Properties of Primary Cosmic Ray Proton, Helium, Carbon and Oxygen Measured with AMS

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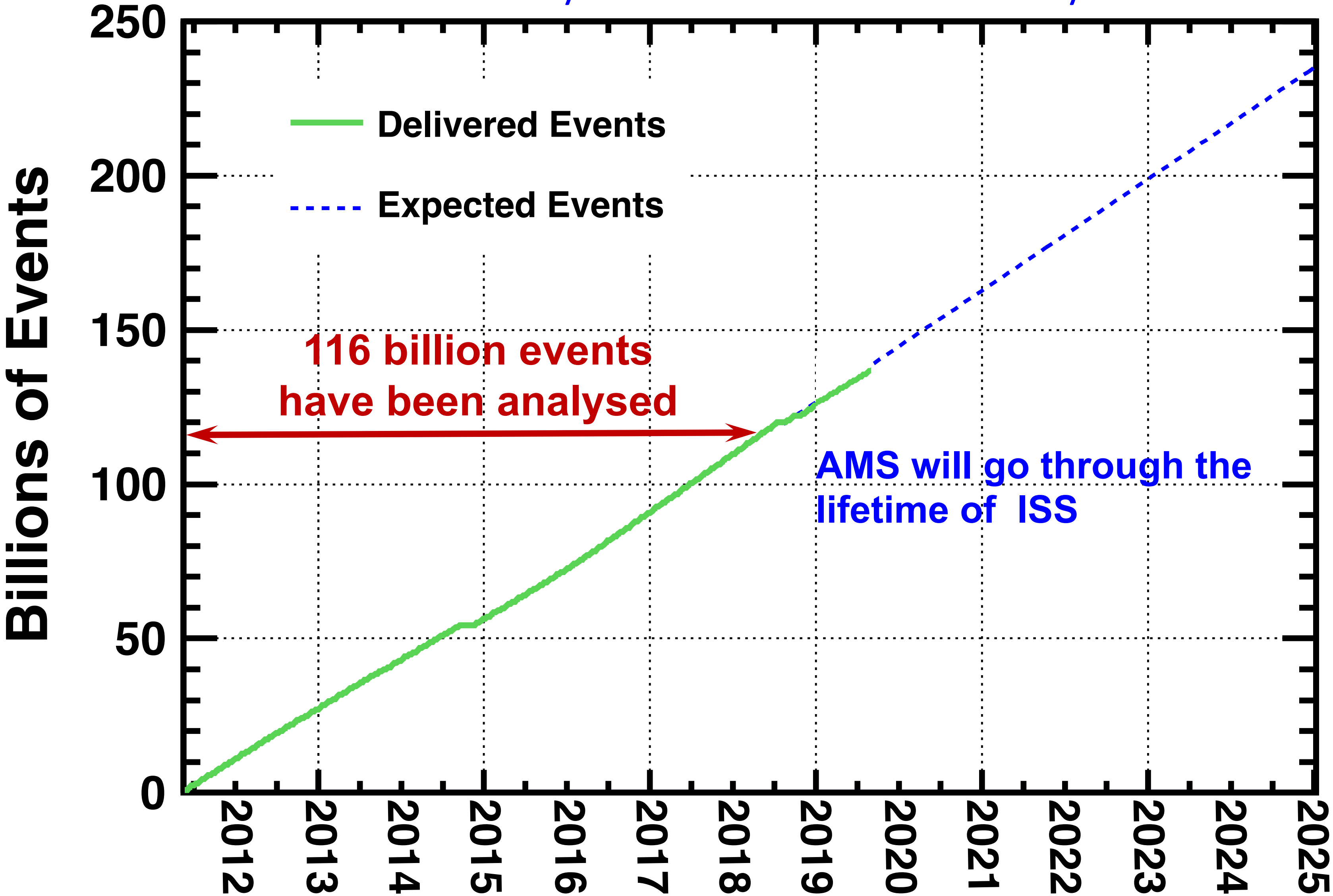
36th International Cosmic Ray Conference, Madison, USA

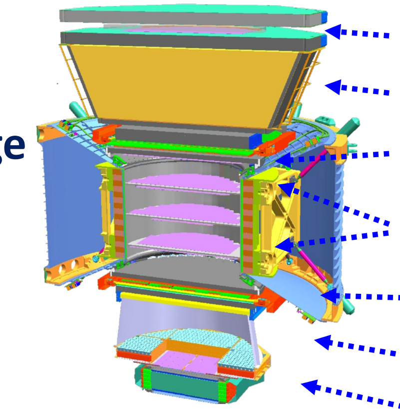
AMS Data Taking

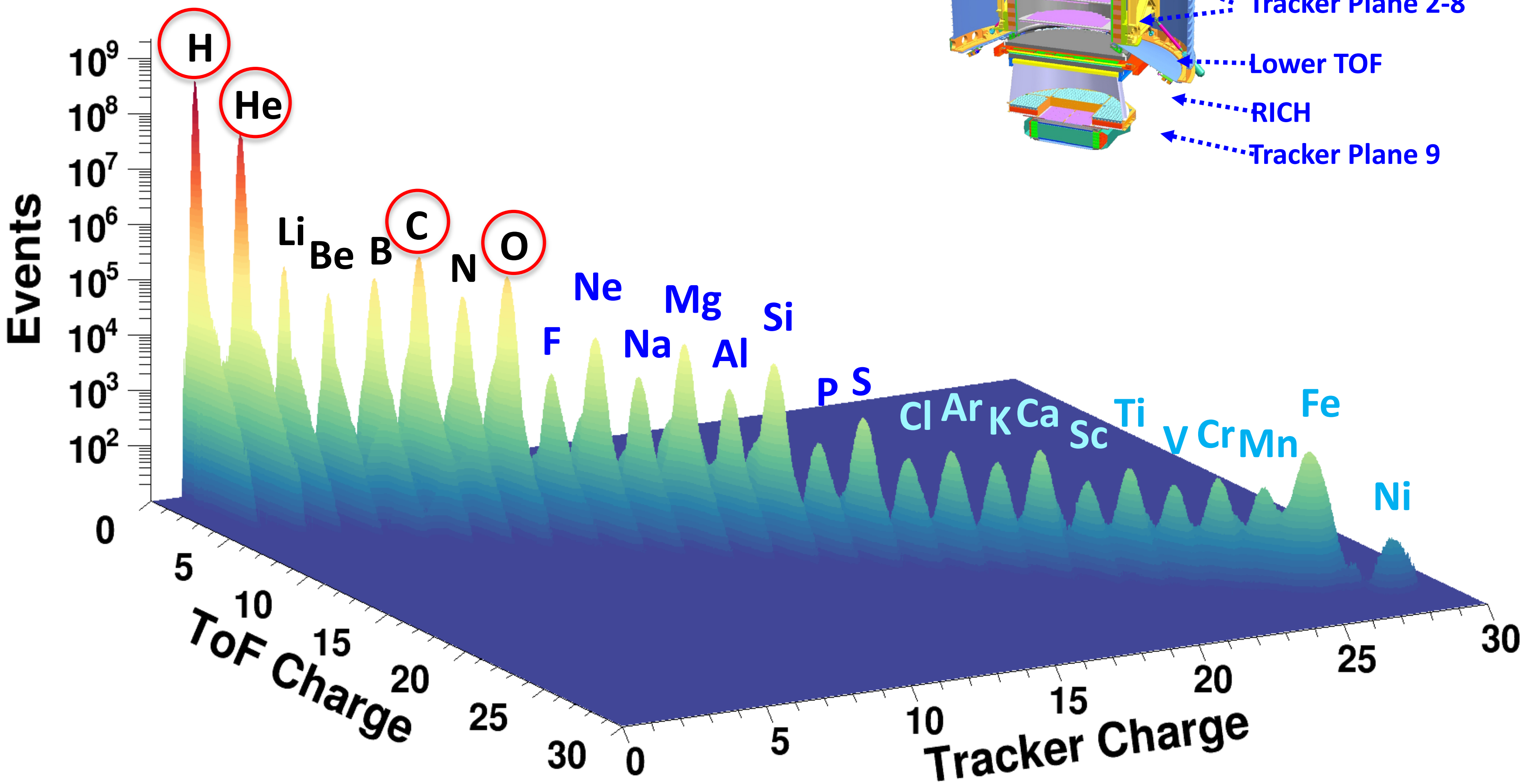
AMS was installed on the International Space Station (ISS) in May 2011. To data, over 140 billion comic ray events has been collected by AMS.



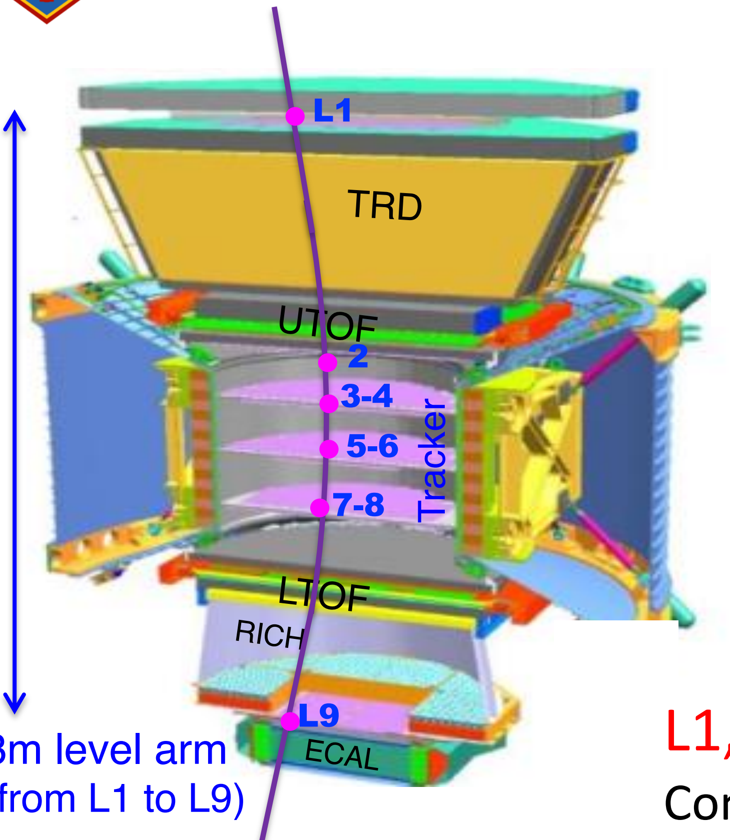
Cosmic Ray Chemical Composition measured by AMS

AMS has seven instruments which independently measure Cosmic Nuclei charge





Cosmic Ray Proton, Helium and Light Nuclei Measured by AMS



Tracker (9 Layers) + Magnet: Rigidity

	Coordinate Resolution	MDR
Z=1	10 μm	2 TV
2≤Z≤8	5-7 μm	3.2-3.7 TV

ToF (4 Layers): Velocity and Direction

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

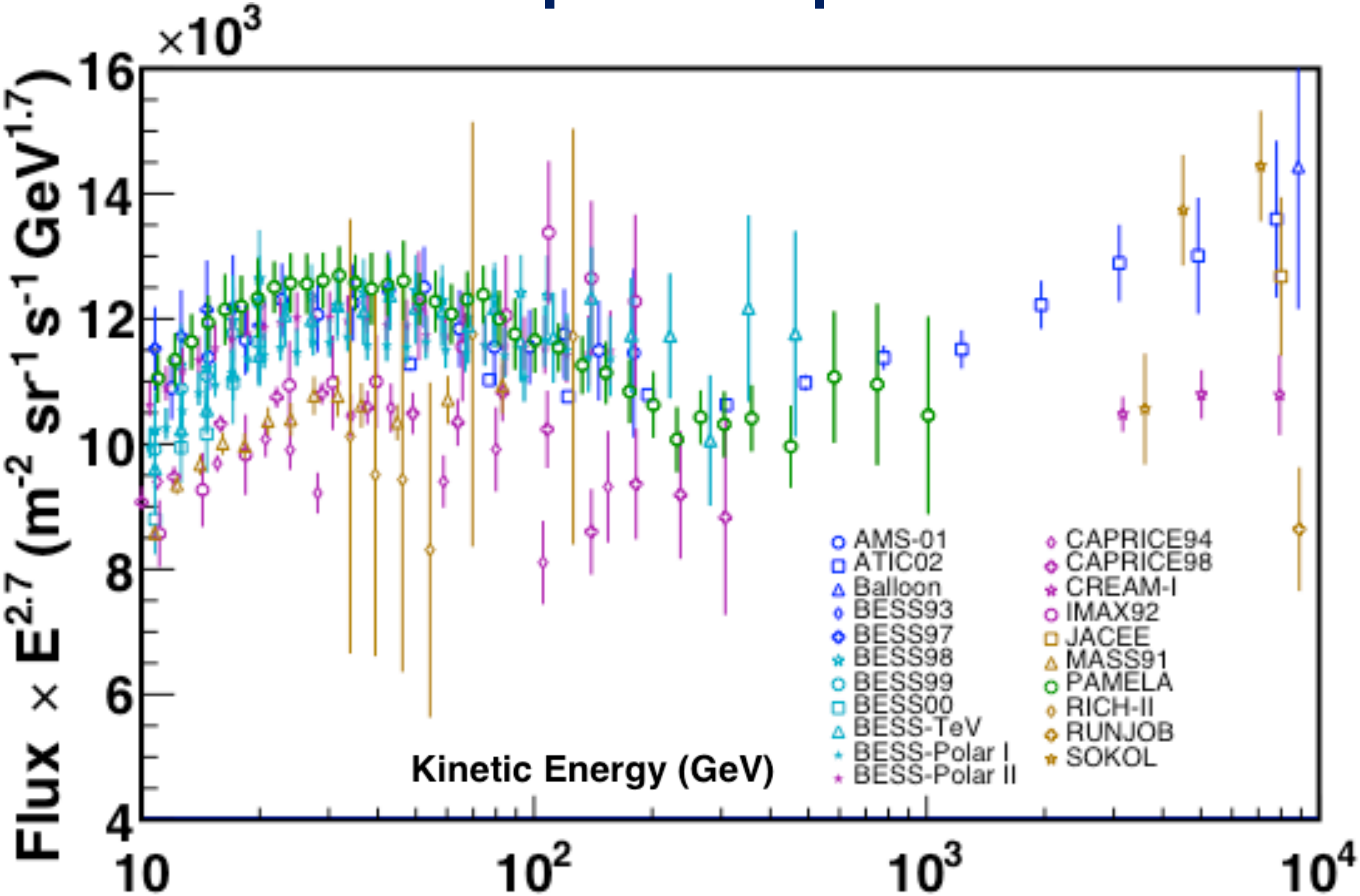
$\Delta\beta/\beta^2 \approx 1\text{-}2\%$ (2≤Z≤8)

