Unique Properties of Secondary Cosmic Rays: Results from the Alpha Magneti Spectrometer

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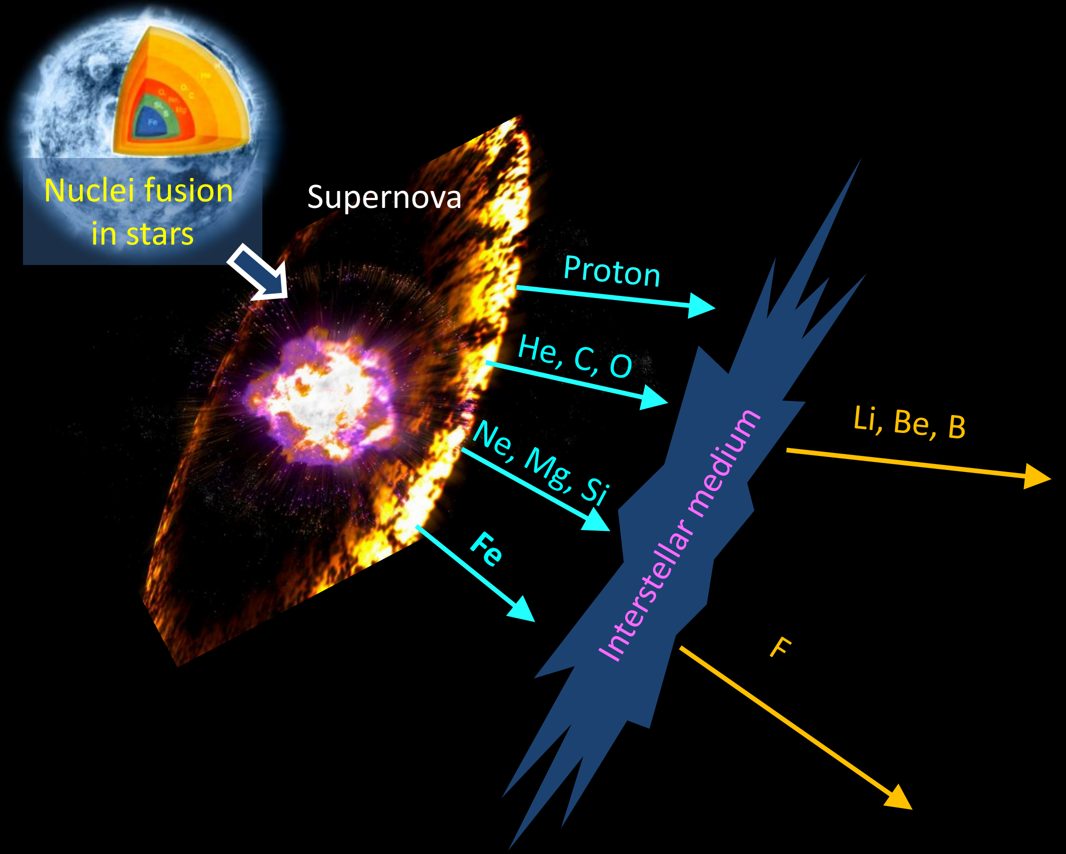
on behalf of the AMS Collaboration

TeVPA 2022, Kingston, Ontario, Canada, Aug 09, 2022

Galactic cosmic ray

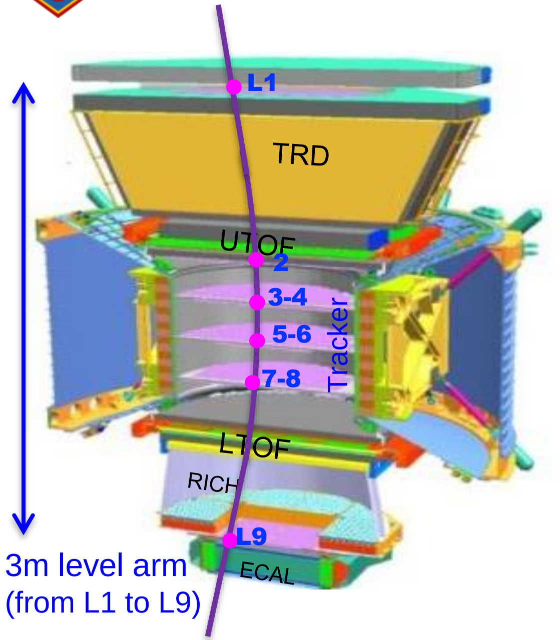


Primary cosmic rays (**Proton, He, C, O, Ne, Mg, Si, ..., Fe**) are mostly produced during the lifetime of stars. They are accelerated in supernovae explosions.

Secondary cosmic rays (Li, Be, B, F, …) are produced by the collision of primary cosmic rays and interstellar medium

The precise measurement of cosmic ray nuclei spectra carries information about cosmic ray **sources**, **acceleration** and **propagation** processes.

AMS performance for Cosmic-Ray Nuclei measurement of charge from 1 to 14



Tracker (9 Layers) + Magnet: Rigidity (Momemtum/Charge)

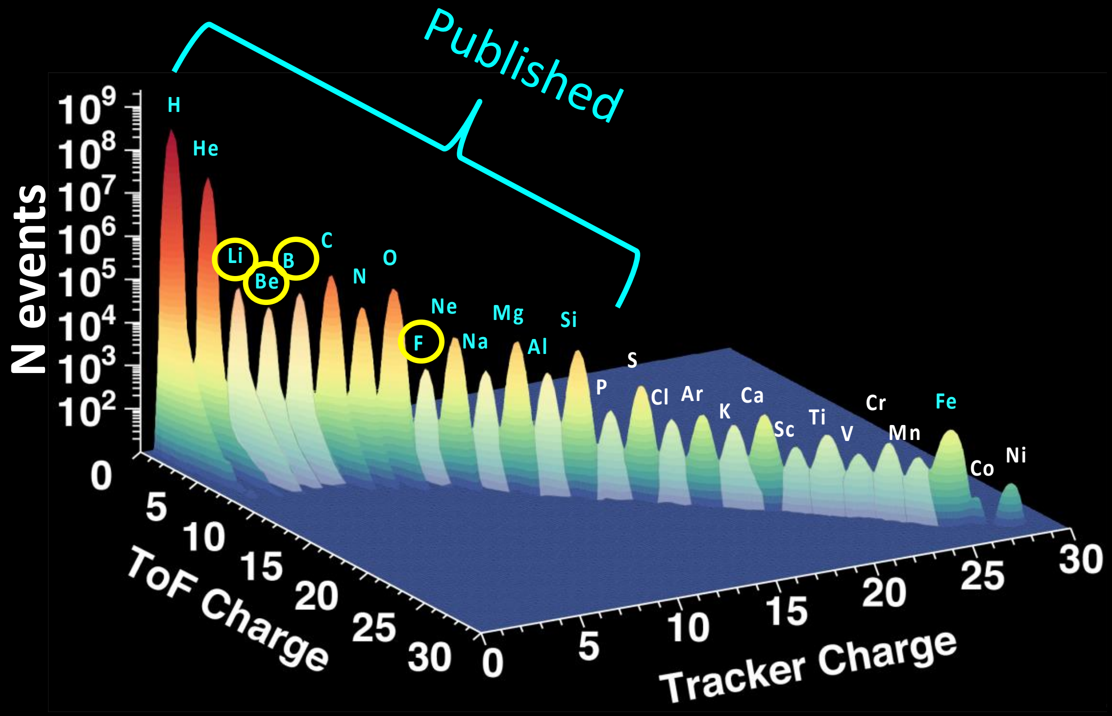
Charge	Coordinate Resolution	MDR
Z=1	~10 μm	2 TV
2≤Z≤8	5-7 μm	3.2-3.7 TV
9≤Z≤14	6-8 μm	3-3.5 TV

