Measurement of Secondary Cosmic Rays Lithium, Beryllium and Boron with the Alpha Magnetic Spectrometer (AMS) on the International Space Station (ISS)

Yi Jia, MIT

On behalf of AMS Collaboration

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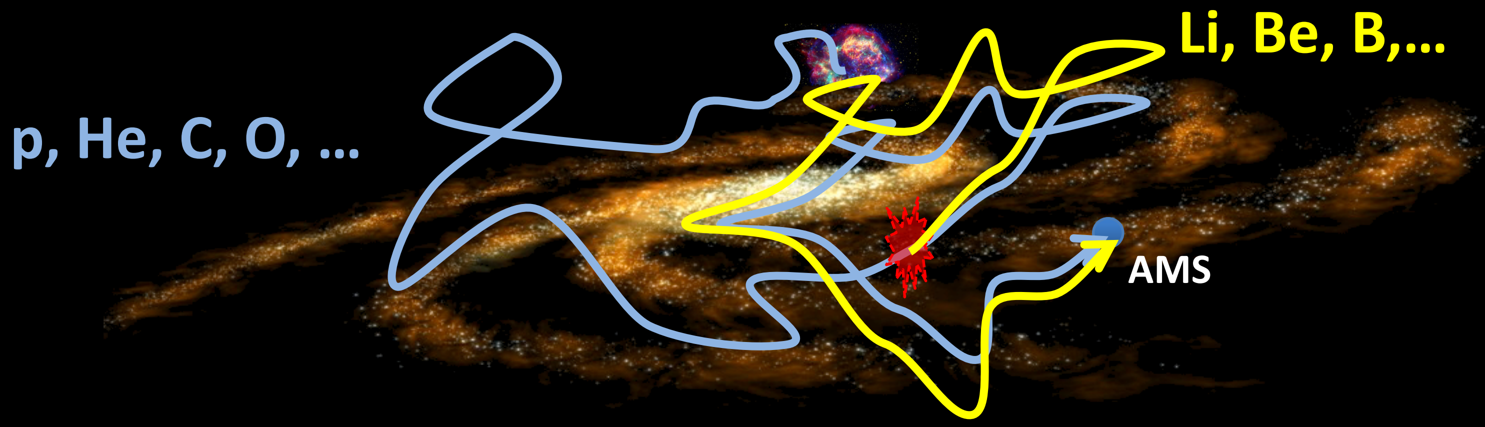
Traditionally, there are two prominent classes of cosmic rays:

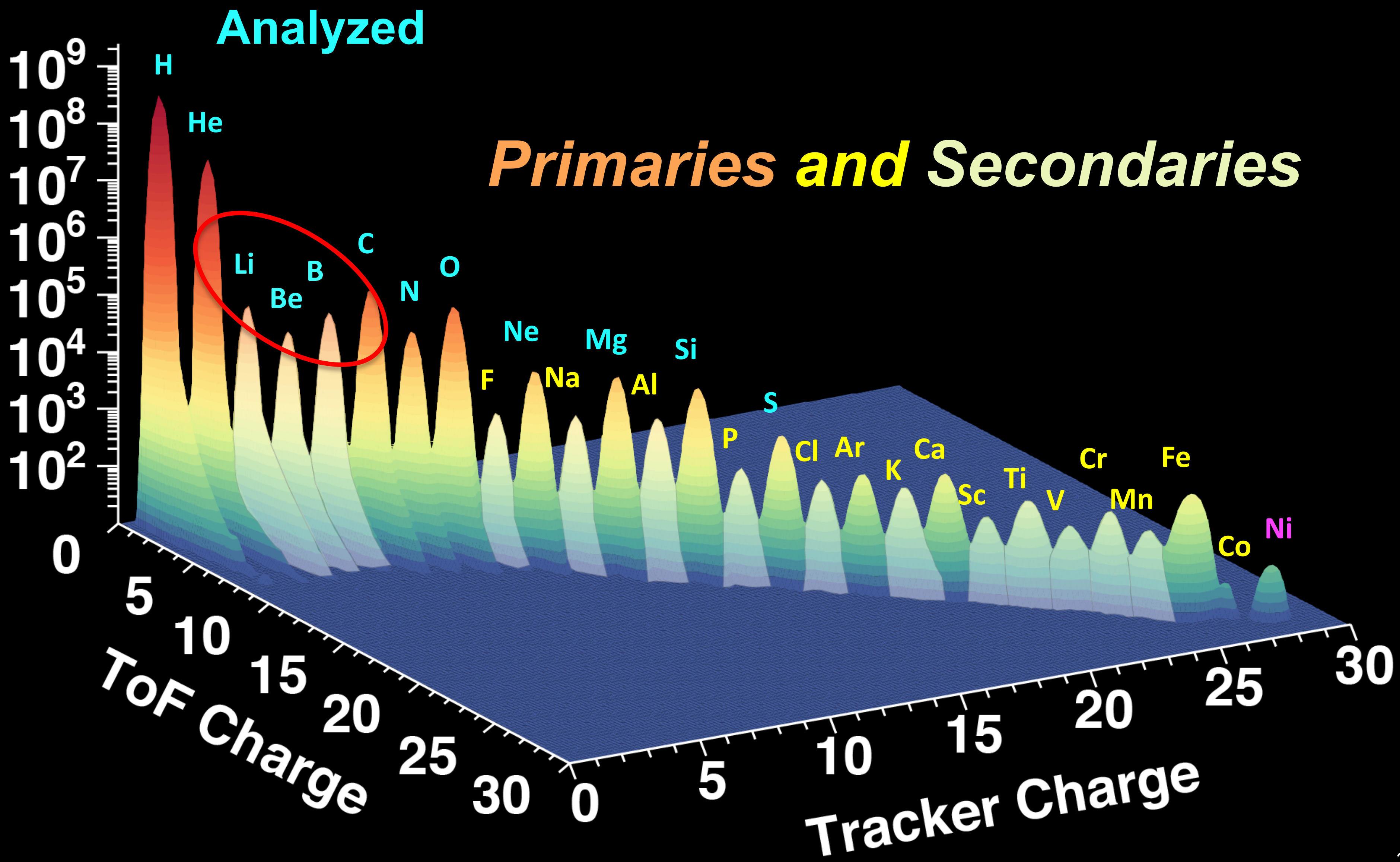
Primary (p, He, C, O,…) and Secondary (Li, Be, B, …).

Primary Cosmic Rays are produced and accelerated at the source (such as SNR). They carry information on their sources and the history of travel.



Secondary Cosmic Rays 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 matter.

AMS Measurements on Secondary Cosmic Rays



Precision Measurement of Cosmic Rays

AMS has seven instruments which independently measure Cosmic Nuclei

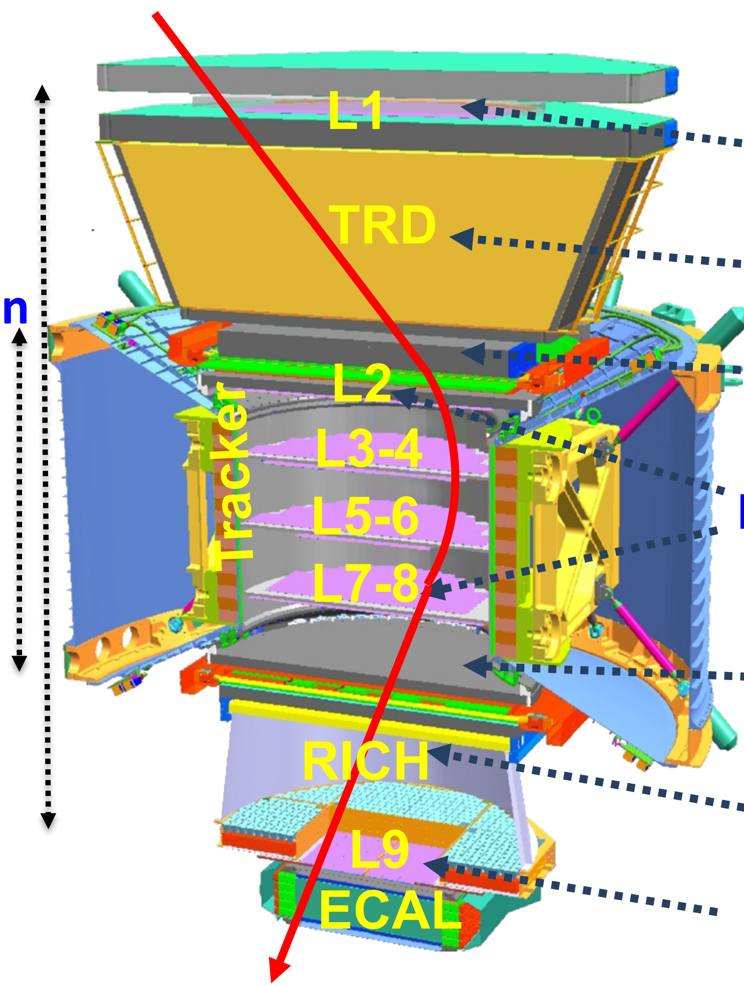
Energy (E) or Momentum(P)

Tracker and Magnet:
Rigidity R = P/Z

Bending Spatial Resolution (Z=3-5) ≈ 5.5 μm

Maximum Detectable Rigidity (Z=3-5) ≈ 3.6 TV

TOF: β
Δβ (β=1,Z=3-5) ≈ 0.01



Charge	Z=5 ΔZ
Tracker Layer 1	0.30
TRD	0.33
Upper TOF	0.16
Inner Tracker (L2-L8)	0.12
Lower TOF	0.16
RICH	0.32
Tracker Layer 9	0.30

Flux Measurement

Isotropic flux in the i^{th} rigidity bin $(R_i, R_i + \Delta R_i)$

Number of selected events (subtracted for backgrounds and corrected for bin-to-bin migration)

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

Bin width (68 bins between 2 GV to 3 TV)

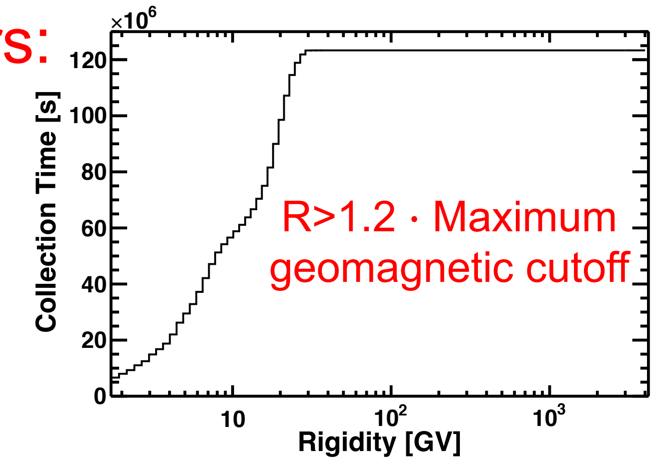
Effective acceptance (from MC, verified with data)

Trigger efficiency (>97% over entire R range)

