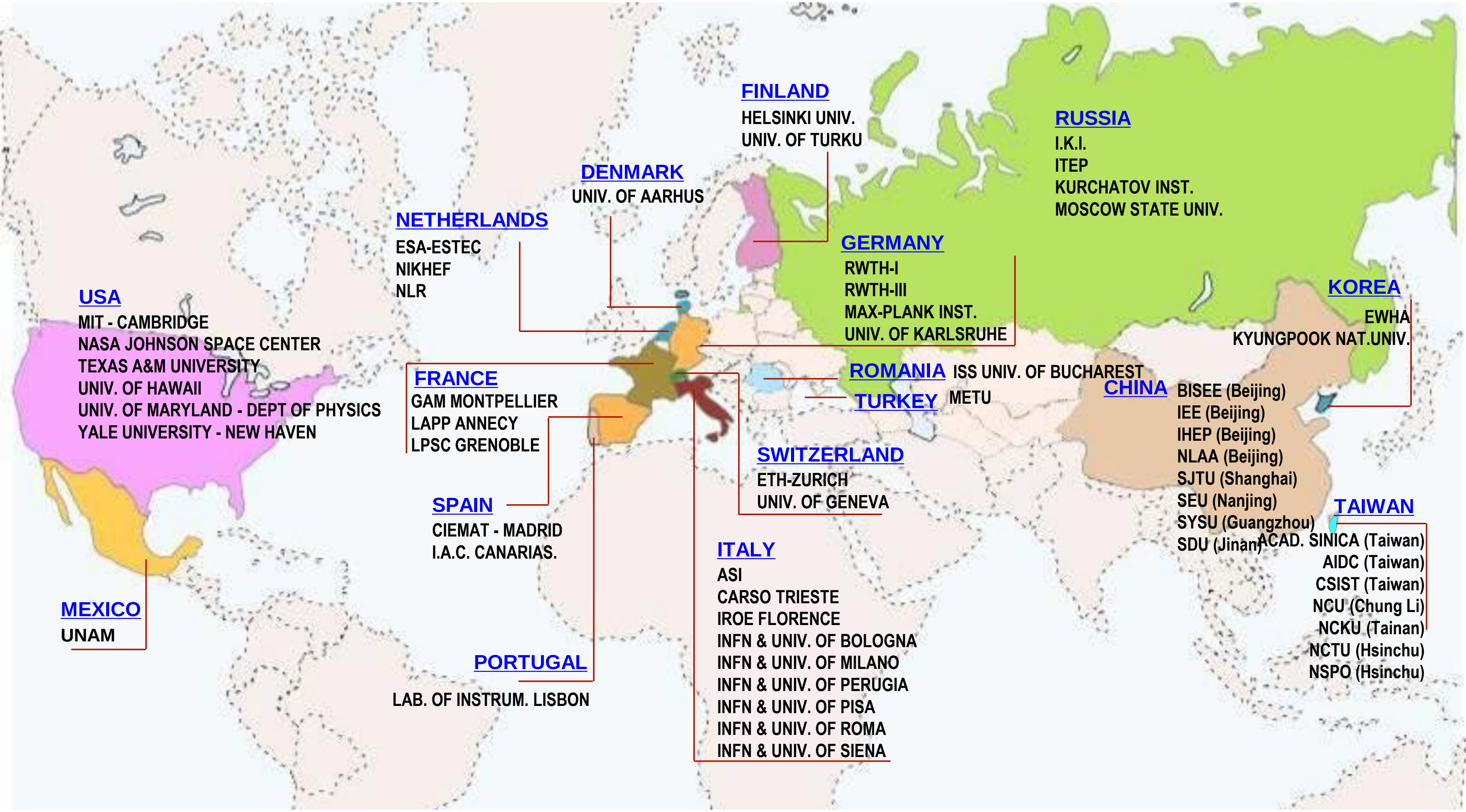
First Result from

the Alpha Magnetic Spectrometer (AMS) Experiment
on the International Space Station.

ISS: 109 m x 80 m
Cost: $ 100 billion
Life time 20 years

S. Ting
2013

AMS: a U.S. DOE sponsored international collaboration



Strong support from

NASA (D. Goldin, C. Bolden, L. Garver, G. Abbey, W. Gerstenmaier, M. Sistilli, T. Martin, K. Bollweg, …)

and DOE (J. Siegrist, M. Salamon, D.Kovar, S. Gonzalez, R. Staffin, J. O'Fallon, …)

Italy in AMS

Istituto Nazionale di Fisica Nucleare

agenzia spaziale italiana

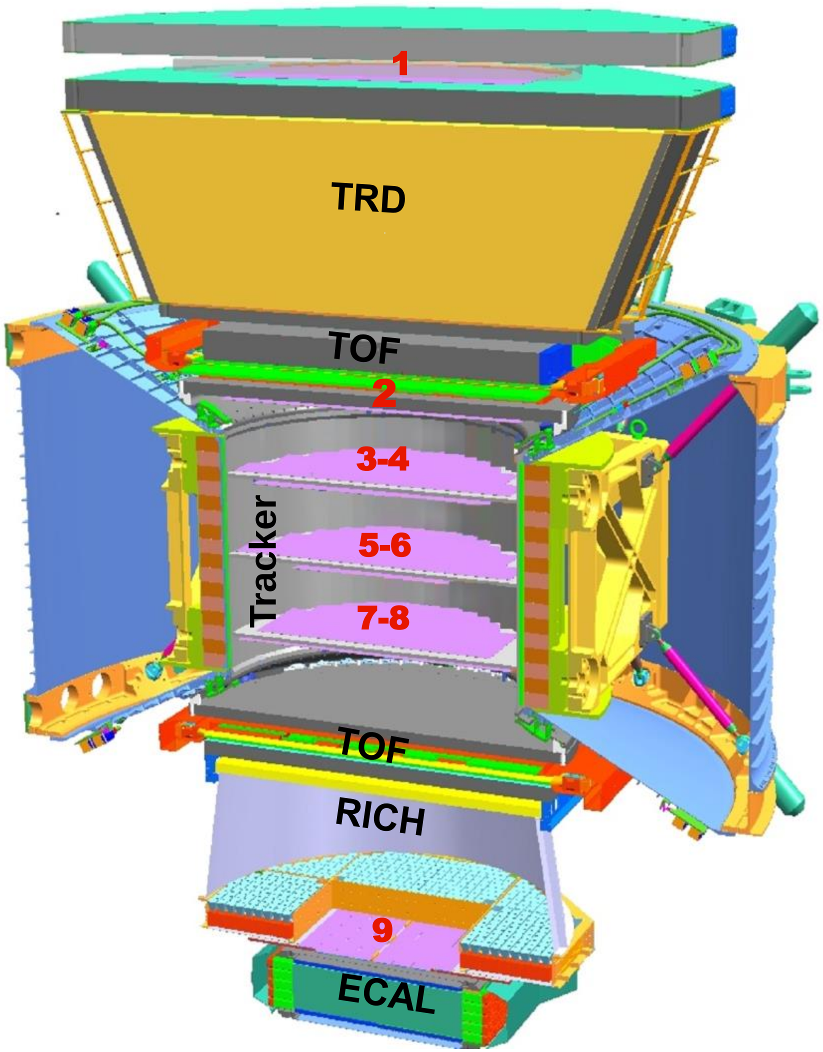
60 Scientists and Engineers
- 6 Universities
- 5 INFN Sections
- 2 INFN National Laboratories

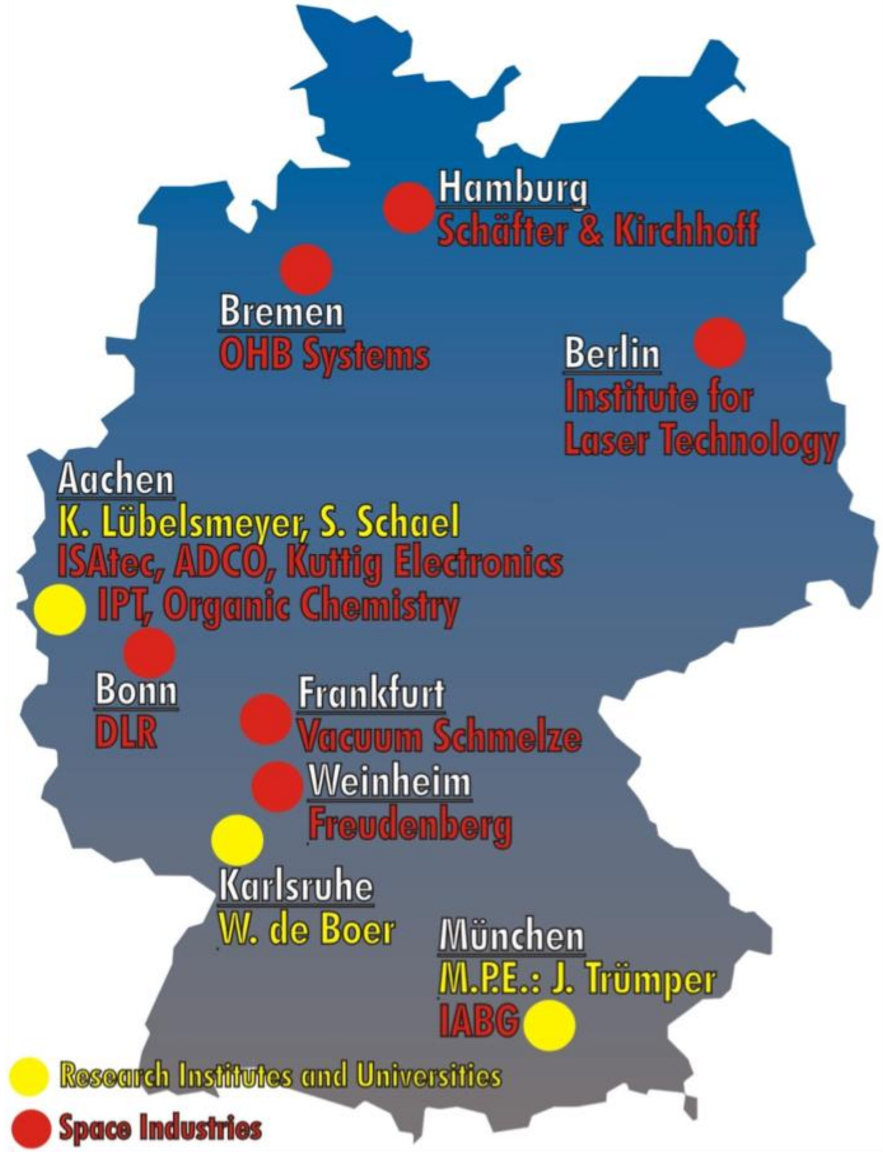
1 INFN Computing center

16 years of collaboration among INFN and ASI

AMS Group at INFN and University of Perugia

Germany in AMS
Magnet and the Tracker,
the Transition Radiation Detector and
the Anti-Coincidence Counter System



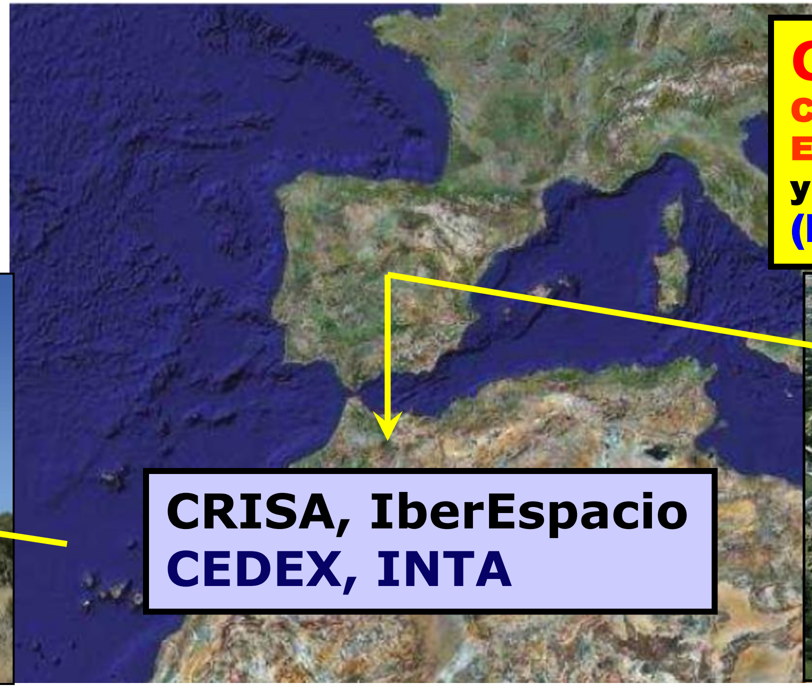


Coordinator 1994-2000: K.Luebelsmeyer
Coordinator 2000 - : St.Schael

Completion of the TRD required a 10 year full-time effort

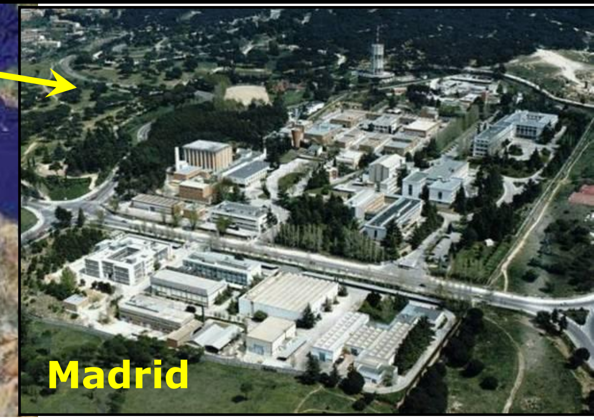
SPAIN IN AMS

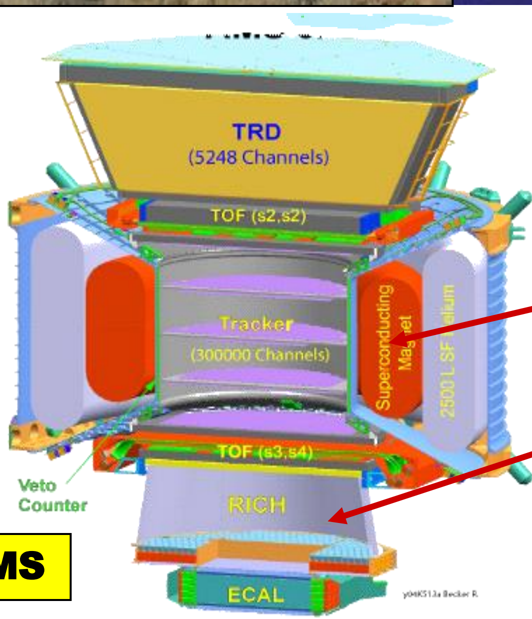
IAC
Instituto de Astrofísica de Canarias
(MINECO)



CRISA, IberEspacio
CEDEX, INTA

CIEMAT
Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas
(MINECO)





AMS

- **Magnet**
- **Cherenkov Detector**

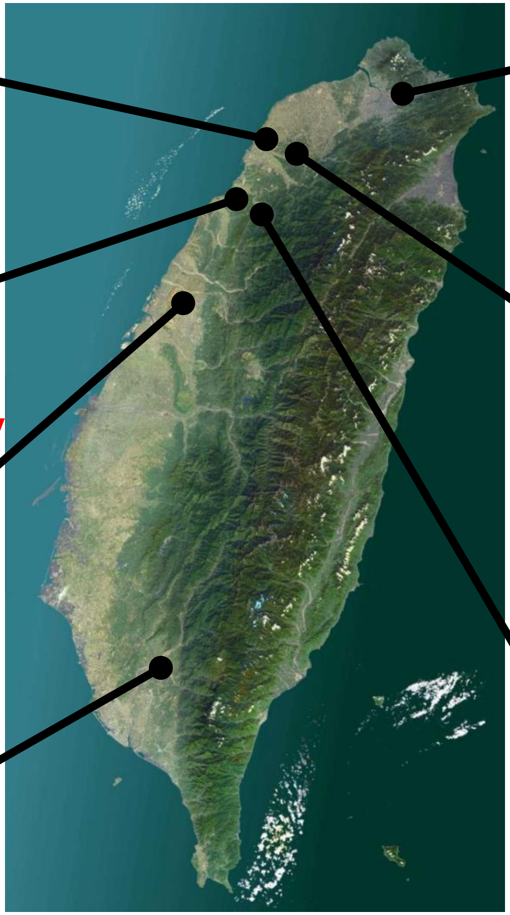
AMS Collaboration Management

AMS — CIEMAT

China in AMS

CAST
IEE
NLAA
IHEP
SDU
SEU
SJTU
SYSU
Hailar
Qiqihar
Harbin
Changchun
Shenyang
Yining
Kuqa
Urumqi
Aksu
Korla
Turpan
Kashgar
Yellow River
Hohhot
Beijing
Dunhuang
Jiayuguan
Baotou
Hetian
Yinchuan
Datong
Tianjin
Golmud
Xining
Shijiazhuang
Lanzhou
Taiyuan
Qingdao
Zhengzhou
Tibet
Xian
Kaifeng
Luoyang
Nanjing
Suzhou
Lhasa
Hefei
Shanghai
Shigatse
Tsedang
Chengdu
Yichang
Wuhan
Hangzhou
Tingri
Gyangtse
Chongqing
Huangshan
Zhangmu
Everest
Changsha
Lijiang
Nanchang
Diaoyu Islands
Yangtze River
Guiyang
Fuzhou
Dali
Guilin
Kunming
Yangshuo
Xiamen
Guangzhou
Taiwan
Shenzhen
Nanning
Hong Kong
Macau
Haikou
Dongsha Islands
Sanya

Taiwan in AMS



National Central University

National ChiaoTung University

AIDC

National Cheng Kung University

Academia Sinica

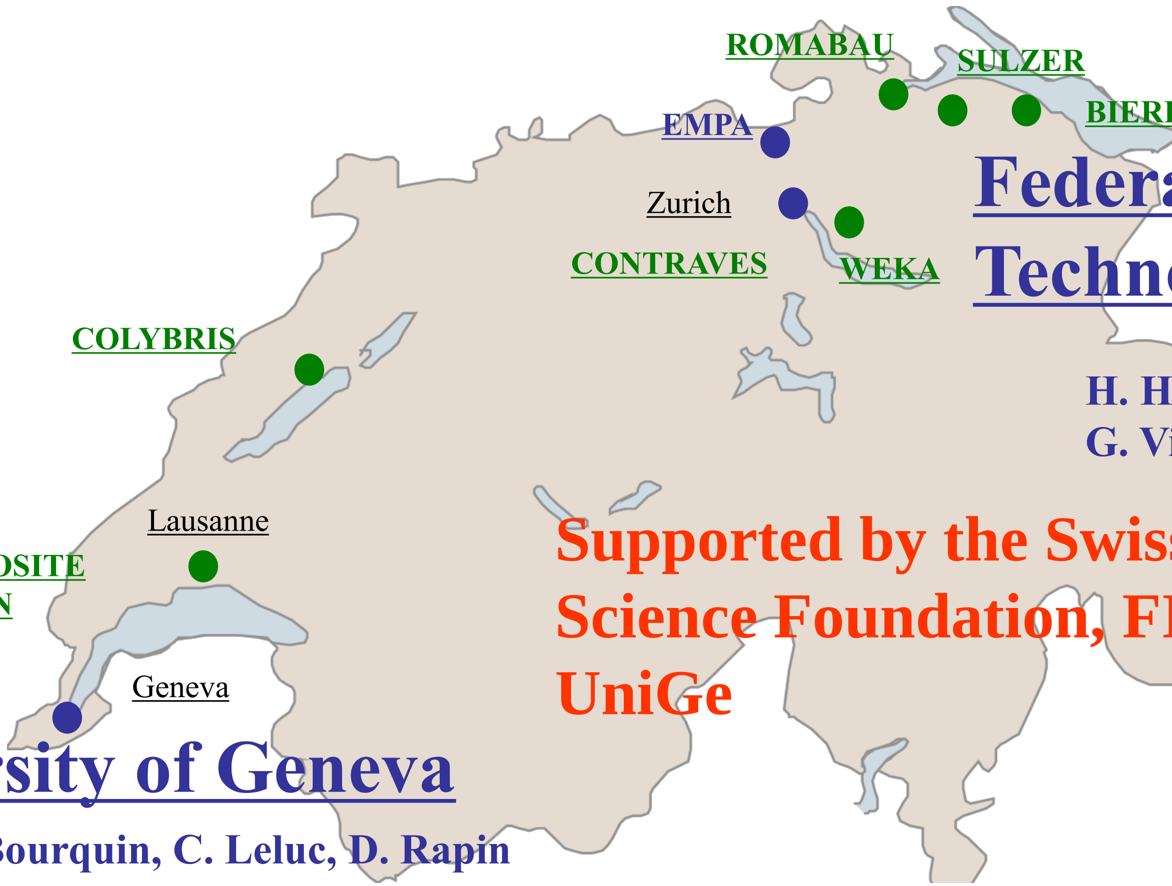
Chung-Shan Institute of Science and Technology

NSPO

National Space Organization

Coordinator Academician S.C. Lee

Swiss Participation in AMS



Federal Institute of Technology Zurich

H. Hofer, F. Pauss,
G. Viertel, J. Ulbricht

Supported by the Swiss National Science Foundation, FIT Zurich, UniGe

University of Geneva

M. Pohl, M. Bourquin, C. Leluc, D. Rapin

Martin Pohl
Director Particle Physics Dept
University of Geneva

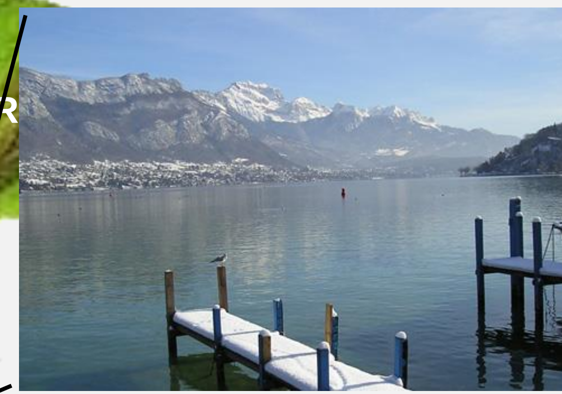
University of Geneva in AMS: A long term commitment

- Two generations of professors
- Two generations of engineers
- Three generations of PhD students

French participation to AMS

FUNDING FROM :
CNRS/IN2P3, University of Grenoble, CNES, RHONE-ALPES, Haute-Savoie

LAPP
Annecy Le Vieux

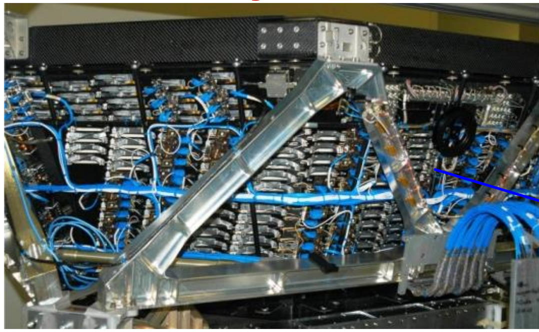


LPSC Grenoble


AMS

AMS: A TeV precision, multipurpose spectrometer

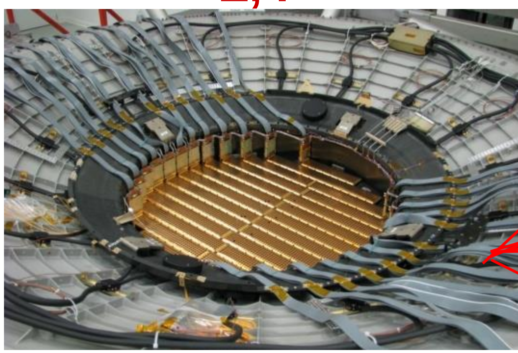
TRD
Identify e^+, e^-

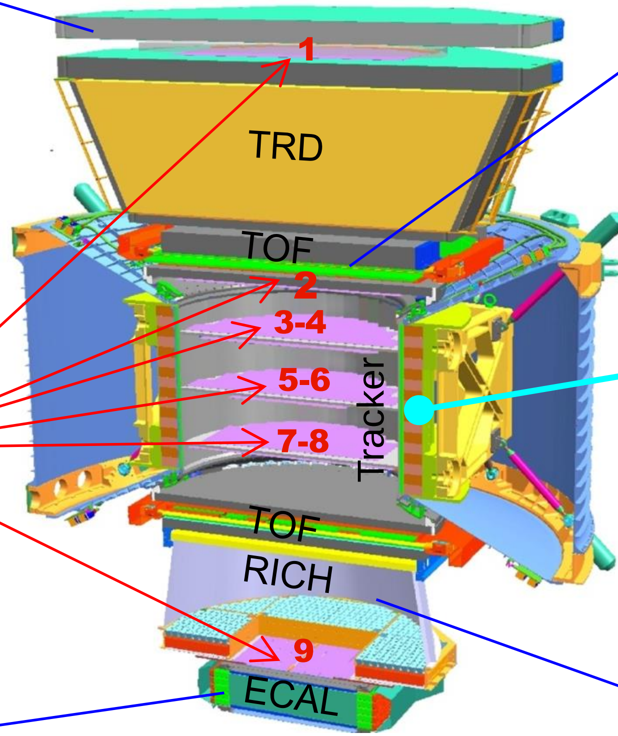


Particles and nuclei are defined by their charge (Z) and energy (E ~ P)