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

Consistent Charge Along Particle Trajectory

Inner Tracker only Resolution ΔZ ≈ 0.05-0.12 (1≤Z≤8)

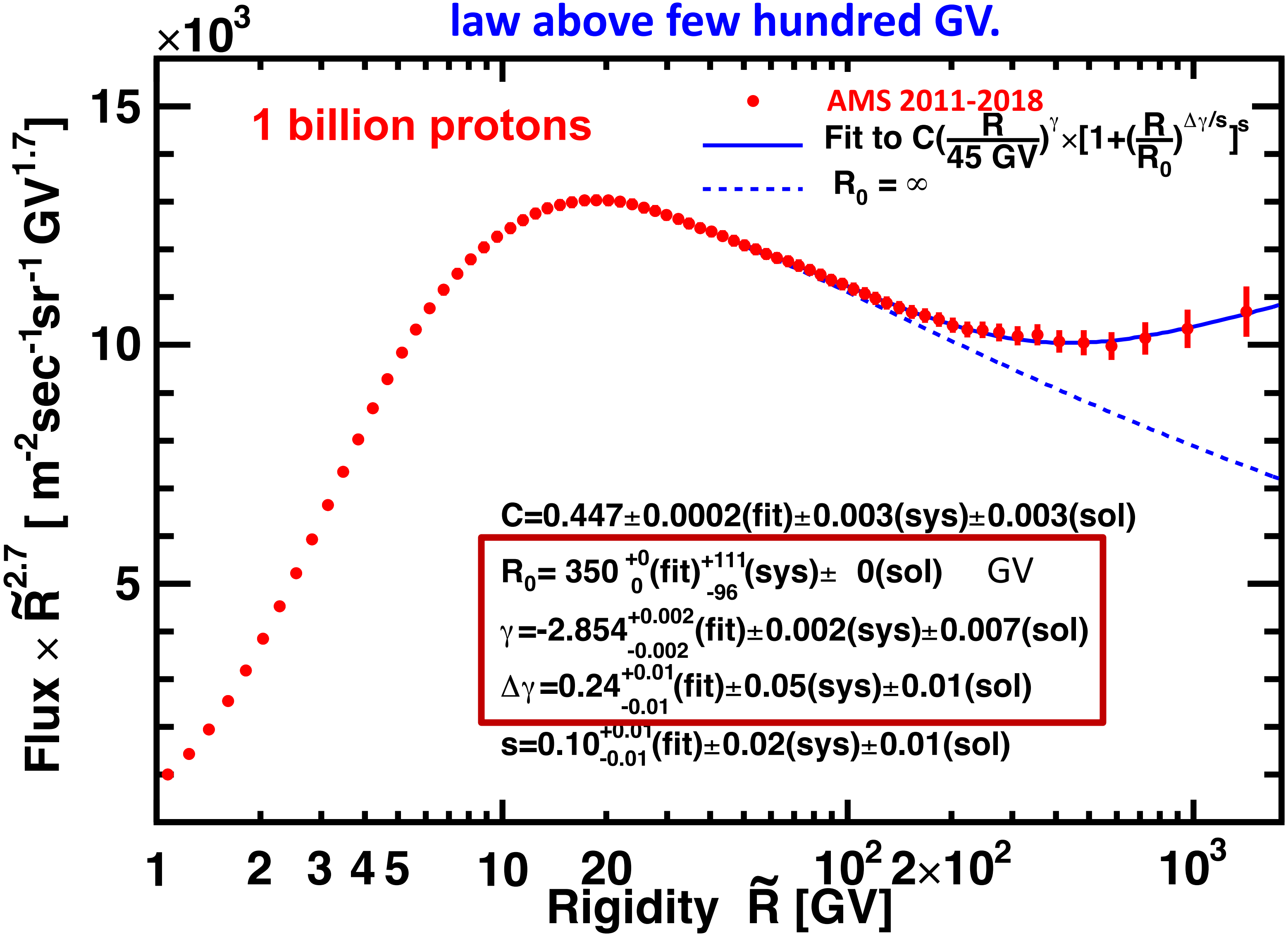
Measurements of proton spectrum before AMS



1. Protons are the most abundant charged cosmic rays.
2. These were the best data over the last hundred years.
3. Nonetheless, the data have large errors and are inconsistent.
4. These data limit the understanding of the production, acceleration and propagation of all cosmic rays.

Structure in the latest proton spectrum

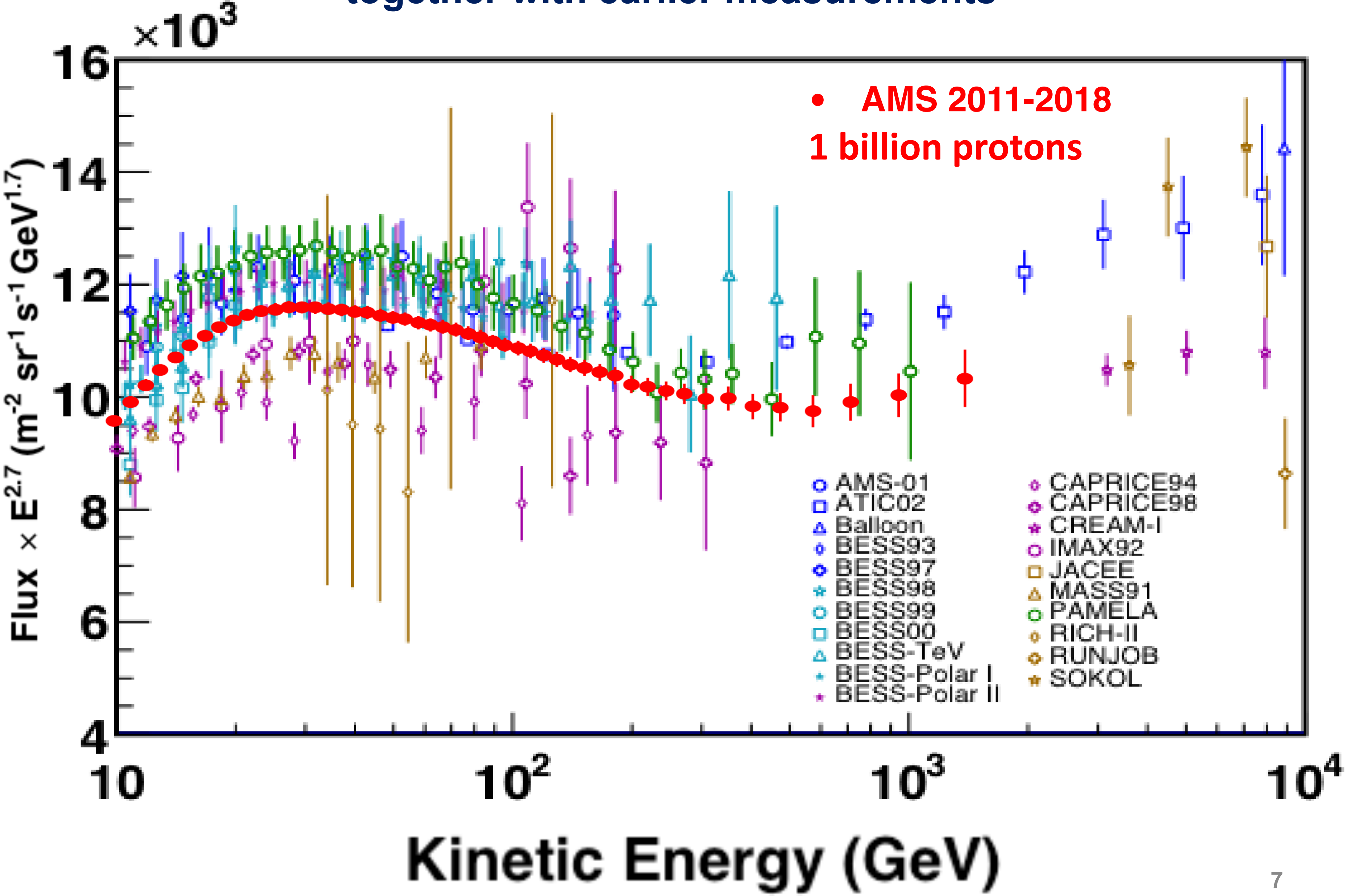
Proton spectrum measured by AMS shows a deviation from a single power law above few hundred GV.



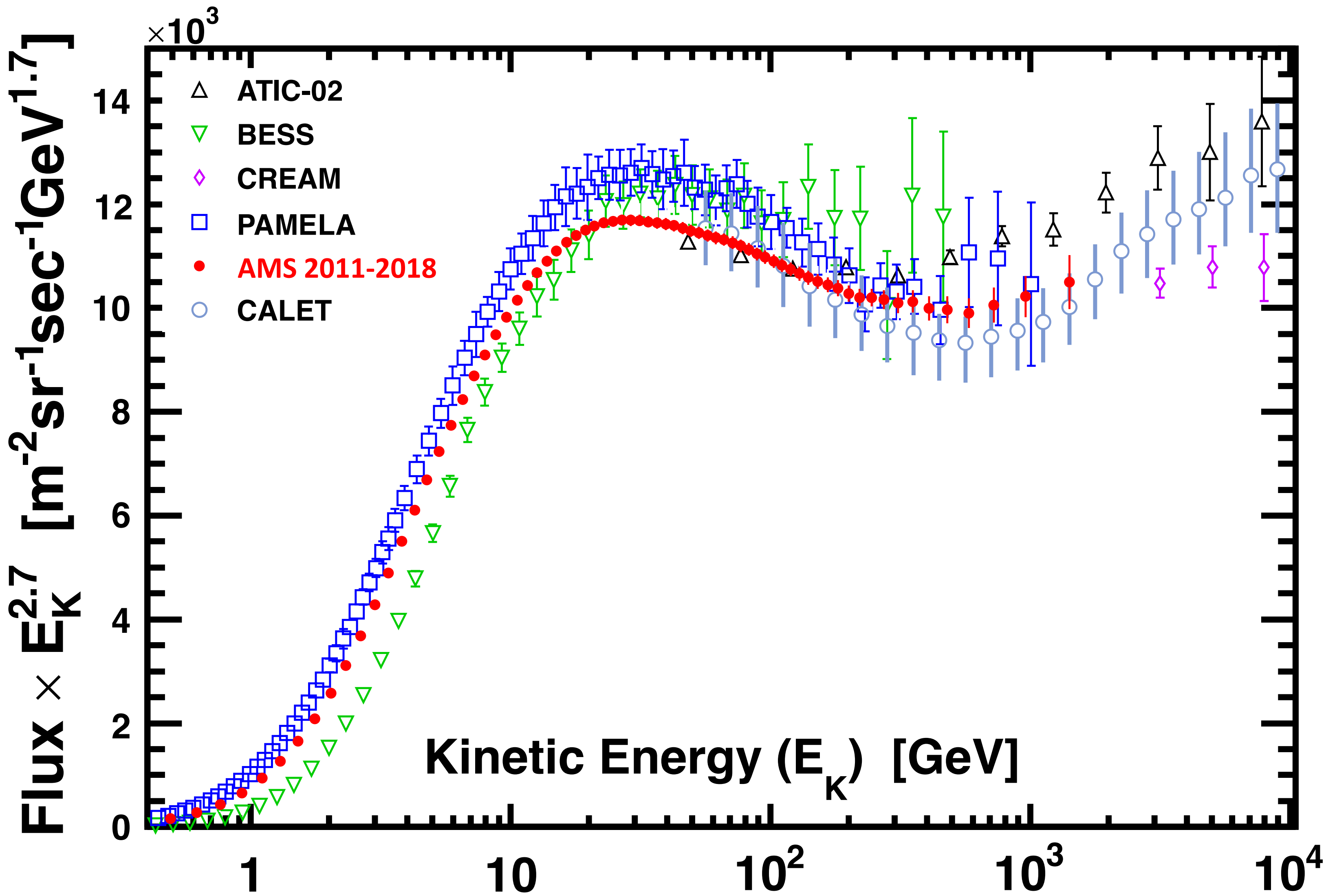
The new AMS result (2011-2018) is consistent with earlier AMS PRL result (2011-2013) "M. Aguilar *et al*., Phys. Rev. Lett., **114,** 171103 (2015)" but with improved accuracy

