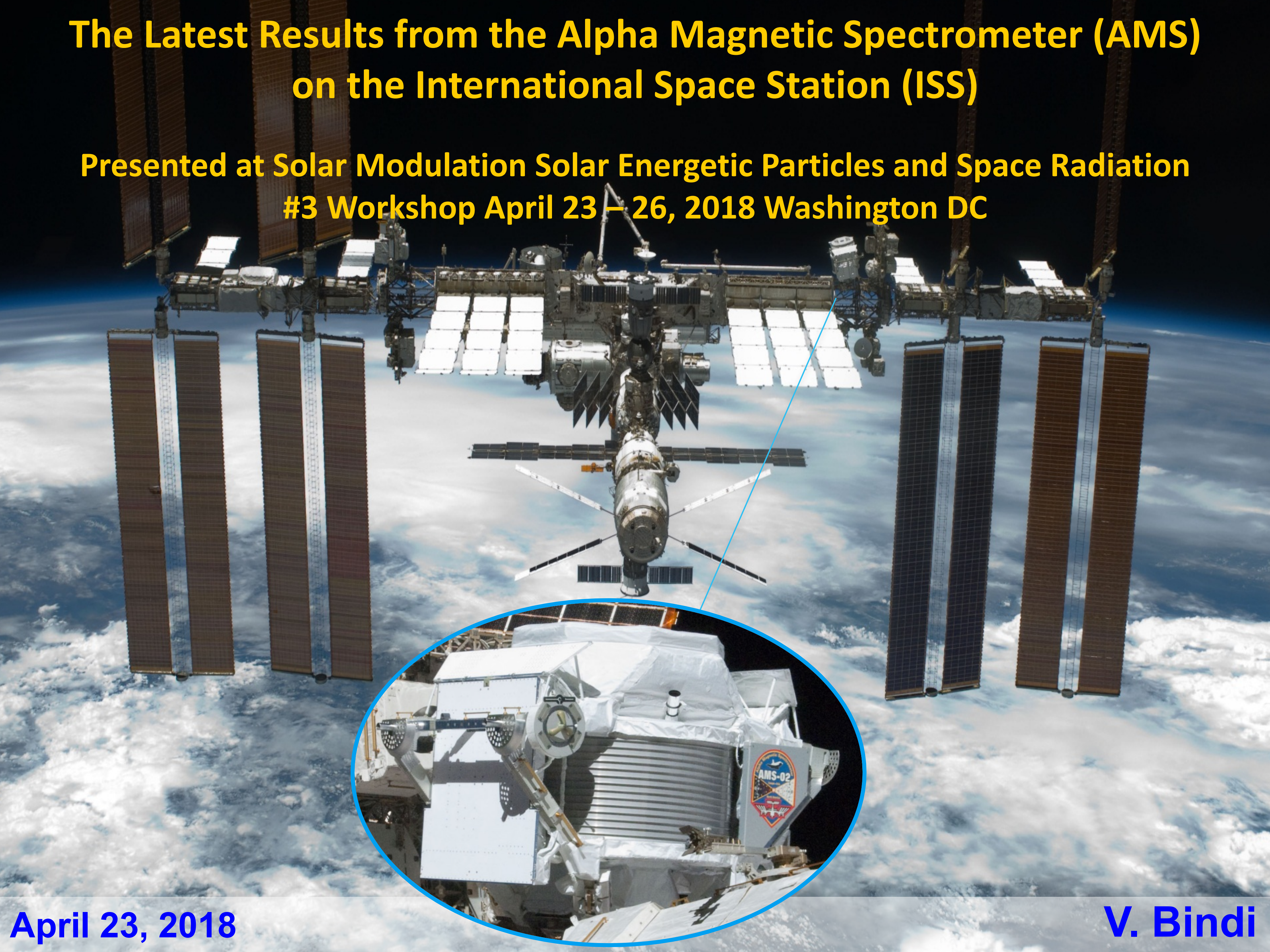


The Latest Results from the Alpha Magnetic Spectrometer (AMS) on the International Space Station (ISS)

Presented at Solar Modulation Solar Energetic Particles and Space Radiation #3 Workshop April 23 – 26, 2018 Washington DC

April 23, 2018

V. Bindi

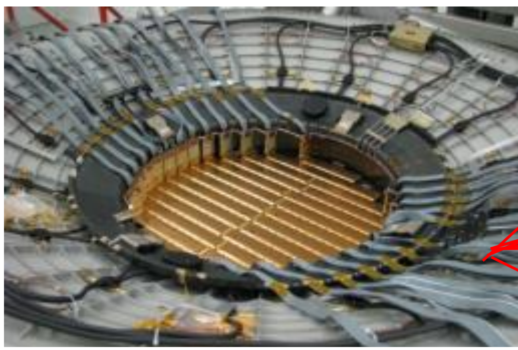
5m x 4m x 3m
7.5 tons

AMS: a unique TeV precision, accelerator-type spectrometer in space

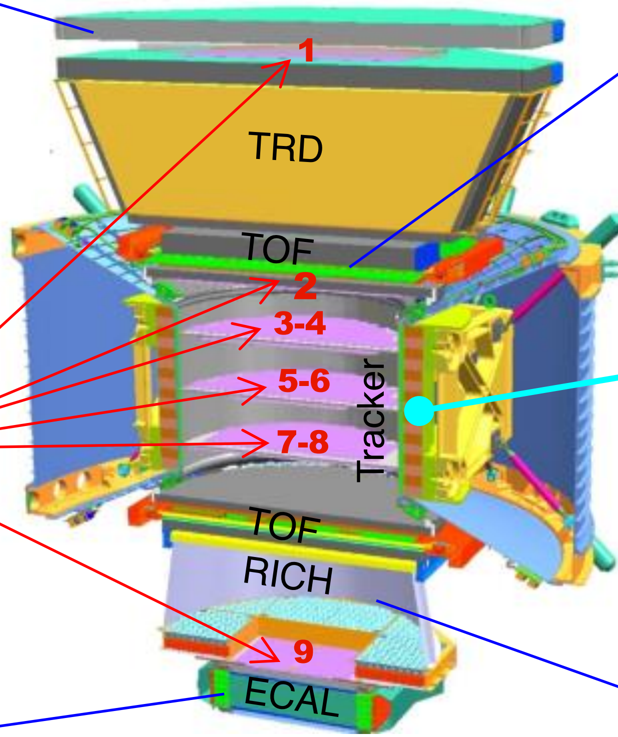
Particles and nuclei are defined by their charge (Z) and energy (E) or momentum (P). Rigidity R = P/Z

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

Silicon Tracker: Z, P

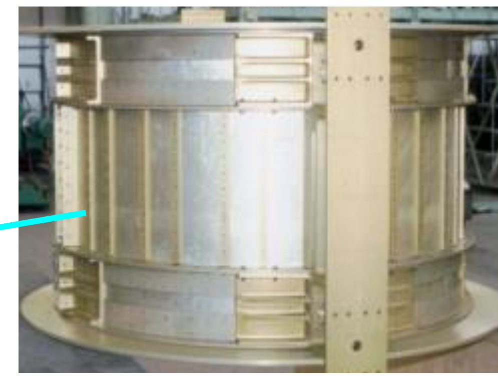


ECAL: E of e^+, e^-



TOF: Z, E

Magnet: ±Z

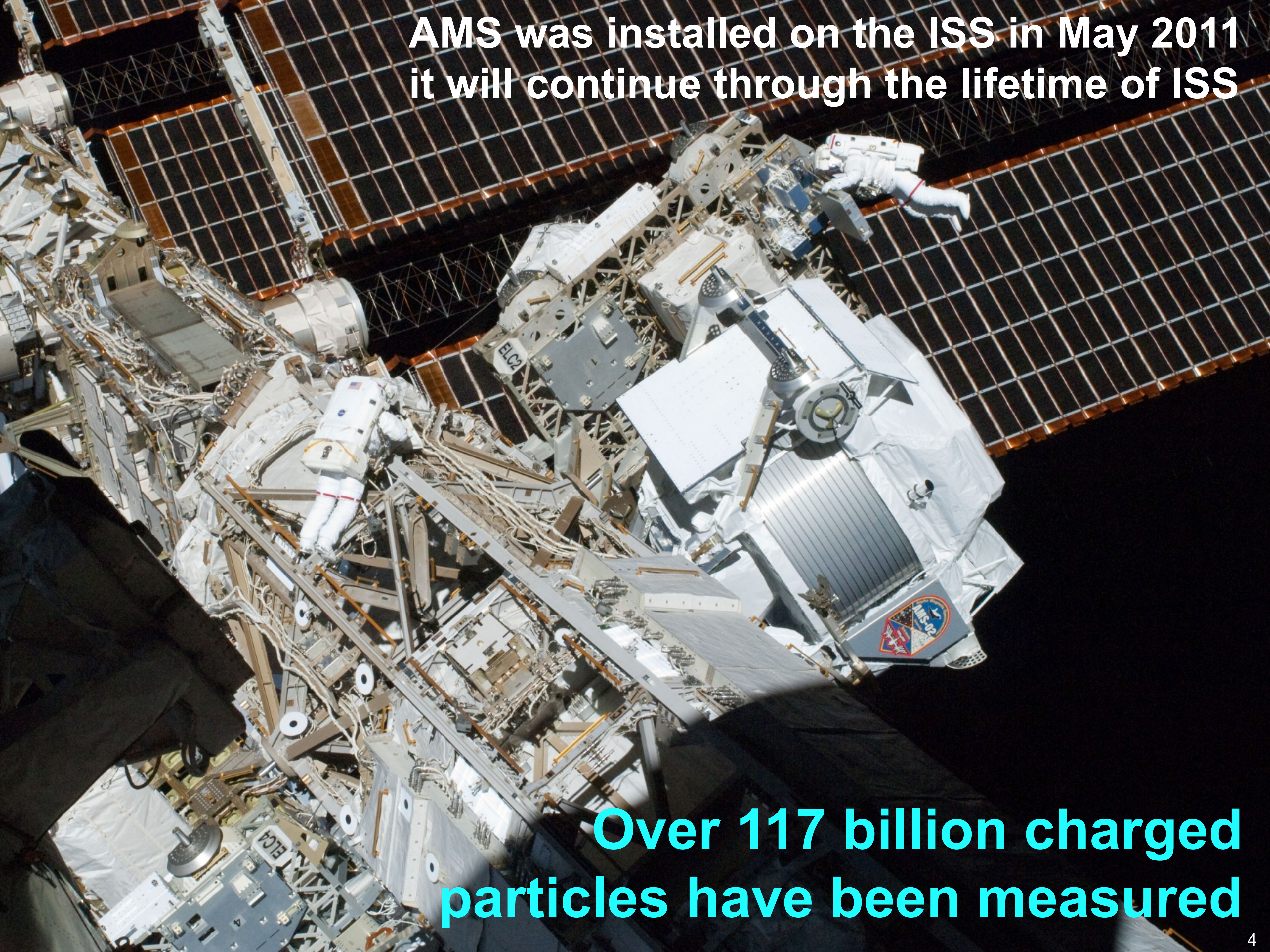


RICH: Z, E

Z and P

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

AMS was installed on the ISS in May 2011
it will continue through the lifetime of ISS

