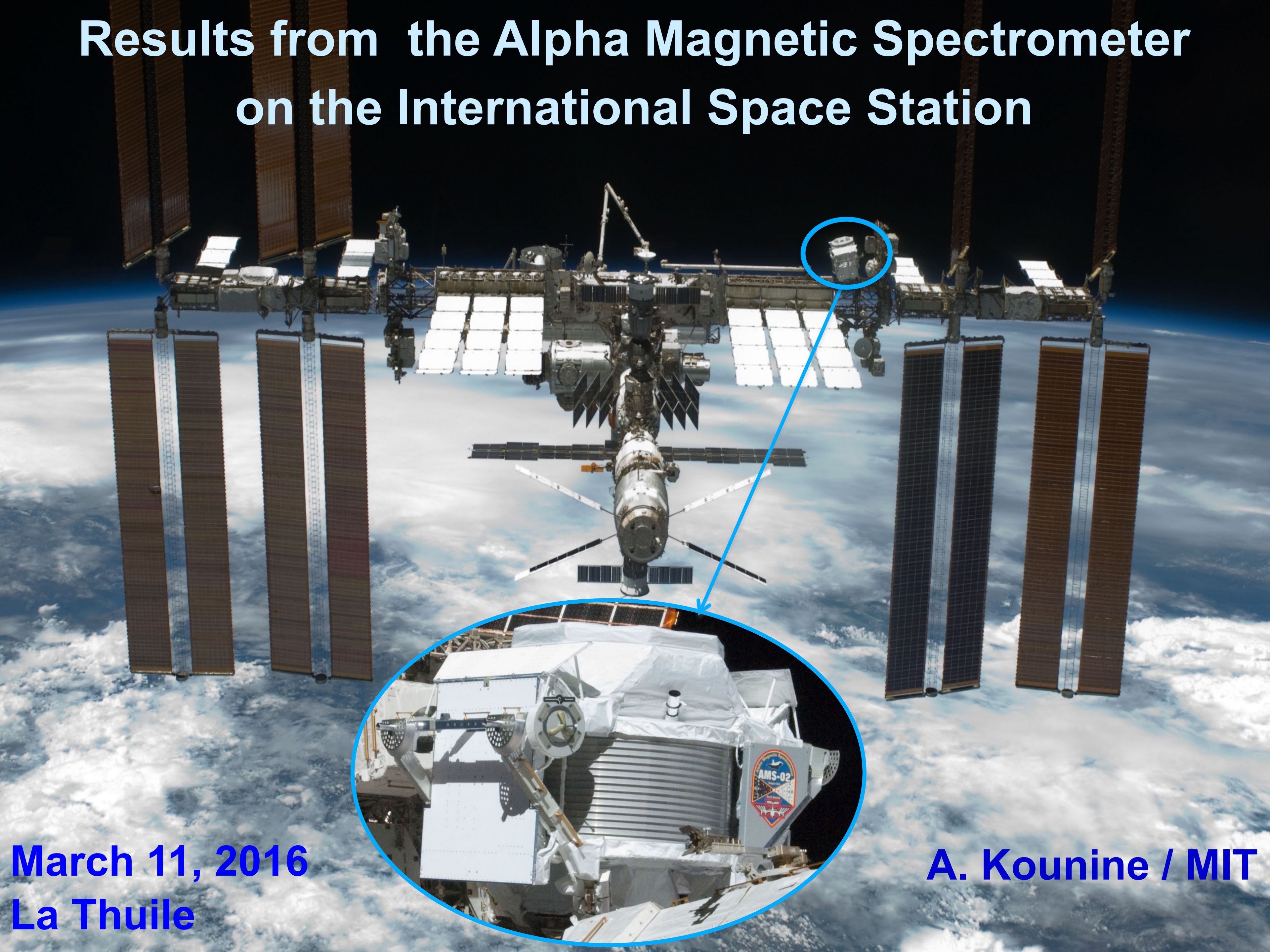
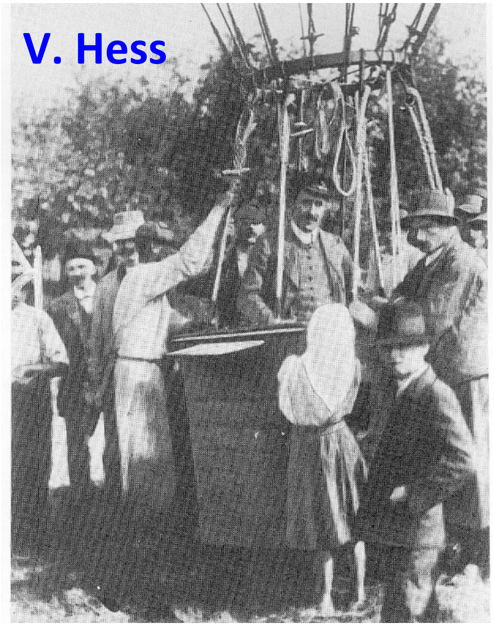
Results from the Alpha Magnetic Spectrometer on the International Space Station



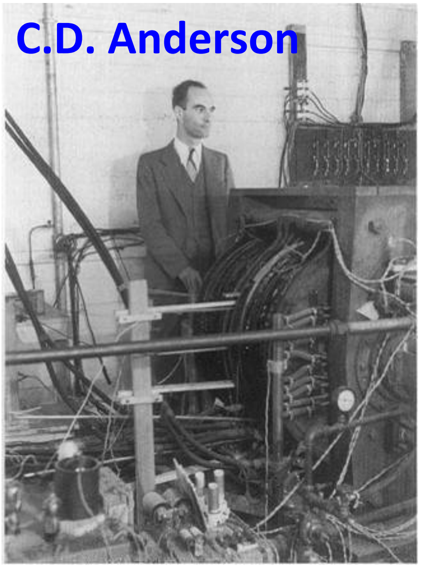
March 11, 2016
La Thuile

A. Kounine / MIT

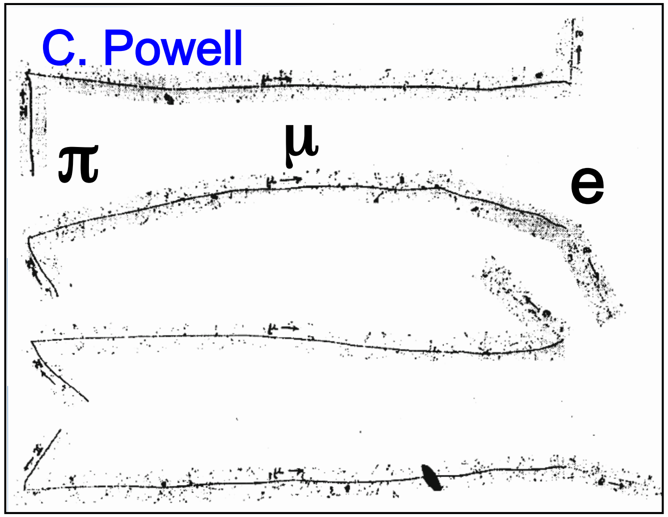
Physics of Charged Cosmic Rays



1912: Discovery of Cosmic Rays



1932: Discovery of positron



1947: Discovery of pions

Discoveries of

1936: Muon (μ)

1938: 10^{15} eV CR

1949: Kaon (K)

1949: Lambda (Λ)

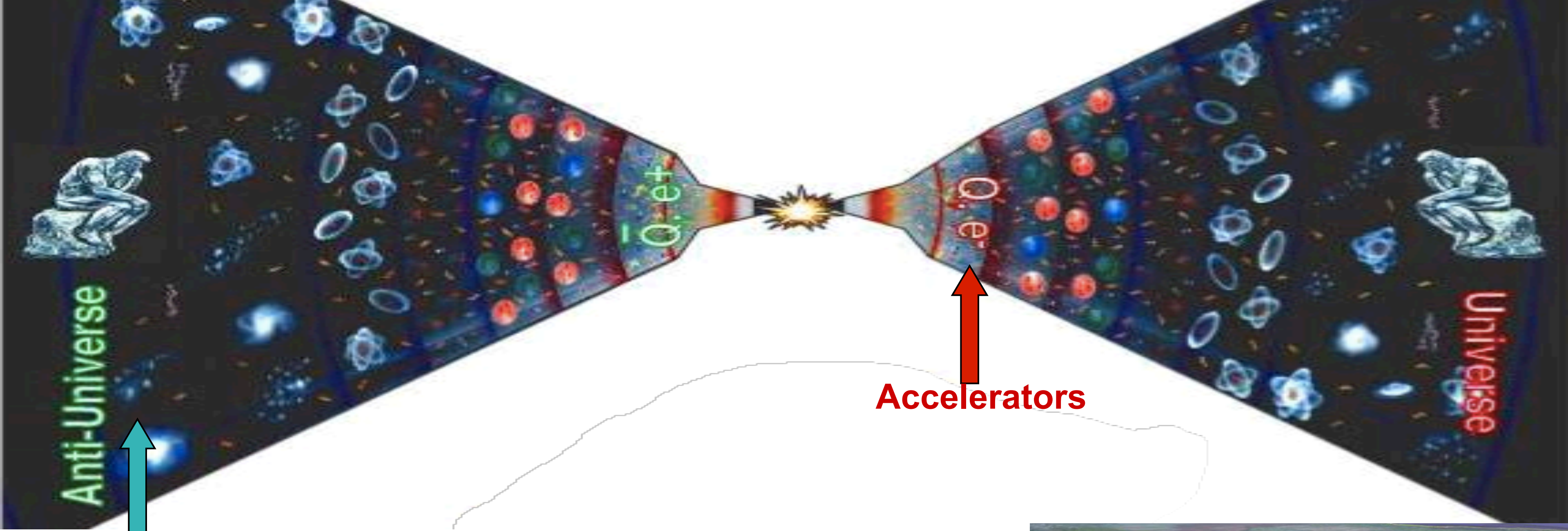
1952: Xi (Ξ)

1953: Sigma (Σ)

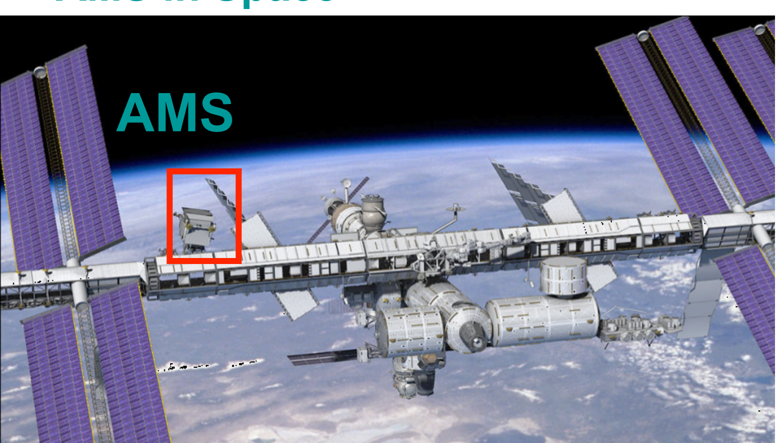
In almost 5 years, AMS has collected over 78 billion cosmic rays.
This is more than all the charged cosmic rays collected in the last 100 years.

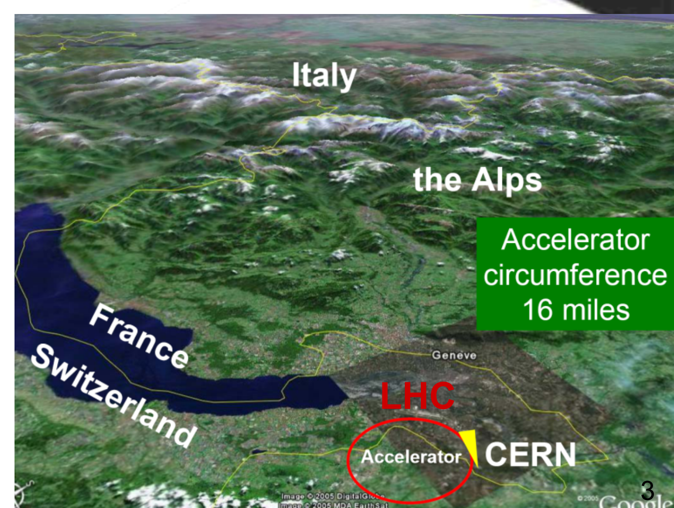
Search for the existence of Antimatter in the Universe

The Big Bang origin of the Universe assumes matter and antimatter are equally abundant at the very hot beginning



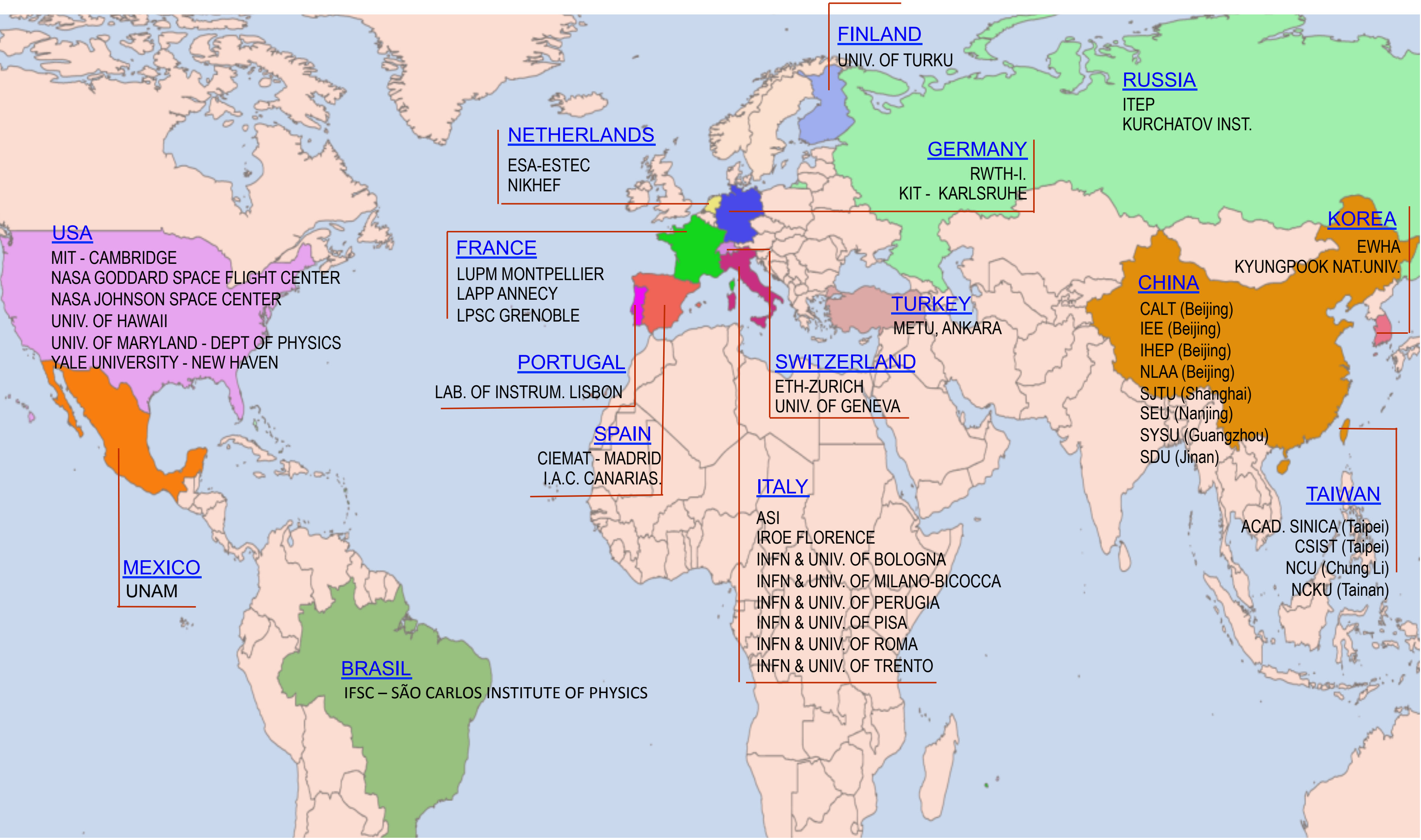
AMS in Space





AMS: a U.S. DOE sponsored International Collaboration
15 Countries, 46 Institutes and 600 Physicists

Strong support from CERN: assembly, testing and the Control Center

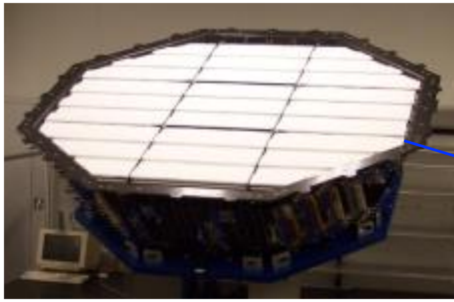


AMS also has the strong support of NASA, ASI, CNES, DLR, ESA, CALT, …

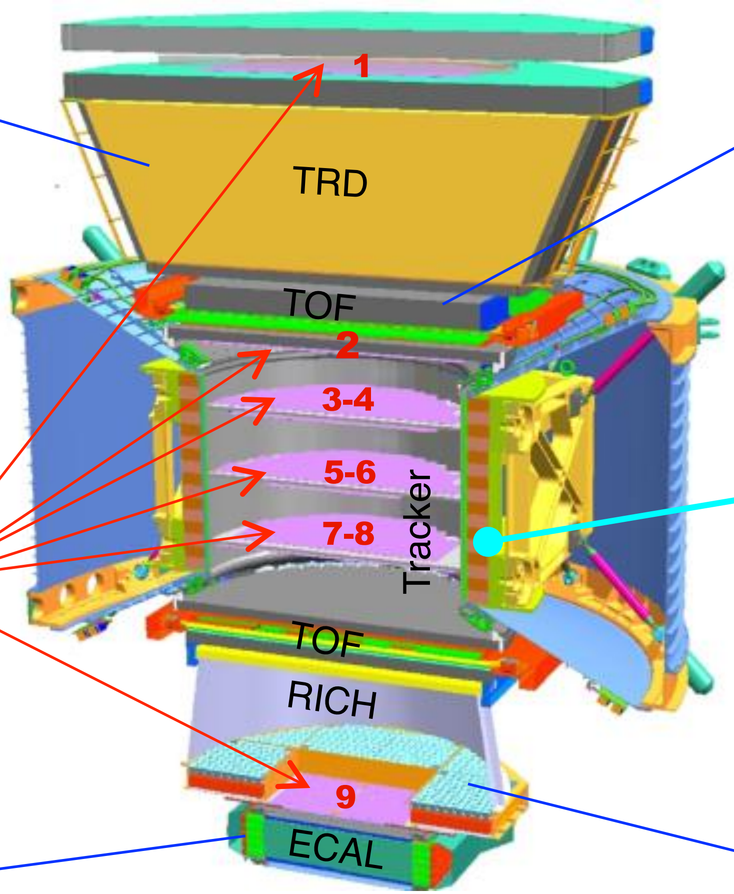

AMS
300,000 electronic channels
650 processors
5m x 4m x 3m
7.5 tons

AMS: A TeV precision, multipurpose spectrometer

Transition Radiation Detector
Identify e^+, e^-

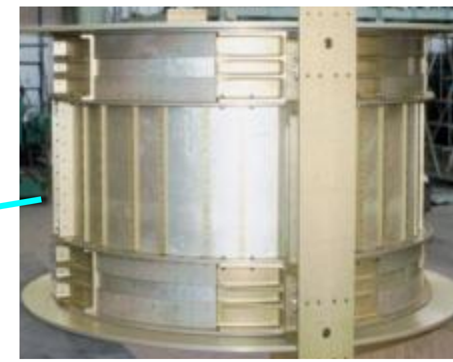


Particles and nuclei are defined by their charge (Z) and energy (E)

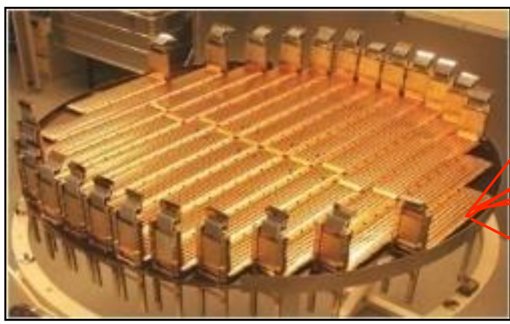


Time of Flight
Z, E

Magnet
±Z

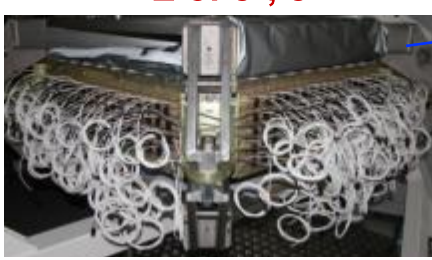


Silicon Tracker
Z, P



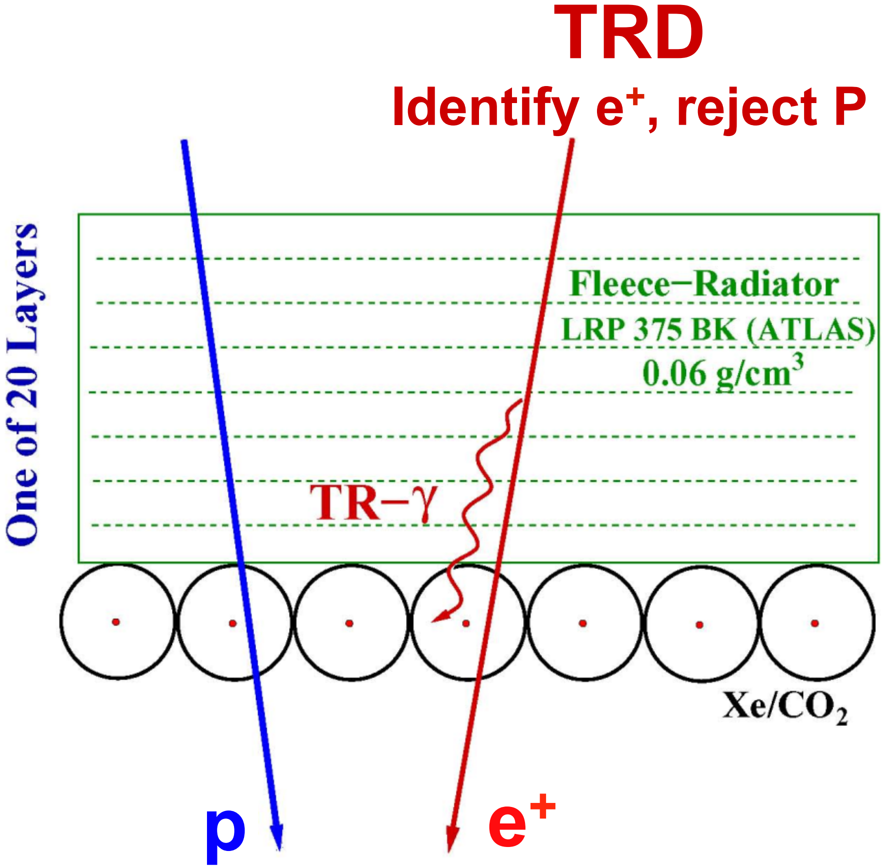
Ring Imaging Cherenkov
Z, E

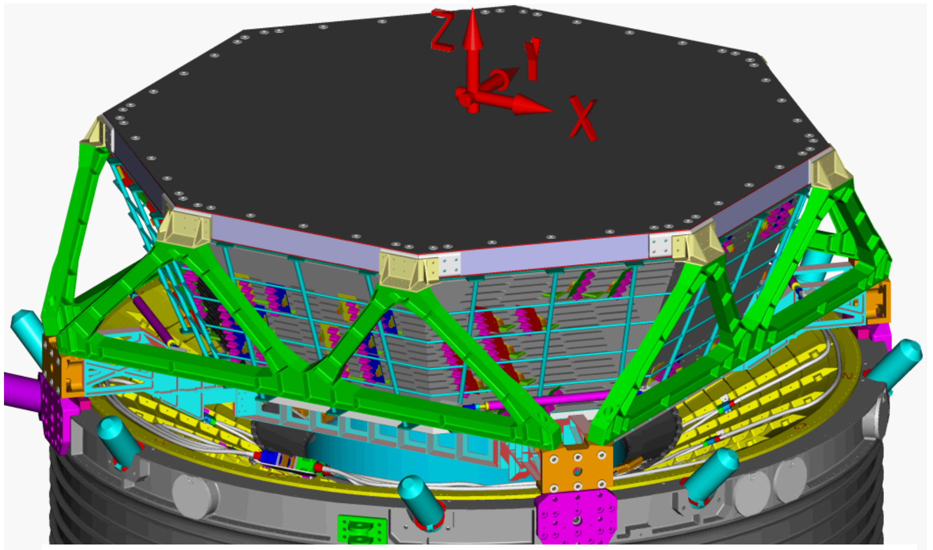
Electromagnetic Calorimeter
E of e^+, e^-

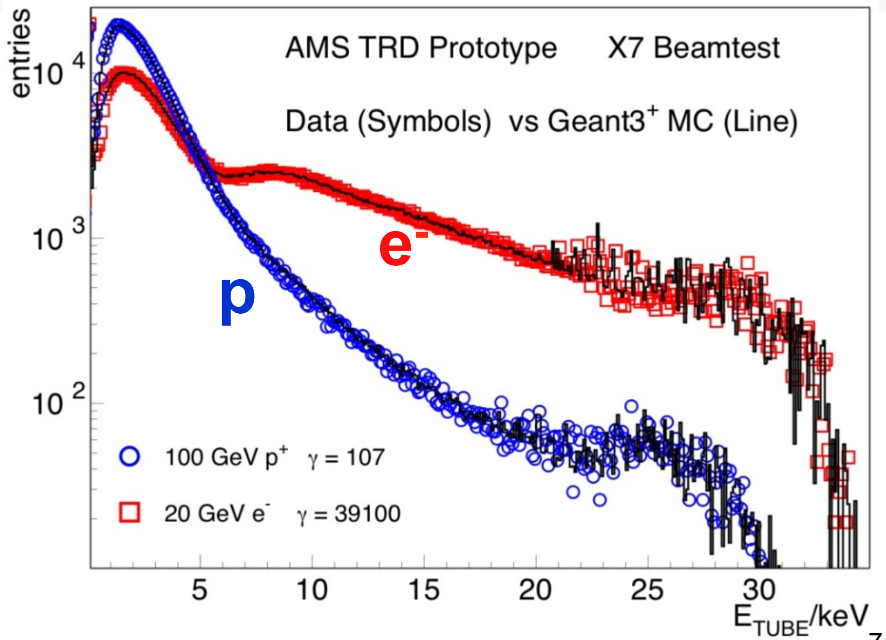


The Charge and Energy are measured independently by many detectors

Transition Radiation Detector:



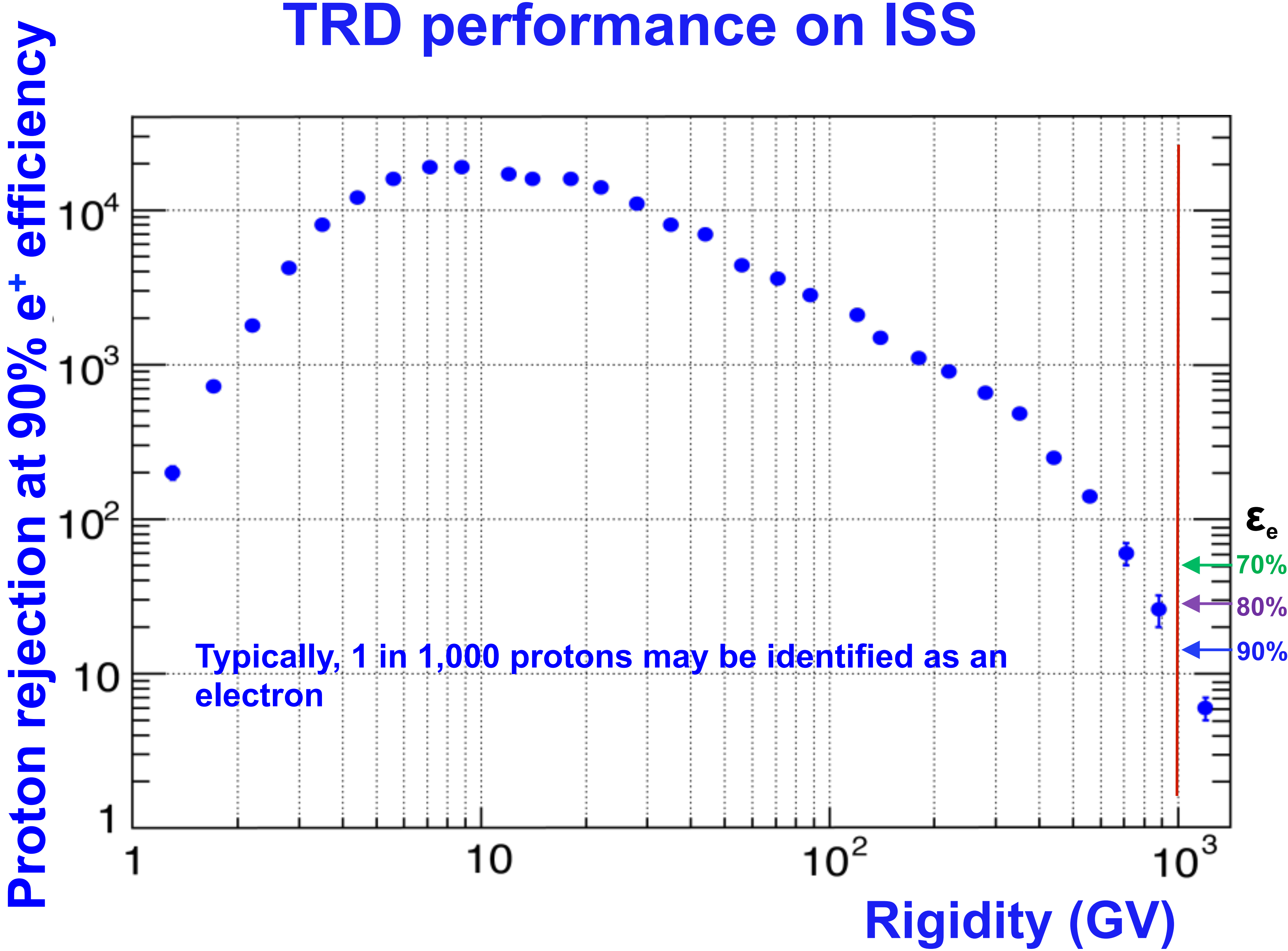




Leak rate: $CO_2 \approx 5\ \mu g/s$

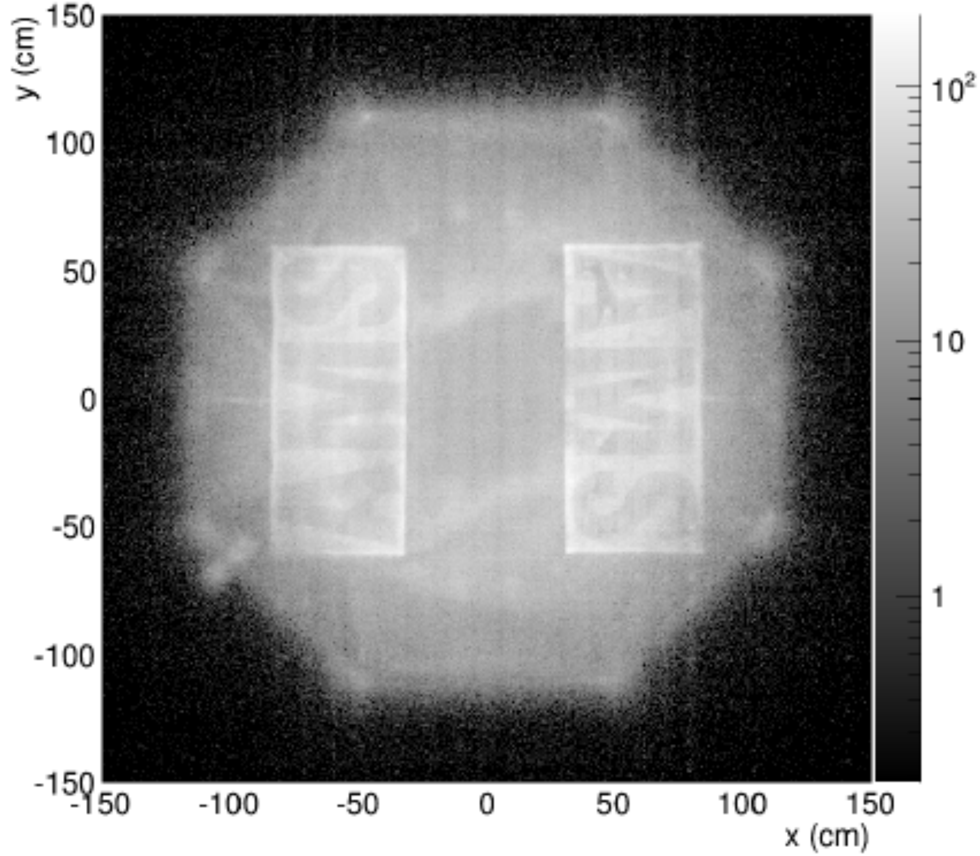
Storage: 5 kg, >20 years lifetime

TRD performance on ISS

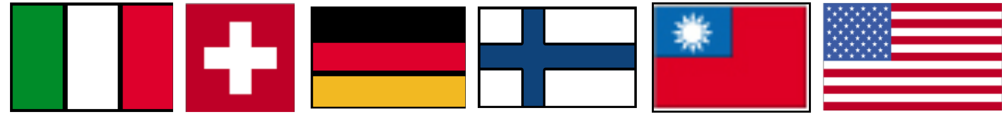


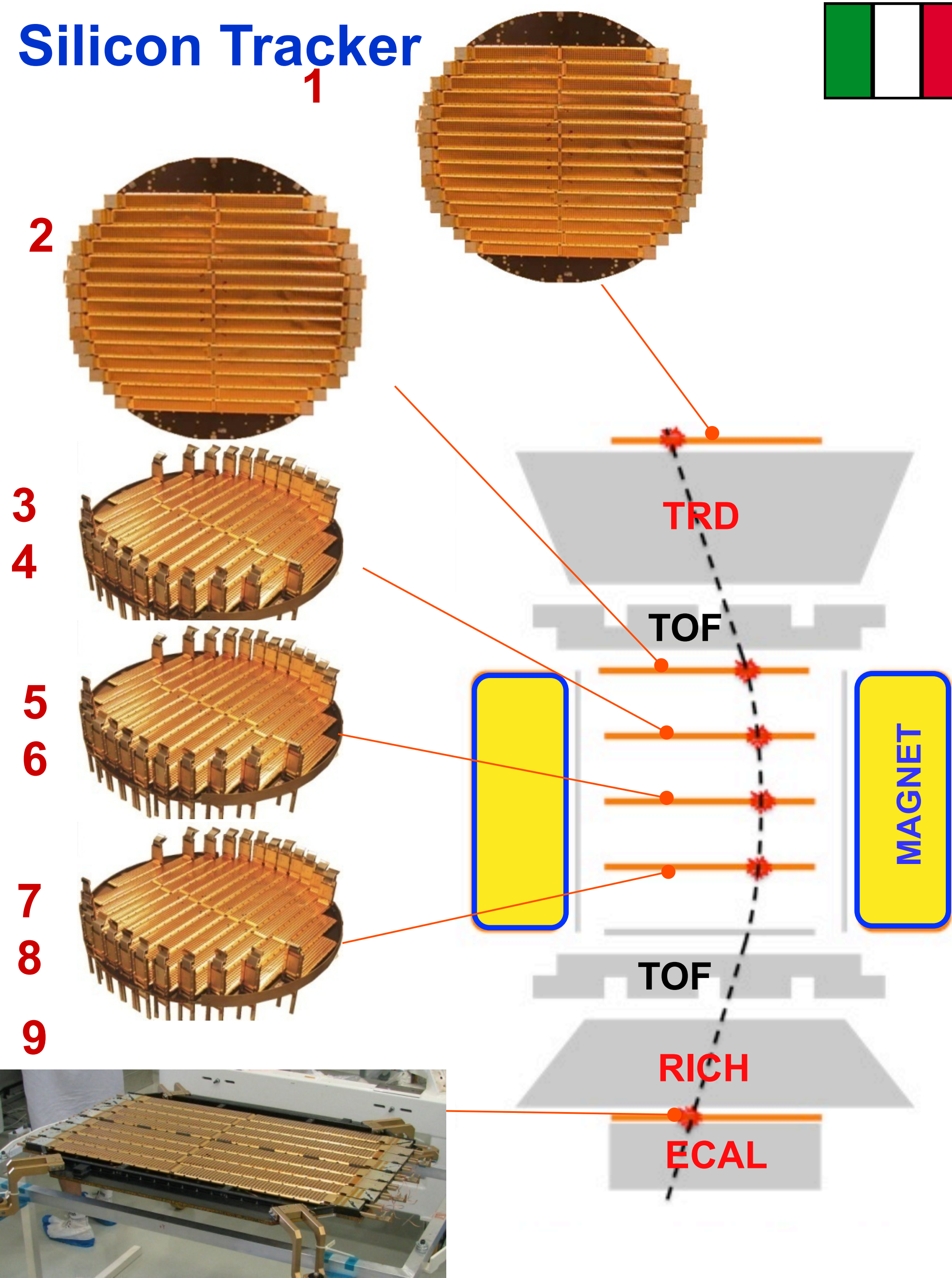
TRD performance on ISS: Tomography with vertices reconstructed in TRD