L1, UToF, Inner Tracker (L2-L8), LToF and L9

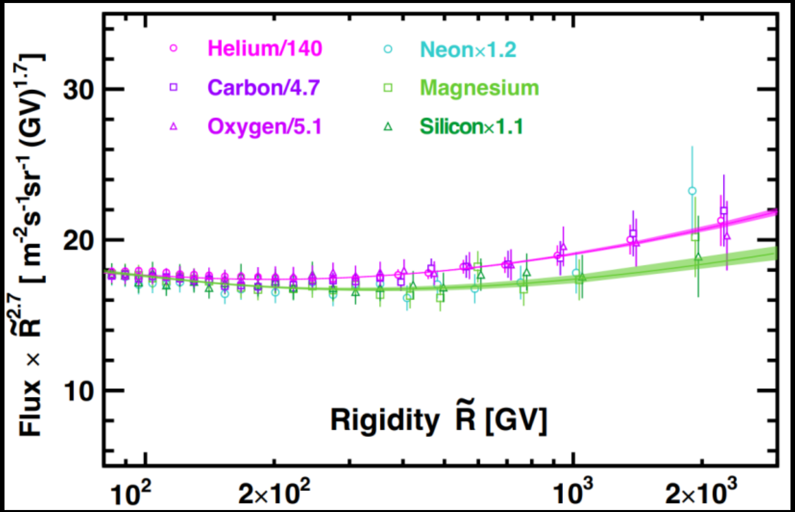
Consistent Charge along Particle Trajectory

Charge	Inner Tracker Charge Resolution (c.u.)
1≤Z≤8	0.05 - 0.12
9≤Z≤14	0.13 - 0.17

Cosmic-ray nuclei measurements with AMS

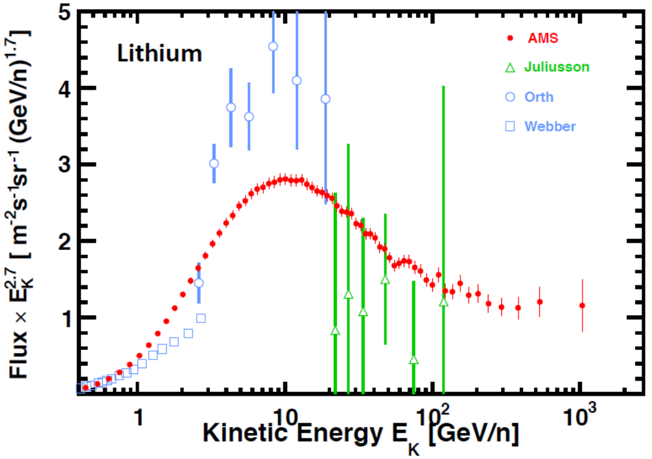


Primary cosmic-ray spectra
(see detail in Y. Jia's talk)



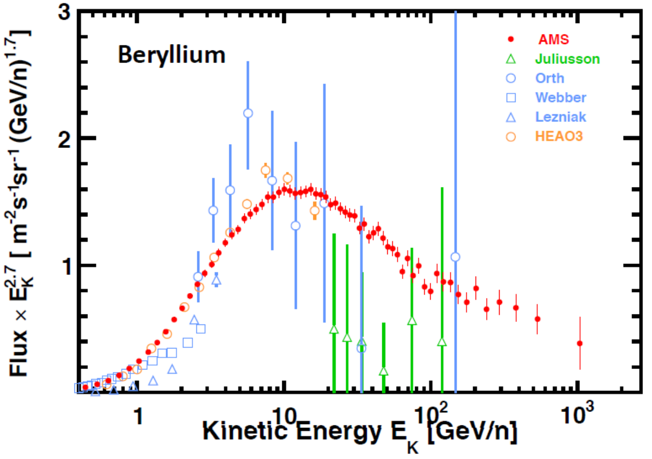
In this talk: Lithium, Beryllium, Boron and Fluorine

AMS Lithium, Beryllium, Boron fluxes

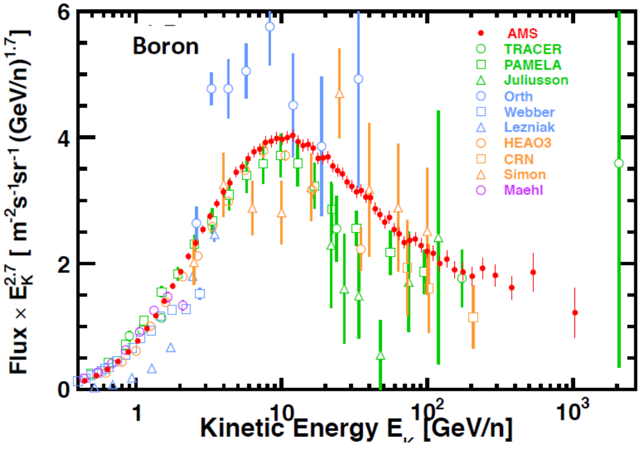


Over the last 50 years, only a few experiments had measured the Li and Be fluxes above a few GV. Typically, these measurements have errors larger than 50% at 50 GeV/n.

For the B flux, measurements have errors larger than 15% at 50 GeV/n.



