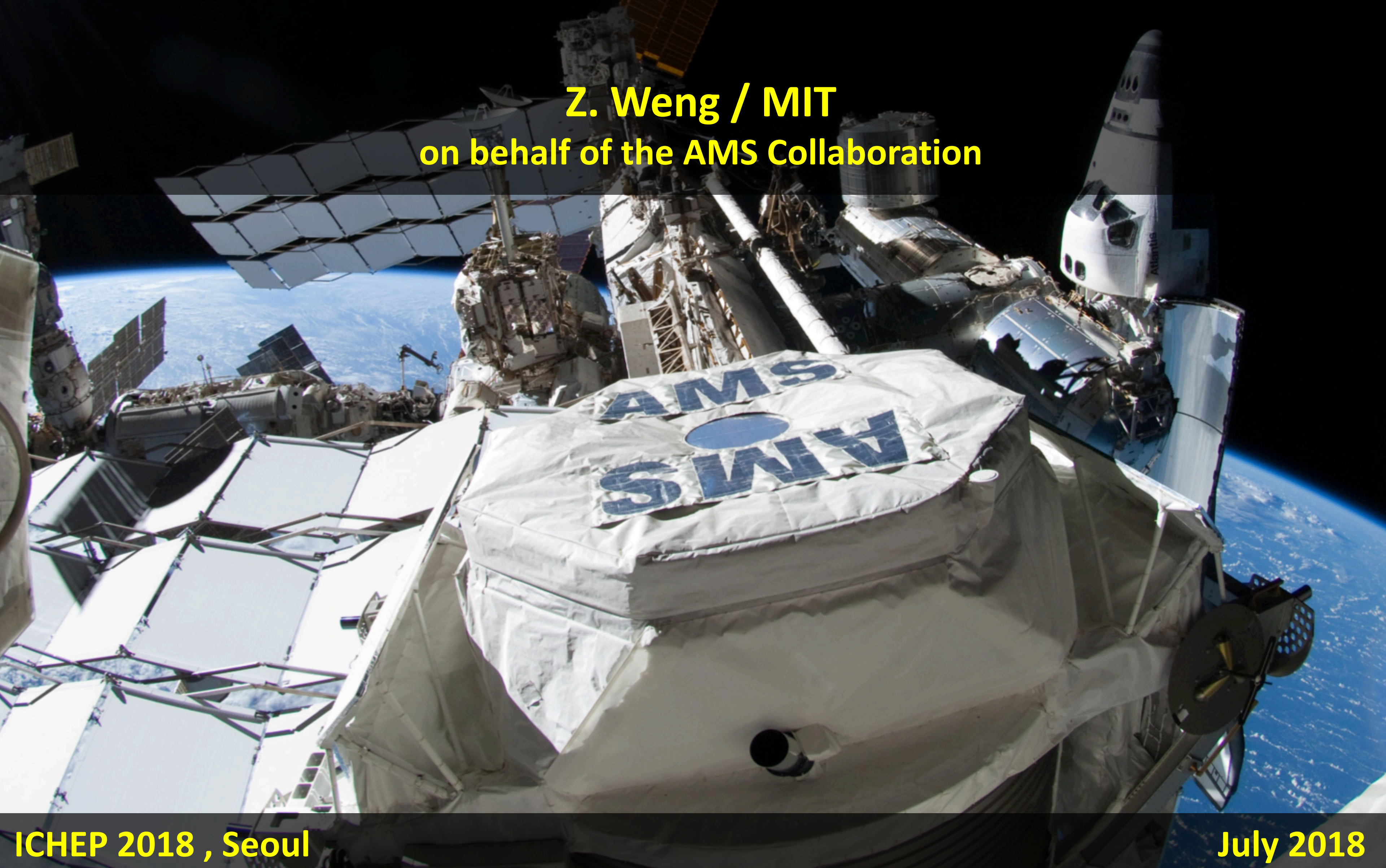
Observation of the Identical Rigidity Dependence of the Primary Cosmic Rays Helium, Carbon and Oxygen fluxes by the Alpha Magnetic Spectrometer on the International Space Station

Z. Weng / MIT

on behalf of the AMS Collaboration



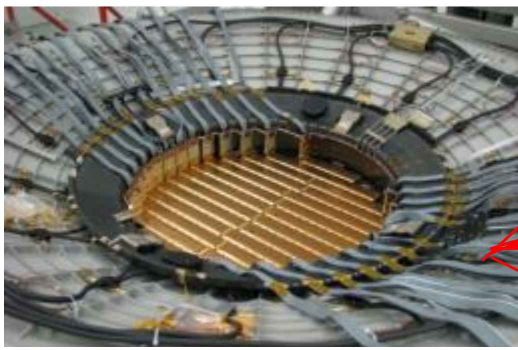
AMS: a unique TeV precision, Magnetic spectrometer in space

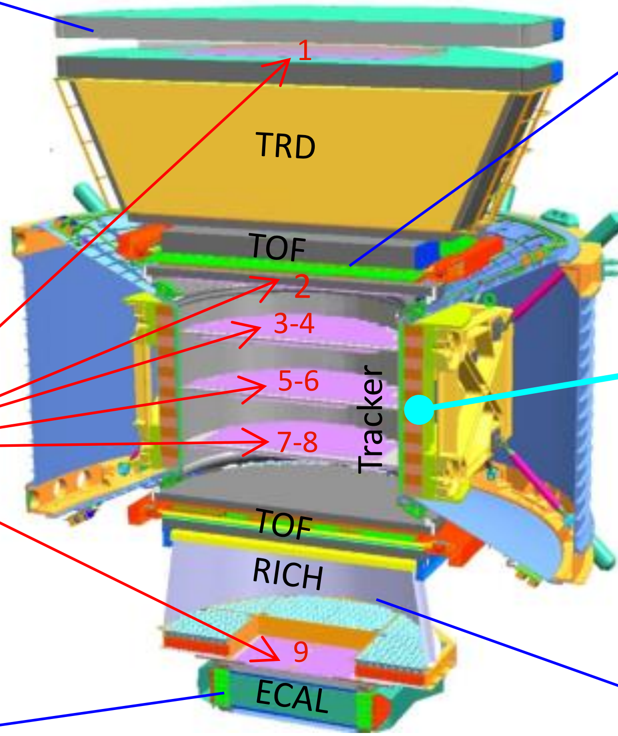
TRD: Identify e^+, e^-, Z

Particles and nuclei are defined by their Charge (Z) and Energy (E), Momentum (P), or Rigidity (P/Z)

