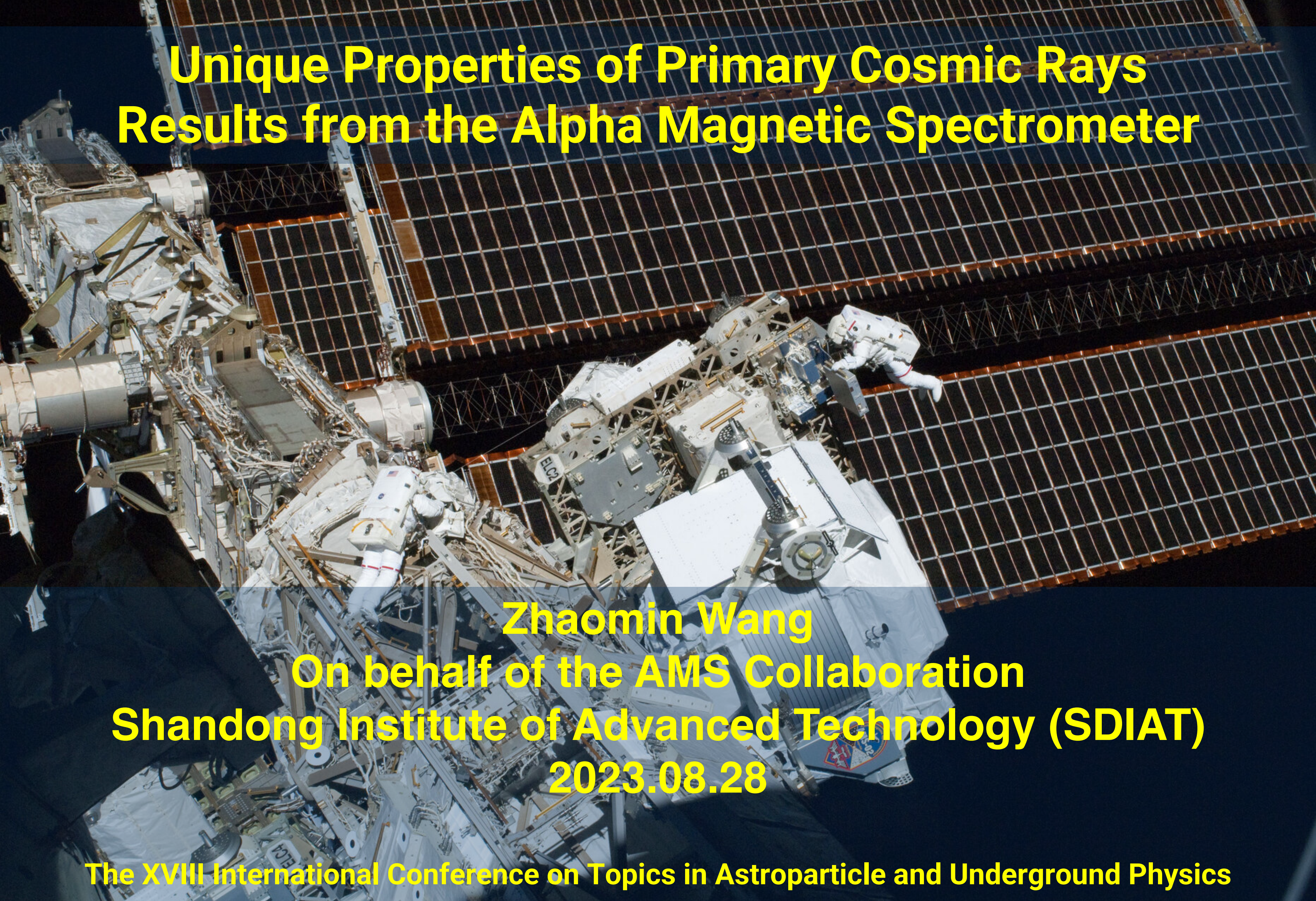


Unique Properties of Primary Cosmic Rays Results from the Alpha Magnetic Spectrometer

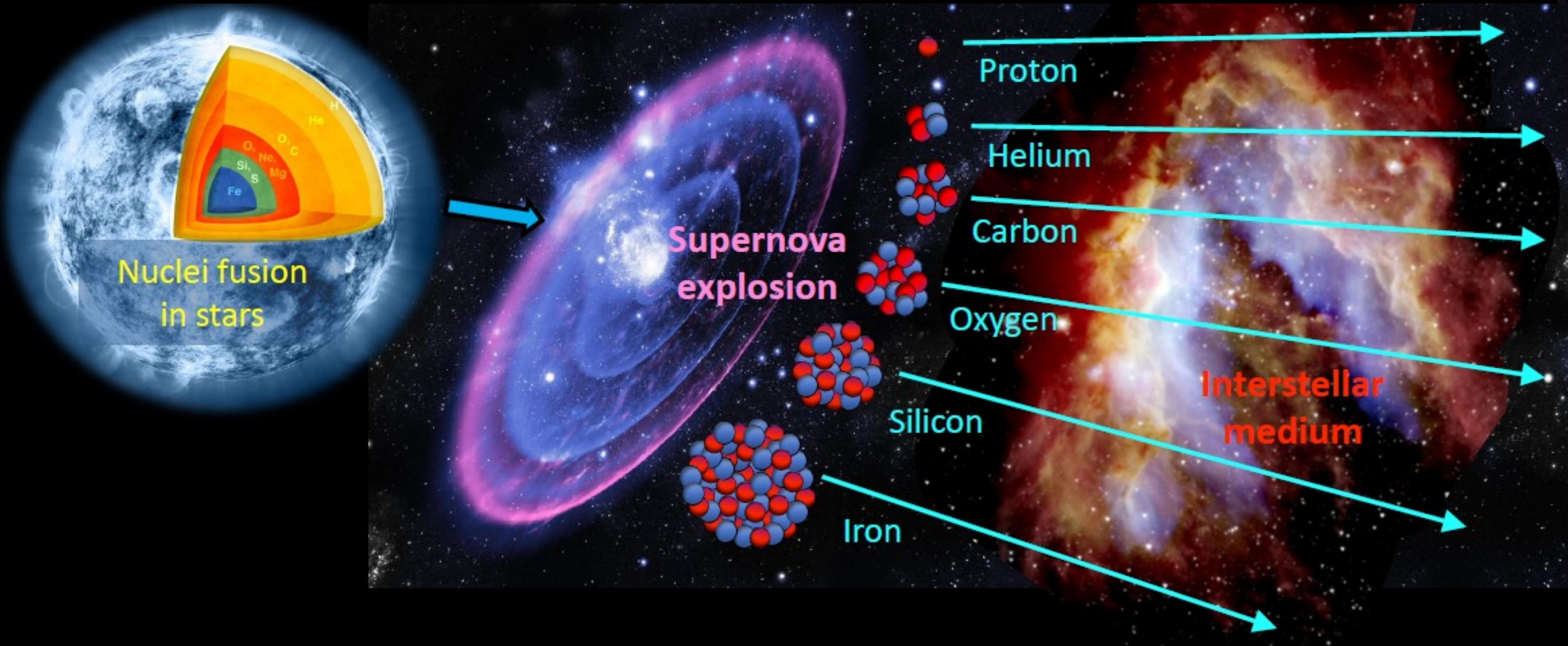
Zhaomin Wang
On behalf of the AMS Collaboration
Shandong Institute of Advanced Technology (SDIAT)

2023.08.28

The XVIII International Conference on Topics in Astroparticle and Underground Physics

Primary cosmic ray

Primary cosmic rays are thought to be mostly produced and accelerated in the supernovae shocks in our galaxy. The primary cosmic rays include proton, helium, carbon, oxygen, silicon and iron etc.



The measurement of primary cosmic ray spectra is essential to understand the cosmic ray origin, acceleration and propagation mechanisms.

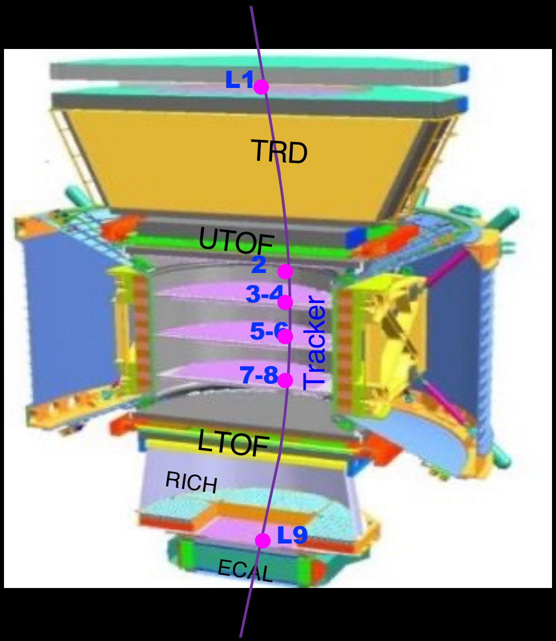
AMS Launch May 2011
Space Shuttle Endeavour
Mission STS-134

To-date ~222 billion cosmic. rays have been measured by AMS: e^+, e^-, p, $\bar{p}$, nuclei, γ,...

400 billion events expected to 2030

AMS installed on the ISS
Near Earth Orbit:
altitude 400 Km
inclination 52°
period 92 min

AMS Nuclei Flux Measurements



Tracker (9 Layers) + Magnet: Rigidity (Momentum/Charge) with multi-TV maximal detectable rigidity (MDR)

	Coordinate Resolution	MDR
Z=1	10 μm	2 TV
Z≥2	5-8 μm	3.0-3.7 TV

ToF (4 Layers): Velocity and Direction

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

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

Consistent Charge Along Particle Trajectory

Inner Tracker Charge Resolution:

$\Delta Z = 0.05 - 0.35$ ($1 \leq Z \leq 28$)

AMS Nuclei Flux Measurements

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

Rigidity p,…Fe 1…3500 GV

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

Time 220,000,000 sec R> 30 GV

Bin width

Effective Acceptance

Trigger Efficiency

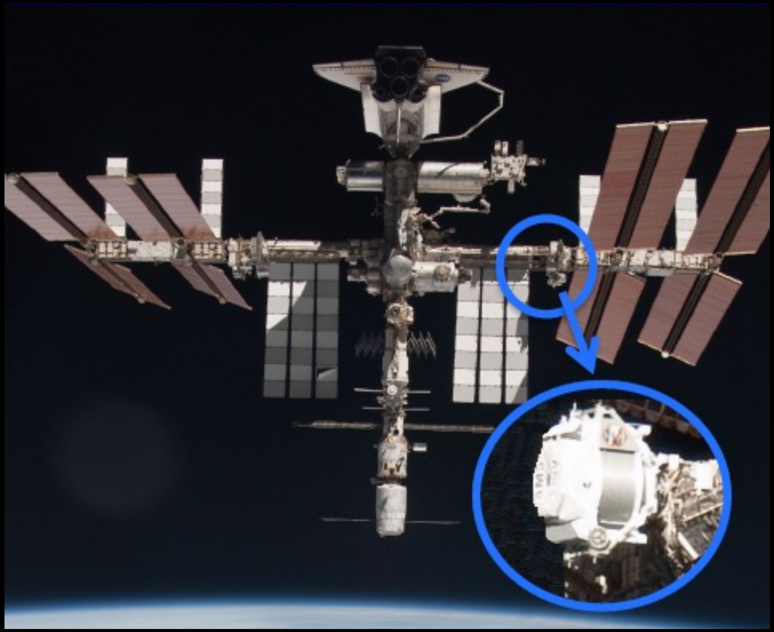
Measurements require knowledge of detector performance details, the resolution functions, acceptance … obtained by AMS Monte Carlo Simulations

