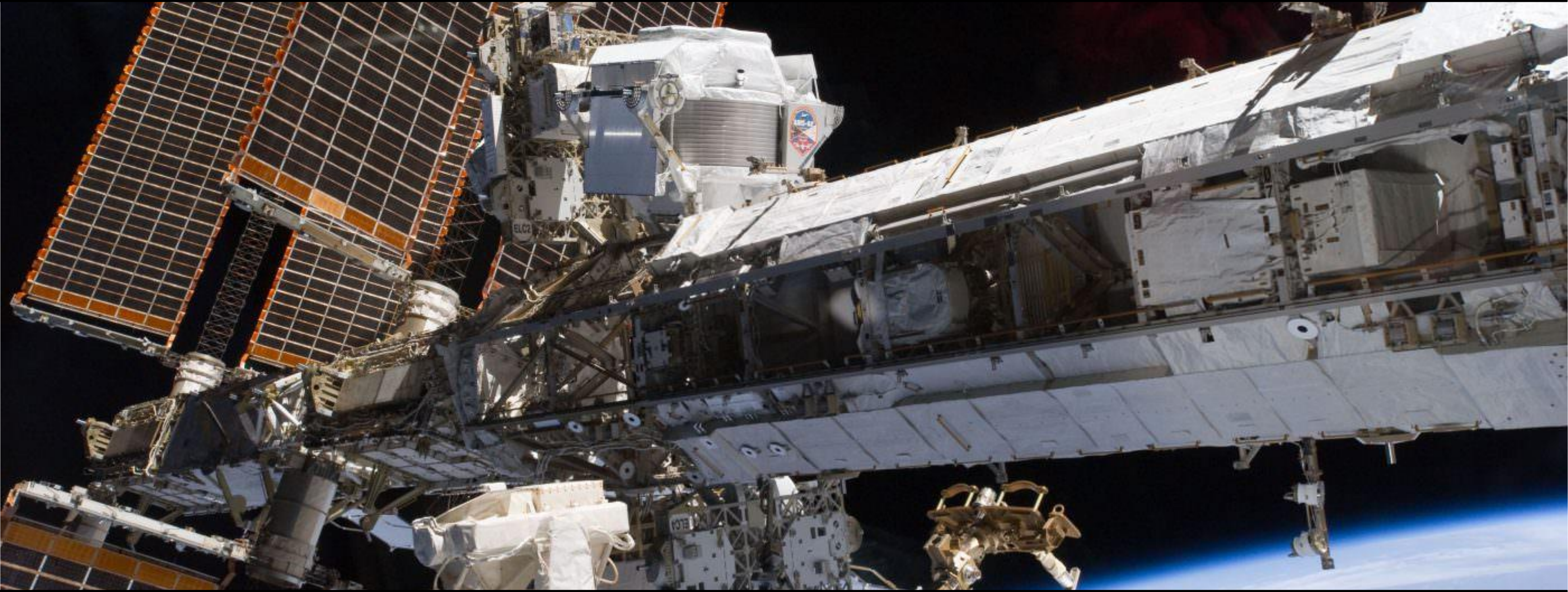
Precision Measurement of Primary Cosmic Rays with the Alpha Magnetic Spectrometer on the International Space Station

Huy Phan, MIT
On behalf of the AMS Collaboration



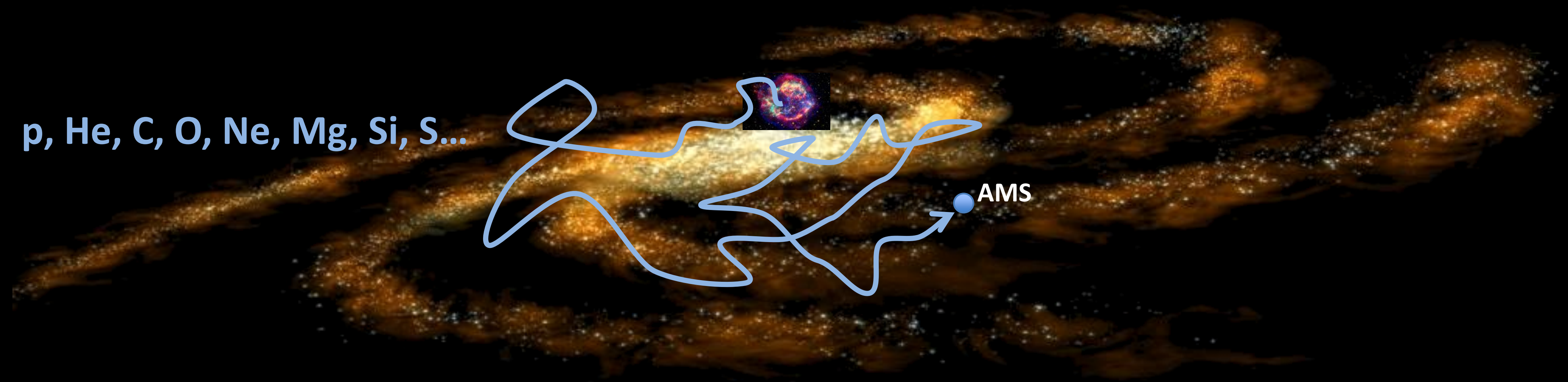
TeVPA2019 Sydney, December 5th 2019

Primary Cosmic Rays

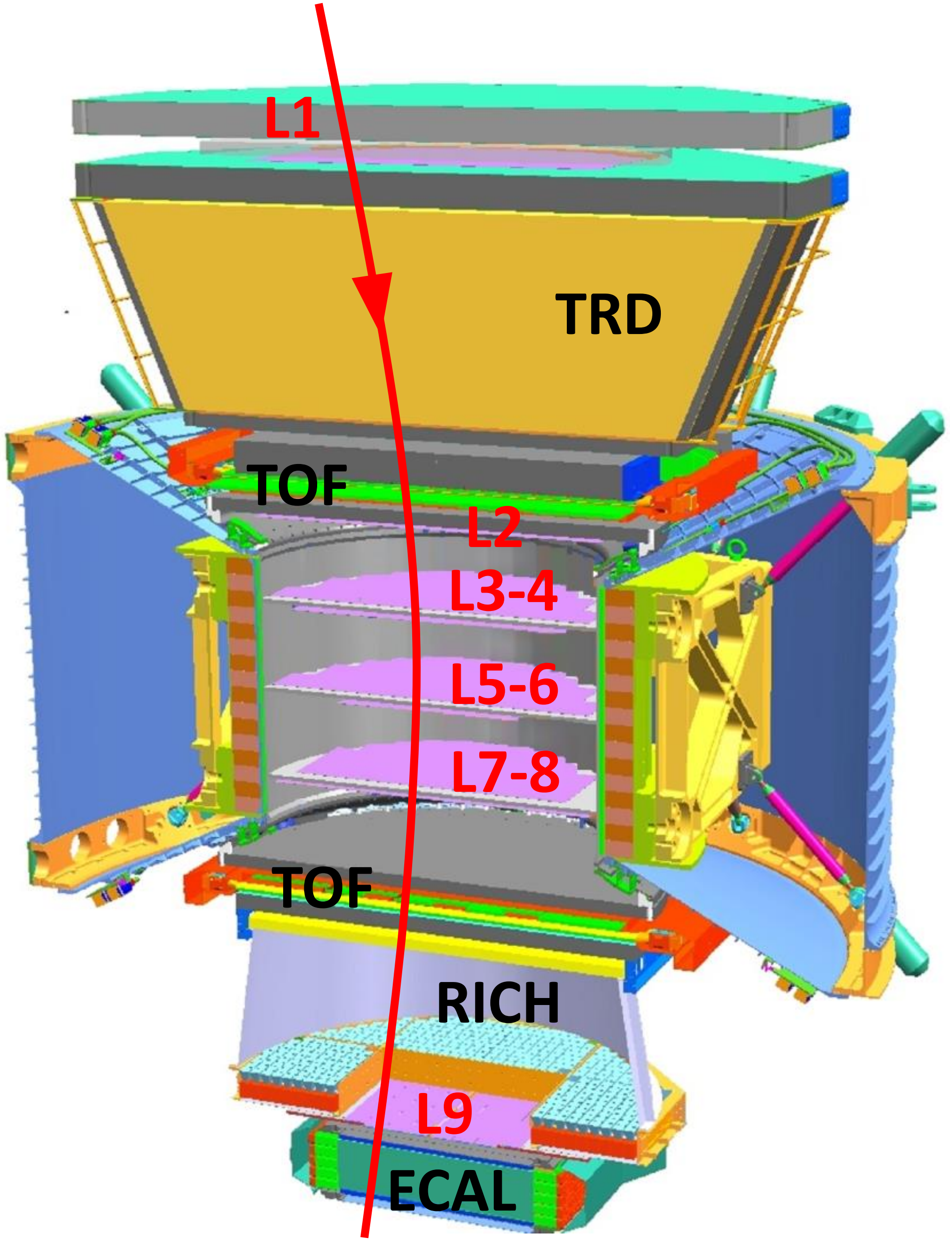
Traditionally, cosmic rays are classified into primary and secondary.

Primary cosmic rays are produced and accelerated at the source (such as Supernovae Remnants)

They propagate across the galactic magnetic field to arrive at AMS, carrying information about their sources and history of travel



Nuclei Measurement from Proton to Sulphur by AMS



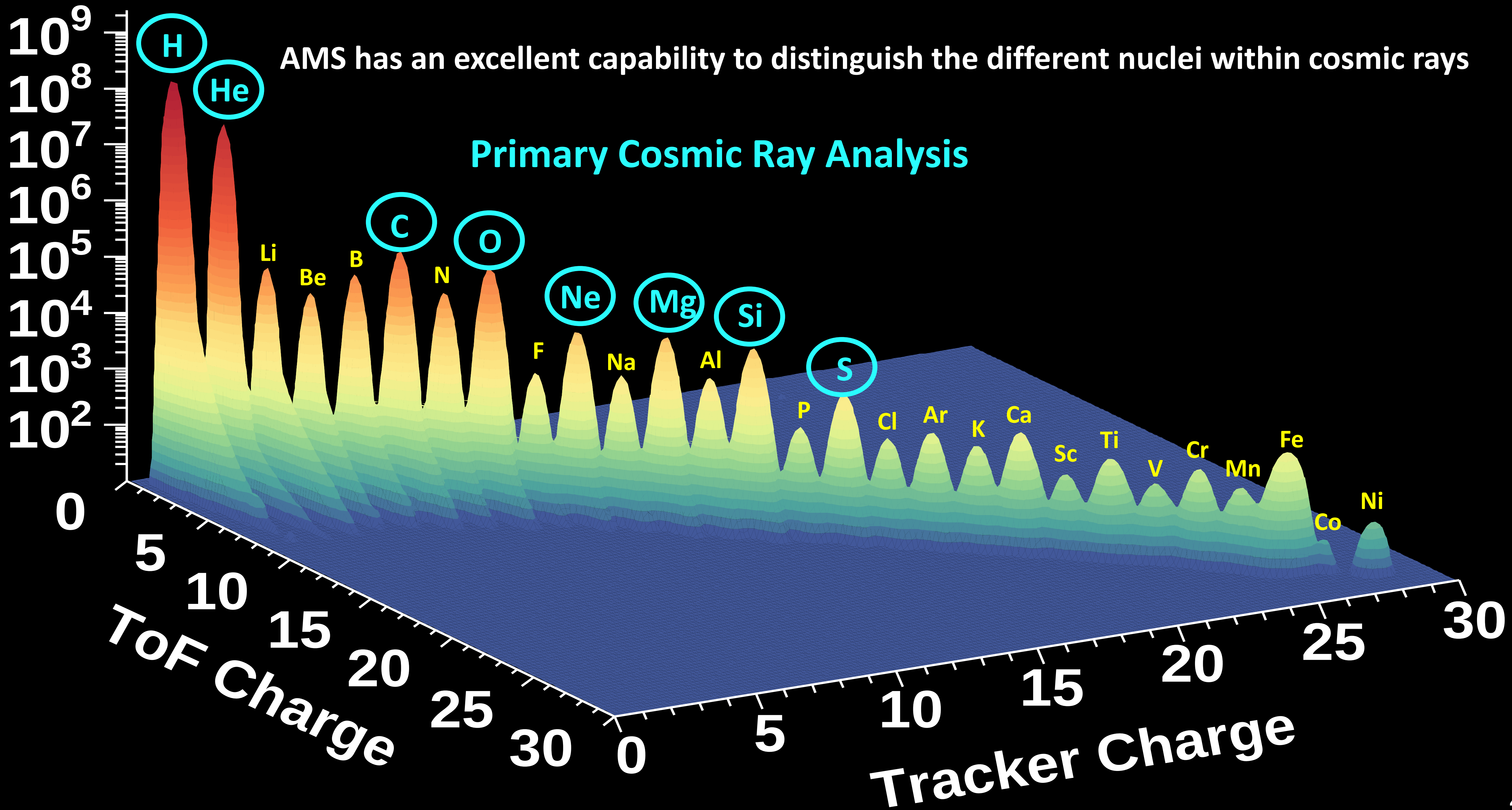
9 Layers of Silicon Trackers (L1, Inner Tracker L2-L8, L9) and **Magnet** measure **Rigidity** (Momentum/Charge)

Charge	Coordinate Resolution	Maximum Detectable Rigidity
Z = 1	~10 μm	2 TV
2 ≤ Z ≤ 8	5 - 7 μm	3.2 - 3.7 TV
9 ≤ Z ≤ 16	6 - 8 μm	3 - 3.5 TV

L1, **Upper TOF**, **Inner Tracker**, **Lower TOF**, **L9** provide consistent **Charge** measurements along the particles' trajectory.

