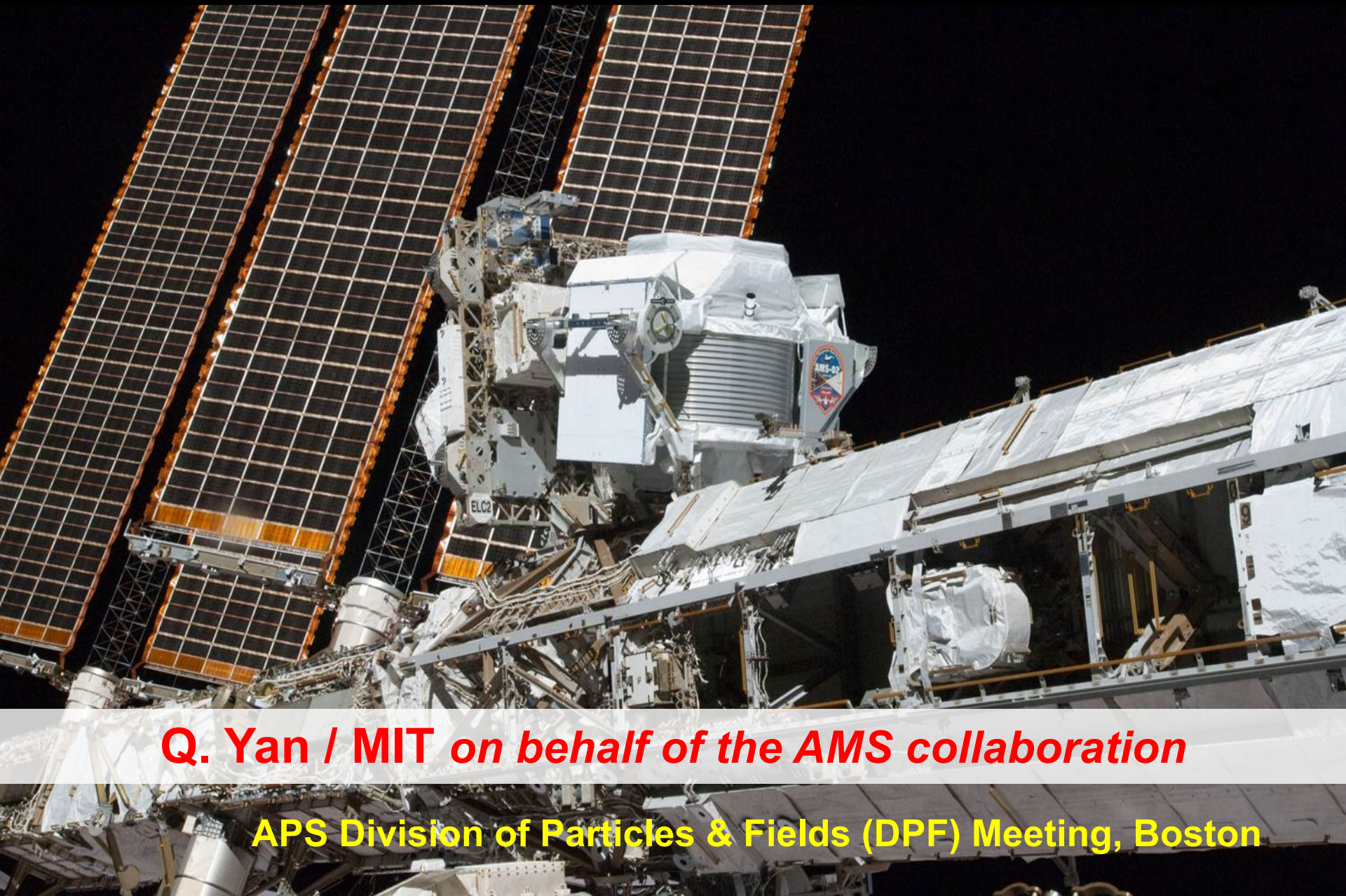
Precision Measurements of Primary Cosmic Rays with Alpha Magnetic Spectrometer (AMS) on the International Space Station



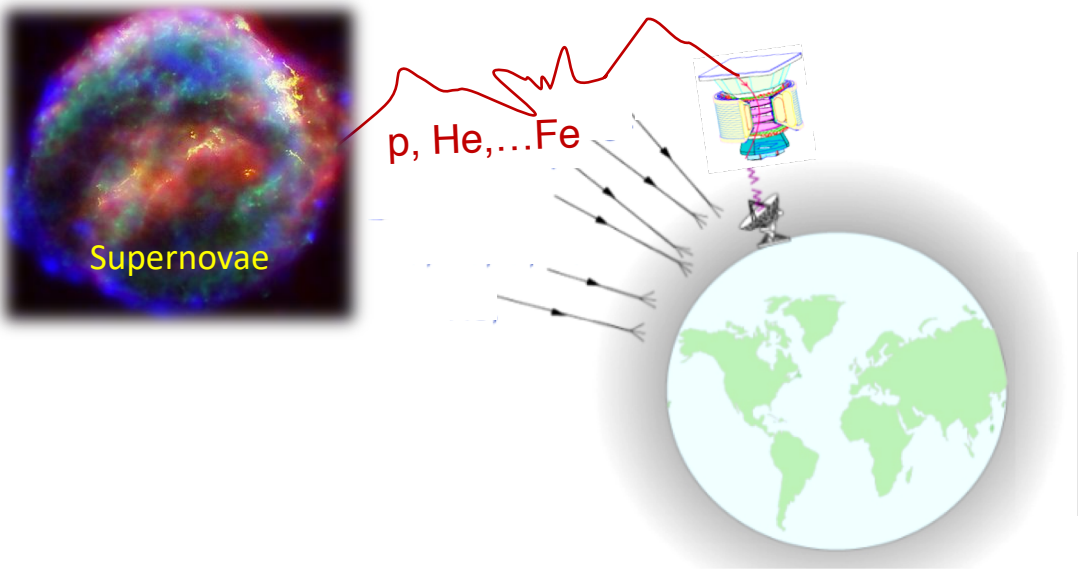
Q. Yan / MIT ***on behalf of the AMS collaboration***

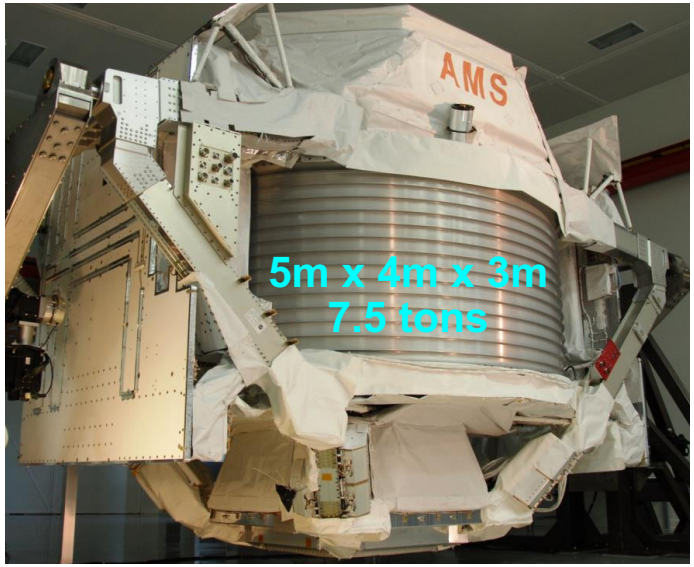
APS Division of Particles & Fields (DPF) Meeting, Boston

Cosmic Rays Measurements with AMS

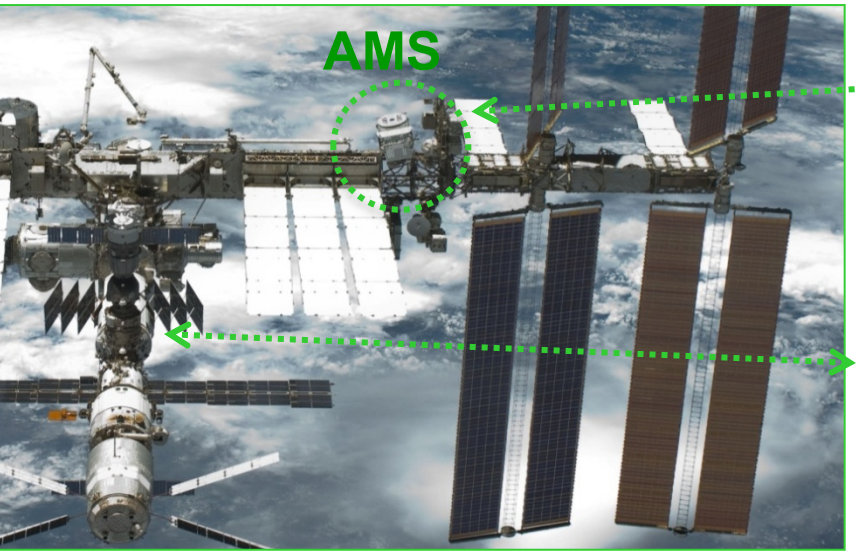
One of the fundamental measurements in cosmic rays is the determination of the energy dependence of spectra of primary cosmic ray p, He, C, O, Ne, Mg, Si, S and Fe. These are thought to be produced and accelerated in the supernova remnants in our Galaxy. Their spectra carry the information about cosmic ray acceleration in the astrophysics sources and propagation in the Galaxy.

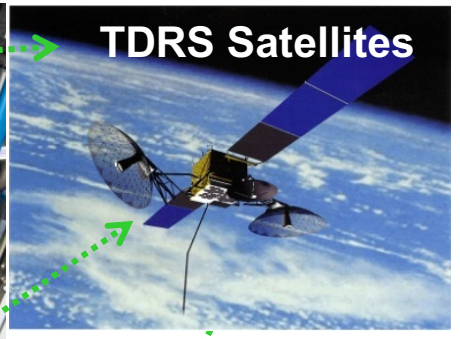
AMS, on the International Space Station, is a large-acceptance, long duration, TV precision magnetic spectrometer; directly measures the original properties of cosmic rays.





AMS Operation





Flight Operations

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

Ground Operations

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

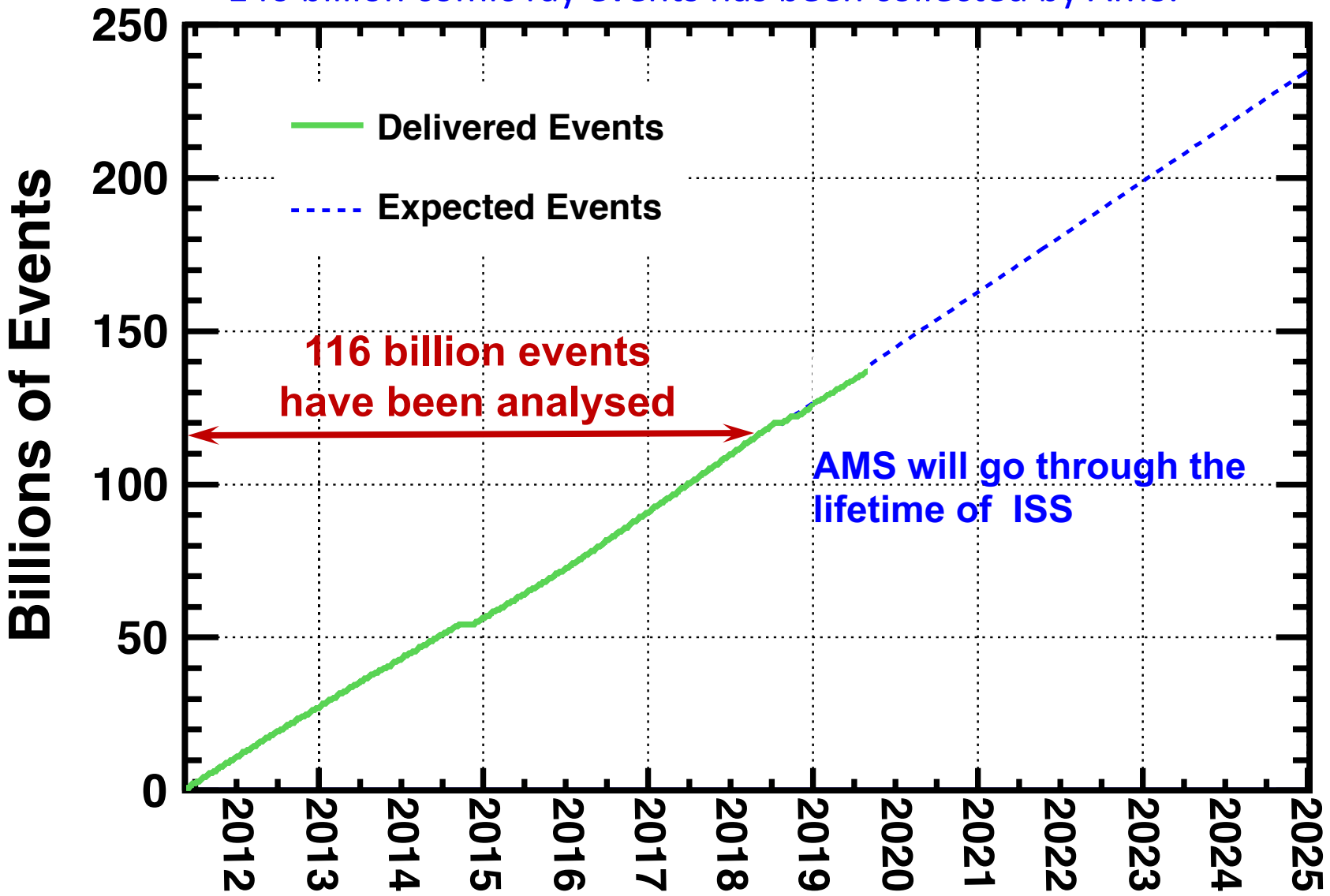
AMS Payload Operations Control and Science Operations Centers (POCC, SOC) at CERN

