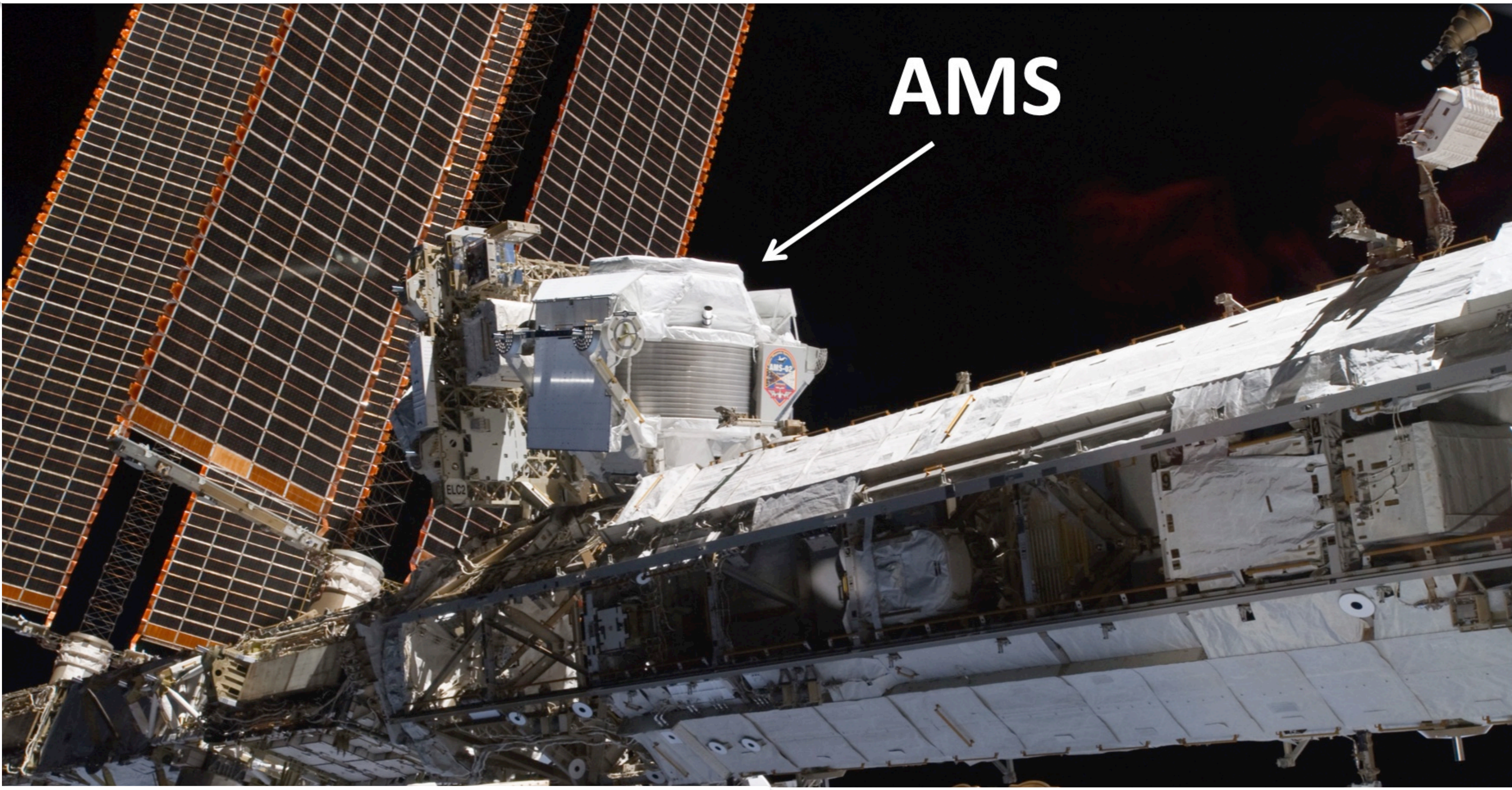
Latest Results from the AMS Experiment



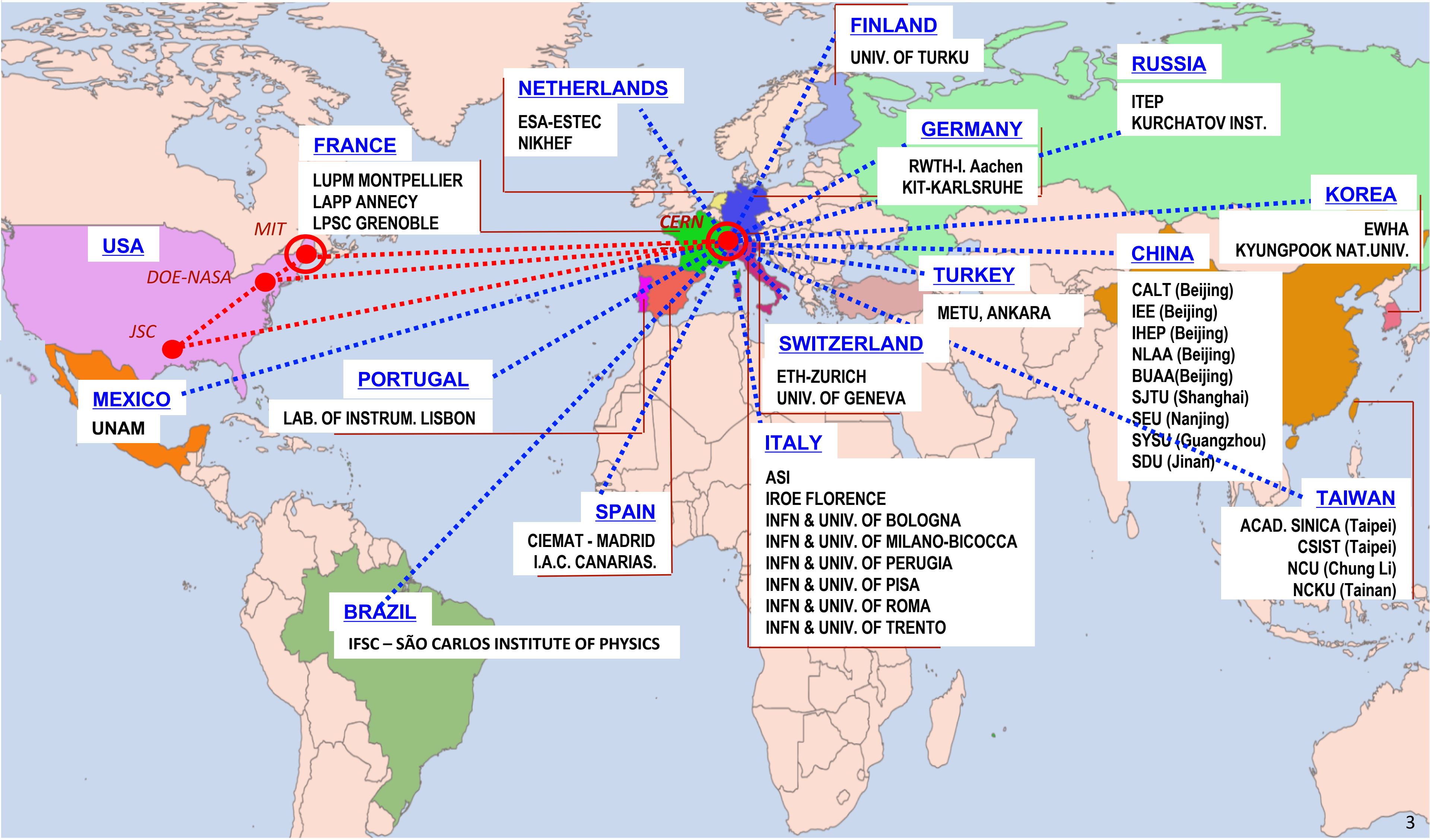
COSPAR 2018
42ND ASSEMBLY | 60TH ANNIVERSARY

S. Schael, RWTH Aachen University
on behalf of the AMS Collaboration

AMS Results Presented at COSPAR 2018

W. Xu	"MEASUREMENT OF ELECTRON AND POSITRON FLUXES IN PRIMARY COSMIC RAYS"
Z. Li	"MEASUREMENT OF THE POSITRON FRACTION IN PRIMARY COSMIC RAYS"
Z. Weng	"ANTIPROTON FLUX AND PROPERTIES OF ELEMENTARY PARTICLE FLUXES IN PRIMARY COSMIC RAYS "
A. Oliva	"ANTIDEUTERON IN PRIMARY COSMIC RAYS"
V. Formato	"IDENTICAL RIGIDITY DEPENDENCE OF THE PRIMARY COSMIC RAYS HELIUM, CARBON AND OXYGEN"
L. Derome	"MEASUREMENTS OF LIGHT NUCLEAR ISOTOPIC COMPOSITION IN COSMIC RAYS"
C. Delgado	"MEASUREMENTS OF ^{3}HE-TO-^{4}HE RATIO AND INDIVIDUAL ^{3}HE AND ^{4}HE FLUXES IN COSMIC RAYS"
V. Choutko	"MEASUREMENT OF THE NITROGEN FLUX IN COSMIC RAYS "
A. Oliva	"MEASUREMENT OF SECONDARY-TO-PRIMARY COSMIC RAYS FLUX RATIOS"
Q. Yan	"NEW PROPERTIES OF SECONDARY COSMIC RAYS LITHIUM, BERYLLIUM, AND BORON"
S. Schael	"COMPLEX TIME STRUCTURES IN THE COSMIC-RAY ELECTRON AND POSITRON FLUXES"
J. Casaus	"ANISOTROPY IN THE ARRIVAL DIRECTIONS OF PRIMARY COSMIC RAYS"
V. Bindi,	"SOLAR MODULATION, FORBUSH DECREASES AND SOLAR ENERGETIC PARTICLES"
S. Della Torre	"MEASUREMENT OF THE MONTHLY PROTON AND HELIUM FLUXES IN COSMIC RAYS"

AMS is an international collaboration based at CERN



It took 650 physicists and engineers 17 years to construct AMS

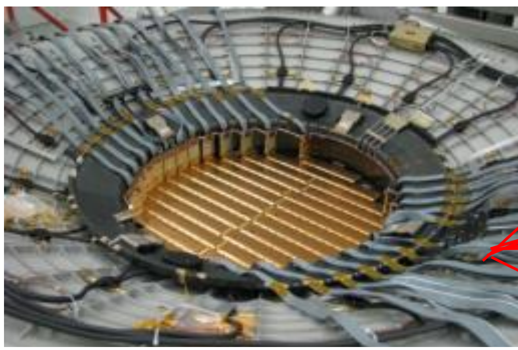

AMS
5m x 4m x 3m
7.5 tons

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

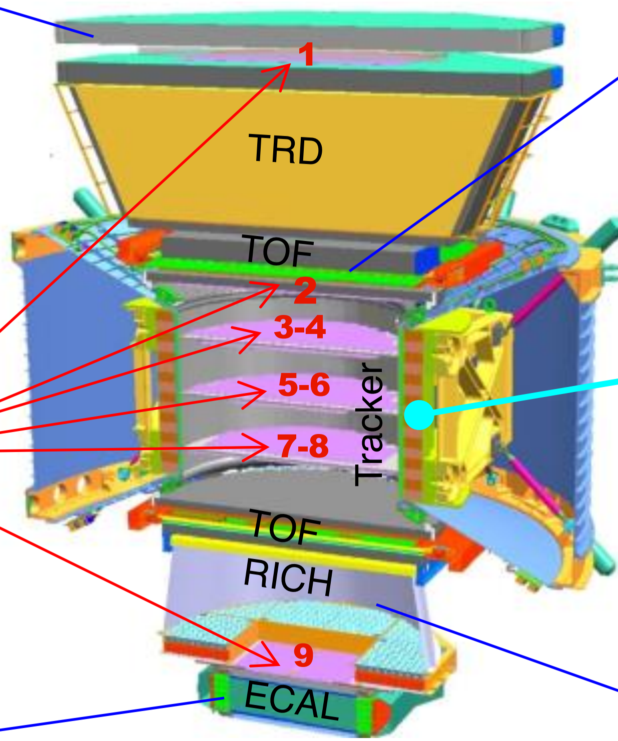
Particles and nuclei are defined by their charge (Z) and energy (E) or momentum (P). Rigidity R = P/Z

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

Silicon Tracker: Z, P

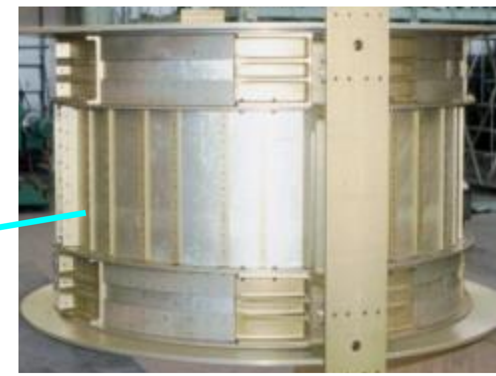


ECAL: E of e^+, e^-



TOF: Z, E

Magnet: ±Z



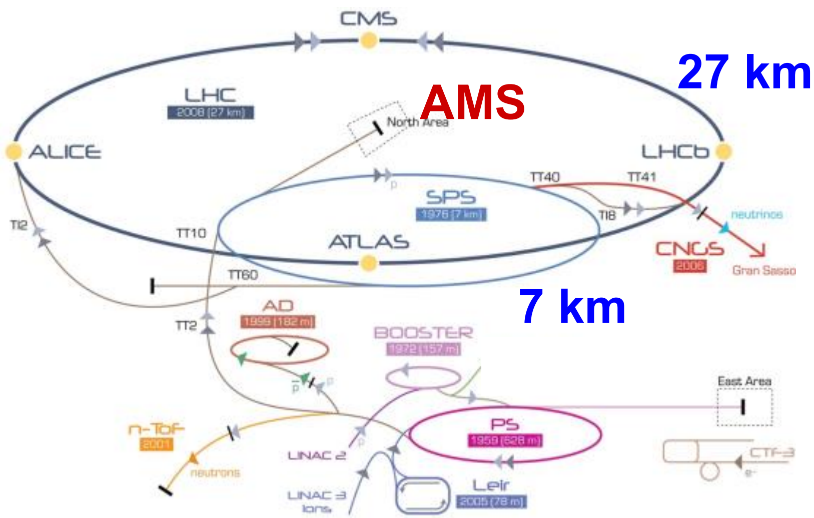
RICH: Z, E

Z and P

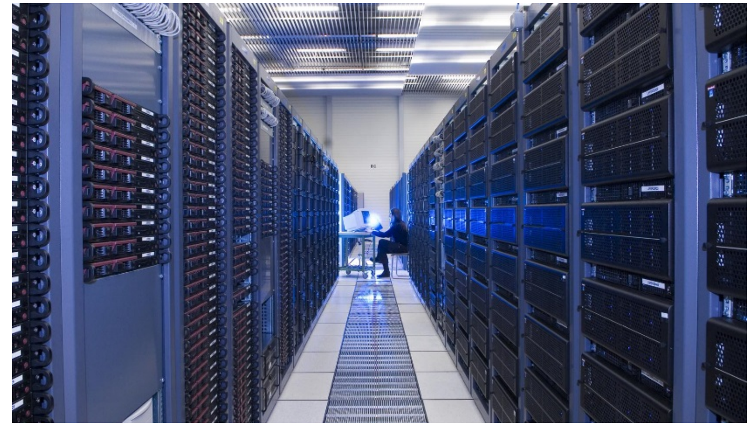
are measured independently by the Tracker, RICH, TOF and ECAL

