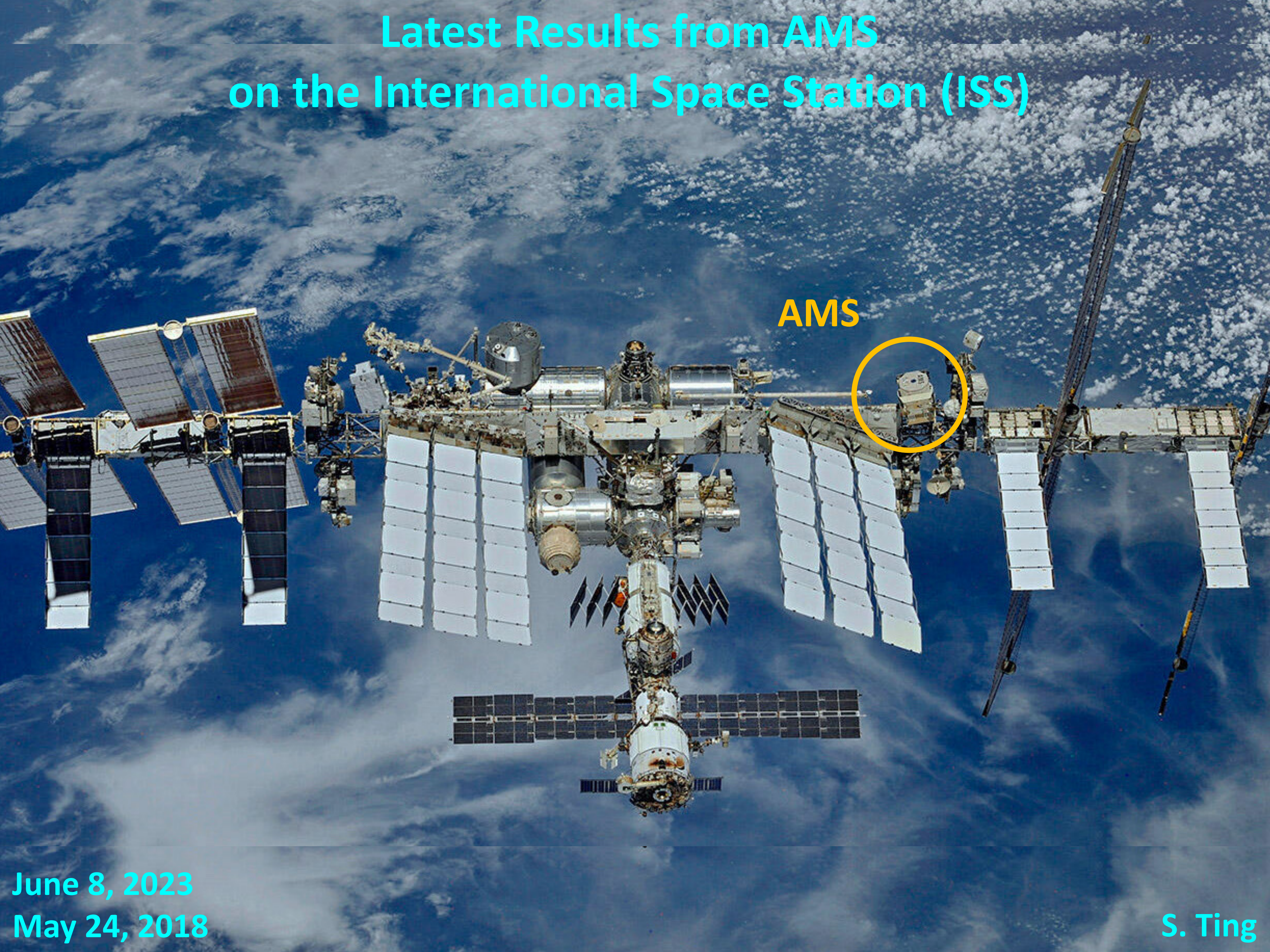
Latest Results from AMS on the International Space Station (ISS)

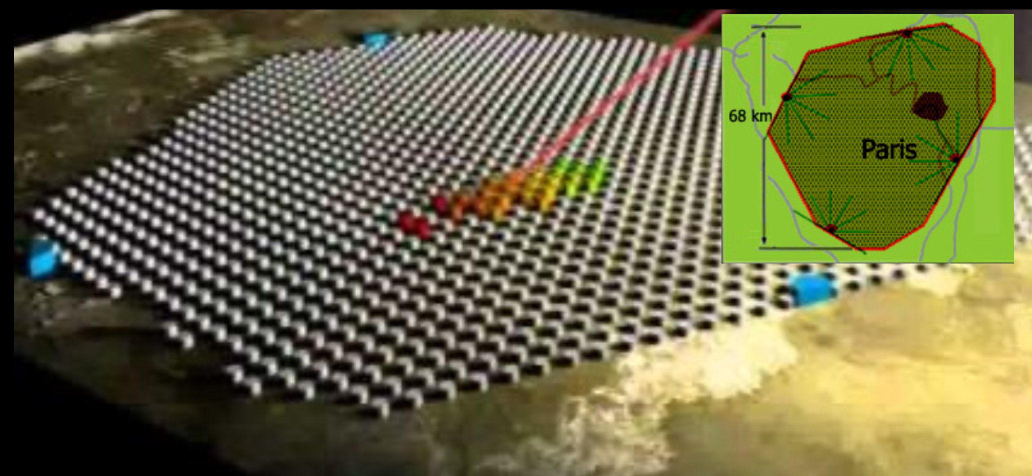


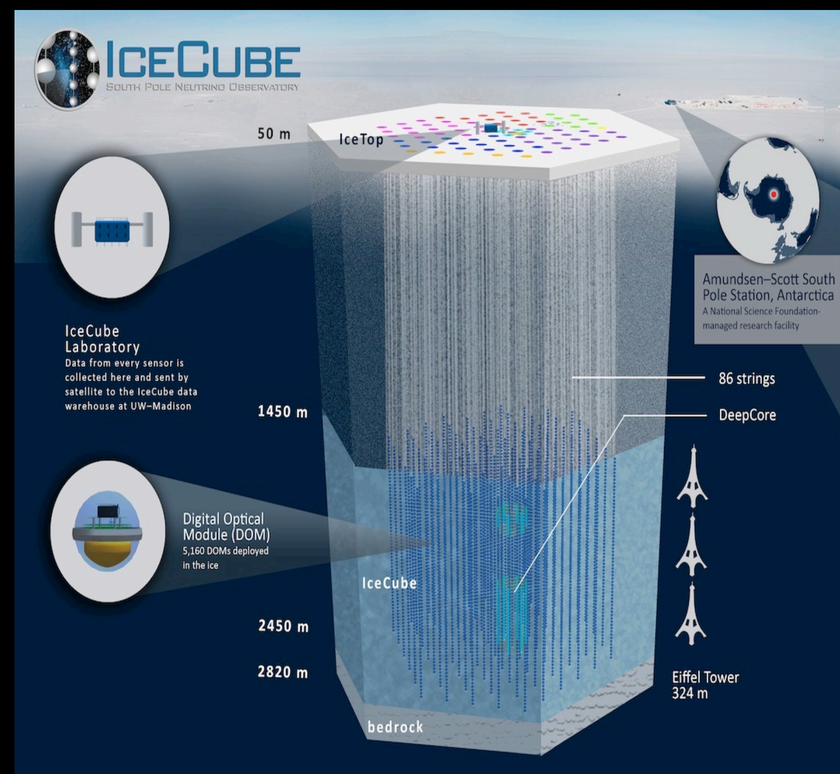
June 8, 2023
May 24, 2018

S. Ting

Examples of Current Ground-Based Cosmic Ray Experiments

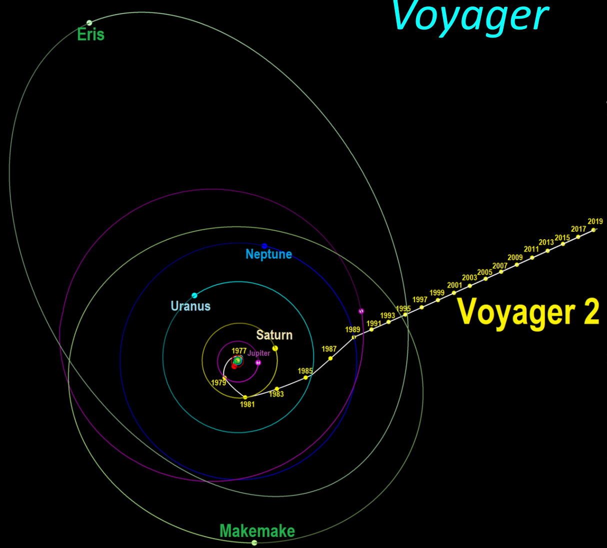
The Pierre Auger Observatory

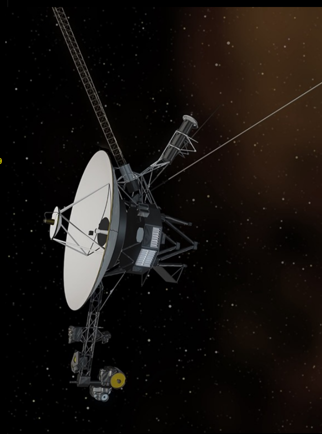




Examples of Current Non-magnetic, Calorimeter Experiments in Space

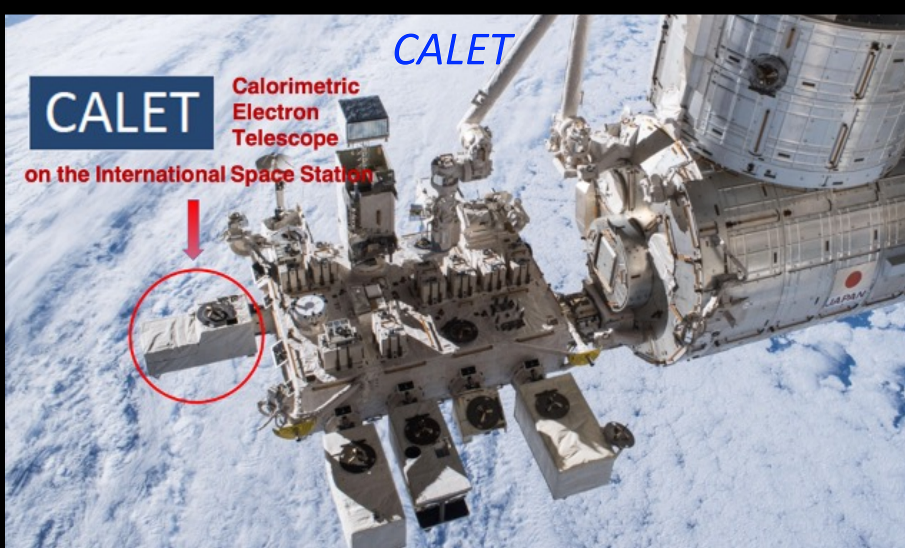
Voyager



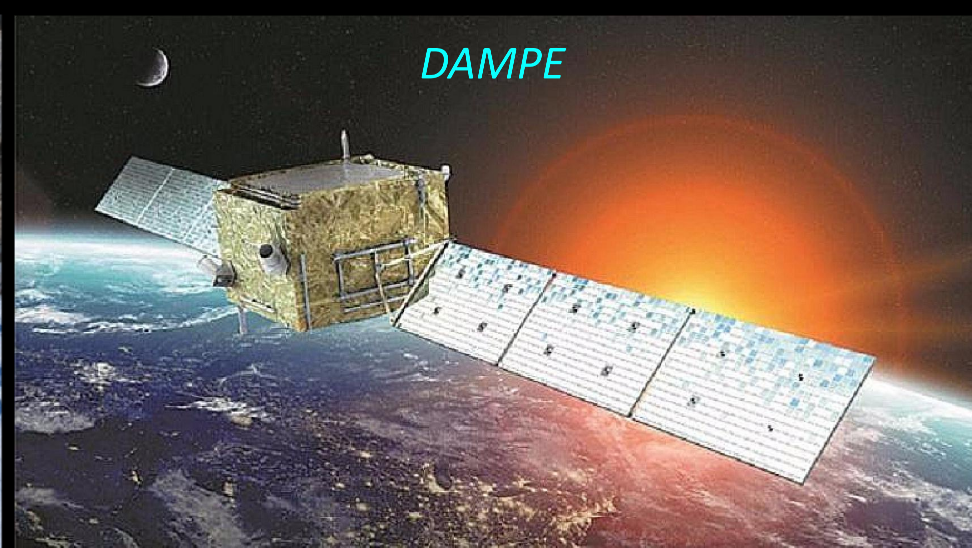


Fermi-LAT

CALET



DAMPE

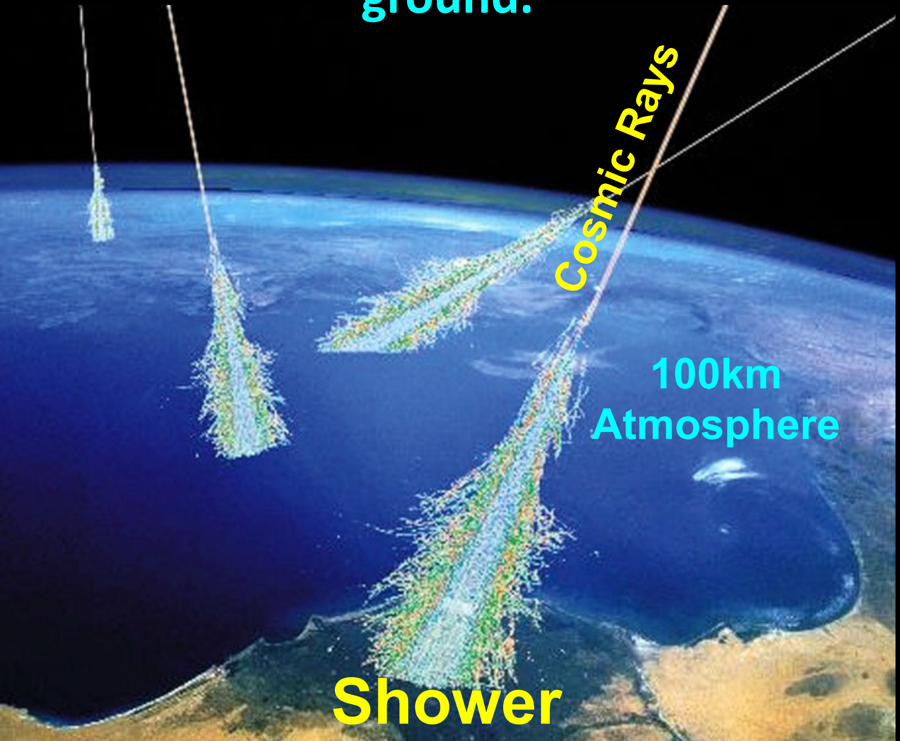


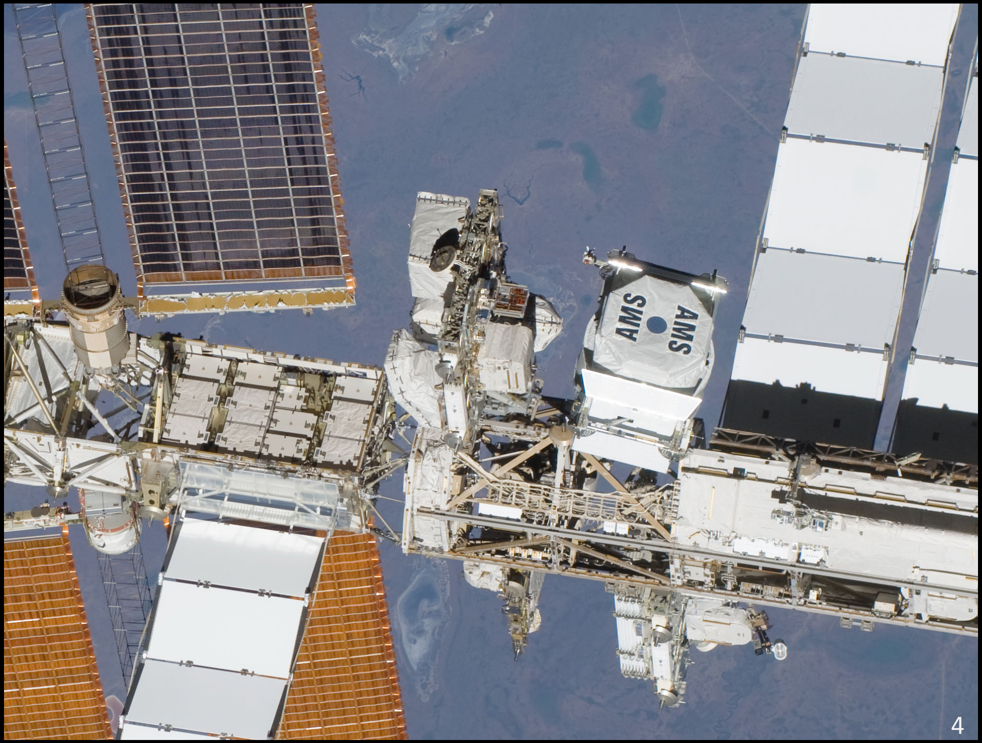
AMS on the Space Station:

Physics of Dark Matter, Antimatter, the Origin of the Cosmos, and new phenomena through the precision, long-duration measurement of charged cosmic rays

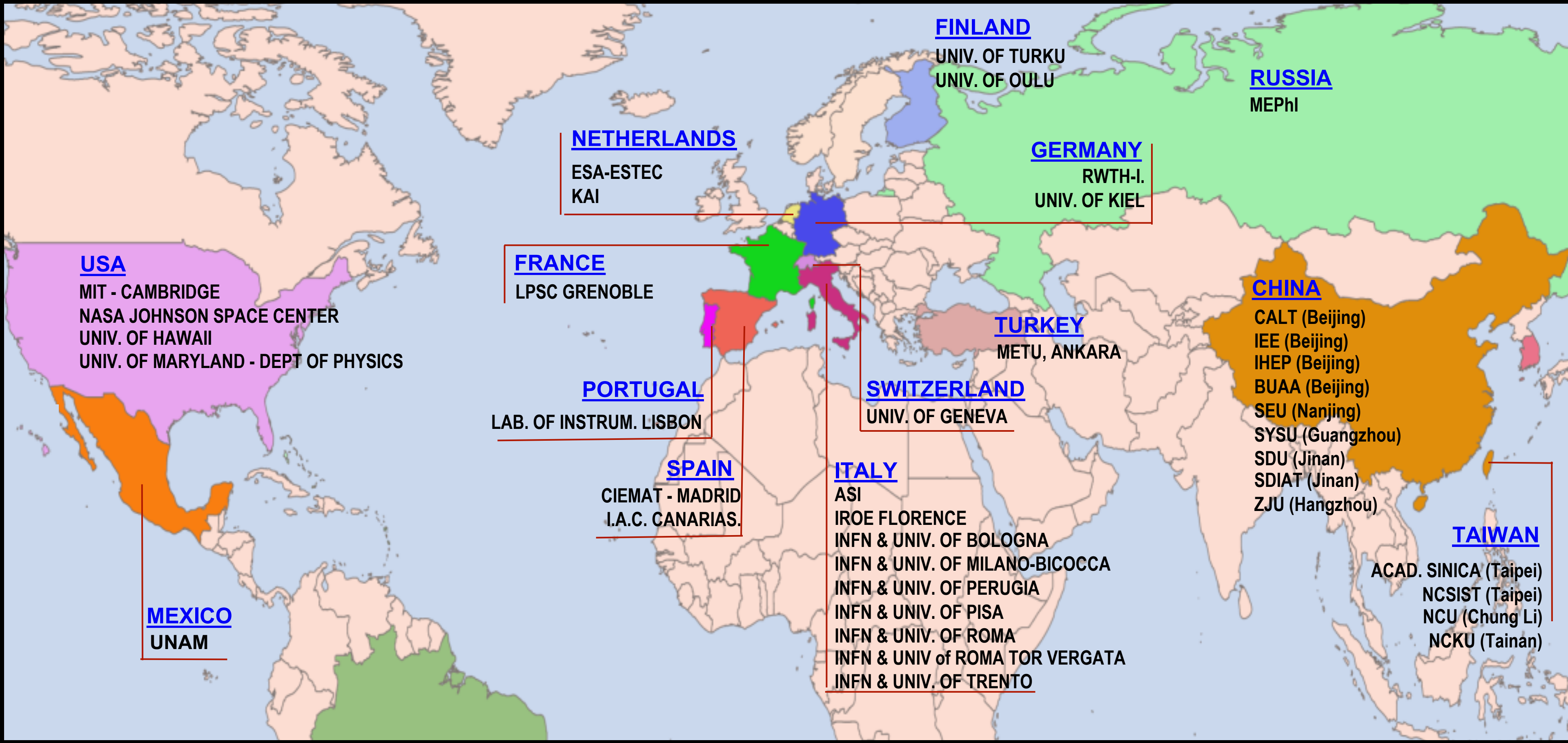
Charged cosmic rays have mass.
They are absorbed by the
100 km of Earth's atmosphere
(10m of water).
The properties ($\pm Z$, P) of charged cosmic rays cannot be studied on the ground.

To measure cosmic ray charge and momentum requires a magnetic spectrometer in space





Alpha Magnetic Spectrometer experiment (AMS) on the Space Station



We thank Professor F. Gianotti, CERN;
NASA and DOE, U.S.; ESA; ASI and INFN, Italy; DLR, RWTH-Aachen, and Julich, Germany;
CNES and CNRS/IN2P3, France; CDTI, Spain; Academia Sinica and NCKU, Taiwan;
IHEP, SDU, SDIAT, and SEU, China; UniGe, Switzerland;
for their strong support.

The strong support from NASA and CERN has been essential to the success of AMS

Ken Bollweg, Manager, AMS Project Office, leads the interface between AMS and NASA

Dr. Corrado Gargiulo
led the assembly of AMS at CERN
and is leading the current AMS upgrade
to increase the acceptance by 300%

We also thank
Dieter Schinzel,
Andrzej Siemko, and
Bernd Panzer-Steindel
for their strong support

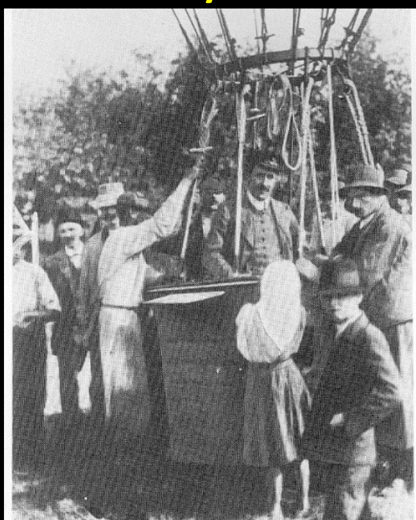
In the past hundred years, measurements of charged cosmic rays by balloons and satellites have typically had ~(30-50)% accuracy.

AMS is providing cosmic ray information with ~1% accuracy. The improvement in accuracy and extension of the energy range is providing new insights.

The AMS results contradict current cosmic ray theories and require the development of a new model of the universe.

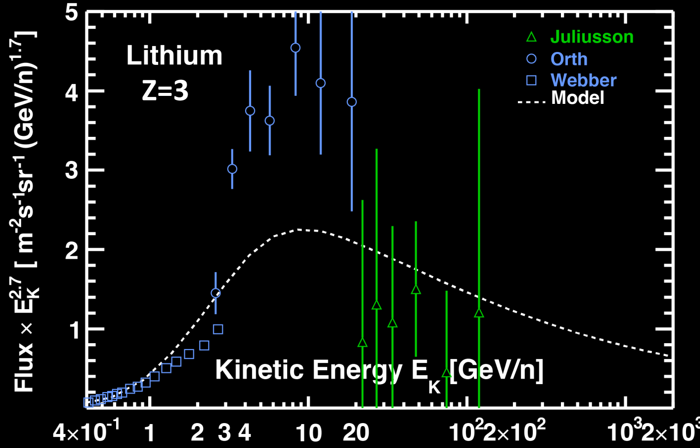
Cosmic Rays in the last 100 years

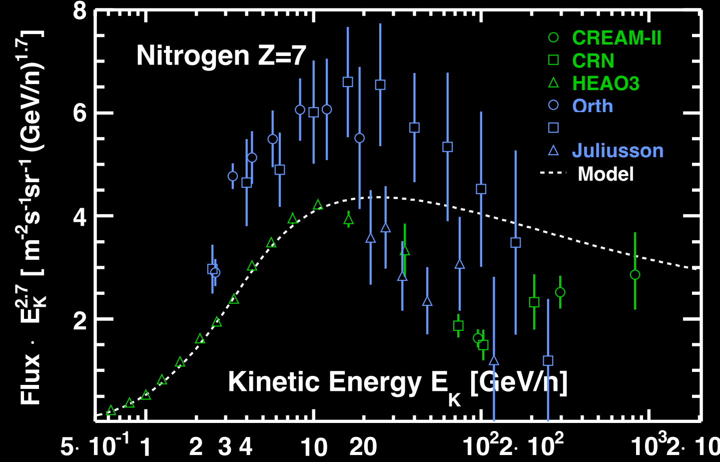
1912: Discovery of Cosmic Rays

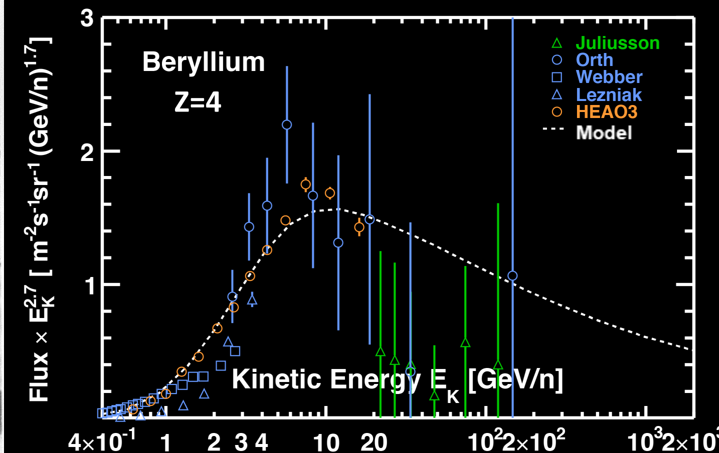


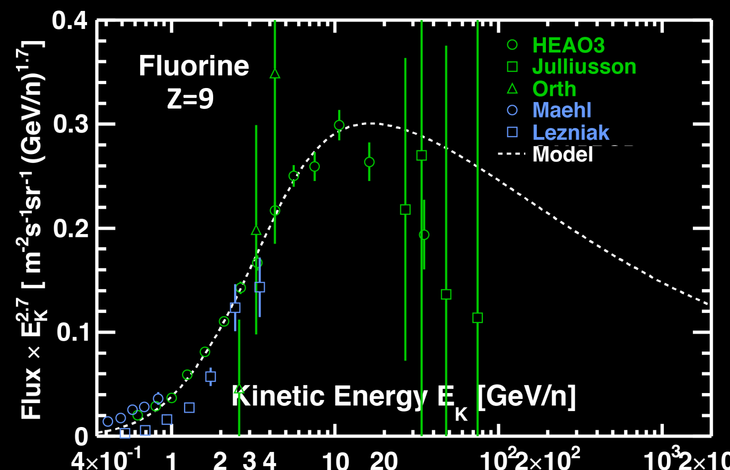
Victor Hess Nobel Prize (1936)

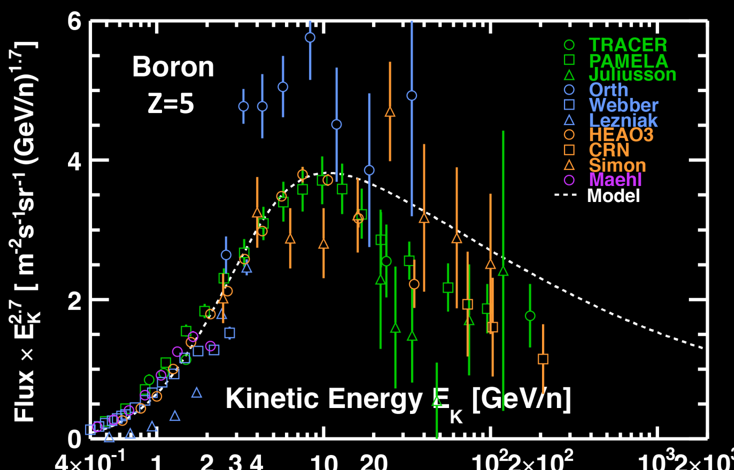
Before AMS: Many theoretical models agree with experimental data

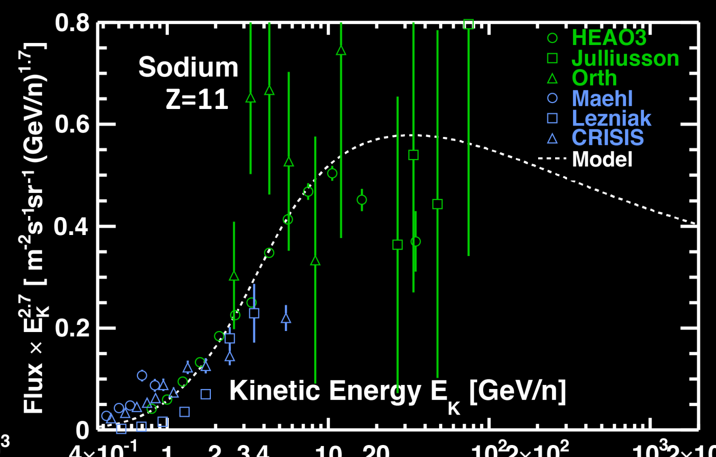






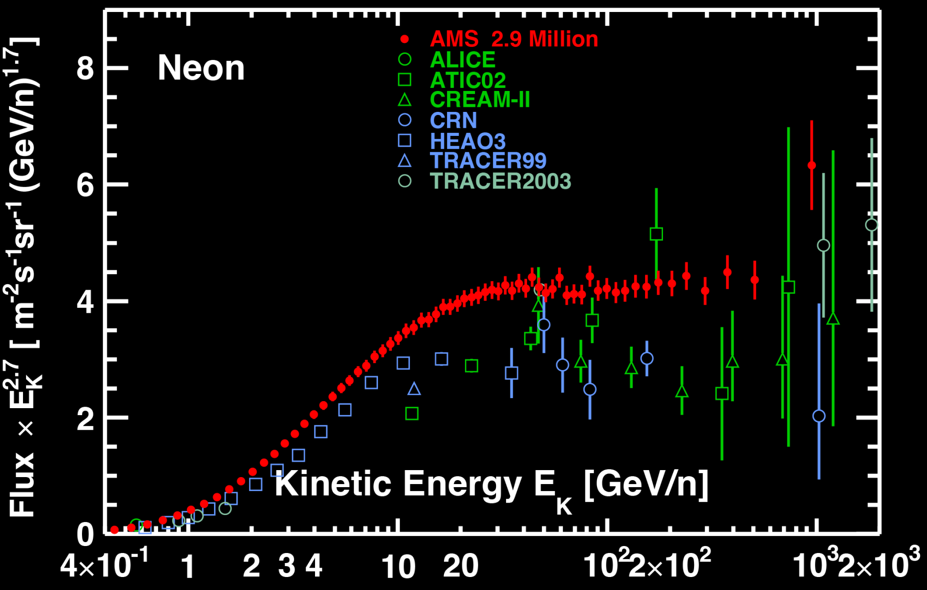


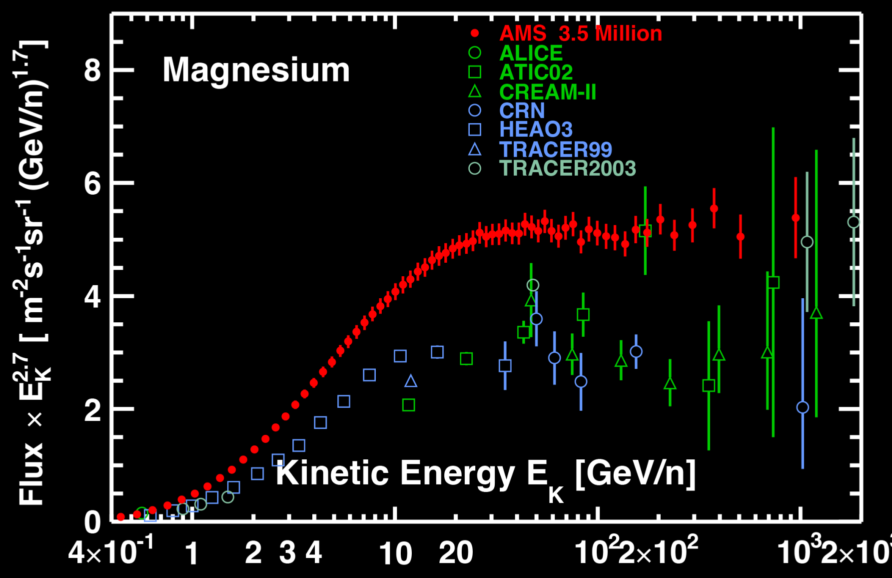


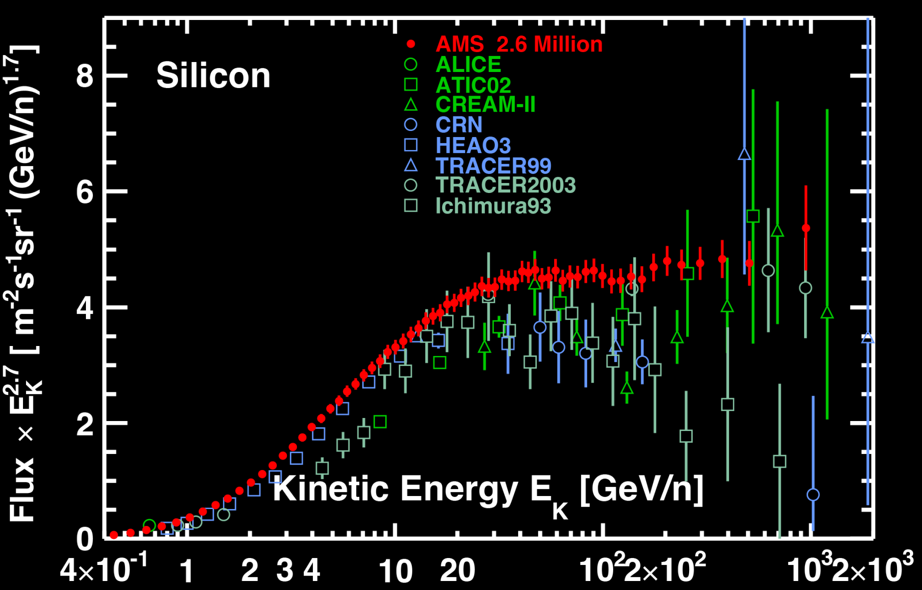


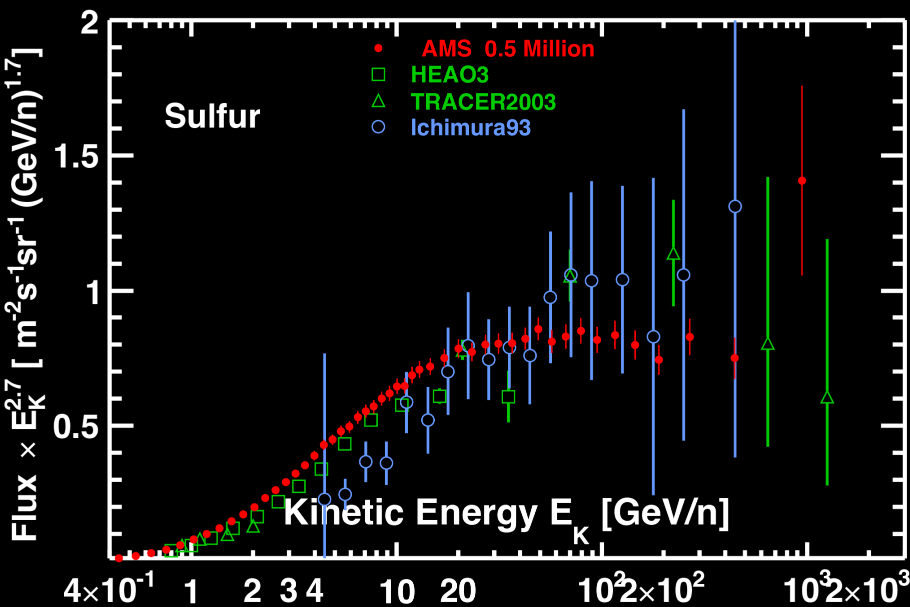
Examples of AMS Results compared with earlier measurements

The precision AMS results cannot be explained by current models.







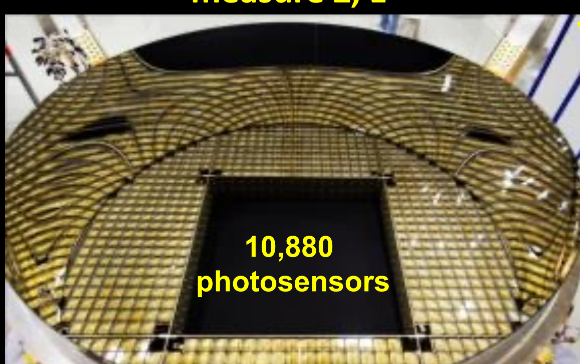


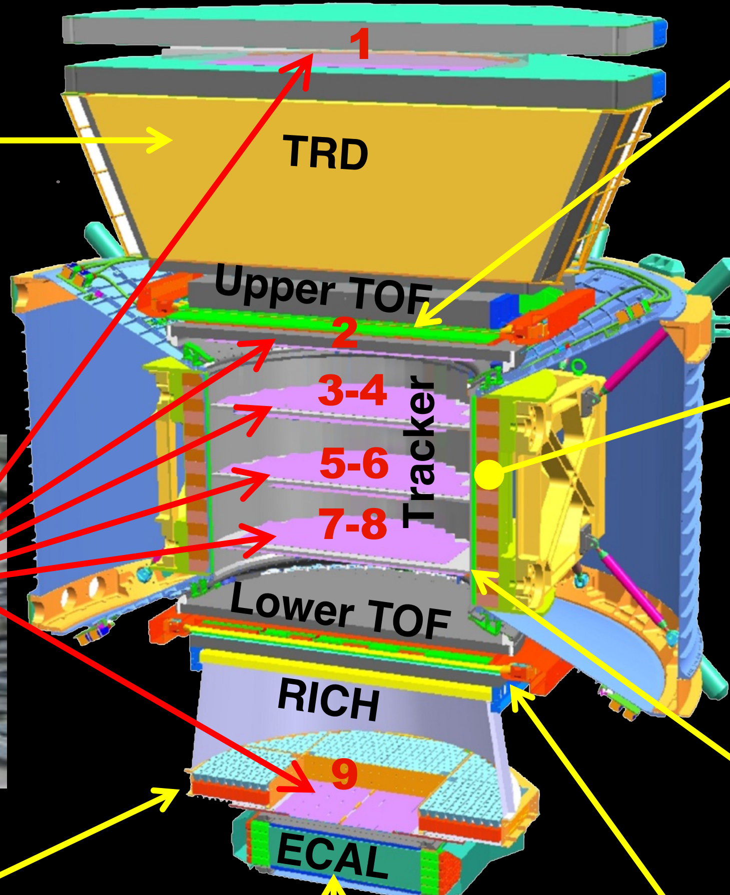
AMS is a space version of a precision detector used at CERN accelerators

Transition Radiation Detector (TRD)
identify e^+, e^-

Silicon Tracker
measure Z, P

Ring Imaging Cerenkov (RICH)
measure Z, E



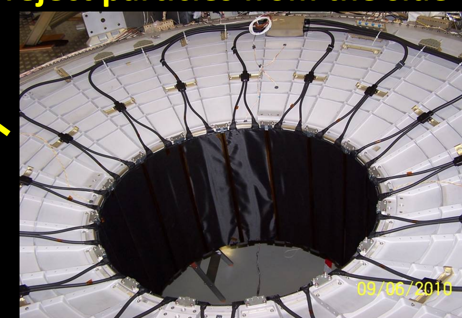


Electromagnetic Calorimeter (ECAL)
measure E of e^+, e^-

Upper TOF measure Z, E

Magnet identify ±Z, P

Anticoincidence Counters (ACC)
reject particles from the side

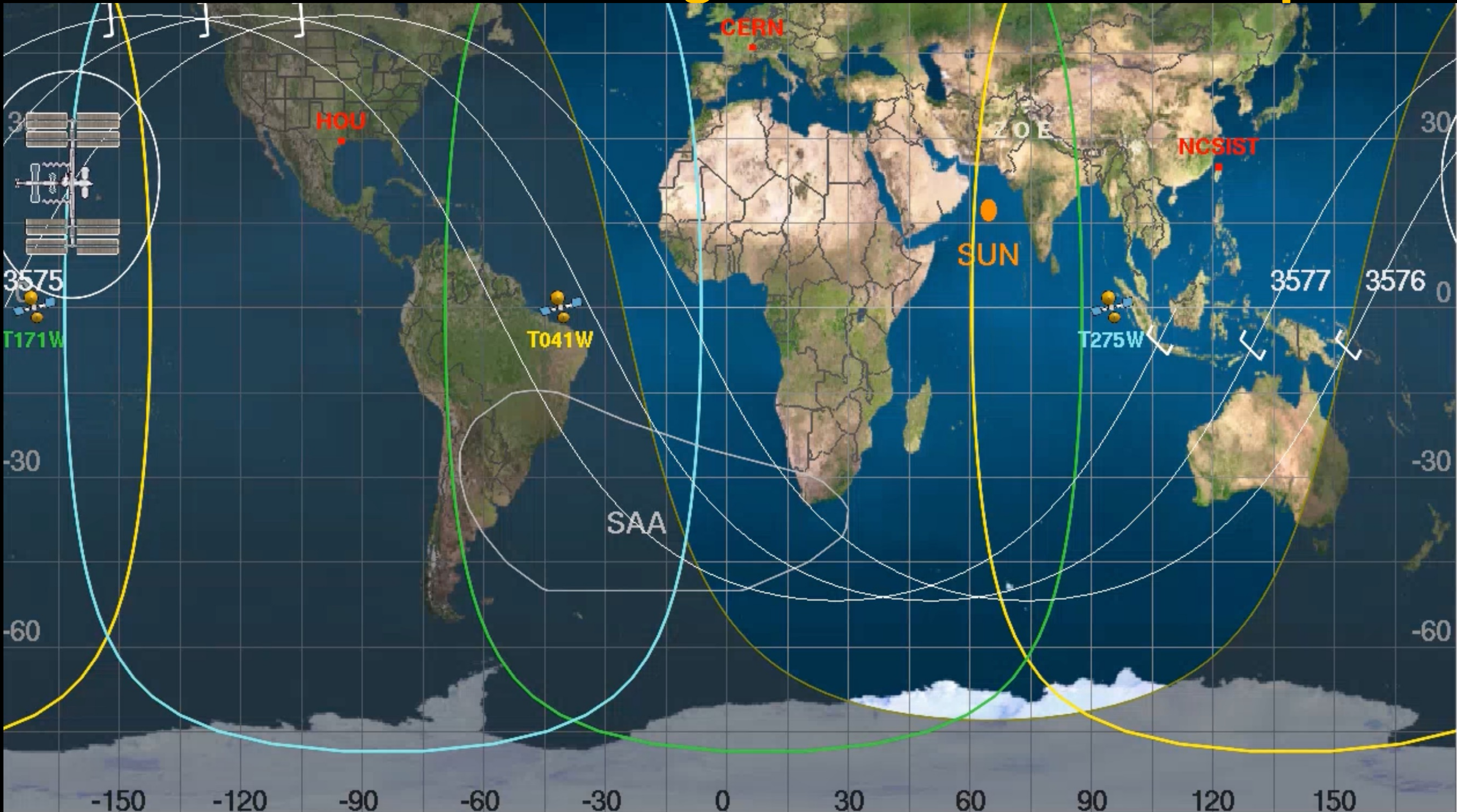


Lower TOF measure Z, E

5m x 4m x 3m
7.5 tons

Endeavour approaching the Space Station, May 18, 2011

2011-2023: AMS is taking data without interruption



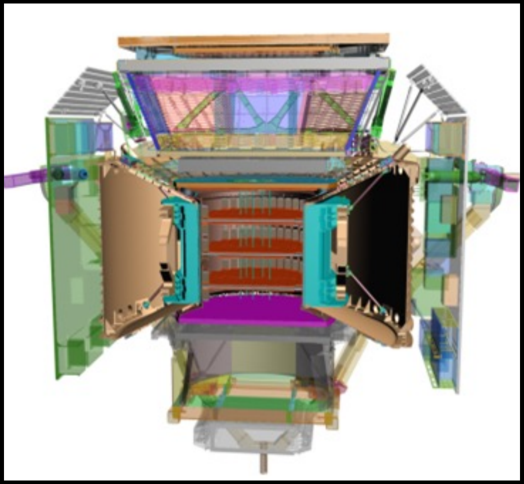
220,182,212,893

AMS Payload Operations Control Center at CERN

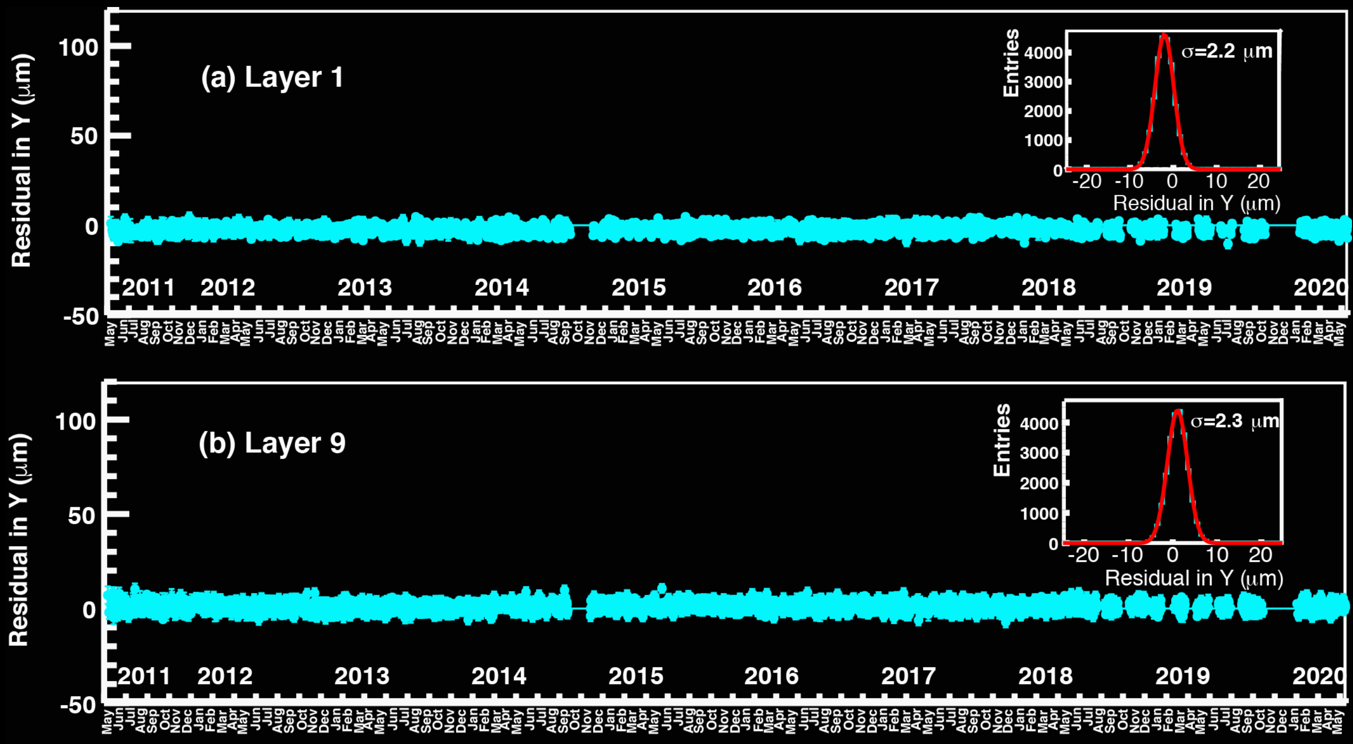
Fully staffed 24 hours per day, 365 days per year

