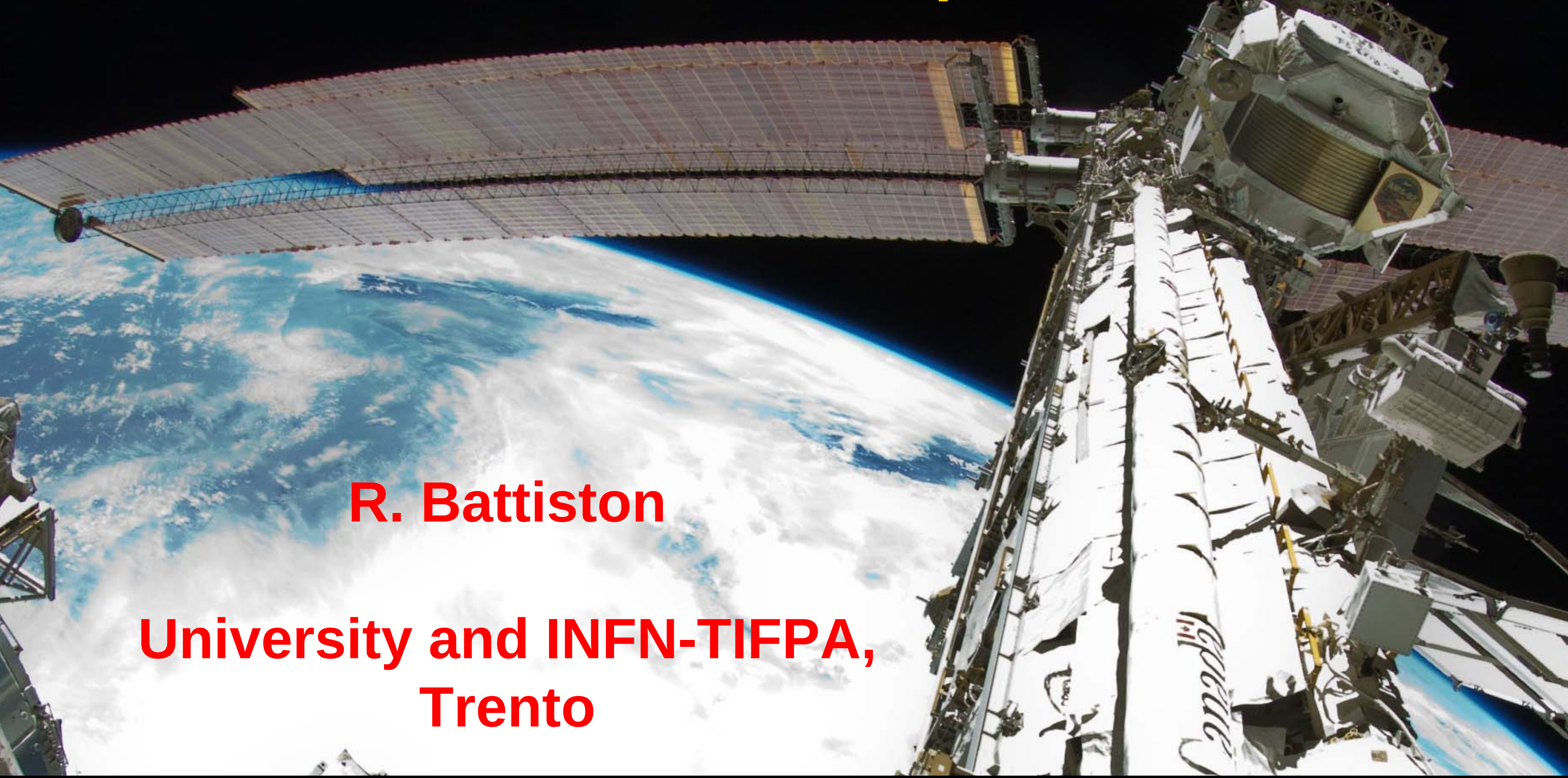
Recent Results from the Alpha Magnetic Spectrometer (AMS) Experiment on the International Space Station



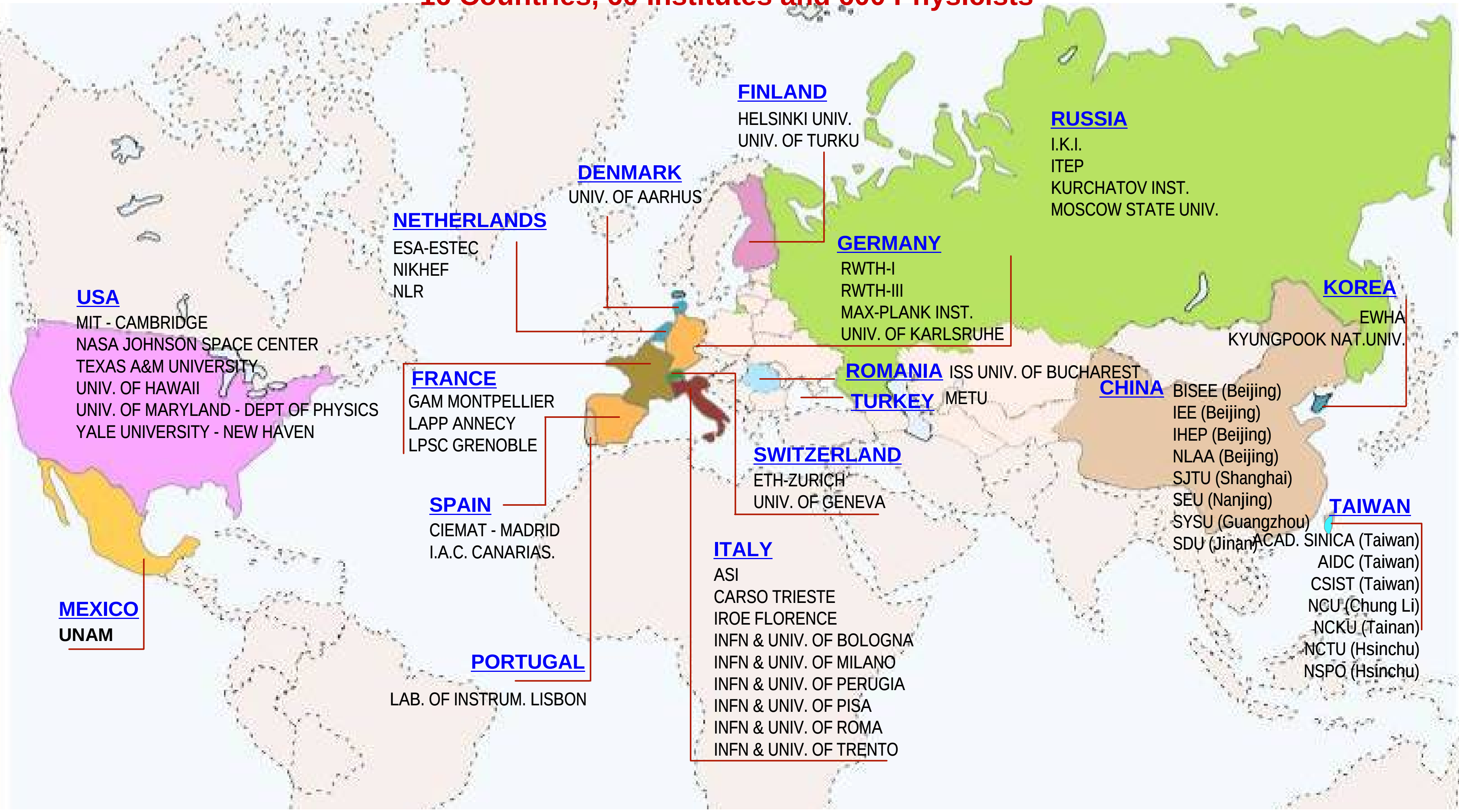
R. Battiston

University and INFN-TIFPA, Trento

16th Lomonosov, Moscow, August 24th 2013

AMS International Collaboration

16 Countries, 60 Institutes and 600 Physicists

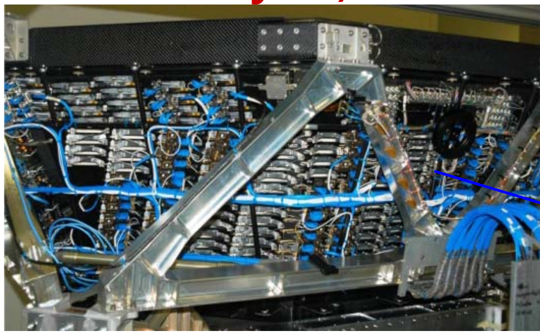


Total cost (US accounting) 2 B$: 95% from Europe and Asia

AMS: A TeV precision, multipurpose spectrometer

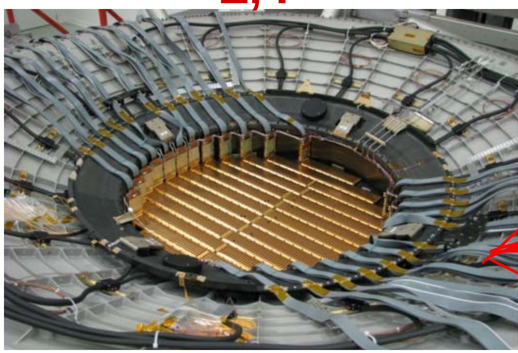
Particles and nuclei are defined by their charge (**Z**) and energy (**E ~ P**)

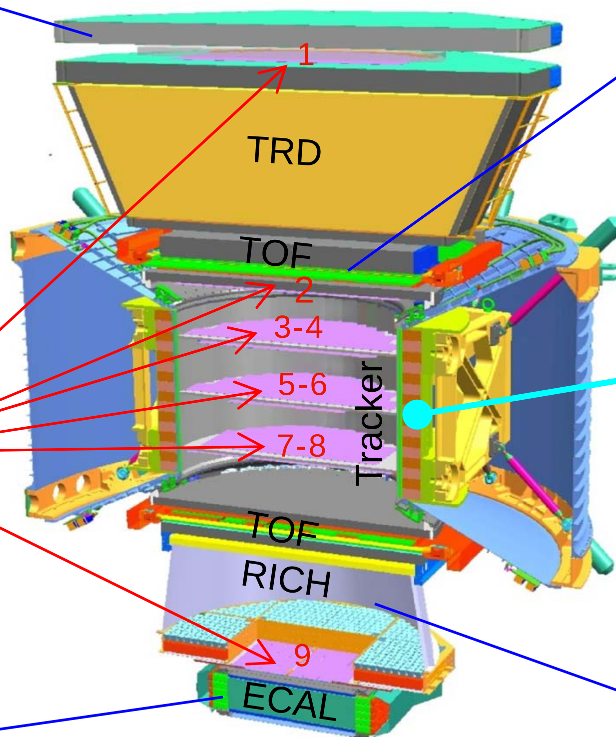
TRD
Identify e^+, e^-



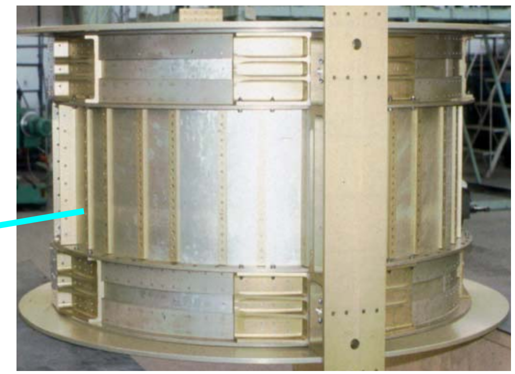
TOF
Z, E

Silicon Tracker
Z, P

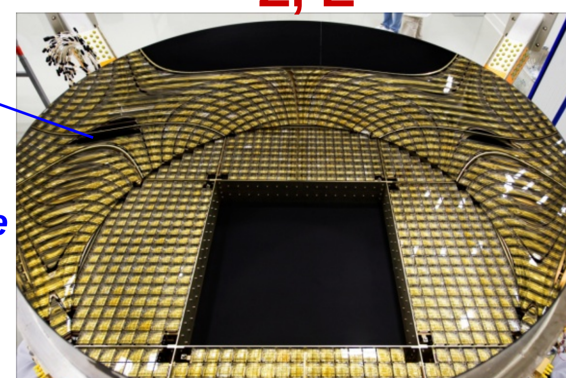




Magnet
±Z



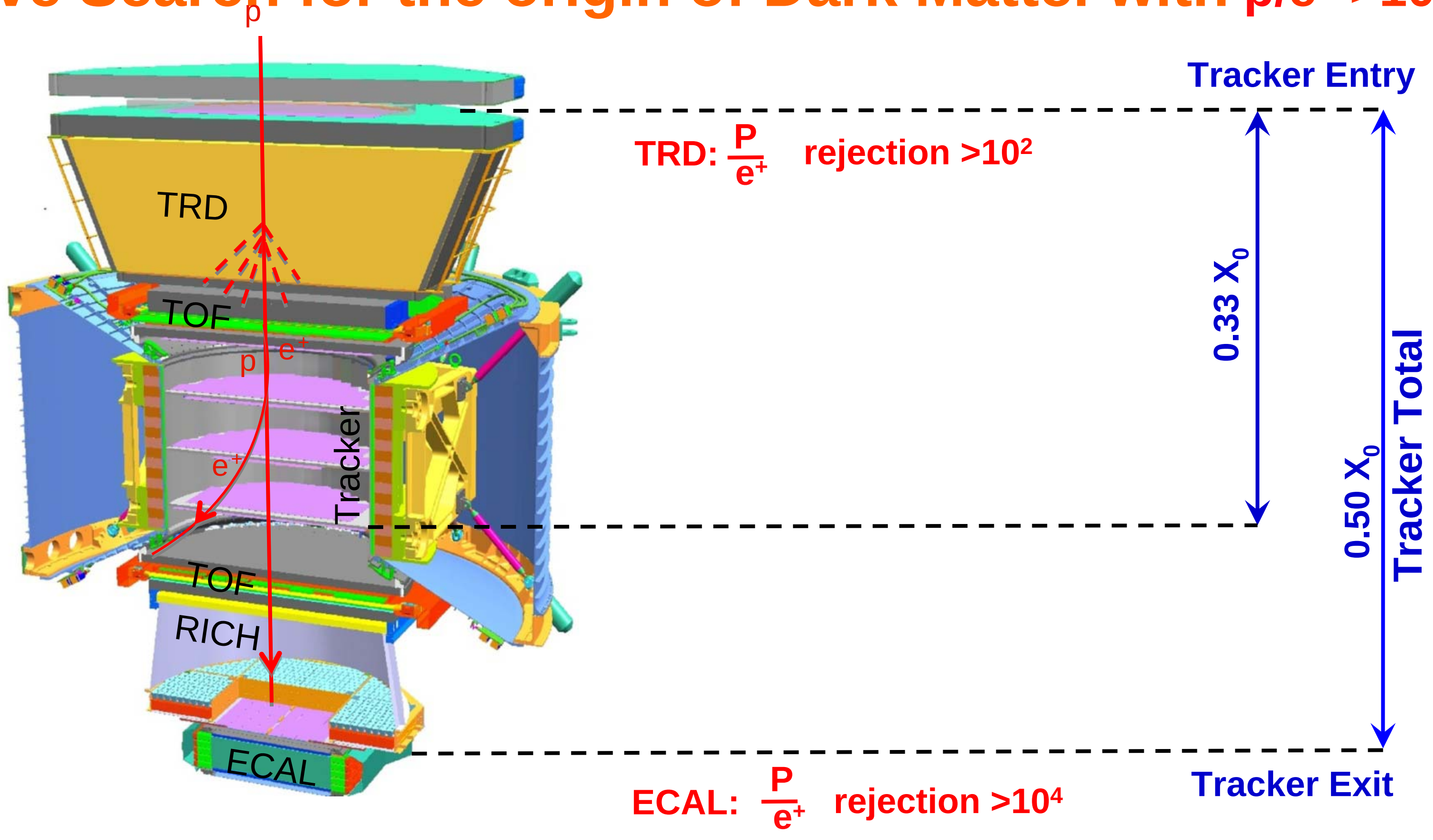
RICH
Z, E



ECAL
E of e^+, e^-, γ

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

Sensitive Search for the origin of Dark Matter with $p/e^+ > 10^6$

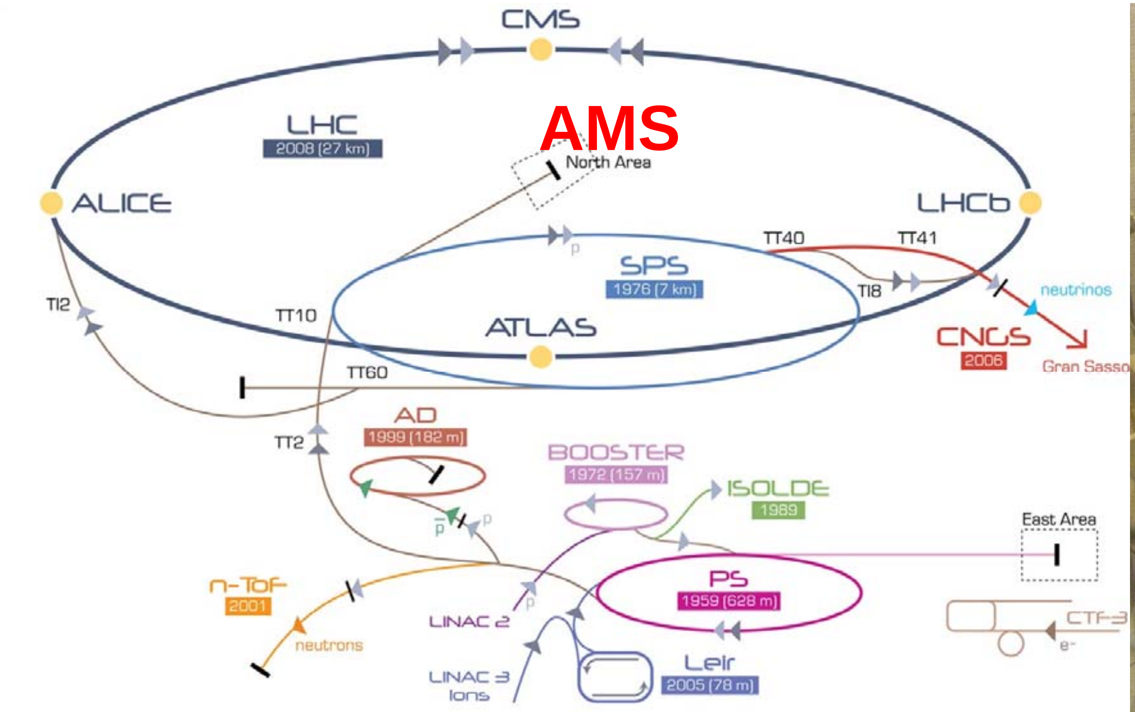


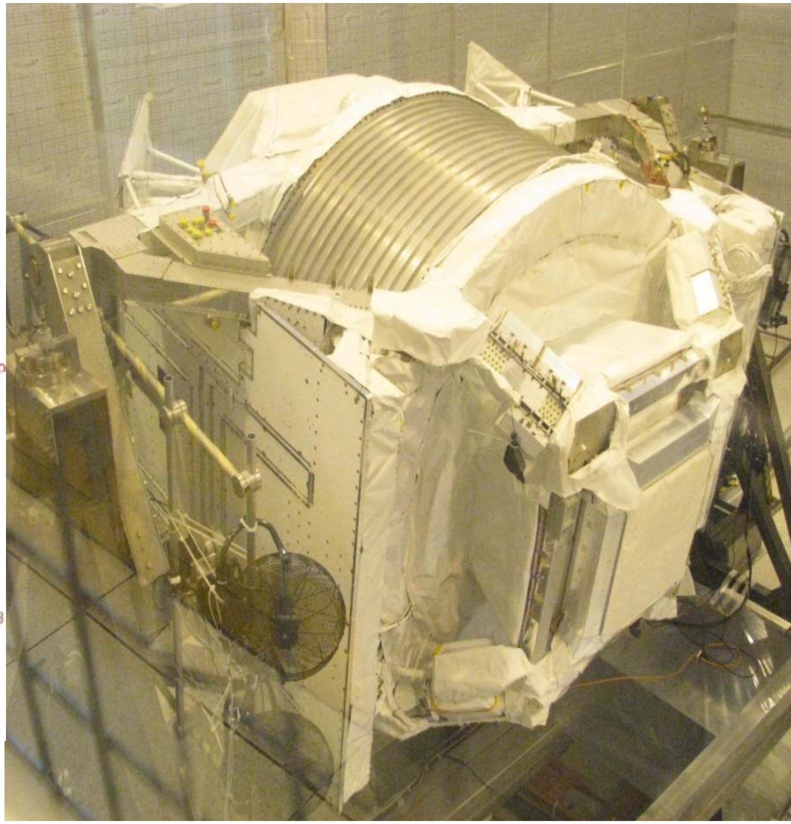
a) Minimal material in the TRD and TOF
So that the detector does not become a source of e^+.

b) A magnet separates TRD and ECAL so that e^+ produced in TRD will be swept away and not enter ECAL
In this way the rejection power of TRD and ECAL are independent

c) Matching momentum of 9 tracker planes with ECAL energy measurements

Intensive Beam Tests at CERN





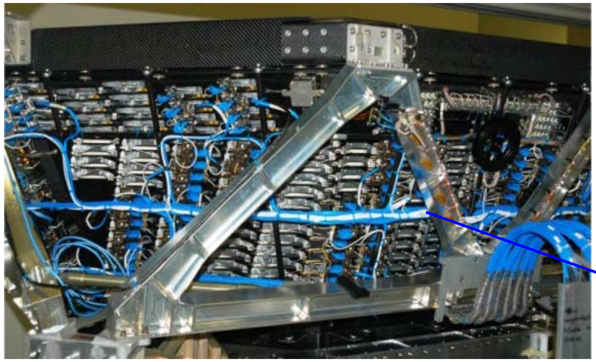
AMS in SPS Test Beam, 2010

Particle	Momentum (GeV/c)	Positions	Purpose
Protons	400 + 180	1,650	Full Tracker alignment, TOF calibration, ECAL uniformity
Electrons	100, 120, 180, 290	7 each	TRD, ECAL performance study
Positrons	10, 20, 60, 80, 120, 180	7 each	TRD, ECAL performance study
Pions	20, 60, 80, 100, 120, 180	7 each	TRD performance to 1.2 TeV

AMS Flight Electronics for Data Acquisition (DAQ)

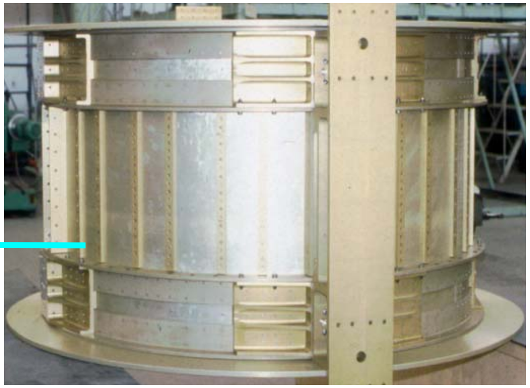
300,000 channels at 2 KHz,
650 computers
designed and built by AMS

TRD: 5248 Signals

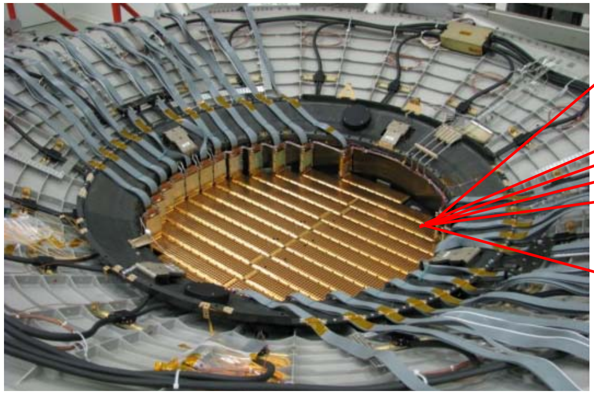


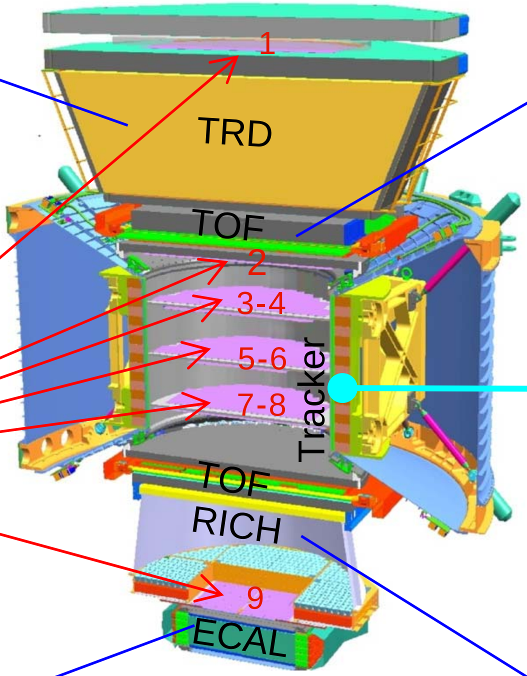
TOF & ACC: 88 Signals

Magnet

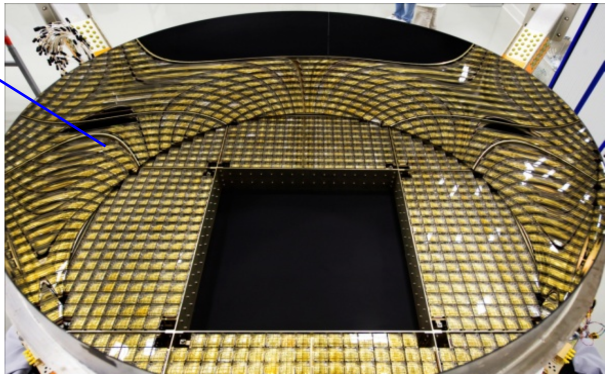


Silicon Tracker: 196,608 Signals

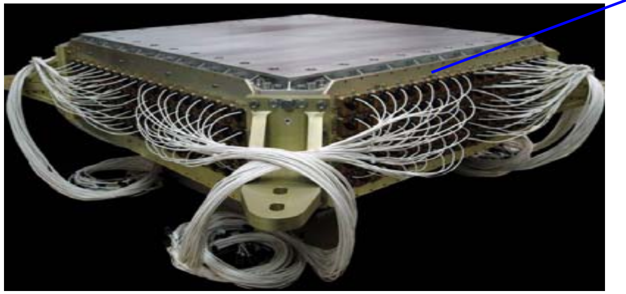




RICH: 10,800 * 2 Signals



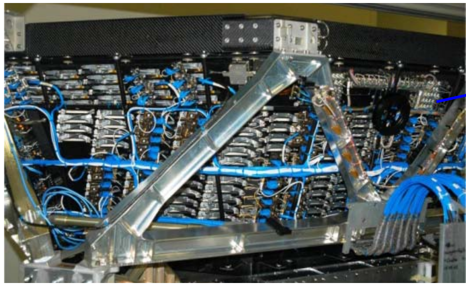
ECAL: 2,916 Signals

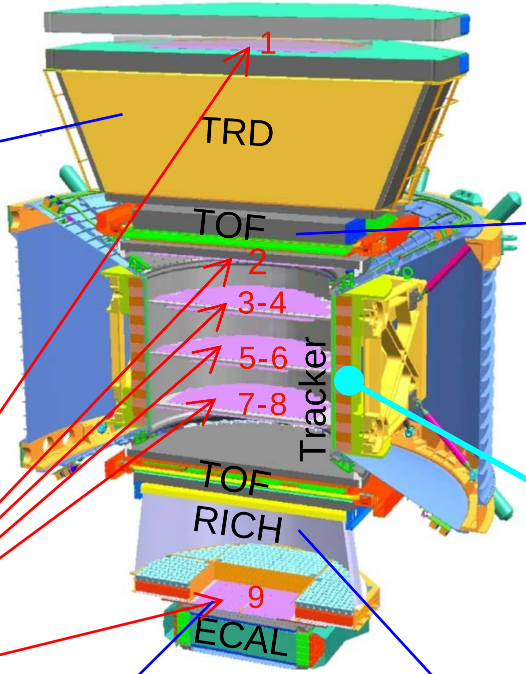


AMS Flight Electronics for Thermal Control

1118 temperature sensors, 298 heaters

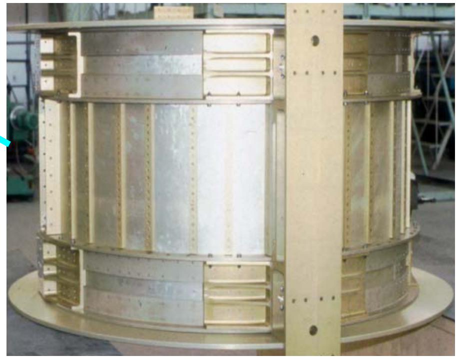
TRD
24 Heaters
8 Pressure Sensors
482 Temperature Sensors



