Unique Properties of Primary Cosmic Rays
Latest Results from AMS

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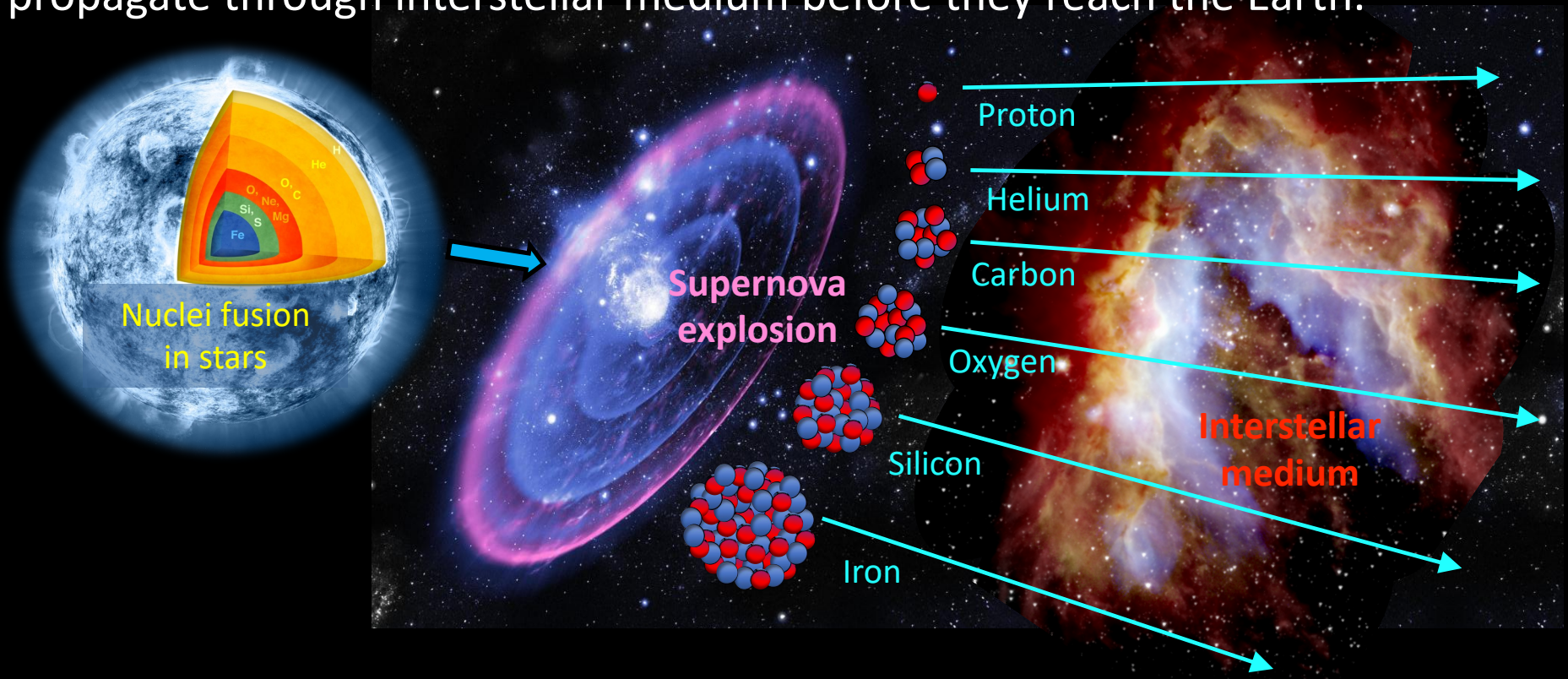
ICHEP 2022, Bologna, Italy

Primary Cosmic Rays

Primary cosmic rays p, He, C, O, ..., Si, ..., Fe are mostly produced during the lifetime of stars and accelerated in supernovae shocks. These particles propagate through interstellar medium before they reach the Earth.



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

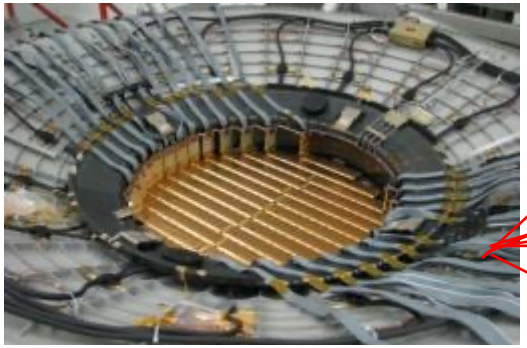
AMS: a unique TeV precision, accelerator-type spectrometer in space

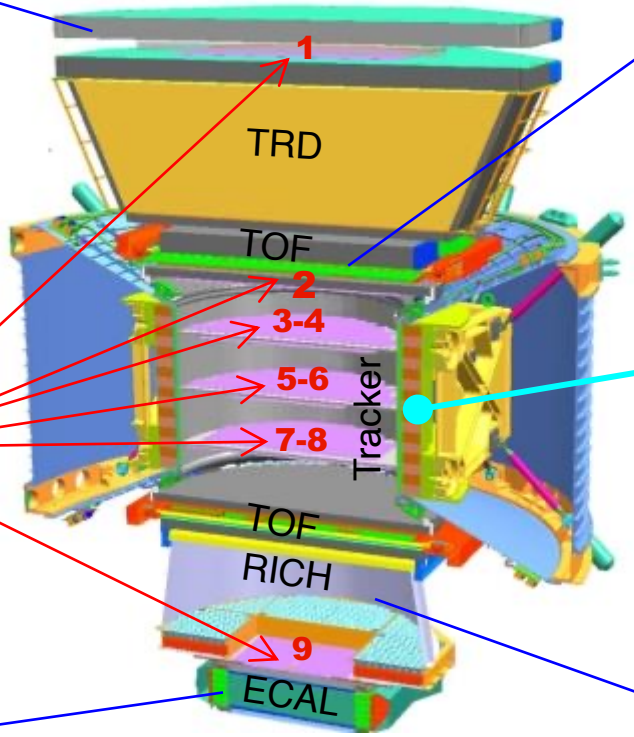
Particles and nuclei are defined by their charge (Z) and energy (E) or momentum (P). Rigidity R = P/Z

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

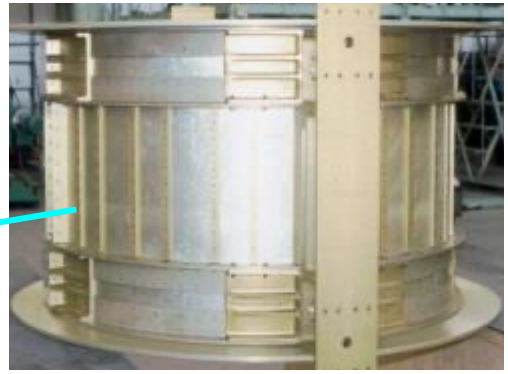
TOF: Z, E

Silicon Tracker: Z, P

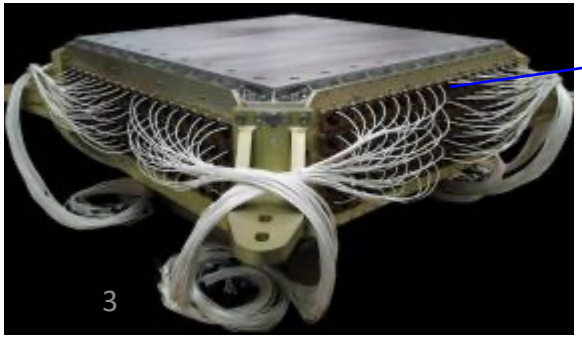




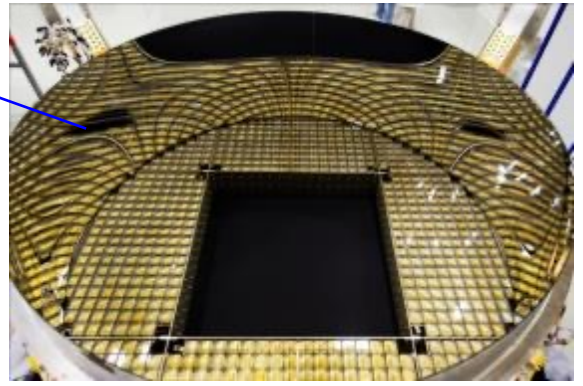
Magnet: ±Z



ECAL: E of e^+, e^-



RICH: Z, E

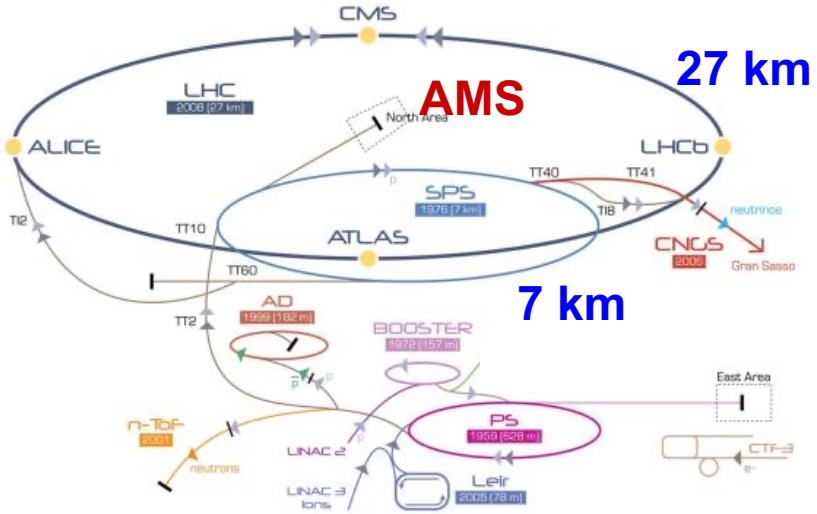


Z and P

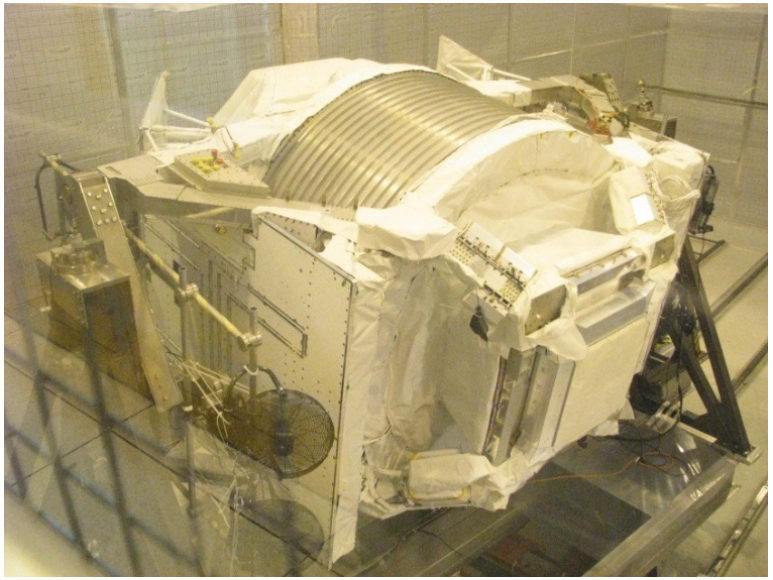
are measured independently by the Tracker, RICH, TOF, and ECAL