Continuous Verification of Detector Performance on Orbit
Example: Tracker Alignment

Inner tracker alignment (< 1 micron) monitored with IR lasers



Outer layers monitored every 2 minutes by cosmic rays

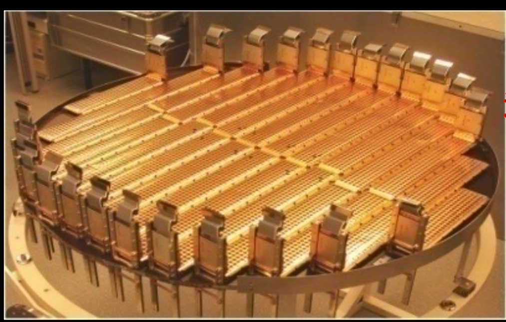


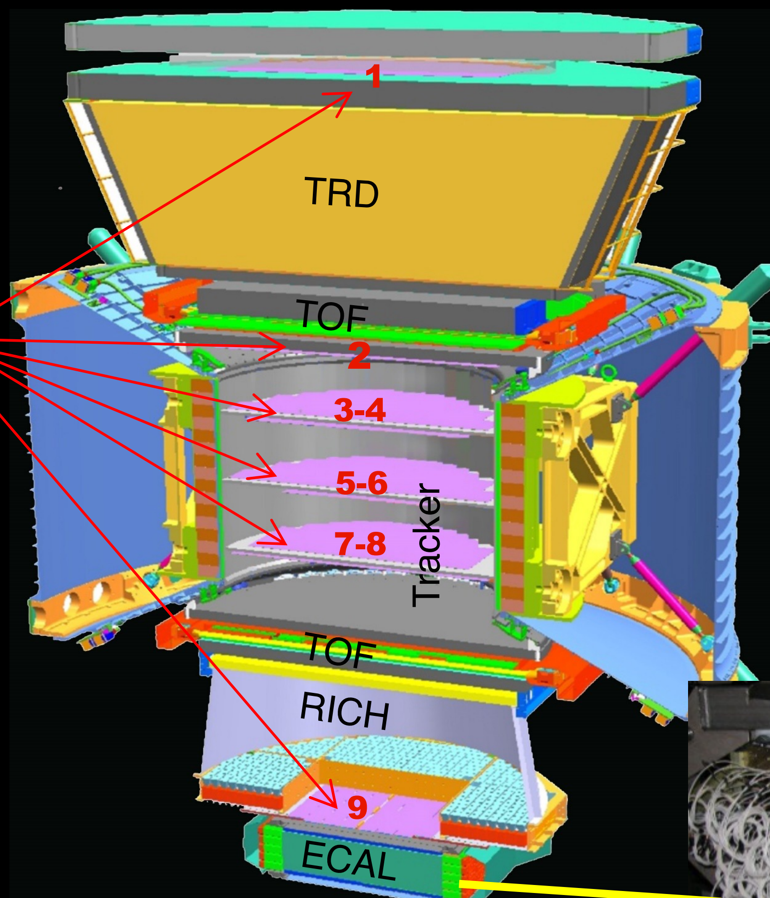
stable to 2 microns over 10 years

Detector Improvements in space

With 12 years of operation and analysis of more than 220 billion events, we now know the details of the detector response and this has enabled us to make significant improvements in the measurements.

Silicon Tracker

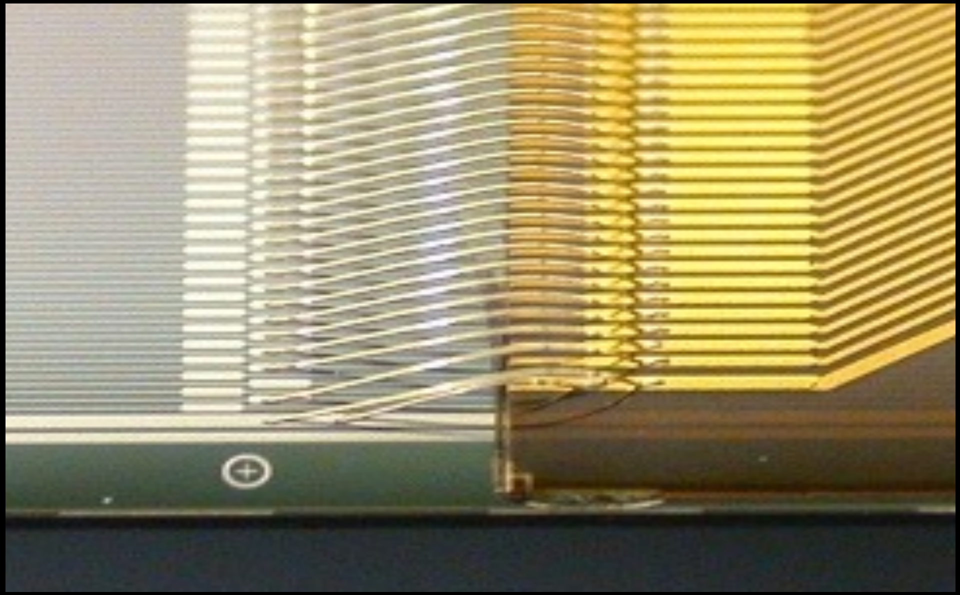


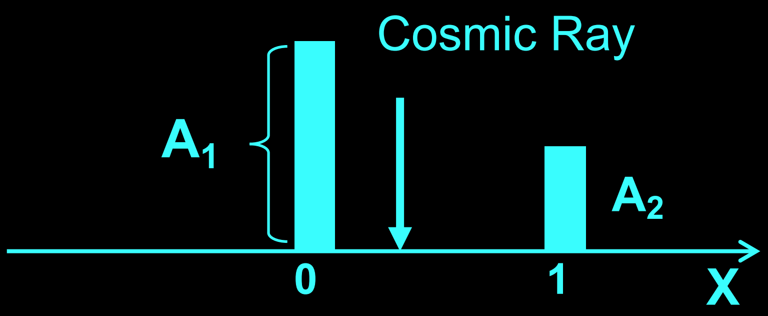


ECAL

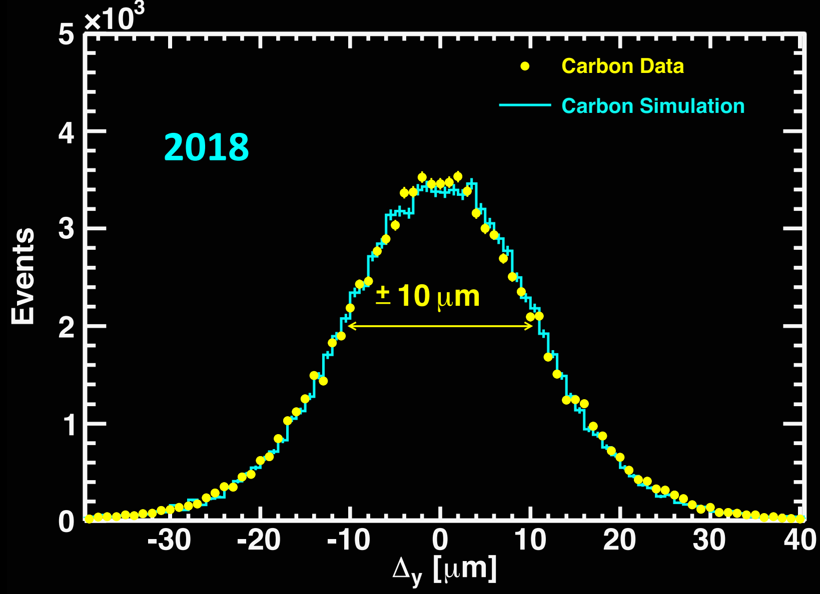
Coordinate resolution improvement

The maximum amplitude is defined as A_1 (x=0) and the next largest adjacent strip as A_2 (x=1).





Traditional method: The A_1/A_2 ratio provides the particle coordinate

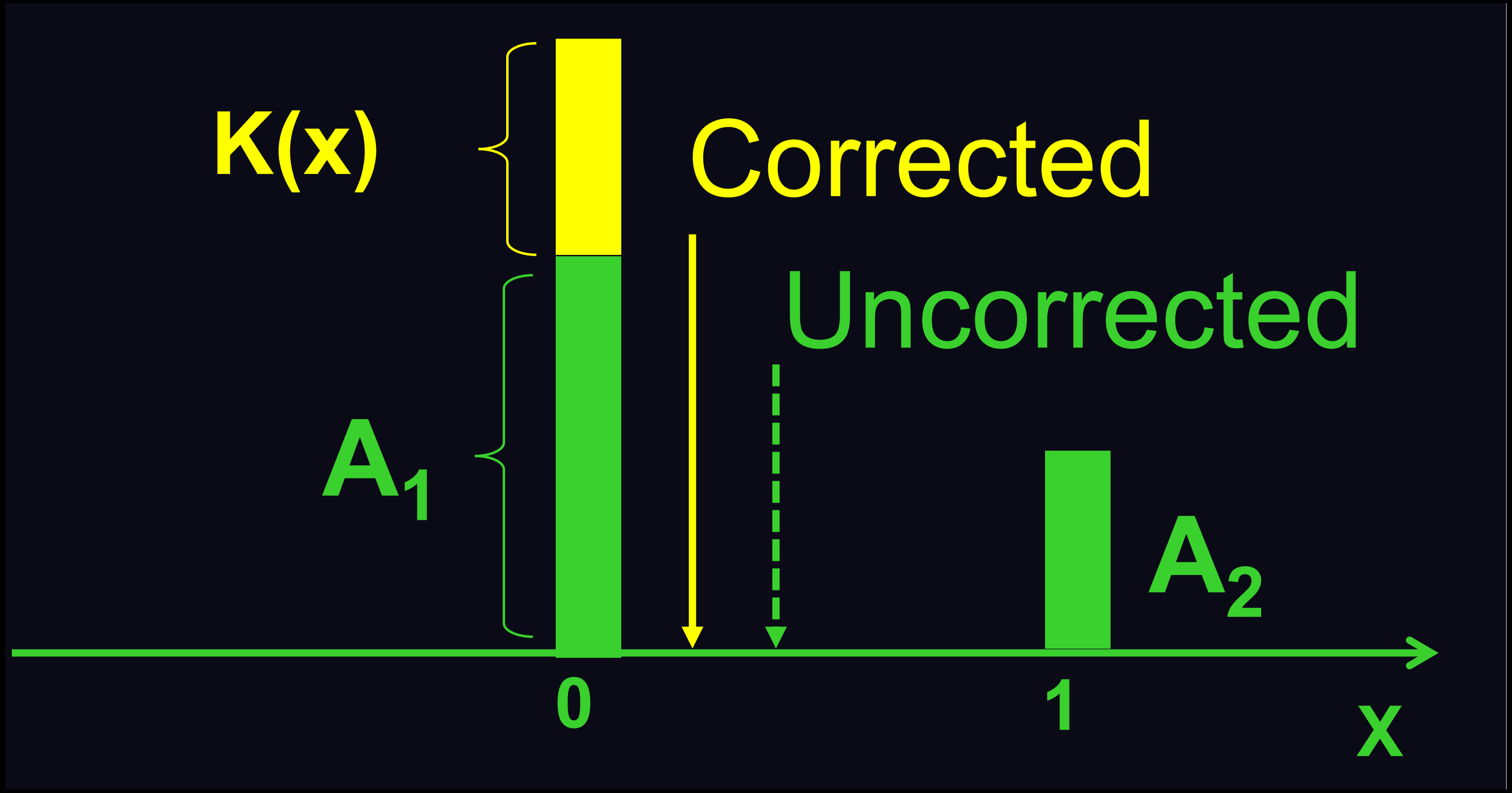


The signals should be proportional to Z^2. For Z>3, A_1 starts to be non-linear, causing resolution degradation.

Coordinate resolution improvement

To correct for the non-linear effect, we find a function **K(x)**

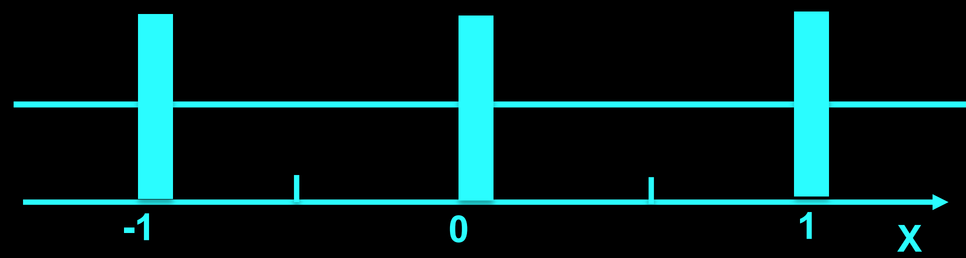
which will restore the non-linear amplitudes $A_1 \rightarrow A_1 + K(x)$



Coordinate resolution improvement

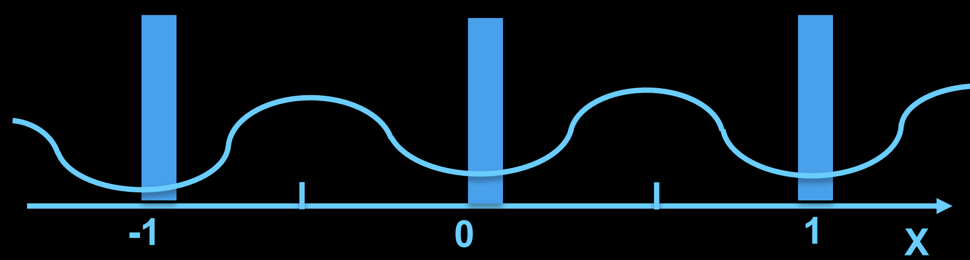
Cosmic rays come uniformly from all directions

Tracker linear response



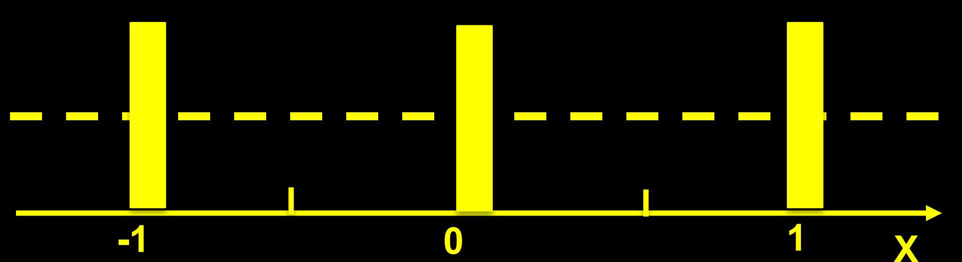
Uniform event position density

Tracker non-linear response

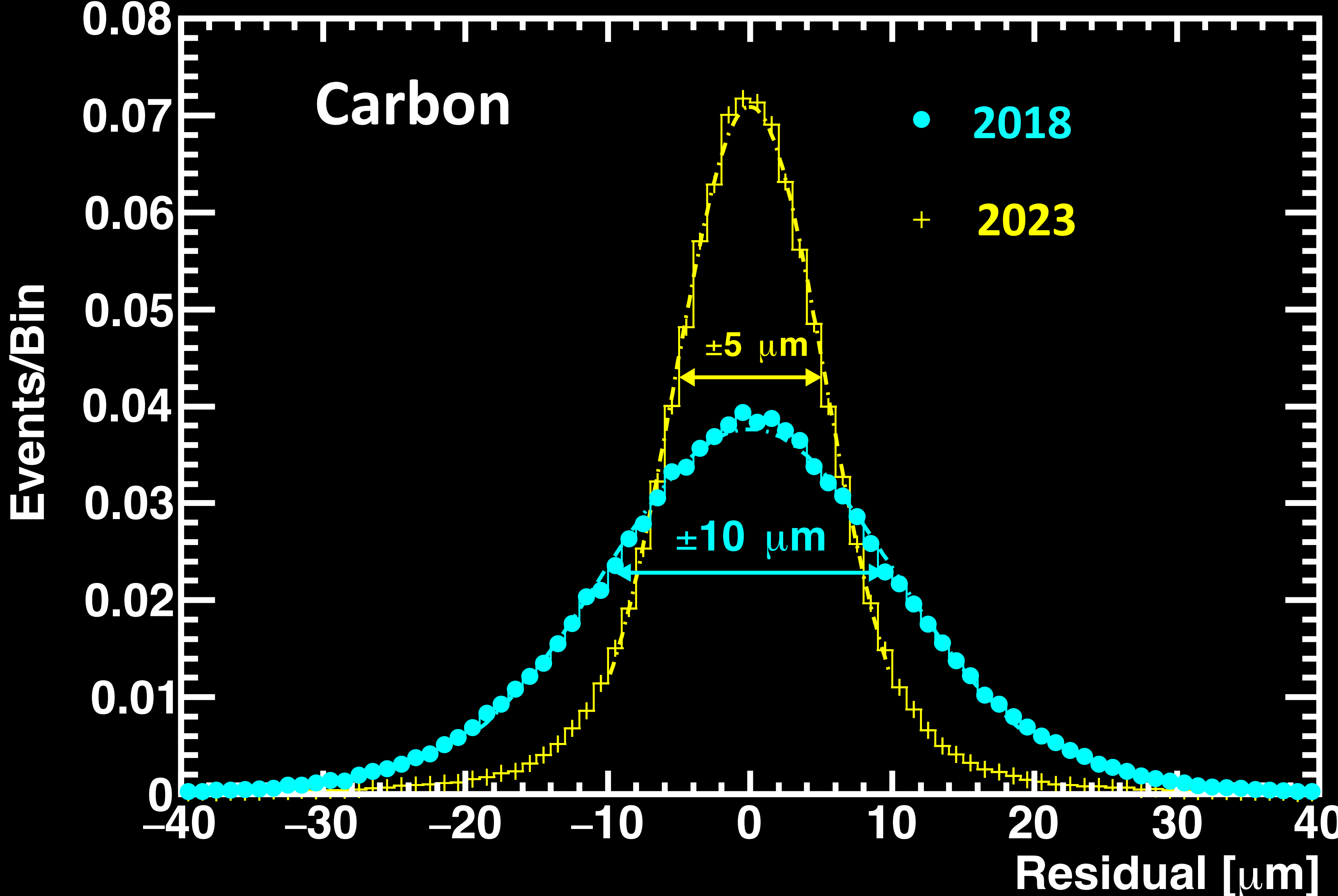


Event density not uniform

We determine K(x) by requiring a uniform event density:

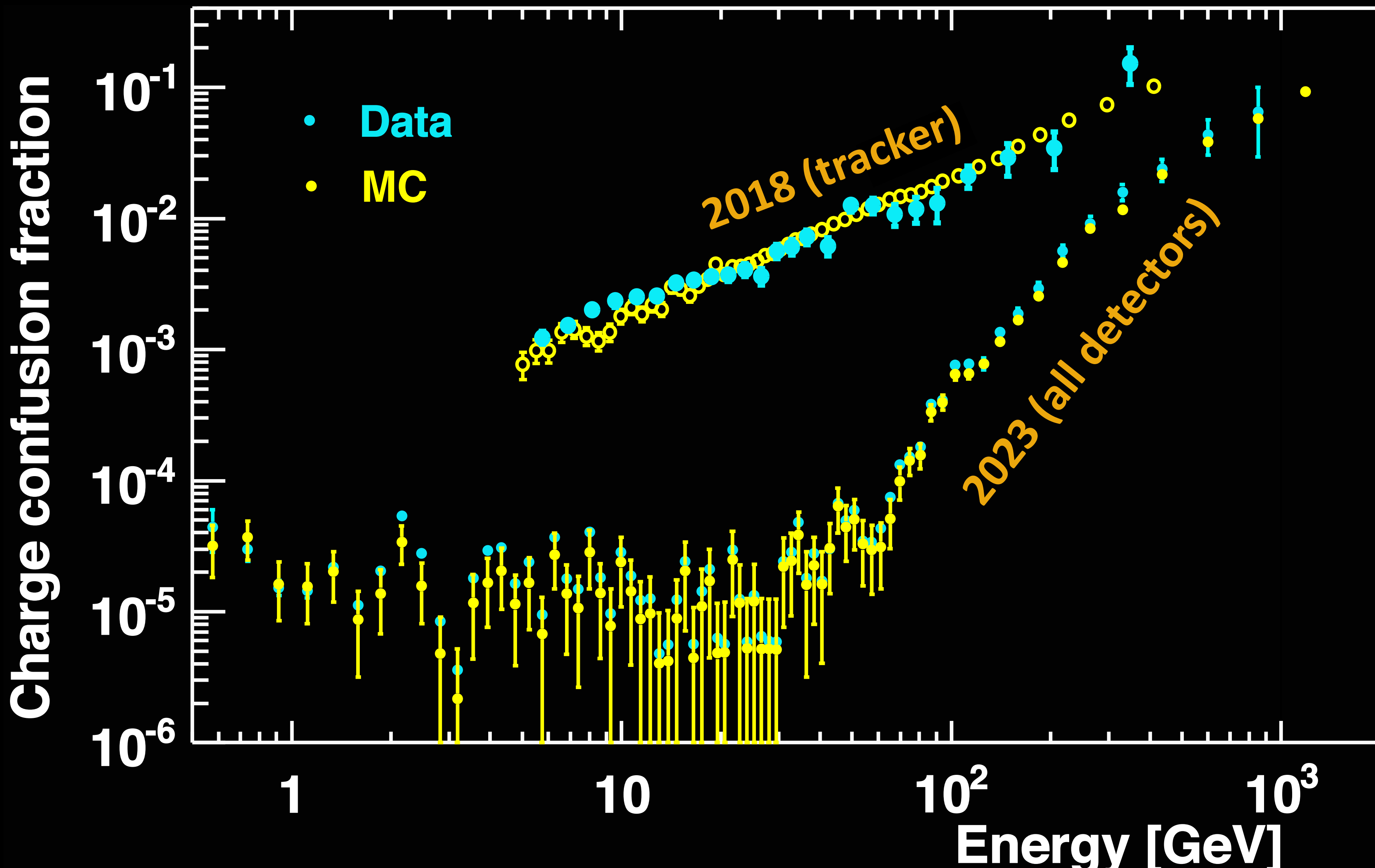


Improvements in the coordinate resolution



Improvements in the $e^{\pm}$ charge-sign determination from all detectors

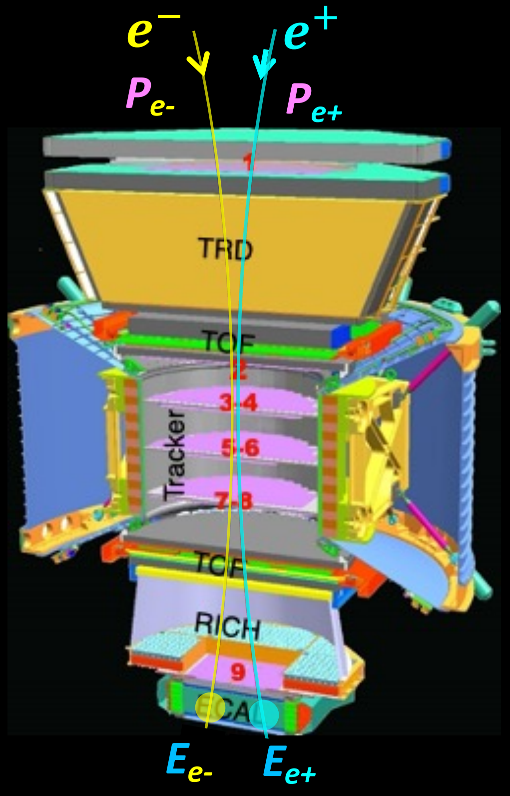
The charge confusion is reduced by a factor of 10 at 500 GeV



Continuous Momentum Scale Verification
(Unique Advantage of a Magnetic Spectrometer)

In AMS, the largest systematic error in the determination of the fluxes at the highest energies is due to the uncertainty in the absolute momentum scale.

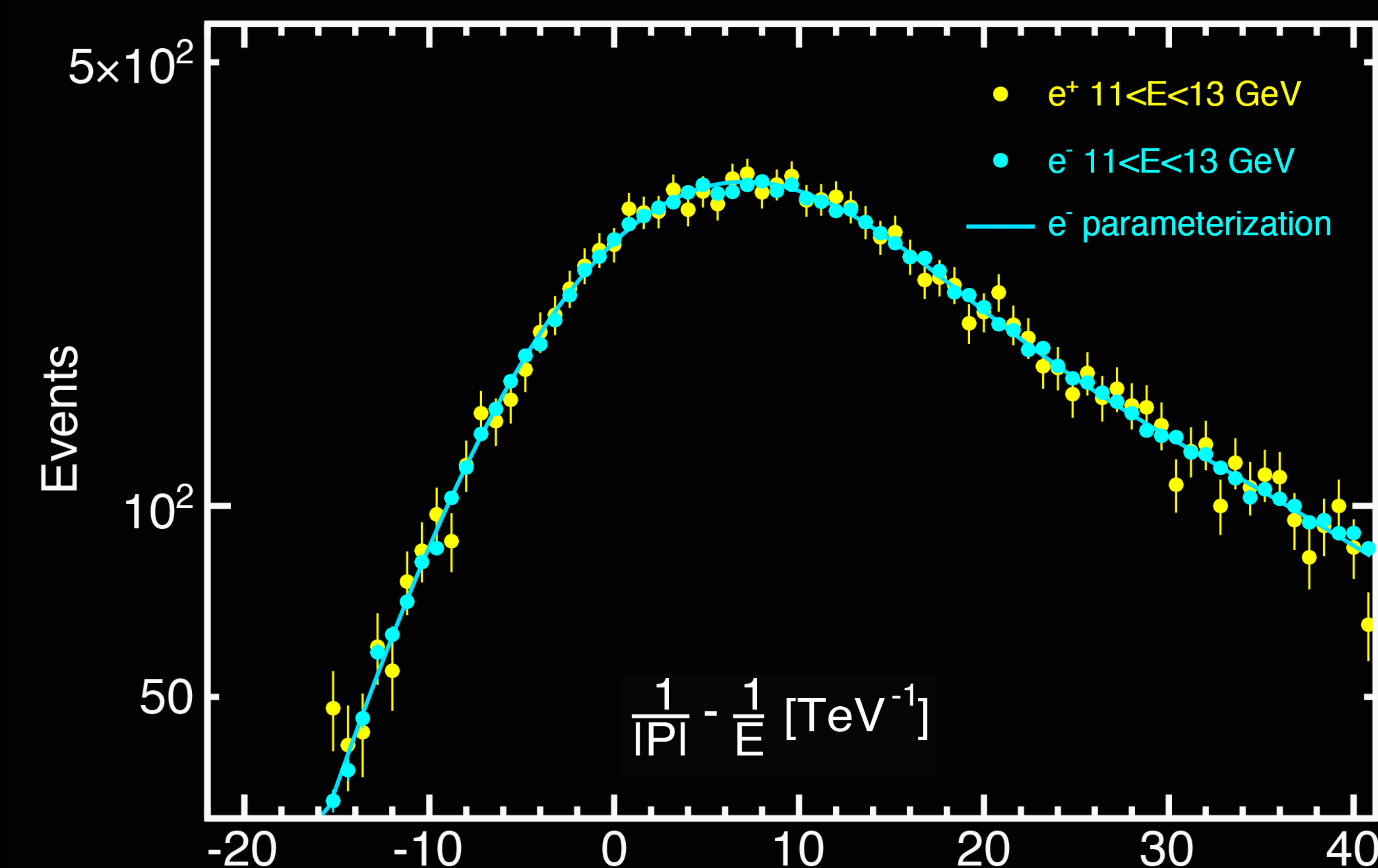
In space continuous outgassing of the supporting structure can affect the position of the tracker sensors at the sub-micron level.



A shift in the central tracker planes of 0.5 microns is sufficient to create a momentum shift of 10% at 1 TeV and bias flux measurements.

Momentum Scale Verification

with 4 independent measurements of P_{e^+}, E_{e^+}, P_{e^-}, E_{e^-}



The accuracy of the momentum scale is determined to be 1/(34,000 GeV);

i.e., at 1 TeV the uncertainty is less than 3%

Examples on the importance of the determination of energy scale:

In calorimeters (like CALET on the ISS) there is no way to know the absolute energy scale

CALET, PRL 126, 241101 (2021)

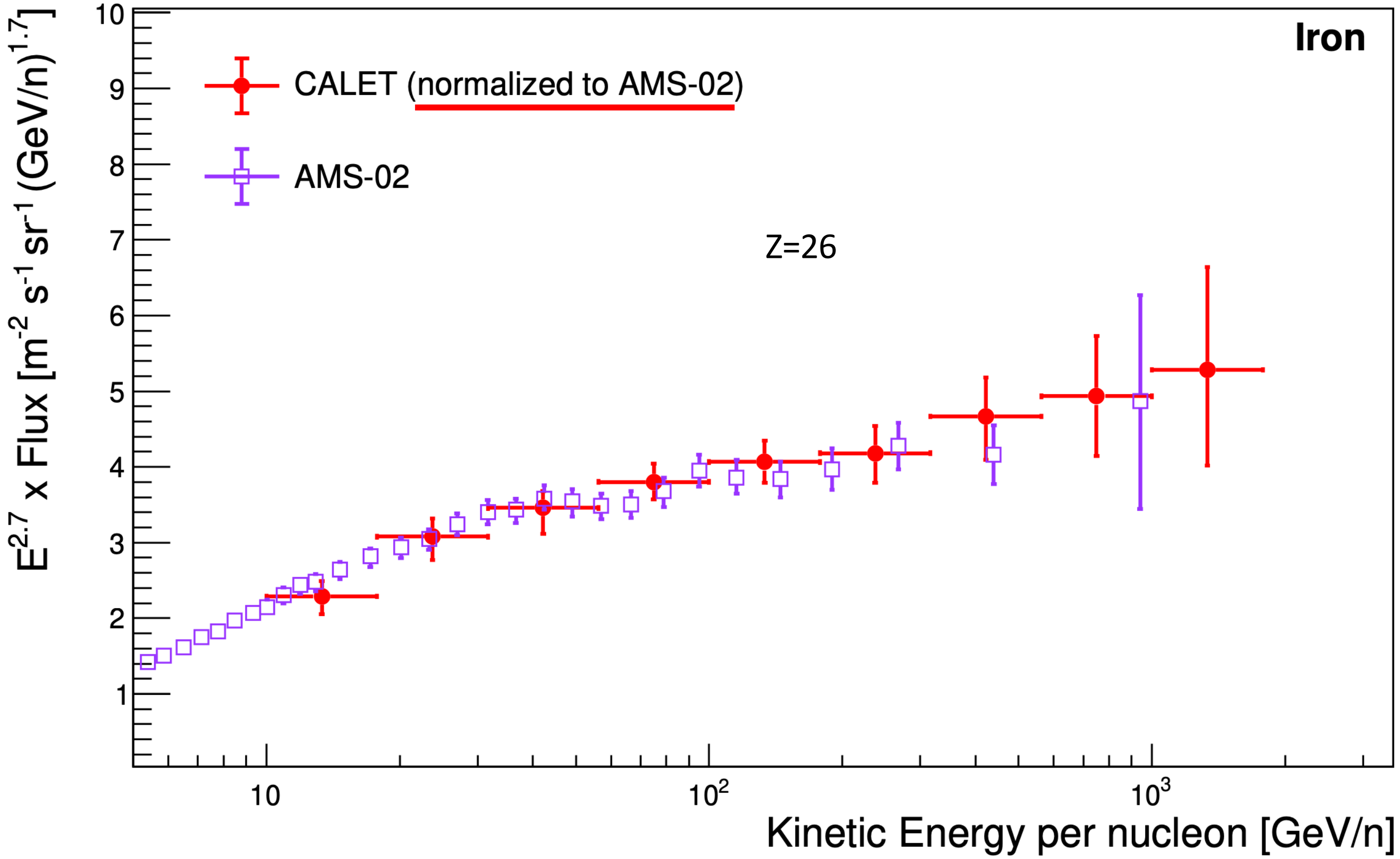
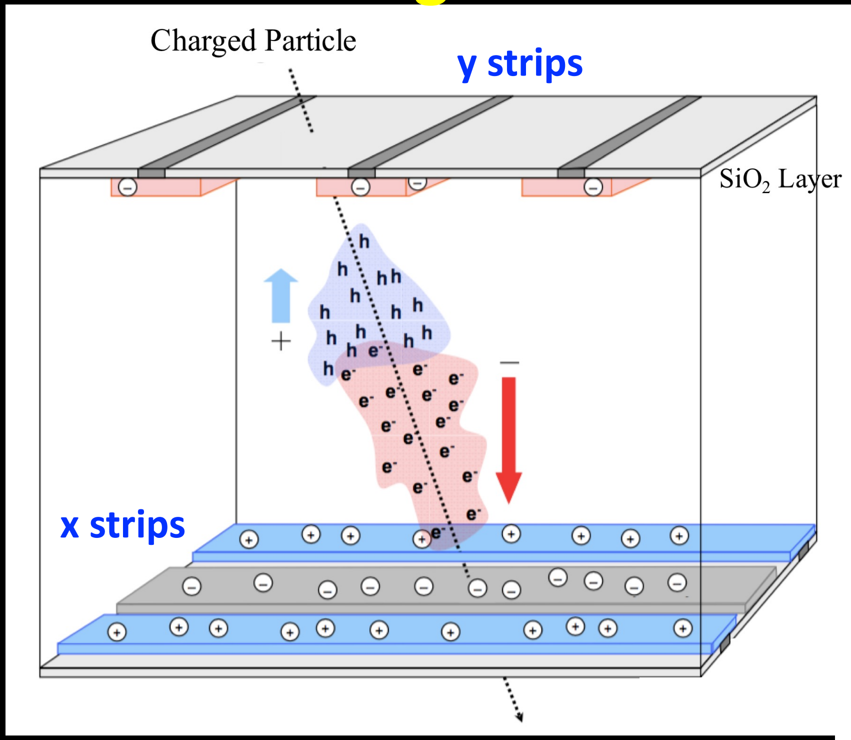


FIG. S12. Iron flux (with multiplicative factor $E^{2.7}$) measured by CALET (red points) with 4 bins/decade, multiplied by 1.20 for comparison with the AMS-02 results [S3]. The error bars of the CALET data are the quadrature sum of statistical and systematic uncertainties.

Charge Resolution improvement for high-Z

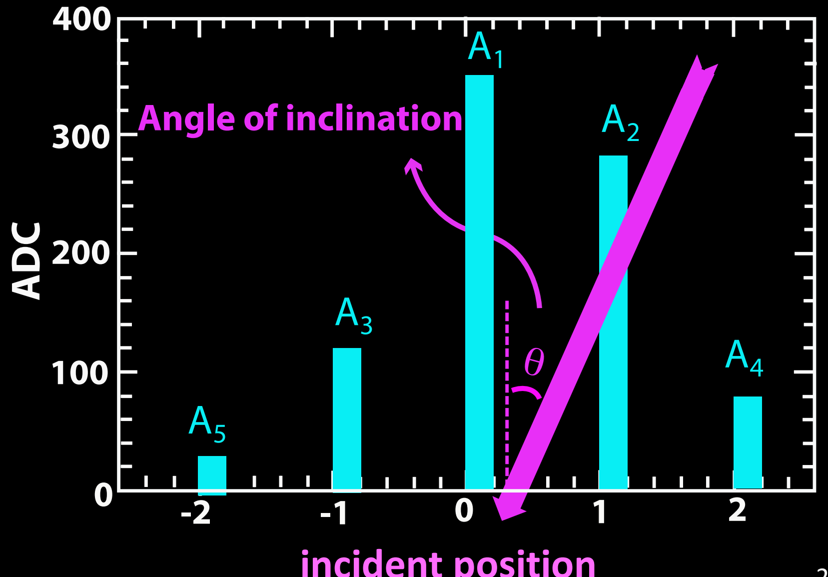
The Tracker measures the charge |Z| with both the x- and y-strips.



The energy loss deposition is collected by several strips on each side.

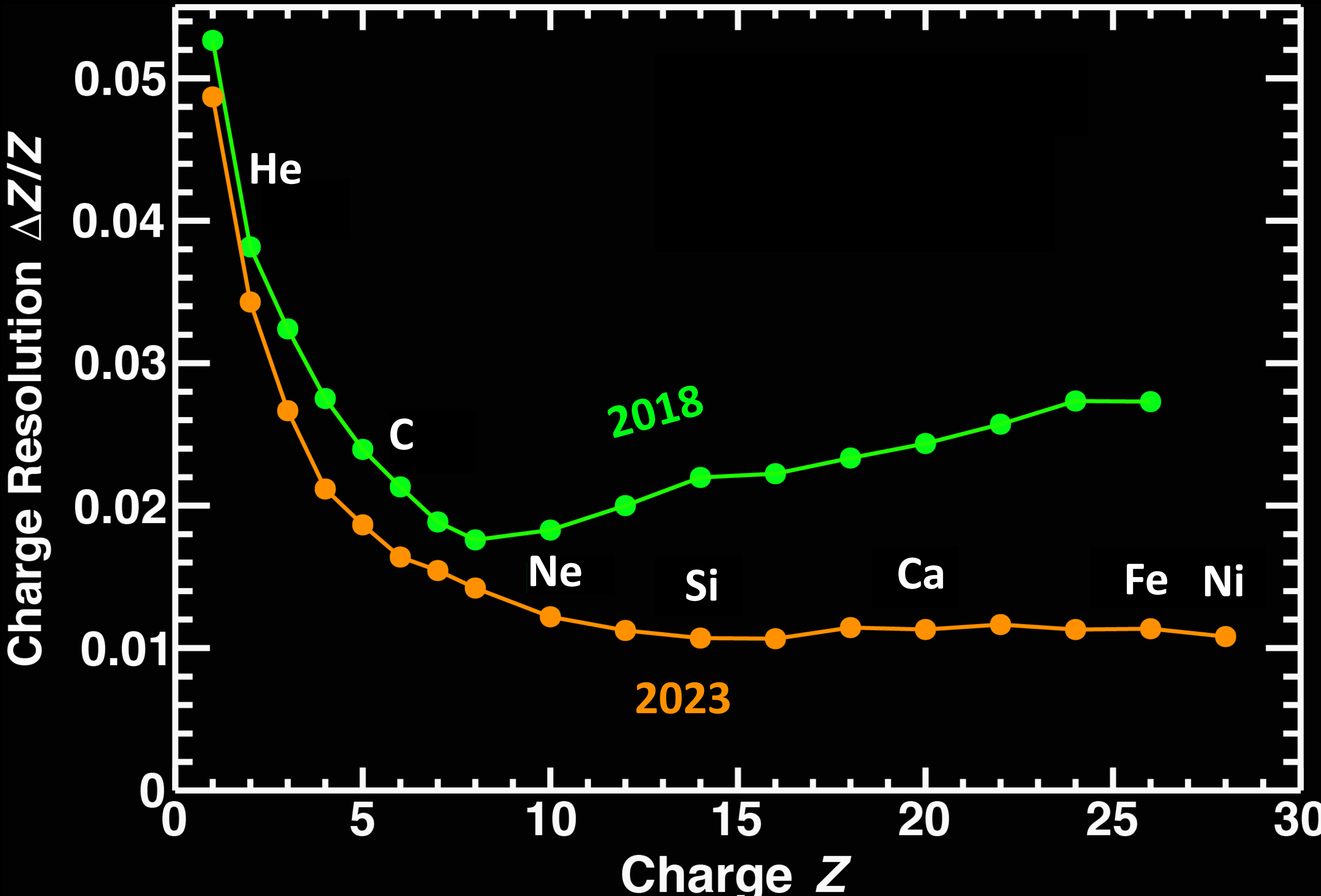
The amplitudes are related to the incident position and angle θ.

The improvement corrects for the saturation strip-by-strip.

