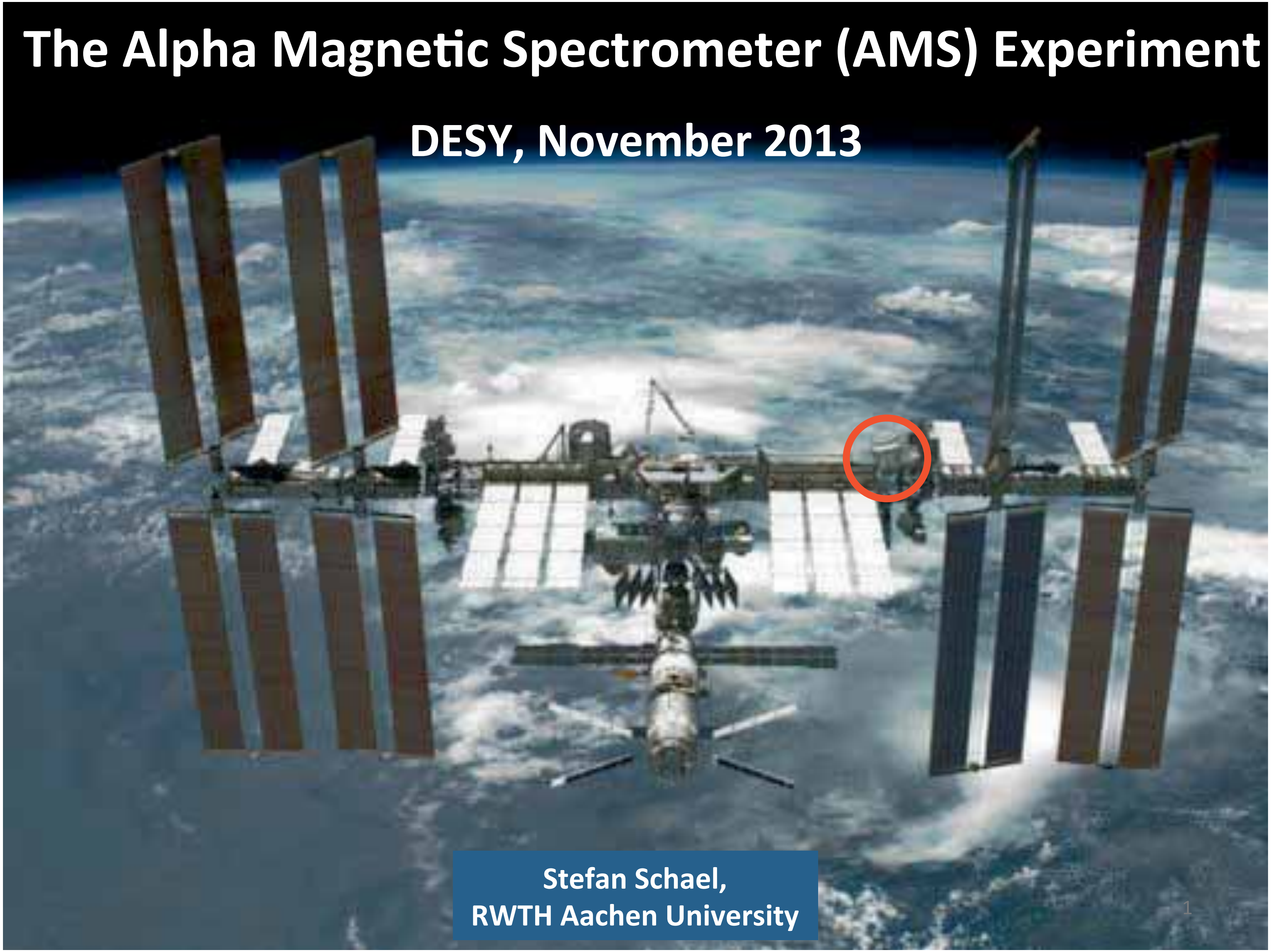
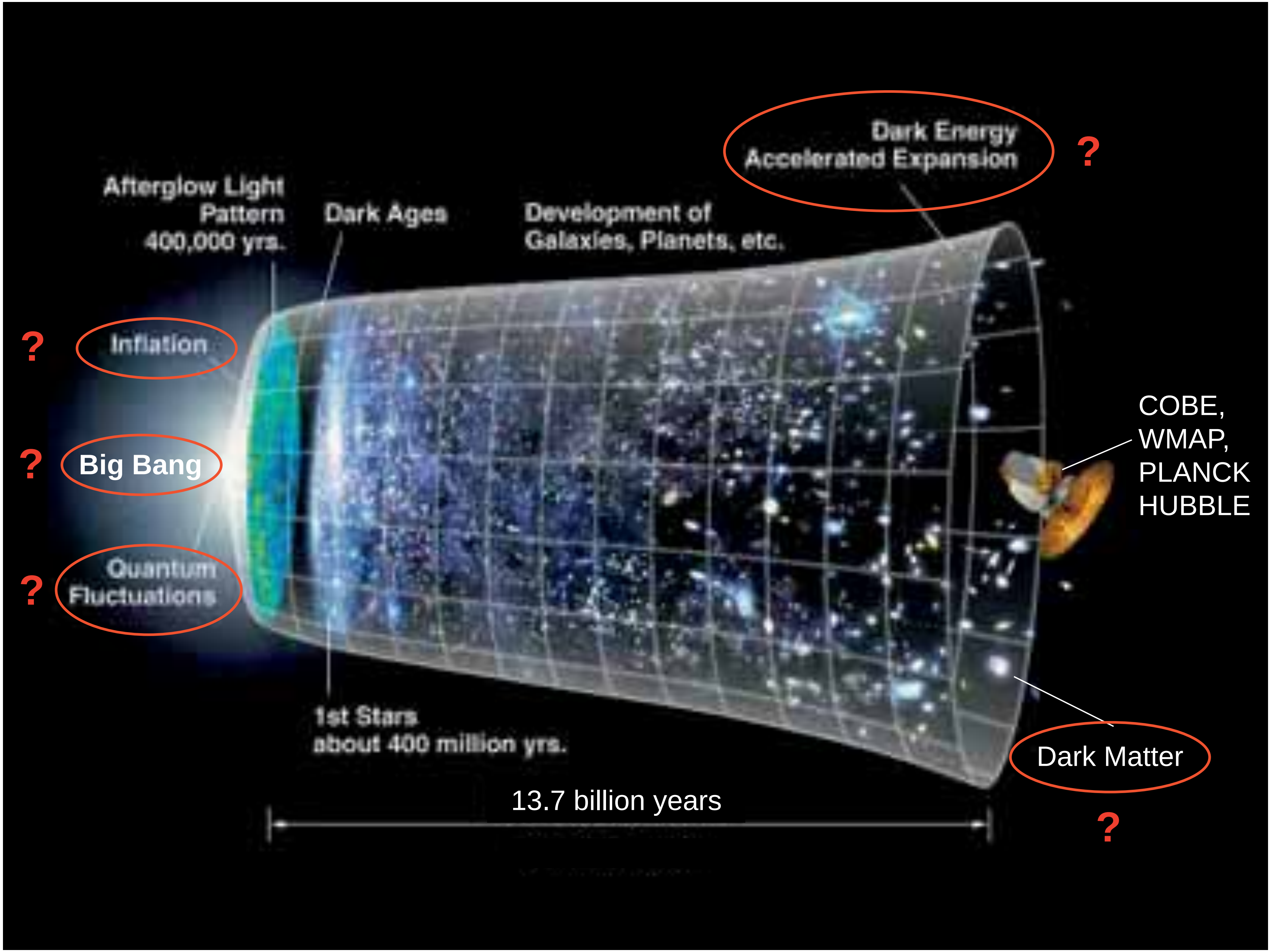
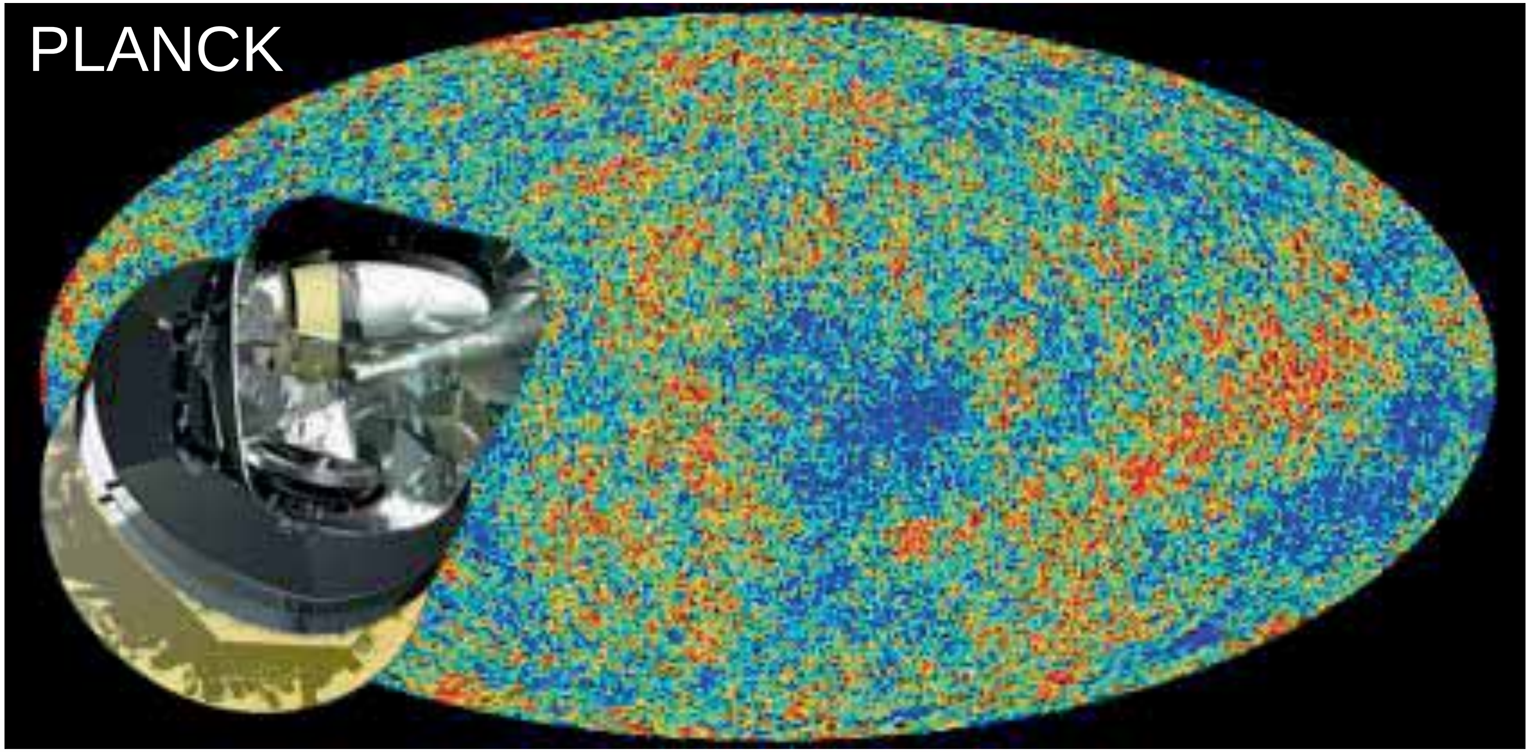
The Alpha Magnetic Spectrometer (AMS) Experiment

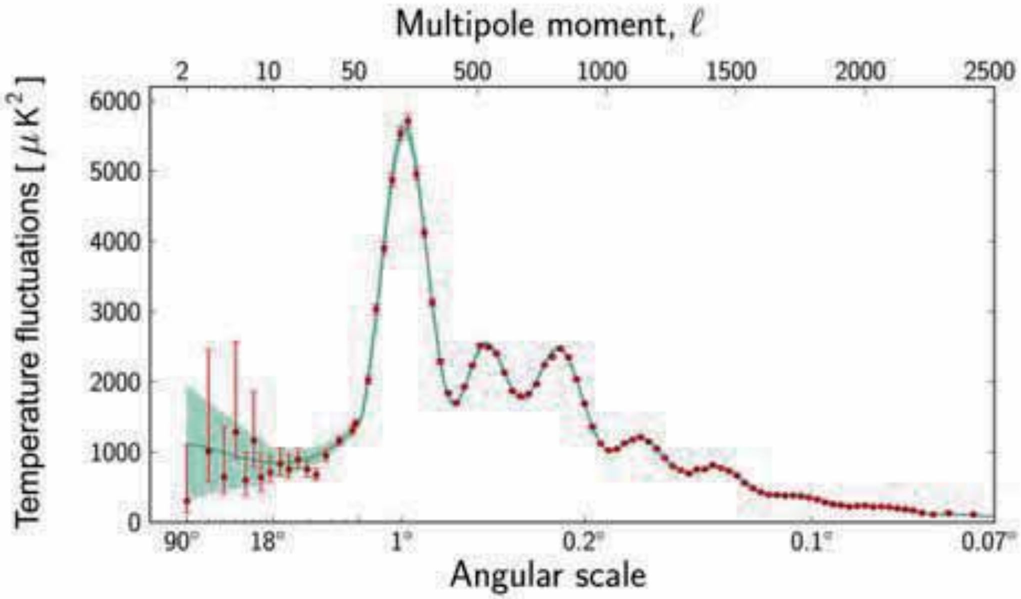
DESY, November 2013

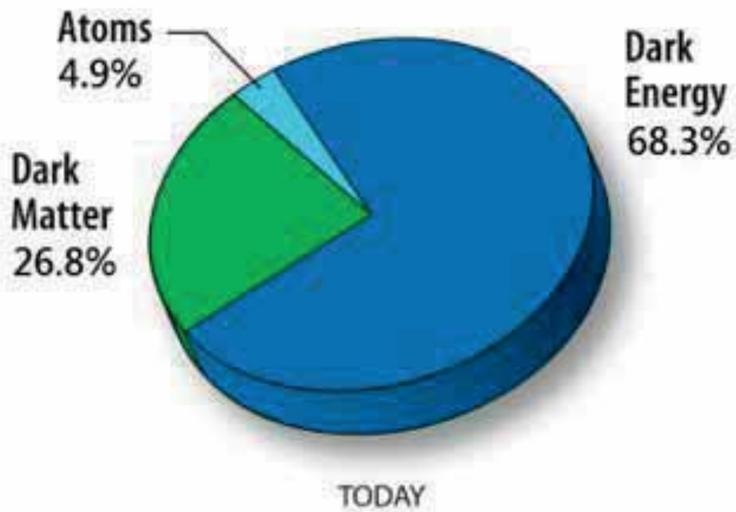


Stefan Schael,
RWTH Aachen University

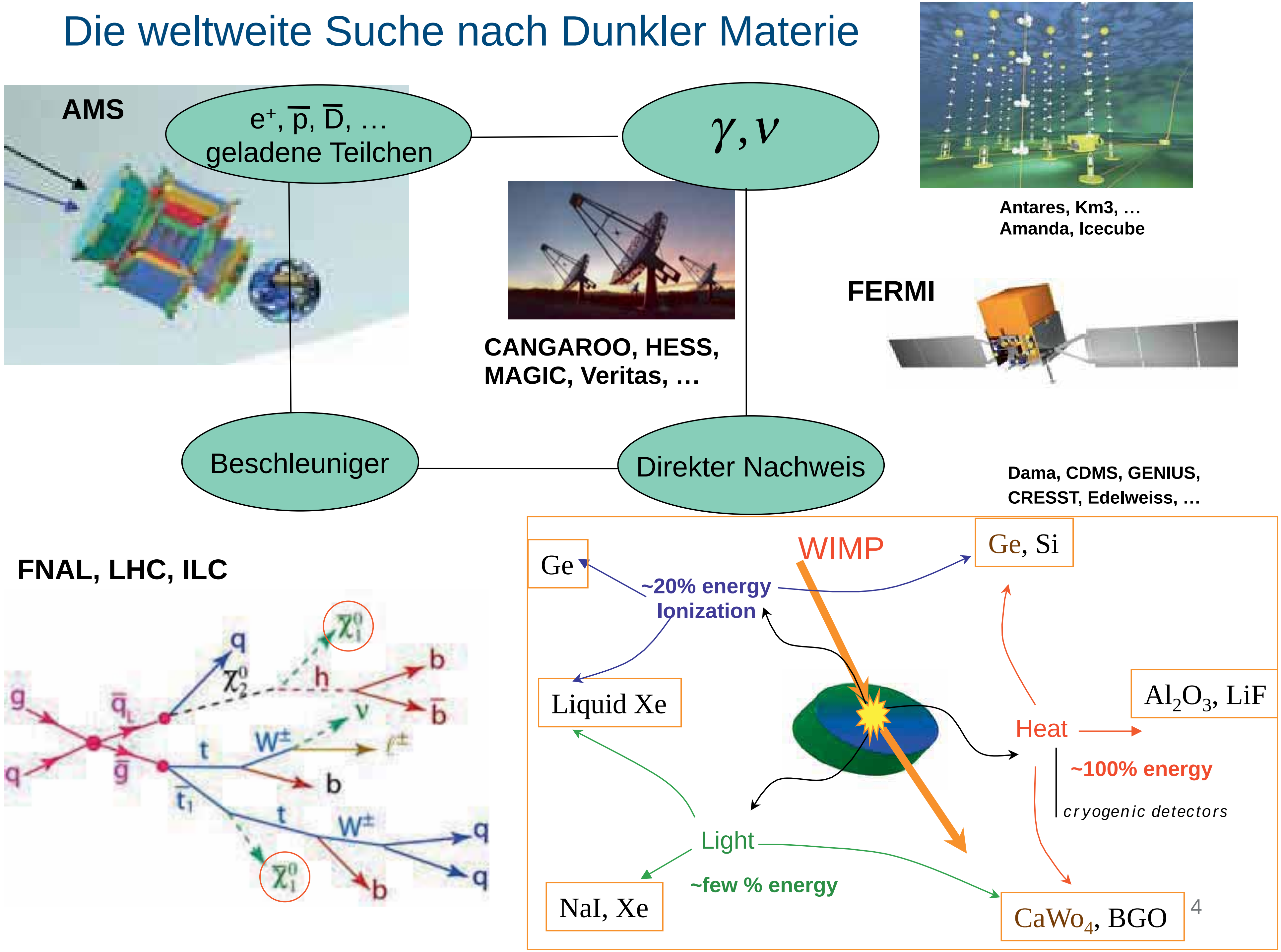

Dark Energy
Accelerated Expansion
?
Afterglow Light
Pattern
400,000 yrs.
Dark Ages
Development of
Galaxies, Planets, etc.
?
Inflation
?
Big Bang
?
Quantum
Fluctuations
COBE,
WMAP,
PLANCK
HUBBLE
1st Stars
about 400 million yrs.
Dark Matter
13.7 billion years
?

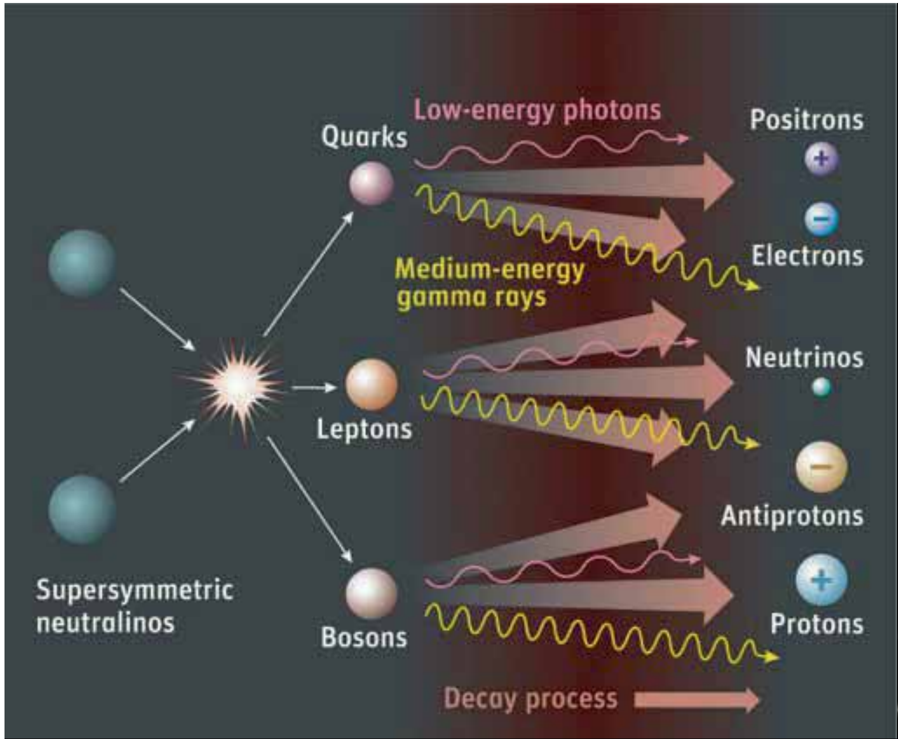

PLANCK


Multipole moment, ℓ
2
10
50
500
1000
1500
2000
2500
Temperature fluctuations [μK²]
6000
5000
4000
3000
2000
1000
0
90°
18°
1°
0.2°
0.1°
0.07°
Angular scale

