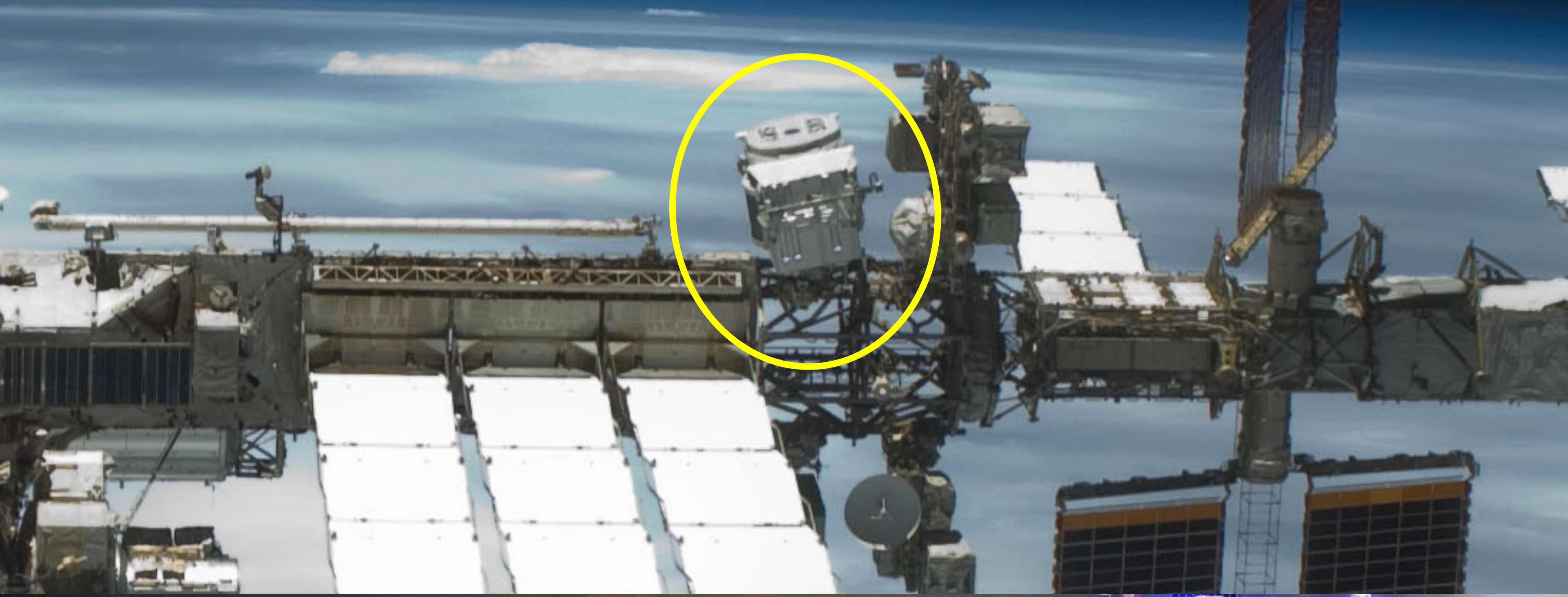
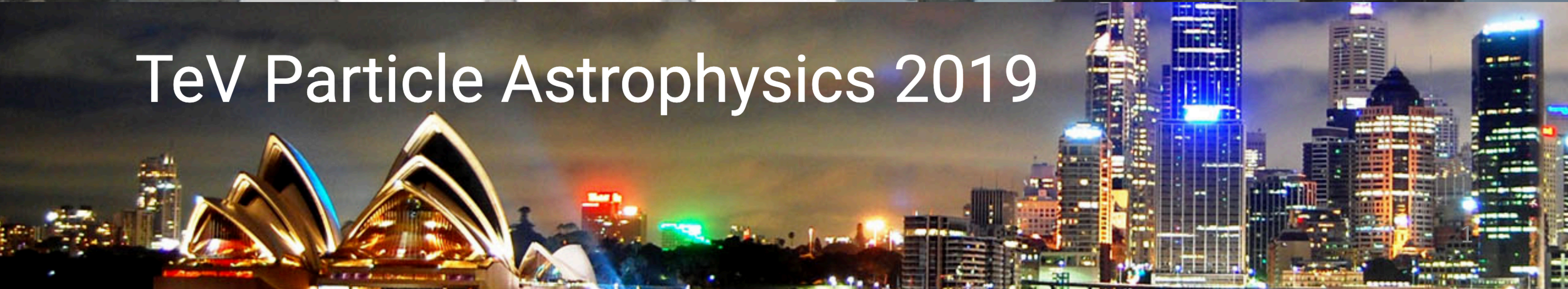
Latest Results from the Alpha Magnetic Spectrometer

Weiwei Xu / Shandong University

on behalf of the AMS Collaboration





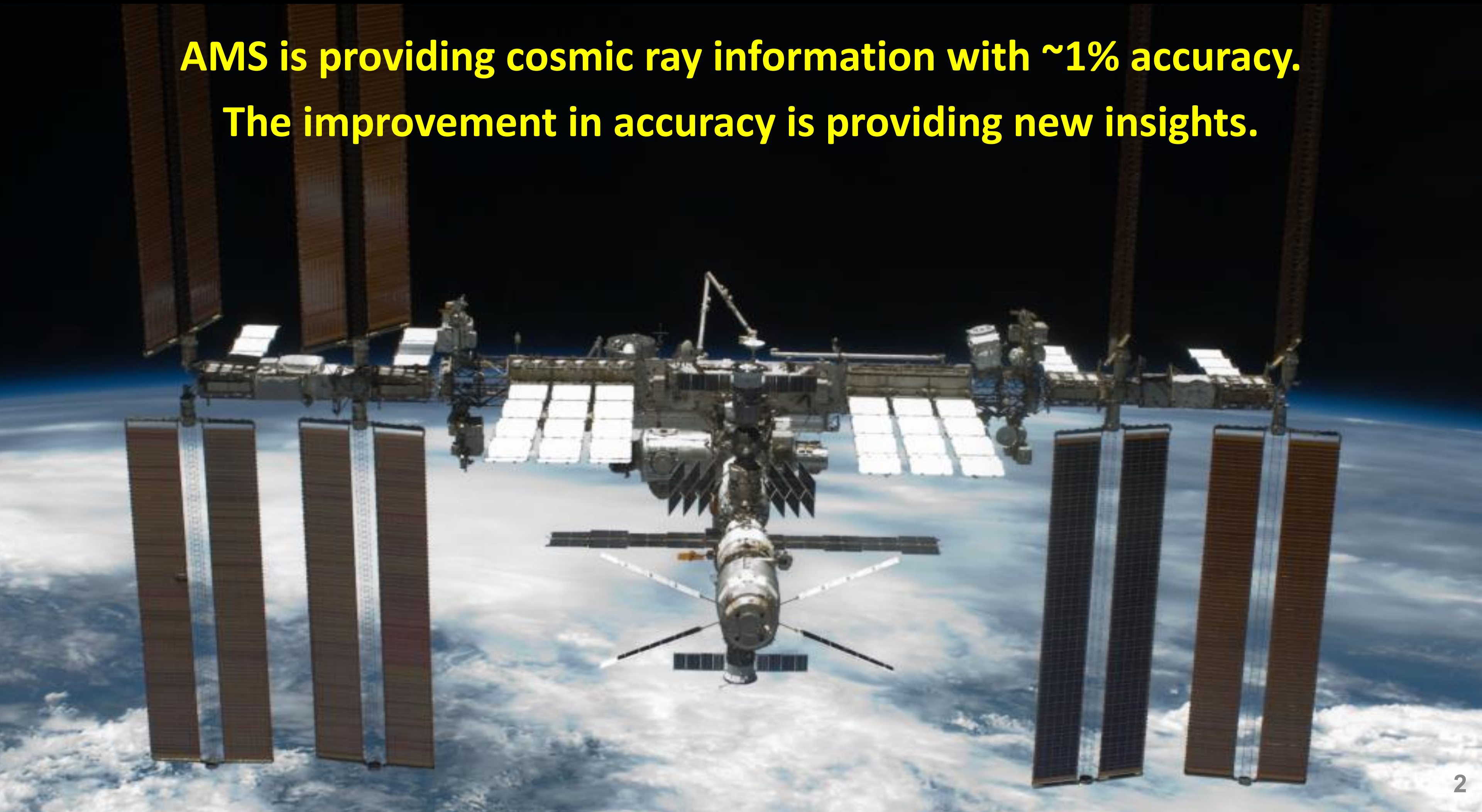
TeV Particle Astrophysics 2019

Space is the ultimate laboratory. It provides the highest energy particles.

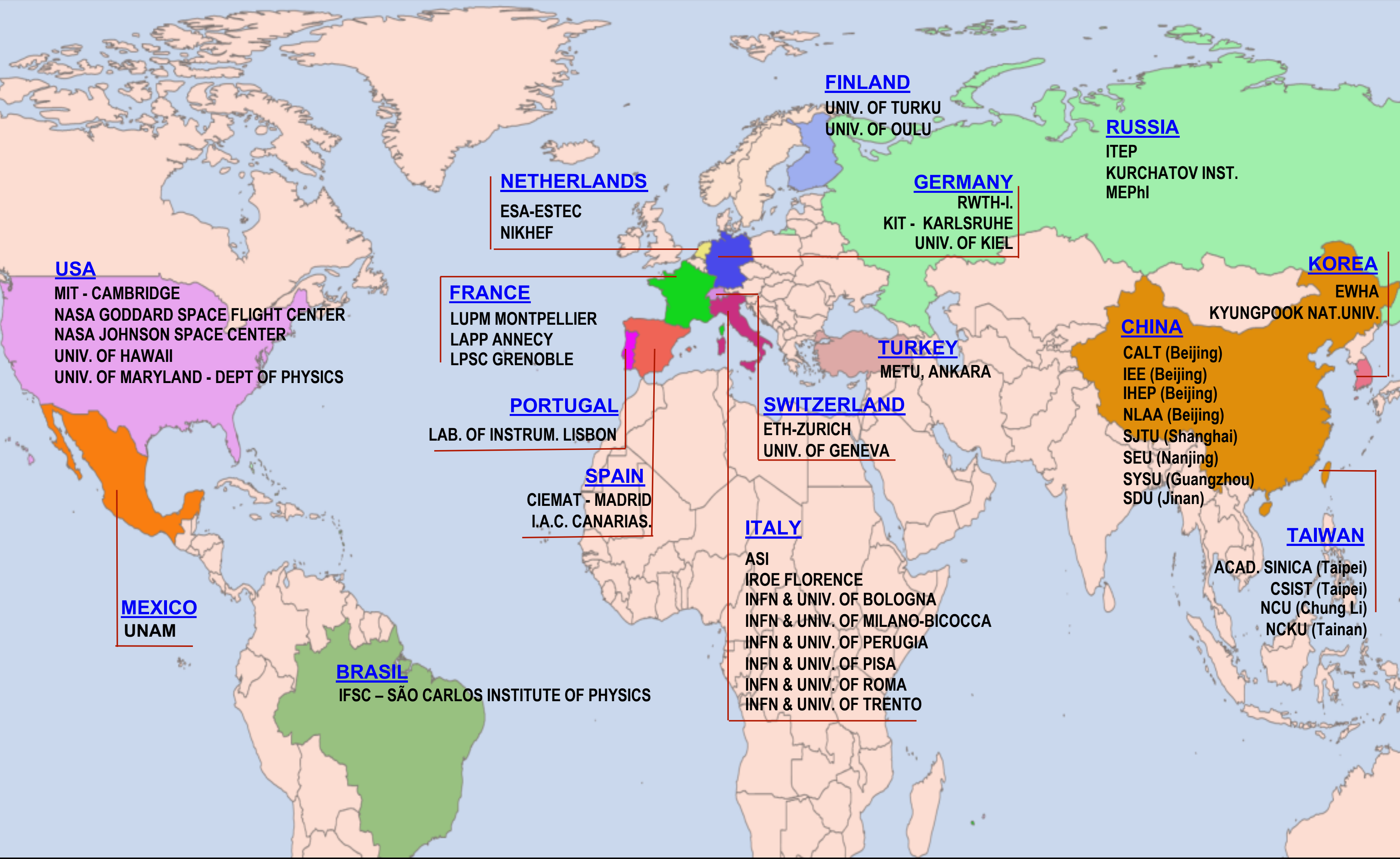
In the past hundred years, measurements of charged cosmic rays by balloons and satellites typically had ~(30-50)% accuracy.

AMS is providing cosmic ray information with ~1% accuracy.

The improvement in accuracy is providing new insights.



AMS Collaboration



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

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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CIEMAT - MADRID
I.A.C. CANARIAS.

ITALY
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IROE FLORENCE
INFN & UNIV. OF BOLOGNA
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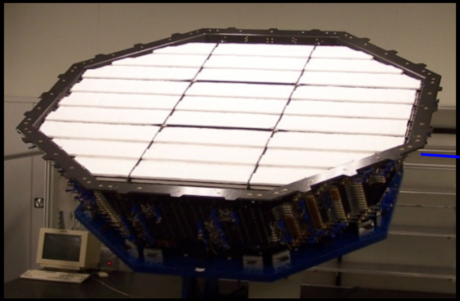
SJTU (Shanghai)
SEU (Nanjing)
SYSU (Guangzhou)
SDU (Jinan)

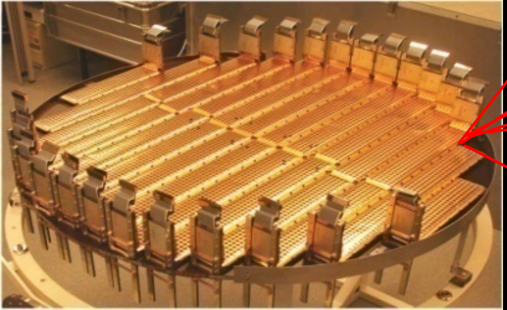
TAIWAN
ACAD. SINICA (Taipei)
CSIST (Taipei)
NCU (Chung Li)
NCKU (Tainan)

AMS is a space version of a precision detector used in accelerators

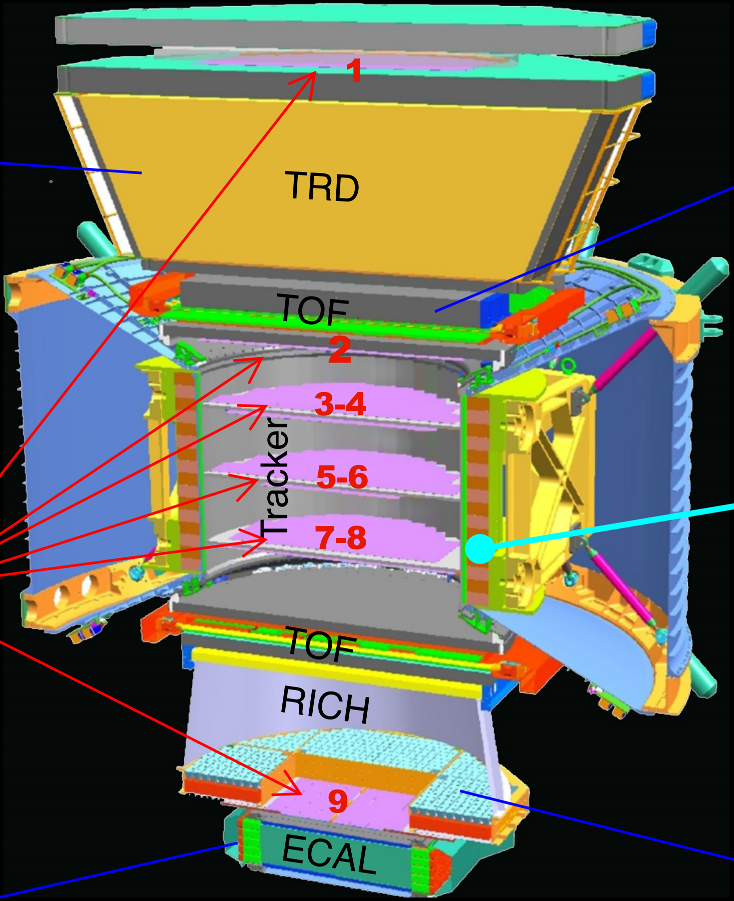
Transition Radiation Detector (TRD)



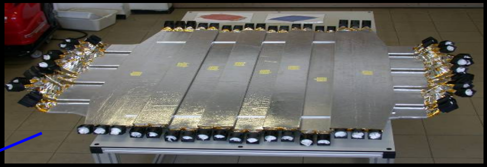
Silicon Tracker



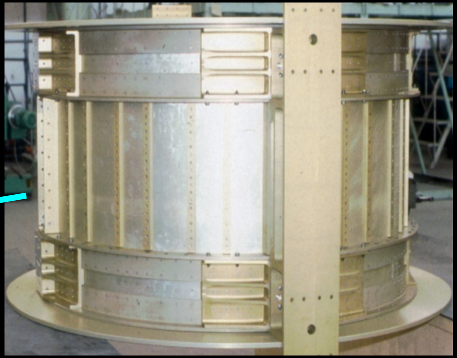
Electromagnetic Calorimeter (ECAL)



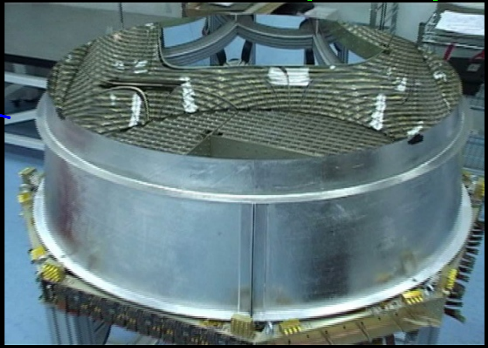
Time of Flight Detector (TOF)



Magnet

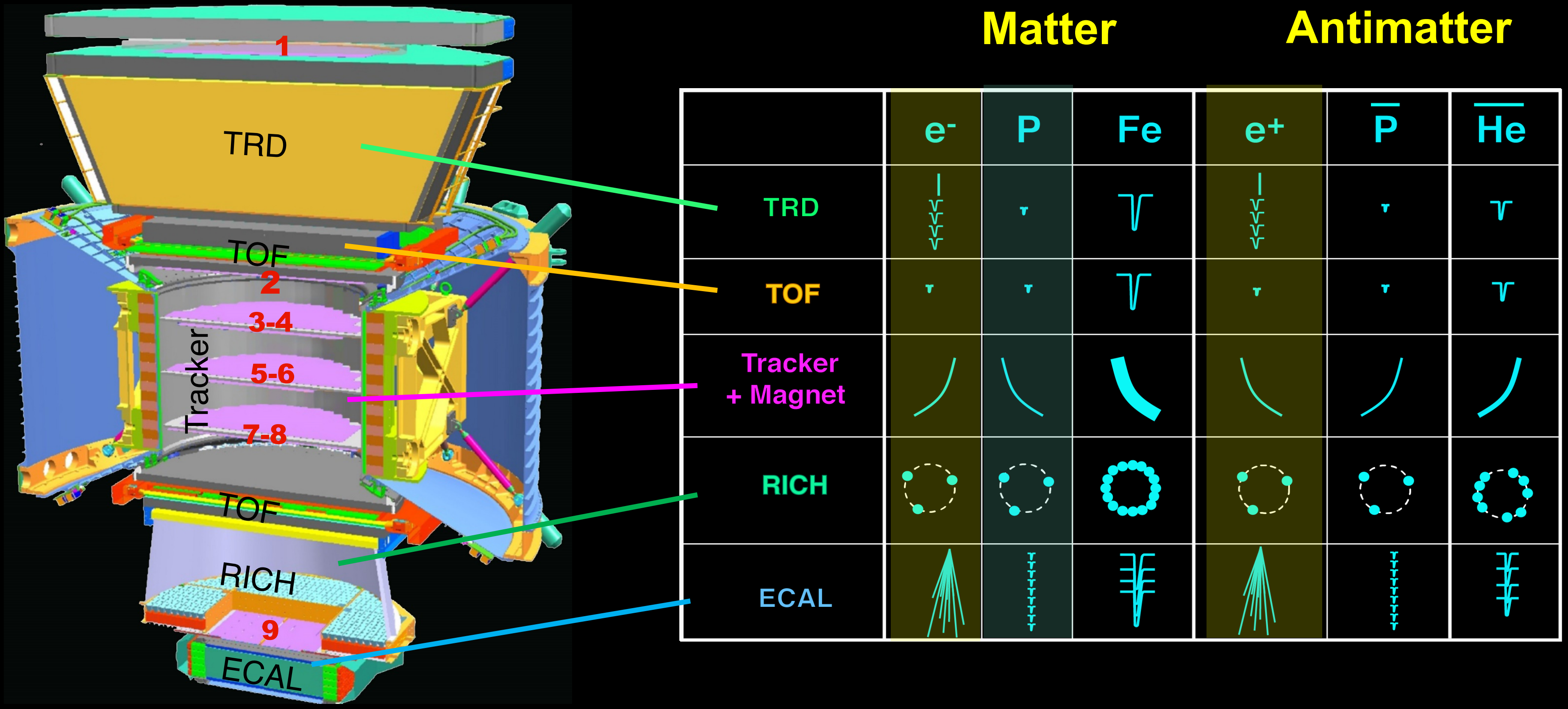


Ring Imaging Cherenkov (RICH)



300,000 electronic channels,
650 fast microprocessors
5m x 4m x 3m
7.5 tons

AMS is a unique magnetic spectrometer in space

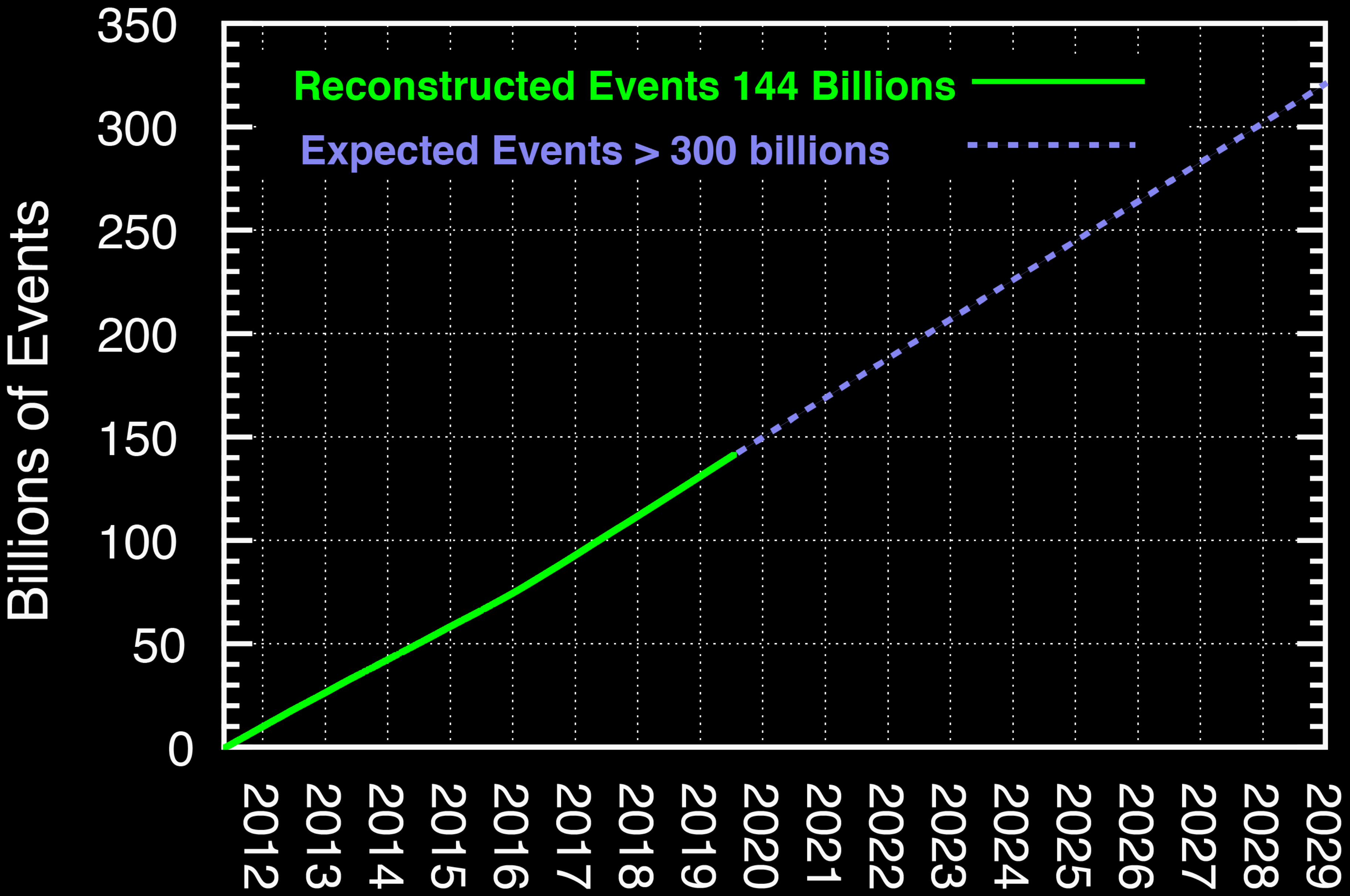


AMS is able to identify 1 positron from 1,000,000 protons;

unambiguously separate positrons from electrons up to a trillion eV;

and accurately measure all cosmic rays to trillions of eV.