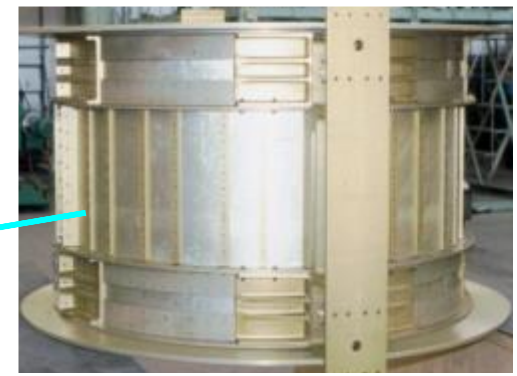
TOF: Z, E

Silicon Tracker: Z, P

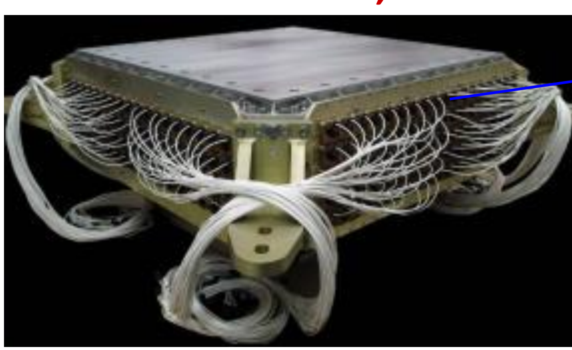




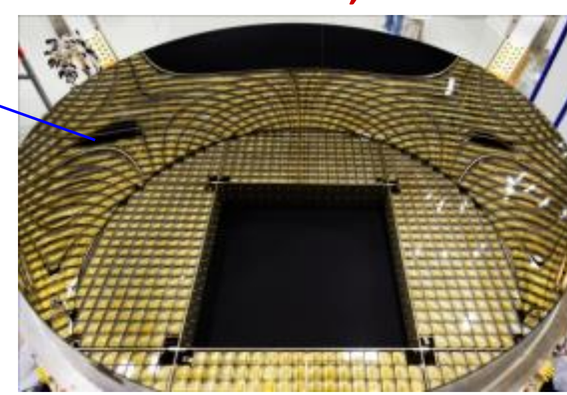
Magnet: ±Z



ECAL: E of e^+, e^-



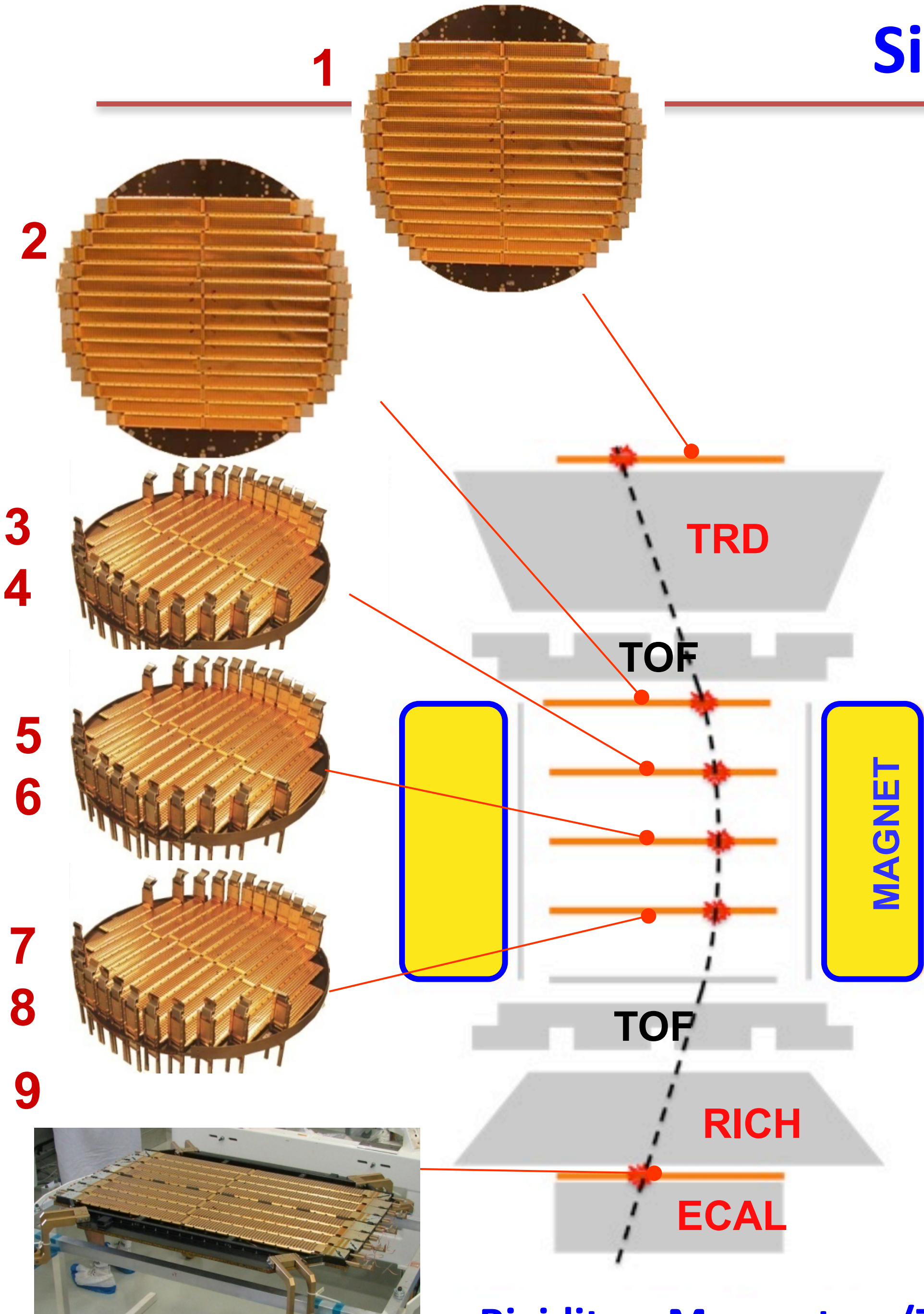
RICH: Z, E



Z and P

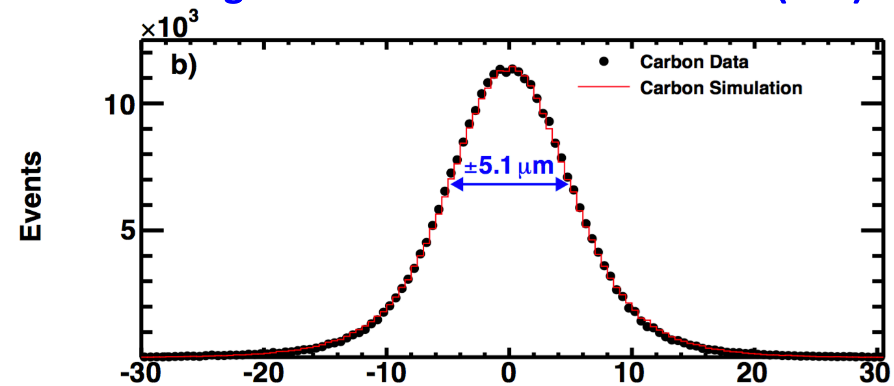
are measured independently by the Tracker, RICH, TOF and ECAL

Silicon Tracker and Magnet



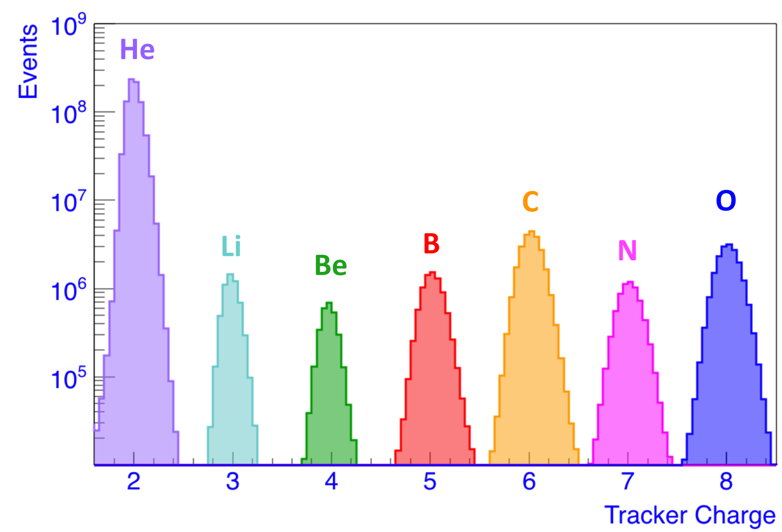
Rigidity = Momentum/Z

Single Point Resolution 5.1micron (Z=6)



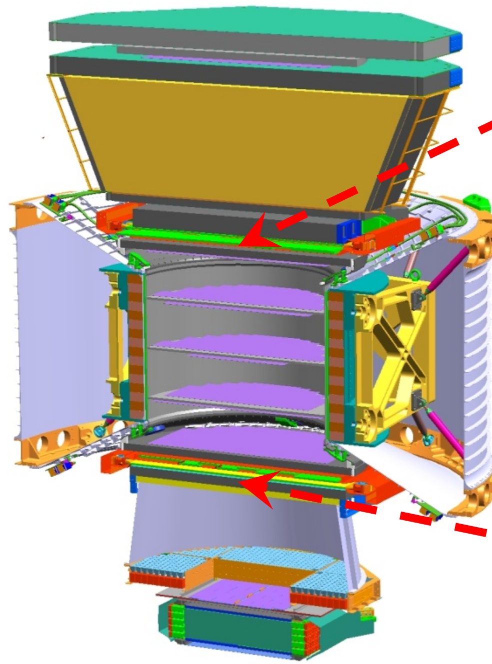
Maximum Detectable Rigidity(MDR)
Z=6 : 3.7 TV

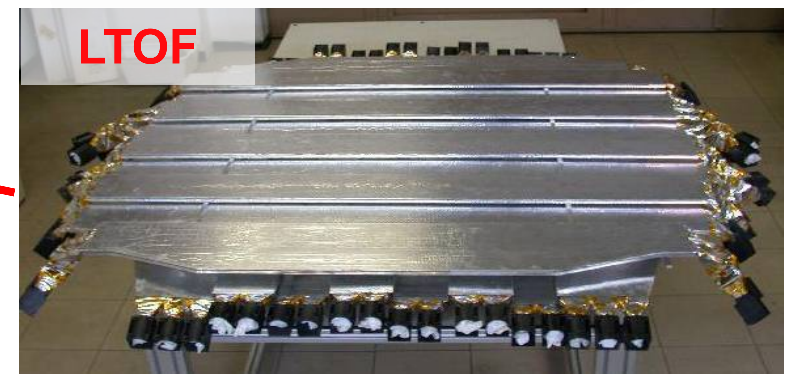
- **Charge Measurement ΔZ=0.12 (Z=6)**

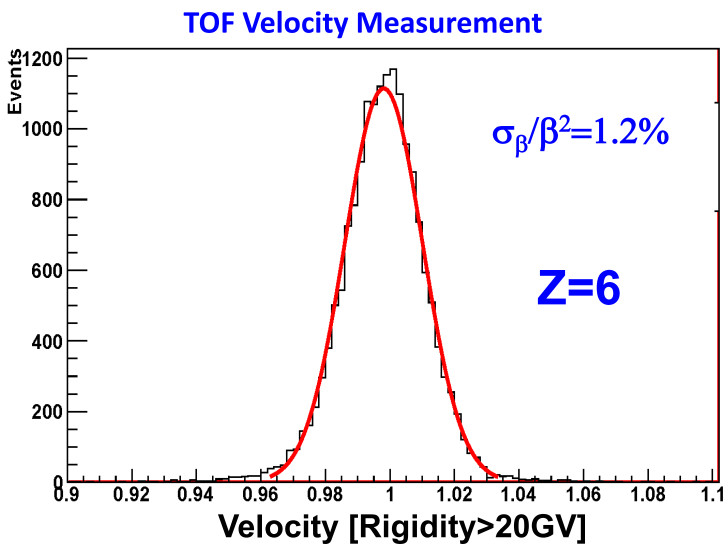


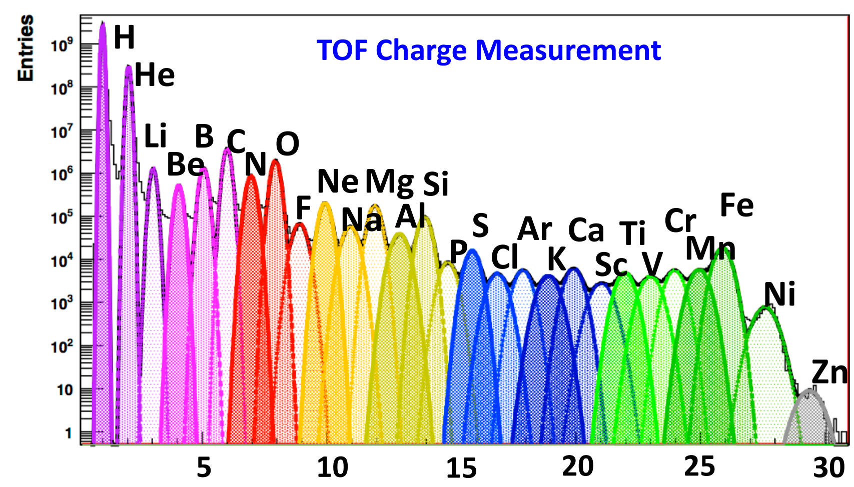
Time of Flight (TOF)

- Provides trigger for charged particles
- Measures direction and velocity
- Time resolution:
  Z=6 : 48ps, σ_β/β^2=1.2%
- Charge measurement:
  ΔZ=0.16 (Z=6) for UTOF and LTOF respetively