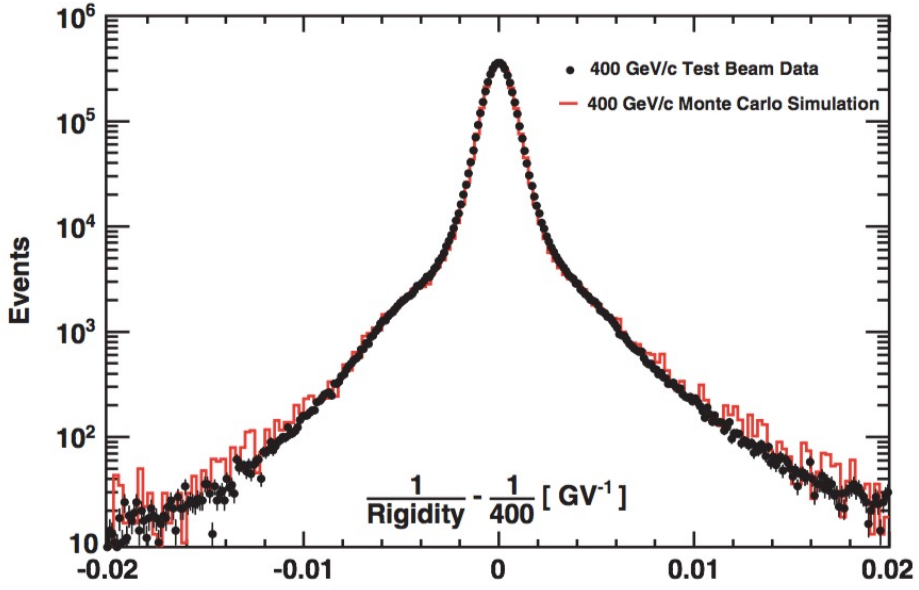
Calibration of the AMS Detector

Test beam at CERN SPS:
p, $e^{\pm}$, $\pi^{\pm}$, 10−400 GeV



2000 positions





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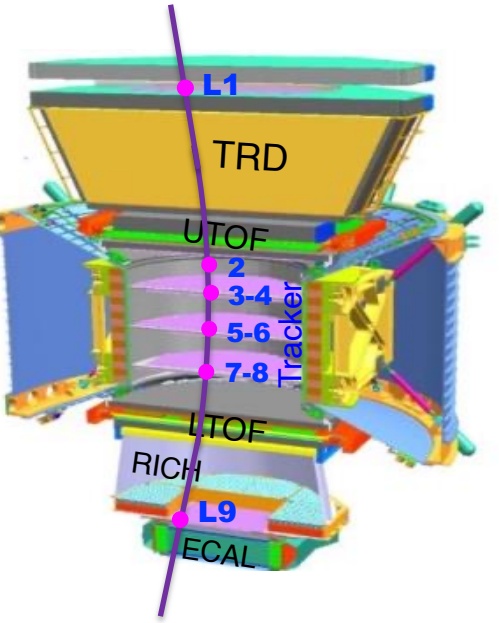
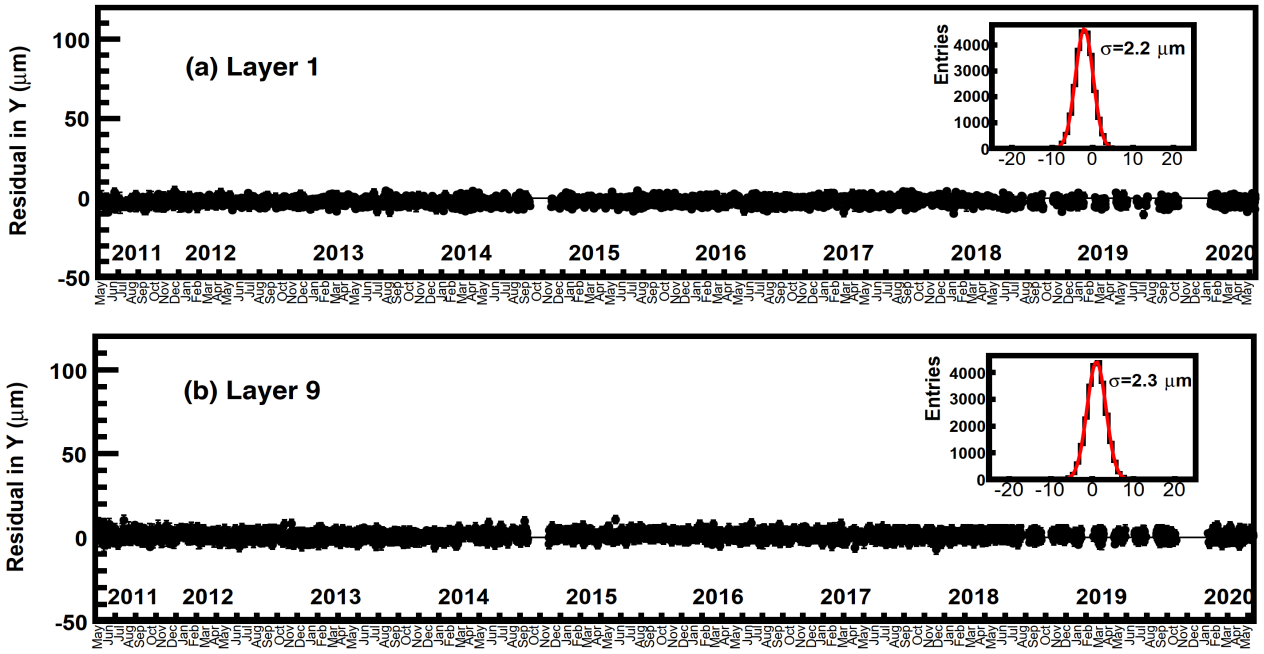
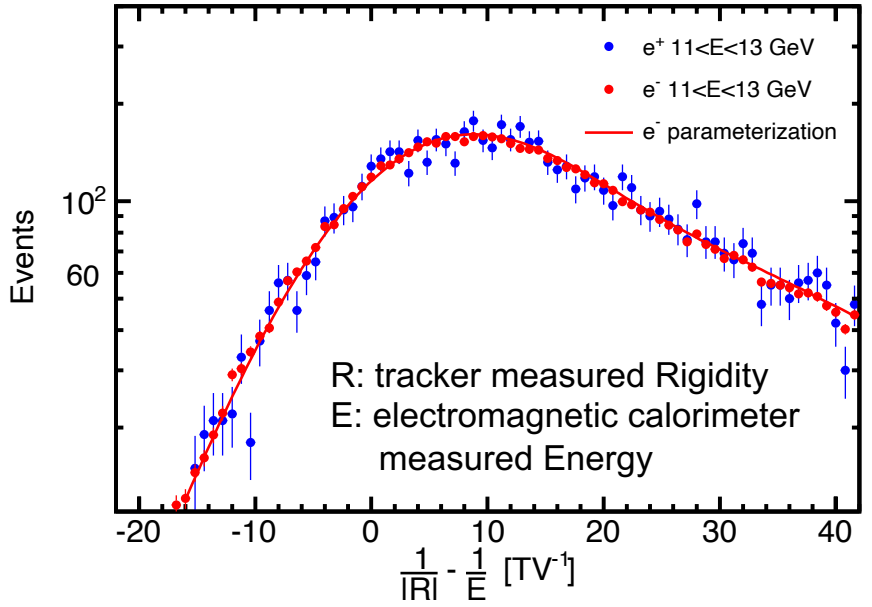
AMS Tracker Alignment & Calibration

The position of the outer layer L1 and L9 are precisely aligned by using cosmic rays events.





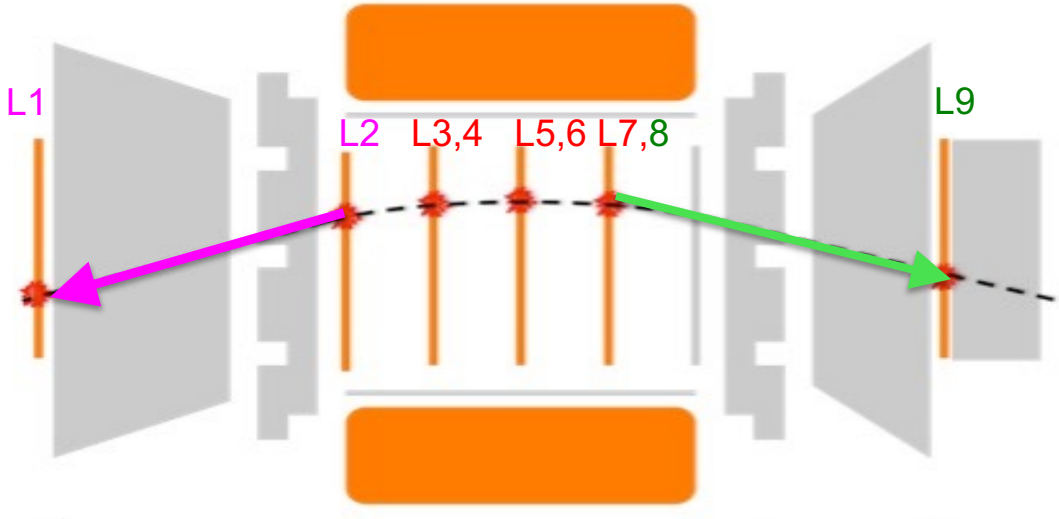
The vibrations and accelerations during the AMS launch into space could change the tracker positions at micron level. This misalignment was precisely corrected in space by analyzing track trajectories of opposite charged particles. This allows to determine the displacement of the L2-L8 layers with an accuracy better than 0.2 μm, corresponding to the accuracy of the tracker rigidity-scale of better than 1/30 TV^{-1}.

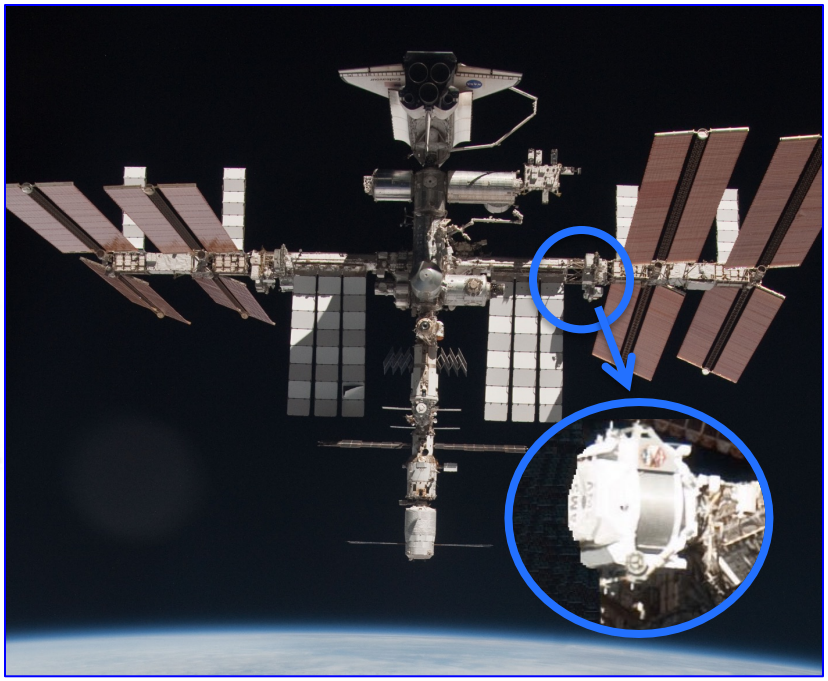


J. Berdugo, V. Choutko, C. Delgado, Q. Yan, Nucl. Instrum. Methods Phys. Res. A 869, 10 (2017).

Nuclei Interaction Cross-Section Measurements with AMS

To accurately measure the spectra of cosmic-ray nuclei, the knowledge of nuclei interaction cross sections with the AMS material are important. The material is composed mostly of *C* and *Al*. The interaction cross sections of *Nu + C, Nu + Al* were not well known before AMS.