Cosmic Ray Events Collected and Measured by AMS



All AMS Publications in *Physical Review Letters*

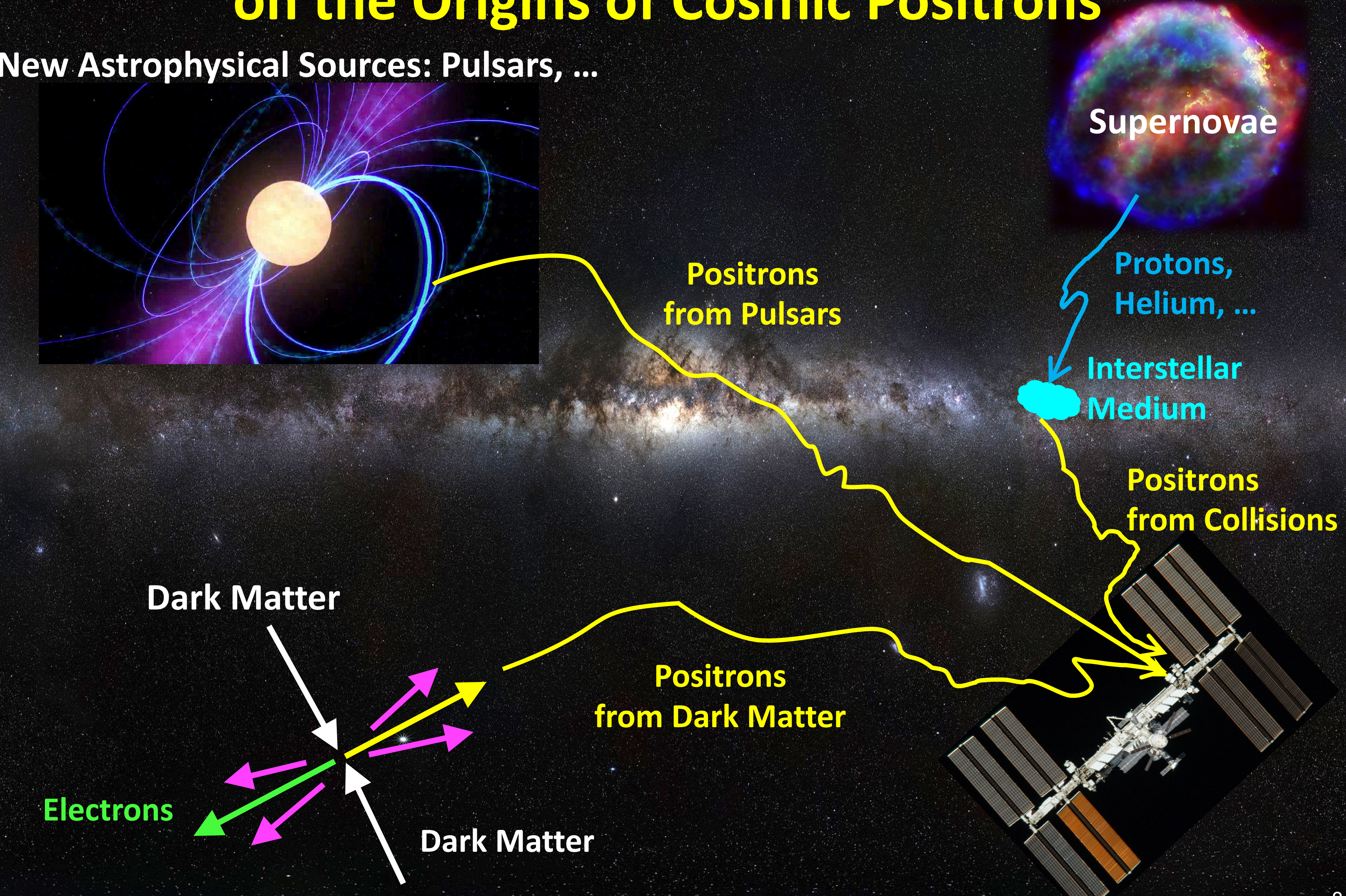
1) M. Aguilar *et. al.*, Phys. Rev. Lett. 110 (2013) 141102. Editor's Suggestion
Viewpoint in Physics, Highlight of the Year 2013. Ten year retrospective of PRL Editors' Suggestions
2) L. Accardo *et al.*, Phys. Rev. Lett. 113 (2014) 121101. Editor's Suggestion
3) M. Aguilar *et. al.*, Phys. Rev. Lett. 113 (2014) 121102. Editor's Suggestion
4) M. Aguilar *et. al.*, Phys. Rev. Lett. 113 (2014) 221102.
5) M. Aguilar *et. al.*, Phys. Rev. Lett. 114 (2015) 171103. Editor's Suggestion
6) M. Aguilar *et. al.*, Phys. Rev. Lett. 115 (2015) 211101. Editor's Suggestion
7) M. Aguilar *et. al.*, Phys. Rev. Lett. 117 (2016) 091103.
8) M. Aguilar *et. al.*, Phys. Rev. Lett. 117 (2016) 231102. Editor's Suggestion

9) M. Aguilar *et. al.*, Phys. Rev. Lett. 119 (2017) 251101.
10) M. Aguilar *et. al.*, Phys. Rev. Lett. 120 (2018) 021101. Editor's Suggestion
11) M. Aguilar *et. al.*, Phys. Rev. Lett. 121 (2018) 051101.
12) M. Aguilar *et. al.*, Phys. Rev. Lett. 121 (2018) 051102. Editor's Suggestion
13) M. Aguilar *et. al.*, Phys. Rev. Lett. 121 (2018) 051103.
14) M. Aguilar *et. al.*, Phys. Rev. Lett. 122 (2019) 041102. Editor's Suggestion
15) M. Aguilar *et. al.*, Phys. Rev. Lett, 122 (2019) 101101.
16) M. Aguilar *et. al.*, Phys. Rev. Lett, 123 (2019) 181102. Editor's Suggestion

17) M. Aguilar *et. al.*, To be submitted to Phys. Rev. Lett.,
"Rigidity Dependence of Ne, Mg, and Si Cosmic Rays"
18) …

For the latest AMS results and news, please visit our new website:
https://ams02.space/

AMS Latest Results: on the Origins of Cosmic Positrons



New Astrophysical Sources: Pulsars, …

Supernovae

Positrons from Pulsars

Protons, Helium, …

Interstellar Medium

Positrons from Collisions

Dark Matter

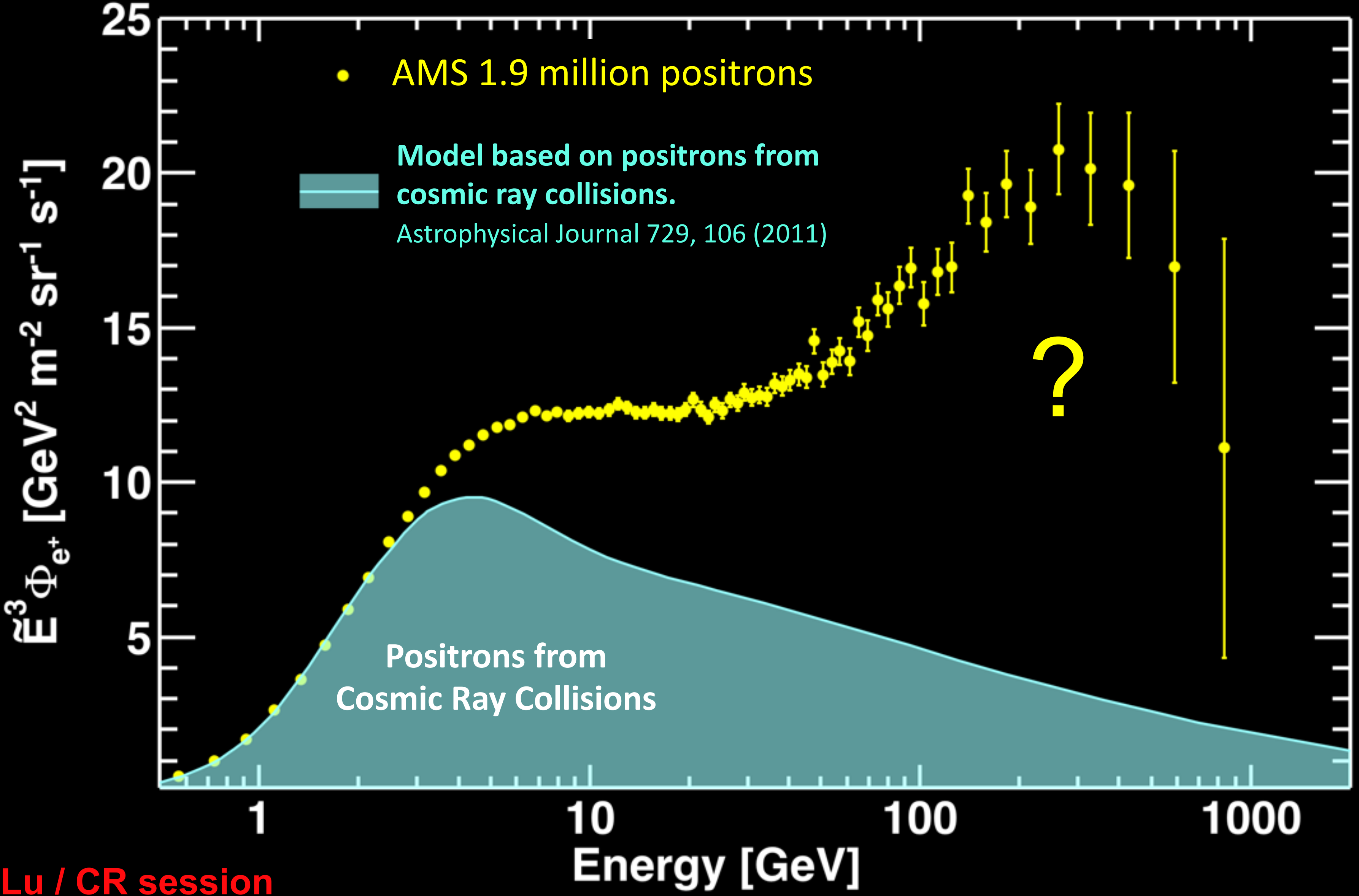
Positrons from Dark Matter

Electrons

Dark Matter

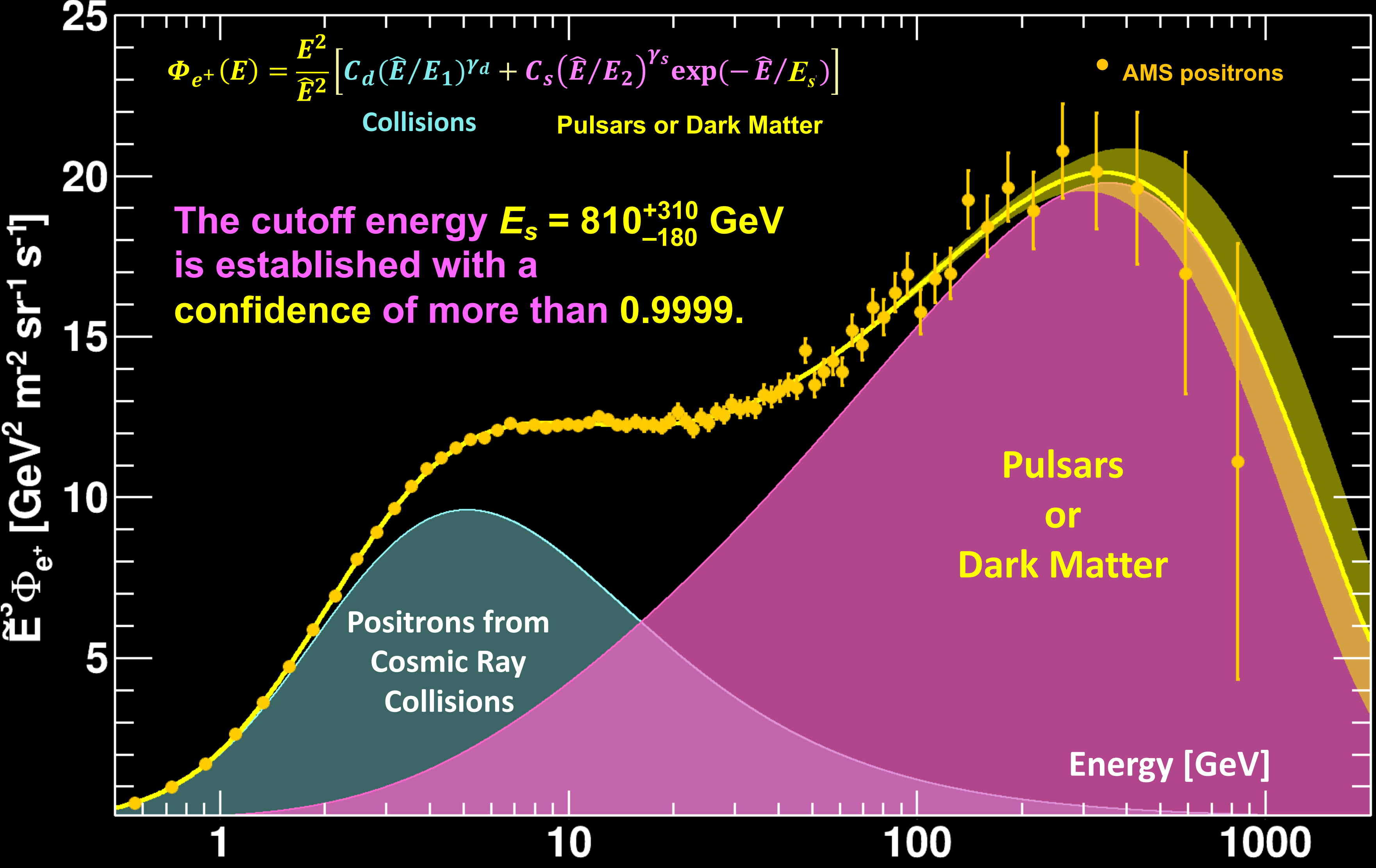
The Origin of Positrons

Low energy positrons mostly come from cosmic ray collisions



S. Lu / CR session

The positron flux is the sum of low-energy part from cosmic ray collisions plus a high-energy part from pulsars or dark matter.



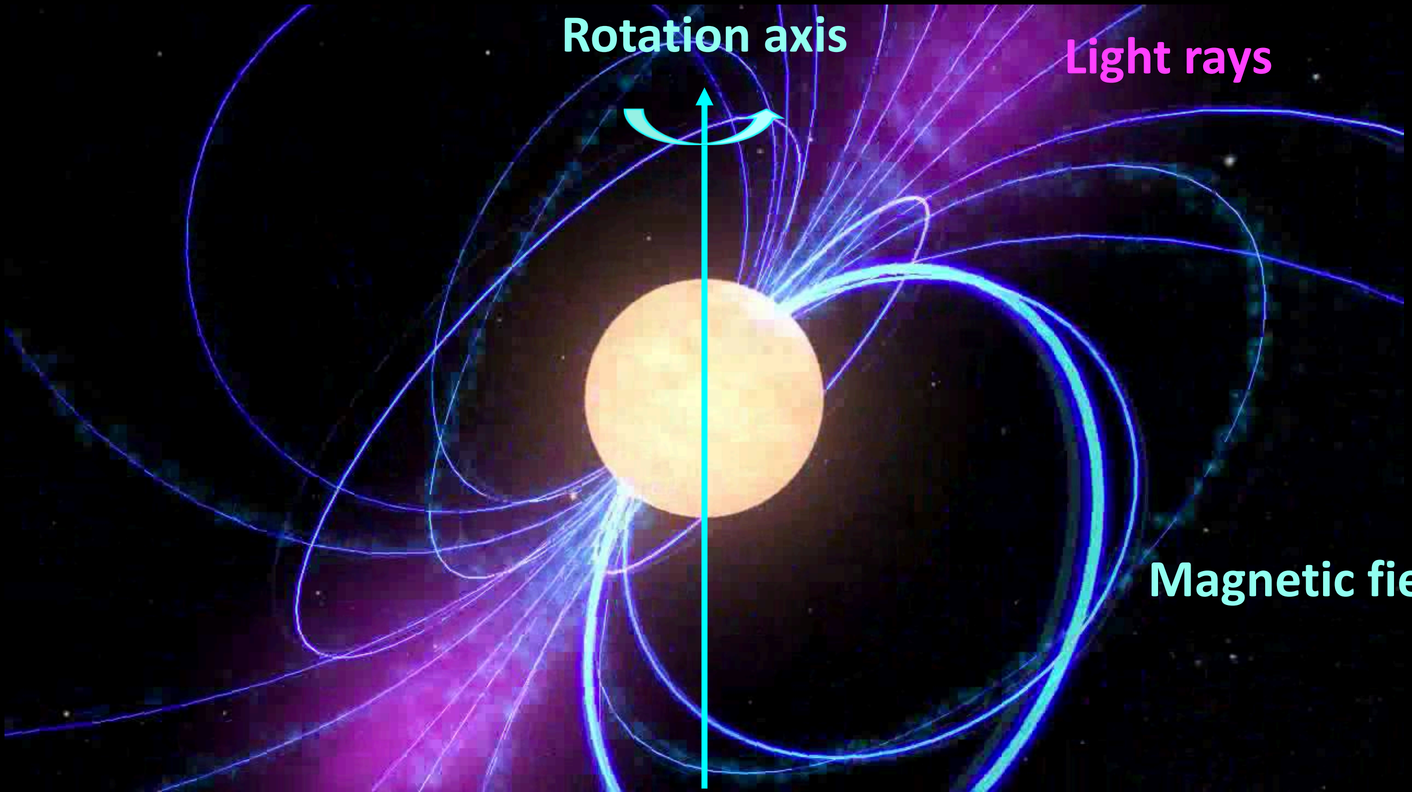
$$\Phi_{e^+}(E) = \frac{E^2}{\hat{E}^2}\left[C_d(\hat{E}/E_1)^{\gamma_d} + C_s(\hat{E}/E_2)^{\gamma_s}\exp(-\hat{E}/E_s)\right]$$

The cutoff energy $E_s = 810^{+310}_{-180}$ GeV is established with a confidence of more than 0.9999.

Positrons from Pulsars

Pulsars produce and accelerate positrons to high energies.

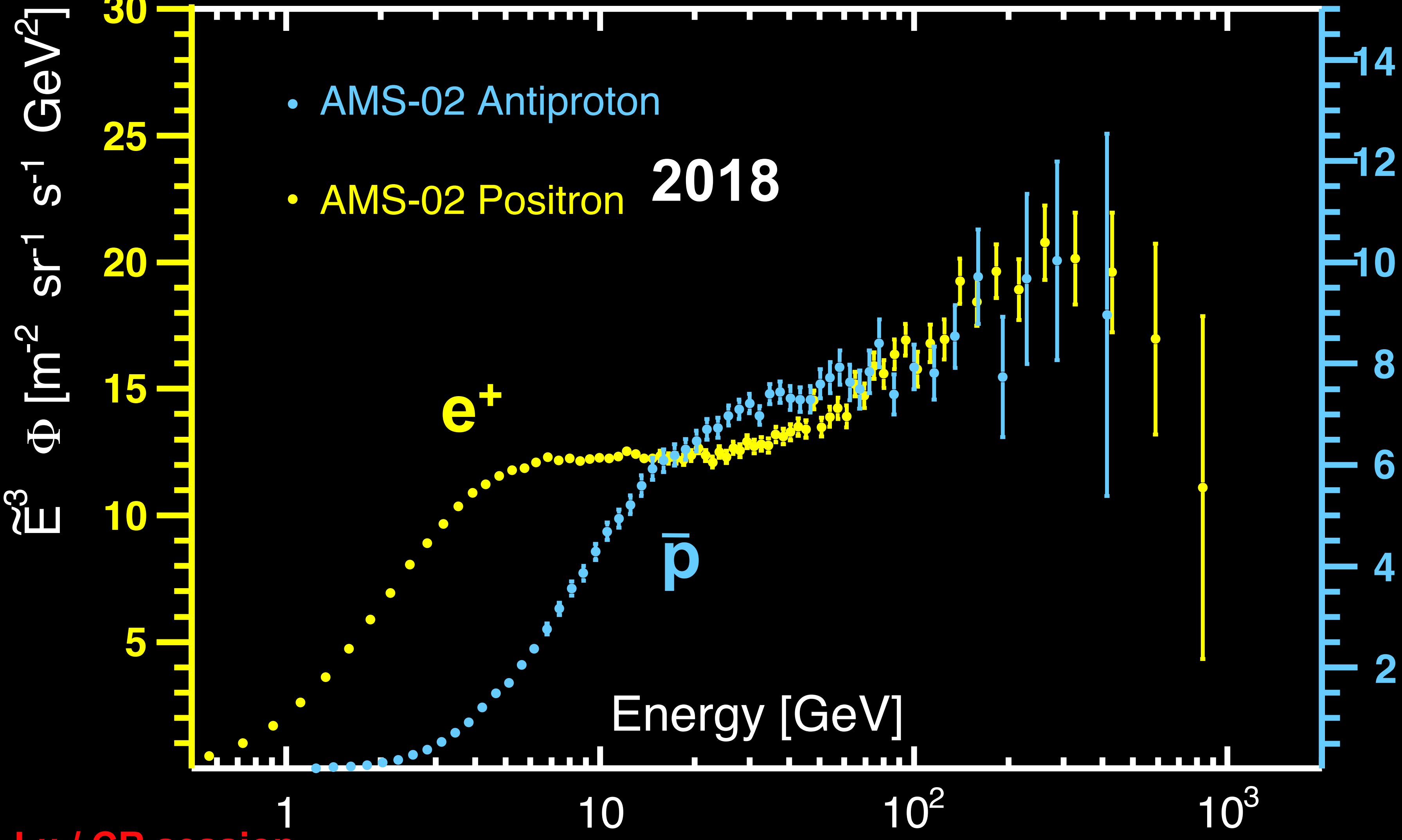
Pulsars do not produce antiprotons.



AMS Latest Results:

Antiproton data show a similar trend as **positrons.**

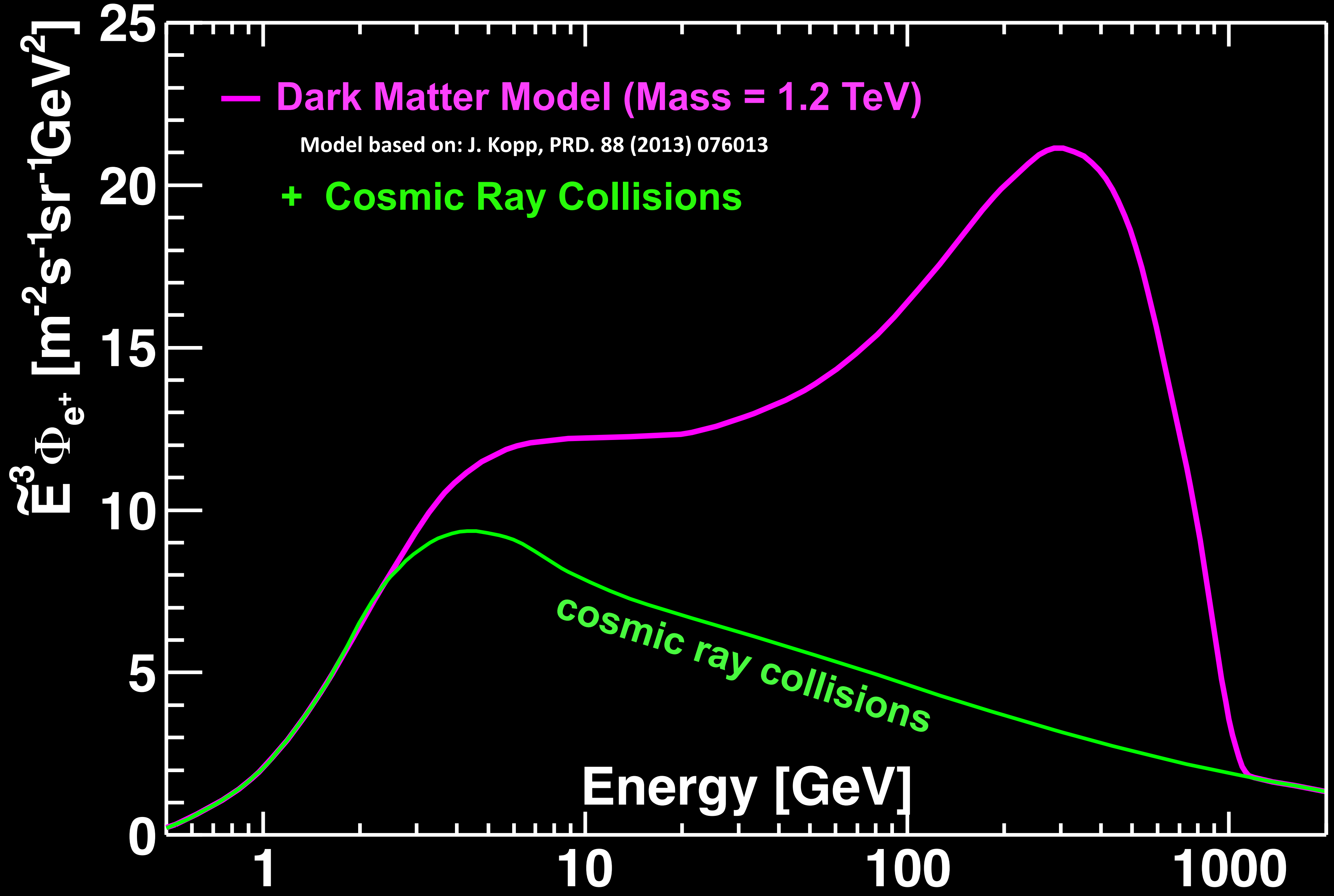
Antiprotons cannot come from pulsars.



