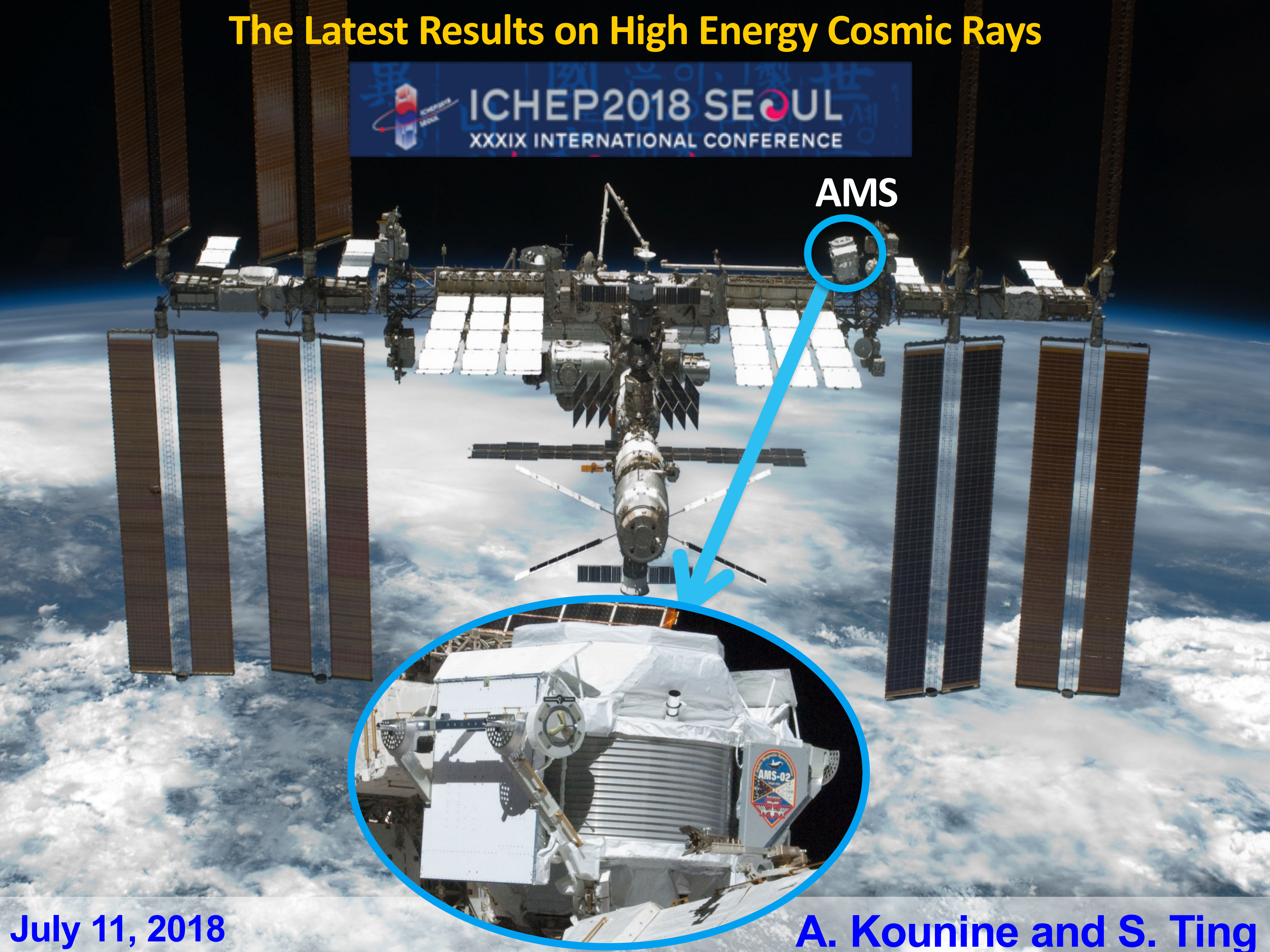
The Latest Results on High Energy Cosmic Rays

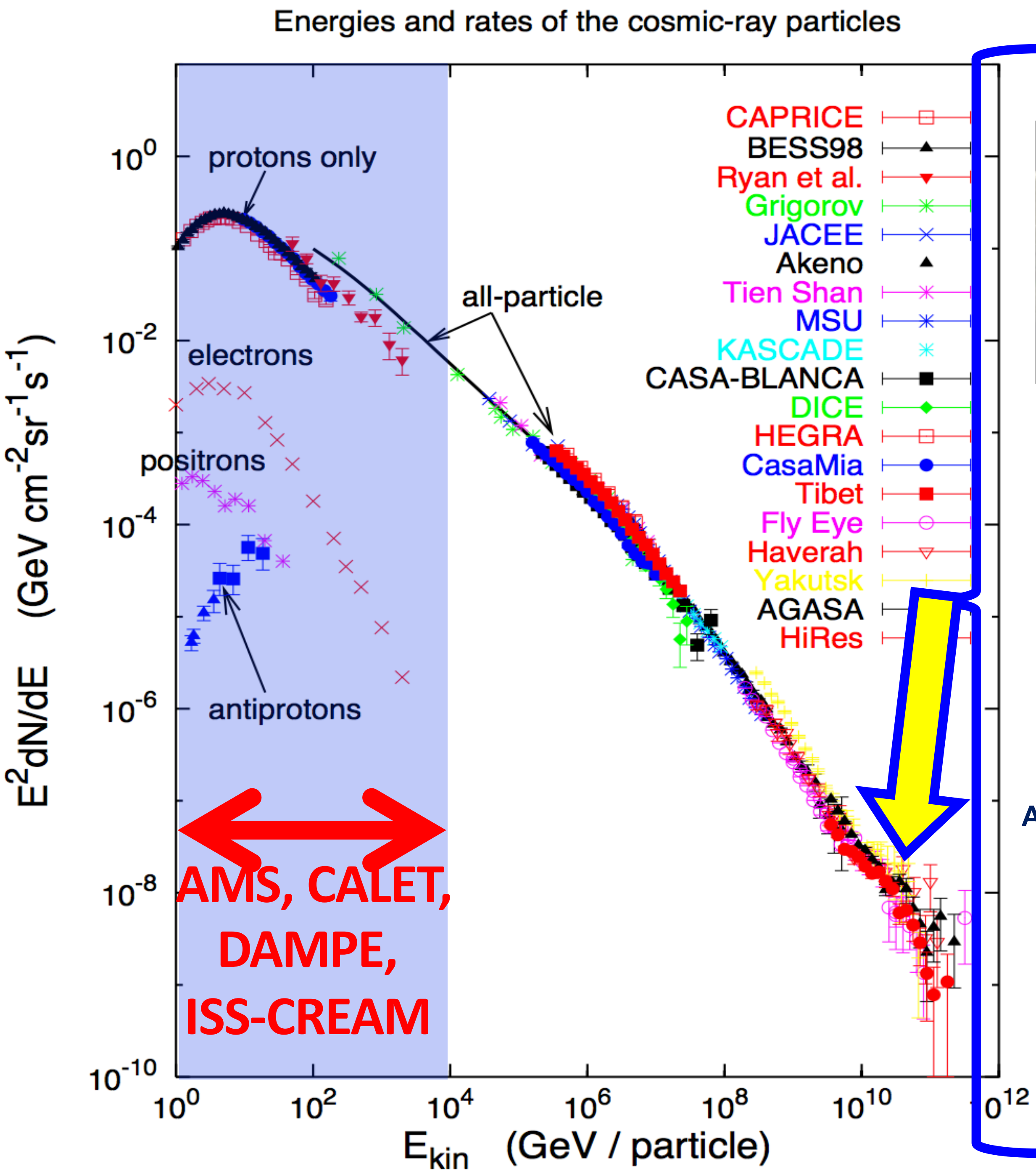
ICHEP2018 SEOUL

XXXIX INTERNATIONAL CONFERENCE



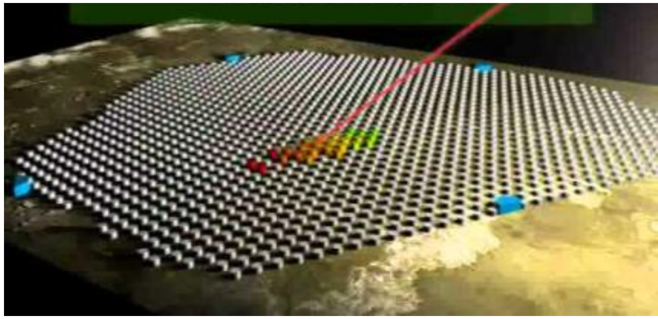
July 11, 2018

A. Kounine and S. Ting



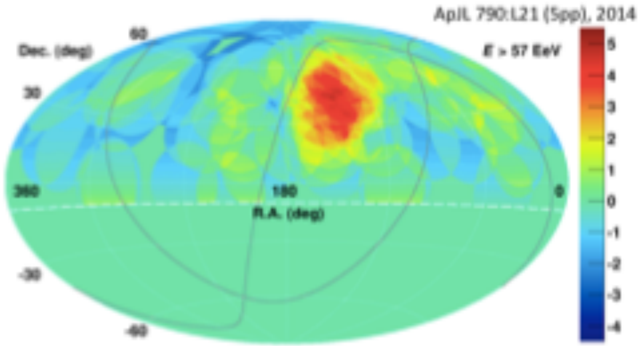
AMS, CALET, DAMPE, ISS-CREAM

The Pierre Auger Observatory



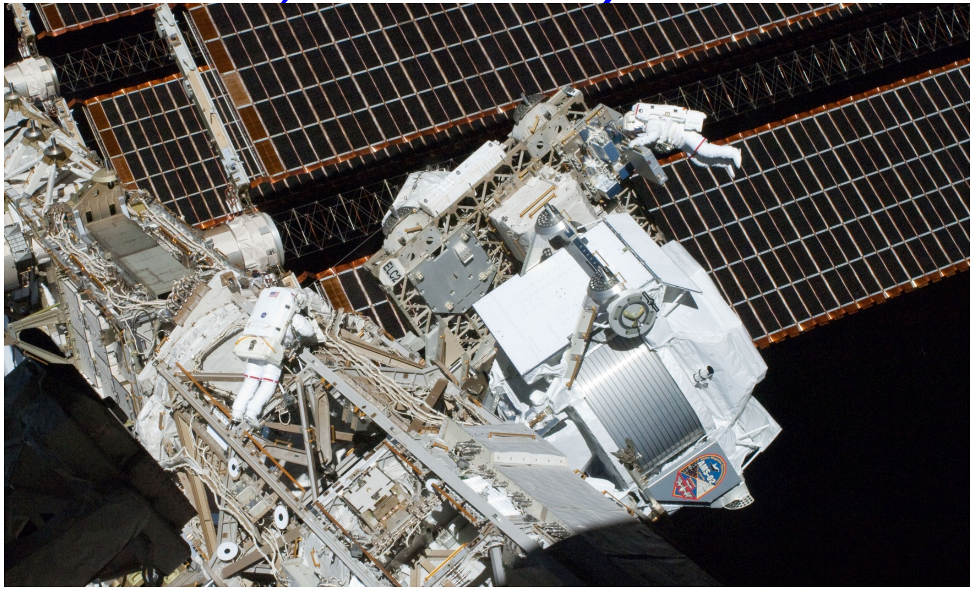
Telescope Array

Anisotropy of cosmic rays E>57 EeV

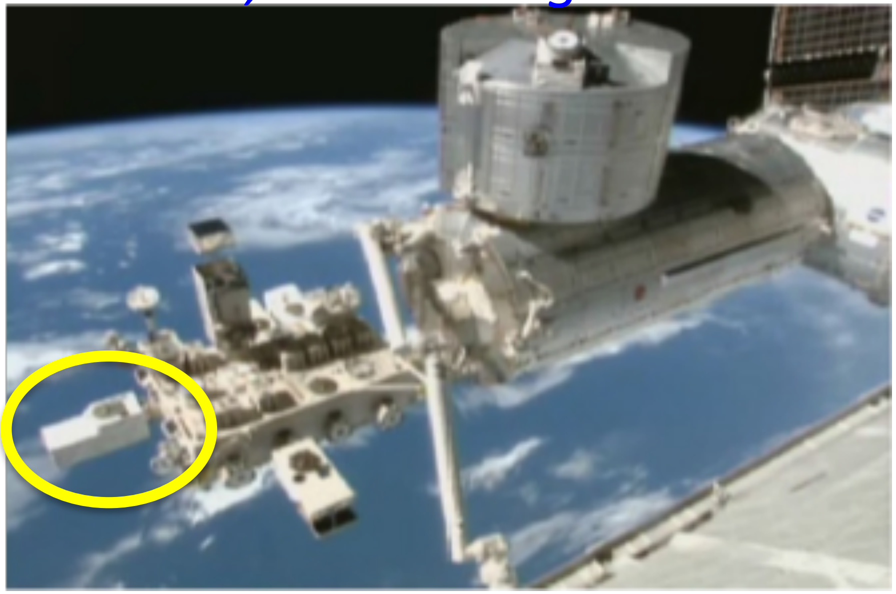


Space-born Cosmic Ray Experiments in operation

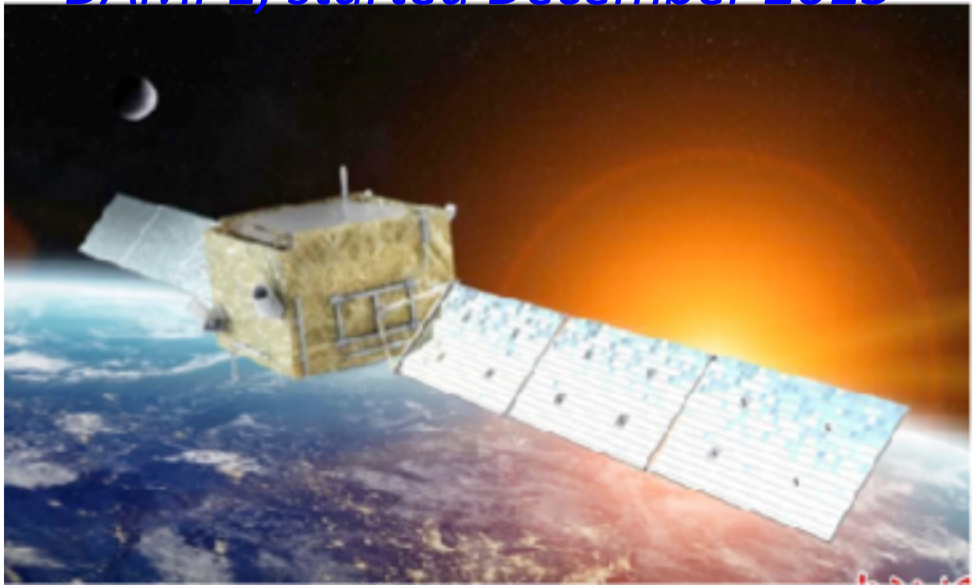
AMS, started May 2011



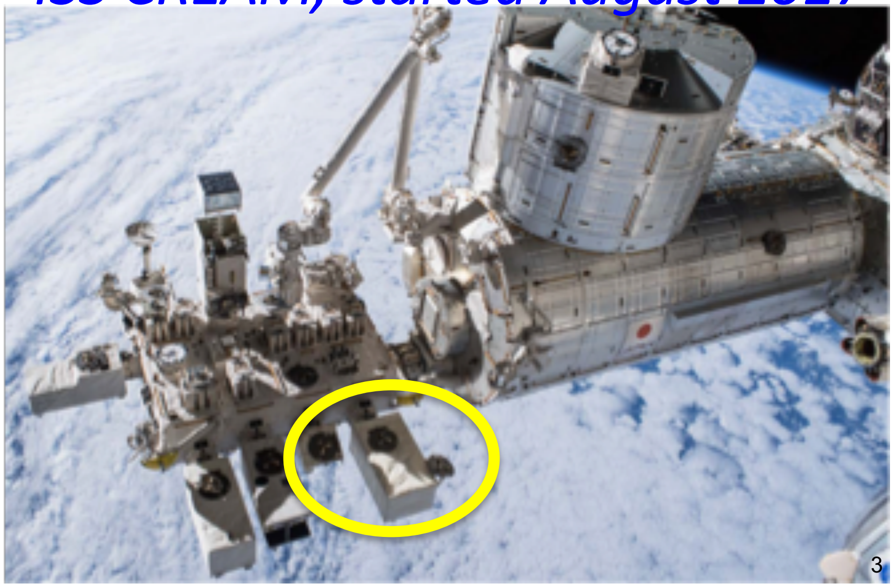
CALET, started August 2015



DAMPE, started December 2015



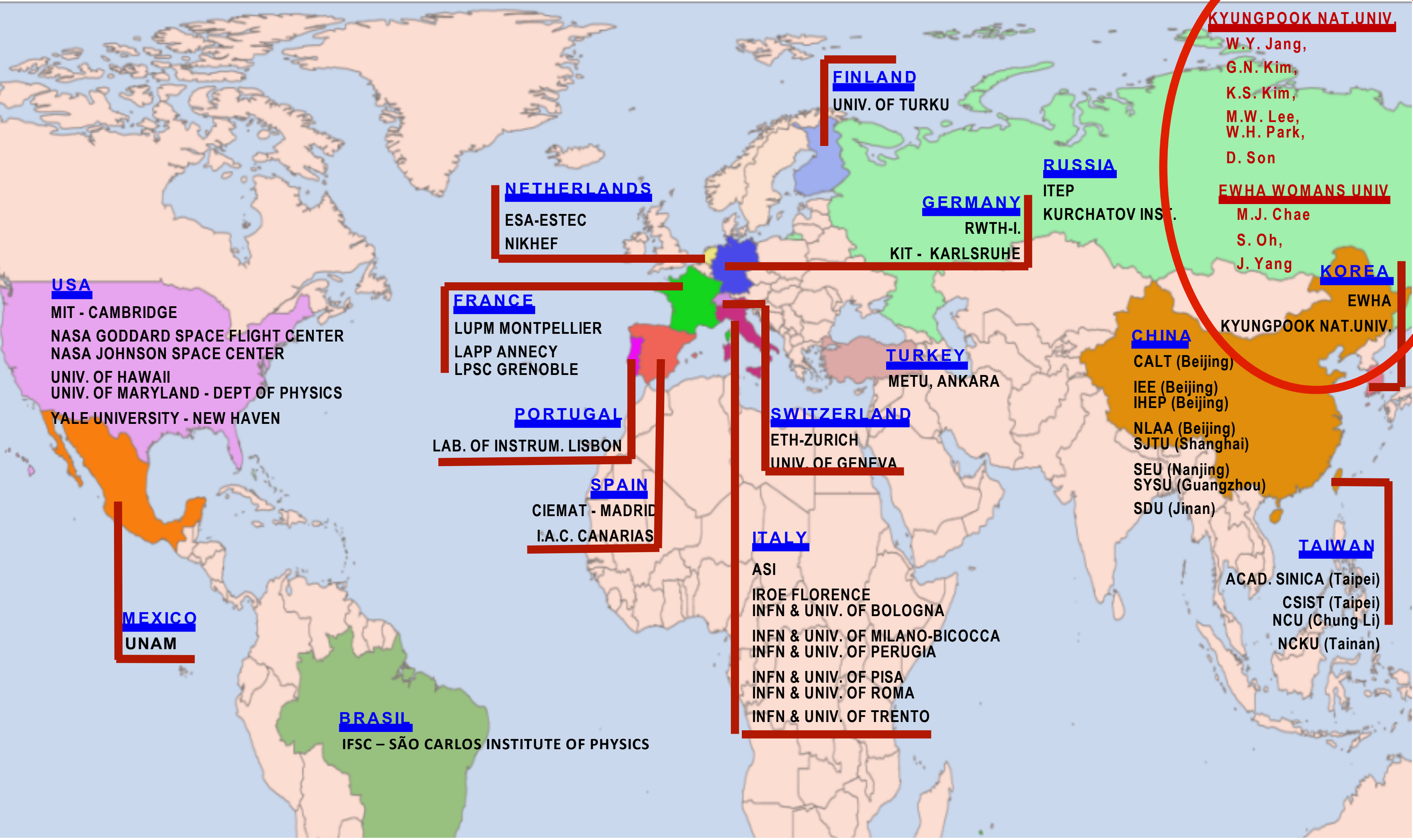
ISS CREAM, started August 2017



AMS is an international collaboration

It took 650 physicists and engineers 17 years to construct AMS

Prof. Dongchul Son



USA
MIT - CAMBRIDGE
NASA GODDARD SPACE FLIGHT CENTER
NASA JOHNSON SPACE CENTER
UNIV. OF HAWAII
UNIV. OF MARYLAND - DEPT OF PHYSICS
YALE UNIVERSITY - NEW HAVEN

MEXICO
UNAM

BRASIL
IFSC – SÃO CARLOS INSTITUTE OF PHYSICS

NETHERLANDS
ESA-ESTEC
NIKHEF

FRANCE
LUPM MONTPELLIER
LAPP ANNECY
LPSC GRENOBLE

PORTUGAL
LAB. OF INSTRUM. LISBON

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ITALY
ASI
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INFN & UNIV. OF BOLOGNA
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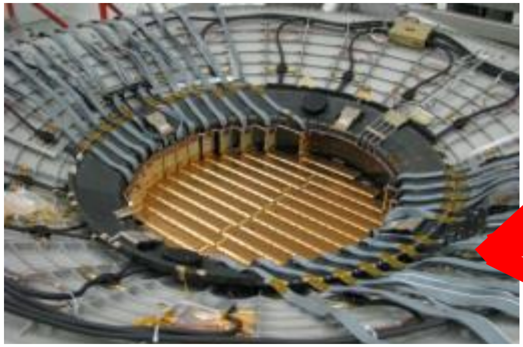
NCU (Chung Li)
NCKU (Tainan)

Prof. Eun-Suk Seo, Univ. of Maryland, has provided AMS with invaluable information on early, important work on cosmic rays by her and by other groups.

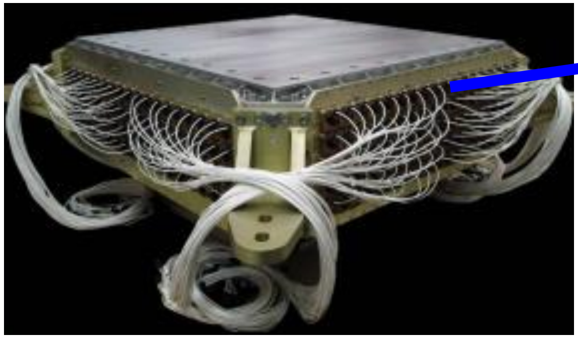
AMS: a TeV precision, accelerator-type spectrometer in space

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

Silicon Tracker: Z, P

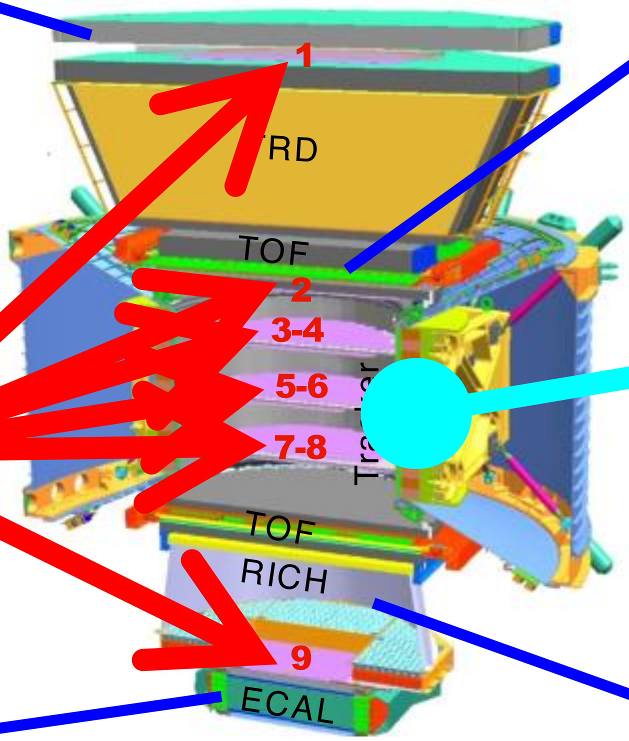


ECAL: E of e^+, e^-



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

Rigidity R = P/Z

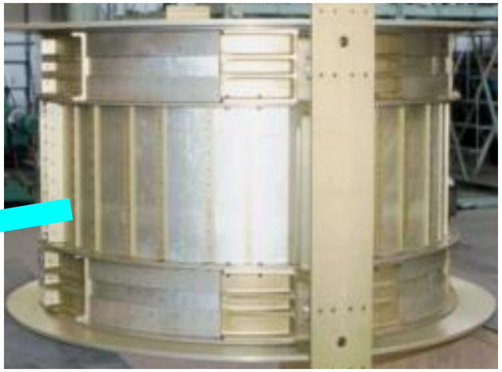


Z and P

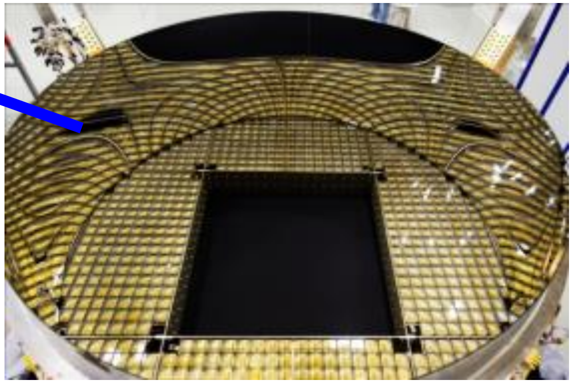
are measured independently by the
Tracker, RICH, TOF and ECAL

TOF: Z, E

Magnet: ±Z



RICH: Z, E

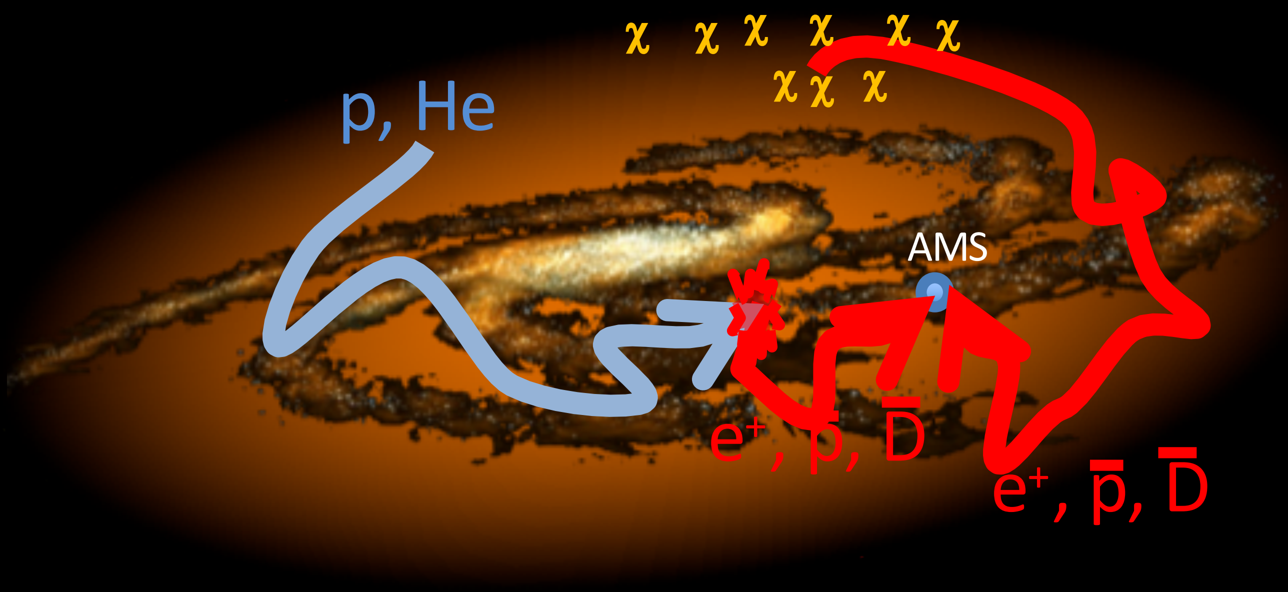


Dark Matter

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

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

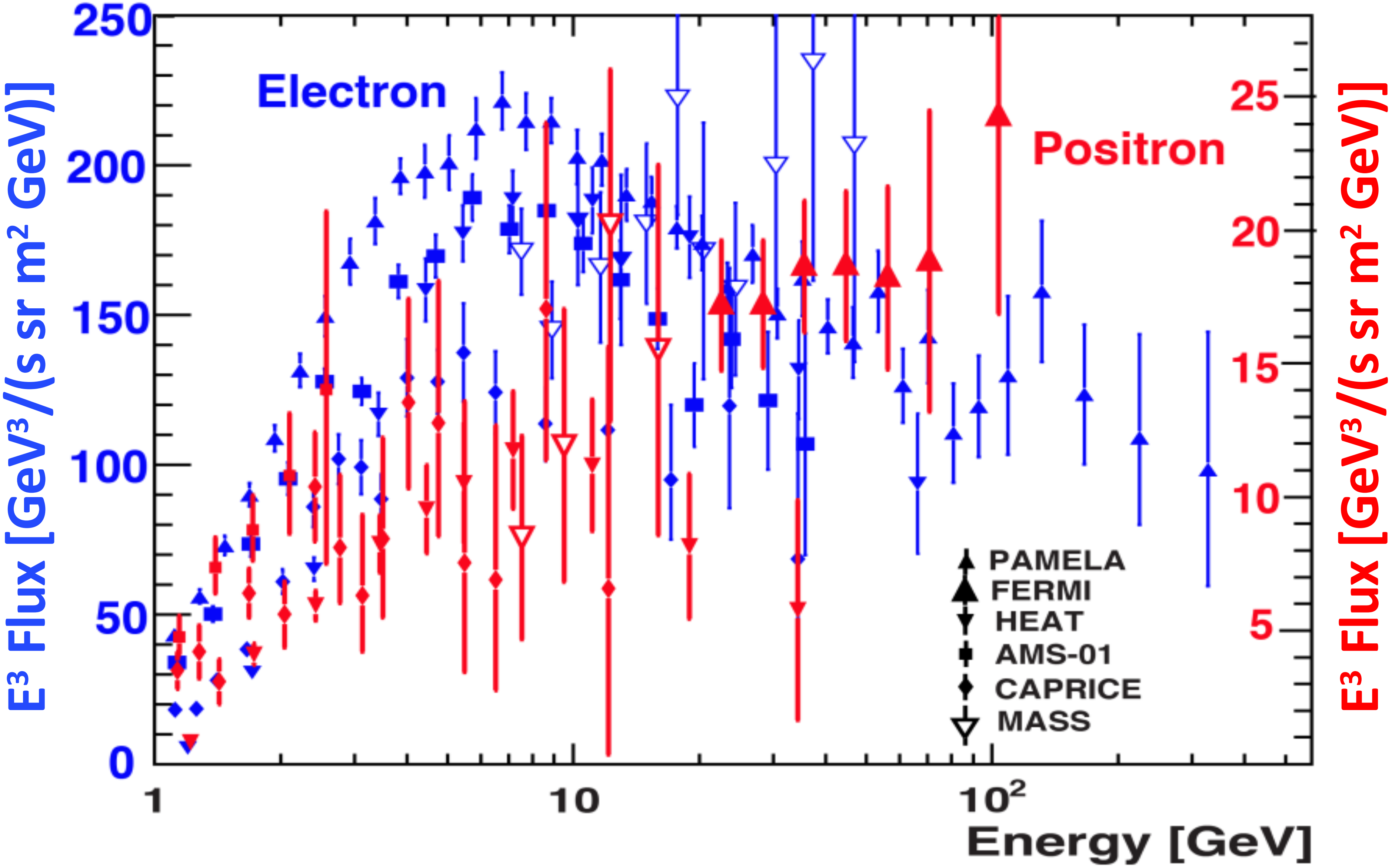
The excess of e^+, $\bar{p}$, $\bar{D}$ from Dark Matter annihilations can be measured by AMS as the background is small



Ordinary matter is also produced by Dark Matter annihilations, but it is not distinguishable from the large background

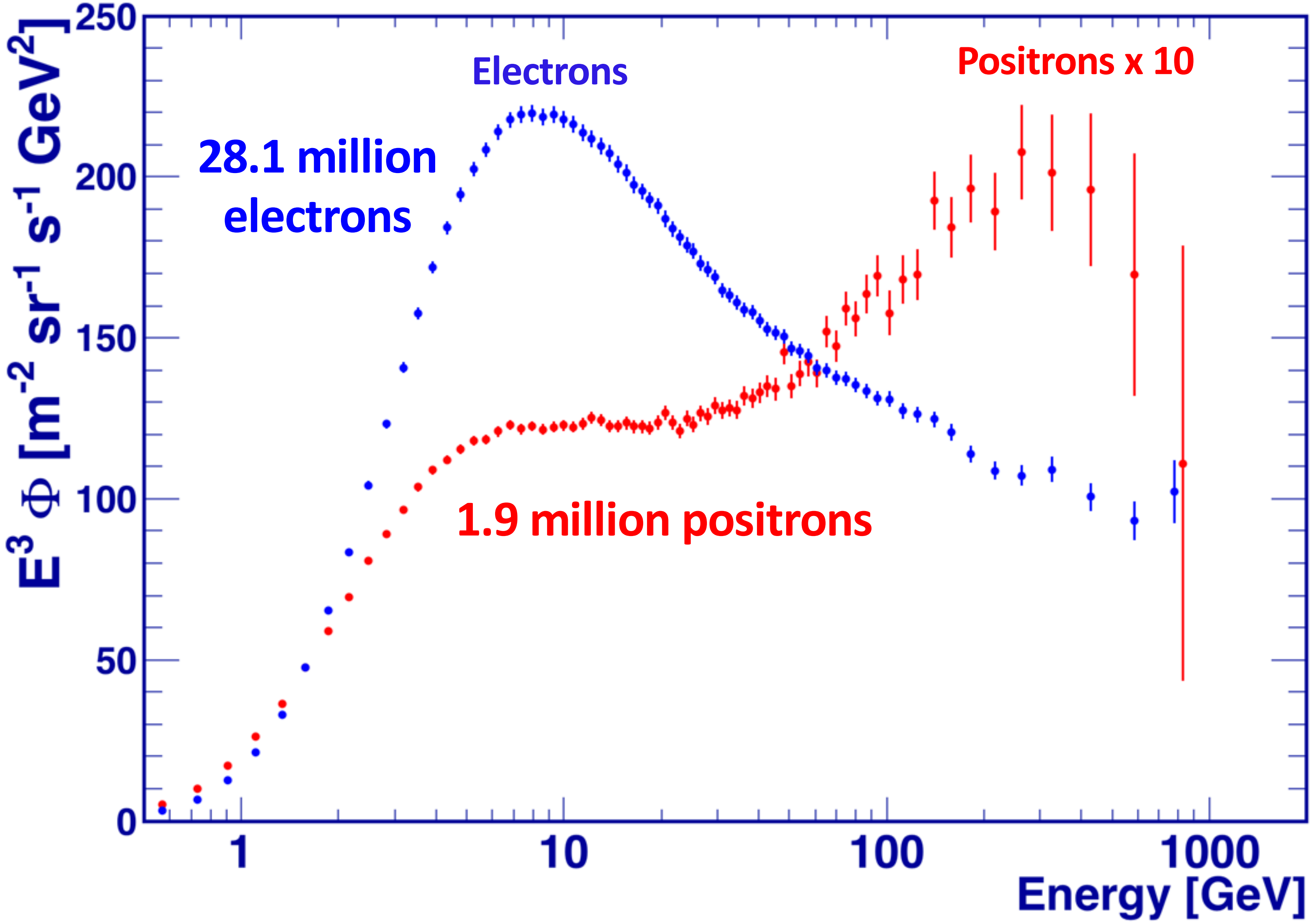
M. Turner and F. Wilczek, Phys. Rev. D42 (1990) 1001; J. Ellis 26th ICRC (1999)