Collection time (5 years, 1.23×10^8 s for R>30 GV)

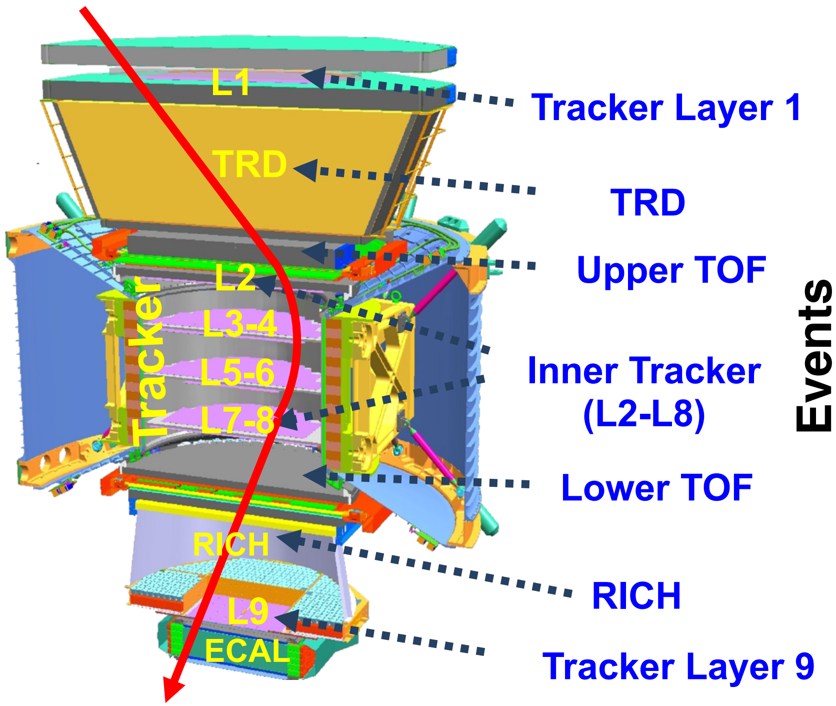
Extensive studies of the systematic errors:

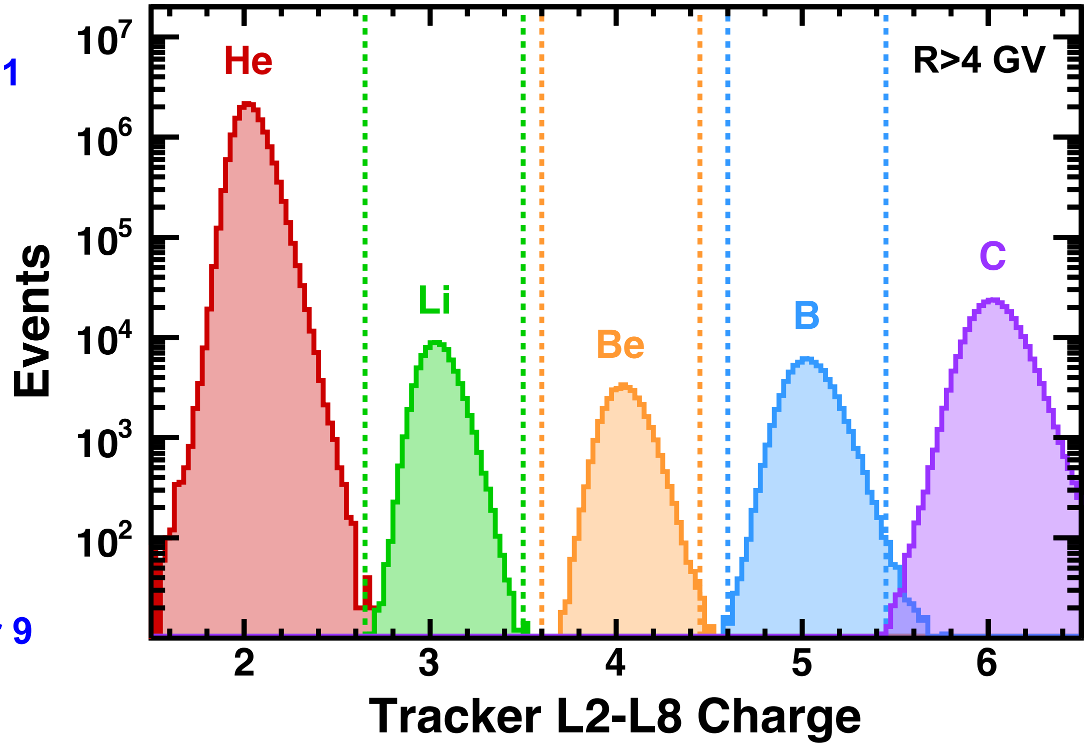
- Background estimations
- Rigidity resolution function
- Acceptance and Trigger efficiency
- Absolute rigidity scale



Nuclei Charge Identification

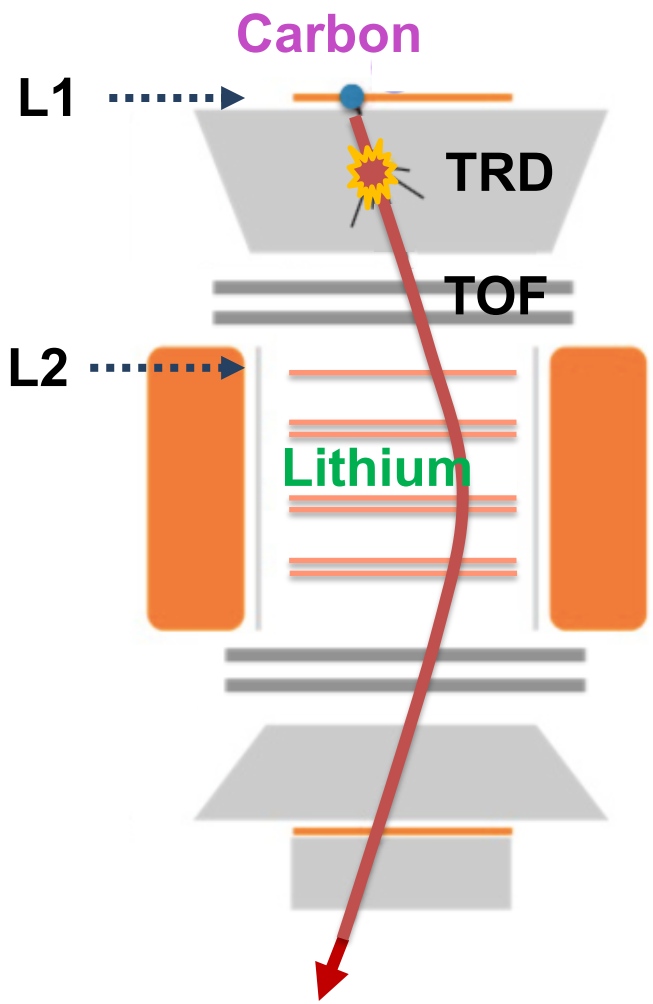
The tracker L2-L8 charge has a very fine resolution of ΔZ=0.08-0.12 ($3 \leq Z \leq 5$).



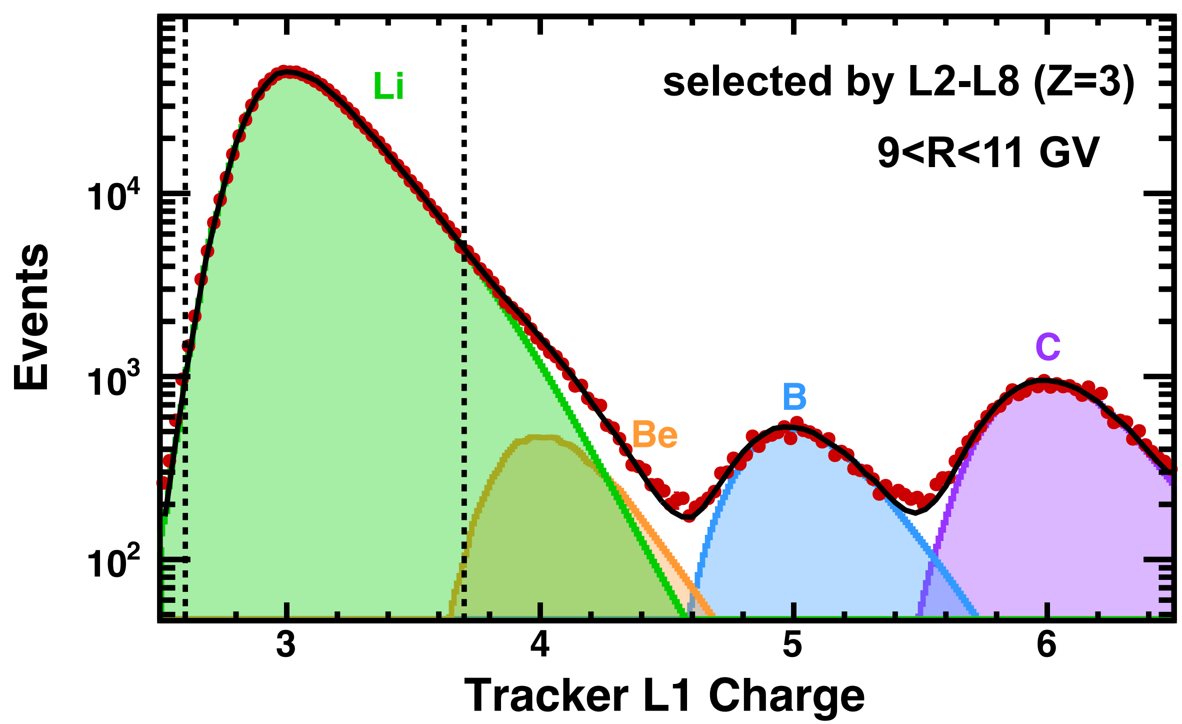


The charge confusion from noninteracting nuclei is negligible.

Accuracy on N_i: Background from interactions between L1 and L2



O,N,C,B,Be + AMS → Li + X



evaluated by fitting the charge distribution of tracker L1

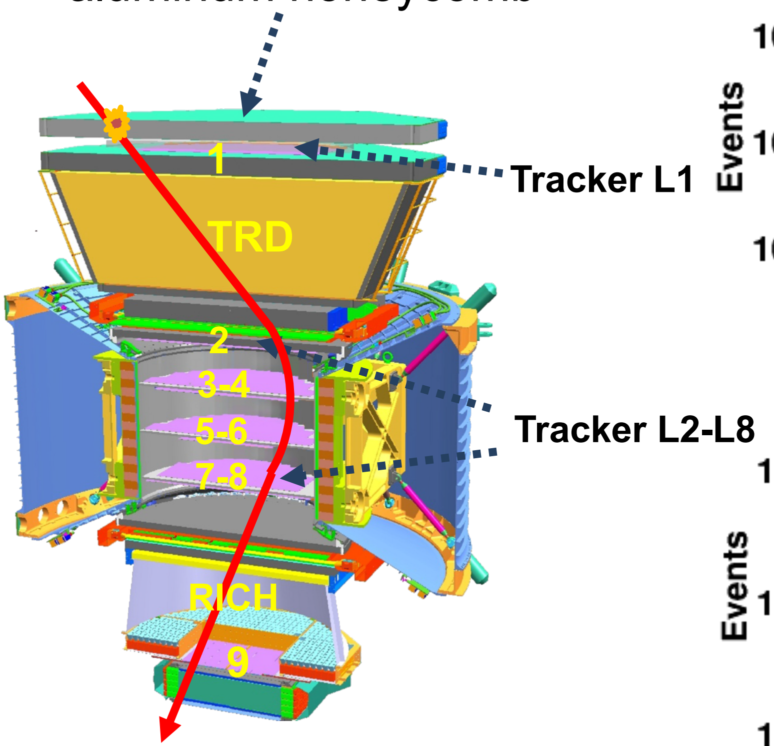
This background is <0.5% for Lithium and Beryllium, <3% for Boron.

