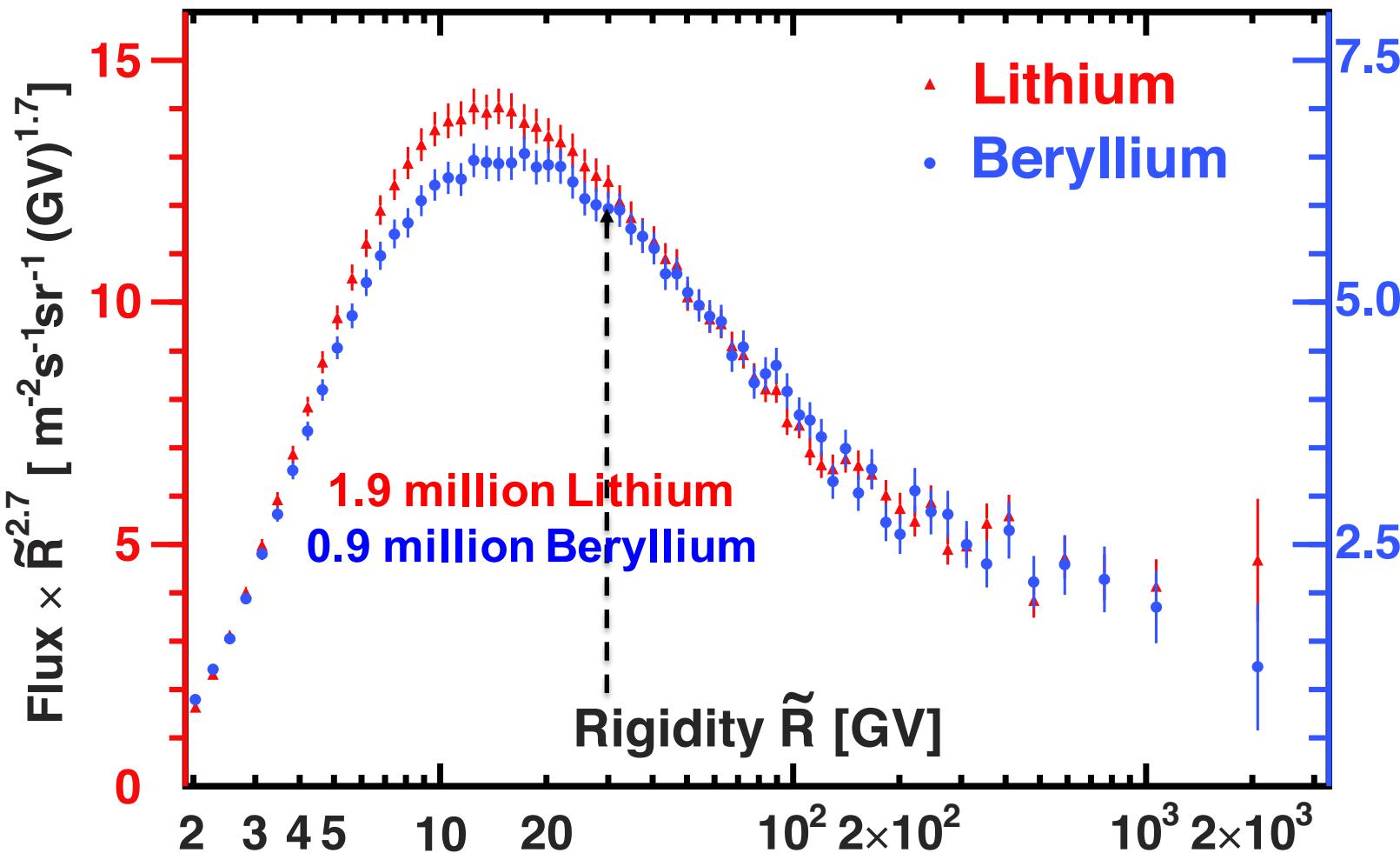
Lithium and Boron Fluxes

Above 7 GV Li and B have identical rigidity dependence



Lithium and Beryllium Fluxes

