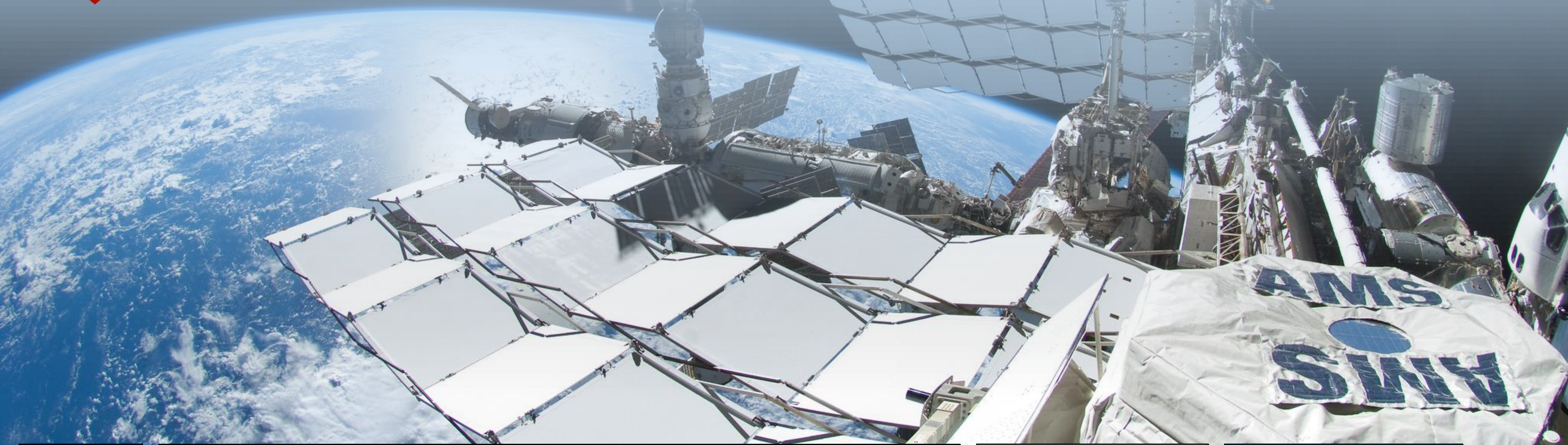
Unique Properties of Secondary Cosmic Rays

Results from the Alpha Magnetic Spectrometer

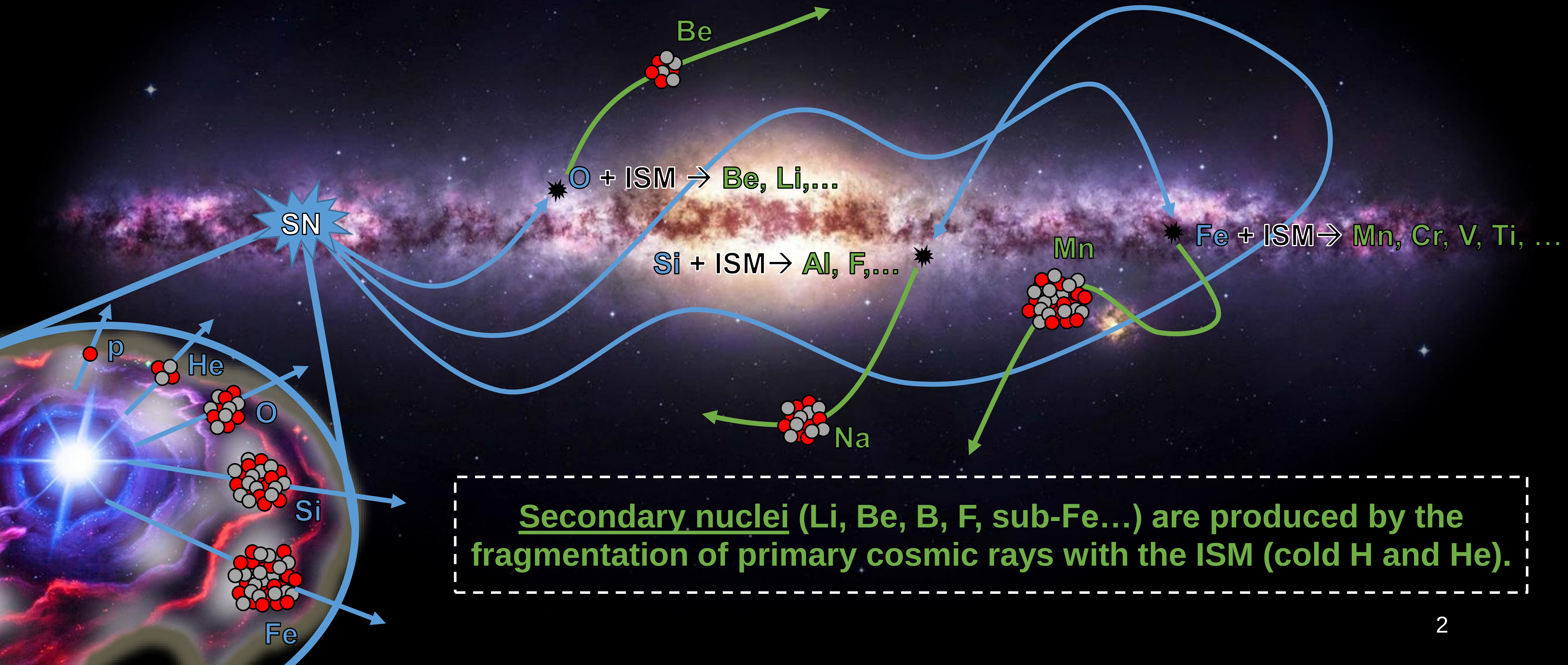
José Ocampo Peleteiro **(CIEMAT)**

on behalf of **AMS Collaboration**



The *Spallation* Picture: Primary and Secondary Cosmic Rays

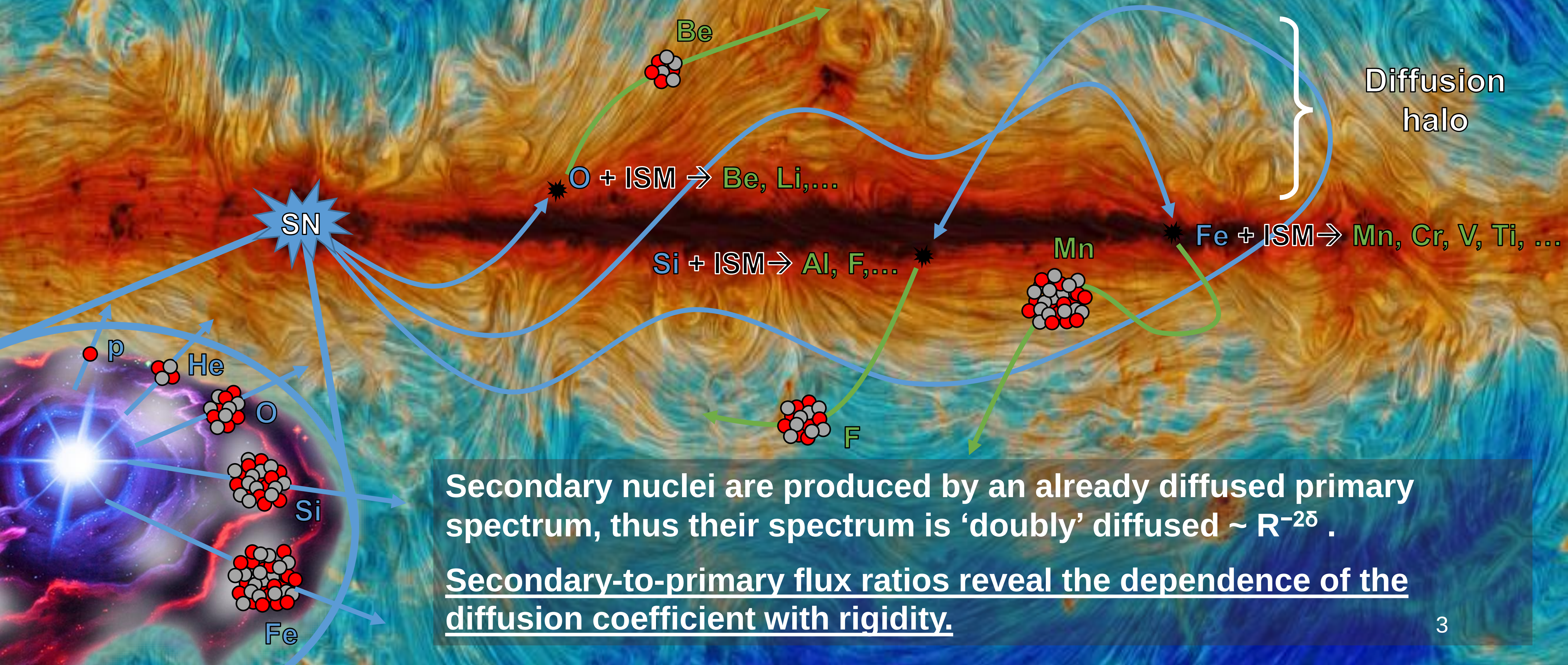
Primary nuclei (He, C, O, Ne, Mg, Si, Fe) are fused in stars through the α-process and injected into the Galaxy in a supernova explosión.