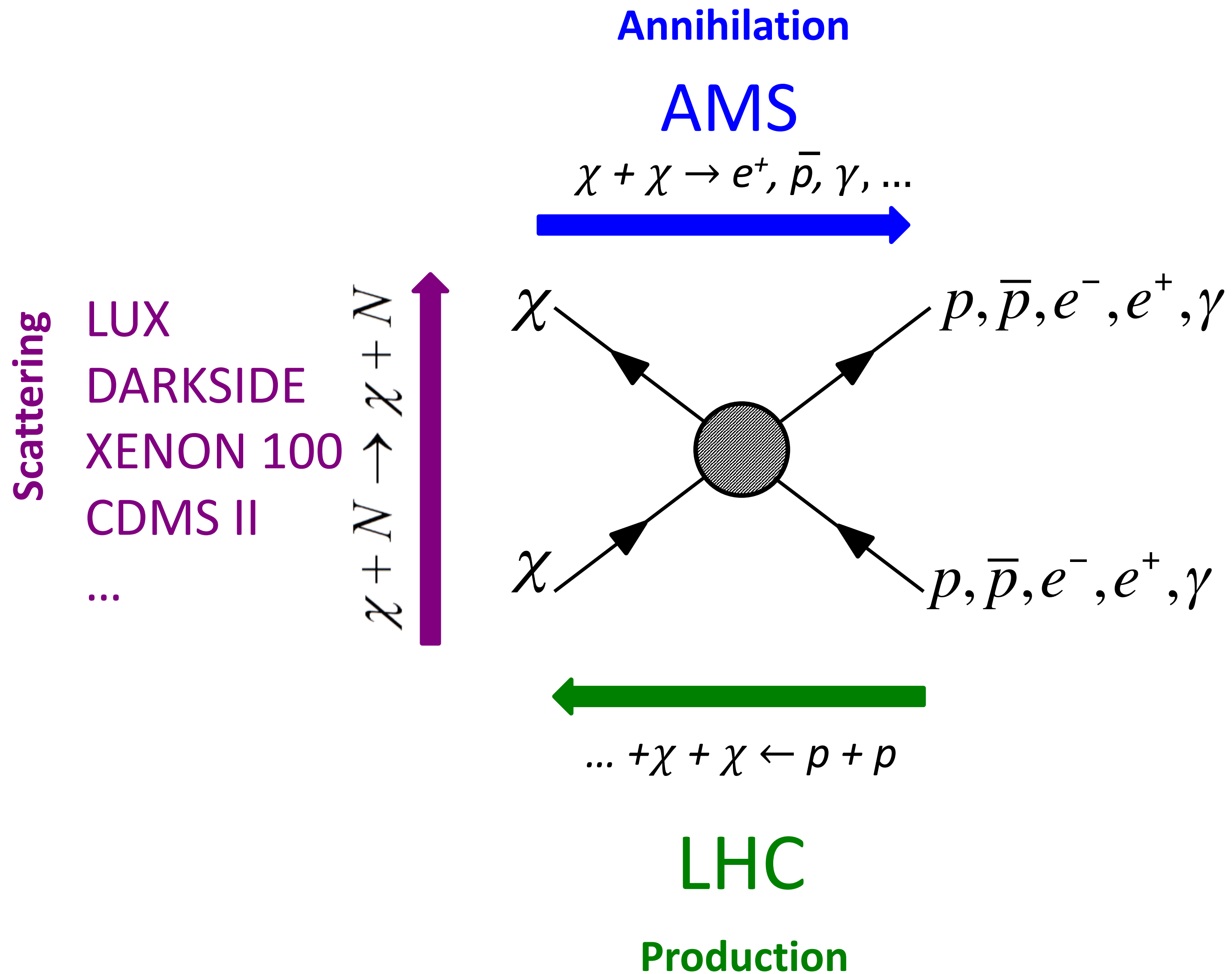


Over 117 billion charged particles have been measured

AMS goals

Look for dark matter in space
New forms of matter
Studies galactic cosmic rays

Three complimentary methods are being used to search for dark matter

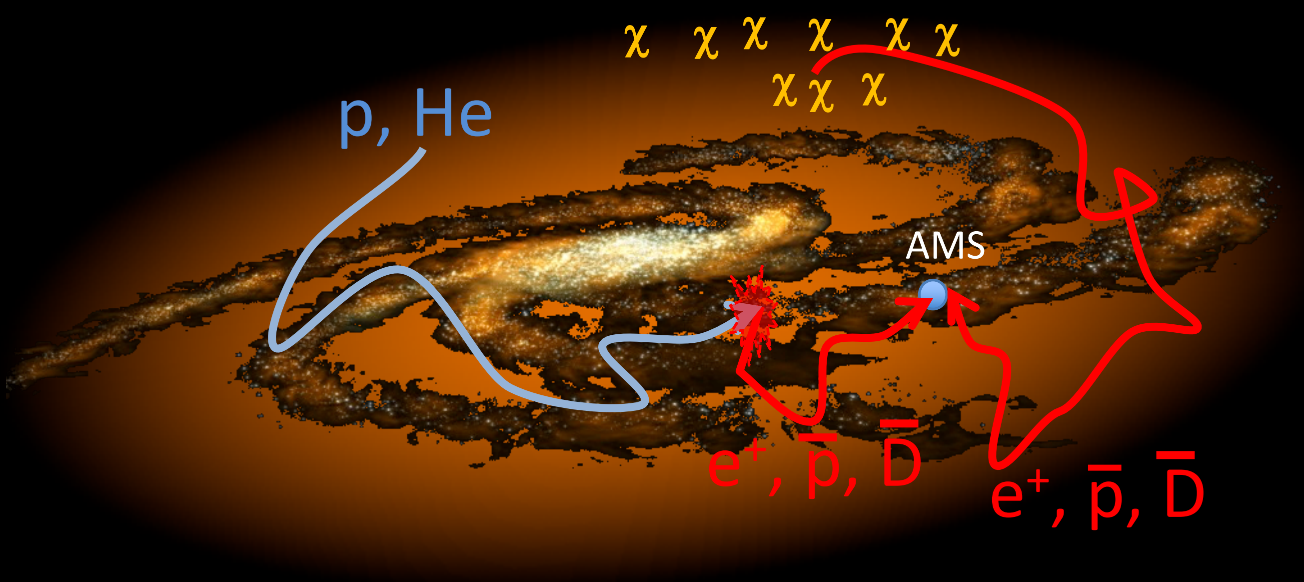


Dark Matter

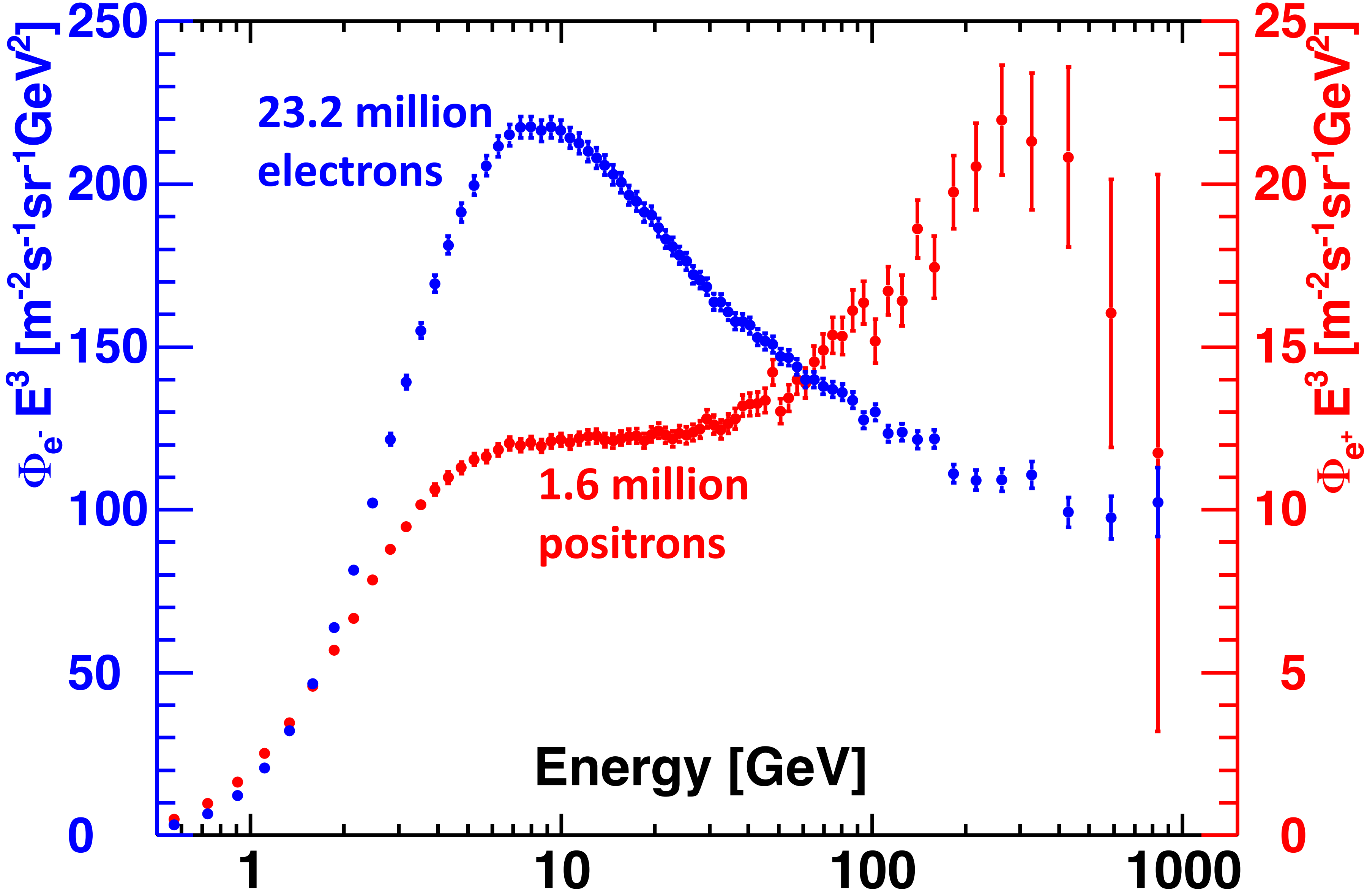
Collision of Cosmic Rays with Interstellar Matter produces e^+, $\bar{p}$, $\bar{D}$

Dark Matter annihilation also produces light antimatter: e^+, $\bar{p}$, $\bar{D}$

The excess of e^+, $\bar{p}$, $\bar{D}$ from Dark Matter annihilations can be measured by AMS

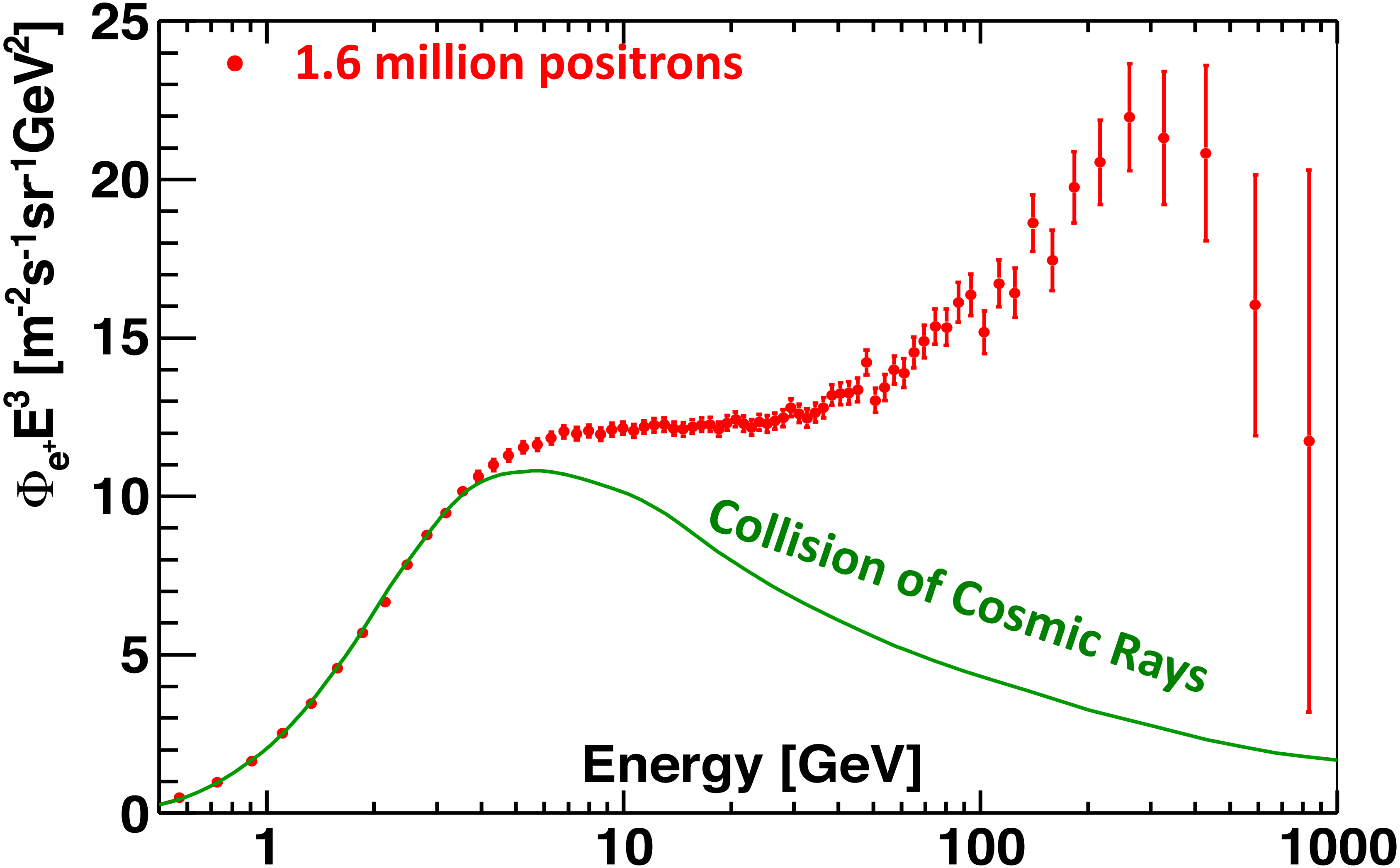


Latest results on electron flux and positron fluxes

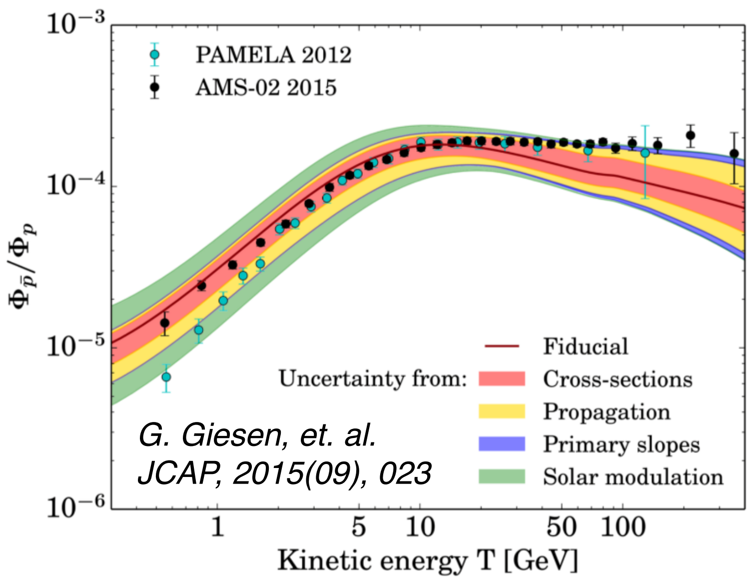


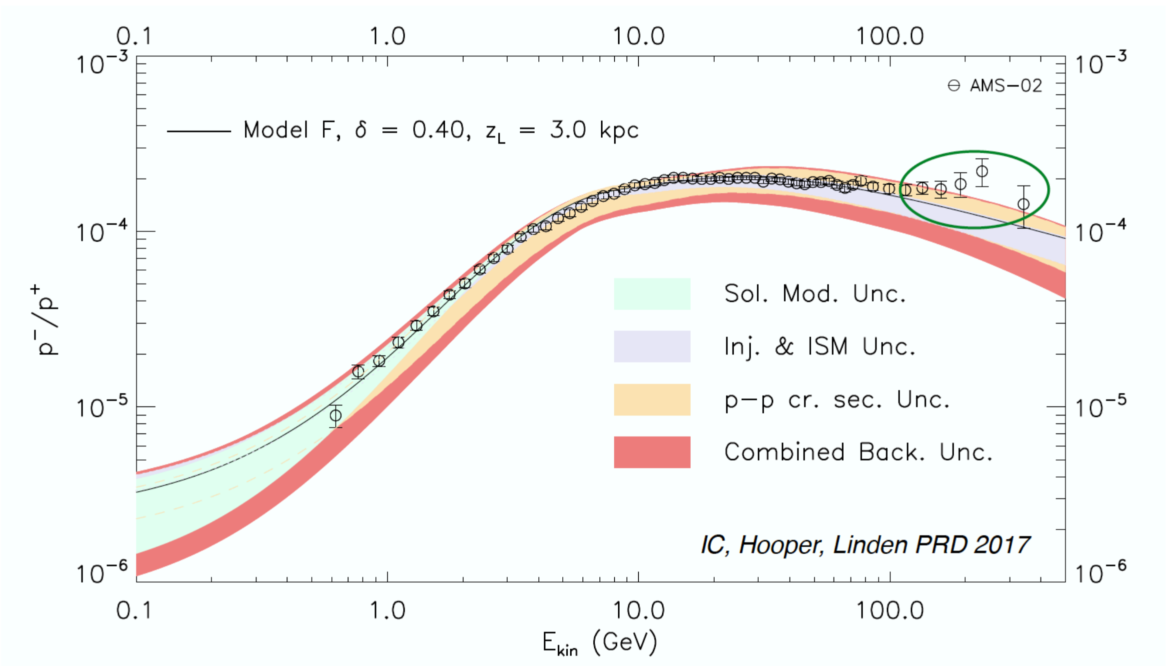
Nature of the positrons excess is still unknown

Dark matter contribution? Pulsars? Super Novae physics?
Anisotropic Local effects of propagation of cosmic rays?