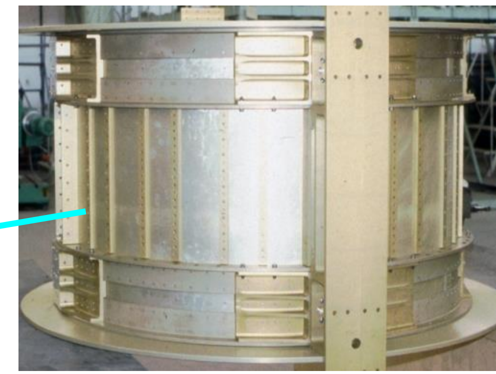
TOF
Z, E

Silicon Tracker
Z, P

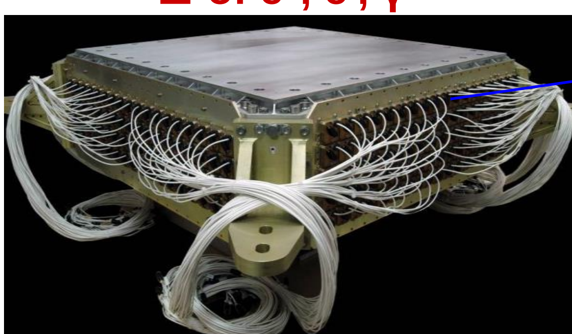




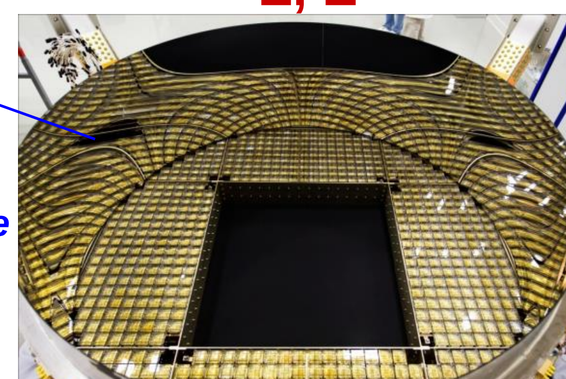
Magnet
±Z



ECAL
E of e^+, e^-, γ

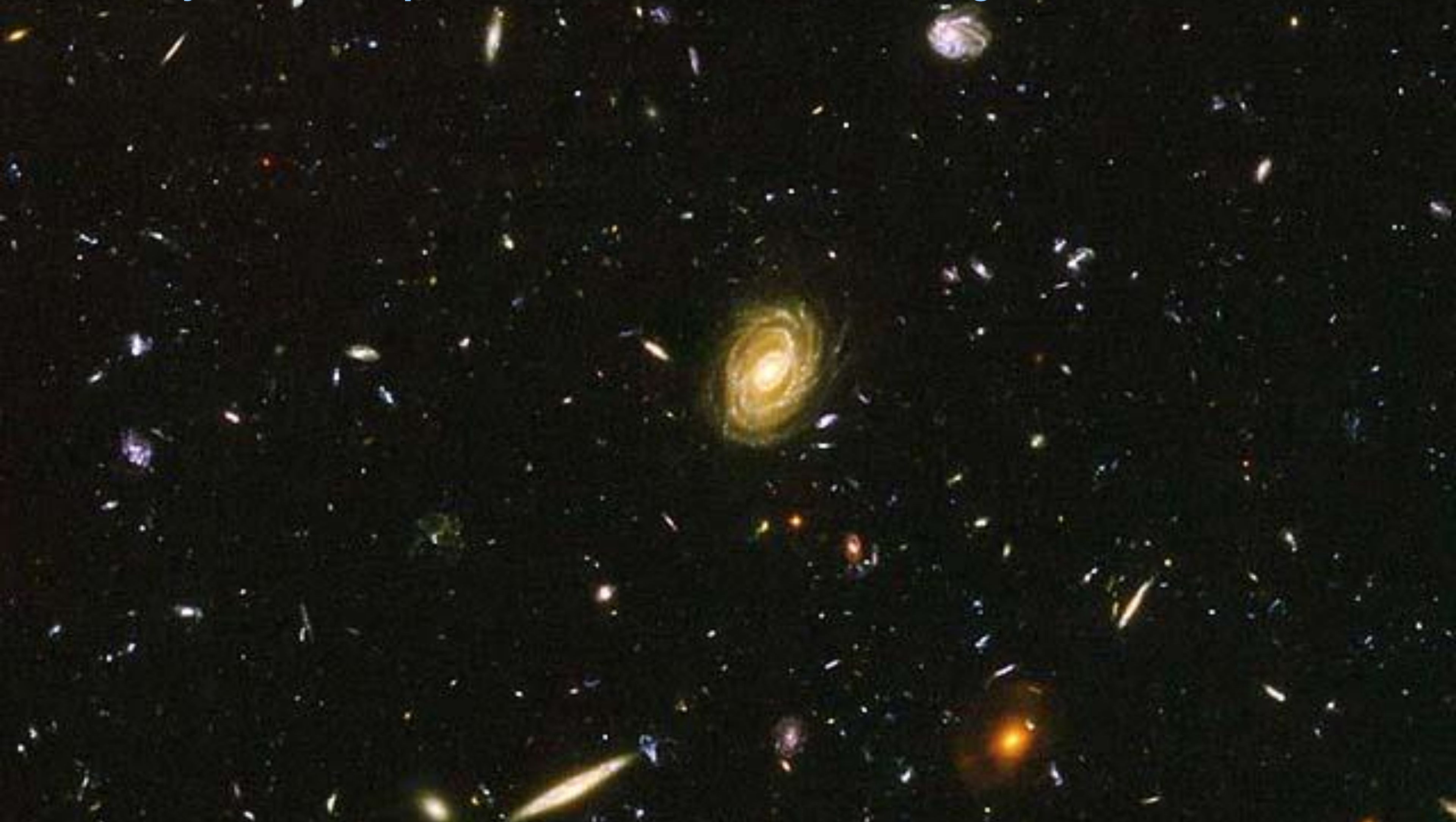


RICH
Z, E



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

Physics Example of AMS: Search for the origin of Dark Matter:

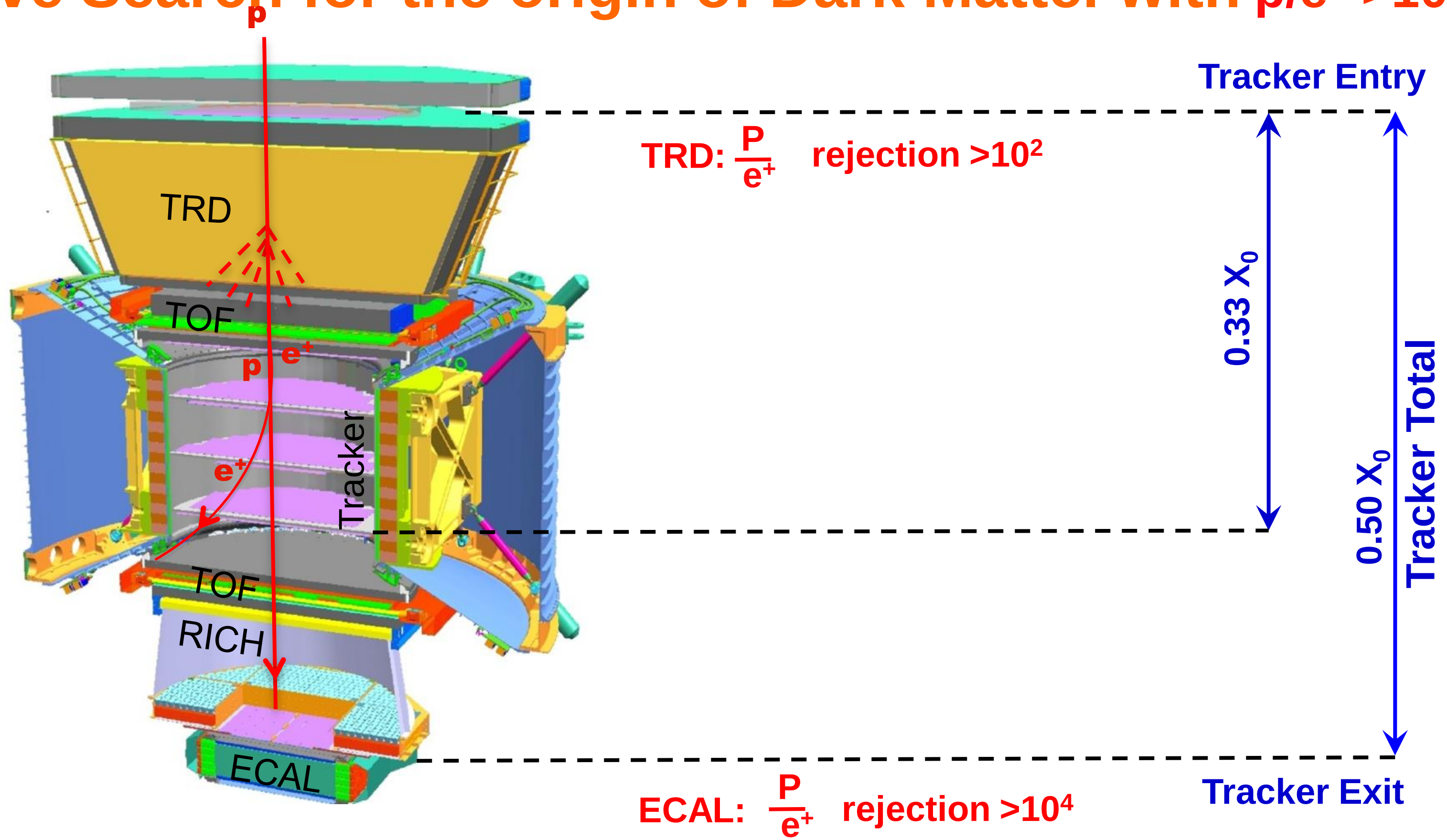


Collision of Cosmic Rays produce e+ …

Collisions of Dark Matter will produce additional e+

These characteristics of additional e+ can be measured very accurately by AMS

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

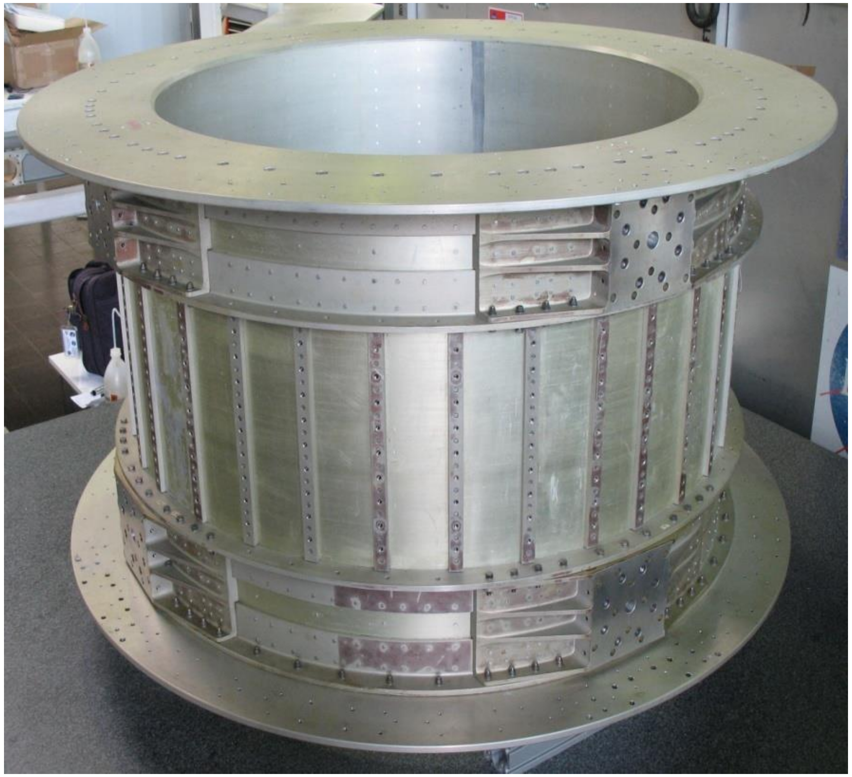


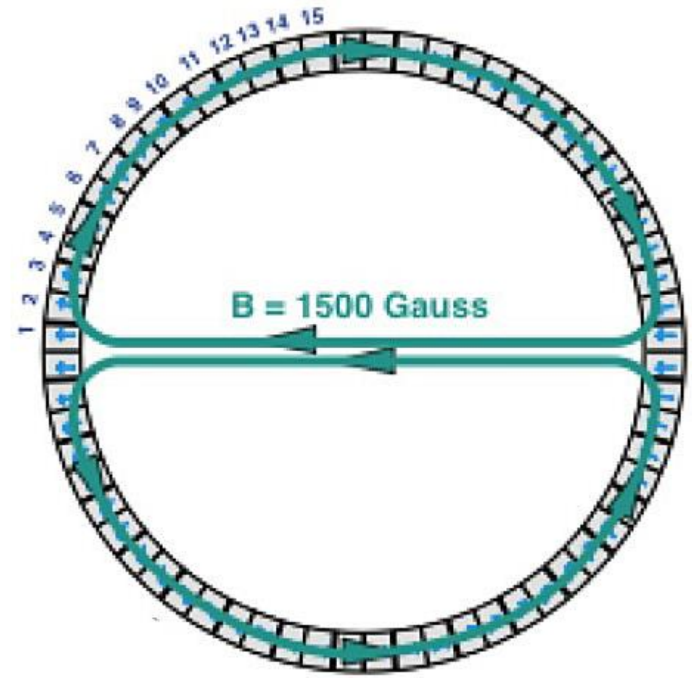
a) Minimal material in the TRD and TOF
So that the detector does not become a source of e^+.

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

The Magnet



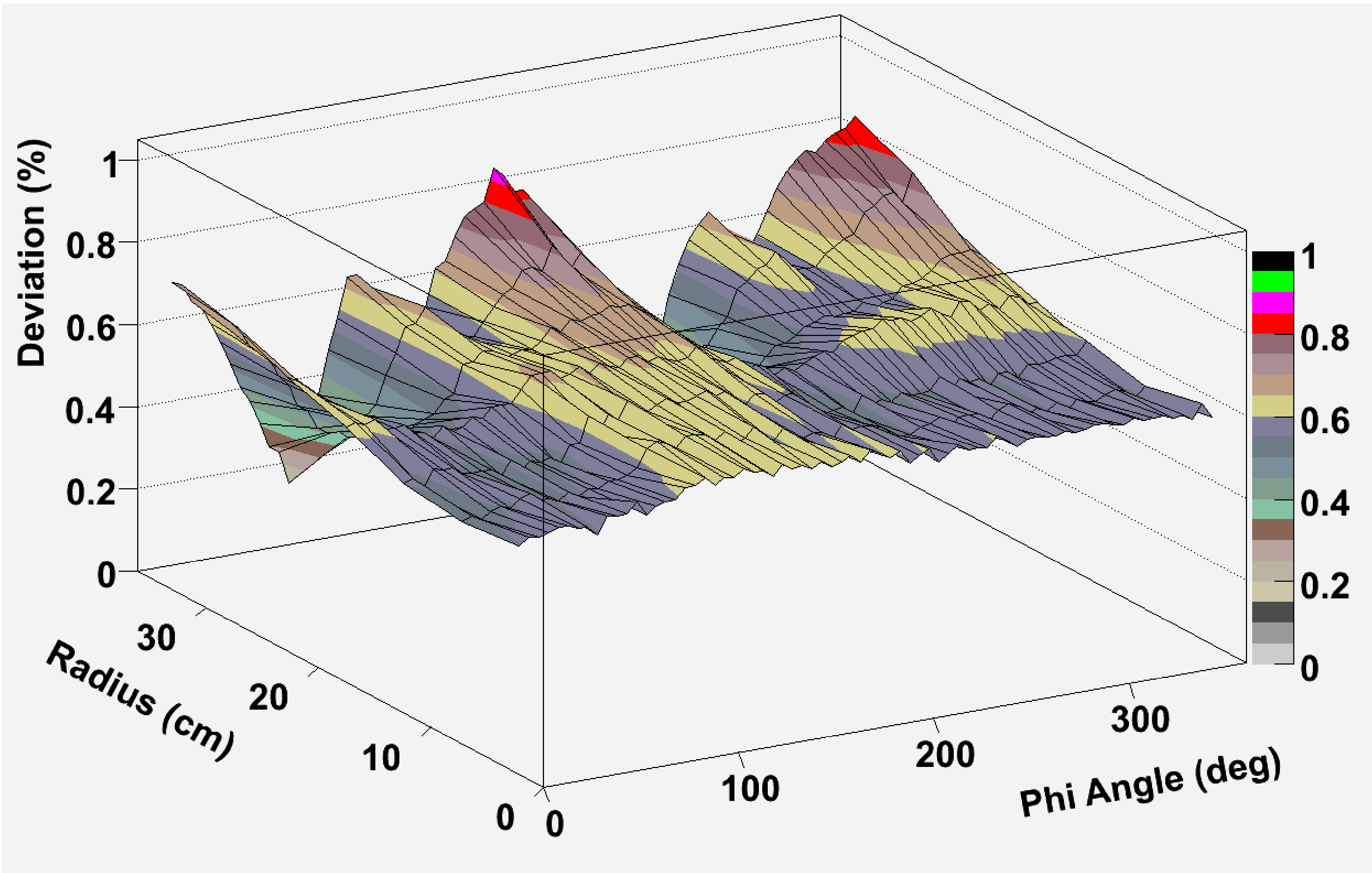


1. Stable: no torque
2. Safety : no field leak out of the magnet
3 . Low weight: no iron

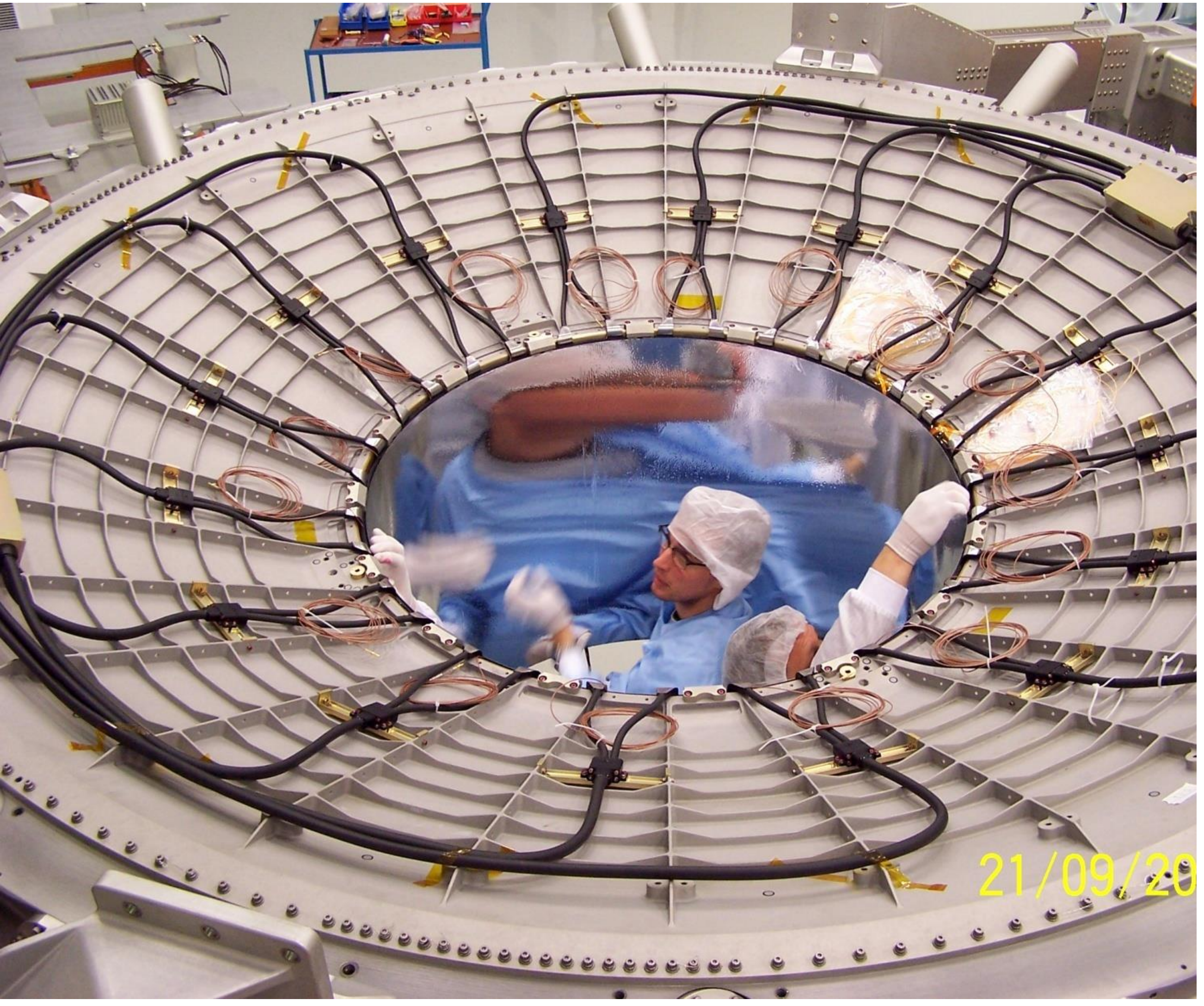
The detailed 3D field map (120k locations) was measured in May 2010

It was found that the deviation from the 1997 measurement had remained the same to <1%

Deviation from 1997 measurements in R-Phi coordinates, Z=0



Veto System rejects random cosmic rays

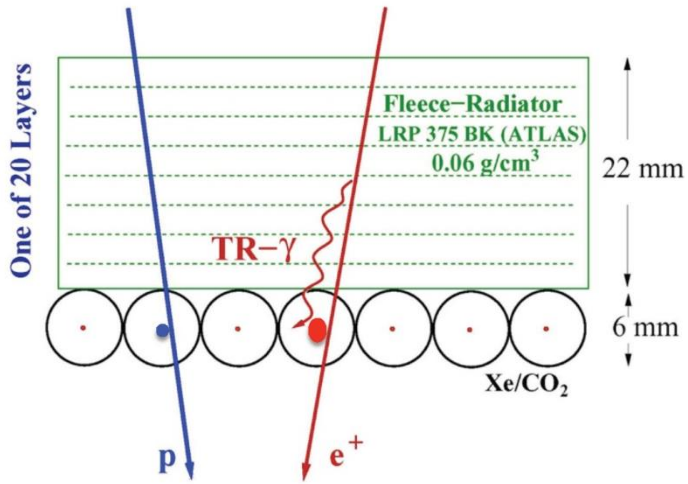


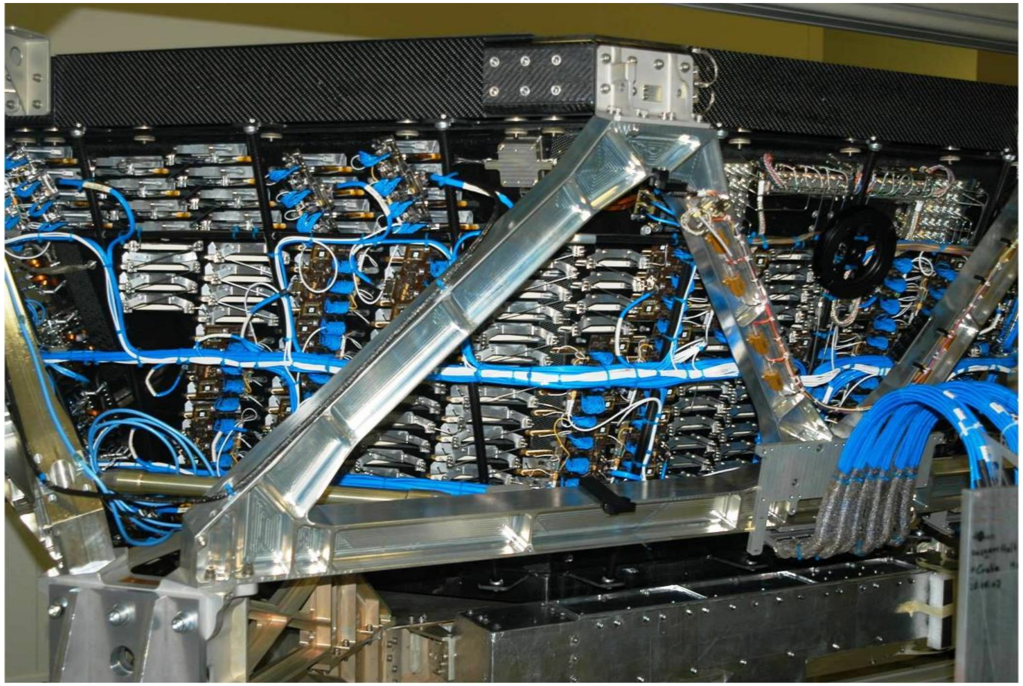
Measured veto(ACC) efficiency better than 0.99999

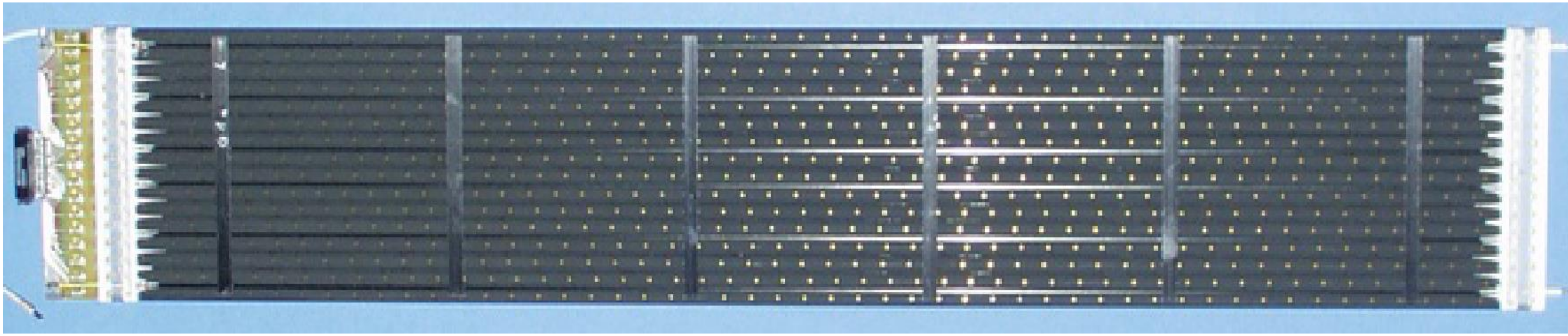
Transition Radiation Detector (TRD) Identifies Positrons, Electrons by transition radiation and Nuclei by dE/dX