AMS measurement of the proton spectrum

together with earlier measurements

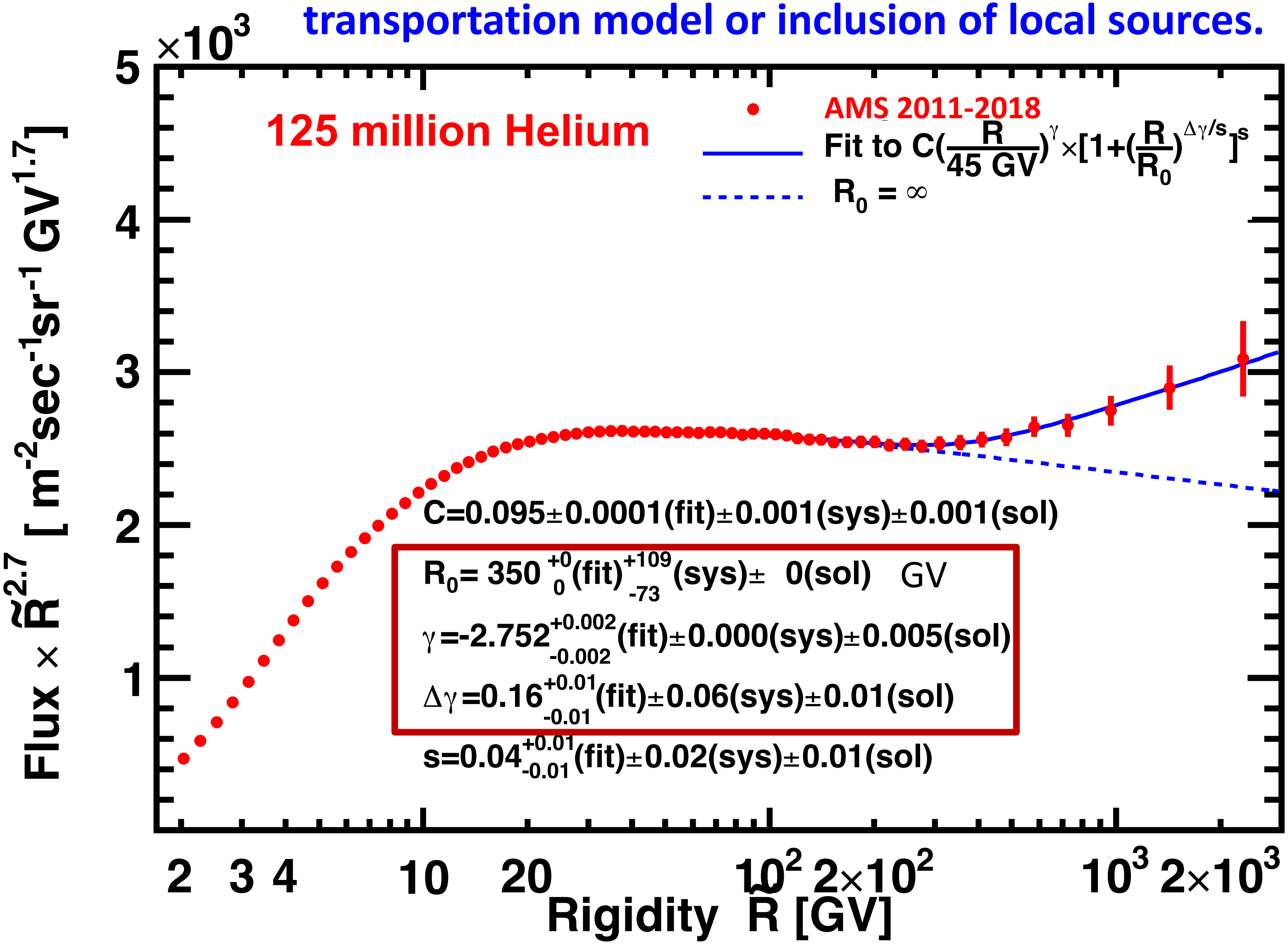


Measurement of proton spectrum with AMS



Origin of Structure in the latest helium spectrum

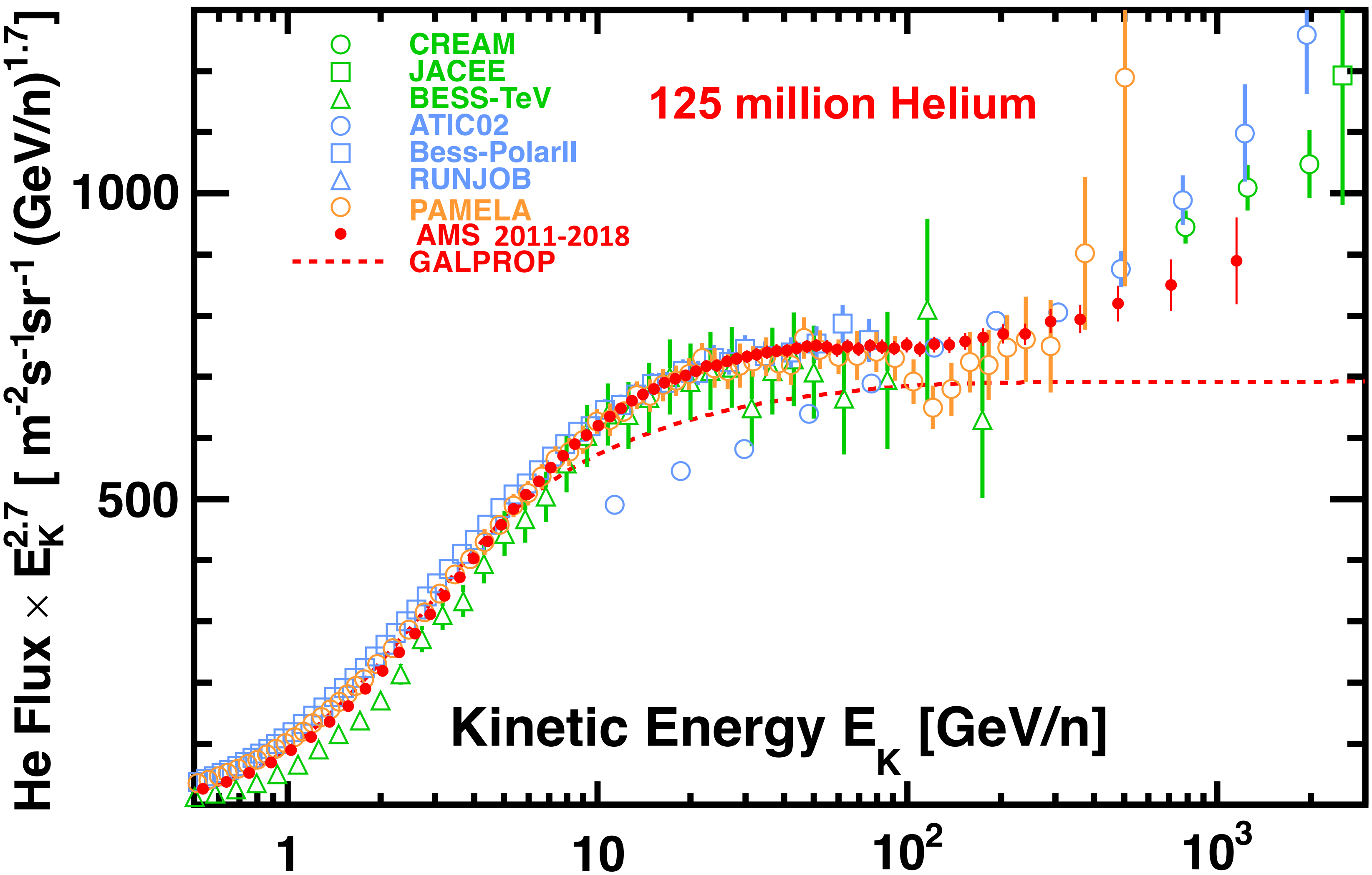
The structure in He (P) spectrum requires modification of cosmic ray transportation model or inclusion of local sources.



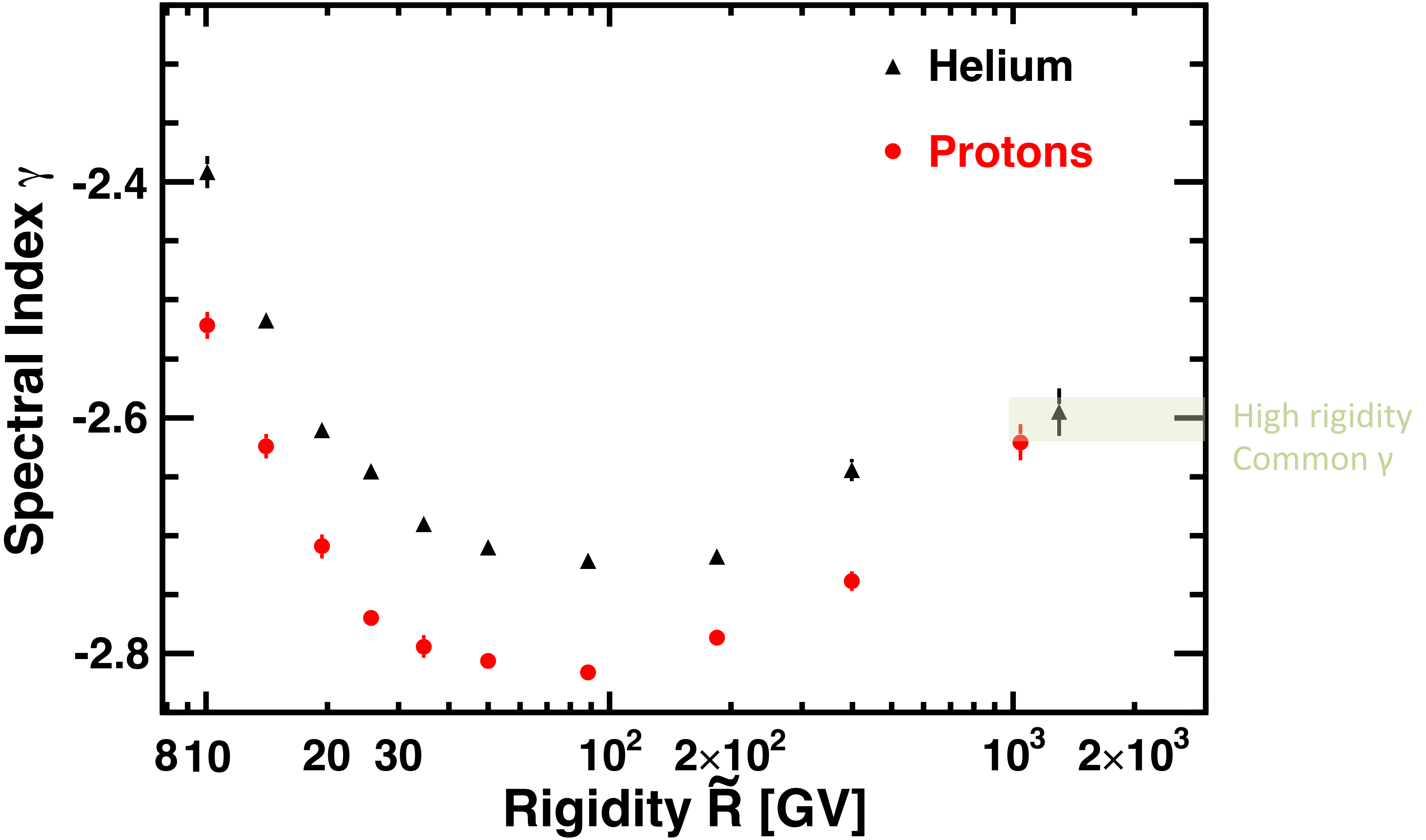
The new AMS result (2011-2018) is consistent with earlier AMS PRL result (2011-2016) "M. Aguilar *et al.*, Phys. Rev. Lett., **119**, 251101 (2017)" but with improved accuracy