Calibration of the AMS Detector

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

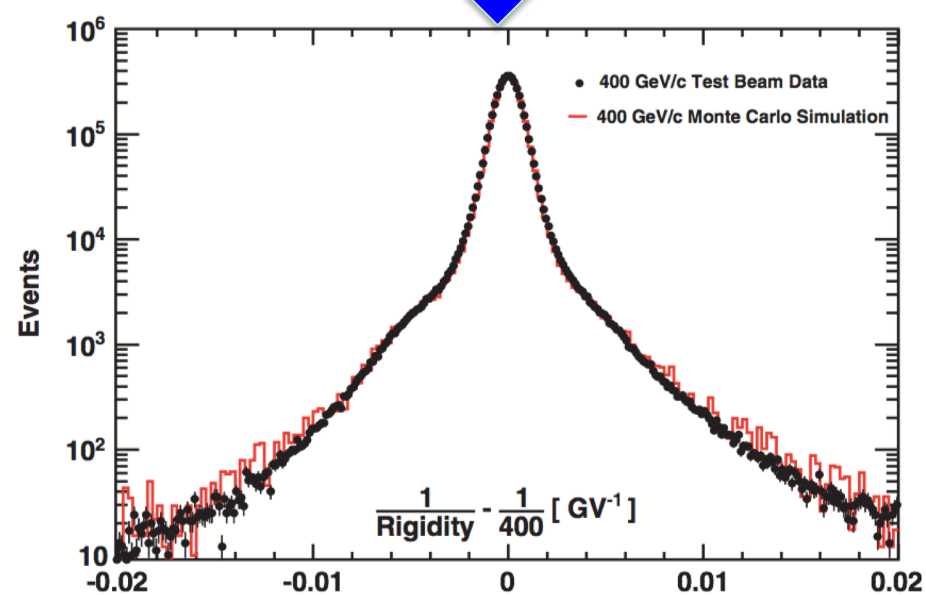


12,000 CPU cores at CERN

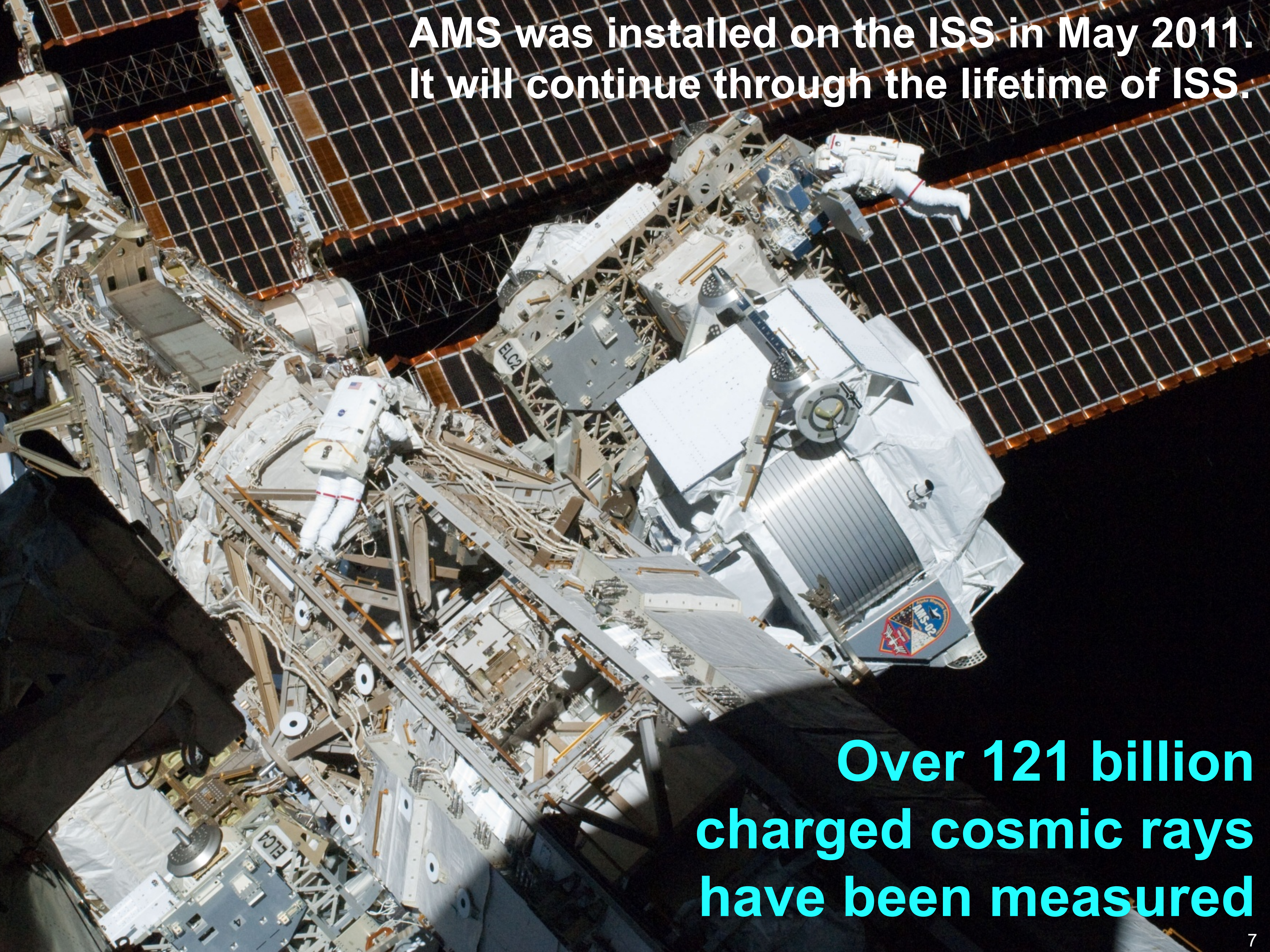


Computer simulation:
Interactions, Materials, Electronics

2000 positions

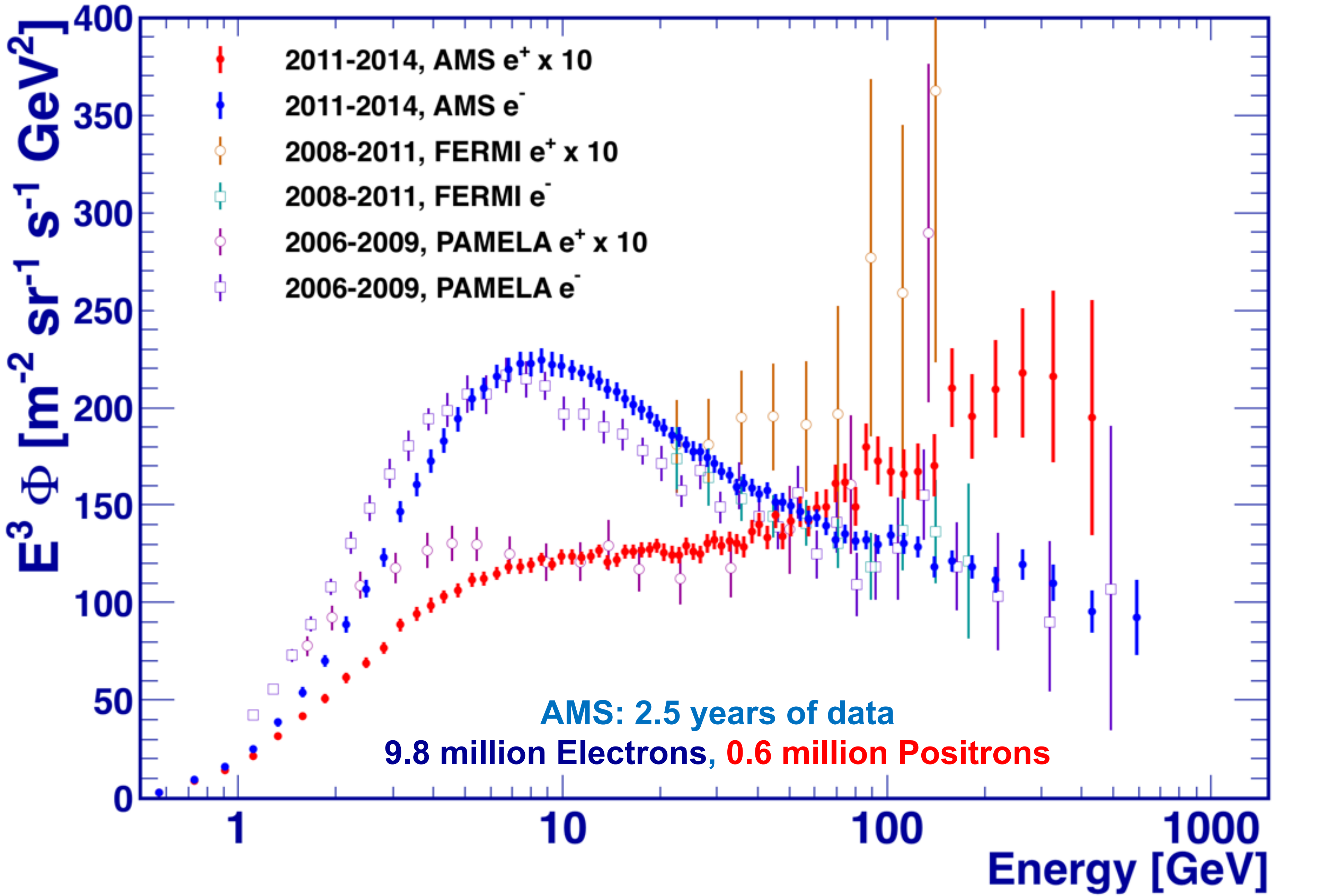


AMS was installed on the ISS in May 2011.
It will continue through the lifetime of ISS.



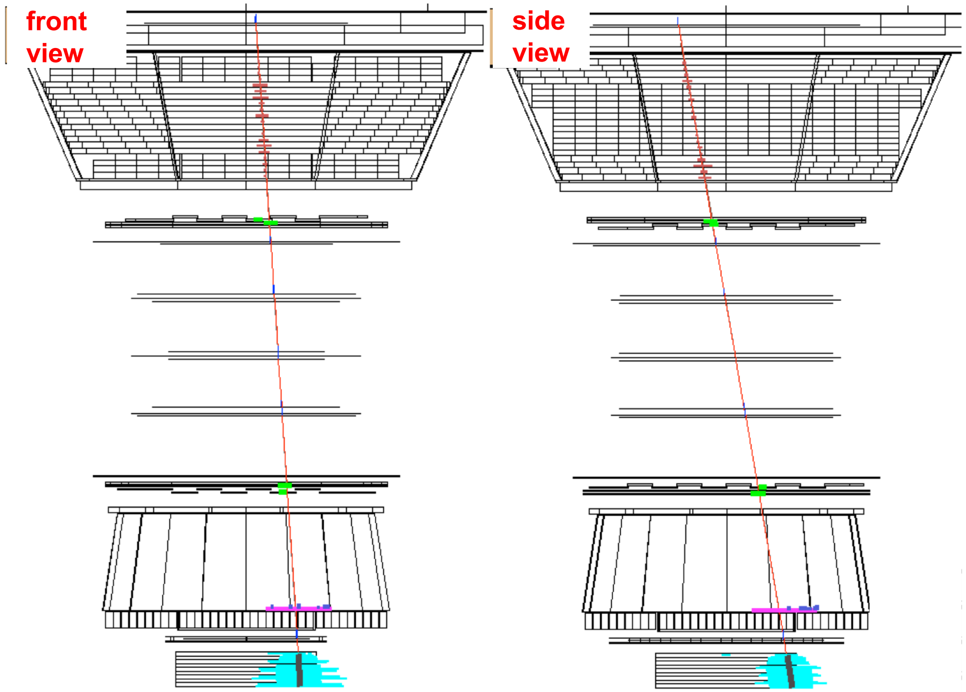
Over 121 billion
charged cosmic rays
have been measured

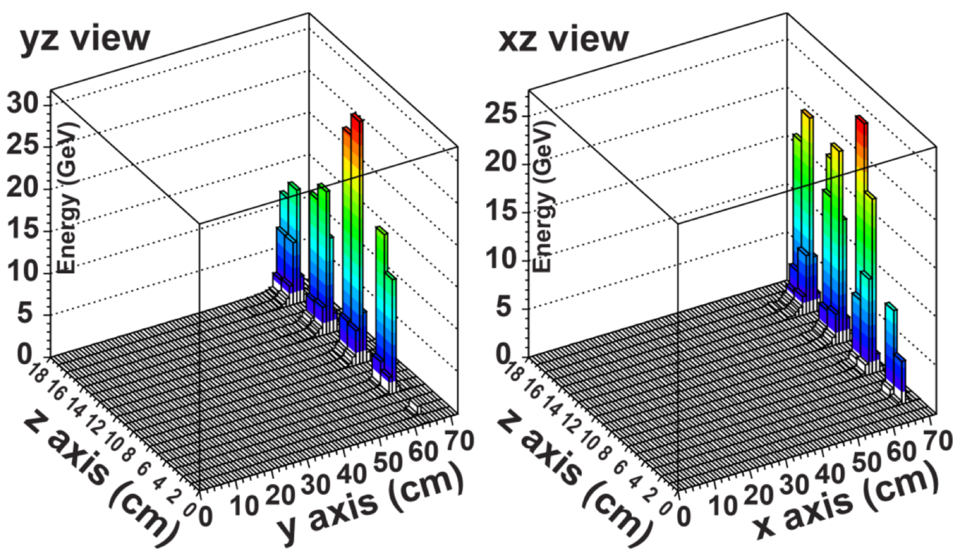
Recent Measurements of the Cosmic Ray Electron and Positron Fluxes



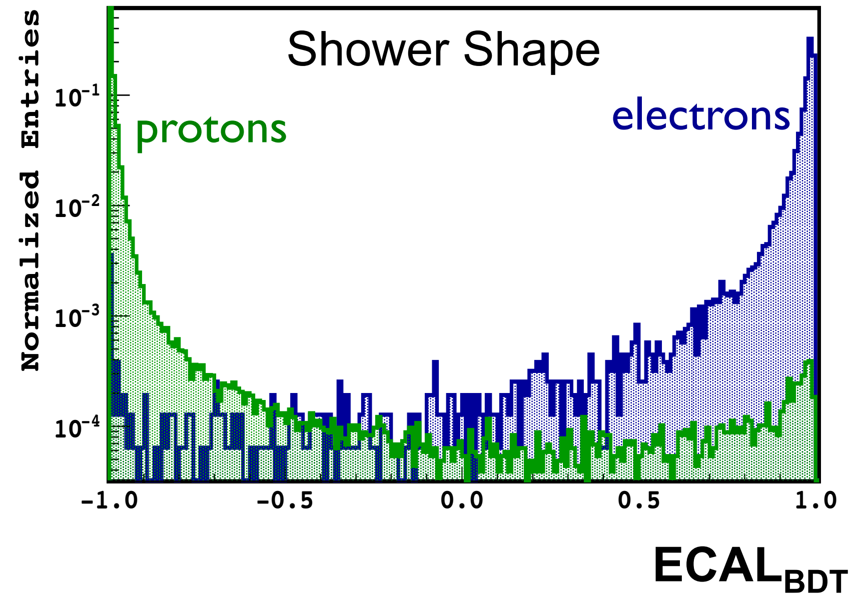
Positron E=636 GeV

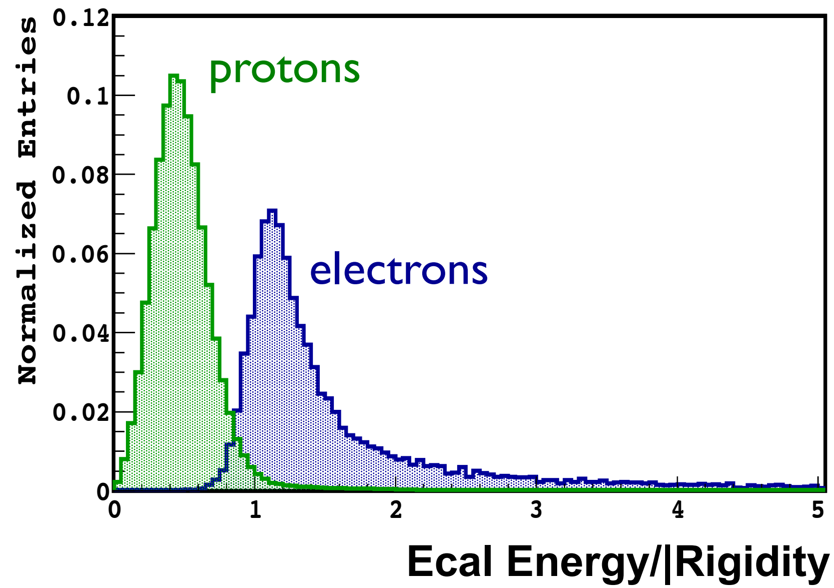
Run/Event 133119-743/ 56950



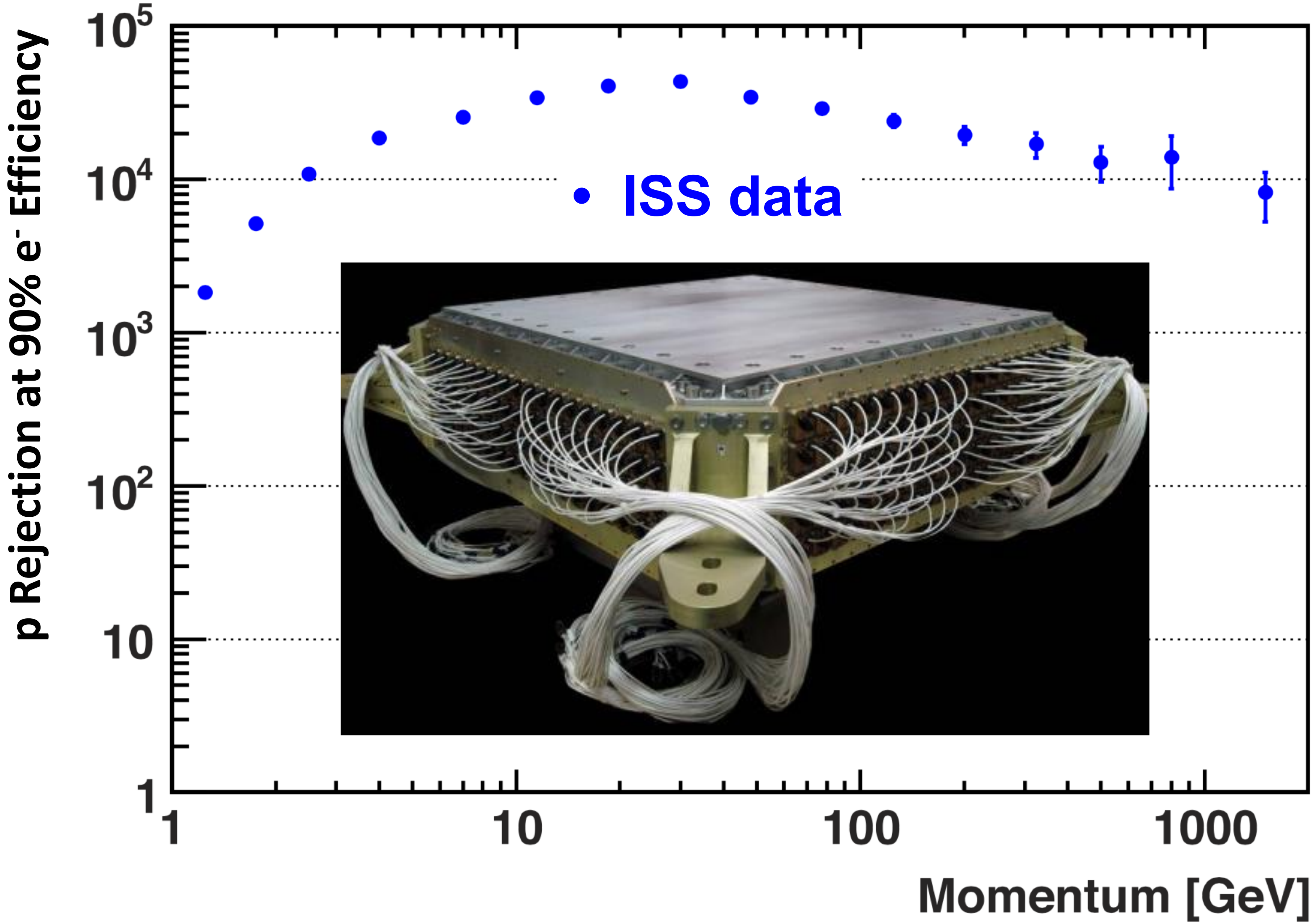


ECAL$_{BDT}$: Combination of multiple correlated observables into one estimator.





Proton Rejection by ECAL and Tracker

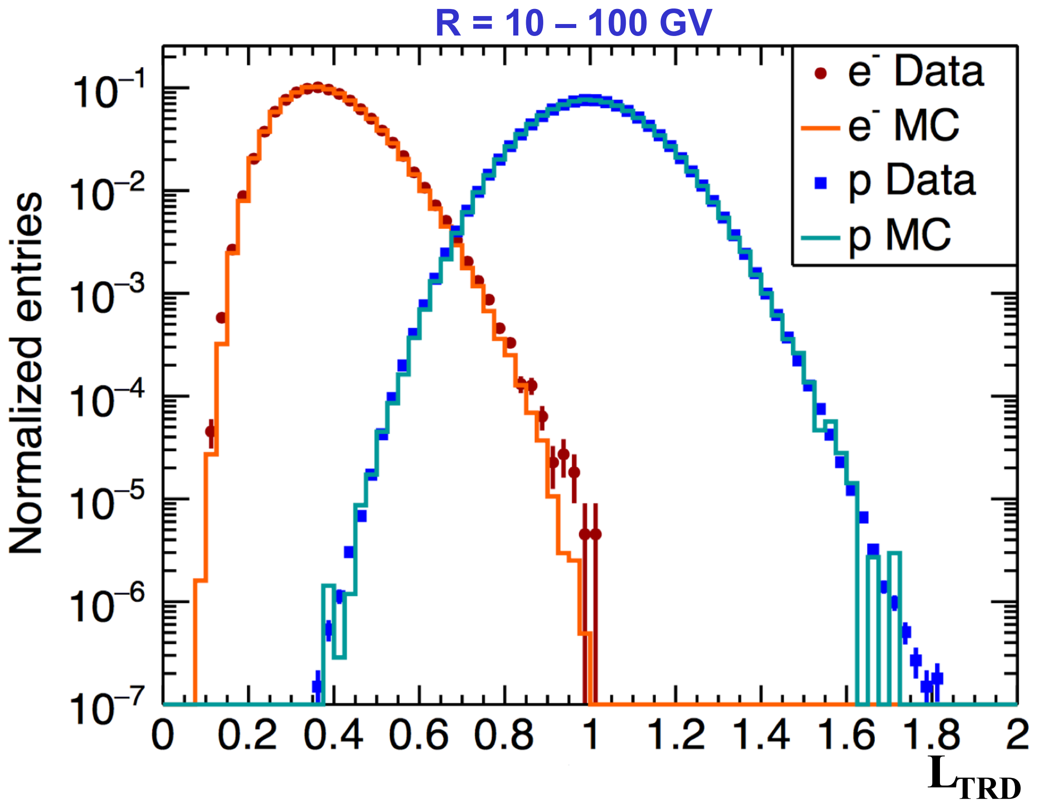


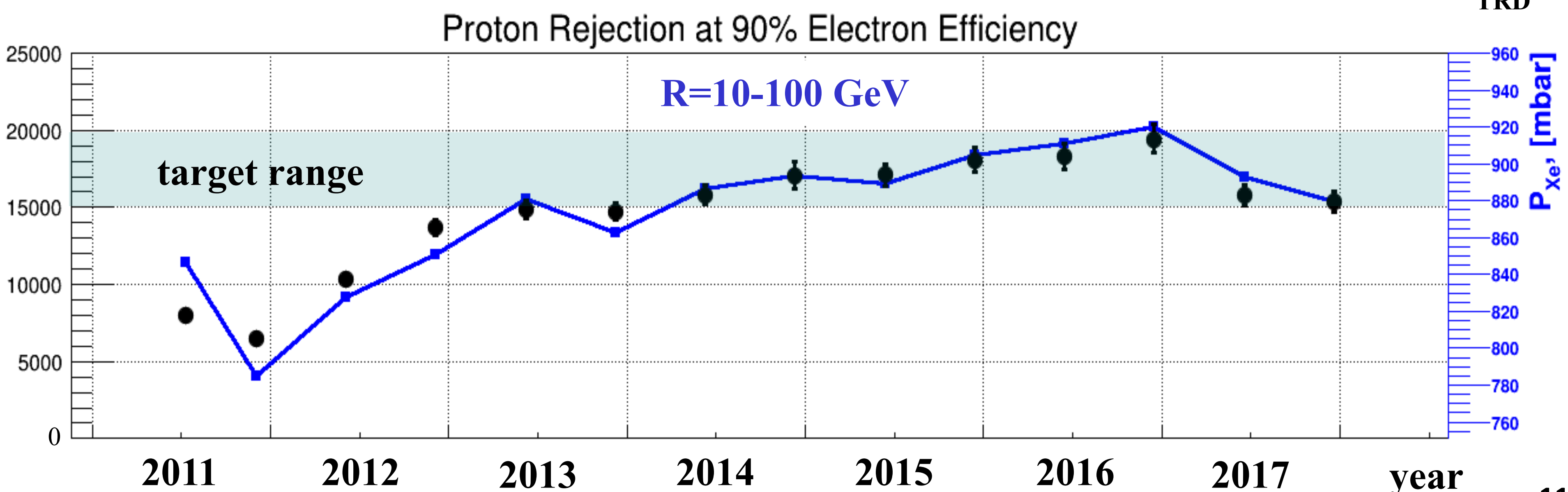
A. Kounine et al., NIM A 869 (2017) 110–117