Electron and Positron spectra before AMS



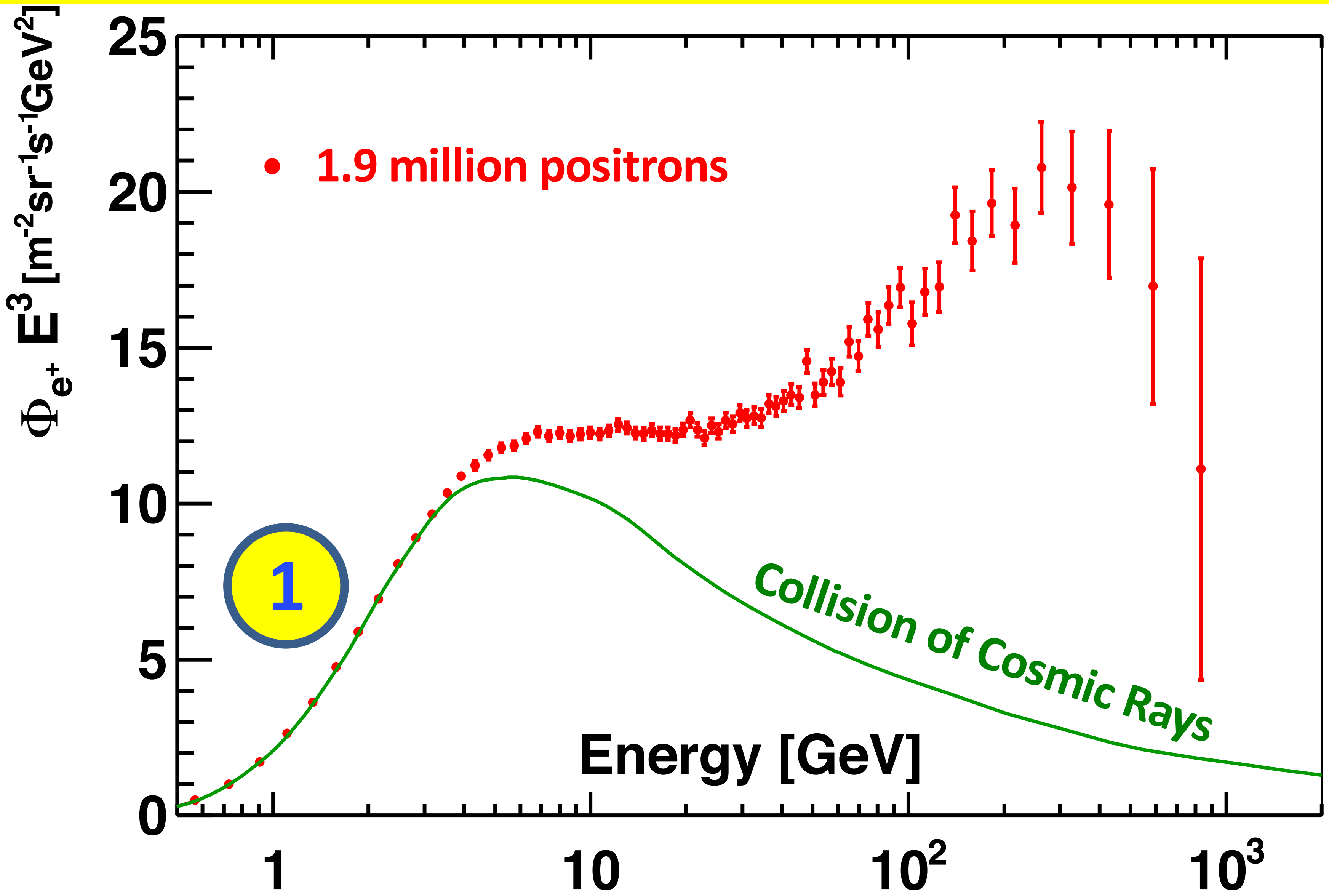
These are very difficult experiments

Latest AMS results on positron and electron fluxes



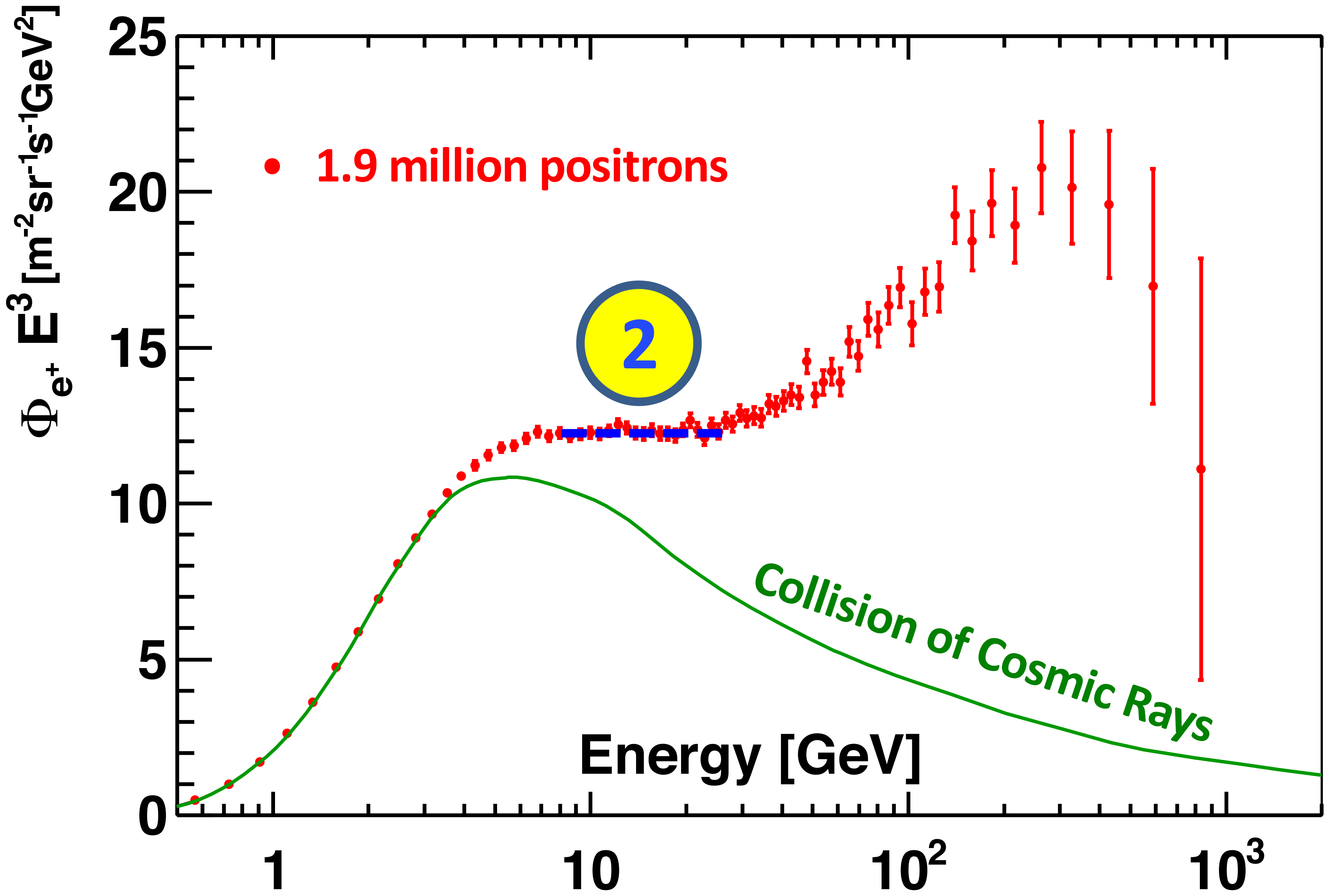
Properties of the Positron Flux

Observation 1: At low energies, the data agrees well with the predictions from the collisions of cosmic rays



Properties of the Positron Flux

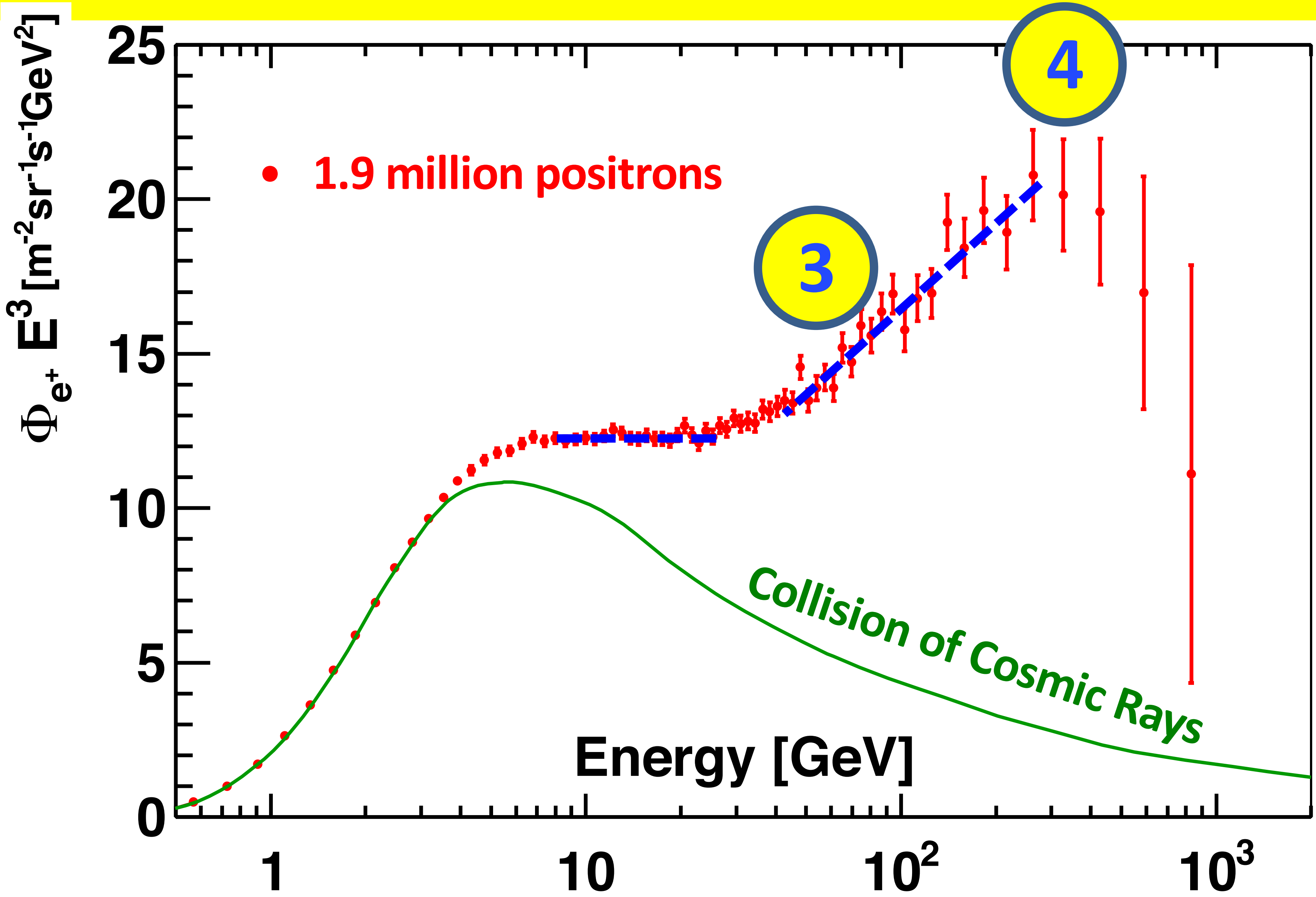
Observation 2: Above 8 GeV, the data flatten out



Properties of the Positron Flux

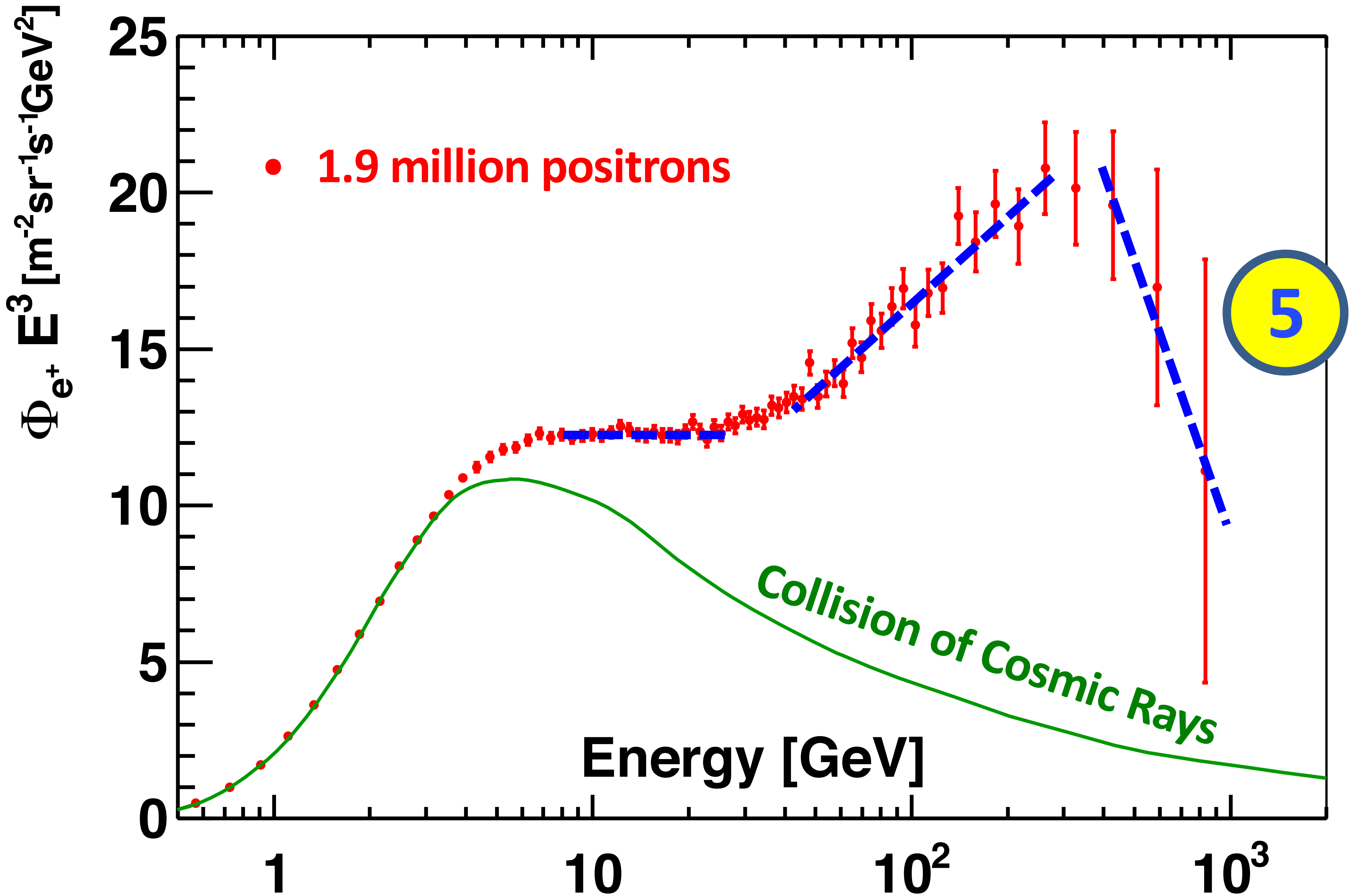
Observation 3: Above 30 GeV, the data increase again.

Observation 4: It reaches a maximum at ~300 GeV

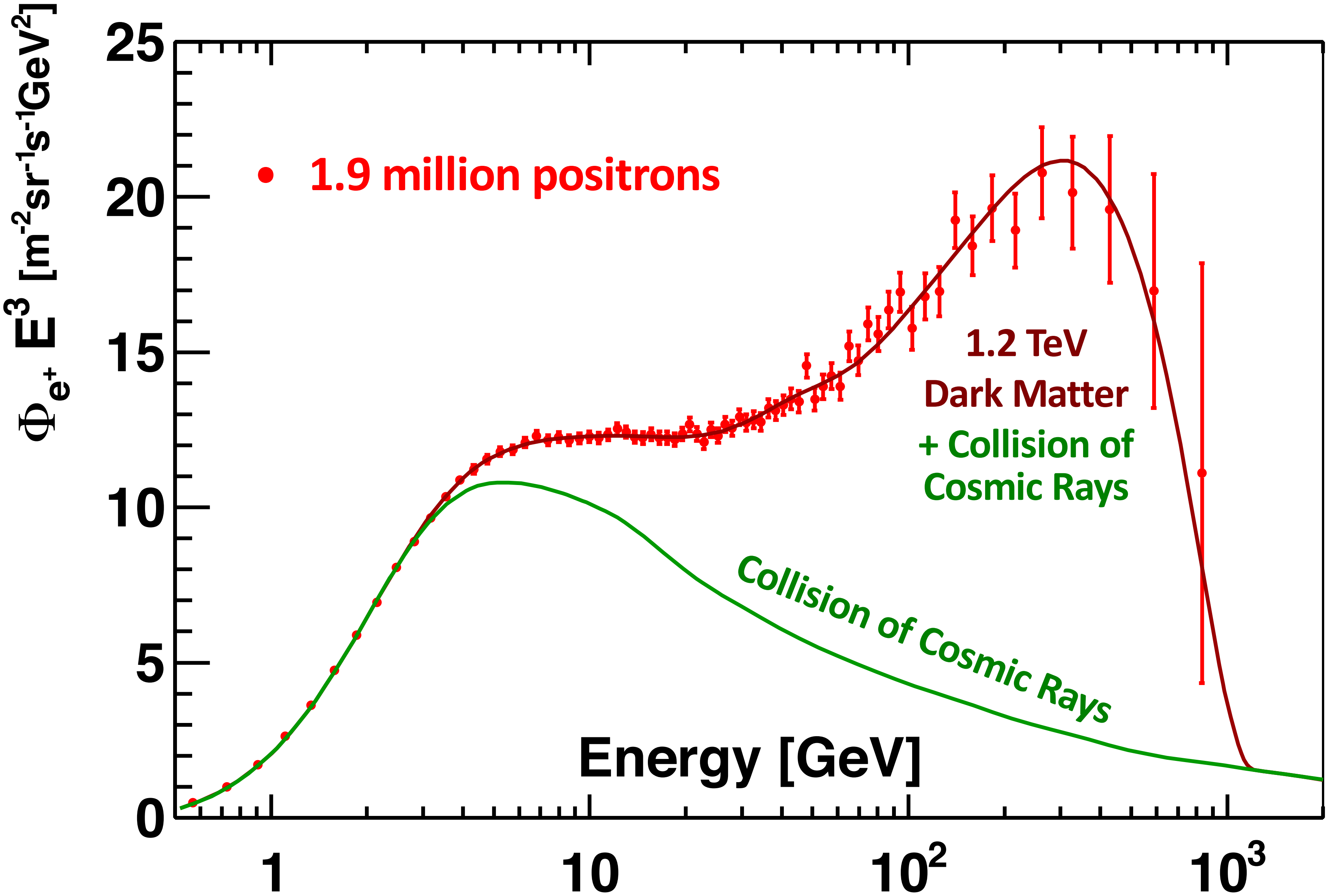


Properties of the Positron Flux

Observation 5: The data drops sharply above 300 GeV



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))



Many models proposed to explain the physics origin of the observed behavior

(>2000 citations of the AMS results)

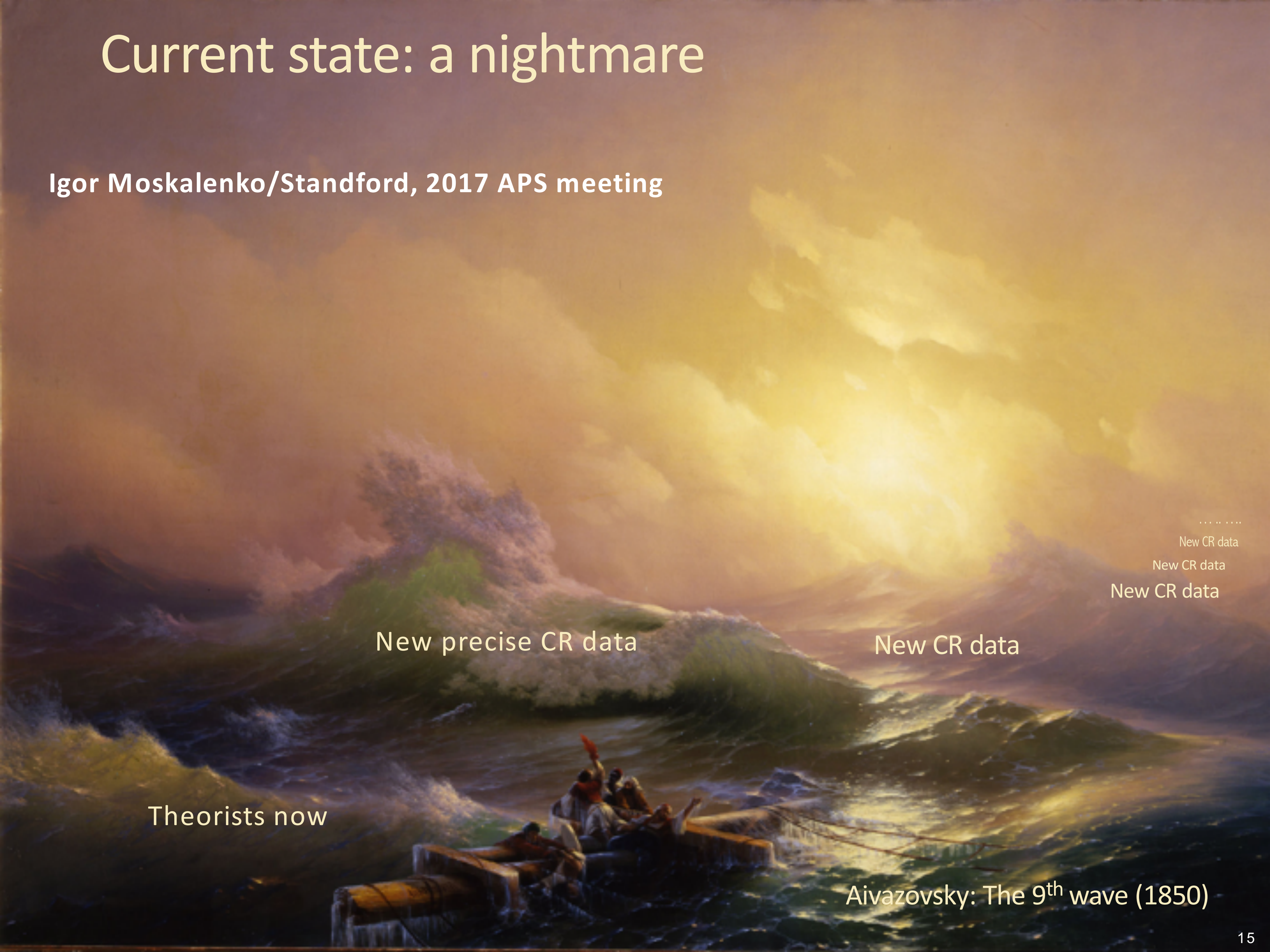
1) Particle origin: Dark Matter
2) Astrophysics origin: Pulsars, SNRs
3) Propagation of cosmic rays

Models based on very different assumptions describe observed trends of a single measurement.

Simultaneous description of several precision measurements is difficult in the framework of a single model

Current state: a nightmare

Igor Moskalenko/Standford, 2017 APS meeting



……. ….

New CR data

New CR data

New CR data

New precise CR data

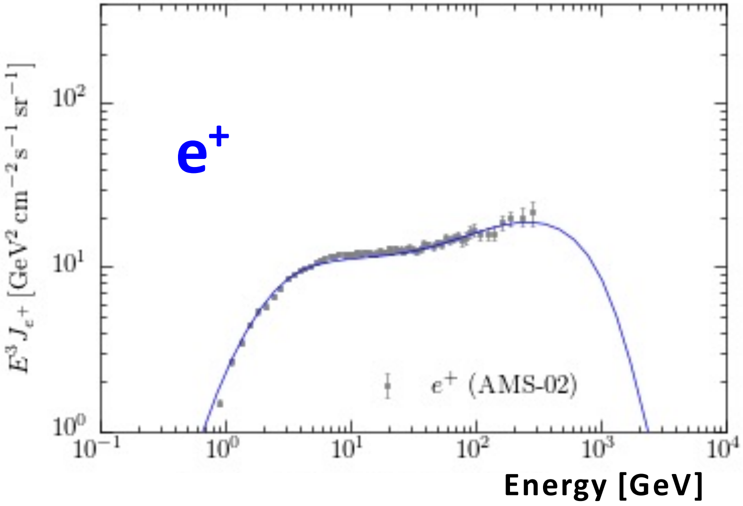
New CR data

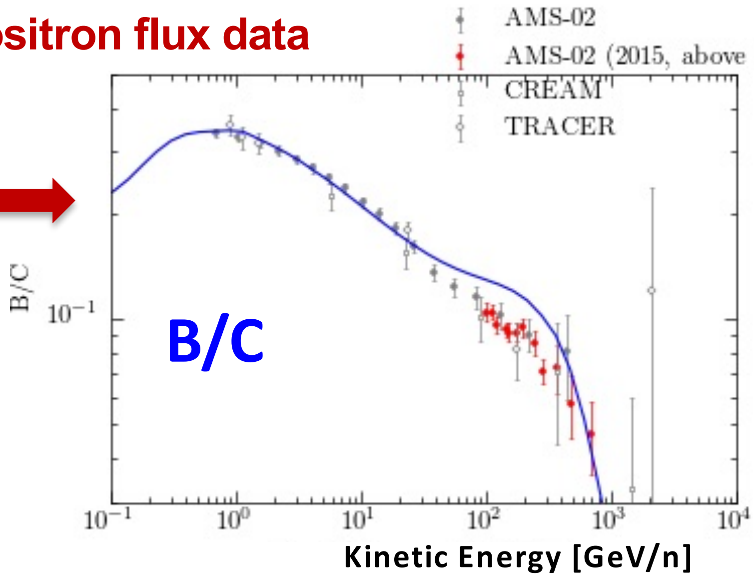
Theorists now

Aivazovsky: The 9th wave (1850)

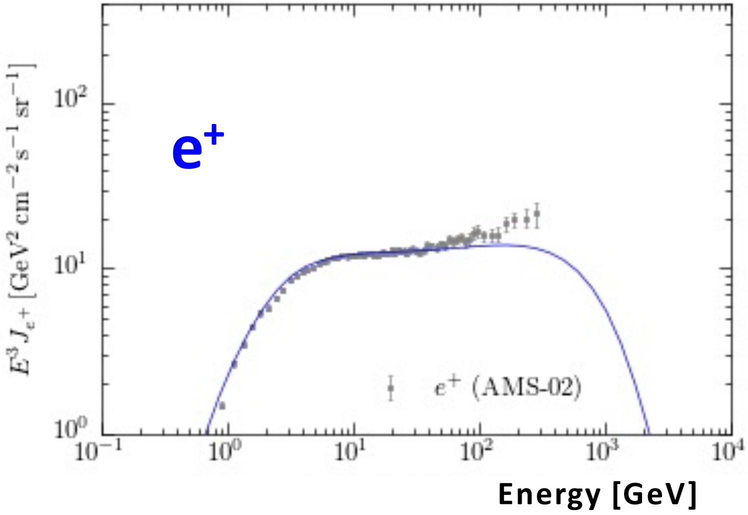
Astrophysical sources: Supernova Remnants

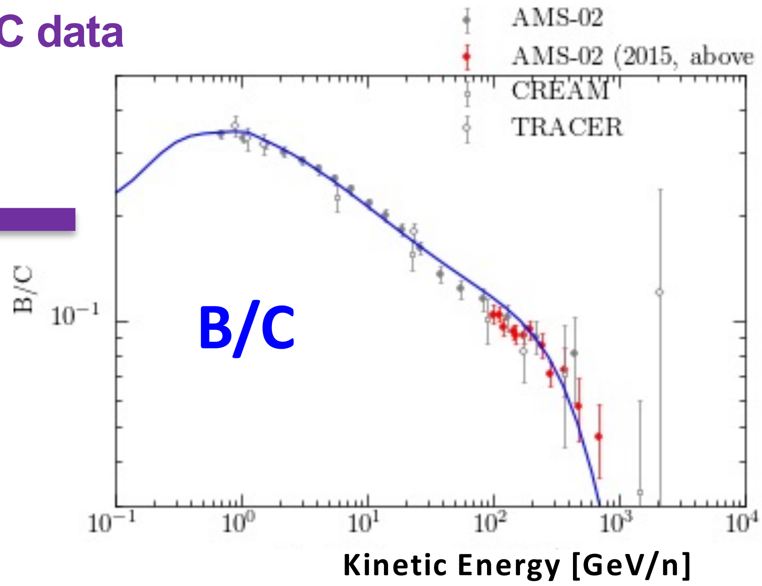
Model parameter tuned to fit the positron flux data





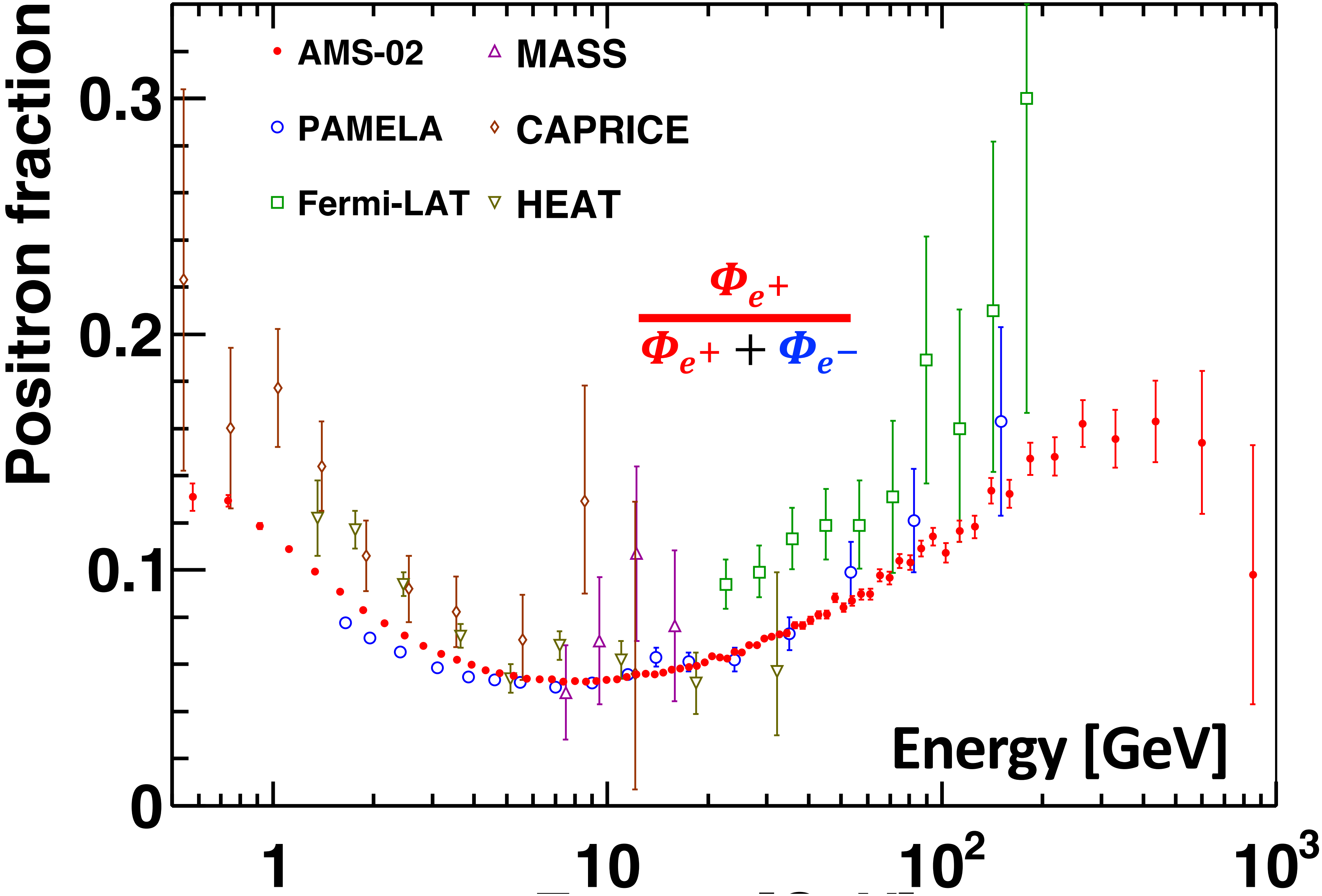
Model parameter tuned to fit the B/C data