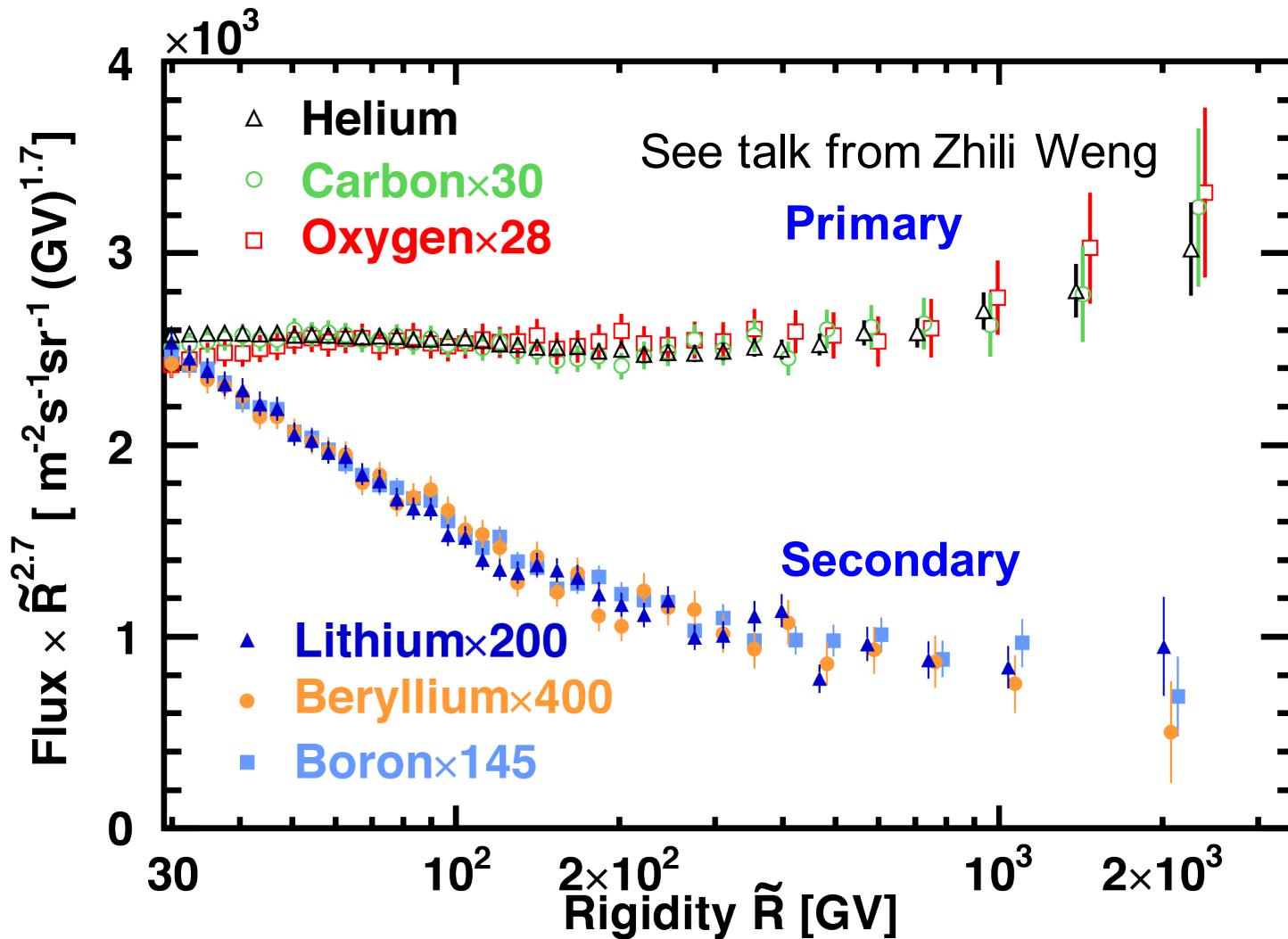
Above 30 GV Li and Be have identical rigidity dependence.
The fluxes are different by a factor of 2.