M. Aguilar *et al.*, Phys. Rep. **894** (2021) 1–116



Detail Understanding on Lithium, Beryllium, Boron fluxes

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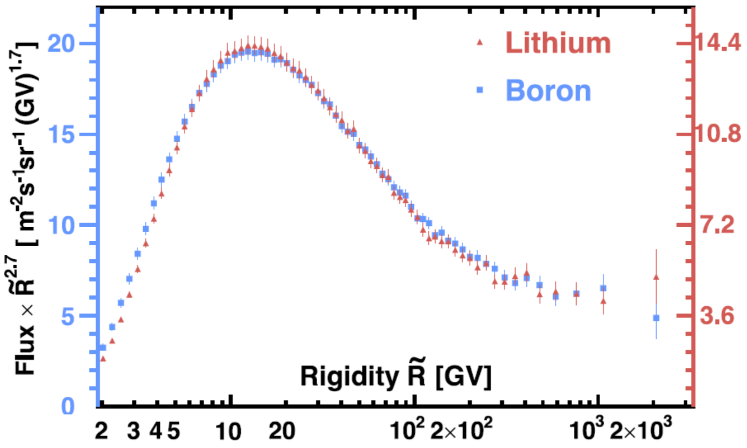
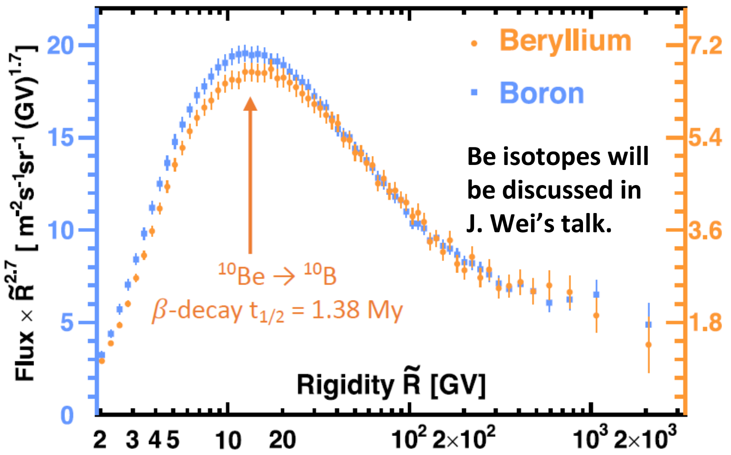
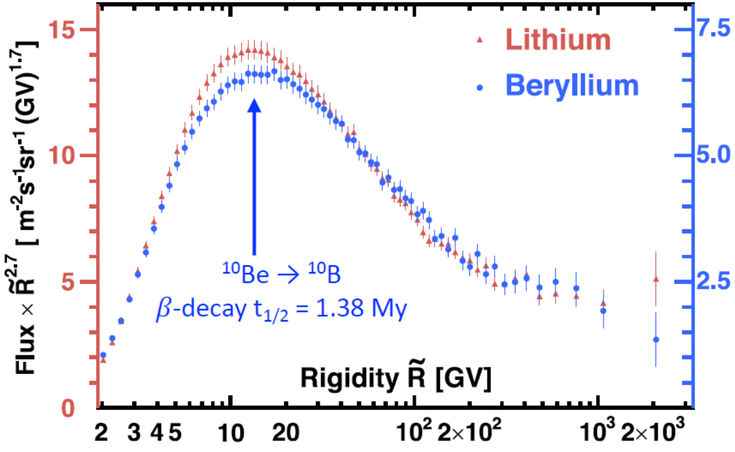


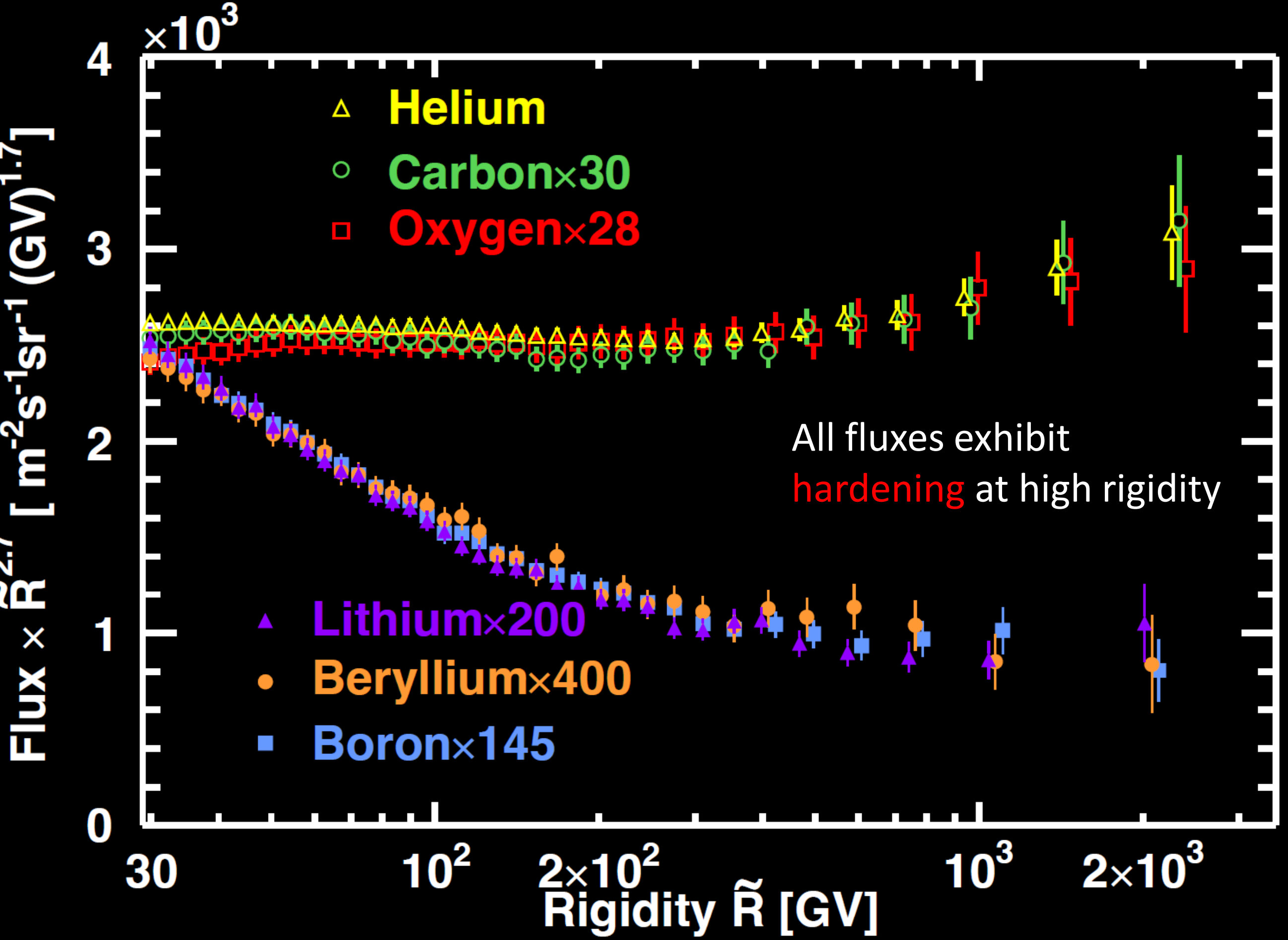




The Li and B fluxes have an identical rigidity dependence above 7 GV.