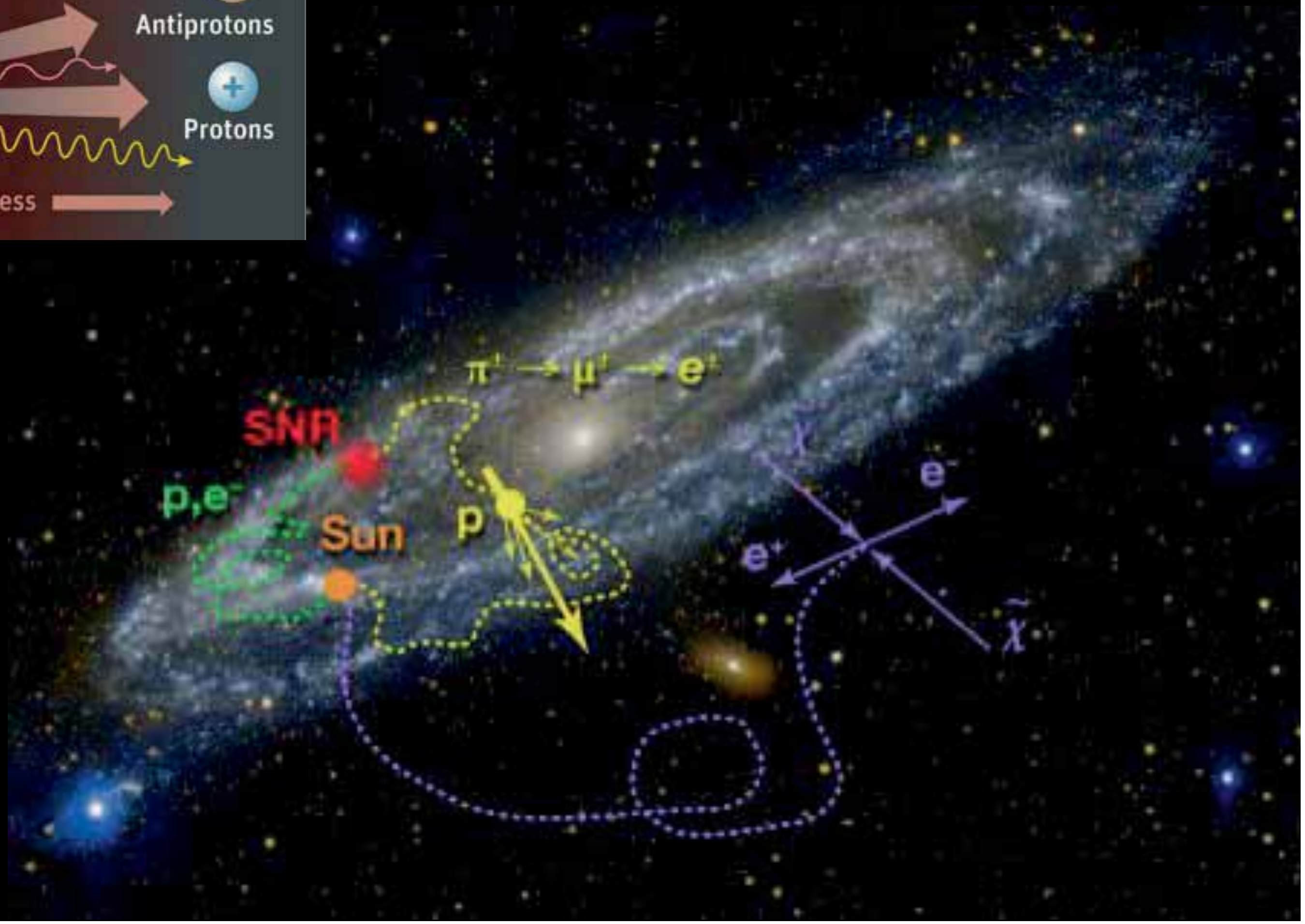

Atoms
4.9%
Dark
Energy
68.3%
Dark
Matter
26.8%
TODAY

Die weltweite Suche nach Dunkler Materie



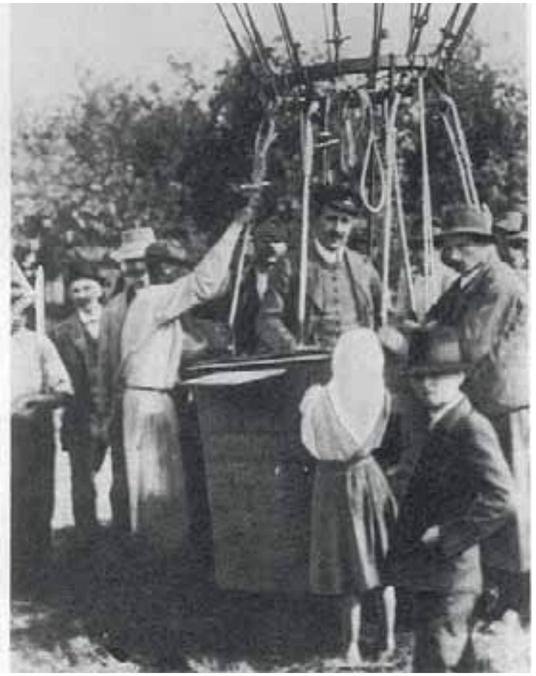


Low-energy photons
Quarks
Positrons
Electrons
Medium-energy gamma rays
Neutrinos
Leptons
Antiprotons
Supersymmetric neutralinos
Bosons
Protons
Decay process



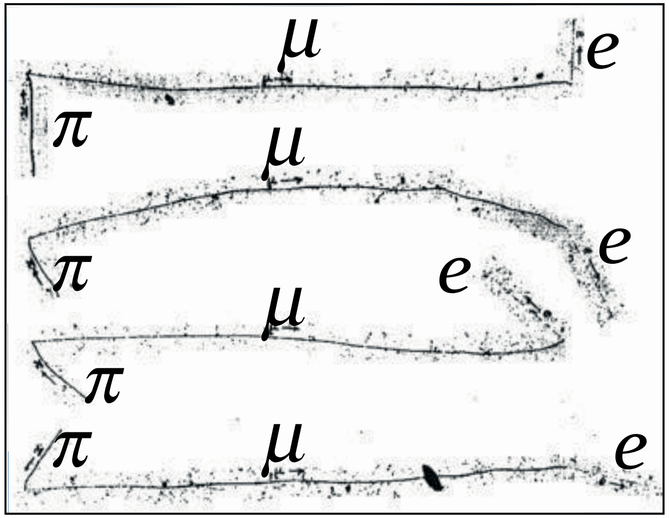
SNR
p,e⁻
Sun
p
π± → μ± → e±
e⁻
e⁺

Physics of Charged Cosmic Rays



1912: Discovery of Cosmic Rays
V. Hess

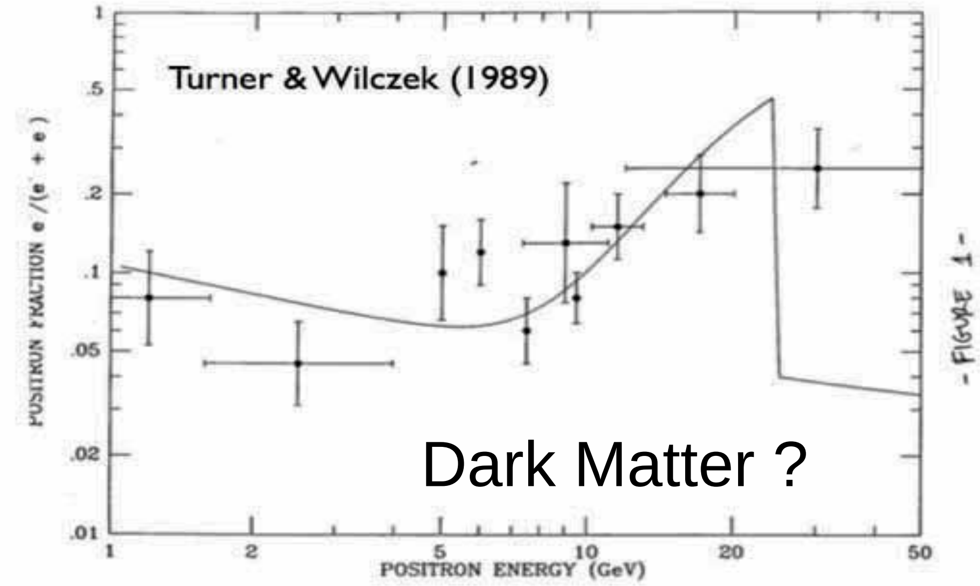
1932: Discovery of positron
C.D. Anderson

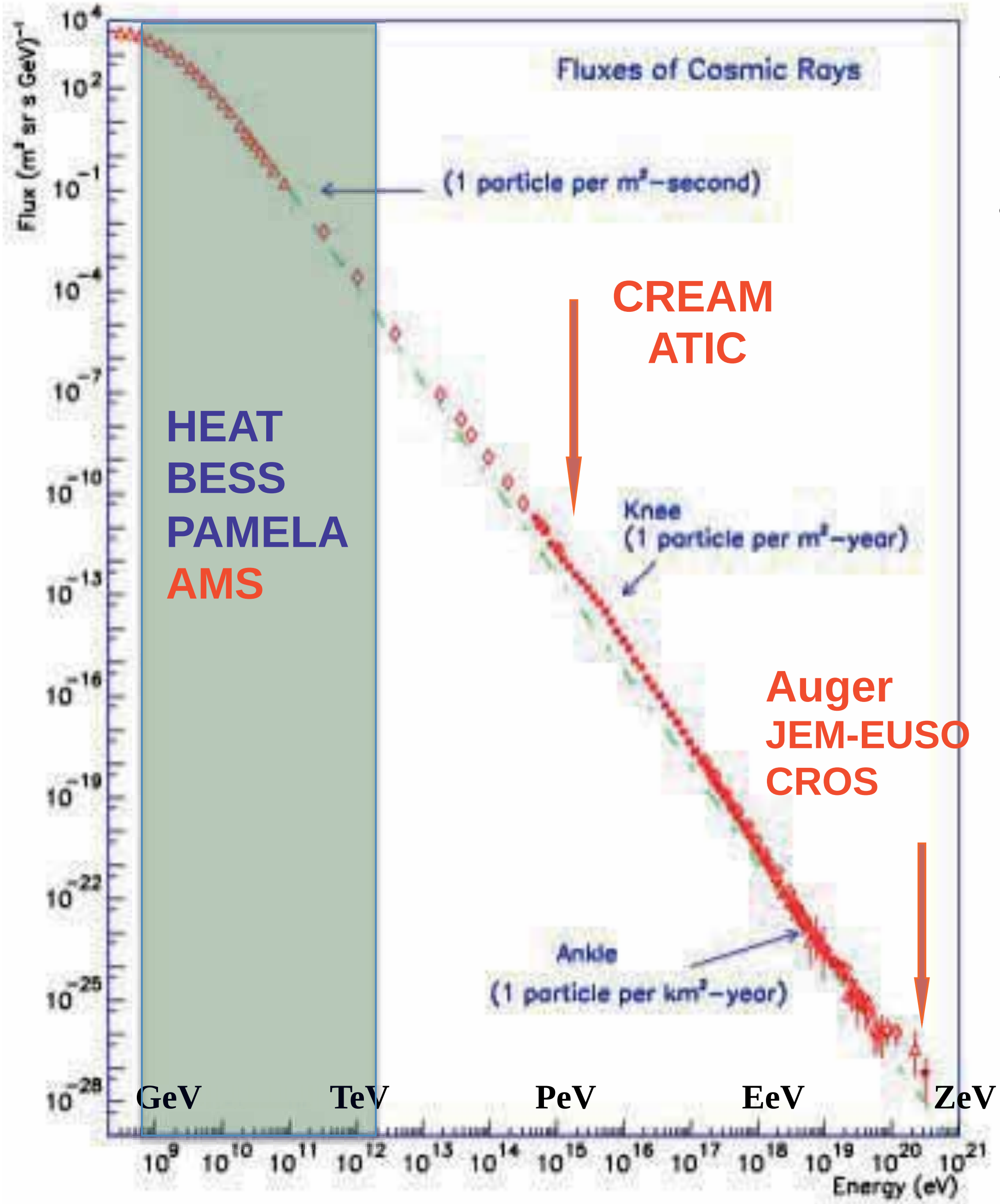


1947: Discovery of pions
C. Powell

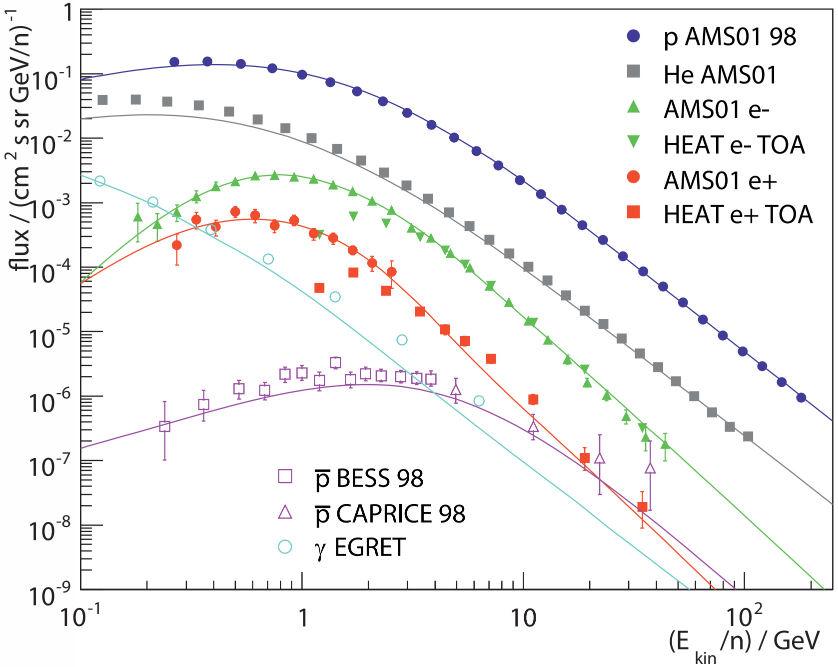
Discoveries of

- 1936: Muon (μ)
- 1938: 10^{15} eV CR
- 1949: Kaon (K)
- 1949: Lambda (Λ)
- 1952: Xi (Ξ)
- 1953: Sigma (Σ)





Ref: B Beischer *et al* 2009 *New J. Phys.* 11 105021



Experimental Challenges

to search for new physics:

$$\chi\chi \to X \to e^+e^-, p\bar{p},$$

Signal/background=$e^+/p < 10^{-4}$
rejection of background<$1/10^6$

nature International weekly journal of science

FIGURE 2. PAMELA positron fraction with other experimental data and with secondary production model.

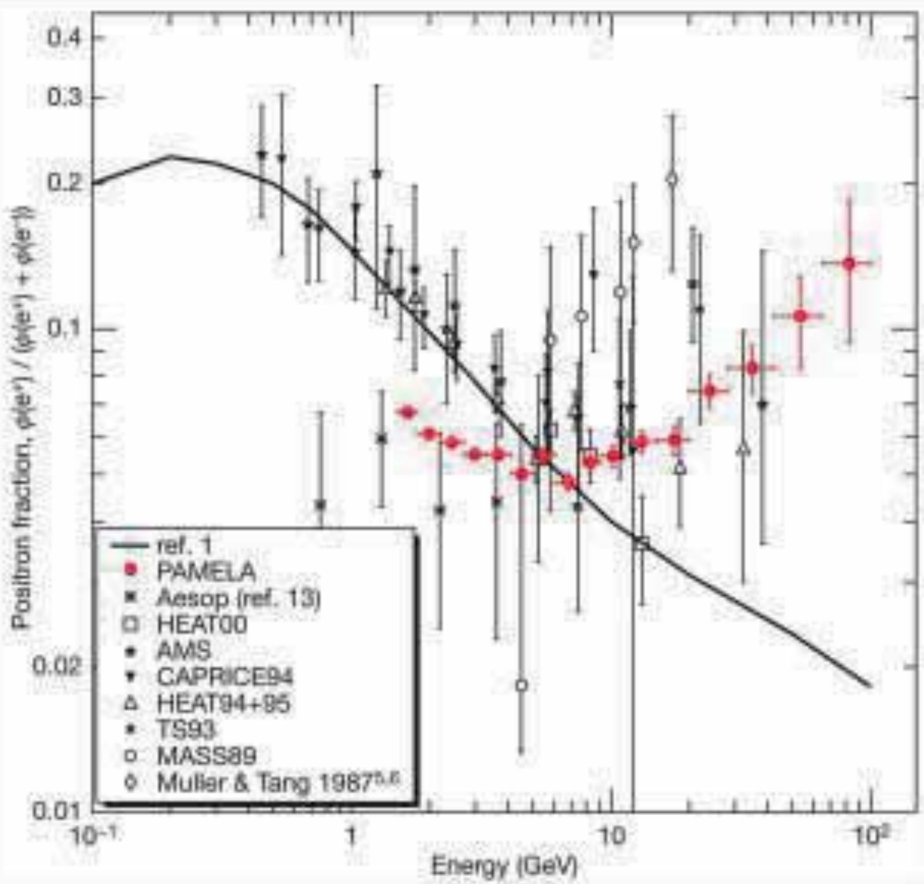
Oct. 2013: 1120 citations

From the following article:
An anomalous positron abundance in cosmic rays with energies 1.5–100 GeV

O. Adriani, G. C. Barbarino, G. A. Bazilevskaya, R. Bellotti, M. Boezio, E. A. Bogomolov, L. Bonechi, M. Bongi, V. Bonvicini, S. Bottai, A. Bruno, F. Cafagna, D. Campana, P. Carlson, M. Casolino, G. Castellini, M. P. De Pascale, G. De Rosa, N. De Simone, V. Di Felice, A. M. Galper, L. Grishantseva, P. Hofverberg, S. V. Koldashov, S. Y. Krutkov, A. N. Kvashnin, A. Leonov, V. Malvezzi, L. Marcelli, W. Menn, V. V. Mikhailov, E. Mocchiutti, S. Orsi, G. Osteria, P. Papini, M. Pearce, P. Picozza, M. Ricci, S. B. Ricciarini, M. Simon, R. Sparvoli, P. Spillantini, Y. I. Stozhkov, A. Vacchi, E. Vannuccini, G. Vasilyev, S. A. Voronov, Y. T. Yurkin, G. Zampa, N. Zampa & V. G. Zverev

Nature **458**, 607–609 (2 April 2009)
doi:10.1038/nature07942

back to article

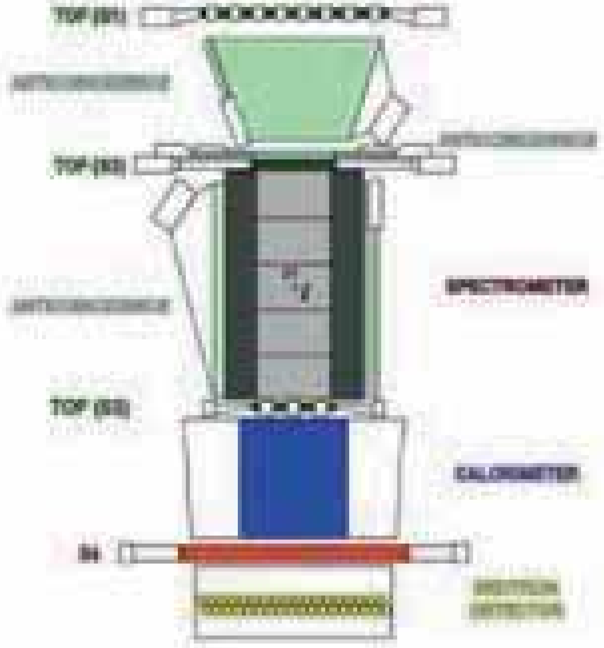


PAMELA Measurements of Cosmic-Ray Proton and Helium Spectra
O. Adriani *et al.*
Science **332**, 69 (2011);
DOI: 10.1126/science.1199172

Oct. 2013: 127 citations

PAMELA Measurements of Cosmic-Ray Proton and Helium Spectra

O. Adriani, G. C. Barbarino, G. A. Bazilevskaya, R. Bellotti, M. Boezio, E. A. Bogomolov, L. Bonechi, M. Bongi, V. Bonvicini, S. Borisov, S. Bottai, A. Bruno, F. Cafagna, D. Campana, R. Carbone, P. Carlson, M. Casolino, G. Castellini, L. Consiglio, M. P. De Pascale, C. De Santis, N. De Simone, V. Di Felice, A. M. Galper, W. Gillard, L. Grishantseva, G. Jerse, A. V. Karelin, S. V. Koldashov, S. Y. Krutkov, A. N. Kvashnin, A. Leonov, V. Malakhov, V. Malvezzi, L. Marcelli, A. G. Mayorov, W. Menn, V. V. Mikhailov, E. Mocchiutti, A. Monaco, N. Mori, N. Nikonov, G. Osteria, F. Palma, P. Papini, M. Pearce, P. Picozza, C. Pizzolotto, M. Ricci, S. B. Ricciarini, L. Rossetto, R. Sarkar, M. Simon, R. Sparvoli, P. Spillantini, Y. I. Stozhkov, A. Vacchi, E. Vannuccini, G. Vasilyev, S. A. Voronov, Y. T. Yurkin, J. Wu, G. Zampa, N. Zampa, V. G. Zverev



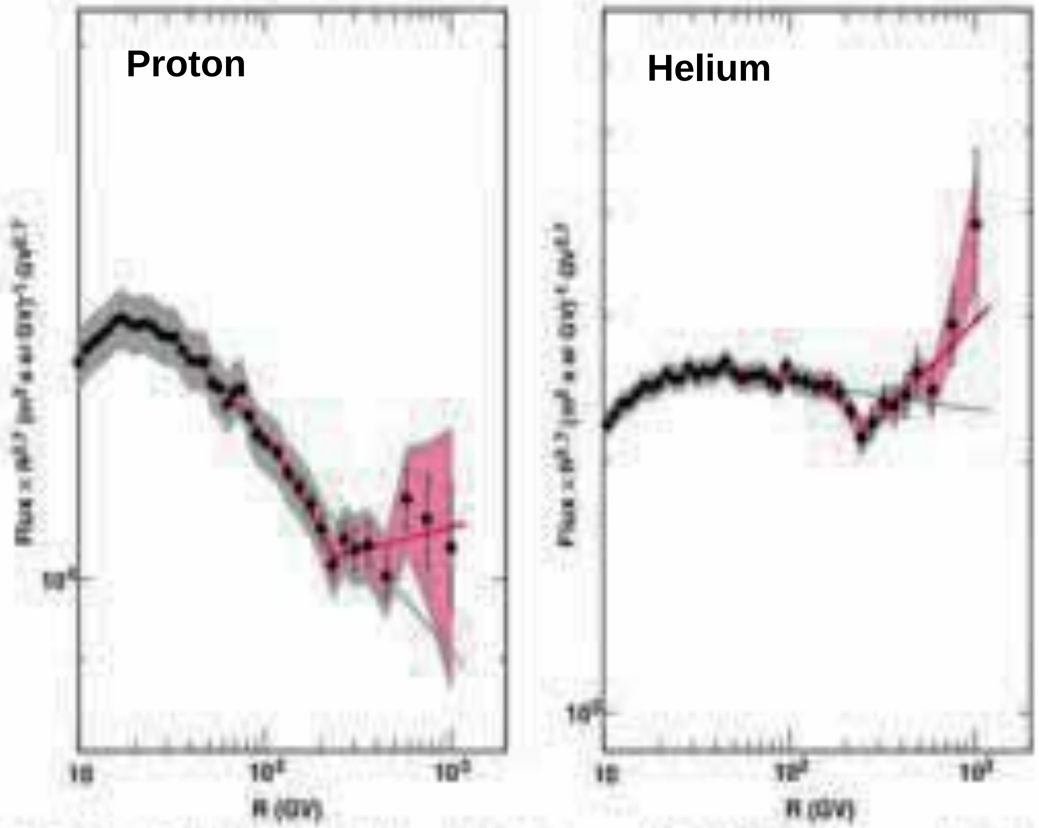


Fig. 4. Proton (**left**) and helium (**right**) spectra in the range 10 GV to 1.2 TV. The gray shaded area represents the estimated systematic uncertainty, and the pink shaded area represents the contribution due to tracker alignment. The green lines represent fits with a single power law in the rigidity range 30 to 240 GV. The red curves represent the fit with a rigidity-dependent power law (30 to 240 GV) and with a single power law above 240 GV.

nature International weekly journal of science

FIGURE 4. Assuming an annihilation signature of Kaluza–Klein dark matter, all the data can be reproduced.