AMS Computers
Marshall Space Flight Center, AL

White Sands Ground Terminal, NM

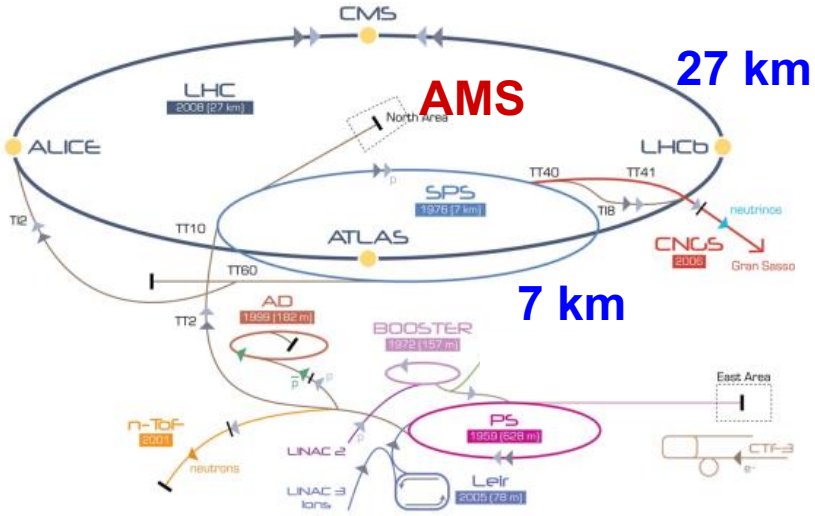
AMS Data Taking

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.

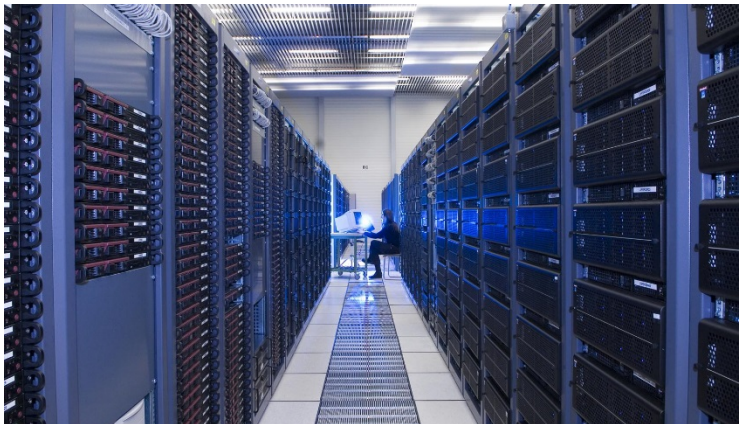


Calibration of the AMS Detector

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

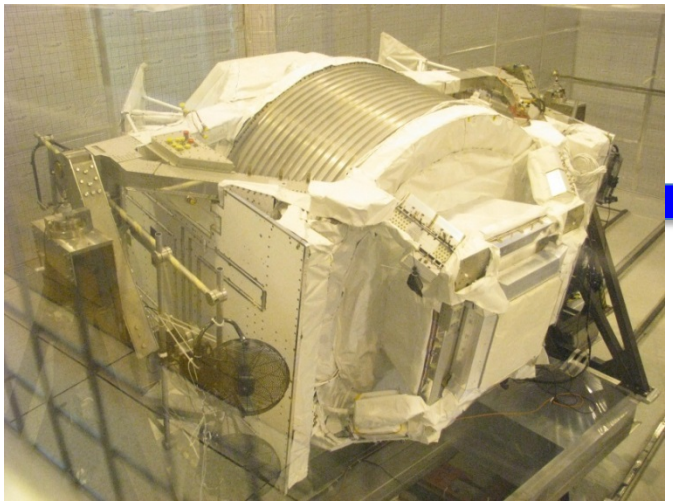


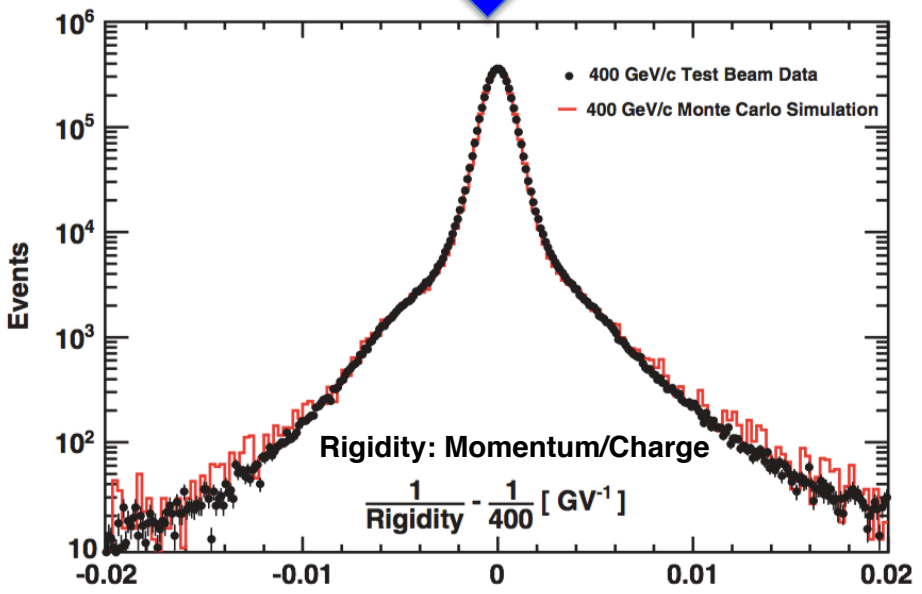
17,000 CPU cores at CERN



Computer simulation:
Interactions, Materials, Electronics

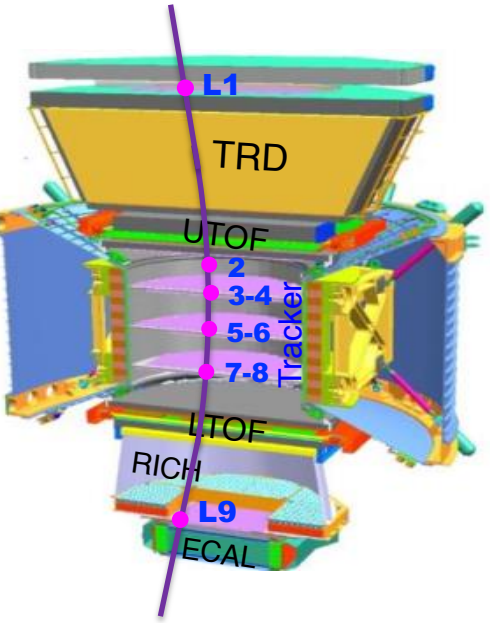
2000 positions

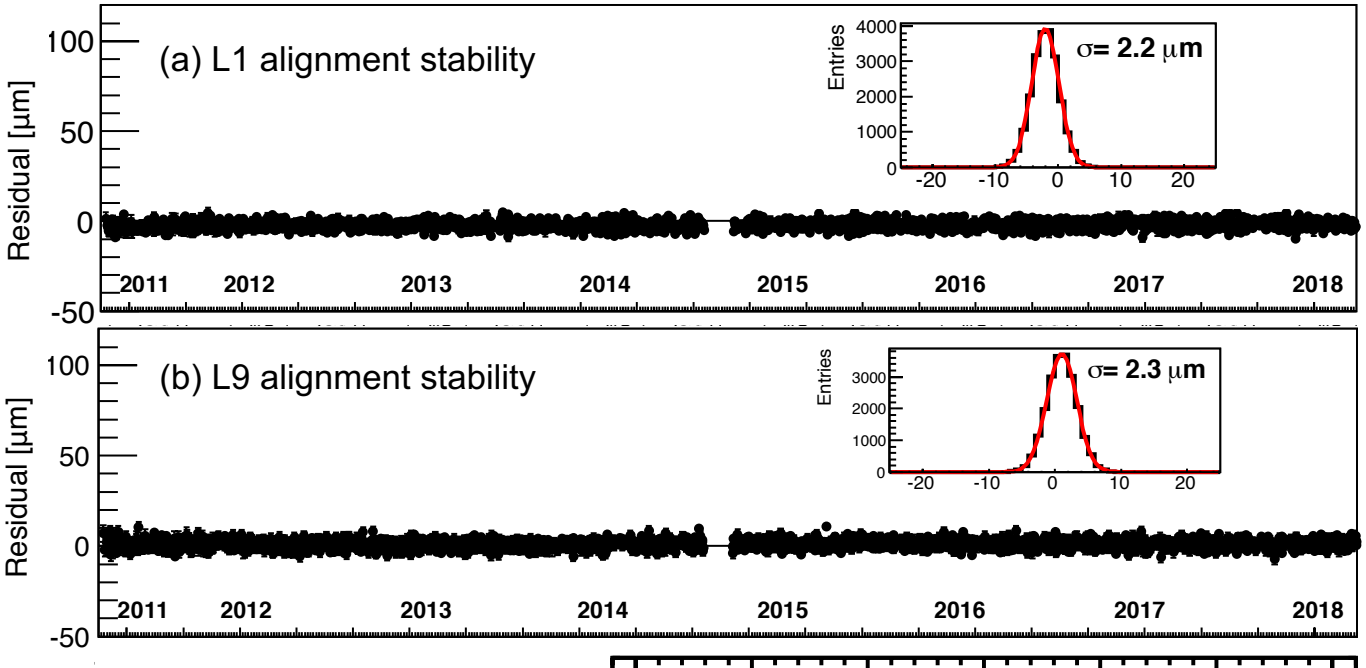




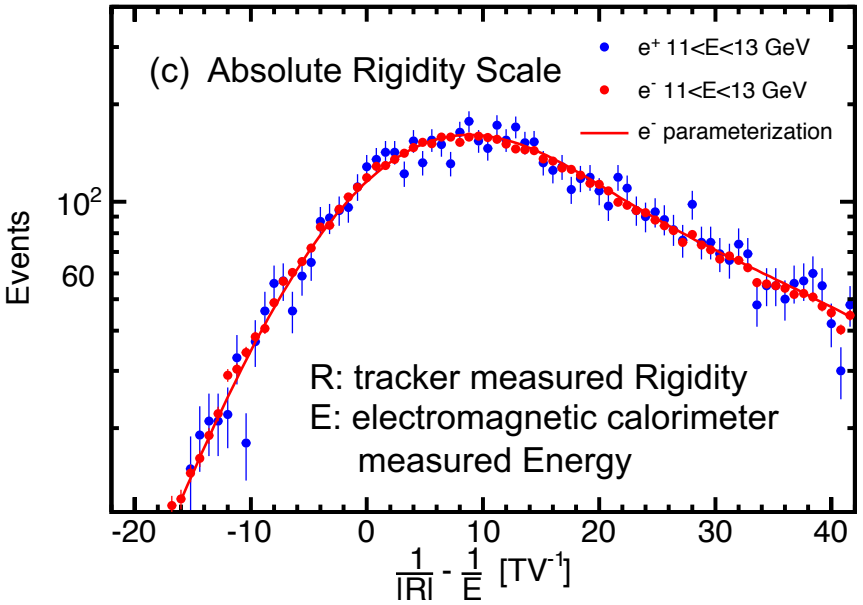
Tracker Alignment & Calibration

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.