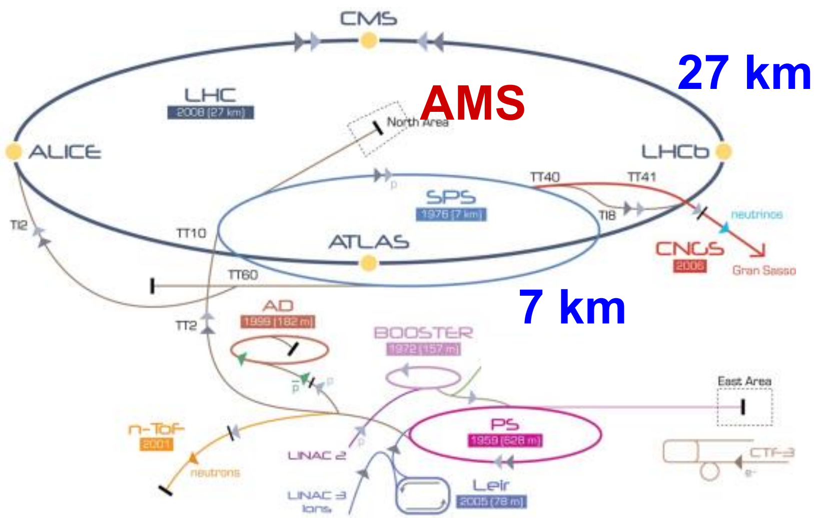




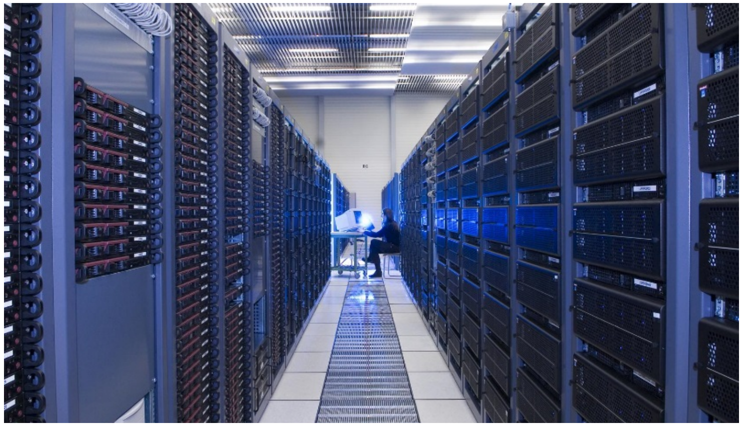


Calibration of the AMS Detector

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

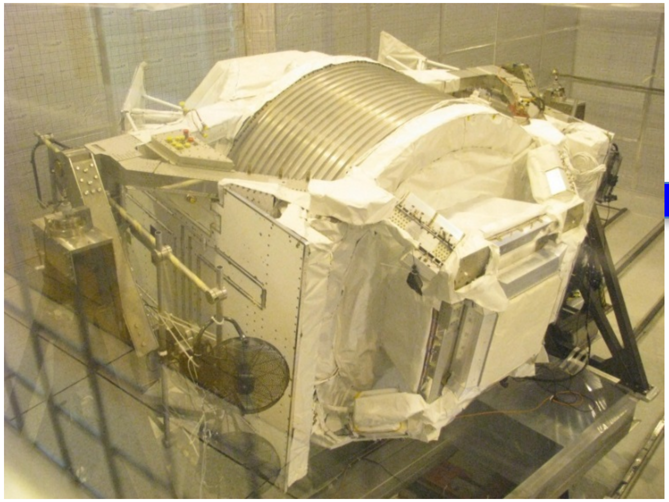


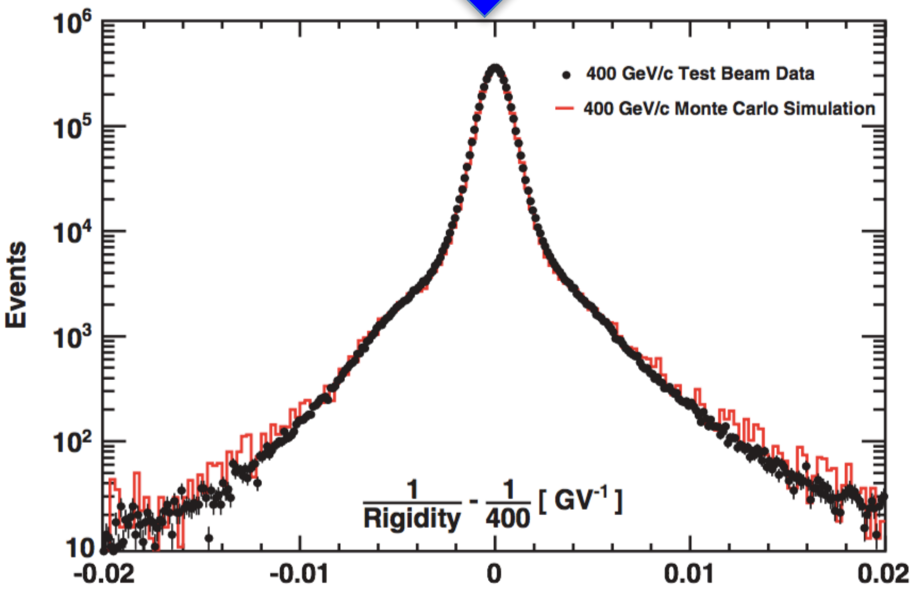
12,000 CPU cores at CERN



Computer simulation:
Interactions, Materials, Electronics

2000 positions

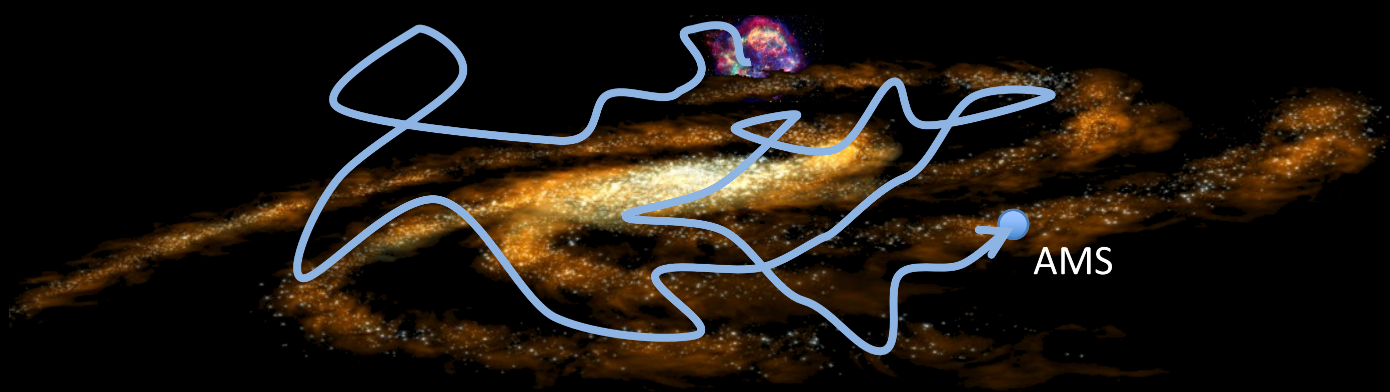




Primary Cosmic Rays

p, He, C, O, are produced at their source and travel through space and are directly detected by AMS.

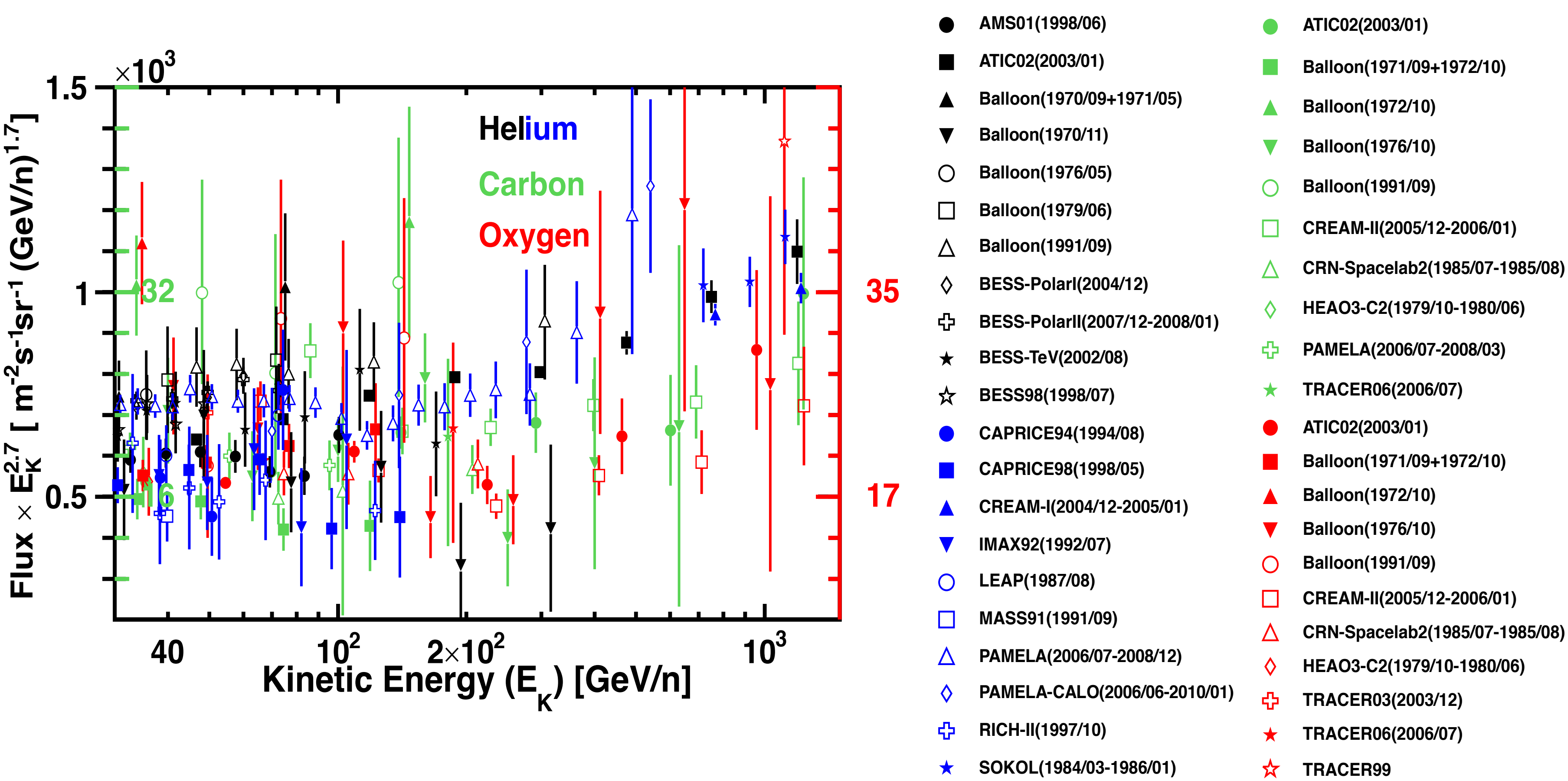
They carry information on their sources and the history of propagation.



Precision measurements of their spectra provides important insights to the origin, acceleration and propagation of cosmic rays in the galaxy.

Before AMS: results on Primary Cosmic Rays

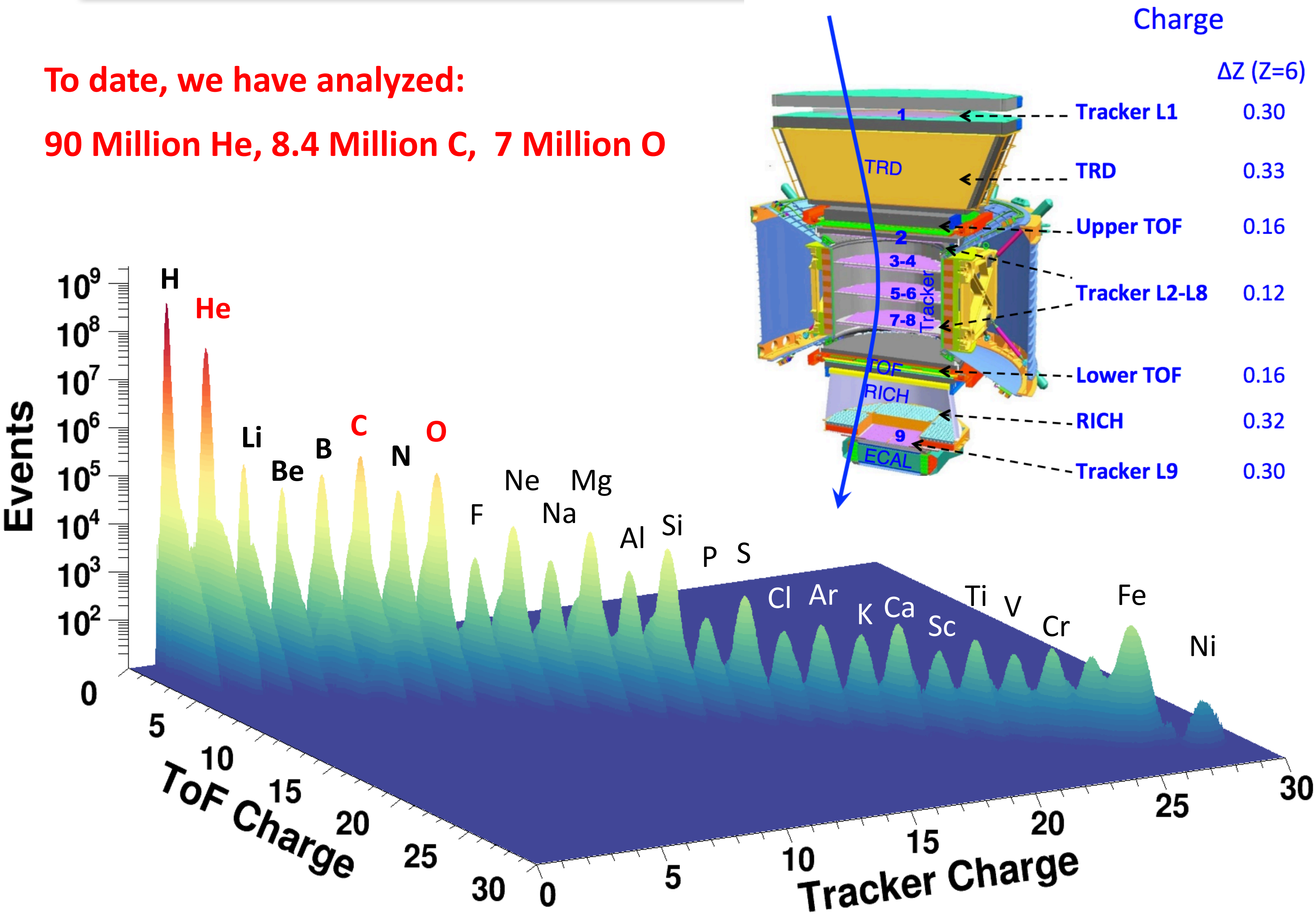
(Helium, Carbon, Oxygen)
from balloon and satellite experiments