AMS Measurement of the helium spectrum

together with earlier measurements

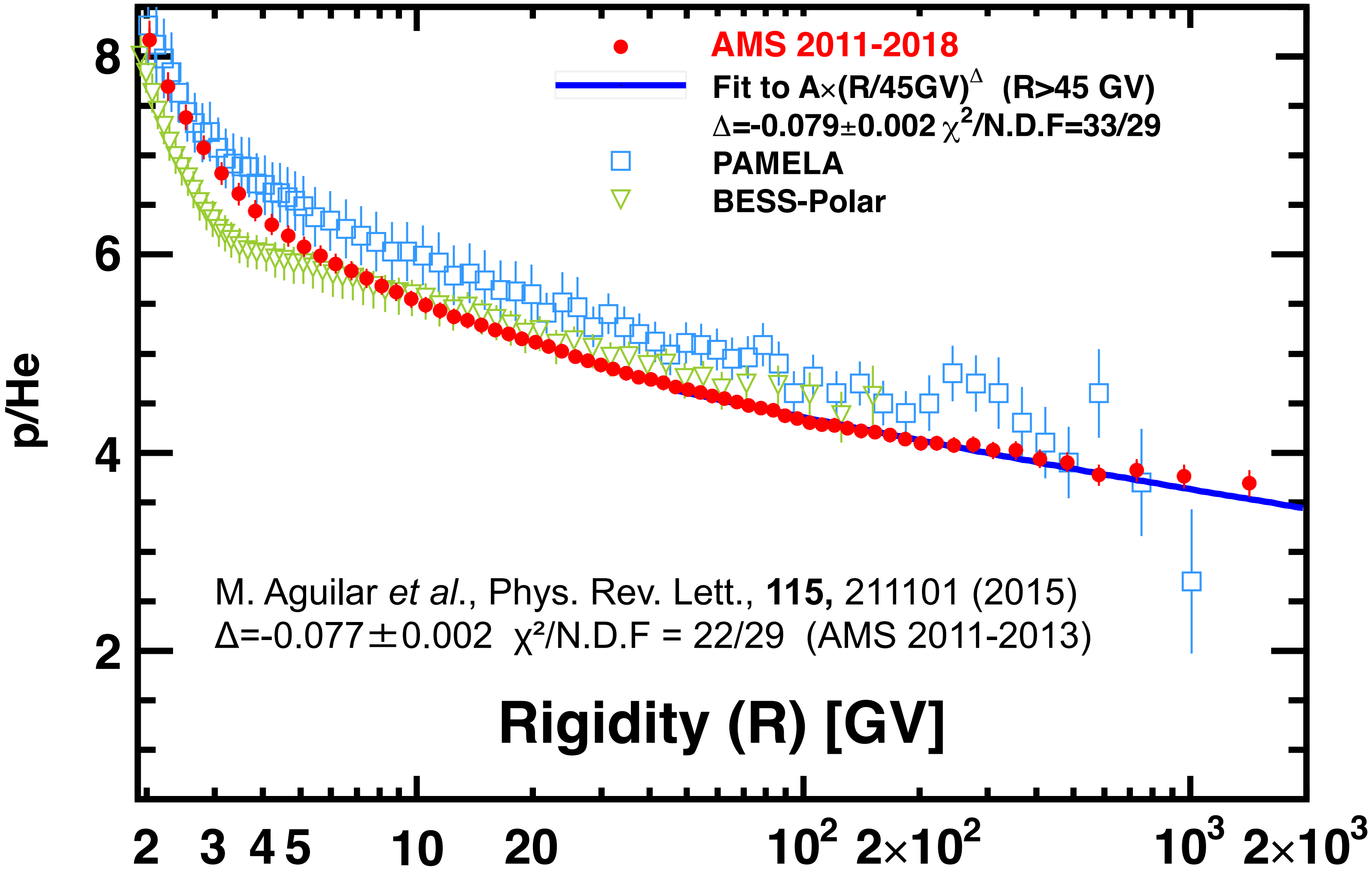


AMS Measurements of P&He Spectral Indices (2011-2018)



The AMS Result on the Proton/Helium Flux Ratio

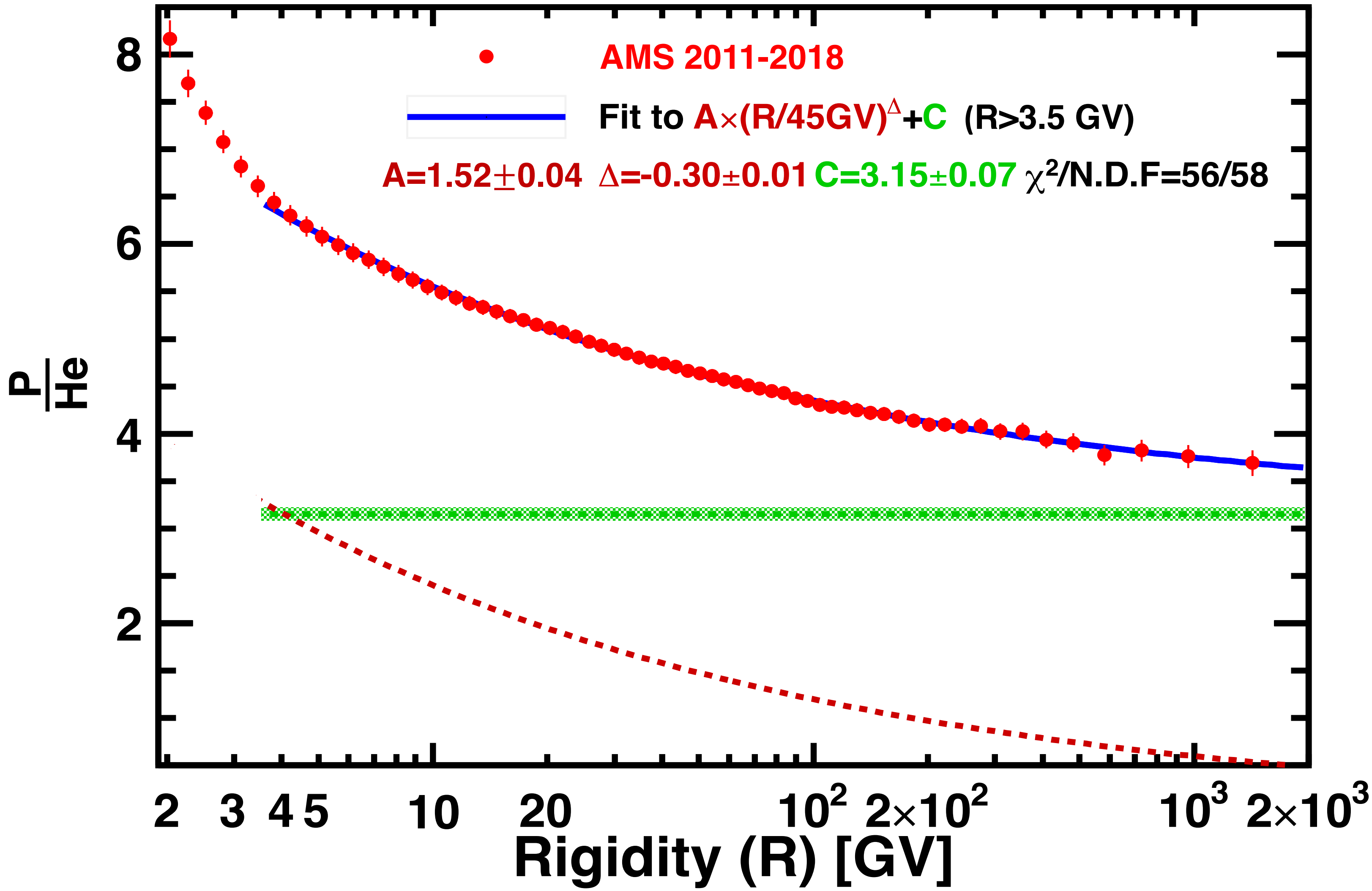
Protons and helium are both primary cosmic rays.
Traditionally, they are assumed to be produced in the same sources
so their flux ratio should be asymptotically rigidity independent.



The AMS Result on the Proton/Helium Flux Ratio

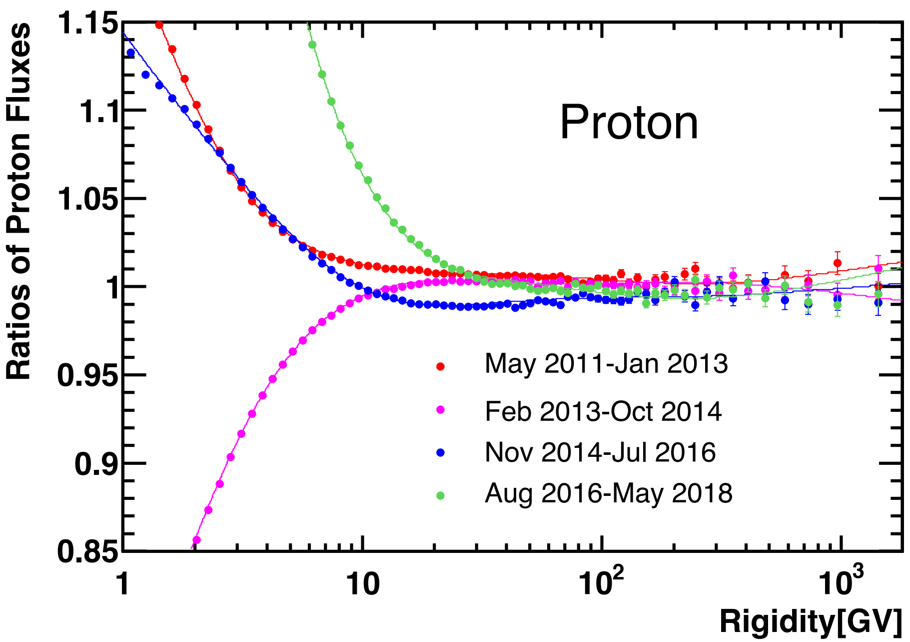
Protons and helium are both primary cosmic rays.

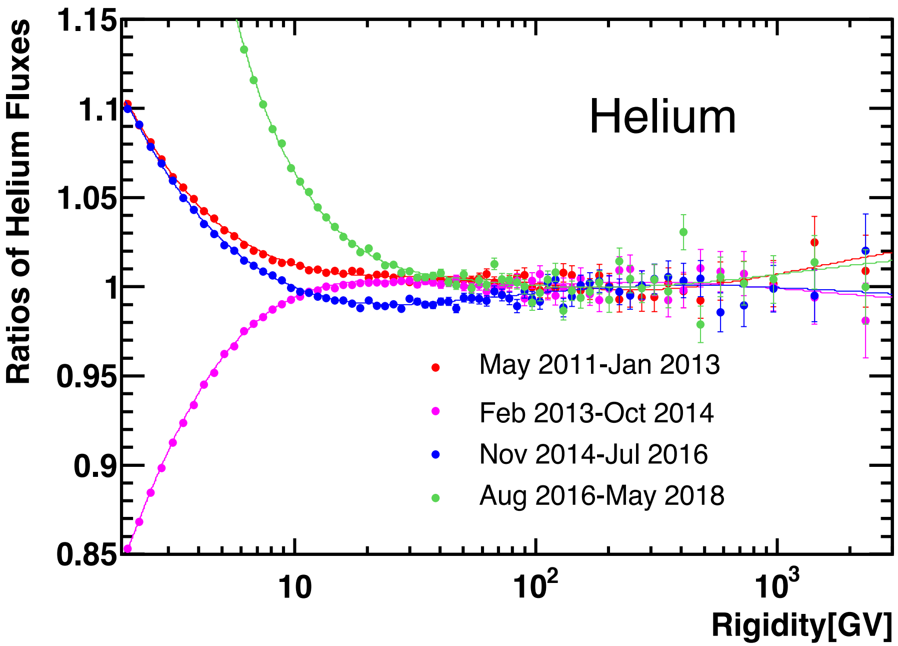
Their flux ratio seems to be rigidity independent at high rigidities.



