

Properties of Primary and Secondary Cosmic Rays measured with the Alpha Magnetic Spectrometer on the International Space Station

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On behalf of AMS Collaboration

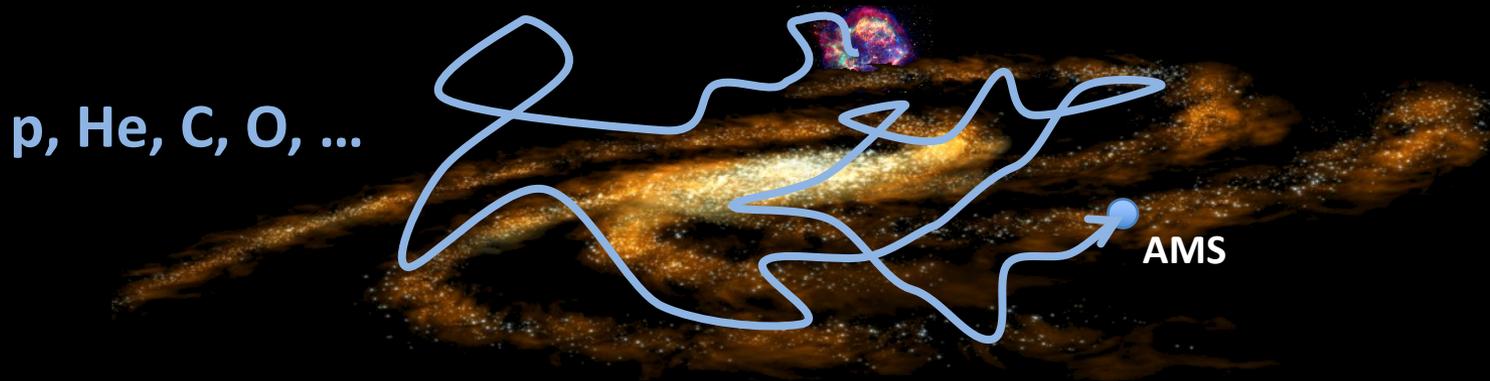


LP2019 Toronto, August 6, 2019

Traditionally, there are two prominent classes
of cosmic rays:

Primary (p, He, C, O, ...) and Secondary.

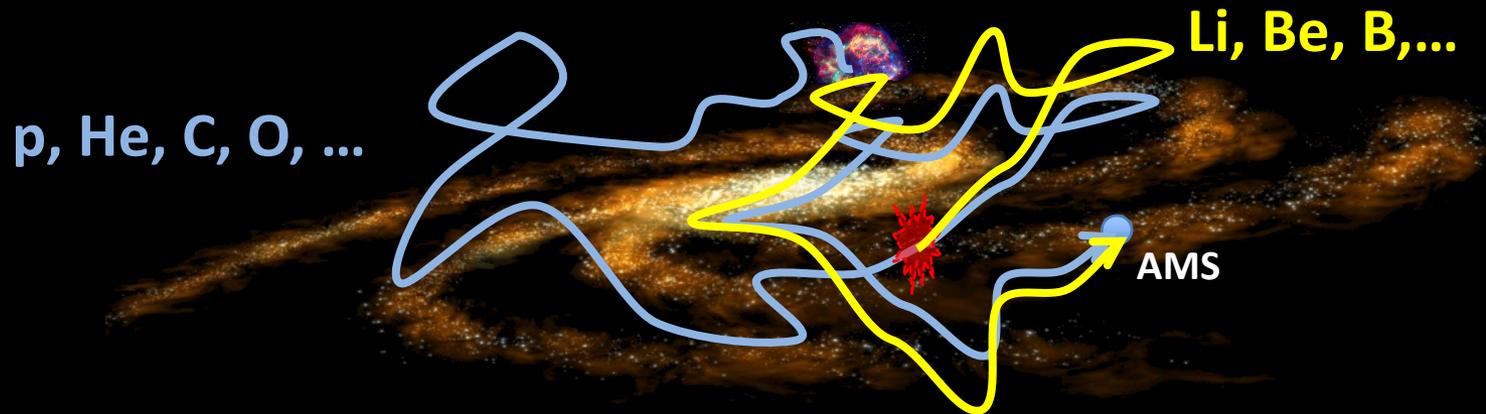
Primary Cosmic Rays are produced and accelerated at the source
(such as SNR). They carry information on their sources and the
history of travel.



Traditionally, there are two prominent classes
of cosmic rays:

Primary and Secondary (Li, Be, B, ...).

Secondary Cosmic Rays are produced in the collisions of
primary cosmic rays. They carry information on the history
of the travel and on the properties of the interstellar
medium.



Precision Measurements of Cosmic Rays

AMS has seven instruments which independently measure Cosmic Nuclei

Energy (E) or Momentum(P)

Tracker and Magnet:

Rigidity $R = P/Z$

Bending Spatial Resolution

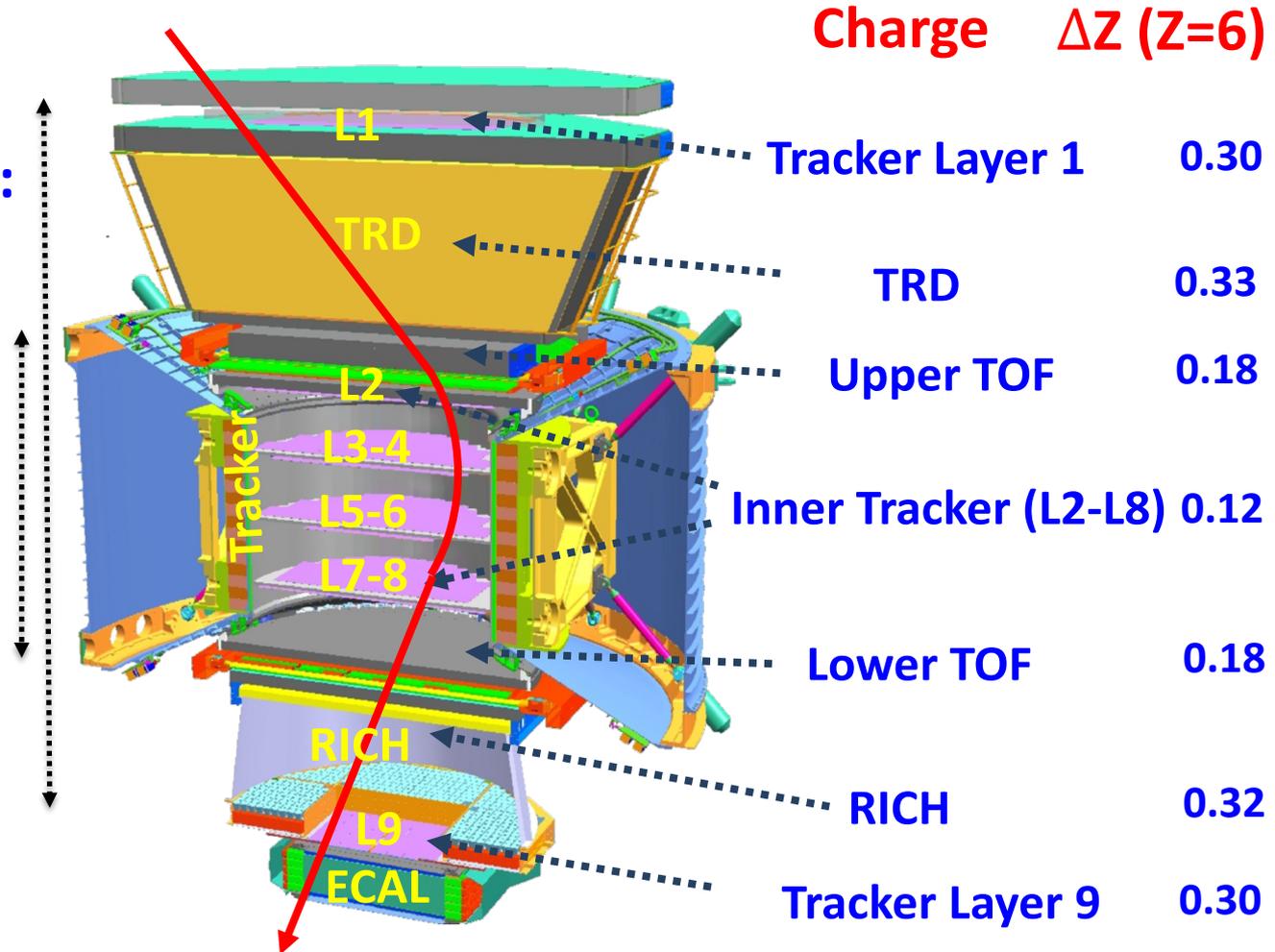
(Z=6) $\approx 5 \mu m$

Maximum Detectable Rigidity (MDR)

