Alpha Magnetic Spectrometer Experiment on ISS

IV International Conference on Particle Physics and Astrophysics
Moscow, Russia

24 October 2018

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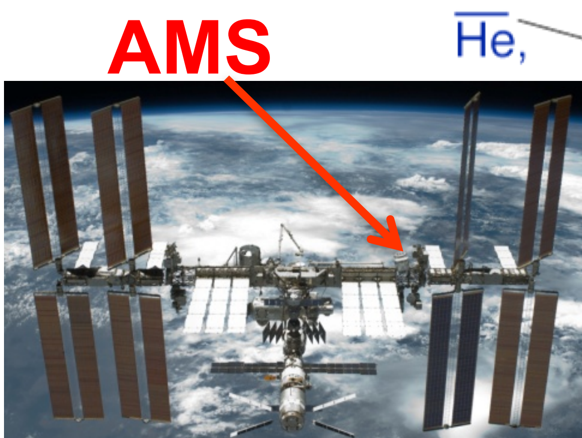
S. Ting

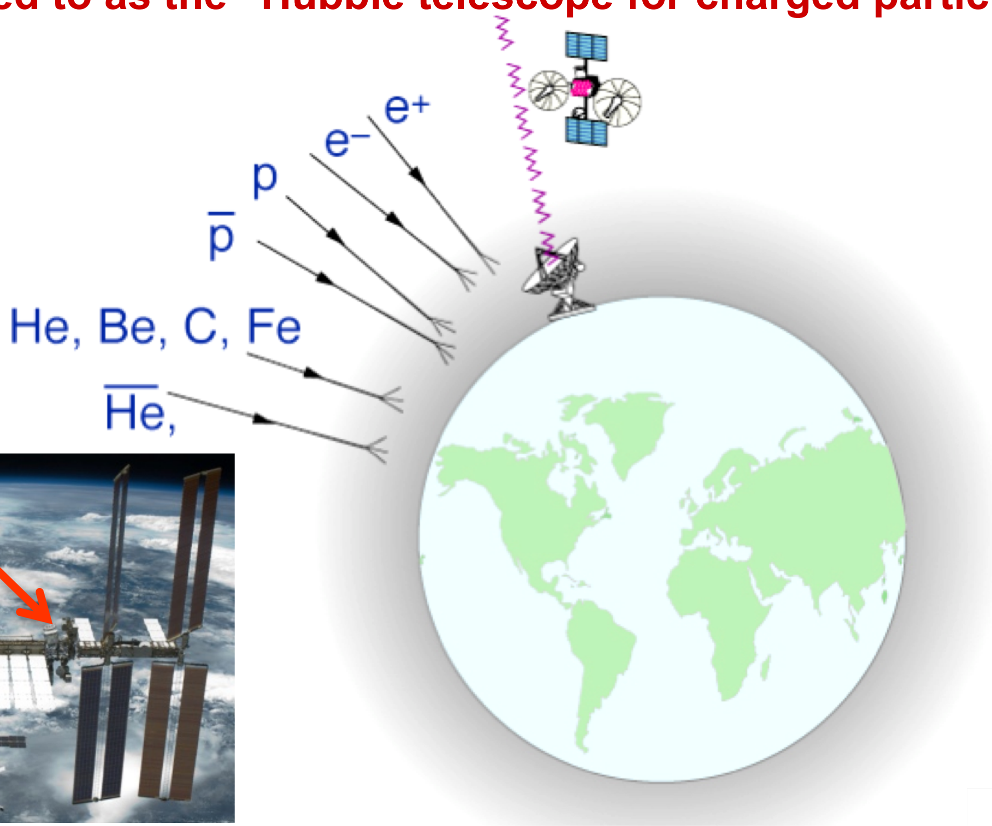
Fundamental Science on the International Space Station (ISS)

There are two kinds of cosmic rays traveling through space

1- Neutral cosmic rays (light rays and neutrinos):
Light rays have been measured (e.g., Hubble) for over 50 years.
Fundamental discoveries have been made.

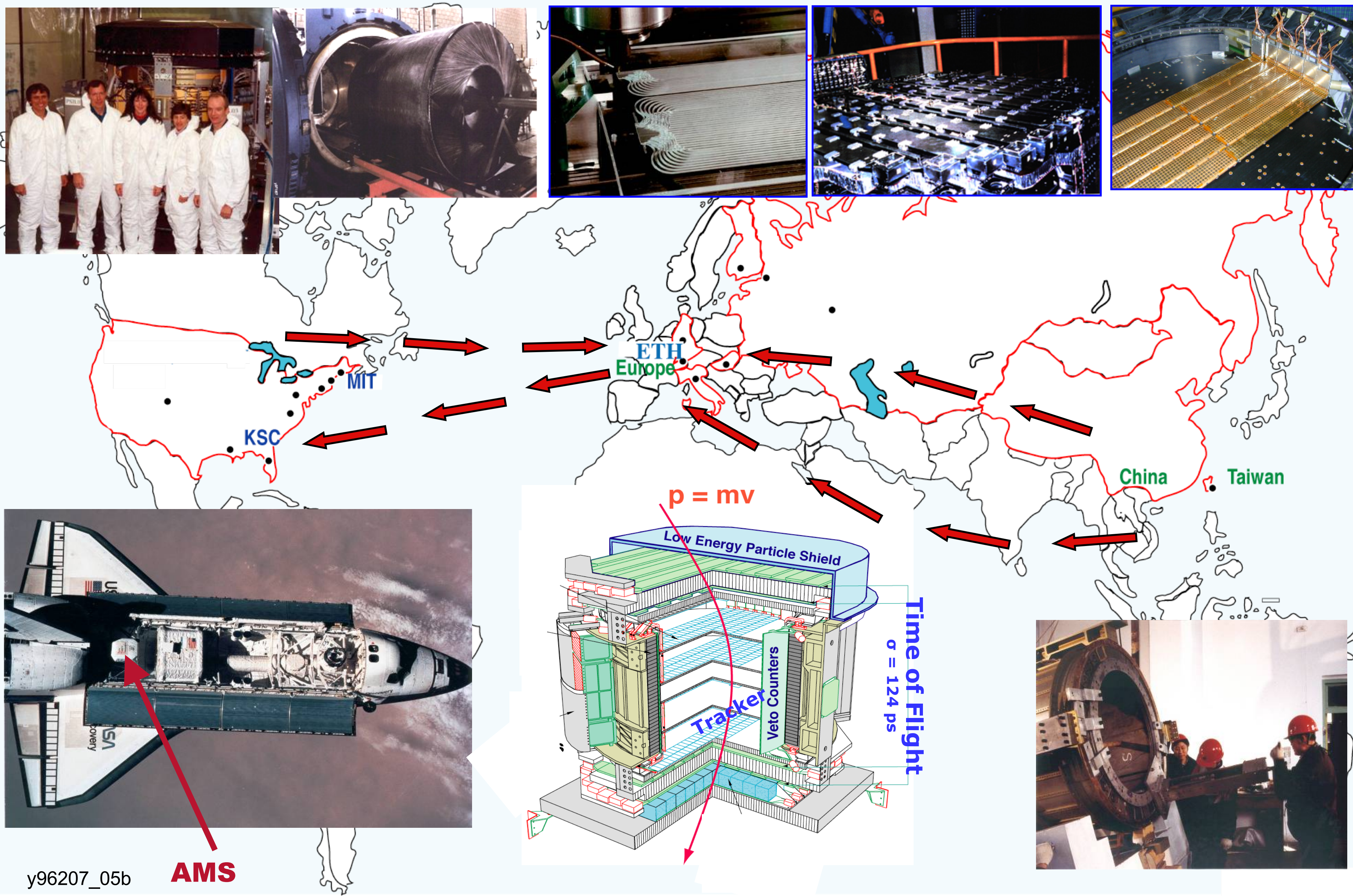
2- Charged cosmic rays: A new region in science. Using a magnetic spectrometer (AMS) on ISS is the only way to provide precision long term (20 years) measurements of high energy charged cosmic rays.
AMS is often referred to as the "Hubble telescope for charged particles".





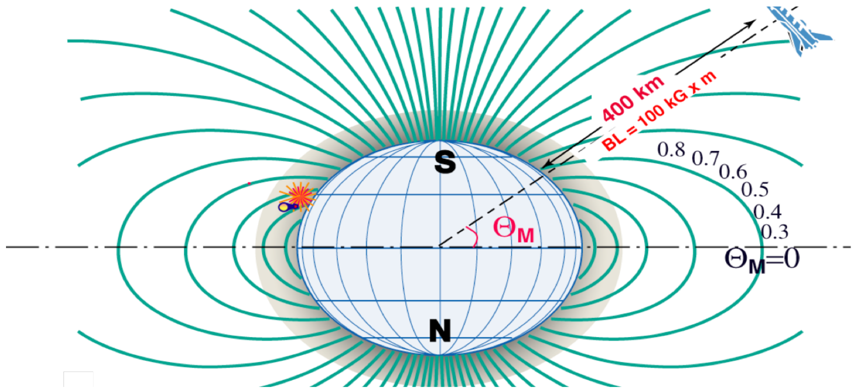
First flight AMS-01

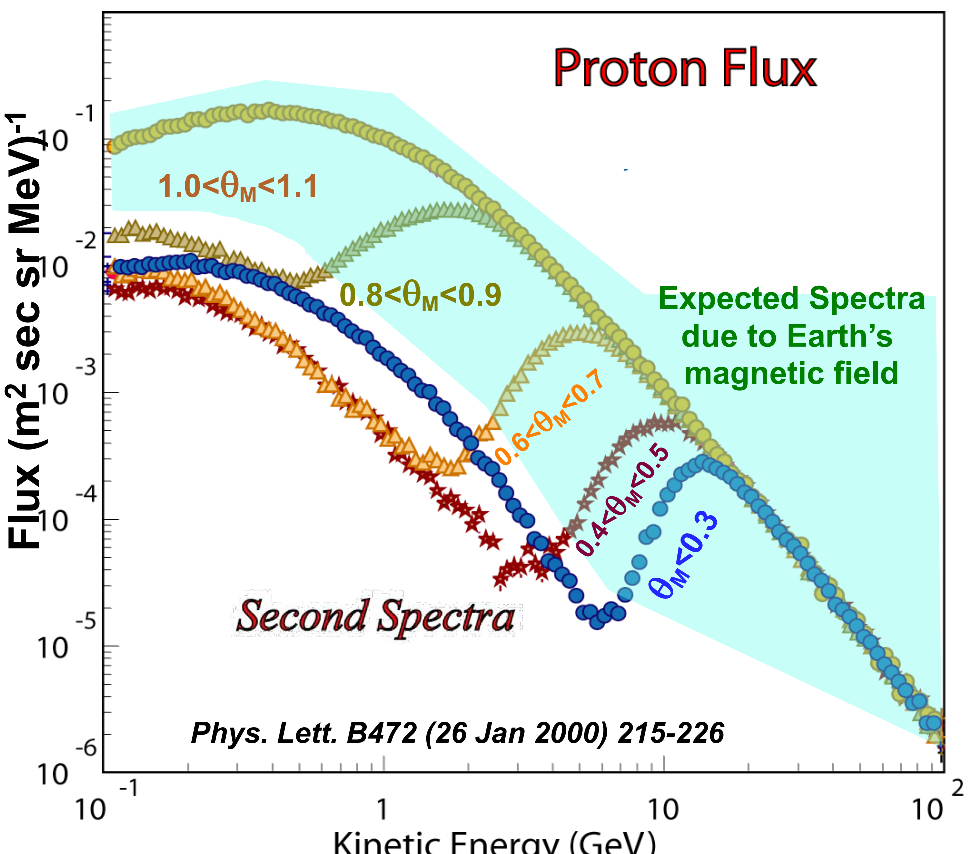
Approval: April 1995, Assembly: December 1997, Flight: 10 days in June 1998



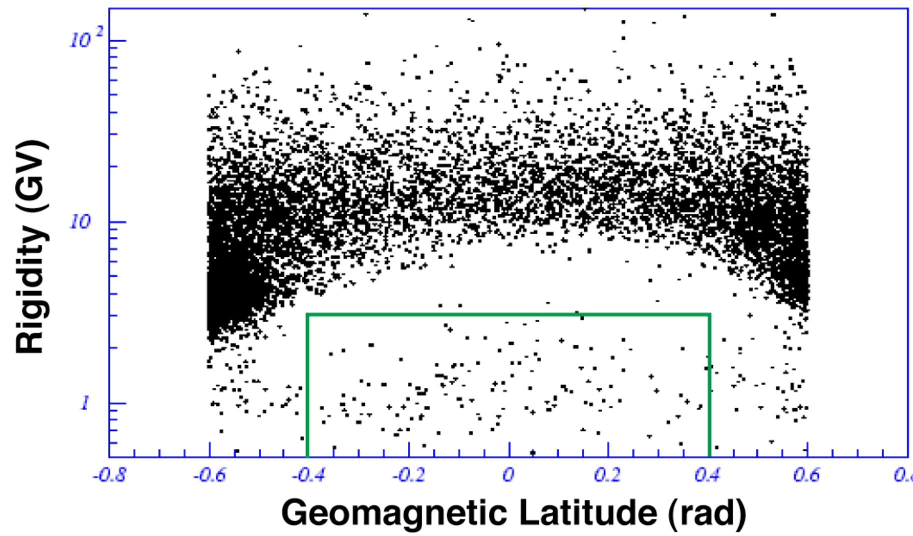
AMS-01 (1998) 10 Days Engineering Flight

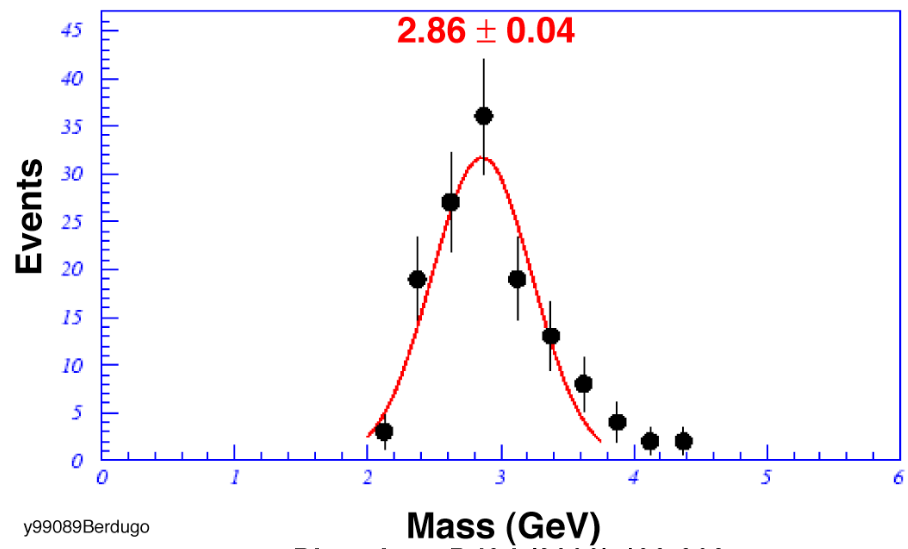
The existence of two Spectra in proton flux





He^4 and He^3 isotopes are completely separated in space





Phys. Lett. B494 (2000) 193-202

PAMELA 2006-2016

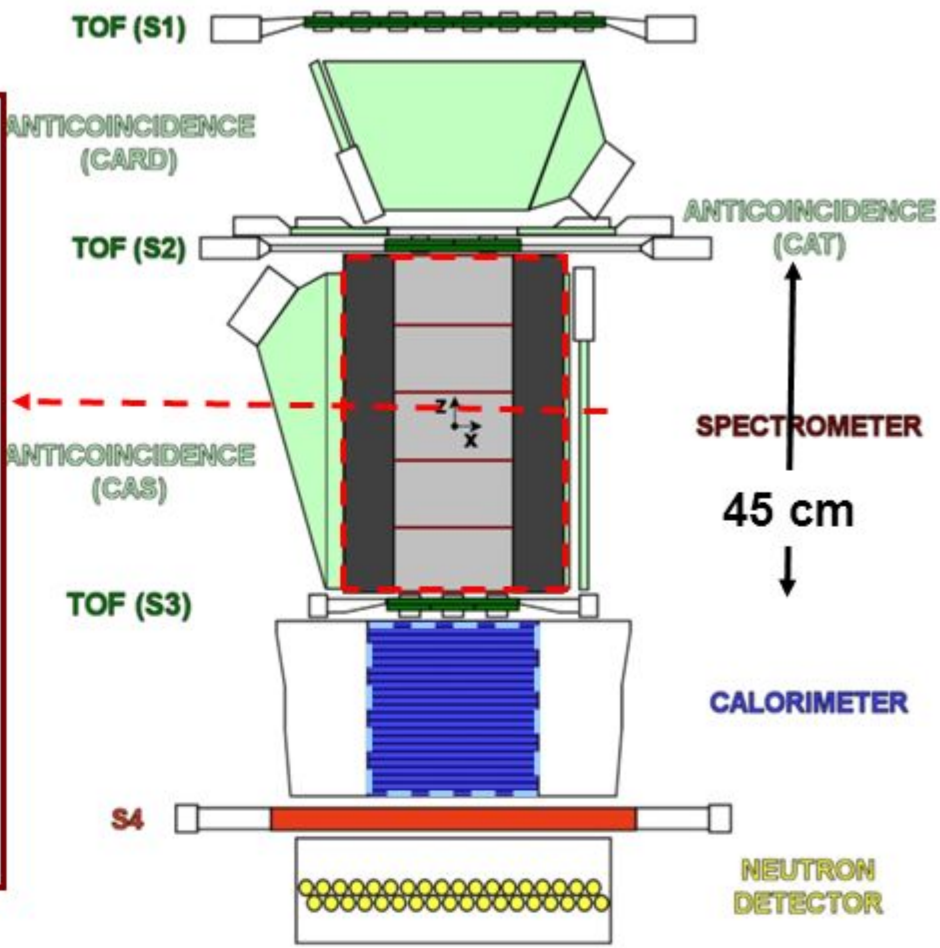
major contributions from Moscow Engineering and Physics Institute (MEPhI)
Professor Arkady Galper

Spectrometer:
Measures Rigidity R: R=p / Z·e

Permanent magnet:
•magnetic field ~ 0.45 T

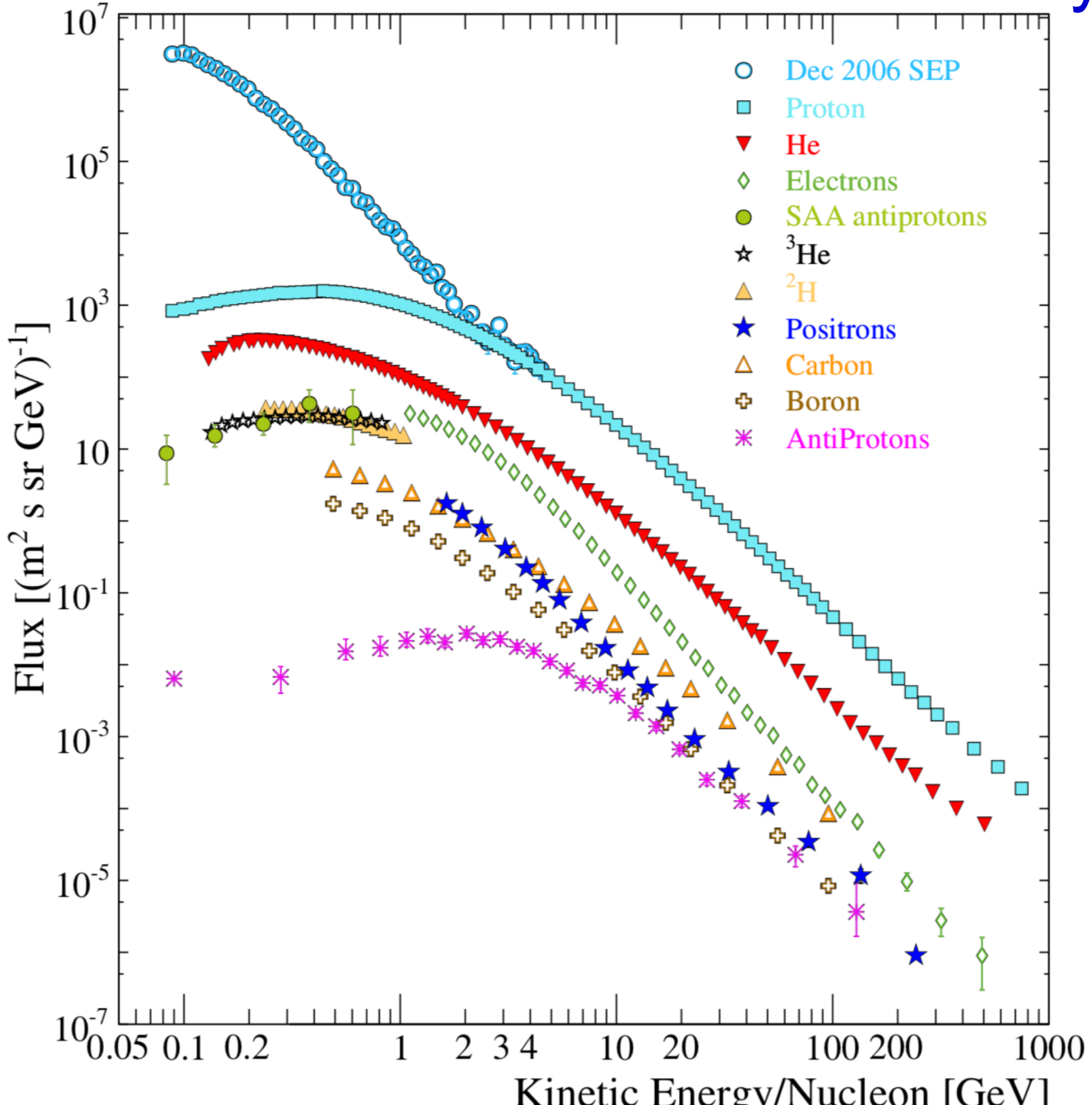
Si-microstrip tracking system:
•6 layers of silicon microstrip detectors
•3 µm resolution in bending view

→ MDR ~ 1 TV

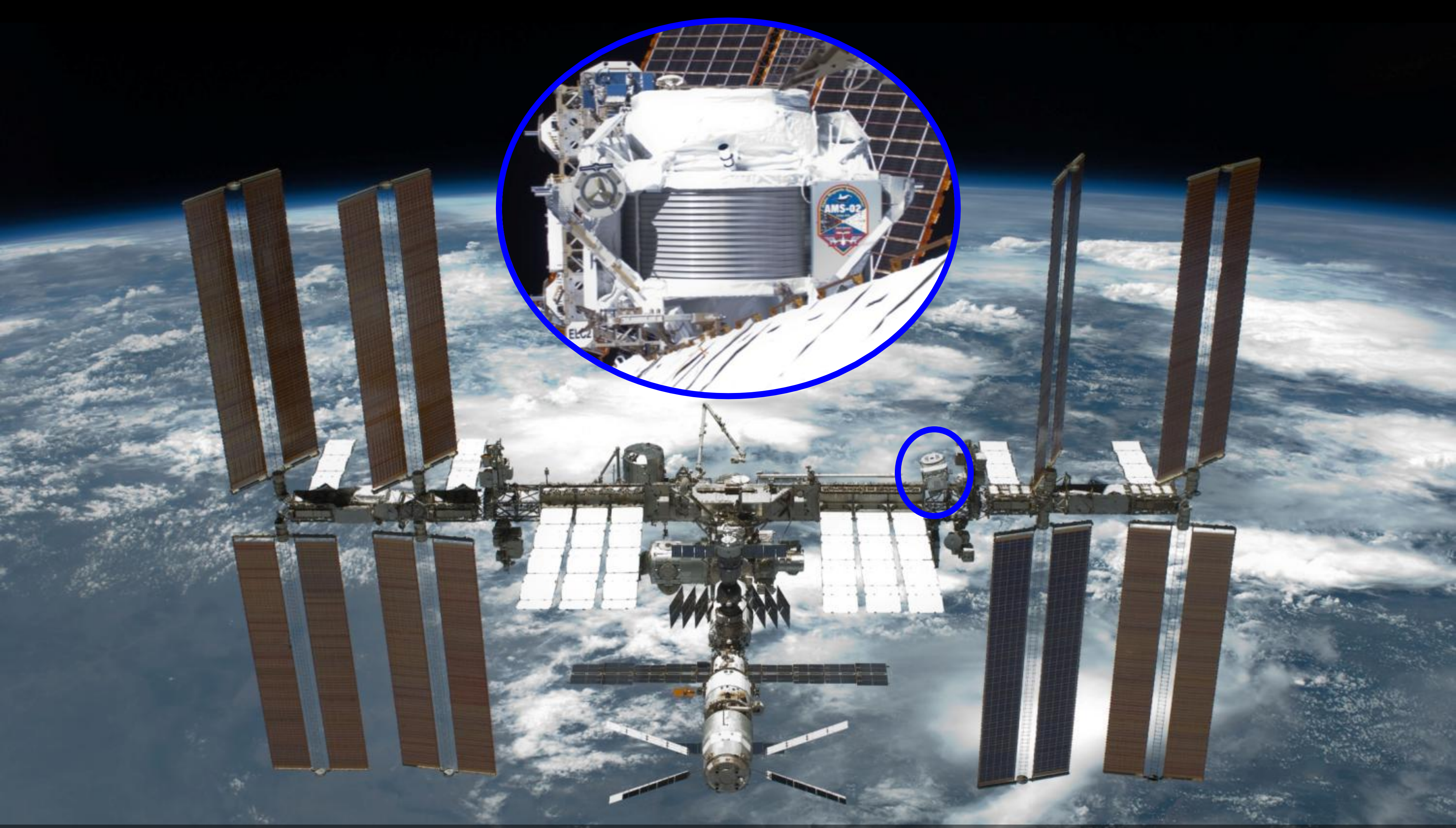


GF: 21.5 cm^2 sr
Mass: 470 kg
Size: 130x70x70 cm^3
Power Budget: 360W

PAMELA Measurements of Cosmic Rays



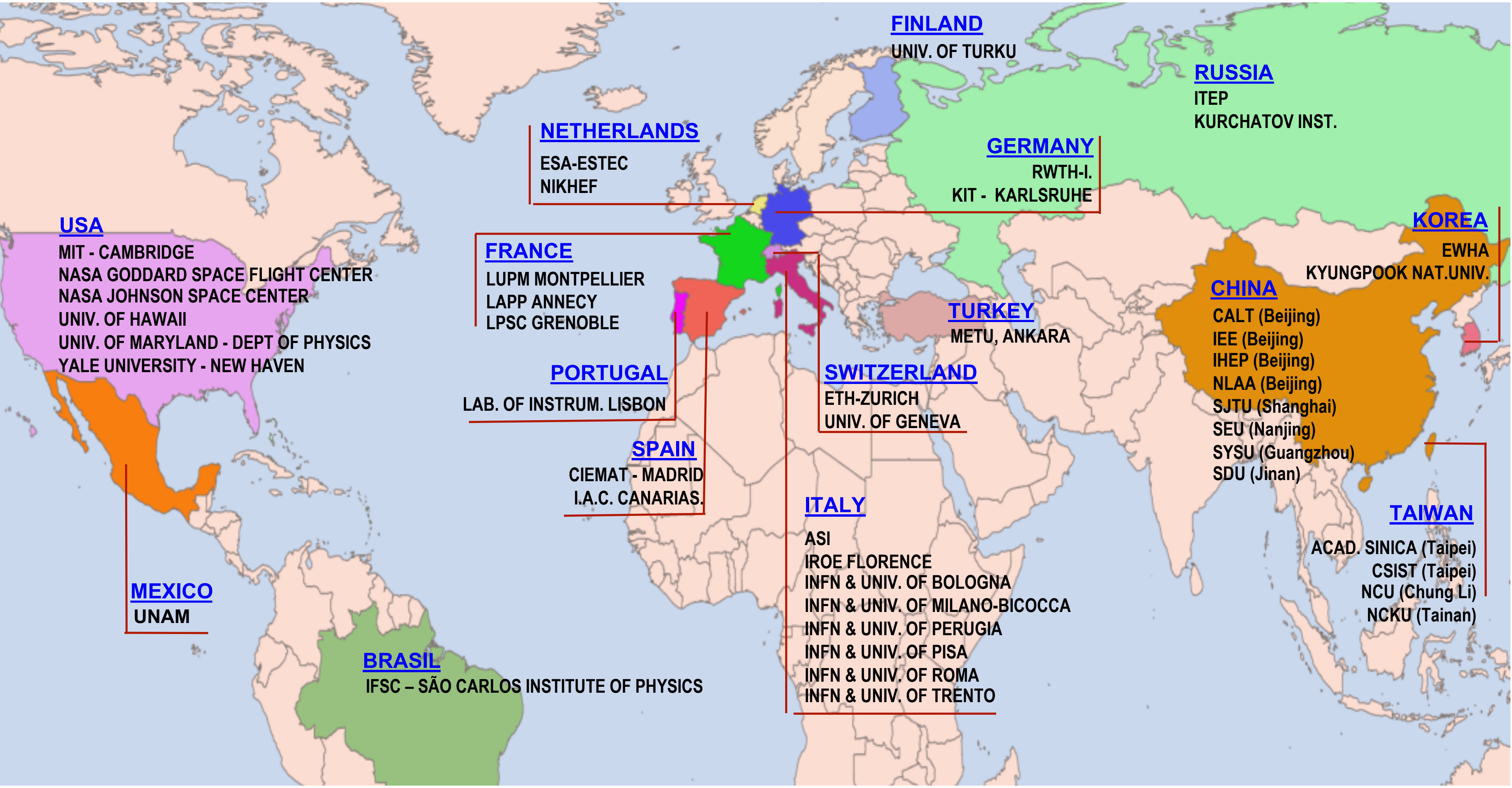
Alpha Magnetic Spectrometer



In 7 years, over 127 billion charged particles have been measured by AMS

AMS is an International Collaboration

The detectors were constructed in Europe and Asia and assembled at CERN.



The DOE reviews of AMS Science with panels of distinguished scientists (Nobel Laureates, Members of the U.S. Academy of Sciences)

is one of the most significant support from DOE.

April 2 - 3, 1995 Committee :

Robert K. Adair
Barry C. Barish
Stephen L. Olsen
Malvin A. Ruderman
David N. Schramm, Chair
George F. Smoot
Paul J. Steinhardt

March 15, 1999 Committee :

Robert K. Adair
Barry C. Barish
Stephen L. Olsen
Malvin A. Ruderman
George F. Smoot
Paul J. Steinhardt

Sept 25, 2006 Committee:

Barry C. Barish, Chair
Elliott D. Bloom
James Cronin
Stephen L. Olsen
George F. Smoot
Paul J. Steinhardt
Trevor Weekes

Sept 10,11, 2013 Committee:

Barry C. Barish, Chair
Jonathan Bagger
Bill Edwards
Francis Halzen
Dan Marlow
Saul Perlmutter
Donald Petit
John Wefel
Michael Witherell

Sept 9, 2016 Committee:

Barry C. Barish, Chair
Bill Edwards
Francis Halzen
Dan Marlow
Donald Petit
George F. Smoot
John Wefel

The legislation unanimously approved by the U.S. House and Senate in 2008:

Section 611 (**H.R. 6063**)

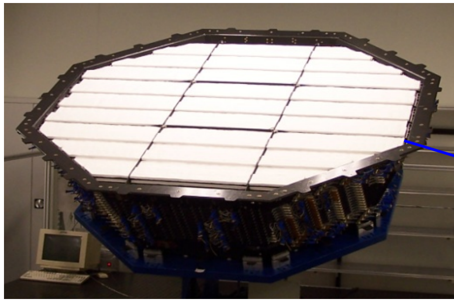
(c) ADDITIONAL FLIGHT TO DELIVER THE ALPHA MAGNETIC SPECTROMETER AND OTHER SCIENTIFIC EQUIPMENT AND PAYLOADS TO THE INTERNATIONAL SPACE STATION.—

(1) IN GENERAL.—In addition to the flying of the baseline manifest as described in subsection (b), the Administrator shall take all necessary steps to fly one additional Space Shuttle flight to deliver the Alpha Magnetic Spectrometer and other scientific equipment and payloads to the International Space Station prior to the retirement of the Space Shuttle. The purpose of the mission required to be planned under this subsection shall be to ensure the active use of the United States portion of the International Space Station as a National Laboratory by the delivery of the Alpha Magnetic Spectrometer, and to the extent practicable, the delivery of flight-ready research experiments prepared under the Memoranda of Understanding between NASA and other entities to facilitate the utilization of the International Space Station National Laboratory, as well as other fundamental and applied life sciences and other microgravity research experiments to the International Space Station as soon as the assembly of the International Space Station is completed.

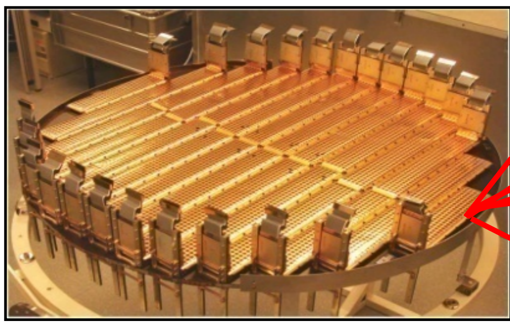

AMS
300,000 electronics channels
650 processors
5m x 4m x 3m
7.5 tons

AMS: A TeV precision, multipurpose spectrometer

TRD
Identify e^+, e^-

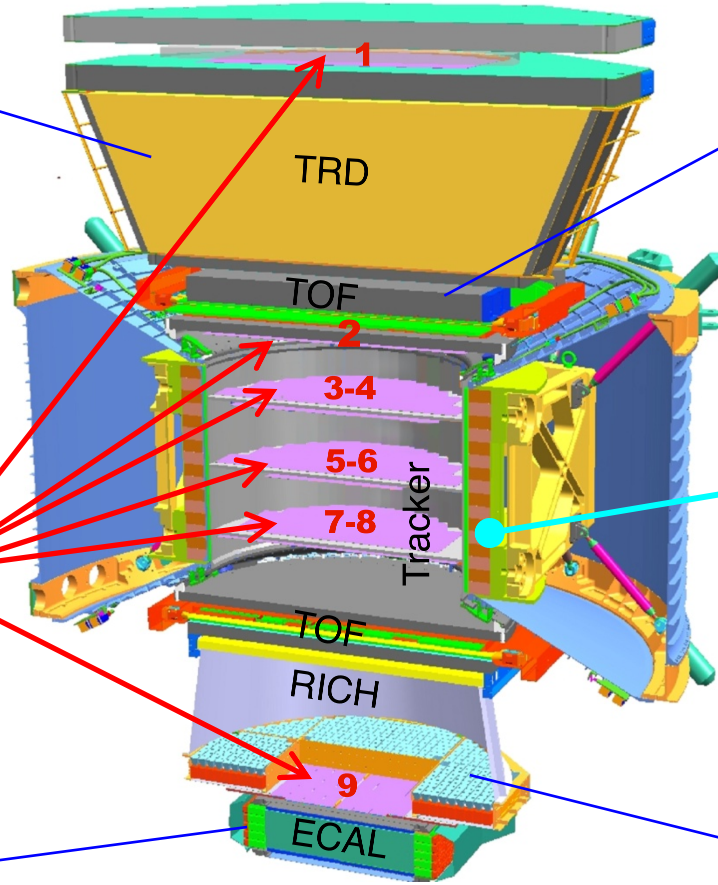


Silicon Tracker
Z, P



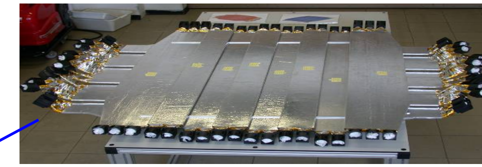
ECAL
E of e^+, e^-, γ

Particles and nuclei are defined by their charge (**Z**) and energy (**E ~ P**)

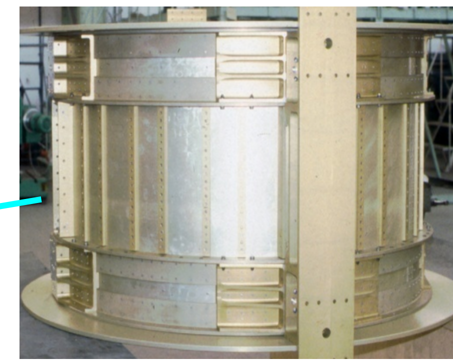


Z, P or R (=P/Z) are measured independently by the Tracker, RICH, TOF and ECAL

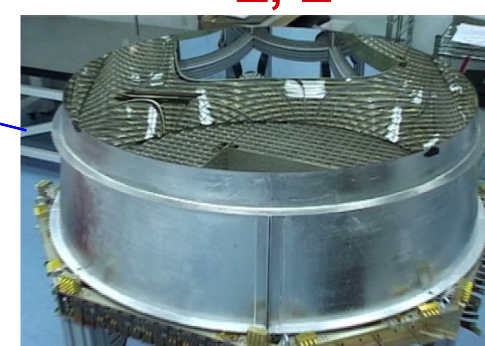
TOF
Z, E



Magnet
±Z



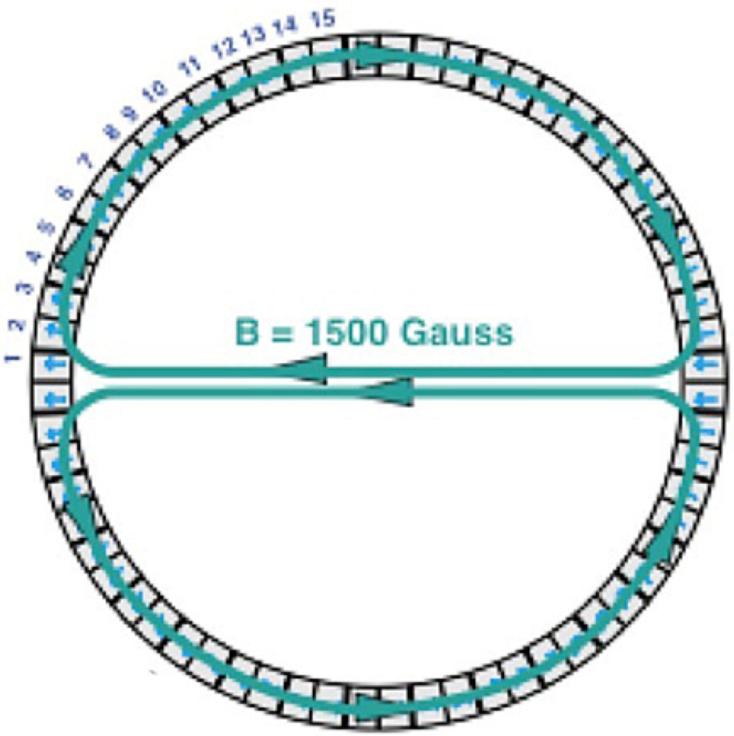
RICH
Z, E



Magnet System: 10 Magnets were made

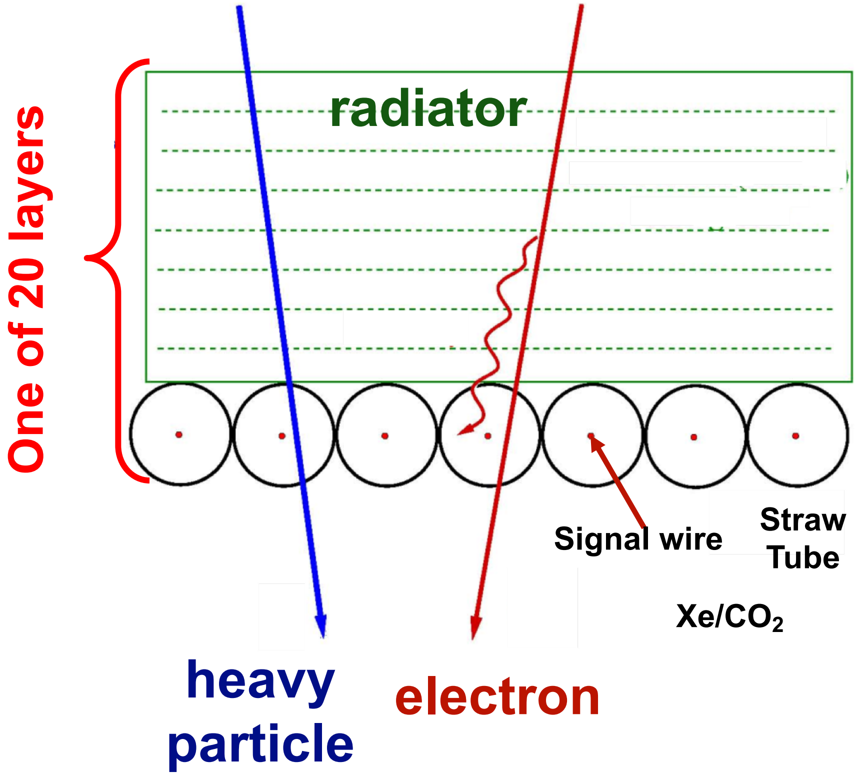
Seven magnets to understand the field calculation, leakage and dipole moment