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

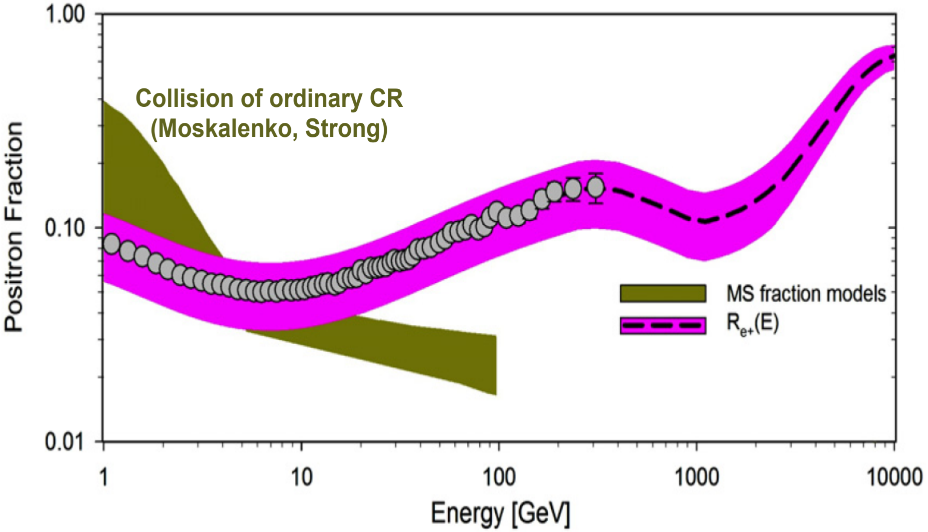
Positron excess also can be expressed in terms of the positron fraction, which explores the same physics



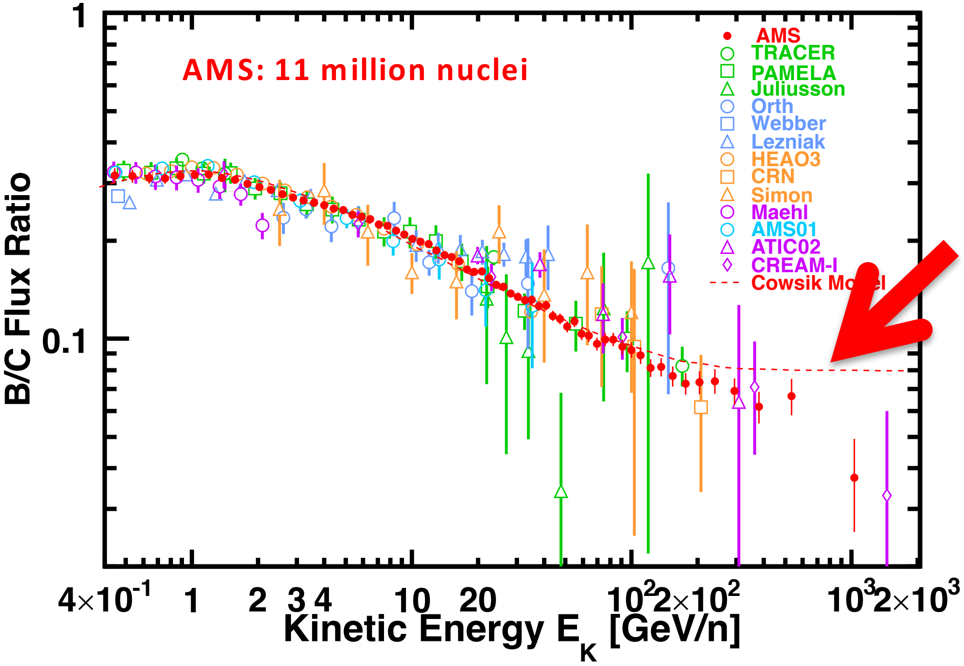
$$\frac{\Phi_{e^+}}{\Phi_{e^+} + \Phi_{e^-}}$$

New Propagation Models explaining the AMS e+ data

Explaining the AMS positron fraction (gray circles) is due to propagation effects.
R. Cowsik *et al.*, Ap. J. 786 (2014) 124, (pink band)



This requires a specific energy dependence of the B/C ratio


AMS: 11 million nuclei

The observed features of the AMS e+ data cannot be explained by standard propagation models

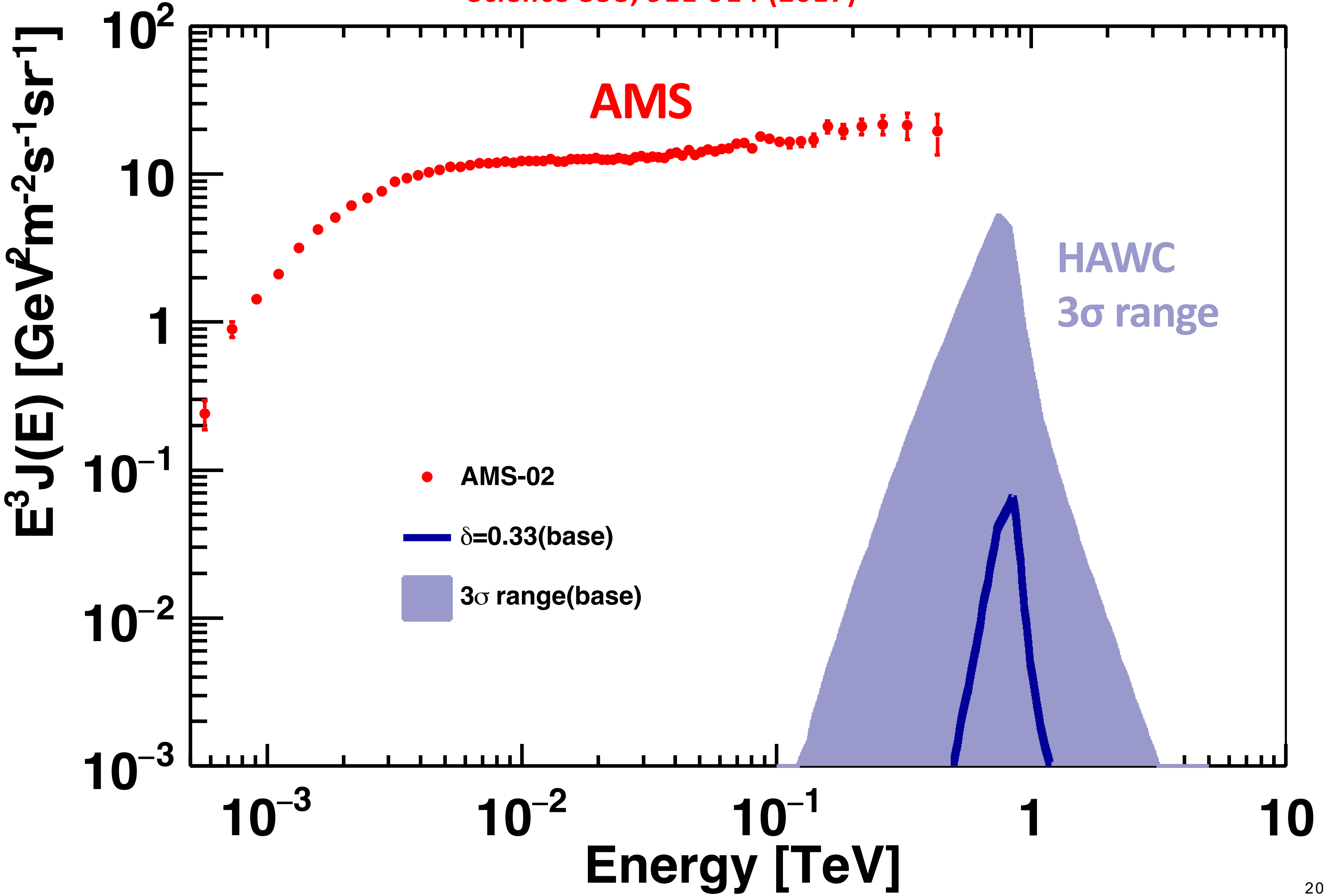
Astrophysical sources: pulsars

The High-Altitude Water Cherenkov Gamma-Ray Observatory

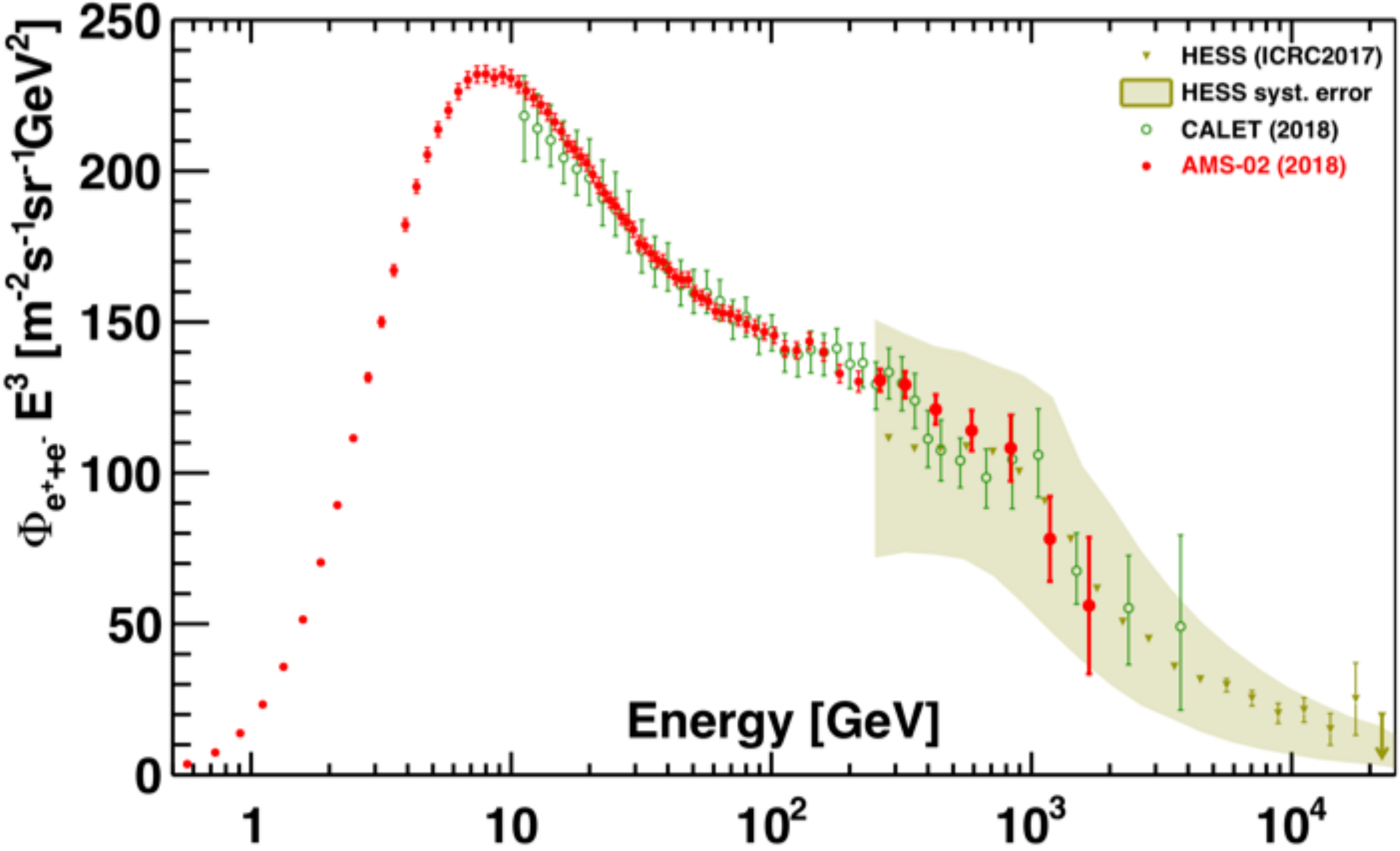
HAWC Collaboration, *Science* 358, 911-914 (2017)

HAWC rules out that the positron excess is from nearby pulsars

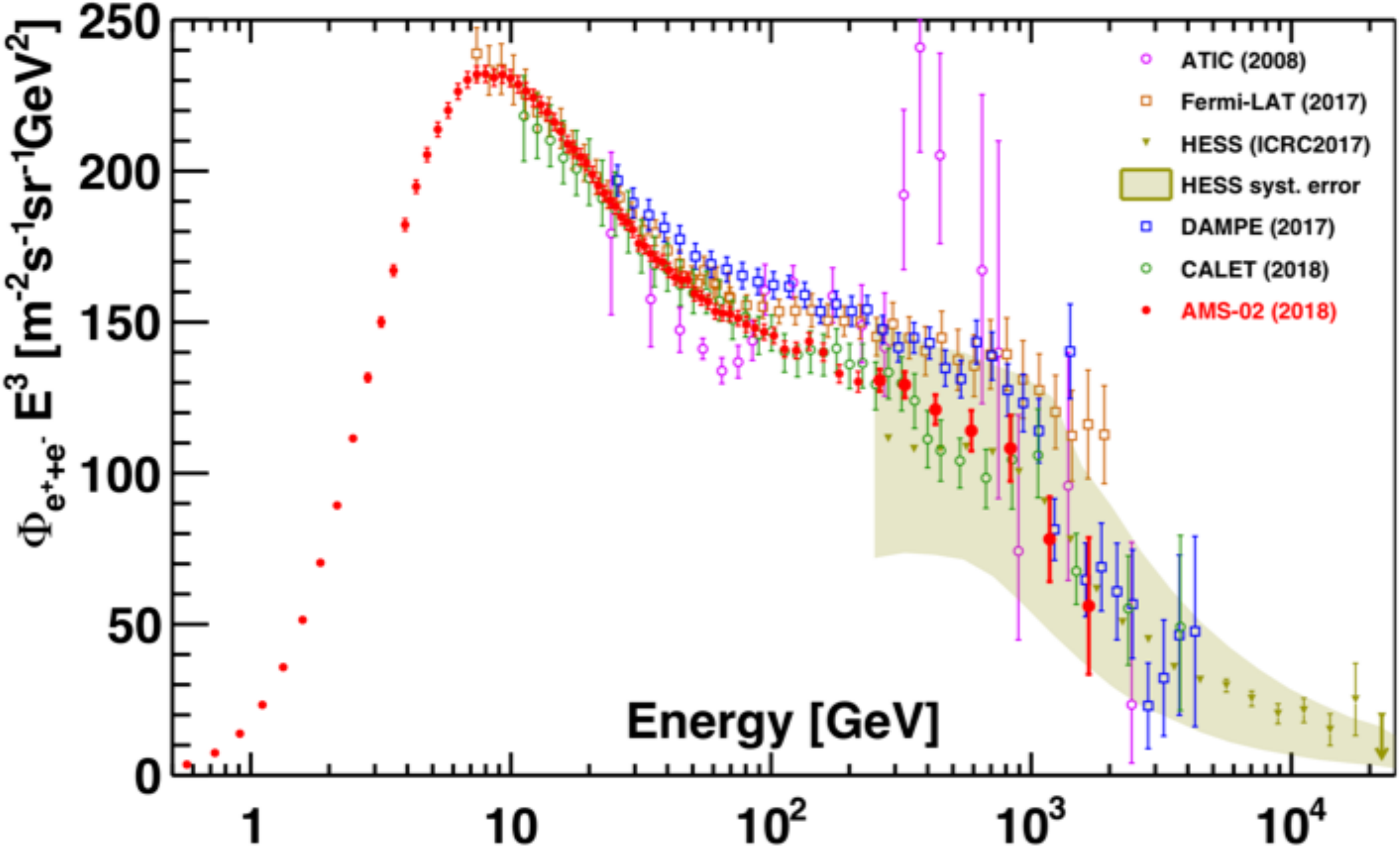
Science 358, 911-914 (2017)



AMS ($e^+ + e^-$) data with non-magnetic detectors

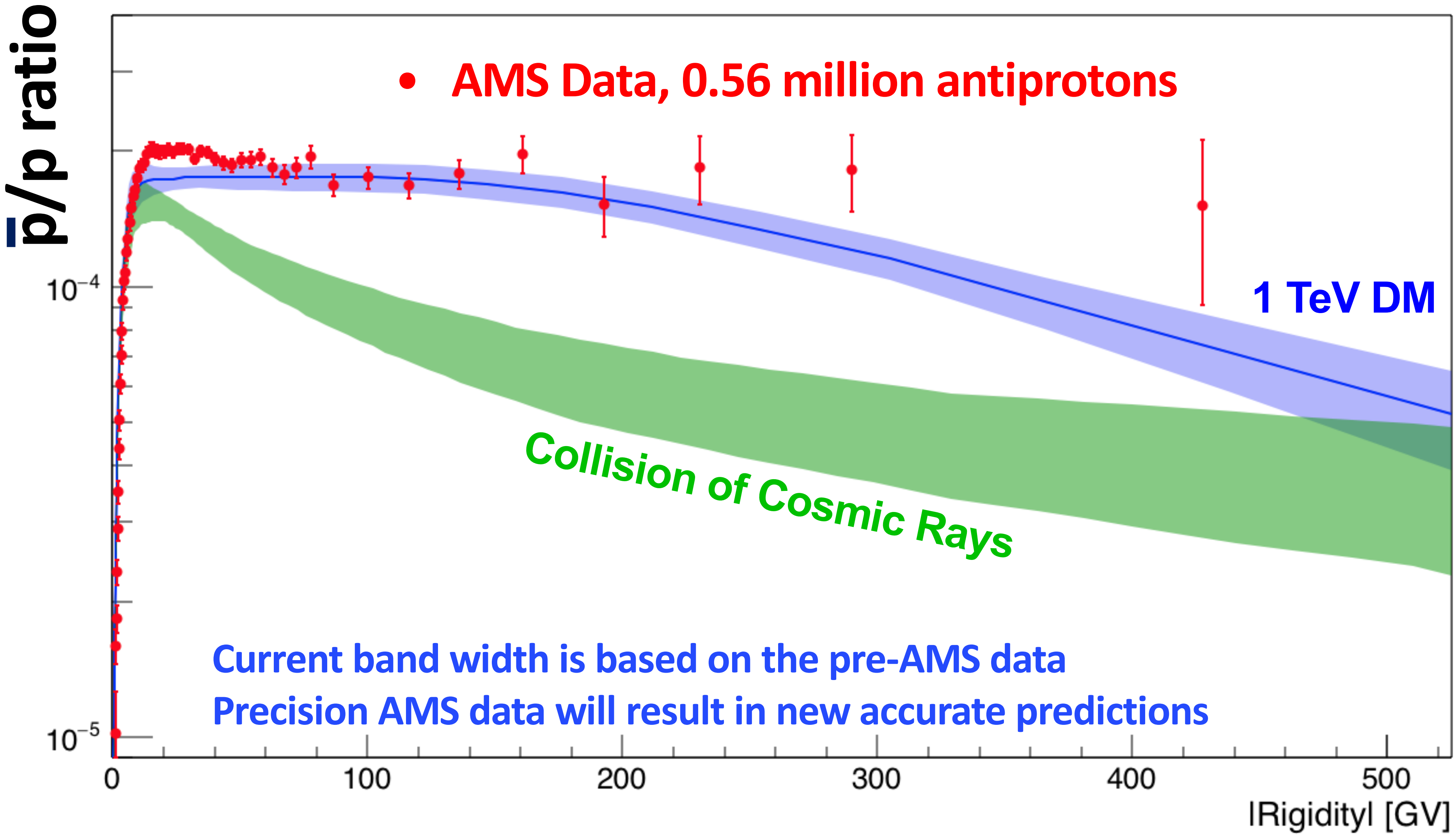


$(e^+ + e^-)$ data with AMS and with non-magnetic detectors



Measuring *e^+* is the most sensitive way to identify *χ* via *$\chi + \chi \rightarrow e^+, e^-, \ldots$*

The $\bar{p}/p$ ratio in comparison with pre-AMS models



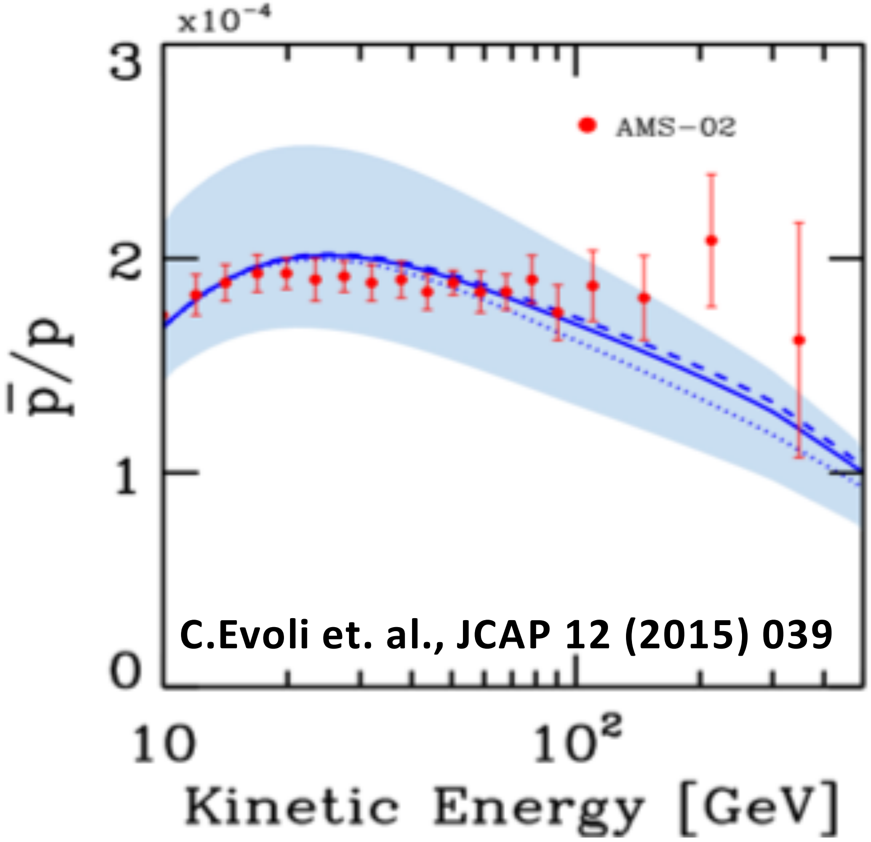
Current band width is based on the pre-AMS data

Precision AMS data will result in new accurate predictions

Donato et al., PRL 102, 071301 (2009); m_χ = 1 TeV

New Models for the $\bar{p}/p$ ratio

The precision AMS data allow for exploration of new phenomena



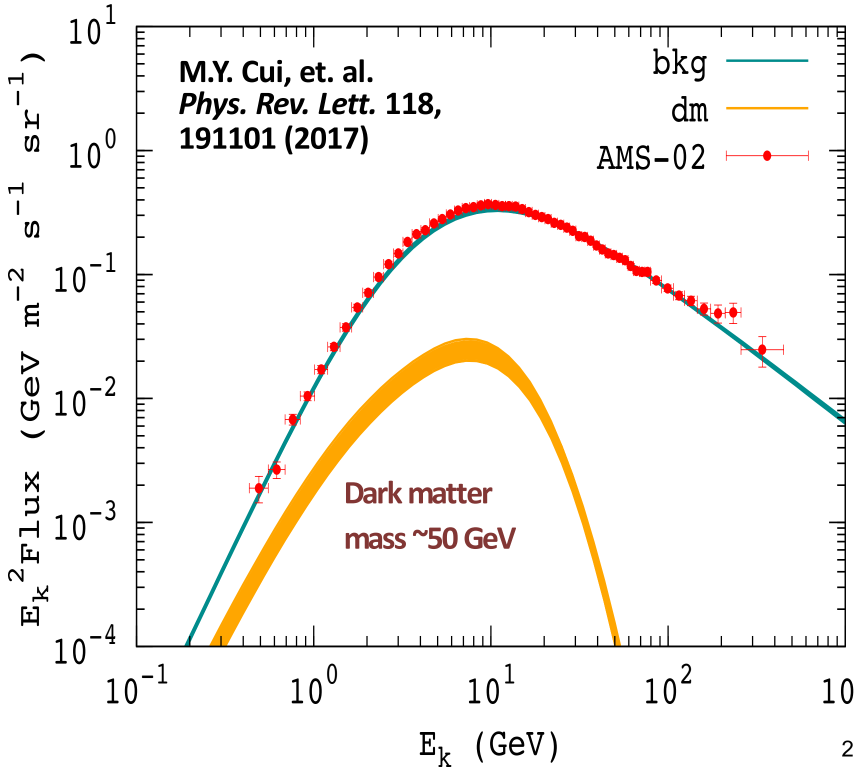
C.Evoli et. al., JCAP 12 (2015) 039

Collision of cosmic rays with interstellar medium:

G.Giesen, et. al., JCAP 09 (2015) 023
C.Evoli et. al., JCAP 12 (2015) 039
R.Kappl et. al., JACP 10(2015) 034
…

The antiproton excess around 10 GV:

A. Cuoco, et. Al.*Phys. Rev. Lett.* 118, 191102
M.Y. Cui, et. al. *Phys. Rev. Lett.* 118, 191101 (2017)
A. Reinert and M.W. Winkler, JCAP 01 (2018) 055

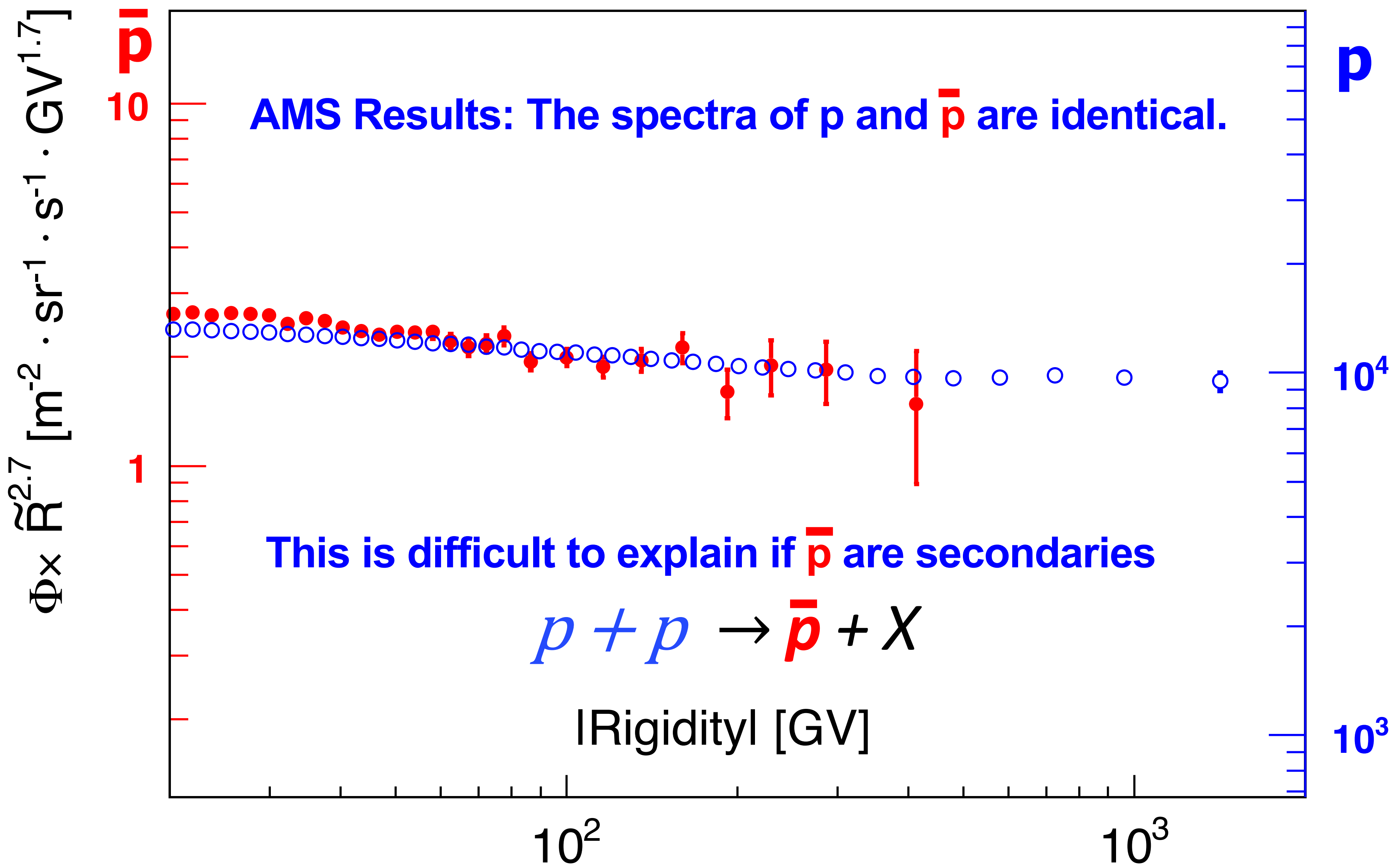


M.Y. Cui, et. al.
Phys. Rev. Lett. 118,
191101 (2017)

Dark matter
mass ~50 GeV

Elementary Particles in Space

Of the hundreds of charged particles only four of them, e-, e+, p, and $\bar{p}$, have infinite lifetime, so they travel in the cosmos forever.

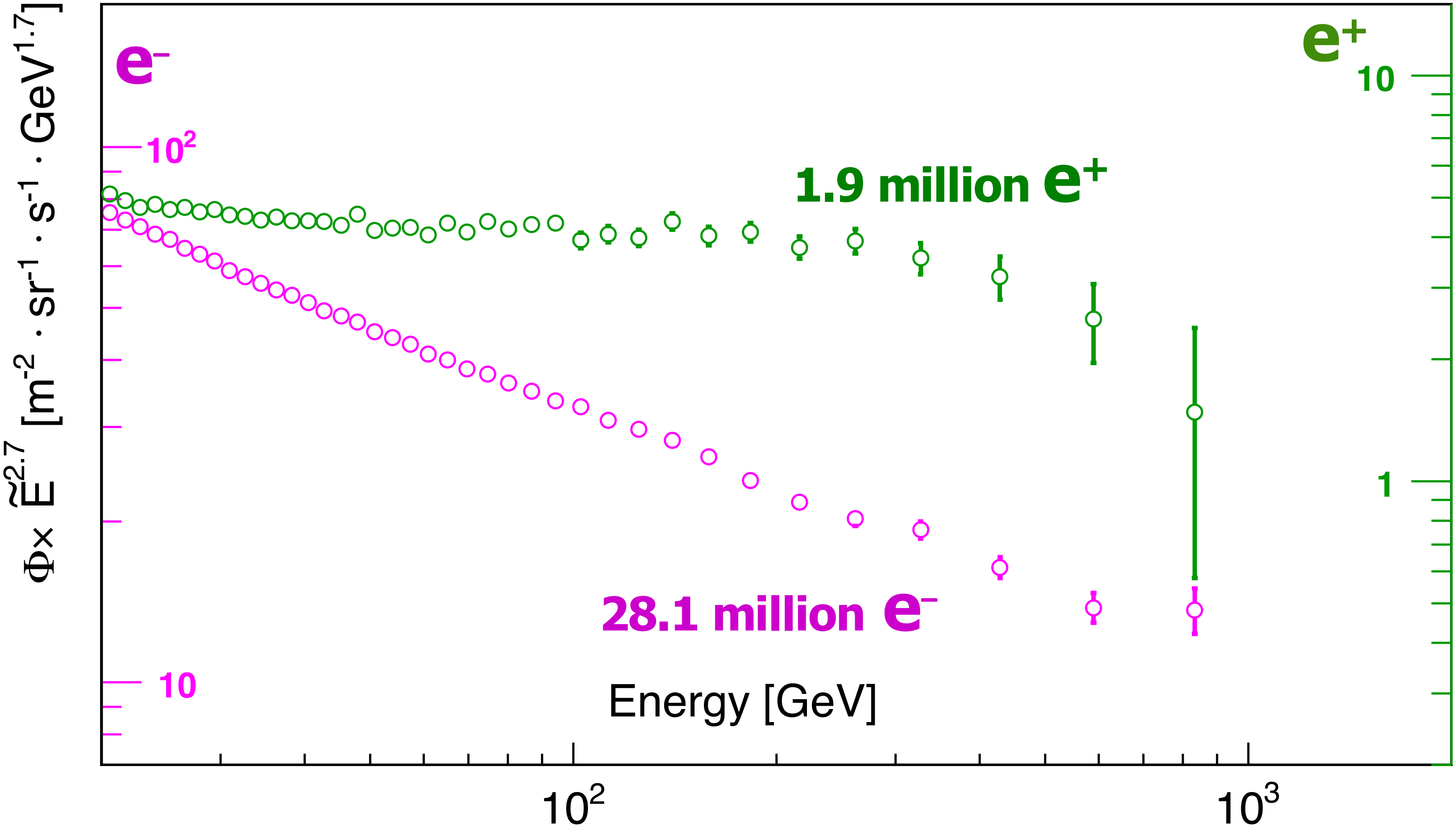


AMS Results: The spectra of p and $\bar{p}$ are identical.