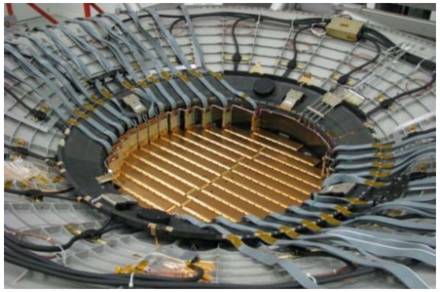


TOF & ACC
64 Temperature Sensors

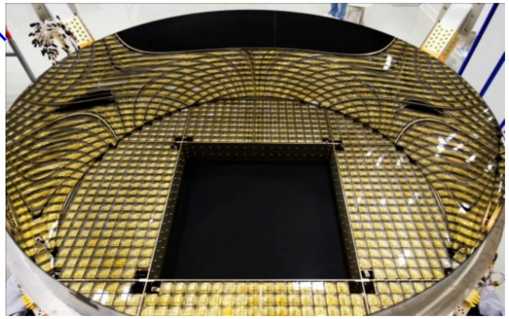
Magnet
68 Temperature Sensors



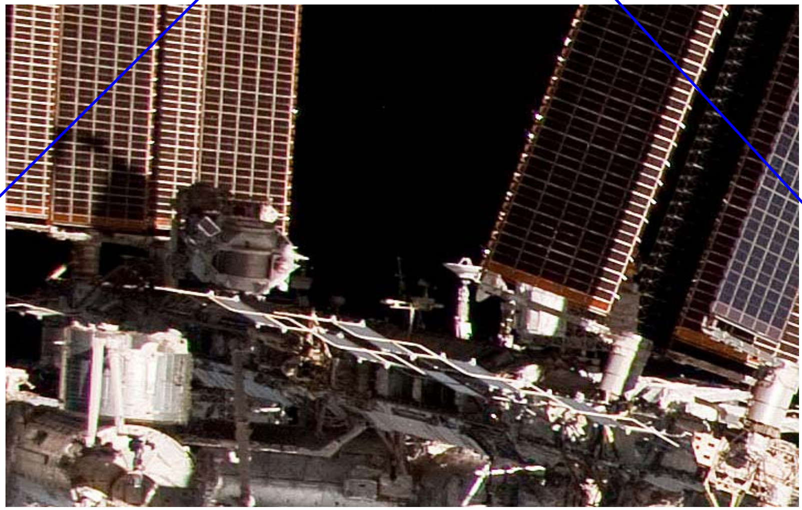
Silicon Tracker
4 -Pressure Sensors
32 Heaters
142 Temperature Sensors



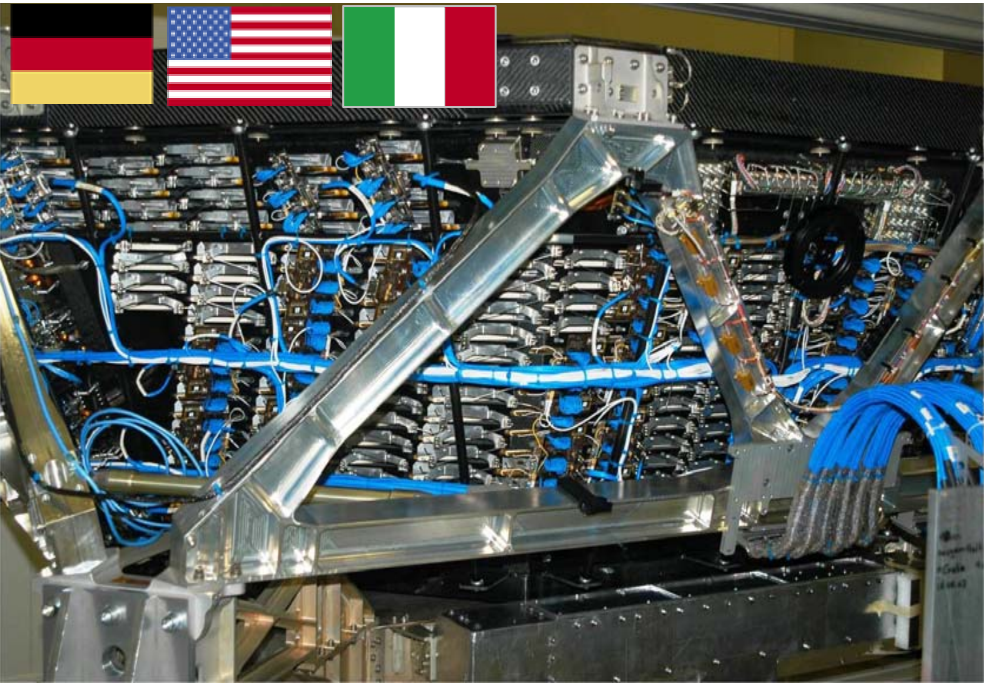
RICH
96 Temperature Sensors

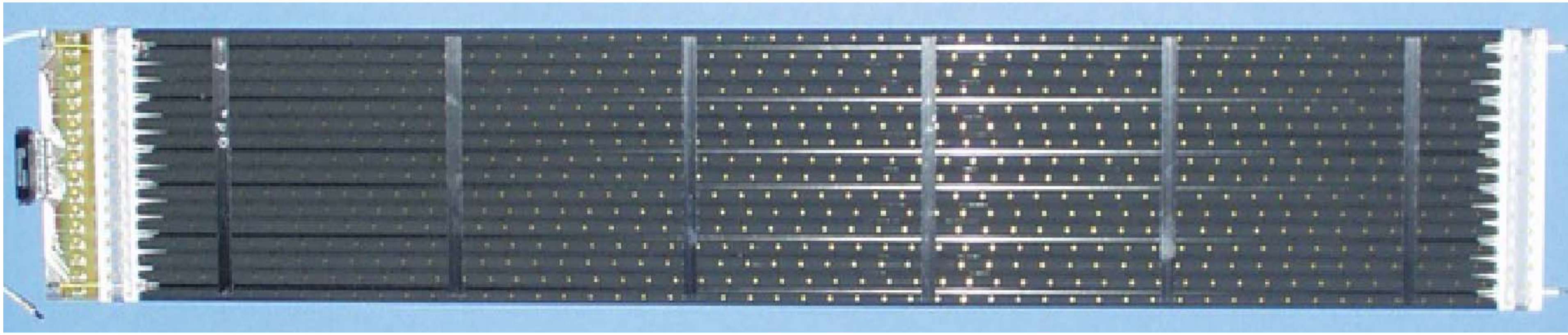


ECAL
80 Temperature Sensors

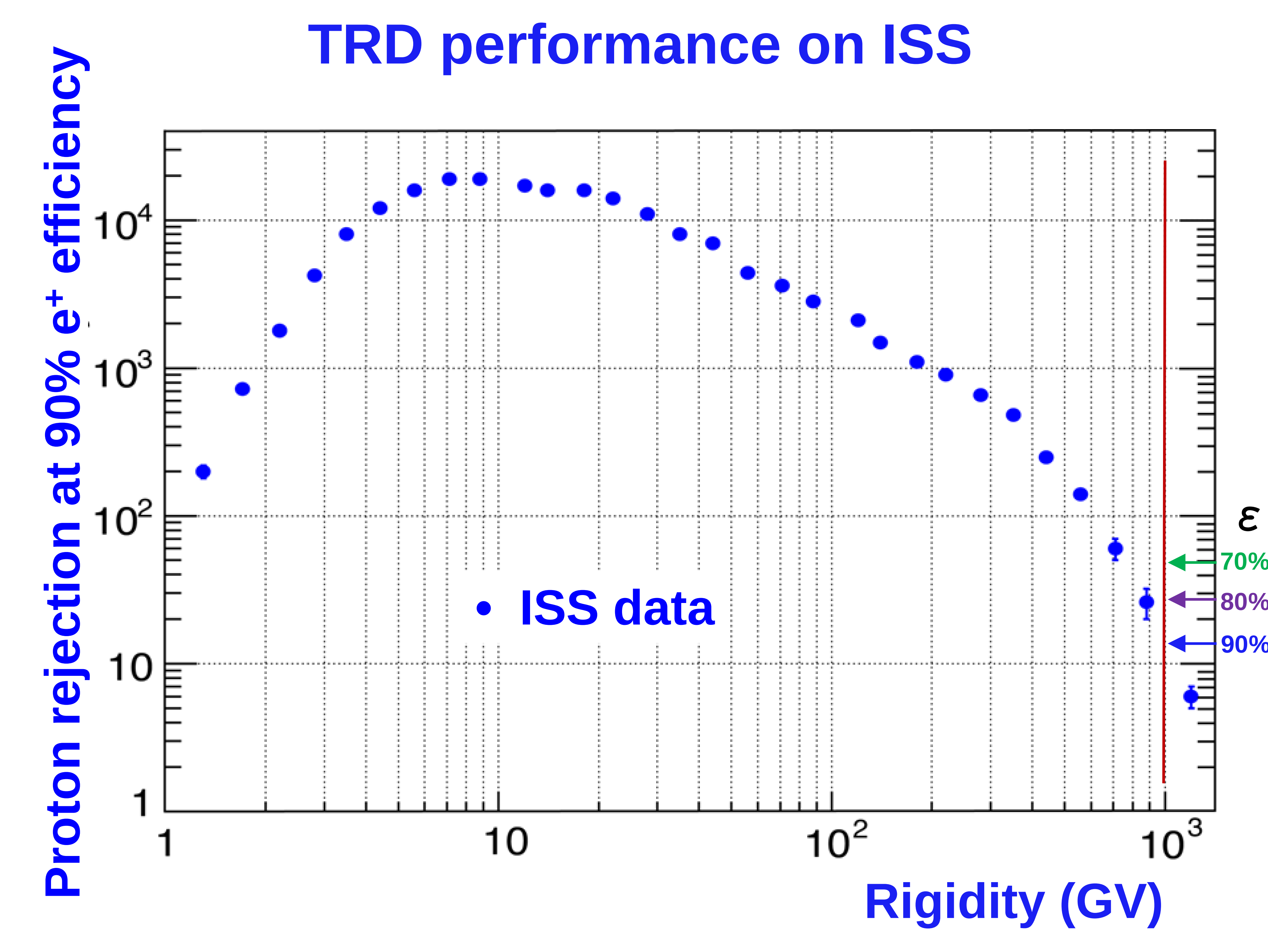


Transition Radiation Detector (TRD) Identifies Positrons, Electrons by transition radiation and Nuclei by dE/dX



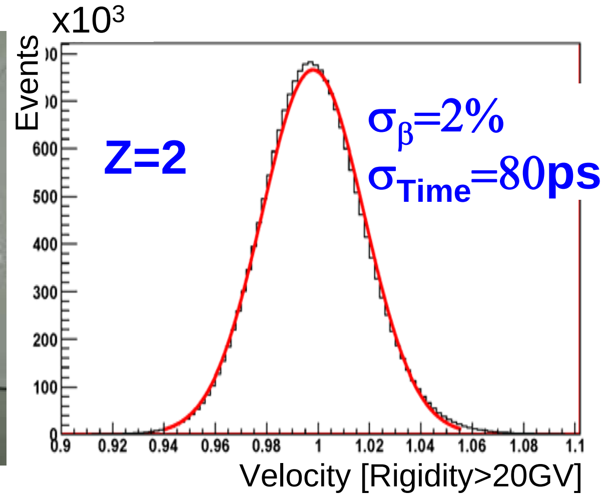


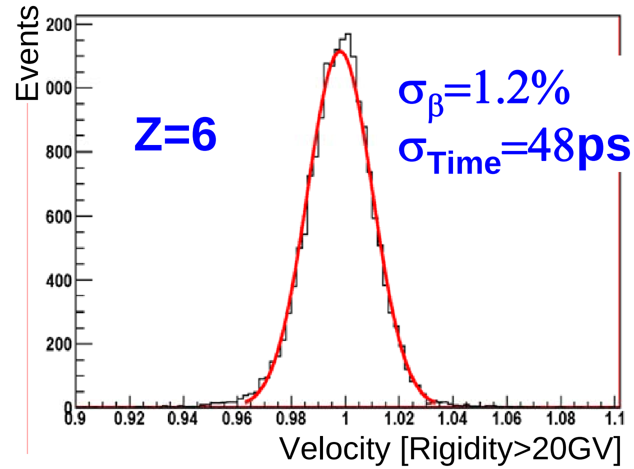
5,248 tubes selected from 9,000, 2 m length centered to 100μm, verified by CAT scanner


TRD performance on ISS
Proton rejection at 90% e+ efficiency
Rigidity (GV)
ISS data
ε
70%
80%
90%
1
10
10^2
10^3
10^4

Data from ISS — Time of Flight System

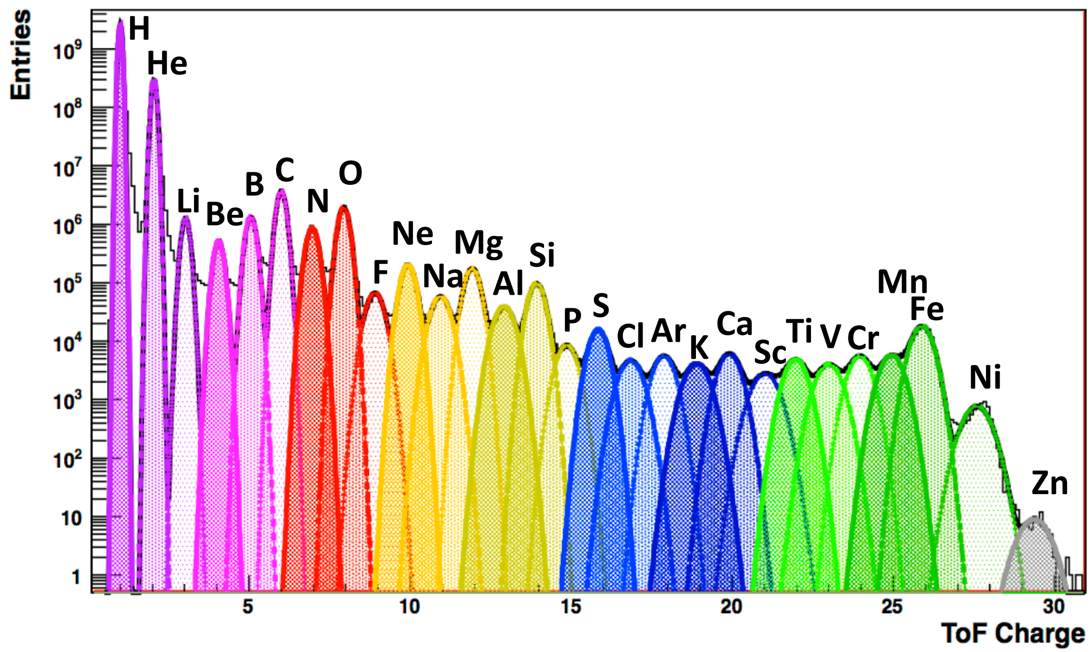
Measures Velocity and Charge of particles





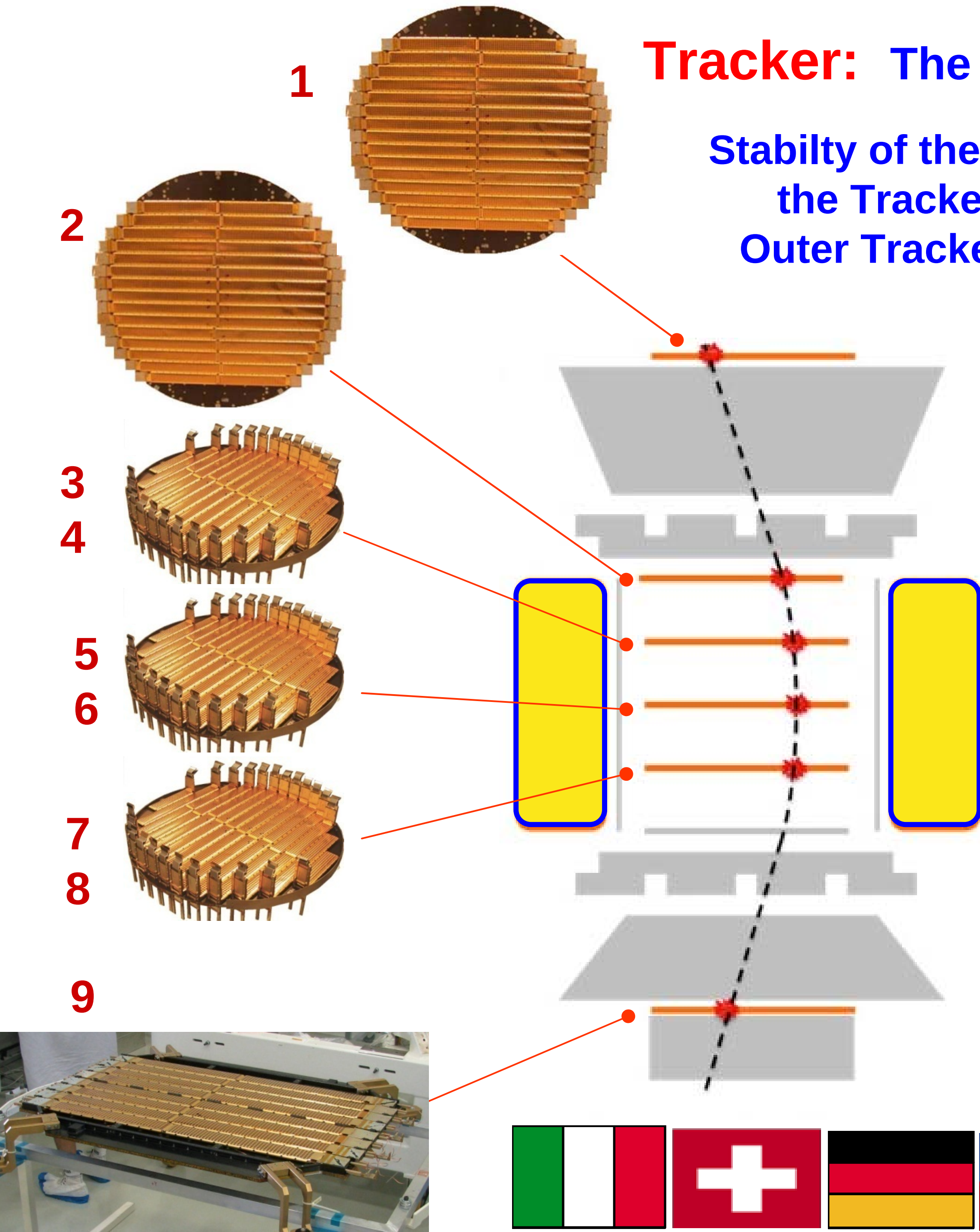
Bologna

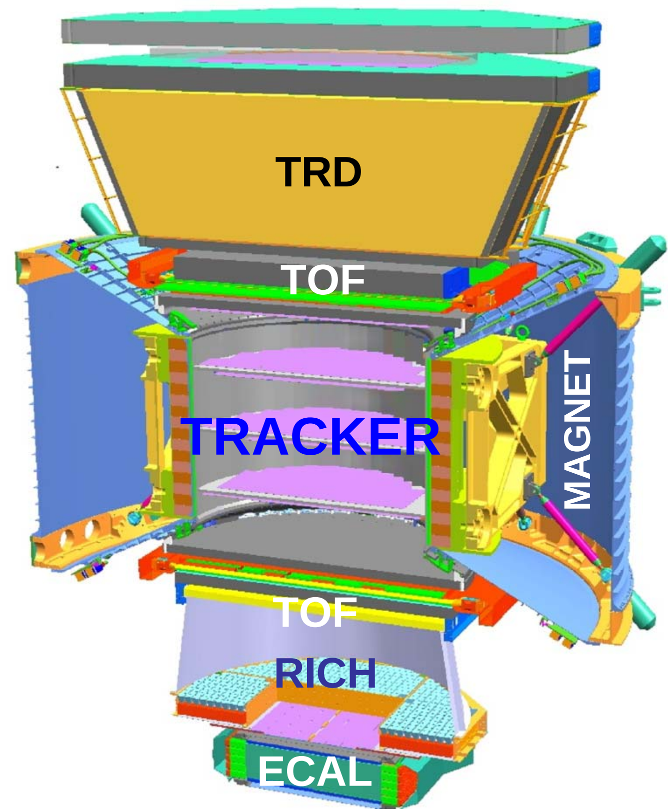
Professors A. Contin, G. Laurenti, F. Palmonari



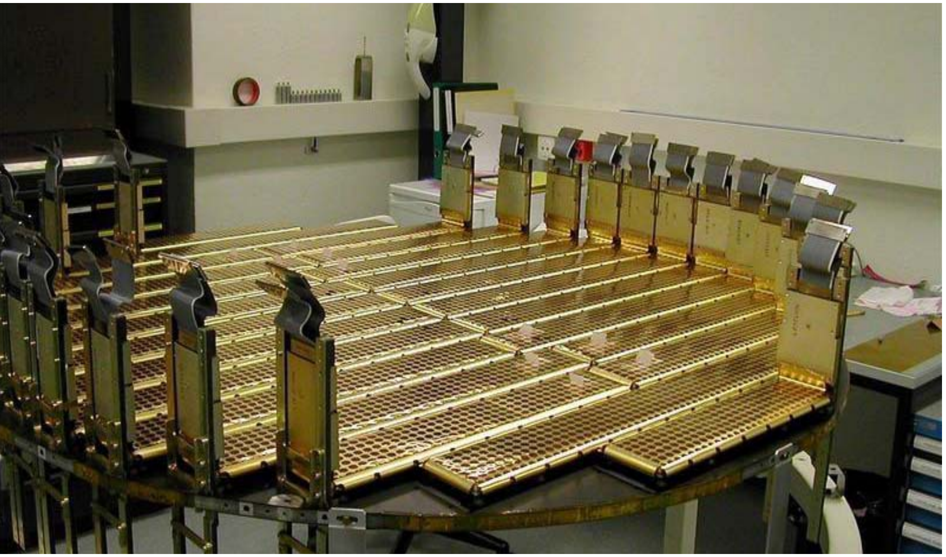
Tracker: The coordinate resolution is 10 μ

Stabilty of the Inner Tracker is monitored by the Tracker Laser Alignment System.
Outer Tracker Alignment via cosmic rays



