Unique Properties of Cosmic Ray Nuclei Fluxes Measured by the Alpha Magnetic Spectrometer

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On Behalf of the AMS Collaboration

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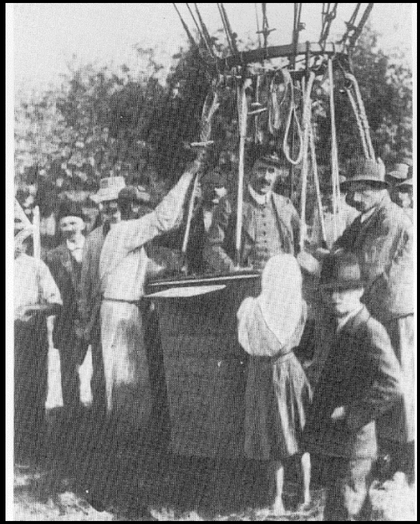
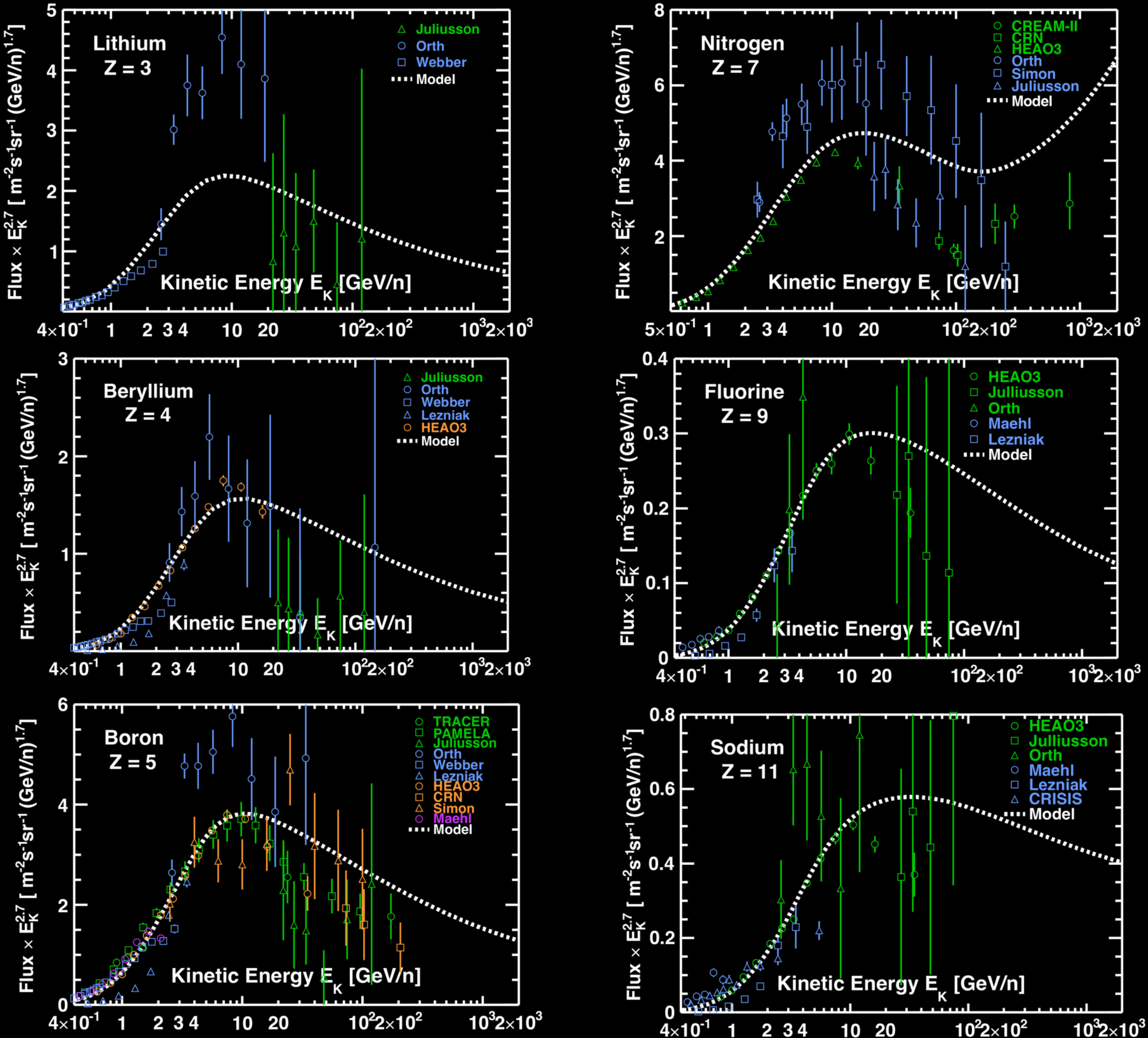
Cosmic Rays
in the last 100 years

1912:
Discovery of Cosmic Rays

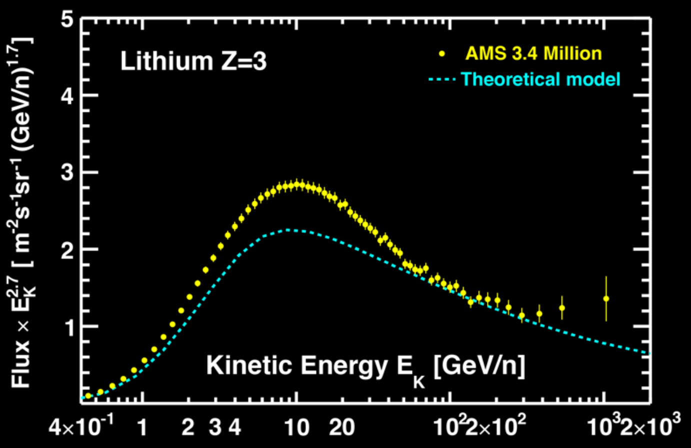


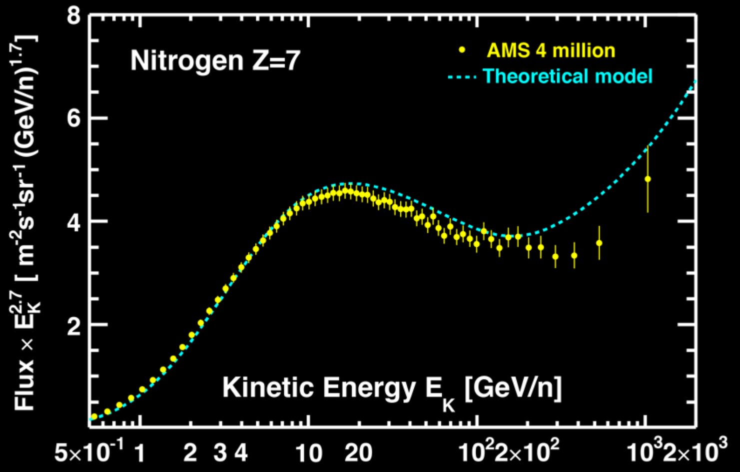
Victor Hess
Nobel Prize (1936)

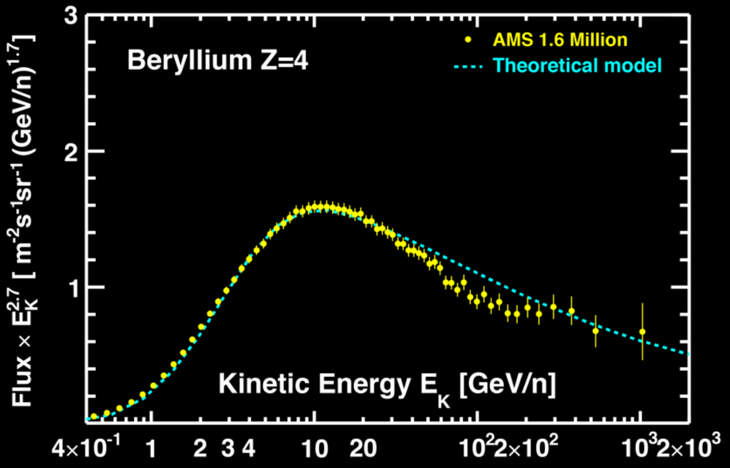
Before AMS:
Many theoretical models agree with experimental data

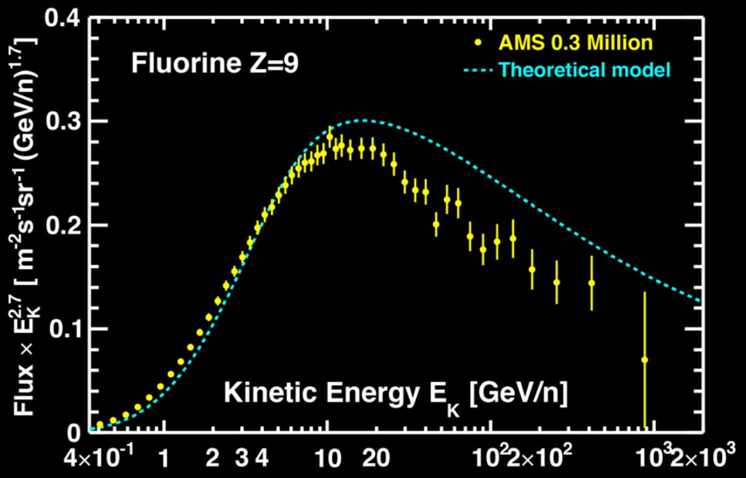


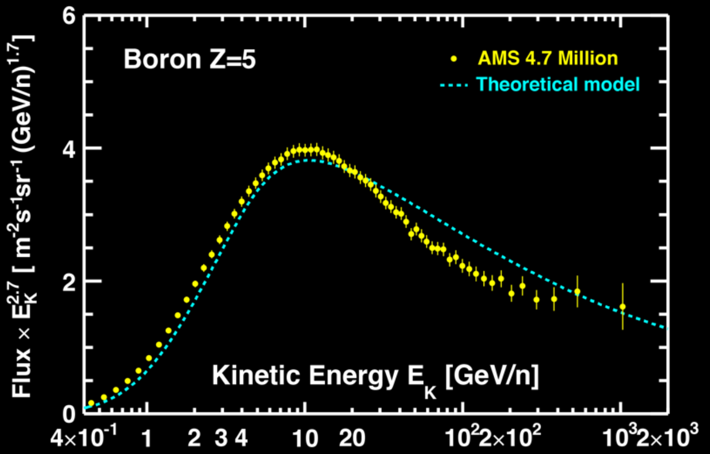
AMS results (~1% accuracy to multi-TeV) contradict current cosmic ray theories and require the development of a new understanding of the universe.

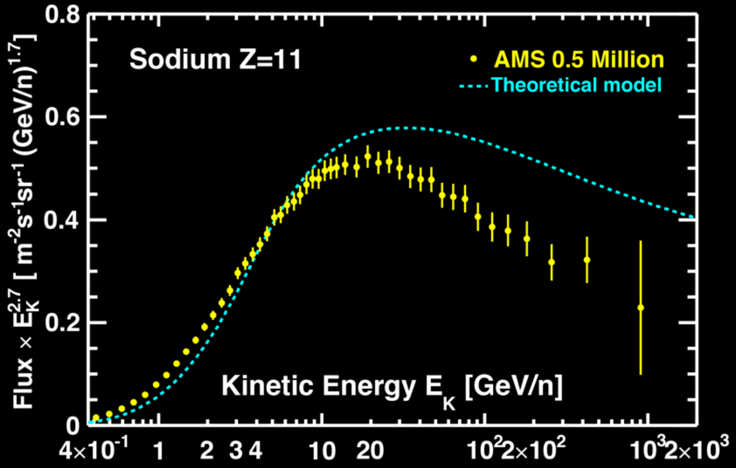






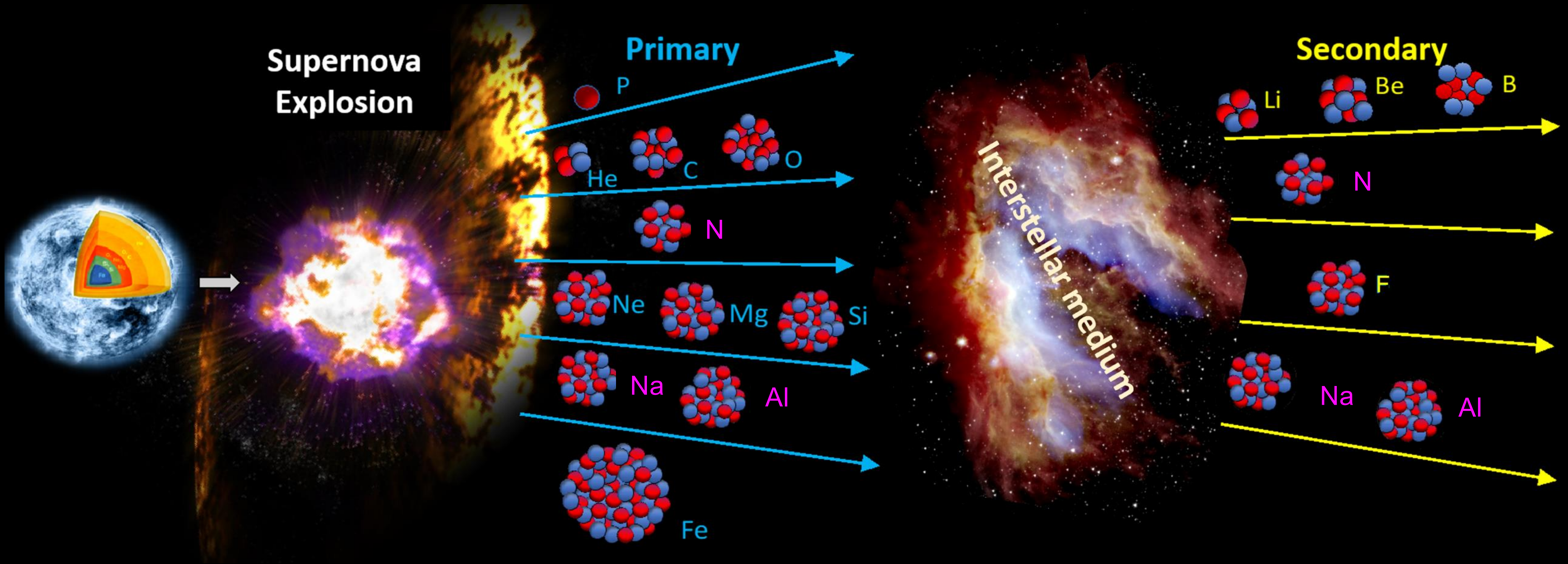






Introduction

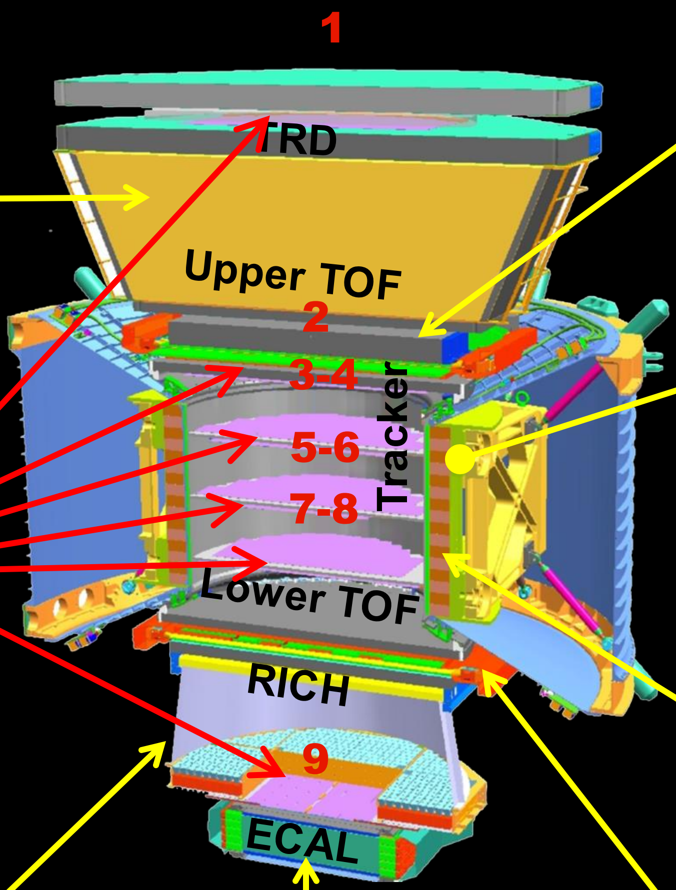
The nuclei in cosmic rays can be separated into two classes according to their origins: the **primary** cosmic rays are produced during the lifetime of stars and accelerated in supernovae shocks; The **secondary** cosmic rays are produced by the collisions of primary nuclei with the interstellar medium. There are also cosmic rays contain both primary and secondary components and are marked as **Third group** of CRs.