Precision Measurements of Cosmic Rays:

To date, we have analyzed:

90 Million He, 8.4 Million C, 7 Million O



Flux Measurement

Isotropic Differential Flux: $$\Phi_i^Z = \frac{N_i^Z}{T_i \, A_i^Z \, \varepsilon_i^Z \, \Delta R_i}$$

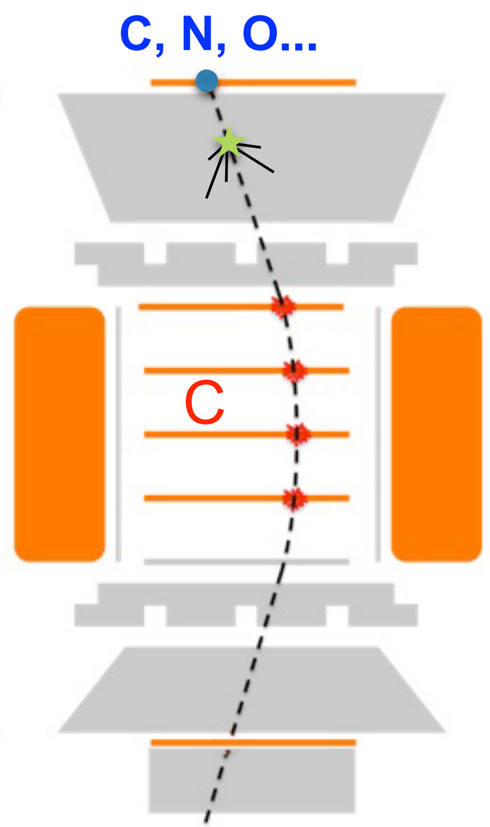
- Number of events are corrected for bin-to-bin migration using unfolding procedure
- Measurement Time: Rigidity dependent, 1.23×10^8 s above 30 GV.
- Effective Acceptance: calculated *from MC Simulation, validated with Data*
- Trigger Efficiency: >94% for He, >97% for C,O
- Energy range and bin Width: 67 bin between 1.9 GV and 3 TV

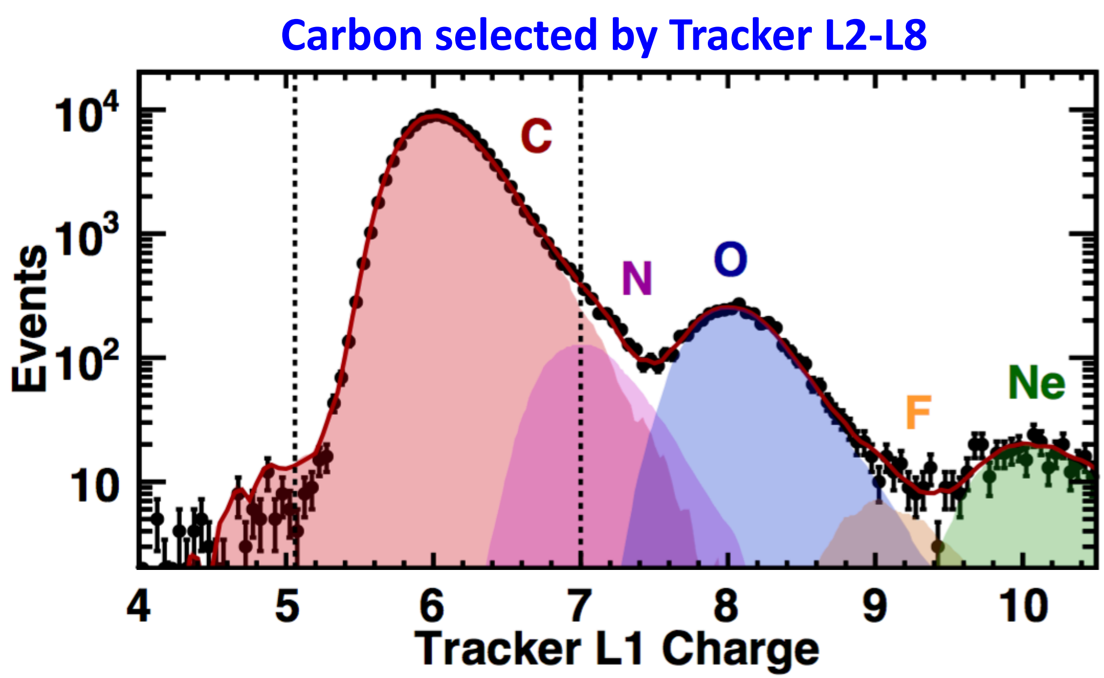
Extensive studies of the systematic errors

- **Background estimations**
- **Trigger efficiency and Acceptance calculation**
- **Rigidity resolution function**
- **Absolute rigidity scale**

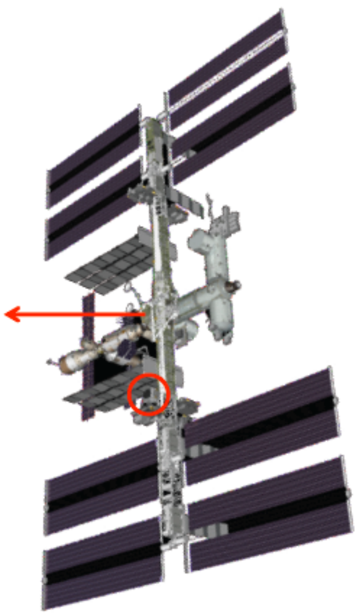
Data purity

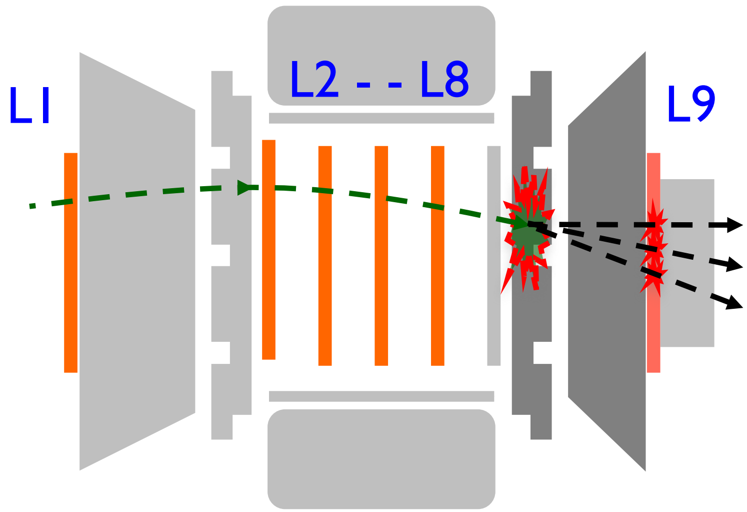
- **The high redundancy of charge measurements allows estimation of background from interactions in the upper part of the detector (between Tracker L1 and L2)**
- With the track defined by the Tracker L2-L8, examine the charge distribution on the tracker L1.
- Data sample purity: >99.9% for Helium, >99% for Carbon, >99.8% for Oxygen
- **Systematic error on the flux: <0.5%**





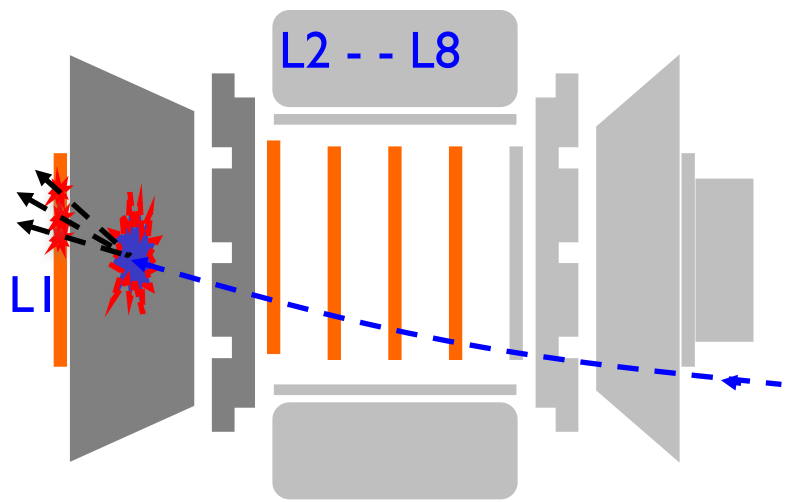
Measurement of nuclear cross sections by AMS





First, use the seven inner tracker layers, L2-L8, to define beams of nuclei: He, C, O, …

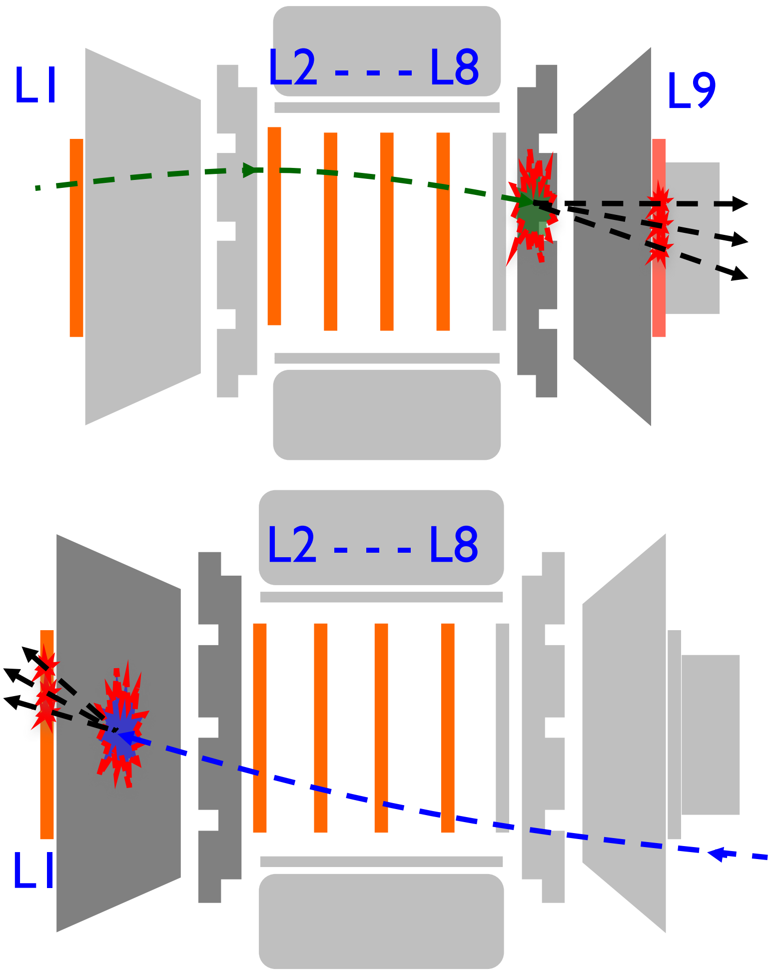
Second, use left-to-right particles to measure the nuclear interactions in the lower part of the detector.