20 Layers each consisting of:

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







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

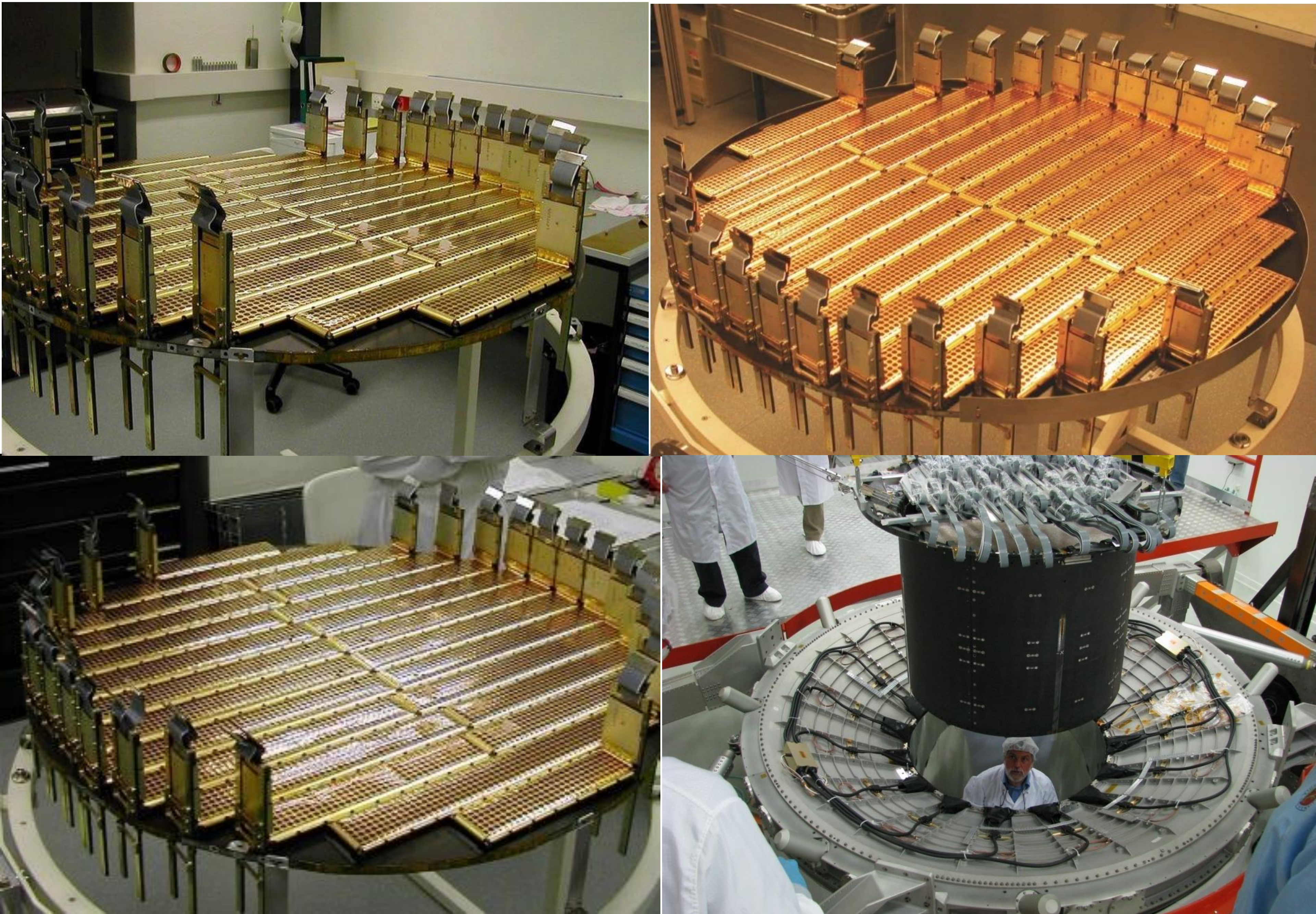
Professor Stefan Schael, RWTH Aachen

Silicon Tracker

The coordinate resolution is 10 microns

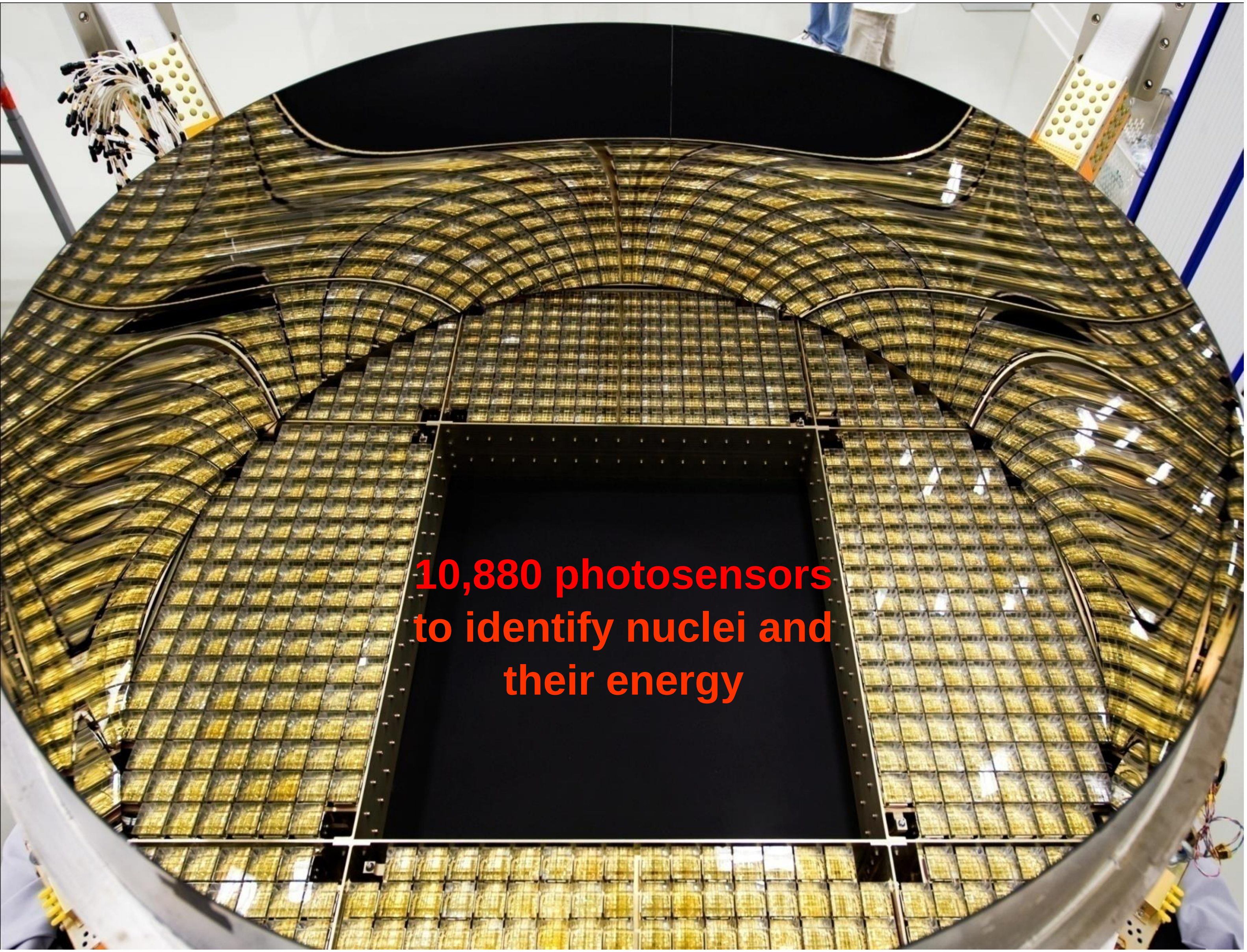
It has taken
50 engineers
3 years
to complete
the silicon
tracker

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



R. Battiston with US Senator B. Nelson, G. Bignami (ASI), J. Woerner (DLR)

Ring Imaging CHerenkov (RICH) 160 Gv



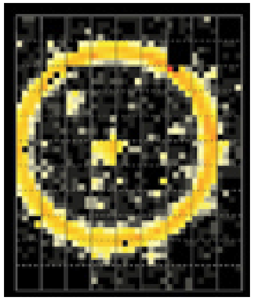
He

Li

C

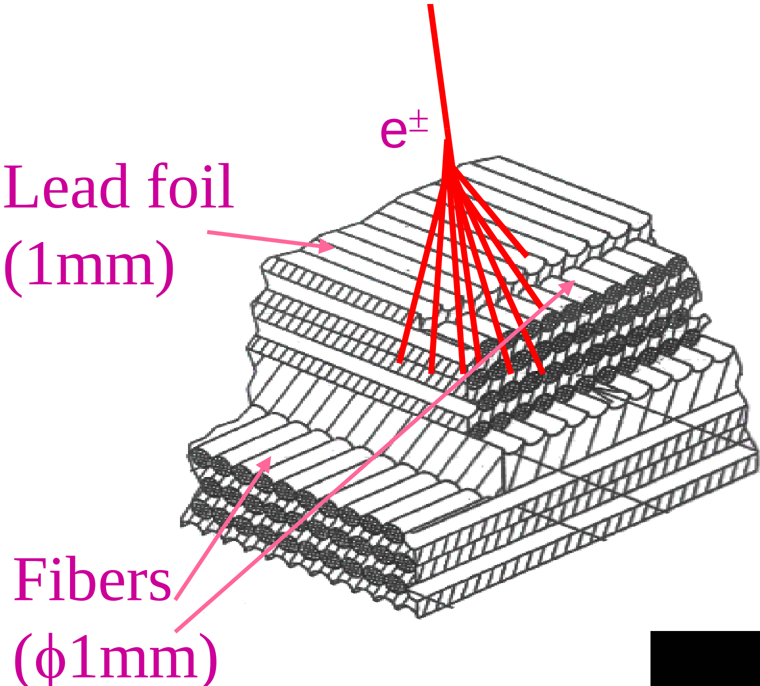
O

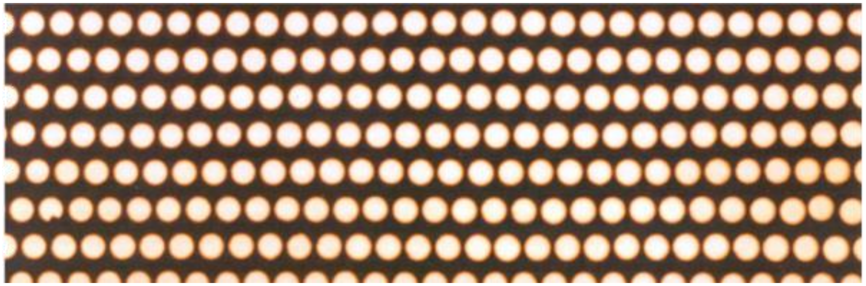
Ca



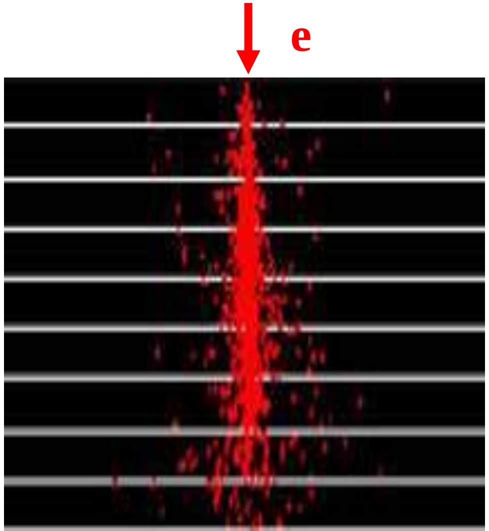
Calorimeter (ECAL)

A precision, 3-D measurement of the directions and energies of light rays and electrons up to 1 TeV

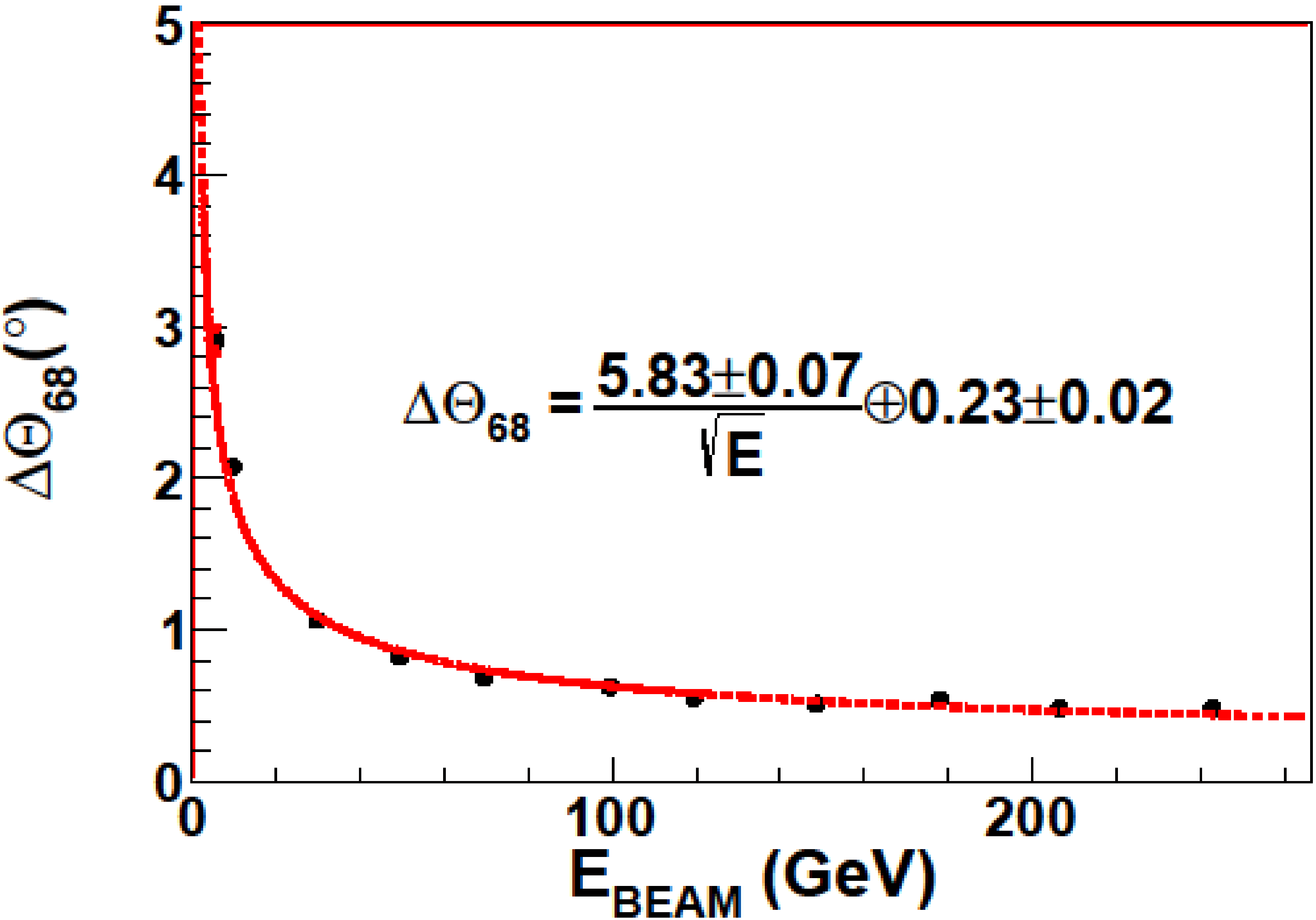




50,000 fibers, $\phi = 1$ mm
distributed uniformly Inside 600 kg of lead
Total 17 X_0



ECAL angular resolution



Professors F. Cervelli, M. Incagli, Pisa

AMS Electronics

Reliability: operational for 20 years.

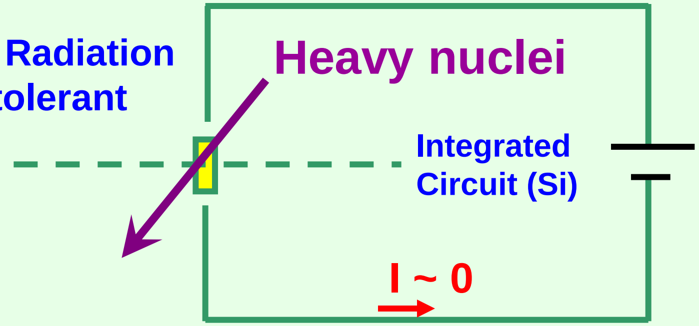
Fast: 10 x the commercial space electronics

Accurate: measure coordinate to 10 microns

Linear: 1 in 10^5, 10 MeV to 1 TeV

Radiation Effects on Components:

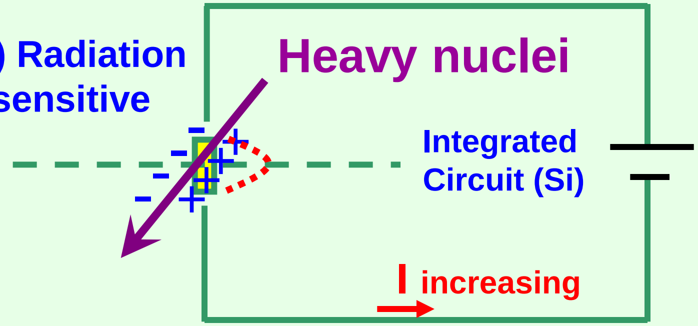
(A) Radiation tolerant



(A) For a radiation tolerant IC, the current induced by a heavy ion is ~ 0

Only radiation tolerant chips (A) are allowed in space.

(B) Radiation sensitive



(B) For a radiation sensitive IC, the current induced by a heavy ion increases, leading to:

1) Bit-flips - a logic state is changed,
2) Latch-ups - the IC or circuit are damaged.

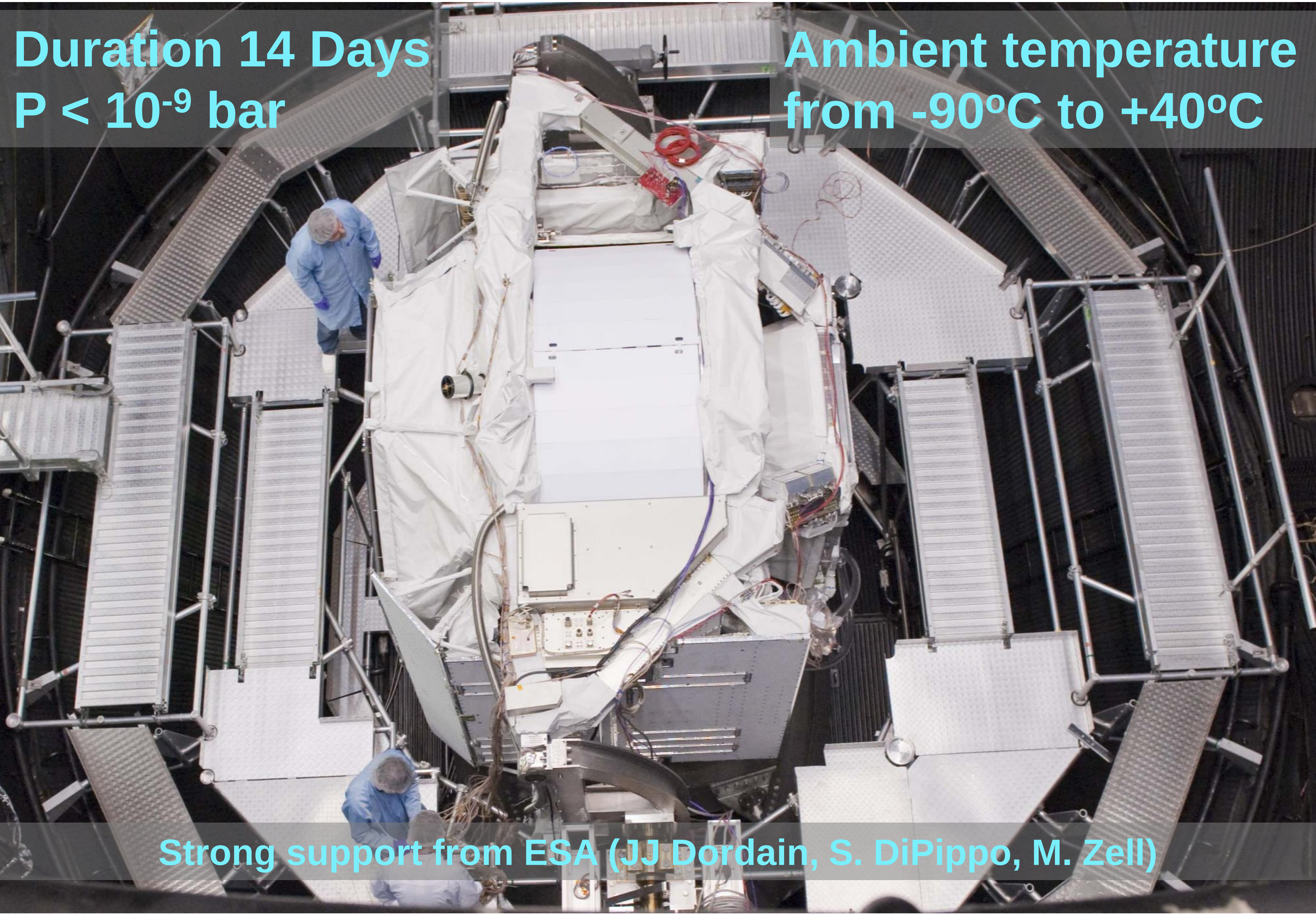
Professor B. Bertucci, Perugia

NASA Associate Administrator for Space Operations William Gerstenmaier visited AMS more than 10 times:

19 June 2011,
1 June 2011,
10 May 2011,
26 October 2010,
15 February 2010,
19 January 2010,
5 July 2009,
1 November 2007,
12 May 2003

5m x 4m x 3m
7.5 tons

AMS in the ESA Thermal Vacuum Chamber, April 2010

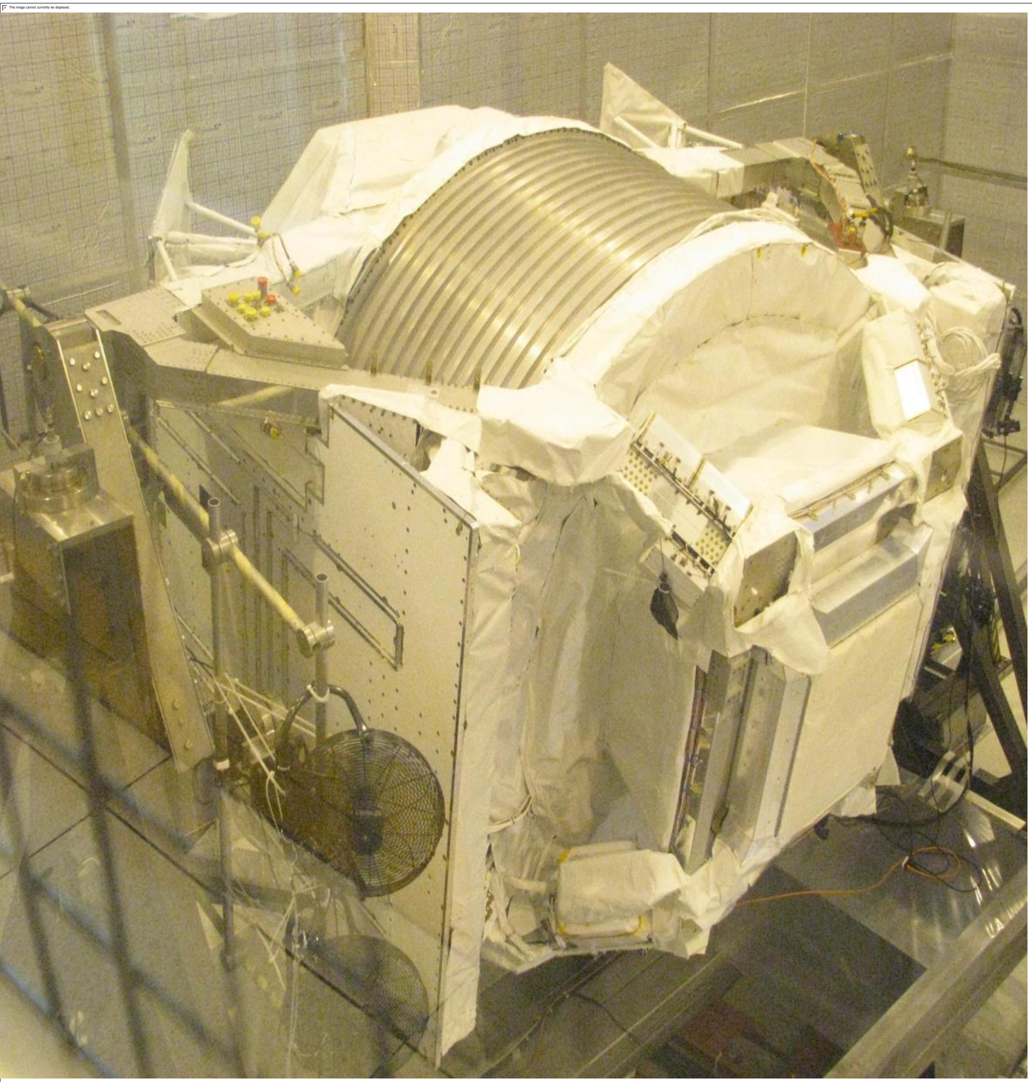


Duration 14 Days
$P < 10^{-9}$ bar

Ambient temperature
from $-90^{o}C$ to $+40^{o}C$

Strong support from ESA (JJ Dordain, S. DiPippo, M. Zell)

Intensive Tests at CERN

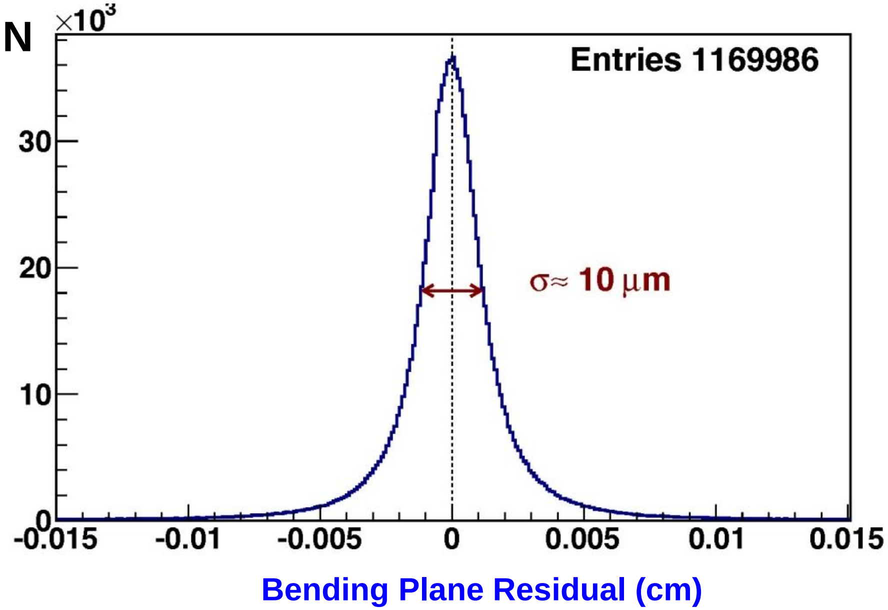


Strong support from CERN (R. Heuer, A. Siemko, S. Meyers, C. Gargiulo)