Z=178.5 cm

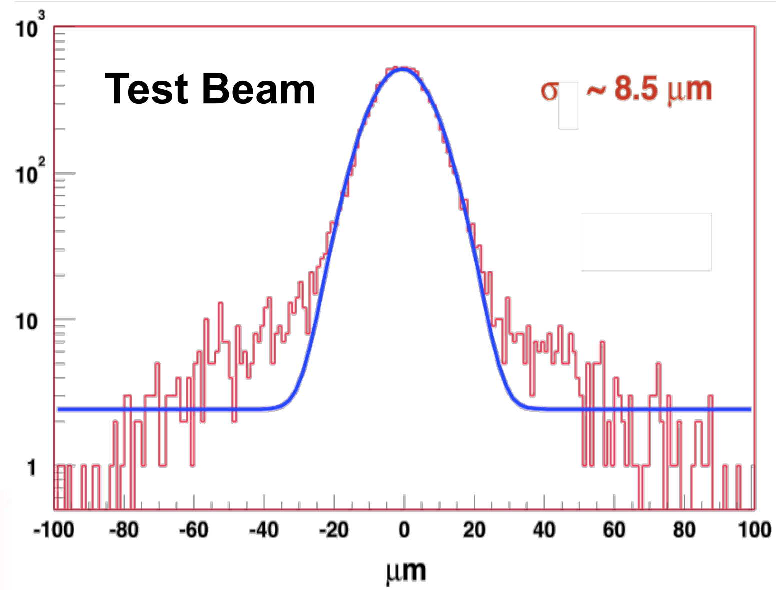


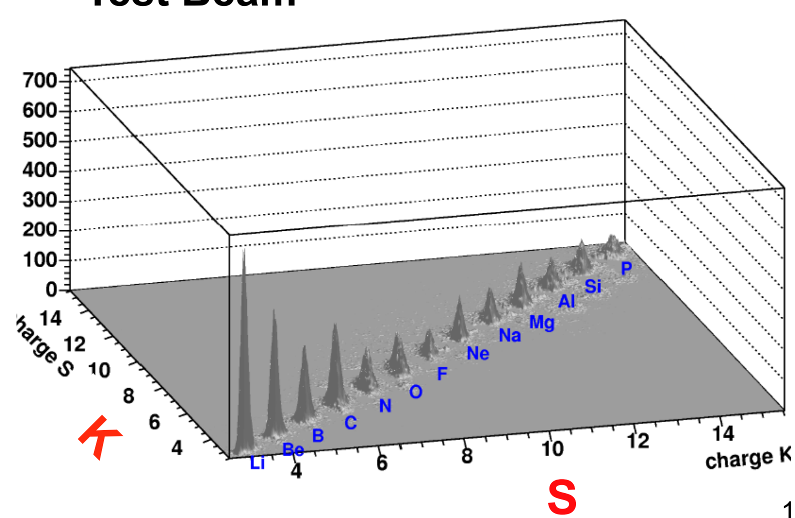
Silicon Tracker





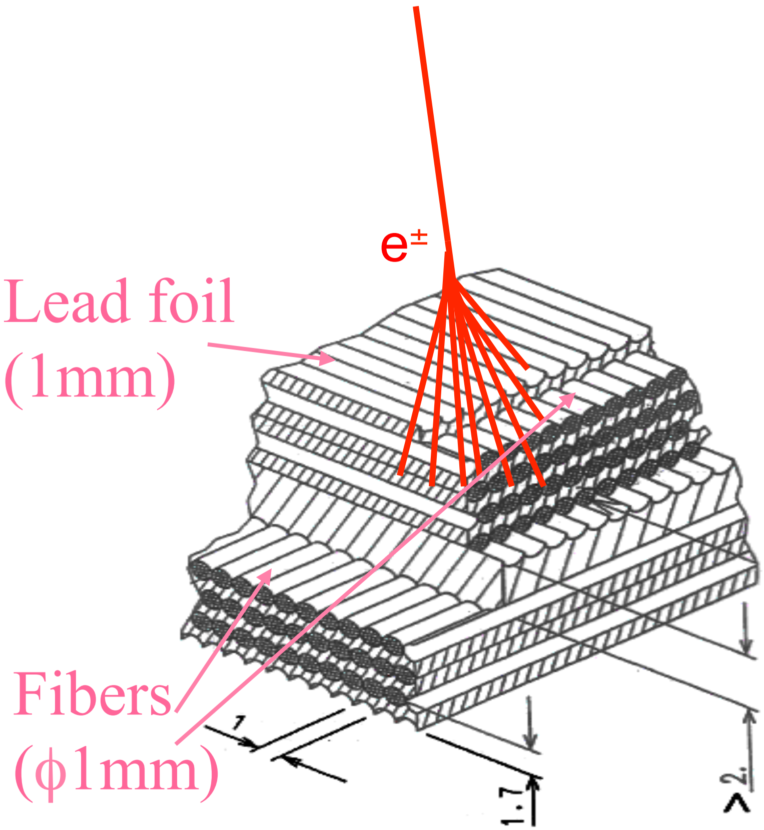
$MDR_P = 2.0$ TV
$MDR_{He} = 3.2$ TV

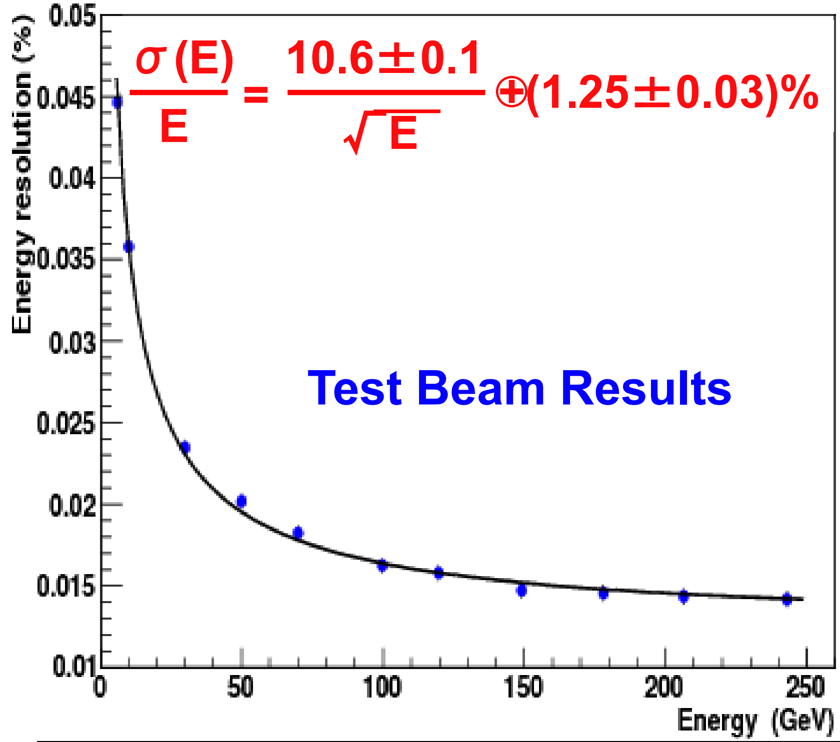


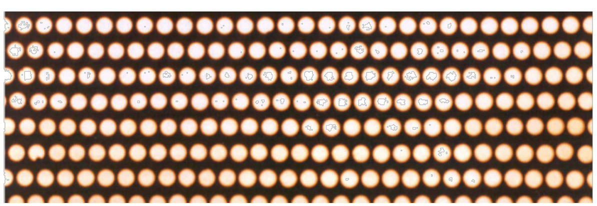


Calorimeter (ECAL)

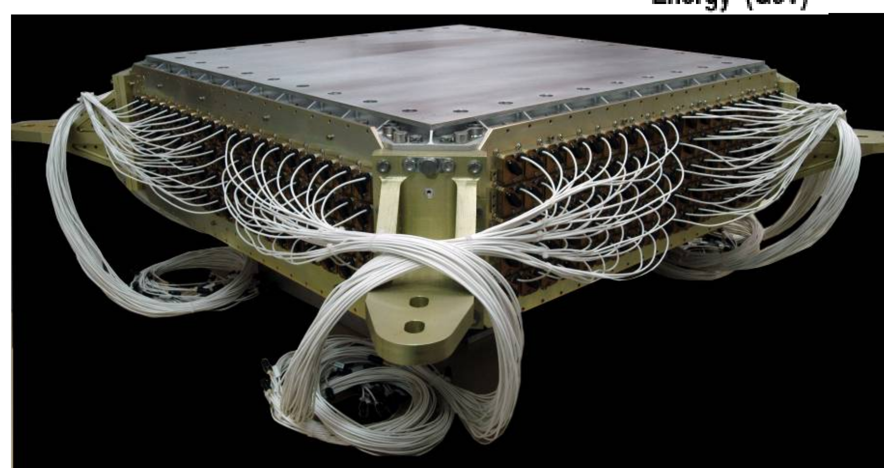
A precision, 17 X_0, TeV, 3-dimensional measurement of the directions and energies of light rays and electrons



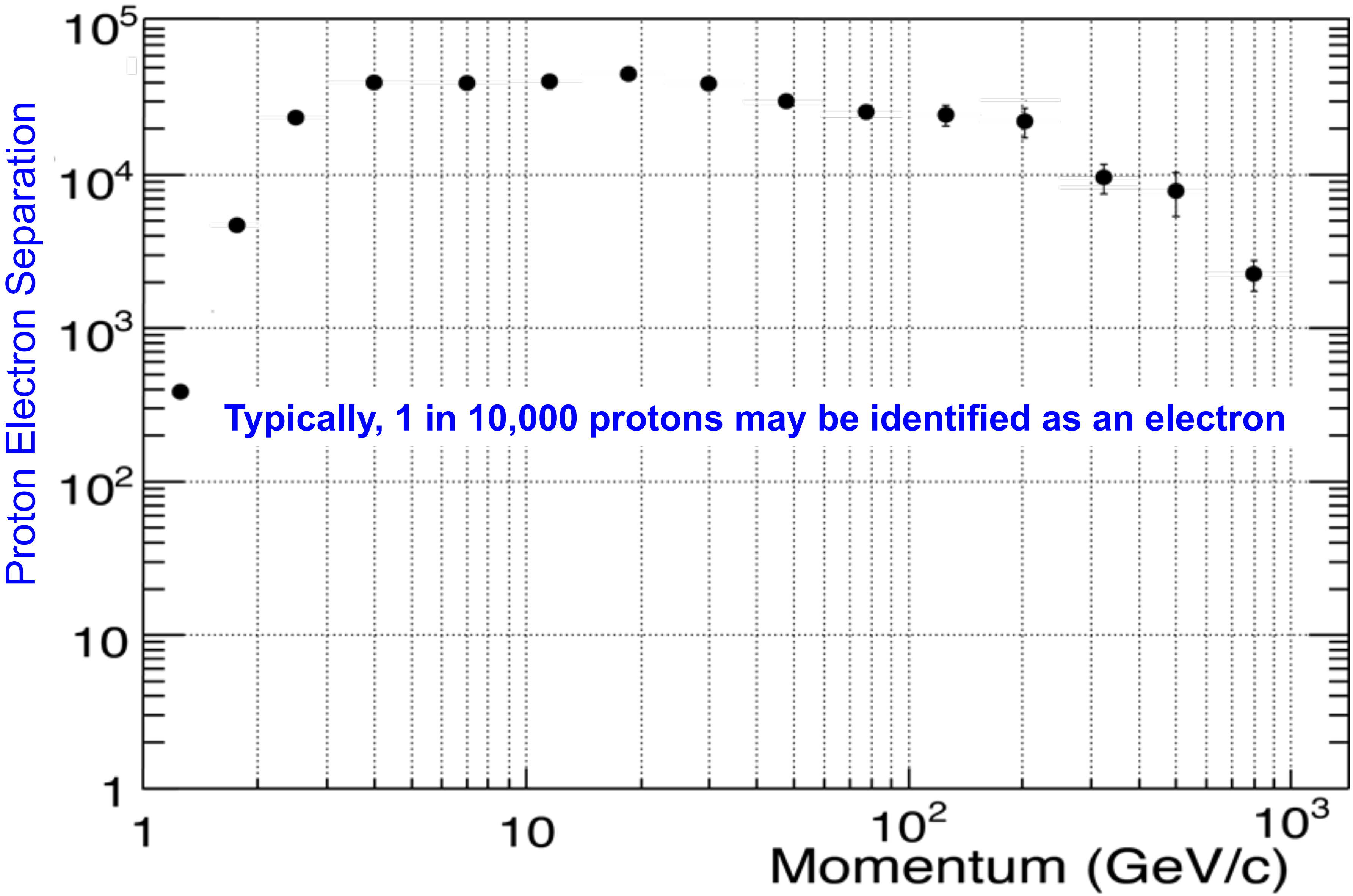




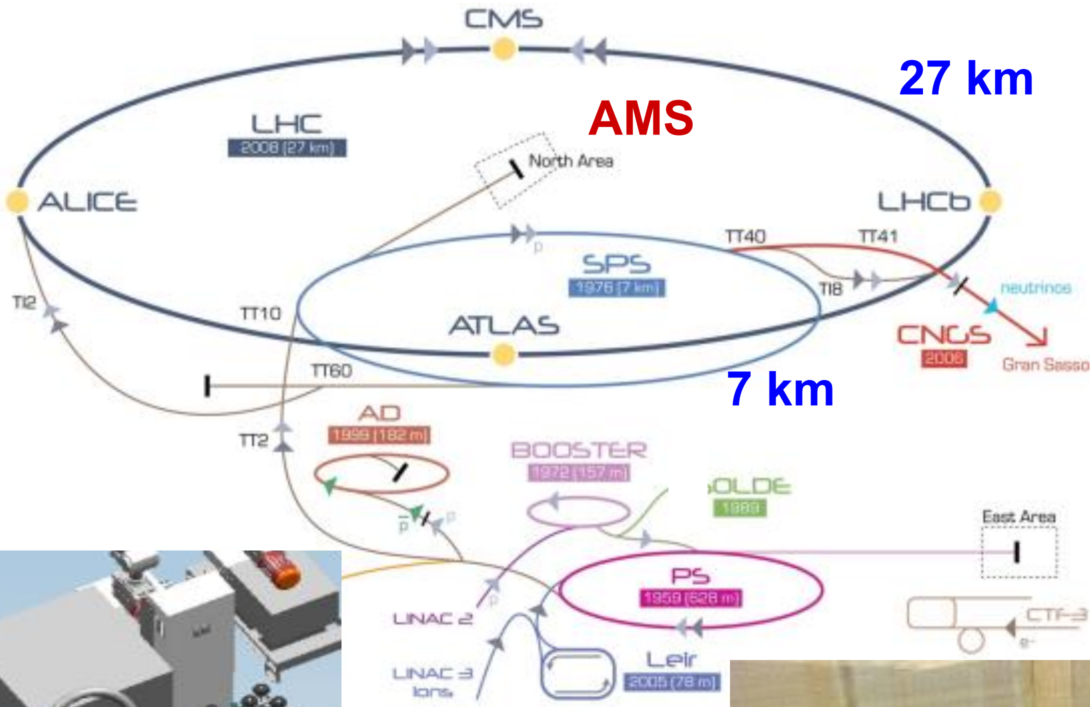
50 000 fibers, $\phi = 1$ mm
distributed uniformly
Inside 1,200 lb of lead



Calorimeter Separation Performance in space

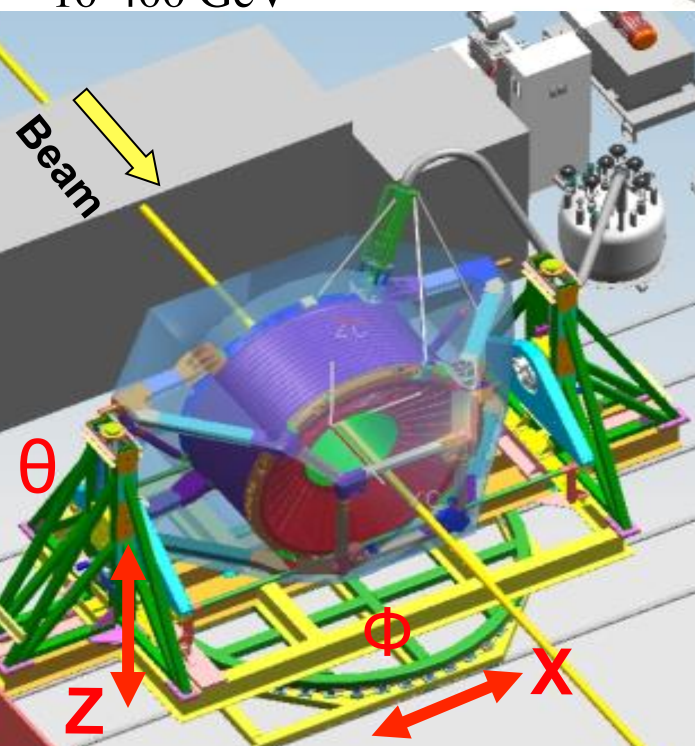


Tests at CERN
AMS in accelerator test beams Feb 4-8 and Aug 8-20, 2010

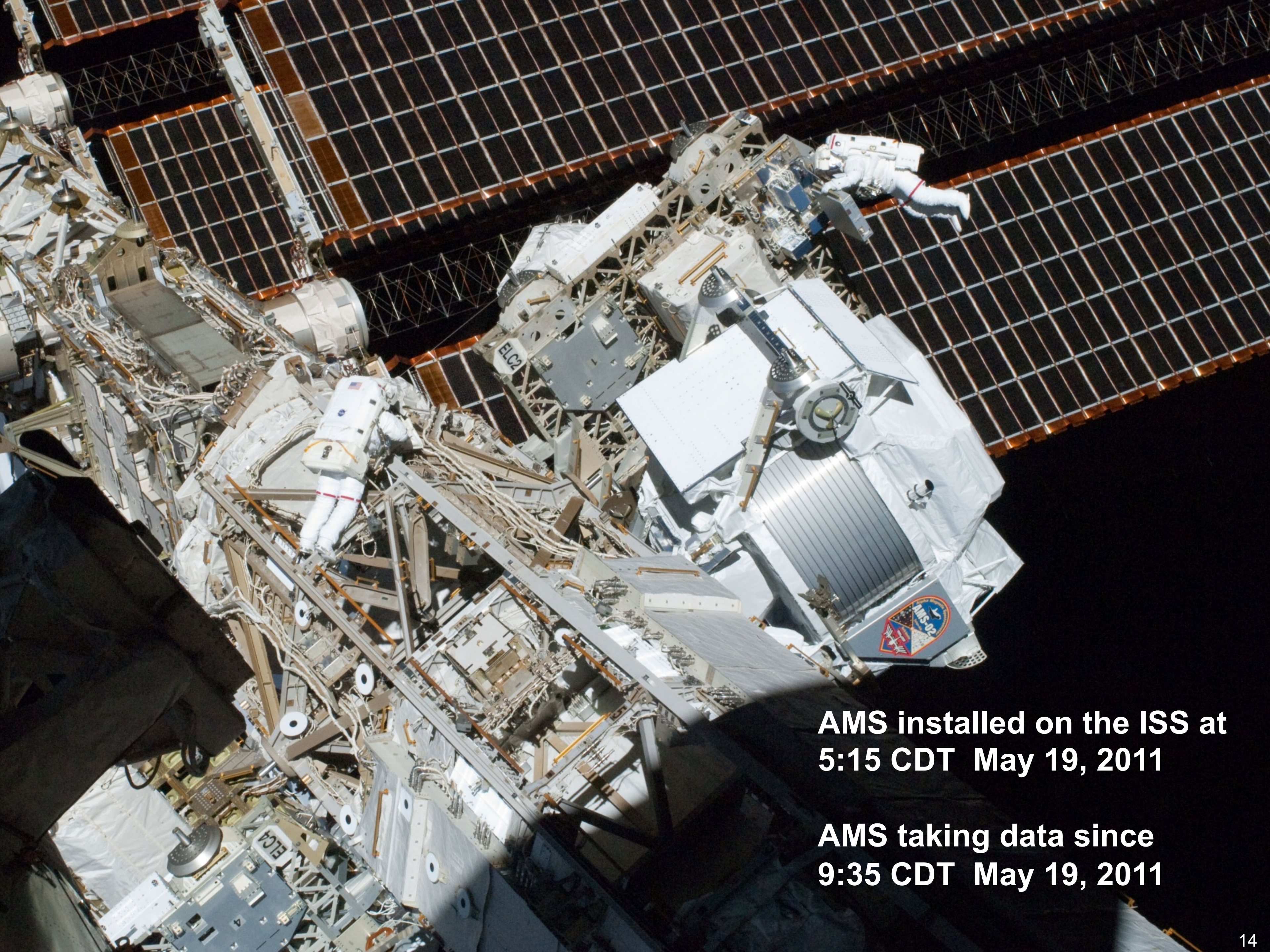


p, e+, e-,π

10-400 GeV



2000 positions



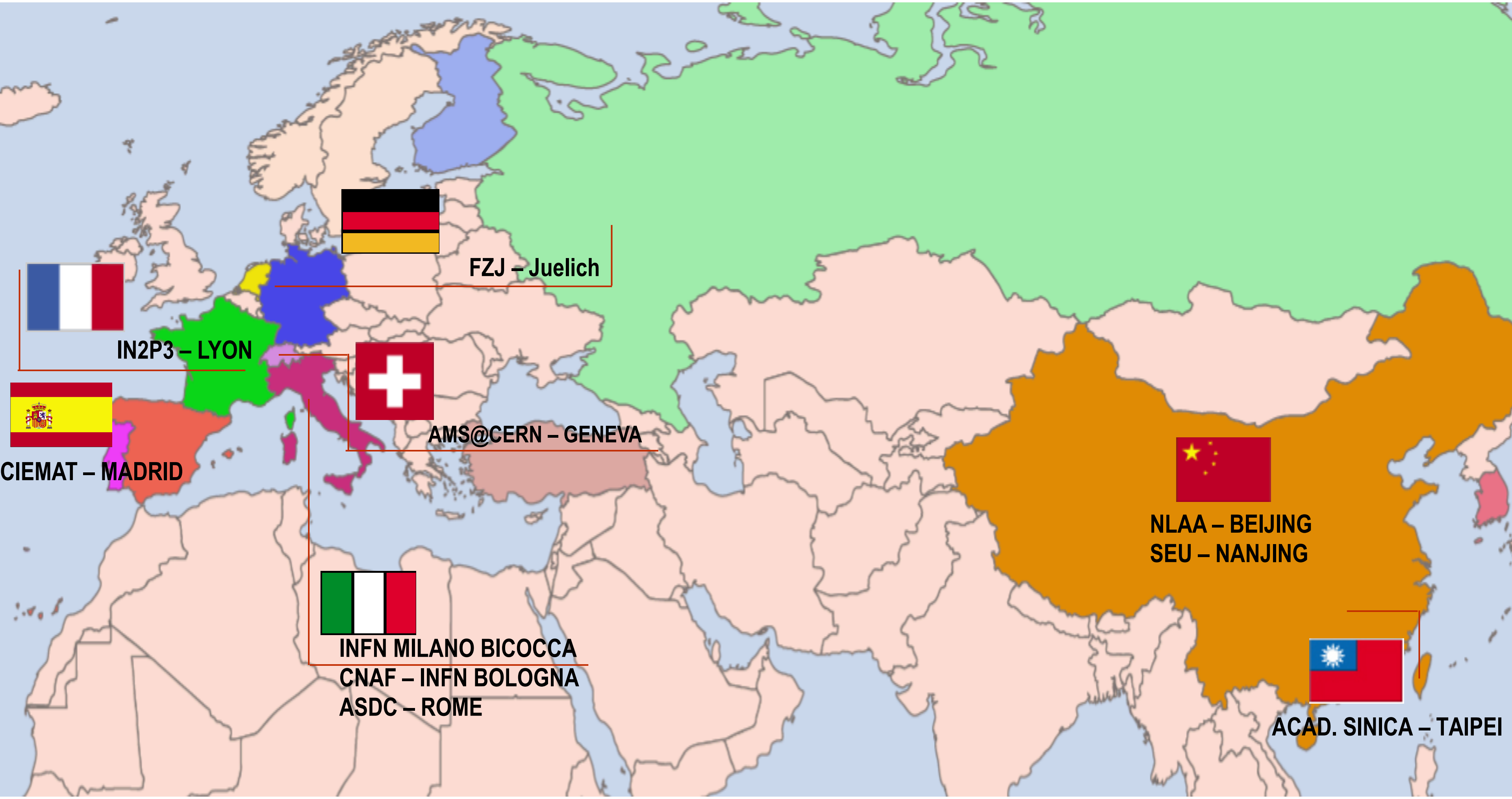
AMS installed on the ISS at 5:15 CDT May 19, 2011

AMS taking data since 9:35 CDT May 19, 2011

AMS Payload Operations and Control Center at CERN

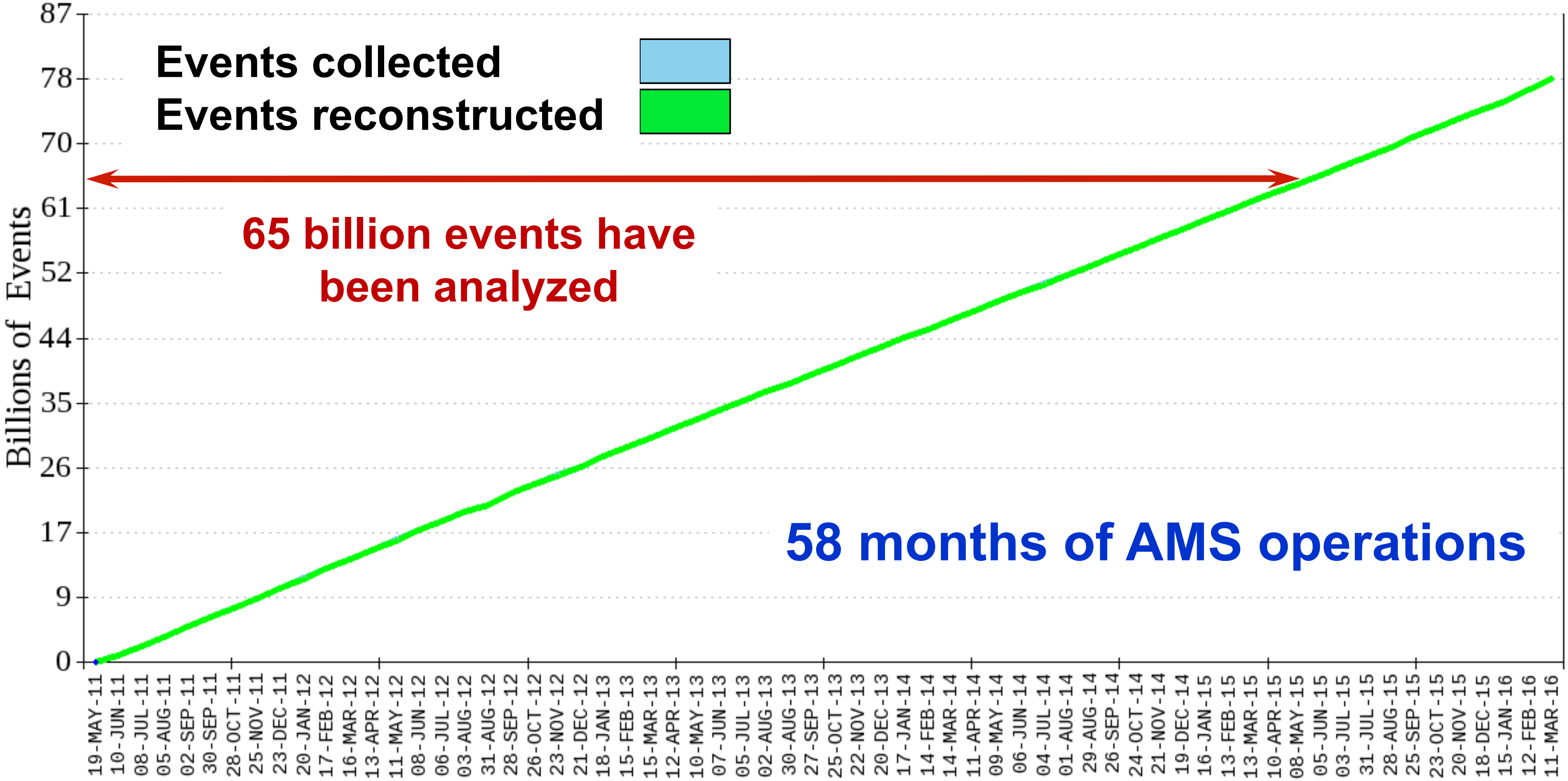
AMS Data Analysis

Conducted at the Science Operations Center at CERN and in the regional centers around the world.



The analysis of each topic is performed by two independent groups

To date AMS collected over 78 billion events



AMS publications

Selected for a Viewpoint in *Physics*

PRL **110**, 141102 (2013) PHYSICAL REVIEW LETTERS week ending 5 APRIL 2013

Editor's Suggestions and 2013 APS Physics Highlights

First Result from the Alpha Magnetic Spectrometer on the International Space Station: Precision Measurement of the Positron Fraction in Primary Cosmic Rays of 0.5–350 GeV

PRL **113**, 121101 (2014) PHYSICAL REVIEW LETTERS week ending 19 SEPTEMBER 2014

Editor's Suggestions

High Statistics Measurement of the Positron Fraction in Primary Cosmic Rays of 0.5–500 GeV with the Alpha Magnetic Spectrometer on the International Space Station

PRL **113**, 121102 (2014) PHYSICAL REVIEW LETTERS week ending 19 SEPTEMBER 2014

Editor's Suggestions

Electron and Positron Fluxes in Primary Cosmic Rays Measured with the Alpha Magnetic Spectrometer on the International Space Station

PRL **113**, 221102 (2014) PHYSICAL REVIEW LETTERS week ending 28 NOVEMBER 2014

Precision Measurement of the $(e^+ + e^-)$ Flux in Primary Cosmic Rays from 0.5 GeV to 1 TeV with the Alpha Magnetic Spectrometer on the International Space Station

PRL **114**, 171103 (2015) PHYSICAL REVIEW LETTERS week ending 1 MAY 2015

Editor's Suggestions

Precision Measurement of the Proton Flux in Primary Cosmic Rays from Rigidity 1 GV to 1.8 TV with the Alpha Magnetic Spectrometer on the International Space Station

PRL **115**, 211101 (2015) PHYSICAL REVIEW LETTERS week ending 20 NOVEMBER 2015

Editor's Suggestions

Precision Measurement of the Helium Flux in Primary Cosmic Rays of Rigidities 1.9 GV to 3 TV with the Alpha Magnetic Spectrometer on the International Space Station

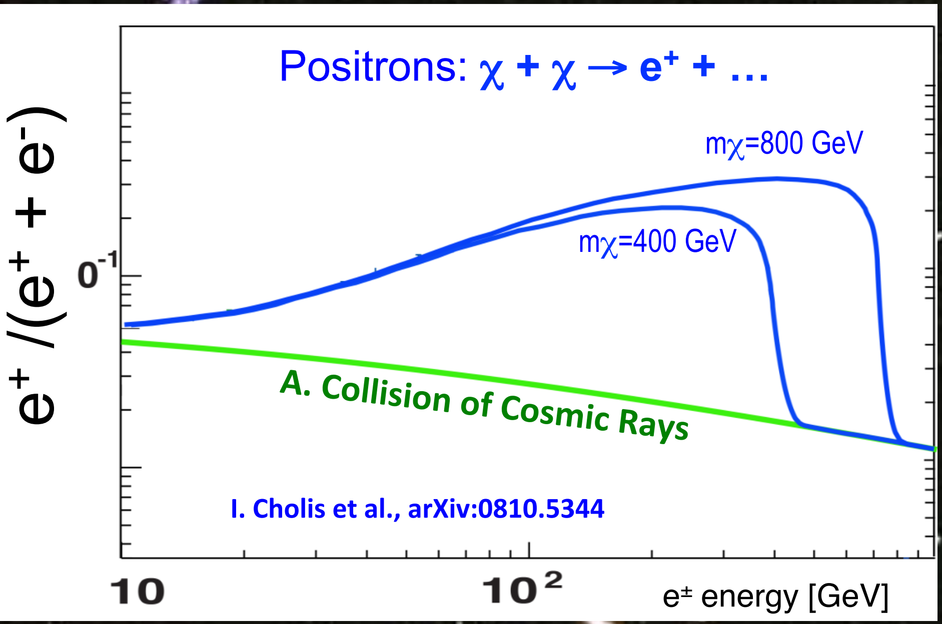
The physics objectives of AMS include:

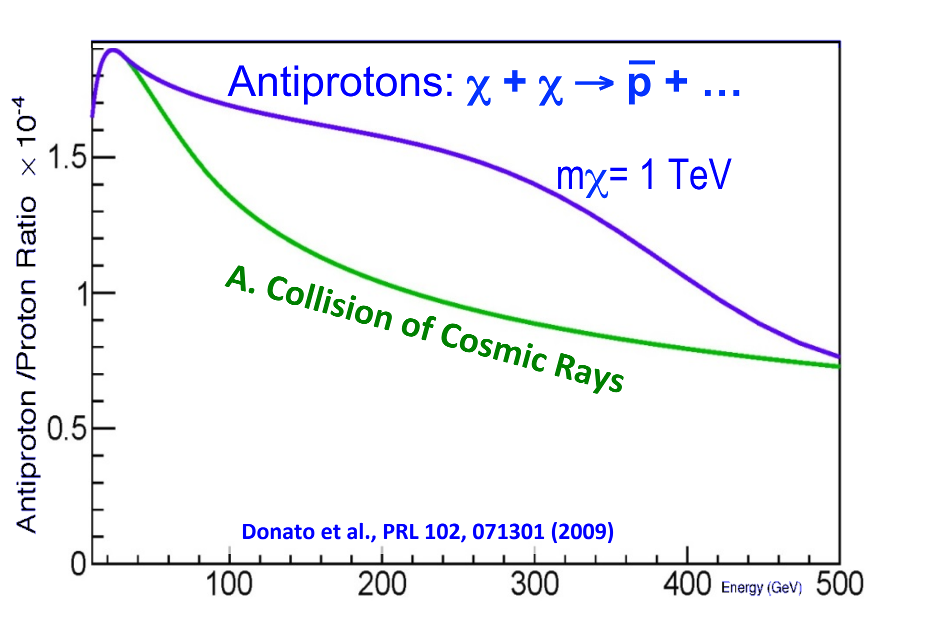
The Origin of Dark Matter

~ 90% of Matter in the Universe is not visible and is called Dark Matter

Collision of "ordinary" Cosmic Rays produce e+, $\bar{p}$..

Collisions of Dark Matter (neutralinos, χ) will produce additional e+, $\bar{p}$, …





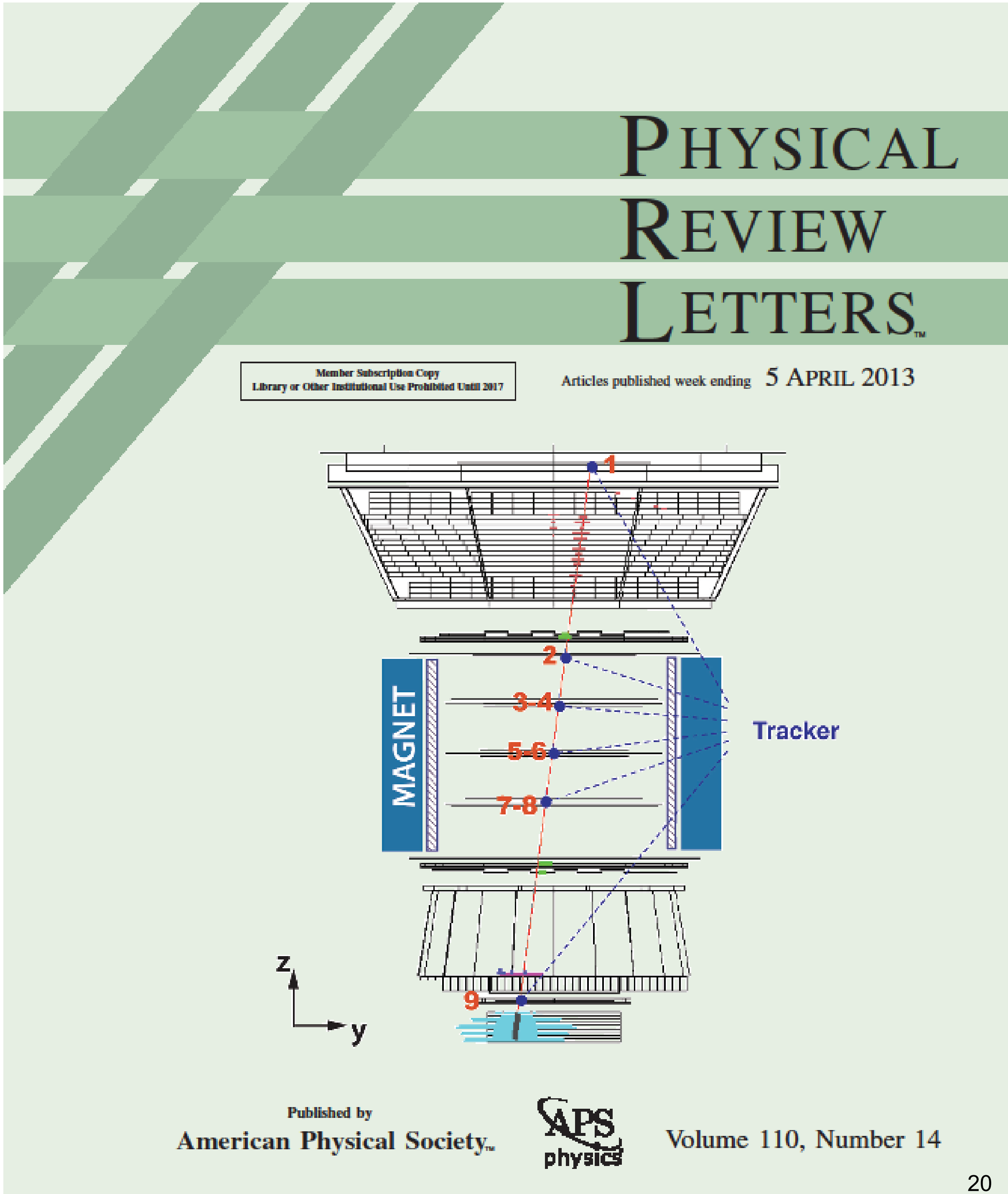
M. Turner and F. Wilczek, Phys. Rev. D42 (1990) 1001

"First Result from the AMS on the ISS: Precision Measurement of the Positron Fraction in Primary Cosmic Rays of 0.5-350 GeV"

Analysis is based on 25 billion events collected during the first 18 months of operations: from May 19, 2011 to December 10, 2012

Selected as APS Highlight of the Year

Cited >400 times



New Results on the Positron Fraction from 11 million e±

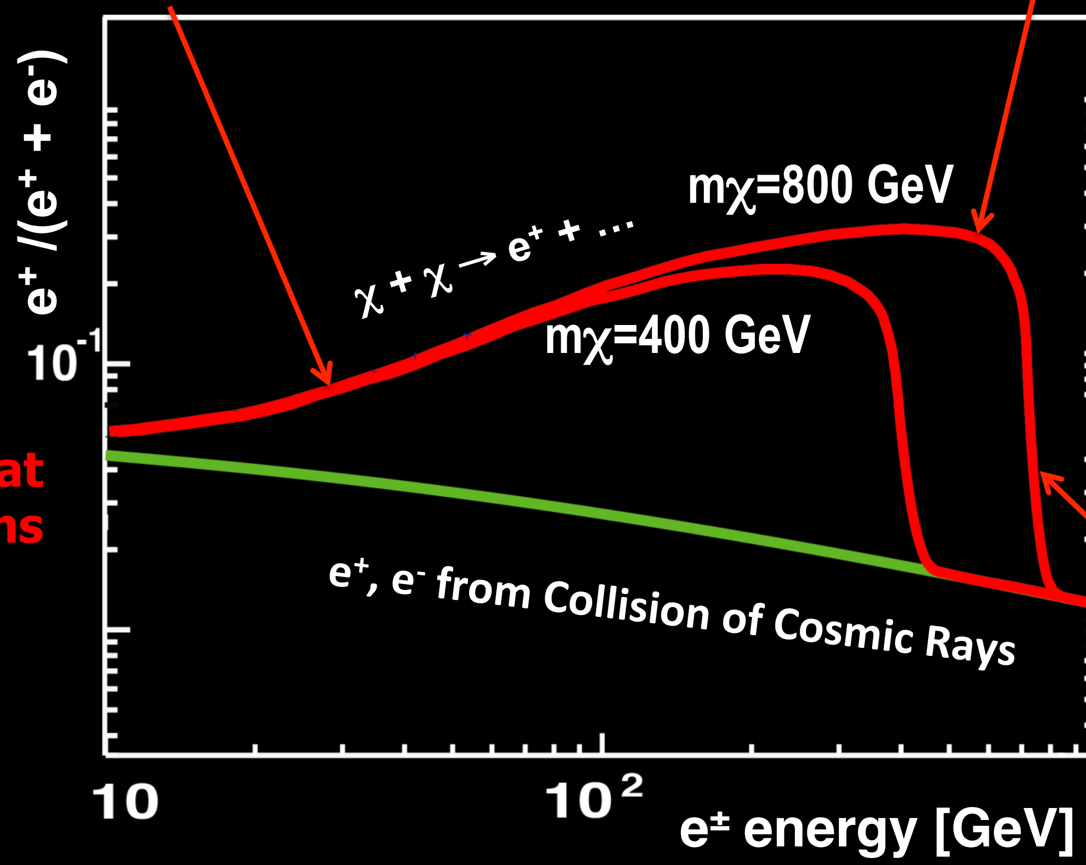
PRL 113, 121101 (2014) PHYSICAL REVIEW LETTERS week ending 19 SEPTEMBER 2014

Editor's Suggestion

High Statistics Measurement of the Positron Fraction in Primary Cosmic Rays of 0.5–500 GeV with the Alpha Magnetic Spectrometer on the International Space Station