This is difficult to explain if $\bar{p}$ are secondaries

$$p + p \rightarrow \bar{p} + X$$

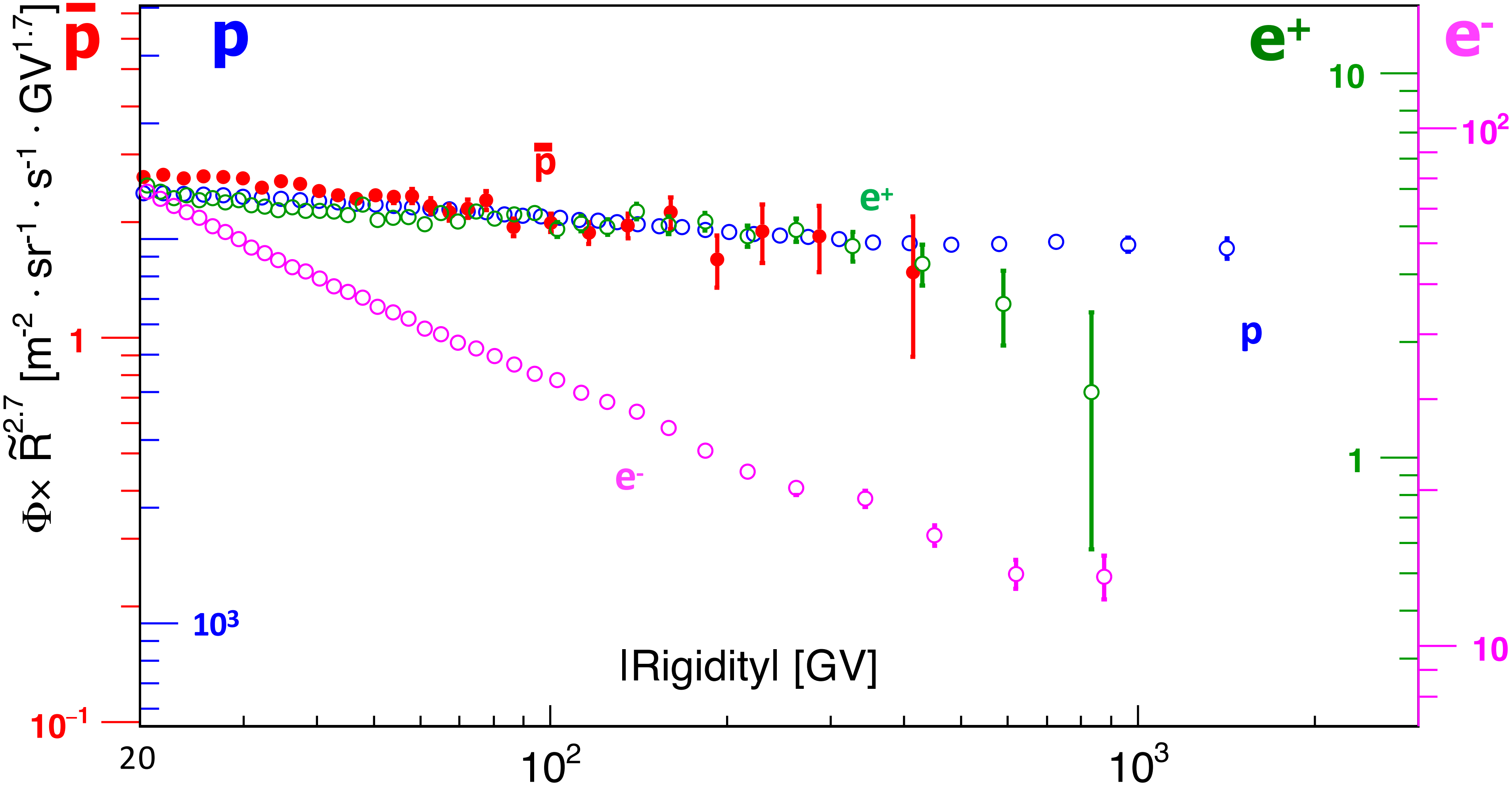
The spectra of electrons and positrons are very different despite the fact that they have identical mass



Most surprisingly:

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

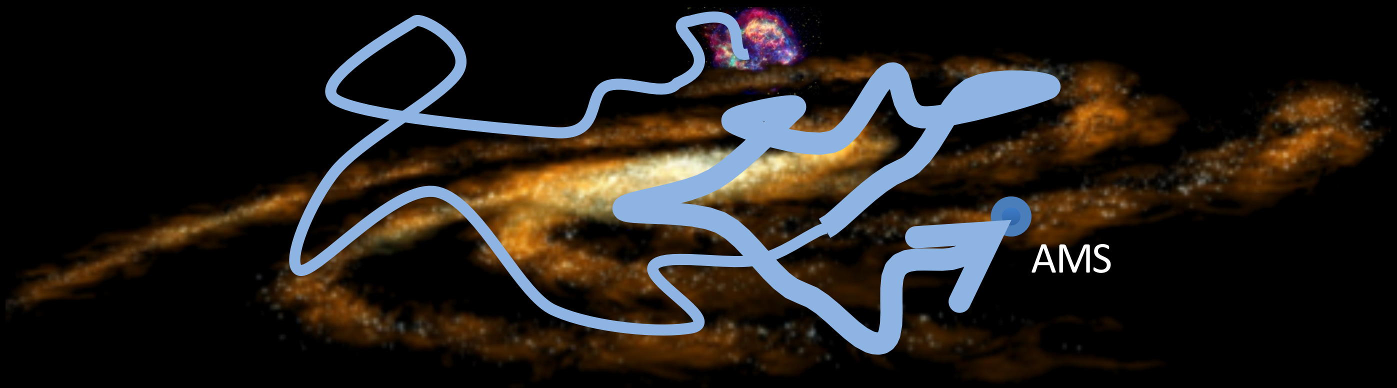
The electron spectrum is different



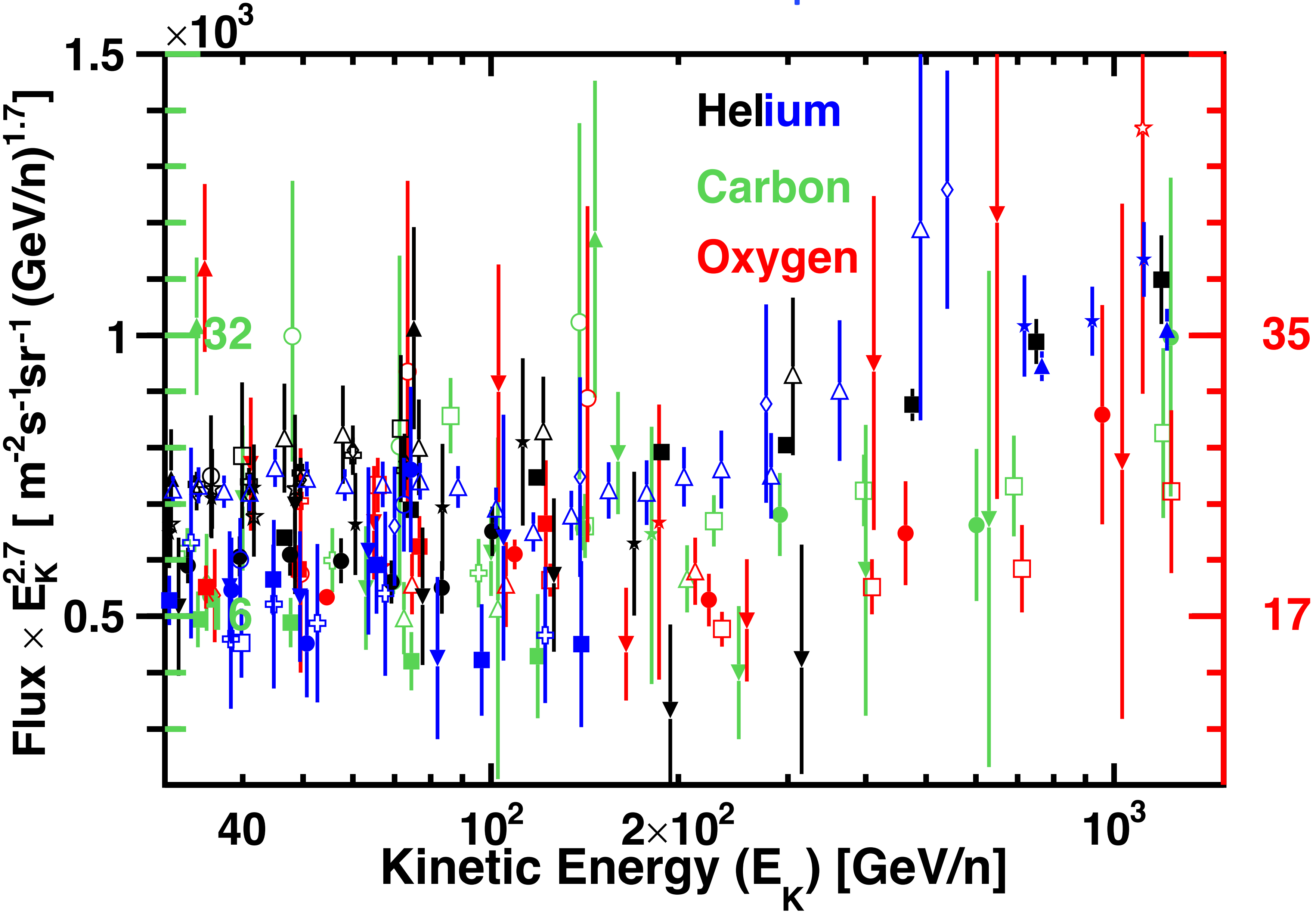
Traditionally, there are two prominent classes of cosmic rays:

Primary Cosmic Rays (p, He, C, O, …)

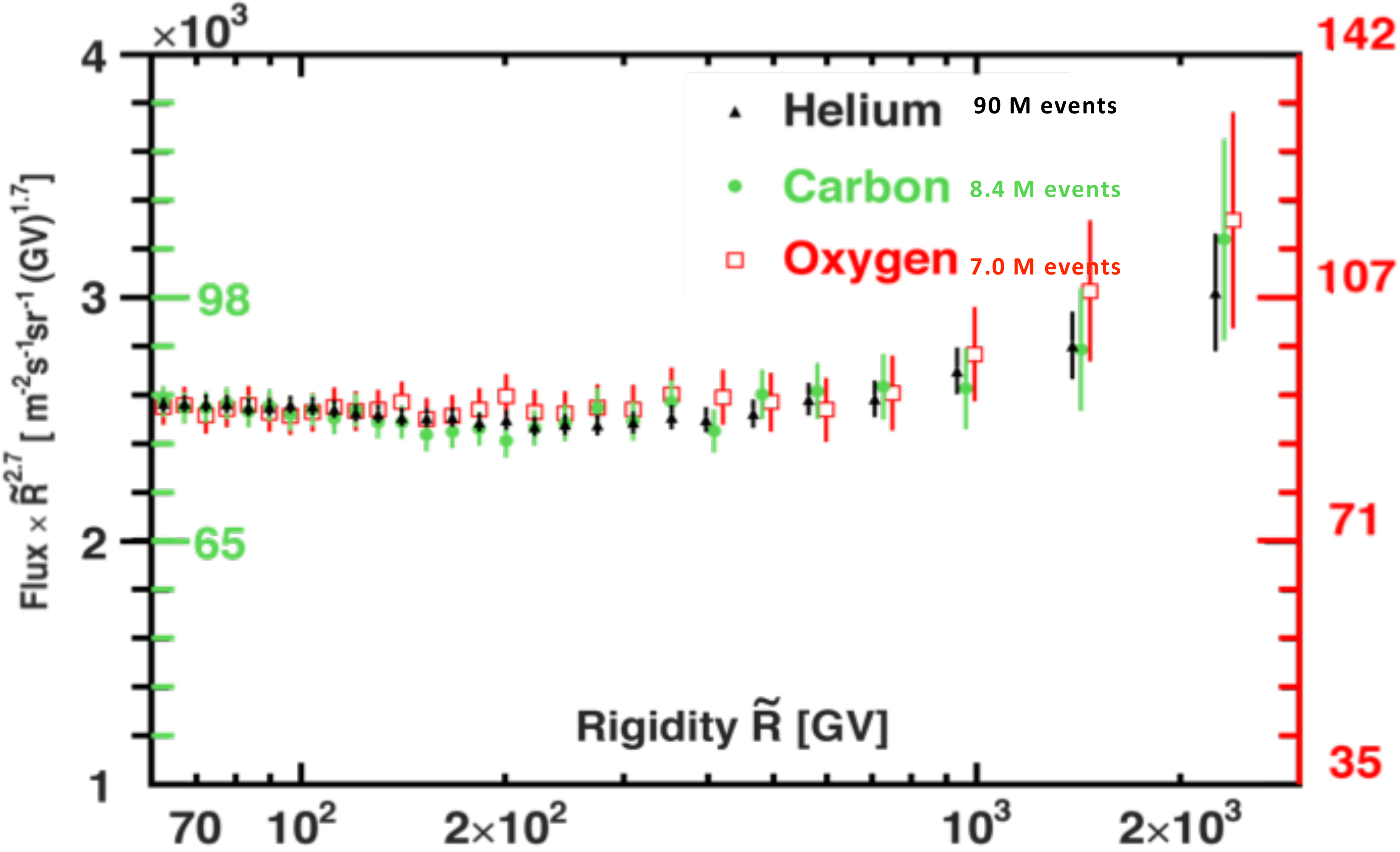
are produced at their source and travel through space and are directly detected by AMS. They carry information on their sources and the history of travel.



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.

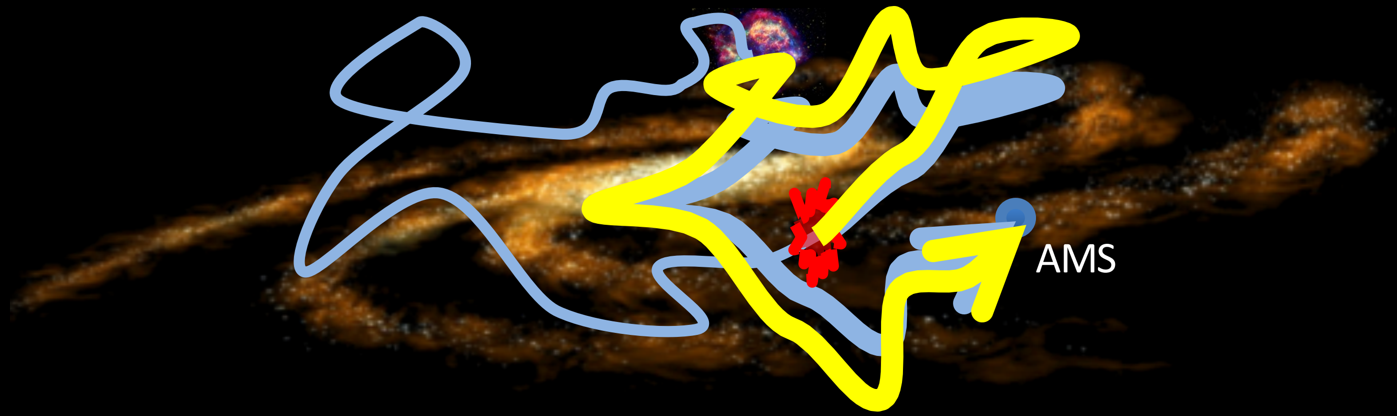


Above 200 GV the data all increase in identical way.

This is unexpected.

Traditionally, there are two prominent classes of cosmic rays:

Primary Cosmic Rays (p, He, C, O, …)



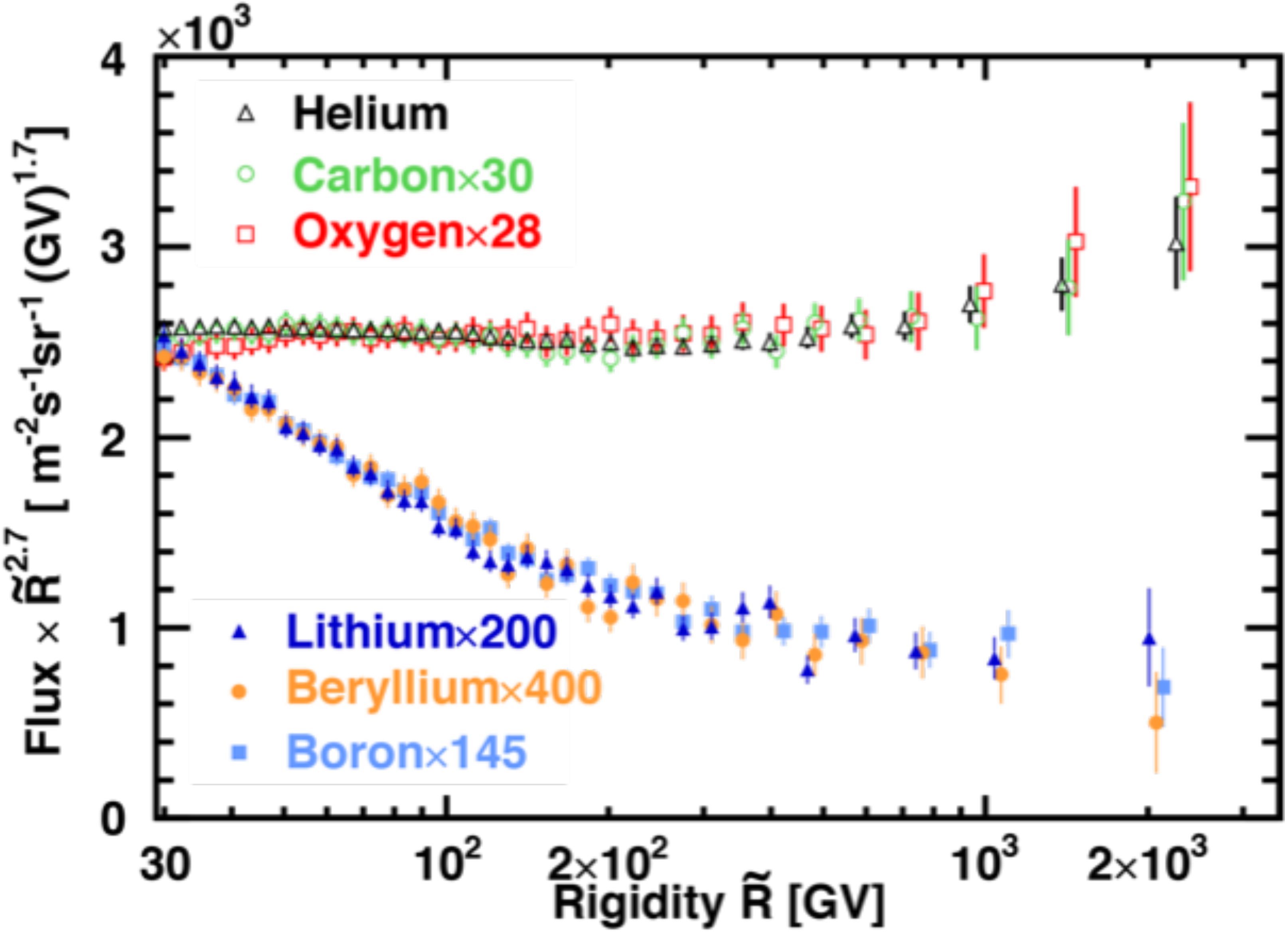
Secondary Cosmic Rays (Li, Be, B, …)

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.

Rigidity dependence of Primary and Secondary Cosmic Rays

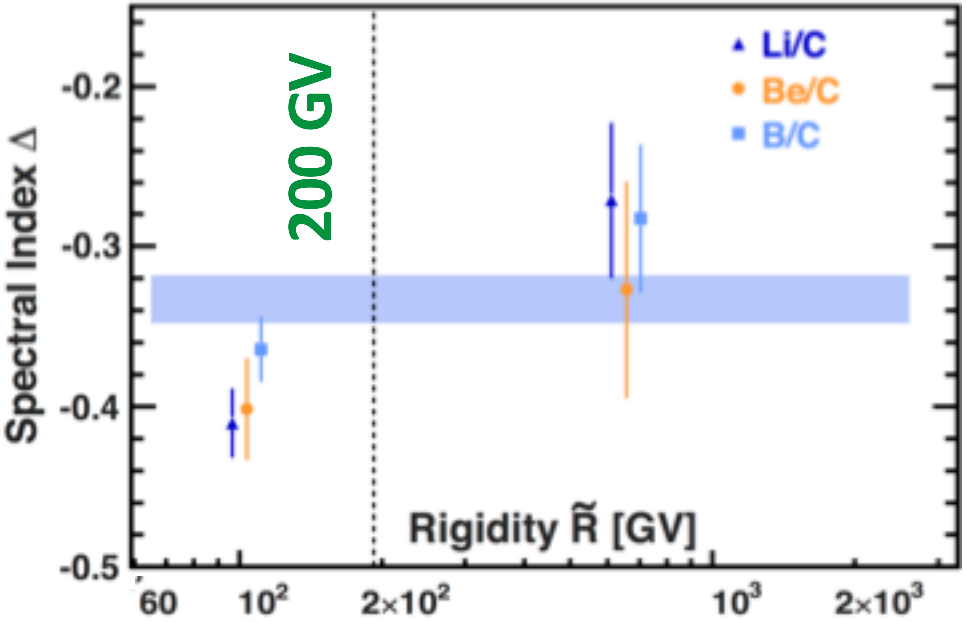
Both deviate from a traditional single power law above 200 GeV.

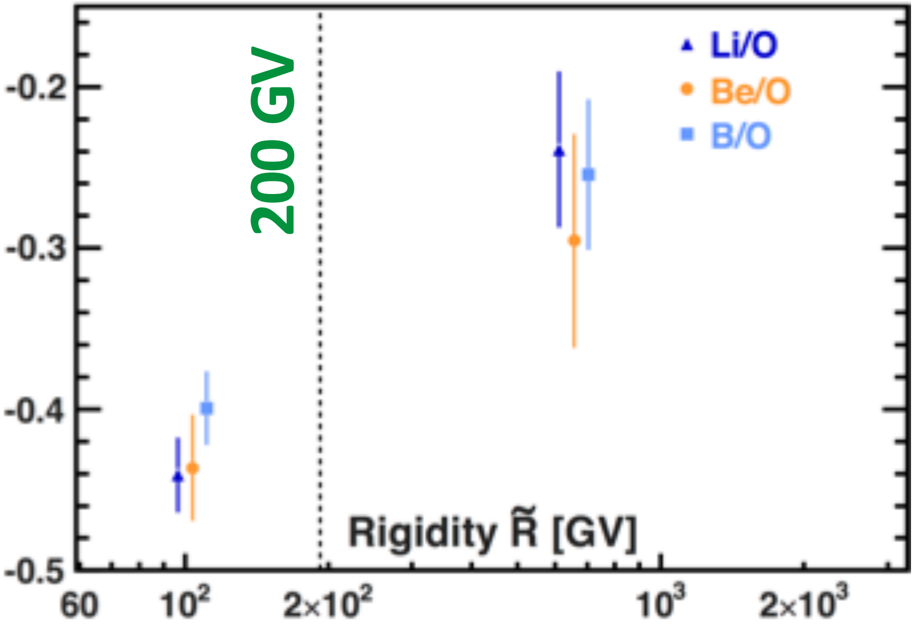
But their rigidity dependences are distinctly different.



New result

Precision Measurement of Secondary Cosmic Ray Spectra versus Primary Cosmic Ray Spectra



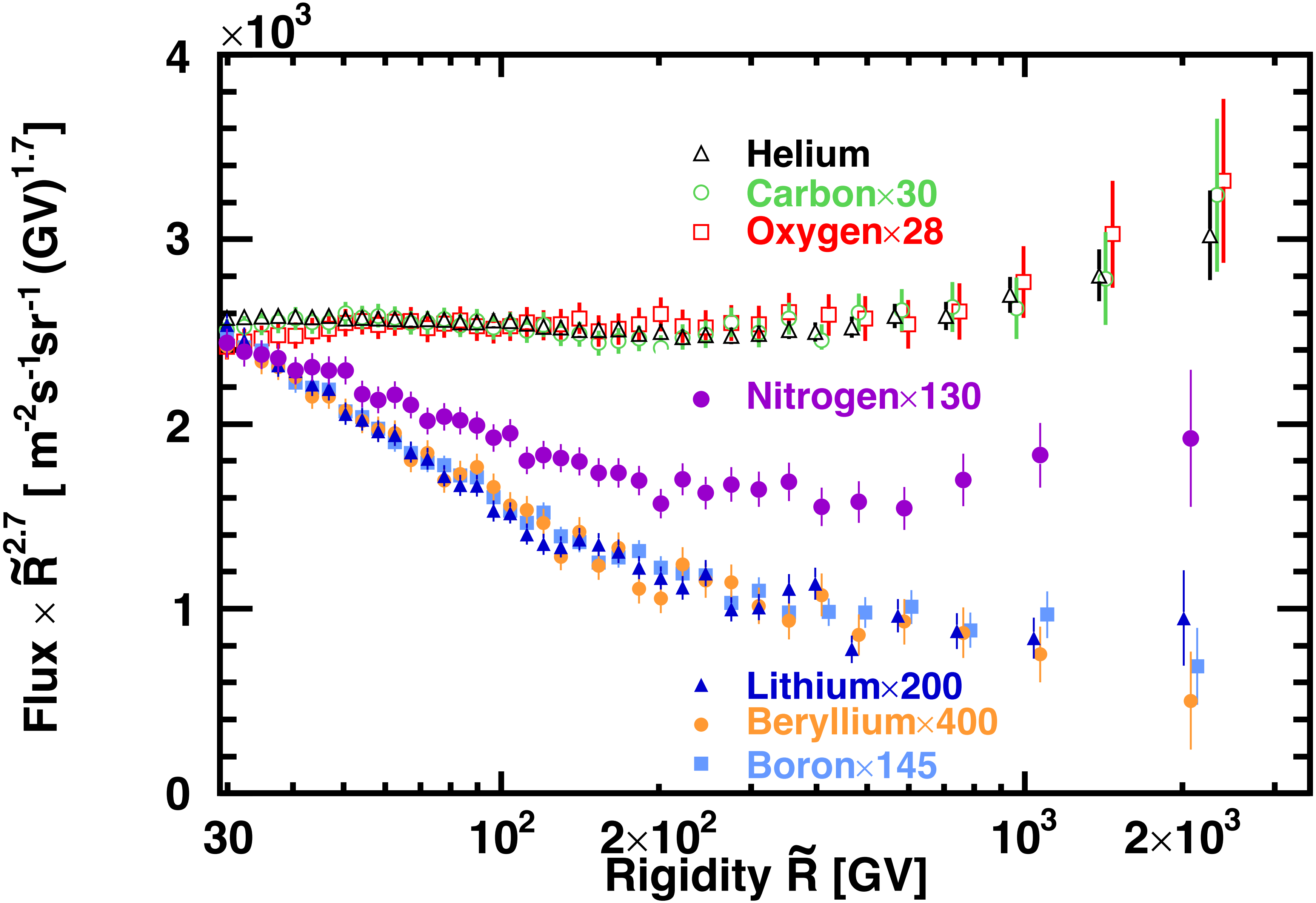


Combining the six ratios,
the secondary over primary flux ratio (B/C, …),
deviates from single power law above 200 GV by 0.13±0.03
Secondary/Primary = KR^{Δ}

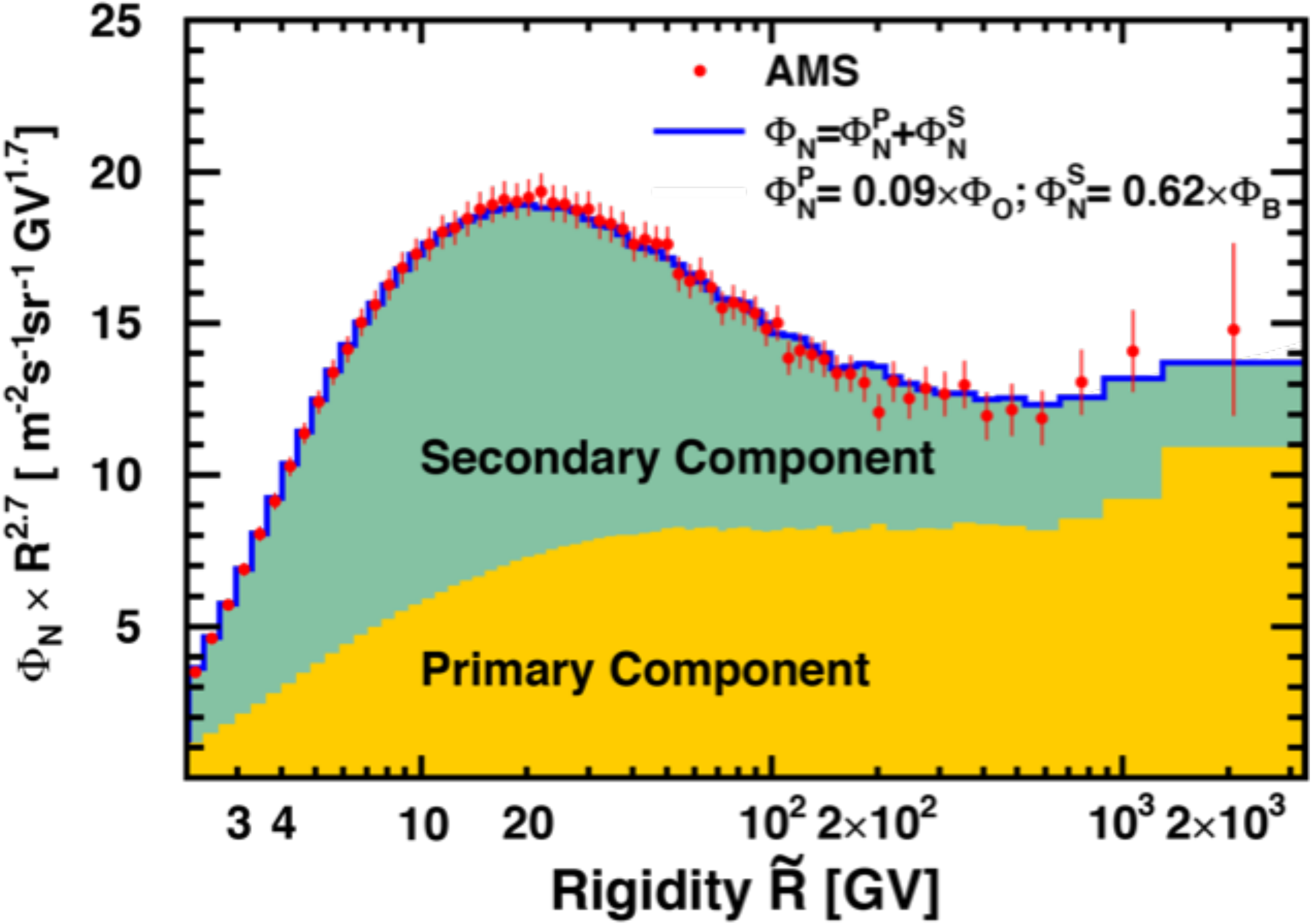
$$\Delta[200\text{-}3300\text{GV}] - \Delta[60\text{-}200\text{GV}] = 0.13 \pm 0.03$$

The Nitrogen flux

together with primary and secondary cosmic rays fluxes.