Secondary nuclei (Li, Be, B, F, sub-Fe…) are produced by the fragmentation of primary cosmic rays with the ISM (cold H and He).

The *Diffusion* Picture: Primary and Secondary Cosmic Rays

Primary nuclei are contained in the Galaxy due to inhomogenous magnetic fields. Their propagation is characterised by a diffusion coefficient ~ $R^{-\delta}$ that modifies their spectrum.



Secondary nuclei are produced by an already diffused primary spectrum, thus their spectrum is ‘doubly’ diffused ~ $R^{-2\delta}$.

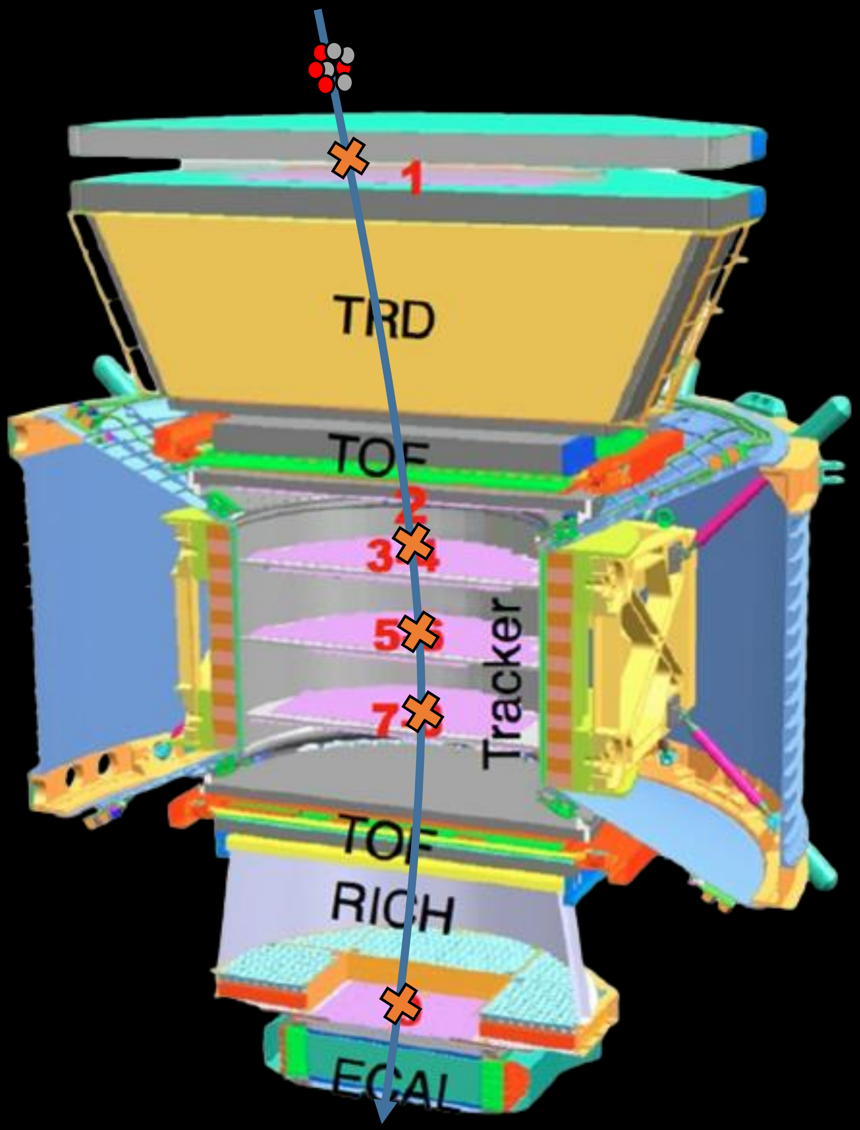
<u>Secondary-to-primary flux ratios reveal the dependence of the diffusion coefficient with rigidity.</u>

Measurement of the Fluxes of Nuclei with AMS

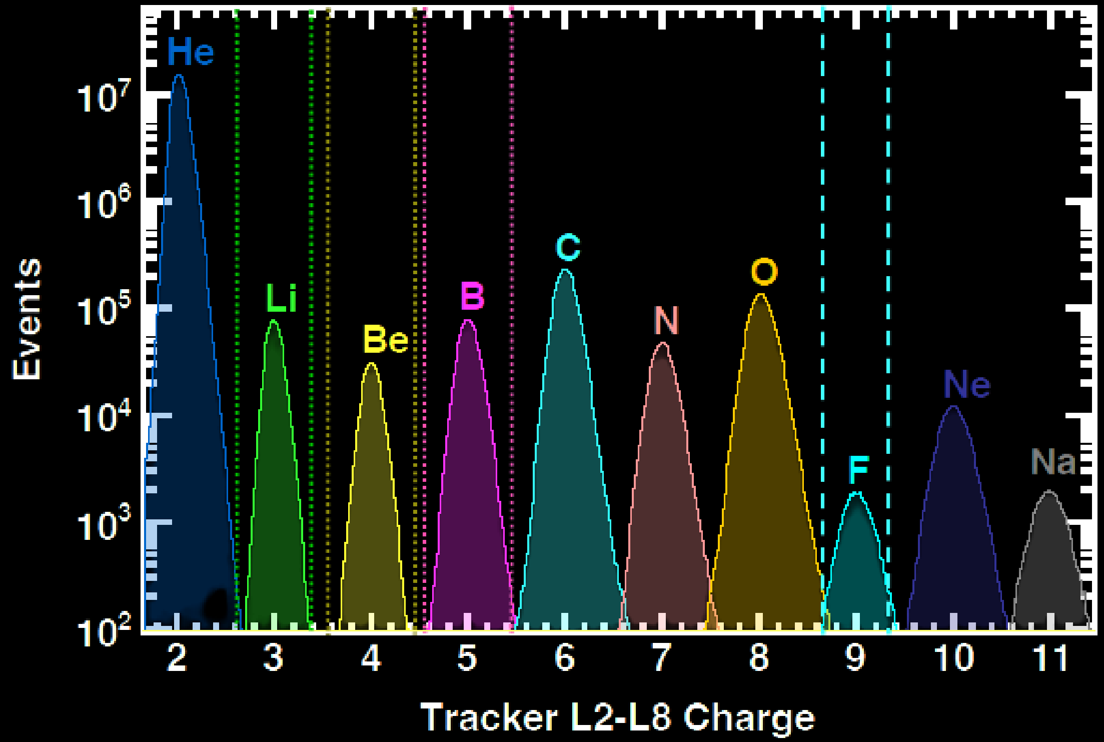
The AMS flux in the rigidty interval $[R_i, R_i + \Delta R_i]$ is computed as:

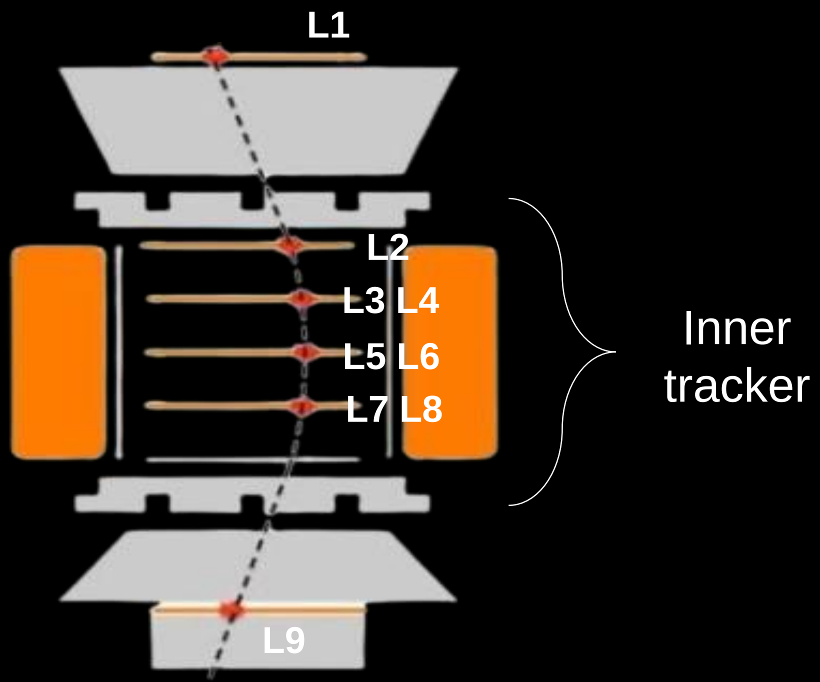
$$\phi_i = \frac{N_i}{A_i T_i \Delta R_i}$$

- N_i **are the selected event counts** corrected for bin-to-bin migrations after background subtraction**,**
- A_i **is the effective acceptance** including geometric factor, selection and reconstruction efficiencies and nuclear interactions
- T_i **is the exposure time**