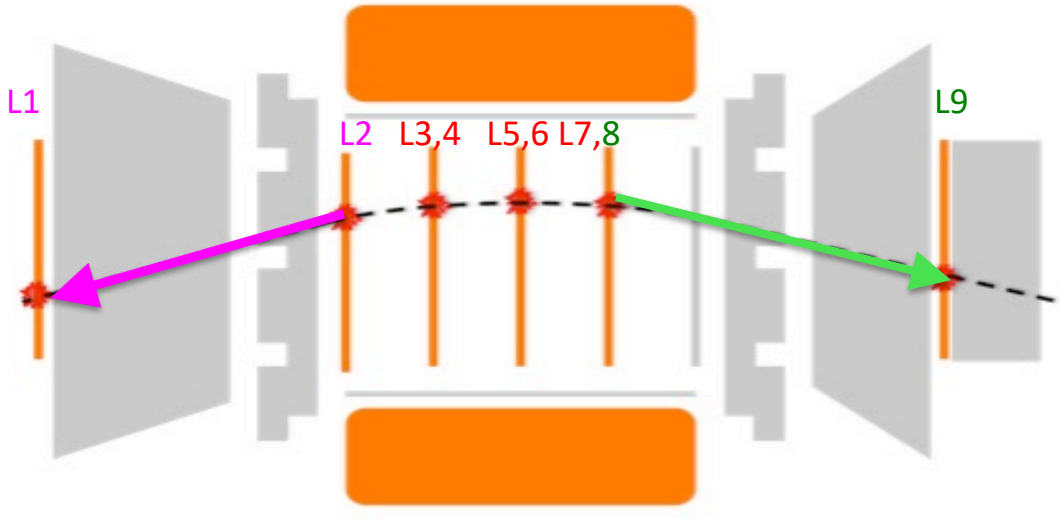


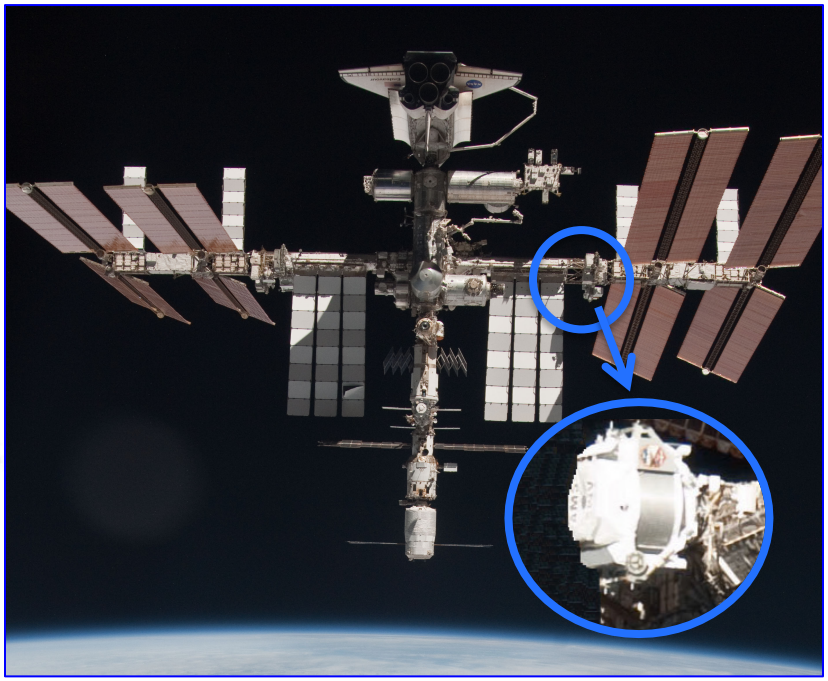
The vibrations and accelerations during the AMS launch into space could change the tracker ladder positions at the submicron level. The resulting misalignment was precisely corrected in space by analyzing track trajectories of opposite charged particles (positron and electron events). This allows to 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 scale of better than 1/30 TV^{-1}.



Nuclei inelastic Cross Section Measurements with Cosmic Rays

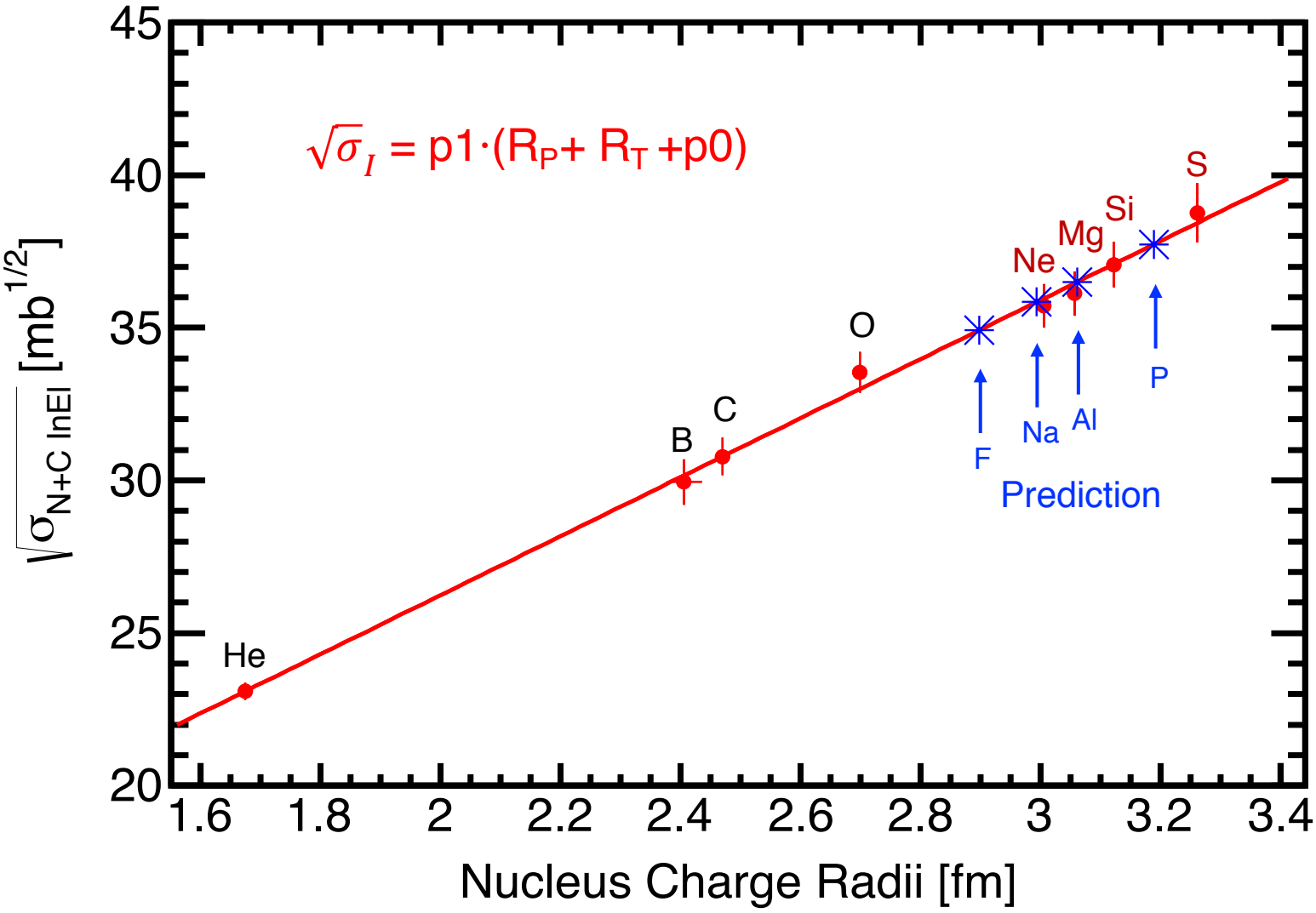
To accurately measure the spectra of cosmic-ray nuclei, the nuclei interaction cross sections with the AMS material are important. The material is composed mostly of Carbon (73%) and Aluminum (17%). The inelastic cross sections of *Nu + C, Nu + Al* were not well known before AMS.





We measured the nuclei survival probability in AMS using data acquired when the attitude of the International Space Station was rotated so that AMS was pointing in a horizontal direction, in which particle can enter AMS both right to the left and left to the right.

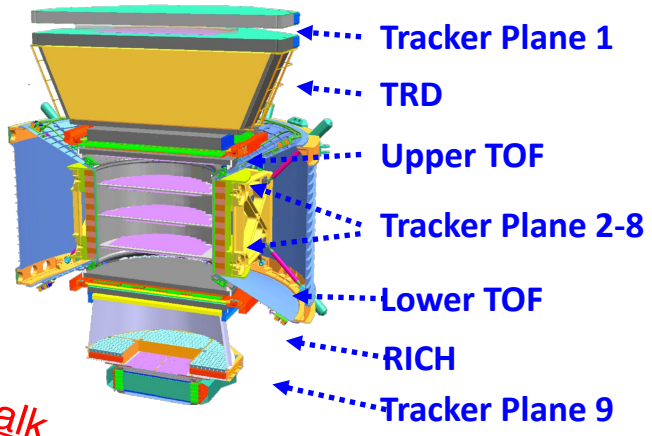
AMS Nuclei + C Inelastic Cross Section Measurements (5-100 GV Rigidity)



I. Angeli and K. P. Marinova. "Table of experimental nuclear ground state charge radii: An update." *Atomic Data and Nuclear Data Tables* 99.1 (2013): 69-95

Cosmic Ray Chemical Composition measured by AMS

AMS has seven instruments which independently measure Cosmic Nuclei charge



primary cosmic ray to be presented in this talk

published in PRL

analysed

analysis on going

Events

10^9 10^8 10^7 10^6 10^5 10^4 10^3 10^2 0

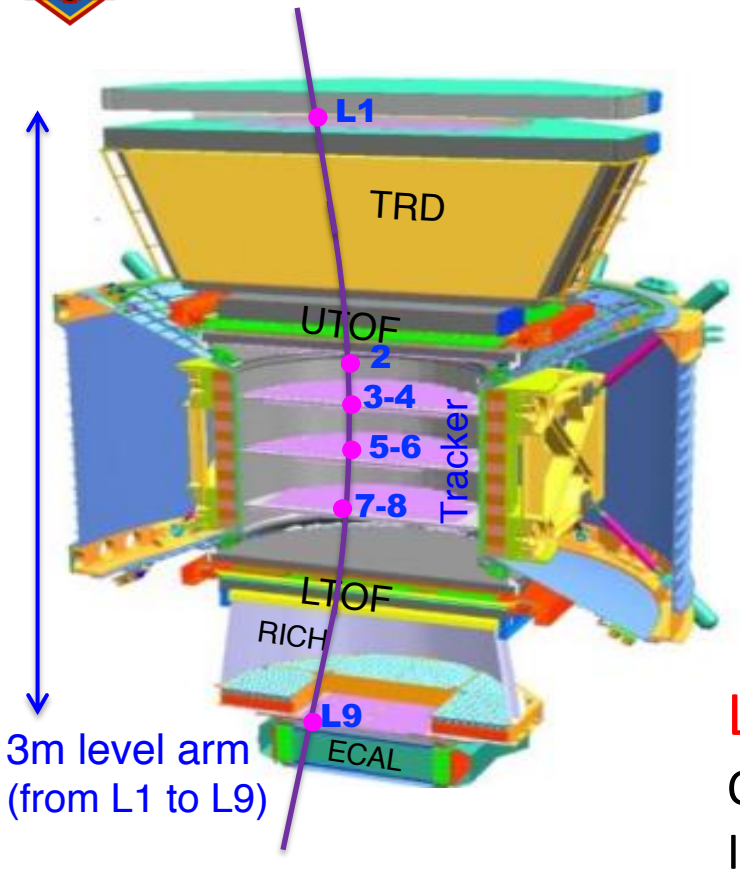
H He Li Be B C N O F Ne Na Mg Al Si P S Cl Ar K Ca Sc Ti V Cr Mn Fe Ni

ToF Charge: 0 5 10 15 20 25 30

Tracker Charge: 0 5 10 15 20 25 30

Cosmic Ray Proton and Nuclei Measured by AMS

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



	Coordinate Resolution	MDR
Z=1	10 μm	2 TV
2≤Z≤8	5-7 μm	3.2-3.7 TV
9≤Z≤16	6-8 μm	3-3.5 TV