Antiproton-to-proton flux ratio





Is there an excess?

An excess of antiproton may be explained by Dark Matter collisions or by new astrophysics phenomena

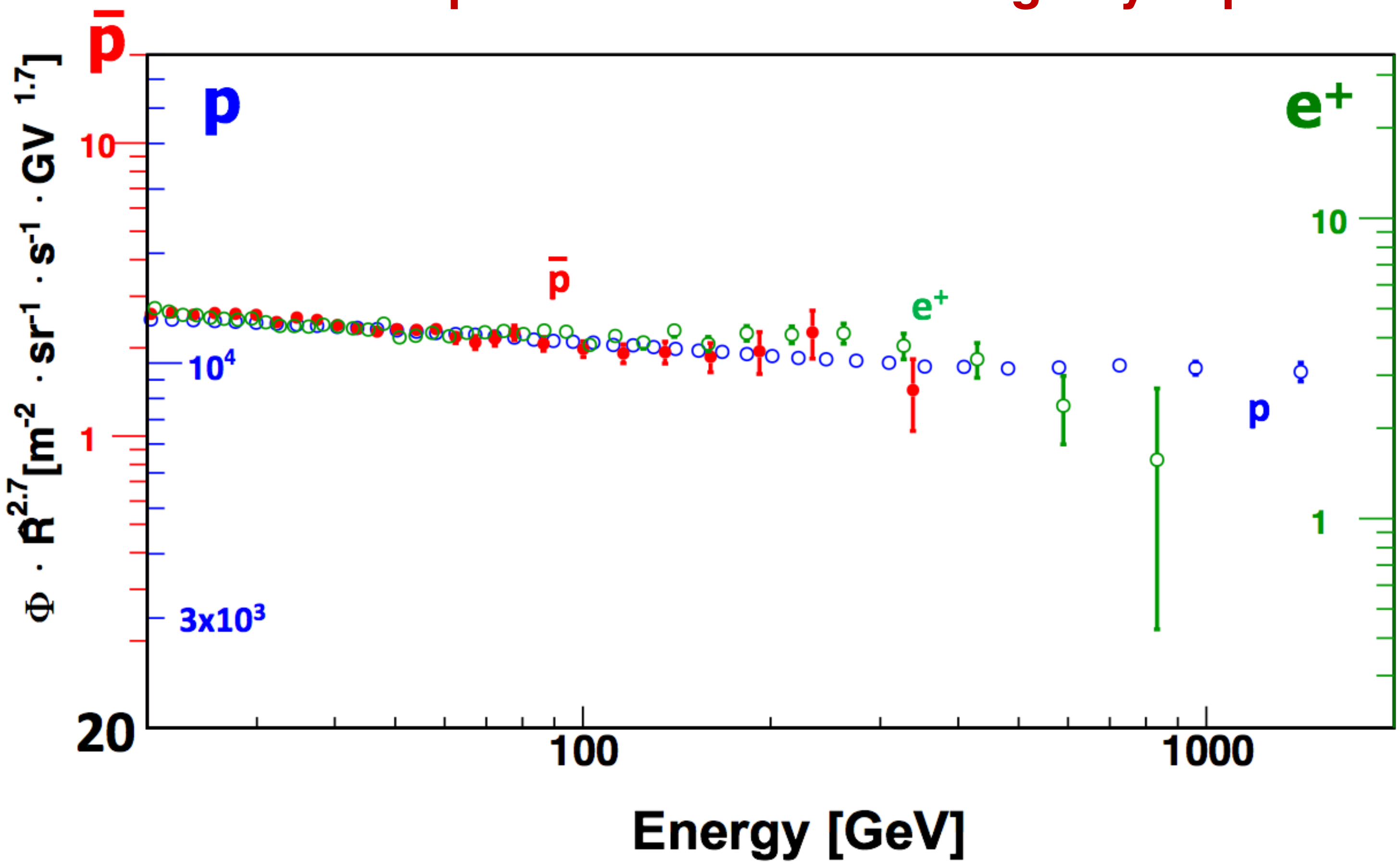
Large uncertainties on the background prediction:

- Primary fluxes
- Secondary fluxes
- Solar modulation
- Nuclear Cross-sections

Latest AMS data will resolve the large uncertainties

Most surprisingly:

The spectra of positrons, antiprotons, and protons are identical but the proton and antiproton mass is 2000 times the positron mass.
Positron and Antiproton have identical rigidity dependence



Protons, anti-protons and positron have very different origin and propagation history. Traditional models predict:
Secondary positrons: softer than proton due to diffusion and energy loss.
Secondary antiprotons are generated by spallation of P with the ISM: softer than P.

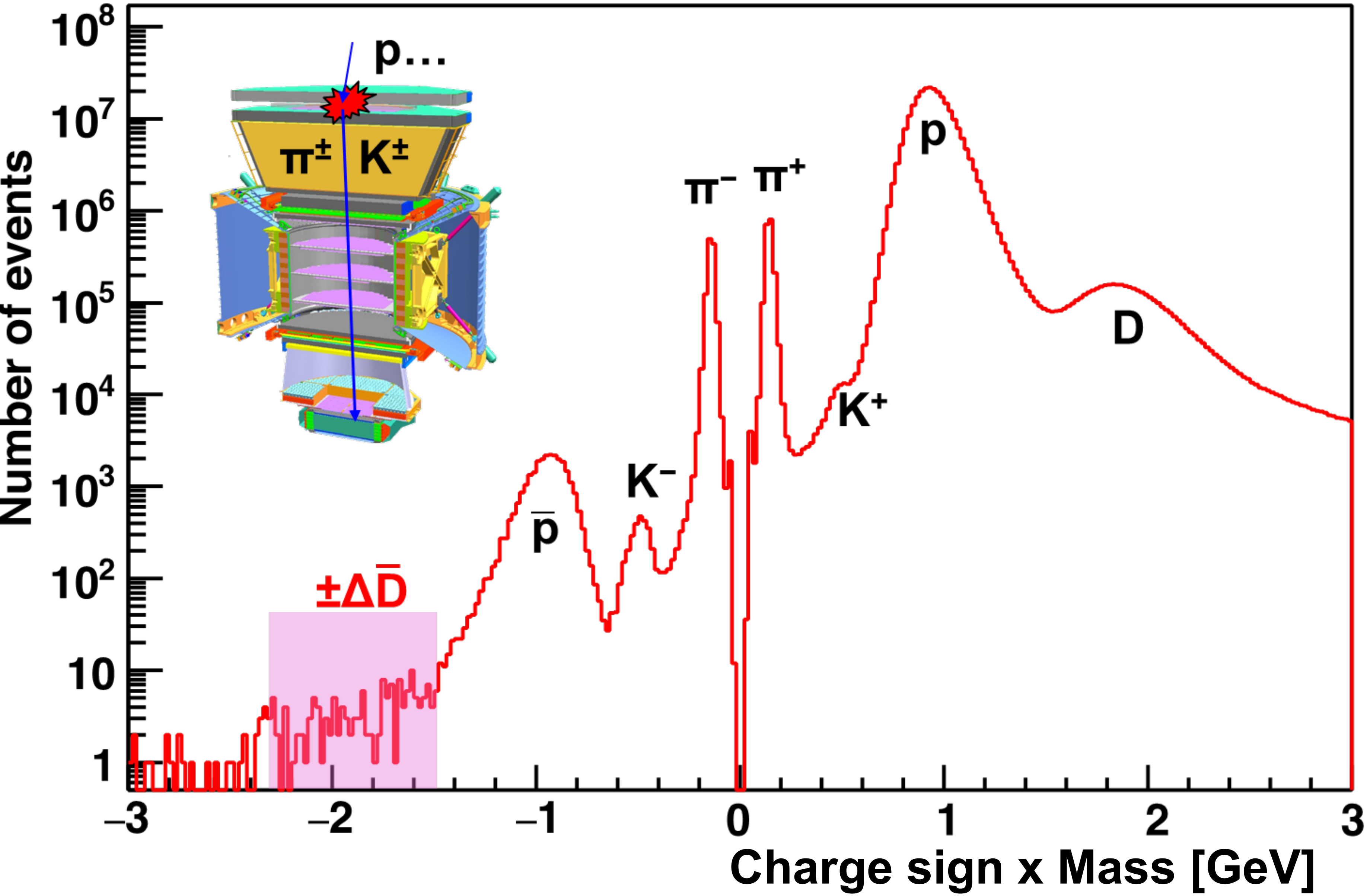
Anti-Deuterons from Dark Matter Annihilations

In six years we have collected
100 million deuterons

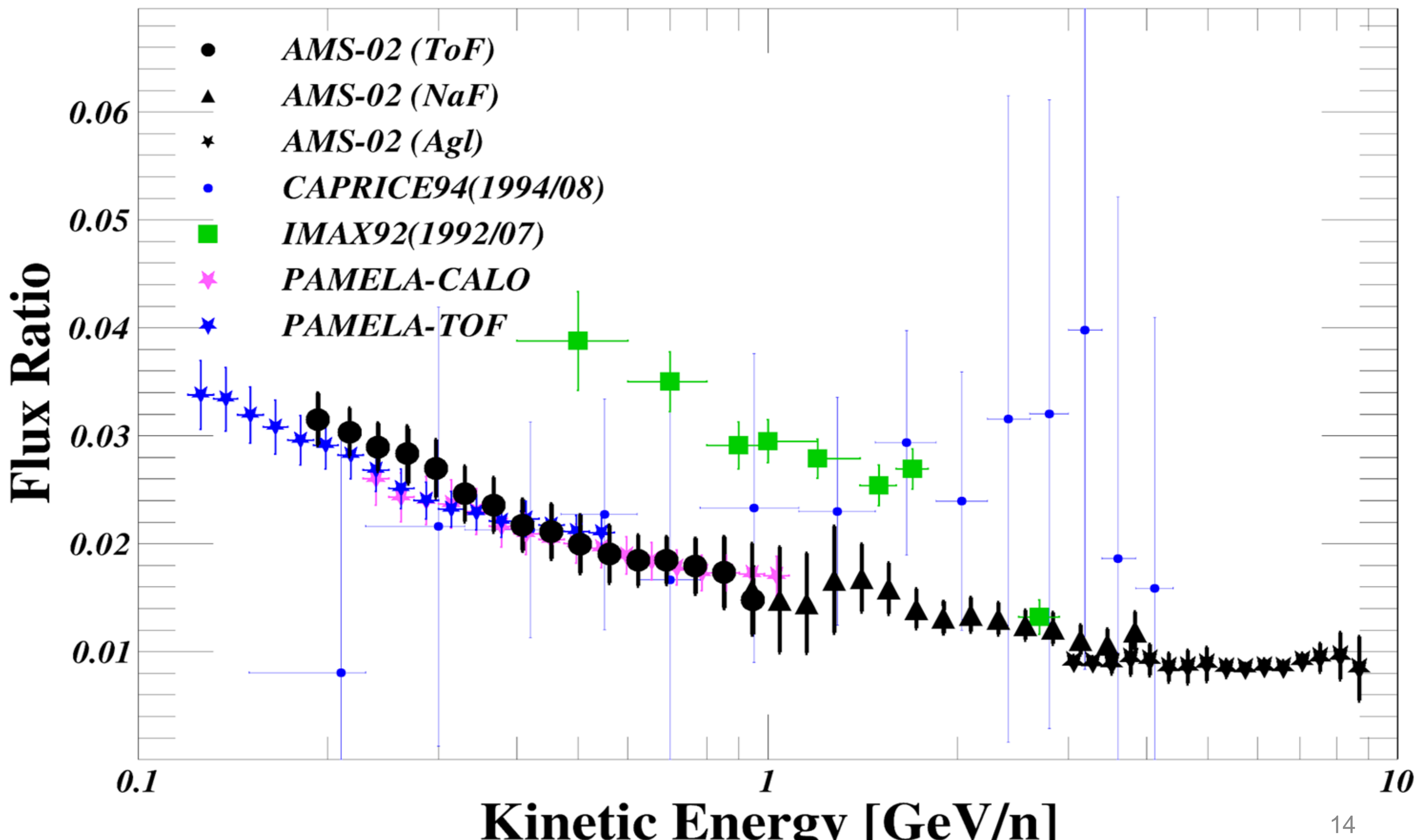
Dark Matter annihilation will produce
anti-Deuterons