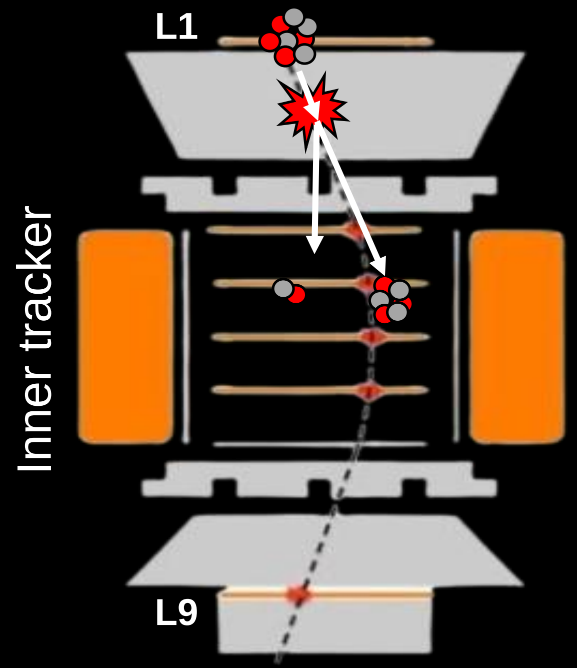
Charge Identification of Nuclei in AMS Analysis

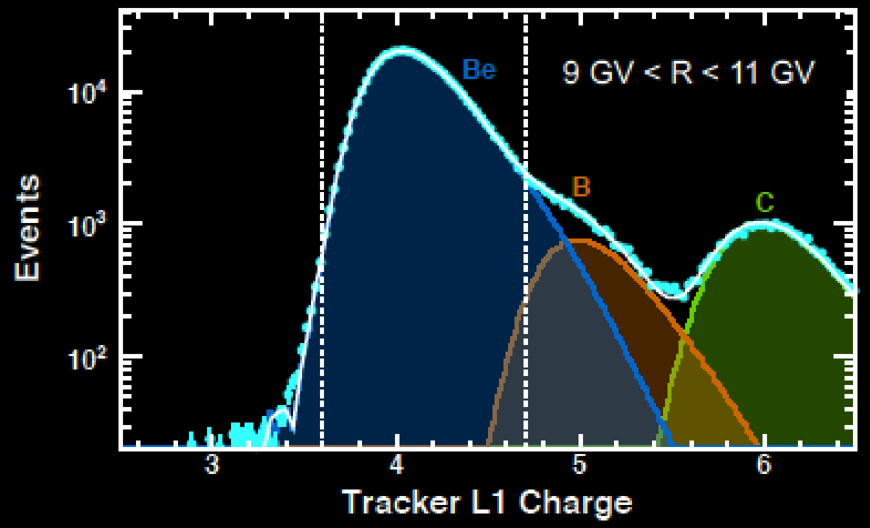


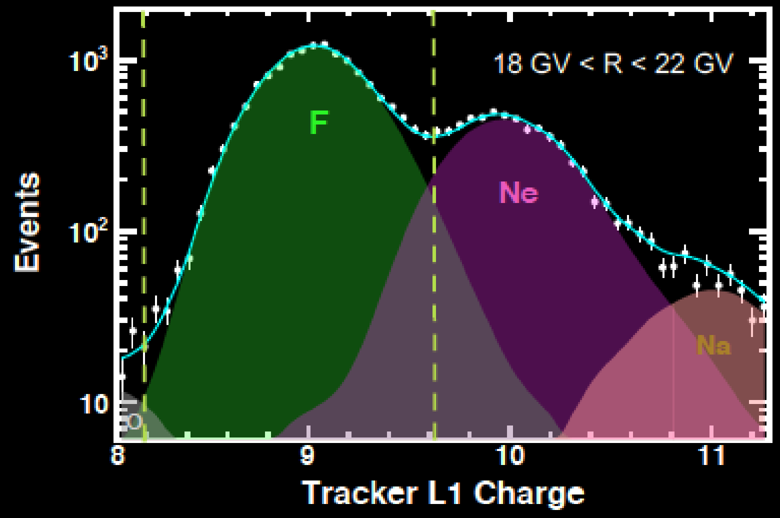


- AMS has good charge measurement capabilities. Inner tracker resolution ~0.05-0.13 c.u. for $3 \leq Z \leq 9$, Y. Jia *et al*., *Nuc. Instr. And Meth. in Phys A* **972**, 164169 (2020).
- **Background due to charge misidentification in non-interacting samples is neglible over the whole rigidity range.**