ToF (4 Layers): Velocity and Direction

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

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

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

Consistent Charge Along Particle Trajectory

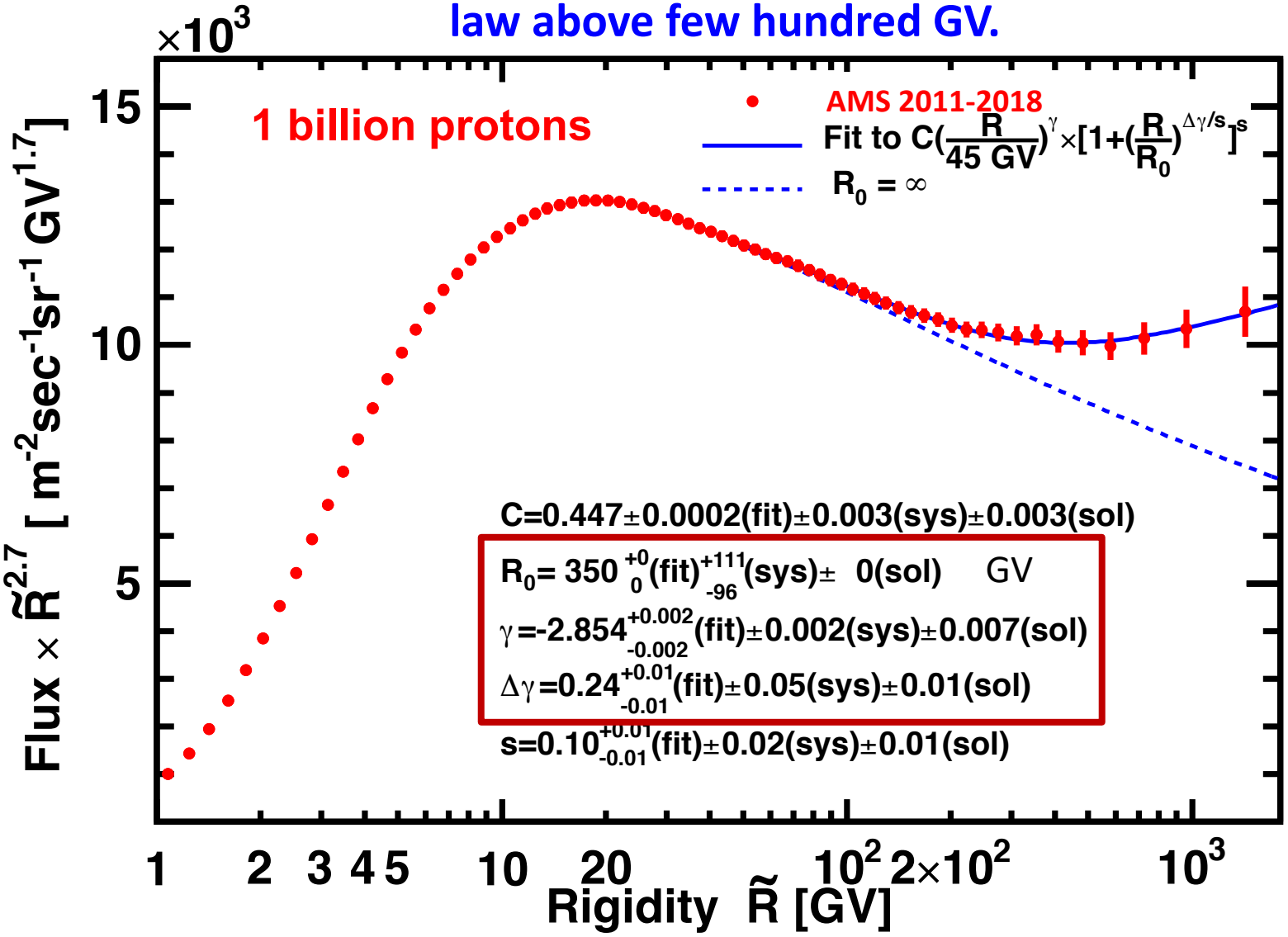
Inner Tracker only Charge Resolution:

$\Delta Z = 0.05\text{-}0.12$ ($1 \le Z \le 8$)

$\Delta Z = 0.13\text{-}0.19$ ($9 \le Z \le 16$)

Structure in the latest proton spectrum

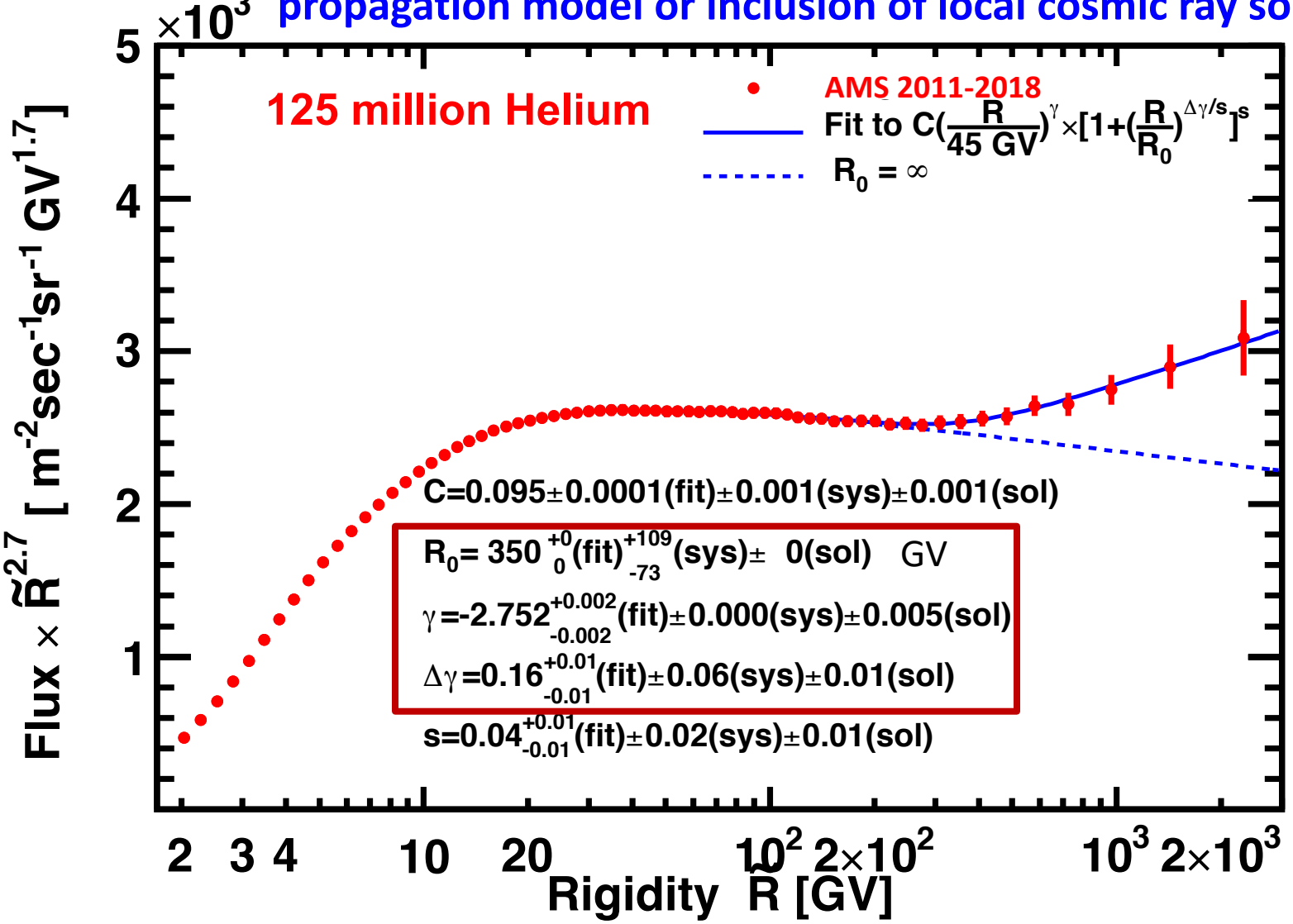
Proton spectrum measured by AMS shows a deviation from a single power law above few hundred GV.



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

Structure in the latest helium spectrum

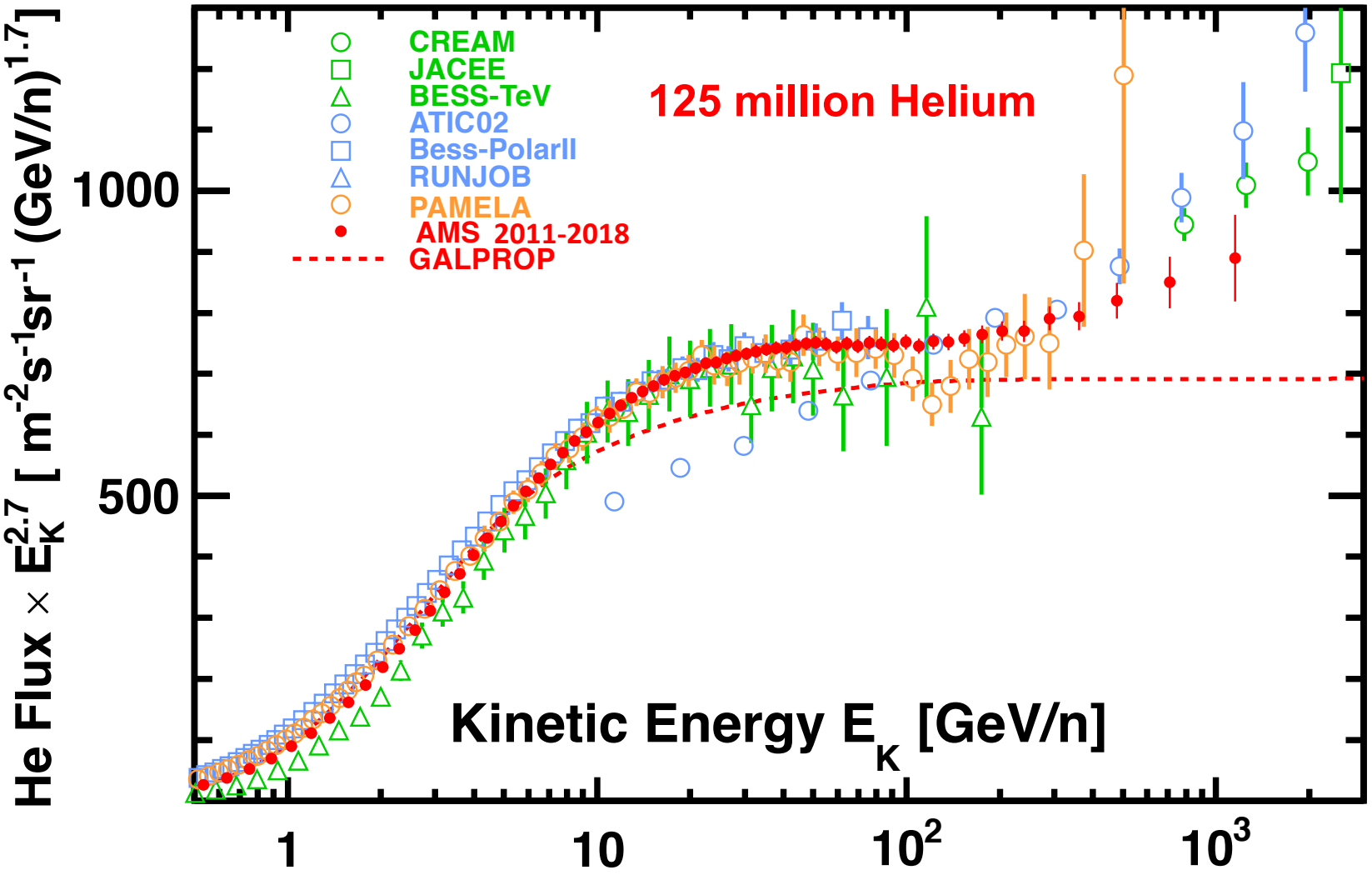
The structure in P &He spectra requires new understanding of cosmic ray propagation model or inclusion of local cosmic ray sources.