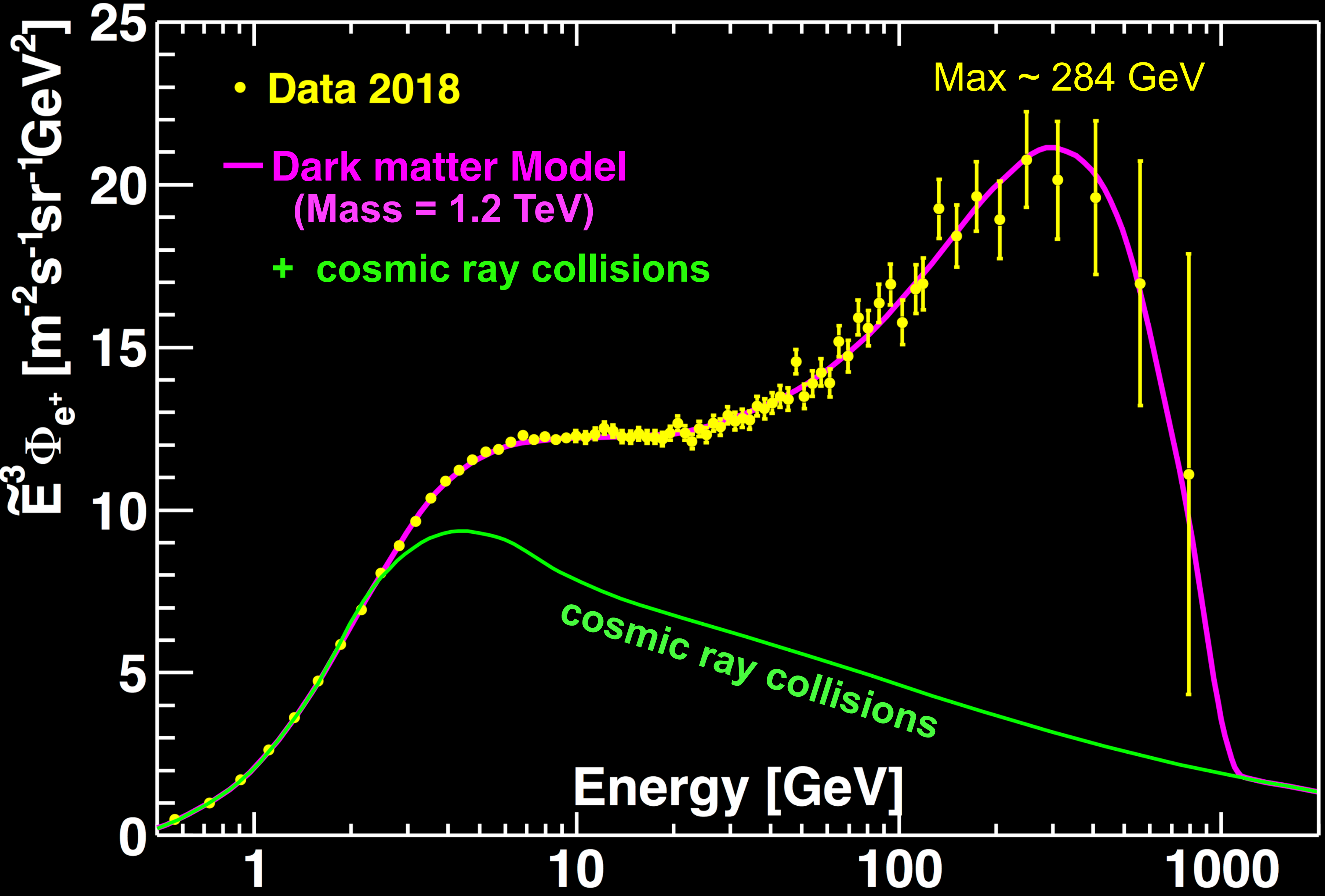
S. Lu / CR session

Dark Matter Model Prediction of Positron Spectrum

with a characteristic sharp drop-off at high energies

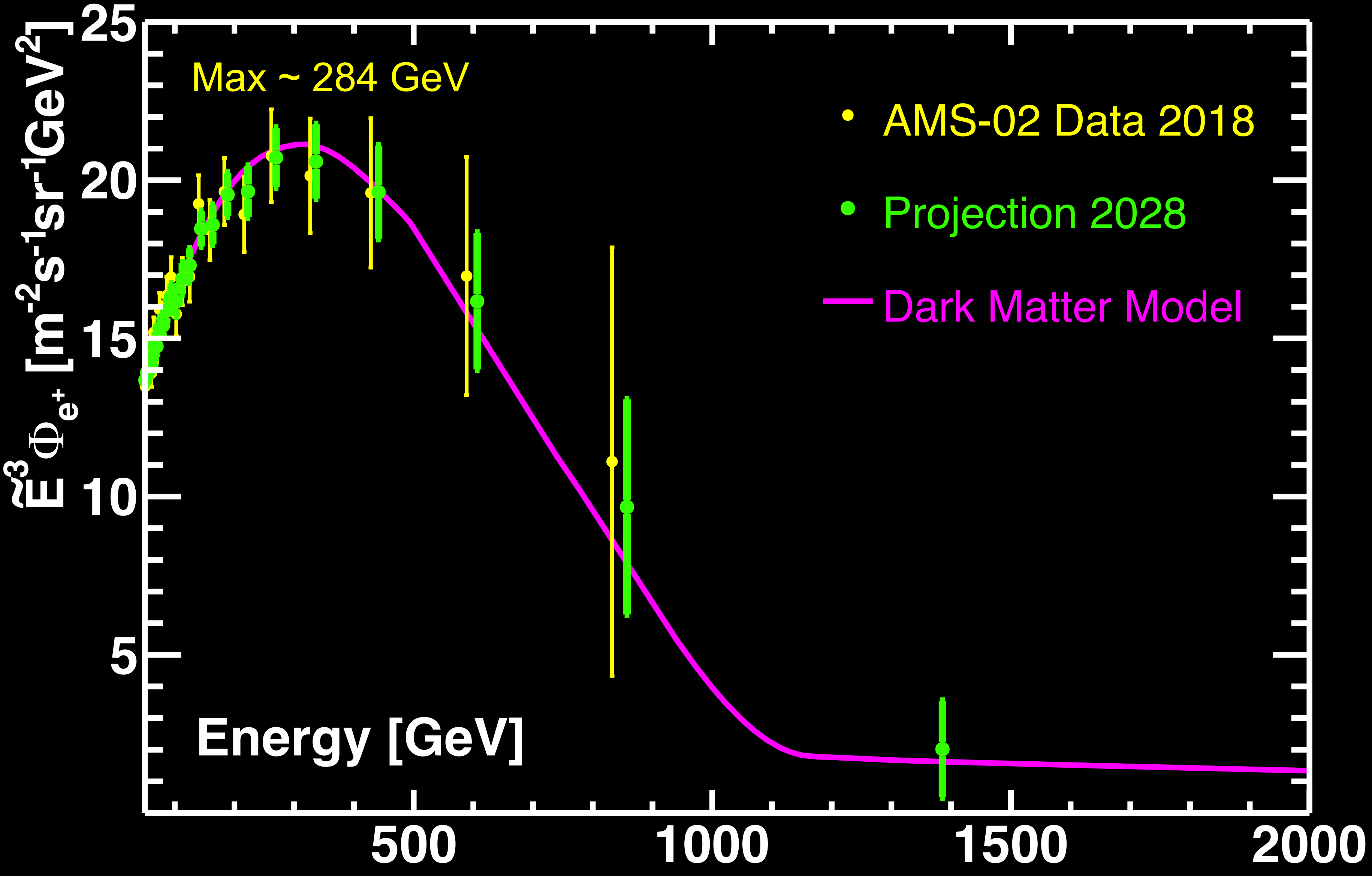


Positrons and Dark Matter Model (2018)

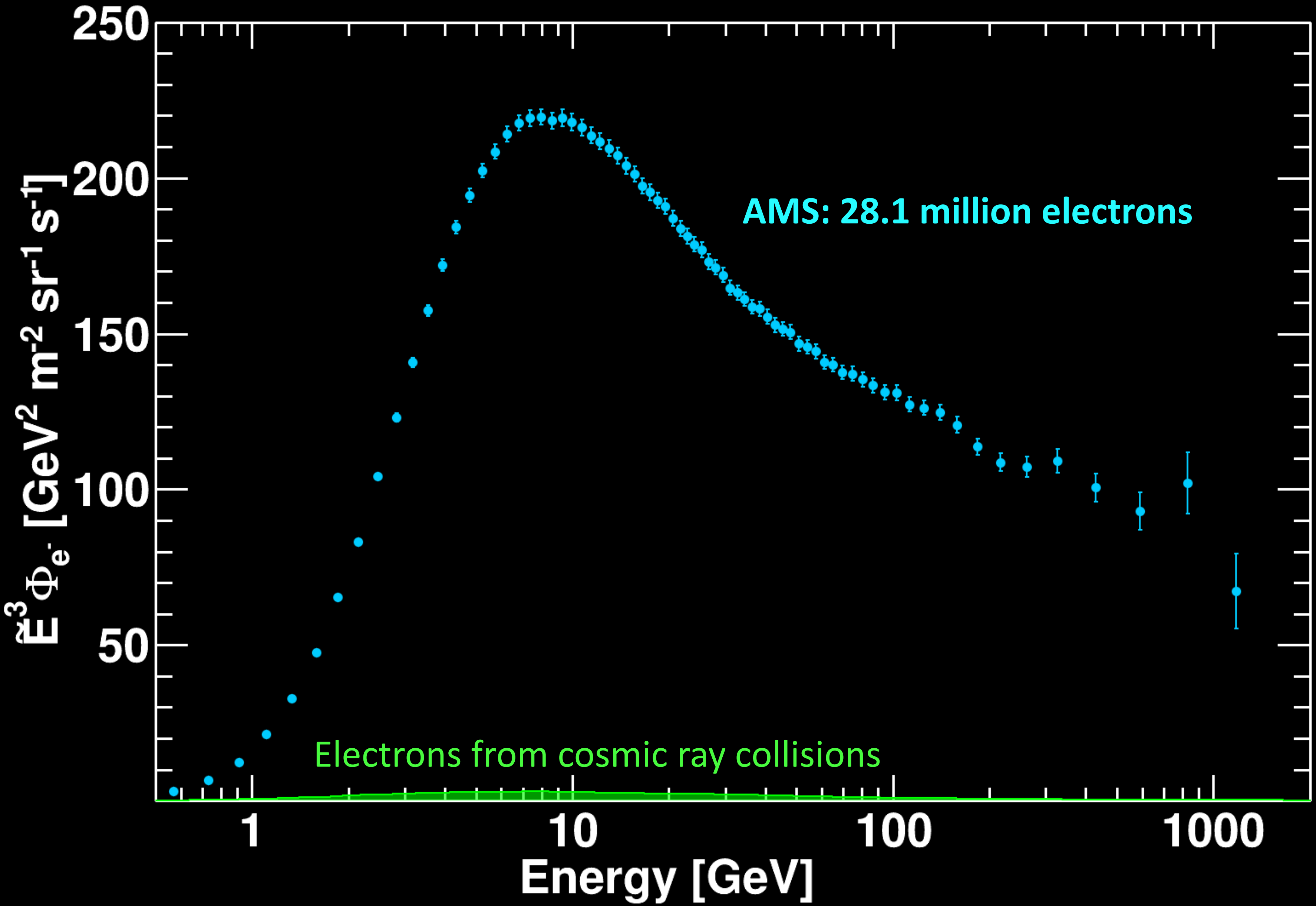


Model based on: J. Kopp, PRD. 88 (2013) 076013

Projection of the Positron Spectrum through 2028 using Dark Matter model



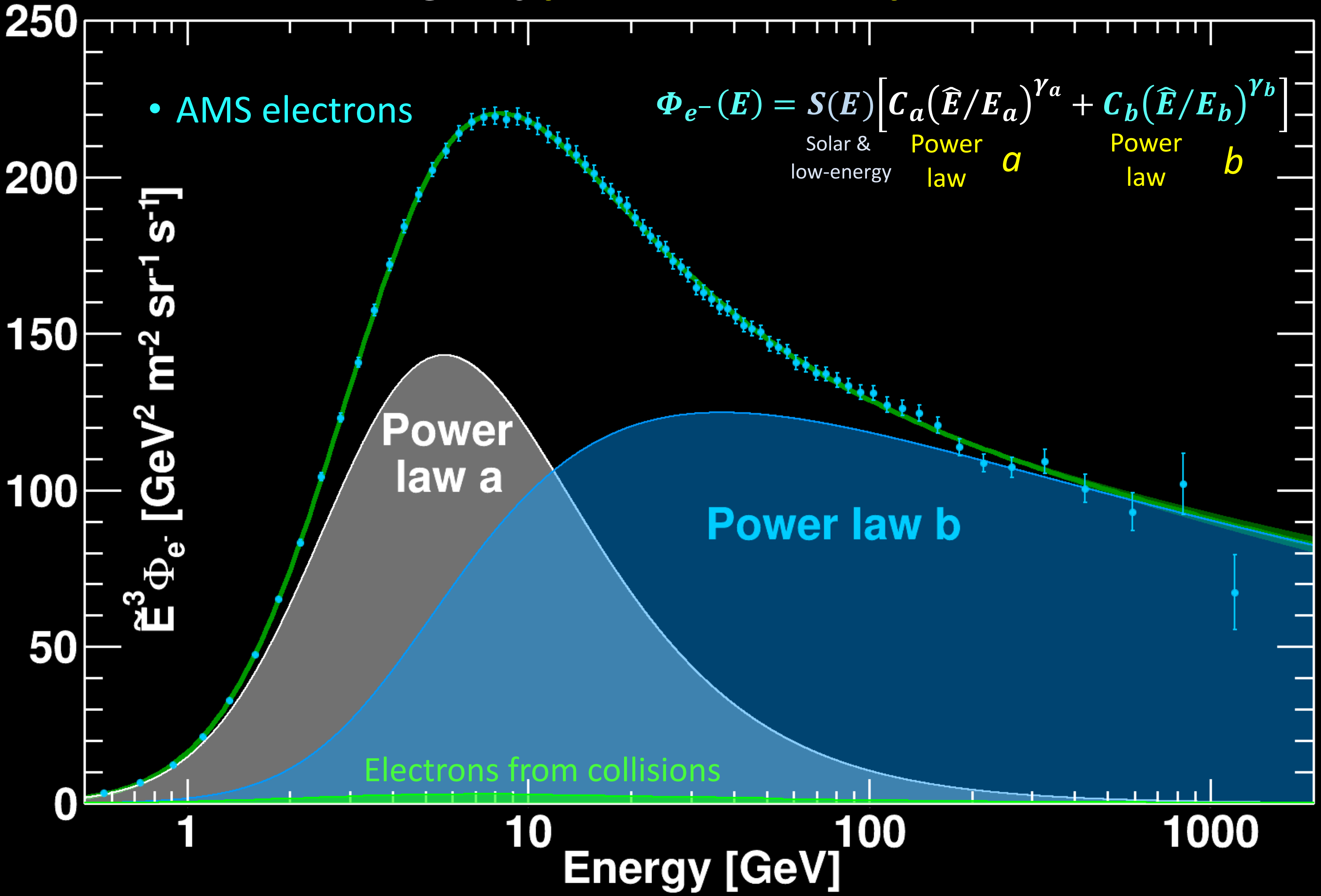
AMS Latest Results: The Origins of Cosmic Electrons



The contribution from cosmic ray collisions is negligible

The electron flux can be described by two power law functions *a* and *b* *and, at 5-sigma, there is no cutoff energy below 1.9 TeV.*

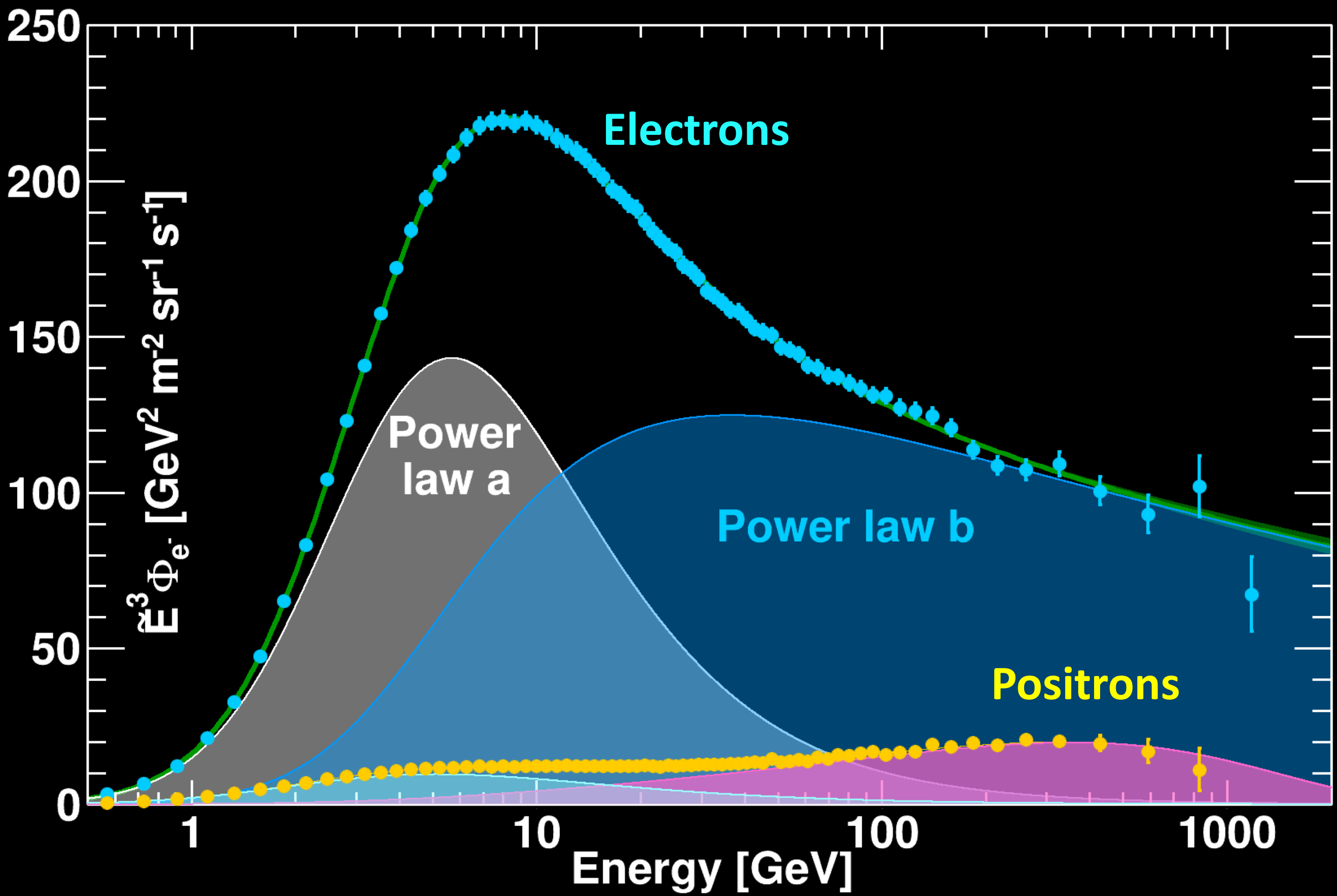
What is the origin of power law a and power law b?



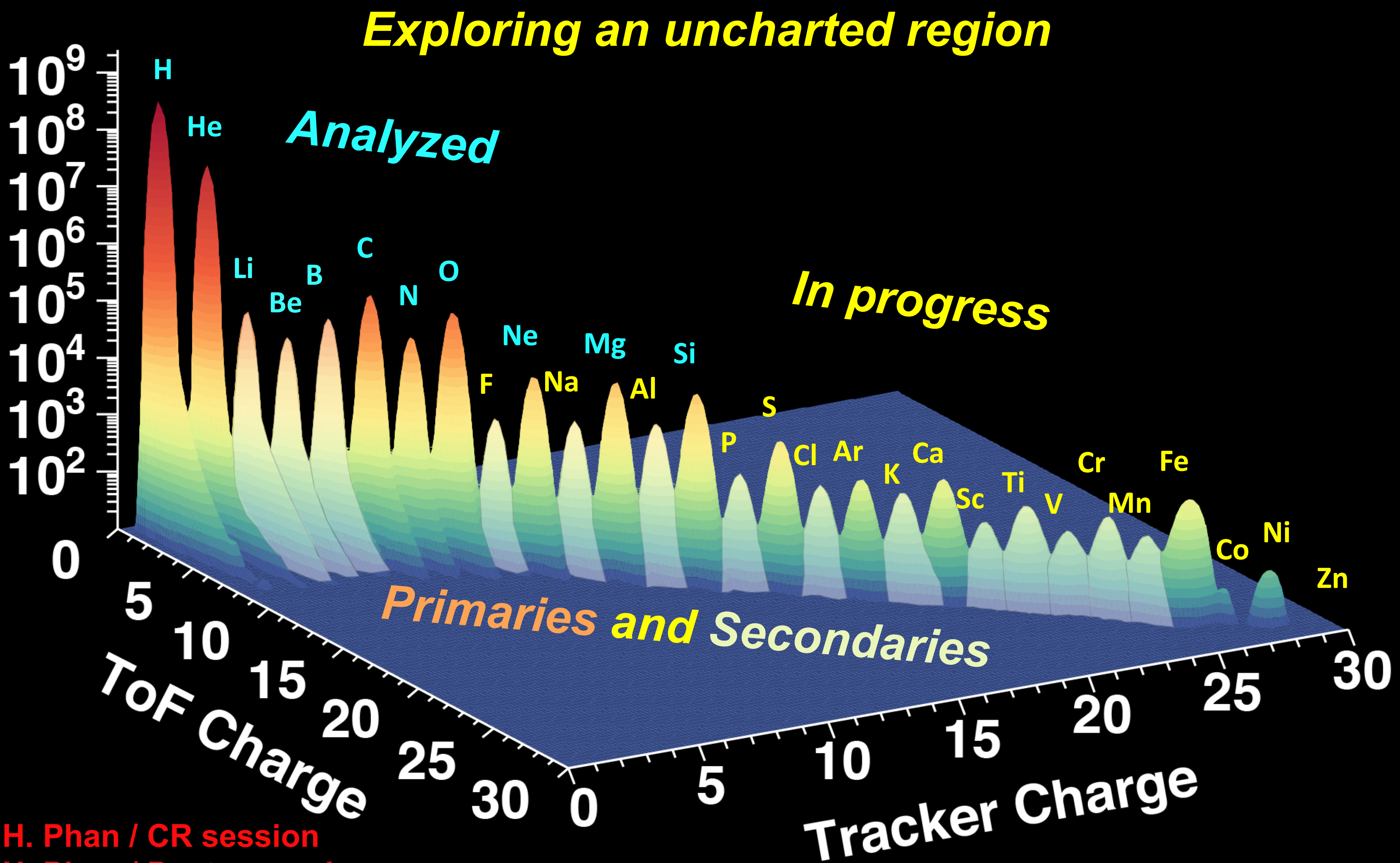
$$\Phi_{e^-}(E) = S(E)\left[C_a\left(\hat{E}/E_a\right)^{\gamma_a} + C_b\left(\hat{E}/E_b\right)^{\gamma_b}\right]$$

AMS Latest Results:

Electrons originate from different sources than positrons;
the electron spectrum comes from two power law contributions.
The positron flux is the sum of low-energy part from cosmic ray collisions plus a high energy part from pulsars or dark matter. The positron flux has a cutoff energy E_S.
The antiproton spectrum challenges the pulsar origin of positrons.