Background Subtraction in AMS Analysis of Nuclei

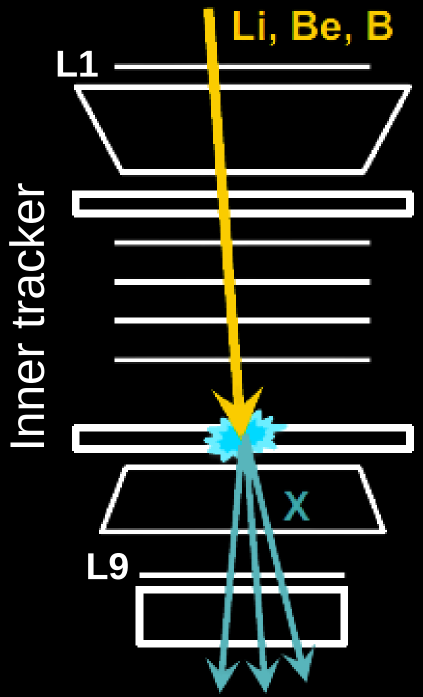


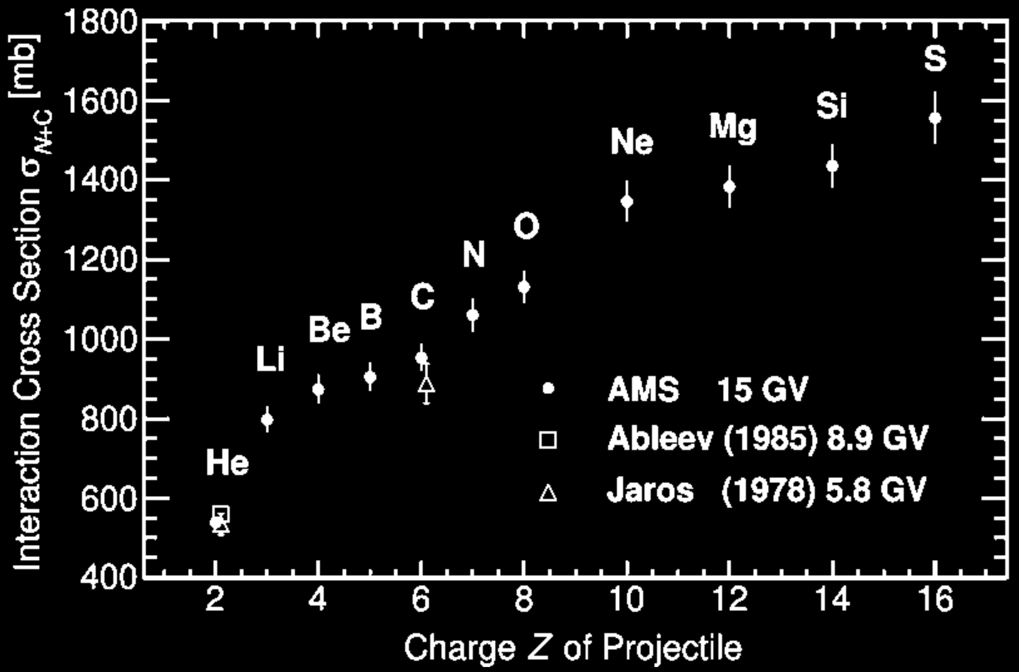


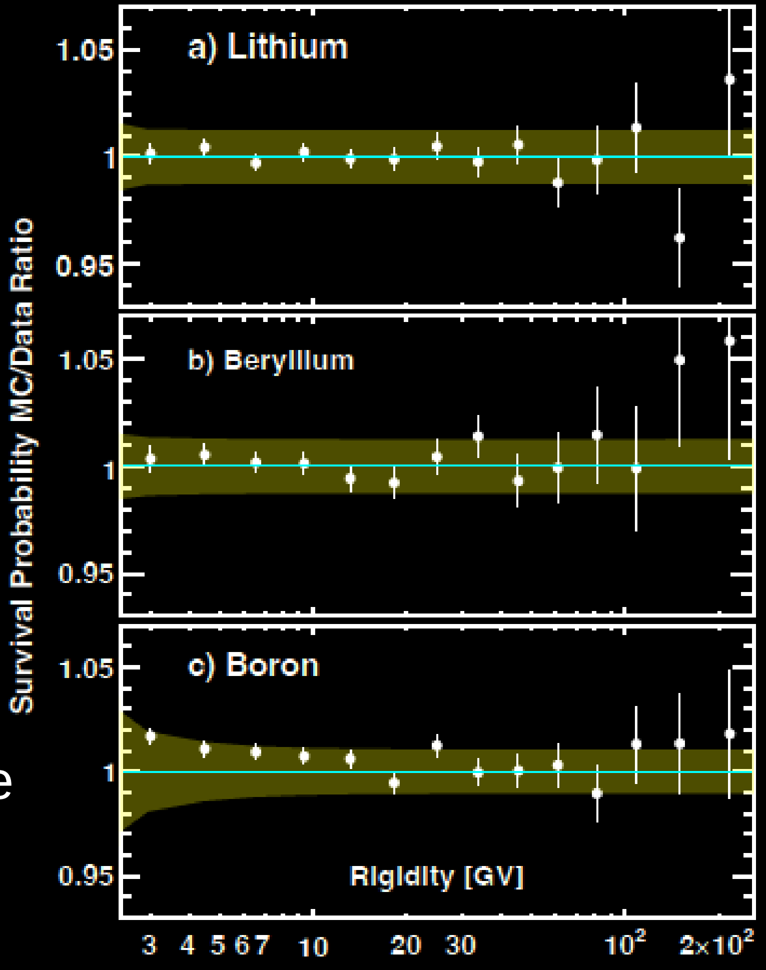


- A residual background originates from nuclear interactions in the material between the inner tracker and the layer 1. A clean sample is obtained with template fits of charge distributions.
- The background from interactions on the little material above L1 has been estimated from simulation using MC samples generated according to AMS flux measurements.
- **The error due to background subtractions typically amounts to few percent** (<2% below 100 GV and <6% below 3 TV).

Fragmentation Studies of Nuclei in AMS



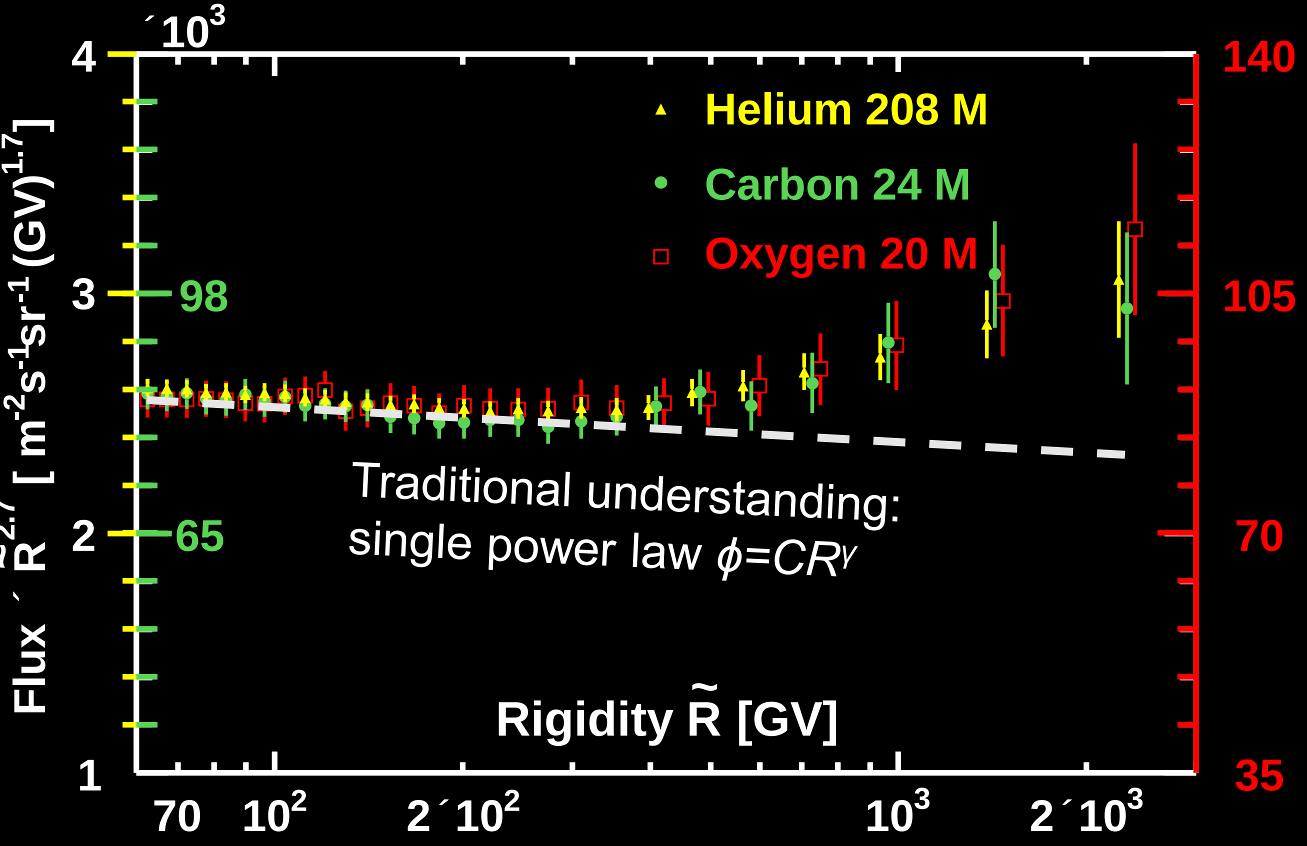




- The absolute normalisation of the fluxes is largely dependent on the **nuclear inelastic cross-section** of cosmic rays **with the material of the instrument** (mostly carbon and aluminium).
- The inelastic cross sections of nuclei with carbon target has been measured by determining the tracker L1-L2 and L8-L9 nuclei survival prob., Q. Yan *et al.*, *Nuclear Physics A* **996**, 121712 (2020).

Recap: Spectral Hardening in the Fluxes of Nuclei

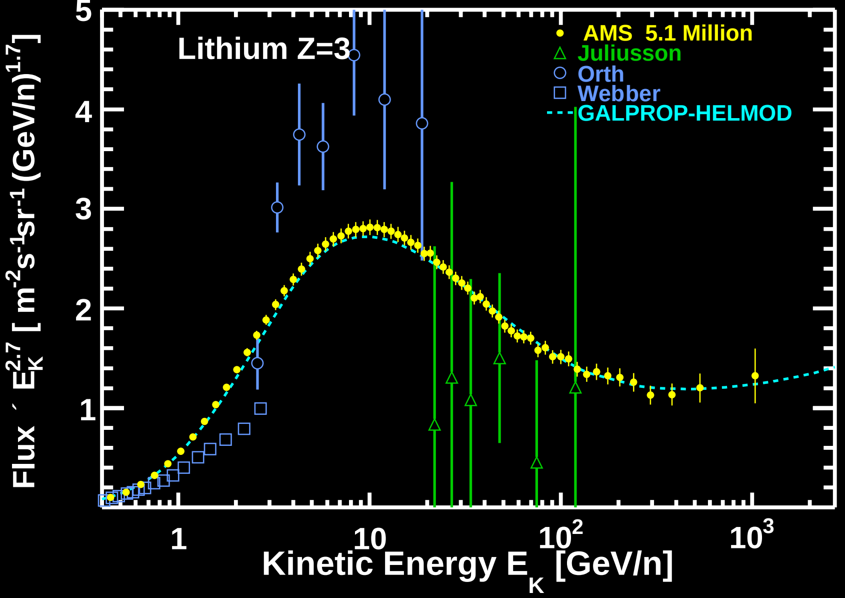
see details in Dr. Valerio Formato's talk