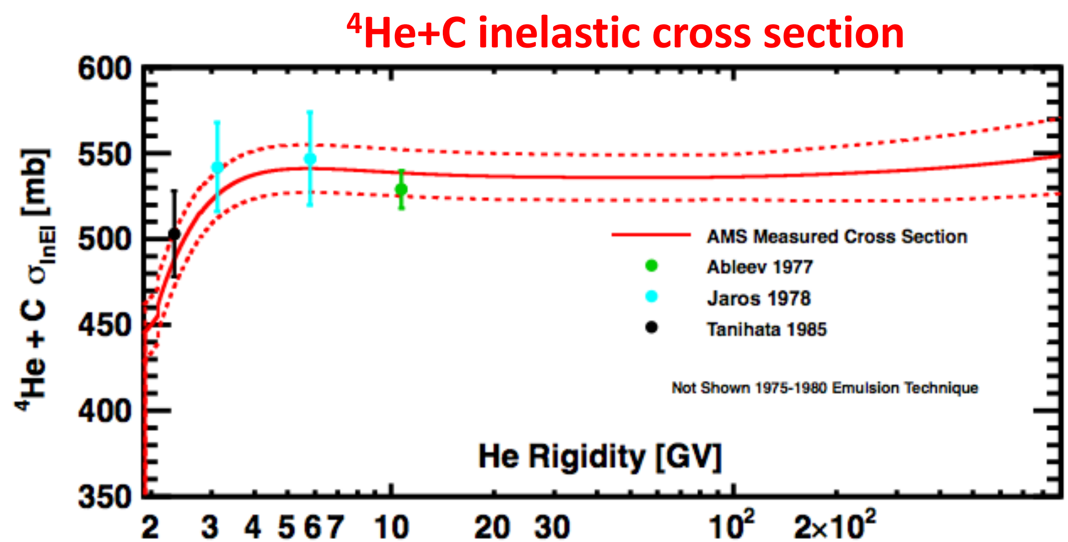


Third, use right-to-left particles to measure the nuclear interactions in the upper part of detector.

Measurement of nuclear cross sections by AMS

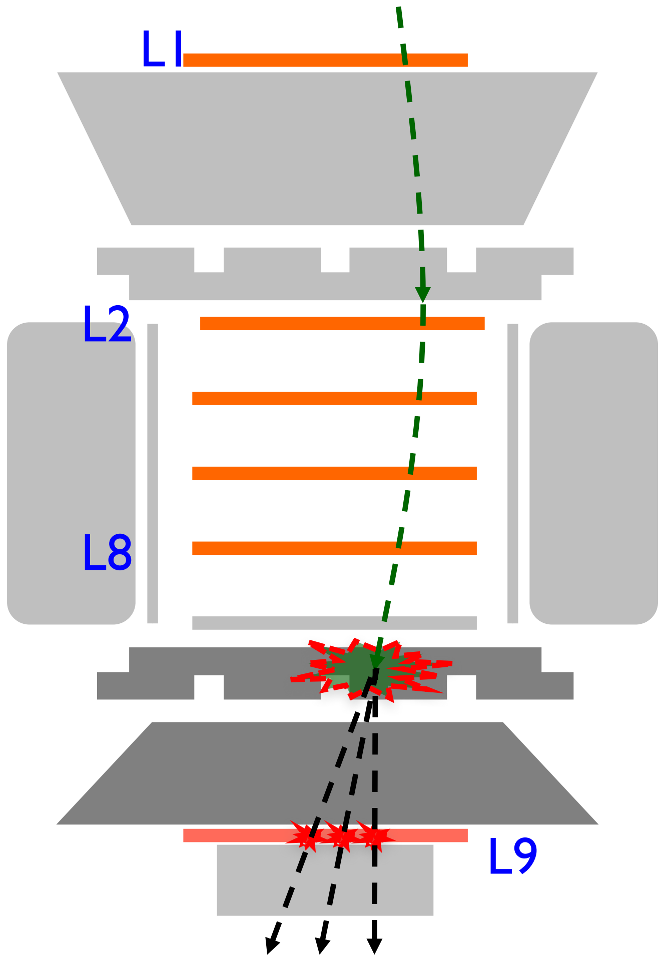
- The cross section is estimated starting from the Glauber-Gribov model.
- The measured "Survival probabilities" from data are compared with the predictions from the MC simulation.
- The inelastic cross section measured from AMS agrees well with experimental results

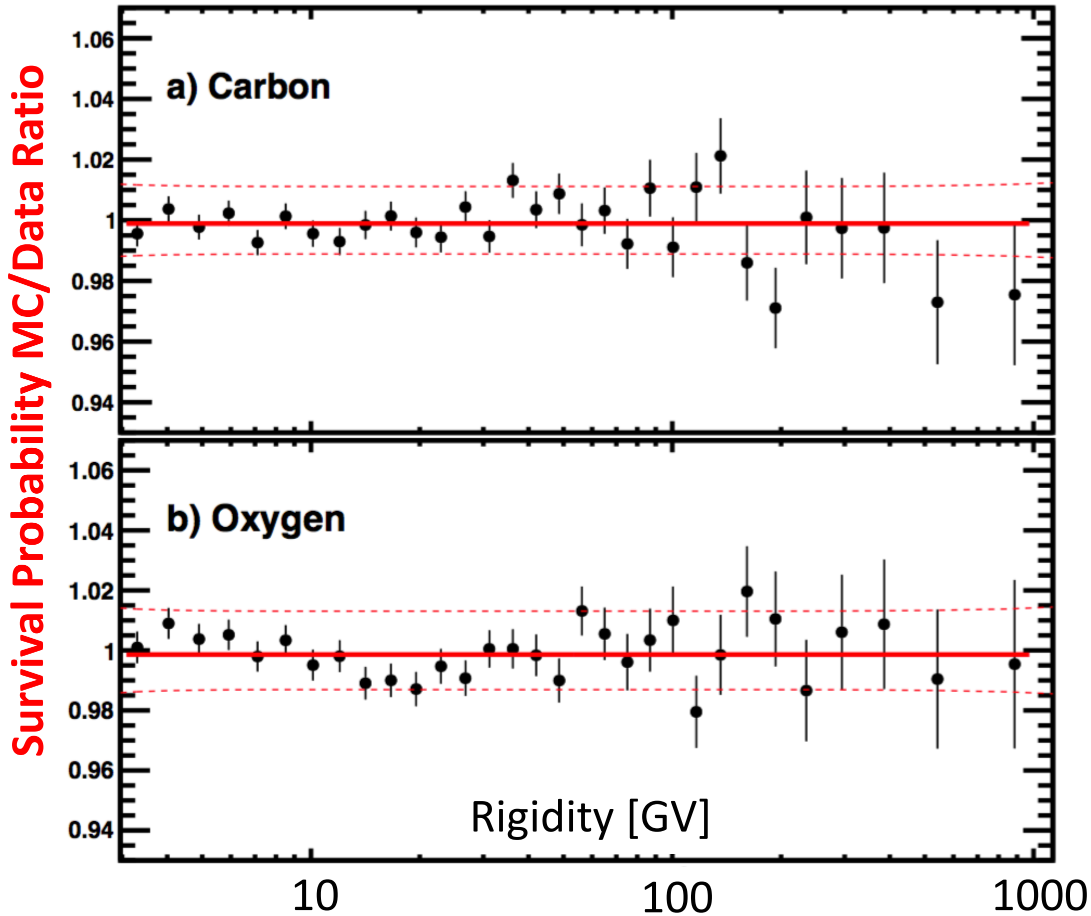




Measurement of nuclear cross sections by AMS

- The measured "Survival probabilities" show good agreement between MC and Data

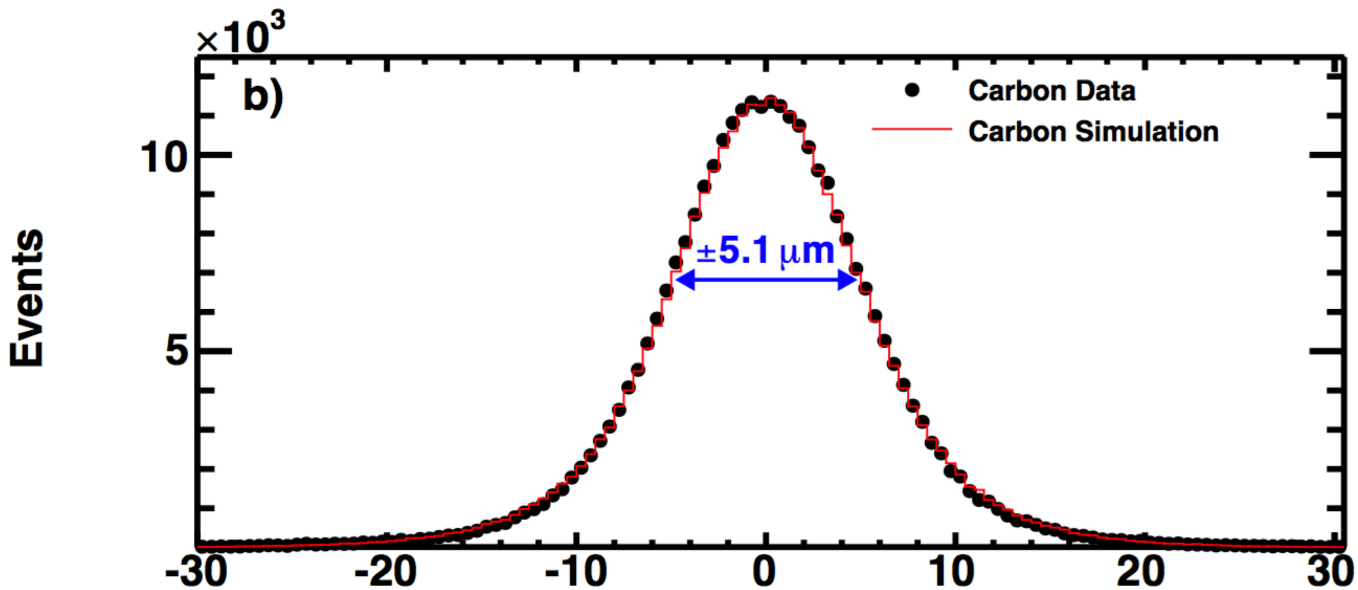




Systematic error on the flux: ~2% up to 100GV, ~3% at 3TV

Rigidity Resolution

- **Knowledge of the rigidity resolution is crucial to the unfolding procedure**
- Resolution function for protons has been measured with the 400GV test beam. MC describes data over several orders of magnitude.
- For heavier nuclei the MC simulations are validated by examining the spatial resolution of the silicon sensors.