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

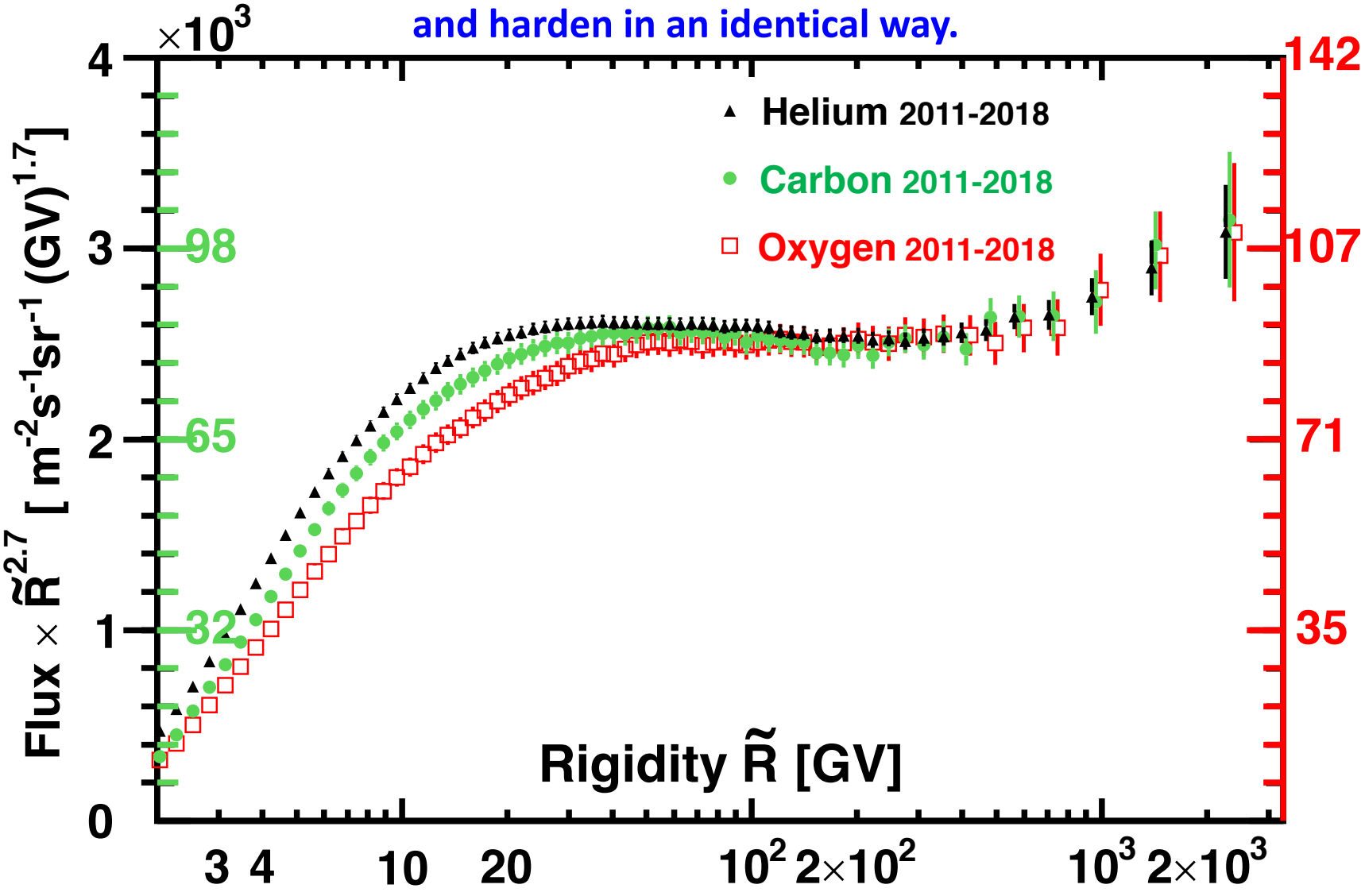
AMS Measurement of the helium spectrum

together with earlier measurements



Latest AMS Measurements of He, C and O spectra

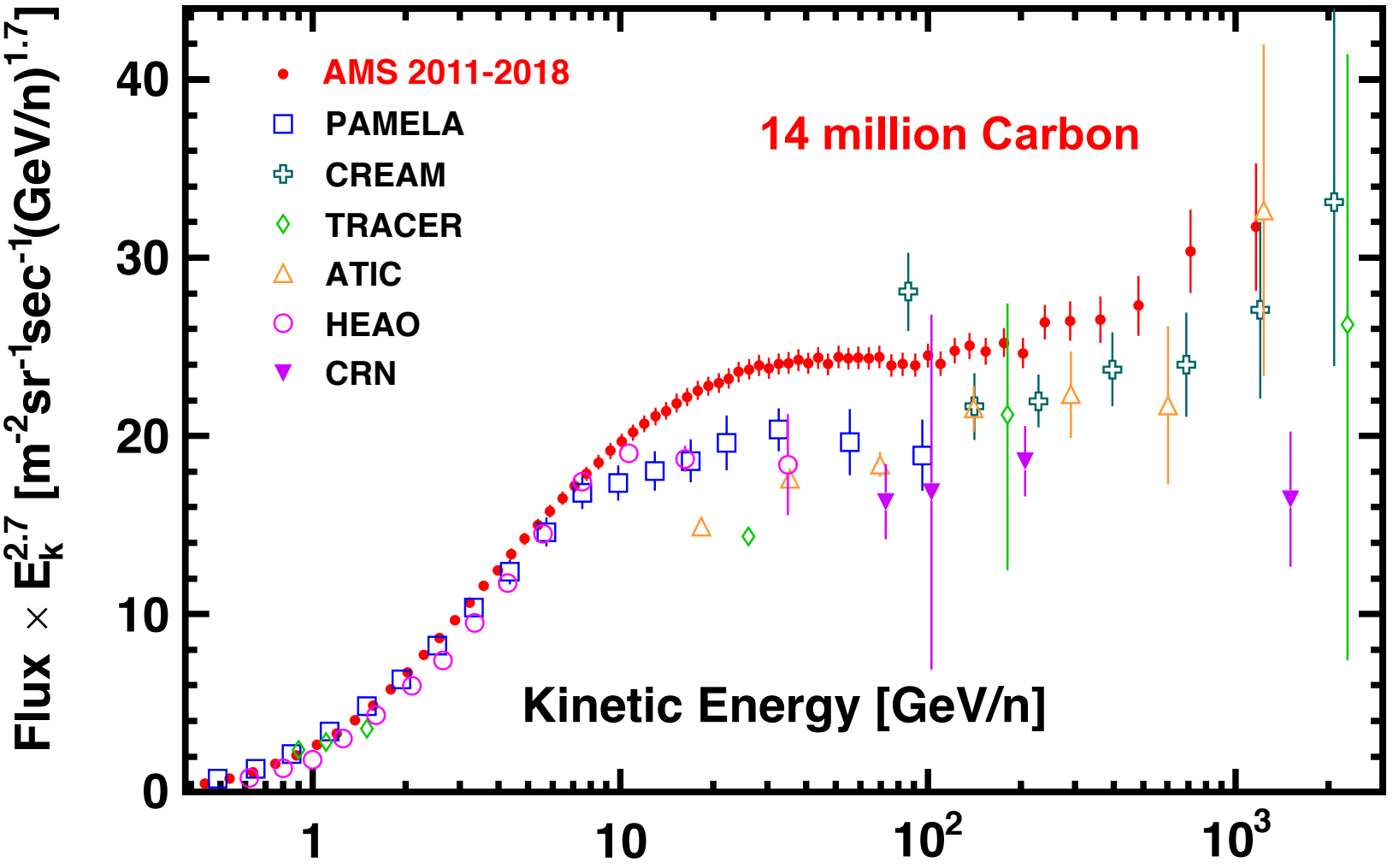
Above few hundred GV, the spectra of He, C, O all deviate from a single power law and harden in an identical way.



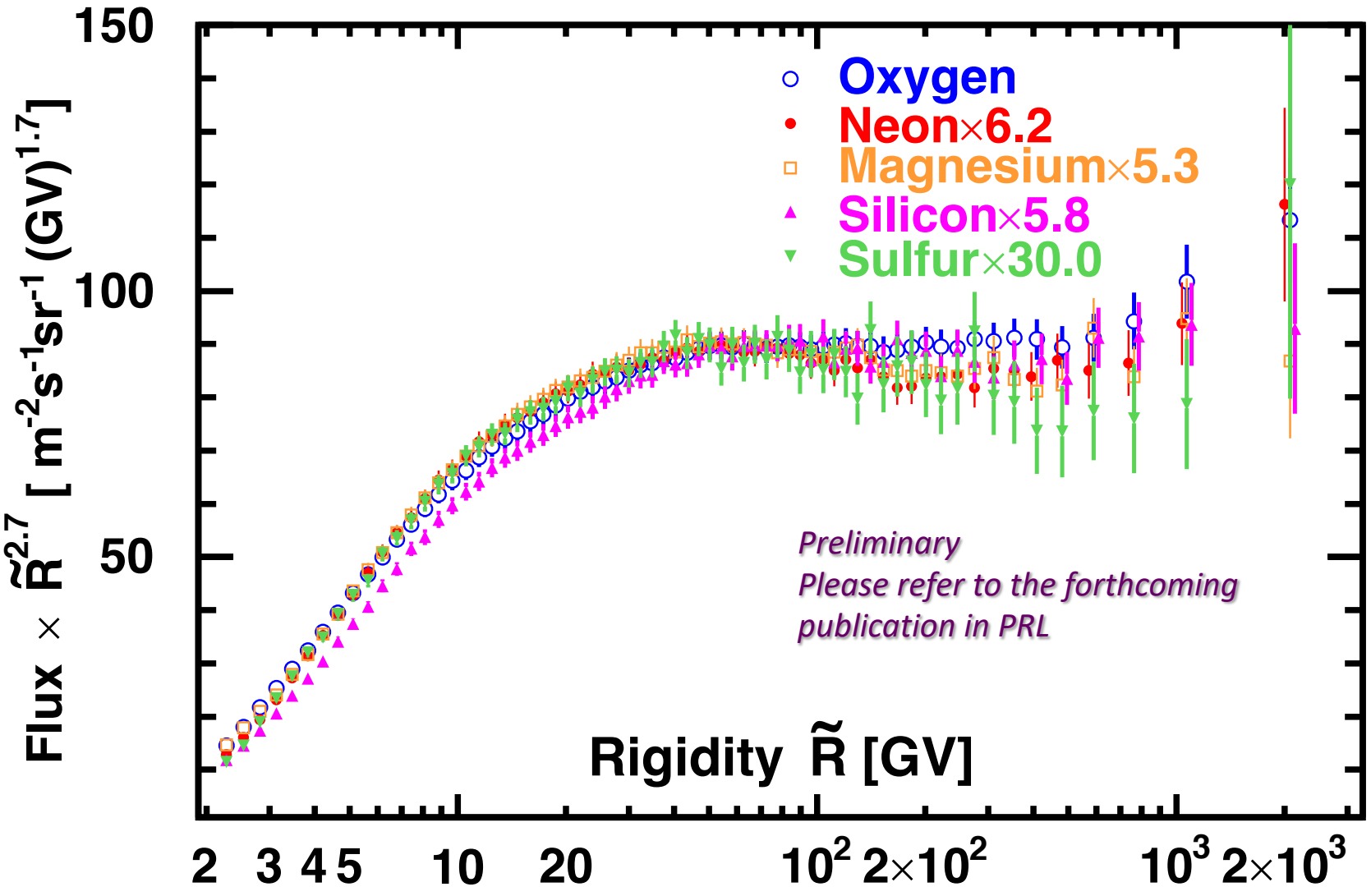
The new AMS result (2011-2018) is consistent with earlier AMS PRL result (2011-2016) "M. Aguilar *et al.*, Phys. Rev. Lett., **119**, 251101 (2017)" but with improved accuracy