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

Test Beam Results shows there is no effect of TVT on Detector Performance



N

Velocity measured to an accuracy of 1/1000 for 400 GeV protons

Reconstructed Velocity

N

$e^{\pm}$ Energy Resolution: 2.5-3%

Energy

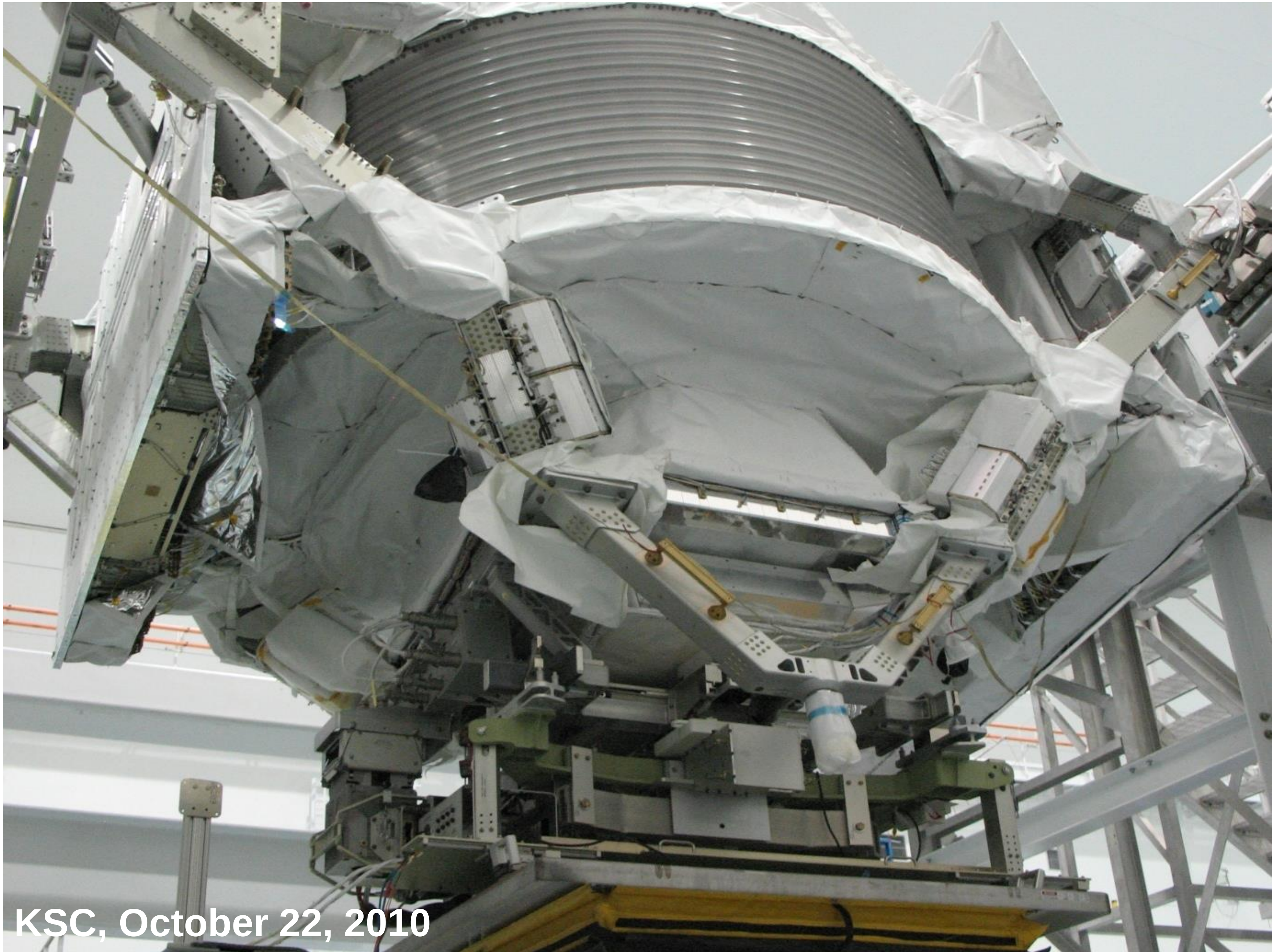
TRD: 400 GeV protons

Measured combined rejection power at 400 GeV: $e^+/p = 10^{-6}$

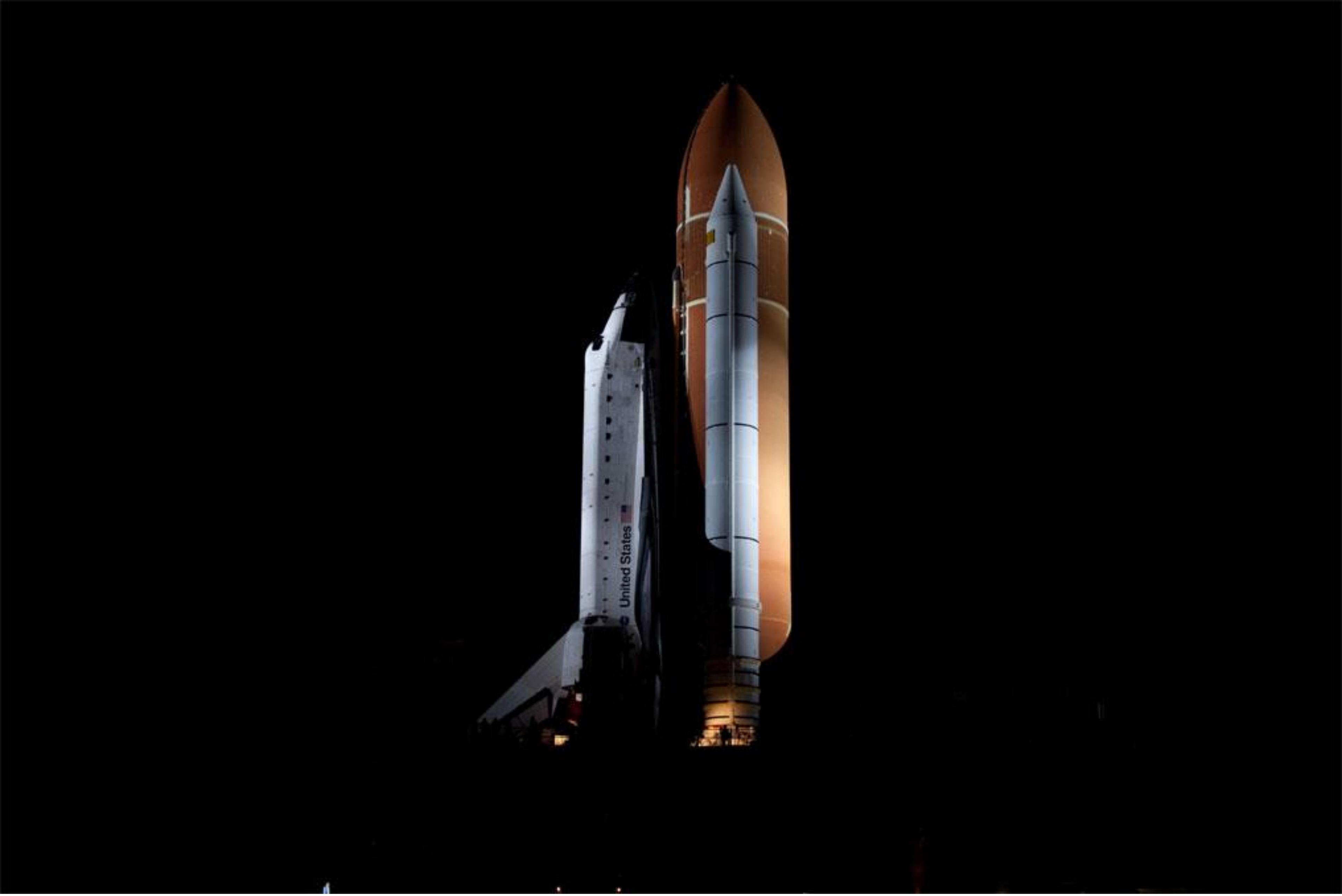
Test beam data in the analysis

1. Tracker alignment
2. Tracker resolution
3. Energy scale of the ECAL
4. ECAL performance
5. TRD performance (TRD estimator)

At KSC, AMS mated with the ISS Payload Attach System simulator



Supporting NASA preflight with the Shuttle Commander, Captain M. Kelly, USN



Transfer of STS-134 to the launch pad

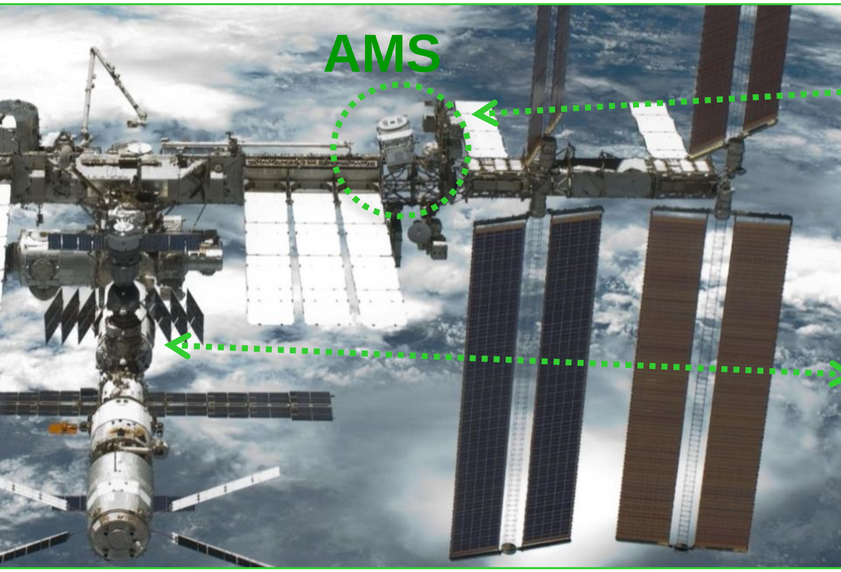

Endeavour: 110 t
External tank: 756 t
2 SRB: 1142 t
(solid rocket boosters)
Total weight: 2008 t
AMS weight: 7.5 t

After 123 seconds,
1,000 tons of fuel is spent.

May 16, 2011

May 19, 2011: AMS installation completed.

AMS Operations



Flight Operations

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

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

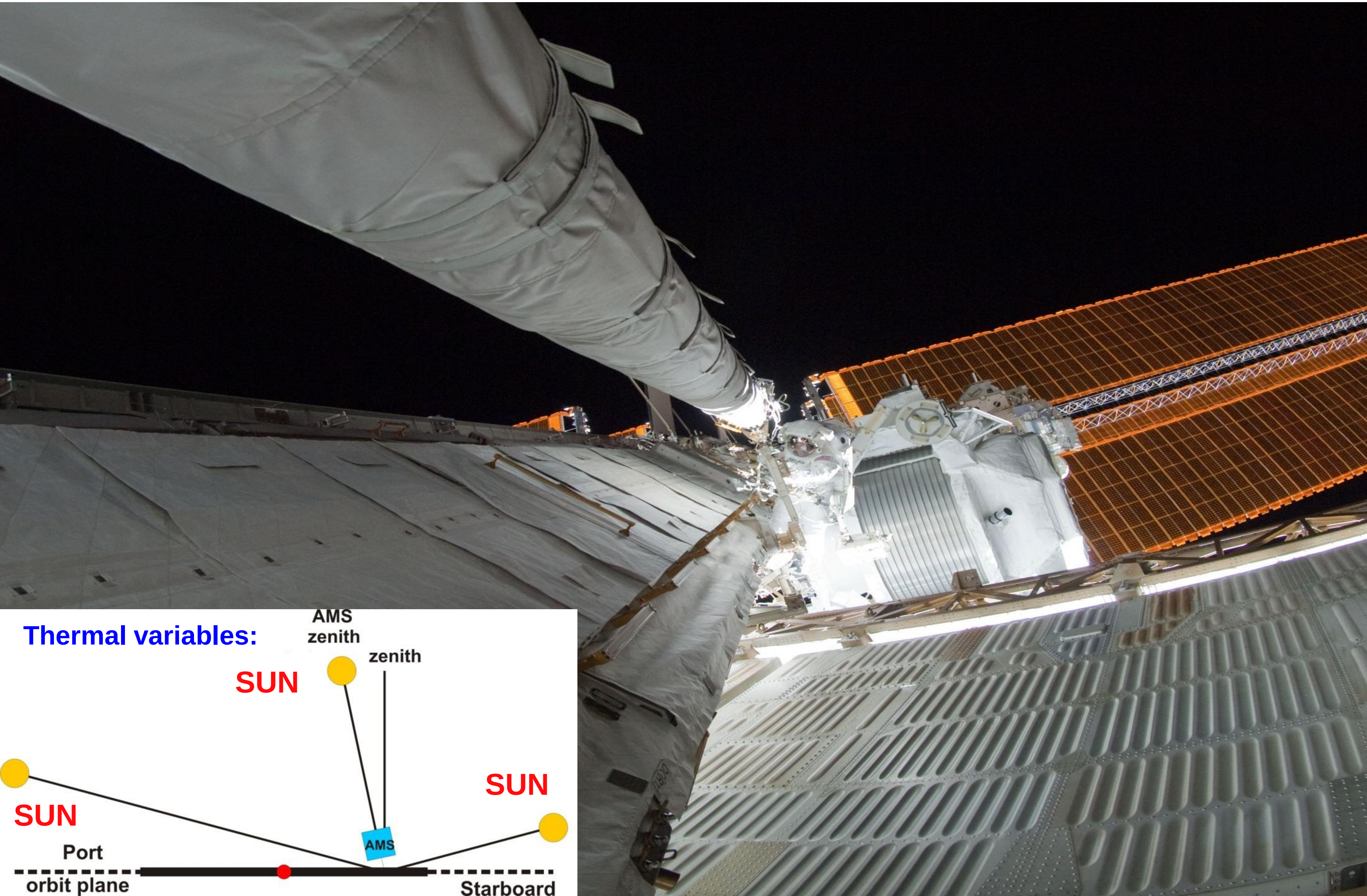
Ground Operations

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

AMS Computers at MSFC, AL

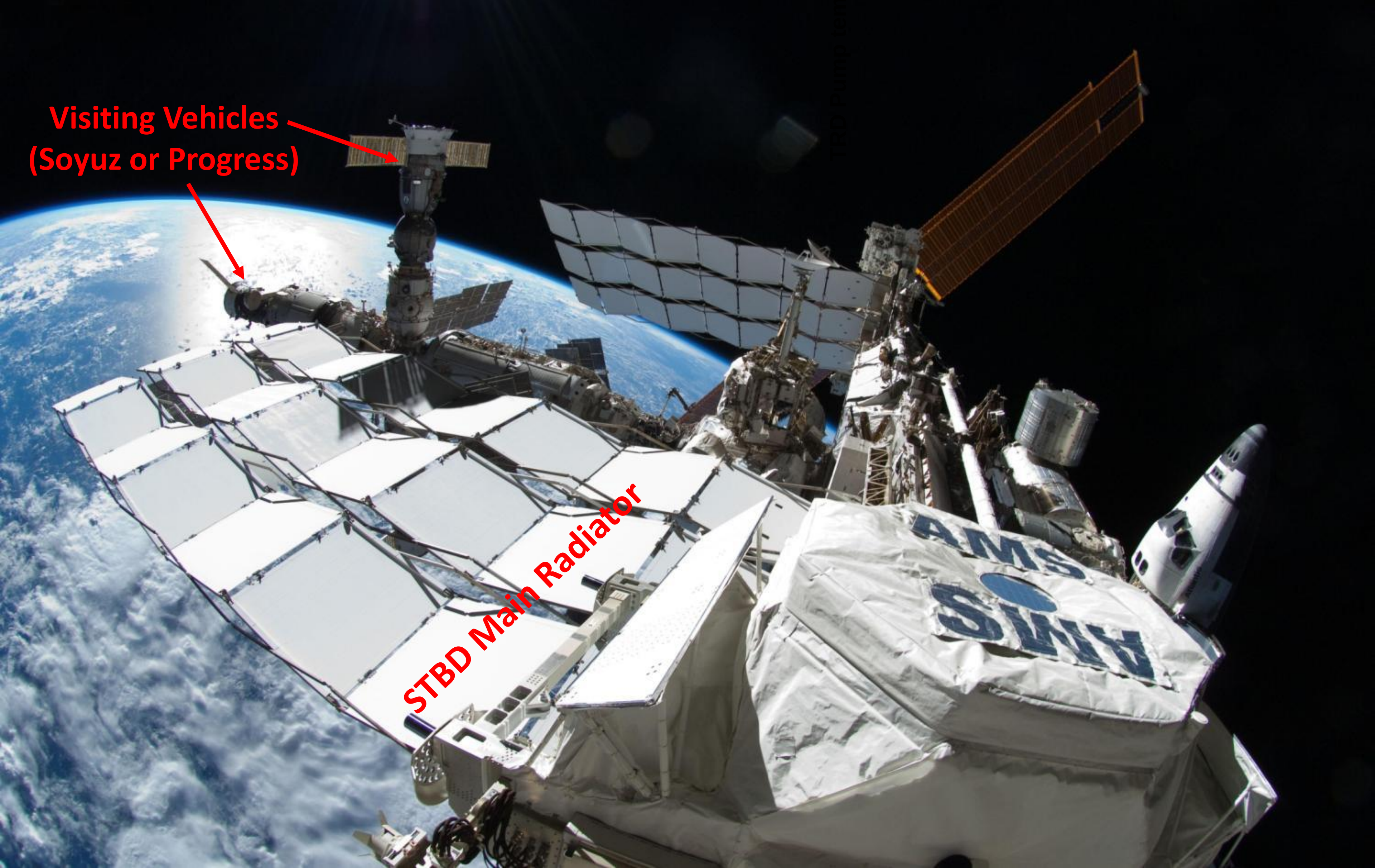
White Sands Ground Terminal, NM

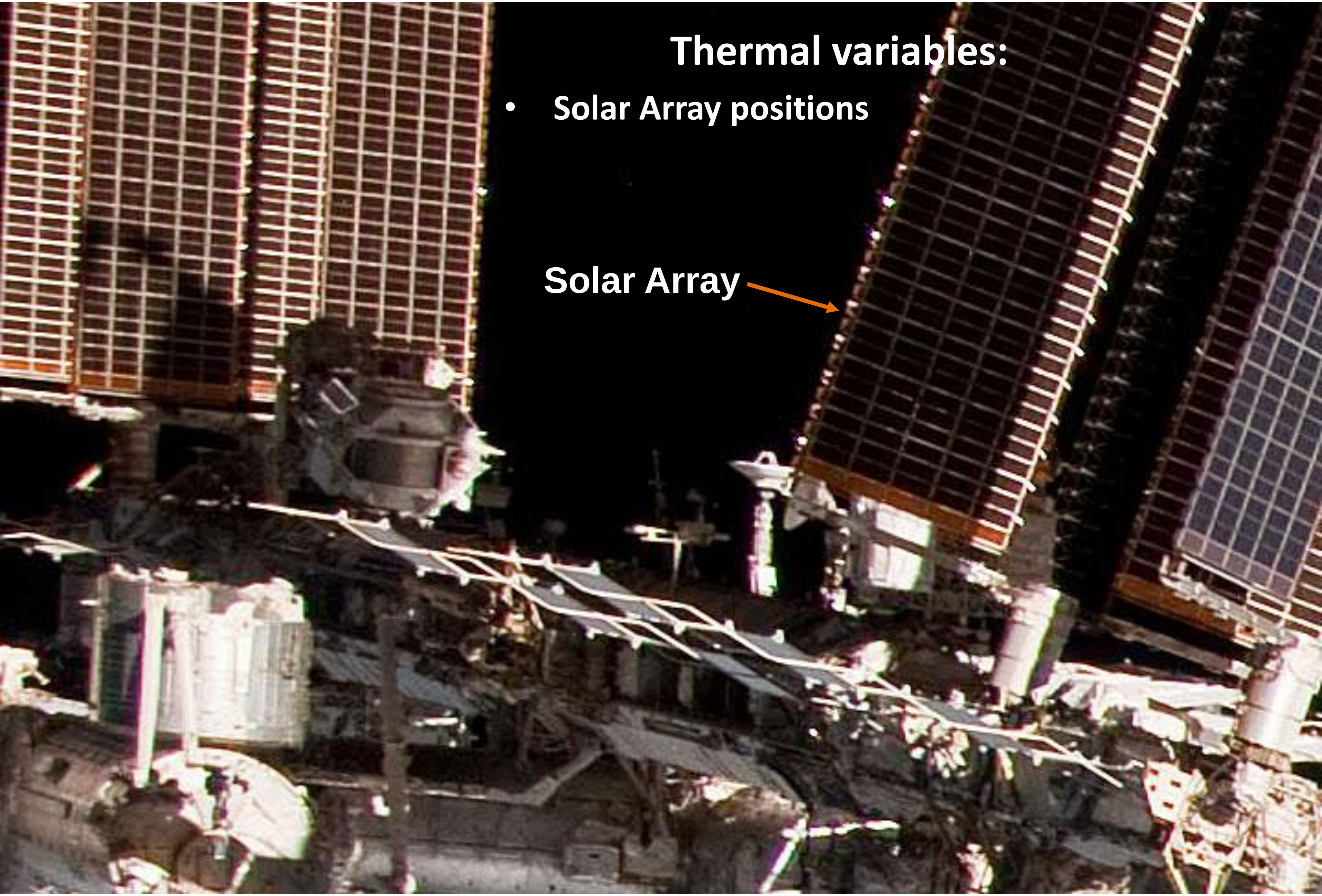
One of the major challenges of operating on the Space Station is the extreme thermal environment to which the experiment is exposed.



Thermal variables:

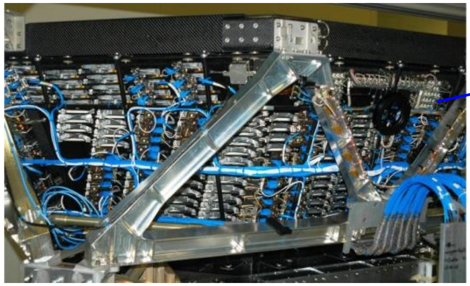
- ISS Radiator positions
- ISS attitude changes (primarily for visiting vehicles)

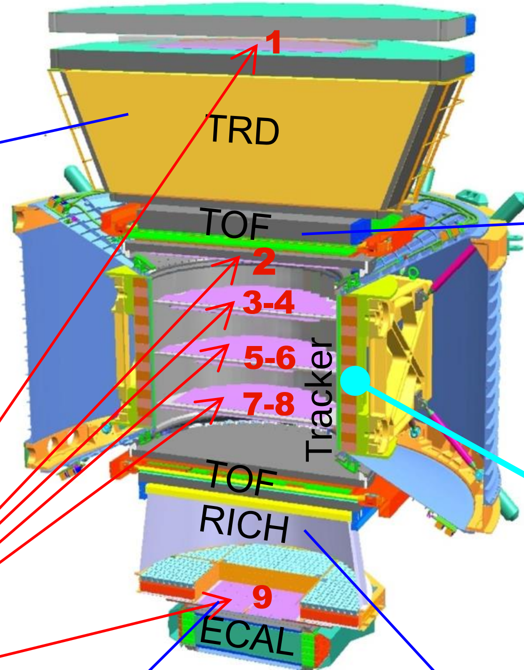



Thermal variables:
• Solar Array positions
Solar Array

AMS Flight Electronics for Thermal Control

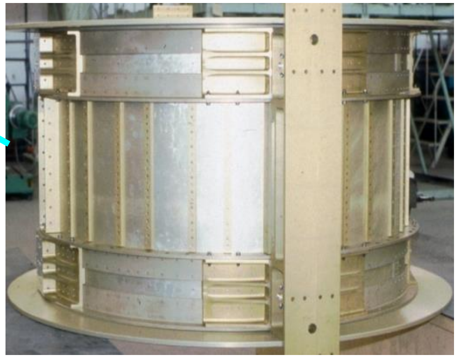
TRD
24 Heaters
8 Pressure Sensors
482 Temperature Sensors



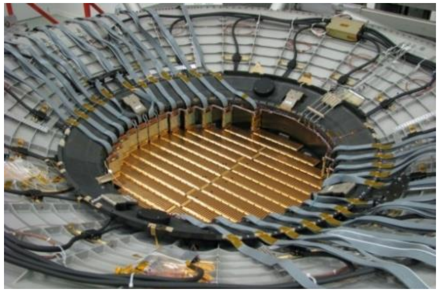


TOF & ACC
64 Temperature Sensors

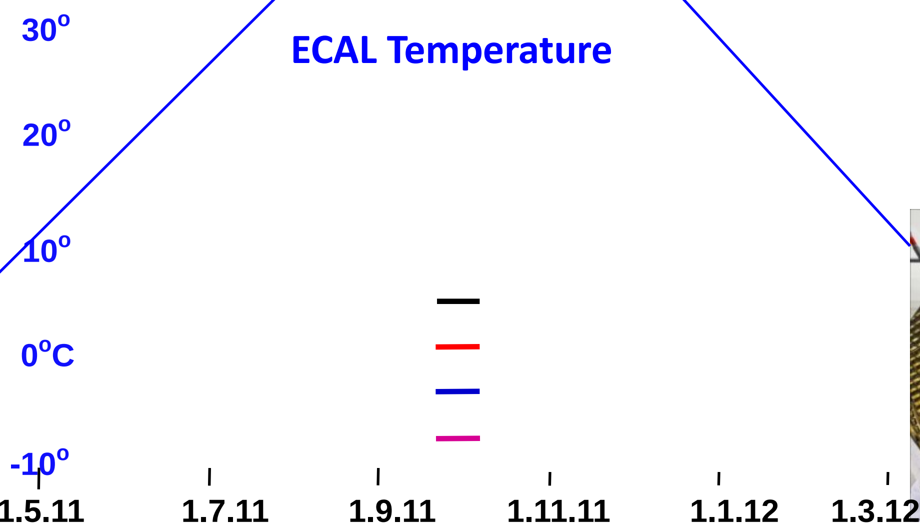
Magnet
68 Temperature Sensors



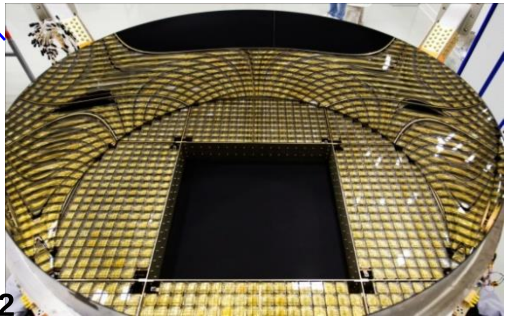
Silicon Tracker
4 -Pressure Sensors
32 Heaters
142 Temperature Sensors



