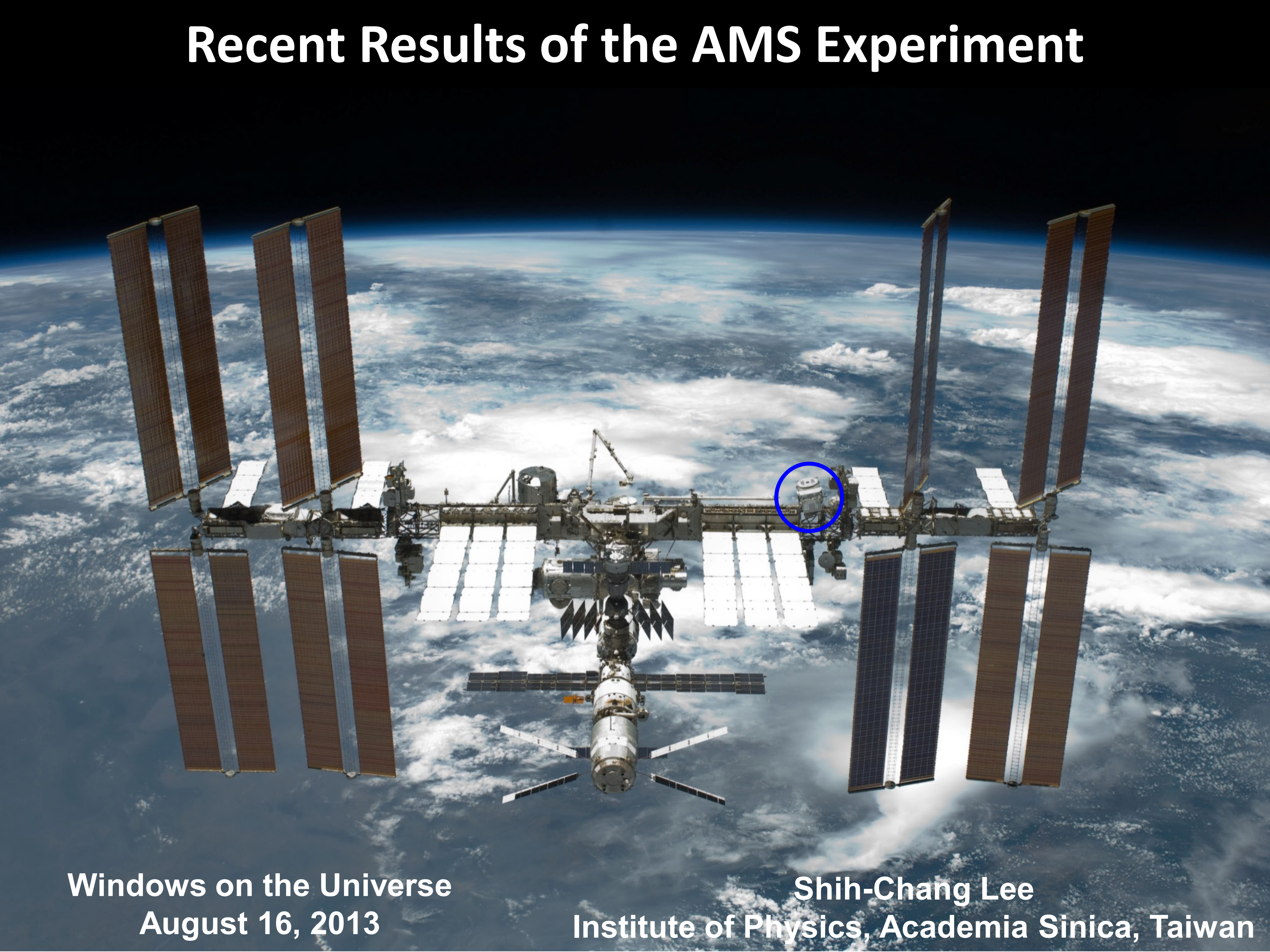
Recent Results of the AMS Experiment

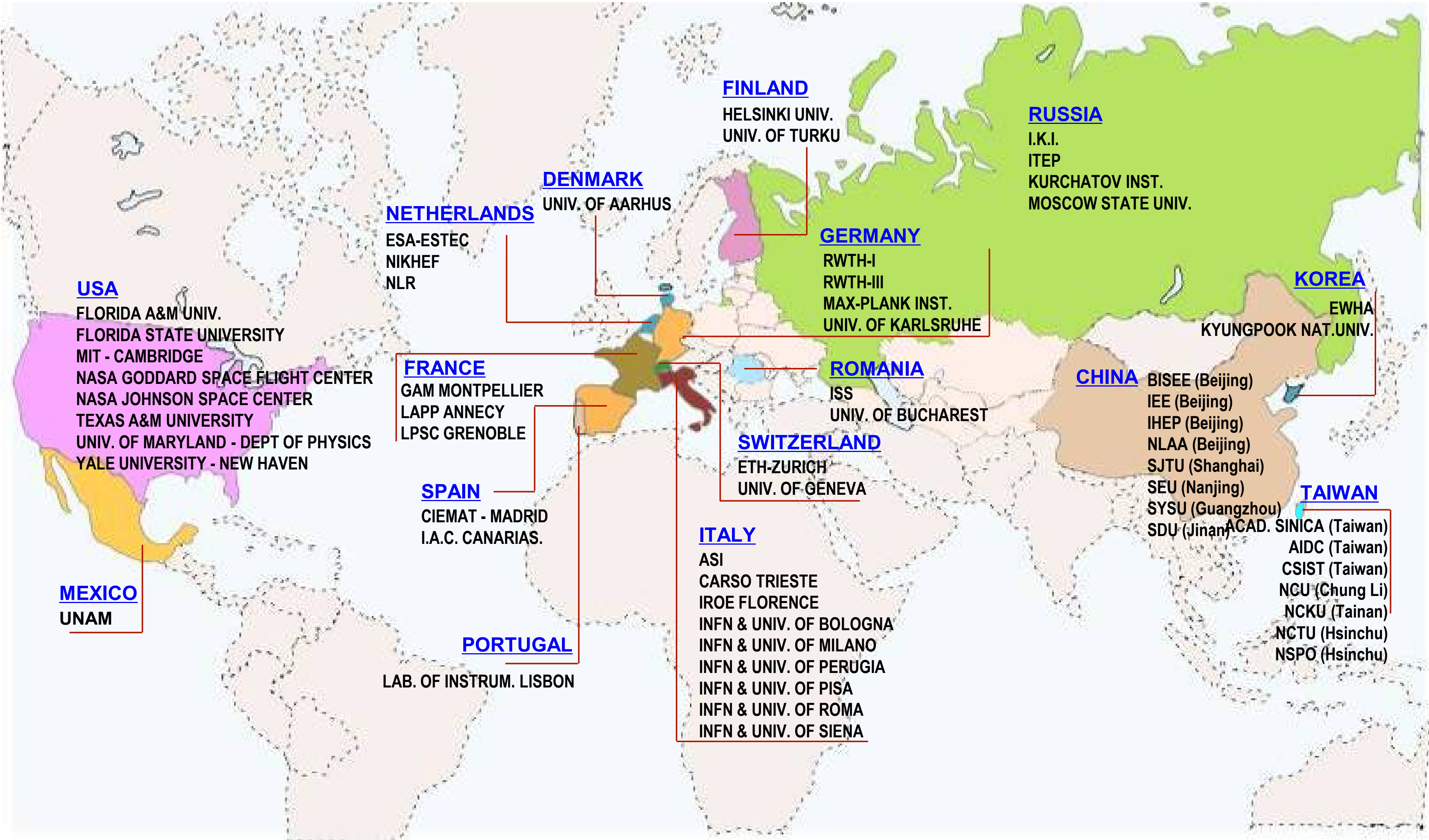


Windows on the Universe
August 16, 2013

Shih-Chang Lee
Institute of Physics, Academia Sinica, Taiwan

AMS is an International Collaboration

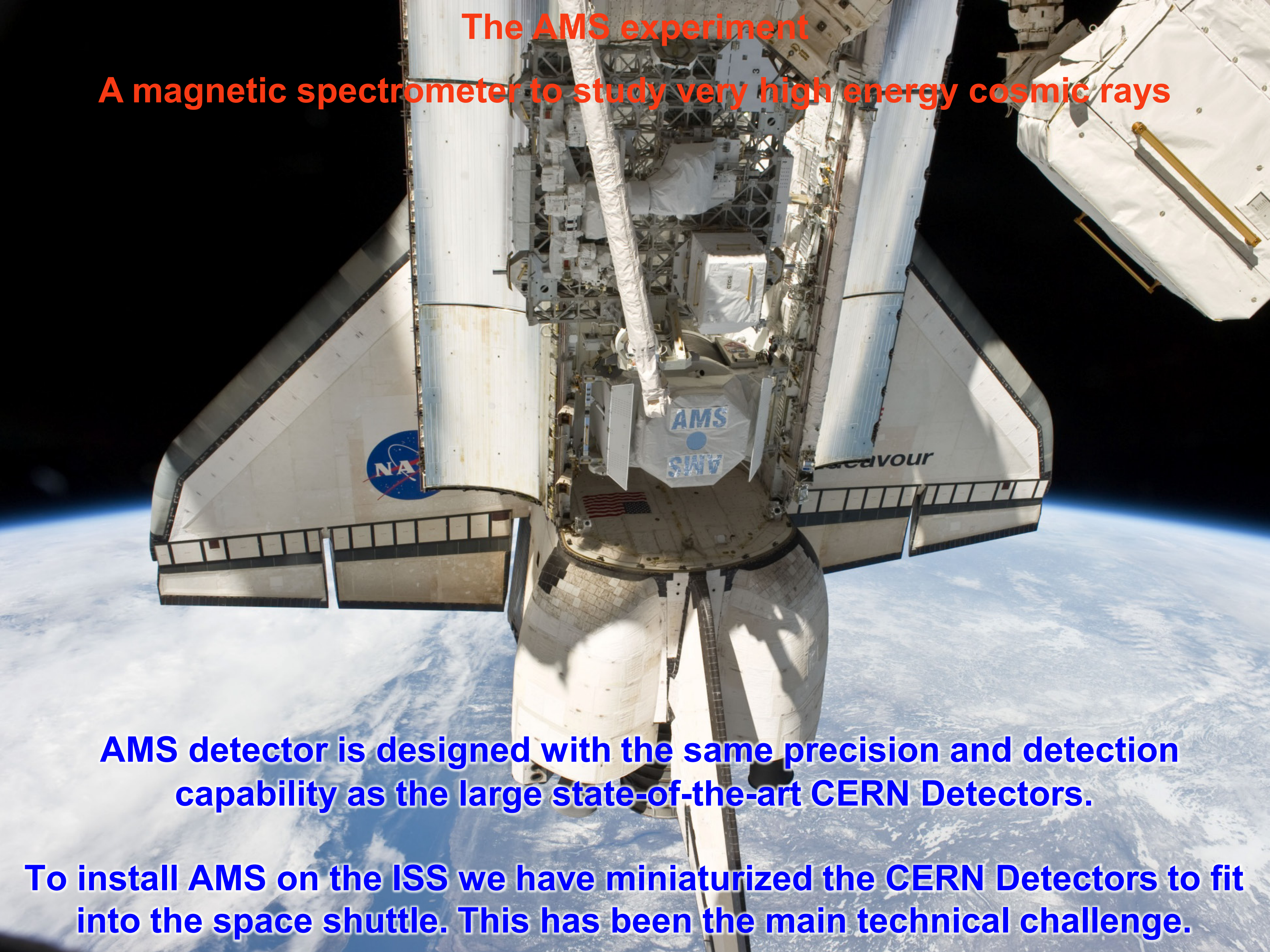
16 Countries, 60 Institutes and 600 Physicists, 17 years



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

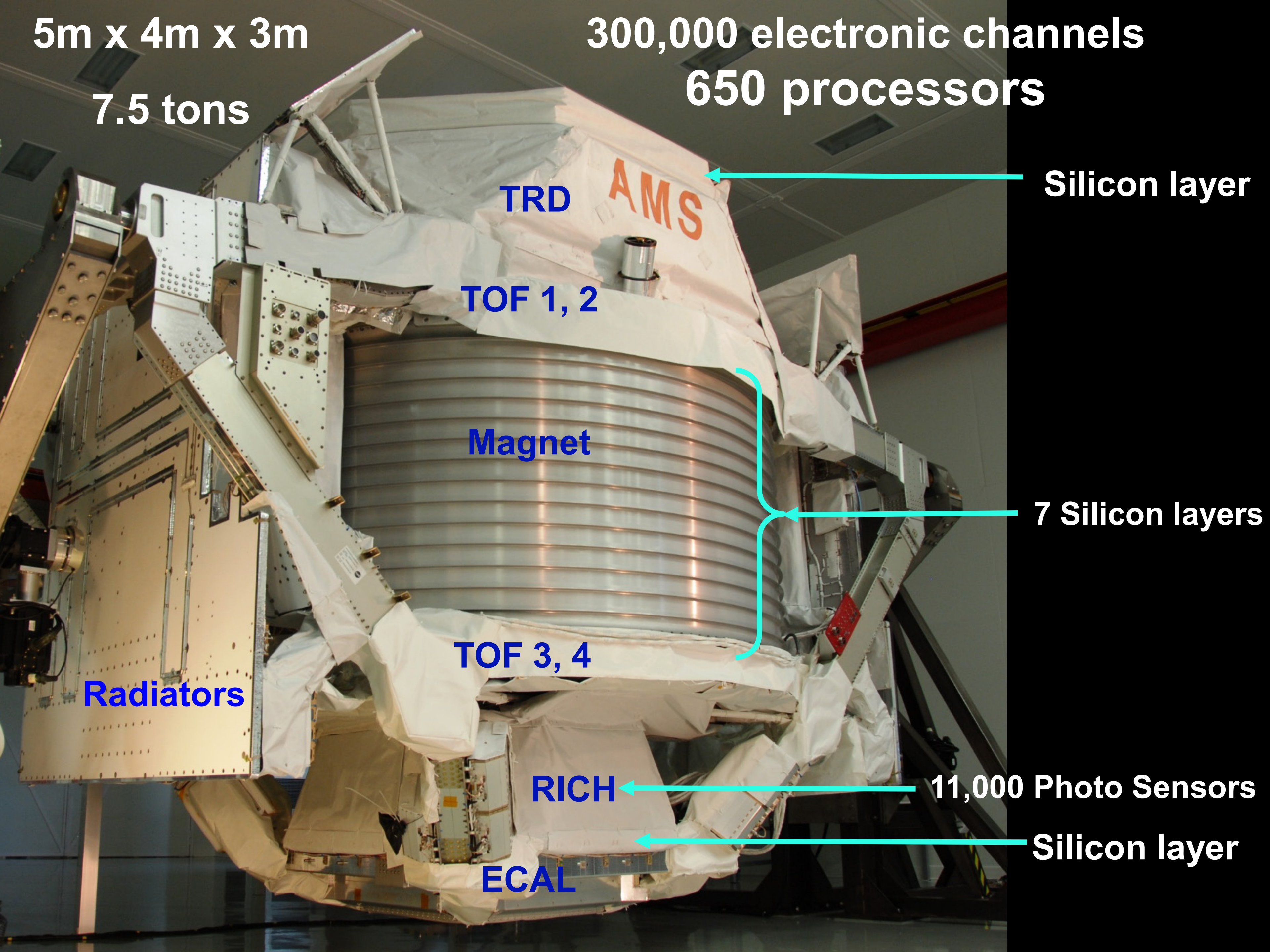
The AMS experiment

A magnetic spectrometer to study very high energy cosmic rays



AMS detector is designed with the same precision and detection capability as the large state-of-the-art CERN Detectors.

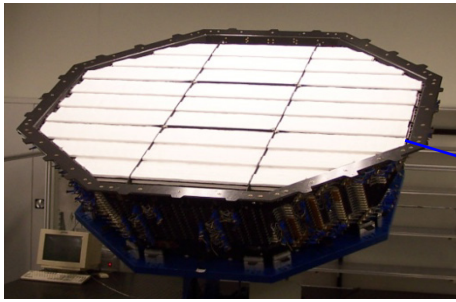
To install AMS on the ISS we have miniaturized the CERN Detectors to fit into the space shuttle. This has been the main technical challenge.


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

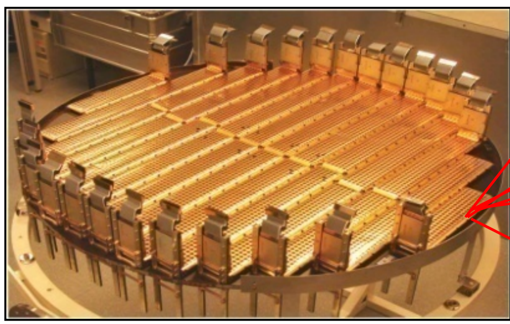
AMS: A TeV precision, multipurpose particle physics spectrometer in space.

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

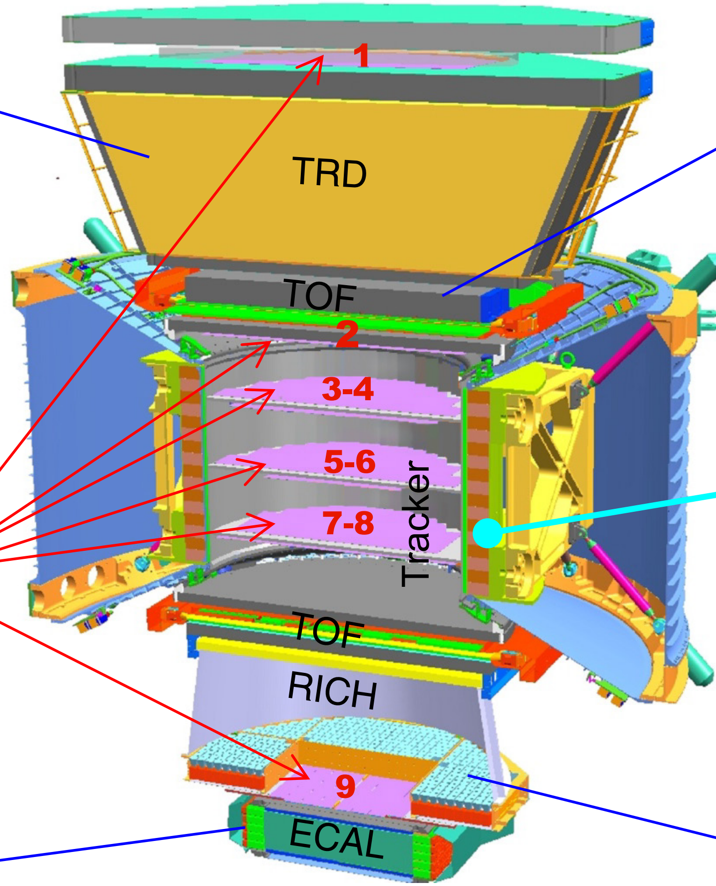
TRD
Identify e+, e-



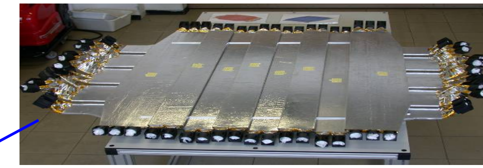
Silicon Tracker
Z, P



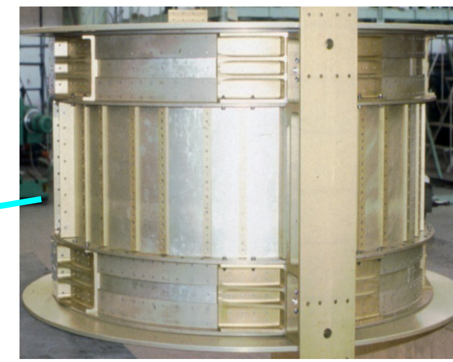
ECAL
E of e+, e-, γ



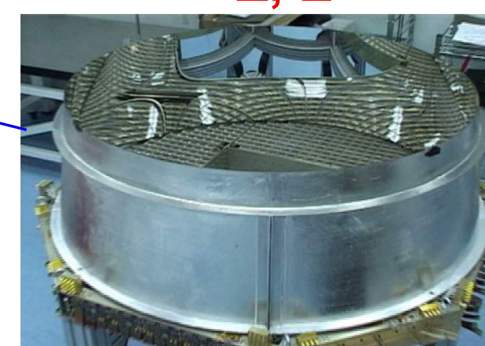
TOF
Z, E



Magnet
±Z



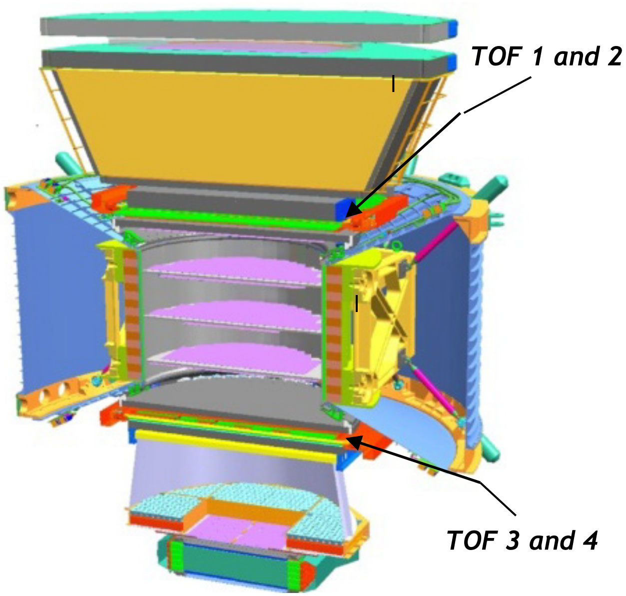
RICH
Z, E

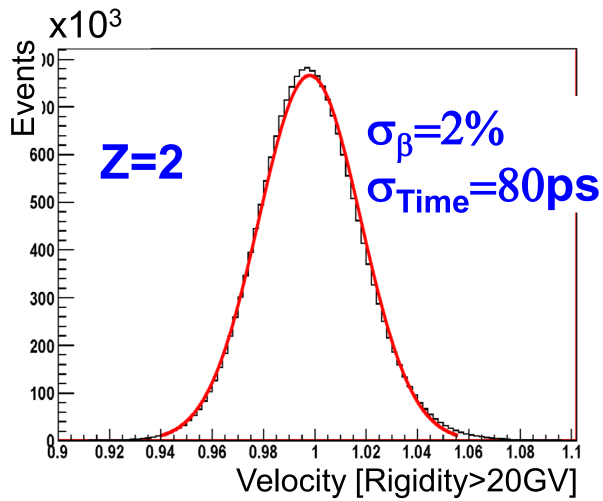


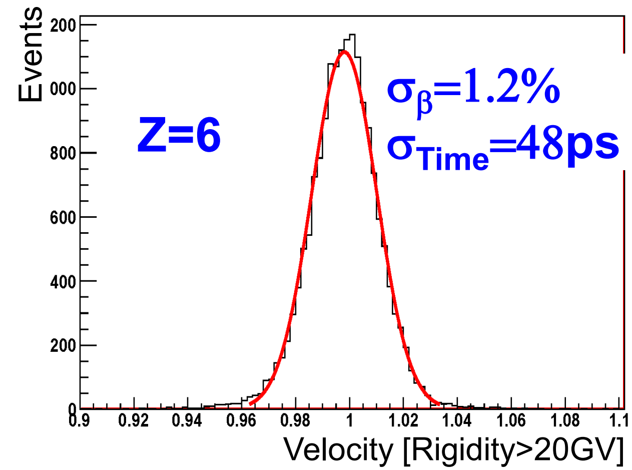
Z, P are measured independently by the Tracker, RICH, TOF and ECAL