2. The rate of increase with energy compared with models

3. The energy beyond which it ceases to increase.

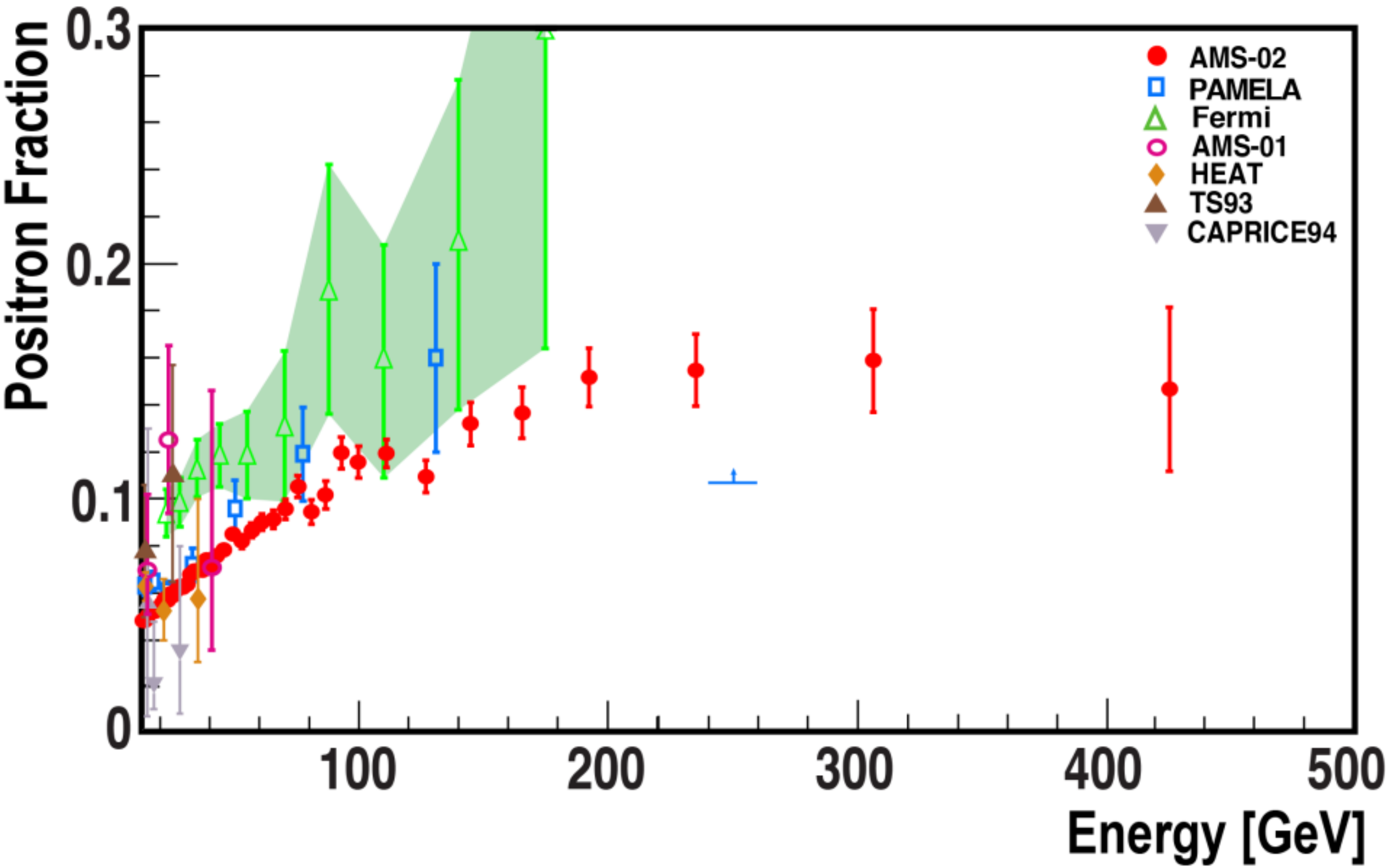


4. Isotropy.

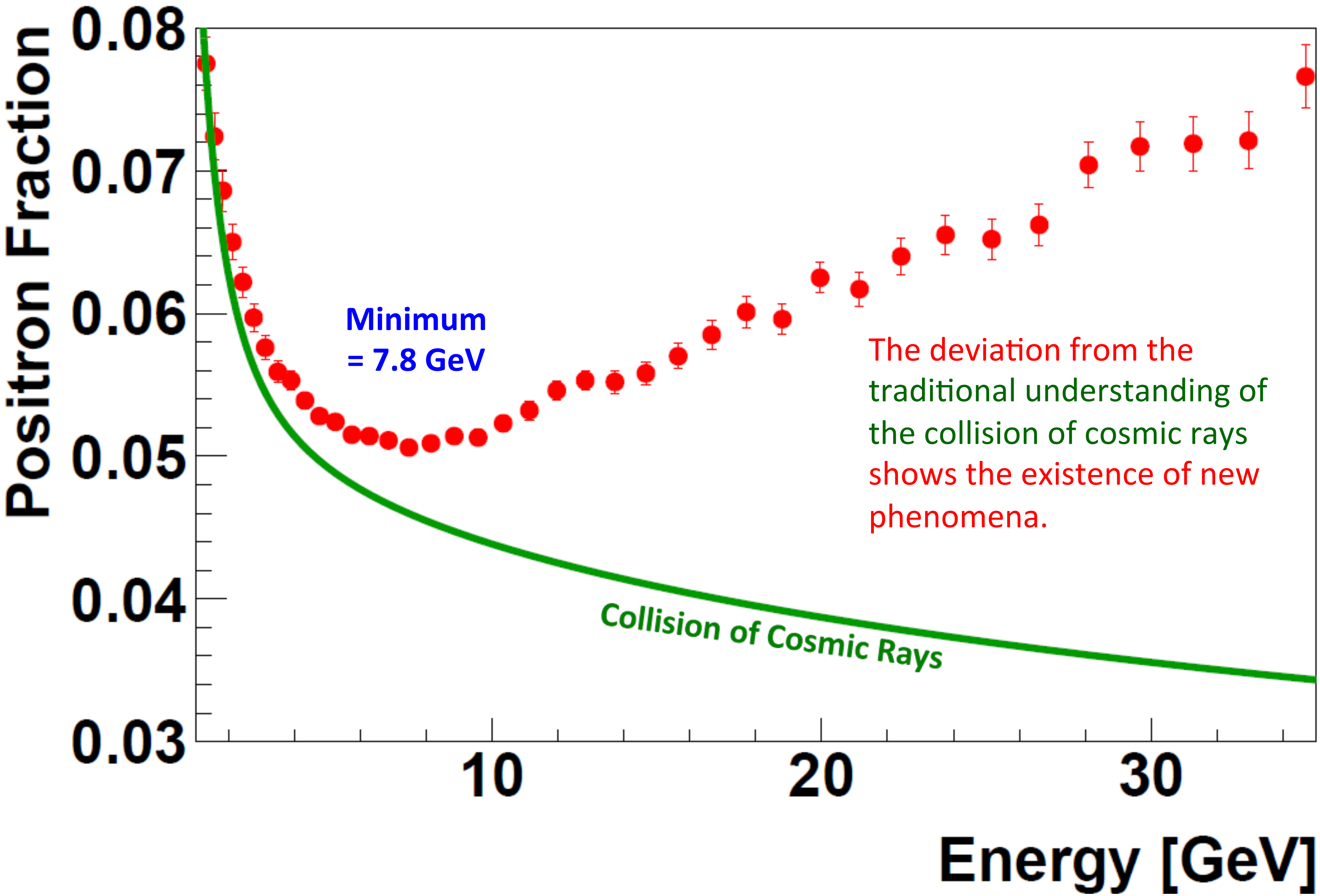
1. The energy at which it begins to increase.

5. The rate at which it falls beyond the turning point.

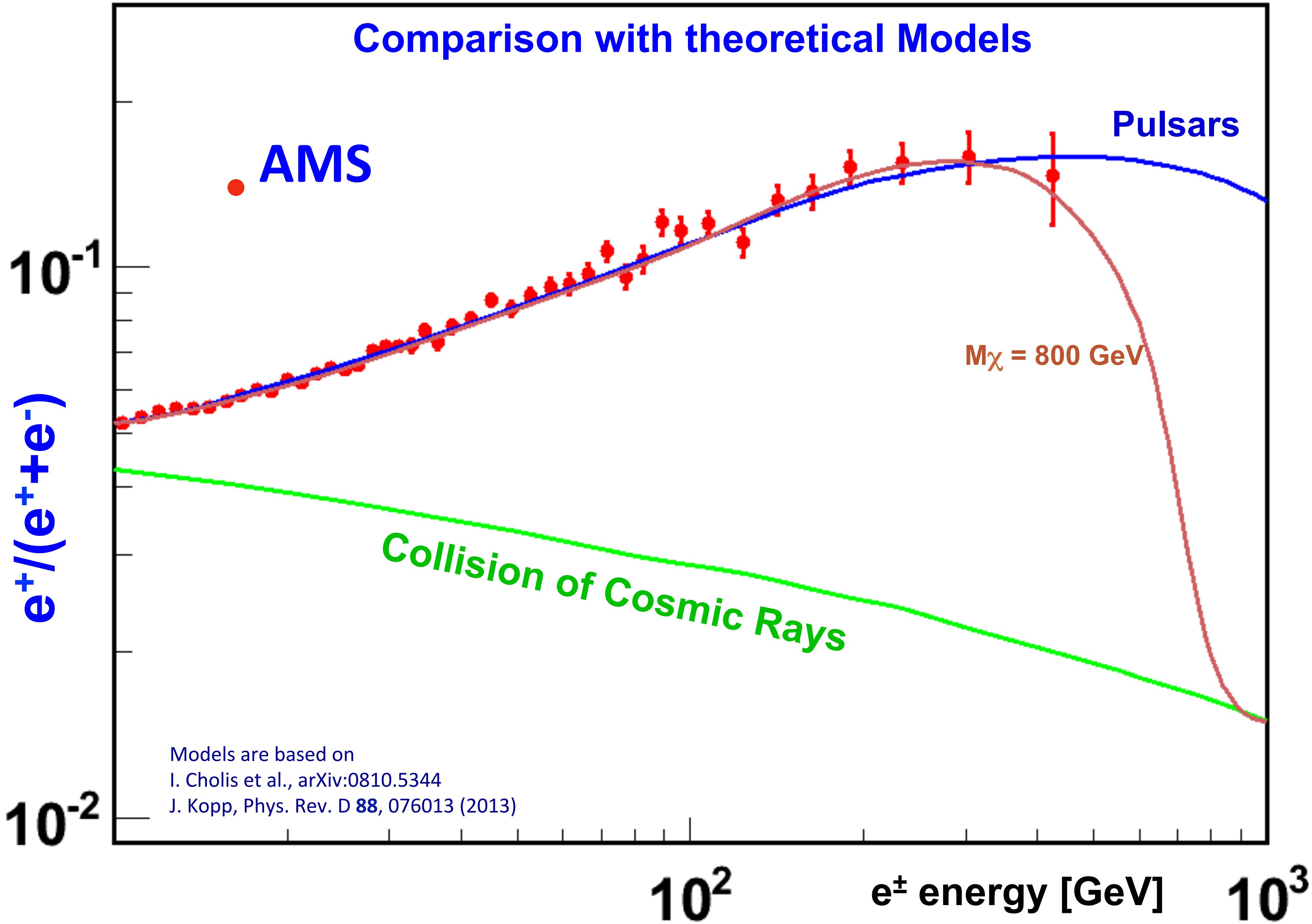
Positron fraction measurement.



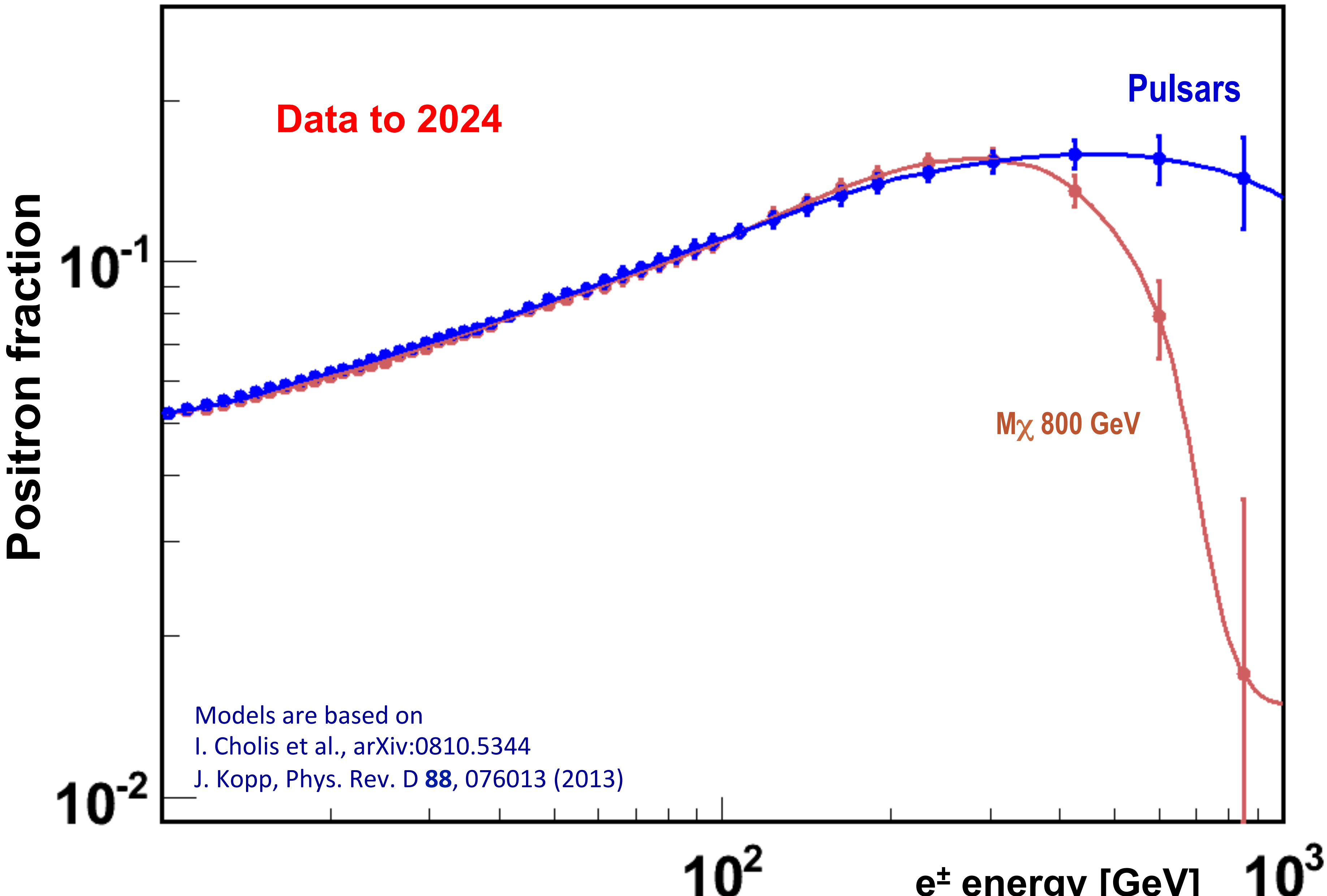
1. The energy at which it begins to increase.



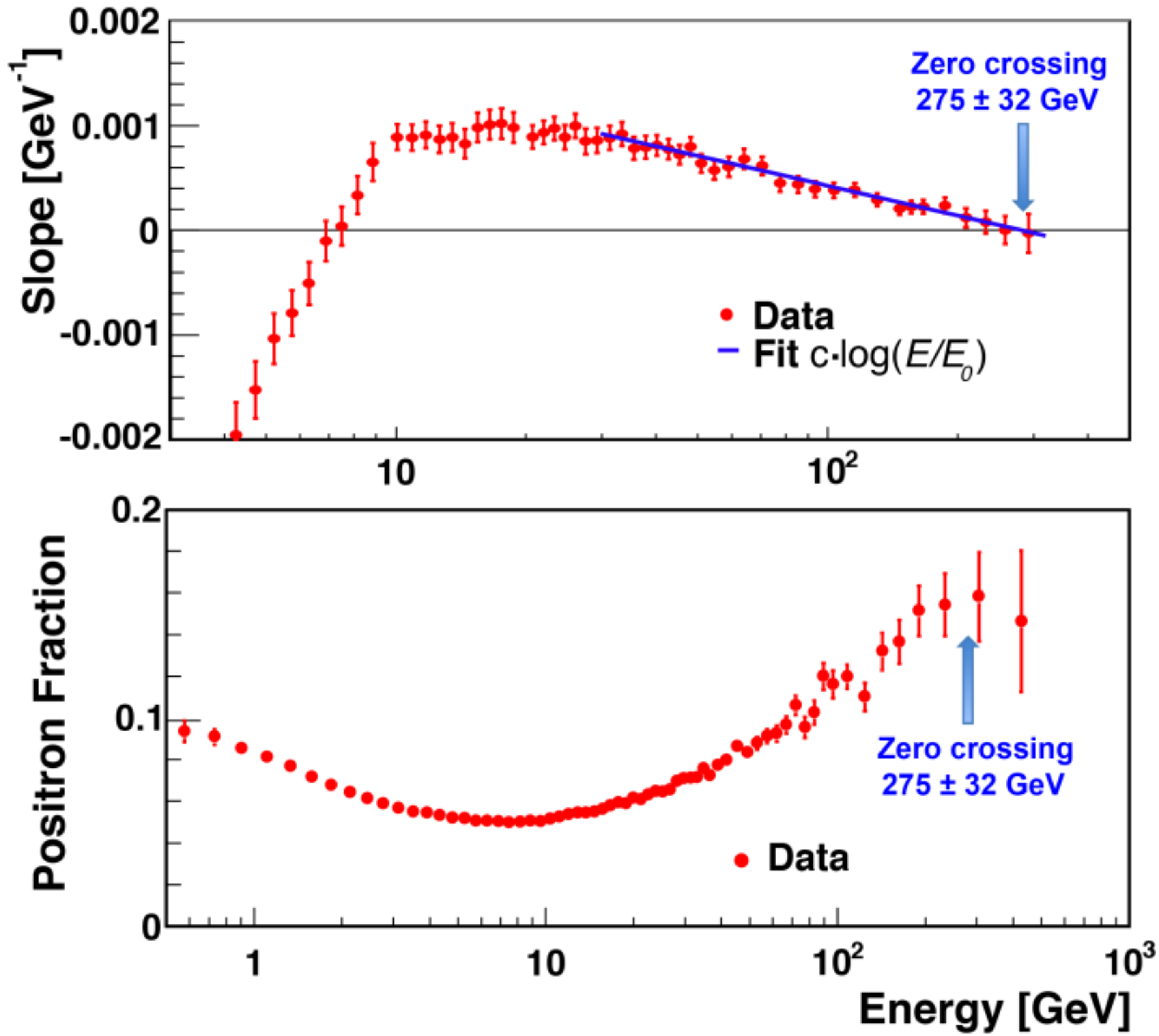
2. The rate of increase with energy.



Positron Fraction Measurement compared with models



3. The energy beyond which it ceases to increase.

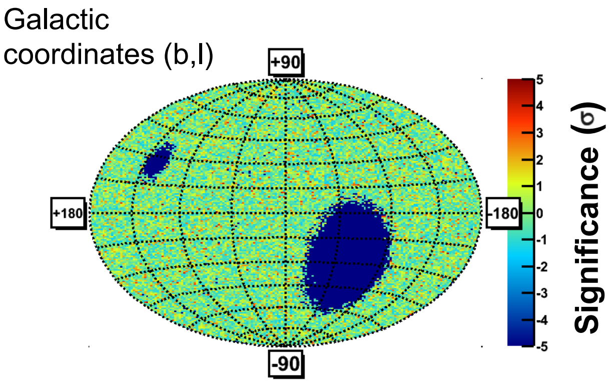


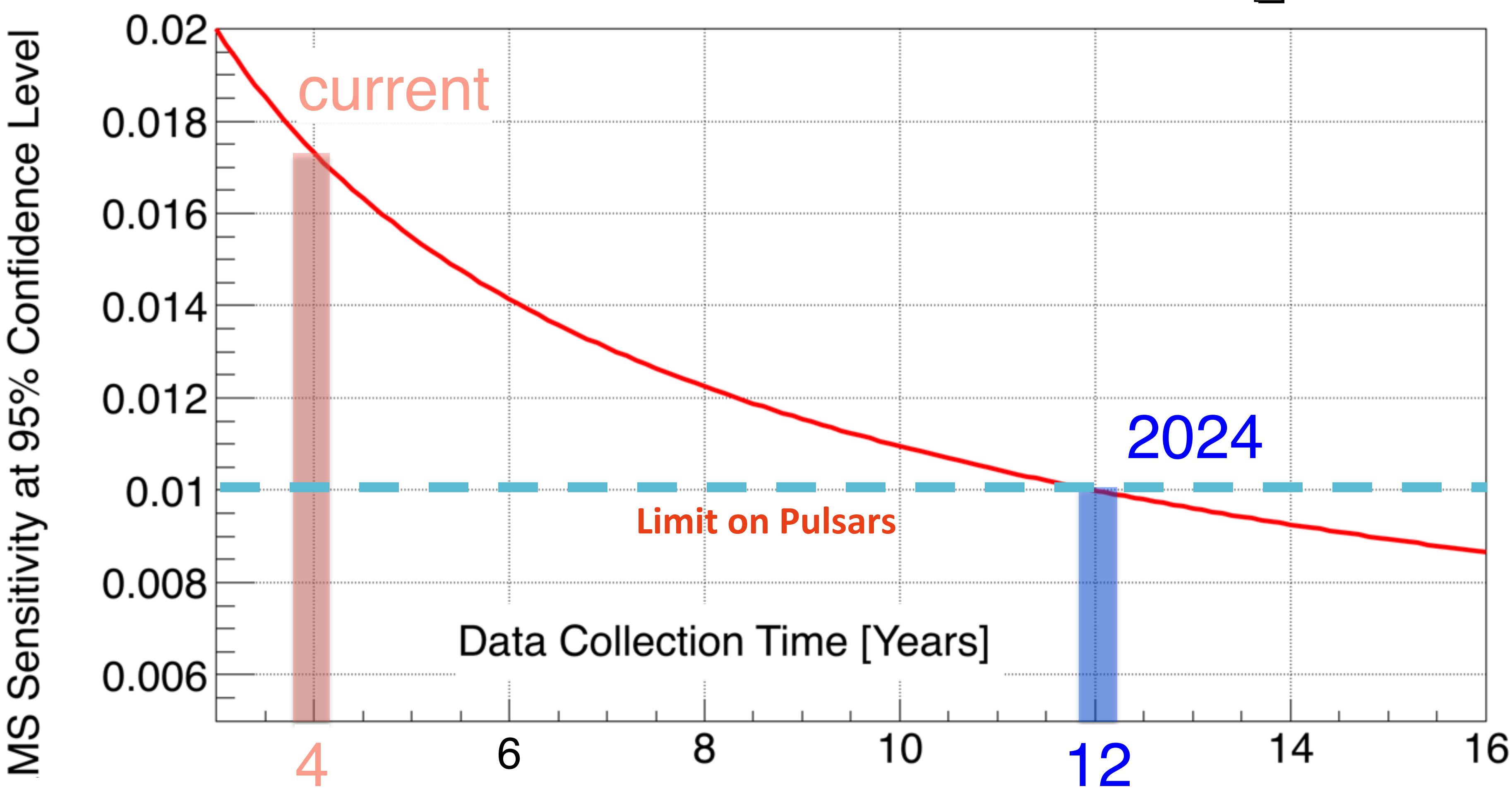
4. The isotropy.

The fluctuations of the positron ratio e^+/e^- are isotropic.

The anisotropy in galactic coordinates

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





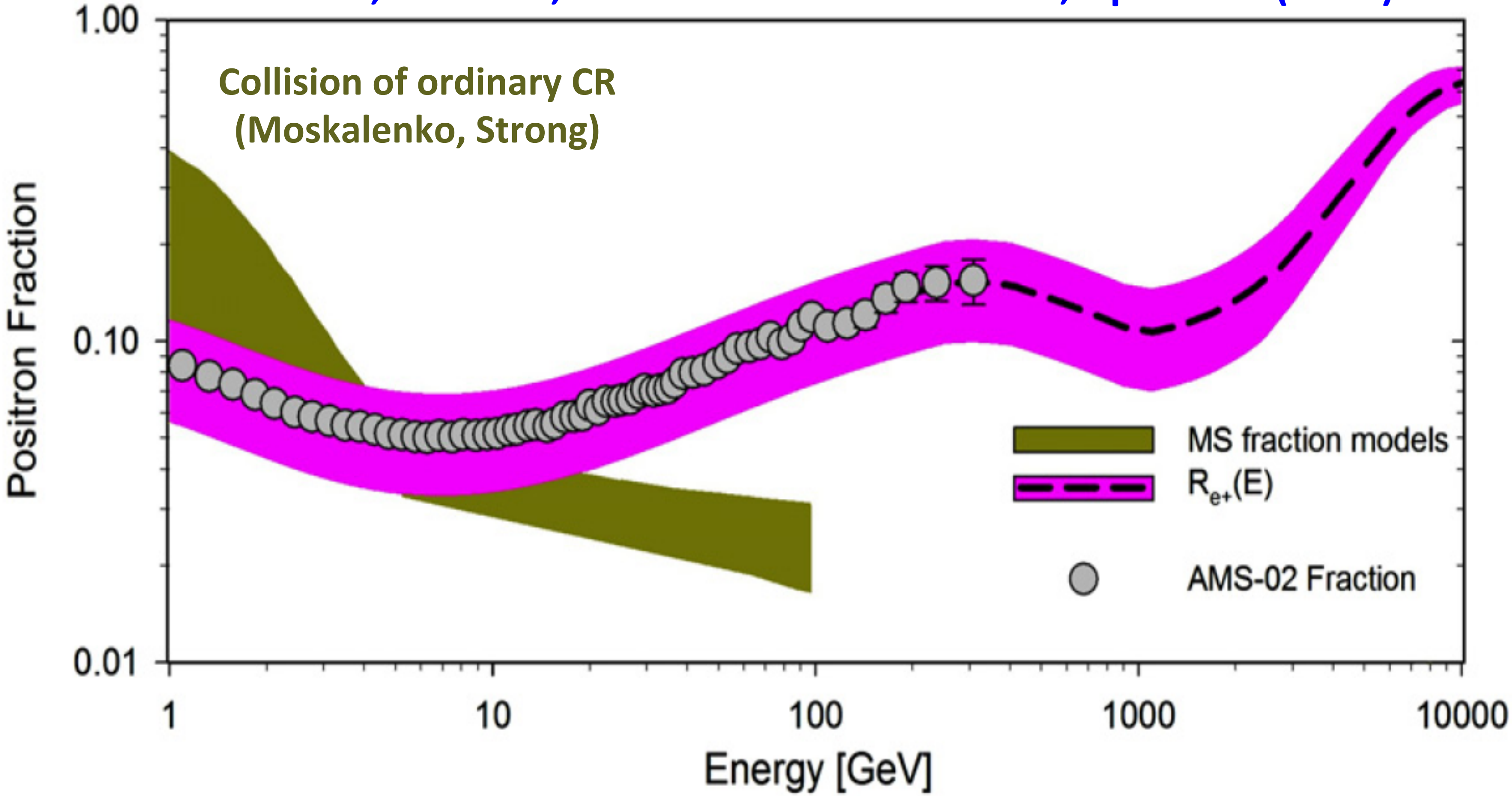
By 2024 we will reach the limit of excluding pulsars

Theoretical models to explain the AMS positron fraction.
Among the 100's of models there are three classes:

a) dark matter
b) peculiarities of the propagation
c) pulsars.

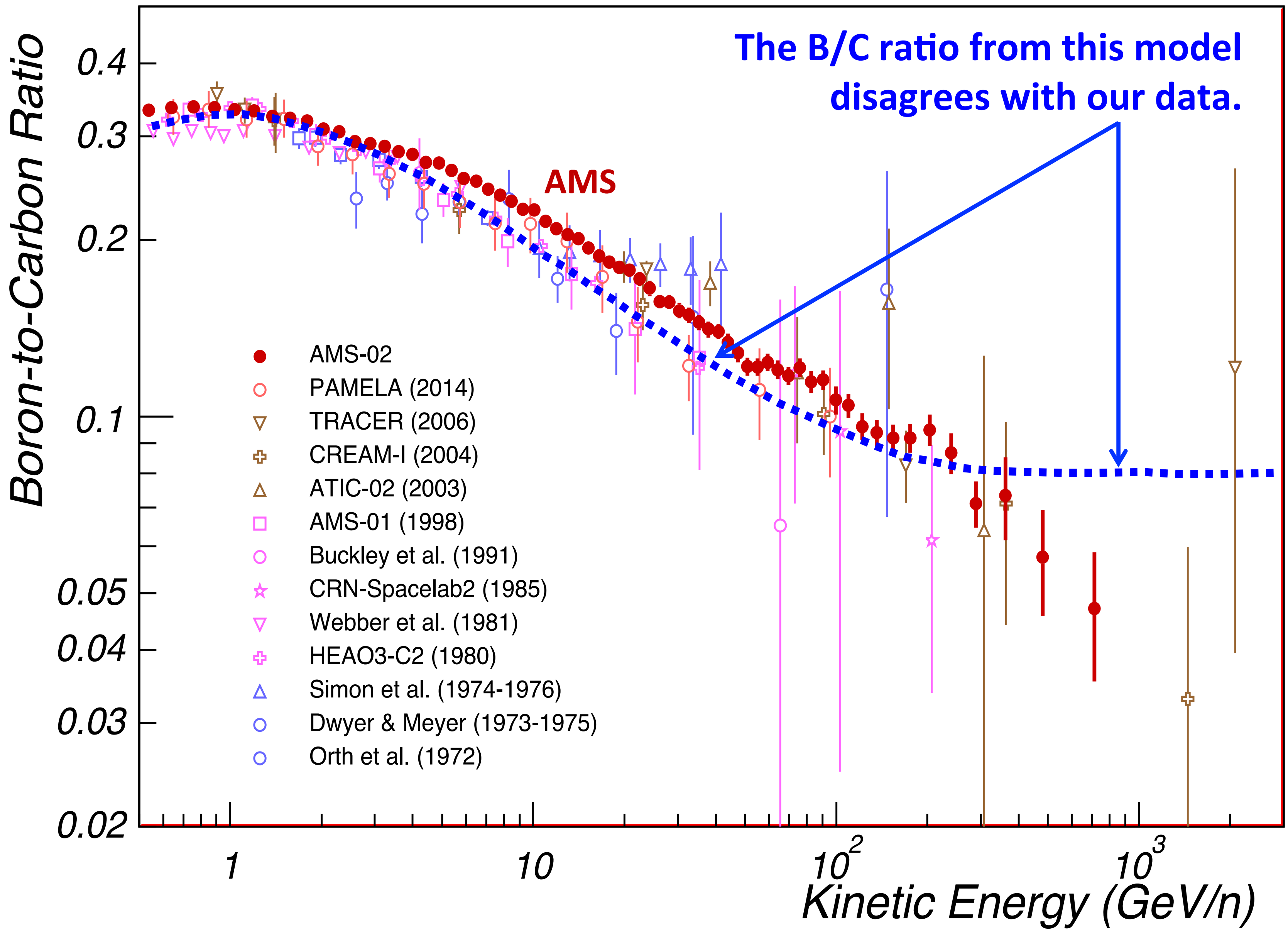
b) An example of propagation model:

R. Cowsik, B. Burch, and T. Madziwa-Nussinov, Ap. J. 786 (2014) 124

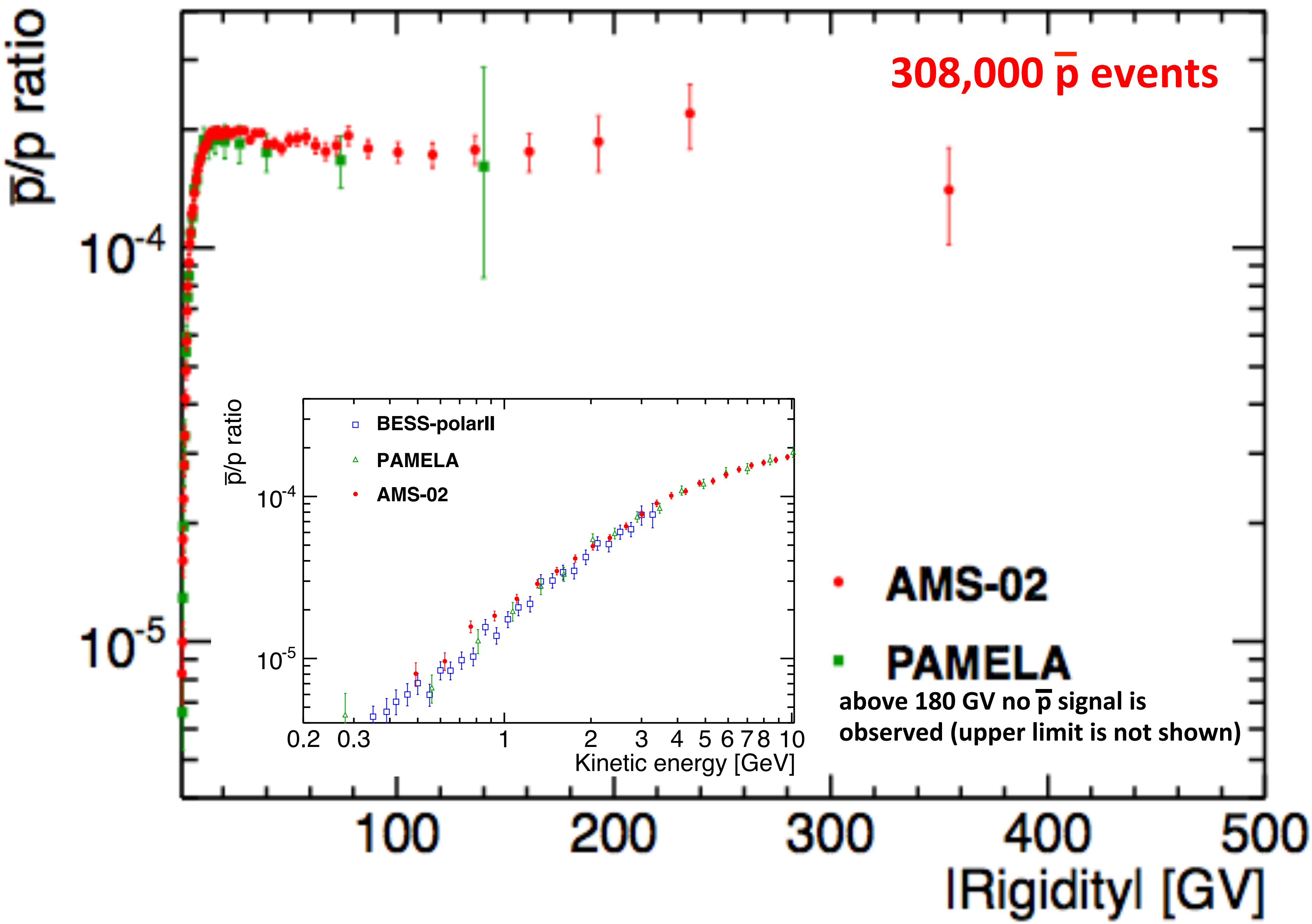


An example of new forms of propagation:

R. Cowsik, B. Burch, and T. Madziwa-Nussinov, Ap. J. 786 (2014) 124

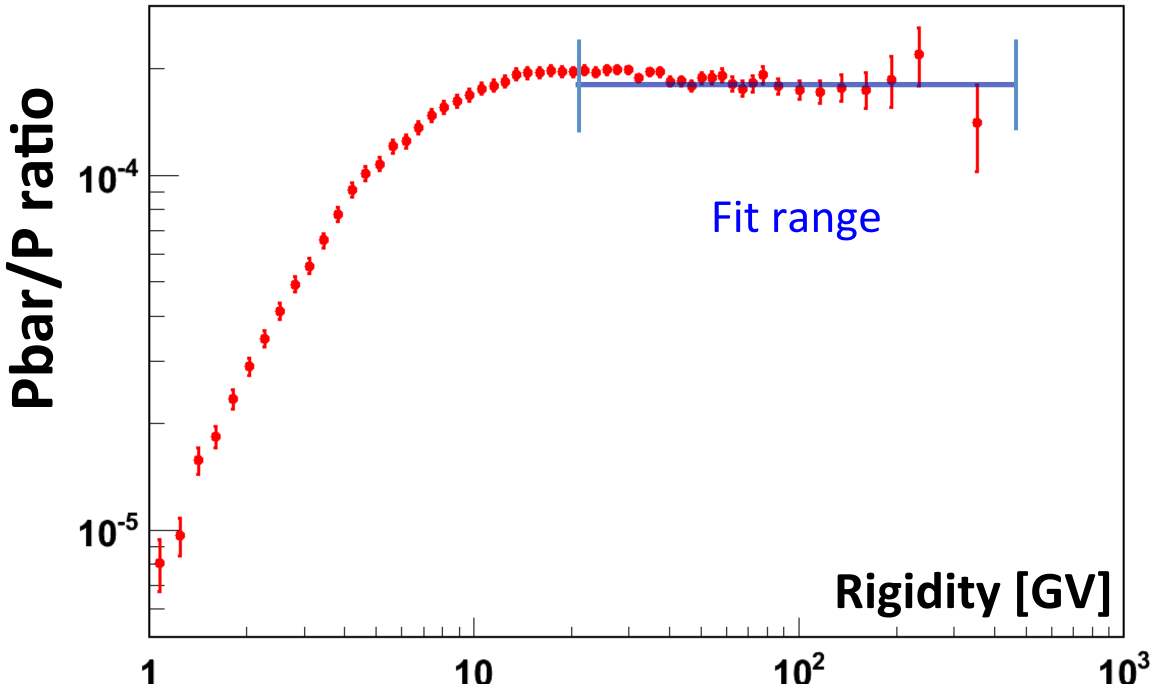


AMS results on the $\bar{p}/p$ ratio



above 180 GV no $\bar{p}$ signal is observed (upper limit is not shown)

Analysis of the behavior of the $\bar{p}/p$ ratio



Fit:

linear dependence

$(\bar{p}/p) = C + kR$

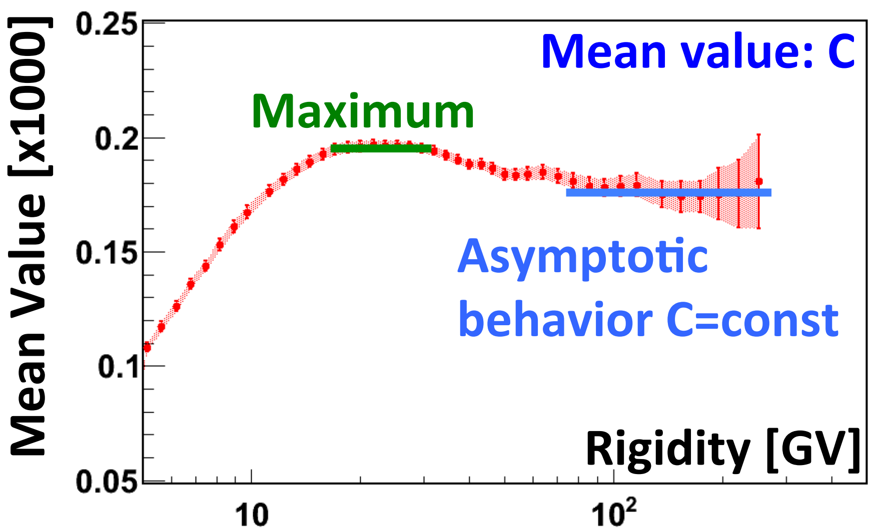
C – mean value

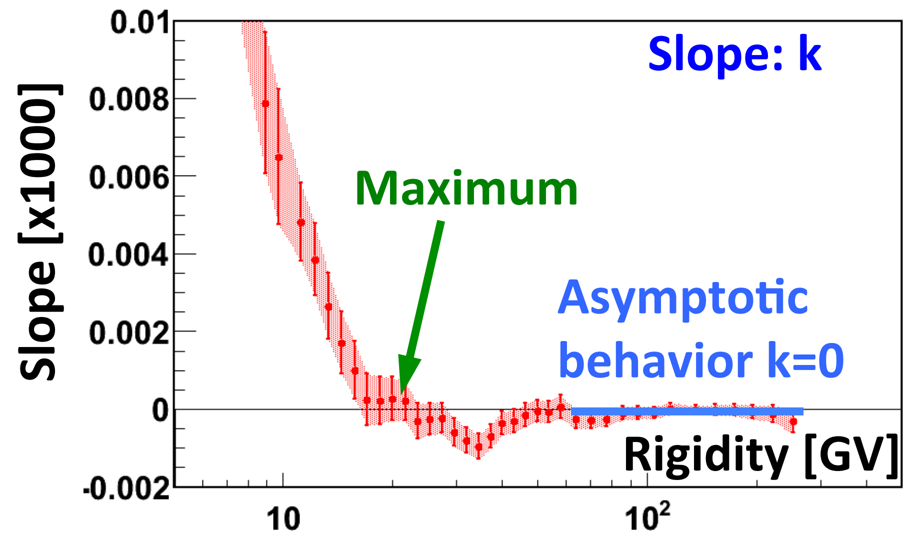
k – slope

Above 60 GV

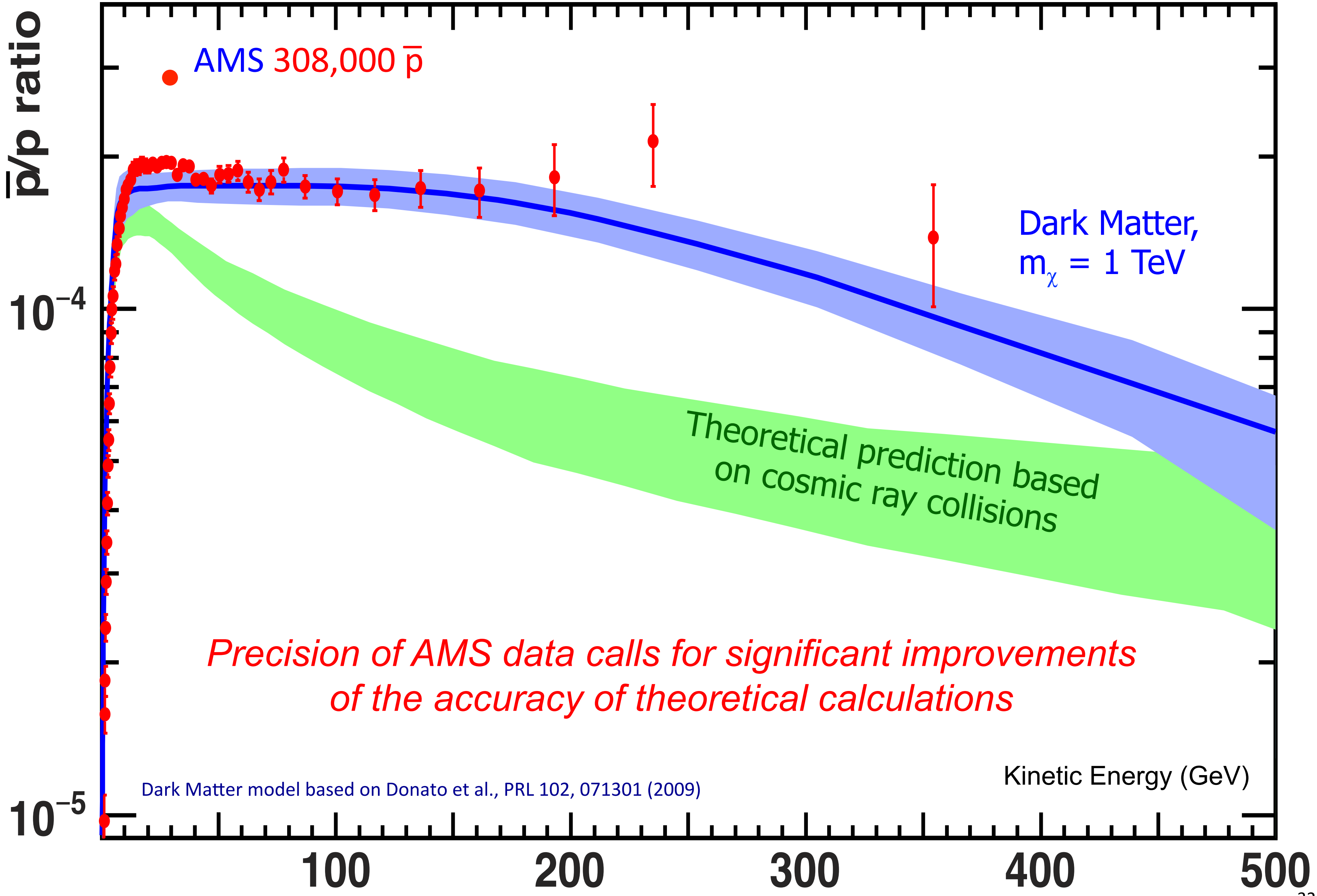
C ~ constant

k ~ 0





Latest AMS results: the $\bar{p}/p$ ratio



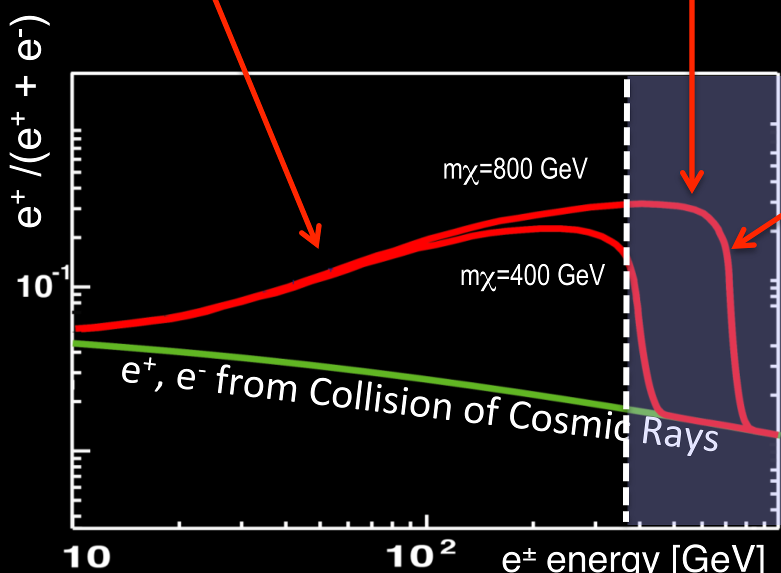
The Search for the Origin of Dark Matter

Signal: Collisions of Dark Matter (neutralinos, χ) will produce e+, $\bar{p}$, …
To identify the Dark Matter signal we need
to measure the e^+ and $\bar{p}$ signal accurately **through 2024**.