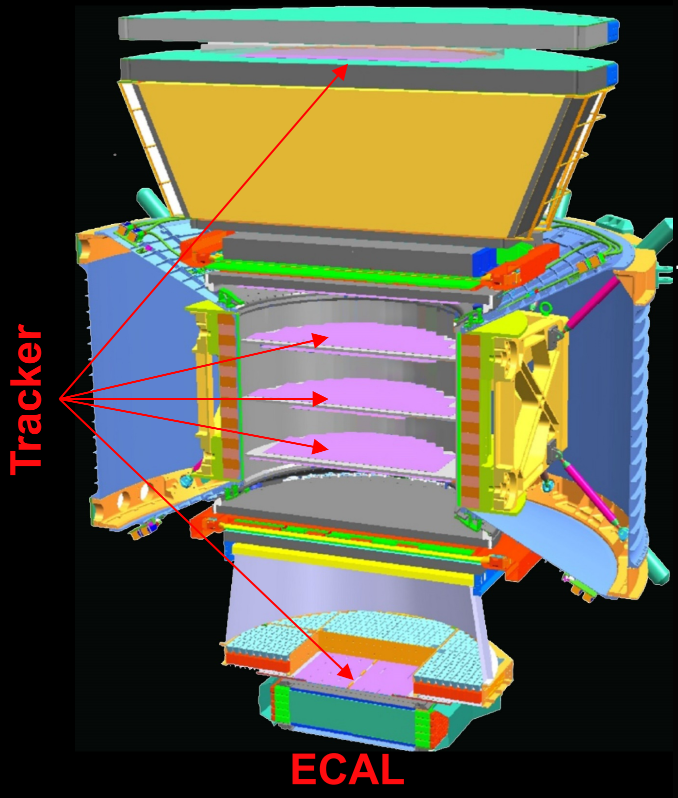
AMS Latest Results:
Precision Study of Cosmic Nuclei

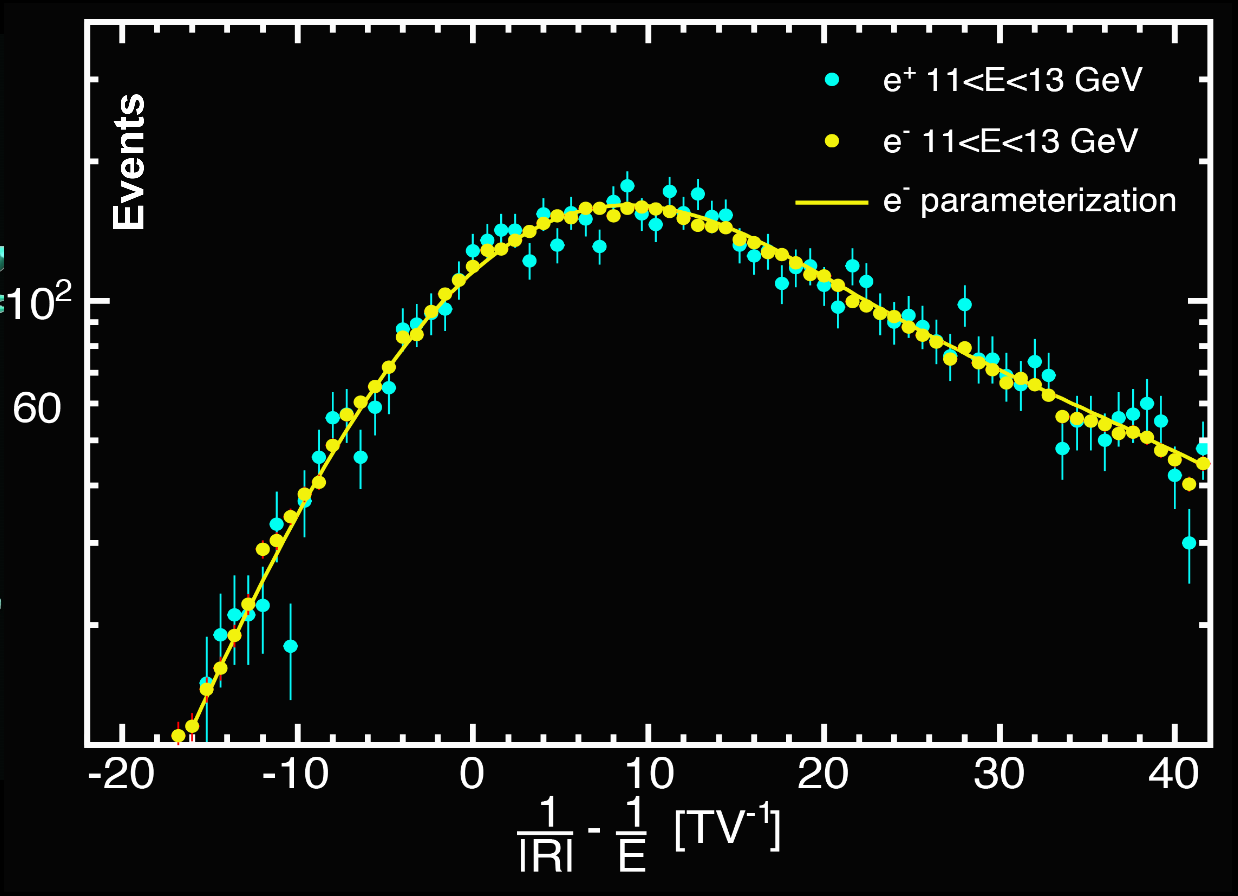


H. Phan / CR session
H. Phan / Poster session

The precision of AMS:

The rigidity scale is obtained by the comparison of the rigidity ***R*** from the tracker, with the energy ***E*** from the ECAL, for positron and electron events.

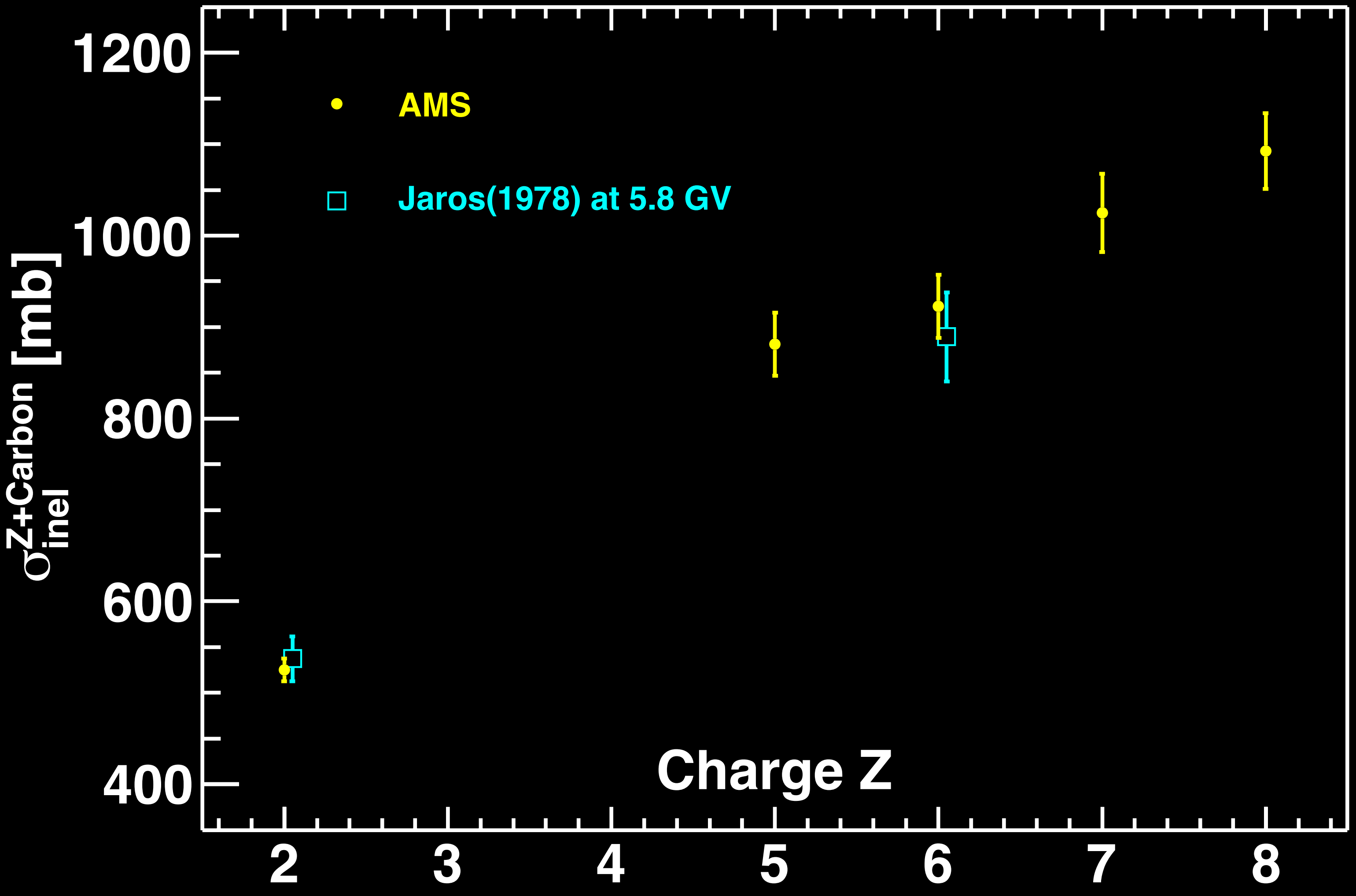




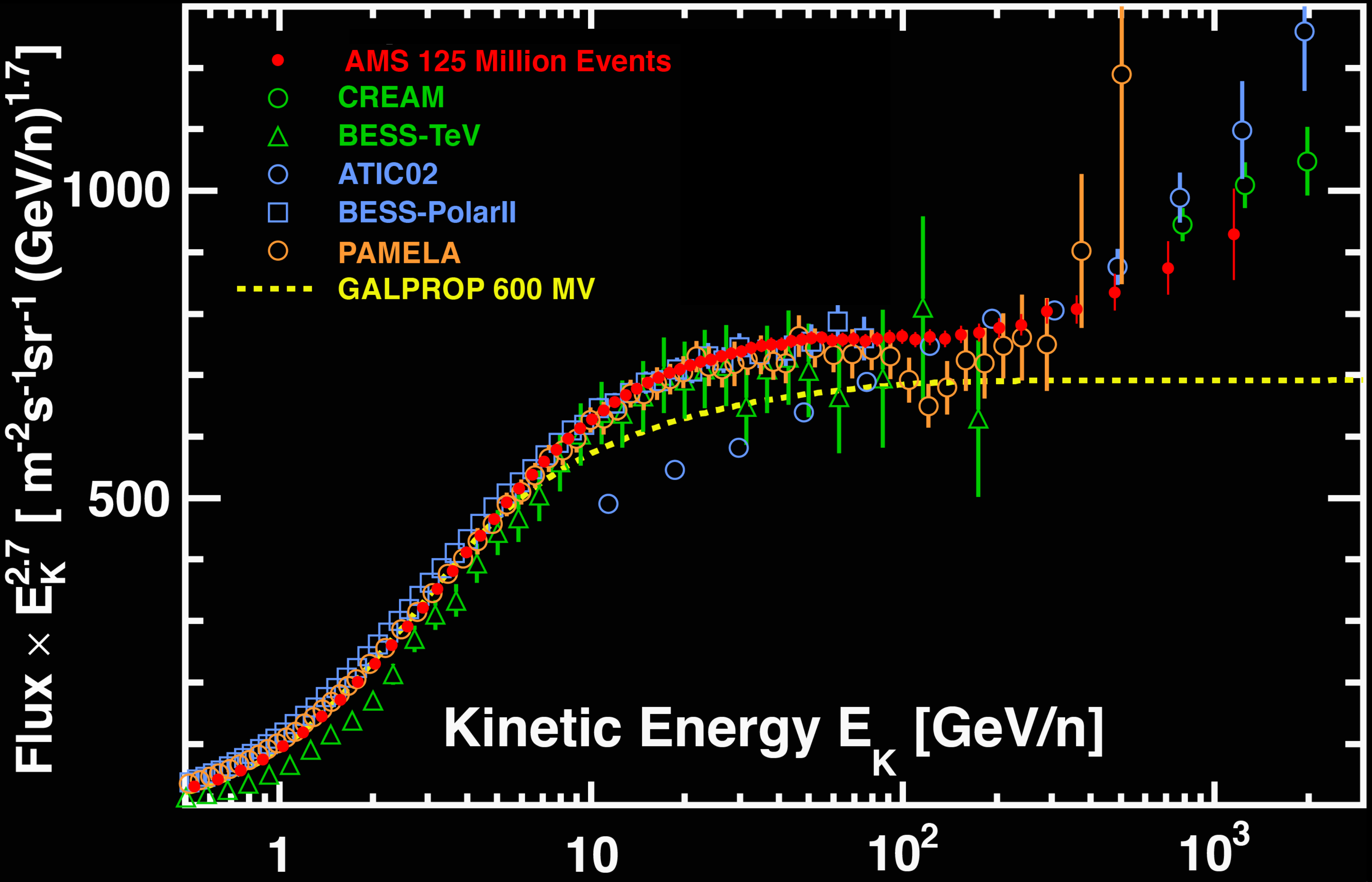
The accuracy of the rigidity scale is **1/30 TV^{-1}** ,
which will be further improved with more positron data.

The precision of AMS:

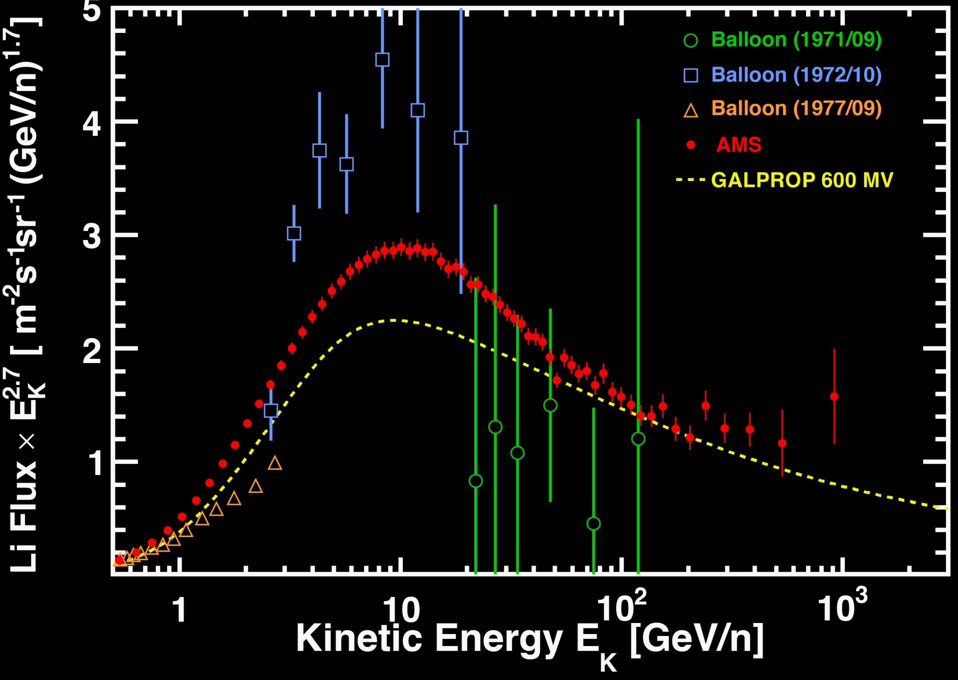
measurement of the nuclear interaction cross sections and their energy dependence, which were not available from accelerator measurements.



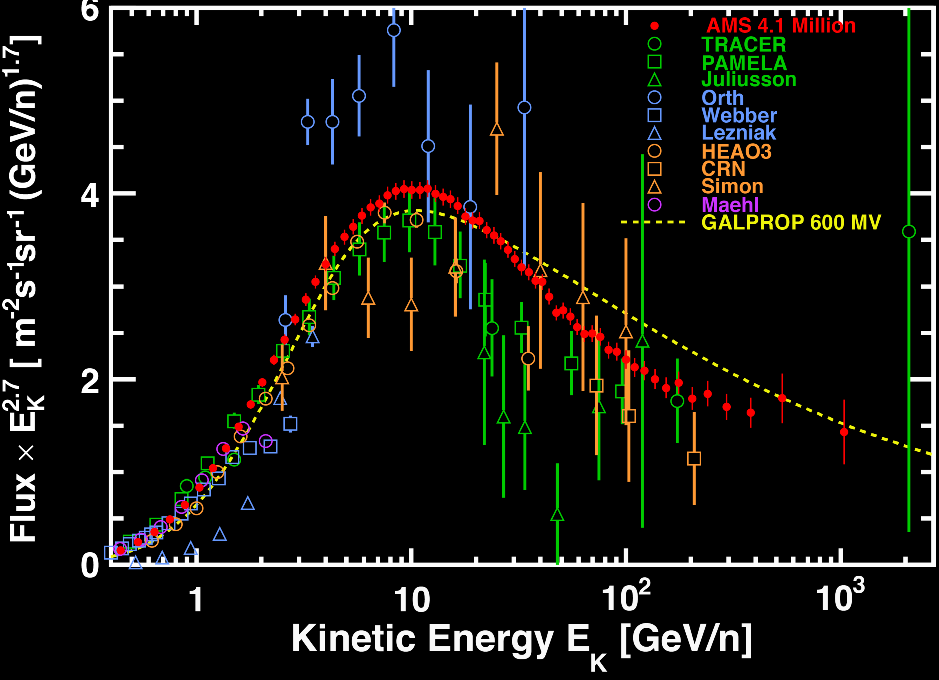
AMS Helium (Z = +2)



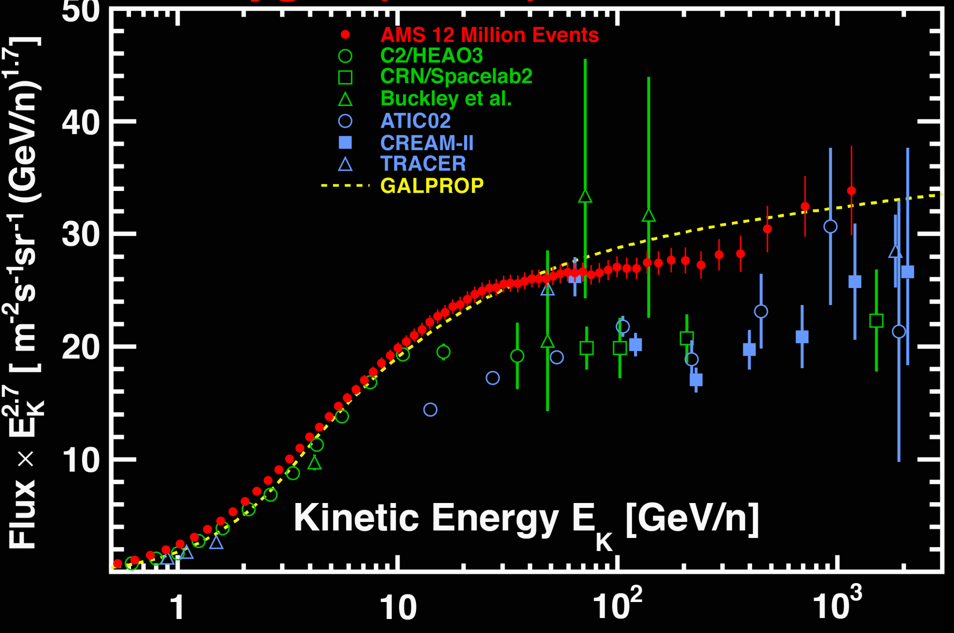
Lithium (Z = +3) 1.9 Million



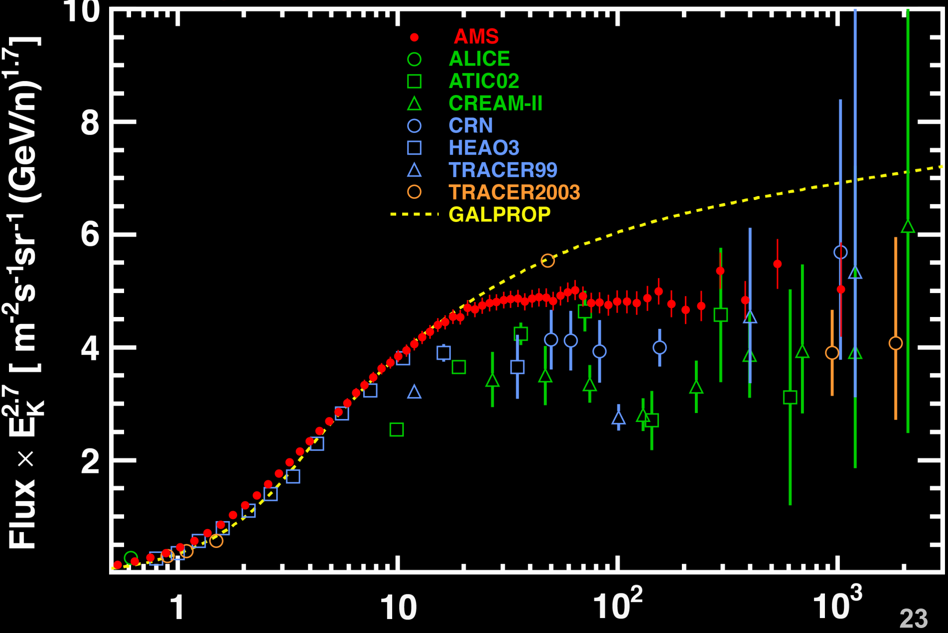
Boron (Z = +5) 4.1 Million



Oxygen (Z = +8) 12 Million



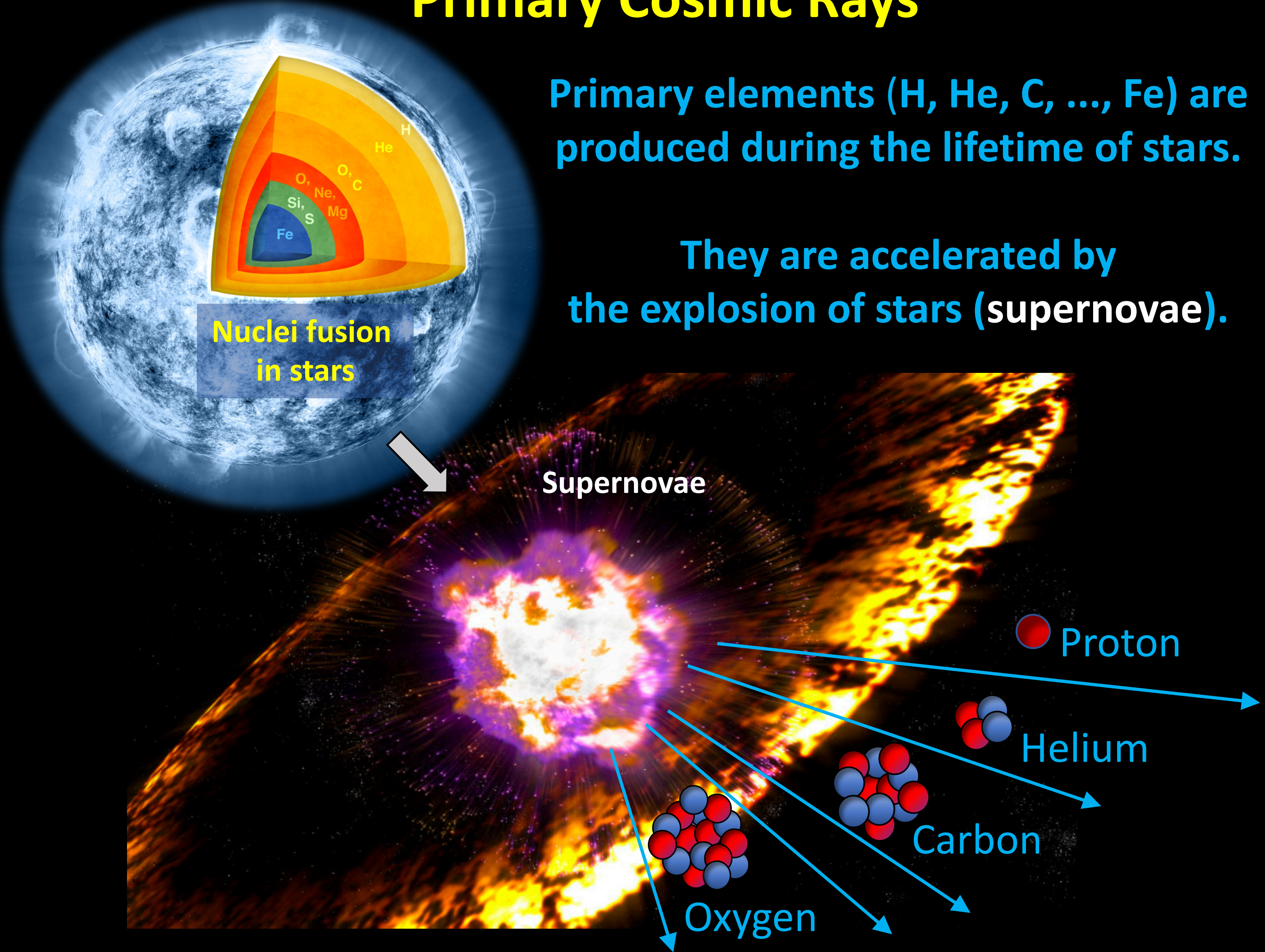
Magnesium (Z = +12) 2.2 Million



Primary Cosmic Rays

Primary elements (H, He, C, ..., Fe) are produced during the lifetime of stars.