All three fluxes have an identical rigidity dependence above 30 GV.

Primary and Secondary Fluxes for Light Ions

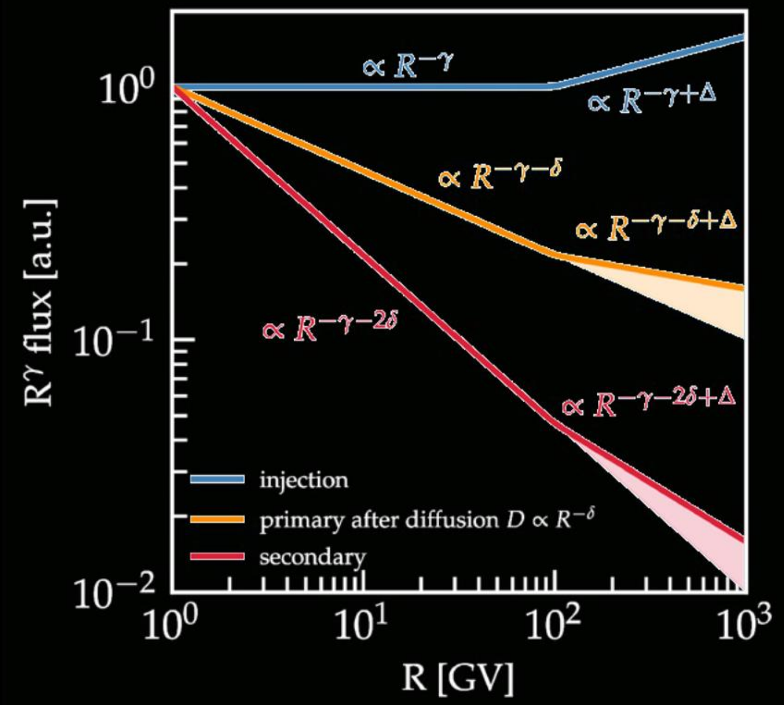


Light primary cosmic rays

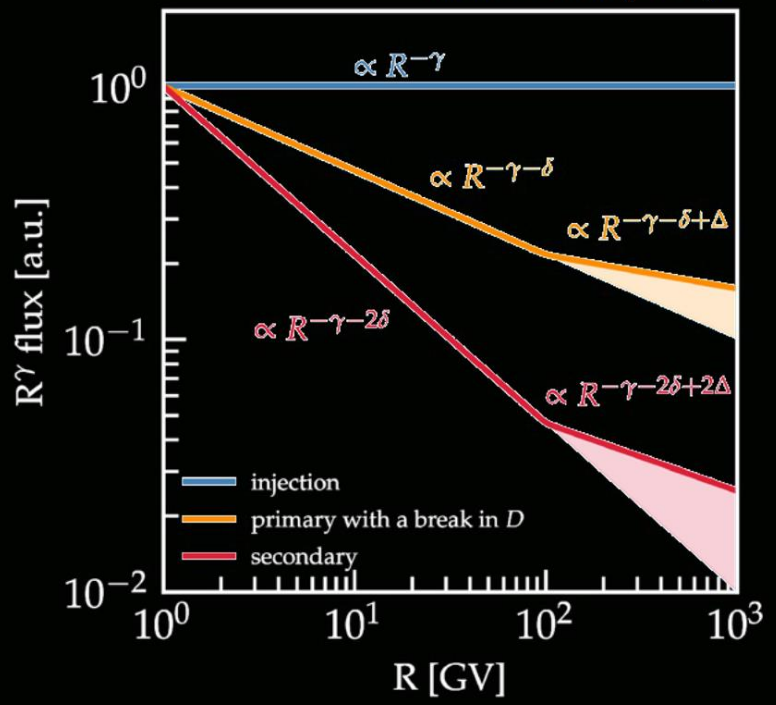
Light secondary cosmic rays

Origin of the spectrum hardening

From C. Evoli (2019).