Anti-Deuterons have never been observed in space

Anti-Deuteron Analysis

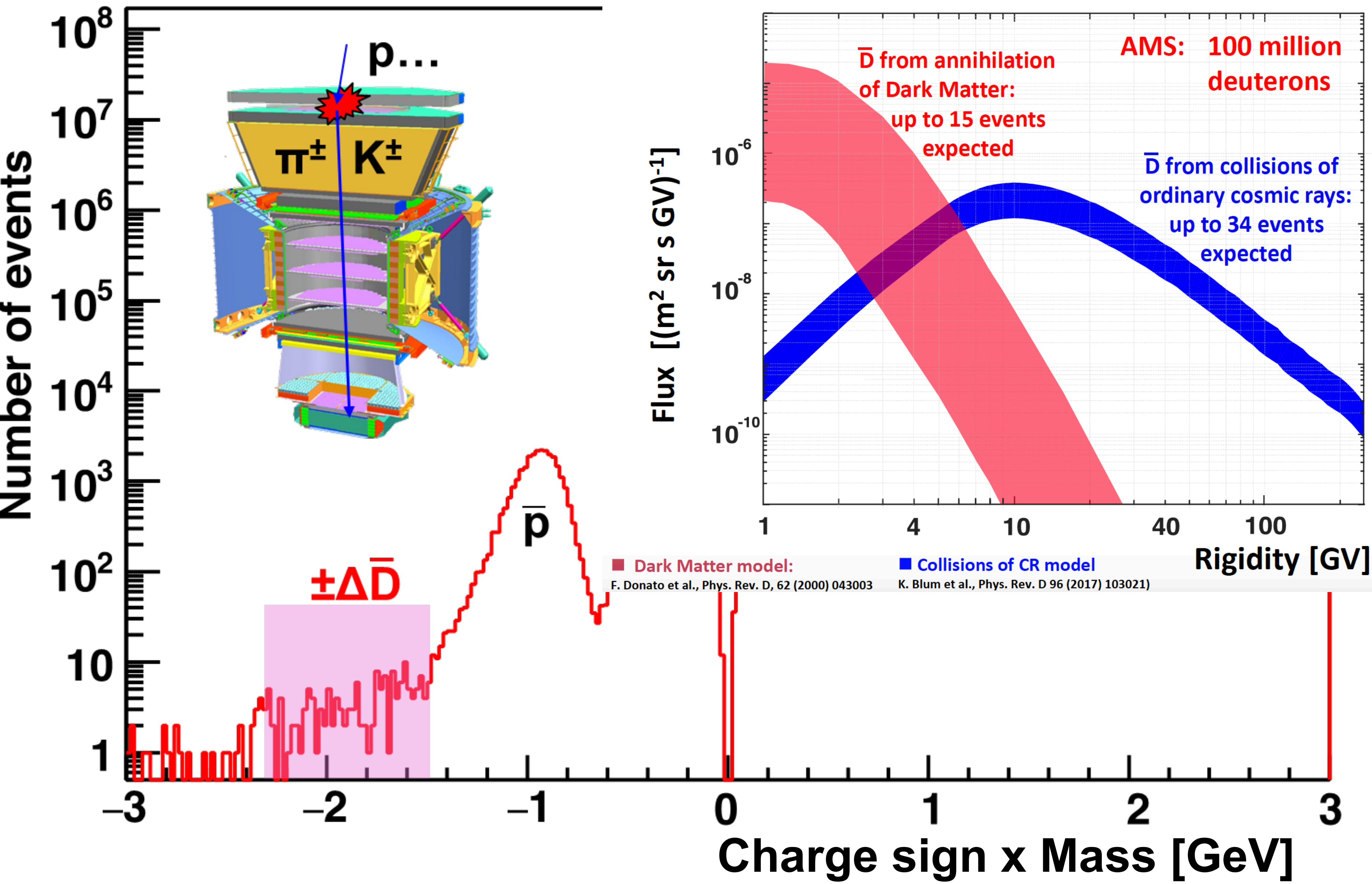


Deuteron to Proton ratio



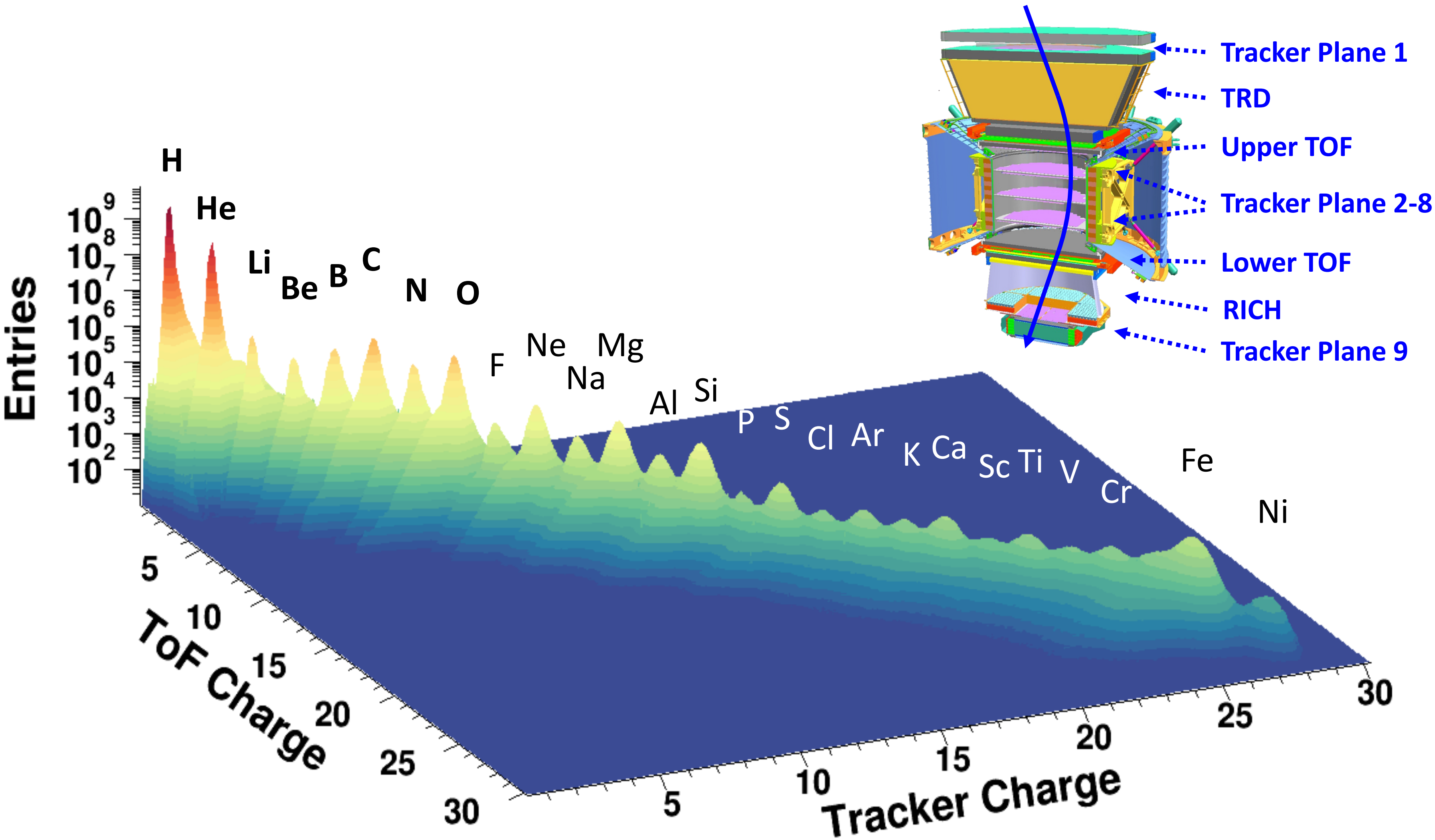
Status of Anti-Deuteron Analysis

MC simulations are on going.



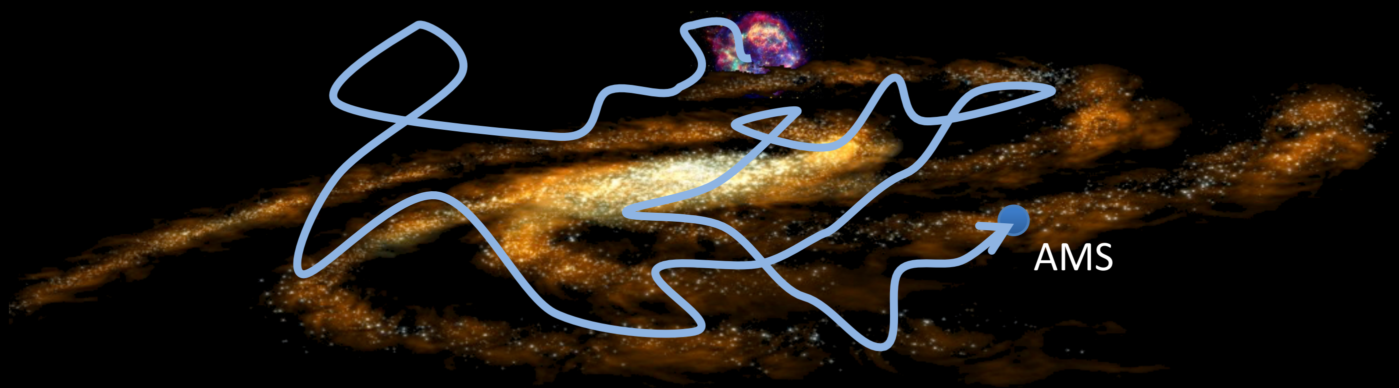
Precision Measurements of Cosmic Rays:

AMS has seven instruments which independently measure Cosmic Nuclei



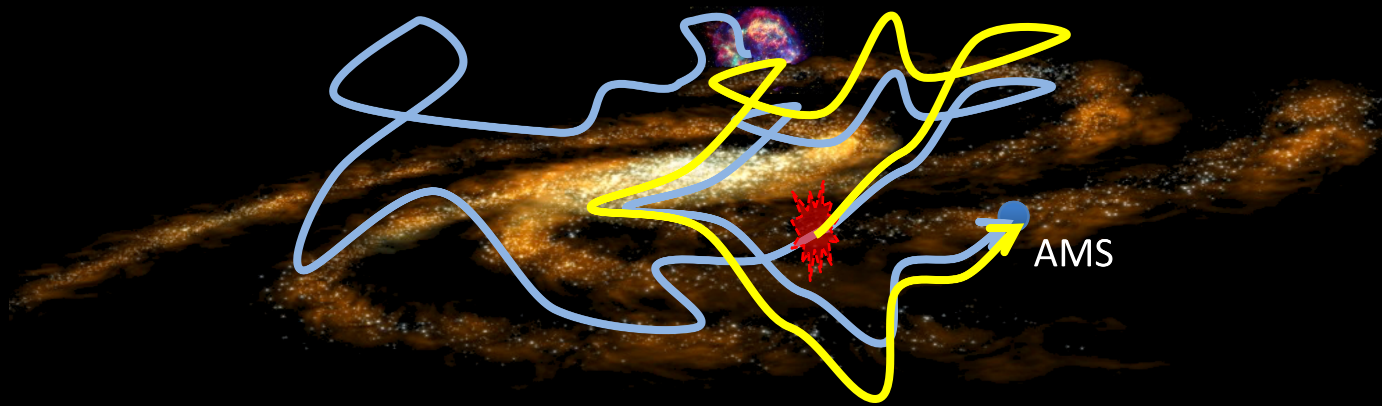
Traditionally, there are two prominent classes of cosmic rays:

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 travel.



Traditionally, there are two prominent classes of cosmic rays:

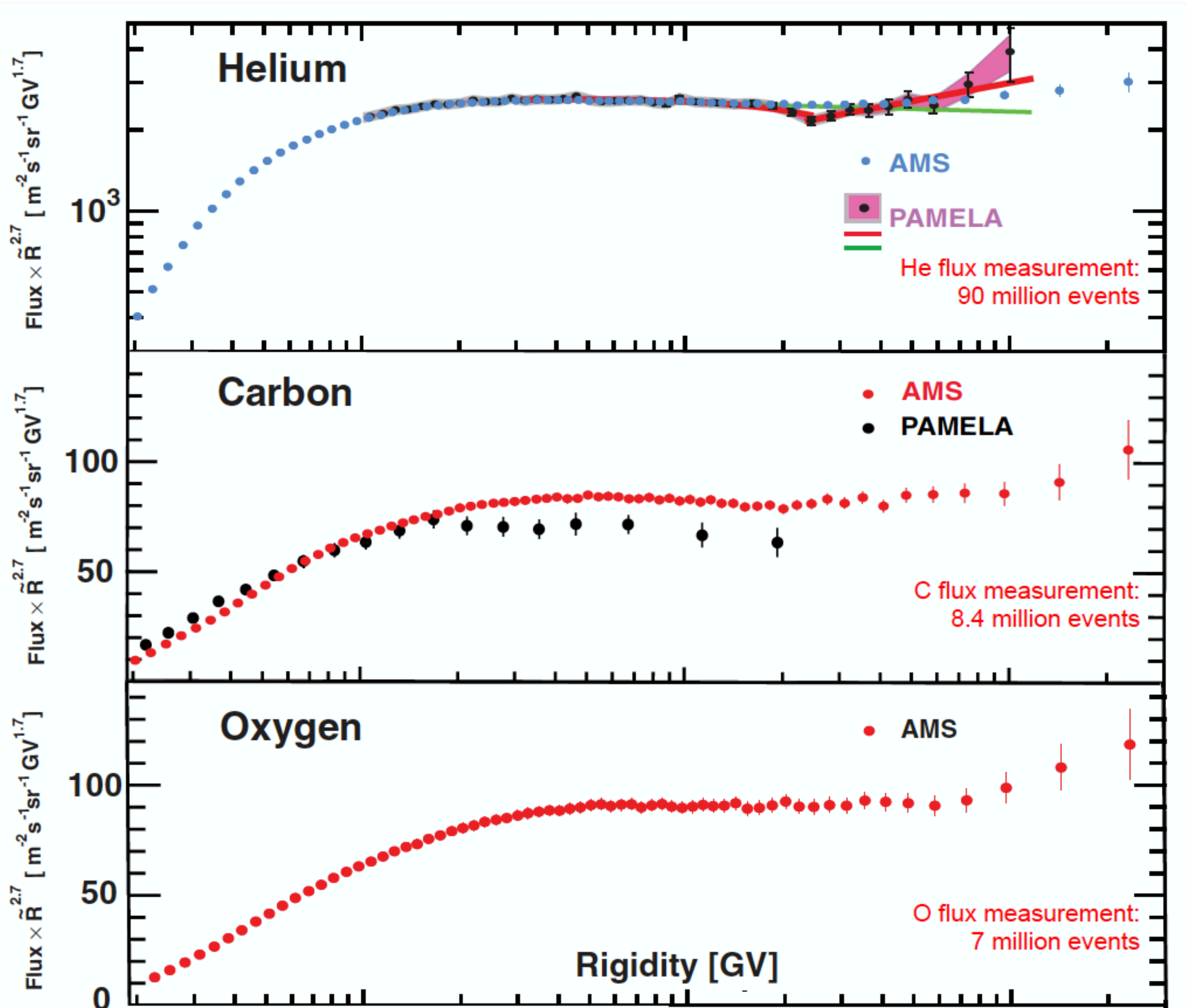
Primary Cosmic Rays (p, He, C, O, …)