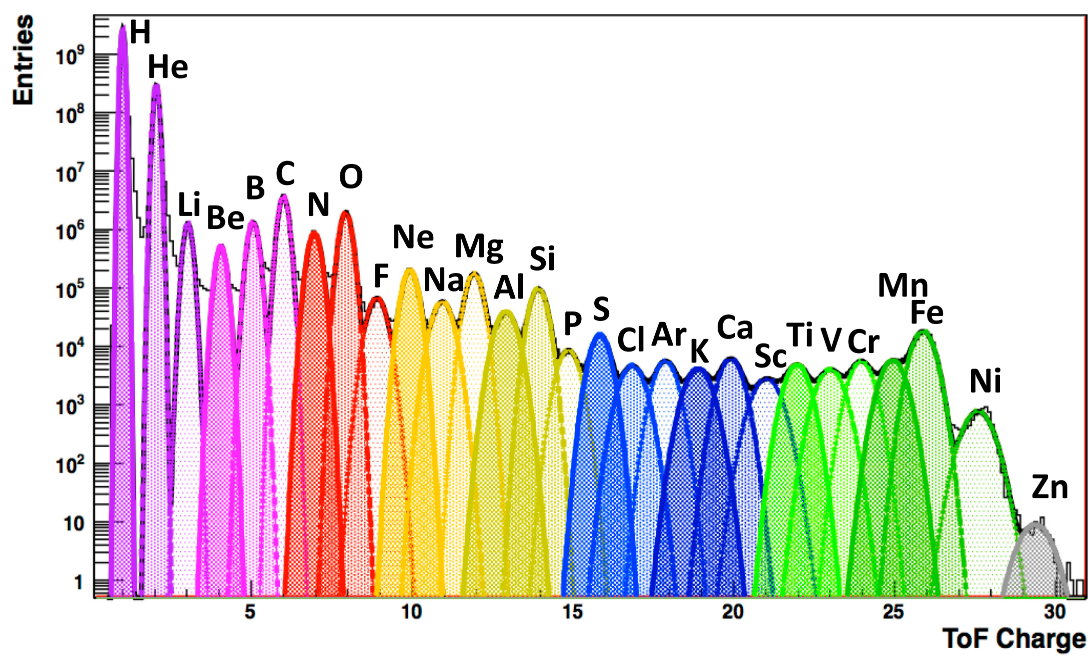
Data from ISS Time of Flight System

Measures Velocity and Charge of particles





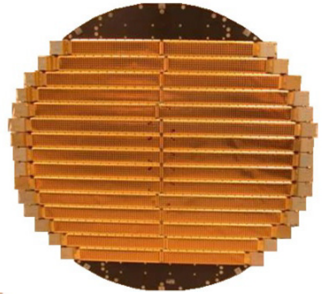


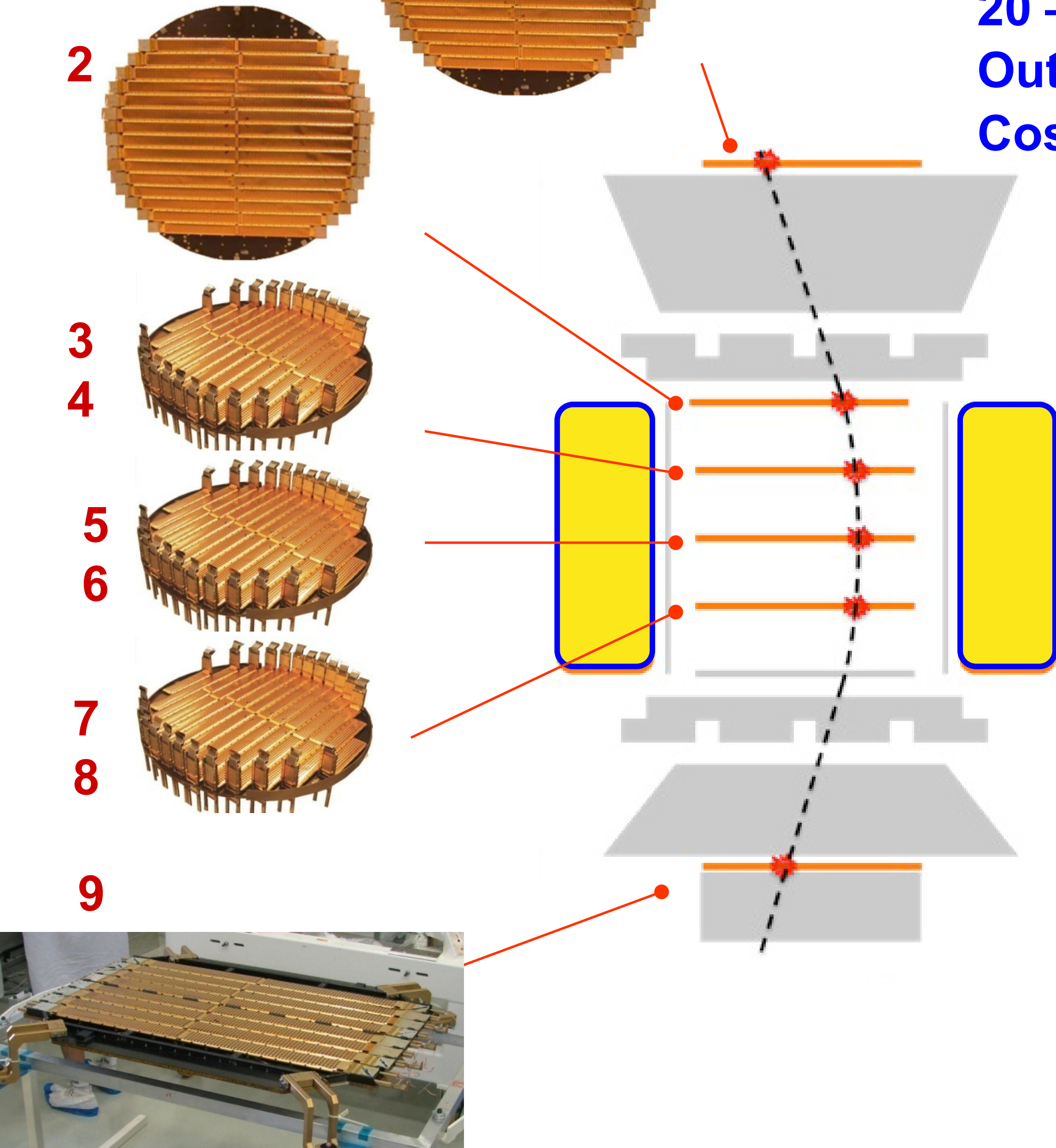


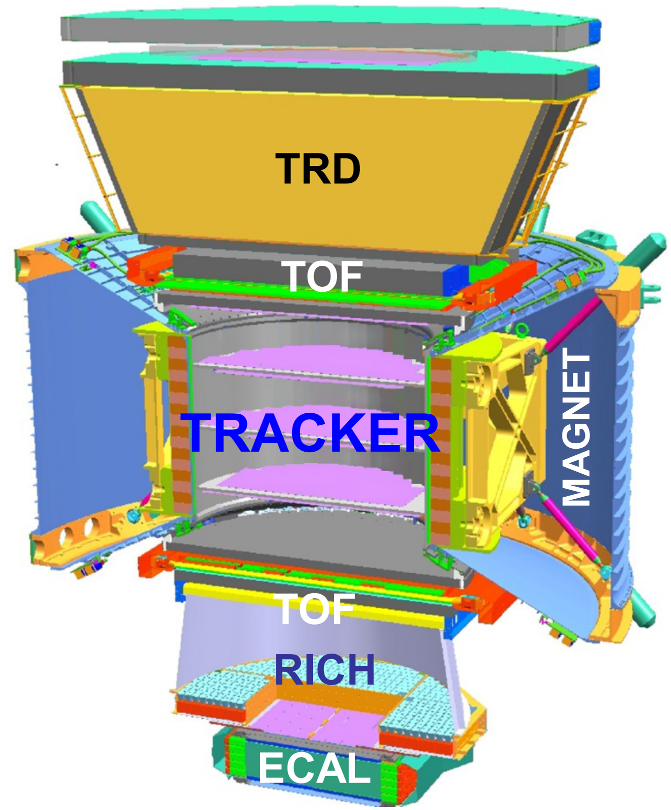
Tracker: The coordinate resolution is 10 μ

Inner Tracker Alignment via 20 –UV Lasers

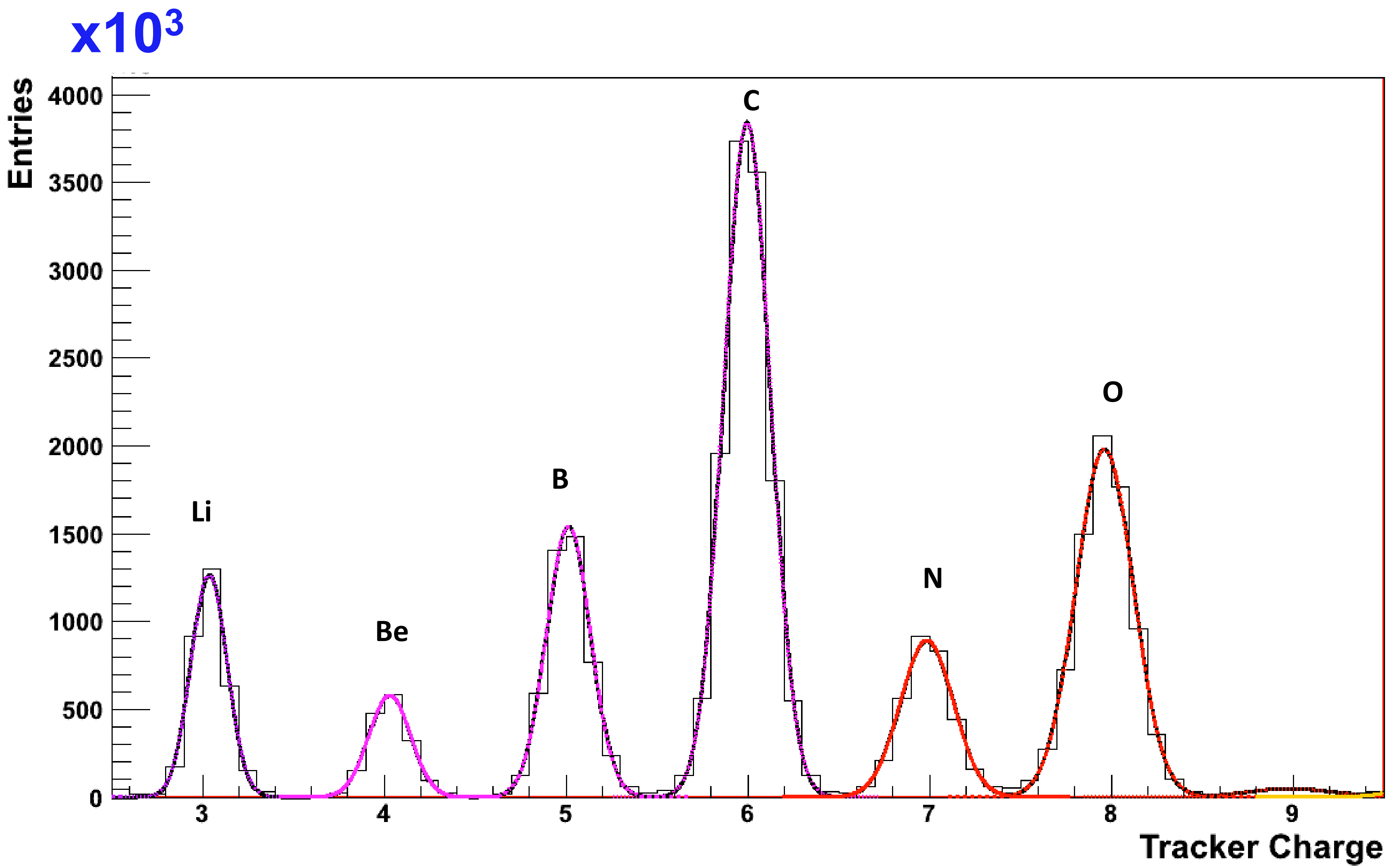
Outer Tracker Alignment via Cosmic rays



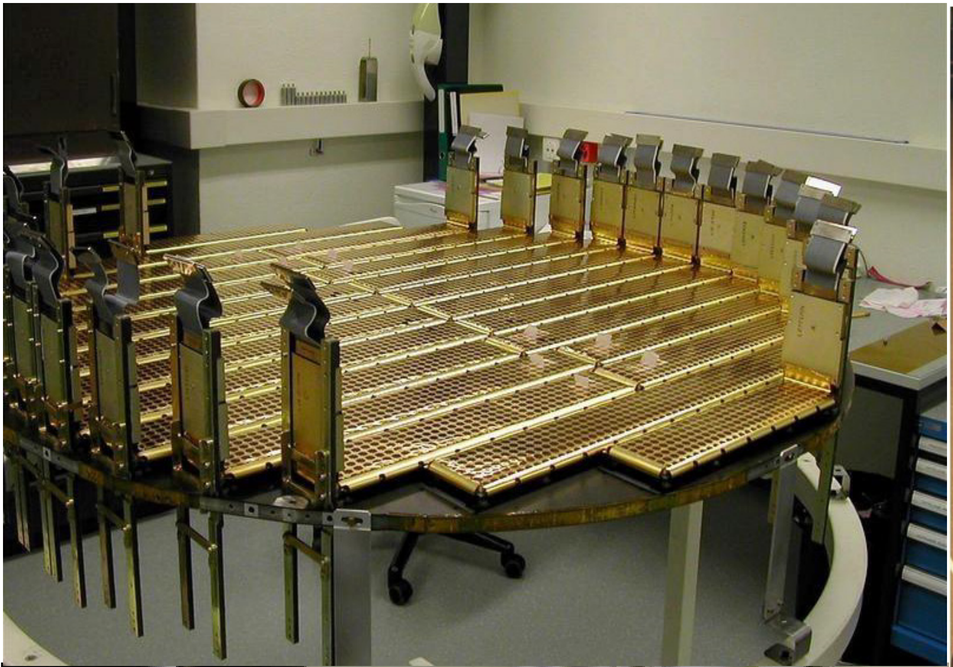


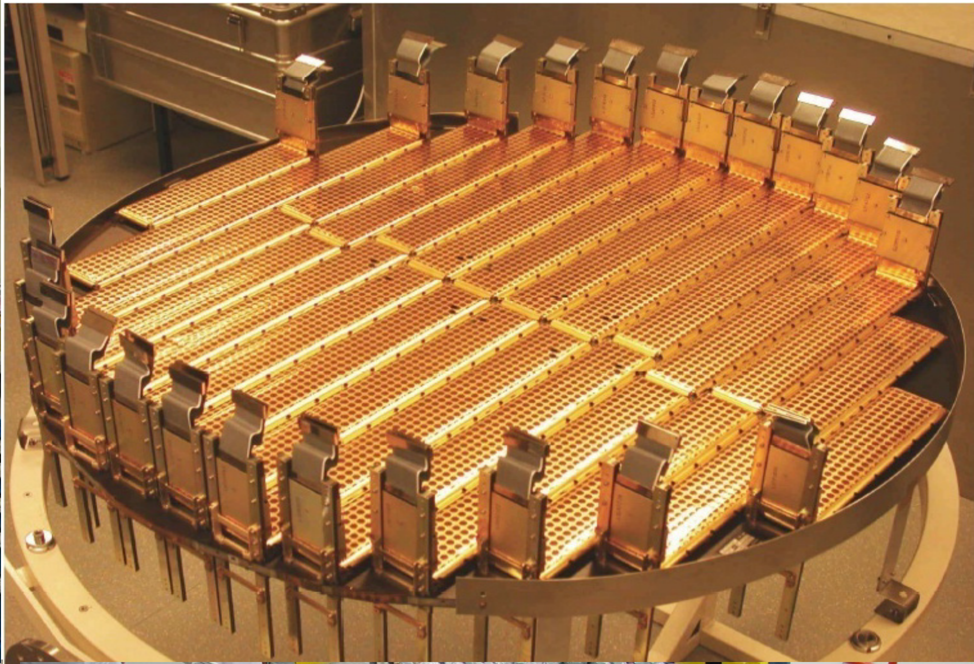


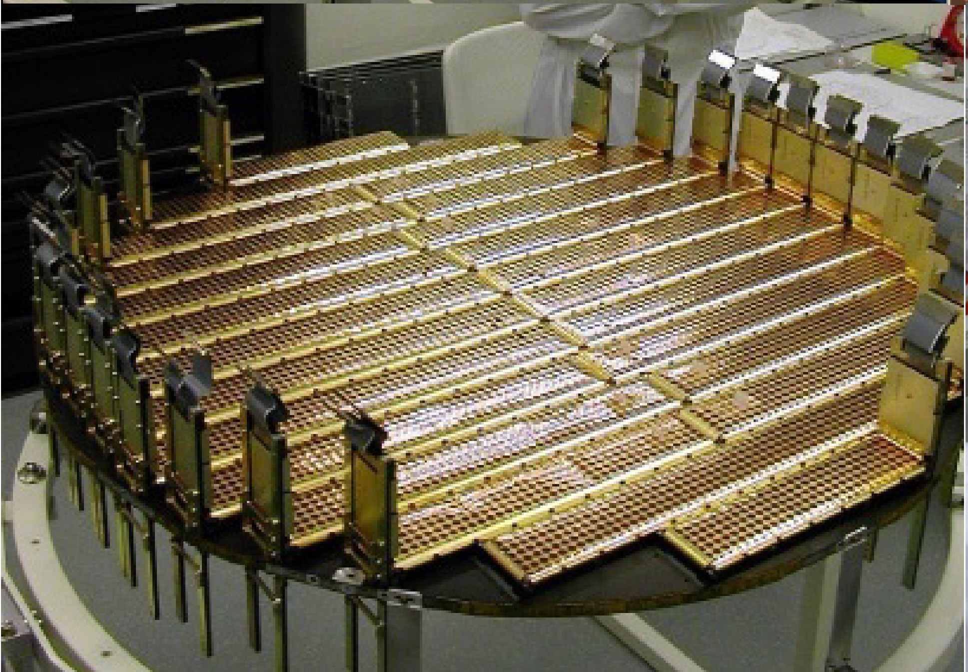
Tracker Charge



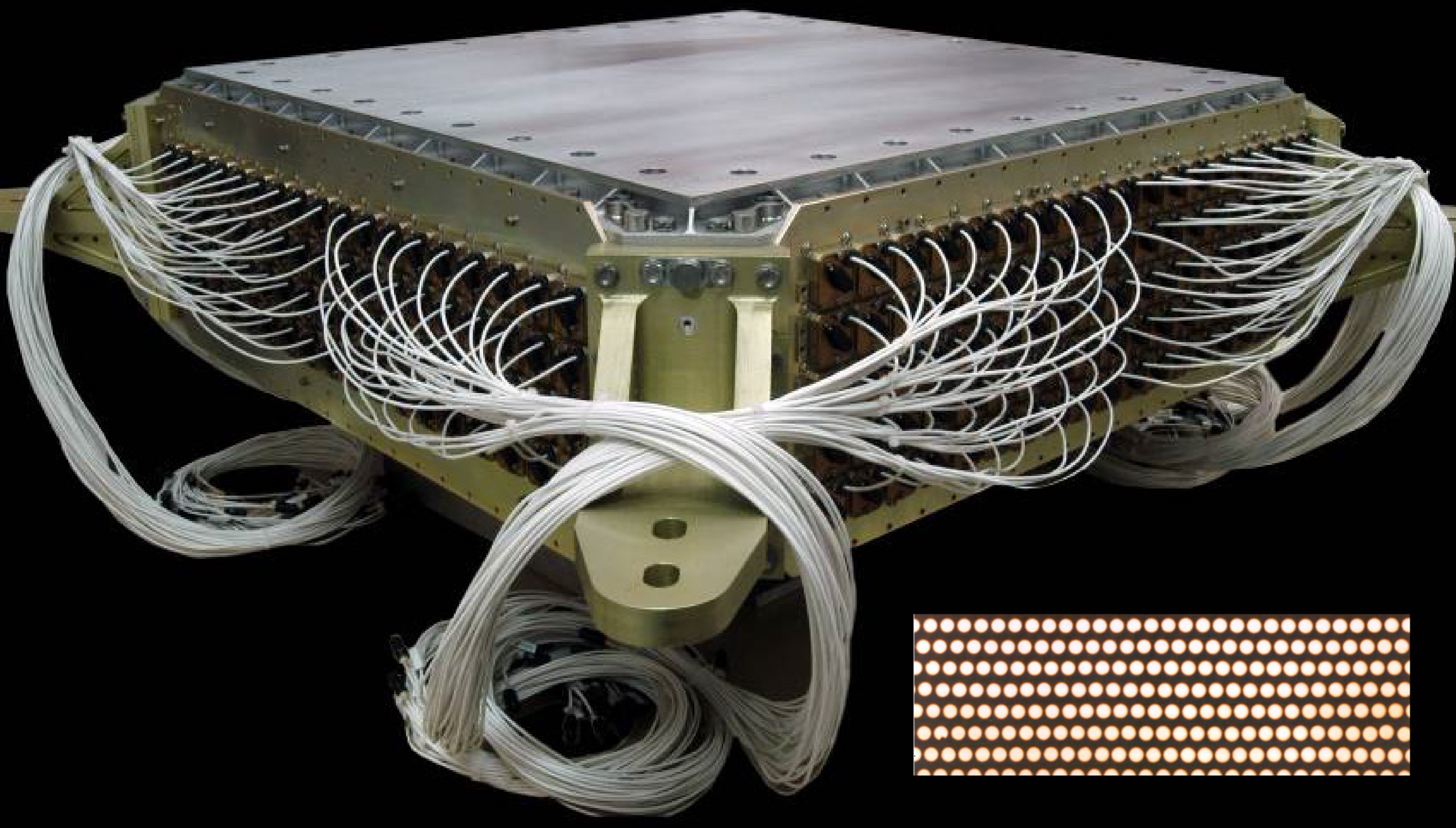
There are 9 planes with 200,000 channels aligned to 3 microns





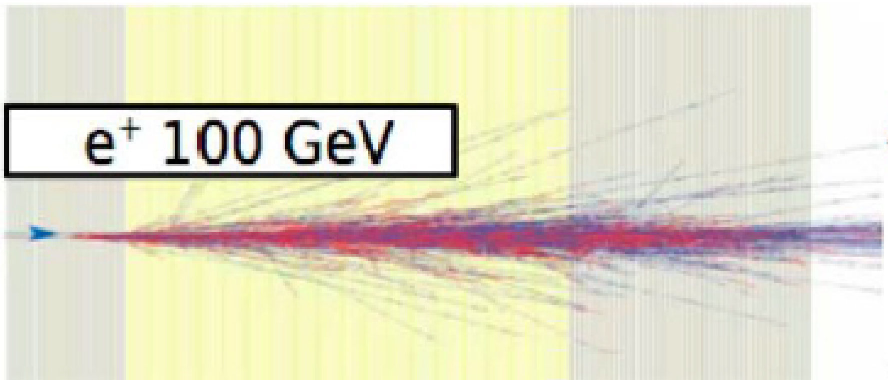


Calorimeter (ECAL)



50,000 fibers, $\phi = 1$mm, distributed uniformly inside 1,200 lb 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

Lepton hadron separation with ECAL

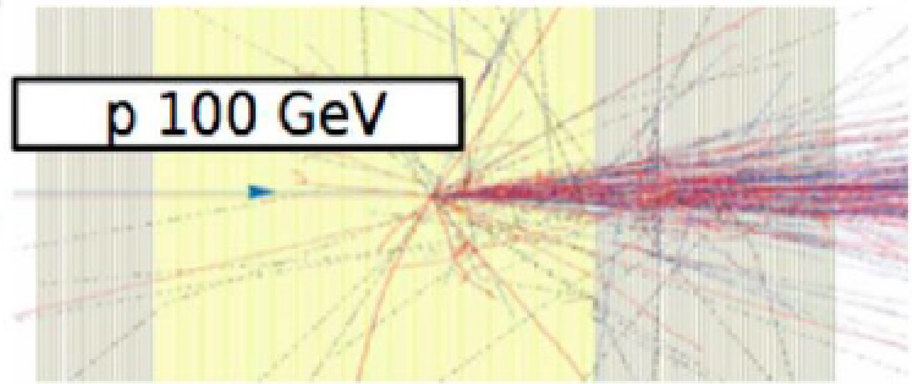


Positron 100 GeV

Longitudinally contained

Shower lateral size ~ $R_{molière}$(2cm)