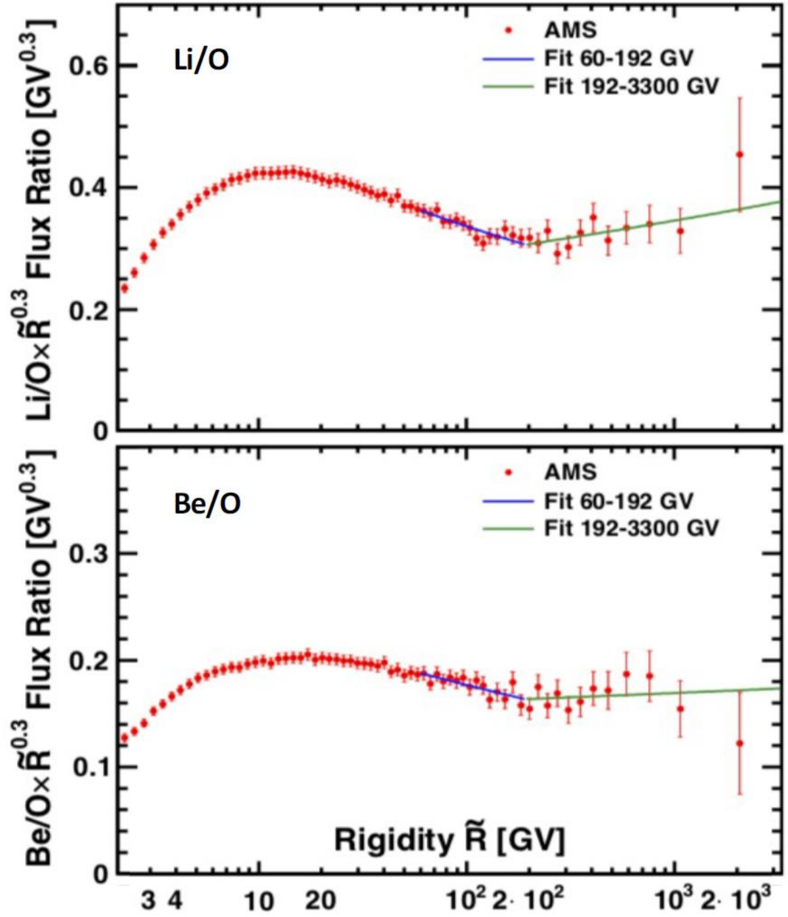


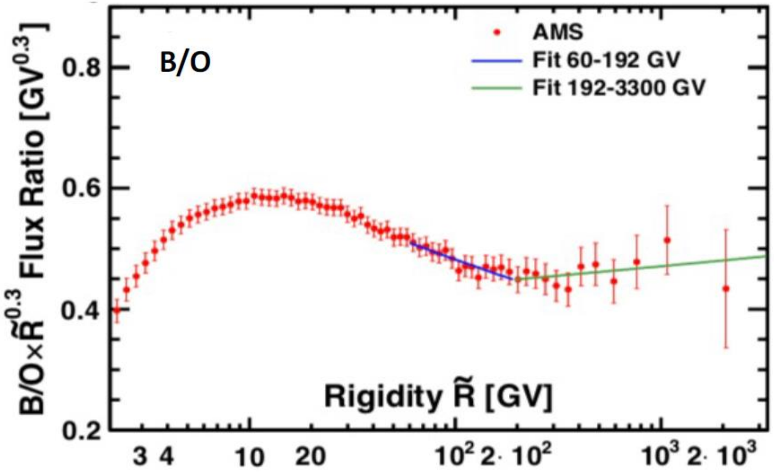
If the hardening in CRs is related to the **injected spectra** at their source, then **similar hardening** is expected both for **secondary** and **primary** cosmic rays.



If the hardening is related to **propagation properties** in the Galaxy, then a **stronger hardening** is expected for the **secondary** with respect to the **primary** cosmic rays.

Light Secondary-to-Primary Ratios





The Li/O, Be/O, and B/O flux ratios were fitted to:

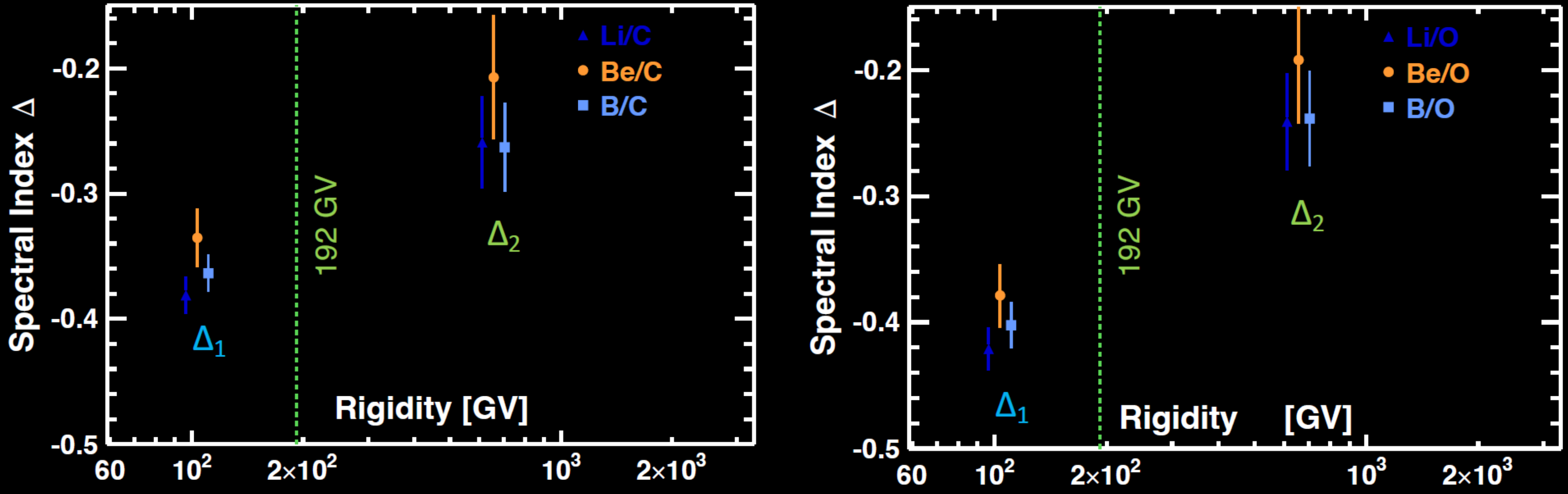
$$\begin{cases} C\,(R/192\ \mathrm{GV})^{\Delta_1}, & R \leq 192\ \mathrm{GV}, \\ C\,(R/192\ \mathrm{GV})^{\Delta_2}, & R > 192\ \mathrm{GV}. \end{cases}$$

Above 192 GV, the secondary-to-primary flux ratios exhibit an additional hardening, or the secondary cosmic rays hardens more than the primary.

Secondary-to-Primary Ratio Spectral Indices

Above 192 GV all six secondary-to-primary flux ratios harden.