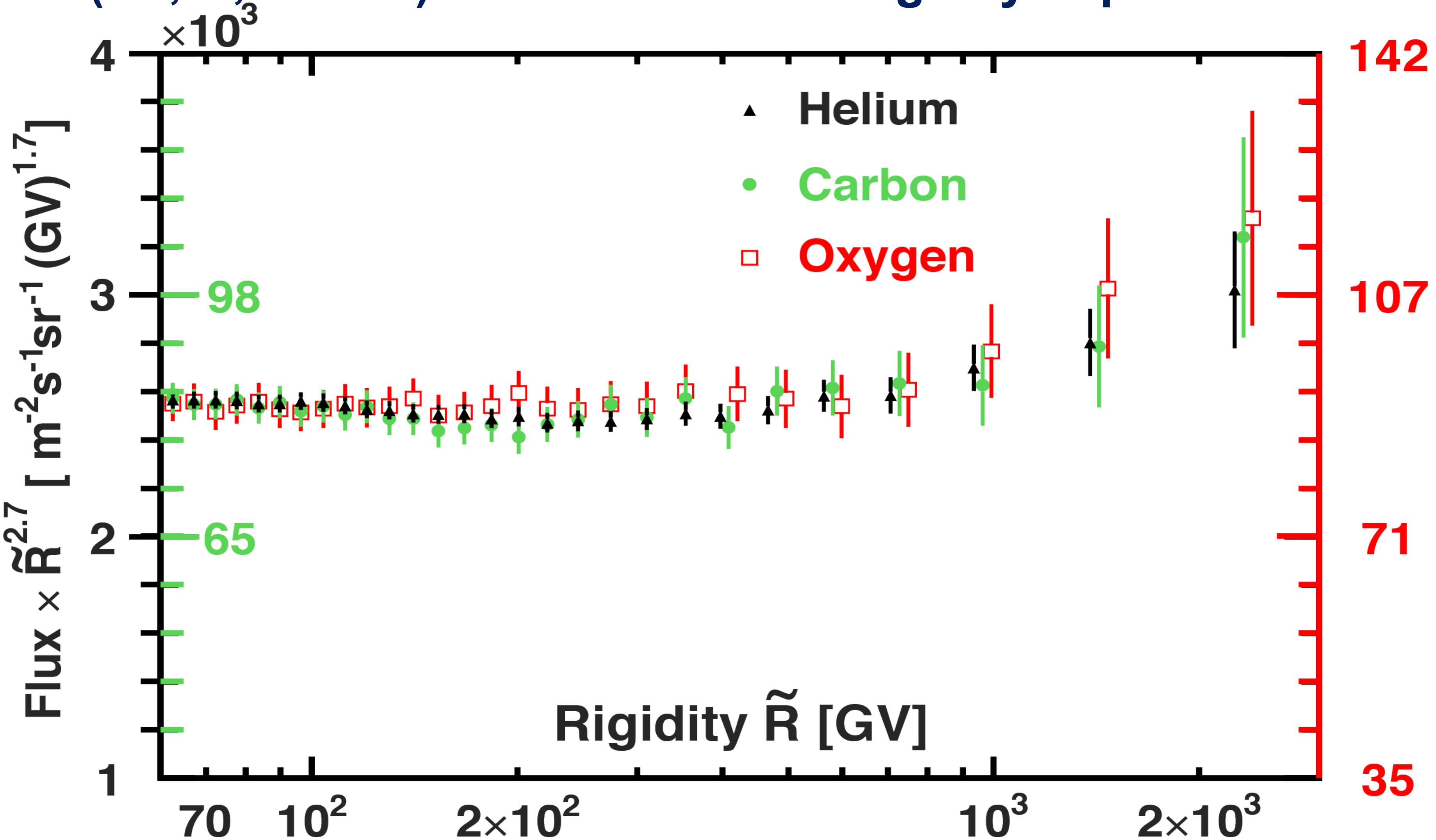
Secondary Cosmic Rays (Li, Be, B, …)

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 matter.

AMS primary cosmic rays fluxes: He, C, and O



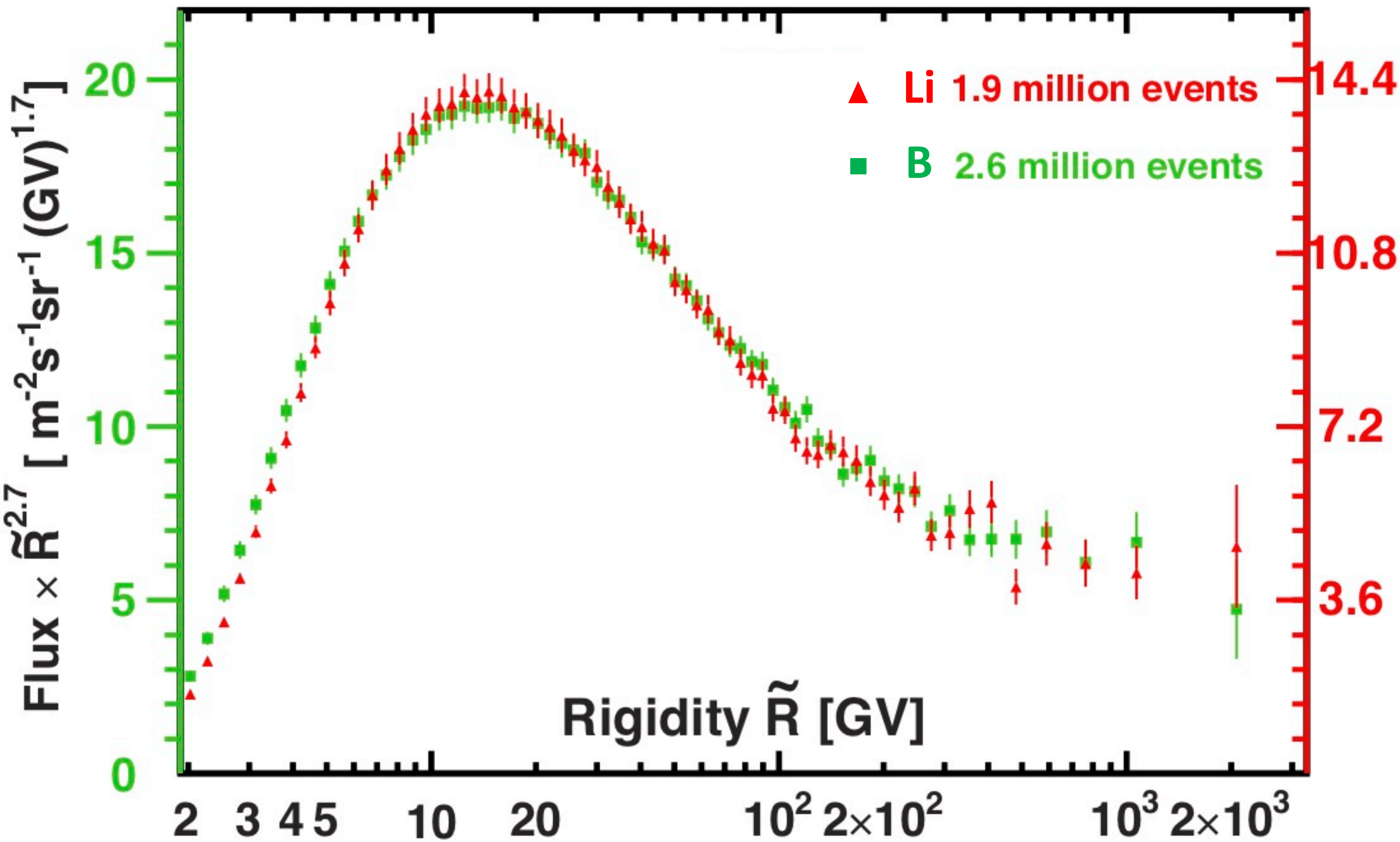
The AMS results show that the primary cosmic rays (He, C, and O) have an identical rigidity dependence.



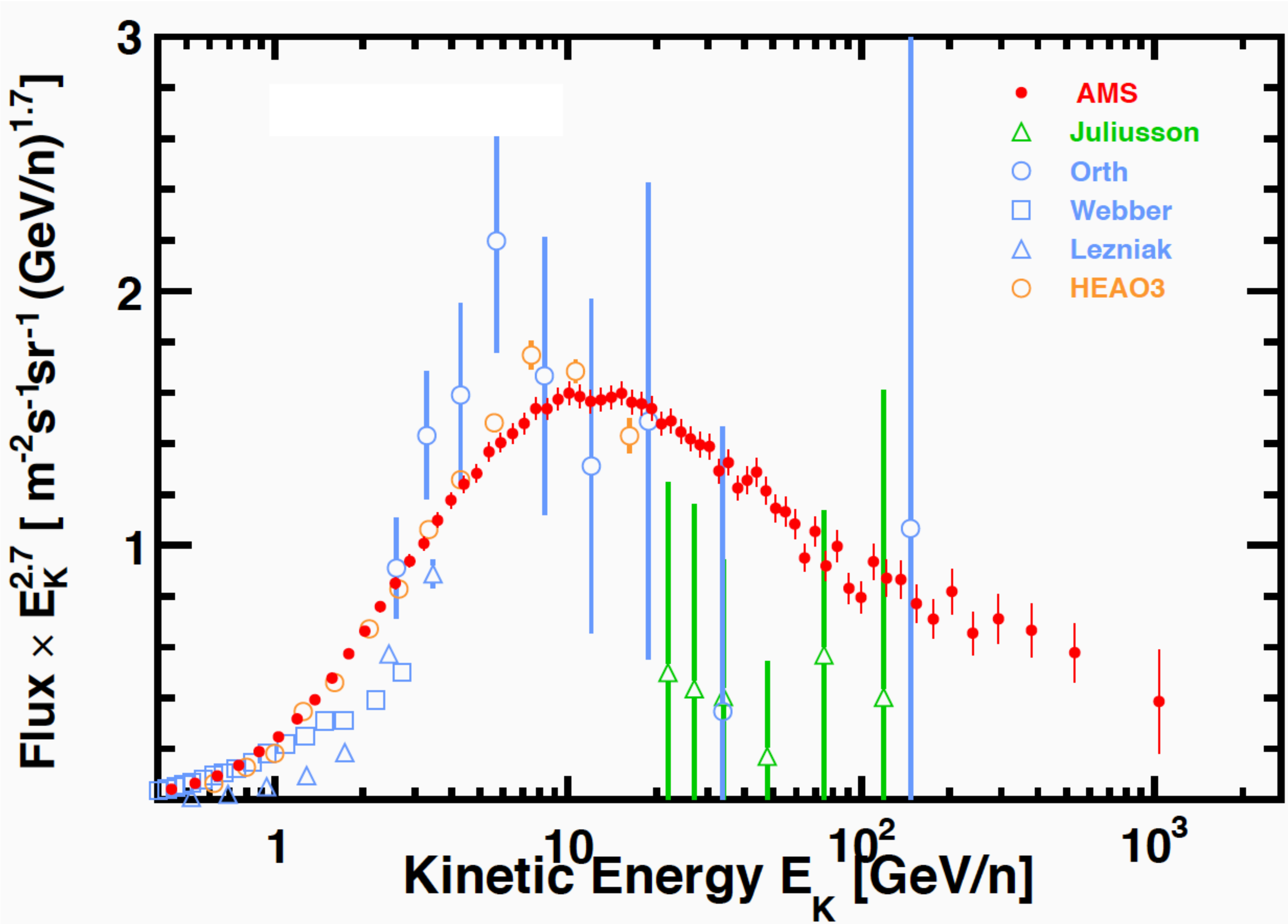
Break at about 200 GV, above the data all increase in identical way.