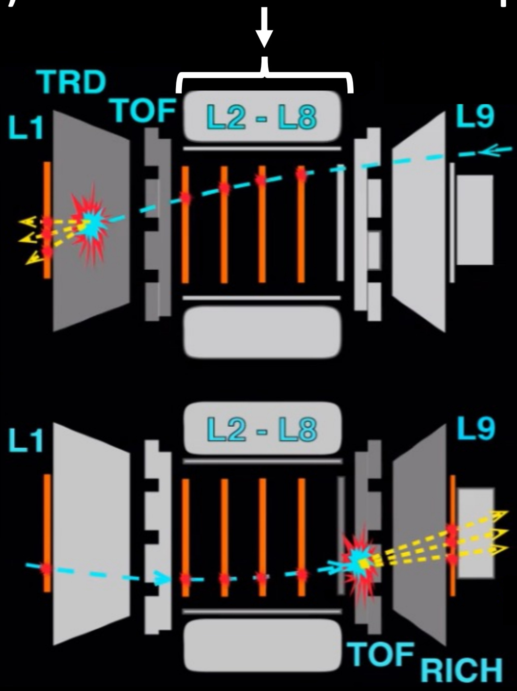
In AMS 2 to 4 independent analysis are done to compute N_i, A_i, ε_i, T_i for each flux

Measurement of nuclear reaction cross-section with cosmic ray

An accurate nuclear reaction cross-section model is a crucial factor in improving the precision of cosmic-ray spectrum measurements. The main composition of AMS material include carbon and aluminum elements. The nuclear reaction cross-section model between various nuclei and carbon or aluminum before AMS experiments exhibit significant uncertainties.

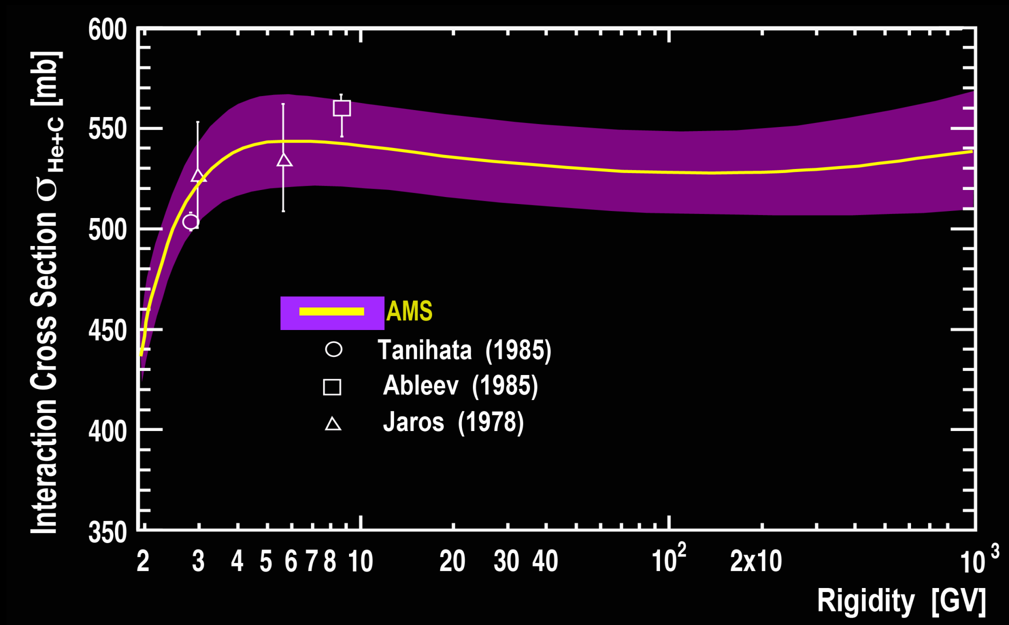
Define (P, Z) of nuclei with the central spectrometer

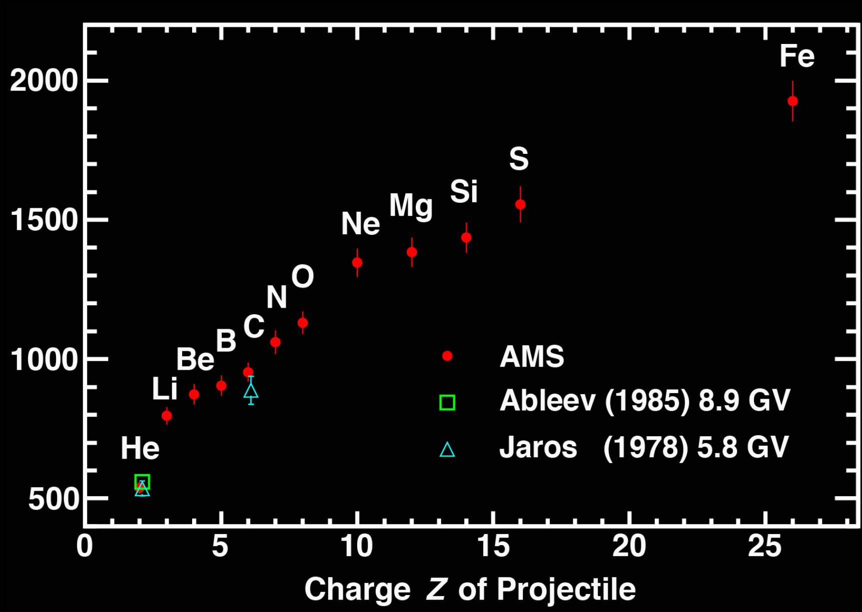




AMS can collect cosmic particles entering the detector from both the right and the left directions when the detector is flying horizontally. This allows the measurement of reaction cross-sections of various nuclei colliding on the AMS material within the GV to TV rigidity range.

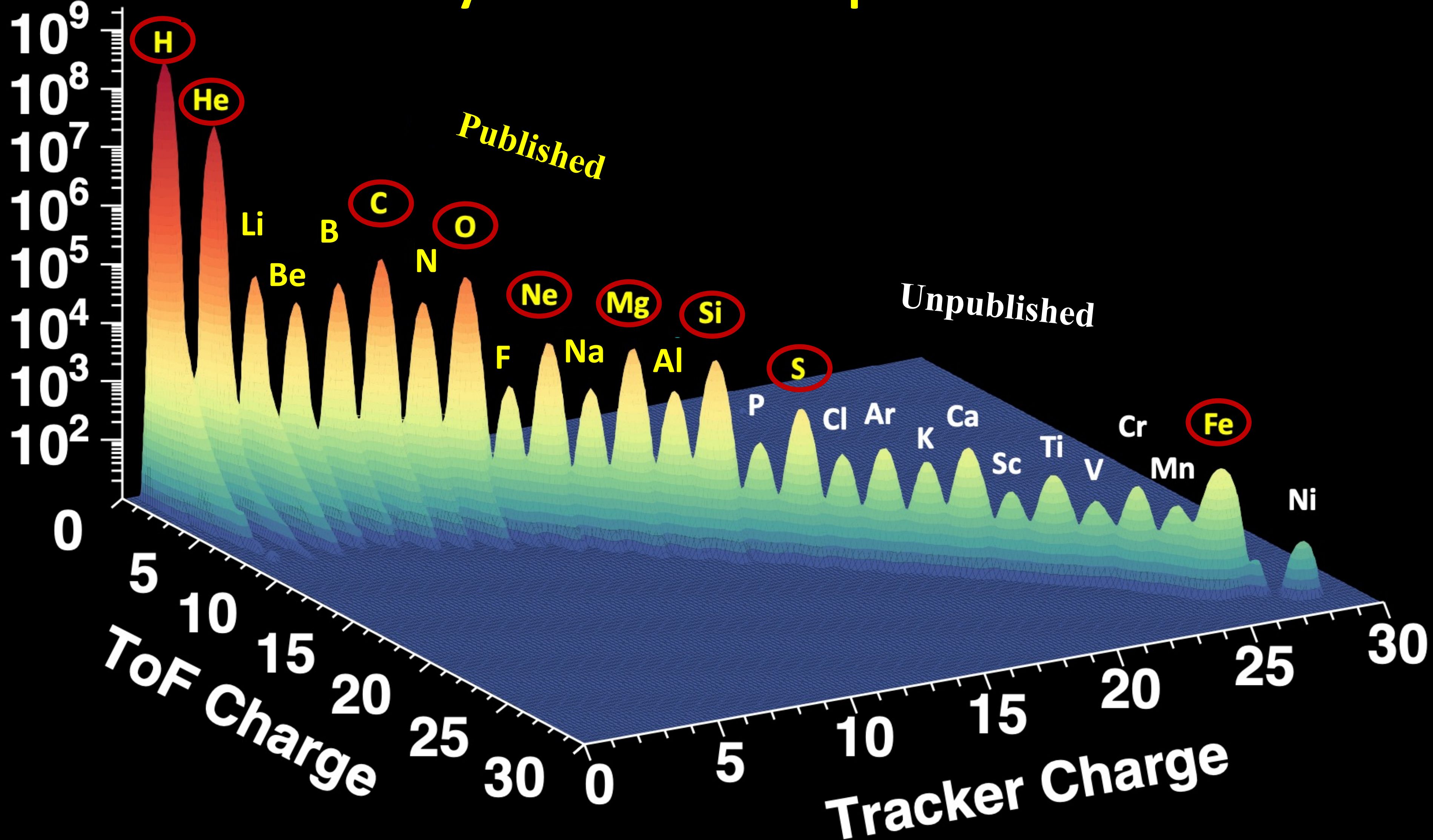
Measurement of nuclear reaction cross-section with cosmic ray