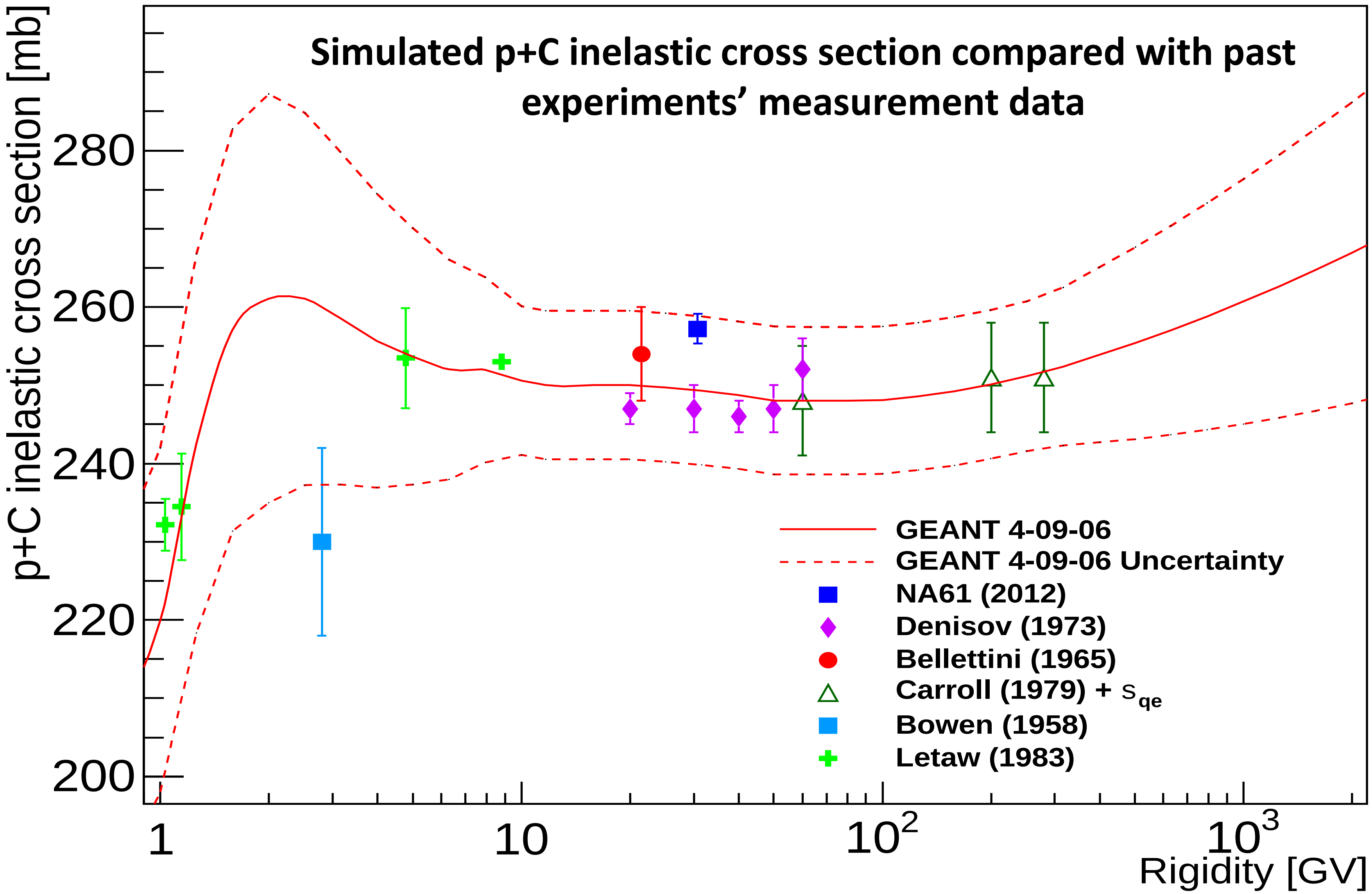
Charge	Inner Tracker Charge Resolution (charge unit)
1 ≤ Z ≤ 8	0.05 – 0.12
9 ≤ Z ≤ 16	0.13 – 0.19

Cosmic Ray Composition



Proton + Carbon Inelastic Cross Section

AMS detector components are made up of mostly Carbon and Aluminum.



Nuclei Inelastic Cross Section Measurement with Light Cosmic Rays (2 ≤ Z ≤ 8)

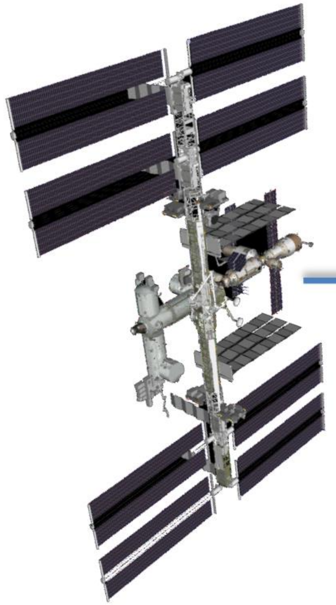
The inelastic cross-section of X+C and X+Al interaction have only been measured for **He** and **C** at low energy below few GeVs.

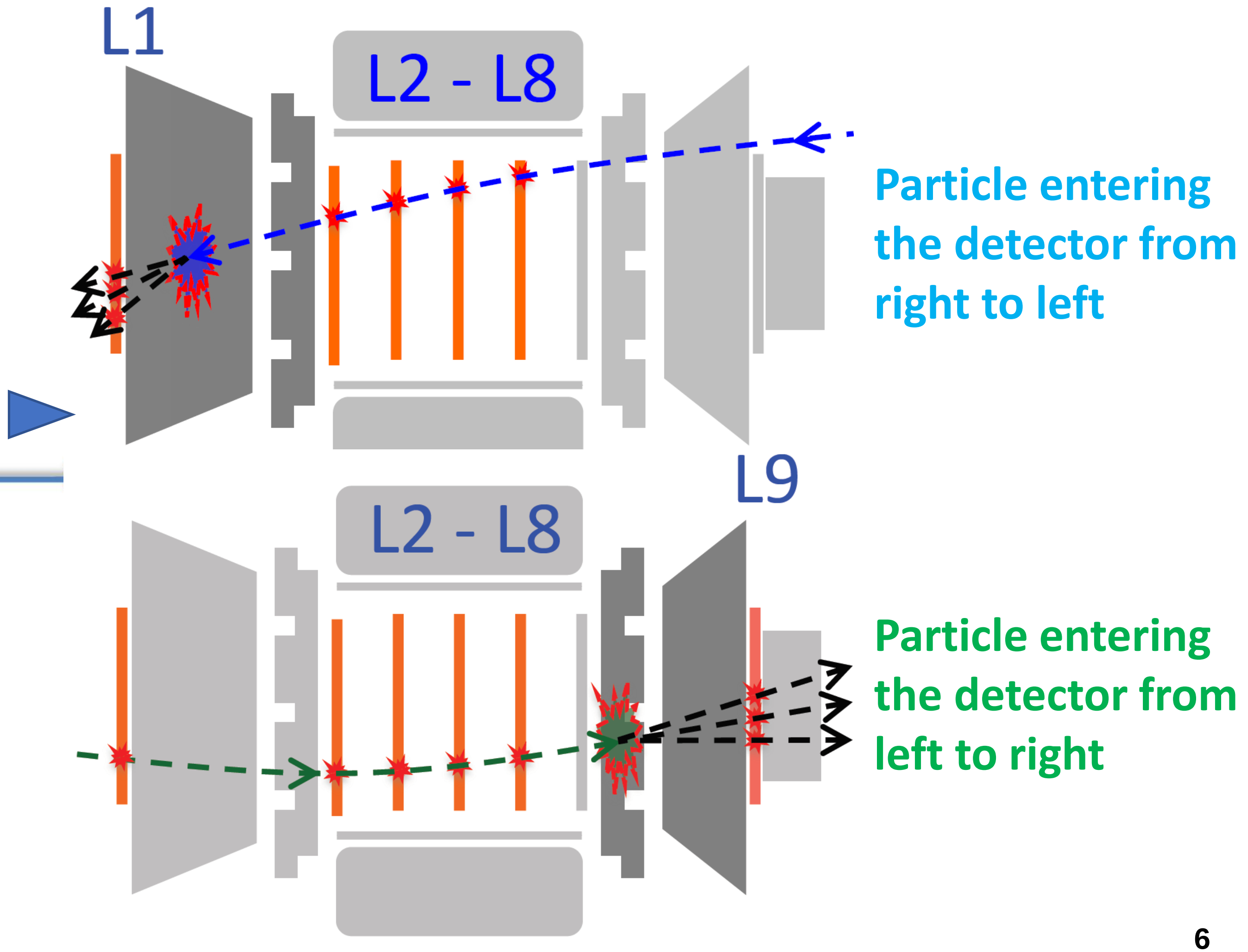
AMS has performed such measurements for nuclei from **He** to **S** at high energy.

1/ **Nuclei inelastic cross section** can be determined by measuring the **survival probability**, which is the proportion of survival nuclei events without inelastic interaction

2/ **Survival probability** is measured when AMS is flying **horizontally**, such that particles can enter the detector both from right to left and left to right.

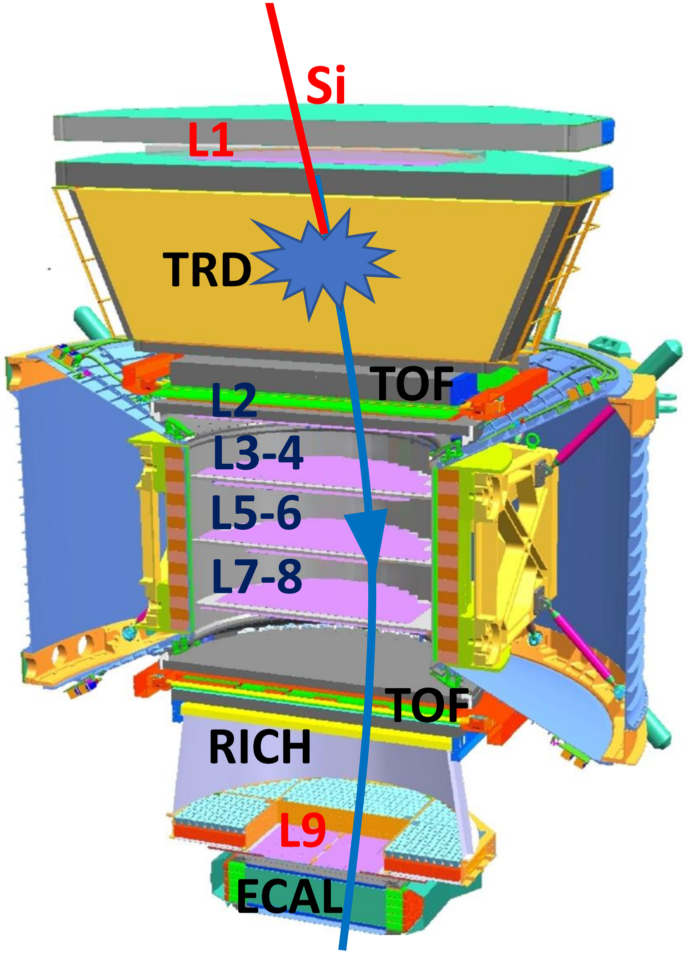
3/ Both the **survival probabilities** in the upper part (L1-L2) and the lower part (L8-L9) of AMS are used to measure the **nuclei inelastic cross-section**.