The nitrogen flux is composed of primary and secondary components

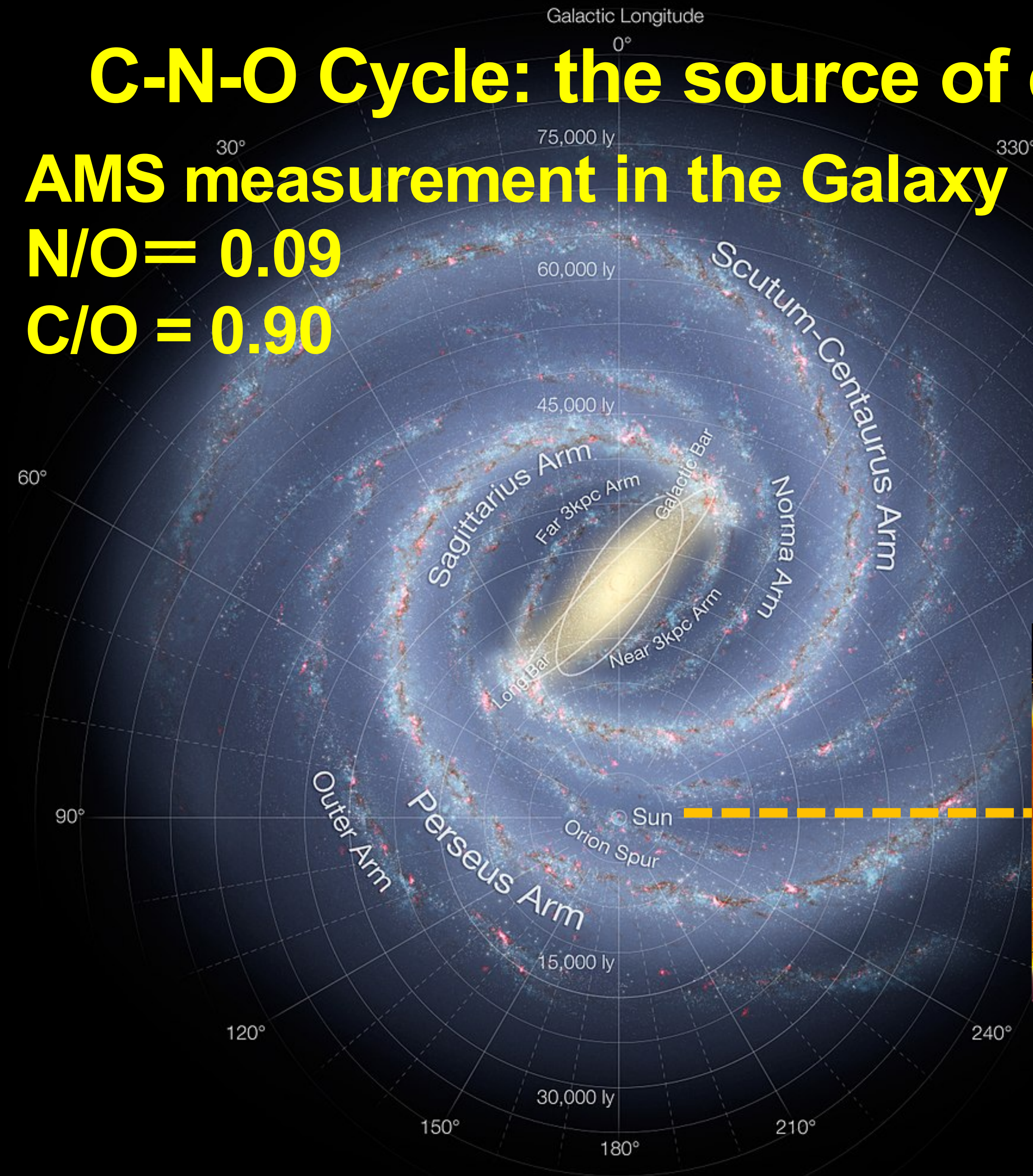


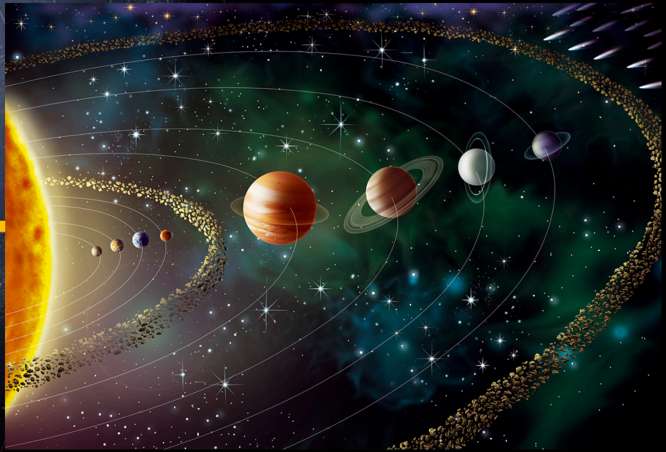
C-N-O Cycle: the source of energy in stars

AMS measurement in the Galaxy

N/O= 0.09

C/O = 0.90



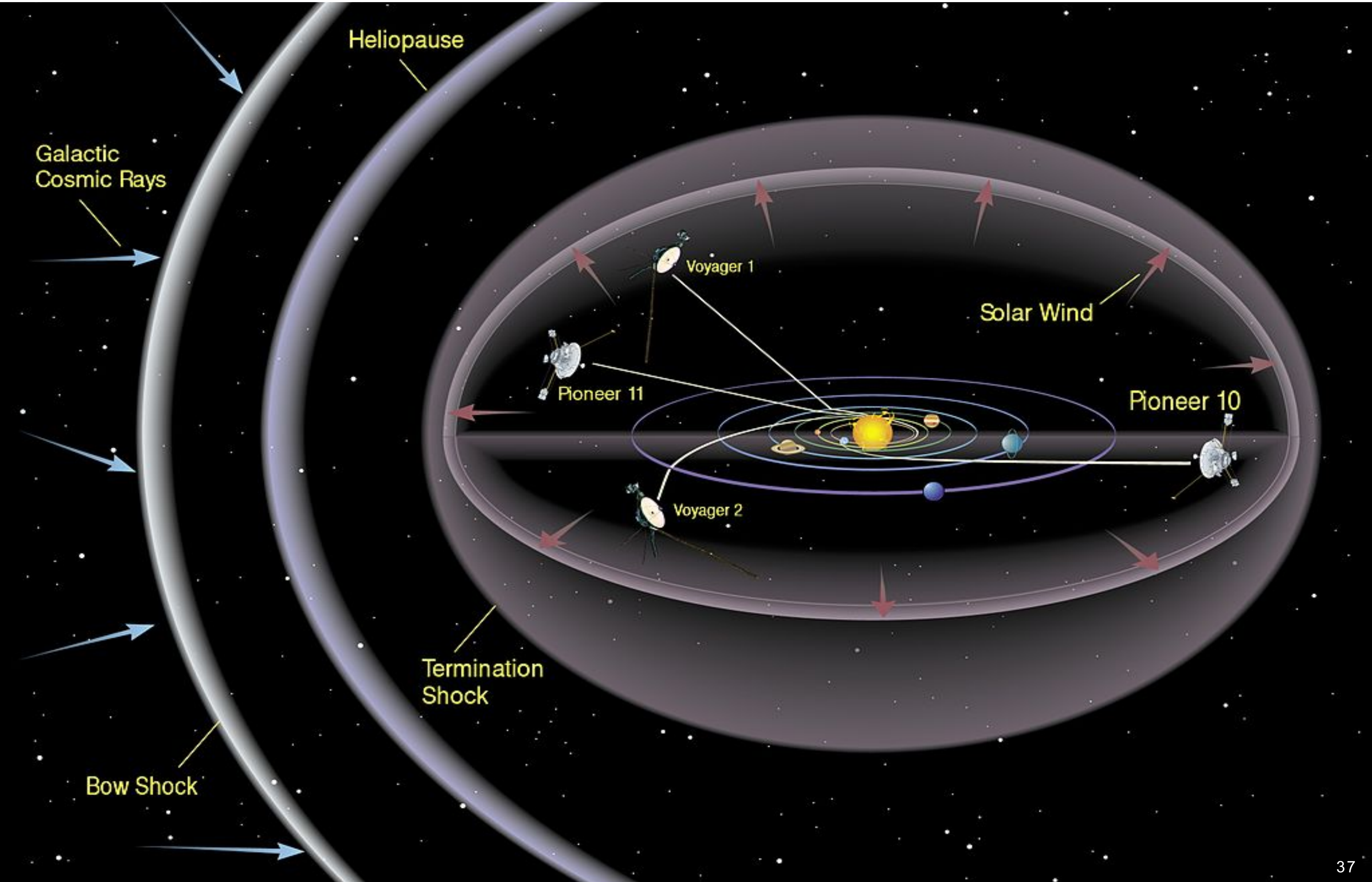


In Solar System:

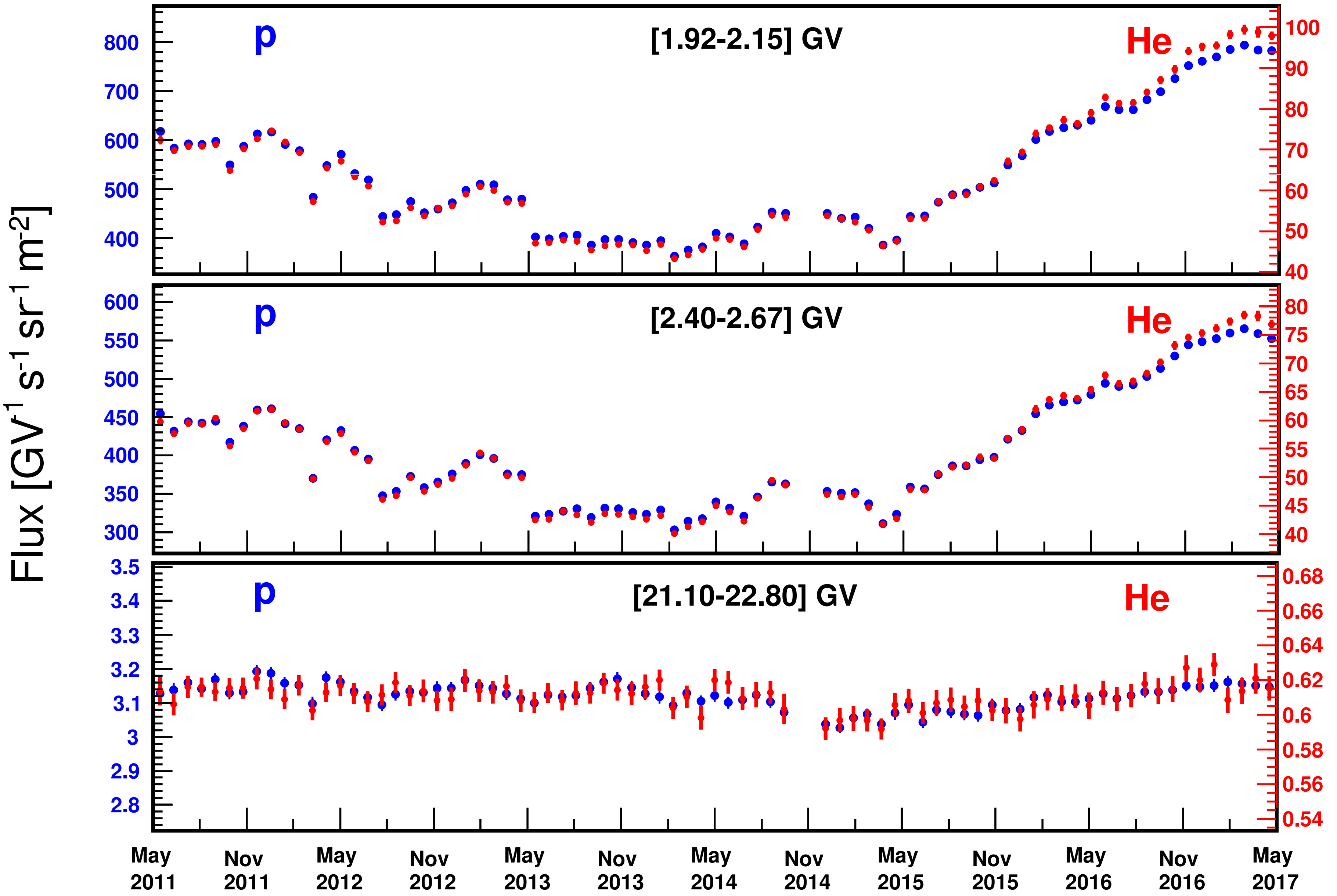
N/O = 0.14

C/O = 0.46

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

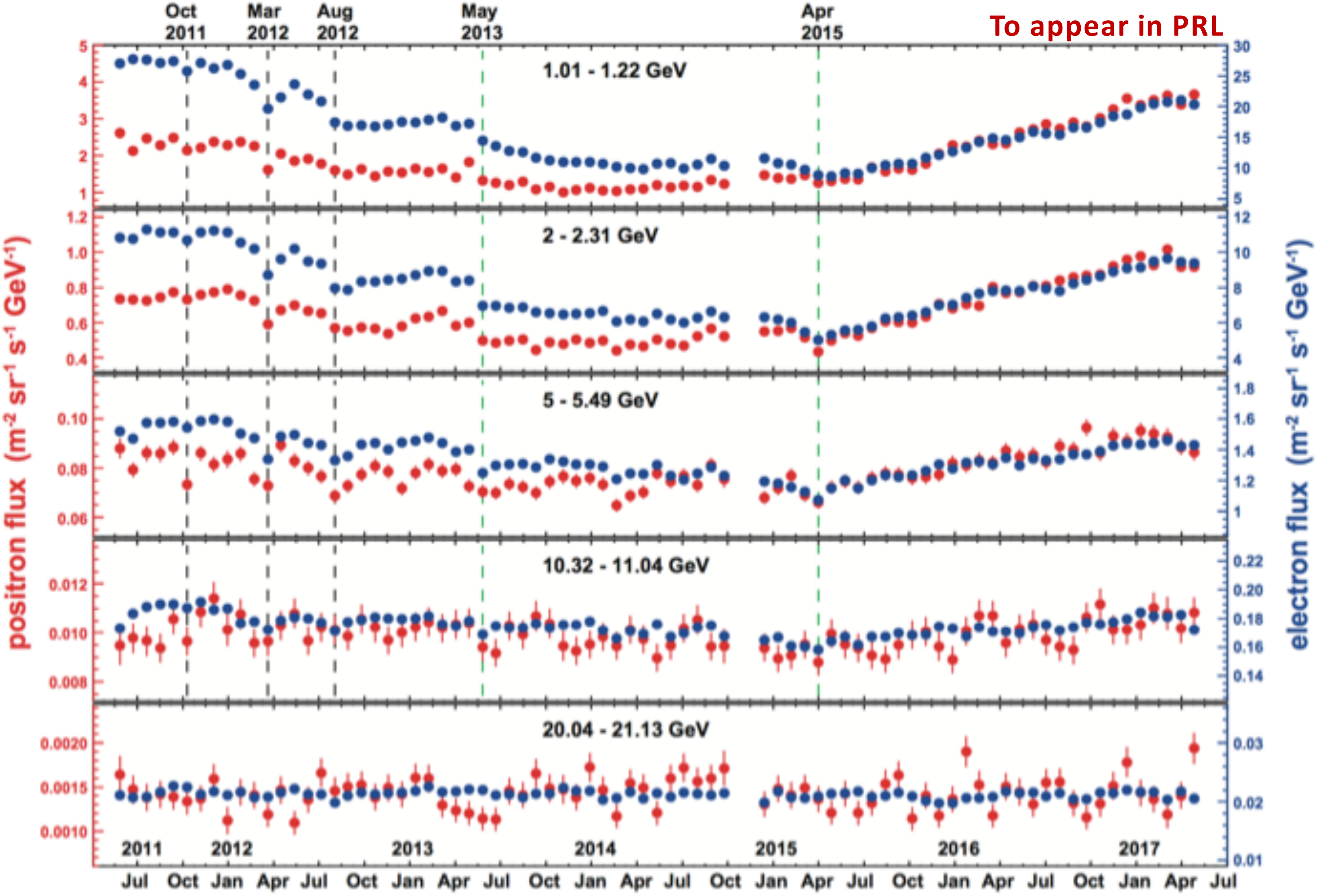


New observation: Identical monthly time variation of the p, He fluxes



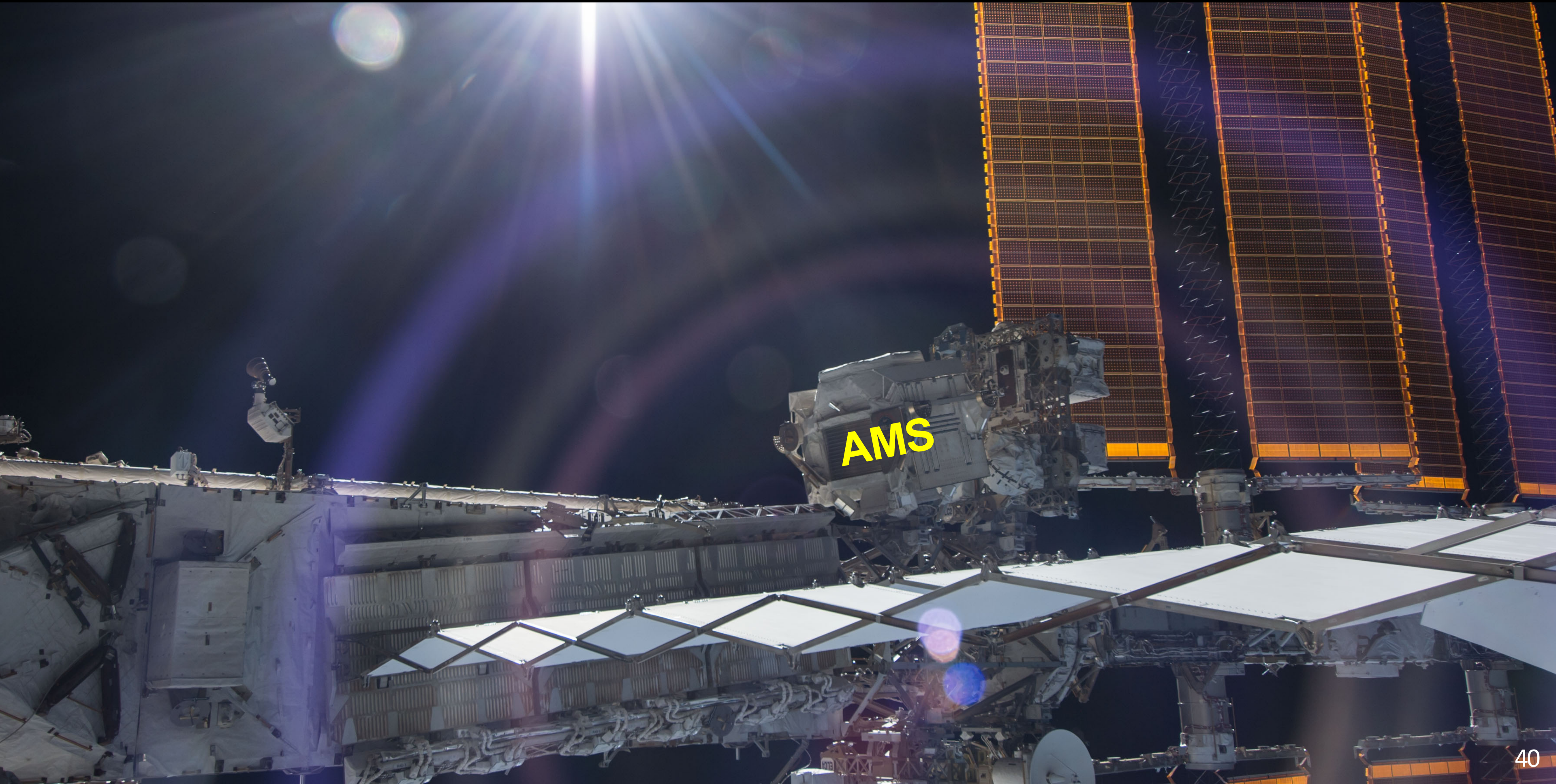
AMS continous measurement of the e+ and e- flux in the energy range 1 -50 GeV over 6 years with a time resolution of 27 days.

To appear in PRL



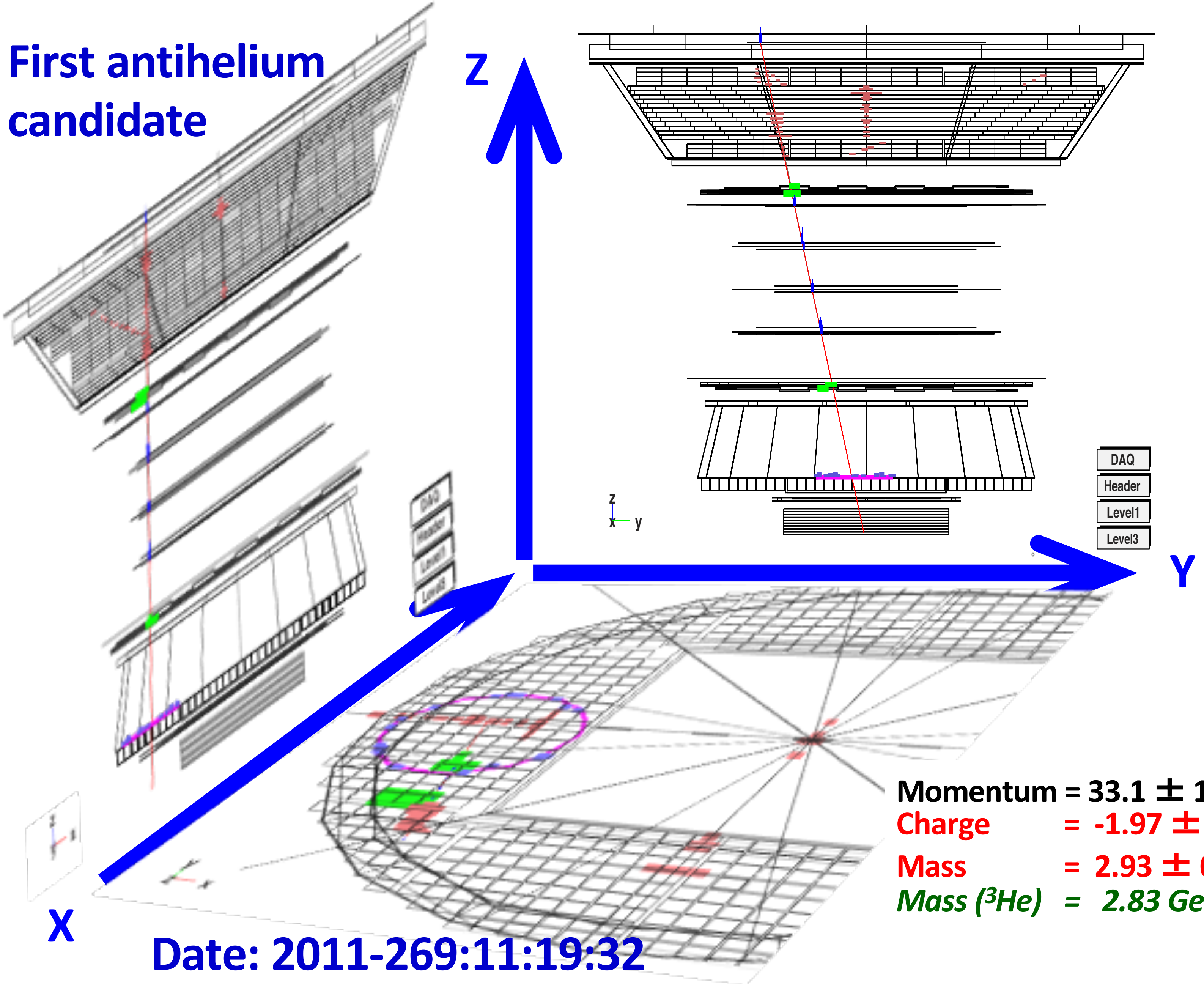
Physics of AMS through the lifetime of the Space Station

Examples: Complex anti-matter – $\overline{\text{He}}$, $\overline{\text{C}}$, $\overline{\text{O}}$
Positrons and Dark Matter
Anisotropy and Dark Matter
High Z cosmic rays



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

First antihelium candidate



Momentum = 33.1 ± 1.6 GeV/*c*

Charge = -1.97 ± 0.05

Mass = 2.93 ± 0.36 GeV/c^2

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

Date: 2011-269:11:19:32

Physics of AMS on ISS: Study of complex anti-matter $\overline{\text{He}}$, $\overline{\text{C}}$, $\overline{\text{O}}$

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

From the collision of cosmic rays:

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

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

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

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

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

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

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

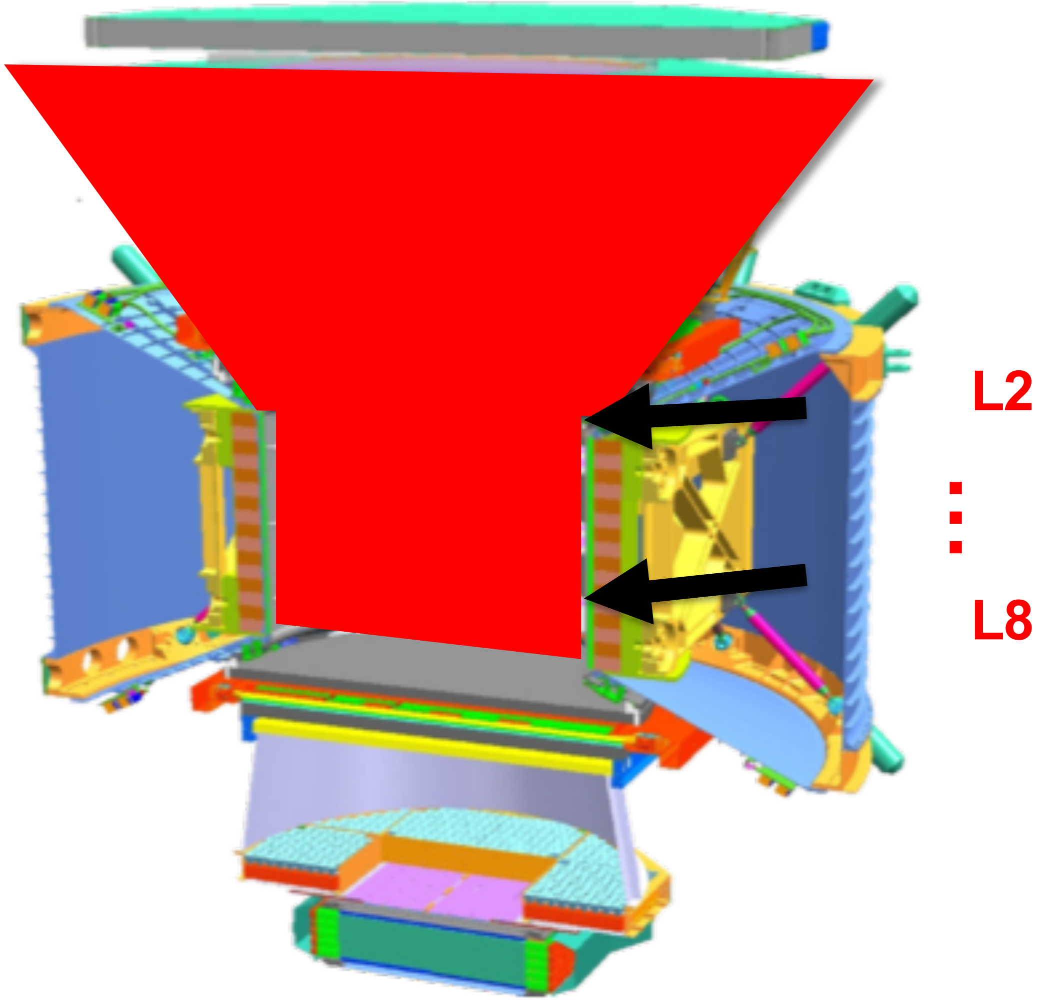
We have also observed two $^{4}\overline{\text{He}}$ candidates.

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

Study of anti-Carbon, anti-Oxygen

The observed anti-helium events are all below 100 GV

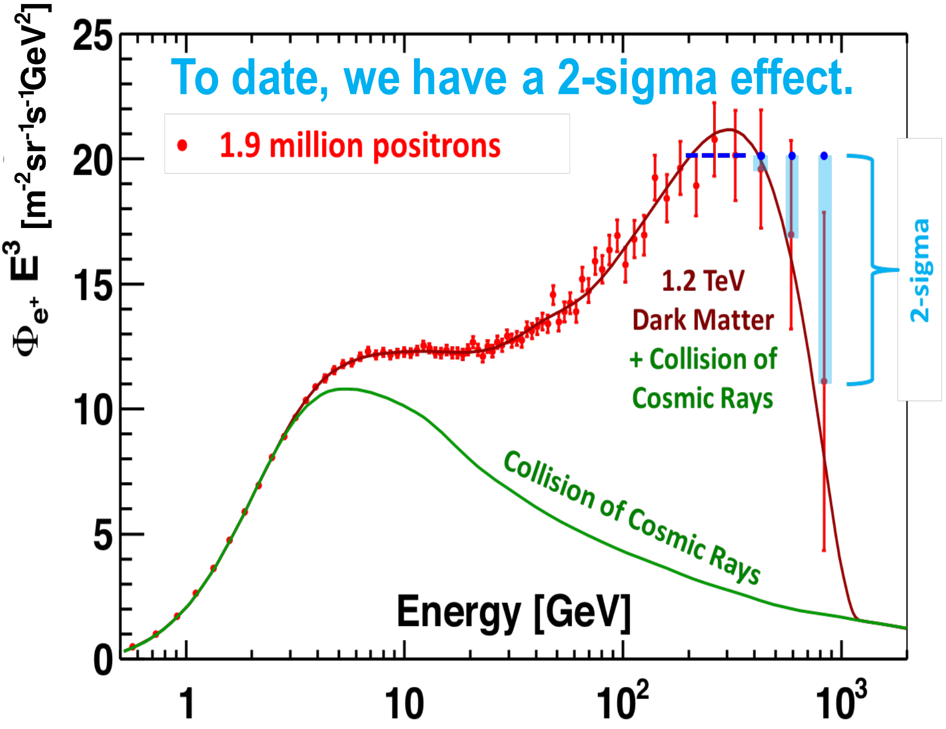
Analysis of $\overline{C}$ and $\overline{O}$ to 100 GV use L2-L8 as for $\overline{He}$

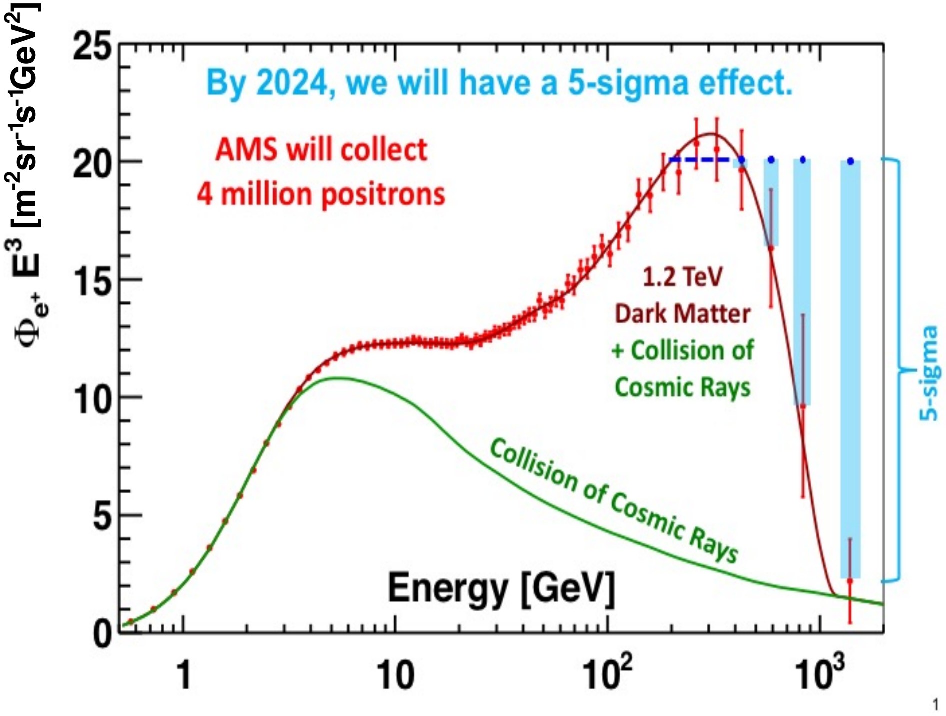


By 2024, AMS will have more than
100 million carbon and oxygen to study anti-carbon and anti-oxygen

Physics of AMS on ISS: Positrons and Dark Matter

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





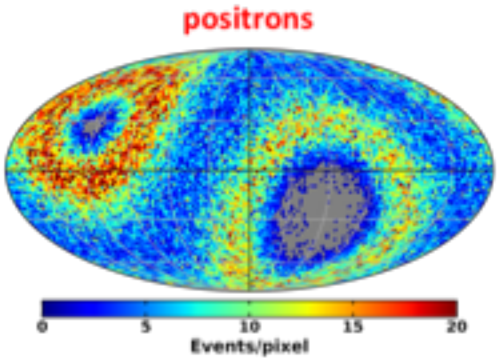
Currently, the approved ISS lifetime is until 2024.
The incremental gain between now and 2024 is from 2-sigma to 5-sigma.

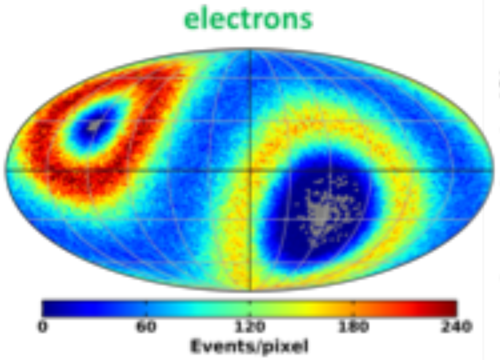
Physics of AMS on ISS: Anisotropy and Dark Matter

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

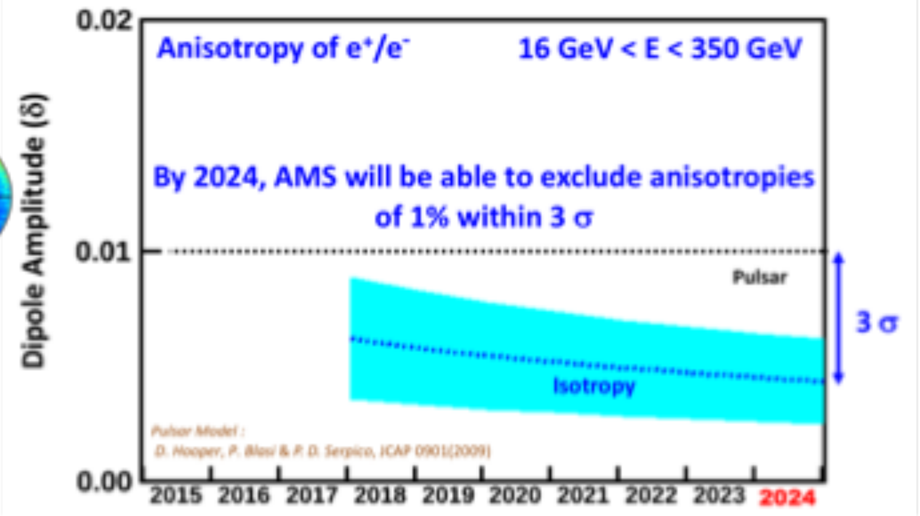
The anisotropy in galactic coordinates

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



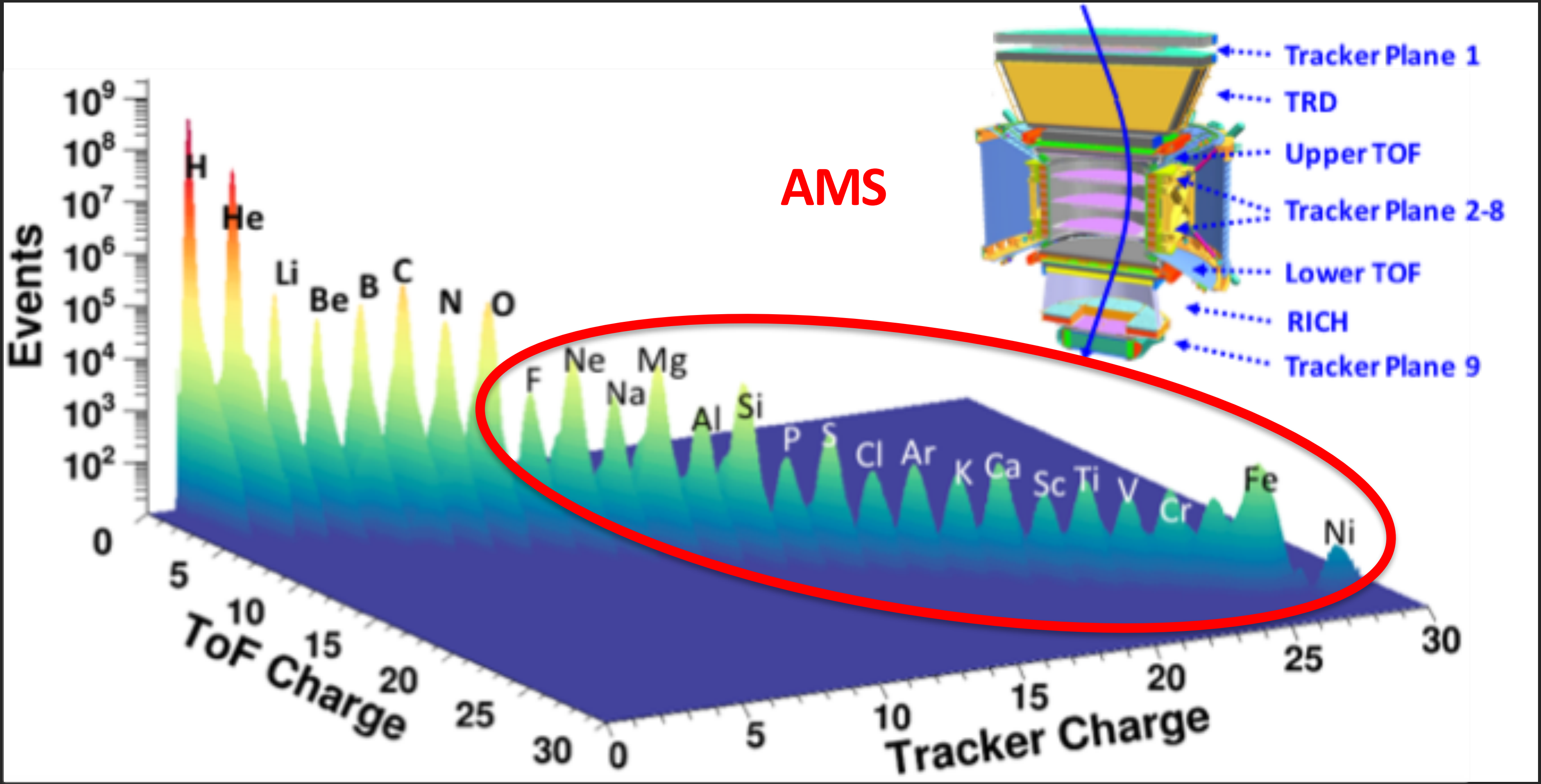


Projected amplitude of the dipole anisotropy



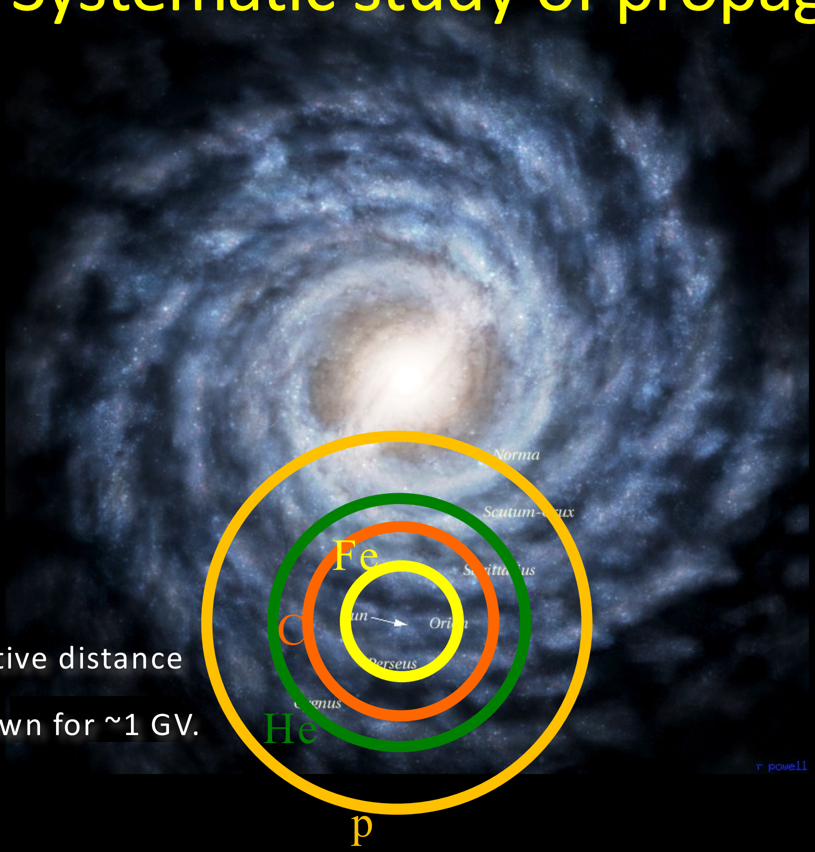
The observation of isotropy at the 3-sigma level is an important confirmation of the projected 5-sigma effect in the positron flux.