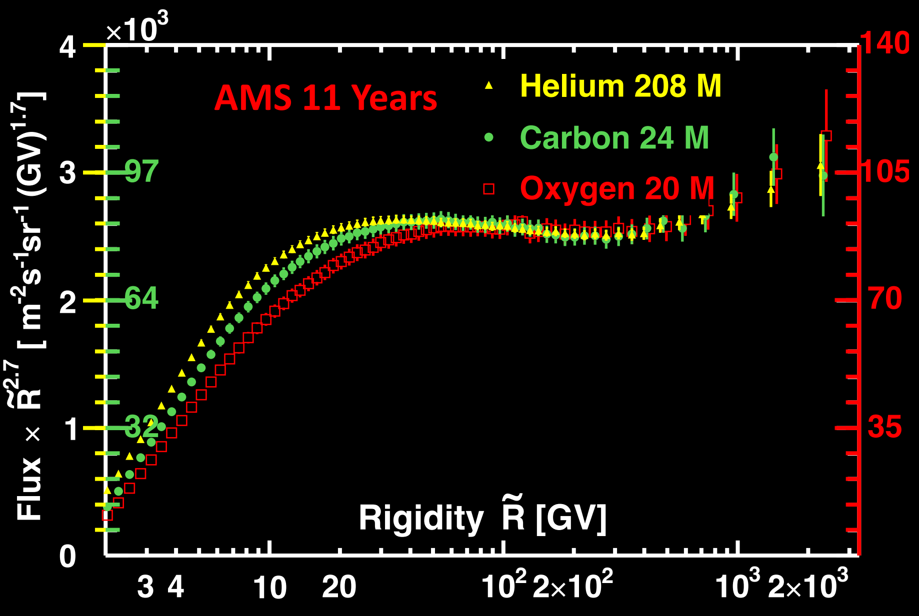


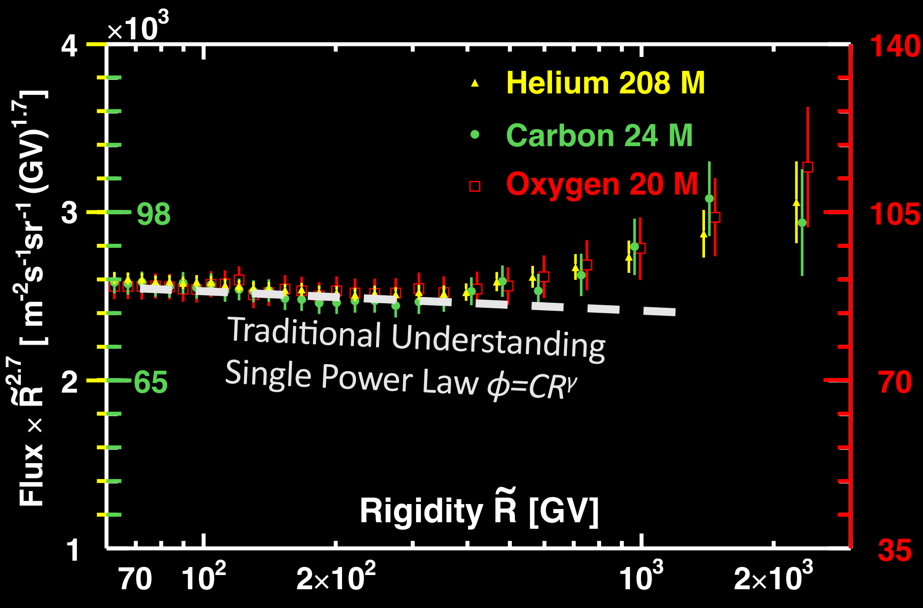
Based on the measurements, AMS adjusted the relevant parameters of nuclear interaction models in the simulation data to guarantee a better precision for the spectra measurements.

Cosmic Rays Chemical Composition with AMS



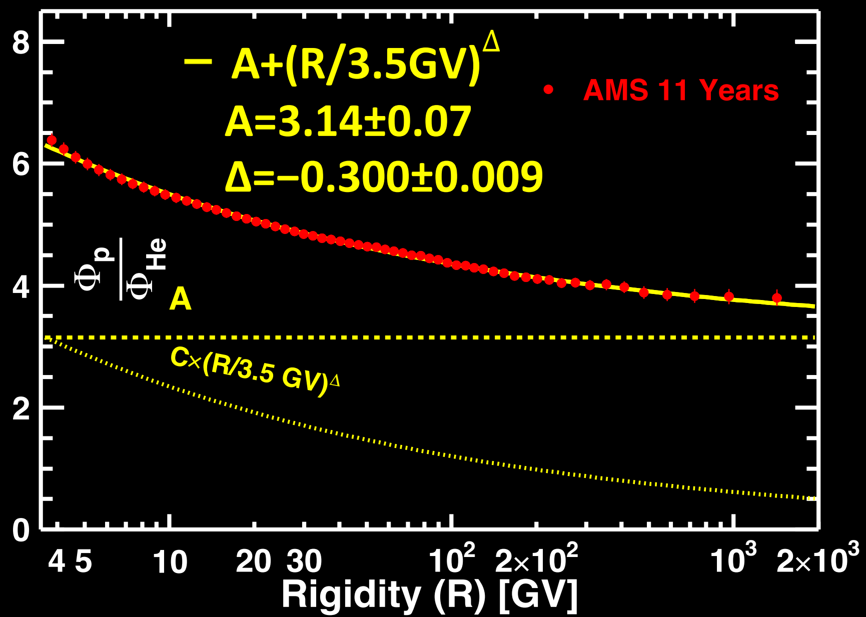
Latest AMS Measurements of He, C and O spectra

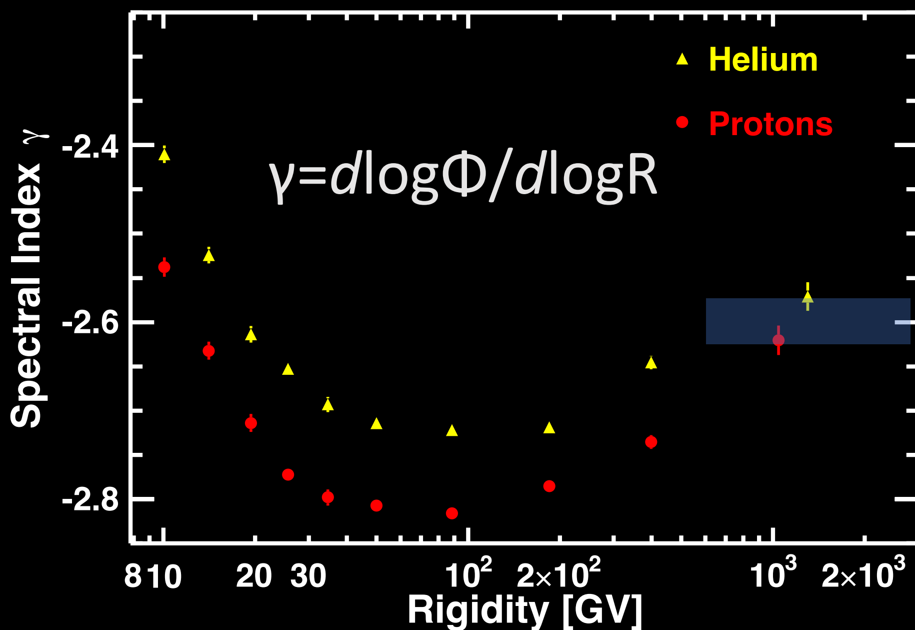




Phys. Rev. Lett. 119, 251101 (2017): AMS found that He, C, O have an identical rigidity dependence above ~60 GV and at higher rigidities they all deviate from a single power in an identical way

p He Flux Ratio and Spectral Indexes



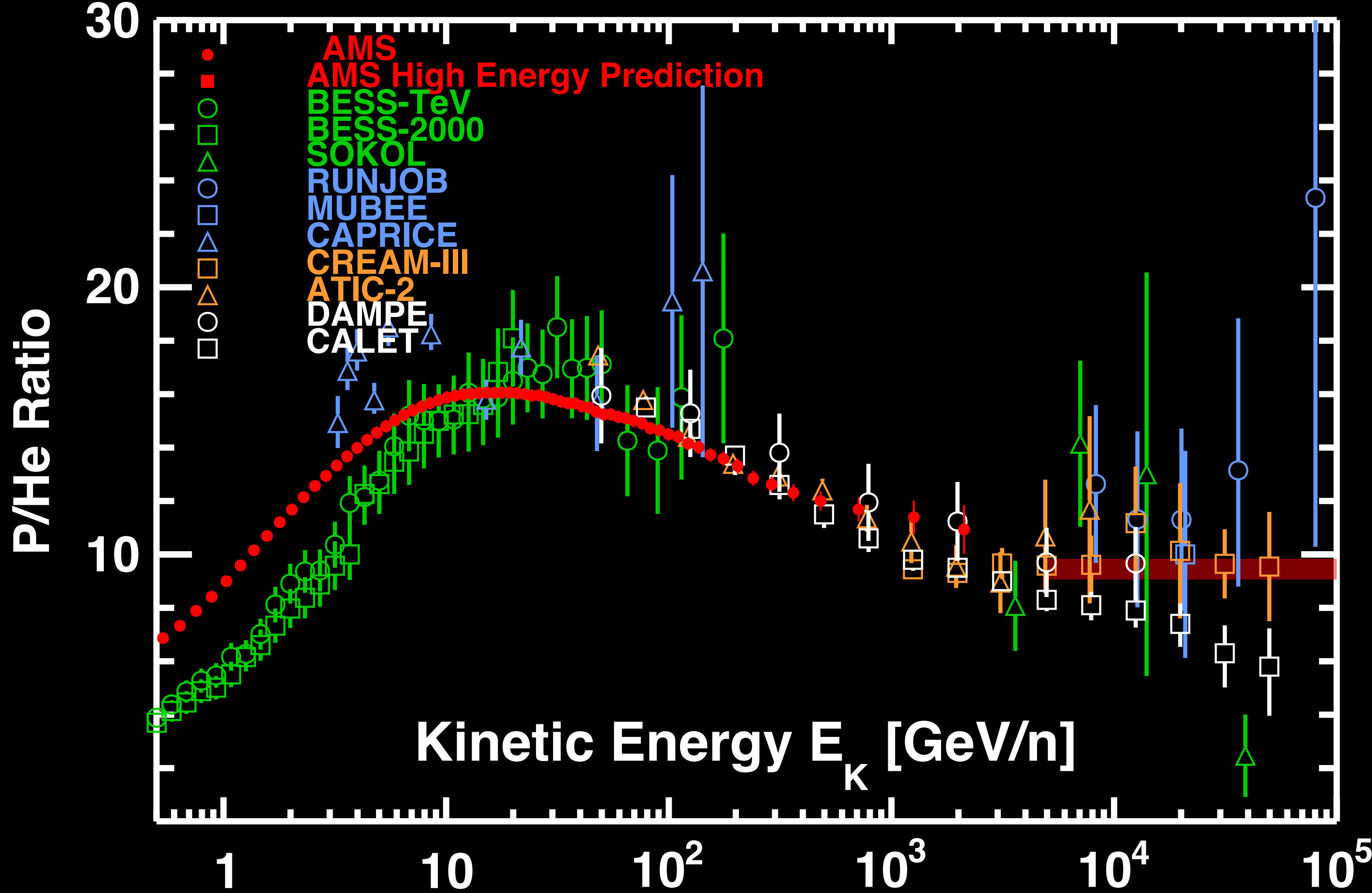


Physics Reports, 894, 1 (2021) :

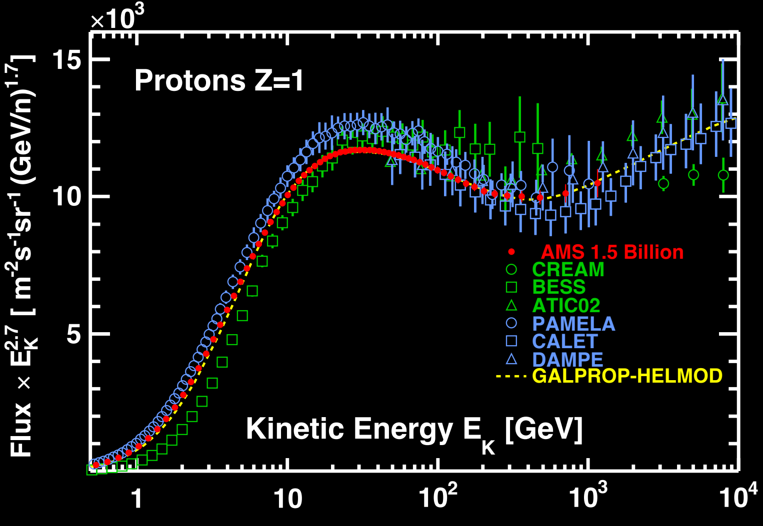
AMS found that proton flux have two components, one is like Helium and another is unique to proton flux.