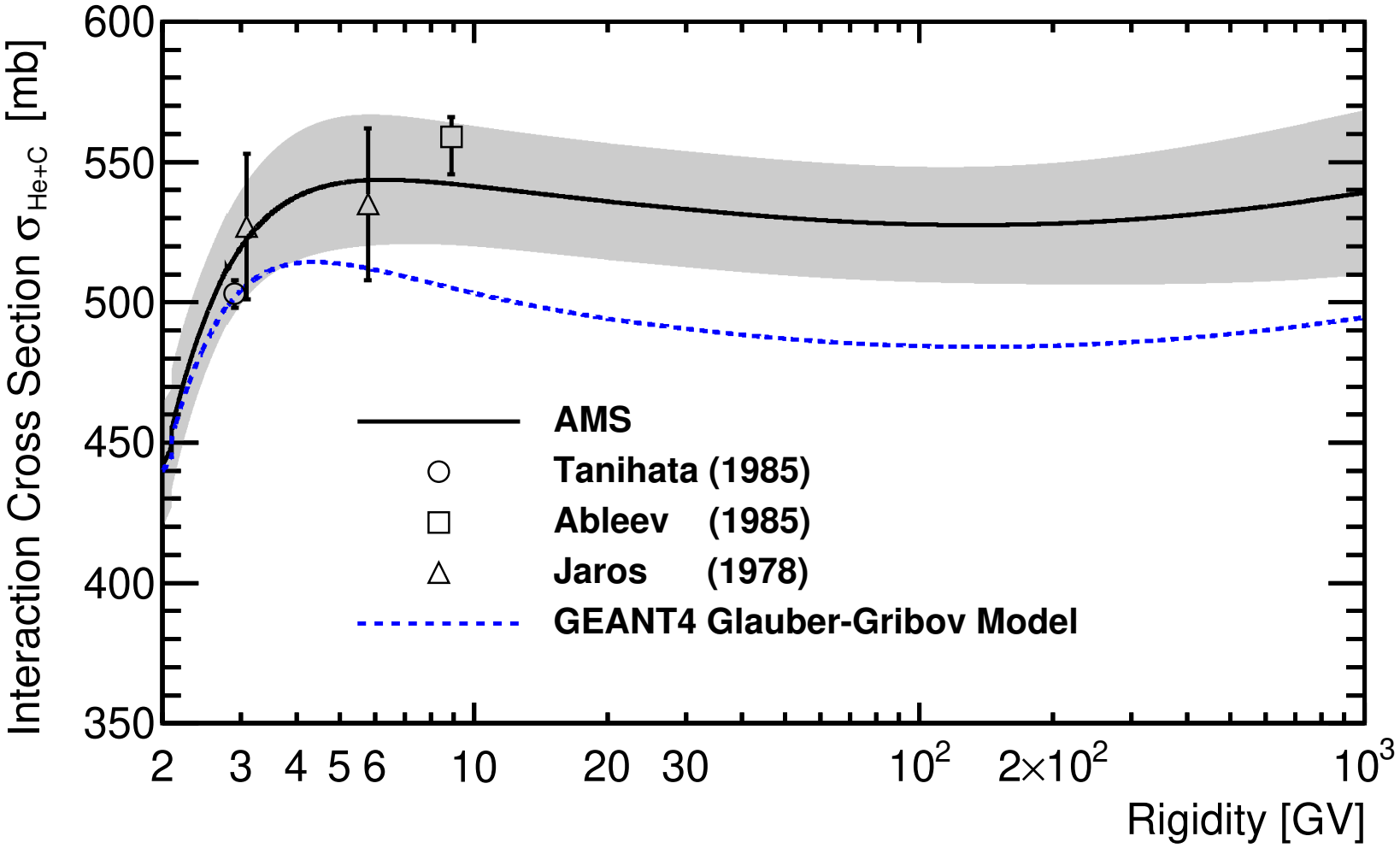


AMS data acquisition when the attitude of the International Space Station was rotated 90 degree, in which particles can enter AMS both right to the left and left to the right.

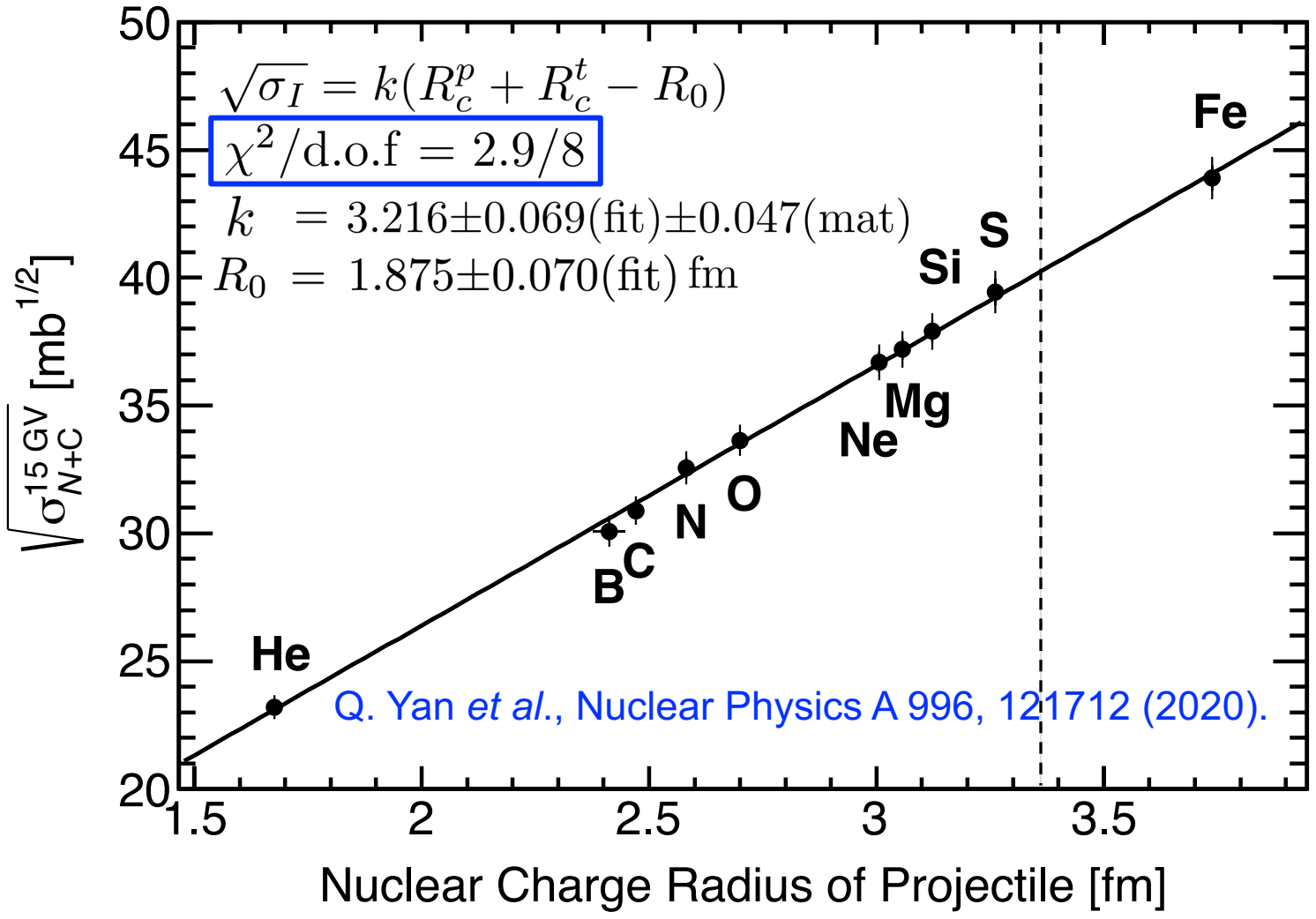
AMS has made nuclei Interaction cross-section measurements in a wide rigidity range from a few GV to TV using the collected cosmic-ray events.

AMS measured He+C Interaction Cross Section

Q. Yan *et al.*, Nuclear Physics A 996, 121712 (2020).



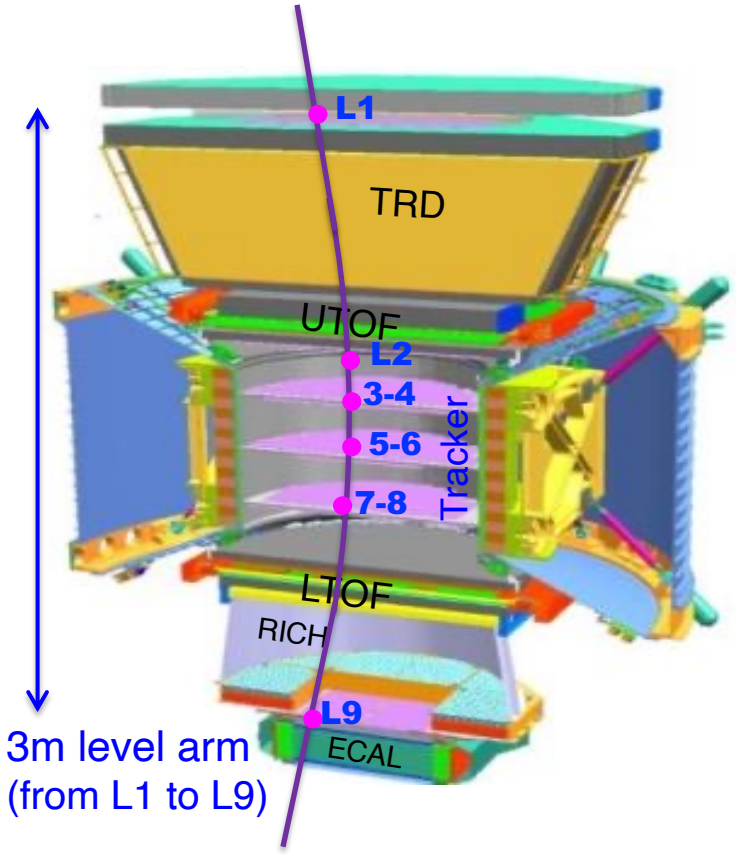
AMS Measured Nuclei+C Interaction Cross Sections



The square root of the interaction cross section on carbon target at rigidity 15 GV as a function of nuclear charge radius (R_c^p) for the projectile nuclei He, B, C, N, O, Ne, Mg, Si, S, and Fe. The nuclear charge radii are from "I. Angeli and K. P. Marinova, Atomic Data and Nuclear Data Tables 99 (2013) 69-95".