$E_{ECAL} \sim P_{TRK}$

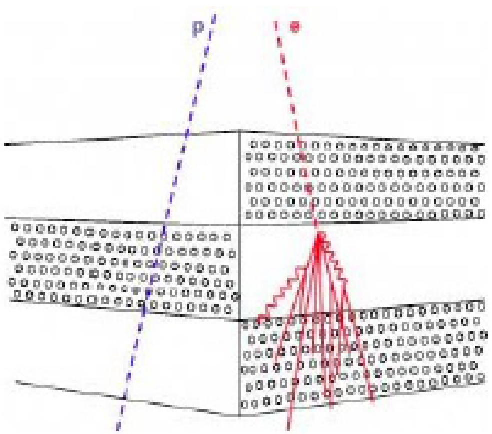


Proton 100 GeV

Longitudinal Leak

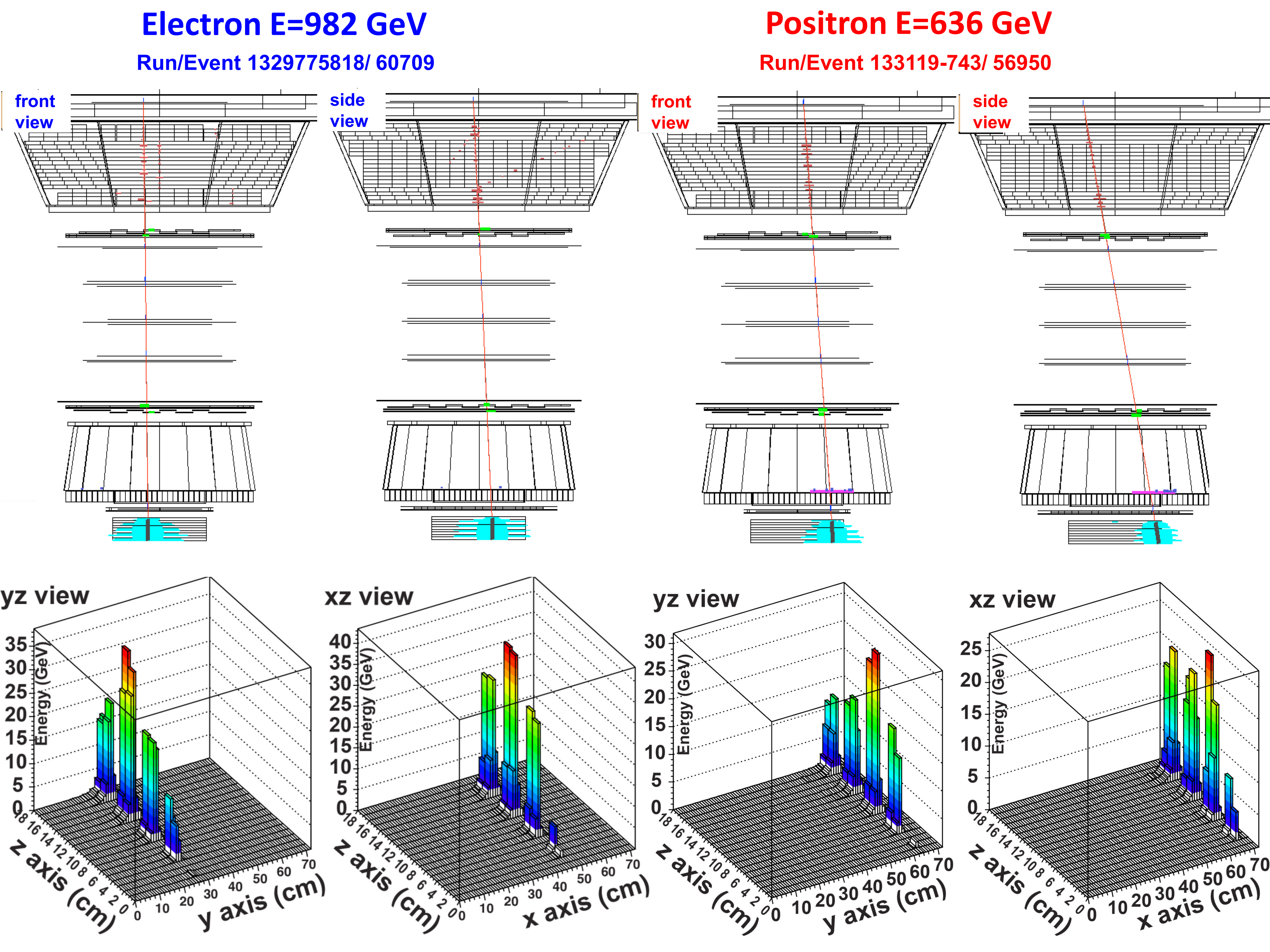
Shower lateral size >> $R_{molière}$

$E_{ECAL} << P_{TRK}$



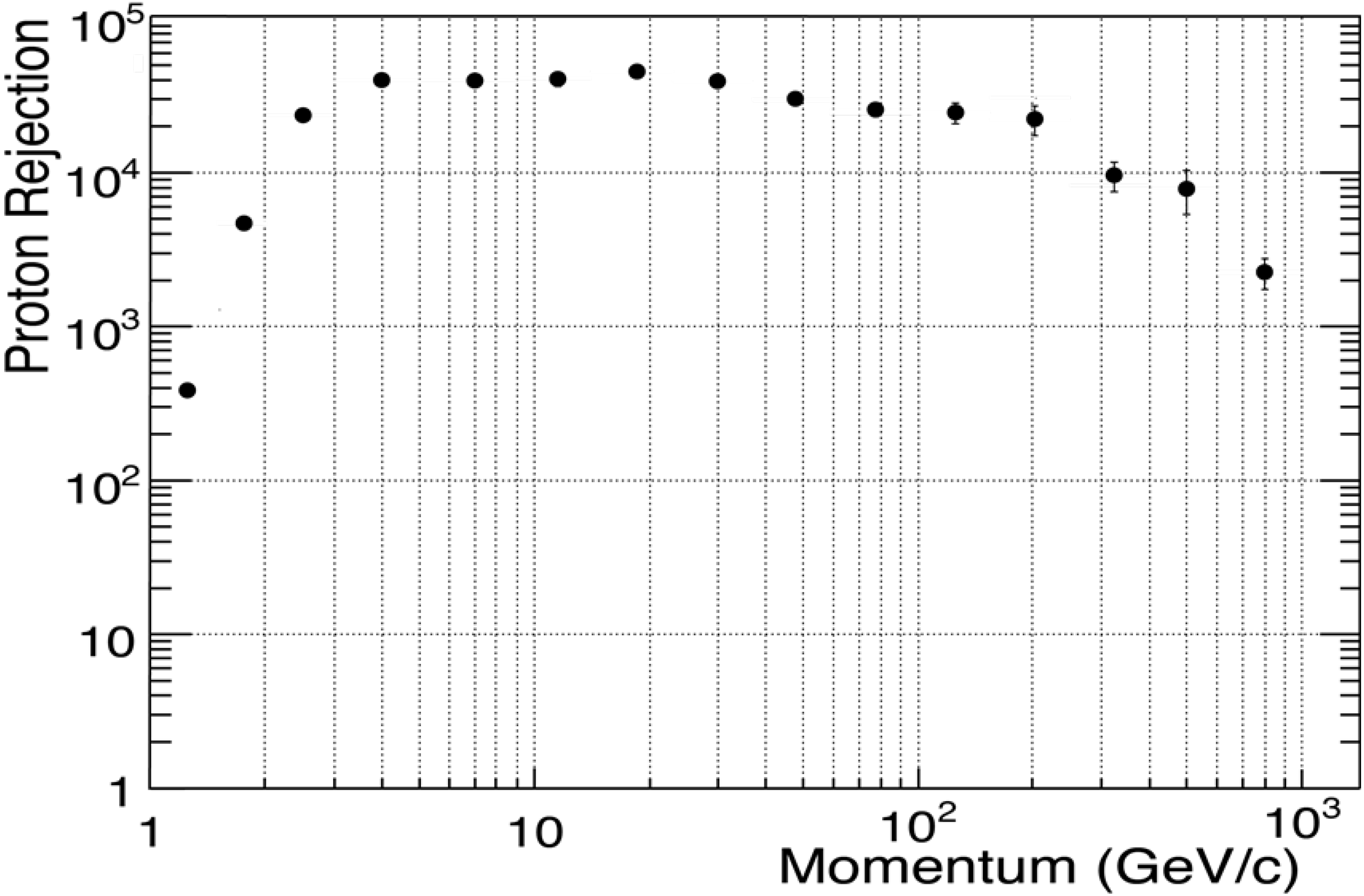
Proton rejection with ECAL:

- ✓ Energy fraction in each layer
- ✓ Shower lateral width in each layer
- ✓ Shower longitudinal profile
- ✓ Shower 3D profile



Electron E=982 GeV
Run/Event 1329775818/ 60709
Positron E=636 GeV
Run/Event 133119-743/ 56950
front view
side view
front view
side view
yz view
xz view
yz view
xz view
Energy (GeV)
z axis (cm)
y axis (cm)
x axis (cm)

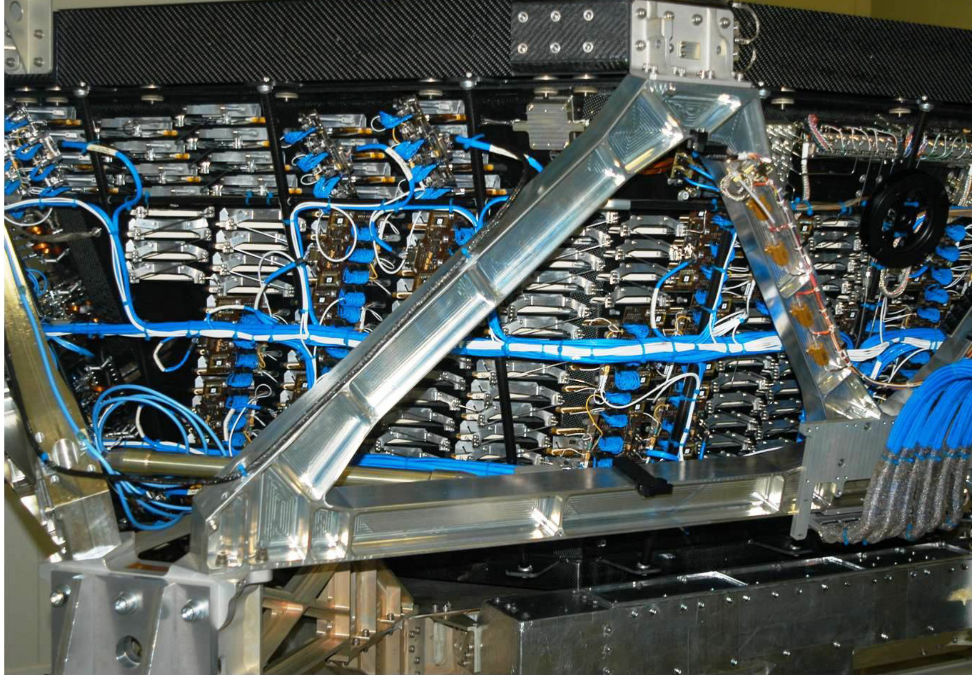
Data from ISS: Proton rejection using the ECAL

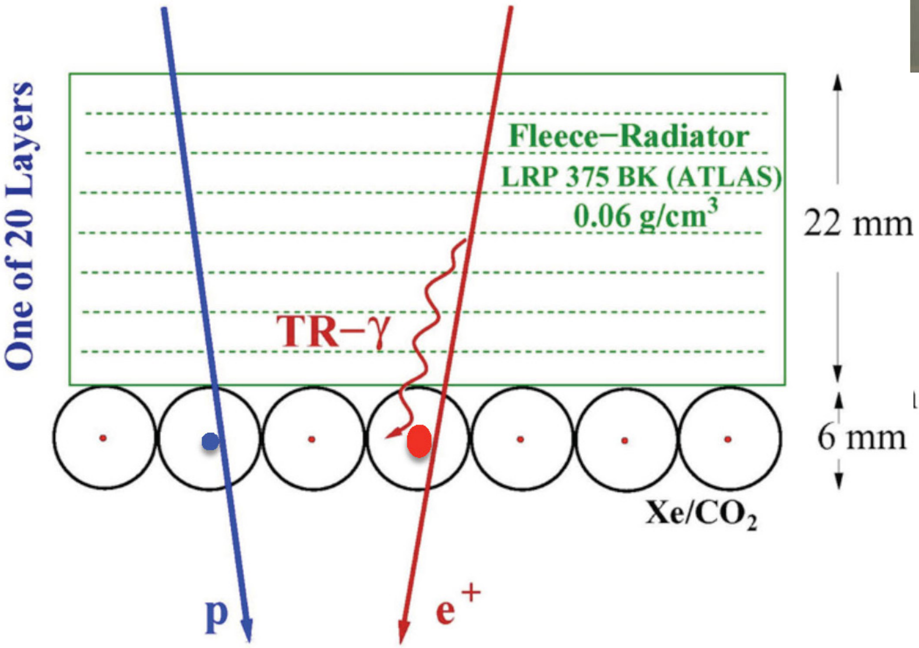


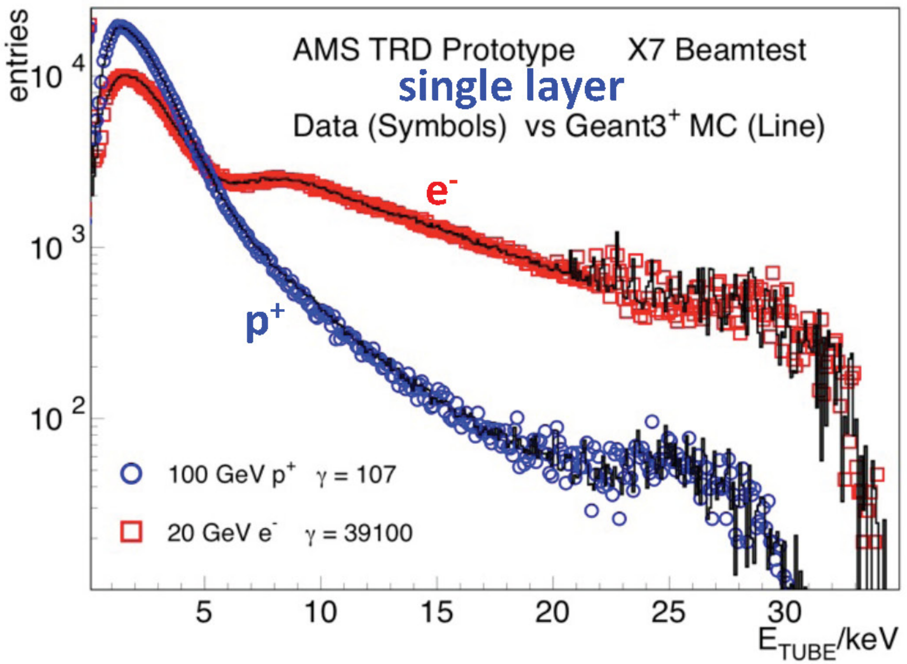
Transition Radiation Detector

20 Layers each consisting of:

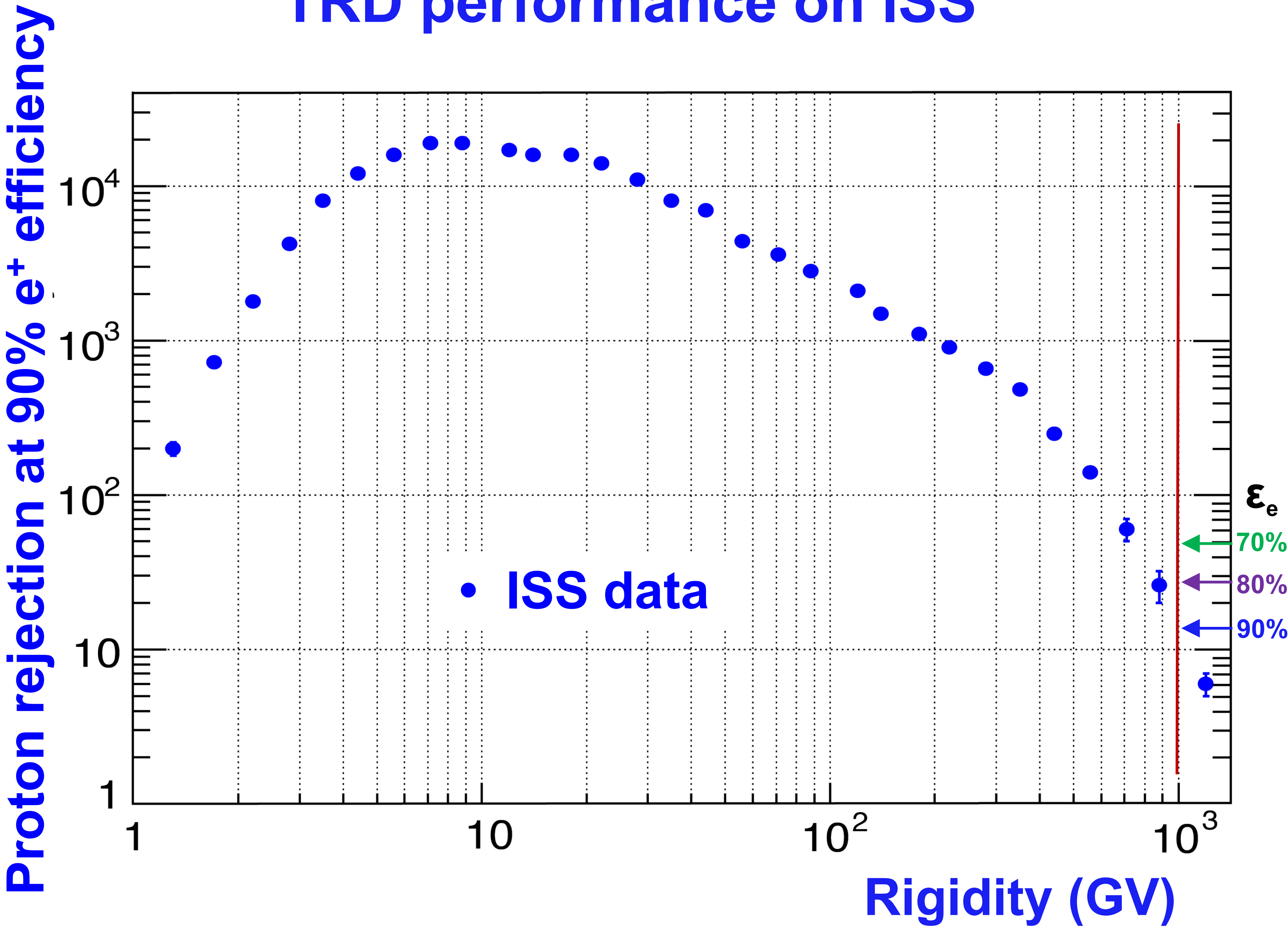
- 22 mm fibre fleece
- Ø 6 mm straw tubes filled with Xe/CO_2 80%/20%



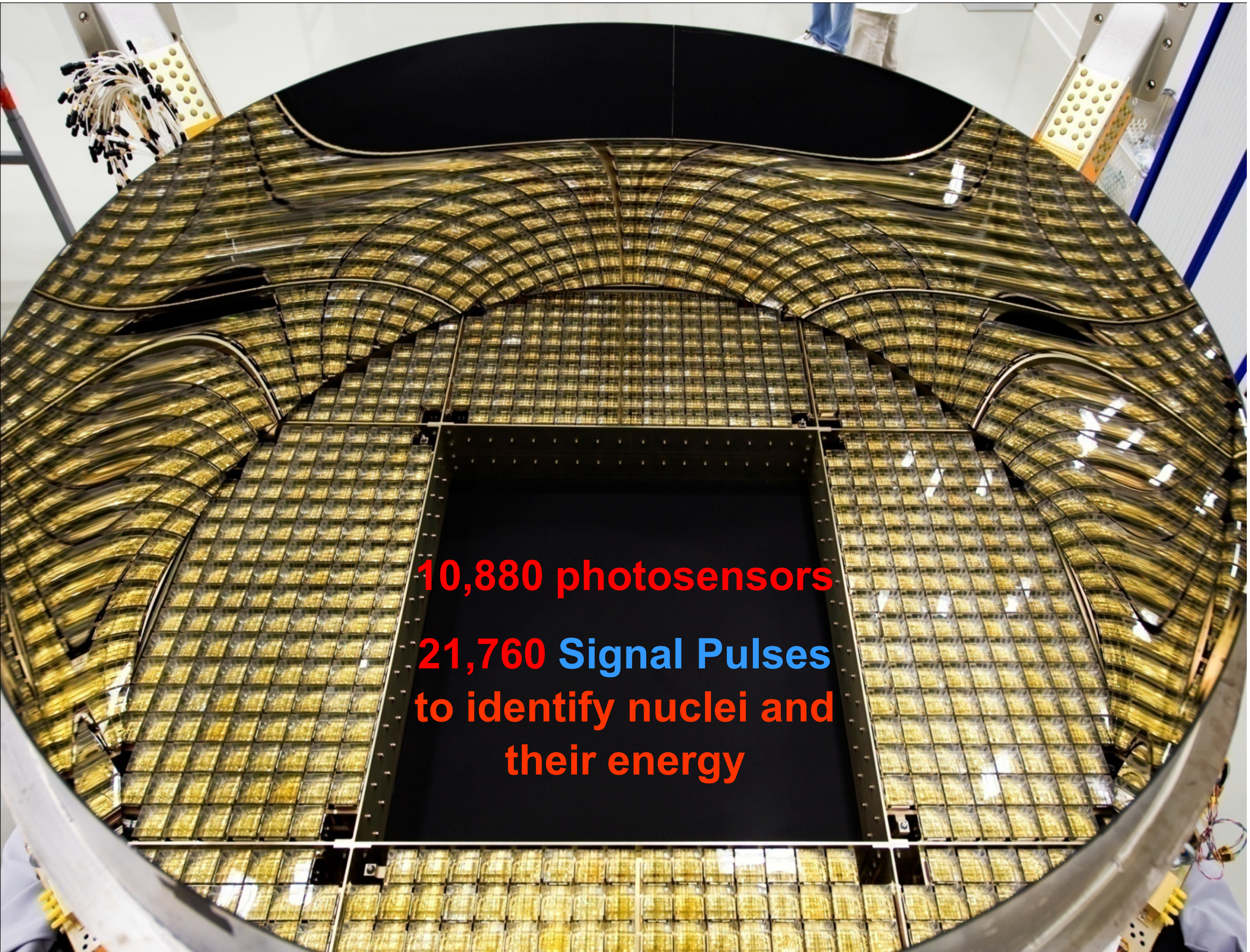




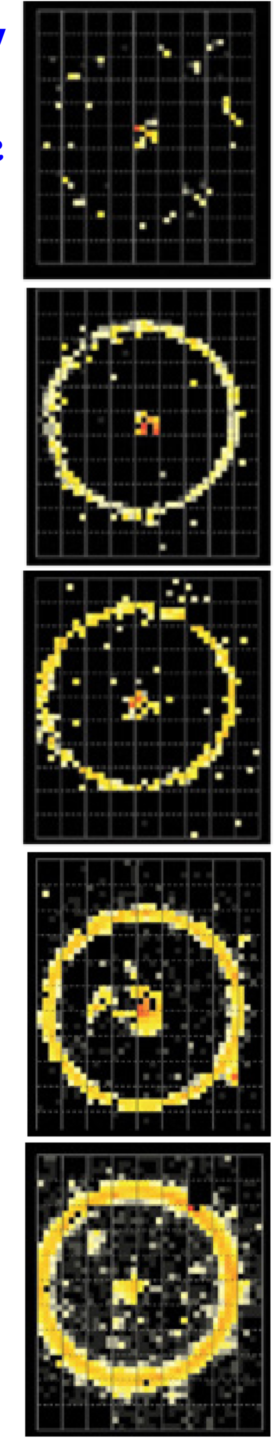
TRD performance on ISS



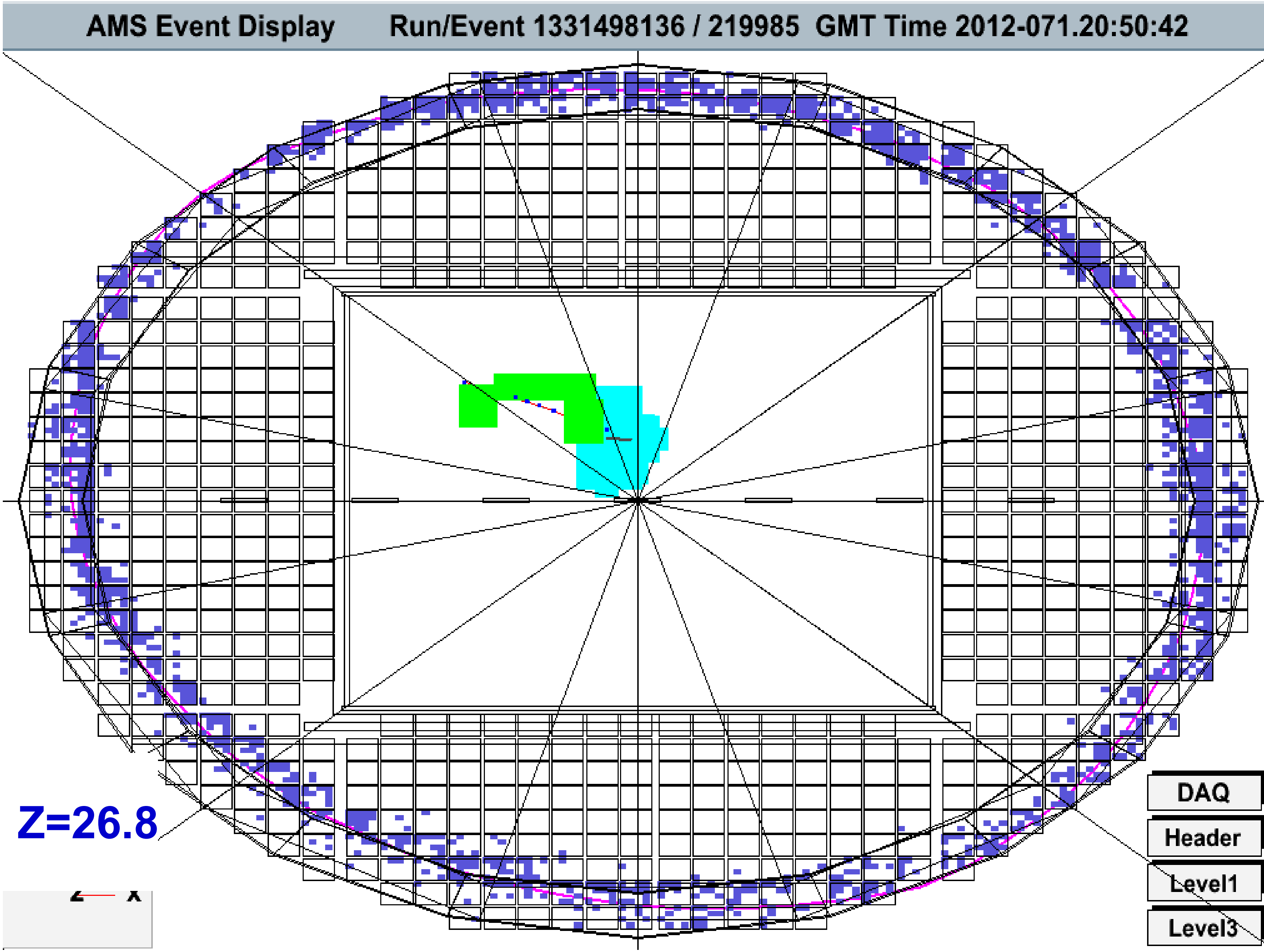
Ring Imaging CHerenkov (RICH)