The systematic error on the fluxes is < 0.5% in the entire rigidity range

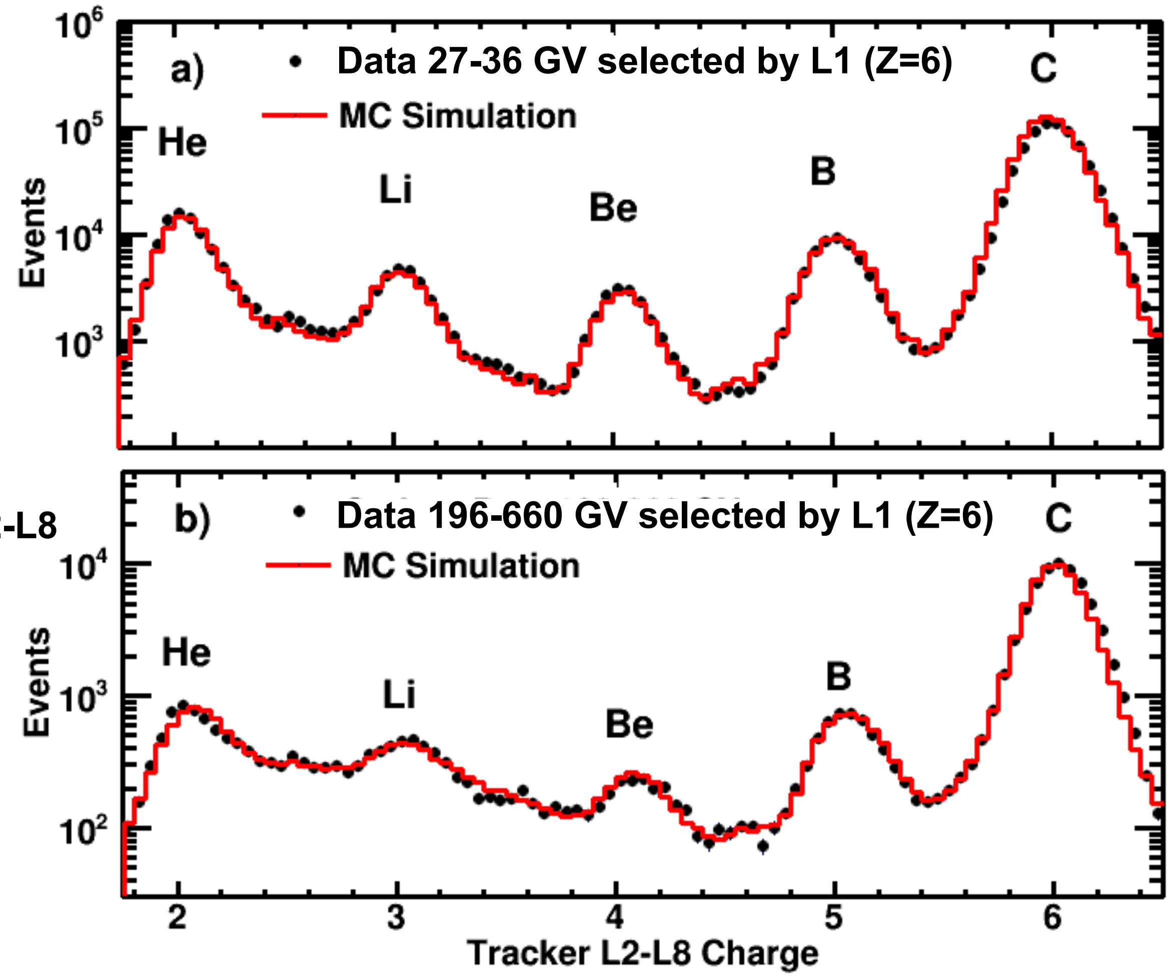
Accuracy on N_i: Background from interactions above L1

estimated from MC simulations which have been validated using data,

thin L1 support structures made by carbon fiber and aluminum honeycomb



for examples:

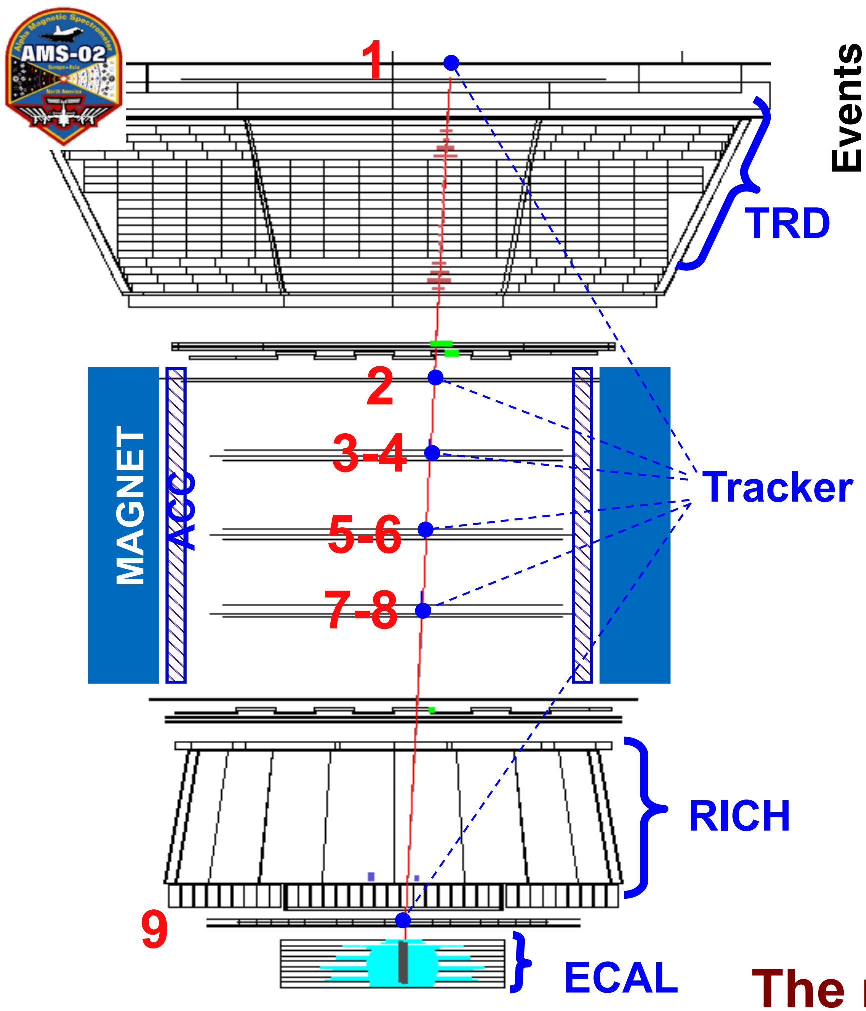


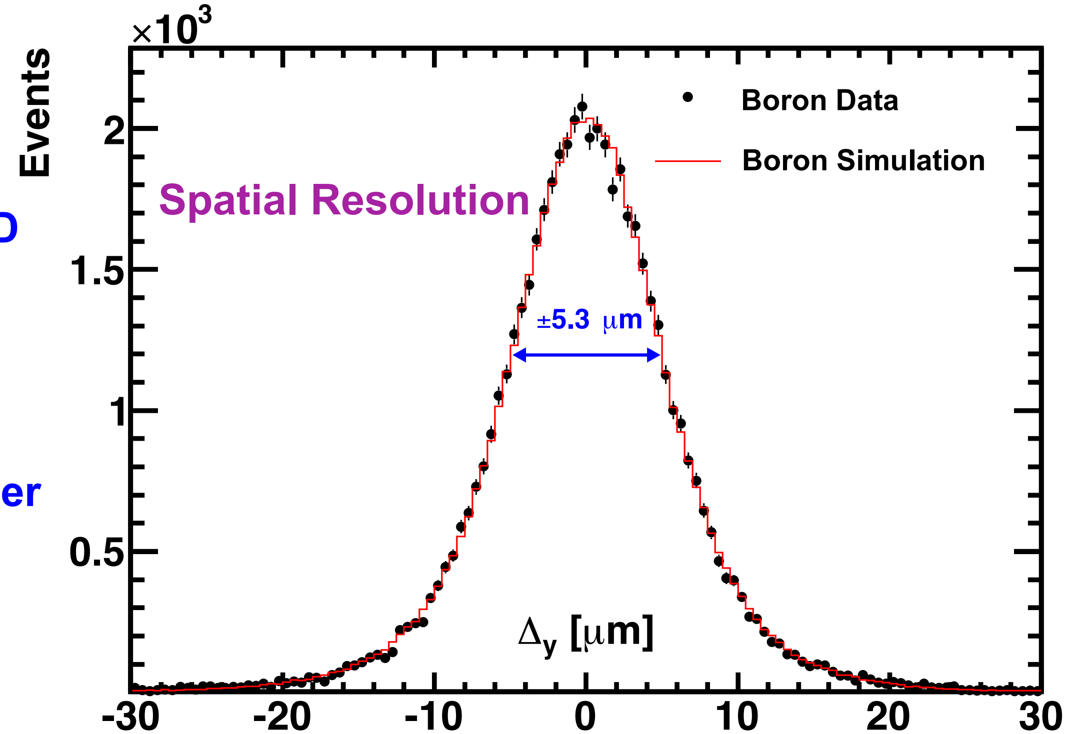
For secondaries, this background can reach up to 10% at 3 TV.

The systematic error on the fluxes is <1.5 % in the entire rigidity range

Accuracy on N_i : Tracker Rigidity Resolution

The systematics associated with the tracker rigidity resolution is well understood.
The tracker spatial resolution is **5.8 μm** for Li, **5.5 μm** for Be, and **5.3 μm** for B.