Unpublished, 10 years data update

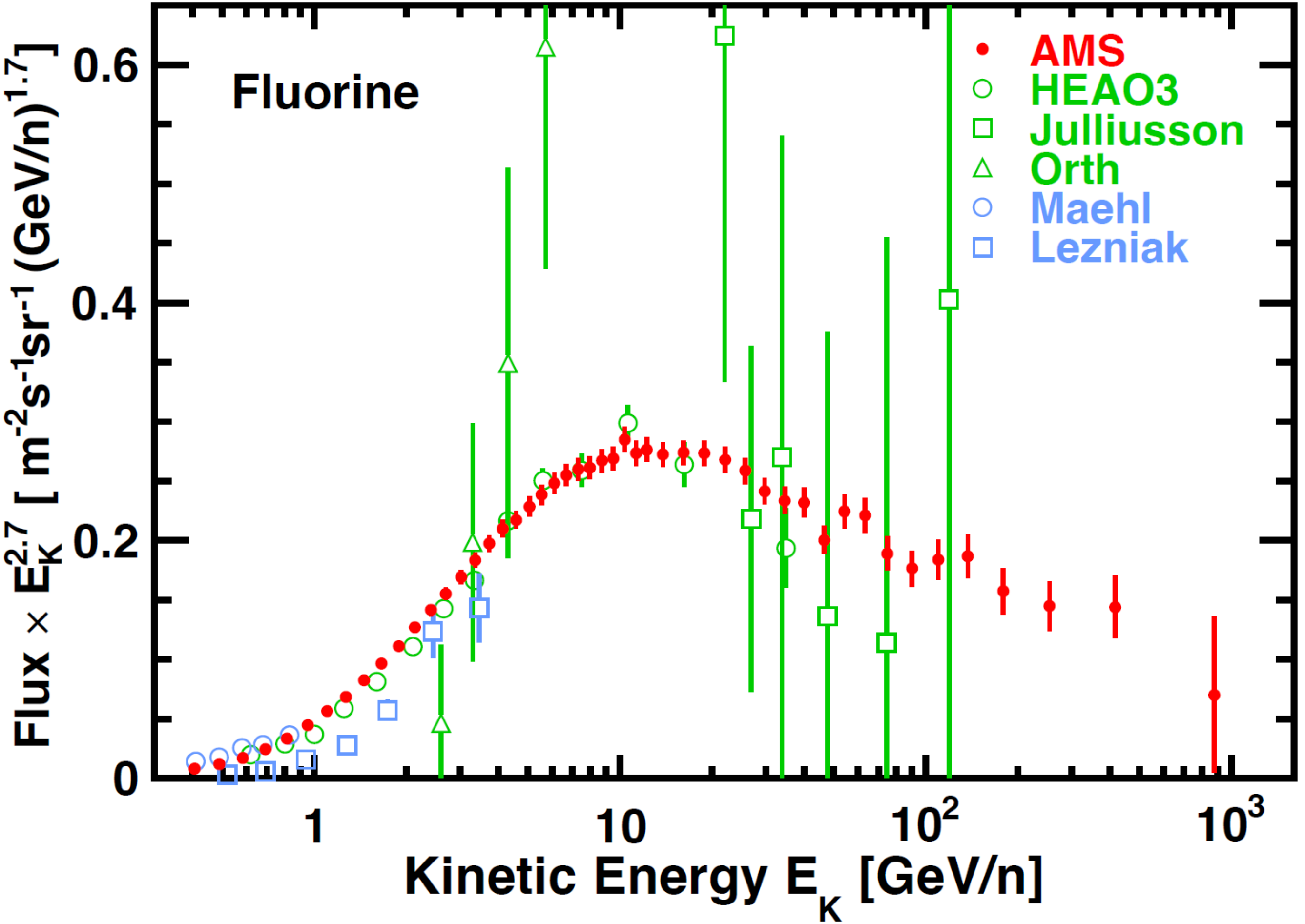


Average **hardening** $\Delta = \Delta_2 - \Delta_1 = 0.145 \pm 0.022$, significance: **$6.5\sigma$**

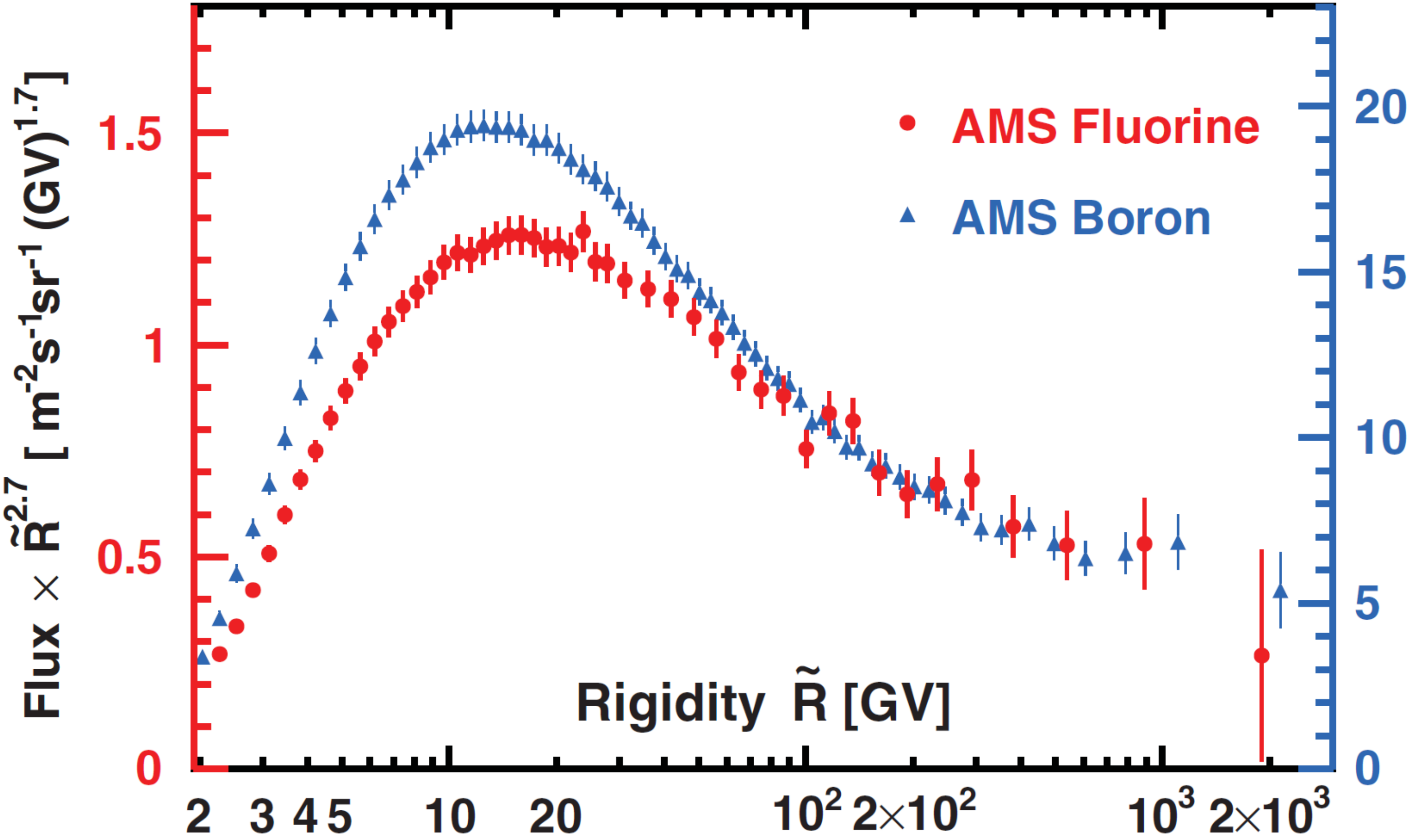
This new observation strongly favors the hypothesis that **the observed spectral hardening** is due to a **propagation effect**