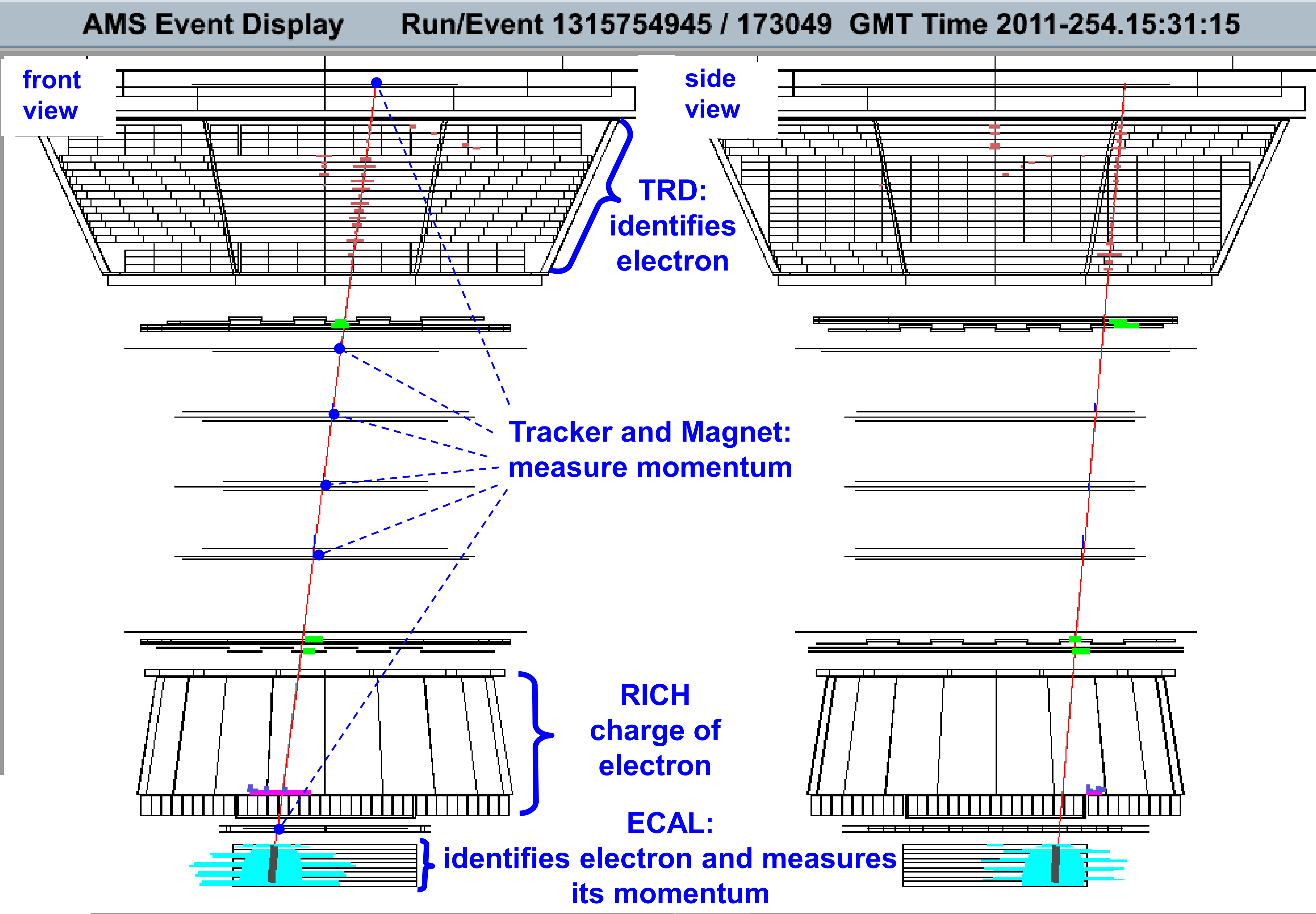
160 GV



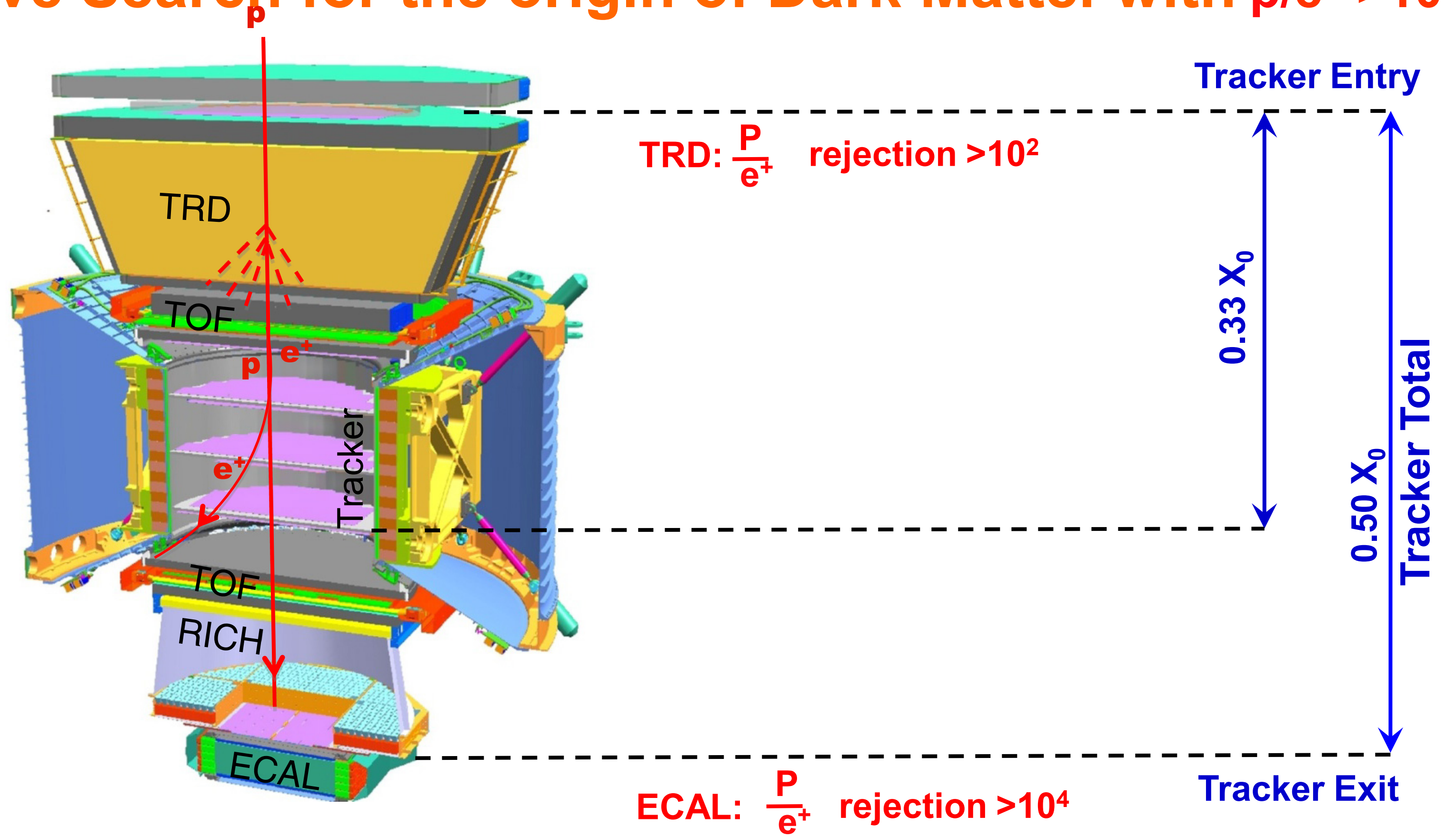
Data from ISS



1.03 TeV electron



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^+.

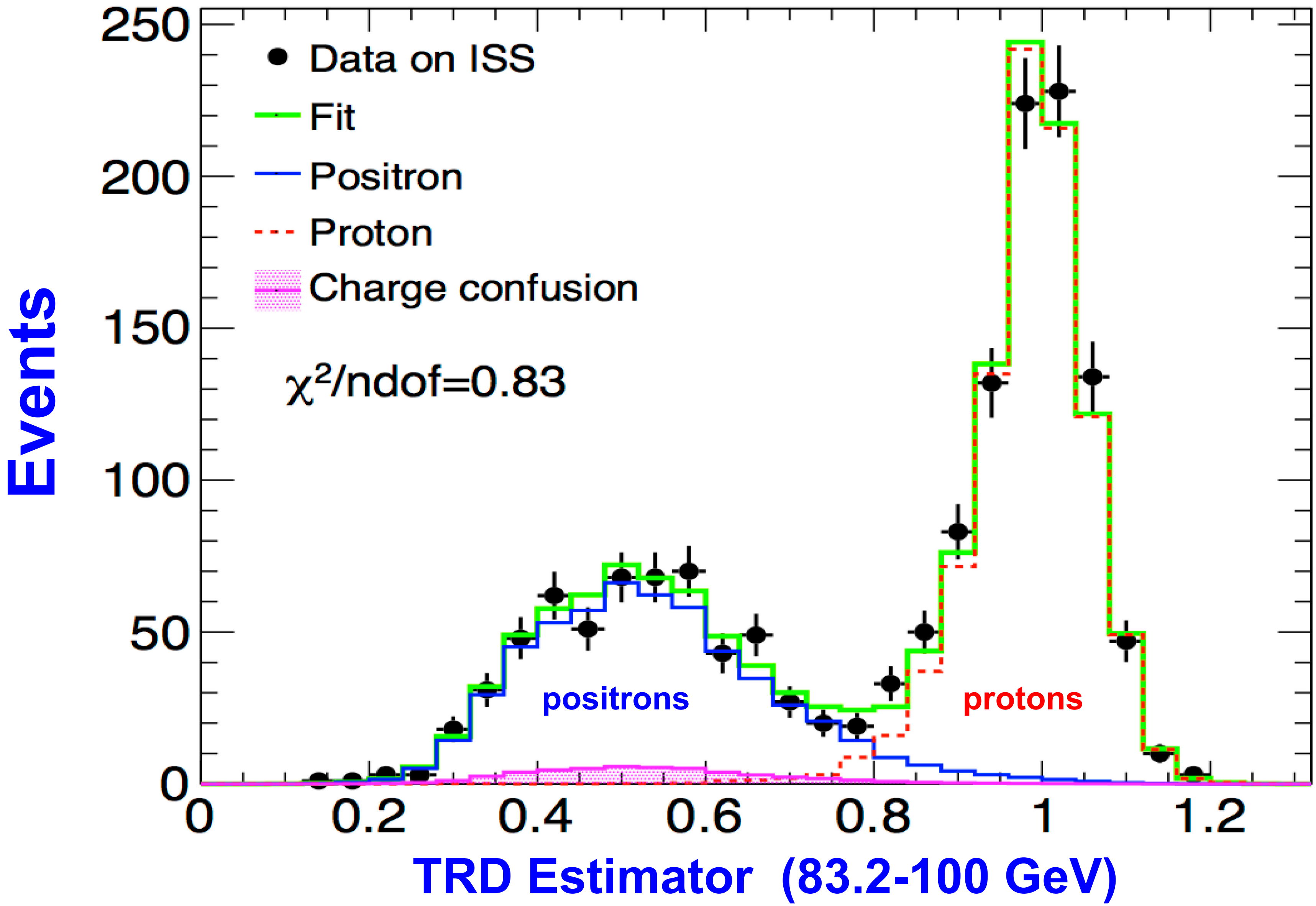
b) A magnet separates TRD and ECAL so that e^+ produced in TRD will be swept away and not enter ECAL

In this way the rejection power of TRD and ECAL are independent

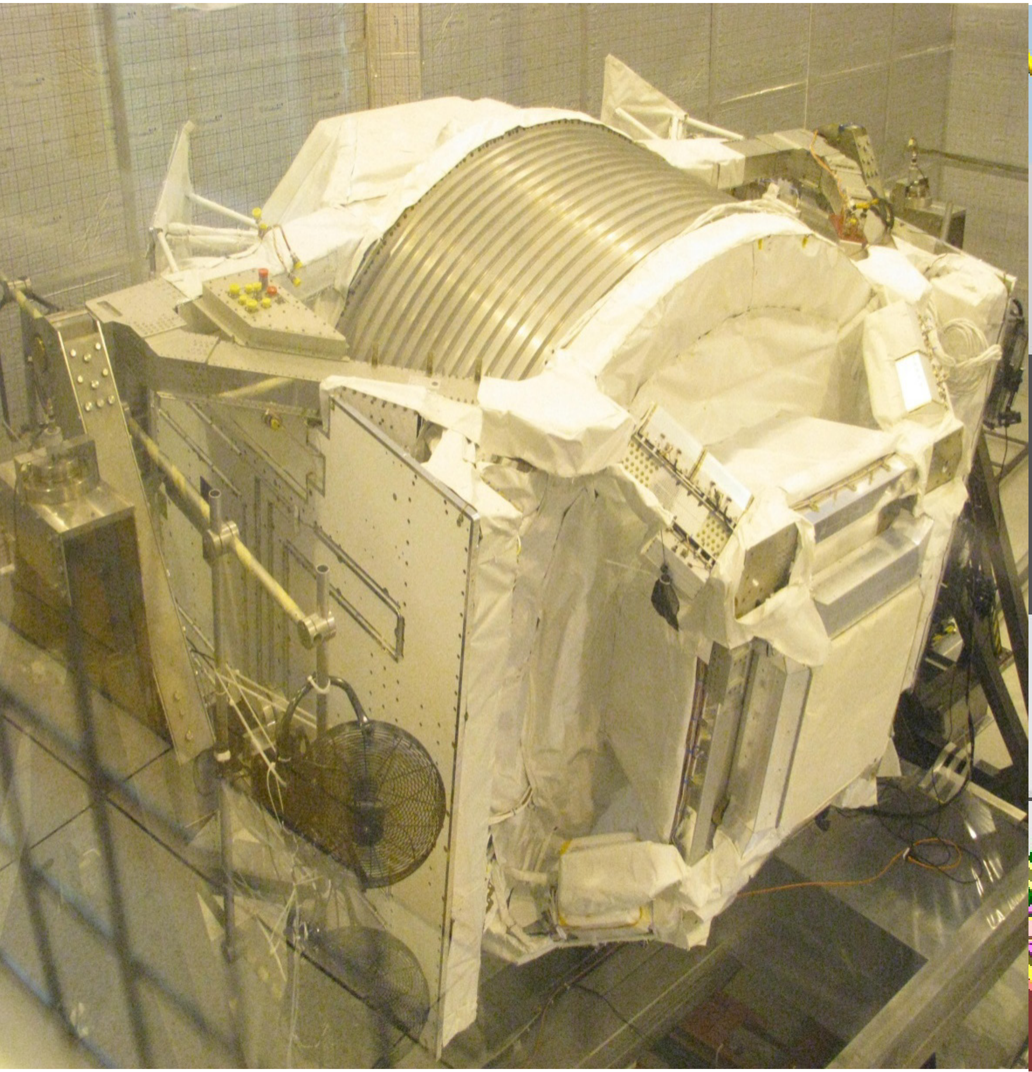
c) Matching momentum of 9 tracker planes with ECAL energy measurements

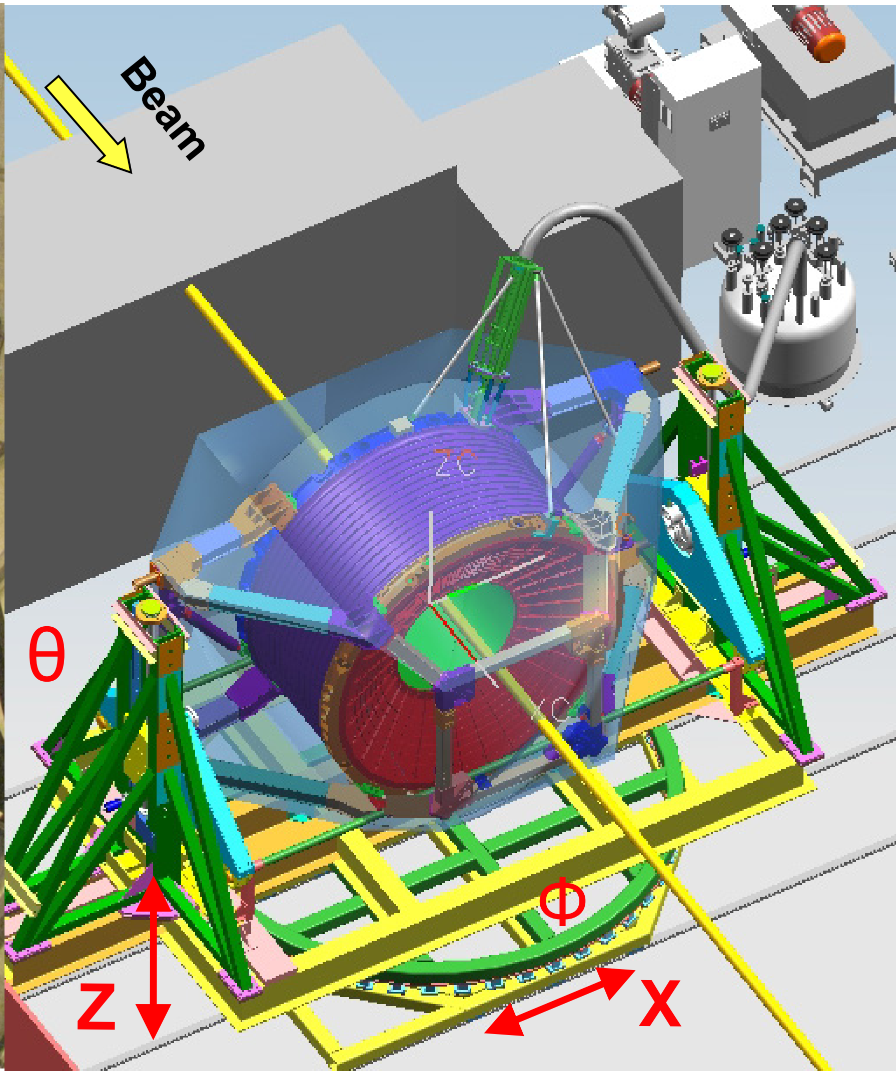
Example of Positron Selection:

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



Intensive Tests at CERN





Strong support from CERN (R. Heuer, A. Siemko, S. Meyers, C. Garguilo)

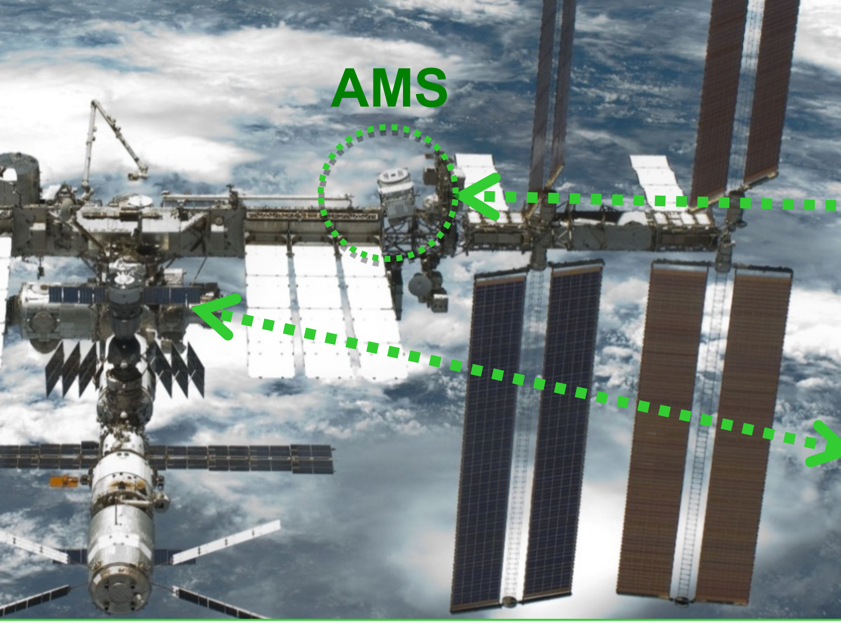
AMS in SPS Test Beam, August 2010

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

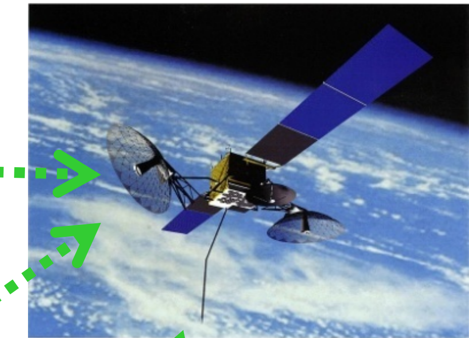
May 19: AMS installation completed at 5:15 CDT, start taking data 9:35 CDT

During the first week, we collected 100 million cosmic rays

AMS Operations



TDRS Satellites



Astronaut at ISS AMS Laptop

Ku-Band
High Rate (down):
Events <10Mbit/s>

S-Band
Low Rate (up & down):
Commanding: 1 Kbit/s
Monitoring: 30 Kbit/s

AMS Payload Operations Control and Science Operations Centers (POCC, SOC) at CERN