Nuclei Inelastic Cross Section Measurement with Heavy Cosmic Rays (9 ≤ Z ≤ 16)

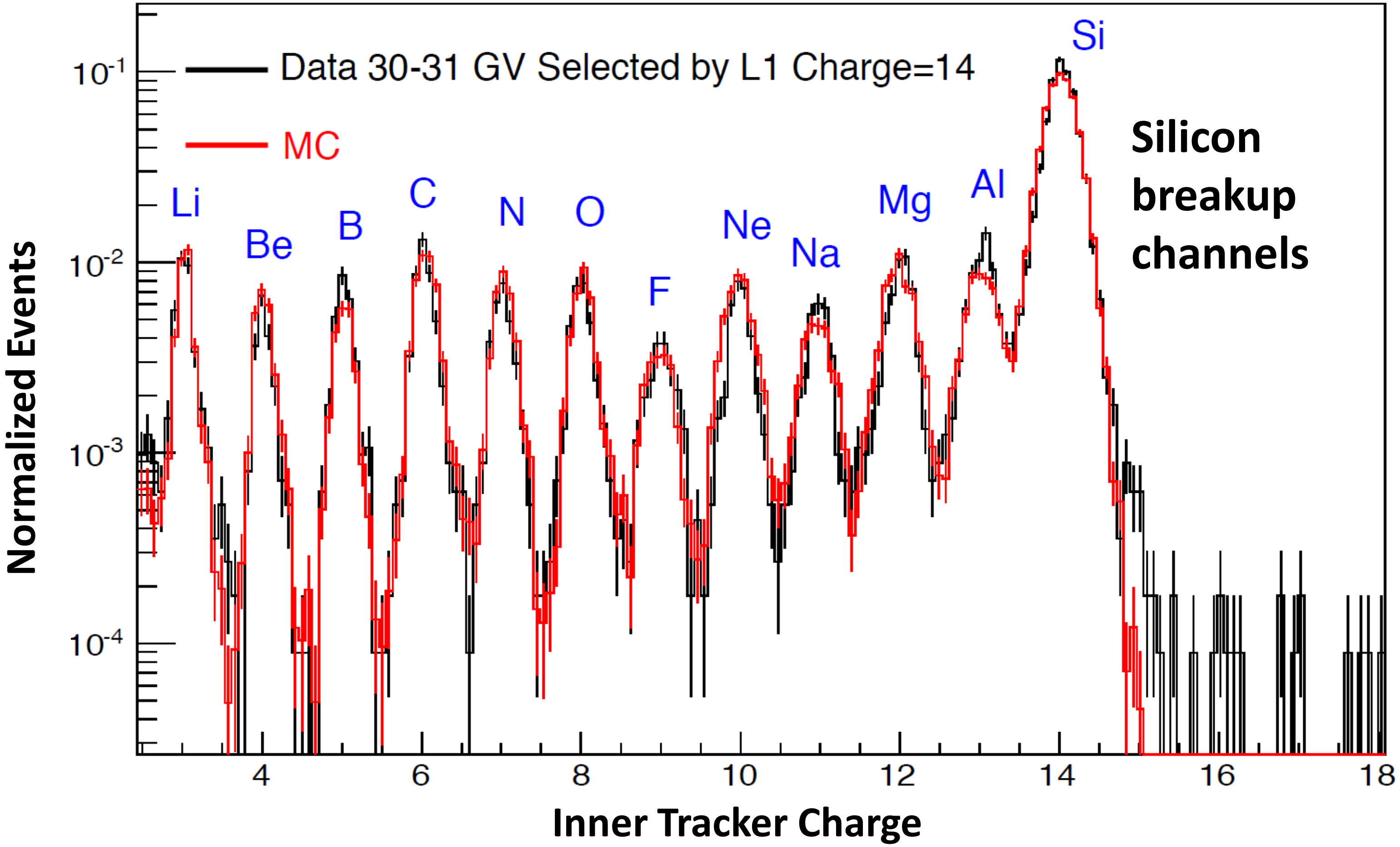
Statistics in “horizontal” runs are **not sufficient** (0.13% of total exposure time) for heavy nuclei survival probability evaluation.



For evaluation of nuclei survival probability between **L1-L2**:

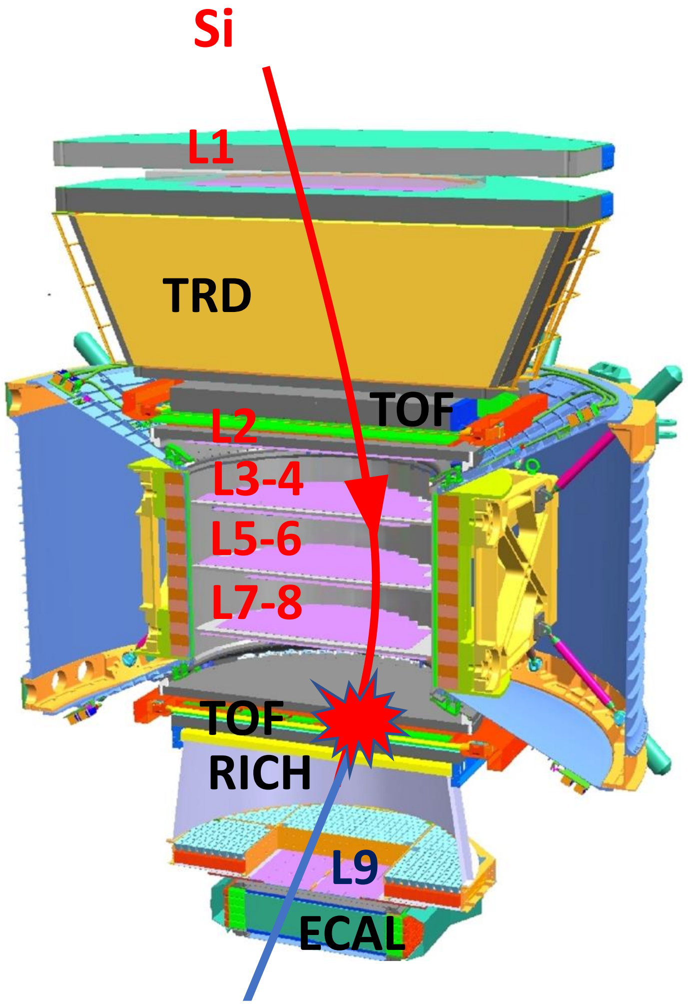
Select primary nuclei by L1 charge.

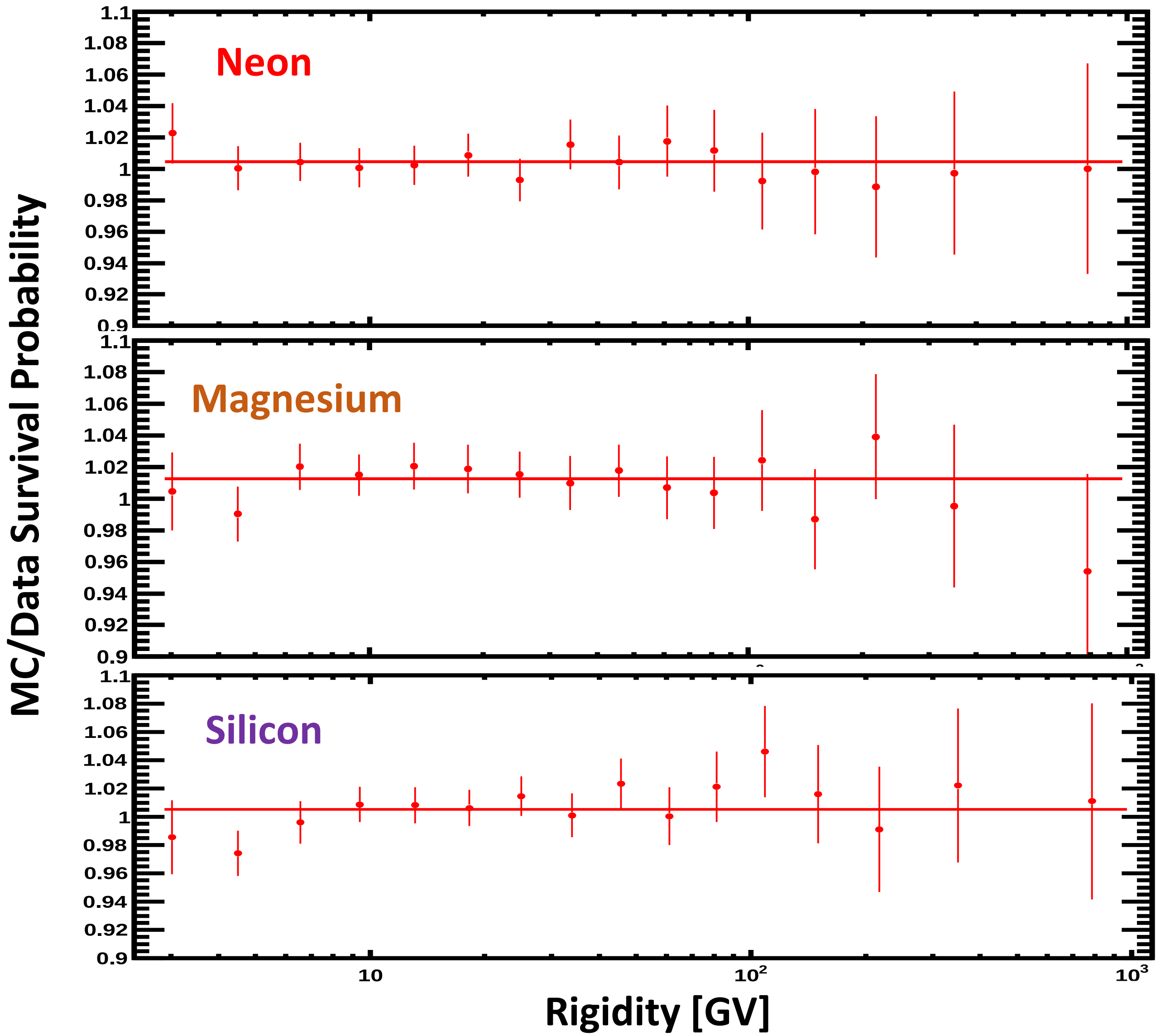
Obtain survival probability by comparing charge measured with inner tracker.



Nuclei Inelastic Cross Section Measurement with Heavy Cosmic Rays (9 ≤ Z ≤ 16)

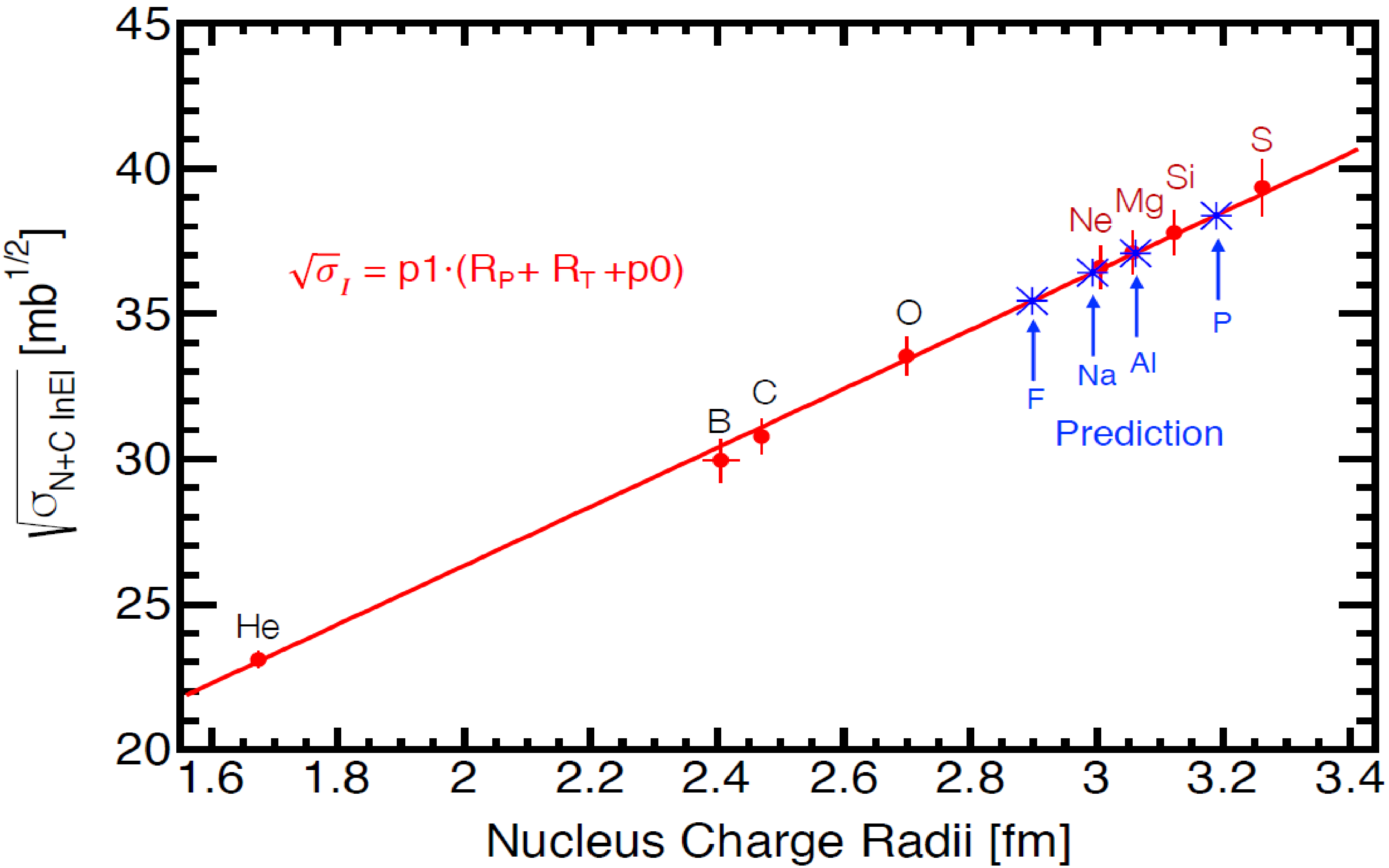
For evaluation of nuclei survival probability between **L8-L9**, we compare the **L8** tracker charge with charge measured by **L9**