Measurements of cosmic ray nuclei fluxes are fundamental to understanding the origin, acceleration, and propagation of cosmic rays in the Galaxy.

Alpha Magnetic Spectrometer (AMS)

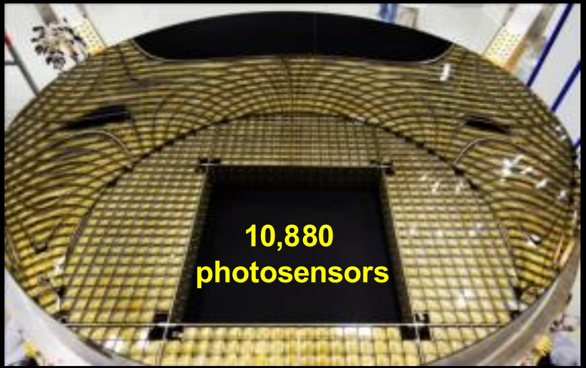
Particle Physics Experiment in Space



Transition Radiation Detector (TRD)
identify e^+, e^-

Silicon Tracker
measure Z, P

Ring Imaging Cerenkov (RICH)
measure Z, E



Electromagnetic Calorimeter (ECAL)
measure E of e^+, e^-

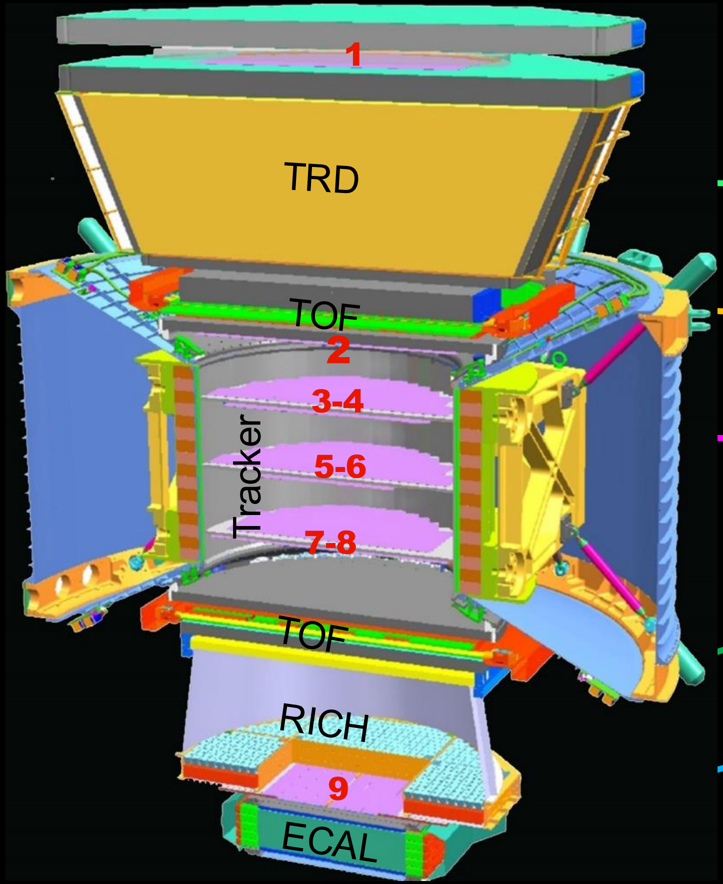
Upper TOF measure Z, E

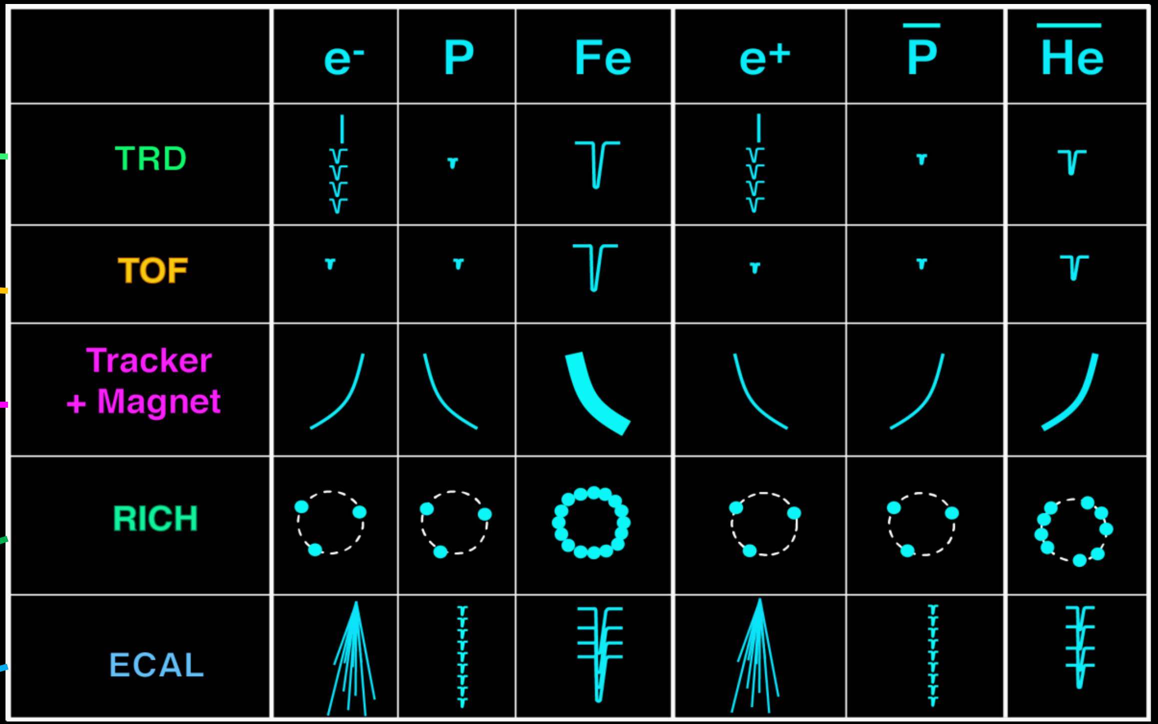
Magnet identify ±Z, P

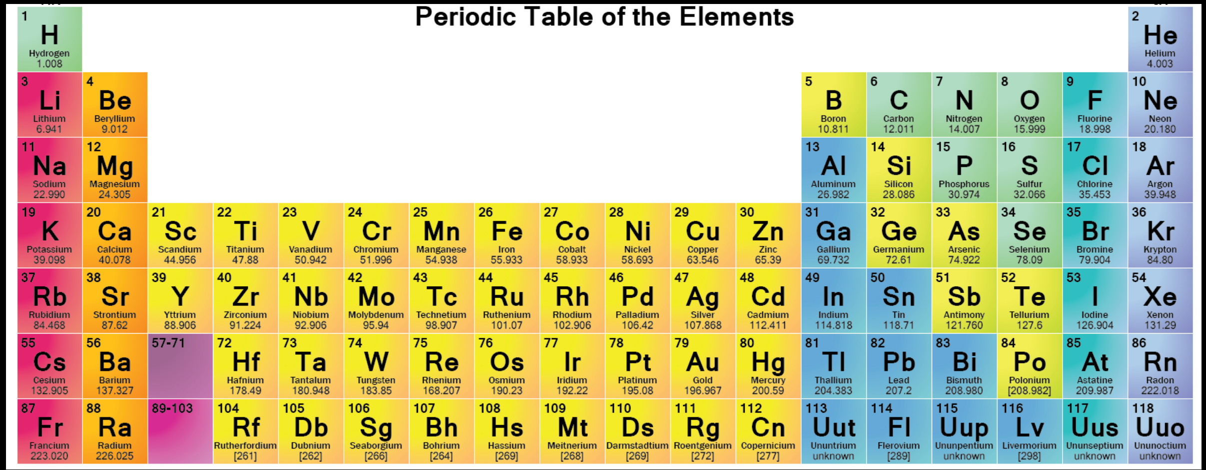
Anticoincidence Counters (ACC)
reject particles from the side

Lower TOF measure Z, E

AMS detectors provide precision information of cosmic rays



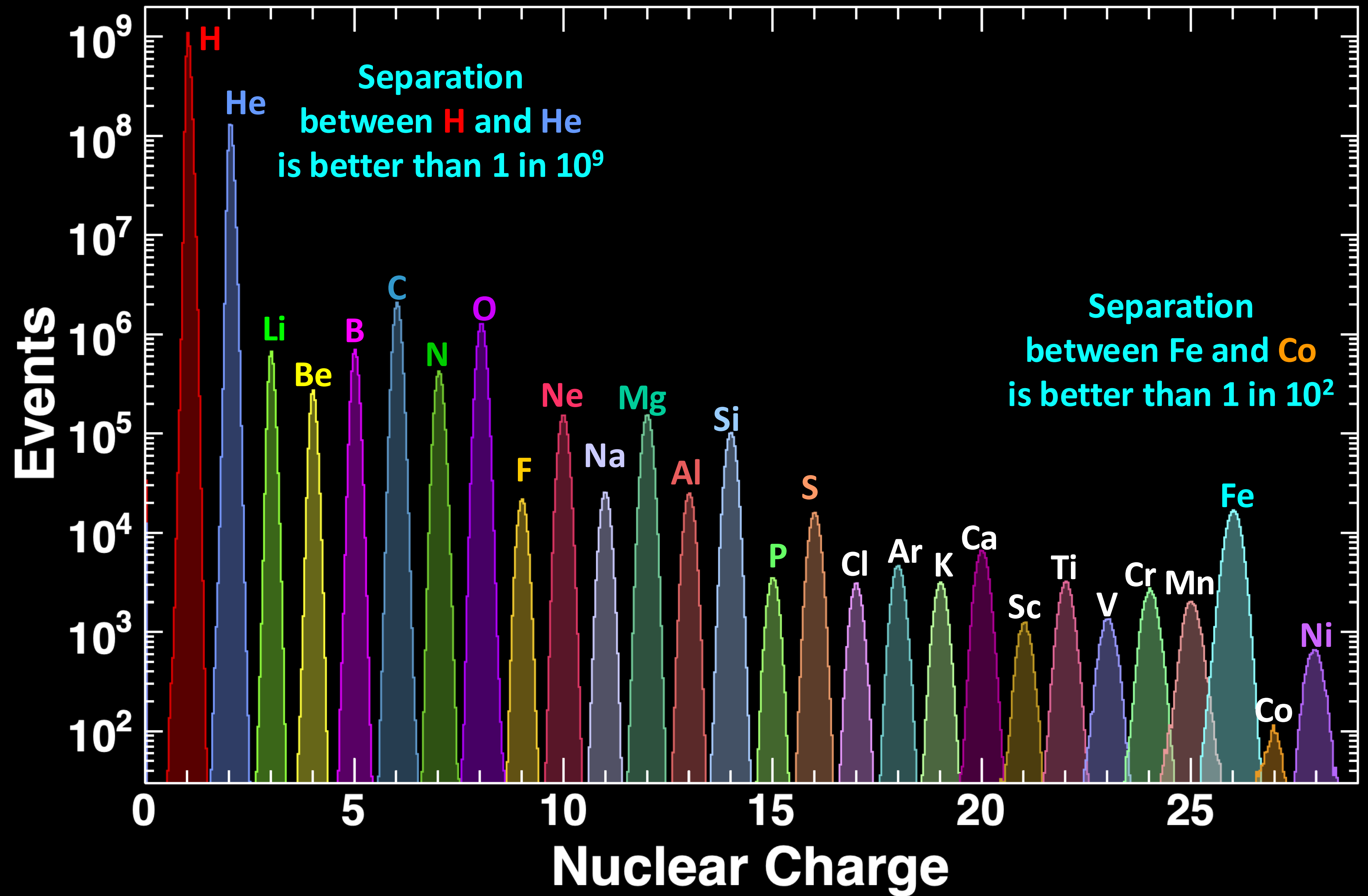




AMS measures :

- Momentum (P, GeV/c)
- Charge (Z)
- Rigidity (R=P/Z, GV)
- Energy (E, GeV/A)
- Flux (signals/(s sr m^2 GeV))

AMS Measurement of Cosmic Ray Nuclei Charge



AMS Nuclei Flux Measurements

Cosmic Ray Flux in i-th Rigidity Bins

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

Selected Events
- Background removed
- Corrected for Bin to Bin Migration

Exposure Time

Effective Acceptance

Trigger Efficiency

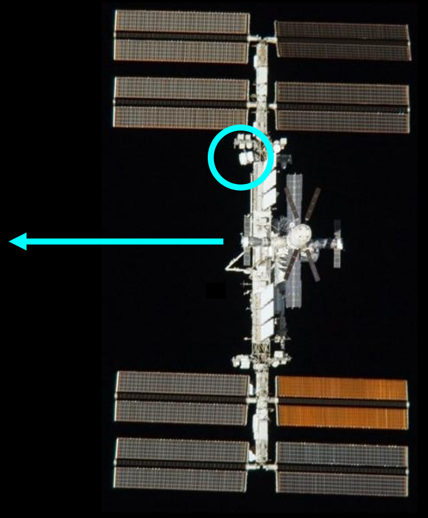
Bin Width

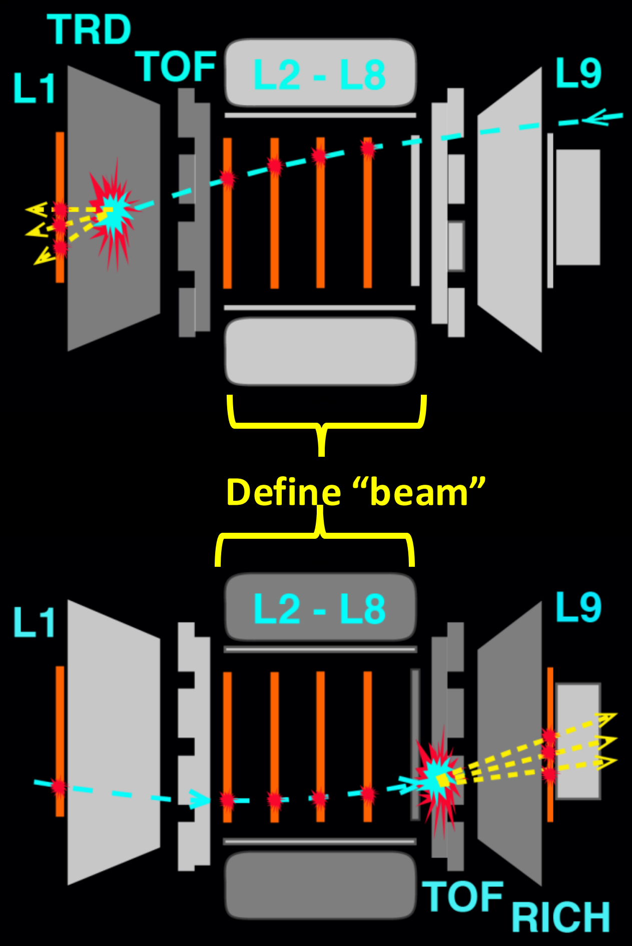
Measurements require knowledge of detector performance details, the resolution functions, acceptance… obtained by AMS Monte Carlo Simulation