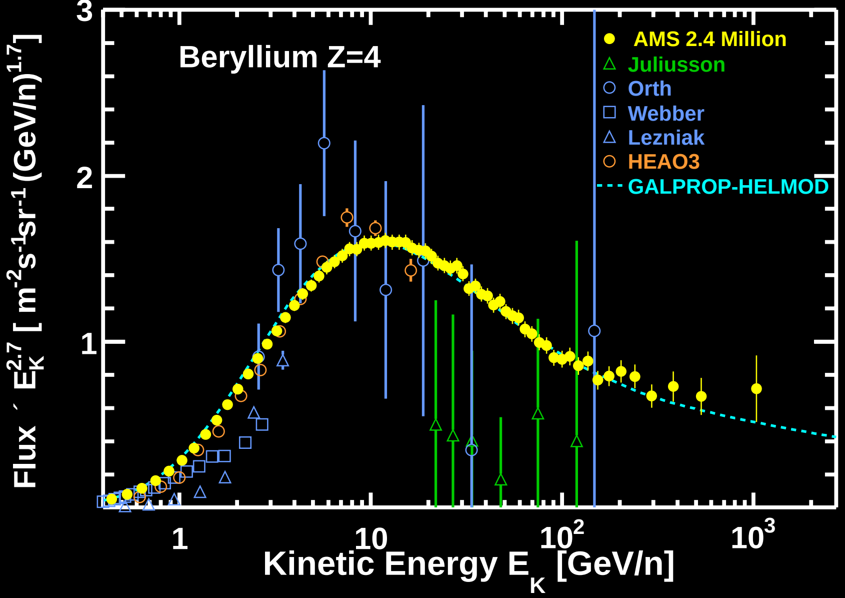


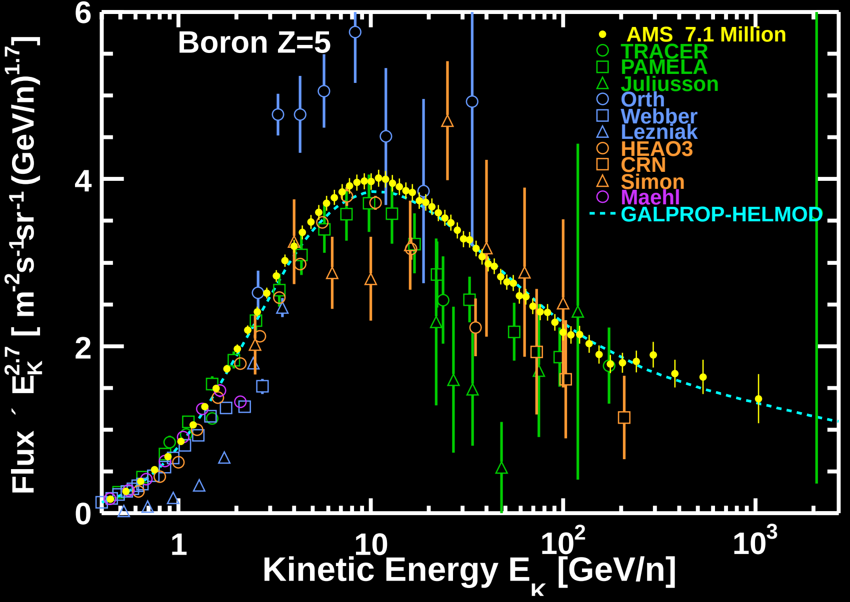
- The spectra of primary He, C and O harden in an indentical way above ~200 GV.
- **This hardening can be attributted to the injection spectrum at the source or in the diffussion coefficient.**

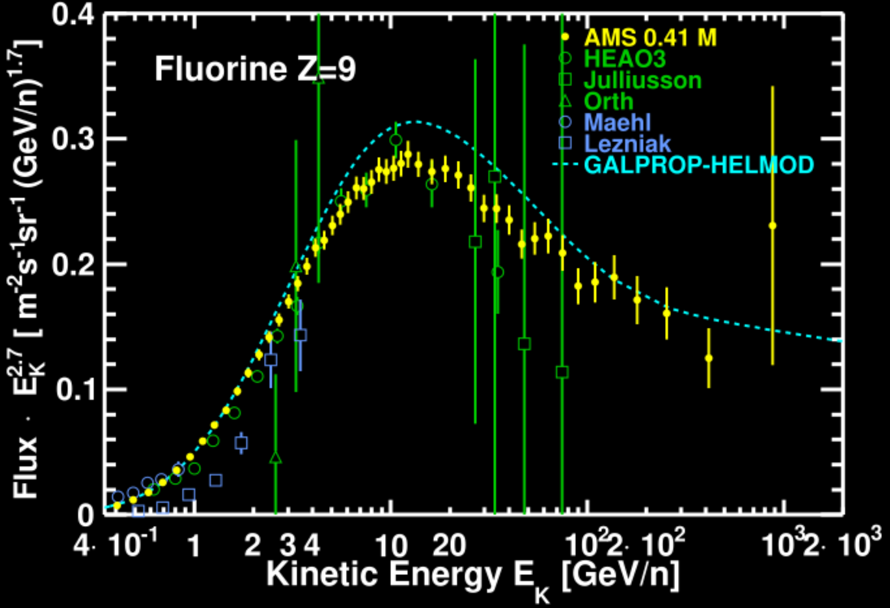
Fluxes of Lithium, Beryllium, Boron and Fluorine