Secondary Cosmic Rays: Lithium and Boron

Above 7 GV Li and B have identical rigidity dependence

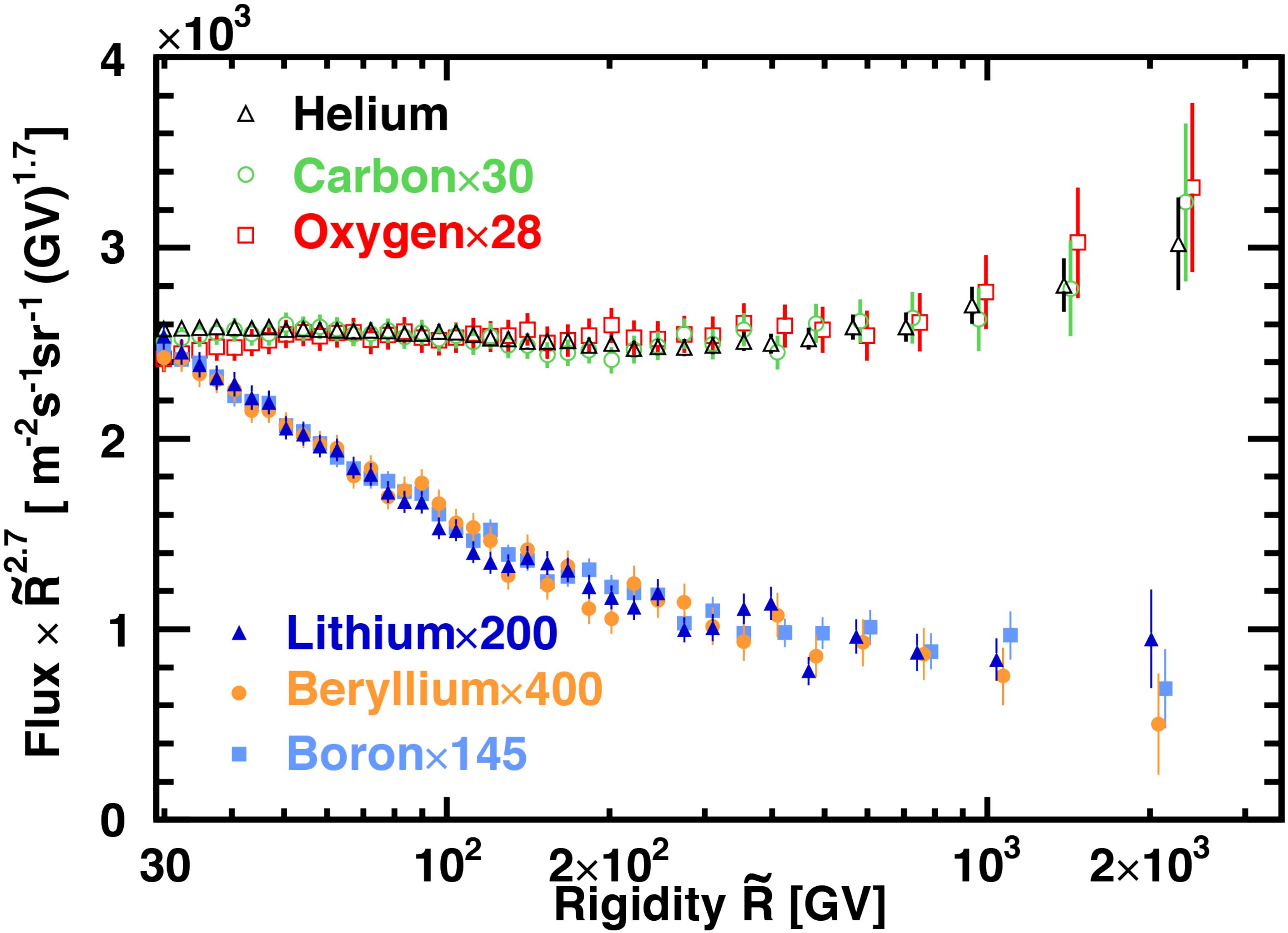


Secondary Cosmic Rays: Beryllium



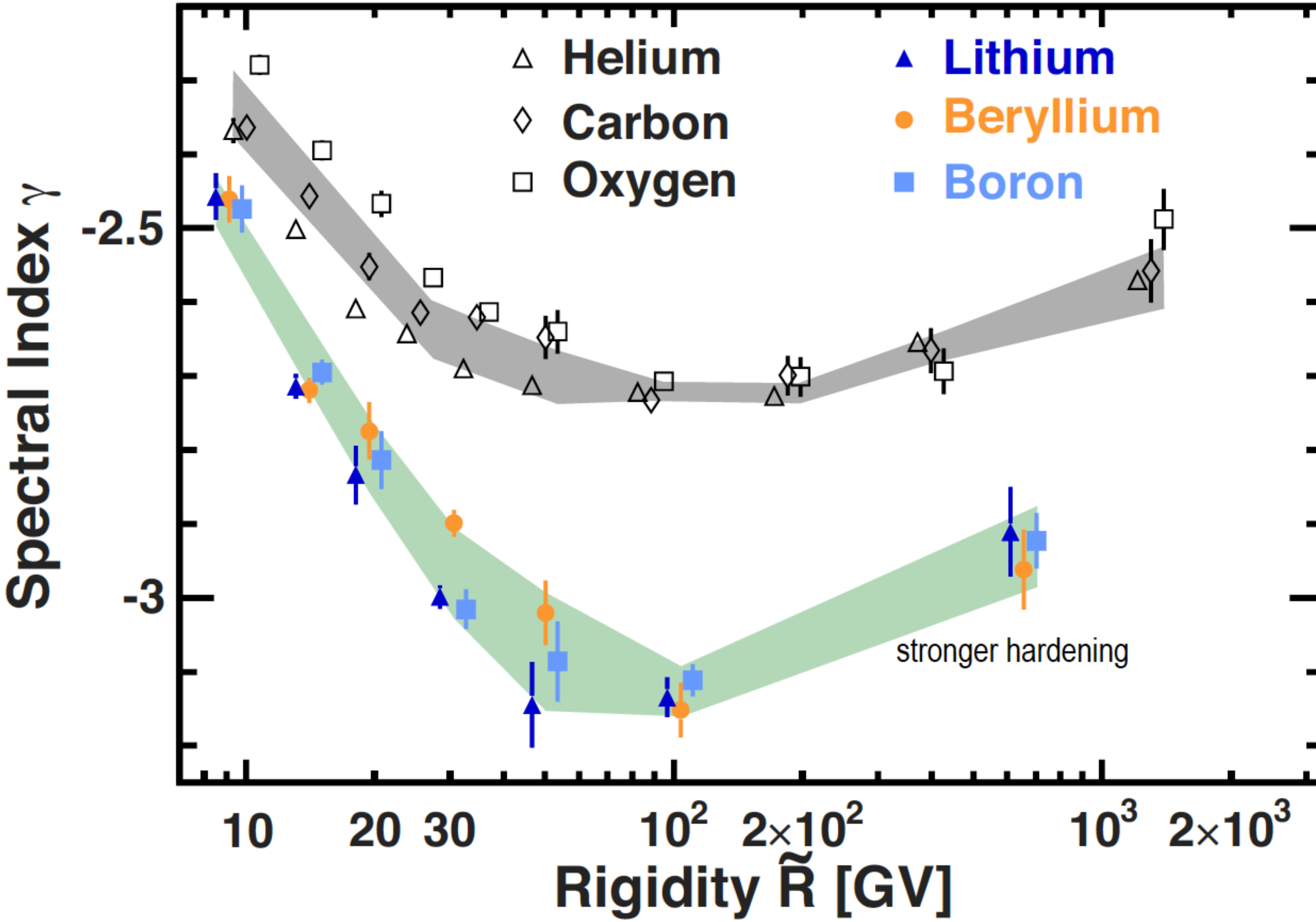
Rigidity dependence of Primary and Secondary Cosmic Rays

Both deviate from a traditional single power law above 200 GeV.
But their momentum dependences are distinctly different.
Secondary have identical rigidity dependence above 7GV



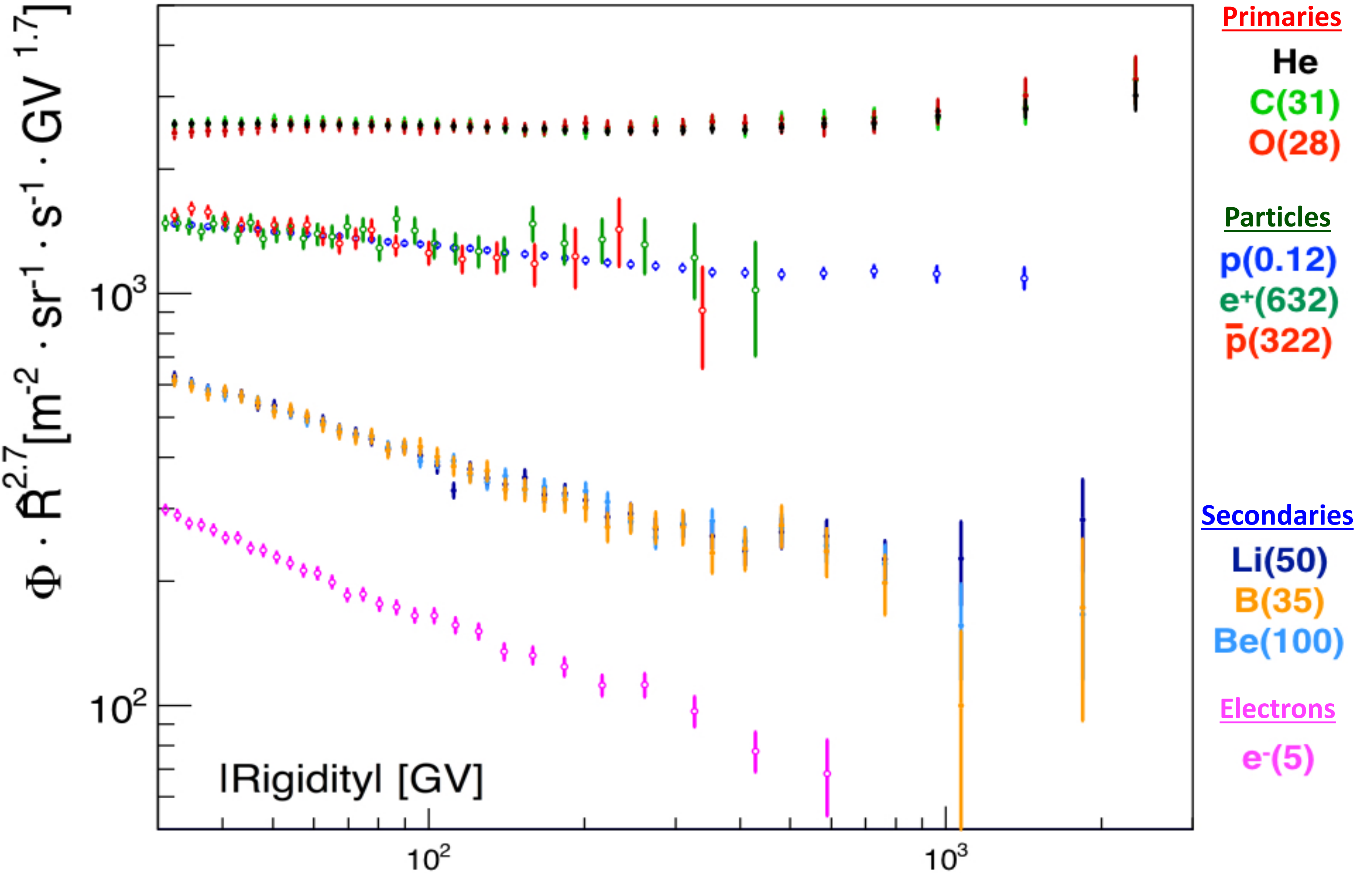
Primary and Secondary Cosmic Rays Spectral Indices

All deviate from single power law above 200 GV. Secondary hardening is stronger. Is it due to propagation?

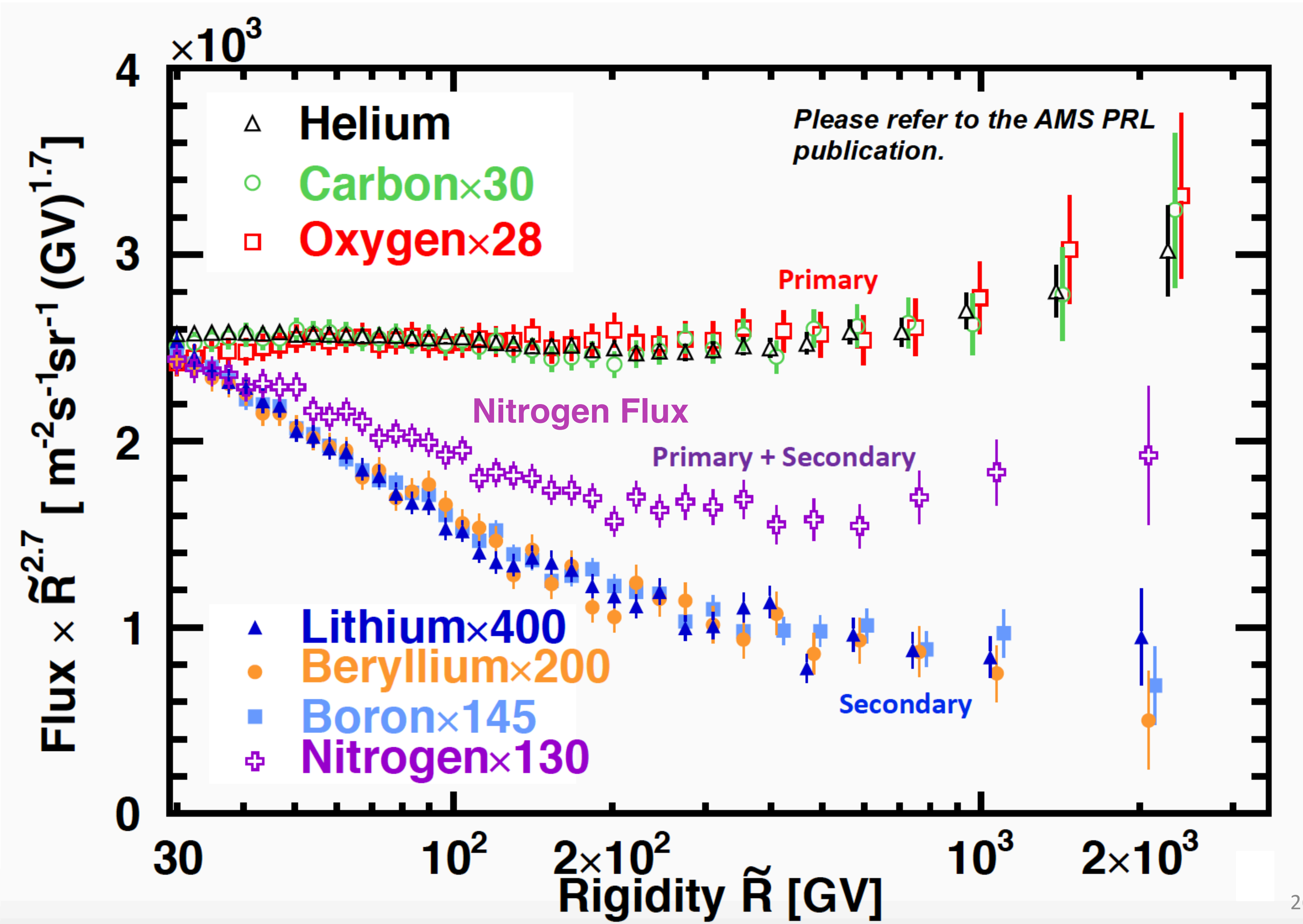


Summary of AMS results on Cosmic Ray Fluxes

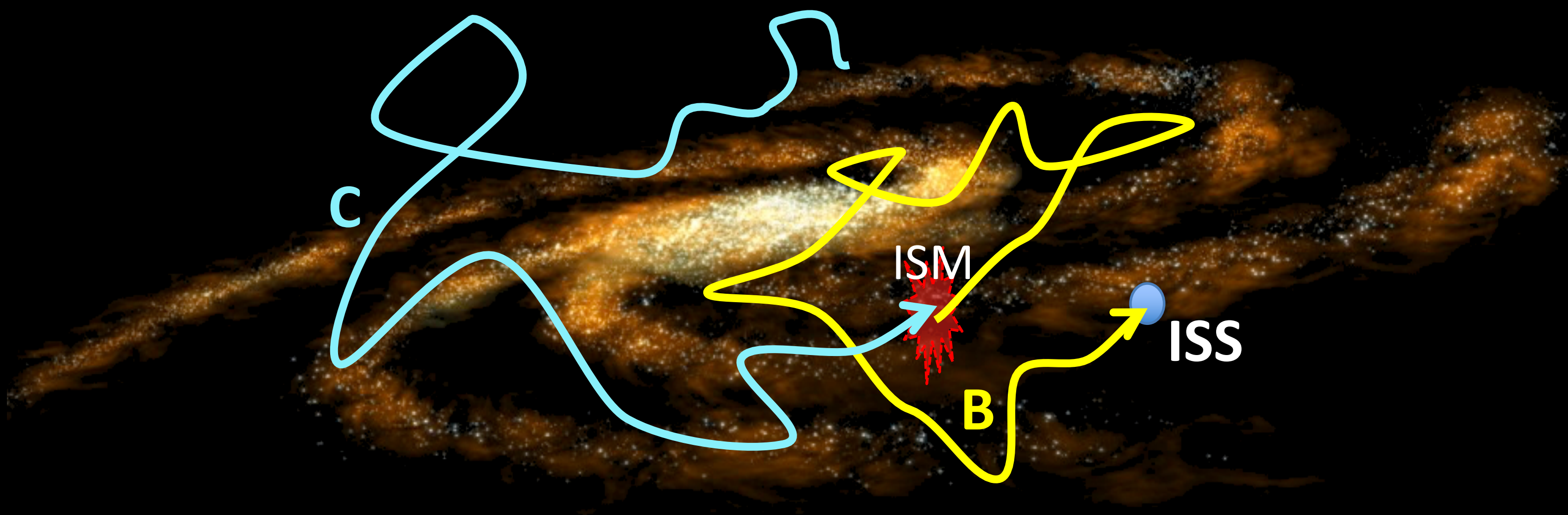
High energy cosmic ray fluxes have 4 classes of rigidity dependence.