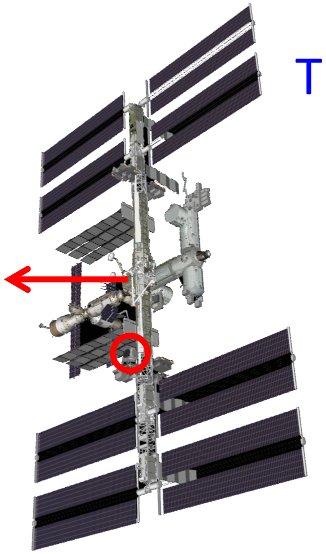




L1 to L9: 3 m level arm
maximum detectable rigidity ≈ 3.6 TV

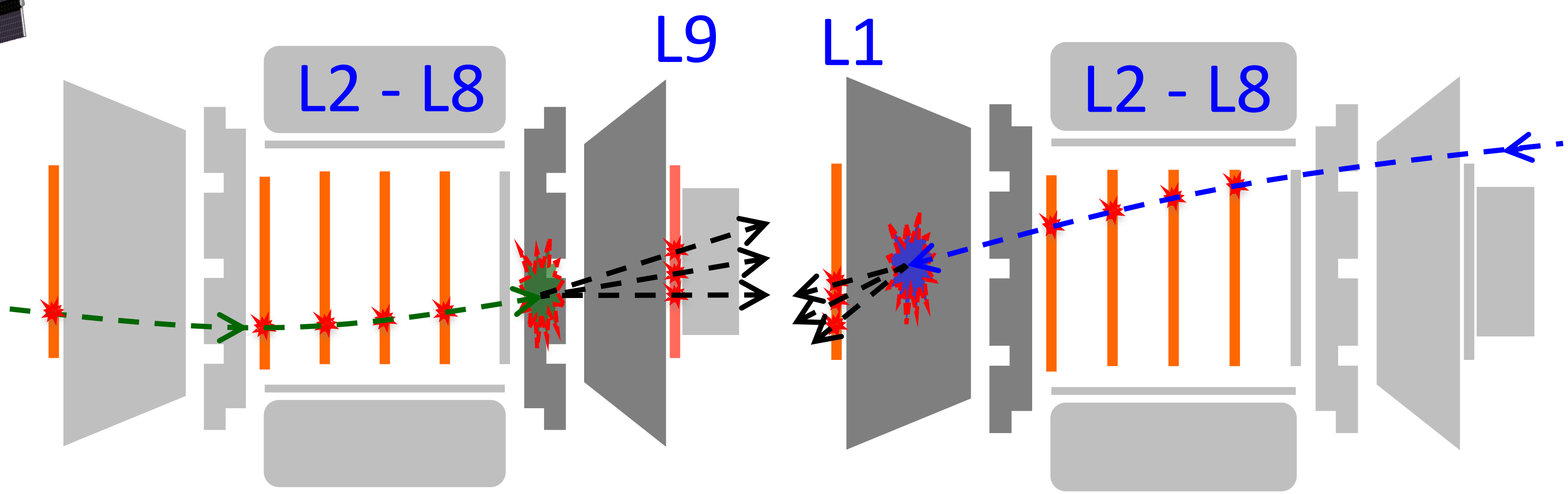
The resulting systematic errors on the fluxes are < 1.5% below 200 GV and 8-10% @ 3 TV

Accuracy on A_i: Measurements of Nuclei Cross Section by AMS



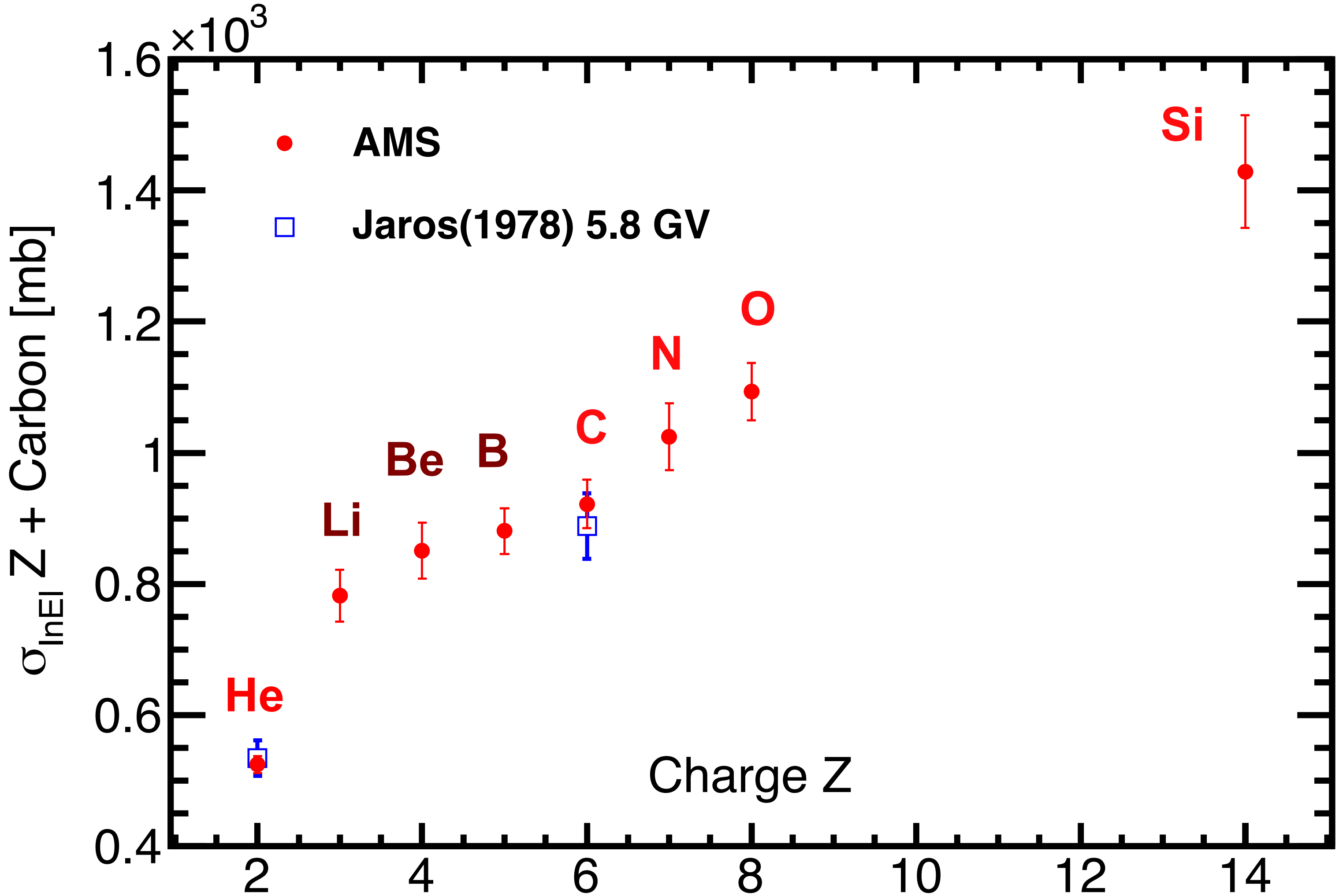
The detector components are mostly made of Carbon and Aluminum.

AMS measured the nuclei survival probability using data acquired when AMS pointing in horizontal direction (~10^5 sec exposure), in which cosmic rays can enter AMS both **left to right** and **right to left**.



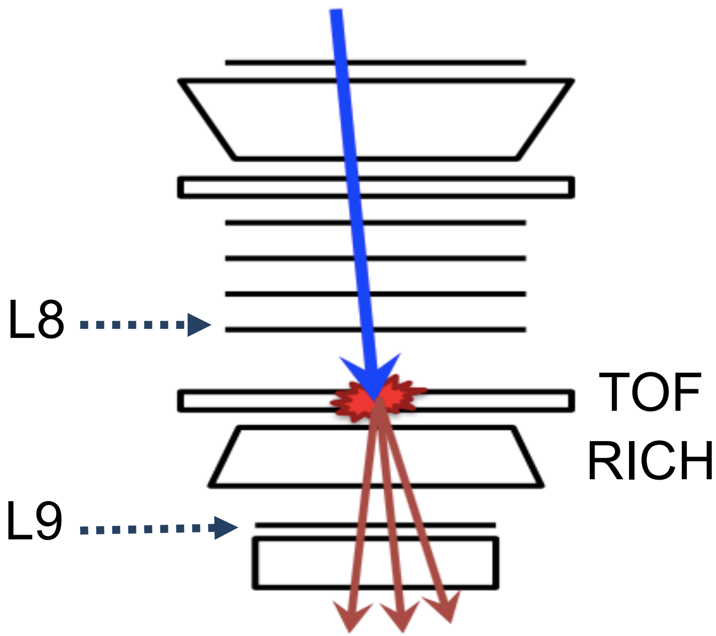
Most importantly, by flying horizontally, AMS was able to make Interaction cross sections measurements which were not available from accelerators.

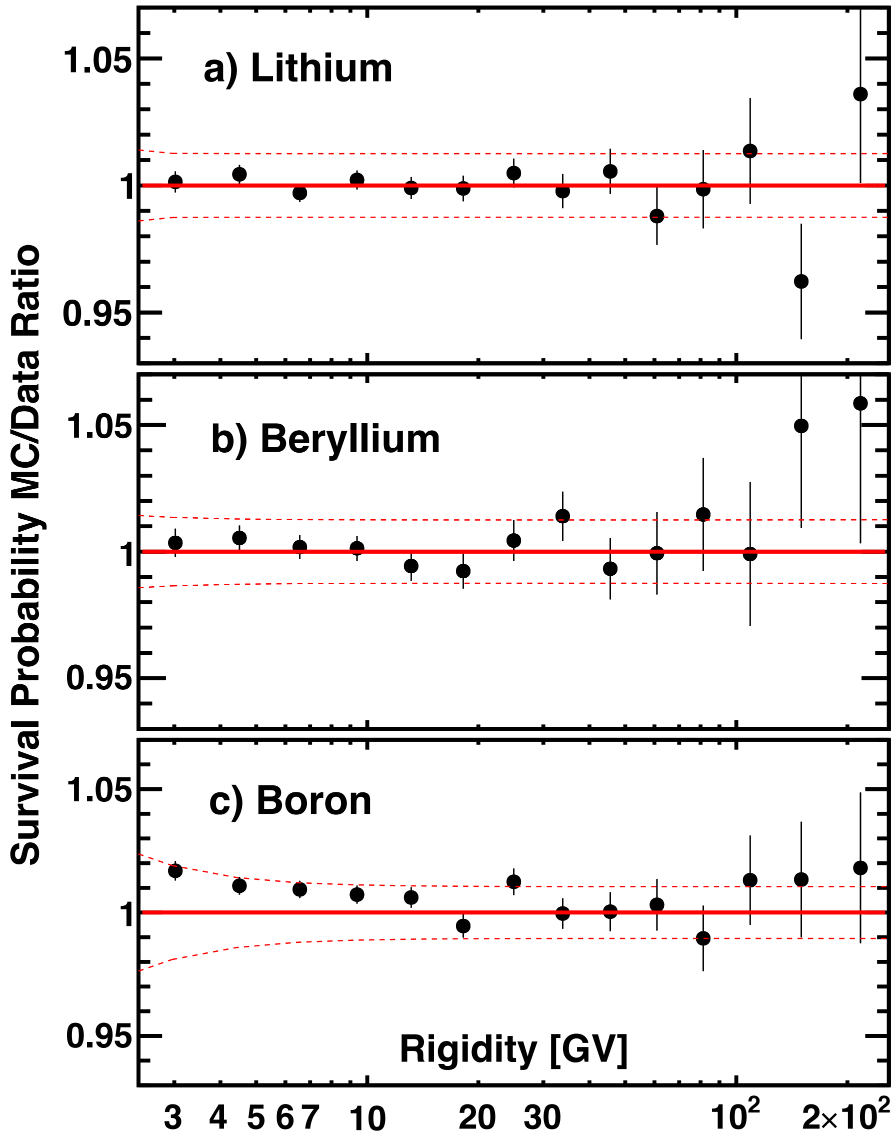
Accuracy on A_i:
AMS Nuclei + C Inelastic Cross Section measurements average in 5-100 GV