AMS TRD Performance in Space

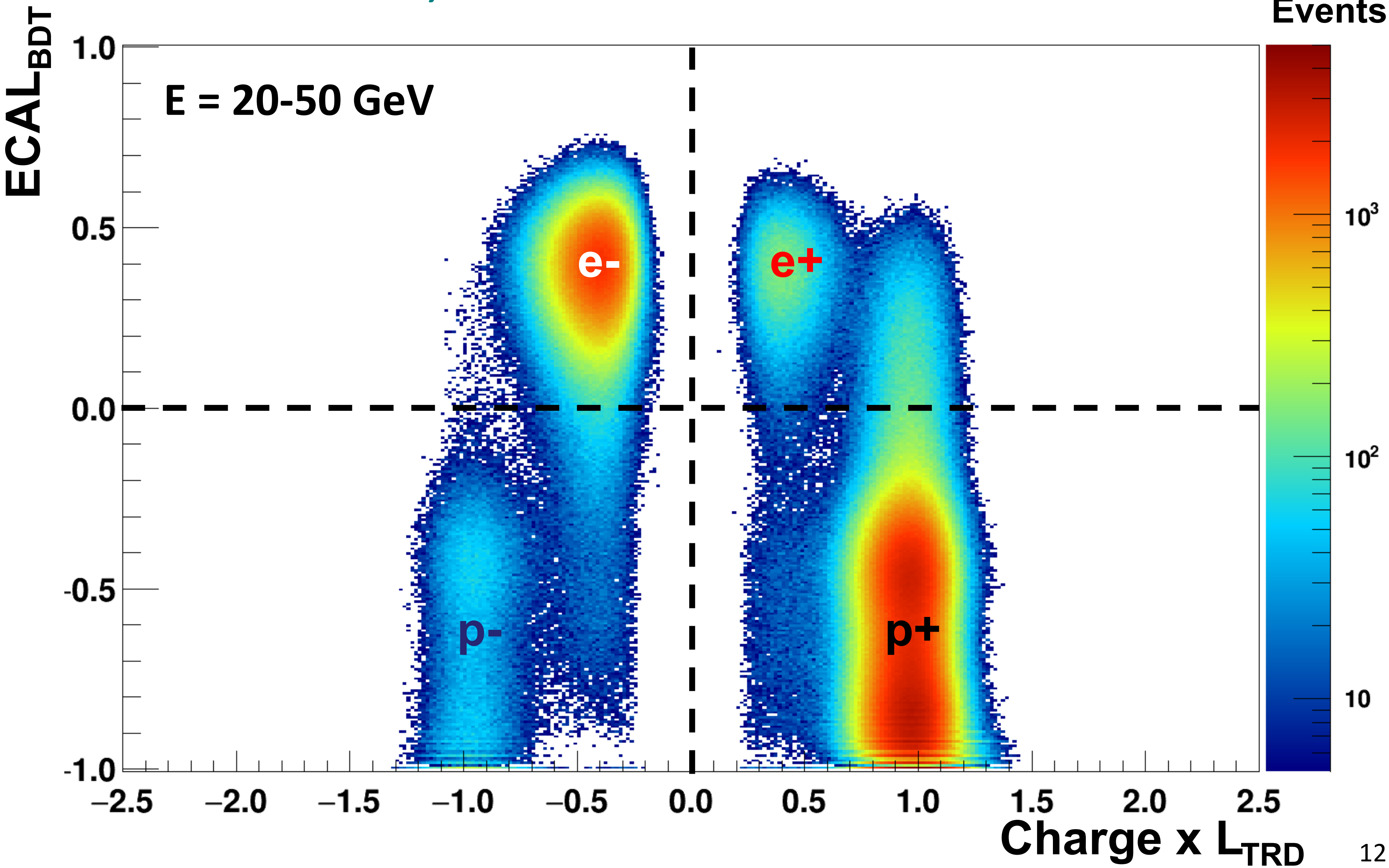
$$L_{e,p} = \sqrt[n]{\prod_i^n p_{e,p}(dE_i/dx_i)}$$

$$L_{\mathrm{TRD}} = -\log \frac{L_e}{L_e + L_p}$$

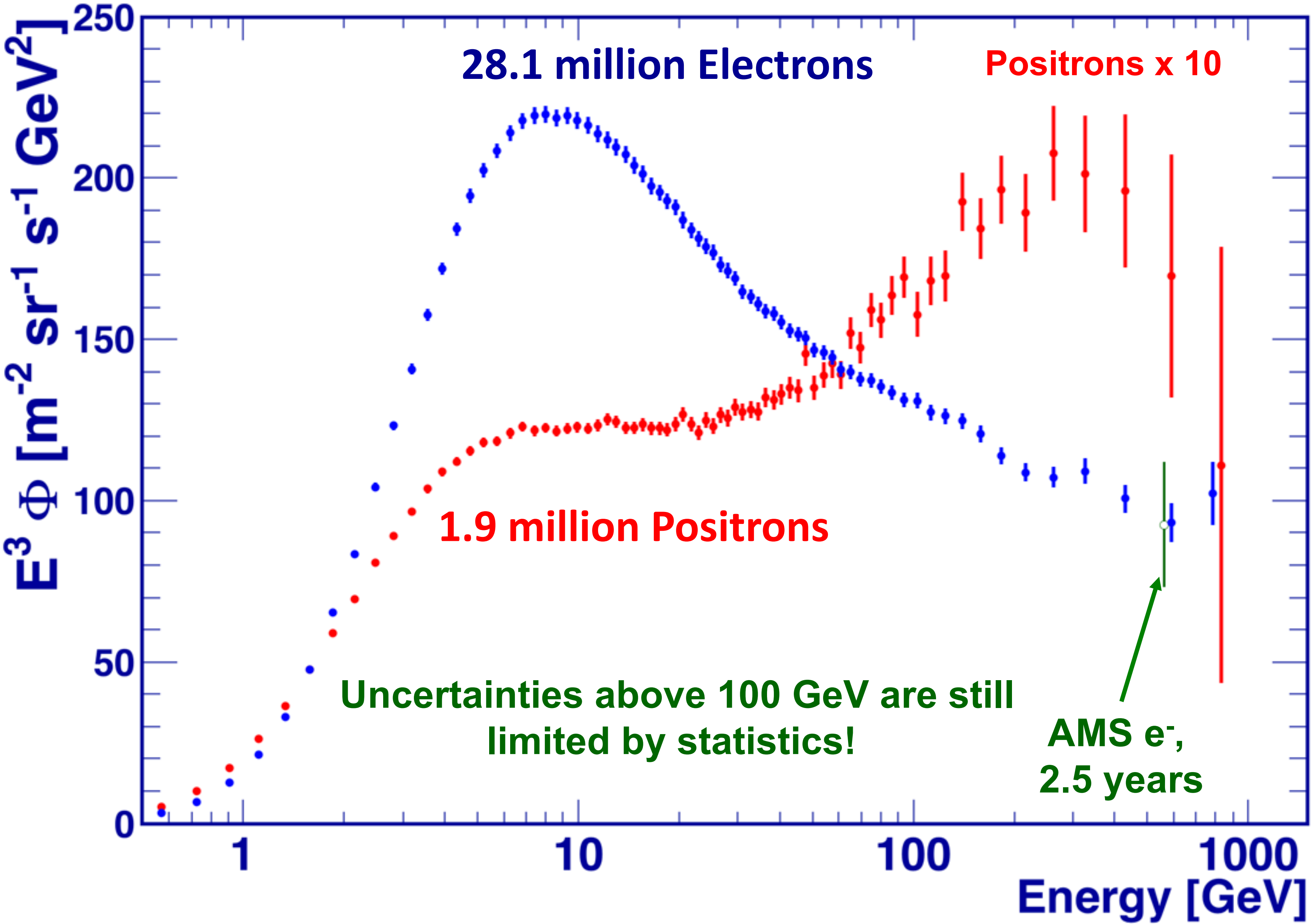




Due to its magnetic spectrometer AMS can accurately identify four components combining the Tracker, ECAL - and TRD - Measurements.



AMS results on Positron and Electron fluxes from 6.5 years



A sample of papers on AMS data from more than 2300 publications

Dark Matter explaining the AMS e+ data

1) J. Kopp, Phys. Rev. D 88, 076013 (2013);
2) L. Feng, R.Z. Yang, H.N. He, T.K. Dong, Y.Z. Fan and J. Chang Phys.Lett. B728 (2014) 250
3) M. Cirelli, M. Kadastik, M. Raidal and A. Strumia ,Nucl.Phys. B873 (2013) 530
4) M. Ibe, S. Iwamoto, T. Moroi and N. Yokozaki, JHEP 1308 (2013) 029
5) Y. Kajiyama and H. Okada, Eur.Phys.J. C74 (2014) 2722
6) K.R. Dienes and J. Kumar, Phys.Rev. D88 (2013) 10, 103509
7) L. Bergstrom, T. Bringmann, I. Cholis, D. Hooper and C. Weniger, PRL 111 (2013) 171101
8) K. Kohri and N. Sahu, Phys.Rev. D88 (2013) 10, 103001
9) A. Ibarra, A.S. Lamperstorfer and J. Silk, Phys.Rev. D89 (2014) 063539
10) Y. Zhao and K.M. Zurek, JHEP 1407 (2014) 017
11) C. H. Chen, C. W. Chiang, and T. Nomura, Phys. Lett. B 747, 495 (2015)
12) H. B. Jin, Y. L. Wu, and Y.-F. Zhou, Phys.Rev. D92, 055027 (2015)
13) A. Reinert and M. W. Winkler JCAP 01 (2018) 055

and many other excellent papers **…**

New Propagation Models explaining the AMS e+ data

1) R.Cowsik, B.Burch, and T.Madziwa-Nussinov, Ap.J. 786 (2014) 124
2) K. Blum, B. Katz and E. Waxman, Phys.Rev.Lett. 111 (2013) 211101
3) R. Kappl and M. W. Winkler, J. Cosmol. Astropart. Phys. 09 (2014) 051
4) G.Giesen, M.Boudaud, Y.Gènolini, V.Poulin, M.Cirelli, P.Salati and P.D.Serpico, JCAP09 (2015) 023;
5) C.Evoli, D.Gaggero and D.Grasso, JCAP 12 (2015) 039.
6) R.Kappl, A.Reinert, and M.W.Winkler, arXiv:1506.04145 (2015)

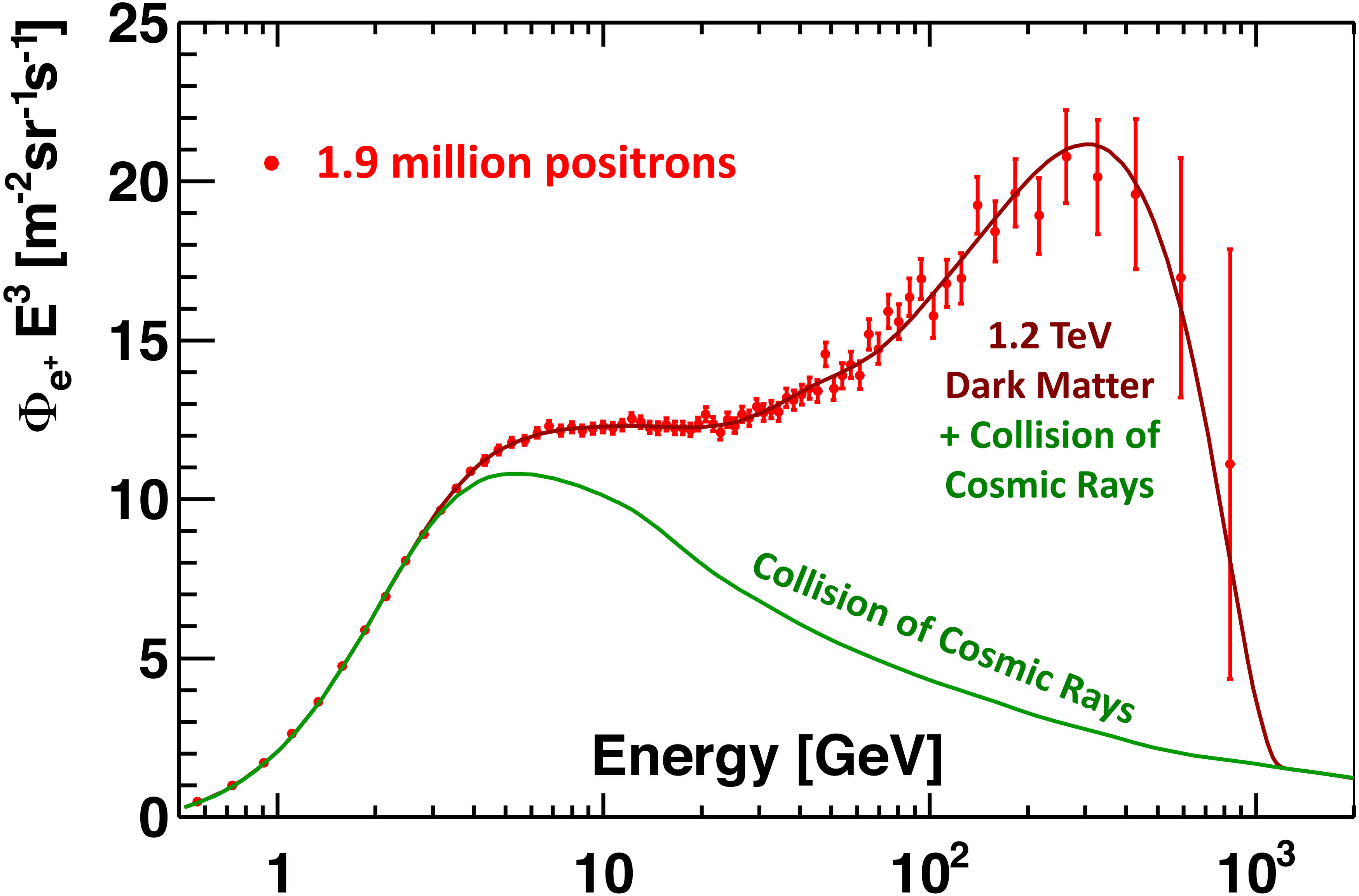
and many other excellent papers …

New Astrophysical Sources explaining the AMS e+ data

1) T. Linden and S. Profumo, Astrophys.J. 772 (2013) 18
2) P. Mertsch and S. Sarkar, Phys.Rev. D 90 (2014) 061301
3) I. Cholis and D. Hooper, Phys.Rev. D88 (2013) 023013
4) A. Erlykin and A.W. Wolfendale, Astropart.Phys. 49 (2013) 23
5) P.F. Yin, Z.H. Yu, Q. Yuan and X.J. Bi, Phys.Rev. D88 (2013) 2, 023001
6) A.D. Erlykin and A.W. Wolfendale, Astropart.Phys. 50-52 (2013) 47
7) E. Amato, Int.J.Mod.Phys.Conf.Ser. 28 (2014) 1460160
8) P. Blasi, Braz.J.Phys. 44 (2014) 426
9) D. Gaggero, D. Grasso, L. Maccione, G. DiBernardo and C Evoli, Phys.Rev. D89 (2014) 083007
10) M. DiMauro, F. Donato, N. Fornengo, R. Lineros and A. Vittino, JCAP 1404 (2014) 006
11) K. Kohri, K. Ioka, Y. Fujita, and R. Yamazaki, Prog. Theor. Exp. Phys. 2016, 021E01 (2016)

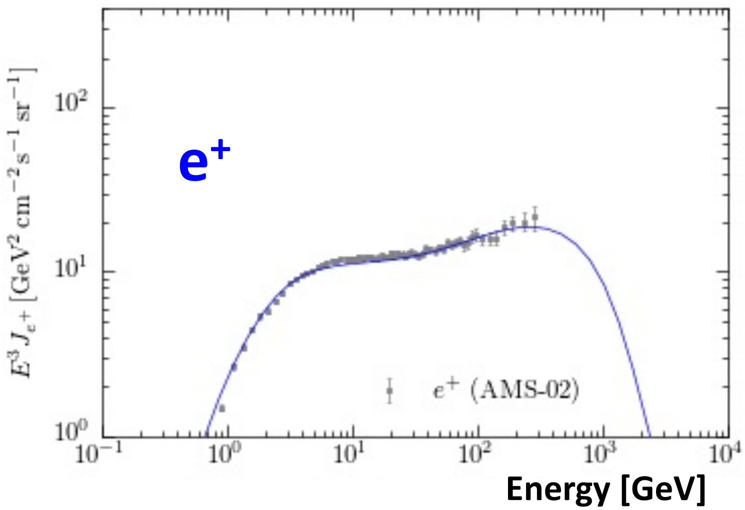
and many other excellent papers …

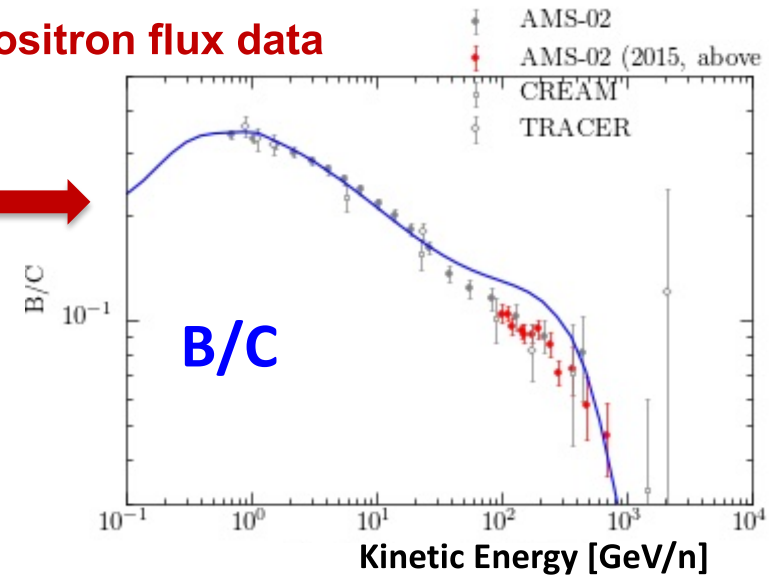
The positron flux appears to be in agreement with predictions from a 1.2 TeV Dark Matter model (J. Kopp, Phys. Rev. D 88, 076013 (2013))



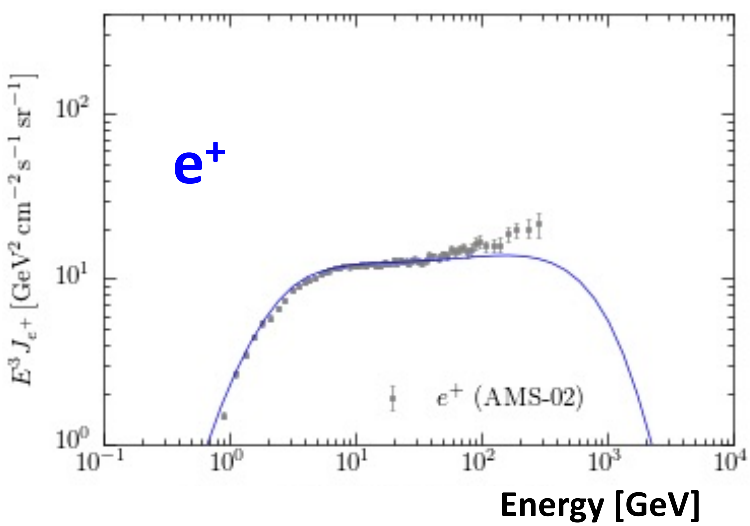
Astrophysical sources: Supernova Remnants