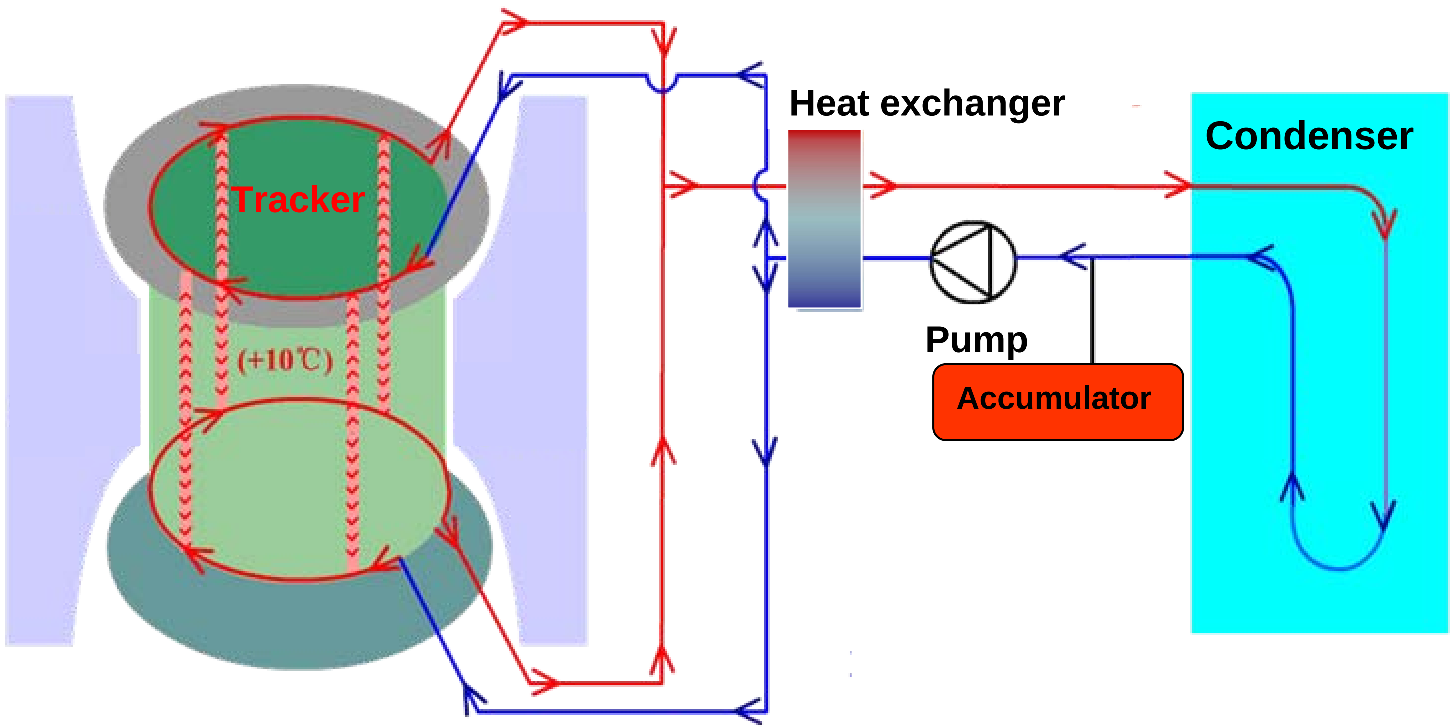


Tracker



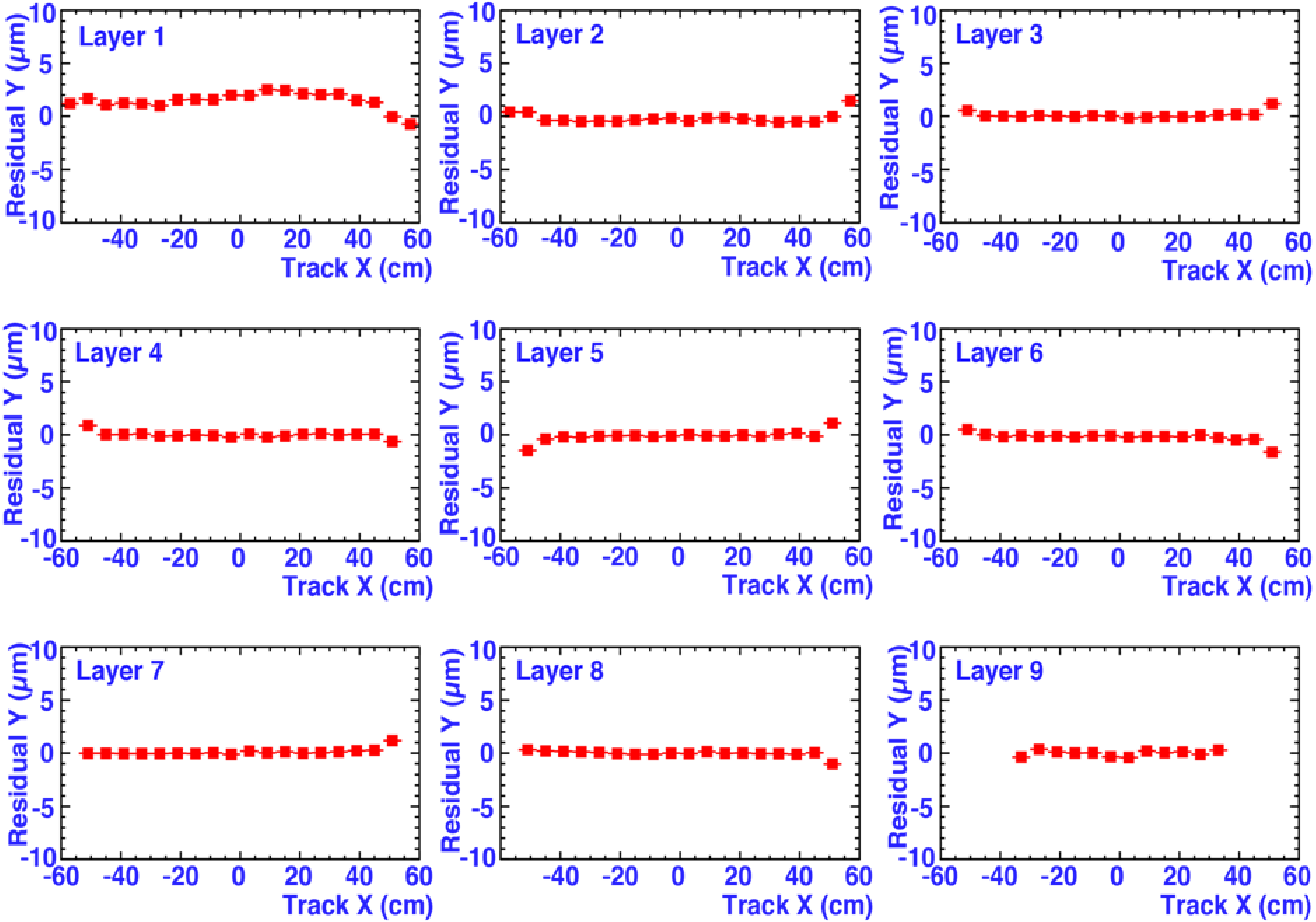
Perugia (Prof. Battiston and Bertucci) and Geneva (Prof. ohl) groups

Tracker Thermal Control System in Space

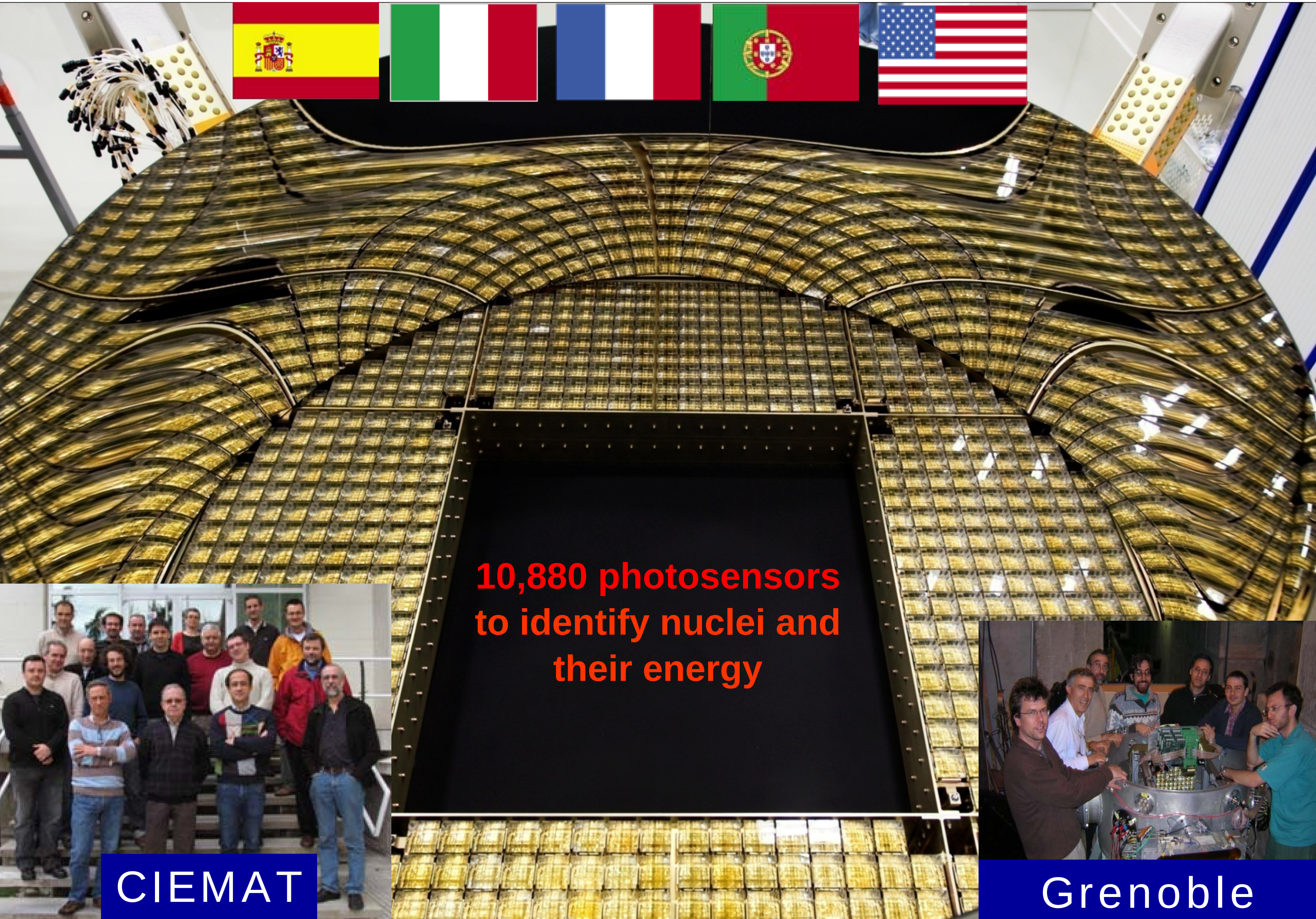


Red line: CO_2 gas/liquid two phase **Blue line: CO_2 liquid phase**

Alignment accuracy of the 9 Tracker layers over 18 months



Ring Imaging CHerenkov (RICH)

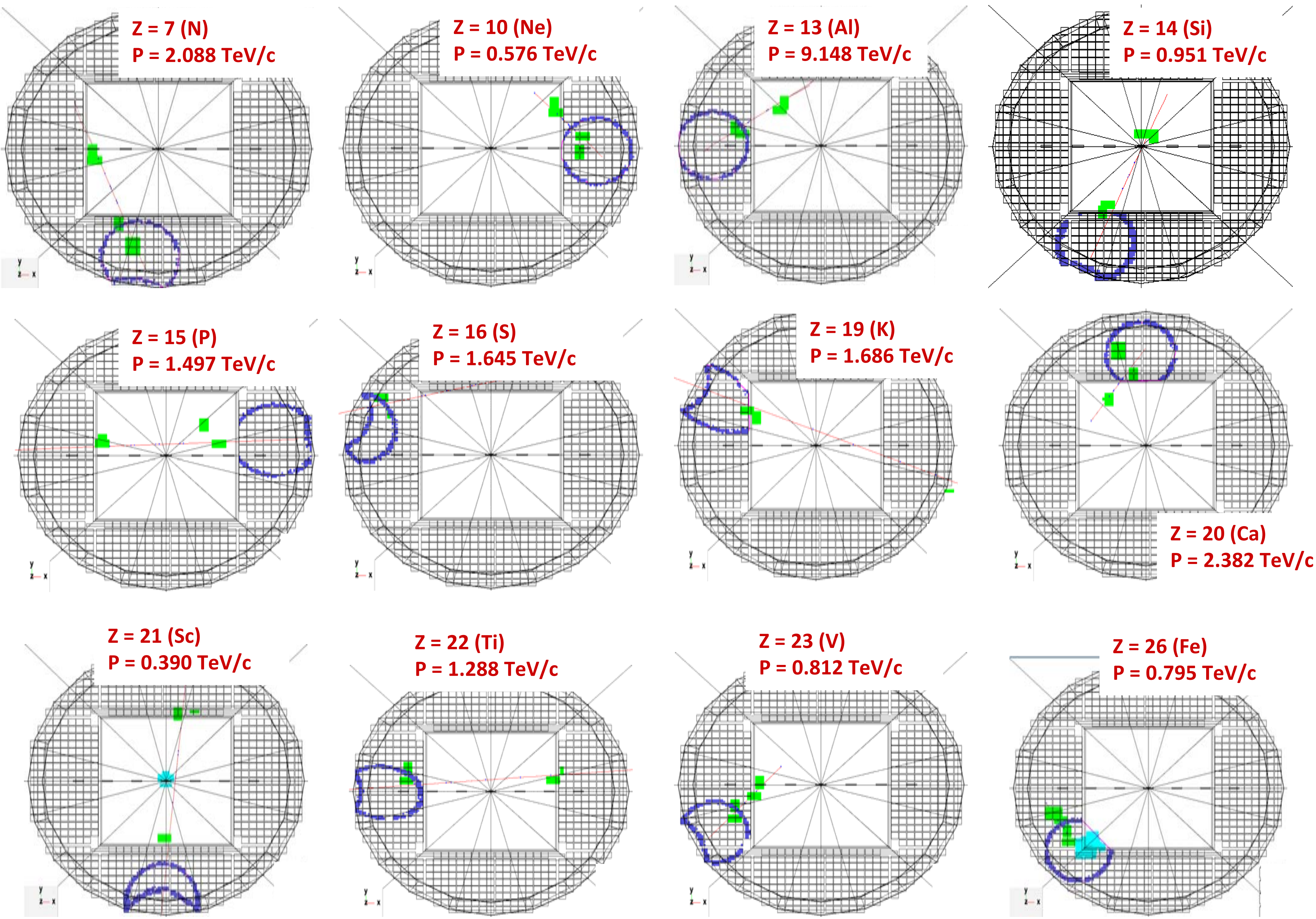


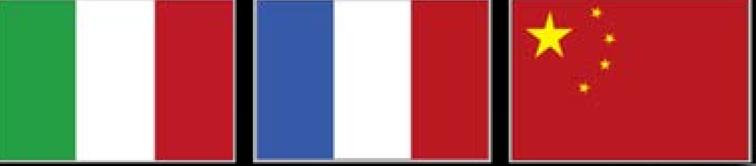
10,880 photosensors to identify nuclei and their energy

CIEMAT

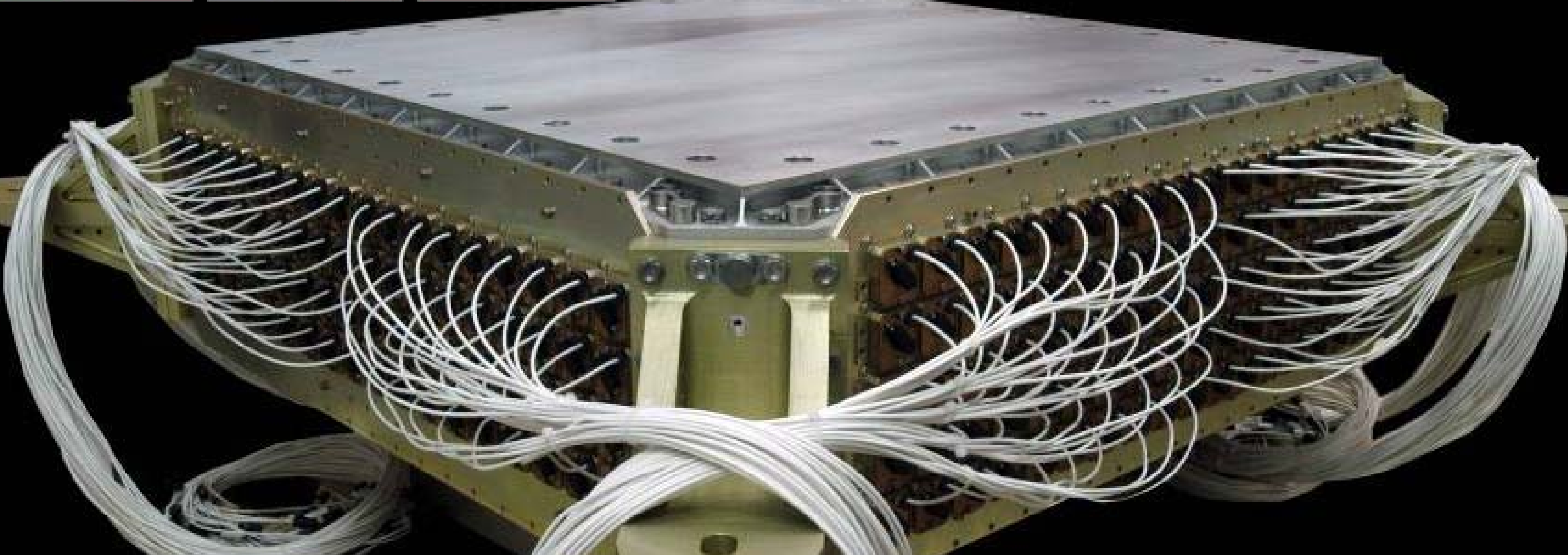
Grenoble

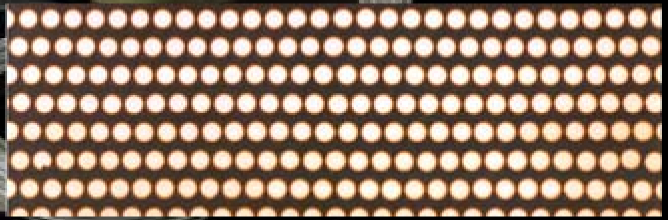
Detector performance on ISS RICH





Calorimeter (ECAL)

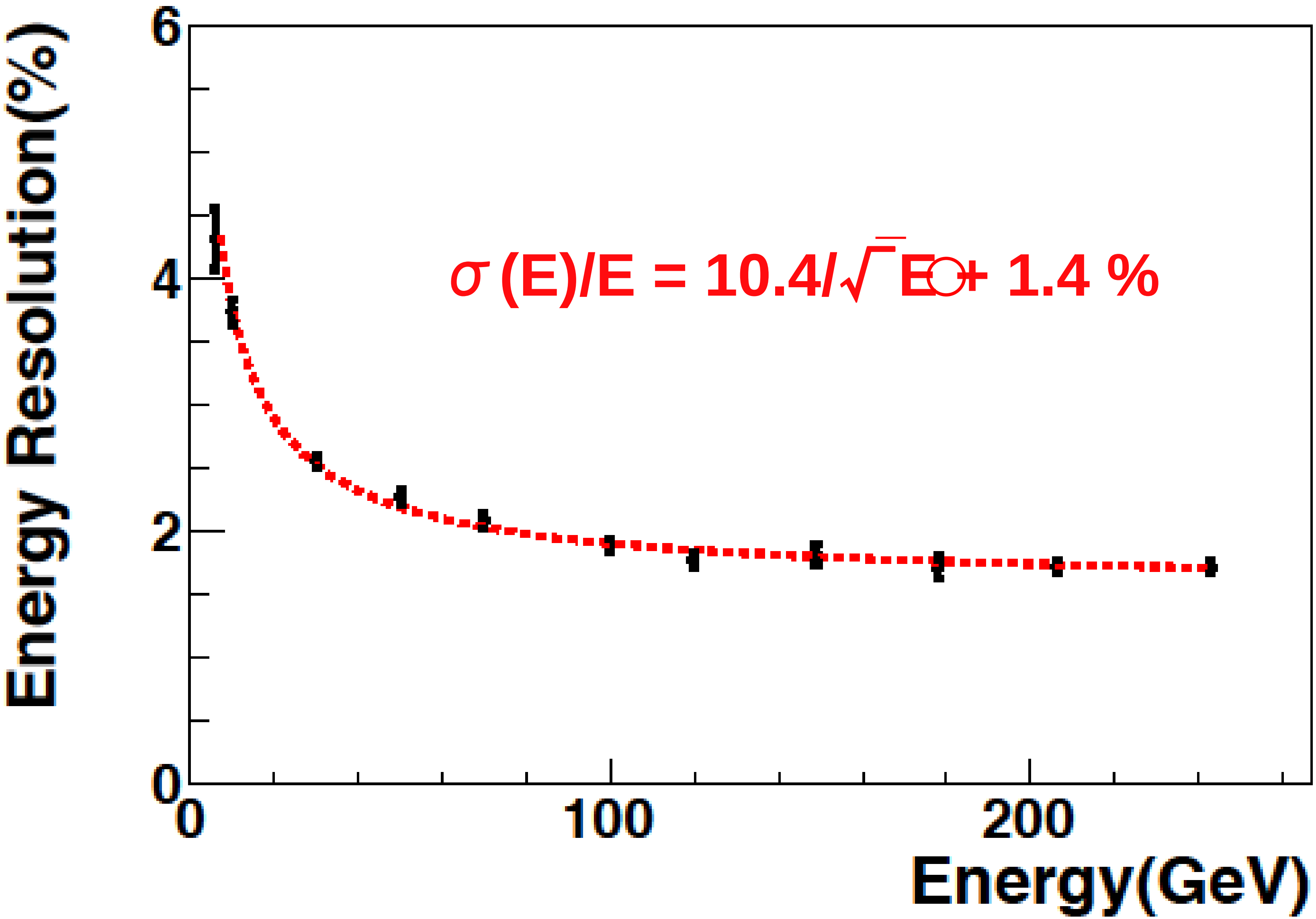




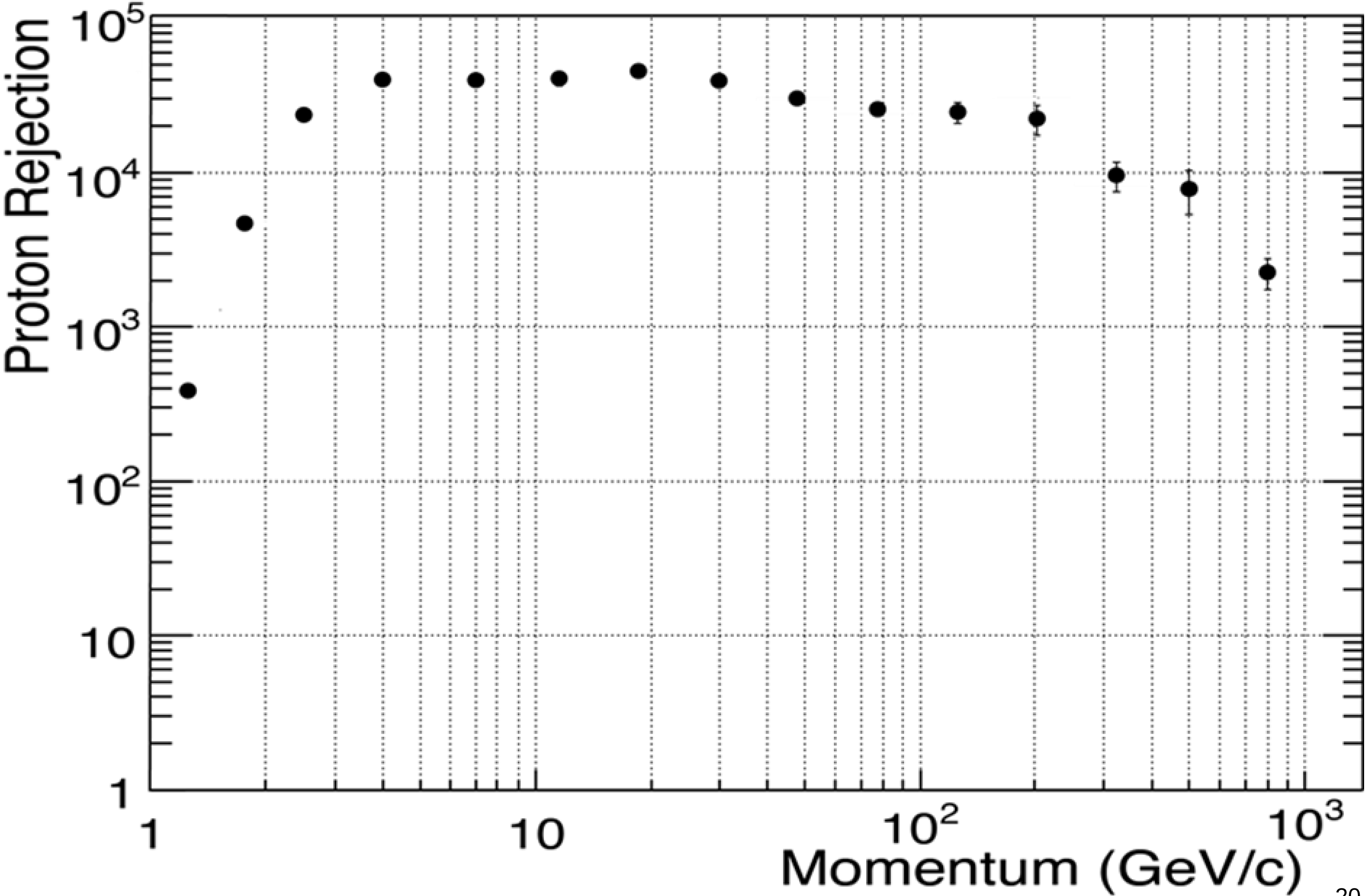
LAPP

50,000 fibers, $\phi = 1$mm, distributed uniformly inside 600 kg of lead which provides a precision, 3-dimensional, $17X_0$ measurement of the directions and energies of light rays and electrons up to 1 TeV

ECAL Performance



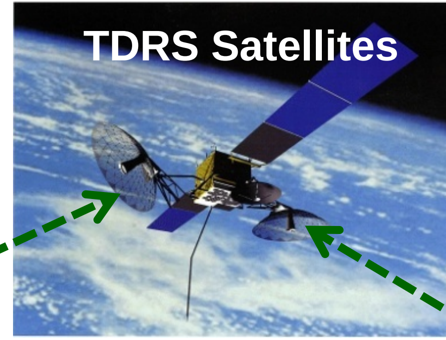
Data from ISS: Proton rejection using the ECAL