Effect of radioactive ${}^{10}\text{Be}$ isotope

Rigidity dependence of Primary and Secondary Cosmic Rays

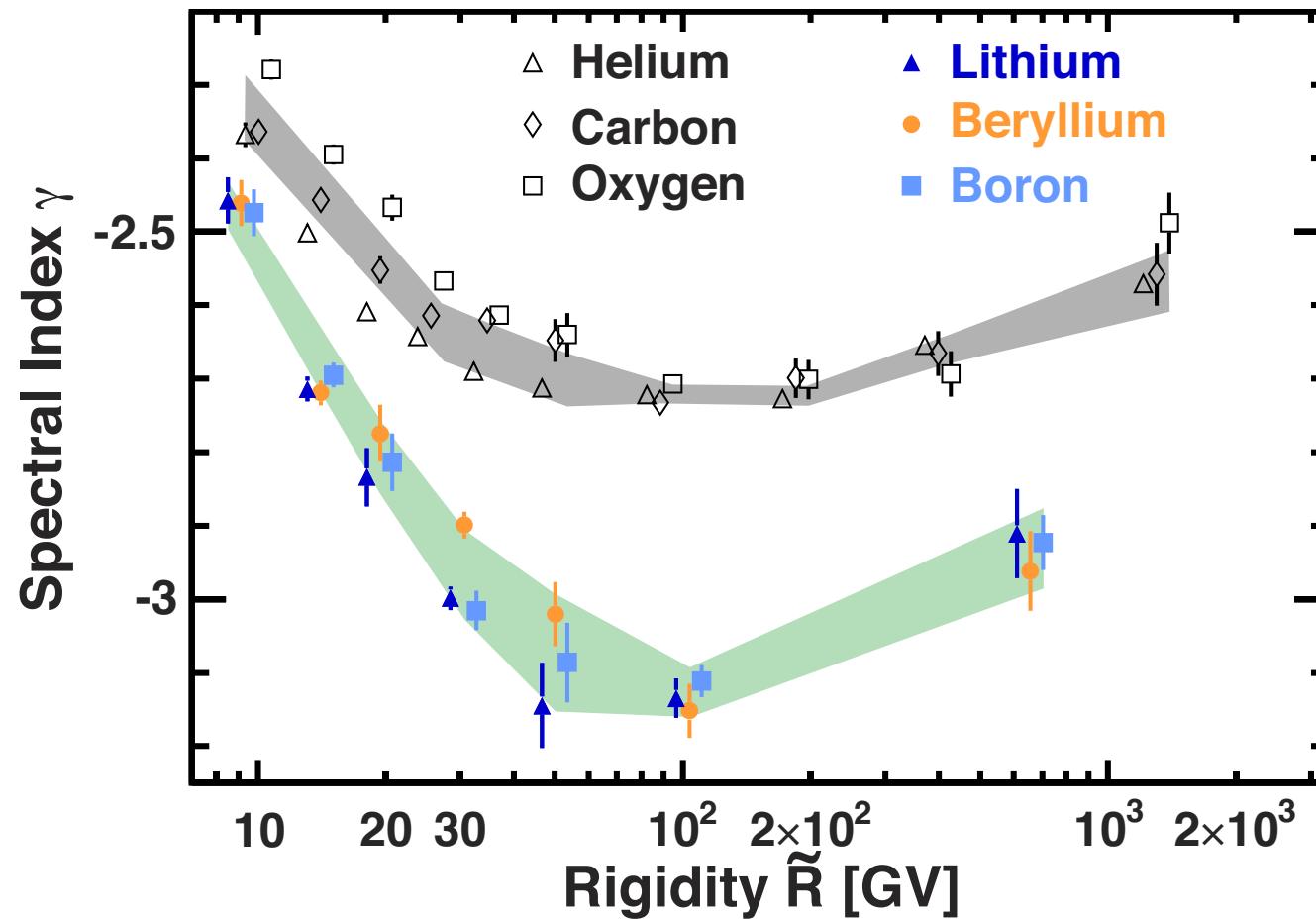
Both deviate from a single power law above 200 GV.
But their rigidity dependences are distinctly different.



Primary and Secondary Cosmic Ray Spectral Indices

$\Phi = CR^\gamma$ (Φ is the flux; C is a constant; γ is the spectral index)