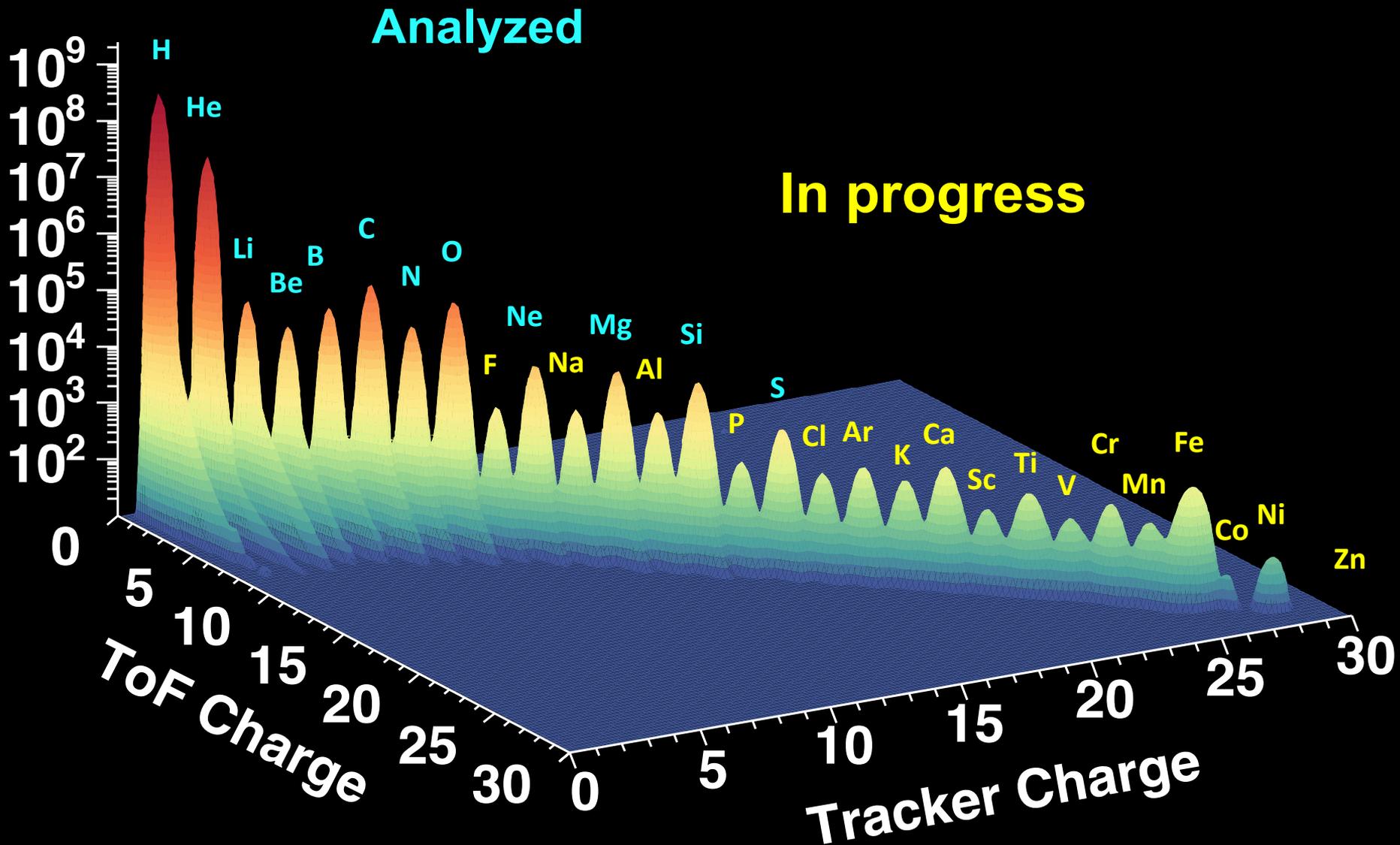
(Z=6) = 3.7 TV

TOF: β

$\Delta\beta$ ($\beta=1, Z=6$) ≈ 0.01



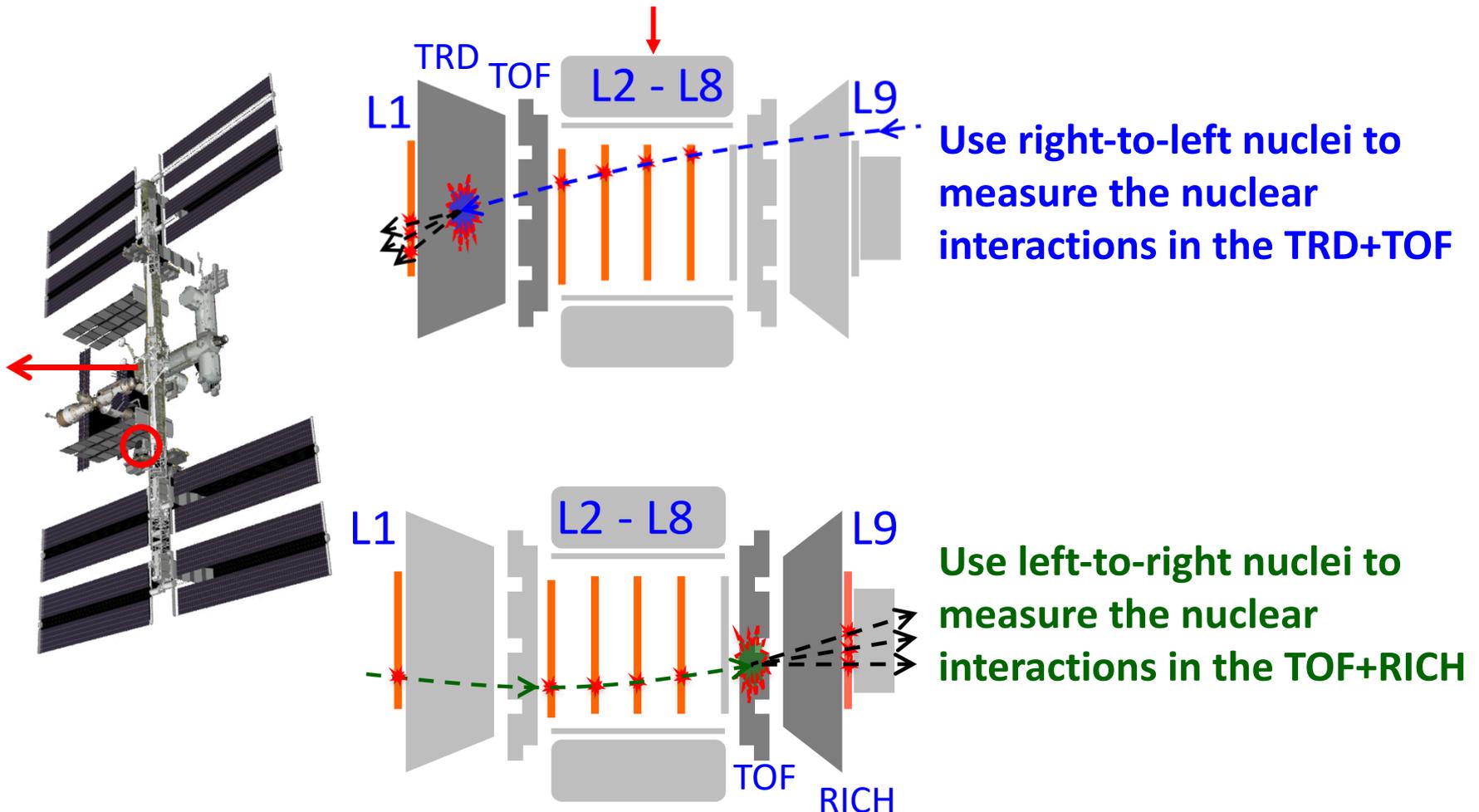
Precision Study of Cosmic Nuclei through the lifetime of ISS



Unique properties of AMS: determination of Nuclei Cross Section in the detector

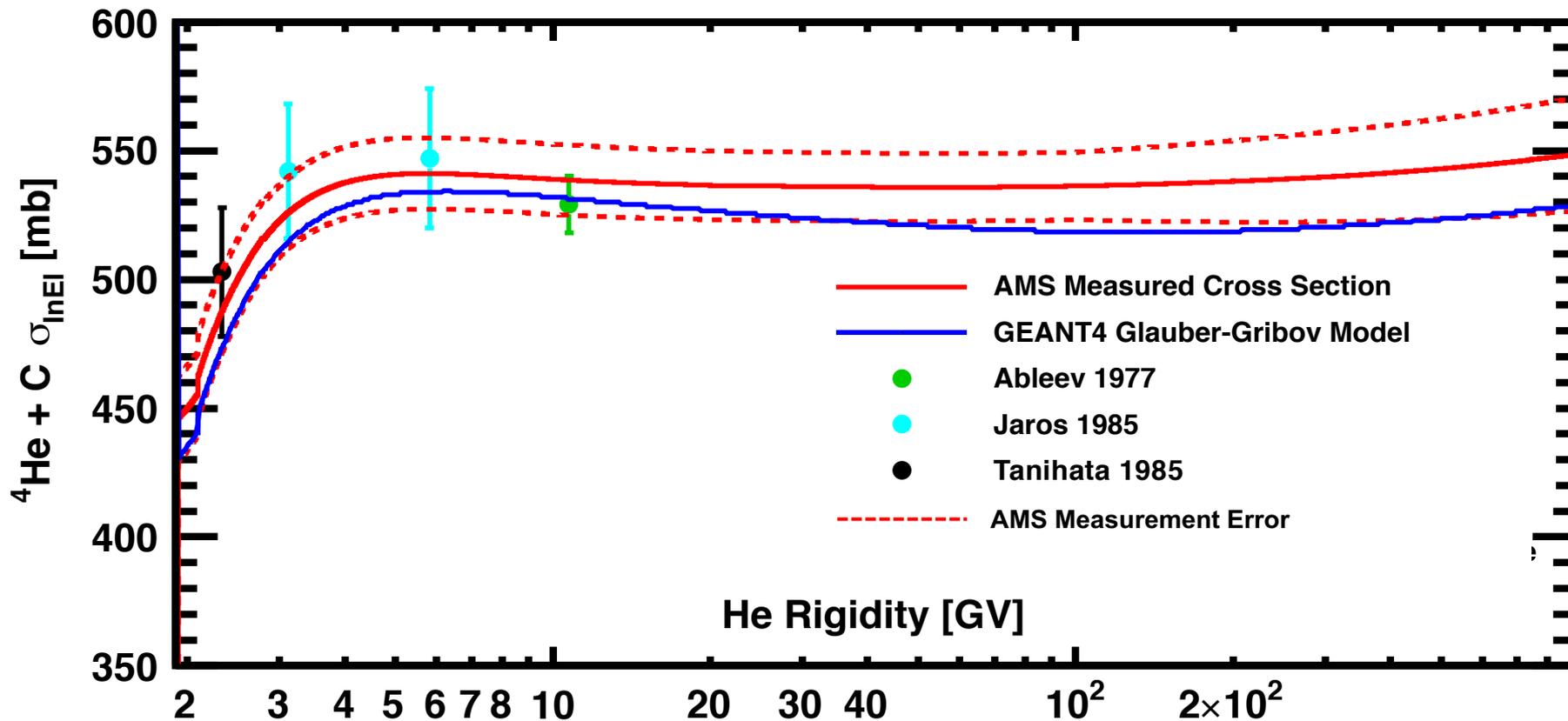
We measured the nuclei survival probability using data acquired when ISS attitude was rotated so that AMS was pointing in a horizontal direction.

Define beams of nuclei: He, C, O, ...



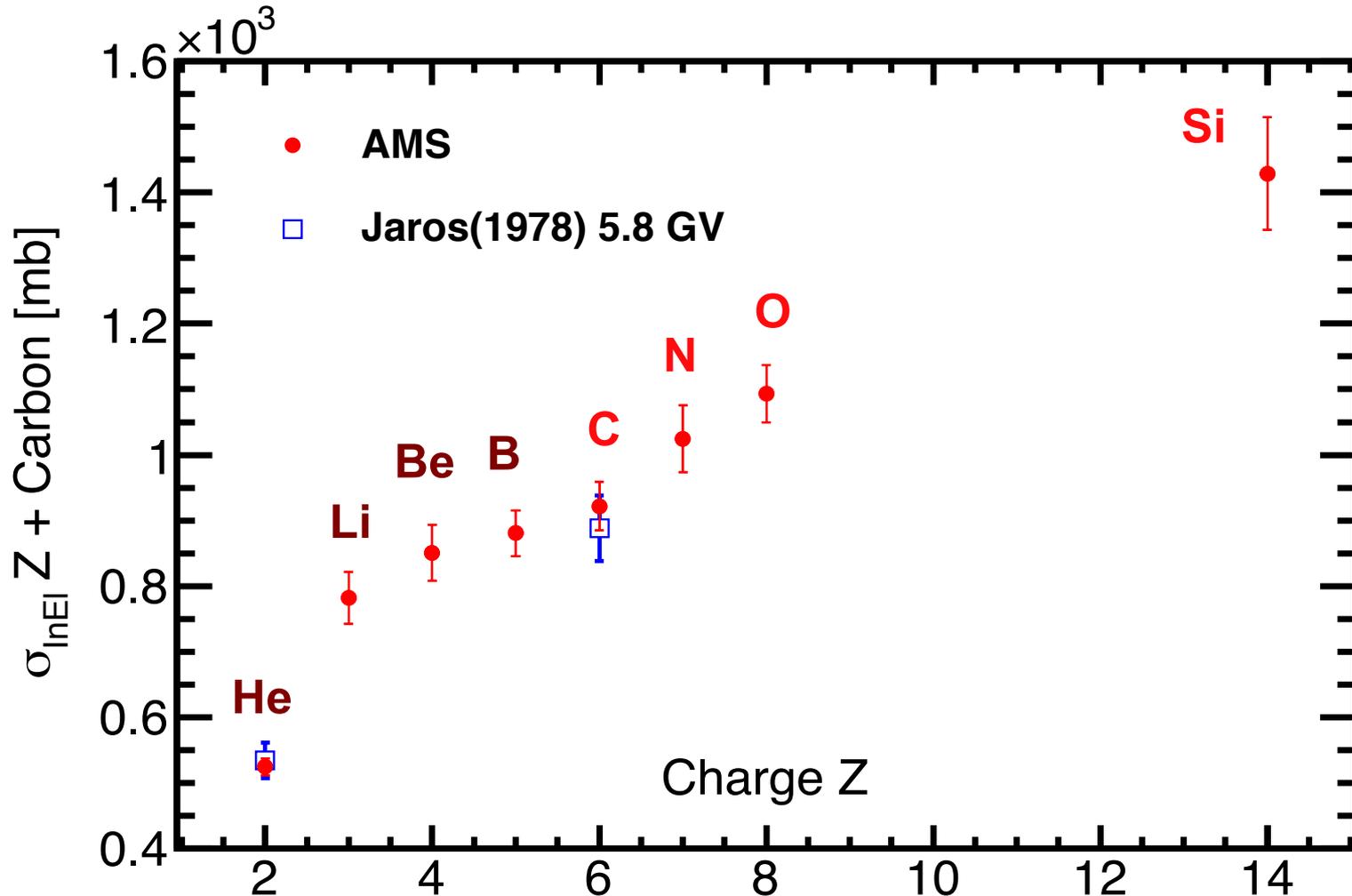
AMS He + C Inelastic Cross Section Measurement