AMS Computers at MSFC, AL

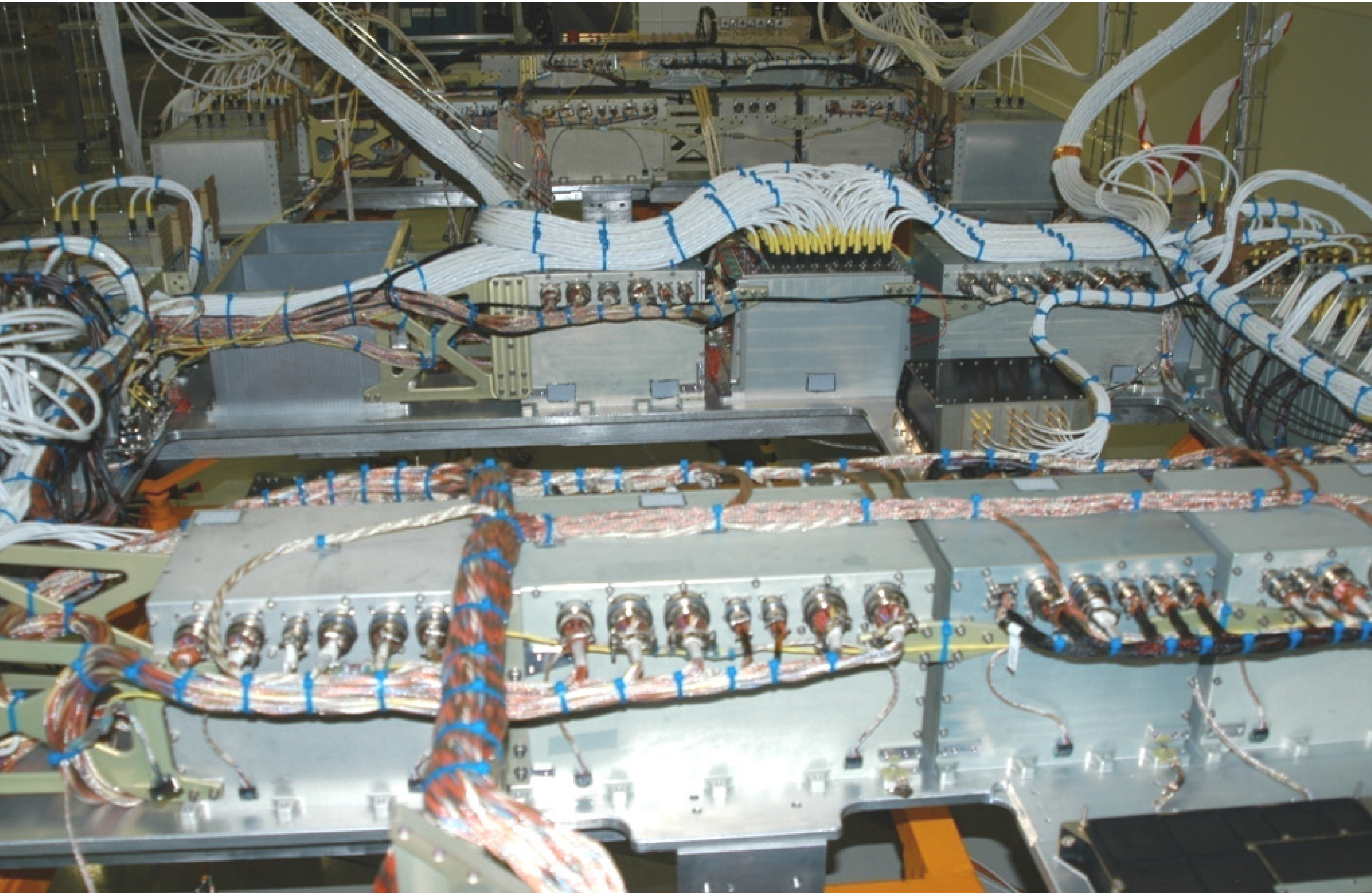
White Sands Ground Terminal, NM

General Charles Bolden, NASA Administrator, inaugurated AMS POCC, June 23, 2011

NASA Officials Certified Asia POCC
at Taiwan on June 22, 2012

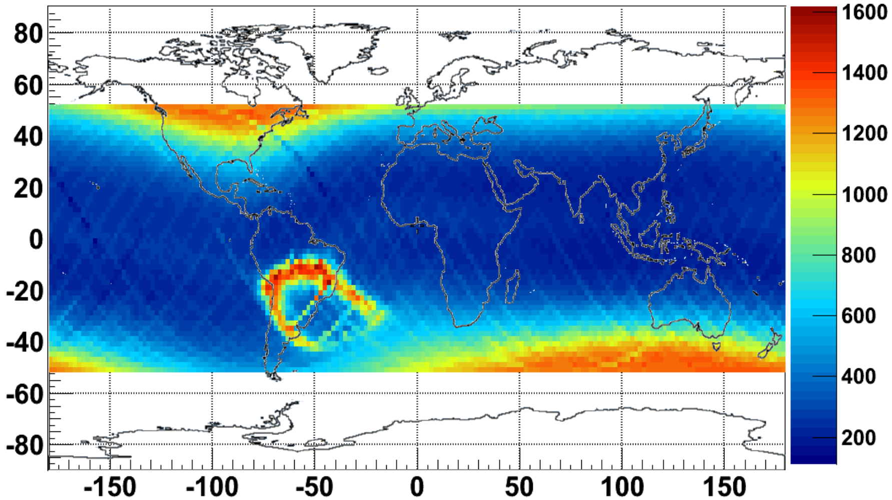
AMS electronics

650 computers, 300,000 channels, up to 400% redundancy

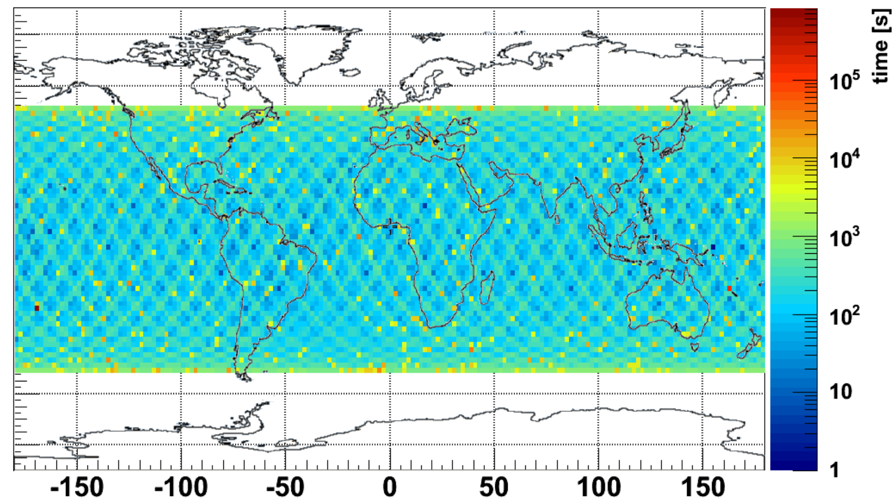


Orbital DAQ parameters

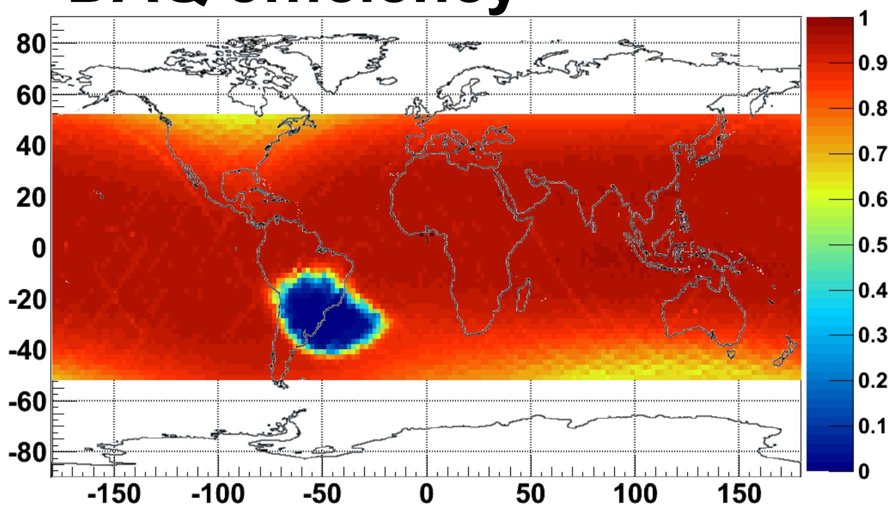
Acquisition rate [Hz]



Time at location [s]



DAQ efficiency



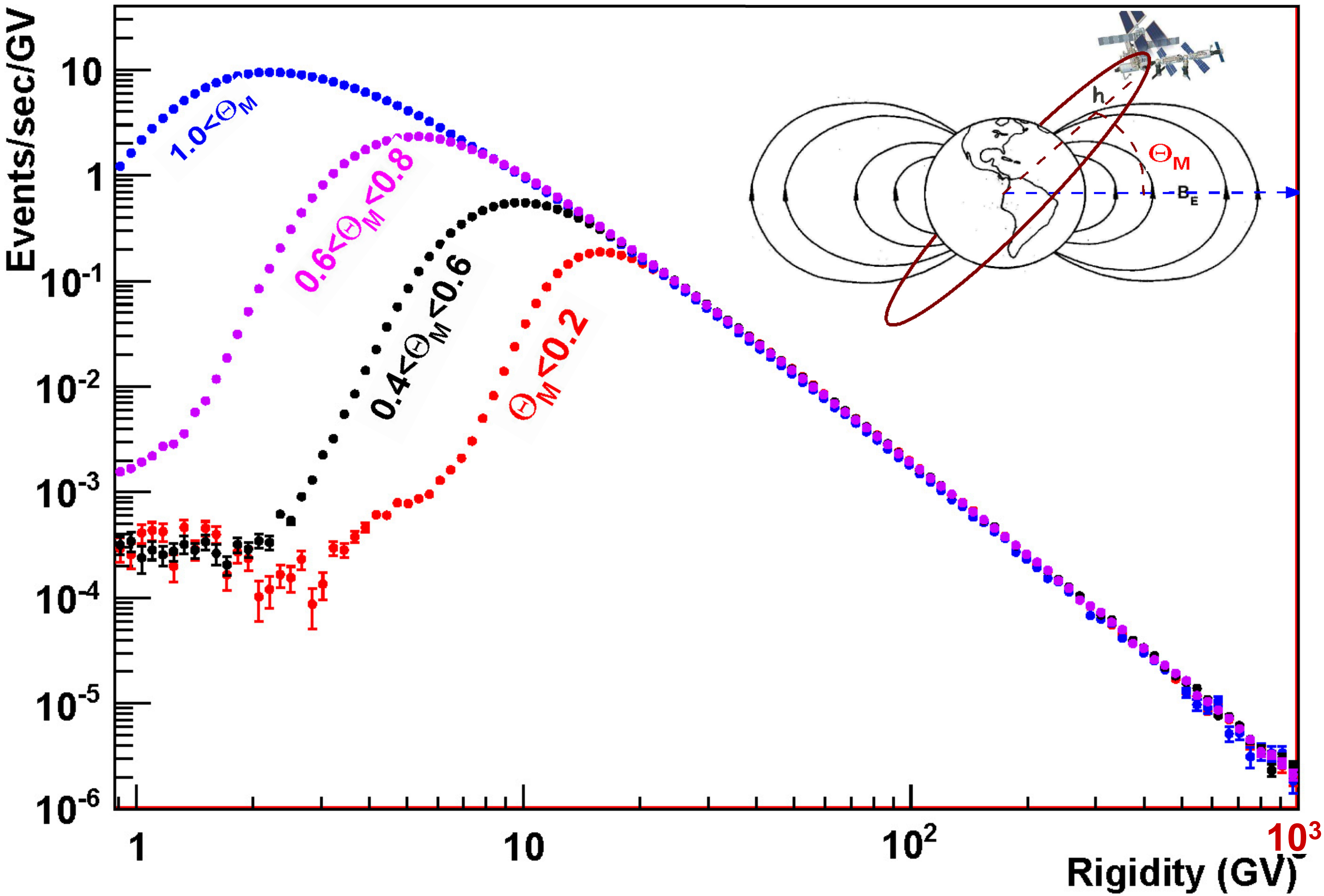
Particle rates vary from 200 to 2000 Hz per orbit

On average:

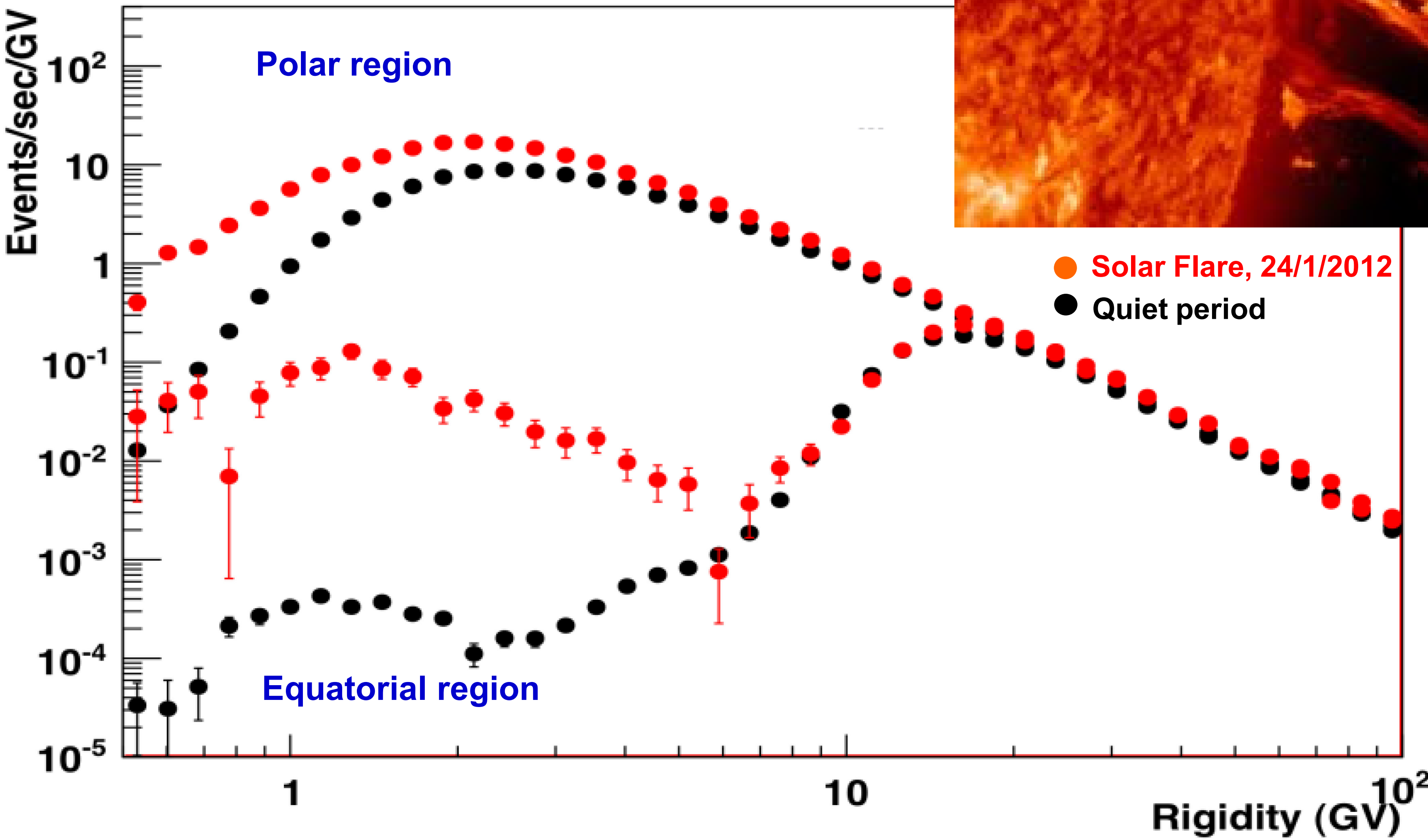
DAQ efficiency 86%

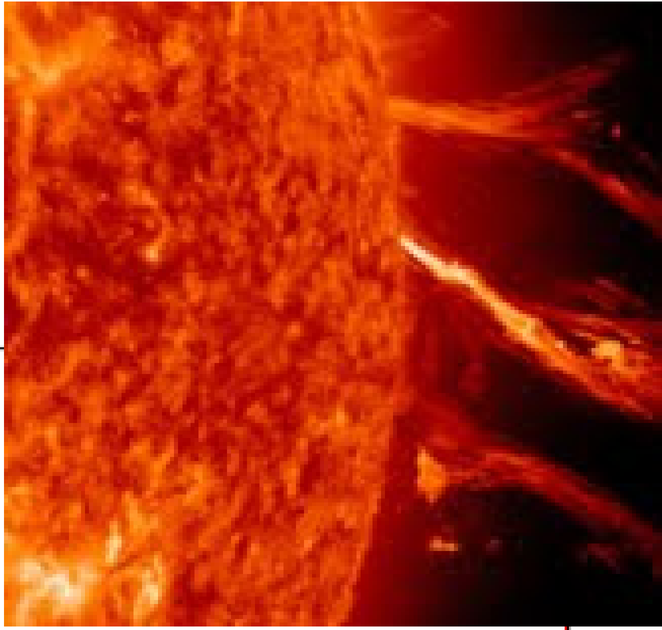
DAQ rate ~600Hz

AMS data on ISS: He rate

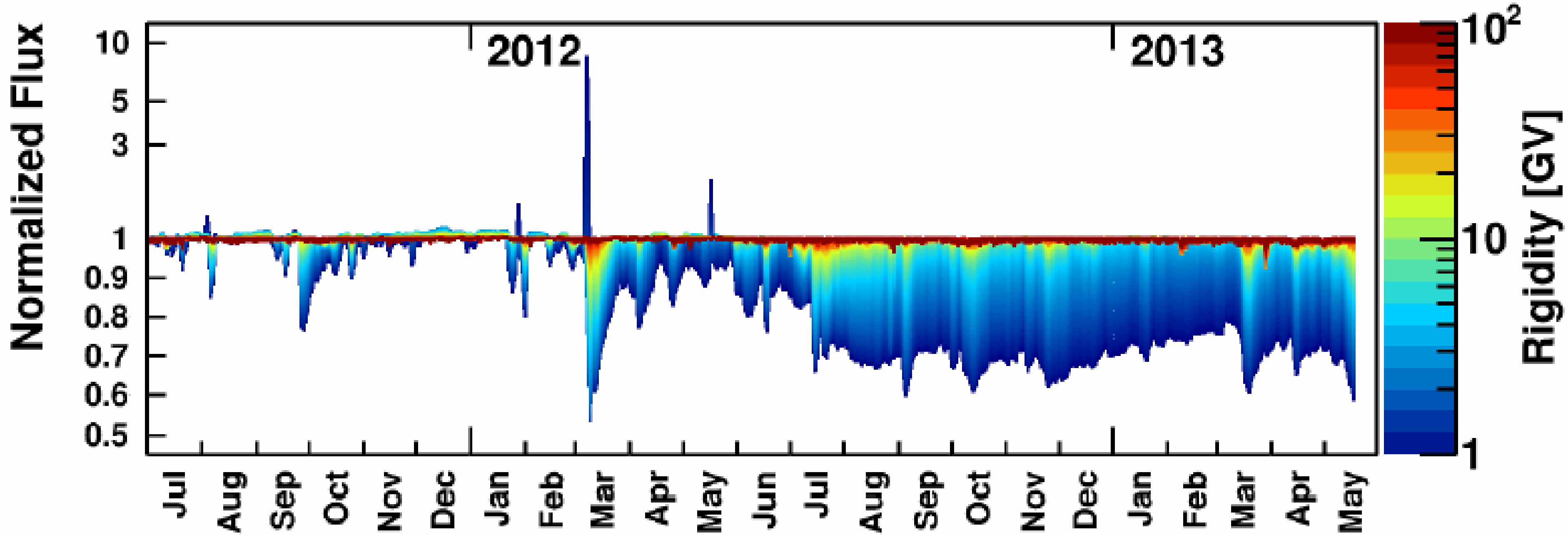


AMS data: He rate and Solar Flare





Daily Variation of Normalized Proton Flux



1. Low energy proton flux is decreasing as we enter solar maximum. High energy proton flux is less affected.
2. Major solar flare events were detected as spikes in ~1GV proton flux.

Data from AMS and Detector Performance

The detectors function as designed and,
in 24 months, we have collected 32 billion events.

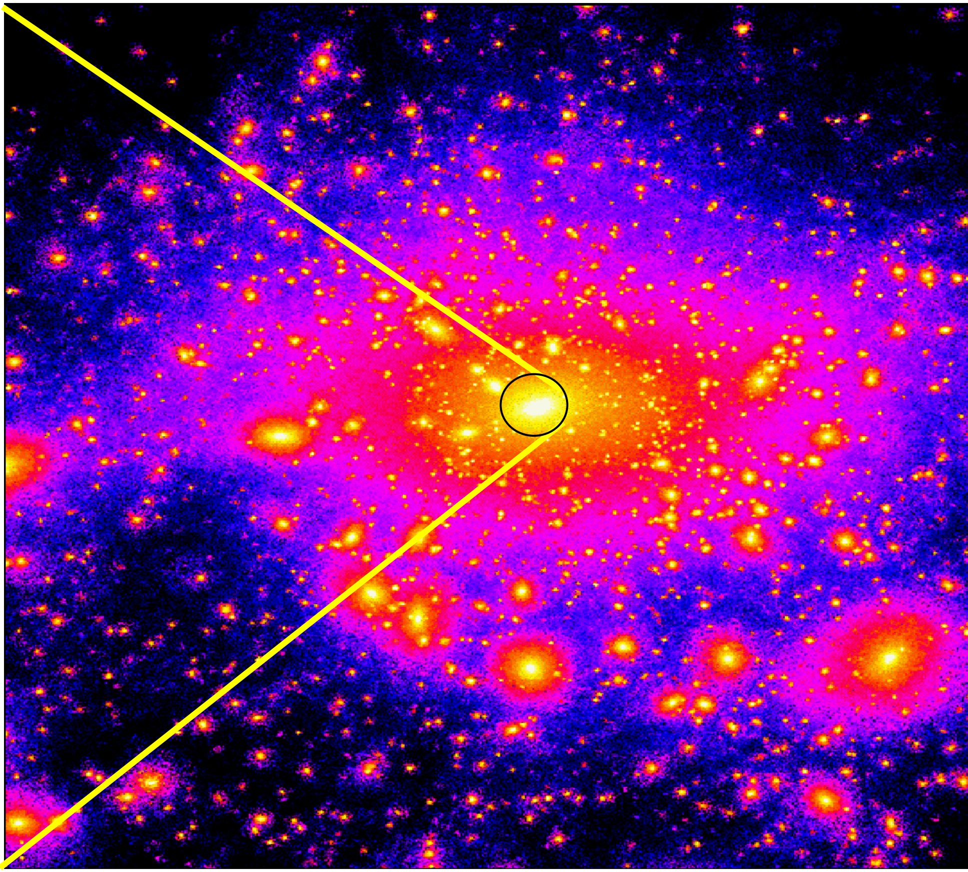
Every year, we will collect $16*10^9$ events
and in 10-20 years we will collect $160\text{-}320*10^9$ events.

