Properties of Secondary Cosmic Rays

Results from the Alpha Magnetic Spectrometer

José Ocampo Peleteiro **(CIEMAT)**

on behalf of **AMS Collaboration**

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PRAGUE

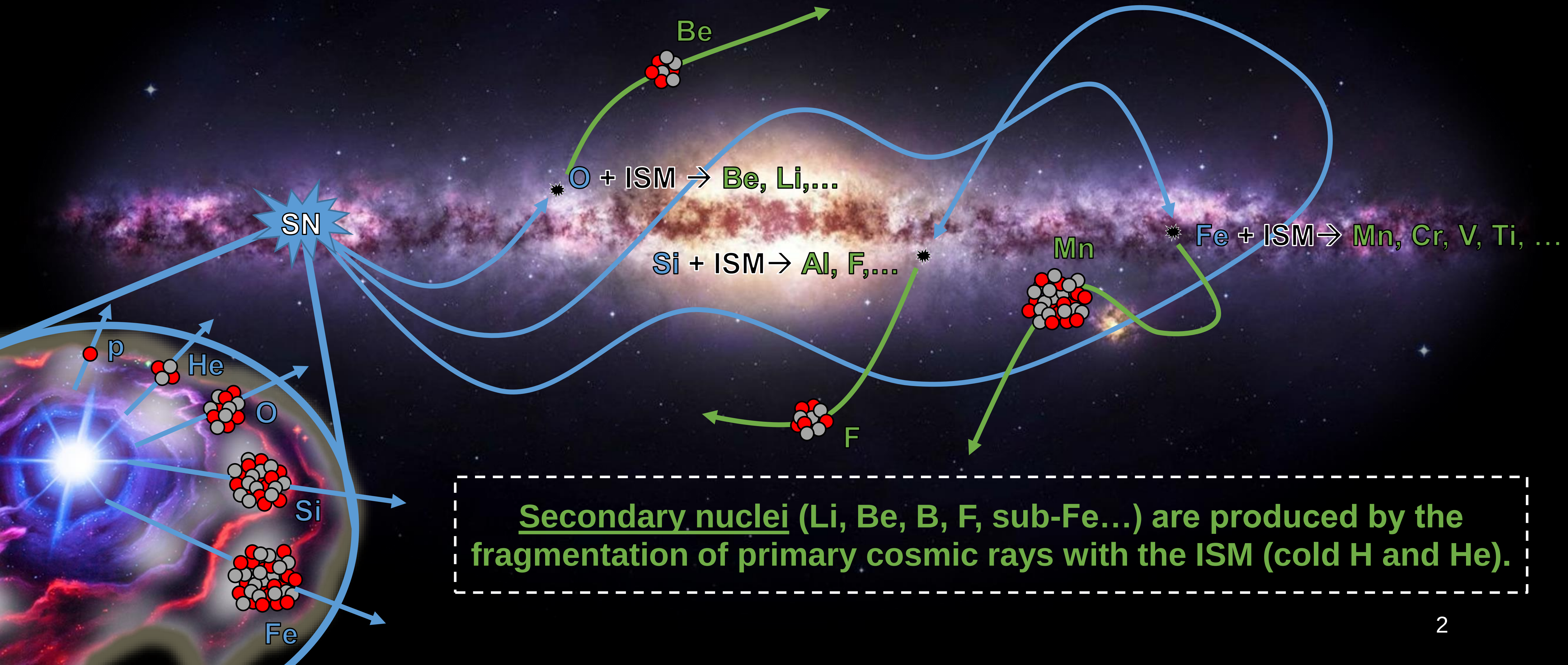
GOBIERNO DE ESPAÑA

MINISTERIO DE CIENCIA, INNOVACIÓN Y UNIVERSIDADES

Ciemat
Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

The *Spallation* Picture: Primary and Secondary Cosmic Rays

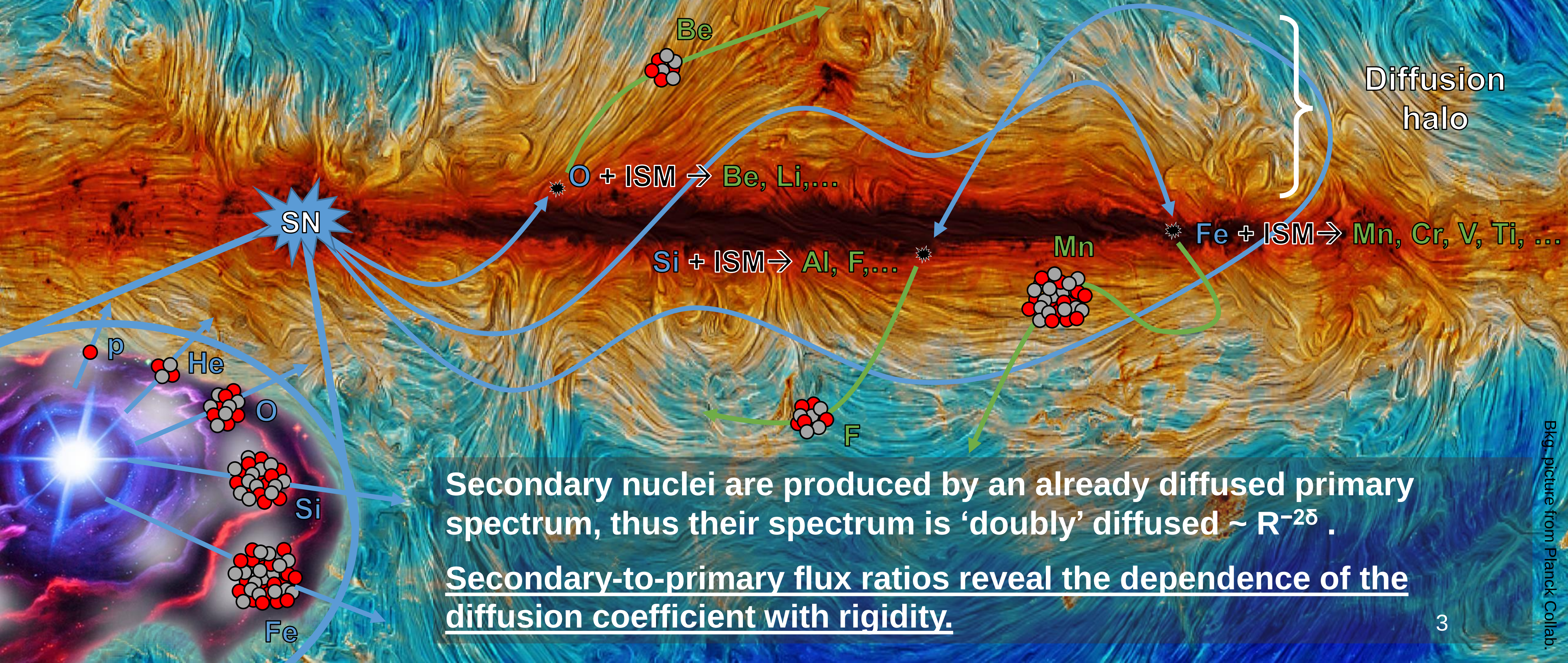
Primary nuclei (He, C, O, Ne, Mg, Si, Fe) are fused in stars through the α-process and injected into the galaxy in a supernova explosion.



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>

Bkg. picture from Planck Collab.