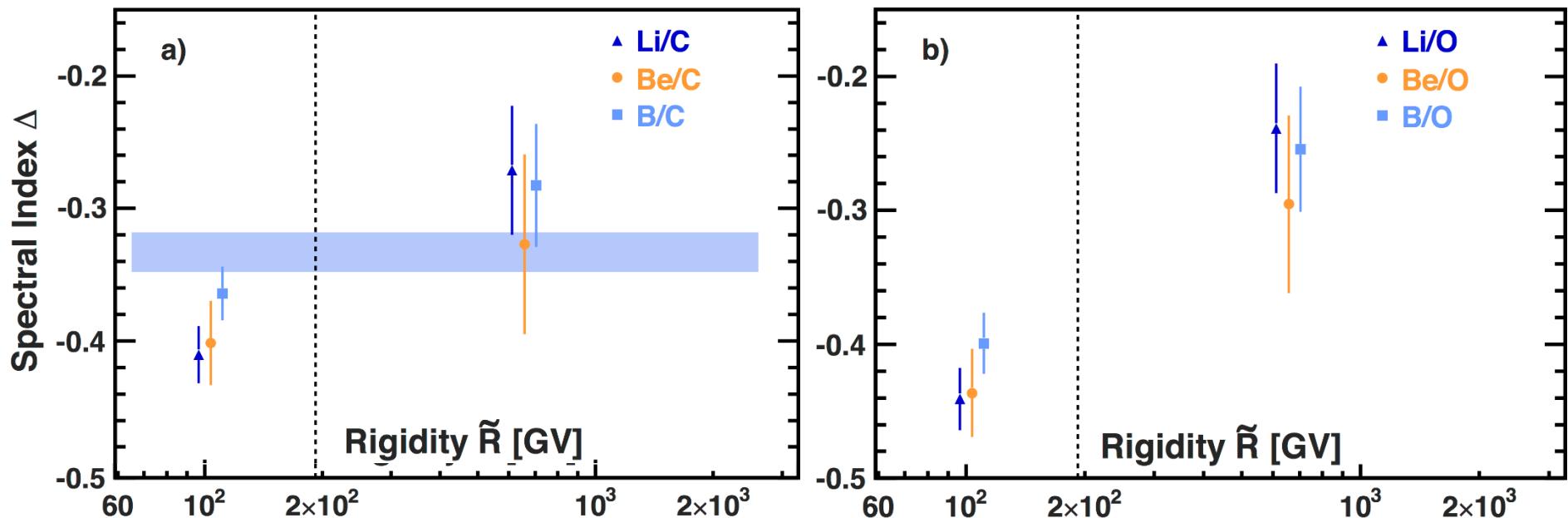
The magnitude and the rigidity dependence of the secondary cosmic ray spectral indices are nearly identical, but **distinctly different** from the rigidity dependence of the primary cosmic rays.



Above 200GV, Li, Be, B all harden more than He, C, and O.

Secondary to Primary Flux Ratio Spectral Indices

$$\Phi_S/\Phi_P = CR^\Delta$$



Combining the six ratios, the spectral indices exhibit an average hardening above 200GV:

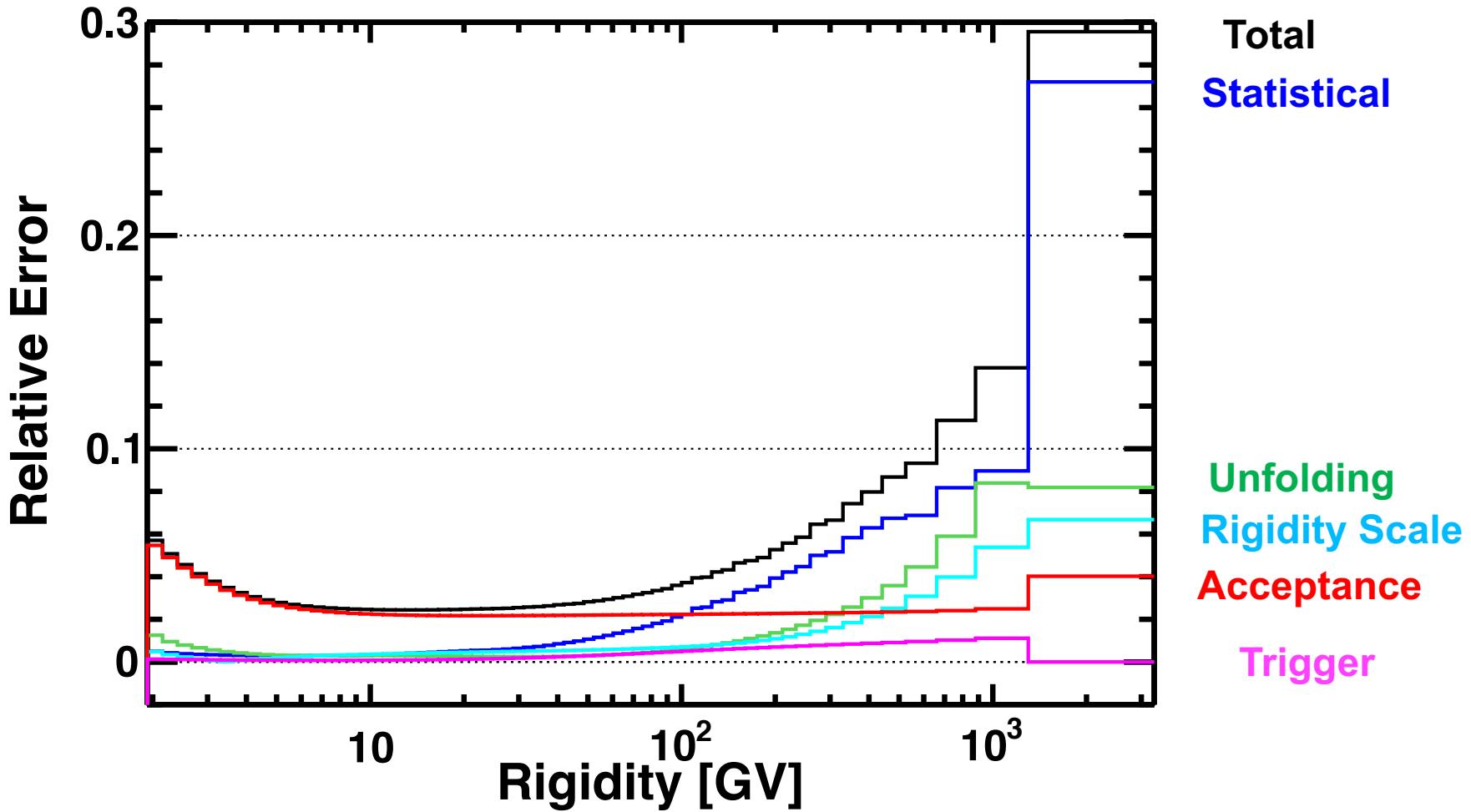
$$\Delta[200-3300\text{GV}] - \Delta[60-200\text{GV}] = 0.13 \pm 0.03$$