Latest AMS Measurement of the carbon spectrum

together with earlier measurements

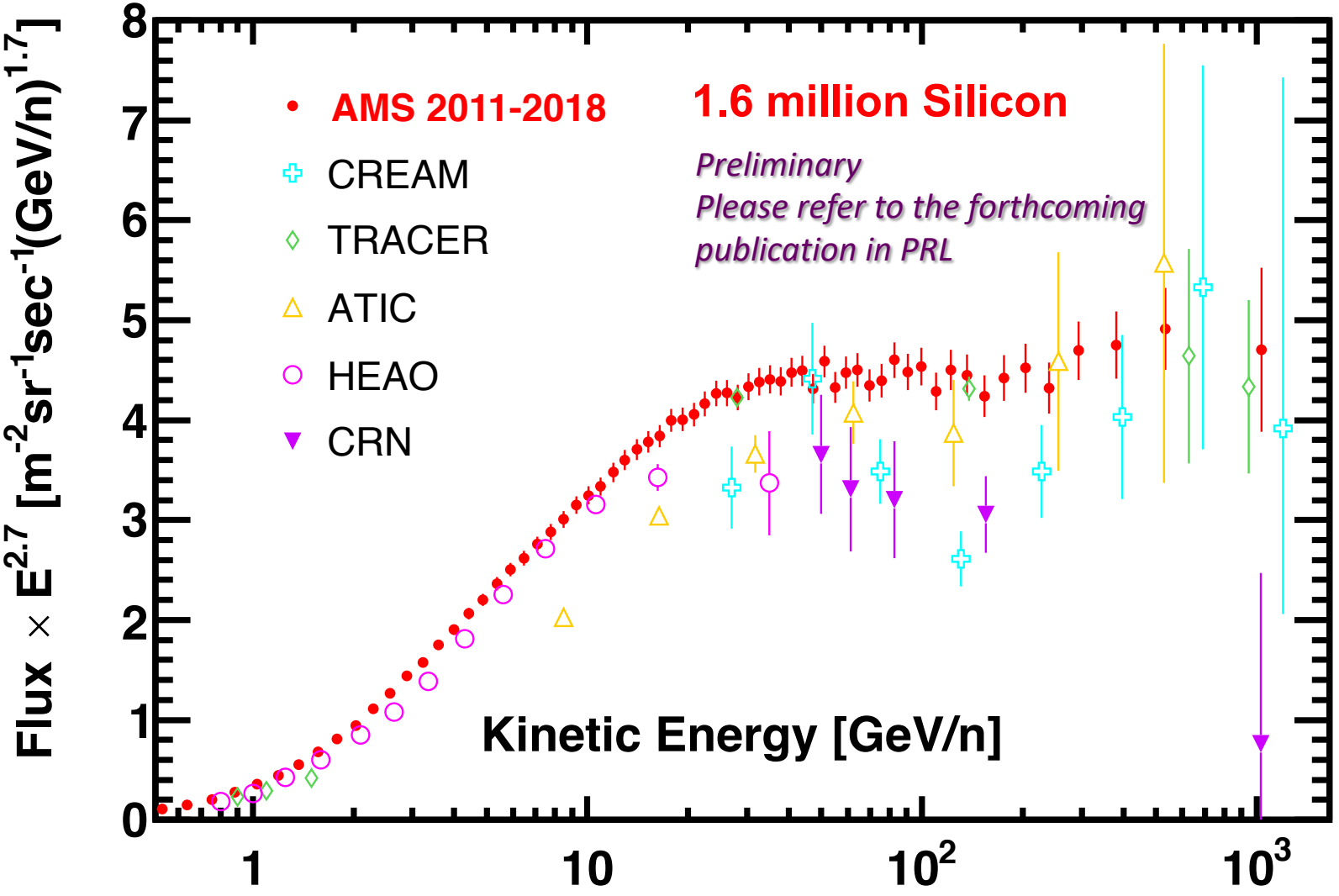


Latest AMS Measurements of O, Ne, Mg, Si and S spectra

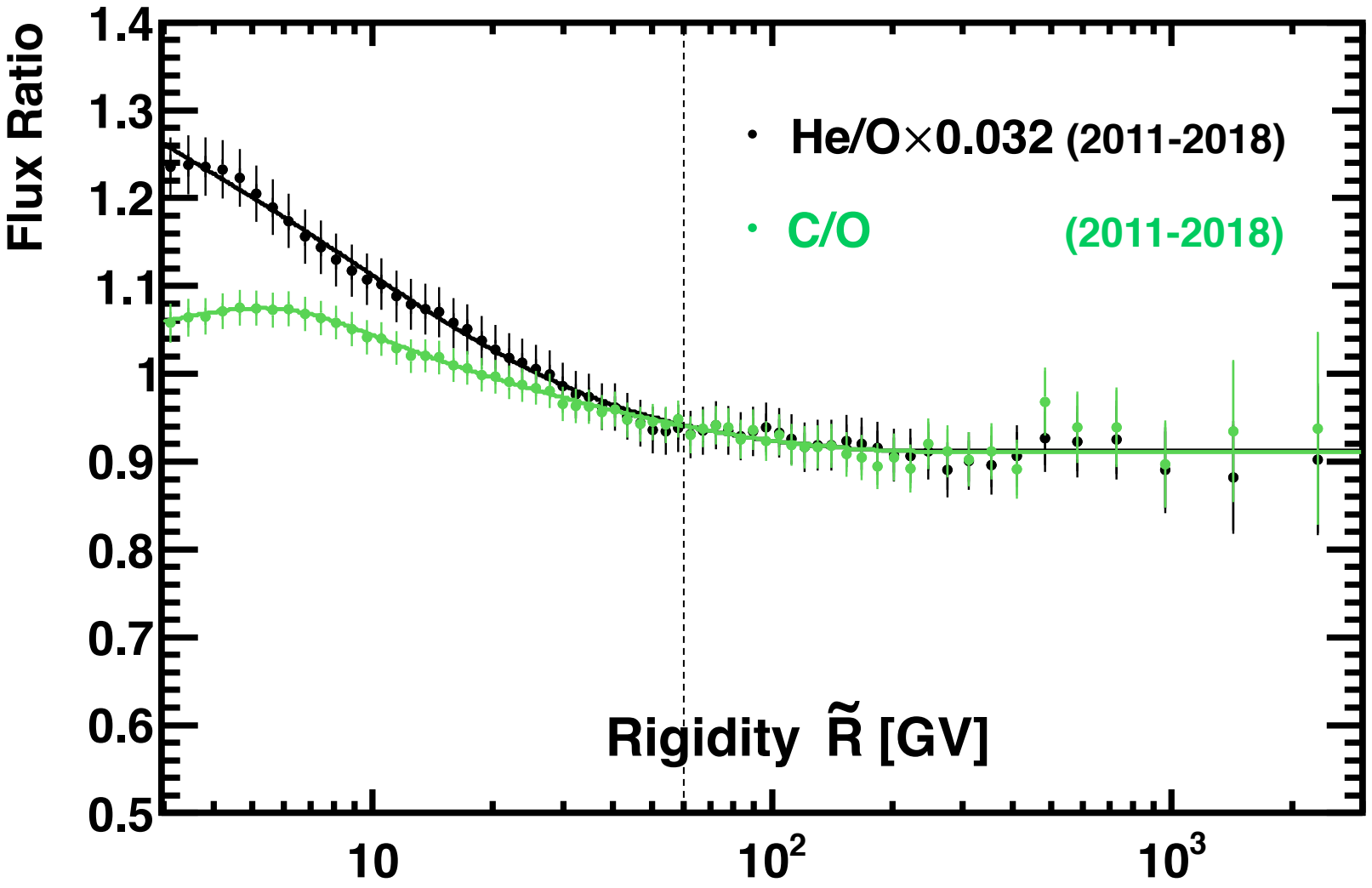


Latest AMS Measurement of the Silicon spectrum

together with earlier measurements

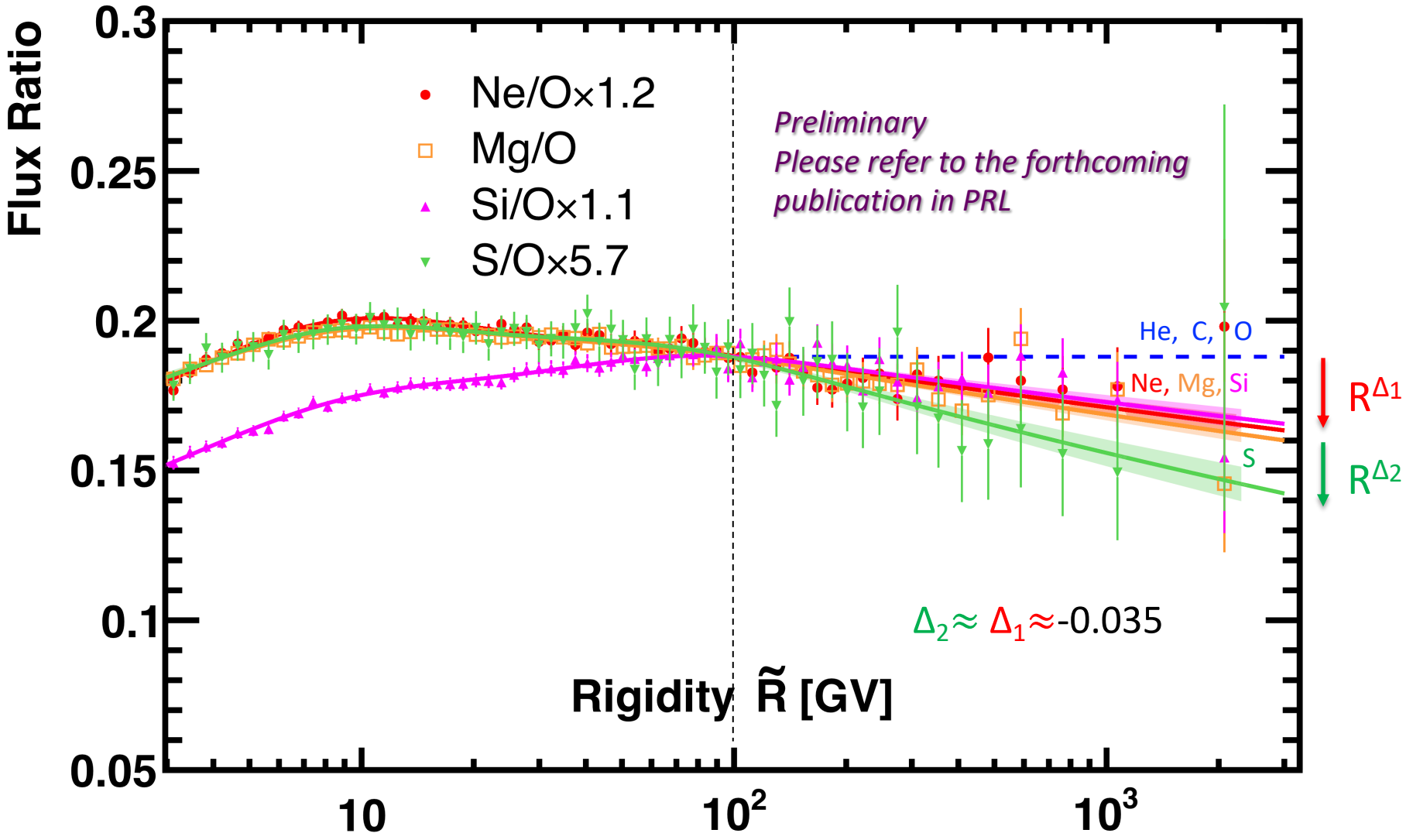


The latest AMS Results on He/O and C/O Flux Ratios



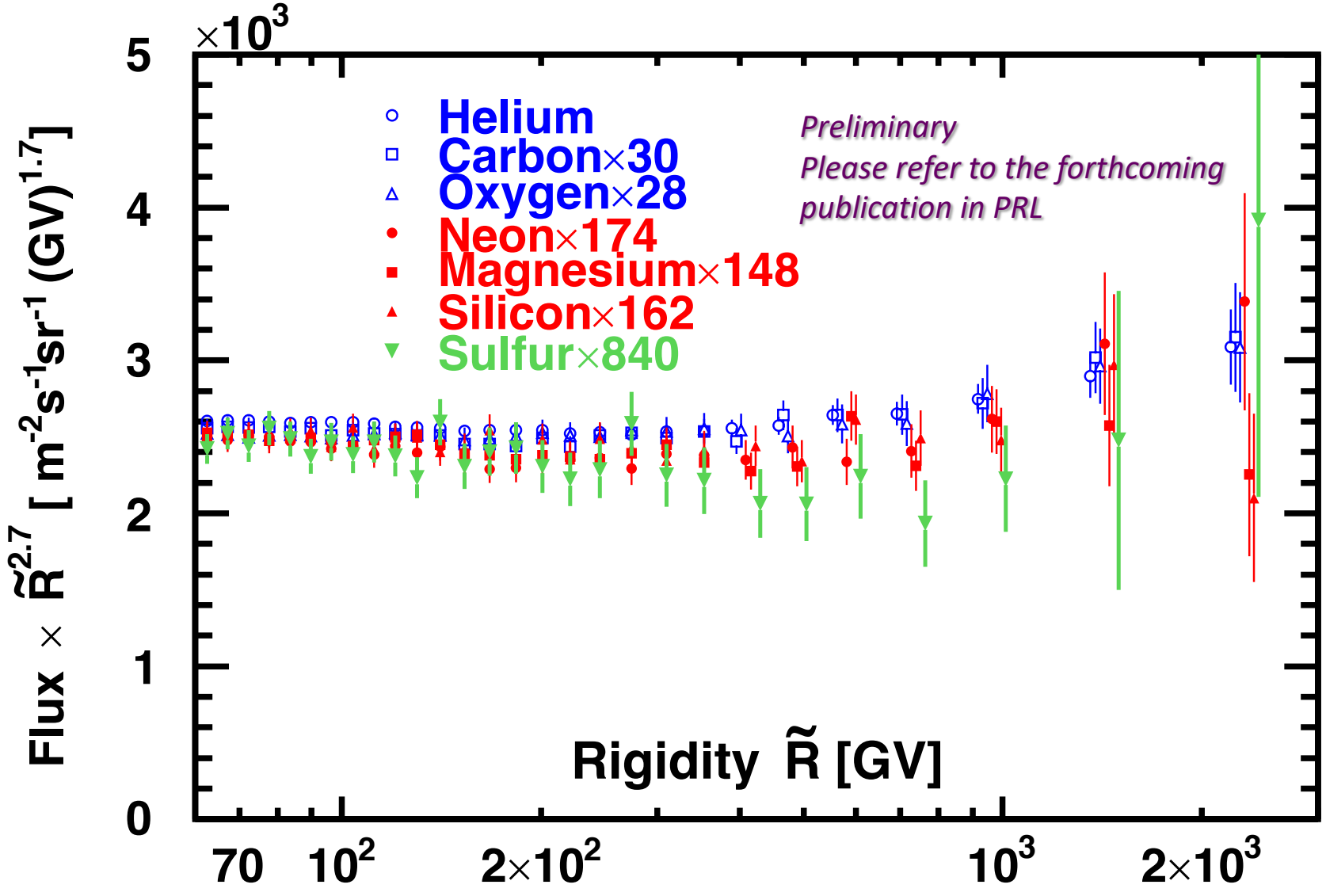
Above ~60 GV, the He, C and O spectra have identical rigidity dependence.

The latest AMS Results on Ne/O, Mg/O, Si/O and S/O Flux Ratios



So far, AMS observed 3 groups of primary cosmic ray nuclei above 100 GV: He (C, O), Ne (Mg, Si) and S.