11 years
AMS data



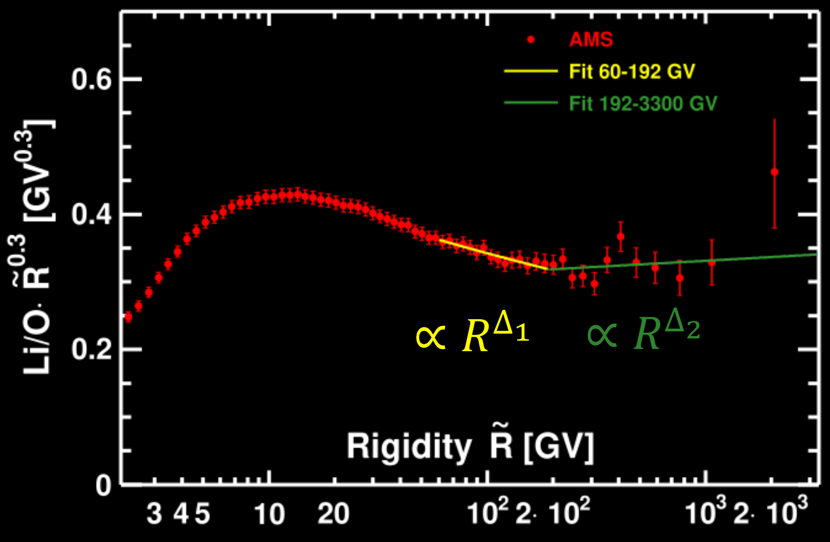


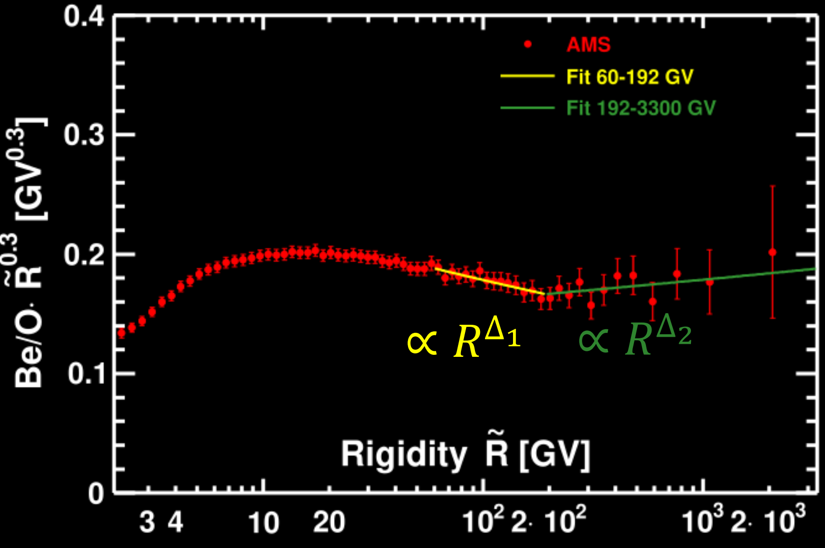


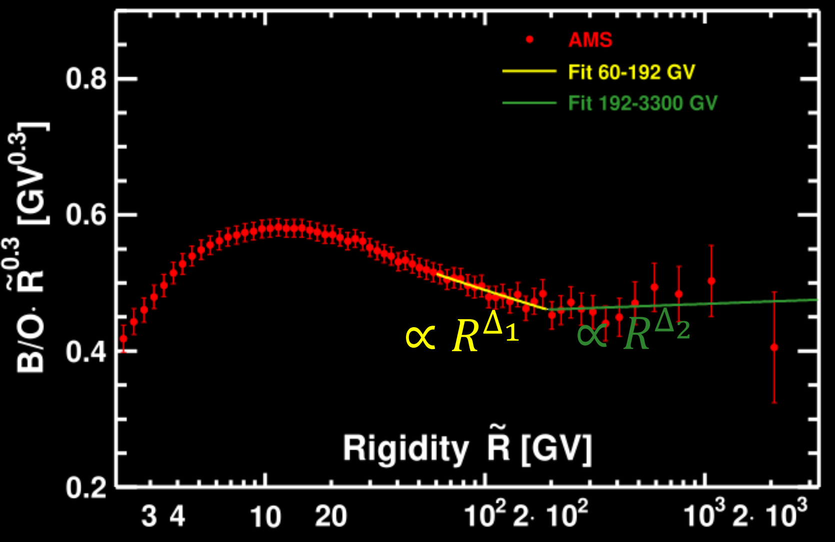


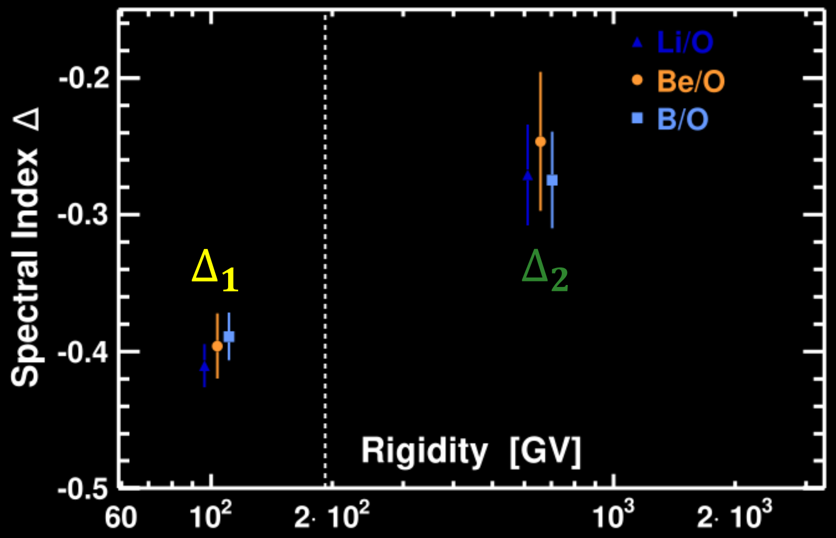
Secondary-to-Primary Flux Ratios

11 years
AMS data





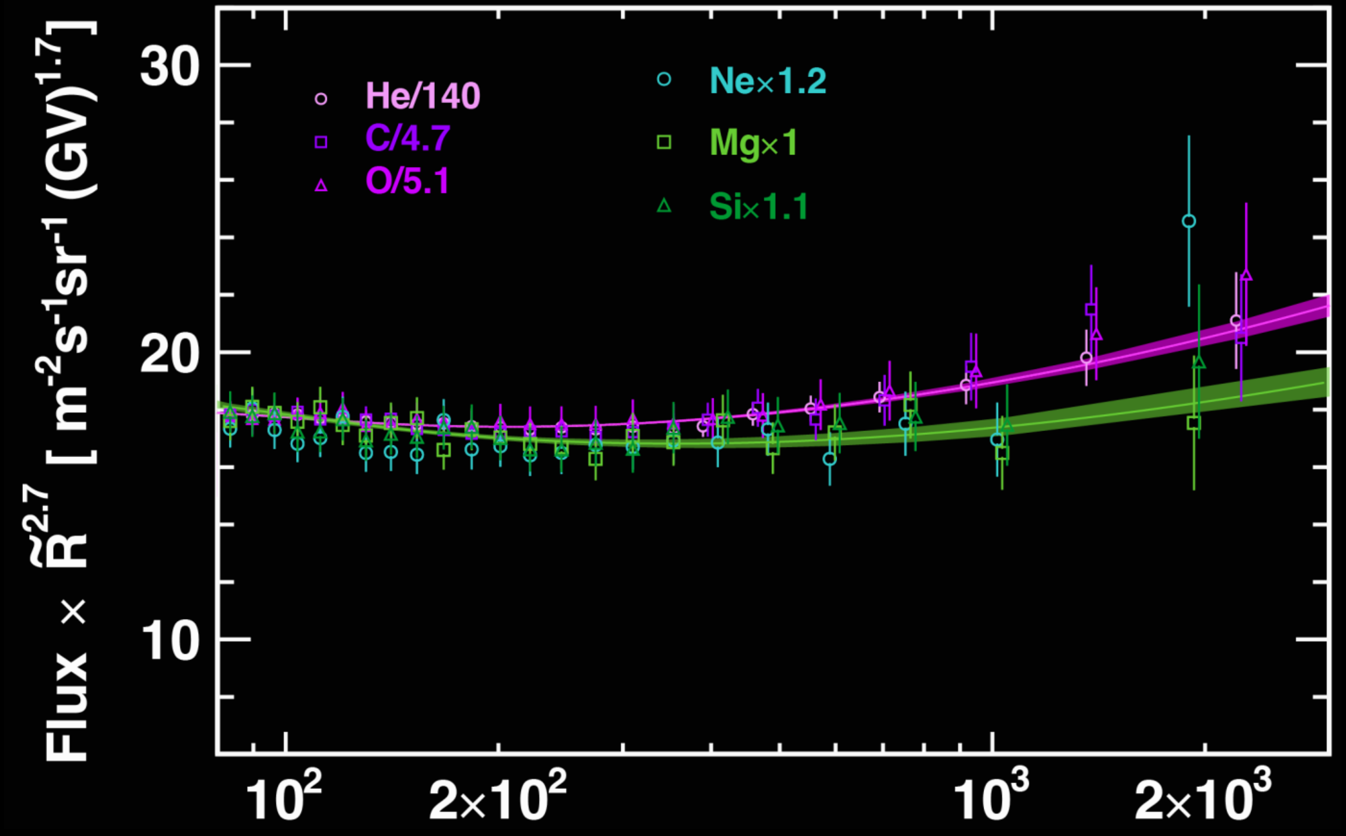




- All spectra of secondary nuclei harden above ~200 GV.
- Above 200 GV all three secondary-to-primary flux ratios harden, $\Delta_2 - \Delta_1 = \mathbf{0.11 \pm 0.02}$.
- This hardening is similar to that found for primary nuclei.
- **AMS data support a spectral hardening of the fluxes of nuclei due to propagation with more than 5σ significance.**

Recap: Two Classes of Primary Cosmic Rays

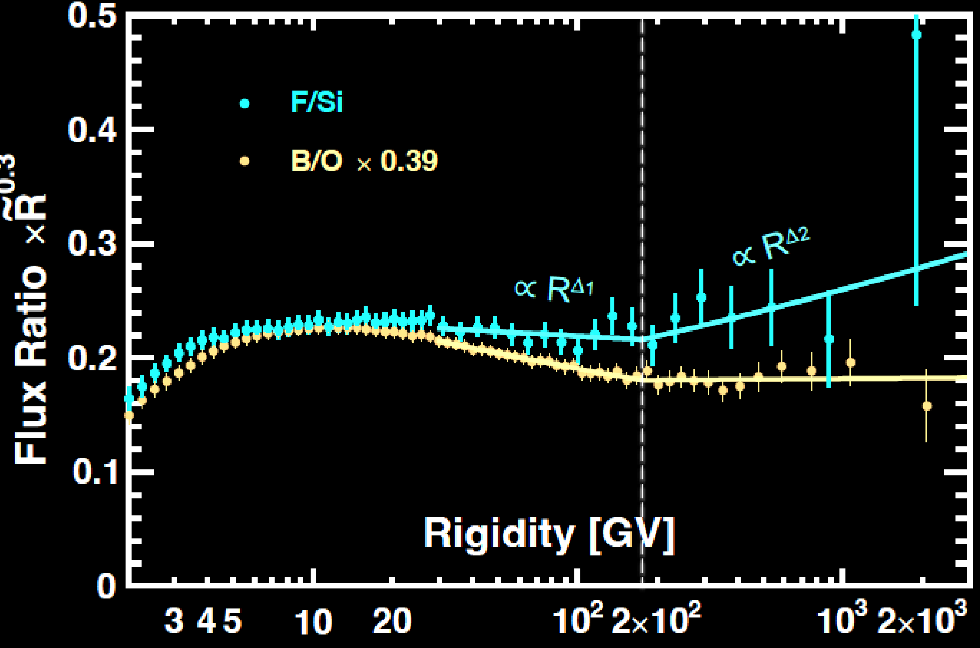
see details in Dr. Valerio Formato's talk

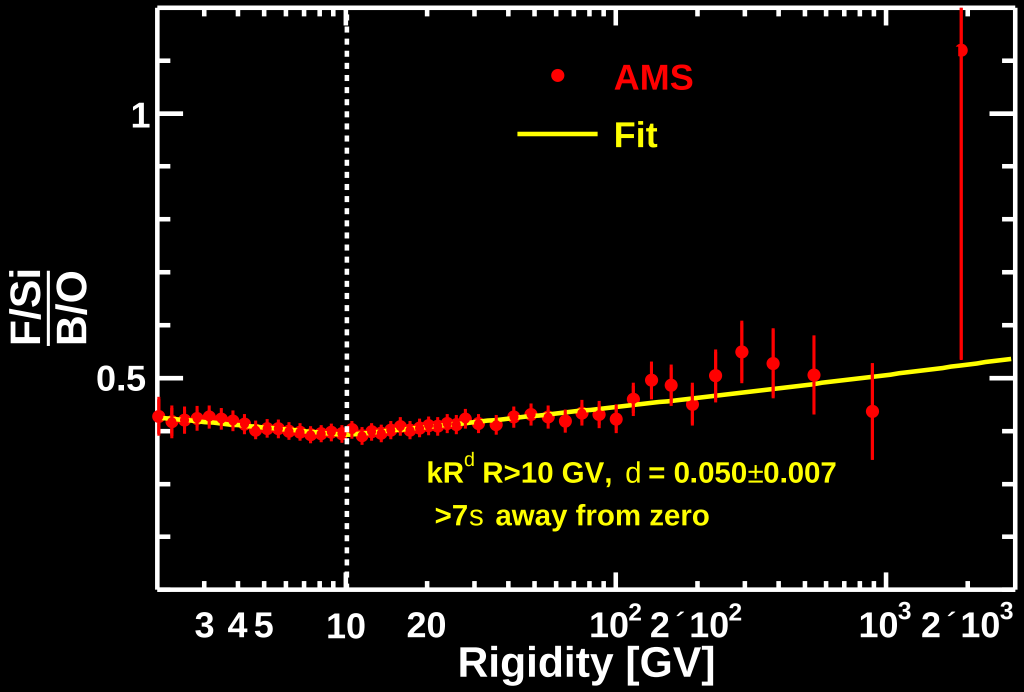


- AMS data show that above 86.5 GV He, C and O have a distinct rigidity dependence than Ne, Mg and Si: $\gamma_{HeCO} = \gamma_{NeMgSi} + 0.032 \pm 0.006$.