Conclusions

- Lithium, Beryllium and Boron have been measured in the rigidity range **1.9 GV to 3.3 TV** with a total of **5.4×10^6** nuclei collected by AMS during the first 5 years of operation.
- The Li and B fluxes have identical rigidity dependence above **7 GV** and **all three fluxes have identical rigidity dependence above 30 GV** with the Li/Be flux ratio of 2.0 ± 0.1 .
- The Li, Be and B fluxes deviate from a single power law above **200 GV** in an identical way. **But their rigidity dependences are distinctly different from the primary cosmic rays.** In particular, above 200 GV, the secondary cosmic rays harden more than the primary cosmic rays.

Back up

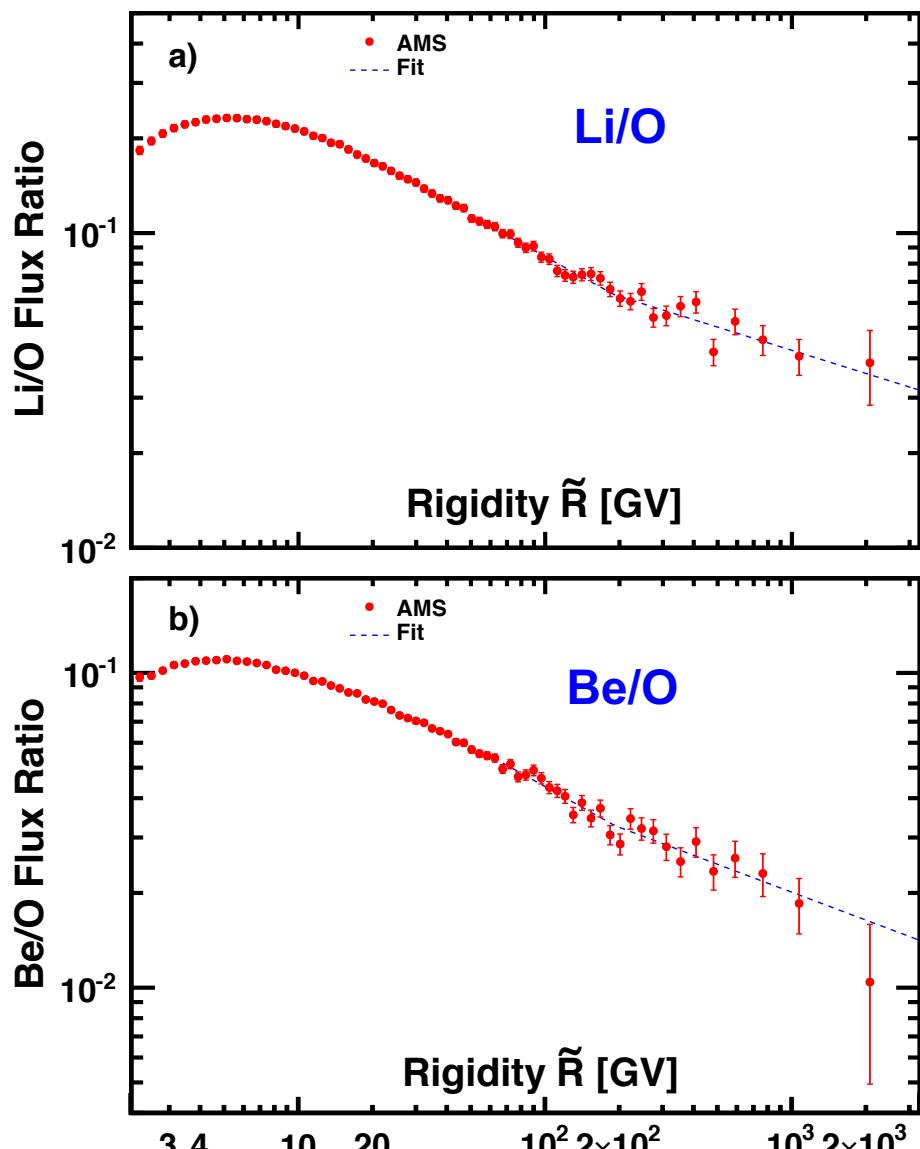
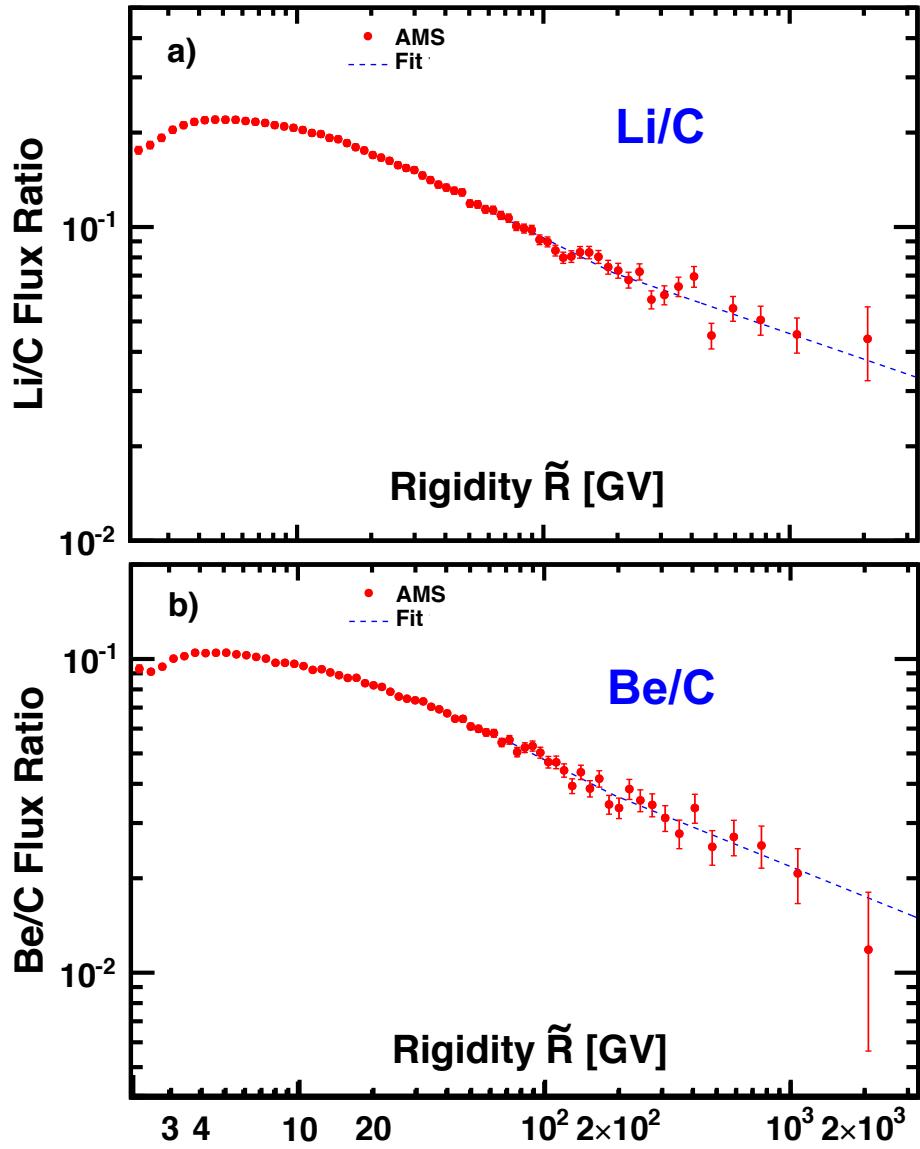
Flux Errors Breakdown (Boron)