May 16, 2011

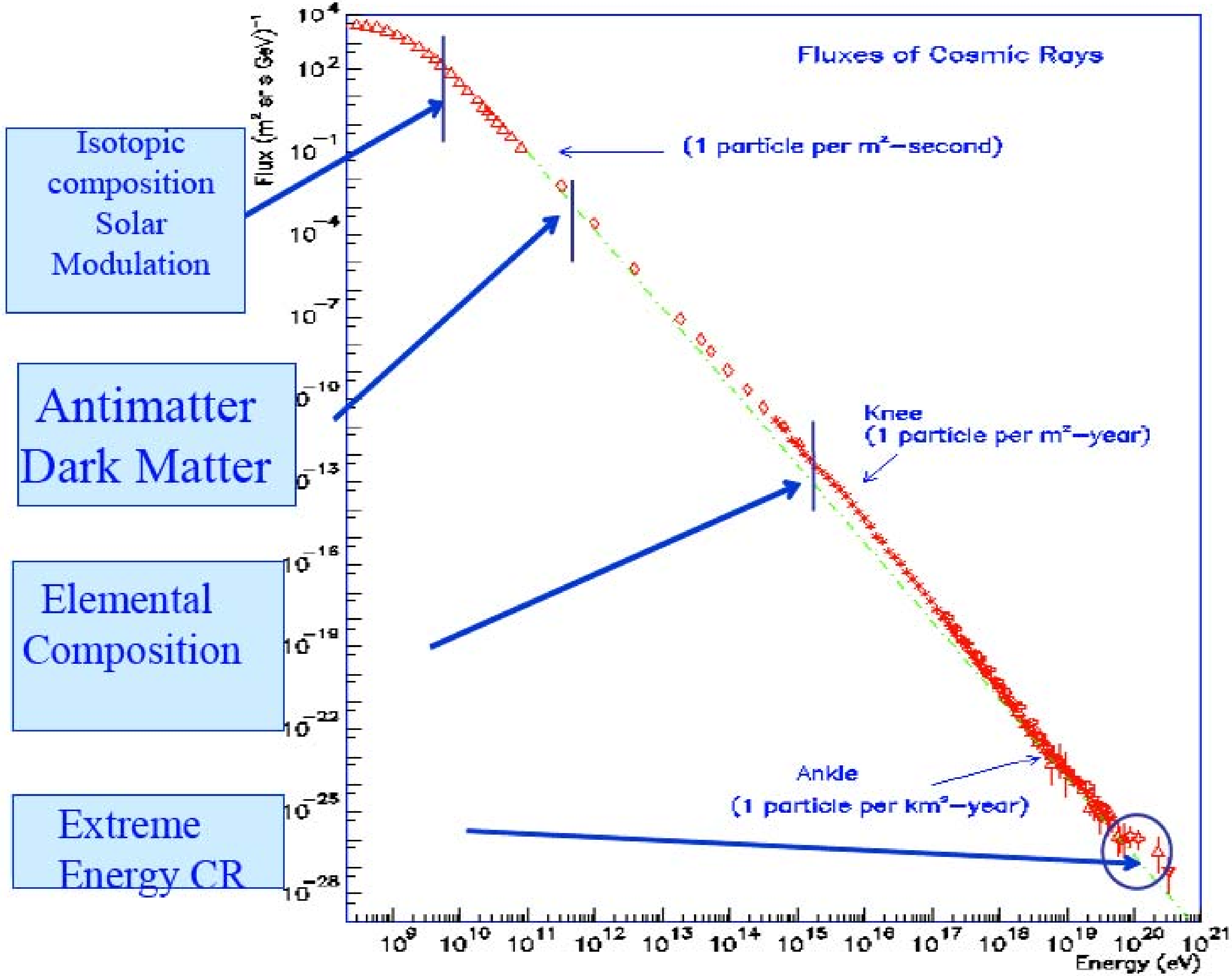
AMS today

AMS Operations



**24 hours
x 365 days
x 10-20 years**

White Sands, NM

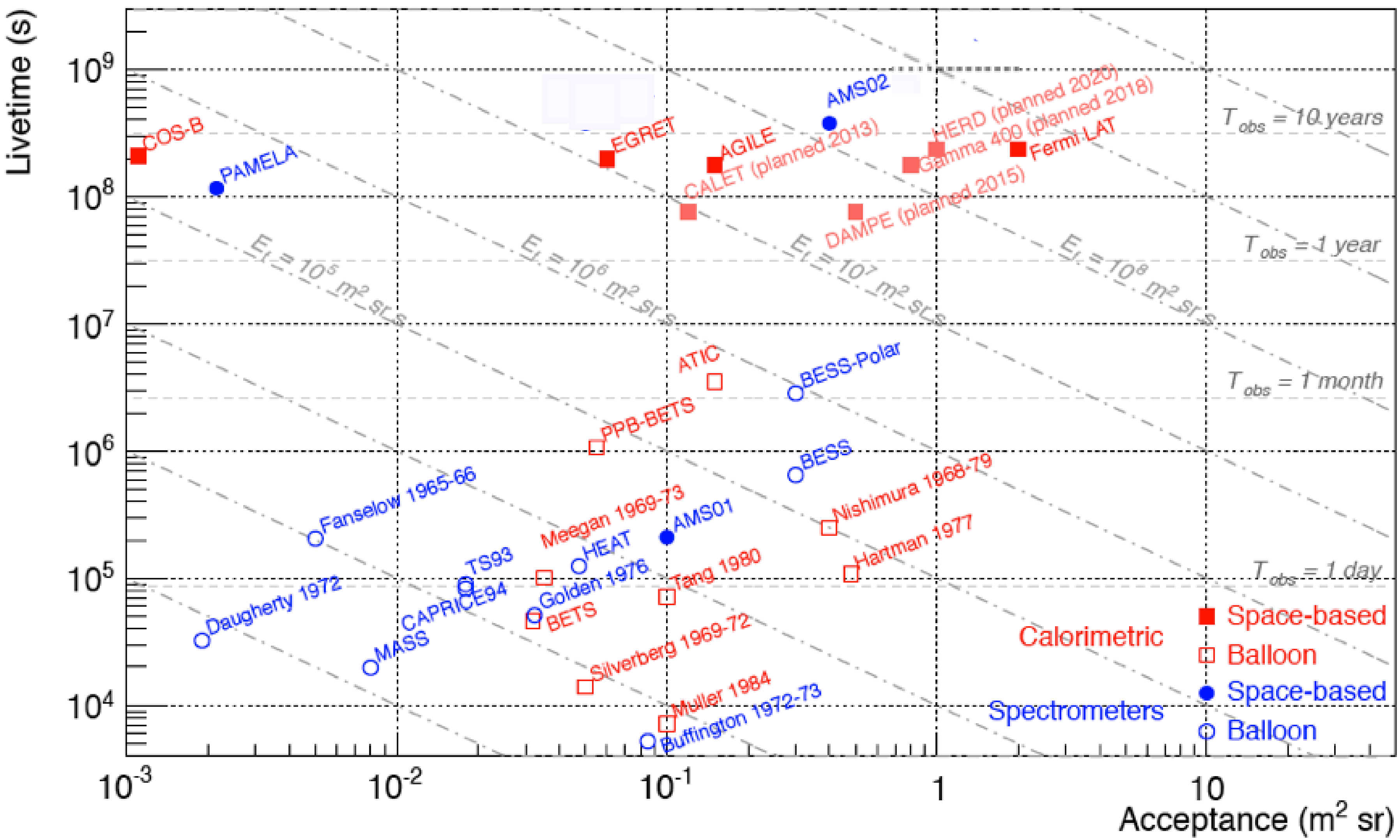


J. Cronin ,T.K. Gaisser & S.P. Swordy, Sci. Amer. 276 (1997) 44

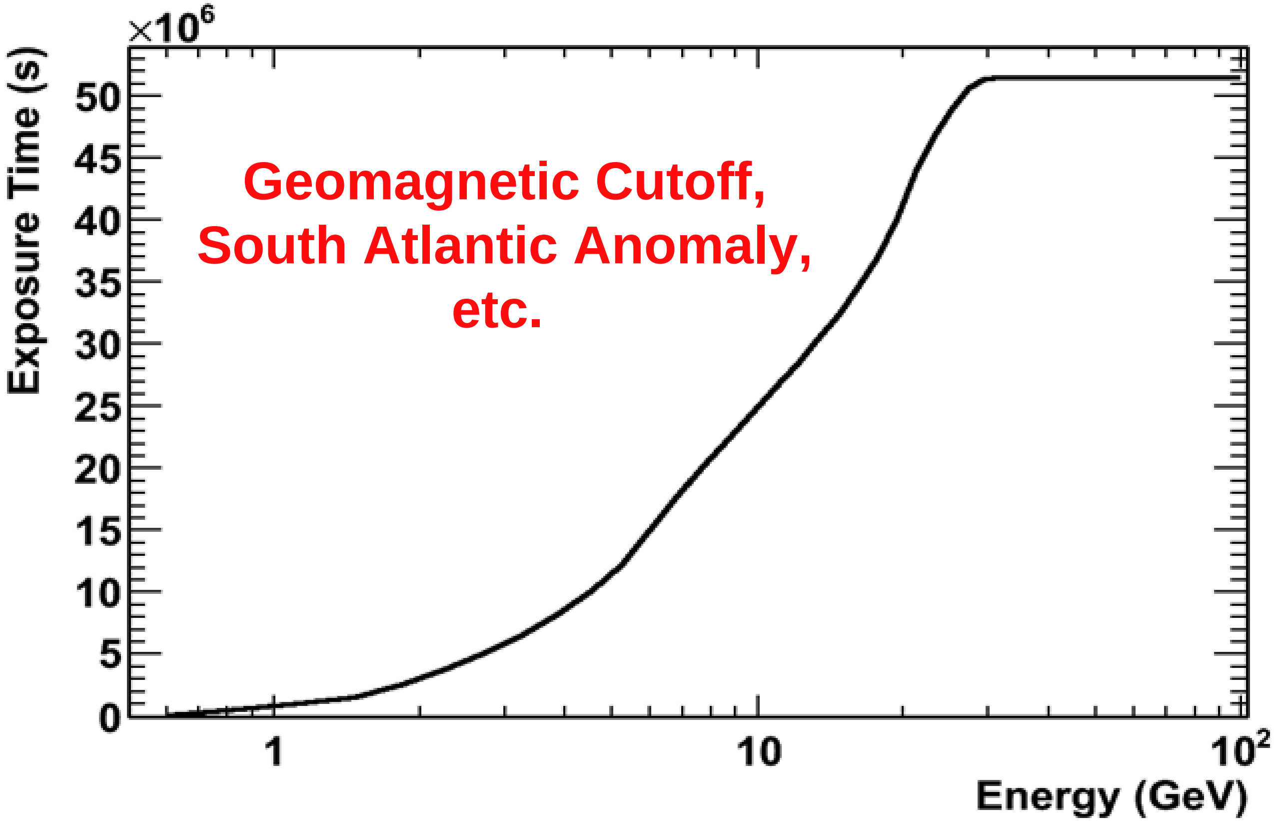
AMS

Physics results

A Large Magnetic Spectrometer in Space : a game changing for the study of Cosmic Ray



Results from
the first 2 years of AMS



Average live time = 82 %

Data analysis in AMS (2 years of data)

AMS is a very precise particle physics detector.

Precision physics results require attention to detail and a large analysis effort.

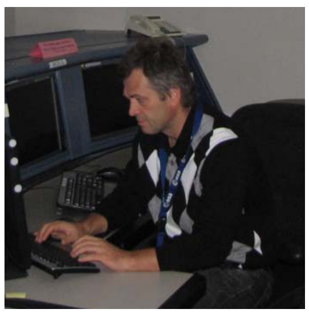
The data are analysed by two independent AMS international teams.

Example: the positron fraction paper

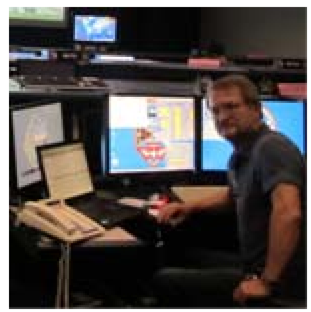
Group A

Group

B. Bertucci

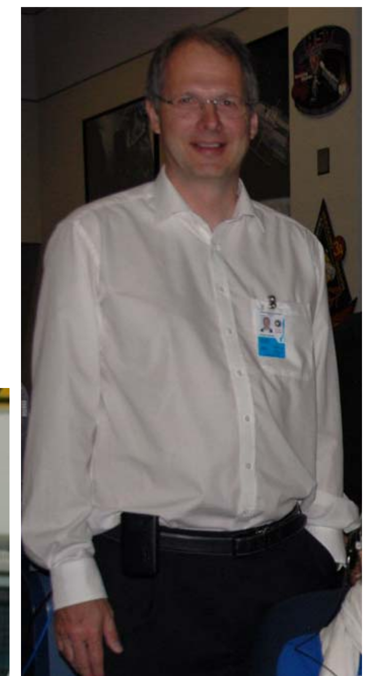


V. Choutko



A. Kounine

J. Berdugo



S. Schael

M. Incagli

S. Rosier-Lees

S. Haino, A. Oliva

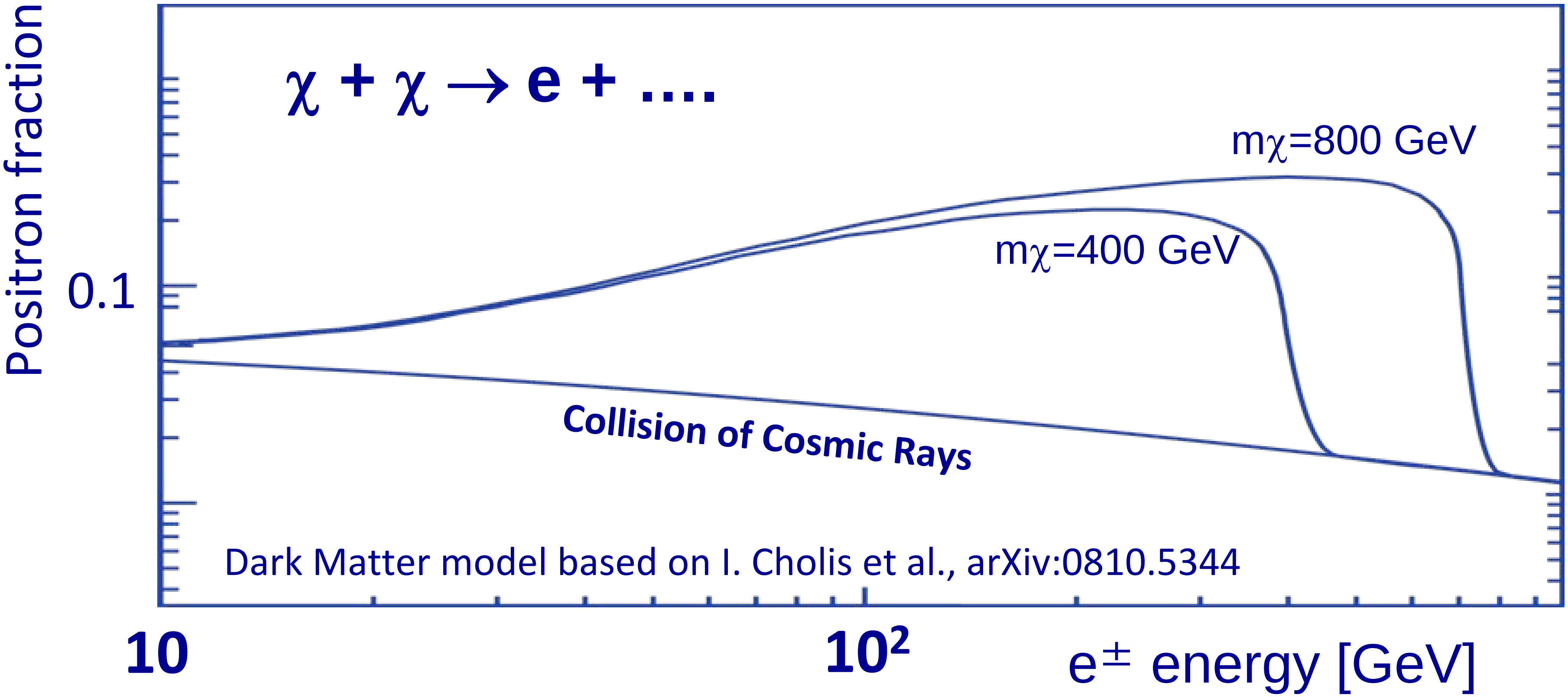
J. Casaus, P. Zuccon

Physics results (ICRC 2013)

1. $e^+/(e^+ + e^-)$ ratio and anysotropy
2. Proton spectrum
3. Helium spectrum
4. Electron Spectrum
5. Positron Spectrum
6. All electron spectrum
6. Boron-to-Carbon ratio

Physics of Positron Fraction: $e^+/(e^+ + e^-)$

M. Turner and F. Wilczek, Phys. Rev. D42 (1990) 1001;
J. Ellis, 26th ICRC Salt Lake City (1999) astro-ph/9911440;
H. Cheng, J. Feng and K. Matchev, Phys. Rev. Lett. 89 (2002) 211301;
S. Profumo and P. Ullio, J. Cosmology Astroparticle Phys. JCAP07 (2004) 006;
D. Hooper and J. Silk, Phys. Rev. D 71 (2005) 083503;
E. Ponton and L. Randall, JHEP 0904 (2009) 080;
G. Kane, R. Lu and S. Watson, Phys. Lett. B681 (2009) 151;
D. Hooper, P. Blasi and P. D. Serpico, JCAP 0901 025 (2009) 0810.1527; B2
Y–Z. Fan et al., Int. J. Mod. Phys. D19 (2010) 2011;
M. Pato, M. Lattanzi and G. Bertone, JCAP 1012 (2010) 020.



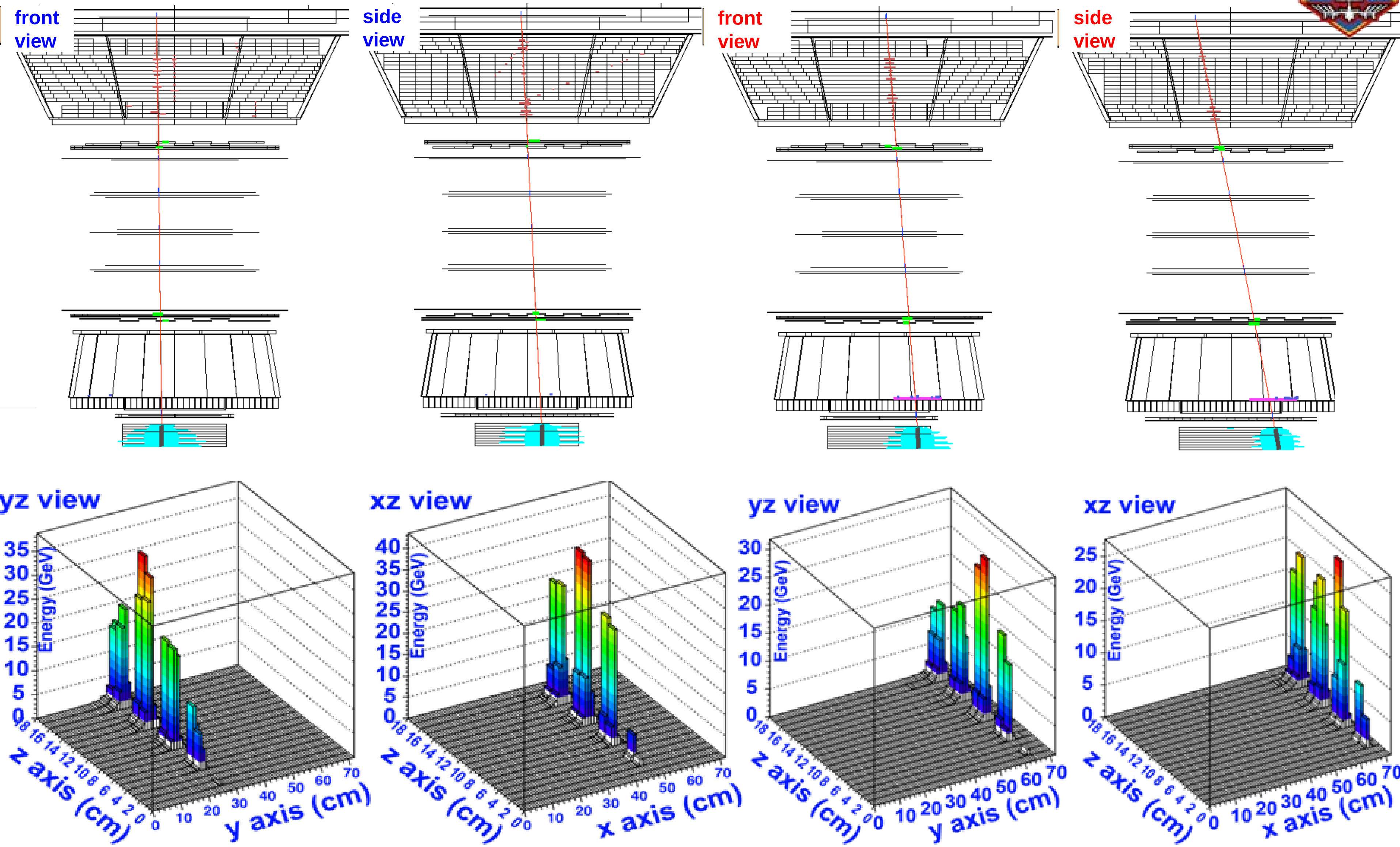
In the first 1.5 years in space, AMS has collected over 25 billion events. 6.8 million are electrons or positrons.

Electron E=982 GeV

Run/Event 1329775818/ 60709

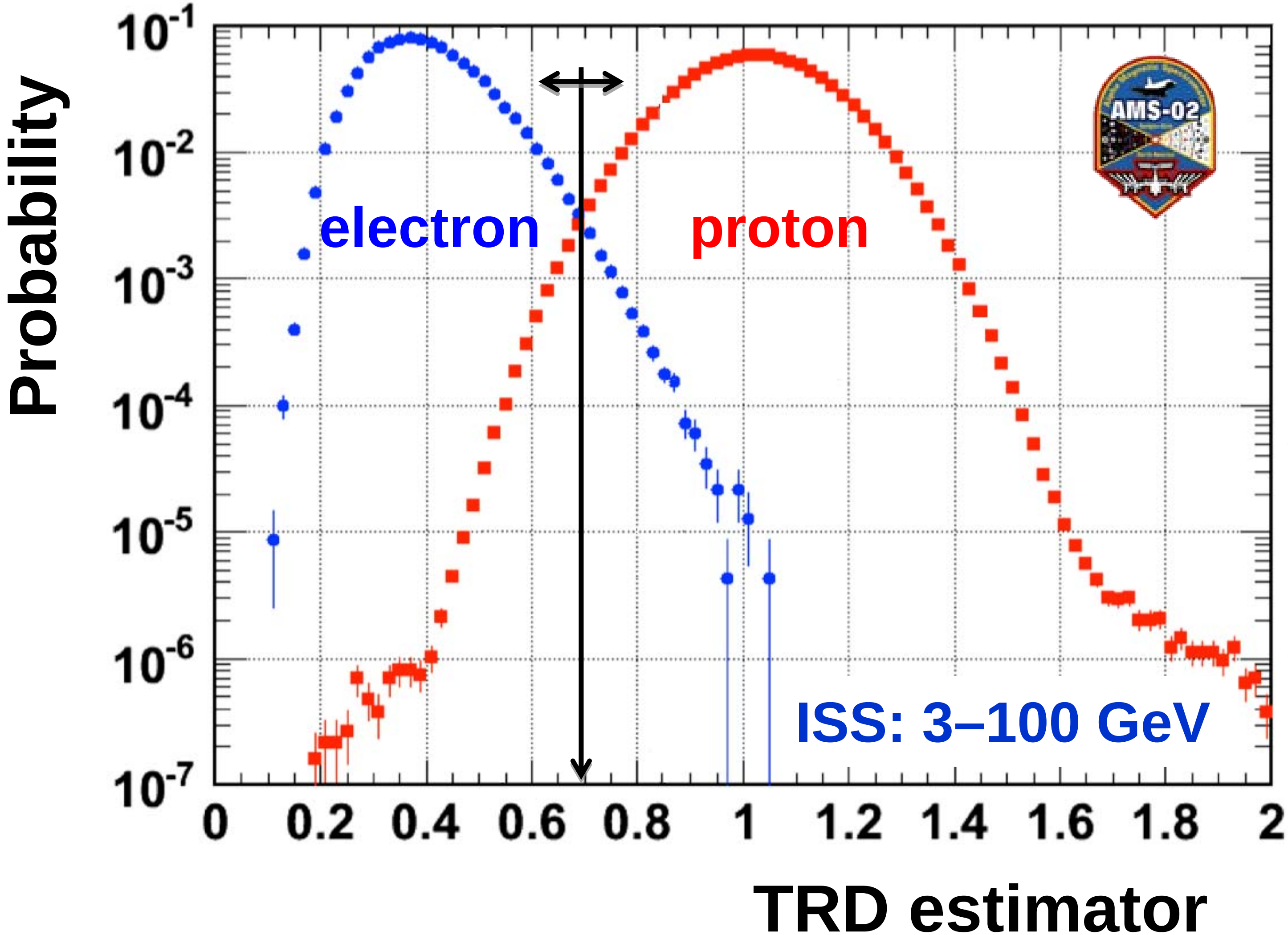
Positron E=636 GeV

Run/Event 133119-743/ 56950



TRD performance on ISS

TRD estimator = $-\ln(P_e/(P_e+P_p))$

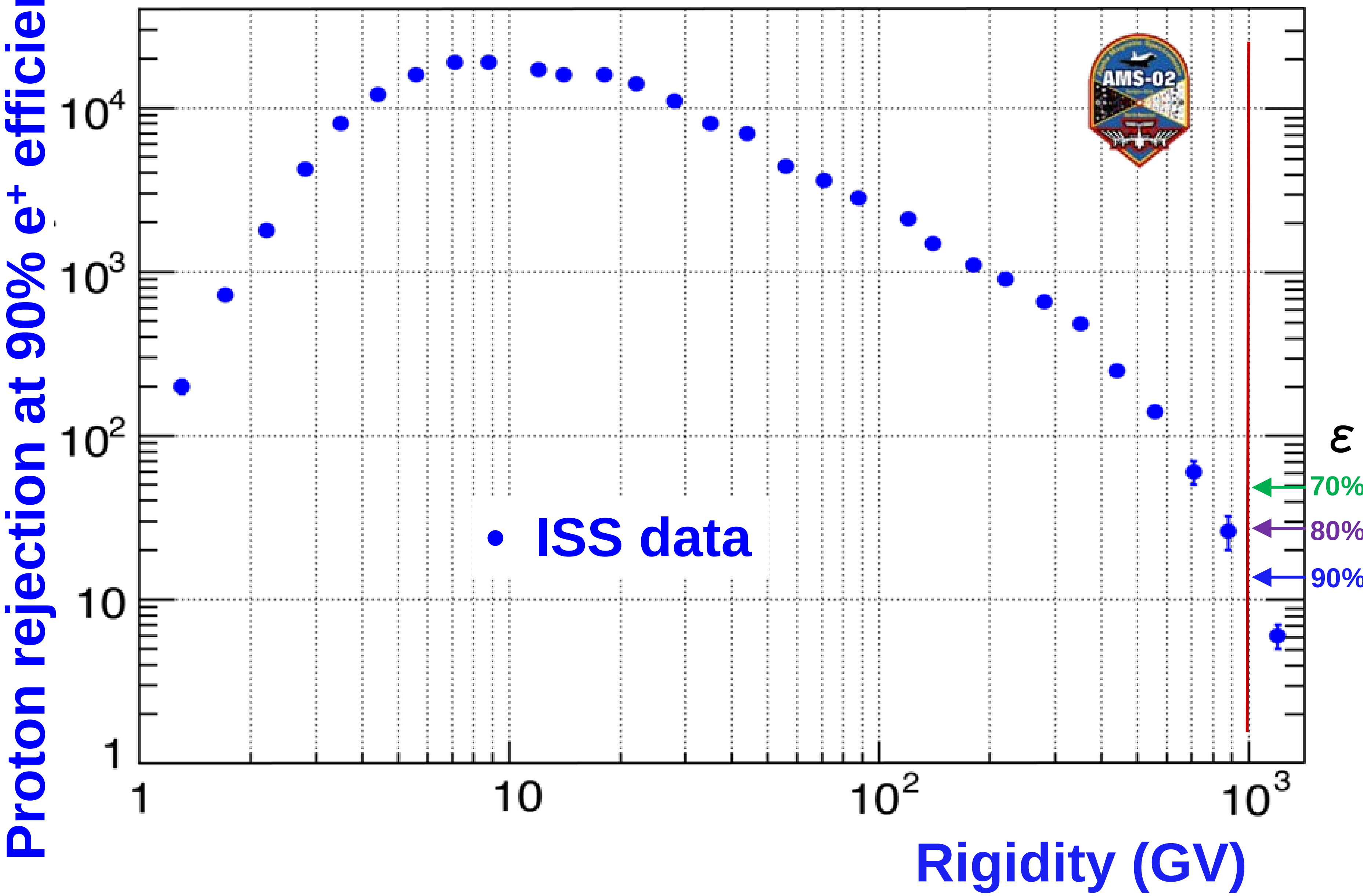


Normalized probabilities P_e and P_p

$$P_e = \sqrt[n]{\prod_i^n P_e^{(i)}(A)}$$

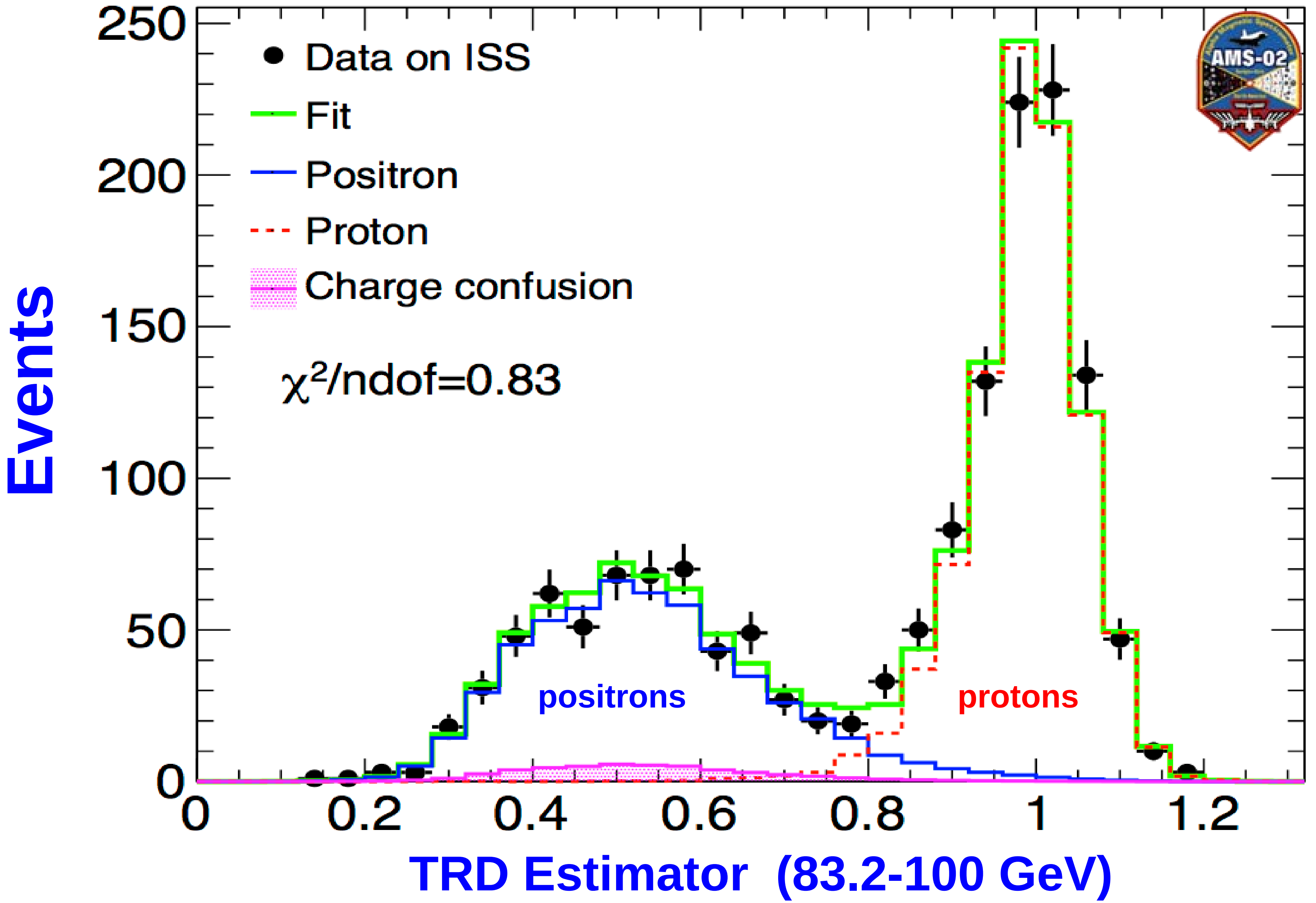
$$P_p = \sqrt[n]{\prod_i^n P_p^{(i)}(A)}$$