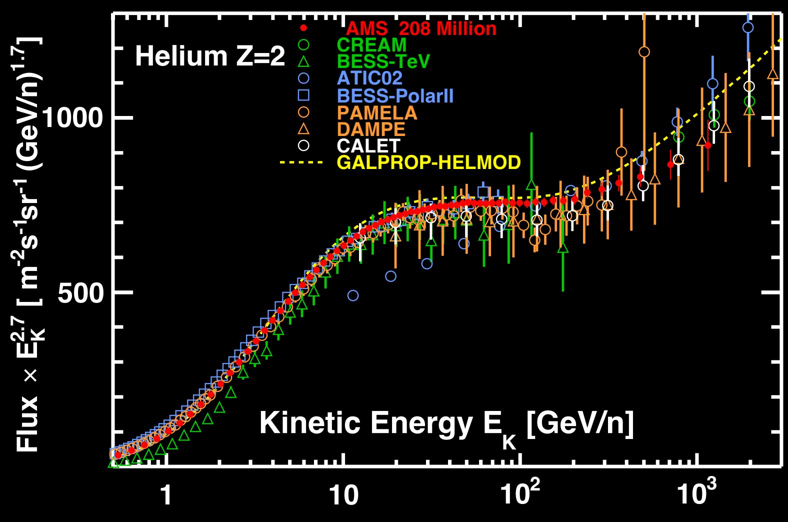
p and He may have same spectral index at highest rigidites