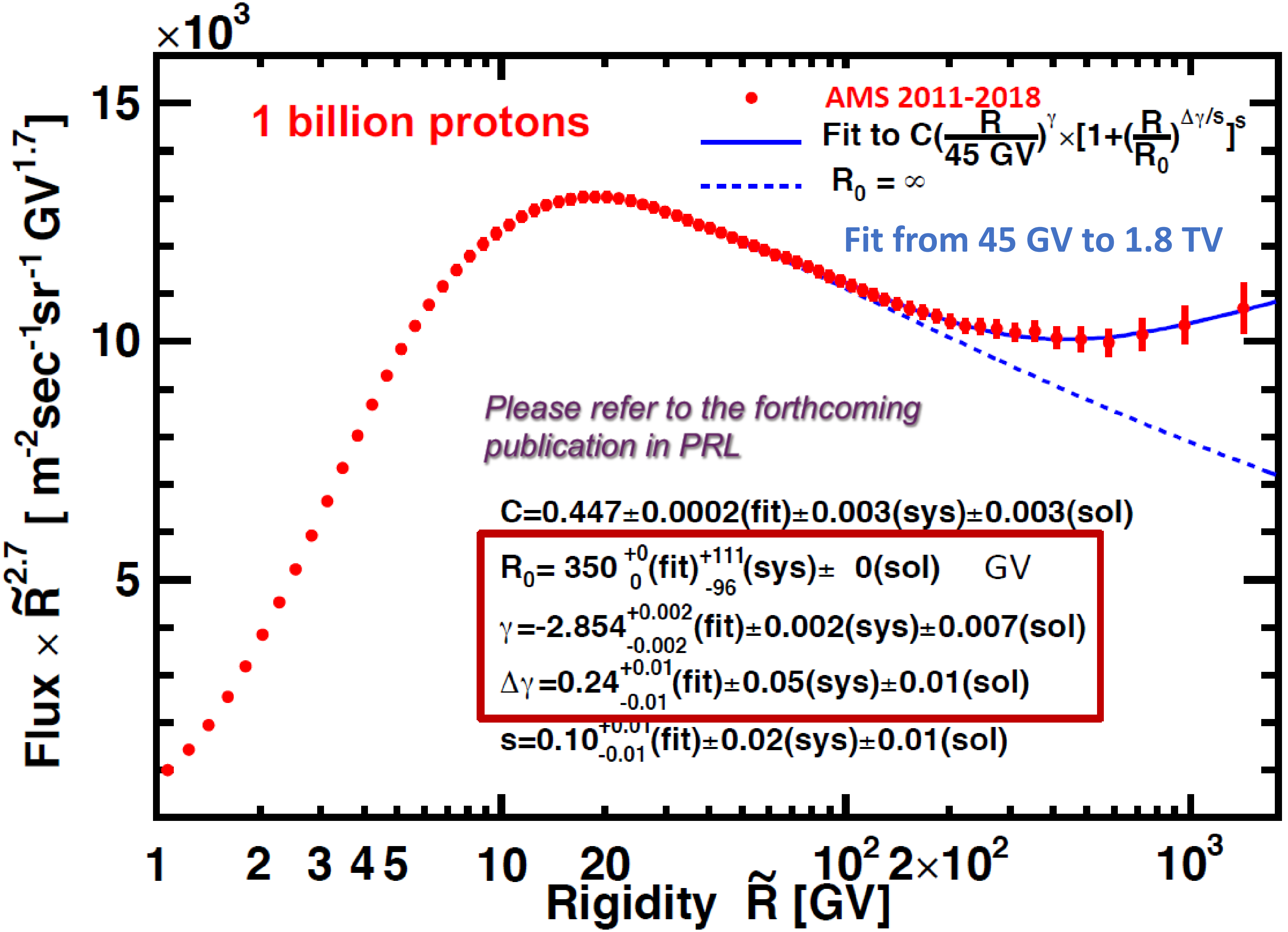
AMS Nucleus + C Inelastic Cross Section (5-100 GV)

Interestingly, $\sqrt{\sigma_{N+C\ InEl}}$ shows a linear dependence on charge radius



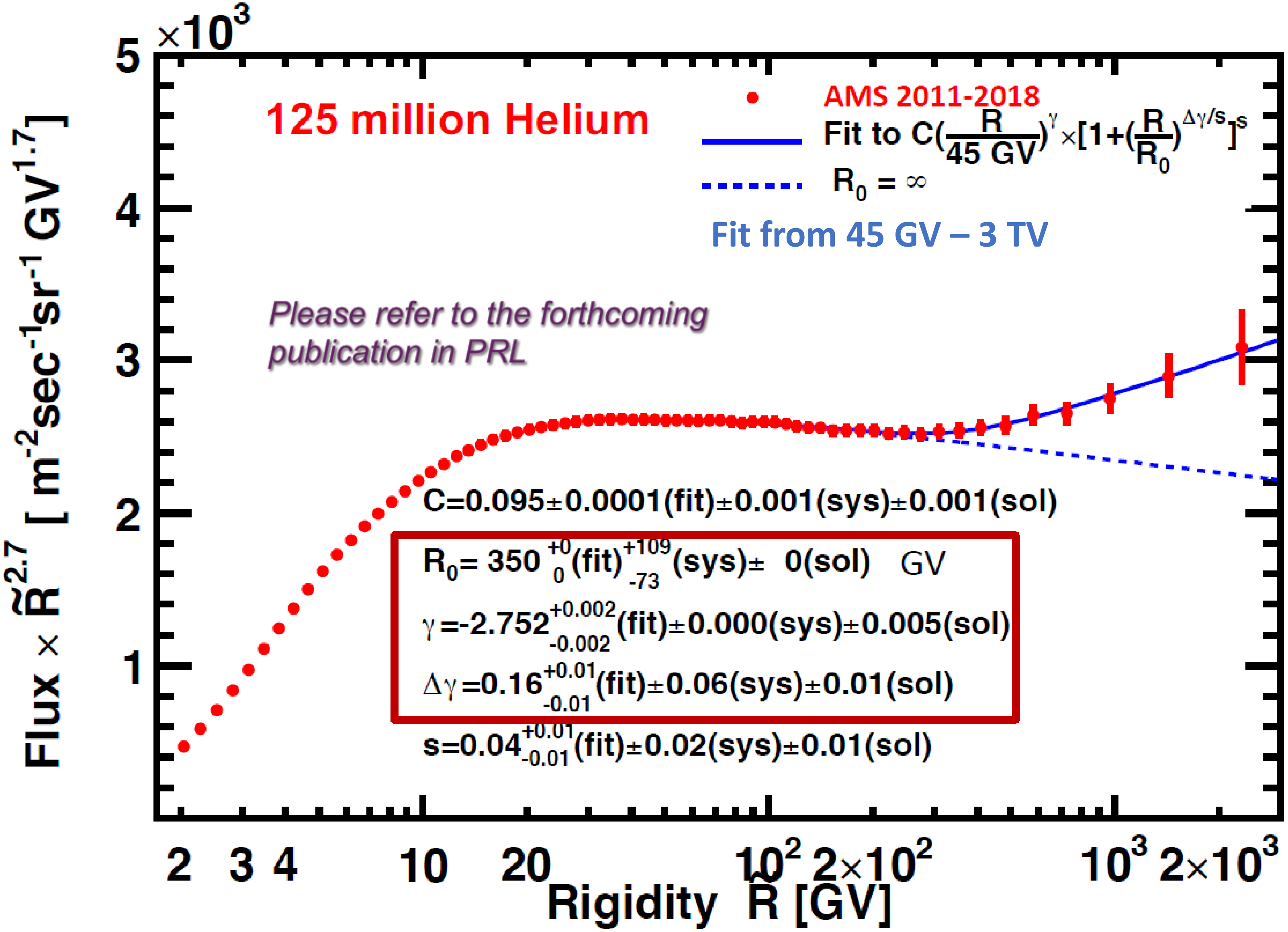
I. Angeli and K. P. Marinova. "Table of experimental nuclear ground state charge radii: An update." *Atomic Data and Nuclear Data Tables* 99.1 (2013): 69-95

Latest AMS Measurement of Proton Spectrum



The new AMS result (2011-2018) is consistent with earlier AMS PRL result (2011-2013) "M. Aguilar et al., Phys. Rev. Lett., **114**, 171103 (2015)" but with improved accuracy.

Latest AMS measurement of Helium Spectrum



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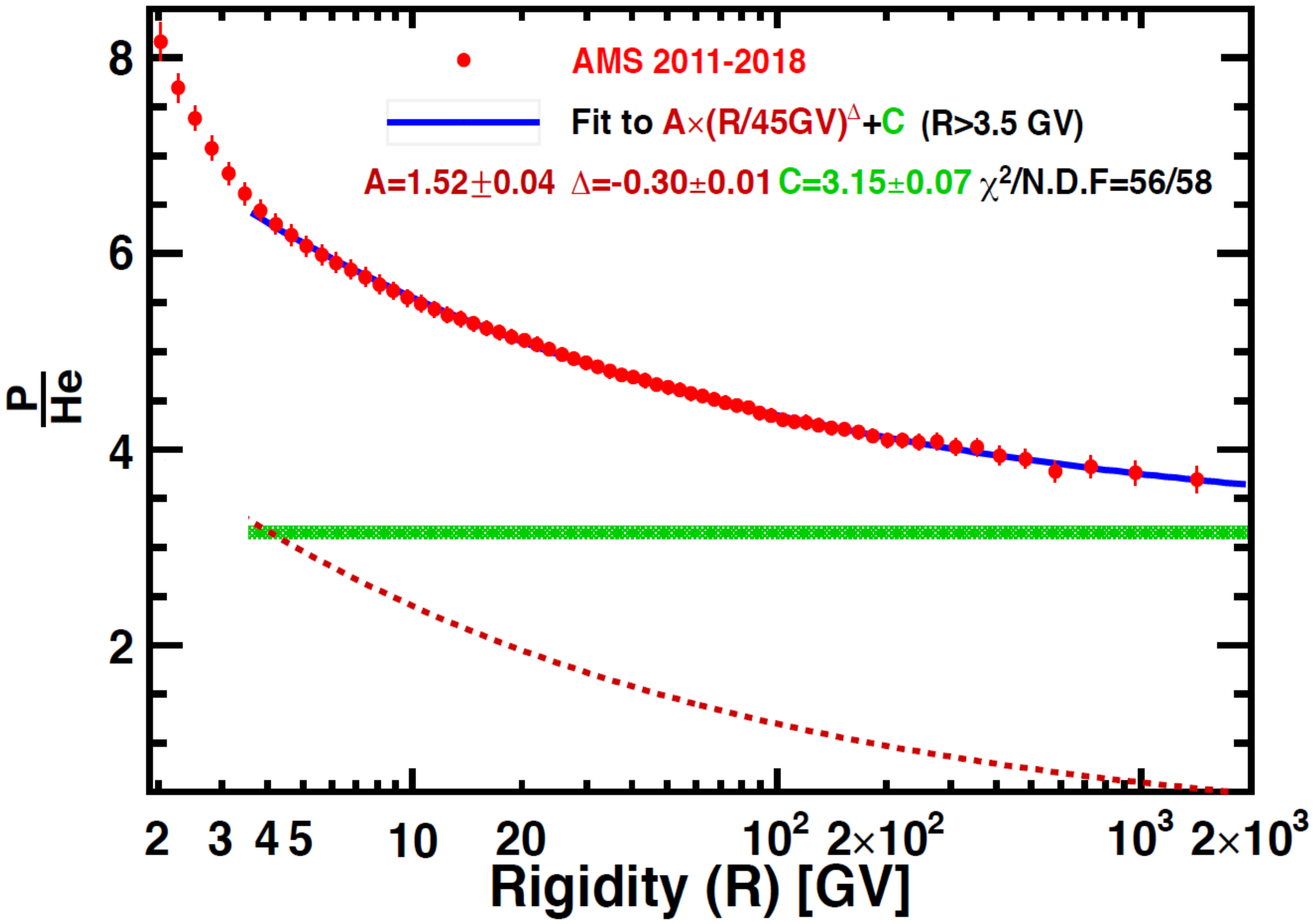
p/He Flux Ratio