The systematic errors include the uncertainties in the background estimations, the trigger efficiency, the geomagnetic cutoff factor, the acceptance calculation, the rigidity resolution function, and the absolute rigidity scale.

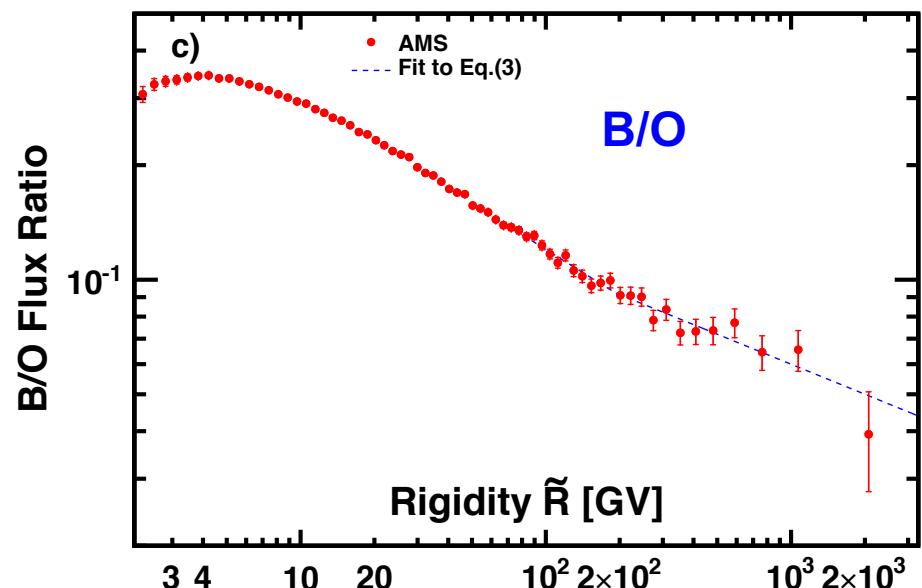
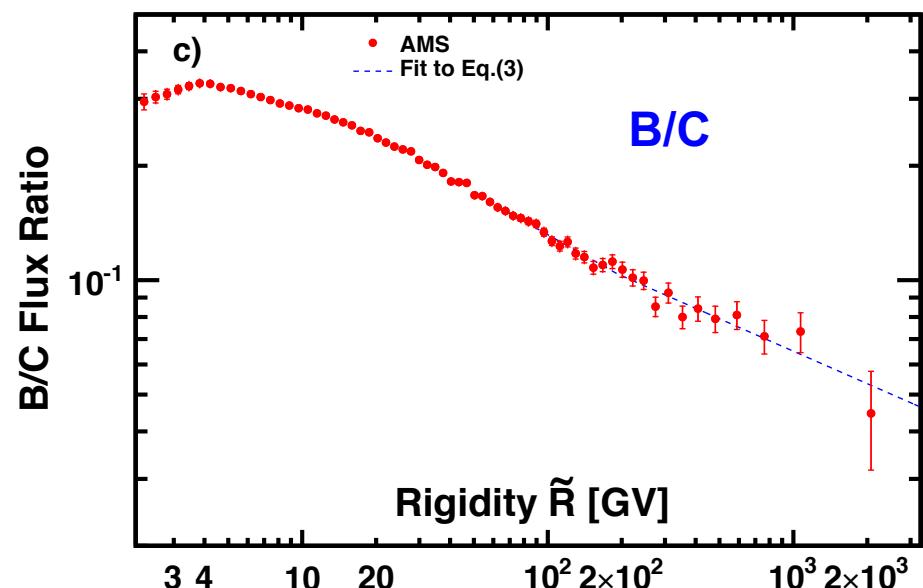
Secondary to Primary Flux Ratio