2. The rate of increase with energy

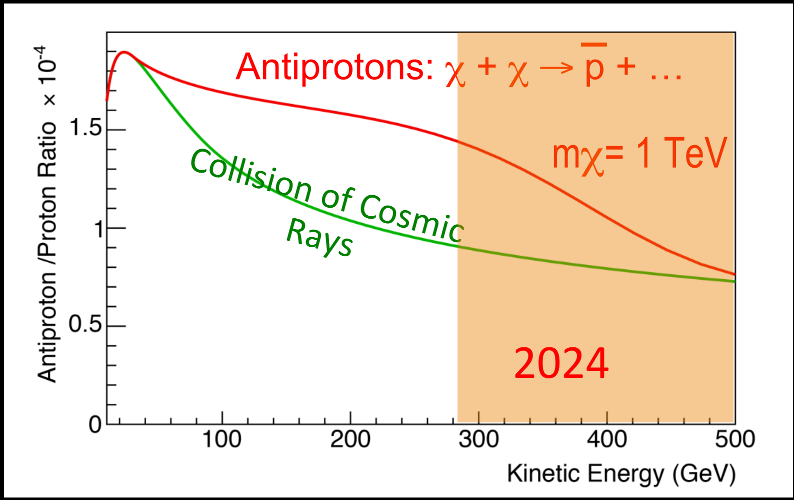
3. The turn over energy.

4. Isotropy.



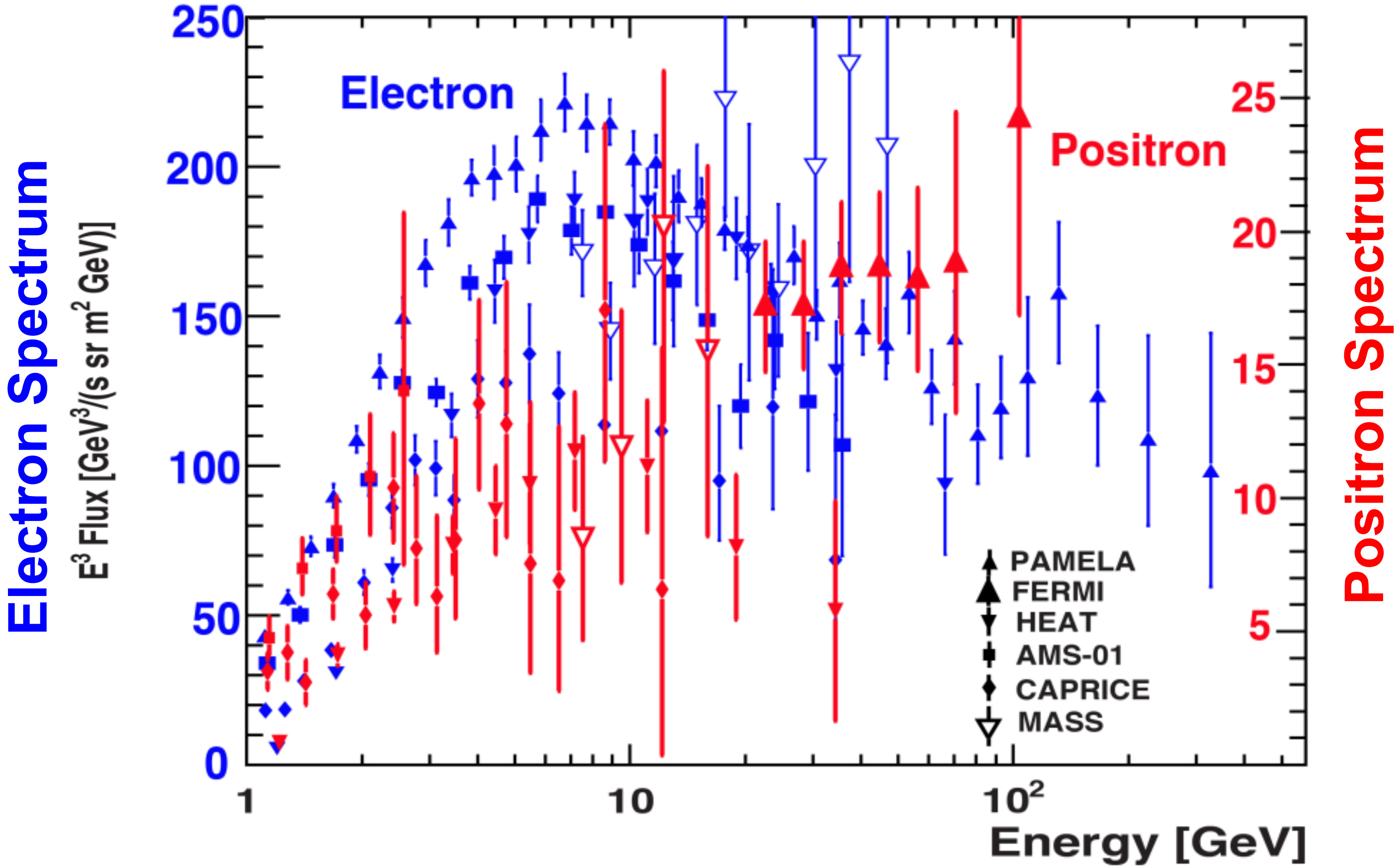
5. The rate at which it falls beyond the turning point.

This will take until 2024.



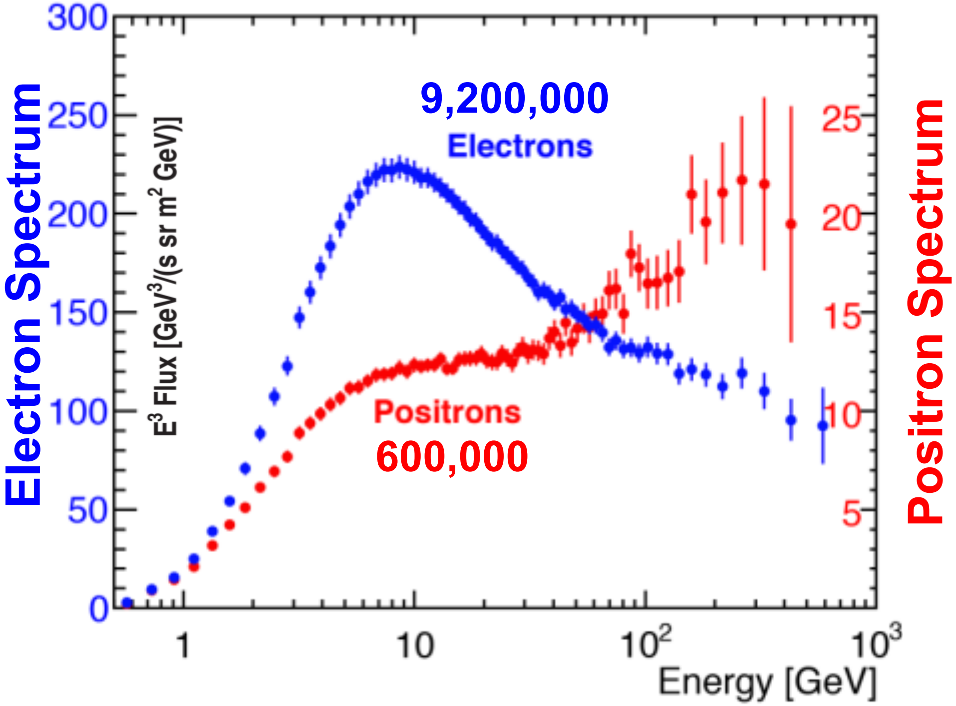
1. The energy at which it begins to increase.

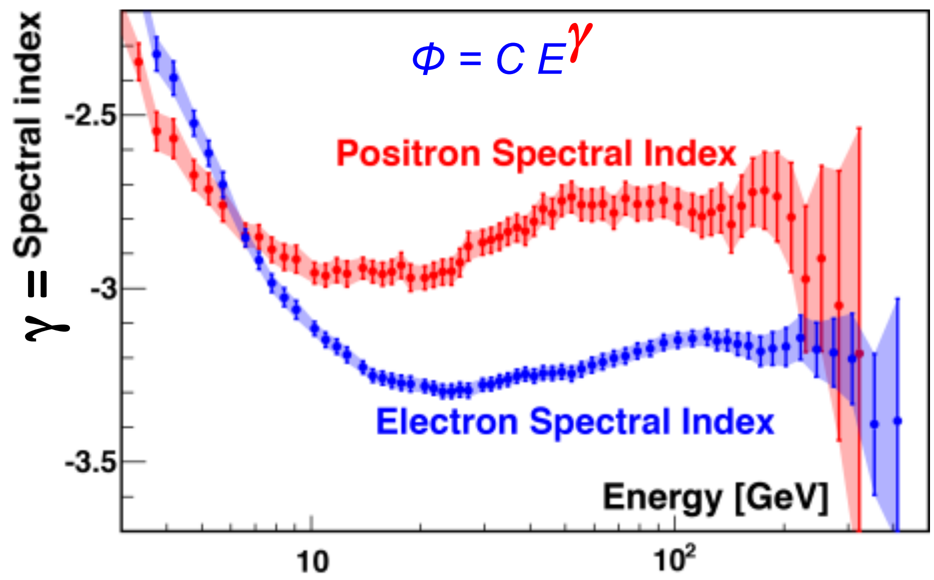
Measurements of Electron and Positron spectra before AMS



1. These were the best data over the last hundred years.
2. Nonetheless, the data have large errors.
3. The data has created many theoretical speculations.

AMS measurements of the Electron and Positron spectra

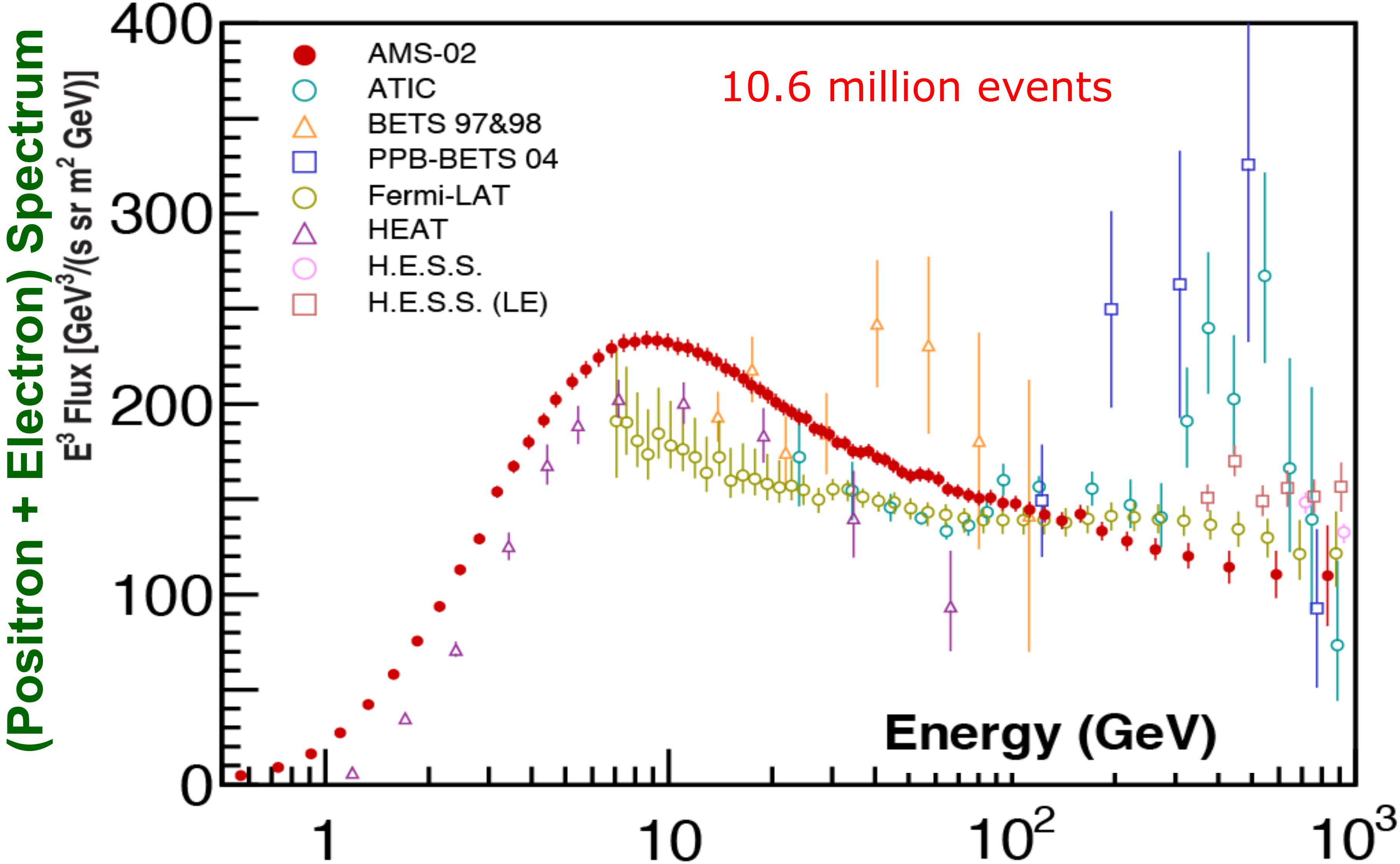




Results:

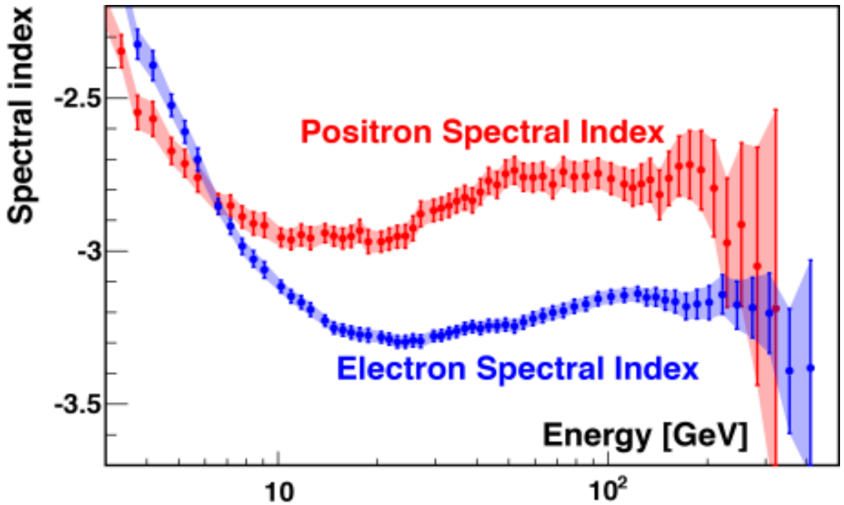
1. AMS data clearly exhibit the different behavior of the electron and positron spectra both in magnitude and in the energy dependence
2. Both spectra cannot be described by single power law $\Phi = C\,E^{\gamma}$.
3. The spectral indices γ of electrons and positrons are not constant (γ=-3), but changes with energy.
4. The rise in the positron fraction is due to an excess of positrons, not the loss of electrons.

Precision Measurement of the $(e^+ + e^-)$ Flux in Primary Cosmic Rays from 0.5 GeV to 1 TeV with the Alpha Magnetic Spectrometer on the International Space Station



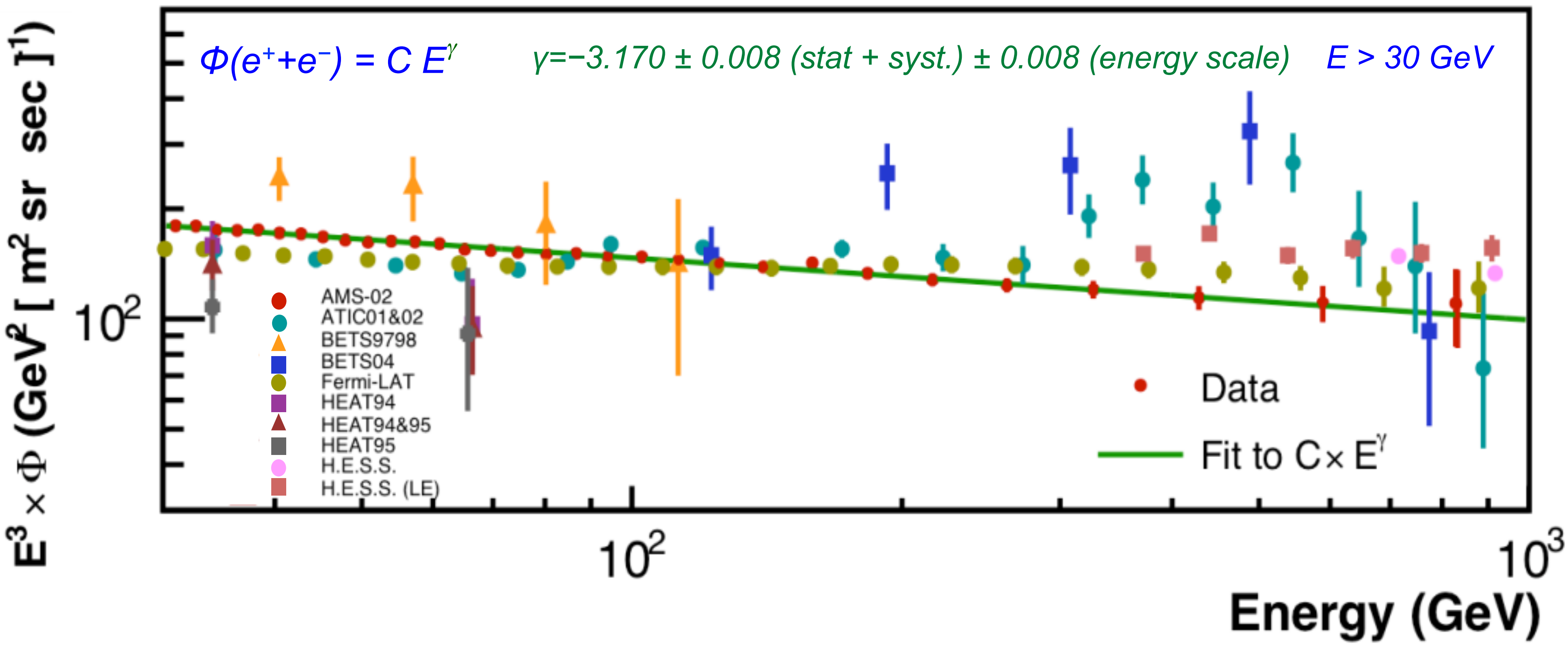
This accurate result contradicts all previous results

Spectral Indices of electrons, positrons, and (electrons + positrons)

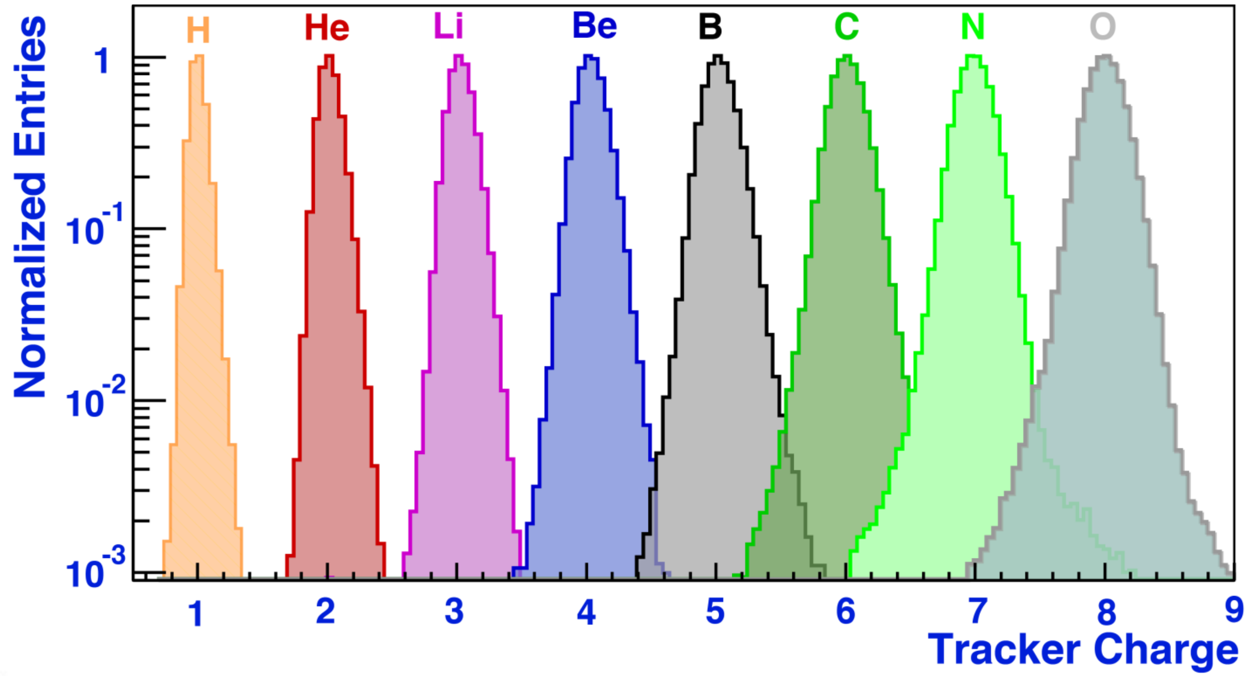


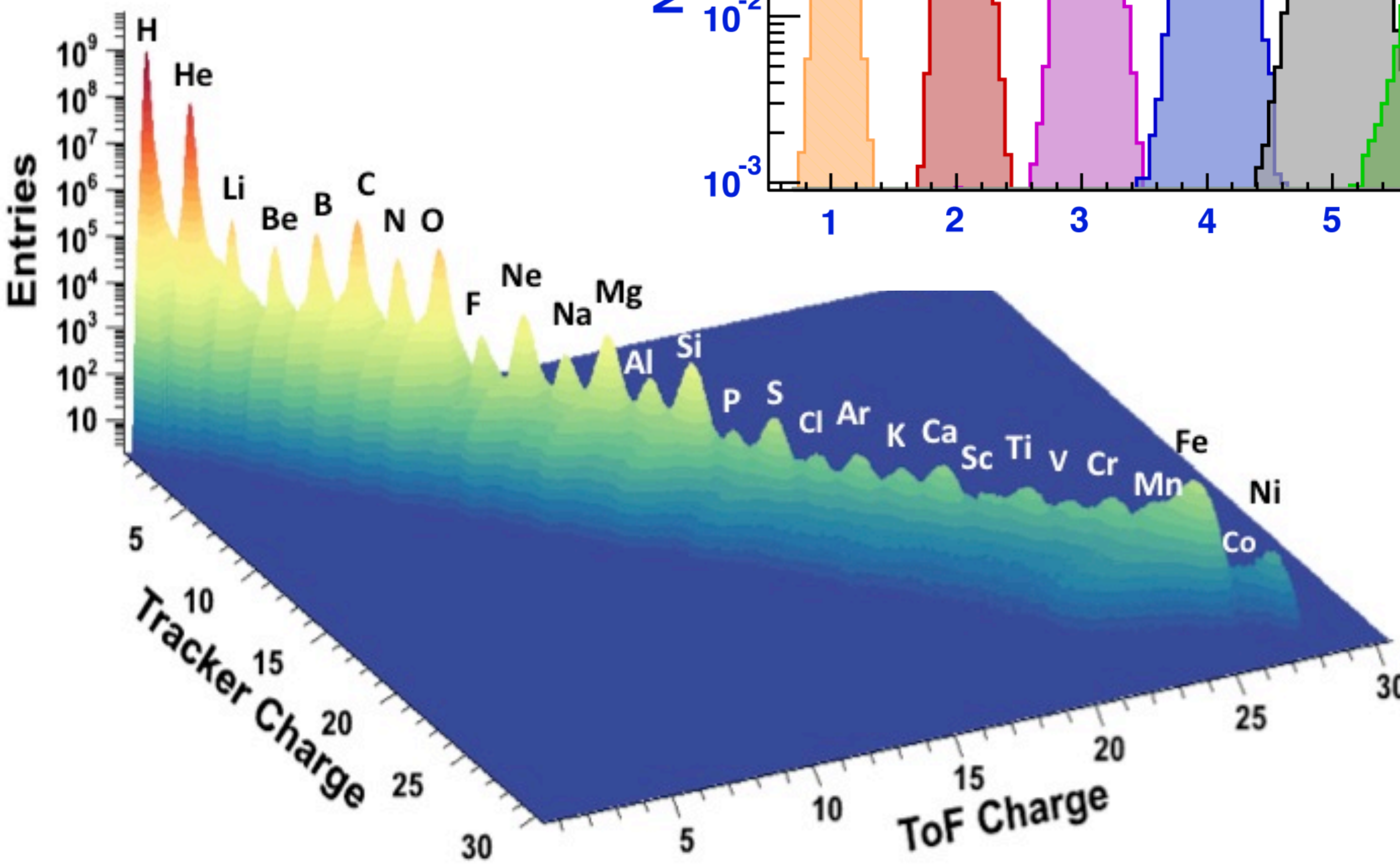
The spectral indices of electrons and positrons are not constant (γ=-3), but change with energy

The spectral index of (e^+ + e^-) is energy independent

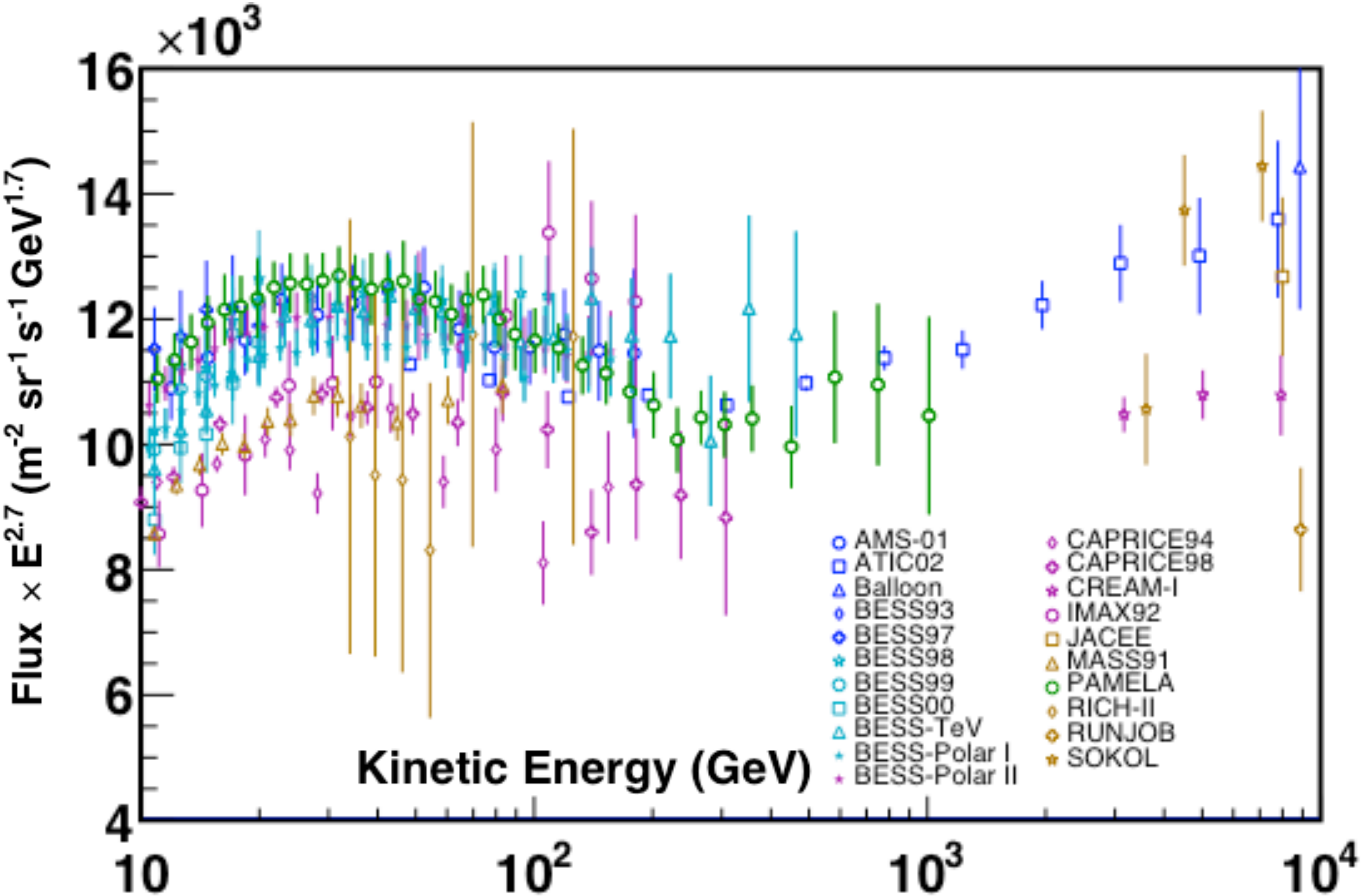


AMS Measurements of Nuclei





Measurements of proton spectrum before AMS



Protons are the most abundant primary cosmic rays.

Precision Measurement of the Proton Flux in Primary Cosmic Rays from Rigidity 1 GV to 1.8 TV with the Alpha Magnetic Spectrometer on the International Space Station

M. Aguilar,[26] D. Aisa,[33,34] B. Alpat,[33] A. Alvino,[33] G. Ambrosi,[33] K. Andeen,[22] L. Arruda,[24] N. Attig,[21] P. Azzarello,[33,16]

The isotropic proton flux Φ_i for the i^{th} rigidity bin (R_i, $R_i + \Delta R_i$) is

$$\Phi_i = \frac{N_i}{A_i \varepsilon_i T_i \Delta R_i}$$

N_i is the number of events; **A_i is the effective acceptance;**

ε_i is the trigger efficiency; **T_i is the collection time (which depends on the geomagnetic cutoff).**

To match the statistics of 300 million events, extensive systematic errors studies have been made.

TABLE I: The proton flux Φ as a function of rigidity

Rigidity [GV]	Φ	$\sigma_{\text{stat.}}$	$\sigma_{\text{trig.}}$	$\sigma_{\text{acc.}}$	$\sigma_{\text{unf.}}$	σ_{scale}	$\sigma_{\text{syst.}}$
100 – 108	(4.085	0.007	0.006	0.040	0.035	0.022	0.058) $\times 10^{-2}$
108 – 116	(3.294	0.007	0.005	0.033	0.028	0.018	0.047) $\times 10^{-2}$
116 – 125	(2.698	0.006	0.004	0.027	0.023	0.016	0.039) $\times 10^{-2}$
125 – 135	(2.174	0.005	0.004	0.022	0.019	0.013	0.032) $\times 10^{-2}$

1) $\sigma_{\text{trig.}}$: trigger efficiency

2) $\sigma_{\text{acc.}}$:

- **a. the acceptance and event selection**
- **b. background contamination**
- **c. geomagnetic cutoff**

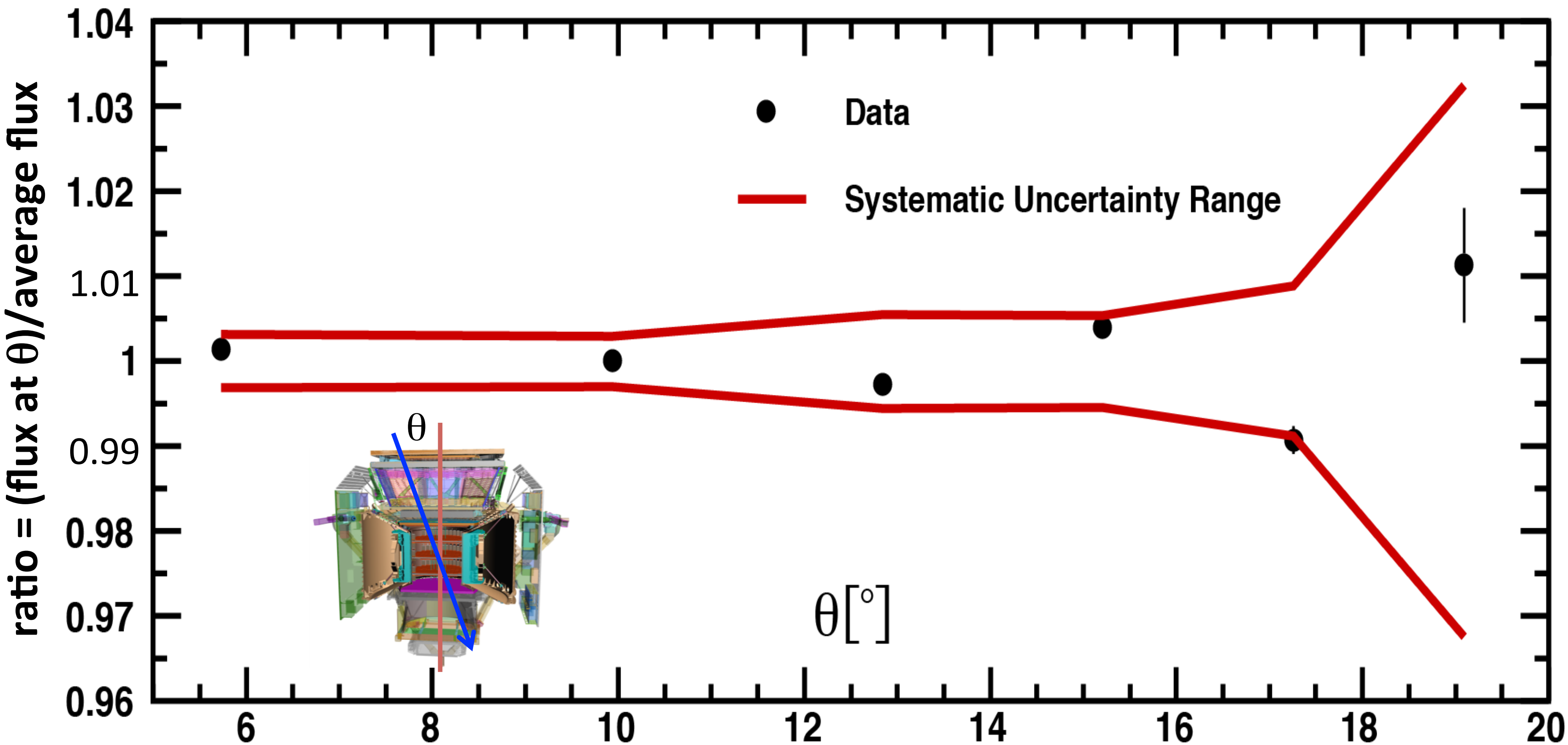
3) $\sigma_{\text{unf.}}$

- **a. unfolding**
- **b. the rigidity resolution function**

4) $\sigma_{\text{scale.}}$: the absolute rigidity scale

Verification of the systematic errors (1).