AMS Materials C(73%) Al(20%)

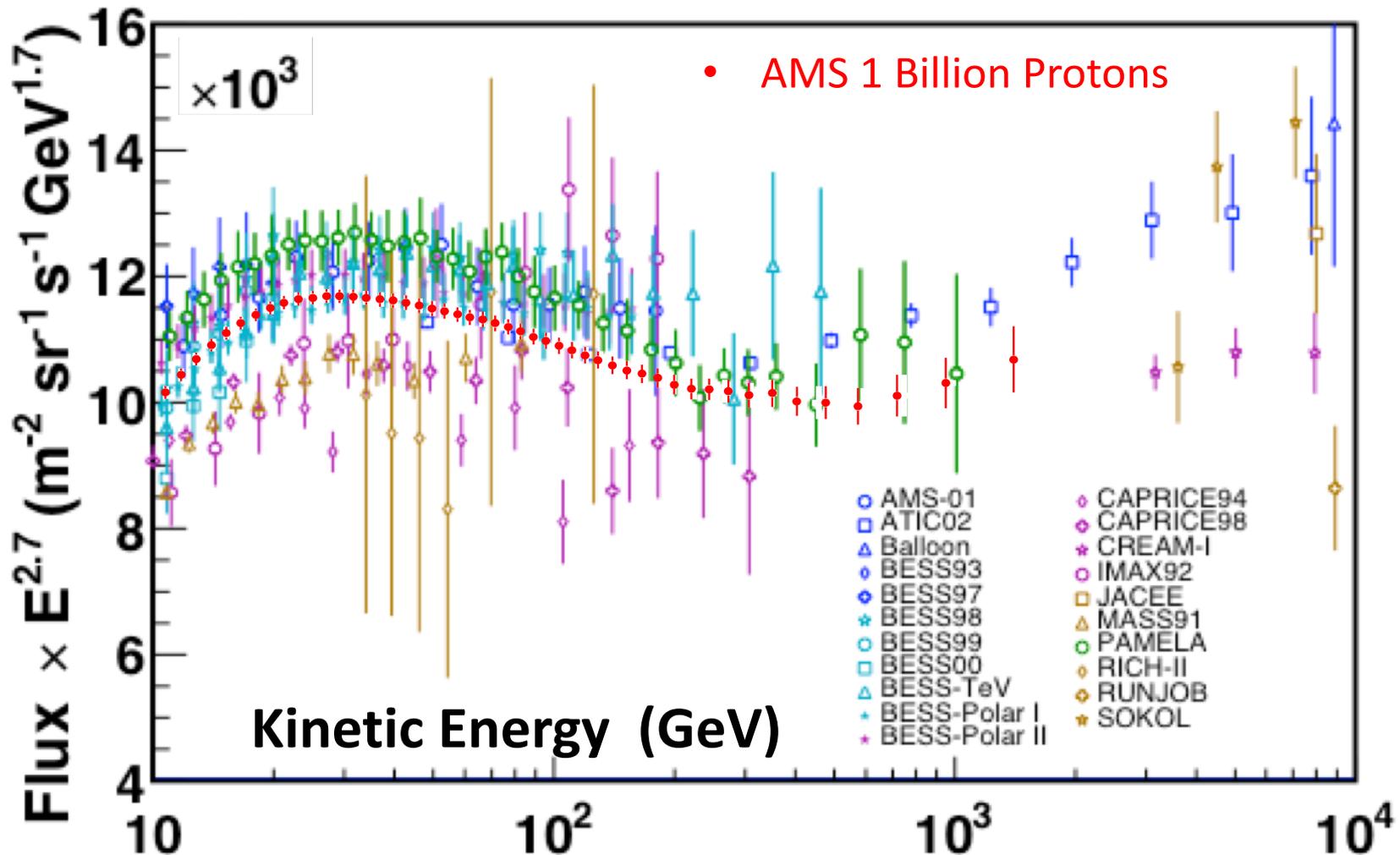


AMS Nuclei + C Inelastic Cross Section measurements average in 5-100 GV

not available from accelerators.

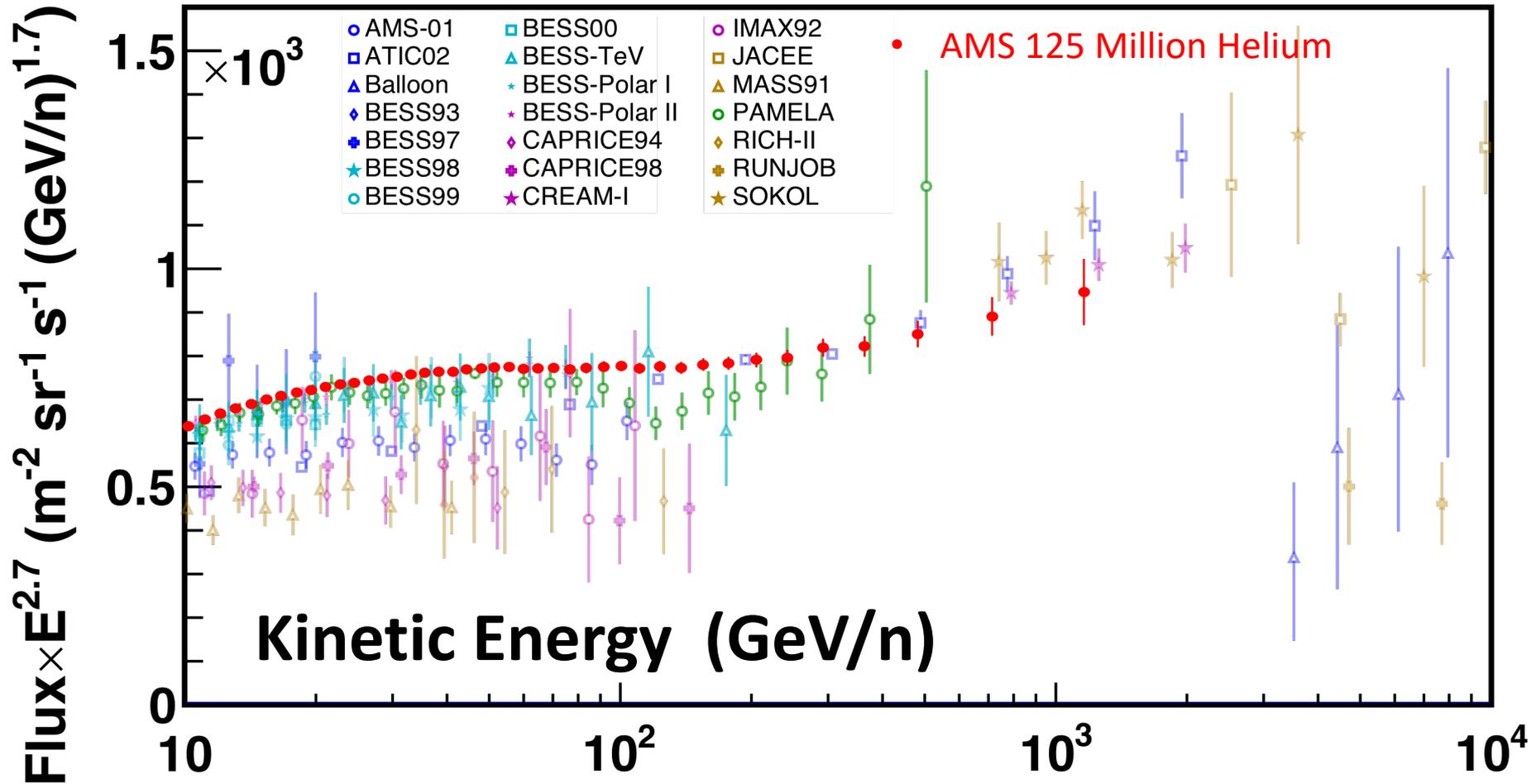


AMS results (2011-2018) on proton spectrum



refer to upcoming AMS publication

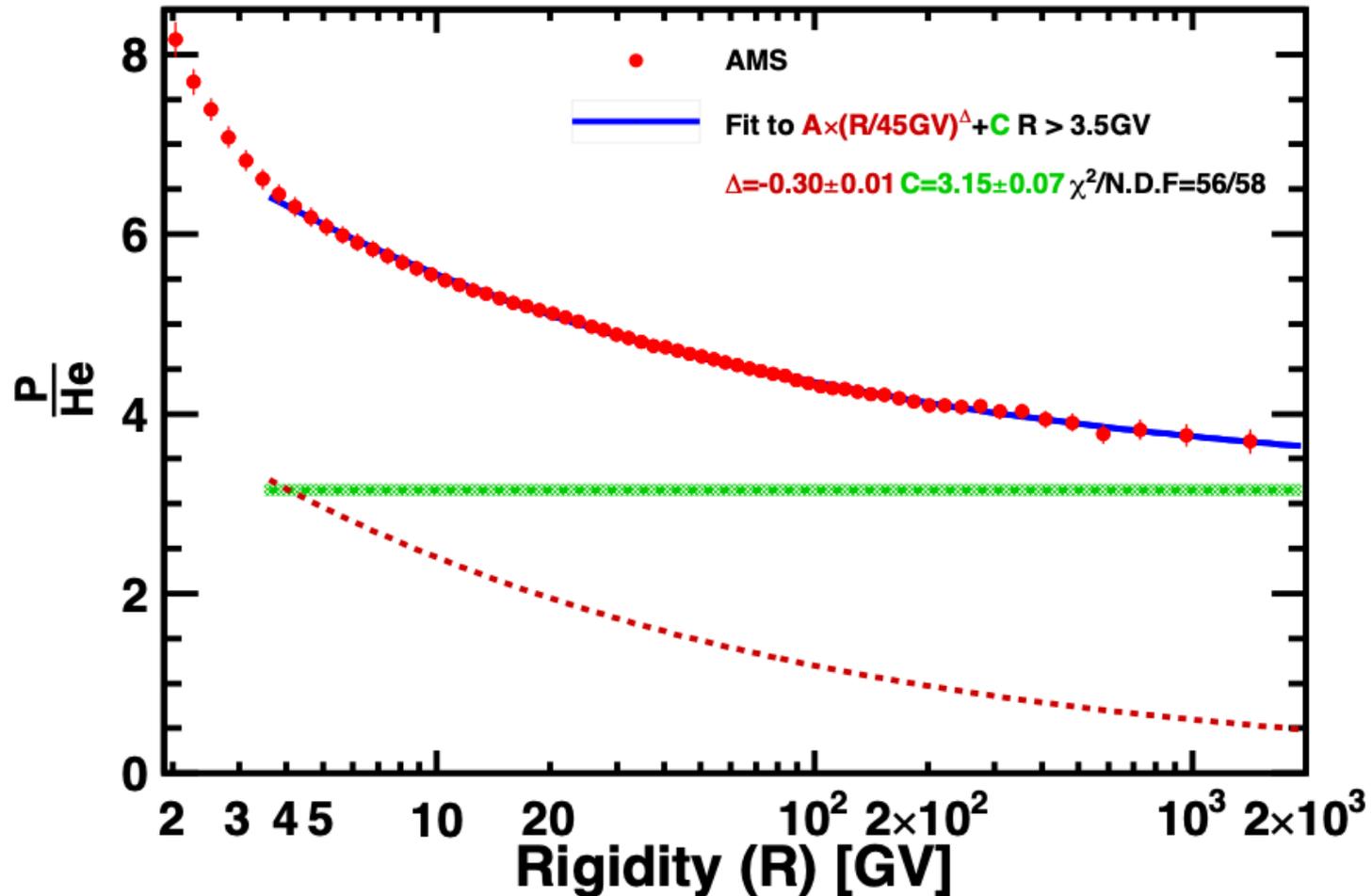
AMS results (2011-2018) on helium spectrum