ECAL
80 Temperature Sensors

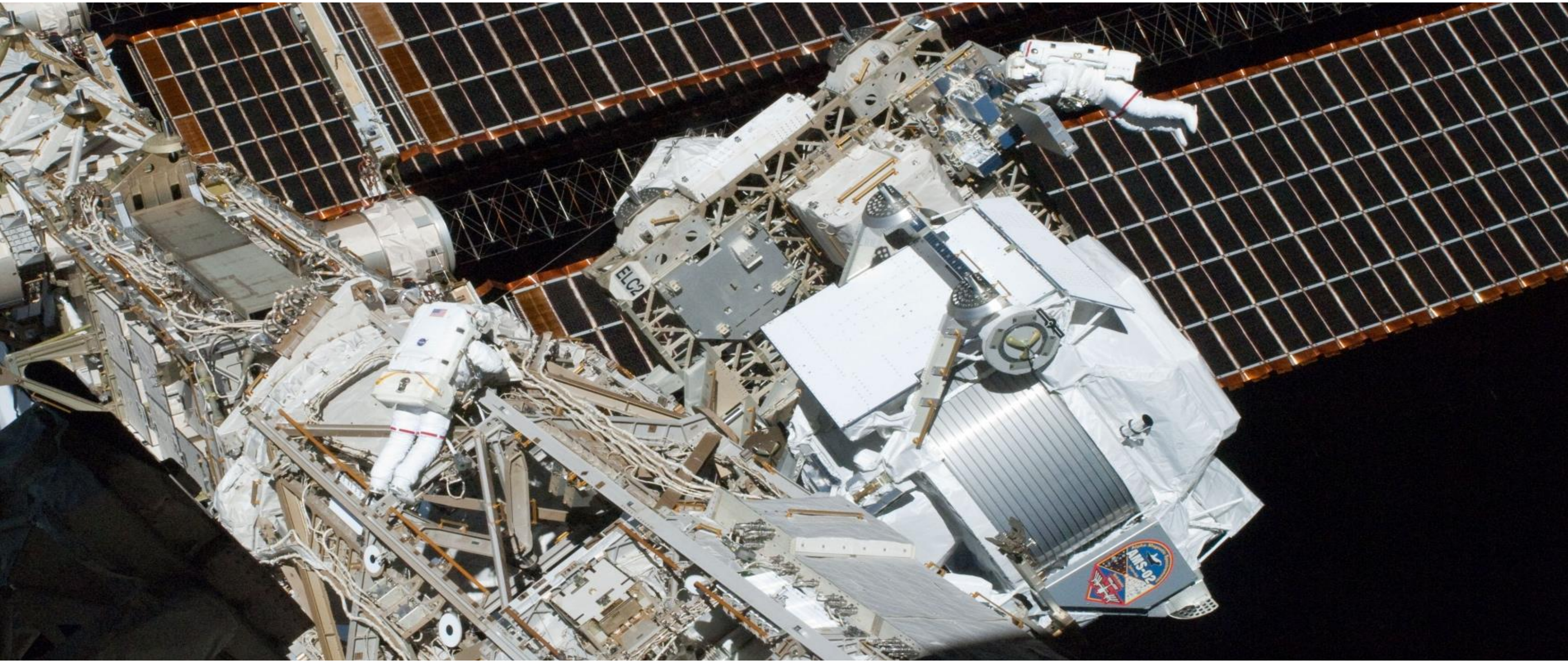


RICH
96 Temperature Sensors



Flight Operations:

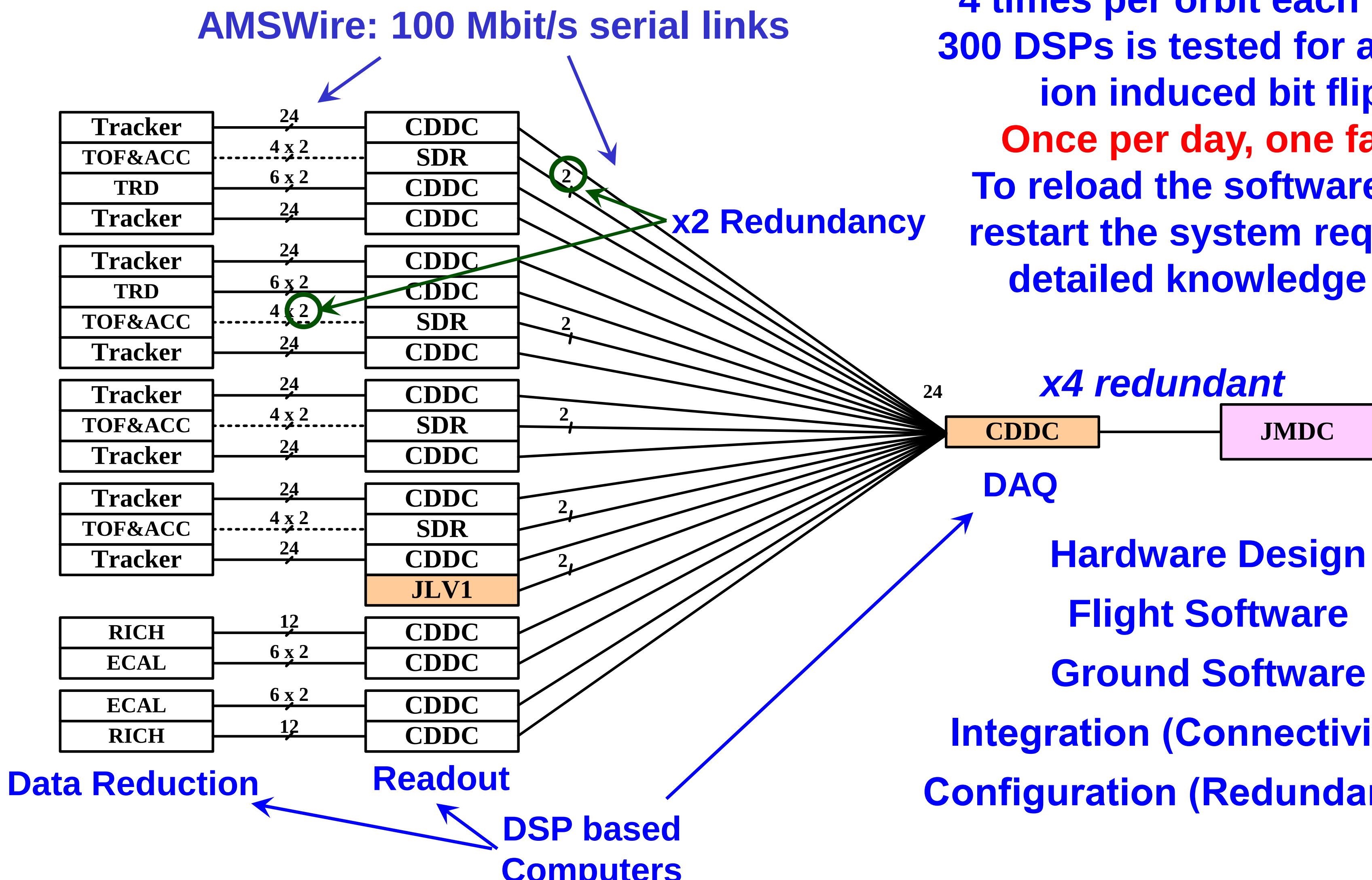
AMS Data Acquisition System



To read out 300,000 channels at up to 2 KHz, the AMS Team developed a large set of computers (650) which are programmable from the POCC and which readout all the different detectors with up to 400% redundancy. Hundreds of these computers are interconnected in a tree like structure with an 100 MBit/s serial link.

AMS Data Acquisition Readout Tree

4 times per orbit each of the 300 DSPs is tested for a heavy ion induced bit flip.
Once per day, one fails.
To reload the software and restart the system requires detailed knowledge of:



Hardware Design
Flight Software
Ground Software
Integration (Connectivity,…)
Configuration (Redundancy,…)

CDDC: Command Distributor & Data Concentrator based on Digital Signal Processor (DSP)

TRD Readout Computers

5,248 Channels, 112 Voltages,

5,248 Pulse Heights

24 TRD Data Reduction Computers (UDR)

AMSWire

Busy

Trigger

4 Readout Computers (JINF-U)

AMSWire

To next level

Busy

Trigger

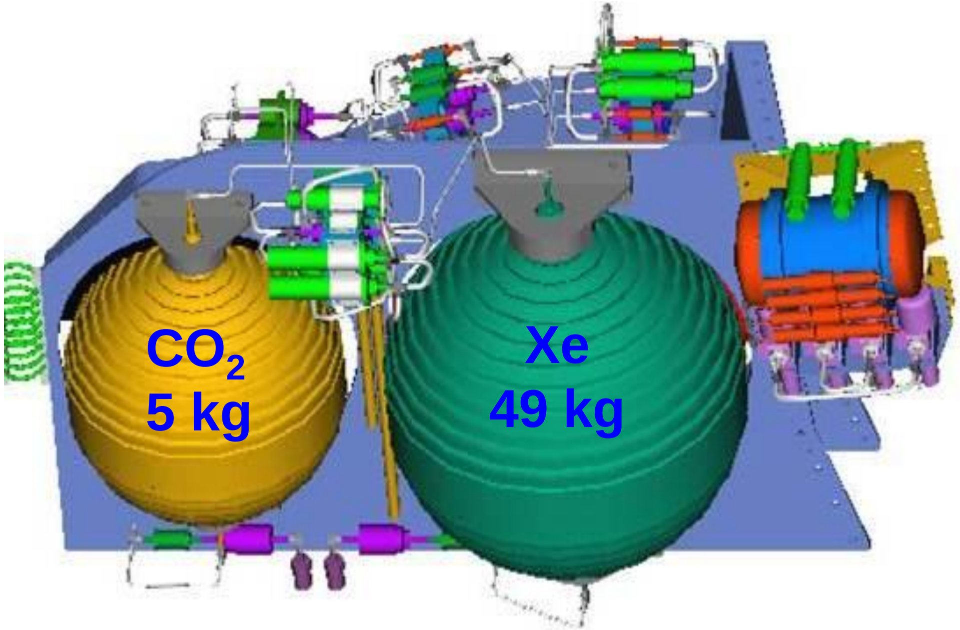
High & Low Voltage Control

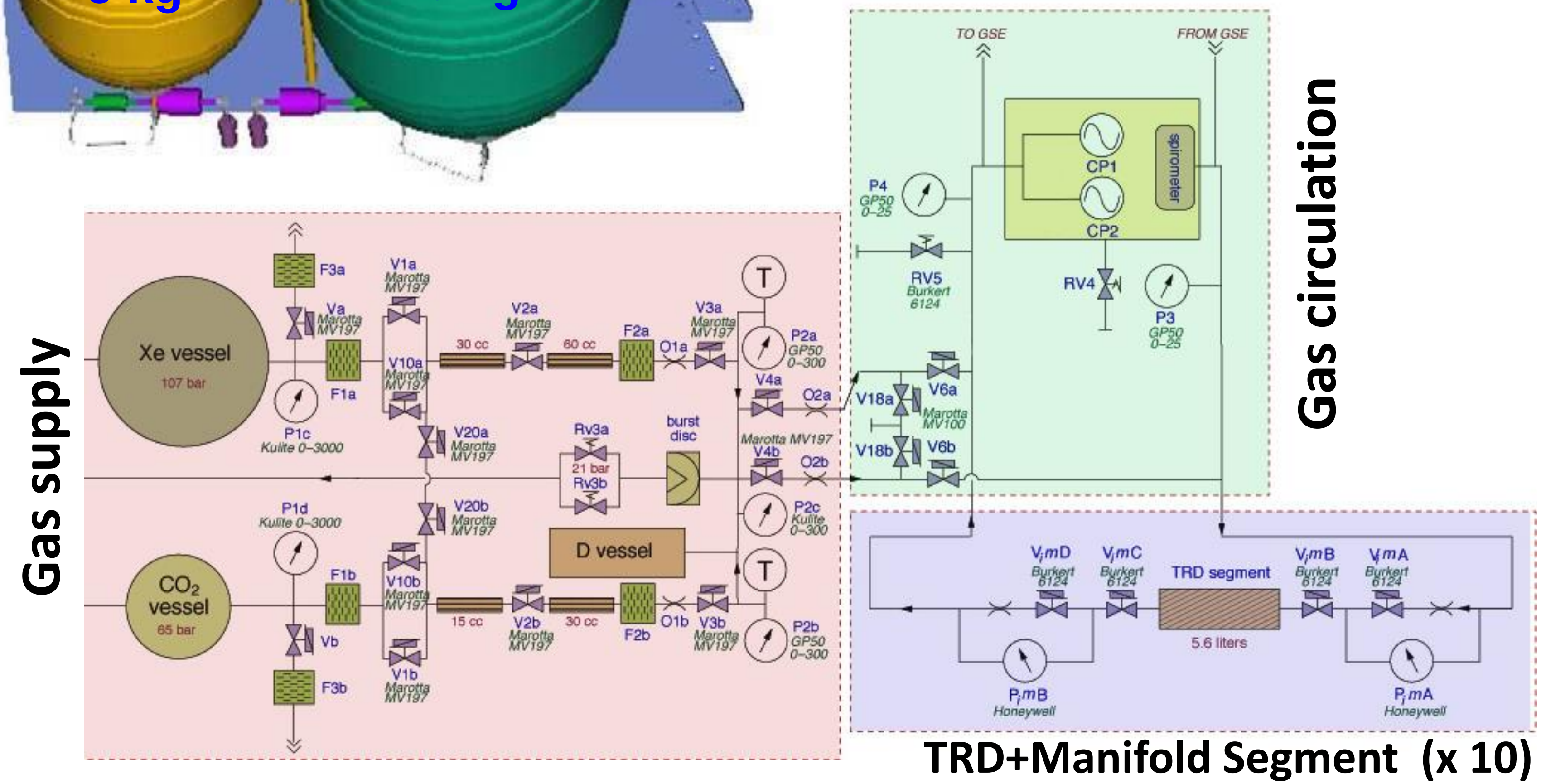
- Analog to digital conversion
- Data reduction:
  - Pedestal subtraction
  - Remove empty channels
- Format, send to next level

- Collect data from UDRs
- Format, send to next level
- Control High & Low Voltage
- Distribute command to UDR
- Combine Busy signals
- Distribute Trigger

TRD Gas circuit general layout

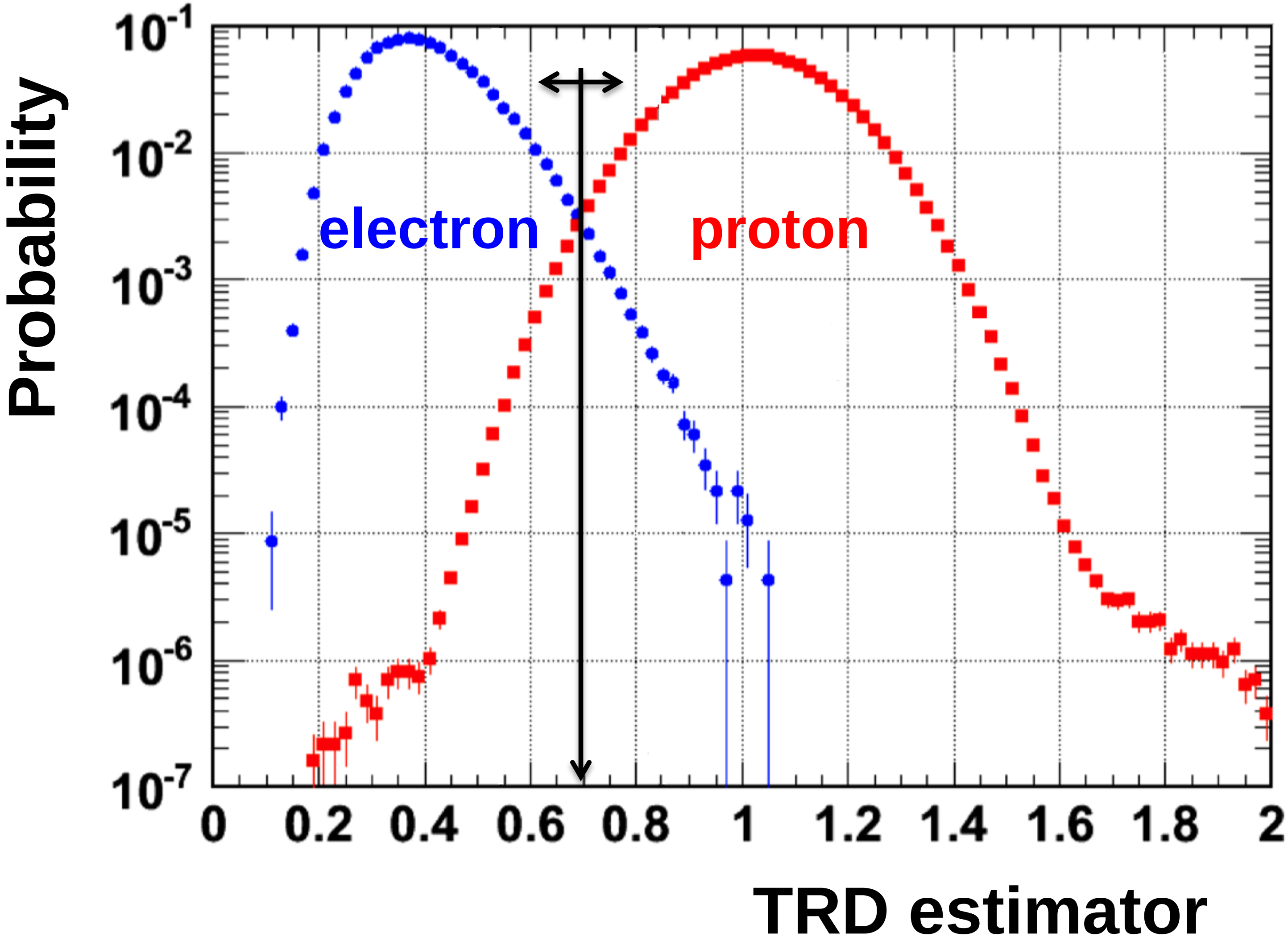
Leakrate of 5 µg/s caused by CO_2 diffusion corresponds to a Life time ~30 years in Space





TRD performance on ISS

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

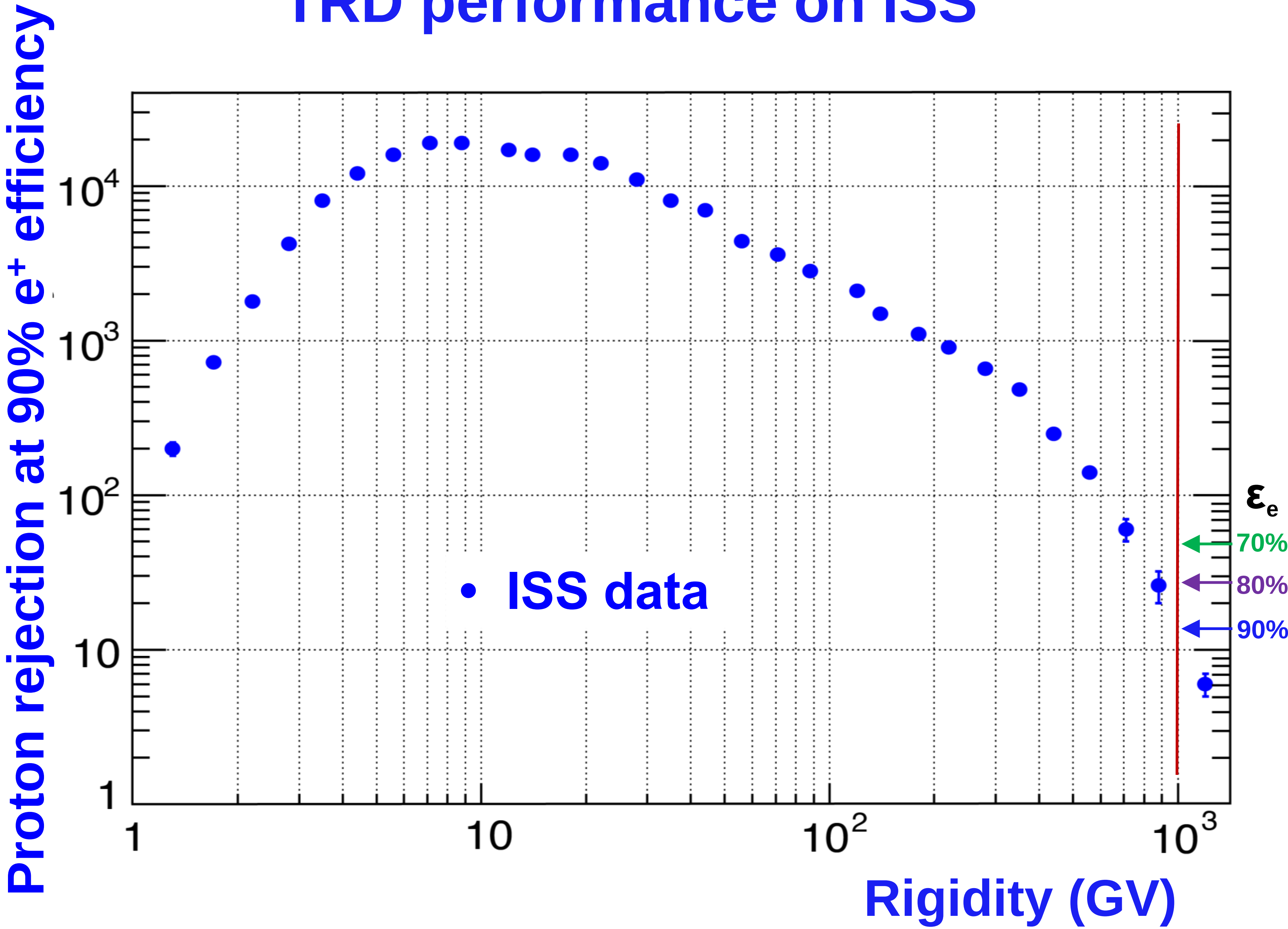


Normalized probabilities P_e and P_p

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

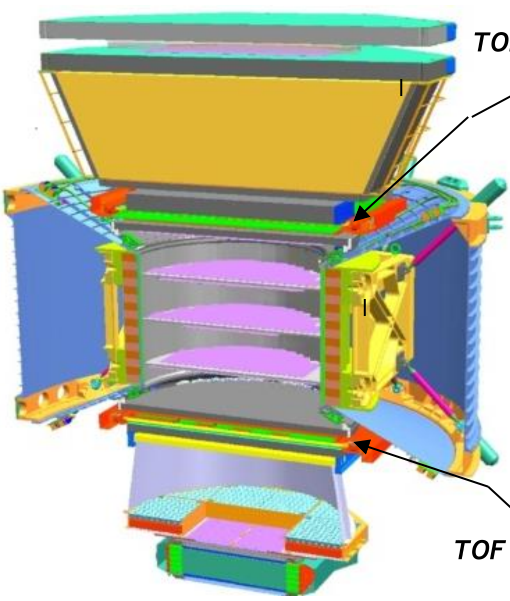
$$P_p = \sqrt[n]{\prod_{i}^{n} P_p^{(i)}(A)}$$

TRD performance on ISS



Data from ISS Time of Flight System

Measures Velocity and Charge of particles



x10[3]

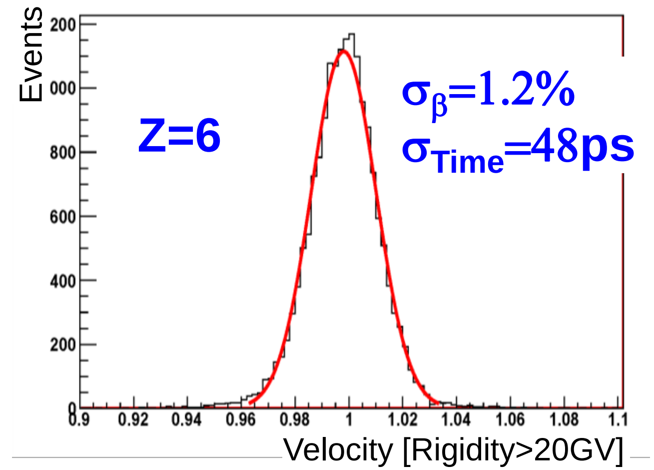
Events

Z=2

σ_β=2%

σ_{Time}=80ps

Velocity [Rigidity>20GV]



H He Li Be B C N O F Ne Na Mg Al Si P S Cl Ar K Ca Sc Ti V Cr Mn Fe Ni Zn

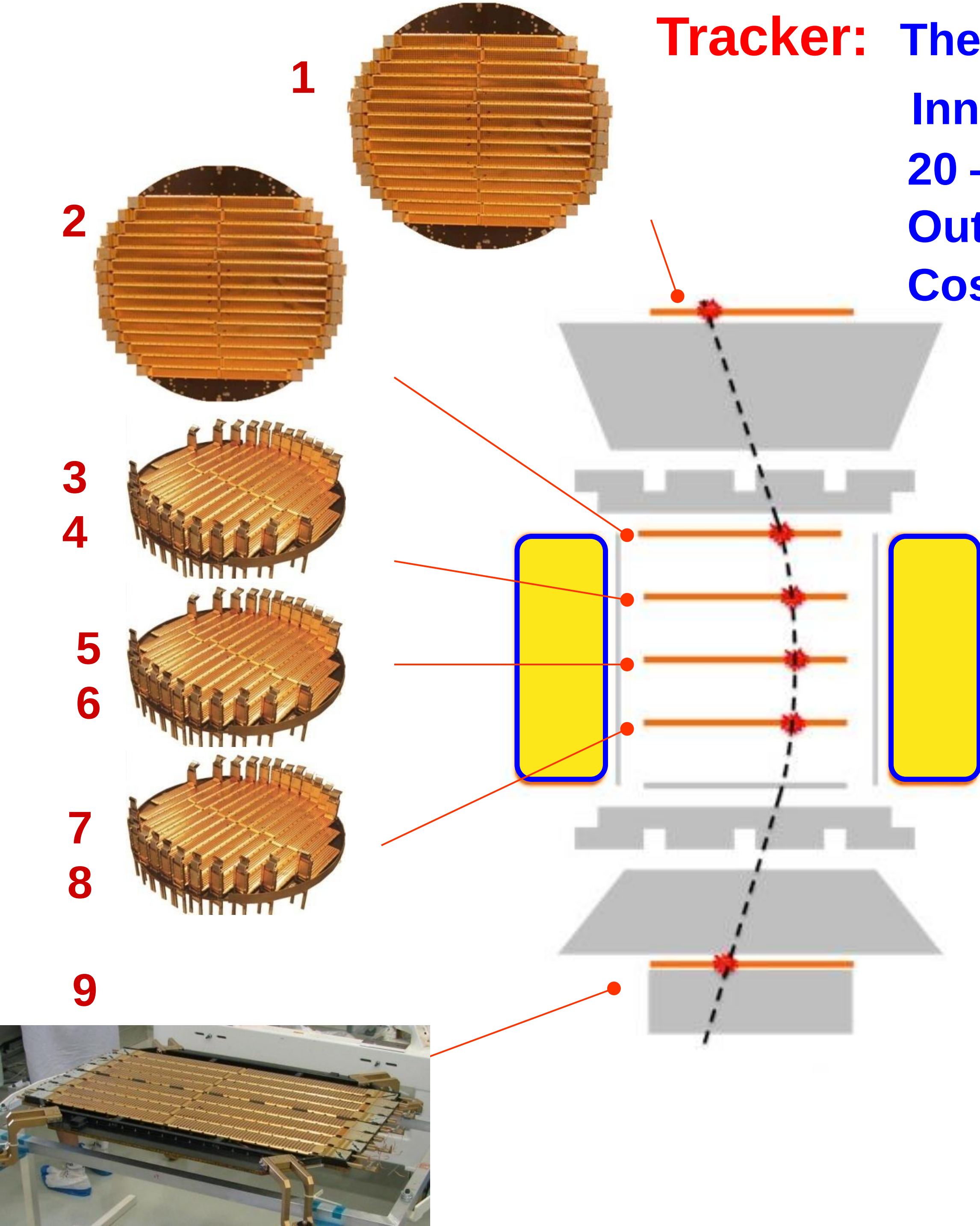
Tracker: The coordinate resolution is 10 μ