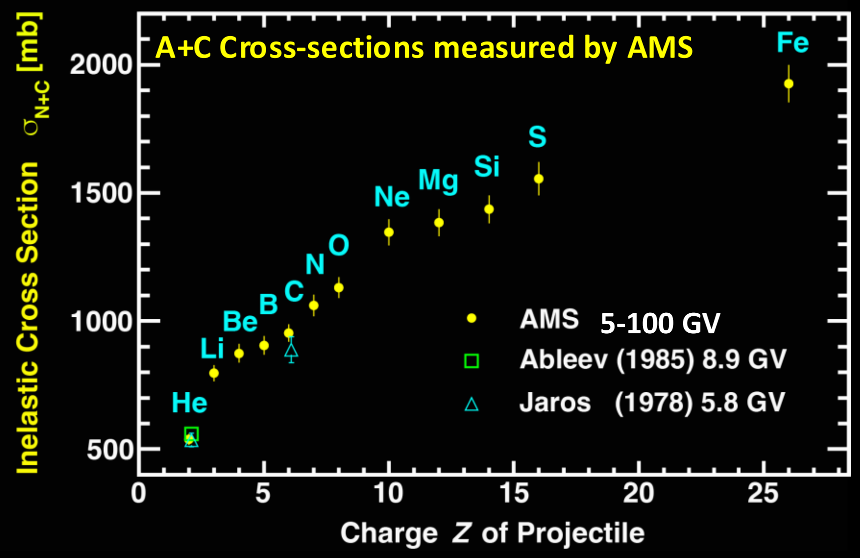
In AMS, 2 to 4 independent analysis are done to compute N_i, A_i, ε_i, T_i, for each flux

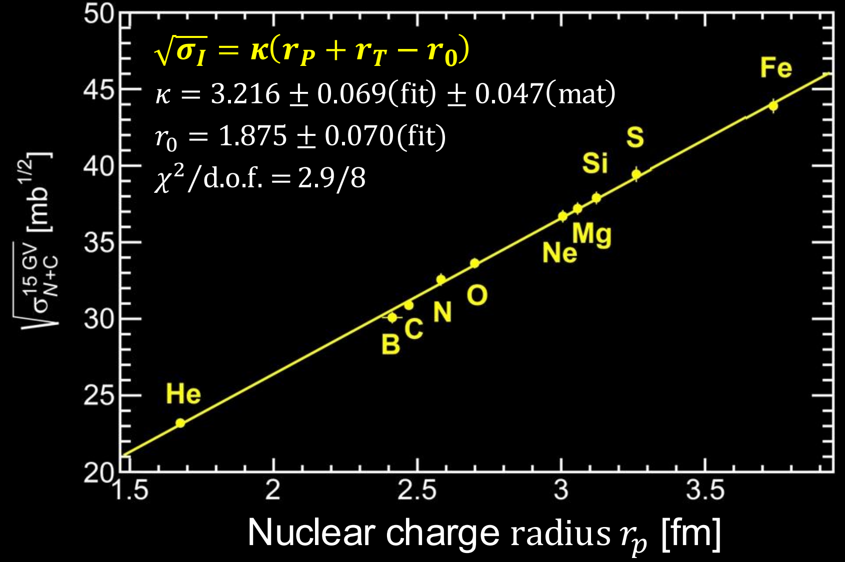
Unique of AMS: Measure the Nuclear Cross-section using Cosmic Rays

AMS collect cosmic particles entering the detector from both downward and upward directions when ISS is flying horizontally. This allows the measurement of nuclei interaction in the GV to TV rigidity ranges.

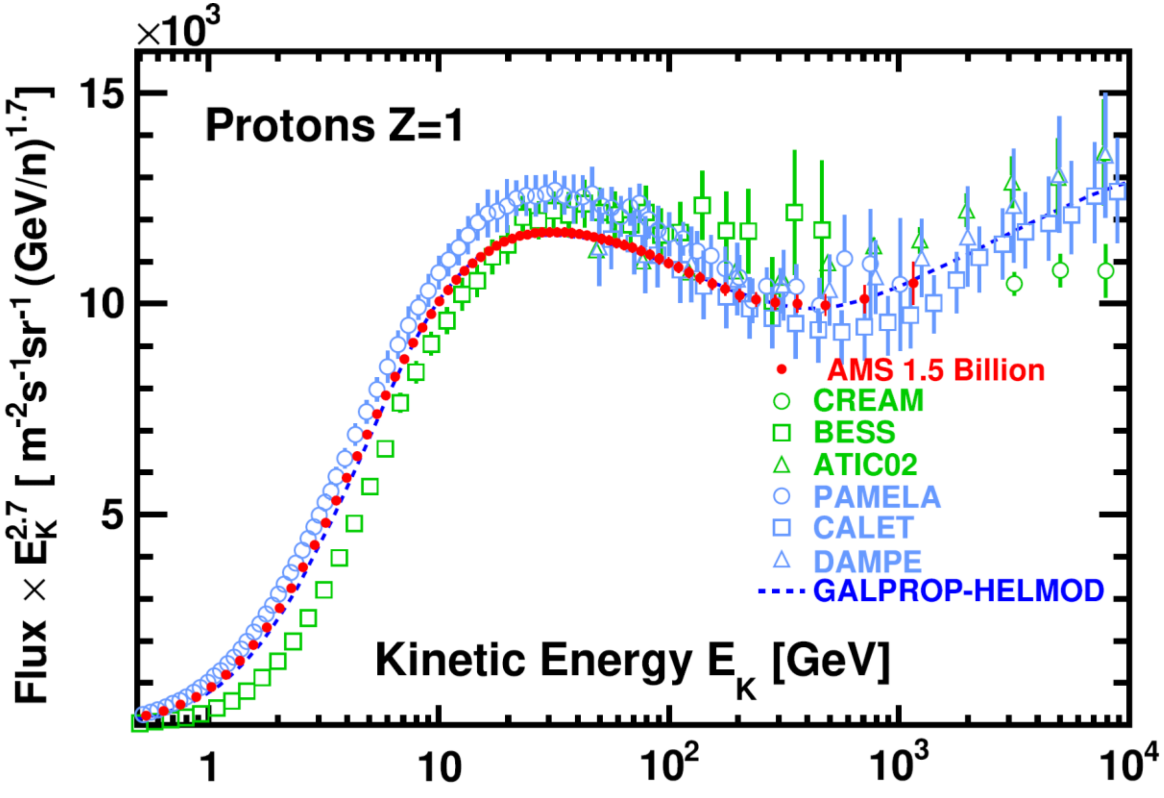


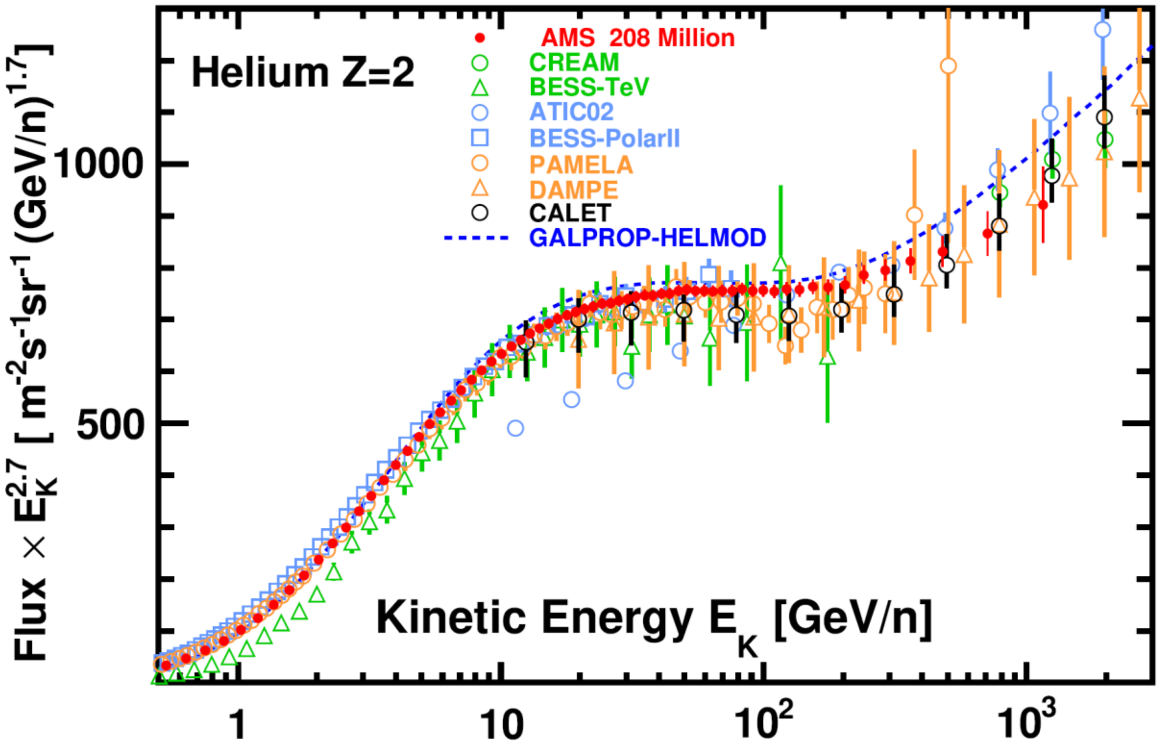






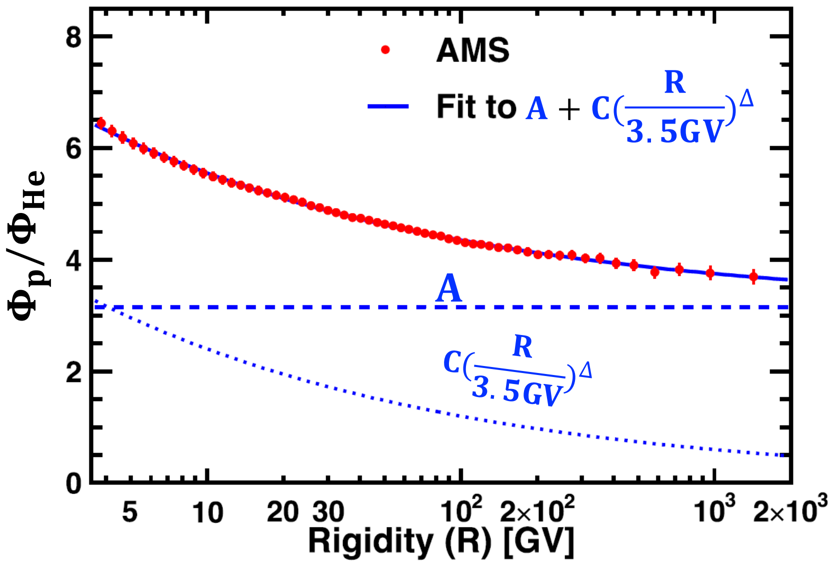
Primary Cosmic Rays: Proton and Helium

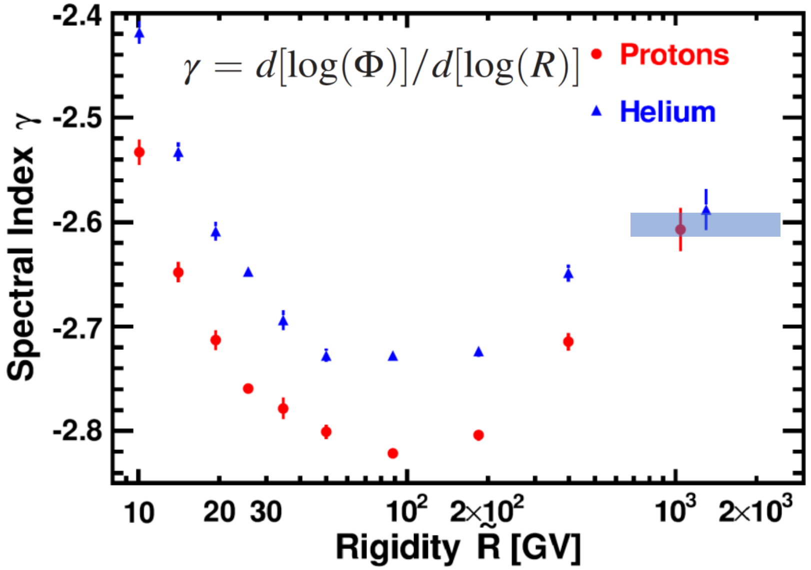


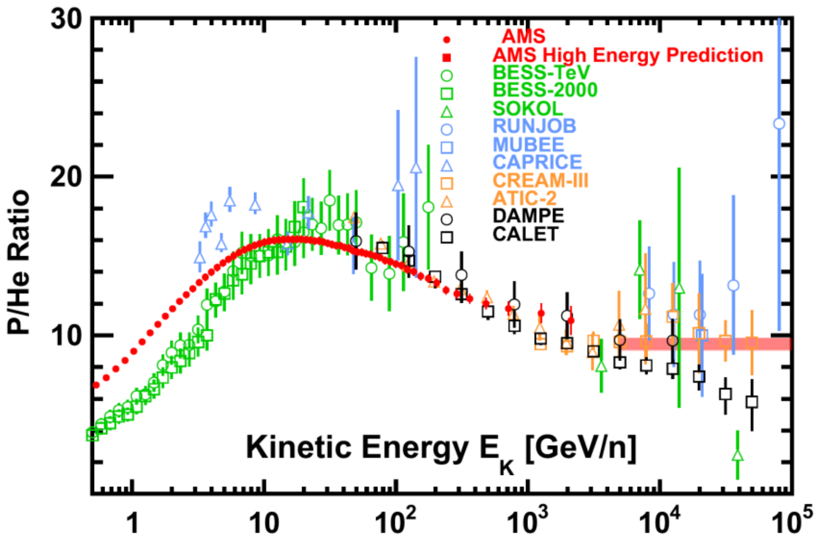


Proton(p) and Helium(He) are the two most abundant cosmic rays. AMS provides the most accurate results on p and He fluxes in its measured energy ranges, the results show that both spectra deviate from "single power law" at few hundreds GeV/n(GeV).