refer to upcoming AMS publication

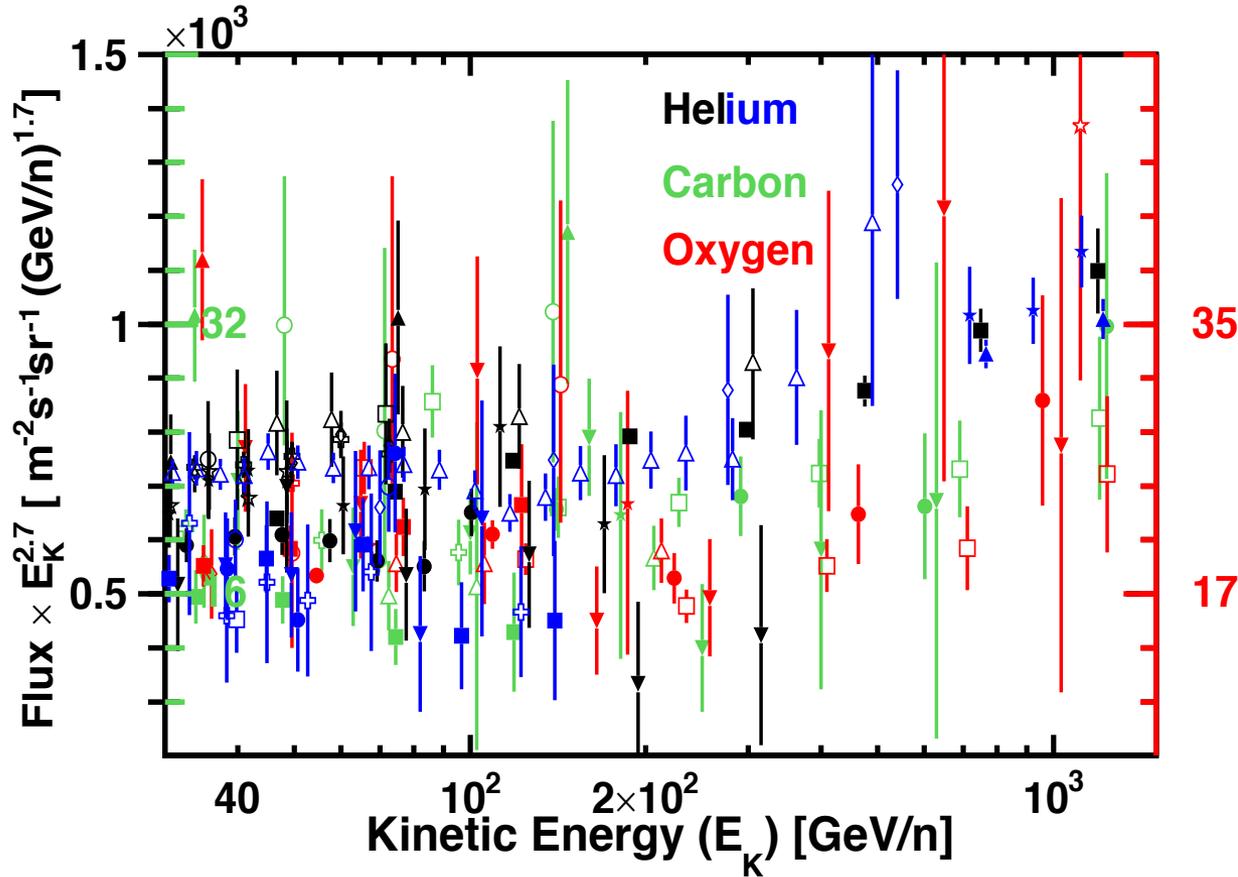
Latest AMS results (2011-2018) on p/He ratio

At high rigidities, p/He ratio approaches a constant (~3.15)
Rigidity dependence of proton and helium fluxes is becoming nearly identical



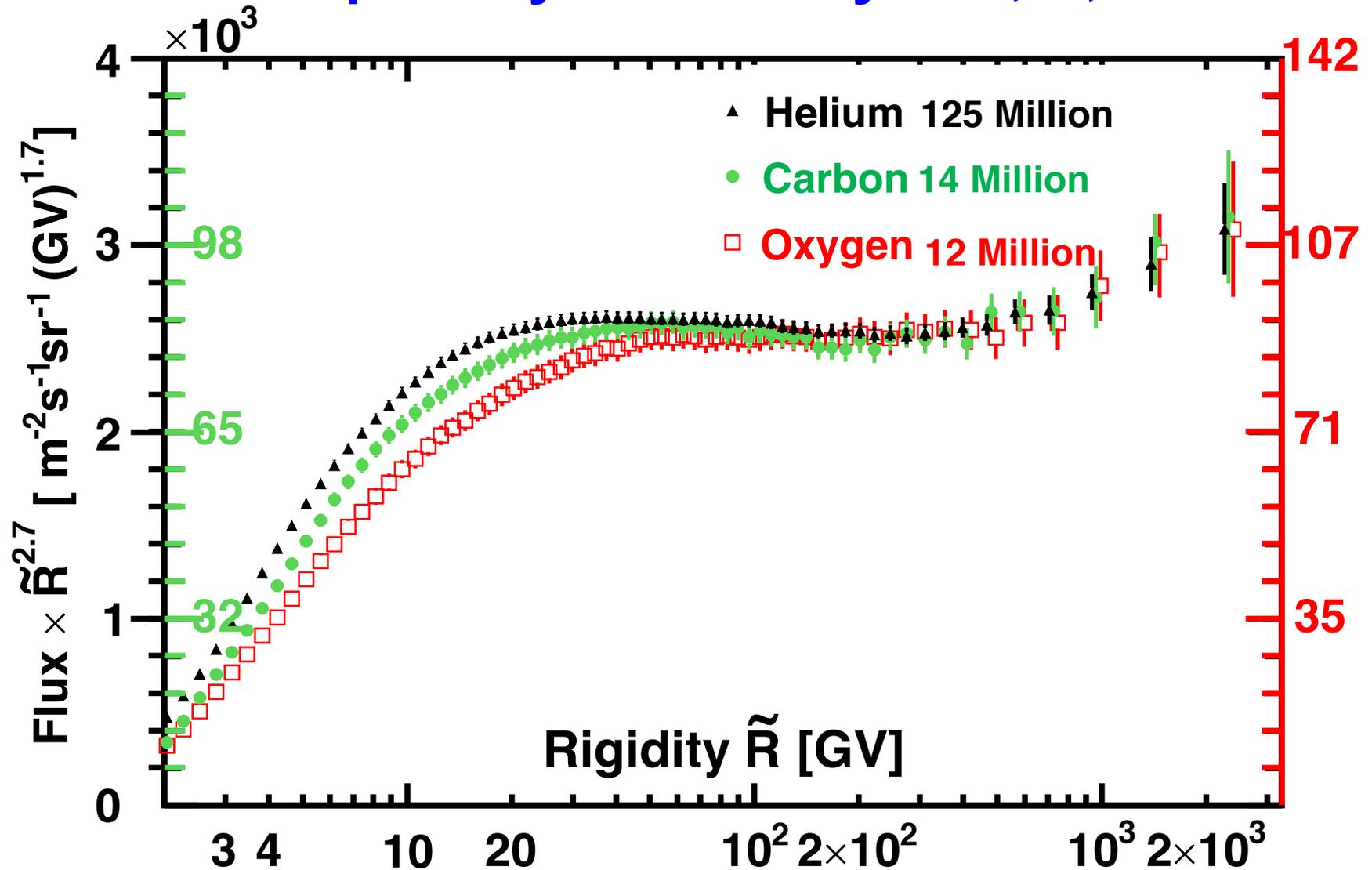
refer to upcoming AMS publication

Before AMS: Results on Primary Cosmic Rays (Helium, Carbon, Oxygen) from balloon and satellite experiments



- | | |
|---------------------------------|----------------------------------|
| ● AMS01(1998/06) | ● ATIC02(2003/01) |
| ■ ATIC02(2003/01) | ■ Balloon(1971/09+1972/10) |
| ▲ Balloon(1970/09+1971/05) | ▲ Balloon(1972/10) |
| ▼ Balloon(1970/11) | ▼ Balloon(1976/10) |
| ○ Balloon(1976/05) | ○ Balloon(1991/09) |
| □ Balloon(1979/06) | □ CREAM-II(2005/12-2006/01) |
| △ Balloon(1991/09) | △ CRN-Spacelab2(1985/07-1985/08) |
| ◇ BESS-PolarI(2004/12) | ◇ HEAO3-C2(1979/10-1980/06) |
| ⊕ BESS-PolarII(2007/12-2008/01) | ⊕ PAMELA(2006/07-2008/03) |
| ★ BESS-TeV(2002/08) | ★ TRACER06(2006/07) |
| ☆ BESS98(1998/07) | ● ATIC02(2003/01) |
| ● CAPRICE94(1994/08) | ■ Balloon(1971/09+1972/10) |
| ■ CAPRICE98(1998/05) | ▲ Balloon(1972/10) |
| ▲ CREAM-I(2004/12-2005/01) | ▼ Balloon(1976/10) |
| ▼ IMAX92(1992/07) | ○ Balloon(1991/09) |
| ○ LEAP(1987/08) | □ CREAM-II(2005/12-2006/01) |
| □ MASS91(1991/09) | △ CRN-Spacelab2(1985/07-1985/08) |
| △ PAMELA(2006/07-2008/12) | ◇ HEAO3-C2(1979/10-1980/06) |
| ◇ PAMELA-CALO(2006/06-2010/01) | ⊕ TRACER03(2003/12) |
| ⊕ RICH-II(1997/10) | ★ TRACER06(2006/07) |
| ★ SOKOL(1984/03-1986/01) | ☆ TRACER99 |