Systematic error on the flux: 1% below 300 GV, 4% at 3TV

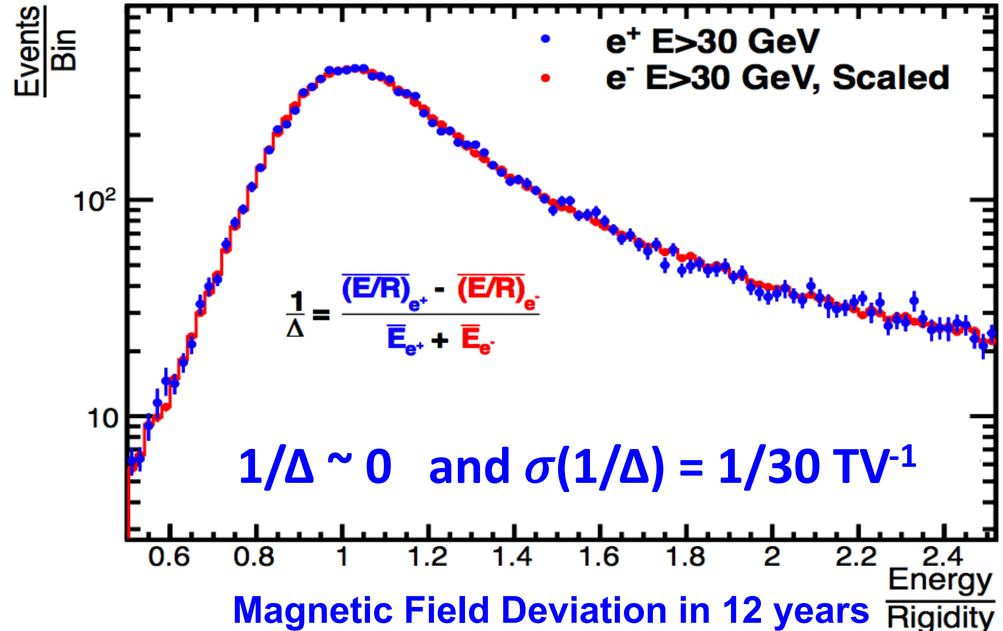
Rigidity Scale

Two contributions to this uncertainty:

Residual tracker misalignment

Checked with Energy/Rigidity using electrons and positrons

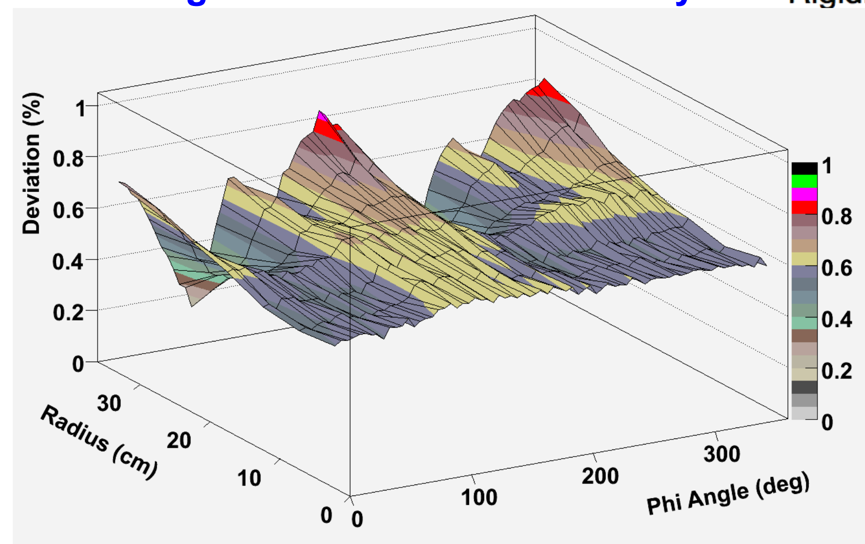
Rigidity Scale error: 1/30 TV^{-1}



Magnetic field

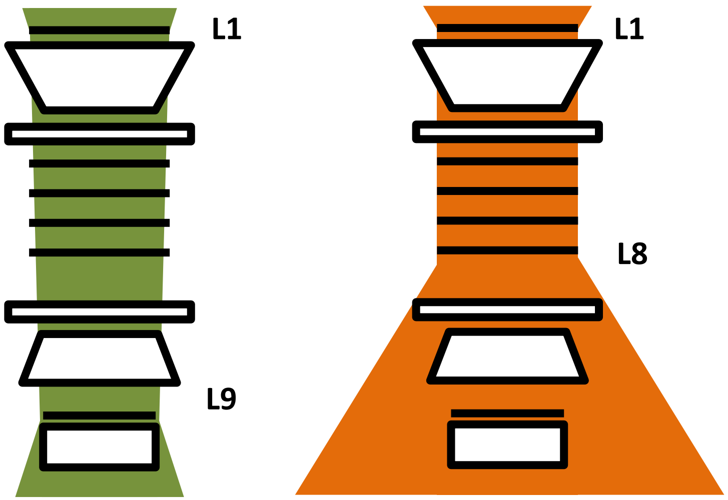
- **In 12 years the field has remained the same to <1%**
- Systematic uncertainties: Magnetic field mapping measurement (0.25%), Field variation on temperature (0.1%)

Magnetic Field Deviation in 12 years



Systematic error on the flux: <1% below 300 GV, 6.5% at 3TV

Measurement verification

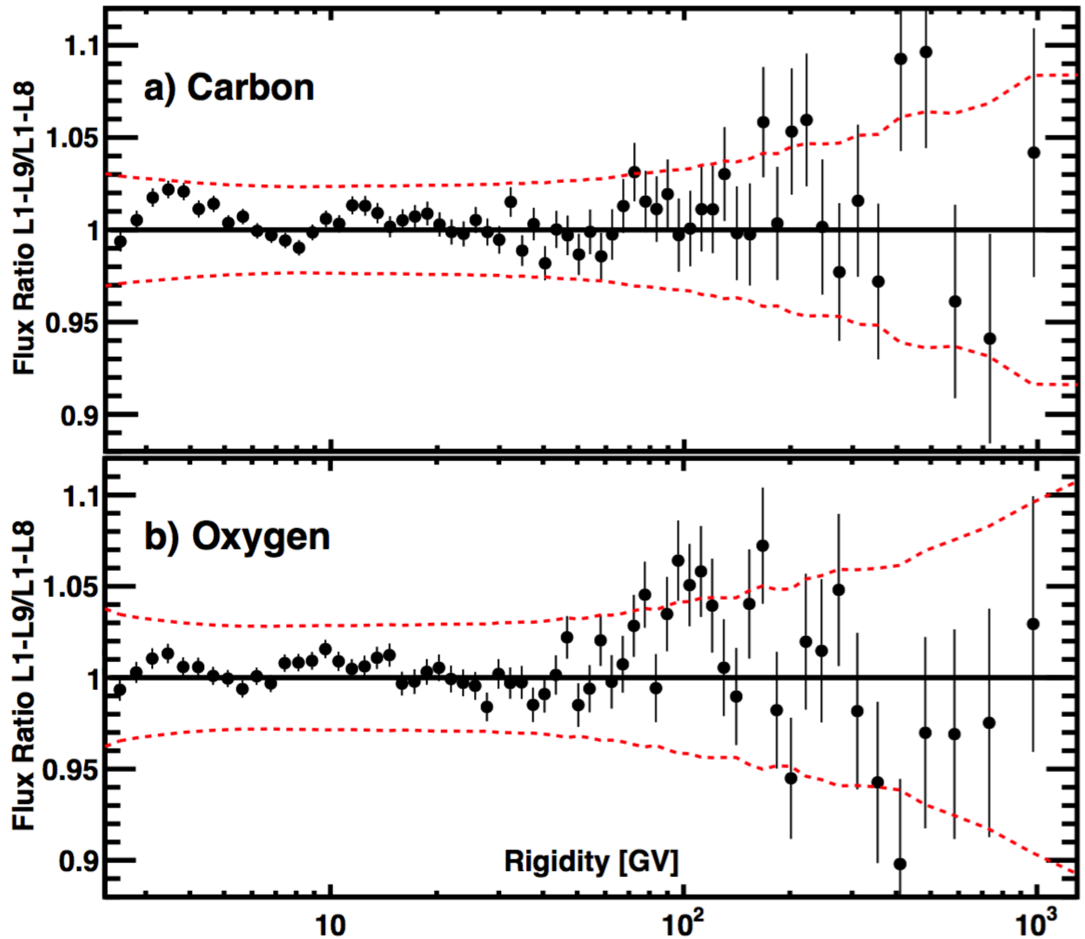


MDR(Carbon): 3.7 TV

MDR(Carbon): 1.5 TV

Fluxes measured using events passing through L1-L9

Fluxes measured using events passing through L1-L8

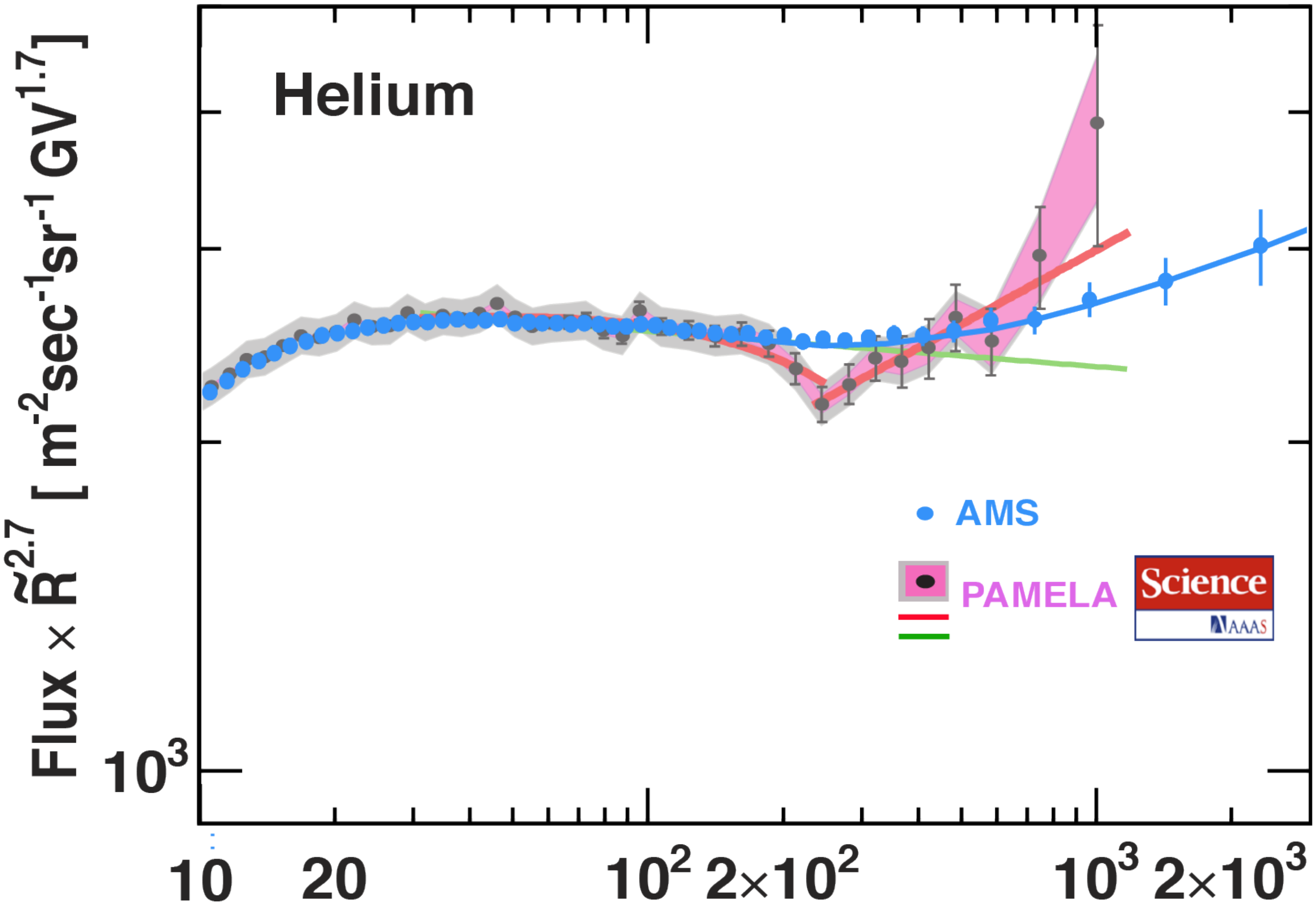


The measurements agree within quoted systematic error.
These verifies the acceptance and unfolding procedure

The AMS results on primary cosmic rays He, C, and O.