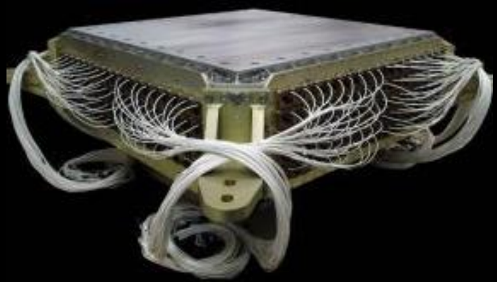
AMS: A TeV-Precision Spectrometer in Space

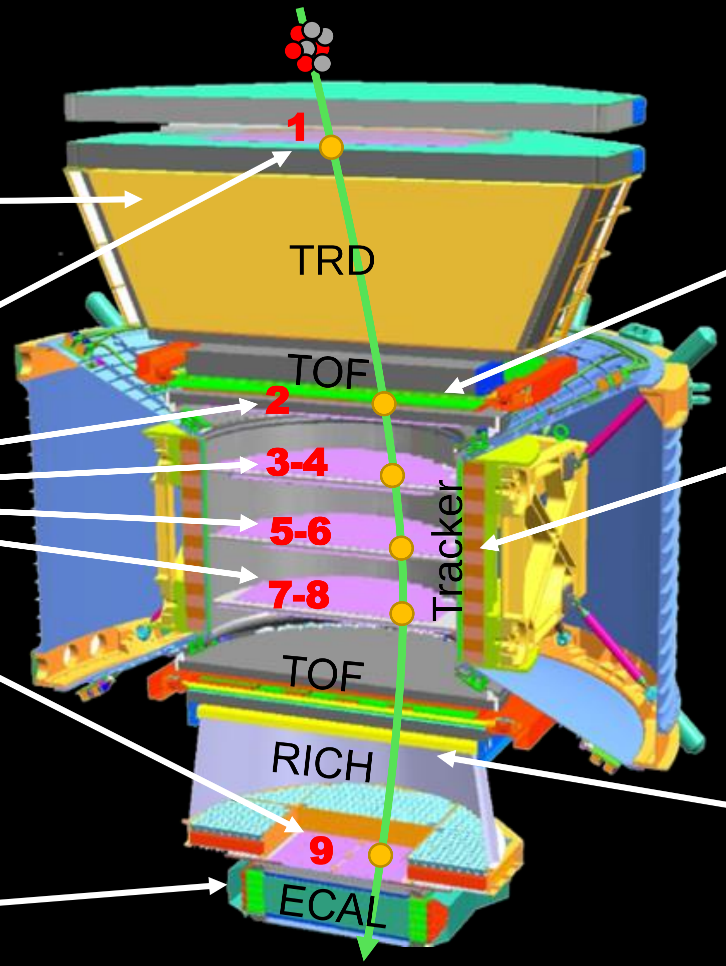
Particles and nuclei are defined by their charge (Z) and energy (E) or momentum (P). Rigidity R = P/Z

TRD: Identify e^+, e^-, Z

Silicon Tracker: Z, P

ECAL: E of e^+, e^-

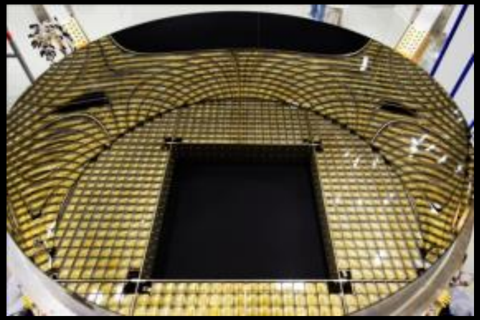




TOF: Z, E

Magnet: ±Z

RICH: Z, E



Z and P (or E)

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

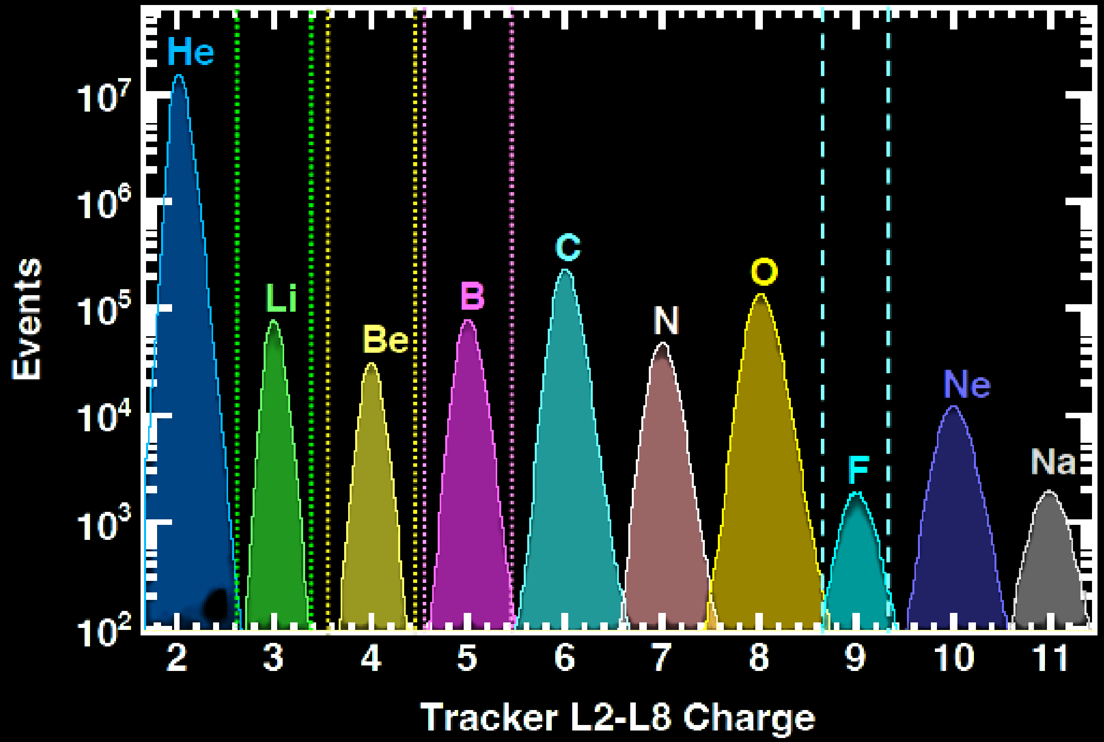
Measurement of the Fluxes of Nuclei with AMS

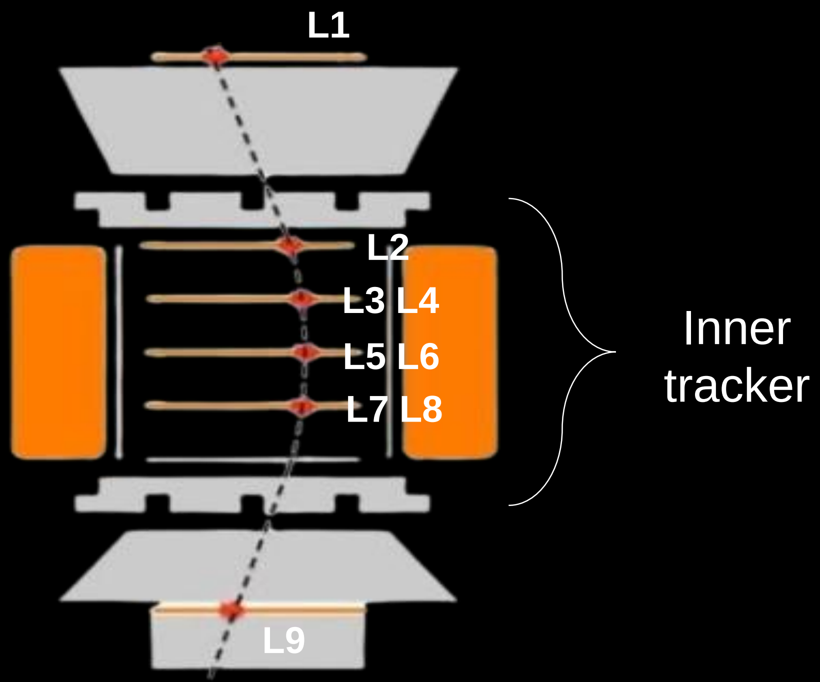
The AMS flux in the rigidity interval $[R_i, R_i + \Delta R_i]$ is computed as:

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

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

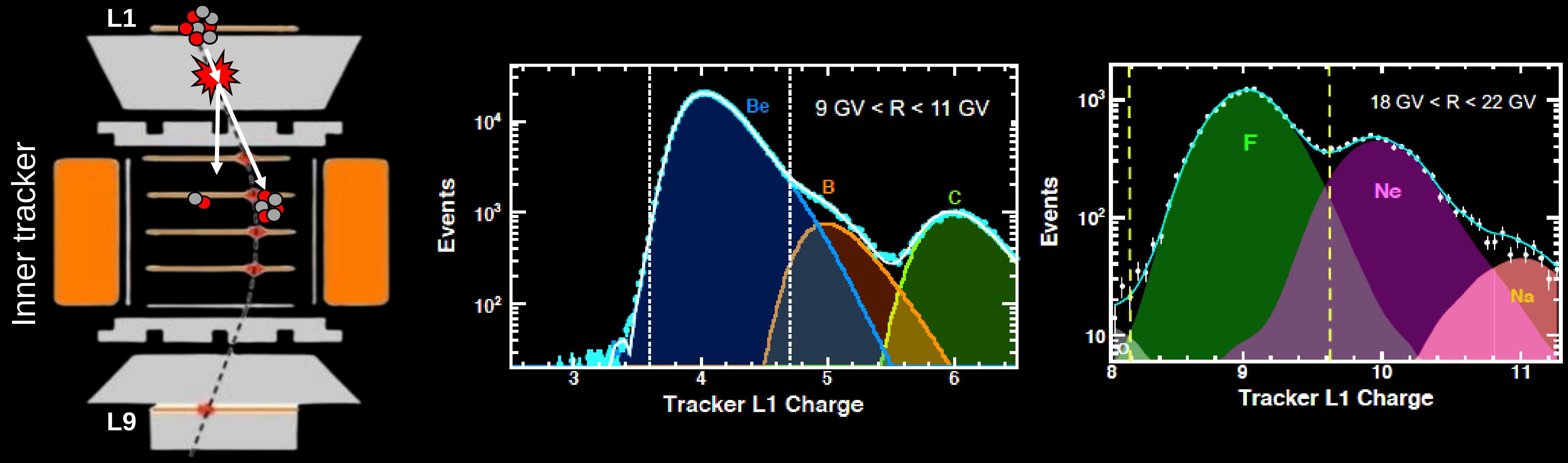
Charge Identification of Nuclei in AMS Analysis





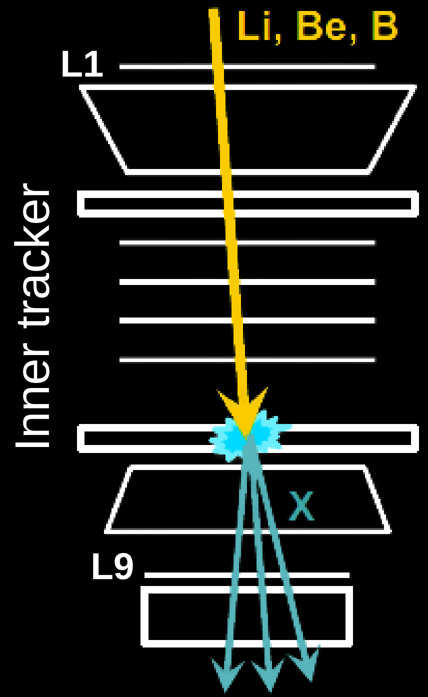
- AMS has good charge measurement capabilities. Inner tracker resolution ~0.05-0.13 c.u. for $3 \leq Z \leq 9$, Y. Jia *et al*., *Nuc. Instr. And Meth. in Phys A* **972**, 164169 (2020).
- **Background due to charge misidentification in non-interacting samples is neglible over the whole rigidity range.**

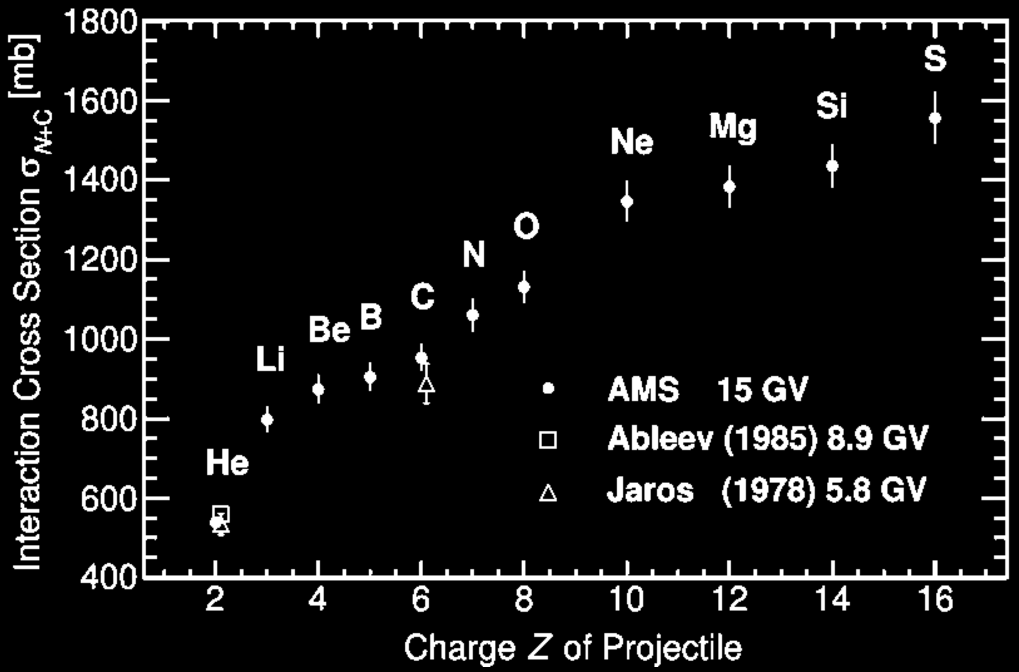
Background Subtraction in AMS Analysis of Nuclei

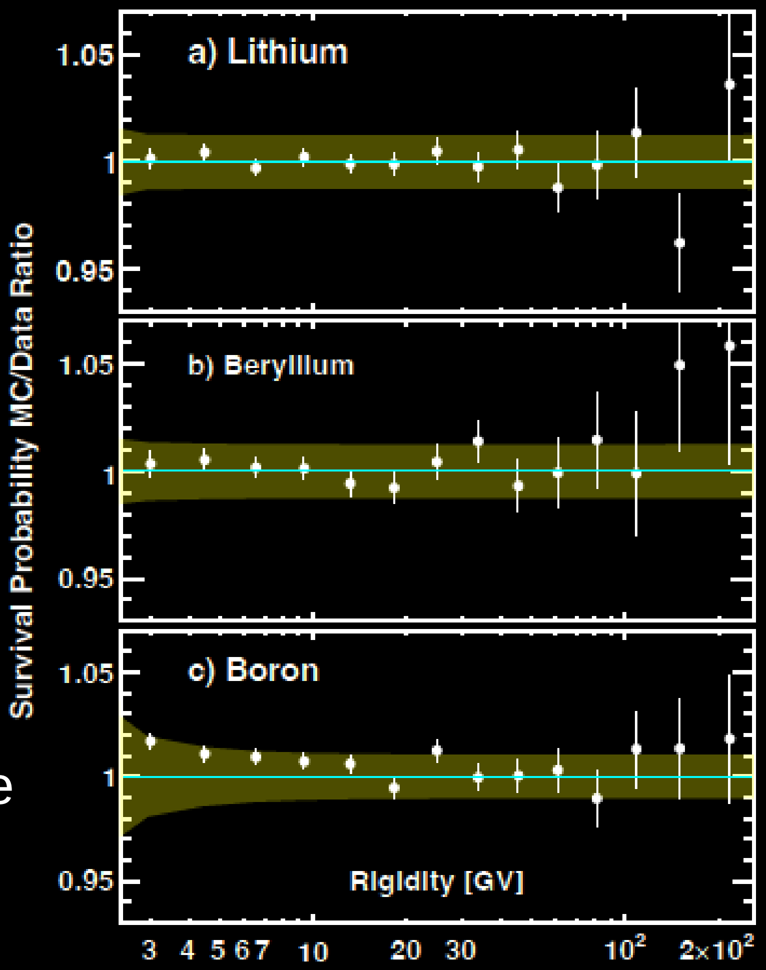


- A residual background originates from nuclear interactions in the material between the inner tracker and the layer 1. A clean sample is obtained with template fits of charge distributions.
- The background from interactions on the little material above L1 has been estimated from simulation using MC 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