TRD performance on ISS

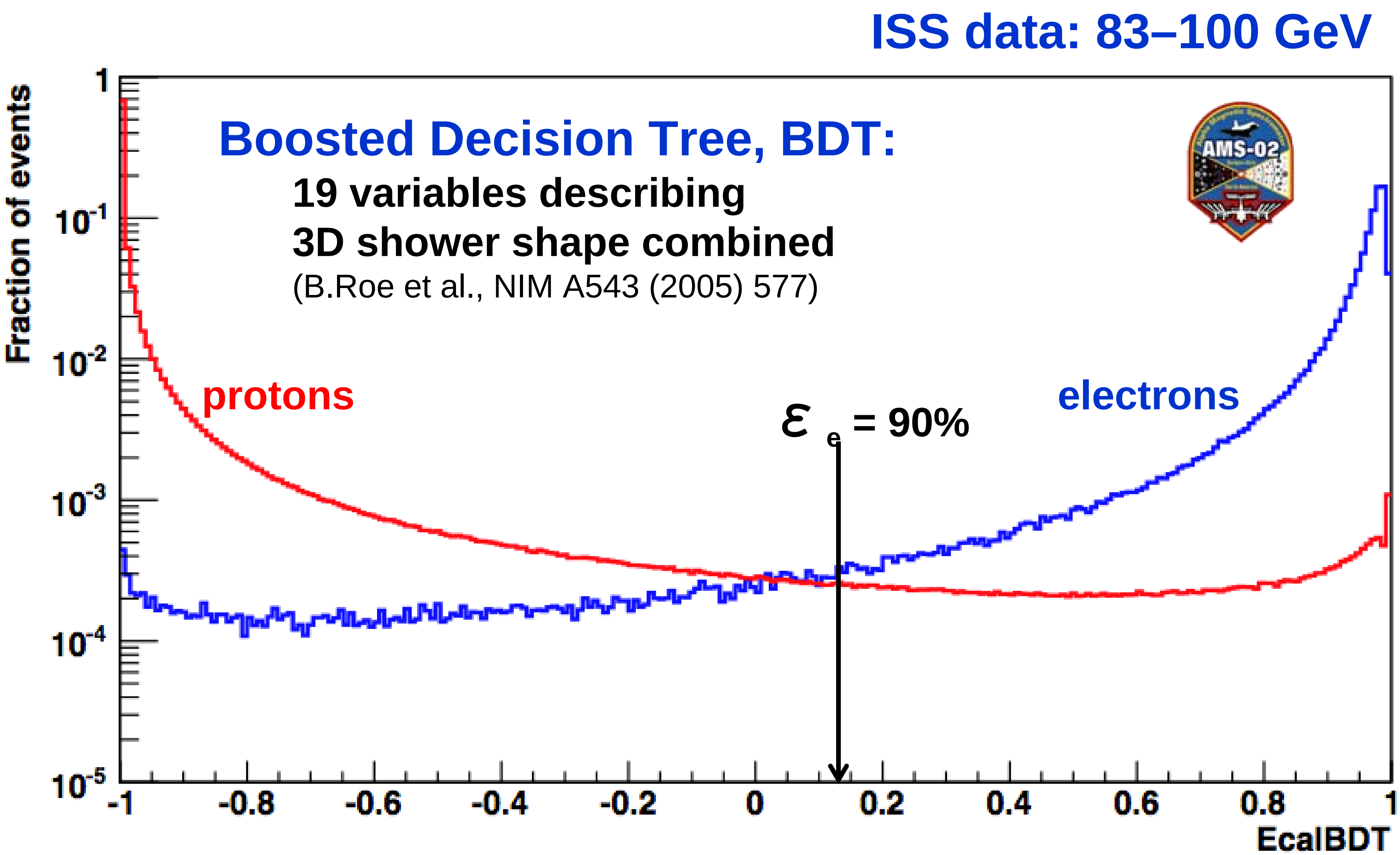


Results of the fit:

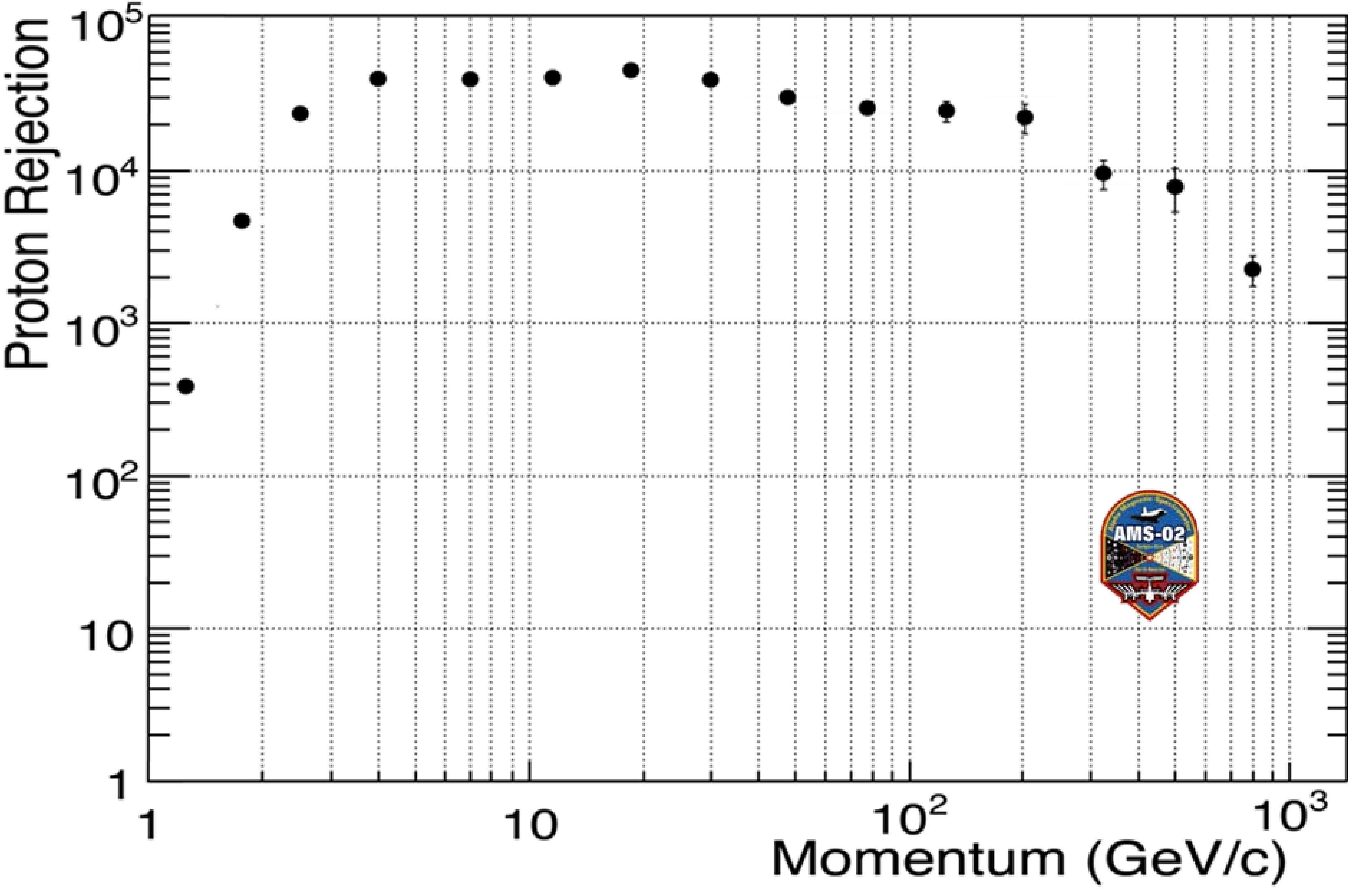
The TRD Estimator shows clear separation between protons and positrons with a small charge confusion background



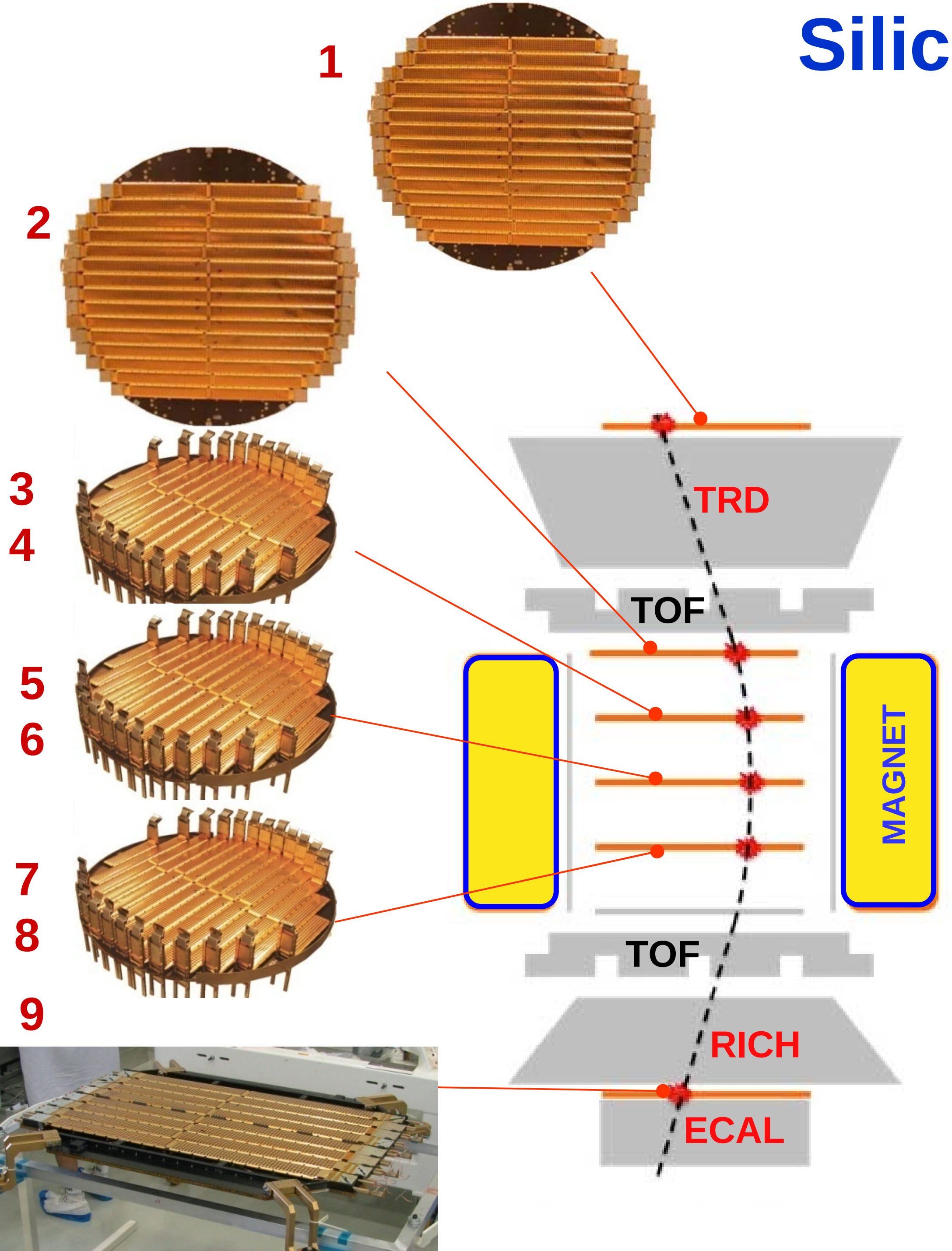
Separation of protons and electrons with ECAL

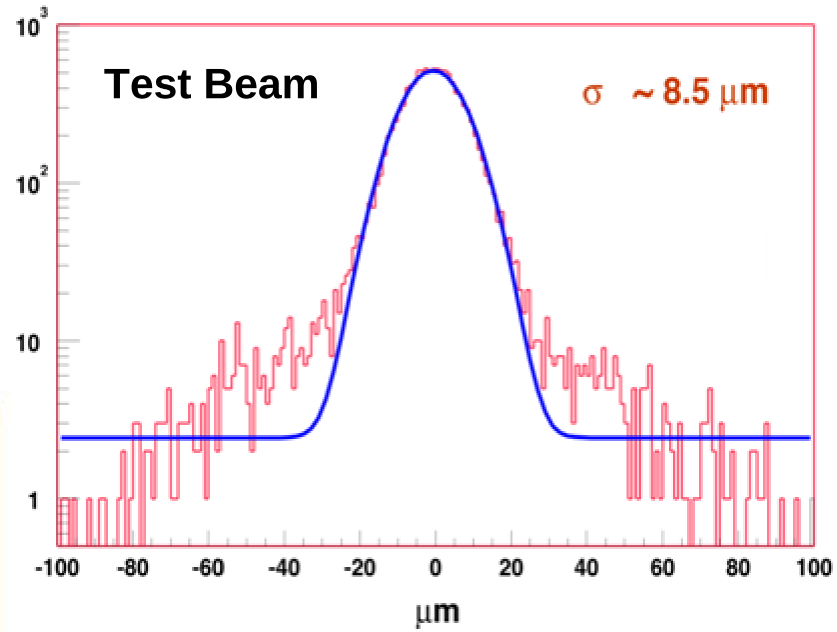


Data from ISS: Proton rejection using the ECAL



Silicon Tracker

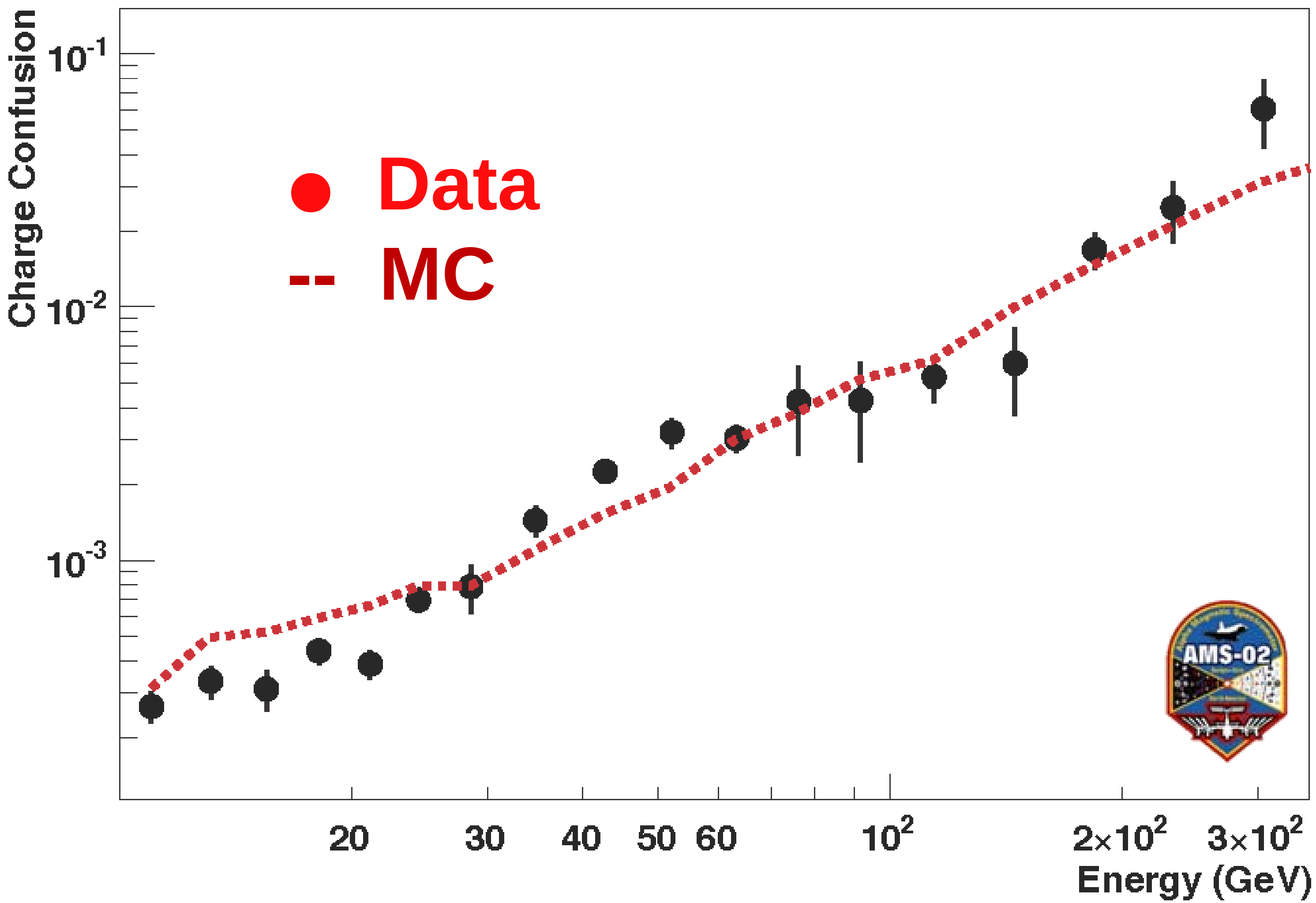




MDR ~2.0 TV

E / |p| matching

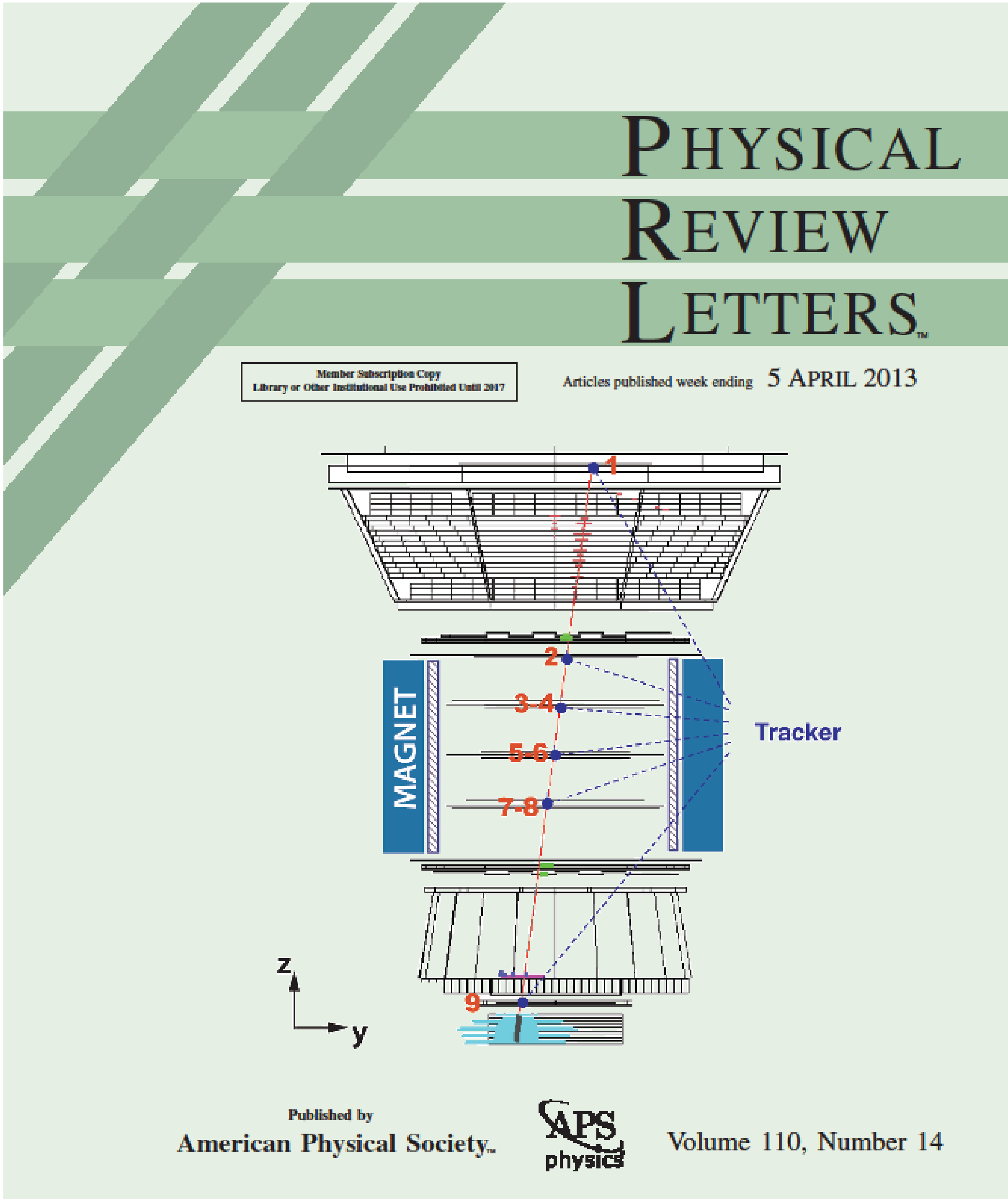
Systematic error on the positron fraction: e+/- Charge confusion



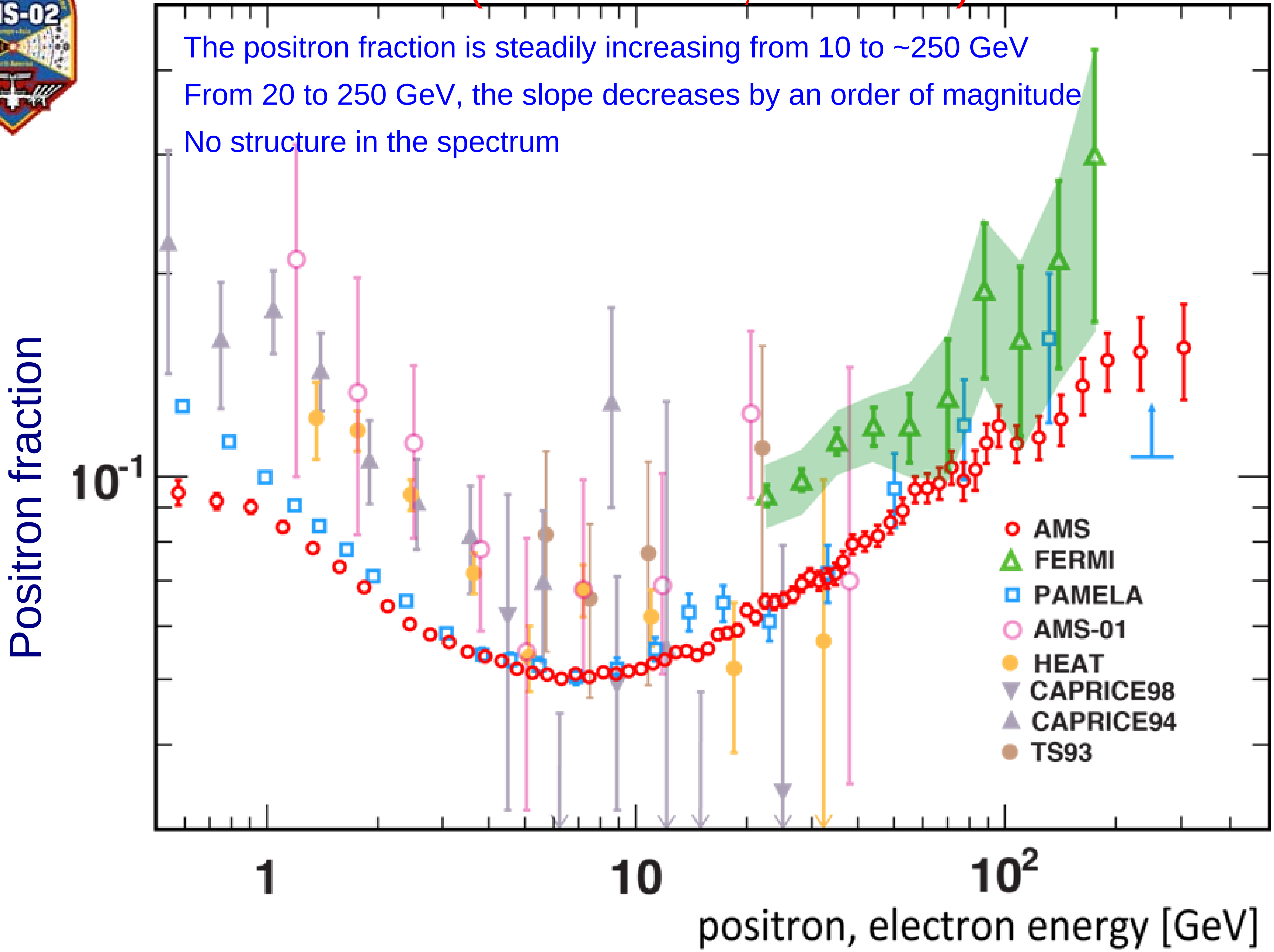
Two sources: large angle scattering and production of secondary tracks along the path of the primary track. Both are well reproduced by MC. Systematic errors correspond to variations of these effects within their statistical limits.