The physics of AMS include:

The Origin of Dark Matter

~ 85% of Matter in the Universe is not visible and is called Dark Matter

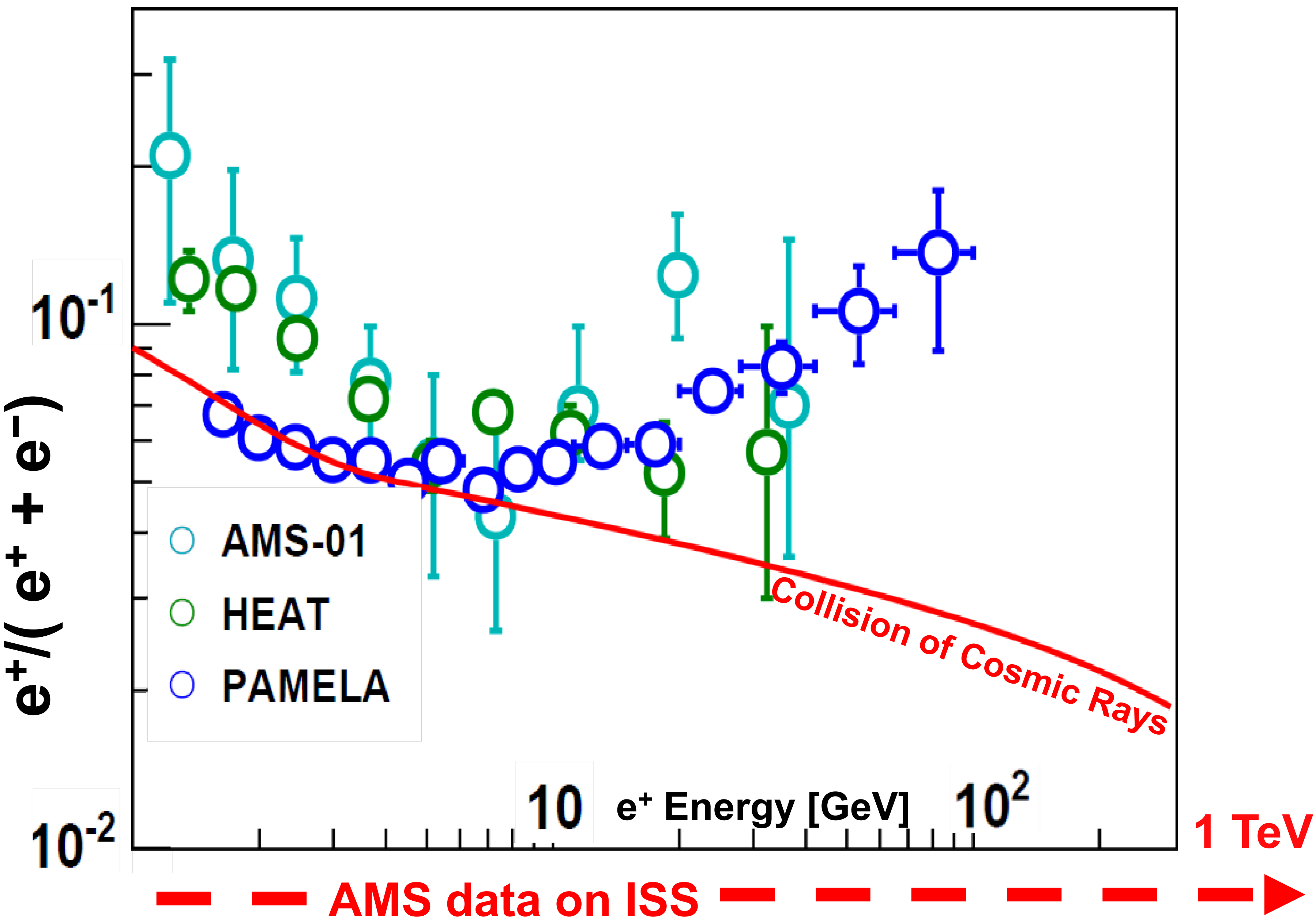
A Galaxy as seen by telescope



If we could see Dark Matter in the Galaxy

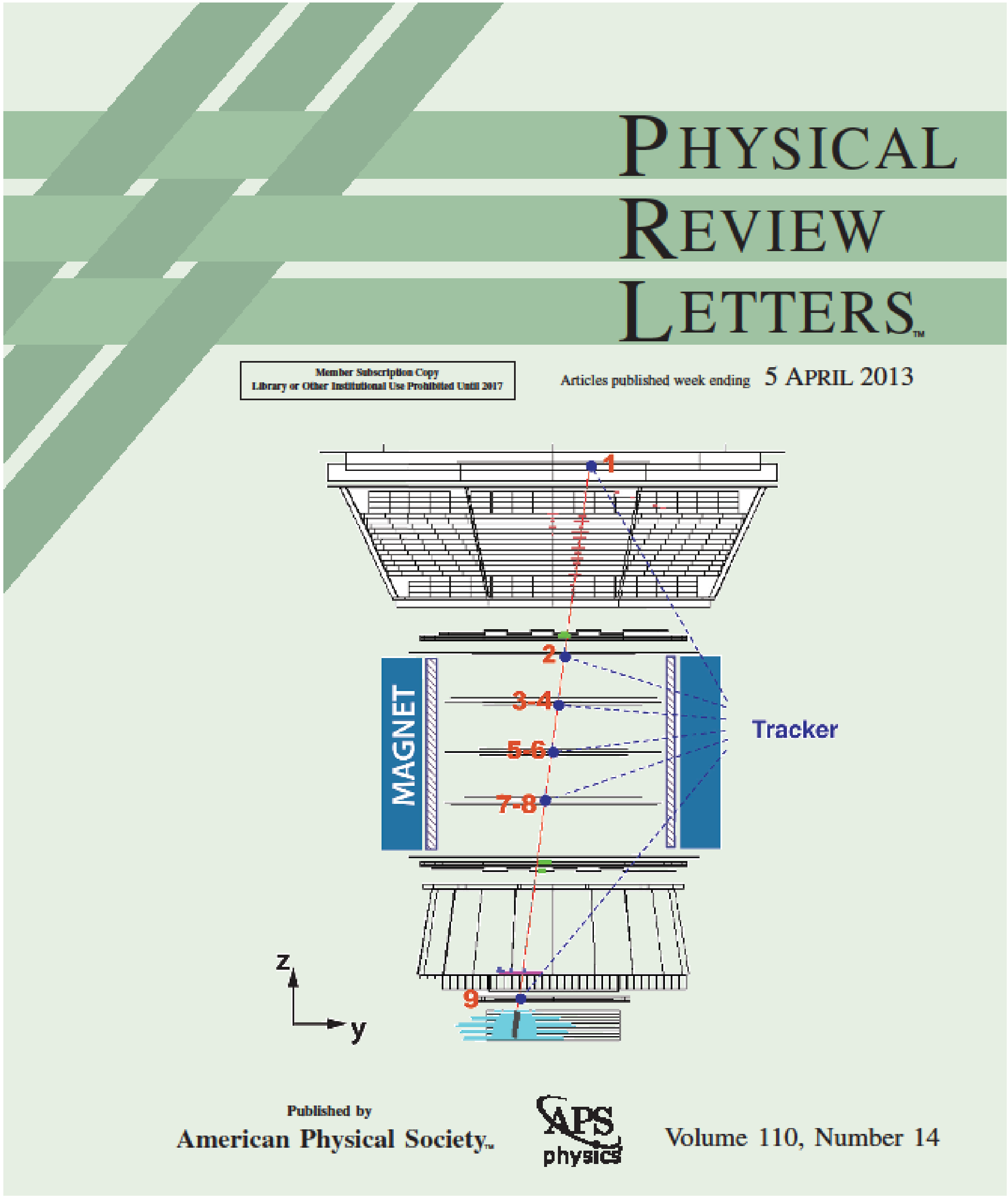
The leading candidate for Dark Matter is a SUSY neutralino (χ^0)

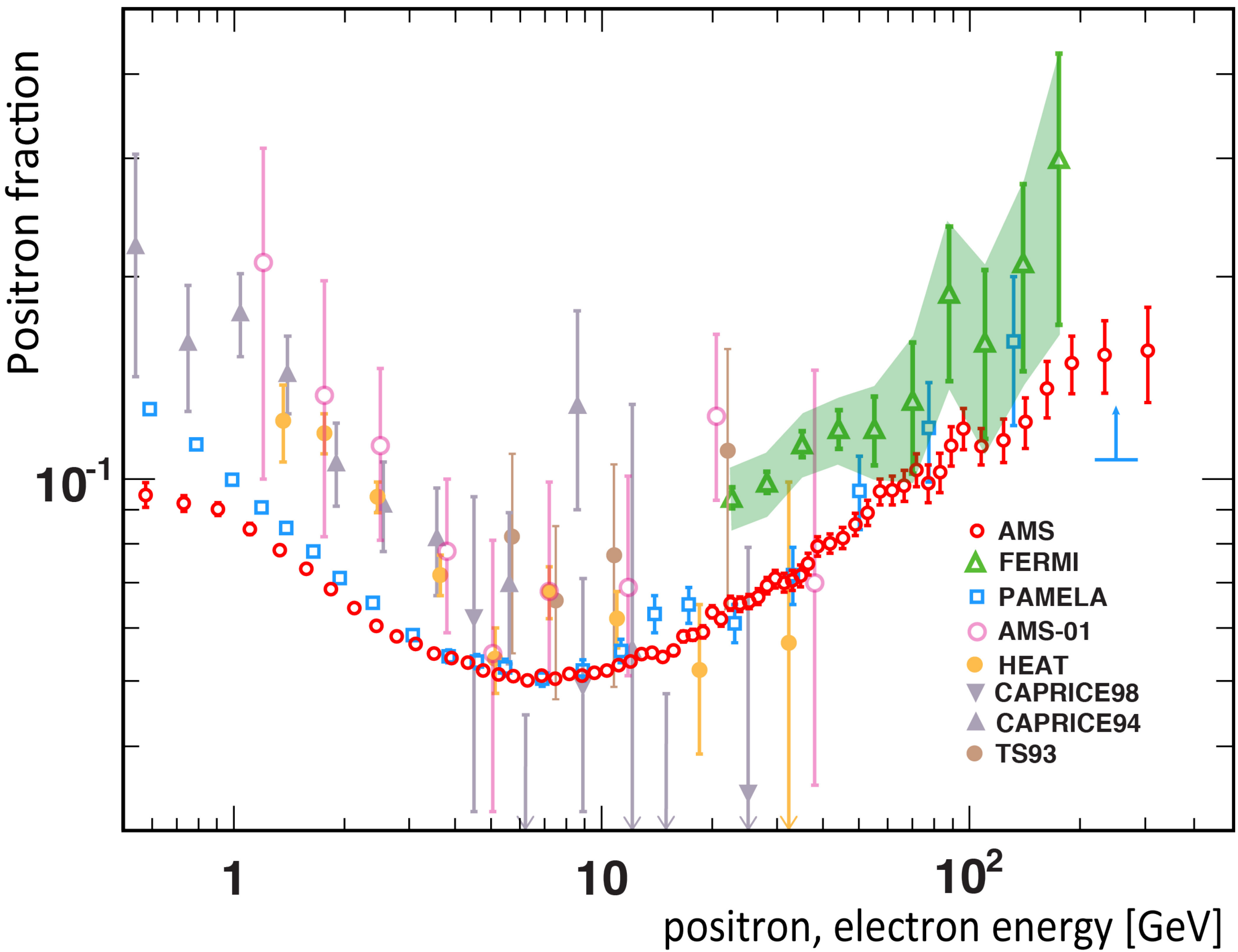
Collisions of χ^0 will produce excess in the spectra of e^+ different from known cosmic ray collisions



“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, 141102(2013)]

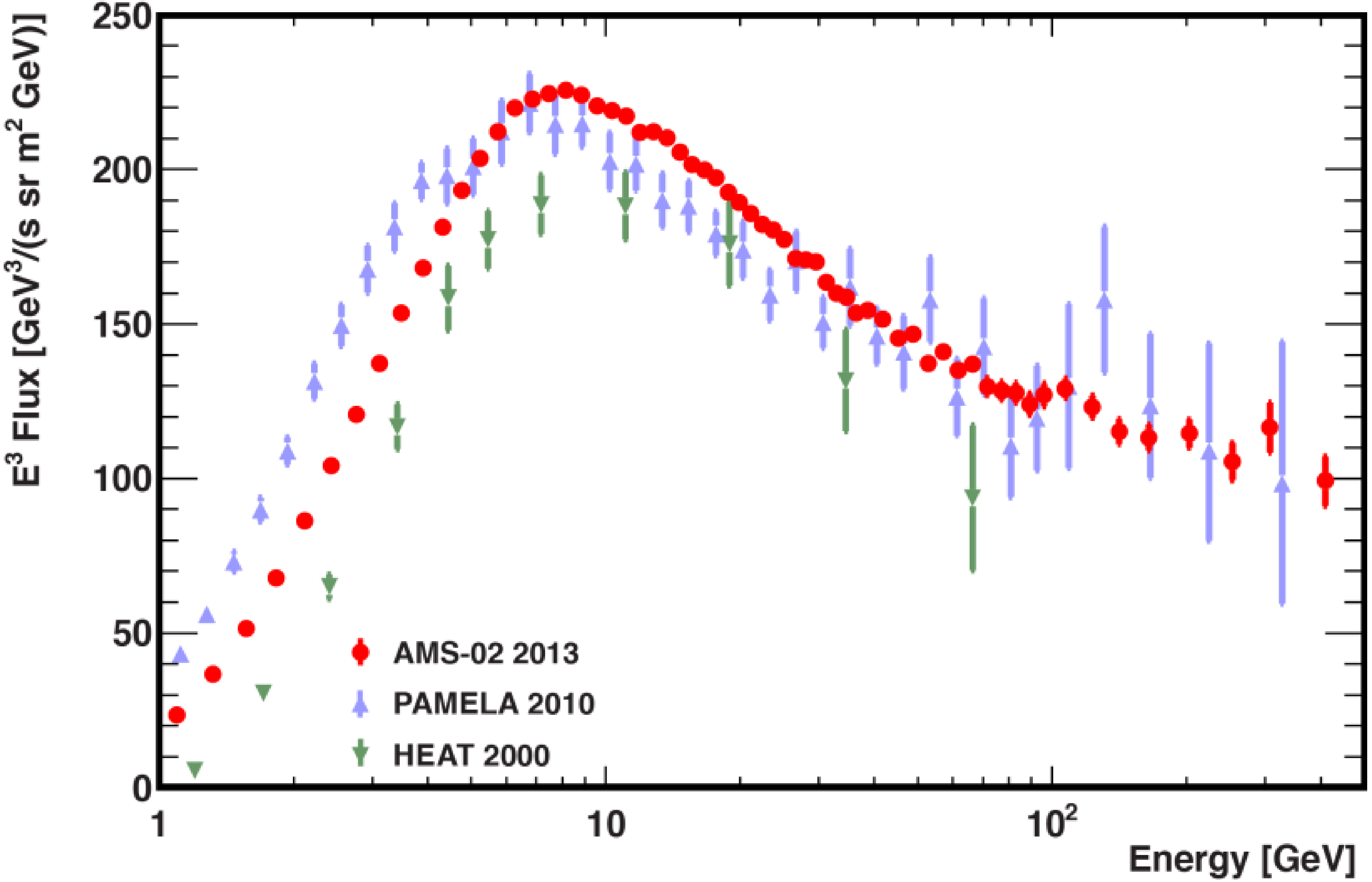



Positron fraction
10^{-1}
1
10
10^2
positron, electron energy [GeV]
AMS
FERMI
PAMELA
AMS-01
HEAT
CAPRICE98
CAPRICE94
TS93

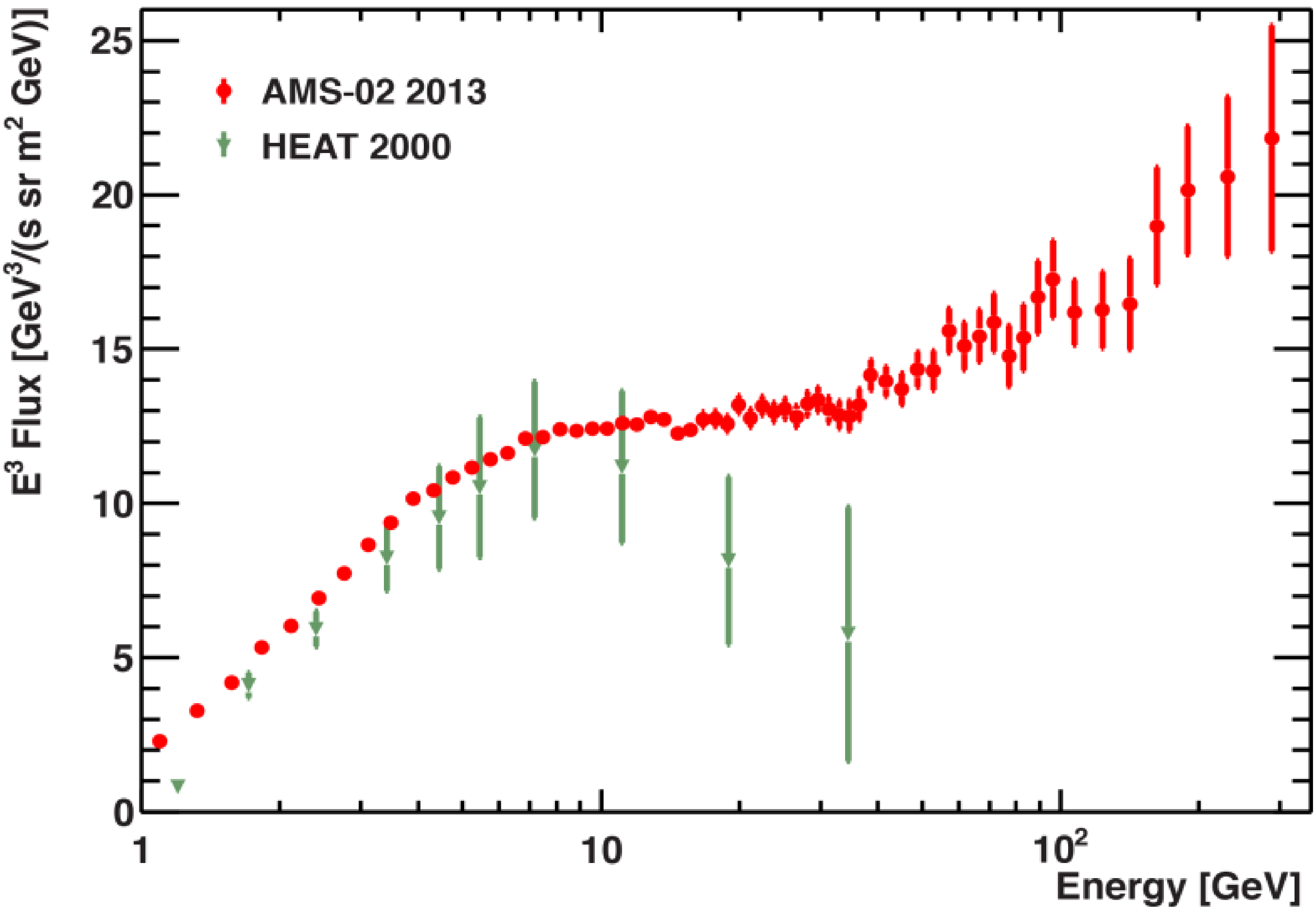
Representative bins of the positron fraction

positron fraction				Systematic Errors					
Energy [GeV]	N_{e+}	Fraction	statistical error	acceptance asymmetry	event selection	bin-to-bin migration	reference spectra	charge confusion	total systematic uncertainty
Energy[GeV]	N_{e+}	Fraction	$\sigma_{stat.}$	$\sigma_{acc.}$	$\sigma_{sel.}$	$\sigma_{mig.}$	$\sigma_{ref.}$	$\sigma_{c.c.}$	$\sigma_{syst.}$
1.00 -1.21	9 335	0.0842	0.0008	0.0005	0.0009	0.0008	0.0001	0.0005	0.0014
1.97 -2.28	23 893	0.0642	0.0004	0.0002	0.0005	0.0002	0.0001	0.0002	0.0006
3.30 -3.70	20 707	0.0550	0.0004	0.0001	0.0003	0.0000	0.0001	0.0002	0.0004
6.56 -7.16	13 153	0.0510	0.0004	0.0001	0.0000	0.0000	0.0001	0.0002	0.0002
09.95 -10.73	7 161	0.0519	0.0006	0.0001	0.0000	0.0000	0.0001	0.0002	0.0002
19.37 -20.54	2 322	0.0634	0.0013	0.0001	0.0001	0.0000	0.0001	0.0002	0.0003
30.45 -32.10	1094	0.0701	0.0022	0.0001	0.0002	0.0000	0.0001	0.0003	0.0004
40.00 -43.39	976	0.0802	0.0026	0.0002	0.0005	0.0000	0.0001	0.0004	0.0007
50.87 -54.98	605	0.0891	0.0038	0.0002	0.0006	0.0000	0.0001	0.0004	0.0008
64.03 -69.00	392	0.0978	0.0050	0.0002	0.0010	0.0000	0.0002	0.0007	0.0013
74.30 -80.00	276	0.0985	0.0062	0.0002	0.0010	0.0000	0.0002	0.0010	0.0014
86.00 -92.50	240	0.1120	0.0075	0.0002	0.0010	0.0000	0.0003	0.0011	0.0015
100.0 -115.1	304	0.1118	0.0066	0.0002	0.0015	0.0000	0.0003	0.0015	0.0022
115.1 -132.1	223	0.1142	0.0080	0.0002	0.0019	0.0000	0.0004	0.0019	0.0027
132.1 -151.5	156	0.1215	0.0100	0.0002	0.0021	0.0000	0.0005	0.0024	0.0032
151.5 -173.5	144	0.1364	0.0121	0.0002	0.0026	0.0000	0.0006	0.0045	0.0052
173.5 -206.0	134	0.1485	0.0133	0.0002	0.0031	0.0000	0.0009	0.0050	0.0060
206.0 -260.0	101	0.1530	0.0160	0.0003	0.0031	0.0000	0.0013	0.0095	0.0101
260.0 -350.0	72	0.1550	0.0200	0.0003	0.0056	0.0000	0.0018	0.0140	0.0152