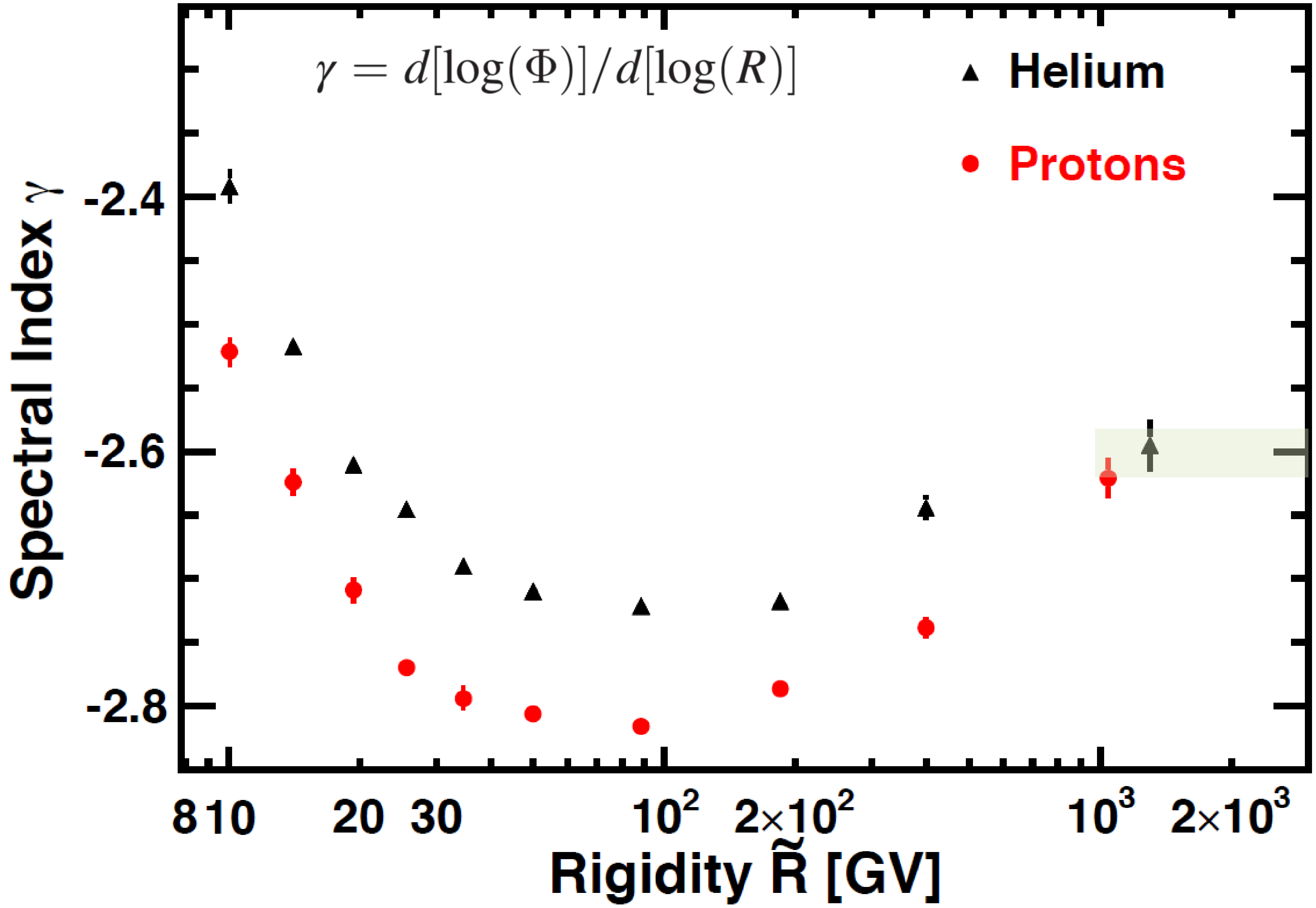


1/ p/He ratio can be parametrized as the sum of a **power law** and a **constant value** above 3.5 GV

2/ The ratio seems to **approach a constant value** at high energy

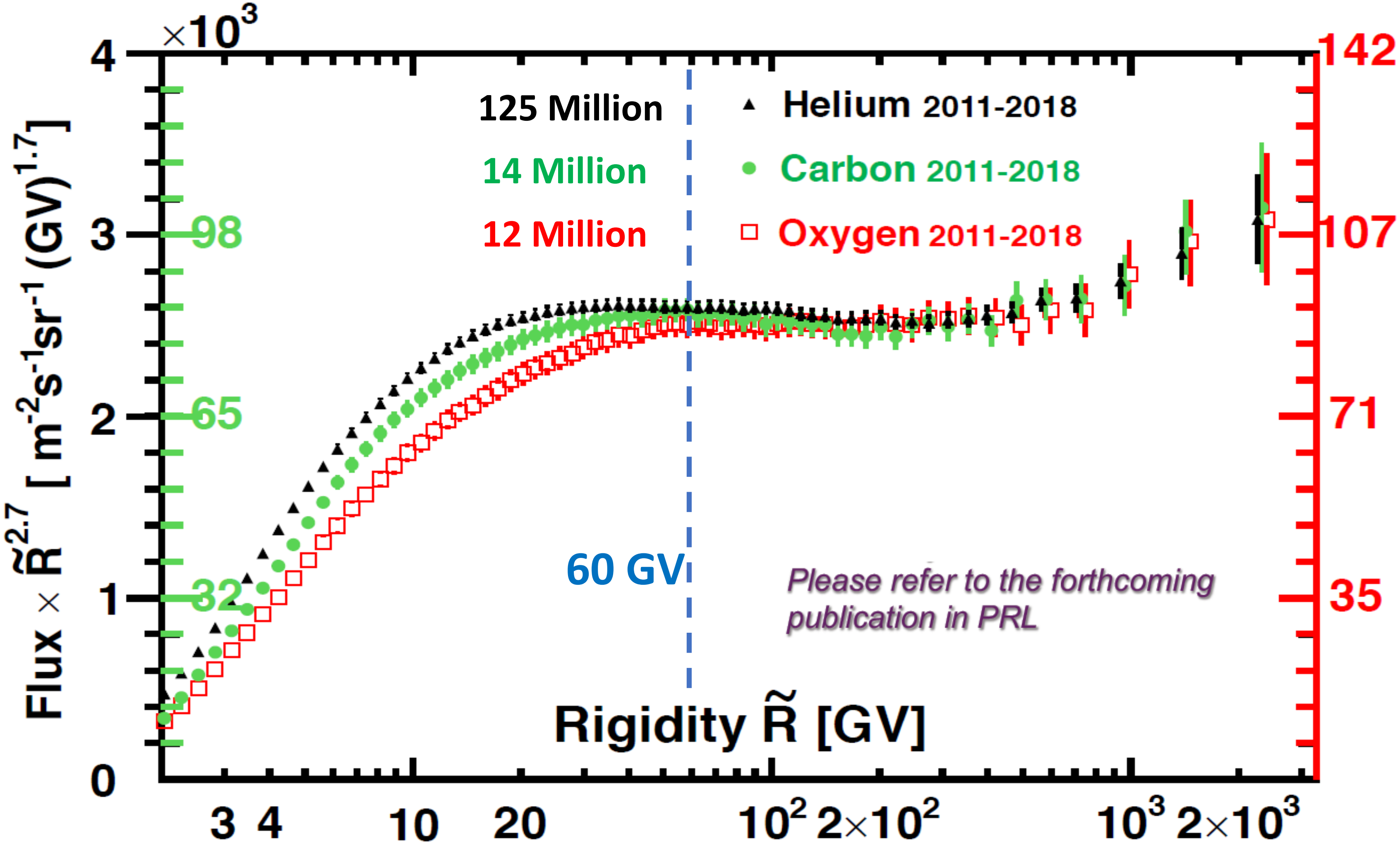
Proton and Helium Spectral Indices γ

Proton and **Helium** seem to share the **same spectral index at high rigidity** (~1 TV).



Latest AMS Measurement of He, C and O fluxes

He, **C** and **O** fluxes all **deviate from a single power law** above hundred GV. Furthermore, they seem have **identical rigidity dependence above 60 GV**.



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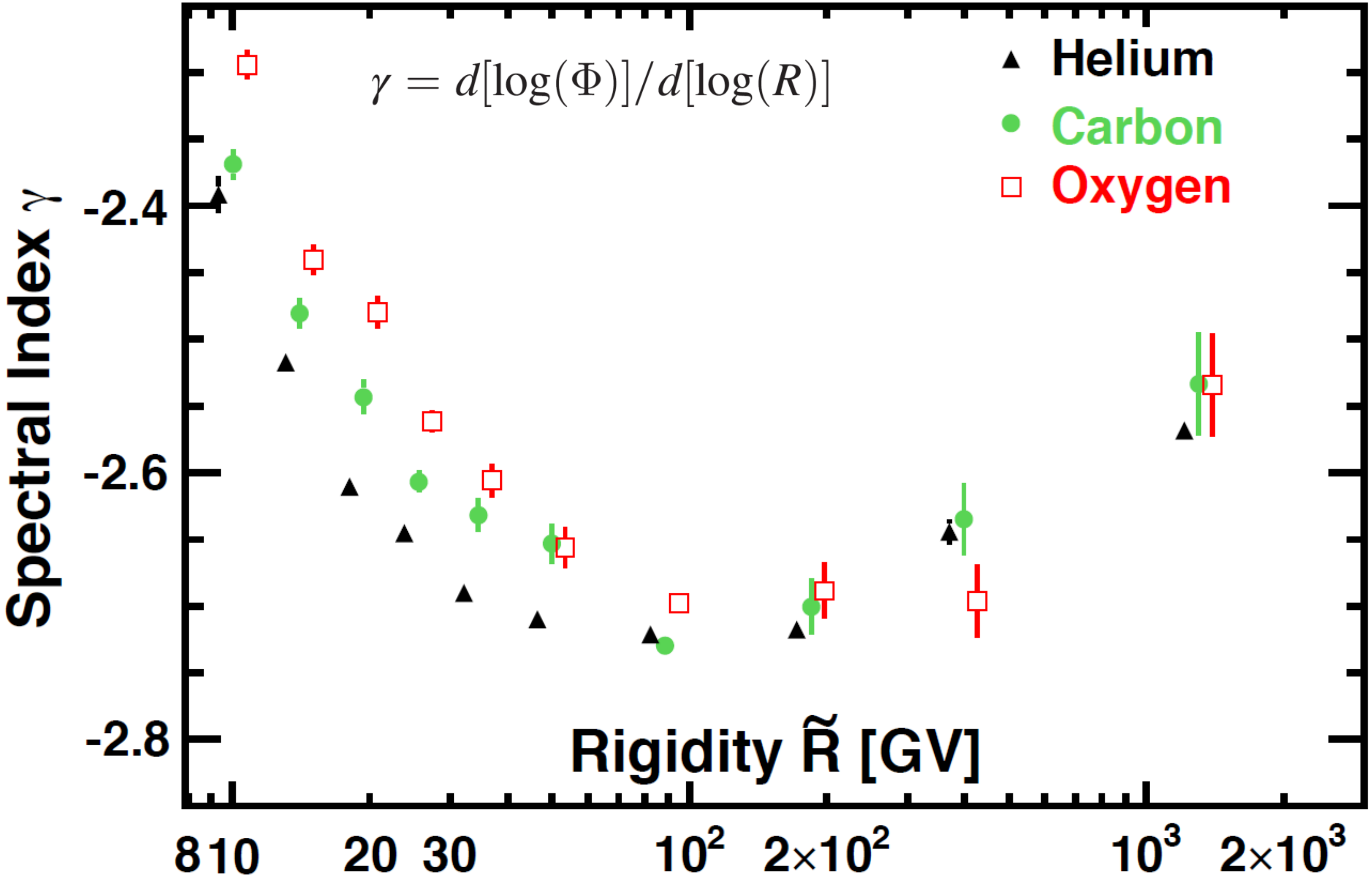
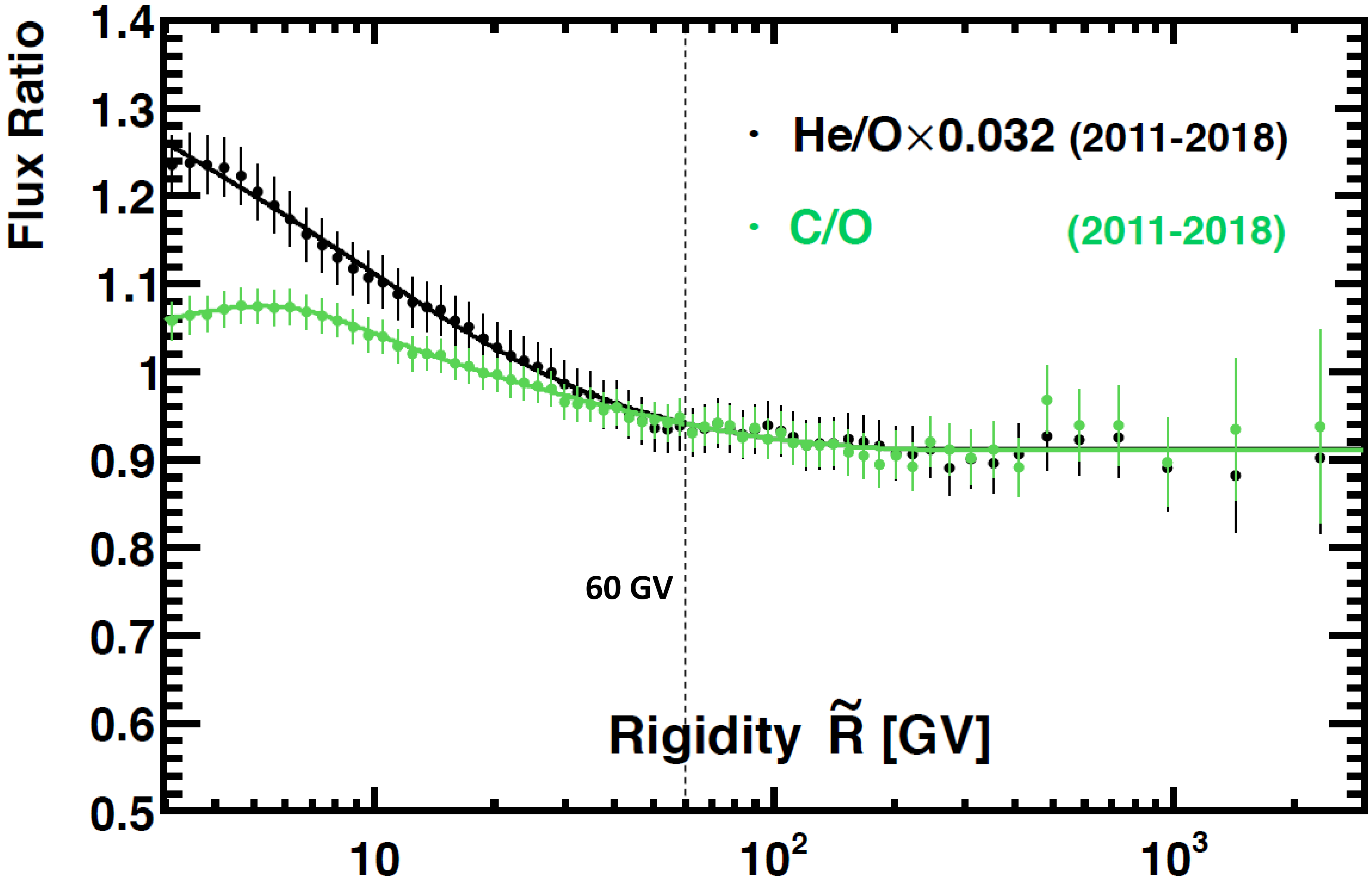
He, C and O Spectral Indices γ