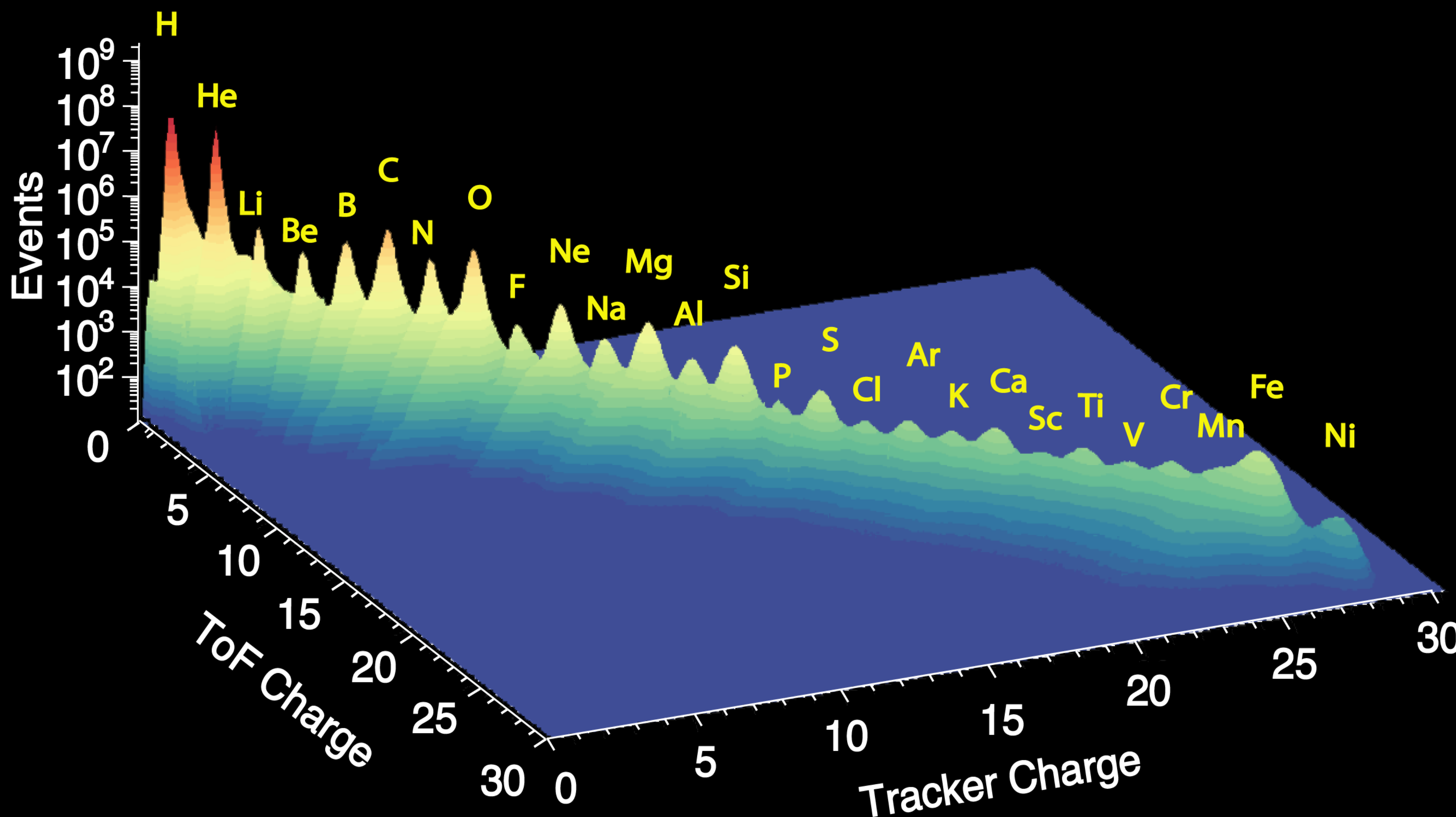


Improvement in the charge resolution

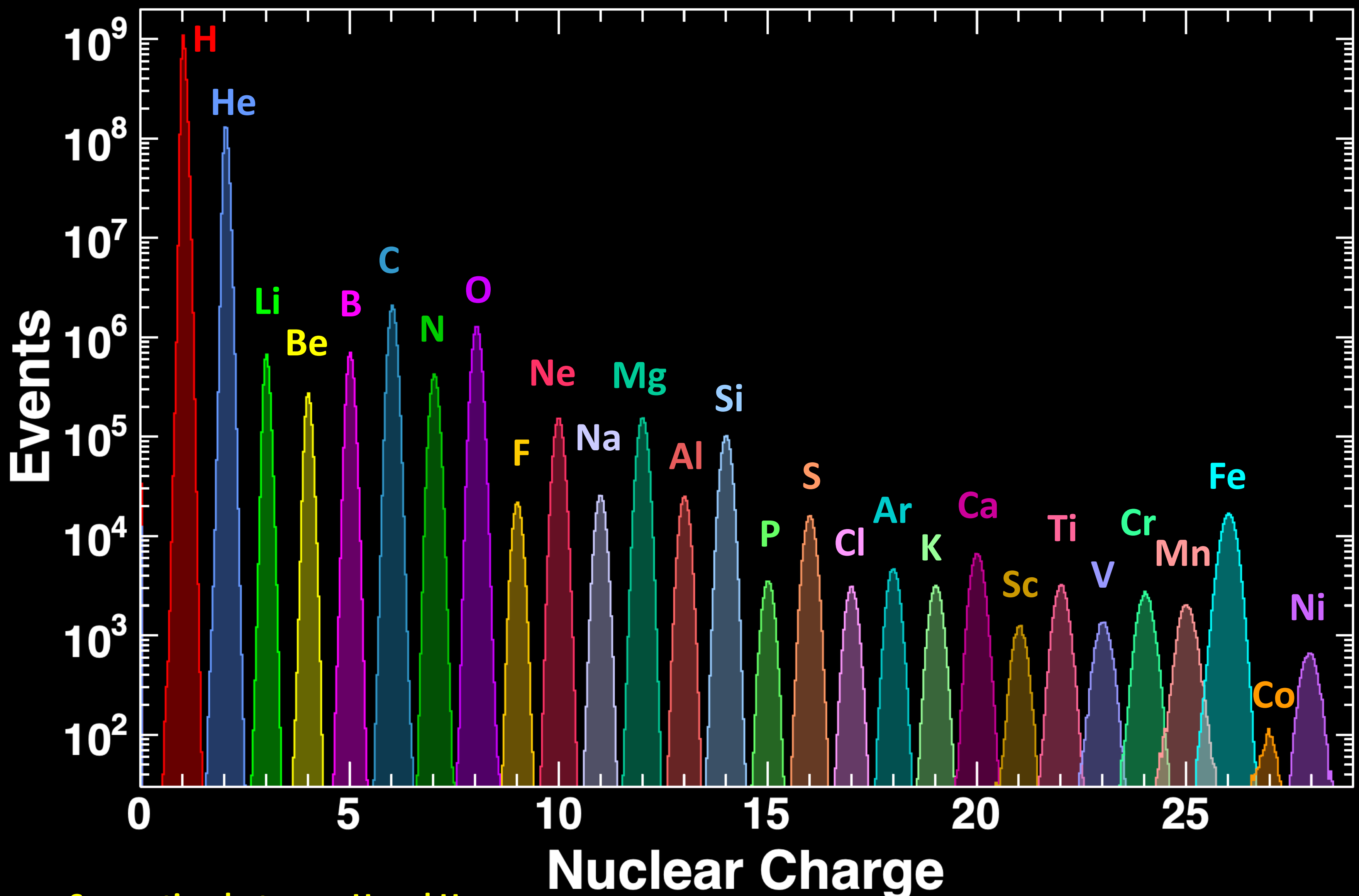
Improved by 200% and more



Charge Measurement in 2018



Charge Measurement in 2023

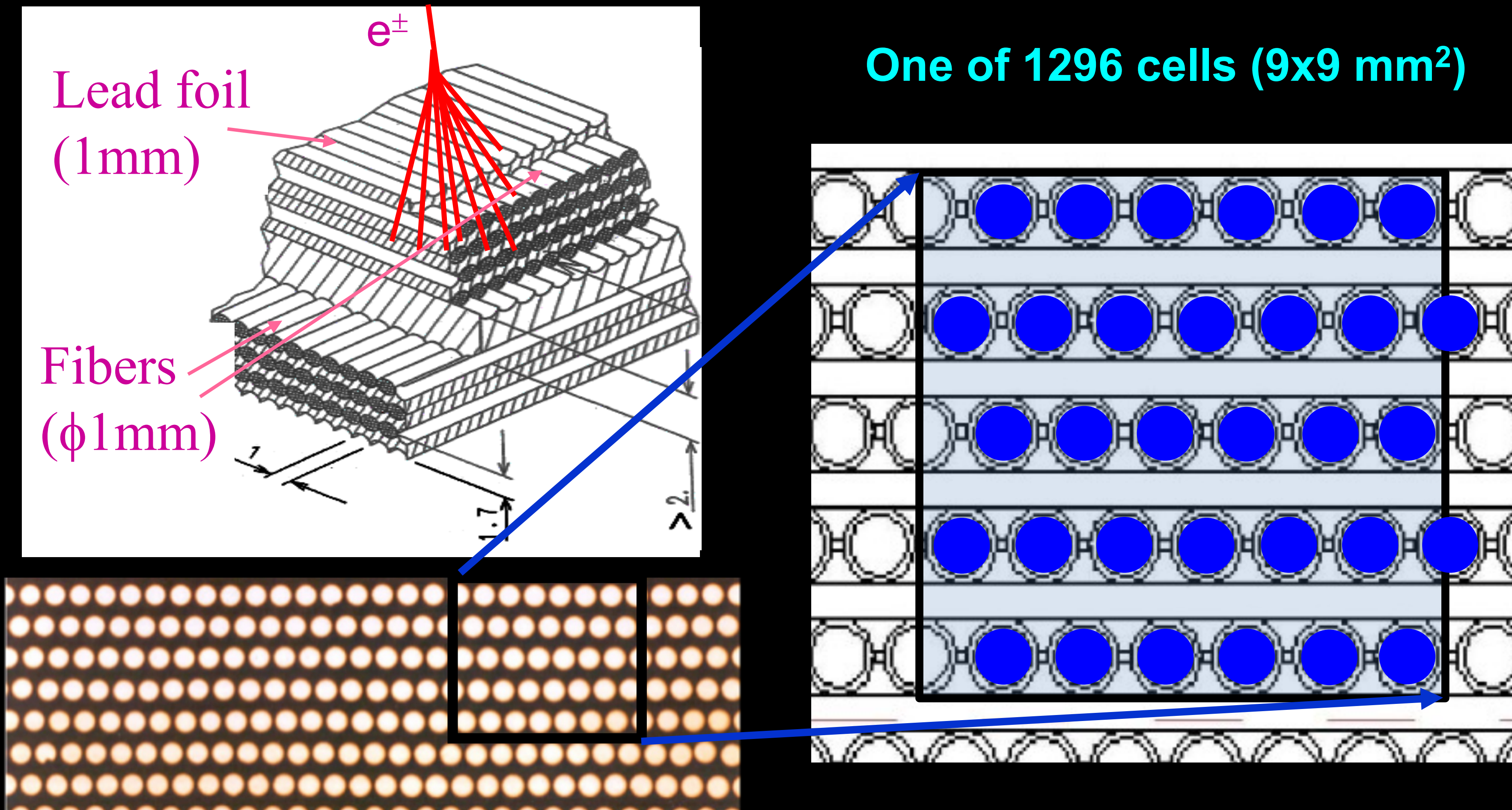


Separation between H and He is better than 1 in 10^9

Separation between Fe and Co is better than 1 in 10^2

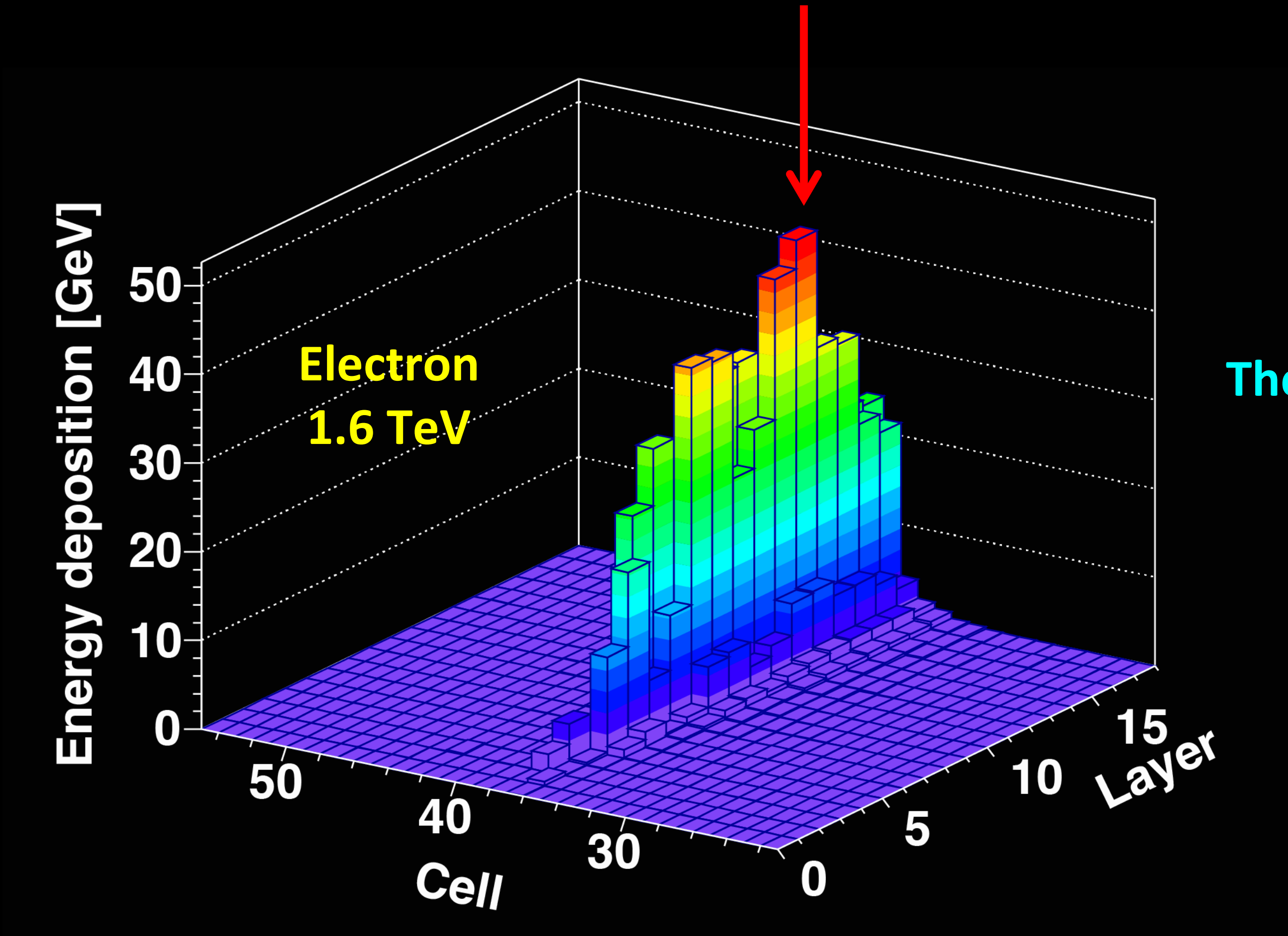
Improvement in Electromagnetic Calorimeter (ECAL)

3-D measurement over 17 radiation lengths of the directions and energies of electrons and positrons



High energy measurements for positrons and electrons

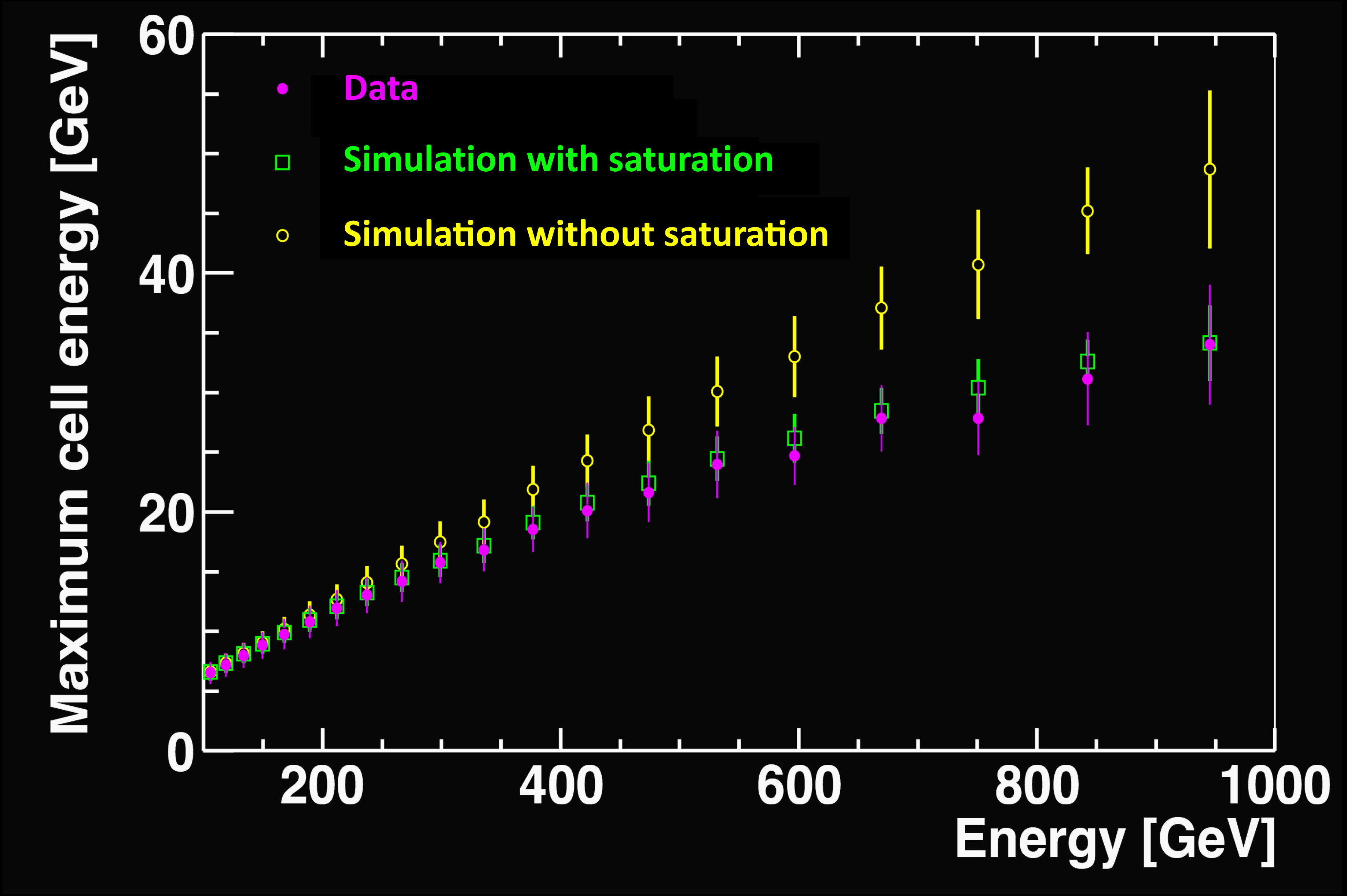
For the highest energy $e^{\pm}$, the response in cells in the center of the shower is saturated in the fibers.



The rest of the cells carry all the information about the shower

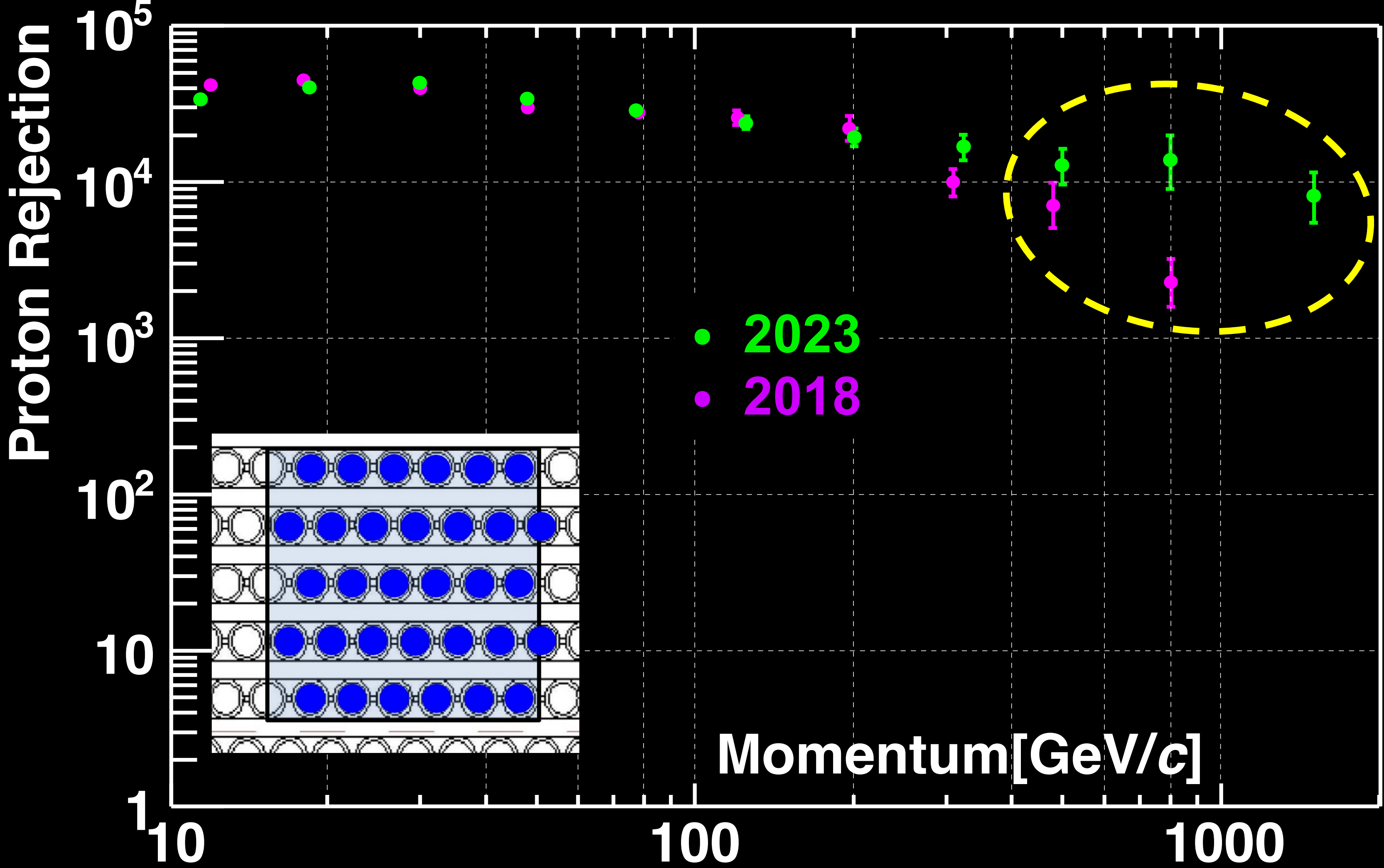
In space the rate is low. We have developed a technique that uses only these surrounding cells to reconstruct the overall shower, its energy and direction.

Improvement in high-energy measurements for e$^{\pm}$



The total energy correction for 1 TeV Electromagnetic showers is 8%

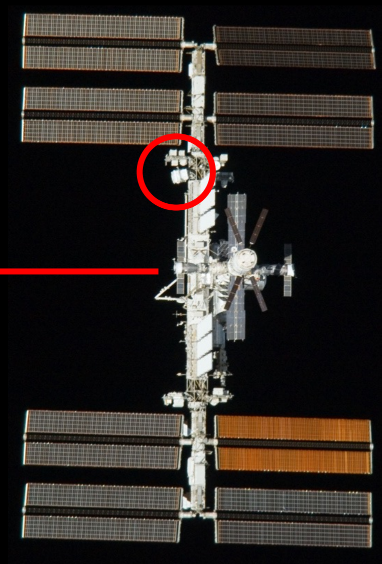
Improvement in the high-energy proton rejection by modeling energy deposition in each fiber of the ECAL

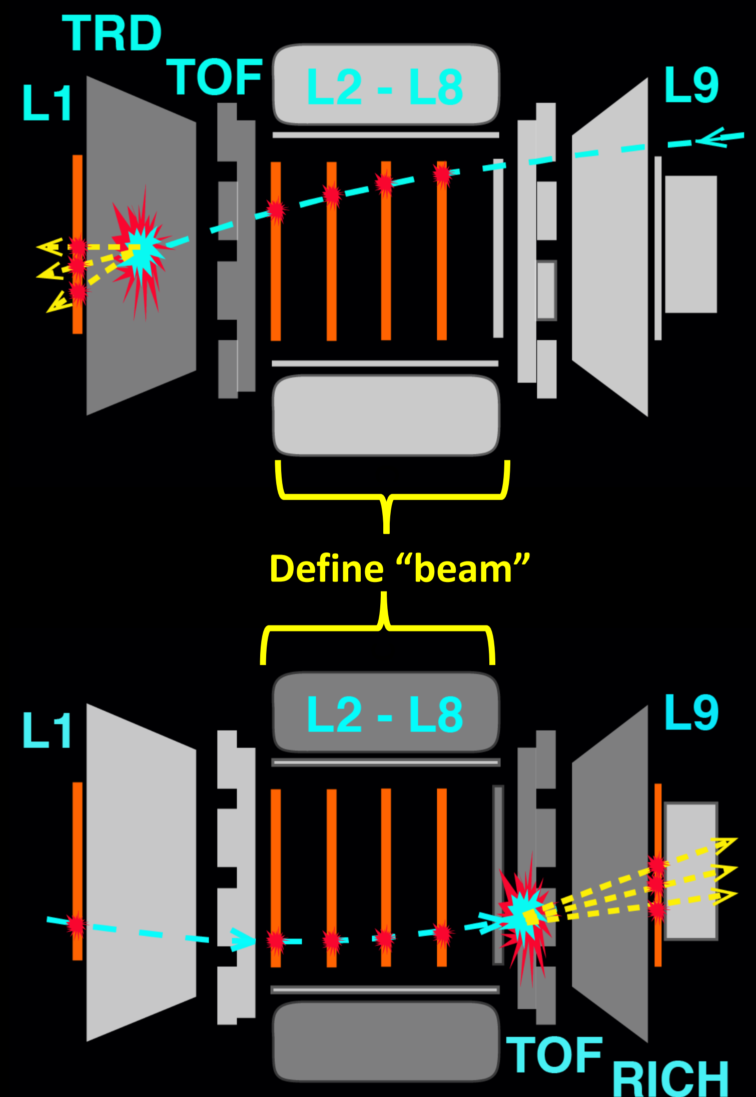


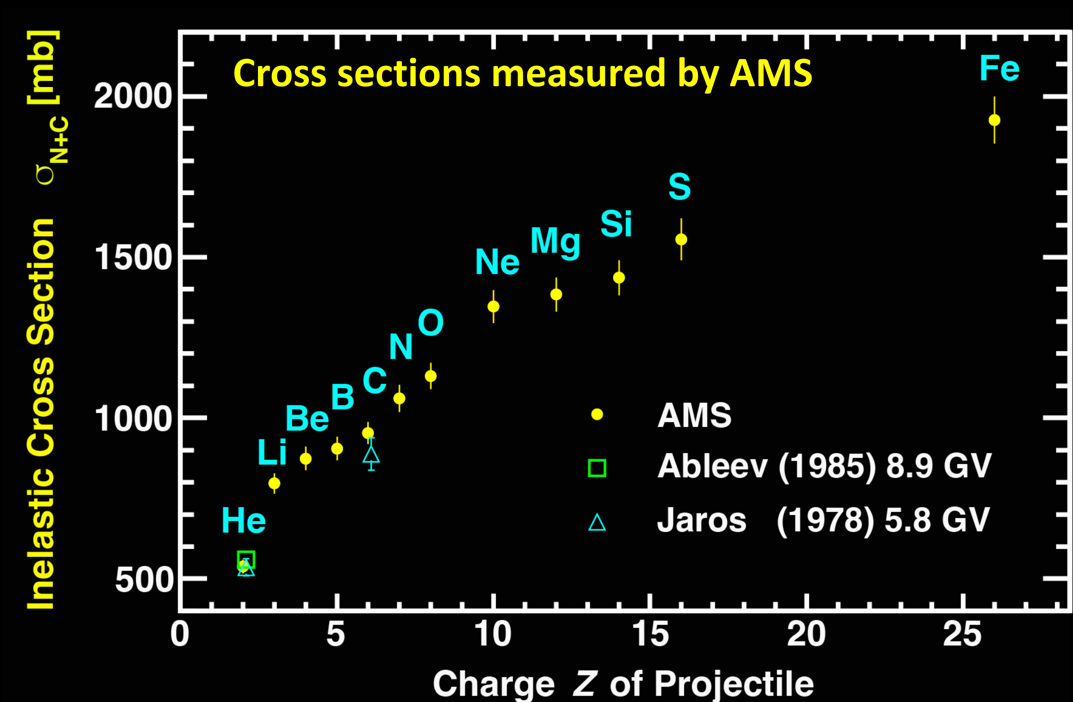
At 1 TeV, proton rejection power improved by a factor of 5.

This enables AMS to measure positrons and electrons to 2 TeV.

Precision measurements of interactions in the detector for accurate flux determination







AMS on ISS

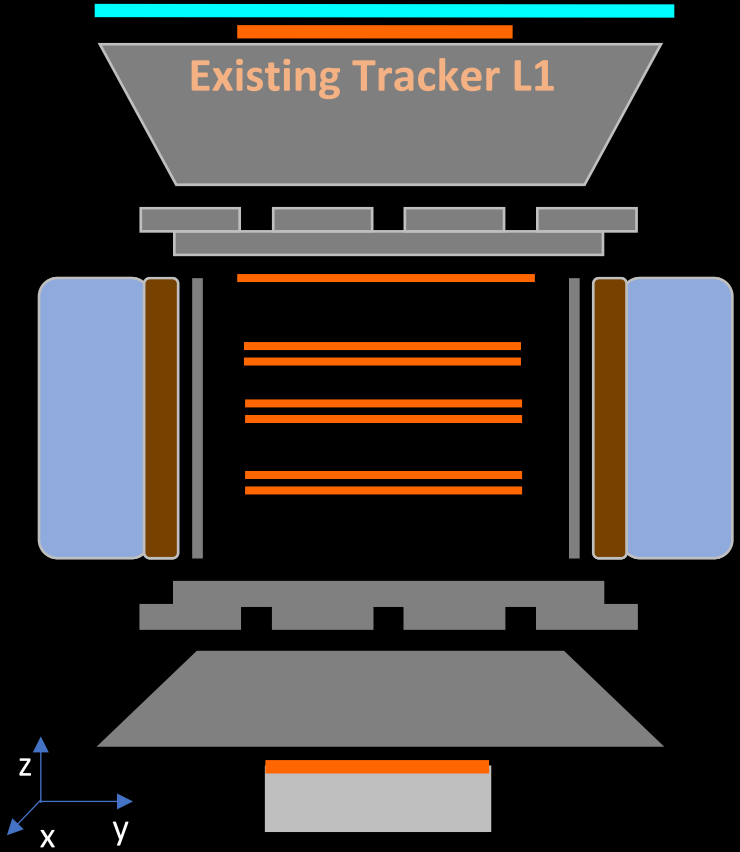
AMS 2011-2025

Continuous data-taking

AMS 2025-2030

New 8m^2 Silicon Tracker Layer

Acceptance increased to 300%



Latest Results: 2011-2022 and Projections

Three independent methods to search for Dark Matter χ

AMS

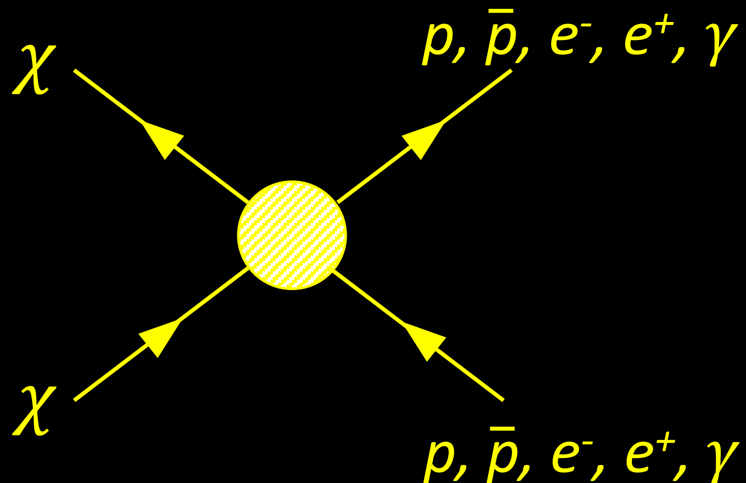
Annihilation in space

$\chi + \chi \rightarrow e^{+}, \bar{p}, \bar{D}, \gamma, \ldots$

XENON
DARKSIDE
DAMA/LIBRA
LUX
CDMS II
PandaX
…

Scattering underground

$\chi + N \rightarrow \chi + N$



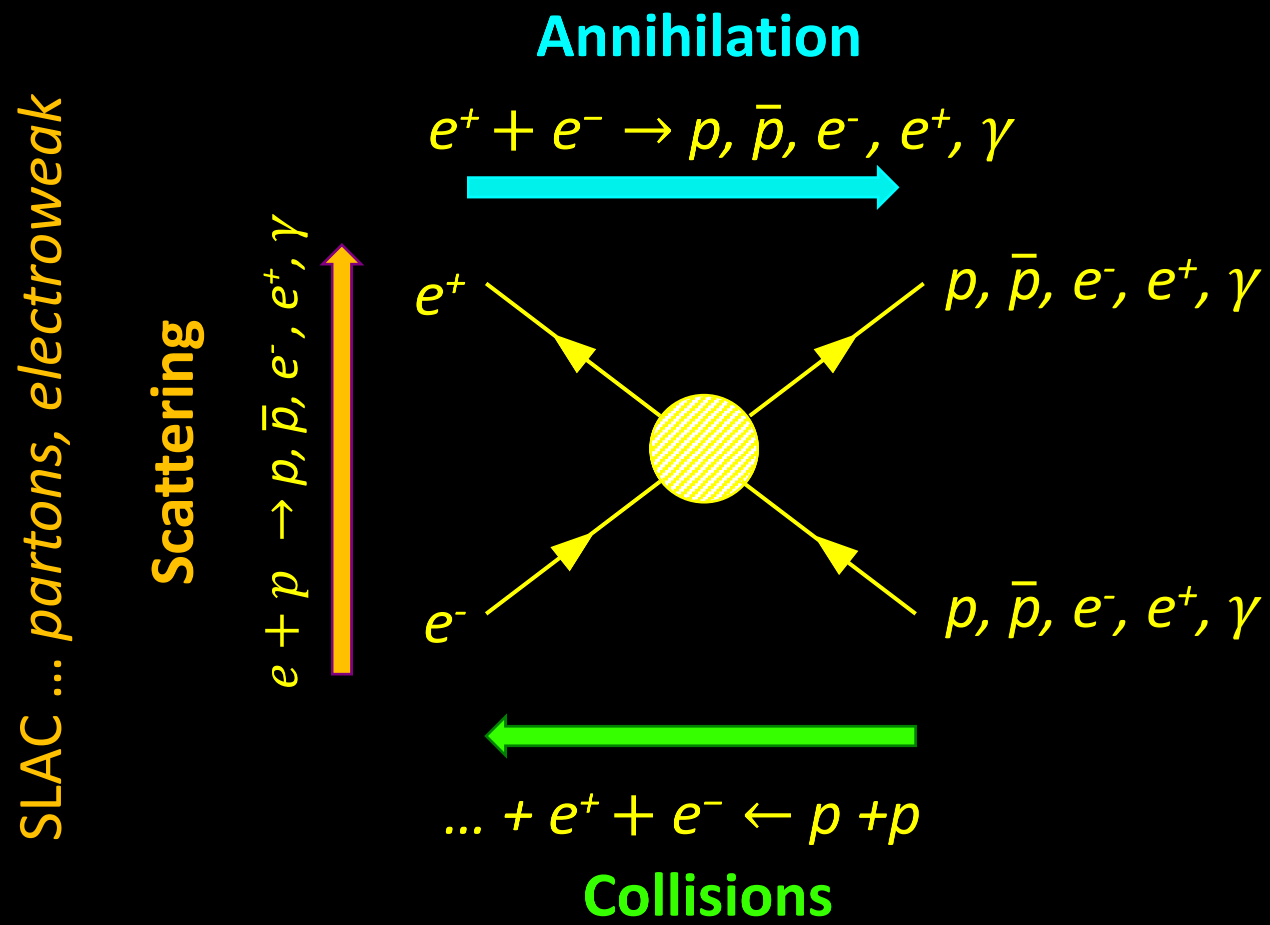
$\ldots + \chi + \chi \leftarrow p + p$

Production in accelerators

LHC CERN

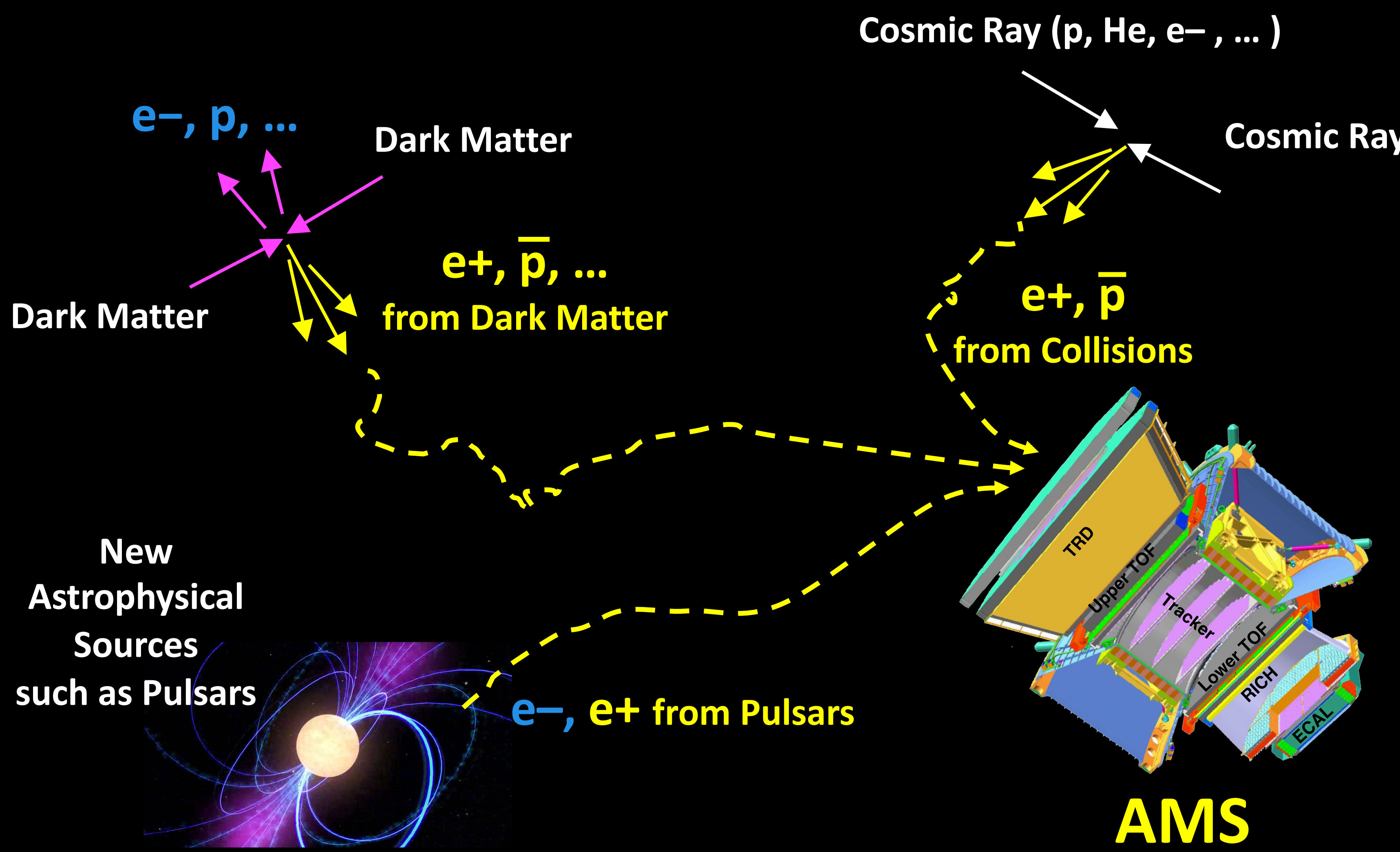
Physics of electrons and protons

SPEAR, DORIS, PEP, PETRA, LEP, … *Ψ, τ*



BNL, FNAL, LHC … *J, Y, T, Z, W,* h^0

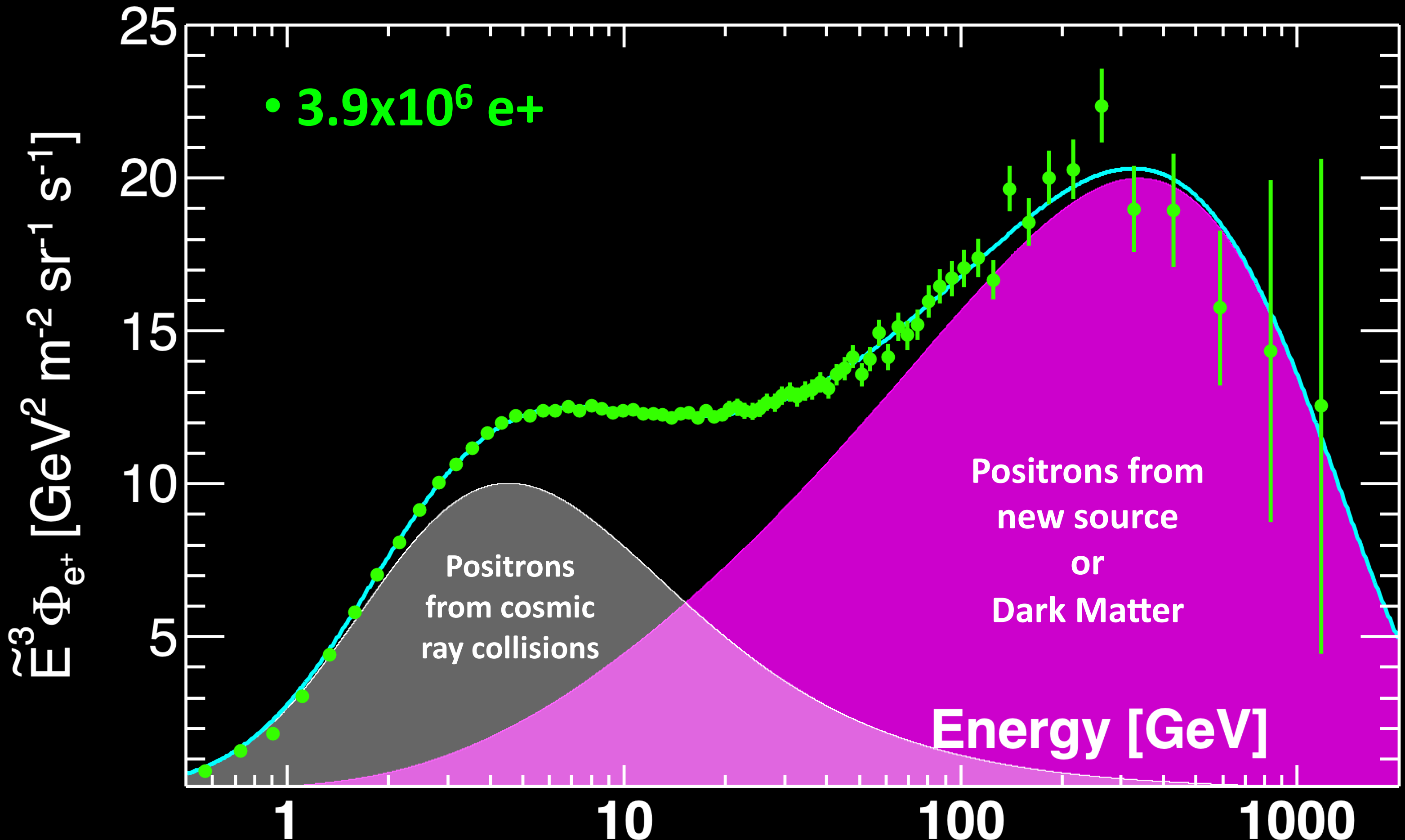
Latest AMS Results on e+, e−, and $\bar{p}$