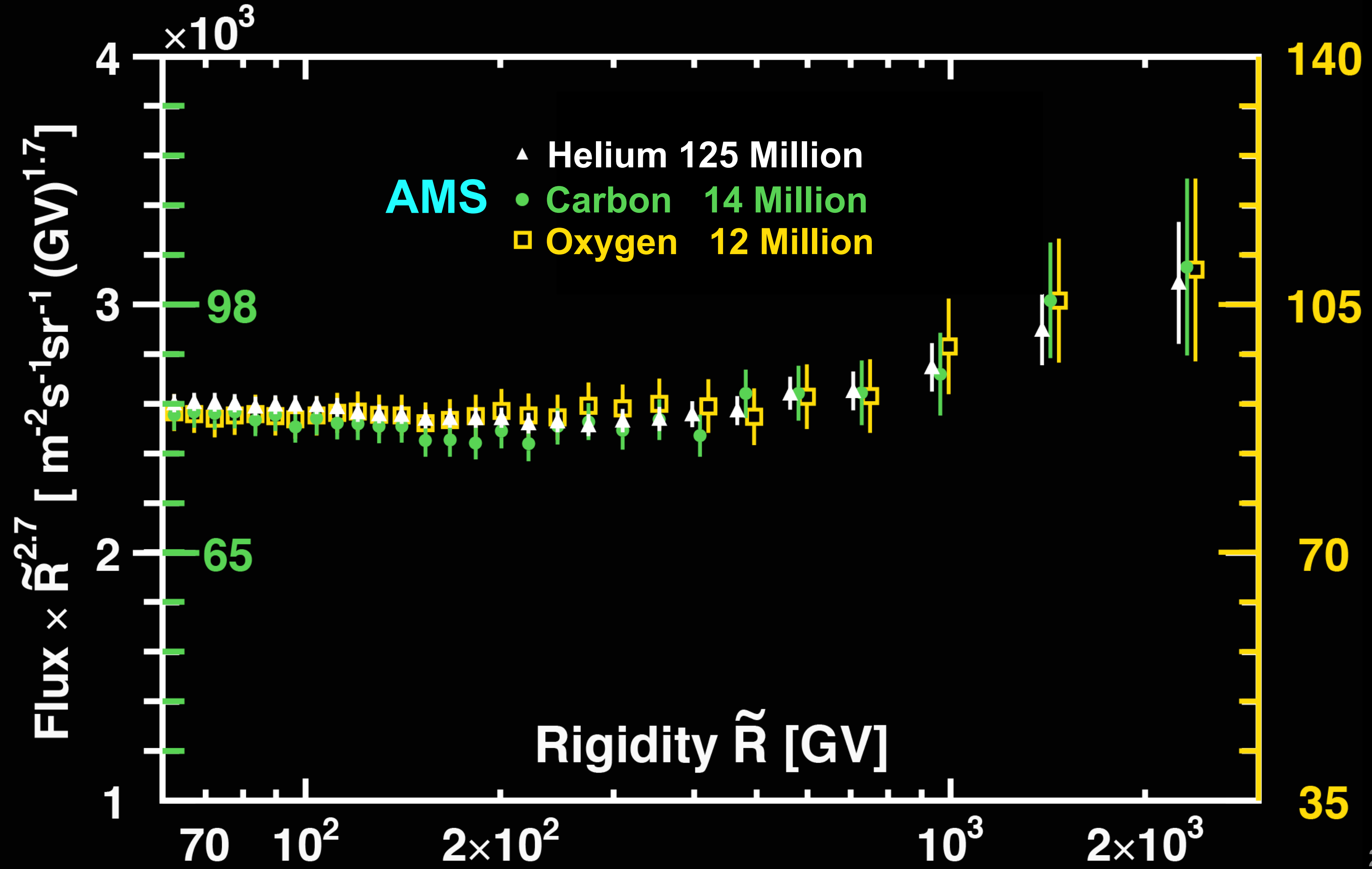
They are accelerated by the explosion of stars (**supernovae**).



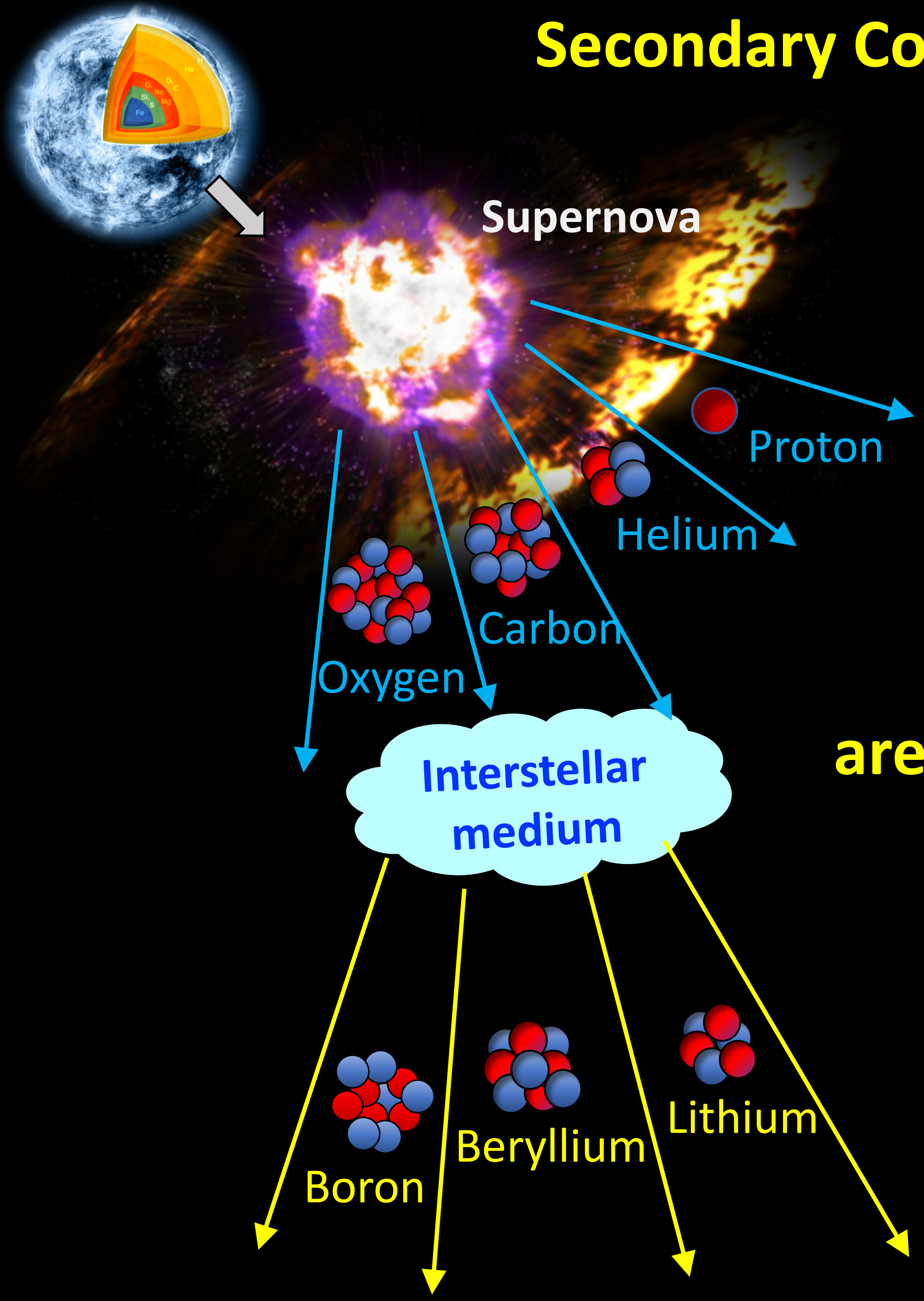
AMS Physics Results:

The primary cosmic rays have identical rigidity dependence above 60 GV.

They all deviate from single power law starting from ~200 GV



Secondary Cosmic Rays



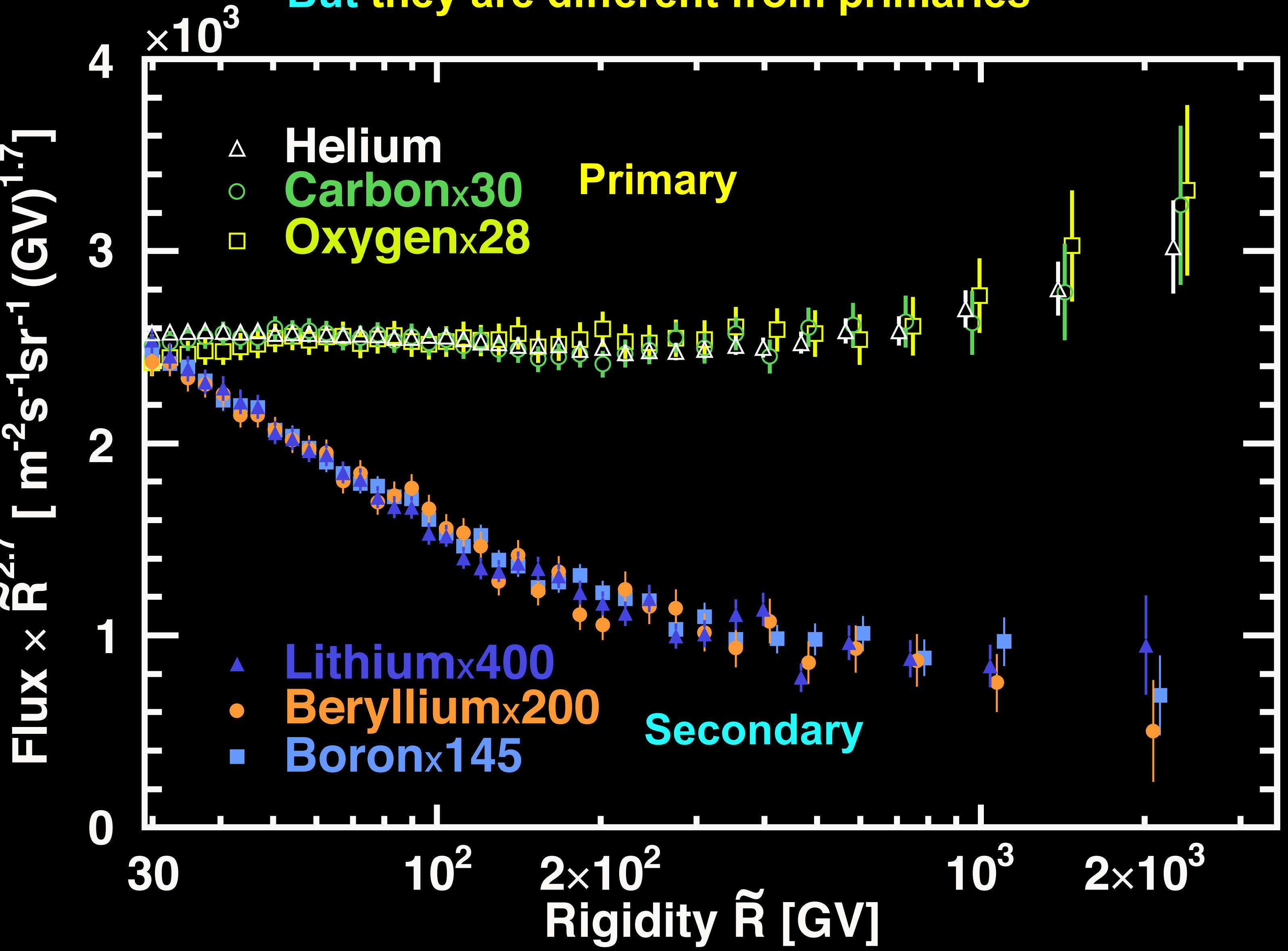
Secondary cosmic nuclei
(Li, Be, B, …)
are produced by the collision of
primary cosmic rays and
interstellar medium

AMS Physics Results:

Li, Be, and B also have identical rigidity dependence above 30 GV.

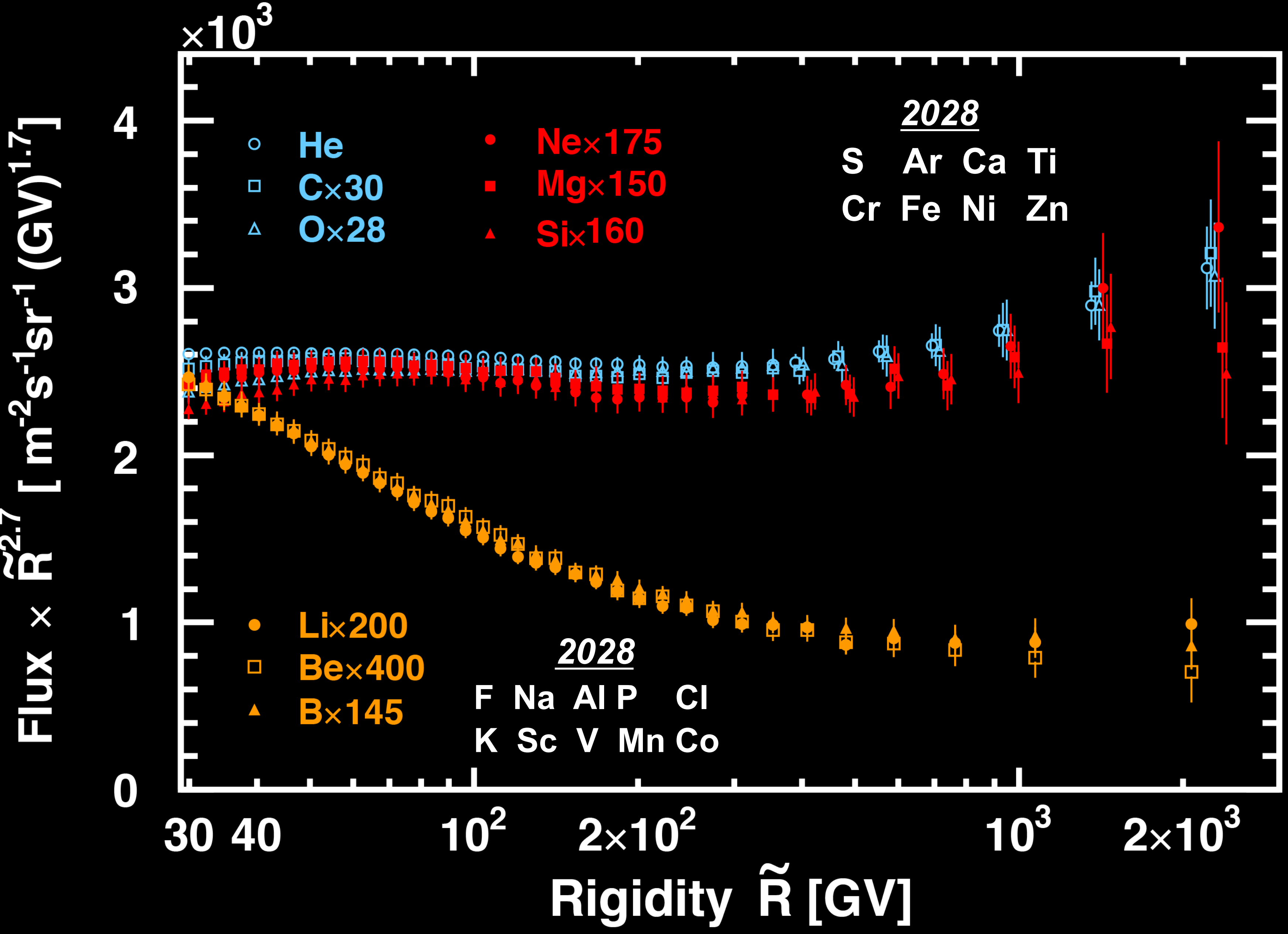
They also all deviate from single power law.

But they are different from primaries



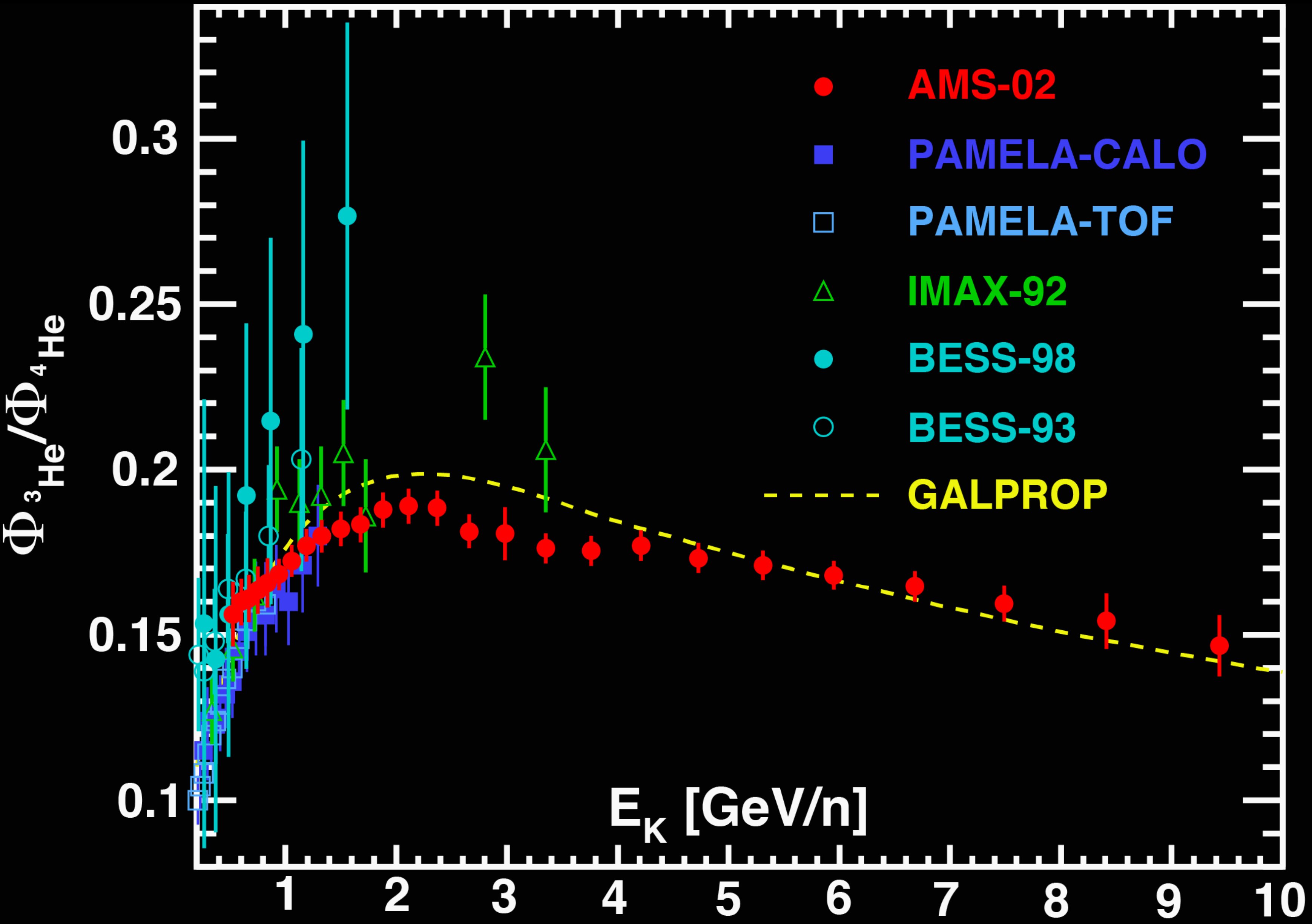
AMS physics in the lifetime of ISS :

How many classes of cosmic rays exist in the universe?



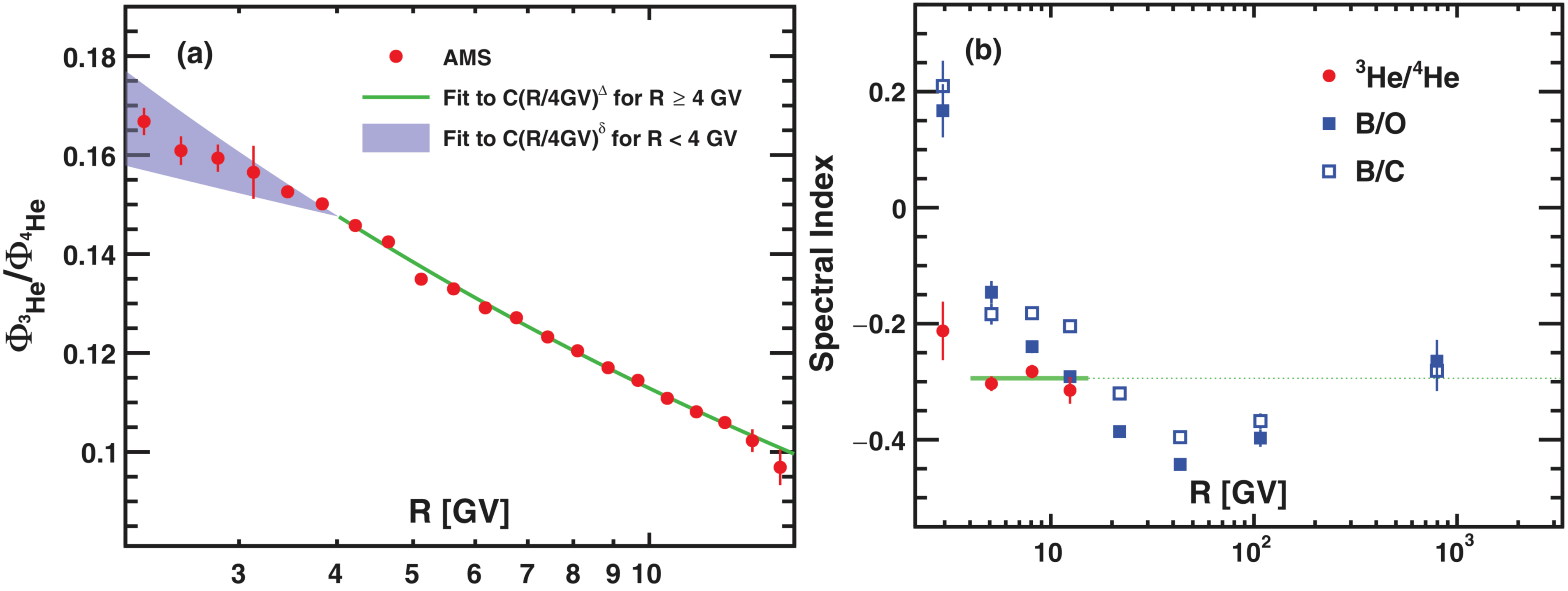
AMS First Isotope Results: ^{3}He and ^{4}He

PRL 123 (2019) 181102



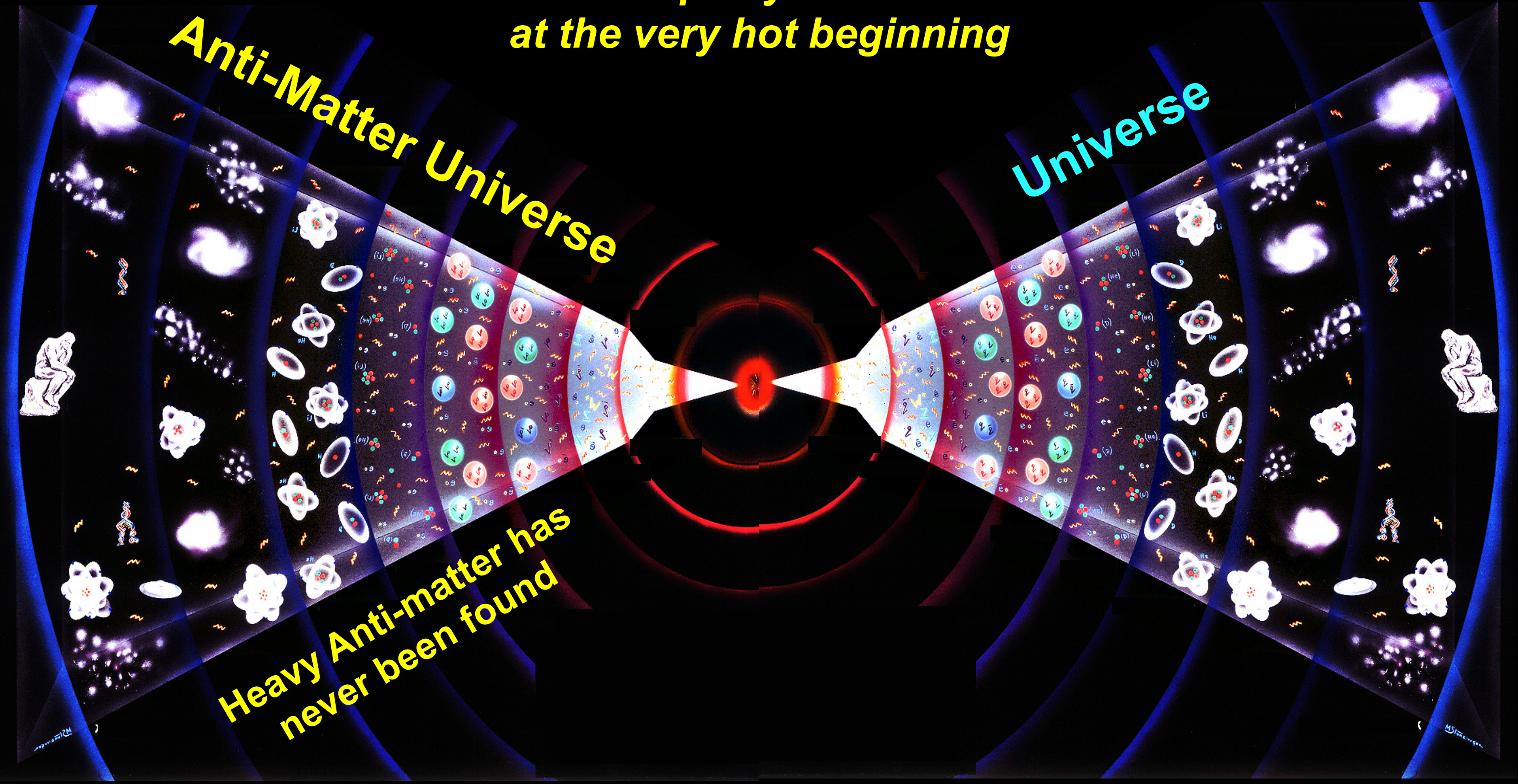
AMS Results on ^{3}He/^{4}He flux ratio

Above 4 GV , ^{3}He/^{4}He follows a single power law with a spectral index of $\Delta=-0.294 \pm 0.004$, which agrees with B/C and B/O at TV rigidities.