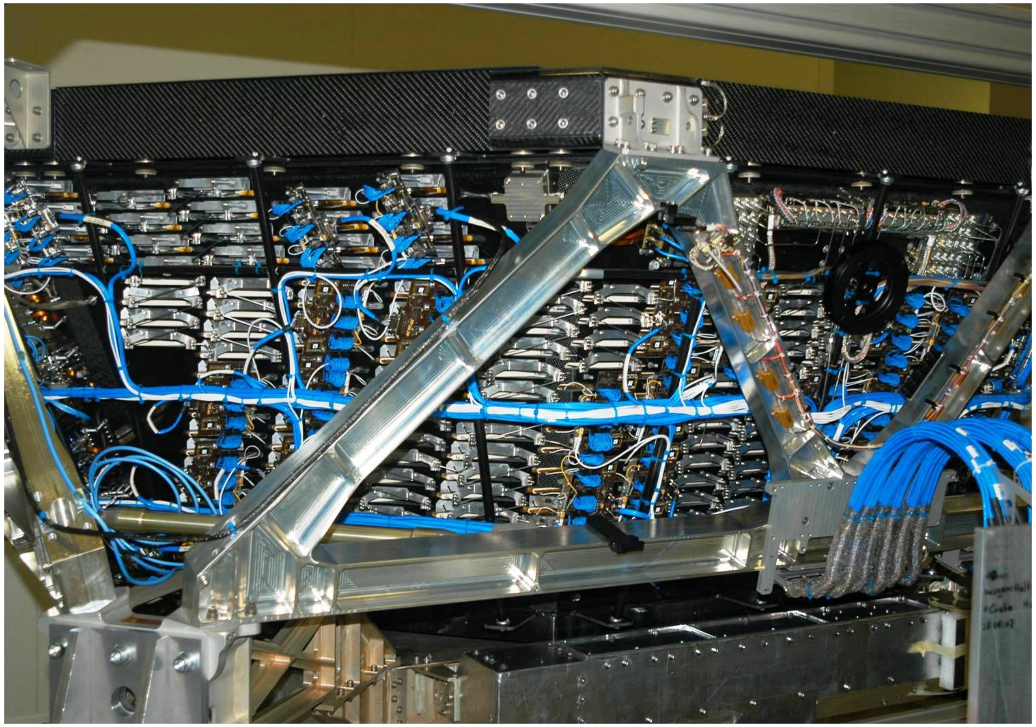
Three full-size magnets for 1) space qualification, 2) destructive testing and 3) flight

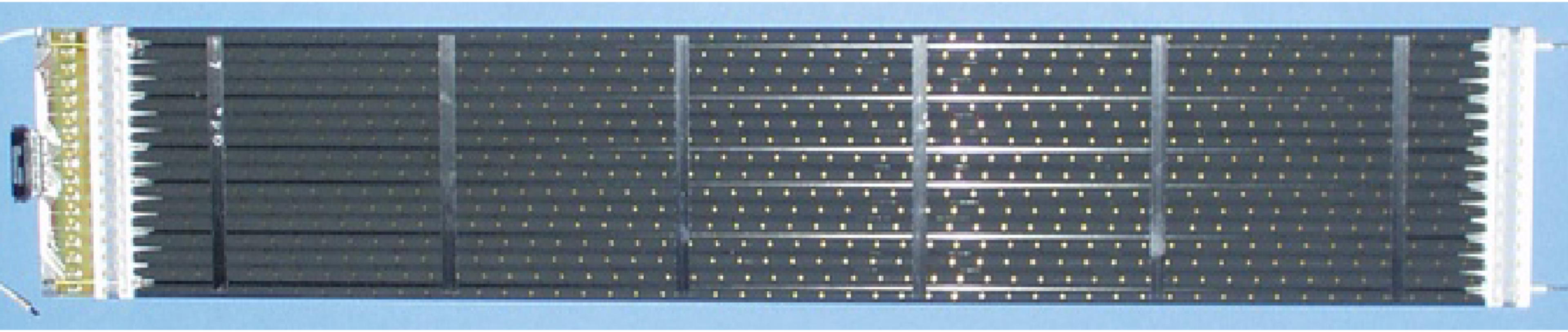


Magnet vibration qualification

Transition Radiation Detector (TRD): identifies Positrons and Electrons

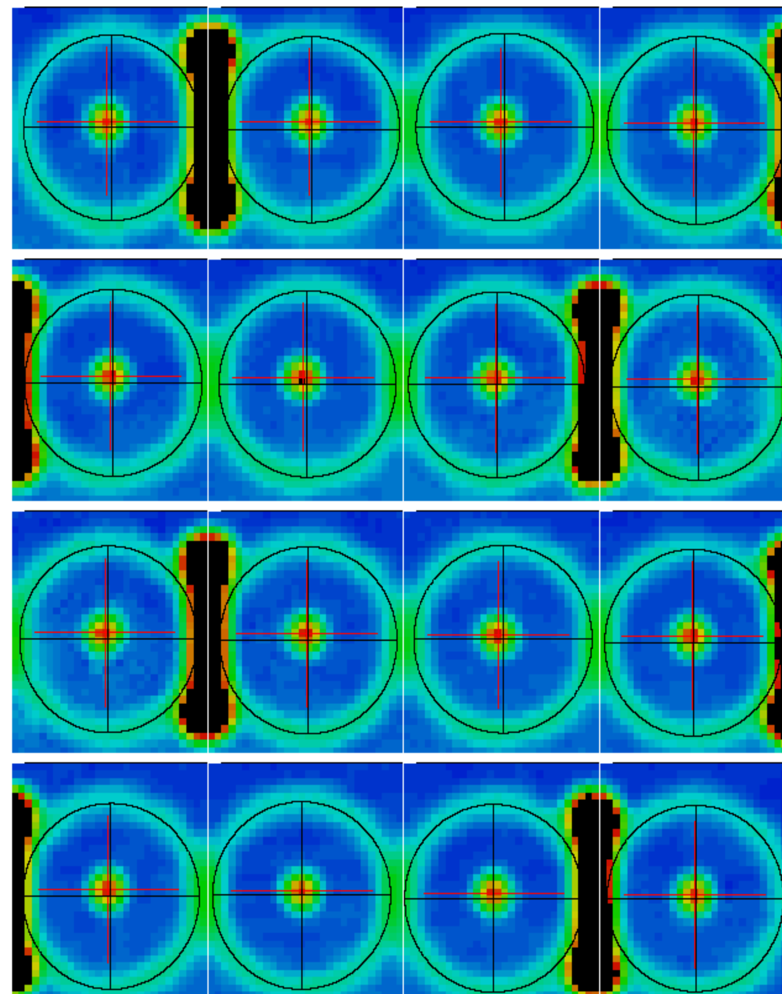




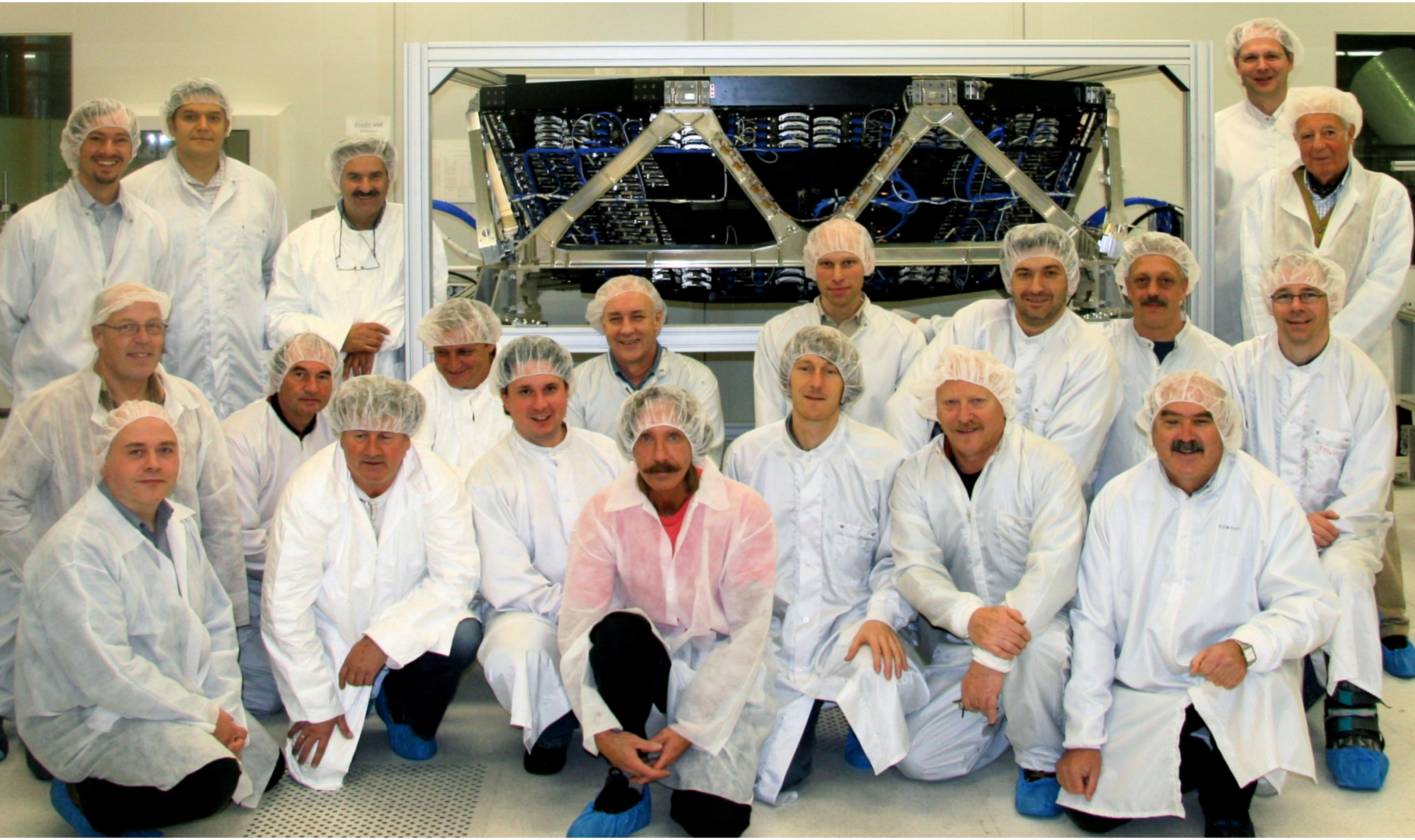


9,000 Straw Tubes Manufactured

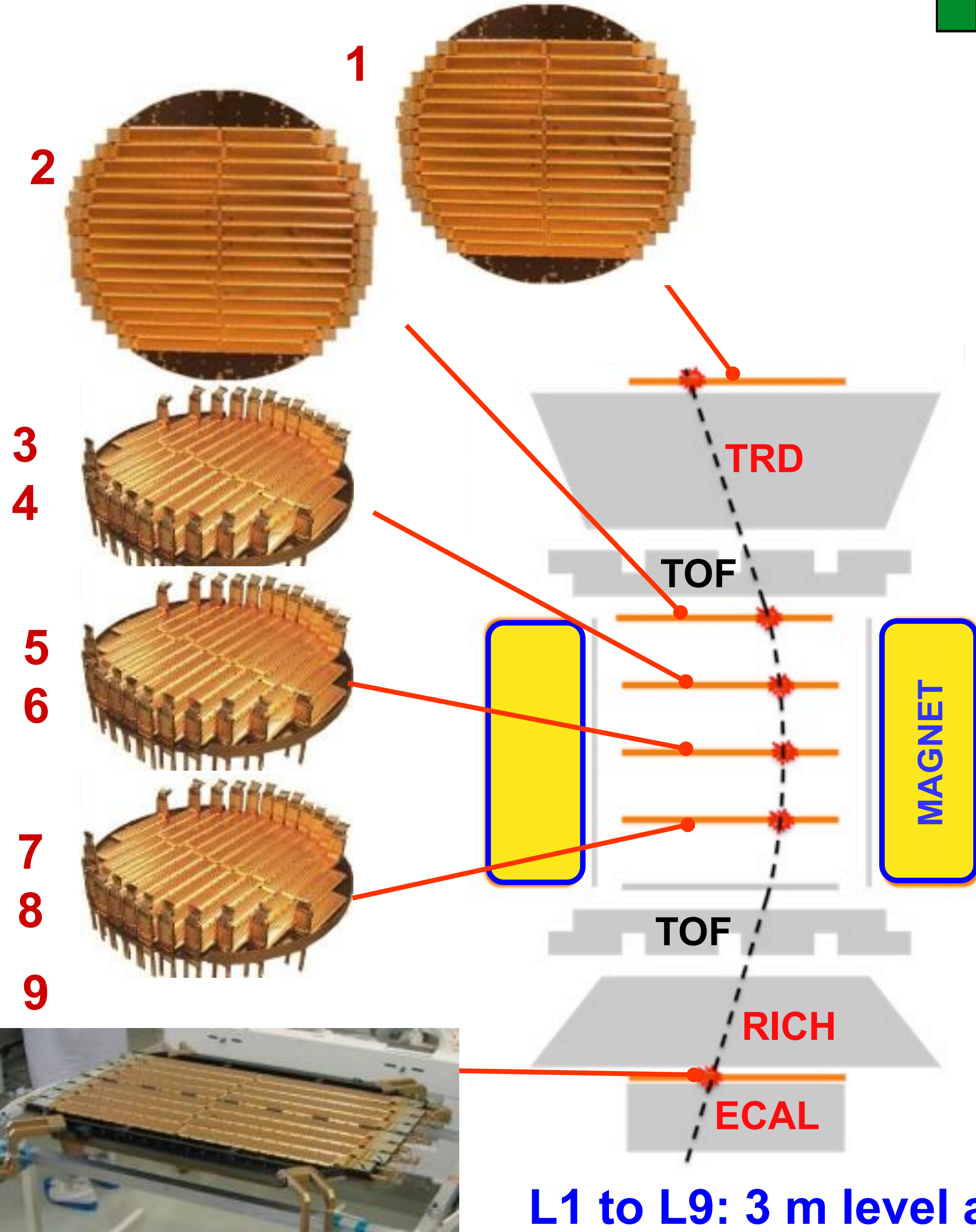
5,248 tubes selected from 9,000,
2 m length centered to 100μm,
verified by CAT scanner

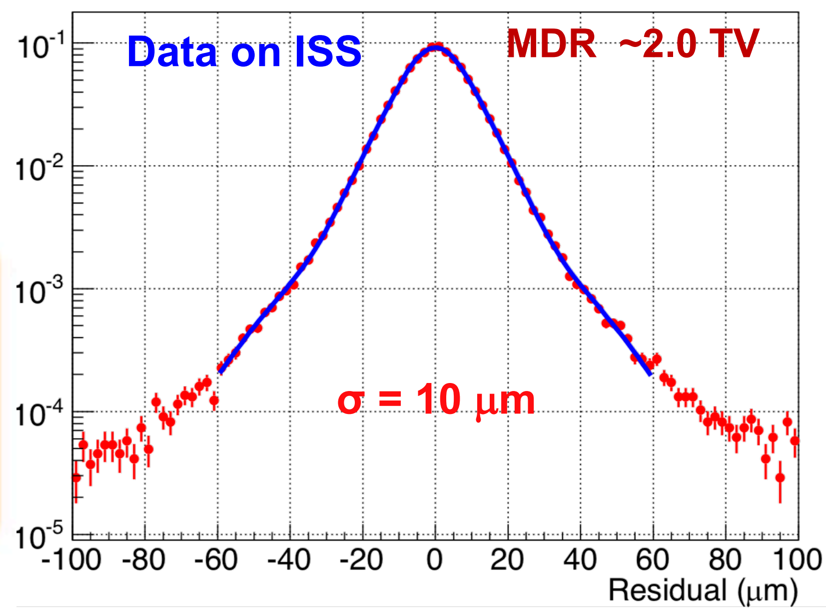


Transition Radiation Detector (TRD)
A 10 year construction effort



Silicon Tracker

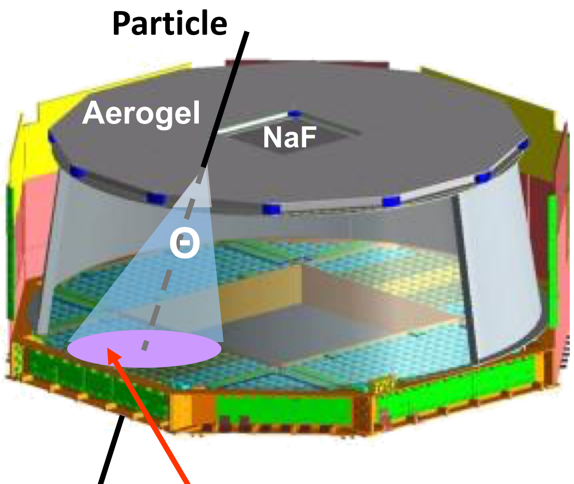




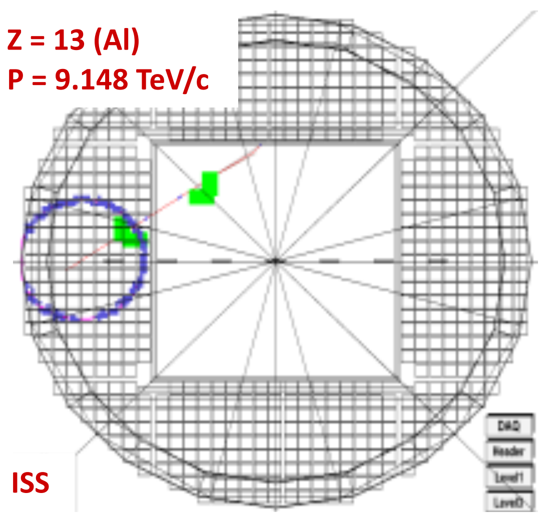
L1 to L9: 3 m level arm

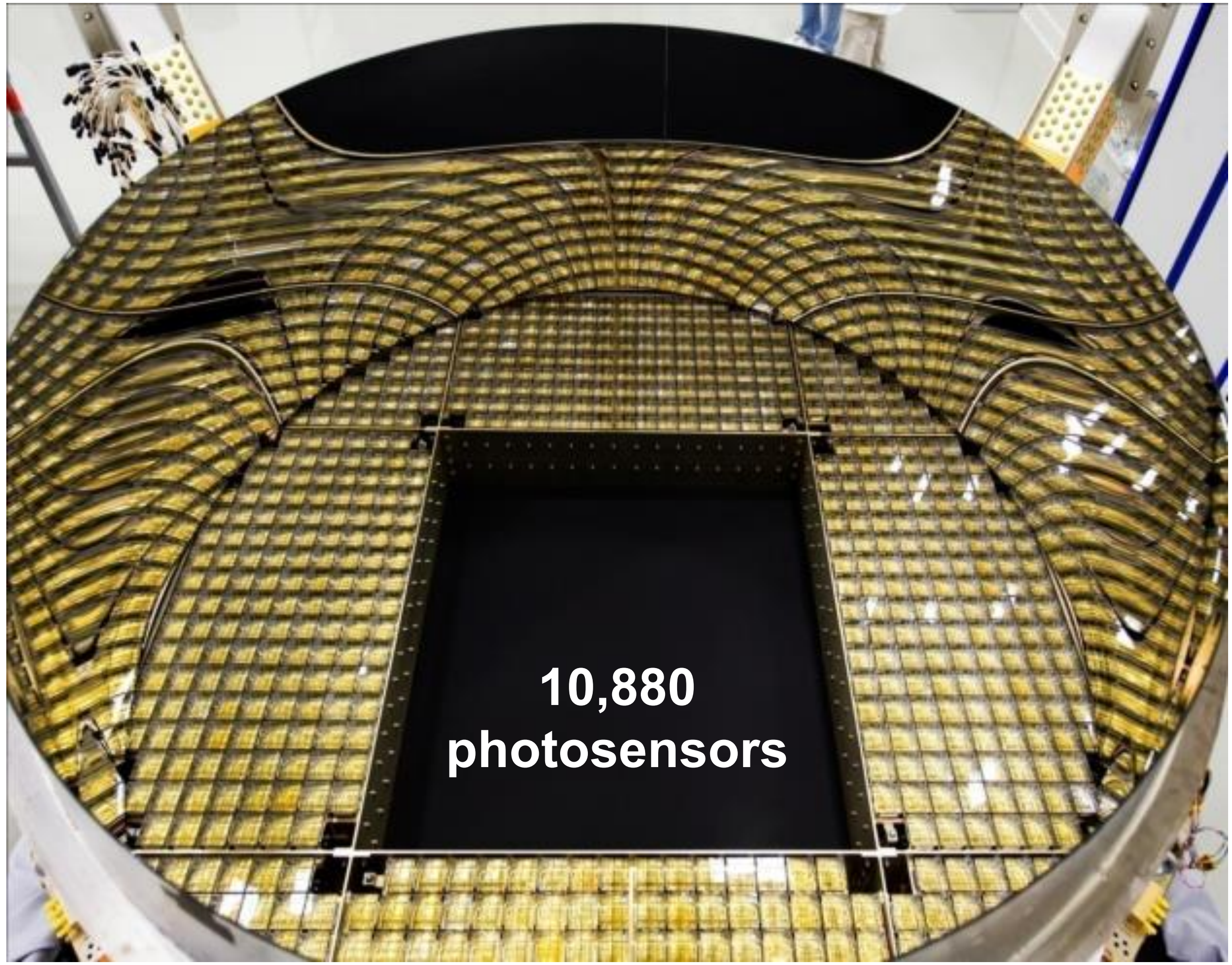
Ring Imaging CHerenkov (RICH)

Measurement of Nuclear Charge and its Velocity to 1/1000



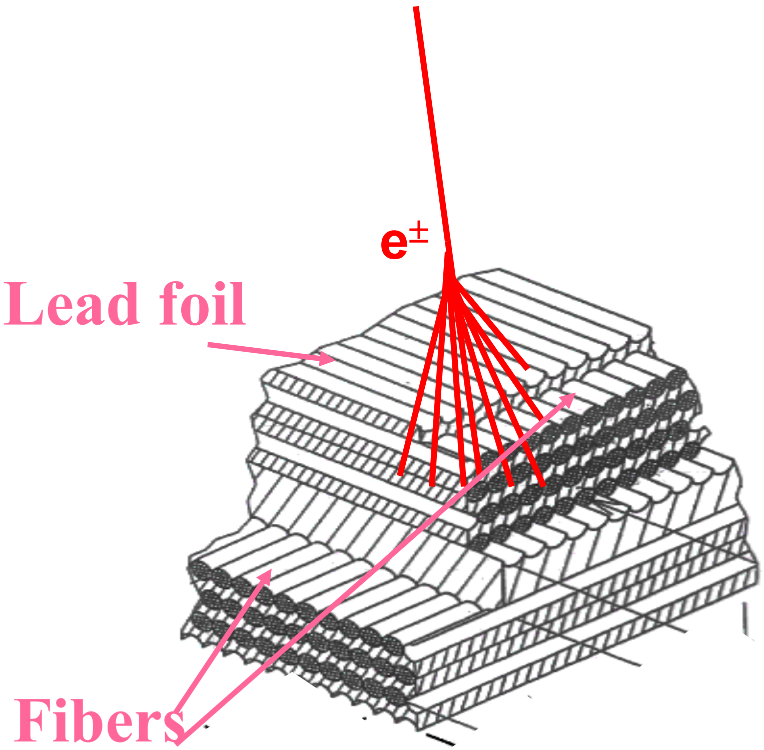
Intensity ⇒ Z^2 **Θ ⇒ V**





Electromagnetic Calorimeter

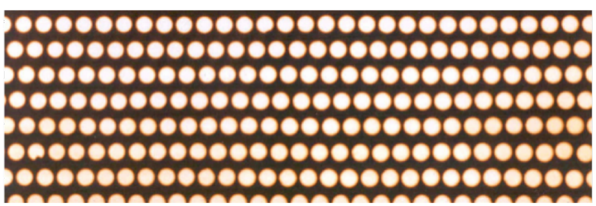
provides a precision, 17 X_0, TeV, 3-dimensional measurement of



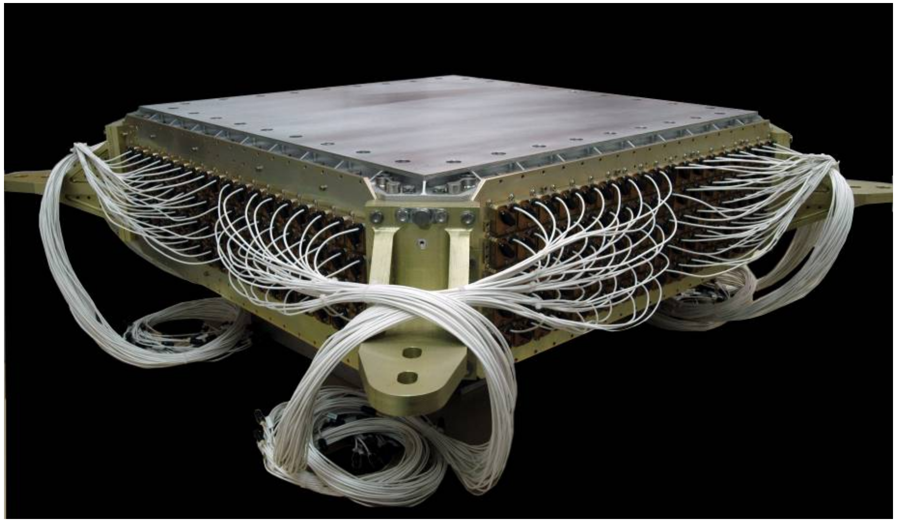
1. the directions to ± 1 degree

2. the energy resolution of 2%

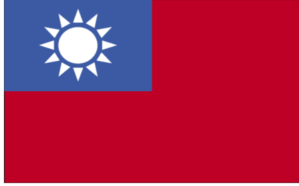
3. Distinguishes electrons and positrons from protons, helium, …by a factor of 10,000



50 000 fibers, $\phi = 1$ mm distributed uniformly inside 600 Kg of lead

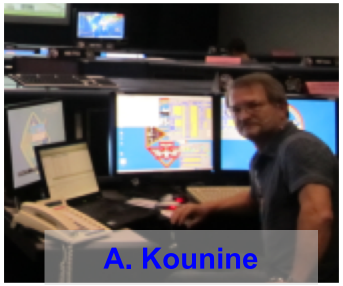


Electronics



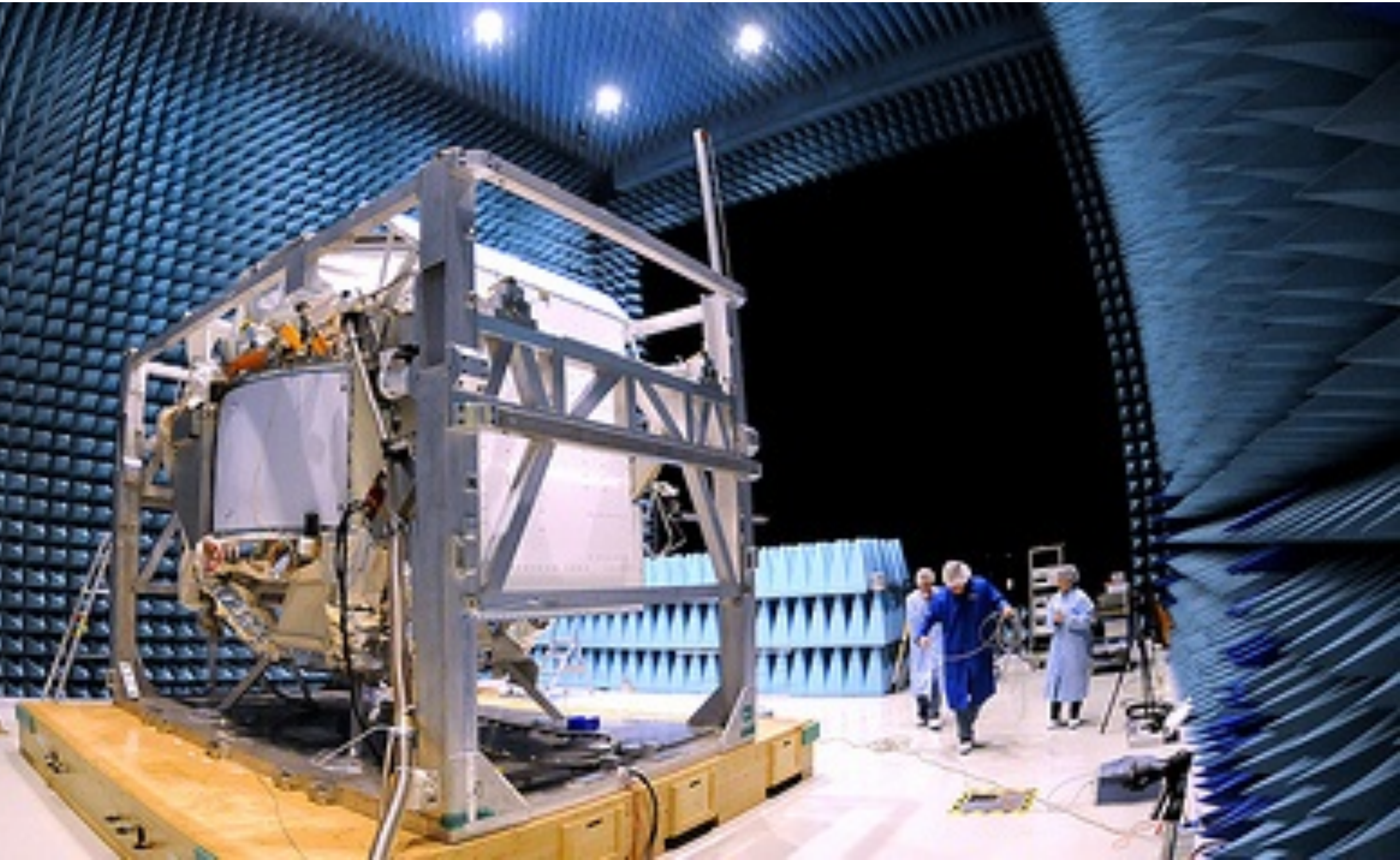
To get one board working on orbit, we needed to make ~10 boards
In total: 464 boards on orbit of 70 different types.

MIT team

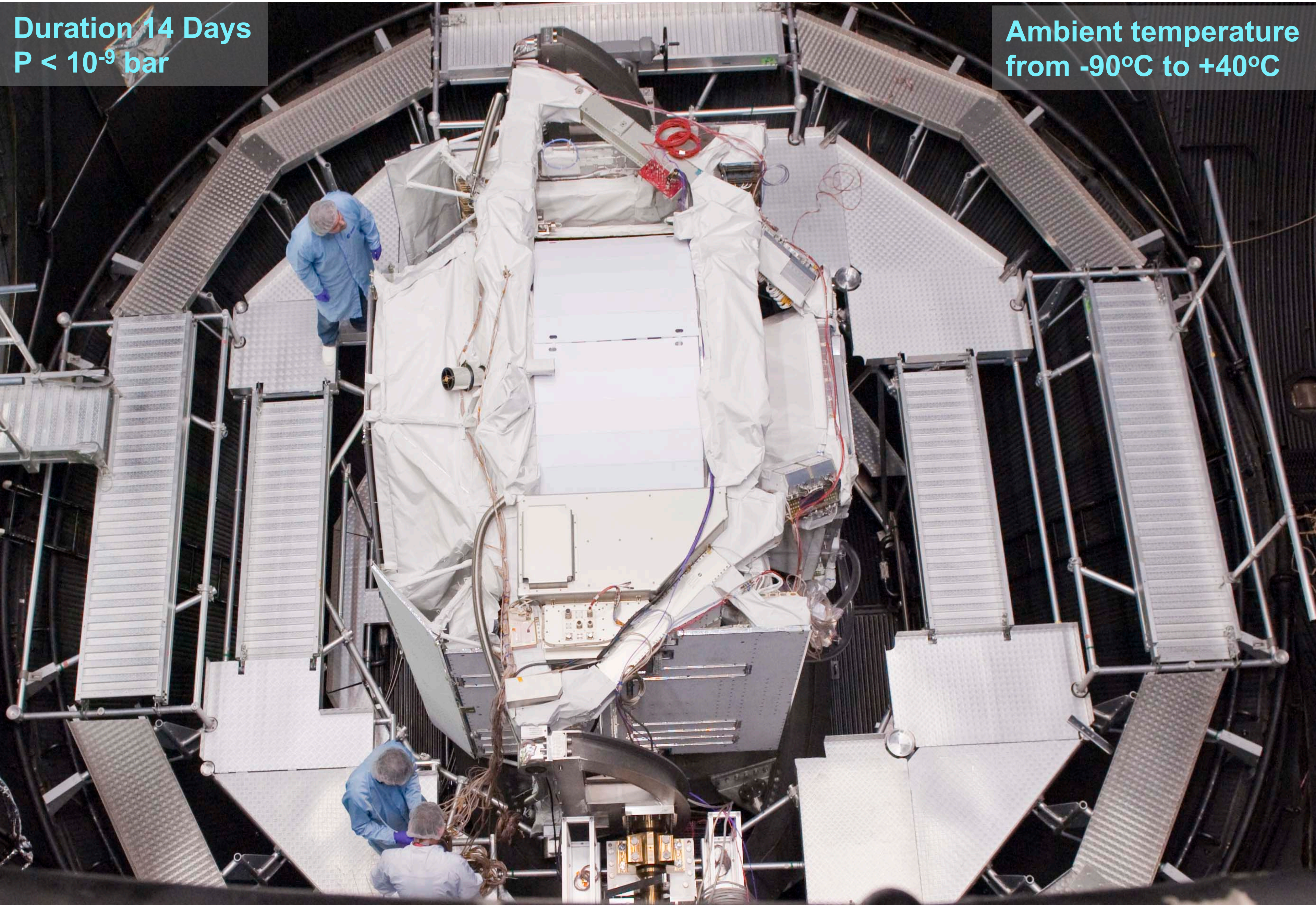


Taiwan provided 70 engineers for 10 years with active MIT and NASA participation

AMS in the ESA Electromagnetic Interference (EMI) Chamber, March 2010, ESTEC, Noordwijk, the Netherlands

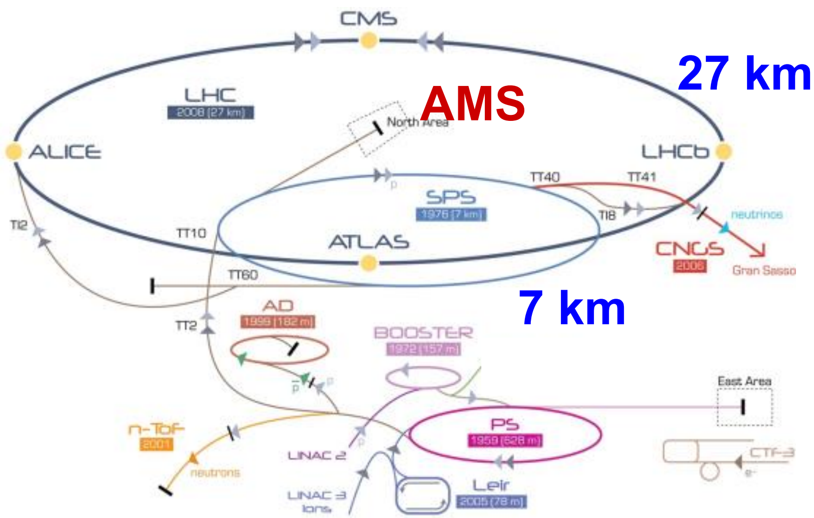


AMS in the ESA TVT Chamber, April 2010, ESTEC

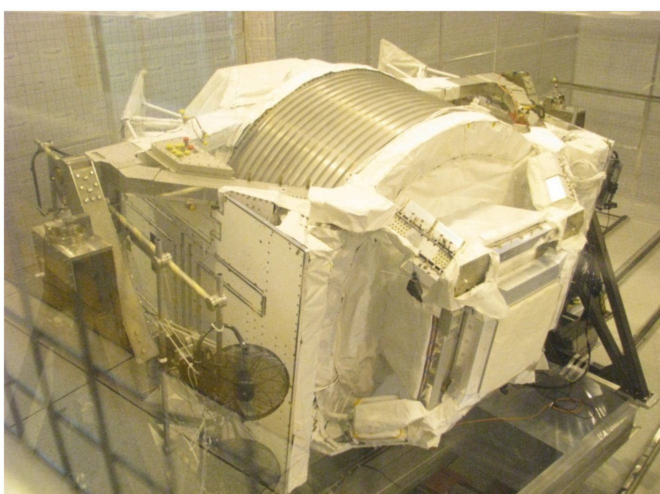


Calibration of the AMS Detector

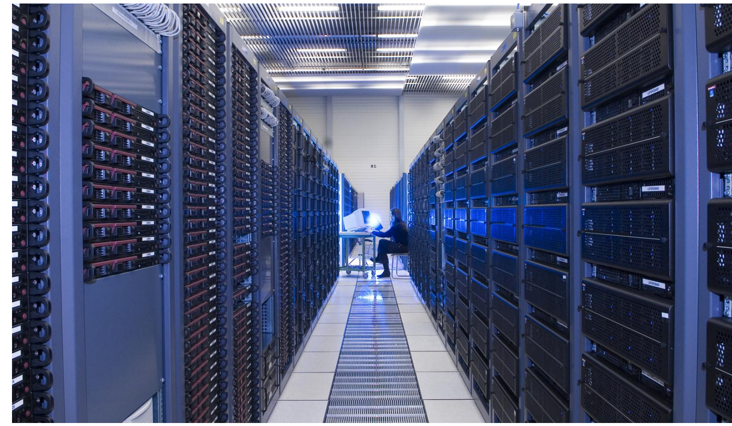
Test beam at CERN SPS:
p, $e^{\pm}$, $\pi^{\pm}$, 10−400 GeV



2000 positions

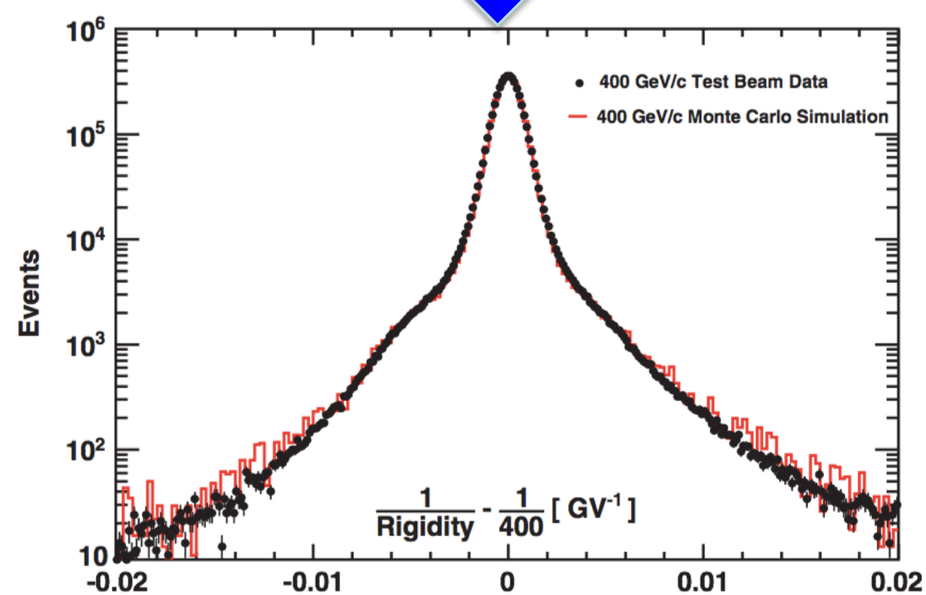


10,000 CPU cores provided by CERN



Computer simulation:

Interactions, Materials, Electronics

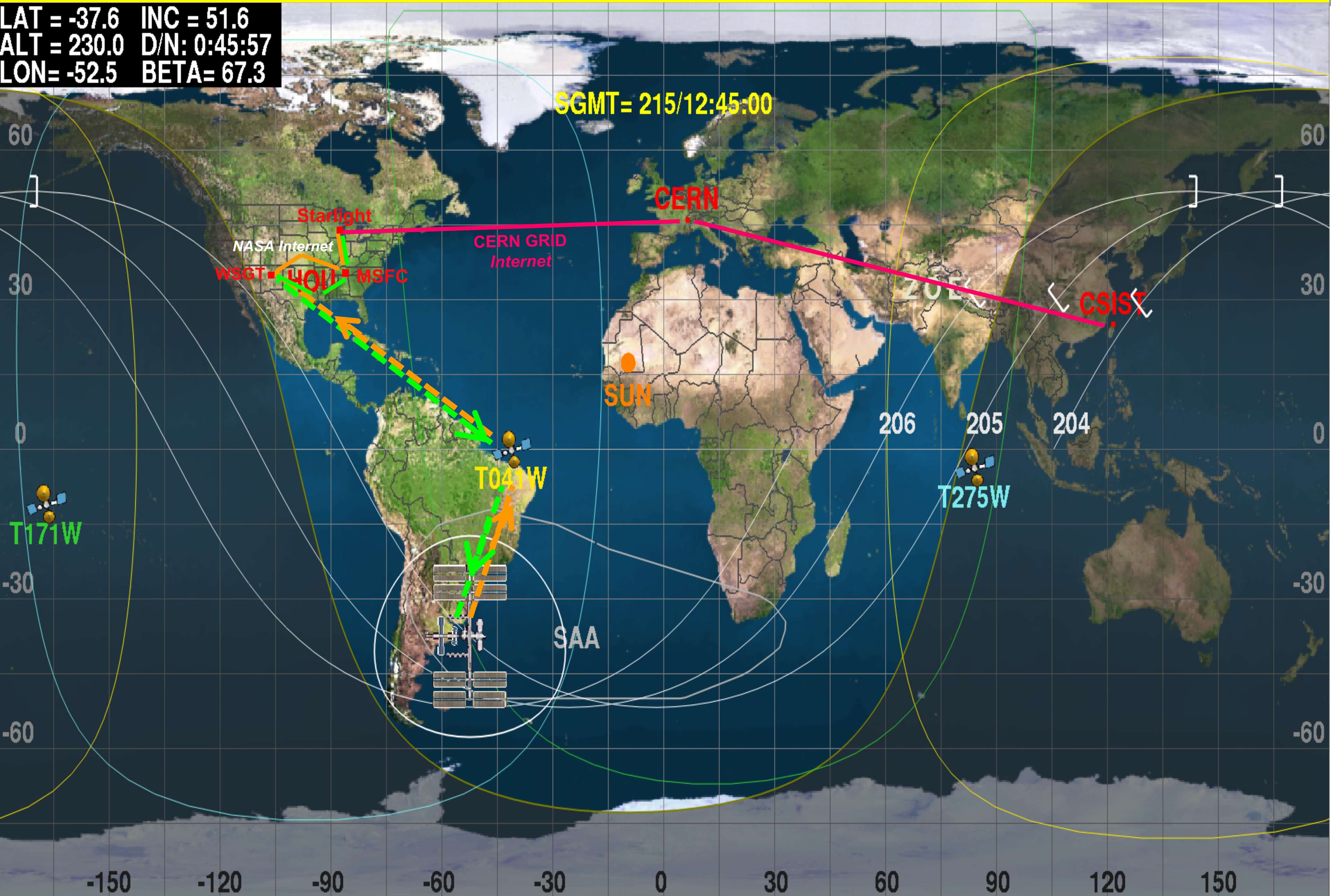



May 16, 2011, 08:56 AM
Total weight: 2008 t
AMS weight: 7.5 t

May 19: AMS installation completed at 5:15 AM.
Data taking started at 9:35 AM

Communications for AMS on ISS

To prevent damage to AMS, we need to know the conditions within 4 hours



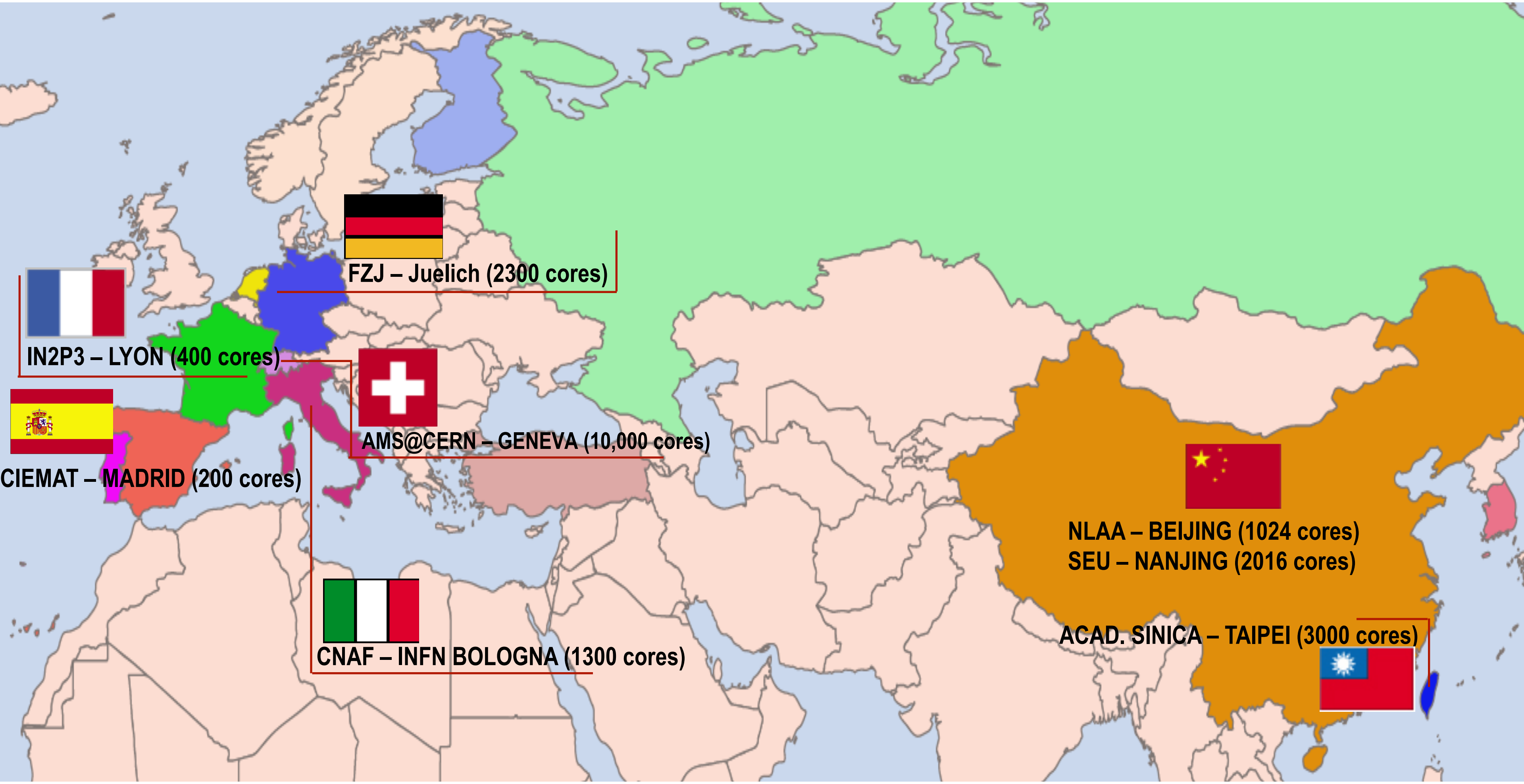
AMS POCC at CERN

The AMS Flight Control Team in the POCC is in constant communication with the ISS Flight Control Team at the JSC.