M. Aguilar et al. Phys Rev Lett, 2017 vol. 119(25) p. 251101

- **The AMS helium flux is distinctly different from previous measurement.**
- **He flux shows a smooth change of behavior towards high energy starting from 300 GV.**



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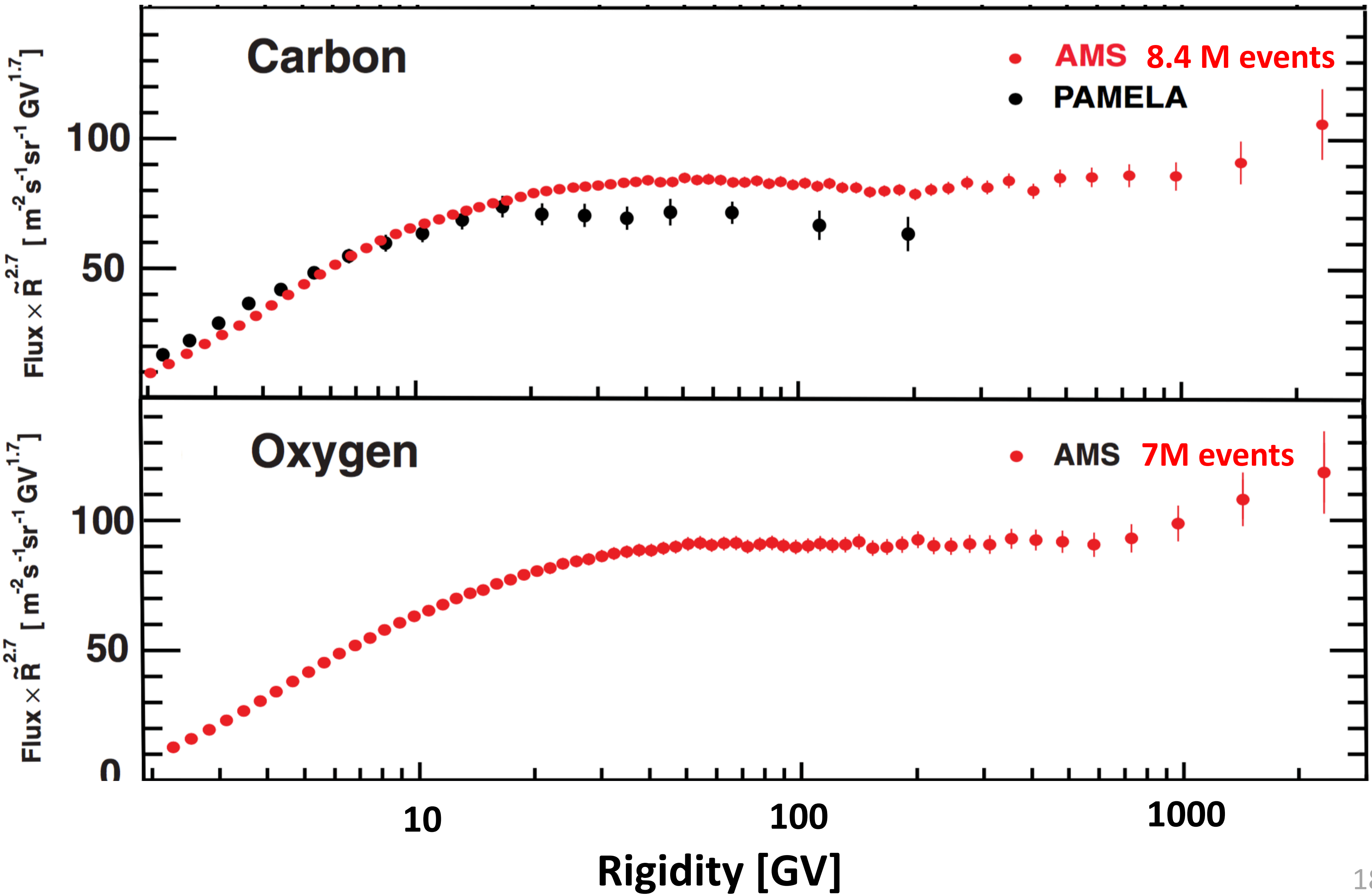
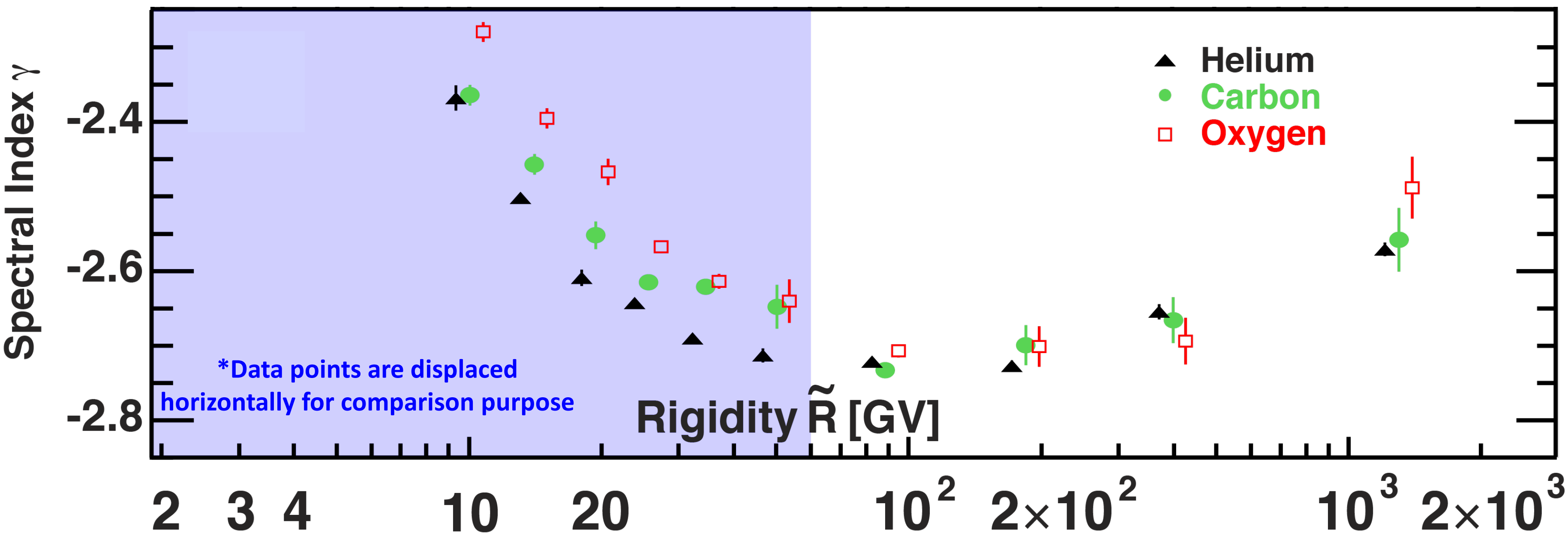


Identical Rigidity Dependence of He, C, O fluxes

Cosmic rays spectrum is characterized by power law function

$$\Phi = CR^{\gamma}$$

where γ is the spectral index and R is the Rigidity.



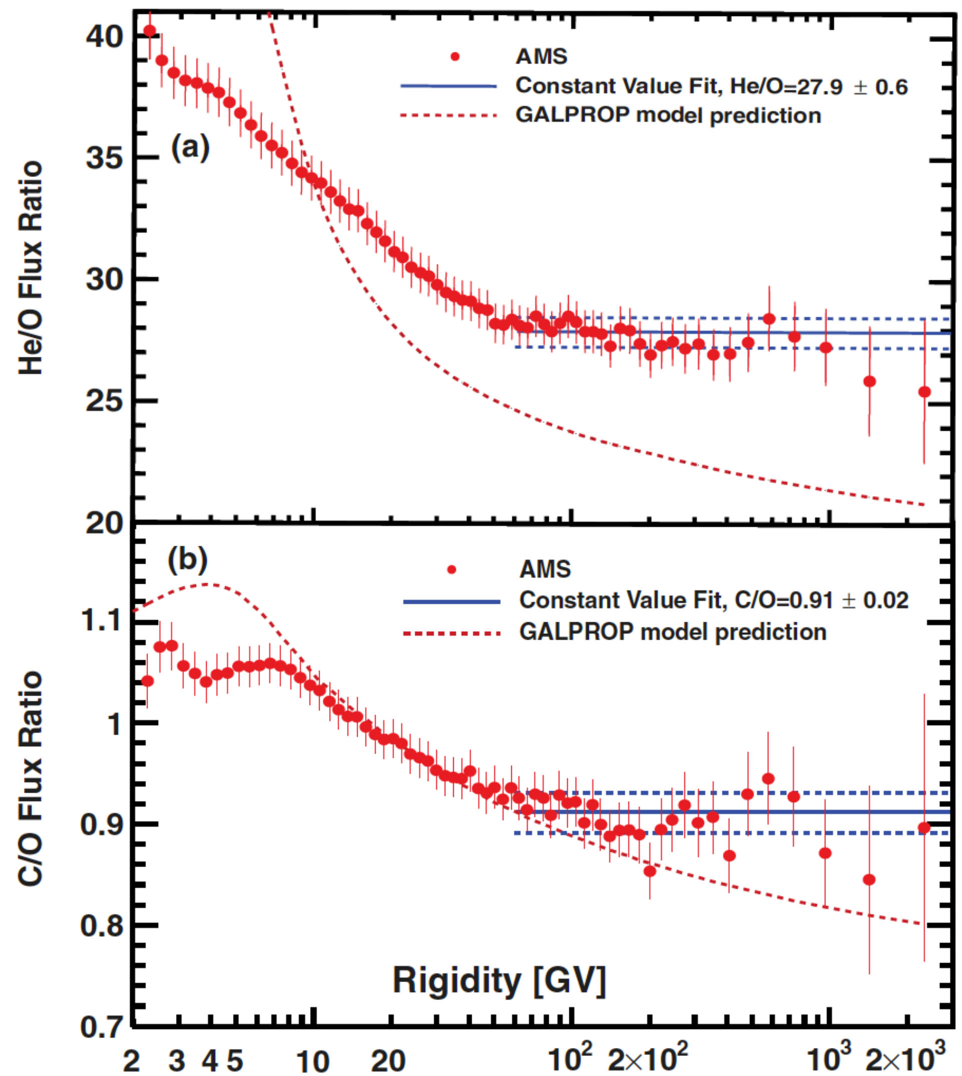
Above 60 GV the spectral indices are identical

Above 200 GV, the spectral indices change in an identical way

Identical Rigidity Dependence of He, C, O fluxes

- Above 60 GV the He/O ratio measured by AMS is well fit by a constant value.
- This is in disagreement with the GALPROP model which predicts a He/O ratio decreasing with rigidity.

- Similarly, the ratio of the carbon flux to the oxygen flux, is well fit by a constant.
- This is again in disagreement with the GALPROP model.