Primary Cosmic Rays: Proton and Helium





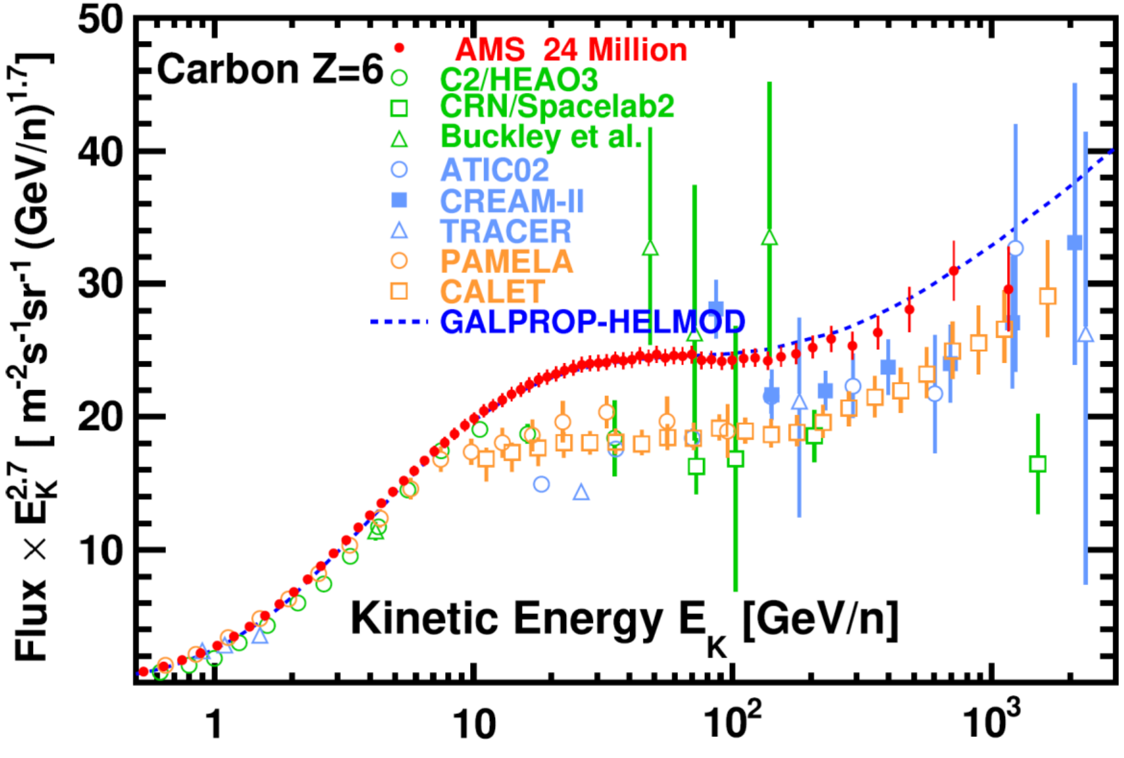


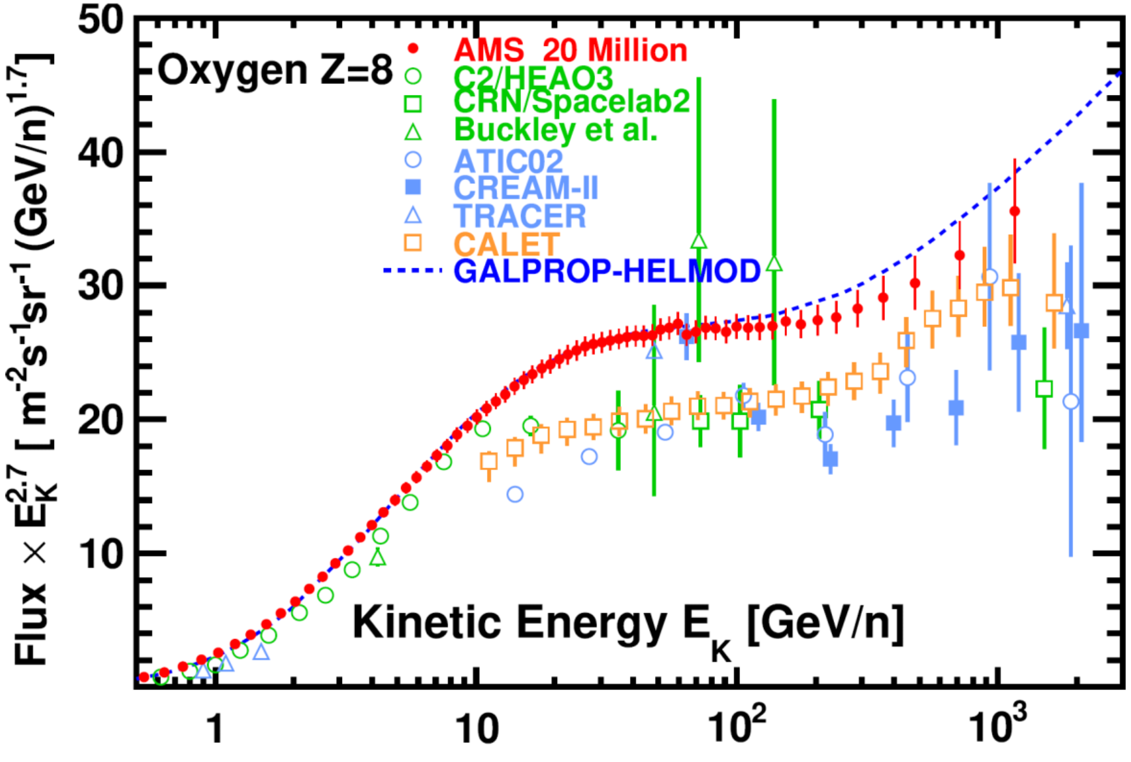
p flux have two components, one is like He and another is unique to proton flux (Δ=-0.3$\pm$0.01).

p and He may have same spectral index at highest rigidities.

AMS predicts that at high energy(>1TeV/n), the p/He ratio flattens asymptotically.

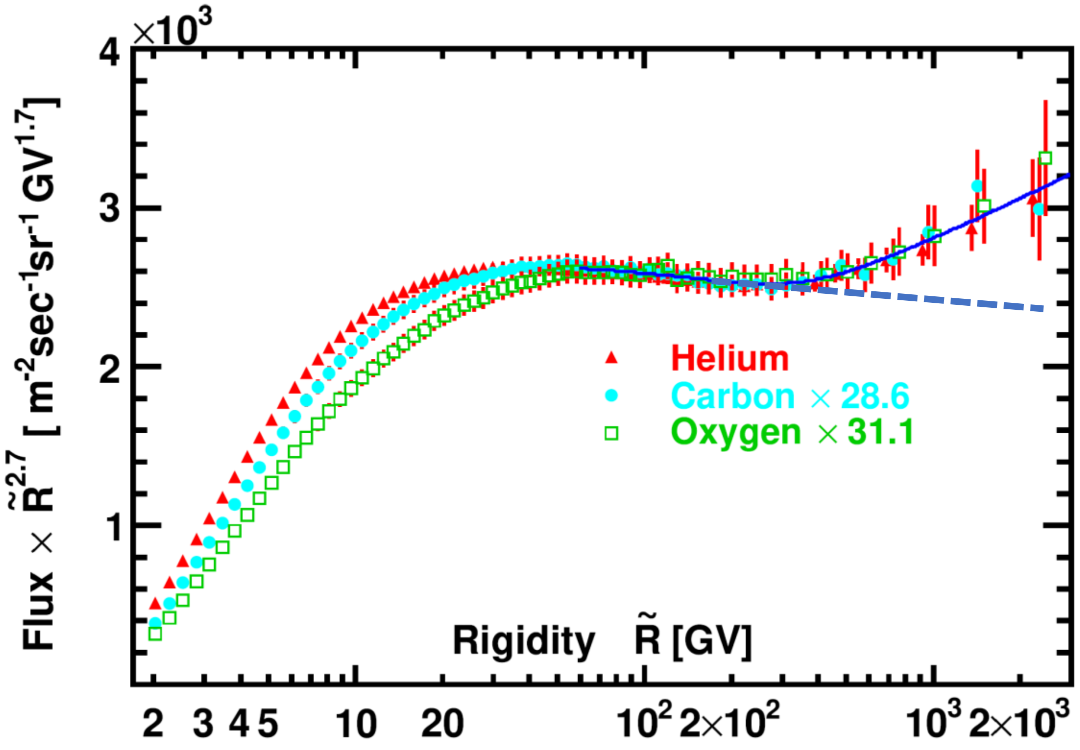
Primary Cosmic Rays: Carbon and Oxygen



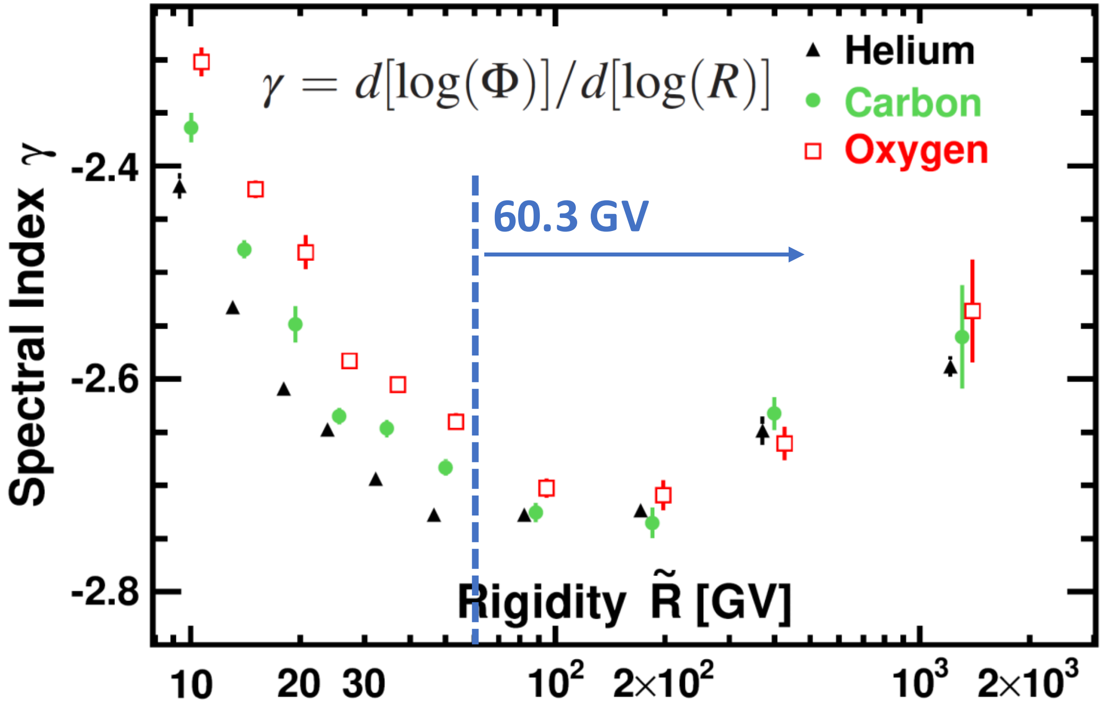


AMS provides the most accurate results on Carbon(C) and Oxygen(O) fluxes in its measured energy ranges, the results show some difference with previous measurements.

Primary Cosmic Rays: Carbon and Oxygen

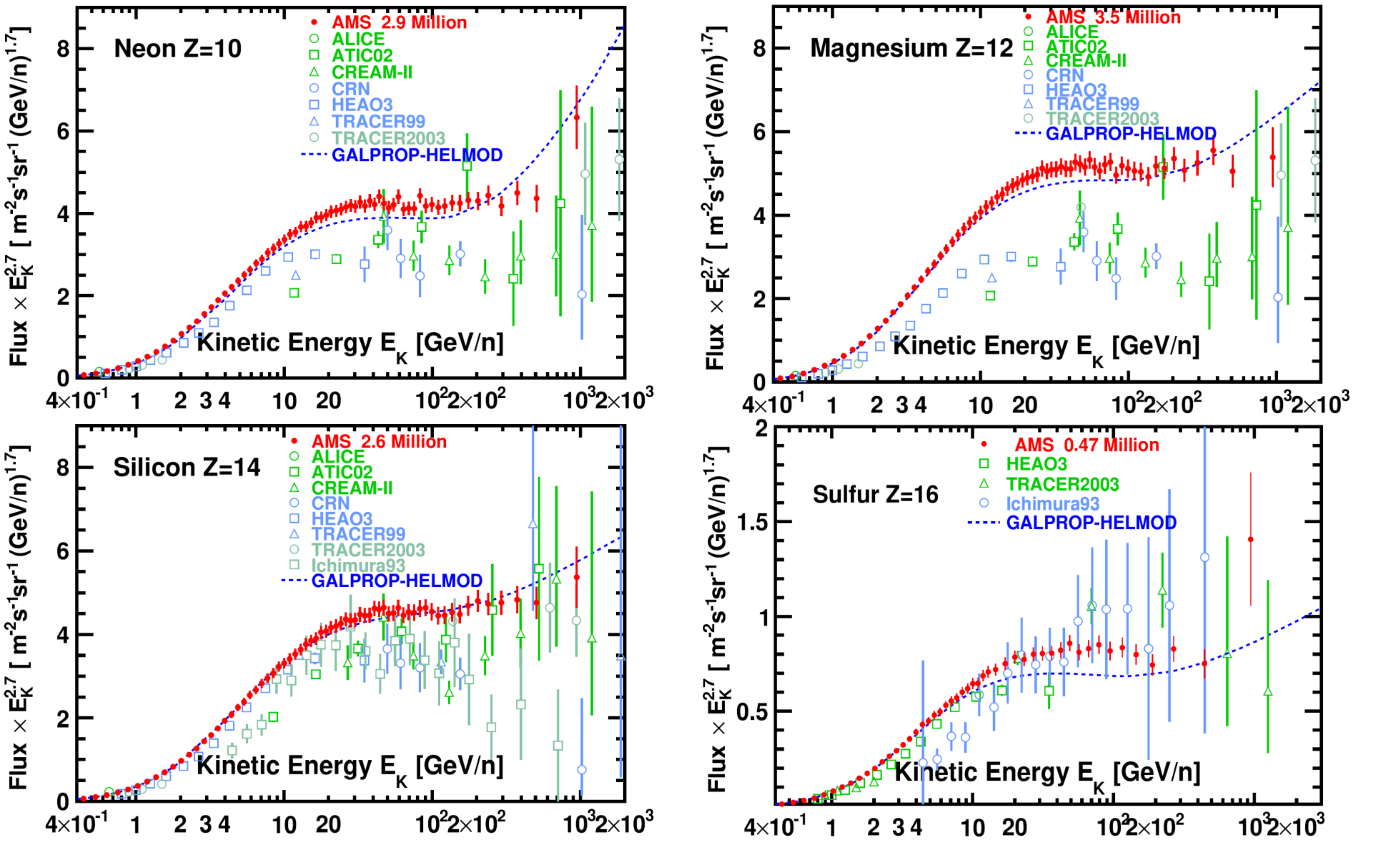


He, C and O all deviate from a single power in an identical way



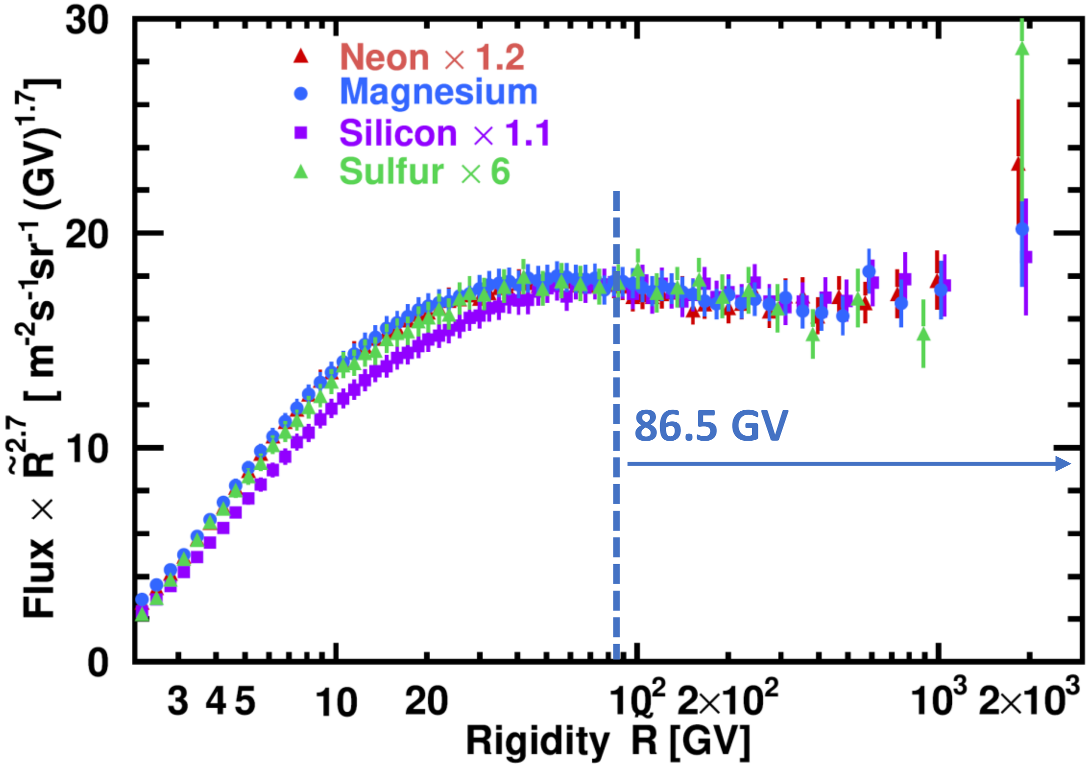
He, C and O have an identical rigidity dependence above ~60 GV which indicates that He C and O belong to the same class of primary cosmic rays.