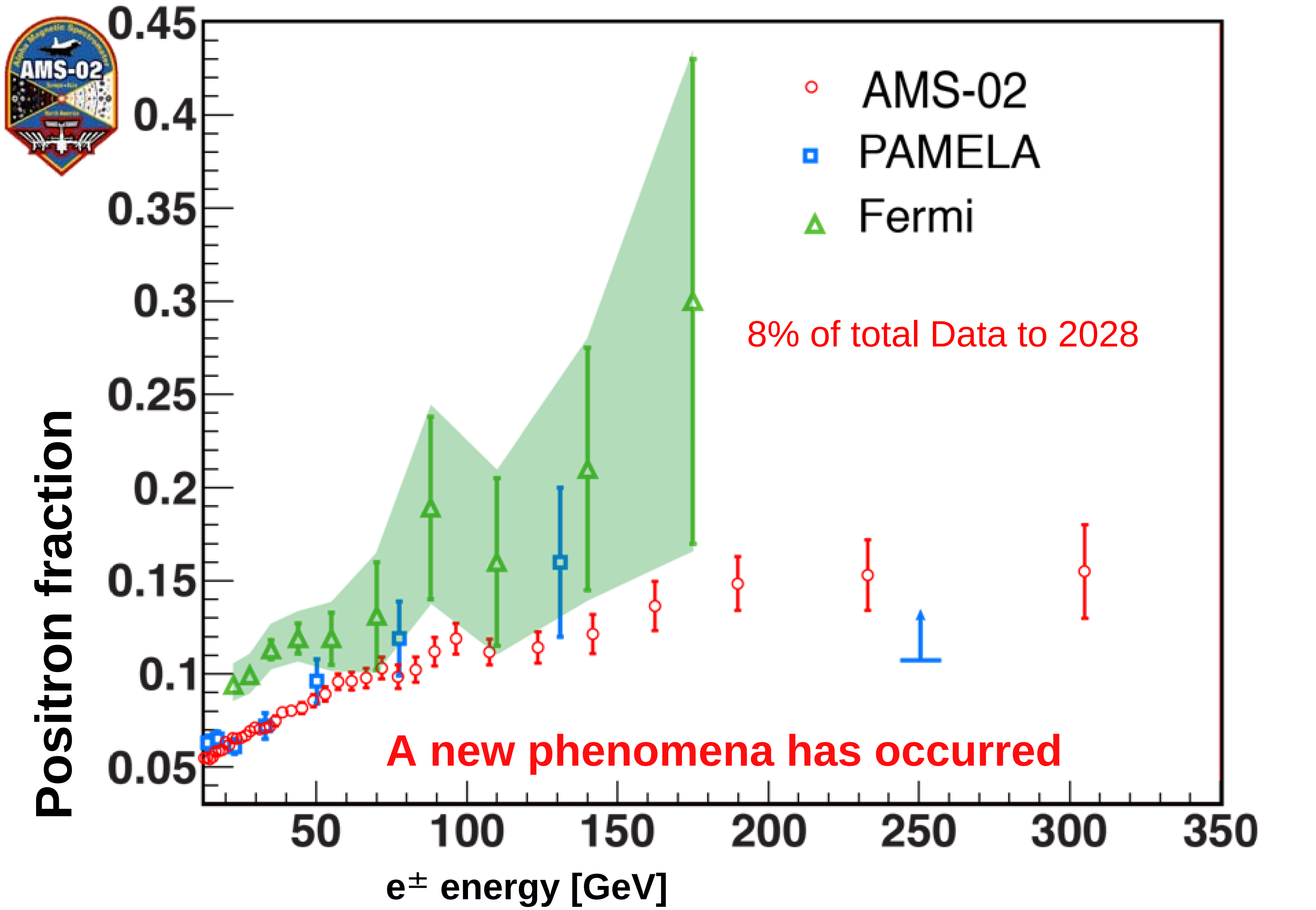
“First Result from the AMS on the ISS: Precision Measurement of the Positron Fraction in Primary Cosmic Rays of 0.5-350 GeV”

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



AMS-02 (6.8 million e^+, e^- events)

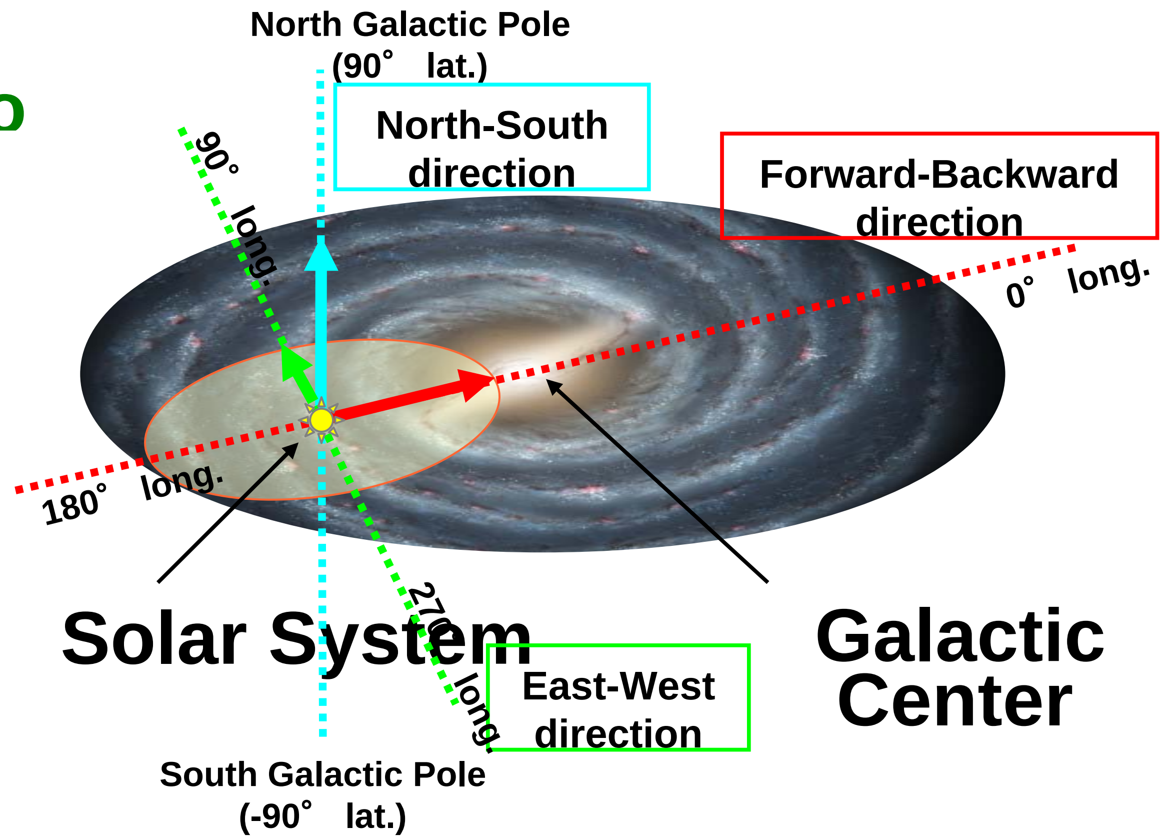




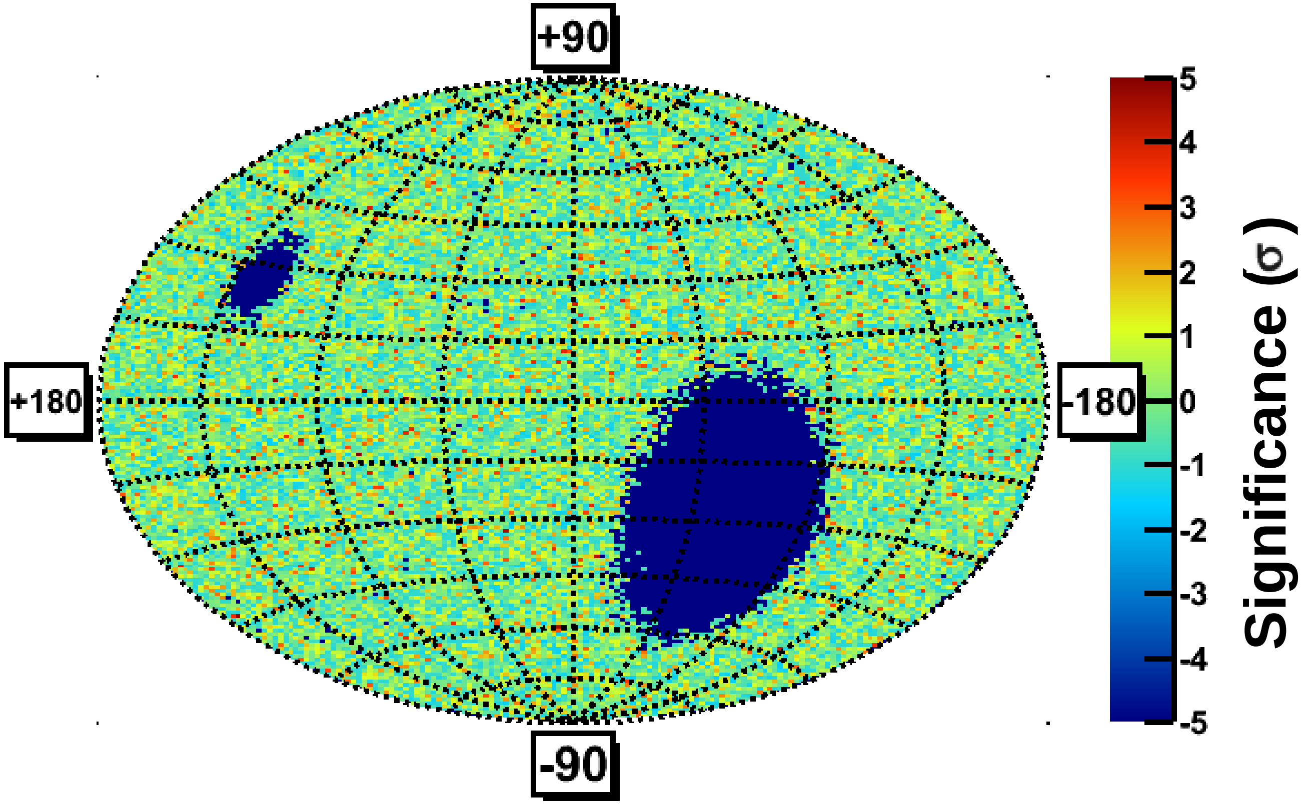
To be presented by A. Kounine (8 July 14:30, ICRC-1264)

Selected events are grouped into 5 cumulative energy bins: 16-350, 25-350, 40-350, 65-350 and 100-350 GeV.

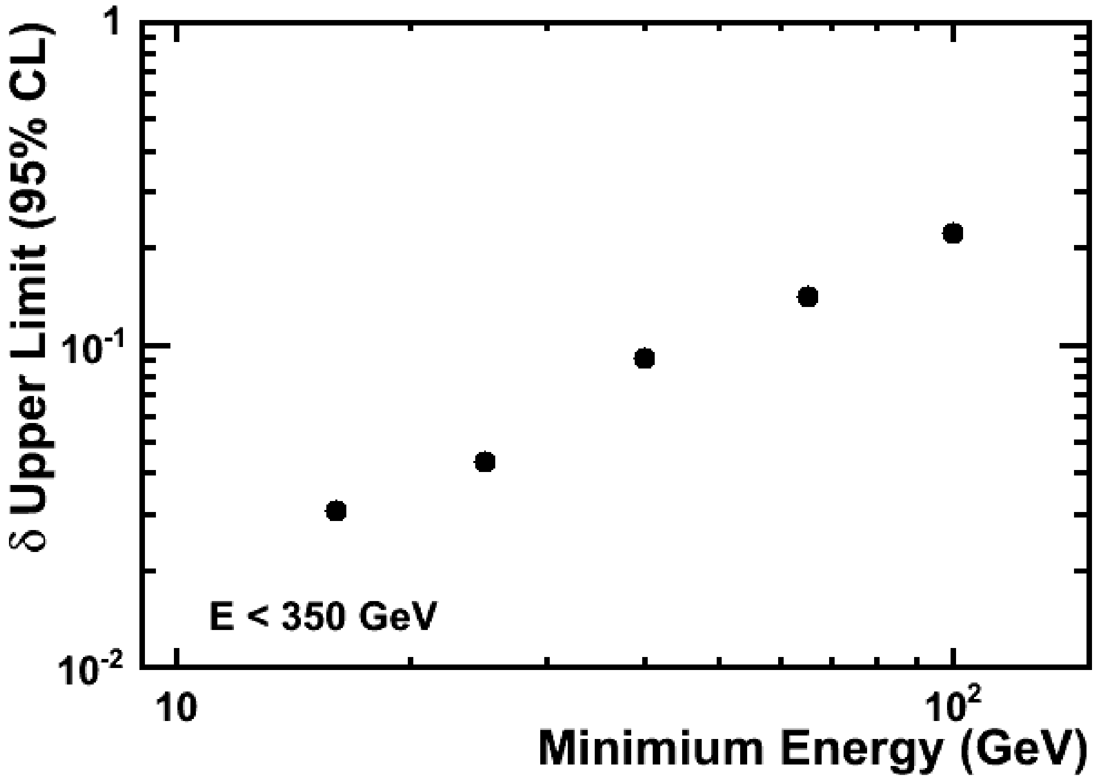
Their arrival directions are used to build sky maps in galactic coordinates, +e /○, , containing the number of observed positrons and electrons



The relative fluctuations of the positron ratio, e^+/e^-, across the observed sky map show no evident pattern