AMS physics in the lifetime of ISS :
Properties of Antimatter

The Big Bang origin of the Universe requires
matter and antimatter
to be equally abundant
at the very hot beginning

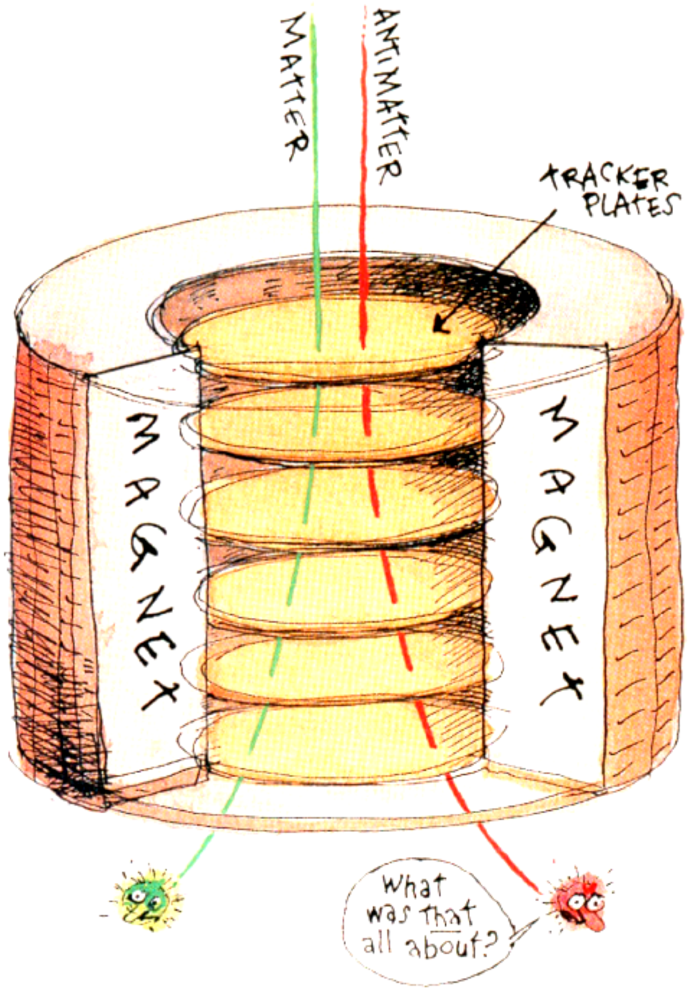


Anti-Matter Universe

Universe

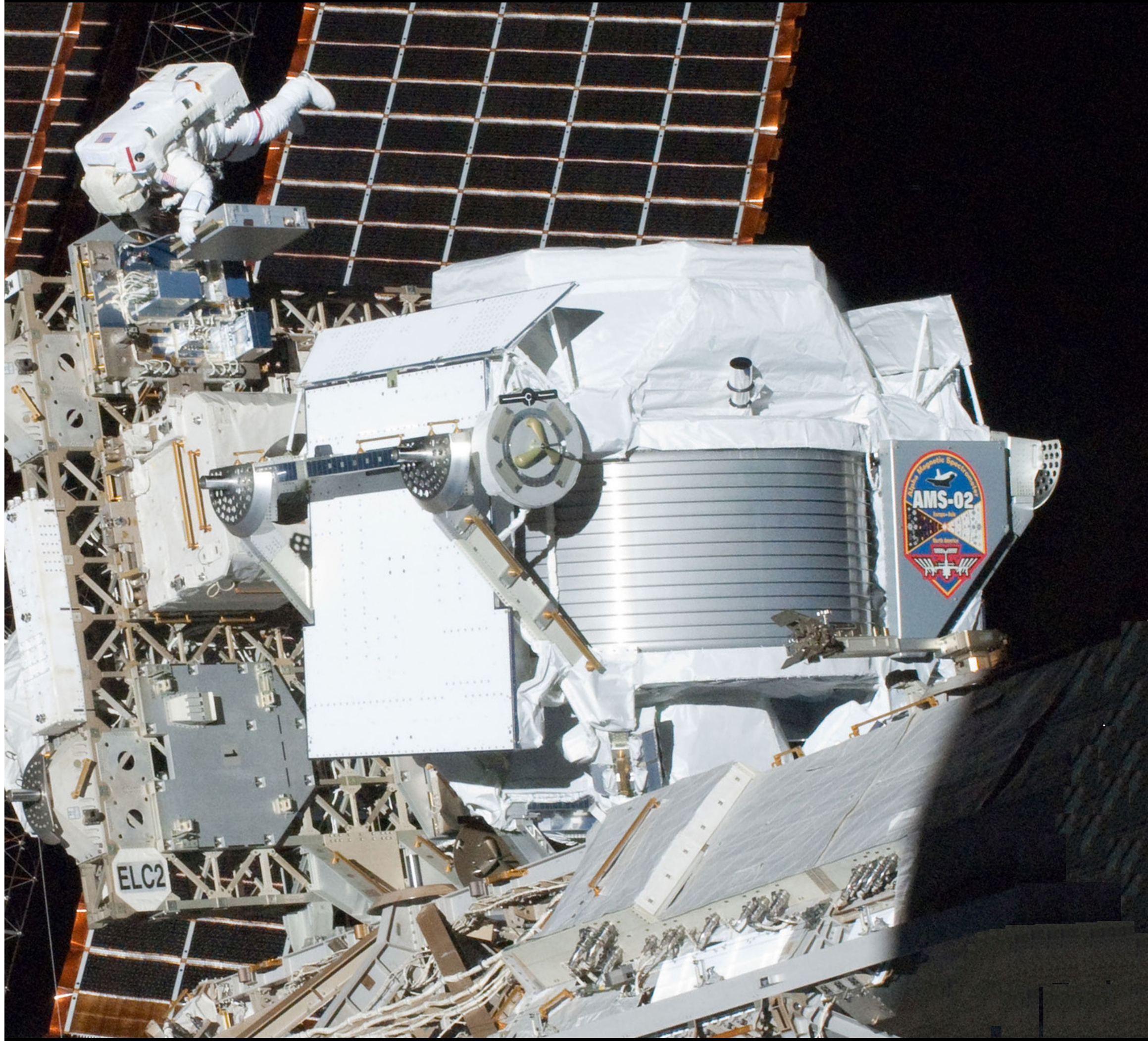
Heavy Anti-matter has never been found

AMS – a Direct Search for Antimatter

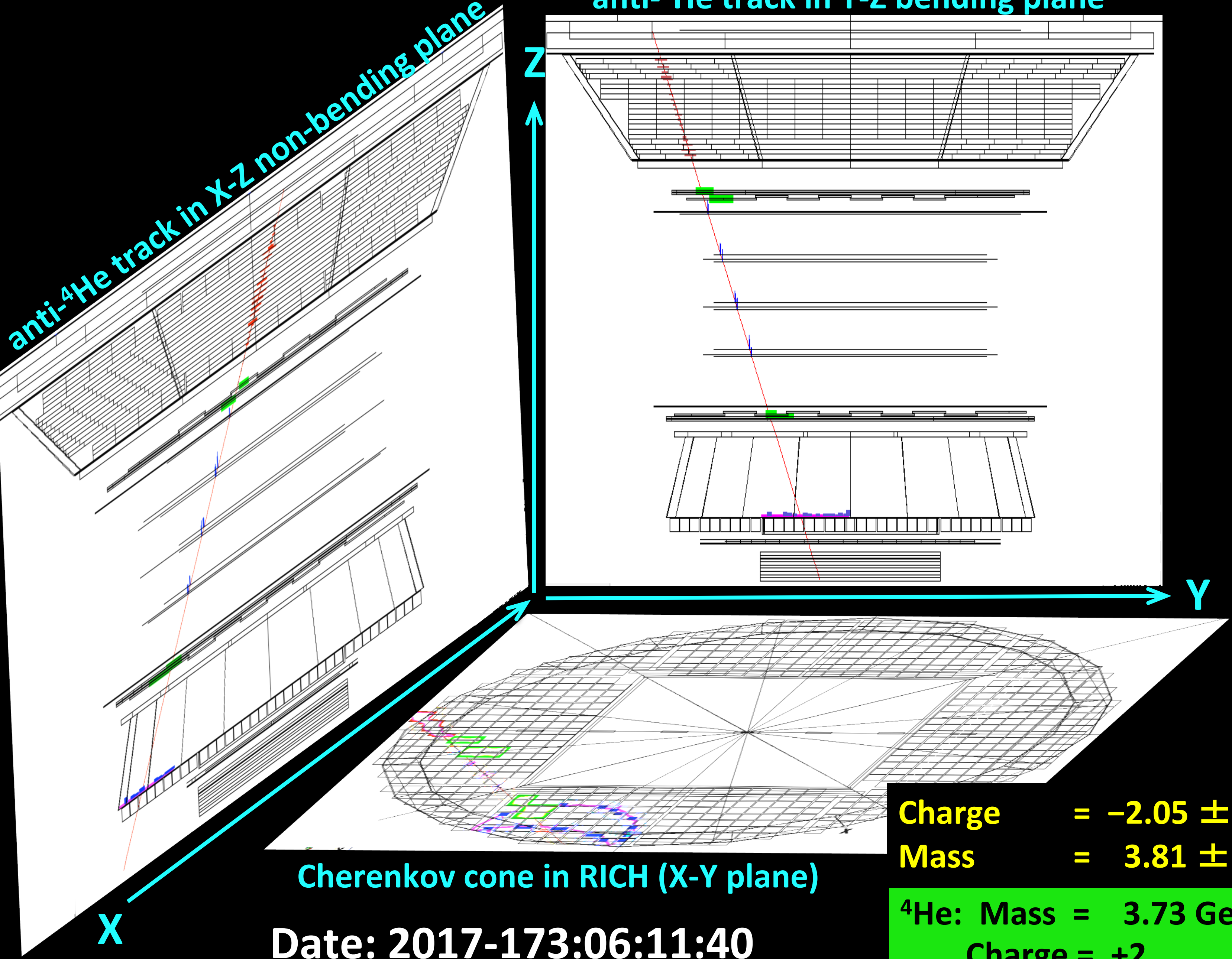


Air and Space
Smithsonian Institution, May 2001

y02K042b



Observation of anti-He events



anti-^{4}He track in X-Z non-bending plane

anti-^{4}He track in Y-Z bending plane

Cherenkov cone in RICH (X-Y plane)

Date: 2017-173:06:11:40

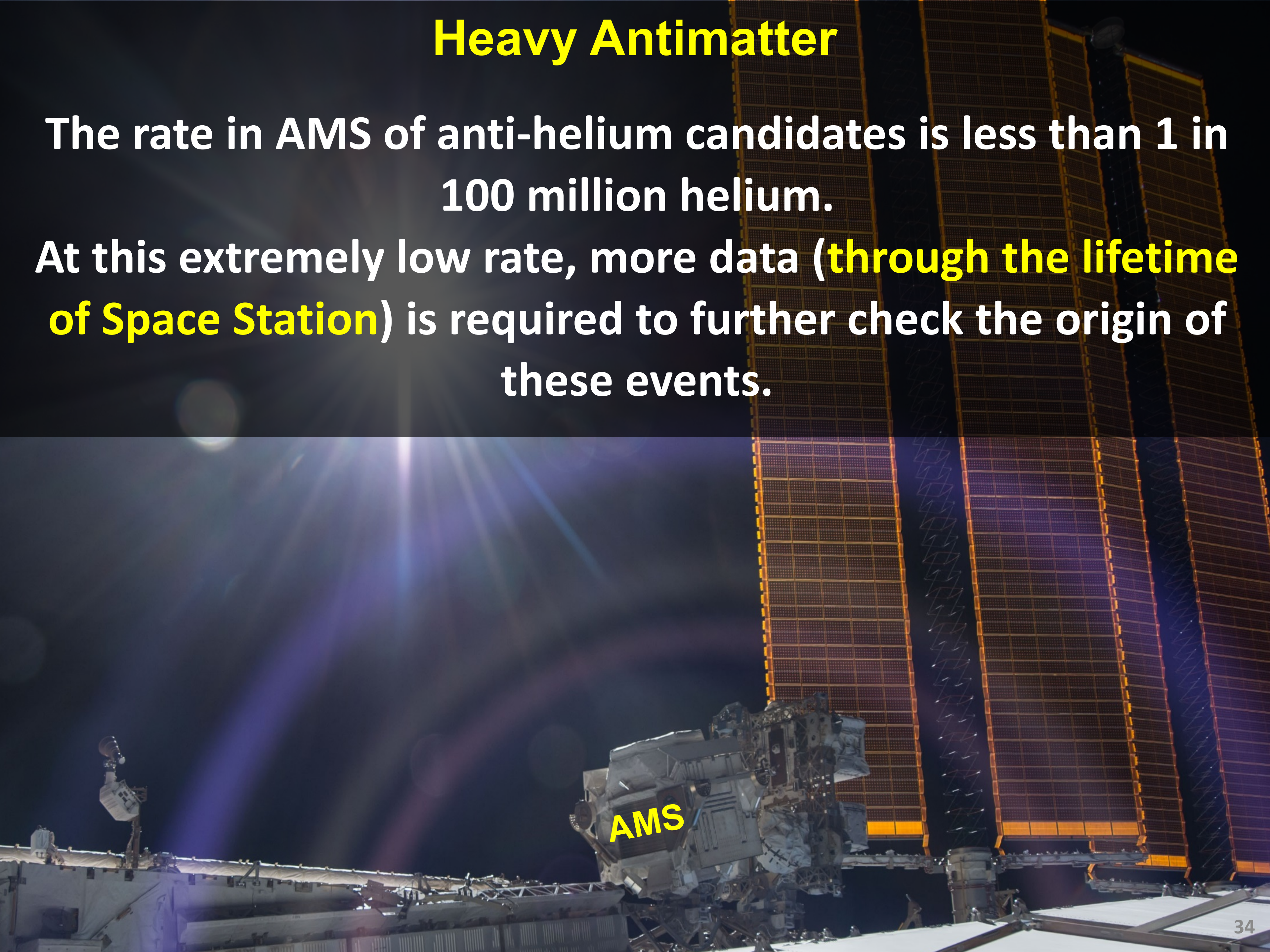
Charge = -2.05 ± 0.05
Mass = 3.81 ± 0.29 GeV/c^2

^{4}He: Mass = 3.73 GeV/c^2
Charge = +2

Heavy Antimatter

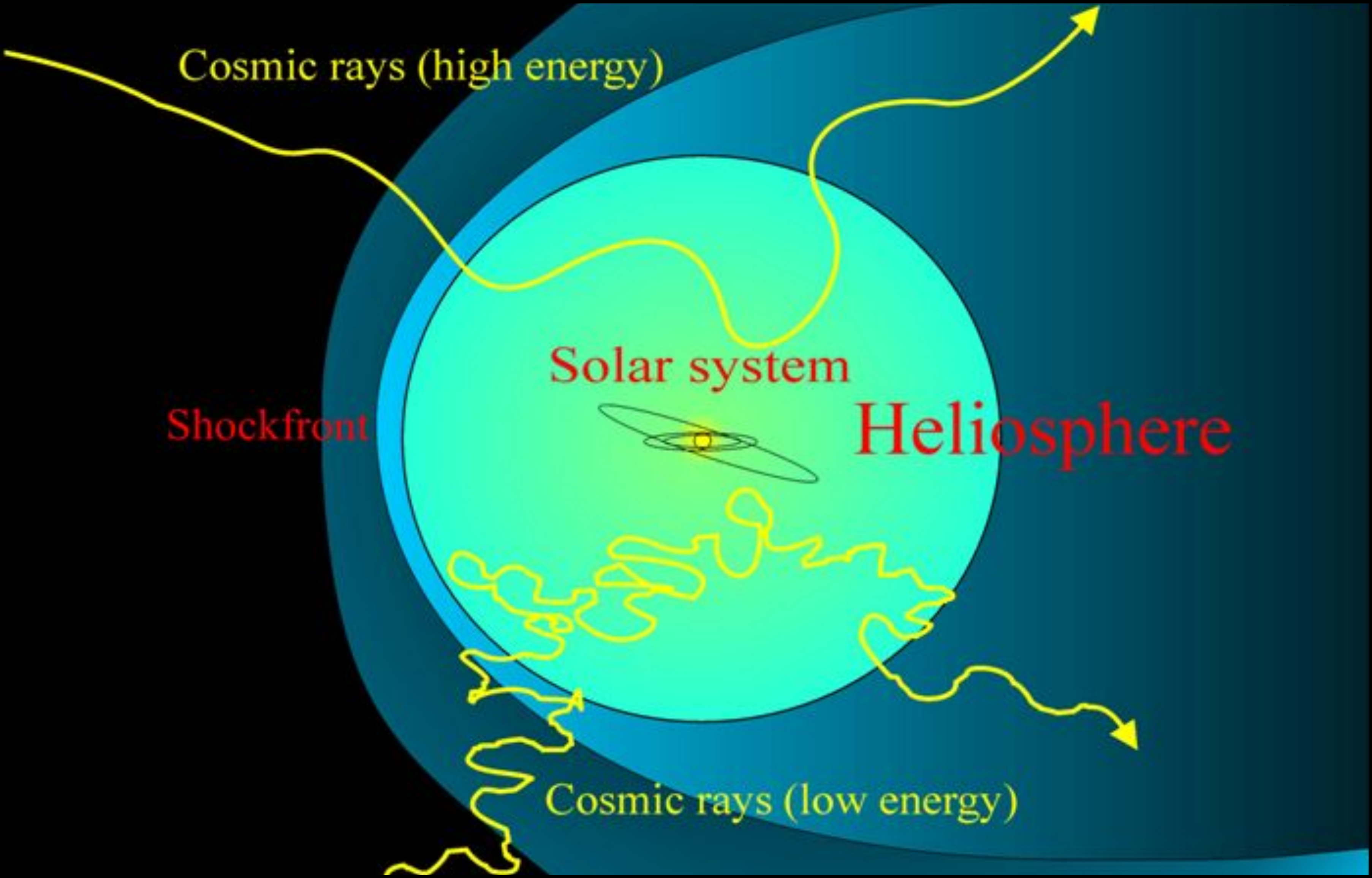
The rate in AMS of anti-helium candidates is less than 1 in 100 million helium.

At this extremely low rate, more data (through the lifetime of Space Station) is required to further check the origin of these events.



AMS Physics in the lifetime of ISS:

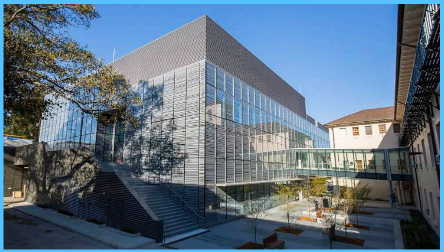
Space radiation over a complete solar cycle (2011 – 2028)



Radiation from Cosmic Rays is ~ 90 rem/y. The lethal dose is ~ 300 rem.
On Earth, the dose is ~0 because we are protected by

I. Earth’s magnetic field
500,000 Gm

II. 100 km of air
=
10 m of water



Sydney Nanoscience Hub

III. Earth’s Shadow

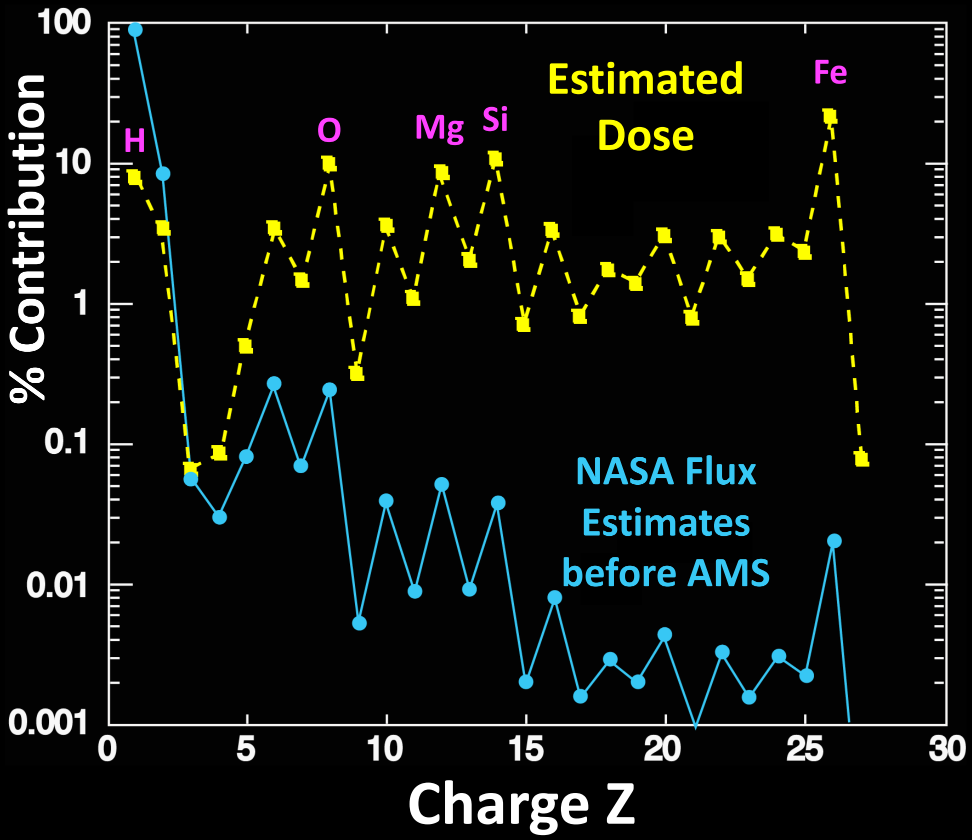
Application of AMS Solar Physics Results:

Radiation Effects and Protection for Moon and Mars Missions

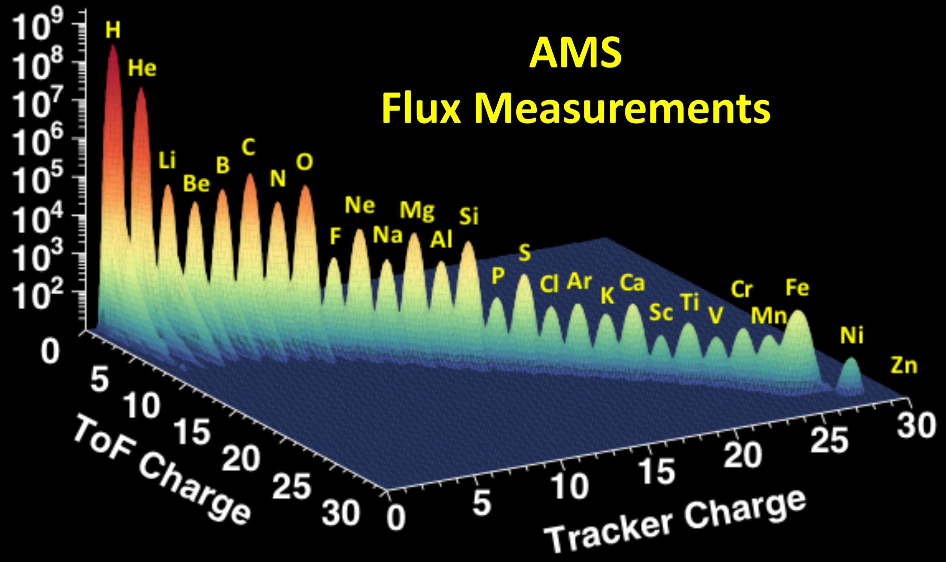
Thomas A. Parnell (MSFC), Jon W. Watts Jr. (MSFC), and Tony W. Armstrong (SAIC)

Sixth ASCE Specialty Conference and Exposition on Engineering, Construction, and Operations in Space

Radiation Dose is proportional to Z^2.