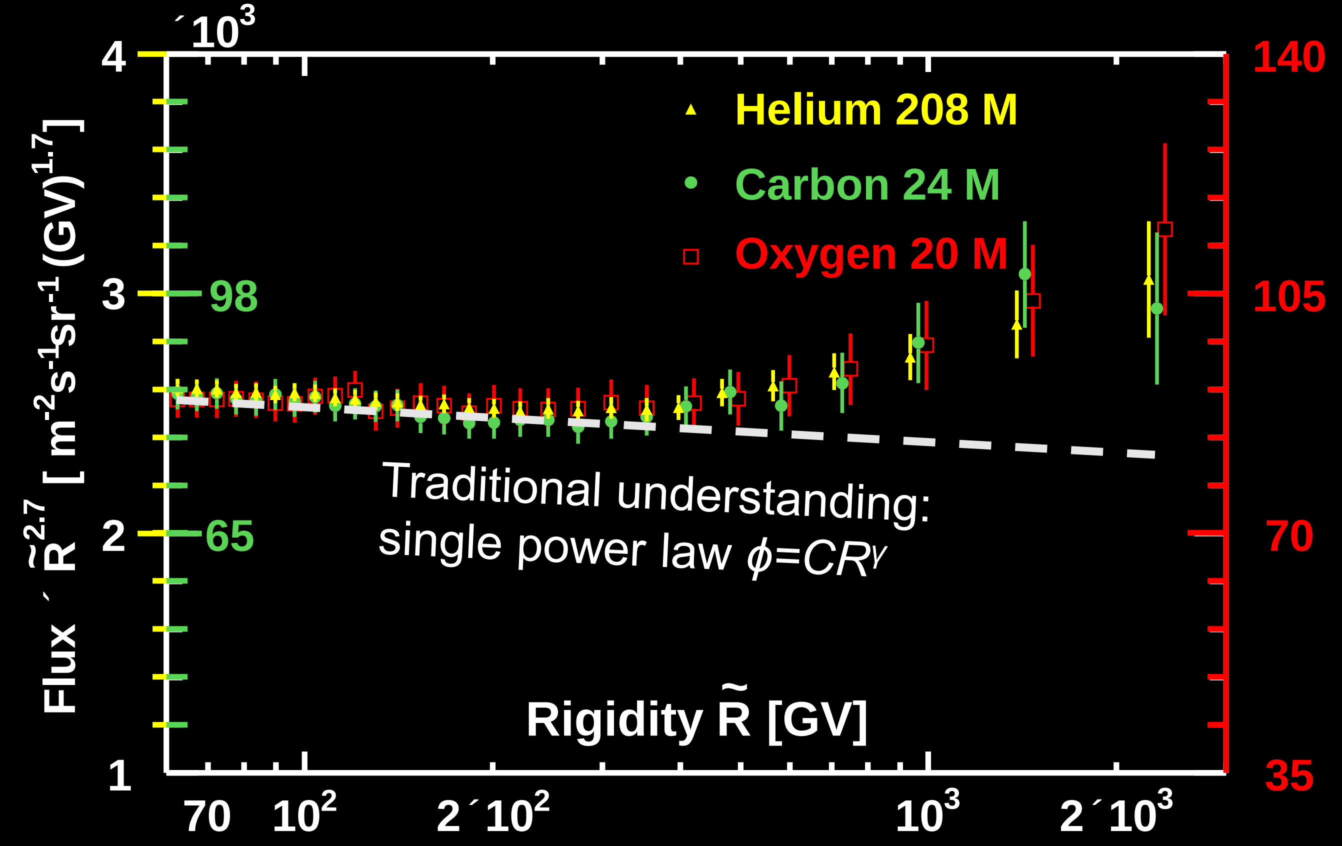




- The absolute normalisation of the fluxes is largely dependent on the **nuclear inelastic cross-section** of cosmic rays **with the material of the instrument** (carbon and aluminium).
- The inelastic cross sections of nuclei with carbon target has been measured by determining the tracker L1-L2 and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

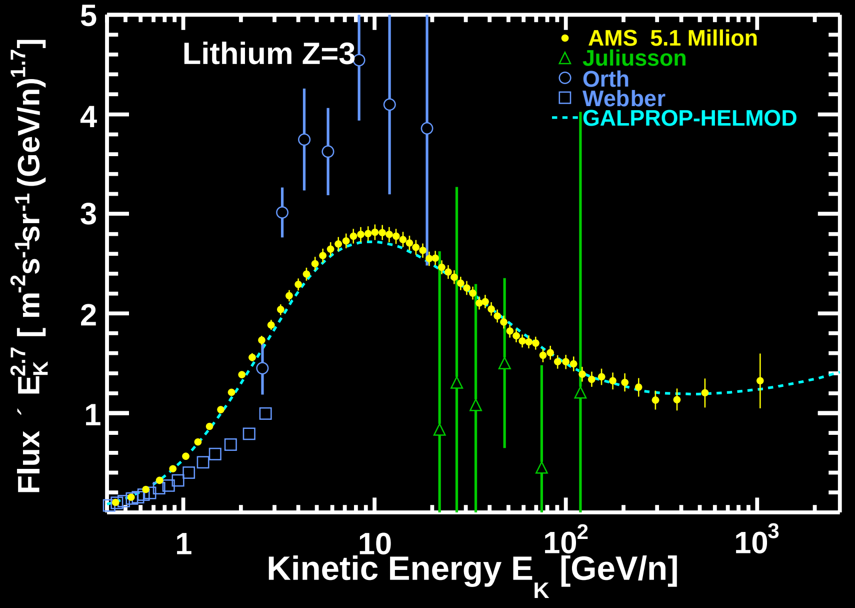
Recap: Spectral Hardening in the Fluxes of Nuclei