Analysis is conducted at the AMS Science Operations Center (SOC) at CERN and in the regional centers around the world.

Coordinated by V. Choutko and A. Kounine of MIT.

Each physics topic is analysed by at least two independent groups

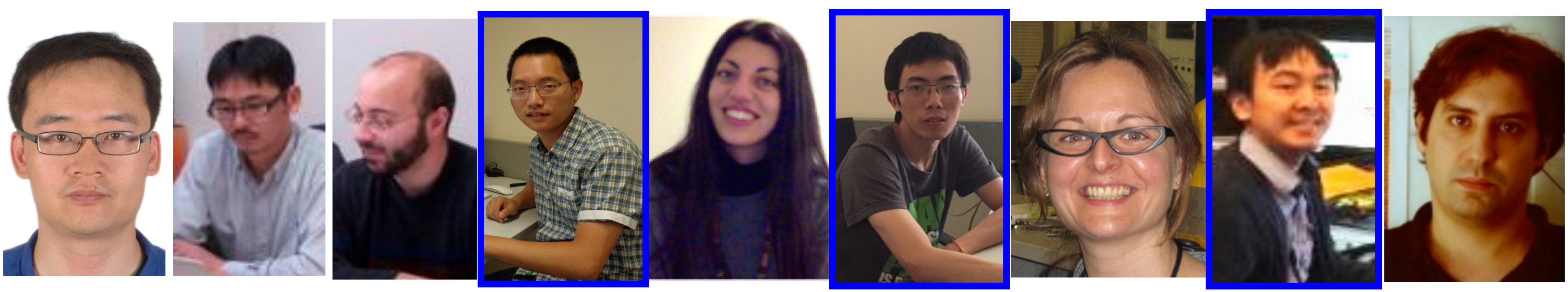


U.S. DOE is making a major contribution to the computing effort

A few of the key physicists in AMS analysis:

V. Choutko | A. Kounine | J. Berdugo | B. Bertucci | S. Schael | V. Bindi | M. Heil | H. Gast

M. Duranti | F. Giovacchini | I. Gebauer | V. Formato | J. Casaus | L. Derome | C. Delgado | D. Grandi | N. Zimmermann



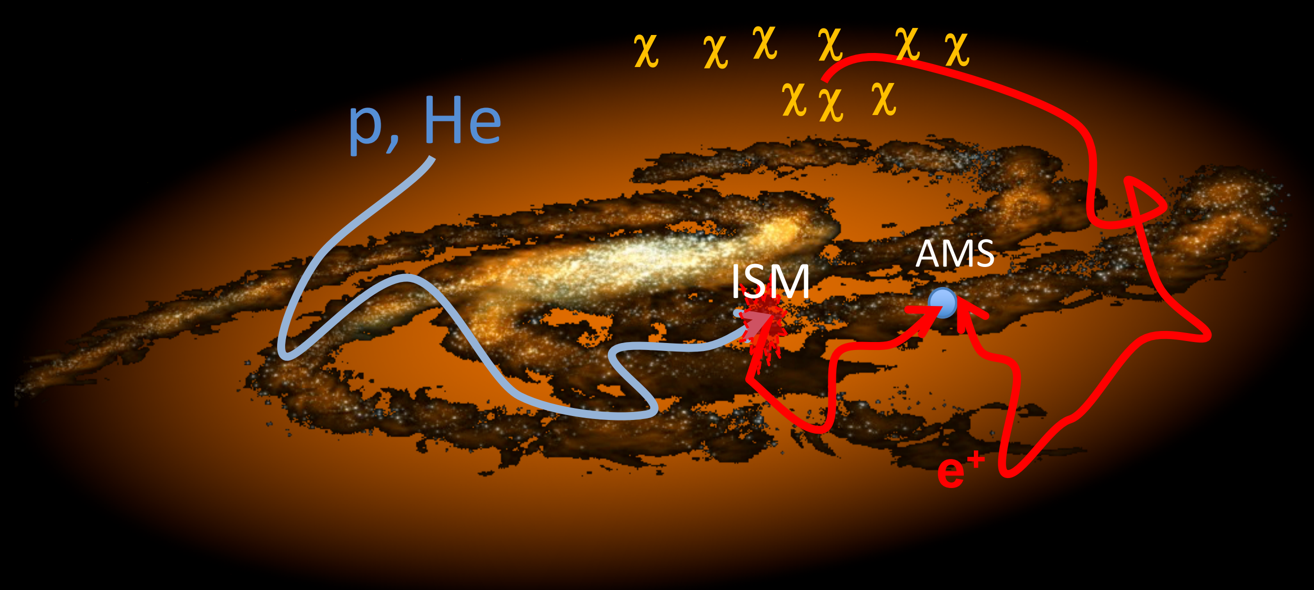
Z. Li | S. Haino | A. Oliva | W. Xu | M. Graziani | Q. Yan | C. Consolandi | Z. Weng | N. Tomassetti

Dark Matter

Collision of Cosmic Rays with Interstellar Matter (ISM) produces e^+

Dark Matter annihilation also produces light antimatter: e^+

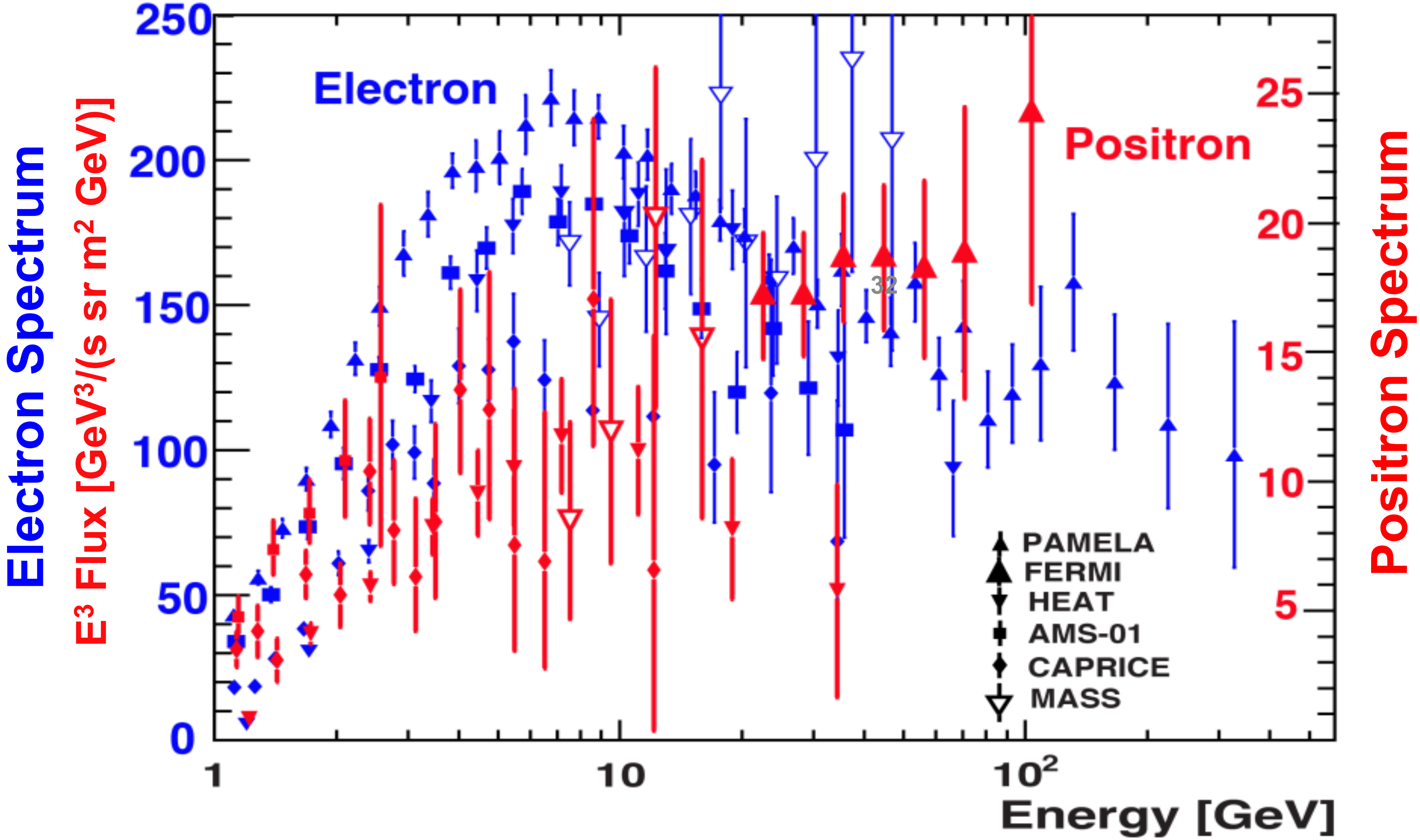
The excess of e^+, from Dark Matter annihilations can be measured by AMS



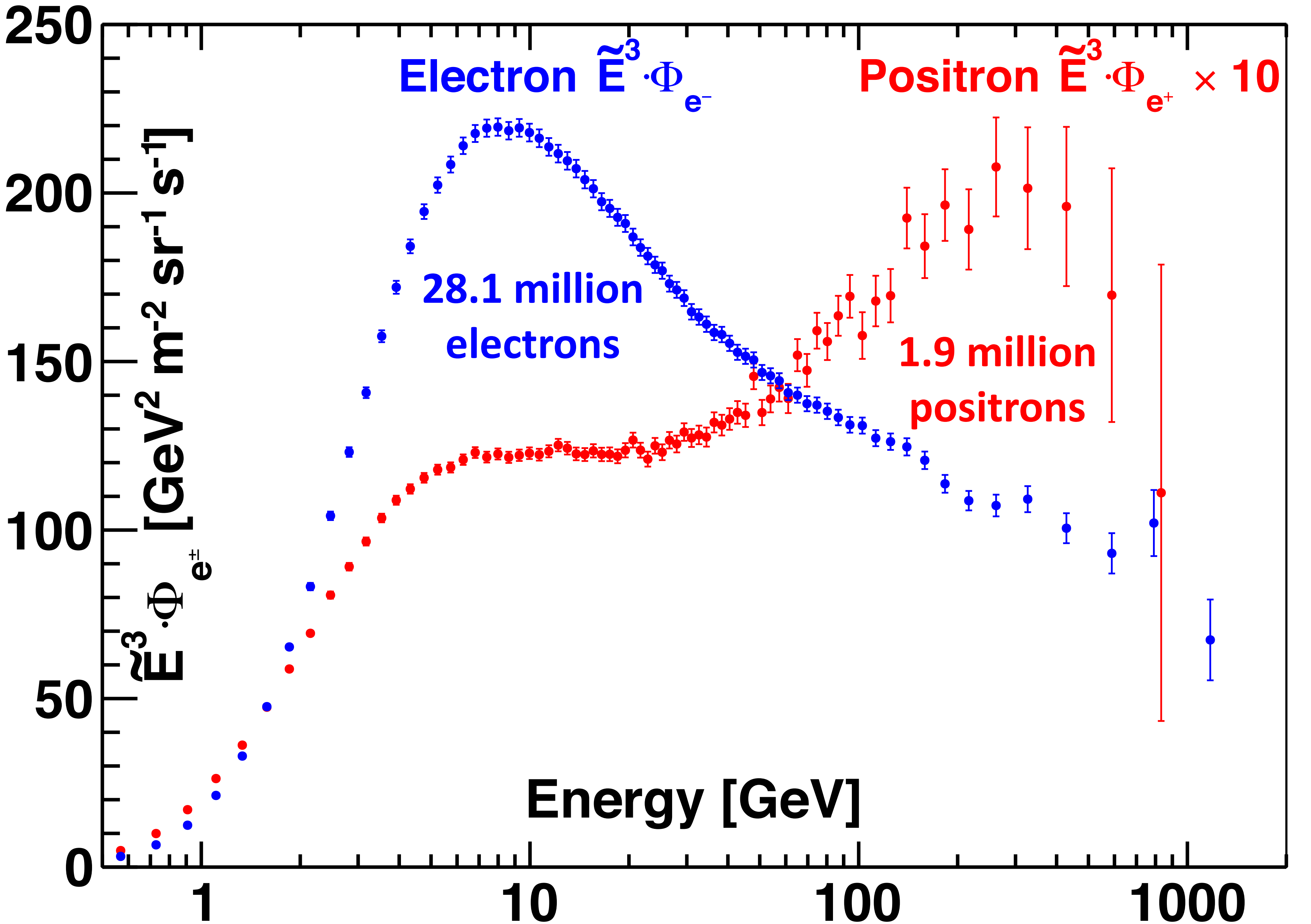
M. Turner and F. Wilczek, Phys. Rev. D42 (1990) 1001; J. Ellis 26th ICRC (1999)

Electron and Positron spectra before AMS

1. These were the best data.
2. Nonetheless, the data have large errors and are inconsistent.
3. The data has created many theoretical speculations.

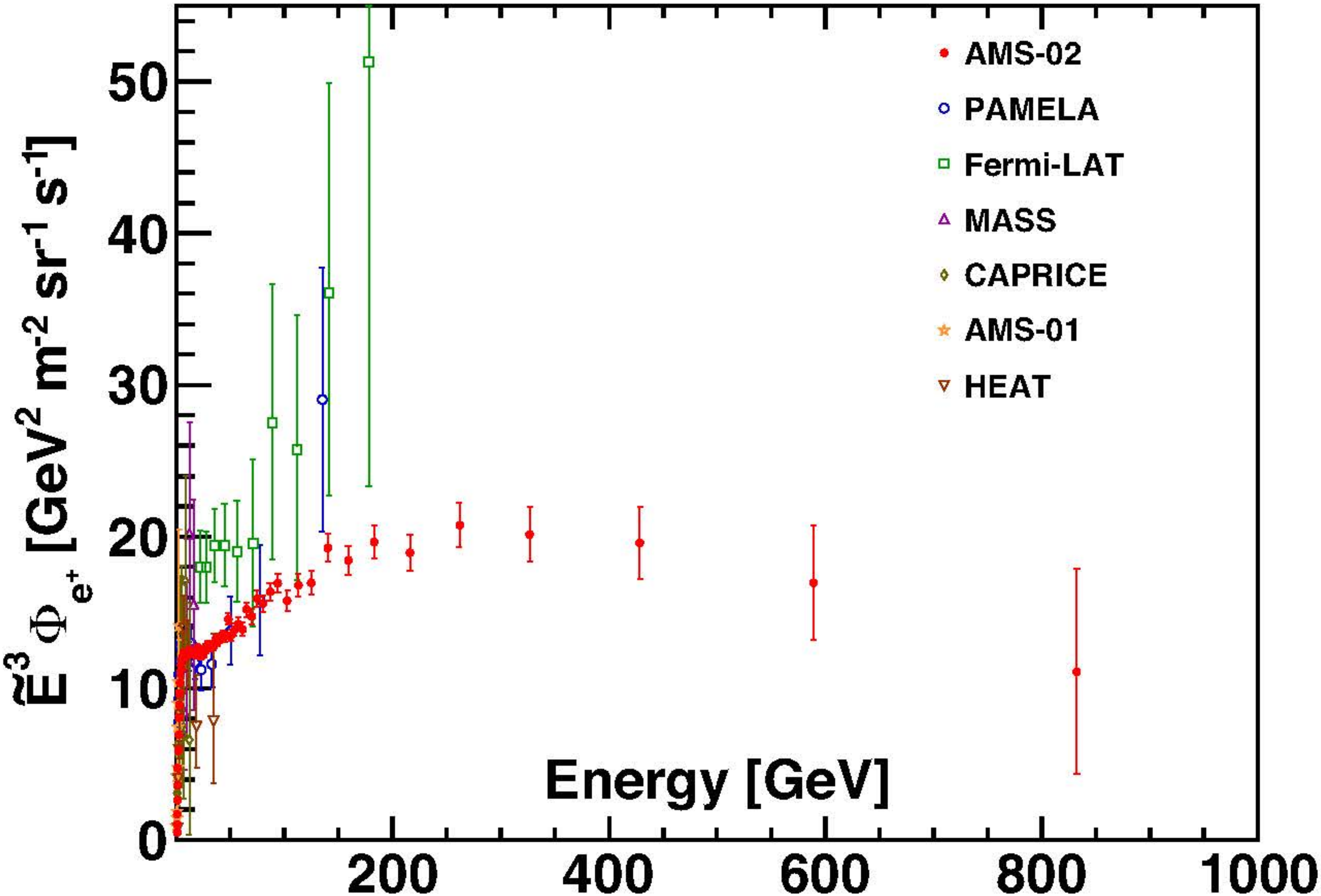


Distinct features of the positron flux and of the electron flux



AMS (2018)

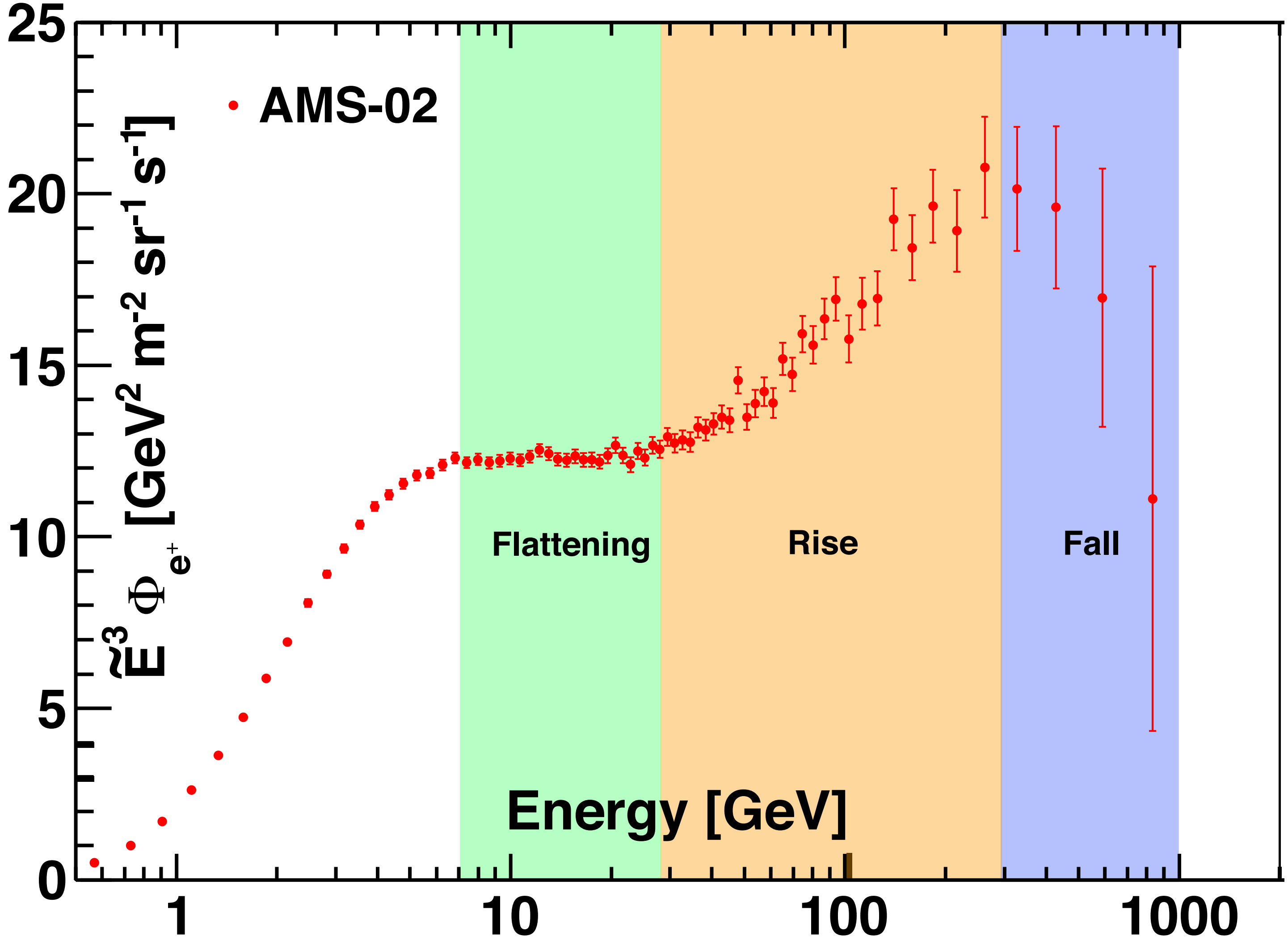
compared with earlier experiments



Origins of Cosmic Positrons

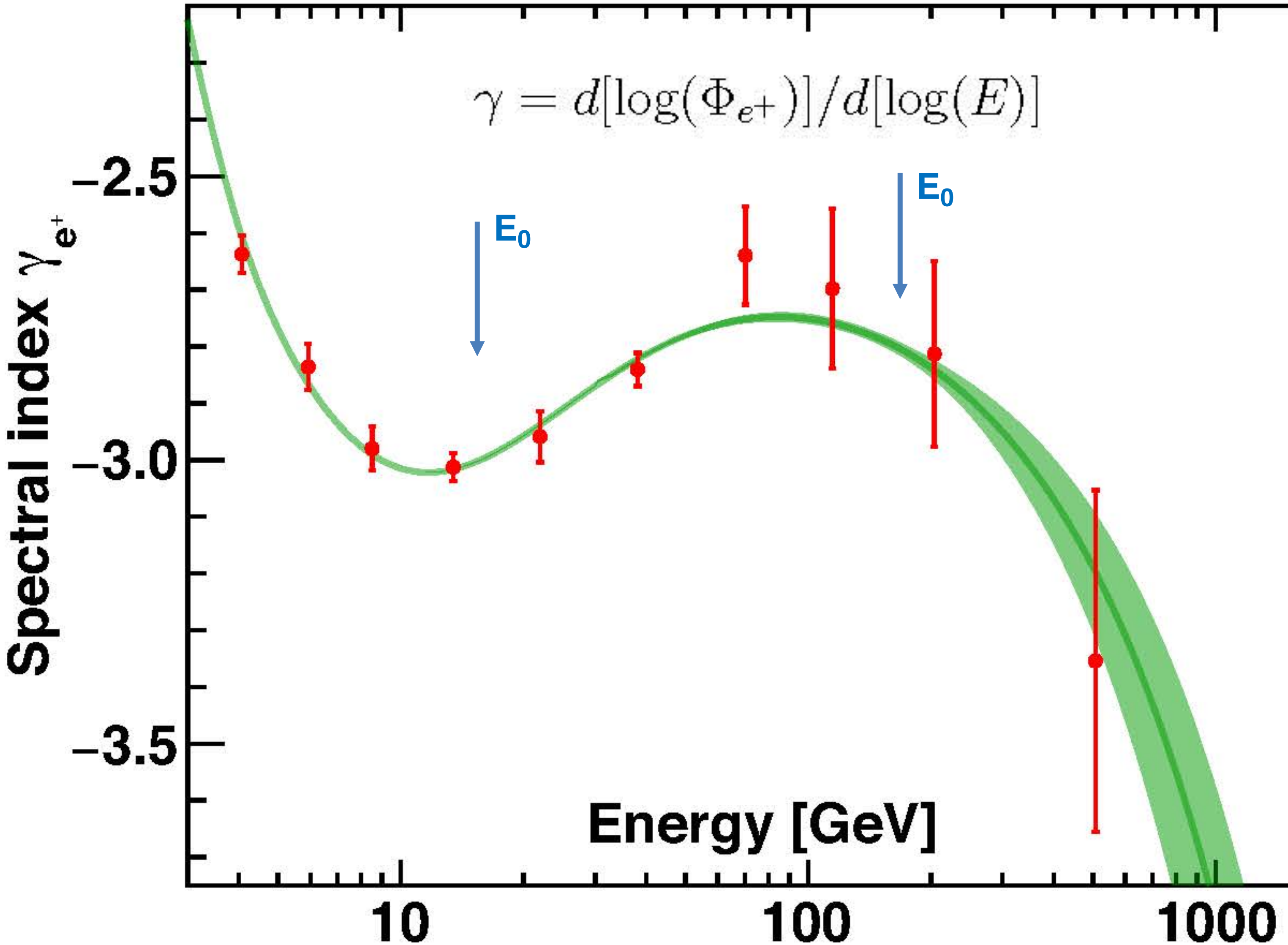
Based on 1.9 million positrons with energies from 0.5 GeV to 1 TeV

The positron spectrum, $E^3\Phi_{e+}$. The vertical color bands indicate the energy ranges corresponding to changing behavior of the spectrum: flattening, rising, and falling spectrum.



The spectral index of the positron flux.

The spectral index has complex energy dependence with a significant decrease towards higher energies.

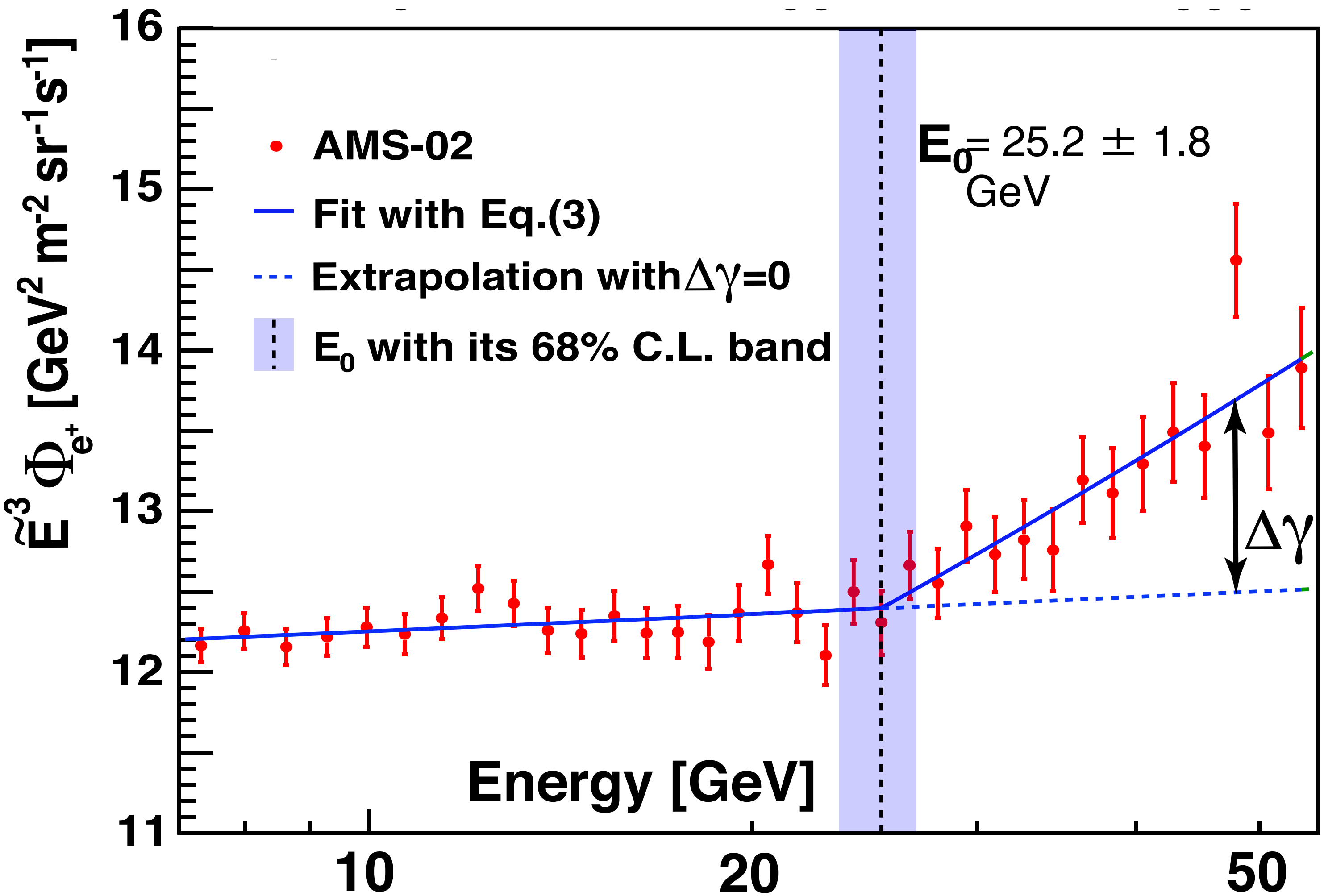


Four important observations:

From fit the data in the low energy region (7.10 – 55.58 GeV) to

$$\Phi_{e^+}(E) = \begin{cases} C(E/55.58\,\mathrm{GeV})^{\gamma}, & E \le E_0; \\ C(E/55.58\,\mathrm{GeV})^{\gamma}(E/E_0)^{\Delta\gamma}, & E > E_0. \end{cases}$$

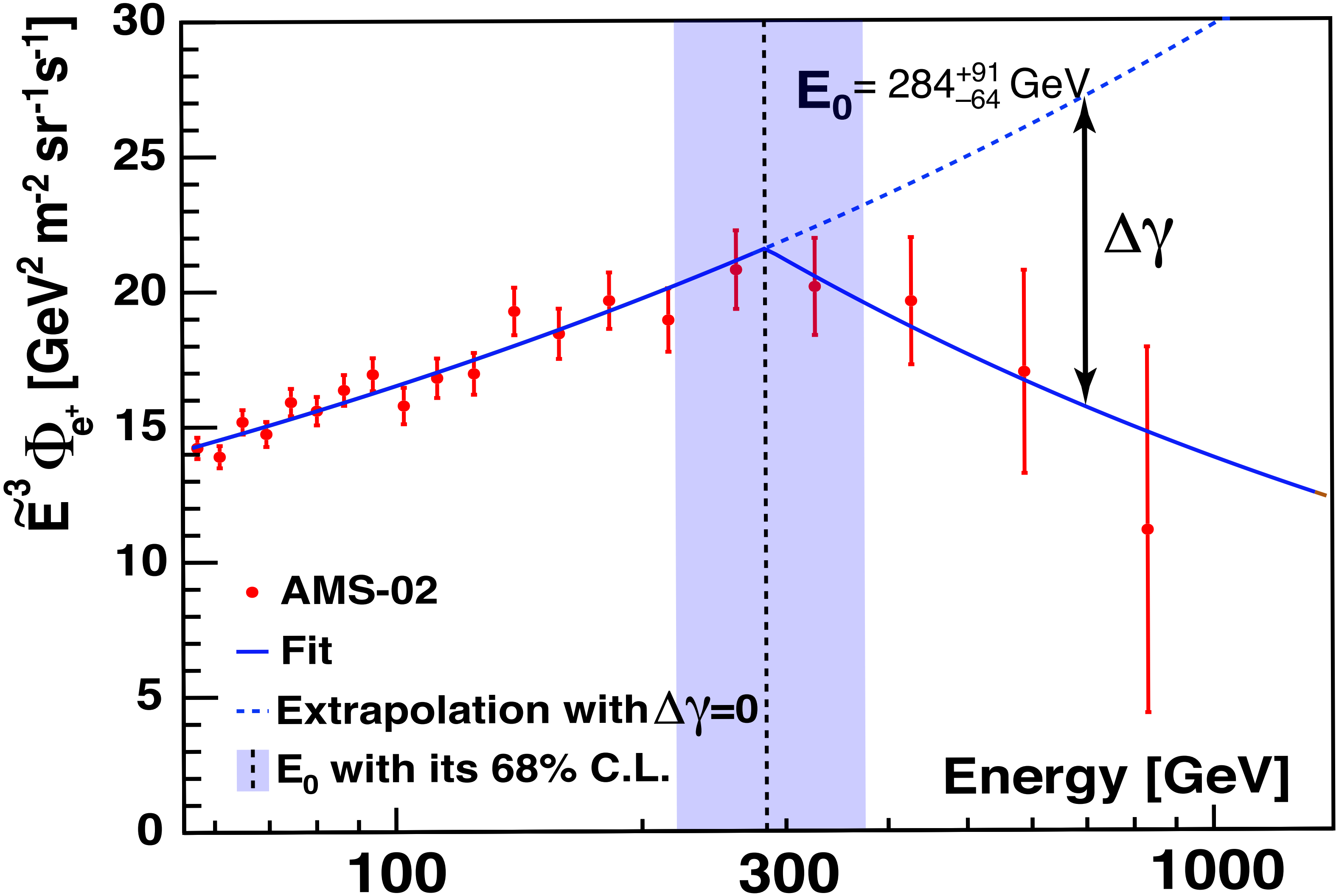
(a) A significant excess of positrons starting from E_0 = 25.2 ± 1.8 GeV compared to the lower energy trends



From fit the data in the high energy region 55.58 – 1000 GeV to

$$\Phi_{e^+}(E) = \begin{cases} C(E/55.58\,\mathrm{GeV})^{\gamma}, & E \le E_0; \\ C(E/55.58\,\mathrm{GeV})^{\gamma}(E/E_0)^{\Delta\gamma}, & E > E_0. \end{cases}$$

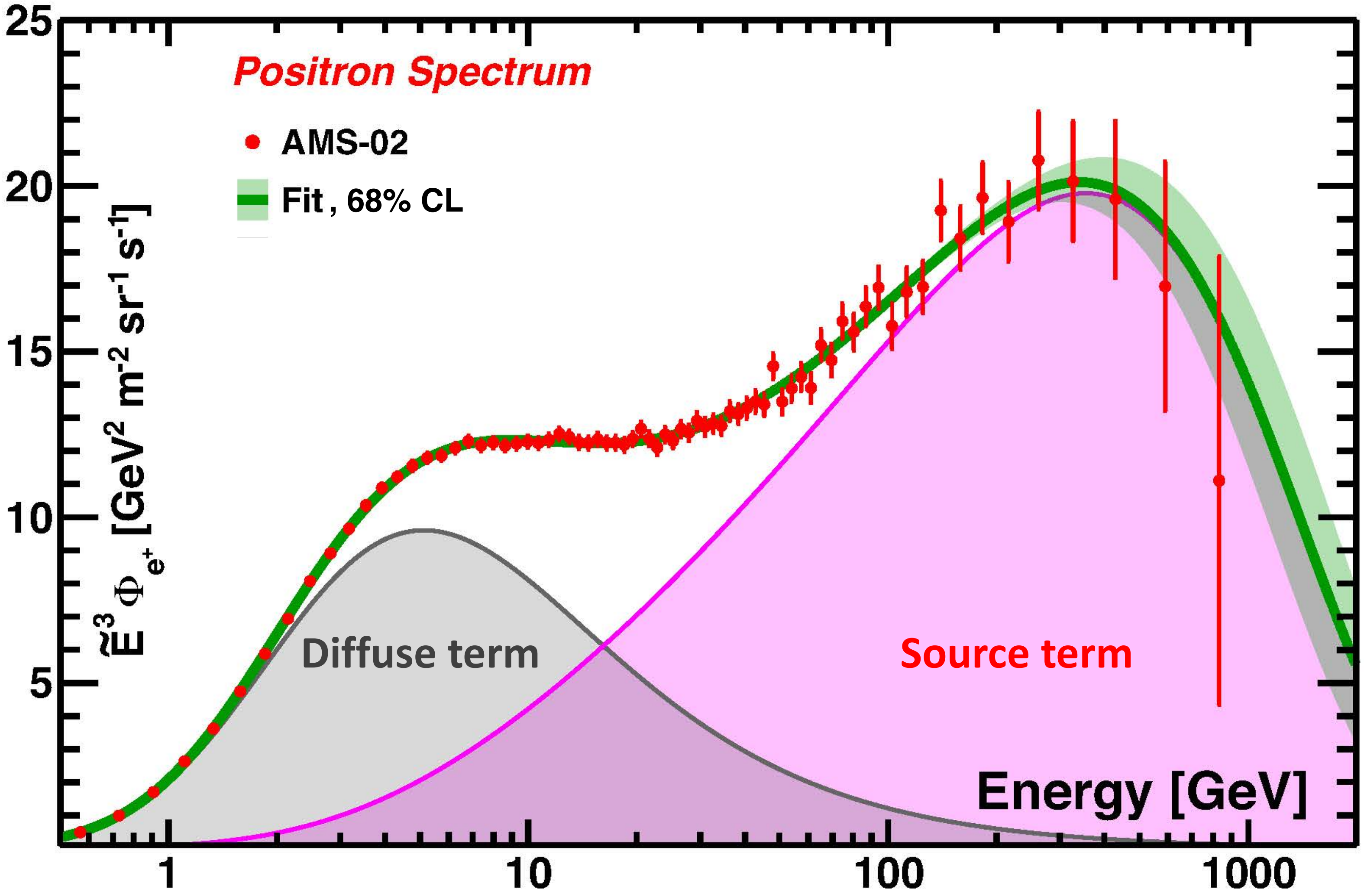
(b) A sharp drop-off of the flux above 284^{+91}_{-64} GeV.