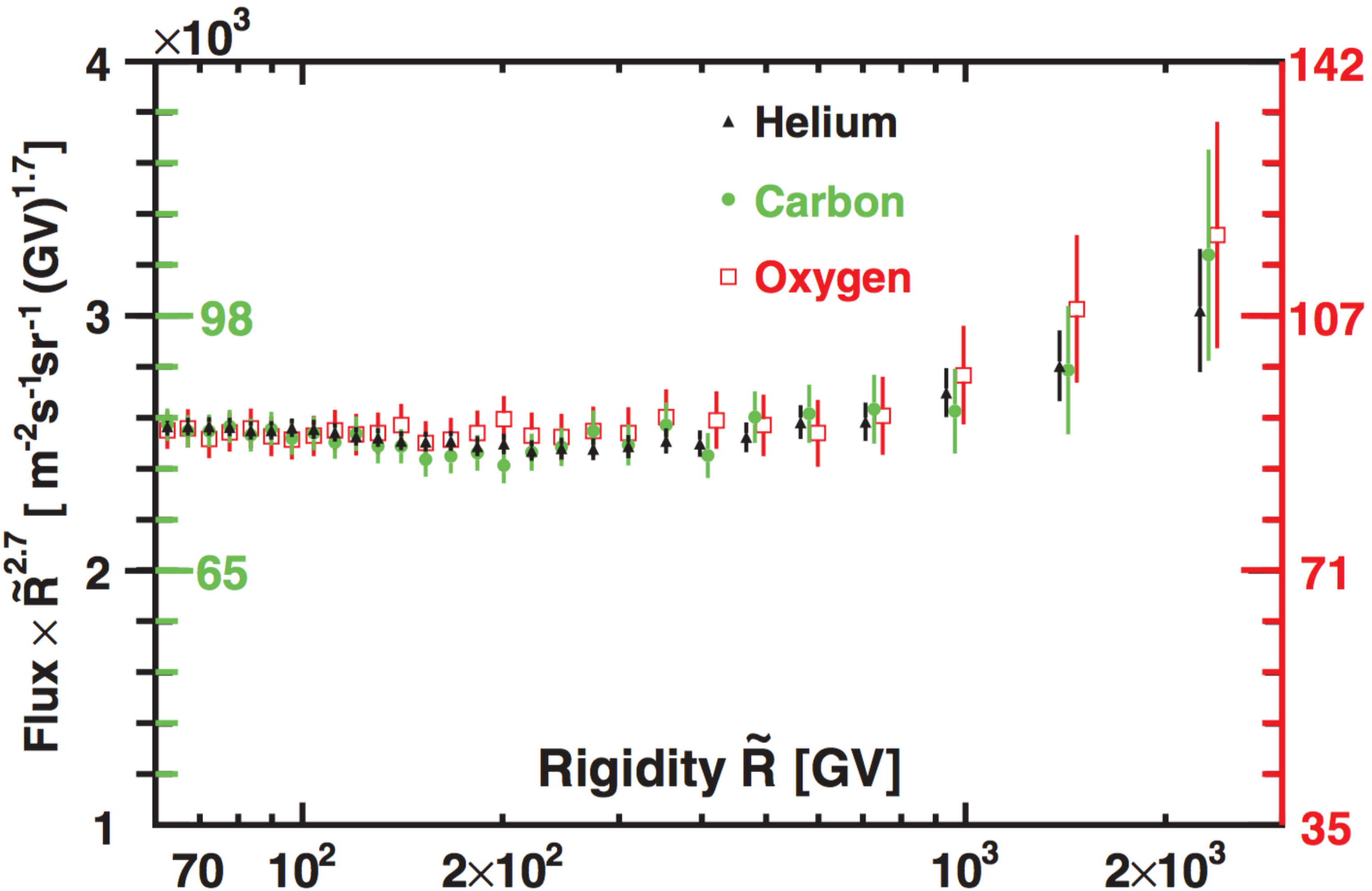


These result can not be explained by current understanding of cosmic rays.

New Observation

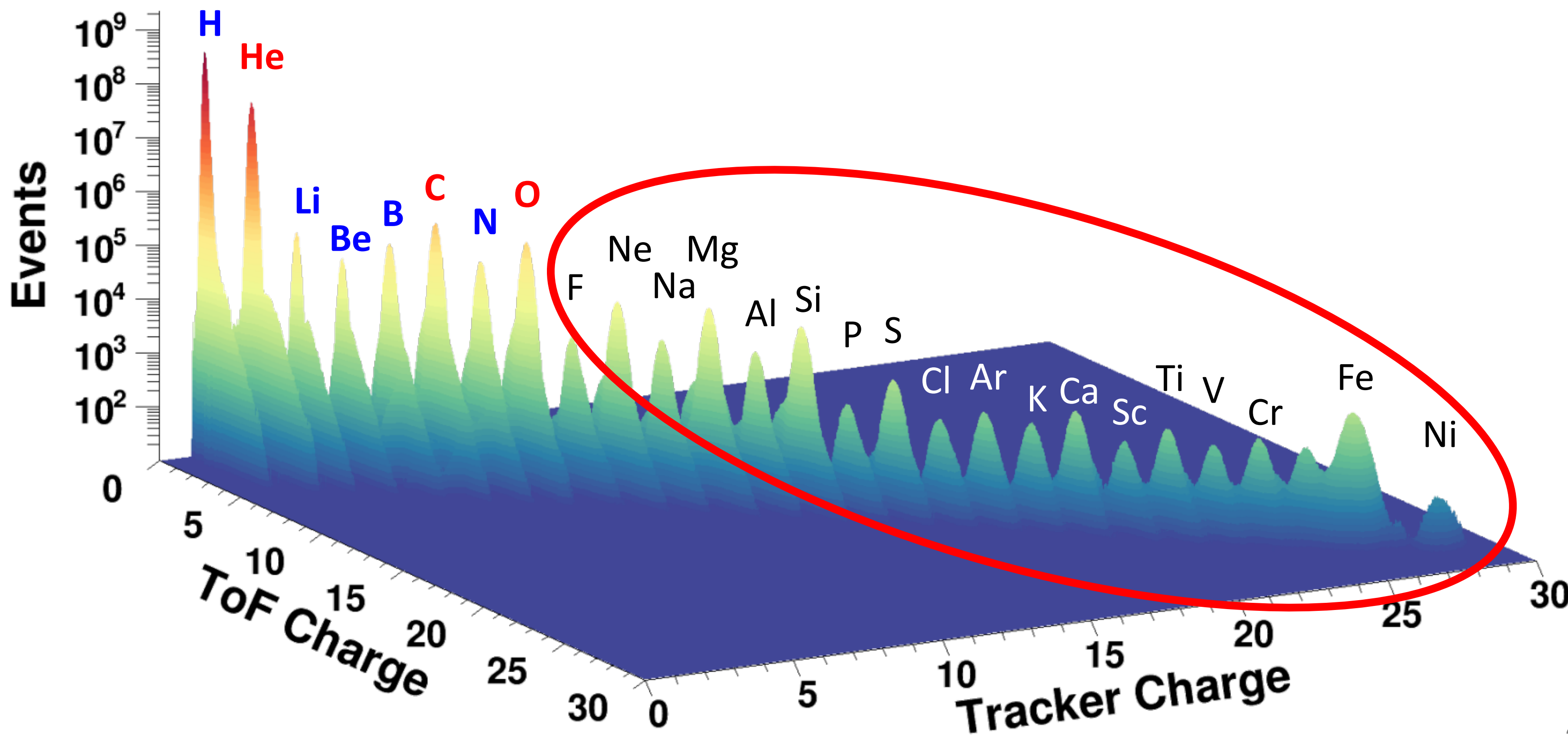
The AMS results show that the primary cosmic rays (He, C, and O) have an identical rigidity dependence above 60 GV.

Above 200 GV their behavior all change in an identical way.

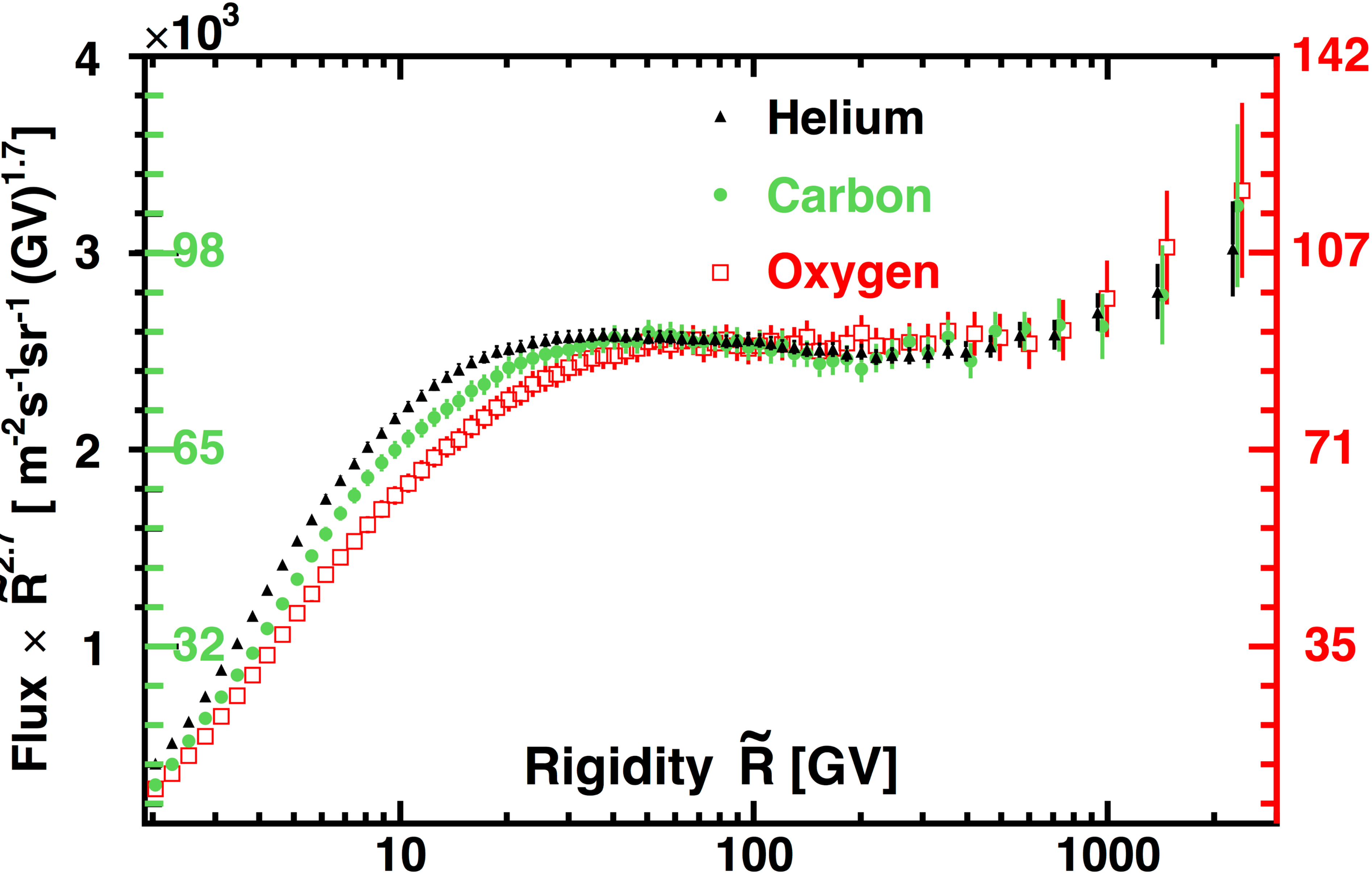


Conclusion and Outlook

- **AMS observation of identical rigidity dependence of primary cosmic ray He, C, O is challenging current model of CR production, acceleration, and propagation.**
- **Simultaneous measurement of many CR species is crucial for acquiring knowledge of cosmic ray physics and for the discovery of new phenomena.**
- **AMS will continue collecting data for the live time of the ISS, provide precision measurements of cosmic rays fluxes up to Iron and beyond.**



The AMS results on primary cosmic rays He, C, and O.



Primary cosmic rays He, C, and O in E_{kin}/n