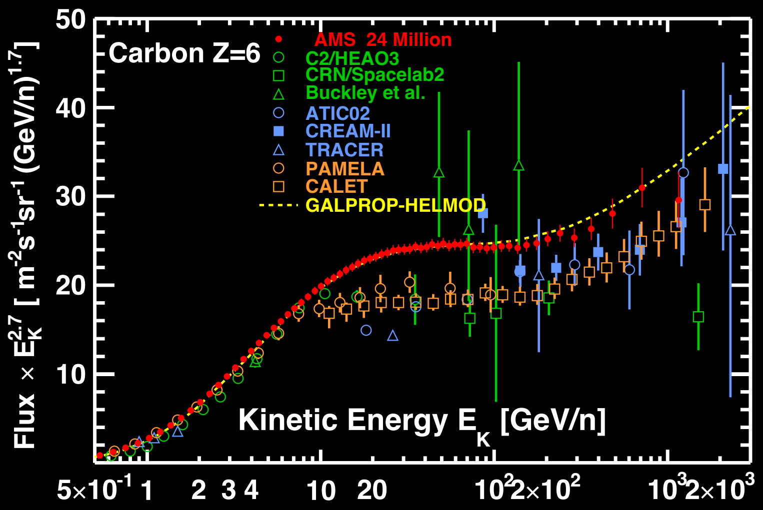
Proton/Helium Flux Ratio

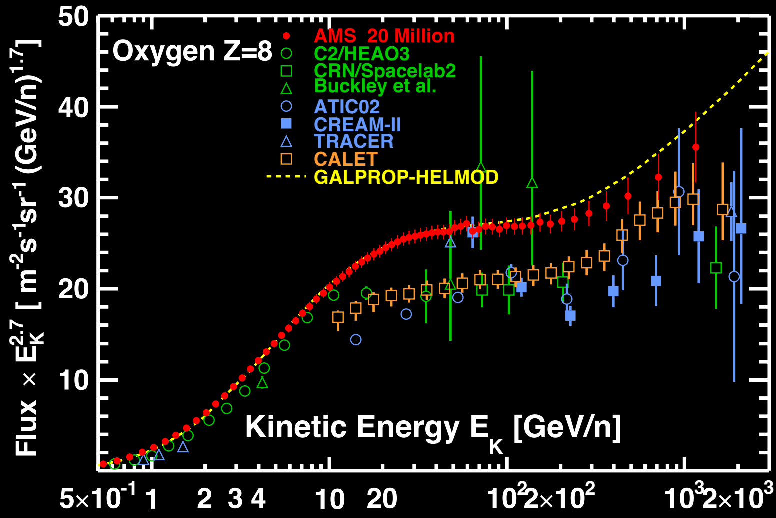


AMS p He C and O Fluxes Comparison with Other Experiments



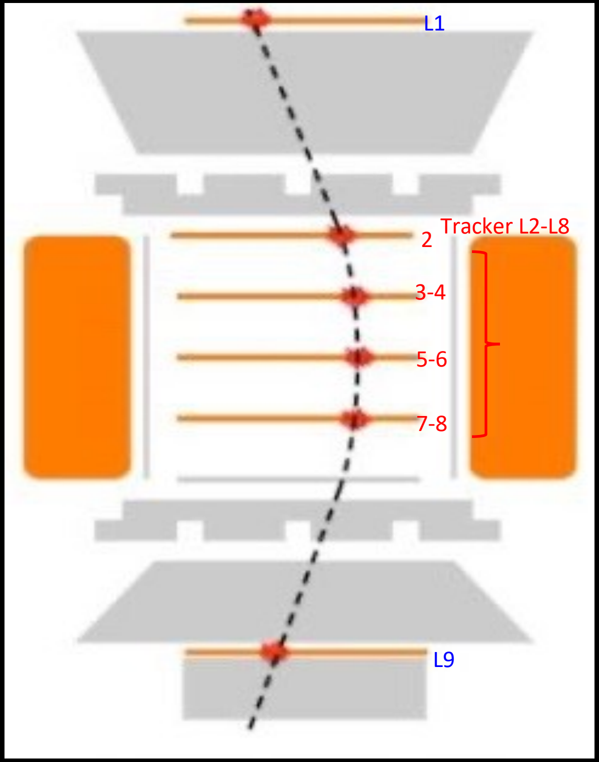


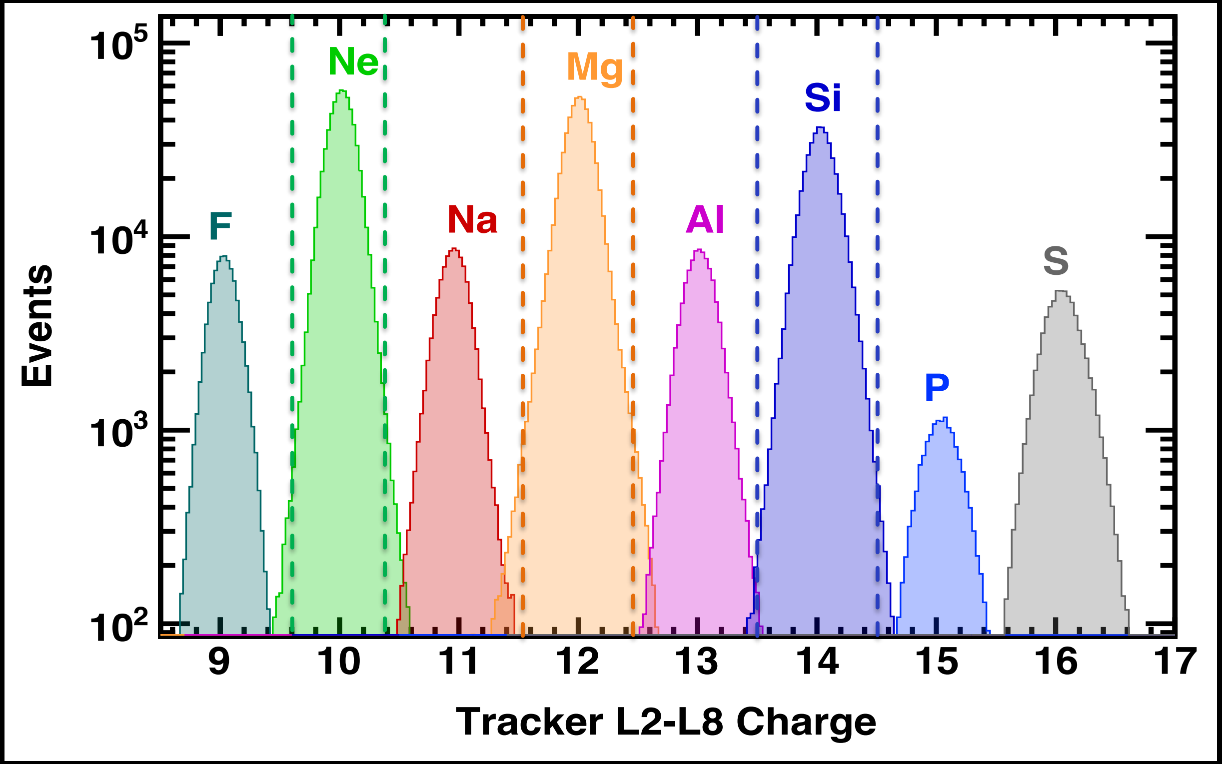




Ne, Mg, and Si : Heavier Primary Cosmic Rays

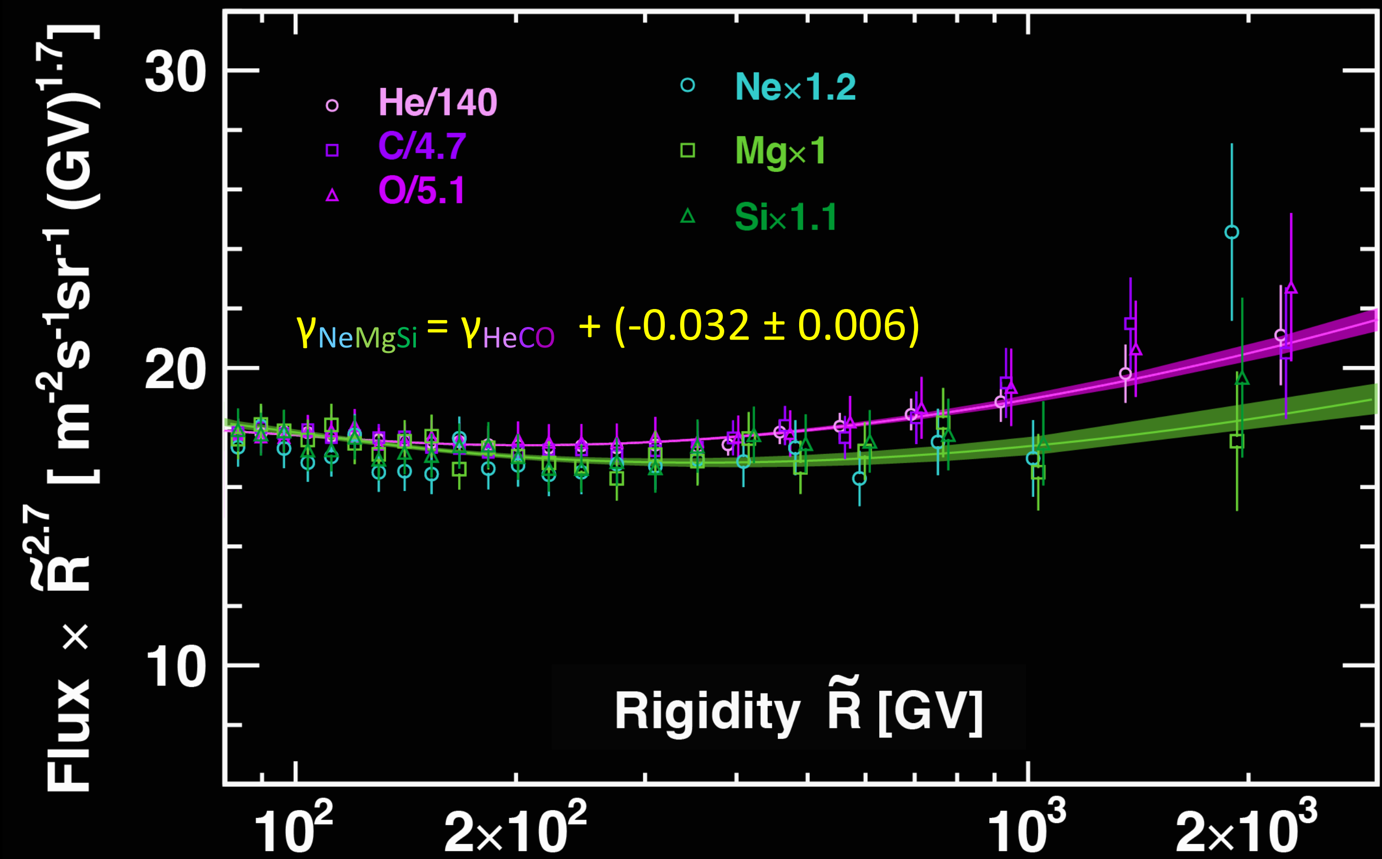
Charge misidentification from non-interacting nuclei is negligible <0.1%





For the events R > 4 GV selected by Tracker L1, Upper TOF and Lower TOF.

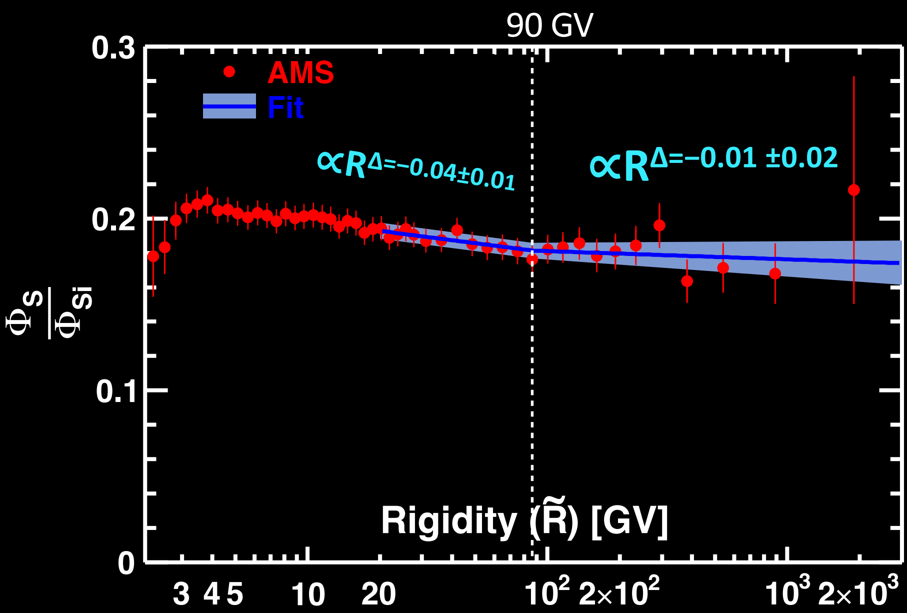
He-C-O and Ne-Mg-Si fluxes Rigidity Dependence

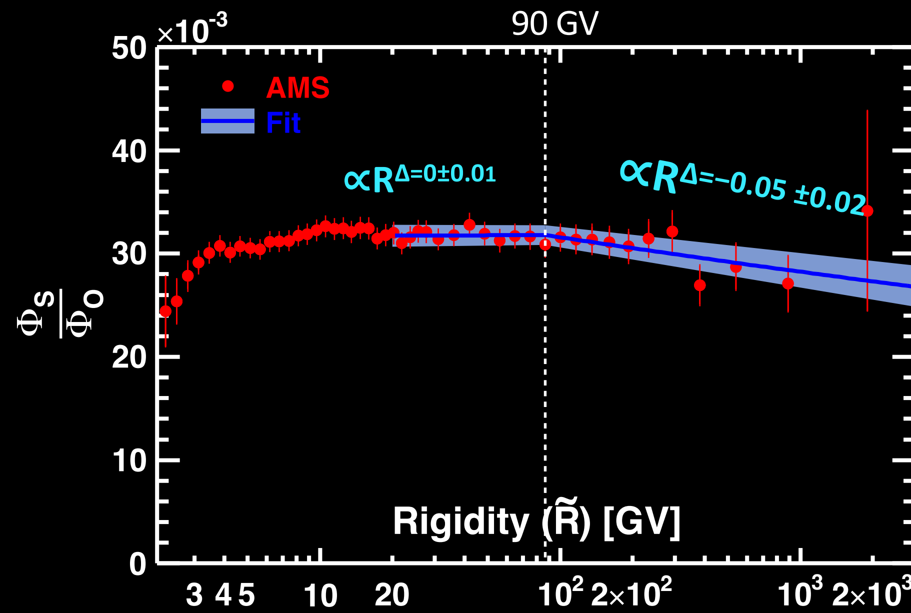


Phys. Rev. Lett. 124, 211102 (2020): AMS previously observed that light primary cosmic rays He, C, and O have identical rigidity dependence above 60 GV and deviate from a single power law above 200 GV. Surprisingly, heavy primary cosmic rays Ne, Mg, and Si also have identical rigidity dependence above 86 GV, but it is distinctly different from light primary cosmic rays.

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

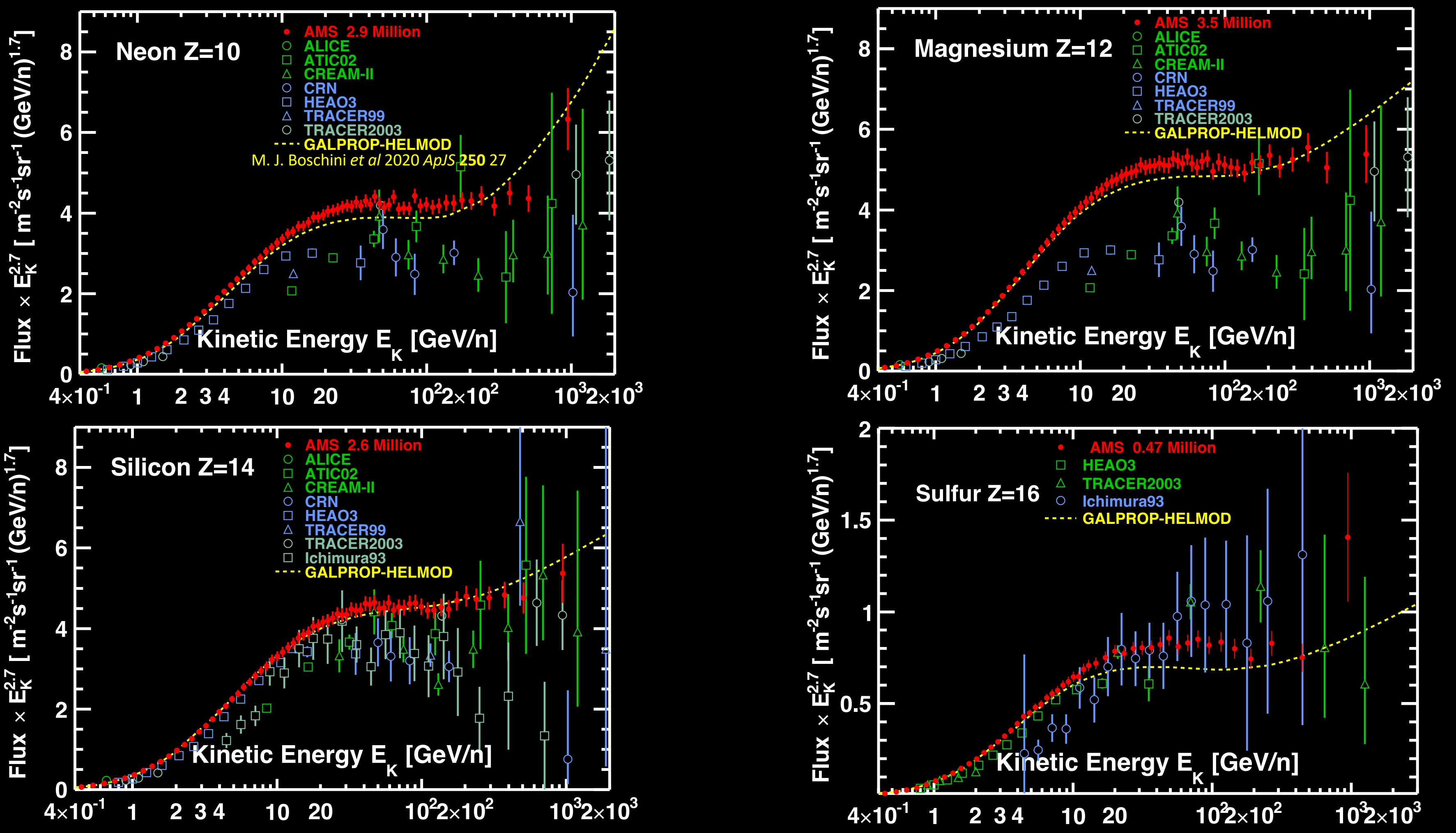
Latest AMS Results: Sulfur Rigidity Dependence





Phys. Rev. Lett. 130, 211002 (2023): Sulfur belongs to the same class as Ne, Mg, and Si.