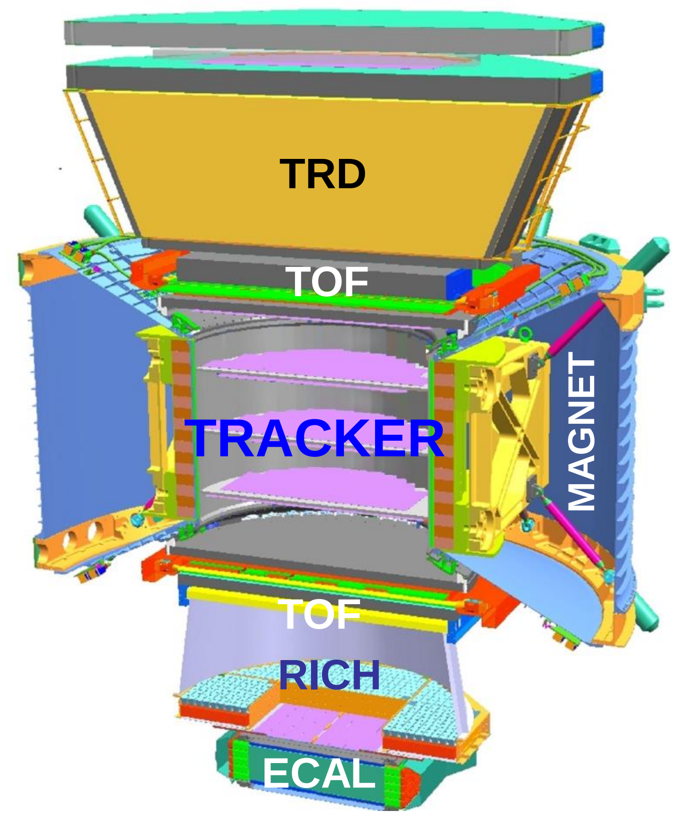
Inner Tracker Alignment via

20 –UV Lasers

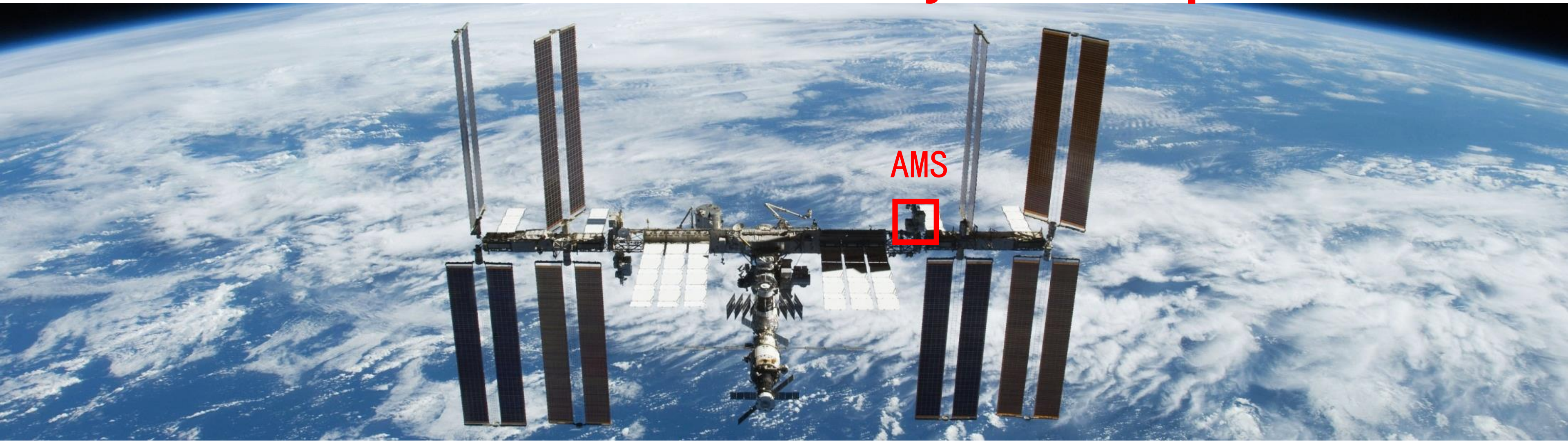
Outer Tracker Alignment via

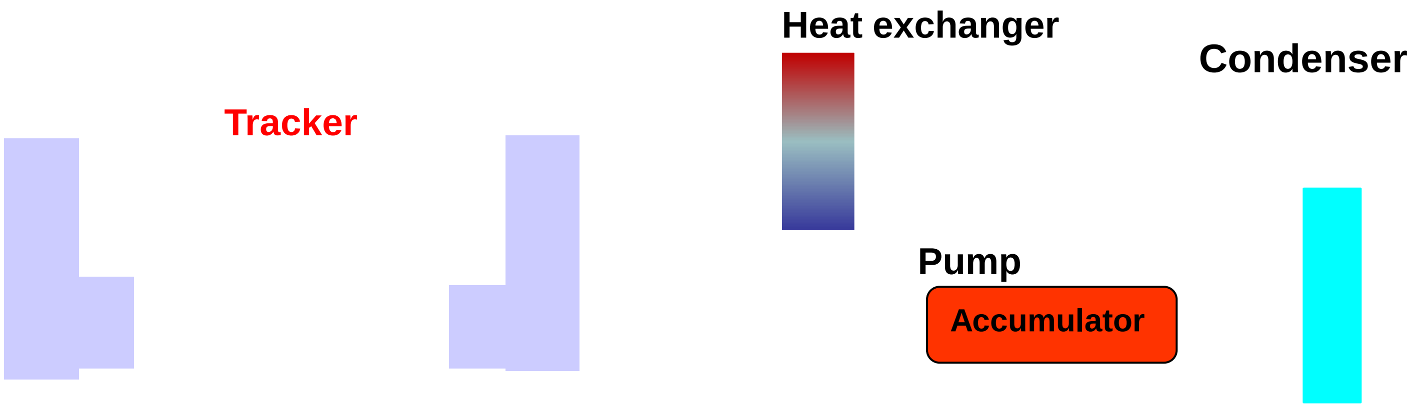
Cosmic rays





Tracker Thermal Control System in Space

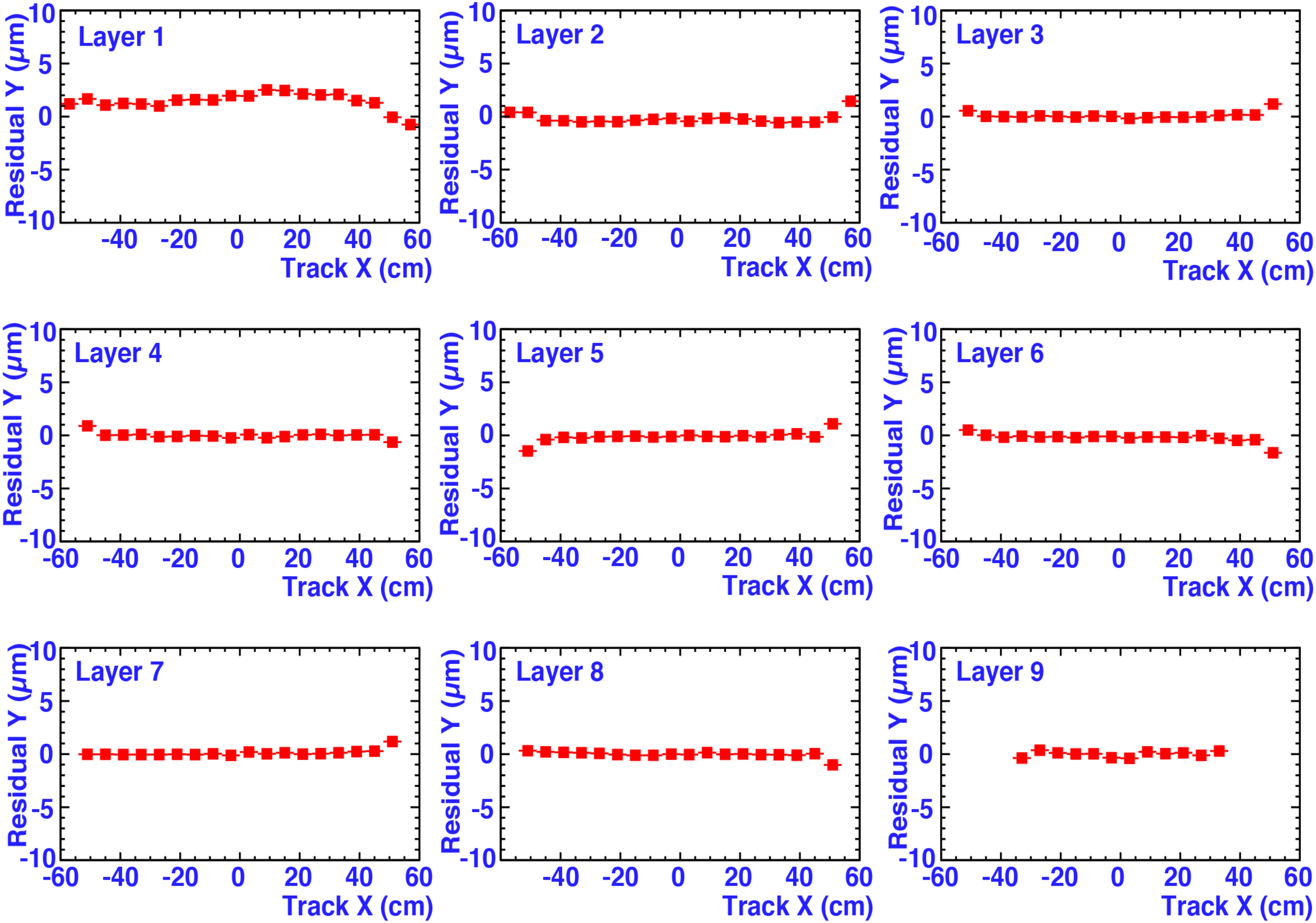




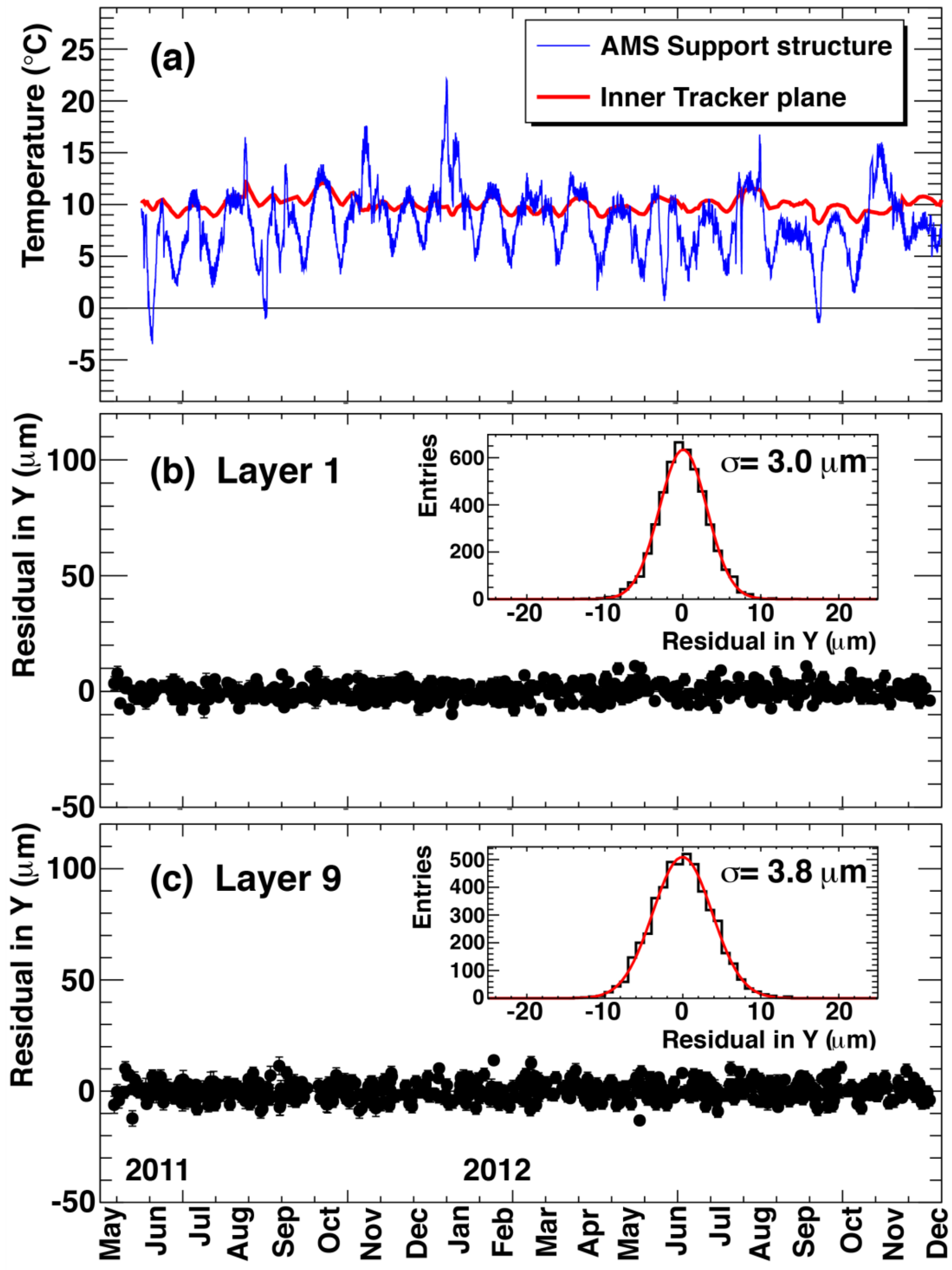
Red line: CO_2 gas/liquid two phase

Blue line: CO_2 liquid phase

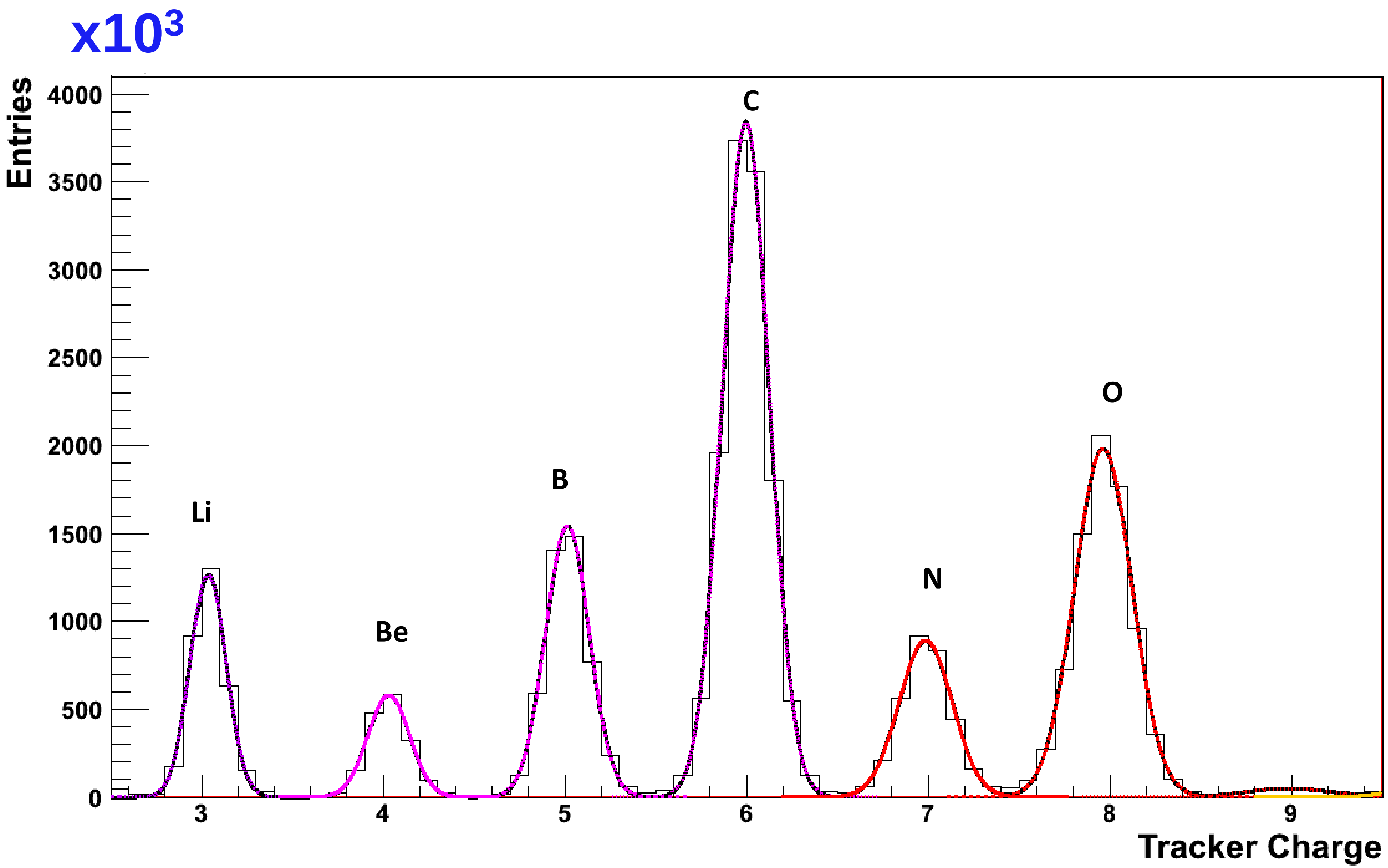
Alignment accuracy of the 9 Tracker layers over 18 months



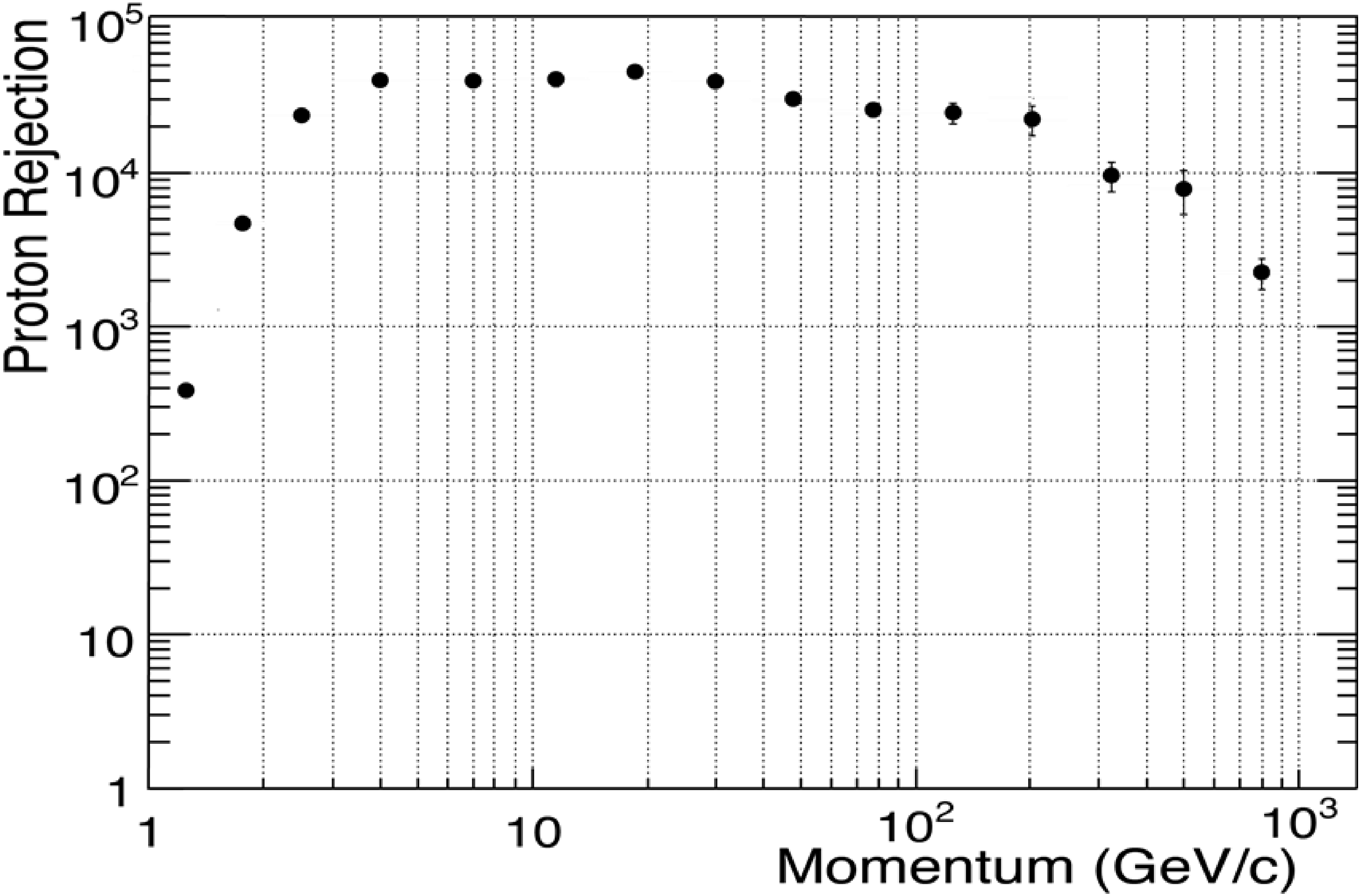
Stability of the alignment on Tracker plane 1 & 9



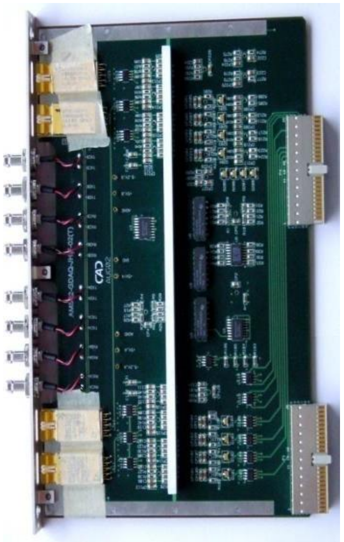
Tracker Charge



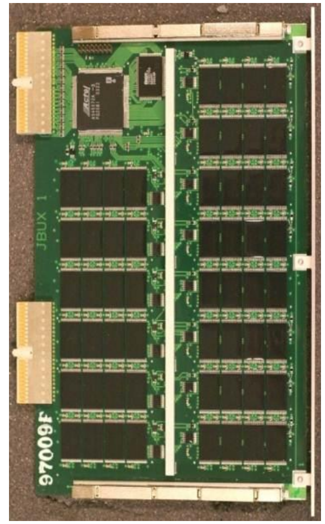
Data from ISS: Proton rejection using the ECAL



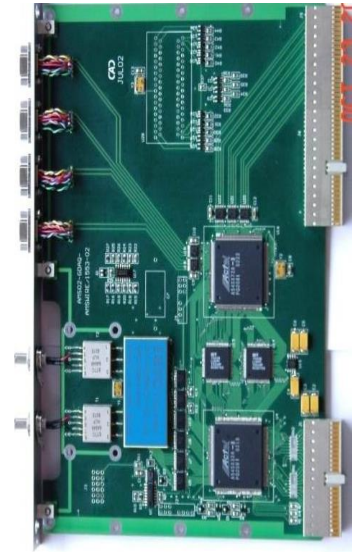
4 AMS Main Data Computers, each with:


High Rate Interface


400 MHz Processor


112 GB Flash Memory


CAN bus interface


AMSWire & Low Rate Interfaces

- Collect data, format, compress reconstruct, buffer, send to POCC
- On-board buffer for ~1 day of data
- Interface to ISS Avionics
- Execute commands from the POCC
- Collect monitoring data, analyze, respond, buffer, send to POCC

DAQ Computers ⟷ AMSWire 100 MBit/s

ISS Avionics ⟷ HRDL 100 MBit/s, LRDL

AMS CAN Buses

Main Computer Power	Monitoring (TAS, GPS, Star Tracker)	TRD Gas, Temperature	Tracker Thermal Control	Power Distribution
USCM-J	USCM-M	UGSCM	TTCE	PDS

POCC at CERN in control of AMS since 19 June 2011

Key persons in the POCC all have major responsibilities for AMS electronics

Dr. V. Koutsenko

Dr. X.D. Cai

Dr. A. Lebedev

Drs. A. Kounine, J. Burger, M. Capell

AMS POCC in continuous communication with MFSC and ISS Mission Control Center, JSC

AMS today

Lessons learned after 22 months of AMS operations on the ISS:

1. Operating a particle physics experiment on the ISS is fundamentally different from operating an experiment in the LHC.

   On the ISS, the thermal conditions can easily destroy AMS unless all electronics components and Station parameters are constantly monitored to avoid exposing the detector to a dangerous condition from which there is no recovery.

   We have learned that to mitigate risks to AMS, immediate actions must be implemented by the AMS experts who designed, manufactured and tested all the electronics and thermal sensors.

Lessons learned after 22 months of AMS operations on the ISS:

2. Operating AMS on the ISS is also different from operating on a "free flying" satellite because we have no control over the ISS orientation, attitude and beta angle – all of which affect the thermal environment.

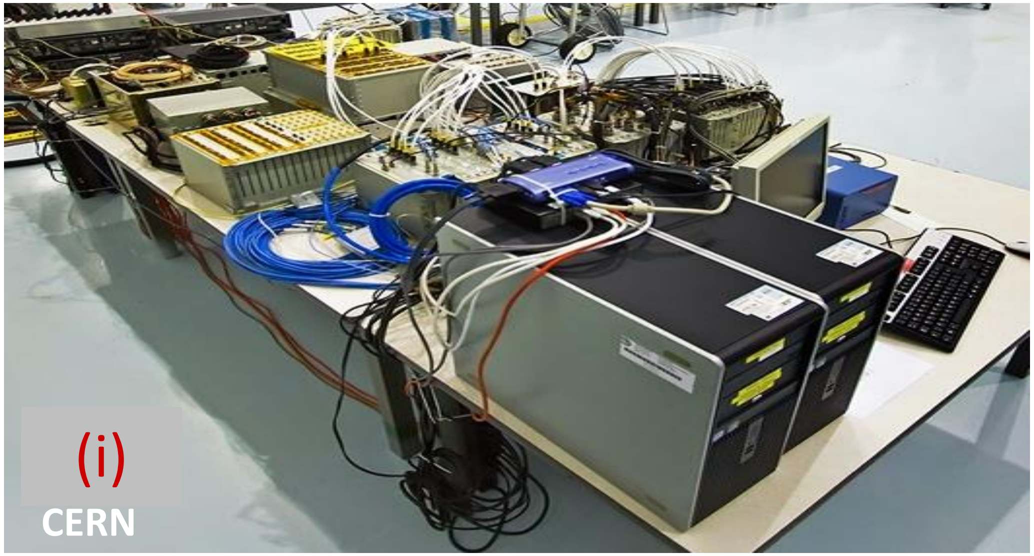
   This requires the full attention of the AMS experts so as to be able to communicate the approaching dangerous thermal environment to the NASA ISS Mission Control to request change of ISS flying conditions.