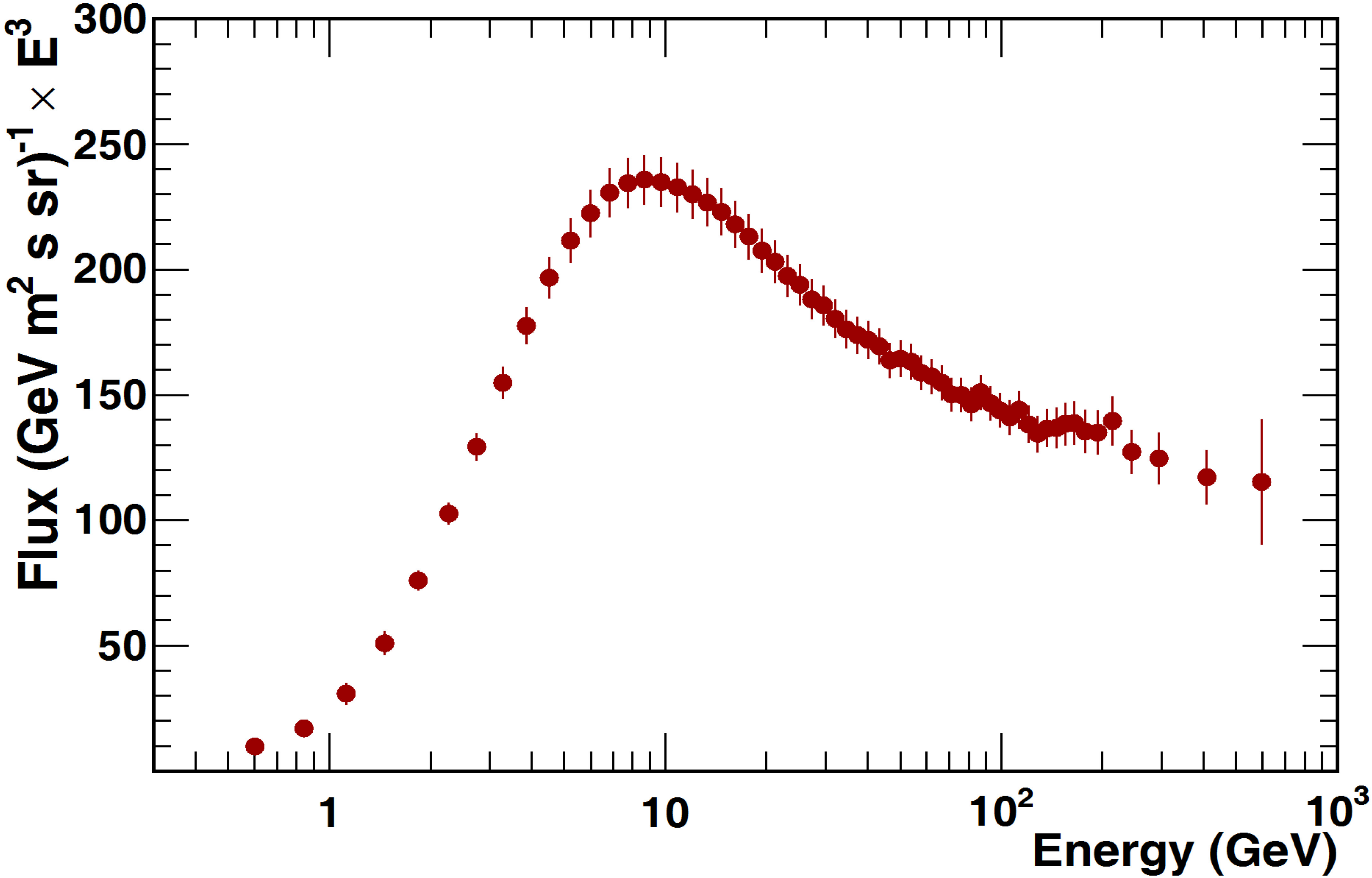
New results from AMS
Electron Spectrum



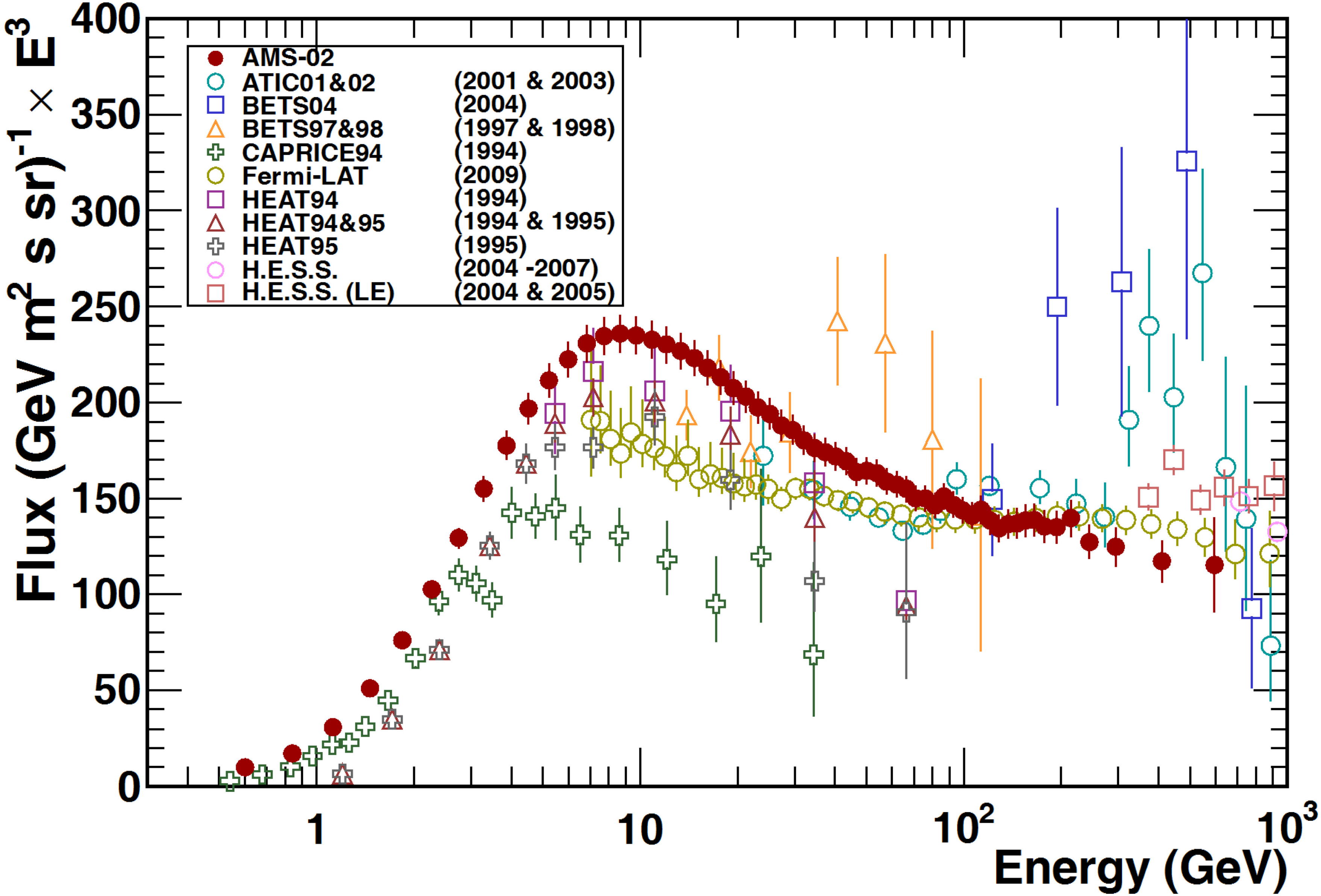
New results from AMS
Positron Spectrum



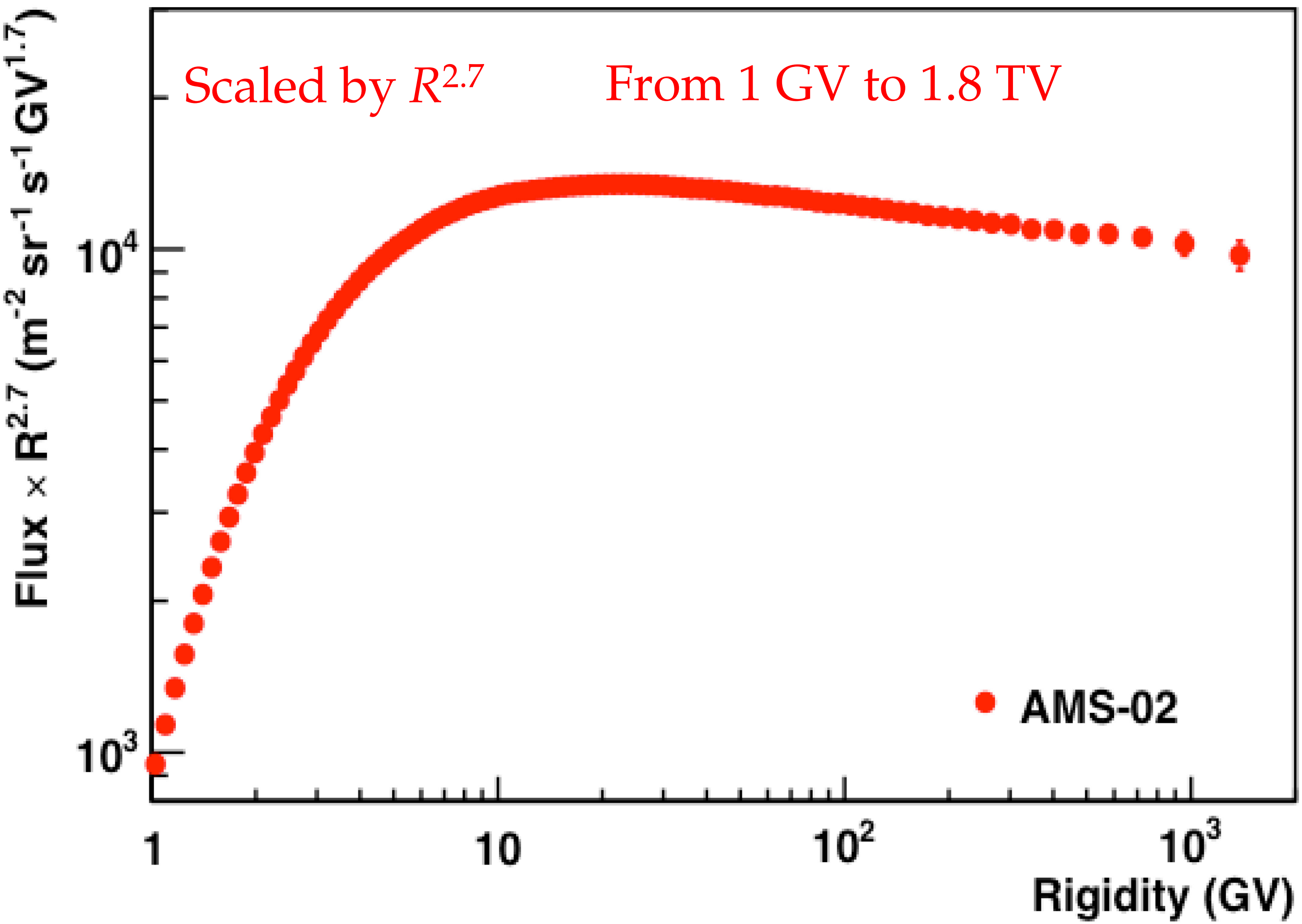
New results from AMS
(Electron plus Positron) Spectrum