Primary Cosmic Rays: Neon Magnesium Silicon and Sulfur

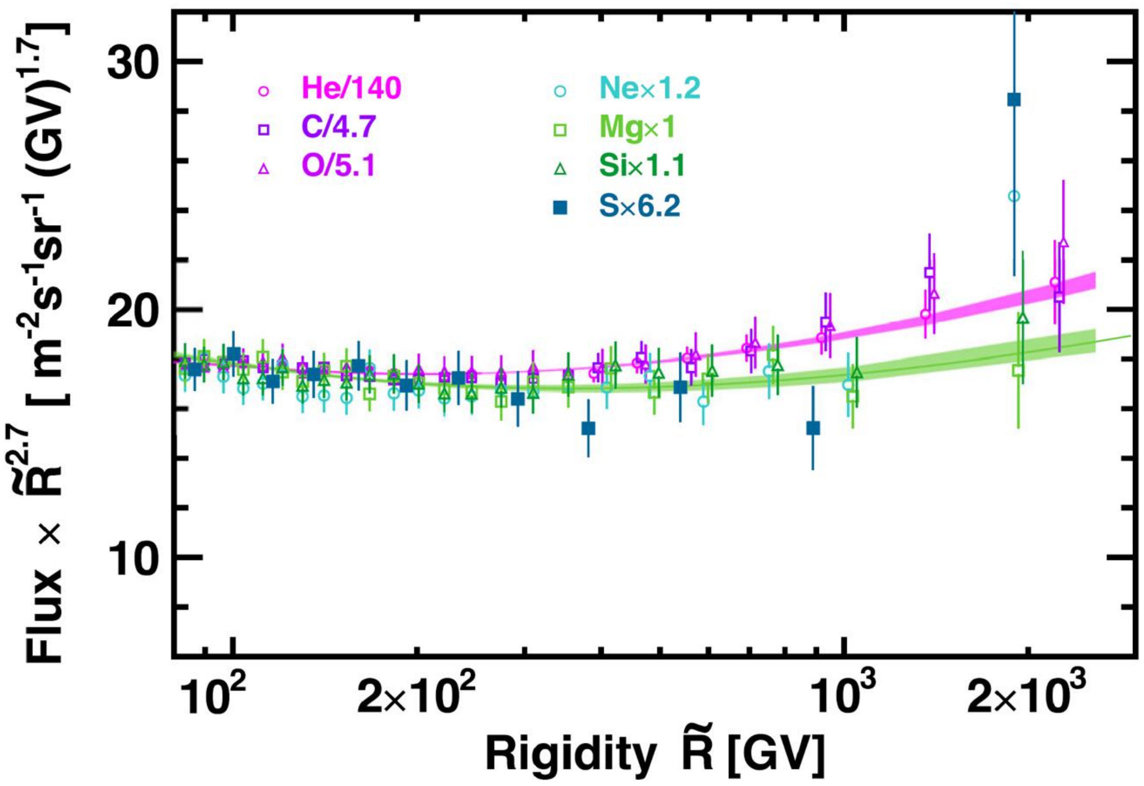


The AMS measurements on Neon(Ne), Magnesium(Mg), Silicon(Si) and Sulfur(S) fluxes all show some differences with previous experiment results.

Primary Cosmic Rays: Neon Magnesium Silicon and Sulfur

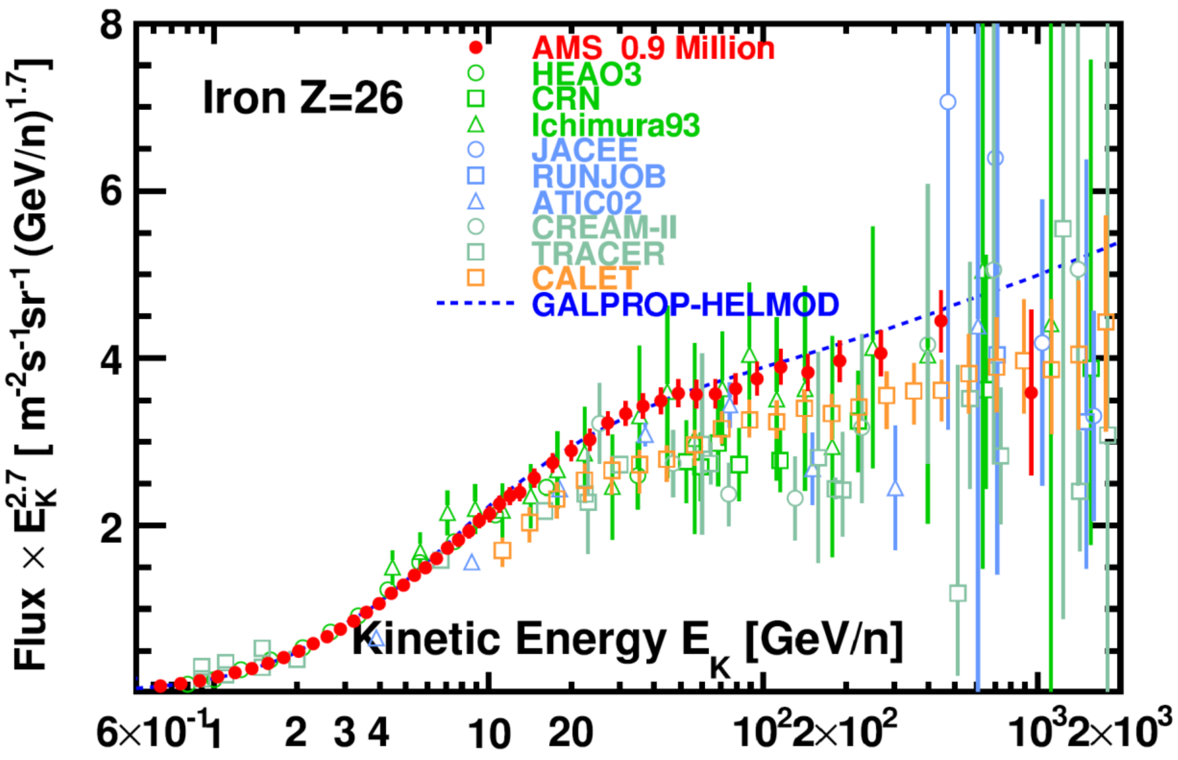


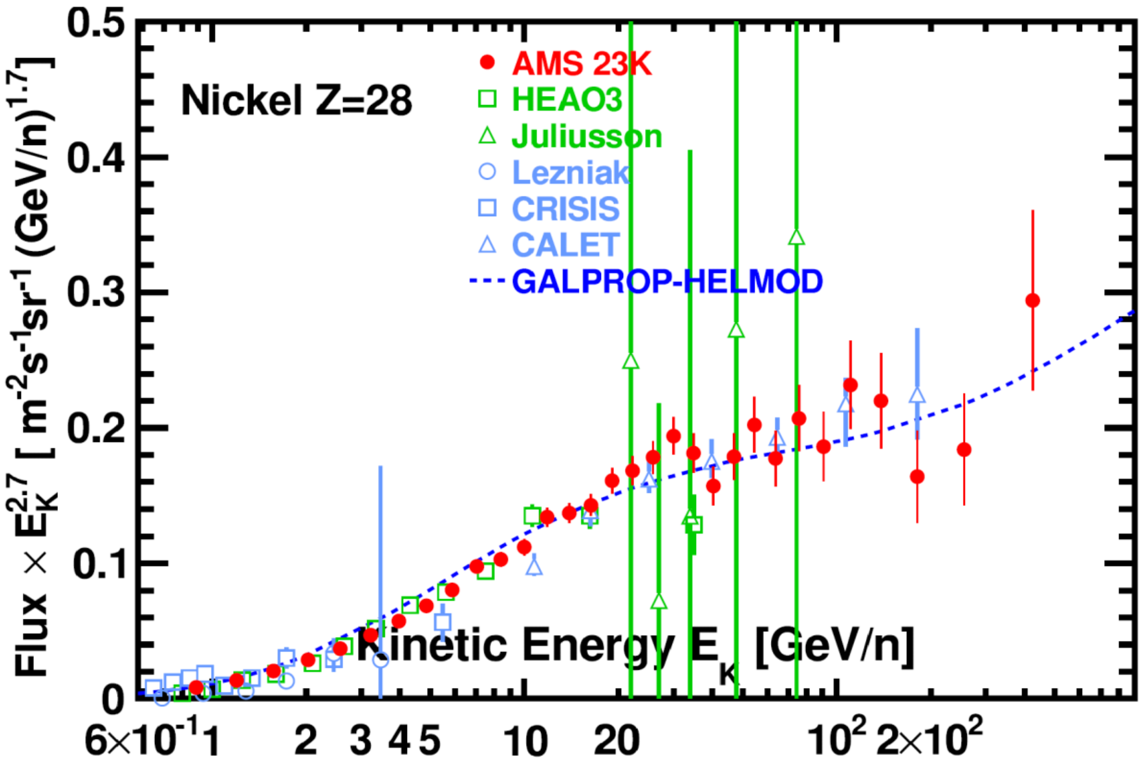
Above 86.5 GV, the Ne Mg Si and S fluxes have the same rigidity dependence.



The rigidity dependence of Ne-Mg-Si-S fluxes are distinctly different with He-C-O, which show that there are at least two classes of primary cosmic rays.

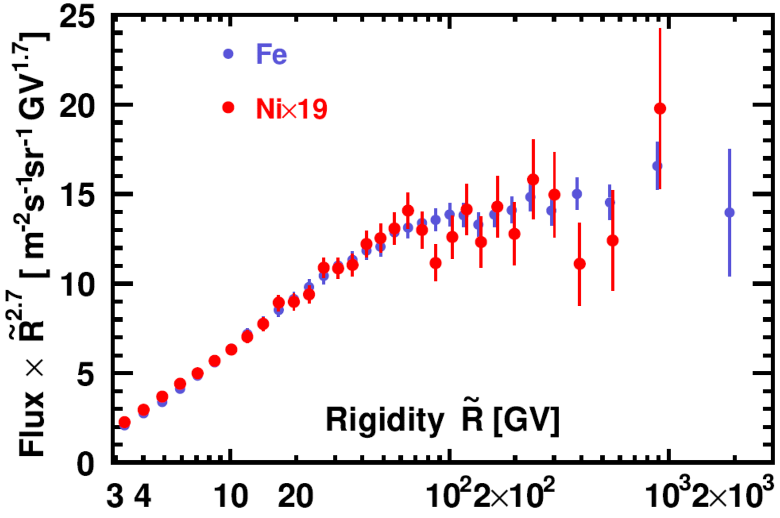
Primary Cosmic Rays: Iron and Nickel



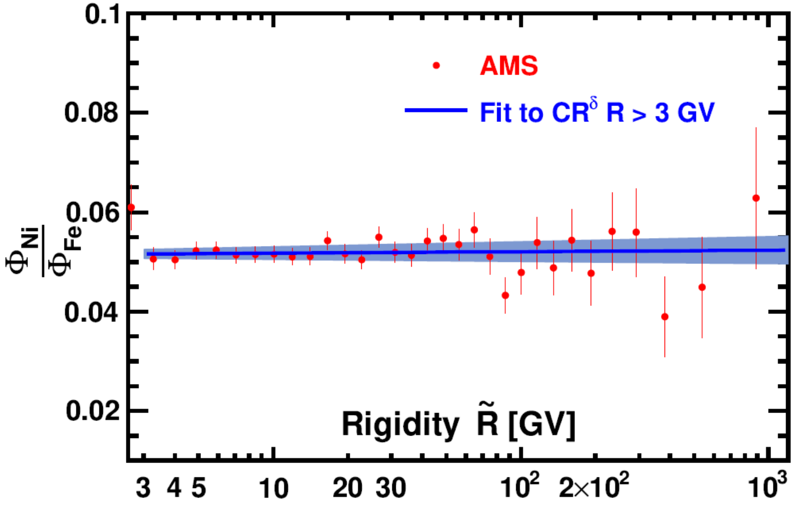


The AMS Iron (Fe) and Nickel (Ni) fluxes are the most accurate measurements, the Ni flux is also the measurement with highest energy.

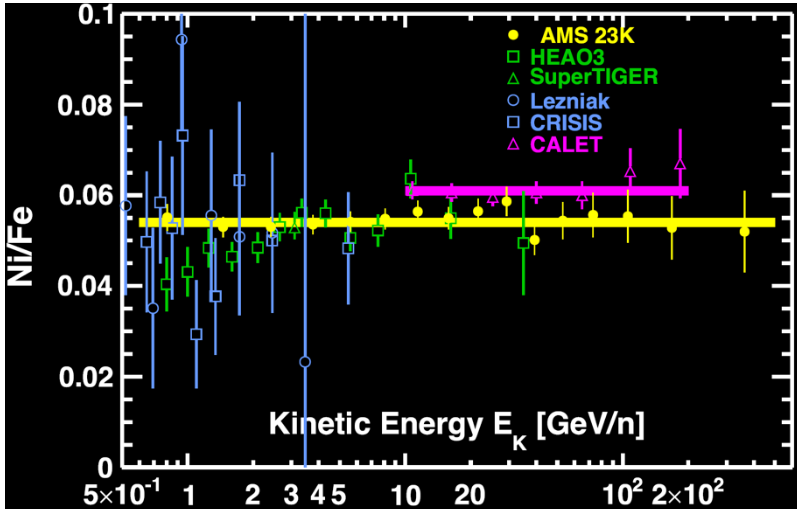
Primary Cosmic Rays: Iron and Nickel



Fe and Ni fluxes show same rigidity dependence over all the measured rigidity range.

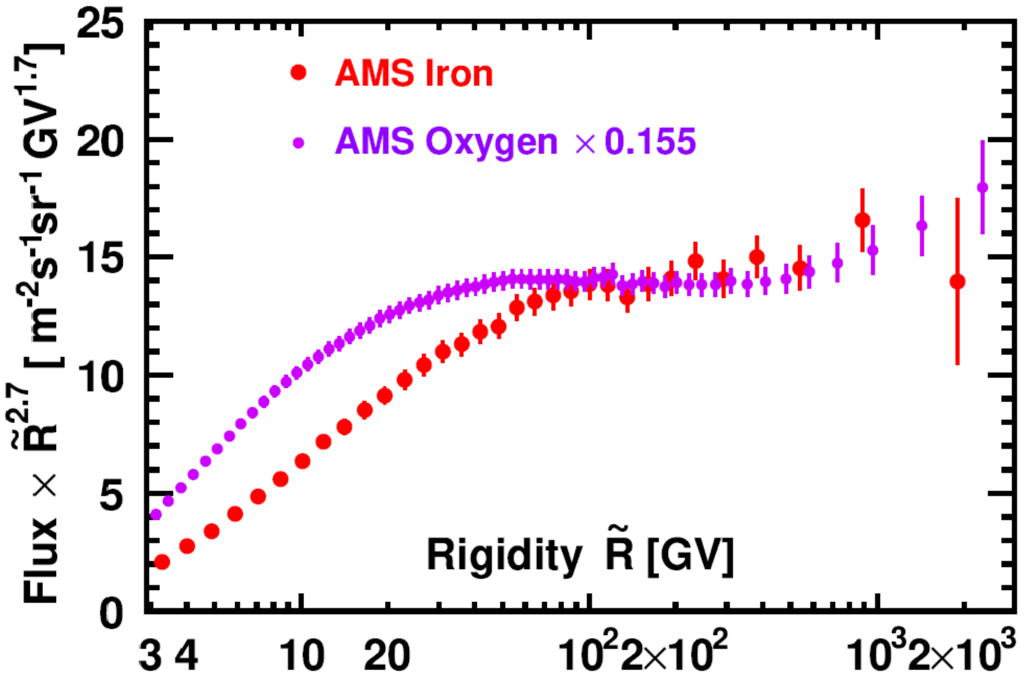


The flux ratio of Fe and Ni can be well fitted with single pow law with index $\delta = 0.0025 \pm 0.0085$, which is compatible with 0.