Secondary-to-Primary Flux Ratios

11 years
AMS data

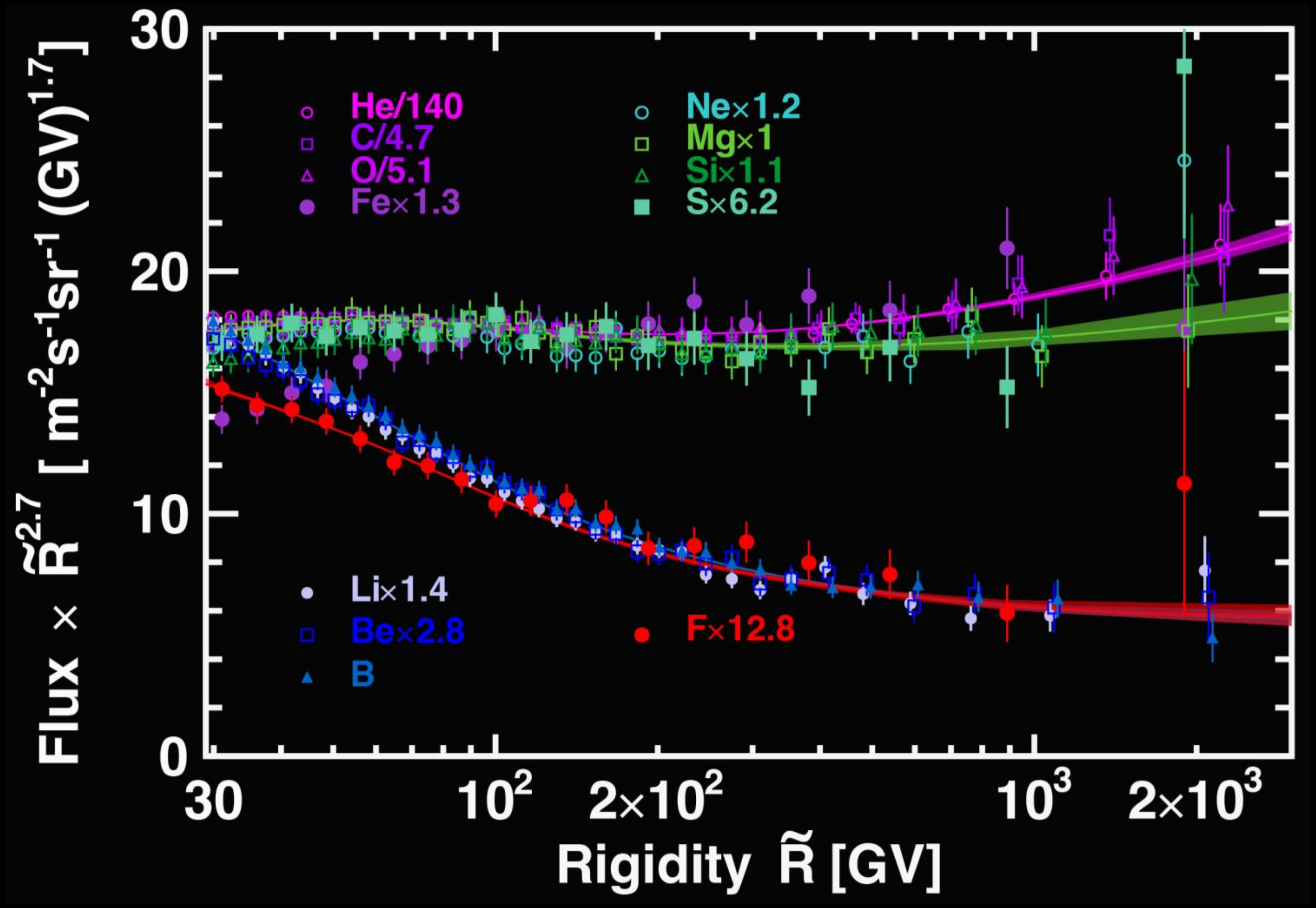




- Above 175 GV, the F/Si ratio exhibits a hardening $\Delta_2^{F/Si} - \Delta_1^{F/Si} = 0.13 \pm 0.06$ compatible with the AMS result on the hardening of B/O flux ratio.
- Above 10 GV, the (F/Si)/(B/O) ratio is not flat but can be described by a single power law with $\delta = 0.055 \pm 0.006$.

Fluxes of Lithium, Beryllium, Boron and Fluorine

11 years
AMS data



Conclusions

- The measurement of the fluxes of secondary nuclei is paramount for the understanding of the physics of diffusion of cosmic rays in the galaxy.

- AMS has presented **high-statistics** measurments of the fluxes of secondary nuclei **lithium, beryllium, boron and fluorine** in the range 2 GV to 3 TV with **detailed study of systematic errors**.

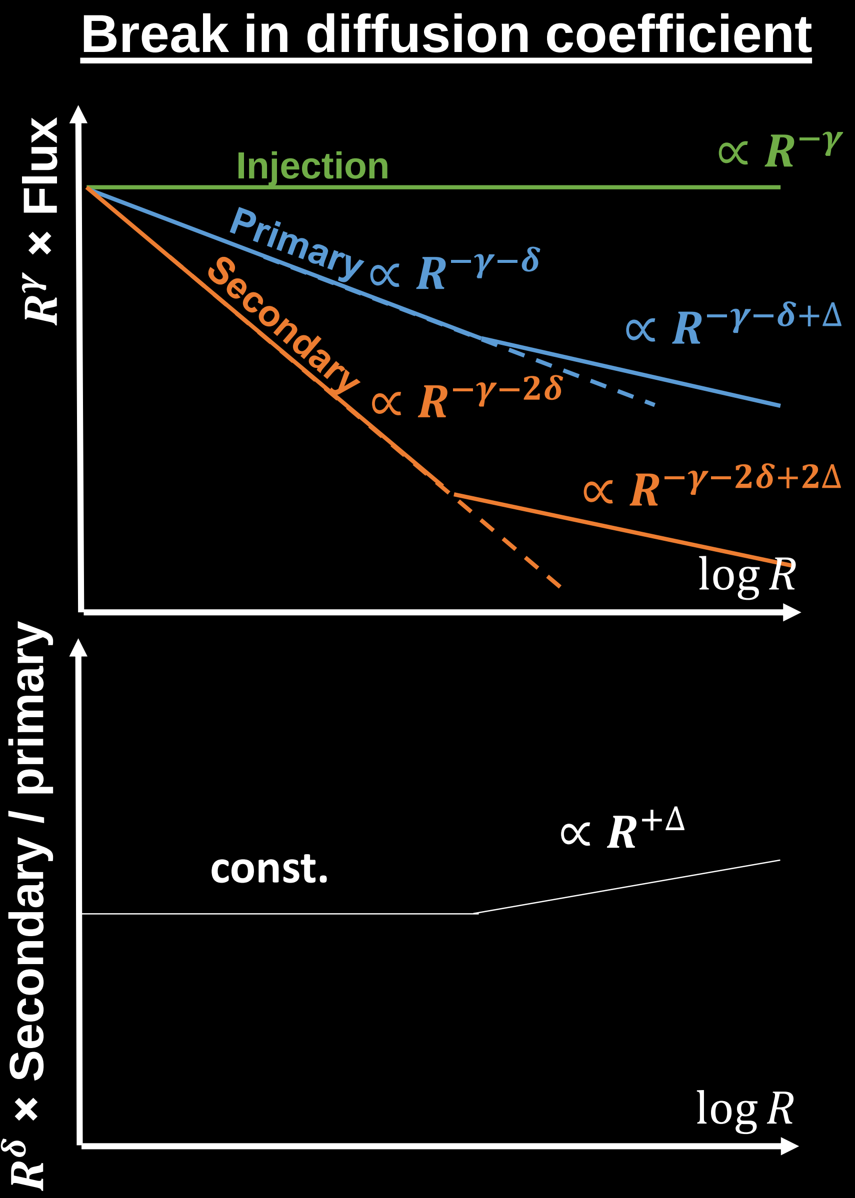
- **The fluxes of secondary nuclei consistently harden above ~ 200 GV and secondary-to-primary flux ratios support the hypothesis of a spectral hardening related to a propapagation effect.**