AMS Fluorine Flux

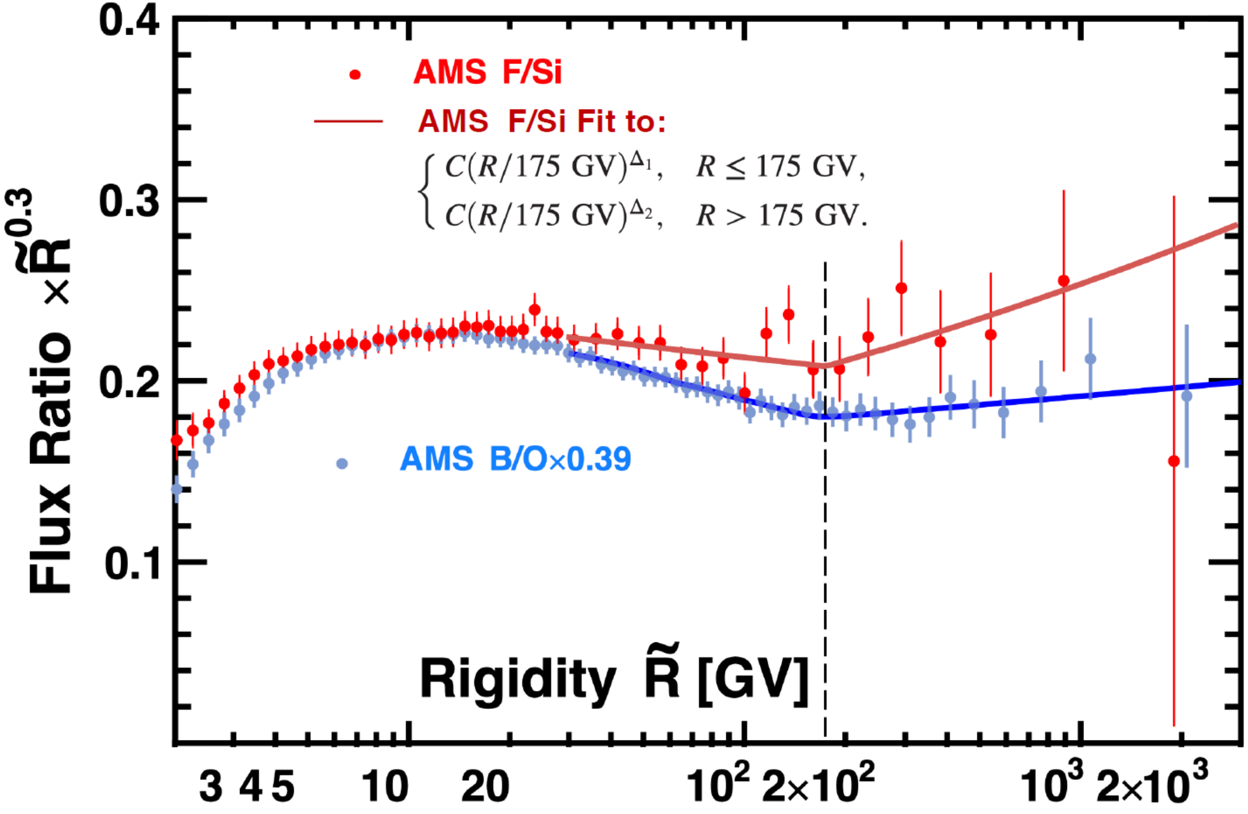
M. Aguilar *et al.*, Phys. Rev. Lett. **126** (2021) 081102