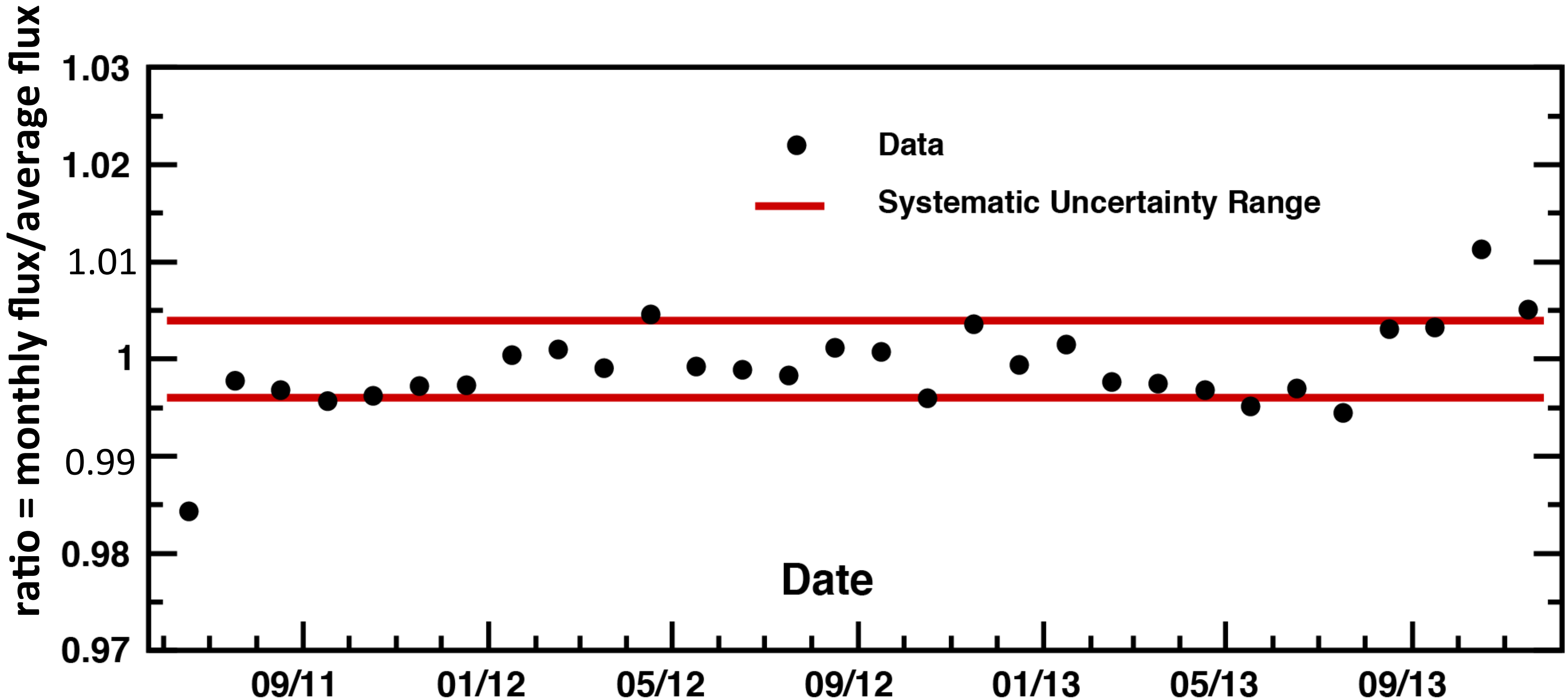
Study the dependence of the integral of the proton flux above 30 GV on the angle ϑ between the incoming proton direction and the AMS zenith axis.



This verifies the systematic error assigned to the acceptance.

Verification of the systematic errors (2).

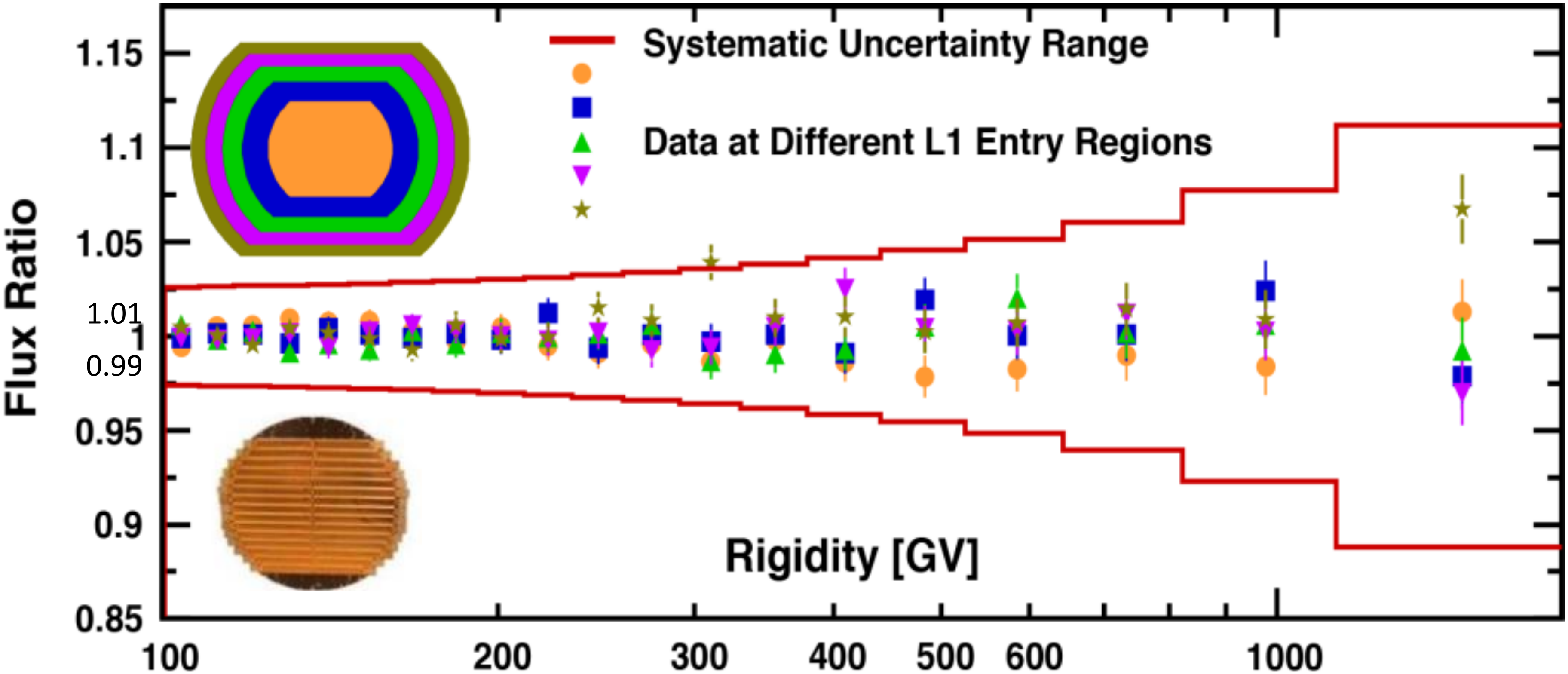
The monthly integral flux above 45GV is within the systematic error of 0.4%.



This verifies that the flux above 45GV shows no observable effect from solar modulation fluctuations and that the detector performance is stable.

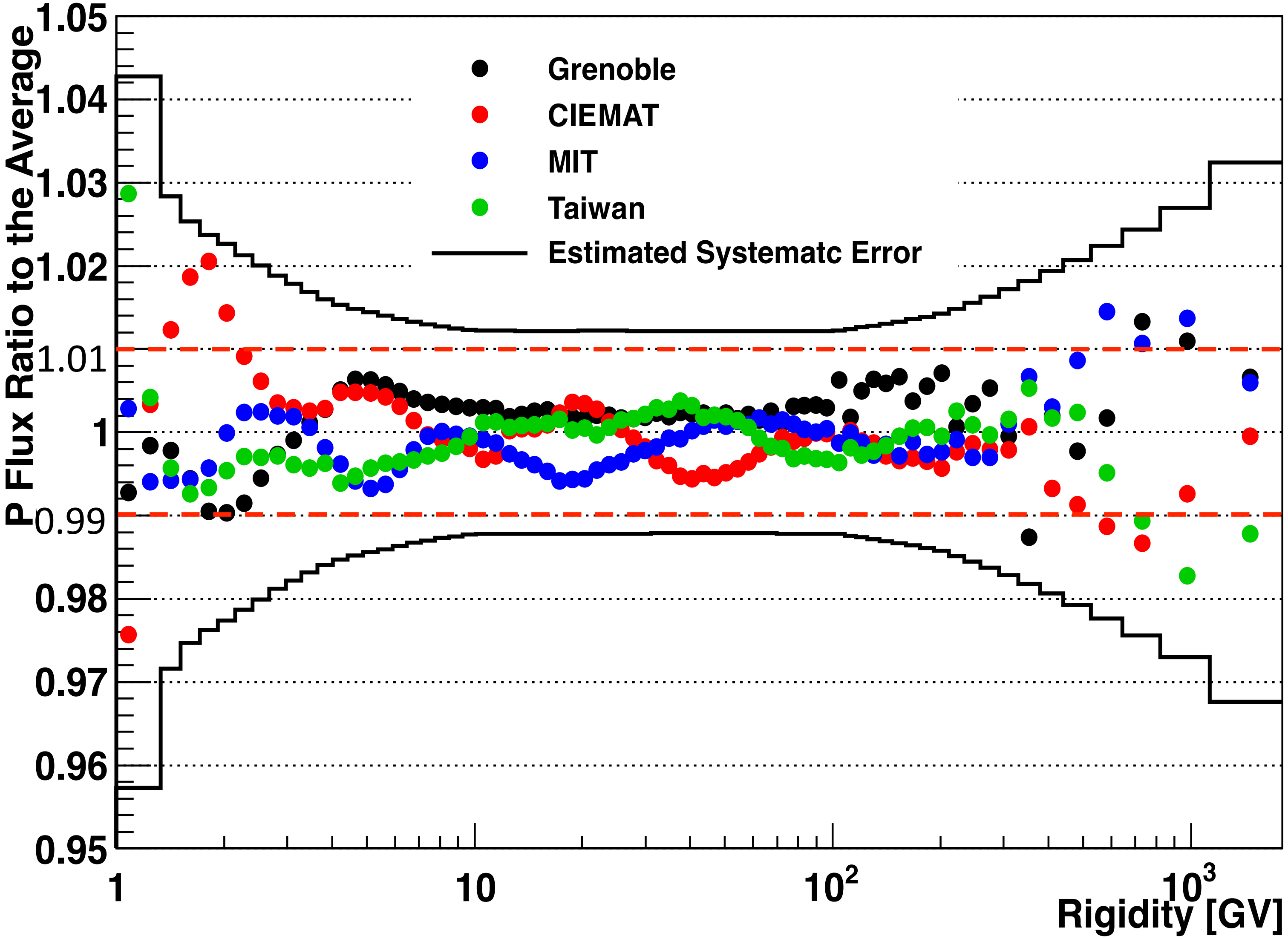
Verification of the systematic errors (3).

The ratios of fluxes obtained using events which pass through different sections of L1 to the average flux is in good agreement and within the assigned systematic errors.

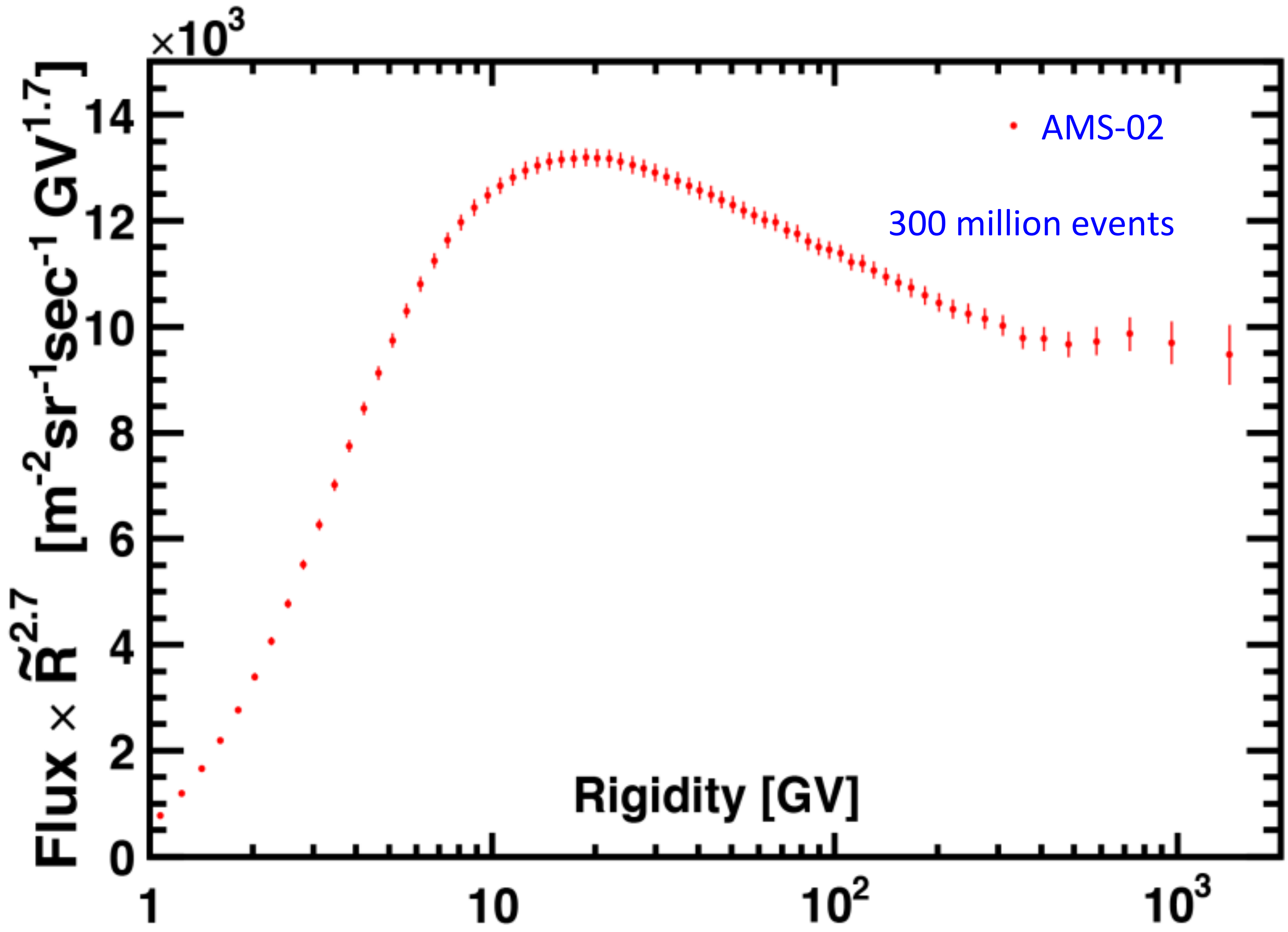


This verifies the errors assigned to the tracker alignment.

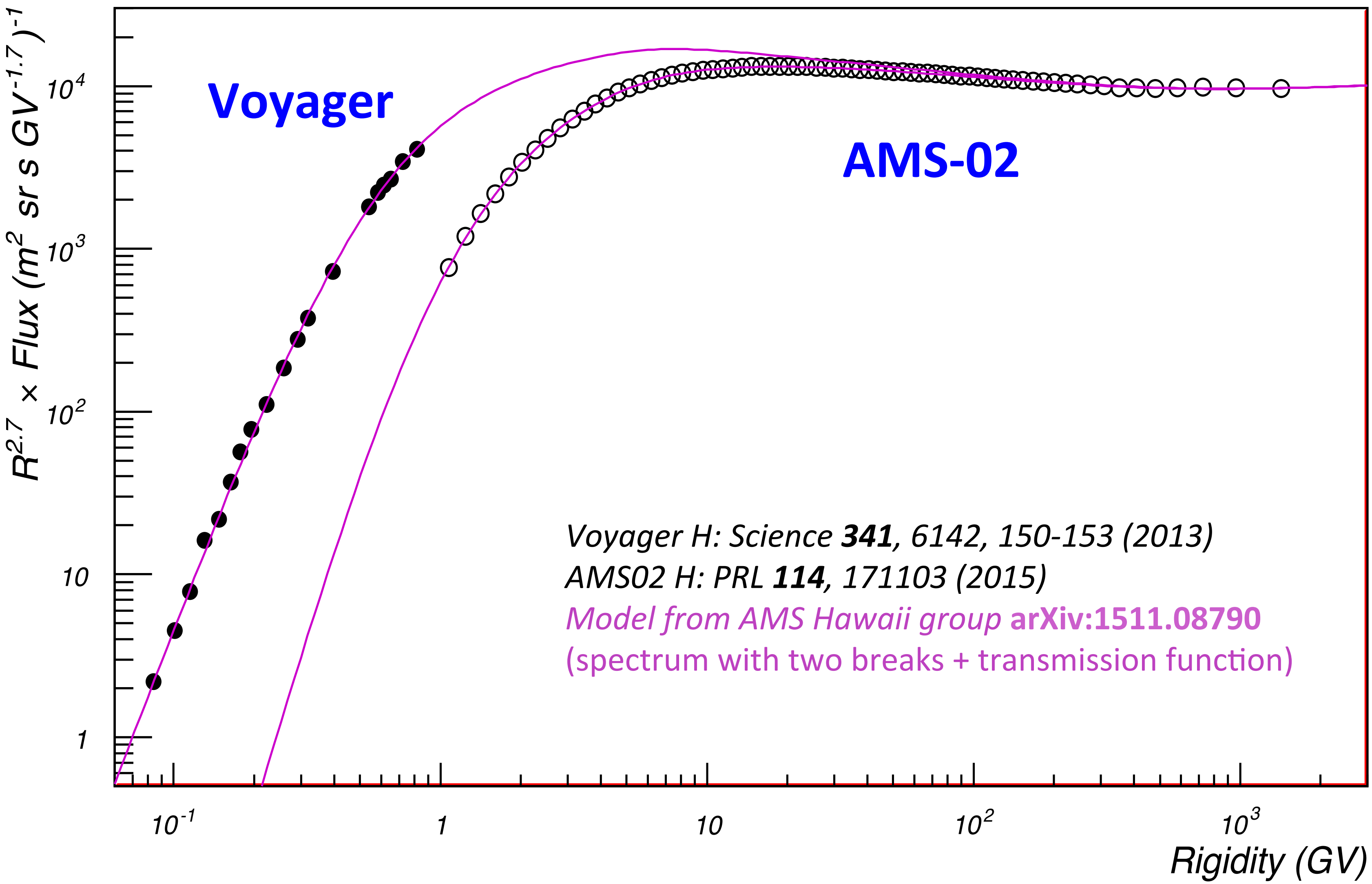
There are no plans to put another Magnetic Spectrometer in space.
The AMS proton, helium, … fluxes are unique.
These fluxes are analyzed by 4 independent study groups.



AMS proton flux

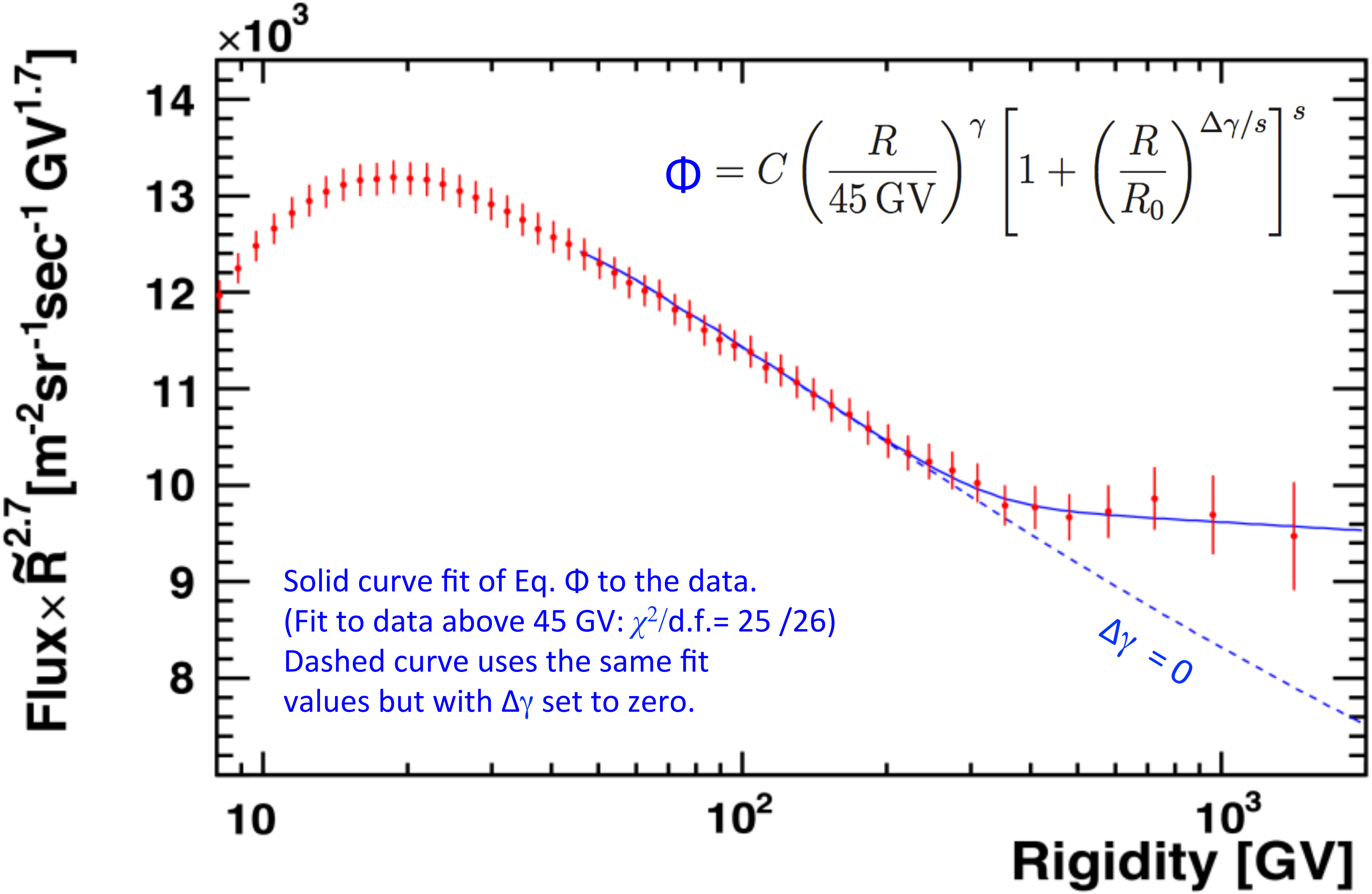


Fit Solar Modulation Potential:
Fit AMS Proton data with model from AMS Hawaii group



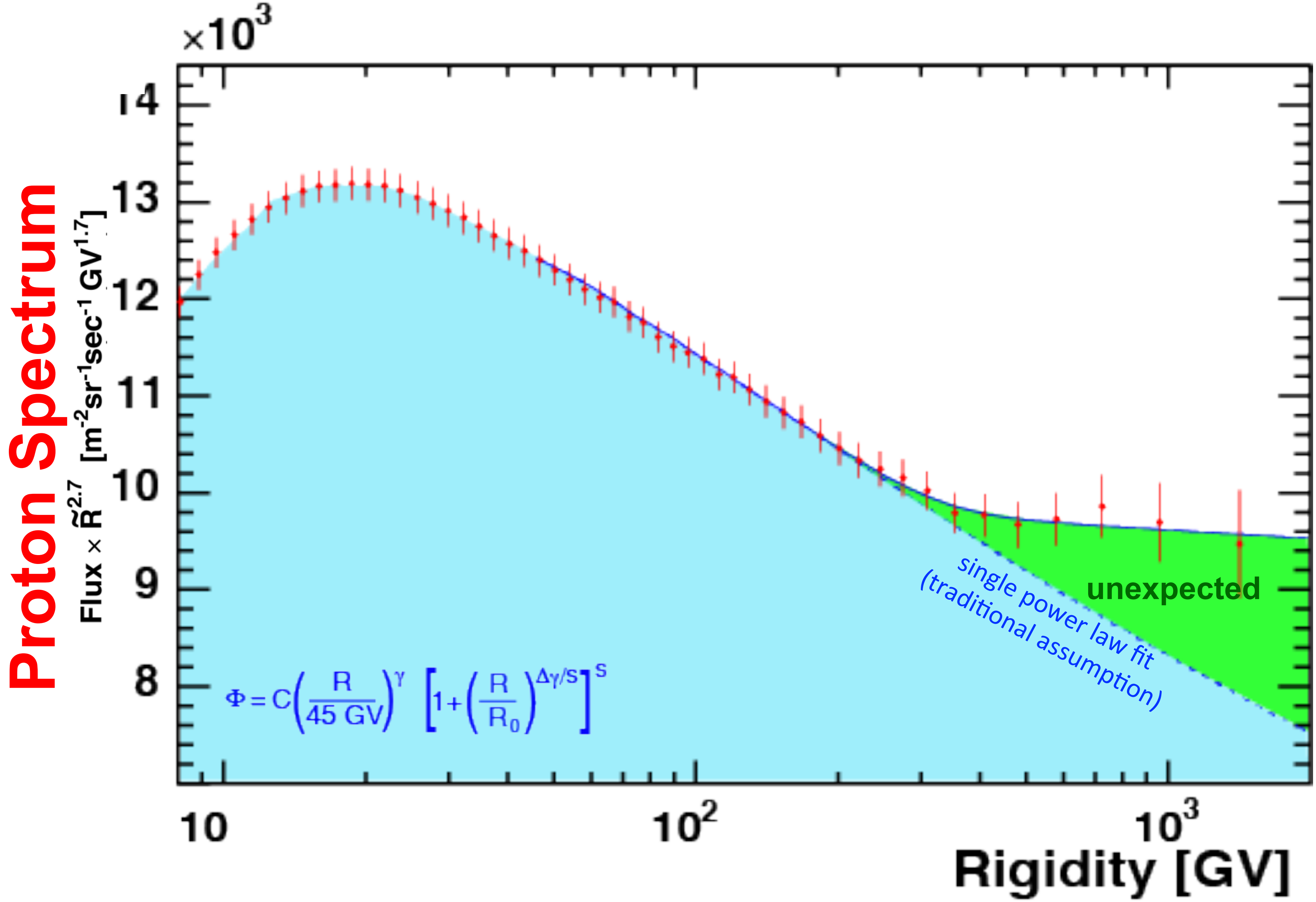
AMS proton flux fit with two power laws:

R^{γ}, $R^{\gamma+\Delta\gamma}$ with a characteristic transition rigidity R_0 and smoothness s

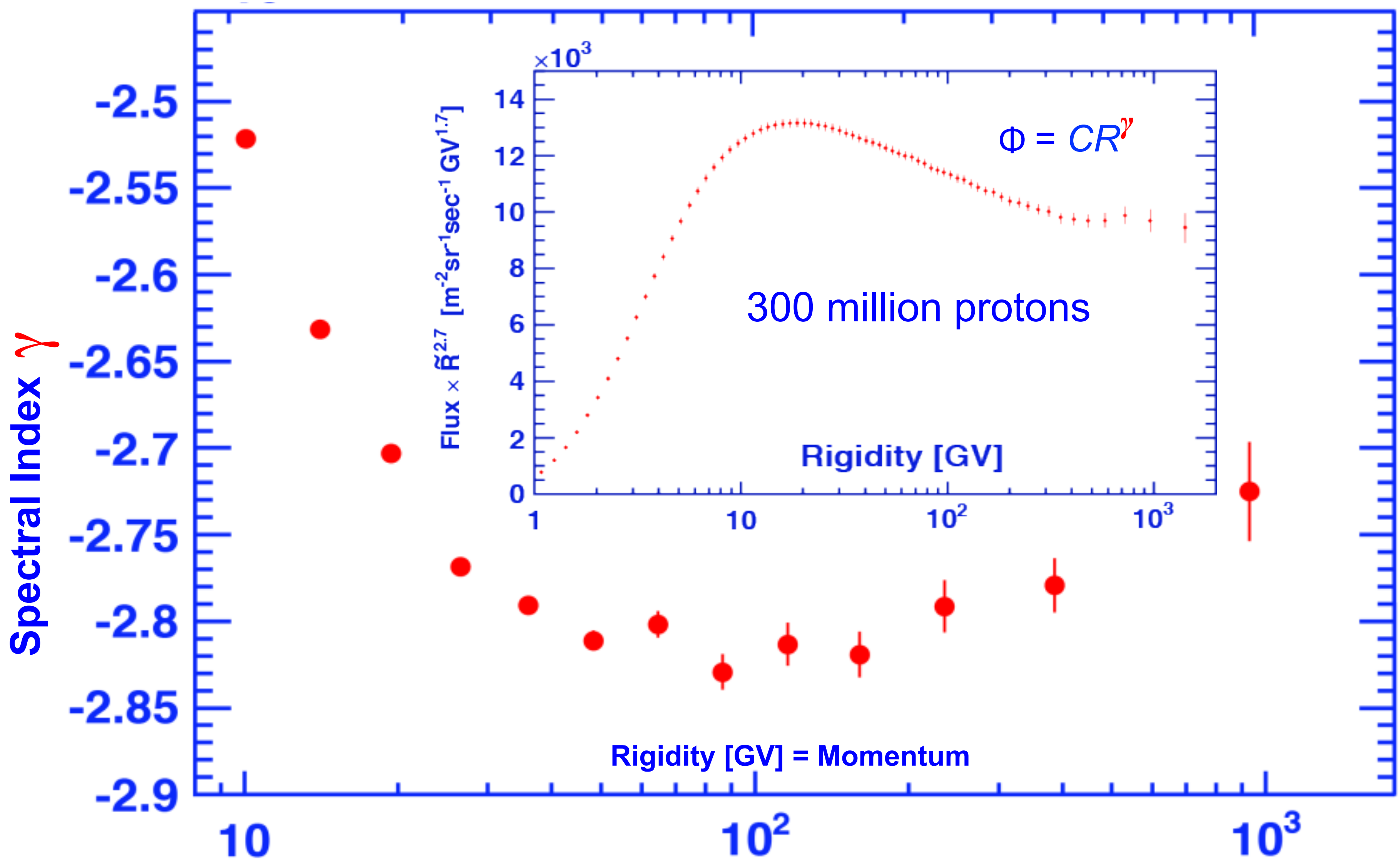


AMS proton flux

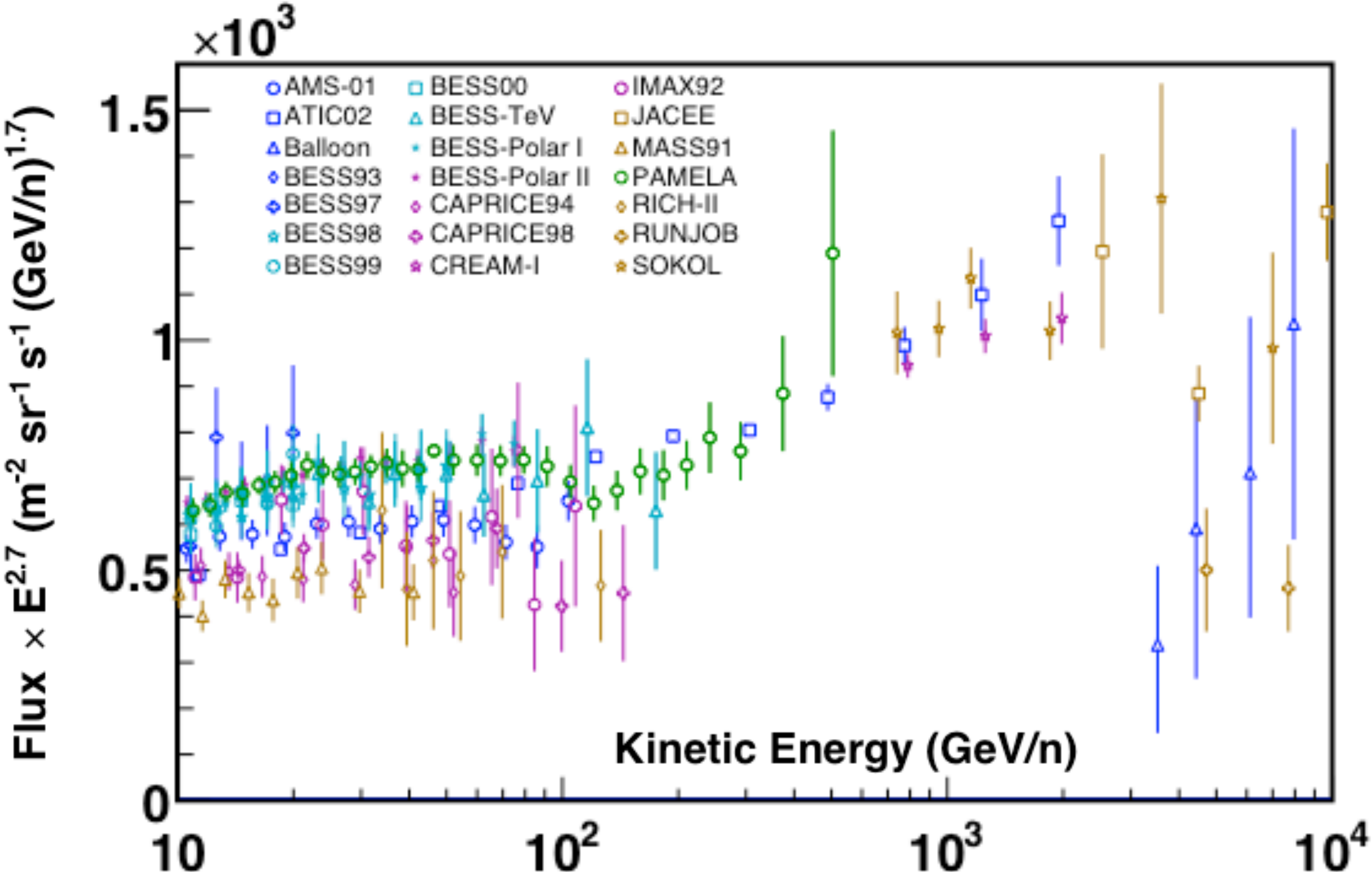
New information: The proton flux cannot be described by a single power law = CR^{γ}



New information:
The proton spectral index changes with momentum
It does not have a constant value γ = -2.7 as traditionally assumed



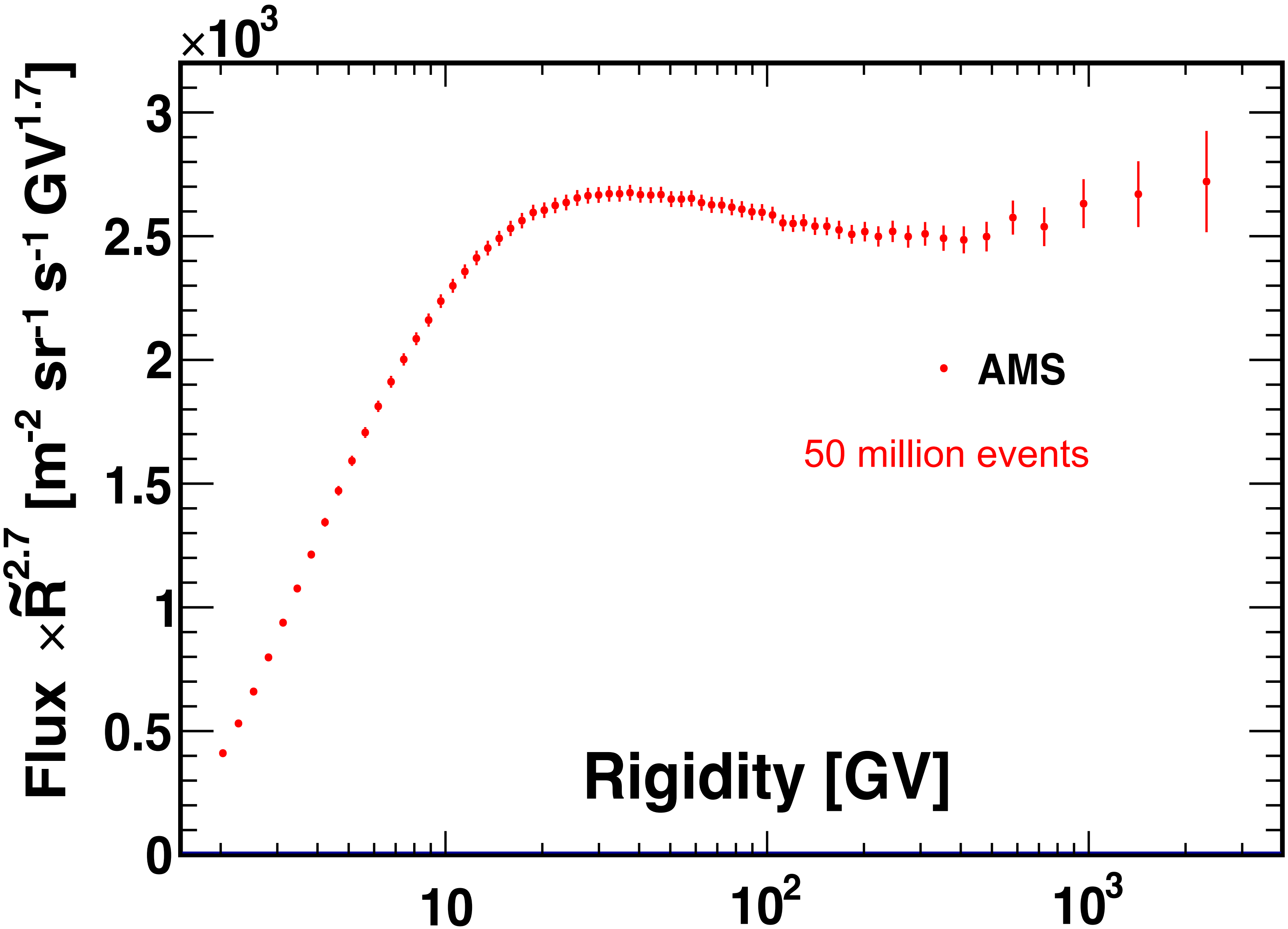
Measurements of helium spectrum before AMS



He is the 2nd most abundant type of primary cosmic rays

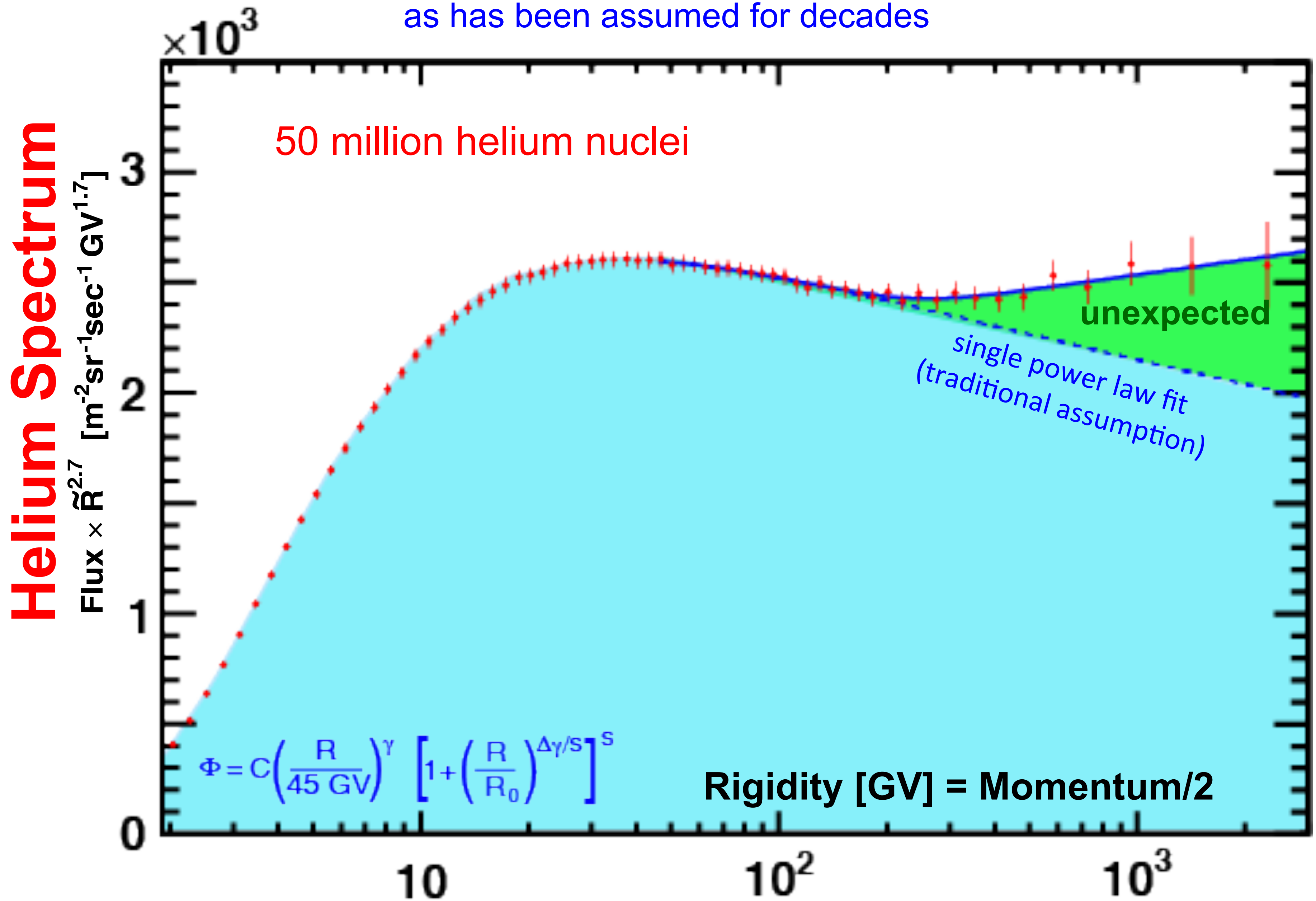
Editor's Suggestions

Precision Measurement of the Helium Flux in Primary Cosmic Rays of Rigidities 1.9 GV to 3 TV with the Alpha Magnetic Spectrometer on the International Space Station