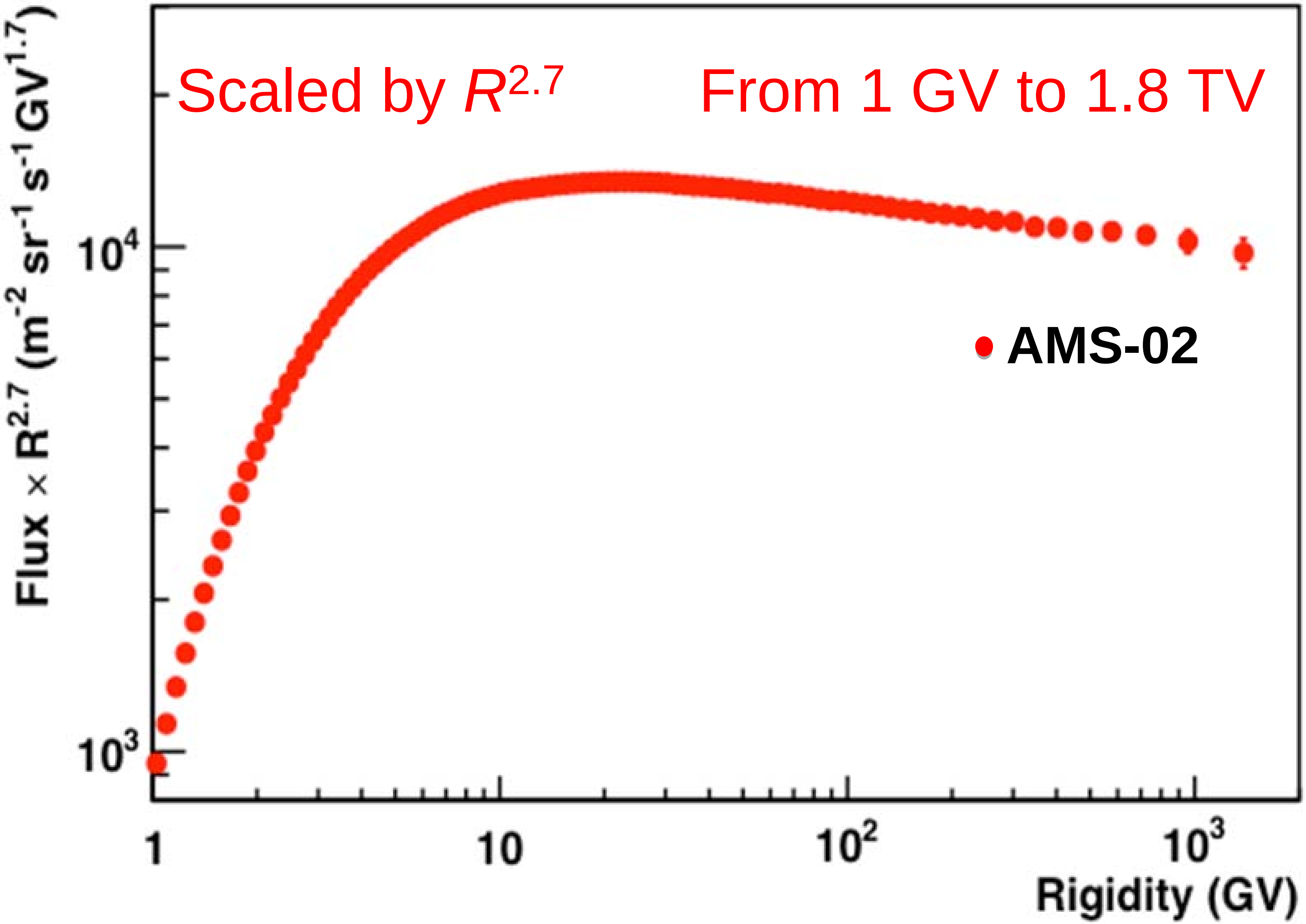


AMS upper limits on δ at the 95% CL



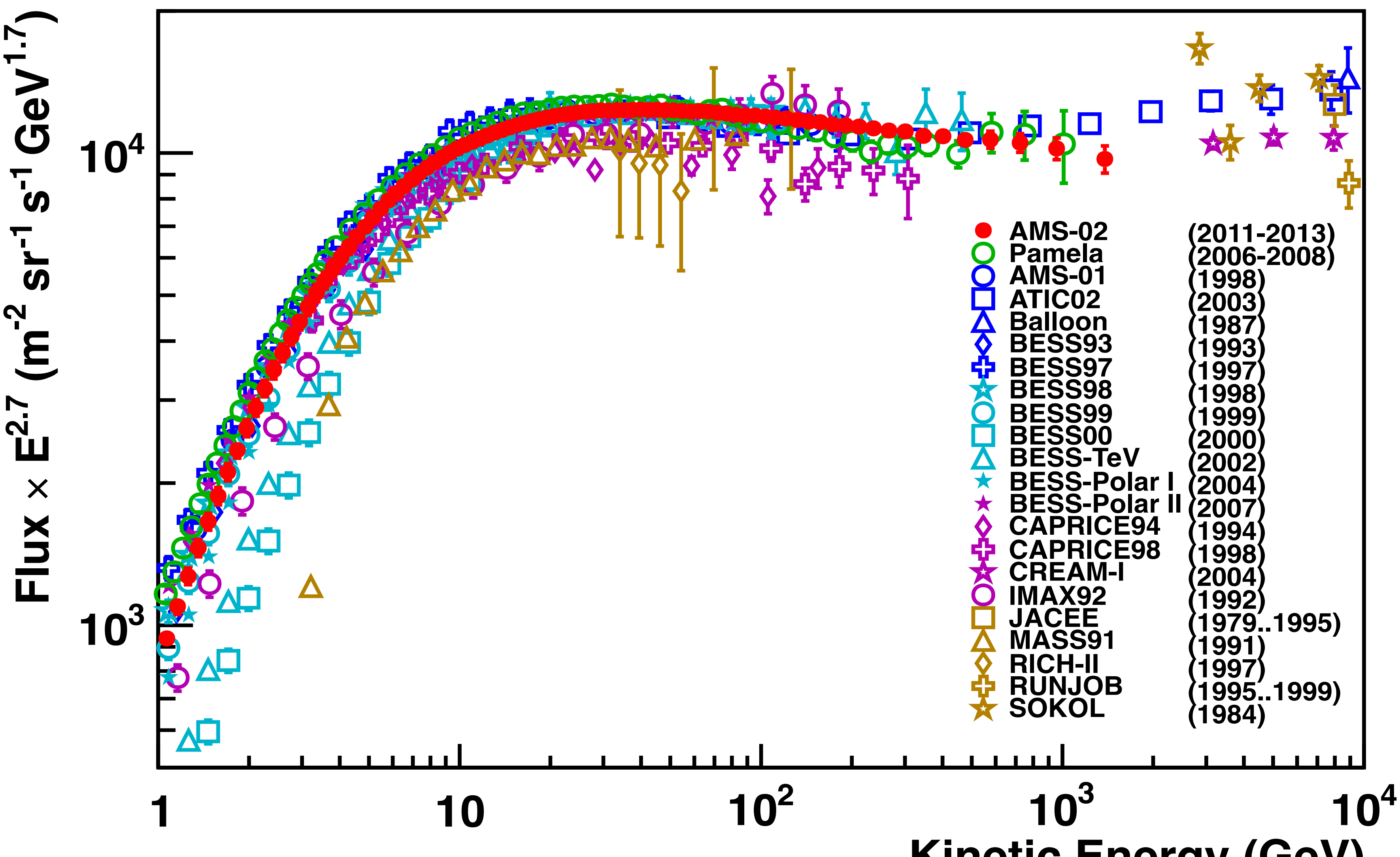
δ <0.030 for 16<E<350GeV

New results from AMS
2) Proton flux

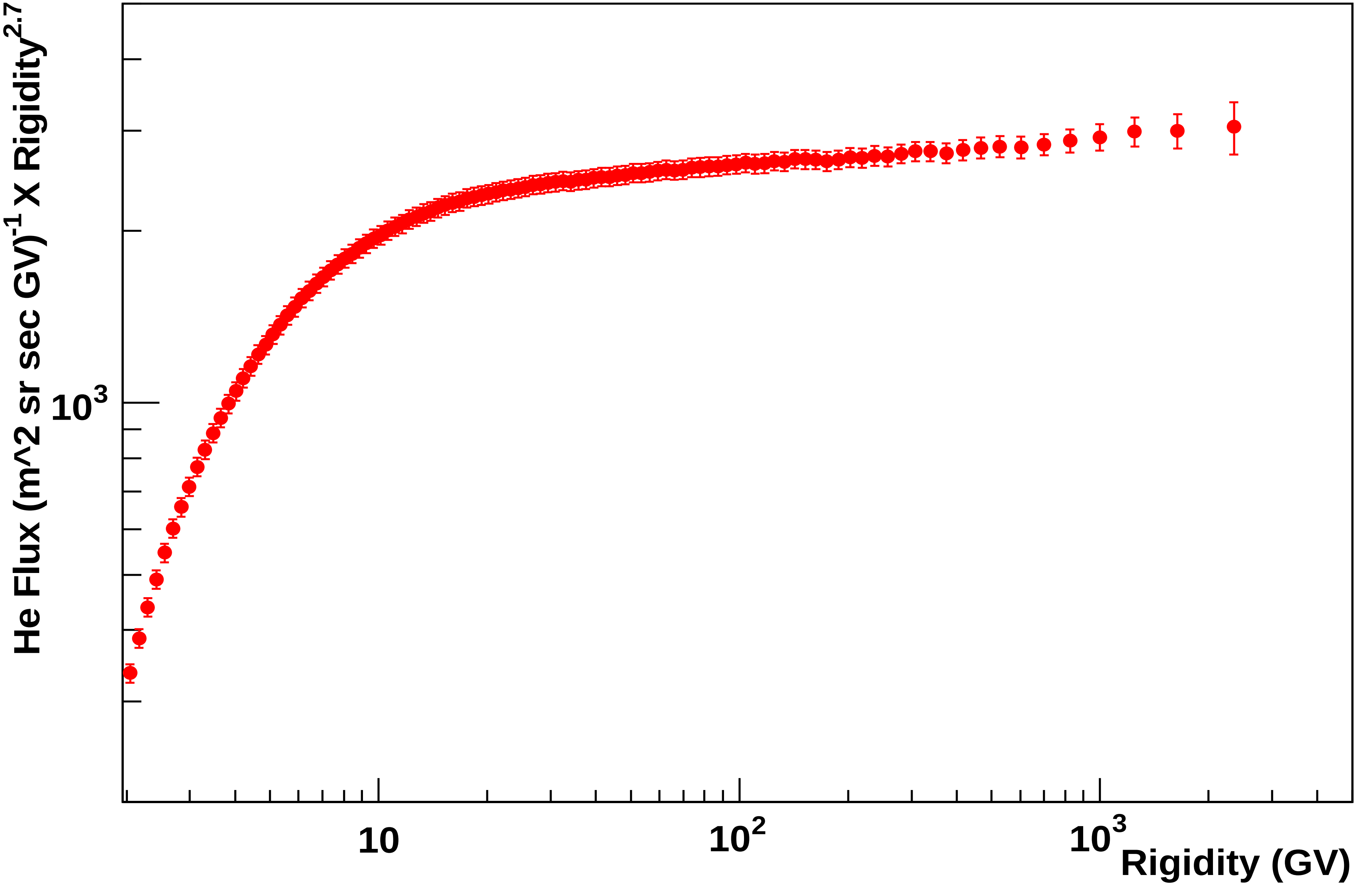


Proton flux

Comparison with past measurements

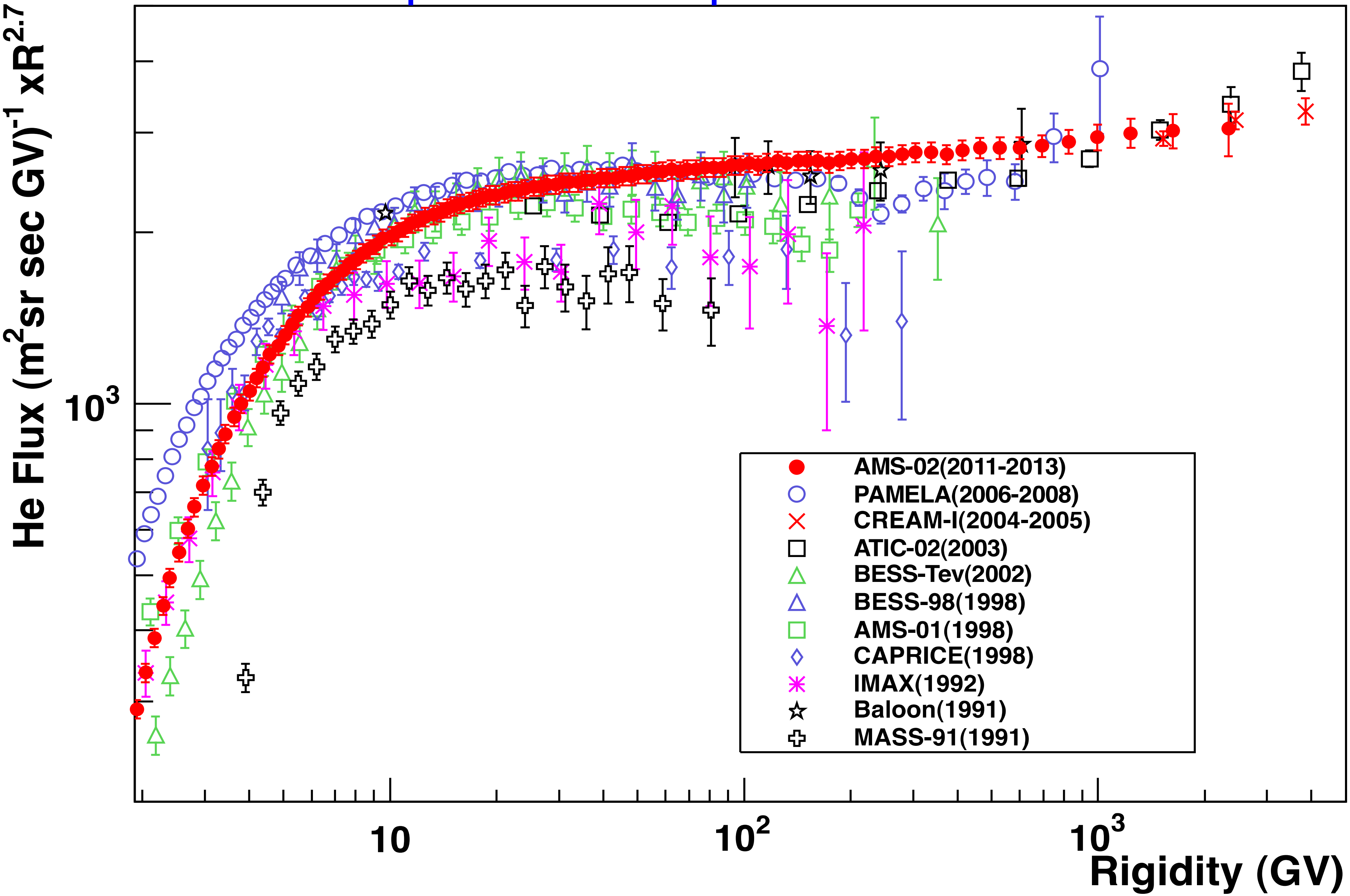


New Results from AMS
3) Helium flux



Helium flux

Comparison with past measurements



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PAMELA Measurements of Cosmic-Ray Proton and Helium Spectra
O. Adriani *et al.*
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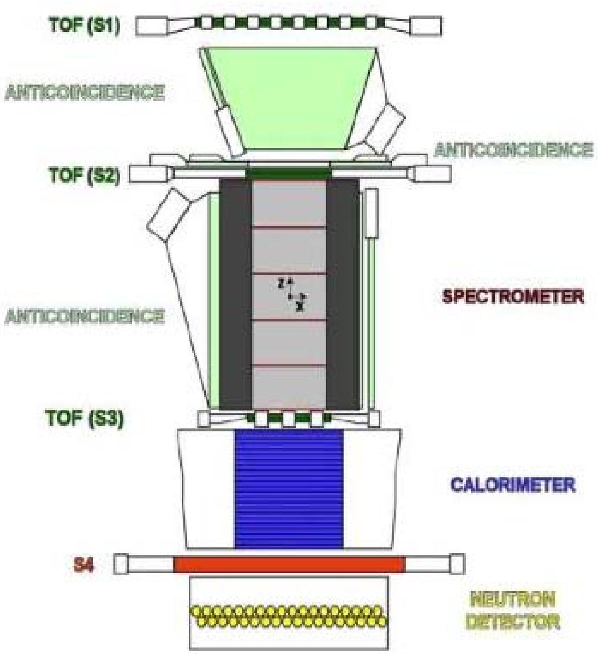
PAMELA Measurements of Cosmic-Ray Proton and Helium Spectra

O. Adriani,[1,2] G. C. Barbarino,[3,4] G. A. Bazilevskaya,[5] R. Bellotti,[6,7] M. Boezio,[8] E. A. Bogomolov,[9] L. Bonechi,[1,2] M. Bongi,[2] V. Bonvicini,[8] S. Borisov,[10,11,12] S. Bottai,[2] A. Bruno,[6,7] F. Cafagna,[7] D. Campana,[4] R. Carbone,[4,11] P. Carlson,[13] M. Casolino,[10] G. Castellini,[14] L. Consiglio,[4] M. P. De Pascale,[10,11] C. De Santis,[10,11] N. De Simone,[10,11] V. Di Felice,[10] A. M. Galper,[12] W. Gillard,[13] L. Grishantseva,[12] G. Jerse,[8,15] A. V. Karelin,[12] S. V. Koldashov,[12] S. Y. Krutkov,[9] A. N. Kvashnin,[5] A. Leonov,[12] V. Malakhov,[12] V. Malvezzi,[10] L. Marcelli,[10] A. G. Mayorov,[12] W. Menn,[16] V. V. Mikhailov,[12] E. Mocchiutti,[8] A. Monaco,[6,7] N. Mori,[1,2] N. Nikonov,[9,10,11] G. Osteria,[4] F. Palma,[10,11] P. Papini,[2] M. Pearce,[13] P. Picozza,[10,11]* C. Pizzolotto,[8] M. Ricci,[17] S. B. Ricciarini,[2] L. Rossetto,[13] R. Sarkar,[8] M. Simon,[16] R. Sparvoli,[10,11] P. Spillantini,[1,2] Y. I. Stozhkov,[5] A. Vacchi,[8] E. Vannuccini,[2] G. Vasilyev,[9] S. A. Voronov,[12] Y. T. Yurkin,[12] J. Wu,[13]† G. Zampa,[8] N. Zampa,[8] V. G. Zverev[12]



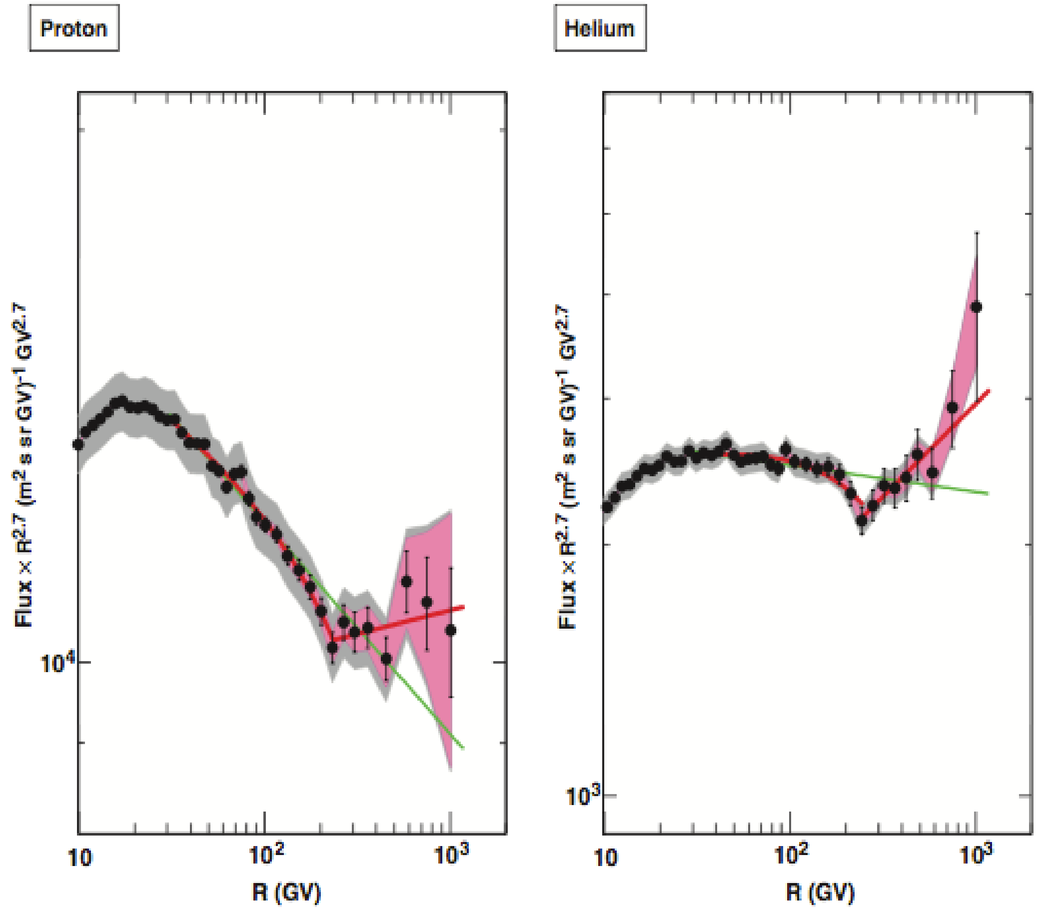
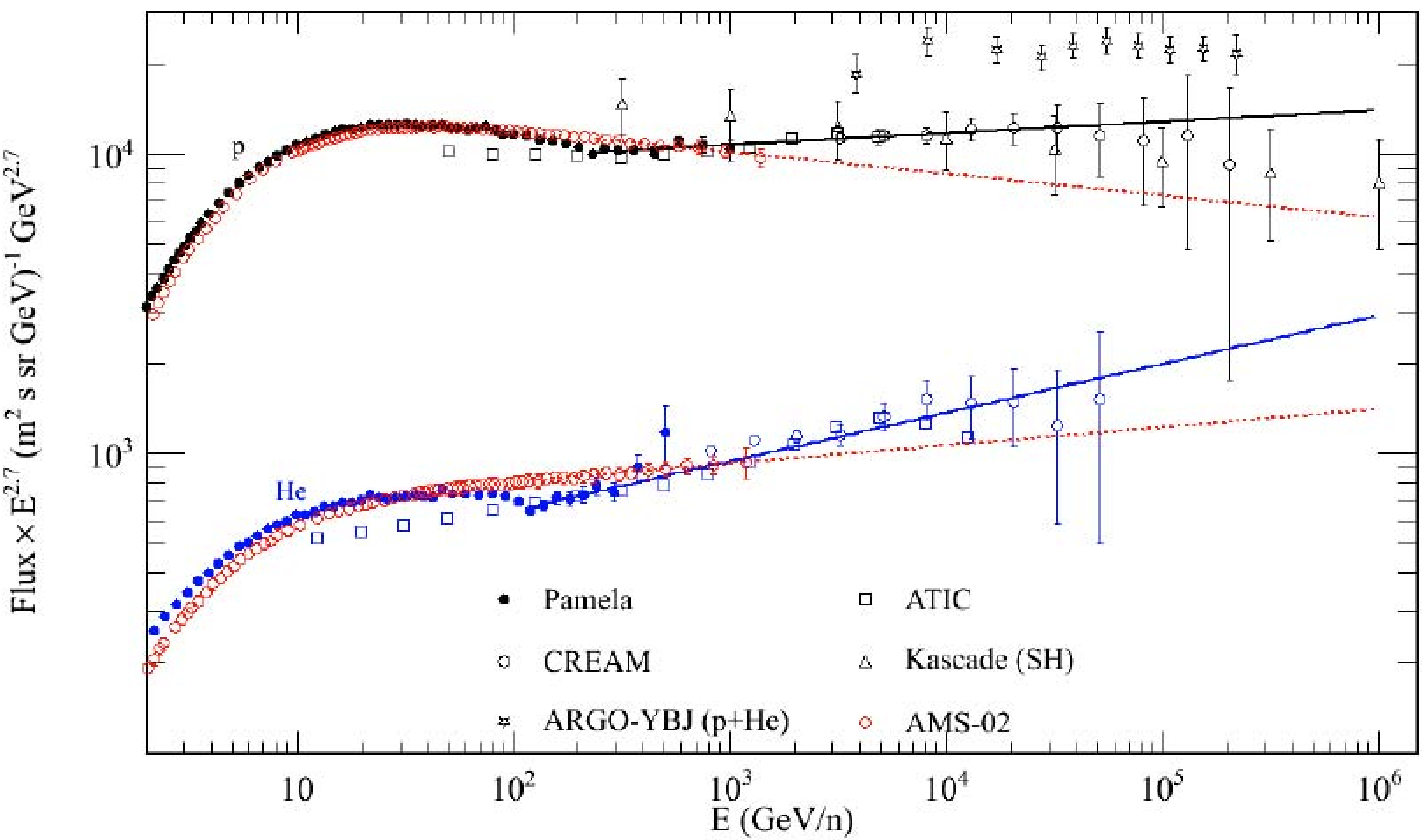
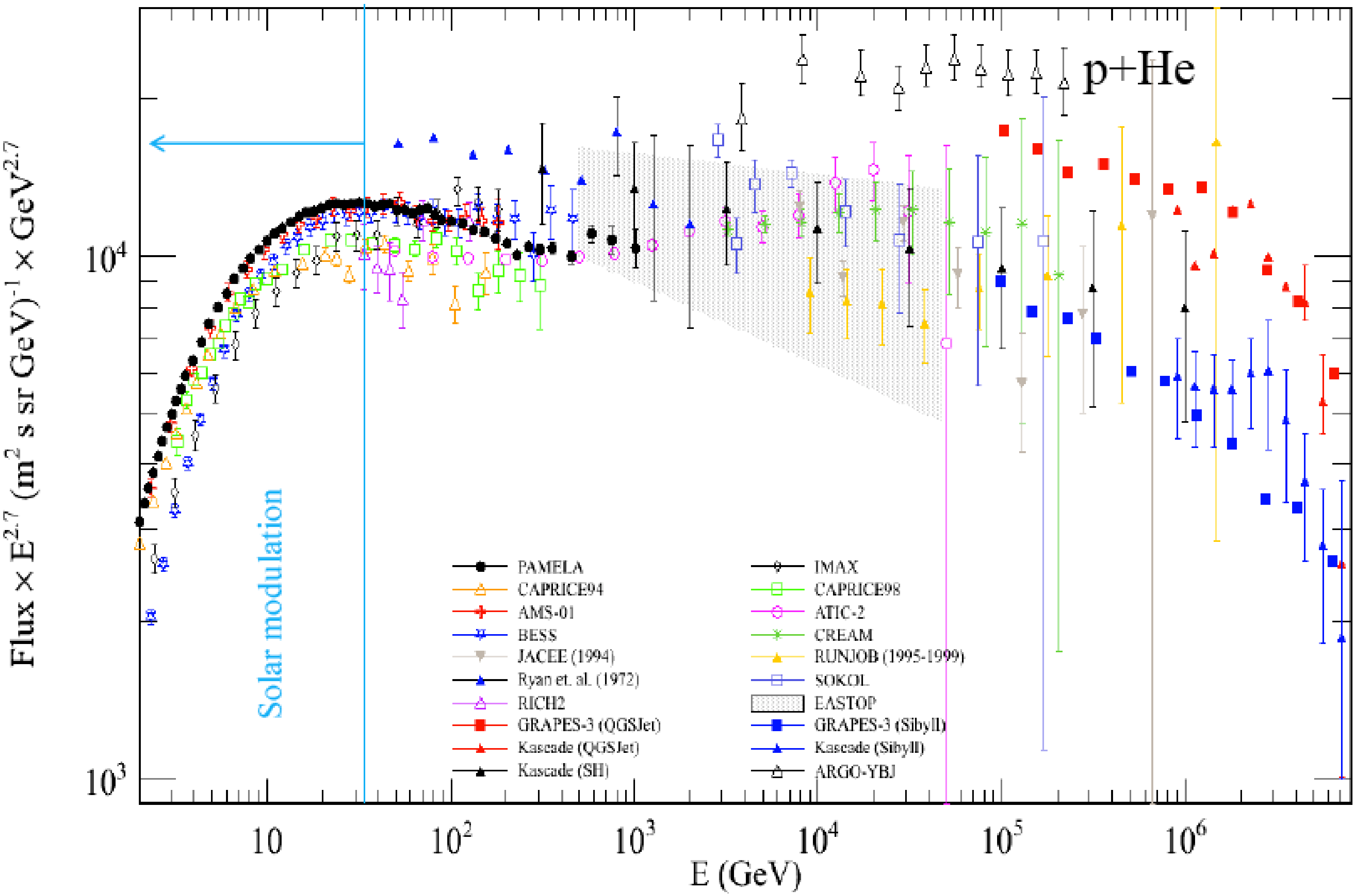


Fig. 4. Proton (**left**) and helium (**right**) spectra in the range 10 GV to 1.2 TV. The gray shaded area represents the estimated systematic uncertainty, and the pink shaded area represents the contribution due to tracker alignment. The green lines represent fits with a single power law in the rigidity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

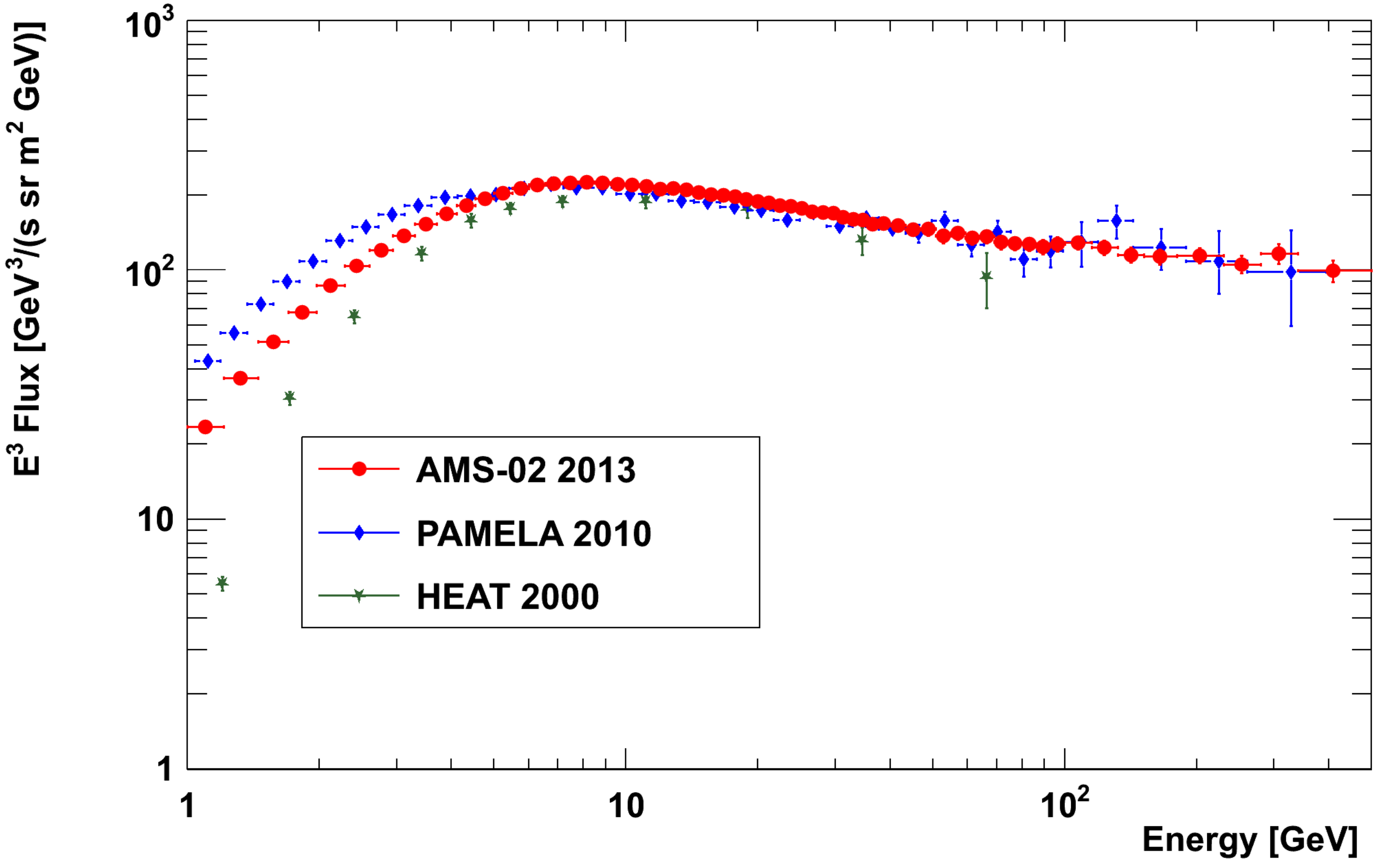
Proton and Helium Nuclei Spectra



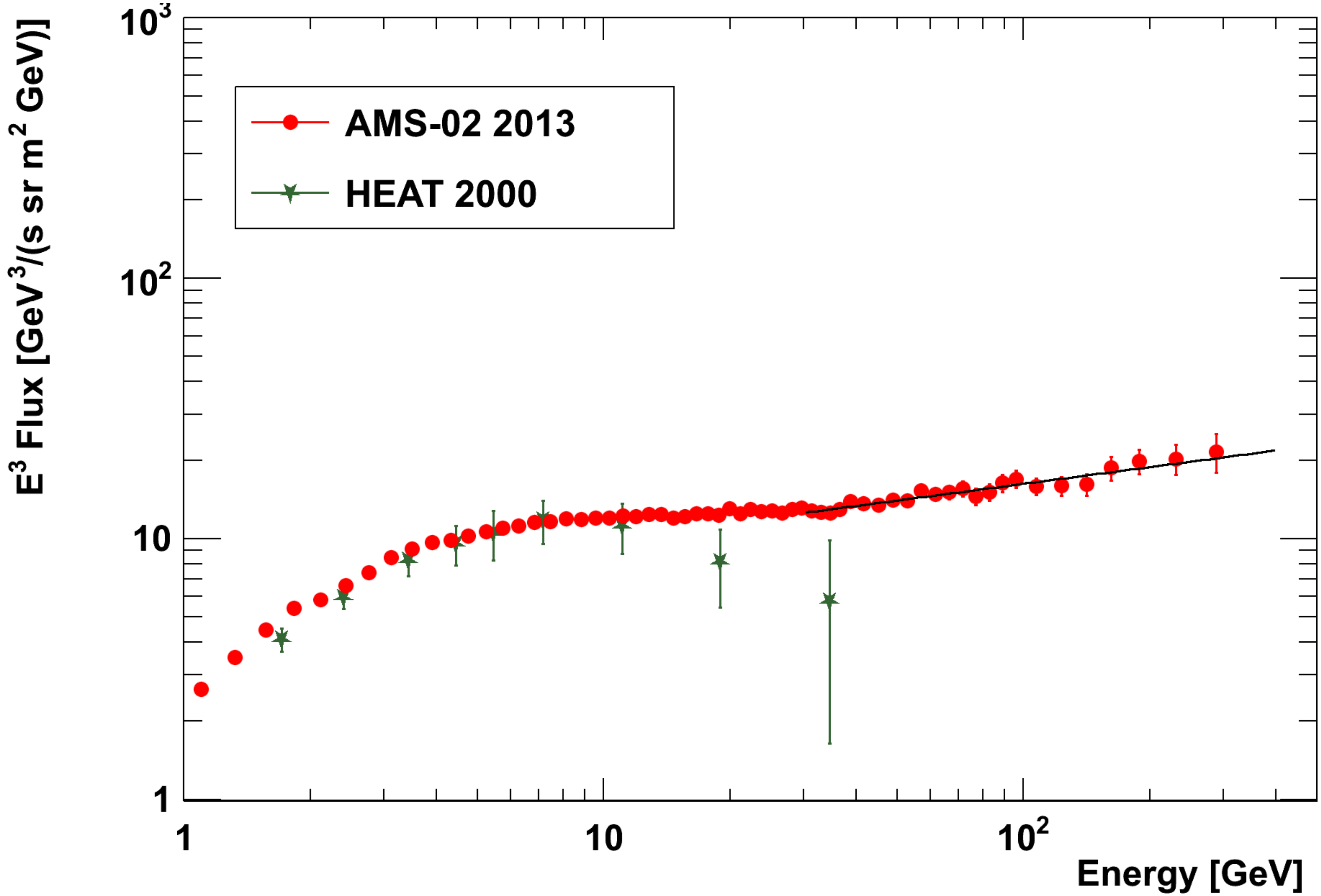
Proton (Hydrogen) Spectrum



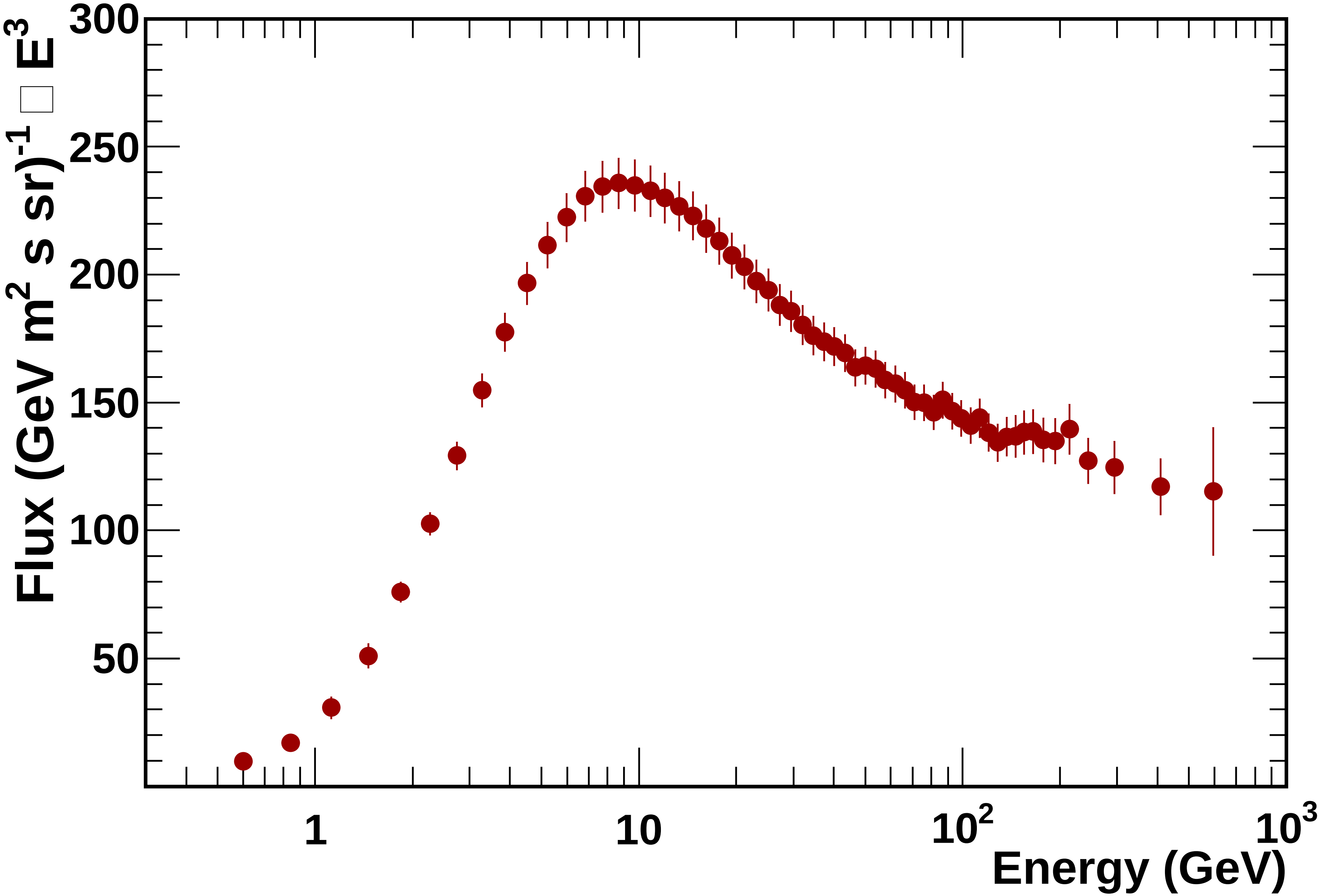
New results from AMS
4) Electron Spectrum