AMS Cosmic-Ray Nuclei Measurements

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



	Coordinate Resolution	MDR
Z =1	10 μm	2 TV
2≤Z≤26	5-8 μm	3-3.7 TV

TOF (4 Layers): Velocity and Direction

$\Delta\beta/\beta^2 \approx 4\%$ (Z=1)

$\Delta\beta/\beta^2 \approx$ 1-2% (Z≥2)

L1, UTOF, Inner Tracker (L2-L8), LTOF* and L9*

Consistent Charge Along Particle Trajectory

	Tracker L2-L8 Charge Resolution (c.u.)
1≤Z≤8	ΔZ ≈ 0.05-0.12
9≤Z≤14	ΔZ ≈ 0.13-0.17
15≤Z≤26	ΔZ ≈ 0.18-0.35

AMS Talks in ICHEP

1: This talk, primary cosmic rays

2: A. Oliva, secondary cosmic rays

3: Y. Chen, third group cosmic rays

4: C. Delgado, cosmic deuteron and ^{3}He

5: J. Wei, cosmic beryllium isotope

6: M. Molero, anisotropy of p and light nuclei

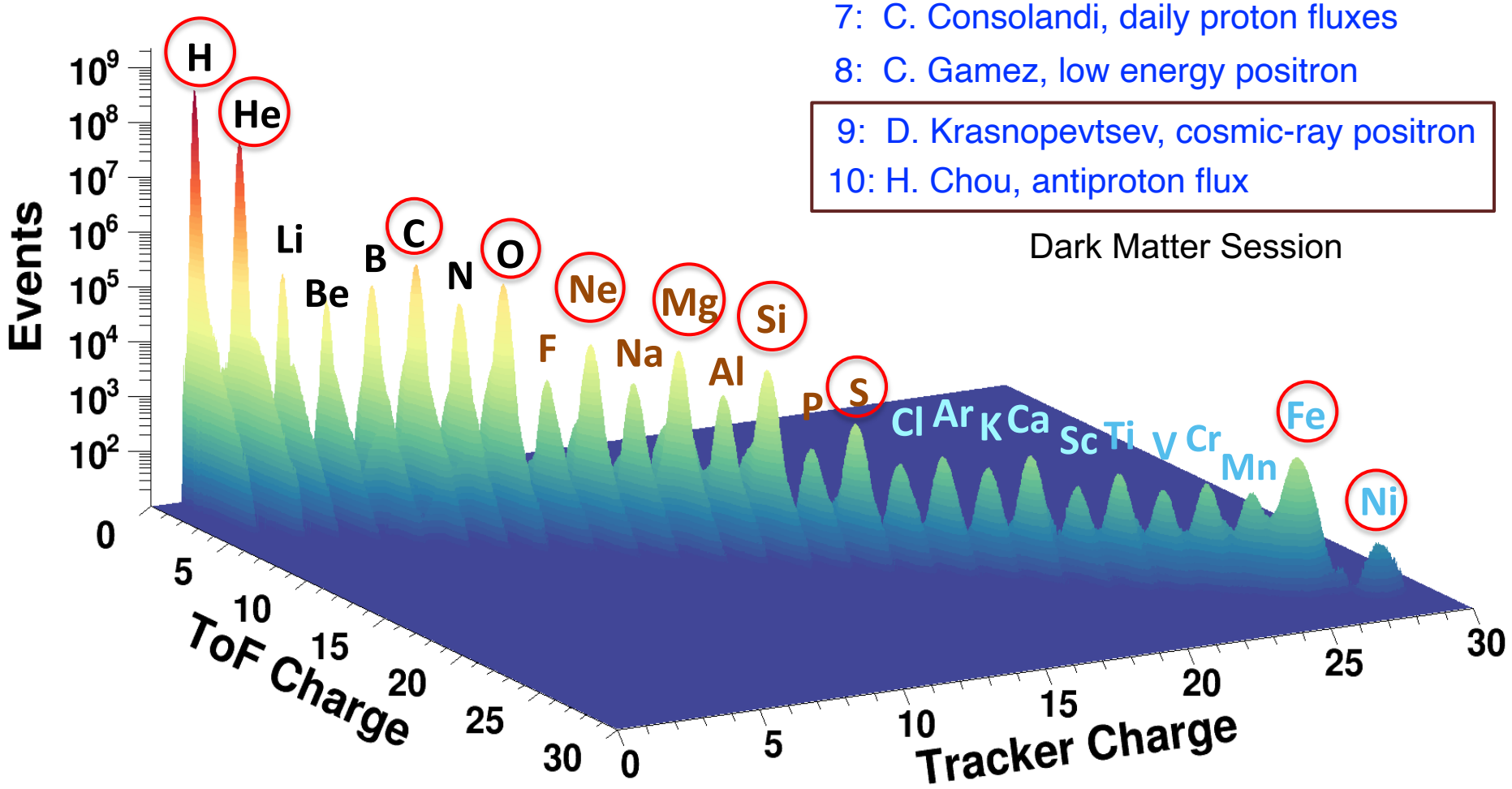
7: C. Consolandi, daily proton fluxes

8: C. Gamez, low energy positron

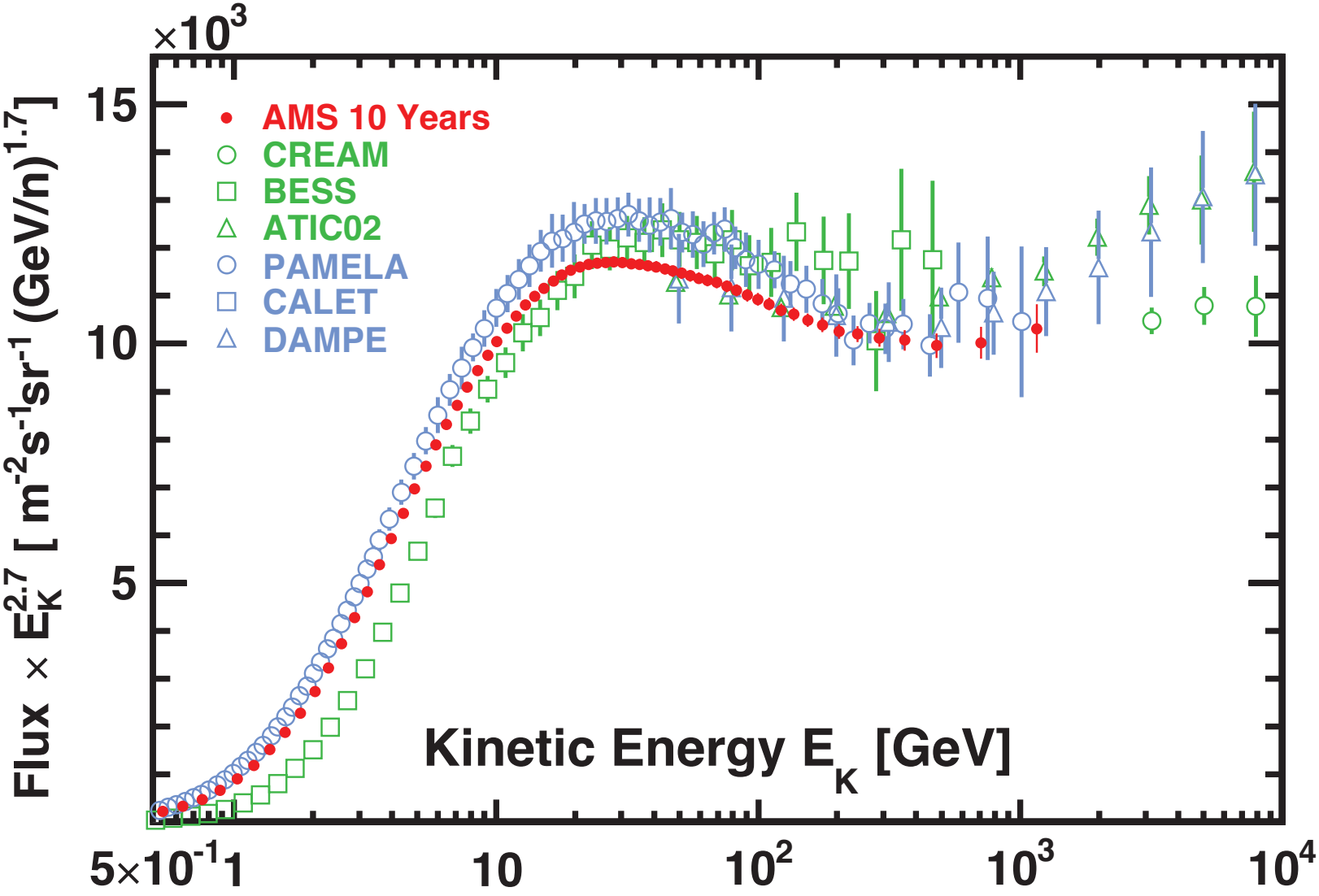
9: D. Krasnopevtsev, cosmic-ray positron