Nitrogen Flux has peculiar Rigidity Dependence

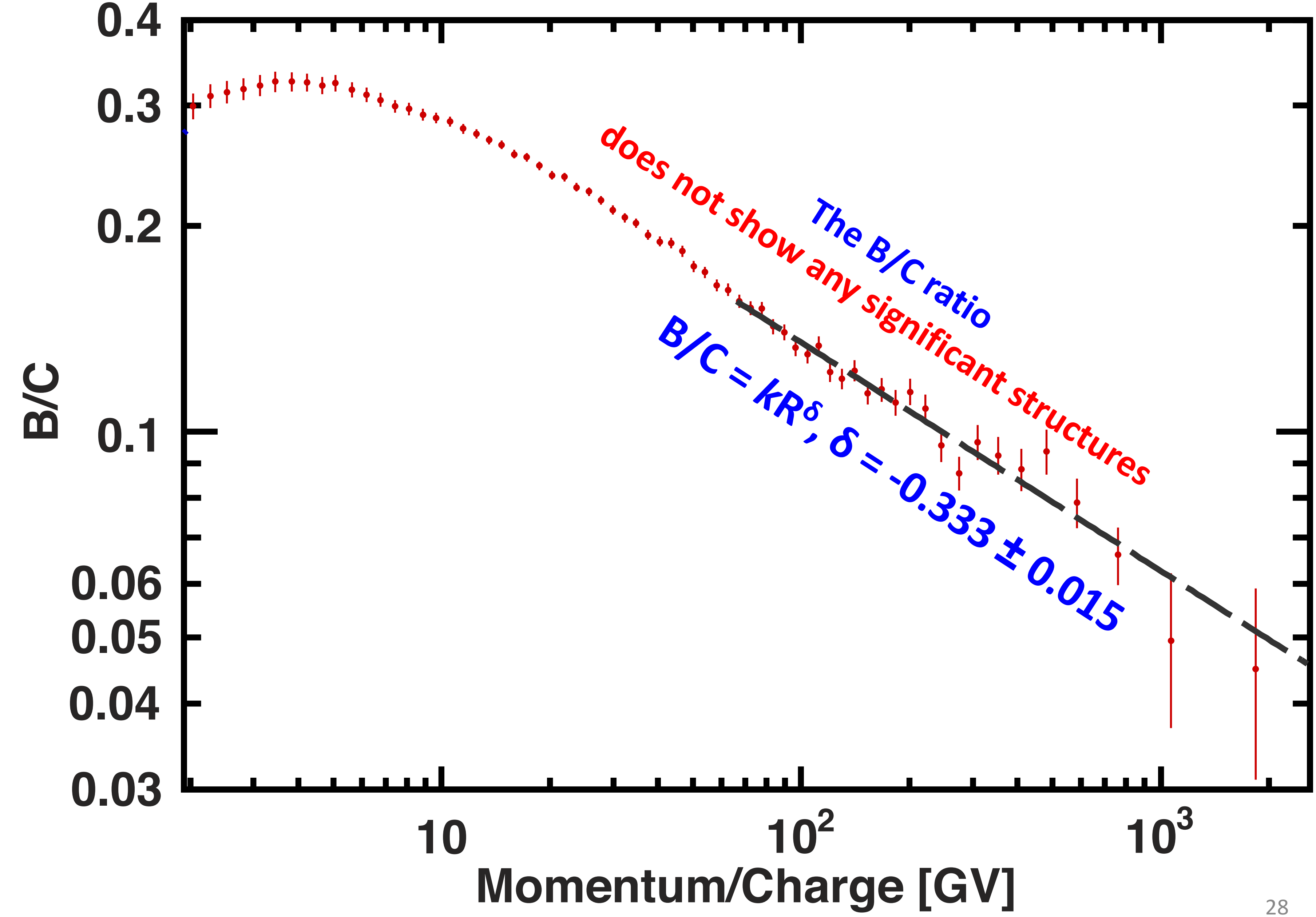


The flux ratio between primaries (C) and secondaries (B) and isotopes (4He and 3He) provides information on propagation and on the Interstellar Medium (ISM).



As most of the B in CR is produced by C spallation, most of 3He is produced by 4He spallation.
He isotopes span a larger distance compared to B/C due to their smaller cross section.

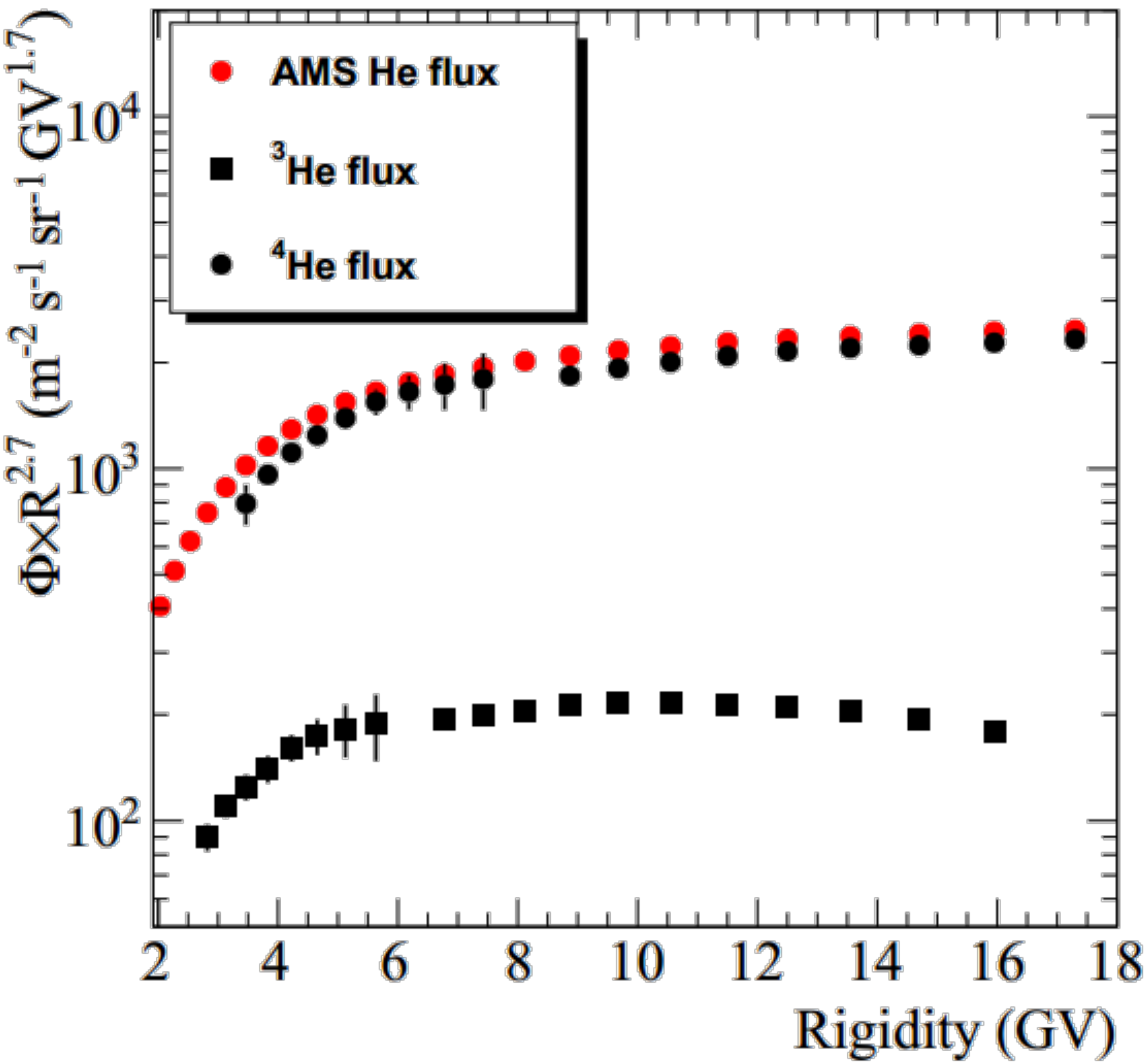
B/C flux ratio



M. Aguilar *et al*., Phys. Rev. Lett. **117,** 231101 (2016)

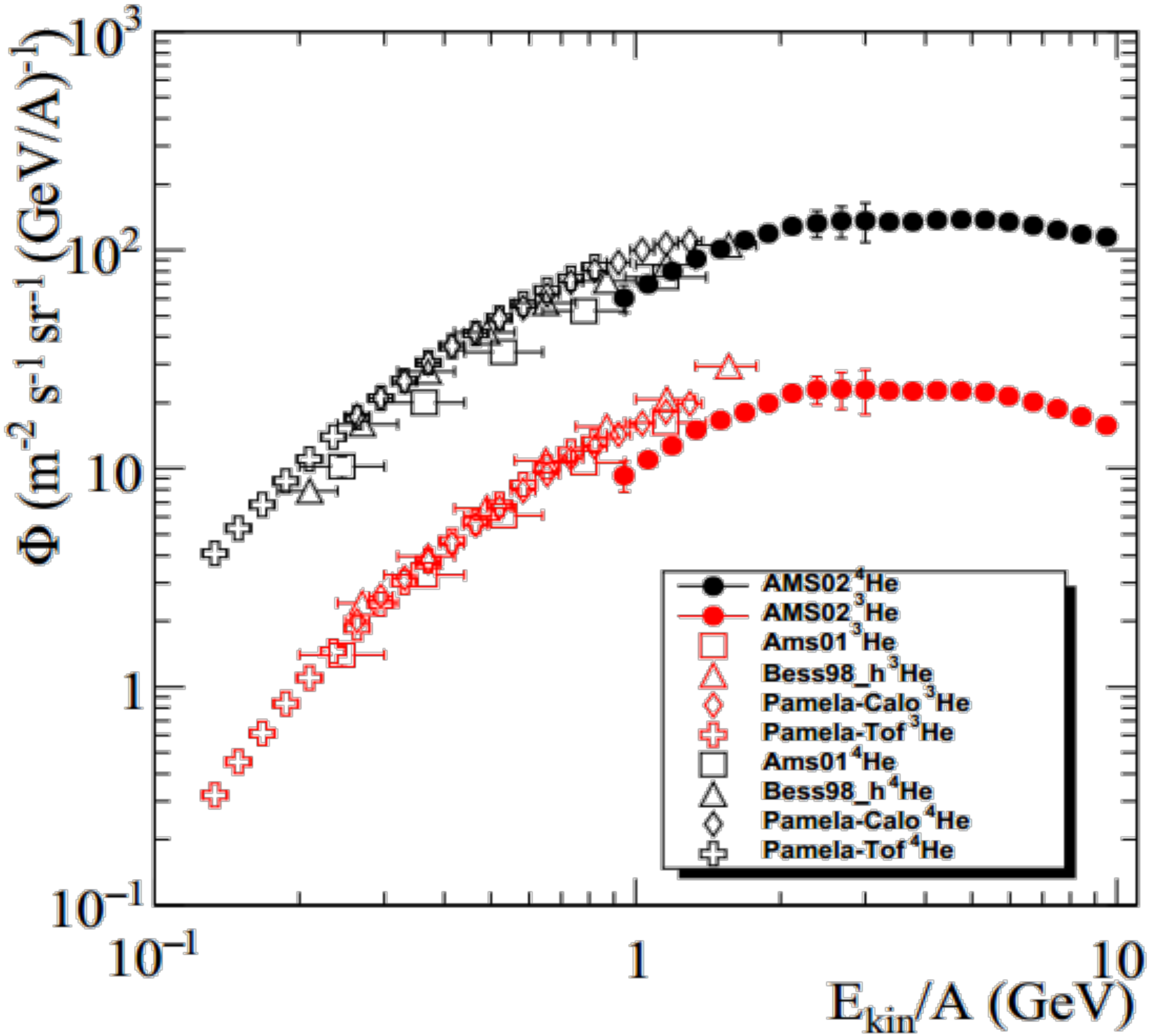
Isotopes with AMS: He Isotopes flux

AMS measurement of He isotopic He3 and He4 fluxes from 1 GeV/a to 10 GeV/A.



He Isotopes flux in context

AMS analysis can be extend to lower energy using TOF.



From P. Blasi (AMS days April 9-12, 2018)

A FEW GENERAL CONSIDERATIONS

- THE SPECTRA OF NUCLEI BEHAVE AS PROTONS, $E^{-\gamma-\delta}$, AT HIGH ENERGIES, WHERE SPALLATION IS WEAK
- AT LOW ENERGIES, WHERE SPALLATION DOMINATES, NUCLEI HAVE THE SAME SPECTRUM AS INJECTION
- AT EVEN LOWER ENERGIES THE SPECTRUM FURTHER HARDENS BECAUSE OF IONIZATION LOSSES
- THE INJECTION SPECTRA OF SECONDARY NUCLEI, POSITRONS AND ANTIPROTONS REFLECT THIS TREND

From P. Blasi (AMS days April 9-12, 2018)

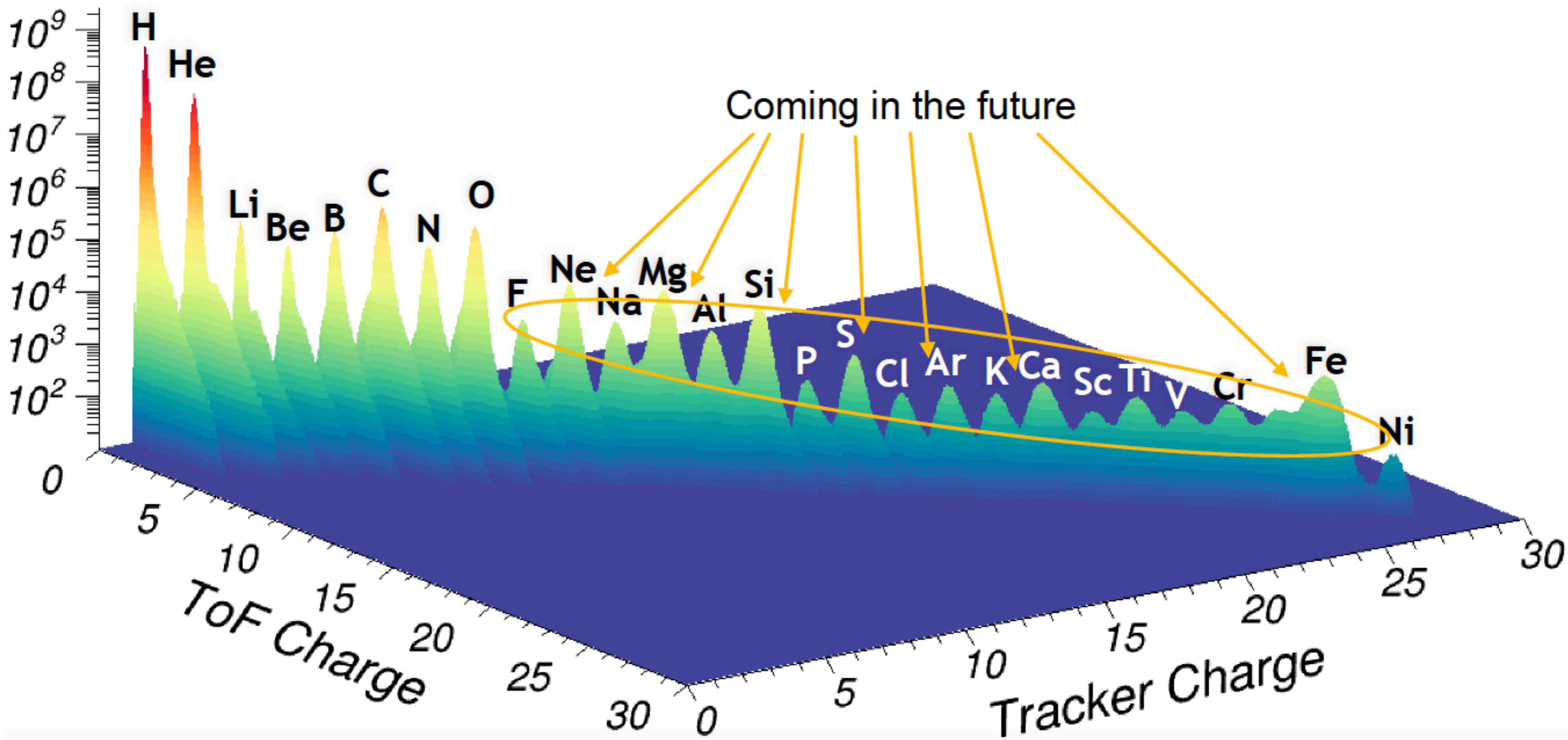
SURPRISES…

- Breaks in the spectra of nuclei
- Proton spectrum different from that of nuclei
- Positron excess
- Secondary nuclei
- Antiprotons, positrons, protons — same spectrum?