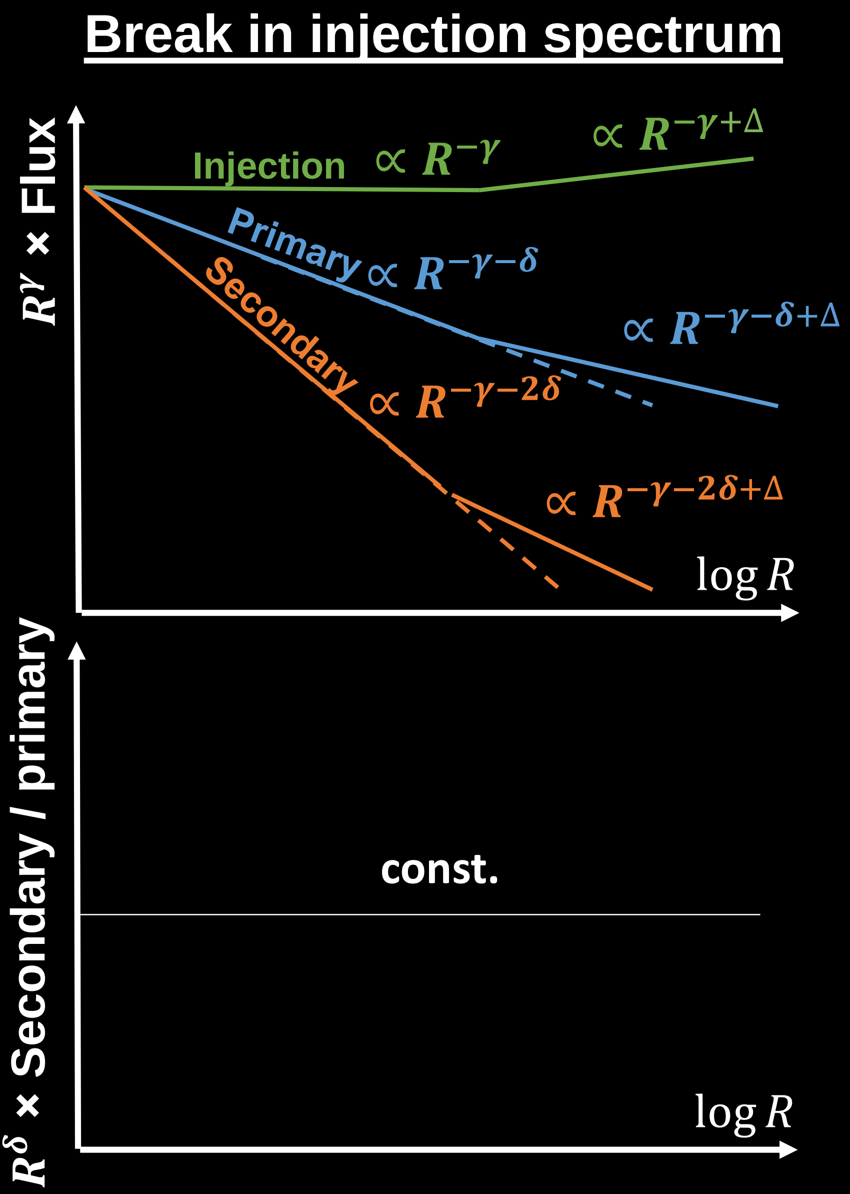
- AMS will continue to provide measurements of the fluxes of secondary nuclei (Z>14) and expanding our knowledge of the cosmic rays.

TeVPA 2023

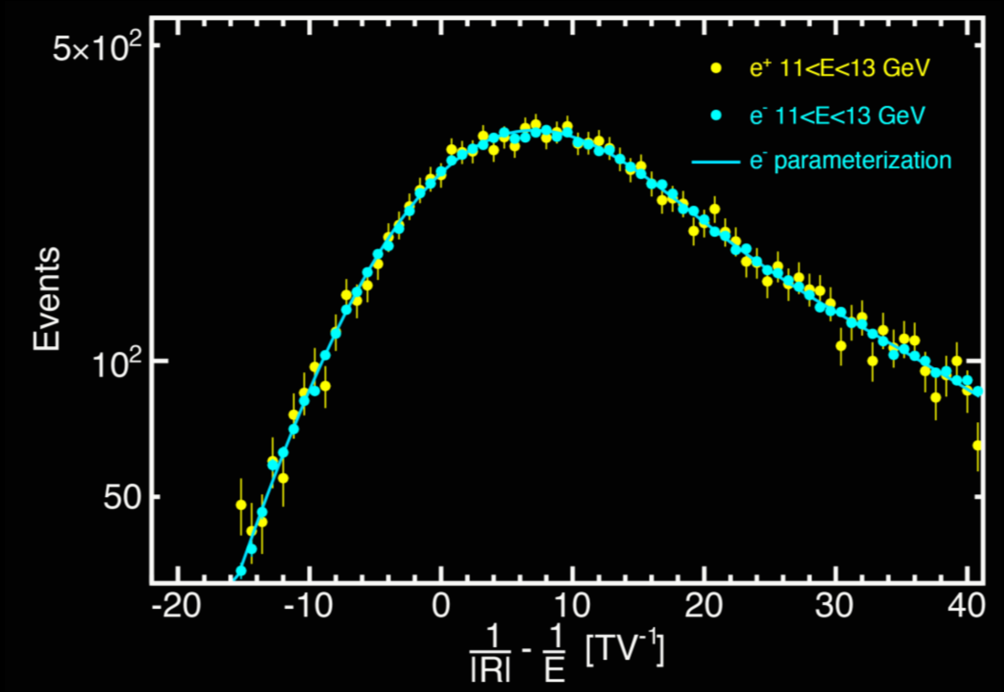
Back-up

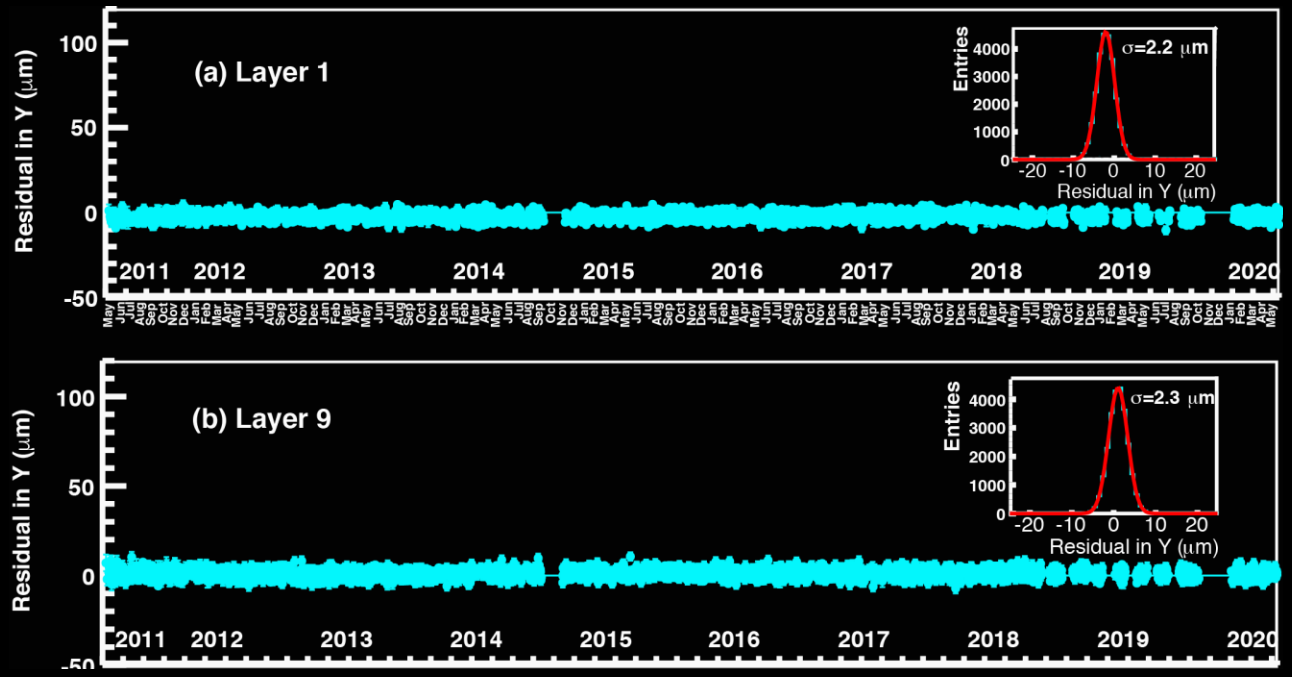
The Break: A Feature of the Source or the Diffusion Coefficient?





Rigidity Scale Determination in AMS





- Calibration tests performed with proton beams at CERN before launch into space.
- After the flight, the position of the outer layer 1 and layer 9 are precisely aligned by using cosmic rays events to a stability of ~2 μm. The stability of inner tracker layers is a tenth of micron.
- **Tracker misalignment is corrected by comparing the measured tracker rigidity and ECAL energy of positron and electron events.** Coordinate resolution ~5-7 μm (3.2-3.7 TV MDR). Q. Yan and V. Choutko, *Eur. Phys. J. C* **83**, 245 (2023)**.**