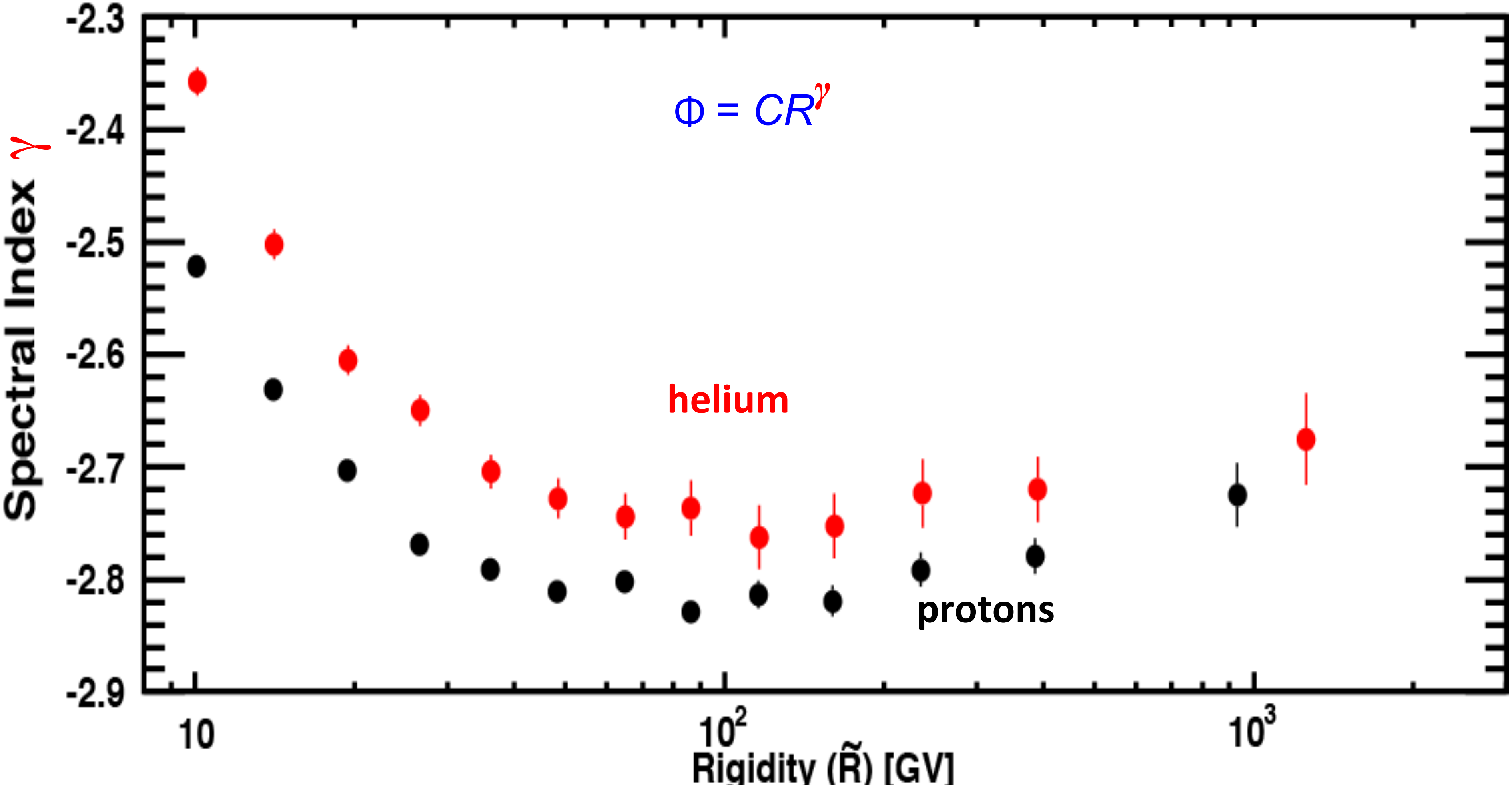
AMS Helium Flux

New information: The helium flux cannot be described by a single power law = CR^{γ}, as has been assumed for decades

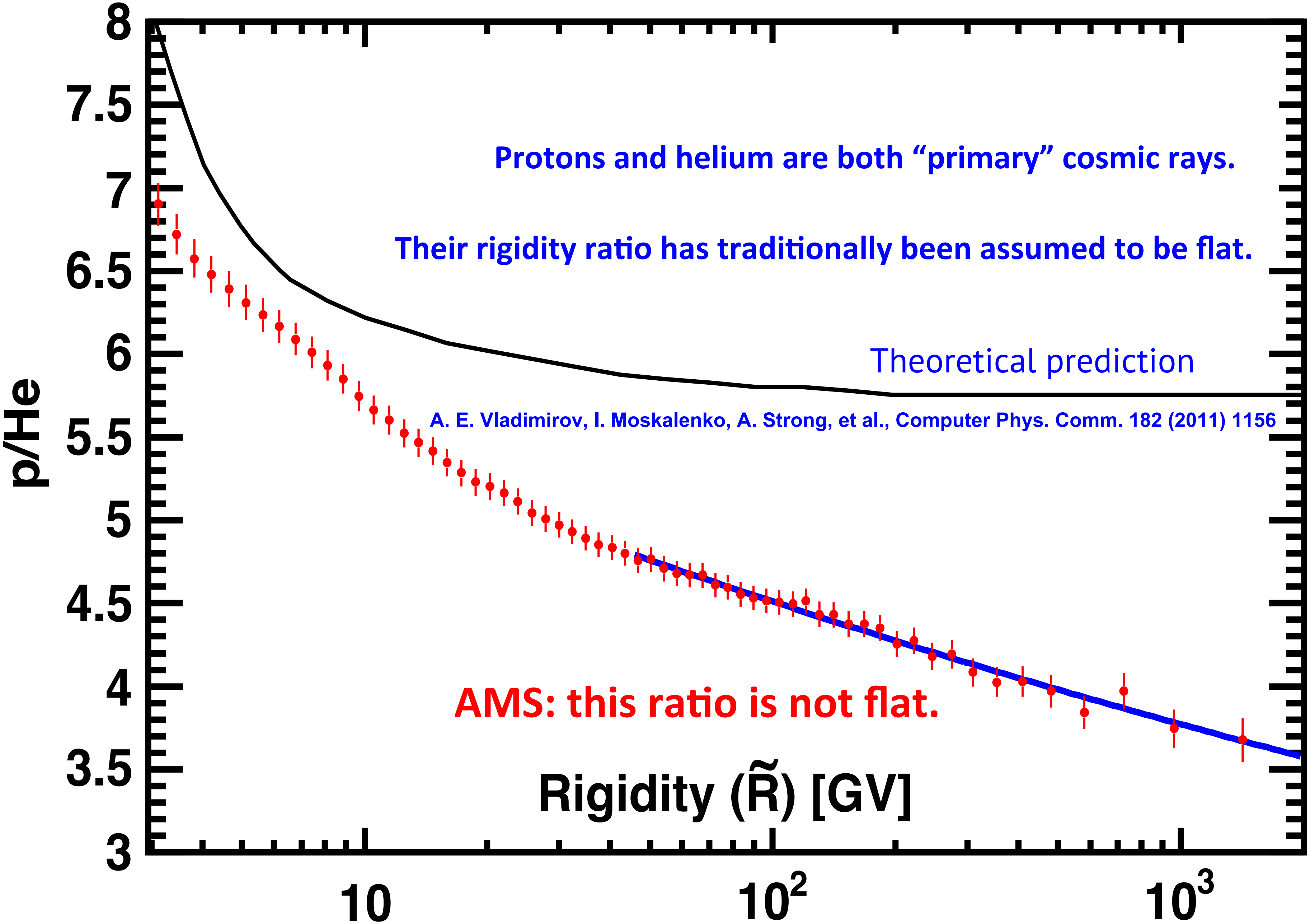


New information:

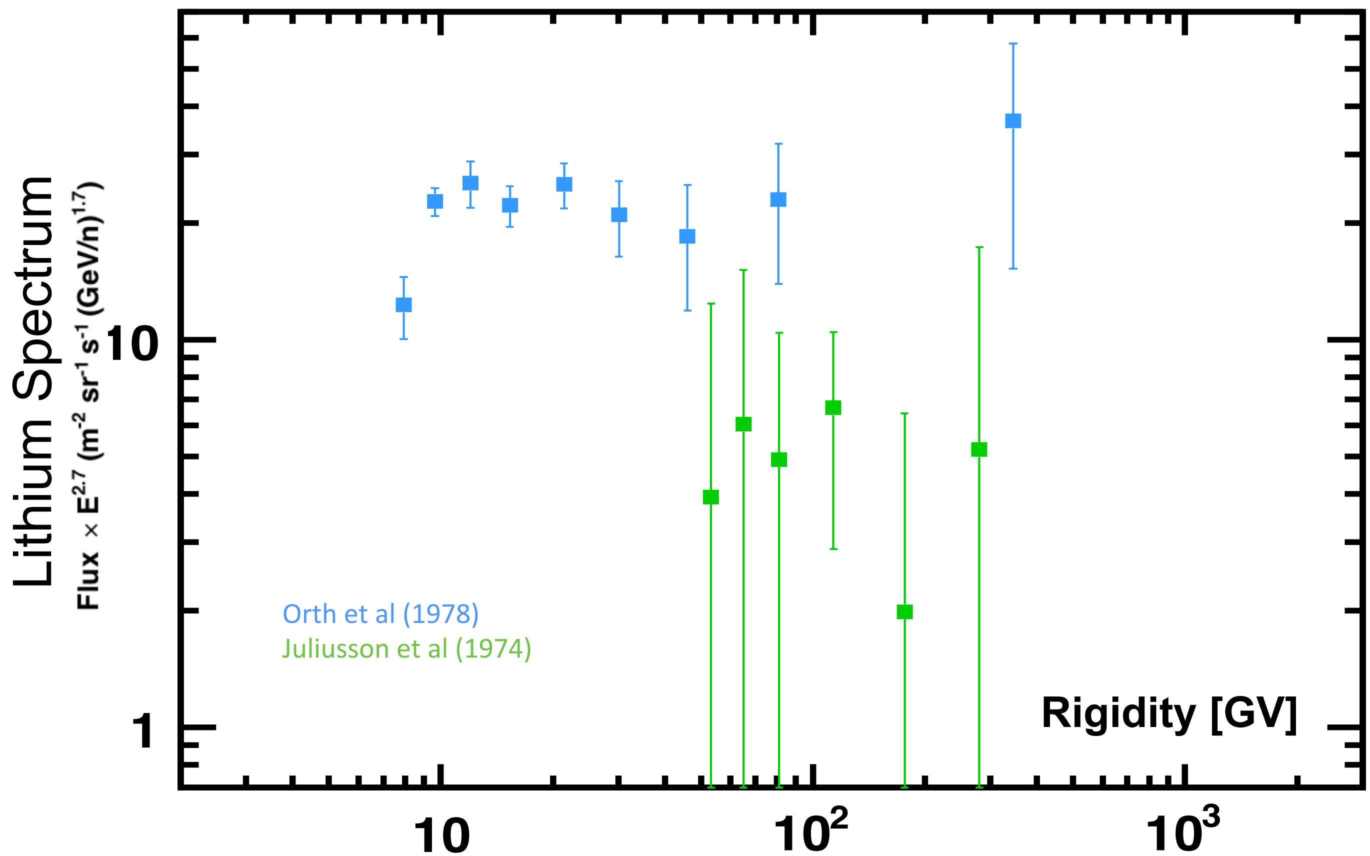
1. The helium spectral index changes with rigidity.
   It is not a constant value γ = -2.7
2. The helium spectral index changes with rigidity in a similar way to that a proton spectrum index but the values are different



The AMS proton/helium flux ratio



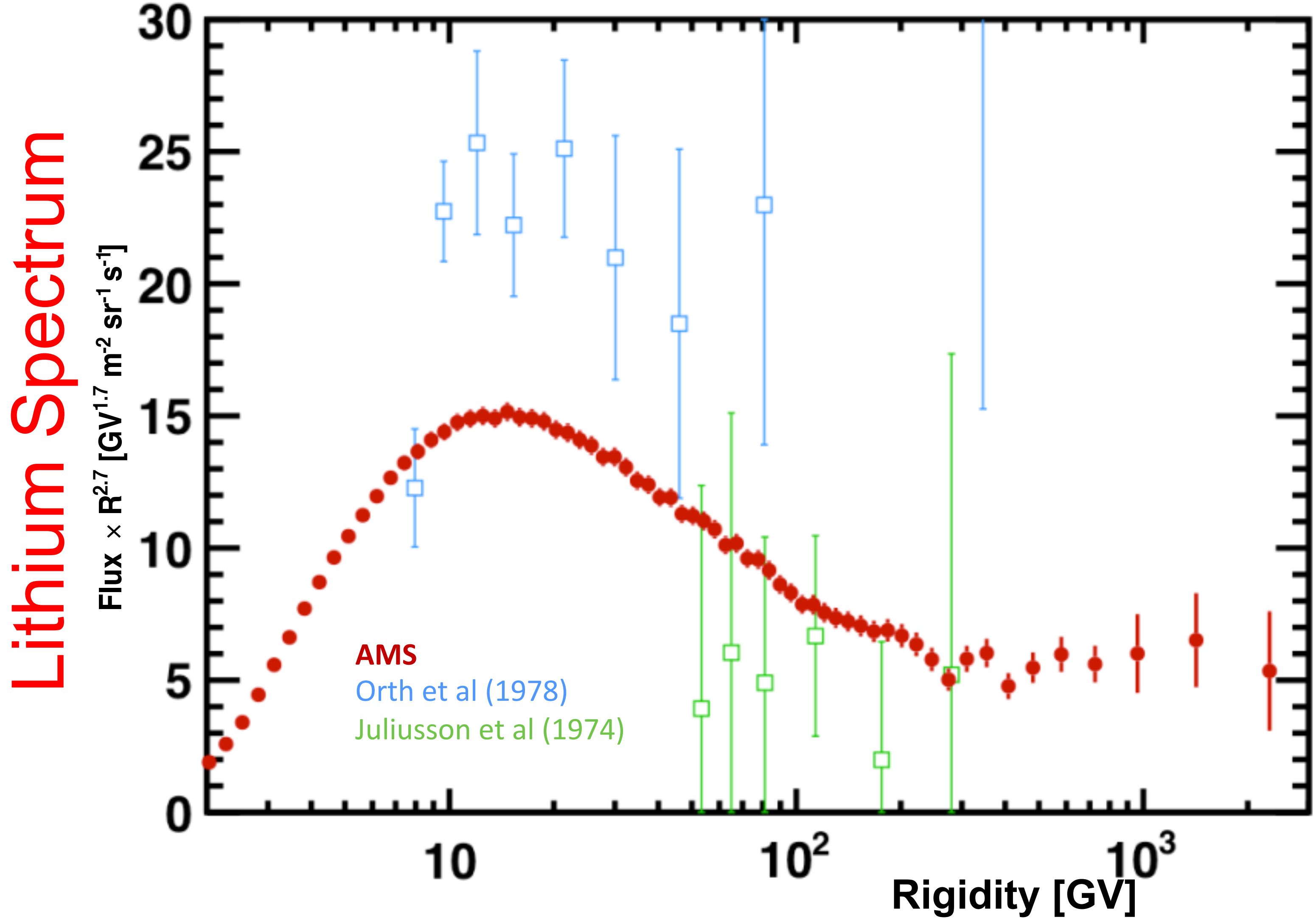
Measurements of lithium spectrum before AMS



1. Lithium were assumed to be purely secondary cosmic rays from the collisions of primary cosmic rays (protons, helium, carbon, oxygen) with interstellar matter.
2. The measurement of the lithium flux provides information on the propagation of cosmic rays in the interstellar medium.
3. The data on the lithium flux was almost non-existent.

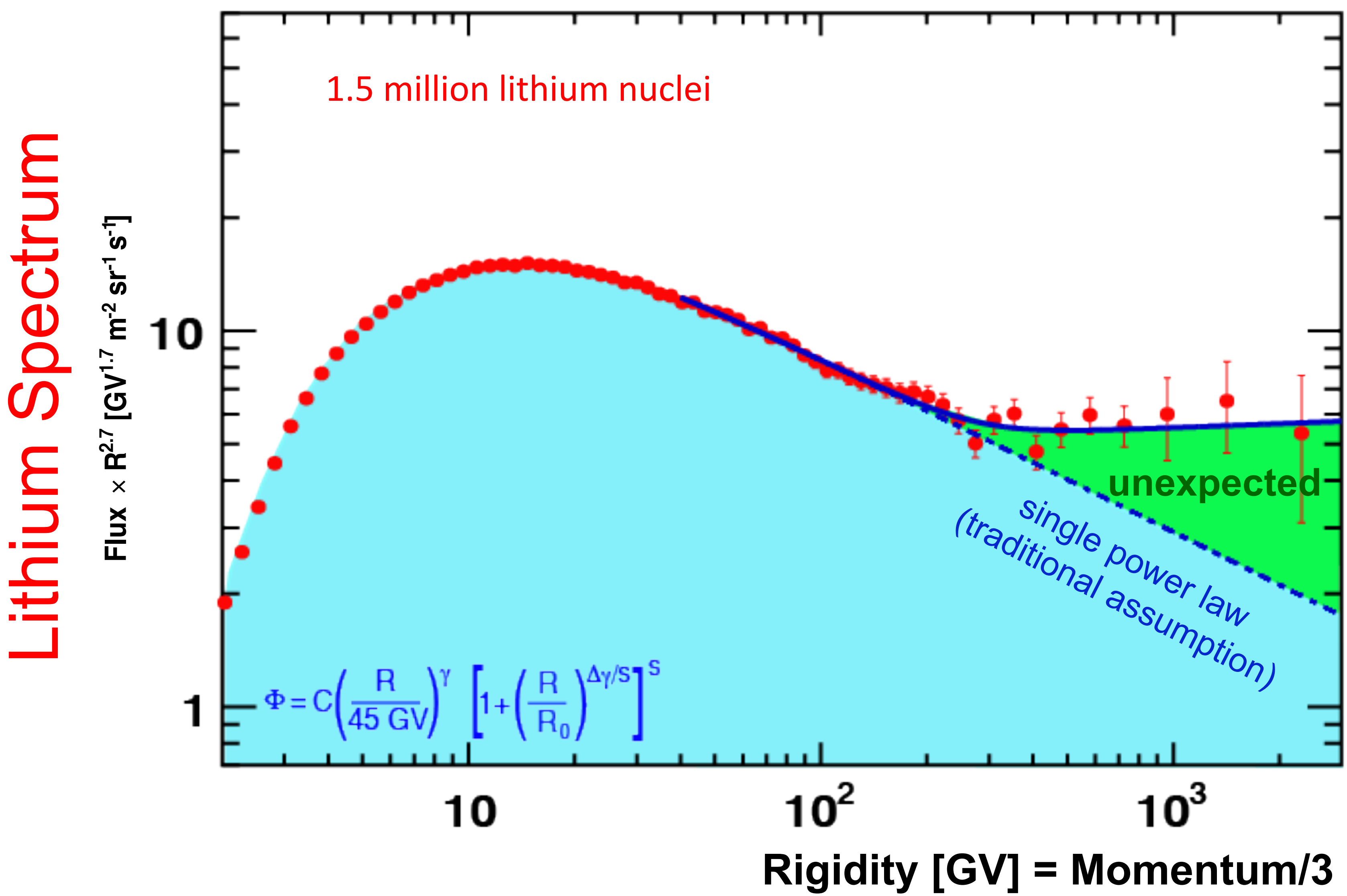
AMS Lithium flux

The results contradict the assumption that cosmic lithium is purely secondary in origin. Purely secondary production of lithium would not produce a sharp transition.



AMS Lithium flux

New information: The lithium flux cannot be described by a single power law = CR^{γ}, as was always assumed

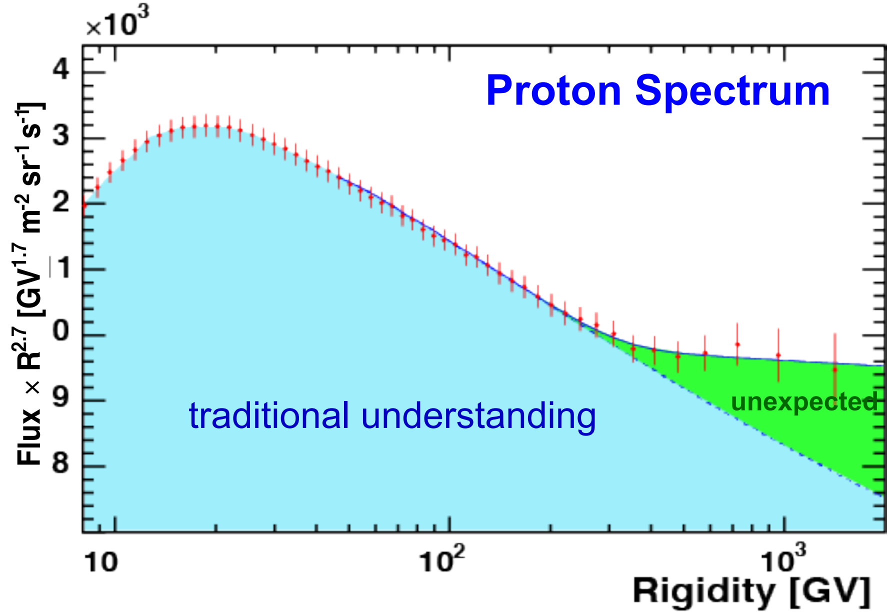


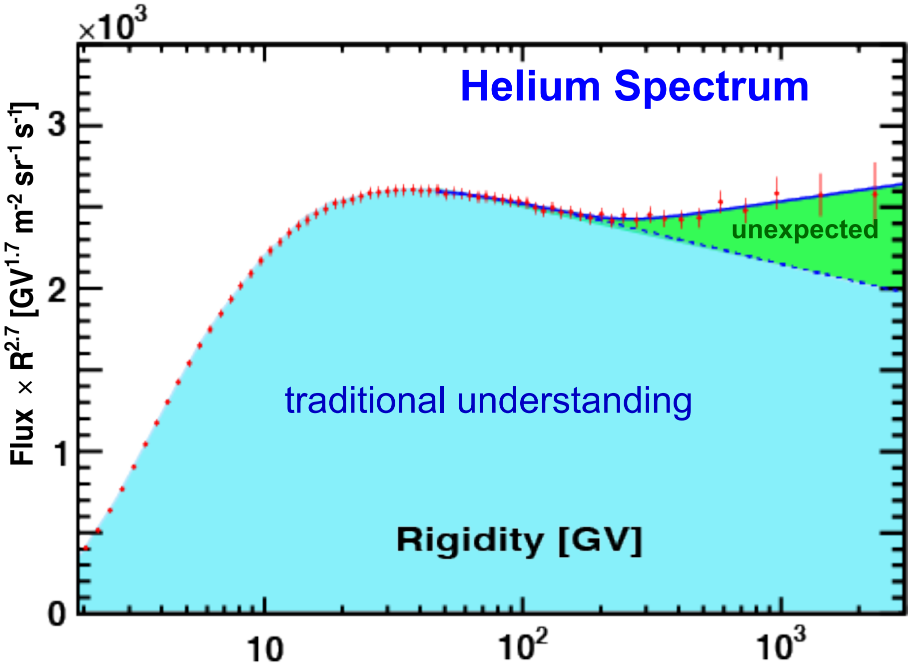
AMS measurements of light nuclei

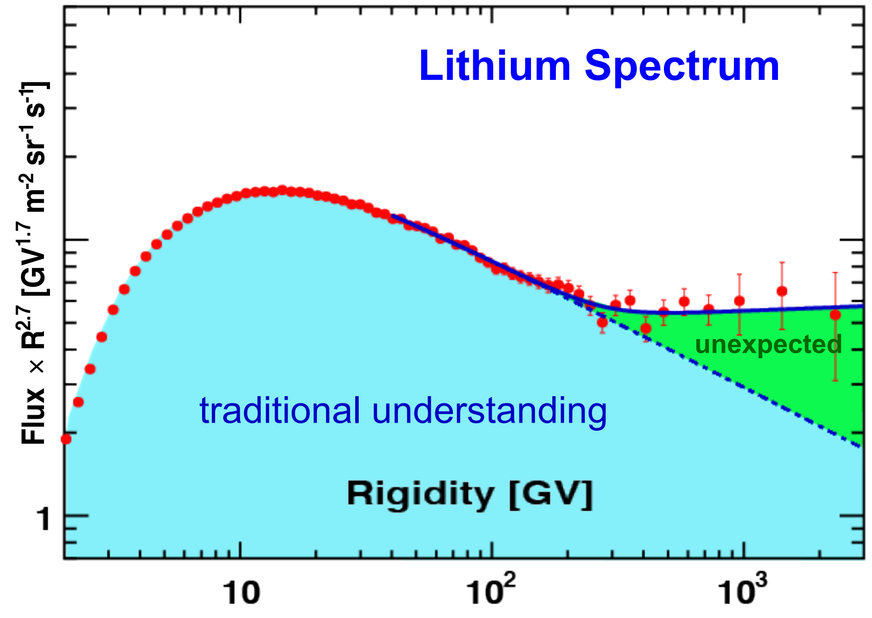
Observation

The flux transitions at about the same rigidity for protons, helium, and lithium.

This new observation contradicts the current understanding of cosmic ray behaviour.

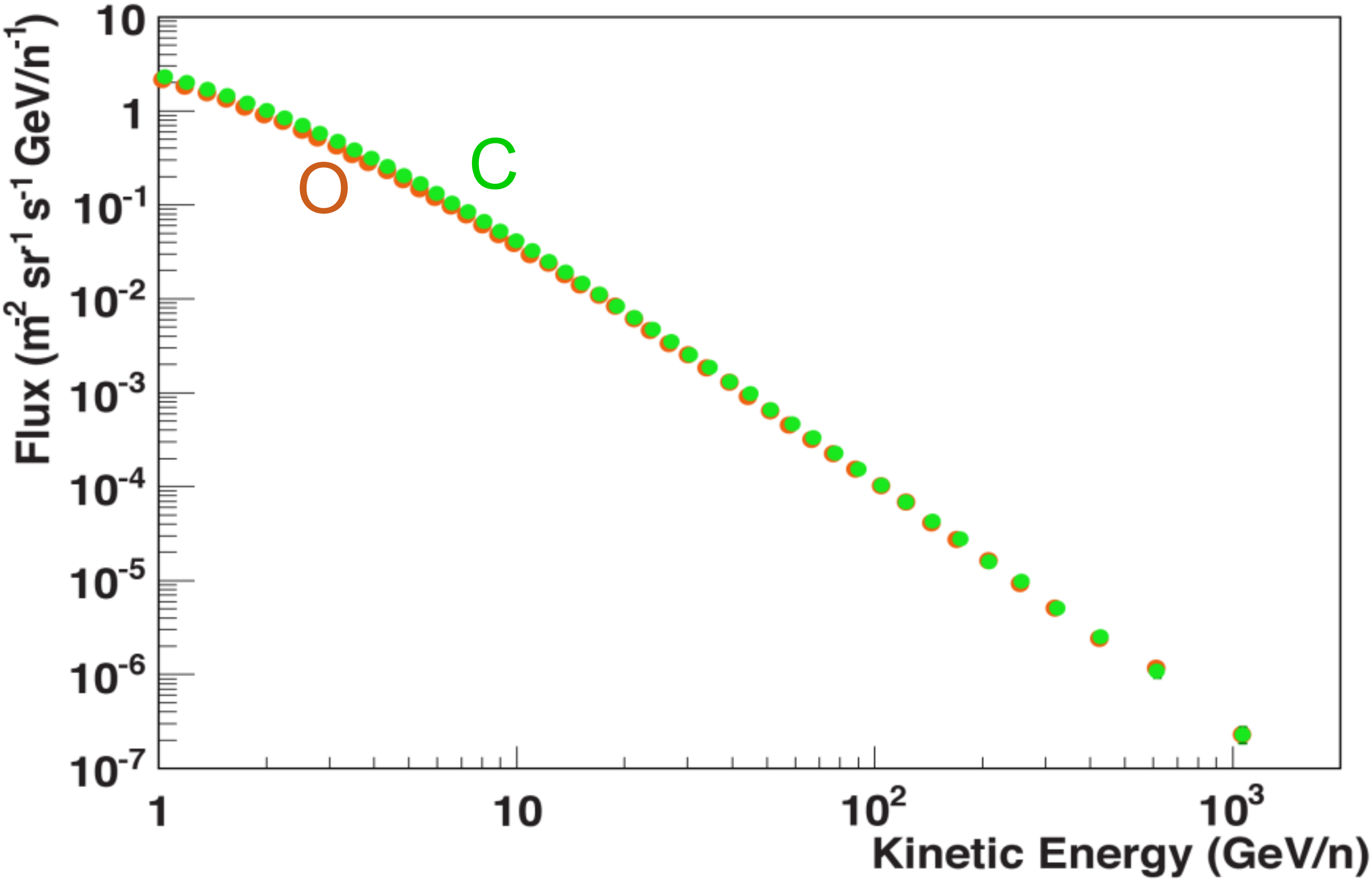




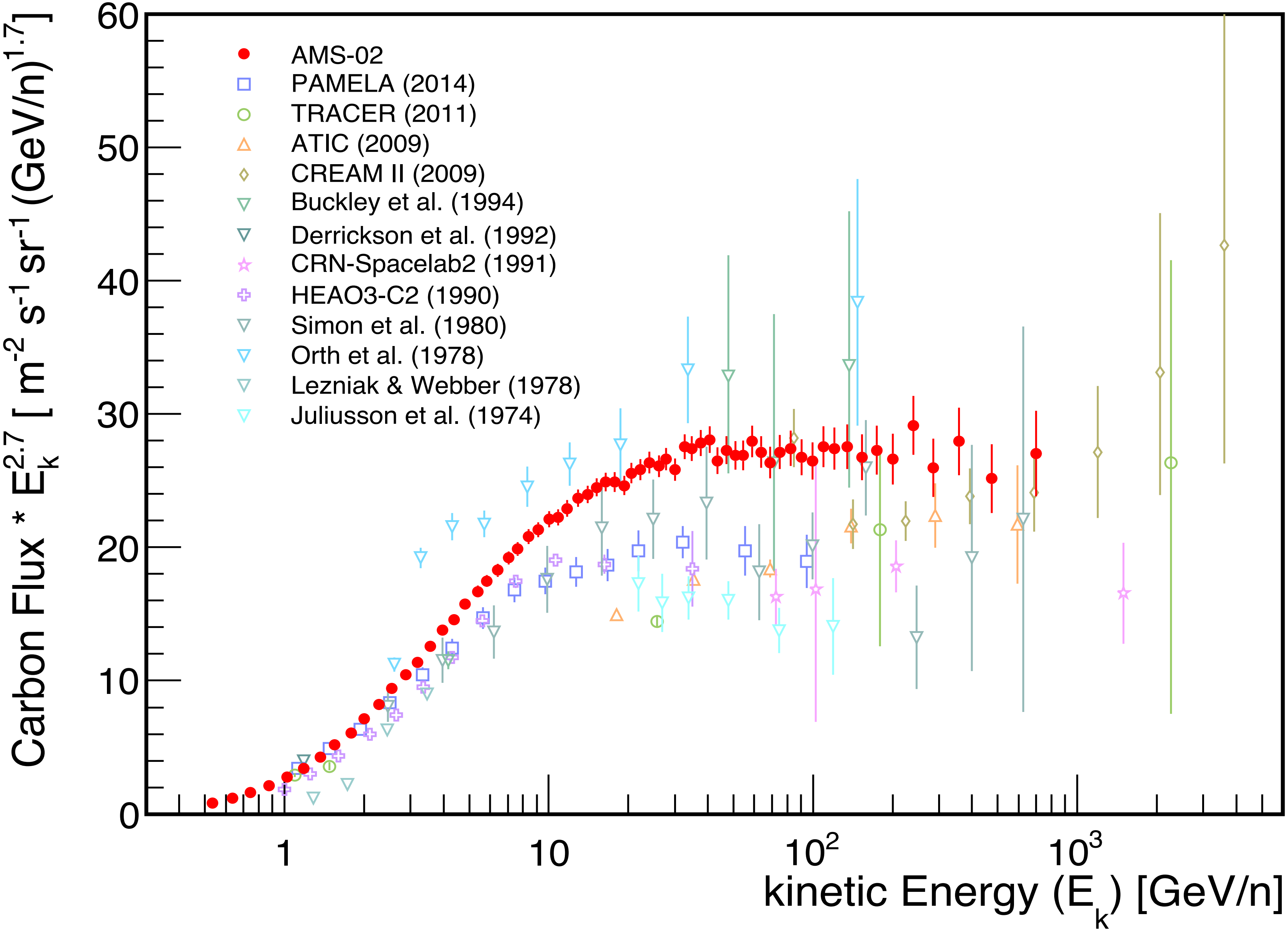


The AMS results have changed the understanding of cosmic rays.

Carbon and Oxygen Fluxes

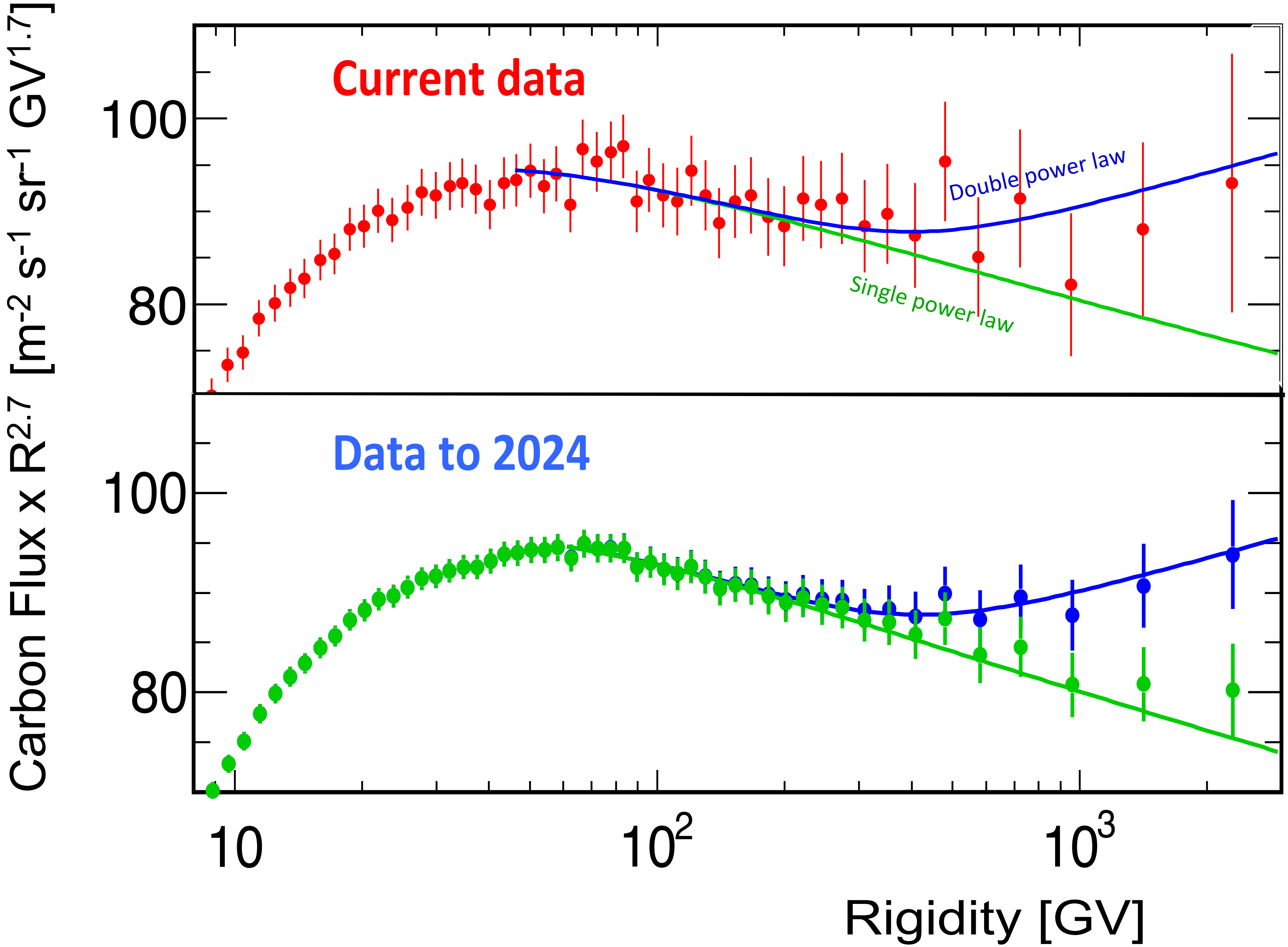


Carbon Flux



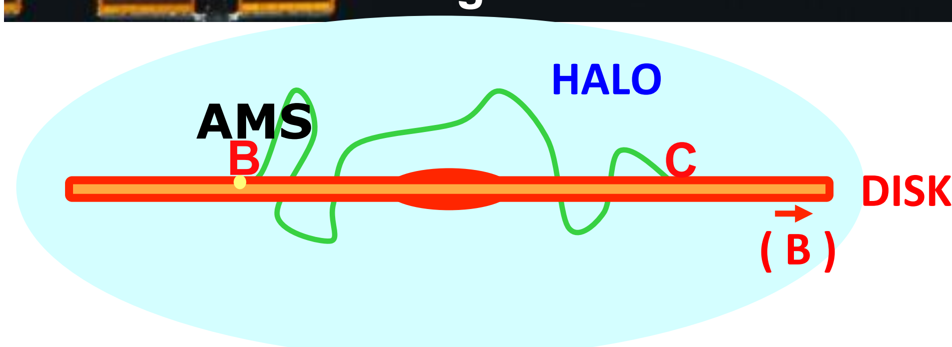
AMS-02
PAMELA (2014)
TRACER (2011)
ATIC (2009)
CREAM II (2009)
Buckley et al. (1994)
Derrickson et al. (1992)
CRN-Spacelab2 (1991)
HEAO3-C2 (1990)
Simon et al. (1980)
Orth et al. (1978)
Lezniak & Webber (1978)
Juliusson et al. (1974)
Carbon Flux * $E_k^{2.7}$ [m^{-2} s^{-1} sr^{-1} $(GeV/n)^{1.7}$]
kinetic Energy (E_k) [GeV/n]
0
10
20
30
40
50
60
1
10
10^2
10^3

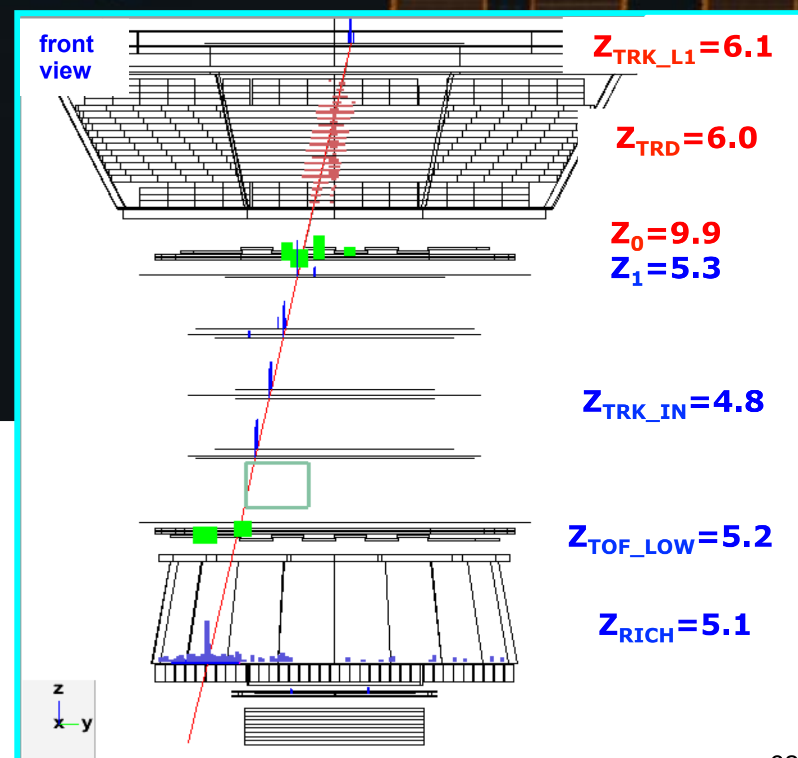
Carbon Flux



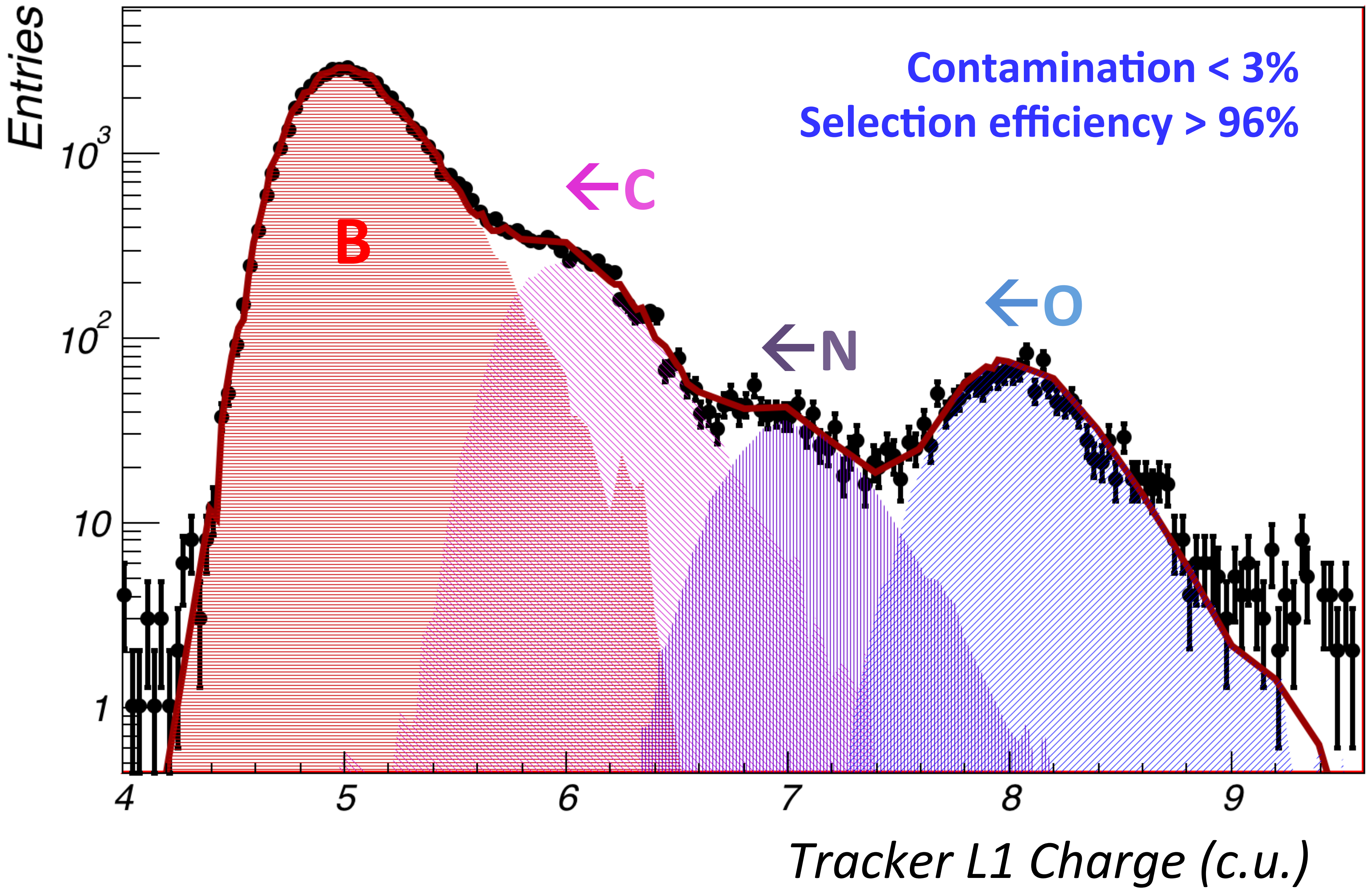
Current data
Double power law
Single power law
Data to 2024
Carbon Flux x R^2.7 [m^-2 s^-1 sr^-1 GV^1.7]
100
80
10
10^2
10^3
Rigidity [GV]

The propagation of cosmic rays and their interactions with the Interstellar Medium (ISM) is measured through the B/C ratio.