The AMS Results on P & He Fluxes Measured Over 7 Years (1.75 Years each)

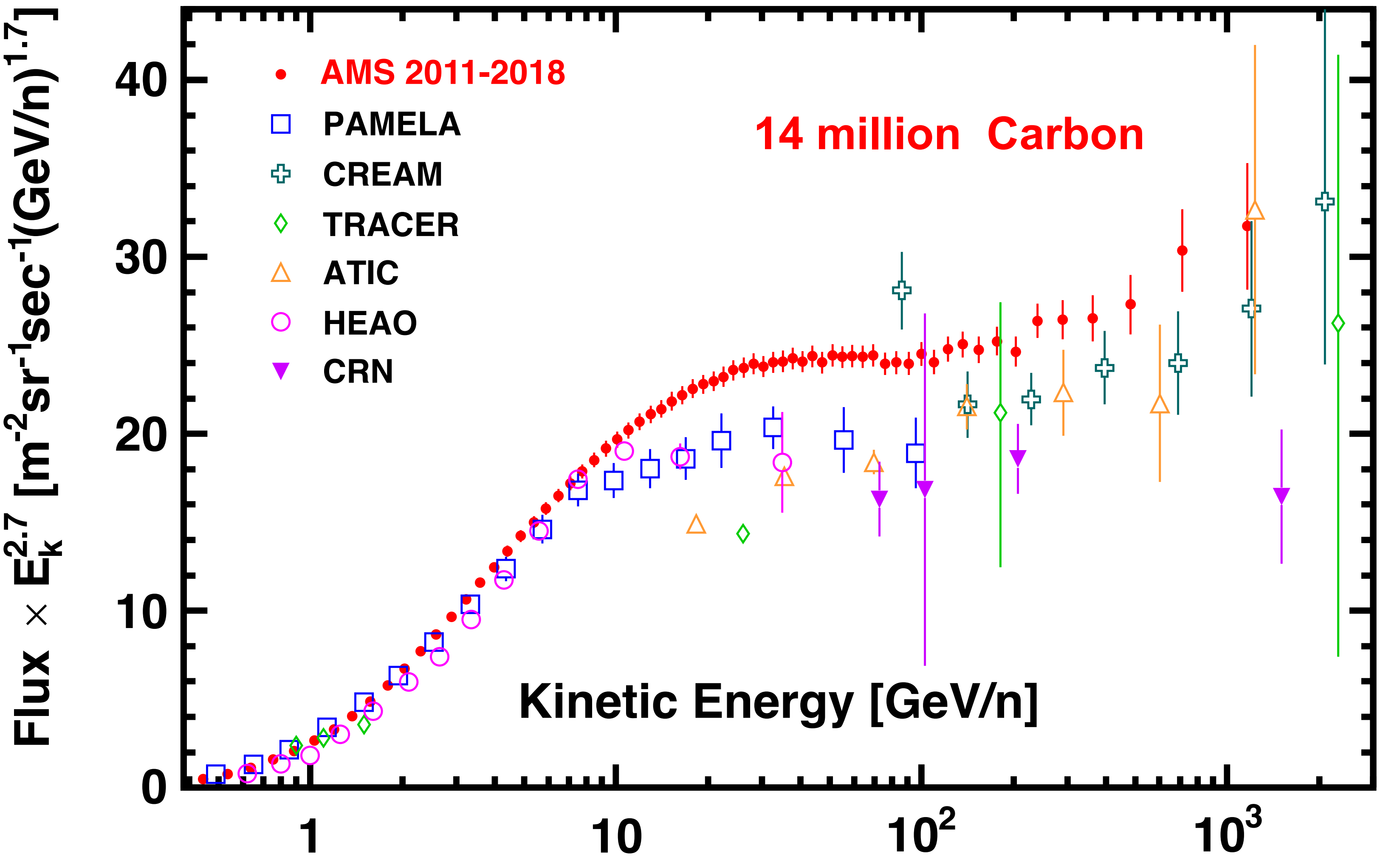
The proton and helium fluxes (ratio to the first 5 years averaged flux) have time dependence upto 100 GV due to solar modulation. At high rigidities (>100 GV), the fluxes are constant within measurement errors.



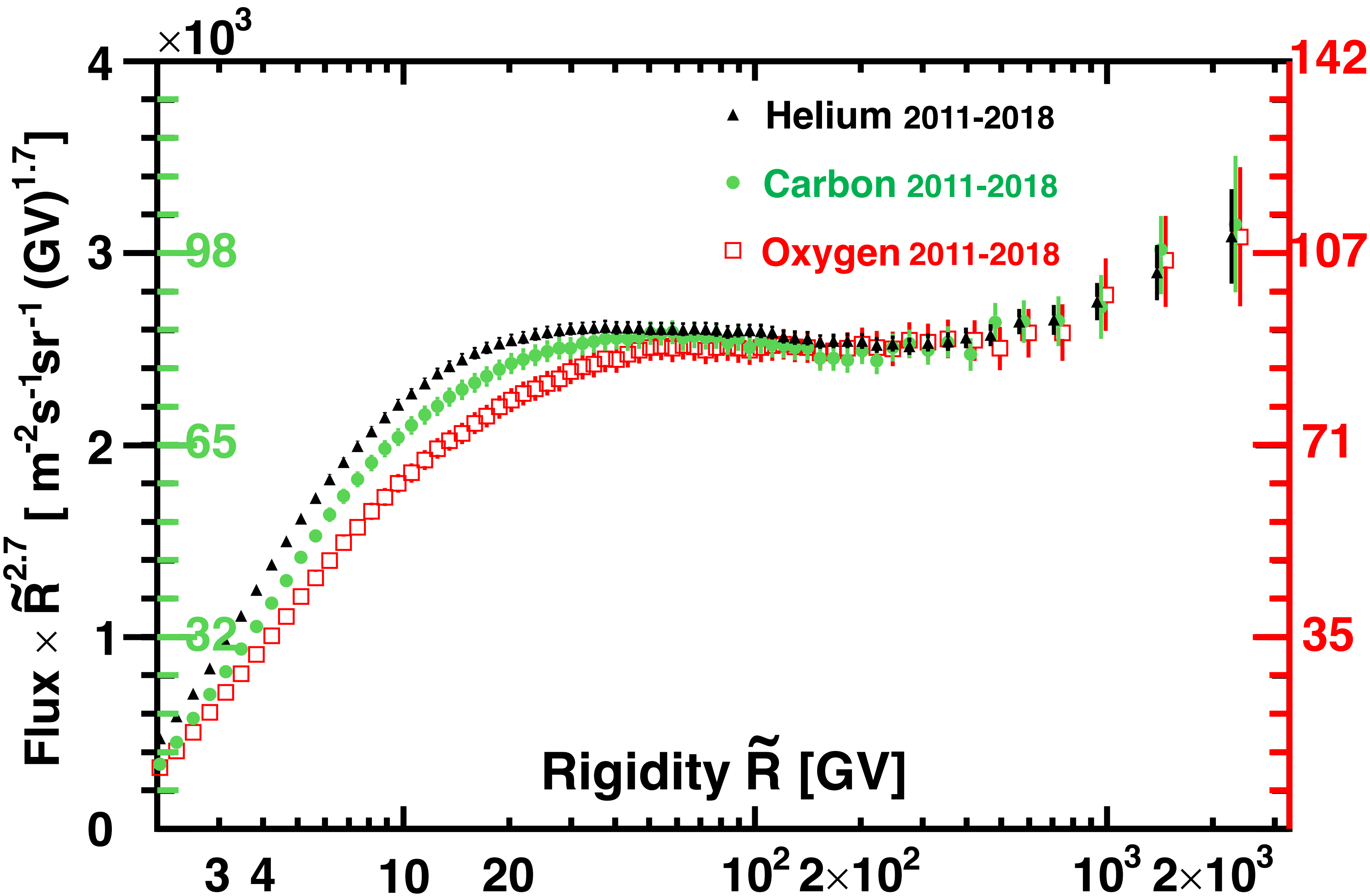


Latest AMS Measurement of the carbon spectrum

together with earlier measurements

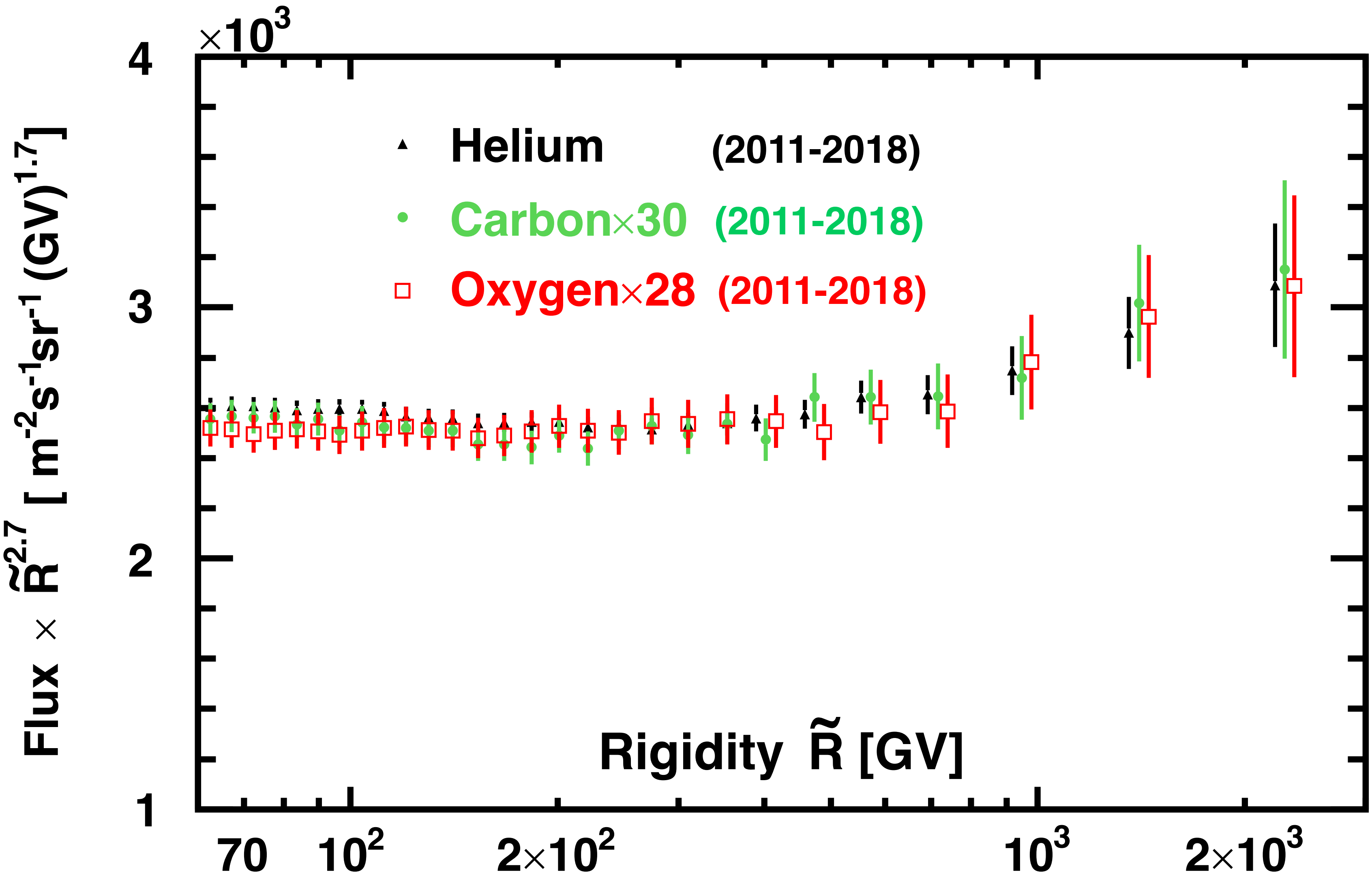


Latest AMS Measurements of He, C and O spectra

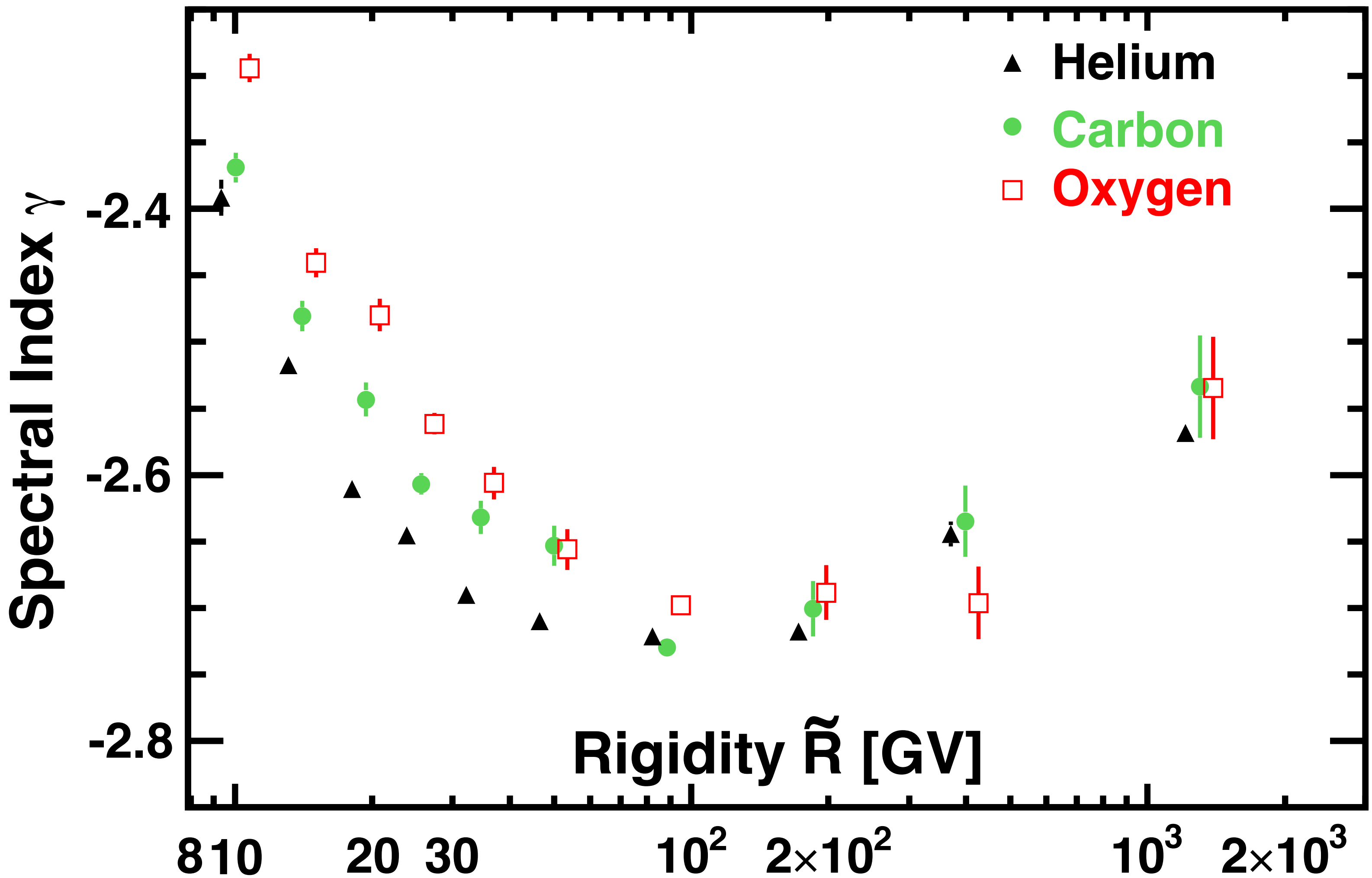


The new AMS result (2011-2018) is consistent with earlier AMS PRL result (2011-2016) "M. Aguilar *et al.*, Phys. Rev. Lett., **119**, 251101 (2017)" but with improved accuracy