(c) In the entire energy range the positron flux is well described by the sum of a diffuse term associated with positrons produced in the collision of cosmic rays, which dominates at low energies and a new source term of positrons, which dominates at high energies

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

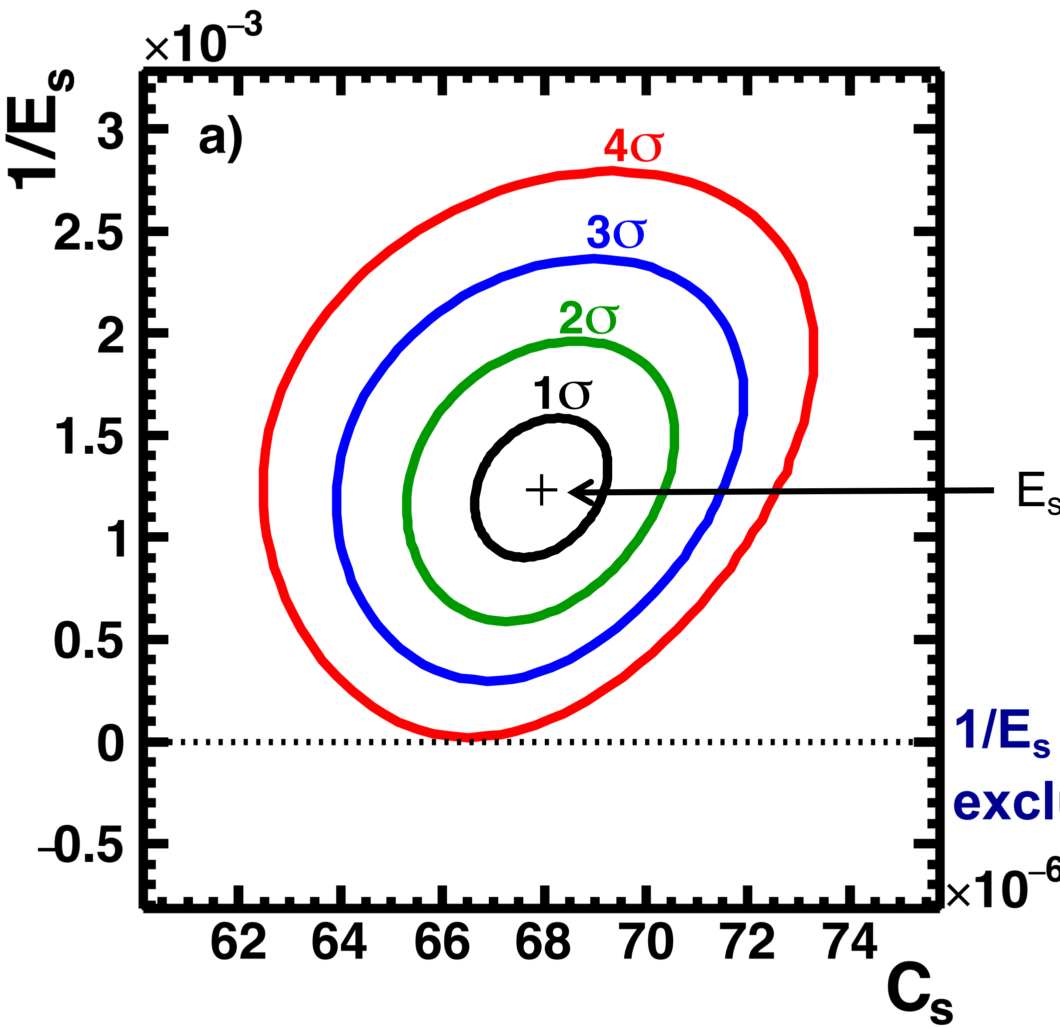
Diffuse term Source term



(d) A finite energy cutoff of the source term $E_s = 810^{+310}_{-180}$ GeV, is established with a significance more than 4**σ**.

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

Diffuse term Source term

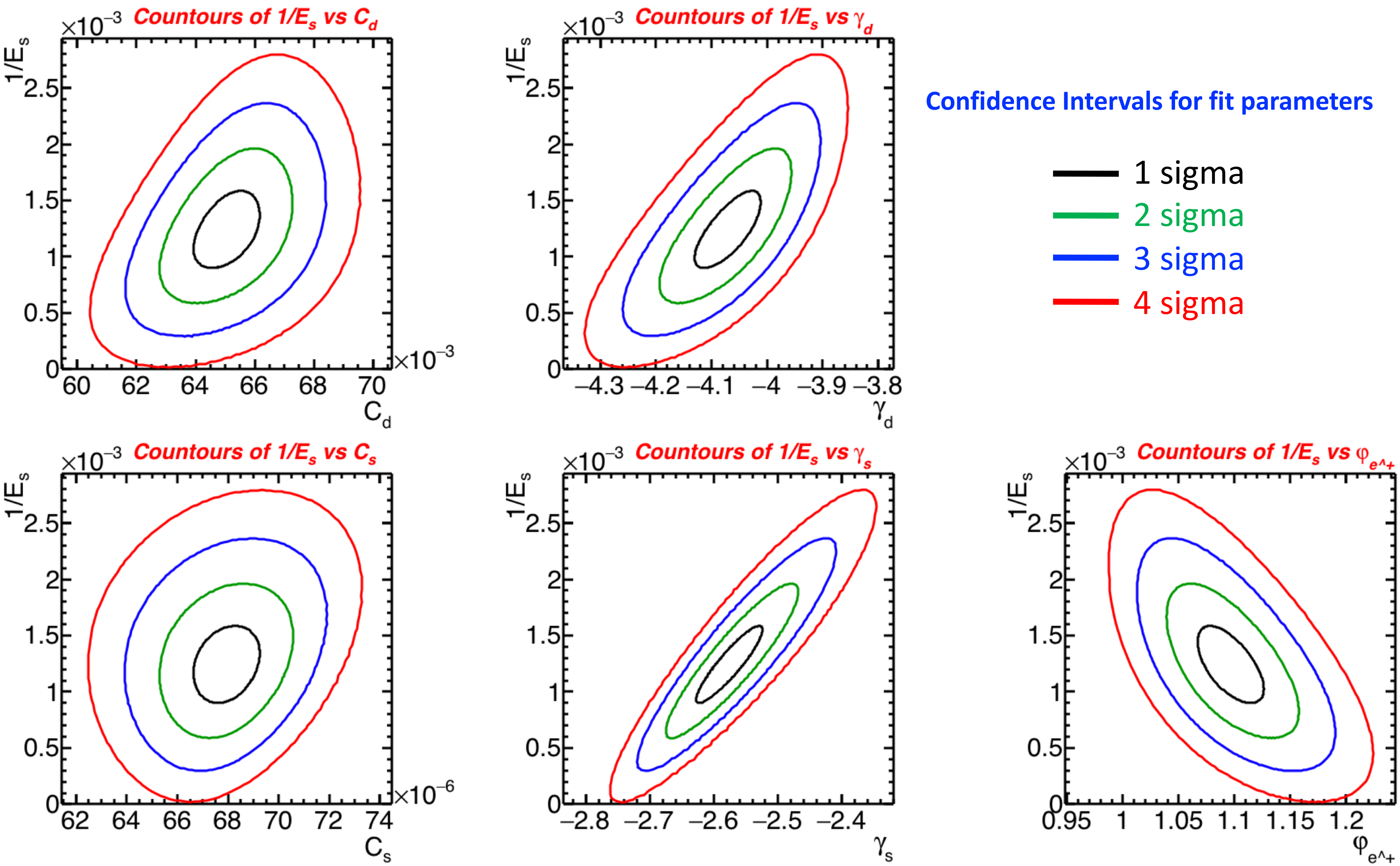


$1/E_s = 0$ or $E_s = \infty$ excluded at 4.07σ

Fit to the positron flux in energy range [0.5,1000]

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

Diffuse term Source term



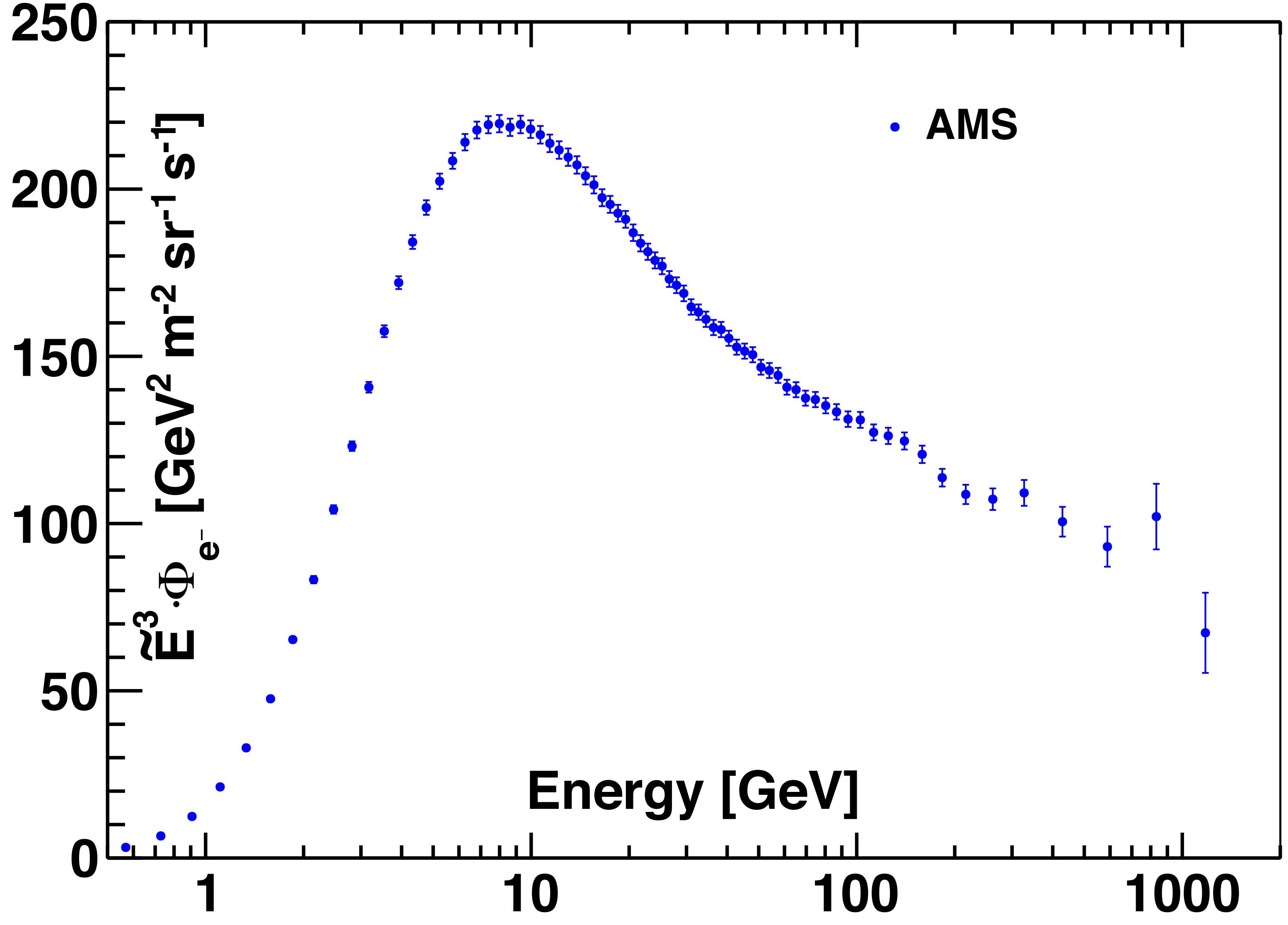
Origins of Cosmic Positrons

1. At low energies positrons originate from the collisions of cosmic rays.

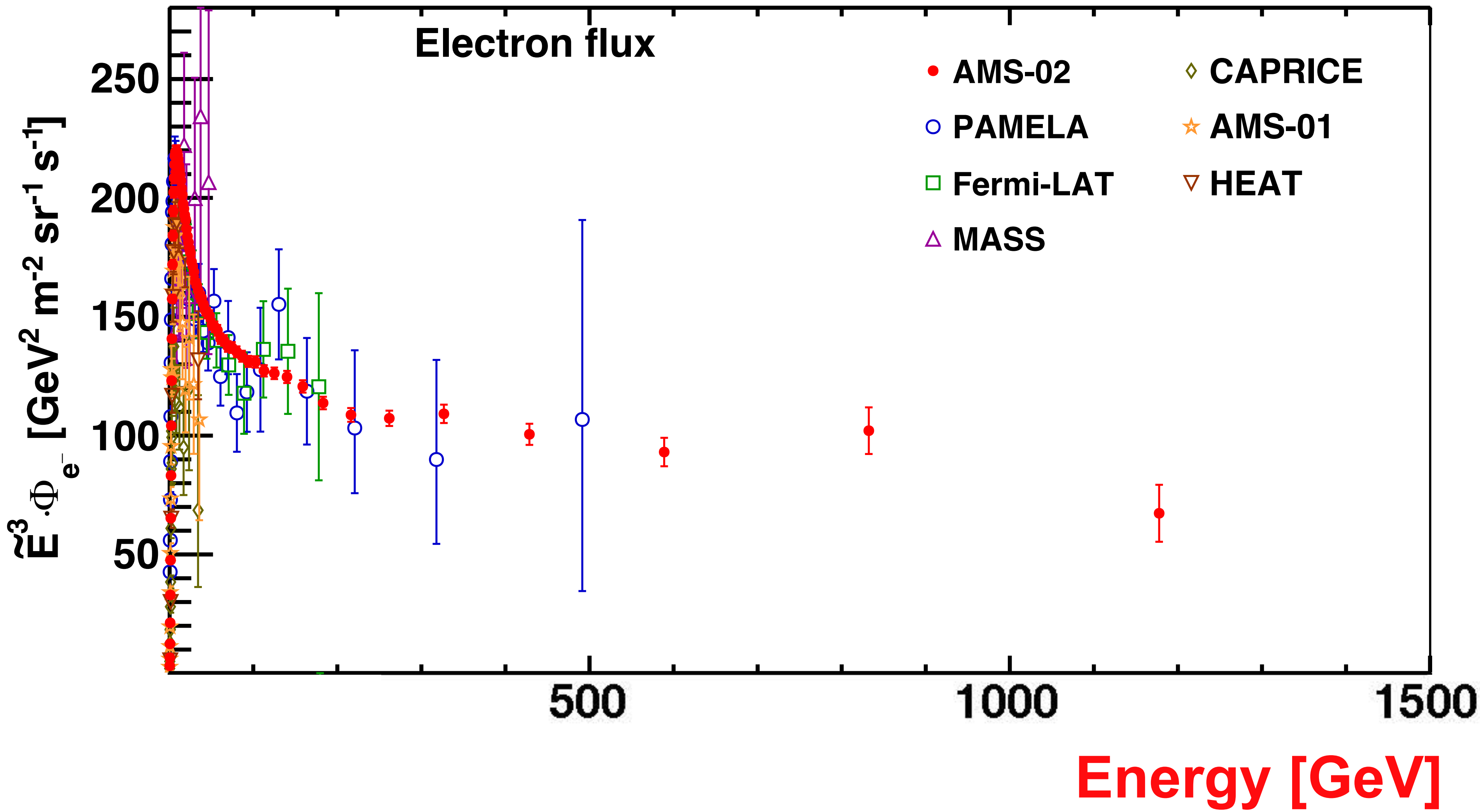
2. At high energies positrons predominately originate either from dark matter collisions or from new astrophysical sources, not from the collisions of cosmic rays.

High Energy Cosmic Electrons

Measurements of the cosmic ray electrons in the energy range from 0.5 GeV to 1.4 TeV based on 28.1 million electrons



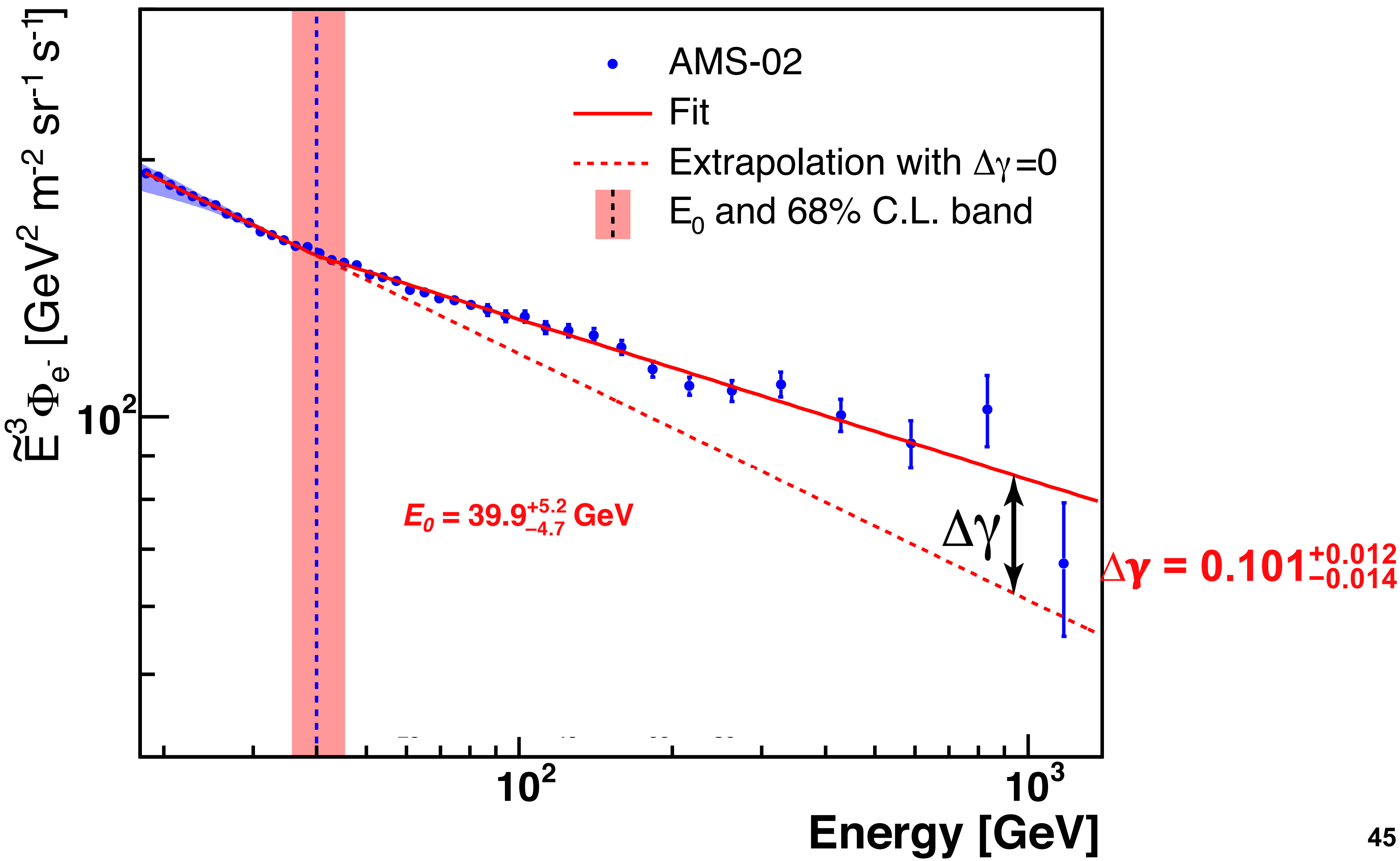
AMS (2018)
compared with earlier experiments



1. From the fit to the data in the range 17.98 – 1400 GeV to

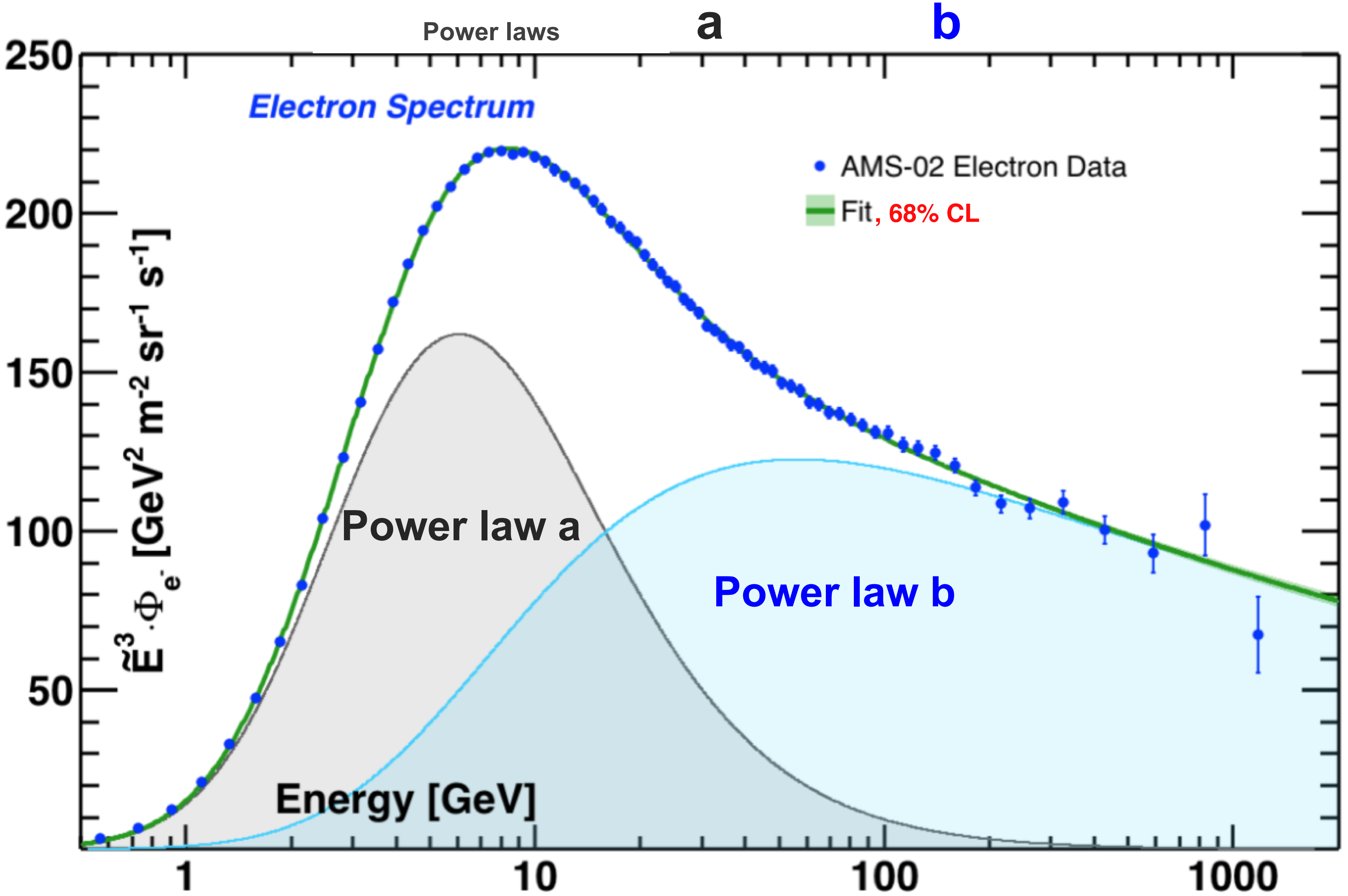
$$\Phi_{e^-}(E) = \begin{cases} C(E/17.98\,\mathrm{GeV})^{\gamma}, & E \le E_0; \\ C(E/17.98\,\mathrm{GeV})^{\gamma}(E/E_0)^{\Delta\gamma}, & E > E_0. \end{cases}$$

A significant excess above $39.9^{+5.2}_{-4.7}$ GeV



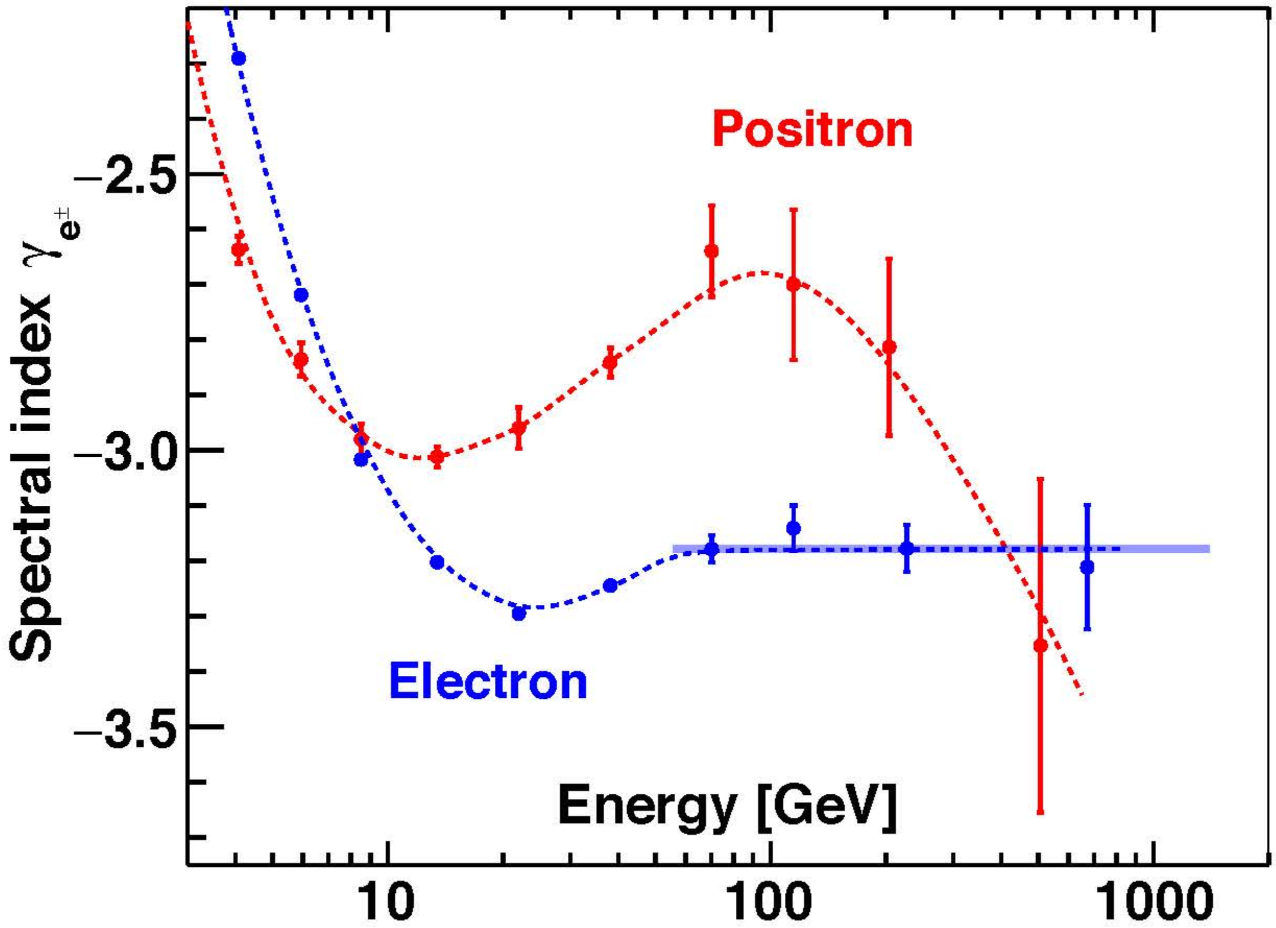
2. From 1 GeV to 1.4 TeV, the flux can be described by two power law functions.

$$\Phi_{e^-}(E) = \frac{E^2}{\hat{E}^2}[C_a(\hat{E}/E_a)^{\gamma_a} + C_b(\hat{E}/E_b)^{\gamma_b})]$$



3. **Comparison of the behavior of the cosmic ray electrons and positrons shows that most high energy electrons originate from a different source than high energy positrons.**

$$\gamma_{e^\pm} = d[\log(\Phi_{e^\pm})]/d[\log(E)]$$

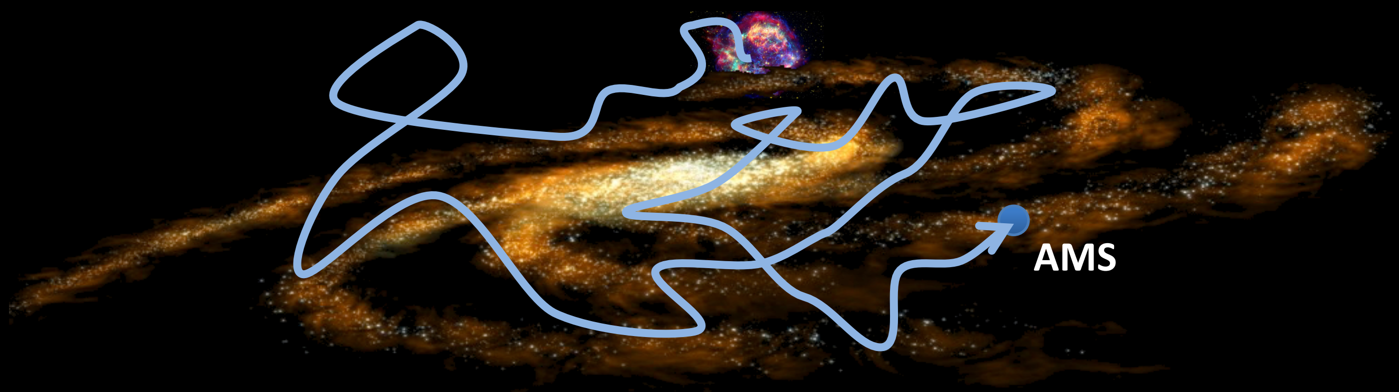


High energy electrons mostly come from a different origin than high energy positrons.

Traditionally, there are two prominent classes of cosmic rays:

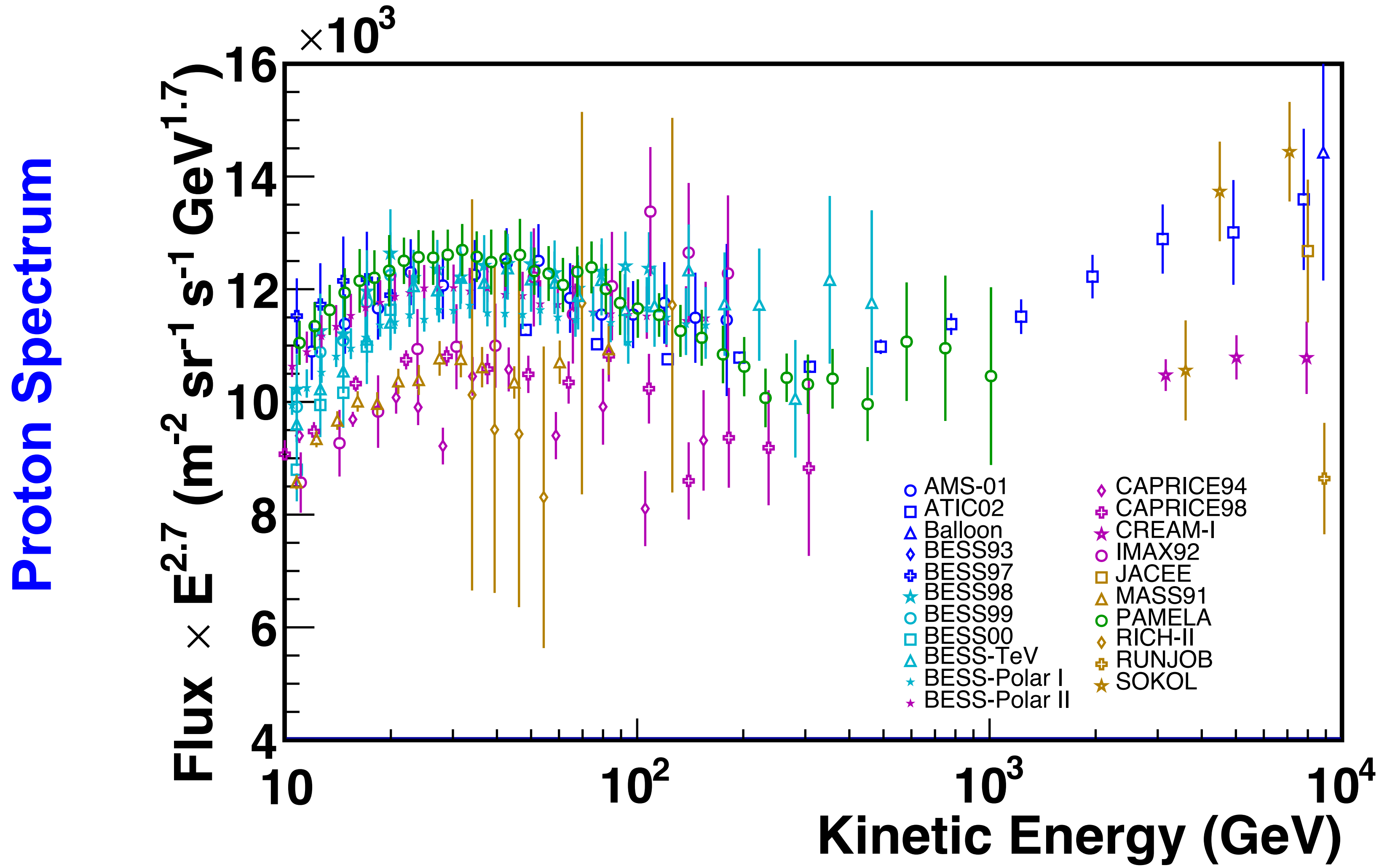
Primary Cosmic Rays (p, He, C, O, …)

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.

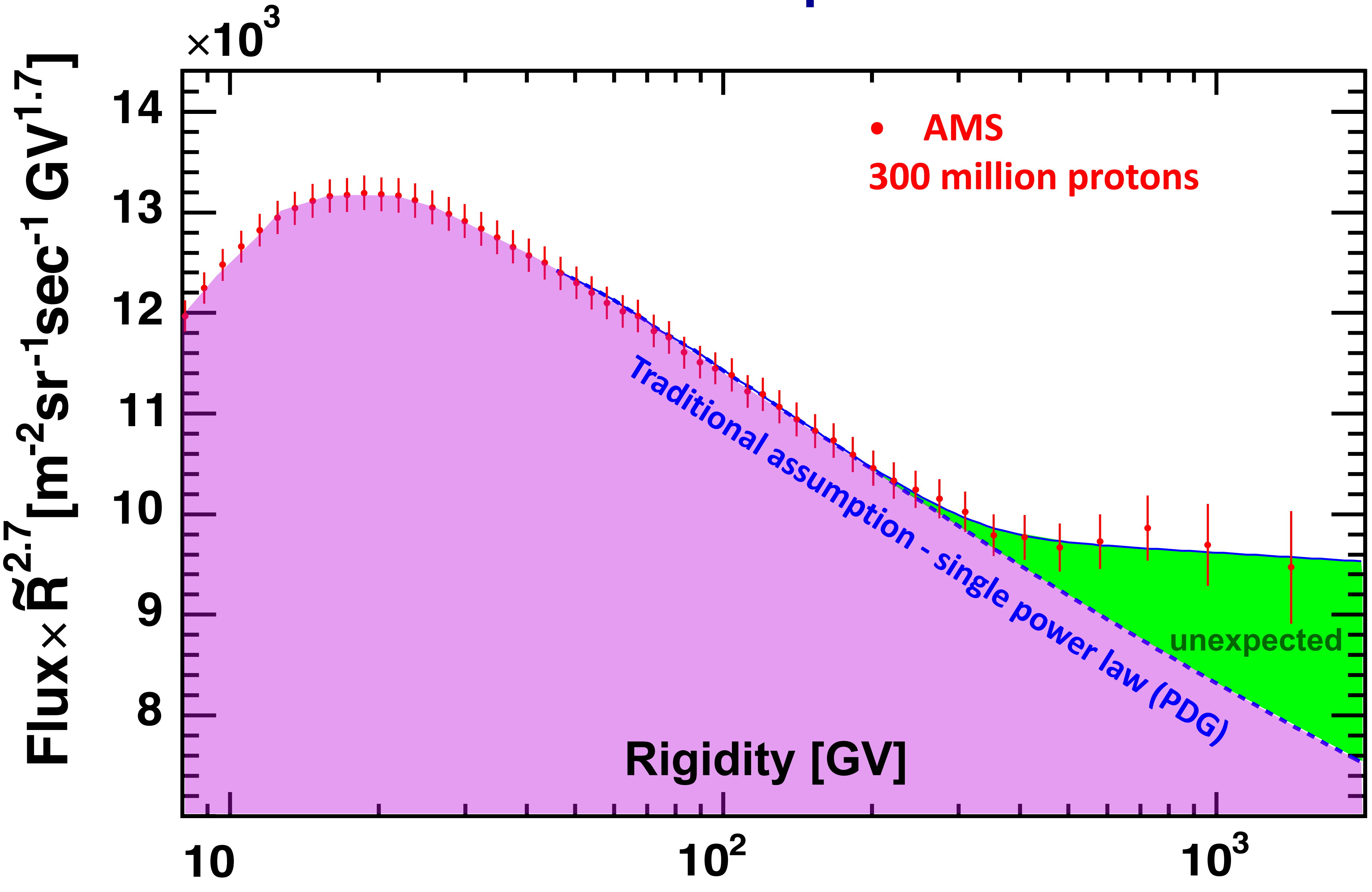


Cosmic Protons

1. Protons are the most abundant cosmic rays.
2. Before AMS there have been many measurements of the proton spectrum.
3. In cosmic rays models, the proton spectral function was assumed to be a single power law $\Phi = CE^{\gamma}$ with $\gamma = -2.7$