Above 200 GV, **Helium**, **Carbon** and **Oxygen** fluxes **harden in an identical manner**.



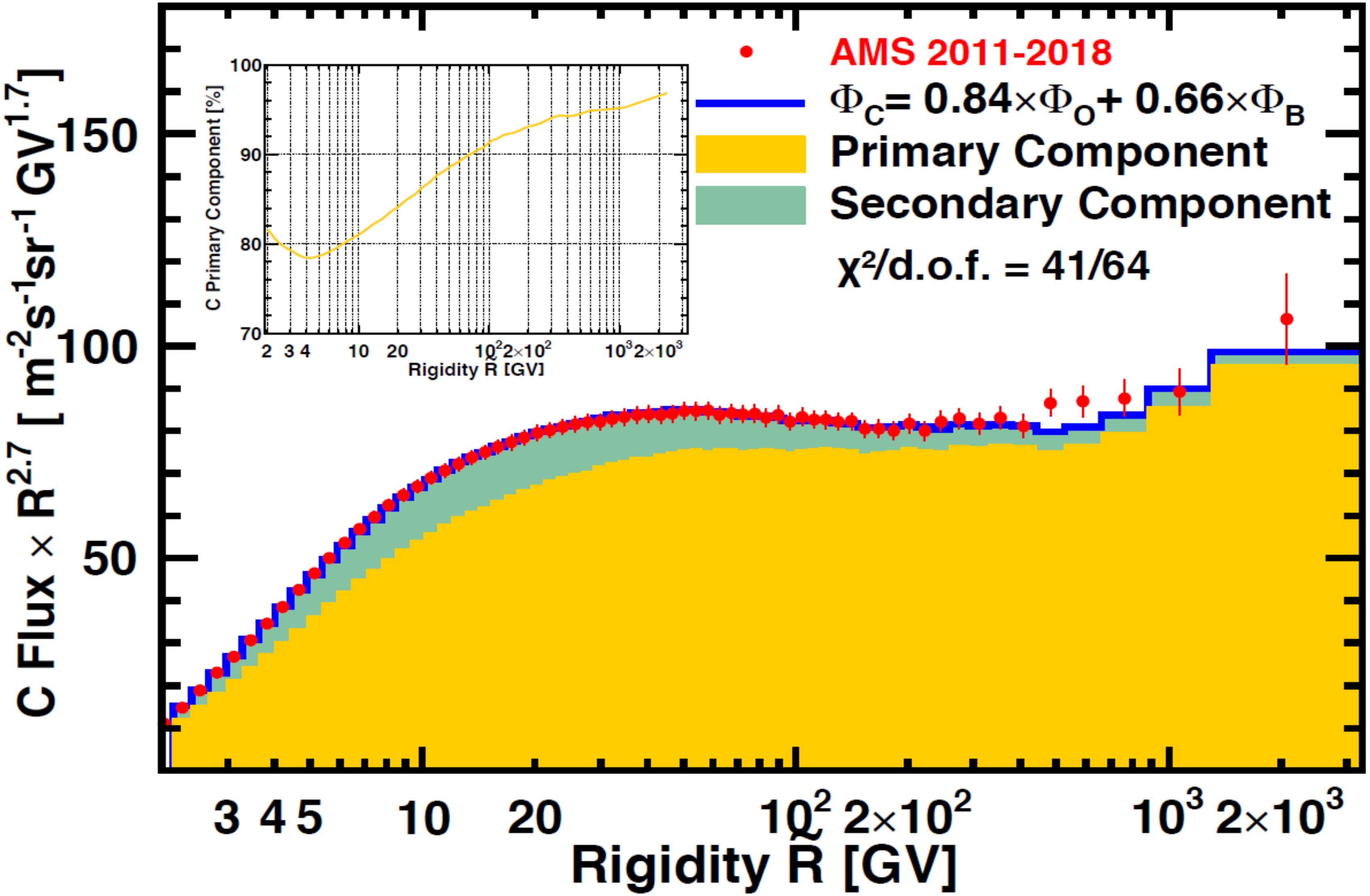
He/O and C/O Fluxes Ratio

He, C and O have **identical rigidity dependence above 60 GV**.



Carbon Spectrum Primary and Secondary Component

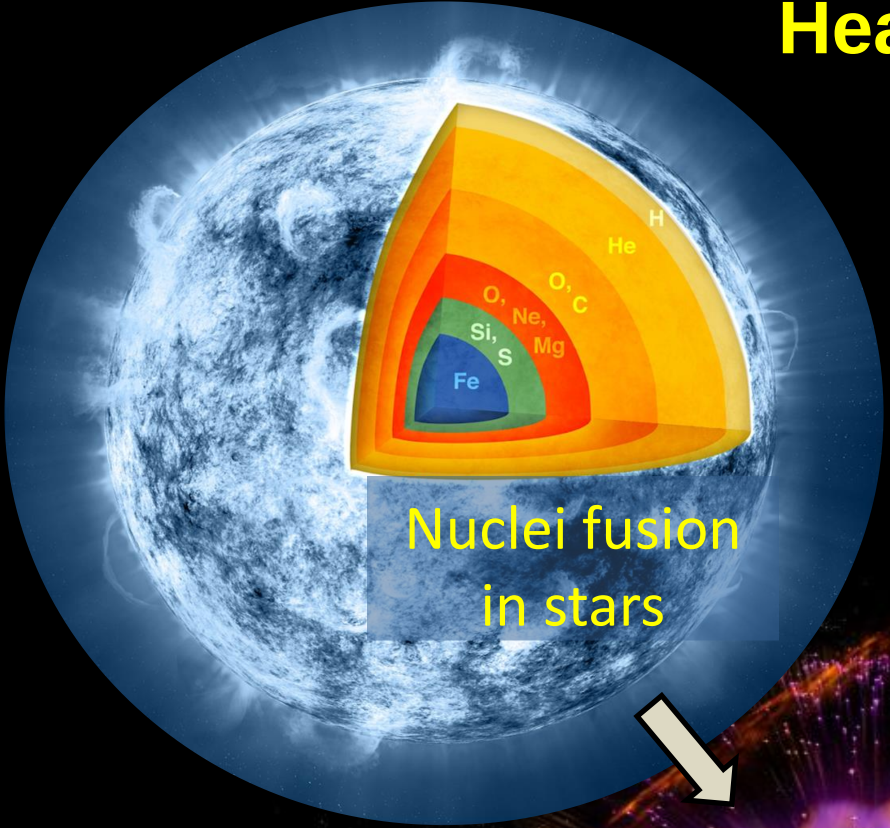
The Carbon flux Φ_C can be described as a **linear combination** of primary flux $\propto \Phi_O$ and a secondary flux $\propto \Phi_B$ over the entire rigidity range