10: H. Chou, antiproton flux

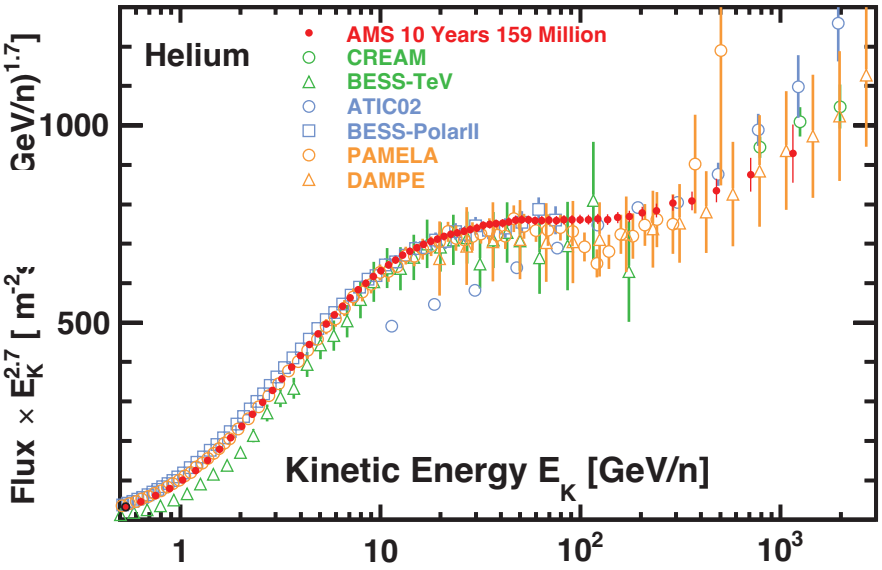
Dark Matter Session

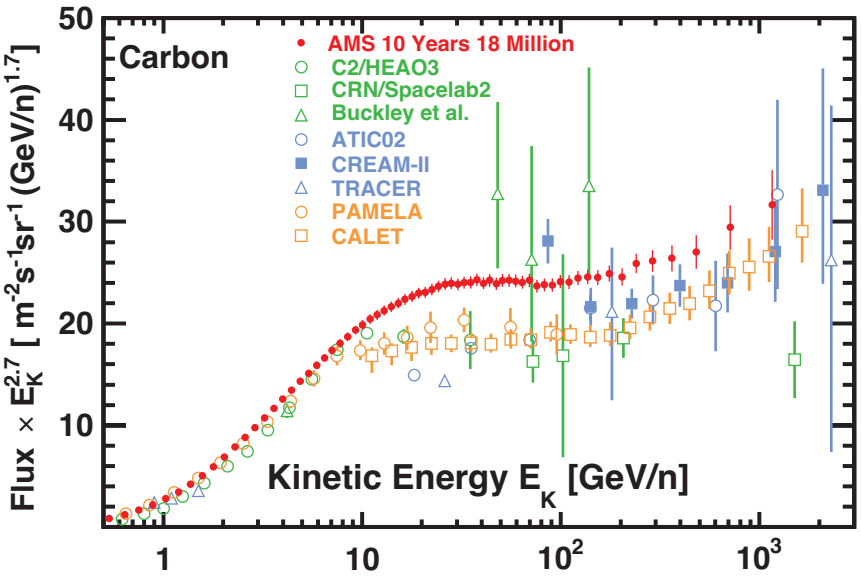


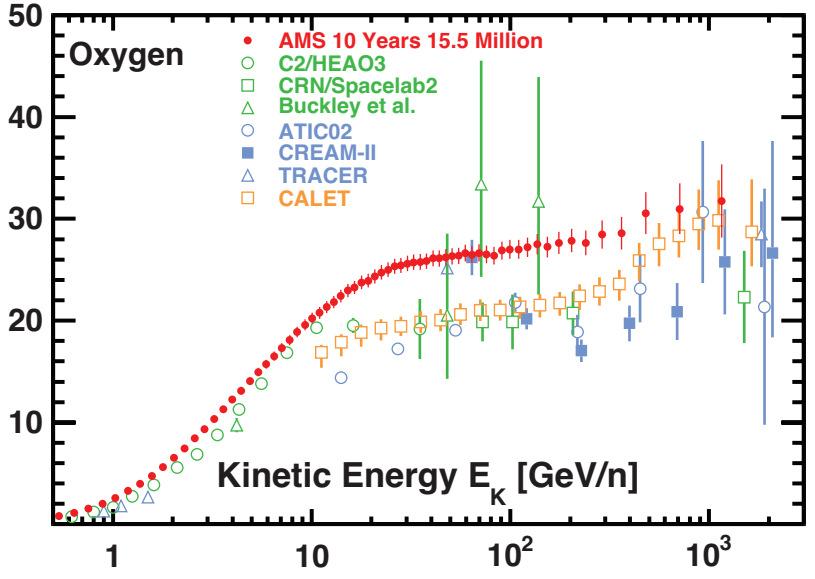
Latest AMS Measurement of Proton Spectrum



Latest AMS Measurements of He, C, O Spectra

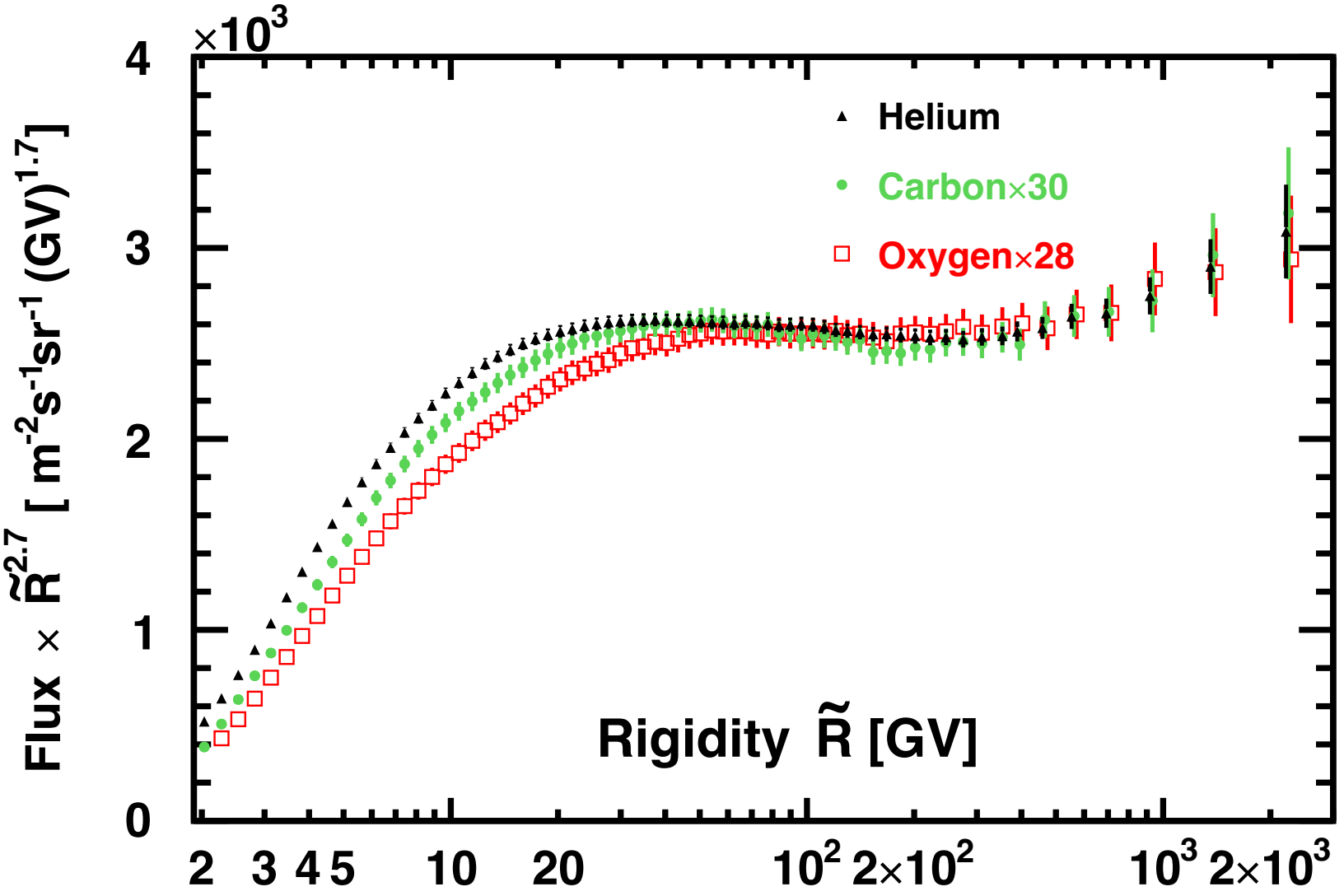






Precision AMS results are different from other measurements.

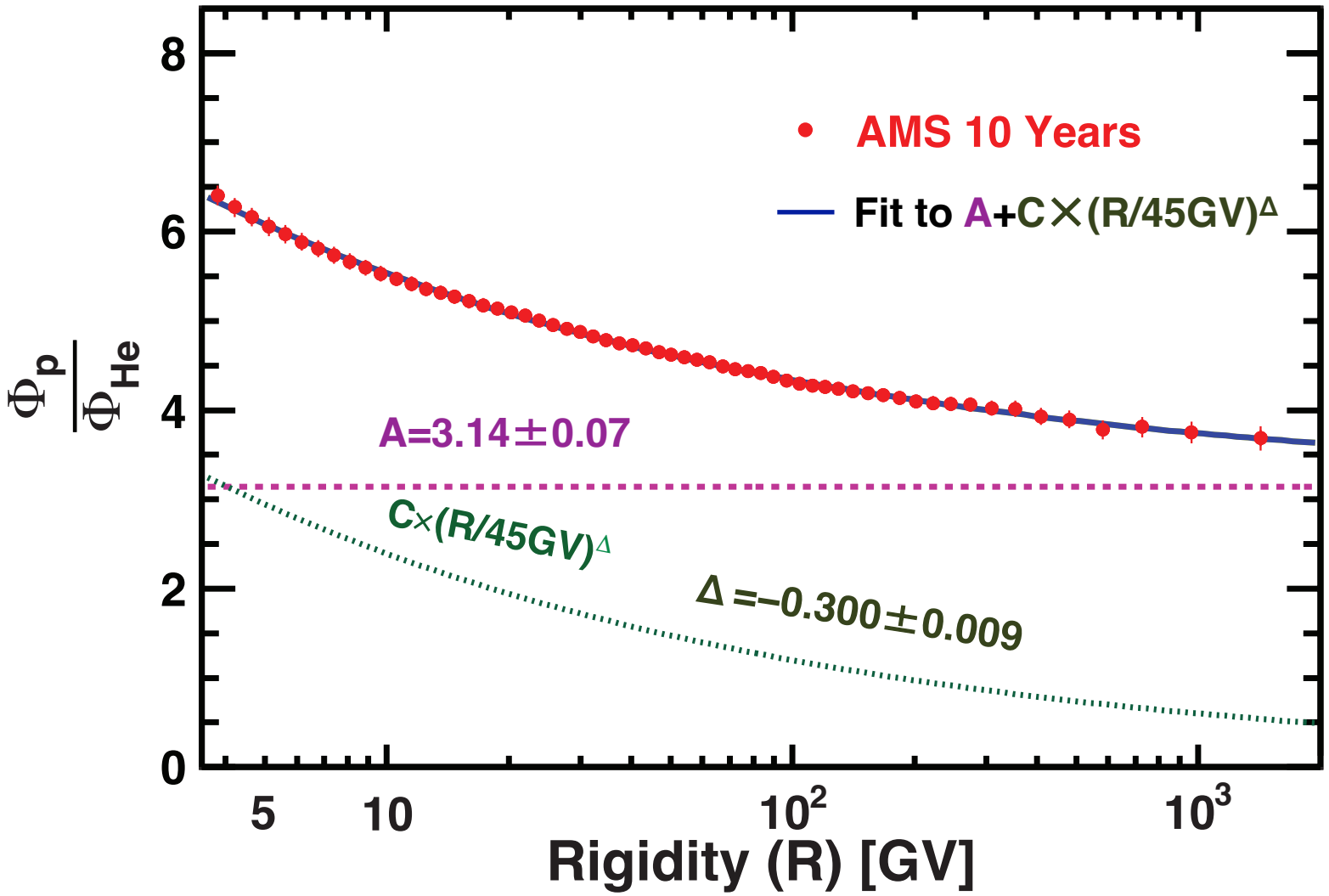
Properties of Light Primary Cosmic-Ray He, C, O



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

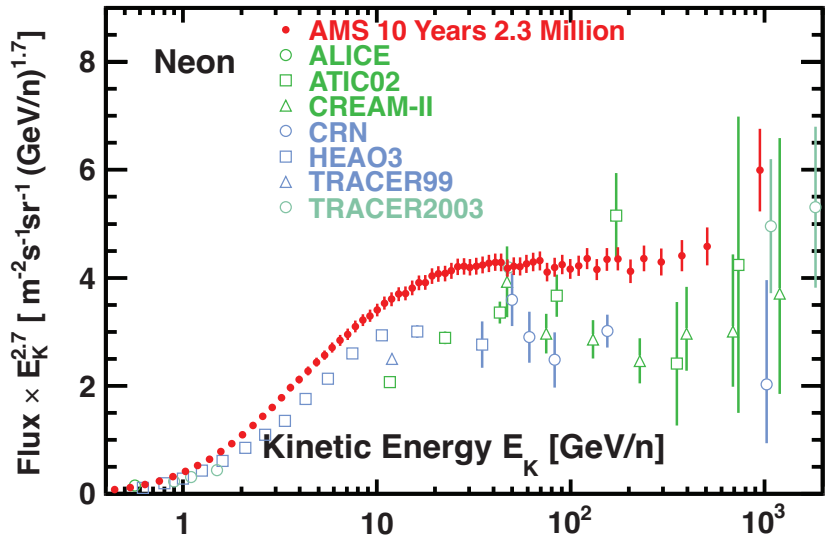
Above 200 GV, they all deviate from a single power law and harden in an identical way.