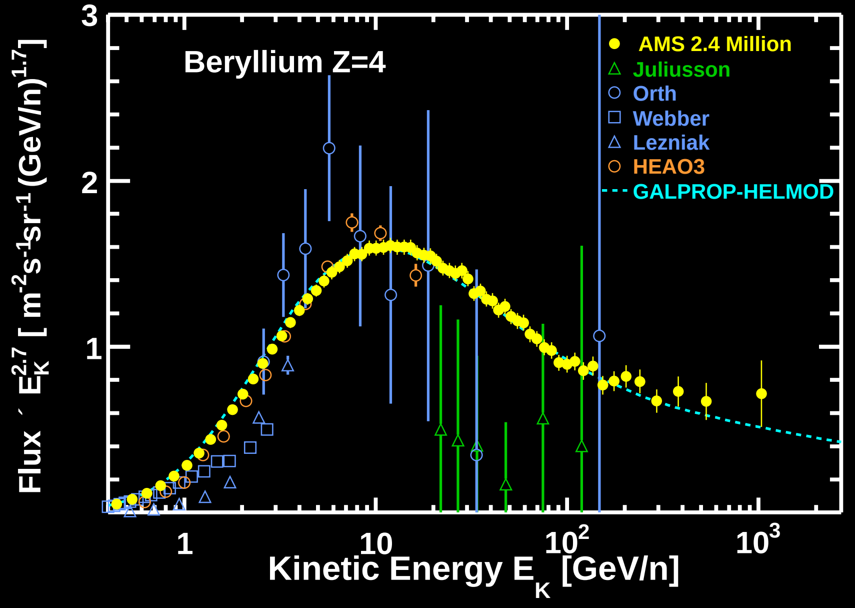
see details in Dr. Qi Yan's talk

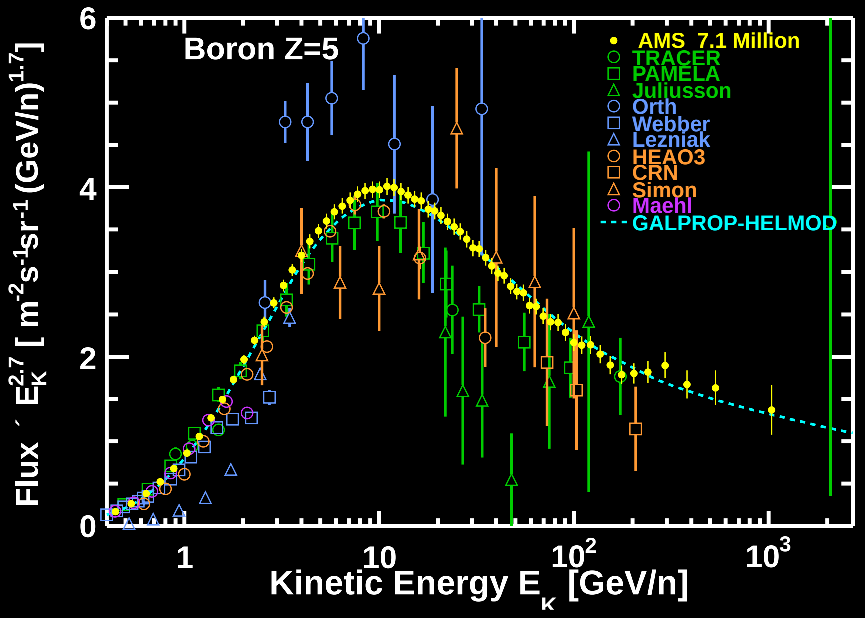


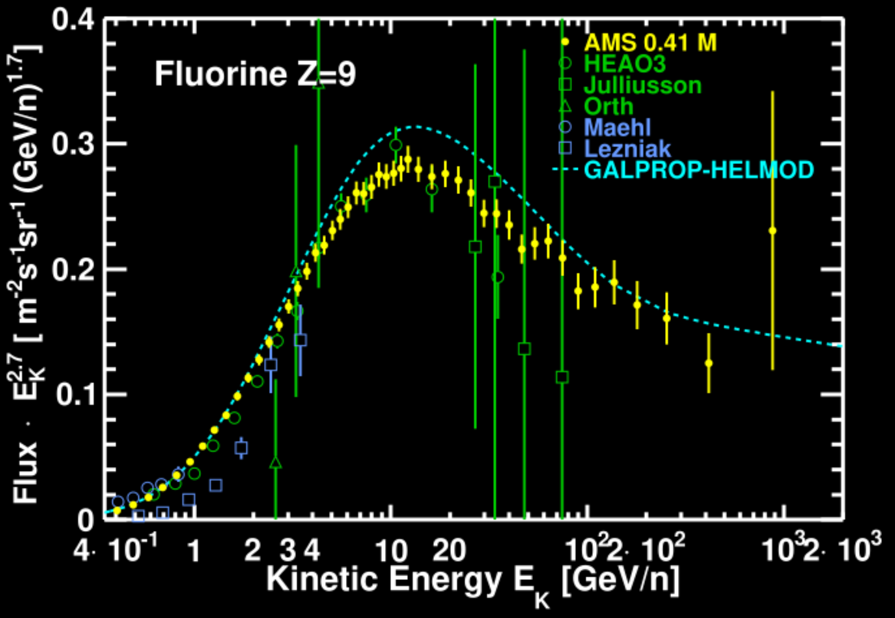
- The spectra of primary He, C and O harden in an indentical way above ~200 GV.
- **This hardening can be attributted to the injection spectrum at the source or in the diffussion coefficient.**