Oct. 2013: 575 citations

From the following article:
An excess of cosmic ray electrons at energies of 300–800 GeV
J. Chang, J. H. Adams, H. S. Ahn, G. L. Bashindzhagyan, M. Christl, O. Ganel, T. G. Guzik, J. Isbert, K. C. Kim, E. N. Kuznetsov, M. I. Panasyuk, A. D. Panov, W. K. H. Schmidt, E. S. Seo, N. V. Sokolskaya, J. W. Watts, J. P. Wefel, J. Wu & V. I. Zatsepin
Nature **456**, 362-365(20 November 2008)
doi:10.1038/nature07477

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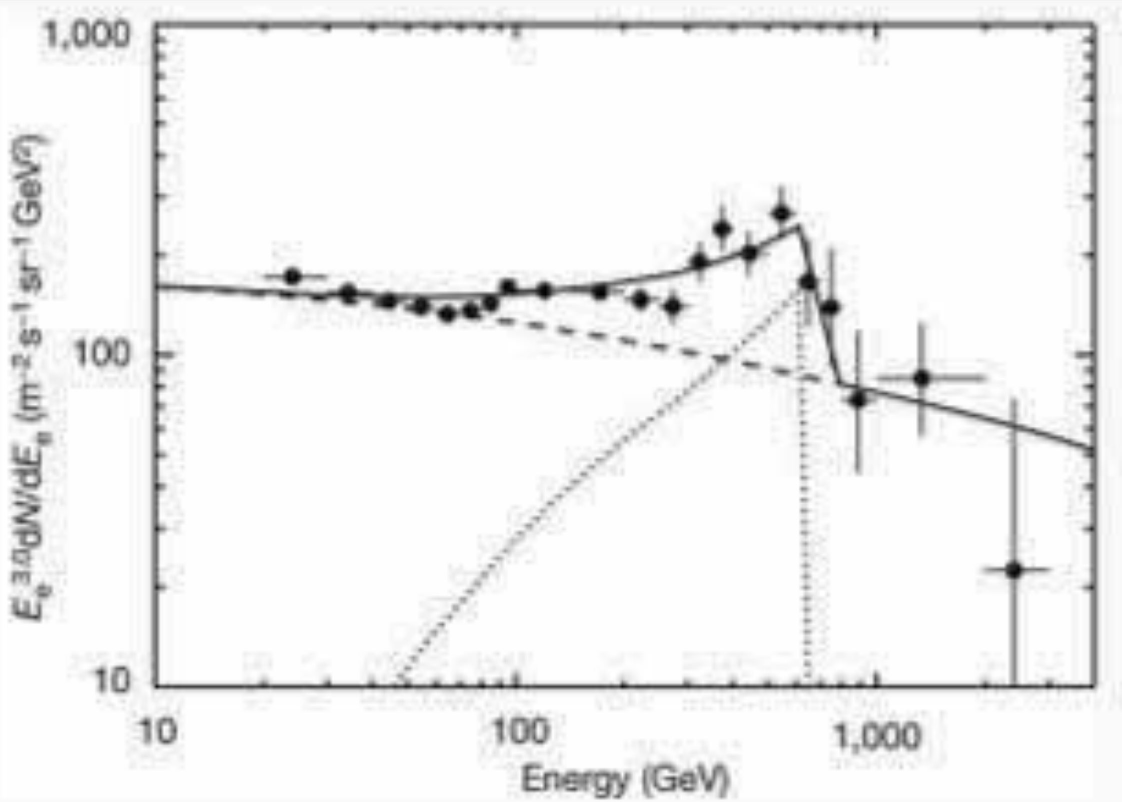
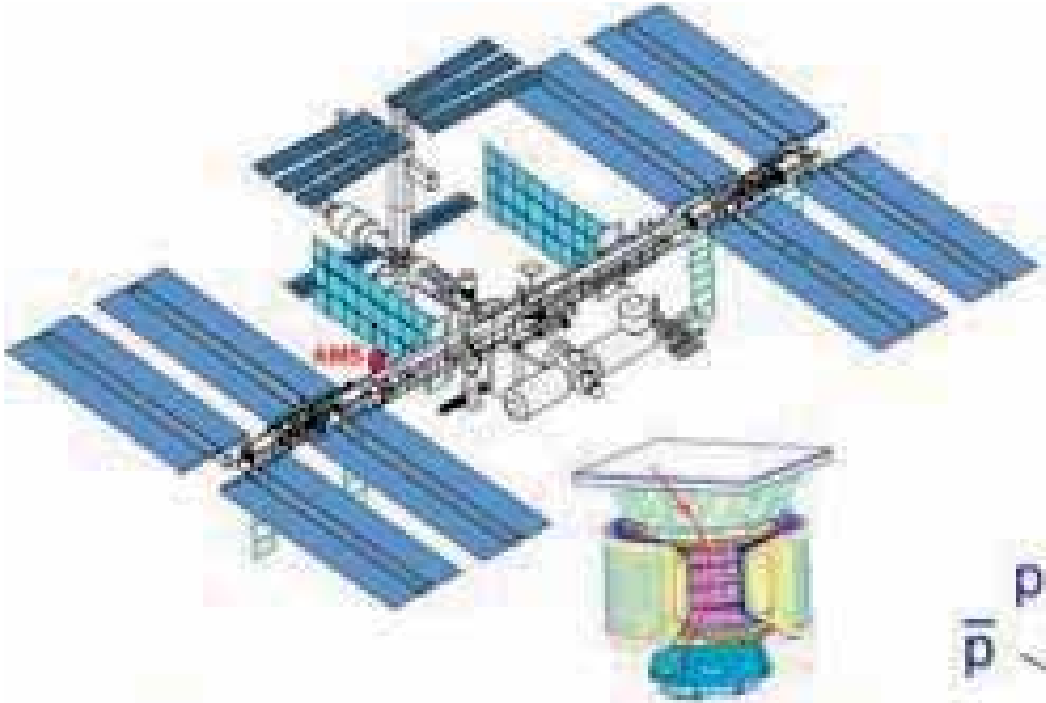


ATIC collaboration



1- Neutral component:

γ, ν

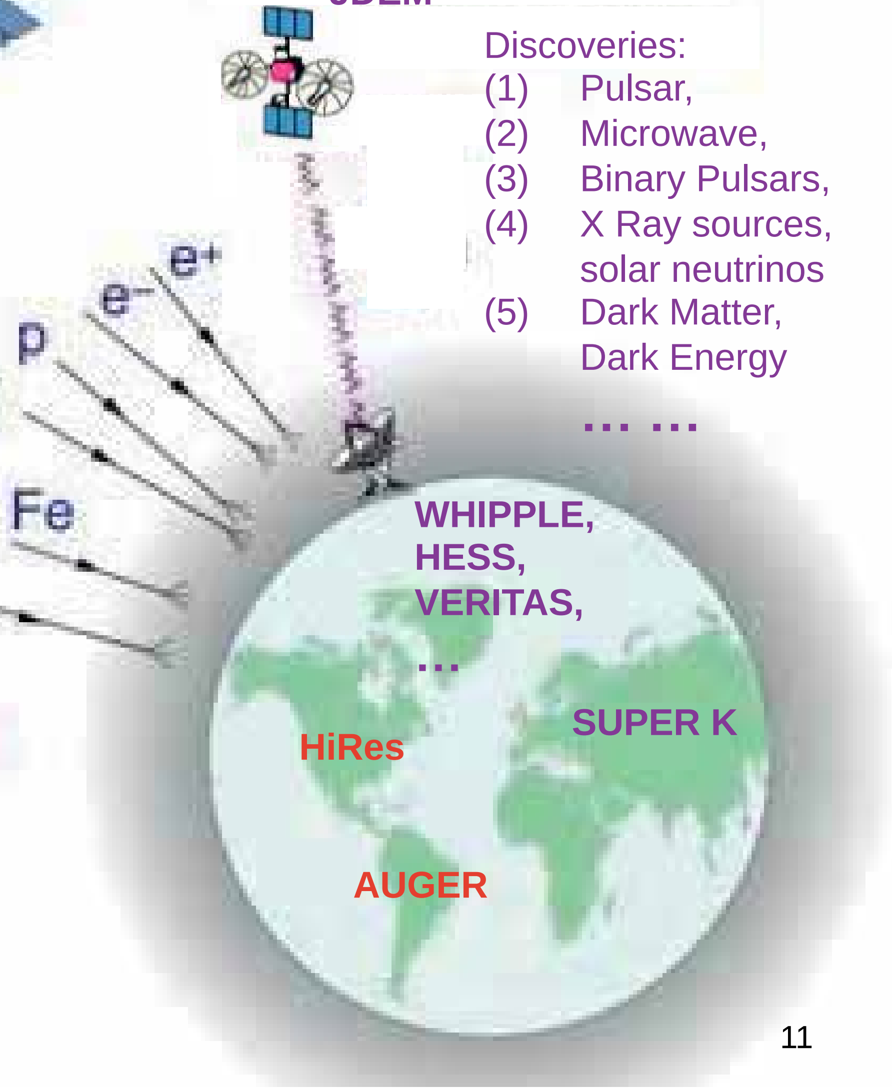
Hubble, Chandra, GLAST, JWST, JDEM

Discoveries:

(1) Pulsar,
(2) Microwave,
(3) Binary Pulsars,
(4) X Ray sources, solar neutrinos
(5) Dark Matter, Dark Energy

… …

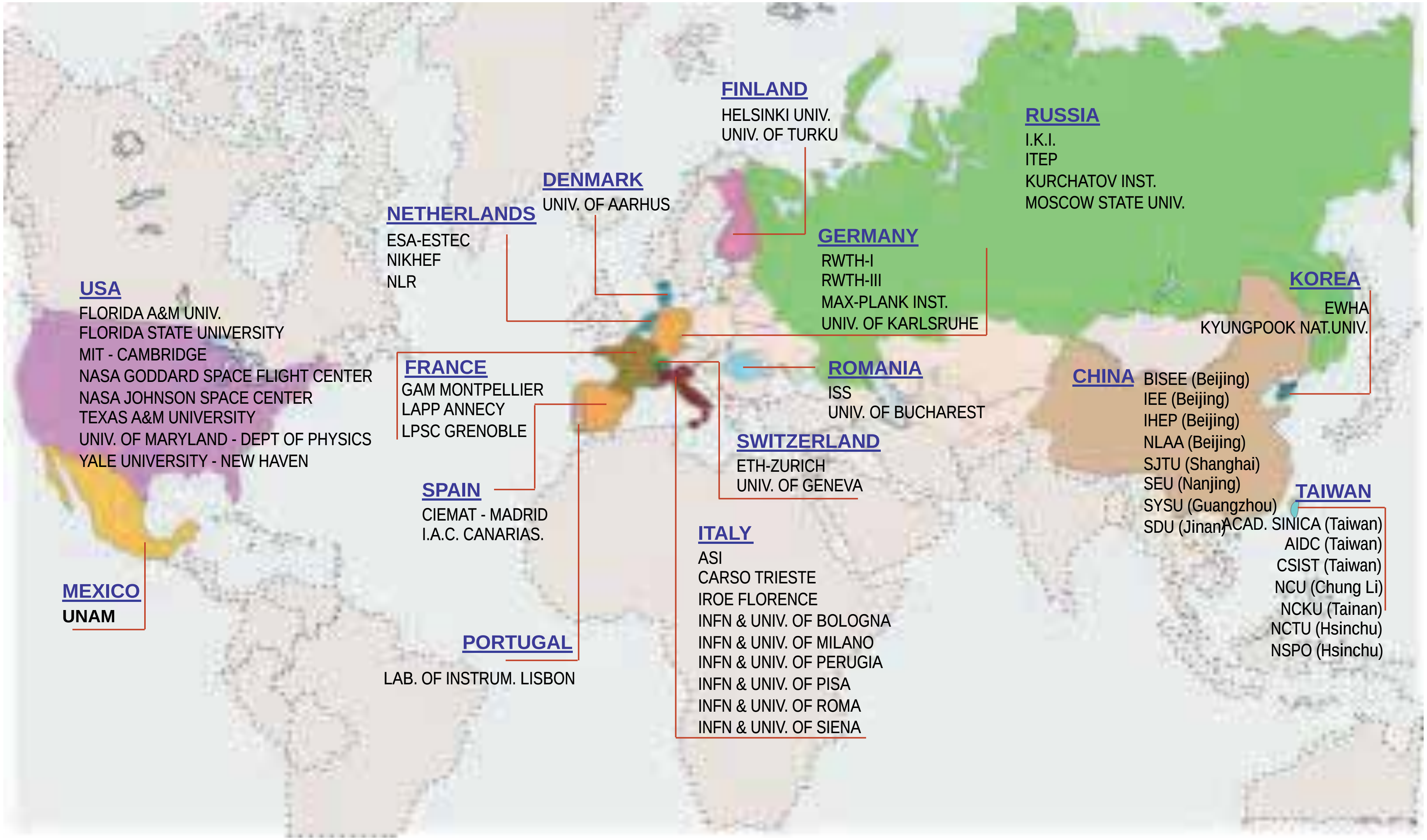
2- Charged component: e^+, e^-, p, $\bar{p}$, He, Be, C, Fe, $\overline{\text{He}}$,



S. Ting, MIT

AMS is US Dept of Energy (DOE) led International Collaboration

16 Countries, 60 Institutes and 600 Physicists, 17 years



The detectors were built all over the world and assembled at CERN, near Geneva, Switzerland

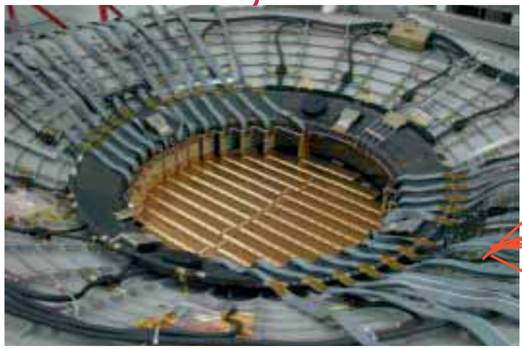
AMS: A TeV precision, multipurpose spectrometer

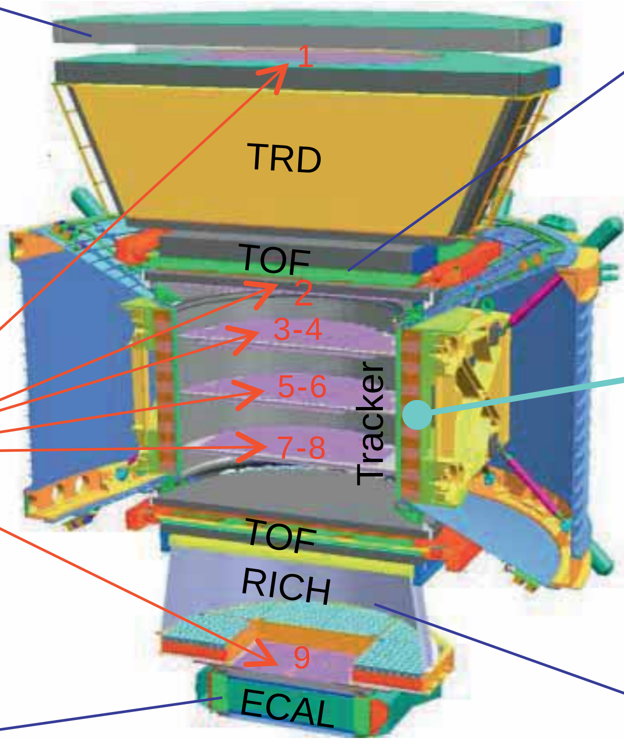
TRD
Identify e⁺, e⁻

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

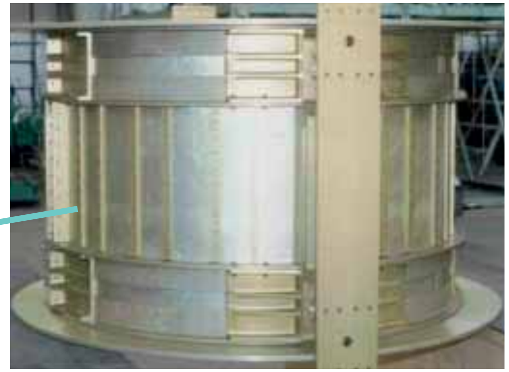
TOF
Z, E

Silicon Tracker
Z, P

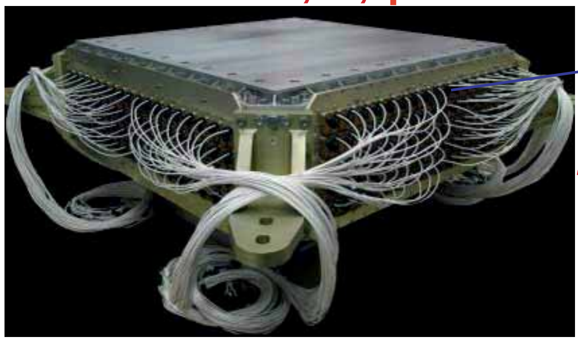




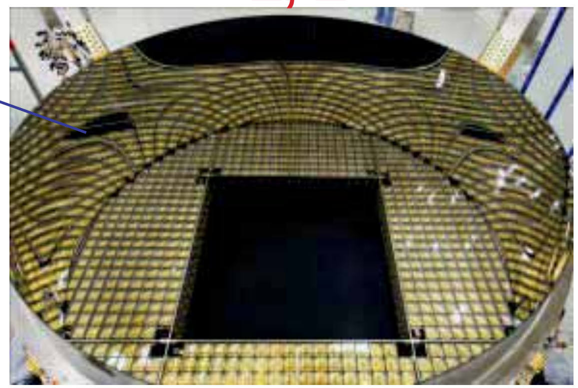
Magnet
±Z



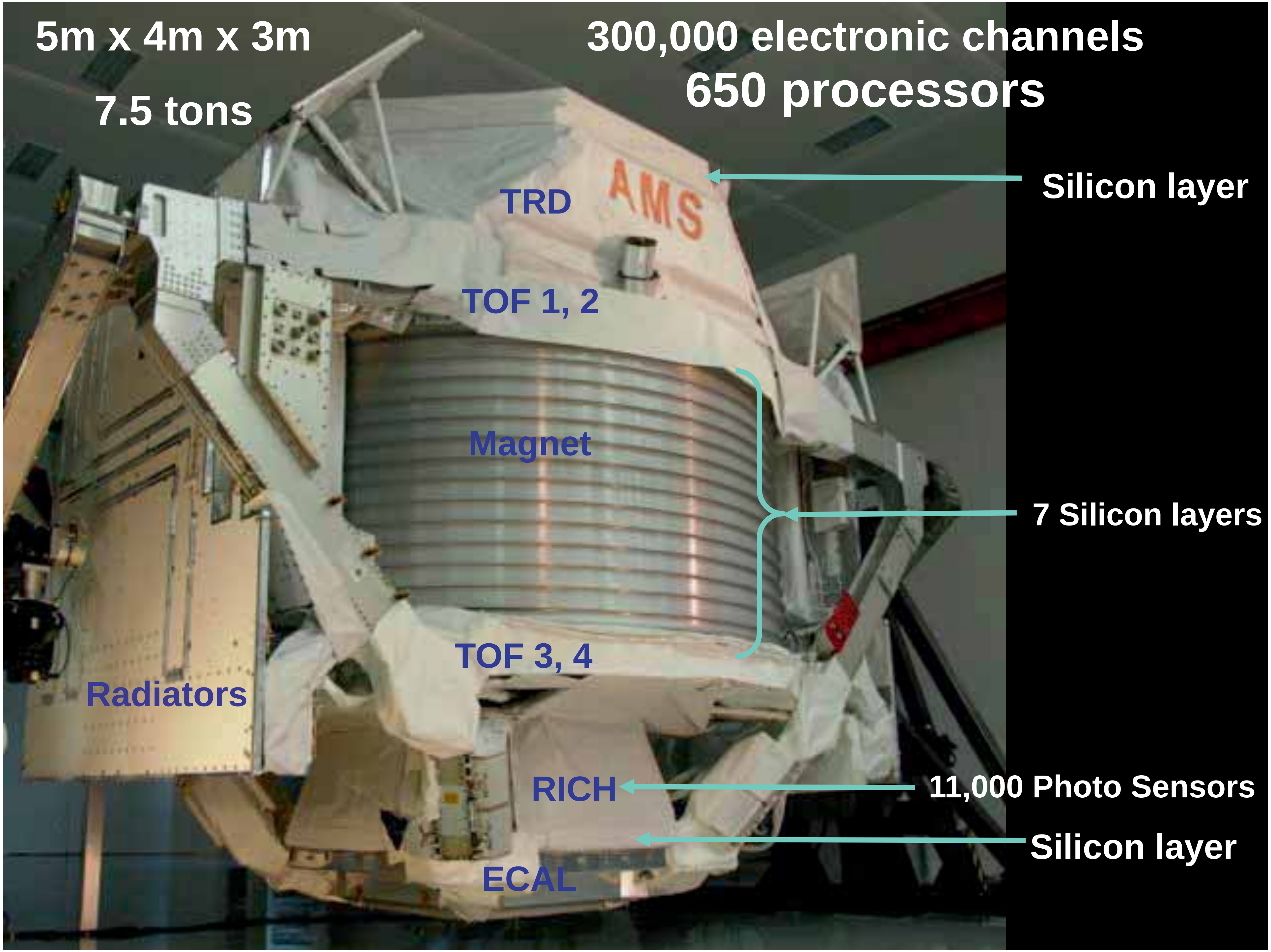
ECAL
E of e⁺, e⁻, γ



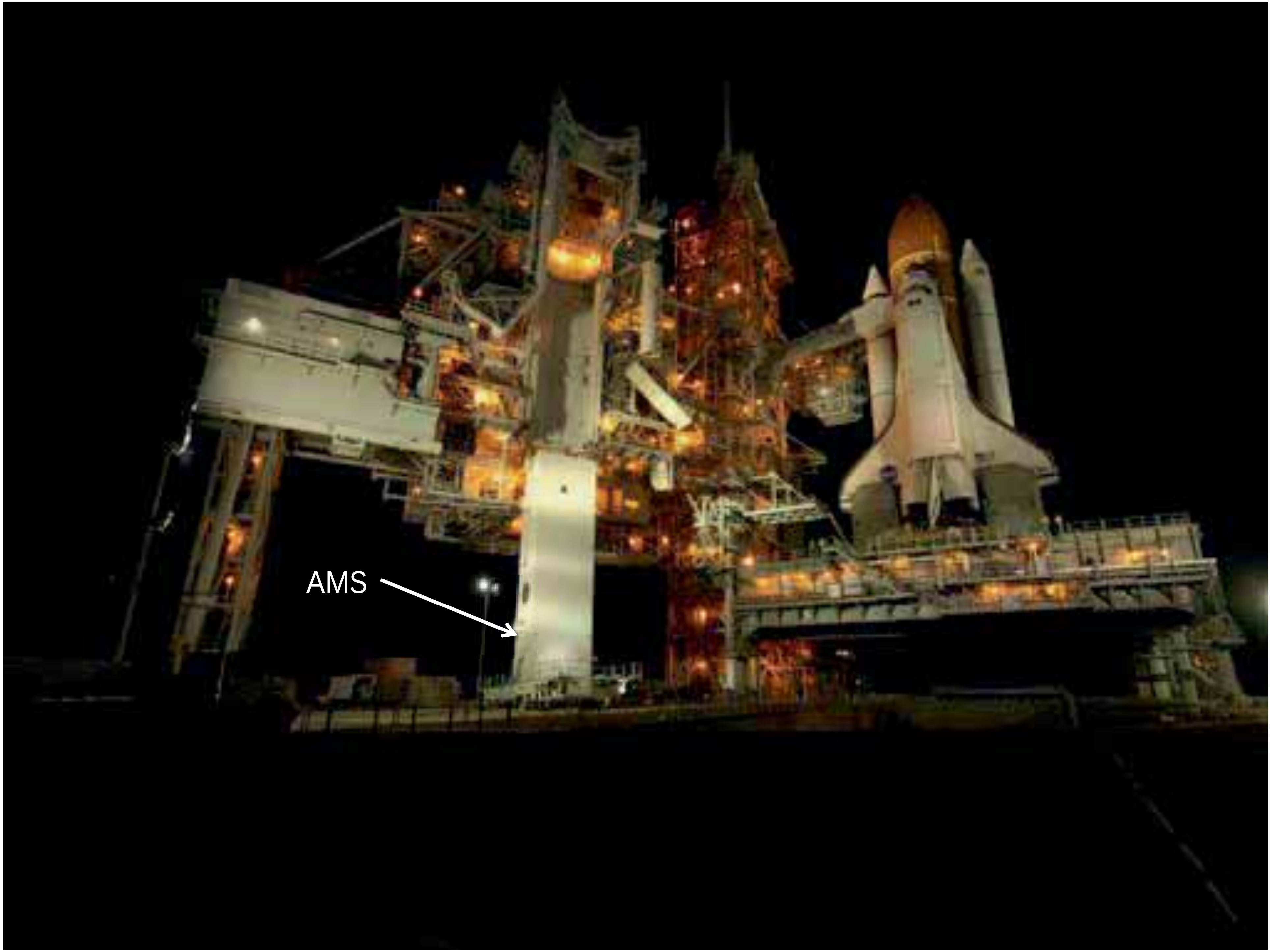
RICH
Z, E



Z, P *are measured independently by the Tracker, RICH, TOF and ECAL*


5m x 4m x 3m
7.5 tons
300,000 electronic channels
650 processors
AMS
TRD
Silicon layer
TOF 1, 2
Magnet
7 Silicon layers
TOF 3, 4
Radiators
RICH
11,000 Photo Sensors
Silicon layer
ECAL