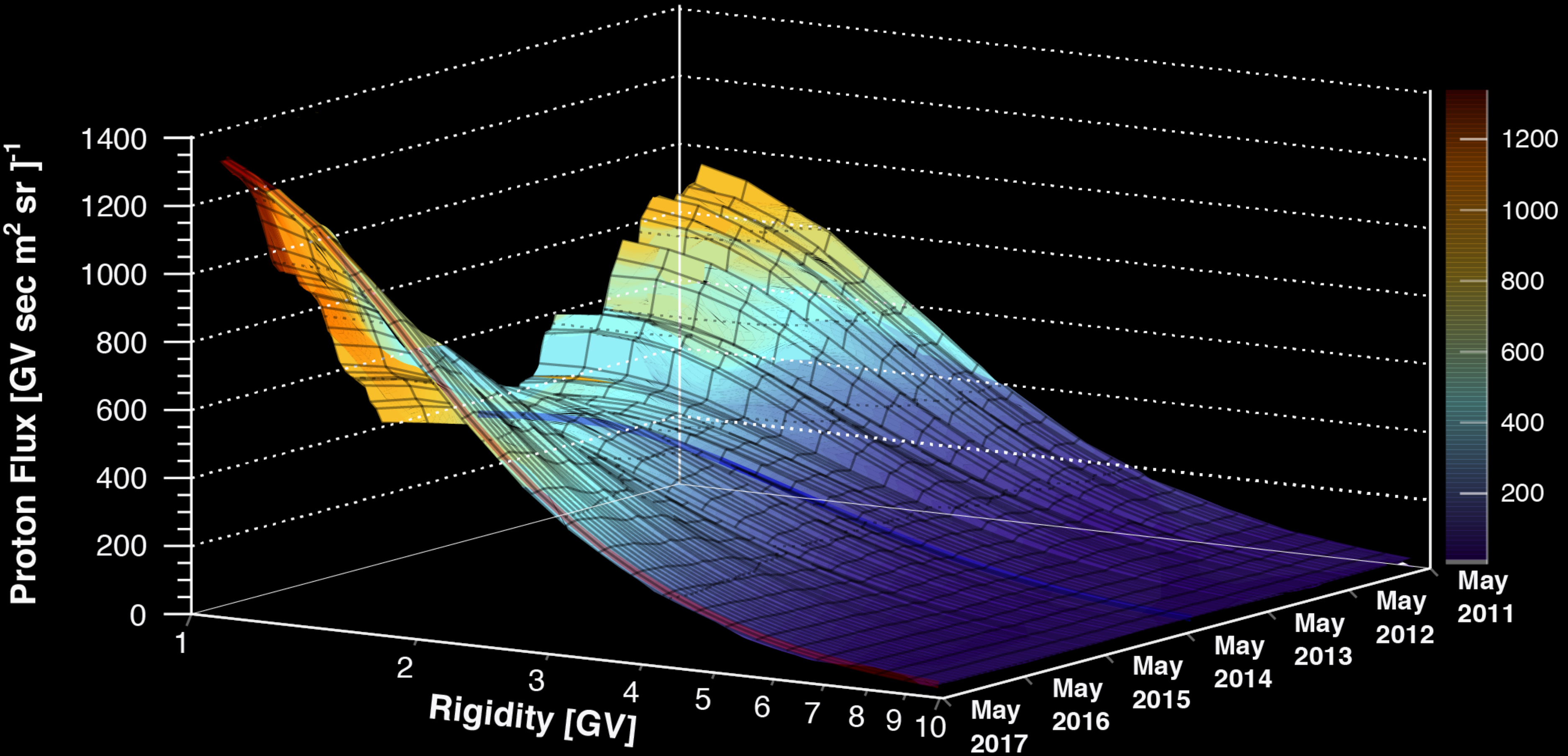


It is important to measure to the highest Z as a function of time and energy



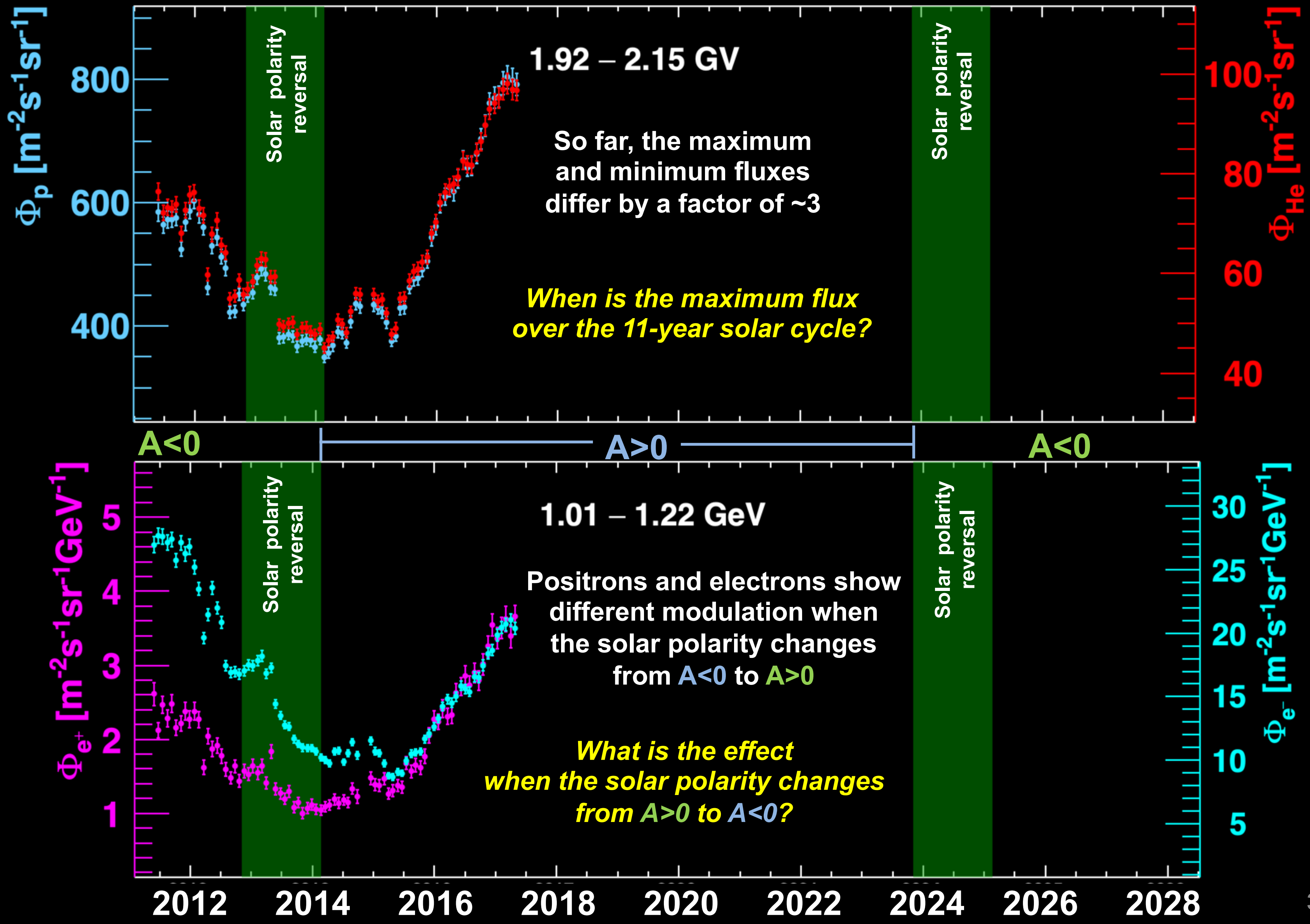
AMS Solar Physics Results:

Time and Energy Variation of the Proton Flux



Protons and Helium: PRL 121 (2018) 051101
Electrons and Positrons: PRL 121 (2018) 051102

Solar physics over a complete 11-year solar cycle



So far, the maximum and minimum fluxes differ by a factor of ~3

When is the maximum flux over the 11-year solar cycle?

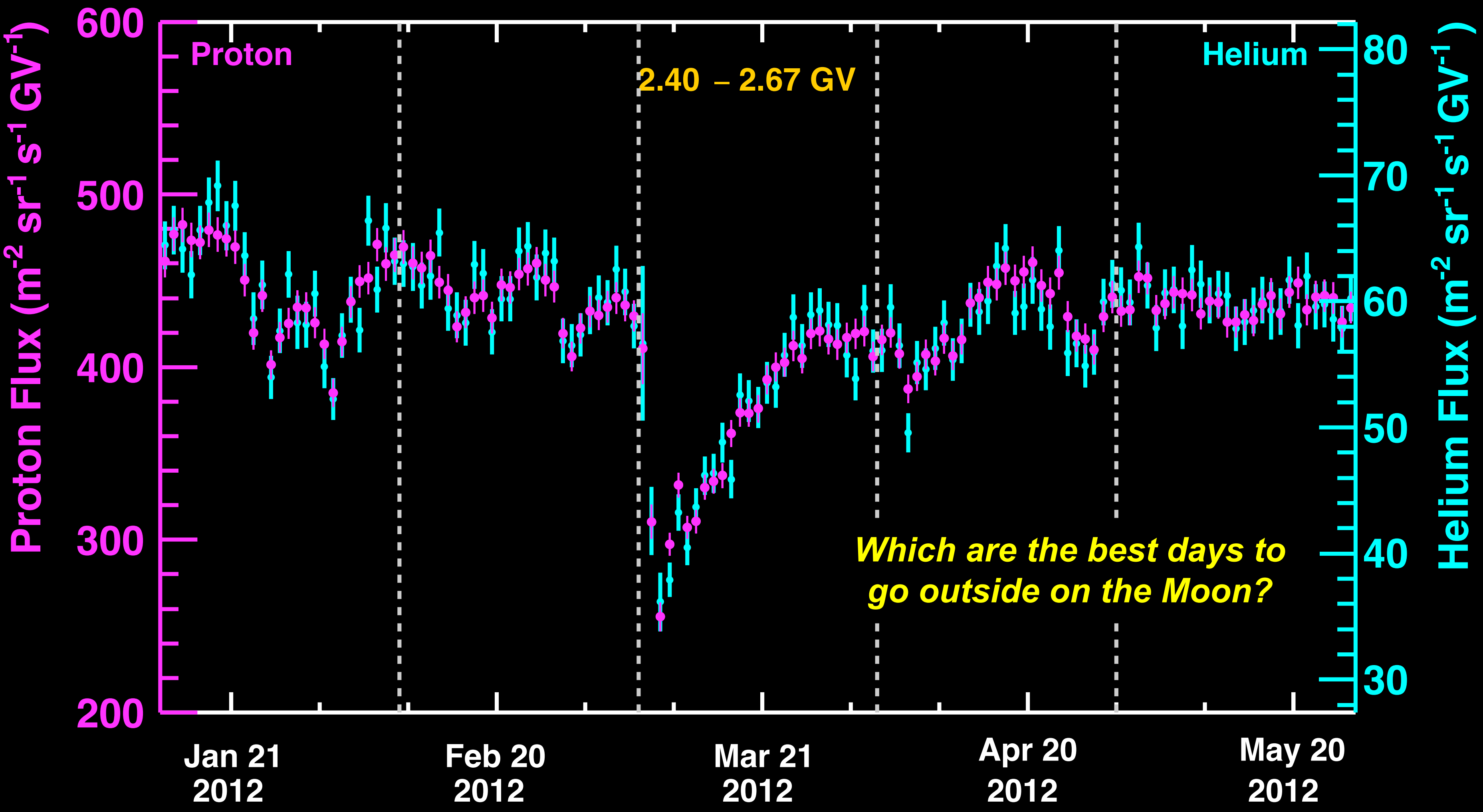
Positrons and electrons show different modulation when the solar polarity changes from A<0 to A>0

What is the effect when the solar polarity changes from A>0 to A<0?

Solar physics – unexpected AMS result

Identical daily time variation of the p, He fluxes

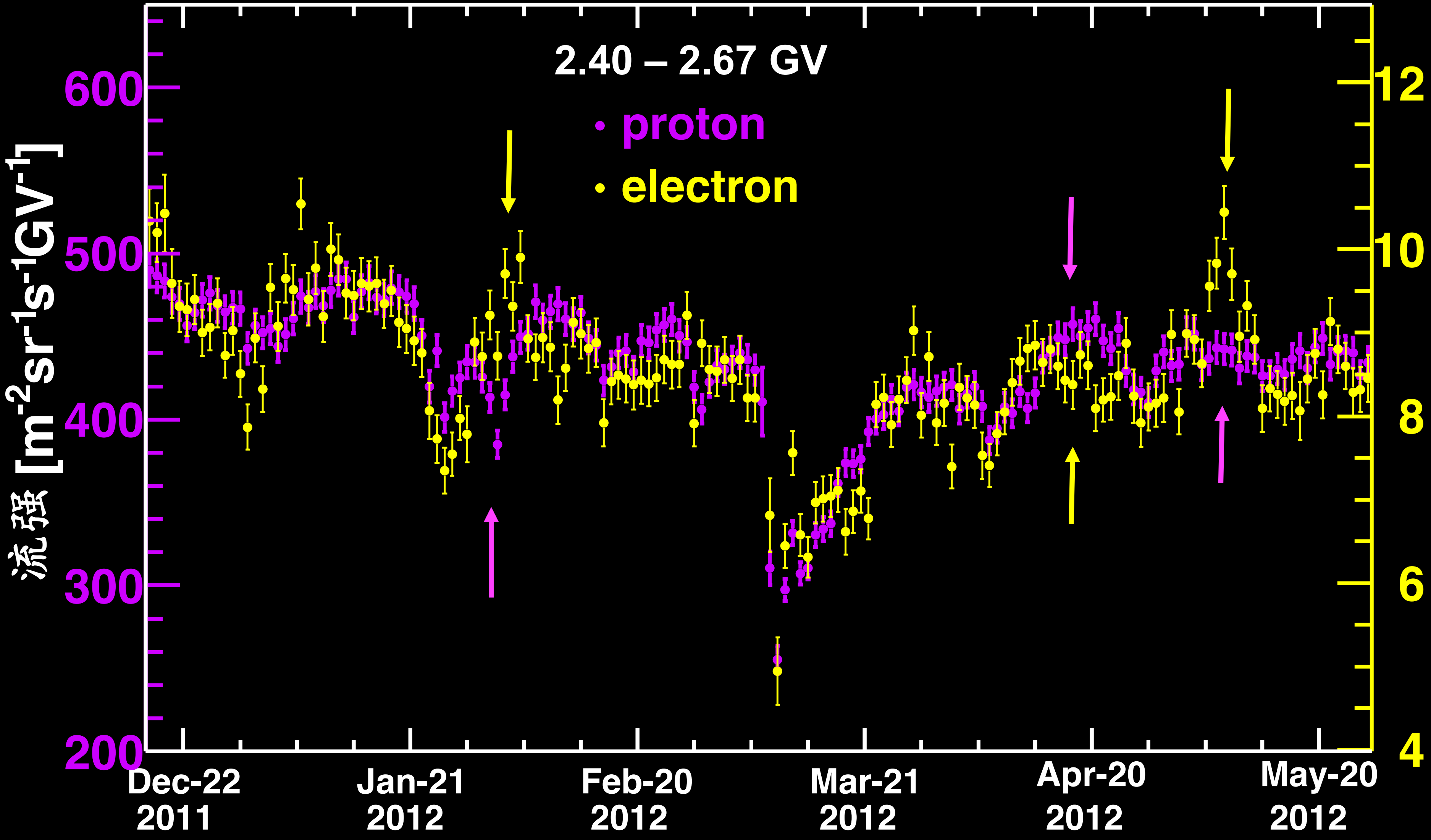
Day by day, the flux can change quickly.



Which are the best days to go outside on the Moon?

Unexpected AMS Results:

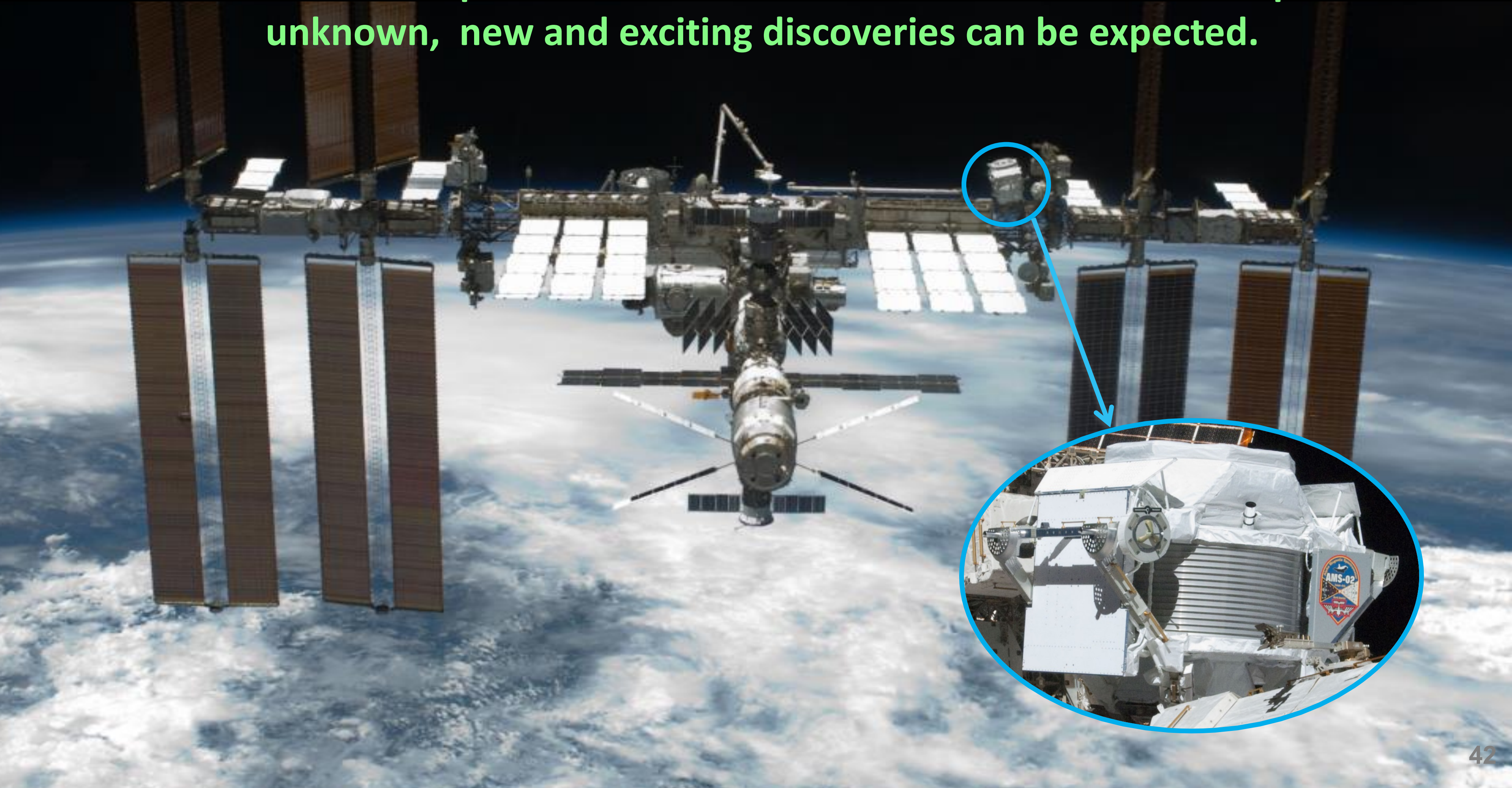
Proton and electron have different time variation during some particular periods.



The accuracy and characteristics of the AMS data on many different types of cosmic rays require the development of a comprehensive theory of the universe.

AMS is the only magnetic spectrometer in space for the foreseeable future

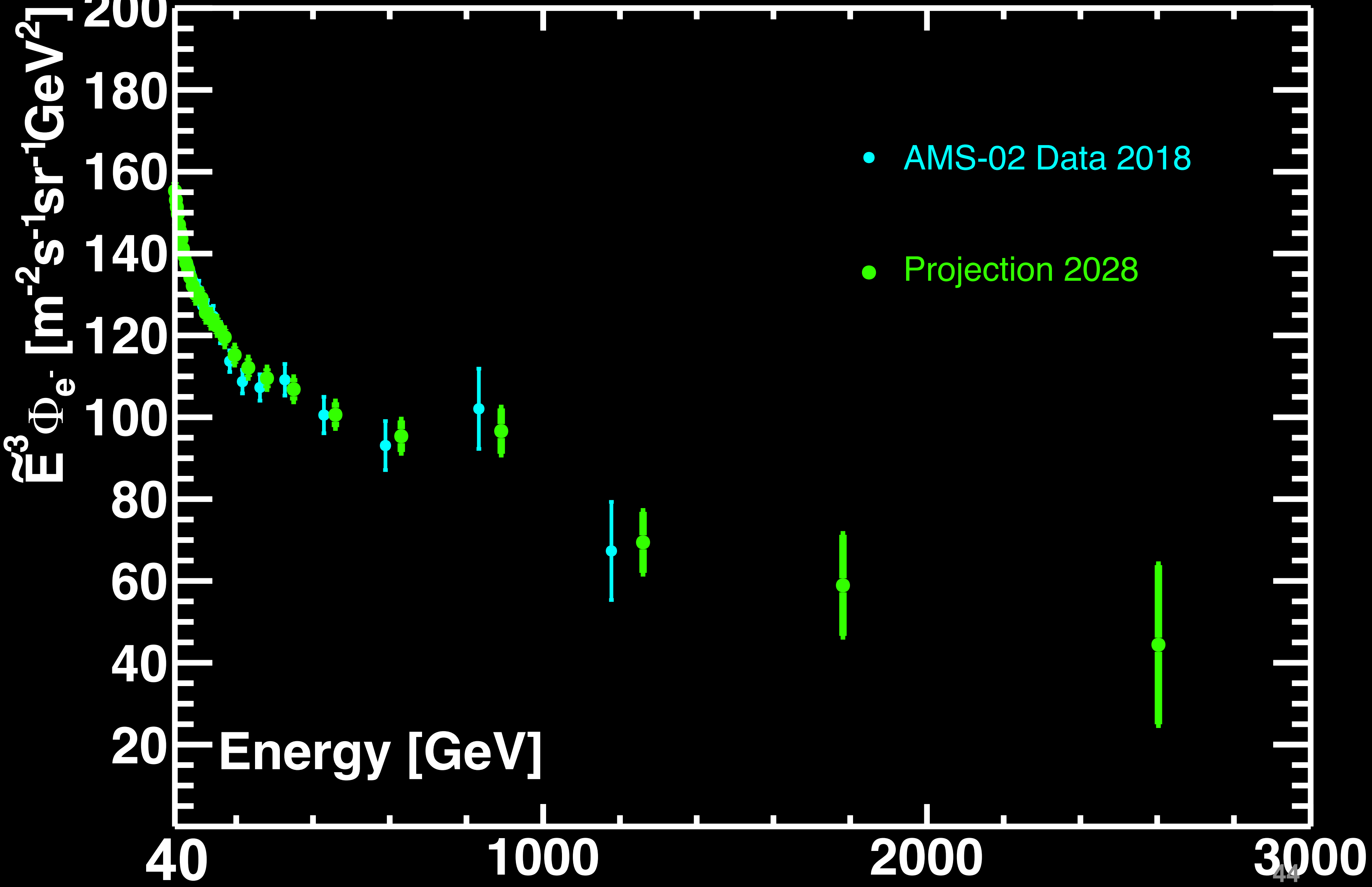
AMS will continue to collect and analyze data for the lifetime of the Space Station because whenever a precision instrument such as AMS is used to explore the unknown, new and exciting discoveries can be expected.



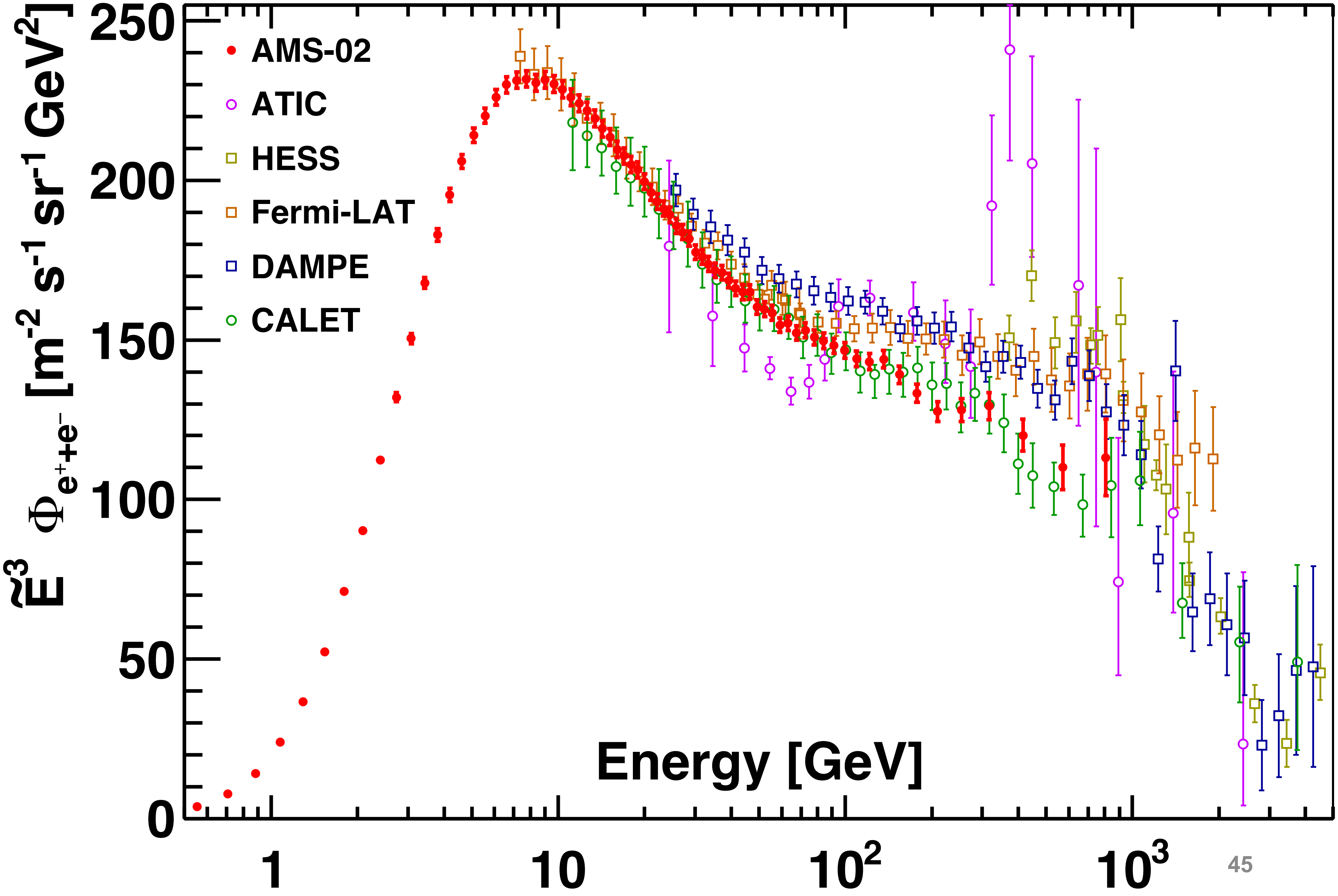
Physics of cosmic electrons to 2028

What is the origin of power law a and power law b?