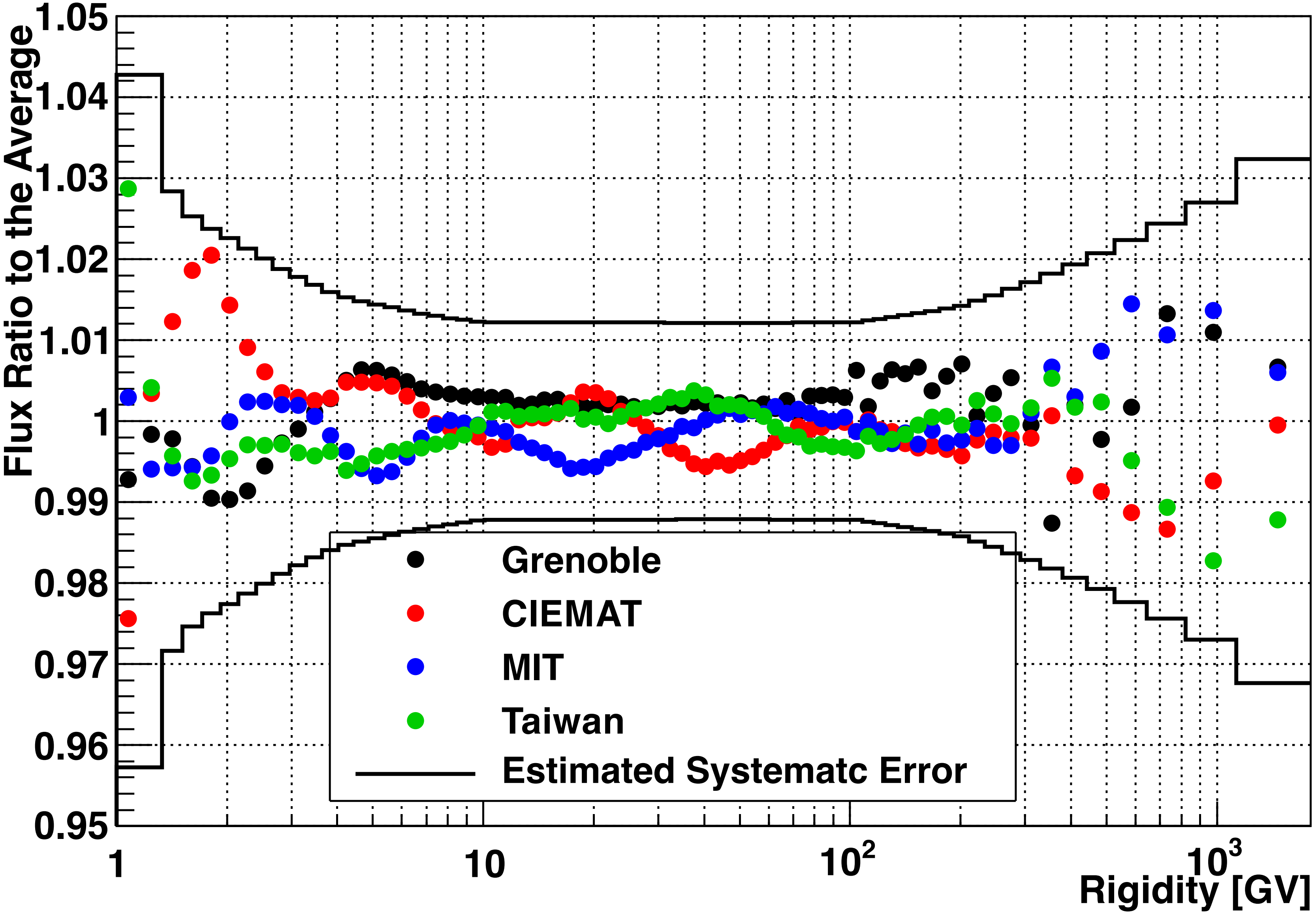


AMS results on the proton flux

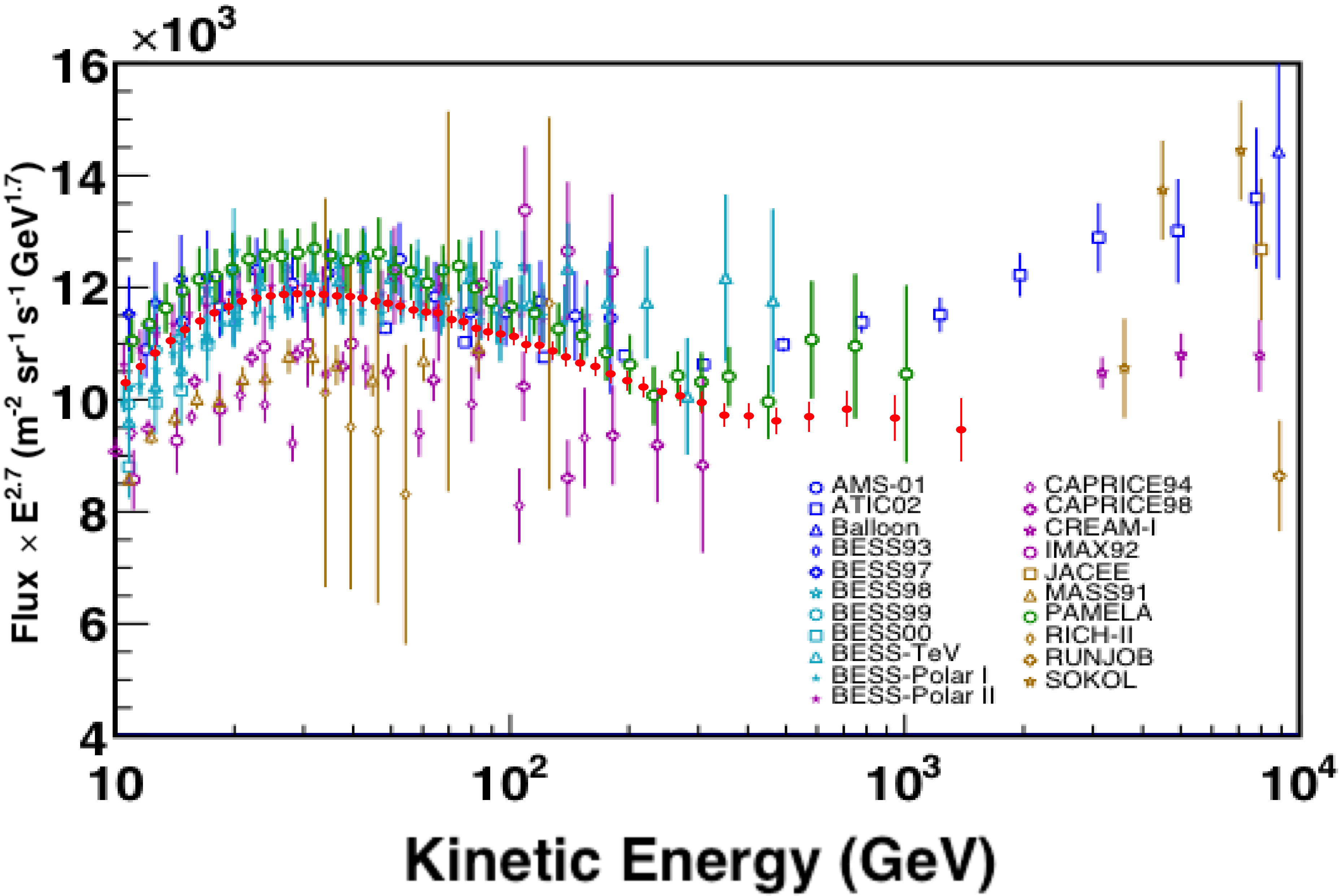


The proton flux cannot be described by a single power law = CR^{γ}

AMS Measurements: Analysis from 4 different countries

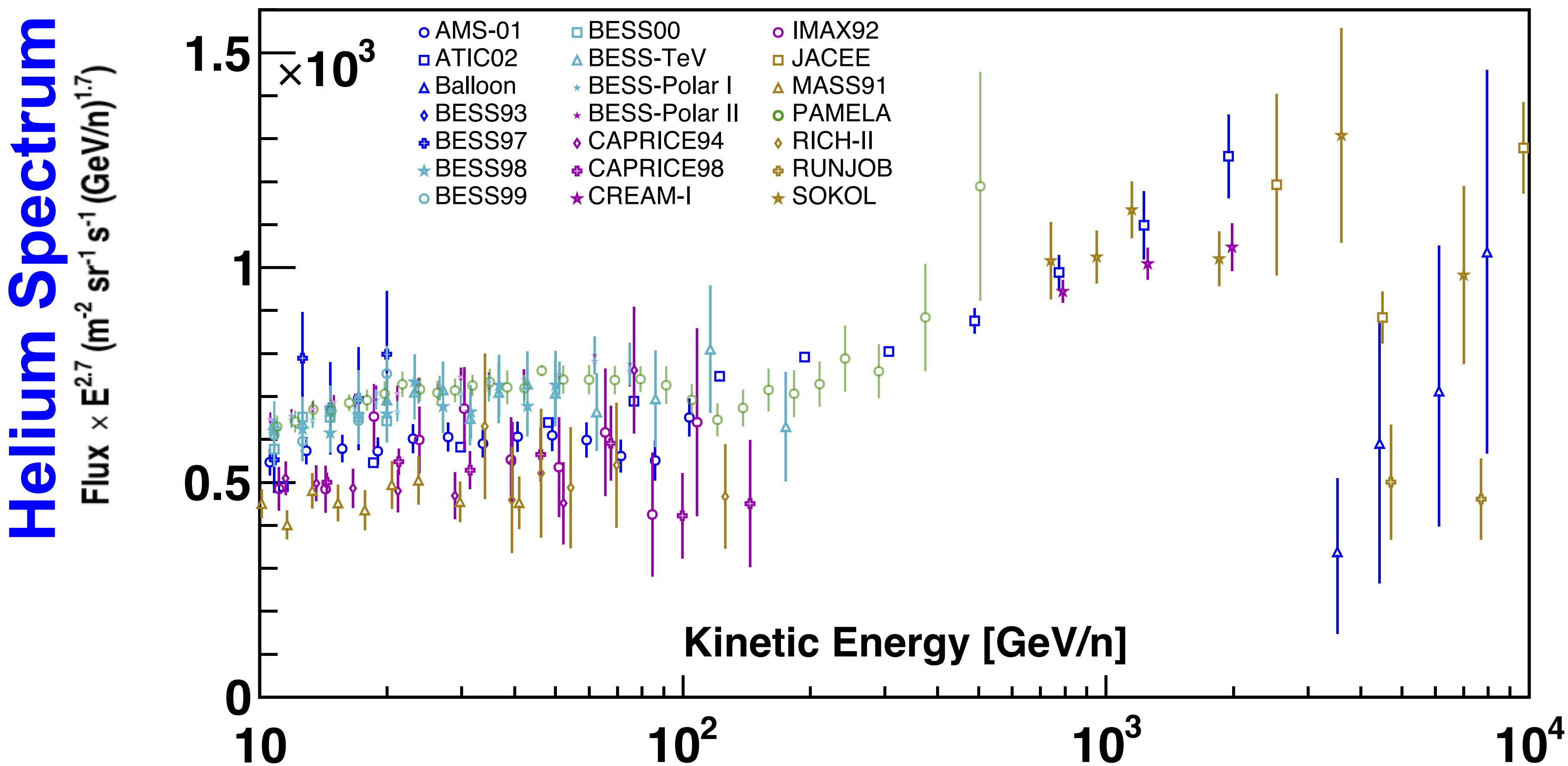


AMS Measurement of the proton spectrum

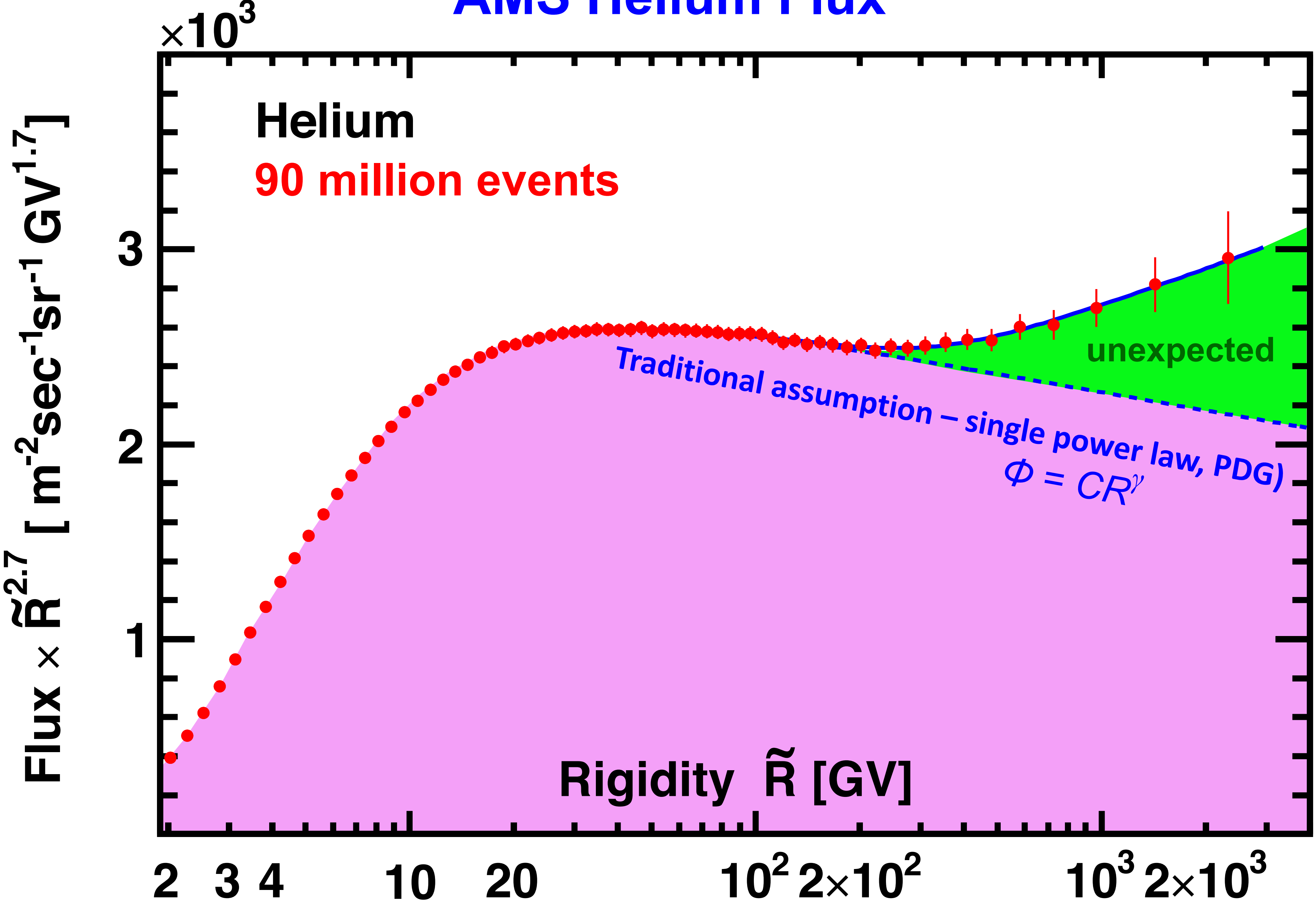


Measurements of the Helium Flux

1. Helium is produced in supernovas and is the 2nd most abundant cosmic ray.
2. It has been studied extensively.
3. In cosmic rays models, the helium spectral function was assumed to be a single power law with γ = -2.7

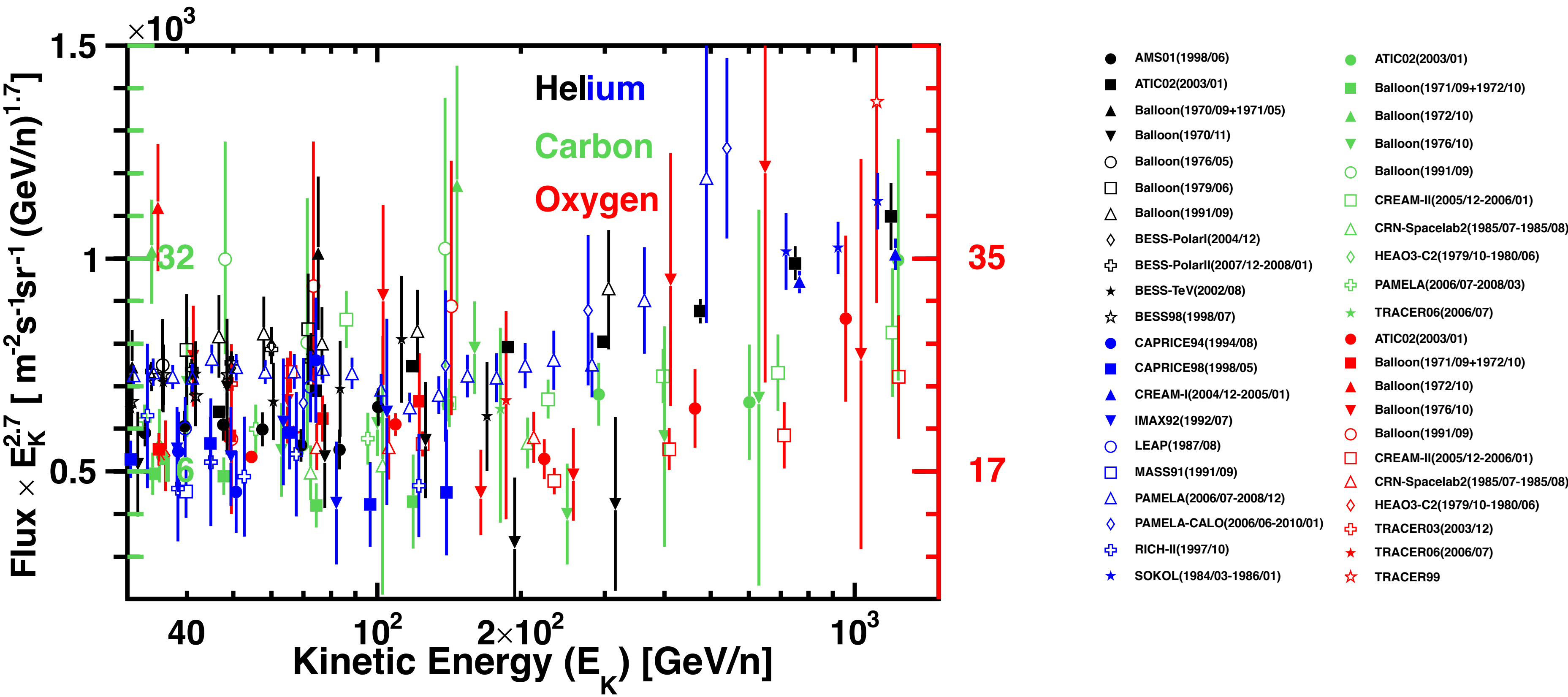


AMS Helium Flux

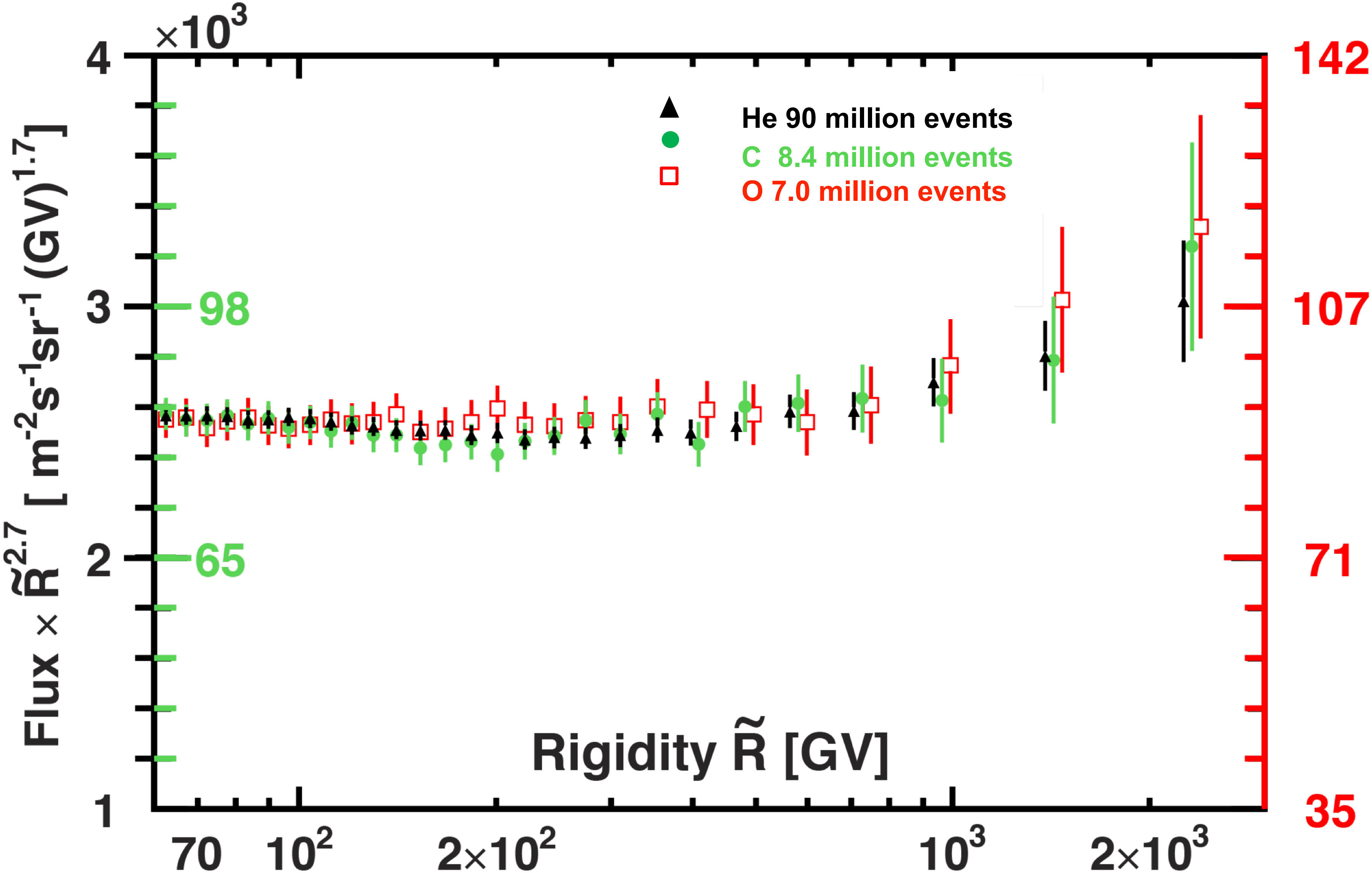


The Helium flux cannot be described by a single power law.

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

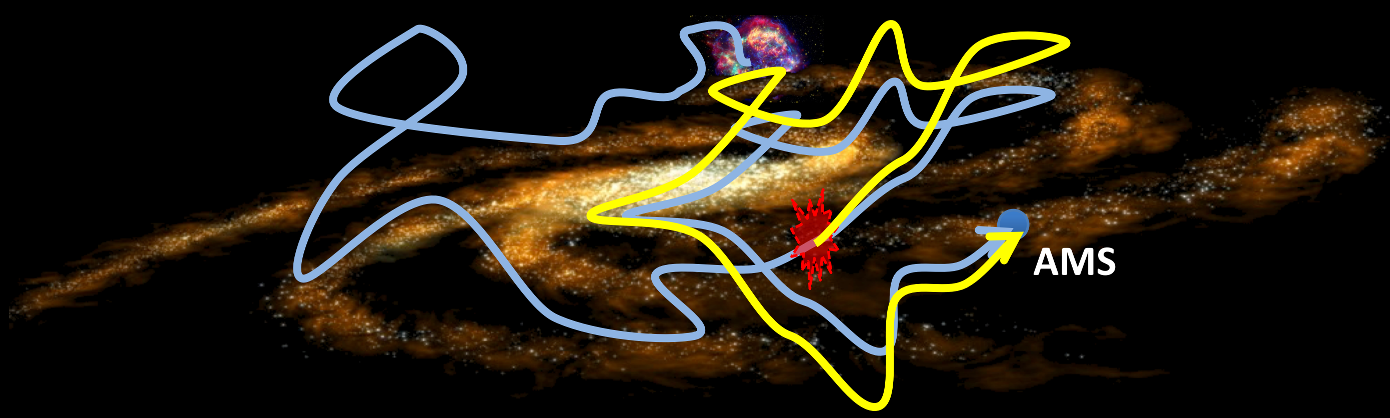


AMS Result: Surprisingly, above 60 GV, these fluxes have identical rigidity dependence.



Traditionally, there are two prominent classes of cosmic rays:

Primary Cosmic Rays (p, He, C, O, …)

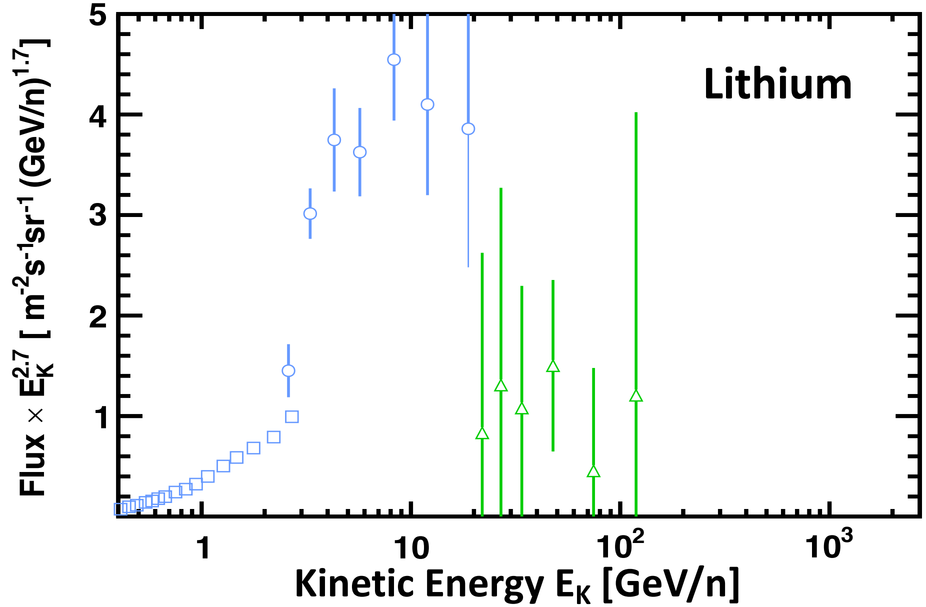


Secondary Cosmic Rays (Li, Be, B, …)

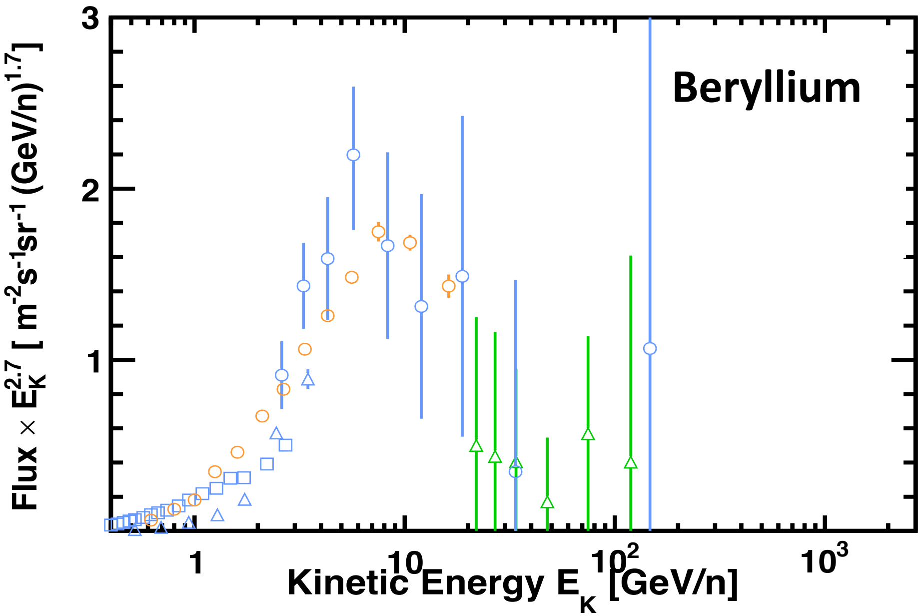
are produced in the collisions of primary cosmic rays. They carry information on the history of the travel and on the properties of the interstellar matter.

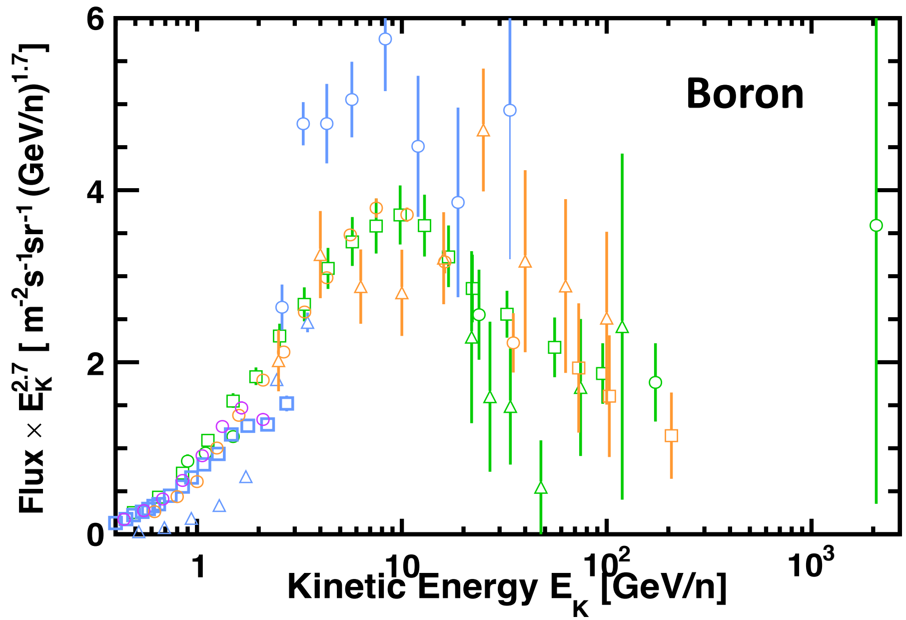
Flux Measurements of Li, Be, B before AMS

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

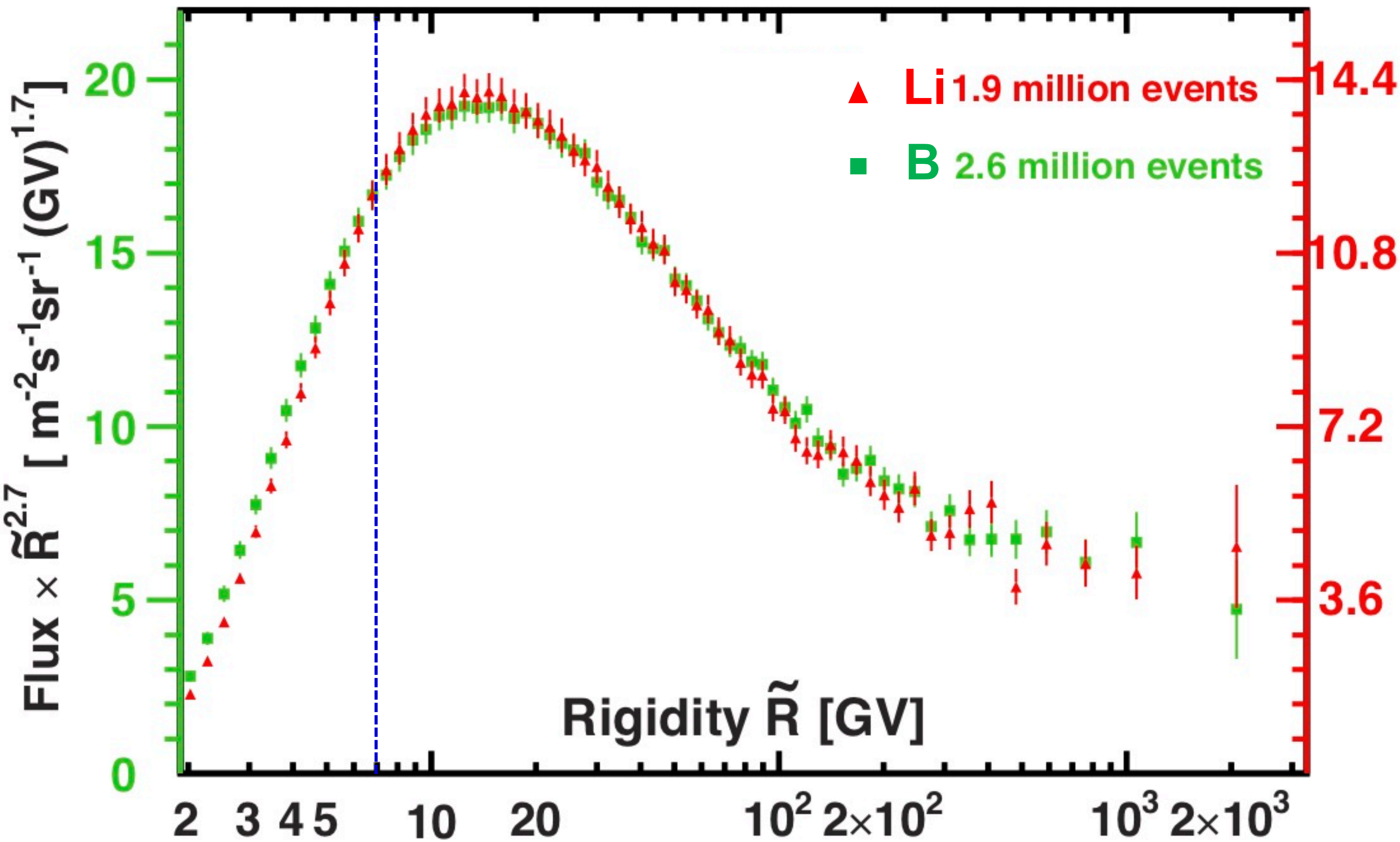


Typically, the error on each flux is larger than 50% at 100 GV

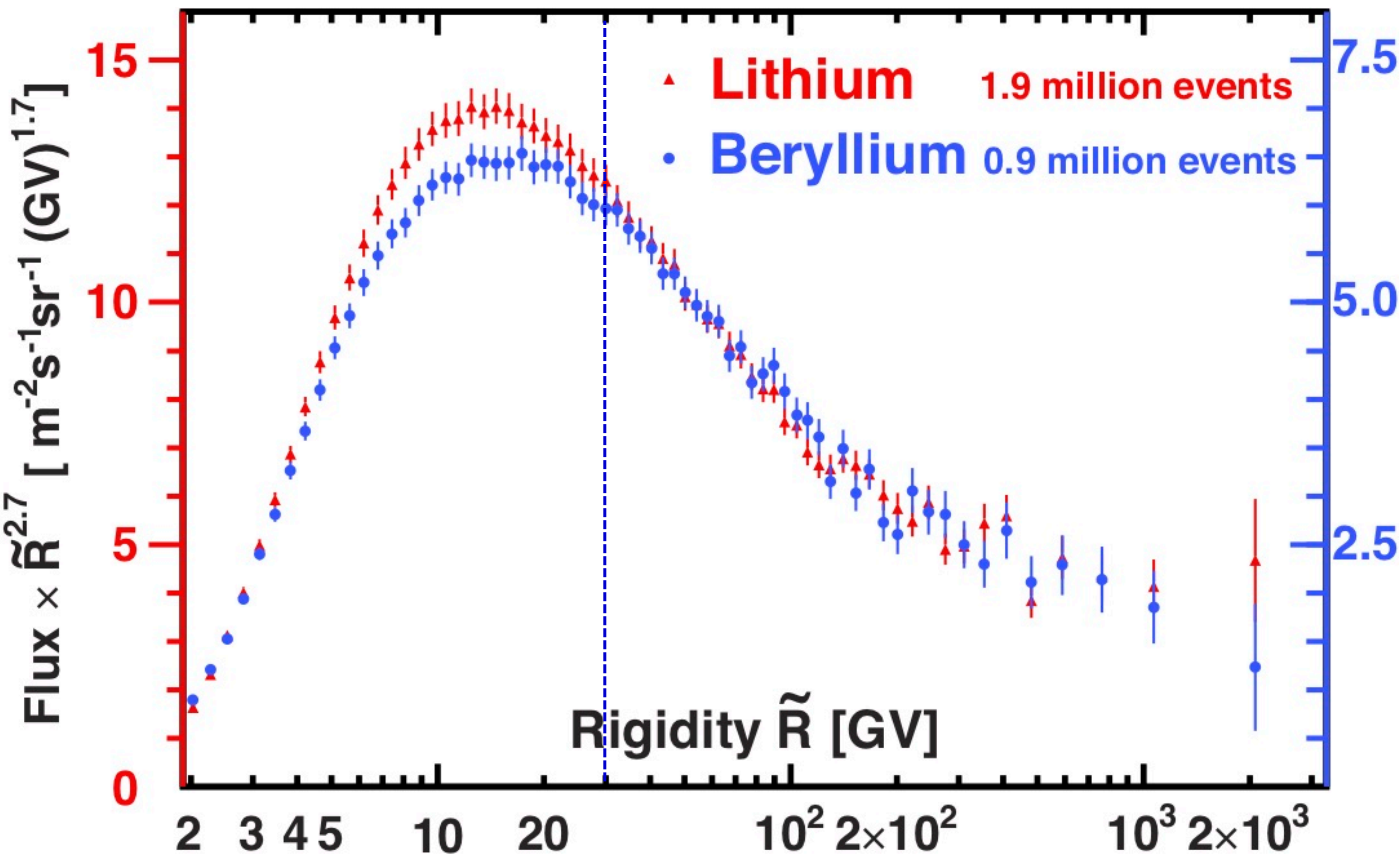




AMS Secondary Cosmic Rays: Lithium and Boron

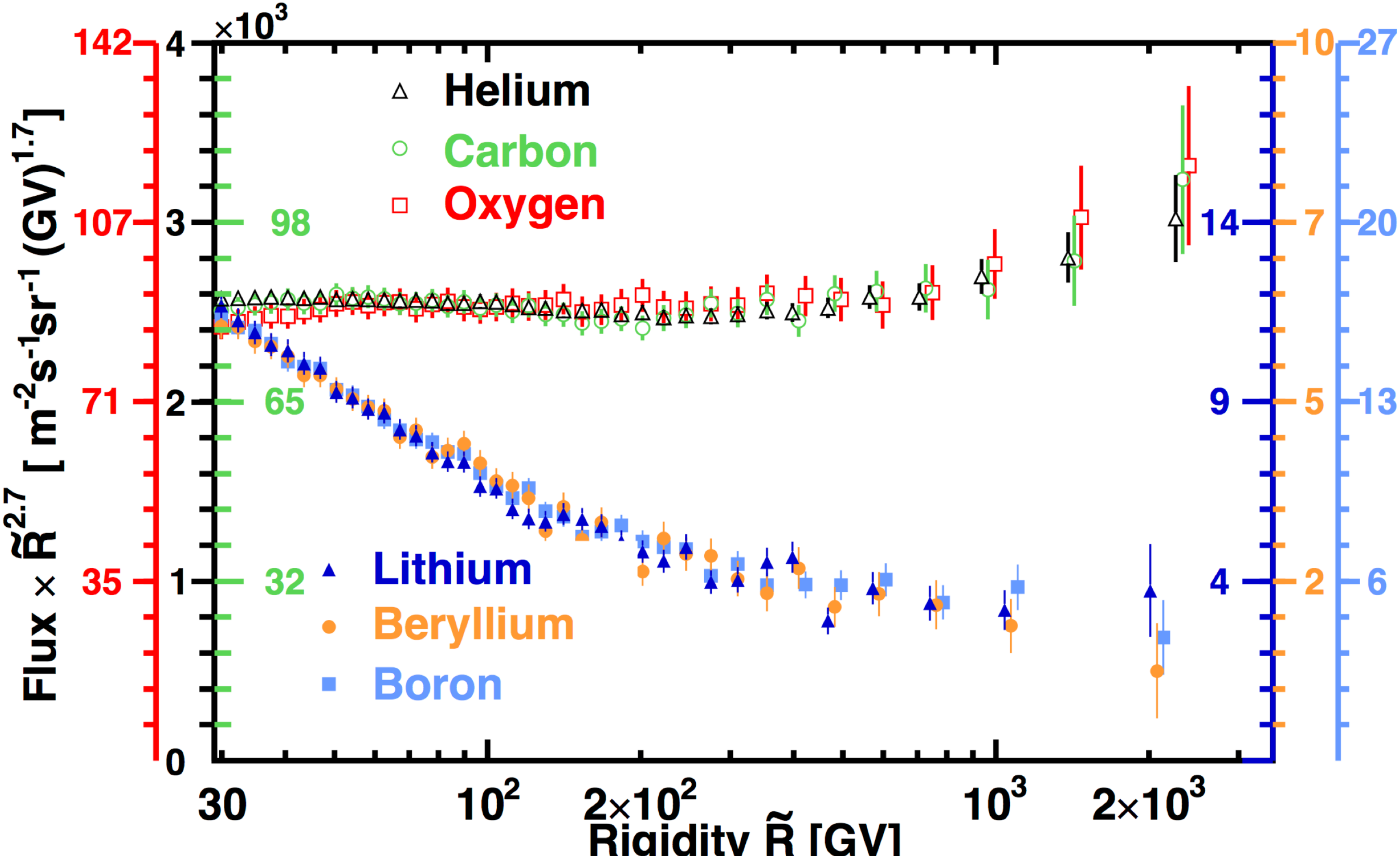


AMS Secondary Cosmic Rays: Lithium and Beryllium

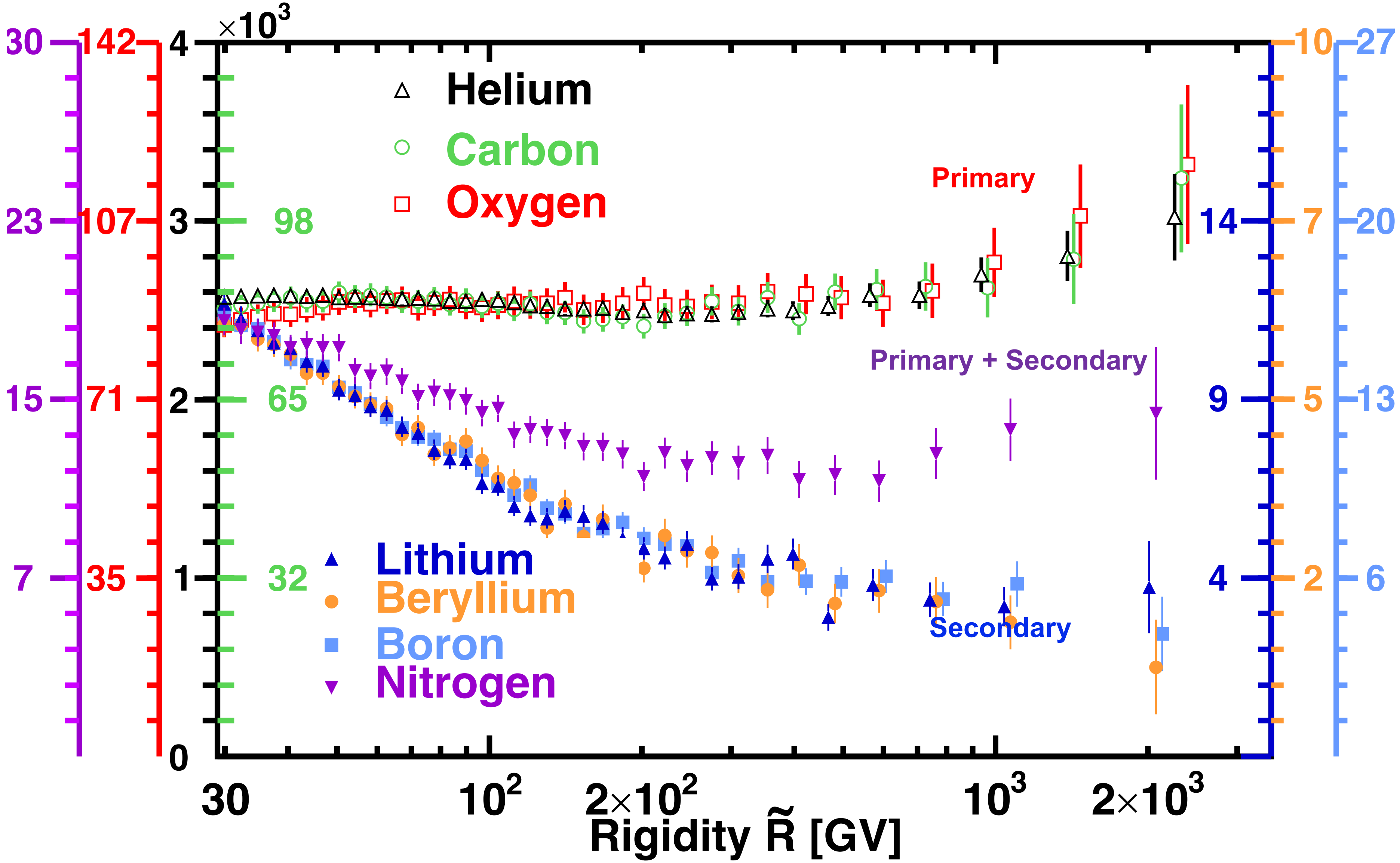


AMS Result:

Secondary cosmic rays Li, Be, and B also have identical rigidity dependence but they are different from primaries



Summary of Flux of Elements

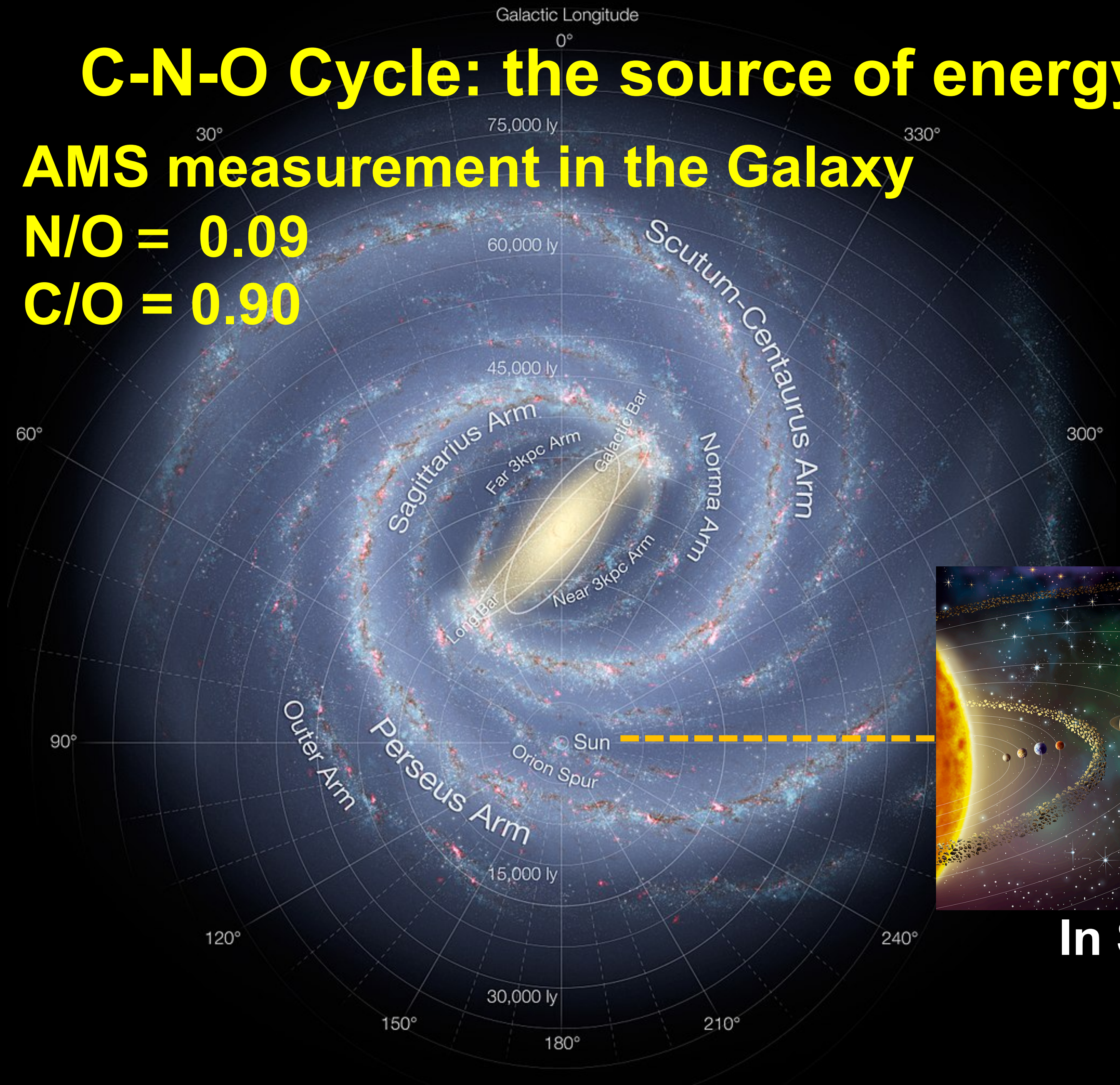


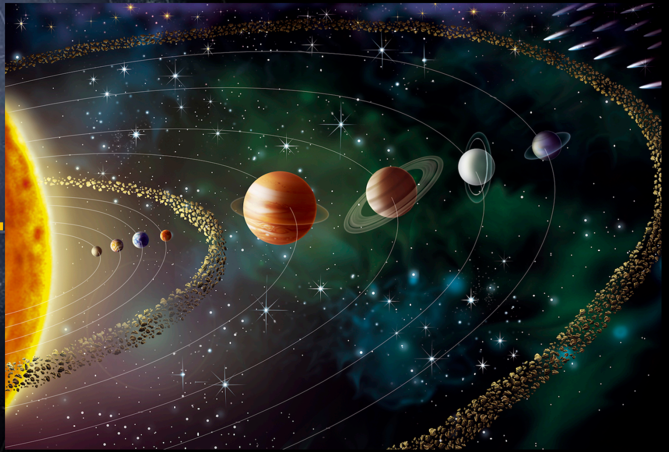
C-N-O Cycle: the source of energy in stars

AMS measurement in the Galaxy

N/O = 0.09

C/O = 0.90



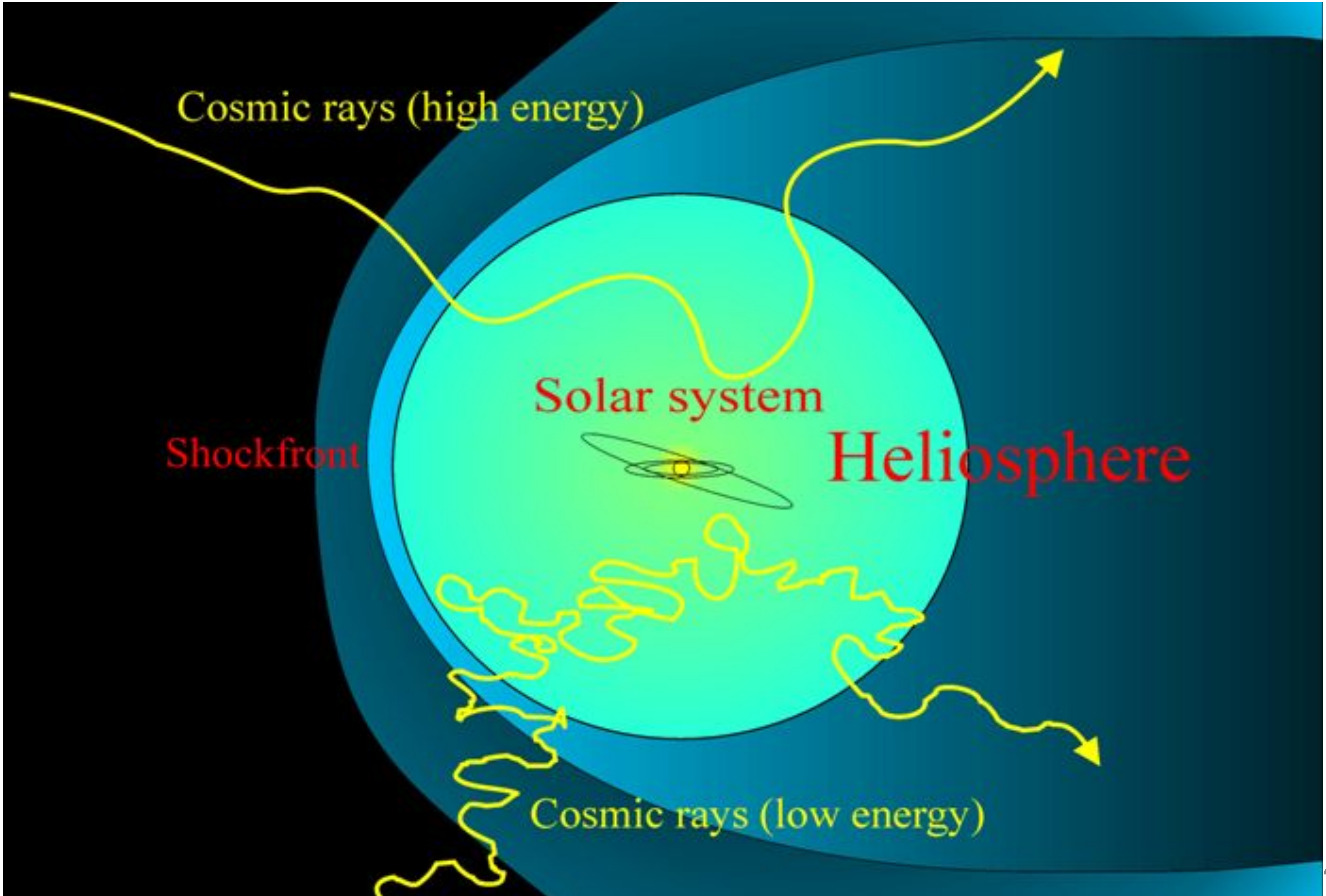


In Solar System:

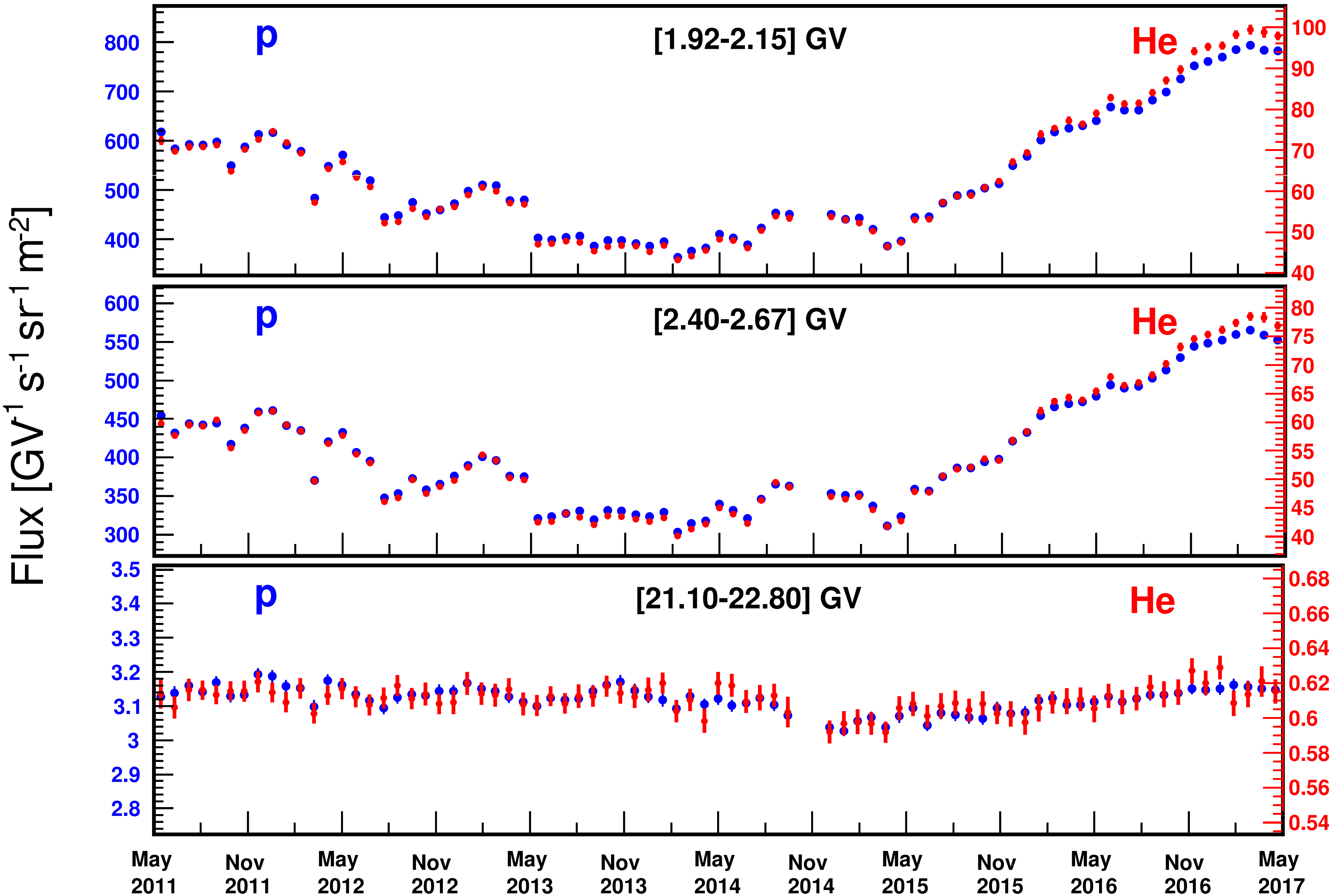
N/O = 0.14

C/O = 0.46

Time structures in the p and He fluxes in Solar System



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

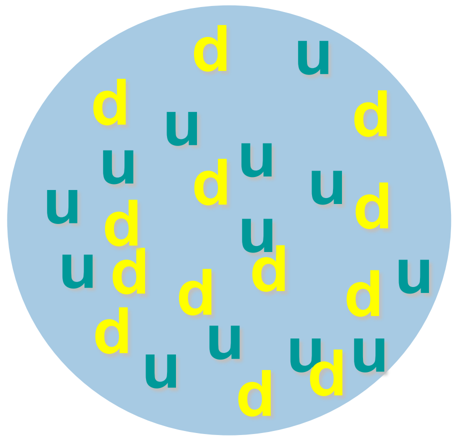


Strange Quark Matter – "Strangelets"

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

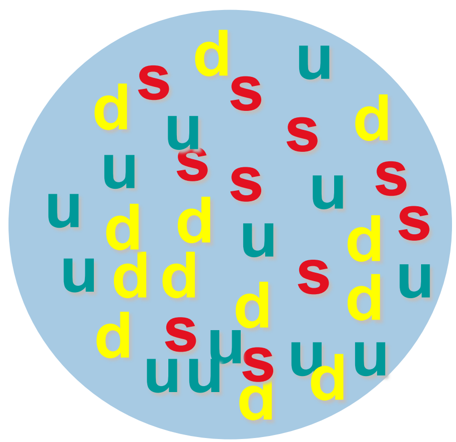
There are six quarks – u, d, s, c, b, and t.

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



Diamond (Z/A ~ 0.5)

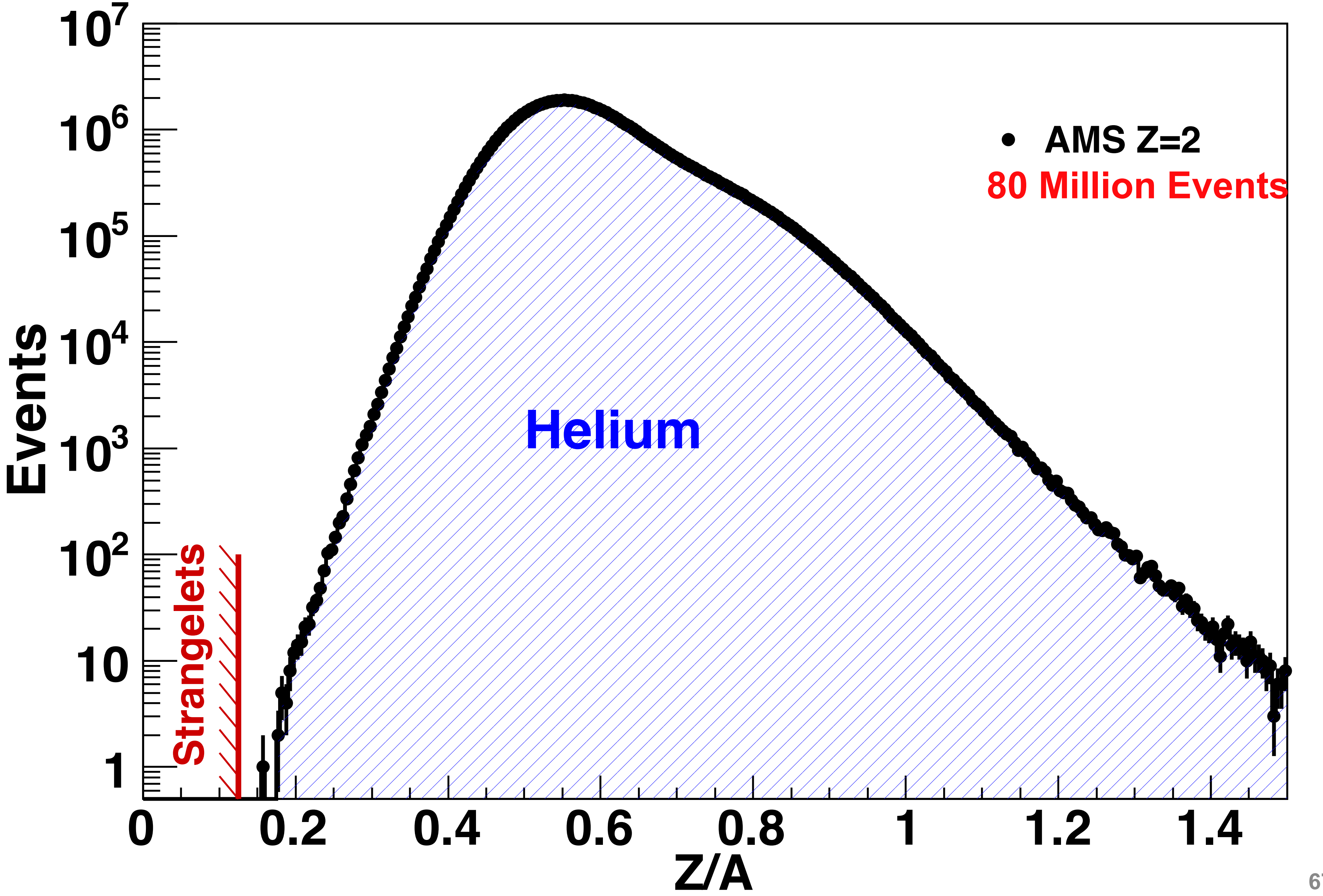
Is there material in the universe made up of u, d, & s quarks?



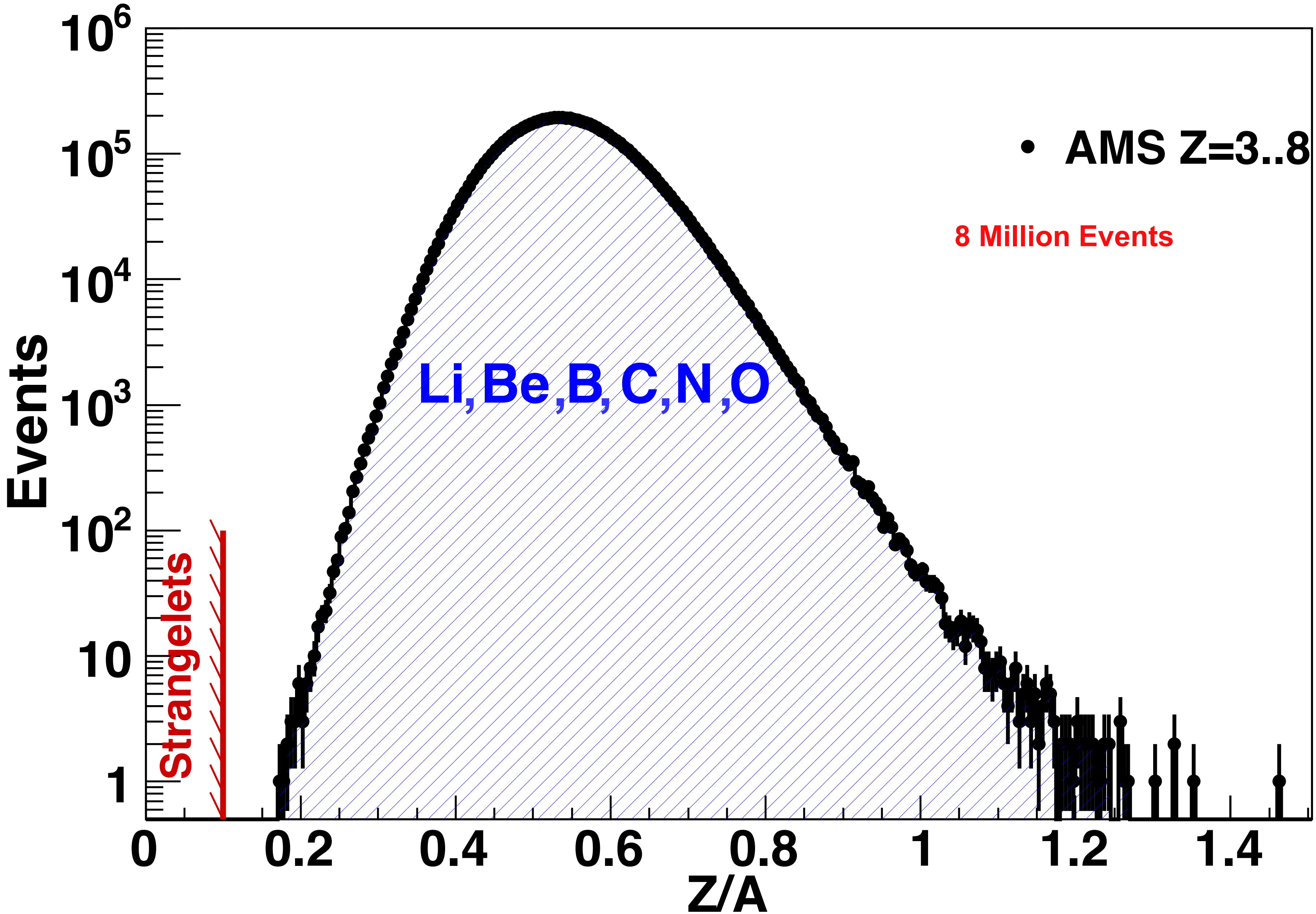
Strangelet (Z/A < 0.1)

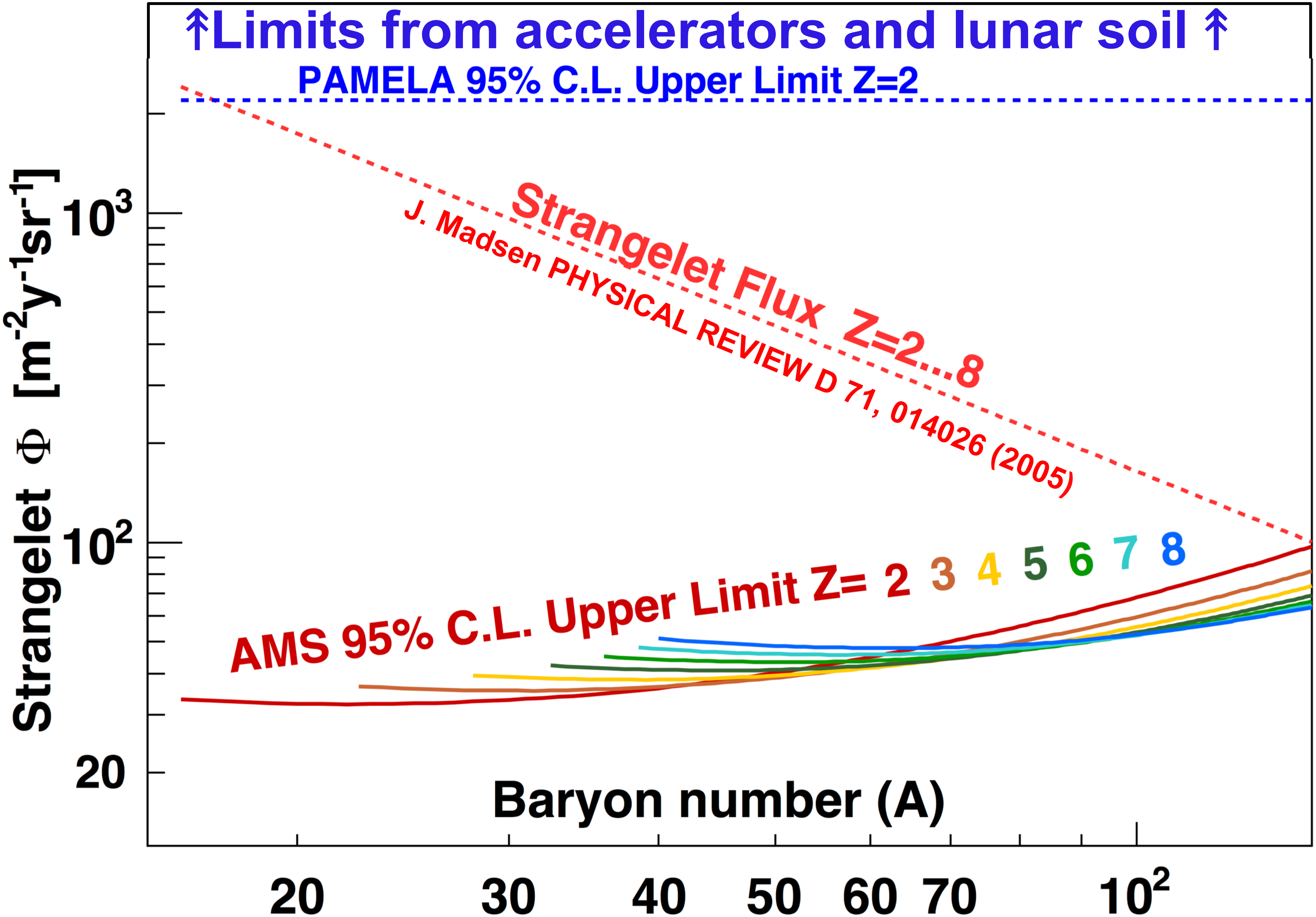
This is being answered by AMS.

Search for Strangelets Z =2



Search for Strangelets Z =3..8





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

International Recognition of AMS Results
AMS Publications (>2600 inSPIRE citations)

1) M. Aguilar *et. al*., Phys. Rev. Lett. 110 (2013) 141102. Editor's Suggestion, Viewpoint in Physics, Highlight of the Year 2013.
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.

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

Since we began Editors' Suggestions 10 years ago, we have published about 3000 PRLs marked as an Editors' Suggestion.
To mark the 10 year anniversary, each week we are posting a placard (like the one I sent you--a link to the paper and a brief description) on our website for one of those papers. So we are picking just 52 out of the 3000 possible candidates (and each candidate was of course already a PRL paper we chose to highlight). 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

Department of Energy
Office of Science
Washington, DC 20585

JUL 30 2018

Professor Samuel Ting
Massachusetts Institute of Technology
Department of Physics
77 Massachusetts Avenue
Cambridge, MA 02139-4307

Dear ~~Professor~~ SAM Ting:

Thanks very much for hosting the DOE meeting with the AMS International Collaboration leadership in May at CERN. That meeting made the international situation with AMS clearer to DOE and updated the Department on science topics being pursued by the international collaborators. We noted that the DOE Portfolio Review's focus on specific science drivers that are identified in the U.S. P5 strategic plan, and MIT's activities in support of AMS excluded the international participants from the review. We understand this caused your collaborators great concern. While noting the results of the Portfolio Review, the broader coverage of the 2016 Blue Ribbon Panel Review provides a more complete picture of AMS science directions for input to DOE decision making.

DOE concludes AMS has been an historic experiment, which has reshaped our understanding of cosmic rays and the astrophysical processes responsible for their creation and propagation through the universe. Based on the results of the 2016 Blue Ribbon Panel Review, there is a compelling science case to continue AMS operations and to expand its landmark dataset. Additional AMS operations through at least 2024, which signifies the current operational window for ISS, are well-justified for this purpose. DOE will therefore continue to support the planned work with NASA to prepare for an EVA for repair of AMS in 2019. These findings and recommendations have been communicated to our colleagues at NASA.

Sincerely,

James Siegrist

James Siegrist
Associate Director of the Office of Science
for High Energy Physics

From: Schael Stefan <schael@physik.rwth-aachen.de>
Date: October 23, 2018 at 7:31:05 PM GMT+3
To: Ting Sam <Samuel.Ting@cern.ch>
Subject: University Kiel in AMS
Dear Sam,

as we have discussed several times, the group
of Prof. B. Heber, University Kiel
has received funding from the German Space Agency
(DLR) to join the AMS Collaboration from 01. October 2018
onward. We had a first meeting today in Aachen to discuss
the physics program.

Prof. Heber is one of the leading experts on low energy cosmic rays
and solar modulation. His group could significantly help us with
the understanding of the time dependent low energy data.
They will also participate in detector shifts

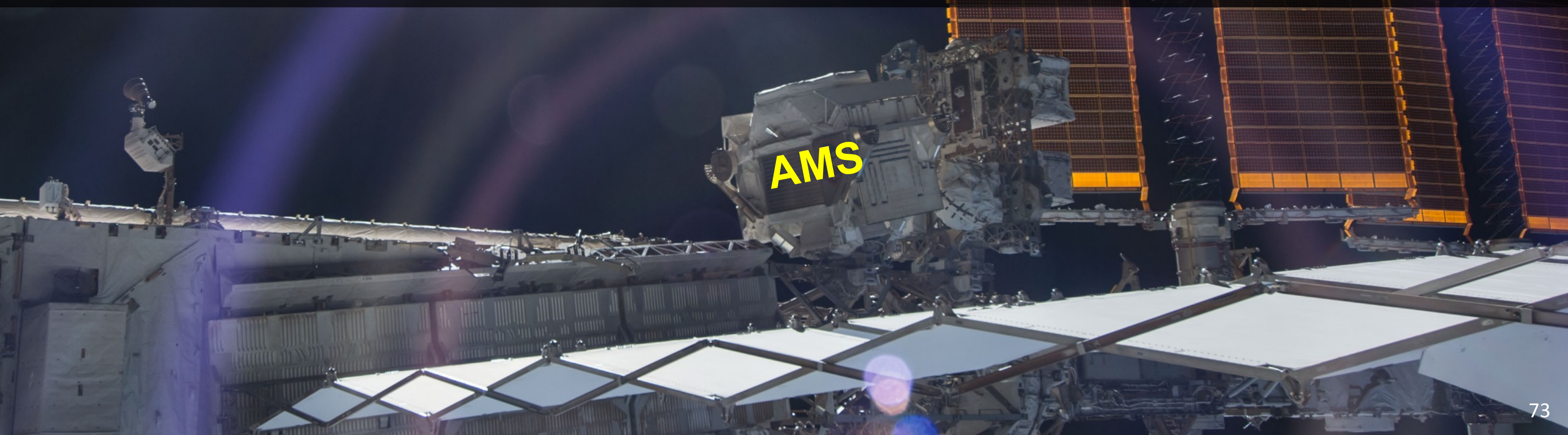
Prof. Heber will attend the next TIM Meeting at CERN in
November. I will introduce him to you.

Best regards, Stefan

Prof. Dr. Stefan Schael
RWTH Aachen
I. Physikalisches Institut
Sommerfeldstr. 14
D-52074 Aachen
Tel.: +49 241 802 7159

The physics of AMS to 2024:

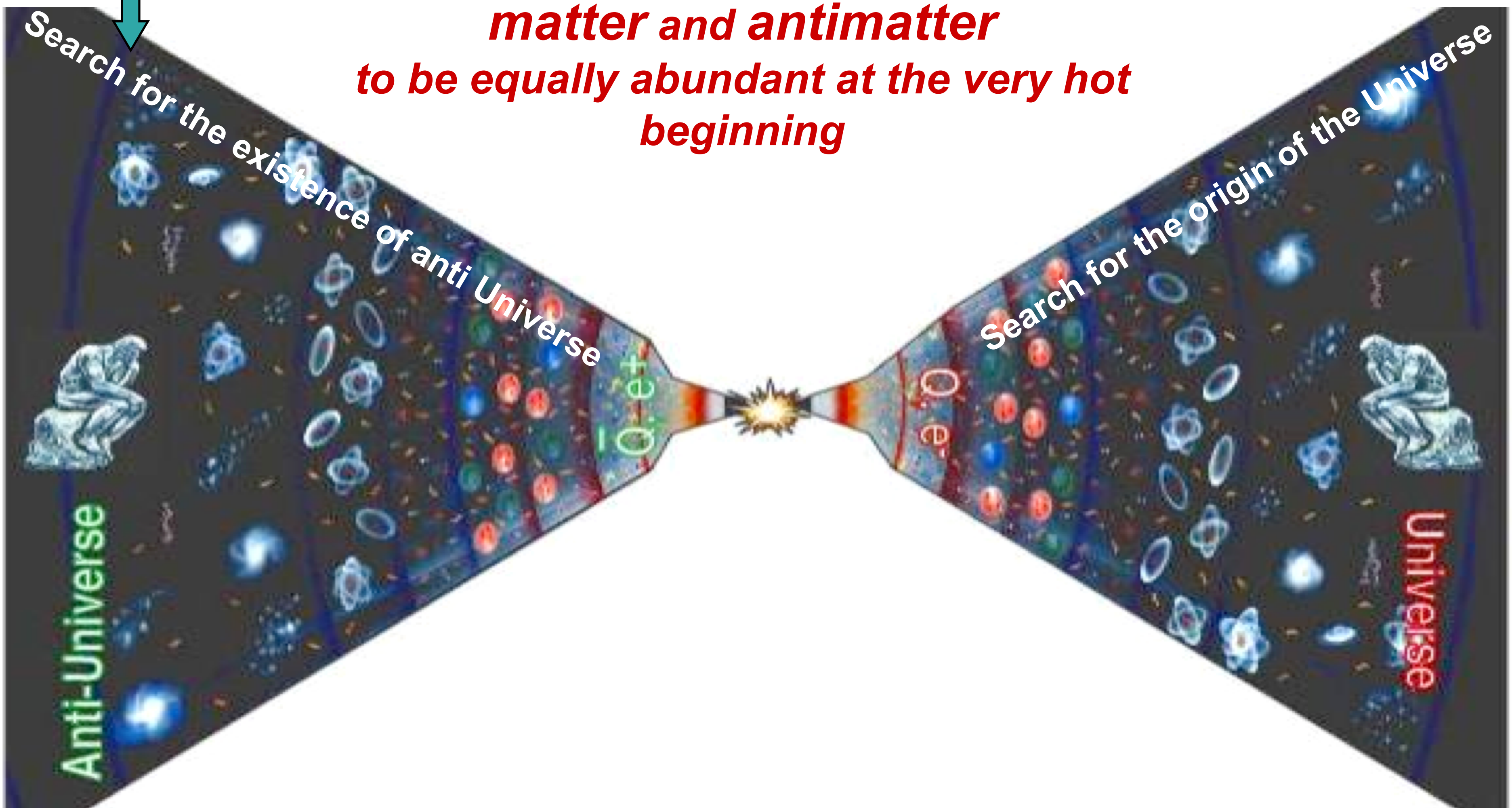
1. Complex anti-matter – $\overline{\text{He}}$, $\overline{\text{C}}$, $\overline{\text{O}}$
2. Positrons and Dark Matter
3. Anisotropy and Dark Matter
4. Anti-deuterons and Dark Matter
5. Study solar physics of p, He, C, O, …
6. Study high Z cosmic rays to the highest energies
7. Unexpected



Complex Antimatter in Cosmic Rays

AMS in Space

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

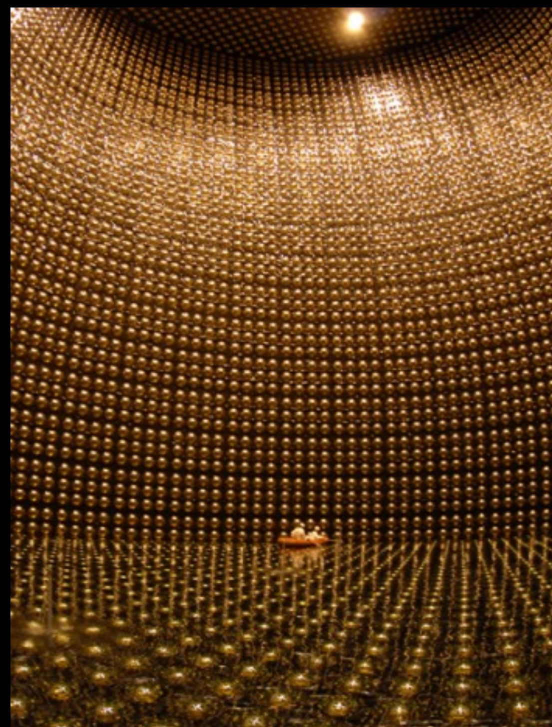


Experimental work on Antimatter in the Universe

Search for Baryogenesis

New symmetry breaking

Proton has finite lifetime



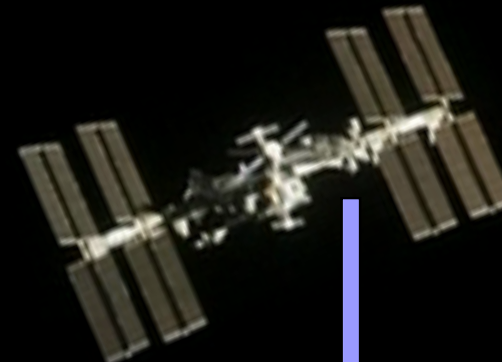
LHC-b, ATLAS,CMS

Super Kamiokande

$\tau_p > 6.6 * 10^{33}$ years

No explanation found for the absence of antimatter
(no reason why antimatter should not exist)

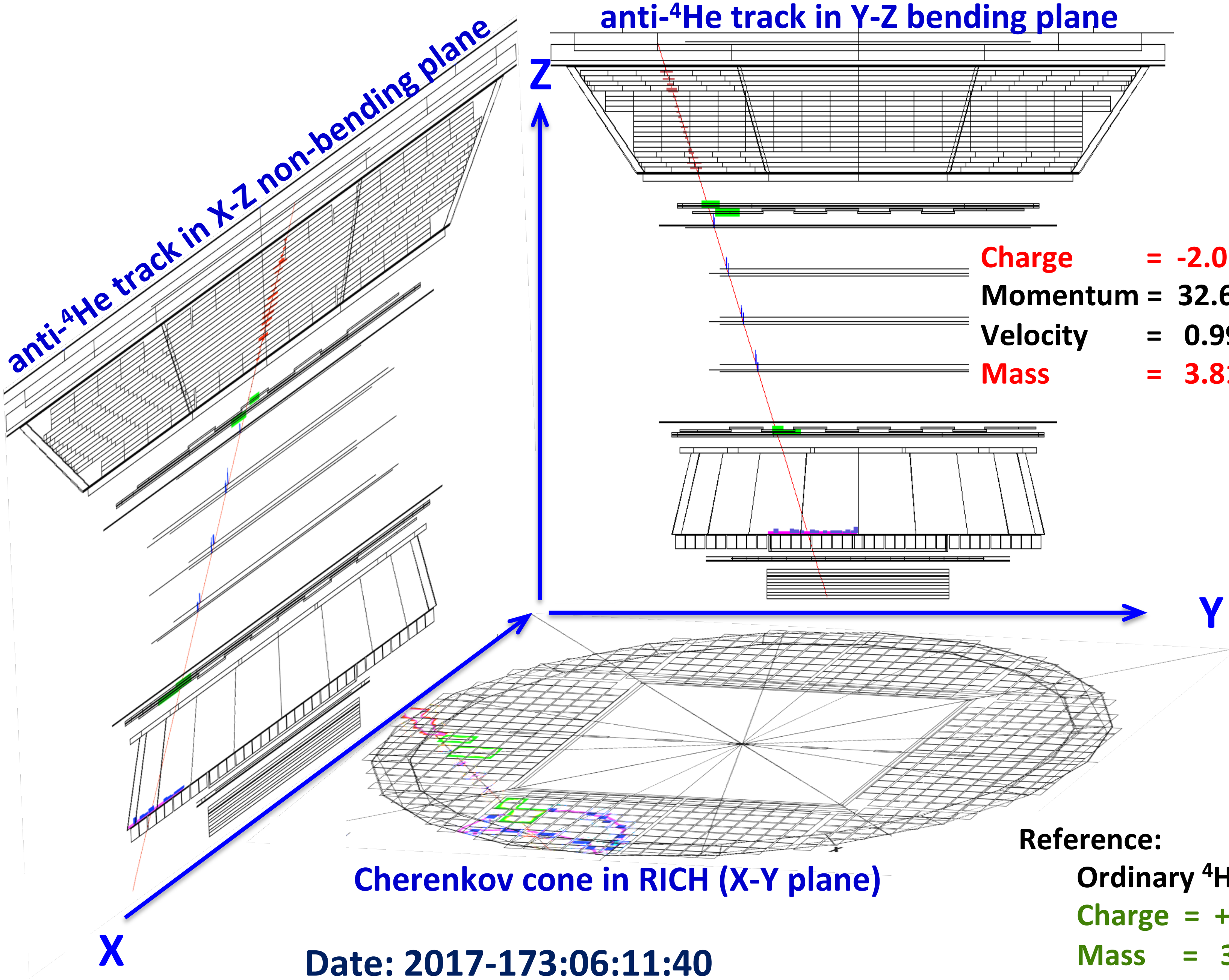
Direct search



AMS

Increase in sensitivity: x 10^3 – 10^6
Increase in energy to ~TeV

Observation of anti-He events



Charge = -2.05 ± 0.05
Momentum = 32.6 ± 2.5 GeV/c
Velocity = $0.9930 \pm 0.0007\ c$
Mass = 3.81 ± 0.29 GeV/c^2

Date: 2017-173:06:11:40

Reference:

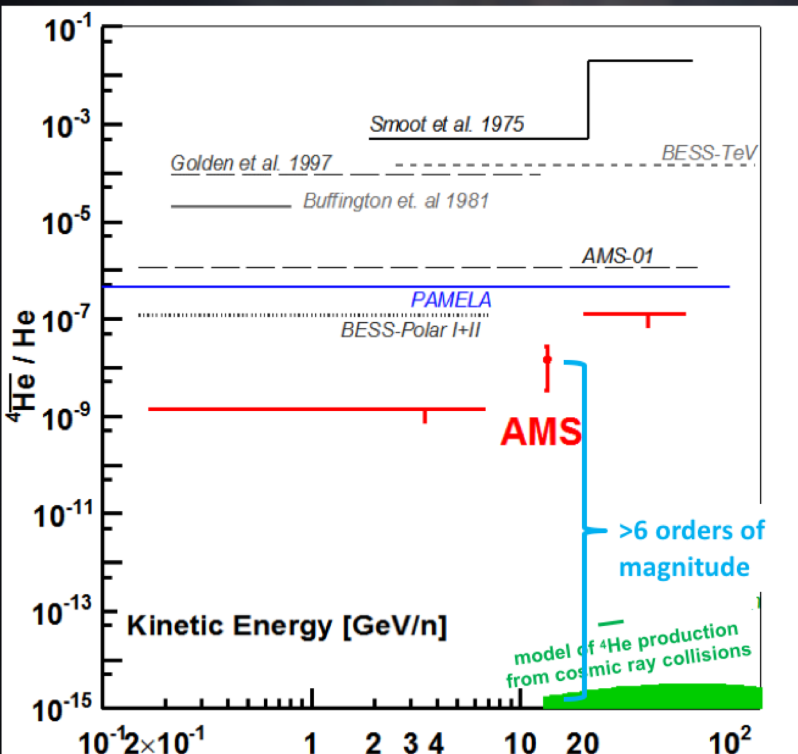
Ordinary ^{4}He:

Charge = +2

Mass = 3.73 GeV/c^2

The physics of AMS to 2024:

1. Complex anti-matter – $\overline{\text{He}}$, $\overline{\text{C}}$, $\overline{\text{O}}$

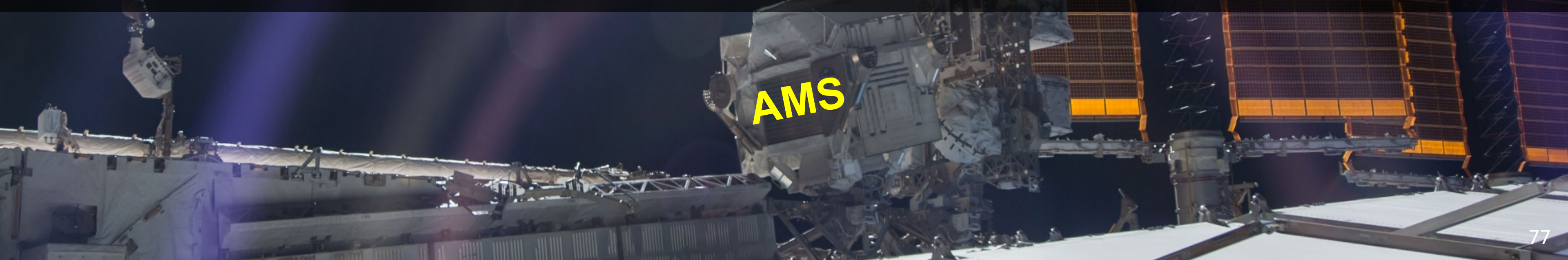


AMS has observed a few antihelium candidates at a rate of one in 10^8 He.