Fluorine Flux compared with Boron flux

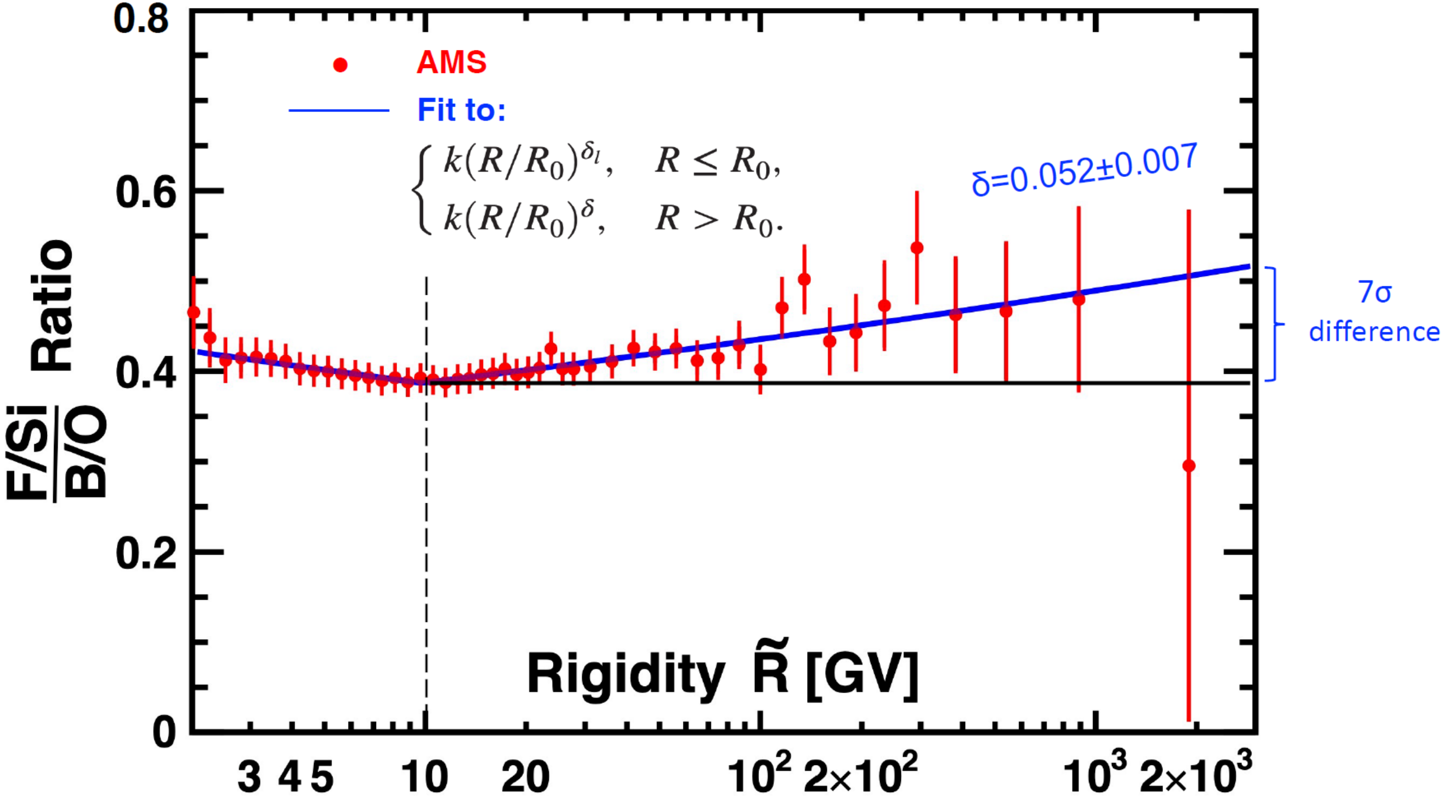


Heavy (F/Si) and Light (B/O) Secondary-to-Primary Ratios



Above 175 GV, the F/Si ratio exhibits a hardening ($\Delta_2^{F/Si} - \Delta_1^{F/Si}$) of 0.15 $\pm$ 0.07 compatible with the AMS result on the hardening of the Li/O, Be/O, and B/O flux ratios.

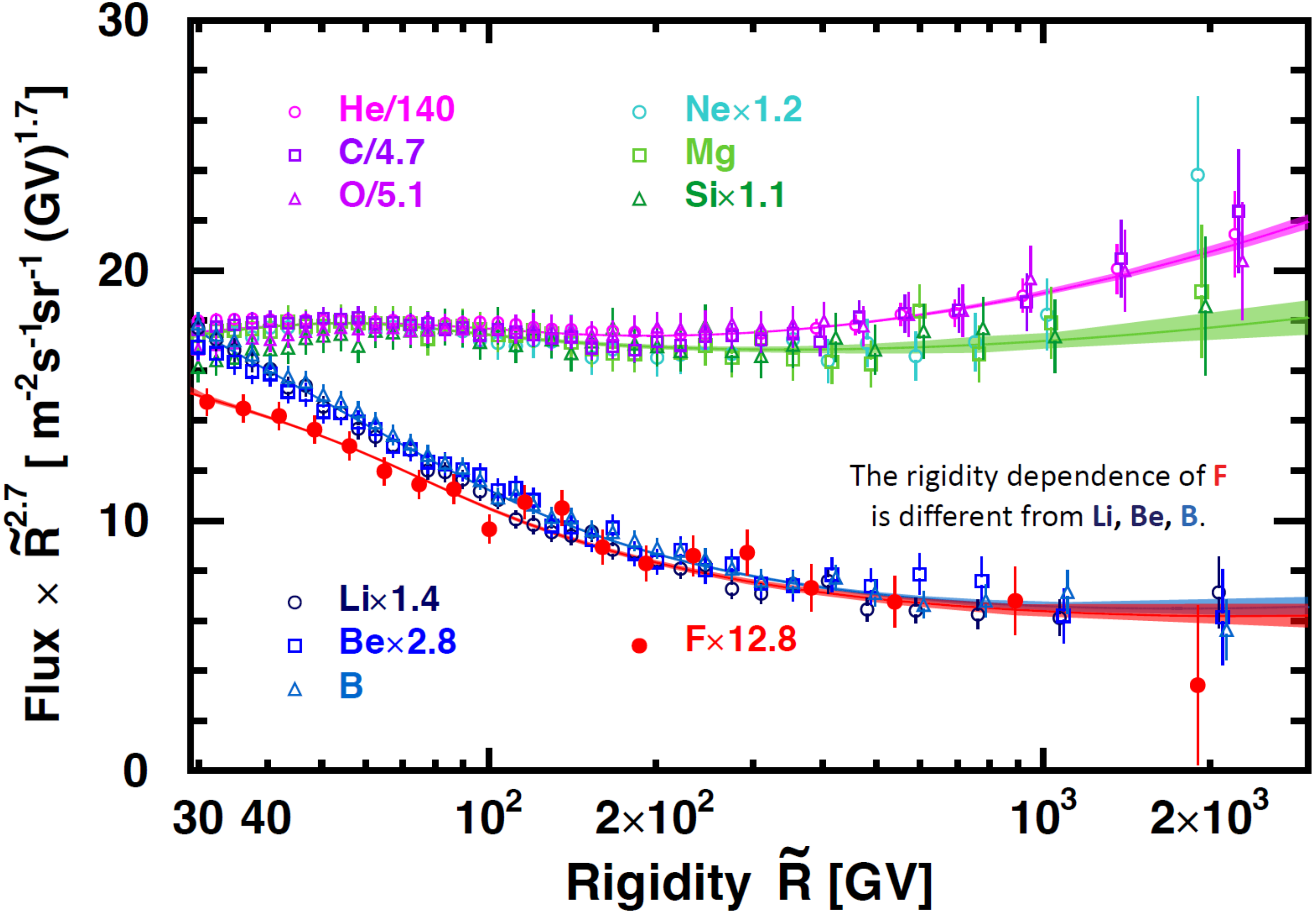
The (F/Si)/(B/O) Ratio



Above 10 GV, the (F/Si)/(B/O) ratio can be described by a single power law with $\delta = 0.052 \pm 0.007$.

The propagation properties of heavy cosmic rays (F–Si), are different from those of light cosmic rays (He–O).

Primary and Secondary Fluxes from He to Si



The primary cosmic rays has two classes: He-C-O and Ne-Mg-Si

The secondary cosmic rays has also two classes: Li-Be-B and F

Summary

- The latest AMS results on the secondary cosmic ray **Li, Be, B,** and **F** fluxes from 2 GV to 3 TV were presented.

- The spectra of secondary cosmic ray Li, Be, B all deviate from single power laws above 200 GV. The **spectral hardening of the secondary cosmic rays is larger than primary** cosmic ray (He, C, O) by more than 5σ. The F flux, and the F/Si ratio, show that this additional hardening is also presented in the heavier secondary cosmic rays.

- Unexpectedly, the rigidity dependence of heavier secondary-to-primary F/Si flux ratio is distinctly different from the lighter B/O ratio by more than 7σ. This reveals that the propagation properties of **heavy cosmic rays**, from F to Si ($9 \leq Z \leq 14$), are **different** from those of **light cosmic rays**, from He to O ($2 \leq Z \leq 8$).

- Future high precision AMS measurements of all heavy secondary cosmic ray ($Z>14$), such as Sub-Fe, will provide **unique insights** into the understanding of the cosmic rays.