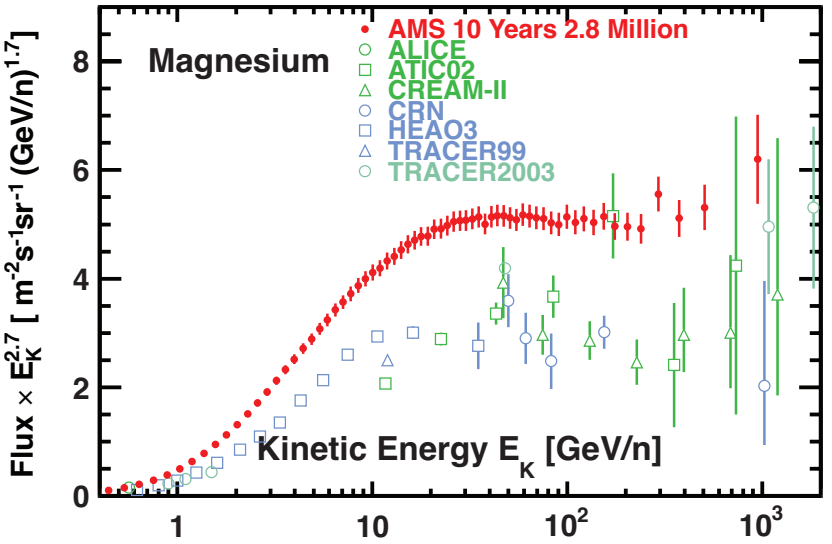
Proton-to-Helium Flux Ratio

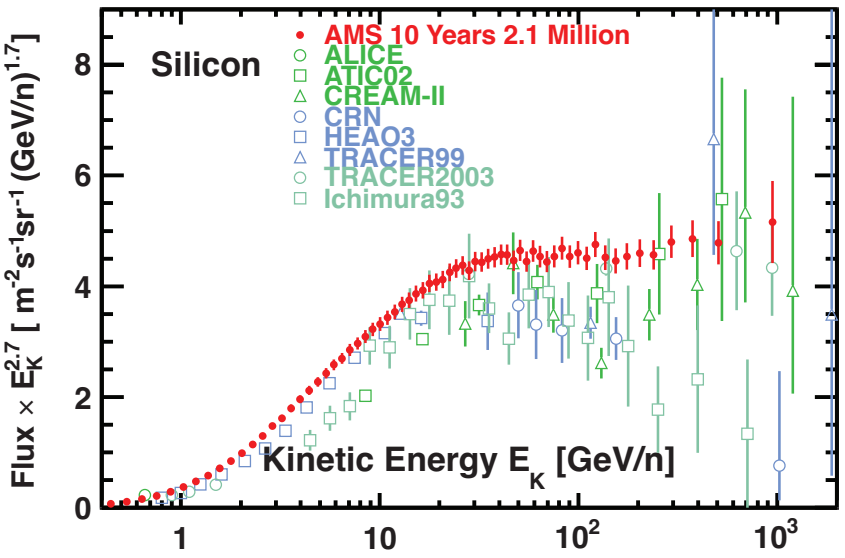


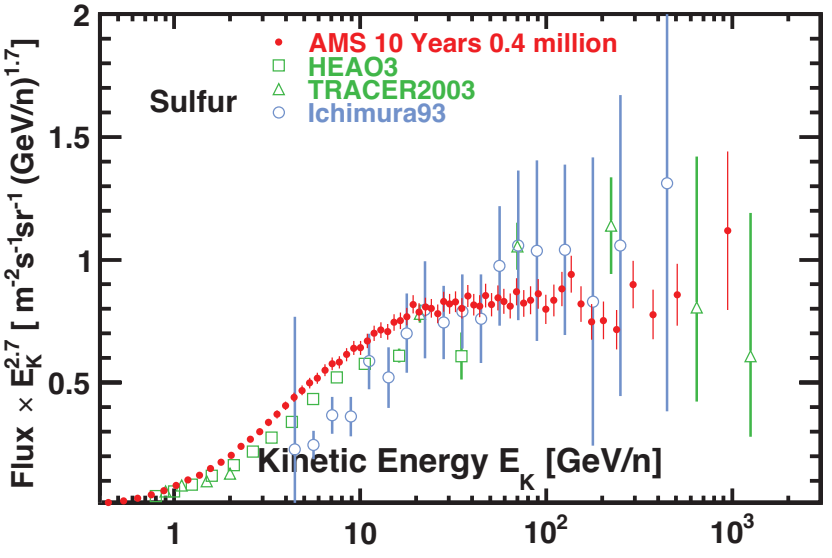
Proton spectrum has two components: 1) helium like component, and 2) softer than helium component.

Latest AMS Measurements of Ne, Mg, Si, S Spectra



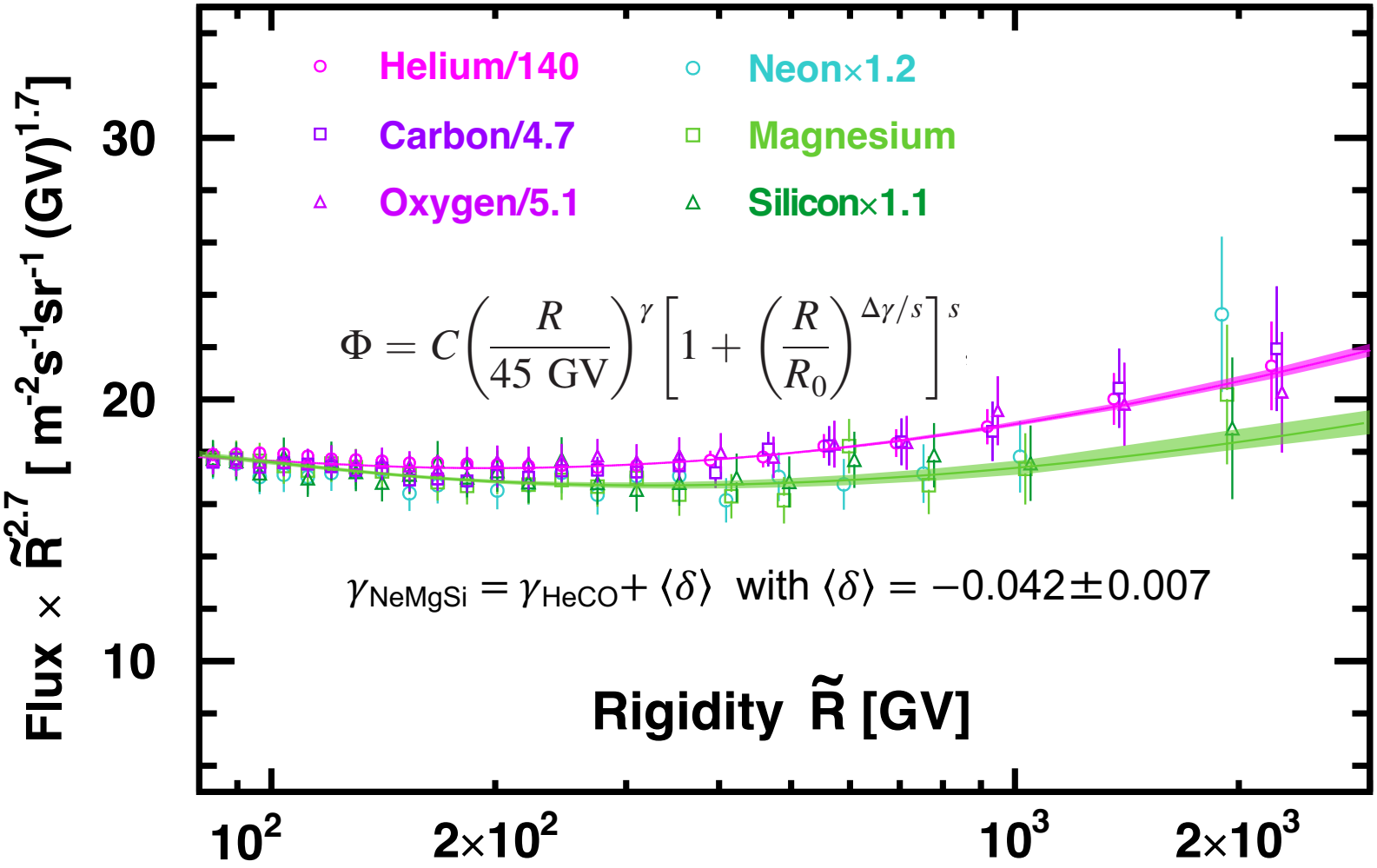






AMS results are different from previous measurements both in magnitude and energy dependence.