Accuracy on A_i: Survival Probability MC/Data Comparison

The nuclei survival probability after traversing the material between L8 and L9 is used to verify the inelastic cross section



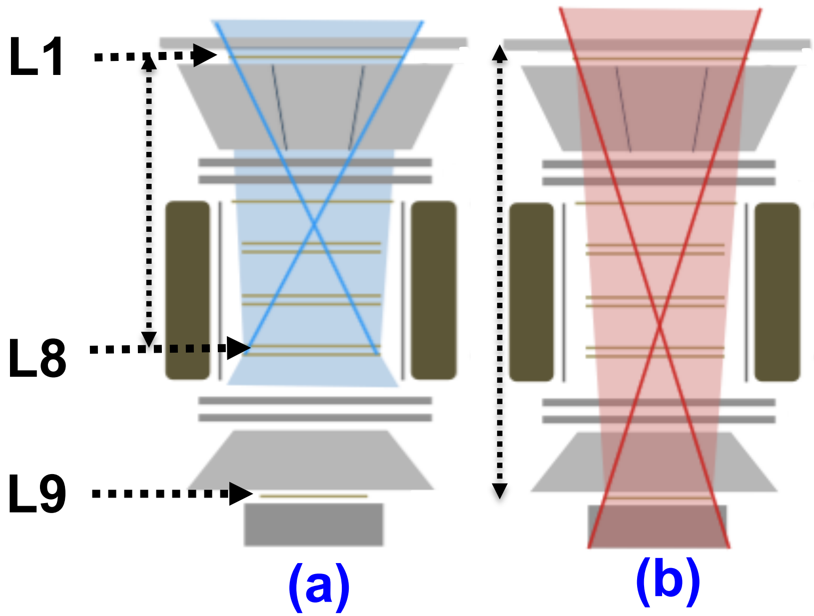


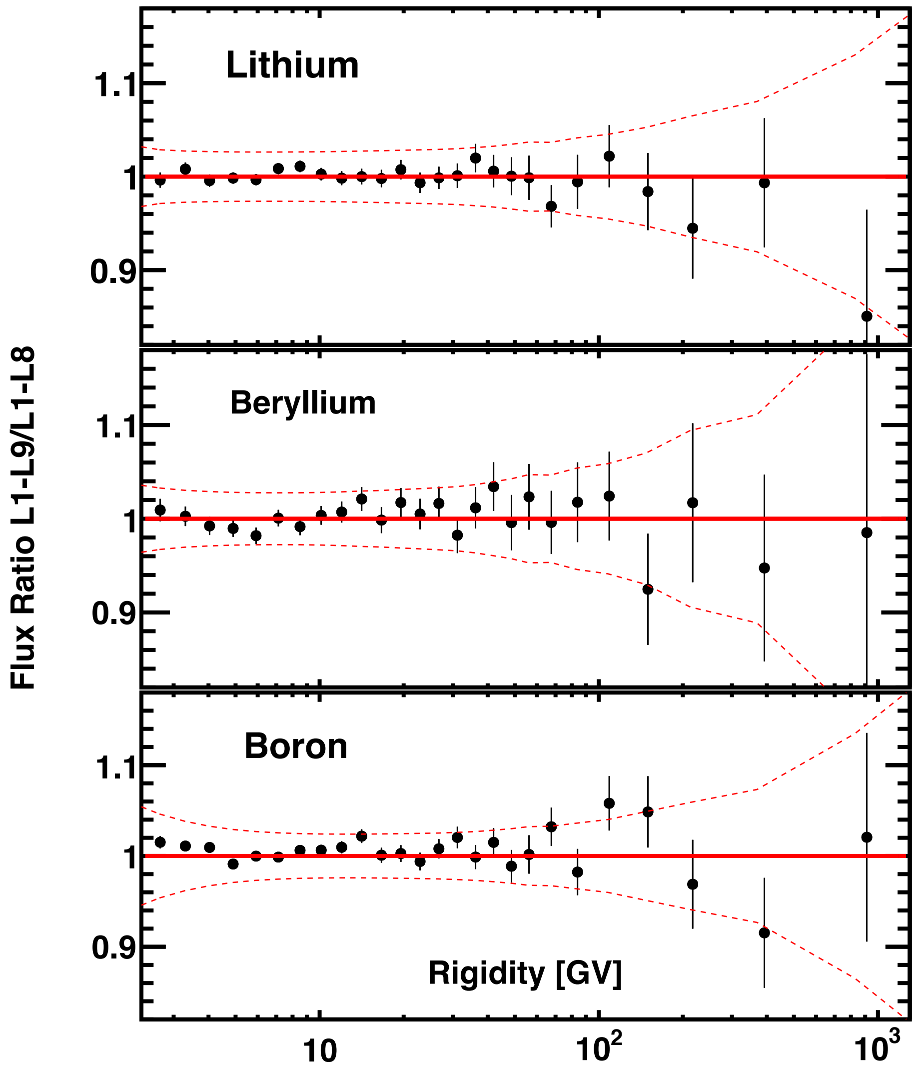
The systematic errors on the fluxes due to uncertainties of inelastic cross sections are < 2%–3% up to 100 GV and < 3%-4% at 3.3 TV.

Flux Measurement Verification Example

The ratio of the fluxes with different acceptances using events

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

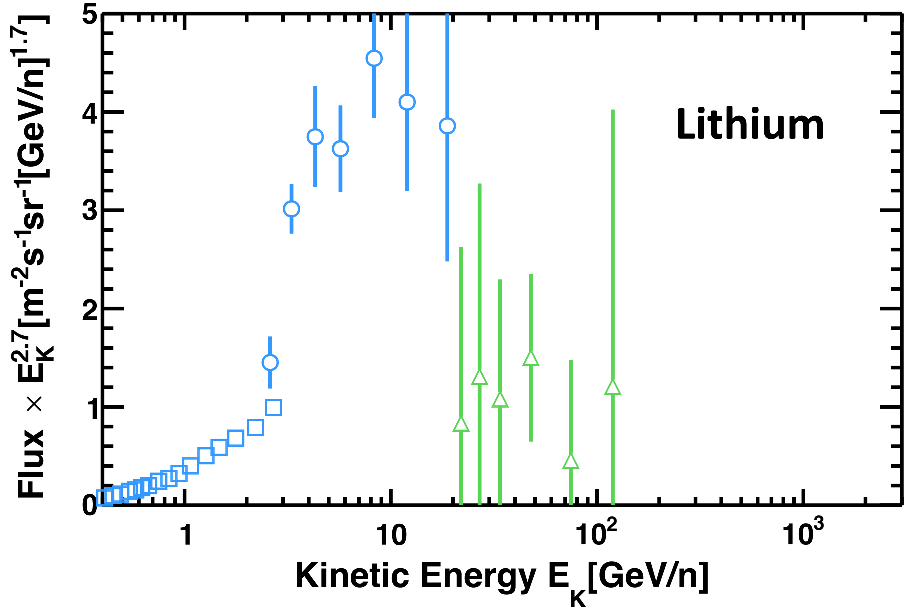




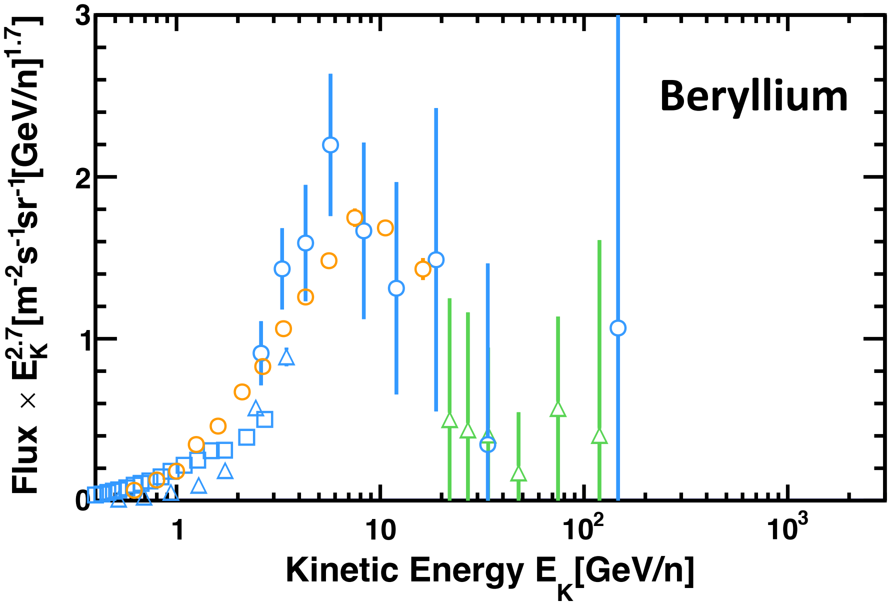
The good agreement verifies the systematic errors on unfolding and acceptance.