A US Air Force C-5 Galaxy
has been used for transport
from Geneva to KSC
25. August 2010

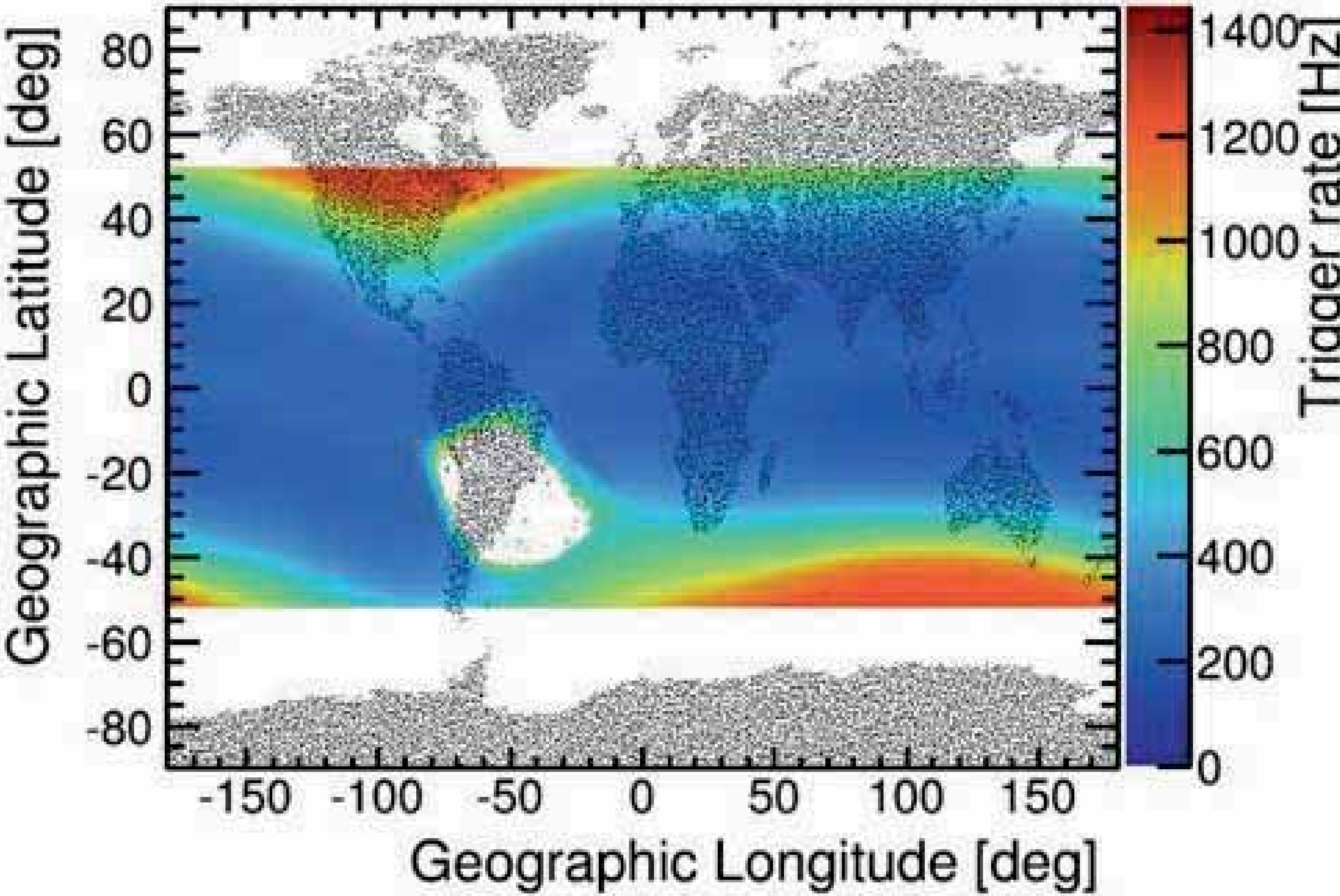

AMS

Closing Endeavour's Payload Bay Doors at the Launch Pad

STS-134 launch   May 16, 2011 @ 08:56 AM

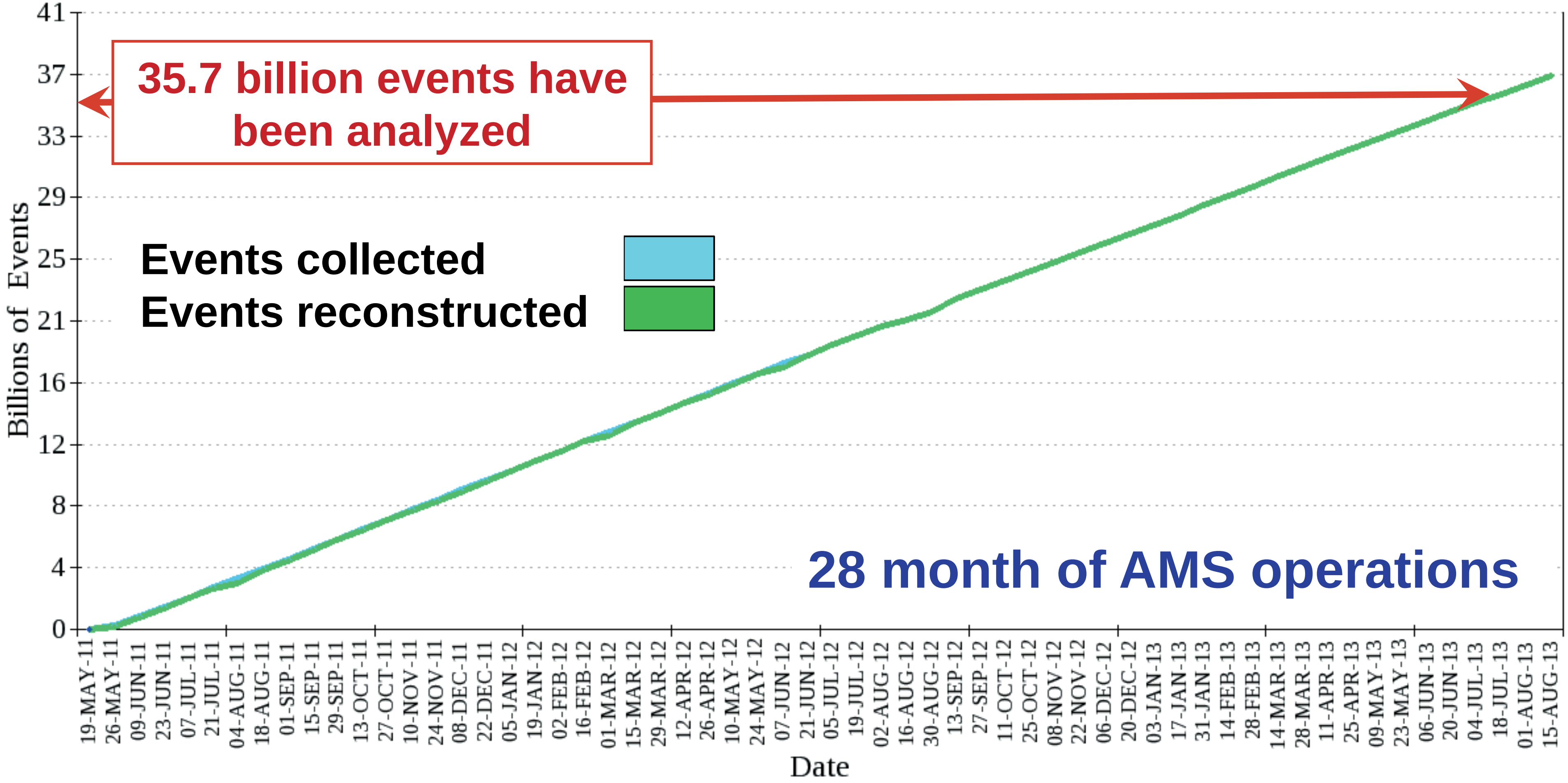
Endeavour approaches the International Space Station


AMS installed on the ISS
Truss and taking data
May 19, 2011

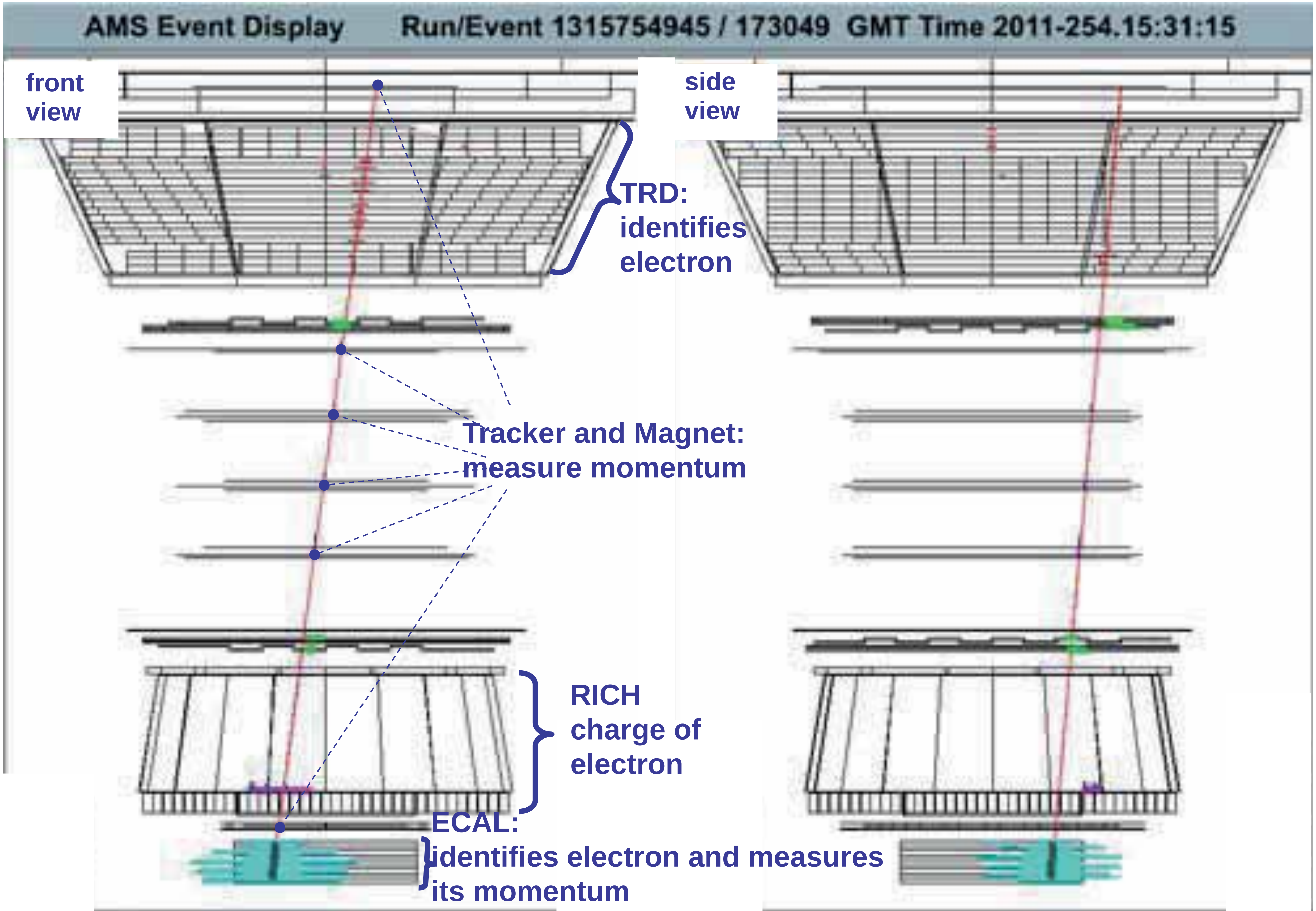


Geographic Latitude [deg]
80
60
40
20
0
-20
-40
-60
-80
-150
-100
-50
0
50
100
150
Geographic Longitude [deg]
Trigger rate [Hz]
1400
1200
1000
800
600
400
200
0

Up to August 26, 2013, 38 billion events have been processed by the Data Production Operations in the POCC