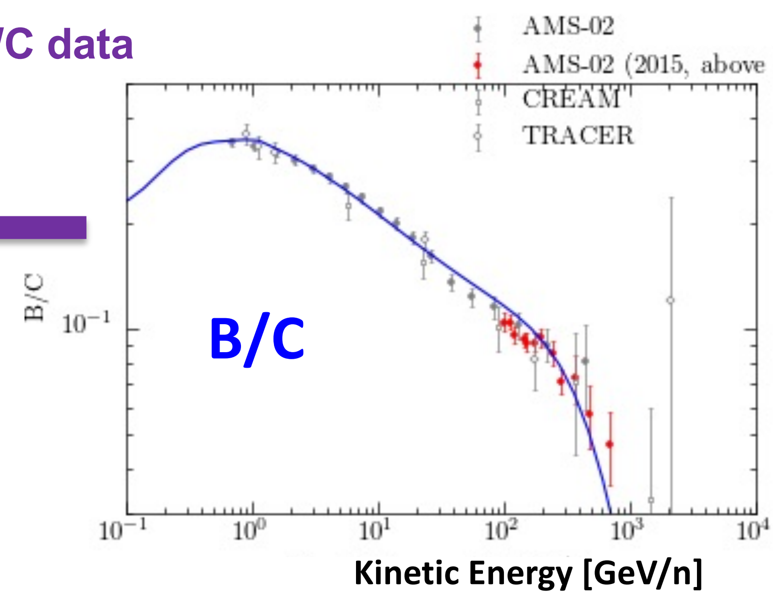
Model parameter tuned to fit the positron flux data





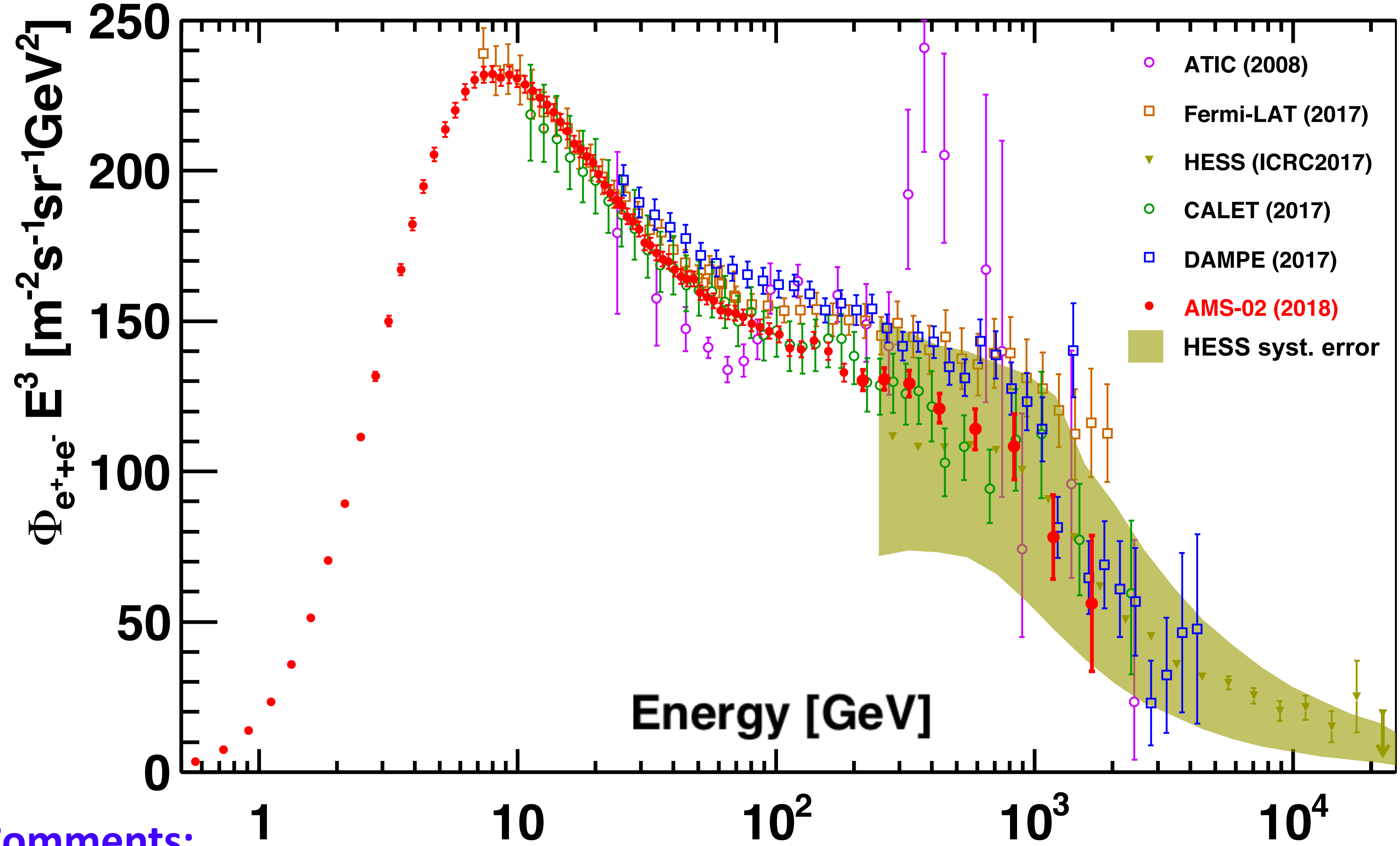
Model parameter tuned to fit the B/C data





P. Mertsch and S. Sarkar, Phys.Rev. D 90 (2014) 061301

$(e^+ + e^-)$ Measurements

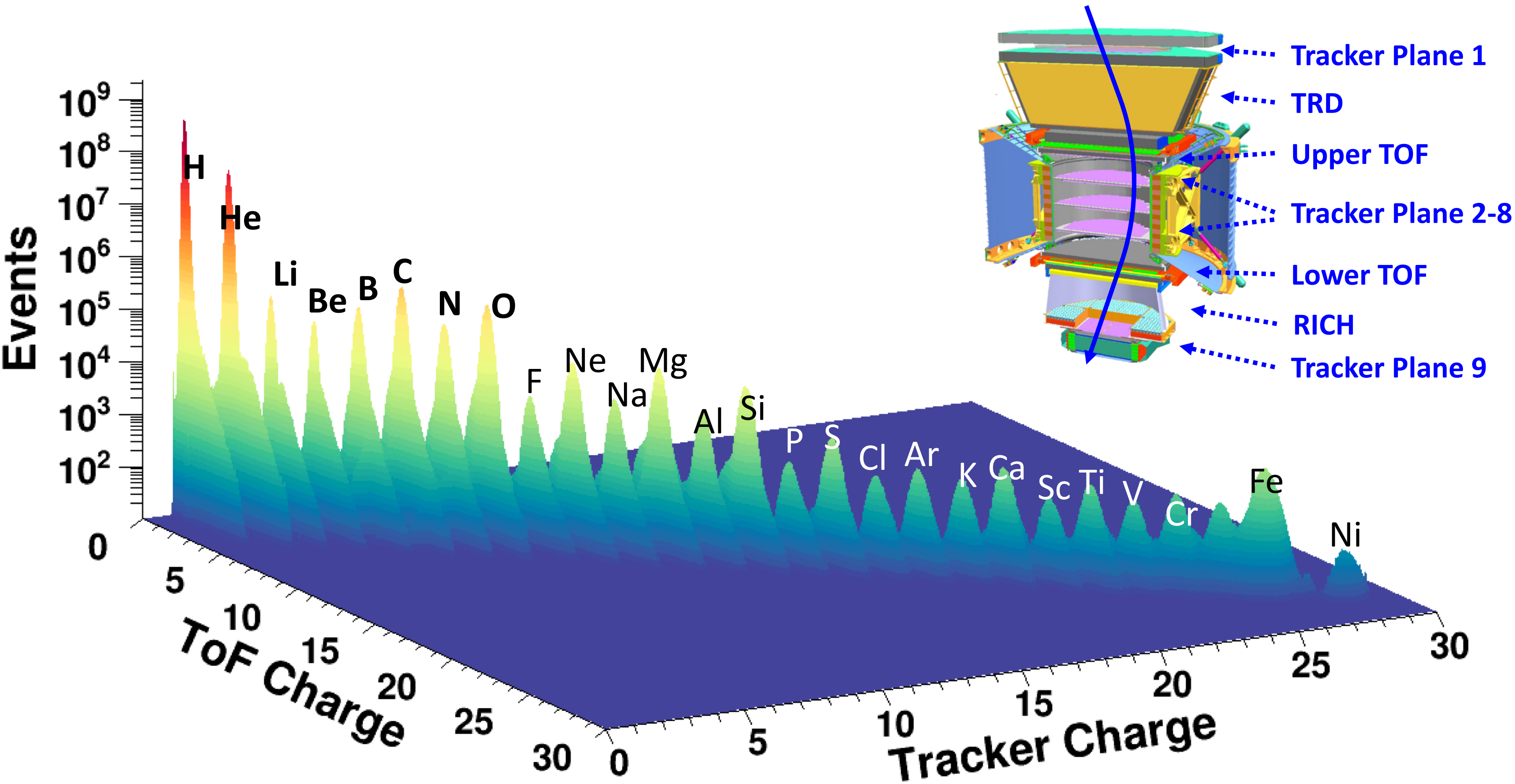


Comments:

1. HESS, DAMPE and AMS all observed a spectral break at ~ 1 TeV
2. The spectral break in the positron flux is at ~300 GeV, i.e. both phenomena might have a different origin.

Precision Measurements of Cosmic Rays:

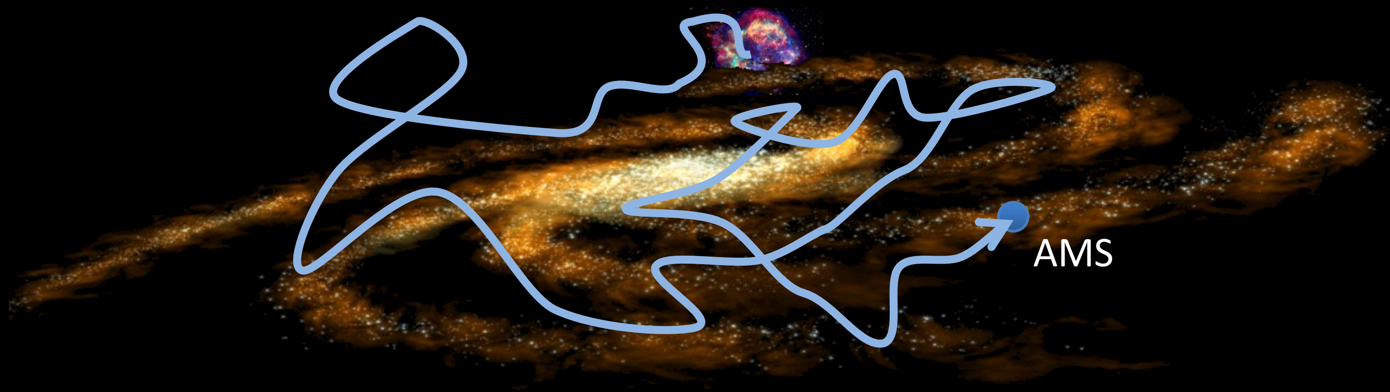
AMS has seven instruments which independently measure Cosmic Nuclei



Traditionally, there are two prominent classes of cosmic rays:

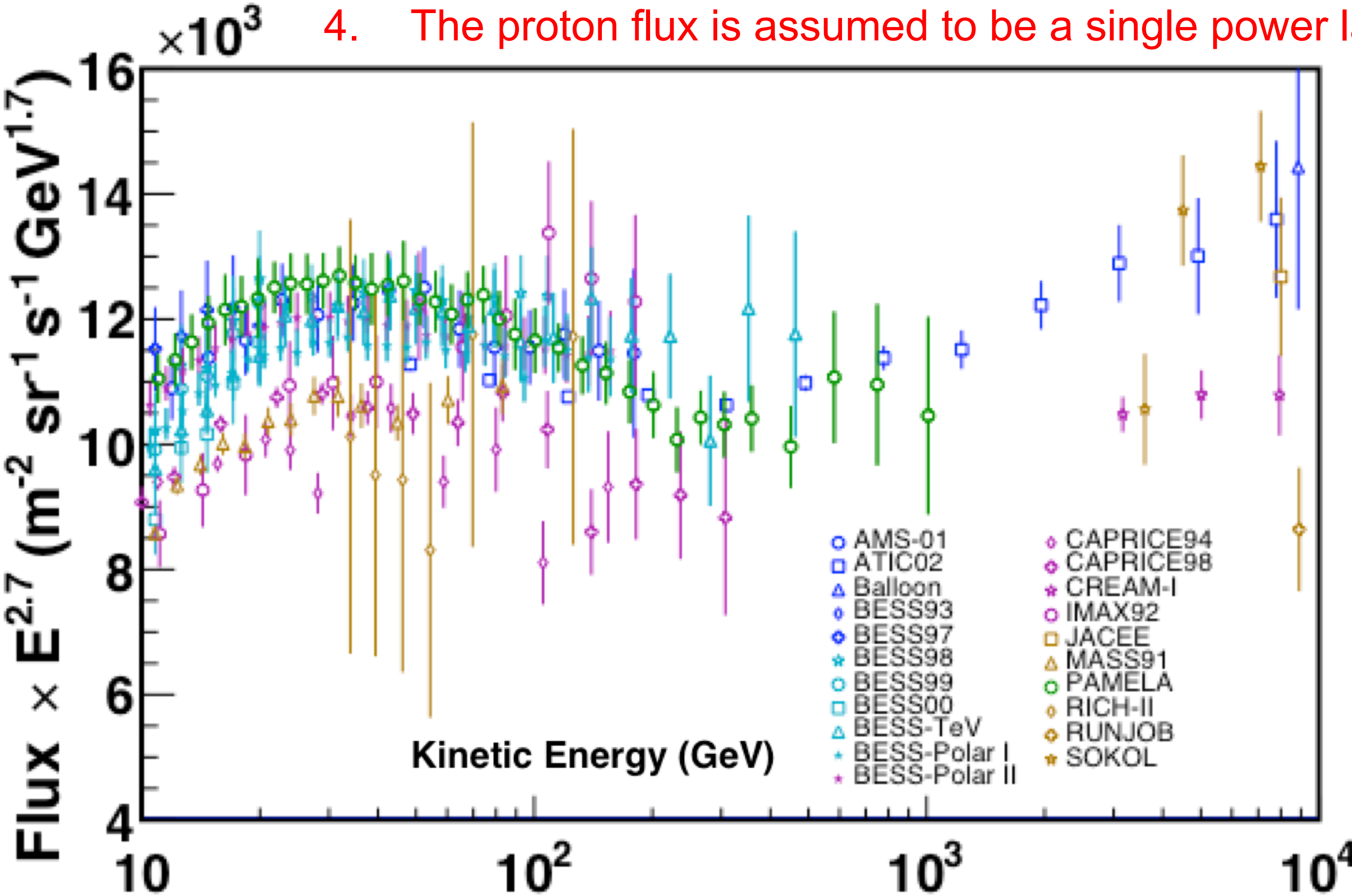
Primary Cosmic Rays (p, He, C, O, …)

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.

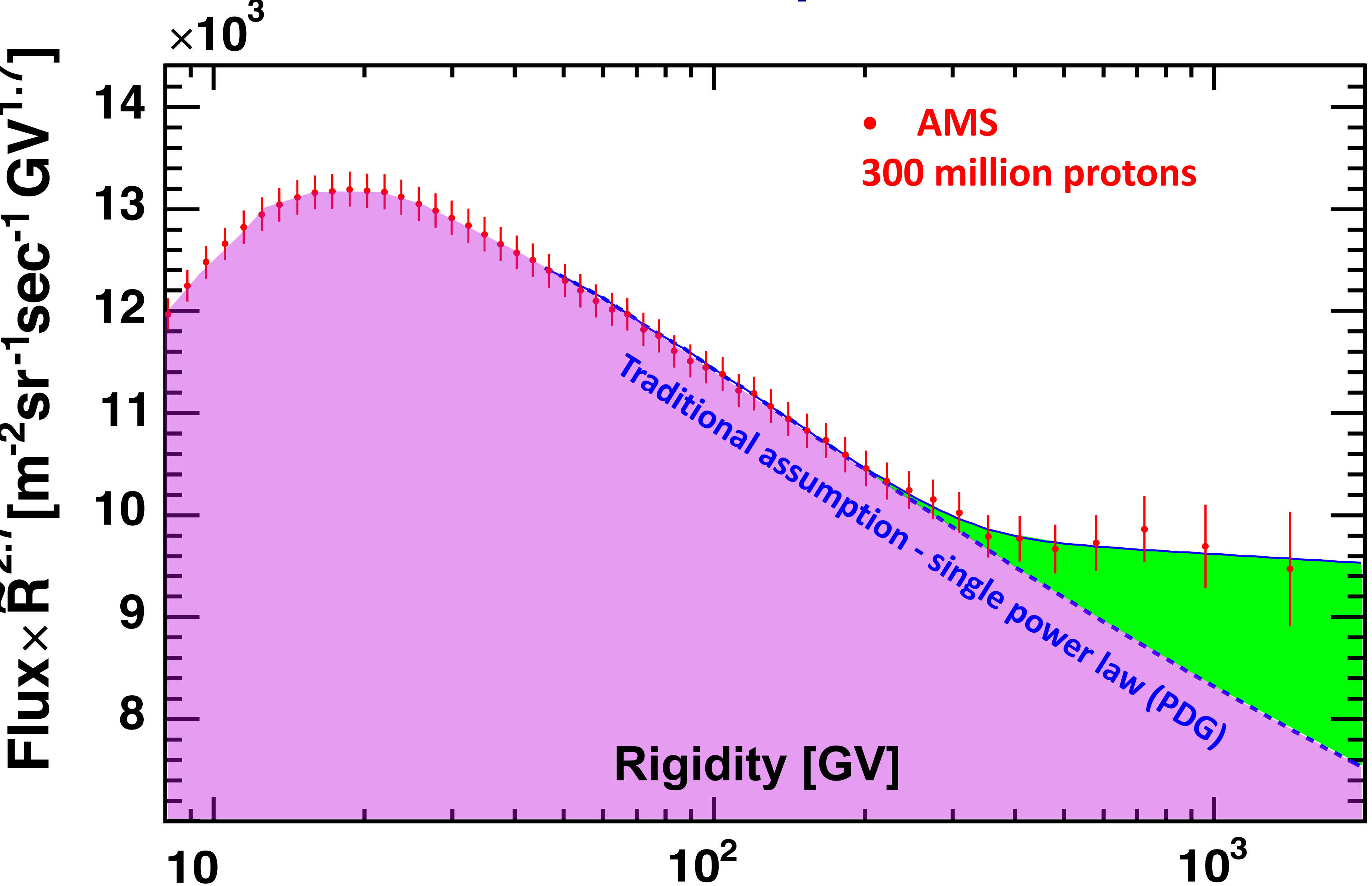


Measurements of proton spectrum before AMS

1. Protons are the most abundant charged cosmic rays.
2. Before AMS, there were many measurements but the data have large errors and are inconsistent.
3. These data limit the understanding of the production, acceleration and propagation of all cosmic rays.
4. The proton flux is assumed to be a single power law = CR^{γ}