Study high Z cosmic rays



AMS, CALET, DAMPE, ISS-CREAM

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



Effective distance

is shown for ~1 GV.

Effective propagation distance:

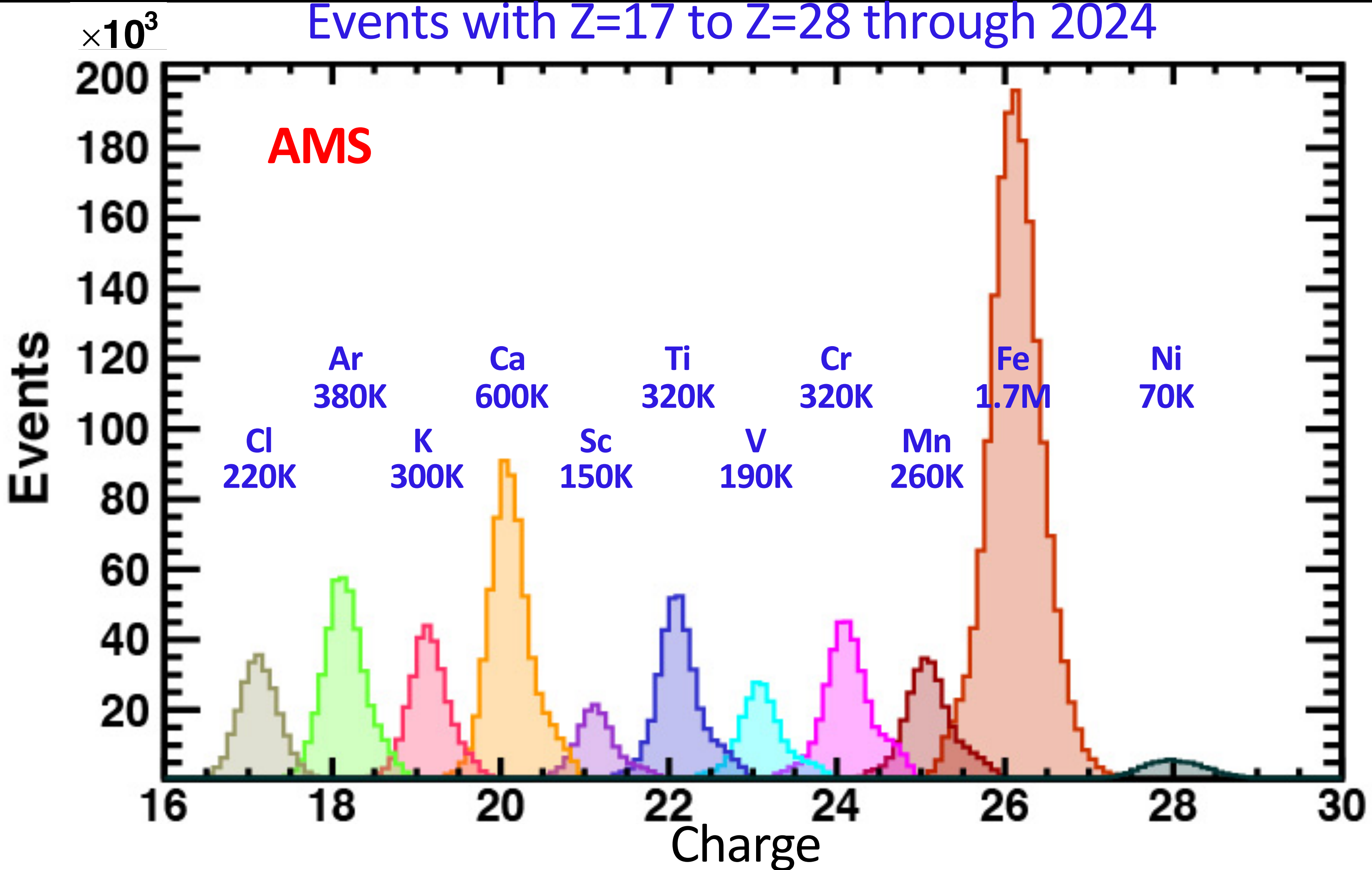
$$\langle X\rangle \sim \sqrt{6D\tau} \sim 2.7\ \mathrm{kpc}\ R^{\delta/2}\,(A/12)^{-1/3}$$

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 $R^{\delta/2}$

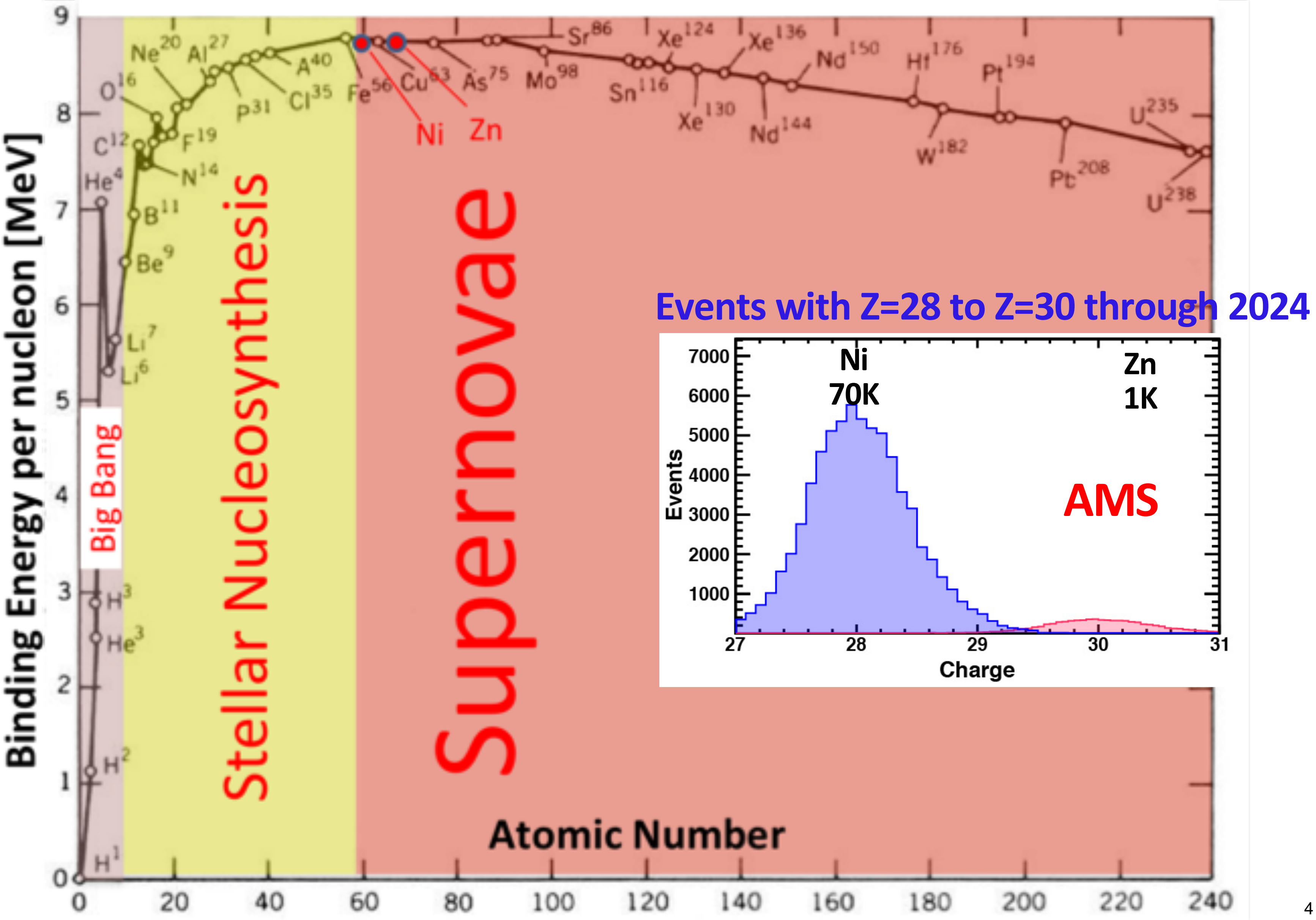
i. Different Z (or A) nuclei probe different distances.

ii. Higher energies probe larger distances

B. 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.



C. The lightest elements created by supernova are Nickel and Zinc. Compare them with elements produced by stellar nucleosynthesis.



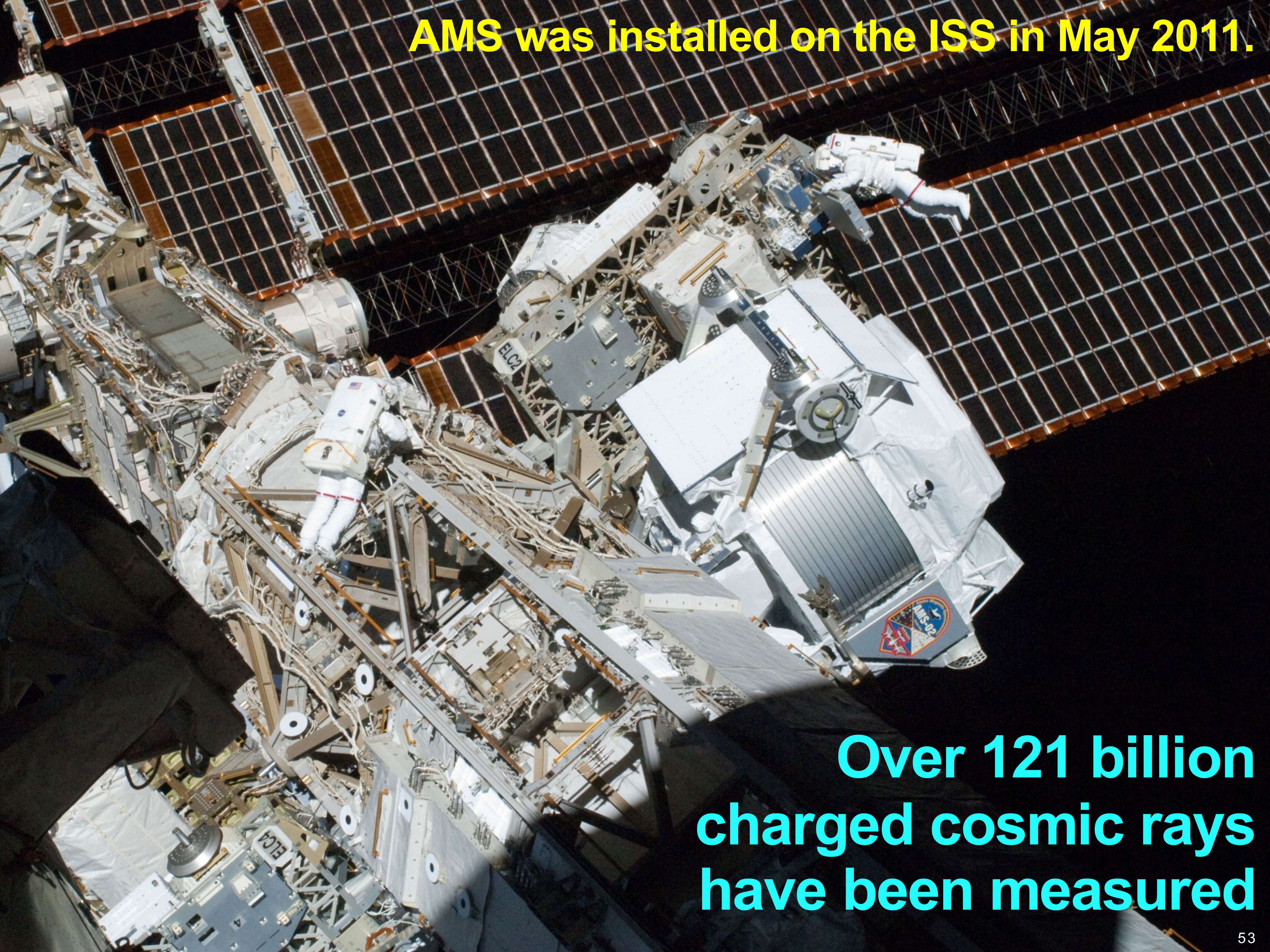
Most of results presented today are unexpected and require much improved accuracy of theoretical predictions.

There are several large scale detectors in space
to study high energy charged cosmic rays:
AMS, CALET, DAMPE, ISS-CREAM

AMS is the only magnetic spectrometer in space
in the foreseeable decades.

With the new precision data we should be able to uncover the origin of many observed unexpected phenomena.

5m x 4m x 3m
7.5 tons



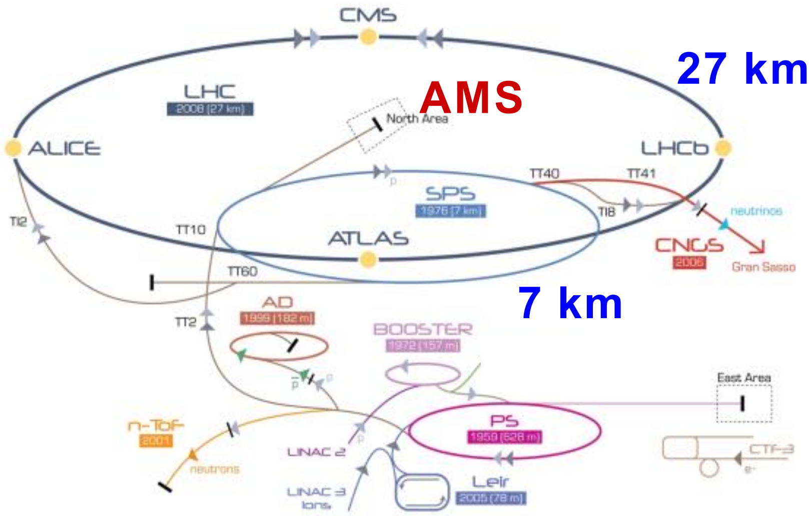
AMS was installed on the ISS in May 2011.

Over 121 billion charged cosmic rays have been measured

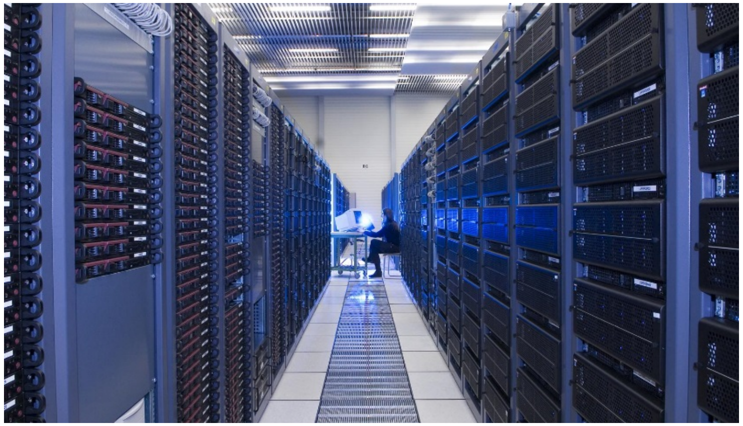
Calibration of the AMS Detector

Test beam at CERN SPS:

p, e±, π±, 10–400 GeV



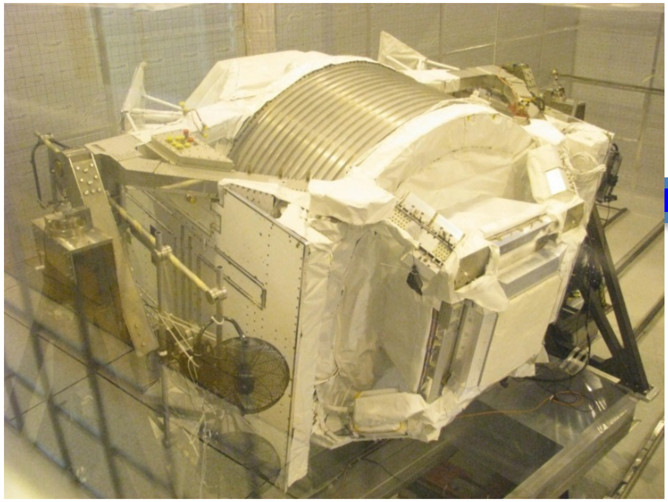
12,000 CPU cores at CERN

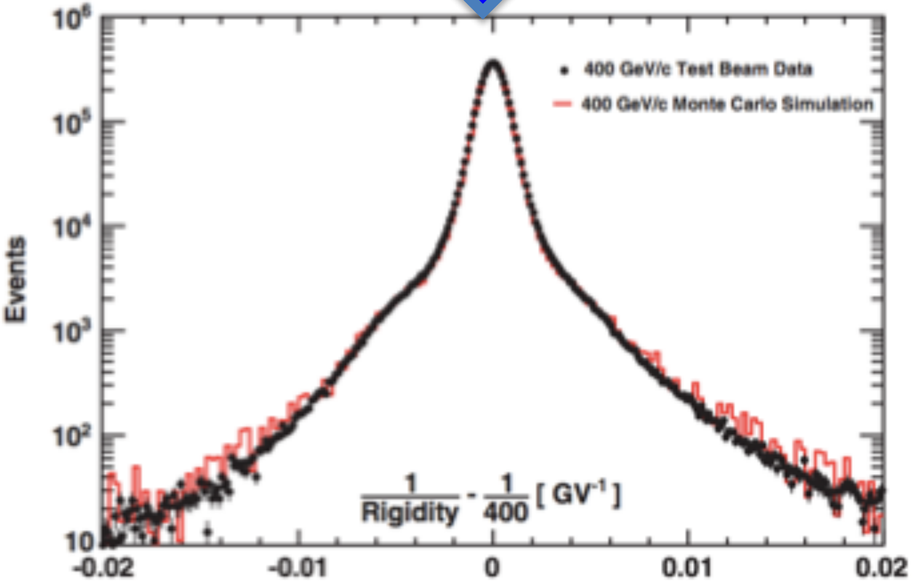


Computer simulation:

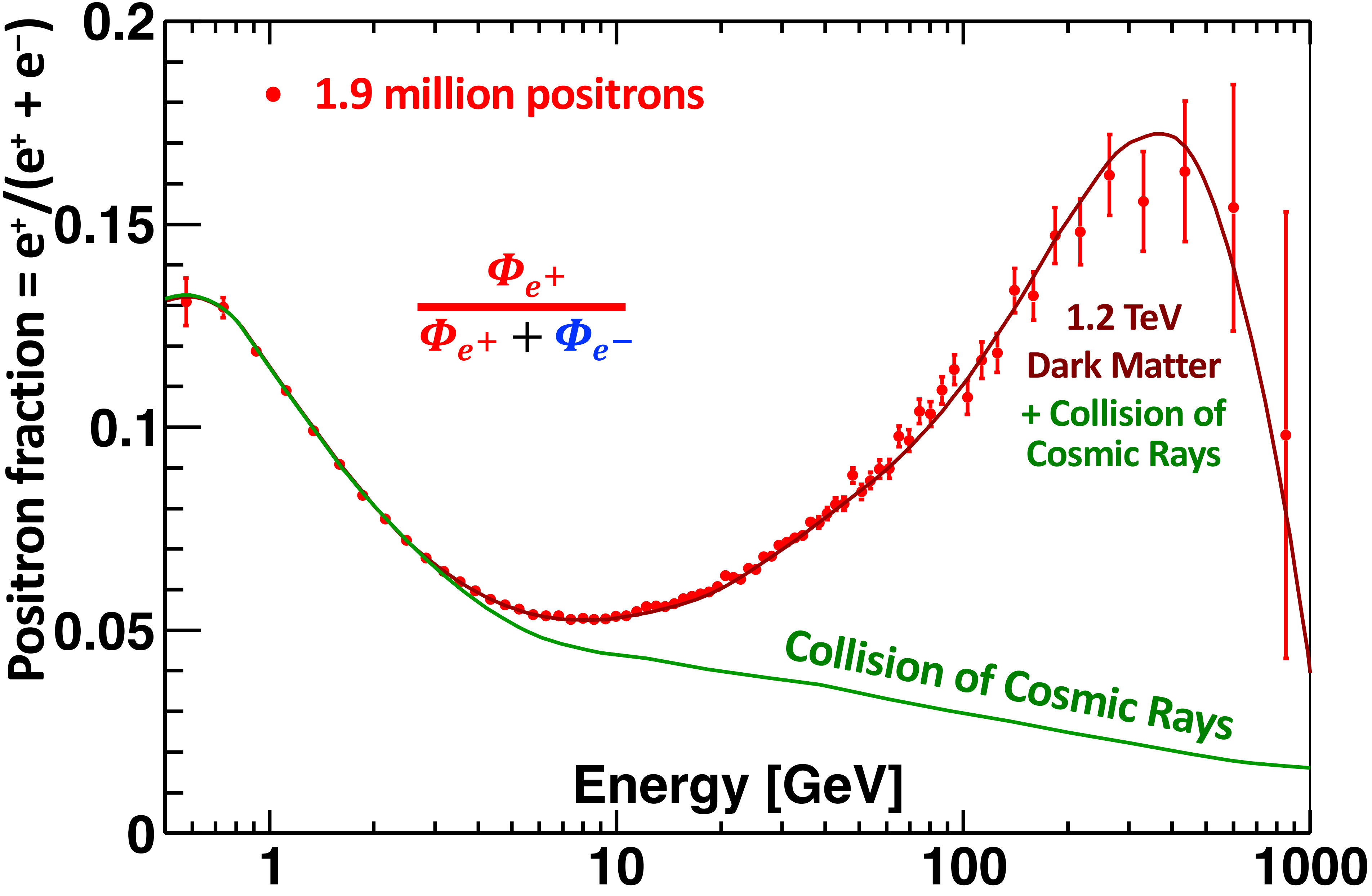
Interactions, Materials, Electronics

2000 positions





Positron excess also can be expressed in terms of the positron fraction, which explores the same physics



$$\frac{\Phi_{e^+}}{\Phi_{e^+} + \Phi_{e^-}}$$

Dark Matter model is based on J. Kopp, Phys. Rev. D 88, 076013 (2013).

A sample of papers on AMS e^+ data

Dark Matter

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)

and many other excellent papers **…**

Propagation Models

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 and A.Reinert, arXiv:1609.01300 (2017)

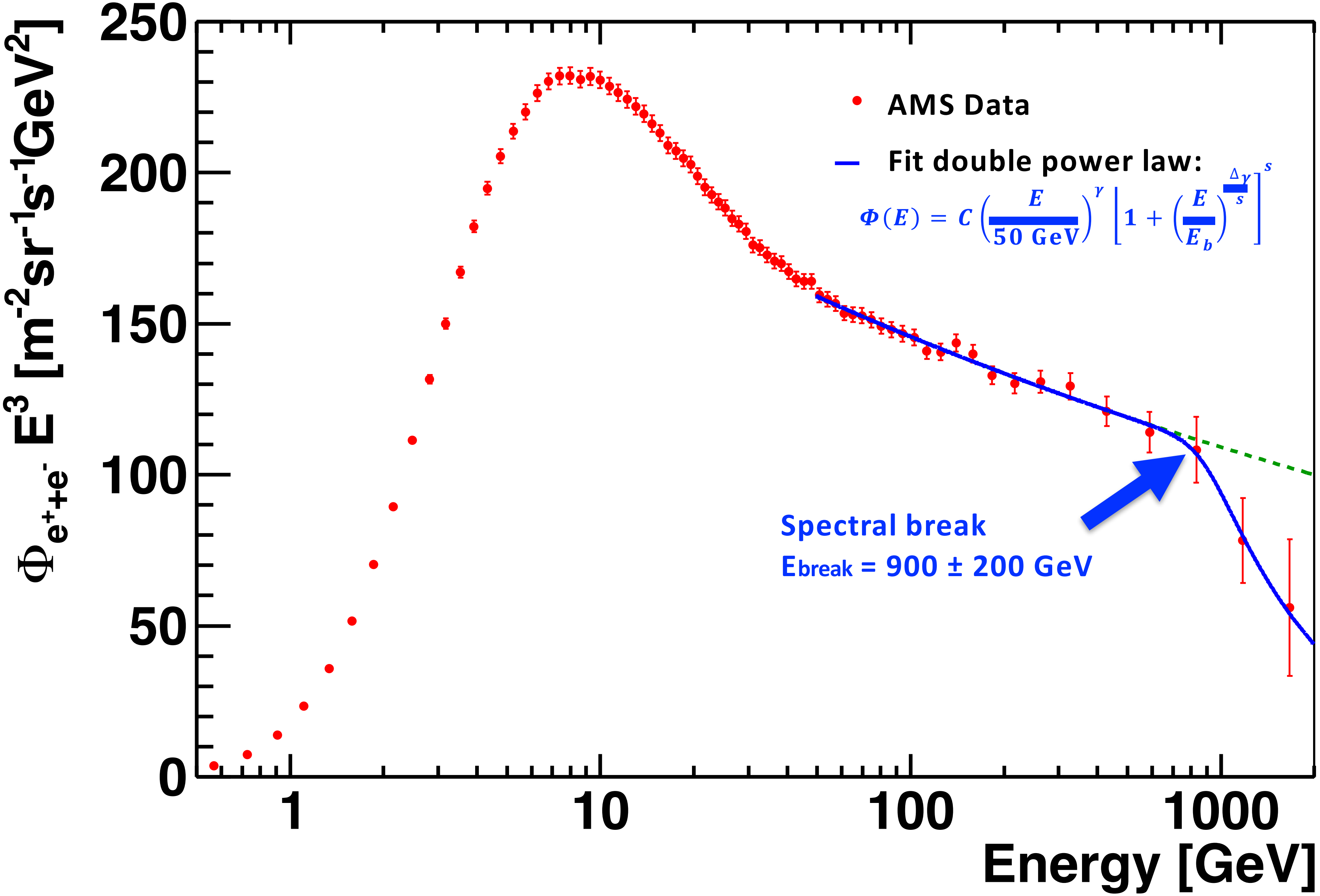
and many other excellent papers …

Astrophysical Sources

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 combined (e+ + e-) energy dependence



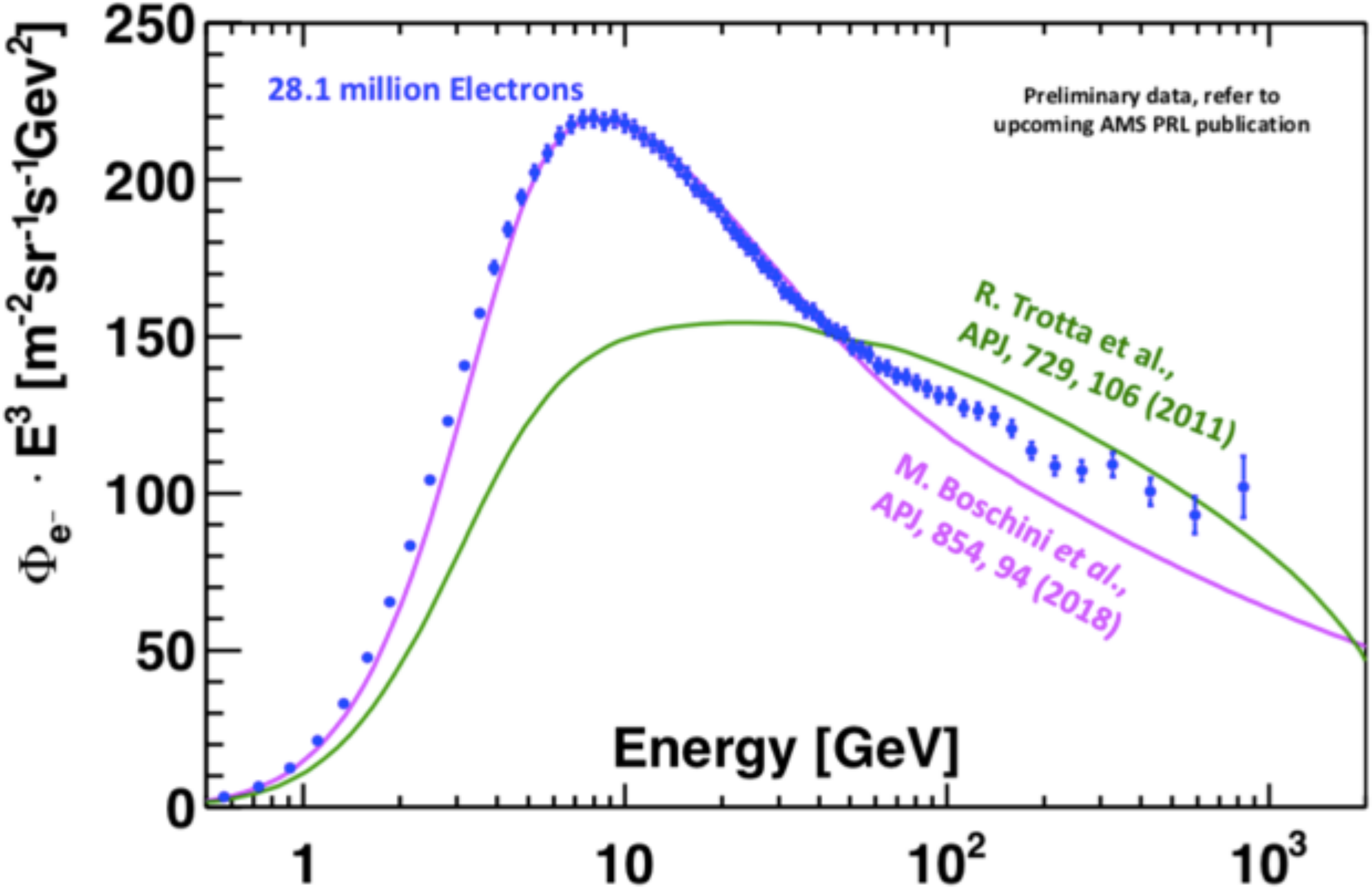
$$\Phi(E) = C\left(\frac{E}{50\ \mathrm{GeV}}\right)^{\gamma}\left[1+\left(\frac{E}{E_b}\right)^{\frac{\Delta\gamma}{s}}\right]^{s}$$

Spectral break

Ebreak = 900 ± 200 GeV

The $(e^+ + e^-)$ flux deviates from a single power law above ~900 GeV

Additional source of cosmic ray Electron

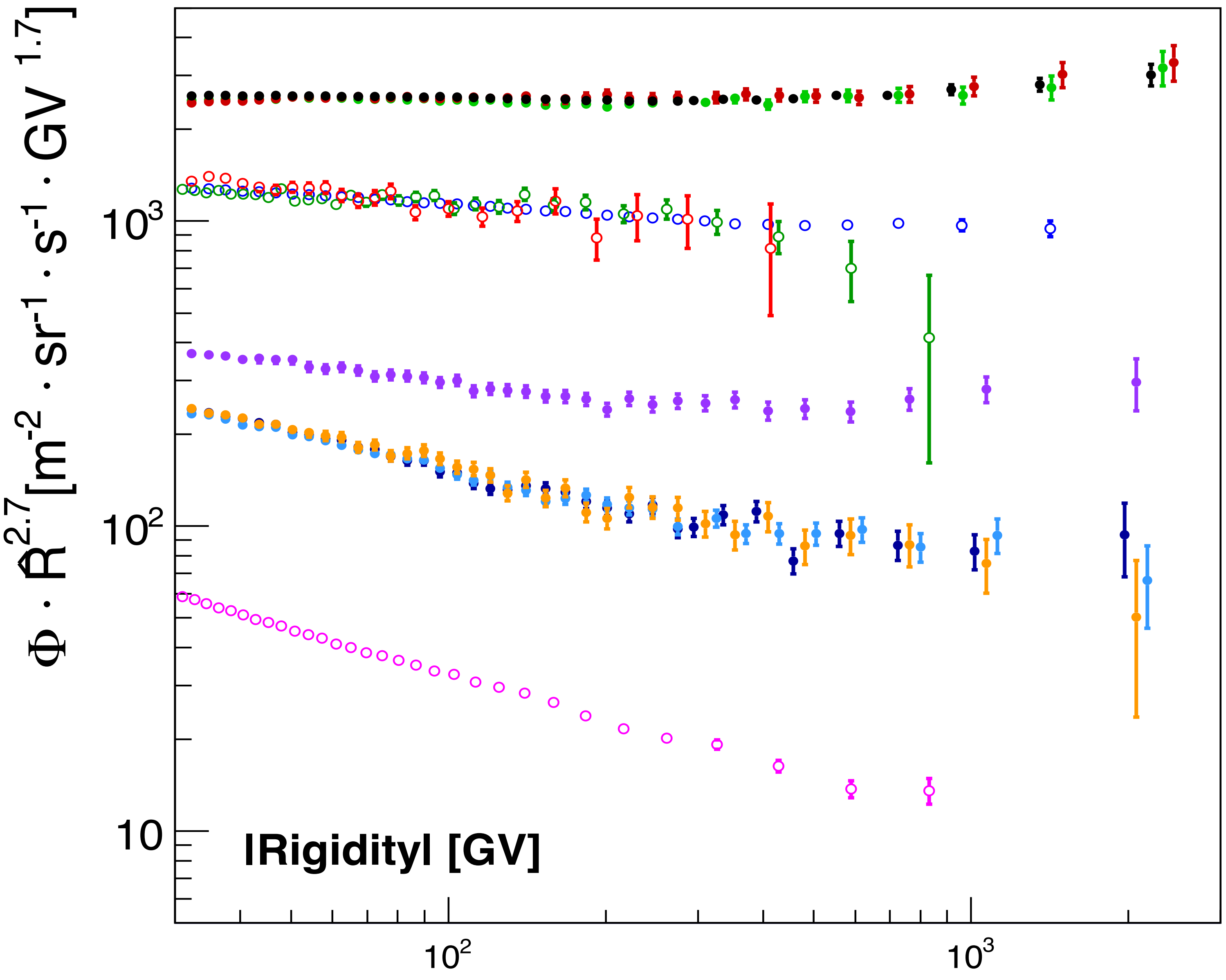


AMS Electron flux disagree with conventional cosmic ray model expectation.
Indicates additional primary source of electron starting ~30GeV