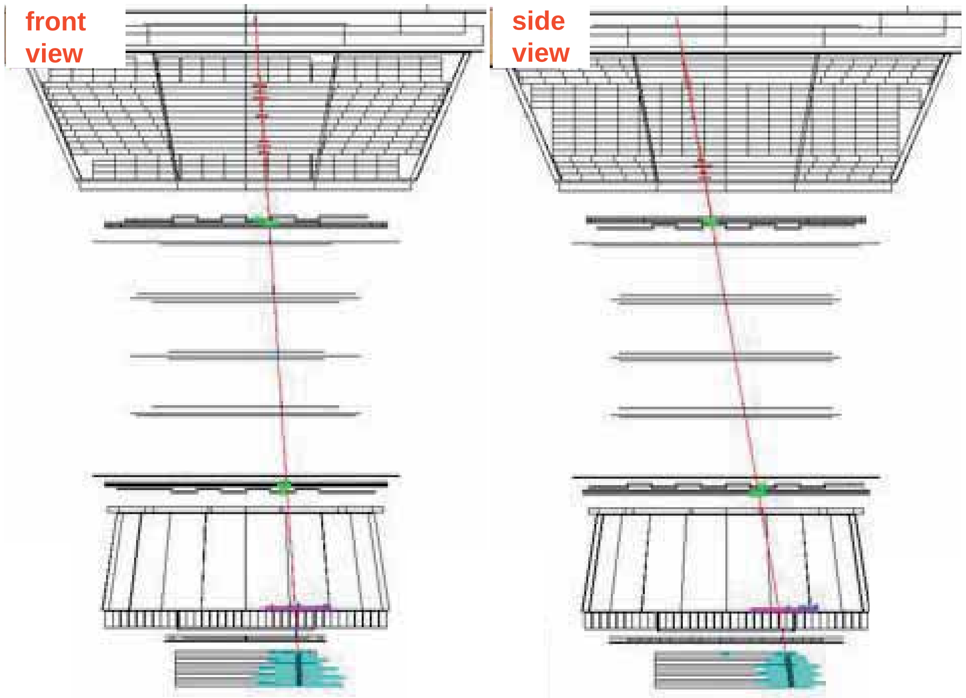


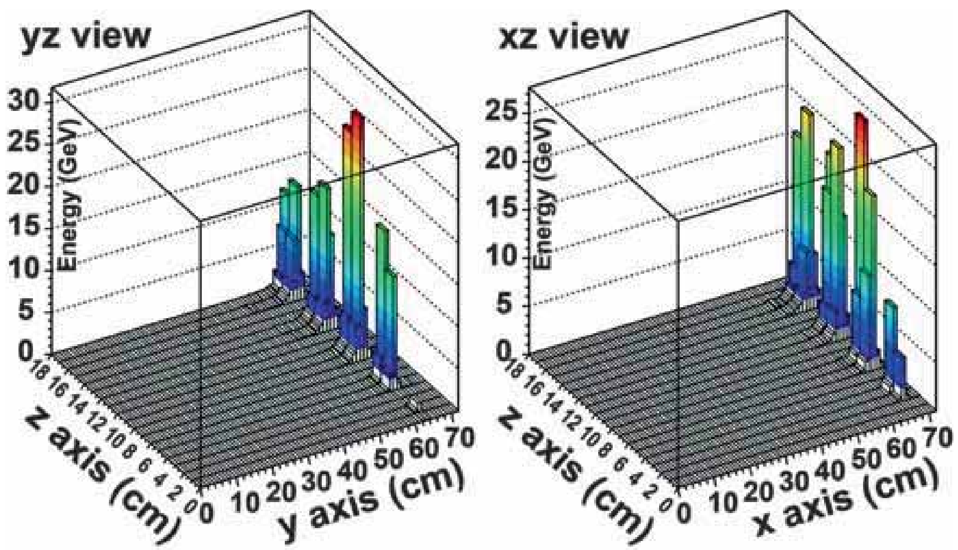
1.03 TeV electron

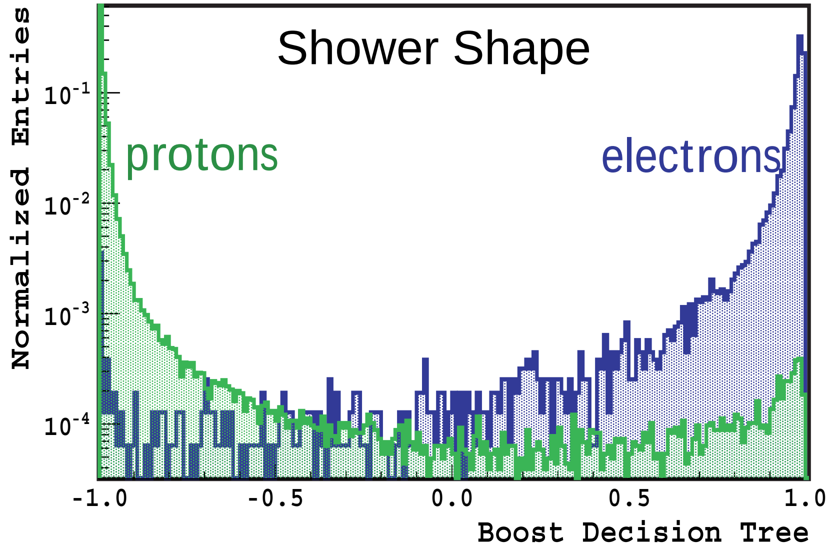


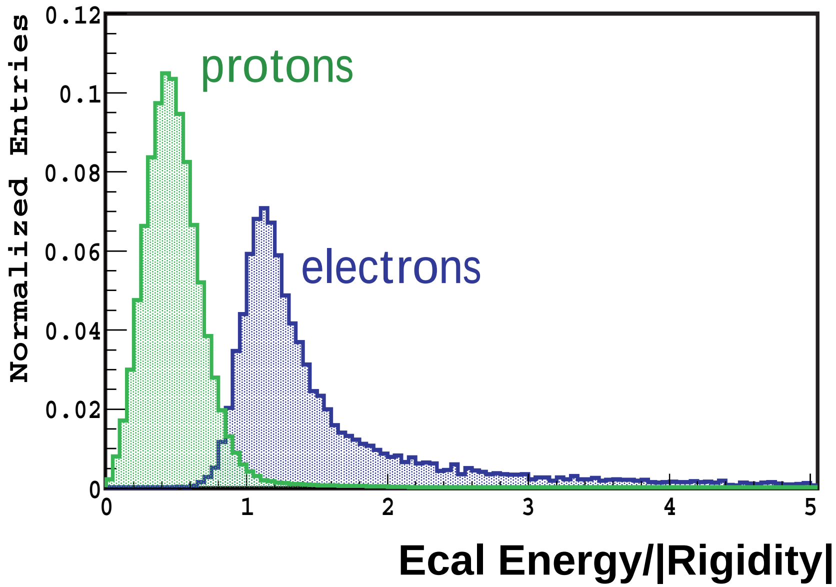
Positron E=636 GeV

Run/Event 133119-743/ 56950

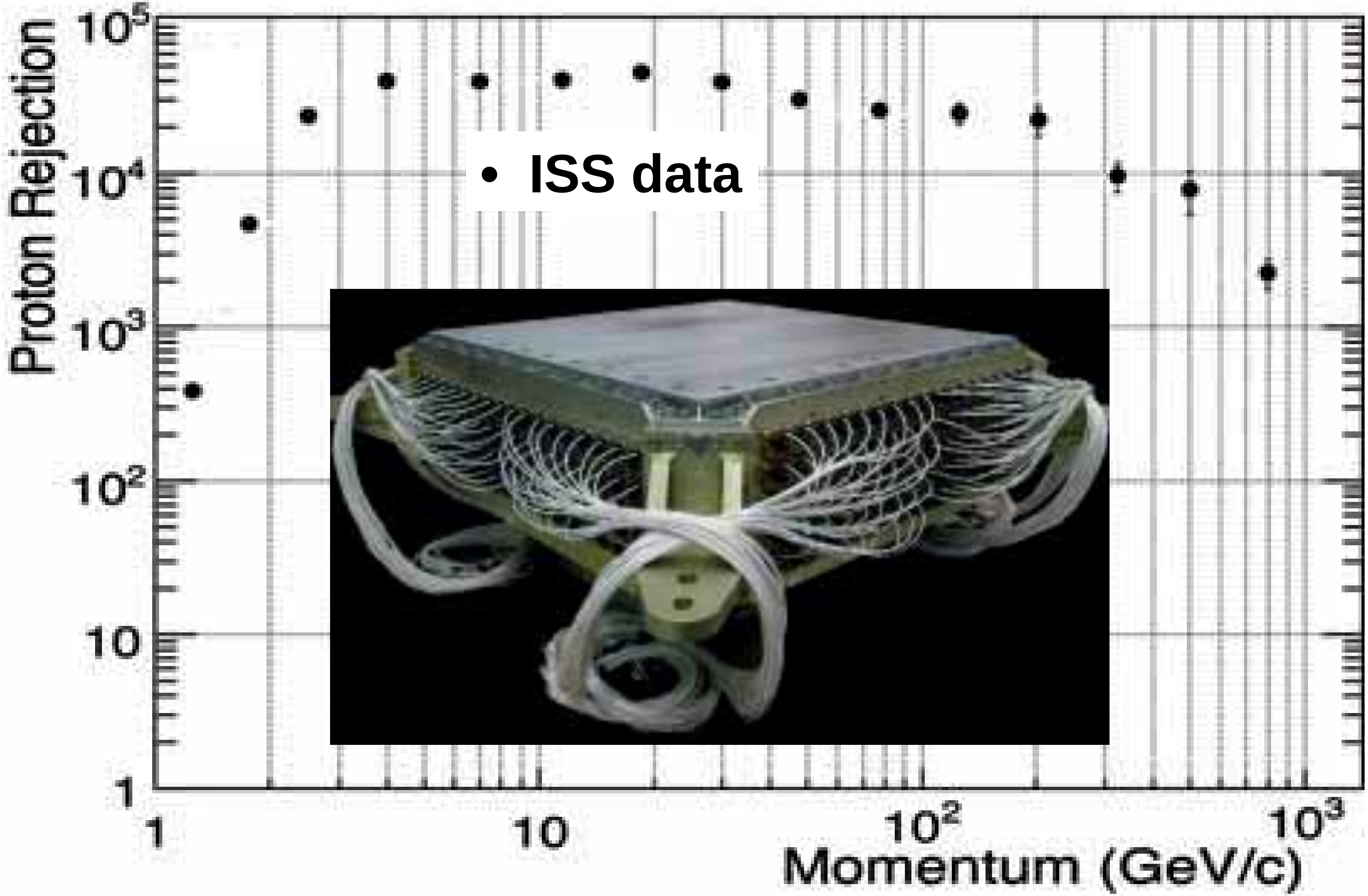








Proton Rejection by ECAL and Tracker



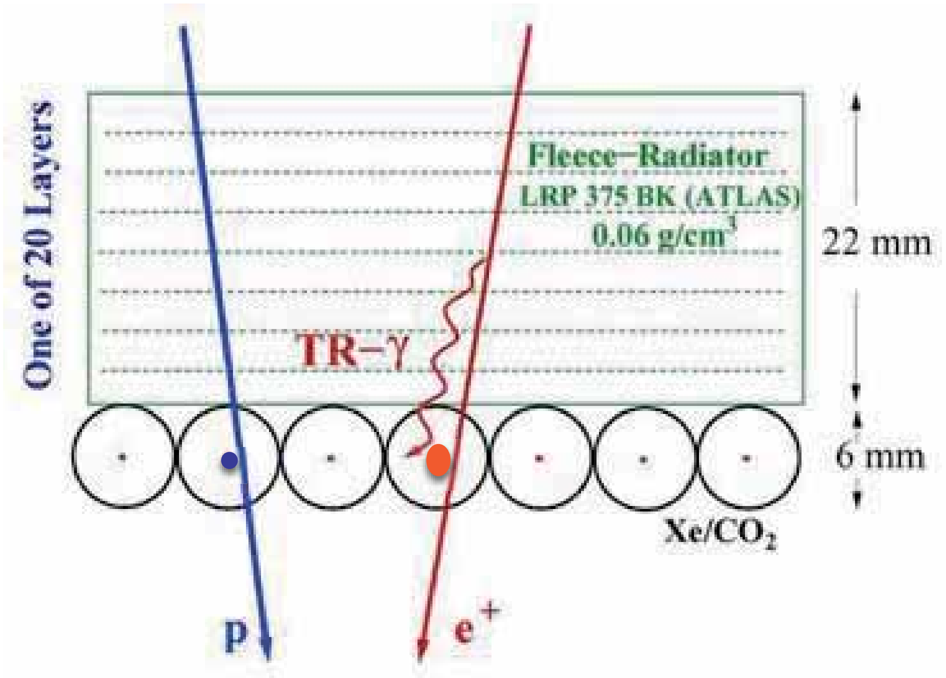
Transition Radiation Detector

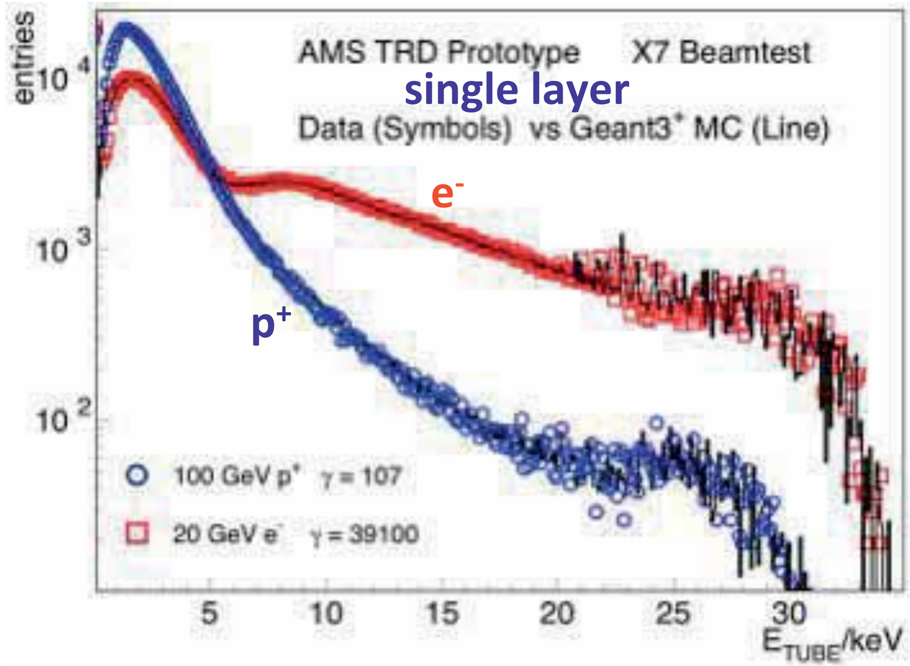
p^+ rejection $>10^2$ 1-400 GeV
acceptance: $0.4 m^2 sr$

20 Layers each consisting of:

- **22 mm fibre fleece**
- **Ø 6 mm straw tubes filled with Xe/CO_2 80%/20%**

P. Doetinchem et al., Nucl.Instrum.Methods A, 558:608641, 2006.

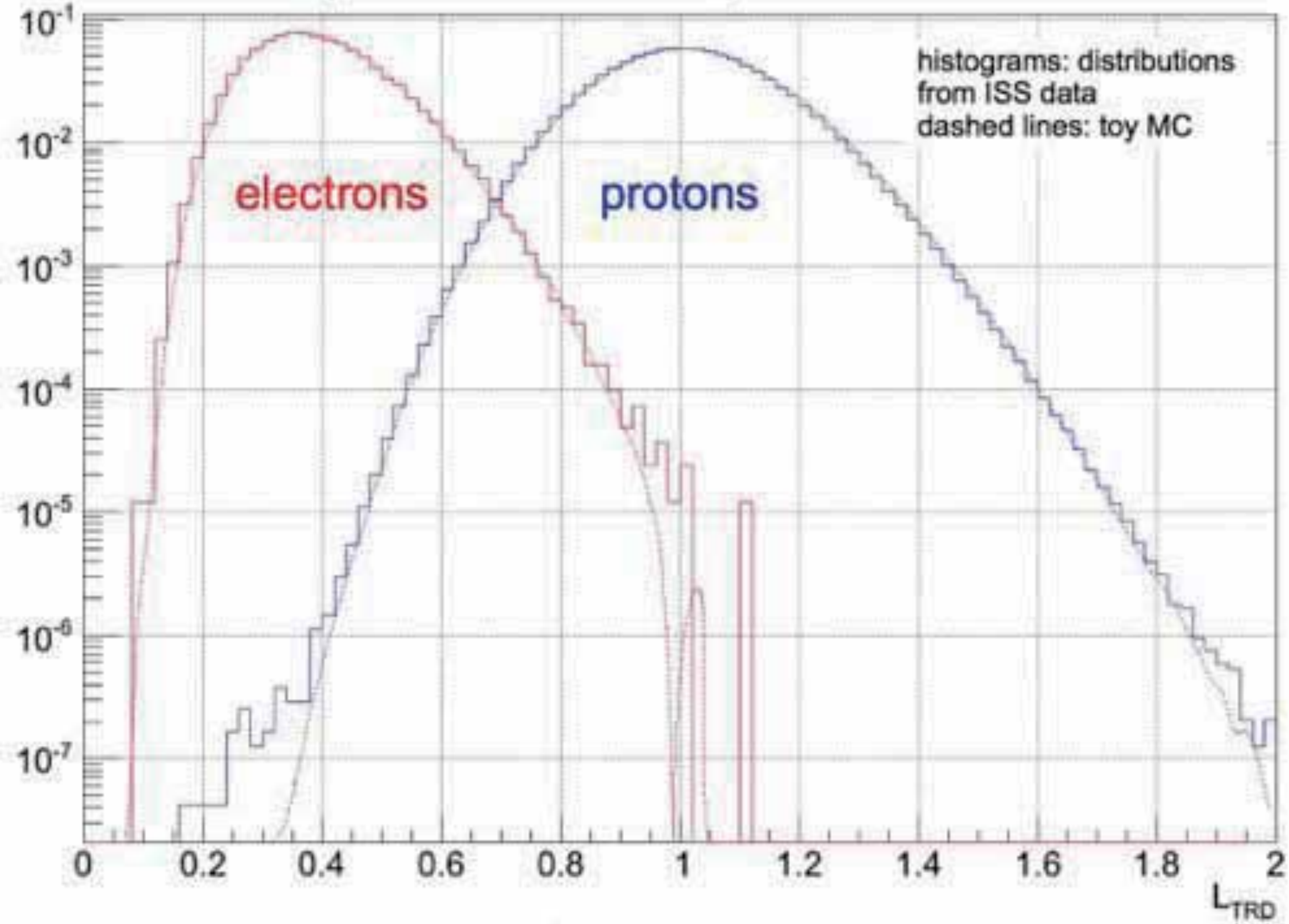




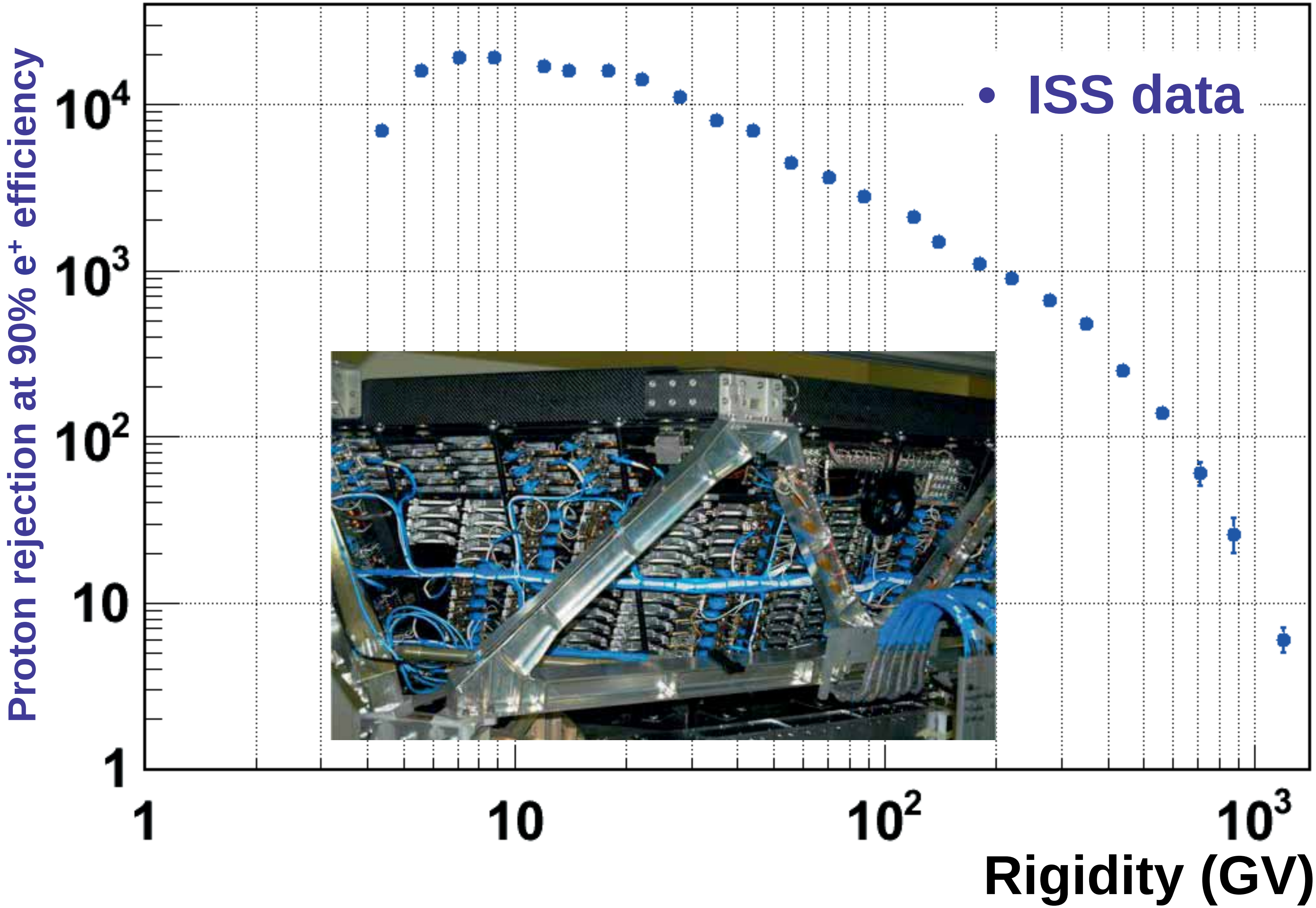
AMS TRD Data on ISS

$$L_{e,p} = \sqrt[n]{\prod_i^n p_{e,p}(dE_i/dx_i)} \quad \rightarrow \quad L_{\mathrm{TRD}} = -\log \frac{L_e}{L_e + L_p}$$

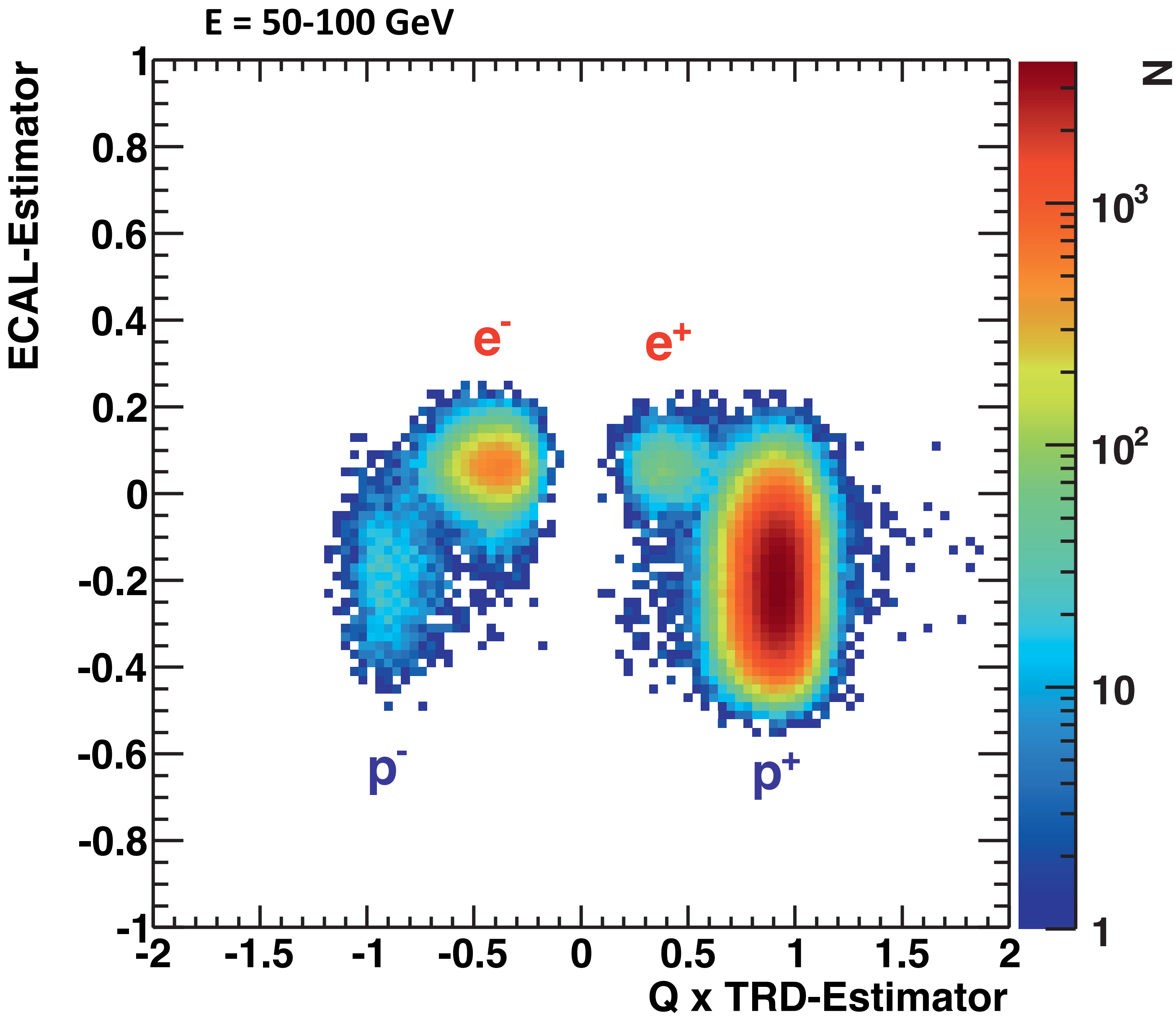
R = 10 – 100 GV



Proton Rejection by TRD



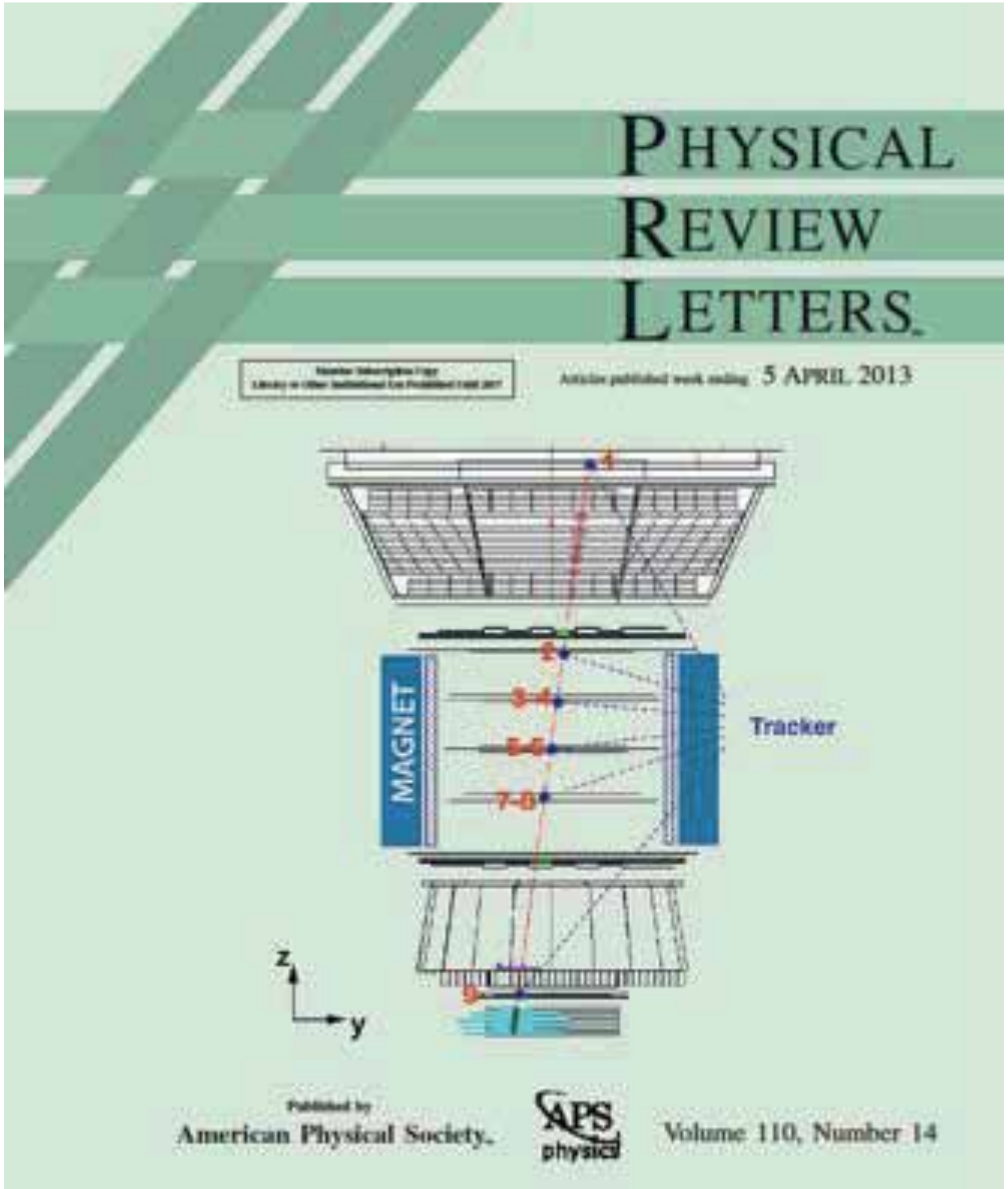
In our data sample we identify four components using an ECAL Estimator and a TRD Estimator.

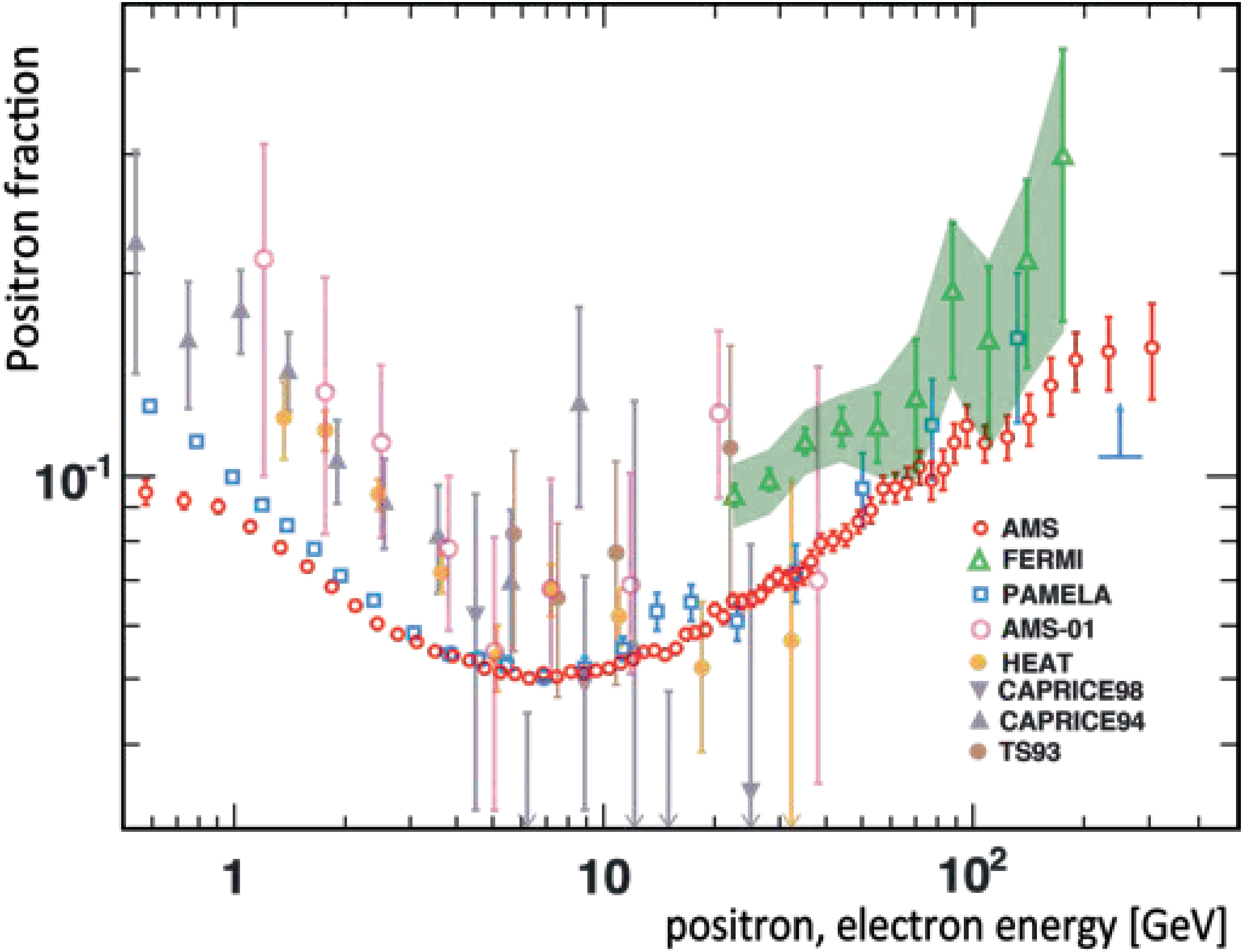


"First Result from the AMS on the ISS: Precision Measurement of the Positron Fraction in Primary Cosmic Rays of 0.5-350 GeV"

Selected for a Viewpoint in Physics and an Editors' Suggestion [Aguilar,M. et al (AMS Collaboration) Phys. Rev. Lett. 110, 1411xx (2013)]