Is there a cutoff for electrons at higher energies?

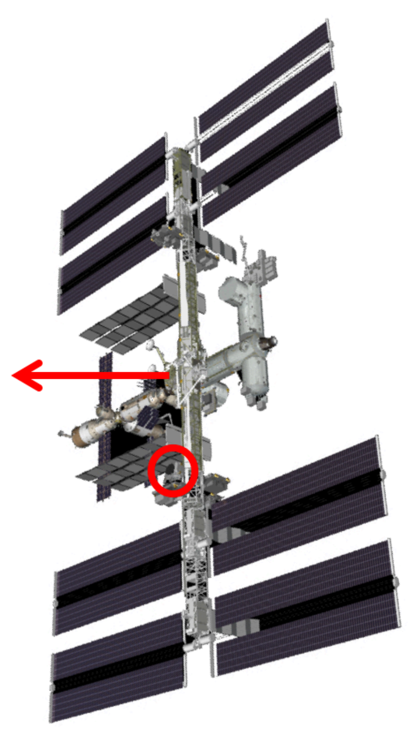


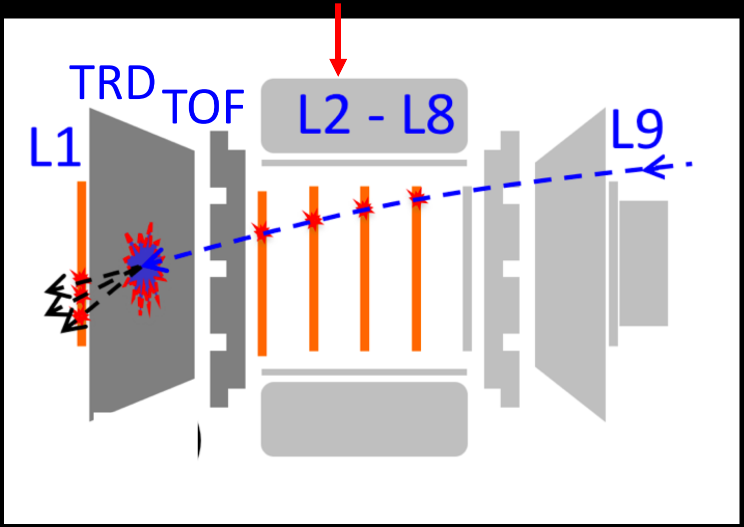
AMS (electron + positron) spectrum with earlier measurements



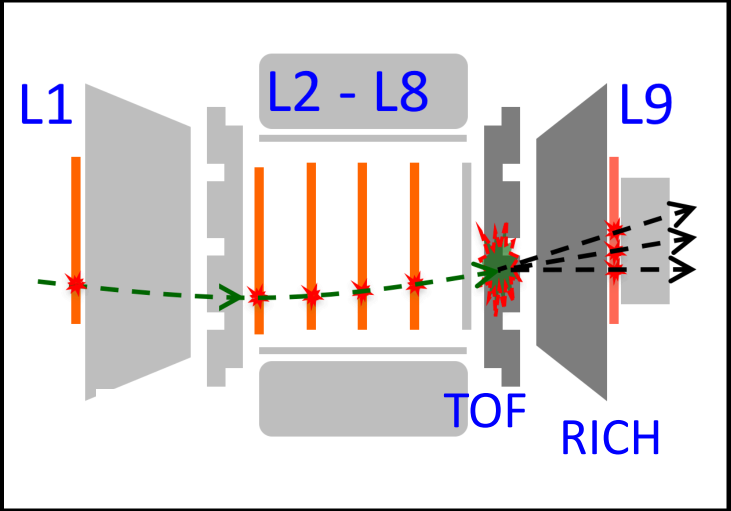
The precision of AMS:
measuring the nuclear interaction cross sections

Define beams of nuclei: He, C, O, …



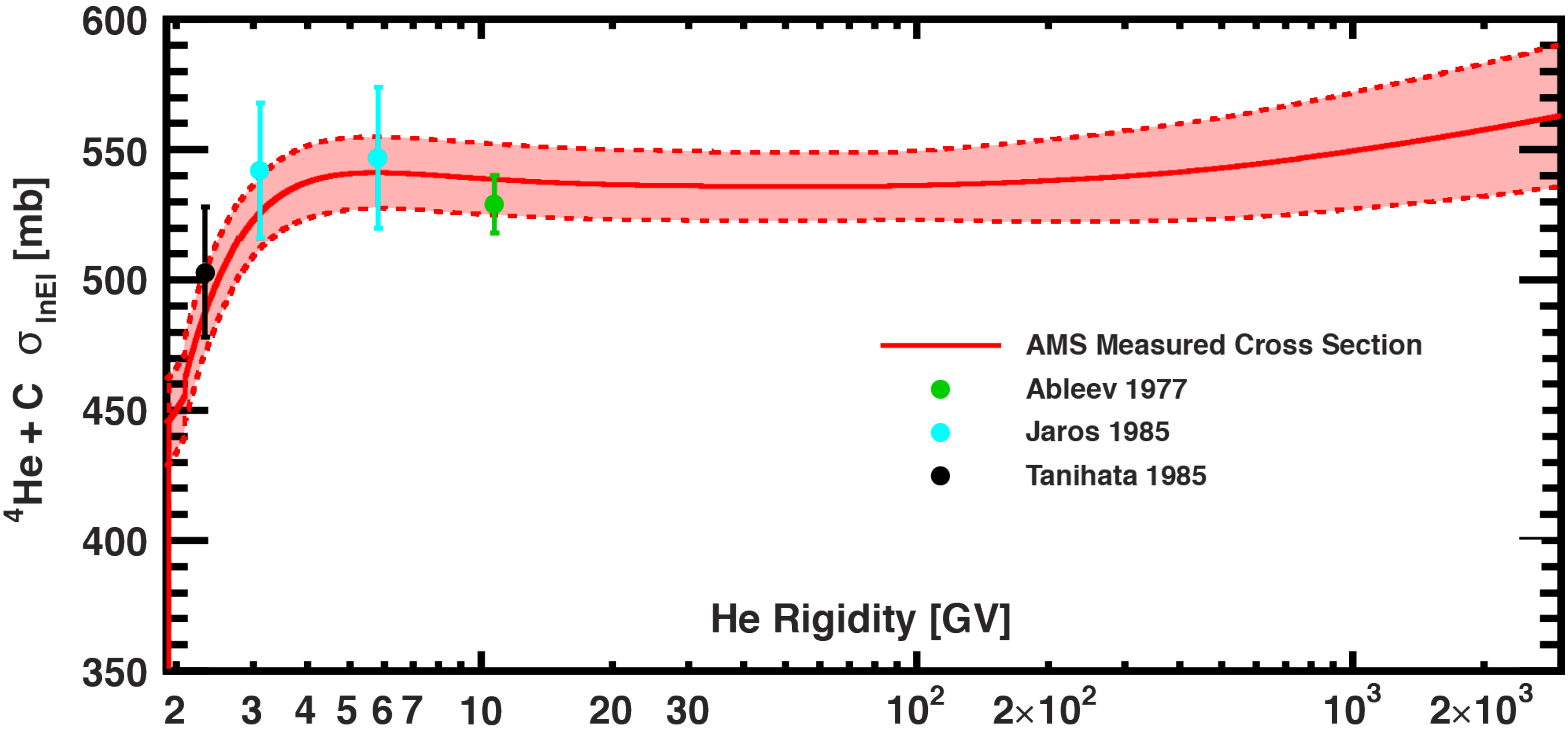


Use right-to-left nuclei to measure the nuclear interactions in the TRD+TOF

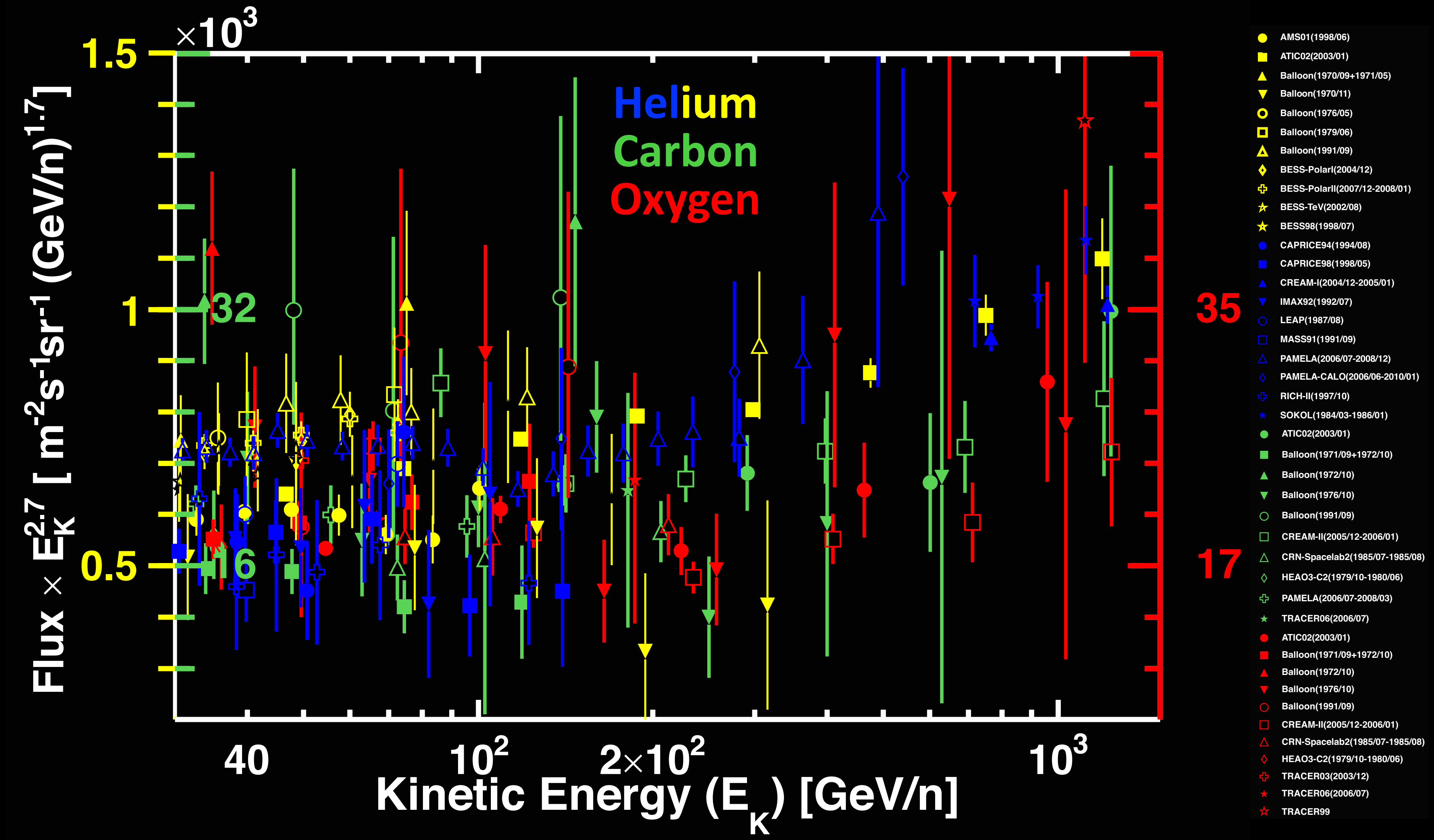


Use left-to-right nuclei to measure the nuclear interactions in the TOF+RICH

AMS Measurement of He Cross Section



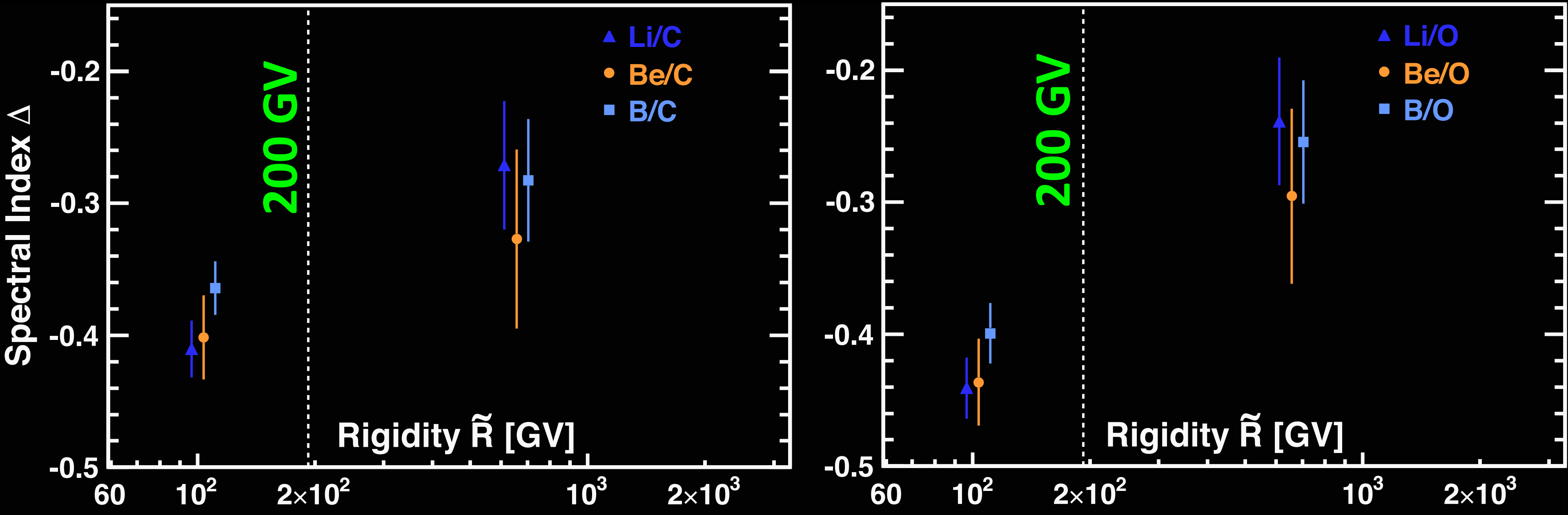
Before AMS there were many results on Primary Cosmic Rays (Helium, Carbon, Oxygen) from balloon and satellite experiments



AMS Latest Results:

The Secondary/Primary Ratios ≠ kR^{Δ}

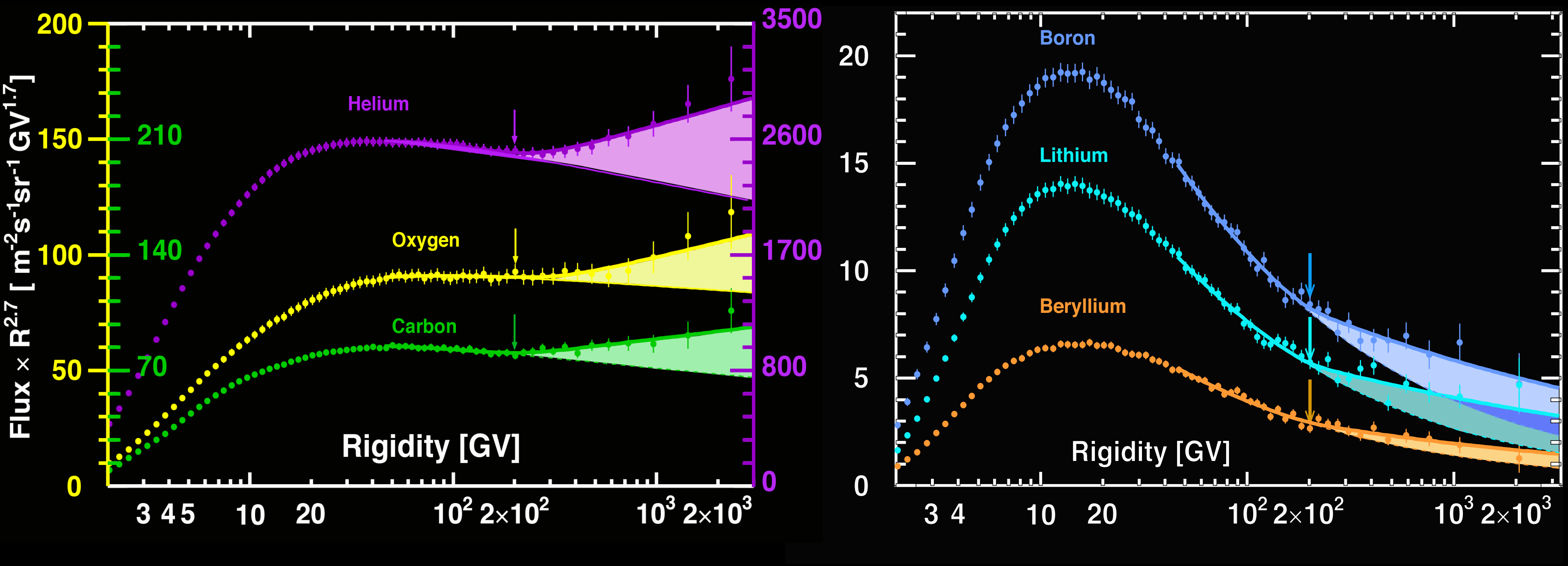
Δ is not a constant



This AMS data provides new and unexpected information on the interstellar medium

AMS physics in the lifetime of ISS :

The measured spectra of Cosmic Rays break at ~200 GV.



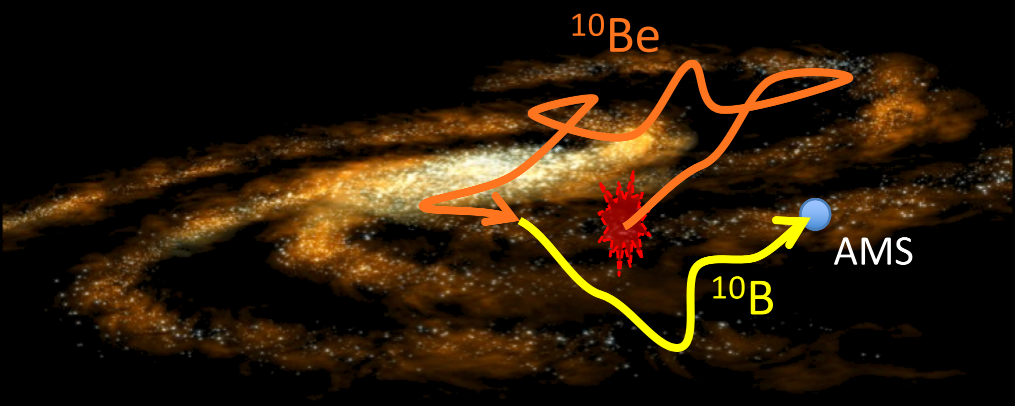
Is there a break for all the elements?
Why?

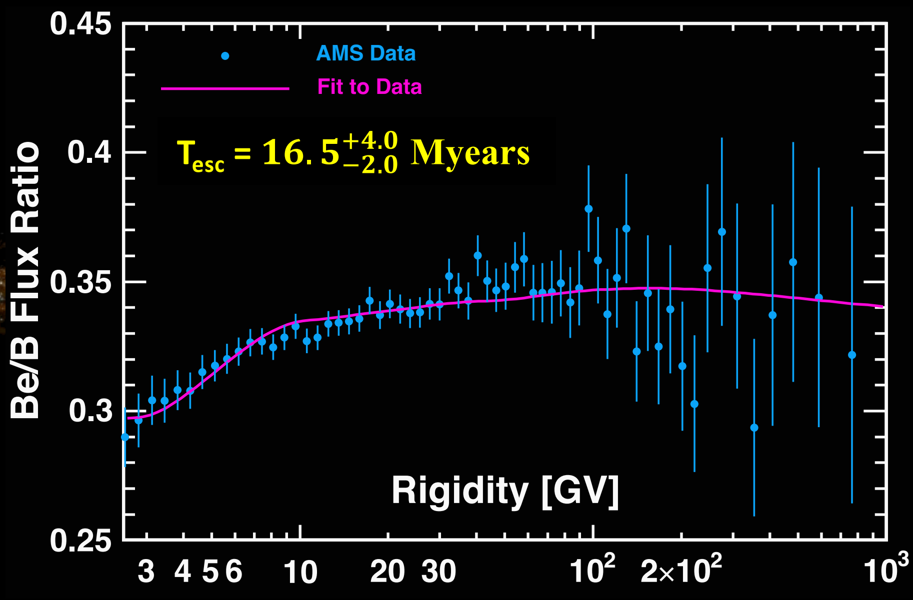
AMS physics in the lifetime of ISS : How old are cosmic rays?

^{10}Be decays with a half-life of 1.5×10^{6} years: $^{10}\mathrm{Be} \rightarrow {}^{10}\mathrm{B} + e^{-} + \nu_e$.

The Be/B ratio is rising with energy due relativistic time dilation.

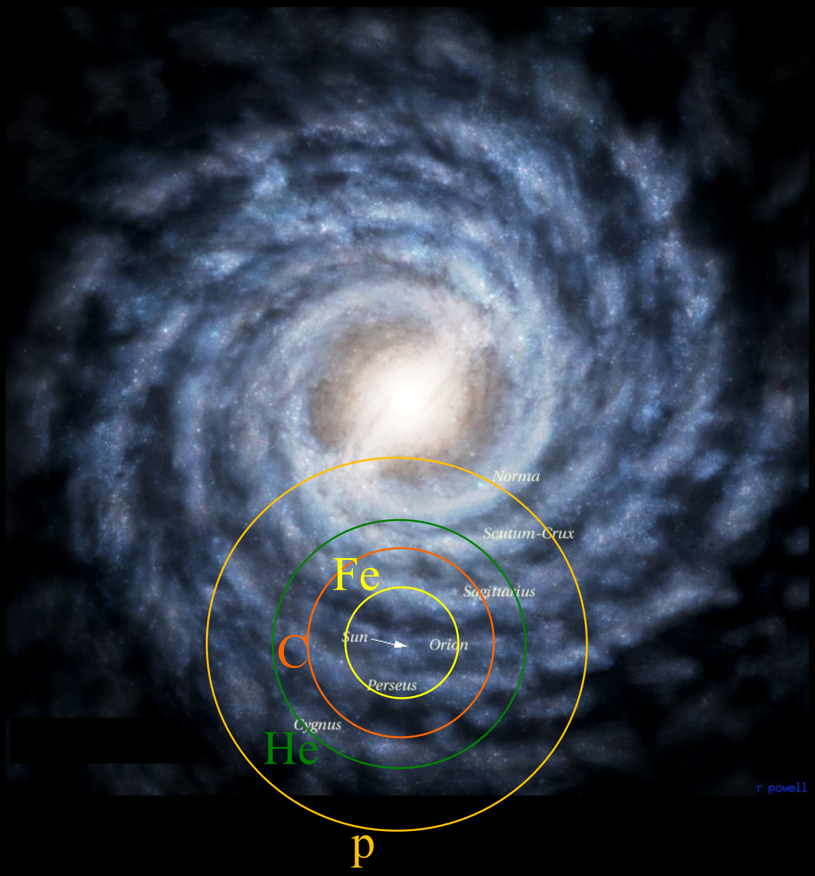
Be/B provides information on the propagation time in the Galaxy.





The measurements of radioactive Aluminum (Z=13), Chlorine (Z=17), and Manganese (Z=25) spectra will precisely establish the age of cosmic rays.

AMS physics in the lifetime of ISS :
How do cosmic rays propagate in the Galaxy?



Effective distance is shown for ~1 GV.

Effective propagation distance

$$\propto R^{-\Delta/2} A^{-1/3}$$

i. Different nuclei A (1 - 60) probe different distances.

ii. Different rigidities R (1 – 3000 GV) probe different distances

From: "garisto@aps.org" <garisto@aps.org>

Editor, Physical Review Letters

Subject: First AMS paper chosen for a ten year retrospective of PRL Editors' Suggestions

Date: April 20, 2017 at 4:49:57 PM GMT+2

… Other papers we have already commemorated in this way include the discovery of element 117, and the observation of gravitational waves by LIGO.

Cheers,
Robert