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

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

Solar Collisions Pulsars or Dark Matter

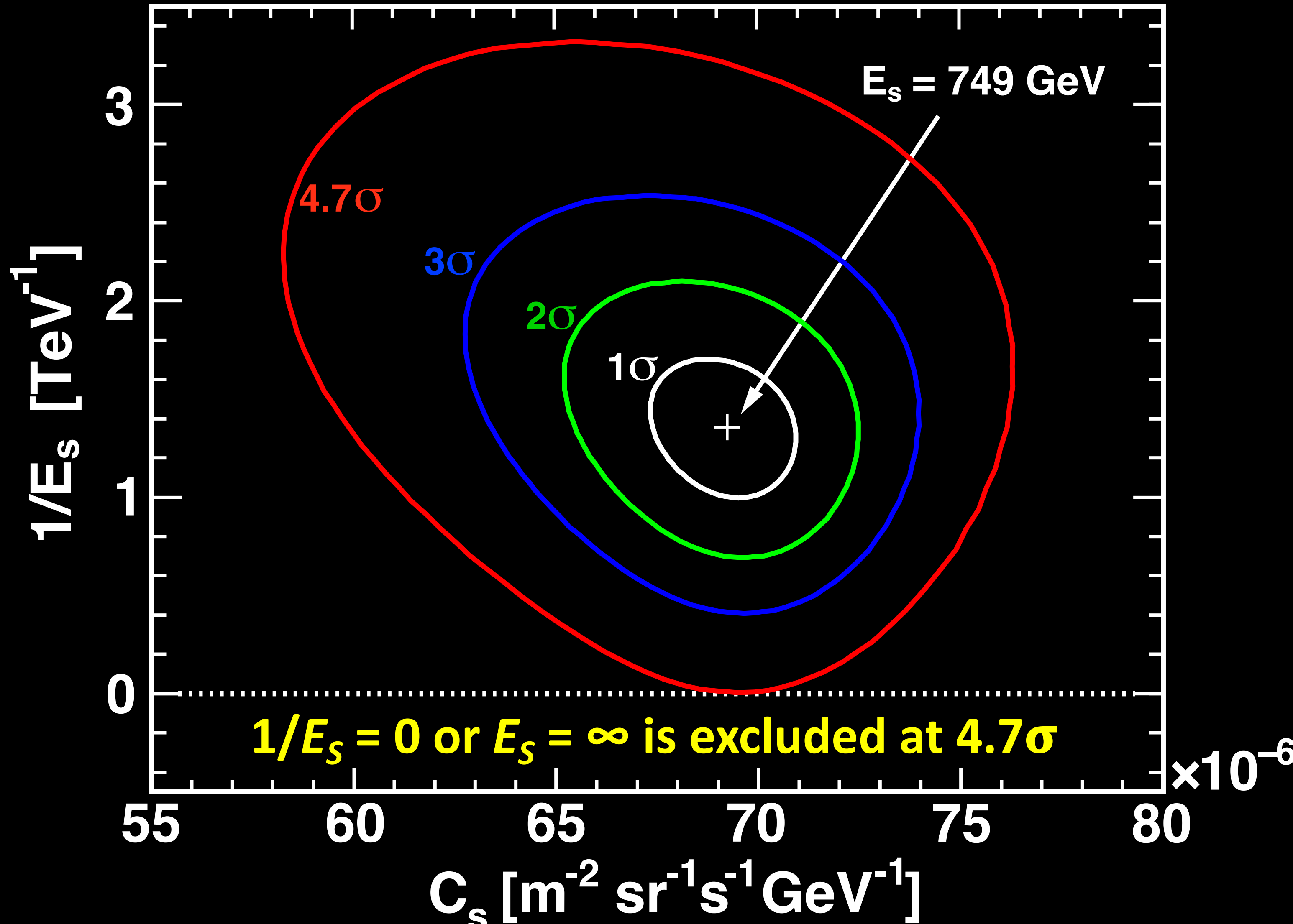


The existence of the finite cutoff energy (4.7σ) is a new and unexpected observation

Determination of the cutoff energy E_S

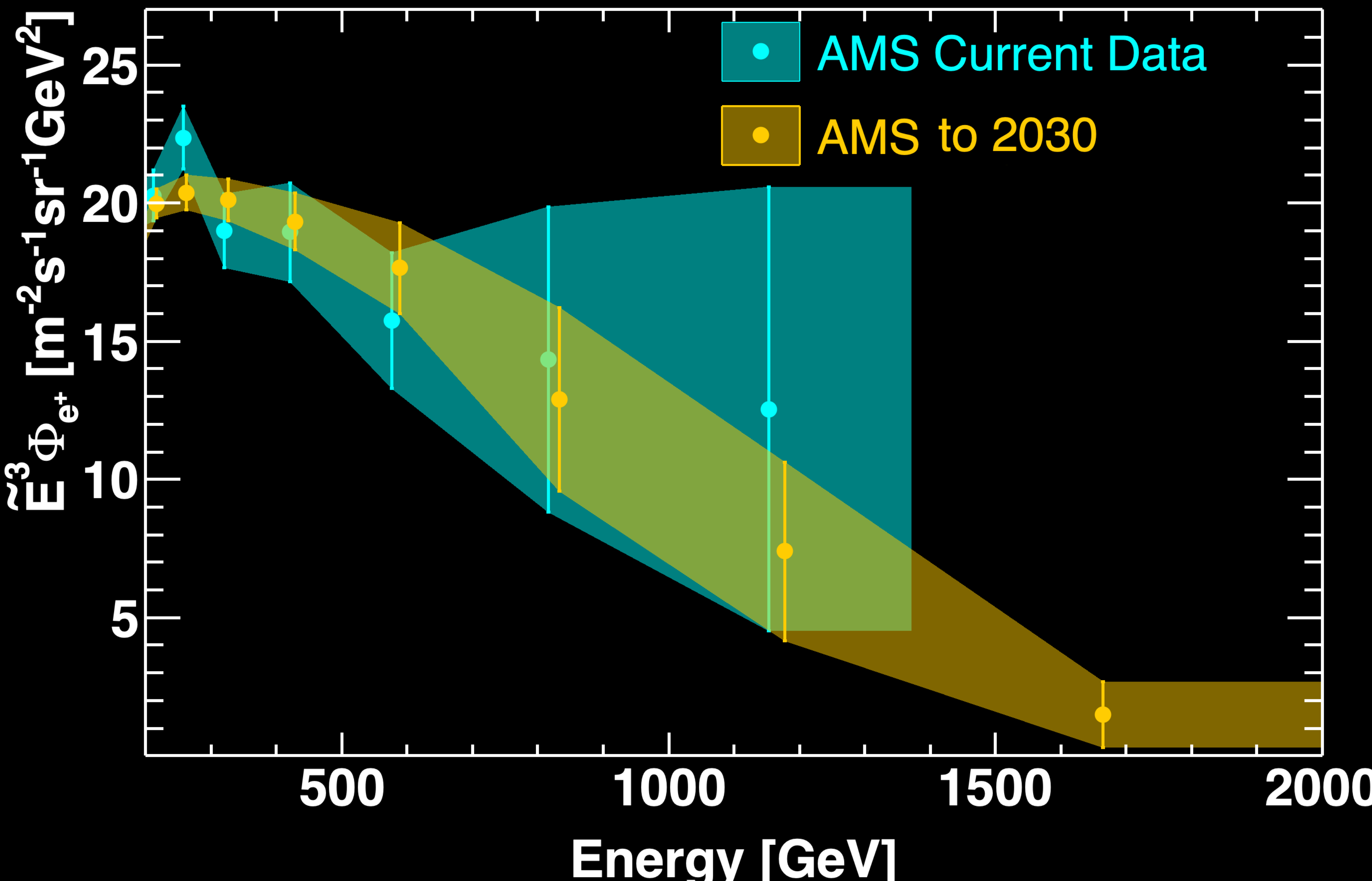
Collisions   New Source or Dark Matter

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



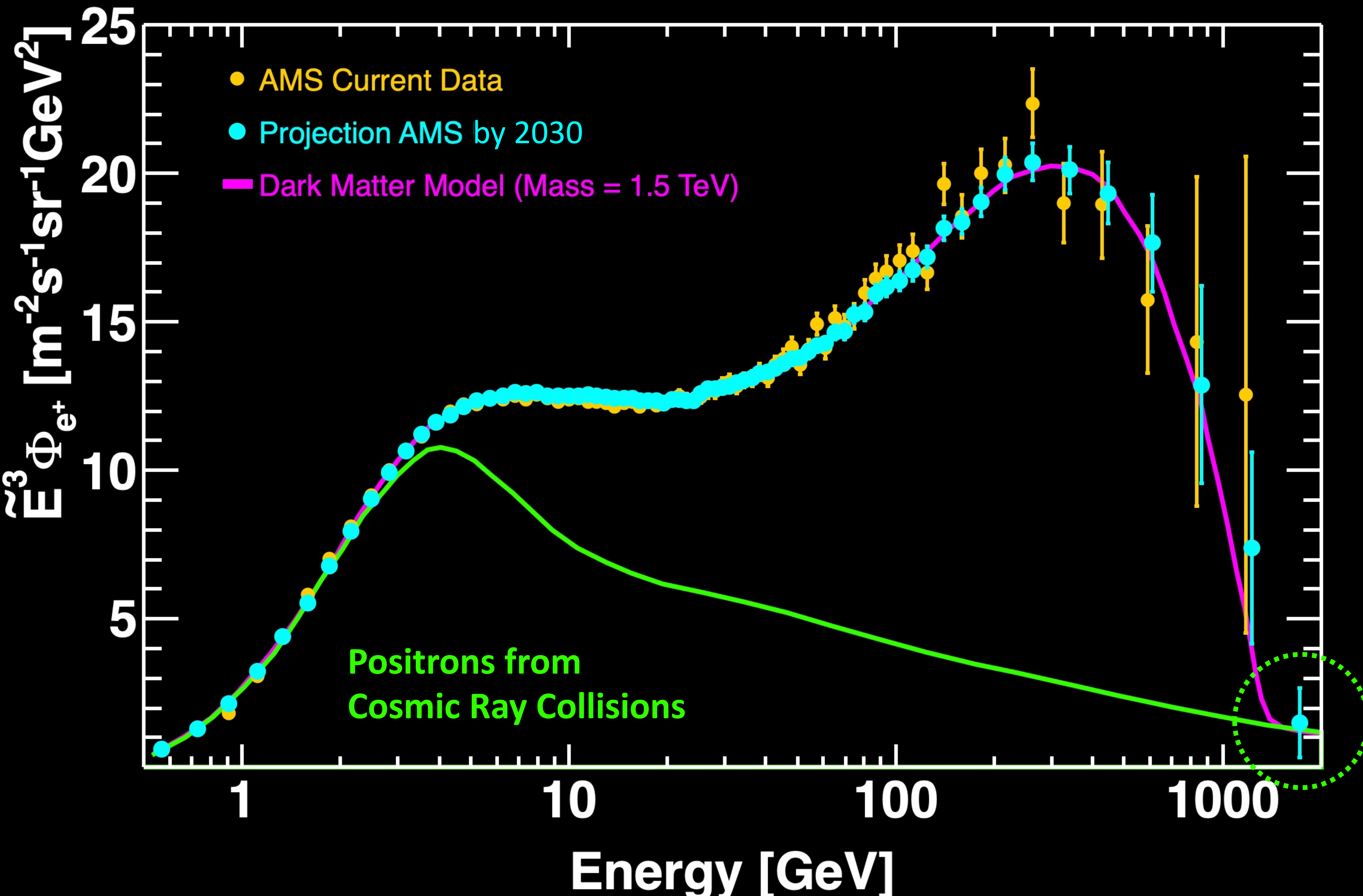
$1/E_S = 0$ or $E_S = \infty$ is excluded at 4.7σ

By 2030, AMS will extend the energy range of the positron flux measurement from 1.4 to 2 TeV and reduce the error by a factor of two compared to current data



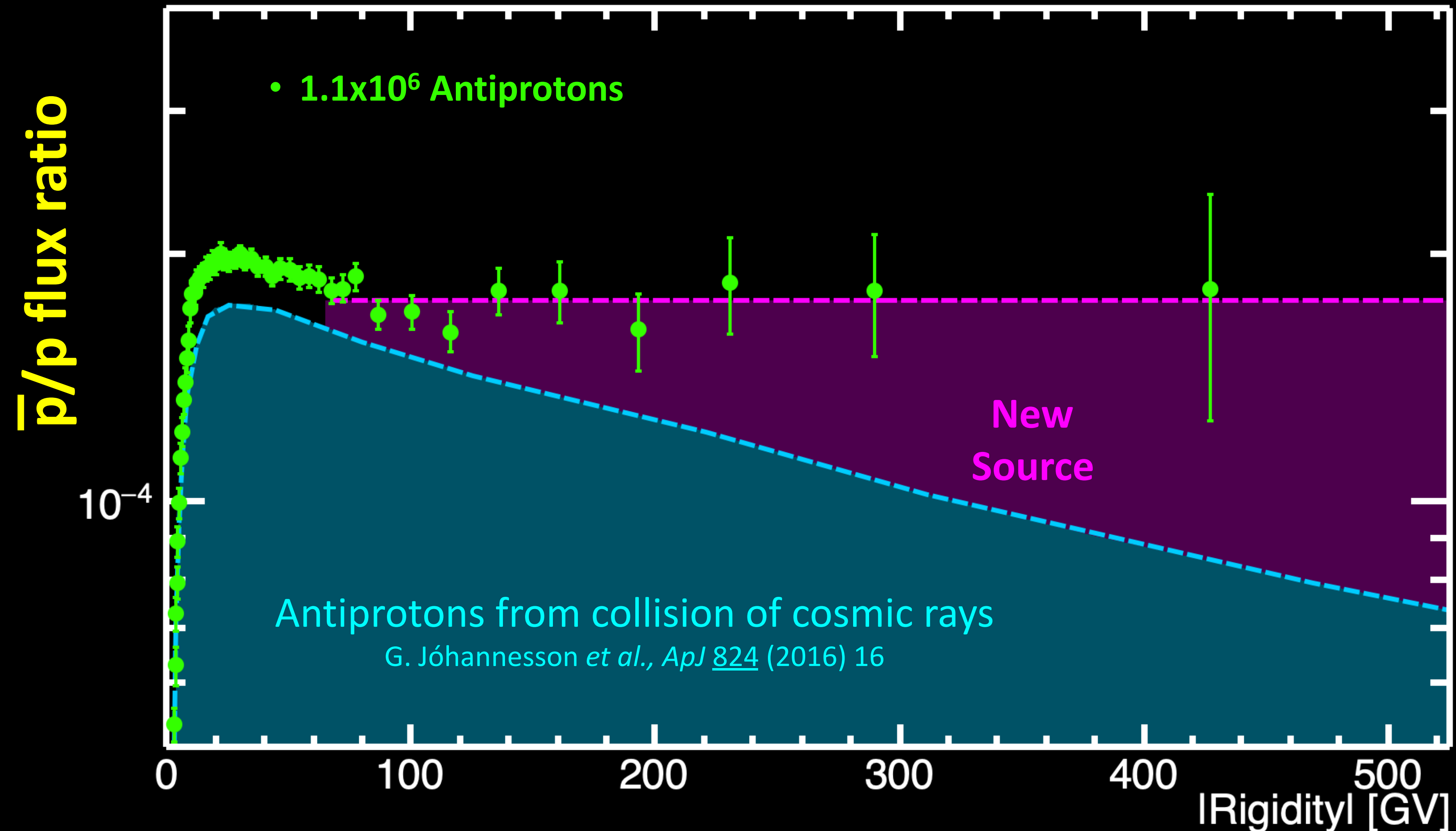
Determination of the Origin of Cosmic Positrons by 2030

AMS will ensure that the measured high energy positron spectrum indeed drops off quickly and, at the highest energies, the positrons only come from cosmic ray collisions as predicted by dark matter models



Properties of Cosmic Antiprotons

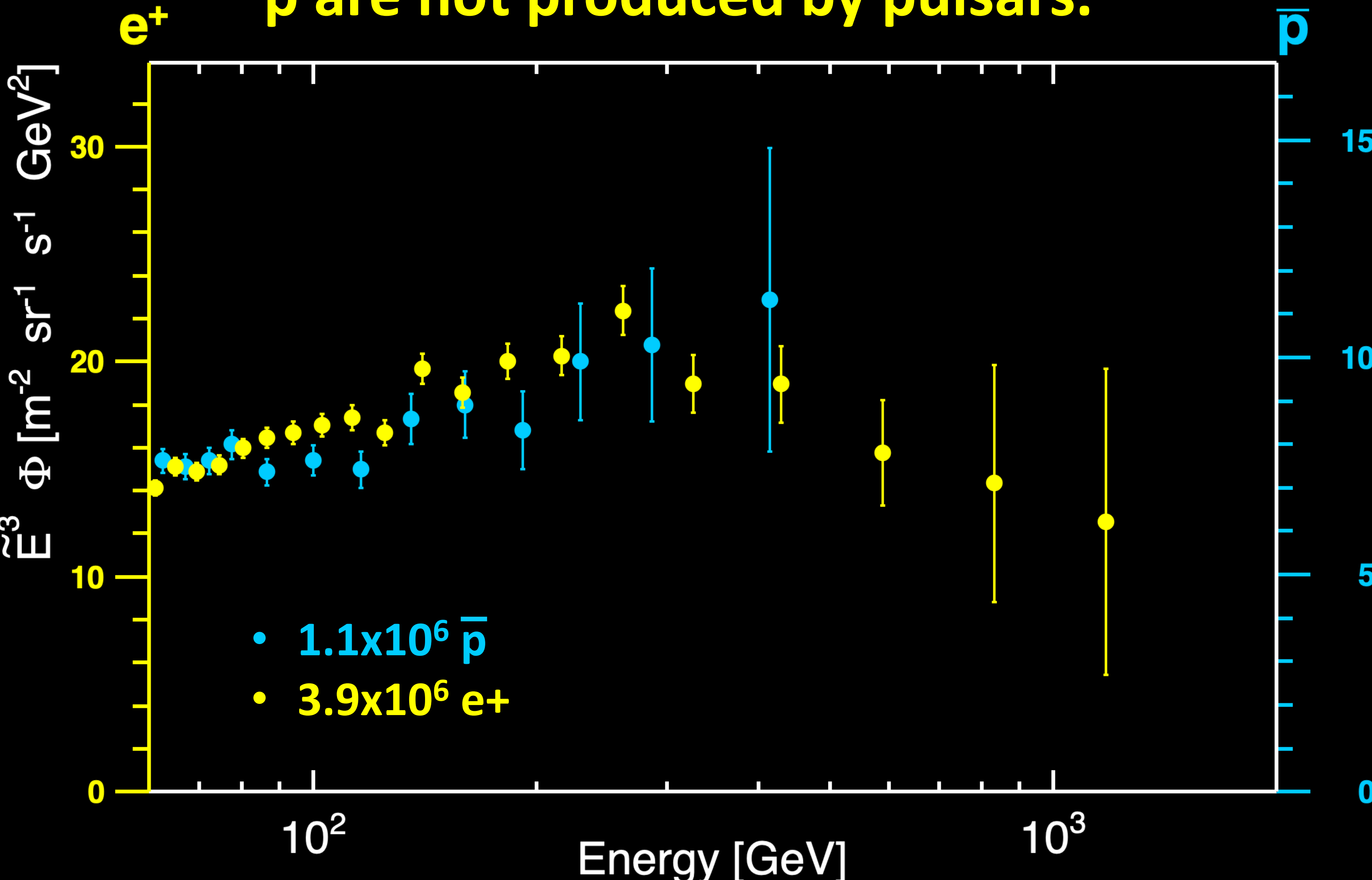
The antiproton-to-proton flux ratio shows that above 60 GV the ratio is energy independent.



Properties of Cosmic Antiprotons

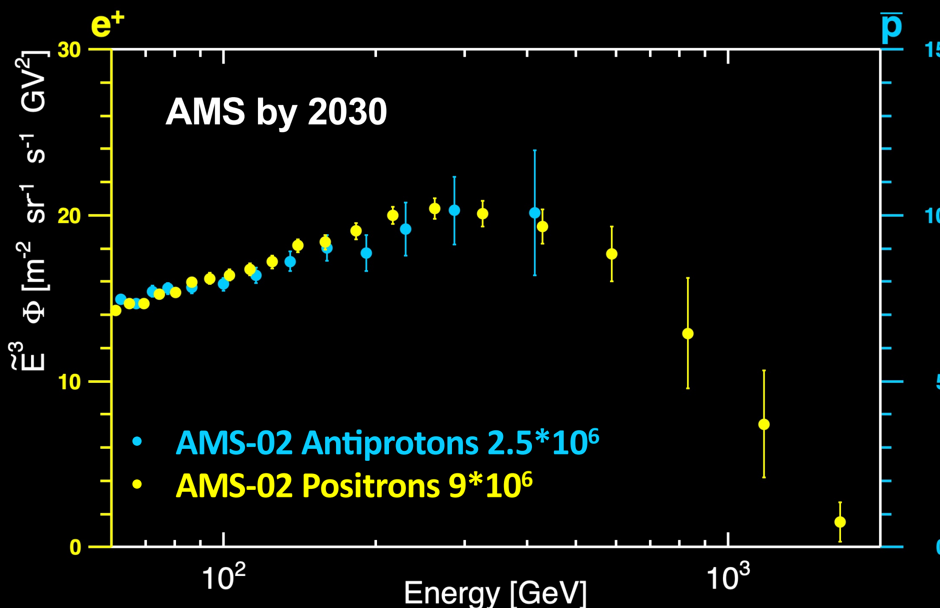
The $\bar{p}$ and e^+ fluxes have identical rigidity dependence.

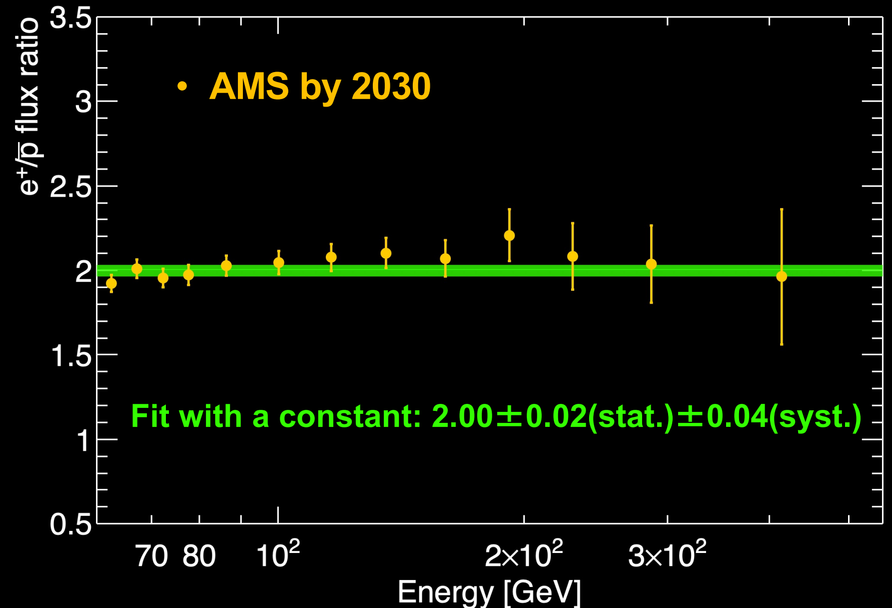
$\bar{p}$ are not produced by pulsars.



By 2030, AMS will greatly improve the accuracy of the antiproton spectra

The identical behaviour of positrons and antiprotons excludes the pulsar origin of positrons



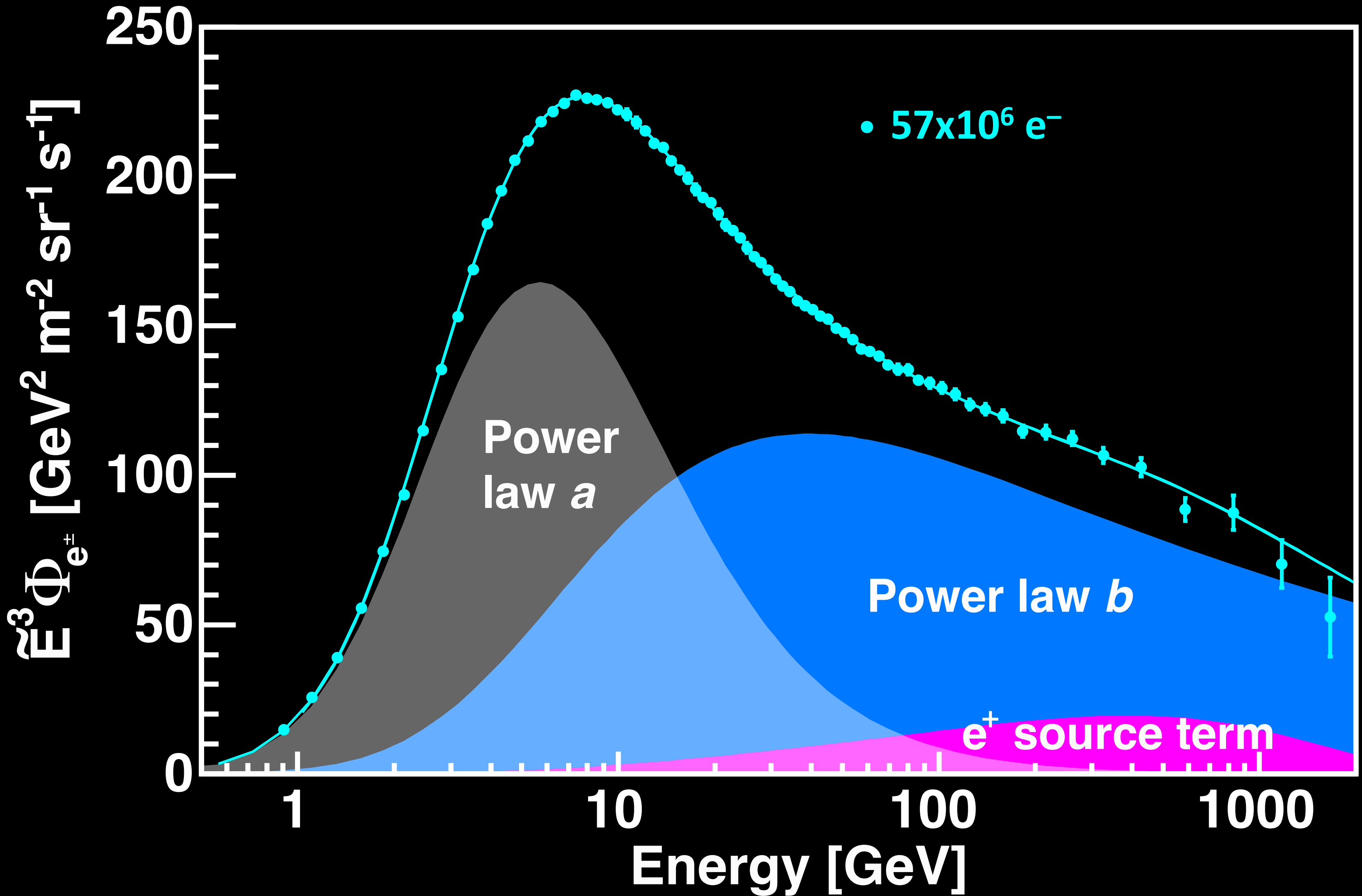


AMS Result on the electron spectrum

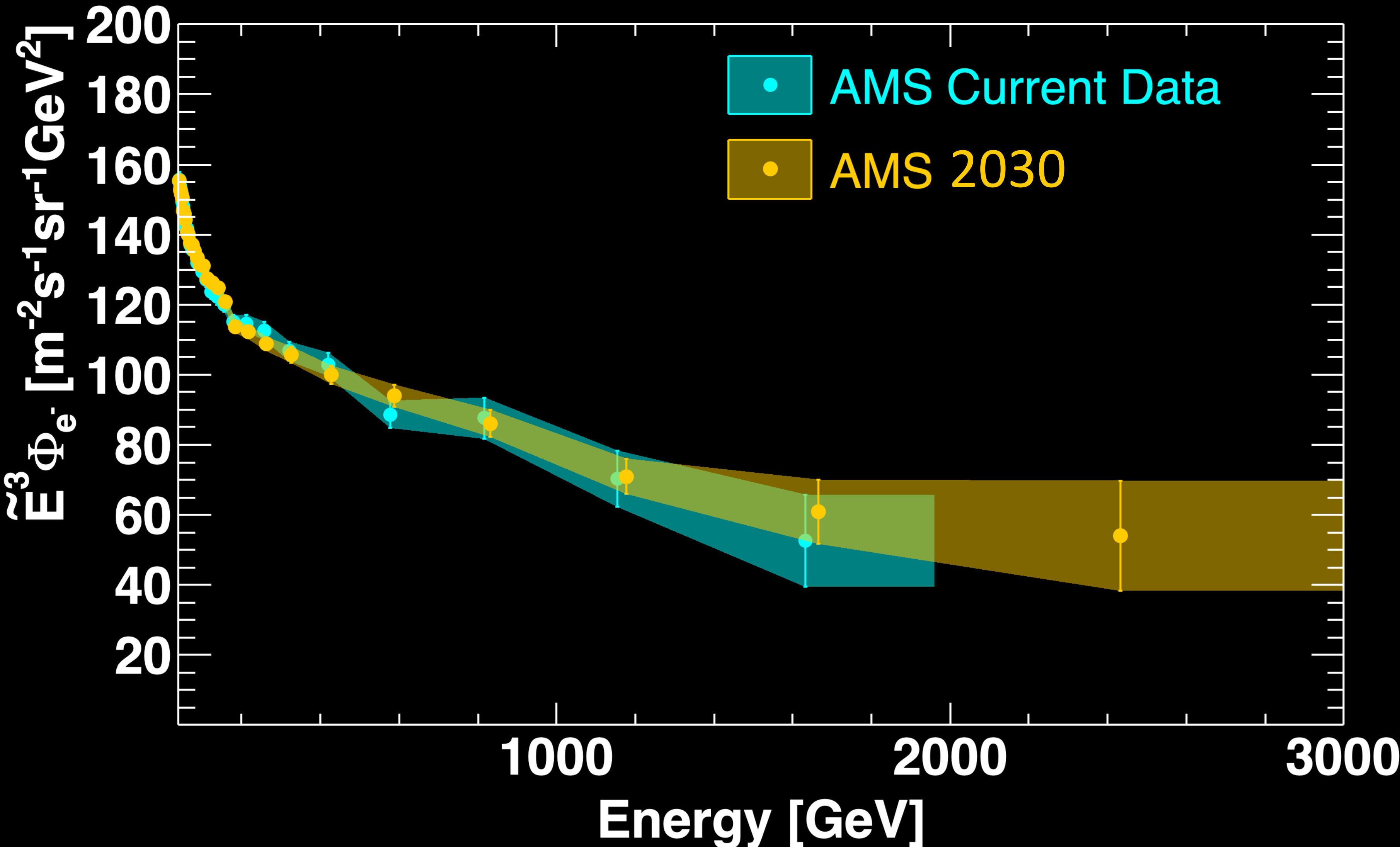
The spectrum fits well with two power laws (*a*, *b*) and a source term like positrons

$$\Phi_{e^-}(E) = \frac{E^2}{\hat{E}^2}\left(C_a \hat{E}^{\gamma_a} + C_b \hat{E}^{\gamma_b} + \text{Positron Source Term}\right)$$

Solar Power law *a* Power law *b*

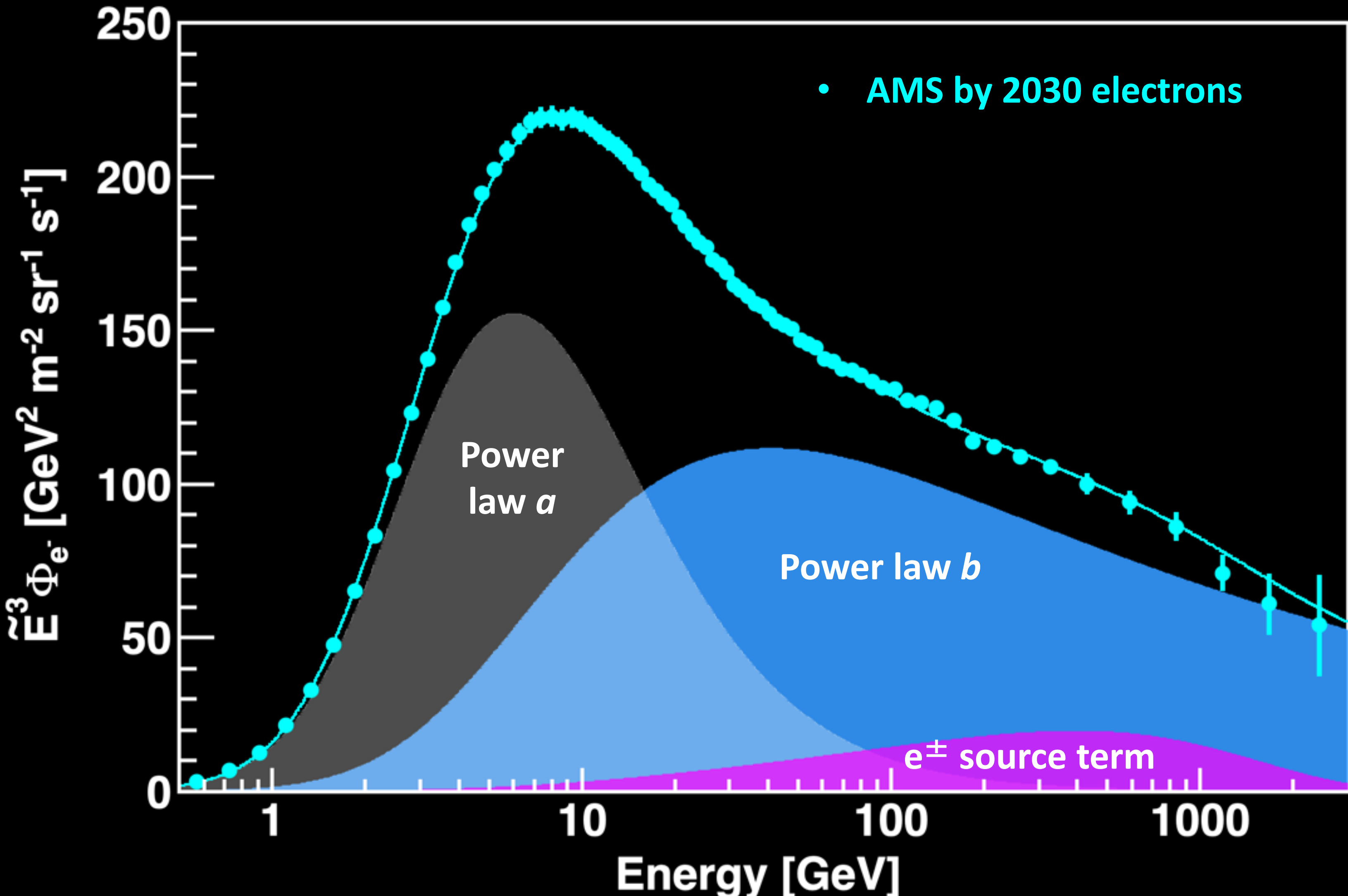


By 2030, AMS will extend the energy range of the electron flux measurement from 2 to 3 TeV and reduce the error by a factor of two compared to current data

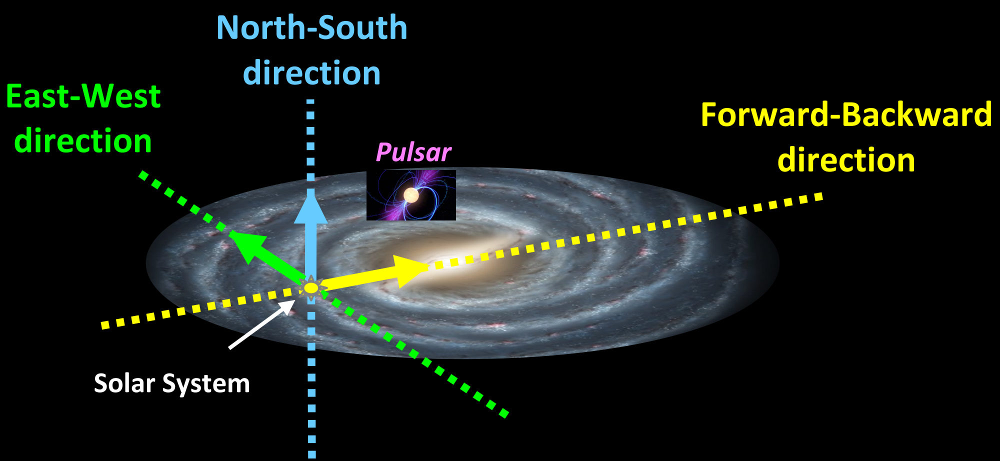


By 2030, the charge-symmetric nature of the high energy source will be established at the 4σ level

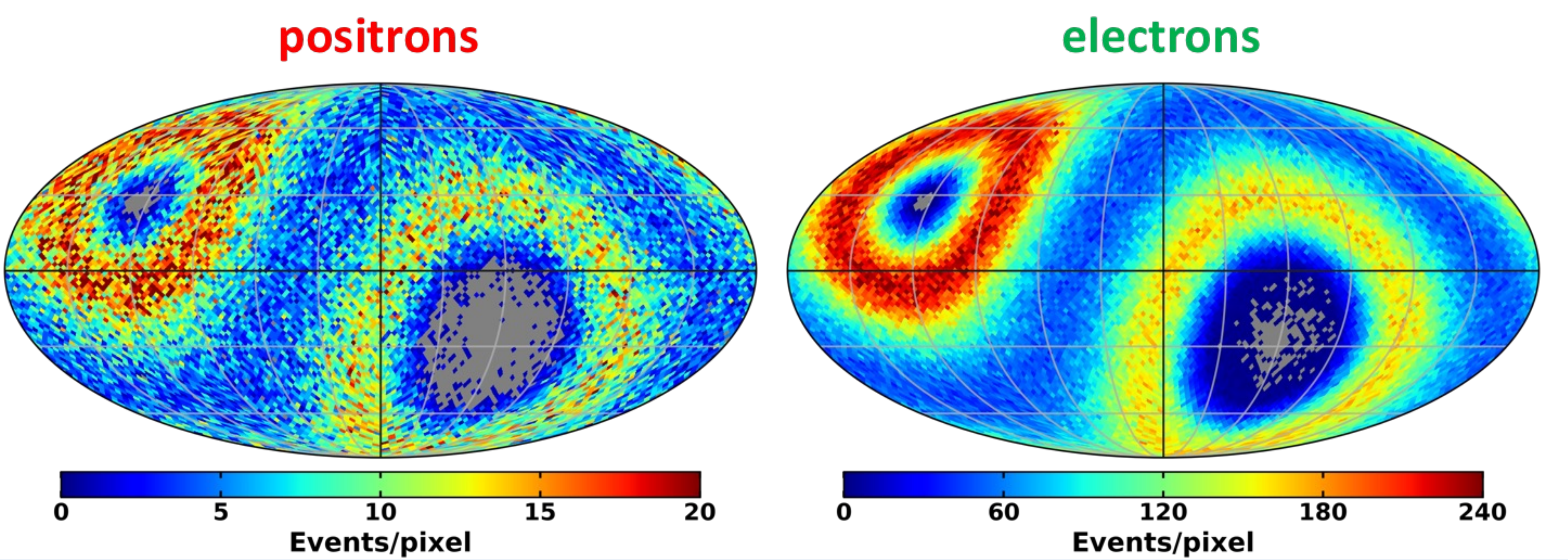
New sources, like Dark Matter or Pulsars, produce equal amounts of e+ and e–



Positron Anisotropy and Dark Matter

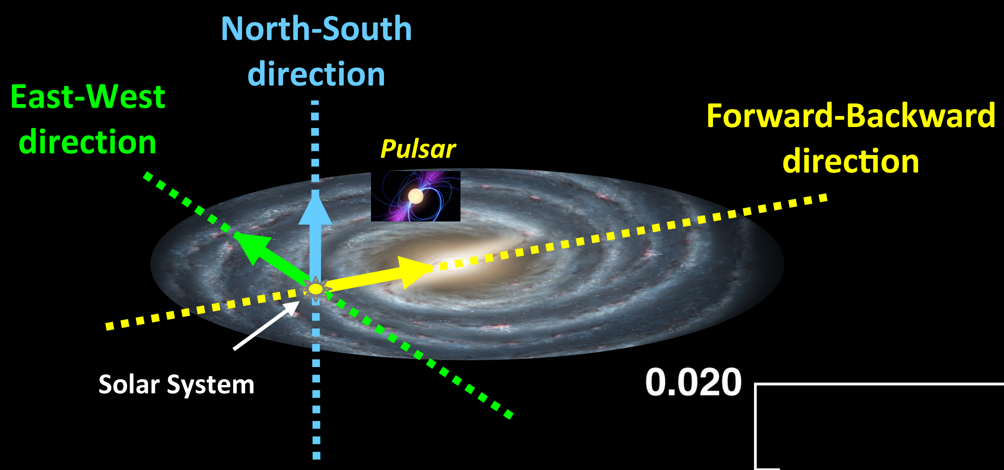


Astrophysical point sources will imprint a higher anisotropy on the arrival directions of energetic positrons than a smooth dark matter halo.