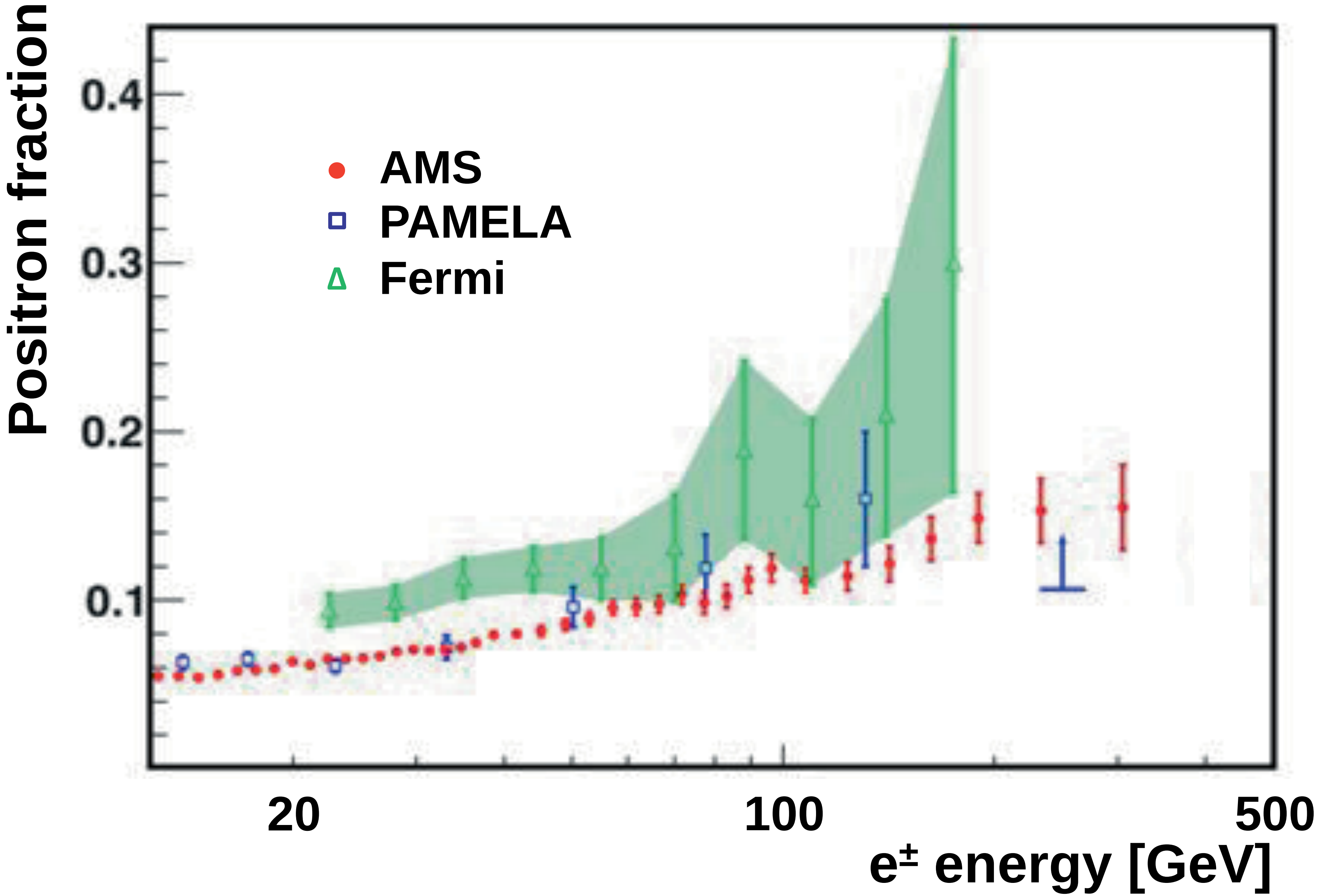
Oct. 2013: 79 citations



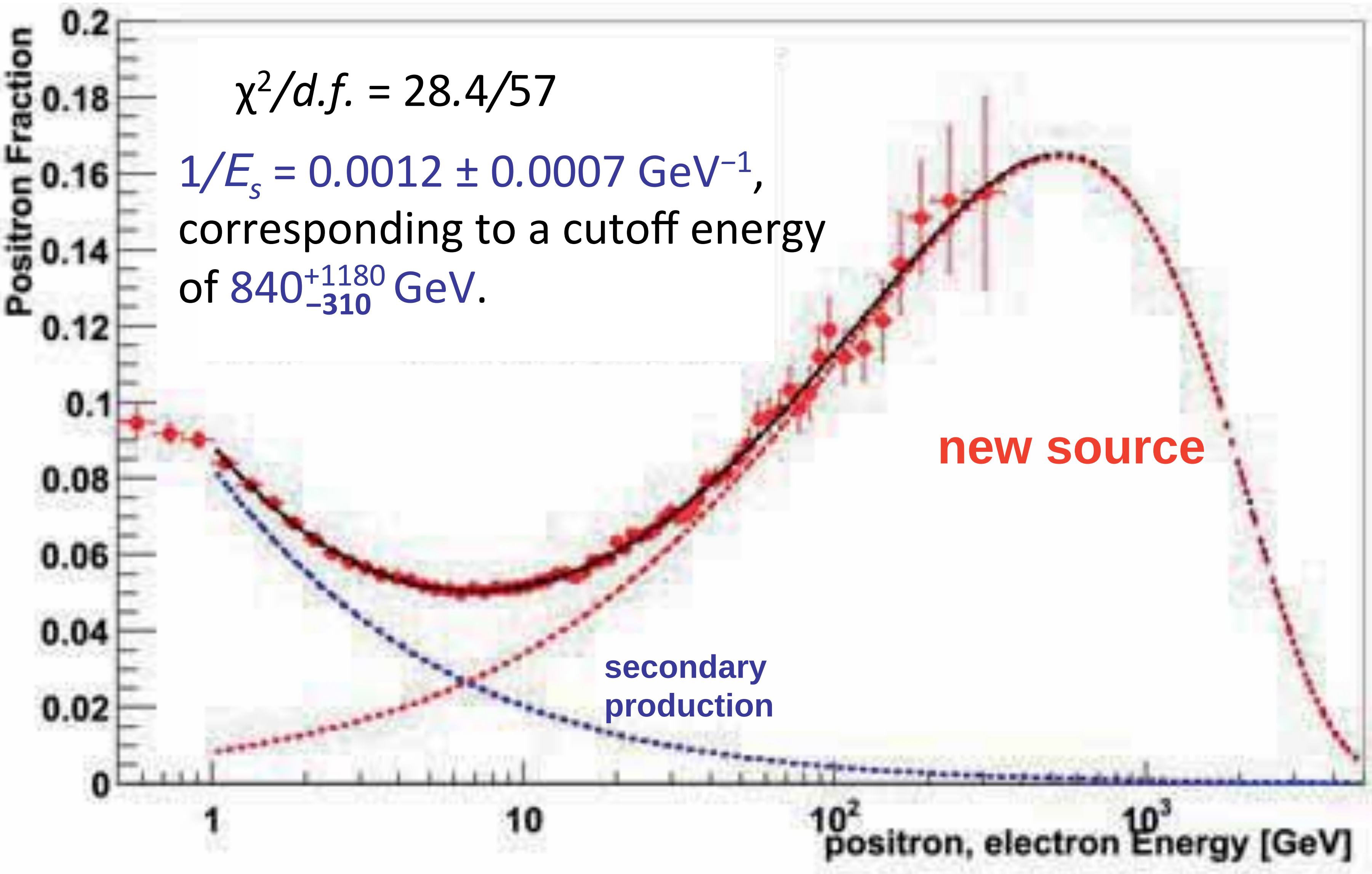


Positron fraction
10^{-1}
1
10
10^2
positron, electron energy [GeV]
AMS
FERMI
PAMELA
AMS-01
HEAT
CAPRICE98
CAPRICE94
TS93

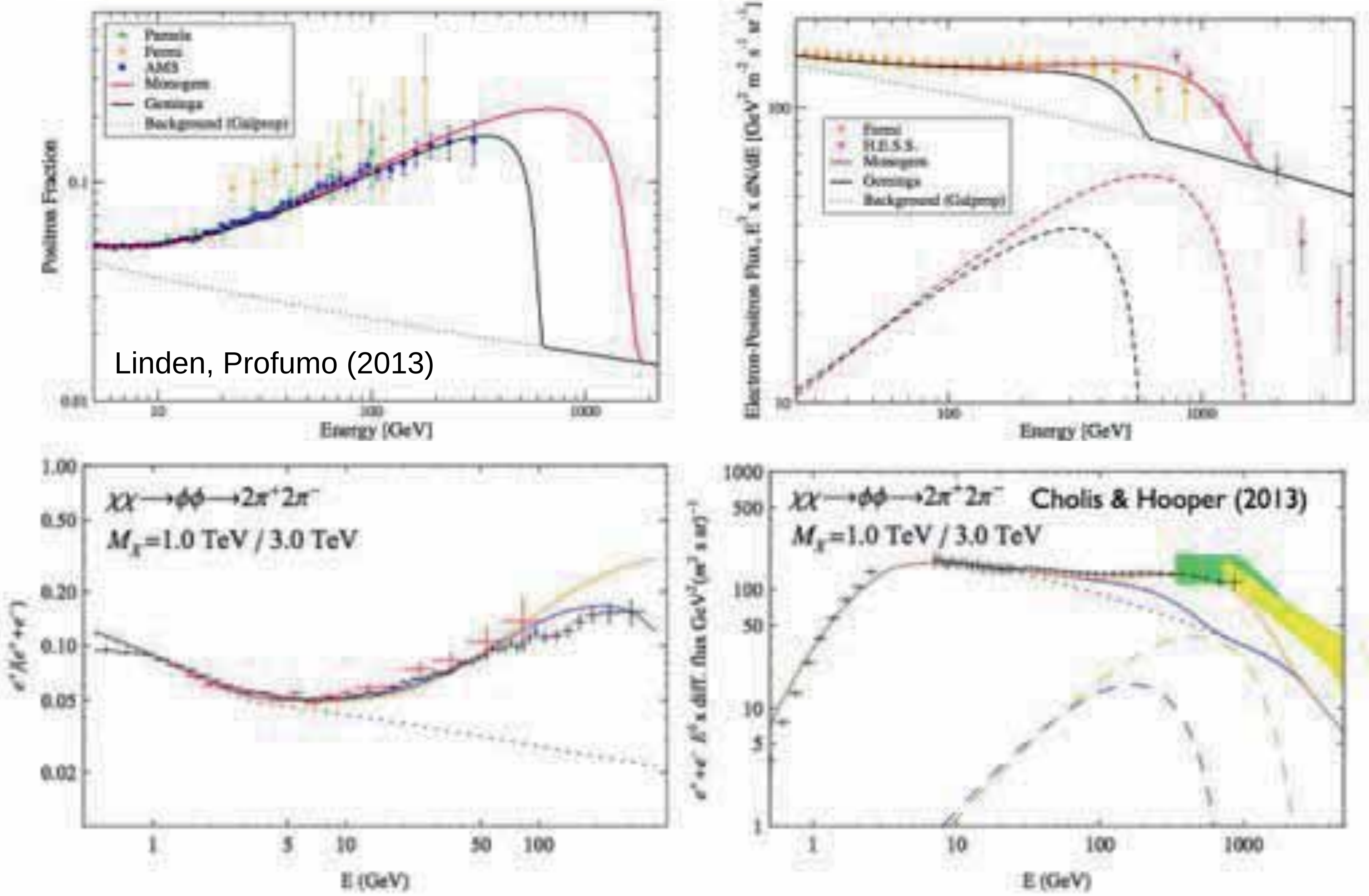
The very accurate data show that the positron fraction is steadily increasing from 10 to 250 GeV, but, from 20 to 250 GeV, the slope decreases by an order of magnitude.



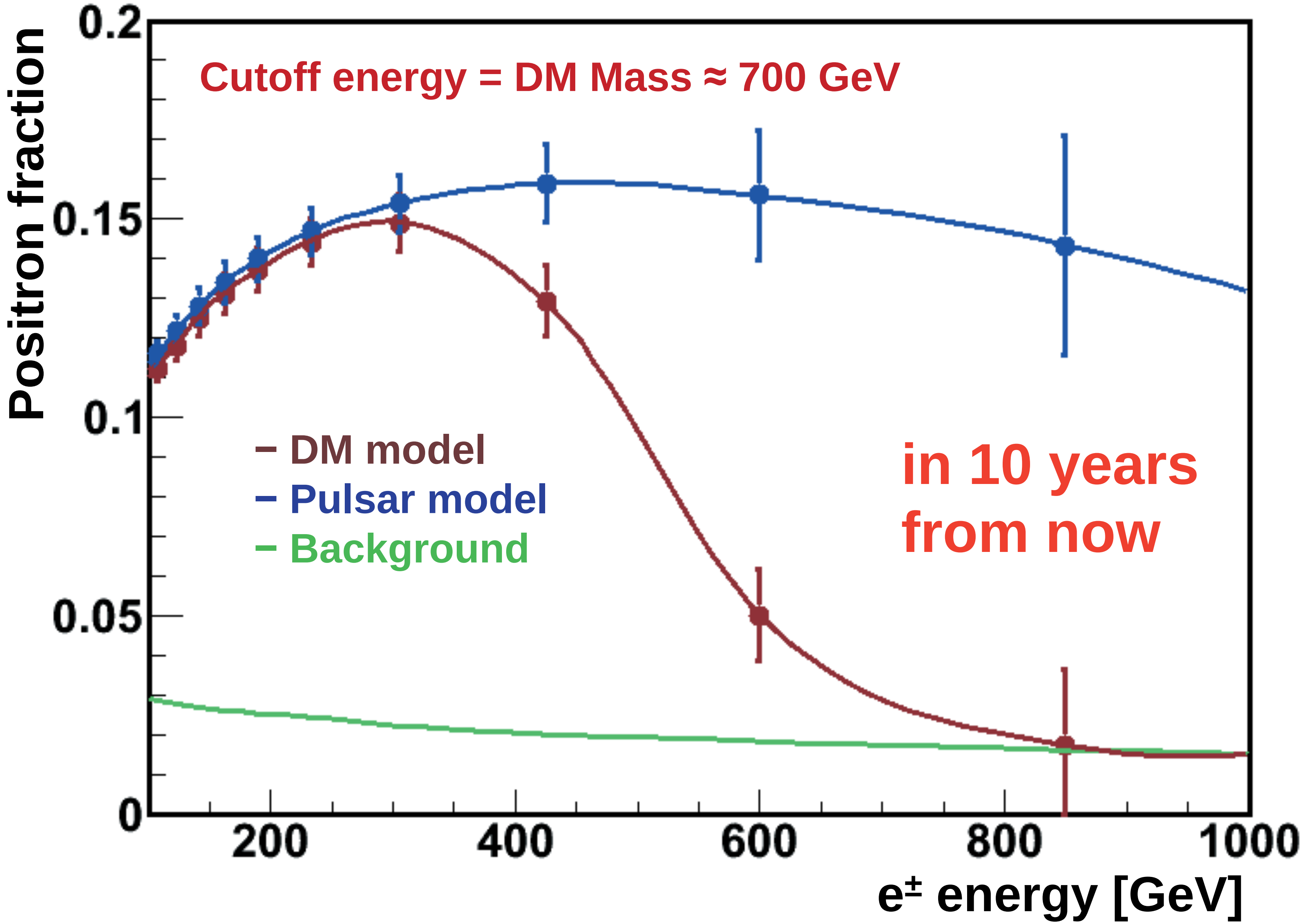
The agreement between the data and the model shows that the positron fraction spectrum is consistent with $e^{\pm}$ fluxes each of which is the sum of its diffuse spectrum and a single common power law source.



Pulsar or Dark Matter ?

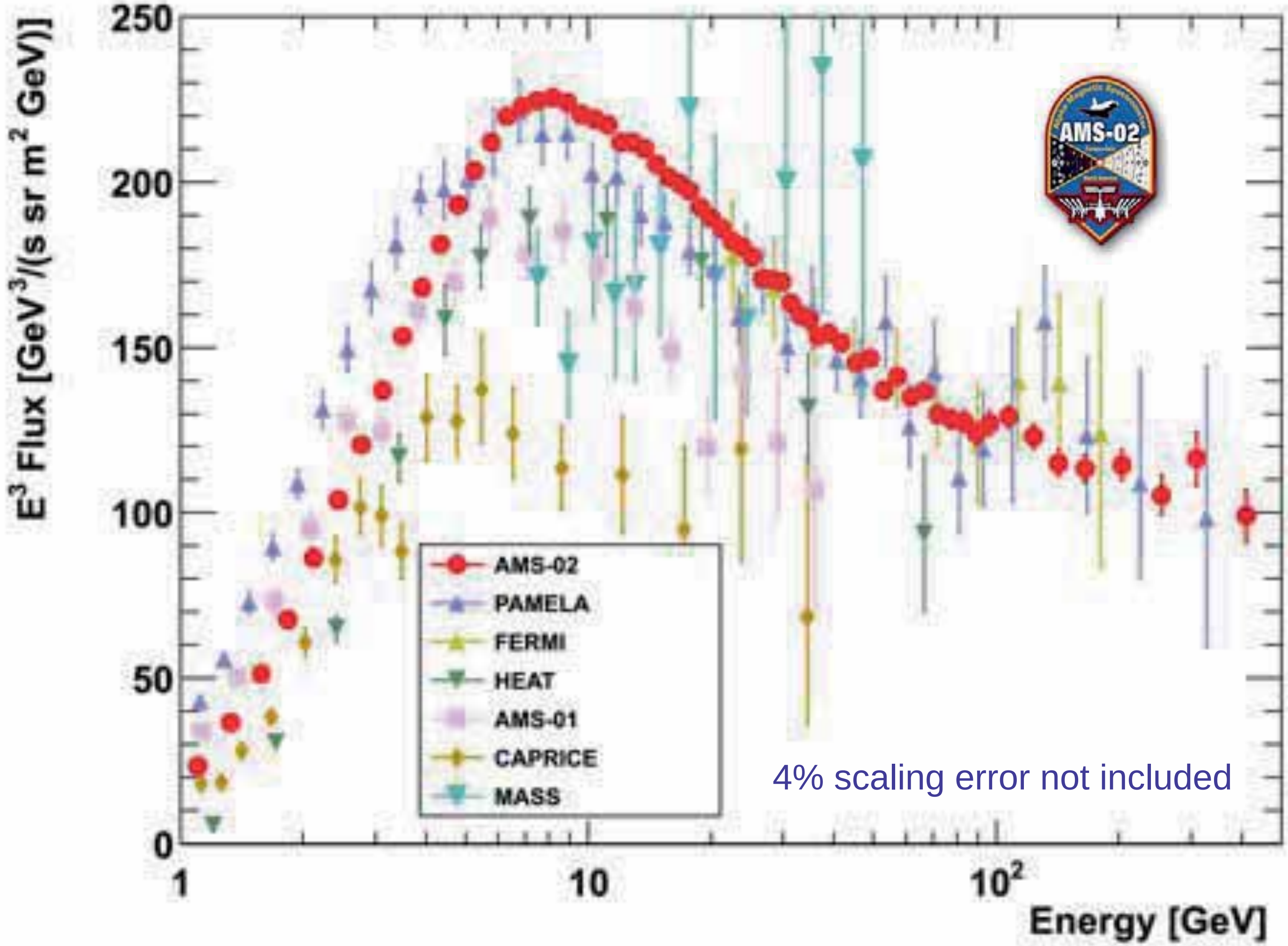


Expected AMS-02 reach in 10 more years



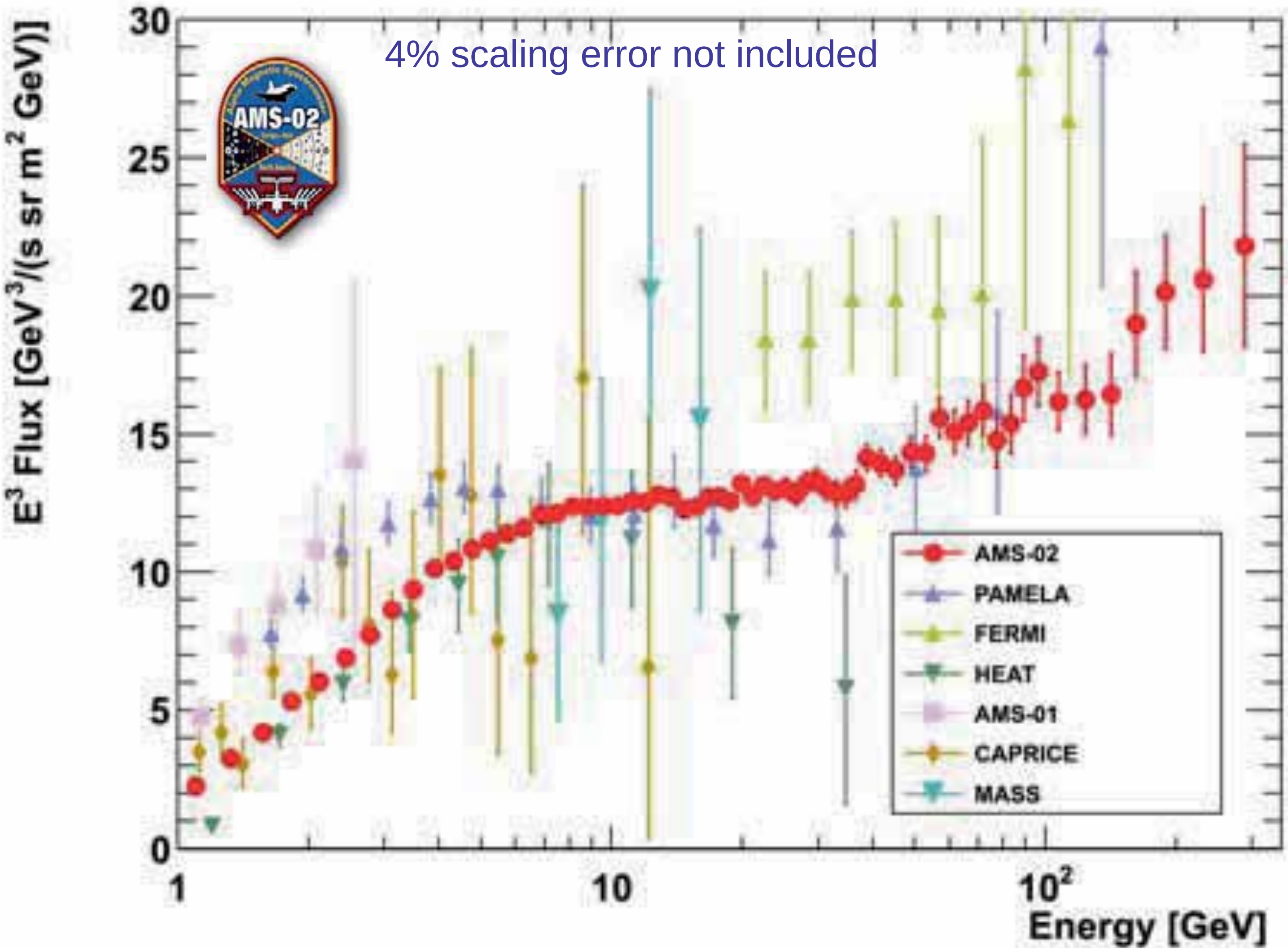
ICRC 2013 Results from AMS: Electron Flux $J_{e-}(E)$

- The electron flux measurement extends up to 500 GeV.
- Multiplied by E^3 it is rising up to 10 GeV and appears to be on a smooth, slowly falling curve above.