AMS results (2011-2018) on primary cosmic rays He, C, O

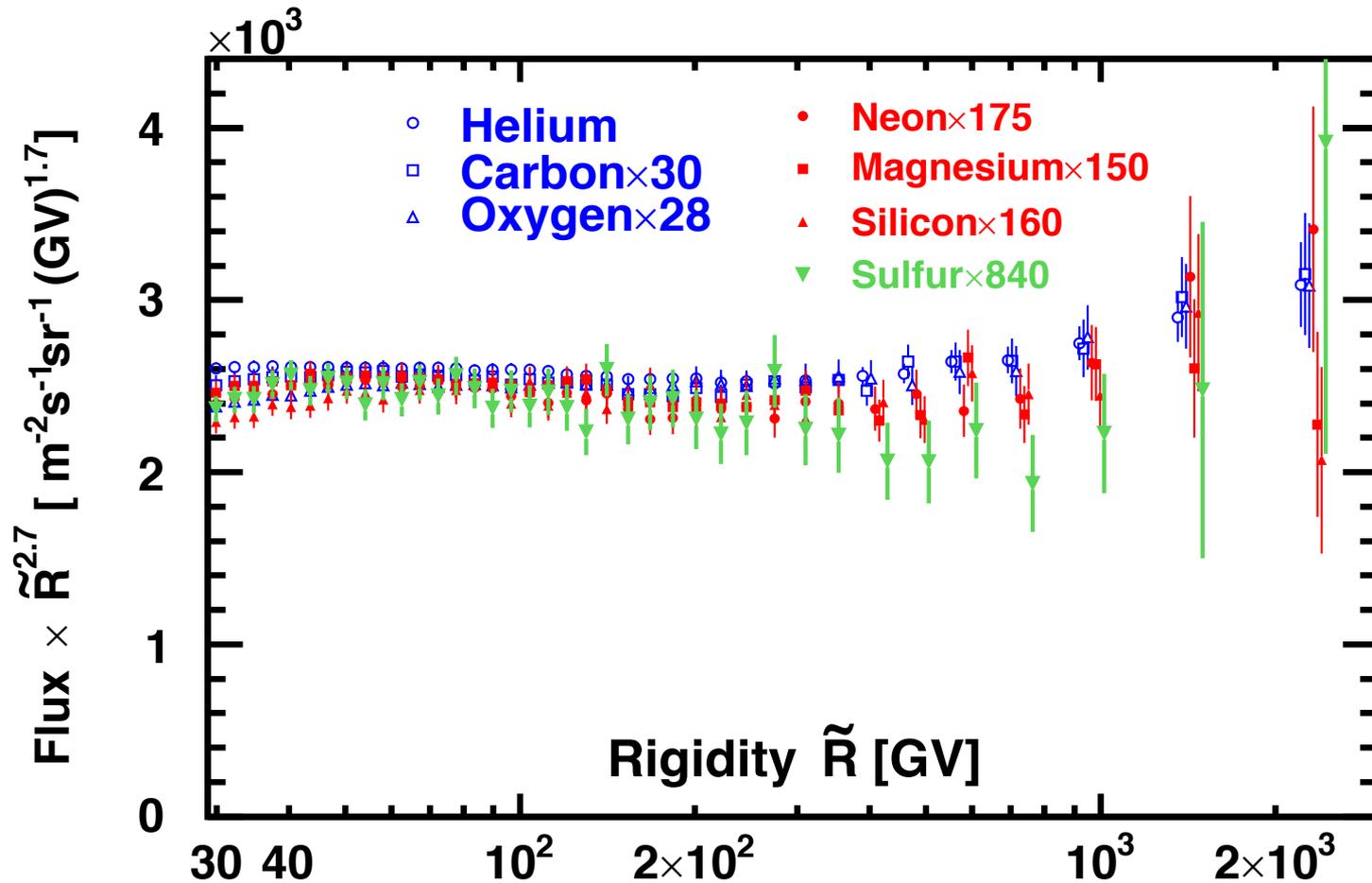


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Latest AMS results (2011-2018)

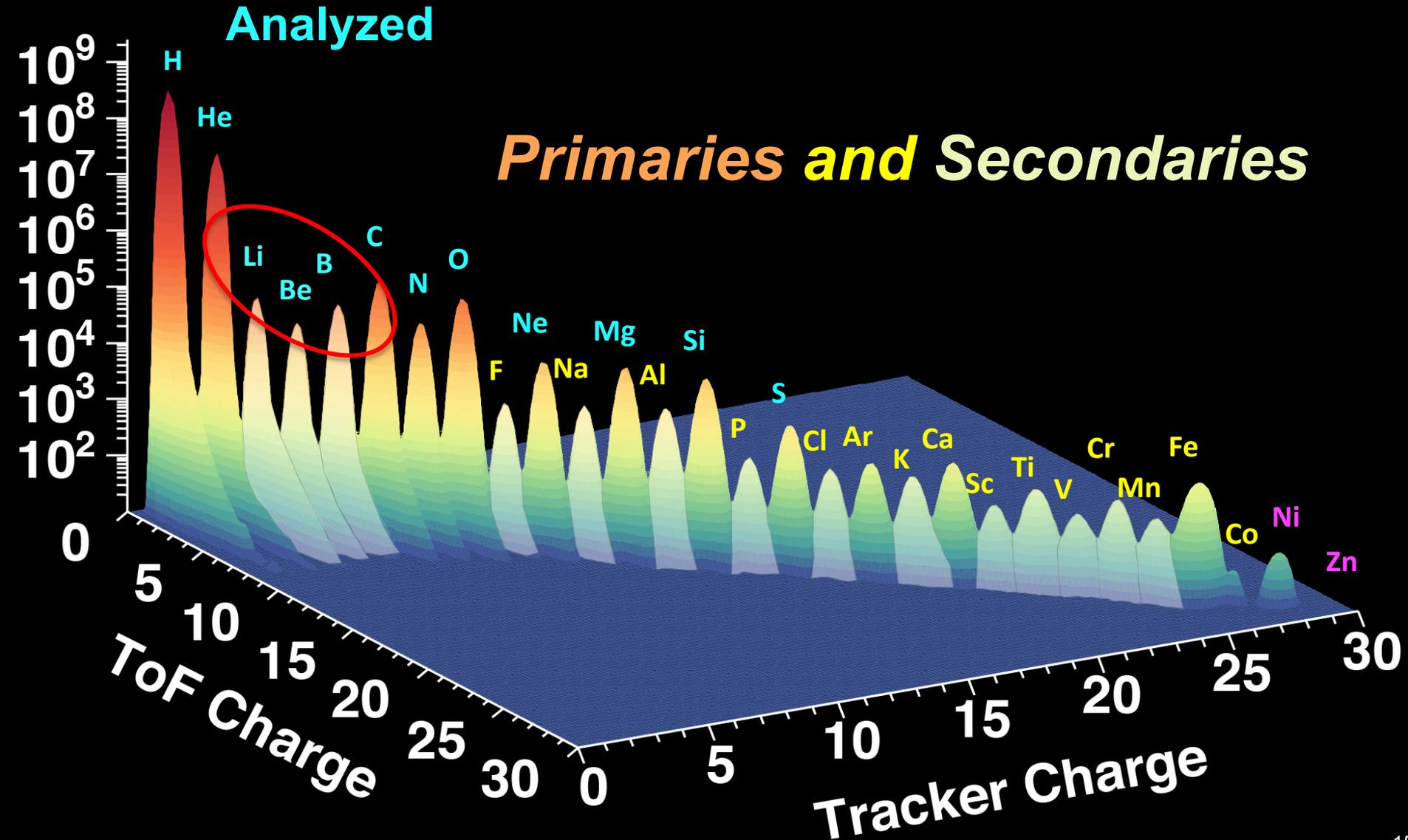
on primary cosmic rays He, C, O, Ne, Mg, Si, S

Above 60 GV, these fluxes have **similar** rigidity dependence.



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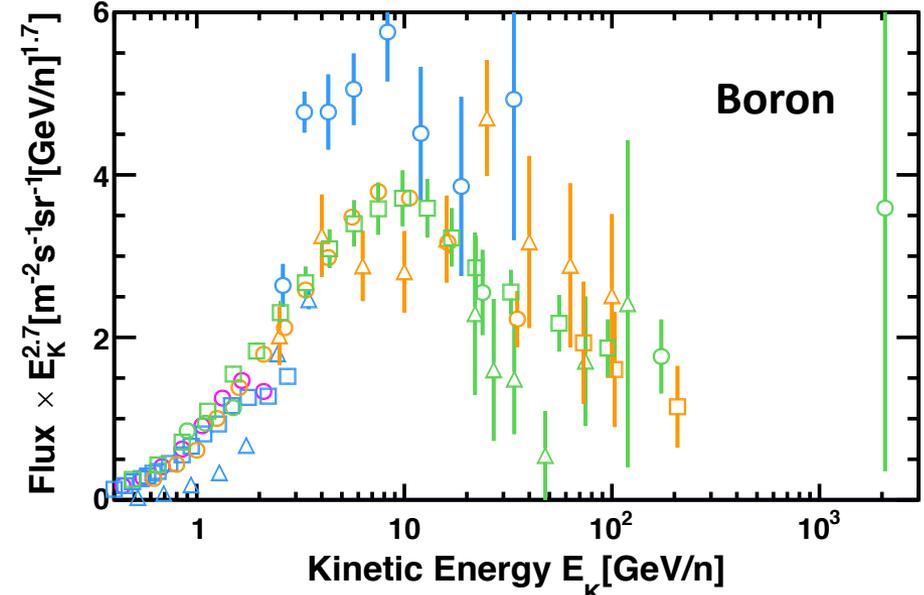
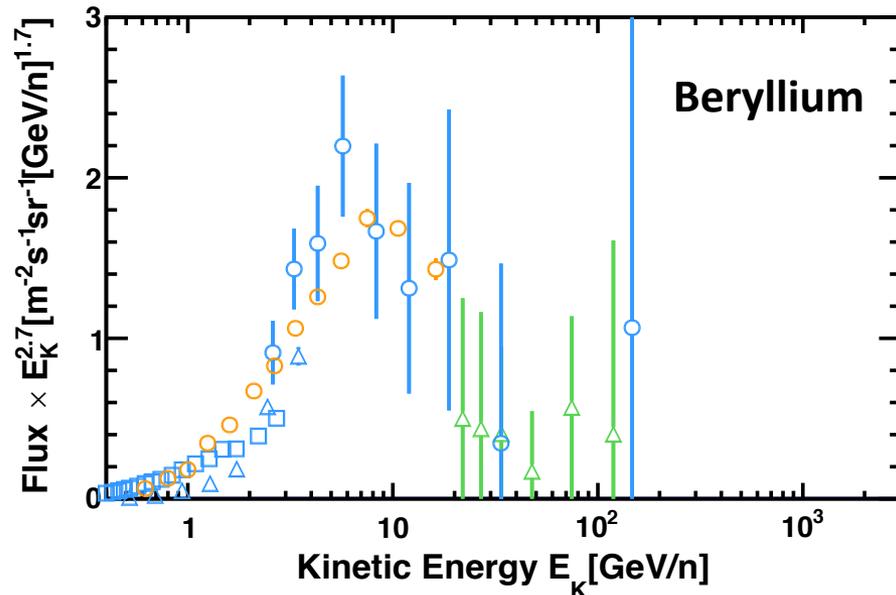
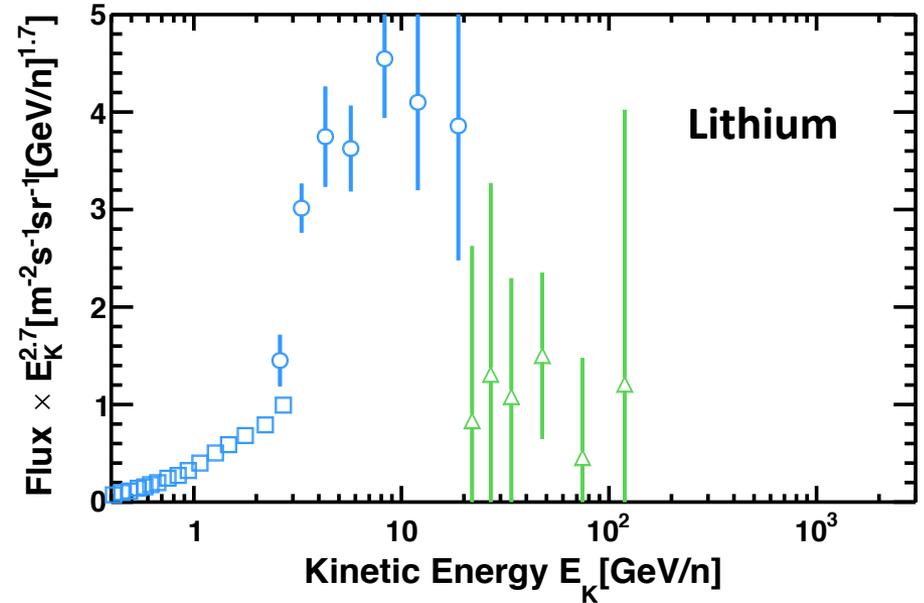
AMS Results on Secondary Cosmic Rays