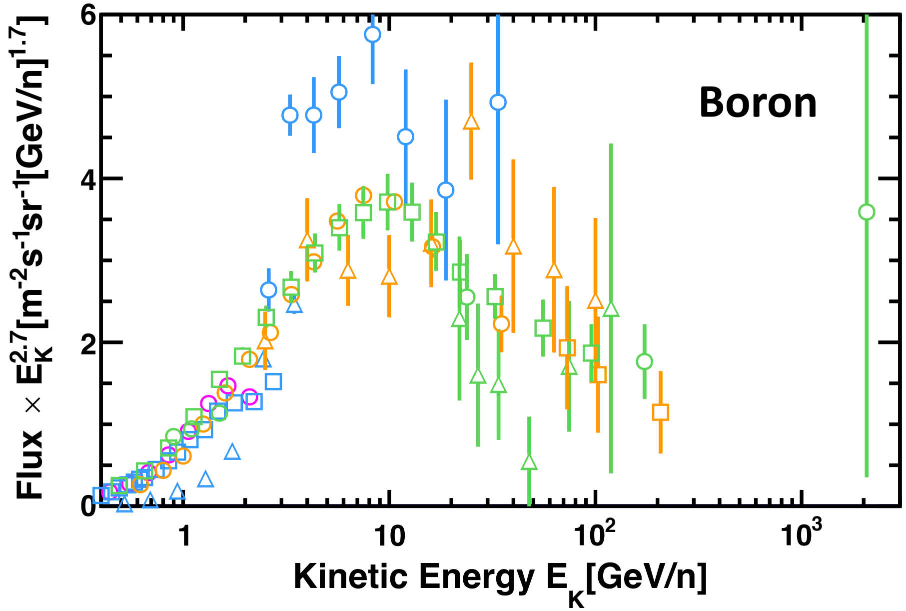
Flux Measurements of Li, Be, B before AMS

- ○ TRACER
- □ PAMELA
- △ Juliusson
- ○ Orth
- □ Webber
- △ Lezniak
- ○ HEAO3
- □ CRN
- △ Simon
- ○ Maehl



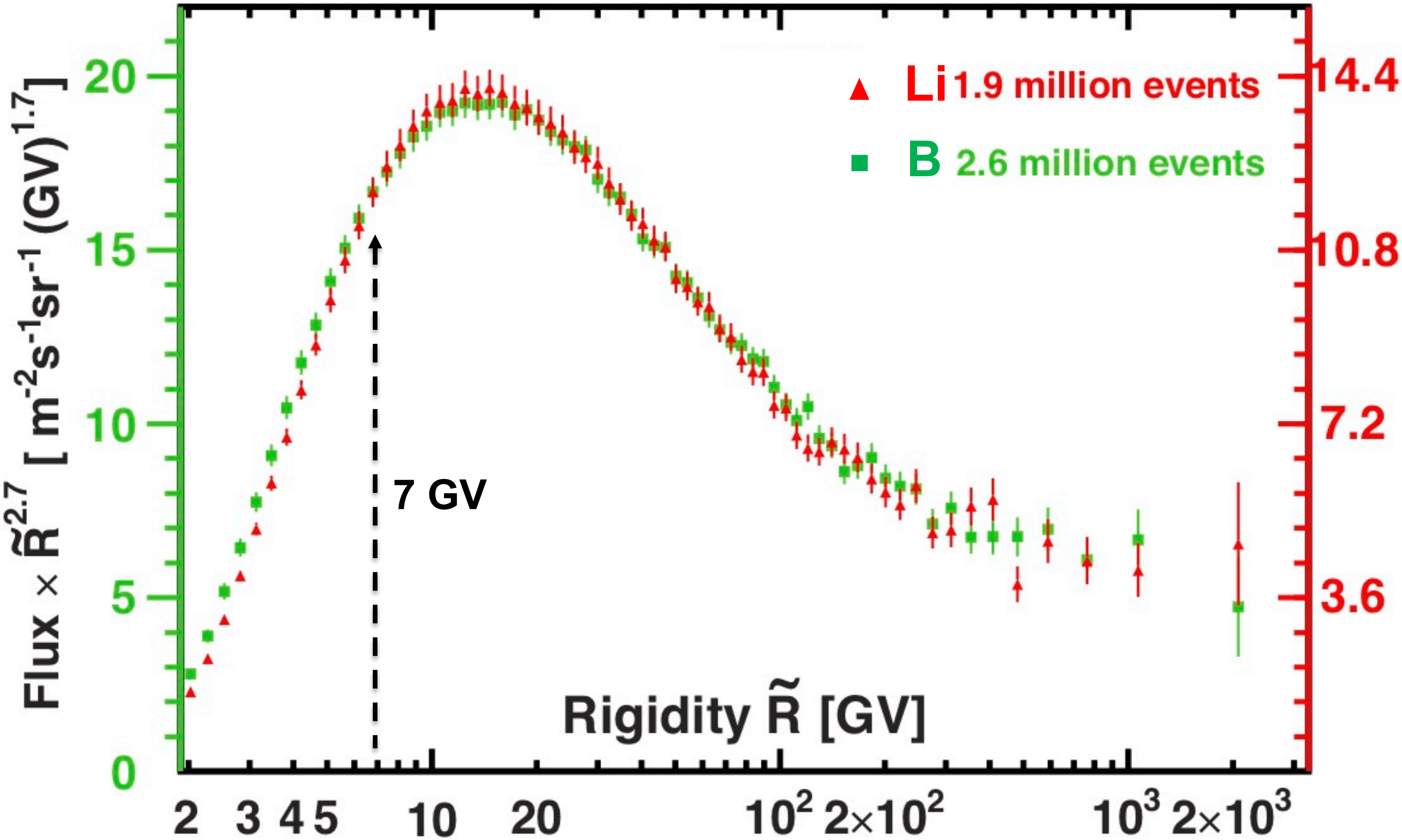
Typically, the error on each flux is larger than 50% at 100 GV





AMS Secondary Cosmic Rays: Lithium and Boron

Above 7 GV Li and B have identical rigidity dependence



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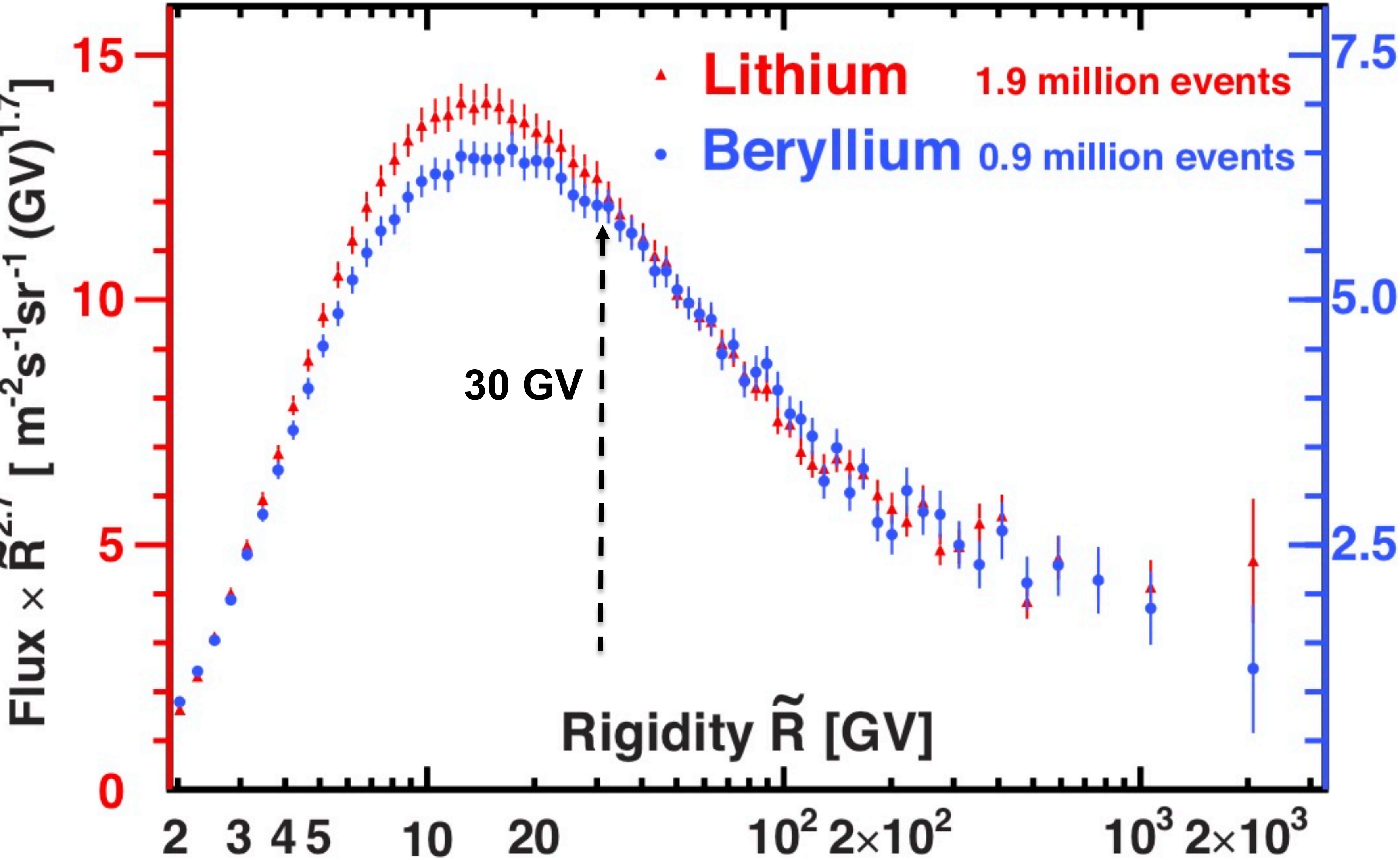
AMS Secondary Cosmic Rays: Lithium and Beryllium

Above 30 GV Li and Be have identical rigidity dependence.
The fluxes are different by a factor of 2.0±0.1.