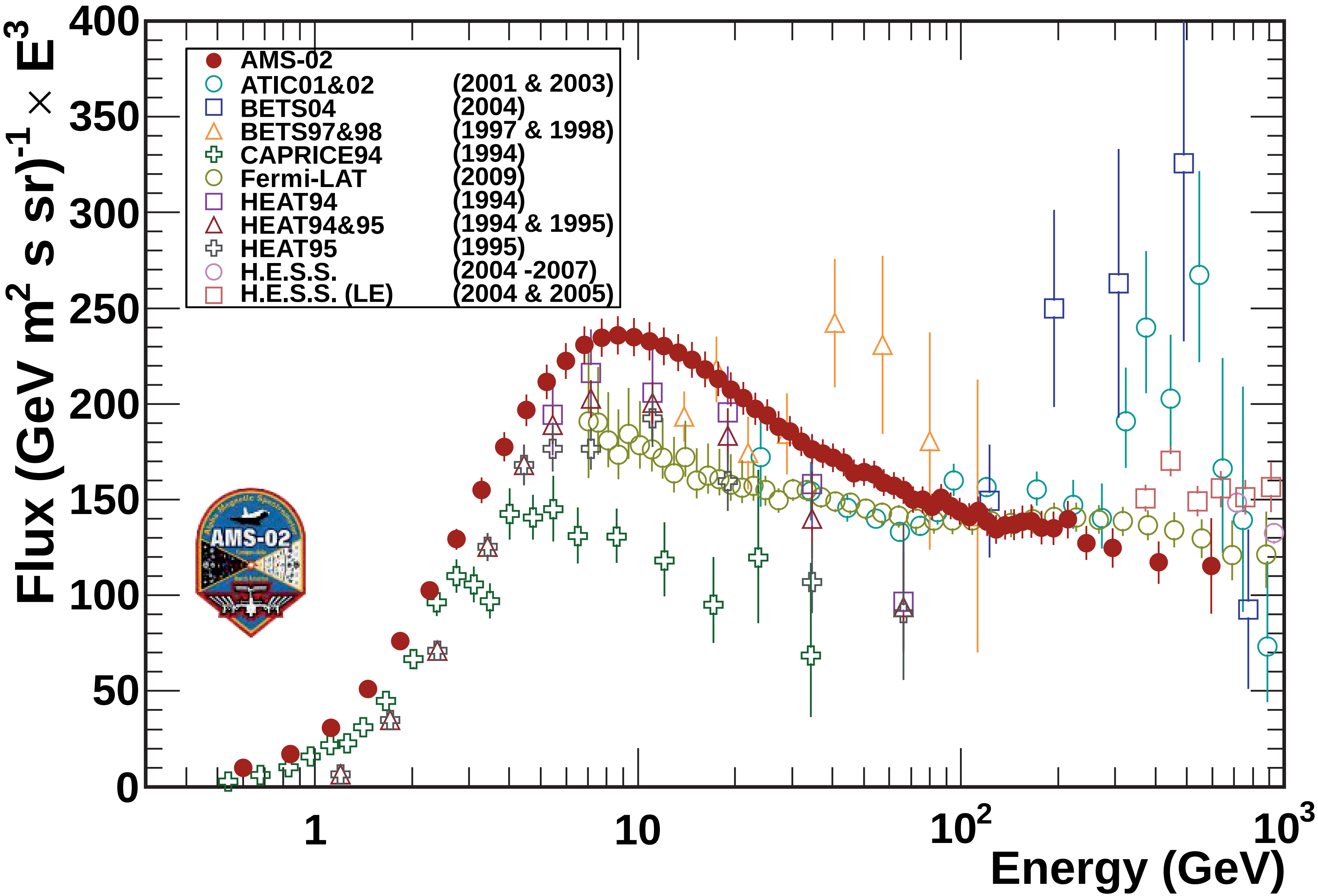


ICRC 2013 Results from AMS: Positron Flux $J_{e+}(E)$

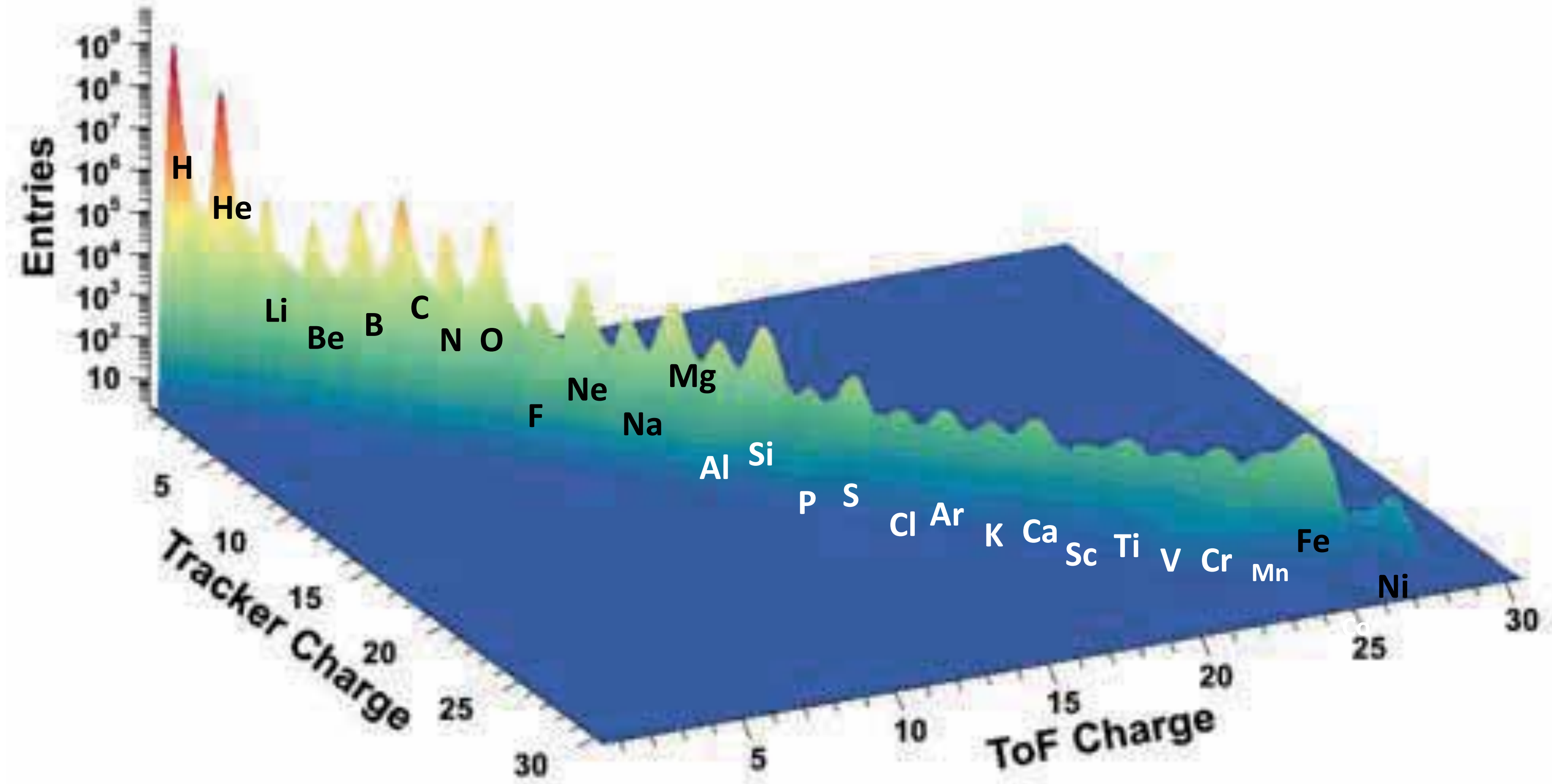
- The positron flux measurement extends up to 350 GeV.
- Multiplied by E^3 it is rising up to 10 GeV, from 10 to 35 GeV the spectrum is flat and above 35 GeV again rising.
- The spectral index and its dependence on energy is clearly different from the electron spectrum.



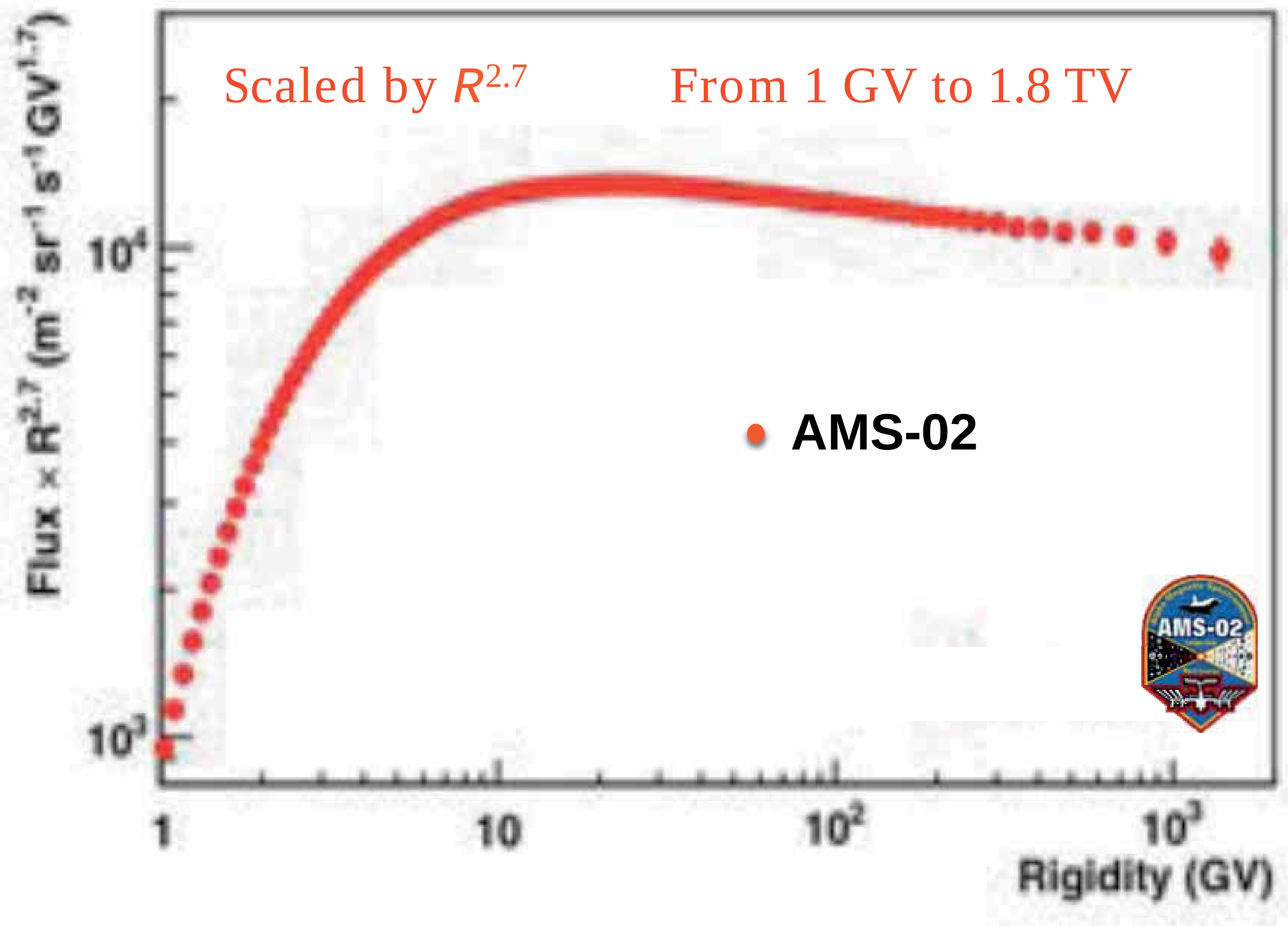
ICRC 2013 Results from AMS: (Electron plus Positron) Spectrum



AMS Nuclei Measurement on ISS

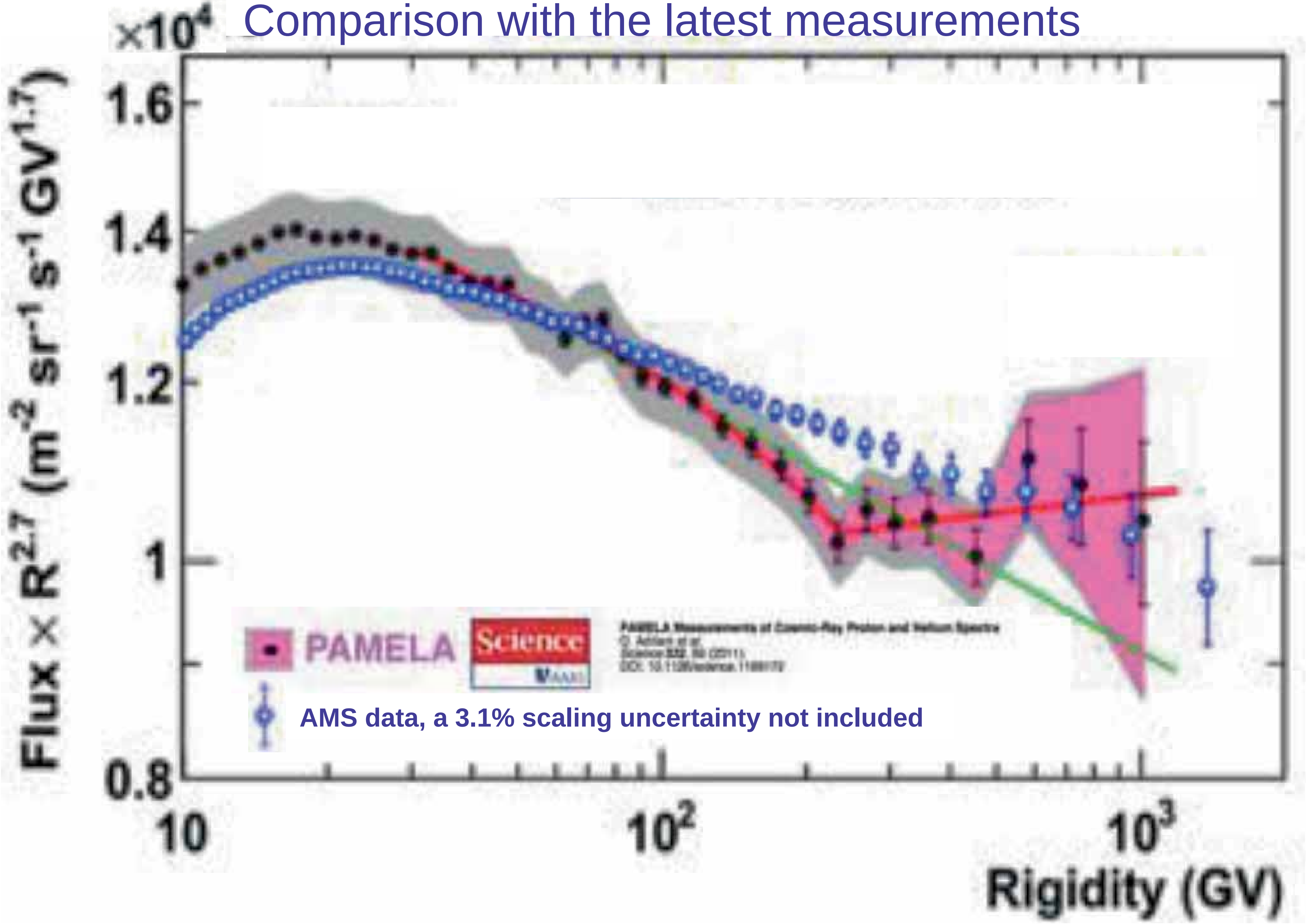


ICRC 2013 Results from AMS: Proton flux

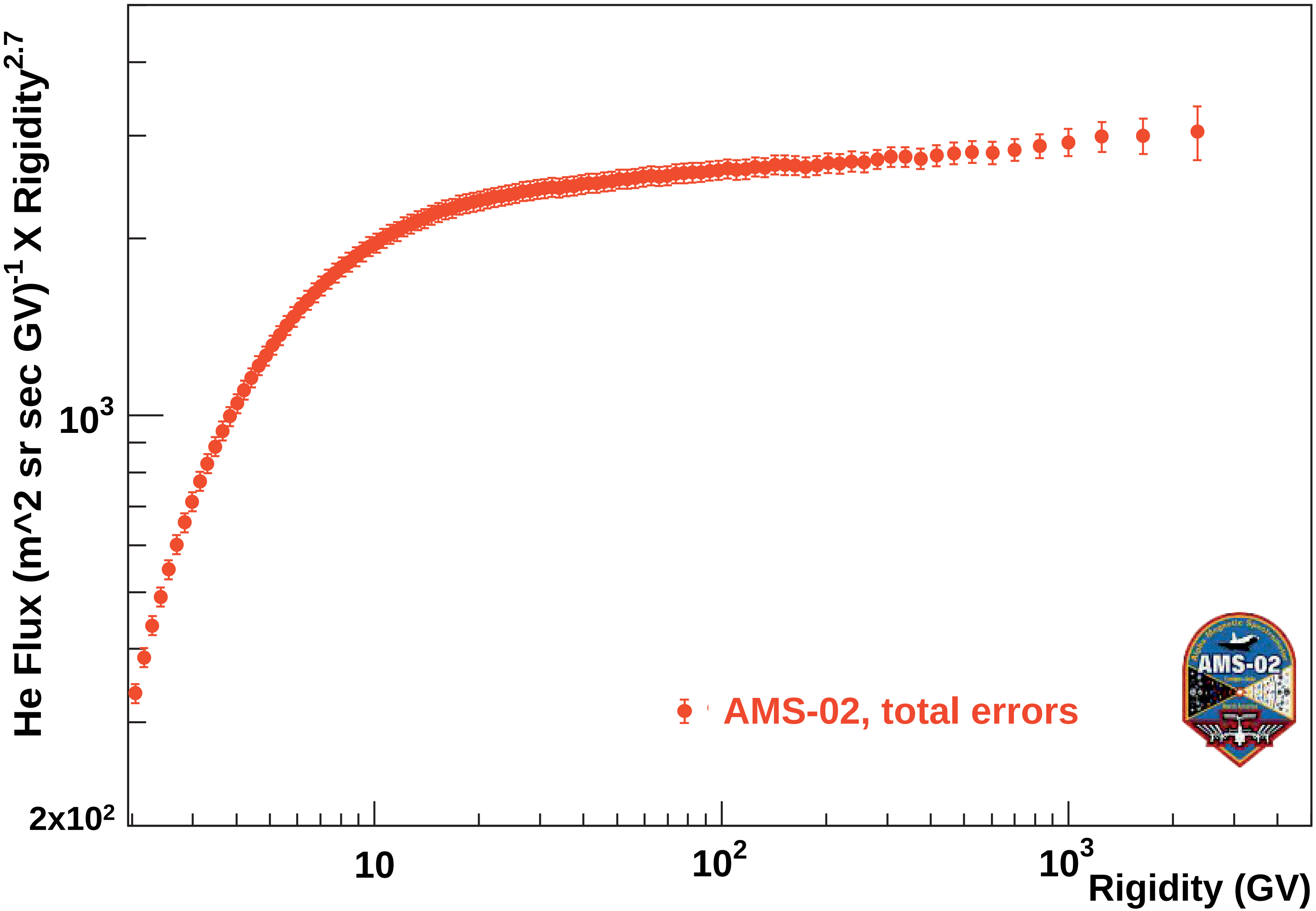


Proton flux

Comparison with the latest measurements

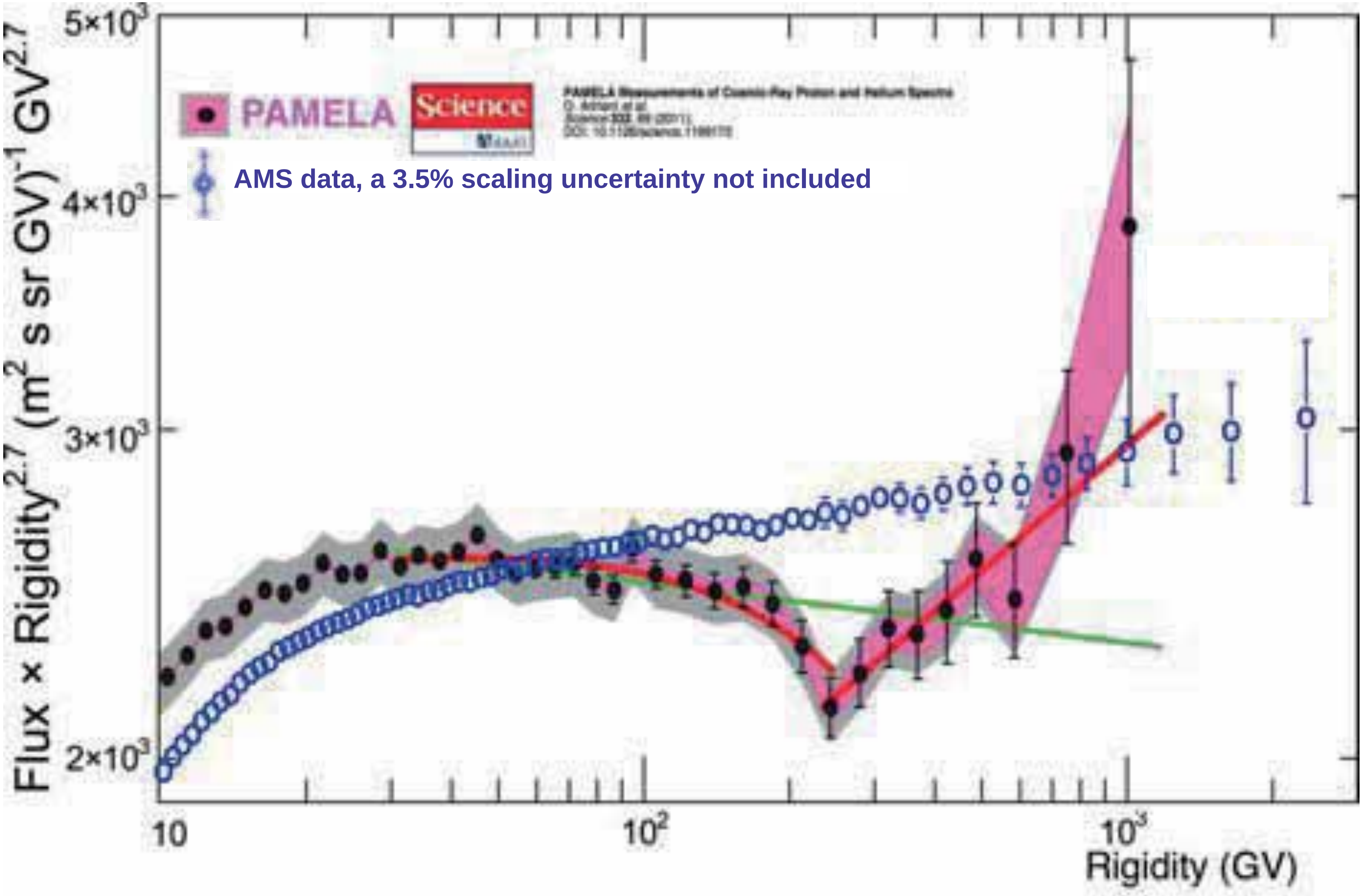


ICRC 2013 Results from AMS:Helium flux



Helium flux

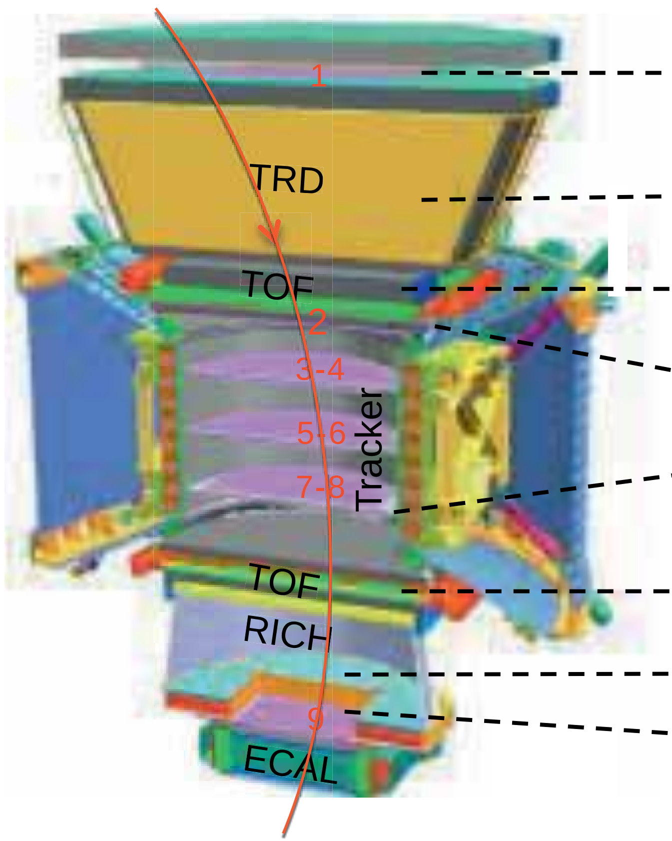
Comparison with the latest measurements



ICRC 2013 Results from AMS
Boron-to-Carbon ratio

Precise measurement of the energy spectra of B/C provides information on Cosmic Ray Interactions and Propagation