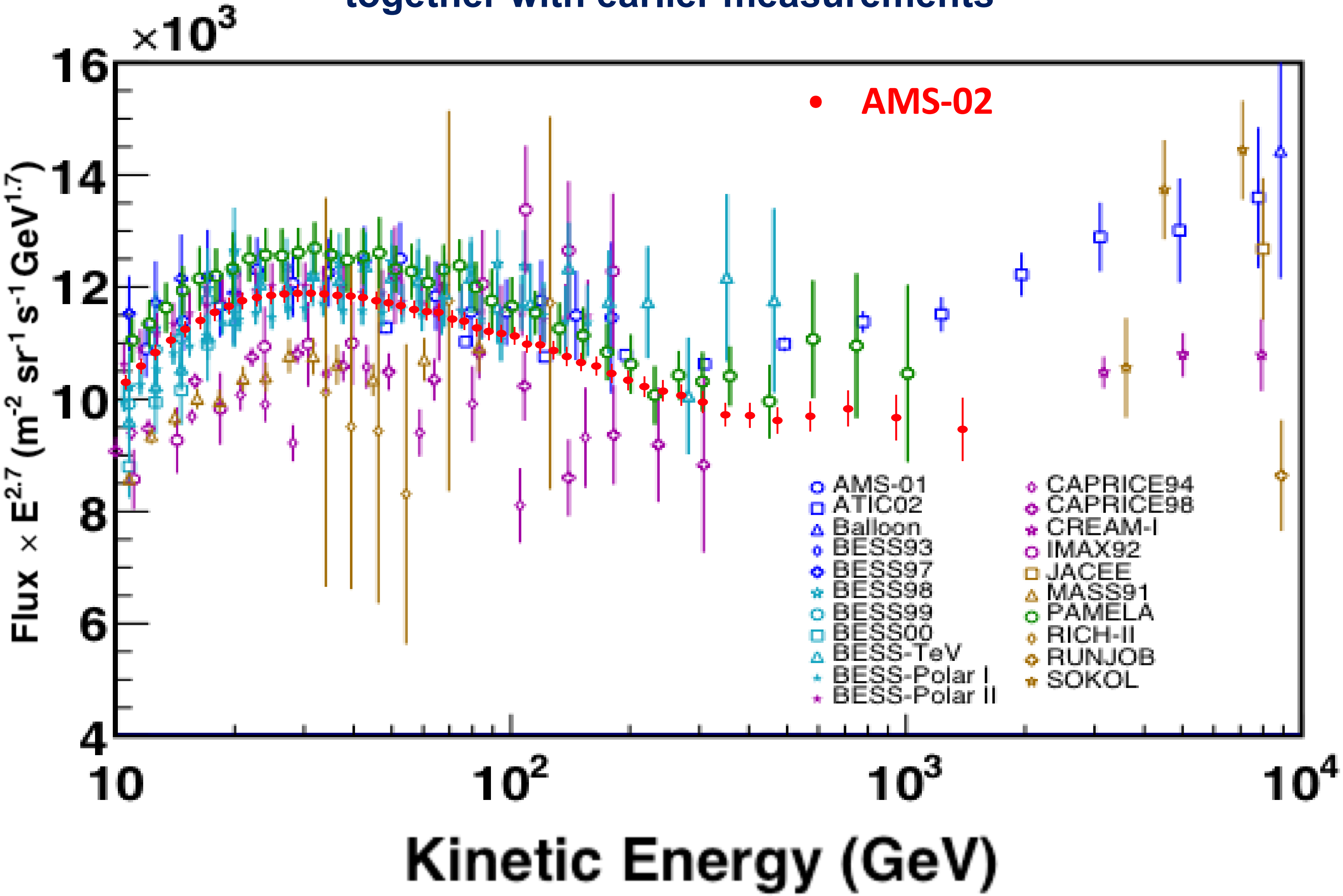
AMS results on the proton flux



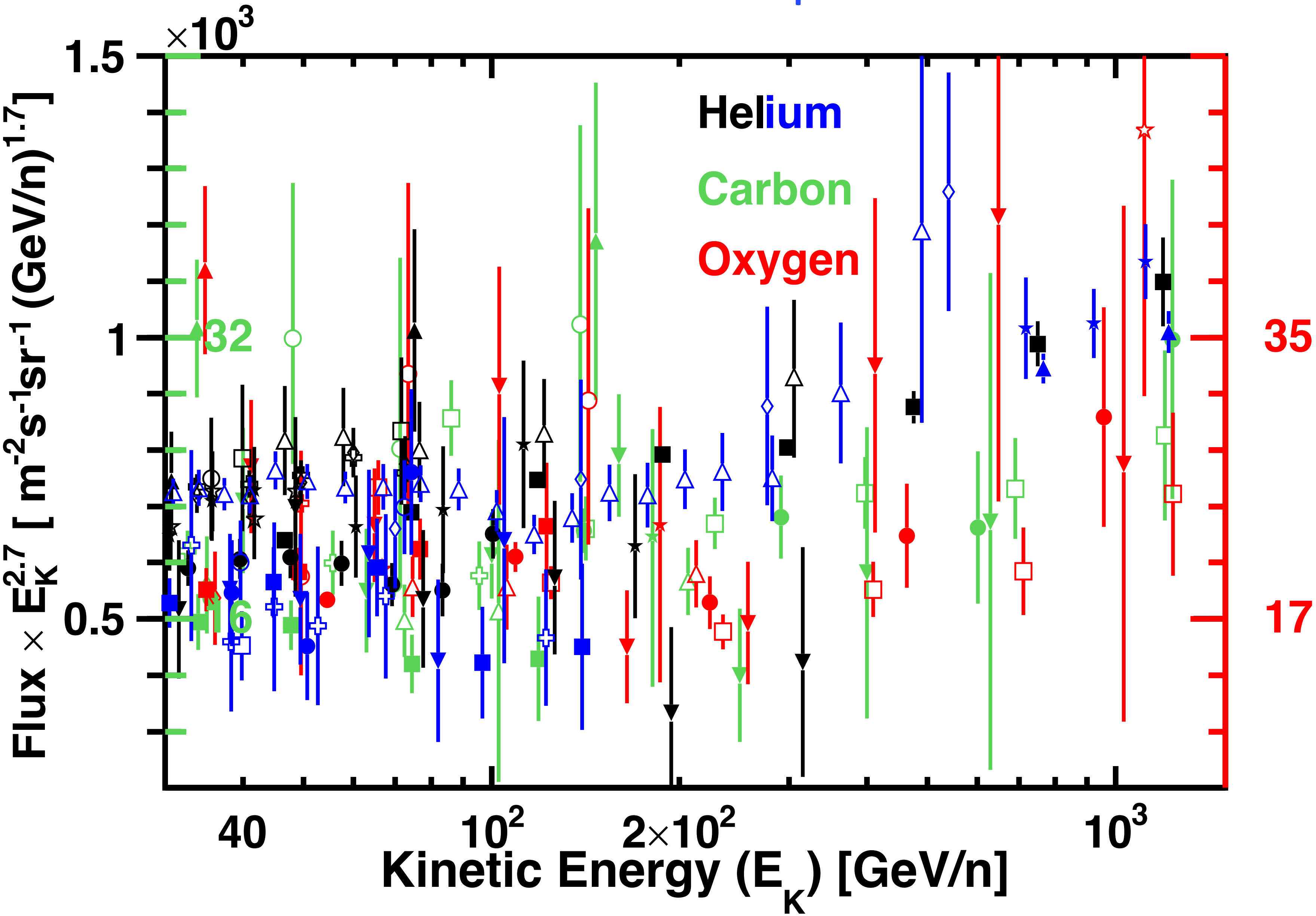
The proton flux **cannot** be described by a single power law = CR^{γ}

AMS Measurement of the proton spectrum

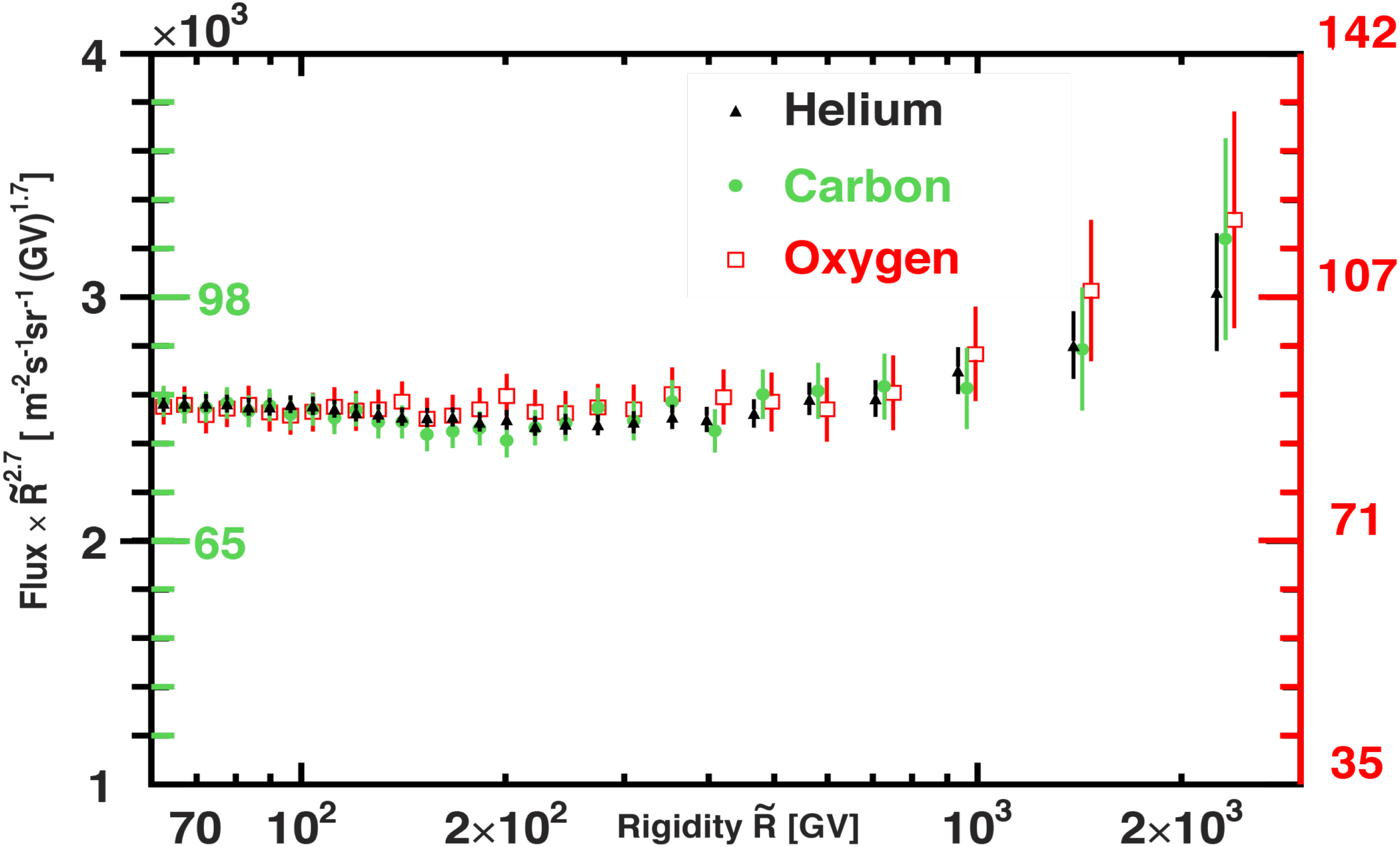
together with earlier measurements



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



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

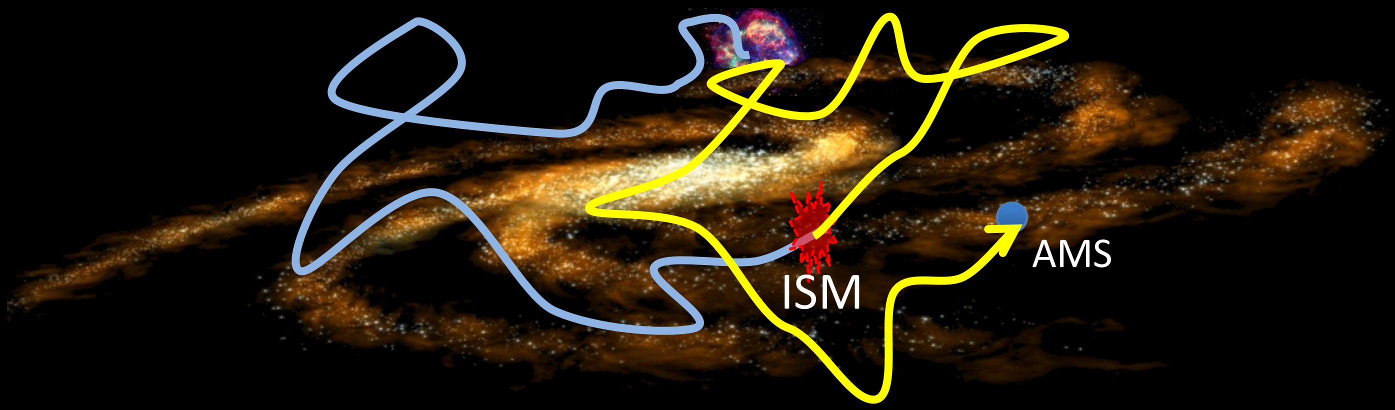


Above 200 GV the data all increase in identical way.

This is unexpected.

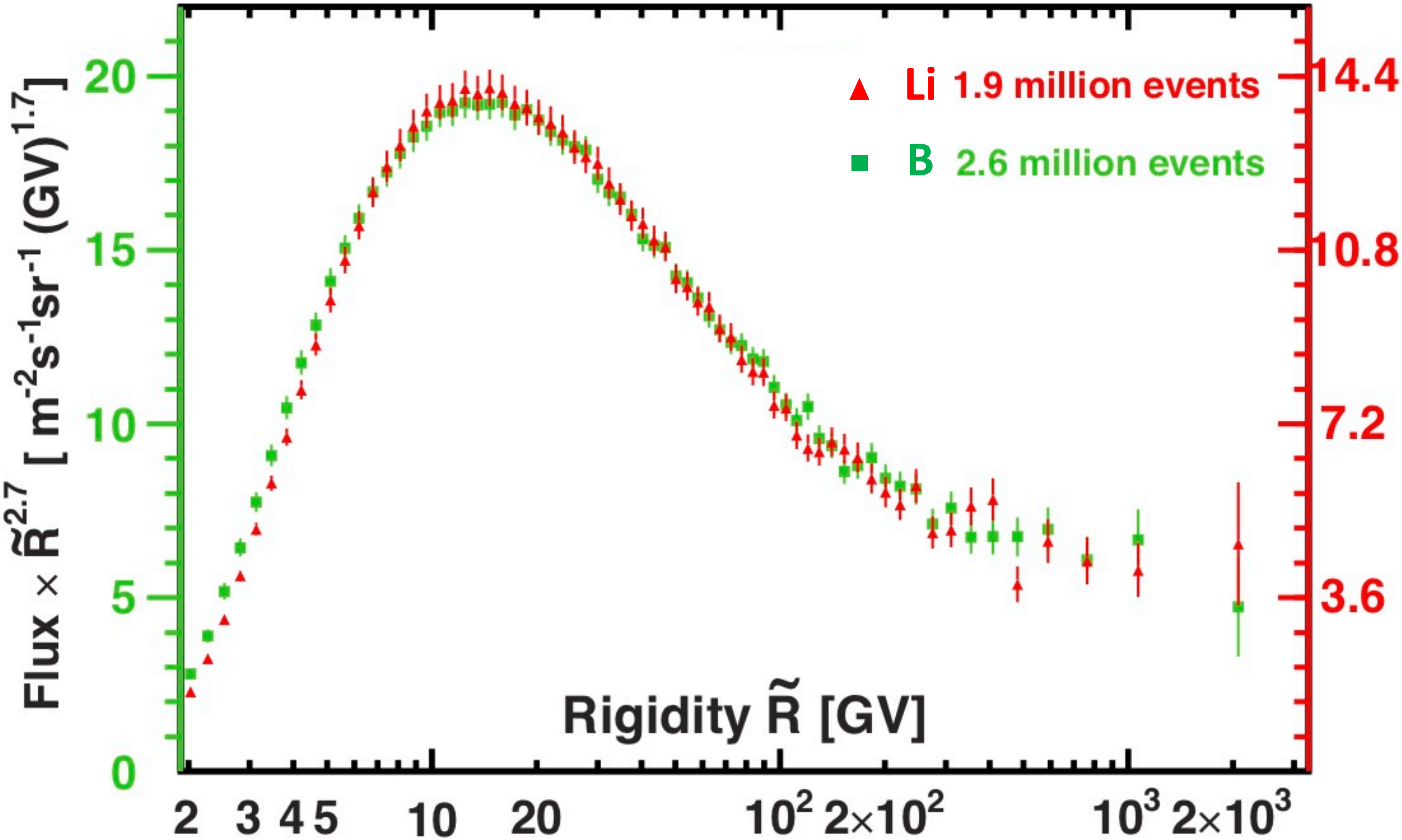
Secondary Cosmic Rays (Li, Be, B, …)

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.



Secondary Cosmic Rays: Lithium and Boron

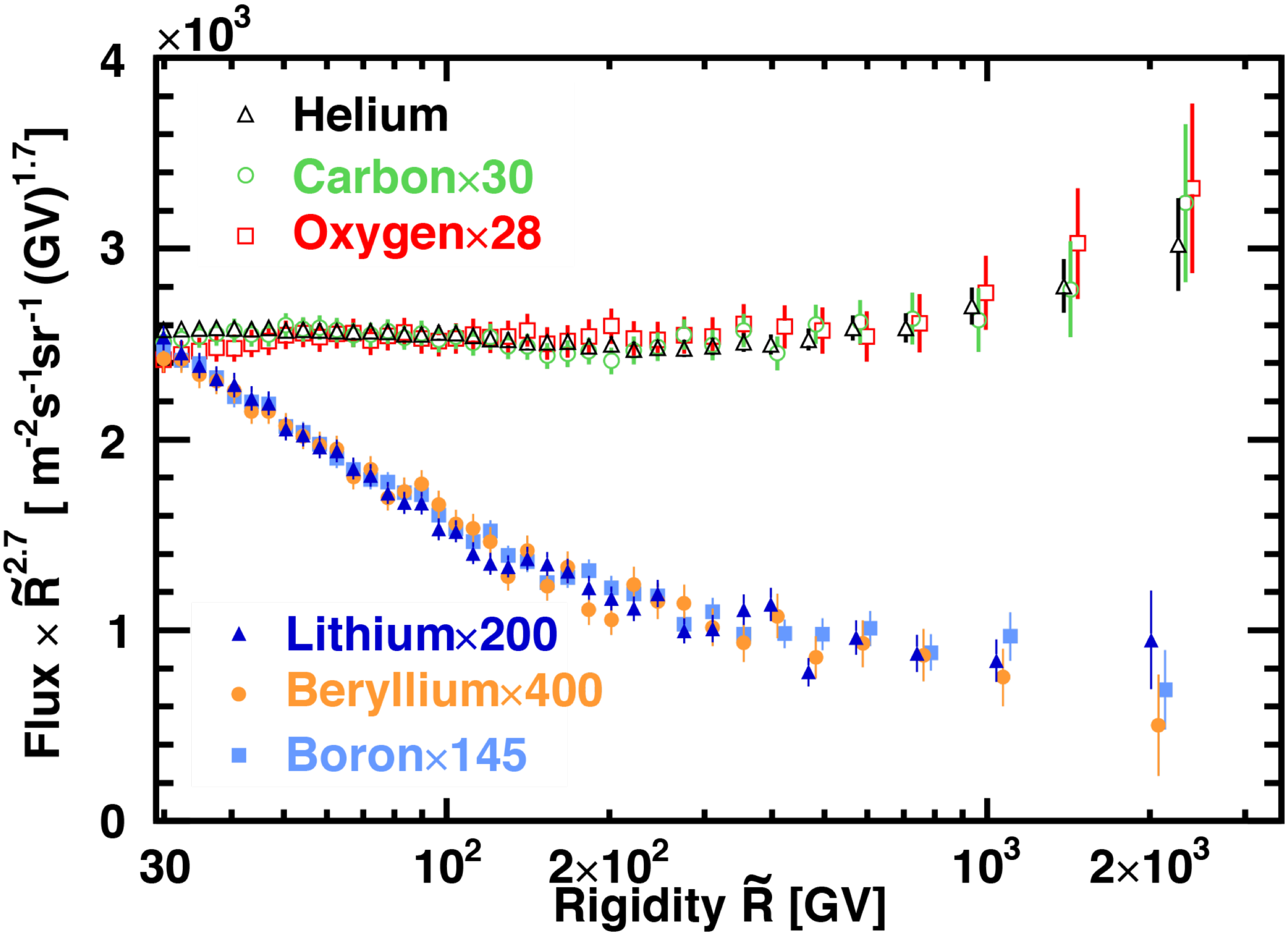
Above 7 GV Li and B have identical rigidity dependence