The Latest AMS Results reveal 3 Groups of rigidity dependence in Primary Cosmic Ray Nuclei: He (C, O), Ne (Mg, Si) and S

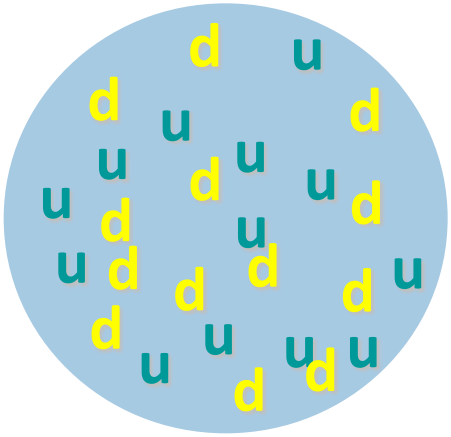


Other AMS Physics Topic: Strange Quark Matter – "Strangelets"

E. Witten, Phys. Rev. D,272-285 (1984)

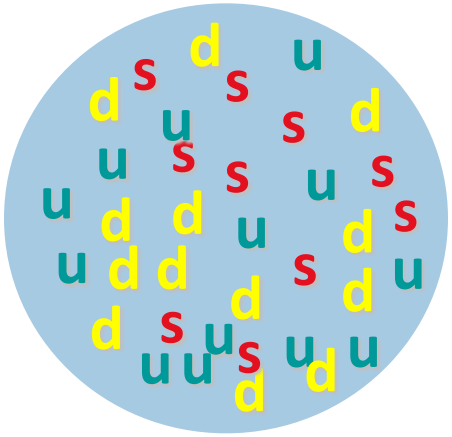
There are six quarks – u, d, s, c, b, and t.

All the material on Earth is made out of u and d quarks



Diamond (Z/A ~ 0.5)

Is there material in the universe made up of u, d, & s quarks?

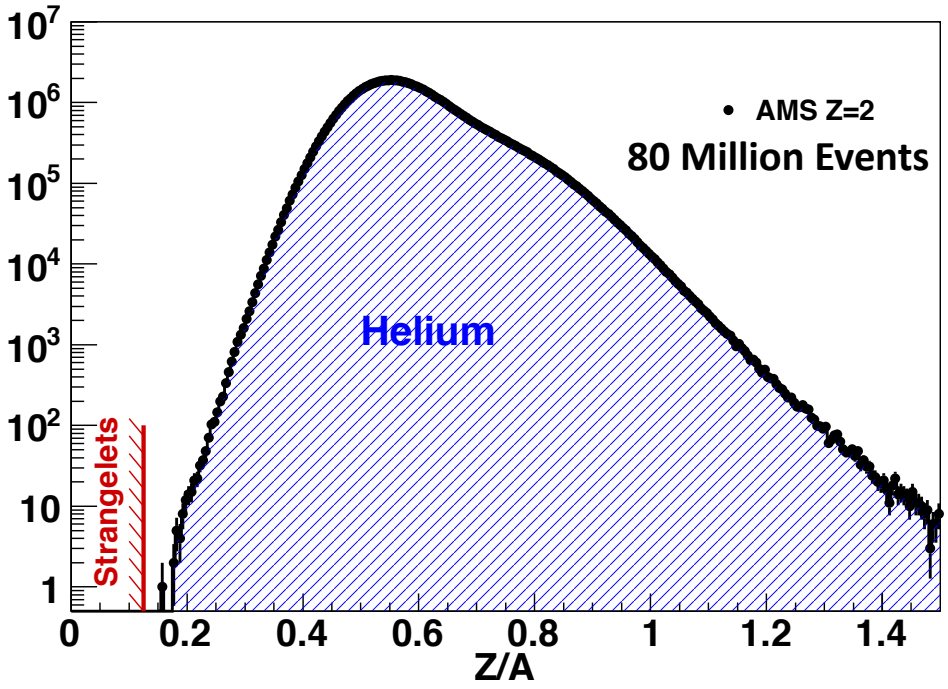


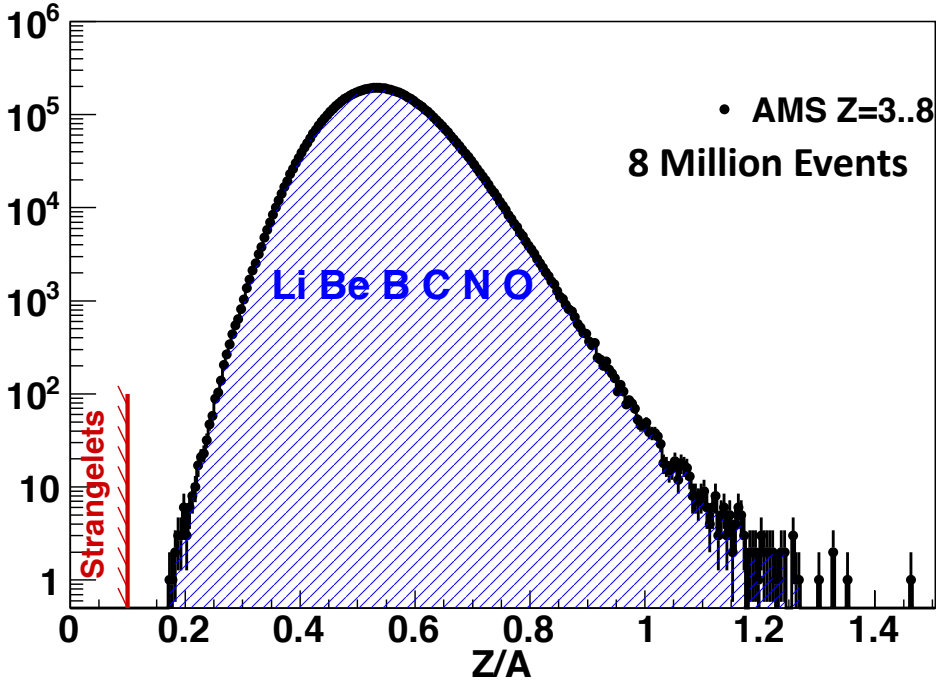
Strangelet (Z/A < 0.1)

This is being answered by AMS.

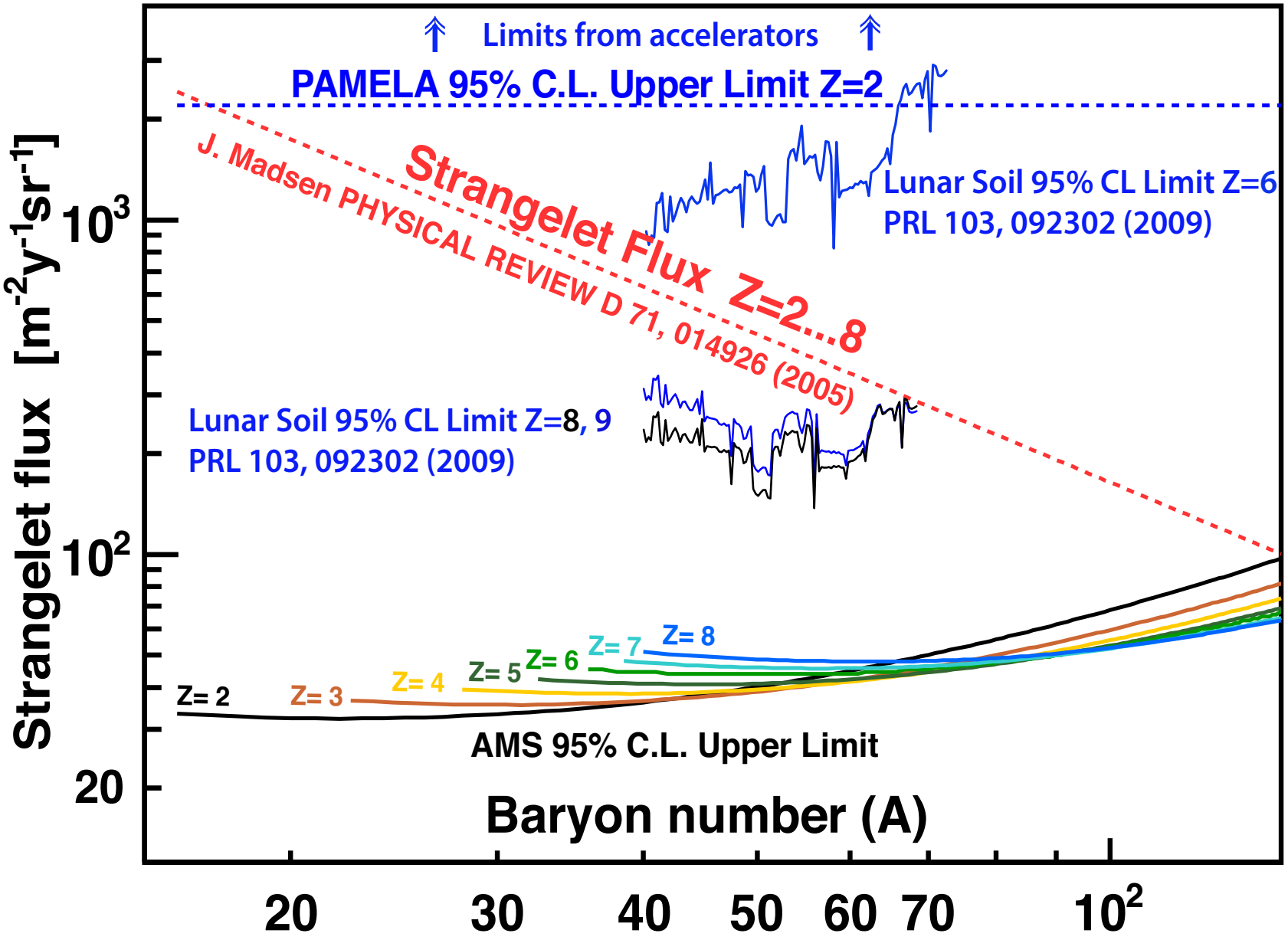
AMS Search for Strangelets Z =2…8 in Cosmic Rays

Preliminary data, refer to the upcoming AMS publication





Preliminary data, refer to upcoming AMS publication



Strangelets with Z = 2 to 8 are ruled out by AMS

Conclusion

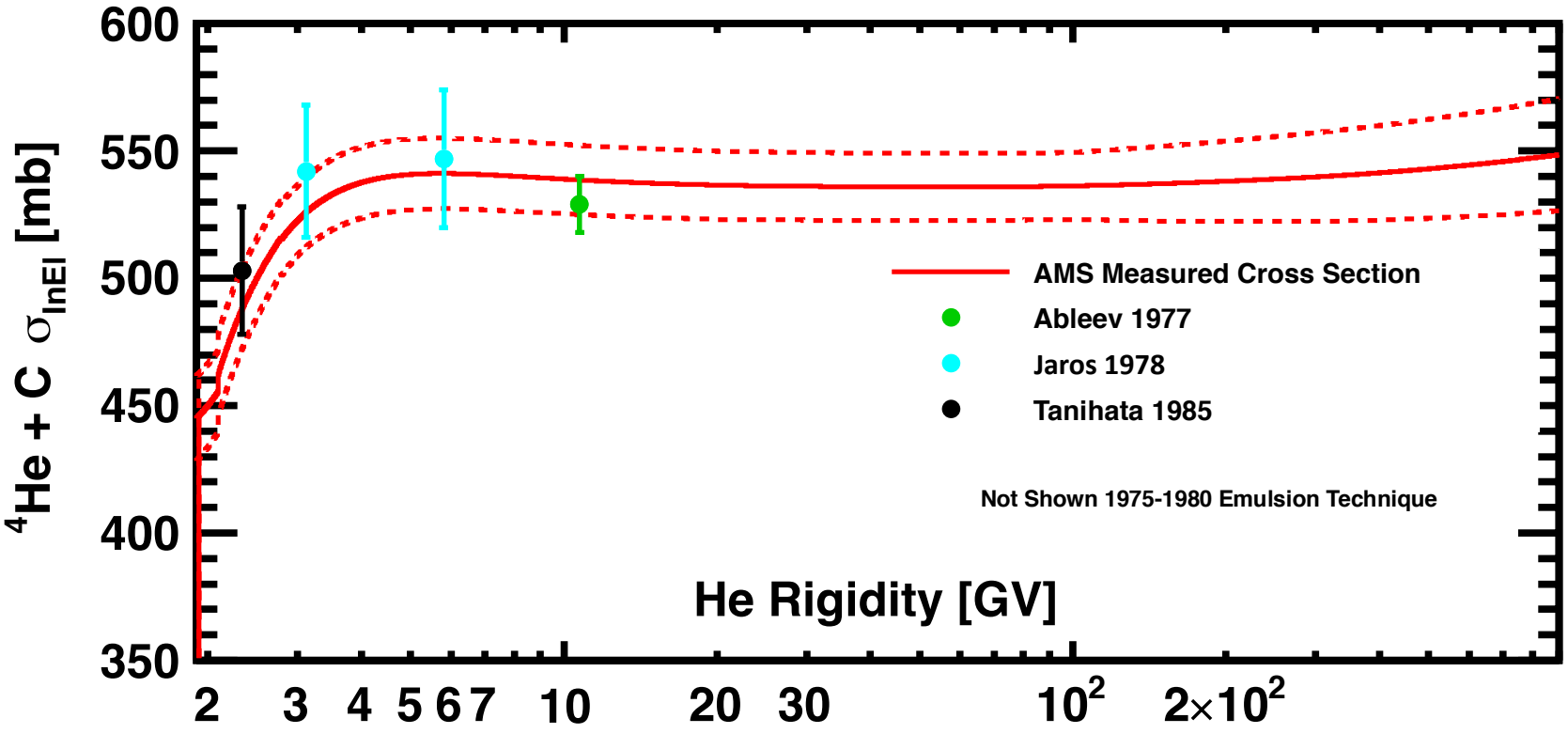
1. The AMS measurements of the cosmic ray spectra of proton and nuclei providing new, precise, and unexpected information.