However, due to large background and its uncertainties from conventional cosmic ray electron, it is difficult to extract source contribution from electron flux alone

Summary of AMS results on Cosmic Ray Fluxes

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



Primaries

He(1)
C(31)
O(28)

Particles

p(0.1)
e^+(280)
$\bar{p}$(550)

Primary + Secondary

N(20)

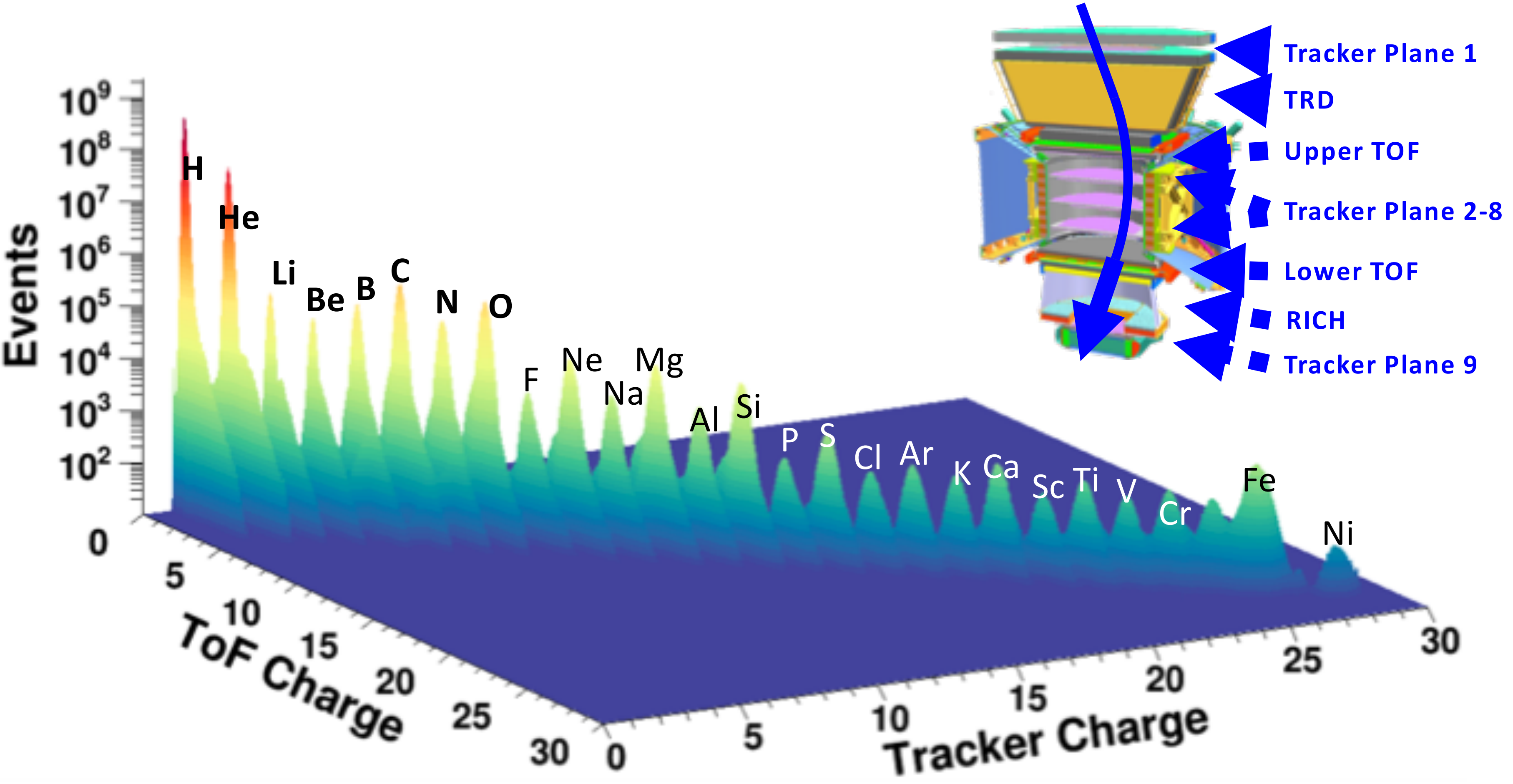
Secondaries

Li(20)
Be(40)
B(14)

Electrons

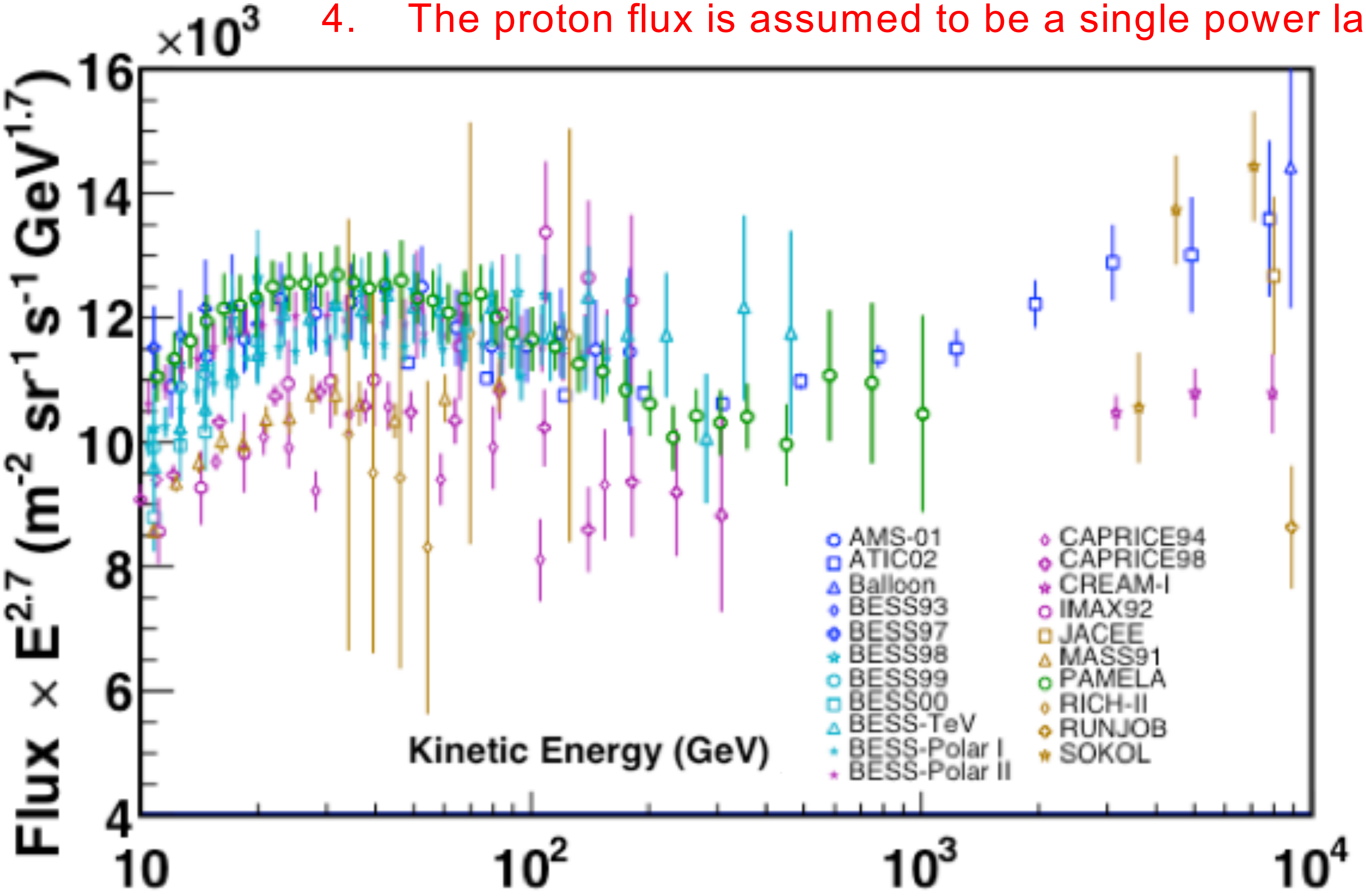
e^-(1)

Precision Measurements of Cosmic Rays:
AMS has seven instruments which independently measure Cosmic Nuclei

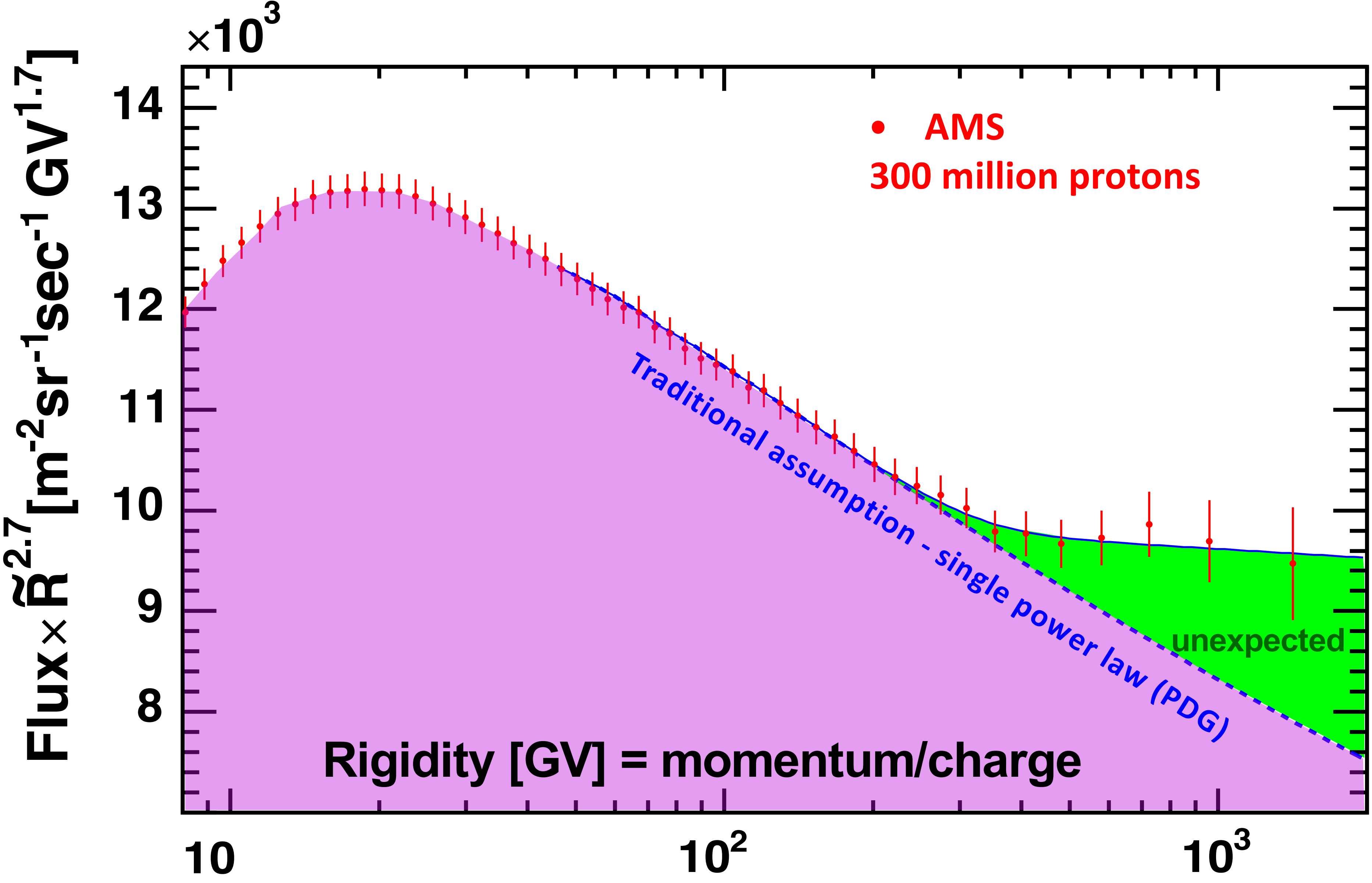


Measurements of proton spectrum before AMS

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}



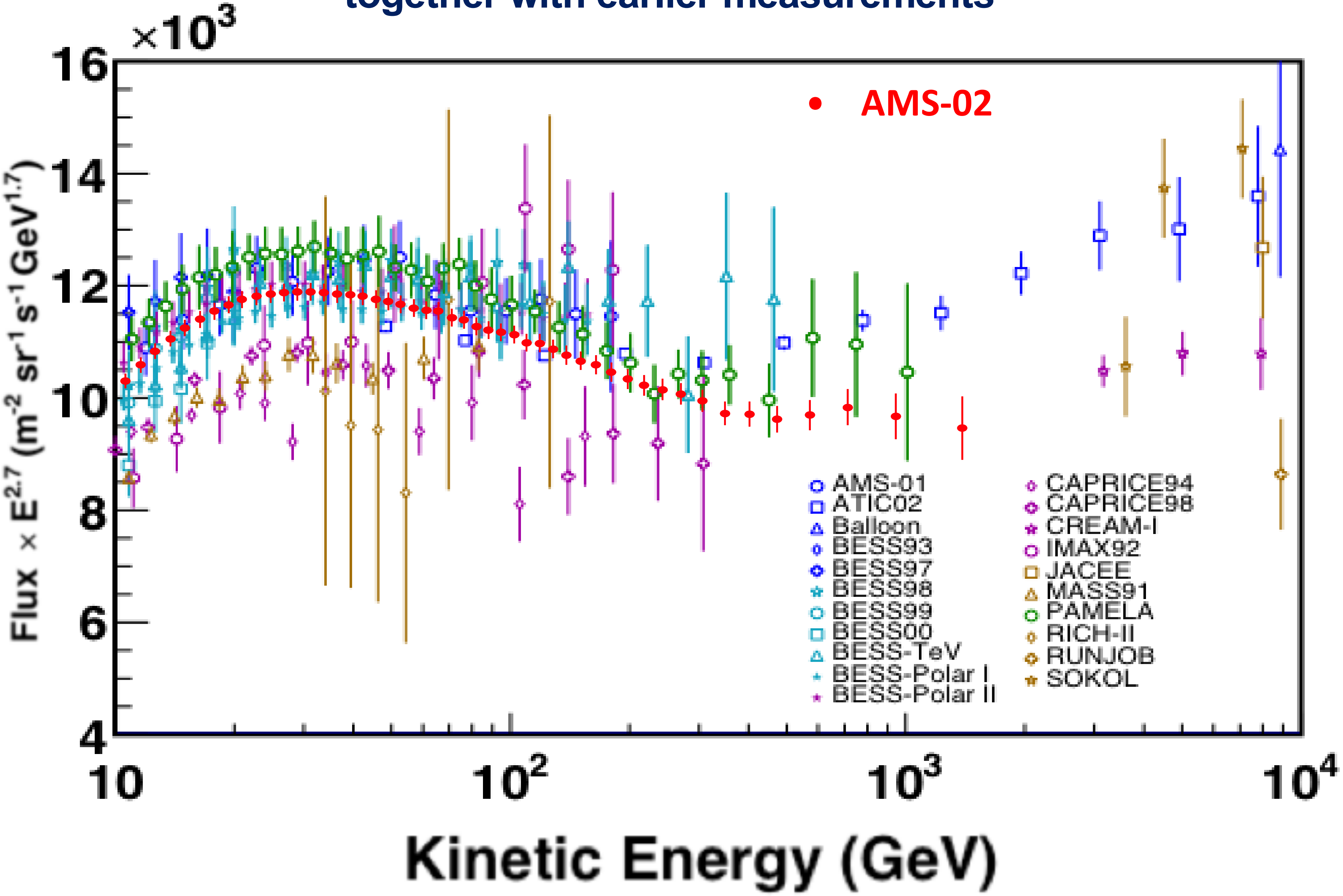
AMS results on the proton flux



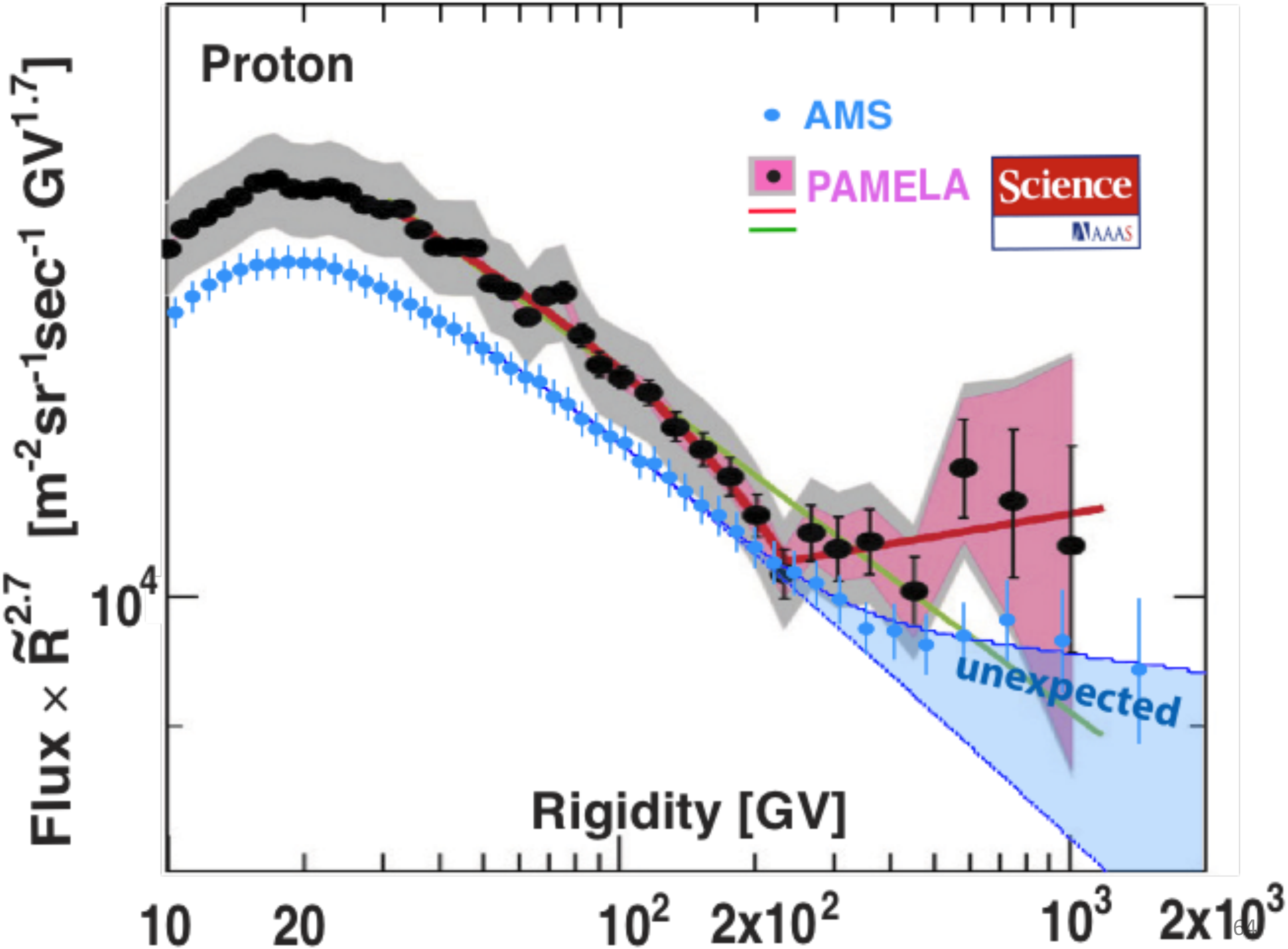
The proton flux cannot be described by a single power law = CR^{γ}

AMS Measurement of the proton spectrum

together with earlier measurements



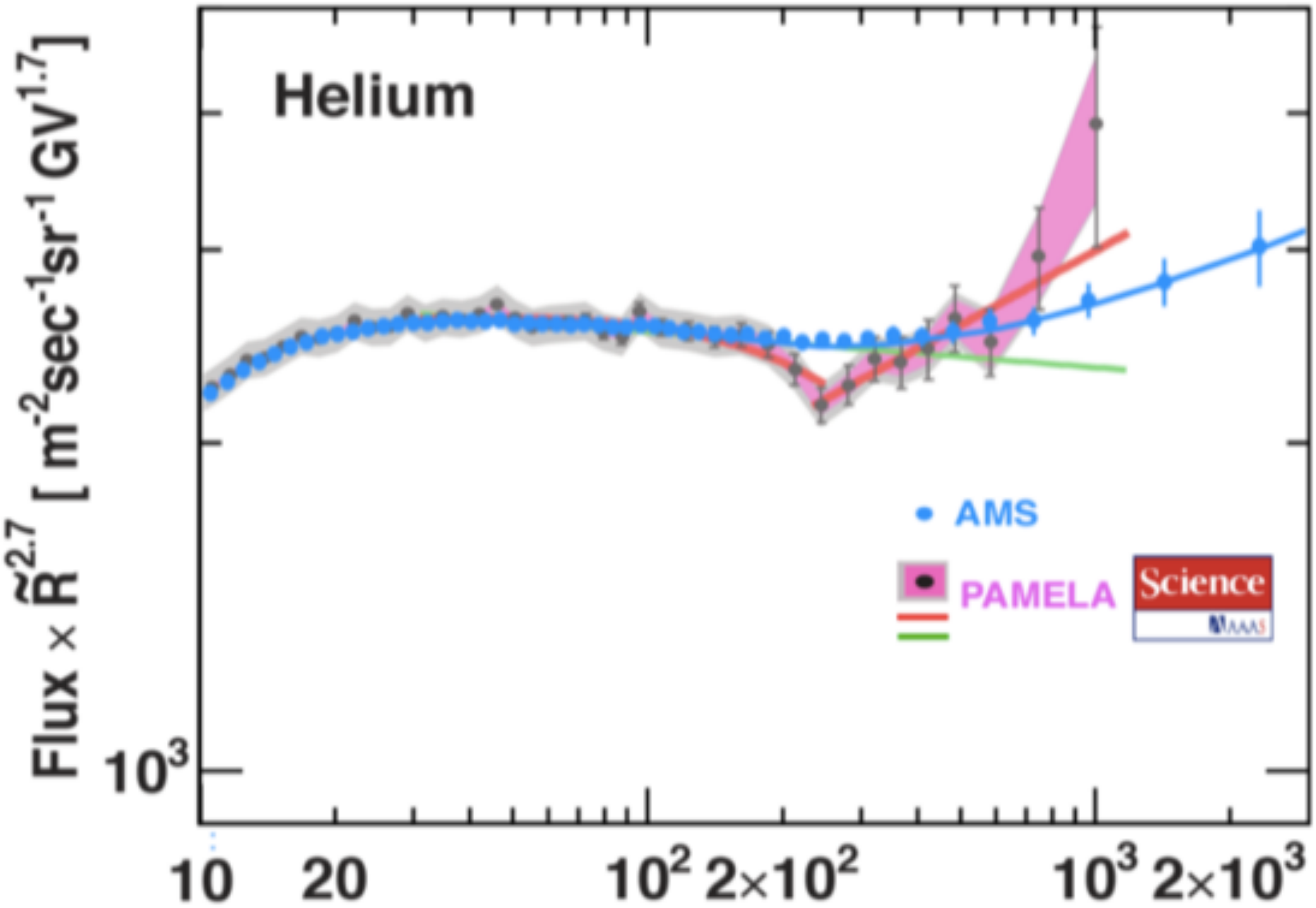
Proton Flux


Proton
AMS
PAMELA
Science
AAAS
unexpected
Rigidity [GV]
Flux × $\tilde{R}^{2.7}$ [m^{-2}sr^{-1}sec^{-1} GV$^{1.7}$]
10^4
10
20
10^2
2×10^2
10^3
2×10^3

The AMS results on primary cosmic rays He, C, and O.

M. Aguilar et al. Phys Rev Lett, 2017 vol. 119(25) p. 251101

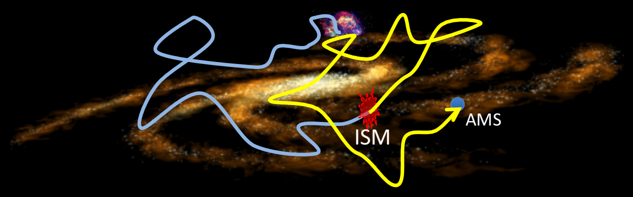
- The AMS helium flux is distinctly different from previous measurement.
- He flux shows a smooth change of behavior towards high energy starting from 300 GV.

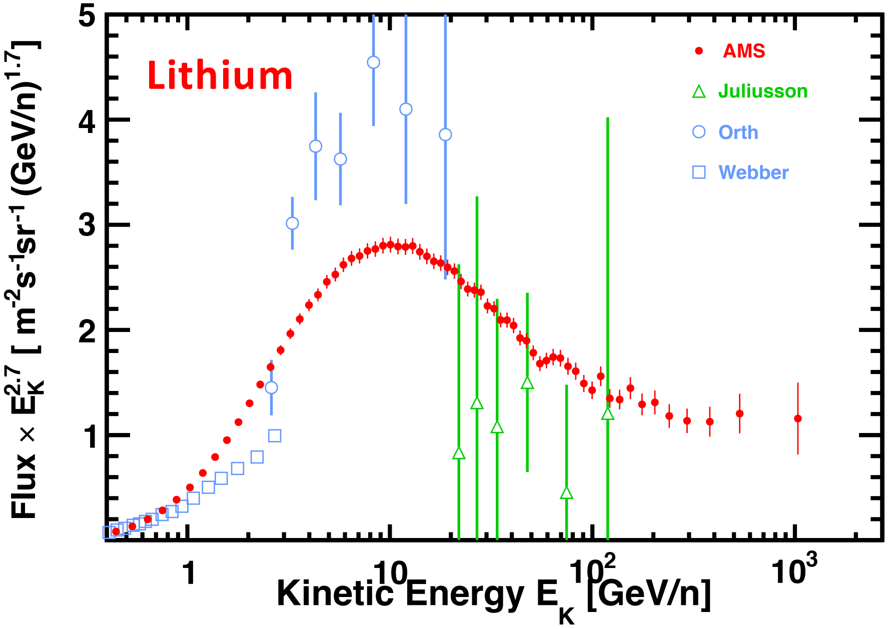


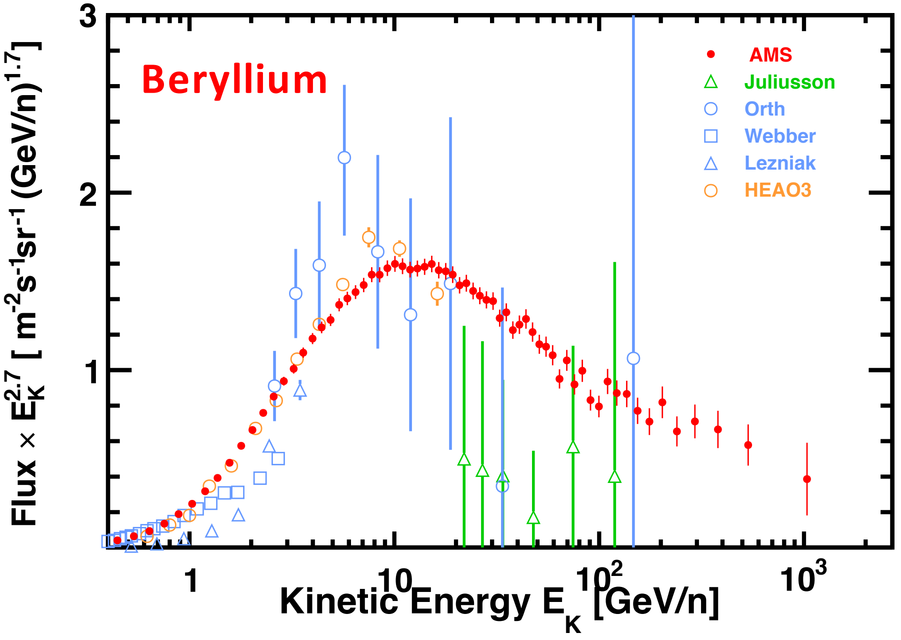
The AMS Result on the Secondary Nuclei Fluxes

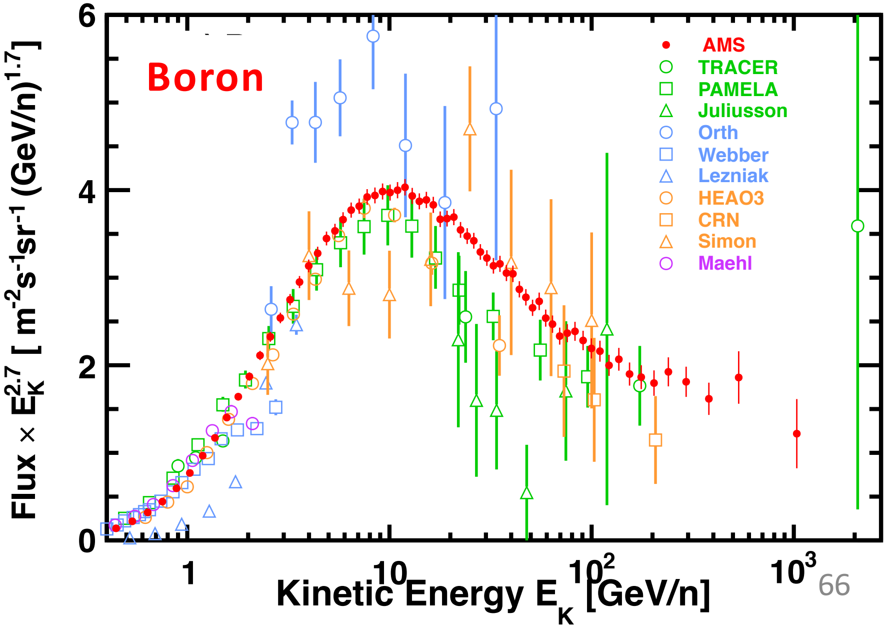
Secondary Cosmic Rays (Li, Be, B, …)

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.