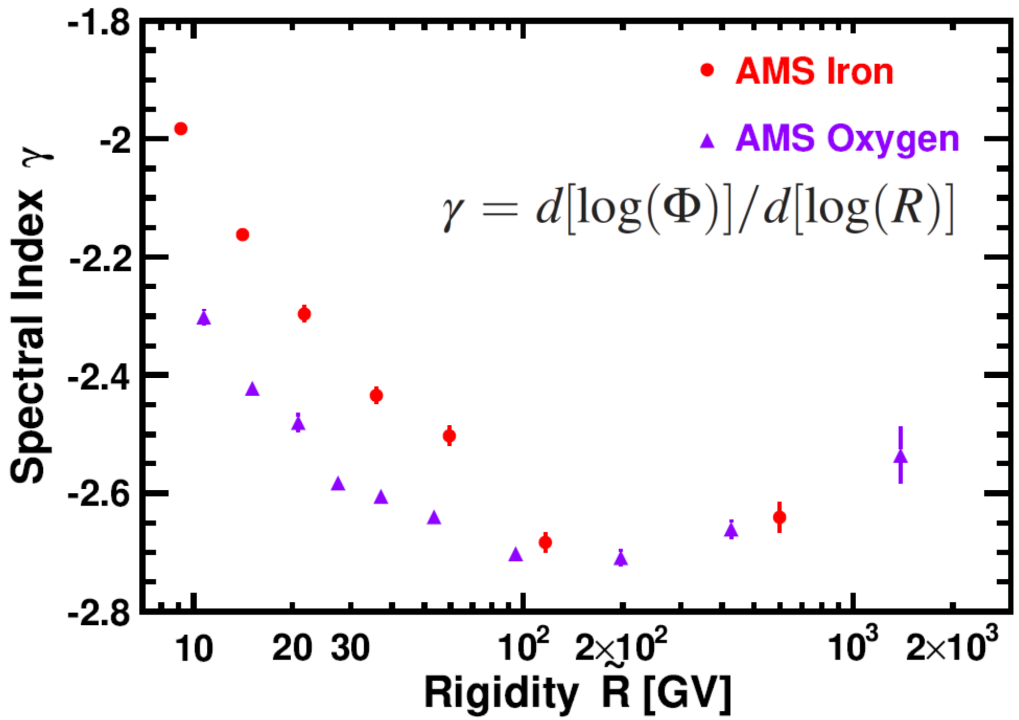


AMS extend the flux ratio of Fe and Ni to higher energy.

Primary Cosmic Rays: Iron and Nickel

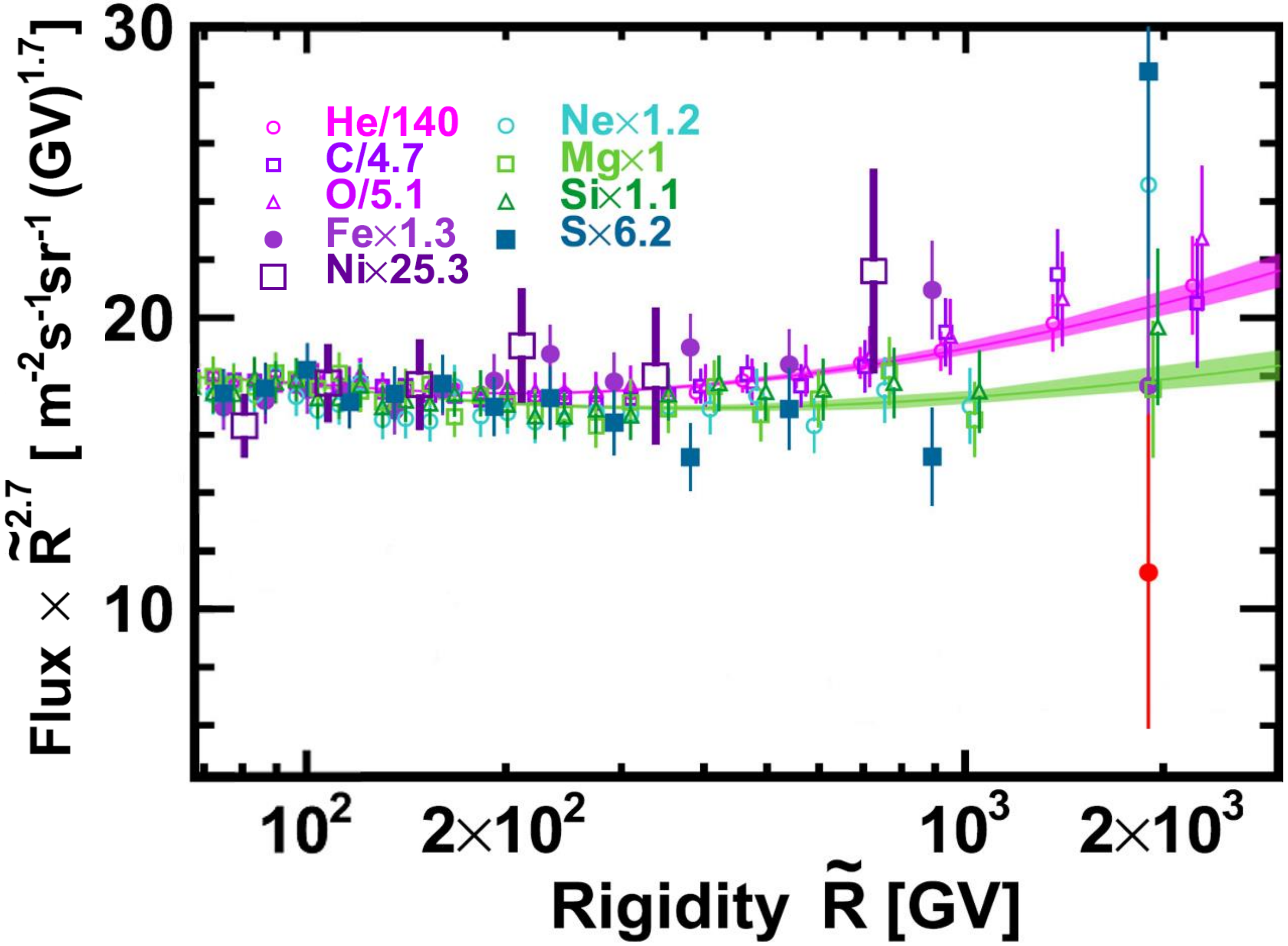


AMS Fe(Ni) show similar rigidity dependence with O at high rigidity.



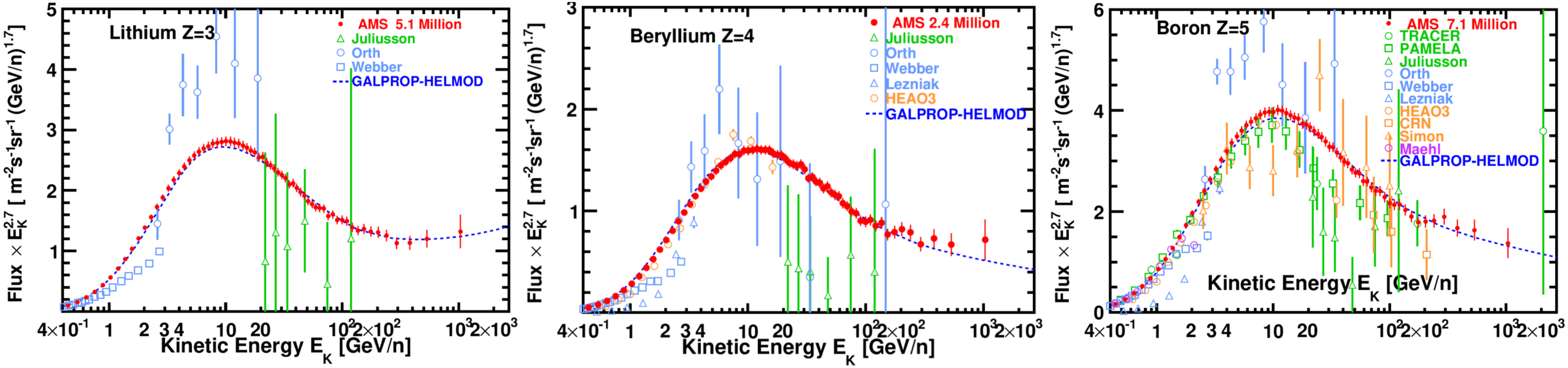
Above 80.5 GV, the spectral index of Fe and O fluxes are compatible, this result unexpectedly shows that Fe(Ni) belongs to the same class with He-C-O other than Ne-Mg-Si-S.

Two Group of Primary Cosmic Rays



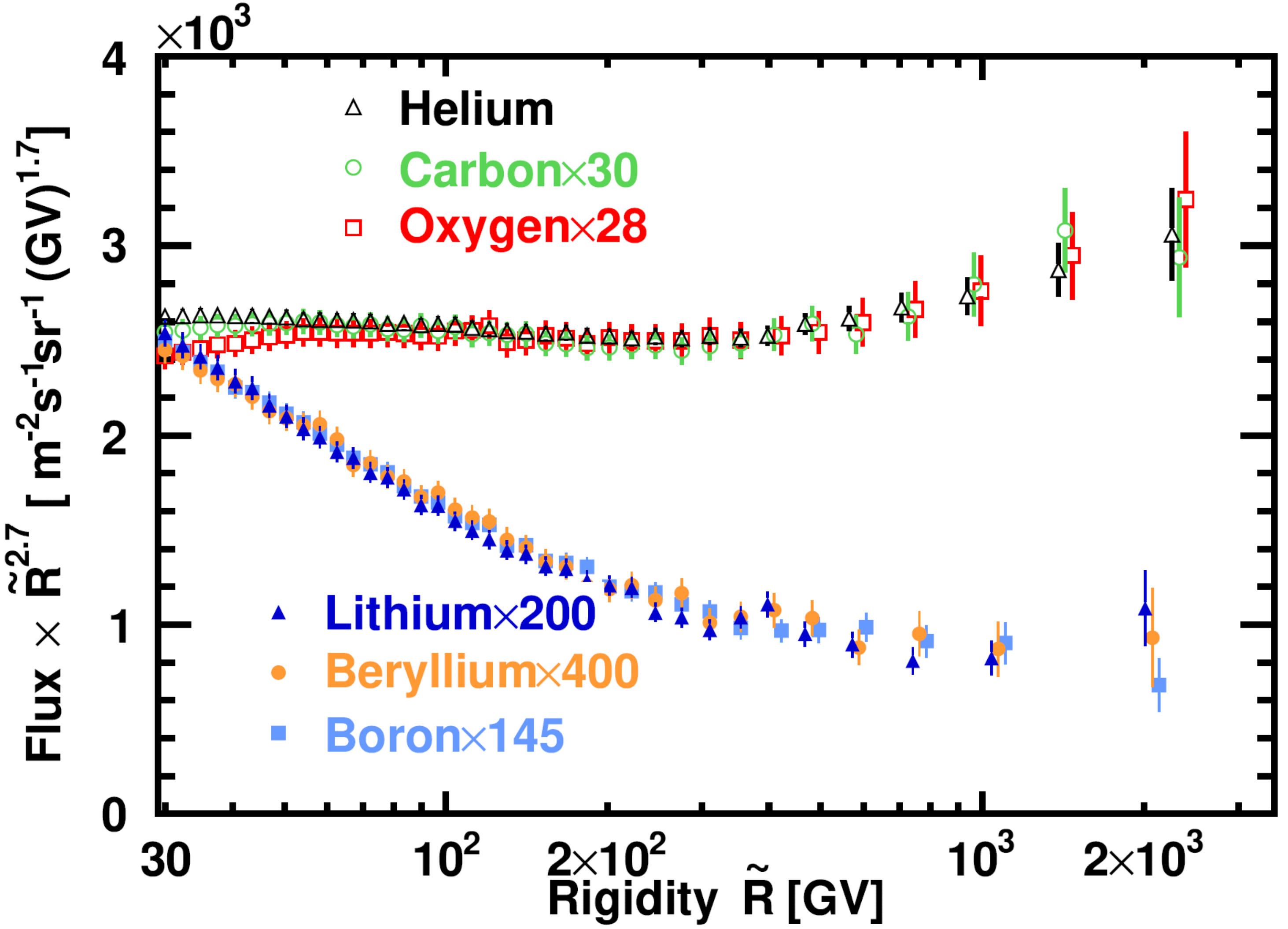
These results show that there are two classes of primary cosmic rays with **He-C-O-Fe-Ni** as one group and **Ne-Mg-Si-S** as the other.

Secondary Cosmic Rays: Lithium, Beryllium and Boron



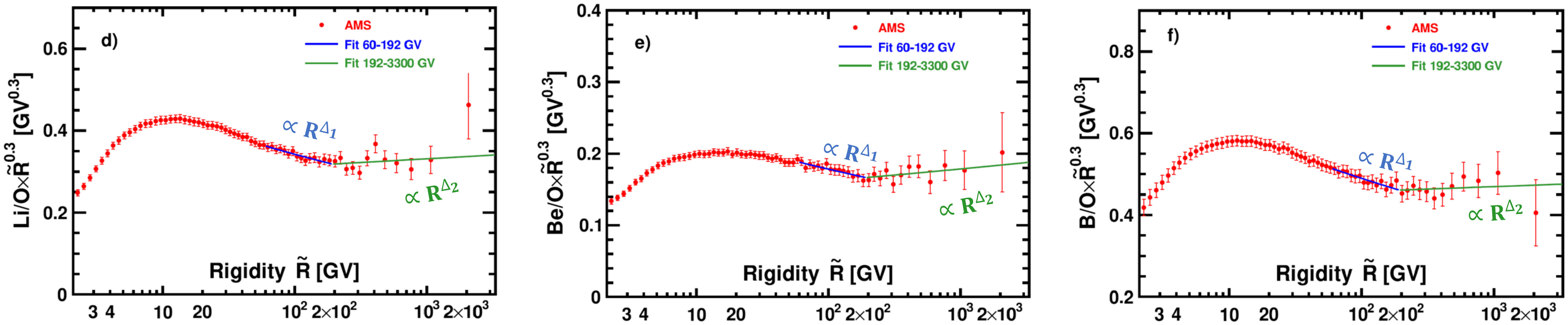
AMS measured the Lithium (Li), Beryllium (Be) and Boron (B) fluxes with unprecedented precision also extended the fluxes to higher energy range.

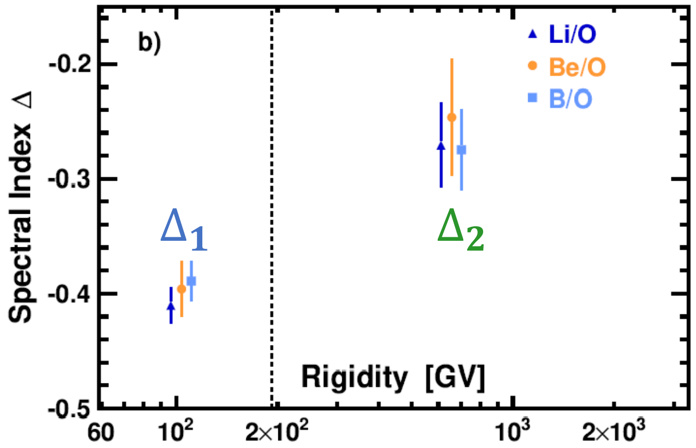
Secondary Cosmic Rays: Lithium, Beryllium and Boron



The secondary Li-Be-B fluxes have the same rigidity dependence above 30 GV, and it is distinctly different with primary cosmic rays.