AMS data force to revisit the models of CR acceleration and propagation.

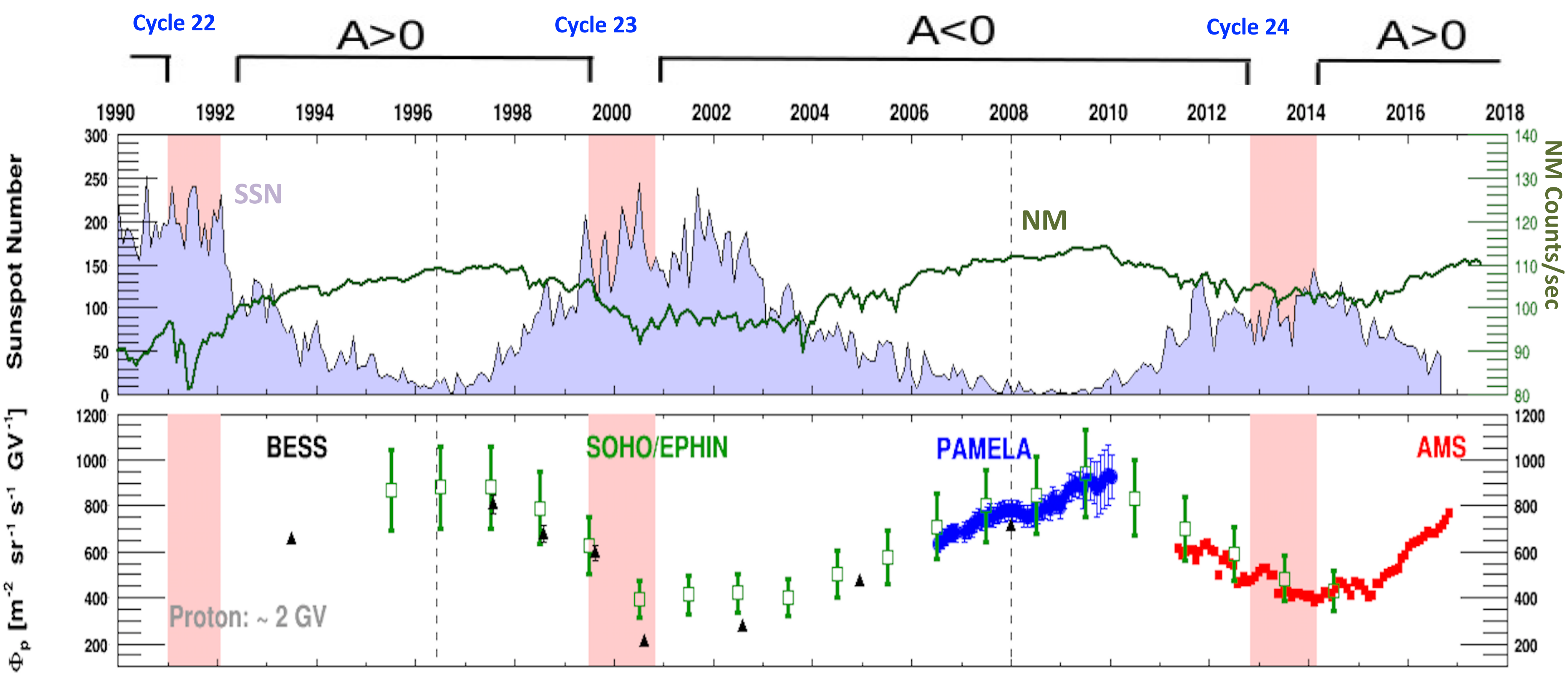
Whether such modifications are a symptom that a major revisitation of the paradigm is needed remains to be understood but there are tools to get there…

Plans for the Future
AMS Periodic Table

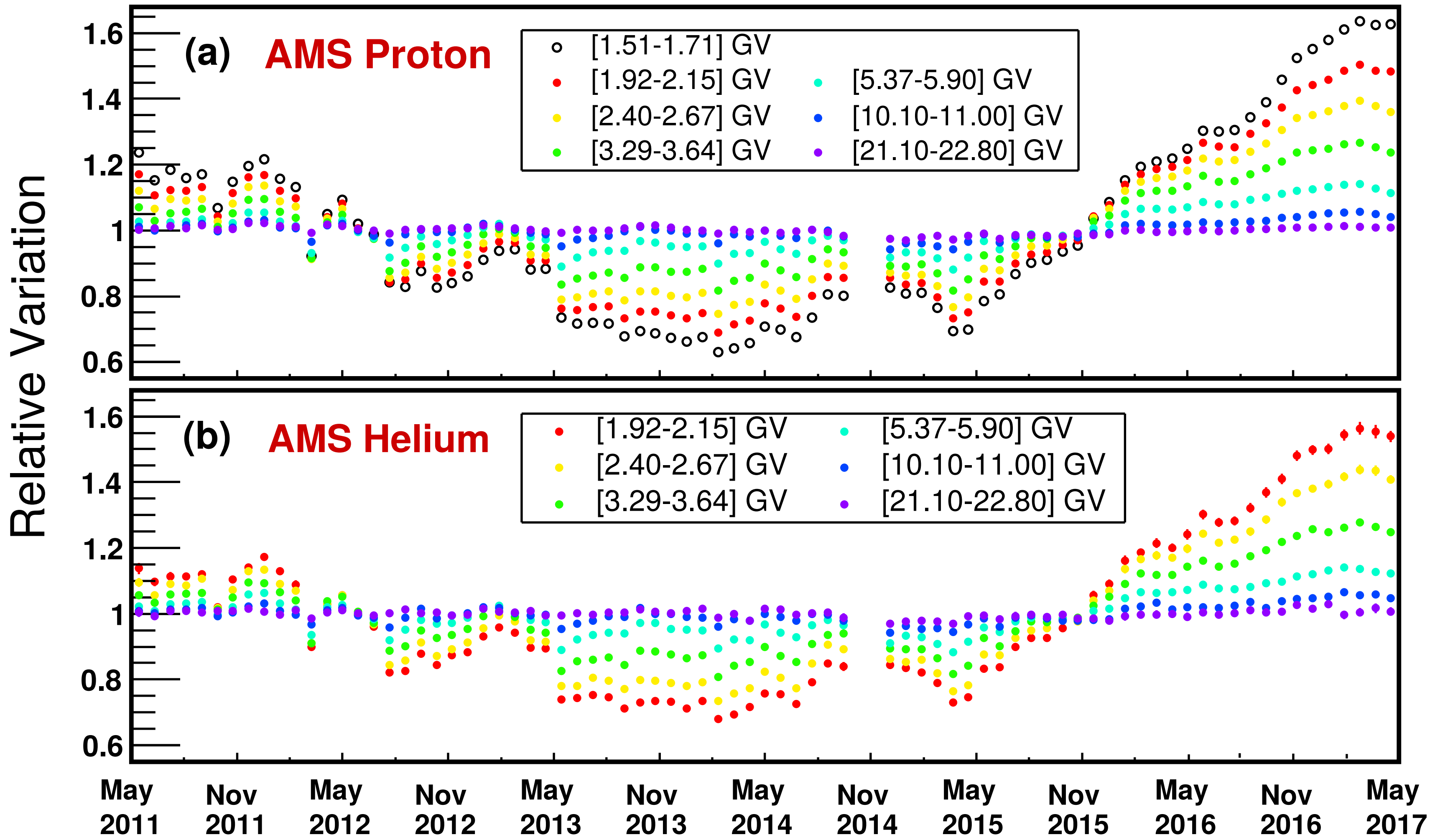


Solar activity measured by AMS

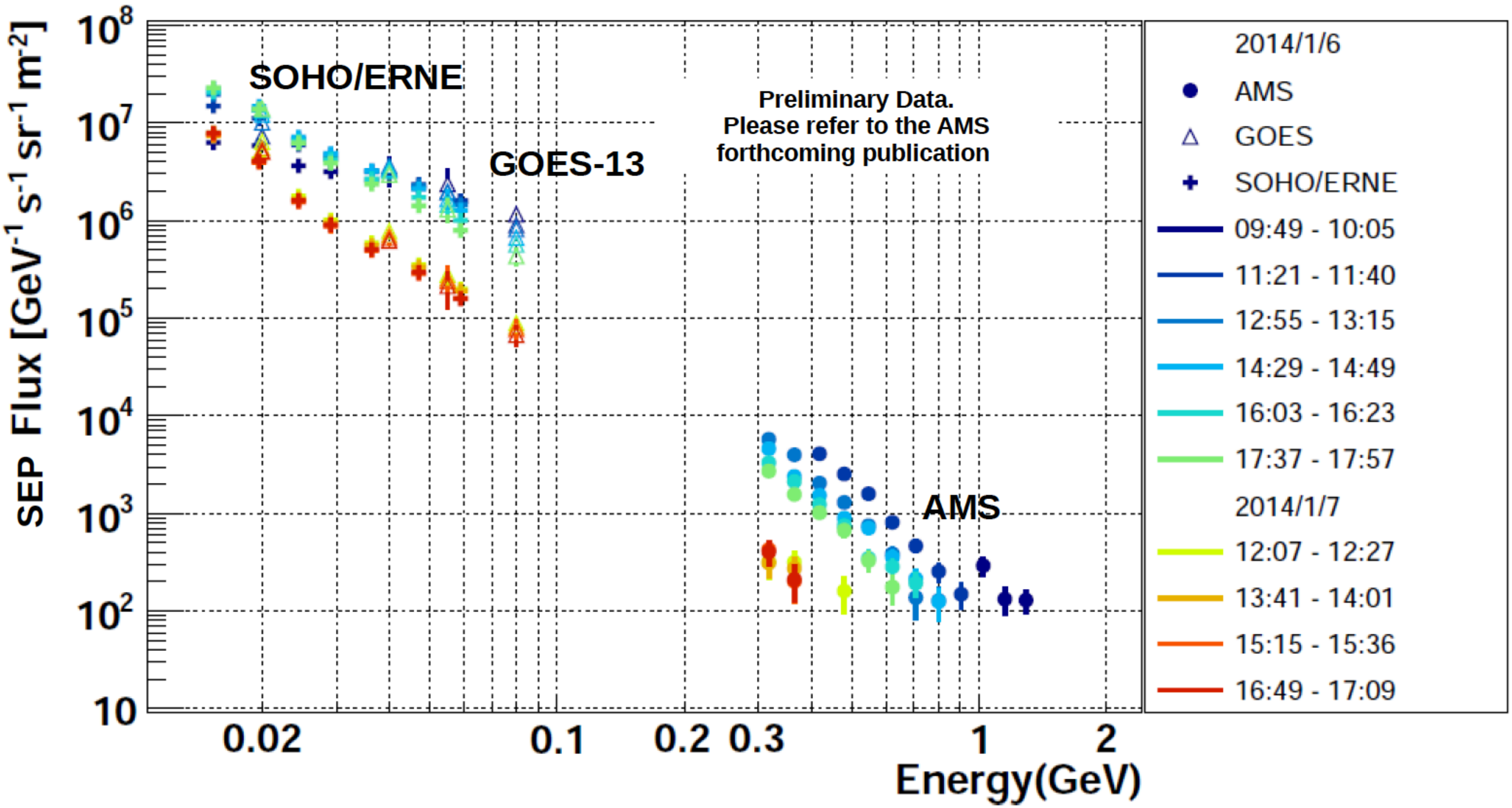
Cosmic rays entering the heliosphere are subject to diffusion, convection, adiabatic energy losses, and magnetic drift.
Cosmic ray flux variation over time correlate with solar activity.



Long term solar modulation
Monthly Proton and Helium time variation



High Energy Solar Energetic Particles



Science at low energy and space radiation with AMS

- Long term solar modulation of GCR and the transport of GCR in the heliosphere -> C. Consolandi's talk
- Short term modulation of GCR (Forbush decrease and their time evolution) -> M. Palermo's talk
- Solar energetic particles and their time evolution -> A. Popkow's talk
- Anisotropies study and differential flux of SEPs
- Direct measurement of geomagnetic cut-off
- Trapped particles (under cut-off), SAA

Conclusions

- The International Space Station is a unique platform for precision physics research for the next decade.

- A new era in galactic cosmic rays understanding has started, at high energy where unexpected results are imposing changes in the GCR acceleration and propagation paradigm, and also at low energy in the region affected by the solar modulation thanks to the precise and continuous observations from space.

- The AMS results are playing a major role in heliophysics for the understanding of solar modulation, SEP and Forbush decrease and in space radiation for future manned mission to the Moon and Mars.

- These measurements will serve as a high-precision baseline for continued studies of GCR solar modulation, SEPs, space radiation hazards, magnetospheric effects, trapped particles and in many other fields.

Backups

7Be fraction (preliminary)

In particular 10Be/9Be allow to put constraint on the confinement time of CR in the galaxy, since 10Be is decay with half life=1.39x10^6 years. it is possible to explore isotopic composition up to ≈ 10 GeV/n, where previous measurement substantially stop at ≈ 1 GeV/n