Fluxes of Lithium, Beryllium, Boron and Fluorine

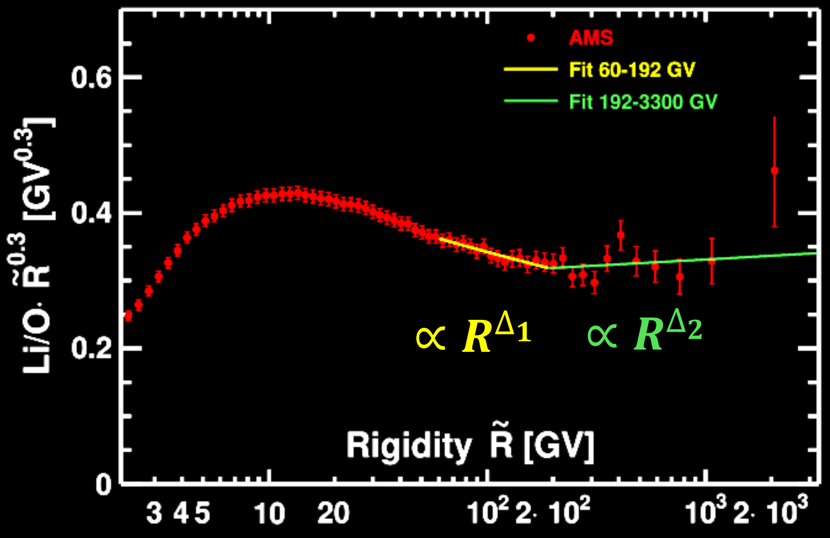


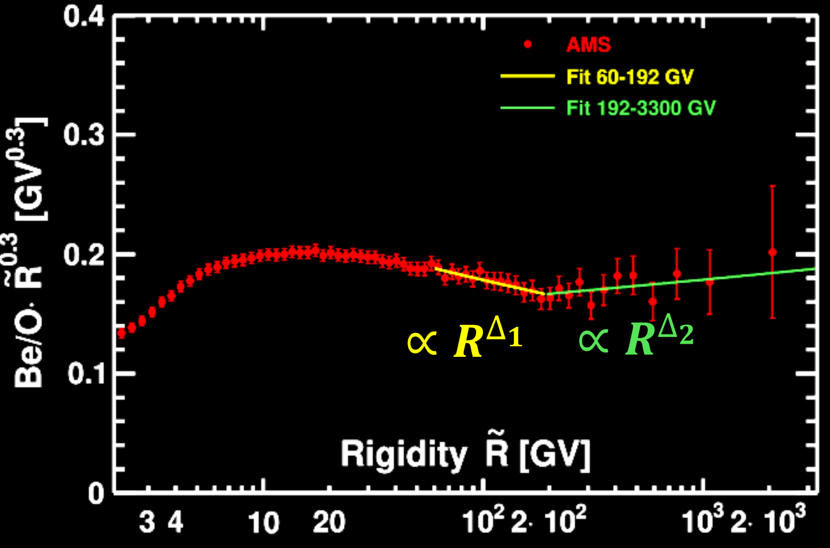


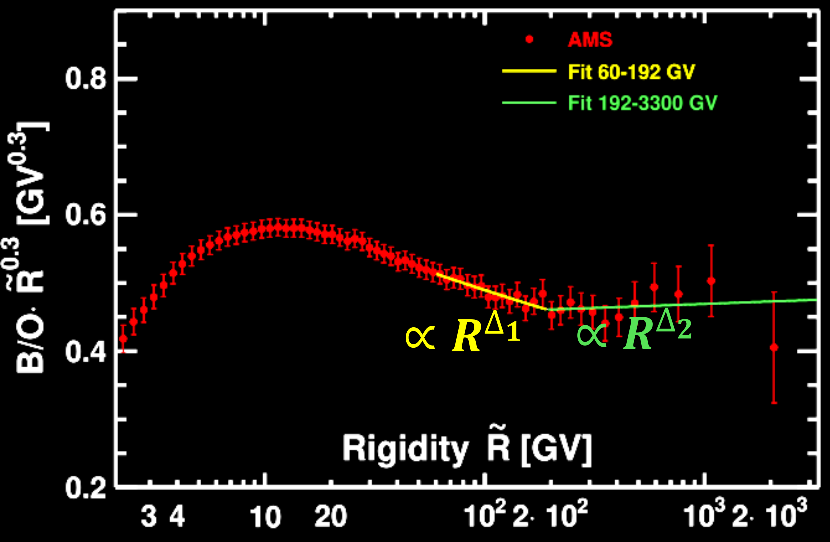


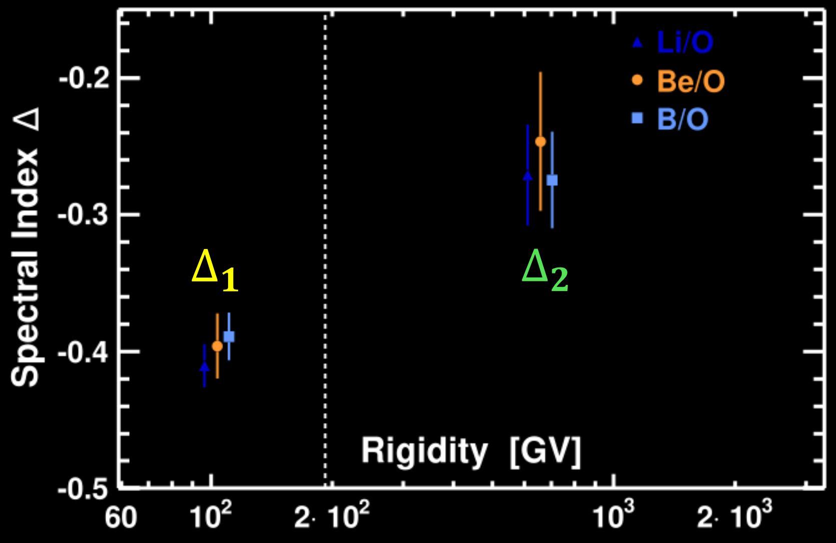


Secondary-to-Primary Flux Ratios





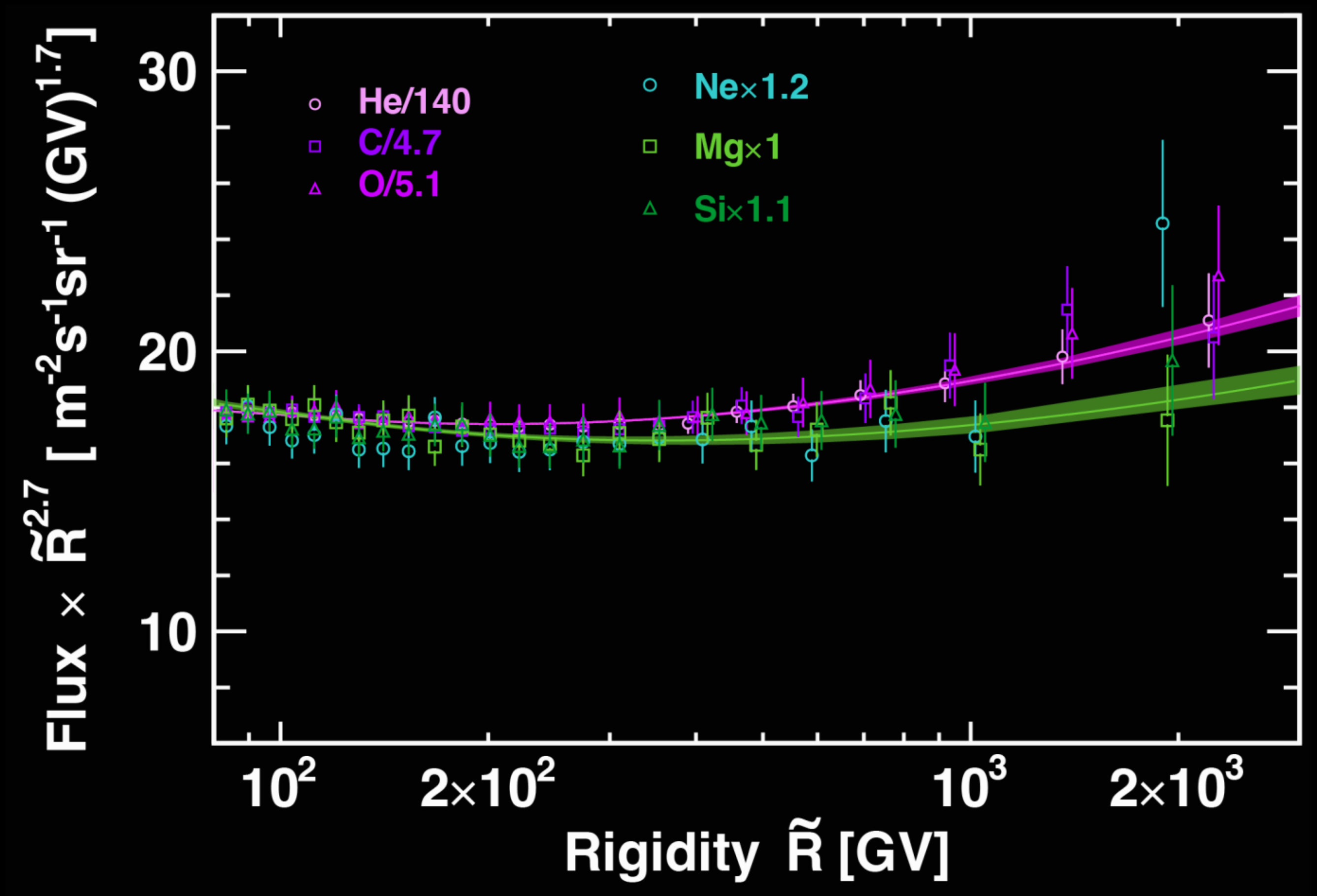




- All spectra of secondary nuclei harden above ~200 GV.
- Above 200 GV all three secondary-to-primary flux ratios harden,
  $\Delta_2 - \Delta_1 = \mathbf{0.130 \pm 0.025}$.
- This hardening is similar to that found for primary nuclei.
- **AMS data show a spectral hardening of the fluxes of nuclei due to propagation with more than 5σ significance.**