The AMS Results show an identical rigidity dependence above ~60 GV

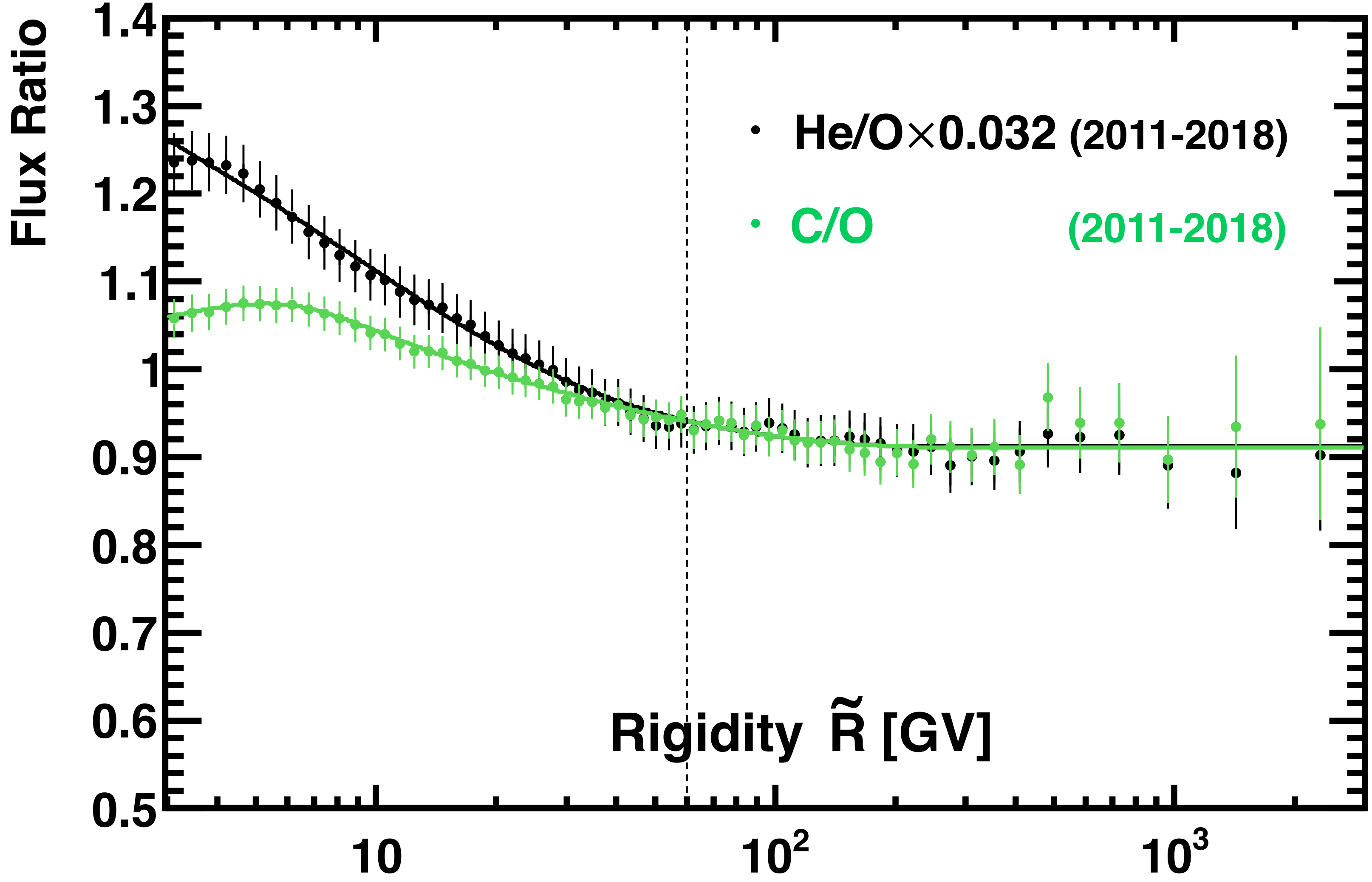


AMS Measurements of He, C and O Spectral Indices (2011-2018)



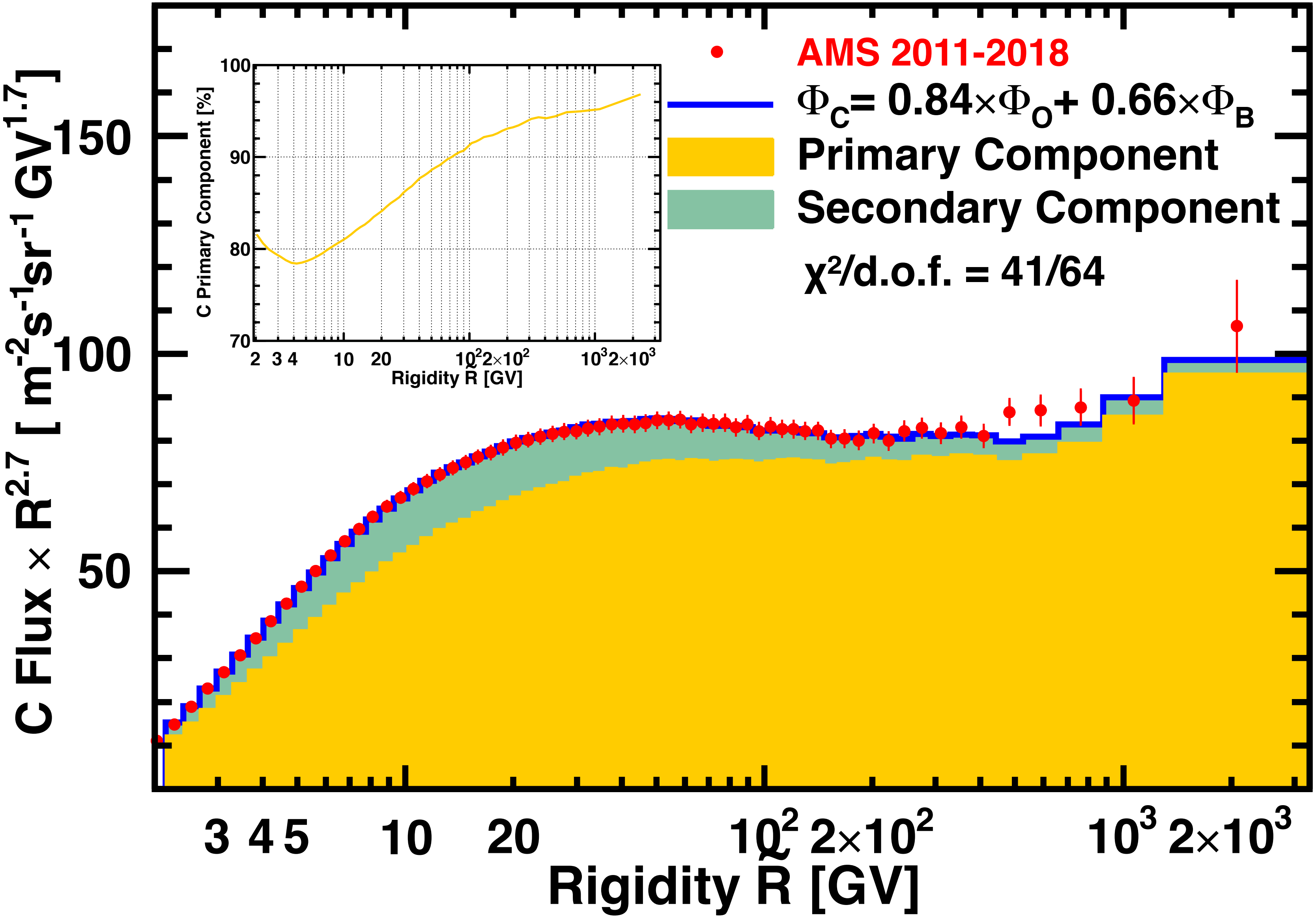
Above 200 GV, they all deviate from a single power law in an identical way

The latest AMS Results on the He/O and C/O Flux Ratios



Above ~60 GV, the He, C and O spectra have identical rigidity dependence

The Primary and Secondary Components of Carbon Flux



Conclusion

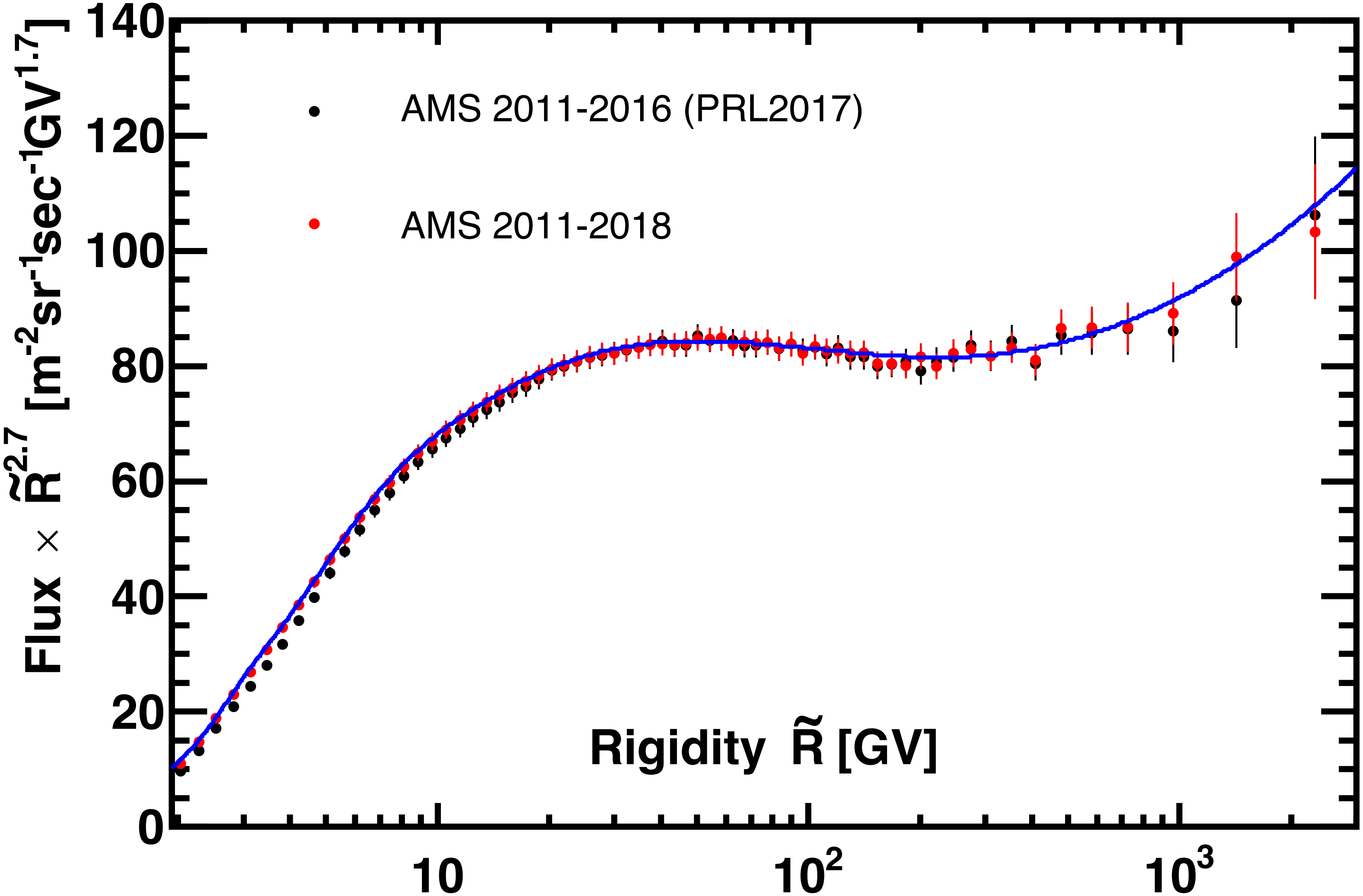
- Latest precision measurements of Primary Cosmic Rays Proton, Helium, Carbon and Oxygen spectra based on 1 billion Proton, 125 million He, 14 million C, and 12 million O events collected by AMS during the first 7 years (2011-2018) of operation have been presented.