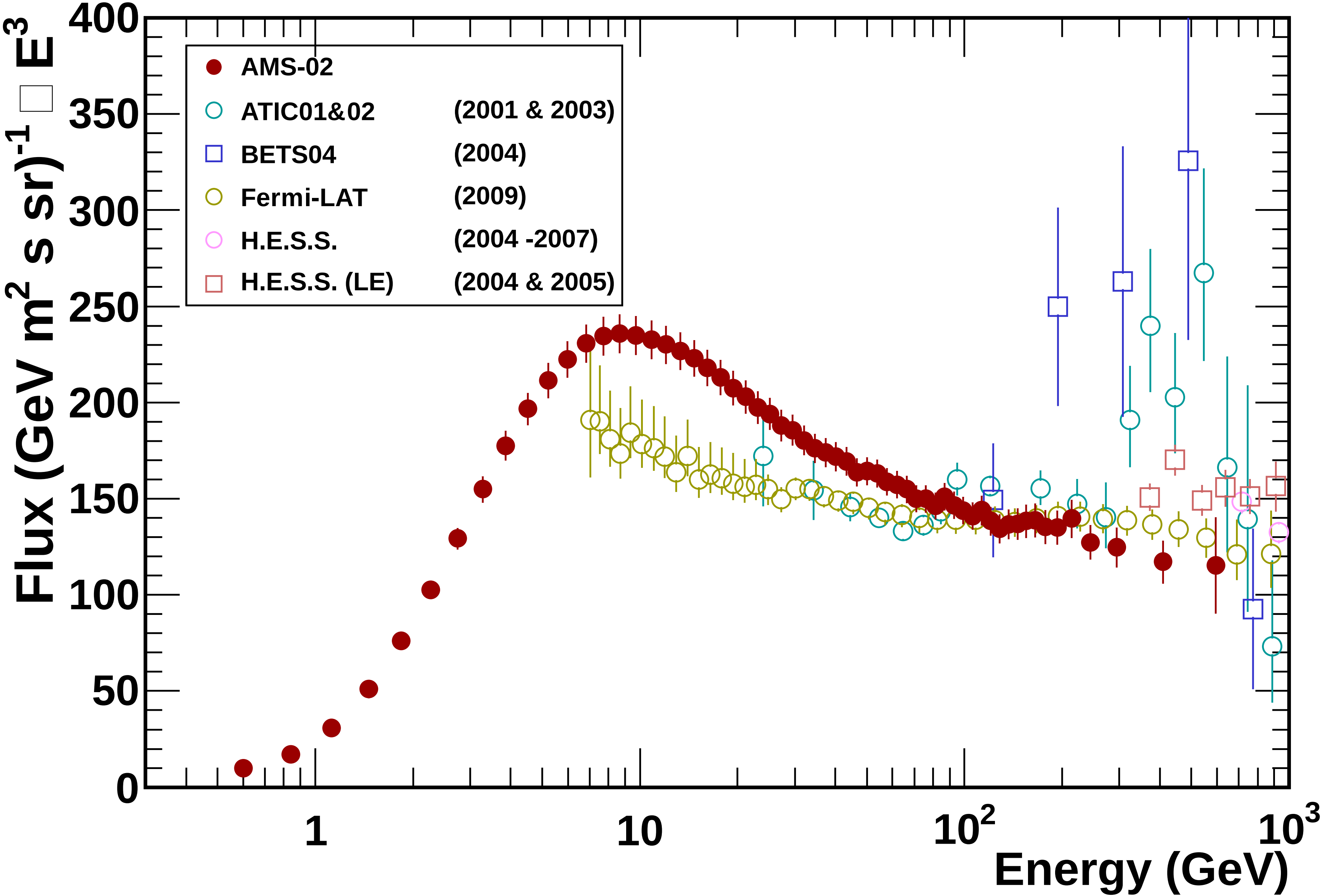
New results from AMS
5) Positron Spectrum



New results from AMS
6) (Electron plus Positron) Spectrum



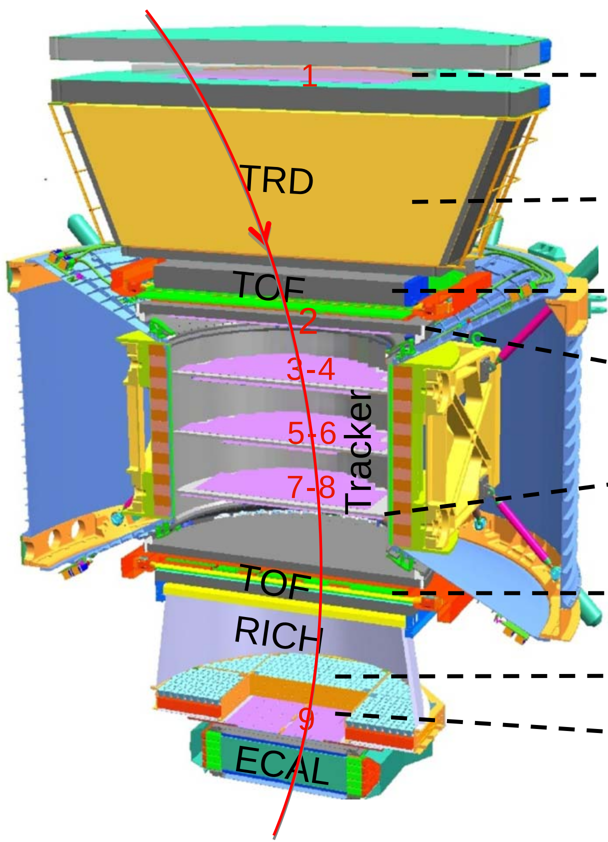
(Electron plus Positron) Spectrum
comparison with recent measurements



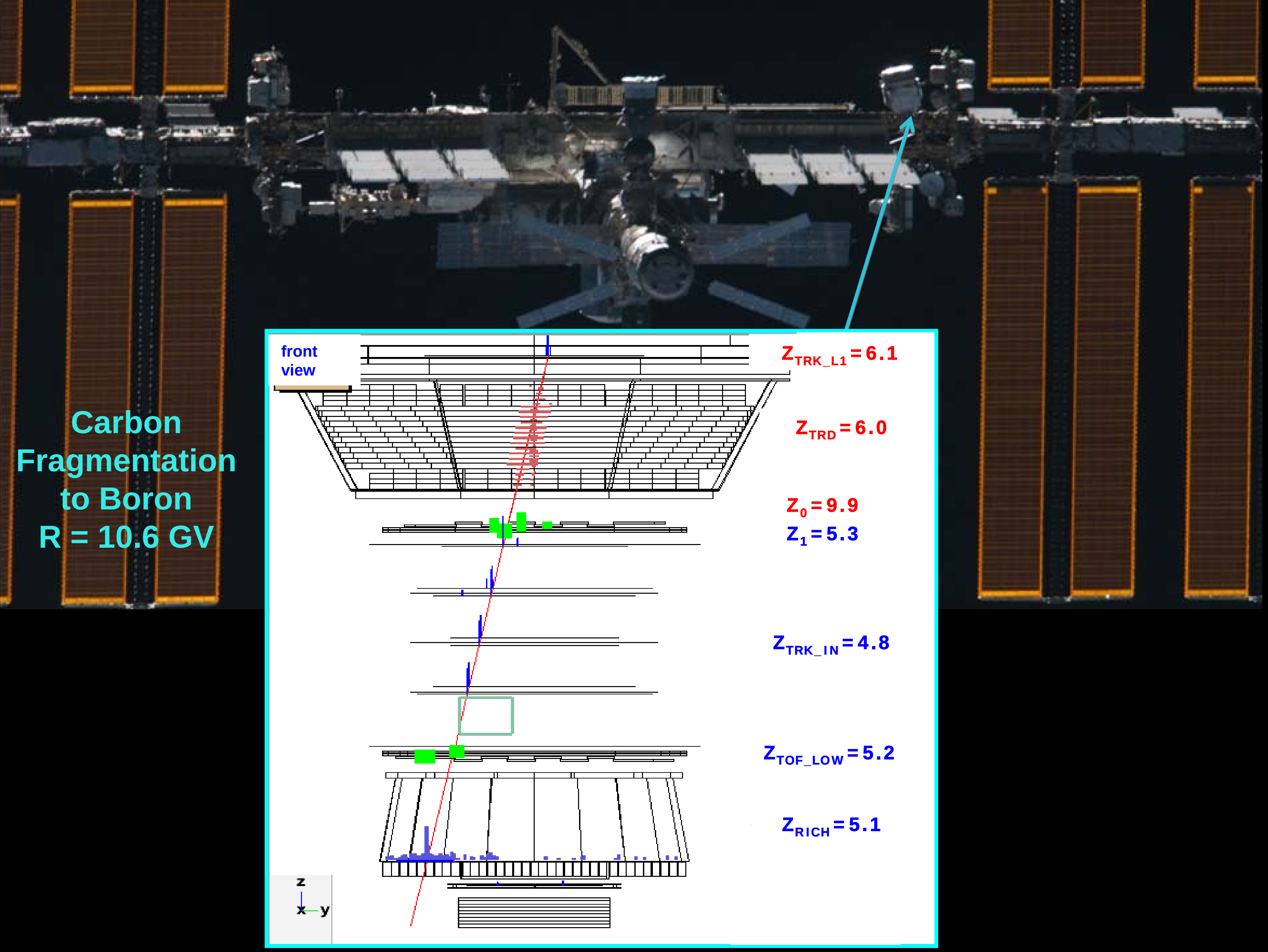
New results from AMS
7) Boron-to-Carbon ratio

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

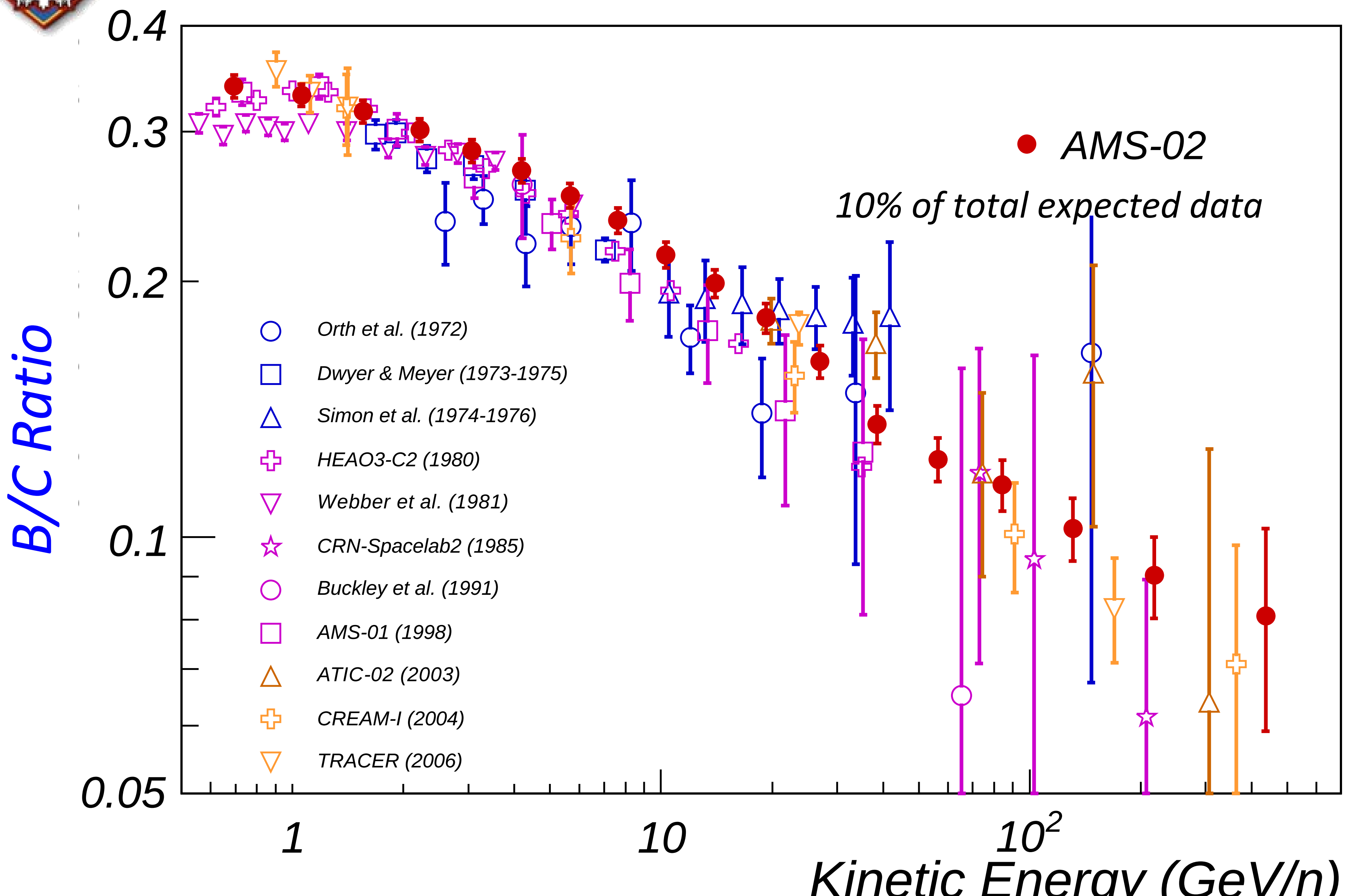
AMS: Multiple Independent Measurements of the Charge (|Z|)



	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


Carbon Fragmentation to Boron
R = 10.6 GV
front view
$Z_{TRK\_L1} = 6.1$
$Z_{TRD} = 6.0$
$Z_0 = 9.9$
$Z_1 = 5.3$
$Z_{TRK\_IN} = 4.8$
$Z_{TOF\_LOW} = 5.2$
$Z_{RICH} = 5.1$
z
x
y

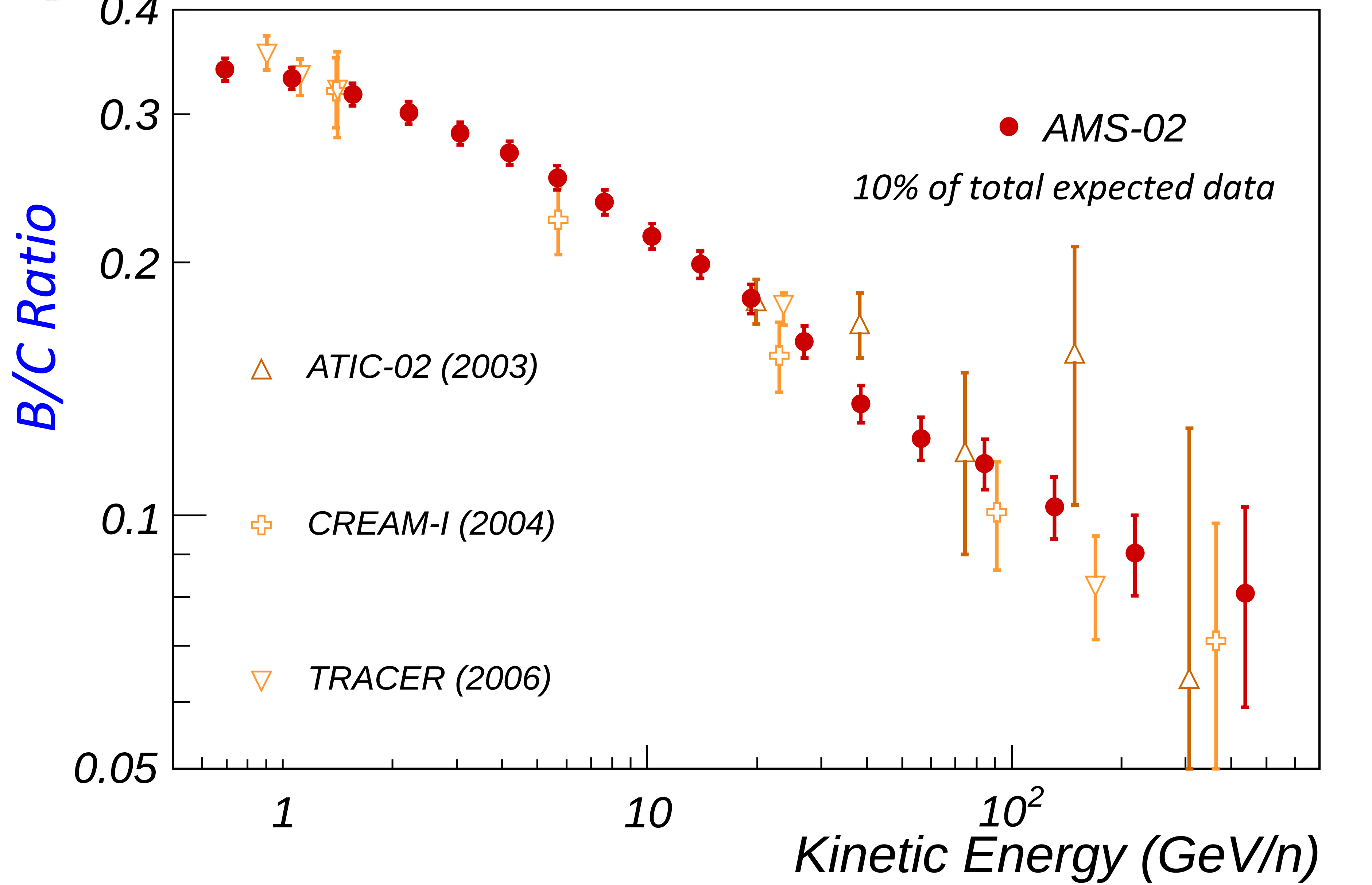
Boron-to-Carbon ratio



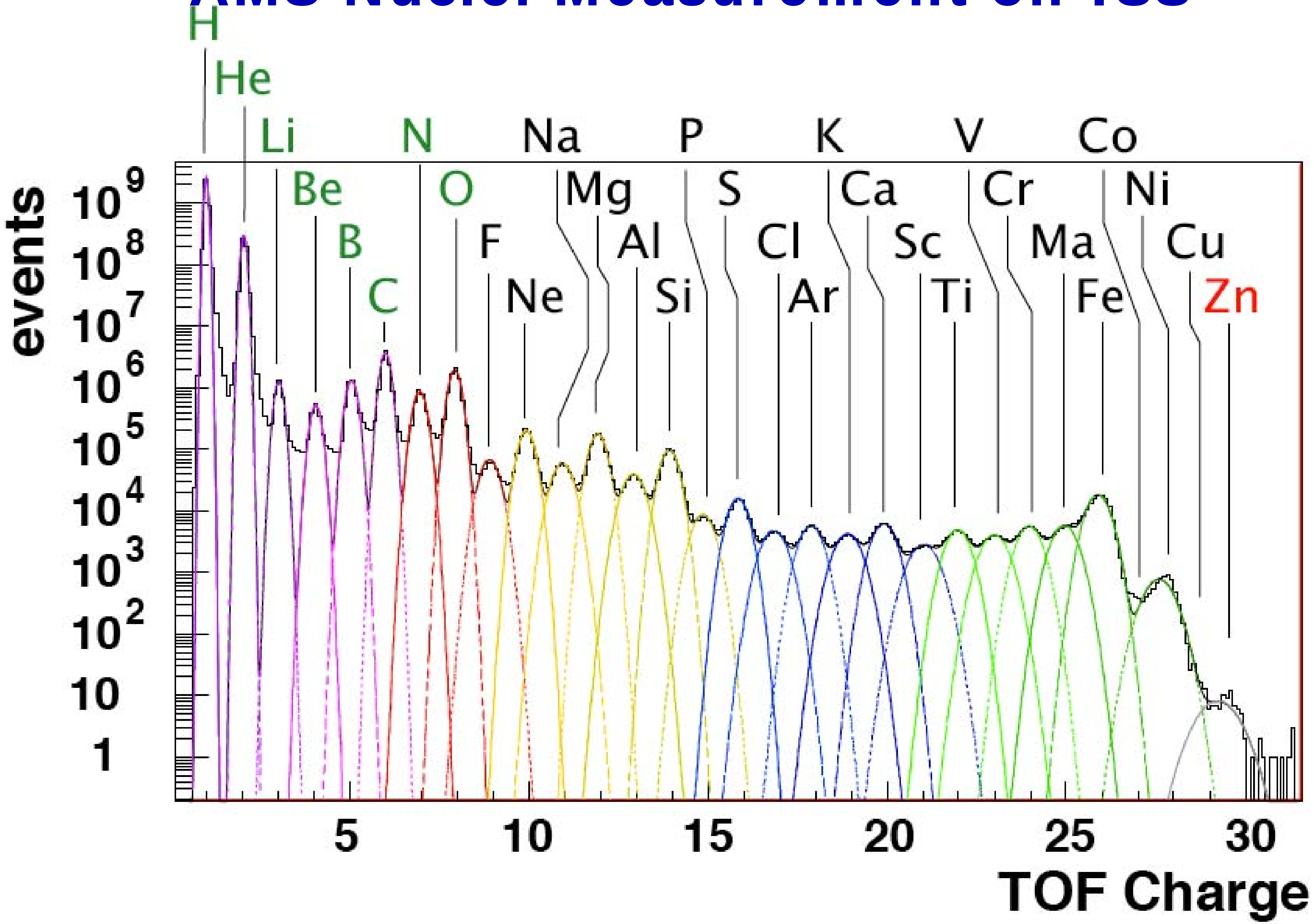
To be presented by in A. Oliva this afternoon

Boron-to-Carbon ratio

comparison with recent data



AMS Nuclei Measurement on ISS



We now understand
the systematic errors to ~1%.

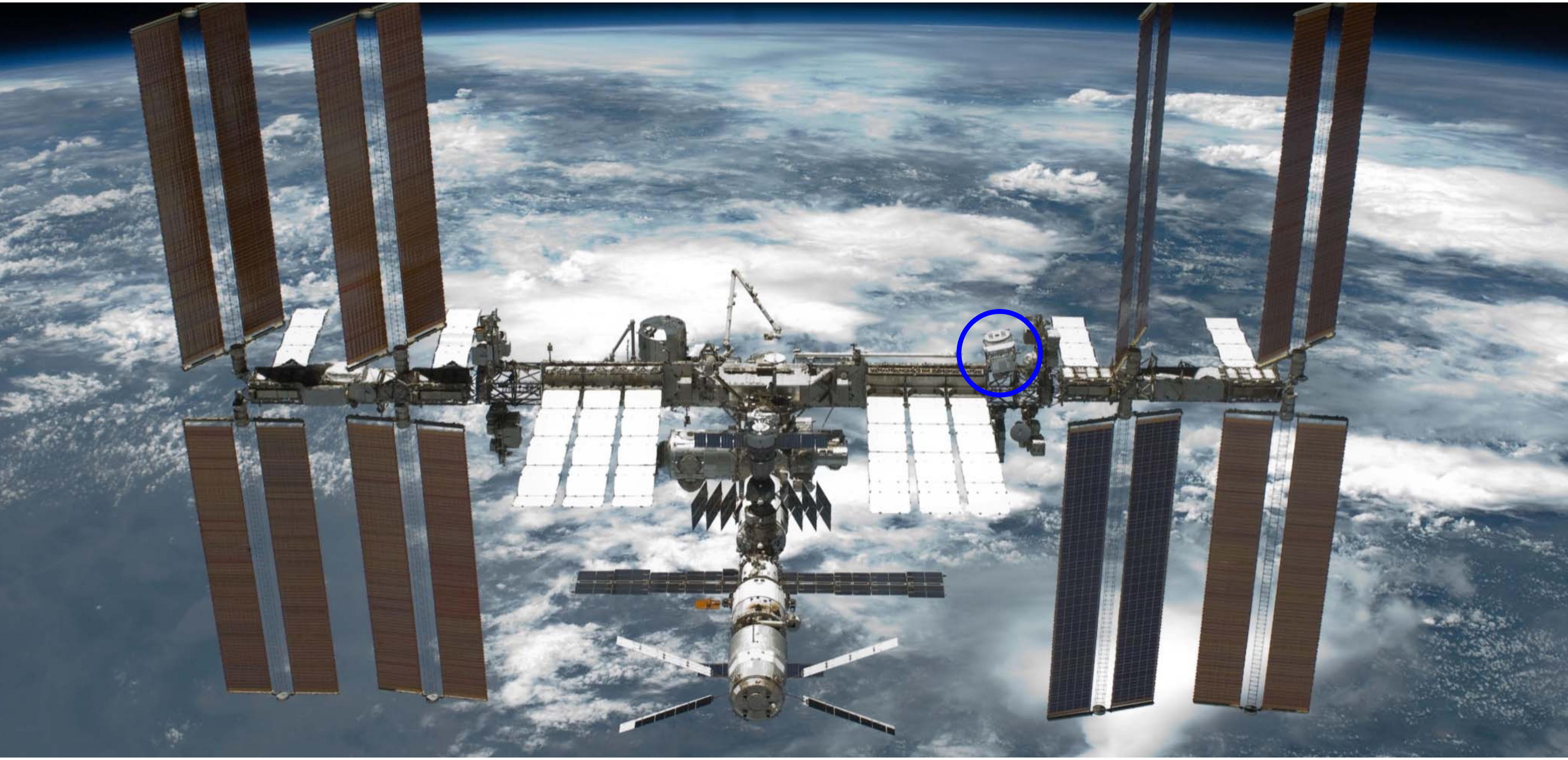
Studies with 1% statistical error
will take time to collect the data.

Physics analysis nearing completion

1. Antiprotons (0.5-300 GeV)
2. Anti-He (@ few 10^8 events)
3. Solar physics
4. Ion fluxes
5. ….

The Cosmos is the Ultimate Laboratory.

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



With AMS-02 on the ISS we have entered the era of precision Cosmic Ray physics to search for phenomena which exist in nature but we have not yet imagined nor had the tools to discover.

Anisotropy Discovery Potential

In 10 years, the projected sensitivity of AMS to a dipole anisotropy is 2σ for δ=0.010 and 3σ for δ=0.014