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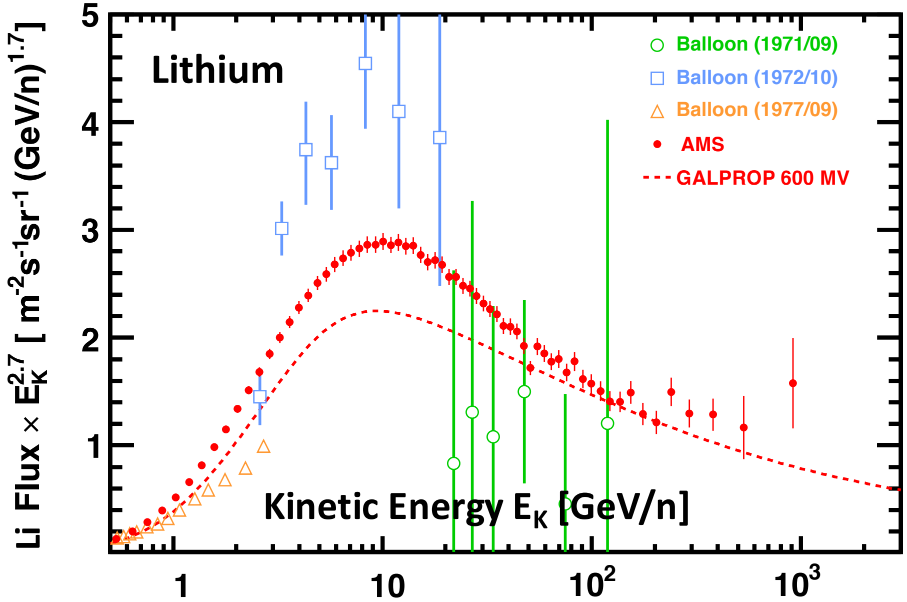
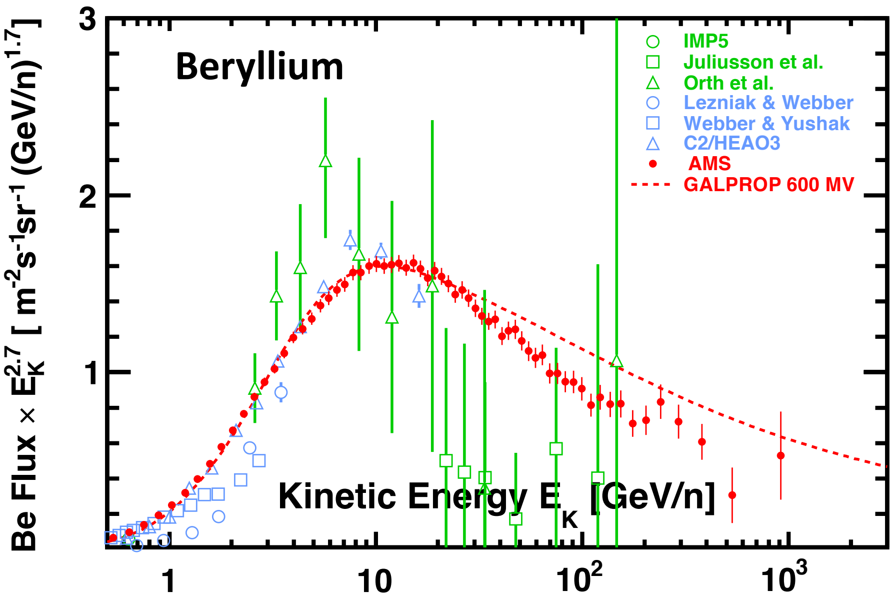
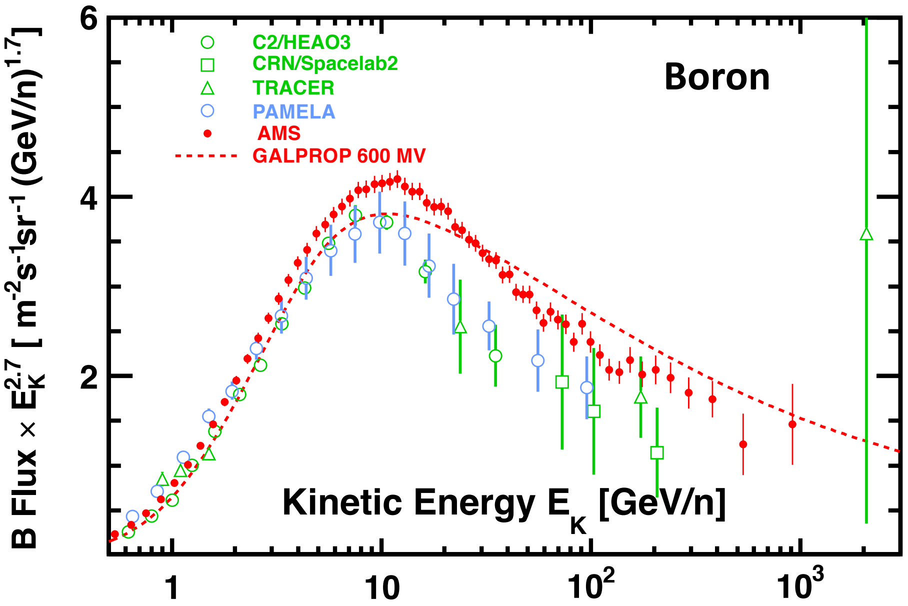
Fluxes Results with Previous Measurements

With AMS, the total error on each flux is **~3%** at ~100 GV.

The red dashed curves show the results from **GALPROP model**.



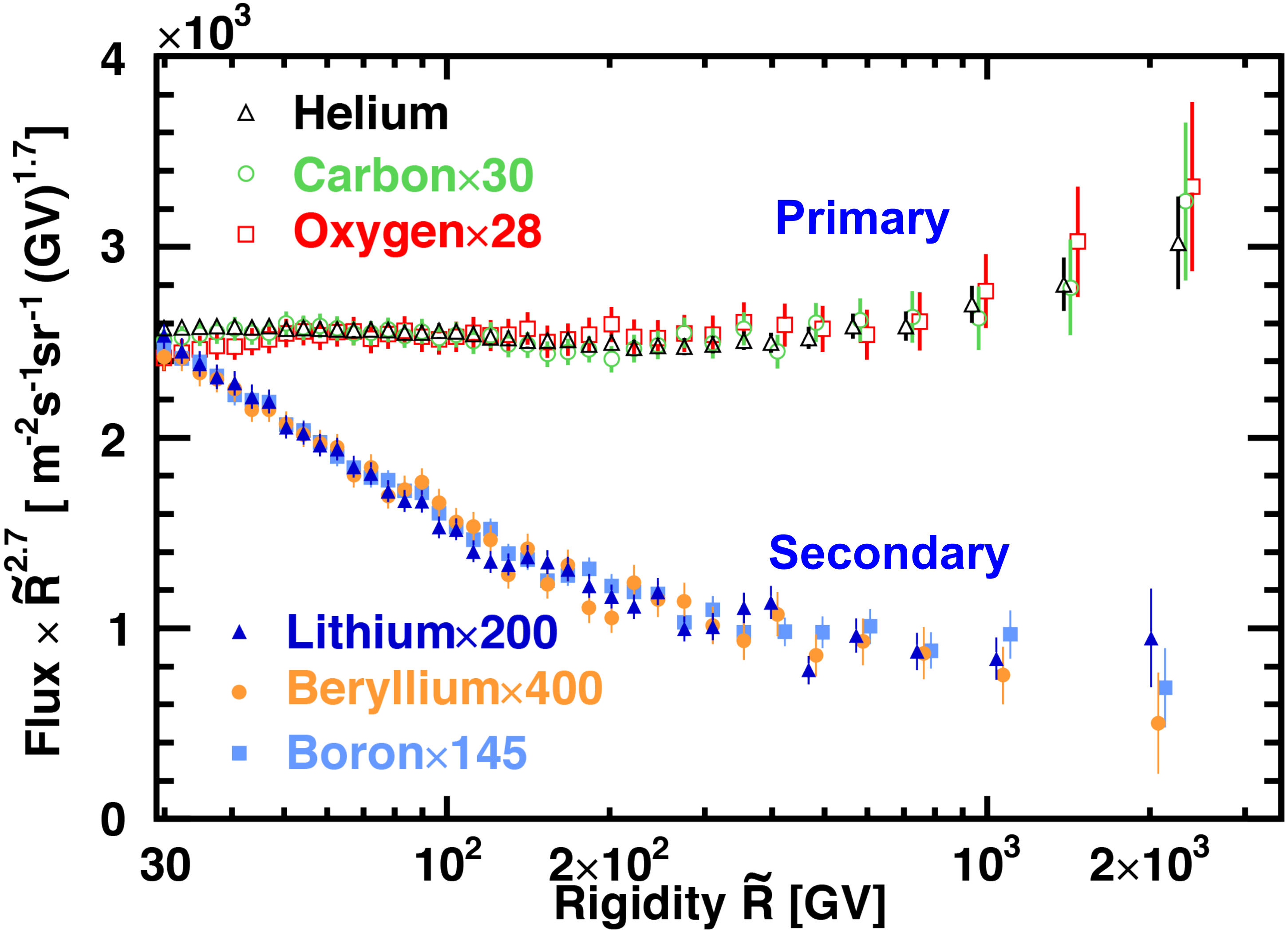




Rigidity dependence of Primary and Secondary Cosmic Rays

Both deviate from a single power law above 200 GV.

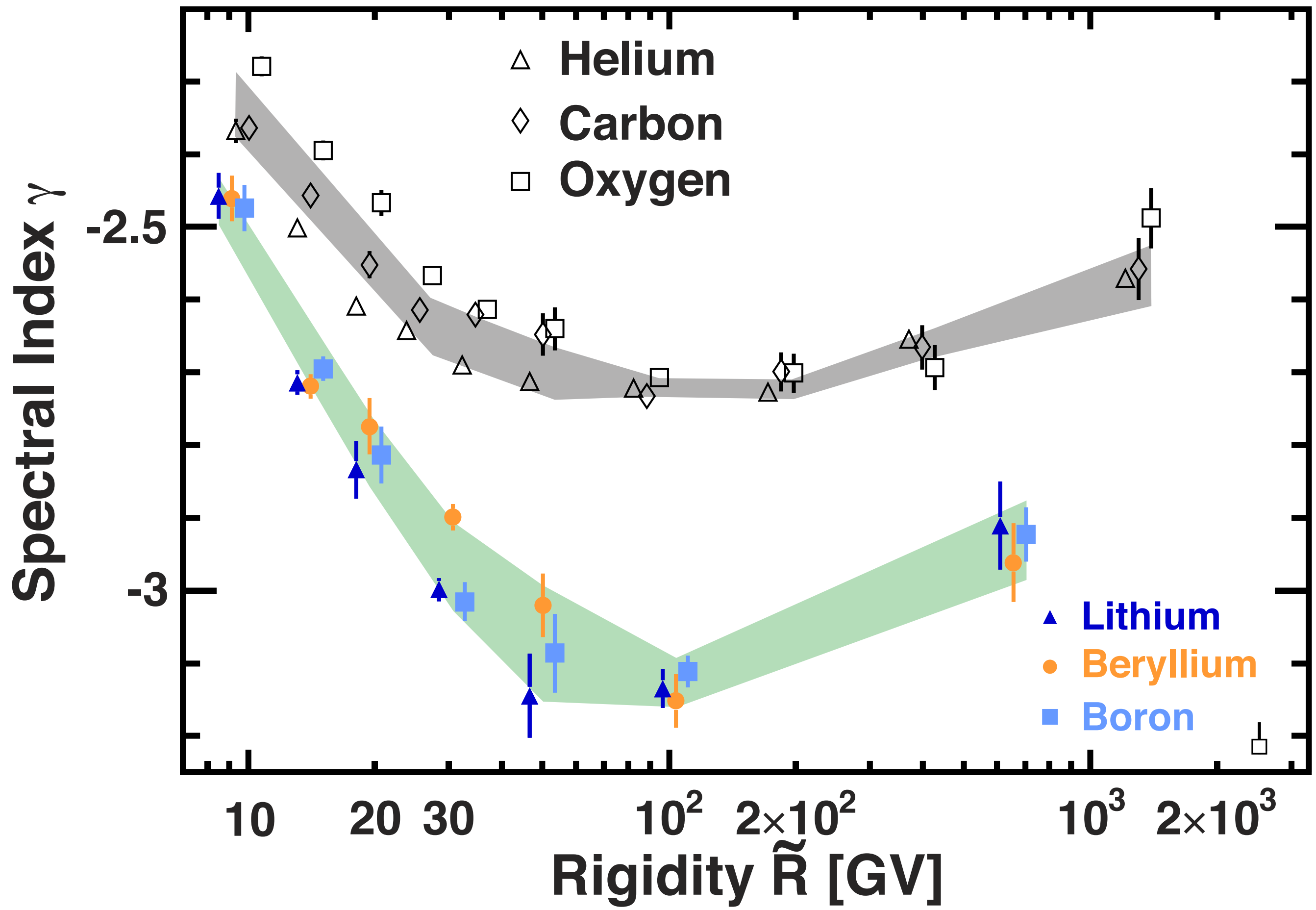
But their rigidity dependences are distinctly different.