- Both Proton and Helium spectra indices show progressive hardening at rigidities larger than 100 GV. However, below 1 TV, the magnitude of spectra index of helium is distinctly different from that of proton. But above 1 TV, their spectra indices are approaching to be identical. With current more accurate AMS data, the proton to helium ratio is observed to be a sum of a single power law component and a constant component above 3.5 GV.

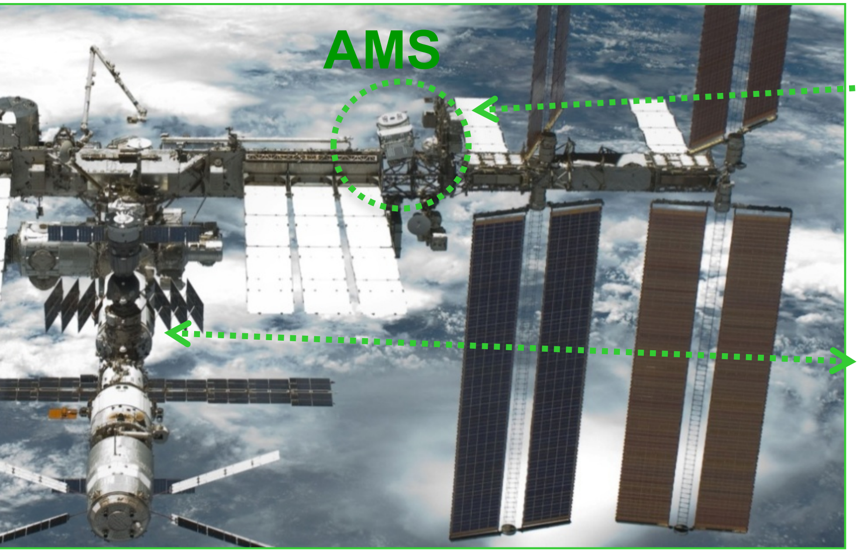
- Different from Proton, the spectra of Helium, Carbon and Oxygen show an identical rigidity dependence above 60 GV. Above 200 GV, they all deviate from a single power law and harden in an identical way.

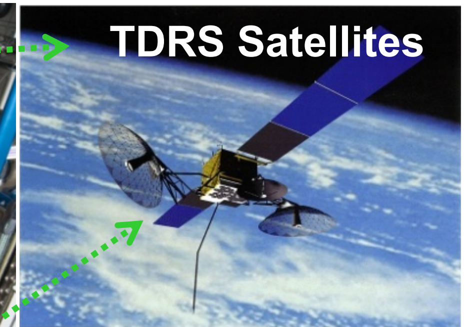
BACKUP SLIDES

The latest AMS Carbon Flux compared with PRL



AMS Operation





Flight Operations

Ku-Band
High Rate (down):
Events <10Mbit/s>

S-Band
Low Rate (up & down):
Commanding: 1 Kbit/s
Monitoring: 30 Kbit/s

Ground Operations

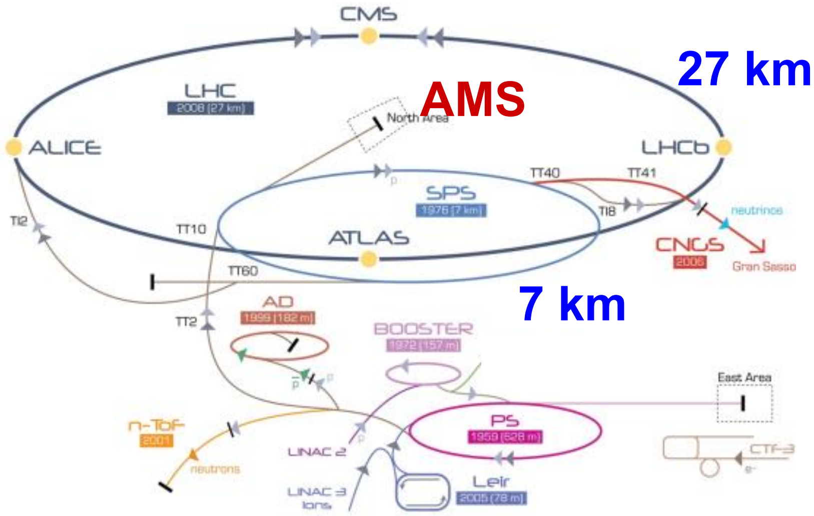
AMS Payload Operations Control and Science Operations Centers (POCC, SOC) at CERN

AMS Computers
Marshall Space Flight Center, AL

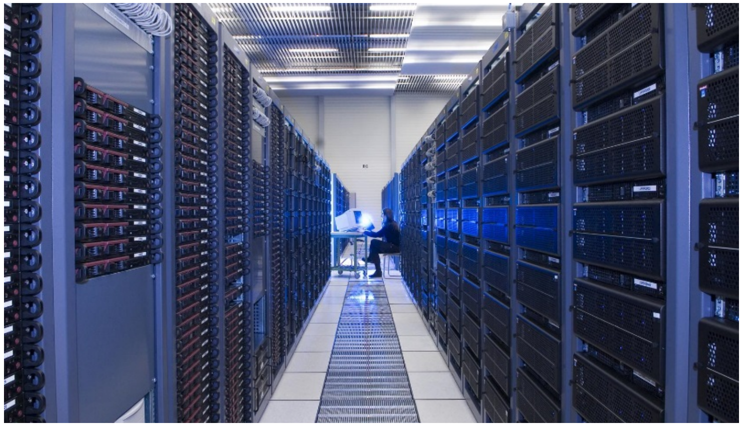
White Sands Ground Terminal, NM

Calibration of the AMS Detector

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

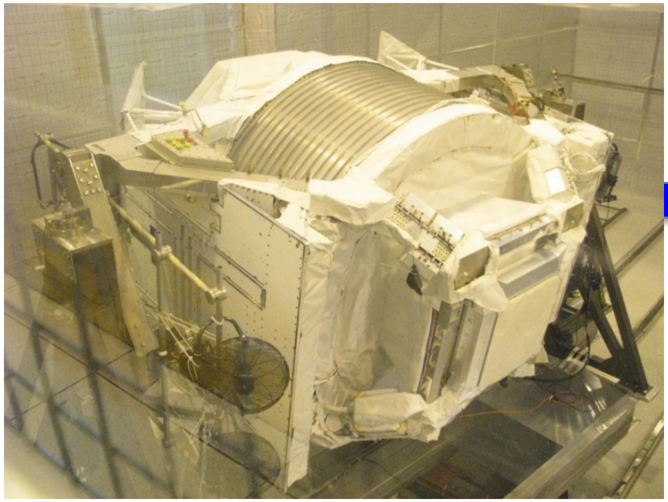


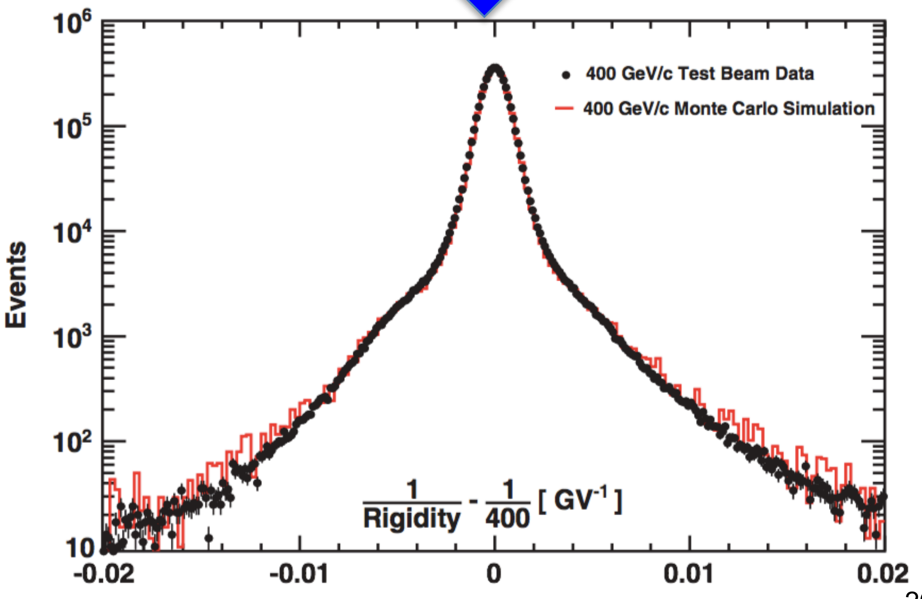
17,000 CPU cores at CERN



Computer simulation:
Interactions, Materials, Electronics

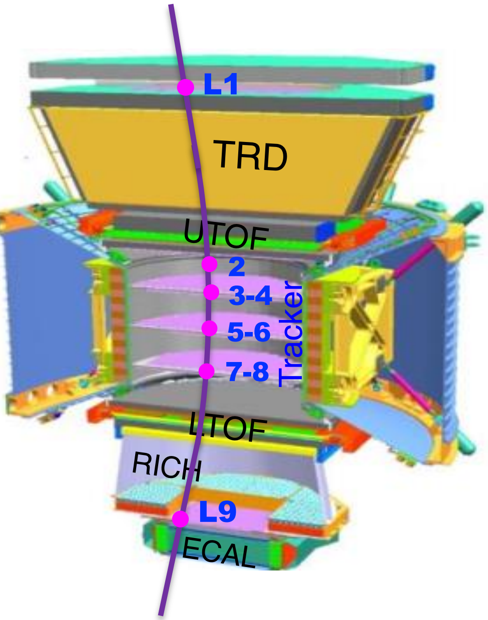
2000 positions

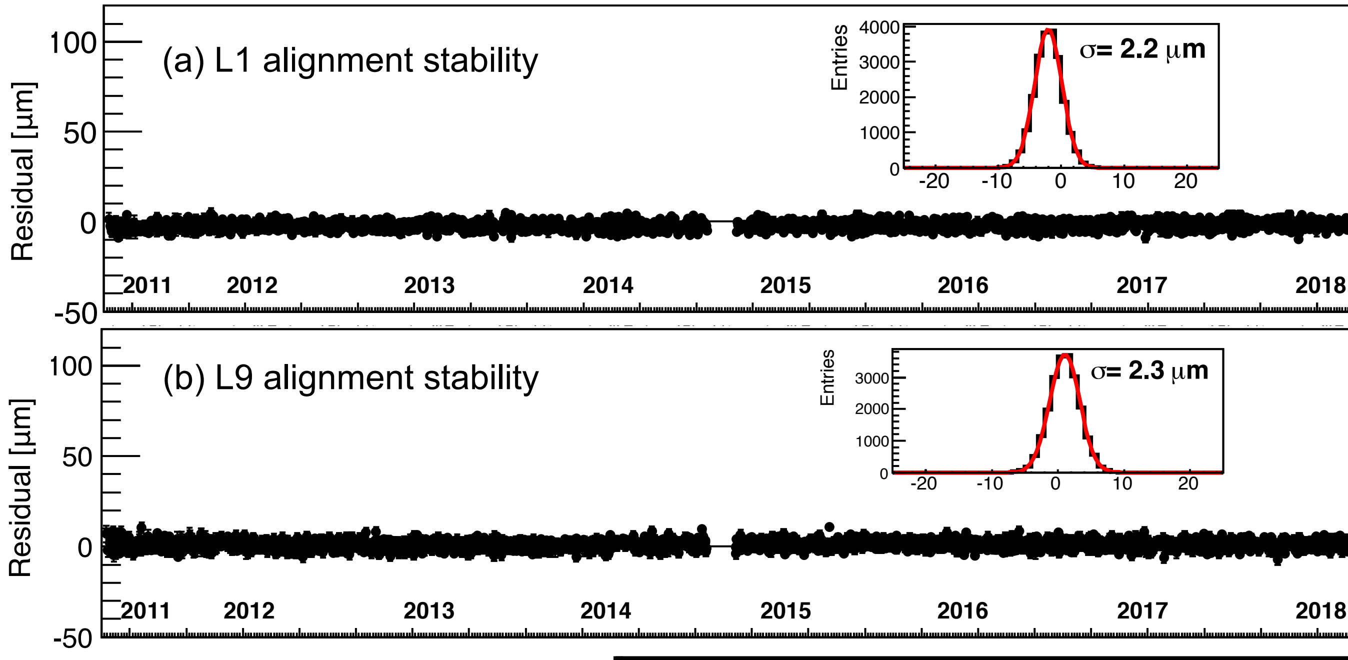




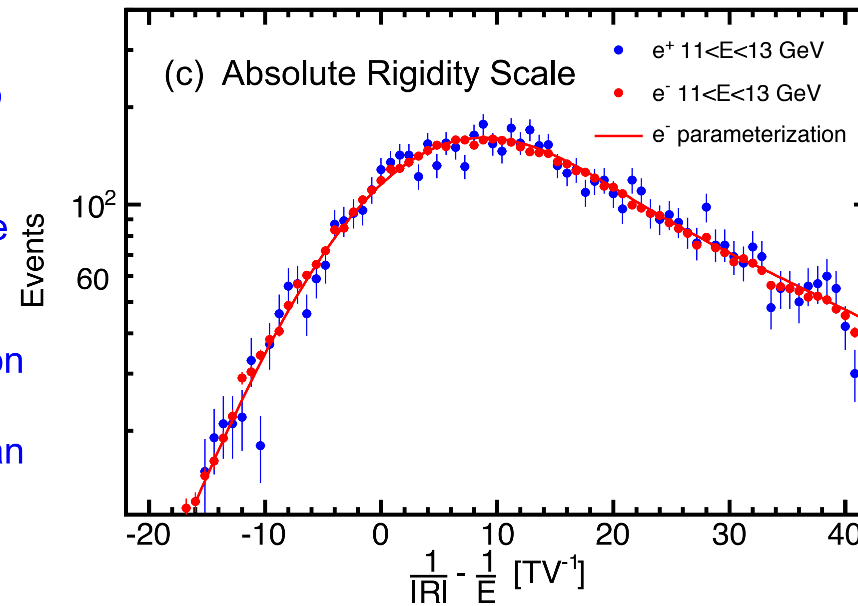
Tracker Alignment & Calibration

The position of the outer planes L1 and L9 are precisely aligned by using cosmic rays events to a stability of better than 3 μm over more than 7 years. The stability of inner tracker layers (L2-L8) is in the order of a tenth a μm.