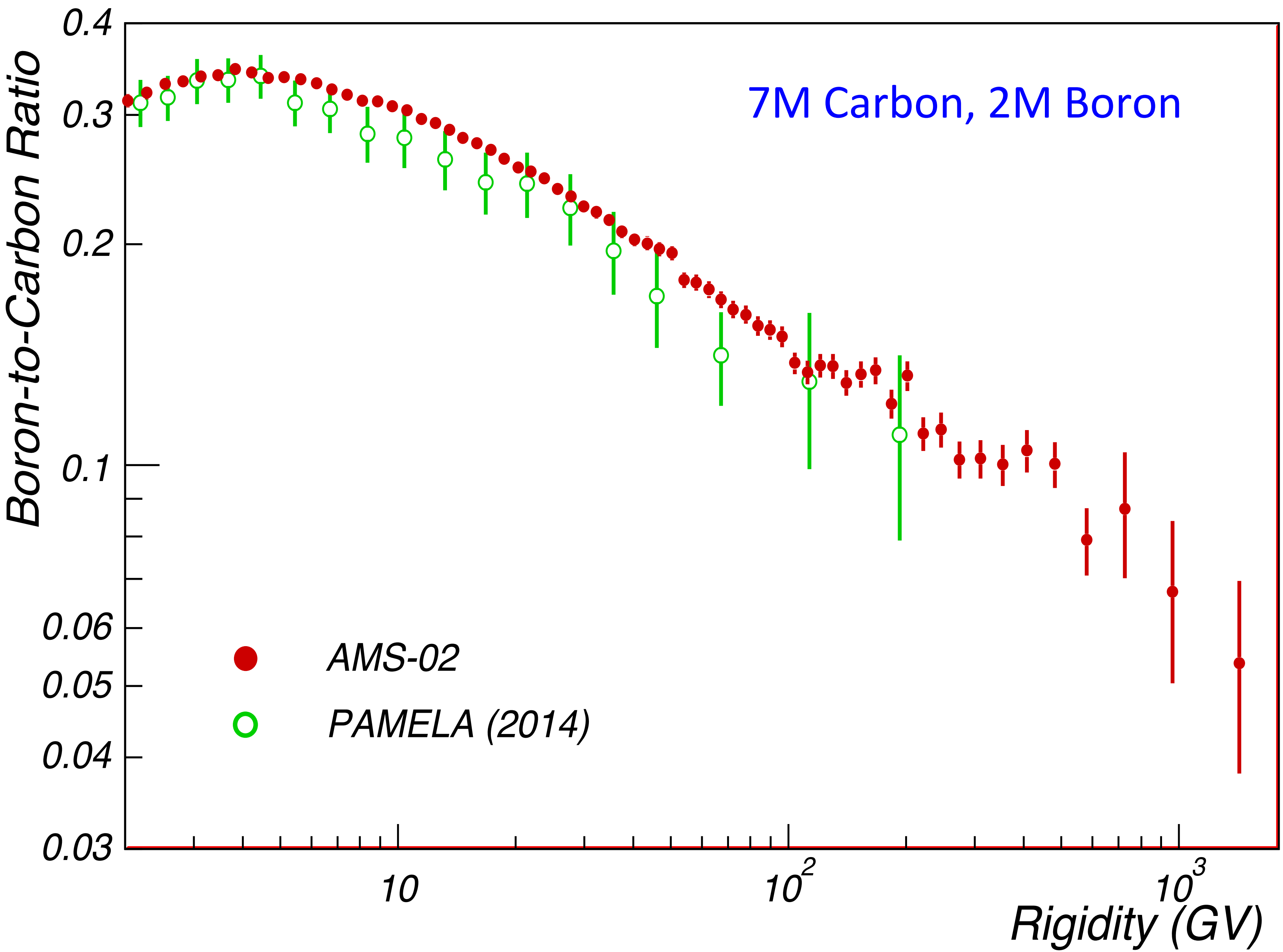




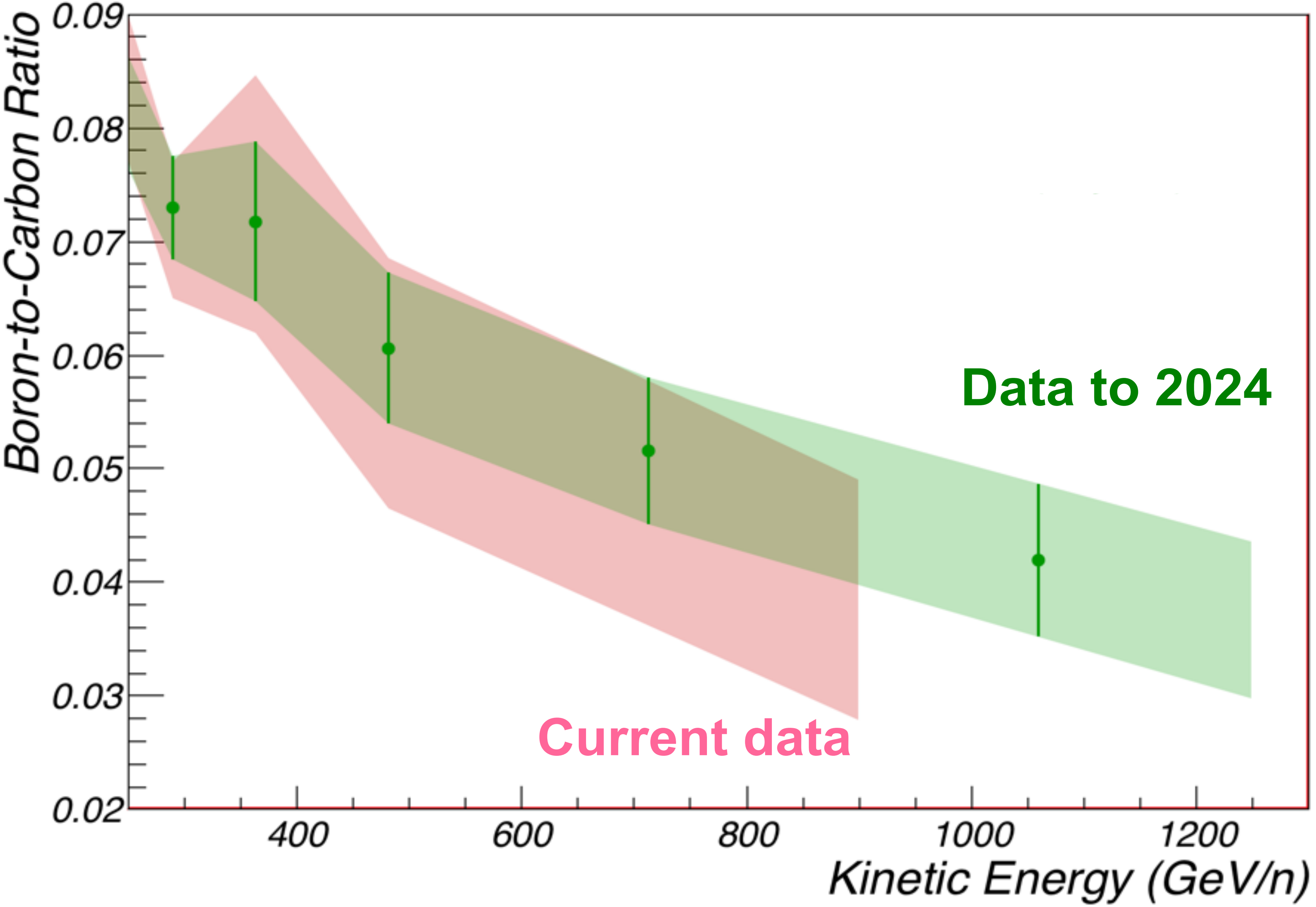
Boron and Carbon: Sample composition



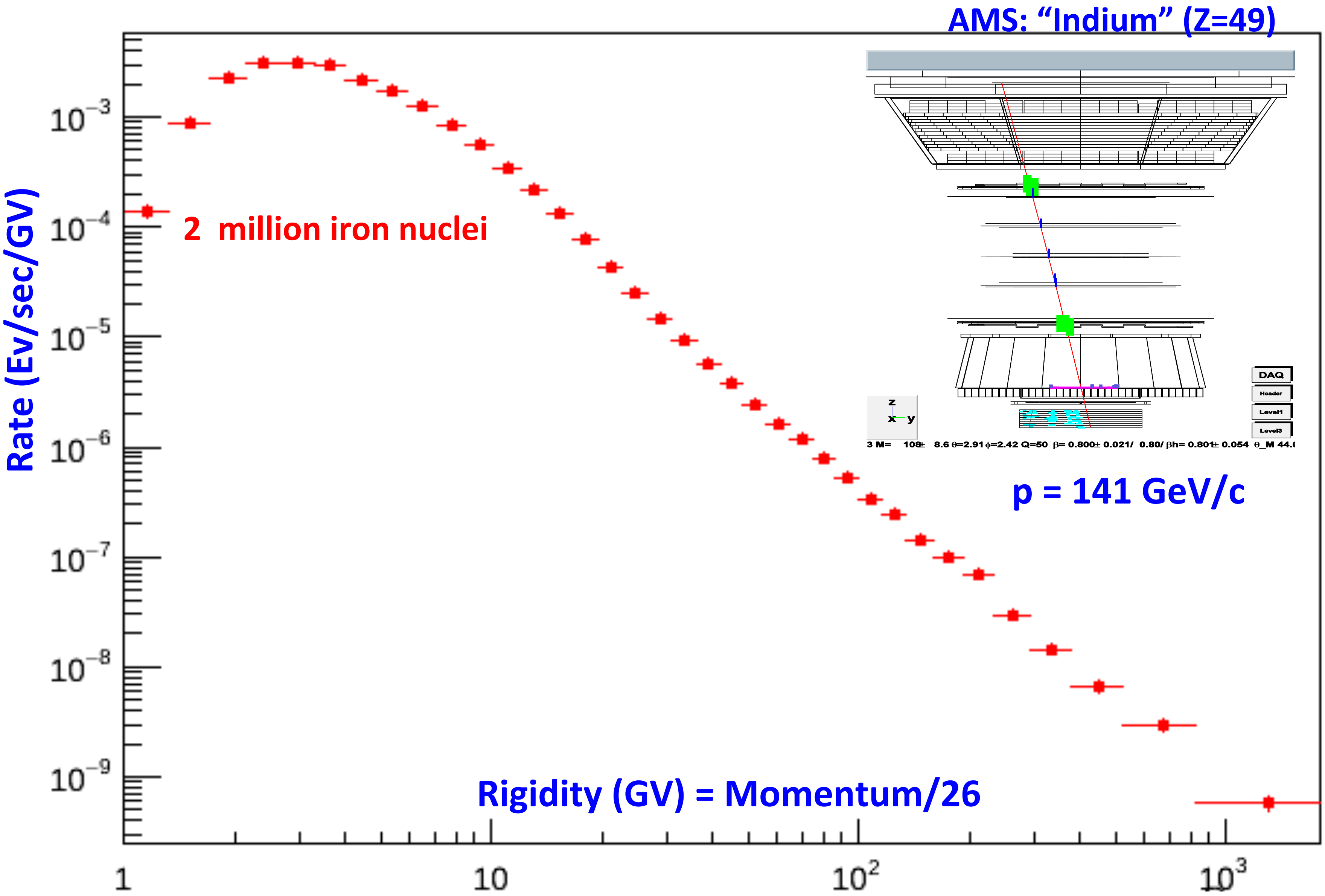
B/C Ratio



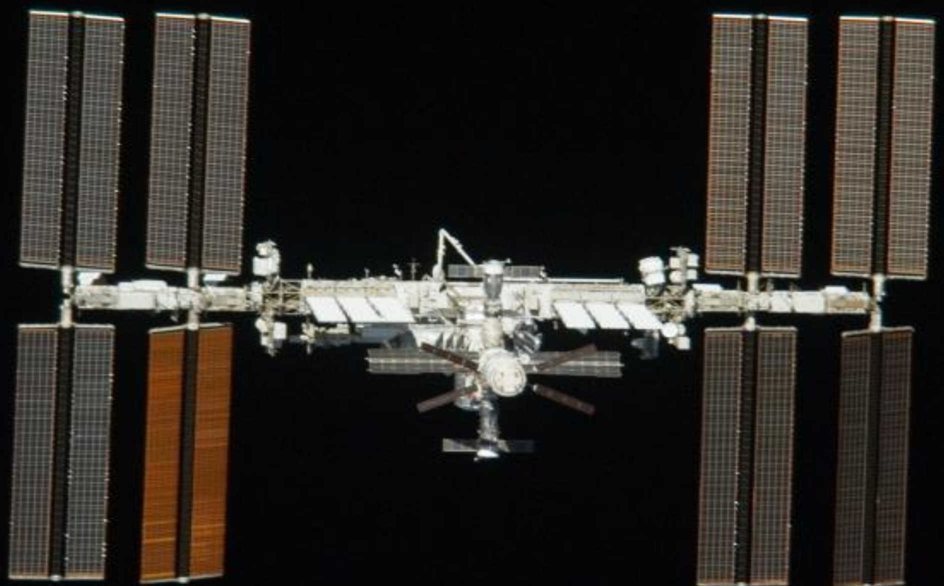
7M Carbon, 2M Boron
Boron-to-Carbon Ratio
0.4
0.3
0.2
0.1
0.06
0.05
0.04
0.03
10
10^2
10^3
Rigidity (GV)
AMS-02
PAMELA (2014)


Boron-to-Carbon Ratio
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
400
600
800
1000
1200
Kinetic Energy (GeV/n)
Data to 2024
Current data

AMS: Nuclei Flux Examples



The latest AMS measurements of the positron fraction, the antiproton/proton ratio, the behavior of the fluxes of electrons, positrons, protons, helium, and other nuclei provide precise and unexpected information. The accuracy and characteristics of the data, simultaneously from many different types of cosmic rays, require a comprehensive model to ascertain if their origin is from dark matter, astrophysical sources, acceleration mechanisms or a combination.



Physics in the next ten years:

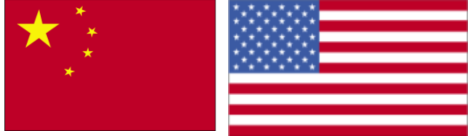
Accurate measurement (~1%) of Cosmic Rays to higher energies including:

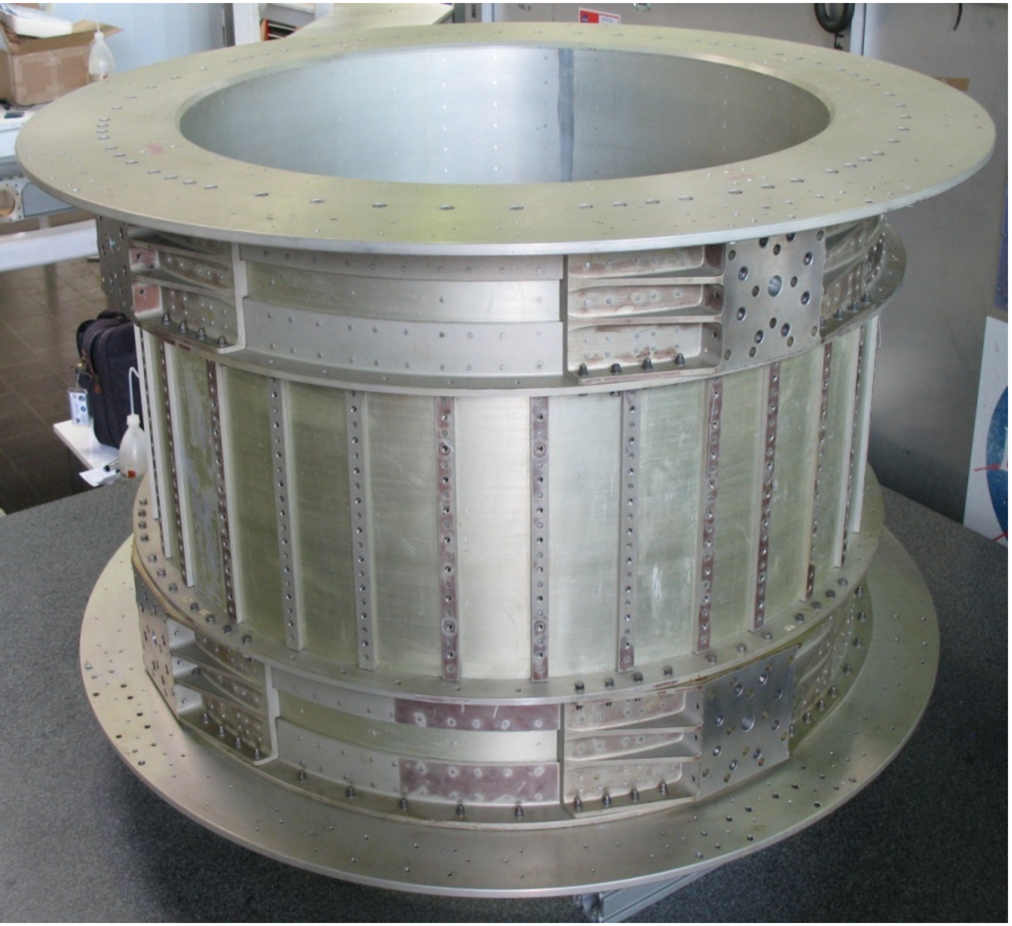
a. Continue the study of Dark Matter

b. Search for the Existence of Antimatter

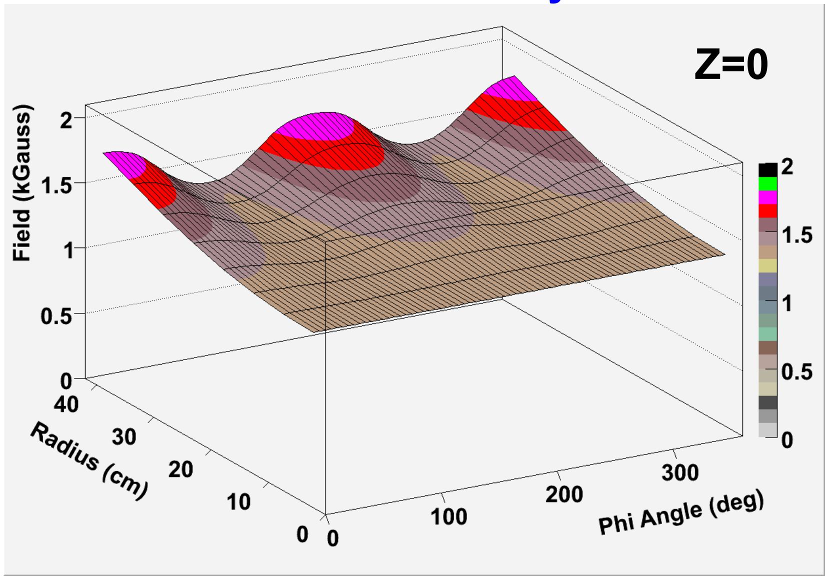
c. Search for New Phenomena, Strangelets …

The Magnet

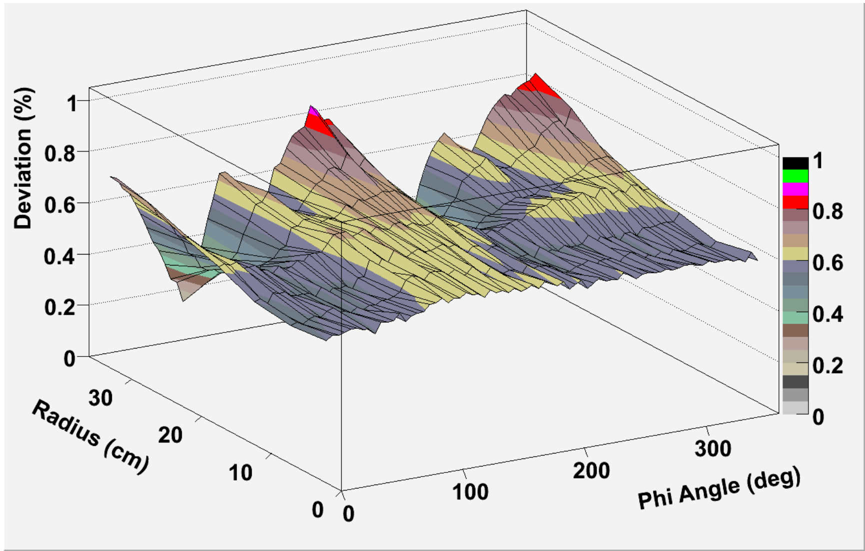




The detailed 3D field map (120k locations) was measured in May 2010

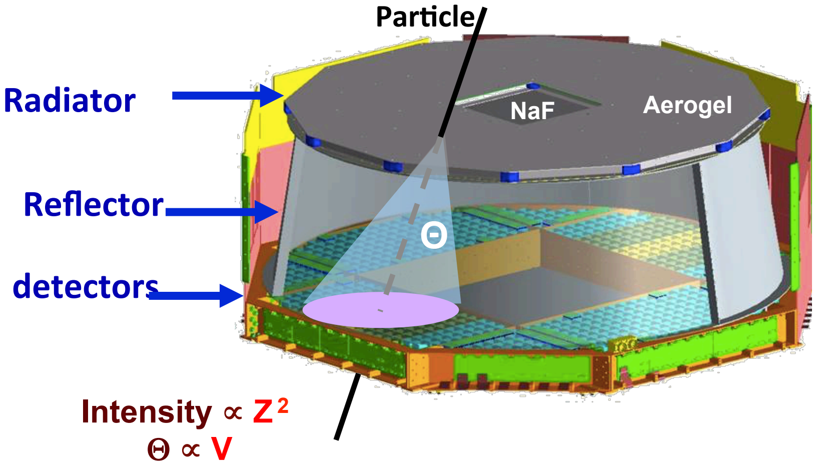


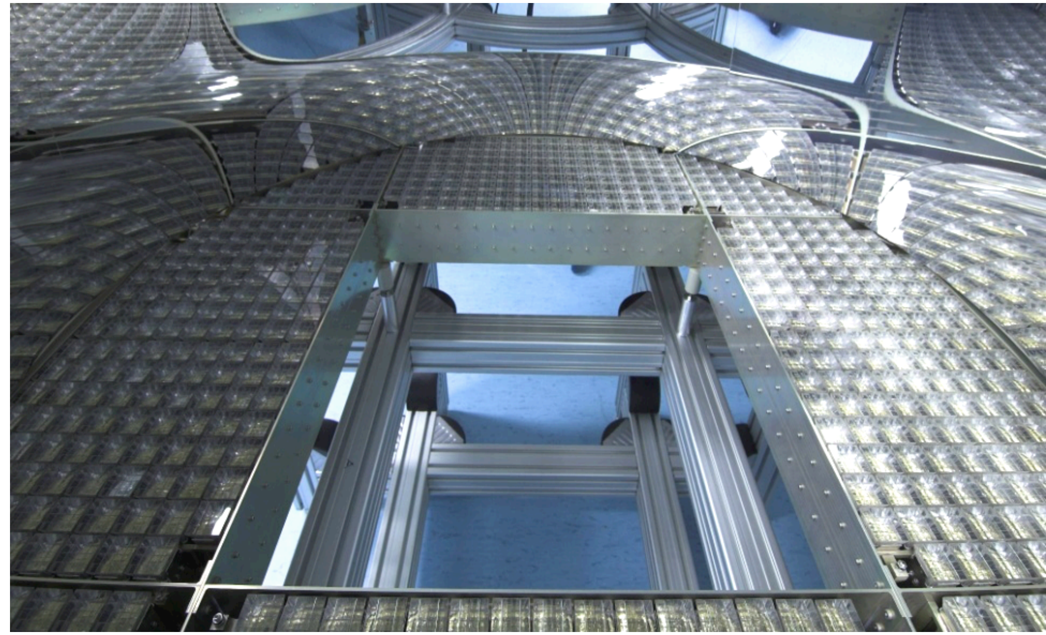
Deviation from 1997 measurement

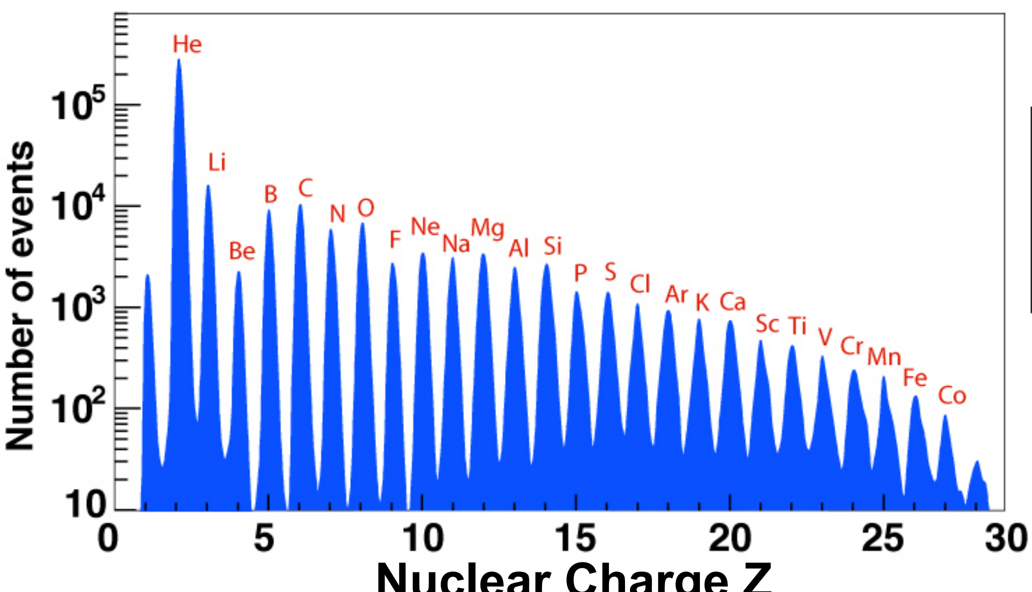


In 12 years the field has remained the same to <1%

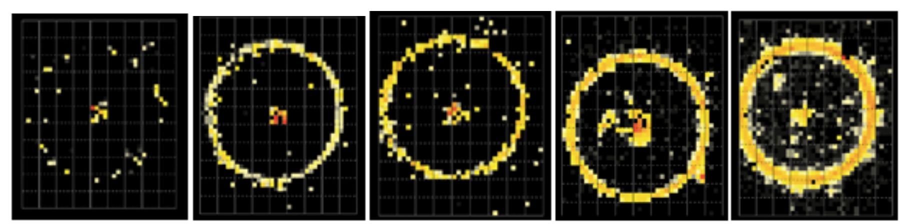
Ring Imaging Cherenkov Detector (RICH)







10,880 photosensors

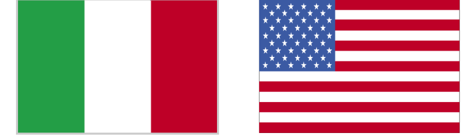


He Li C O Ca

Single Event Displays

RICH test beam E=158 GeV/n

Time of Flight (TOF)

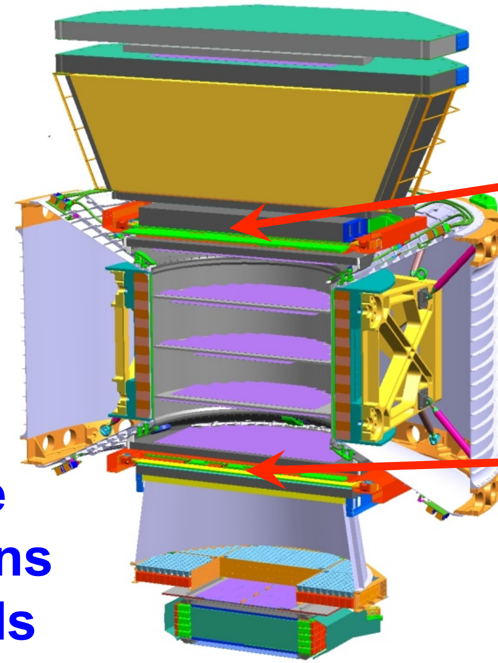


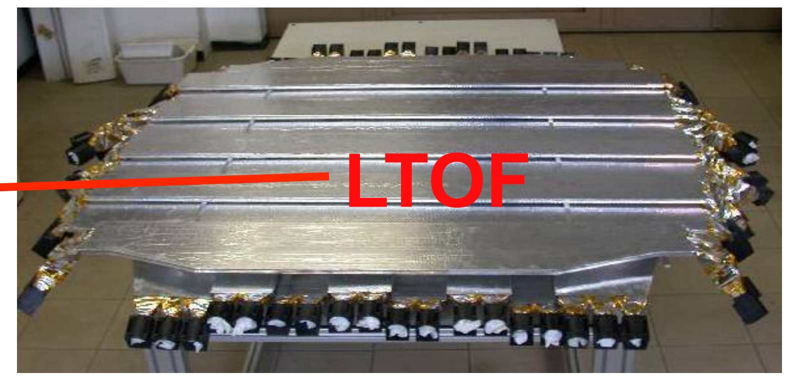
4 scintillator planes

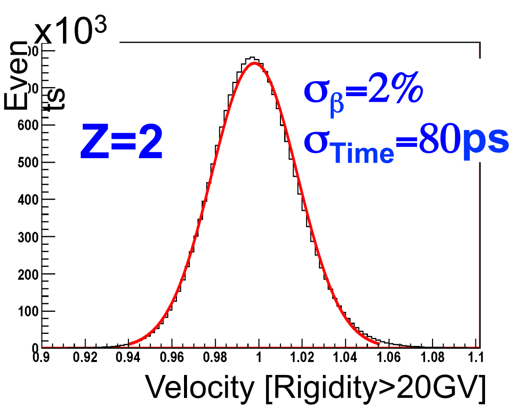
Provides trigger for charged particles

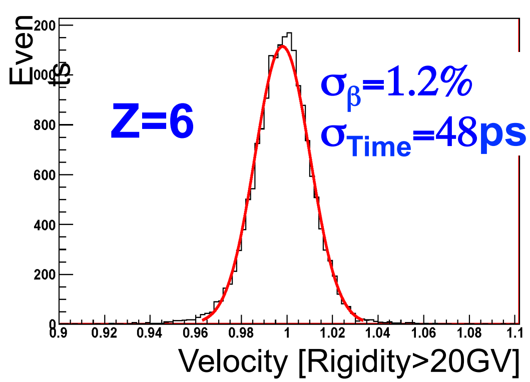
Trigger time is synchronized to UTC time to 1μs

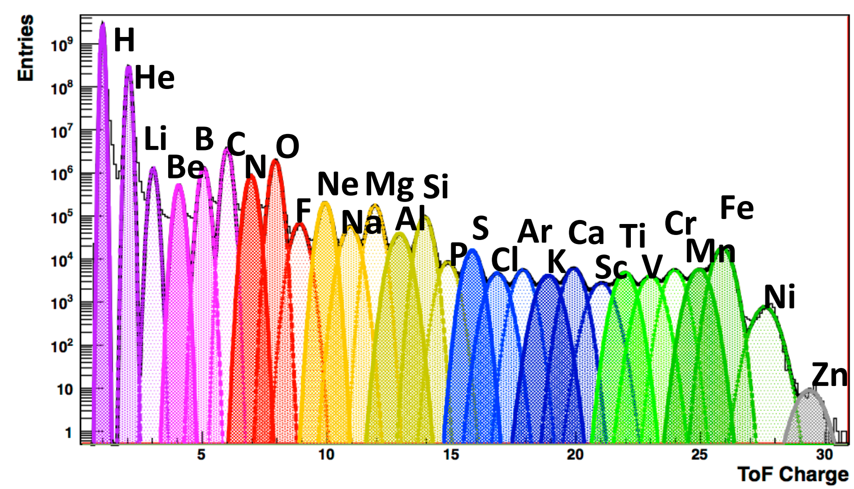
Measures the time of relativistic protons to 160 picoseconds









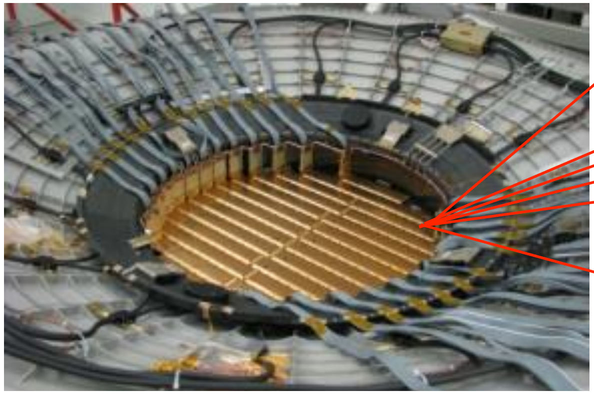


AMS Electronics

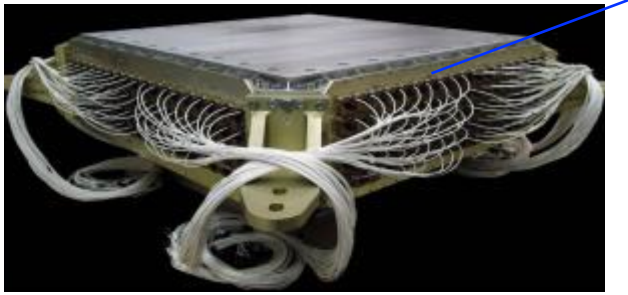
Total of 300,000 channels producing 7 Gbit/s processed by 650 computers to <10 Mbit/s>

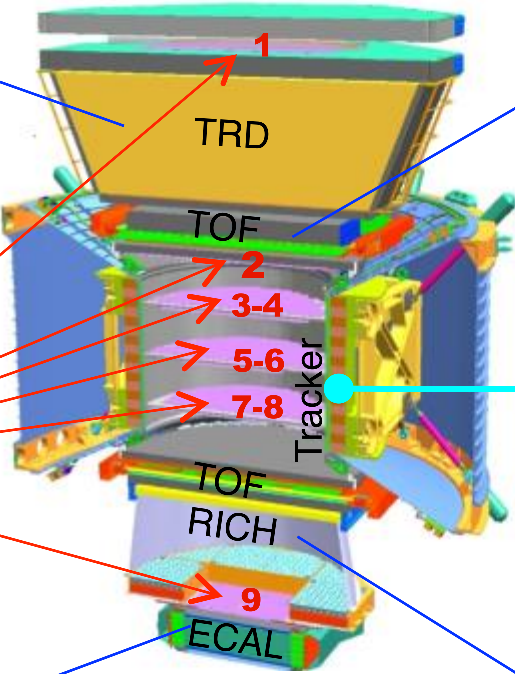
TRD, 30 Computers
5248 Pulse Heights

Silicon Tracker, 212 Computers
196,608 Pulse Heights



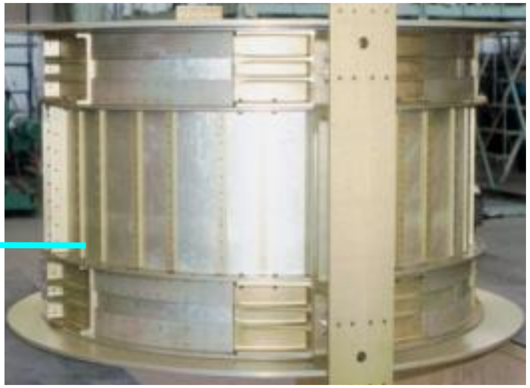
ECAL, 32 Computers
2,916 Pulse Heights



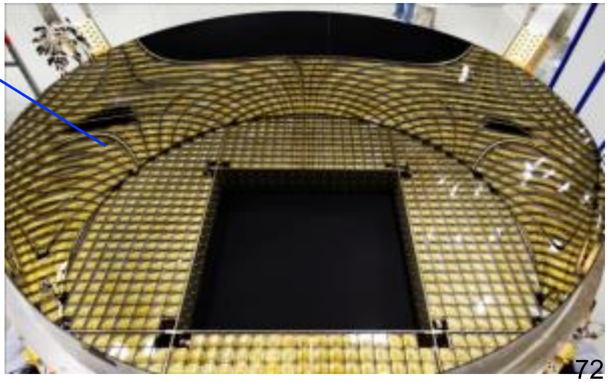


TOF & ACC, 48 Computers
84 Signals

Magnet



RICH, 28 Computers
21,760 Pulse Heights



MIT:
Electronics design, construction and qualification.