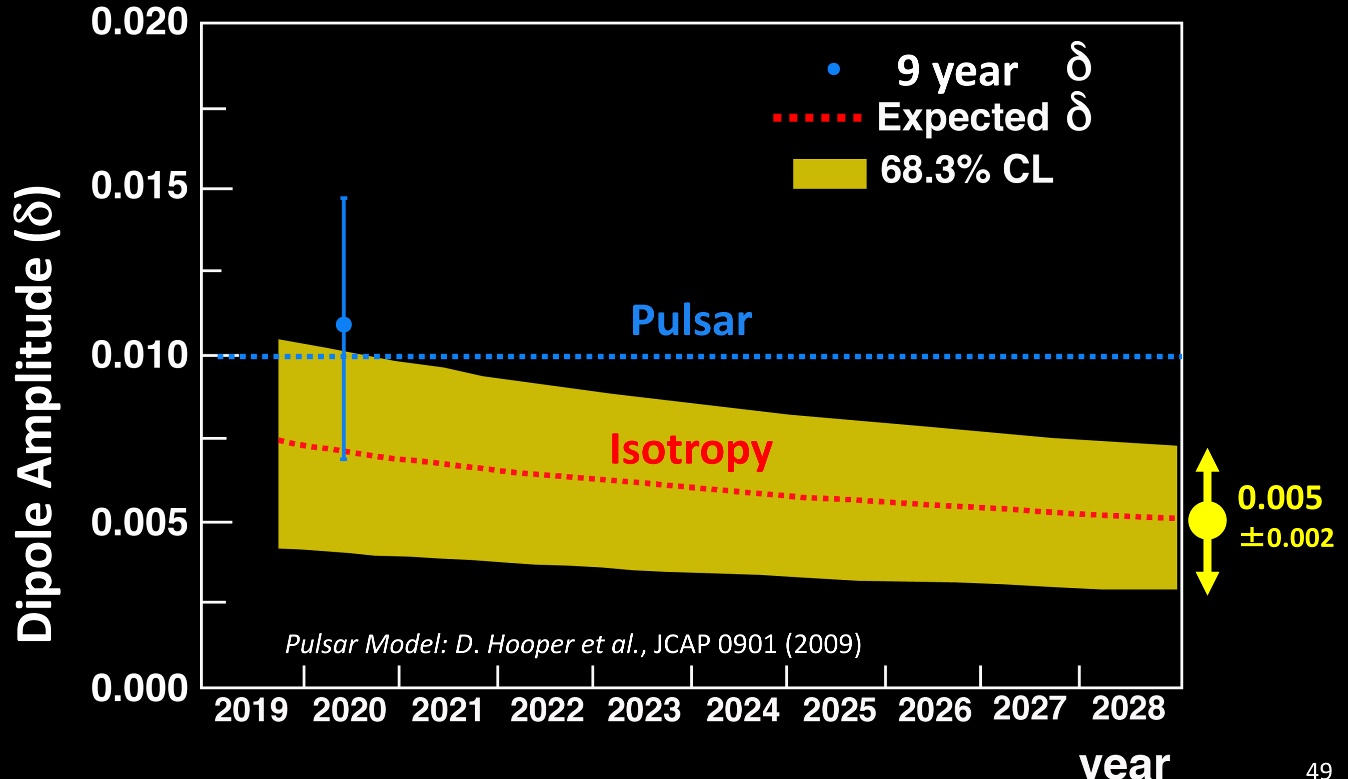


Dipole anisotropy: $\delta = 3\sqrt{C_1/4\pi}$ C_1 is the dipole moment

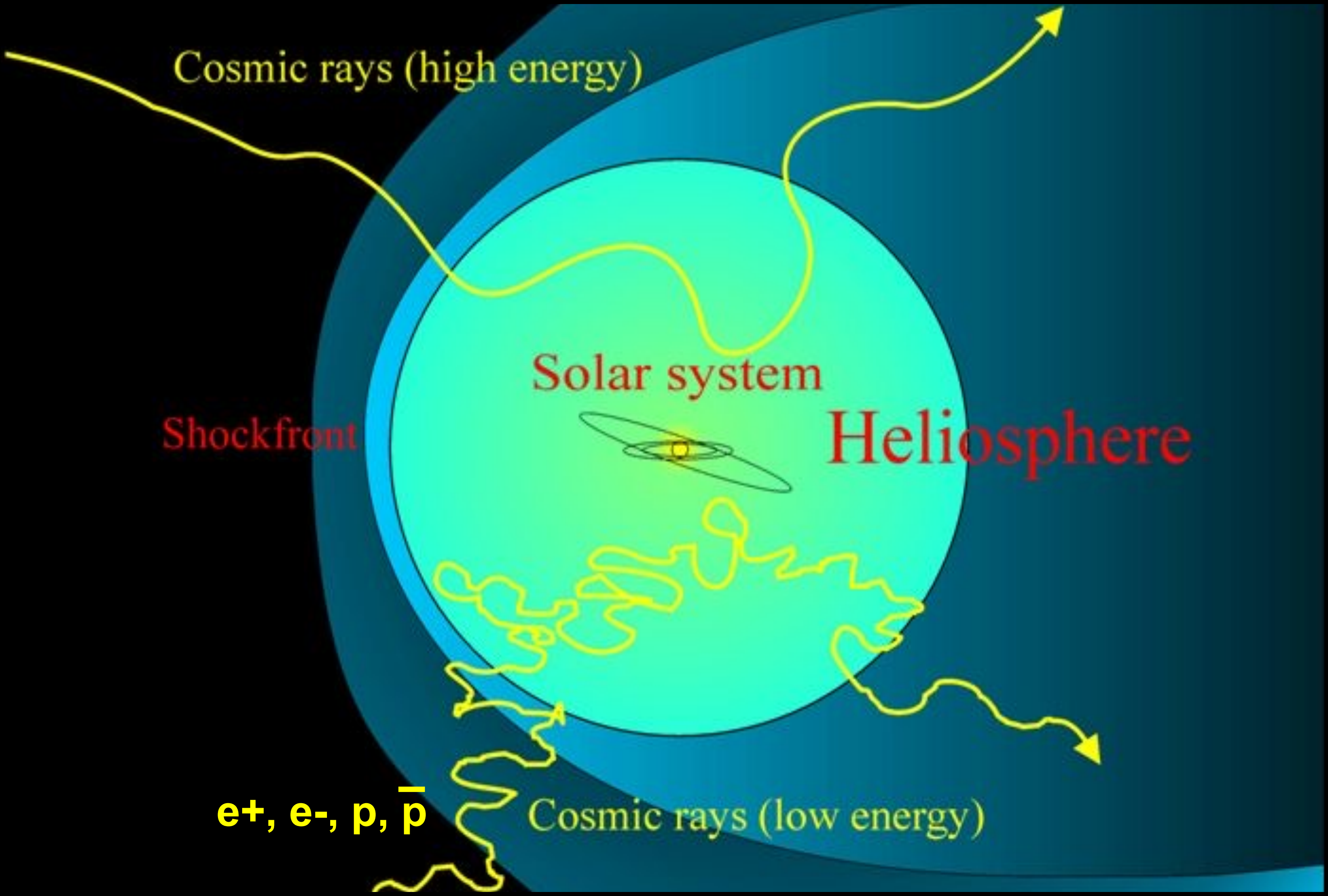
By 2030, the positron statistics will allow us to measure the anisotropy accurately to permit a separation between dark matter and pulsars at the 99.93% C.L.



Positrons from a pulsar would have a preferential direction

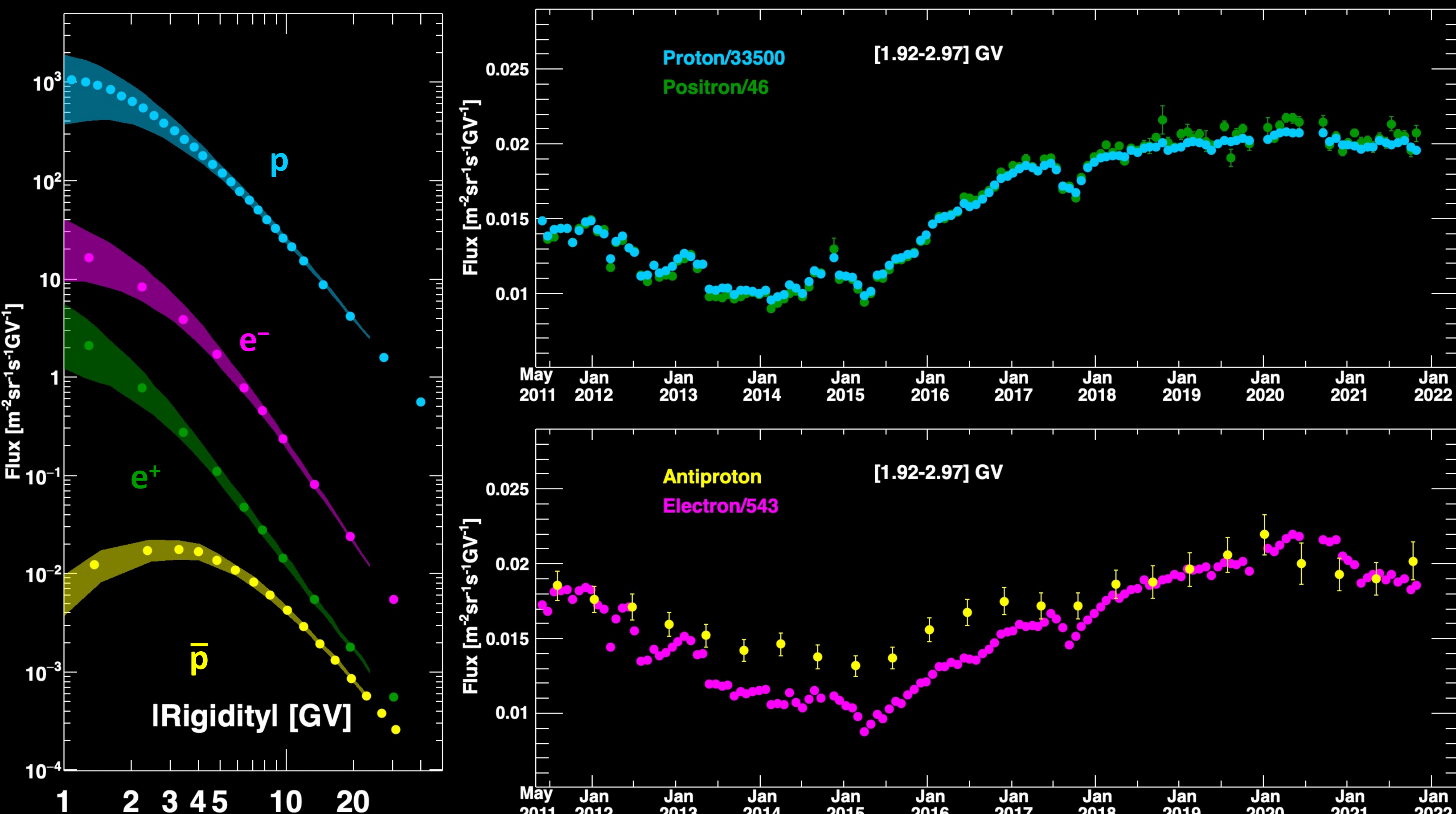


Latest AMS Results on Elementary Particles (e+, e-, p, $\bar{p}$, …) in the Heliosphere over an 11-year Solar Cycle (2011-2022)



By 2030, AMS will study Heliosphere physics over 22-year Solar Cycle

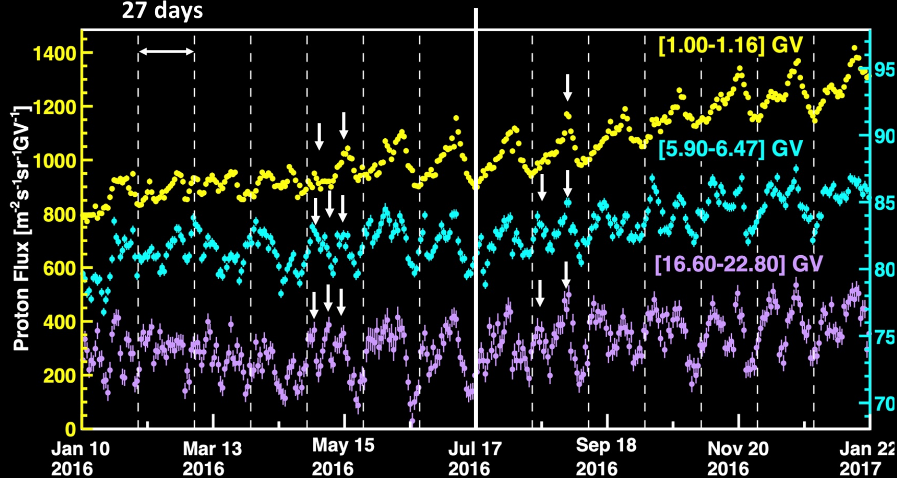
Elementary Particles (e+, e-, p, p̄, …)
in the Heliosphere over an 11-year Solar Cycle (2011-2022)

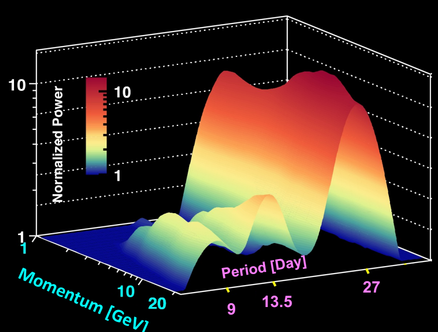


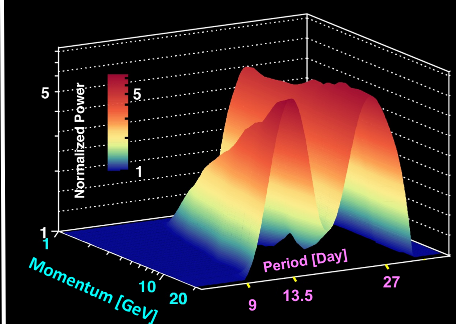
Daily Protons in the Heliosphere

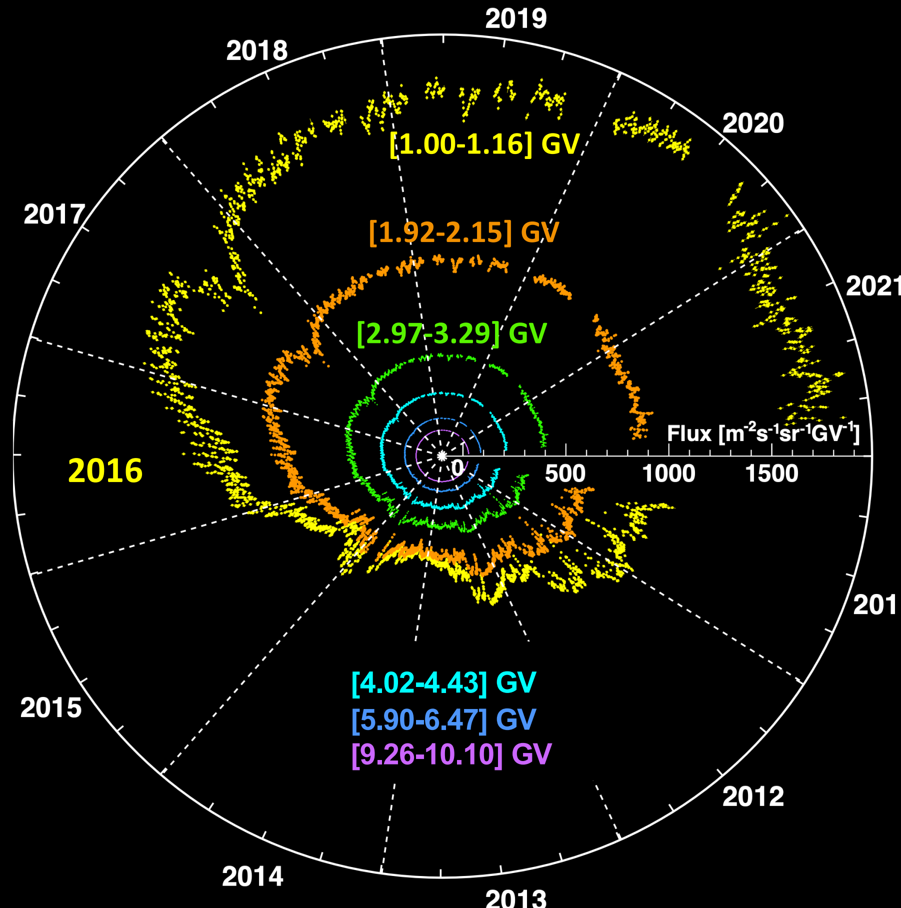
Frequency Analysis of daily fluxes in 2016

Double-peak and triple-peak structures are visible





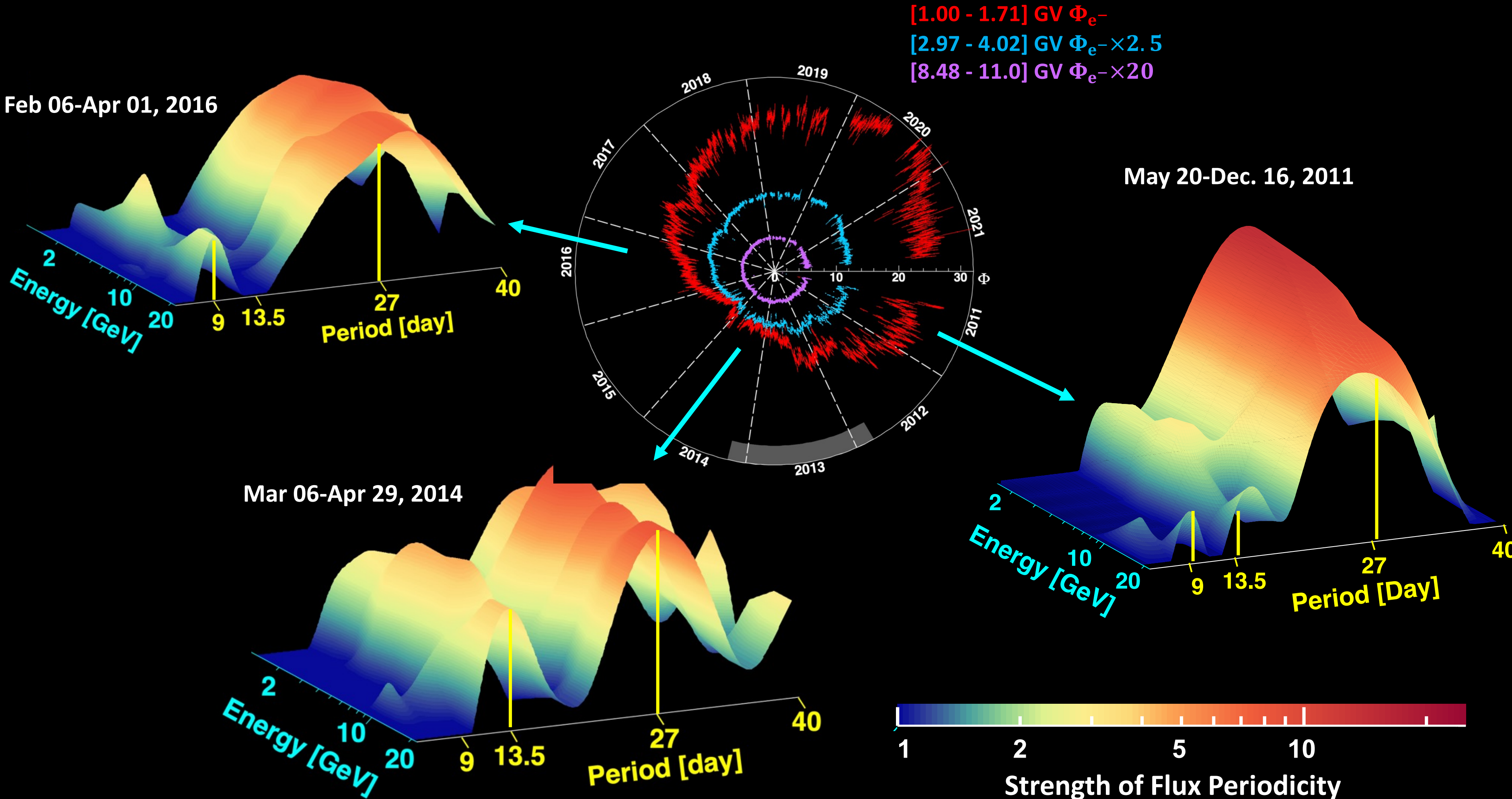




Recurrent variations with periods of 27, 13.5, and 9 days are observed. Unexpectedly, in 2016, the strength of the 9 and 13.5 periodicity increases with increasing rigidity up to 10 and 20 GeV, respectively.

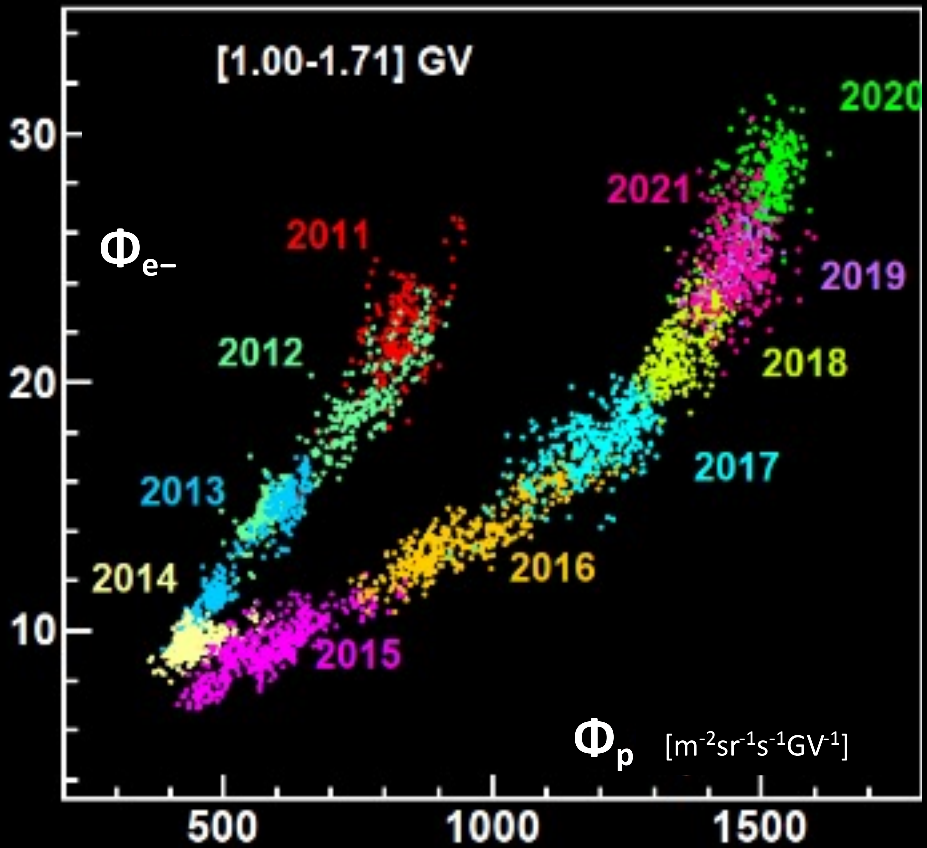
The model expects the strength of the periodicity to decrease with increasing rigidity.

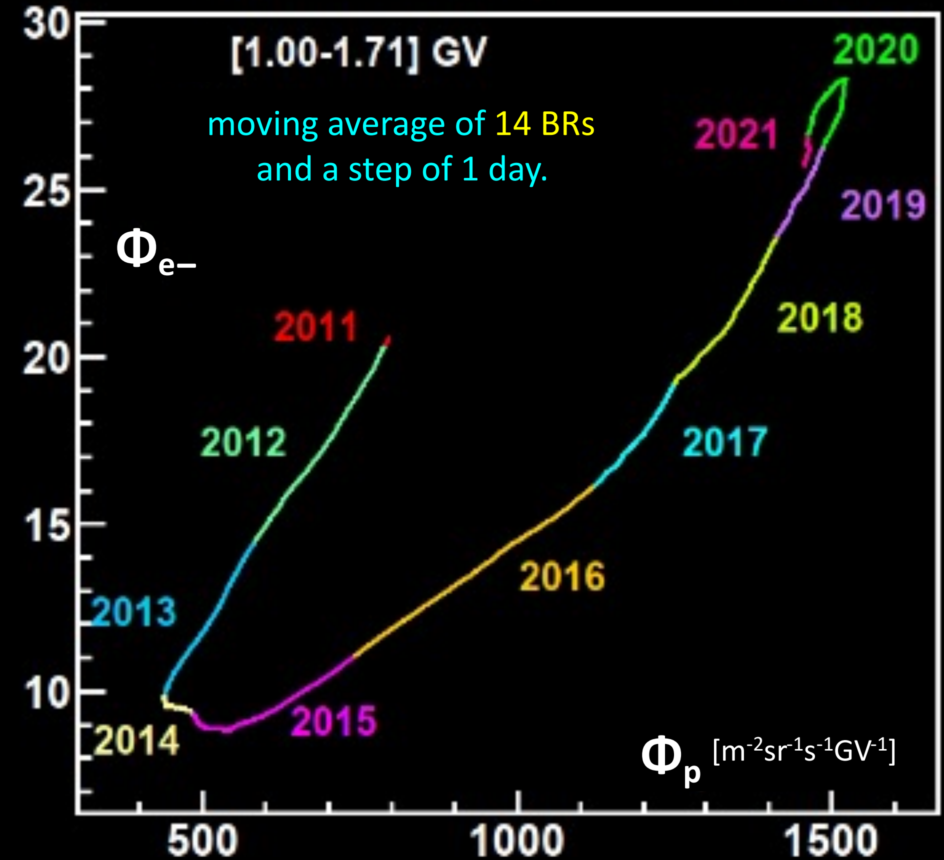
First Observation of Periodicity in the Daily Electron Flux in the Heliosphere



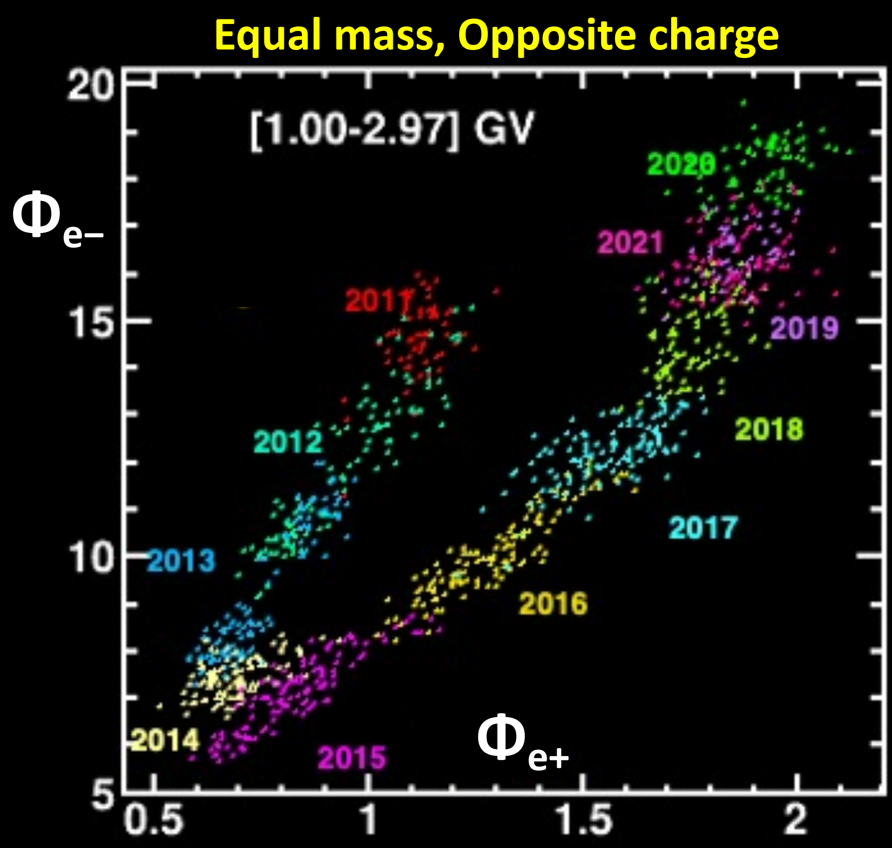
Elementary Particles in the Heliosphere

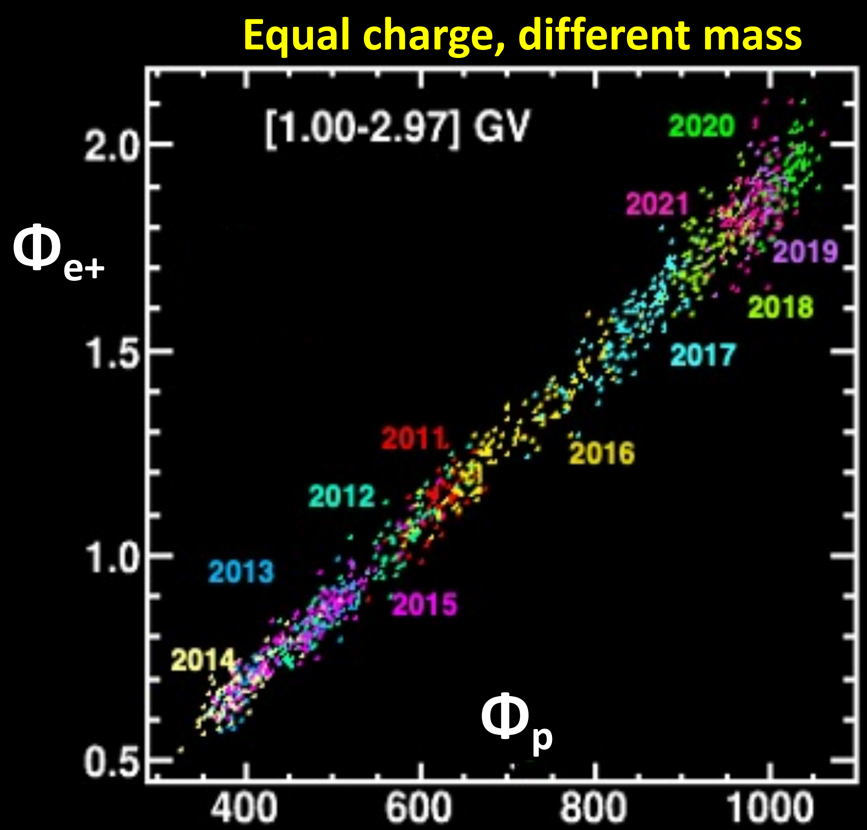
Observation of a hysteresis between daily electron flux Φ_{e-} and daily proton flux Φ_p





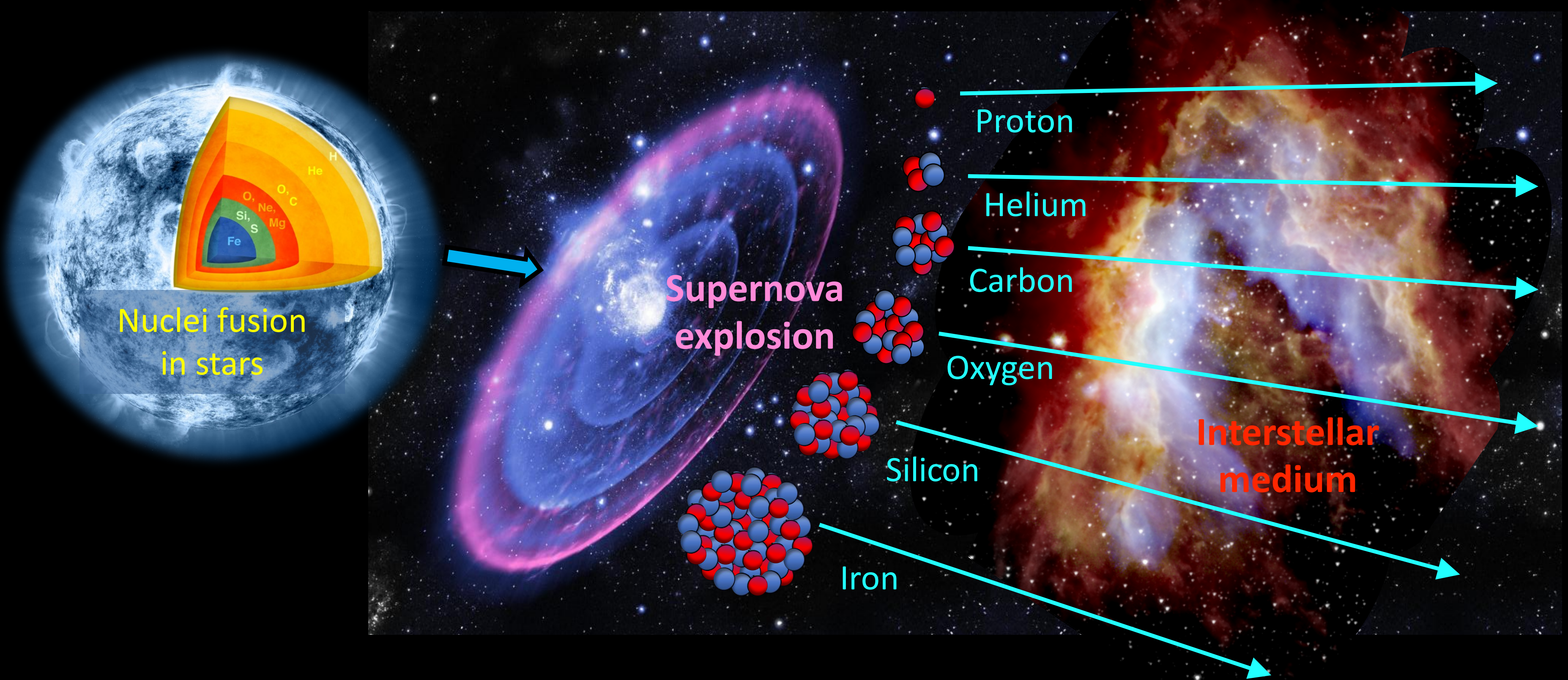
Relationship between charge and mass





Latest AMS Results on Primary Cosmic Rays

Primary cosmic rays p, He, C, O, ..., Si, ..., Fe are produced during the lifetime of stars and accelerated by supernovae. They propagate through interstellar medium before they reach Earth.

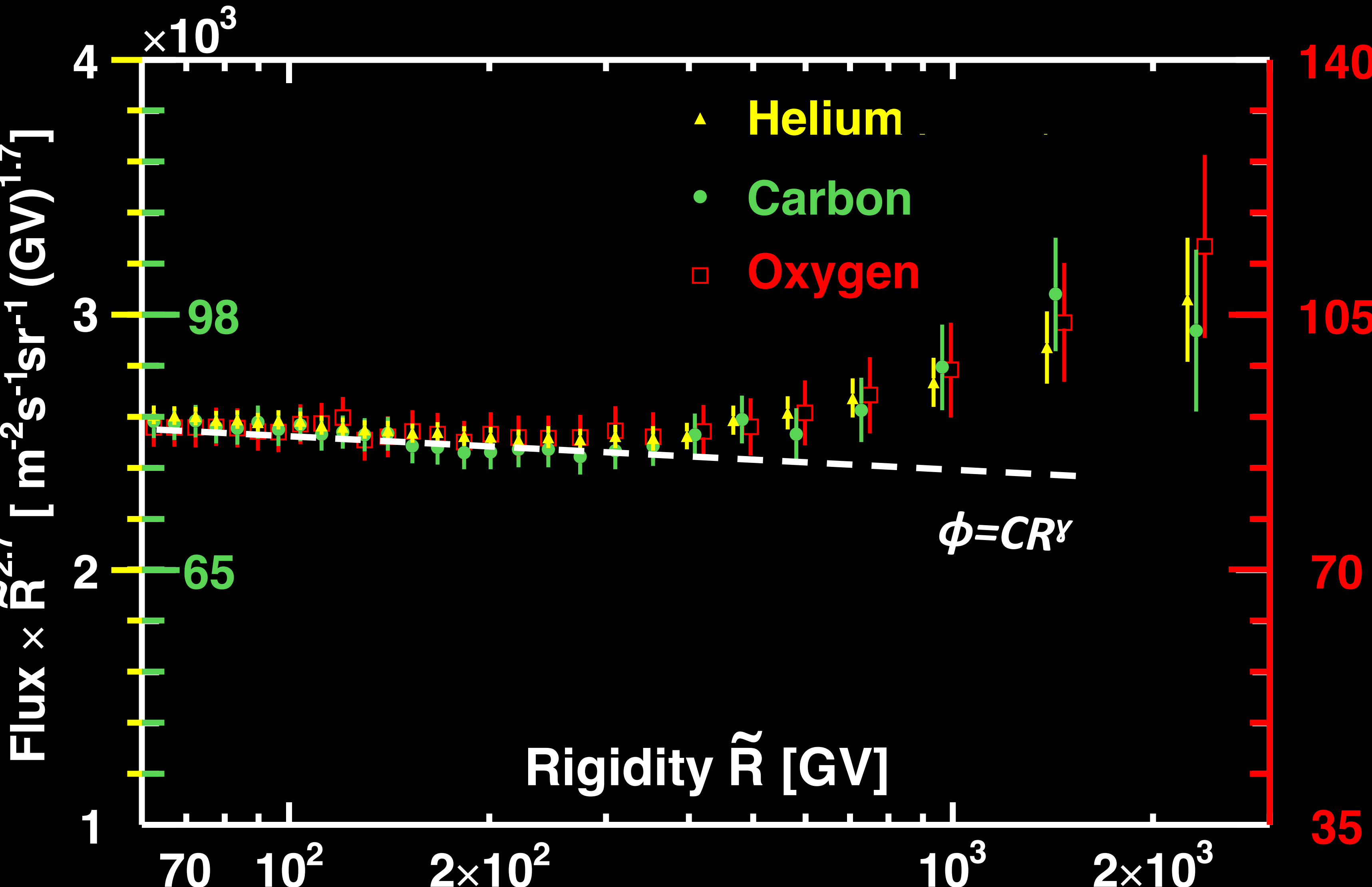


Measurements of primary cosmic ray fluxes are fundamental to understanding the origin, acceleration, and propagation processes of cosmic rays in the Galaxy.

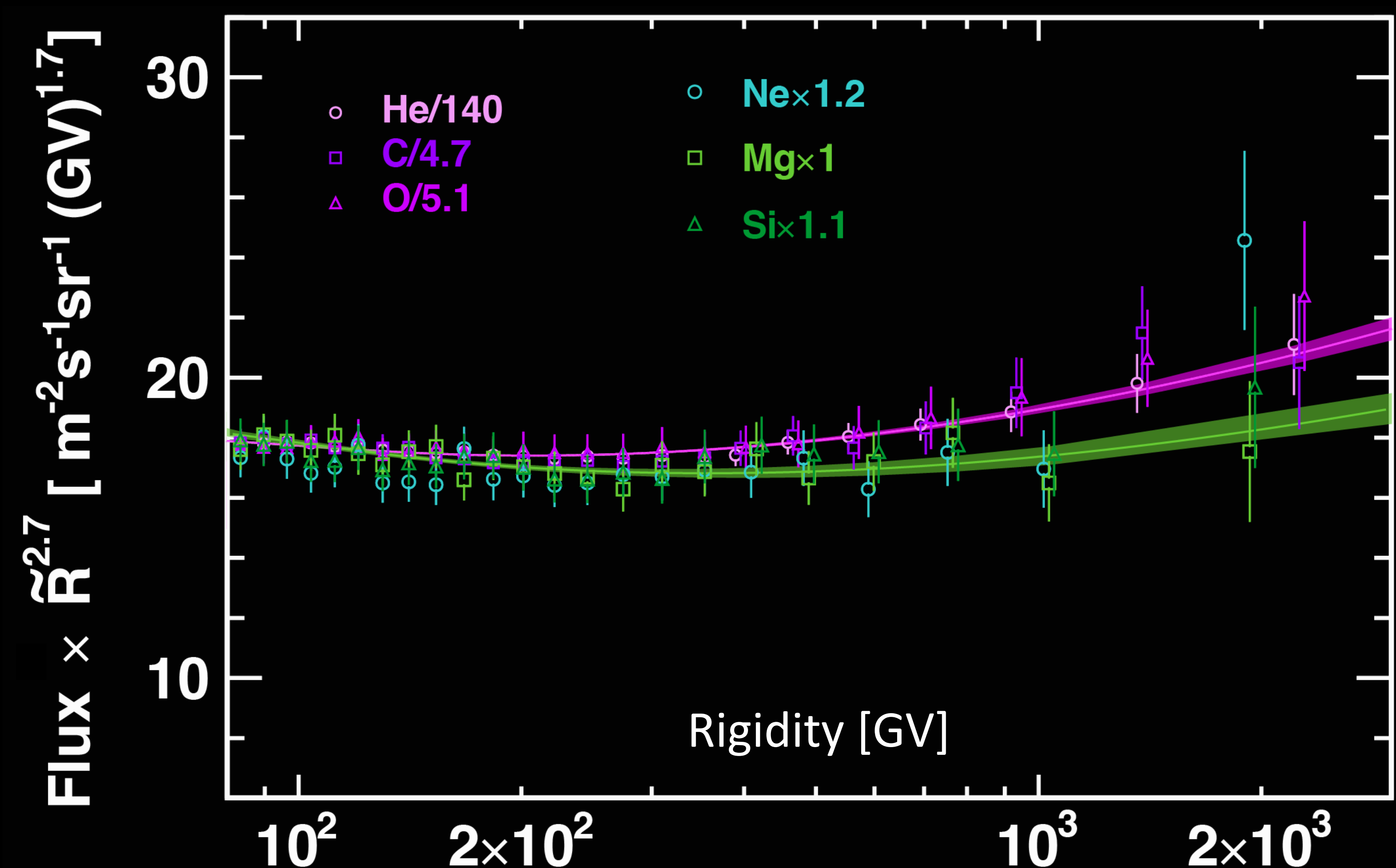
Unexpectedly, above 60 GV, the light primary cosmic rays He-C-O have identical rigidity (R=P/Z) dependence.

In the traditional understanding $\phi = CR^{\gamma}$,

AMS found that He-C-O harden in the same way above ~200 GV.

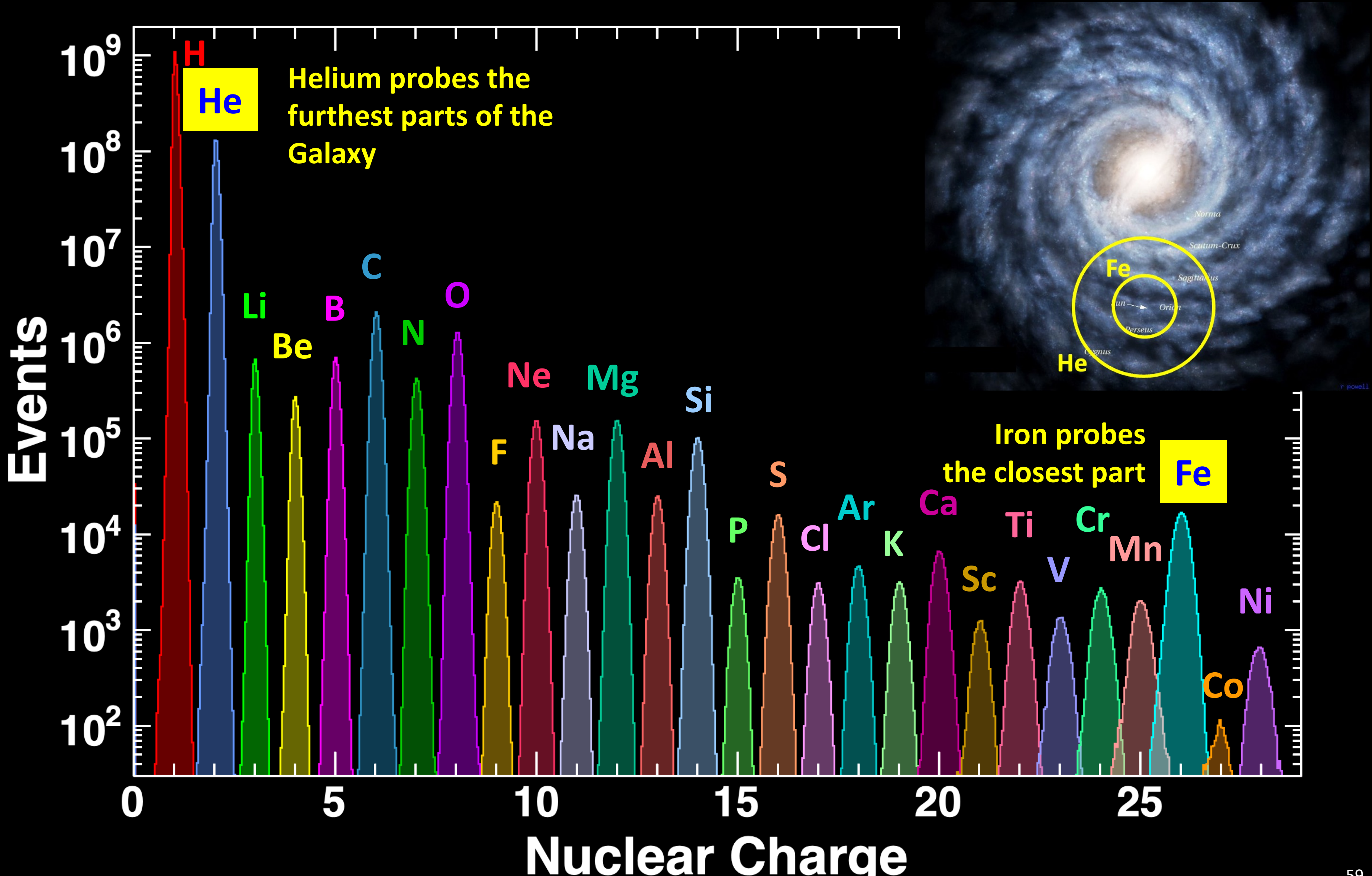


Heavier elements Ne-Mg-Si have their own rigidity dependence, different than the dependence of light elements He-C-O.