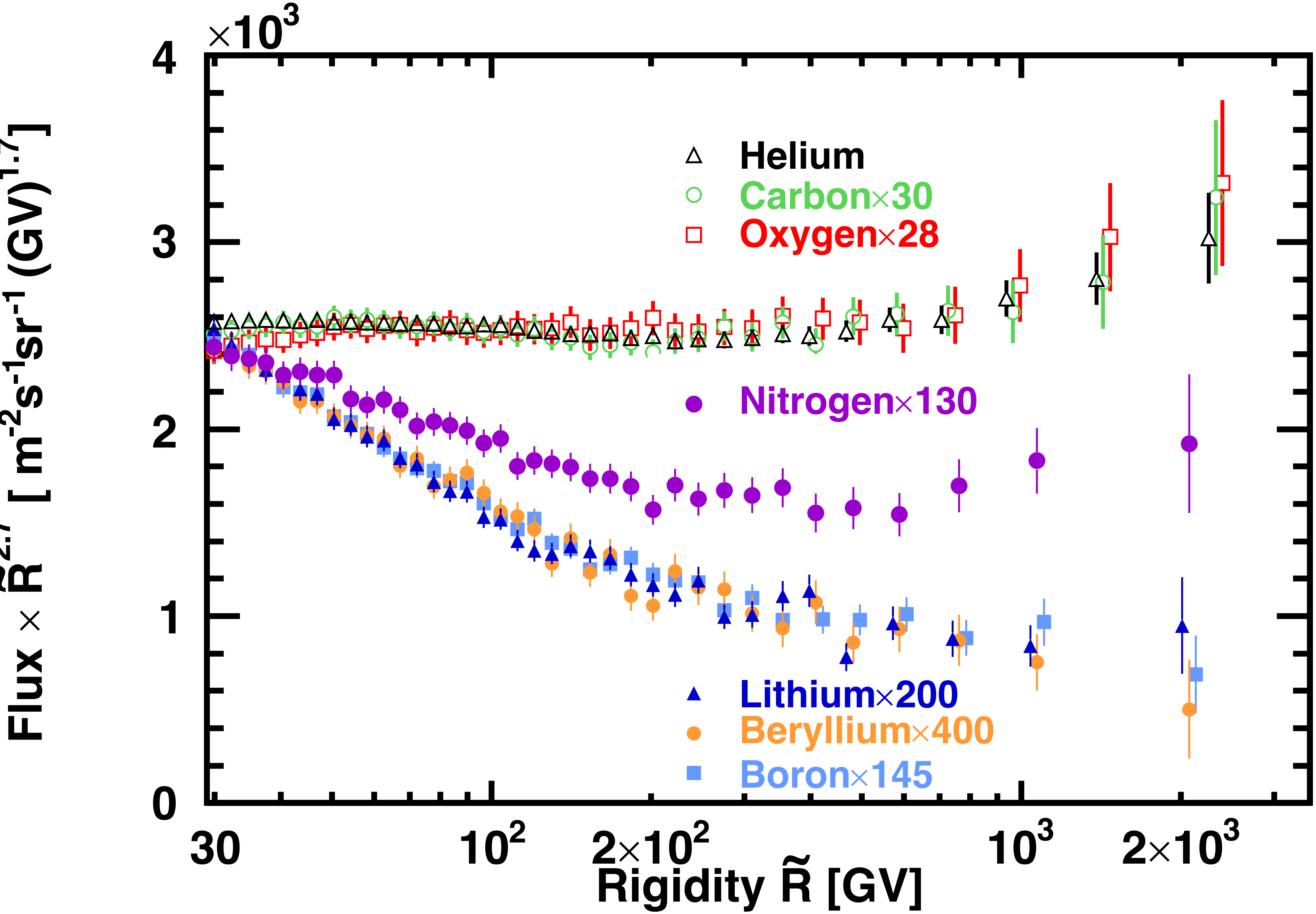
Rigidity dependence of Primary and Secondary Cosmic Rays

Both deviate from a traditional single power law above 200 GeV.

But their rigidity dependences are distinctly different.

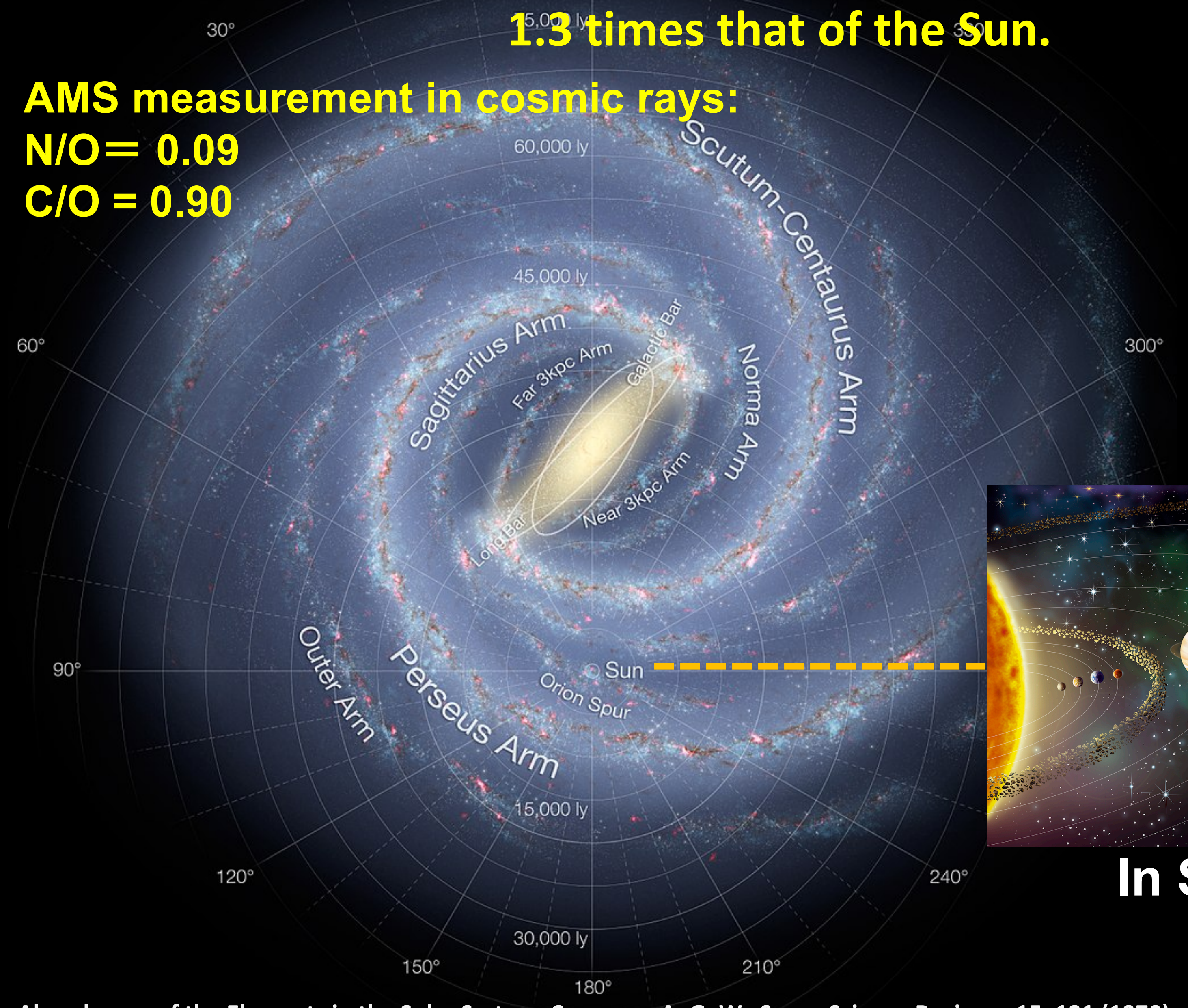


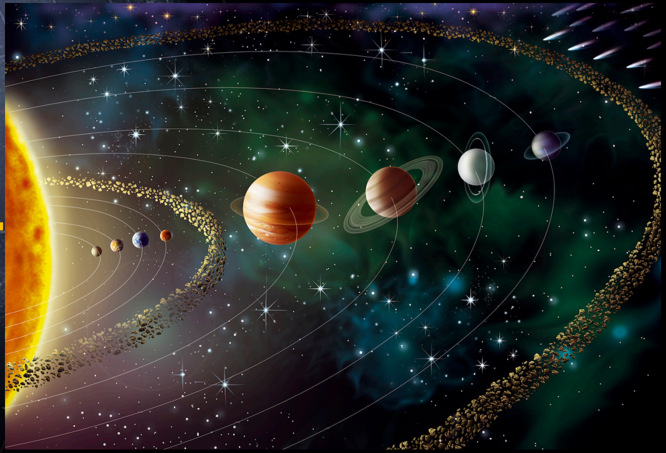
The AMS measurements of the primary cosmic ray fluxes and the secondary cosmic rays fluxes with the nitrogen flux.



Theoretical models suggest that the C-N-O Cycle is the dominant source of energy in stars whose mass is greater than about 1.3 times that of the Sun.

AMS measurement in cosmic rays:
N/O = 0.09
C/O = 0.90



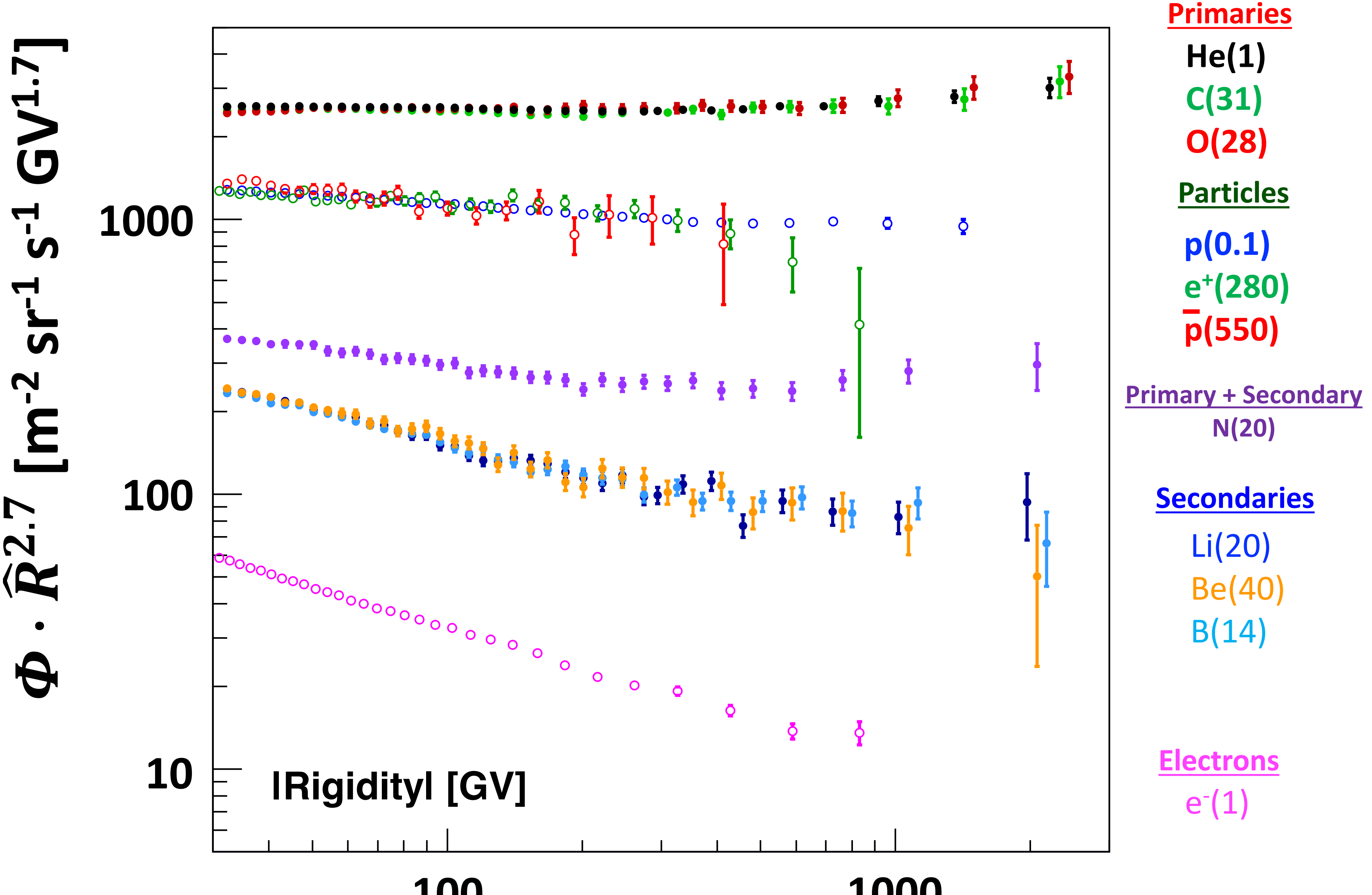


In Solar System:
N/O = 0.17
C/O = 0.54

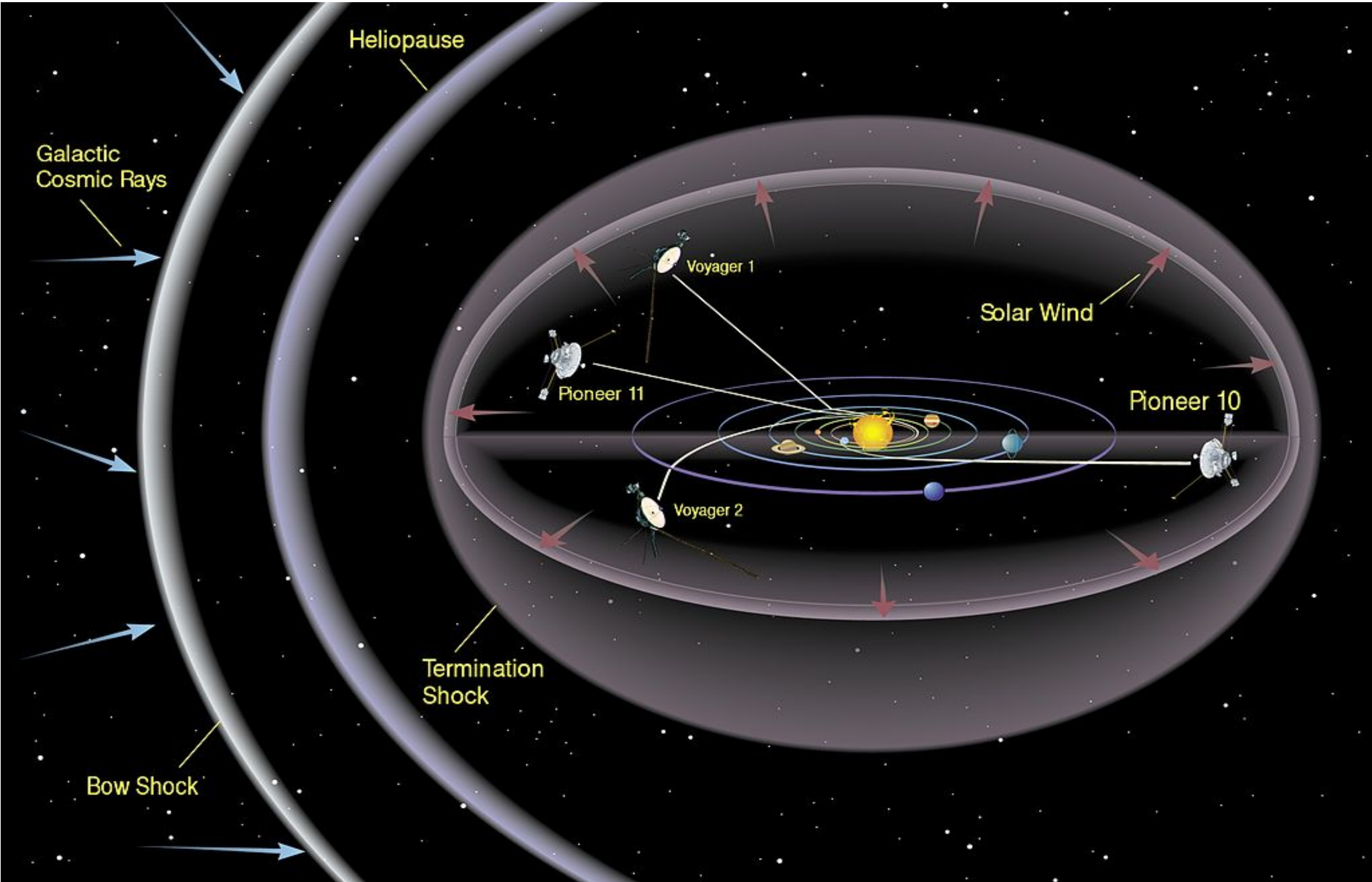
Abundances of the Elements in the Solar System, Cameron, A. G. W., Space Science Reviews, 15, 121 (1970)

Summary of AMS results on Cosmic Ray Fluxes

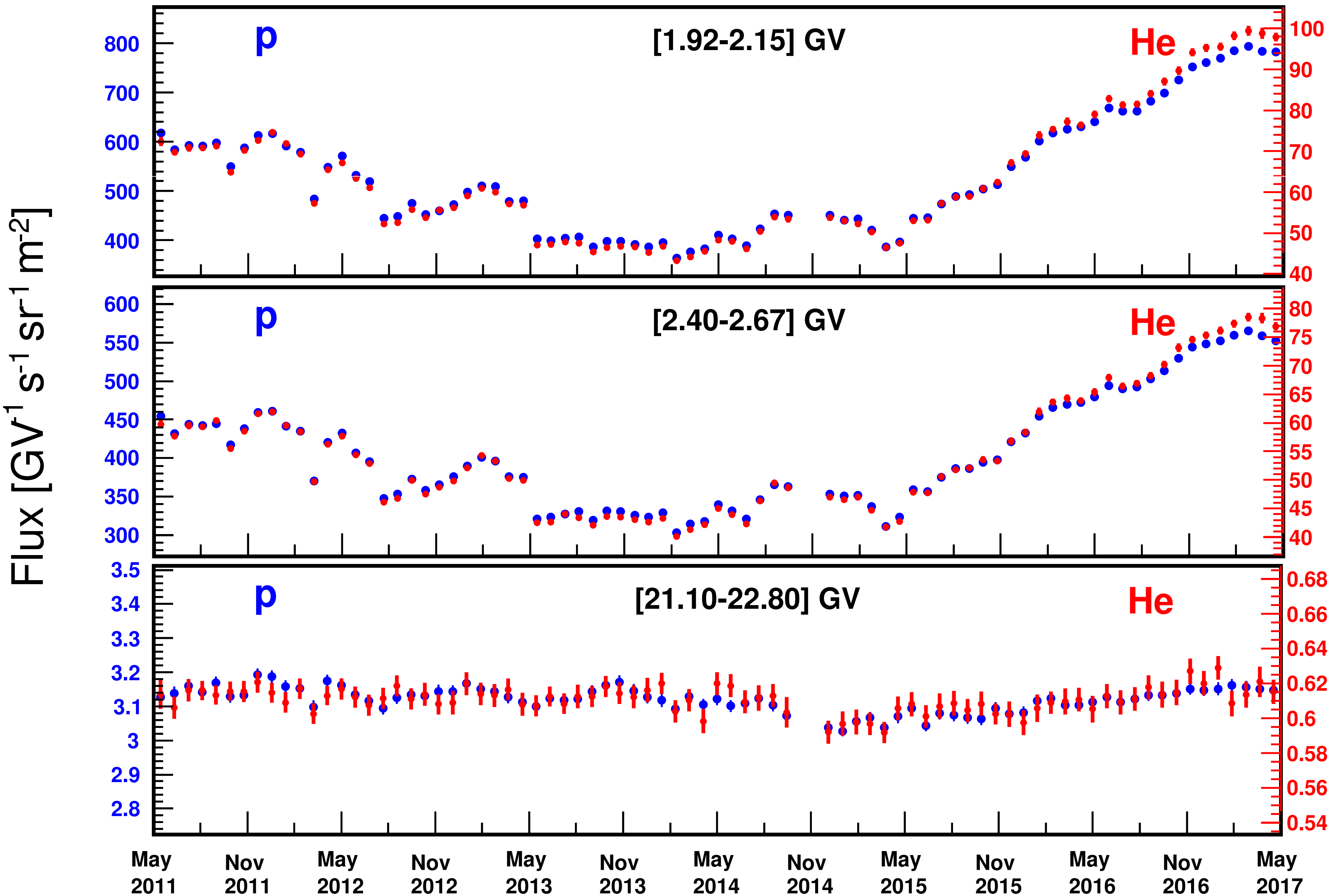
High energy cosmic ray fluxes have 5 classes of rigidity dependence.