Flux Measurements of Li, Be, B before AMS

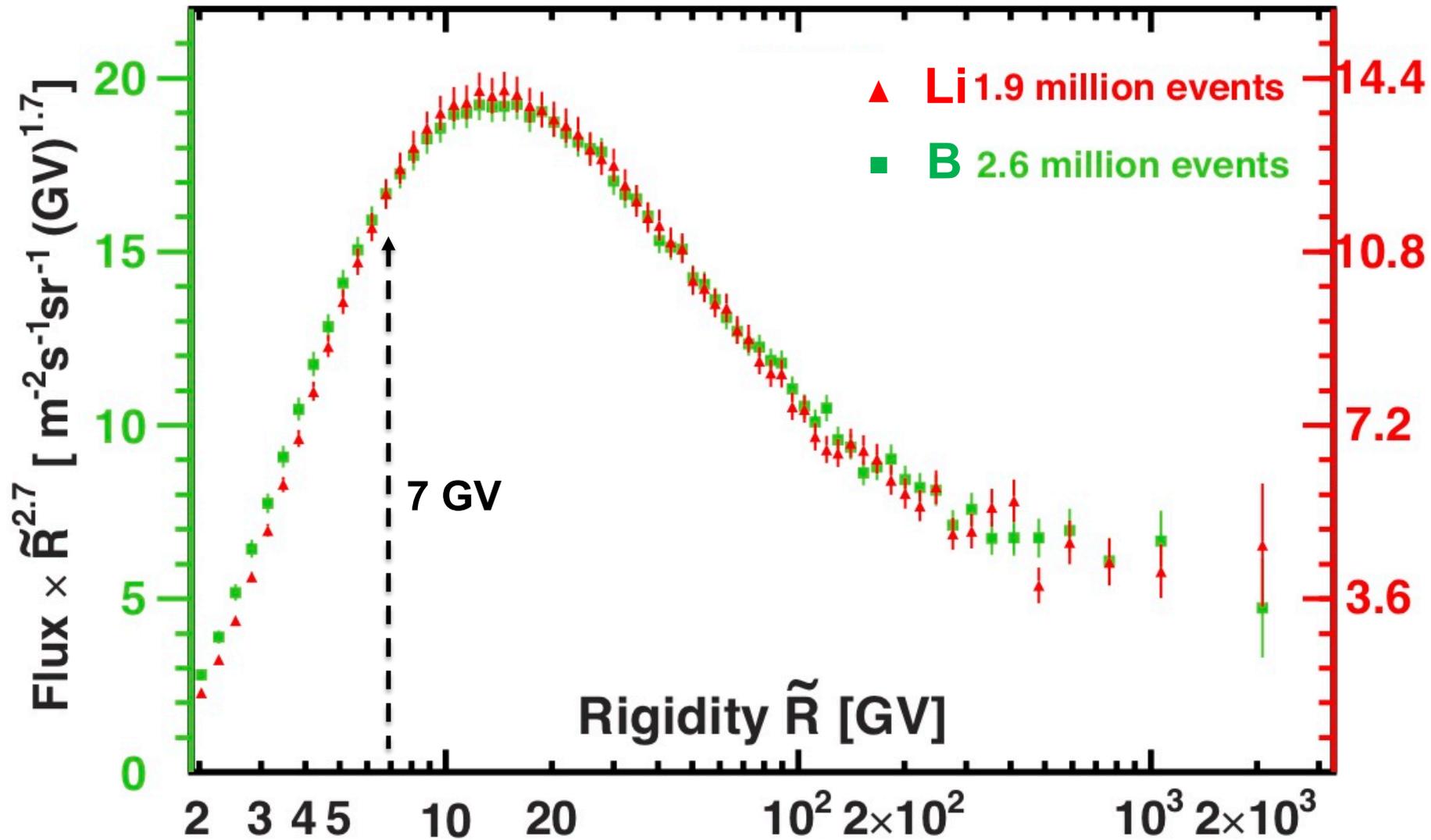
- TRACER
- PAMELA
- △ Juliusson
- Orth
- Webber
- △ Lezniak
- HEAO3
- CRN
- △ Simon
- Maehl

Typically, the error on each flux is larger than 50% at 100 GV



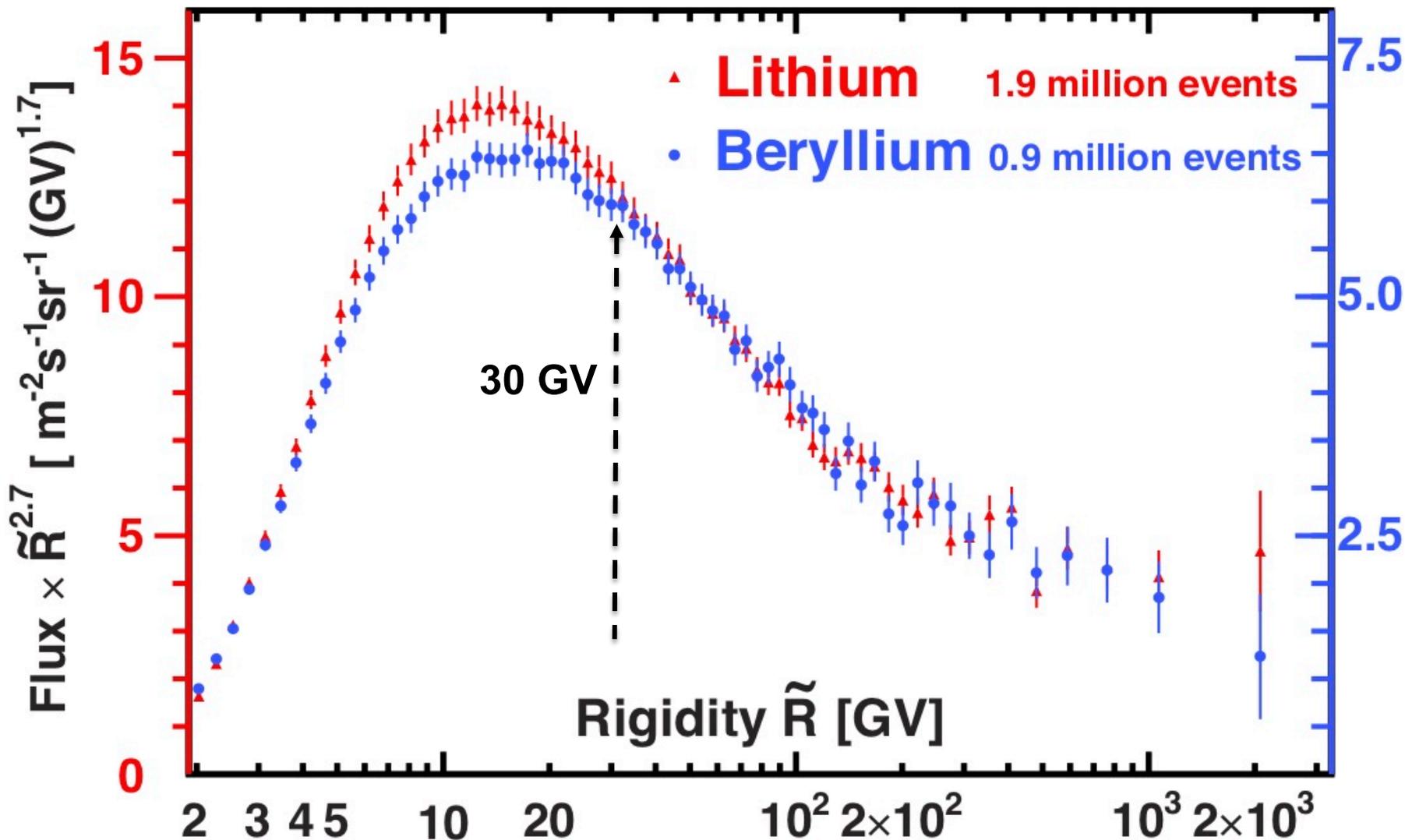
AMS Secondary Cosmic Rays: Lithium and Boron

Above 7 GV Li and B have identical rigidity dependence



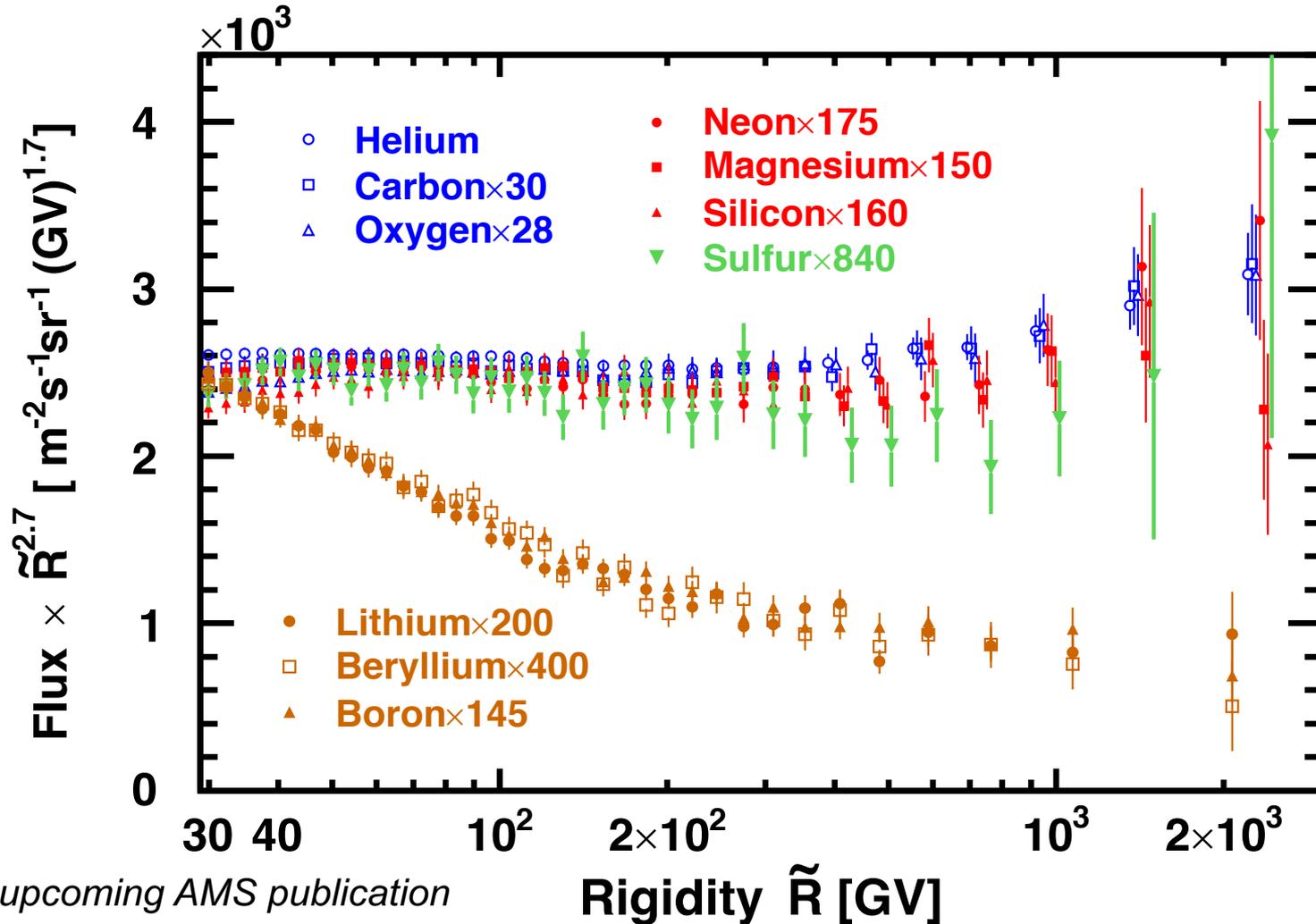
AMS Secondary Cosmic Rays: Lithium and Beryllium

Above 30 GV Li and Be have identical rigidity dependence.
The fluxes are different by a factor of 2.0 ± 0.1 .