Dark Matter Models

1) L. Feng, R.Z. Yang, H.N. He, T.K. Dong, Y.Z. Fan and J. Chang Phys.Lett. B728 (2014) 250
2) M. Cirelli, M. Kadastik, M. Raidal and A. Strumia ,Nucl.Phys. B873 (2013) 530
3) M. Ibe, S. Iwamoto, T. Moroi and N. Yokozaki, JHEP 1308 (2013) 029
4) Y. Kajiyama andH. Okada, Eur.Phys.J. C74 (2014) 2722
5) K.R. Dienes and J. Kumar, Phys.Rev. D88 (2013) 10, 103509
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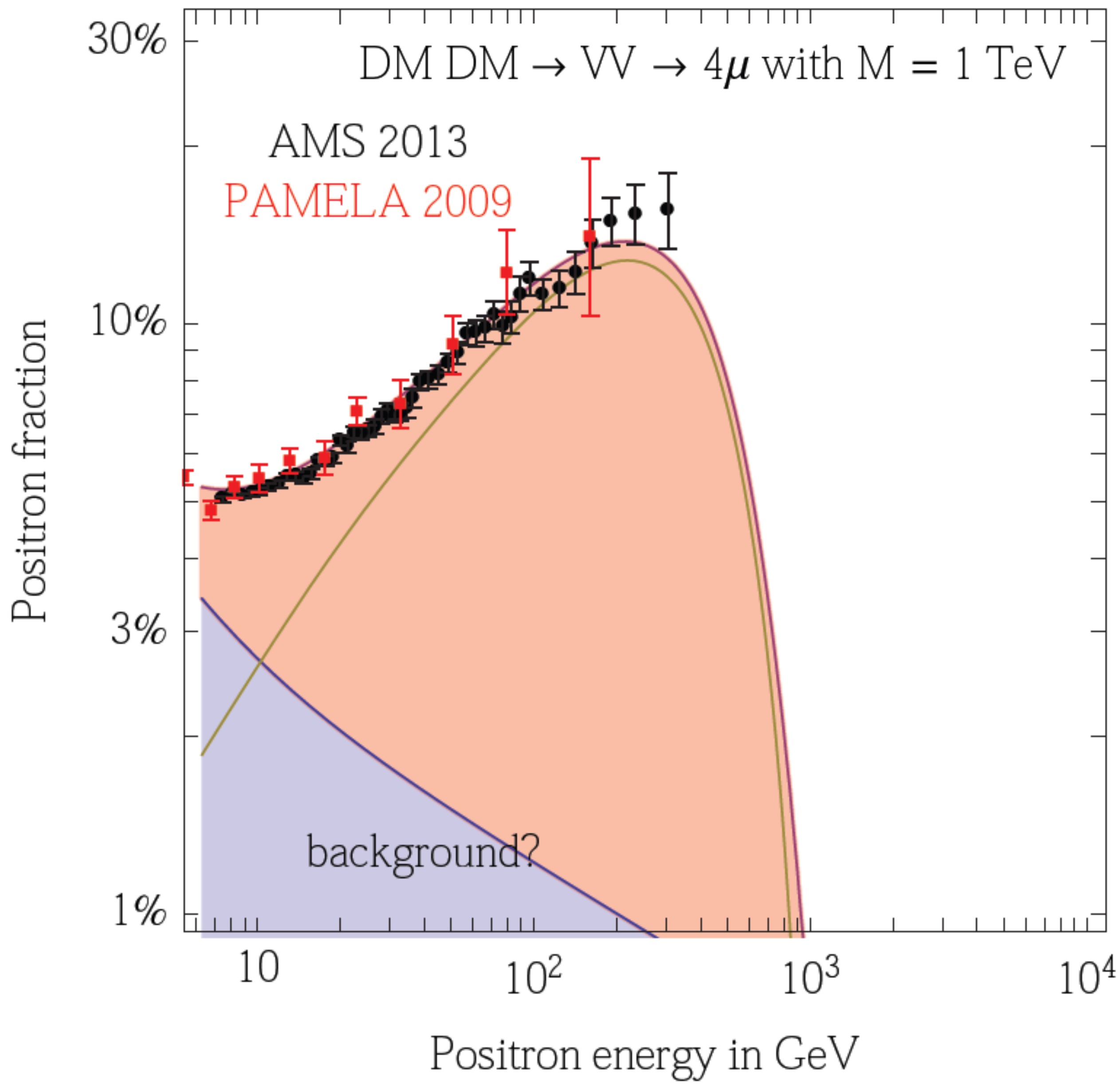

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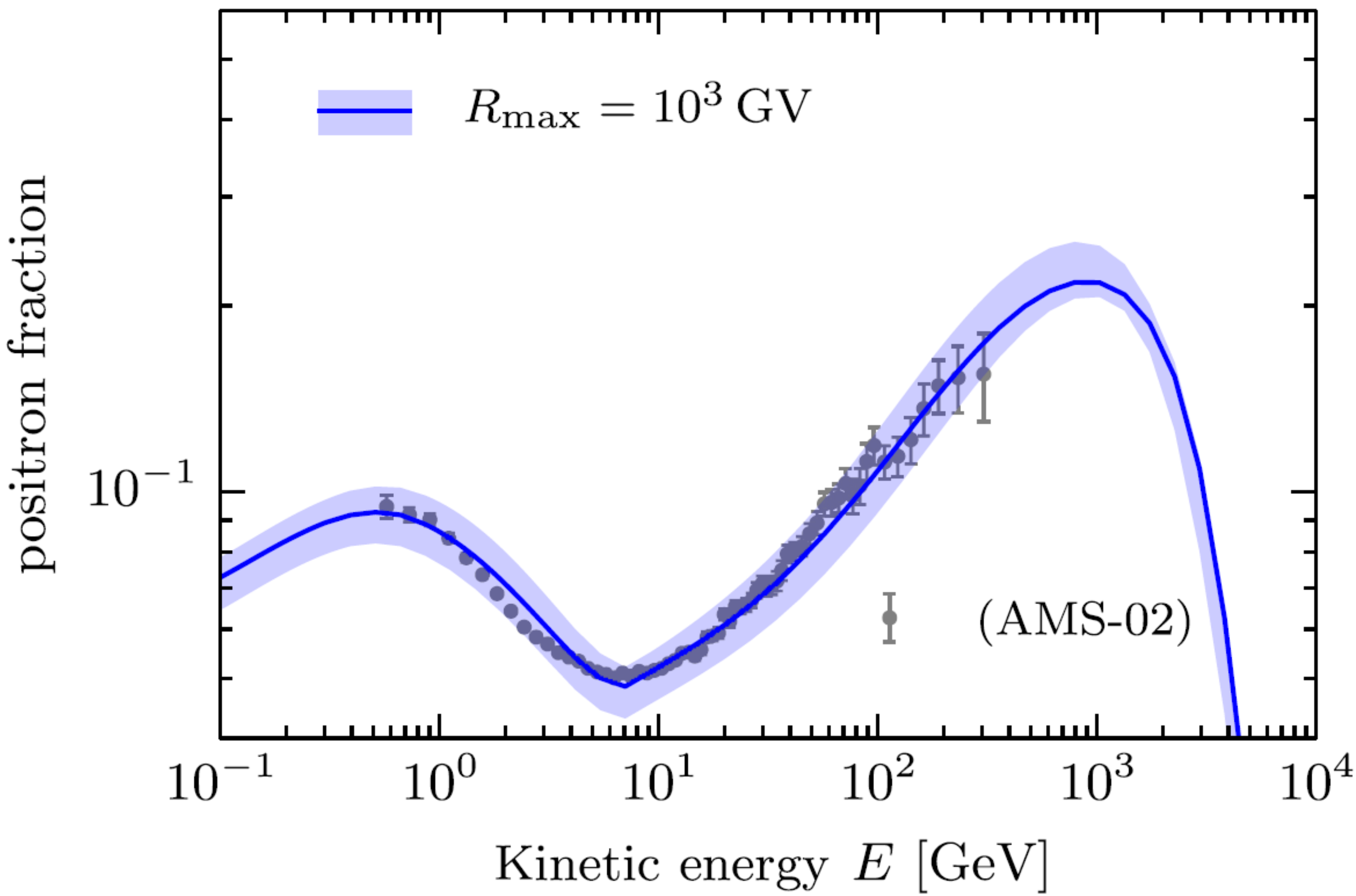

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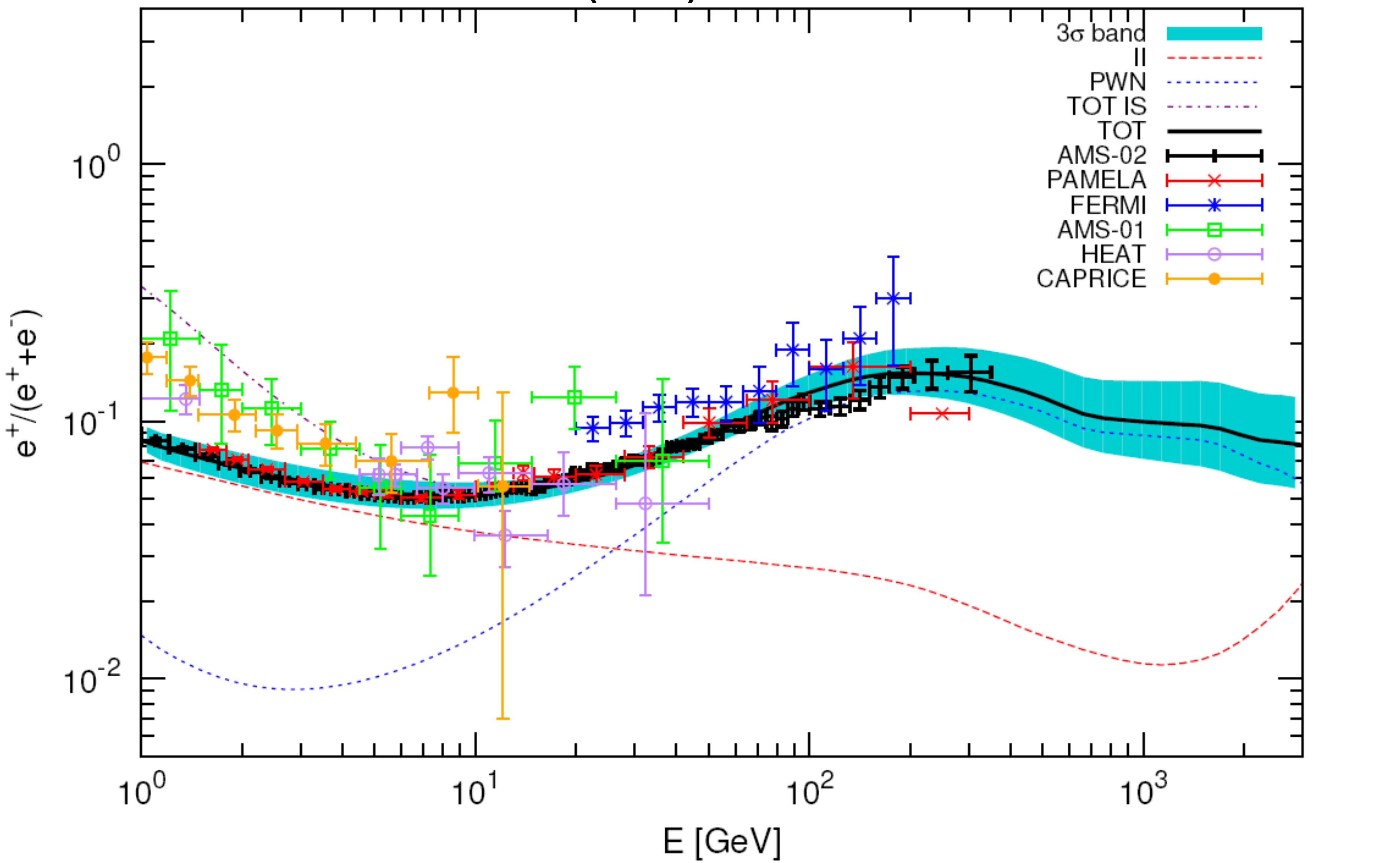

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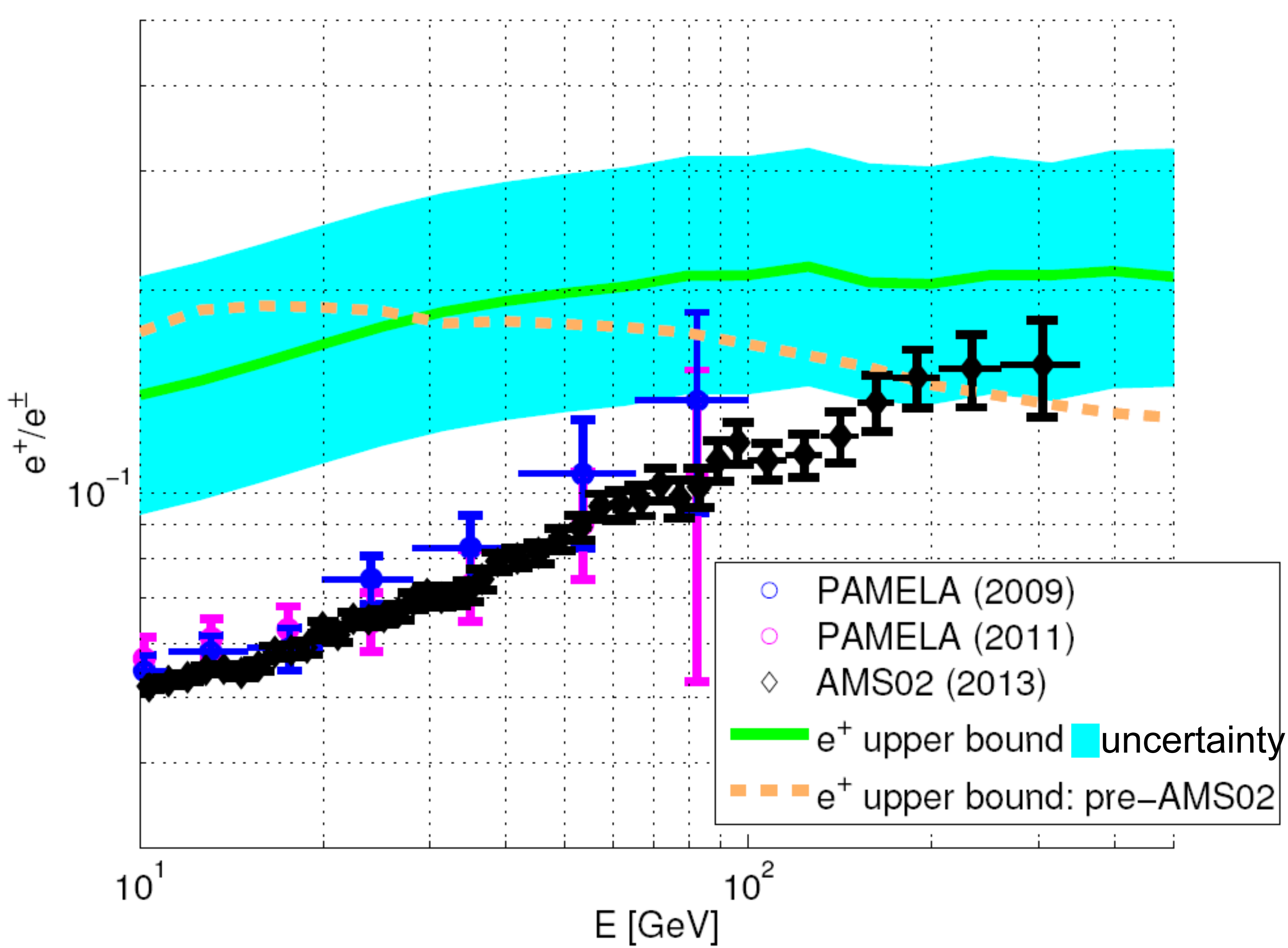


PAMELA (2009)
PAMELA (2011)
AMS02 (2013)
e+ upper bound
uncertainty
e+ upper bound: pre−AMS02
e+/e±
10−1
10^1
10^2
E [GeV]

EXAMPLE:

Minimal Model Fit to the data

Diffuse Flux / Source Flux

$$\Phi_{e^+} = \boxed{C_{e^+} E^{-\gamma_{e^+}}} + \boxed{C_s E^{-\gamma_s} e^{-E/E_s}}$$

$$\Phi_{e^-} = \boxed{C_{e^-} E^{-\gamma_{e^-}}} + \boxed{C_s E^{-\gamma_s} e^{-E/E_s}}$$

Simultaneous fit to

- **a) Positron Fraction from 2GeV**
- **b) Electron + Positron from 2GeV**

- **$(\gamma_{e-} - \gamma_{e+})$, $(\gamma_{e-} - \gamma_s)$, C_{e+}, C_{e-}, C_s, E_s are constant**
- **γ_{e-} is energy dependent below ~15 GeV.**

Minimal Model:

Diffuse Flux | Source Flux

$$\Phi_{e^+} = C_{e^+} E^{-\gamma_{e^+}} + C_s E^{-\gamma_s} e^{-E/E_s}$$

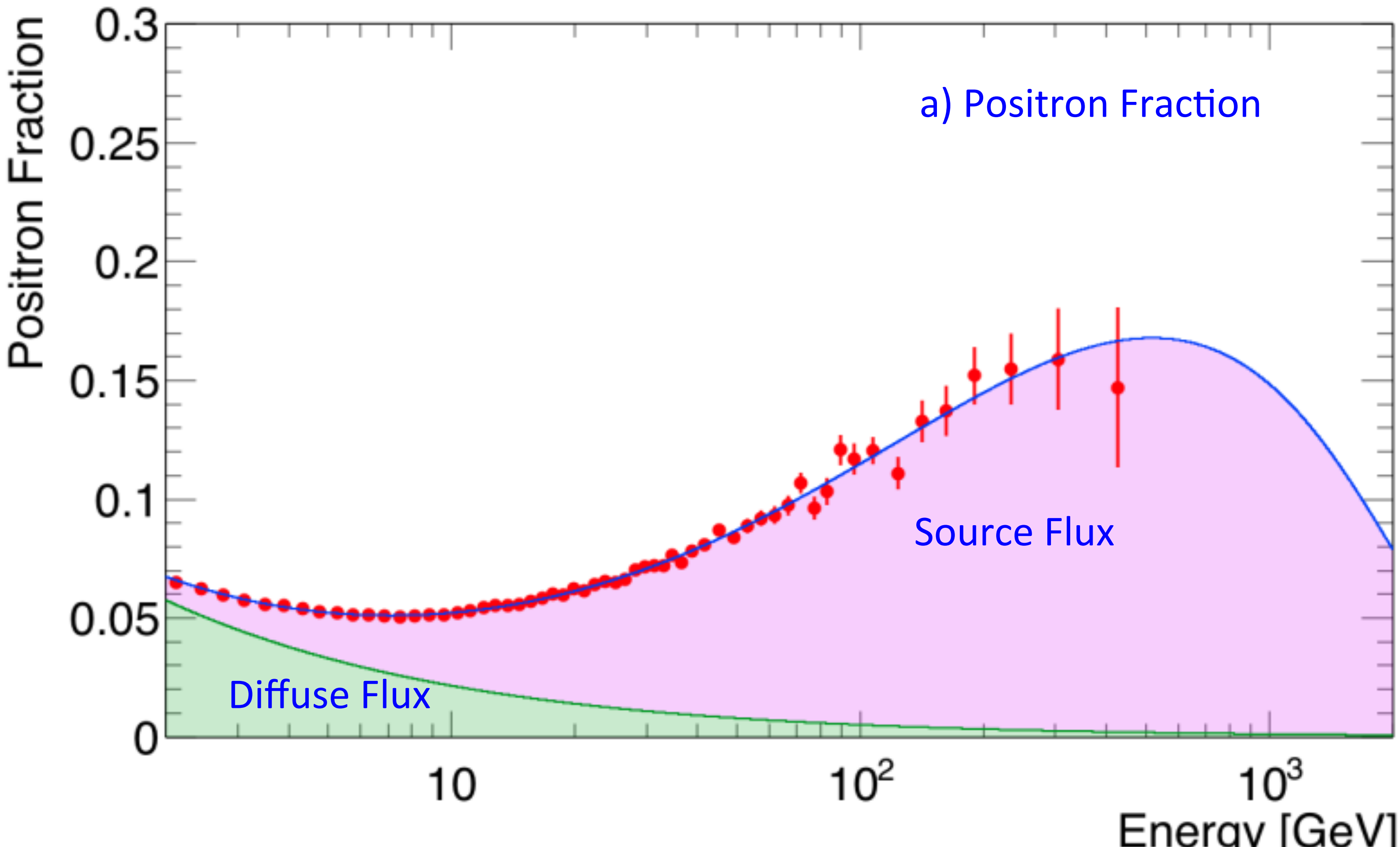
$$\Phi_{e^-} = C_{e^-} E^{-\gamma_{e^-}} + C_s E^{-\gamma_s} e^{-E/E_s}$$

Fit to a) Positron Fraction from 2 GeV determines the relations:

$\gamma_{e-} - \gamma_{e+} = -0.63 \pm 0.06$, $\gamma_{e-} - \gamma_s = 0.66 \pm 0.05$,

$C_{e+} / C_{e-} = 0.095 \pm 0.003$, $C_s / C_{e-} = 0.008 \pm 0.001$

$1/E_s = 1.3 \pm 0.6\ \mathrm{TeV}^{-1}$



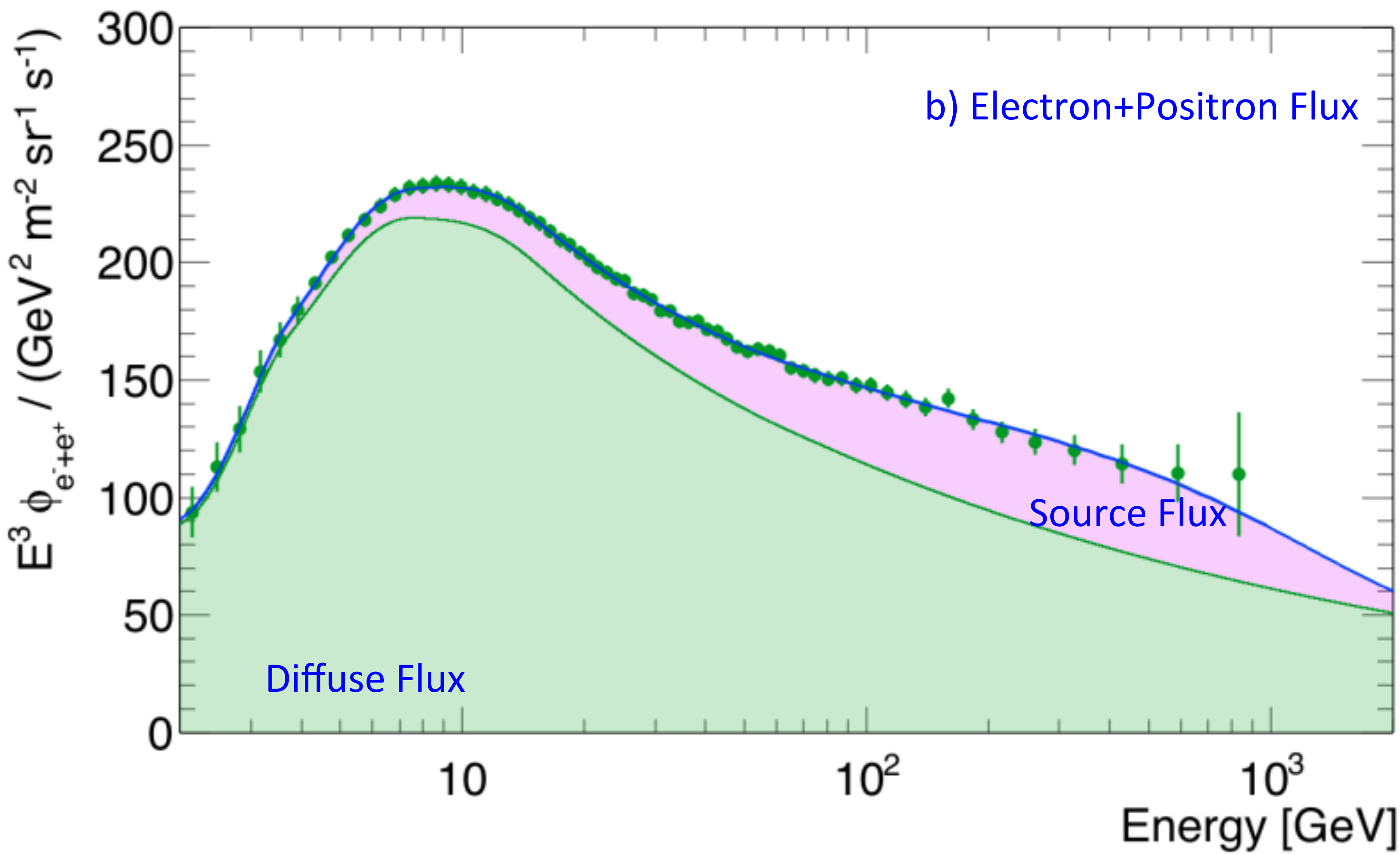
Minimal Model:

$$\Phi_{e^+} = \underbrace{C_{e^+} E^{-\gamma_{e^+}}}_{\text{Diffuse Flux}} + \underbrace{C_s E^{-\gamma_s} e^{-E/E_s}}_{\text{Source Flux}}$$

$$\Phi_{e^-} = C_{e^-} E^{-\gamma_{e^-}} + C_s E^{-\gamma_s} e^{-E/E_s}$$

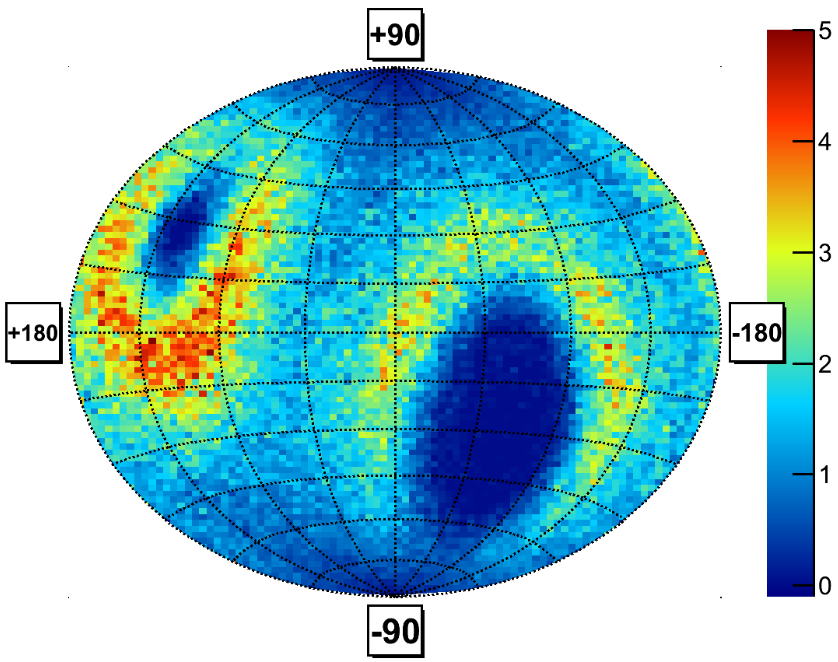
Fit to b) Electron + Positron Flux from 2 GeV determines γ_{e-} and C_{e-}

γ_{e-} is energy dependent below ~15 GeV

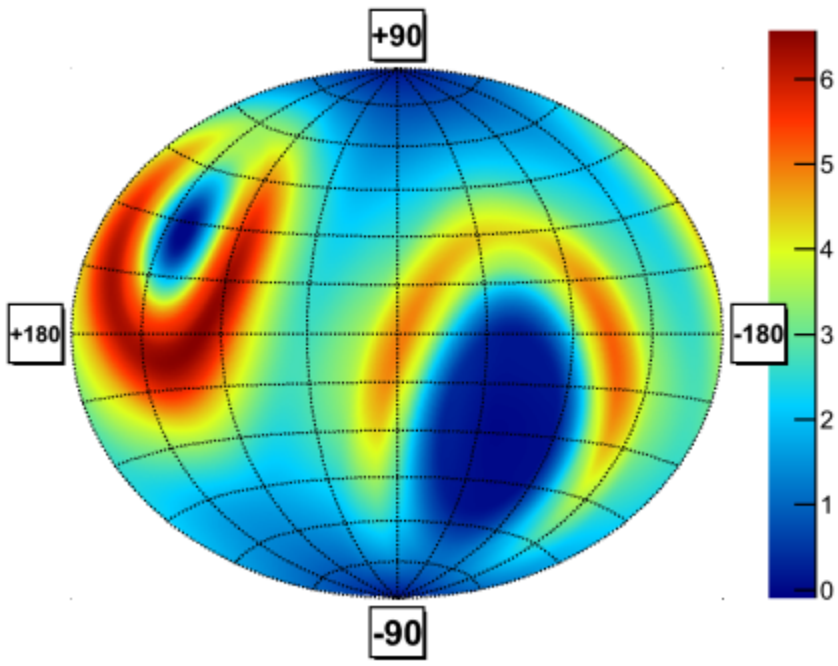


Electron anisotropy

Measured Distribution

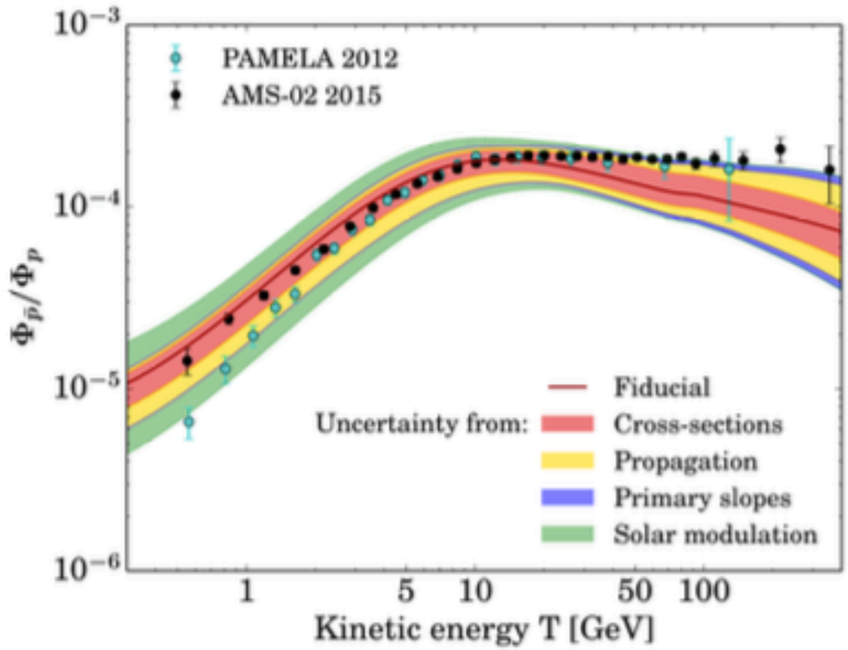


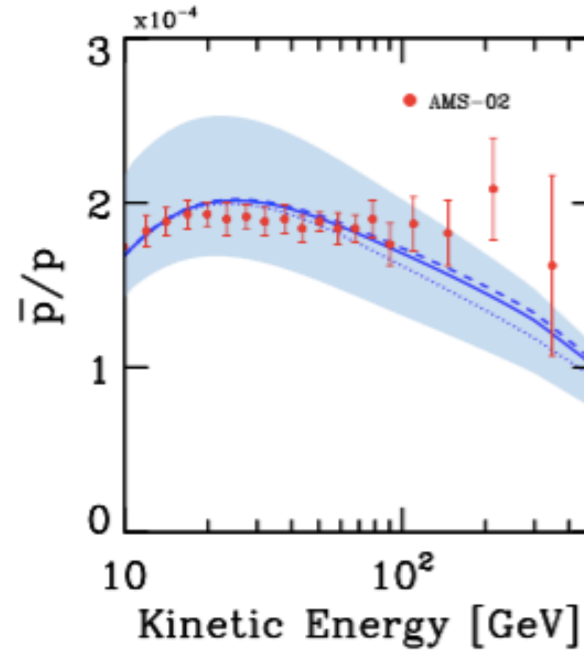
Expected Isotropic Distribution

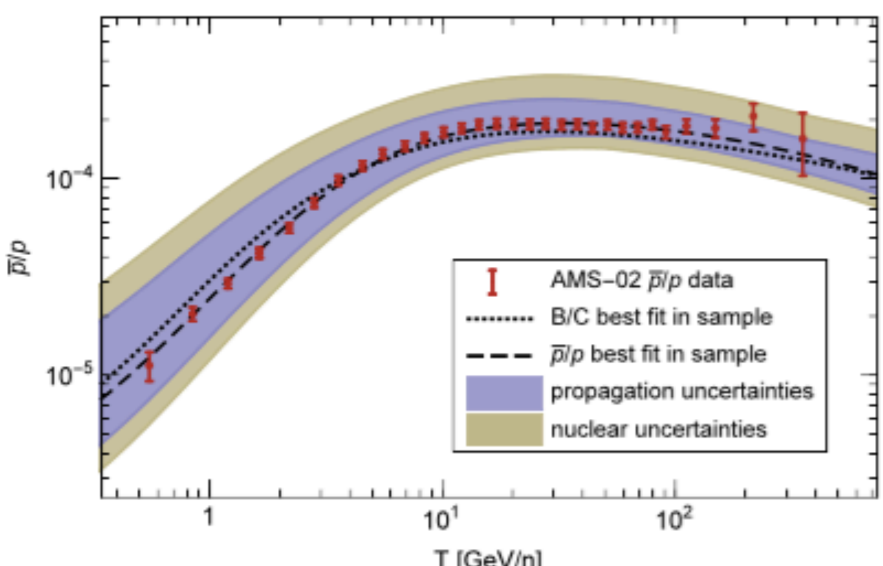


The incoming direction of electrons above 16 GeV in galactic coordinates yields **δ ≤ 0.01 at the 95% confidence level**

Modelling the $\overline{p}/p$ ratio







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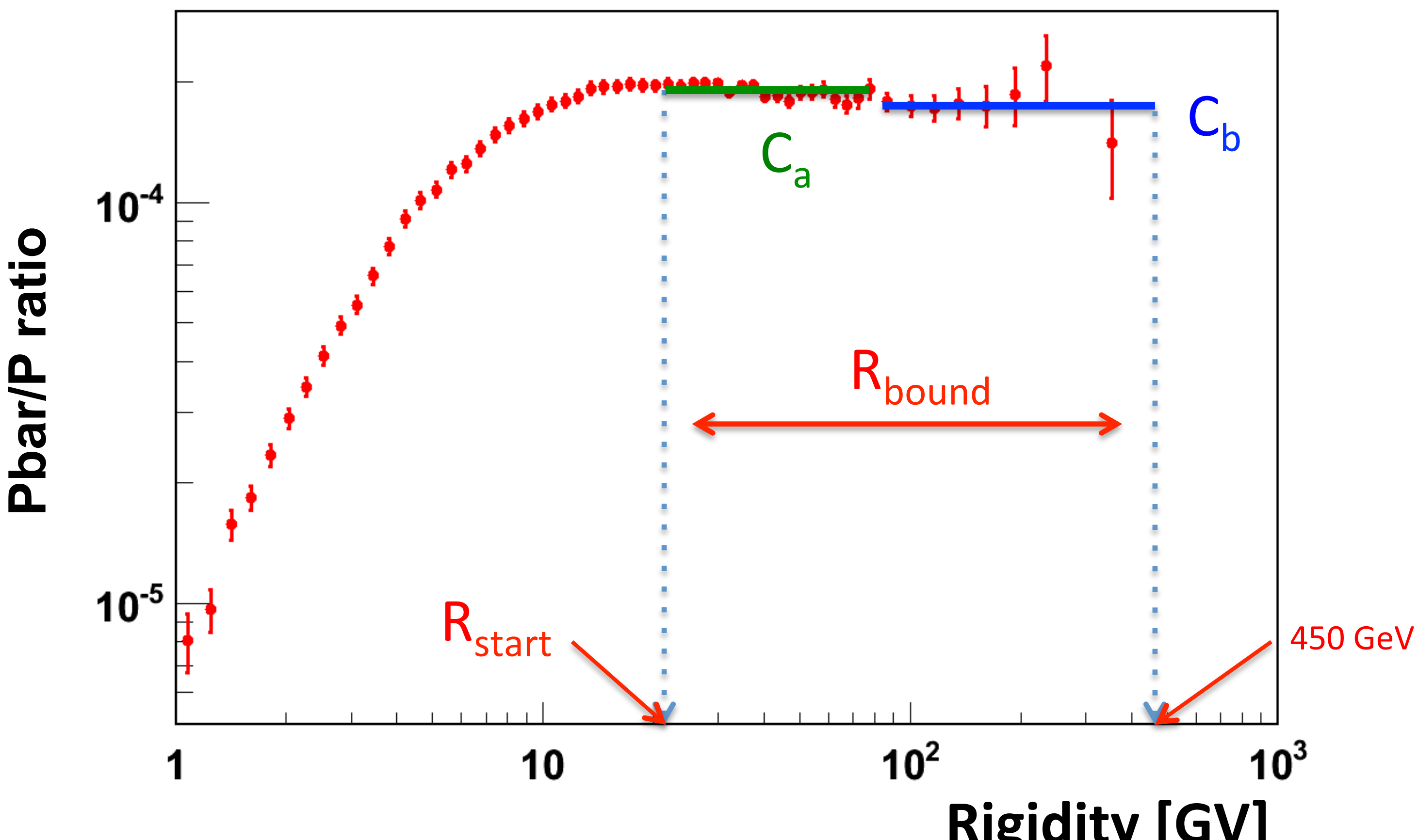
Lower rigidity limit for constant dependence

Study intervals starting with rigidity R_{start}, and ending at the highest rigidity:

- Split an interval into two sections (a and b) by any boundary R_{bound}
- Fit with a constant dependence for each section, $(\bar{p}/p) = C$
- Determine the significance of the difference of the two fits C_a and C_b

The limit is defined by the lowest R_{start} that gives consistent C_a and C_b at the 90% C.L. for any boundary yields ~60 GV



ICRC
The Astroparticle Physics Conference
34th International Cosmic Ray Conference
July 30 - August 6, 2015
The Hague, The Netherlands

Rapporteur talk
Cosmic rays: direct measurements

Paolo Maestro
UNIVERSITÀ DI SIENA 1240
INFN Istituto Nazionale di Fisica Nucleare

Direct measurements summary

Main results presented @ this ICRC (my view):

- Spectral hardening of p and He spectra at 250-300 GV. He spectrum harder than p ←AMS
- Spectral break also observed in Li, not in C (with current statistics) ←AMS
- B/C ratio is approaching TeV/n scale with unprecedented precision ←AMS
- First measurements of the unmodulated energy spectra of nuclei in the LISM Voyager
- UHGCR data seem to indicate that GCR acceleration occurs in OB associations ACE, TIGER
- First primary CR clock (^{60}Fe) was observed. Supports OB association scenario CRIS
- No spectral features neither anisotropy in the electron+positron spectrum ←AMS
- e^+ spectrum is harder than e^- and inconsistent with a pure secondary origin ←AMS
- p-bar/p ratio flat between 50-450 GV. ←AMS

Lots of theoretical work underway to explain and interpret these results.

Several new projects at the horizon. Stay tuned for more data !