Secondary Cosmic Rays: Lithium, Beryllium and Boron

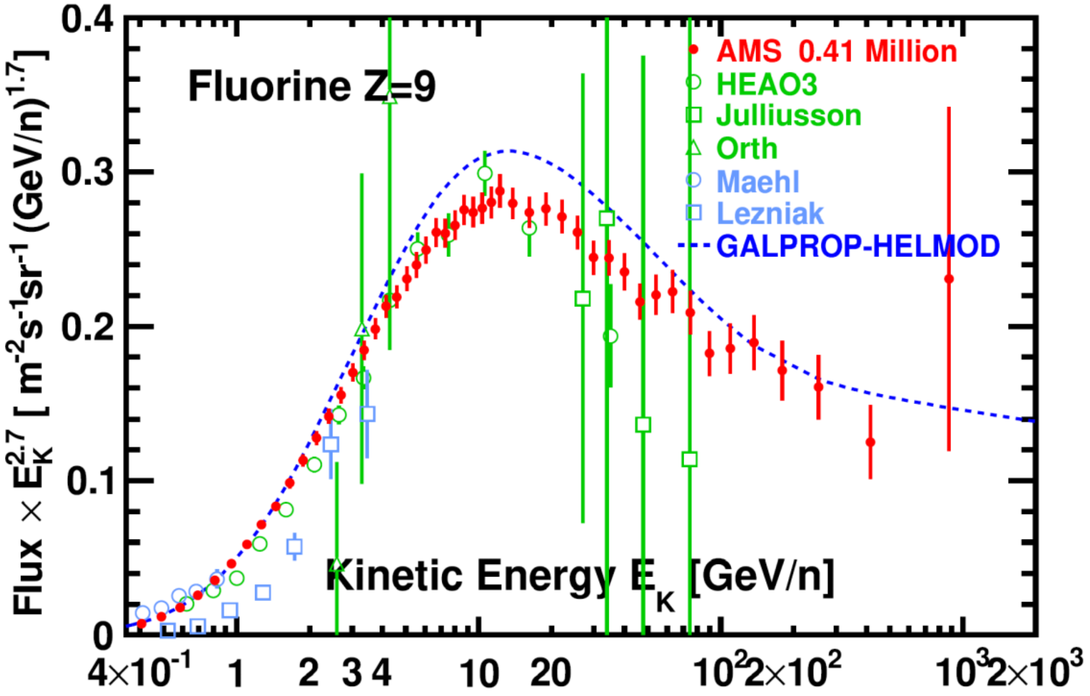


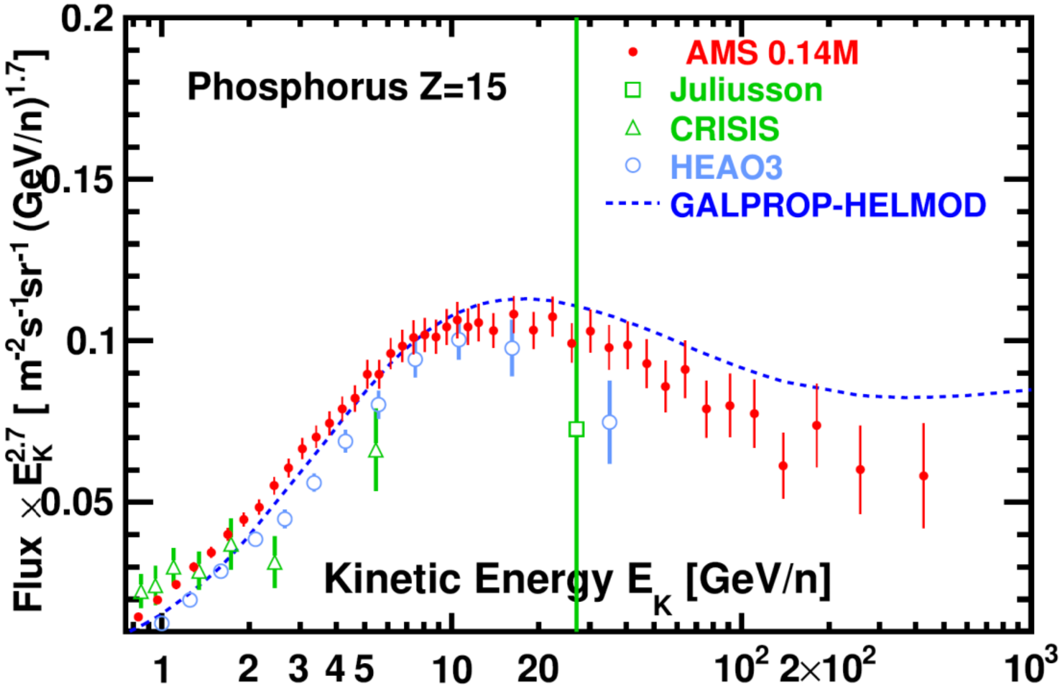


- Above 200 GV, all three secondary-to-primary flux ratios harden with Δ_2 - $\Delta_1 = \mathbf{0.13 \pm 0.025}$

- The Δ_2 is not compatible with Δ_1 with C.L more than 5σ show that the spectral hardening at ~200 GV is due to propagation effect.

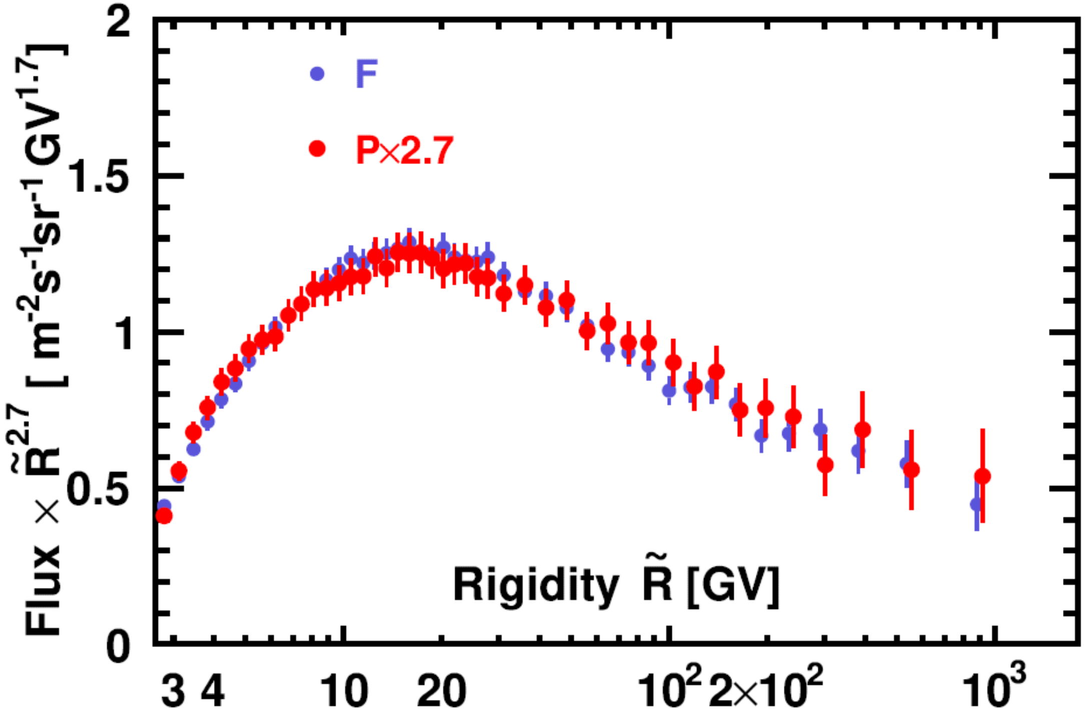
Secondary Cosmic Rays: Fluorine and Phosphorus



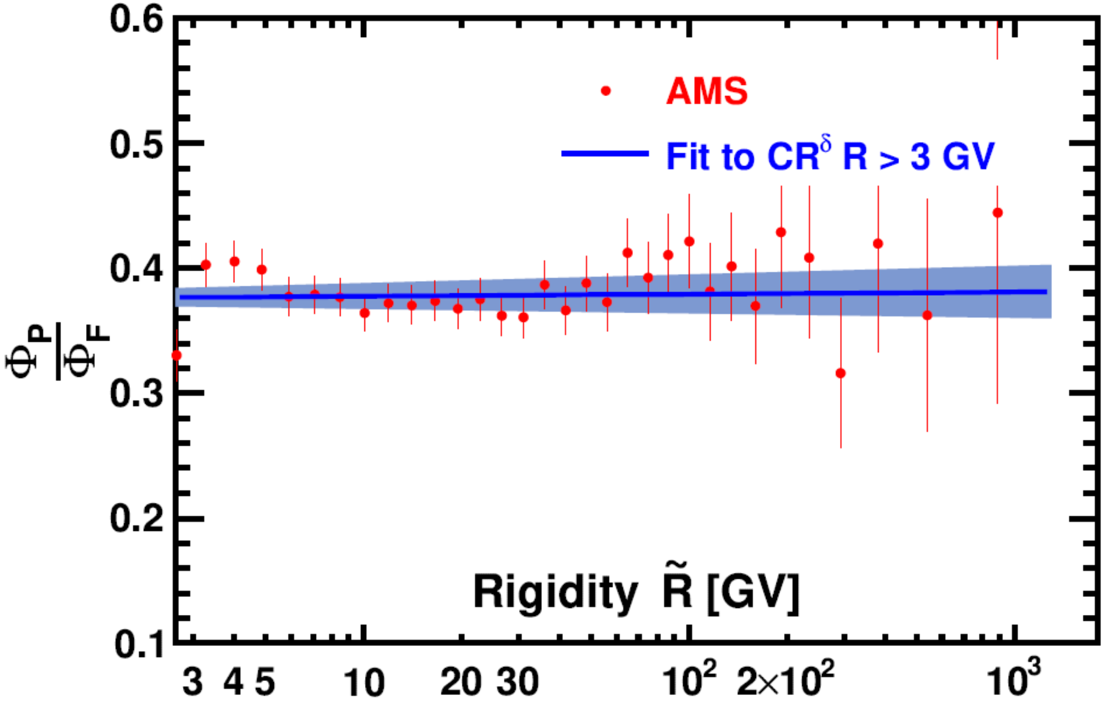


AMS measured the Fluorine (F) and Phosphorus (P) fluxes with unprecedented precision, and extended the measured energy to a much higher range.

Secondary Cosmic Rays: Fluorine and Phosphorus

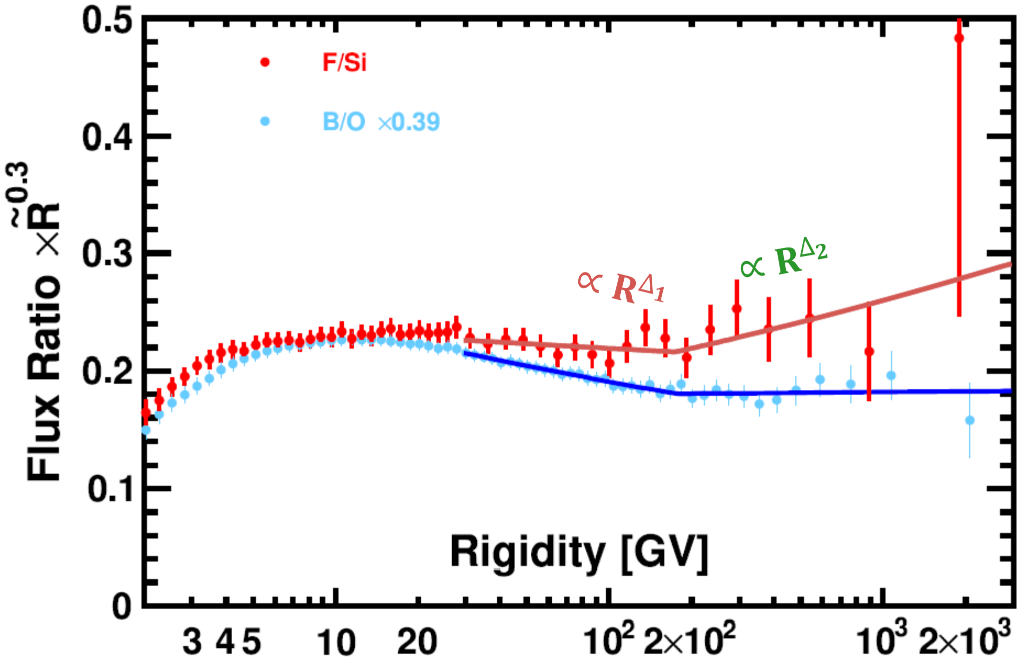


The rigidity dependence of P and F fluxes are very similar over the entire rigidity range

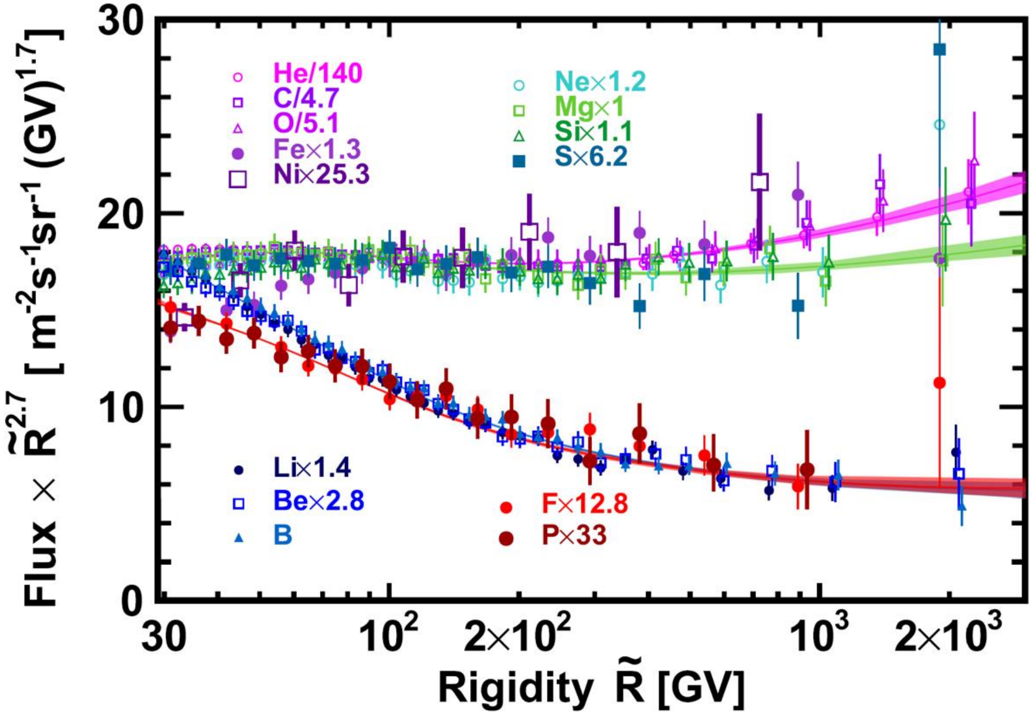


The flux ratio of P and F are fitted with single power law, which yields $\delta = 0.002 \pm 0.009$, the δ is compatible with 0 confirm that P and F have similar rigidity dependence.

Two Groups of Secondary Cosmic Ray

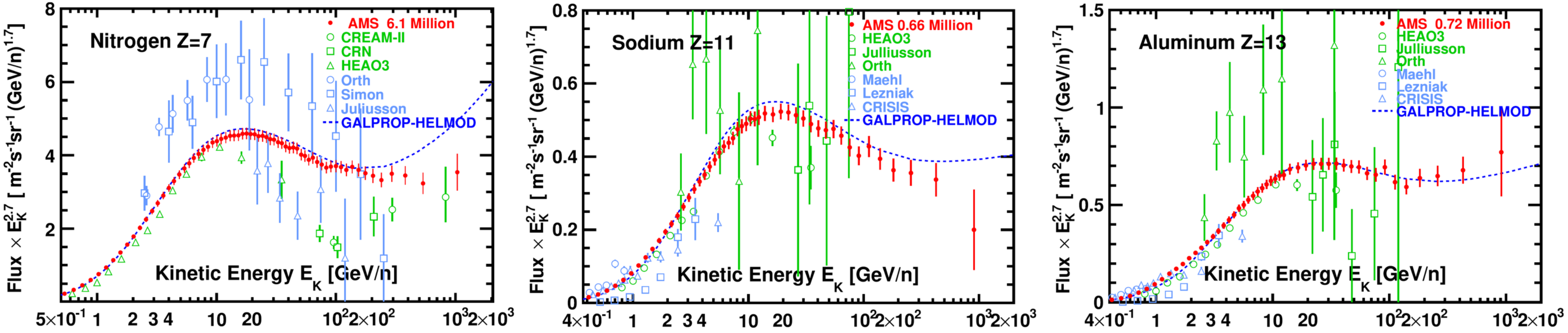


The F/Si flux ratio also show a spectral hardening with Δ_2- $\Delta_1 = 0.14 \pm 0.06$ which is compatible with that of B/O flux ratio hardening with 0.13 ± 0.025. The F/Si is distinctly different with B/O, which indicates that F(P) and Li-Be-B belong to different class of secondary cosmic rays.