Primary and Secondary Cosmic Ray Spectral Indices

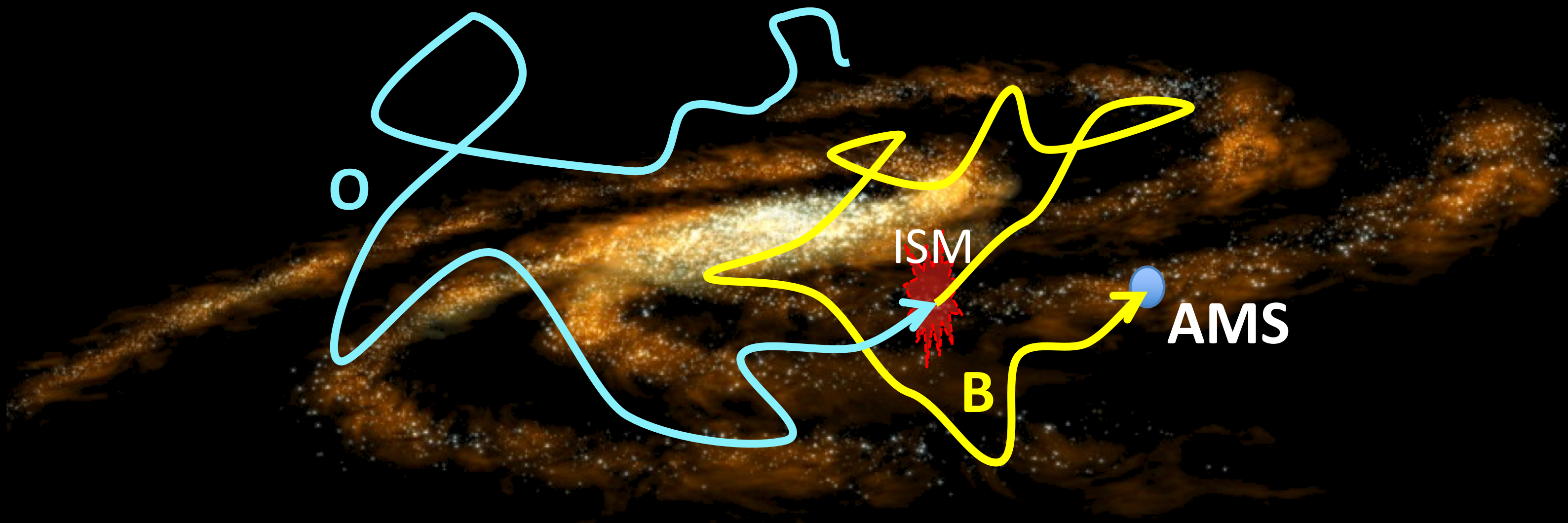
$\Phi = CR^{\gamma}$ (Φ is the flux; C is a constant; γ is the spectral index)

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



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

The flux ratio between primaries (O) and secondaries (B) provides information on propagation and on the Interstellar Medium (ISM)



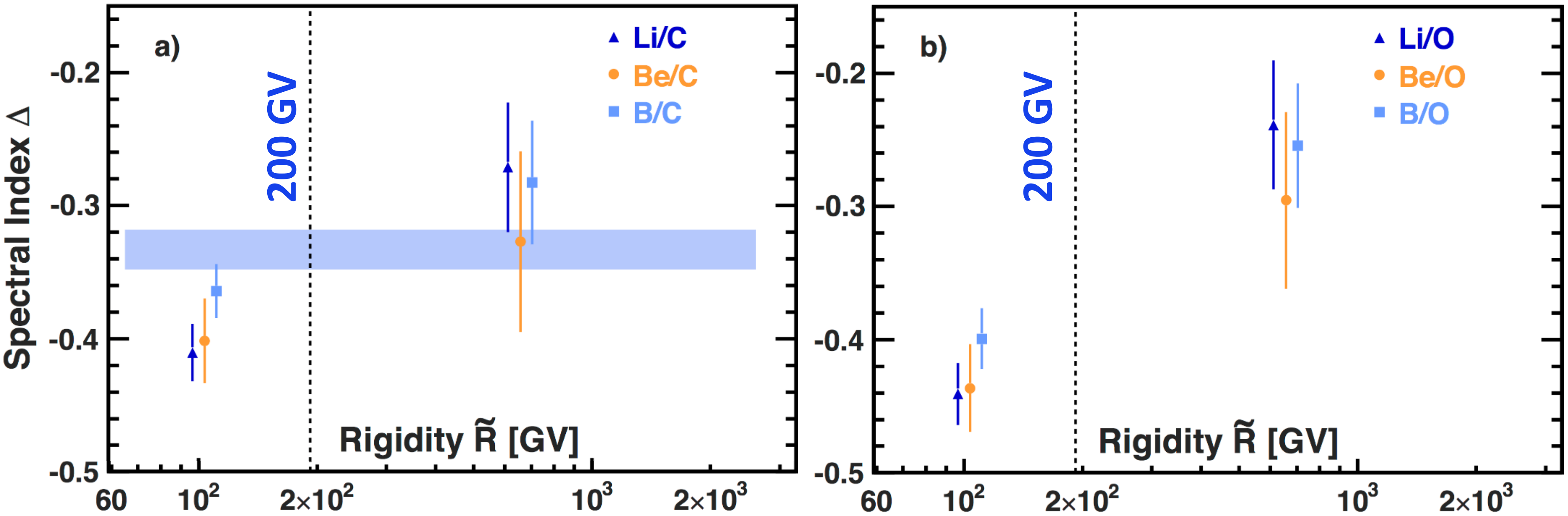
Cosmic ray propagation is commonly modeled as a fast moving gas diffusing through a magnetized plasma.

At high rigidities, models of the magnetized plasma predict
$B/O = kR^{\Delta}$.

With the Kolmogorov turbulence model $\Delta = -1/3$
With Iroshnikov-Kraichnan turbulence model $\Delta = -1/2$

Secondary to Primary Flux Ratio Spectral Indices

$\Delta = d[\log(\Phi_S/\Phi_P)]/d[\log(R)]$ **is not a constant**



Combining the six ratios, the secondary over primary flux ratio (B/C, …) deviates from single power law above 200 GV by 0.13±0.03

Conclusions and Outlook

- **Lithium, Beryllium and Boron** have been measured in the rigidity range **1.9 GV to 3.3 TV** based on nuclei collected by AMS during the first 5 years of operation. Total error on each of the fluxes is **~3%** at 100 GV.

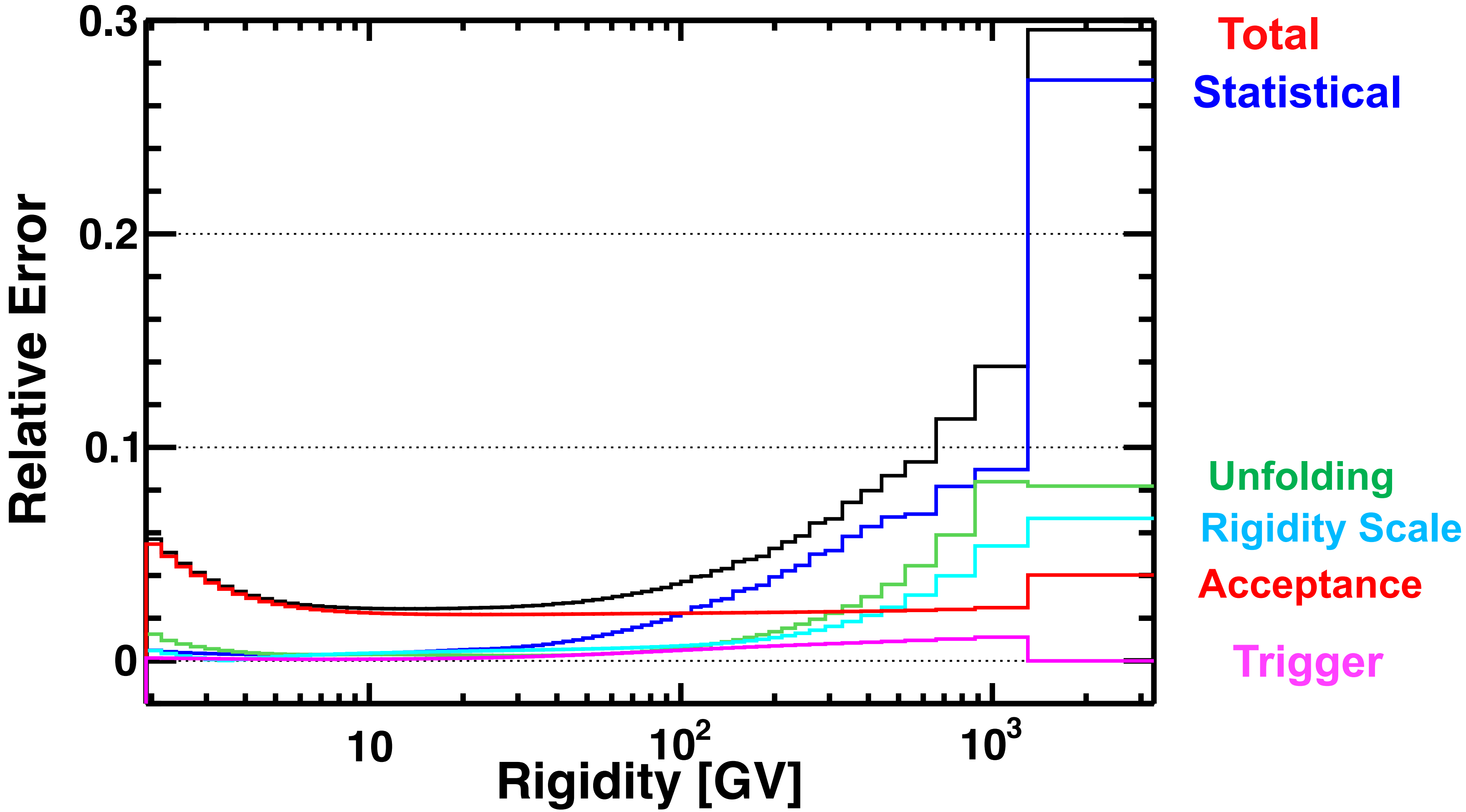
- The Li and B fluxes have identical rigidity dependence above **7 GV** and **all three fluxes have identical rigidity dependence above 30 GV** with the Li/Be flux ratio of 2.0±0.1.

- The Li, Be and B fluxes deviate from a single power law above **200 GV** in an identical way. **But their rigidity dependence is distinctly different from the rigidity dependence of primary cosmic rays.** In particular, above 200 GV, the secondary cosmic rays harden more than the primary cosmic rays.

- AMS will **continue taking data** for the lifetime of the International Space Station (beyond 2024). Measurements of heavier secondary cosmic rays such as F, … , subFe elements (Sc, Ti, V), enable us to explore a new region in 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.