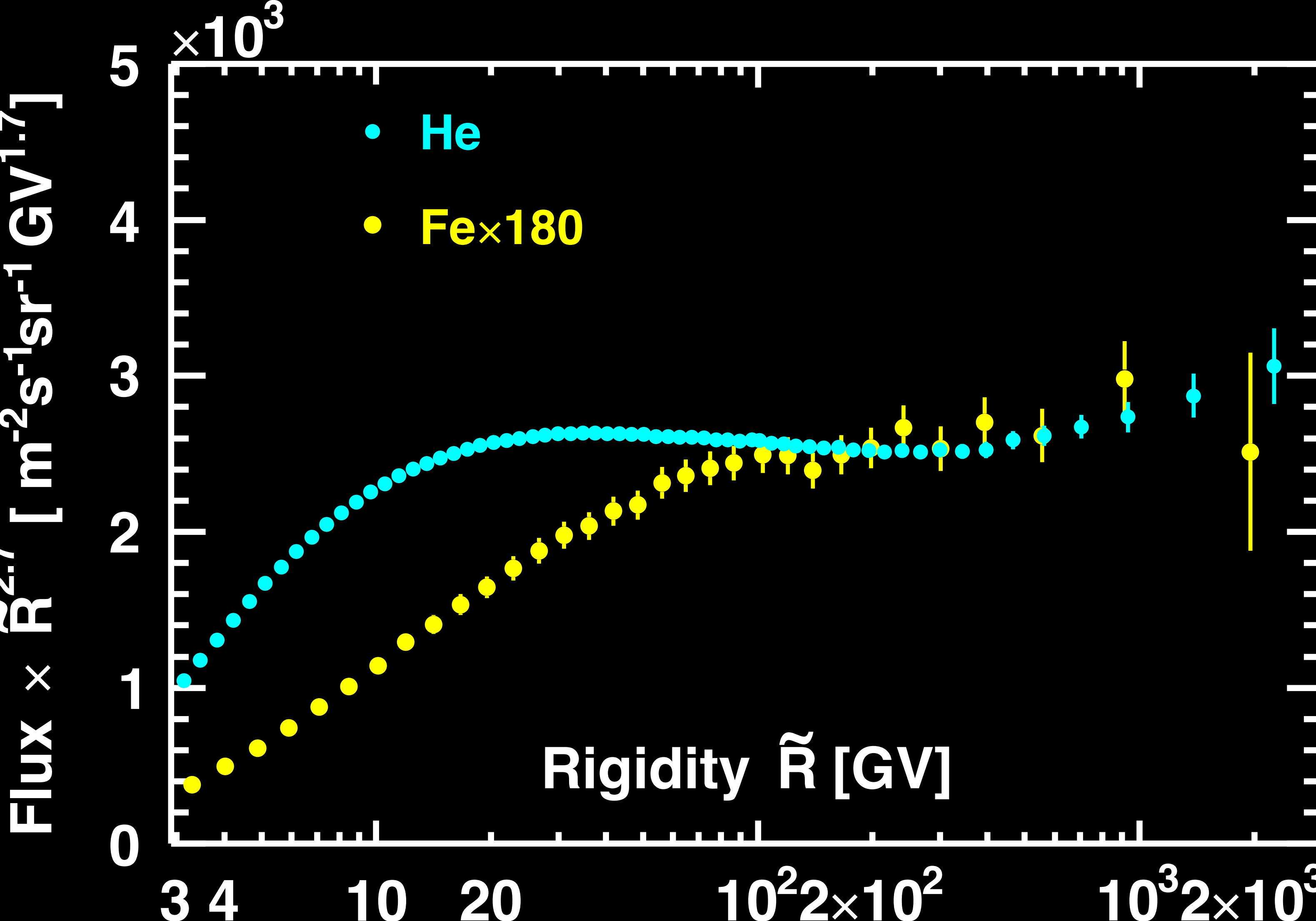


Primary cosmic rays have at least two classes.

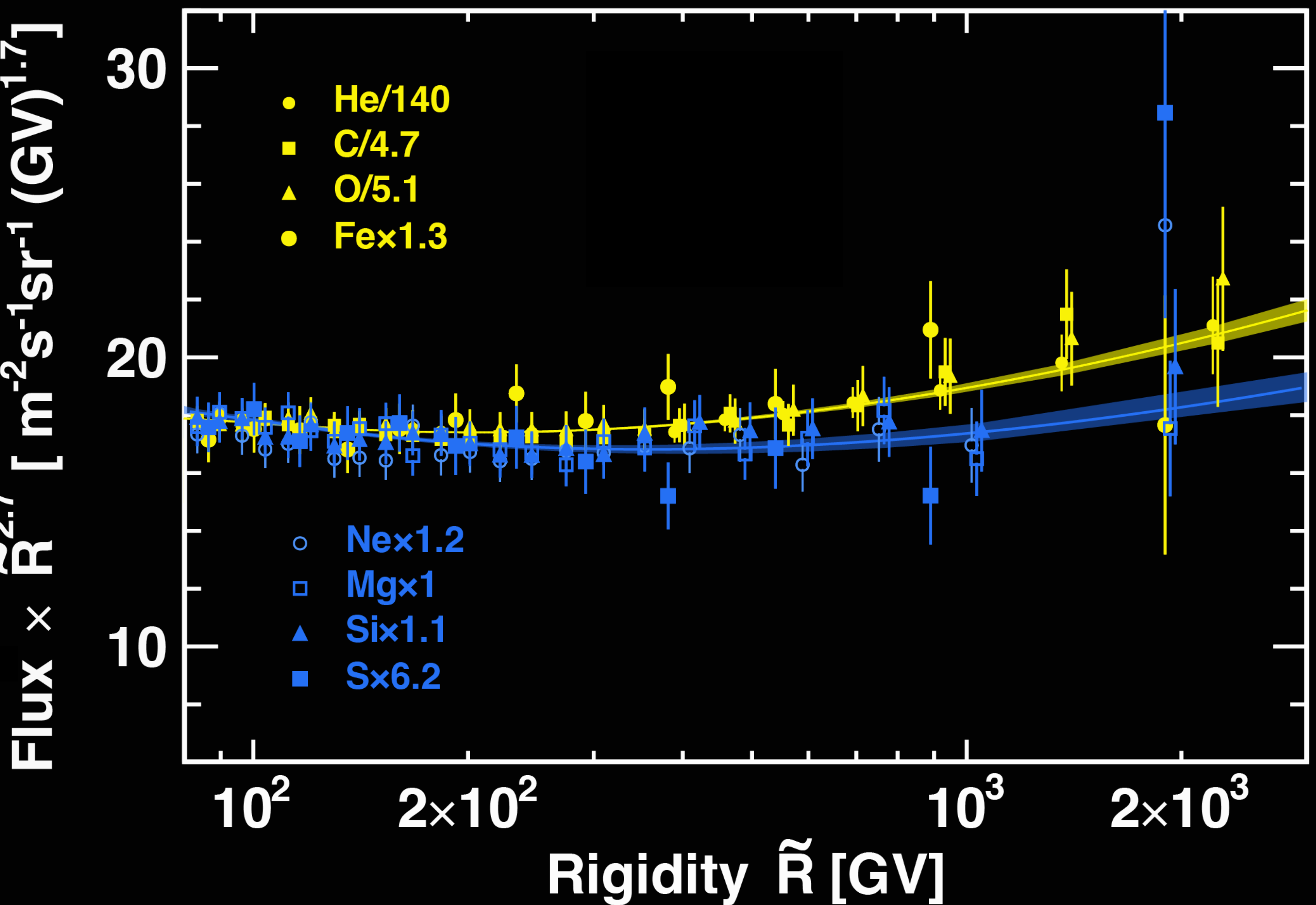
Iron is a very important element in cosmic ray theories because it is the heaviest element produced during stellar evolution. Iron has a large interaction rate with the interstellar medium and comes from the closest part of the Galaxy.



Iron is in the He-C-O primary cosmic ray group instead of the expected heavy Ne-Mg-Si group.



AMS Results on all 8 primary elements: They are in two classes

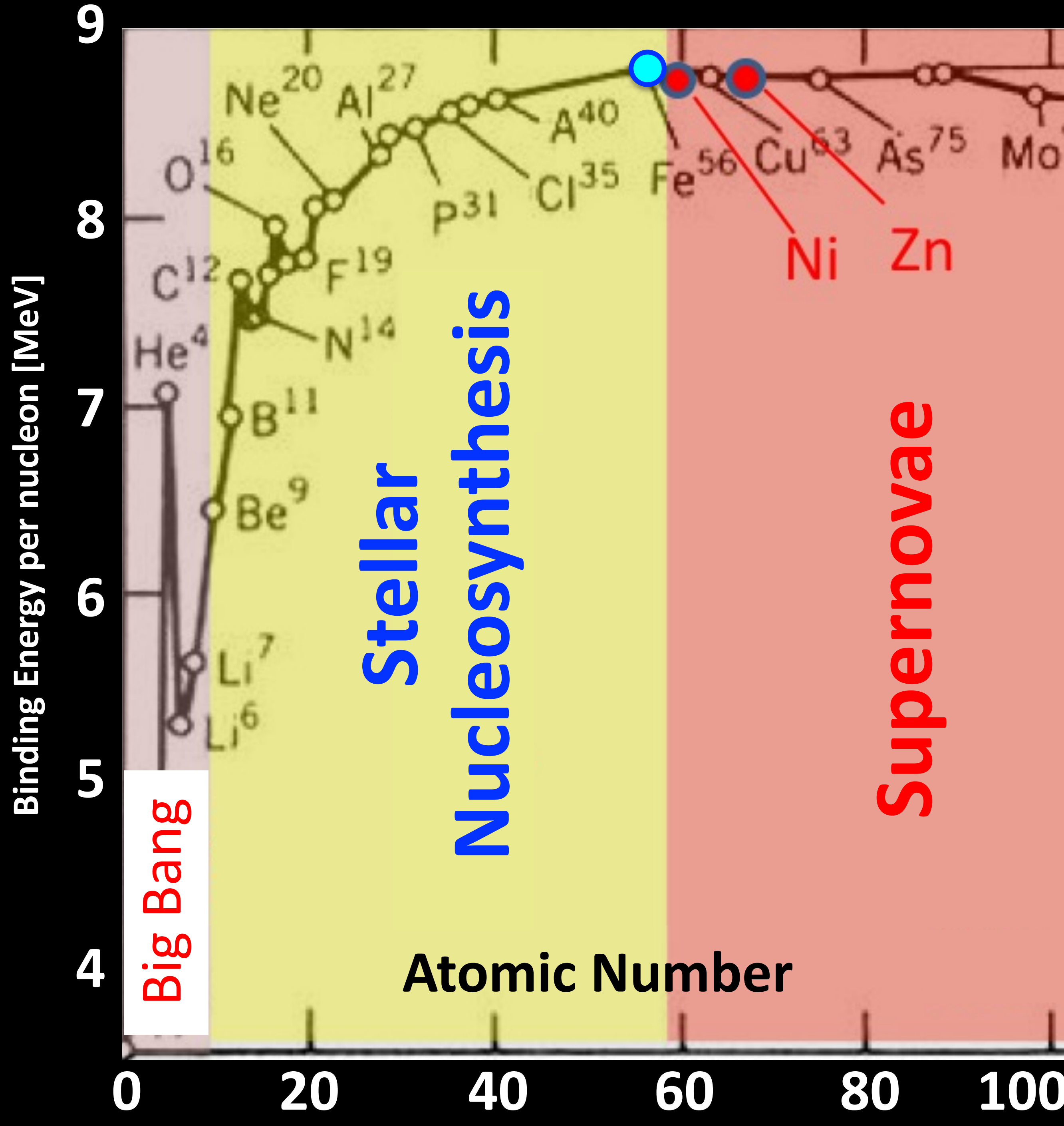


On the origin of cosmic rays

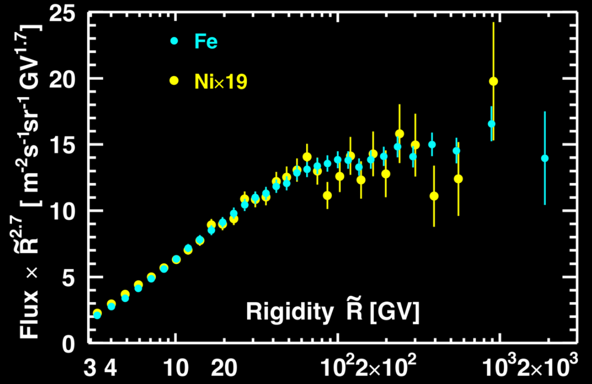
Iron is the heaviest element produced by Stellar Nucleosynthesis

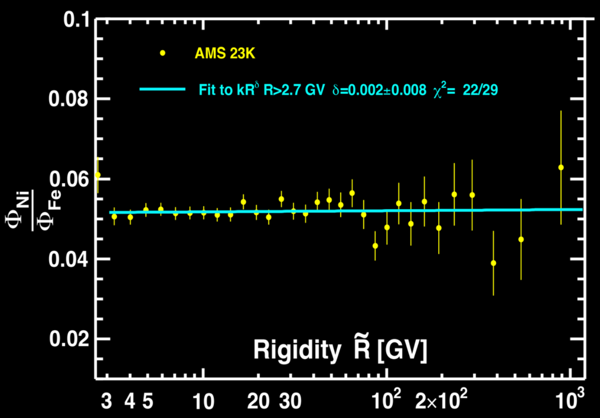
Nickel is the lightest element created by supernovae.

In what way are they different?

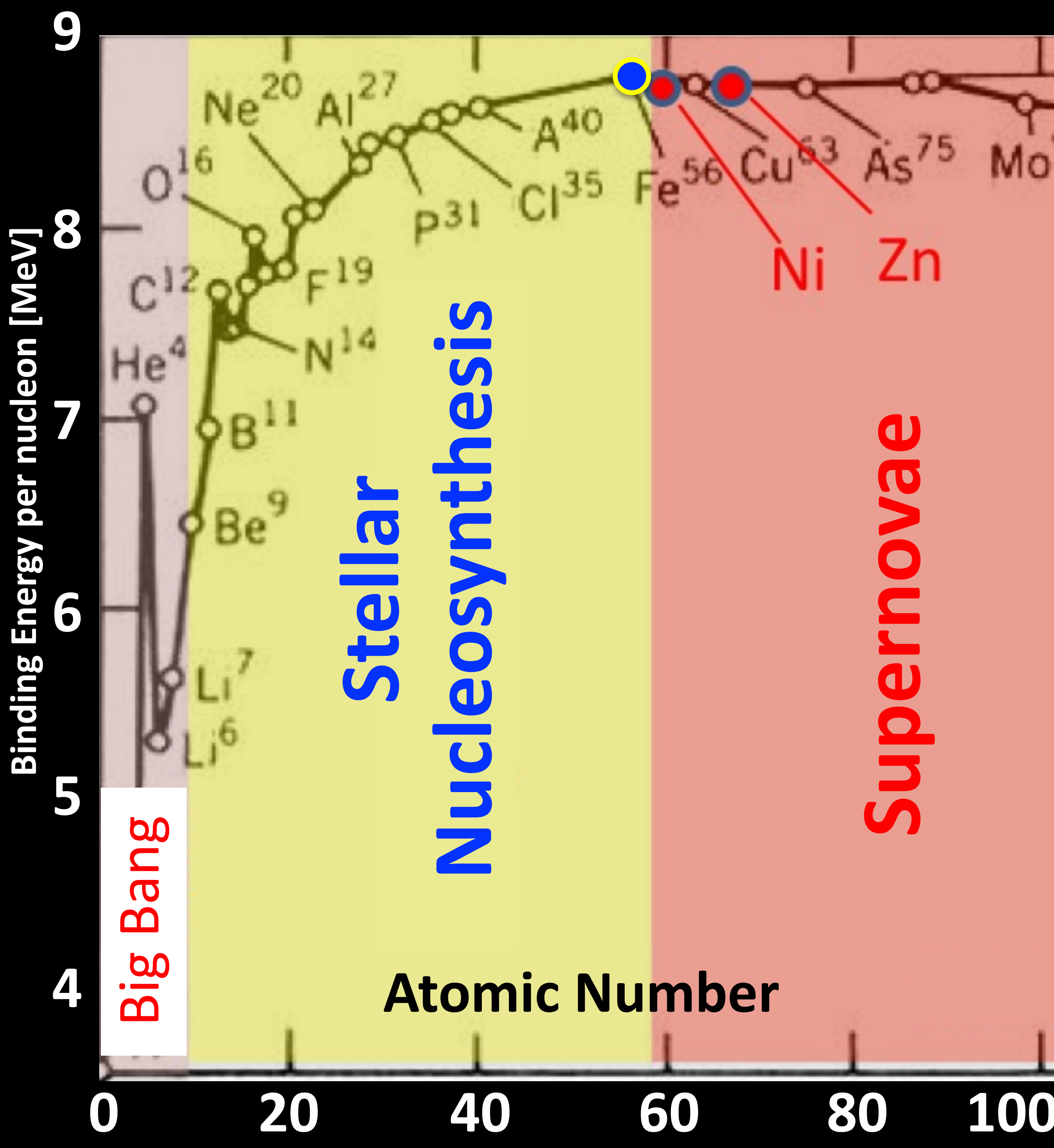


Within the given statistics, the rigidity dependence of Ni is similar to Fe



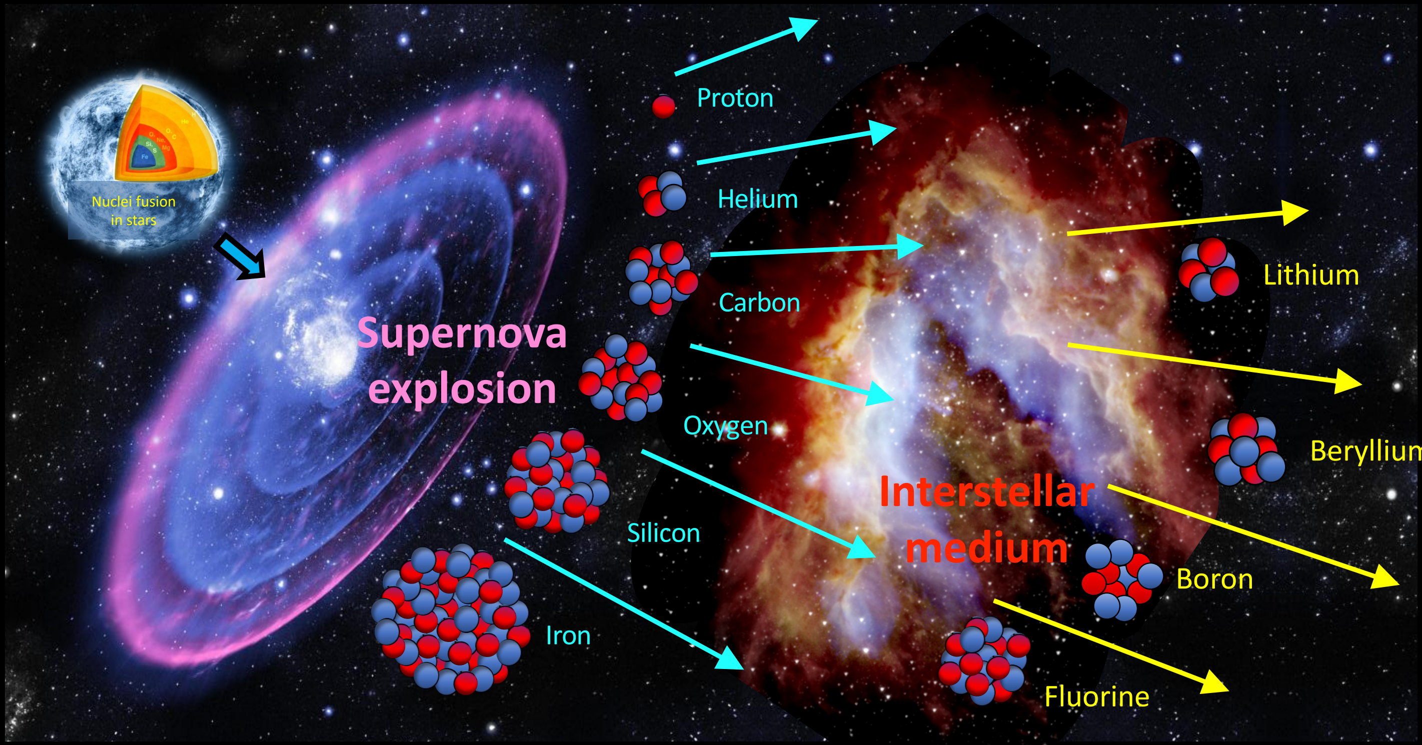


By 2030, we will provide a much more sensitive comparison among Fe, Ni, and Zn.



Latest AMS Results on Secondary Cosmic Ray Nuclei

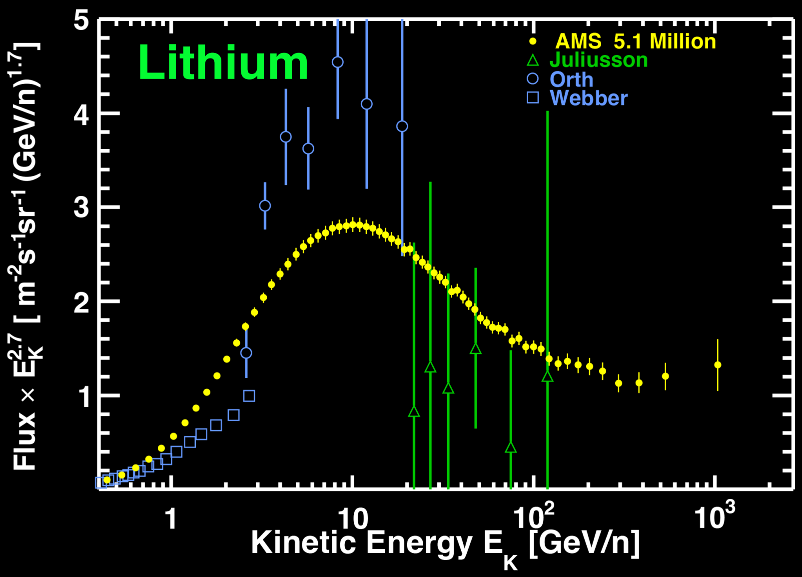
Secondary Li, Be, B, and F nuclei in cosmic rays are produced by the collision of primary cosmic ray C, O, Ne, Mg, Si, …, Fe with the interstellar medium.

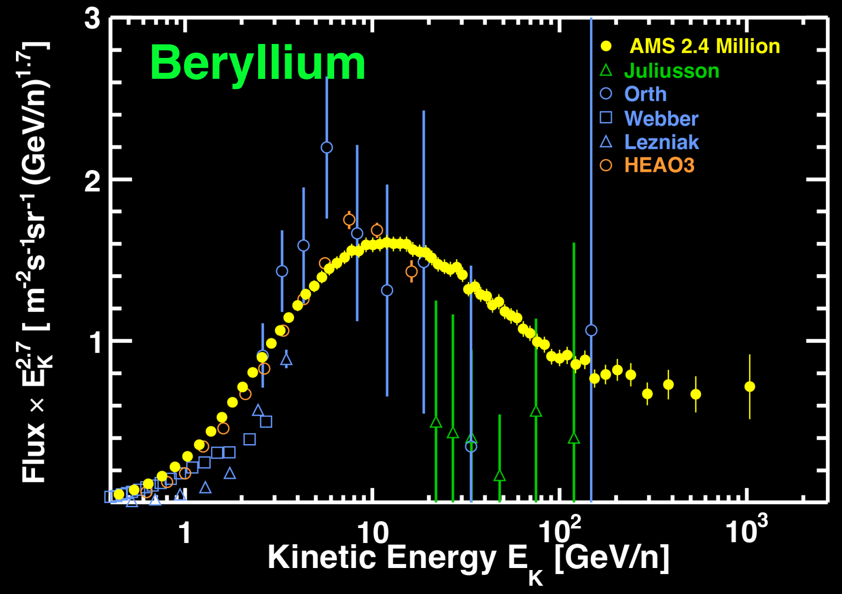


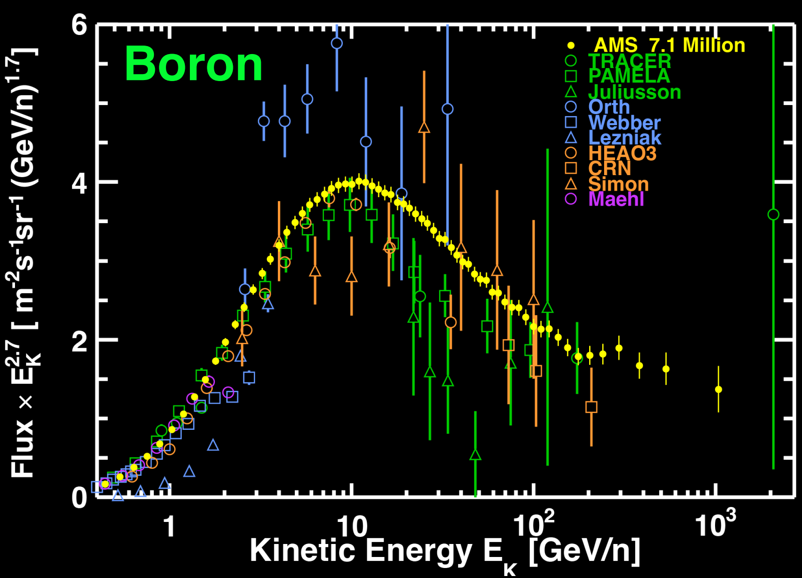
Measurements of the secondary cosmic ray nuclei fluxes are important in understanding the propagation of cosmic rays in the Galaxy.

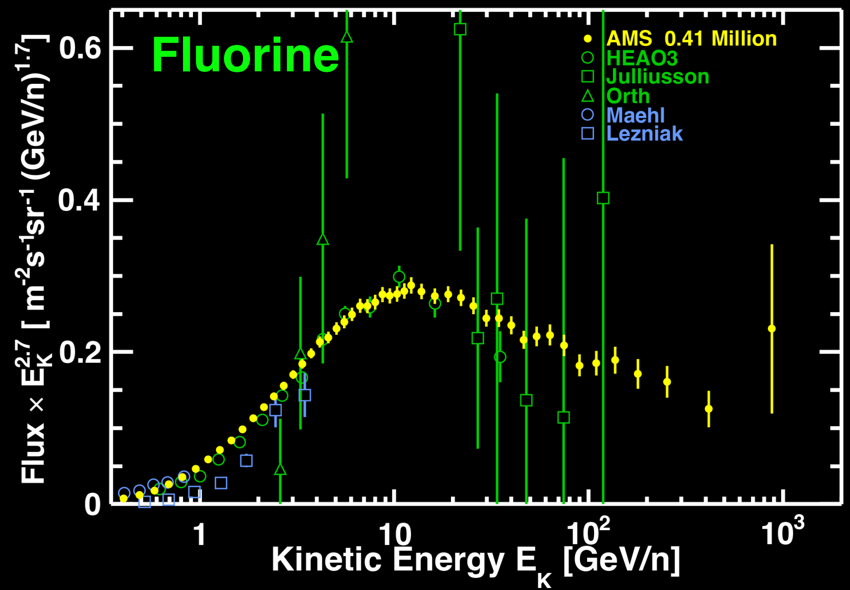
Lithium, Beryllium, Boron, and Fluorine on Earth are produced by cosmic rays.

AMS Secondary nuclei results compared with earlier measurements

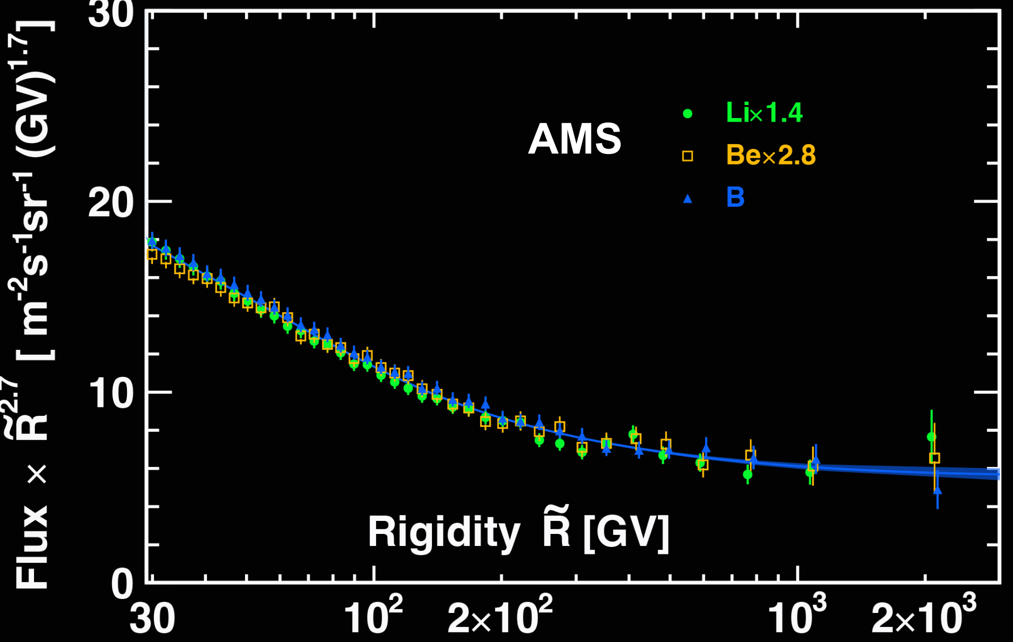


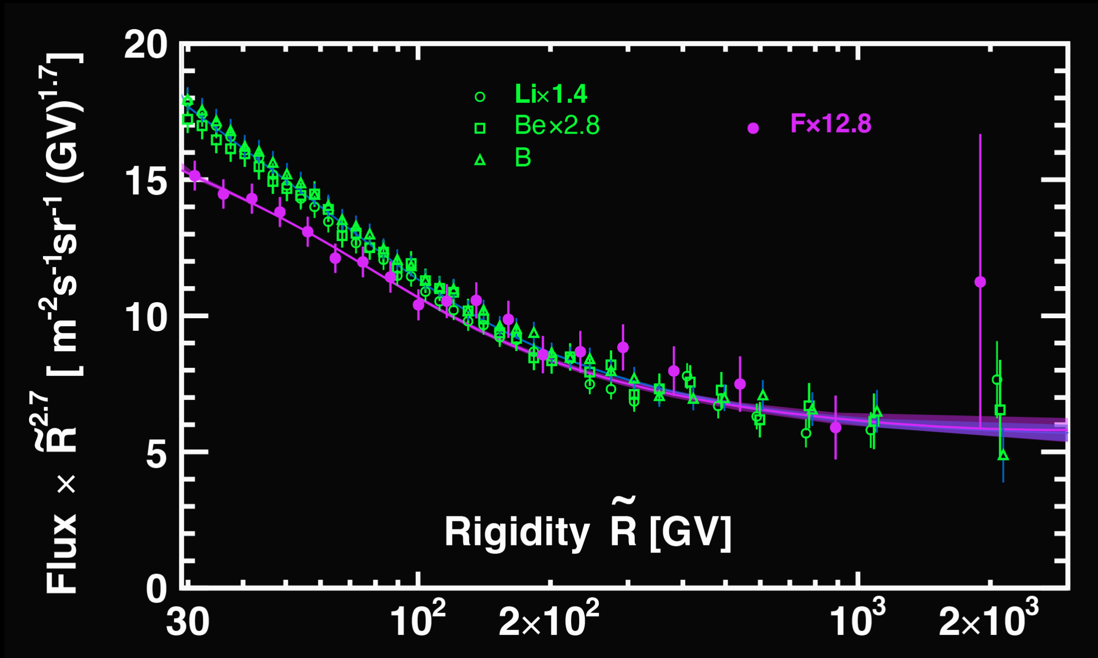




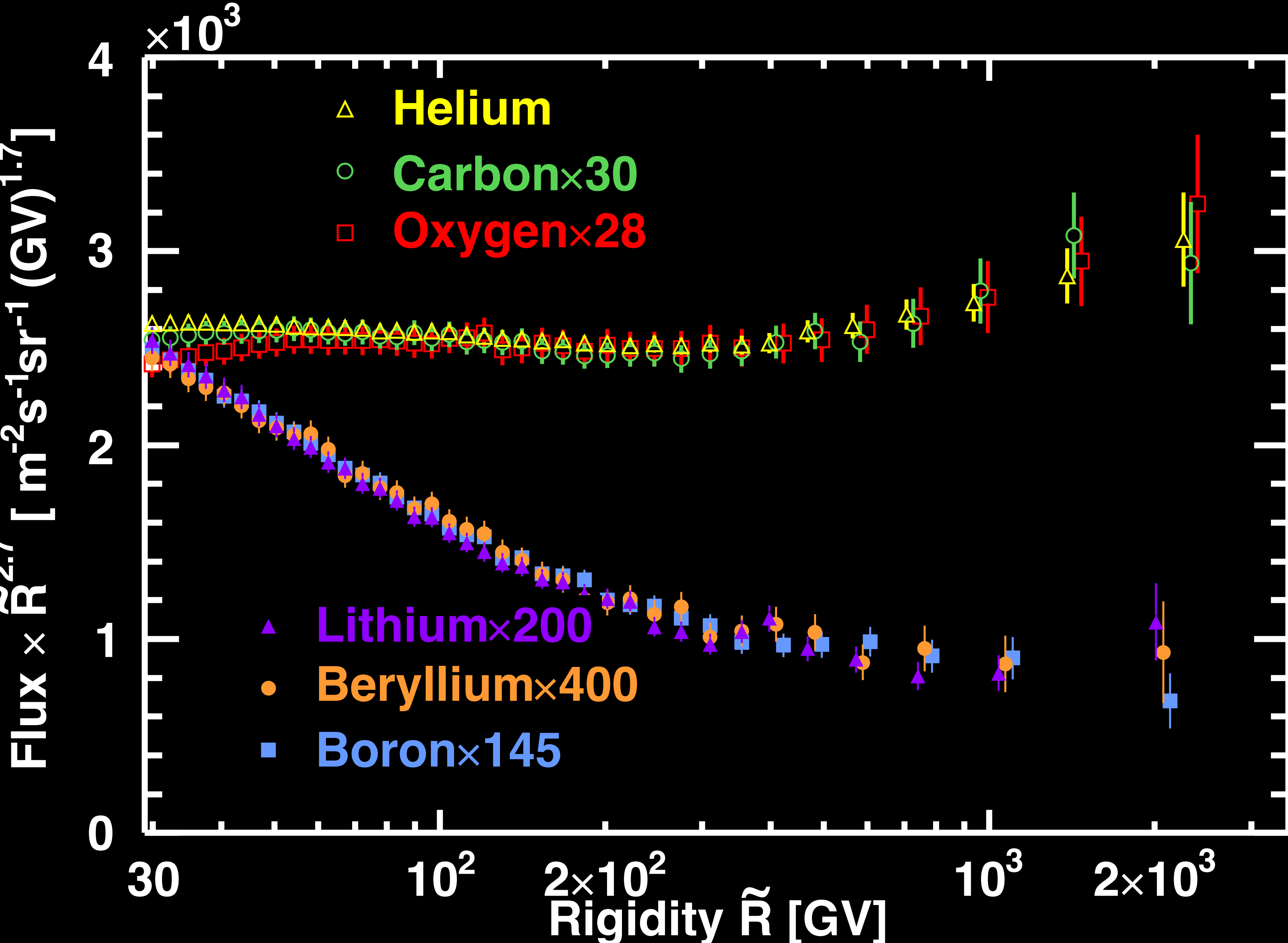


Secondary cosmic rays also have two classes of rigidity dependence

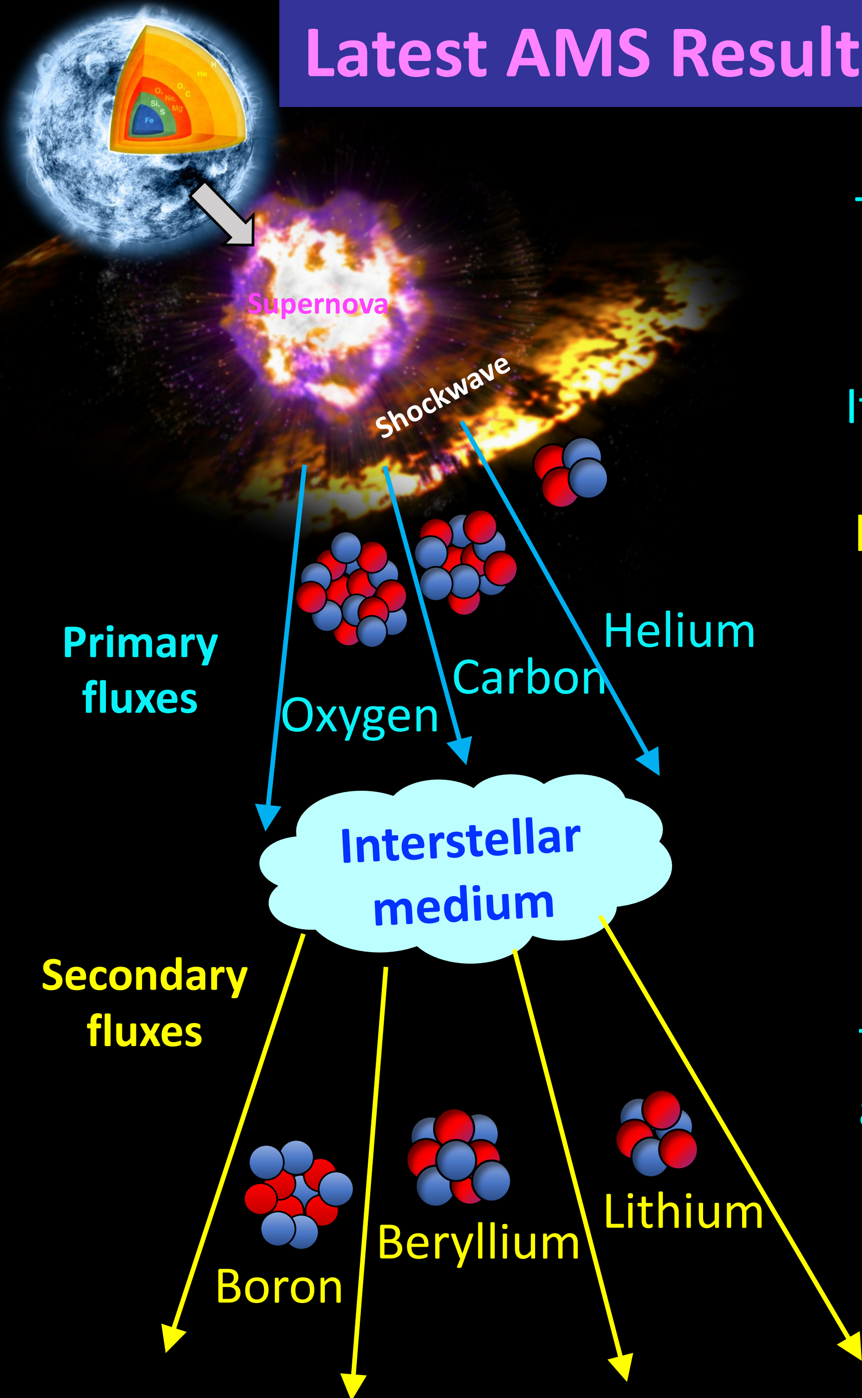




He-C-O primaries compared with Li-Be-B secondaries



Latest AMS Results on Secondary-to-Primary Ratios



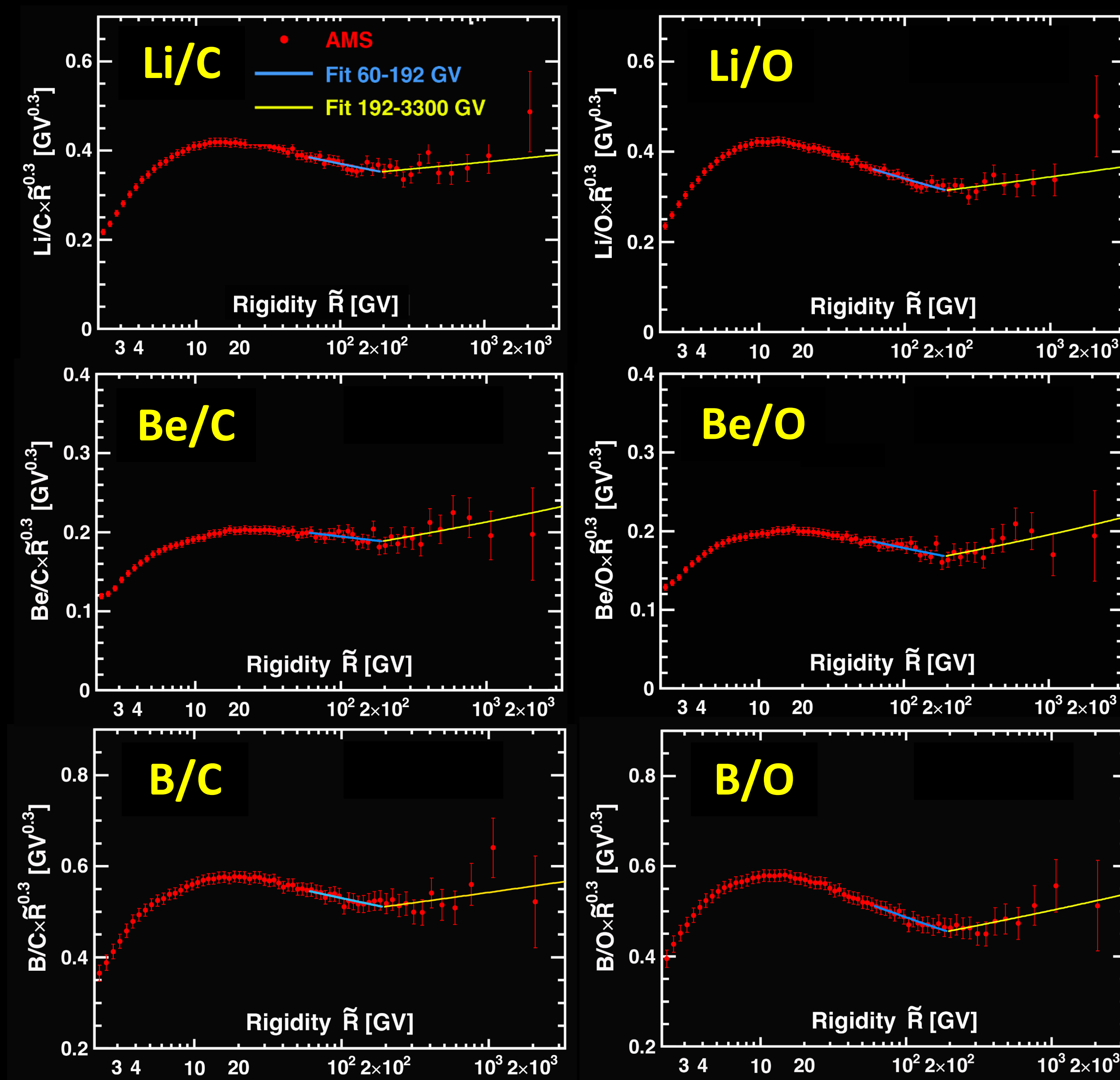
There are many theoretical models describing the behavior of cosmic rays.

If the hardening in cosmic rays is related to the injected spectra at their source, then similar hardening is expected for both secondary and primary cosmic rays.