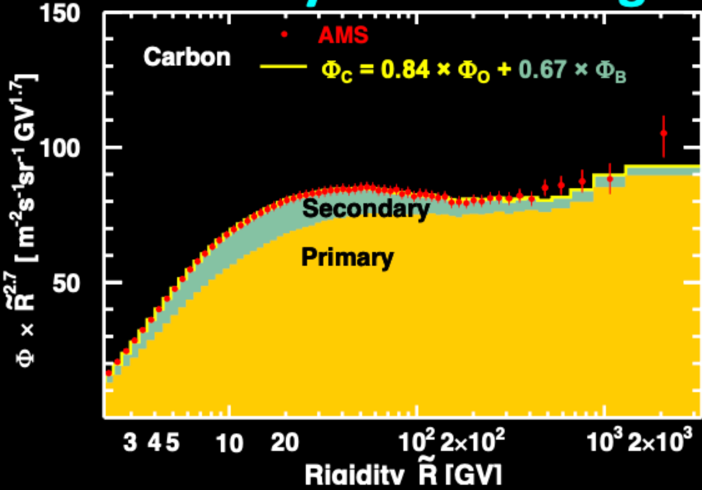
AMS Ne, Mg, Si, and S Nuclei Flux Measurements:

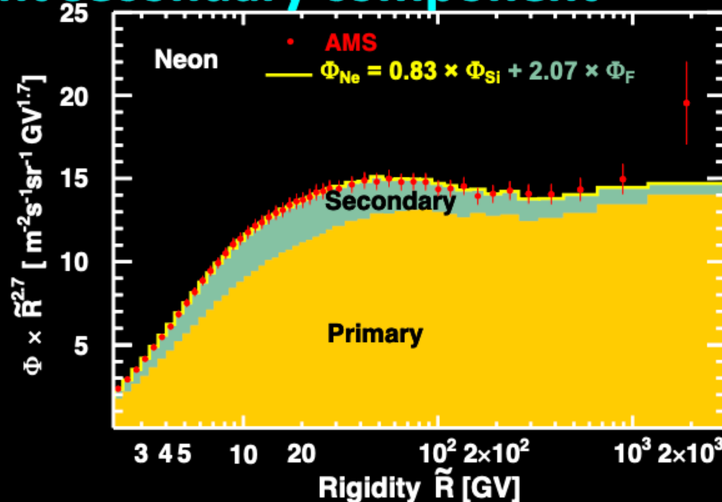


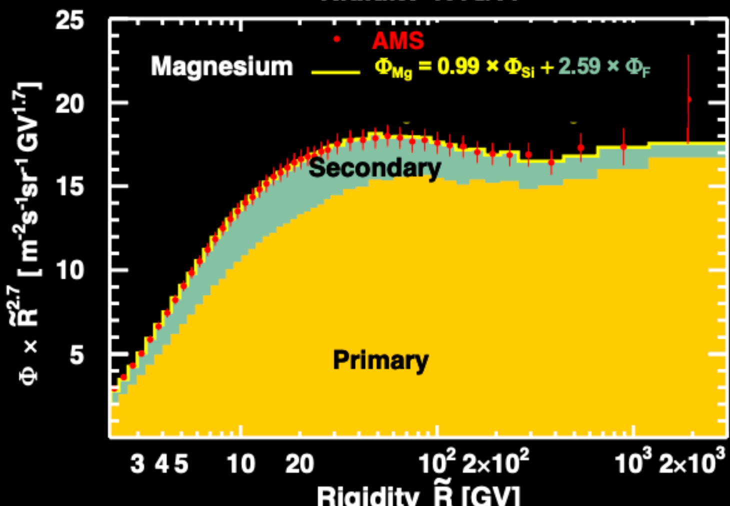
AMS results are different from previous measurements both in magnitude and the energy dependence.

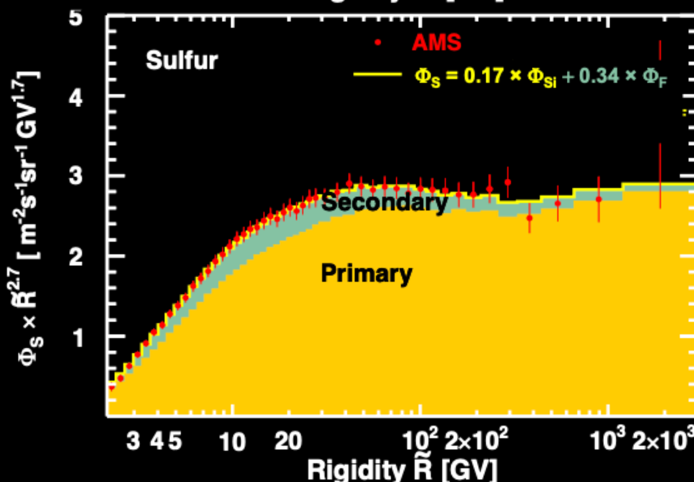
New proprieties of traditional primary cosmic rays

Traditional primary cosmic rays C, Ne, Mg, and S fluxes are not pure primary; they all have a significant secondary component

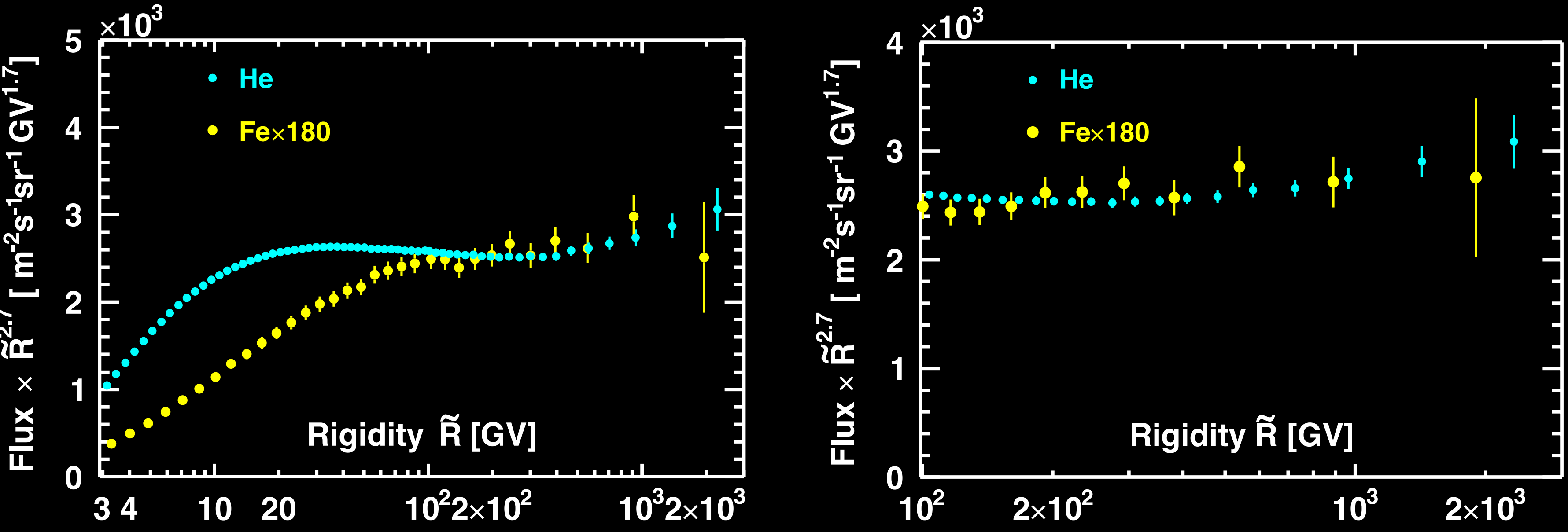






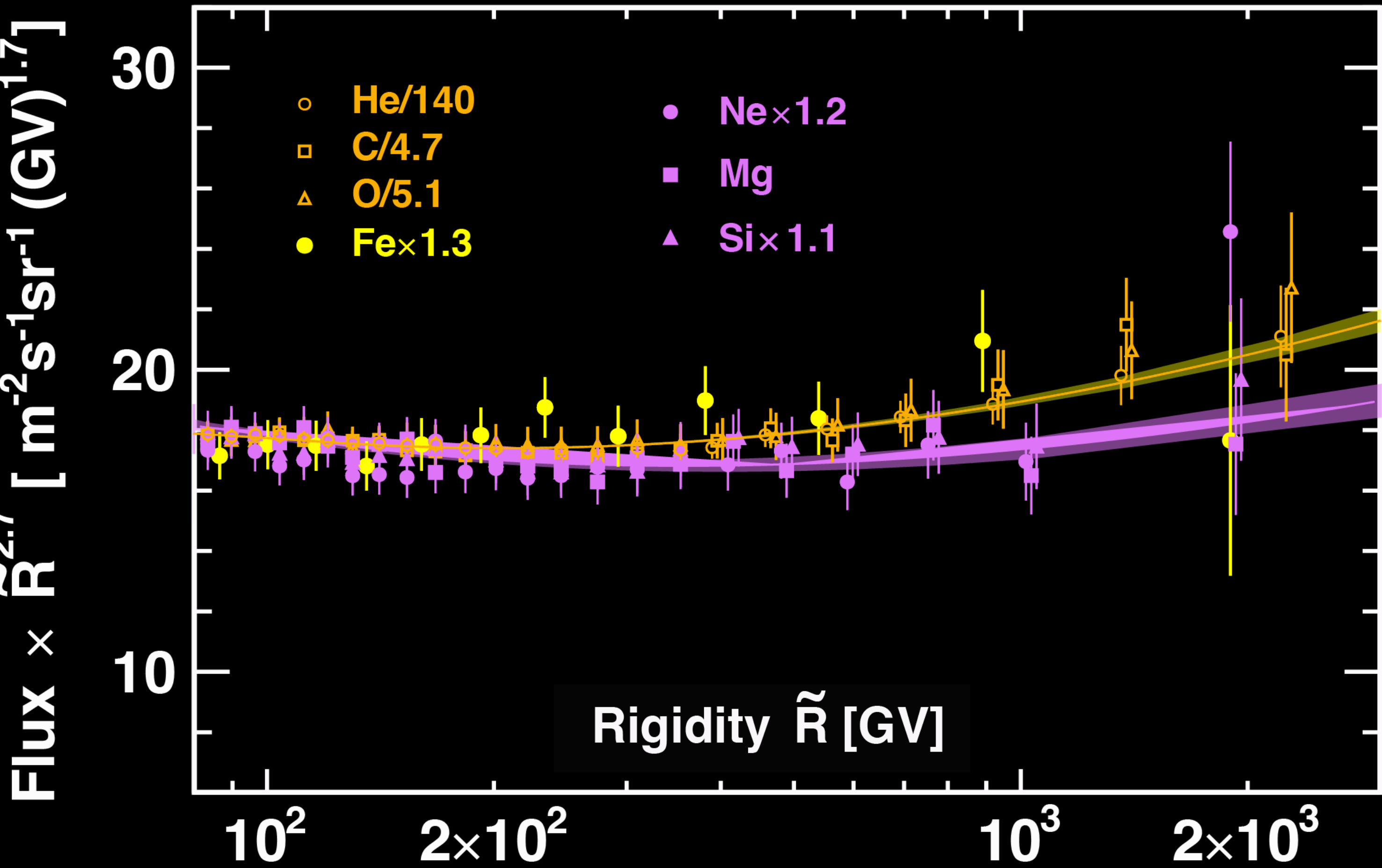


AMS Iron Nuclei Flux Measurements



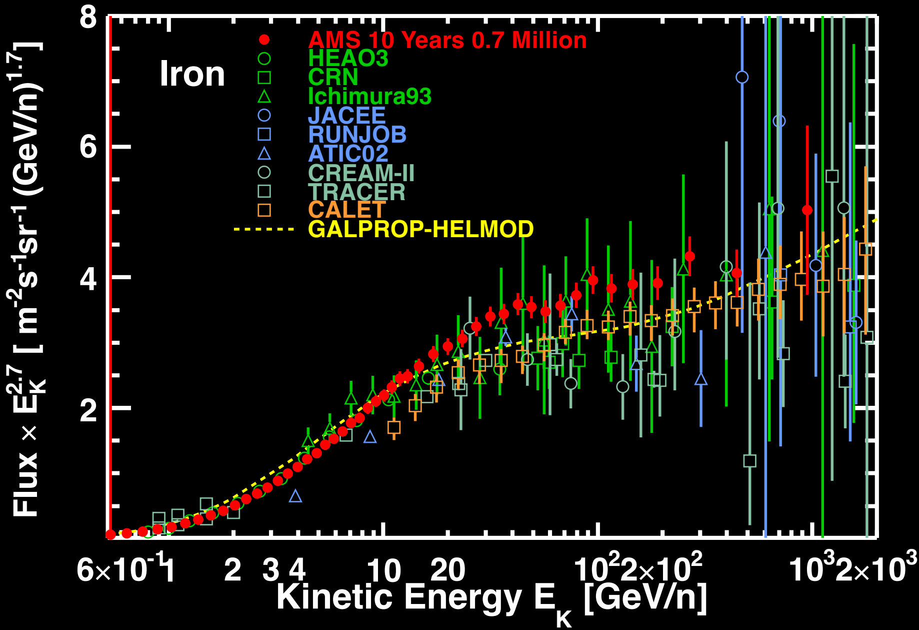
Iron and Helium have identical rigidity dependence at high rigidities