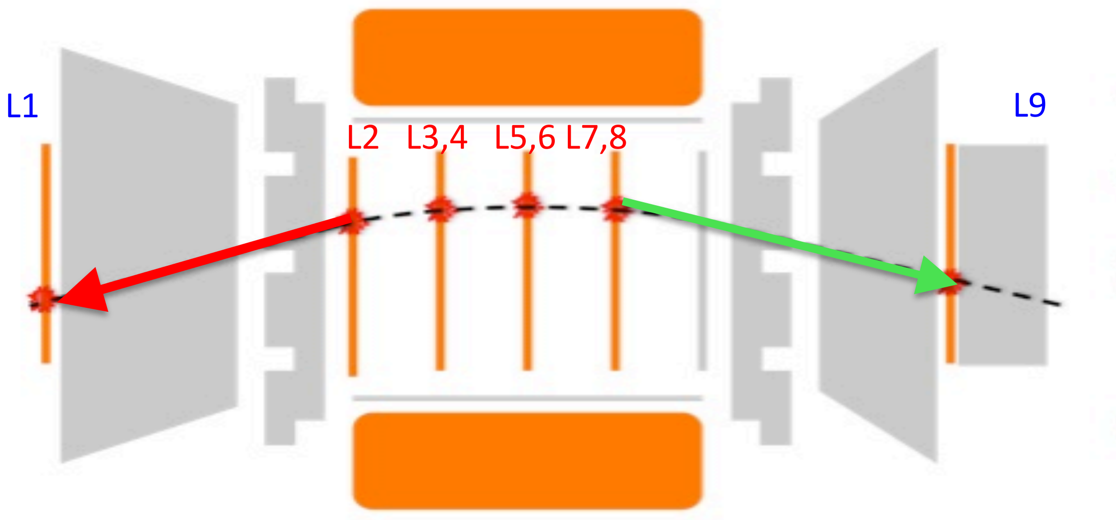
The vibrations and accelerations during the AMS launch into space could change the tracker ladder positions at the submicron level. The resulting misalignment was precisely corrected in space by analyzing track trajectories of opposite charged particles, namely by comparing of the tracker measured rigidity (R=Momentum/Charge) with electromagnetic calorimeter measured energy (E) for positron and electron events. This allows to determine the coherent displacement of the L2-L8 layers with an accuracy better than 0.2 μm, corresponding to the accuracy of the tracker rigidity of better than 1/30 TV^{-1}.

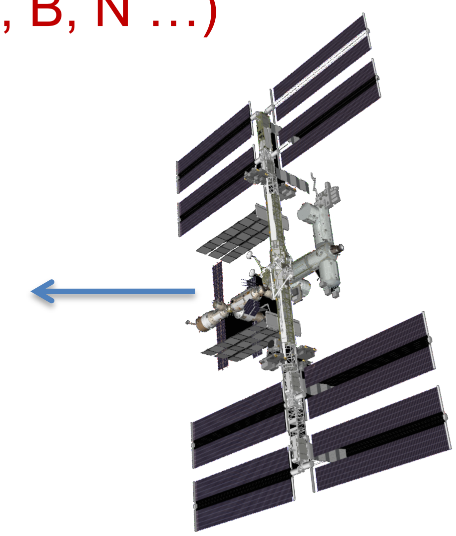


Measurement of nuclei cross sections by AMS

The detector components traversed by the particles is mostly made of C and Al.

The inelastic cross sections of N+ C, N+ Al are only measured below few GV (He, C, O) or not measured (Li, Be, B, N …)

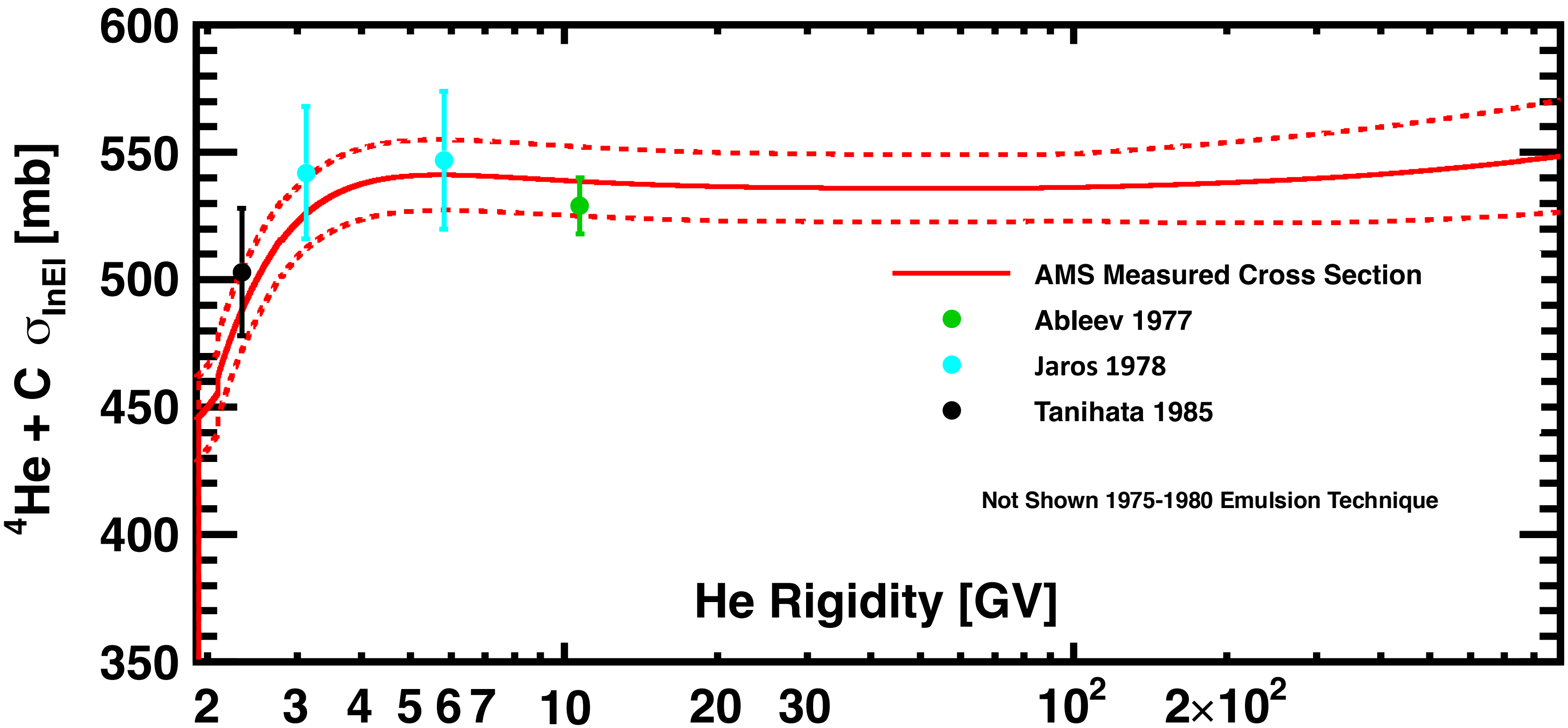




AMS measured the Survival Probabilities during "Horizontal" runs [~10^5 sec exporsure] in which CRs can enter AMS both right to the left and left to the right.

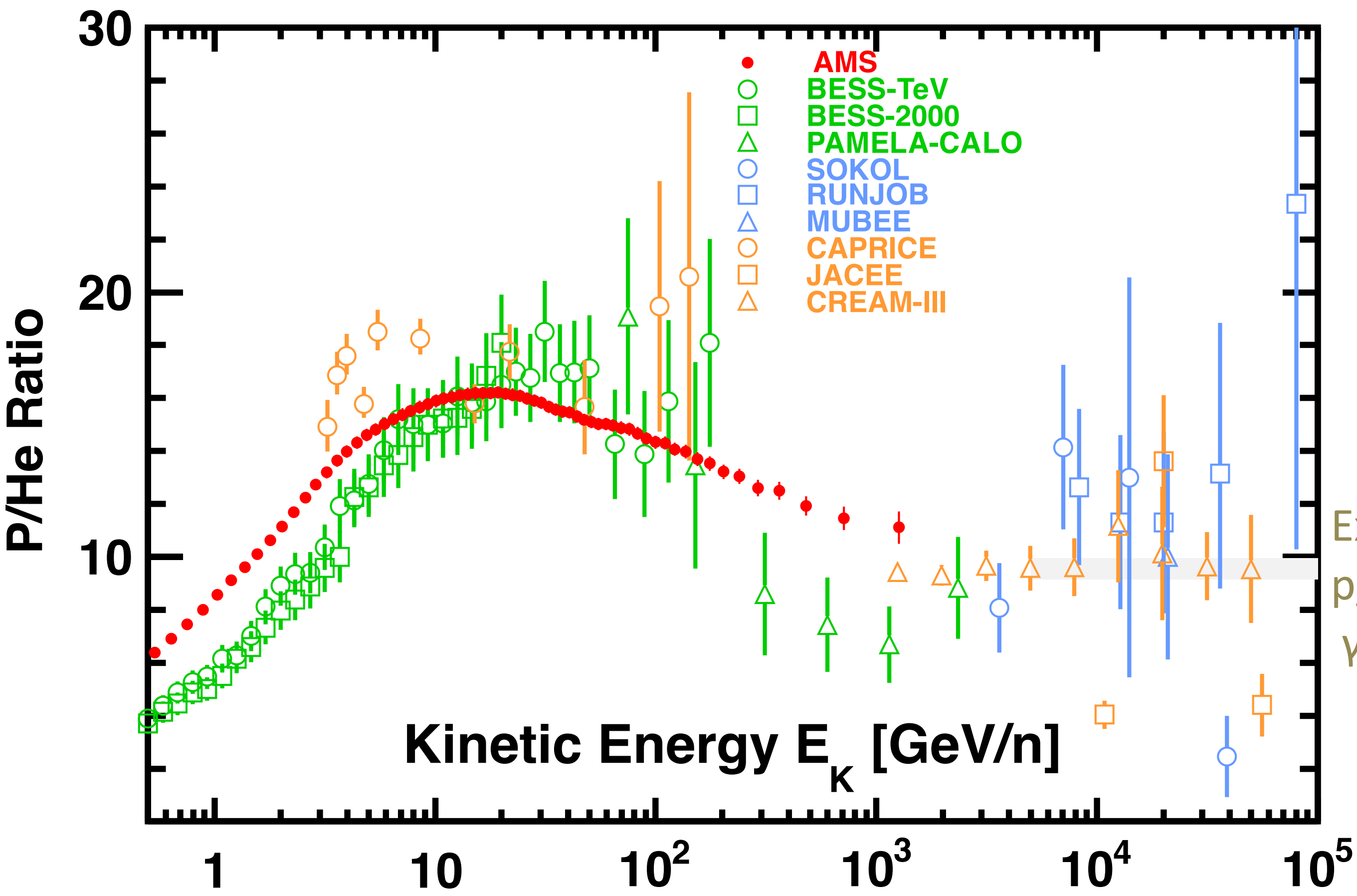
Most importantly, by flying horizontally AMS was able to make Interaction cross sections measurements which were not available from accelerators.

AMS measured He + C inelastic cross section



The AMS measured He+C inelastic cross section in comparison with experimental results. The dashed curve indicates the corresponding systematic errors. The cross section rise on R>100 GV follows the Glauber Gribov model.

p/He Ratio Kinetic Energy



Extrapolated to high energy

p/He (E_K) = 9.55±0.4

$\gamma_{p,He}$ = -2.6±0.06