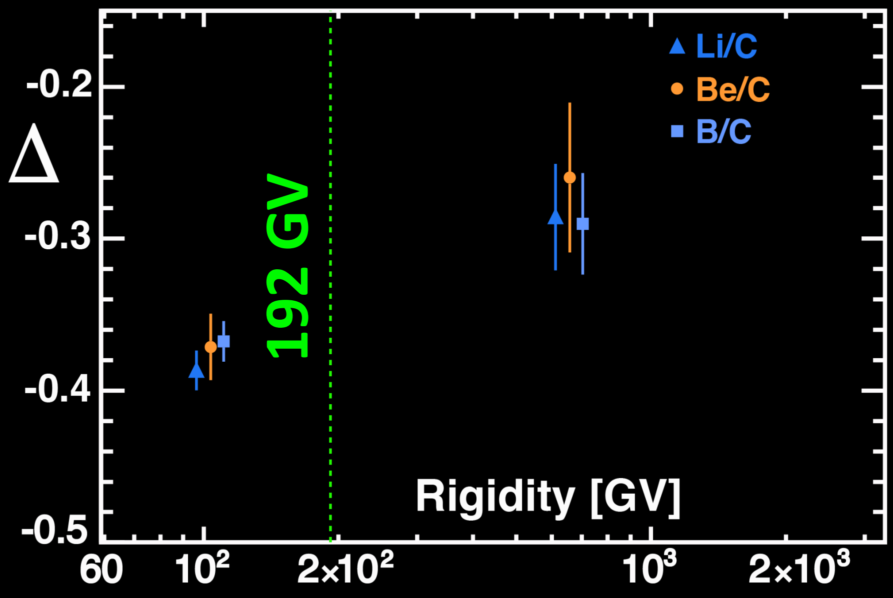
If the hardening is related to propagation properties in the Galaxy, then a stronger hardening is expected for the secondary with respect to the primary cosmic rays.

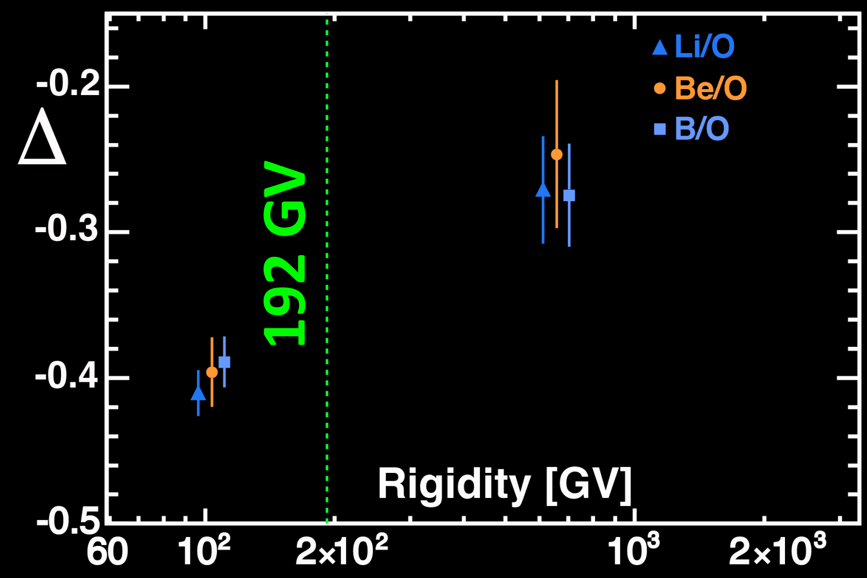
The theoretical models have their limitations, as none of them predicted the AMS observed spectral behavior
of the primary cosmic rays He, C, and O
nor the secondary cosmic rays Li, Be, and B.

Secondary -to- Primary Ratios



Secondary/Primary Ratios (kR^{Δ}) are rigidty dependent

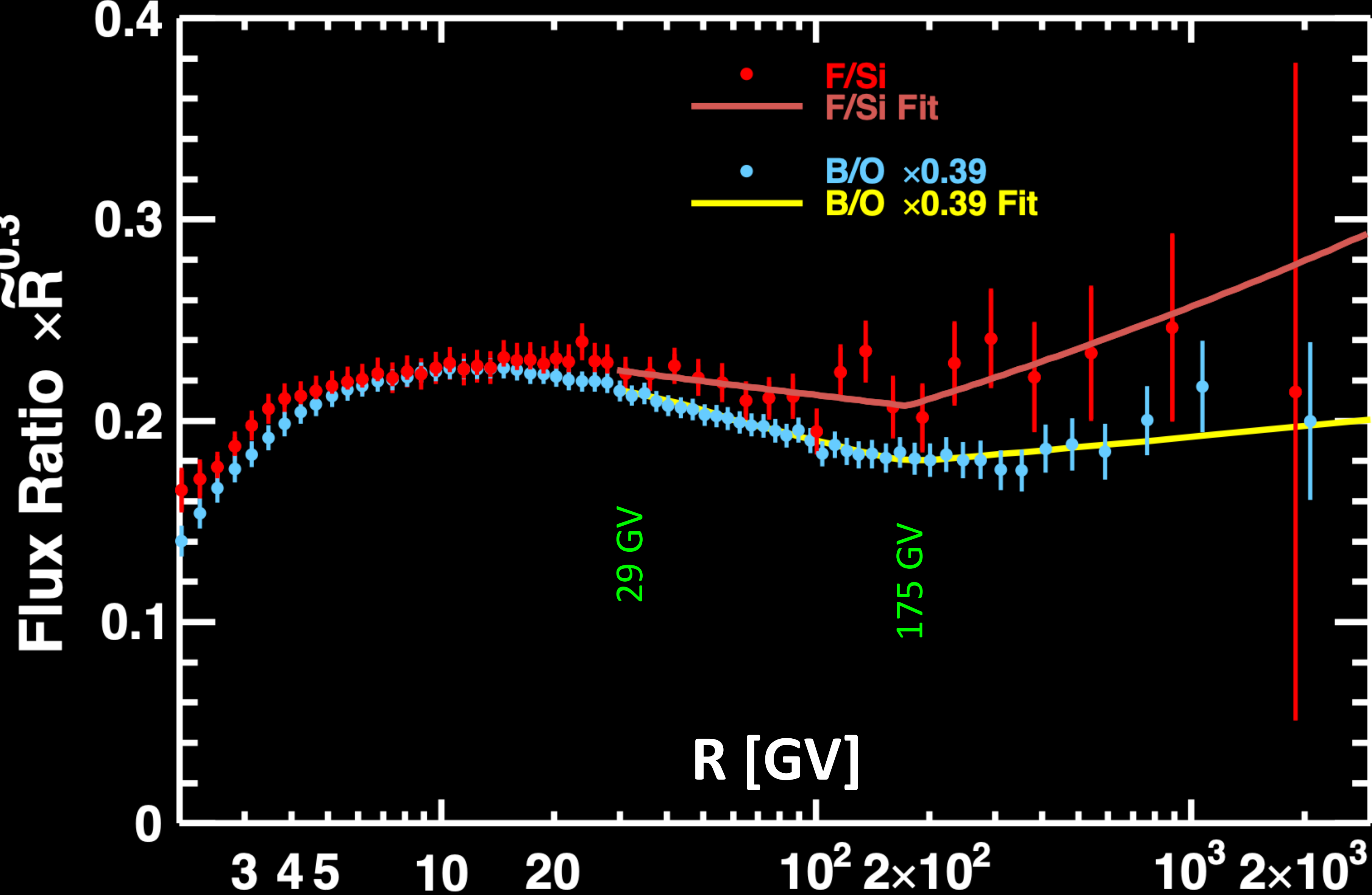




Δ in two rigidity intervals (60 − 192 GV and 192 − 3300 GV) exhibit an average hardening of 0.11±0.02. The significance of this change is 5.5σ.

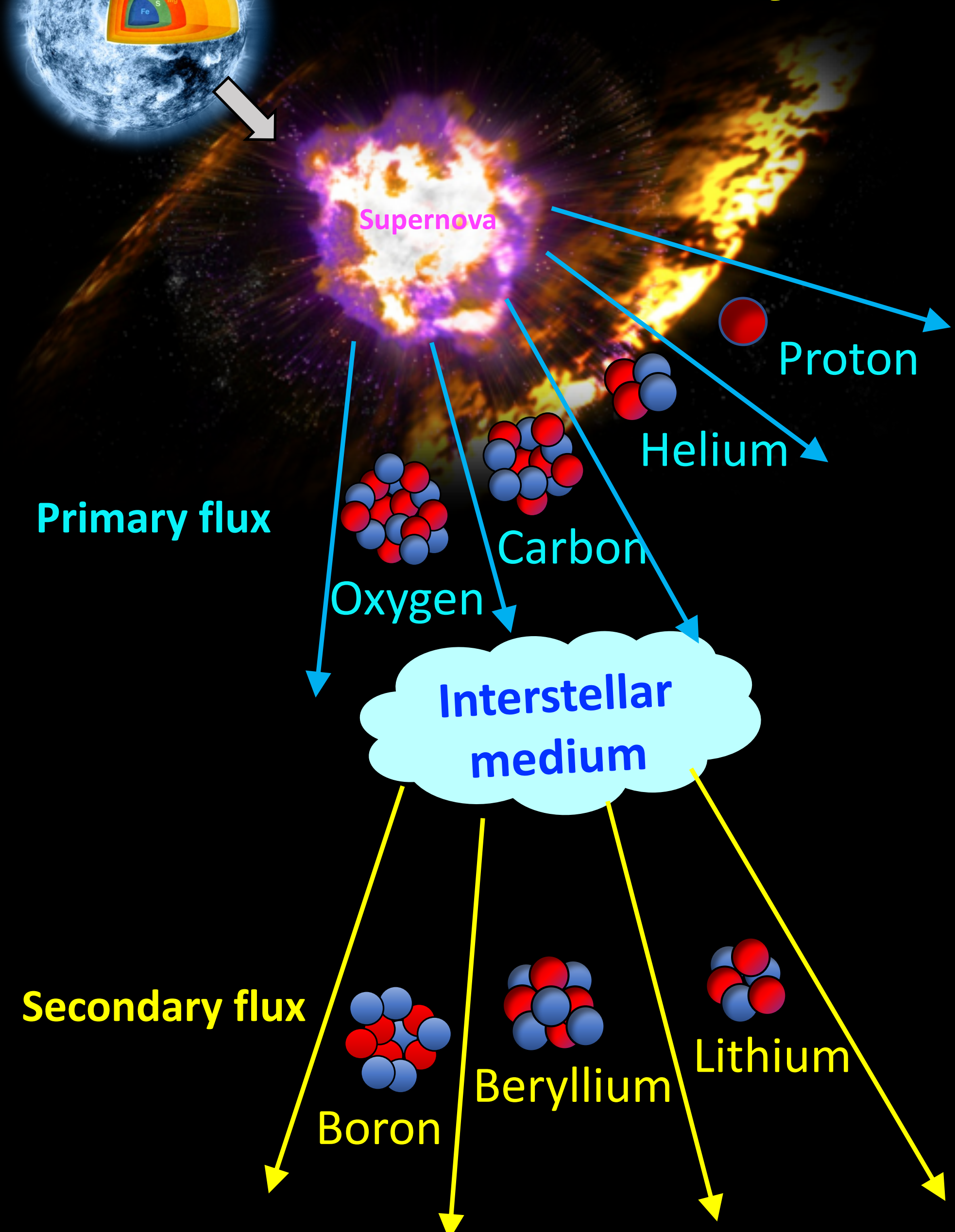
Above ~200 GV secondary cosmic rays harden twice as much as primaries. This strongly supports that the hardening is related to propagation properties in the Galaxy.

F/Si (high-Z) compared to B/O (low-Z)



The Secondary-to-Primary ratios are different for high-Z and low-Z

Secondary-to-Primary Ratios



Before AMS, the secondary-to-primary ratios (B/C …) were assumed to be $\propto R^{\Delta}$ with Δ a constant (independent of R and Z).

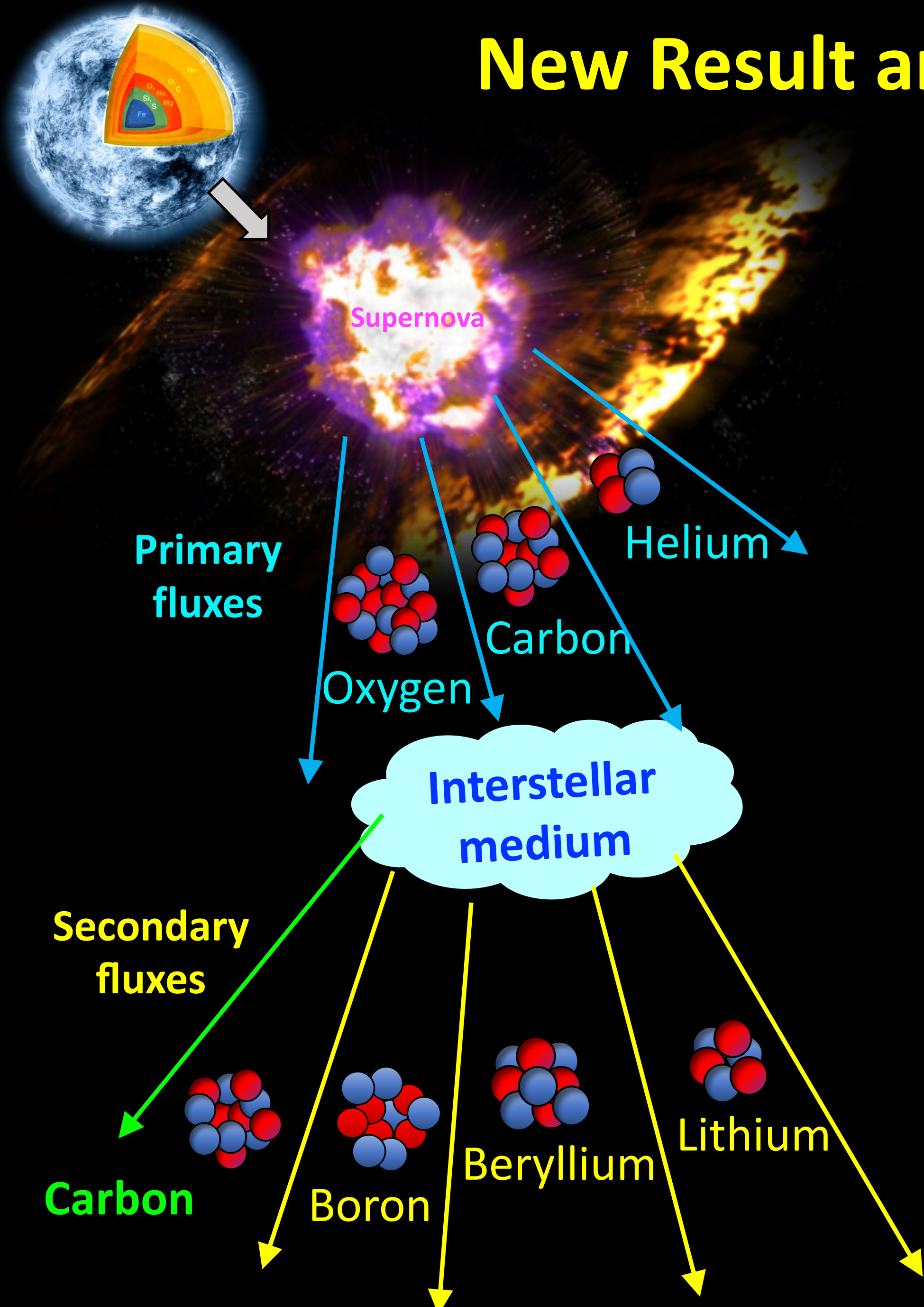
AMS results:

Δ depends on Z

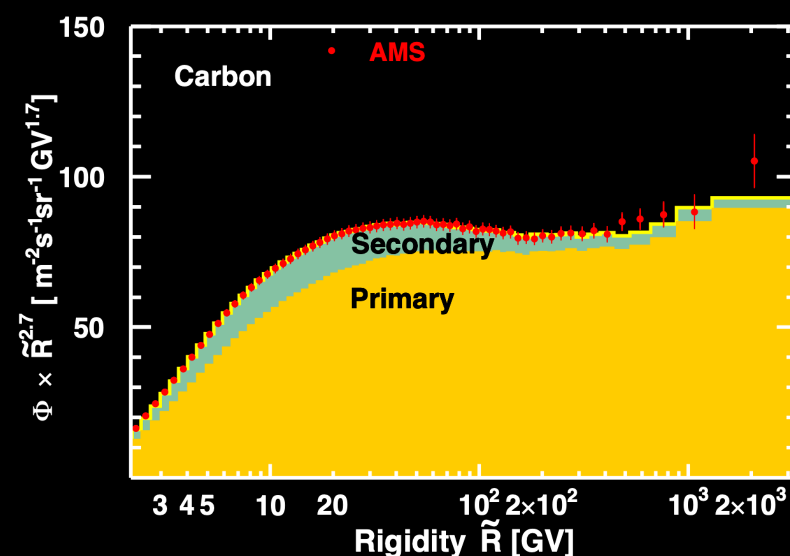
Δ depends on R

The traditional B/C measurement does not describe the Interstellar Medium

New Result and its Implications



Before AMS, taking into account the long-standing idea that C is pure primary and B is pure secondary, the (B/C) ratio has been used in models to describe cosmic ray propagation



But C is NOT pure primary.

Question: how to use (B/C) in cosmic ray models?

Examples of Theoretical Papers based on Boron to Carbon Ratio

1) P.-p. Zhang, et al., “Ultrahigh-energy diffuse gamma-ray emission from cosmic-ray interactions with the medium surrounding acceleration sources”, Phys. Rev. D 105, 023002 (2022).
2) R. C. Anjos and F. Catalani, “Galactic Center as an efficient source of cosmic rays”, Phys. Rev. D 101, 123015 (2020).
3) R. Diesing and D. Caprioli, “Nonsecondary origin of cosmic ray positrons”, Phys. Rev. D 101, 103030 (2020).
4) Y. Génolini et al., “ Cosmic-ray transport from AMS-02 boron to carbon ratio data: Benchmark models and interpretation”, Phys. Rev. D 99, 123028 (2019).
5) L. Derome et al., “Fitting B/C Cosmic-ray data in the AMS-02 era: a cookbook”, Astron. Astrophys. 627, A158 (2019).
6) I. Cholis, T. Linden, and D. Hooper, “A robust excess in the cosmic-ray antiproton spectrum: Implications for annihilating dark matter”, Phys. Rev. D 99, 103026 (2019).
7) M. Kachelrieß, A. Neronov, and D. V. Semikoz, “Cosmic ray signatures of a 2-3 Myr old local supernova”, Phys. Rev. D 97, 063011 (2018).
8) G. Giacinti, M. Kachelrieß and D.V. Semikoz, “Reconciling cosmic ray diffusion with Galactic magnetic field models”, J. Cosmol. Astropart. Phys. 07 (2018) 051.
9) É. Jaupart, É. Parizot, and D. Allard, “Contribution of the Galactic centre to the local cosmic-ray flux”, Astron. Astrophys. 619, A12 (2018).
10) Y. Génolini et al., “Indications for a High-Rigidity Break in the Cosmic-Ray Diffusion Coefficient”, Phys. Rev. Lett. 119, 241101 (2017).
11) D. Eichler, “An Alternative Explanation of the Varying Boron-to-carbon Ratio in Galactic Cosmic Rays”, Astrophys. J. 842, 50 (2017).
12) Q. Yuan et al., “Propagation of cosmic rays in the AMS-02 era”, Phys. Rev. D 95, 083007 (2017).
13) N. Tomassetti, “Solar and nuclear physics uncertainties in cosmic-ray propagation”, Phys. Rev. D 96, 103005 (2017).
14) P. Lipari, “interpretation of the cosmic ray positron and antiproton fluxes”, Phys. Rev. D 95, 063009 (2017).
15) P. Blasi, “On the spectrum of stable secondary nuclei in cosmic rays”, Mon. Not. R. Astron. Soc. 471, 1662 (2017).
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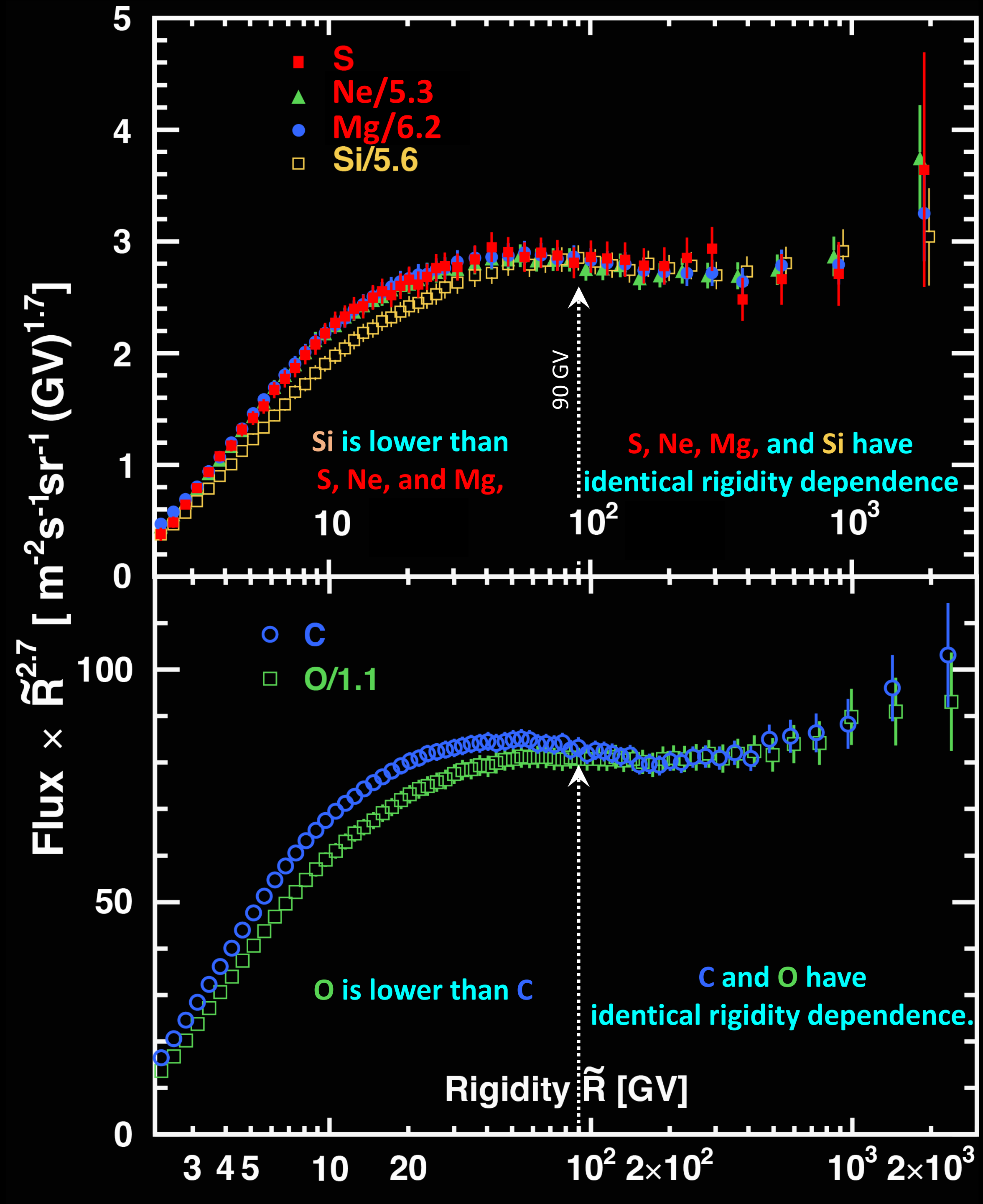
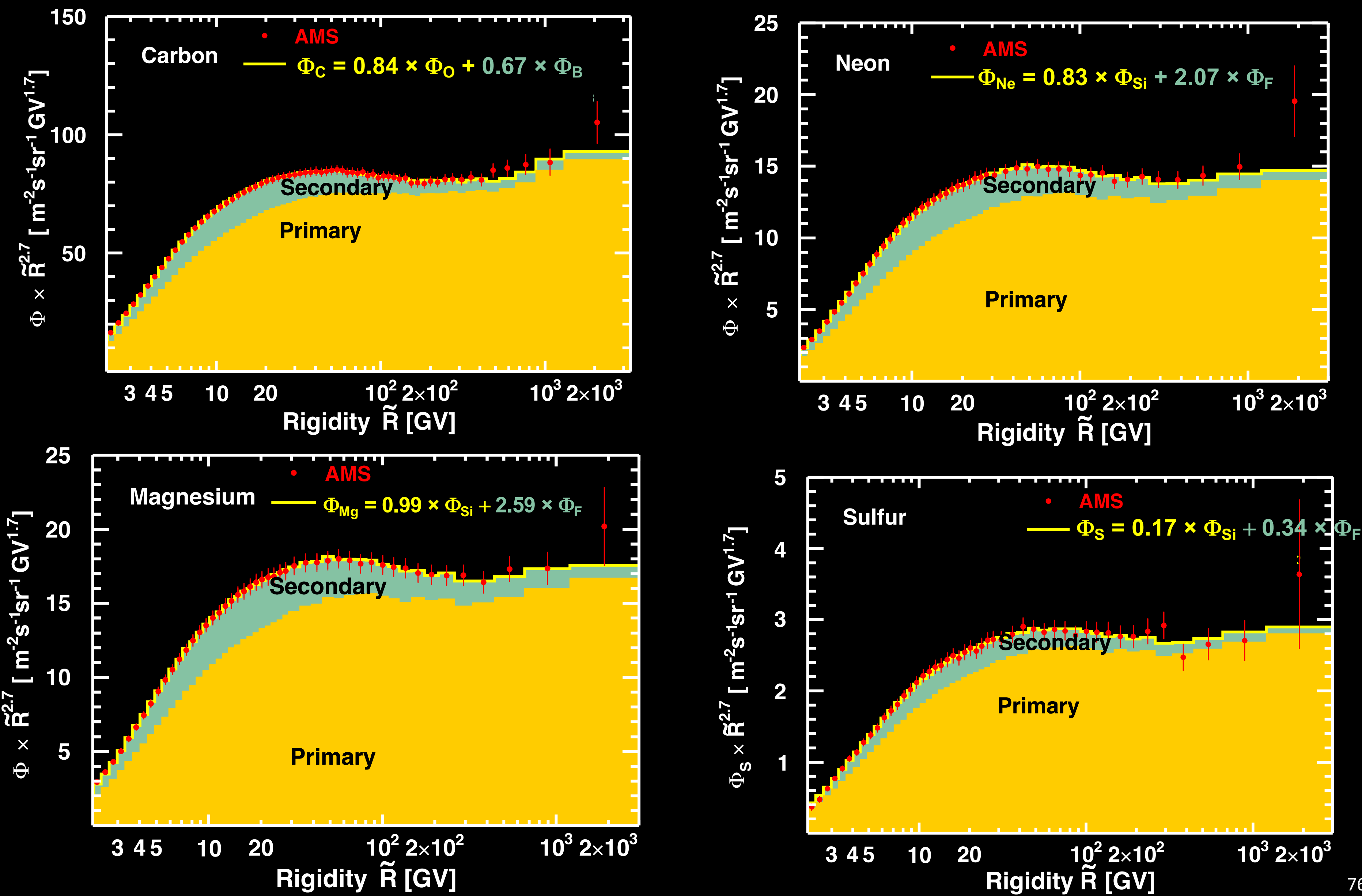
Detailed Properties of Primary Cosmic Rays

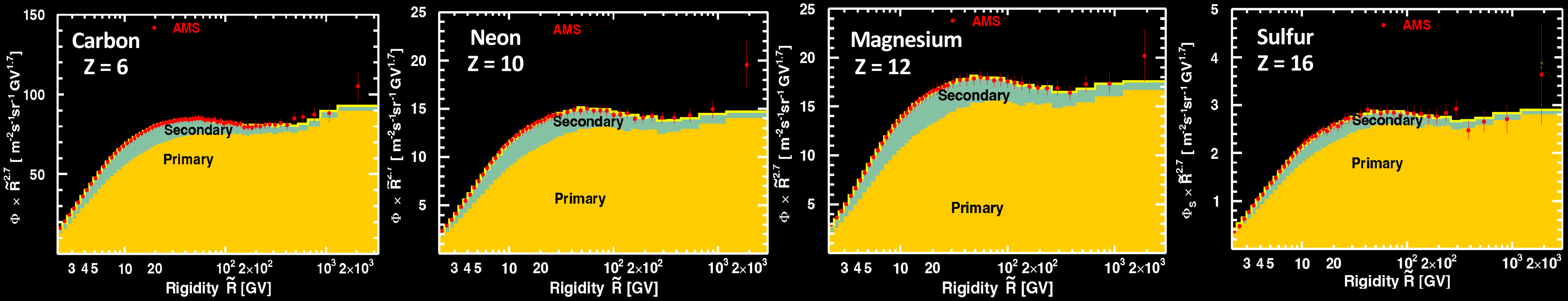


The discrepancies in functional behavior at low rigidity indicate that many primary cosmic rays have a significant secondary component

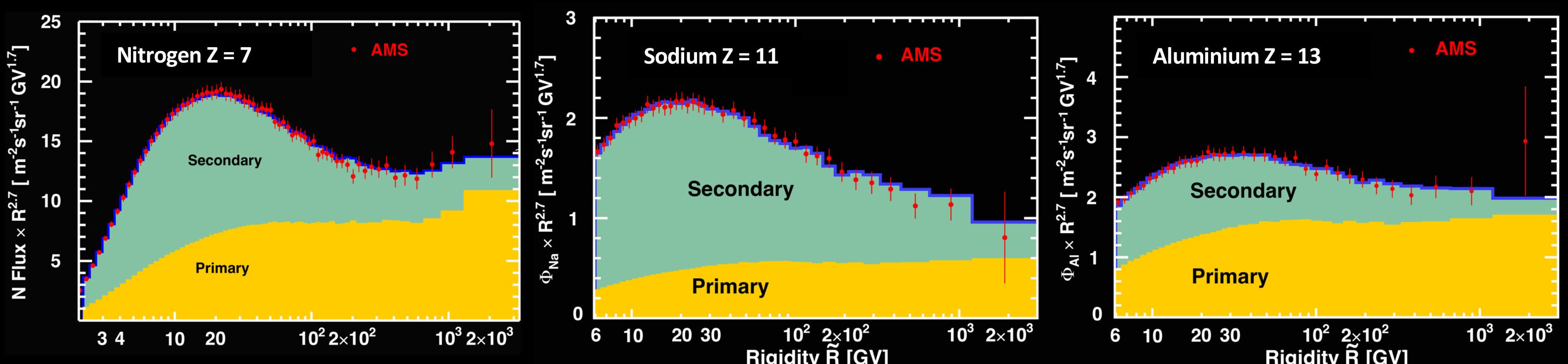
New, unexpected observation:
Traditional primary cosmic rays C, Ne, Mg, and S fluxes are not pure primary; they all have a significant secondary component



Even-Z nuclei and Odd-Z nuclei have distinctly different primary and secondary composition

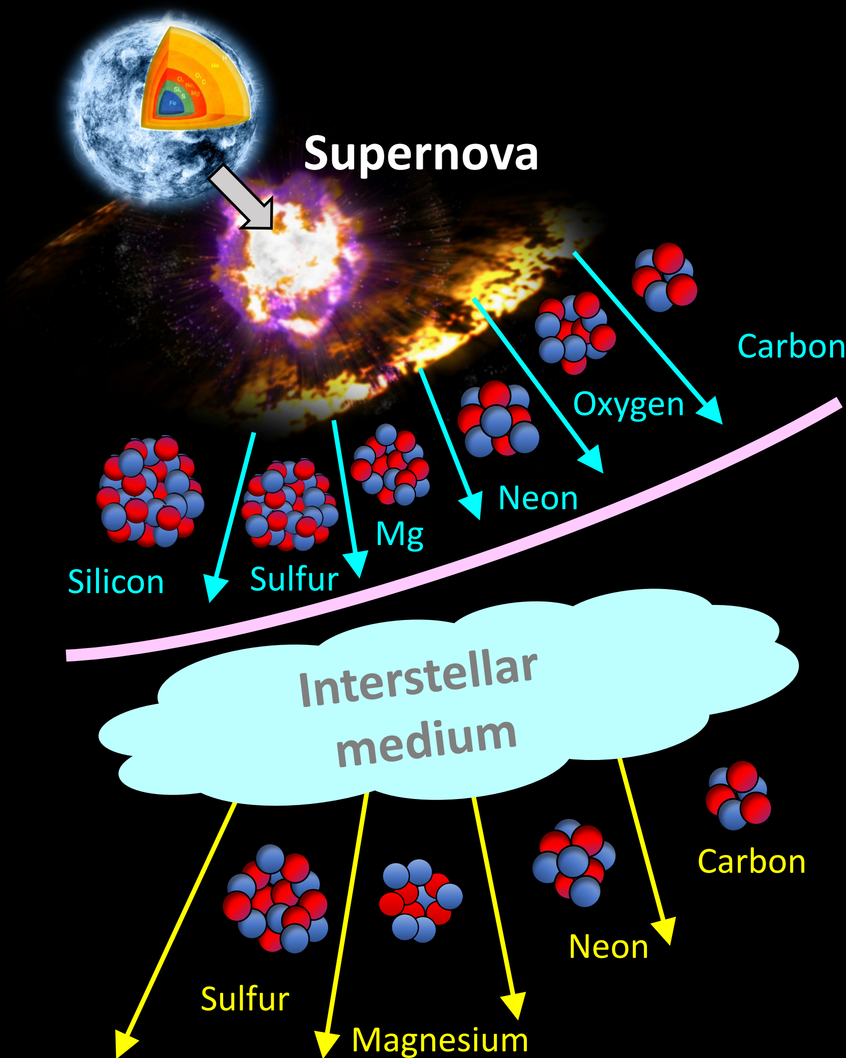


Even-Z nuclei are dominated by primaries



Odd-Z nuclei have more secondaries than even-Z

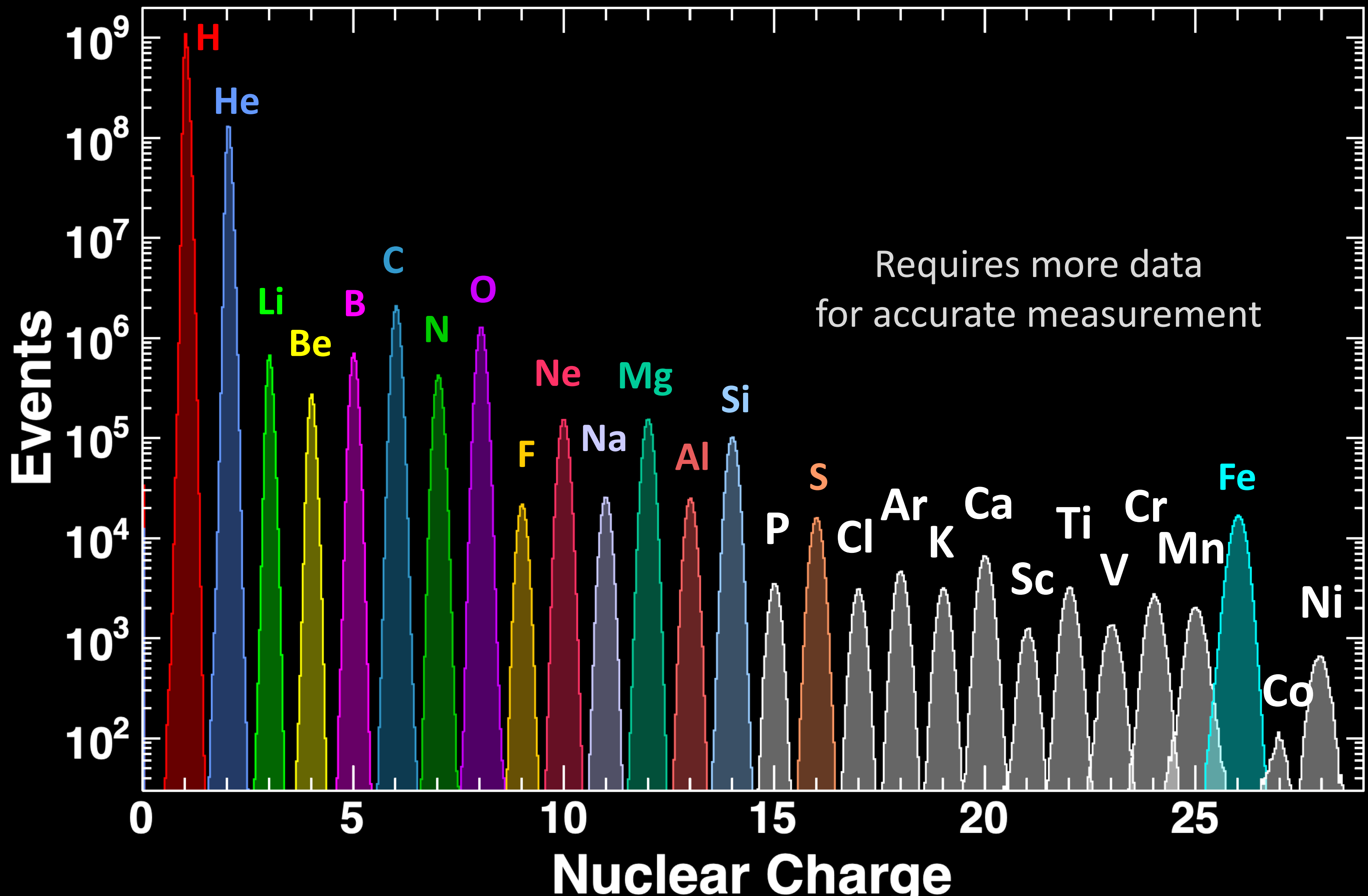
Model-independent measurements of the relative abundances at the source (before cosmic ray propagation)



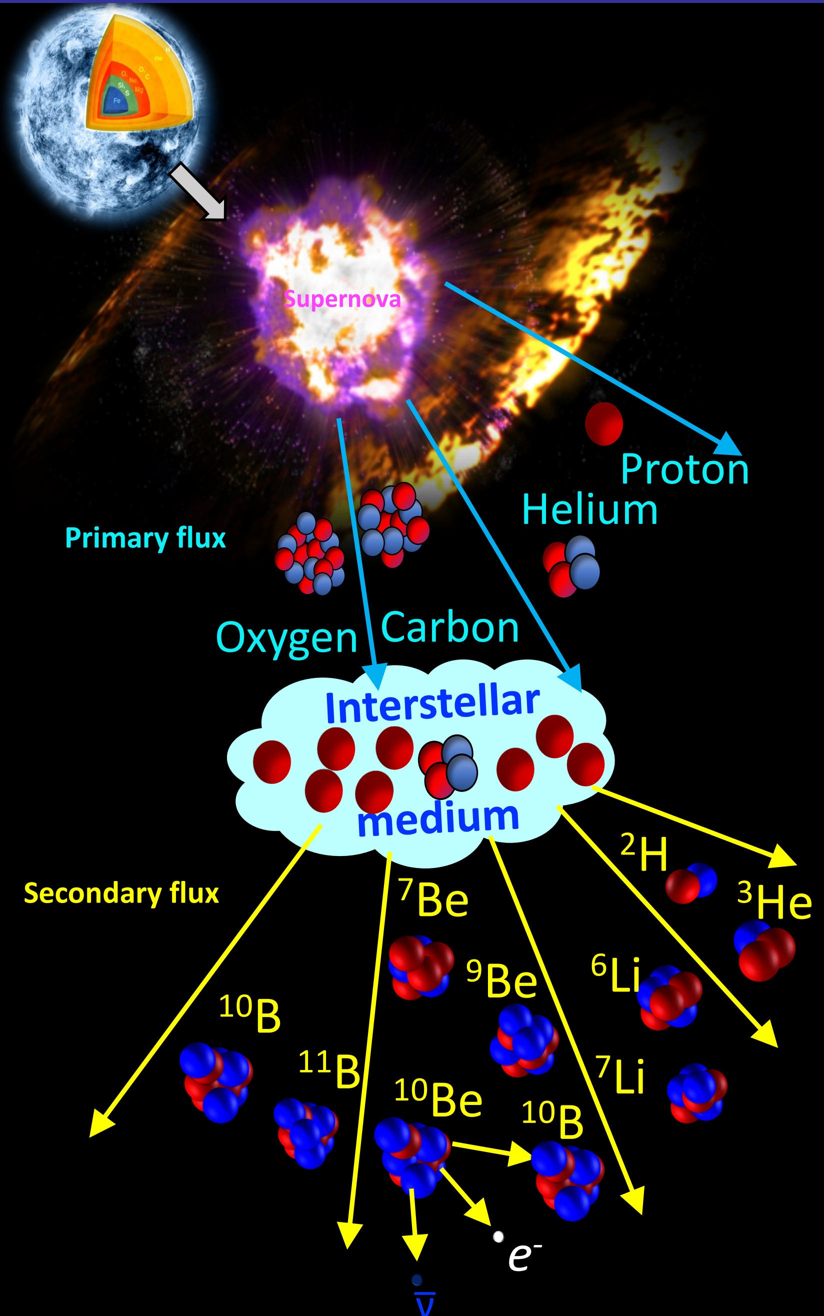
Abundance Ratio	Value at the Source
Φ_C / Φ_O	0.836 ± 0.025
Φ_{Ne} / Φ_{Si}	0.833 ± 0.025
Φ_{Mg} / Φ_{Si}	0.994 ± 0.029
Φ_S / Φ_{Si}	0.167 ± 0.006
Φ_N / Φ_O	0.092 ± 0.002
Φ_{Na} / Φ_{Si}	0.036 ± 0.003
Φ_{Al} / Φ_{Si}	0.103 ± 0.004

Cosmic Ray Nuclei by 2030

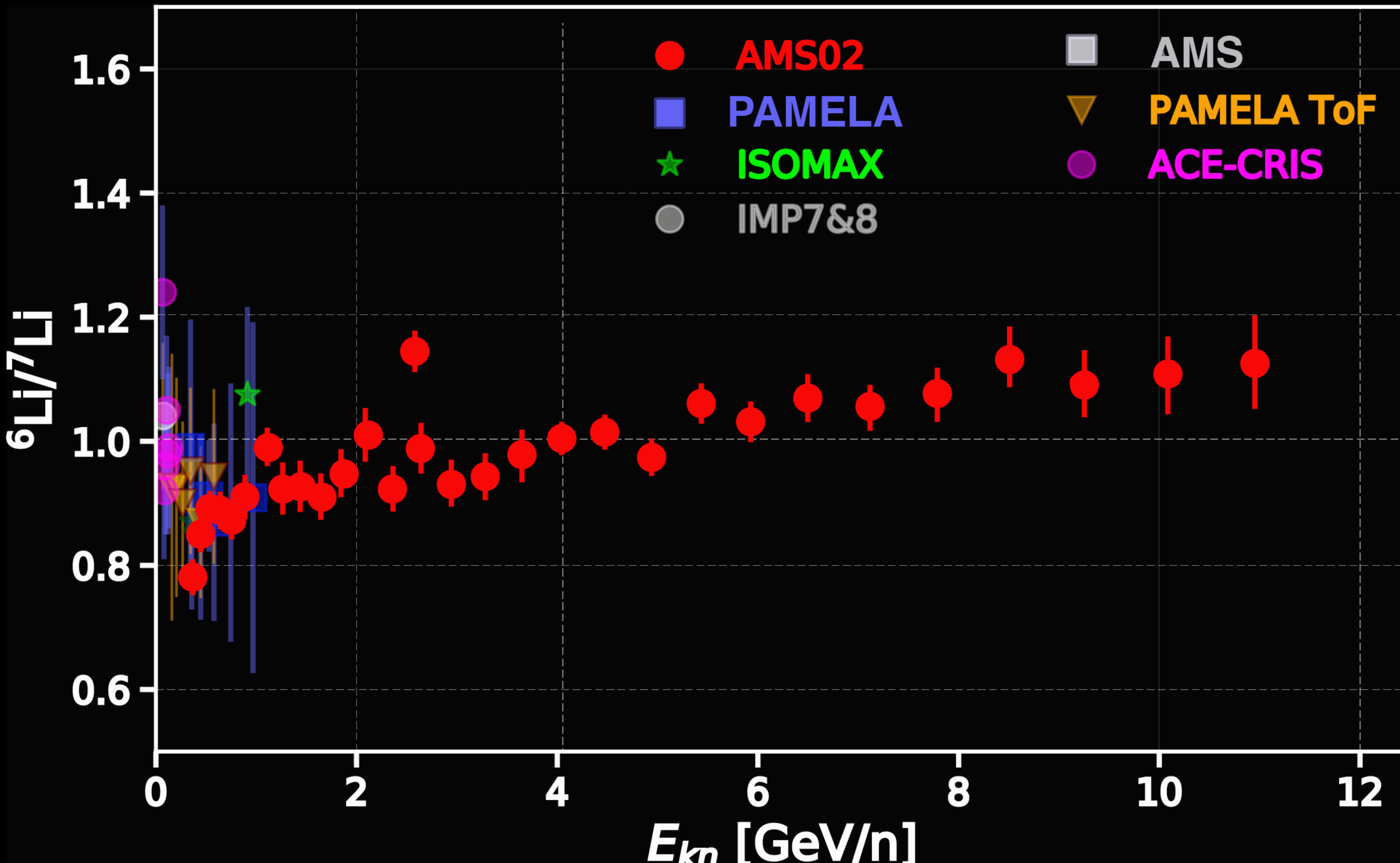
AMS will provide complete and accurate spectra for the
29 elements and provide the foundation for a comprehensive theory of cosmic rays.