The AMS operation is reviewed daily at 5pm with the detector monitor groups in the POCC.

The ISS avionics and software (some written in the 1990's) are constantly being upgraded by NASA and this requires the group to continuously update the electronics software in order to match NASA requirements.

NASA requires us to use the AMS flight simulator regularly to ensure that our software meets NASA specifications and safety.

Three AMS Development and Test Facilities



(i) AMS Simulator Laboratory at CERN

- **Flight Simulator**
- **ISS Avionics Simulator**
- **AMS Laptop Simulator**
- **Development and Test Facilities**

(ii) AMS Flight Equivalent Unit at JSC Software Development and Integration Lab (SDIL)

(iii) AMS ISS Laptop and AMS Ground Software checkout at Marshall Space Flight Center

First Data from AMS

Over the first eighteen months of operations in space, AMS has collected over 25 billion events.

6.8 million are electrons or positrons.

First Data from AMS

Over the first eighteen months of operations in space, AMS has collected over 25 billion events.

6.8 million are electrons or positrons.

Dr. V. Choutko

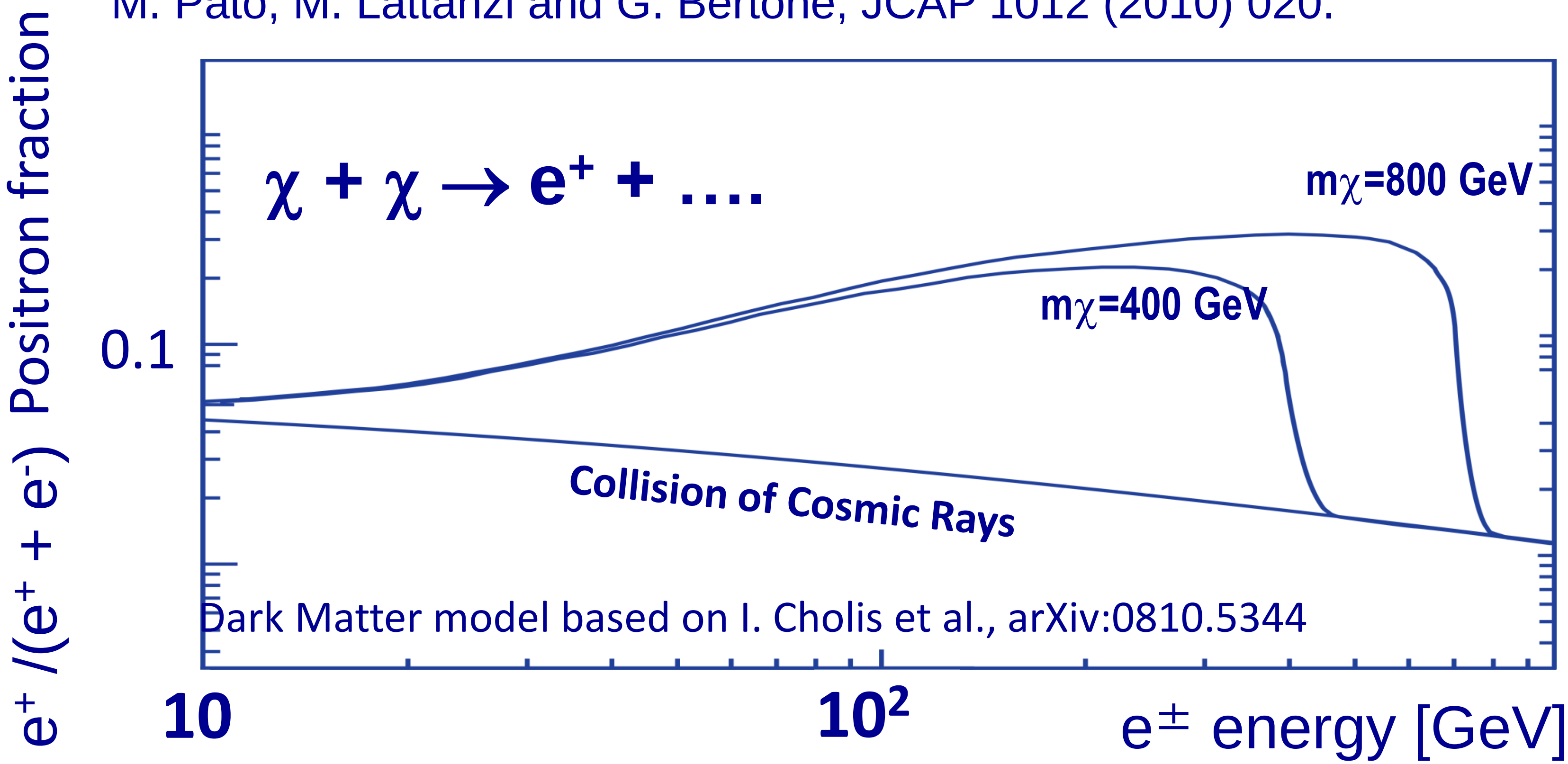
All of the analysis of AMS data is being performed by two independent groups

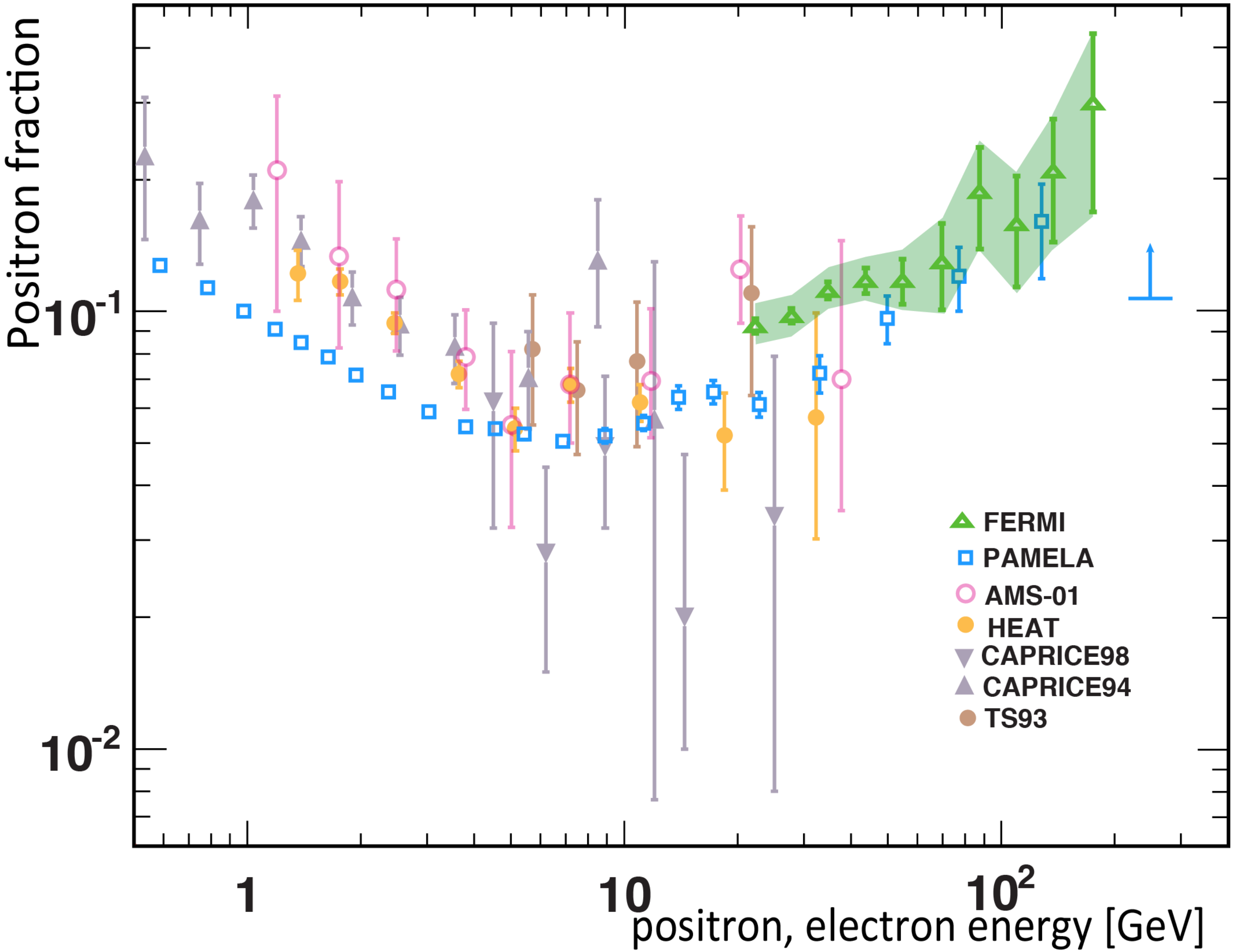
Group A: RWTH-Aachen, Karlsruhe;
Bologna, Milan, Perugia, Pisa, Rome;
MET-Ankara;
Lisbon; …

Group α: MIT, Yale, Hawaii;
LAPP-Annecy, Grenoble;
Academia Sinica, NCU;
IHEP-Beijing;
Geneva;
CIEMAT-Madrid; …

Physics of Positron Fraction

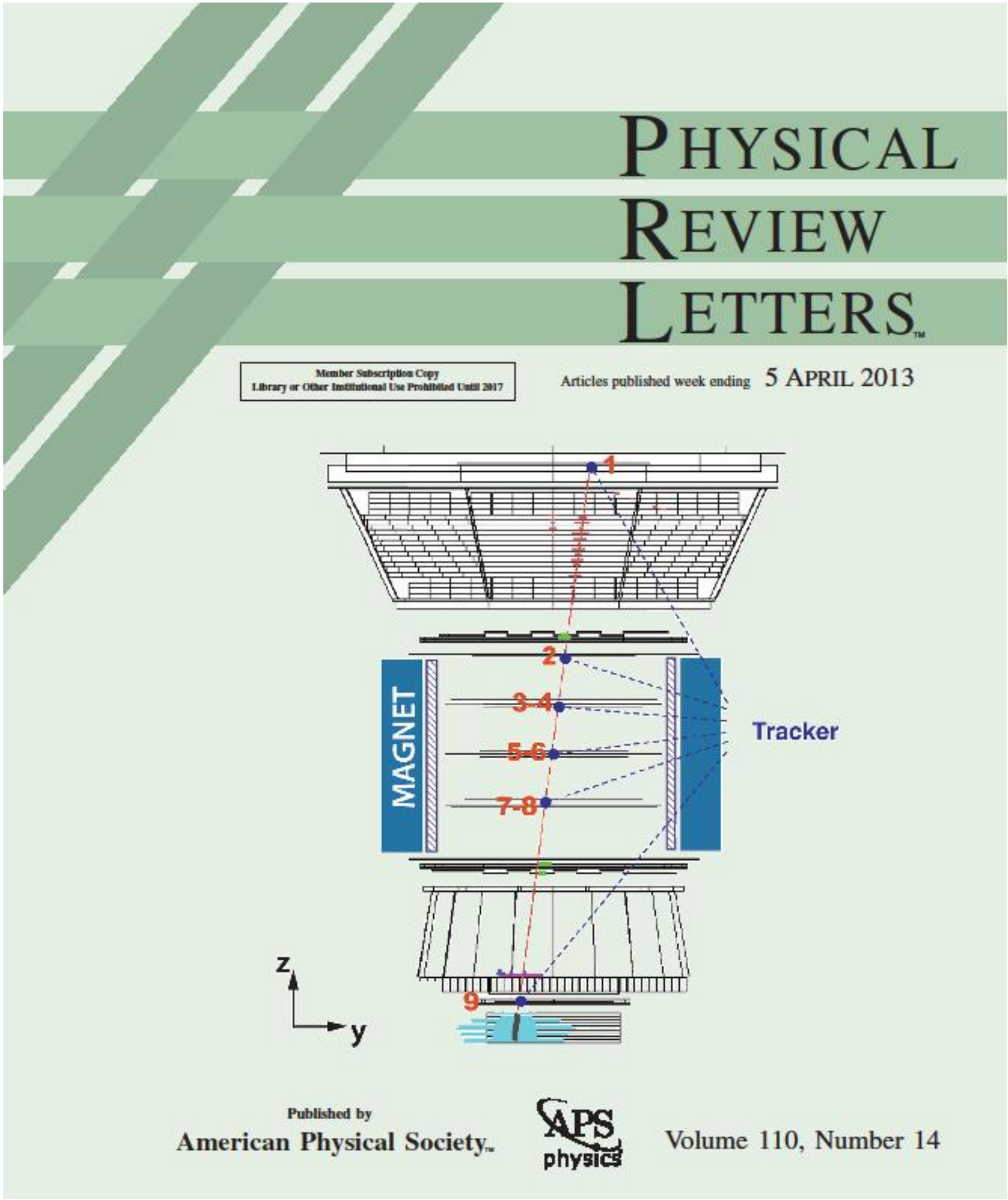
M. Turner and F. Wilczek, Phys. Rev. D42 (1990) 1001;
J. Ellis, 26th ICRC Salt Lake City (1999) astro-ph/9911440;
H. Cheng, J. Feng and K. Matchev, Phys. Rev. Lett. 89 (2002) 211301;
S. Profumo and P. Ullio, J. Cosmology Astroparticle Phys. JCAP07 (2004) 006;
D. Hooper and J. Silk, Phys. Rev. D 71 (2005) 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.

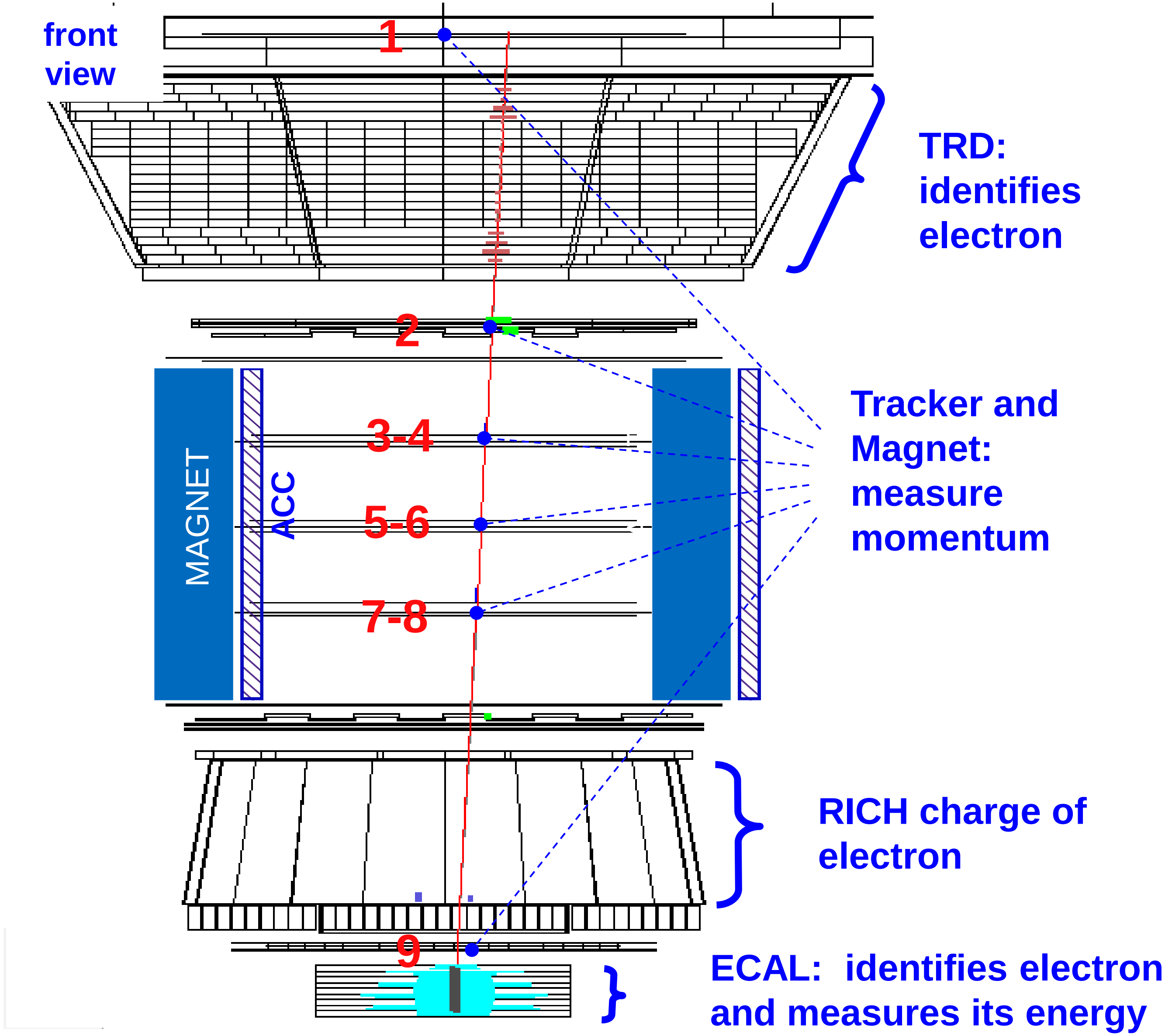



Positron fraction
10^{-1}
10^{-2}
1
10
10^2
positron, electron energy [GeV]
FERMI
PAMELA
AMS-01
HEAT
CAPRICE98
CAPRICE94
TS93

“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)]

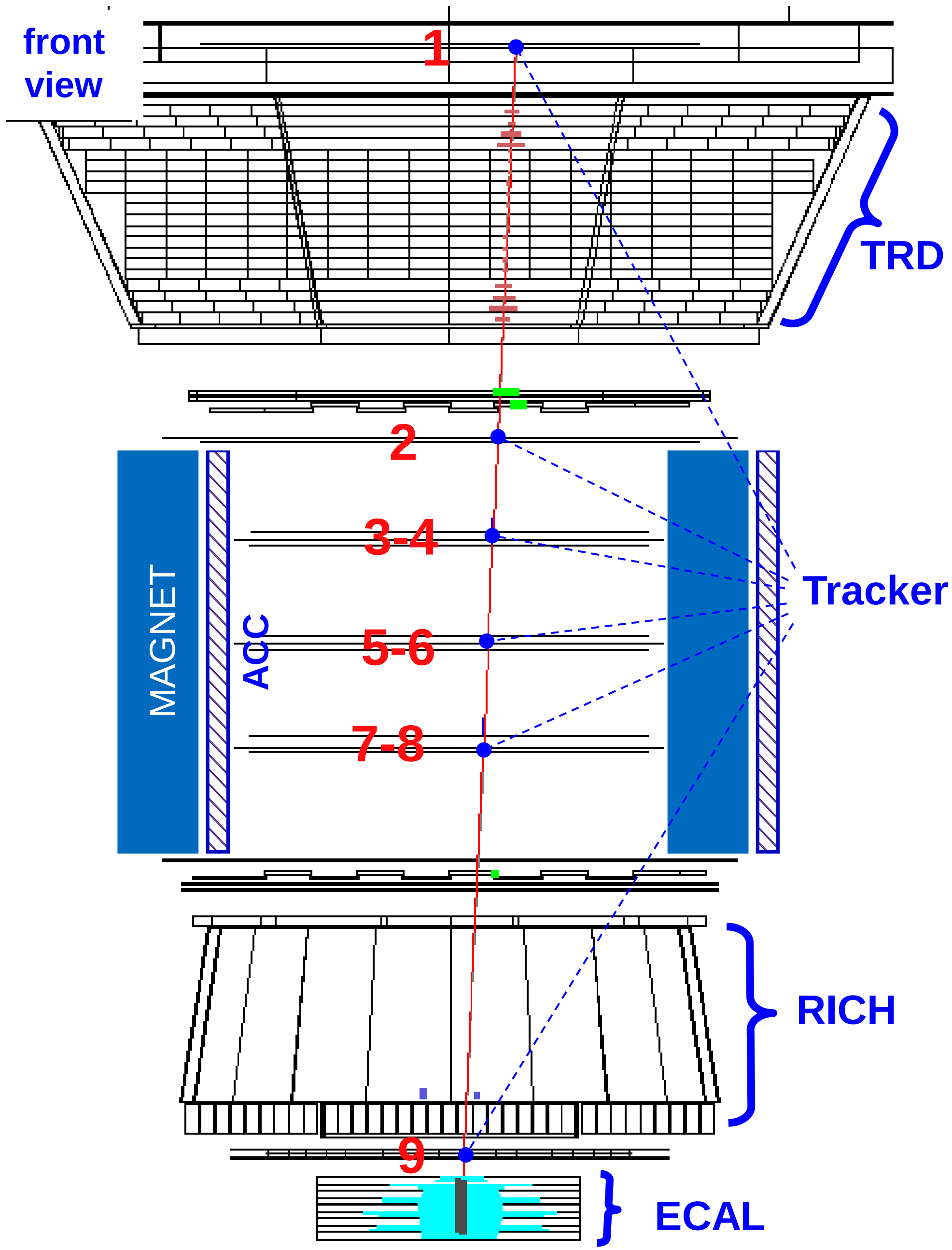


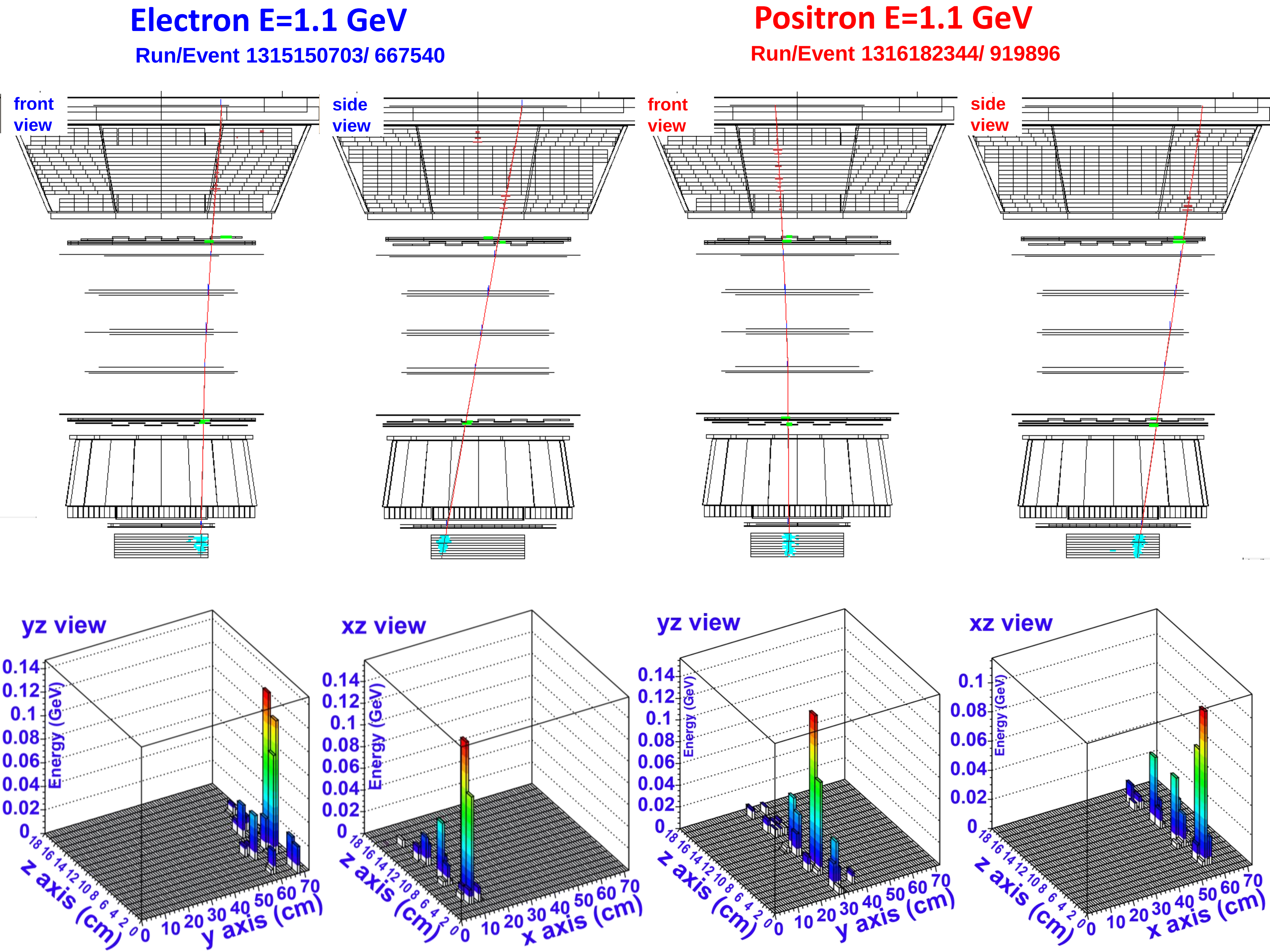


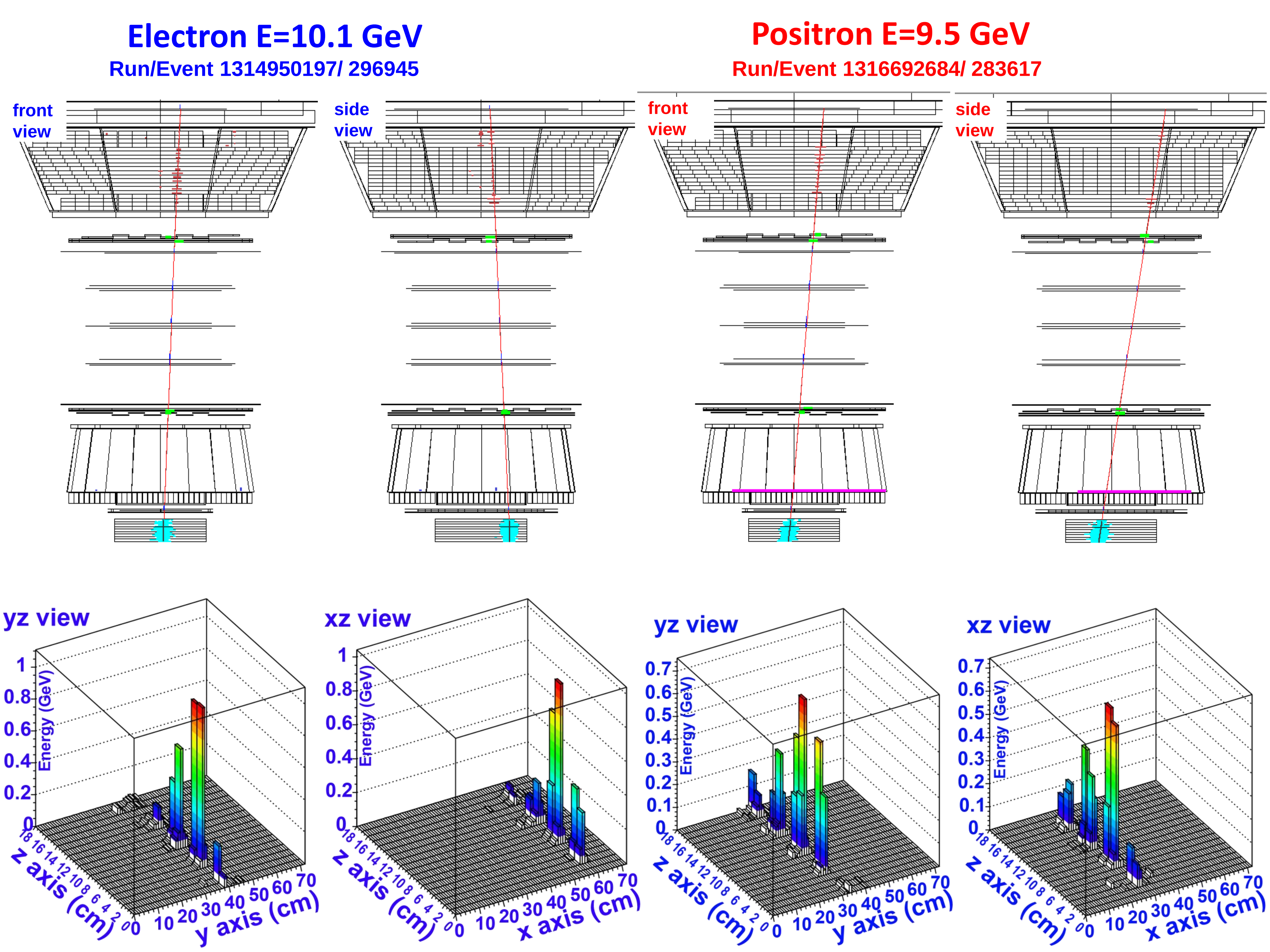
AMS data on ISS: 424 GeV positron

Tracker
A track in the Tracker containing at least one hit in planes 1 or 2 or 9 and hits in planes (3 or 4), (5 or 6) and (7 or 8). In addition, the projected track must pass within 3 cm in x and 10 cm in y of the center of gravity of the ECAL shower.
The relative error on the curvature (inverse of the rigidity) value from the track fit is less than 50 %, which ensures that tracks have rigidities well below their Maximum Detectable Rigidity.
The detector livetime exceeded 50 %, which excludes, for example, the South Atlantic Anomaly.
TOF
The particle velocity measured by TOF β >0.8.
The value of the absolute charge is required to be between 0.8 and 1.4.
TRD
At least 15 TRD hits on the Tracker track traced through the TRD.
ECAL
A shower axis within the ECAL fiducial volume.
The ECAL shower has electromagnetic shape