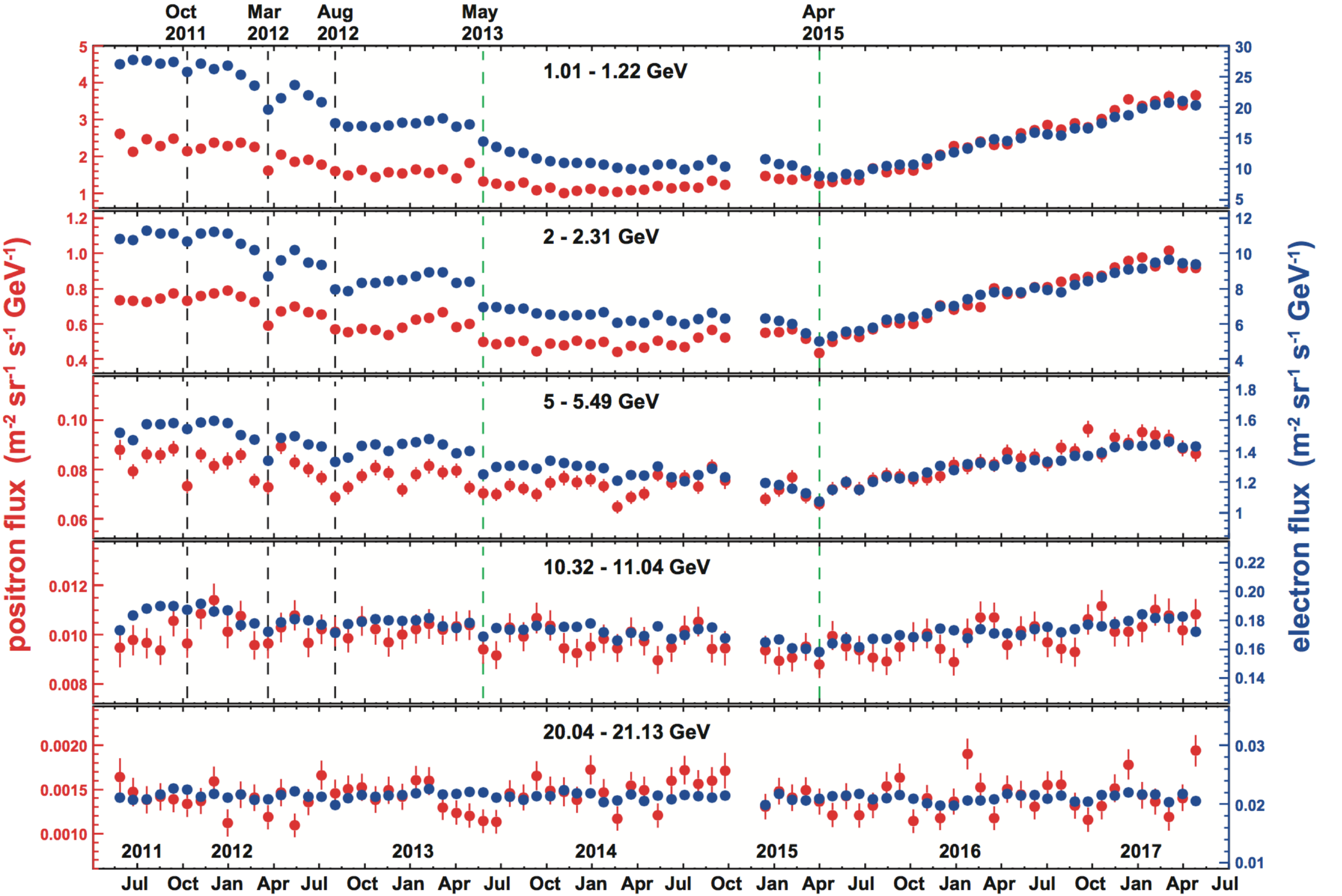
New observations of the monthly time variation of the e+, e-, p, and He fluxes are providing key information for studying solar physics



AMS observes Identical monthly time variation of the p, He fluxes



AMS continous measurement of the e+ and e- flux in the energy range 1 -50 GeV over 6 years with a time resolution of 27 days.



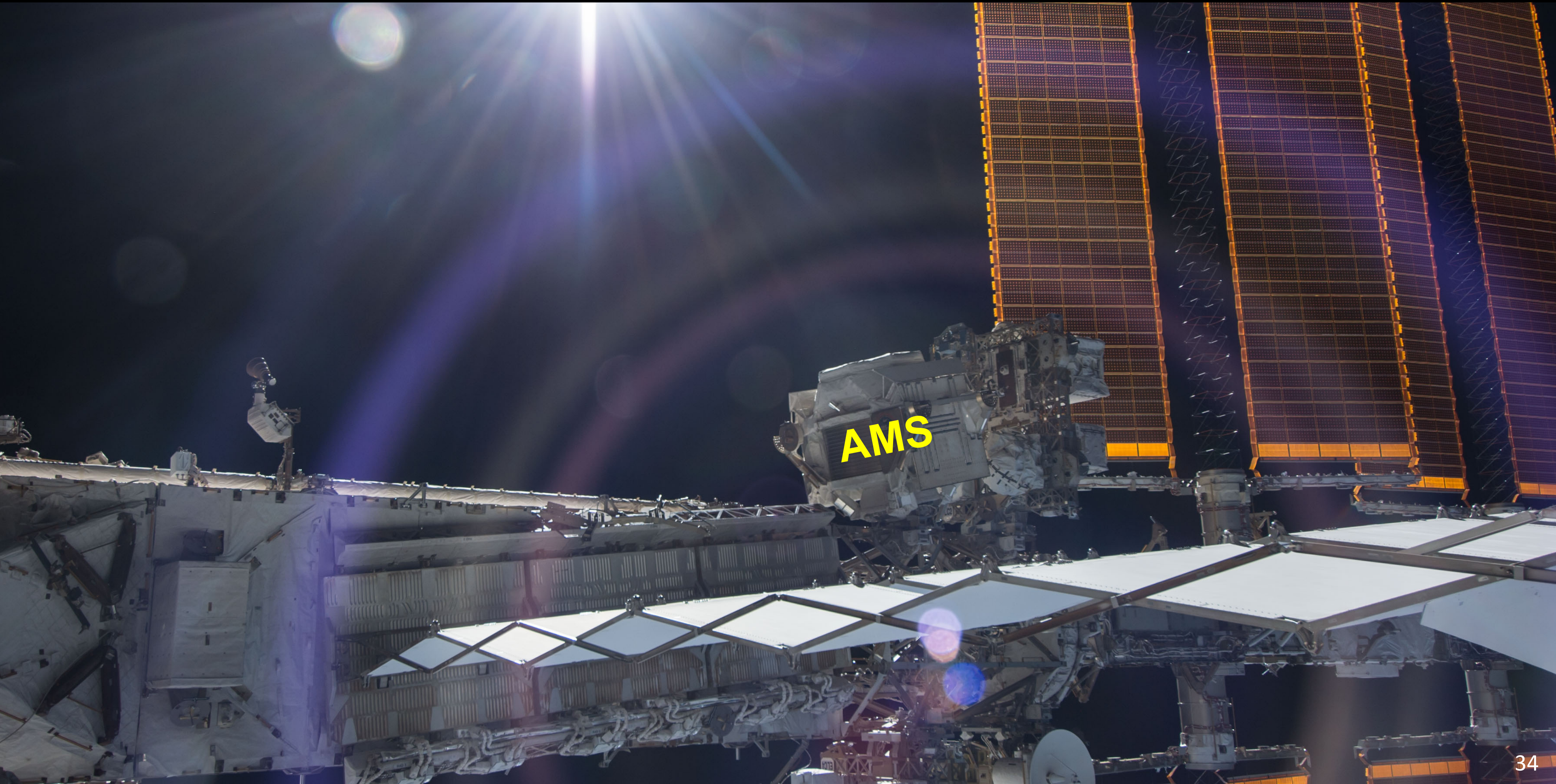
Physics of AMS through the lifetime of the Space Station

Examples: Complex anti-matter – $\overline{He}$, $\overline{C}$, $\overline{O}$

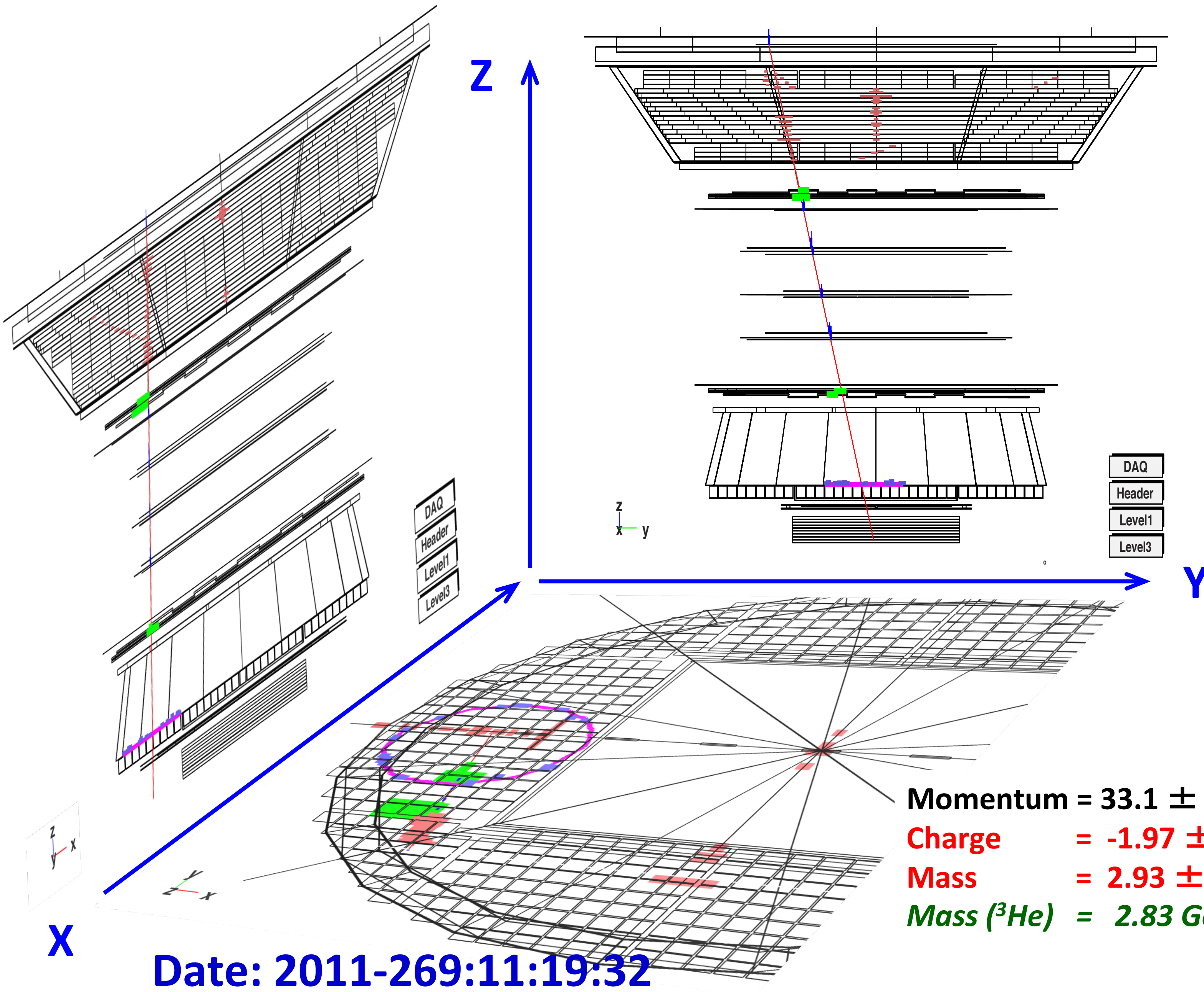
Positrons and Dark Matter

Anisotropy and Dark Matter

High Z cosmic rays



Physics of AMS on ISS: Complex anti-matter $\overline{He}$



Momentum = 33.1 ± 1.6 GeV/*c*

Charge = -1.97 ± 0.05

Mass = 2.93 ± 0.36 GeV/c^2

Mass (^3He) = 2.83 GeV/c^2

Date: 2011-269:11:19:32

$^{3}\overline{He}$/He flux ratio predictions

From the collision of cosmic rays:

R. Duperray et al., Phys. Rev. D **71**, 083013 (2005) **$^{3}\overline{He}$/He[8-40]GV = 6 X 10^{-12}**

M. Cirelli et al., JHEP **8**, 9 (2014): **$^{3}\overline{He}$/He[8-40]GV = 3 X 10^{-11}**

K. Blum et al., Phys. Rev. D **96**, 103021 (2017) **$^{3}\overline{He}$/He[8-40]GV = 6 X 10^{-10}**

E. Carlson et al., Phys. Rev. D **89**, 076005 (2014) **$^{3}\overline{He}$/He[8-40]GV = 1.4 X 10^{-9}**

A. Coogan et al., Phys. Rev. D **96**, 083020 (2017) **$^{3}\overline{He}$/He[8-40]GV ~ 2 X 10^{-8}**

AMS Measurement: **$^{3}\overline{He}$/He[8-40]GV = 2 X 10^{-8}**

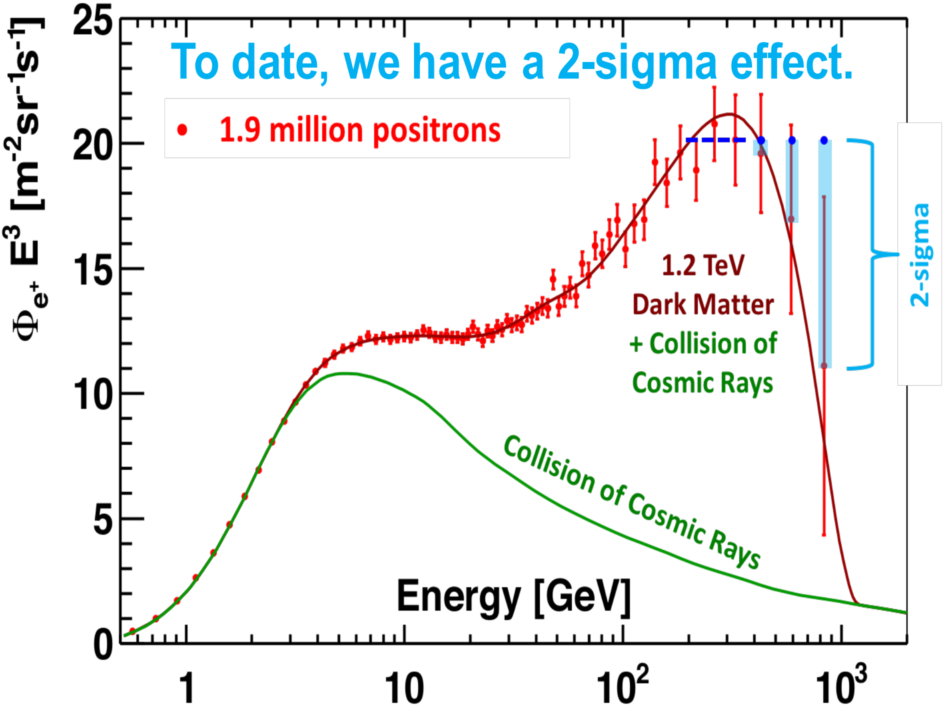
There are large uncertainties in models to ascertain the origin of $^{3}\overline{He}$

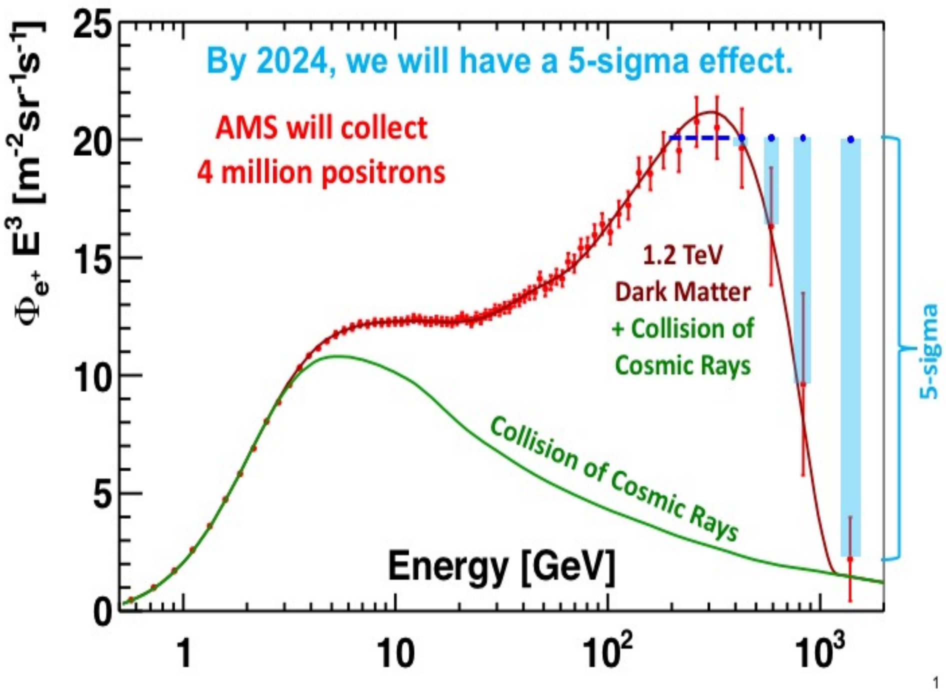
We have also observed two $^{4}\overline{He}$ candidates.

The rate of anti-helium production is typically 1 in 100 million helium.
More events are necessary to confirm that there are no backgrounds.

Physics of AMS on ISS: Positrons and Dark Matter

Extend the measurements to 2 TeV and determine the sharpness of the drop off.





Currently, the approved ISS lifetime is until 2024.
The incremental gain between now and 2024 is from 2-sigma to 5-sigma.

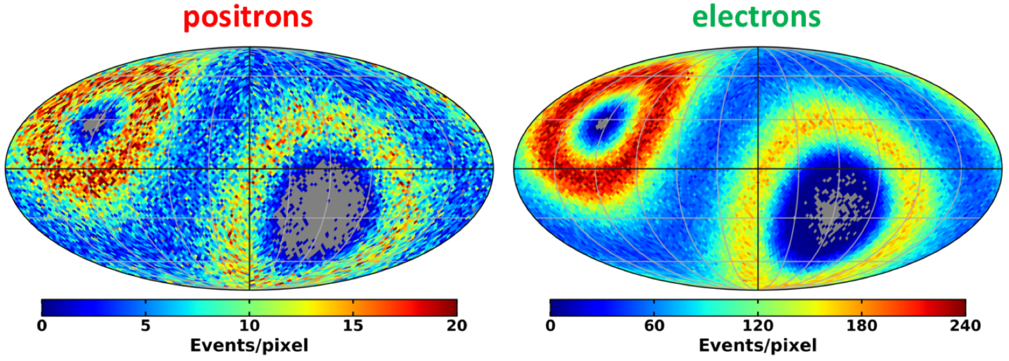
Physics of AMS on ISS: Anisotropy and Dark Matter

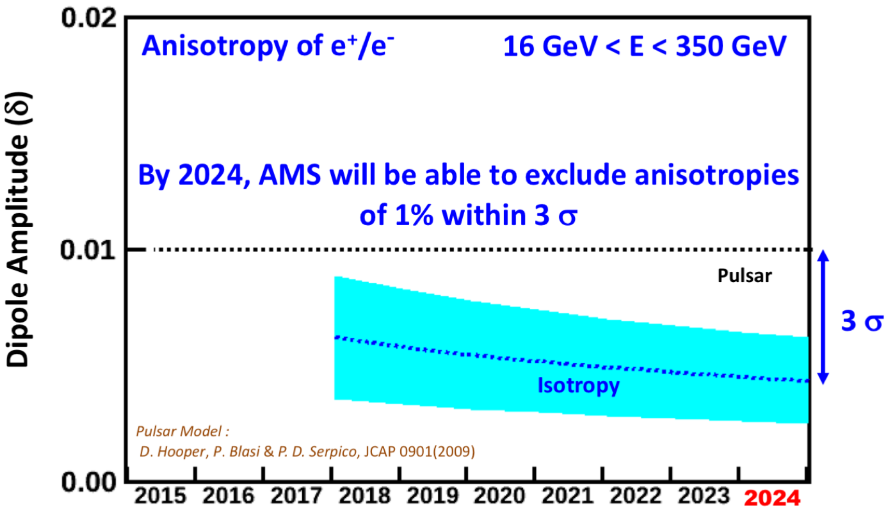
Astrophysical point sources like pulsars will imprint a higher anisotropy on the arrival directions of energetic positrons than a smooth dark matter halo.