2. The accuracy and characteristics of the data, simultaneously from many different types of cosmic rays shows many new phenomena in our universe.

3. AMS will explore the new properties of the cosmic rays nuclei up to Zinc (Z=30) and beyond. With improving understanding of the detector, AMS will continuously explore other new physics in uncharted territory, like highZ strangelets (Z>8), magnetic monopole, anti-nuclei, …

BACKUP SLIDES

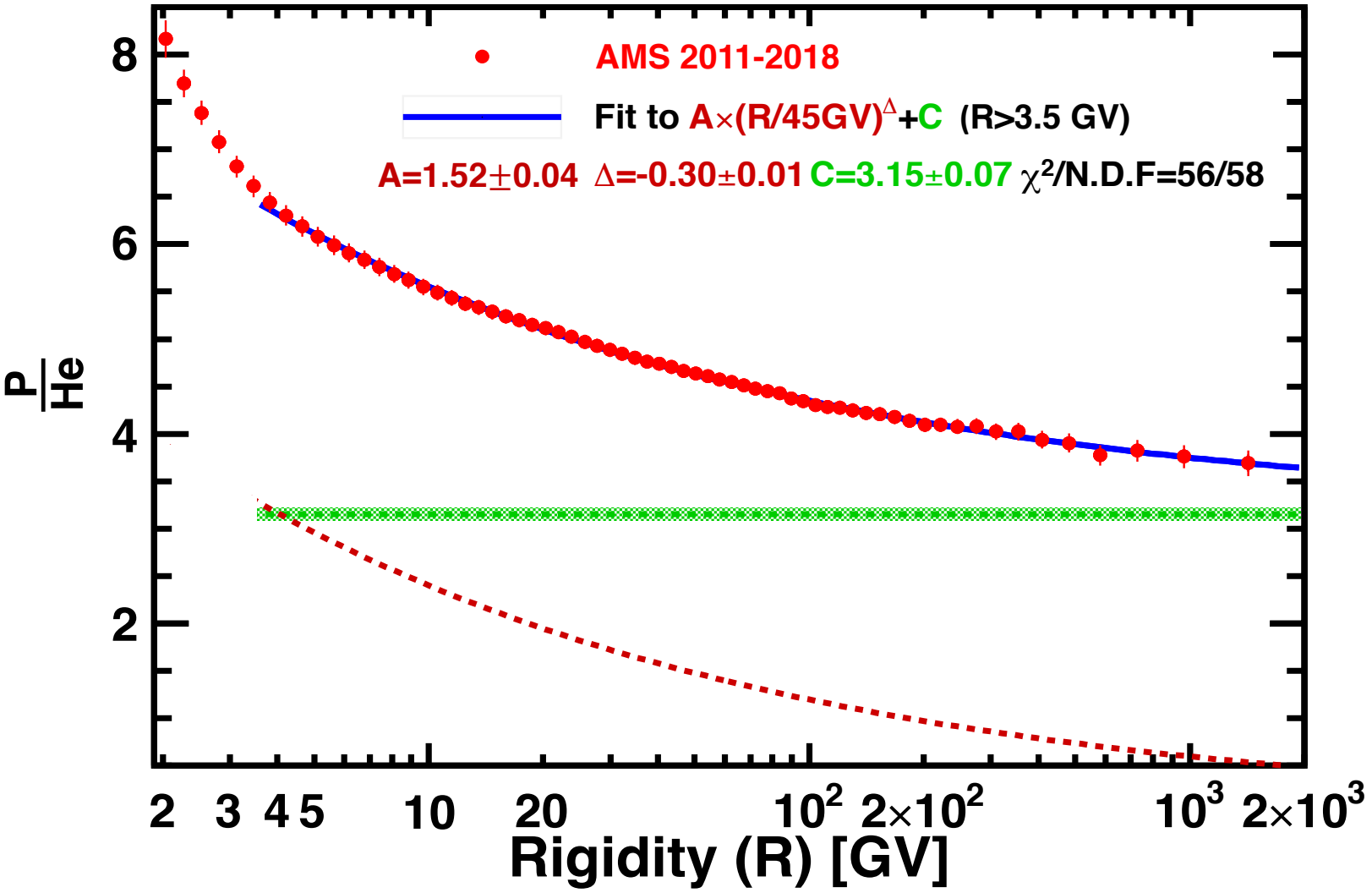
AMS measured He + C inelastic cross section



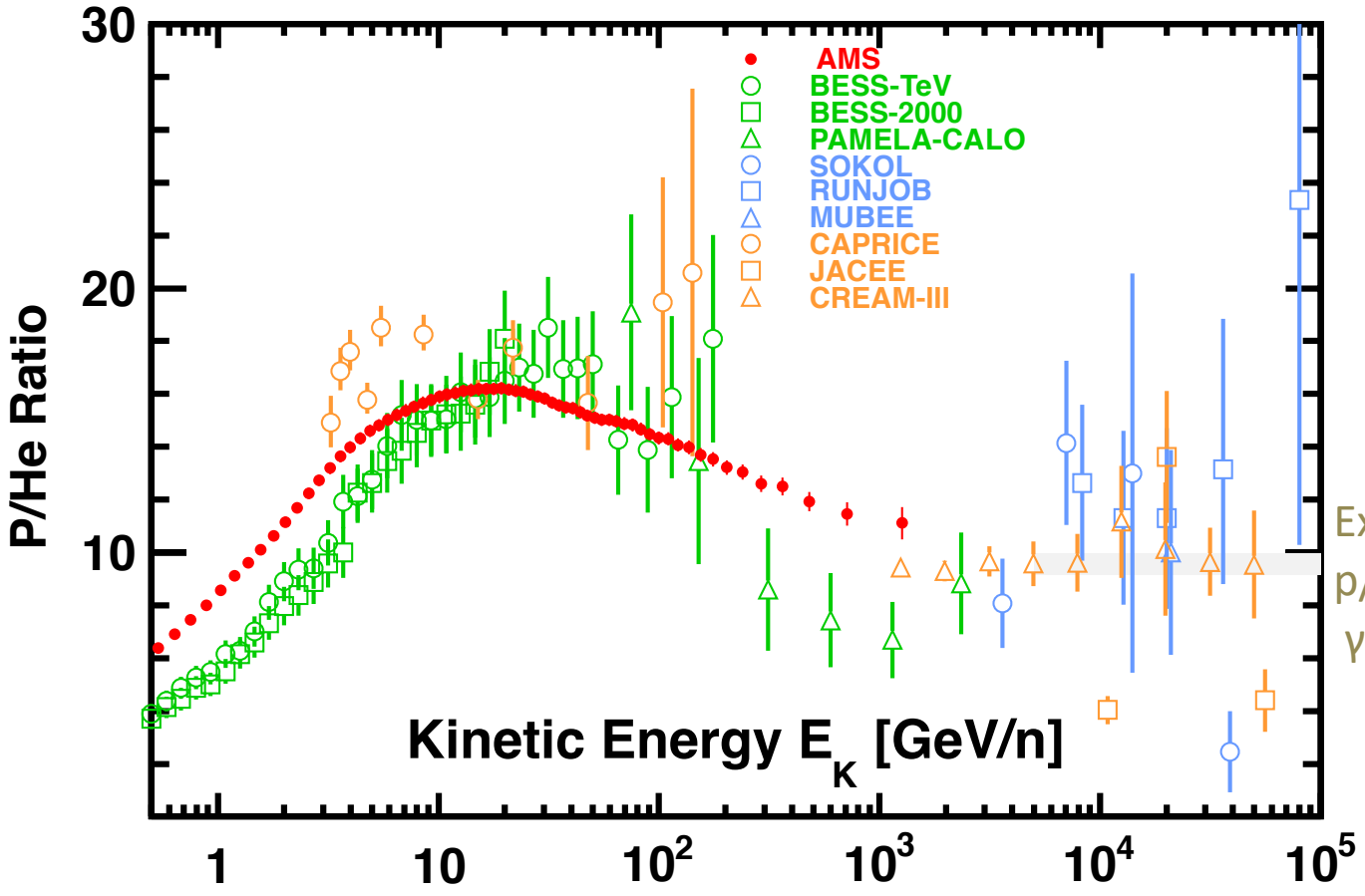
The AMS measured He+C inelastic cross section in comparison with experimental results. The dashed curve indicates the corresponding systematic errors. The cross section rise on R>100 GV follows the Glauber Gribov model.

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.

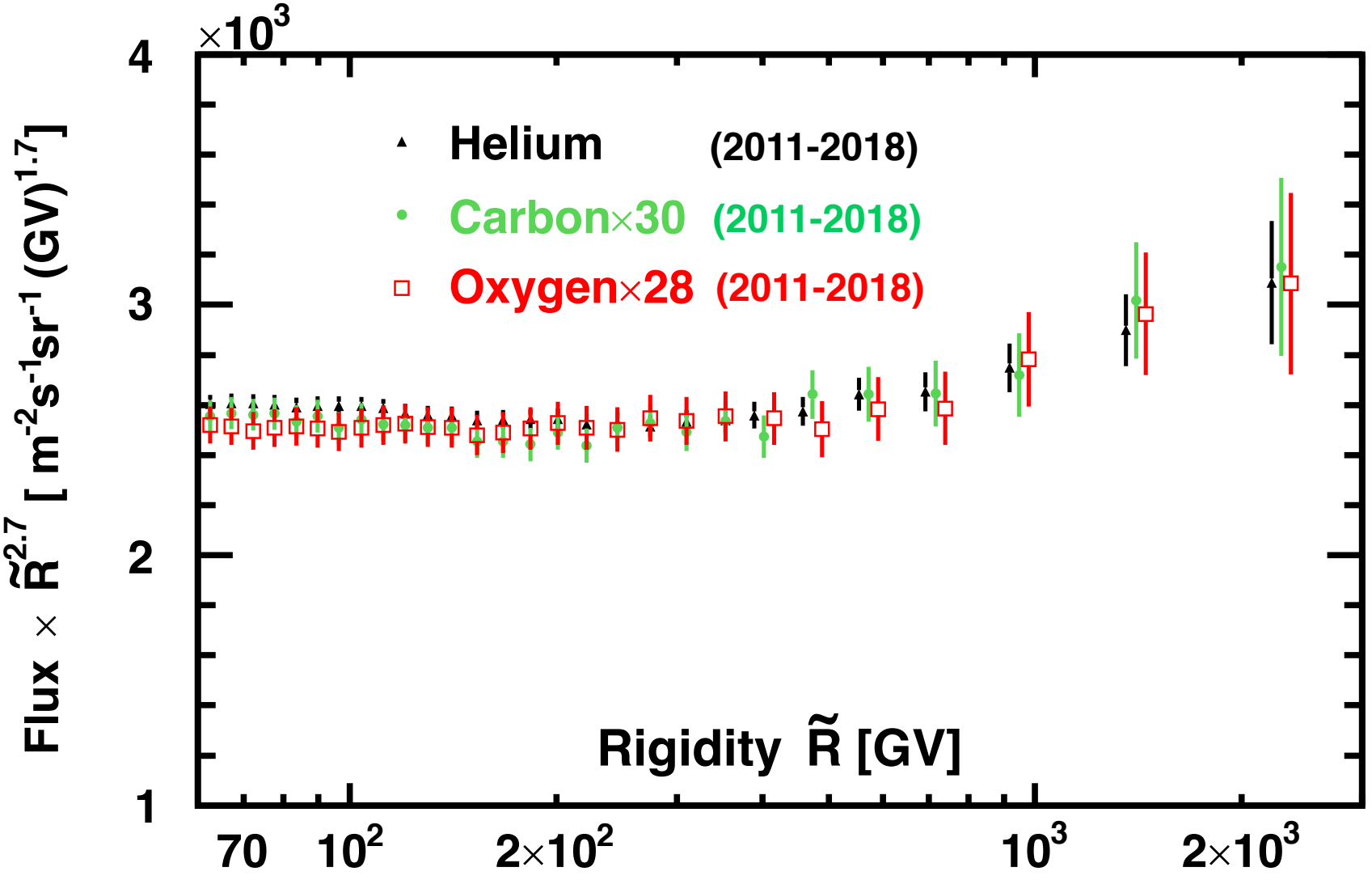


p/He Ratio Kinetic Energy



Extrapolated to high energy

p/He (E_K) = 9.55±0.4

$\gamma_{p,He}$ = -2.6±0.06

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