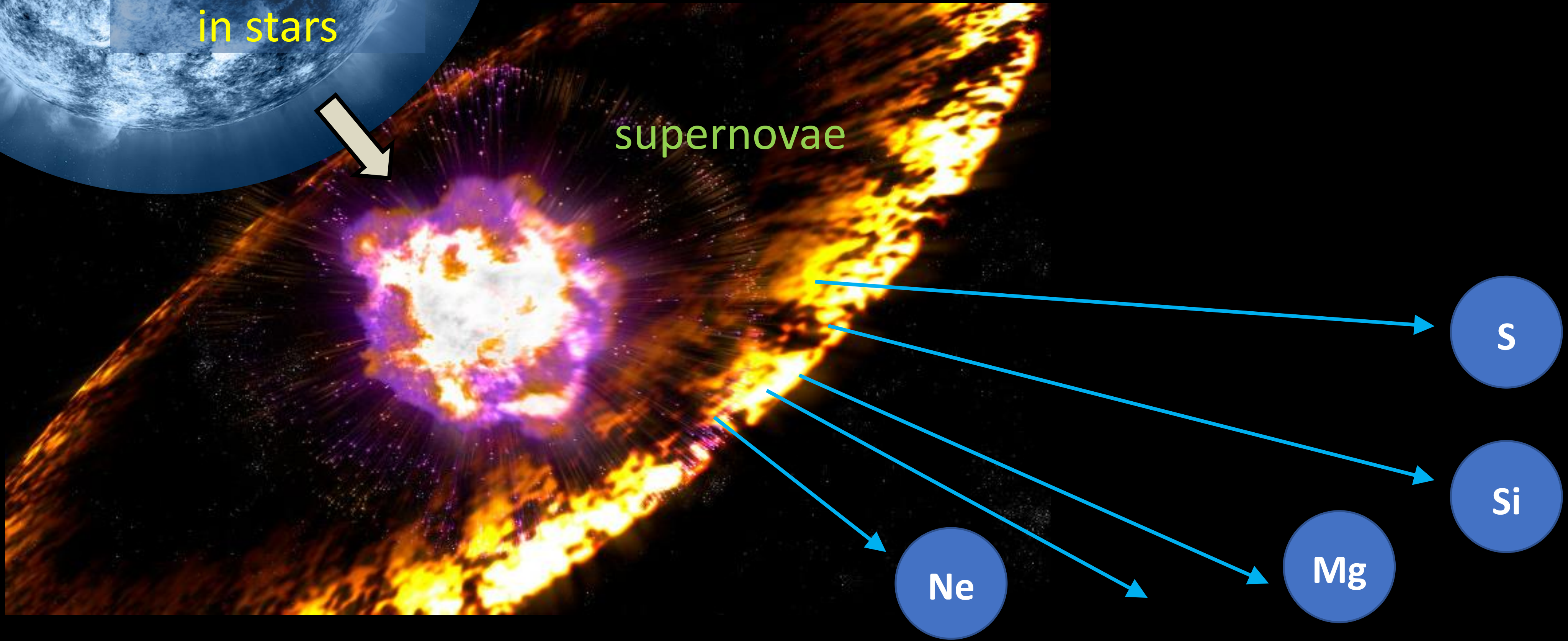


Heavy Primary Cosmic Rays

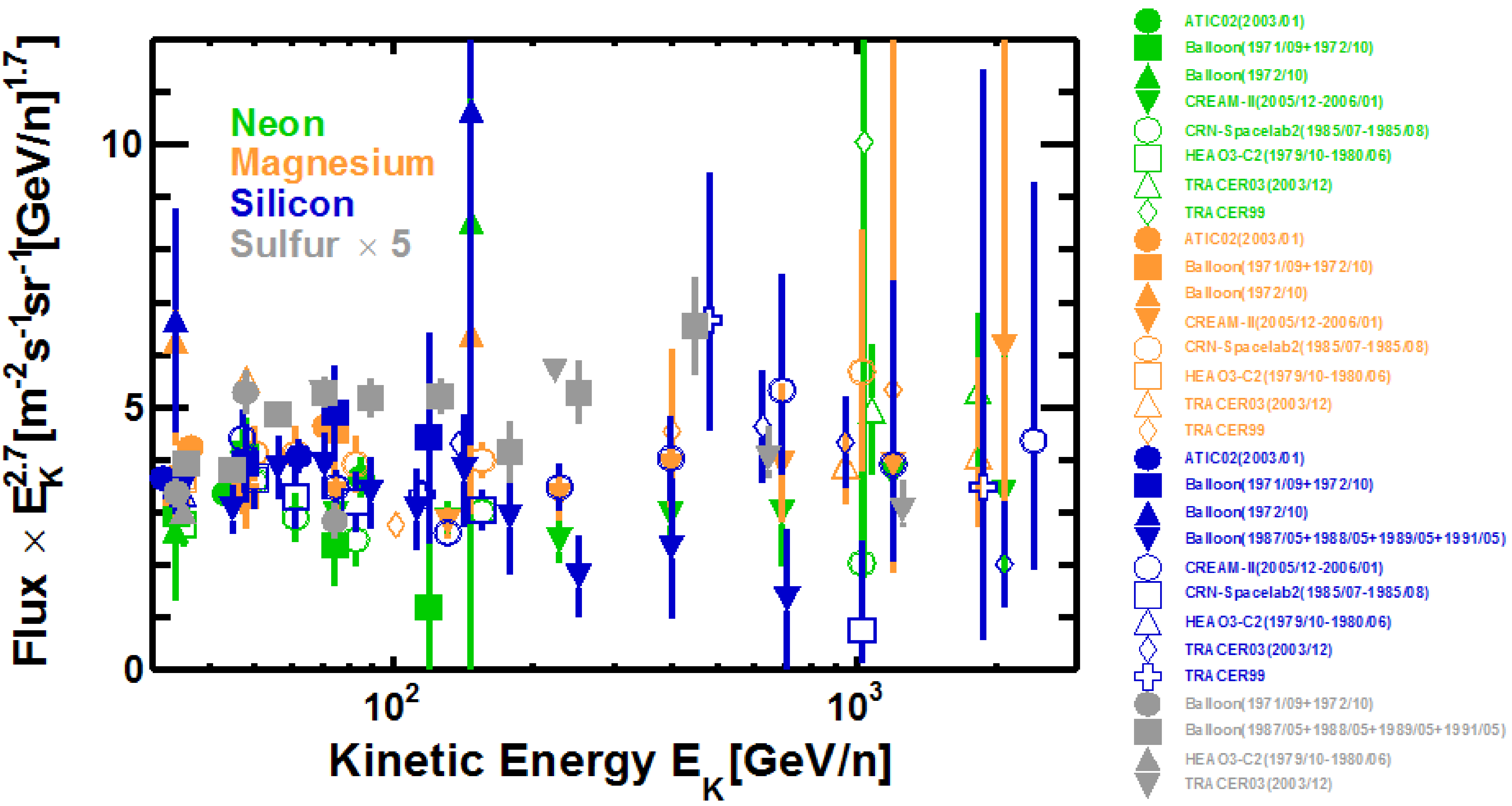
Heavy elements (Ne, Mg, Si, S...) are produced during the lifetime of stars, though at later stage than light nuclei, and accelerated by **supernovae** explosion.

Do they behave the same way as light primaries (He, C, O)?



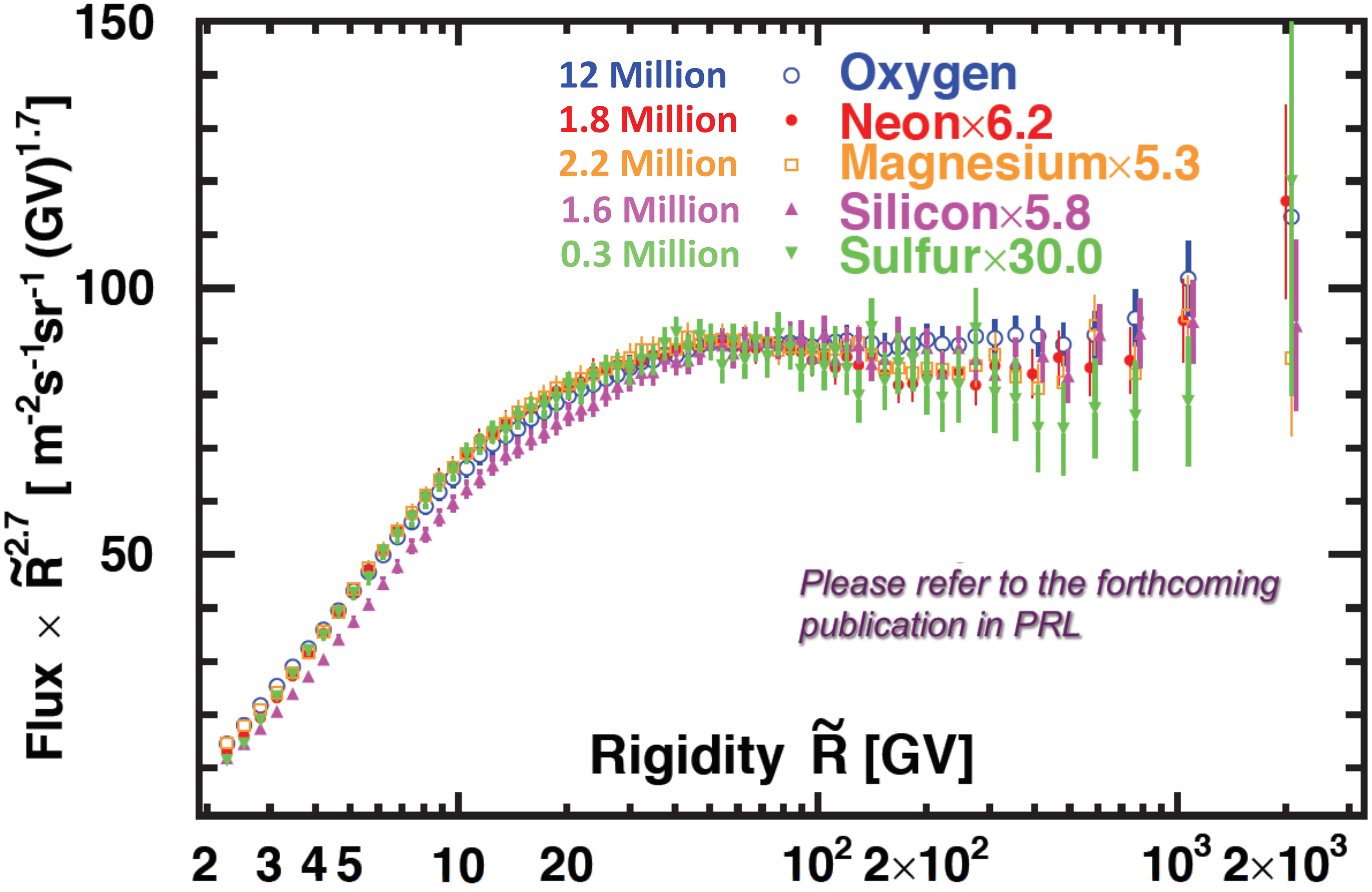


Heavy Nuclei Flux Measurements before AMS

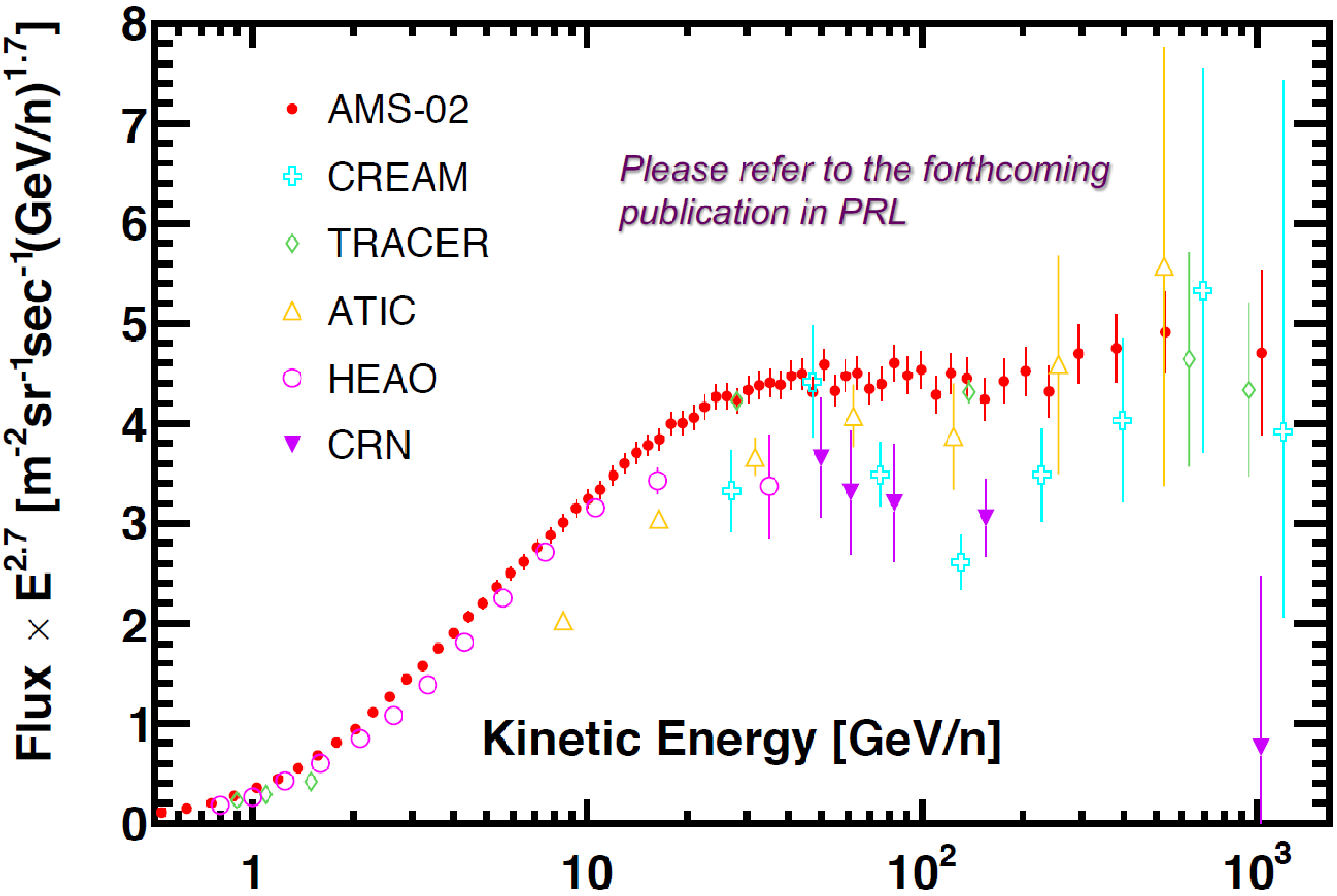


AMS Measurements of Neon, Magnesium, Silicon and Sulphur Spectrum

Ne, **Mg**, **Si** and **S** fluxes all **deviate from a single power law** above hundred GV.