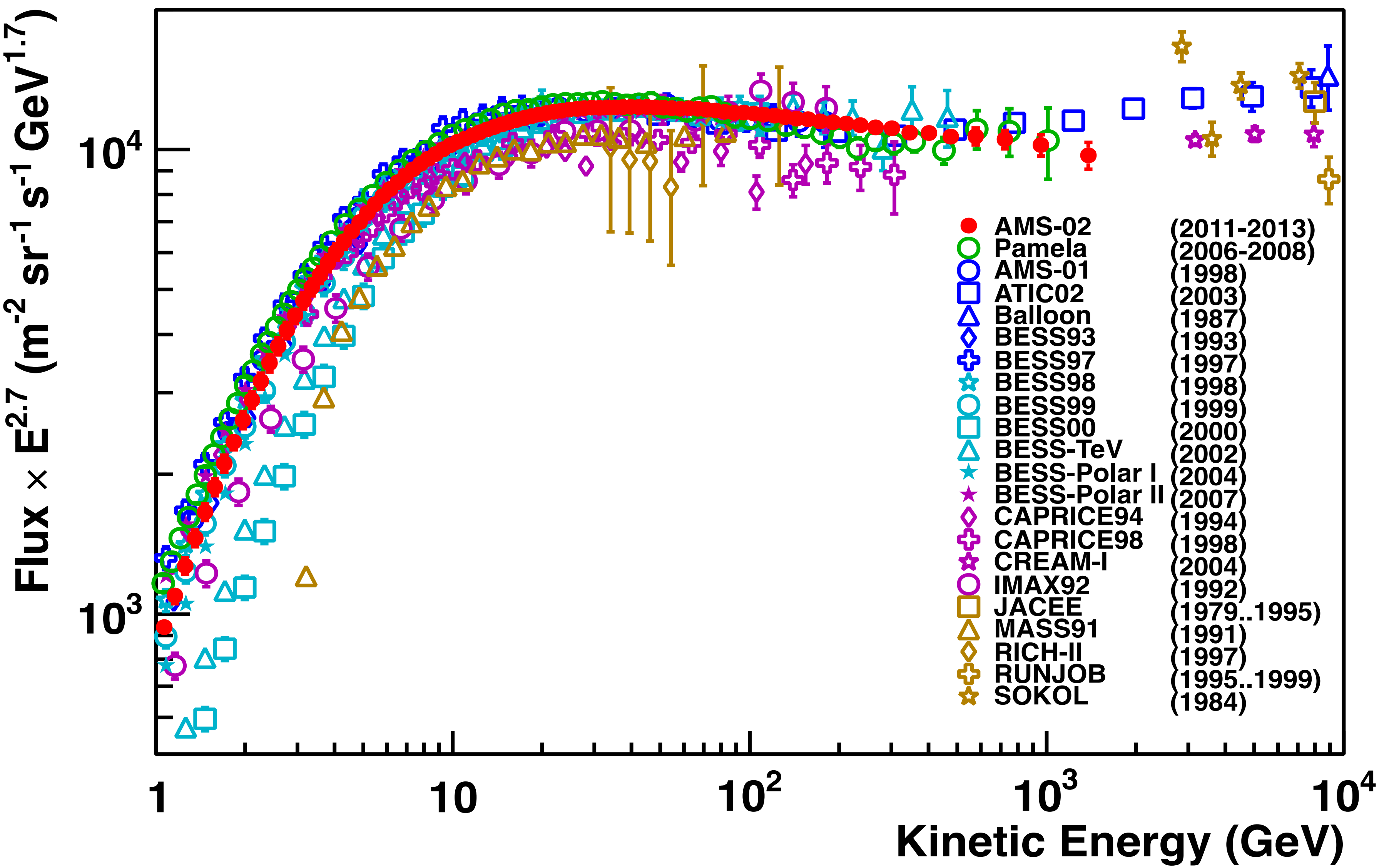
(Electron plus Positron) Spectrum



New results from AMS
Proton Flux

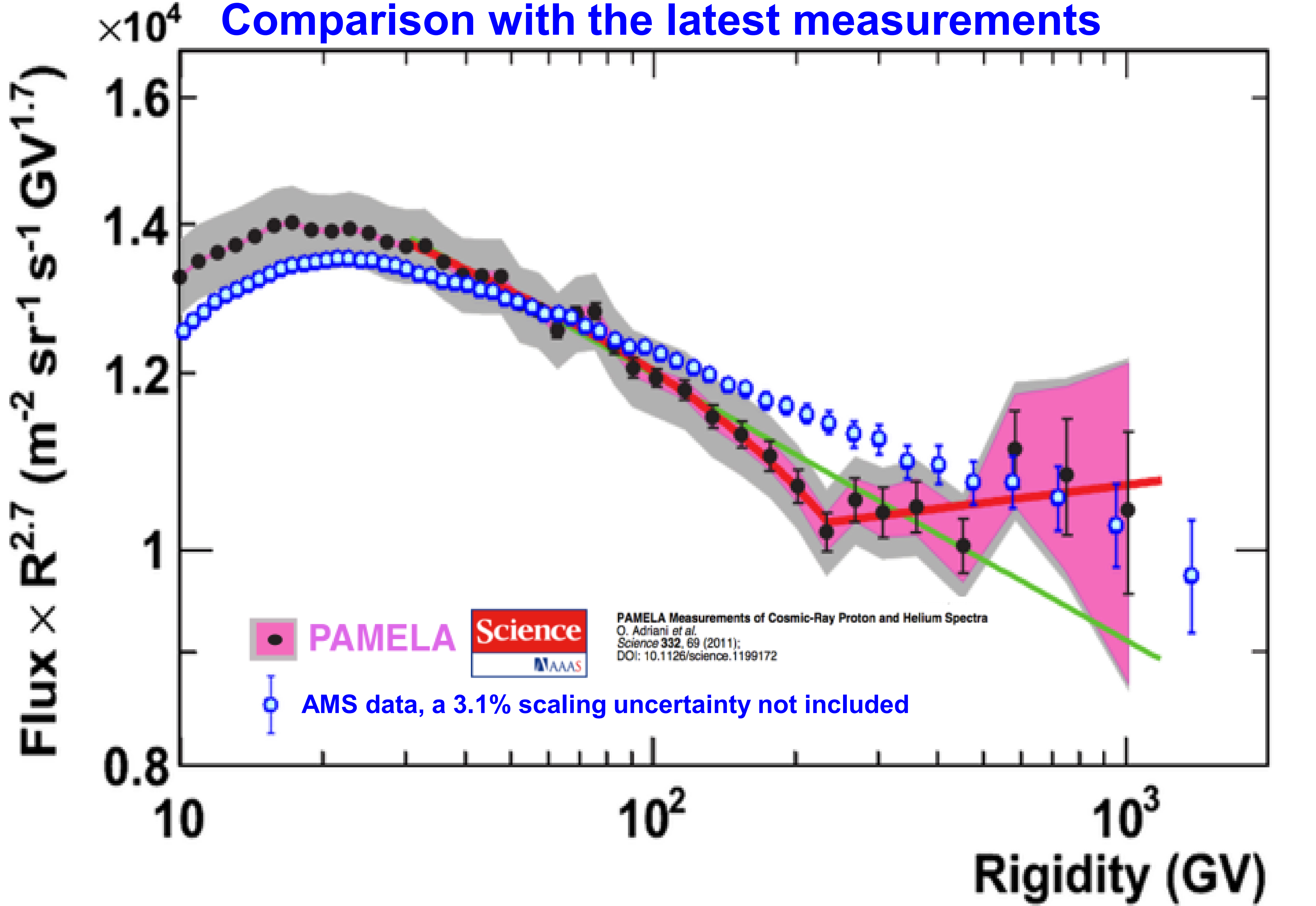


Proton Flux
Comparison with past measurements



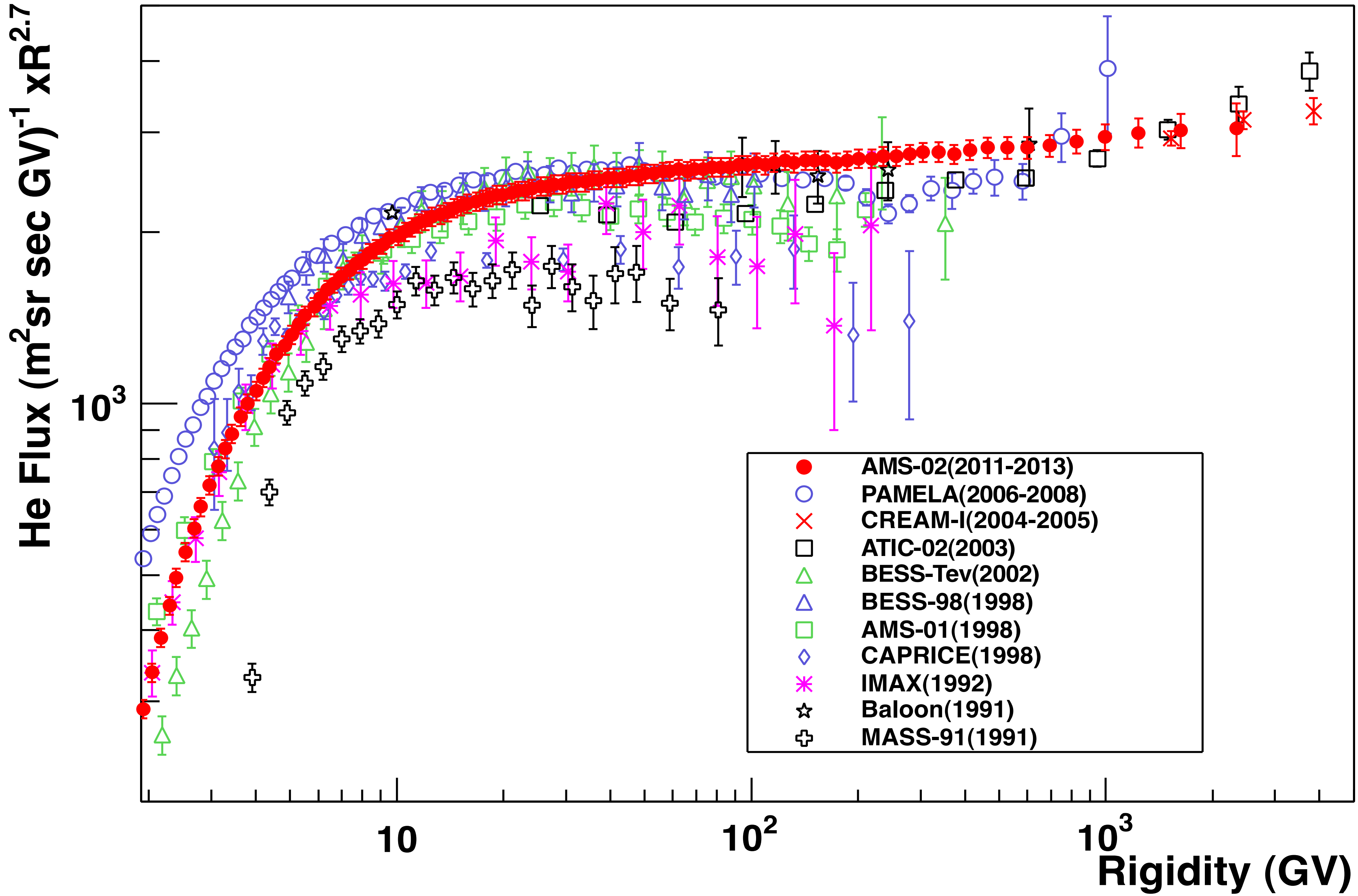
Proton Flux

Comparison with the latest measurements



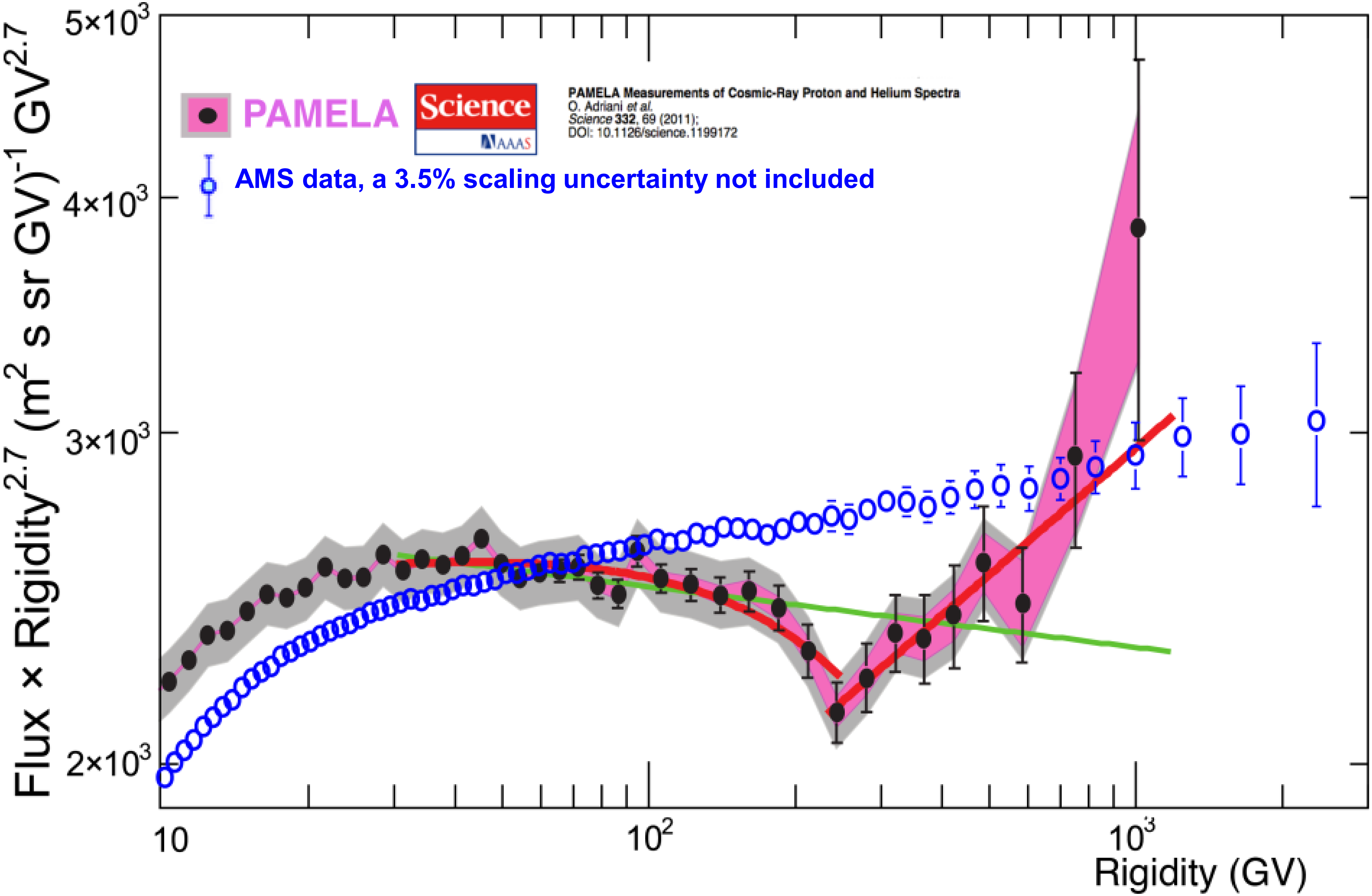
Helium Flux

Comparison with past measurements



Helium Flux

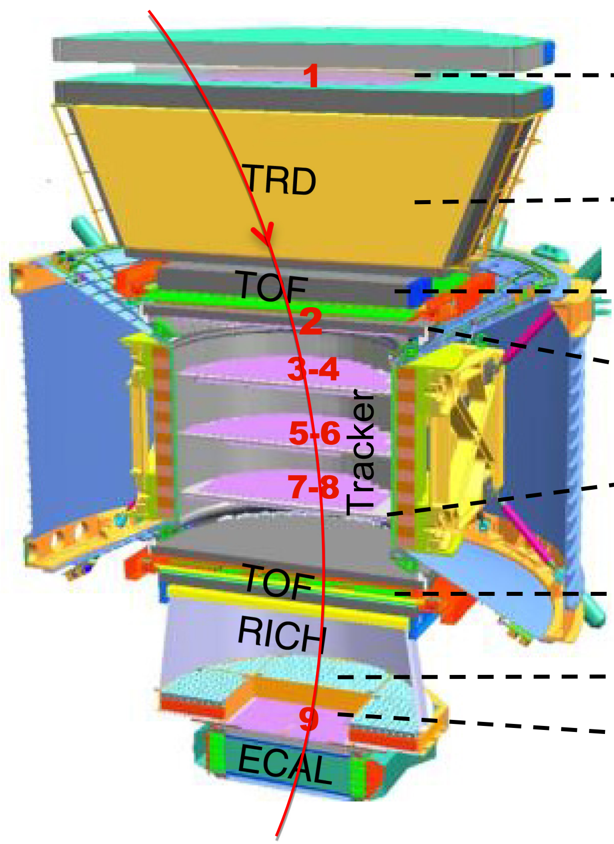
Comparison with the latest measurements



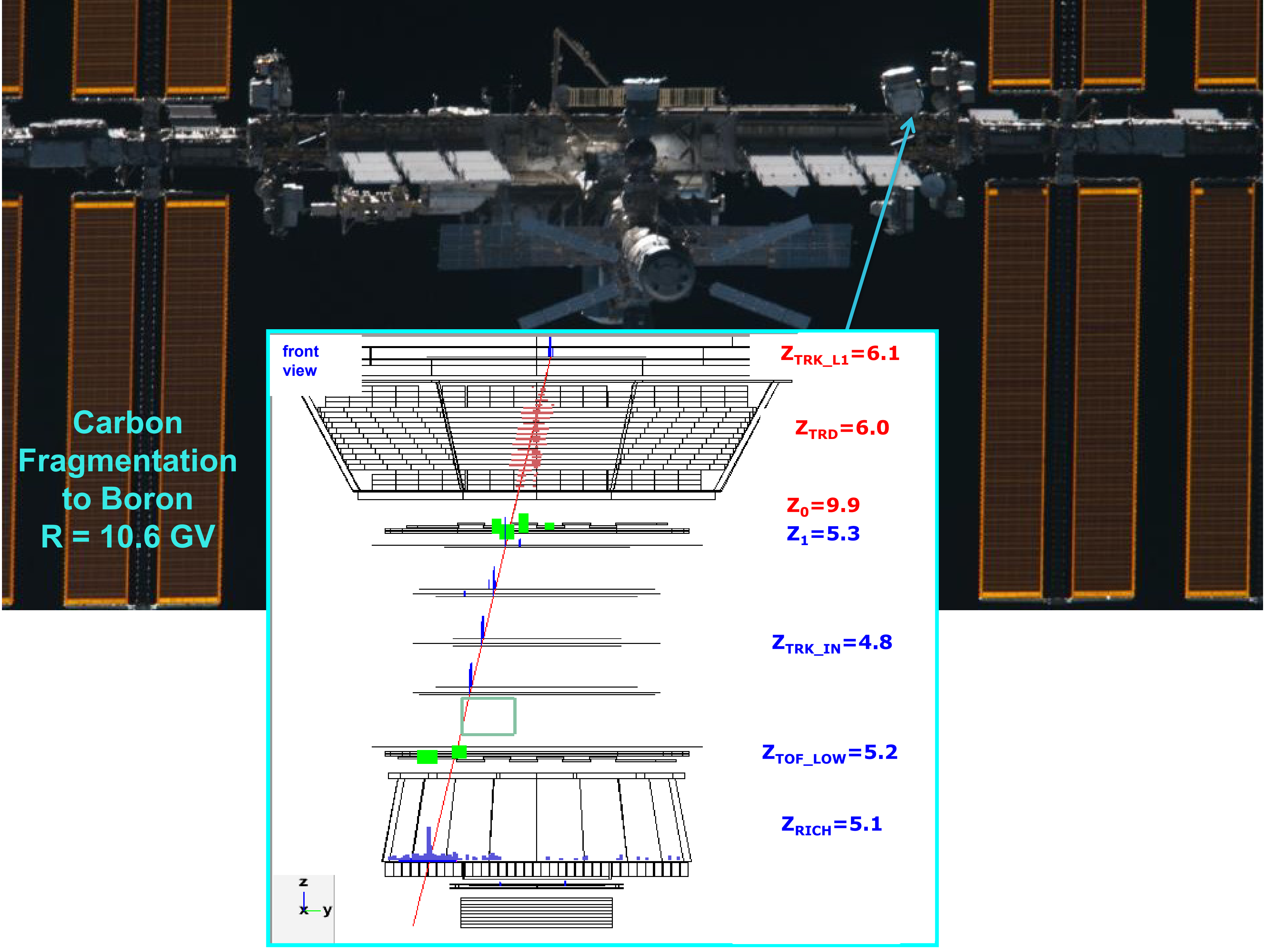
New results from AMS Boron-to-Carbon ratio

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|)



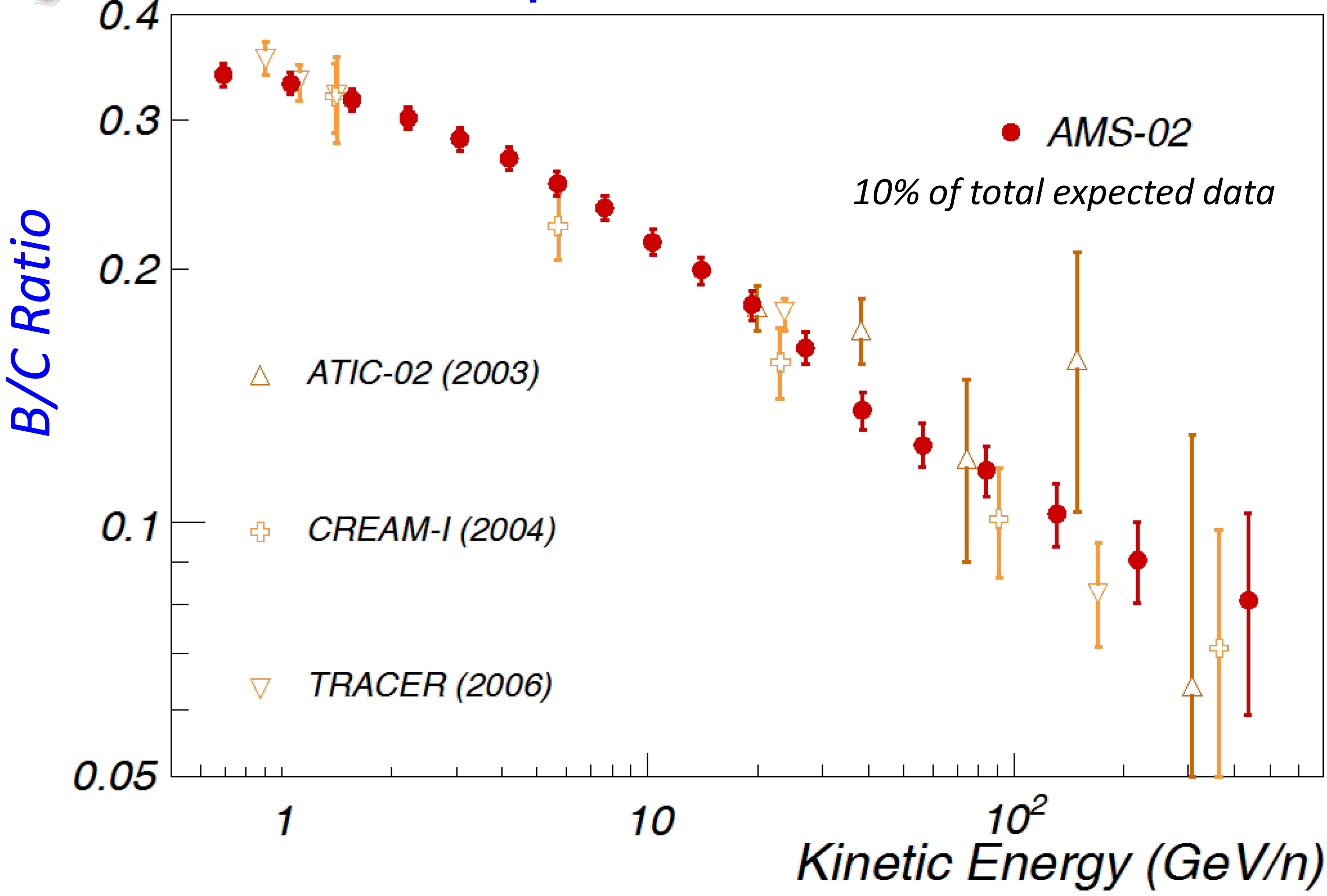
Measurement	Carbon (Z=6) ΔZ (cu)
1. Tracker Plane 1	0.30
2. TRD	0.33
3. Upper TOF (1 counter)	0.16
4. Tracker Planes 2-8	0.12
5. Lower TOF (1 counter)	0.16
6. RICH	0.32
7. Tracker Plane 9	0.30



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

comparison with recent data



We now understand the systematic errors to ~1%.

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

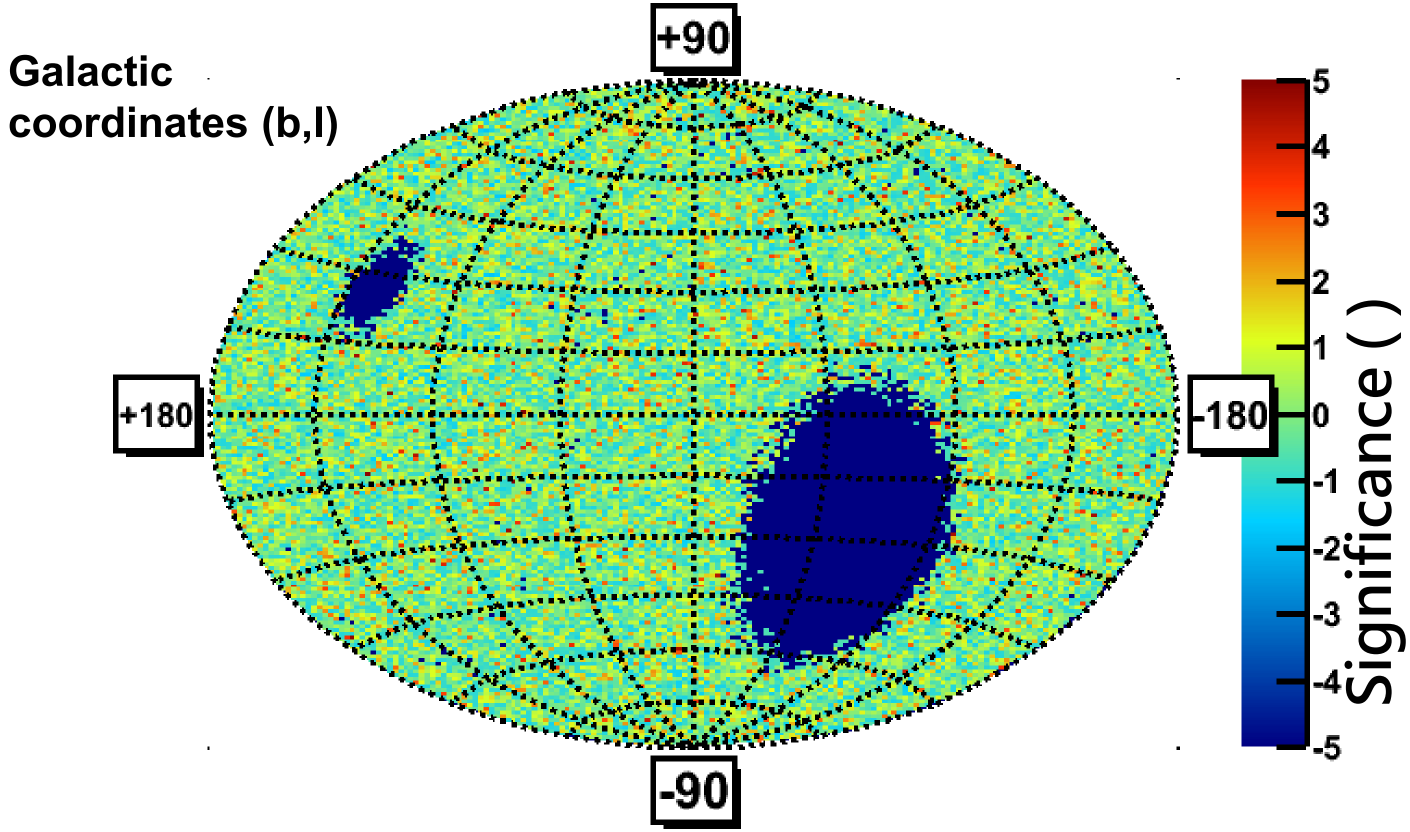
More new results will be announced soon.

Thank You!

New results from first 2 years of AMS

On the origin of excess positrons

If the excess has a particle physics origin, it should be isotropic



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

Limits on the amplitude of a dipole anisotropy in any axis in galactic coordinates on the positron to electron ratio

$\delta \leq 0.030$ at the 95% confidence level

Anisotropy

Primary sources of cosmic ray positrons and electrons may induce some degree of anisotropy of the measured positron to electron ratio, that is, the ratio of the positron flux to the electron flux. Therefore, a systematic search for anisotropies using the selected sample is performed from 16 to 350 GeV.

Arrival directions of electrons and positrons are used to build a sky map in galactic coordinates, (b, l), containing the number of observed positrons and electrons. The fluctuations of the observed positron ratio are described using a spherical harmonic expansion

$$\frac{r_{\rm e}(b,l)}{< r_{\rm e} >} - 1 = \sum_{\ell=0}^{\infty} \sum_{m=-\ell}^{\ell} a_{\ell m}\, Y_{\ell m}(\pi/2 - b, l),$$

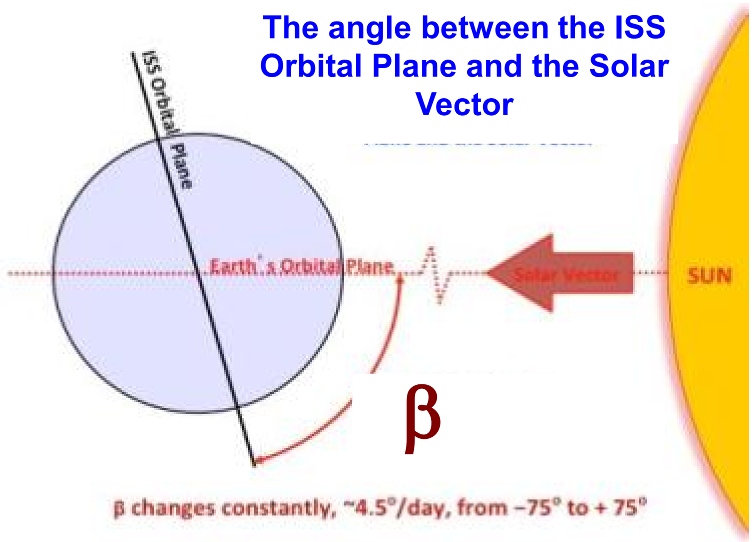
where $r_{\rm e}(b,l)$ denotes the positron ratio at (b,l); $< r_{\rm e} >$ is the average ratio over the sky map; $Y_{\ell m}$ are spherical harmonic functions and $a_{\ell m}$ are the corresponding weights. The coefficients of the angular power spectrum of the fluctuations are defined as

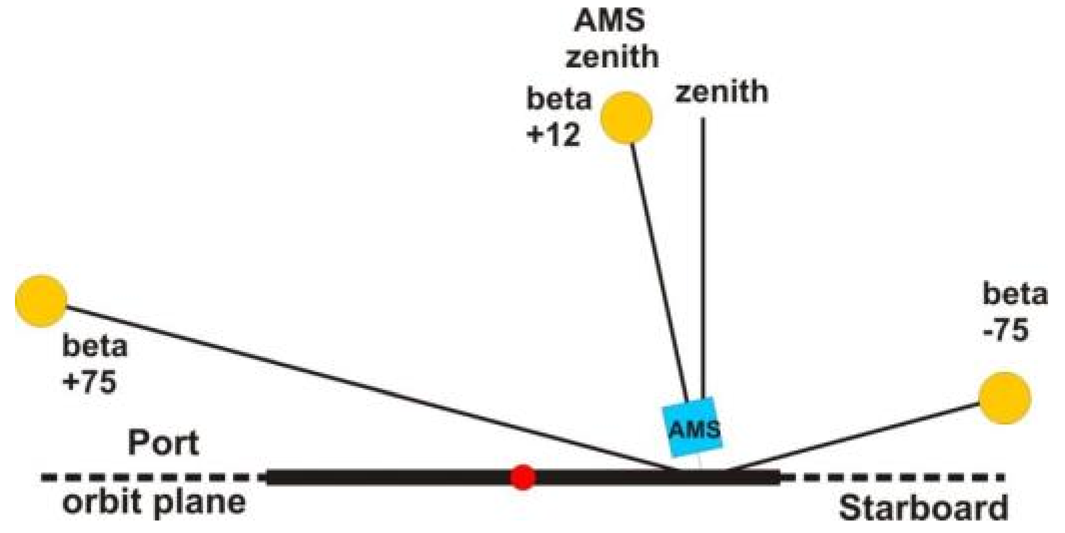
$$C_\ell = \frac{1}{2\ell + 1} \sum_{m=-\ell}^{\ell} |a_{\ell m}|^2.$$

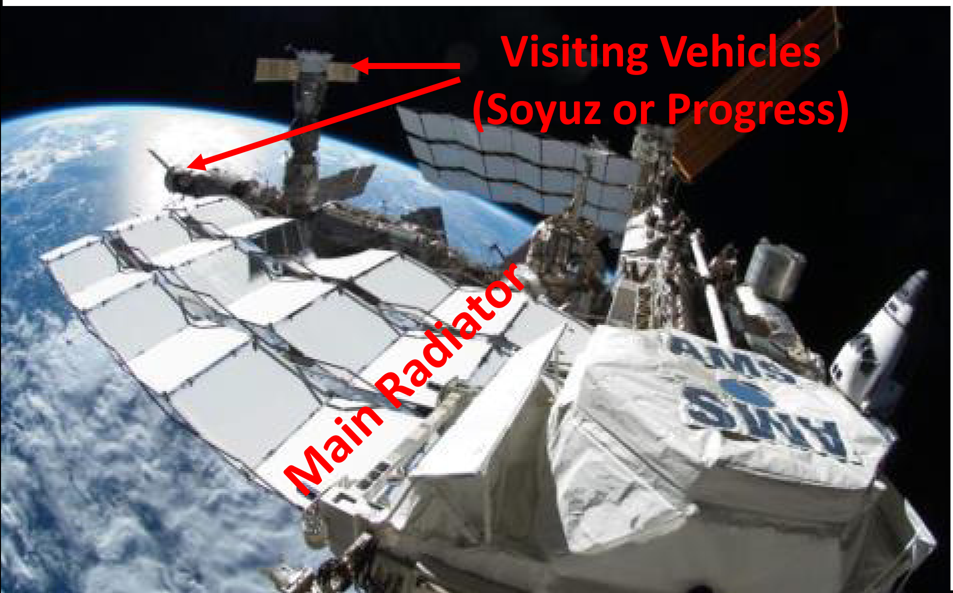
They are found to be consistent with the expectations for isotropy at all energies and upper limits to multipole contributions are obtained. We obtain a limit for any axis in galactic coordinates on the amplitude of dipole anisotropy on the positron to electron ratio of

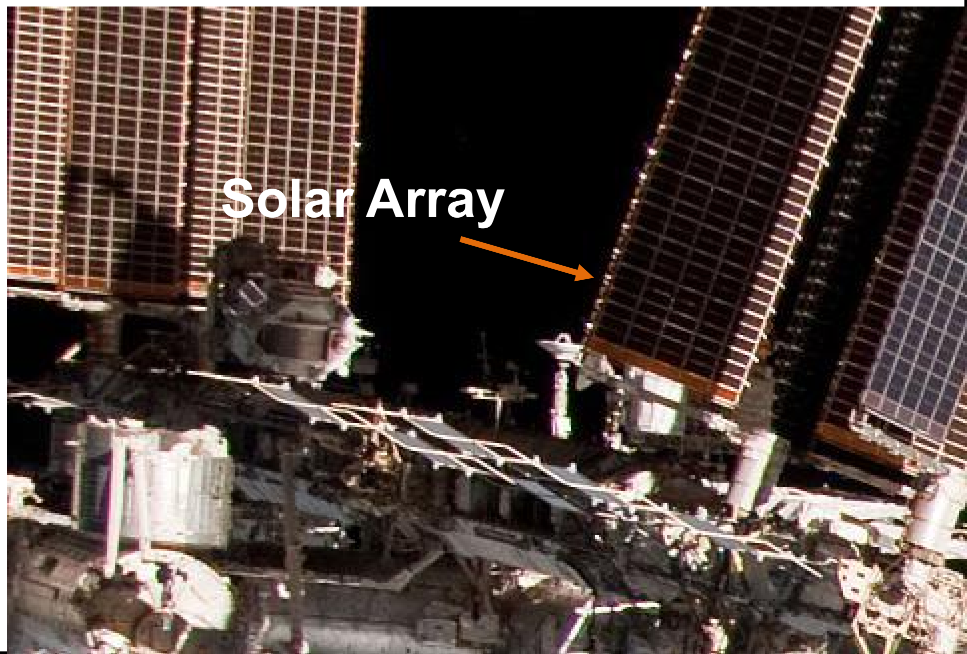
$$\delta = 3\sqrt{C_1/4\pi} \leq 0.036 \quad (95\%\ C.L.)$$

The thermal environment on ISS is constantly changing due to:

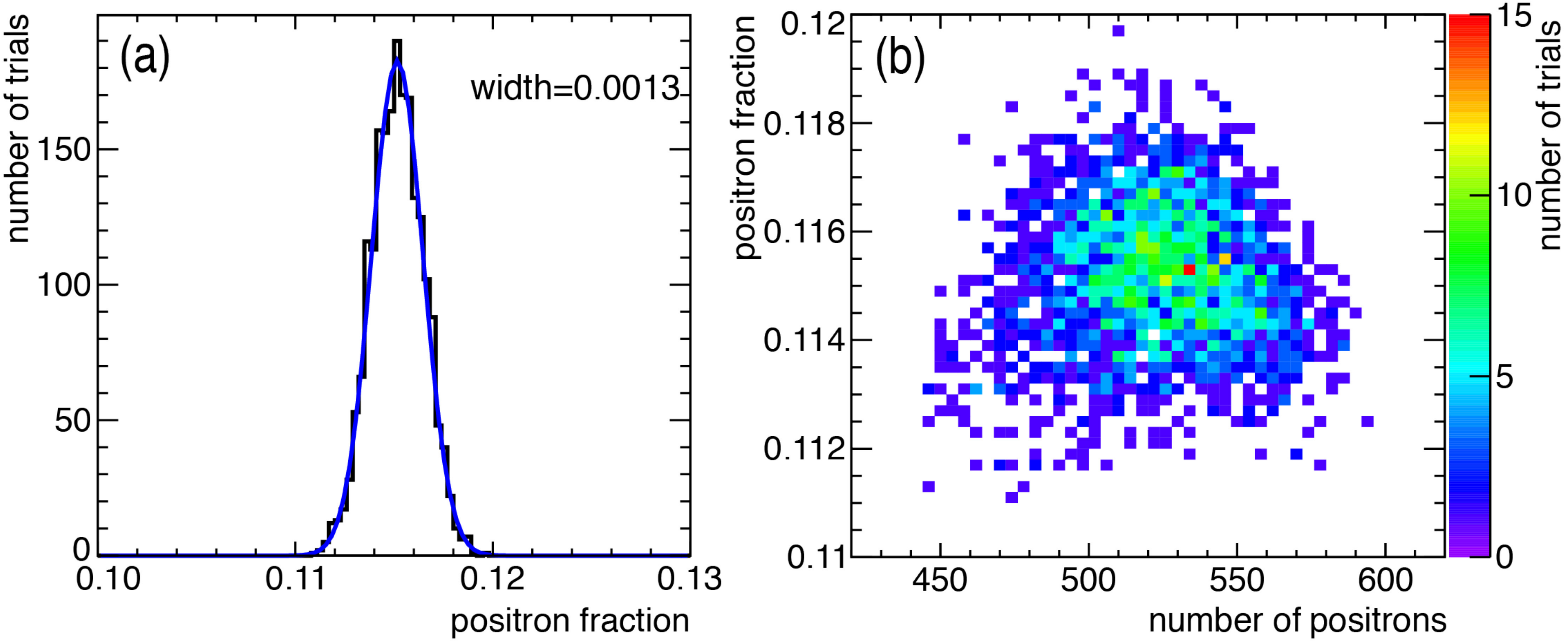








Systematic error on the positron fraction: 2. Selection dependence



The measurement is stable over wide variations of the cuts in the TRD identification, ECAL Shower Shape, E (from ECAL) matched to |P| (from the Tracker), …

For each energy bin, over 1,000 sets of cuts were analyzed.

Selection of Z > 1 particles

Nuclei with charge Z are selected demanding consistency between the TOF and Inner Tracker charge determinations