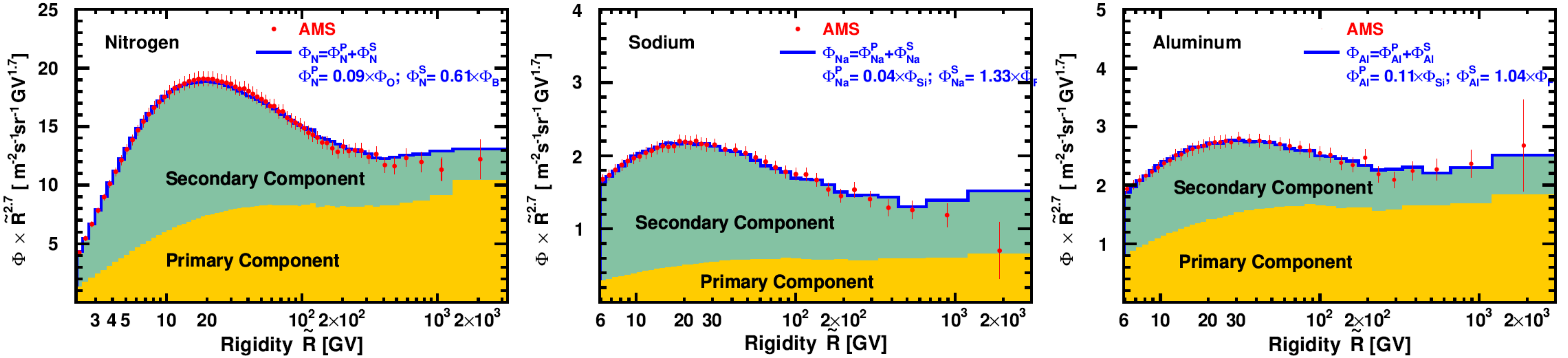
AMS Found that primary cosmic rays have two classes of rigidity dependence with He-C-O-Fe-Ni as one group and Ne-Mg-Si-S as the other; The secondary cosmic rays also have two classes with Li-Be-B as one group and F-P as the other.

Third Group of Cosmic Rays: Nitrogen, Sodium and Aluminum



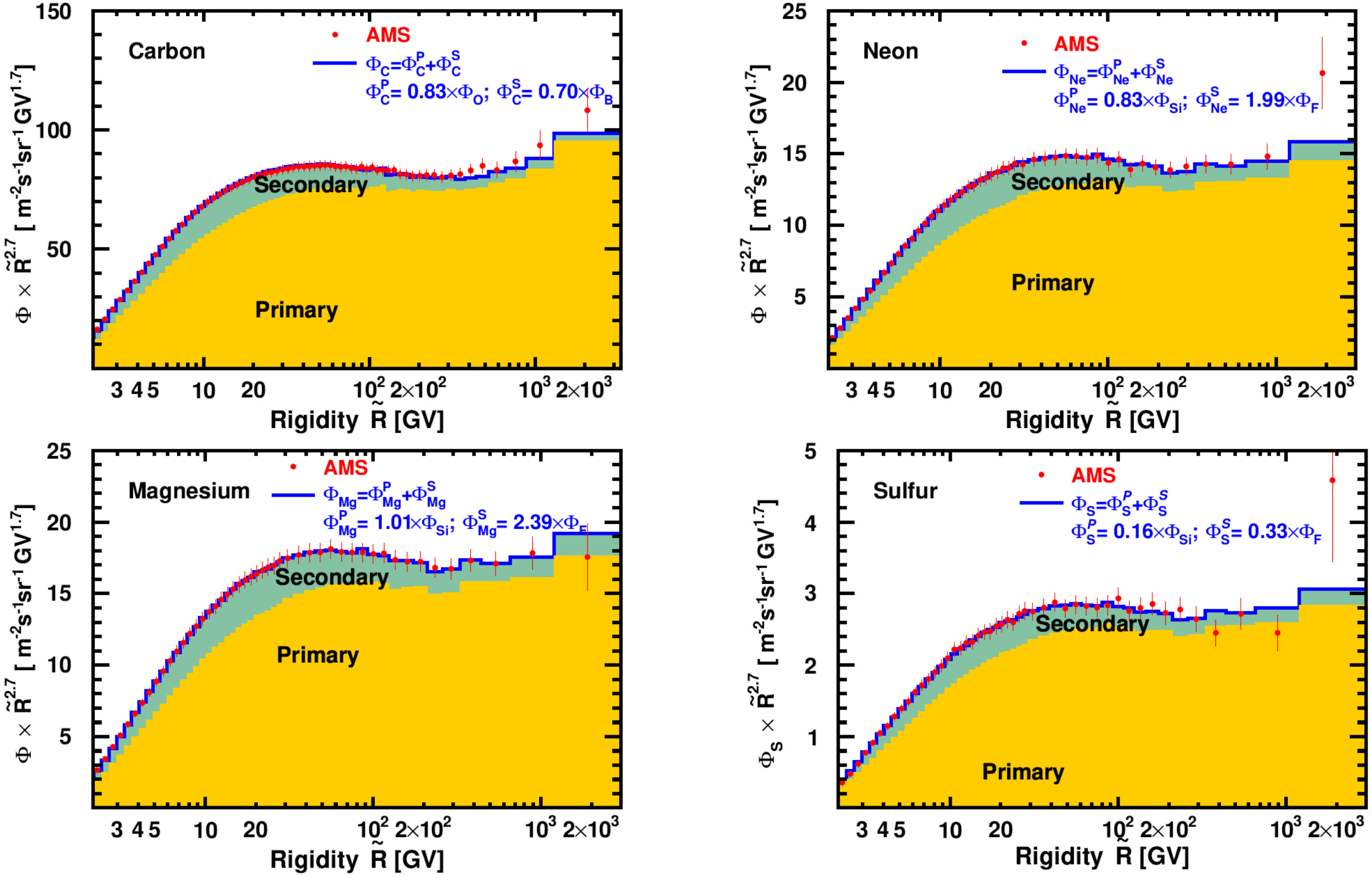
AMS measured the Nitrogen (N), Sodium (Na) and Aluminum (Al) fluxes with unprecedented precision, and extended the measured rigidity to a much higher range.

Primary and Secondary Components of Nitrogen, Sodium and Aluminum



AMS found that N, Na and Al belong to a distinct cosmic ray group and are the combinations of primary and secondary cosmic rays. The N, Na and Al fluxes can be described as the weighted sum of nearby primary (O for N, Si for Na and Al) and nearby secondary(B for N, F for Na and Al) fluxes.

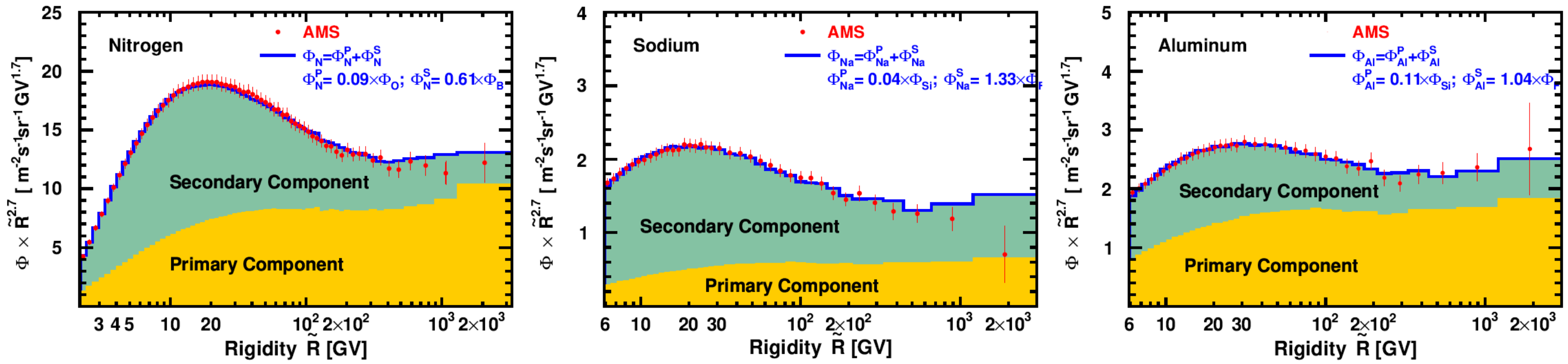
New Discovery：Secondary Components of Carbon, Neon, Magnesium and Sulfur



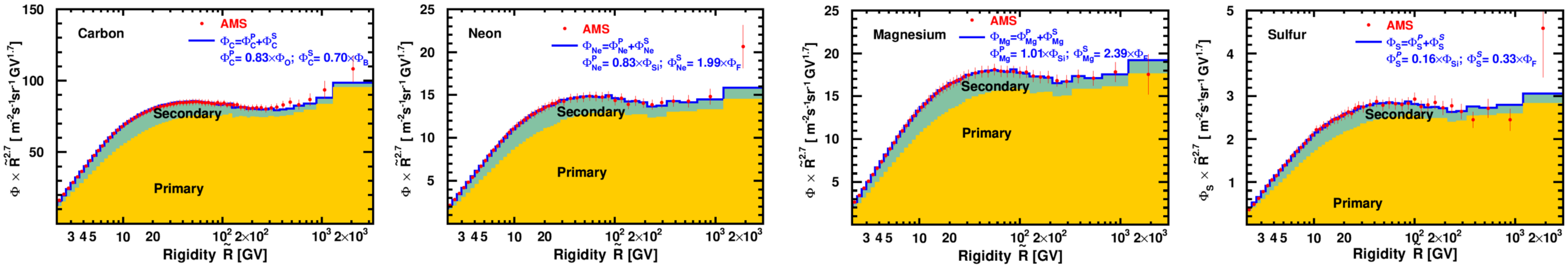
The traditional primary cosmic ray C, Ne, Mg and S also contain sizeable secondary components, their fluxes can be well described by the nearby primary (O for N, Si for Na and Al) and nearby secondary(B for N, F for Na and Al) fluxes.

Secondary Components of Odd Z and Even Z Cosmic Rays

Odd Z



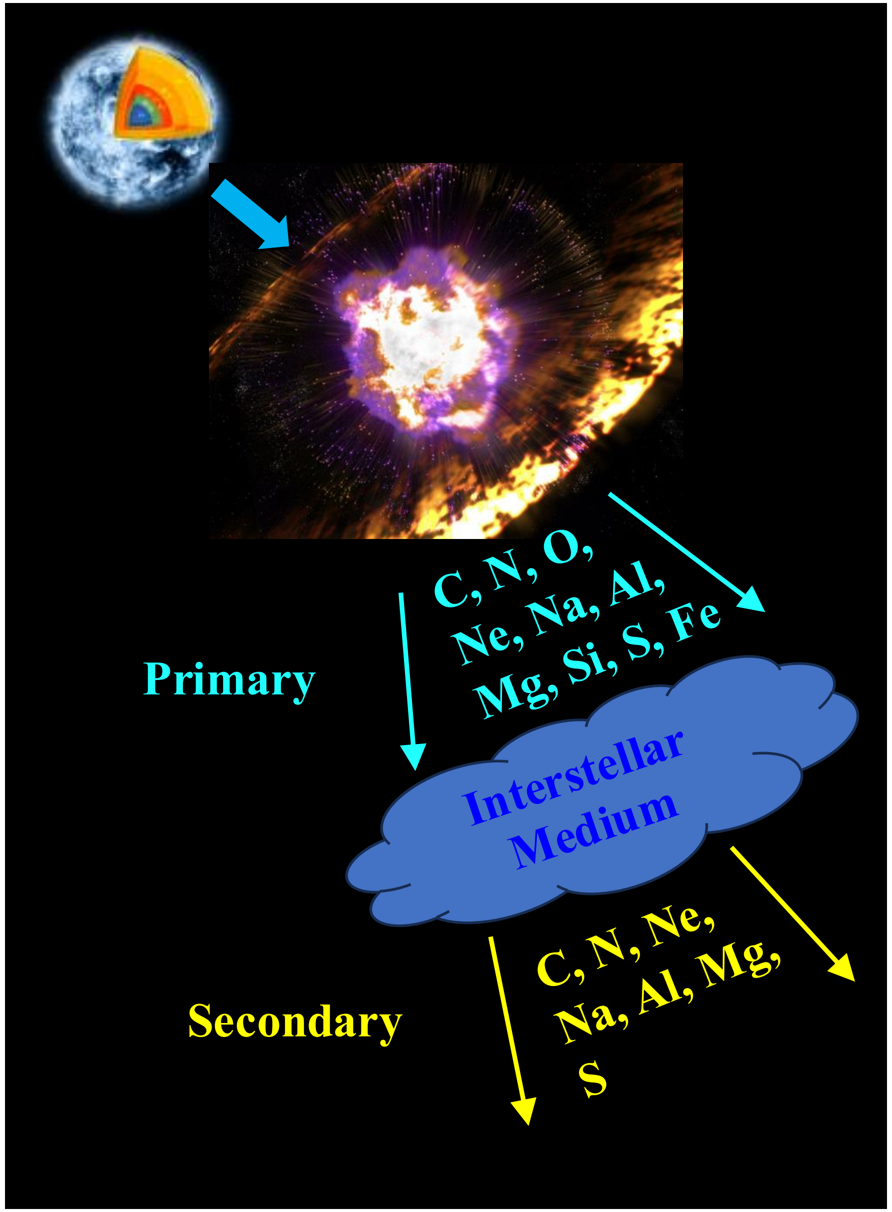
Even Z



	Φ_C	Φ_{Ne}	Φ_{Mg}	Φ_S	Φ_N	Φ_{Na}	Φ_{Al}
Secondary Fraction (% at ~6 GV)	20 ± 1	24 ± 1	25 ± 1	18 ± 3	69 ± 1	81 ± 2	57 ± 2
Secondary Fraction (% at ~2 TV)	4 ± 0.5	5 ± 0.5	5 ± 0.5	3 ± 1	23 ± 2	38 ± 12	22 ± 8

The odd Z nuclei contains more secondary components than even Z nuclei.

Abundance Ratios at Cosmic Ray Sources



Based on the AMS measurements on the primary and secondary components, a model-independent way can be used to compute the primary nuclei abundance ratios at cosmic ray sources.

Fluxes	Abundance Ratio
Φ_C/Φ_O	0.83 ± 0.02
Φ_{Ne}/Φ_{Si}	0.83 ± 0.02
Φ_{Mg}/Φ_{Si}	1.01 ± 0.03
Φ_S/Φ_{Si}	0.162 ± 0.005
Φ_N/Φ_O	0.092 ± 0.002
Φ_{Na}/Φ_{Si}	0.036 ± 0.003
Φ_{Al}/Φ_{Si}	0.103 ± 0.004

Summary

The properties of cosmic rays p, He, Li, Be, B, C, N, O, F, Ne, Na, Mg, Al, Si, P, S, Fe and Ni fluxes have been presented, many new discoveries have been revealed:

- The p flux contains two components, one is just like He the other is unique to p;
- The rest primary cosmic rays can be separated into two classes with **He-C-O-Fe-Ni** as one group and **Ne-Mg-Si-S** as the other;
- The secondary cosmic rays also have two classes with **Li-Be-B** as one group and **F-P** as the other;
- The third group of cosmic ray N, Na and Al can be described as linear combination of primary and secondary cosmic rays.

Thank you