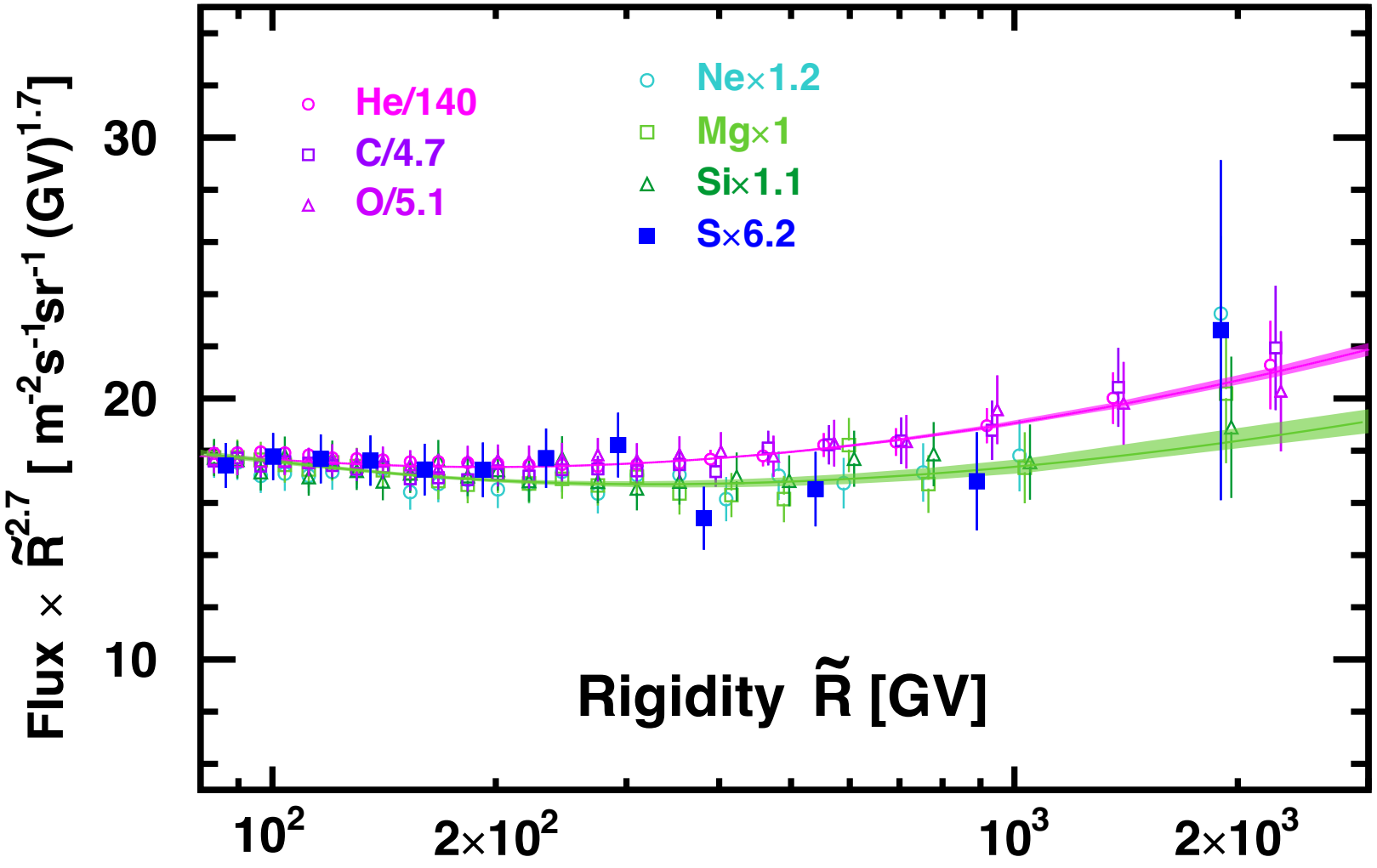
Properties of Heavy Primary Cosmic-Ray Ne, Mg, Si



Surprisingly, above 86.5 GV, the rigidity dependence of heavy primary Ne, Mg, and Si spectra is different from light primary cosmic-ray He, C, and O.

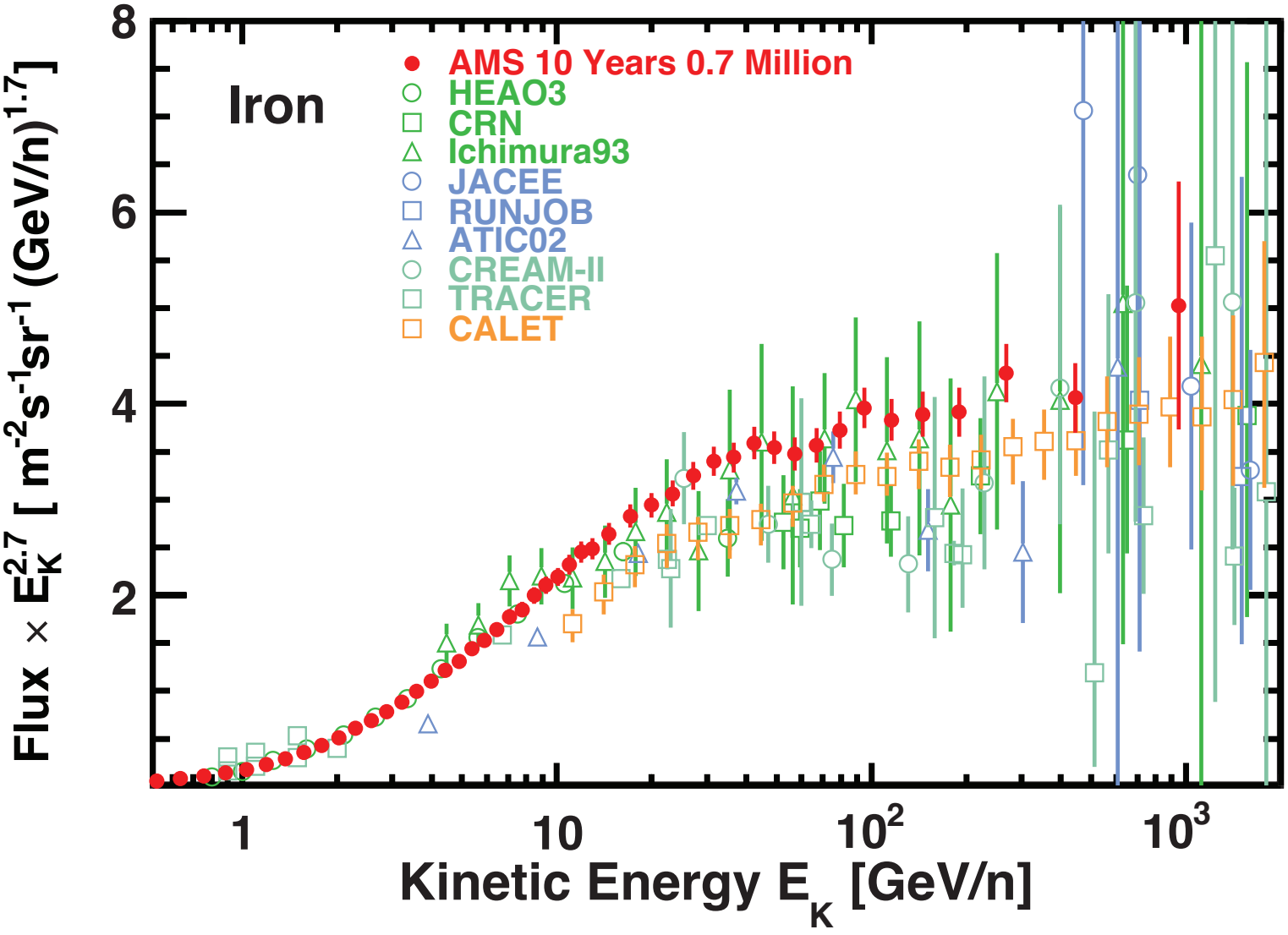
This shows that primary cosmic rays have at least two distinct classes.

Latest AMS Result: Sulfur Spectrum Rigidity Dependence

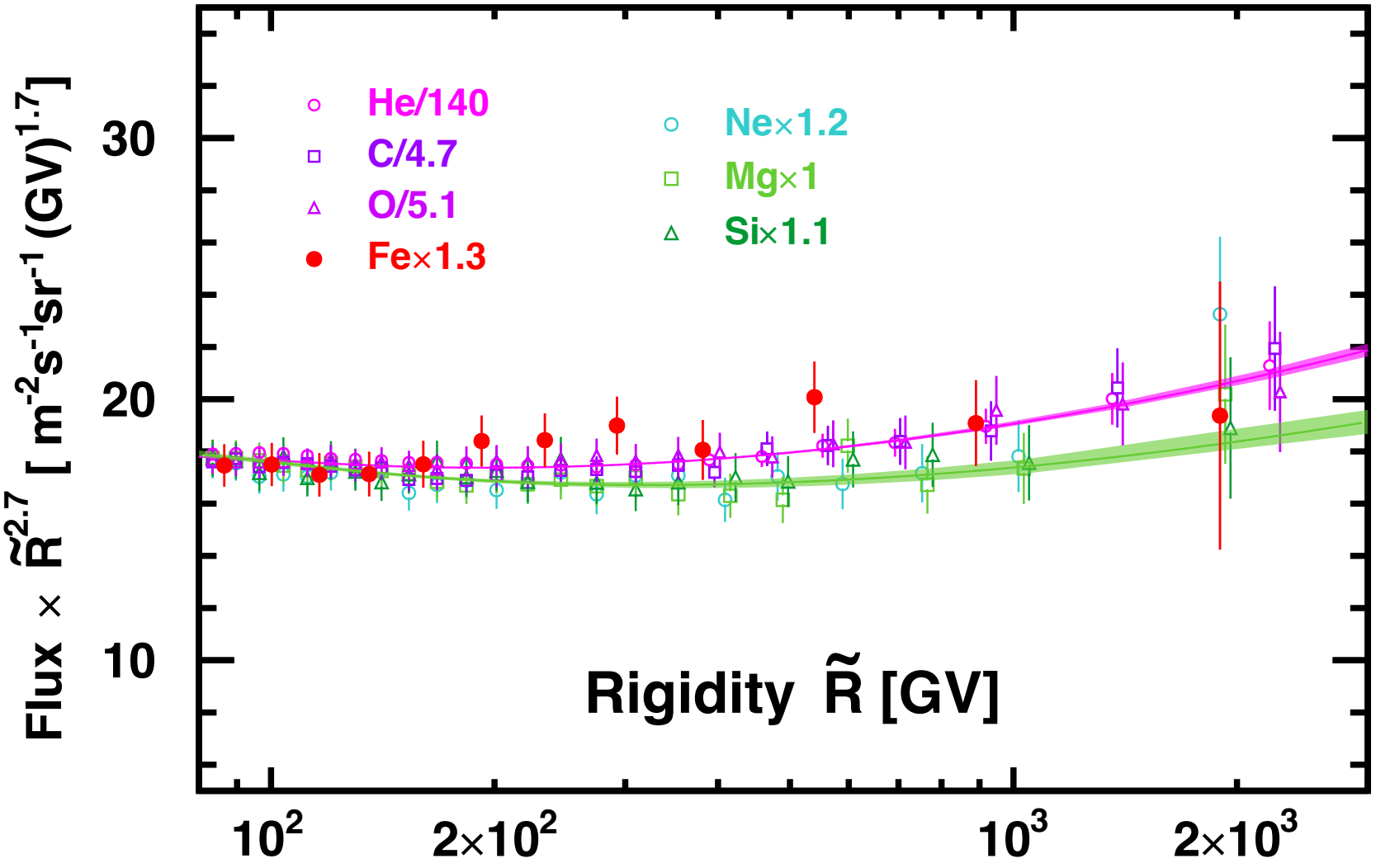


S belongs to the same class as Ne, Mg, Si.