New proprieties of Iron Nuclei Spectrum

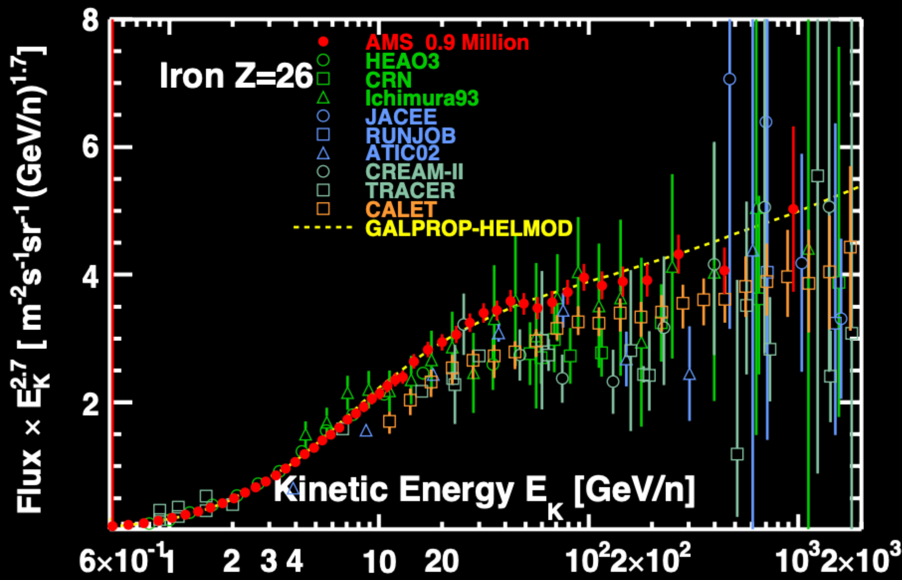


Unexpectedly, the Fe spectrum exhibits same rigidity dependence with primary cosmic rays He-C-O group indicating that Fe belongs to the lighter He-C-O group rather than the heavier Ne-Mg-Si-S group.

Cosmic ray Iron spectrum



Model without consideration of AMS Fe spectrum data M. J. Boschini *et al* 2020 *ApJS* **250** 27

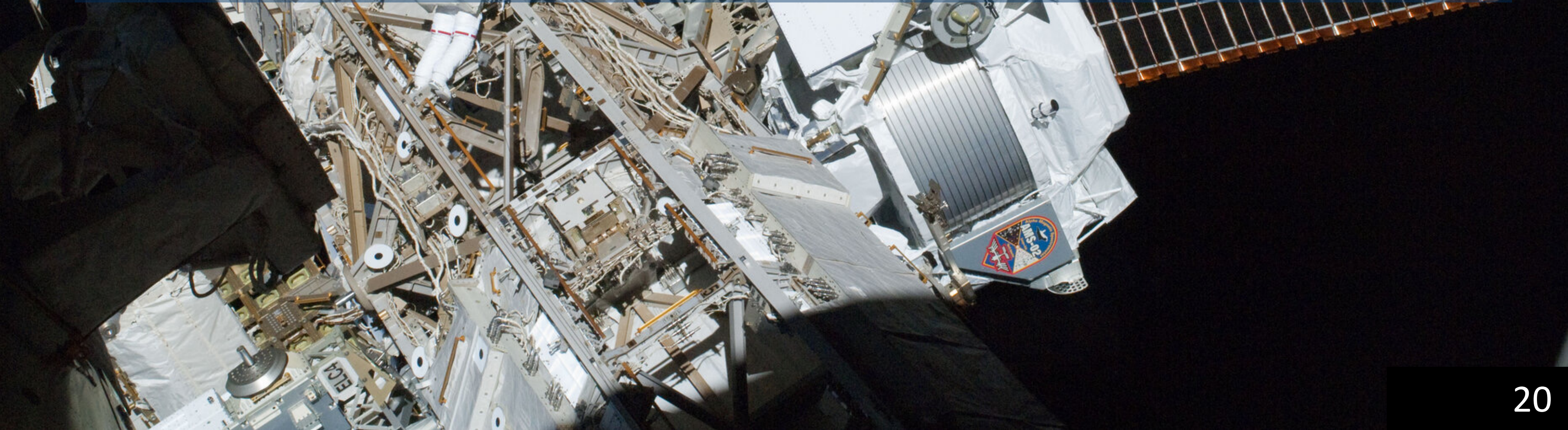


Model with consideration of AMS Fe spectrum data M. J. Boschini *et al* 2021 *ApJS* **213** 5

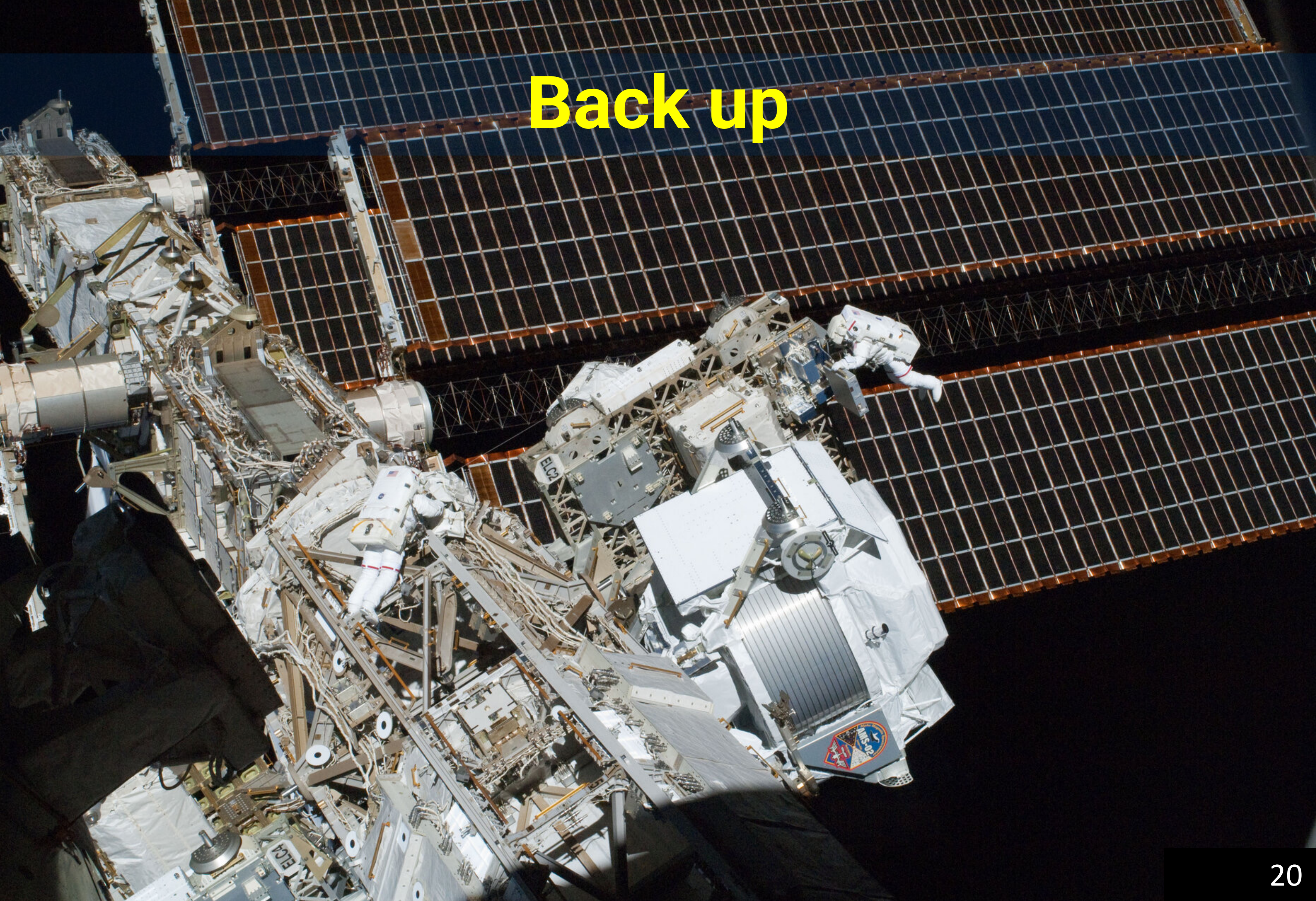
Summary

Up to now, AMS has collected more than 200 billion cosmic rays and measured the spectra of primary cosmic rays with unprecedented precision. In this report we presented the primary cosmic ray p, He, C, O, Ne, Mg, Si, S and Fe spectra from 2 GV to 3 TV based on the latest AMS results, many new unexpected properties are revealed.

Future high-precision AMS data on all cosmic-ray data will continue to provide unique insights into the understanding of cosmic rays.