To ascertain the origin of antihelium, it is most important to study $^4\overline{\text{He}}$. The AMS $^4\overline{\text{He}}$/He ratio is six orders of magnitude greater than predictions based on cosmic ray collisions

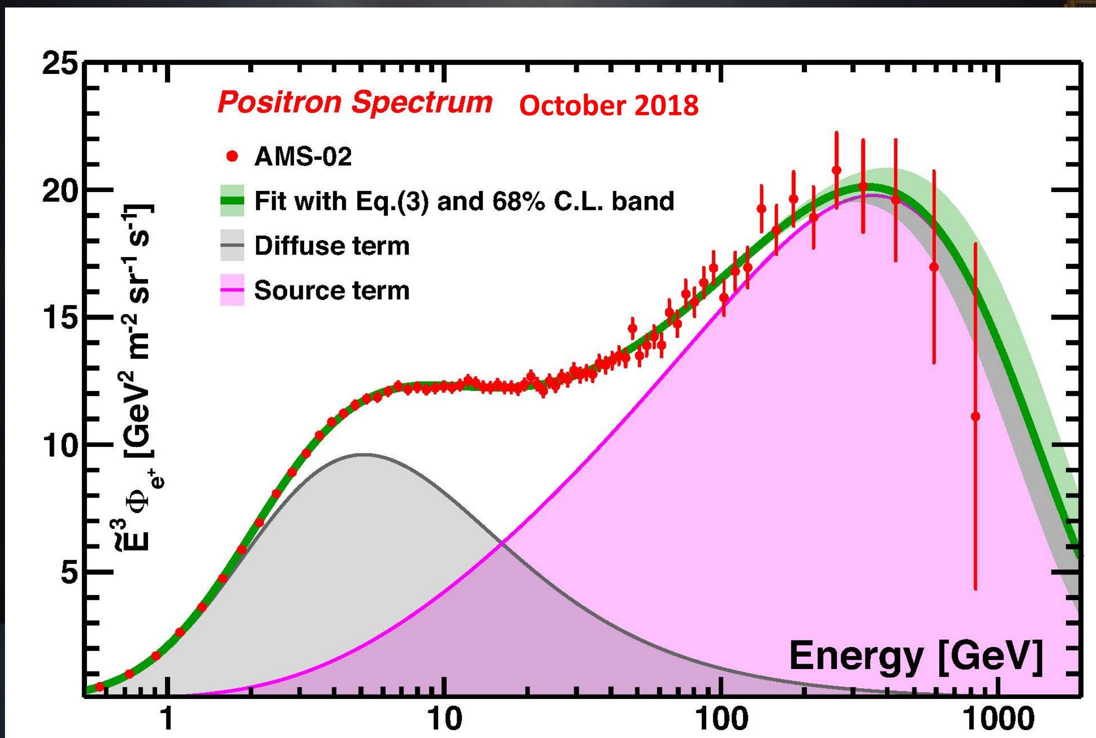
Observations on $^4\overline{\text{He}}$

1. We have two $^4\overline{\text{He}}$ events with a background probability of 3×10^{-3}.
2. Continuing to take data through 2024 the background probability for $^4\overline{\text{He}}$ would be $2\text{x}10^{-7}$.



The physics of AMS to 2024:

2. Positrons and Dark Matter



2018

High energy positrons can come from

dark matter

or

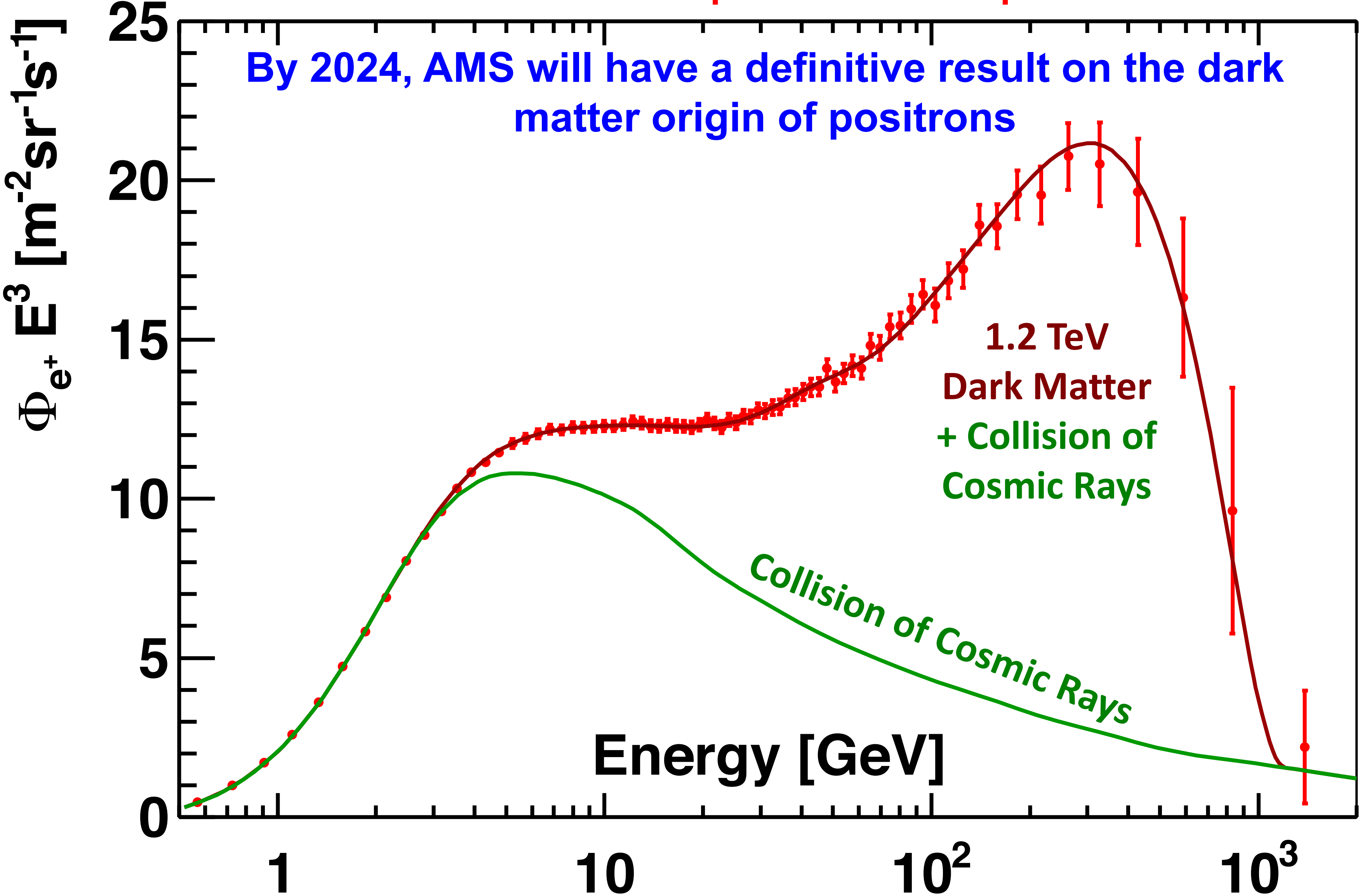
new astrophysical sources

AMS

The Positron Flux through 2024

Extend the measurements to 2 TeV and double the current statistics

to determine the sharpness of the drop off.

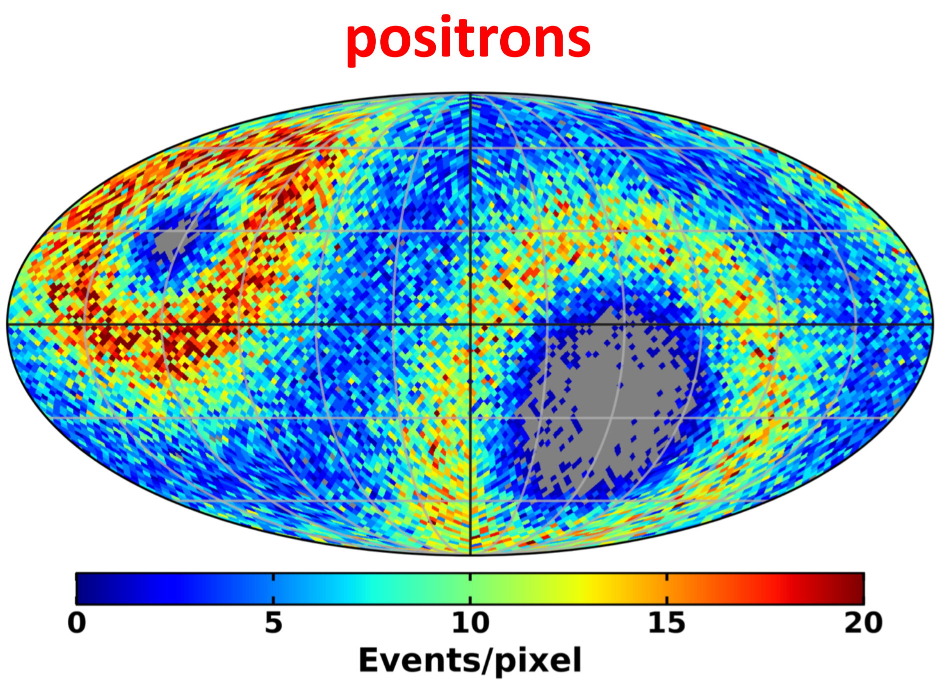


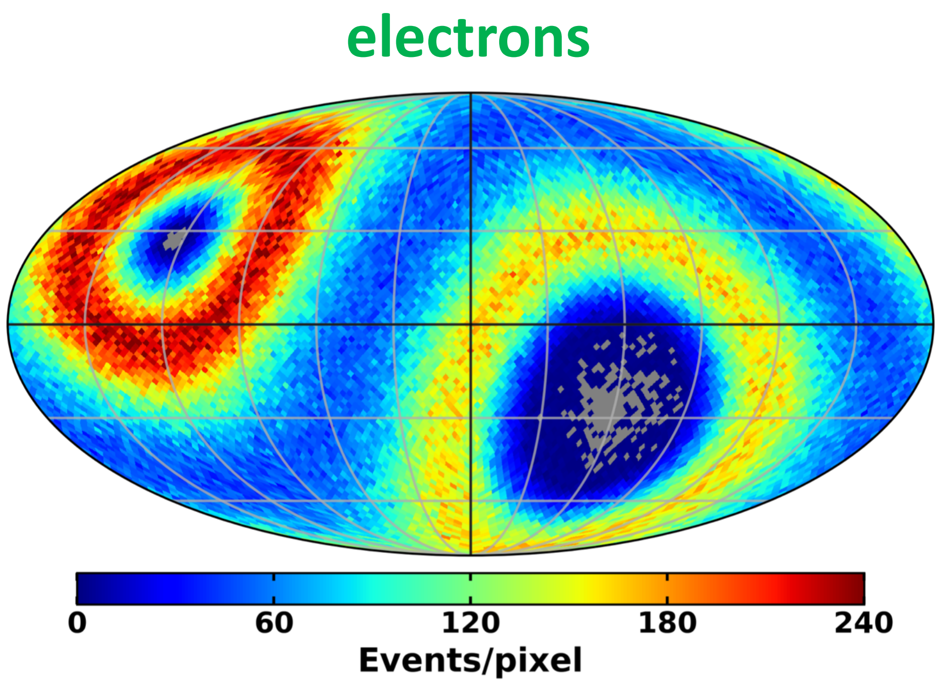
The physics of AMS to 2024:

3. Anisotropy and Dark Matter

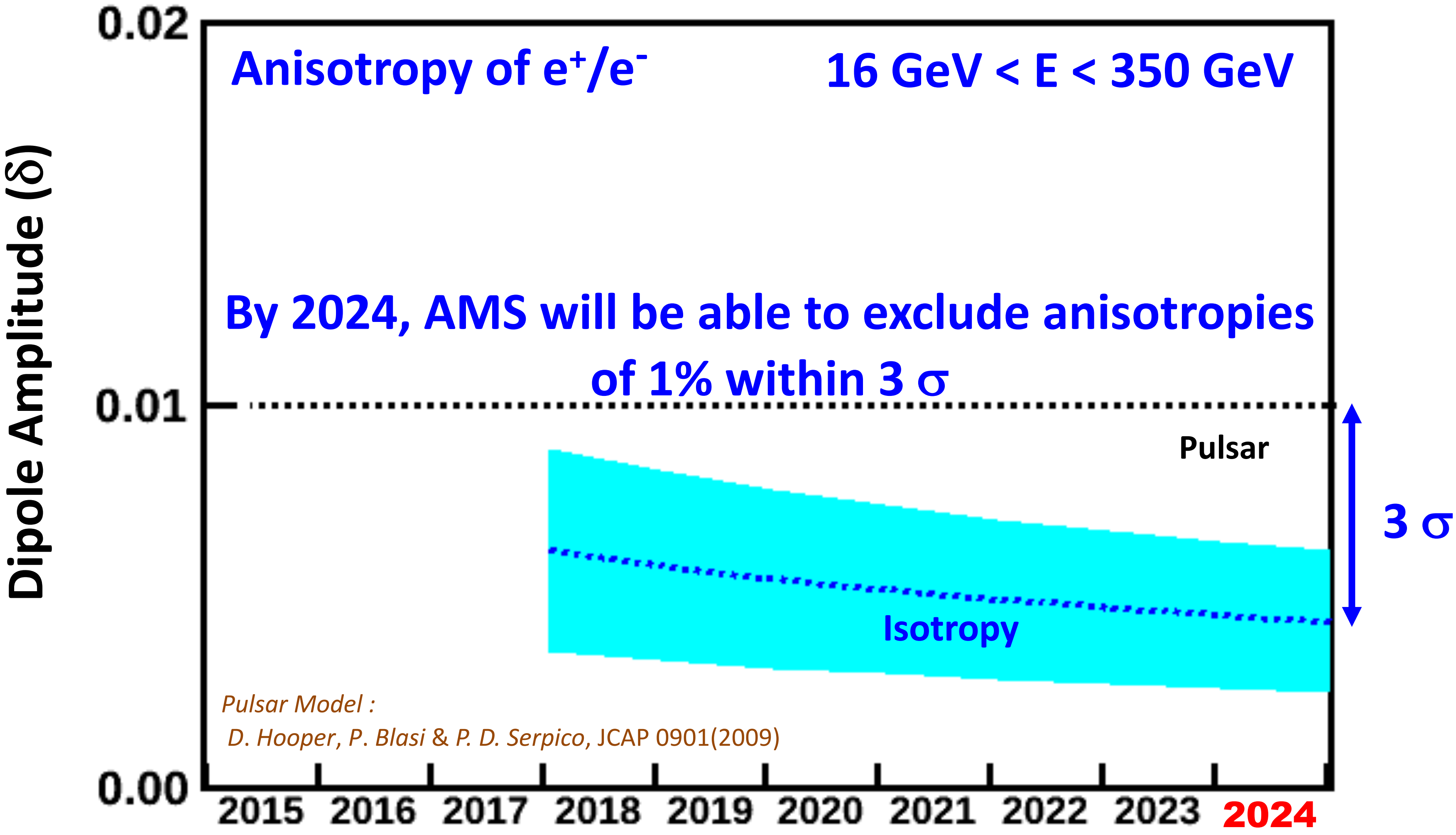
Astrophysical point sources like pulsars will imprint a higher anisotropy on the arrival directions of energetic positrons than a smooth dark matter halo.

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 effect in the positron flux.

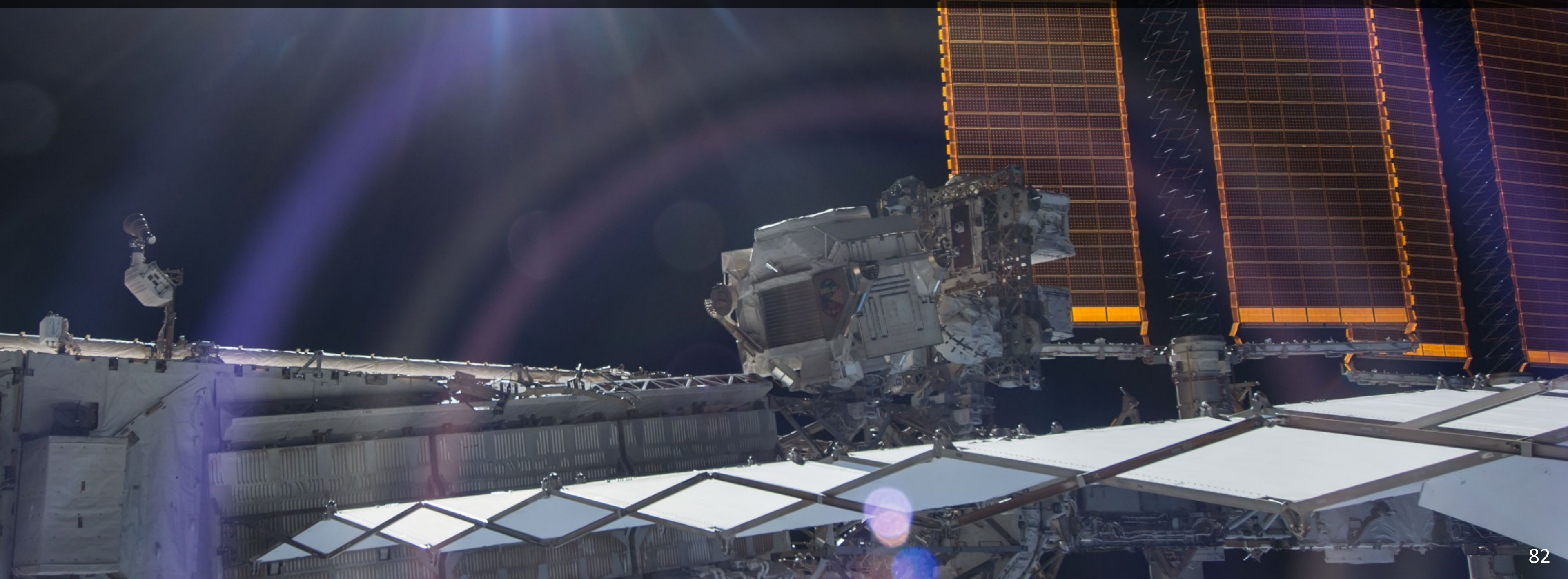
The physics of AMS to 2024:

4. Anti-deuterons and Dark Matter

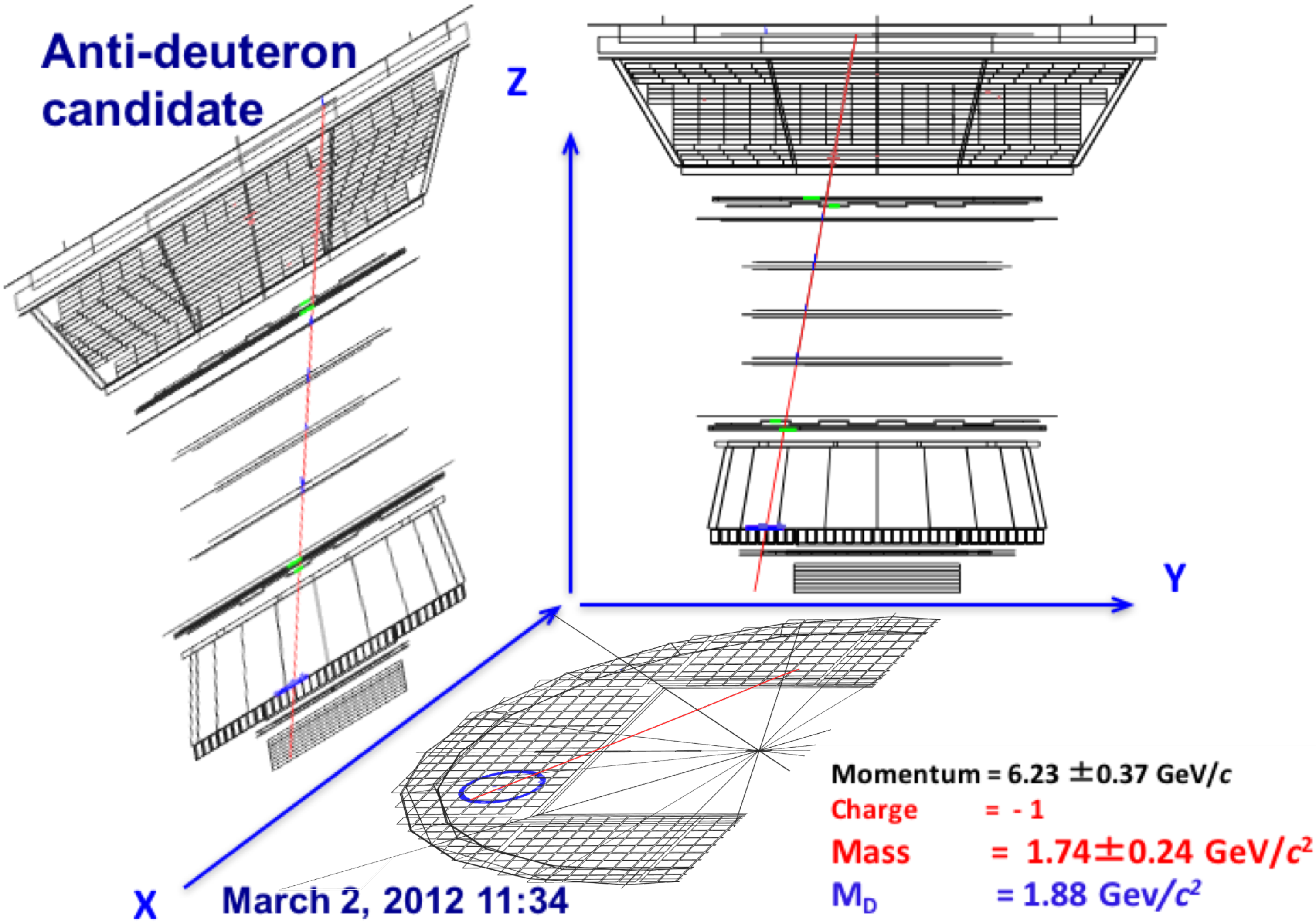
Anti-Deuterons have never been observed in space

By 2024, AMS will have collected more than 200 million deuterons.

Dark Matter annihilation will produce anti-Deuterons



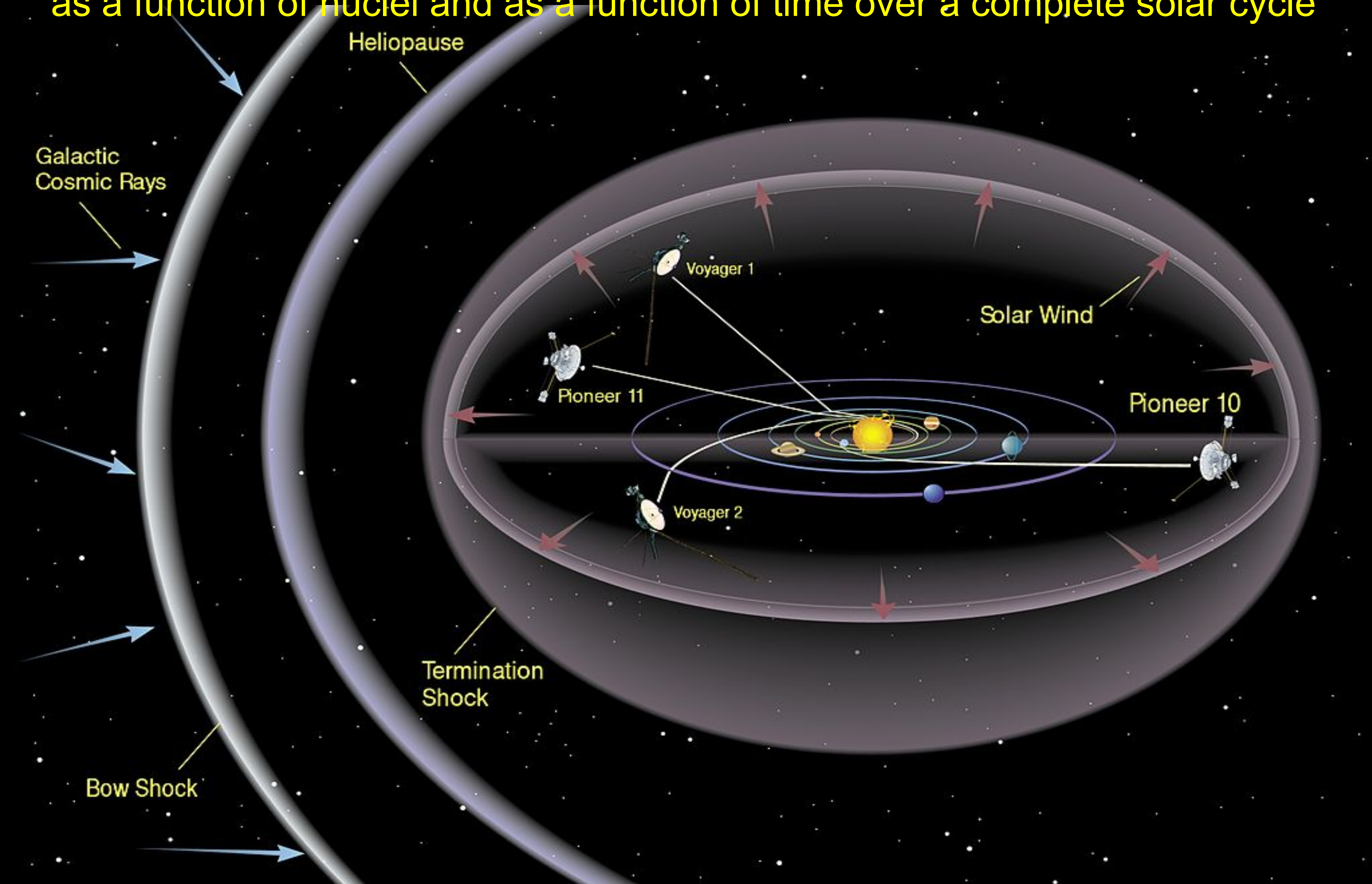
Anti-deuteron candidate



The physics of AMS to 2024:

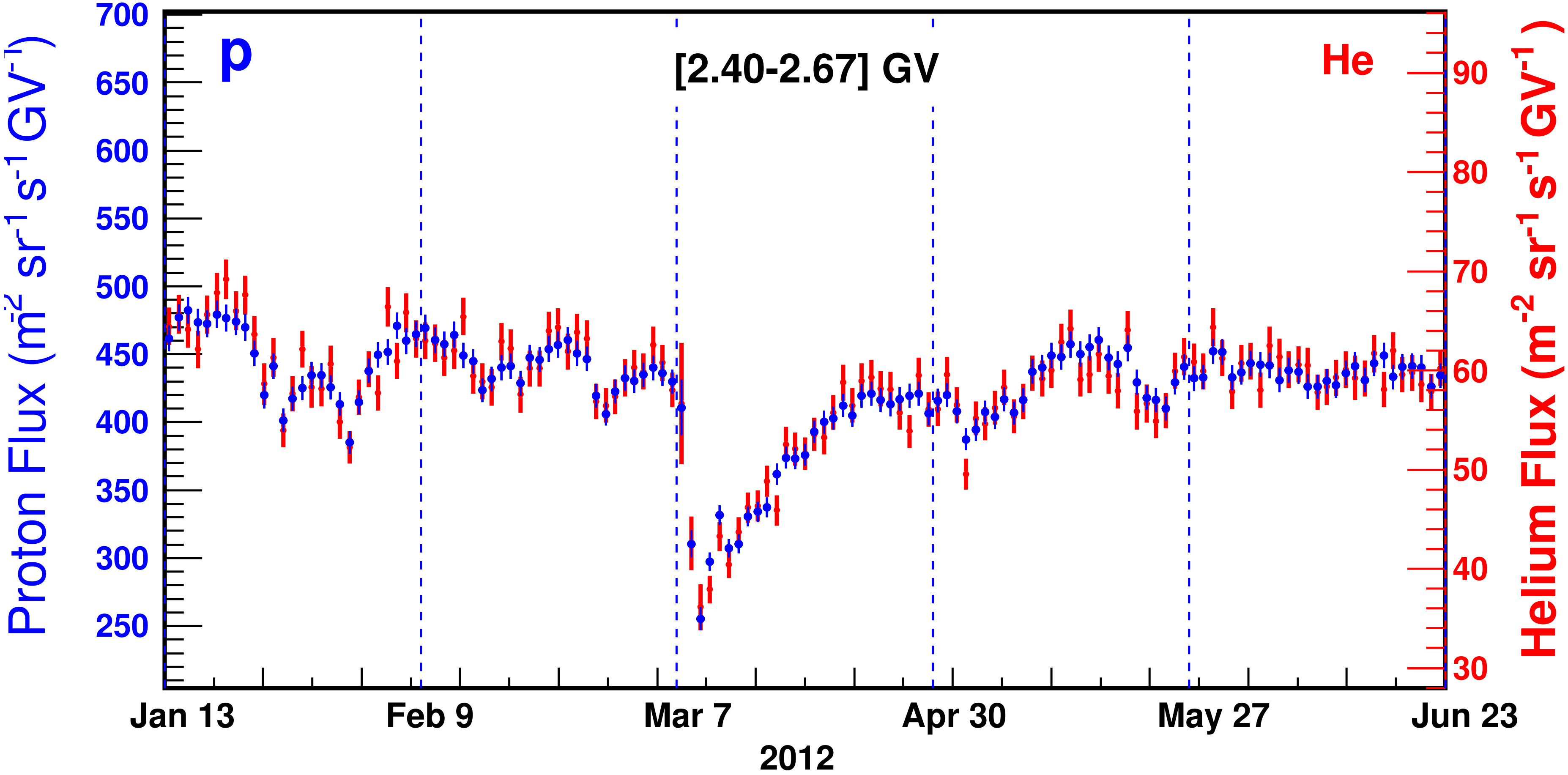
5. Study solar physics of p, He, C, O, …

as a function of nuclei and as a function of time over a complete solar cycle

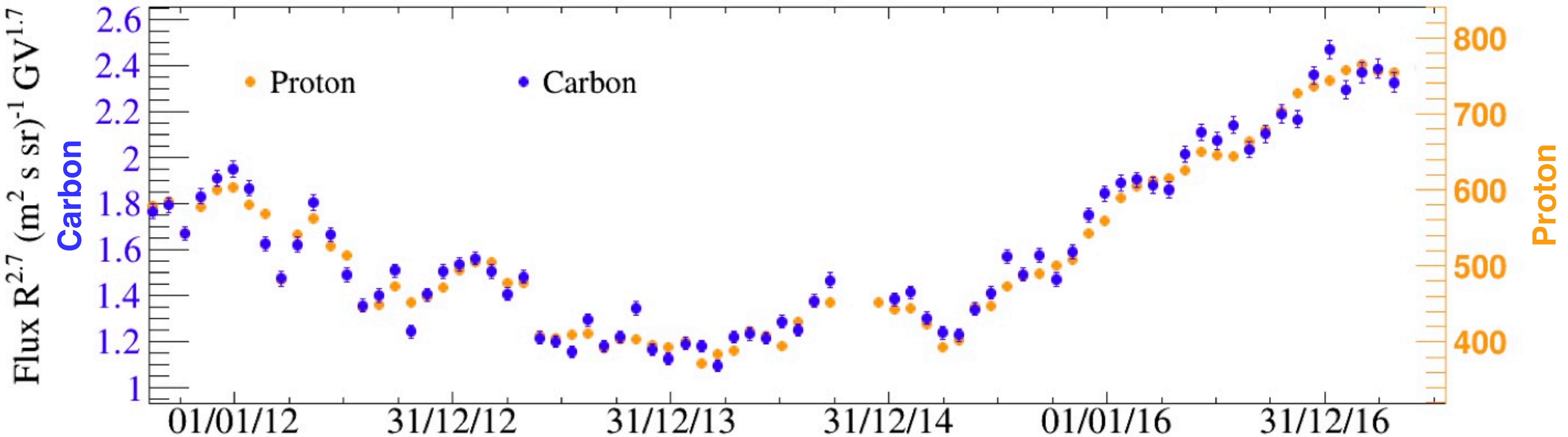


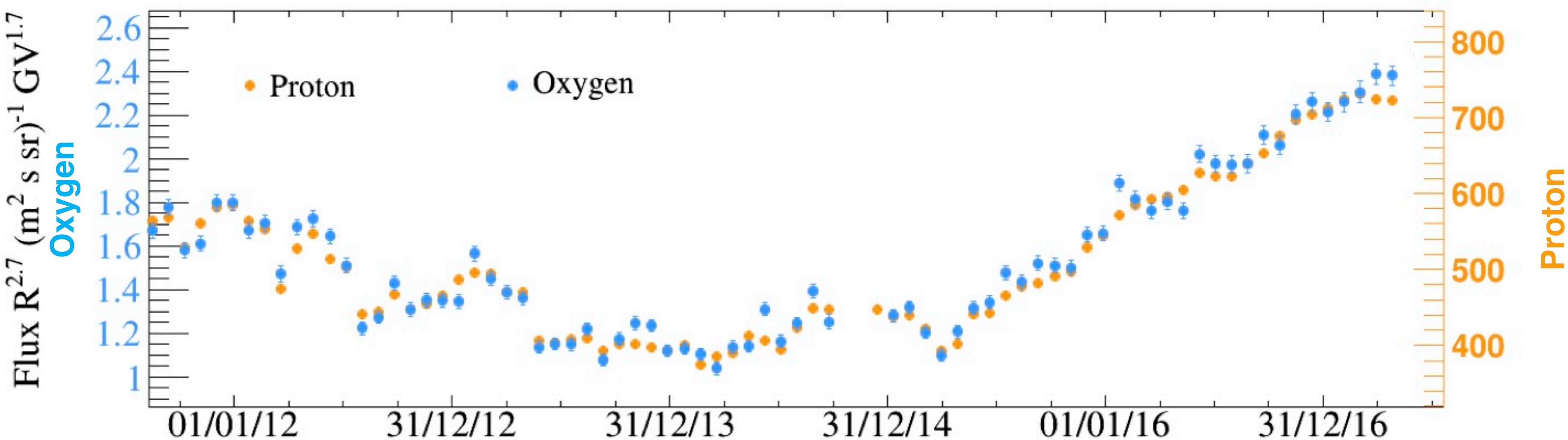
AMS

Identical **daily** time variation of the p, He fluxes



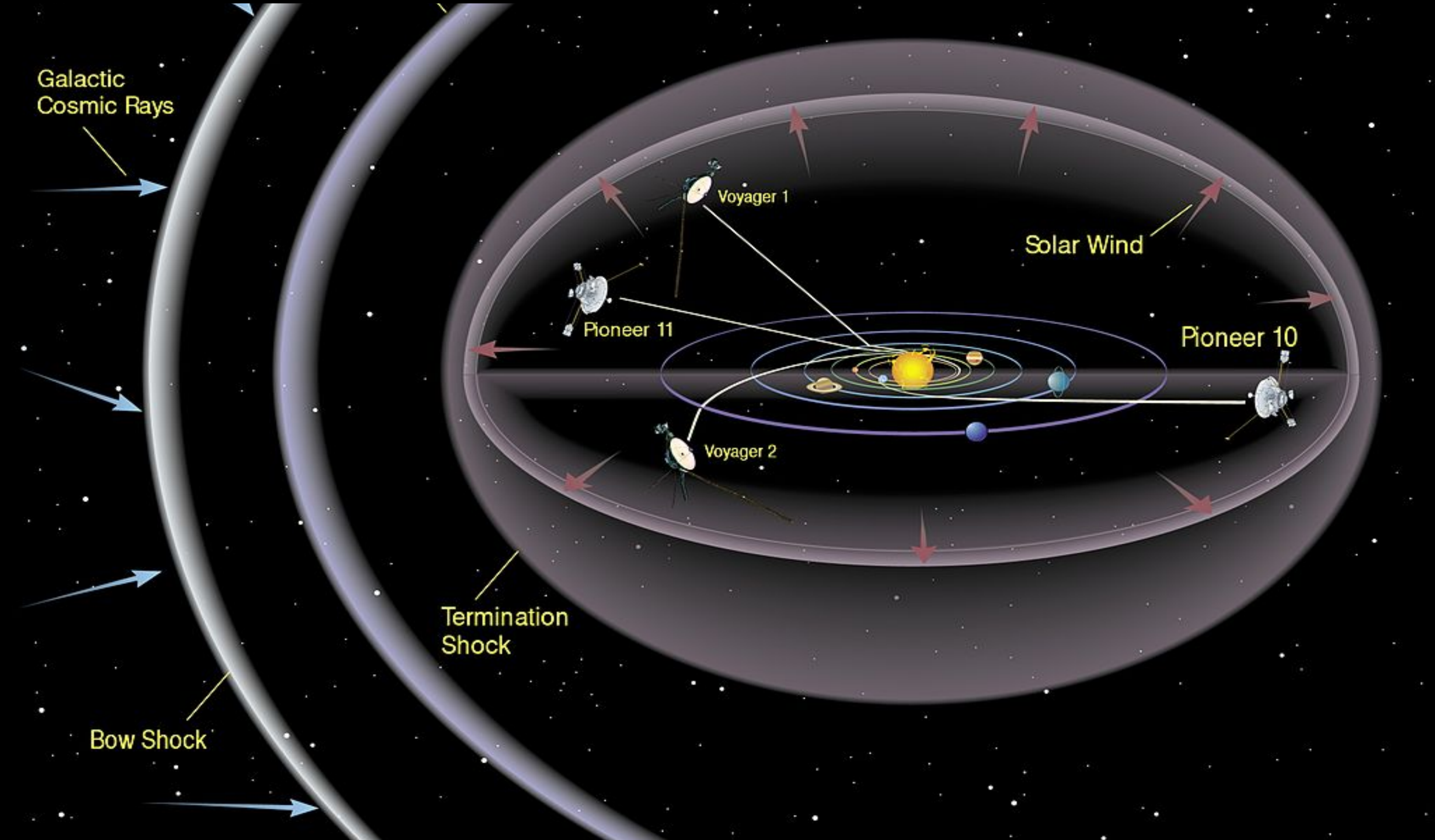
AMS
Time variation of the C and O fluxes





The physics of AMS to 2024:

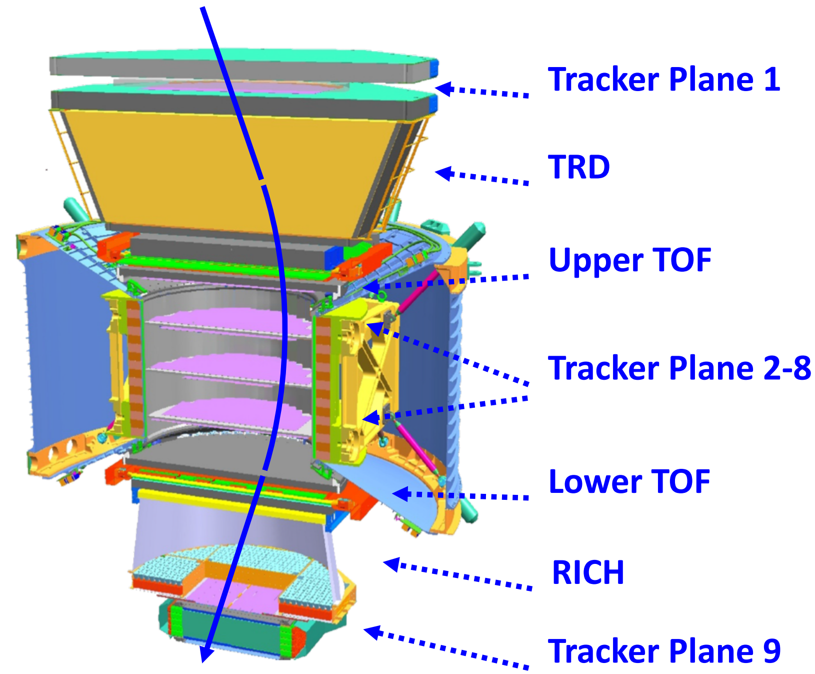
By 2024, AMS will provide an accurate study of the time-variation of nuclei fluxes on a daily basis over a complete solar cycle.