Latest AMS Results on Cosmic Isotopes



Lithium Isotopes



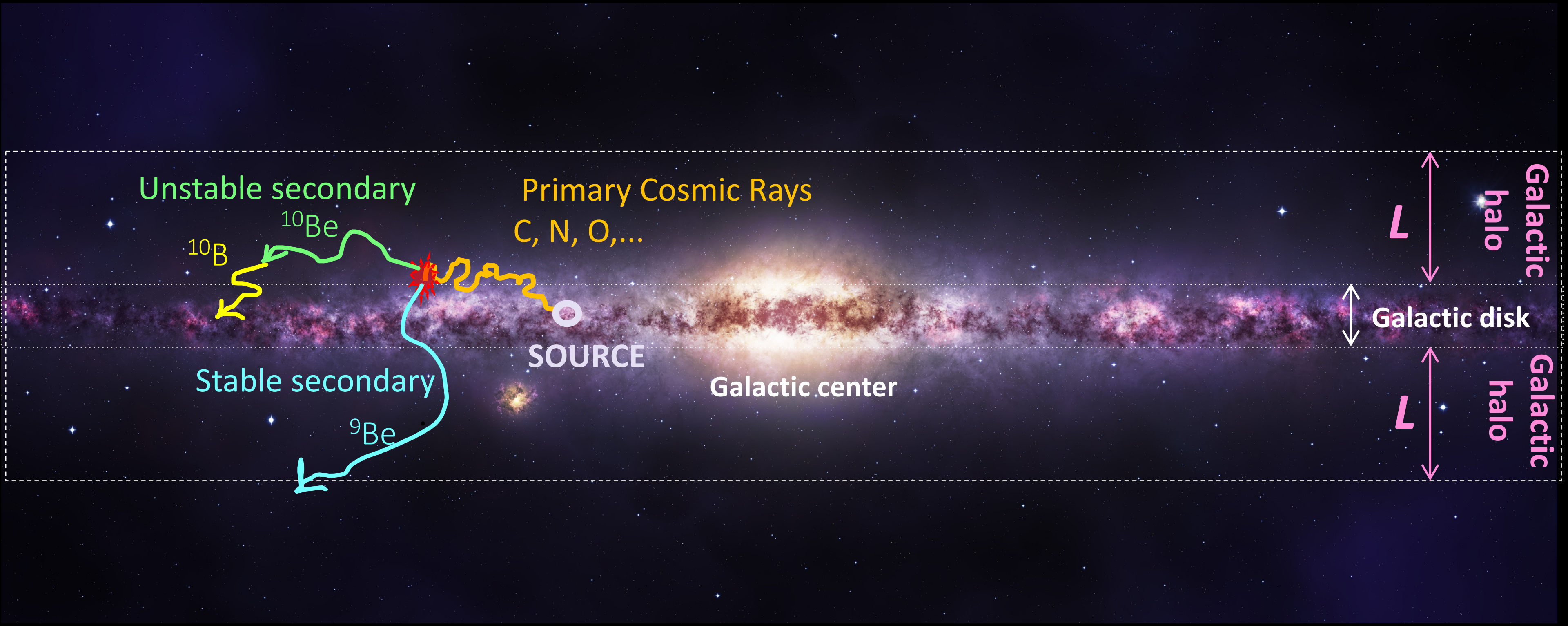
Boschini et al. (ApJ **889**, 167, 2020) predicted primary ^{7}Li from a new mechanism so that, from 5 – 20 GeV/n, ^{6}Li/^{7}Li = 0.6 ± 0.1.

No detectable primary ^{7}Li component.

Be Isotopes

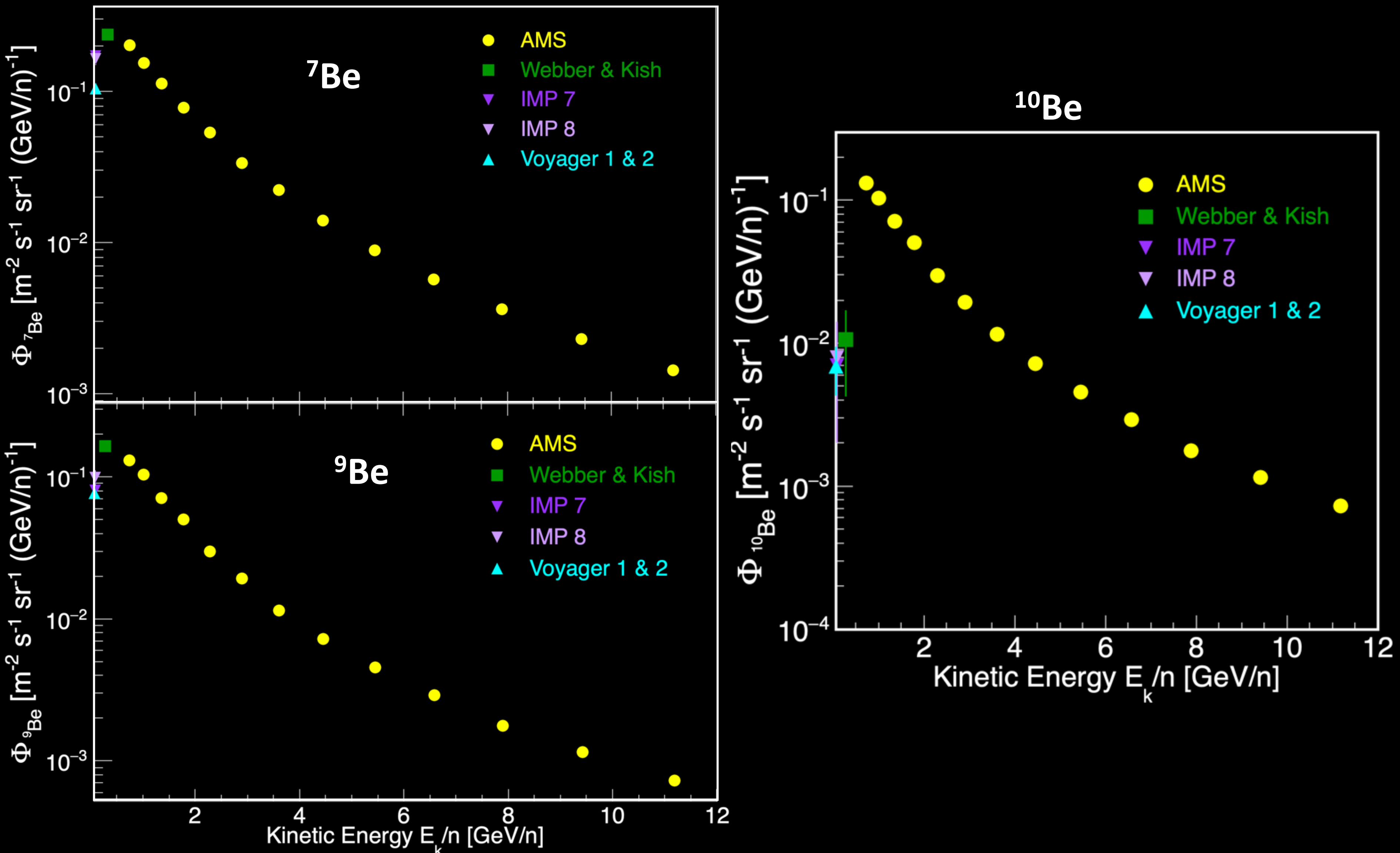
Beryllium nuclei have three isotopes, ^{7}Be, ^{9}Be, and ^{10}Be.

Stable ^{9}Be propagate in the entire galactic halo
while ^{10}Be decay to ^{10}B before reaching the boundary of the Galaxy.

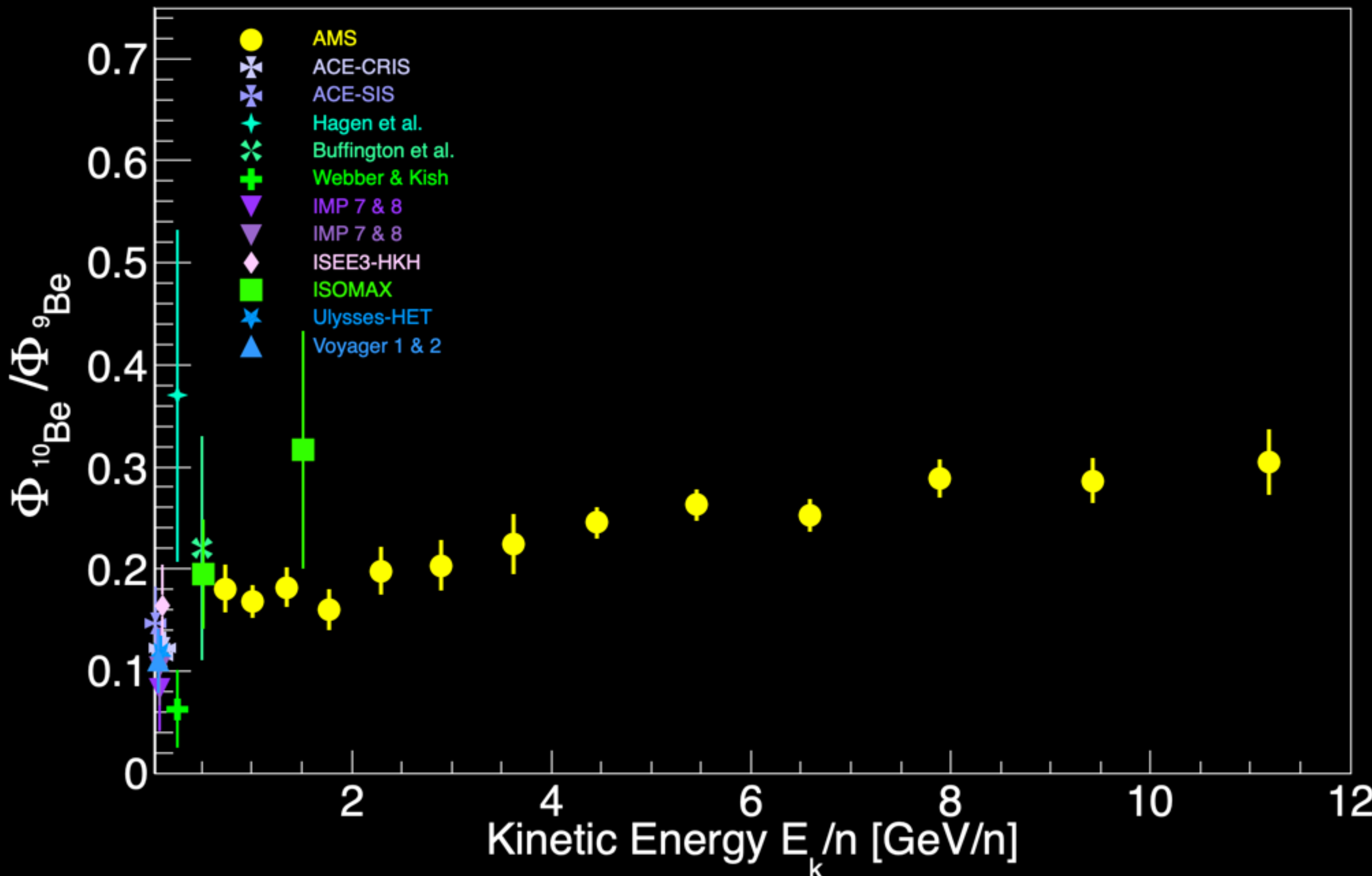


The ratio of unstable-to-stable, $^{10}Be/^{9}Be$, measures the Galactic halo size ***L***
L determines the galactic cosmic ray propagation (or diffusion) volume .

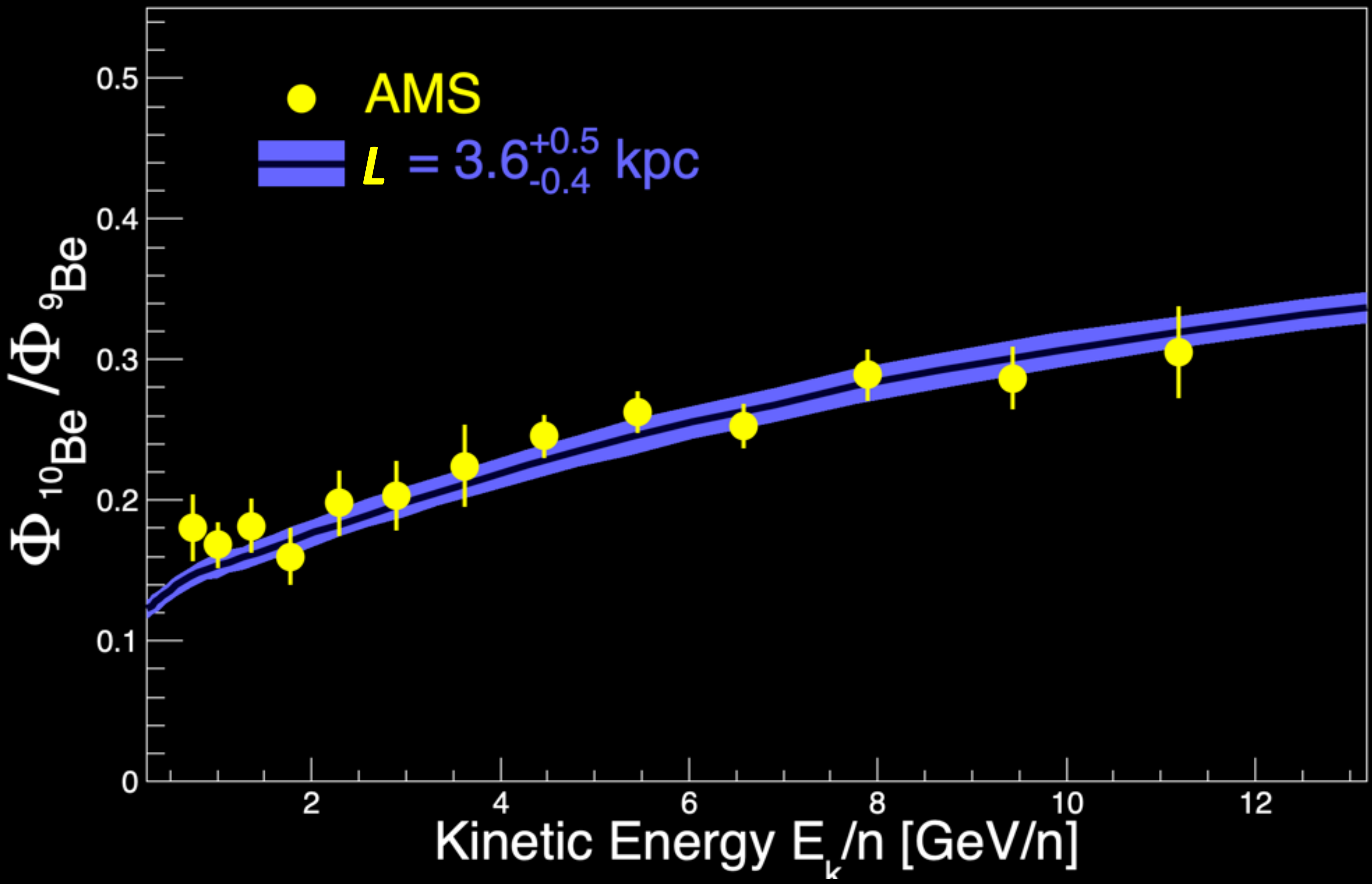
AMS Results on Beryllium isotopes



Latest AMS Results on the $^{10}Be/^{9}Be$ ratio



Measurement of the galactic halo size *L*



The model that fits the AMS measurement has a halo size ***L*** of $3.6^{+0.5}_{-0.4}$ kiloparsecs

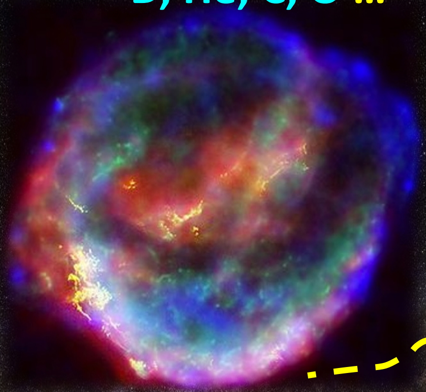
Latest AMS Results on Heavy Antimatter

Matter is defined by its mass *M* and charge *Z*.

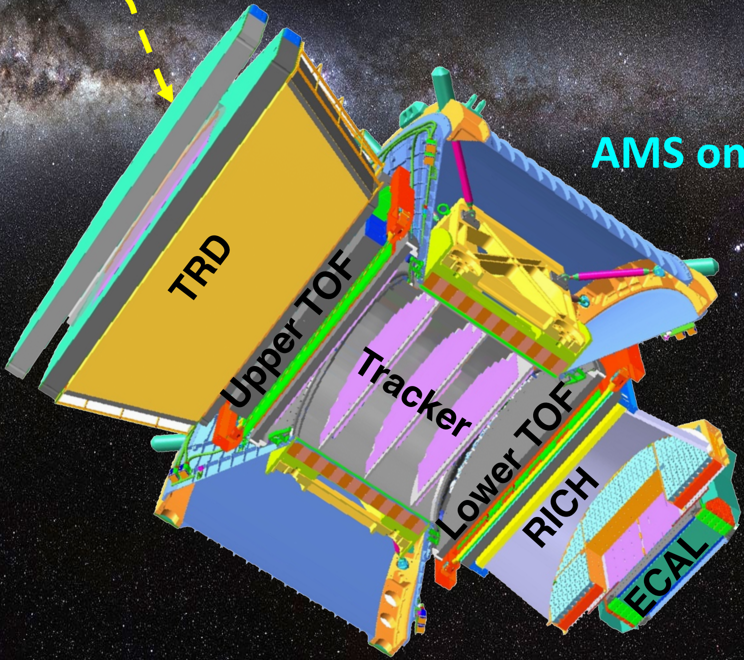
Antimatter has the same mass *M* but opposite charge *–Z*.

$\overline{\mathrm{D}}$, $\overline{\mathrm{He}}$, $\overline{\mathrm{C}}$, $\overline{\mathrm{O}}$ …

Antimatter Star

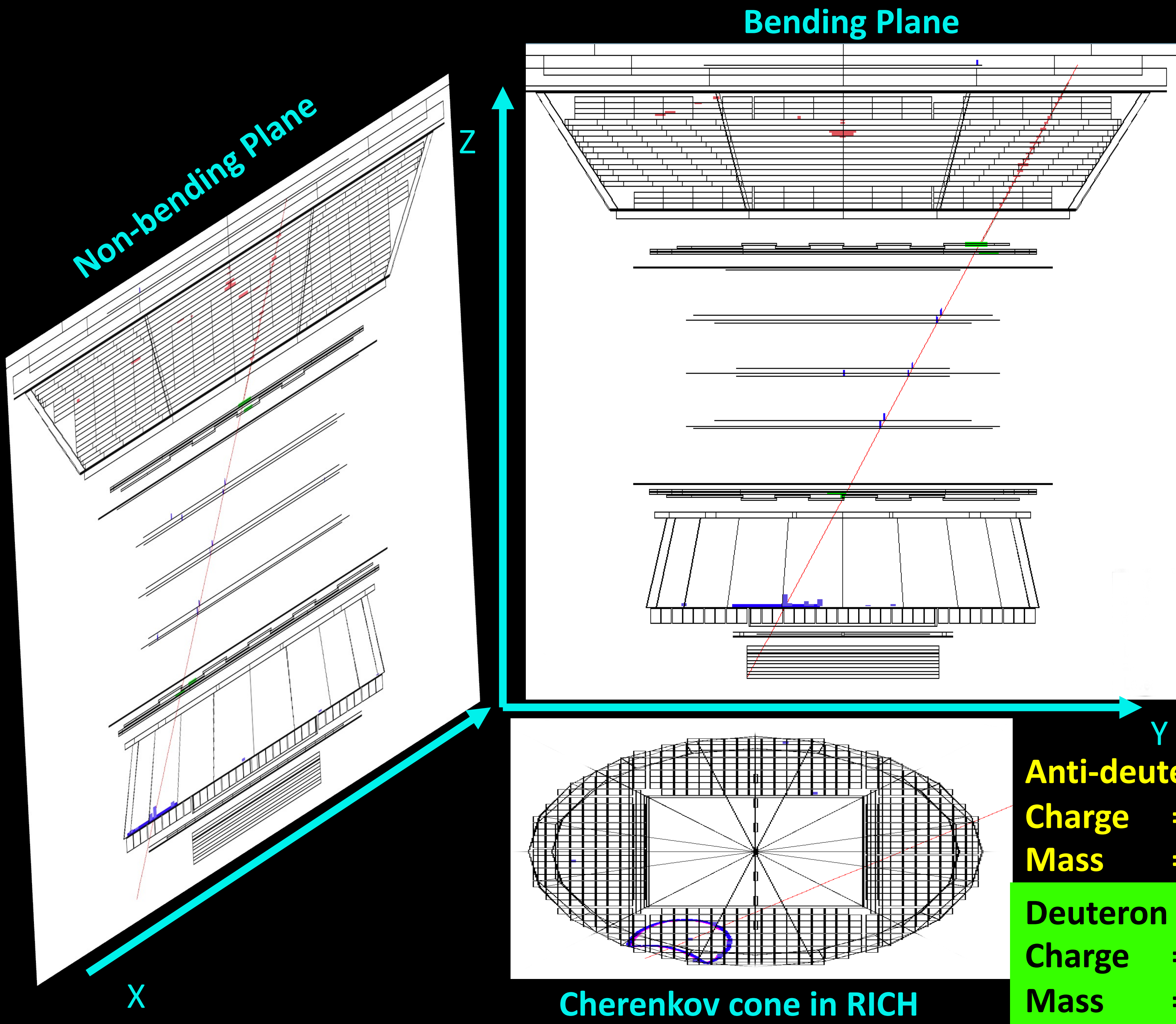


AMS on ISS



AMS is a unique antimatter spectrometer in space

An Anti-Deuteron Candidate from ~100 million deuterons and ~10 billion protons



Anti-deuteron Candidate

Charge = -1.02 ± 0.05

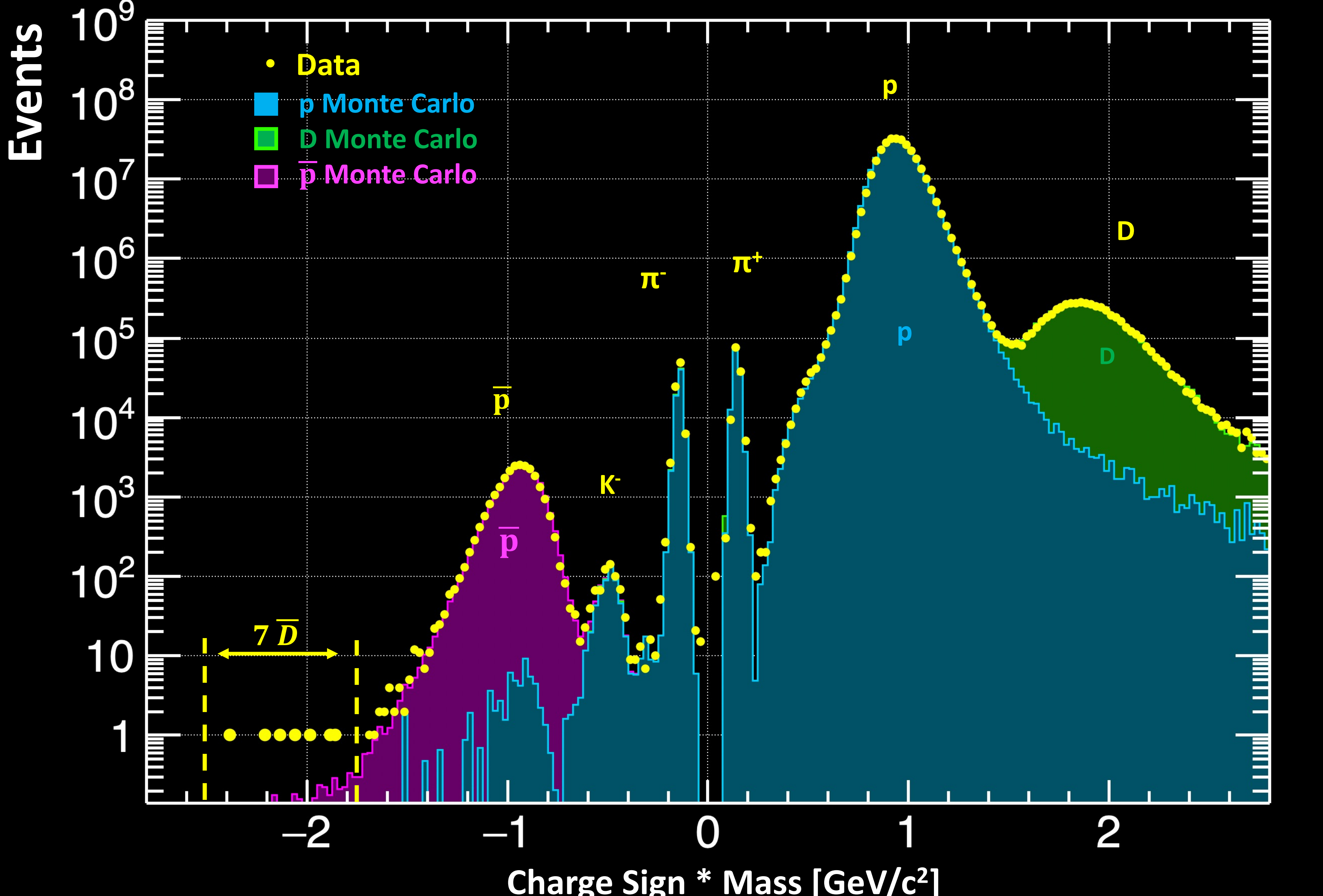
Mass = 1.9 ± 0.1 GeV/c^2

Deuteron

Charge = +1

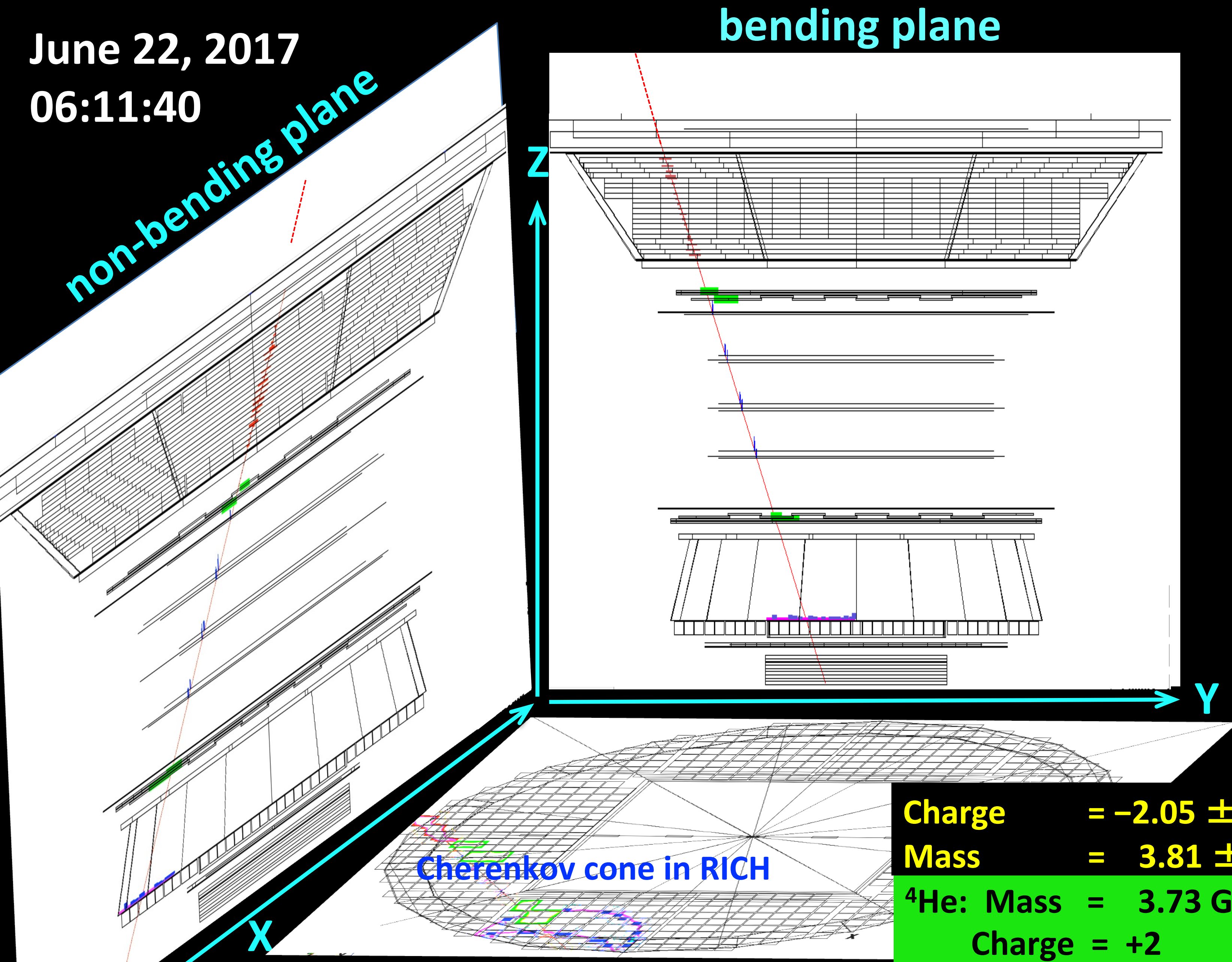
Mass = 1.88 GeV/c^2

Current AMS Anti-Deuteron Results



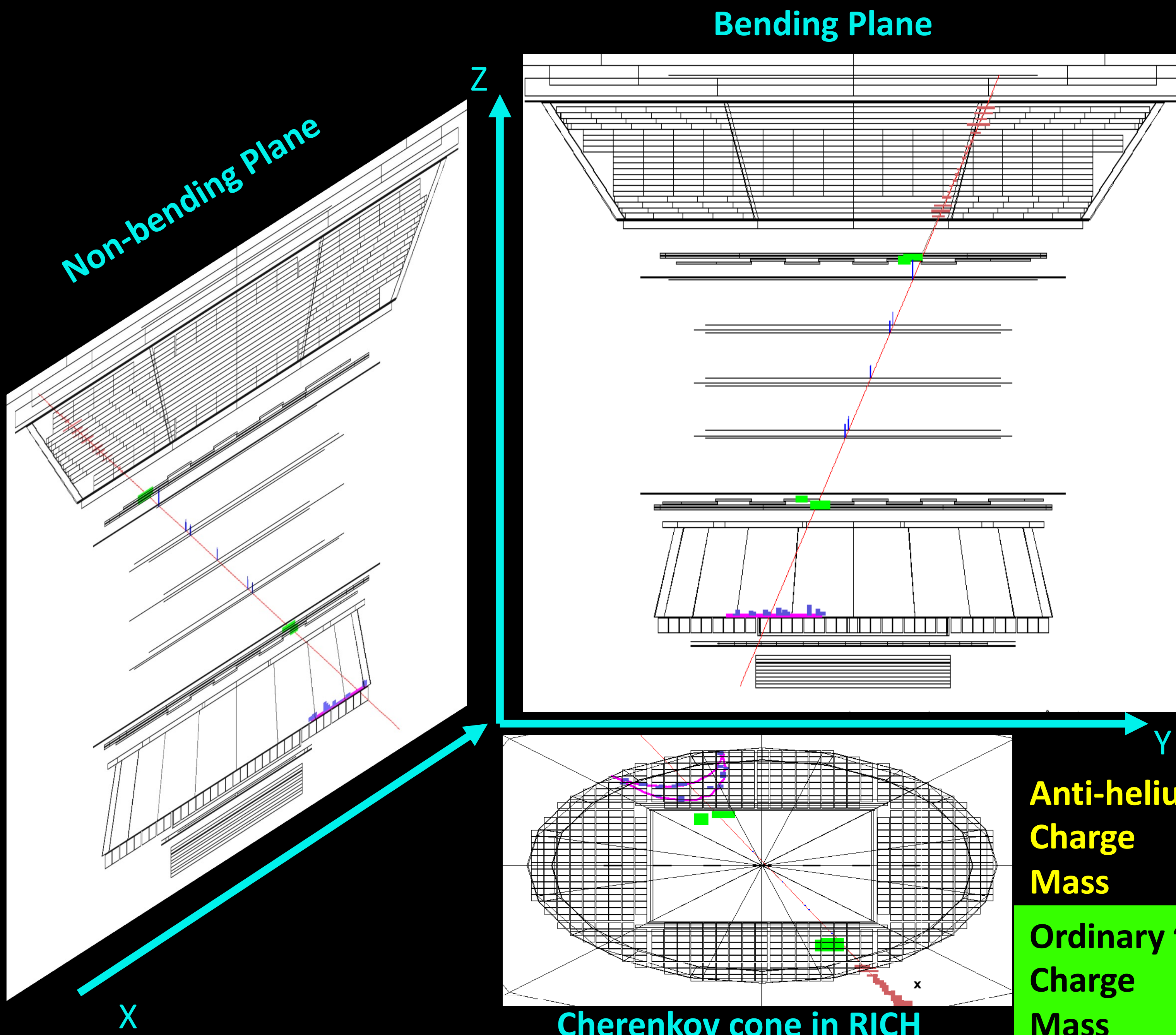
Anti-^{4}Helium Event

June 22, 2017
06:11:40



Charge	$= -2.05 \pm 0.05$
Mass	$= 3.81 \pm 0.29$ GeV/c^2
^{4}He: Mass	$= 3.73$ GeV/c^2
Charge	$= +2$

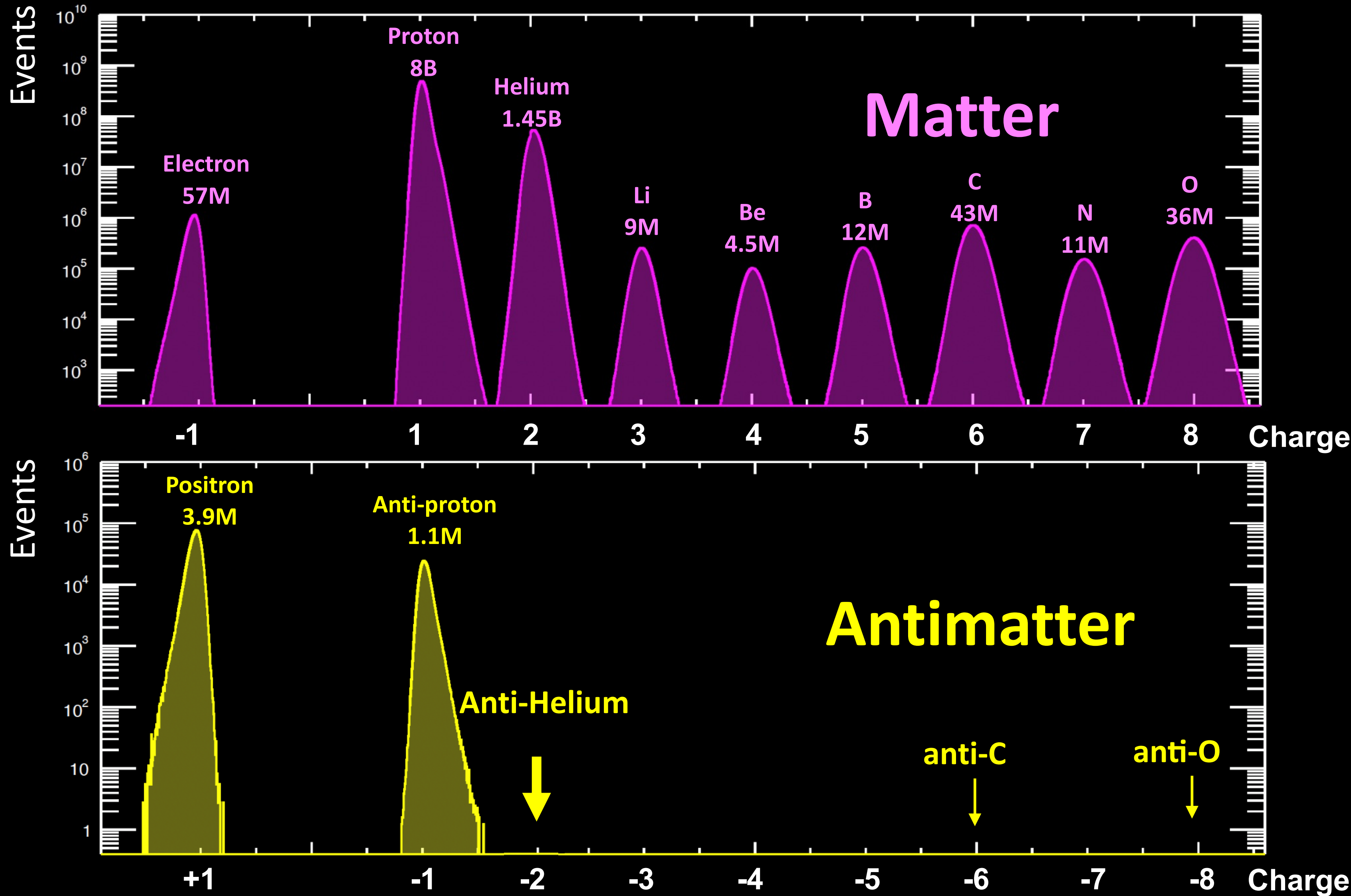
Another Anti-Helium Event (Sept. 20, 2022)



Anti-helium Candidate
Charge = -2
Mass = 3.15±0.53

Ordinary ^{4}He
Charge = +2
Mass = 3.73 *GeV/c²*

Current Matter and Antimatter Statistics



By 2030, AMS will have additional measurement points in the study of antimatter: anti-deuterons, anti-helium, anti-carbon and anti-oxygen.

Scientific American, May 2011

PHYSICS

The Space Station's Crown Jewel

A fancy cosmic-ray detector, the Alpha Magnetic Spectrometer, is about to scan the cosmos for dark matter, antimatter and more

By George Musser, staff editor

THE WORLD'S MOST ADVANCED COSMIC-RAY DETECTOR TOOK 16 YEARS AND $2 billion to build, and not long ago it looked as though it would wind up mothballed in some warehouse. NASA, directed to finish building the space station and retire the space shuttle by the end of 2010, said it simply did not have room in its schedule to launch the instrument anymore. Saving it took a lobbying campaign by physicists and intervention by Congress to extend the shuttle program. And so the shuttle *Endeavour* is scheduled to take off on April 19 for the express purpose of delivering the Alpha Magnetic Spectrometer (AMS) to the International Space Station.

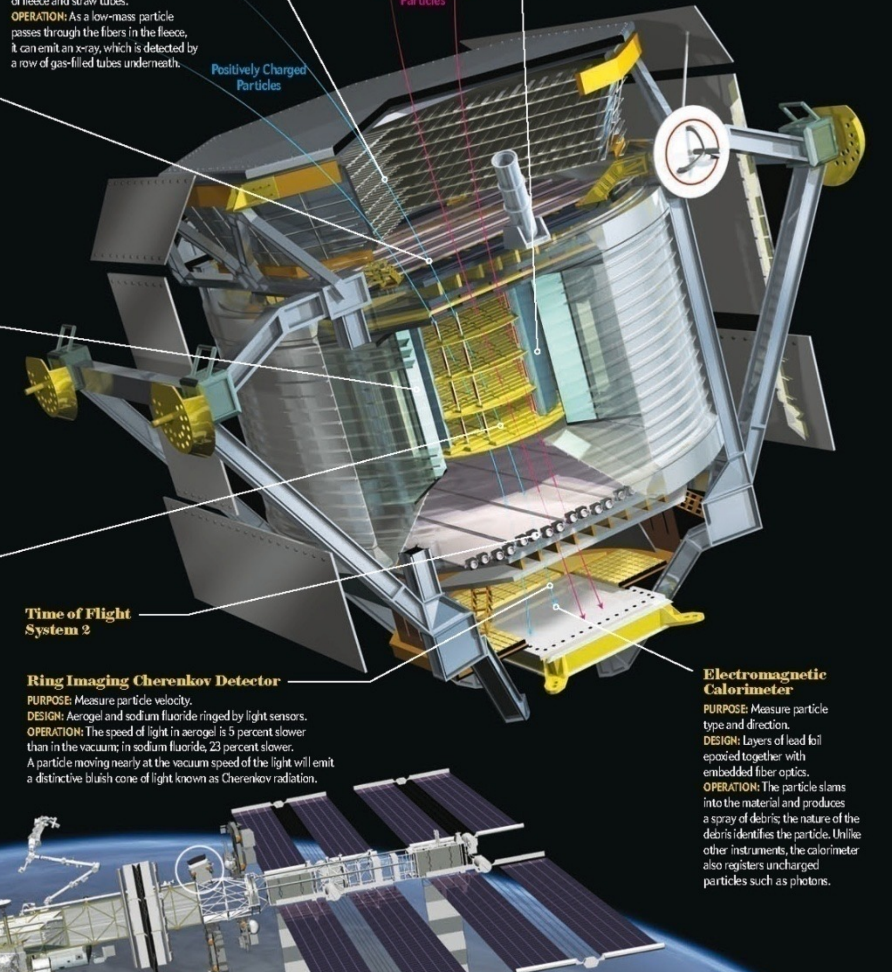
Cosmic rays are subatomic particles and atomic nuclei that zip and zap through space, coming from ordinary stars, supernovae explosions, neutron stars, black holes and who knows what—the last category naturally being of greatest interest and the main impetus for a brand-new instrument. Dark matter is one of those possible mystery sources. Clumps of the stuff out in space might occasionally release blazes of particles that would set the detectors alight. Some physicists also speculate that our planet might be peppered with the odd antiatom coming from distant galaxies made not of matter but of its evil antitwin.

The spectrometer's claim to fame is that it can tell the ordinary from the extraordinary, which otherwise are easily conflated. No other instrument has the combination of detectors that can tease out all the properties of a particle: mass, velocity, type, electric charge. Its closest predecessor is the PAMELA instrument, launched by a European consortium in 2006. PAMELA has seen hints of dark matter and other exotica, but its findings remain ambiguous because it lacks the ability to distinguish a low-mass antiparticle, such as a positron, from a high-mass ordinary particle with the same electric charge, such as a proton.

The AMS instrument is a monster by the standards of the space program, with a mass of seven metric tons (more than 14 times heavier than PAMELA) and a power consumption of 2,400 watts. In a strange symbiotic way, it and the space station have come to justify each other's existence. The station satisfies the instrument's thirst for power and orbital reboosts; the spectrometer, although it could never fully placate the station's many skeptics, at least means the outpost will do world-class research. As CERN's Large Hadron Collider plumbs the depths of nature on the ground, the Alpha Magnetic Spectrometer will do the same from orbit.

SOURCE FOR ISS MODEL: NASA

SCIENTIFIC AMERICAN ONLINE
For more information on how the Alpha Magnetic Spectrometer works, visit ScientificAmerican.com/may2011/ams



In twelve years on the ISS, AMS has recorded more than 220 billion cosmic rays. The accuracy and characteristics of the data simultaneously from many different types of cosmic rays require the development of a new comprehensive model of the universe. AMS will continue to collect data to 2030 with an upgraded detector.