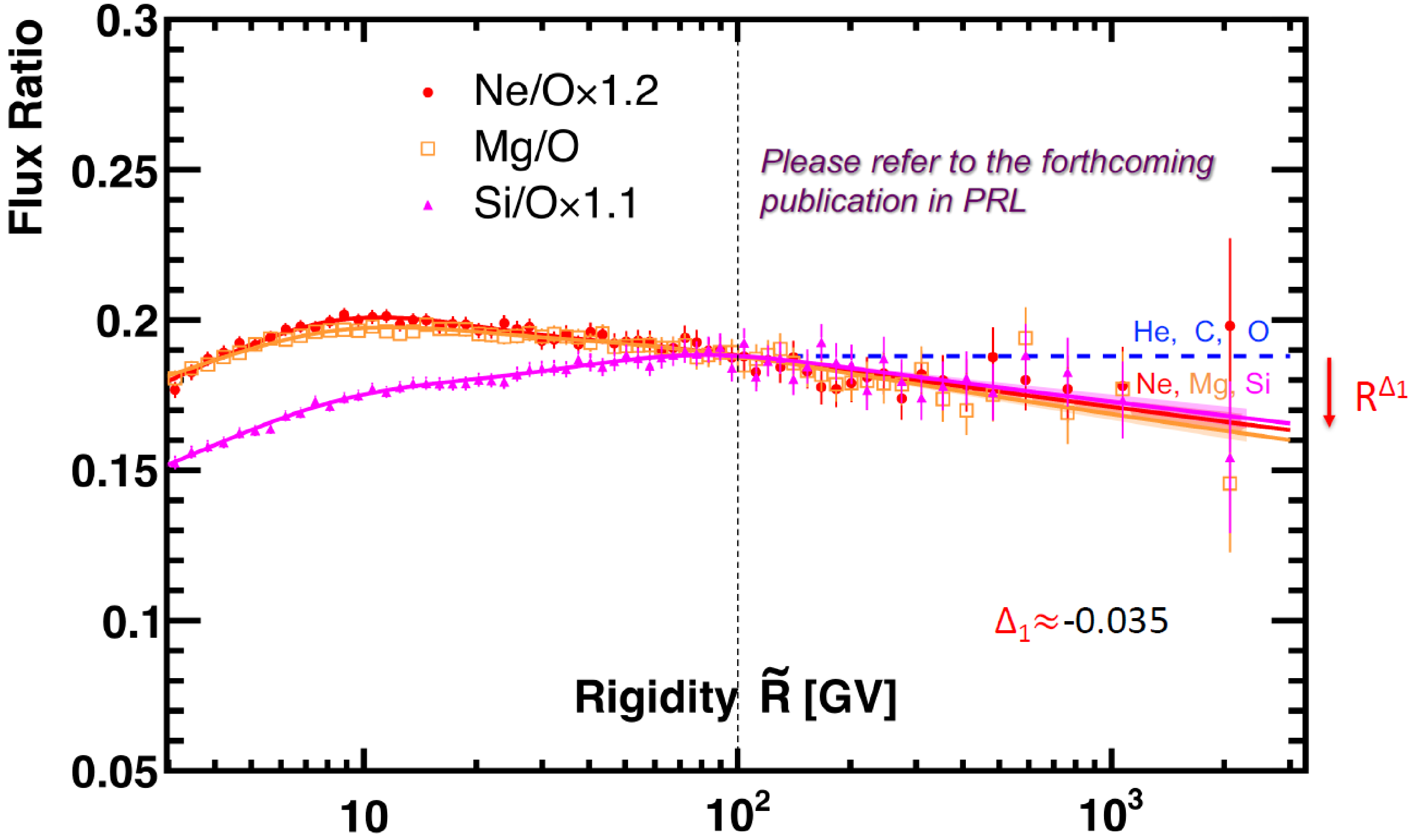


Comparison with previous experiments for Silicon



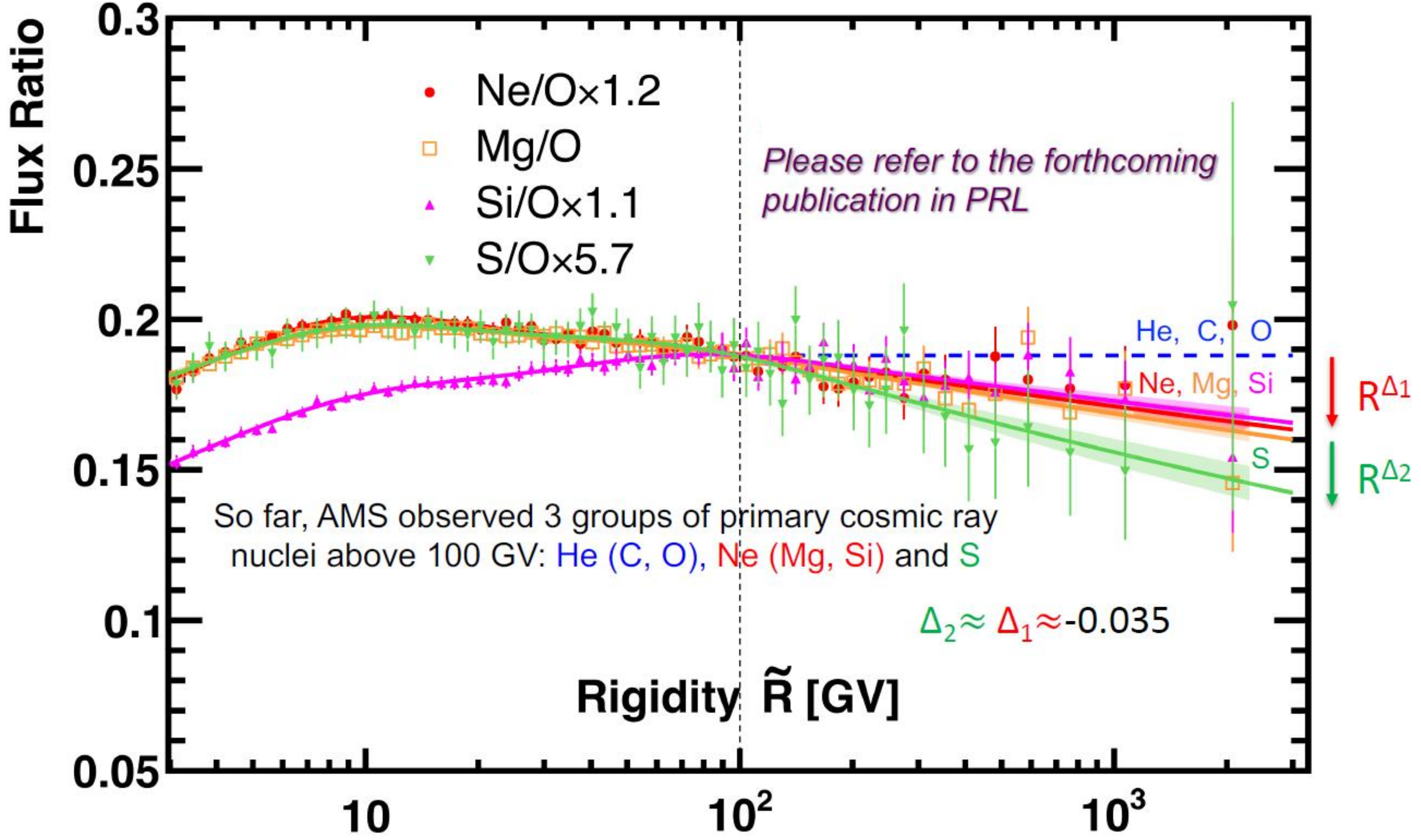
Ratio of Neon, Magnesium, and Silicon Flux over Oxygen

Ne, **Mg**, and **Si** have **identical rigidity dependence** above 100 GV, however, they deviate from **O** by a power law $\boldsymbol{R}^{\Delta_1}$.



Ratio of Neon, Magnesium, Silicon and Sulphur Flux over Oxygen

S is **soften** by a power law R^{Δ_2} compared to **Ne**, **Mg**, **Si** group.



Summary

1. Latest results for the fluxes of primary cosmic rays during a 7-year period of AMS data-taking (2011-2018) have been presented.

2. Cosmic ray nuclei spectra all **deviate from a single power law** and **harden at high rigidity**.

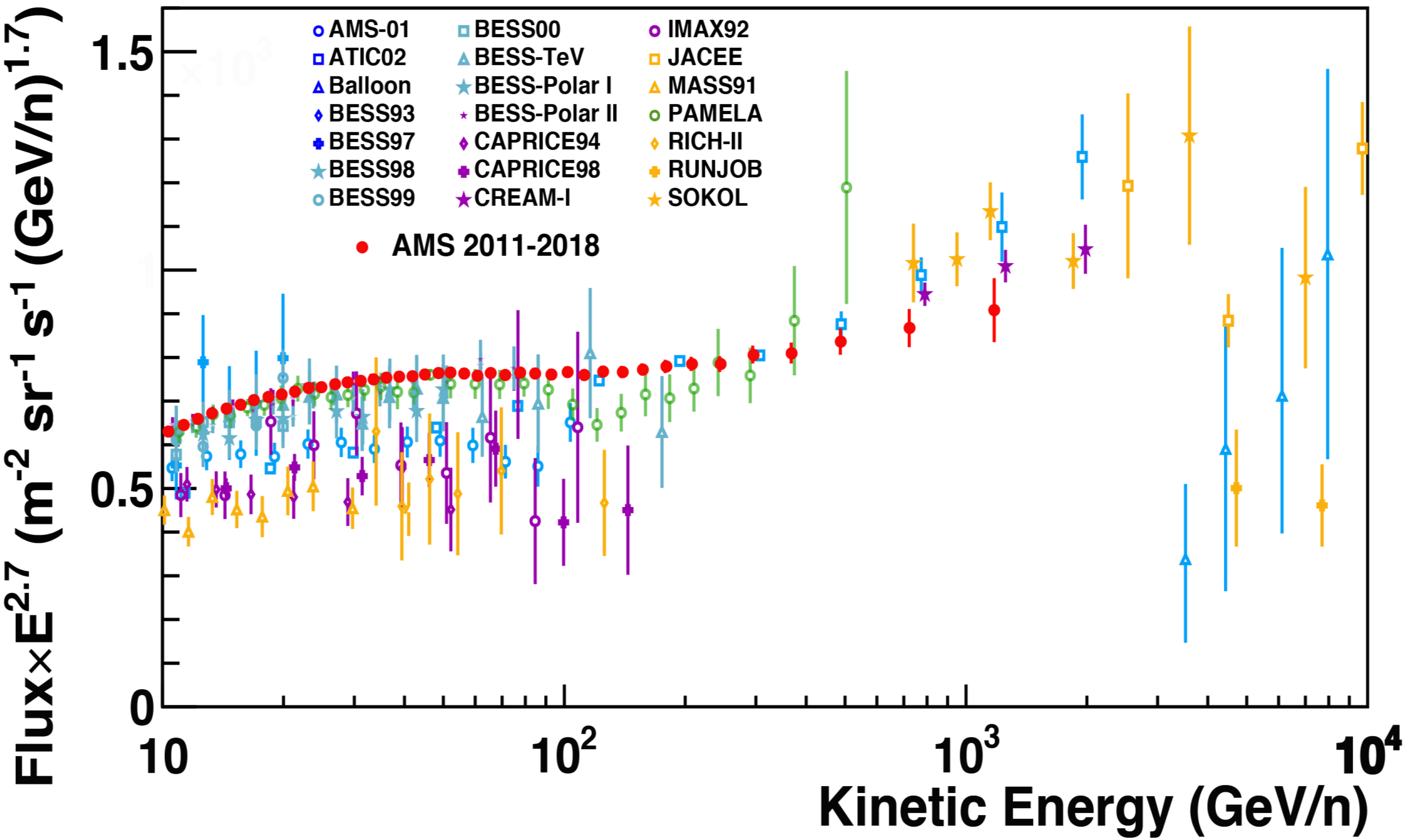
3. Around 1 TV, **Proton** and **Helium** have **identical spectral indices**. The **p/He** ratio can be parametrized as **sum of a single power law component** and **a constant component** above 3.5 GV.

4. **He**, **C** and **O** flux exhibit **identical rigidity dependence** above 100 GV. Above 200 GV, their **spectra harden in an identical manner**. Similarly, the fluxes of **Ne**, **Mg** and **Si** show the same behavior among themselves. However, they differ from **O** by a single power law $\mathbf{R}^{\Delta_1}$ with $\Delta_1 \sim -0.035$.

5. Compared to **Si**, the flux of **S** further differs by a single power law $\mathbf{R}^{\Delta_2}$ with $\Delta_2 \sim \Delta_1$.

Back Up

Latest AMS measurement of Helium Spectrum



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