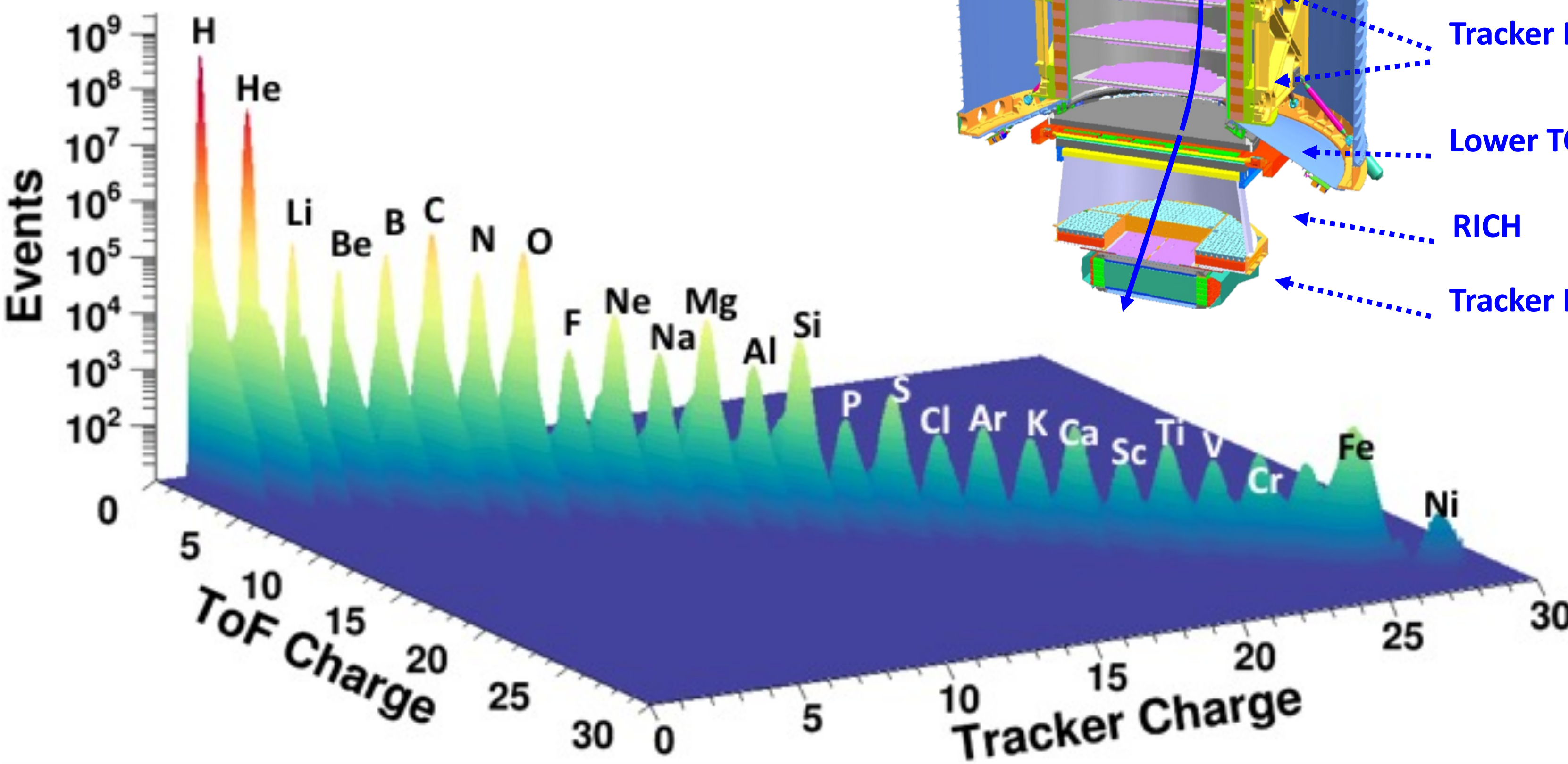


The physics of AMS to 2024:

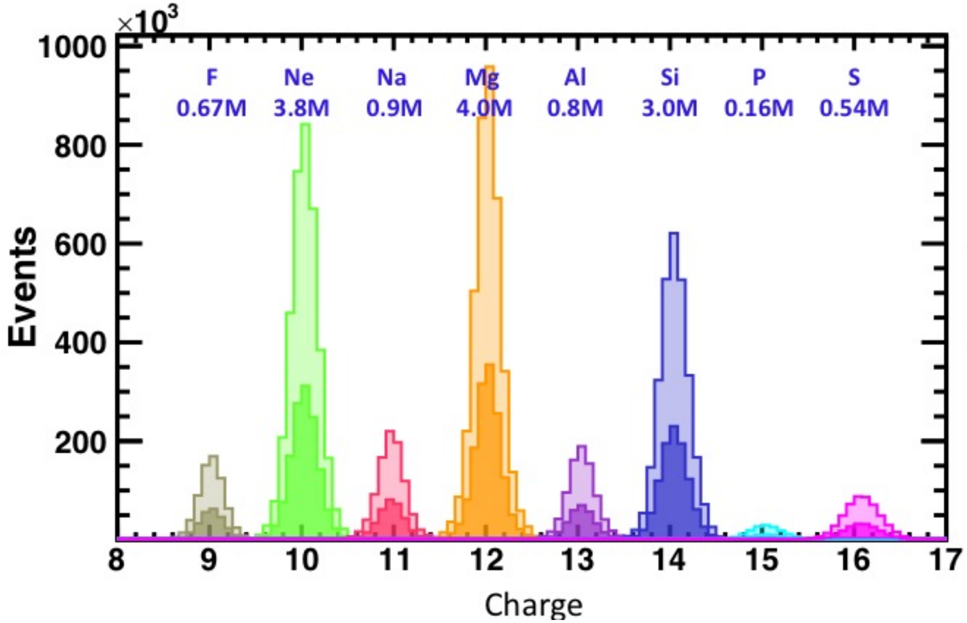
6. Study high Z cosmic rays

AMS has seven instruments which independently measure Cosmic Nuclei

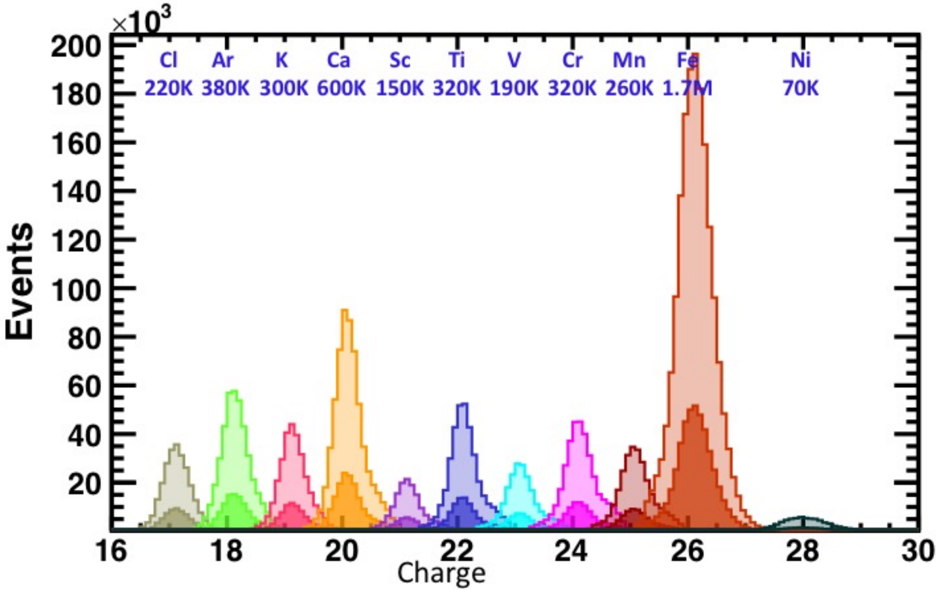




AMS - Expected events to 2024



Z=9 to Z=16

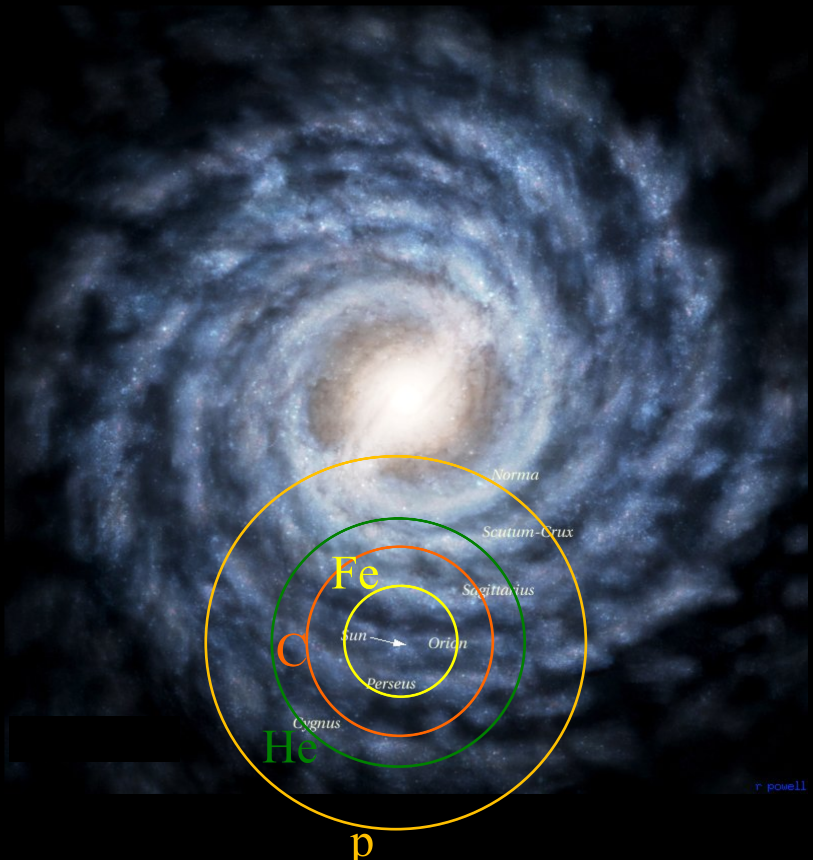


Z=17 to Z=28

Darker shading shows events collected to date

Physics of high Z cosmic rays

I. Probe different galactic distances



Effective distance is shown for ~1 GV.

Effective propagation distance:

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

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

ii. Higher energies probe larger distances

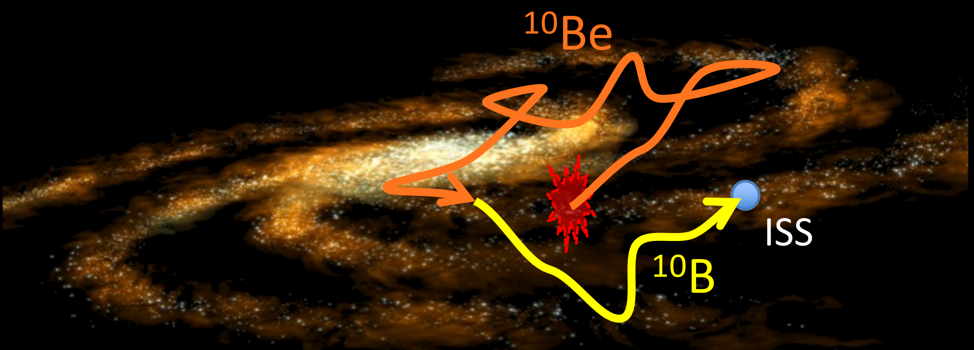
Important discussions with Professor Igor Moskalenko of Stanford University

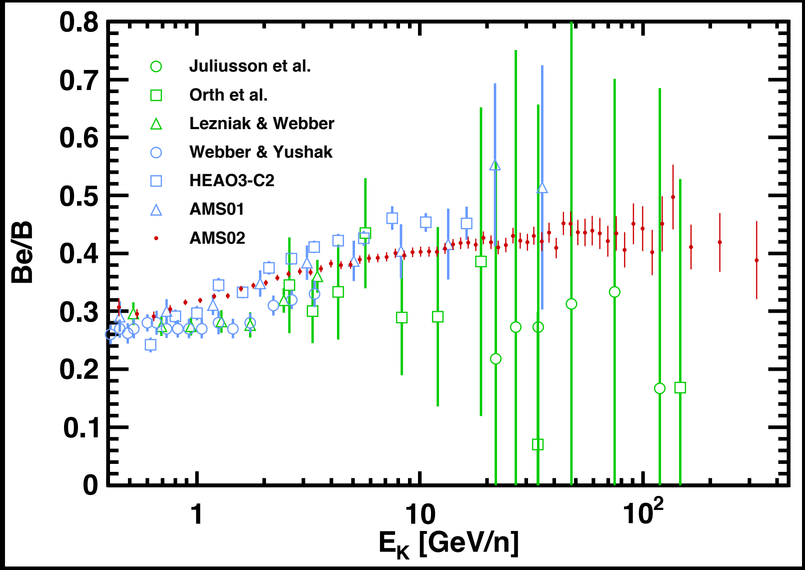
Physics of high Z cosmic rays

II. The Age of Cosmic Rays.

^{10}Be (Z=4) decays with a half-life 1.5×10^6 years $^{10}Be \rightarrow {}^{10}B + e^- + \nu_e$.
The Be/B ratio is rising with energy due relativistic time dilation.

Be/B provides information on the age of cosmic rays





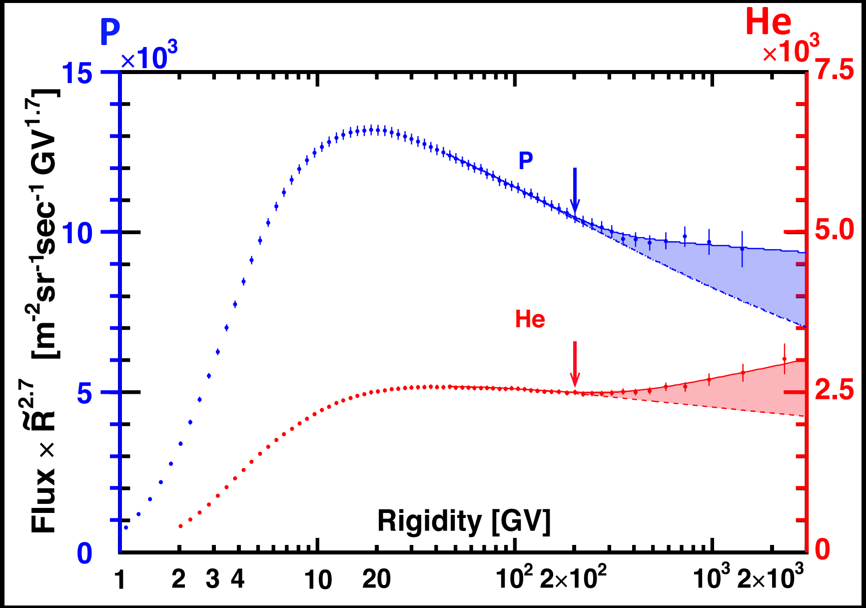
$^{10}Be\ (Z=4) \rightarrow {}^{10}B\ (Z=5) + e^- + \bar{\nu}_e$

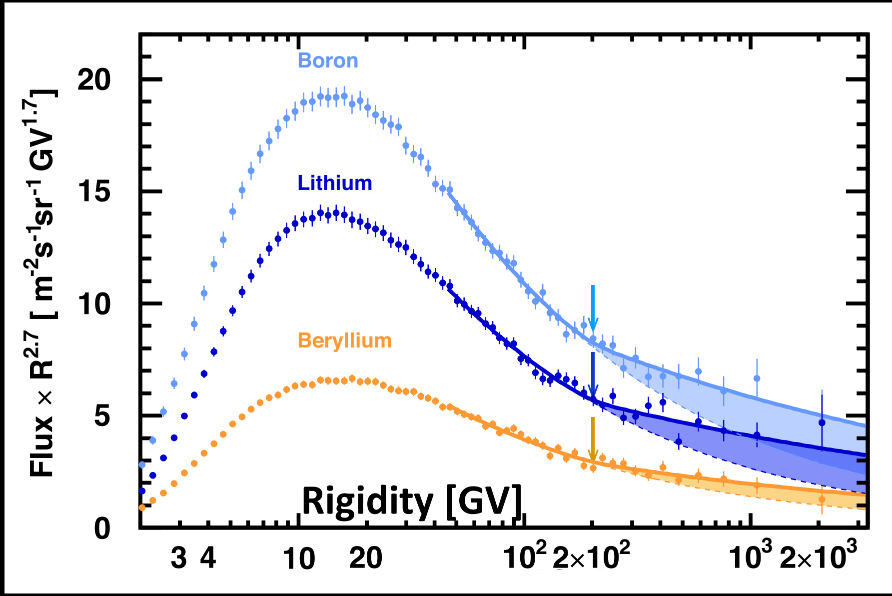
The measurements of the Aluminum (Z=13), Chlorine (Z=17), and Manganese (Z=25) spectra will precisely establish the age of cosmic rays as they (like Be) are radioactive clocks.

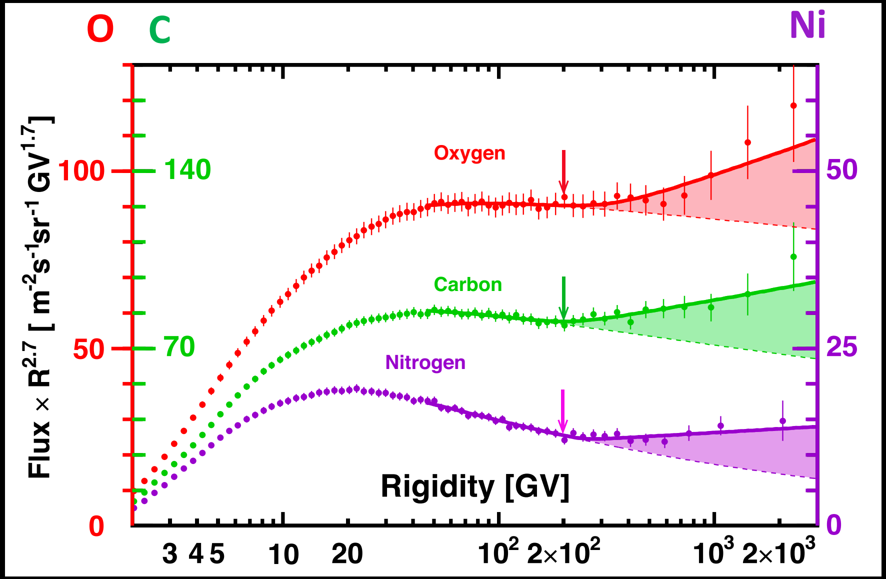
Physics of high Z cosmic rays

III. High-Z Flux break at ~ 200 GV

The spectra of elements Z=1 to Z= 8 do not follow the traditional single power law, they all have a break at ~200 GV

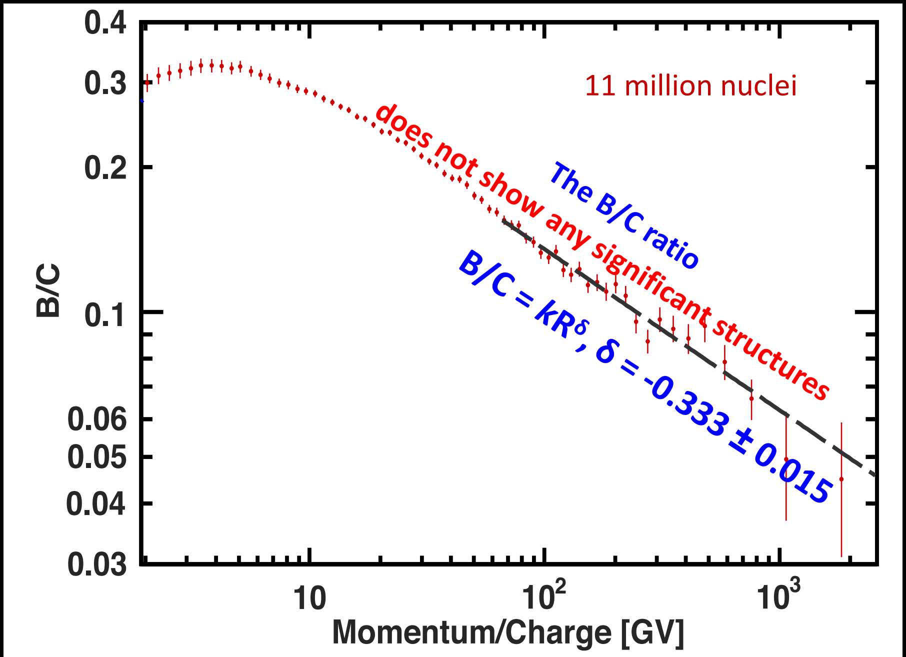


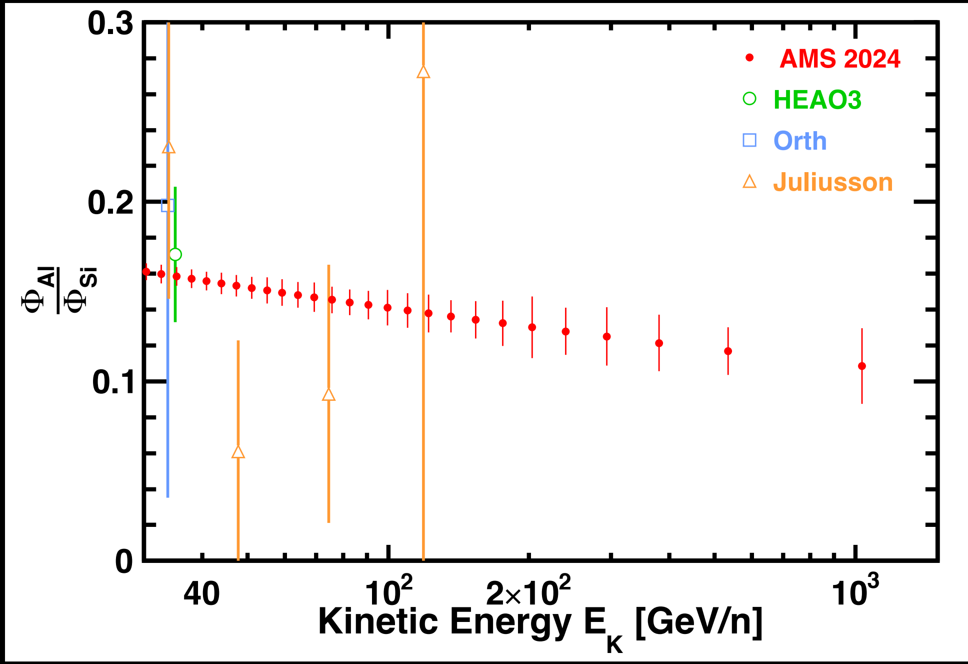




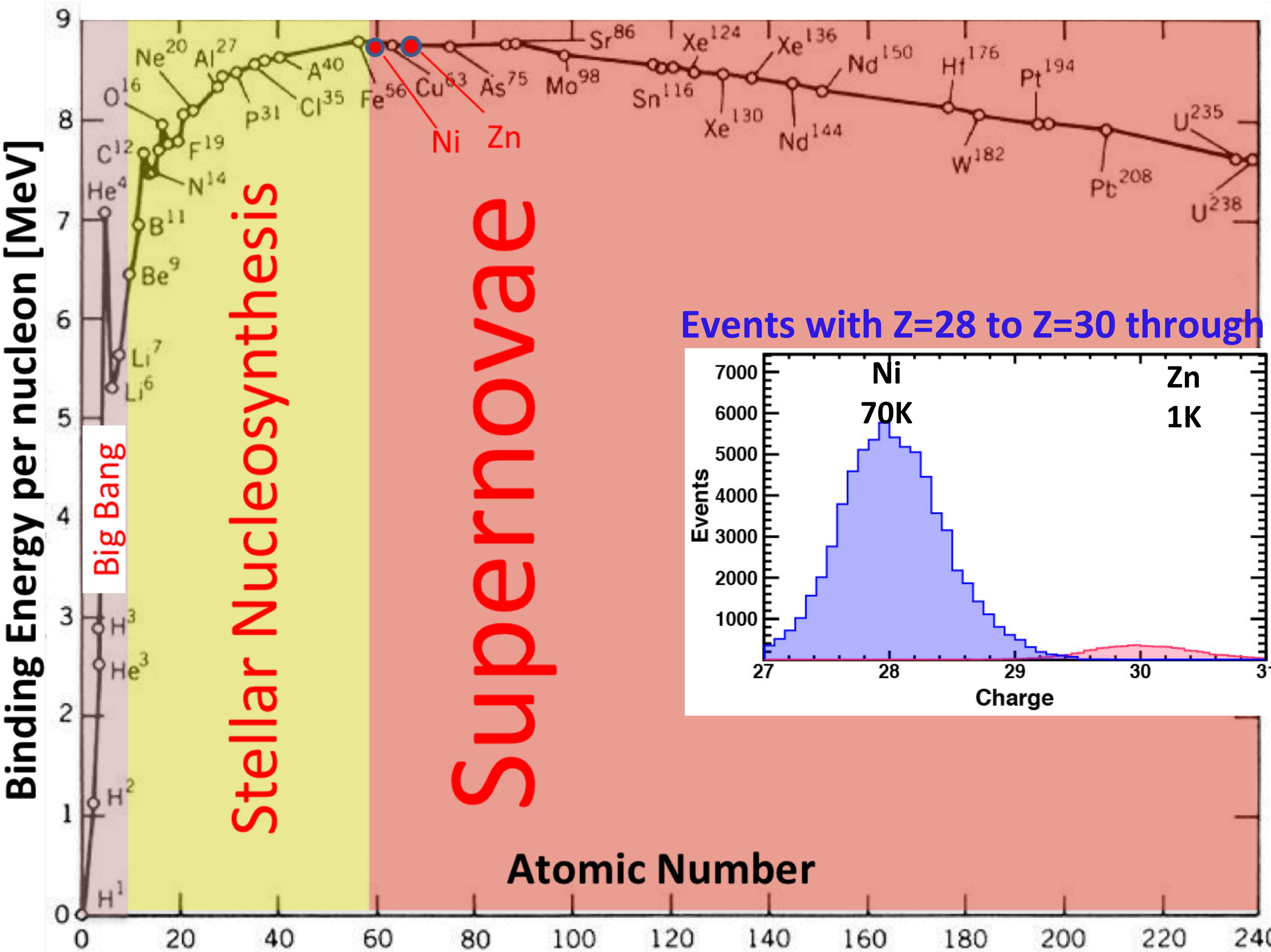
Physics of high Z cosmic rays
IV. Propagation at High-Z:

Like B (Z=5)/C(Z=6), ratios of secondary/primary such as Al(Z=13)/Si(Z=14) and (Scandium(Z=21)+Titanium(Z=22)+Vanadium(Z=23)/Fe(Z=26) will provide new information on propagation for heavy nuclei.





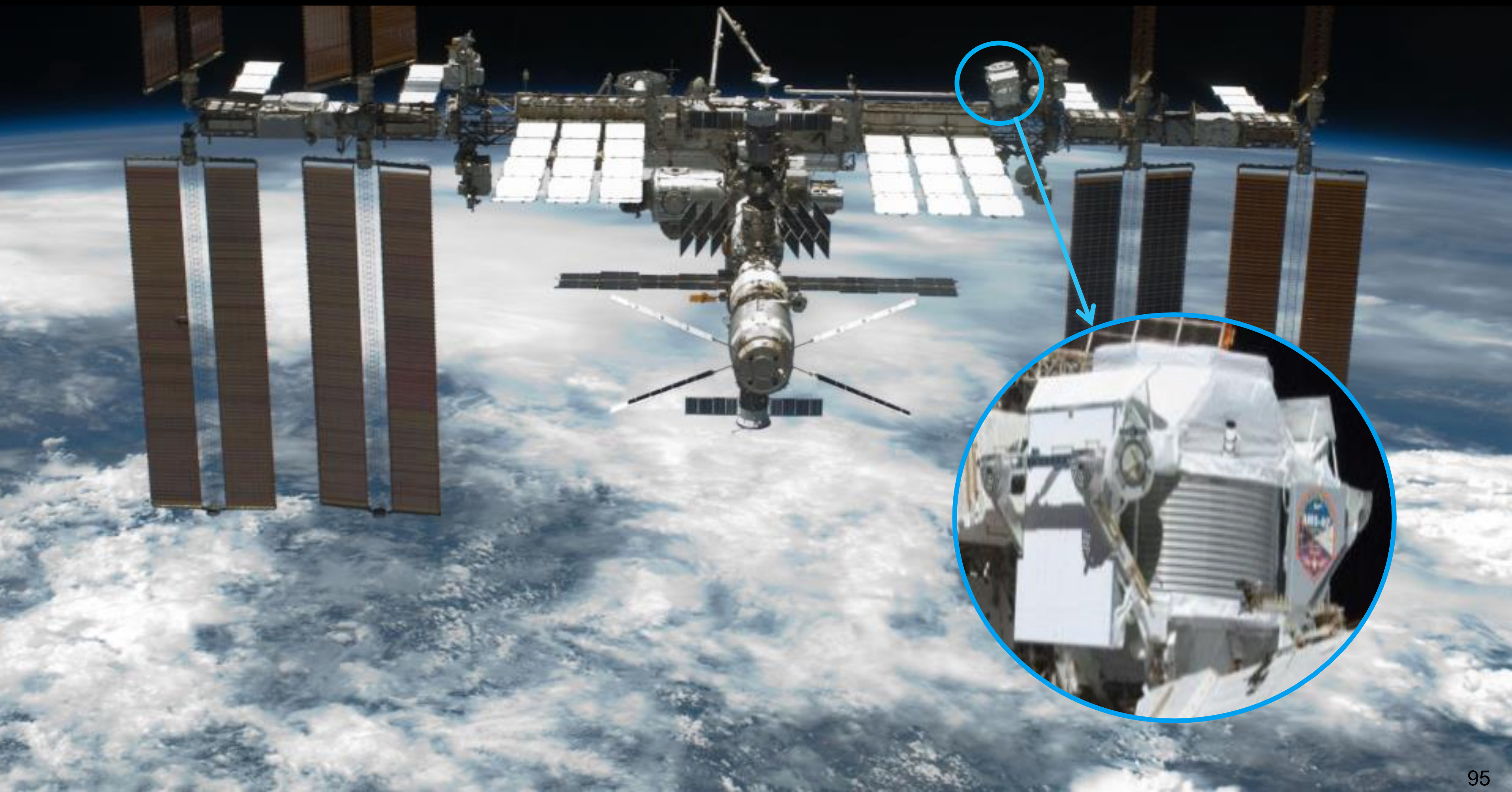
V. The lightest elements created by supernova are Nickel and Zinc. AMS will be able to study their properties for the first time and compare them with elements produced by stellar nucleosynthesis.



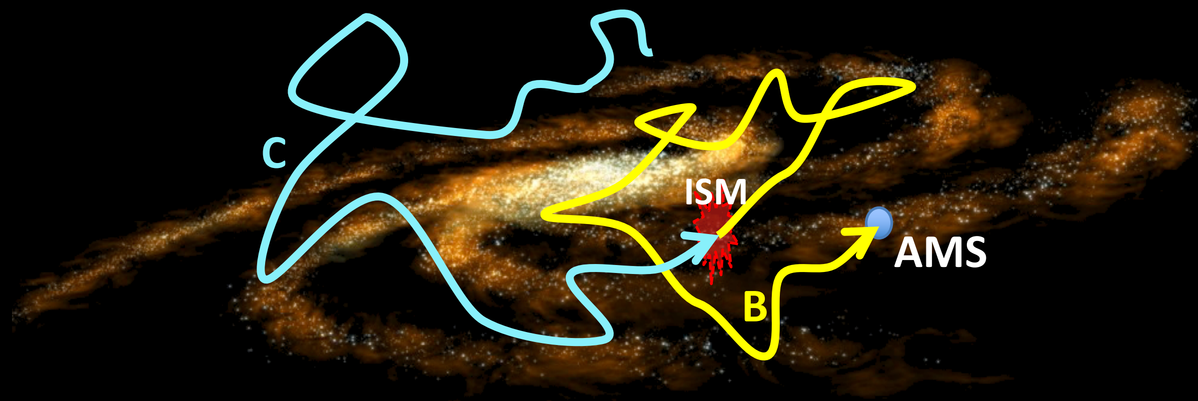
AMS is the only magnetic spectrometer in space.

None of the AMS results were predicted.

The AMS results on Dark Matter and anti-matter are of historic importance. The current and new results on cosmic rays have, and will continue to, change our understanding of the cosmos.



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

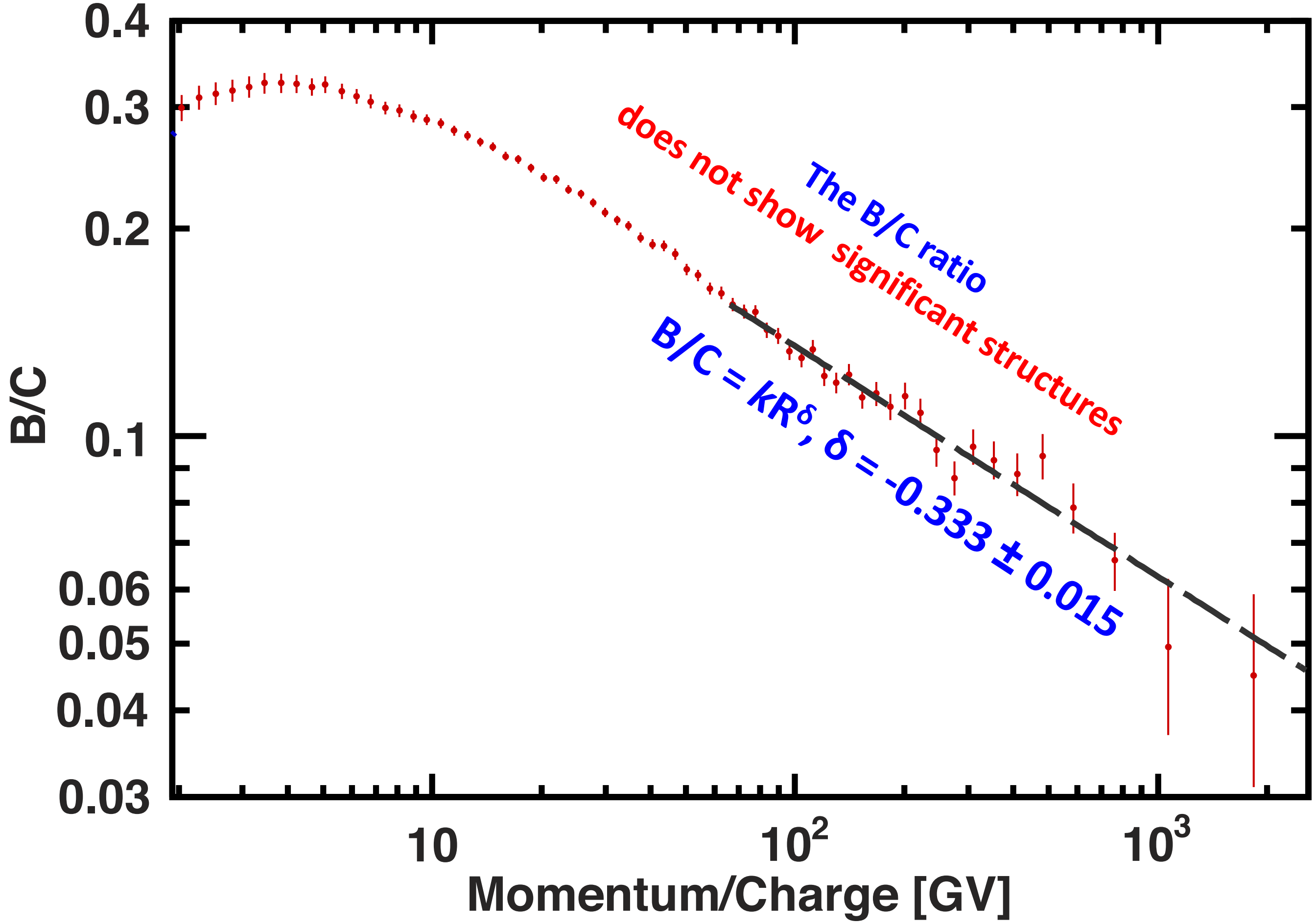


Cosmic ray propagation is commonly modeled as a fast moving gas diffusing through a magnetized plasma.

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

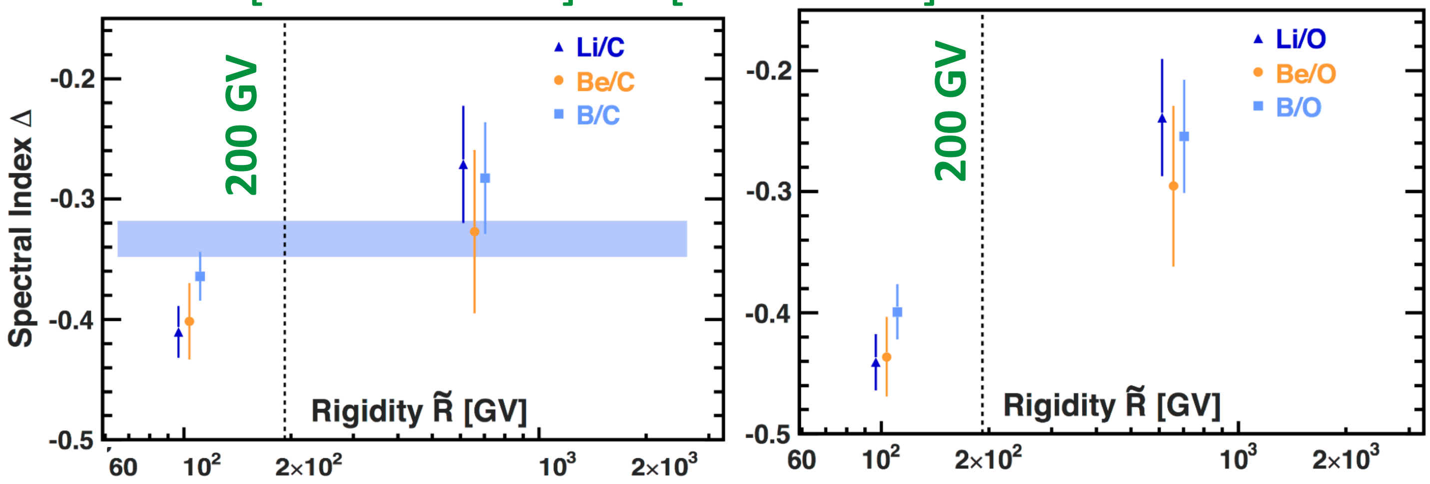


M. Aguilar *et al.*, Phys. Rev. Lett. 117, 231101 (2016)

Precision Measurement of

Secondary/Primary Flux Ratios = KR^{Δ}

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



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

This favors the hypothesis that the hardeining of cosmic rays above 200 GV is connected to propagation effects.