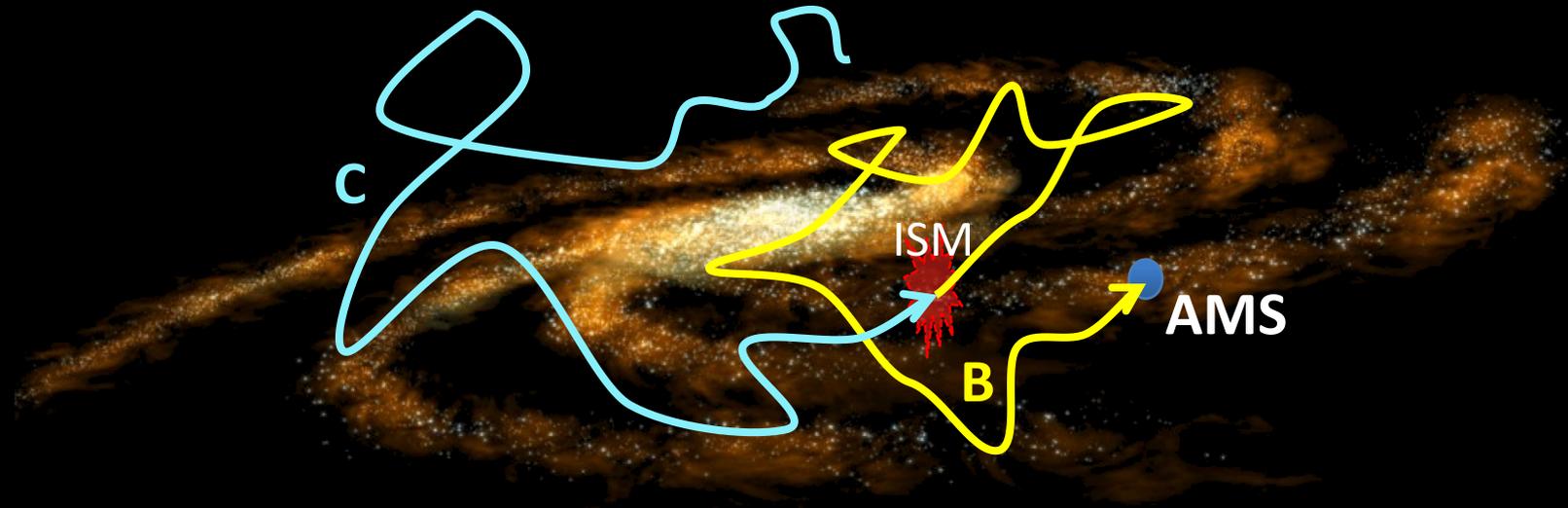
Rigidity dependence of Primary and Secondary Cosmic Rays

Both deviate from a single power law above 200 GV.
But their rigidity dependences are distinctly different.



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The flux ratio between primaries (**C**) and secondaries (**B**) provides information on propagation and on the Interstellar Medium

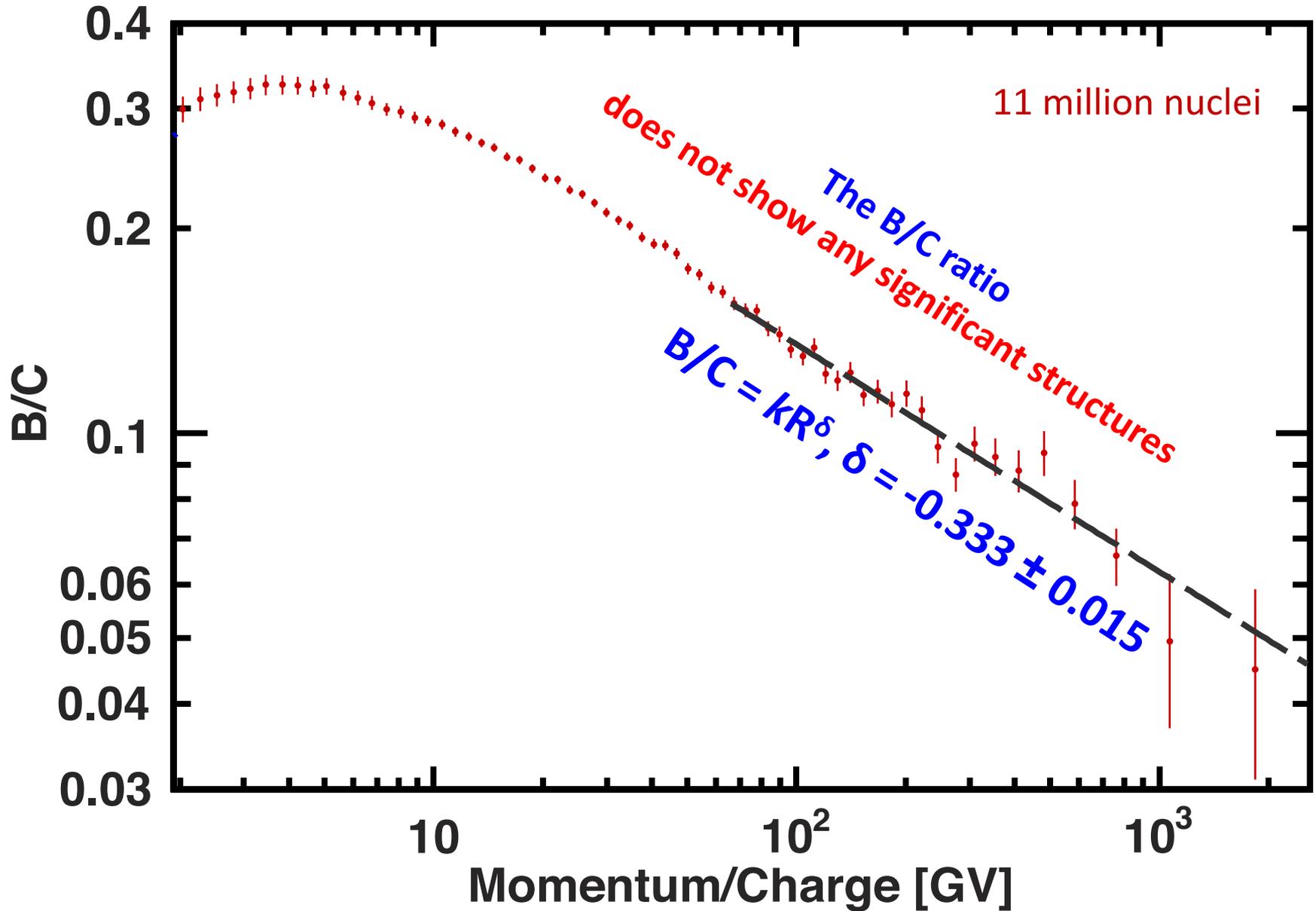


Cosmic ray propagation is commonly modeled as a fast moving gas diffusing through a magnetized plasma.

At high rigidities, models of the magnetized plasma predict different behavior for $B/C = kR^\delta$.

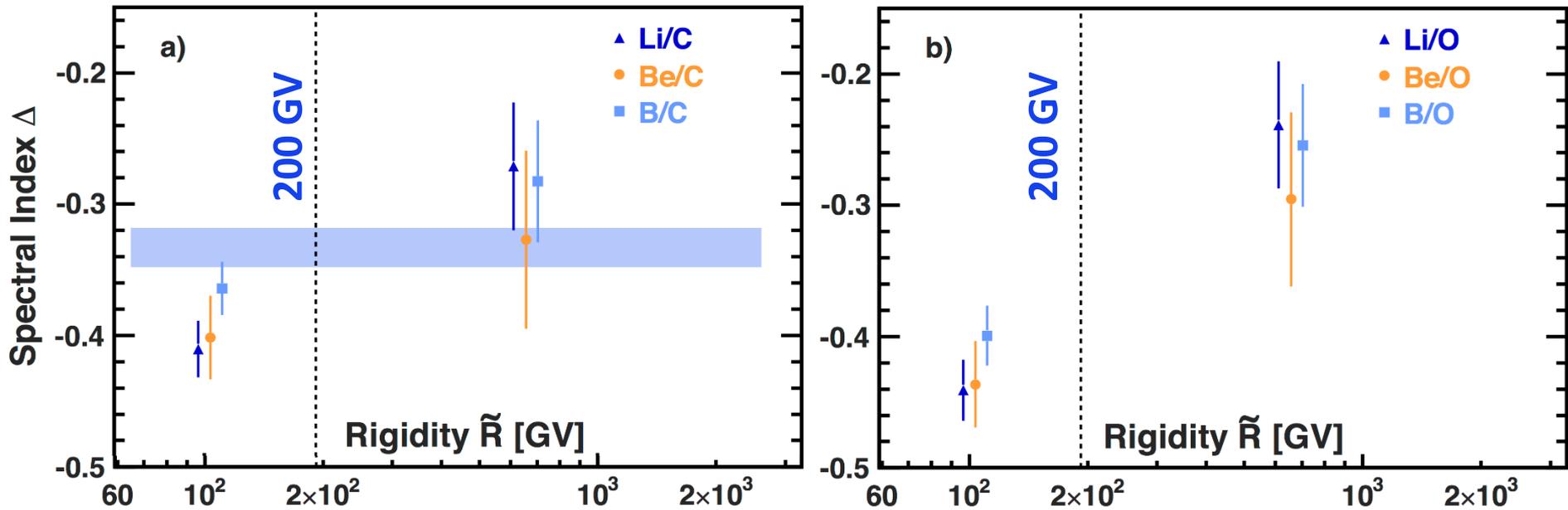
With the Kolmogorov turbulence model $\delta = -1/3$