The anisotropy in galactic coordinates

$\delta = 3\sqrt{C_1/4\pi}$ C_1 is the dipole moment

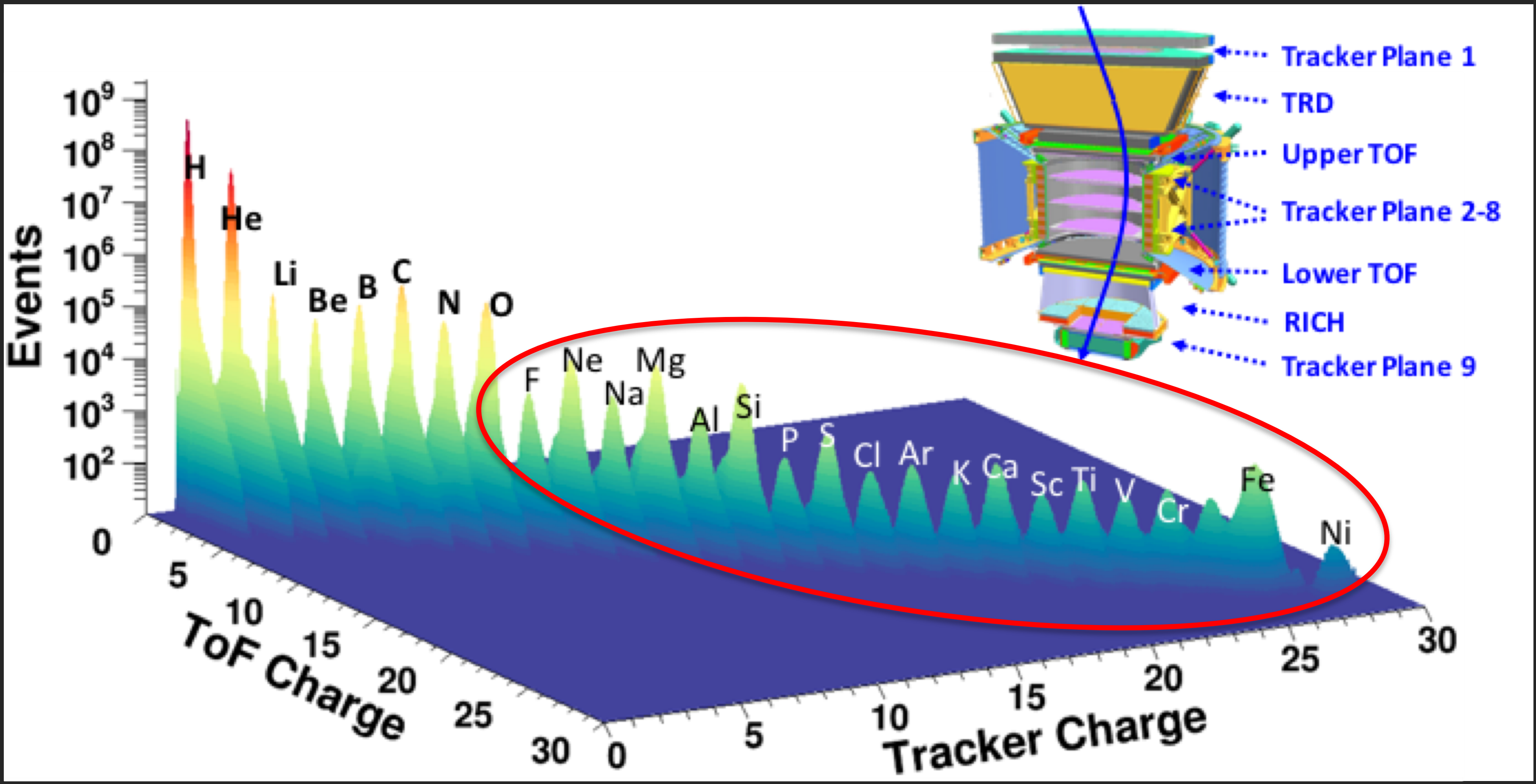
Projected amplitude of the dipole anisotropy



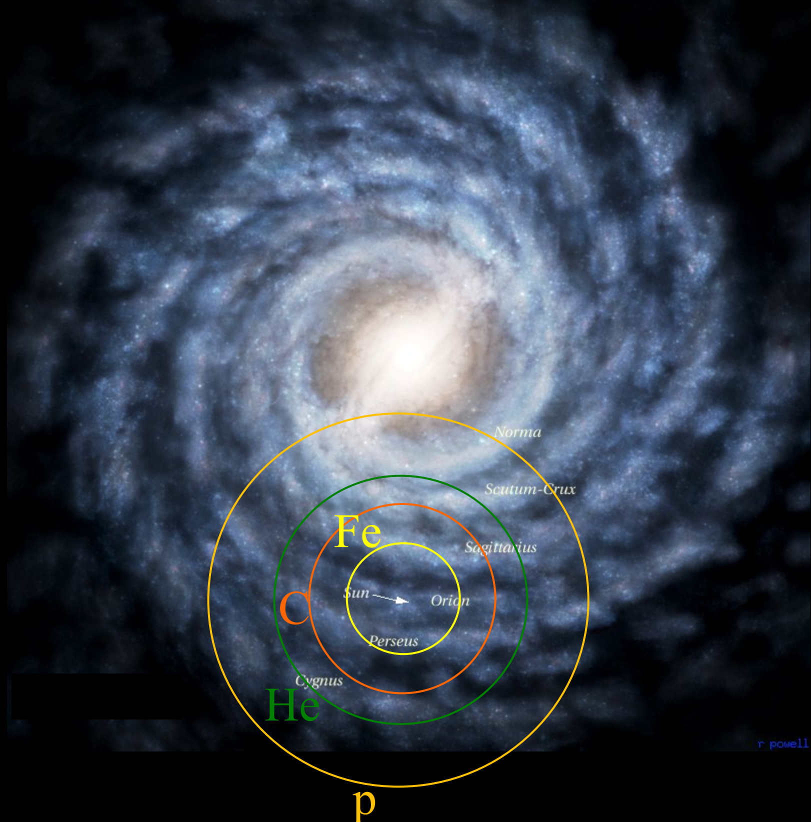


The observation of isotropy is important to understand the origin of the excess in the positron flux.

Physics of AMS on ISS: Study high Z cosmic rays



Physics of high Z cosmic ray spectra at high energies:
Probe different galactic distances
Systematic study of propagation as function *A (Z)* and *R*.



Effective distance is shown for ~1 GV.

Effective propagation distance:

$$\langle X \rangle \sim \sqrt{6D\tau} \sim 2.7 \text{ kpc } R^{\delta/2} (A/12)^{-1/3}$$

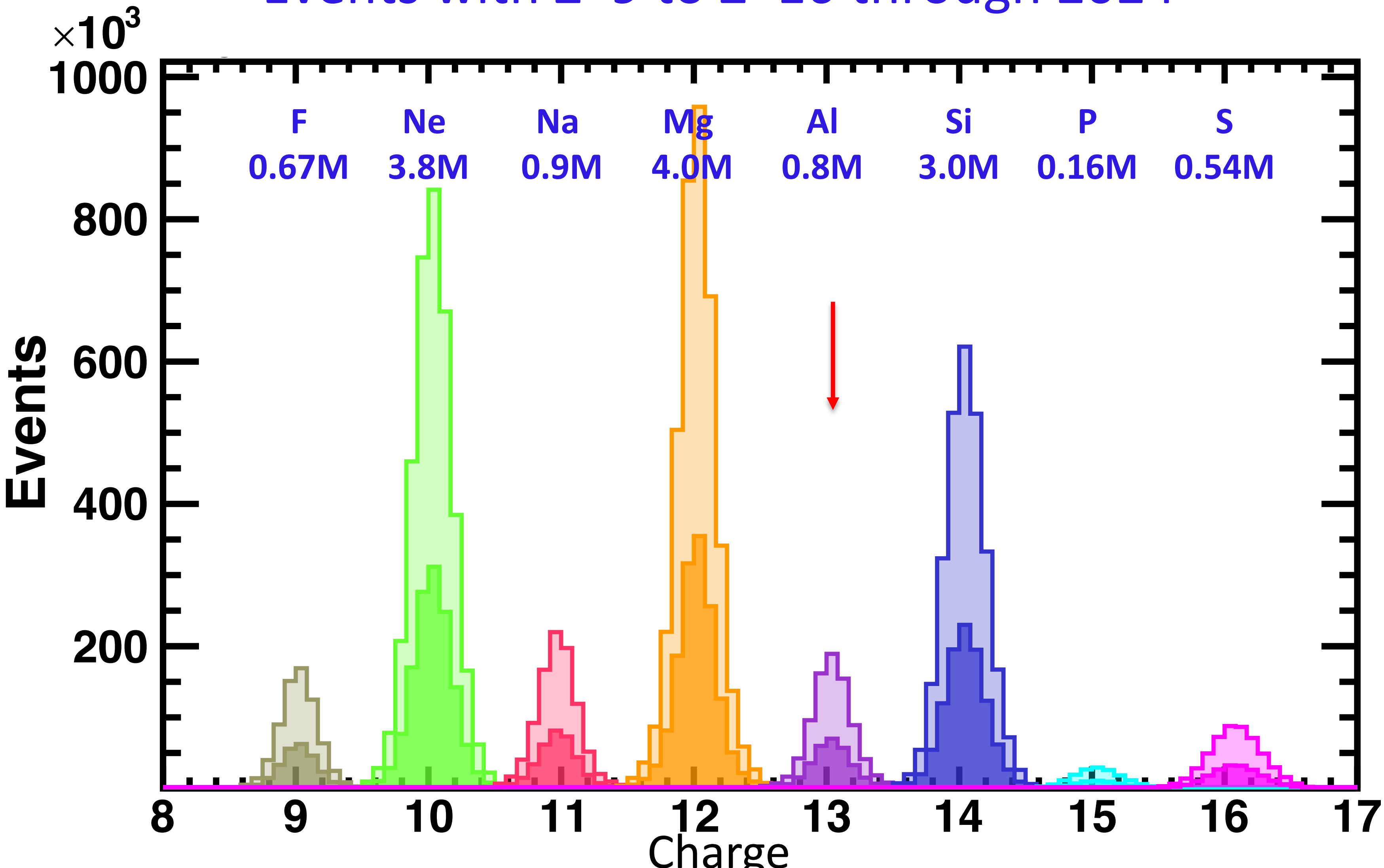
protons:	~ 5.6 kpc $R^{\delta/2}$
Helium:	~ 3.6 kpc $R^{\delta/2}$
Carbon:	~ 2.7 kpc $R^{\delta/2}$
Iron:	~ 1.6 kpc $R^{\delta/2}$

i. Different Z (or A) nuclei probe different distances.

ii. Higher energies probe larger distances

AMS will obtain precise data on heavy nuclei, Z=9 to Z=28, up to the TV region. Particularly interesting is evidence of the flux break at ~200 GV. The measurements of the Aluminum, Chlorine, and Manganese spectra will precisely establish the age of cosmic rays as ^{26}Al, ^{36}Cl, ^{54}Mn are radioactive clocks.

Events with Z=9 to Z=16 through 2024



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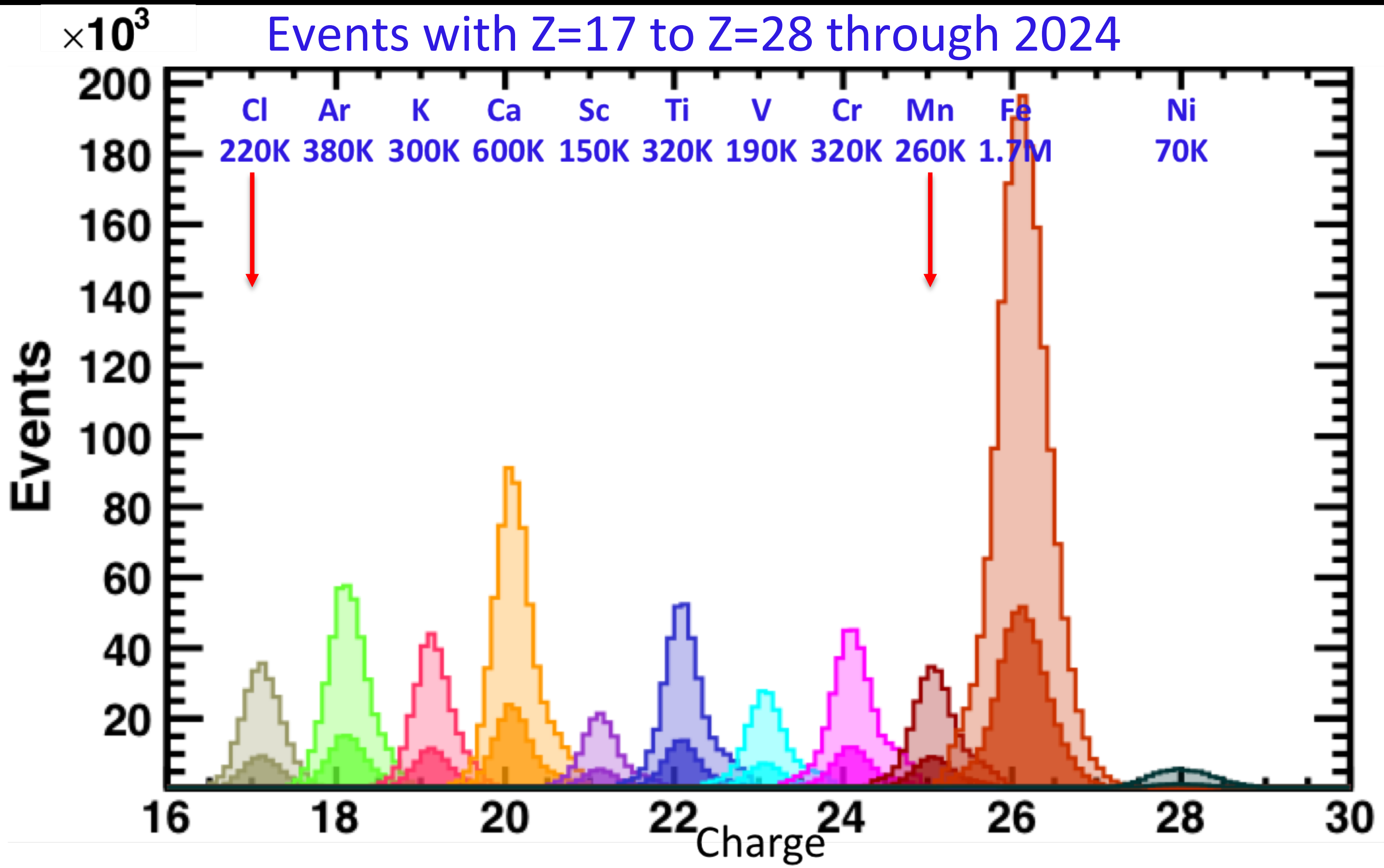
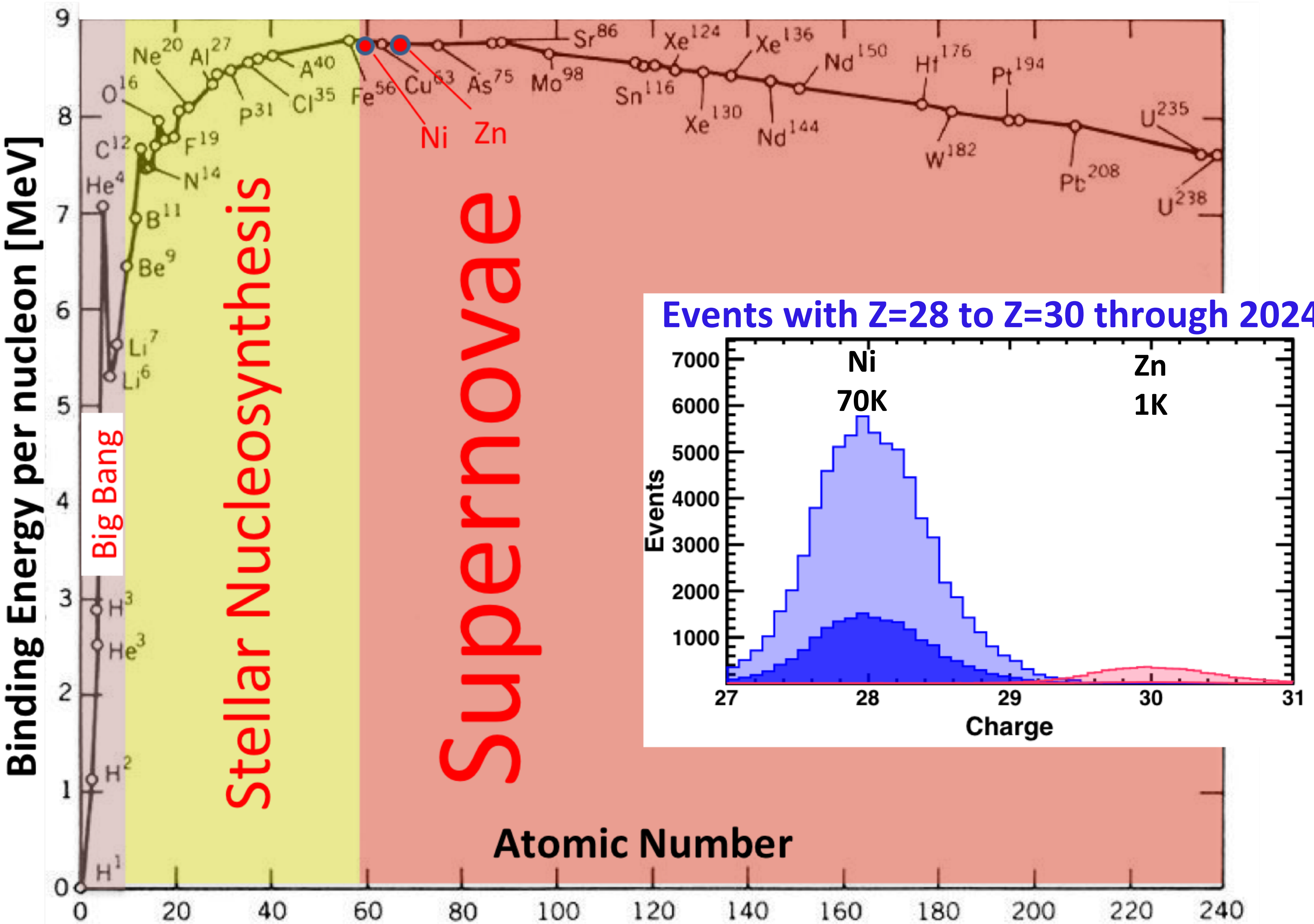


The lightest elements created by supernova are Nickel and Zinc. AMS will be able to study their properties for the first time and compare them with elements produced by stellar nucleosynthesis.



- AMS has collected more than 120 Billion cosmic rays since 2011 and is a unique scientific instrument on board the ISS.
- The high precision cosmic ray flux measurements from AMS present challenges to the present understanding of the nature of cosmic rays and are of fundamental importance for deciphering the properties of Galactic cosmic rays.
- AMS will have collected 240 Billion cosmic rays by 2024 and will continue to take data through the lifetime of the ISS.