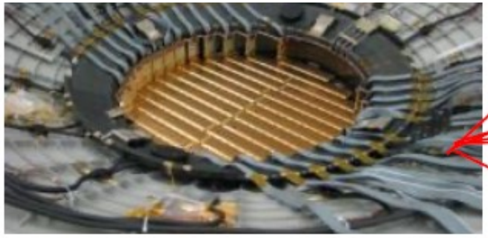
Back up



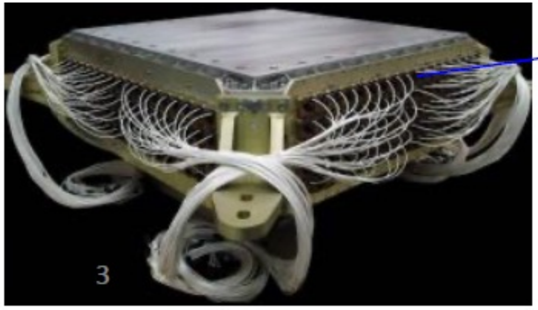
Alpha Magnetic Spectrometer（AMS）

Transition Radiation Detector（TRD）：
$e^{\pm}/p$ identification, charge measurement

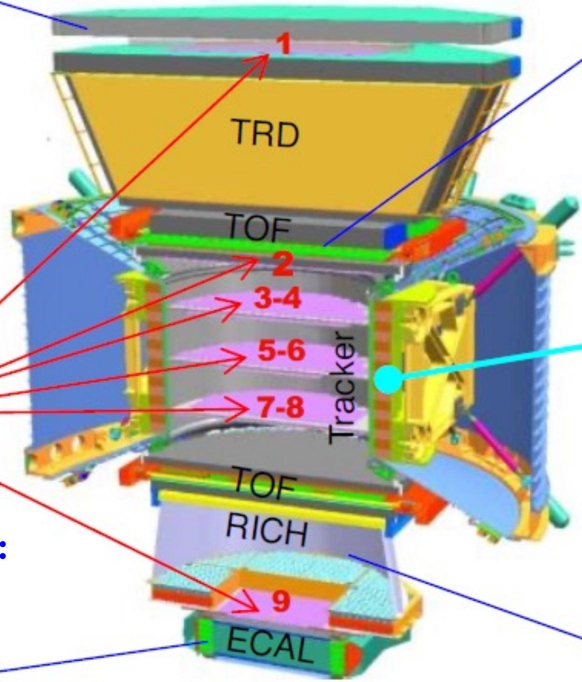
Silicon Tracker:
momentum, position, charge measurement



Electromagnetic Calorimeter（ECAL）：
energy measurement

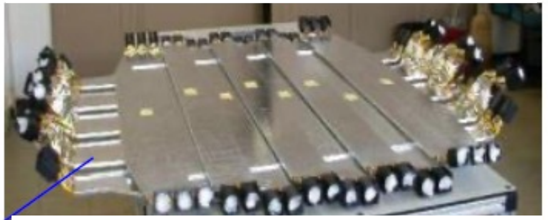


The charge, energy and rigidity(momentum/charge) of cosmic rays carry the key information

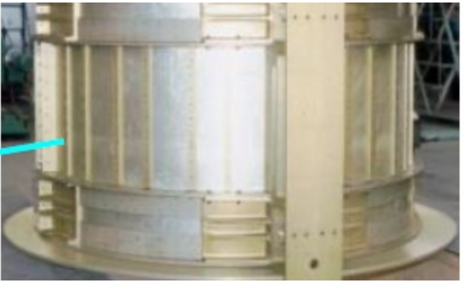


AMS can measure the charge, energy and rigidity of a particle multi-times independently on its trajectory inside the detector

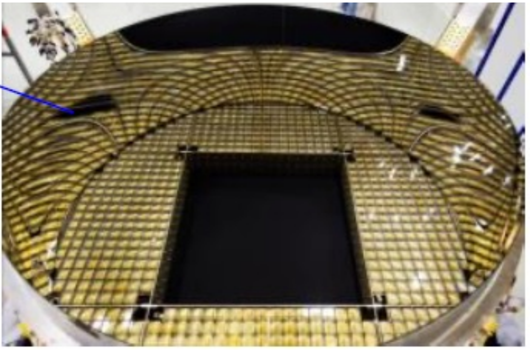
Time Of Flight（TOF）：
velocity, charge measurement



Permanent Magnet:
Anti-particle identification, momentum measurement



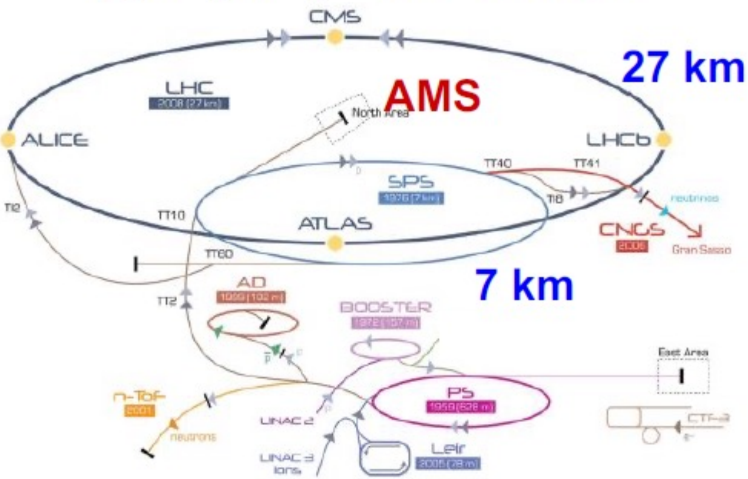
Ring Imaging Cherenkov（RICH）：
velocity, charge measurement

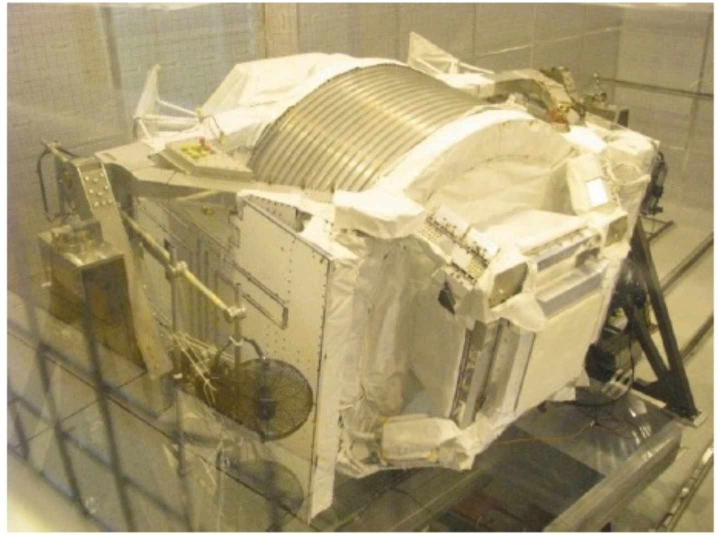


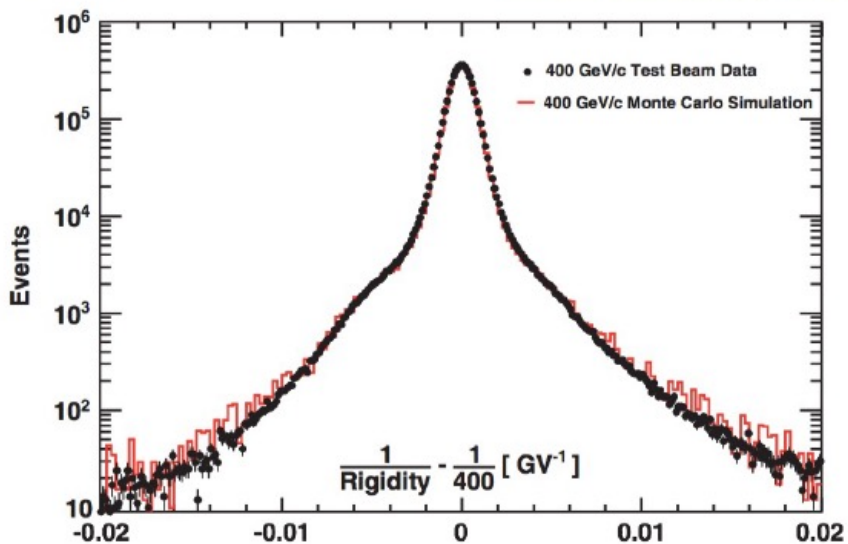
Detector calibration before launch

CERN SPS beam test:

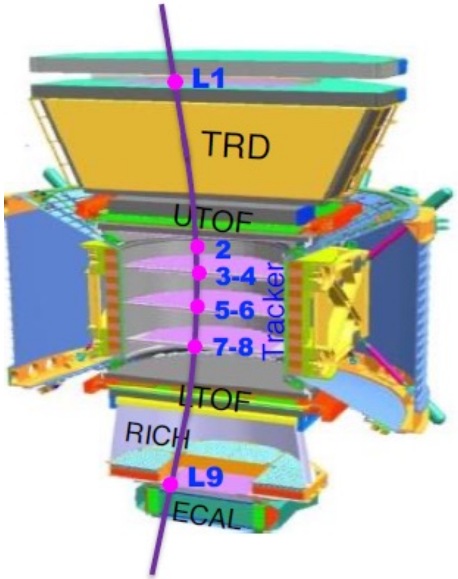
p, e±, π±, 10–400 GeV

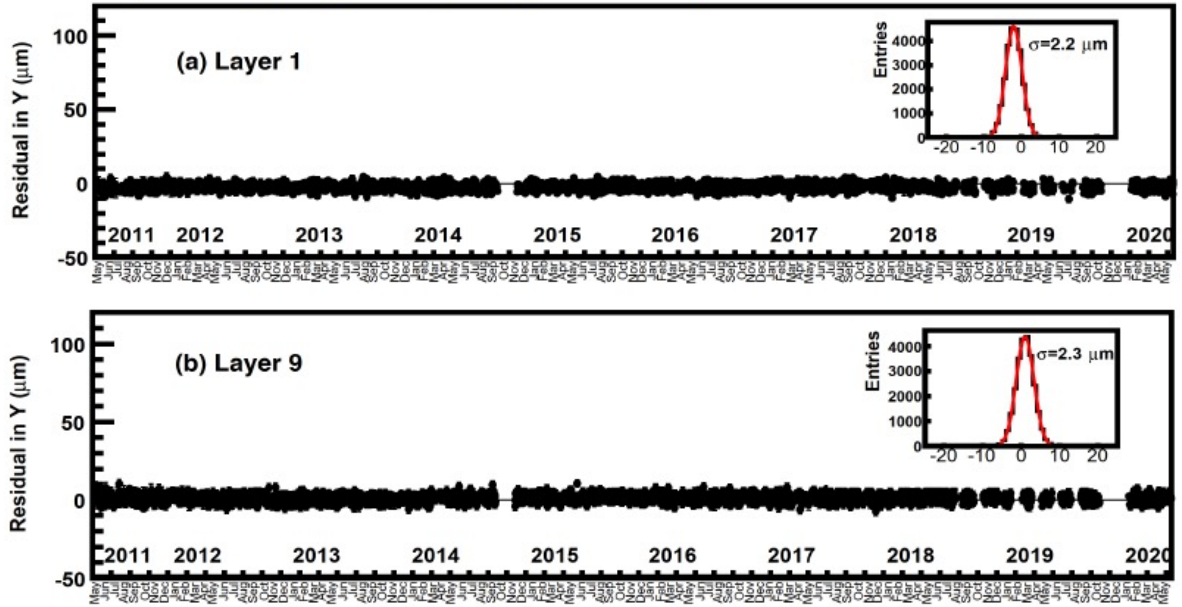






Detector calibration and alignment on orbit





The vibrations and acceleration 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 tracker L2-L8 layers with an accuracy better than 0.2μm, corresponding to the accuracy of the tracker rigidity-scale of better than 1/30TV^{-1} .

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