$$\Phi_S/\Phi_P = CR^\Delta$$

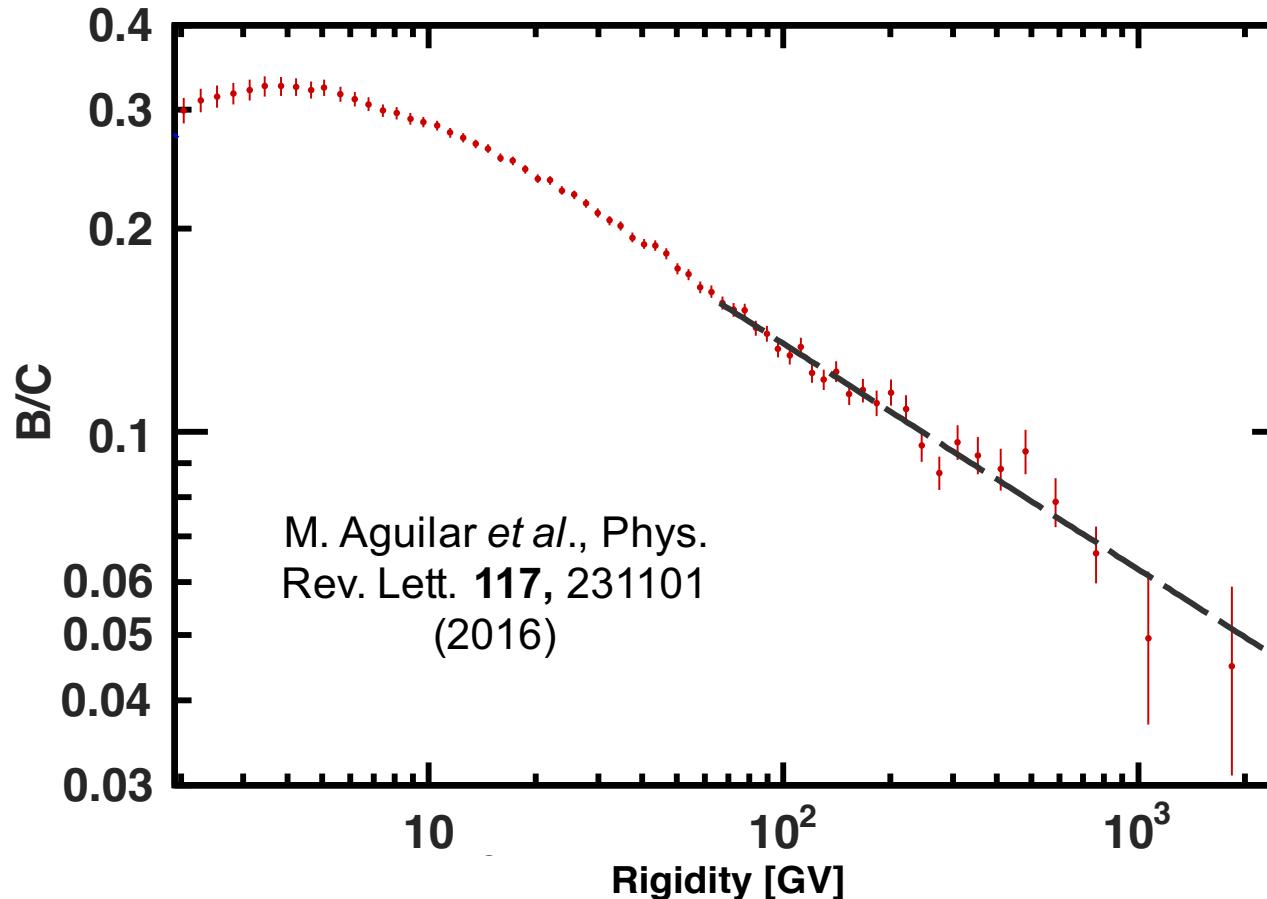


Secondary to Primary Flux Ratio

$$\Phi_S/\Phi_P = CR^\Delta$$



Secondary to Primary Flux Ratio



The B/C ratio **does not show any significant structures**

$$B/C = kR^\delta,$$
$$\delta = -0.333 \pm 0.015$$