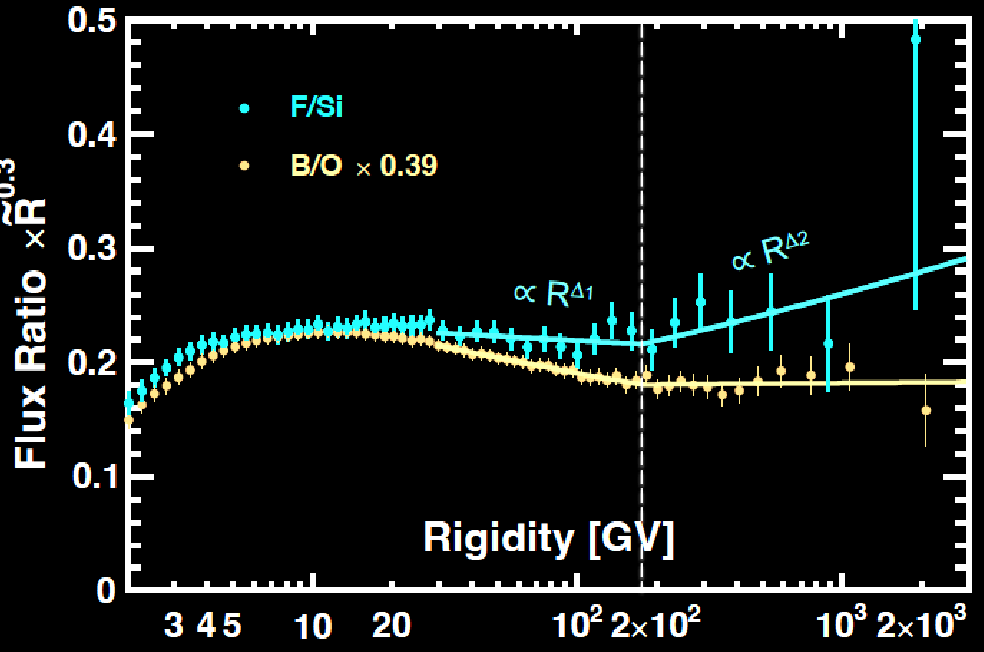
Recap: Two Classes of Primary Cosmic Rays