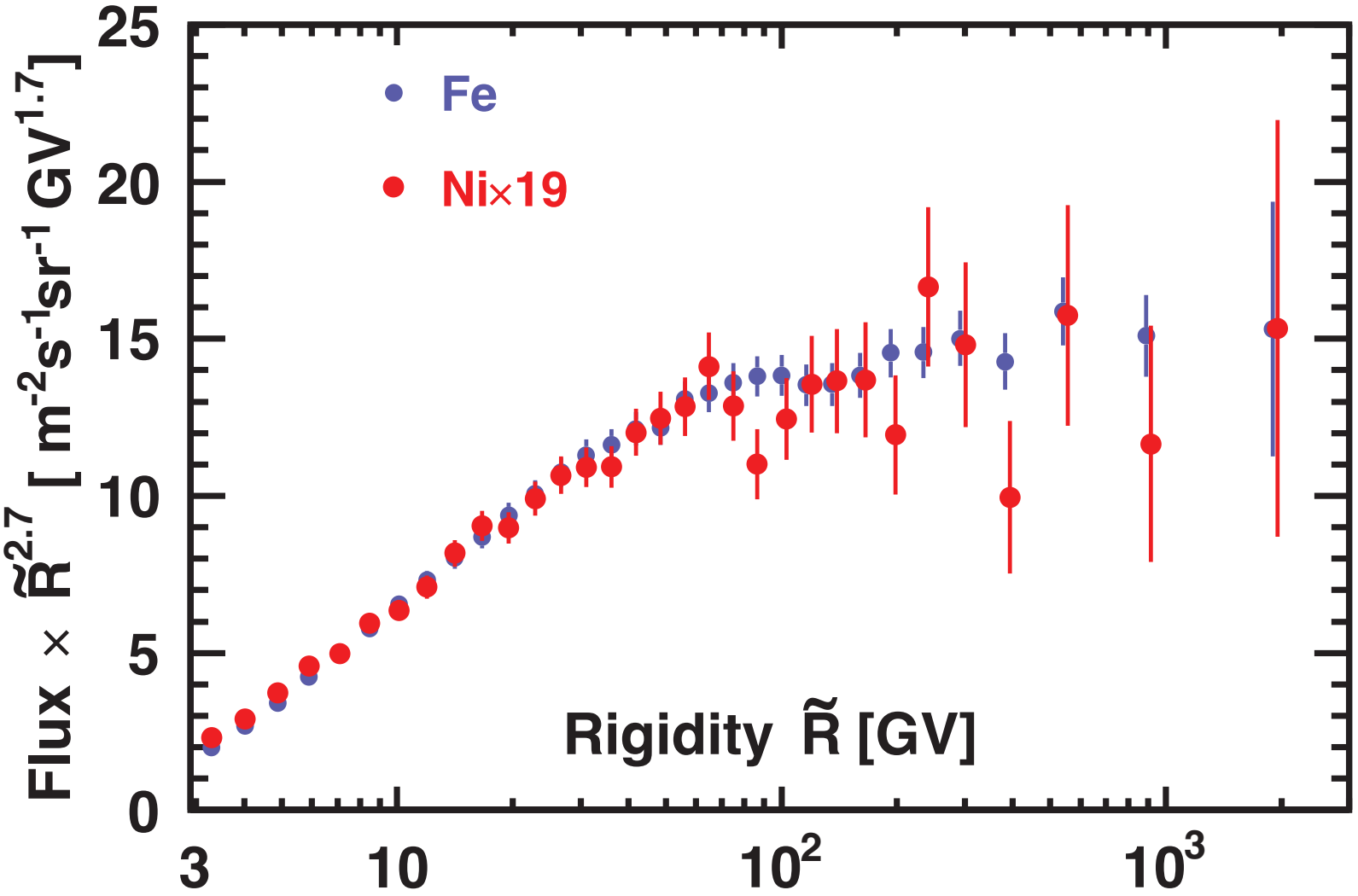
Very Heavy Primary Cosmic Rays: Iron Spectrum



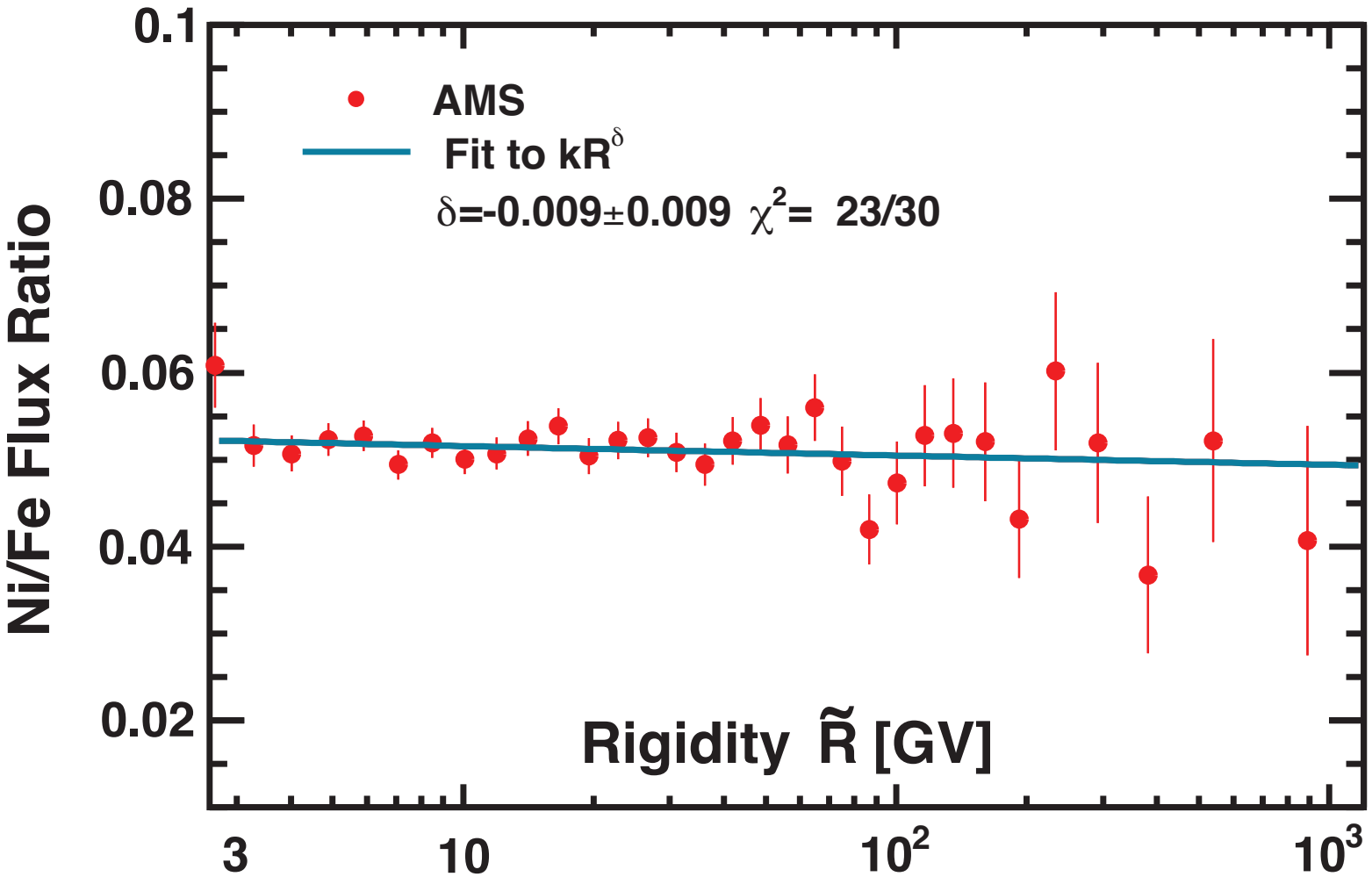
Unexpected Result: Iron is the Same Class as He, C, O



Latest AMS Result: Nickel Spectrum



Nickel-to-Iron Flux Ratio



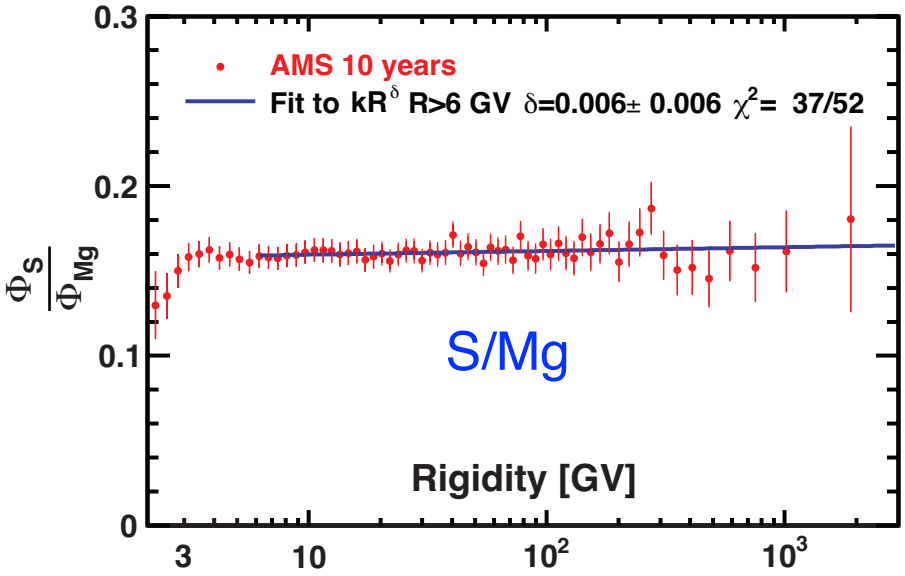
Ni and Fe spectra have identical rigidity dependence.

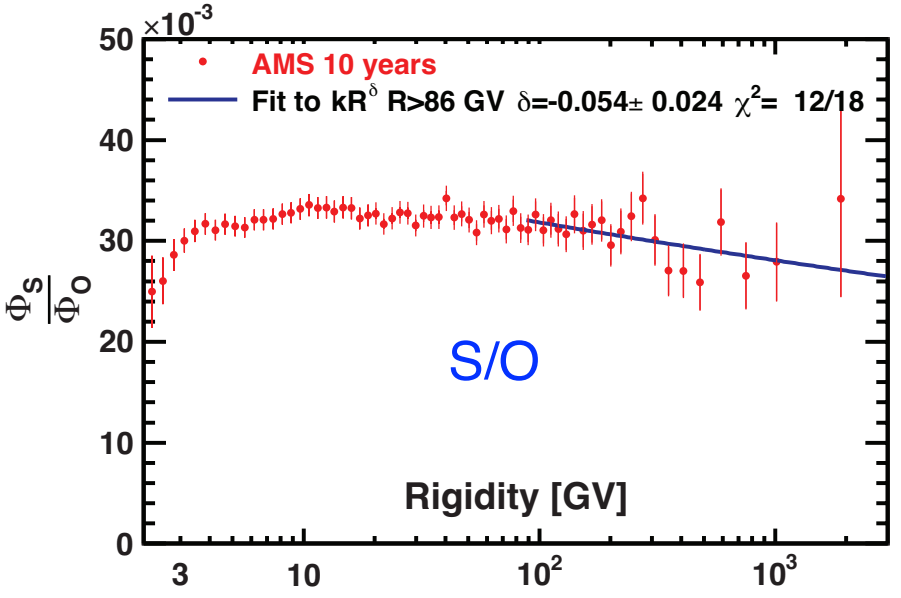
Summary

- In the first 10 years, AMS has collected 180 billion cosmic-ray events. The latest 10 years results on primary cosmic-ray P, He, C, O, Ne, Mg, Si, S, Fe, and Ni from 2 GV to 3 TV were presented.

- Future high precision AMS measurements of all cosmic-ray elements will continuously provide unique insight into the understanding of the cosmic rays.

Sulfur-to-Magnesium Flux Ratio and Sulfur-to-Oxygen Flux Ratio





S belongs to the same class as Ne, Mg, Si.