AMS: Multiple Independent Measurements of the Charge (|Z|)



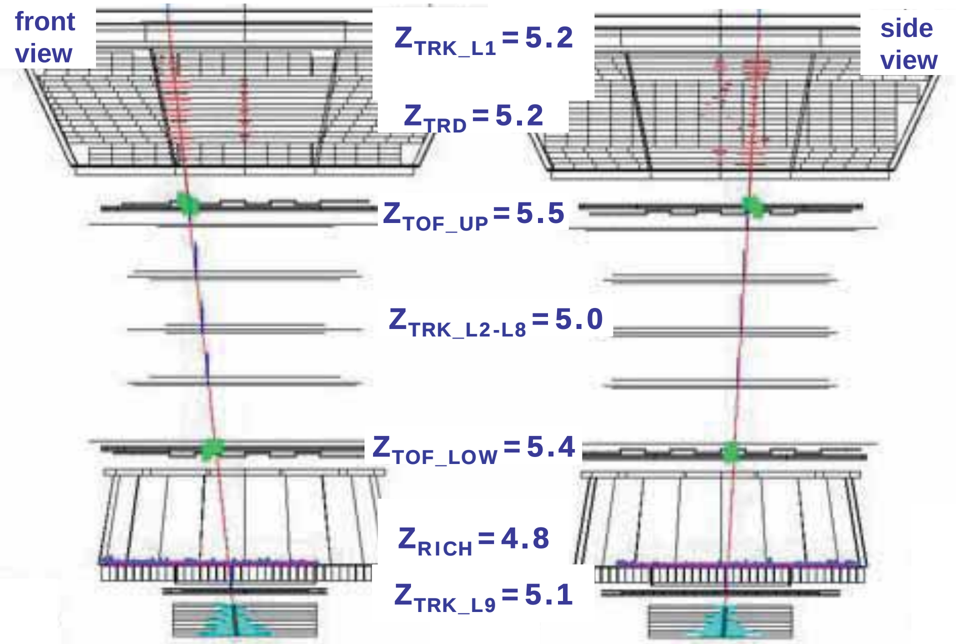
	Carbon (Z=6) ΔZ (cu)
1. Tracker Plane 1	0.30
2. TRD	0.33
3. Upper TOF (1 counter)	0.16
4. Tracker Planes 2-8	0.12
5. Lower TOF (1 counter)	0.16
6. RICH	0.32
7. Tracker Plane 9	0.30

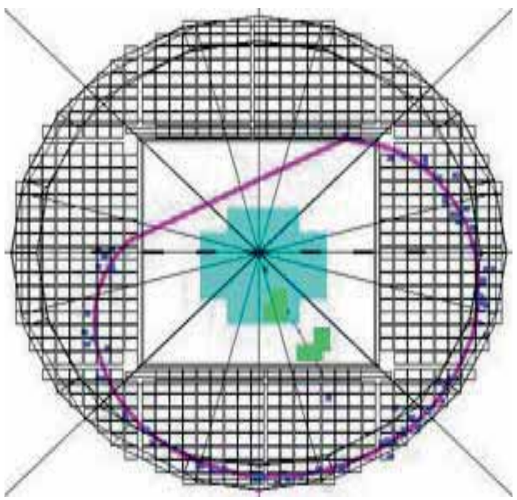
Rigidity ≈ 700 GV

Boron

Rigidity=680 GV

Run/Event 1319990213/ 235892

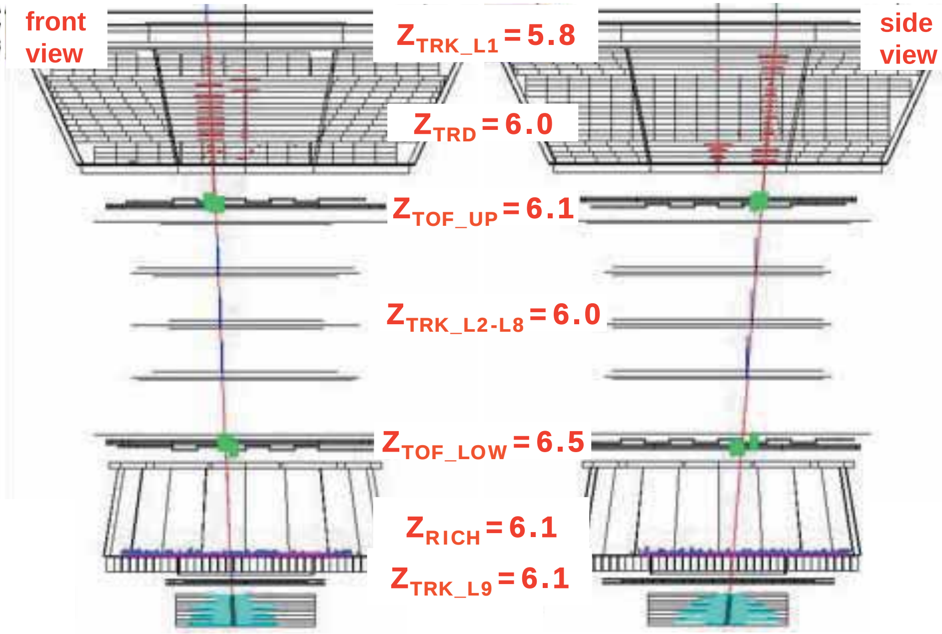


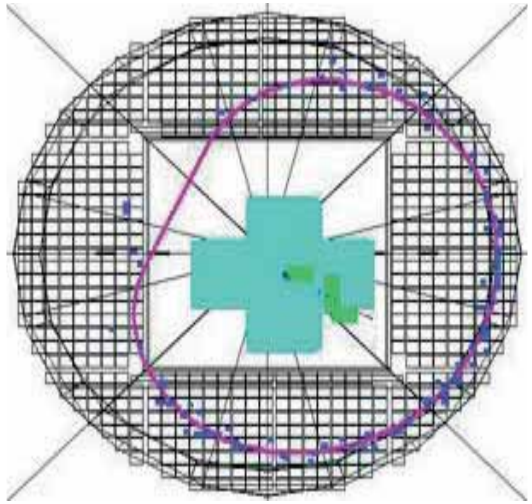


Carbon

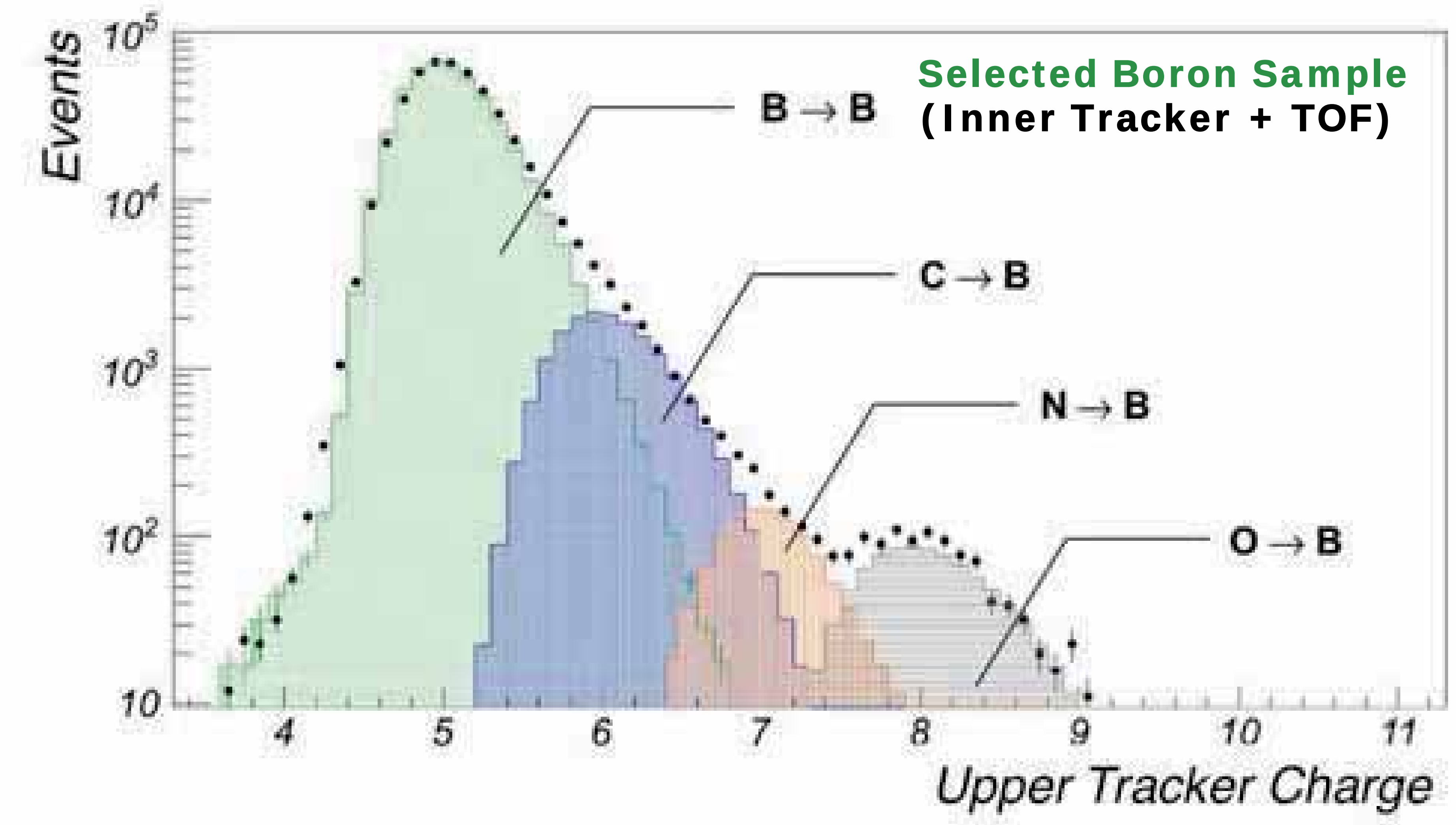
Rigidity=666 GV

Run/Event 1327184805/ 266043



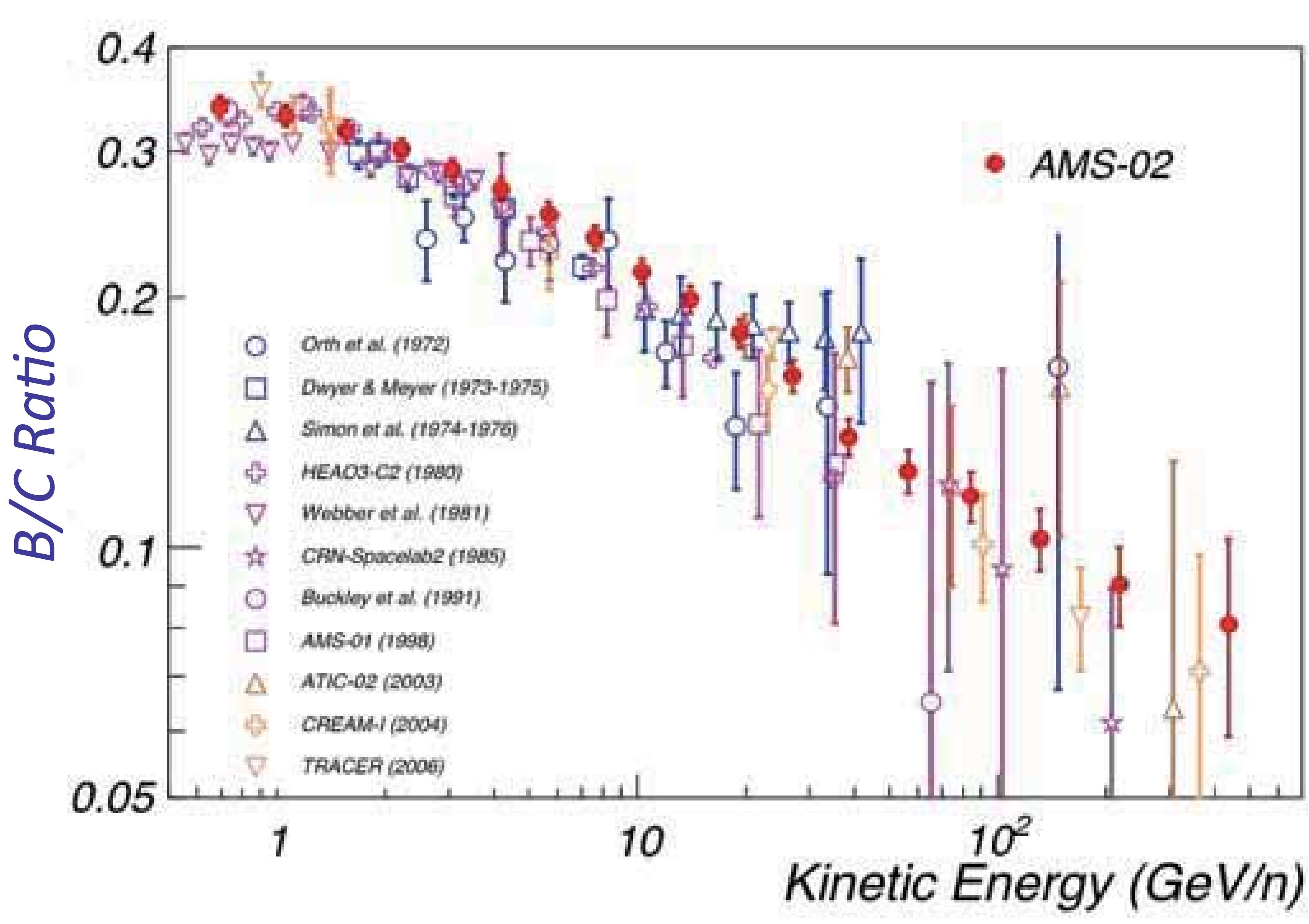


Boron and Carbon: Sample composition



Background estimated to an accuracy of 0.1%.

Boron-to-Carbon ratio

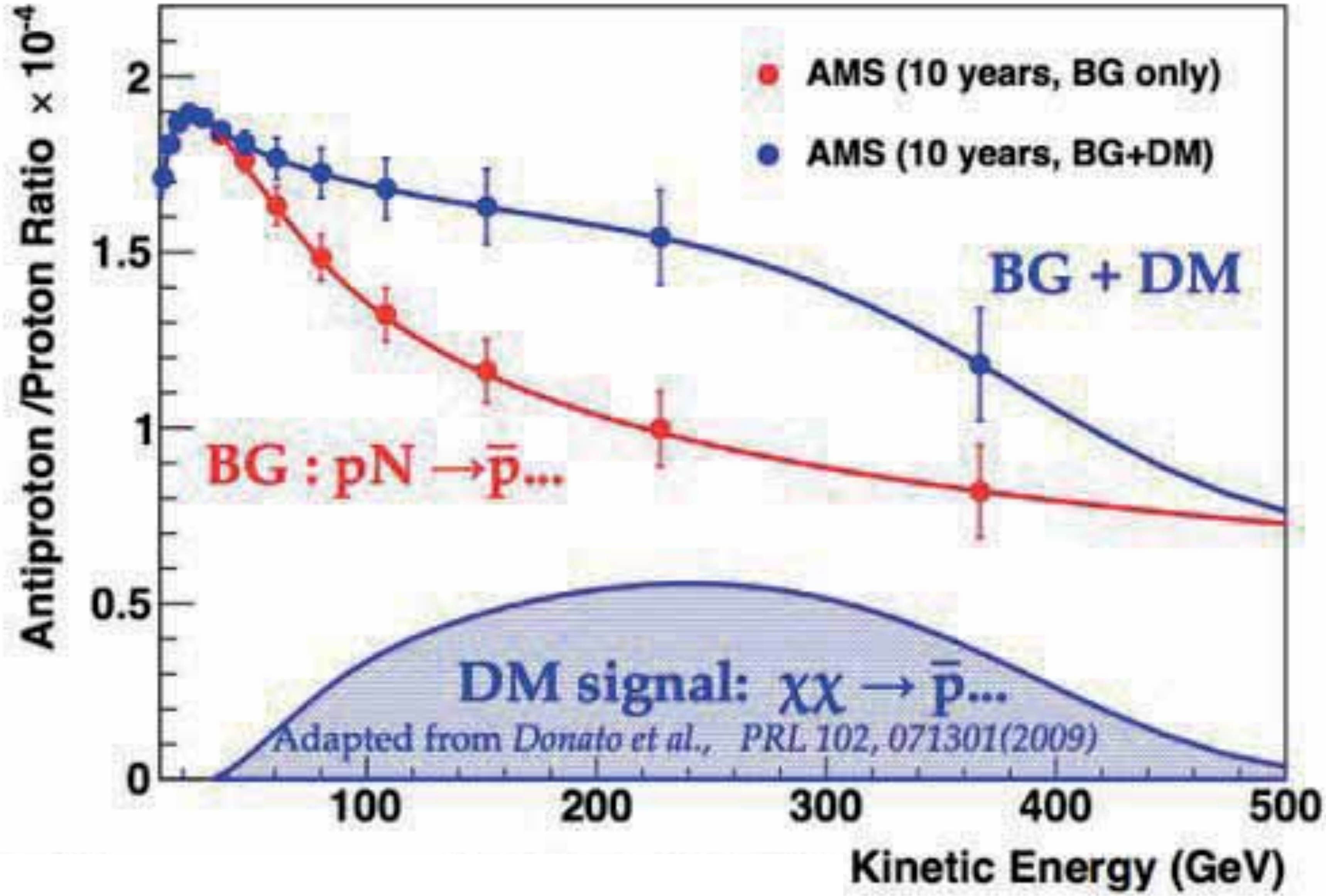


Measurement of Antiproton flux

Physics importance

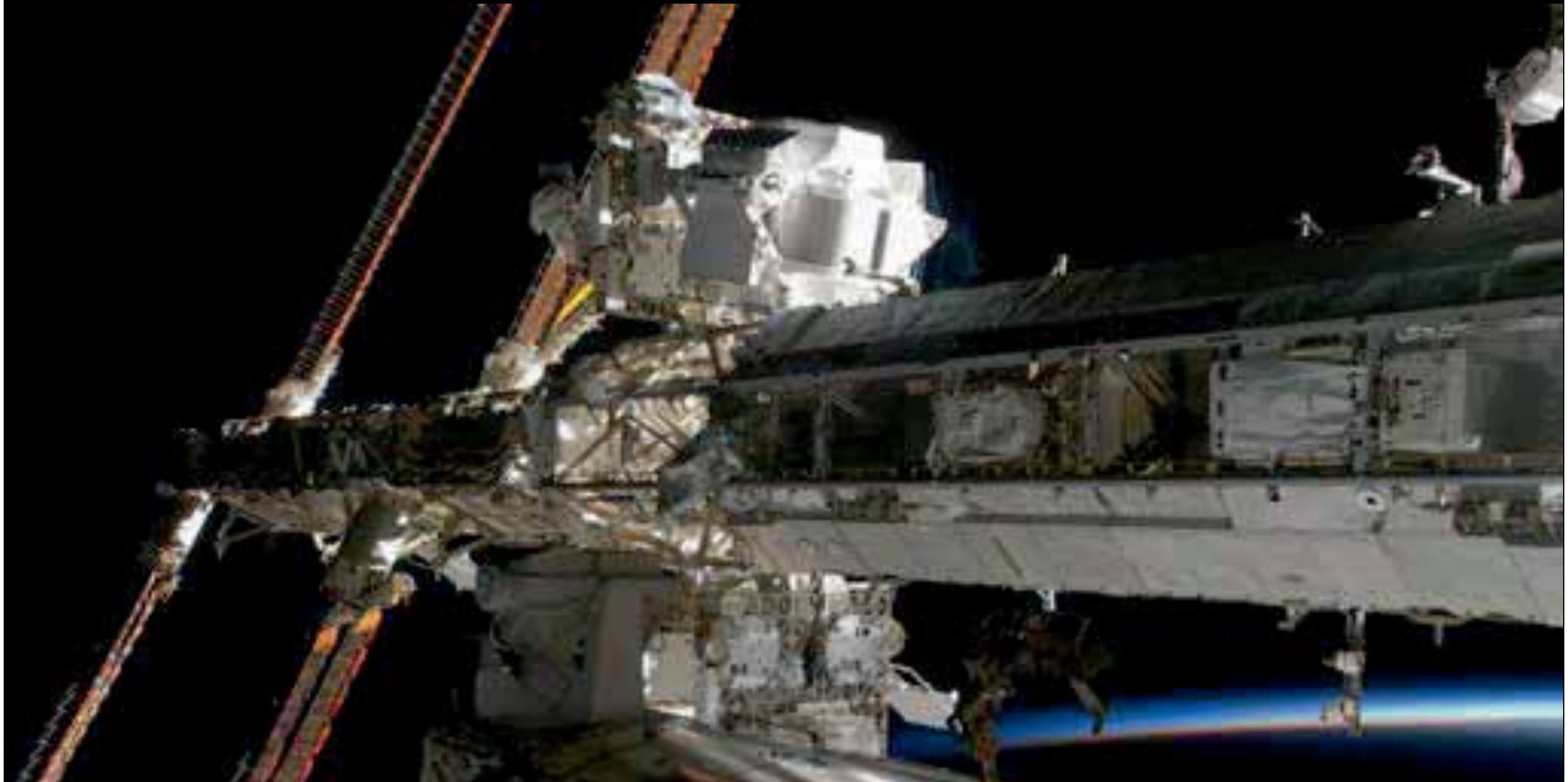
- Antiprotons : Only ~10^{-4} of cosmic ray particles
- Produced by cosmic ray collisions e.g. $pN \rightarrow \bar{p}...$
- Probe of indirect Dark Matter detection e.g. $\chi\chi \rightarrow \bar{p}...$
  Complementary to $\chi\chi \rightarrow e^{+}...$

AMS in ten years from now



The Cosmos is the Ultimate Laboratory.

Cosmic rays can be observed at energies higher than any accelerator.



“Th iting ti i to th n n n
to n n i i in n
th n i gin n th to to i .”

S. Ting