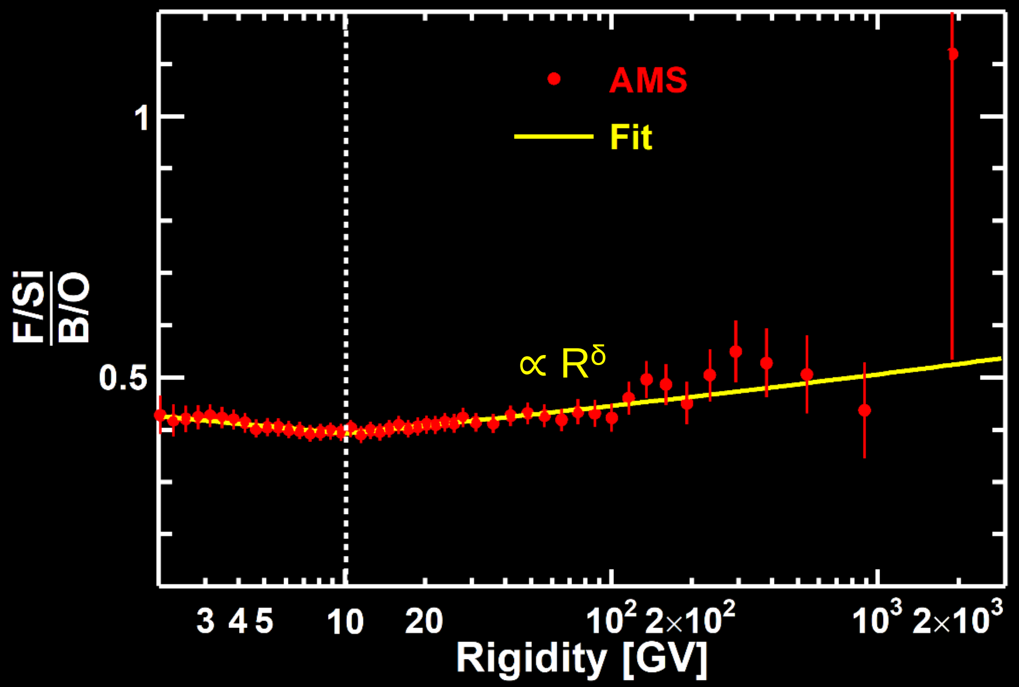
see details in Dr. Qi Yan's talk



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

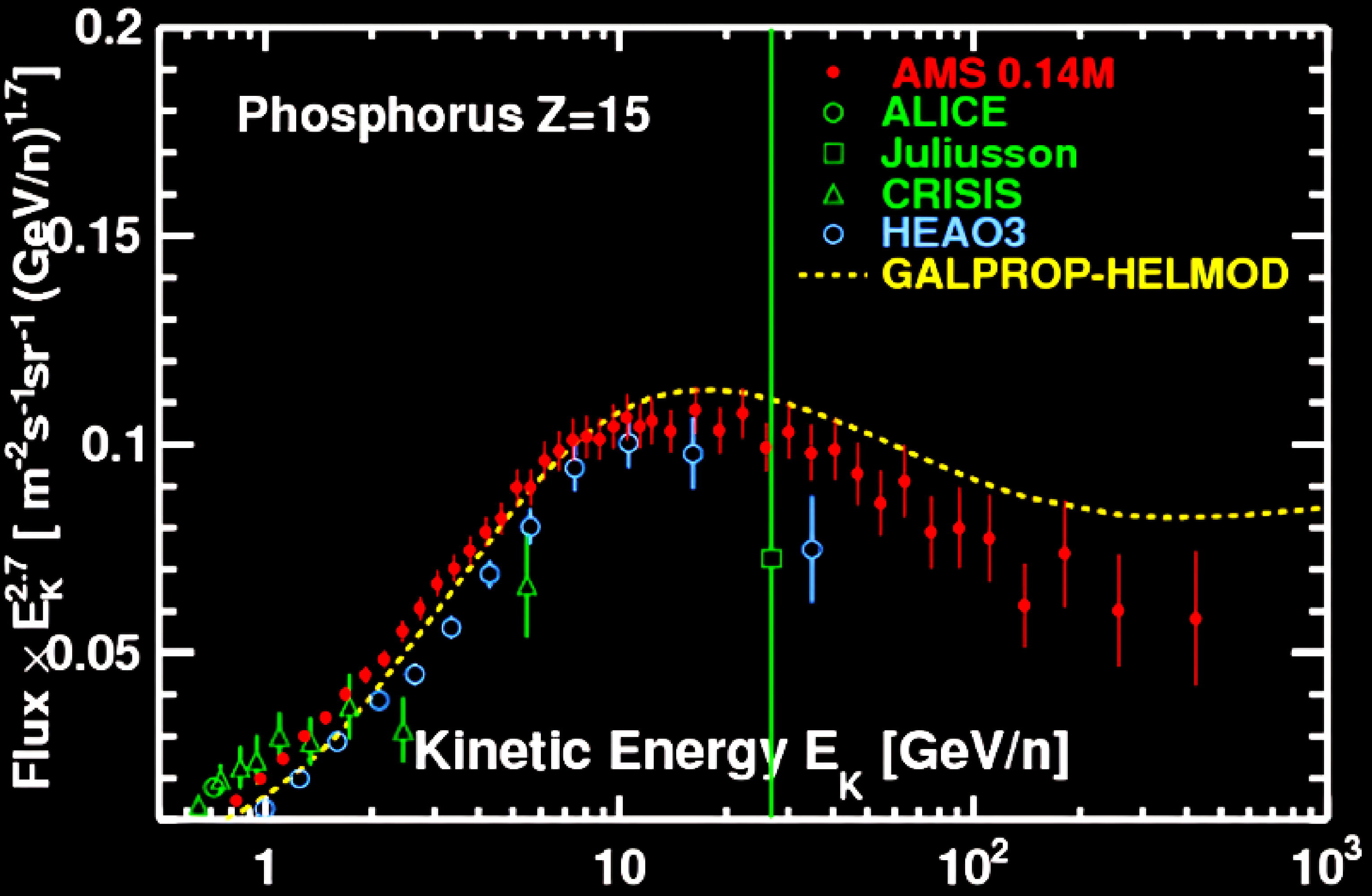
Secondary-to-Primary Flux Ratios





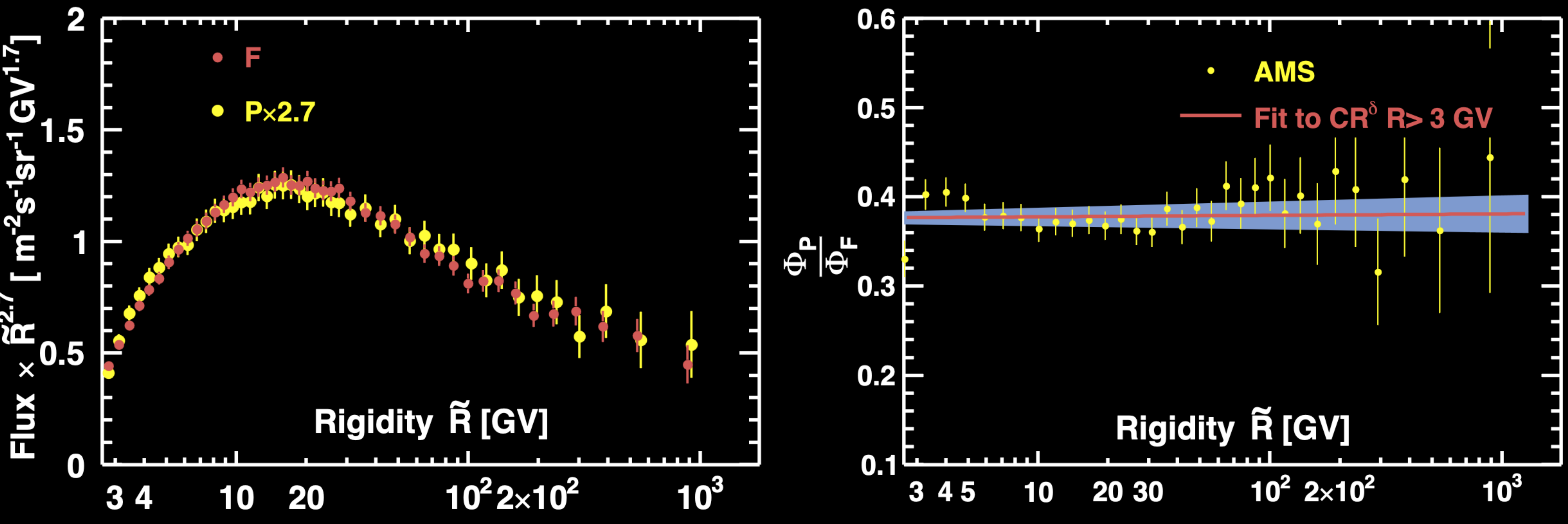
- Above 175 GV, the F/Si ratio exhibits a hardening $\Delta_2 - \Delta_1 = 0.13 \pm 0.06$ compatible with the AMS result on the hardening of B/O flux ratio.
- Above 10 GV, the (F/Si)/(B/O) ratio is not flat but can be described by a single power law with $\delta = 0.050 \pm 0.007$ (>7σ away from zero).

Phosphorus Flux



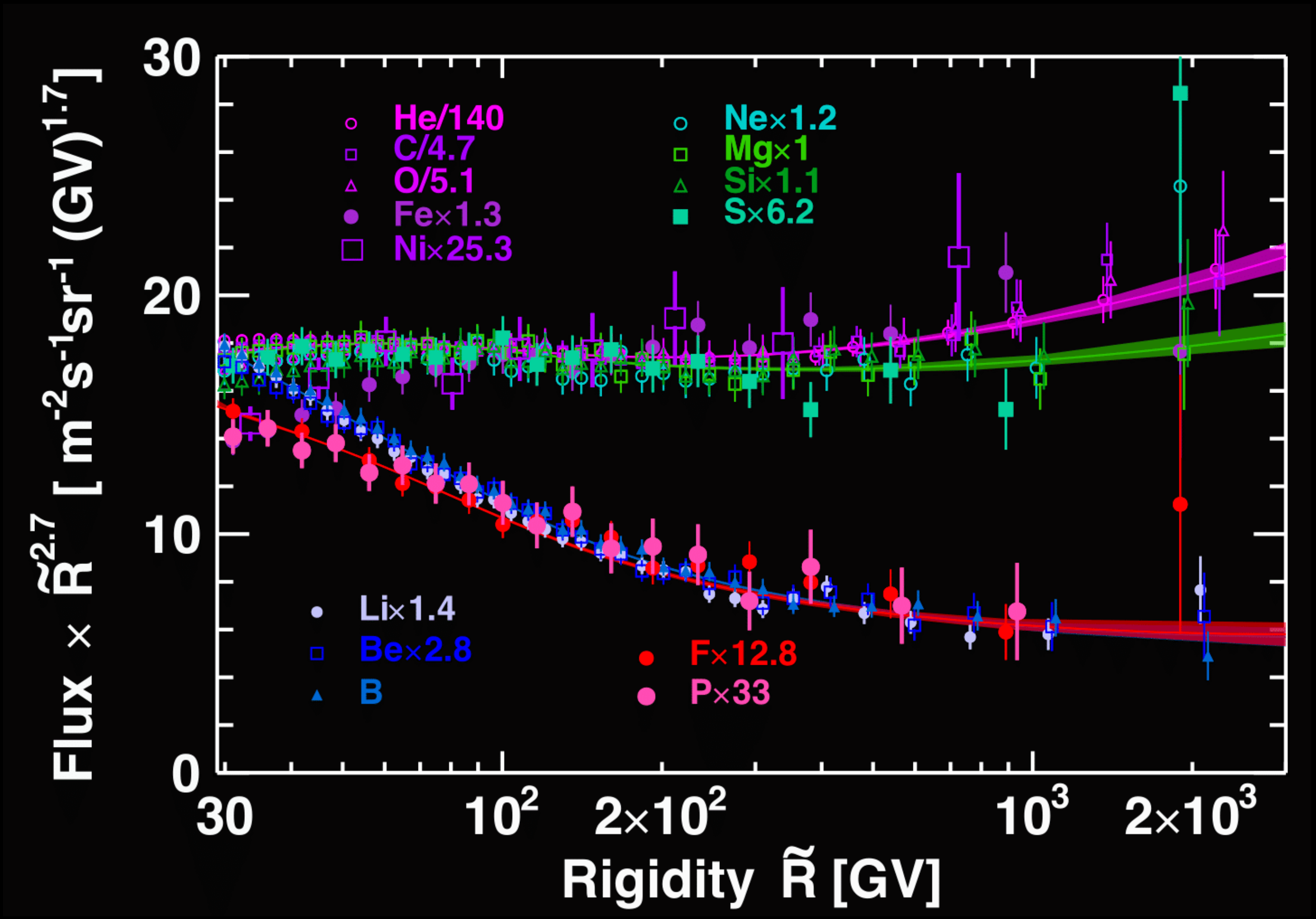
- **AMS has measured the flux of phosphorus (Z=15) from 3 GV to 2 TV with unprecedented precision** (refer to upcoming AMS publication).

Phosphorus Flux



- The phosphorus-to-fluorine flux ratio reveals that both secondary fluxes have the **same rigidity dependence**. Fit to power-law with $\delta = 0.002 \pm 0.009$.

Primary and Secondary Fluxes Measured by AMS



- AMS has measured a third group of cosmic nuclei (see poster 203).

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** measurements of the fluxes of secondary nuclei **lithium, beryllium, boron, fluorine and phosphorus** 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 propagation effect.**

- **The fluxes of fluorine and phosphorus show similar rigidity dependence.**

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