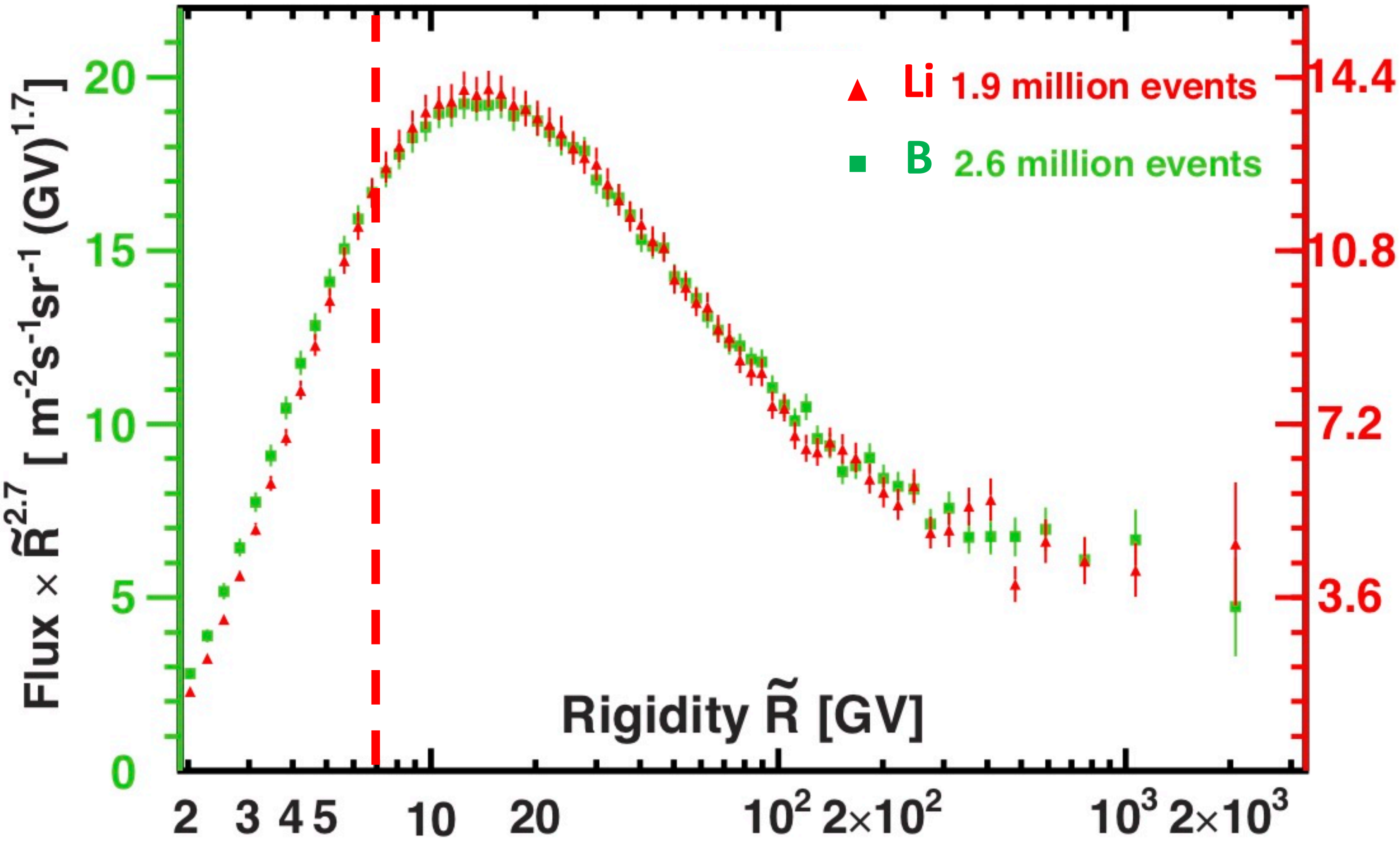






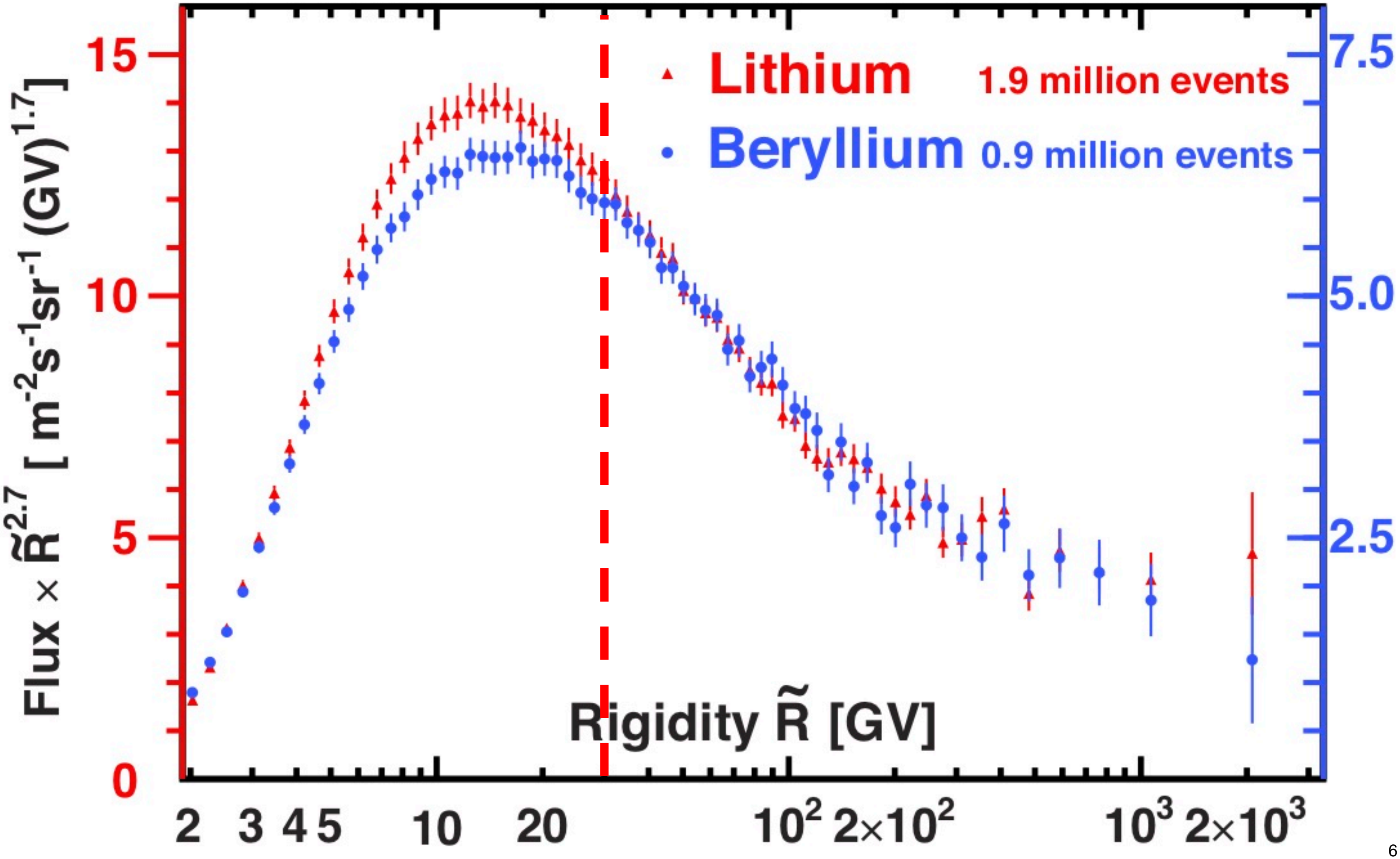
Secondary Cosmic Rays: Lithium and Boron

Above 7 GV Li and B have identical rigidity dependence

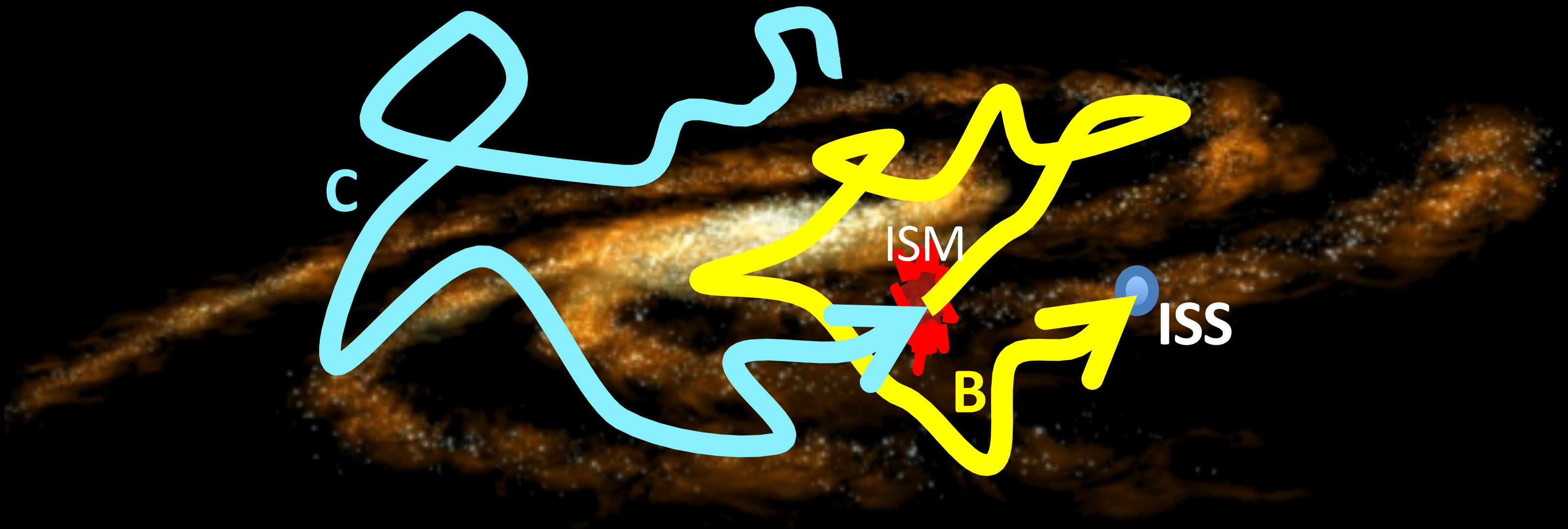


Secondary Cosmic Rays: Lithium and Beryllium

Above 30 GV Li and Be have identical rigidity dependence.
The fluxes are different by a factor of 2.



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

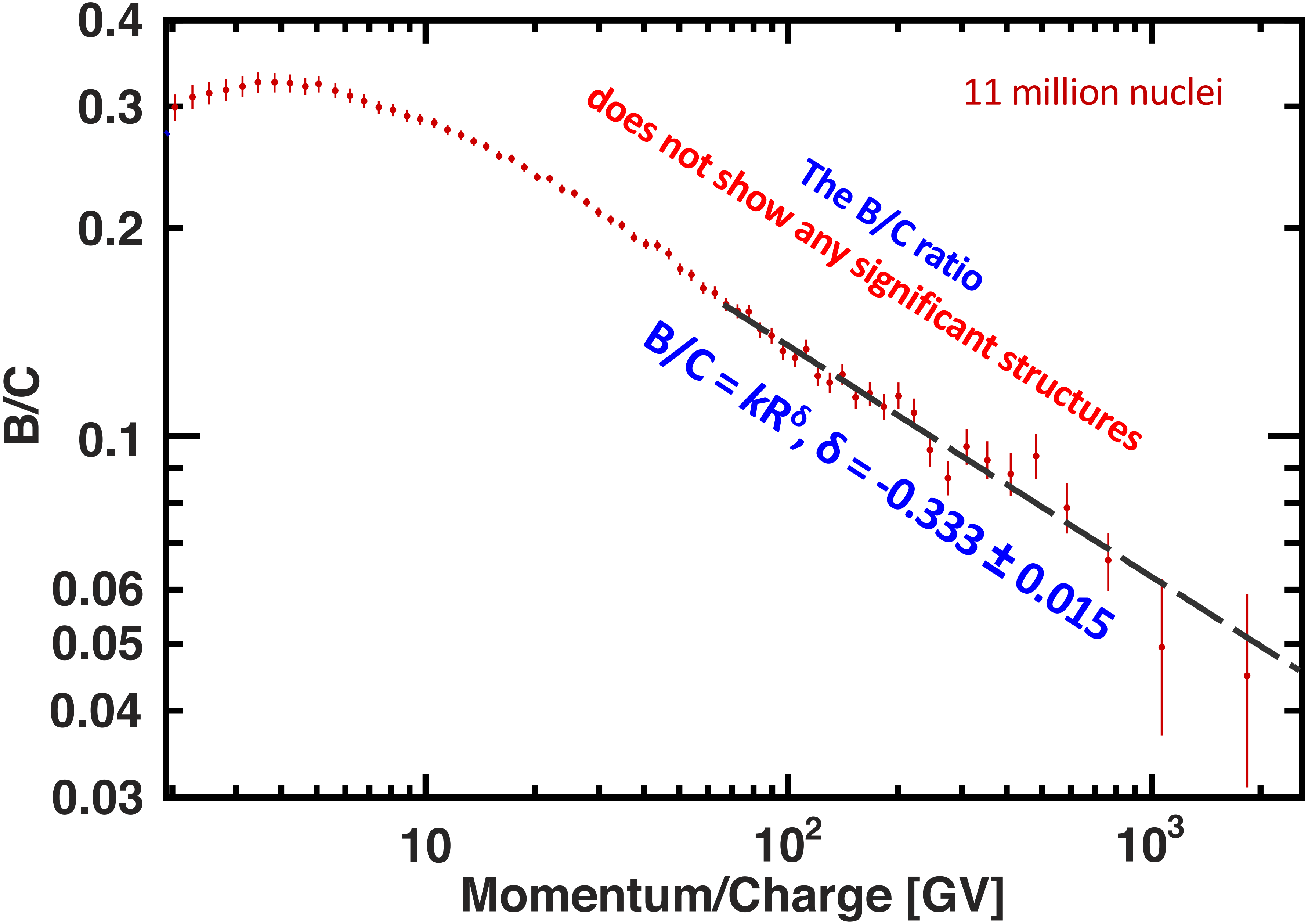


Cosmic ray propagation is commonly modeled as a fast moving gas diffusing through a magnetized plasma.

At high rigidities, models of the magnetized plasma predict different behavior for B/C = kR^{δ}.

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

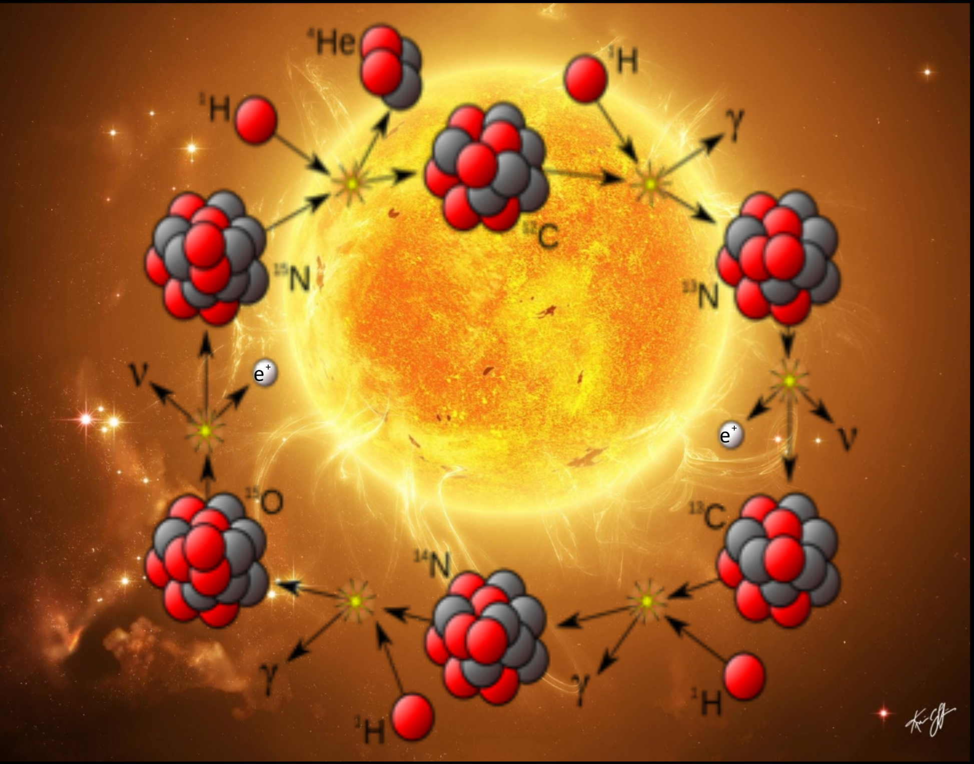
The AMS Boron-to-Carbon (B/C) flux ratio



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

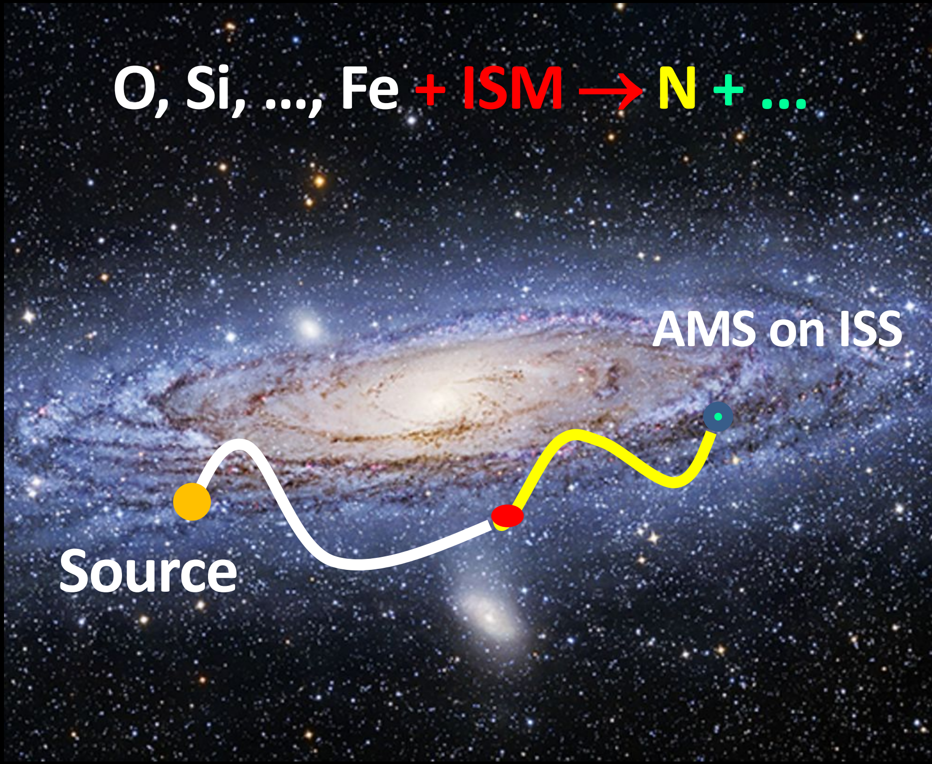
Nitrogen nuclei in cosmic rays

Astrophysical sources,
via the CNO cycle



In the Solar System: N/O ≈ 0.14

Collisions of heavier nuclei
with the interstellar medium



Energy Production in Stars

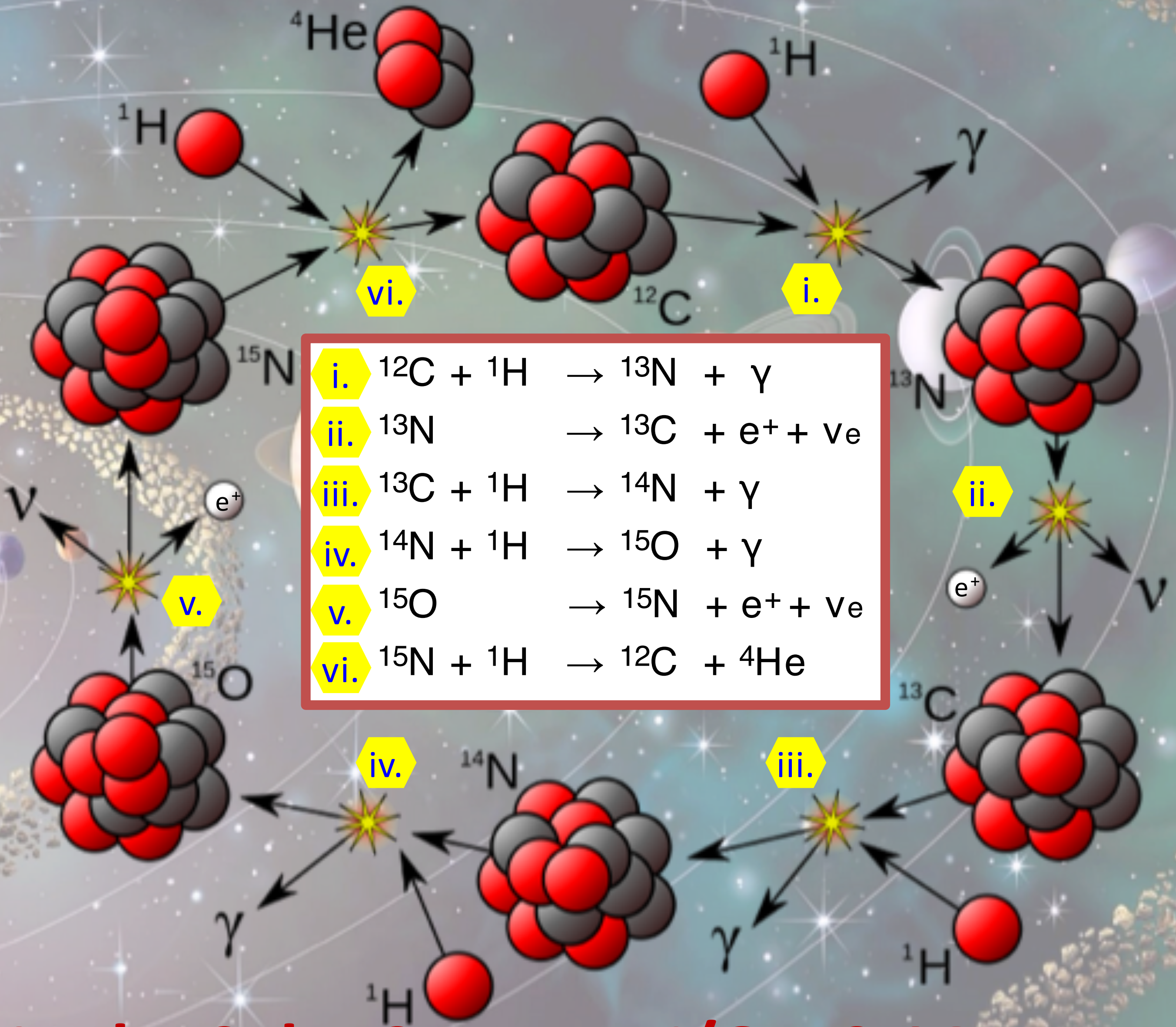
Phys. Rev.
Mar. 1, 1939

H.A. Bethe

Abstract

It is shown that the most important source of energy in ordinary stars is the reactions of carbon and nitrogen with protons. These reactions form a cycle in which the original nucleus is reproduced …

Nobel Prize 1967



i. $^{12}C + {}^{1}H \rightarrow {}^{13}N + \gamma$

ii. $^{13}N \rightarrow {}^{13}C + e^{+} + \nu_e$

iii. $^{13}C + {}^{1}H \rightarrow {}^{14}N + \gamma$

iv. $^{14}N + {}^{1}H \rightarrow {}^{15}O + \gamma$

v. $^{15}O \rightarrow {}^{15}N + e^{+} + \nu_e$

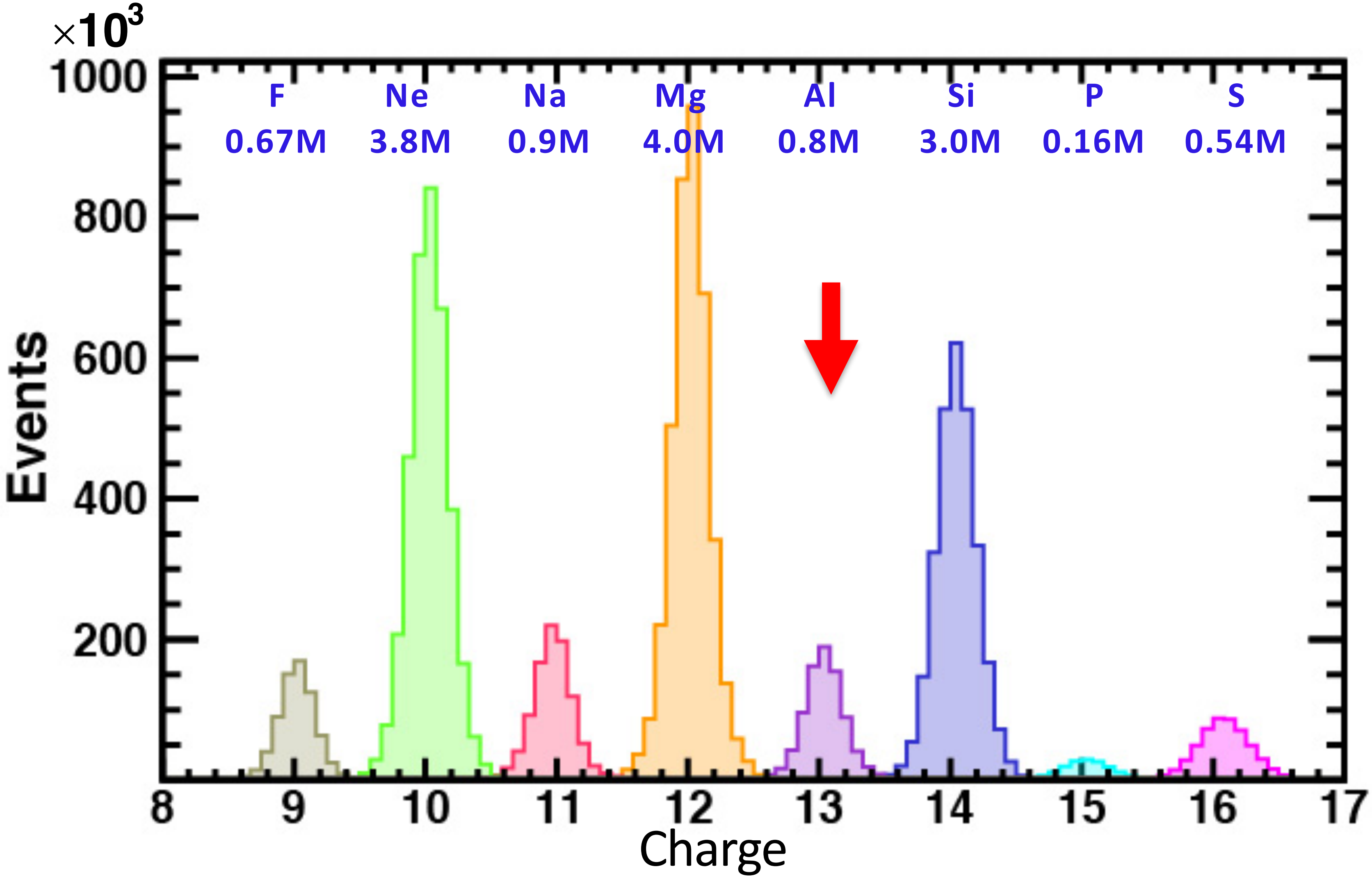
vi. $^{15}N + {}^{1}H \rightarrow {}^{12}C + {}^{4}He$

In the Solar System: N/O = 0.14

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

B. 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.

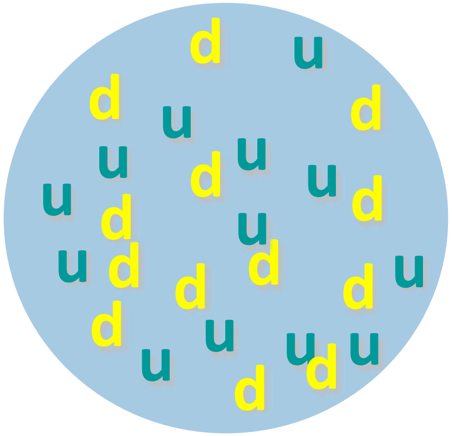
Events with Z=9 to Z=16 through 2024



Science Example: Strange Quark Matter – “Strangelets”

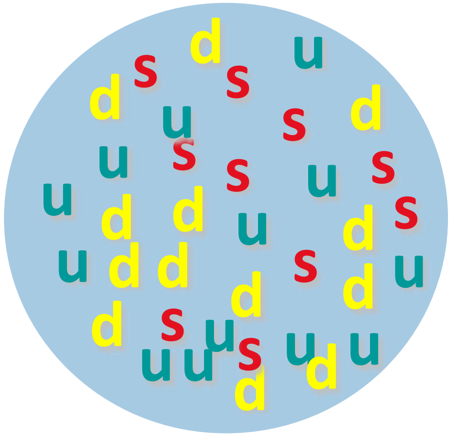
E. Witten, Phys. Rev. D,272-285 (1984)

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



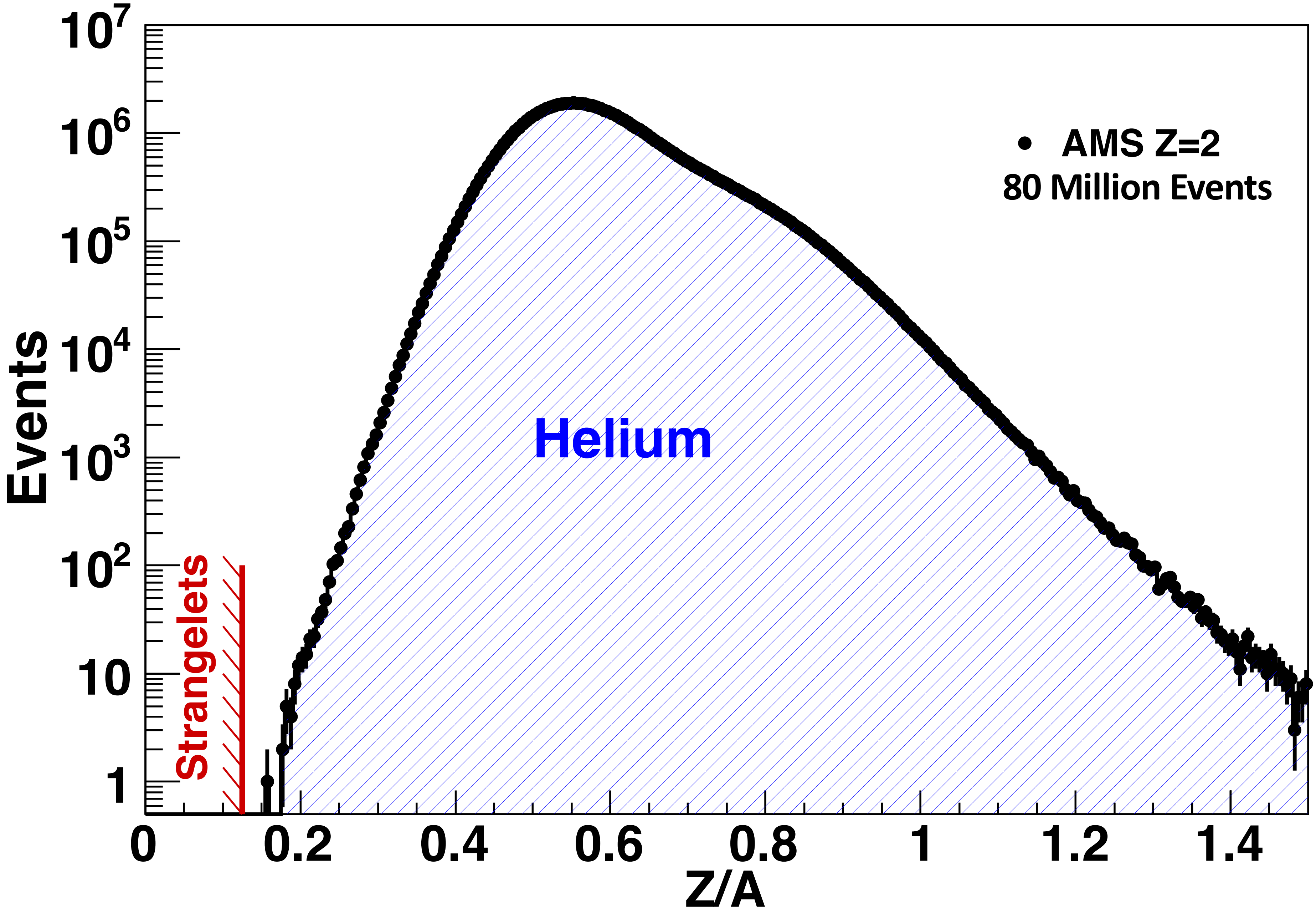
Diamond (Z/A ~ 0.5)

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

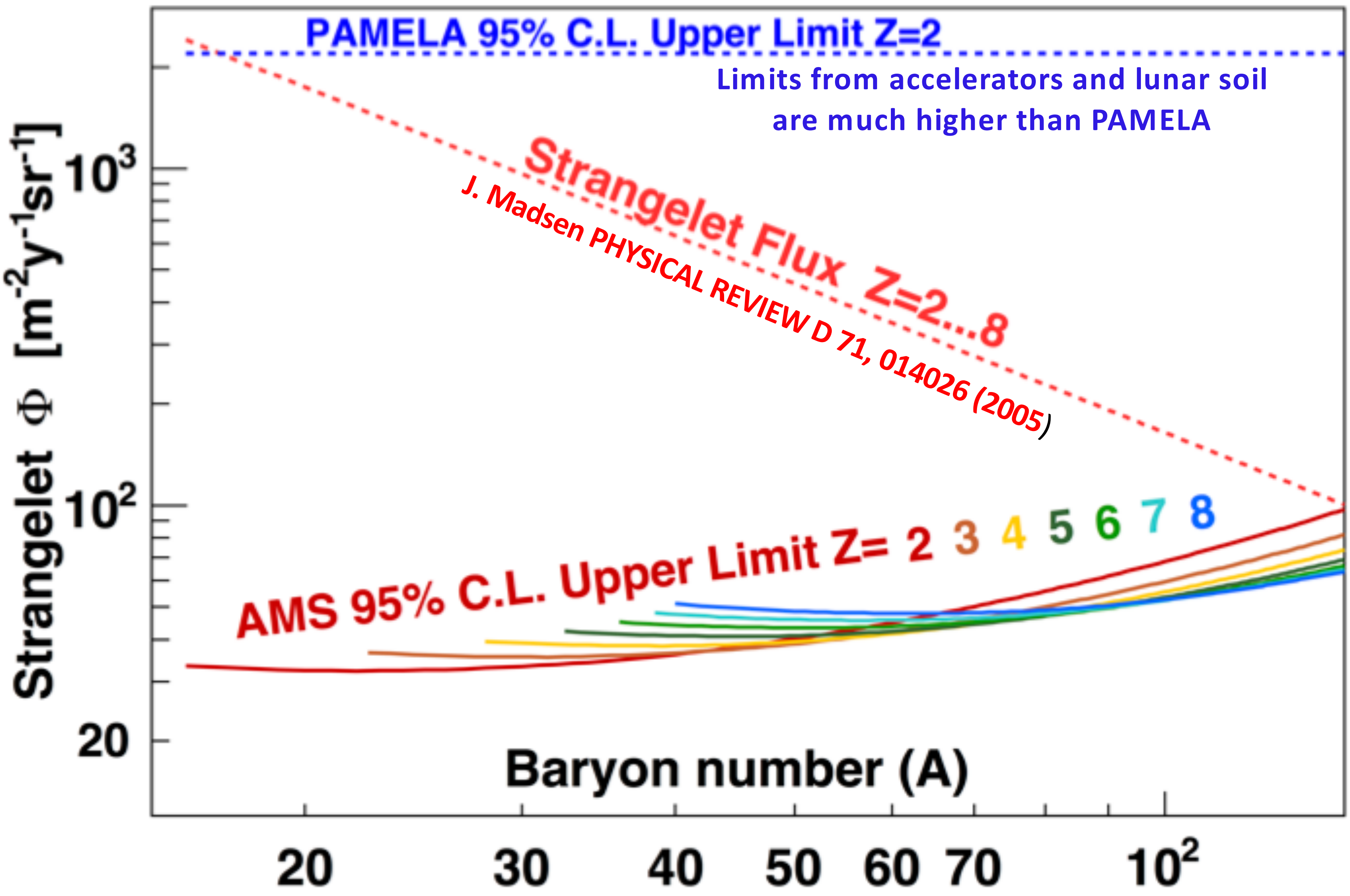


Strangelet (Z/A < 0.1)

This can be answered definitively by AMS.



Events
10^7
10^6
10^5
10^4
10^3
10^2
10
1
● AMS Z=2
80 Million Events
Helium
Strangelets
0
0.2
0.4
0.6
0.8
1
1.2
1.4
Z/A



Limits from accelerators and lunar soil are much higher than PAMELA

J. Madsen PHYSICAL REVIEW D 71, 014026 (2005)

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