The AMS Boron-to-Carbon (B/C) flux ratio



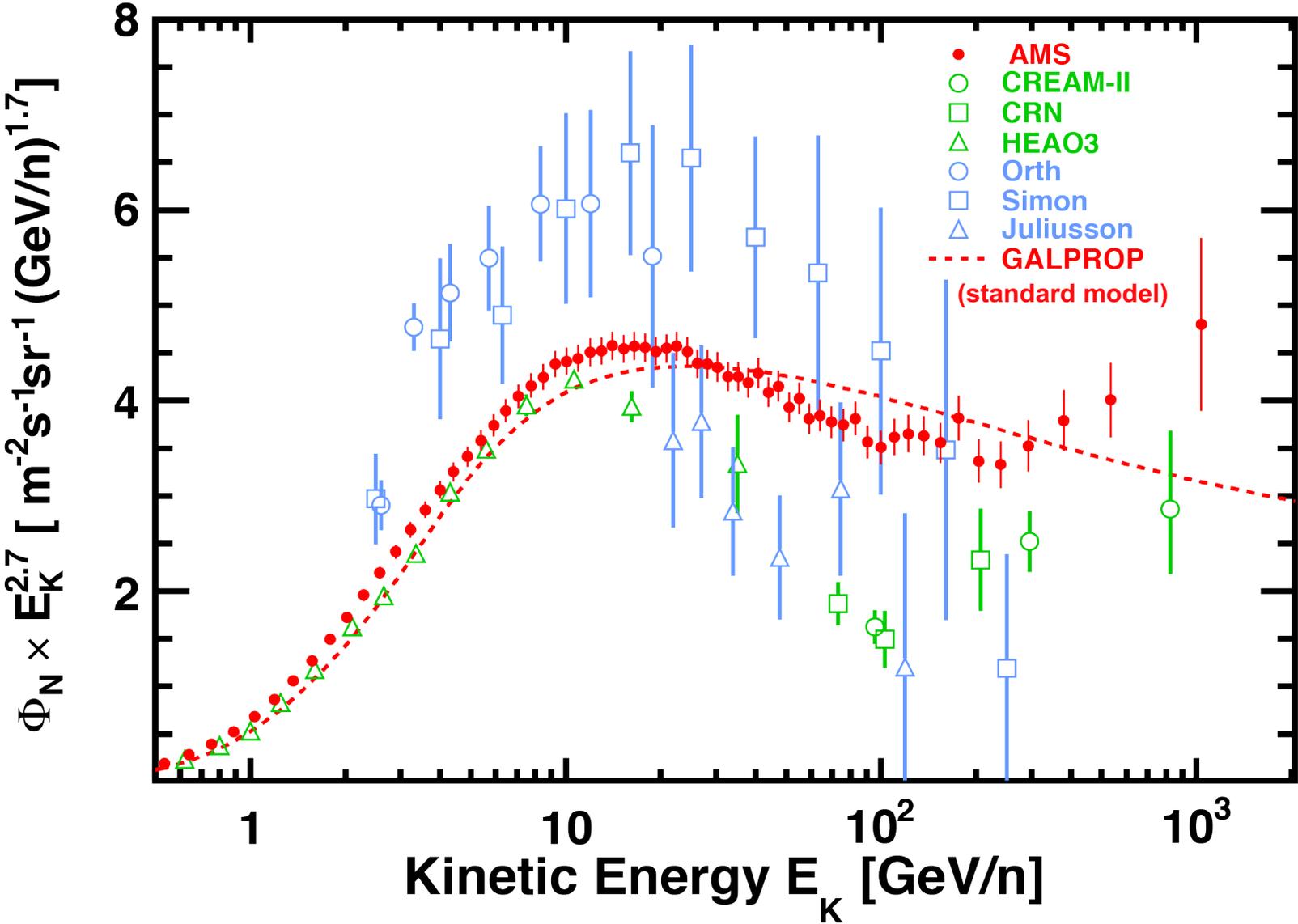
Secondary to Primary Flux Ratio Spectral Indices

$\Delta = d[\log(\Phi_S/\Phi_P)]/d[\log(R)]$ is not a constant

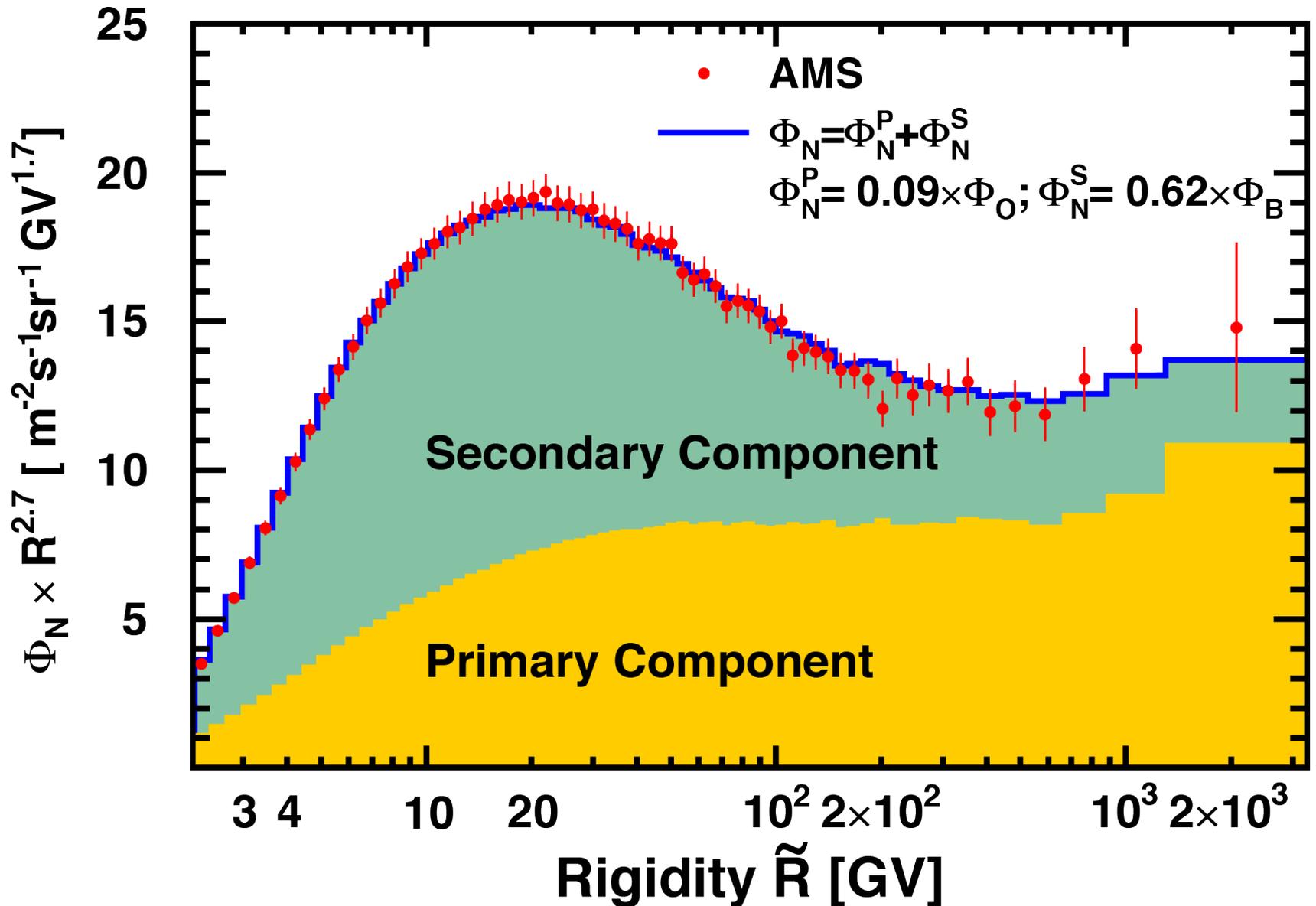


Combining the six ratios, the secondary over primary flux ratio (B/C, ...) deviates from single power law above 200 GV by 0.13 ± 0.03

The AMS nitrogen flux compared with earlier measurements

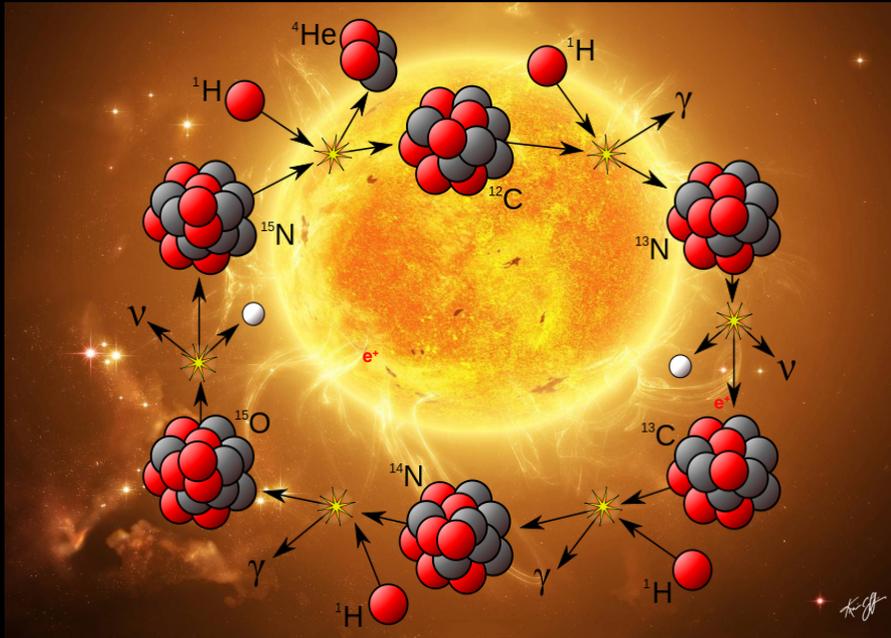


The Nitrogen flux Φ_N is composed of a Primary flux Φ_N^P and a Secondary flux Φ_N^S

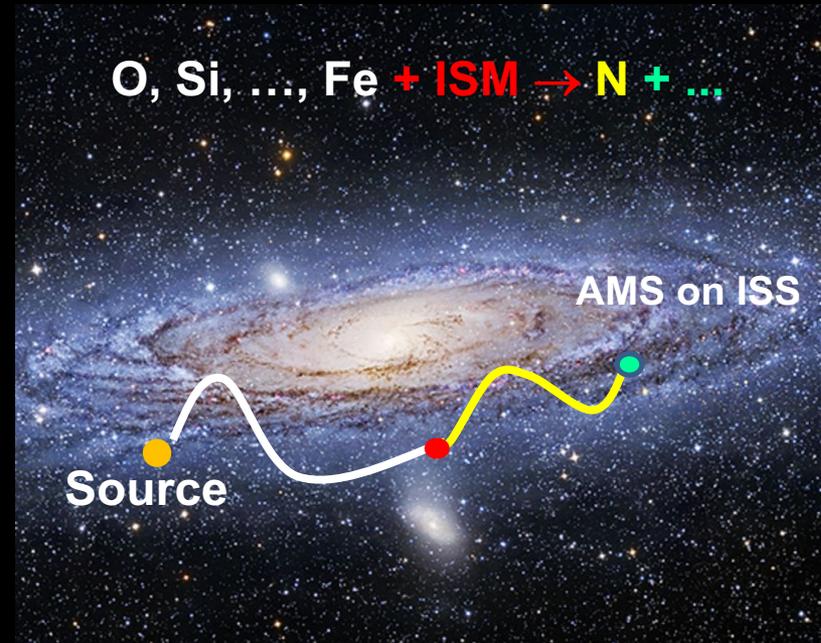


Nitrogen nuclei in cosmic rays: both primary and secondary

Astrophysical sources,
mostly via the CNO cycle



Collisions of heavier nuclei
with the interstellar medium



In the Solar System:

$$\text{N/O} \approx 0.14^{+0.05}_{-0.04}$$

$$\text{C/O} \approx 0.46^{+0.09}_{-0.08}$$

AMS measurement in the Galaxy

(primary component)

$$\text{N/O} = 0.090 \pm 0.002$$

$$\text{C/O} = 0.91 \pm 0.02$$

Conclusions and Outlook

- AMS **precision** measurements of cosmic ray nuclei up to **multi-TeV energies** are challenging our understanding of cosmic ray physics.
- Latest AMS results show proton and helium fluxes become nearly identical at high rigidities. **Identical rigidity dependences** are observed for both primary cosmic rays (He, C, O, Ne, Mg, Si, S) and secondary cosmic rays (Li, Be, B). But they are distinctly different from each other.
- The AMS results on cosmic-ray fluxes do not follow the traditional single power law. **They all have a break at ~200 GV.**
- AMS will **continue taking data** for the lifetime of the International Space Station (beyond 2024). Measurements of heavier species enable us to explore a new region in cosmic rays.

Back up