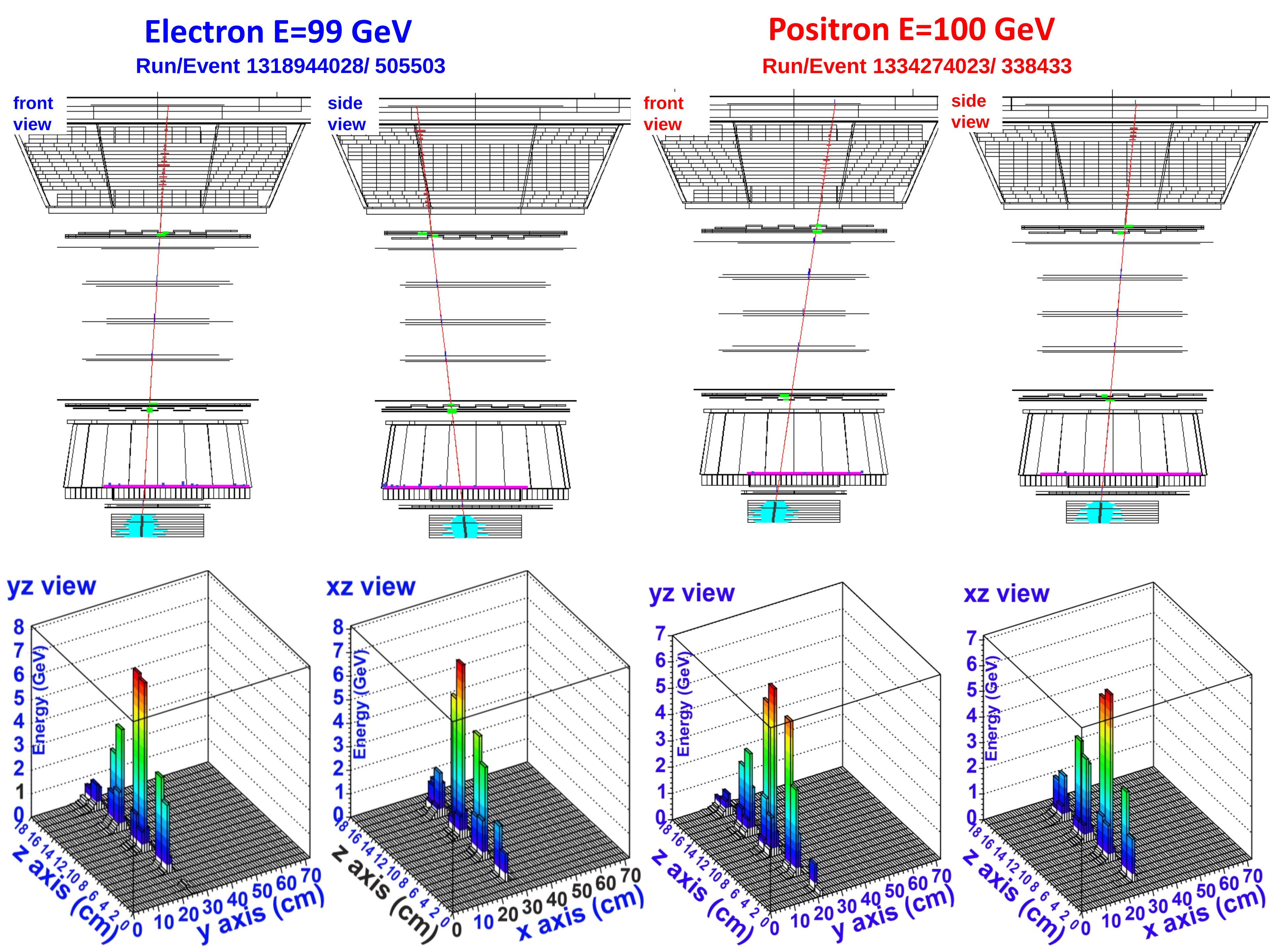
Event selection.



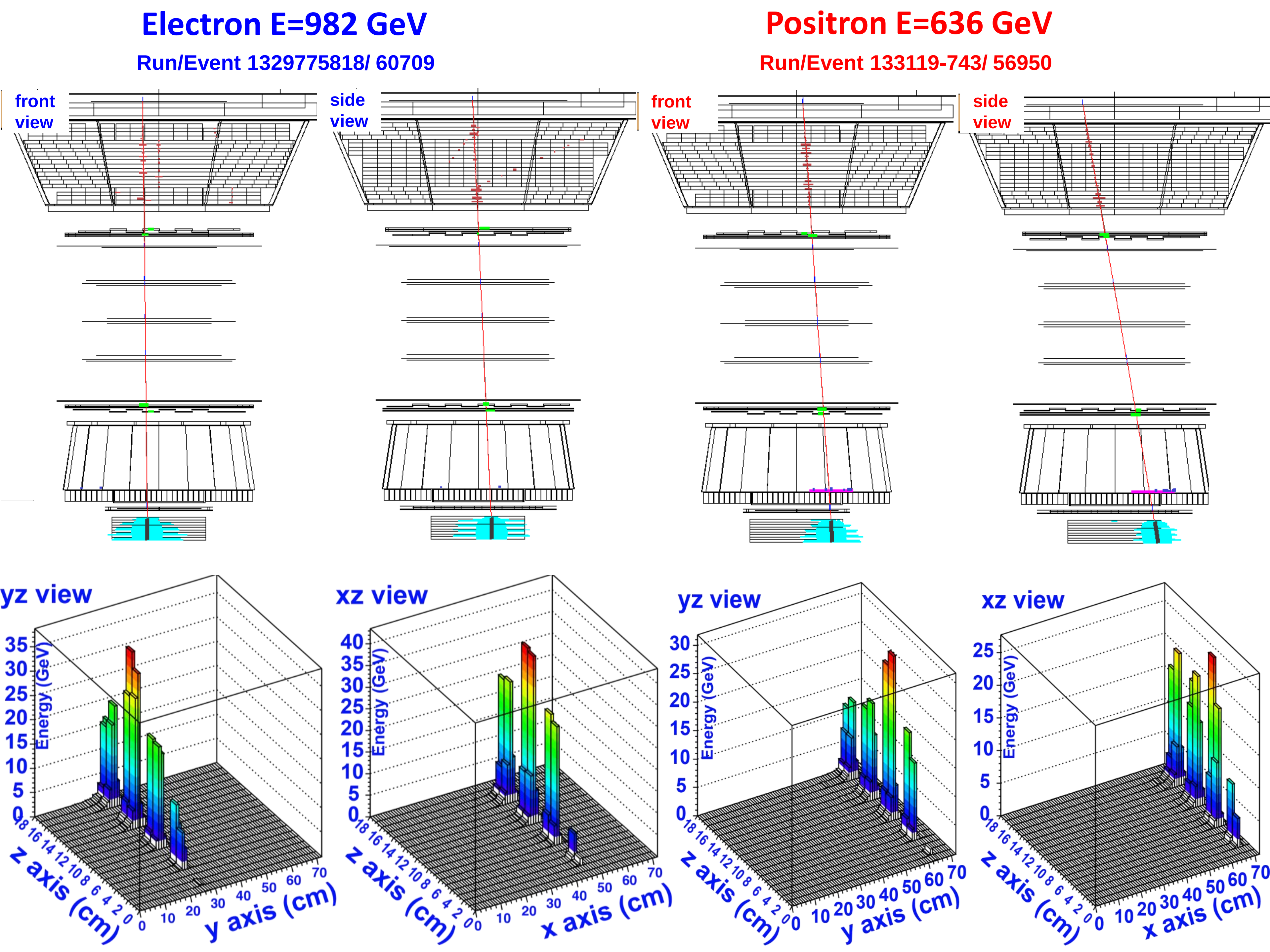

Electron E=1.1 GeV
Run/Event 1315150703/ 667540
Positron E=1.1 GeV
Run/Event 1316182344/ 919896
front view
side view
front view
side view
yz view
xz view
yz view
xz view
Energy (GeV)
z axis (cm)
y axis (cm)
x axis (cm)



Electron E=10.1 GeV
Run/Event 1314950197/ 296945
Positron E=9.5 GeV
Run/Event 1316692684/ 283617
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)



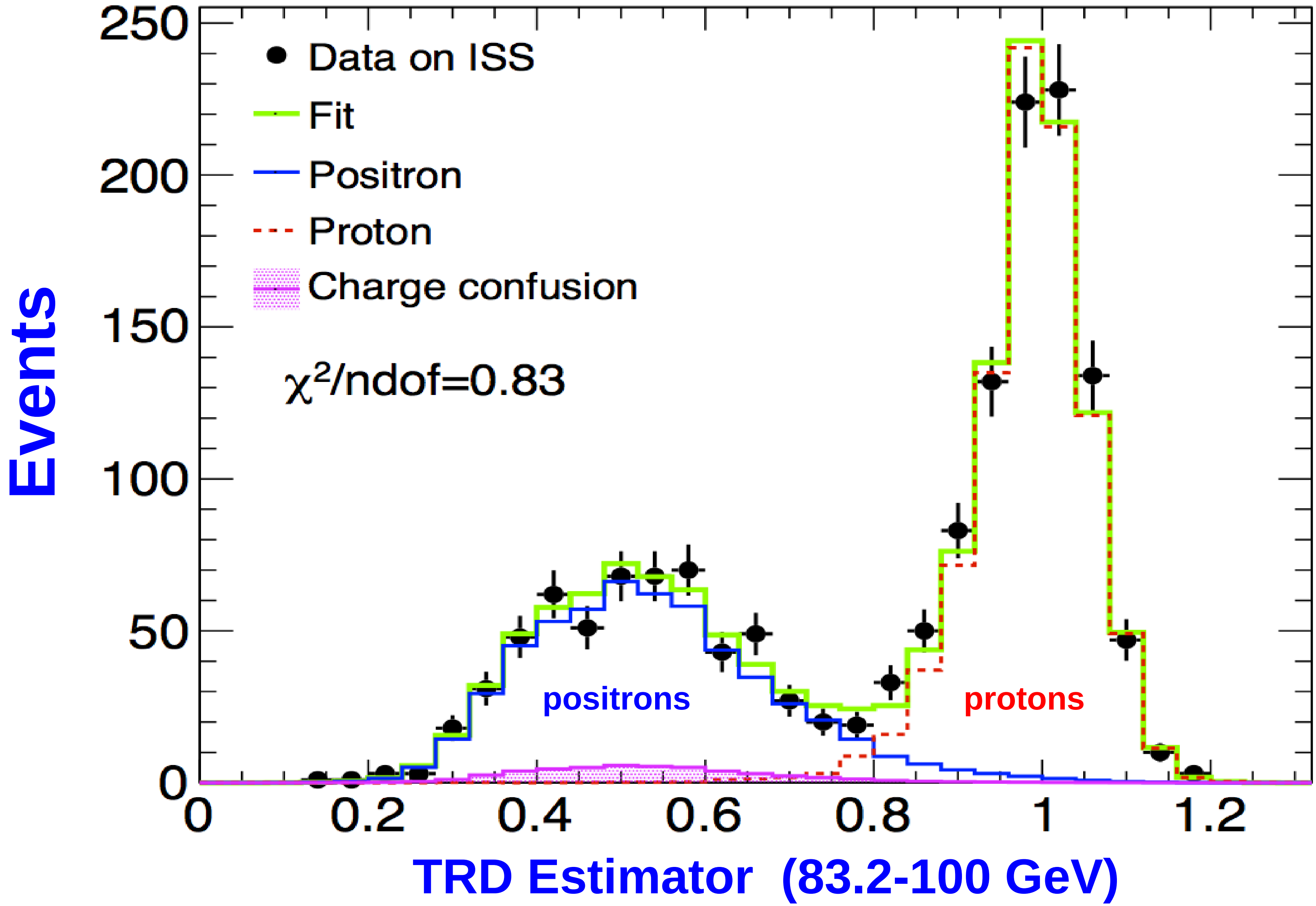
Electron E=99 GeV
Run/Event 1318944028/ 505503
Positron E=100 GeV
Run/Event 1334274023/ 338433
front view
side view
front view
side view
yz view
xz view
yz view
xz view
Energy (GeV)
z axis (cm)
y axis (cm)
x axis (cm)



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

Example of Positron Selection:

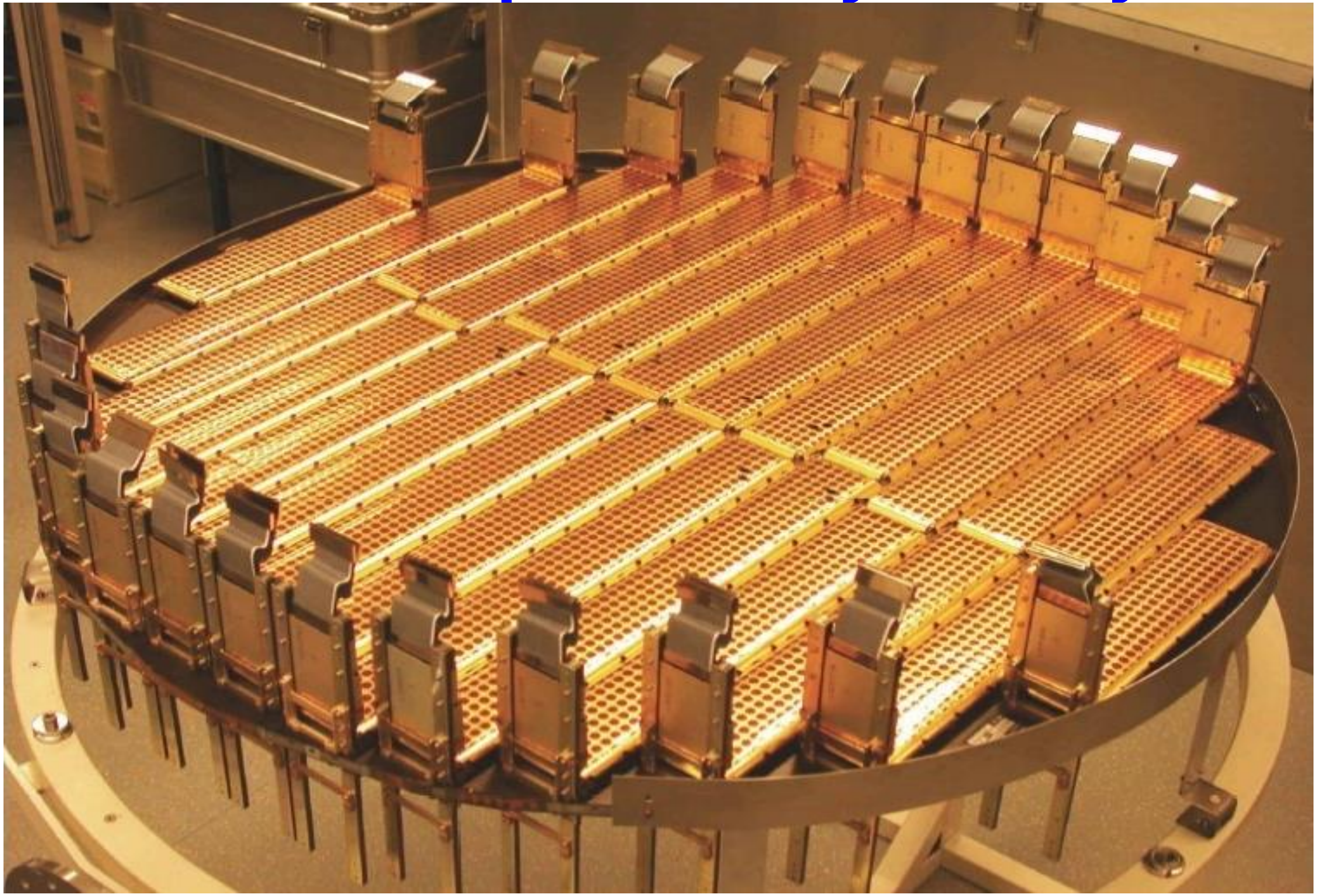
The TRD Estimator shows clear separation between protons and positrons with a small charge confusion background



Systematic errors to positron fraction

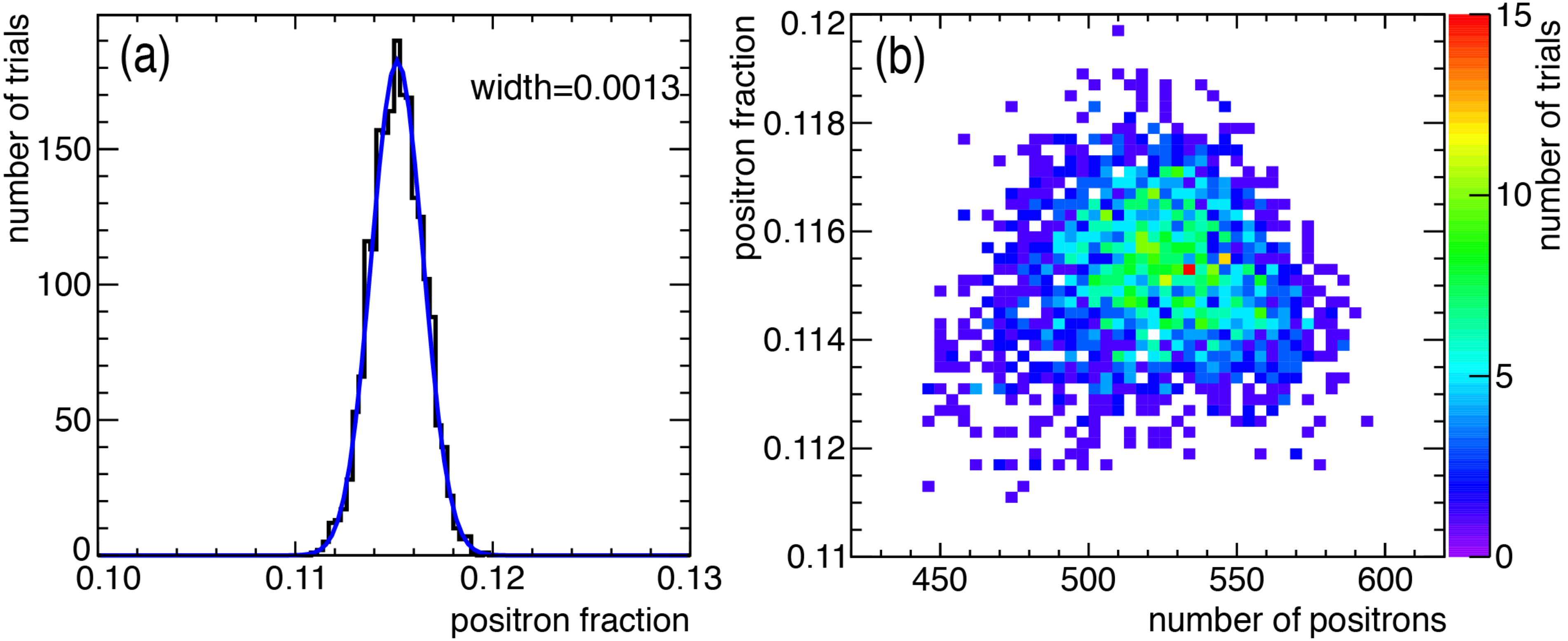
1. **Acceptance asymmetry**
   - Difference between positron and electron acceptance due to known minute tracker asymmetry
2. **Selection dependence**
   - Dependence of the result on the cut values
3. **Migration bin-to bin**
   - Migration of electron and positron events from the neighboring bins affects the measured fraction
4. **Reference spectrum**
   - Definition of the reference spectra is based on pure samples of electrons and protons of finite statistics
5. **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.

Systematic error on the positron fraction: 1. acceptance asymmetry



Difference between positron and electron acceptance due to known minute tracker asymmetry

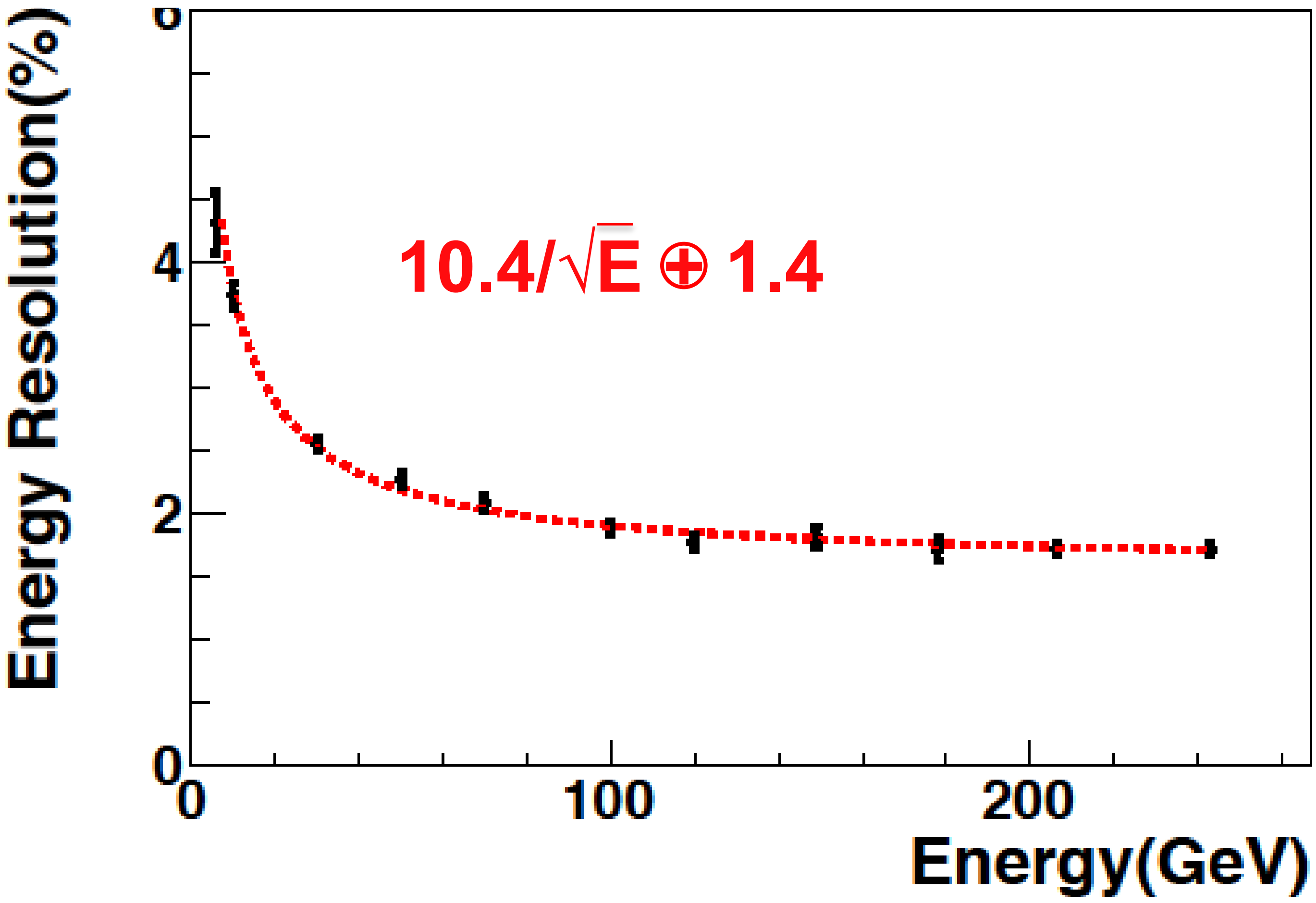
Systematic error on the positron fraction: 2. Selection dependence



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.

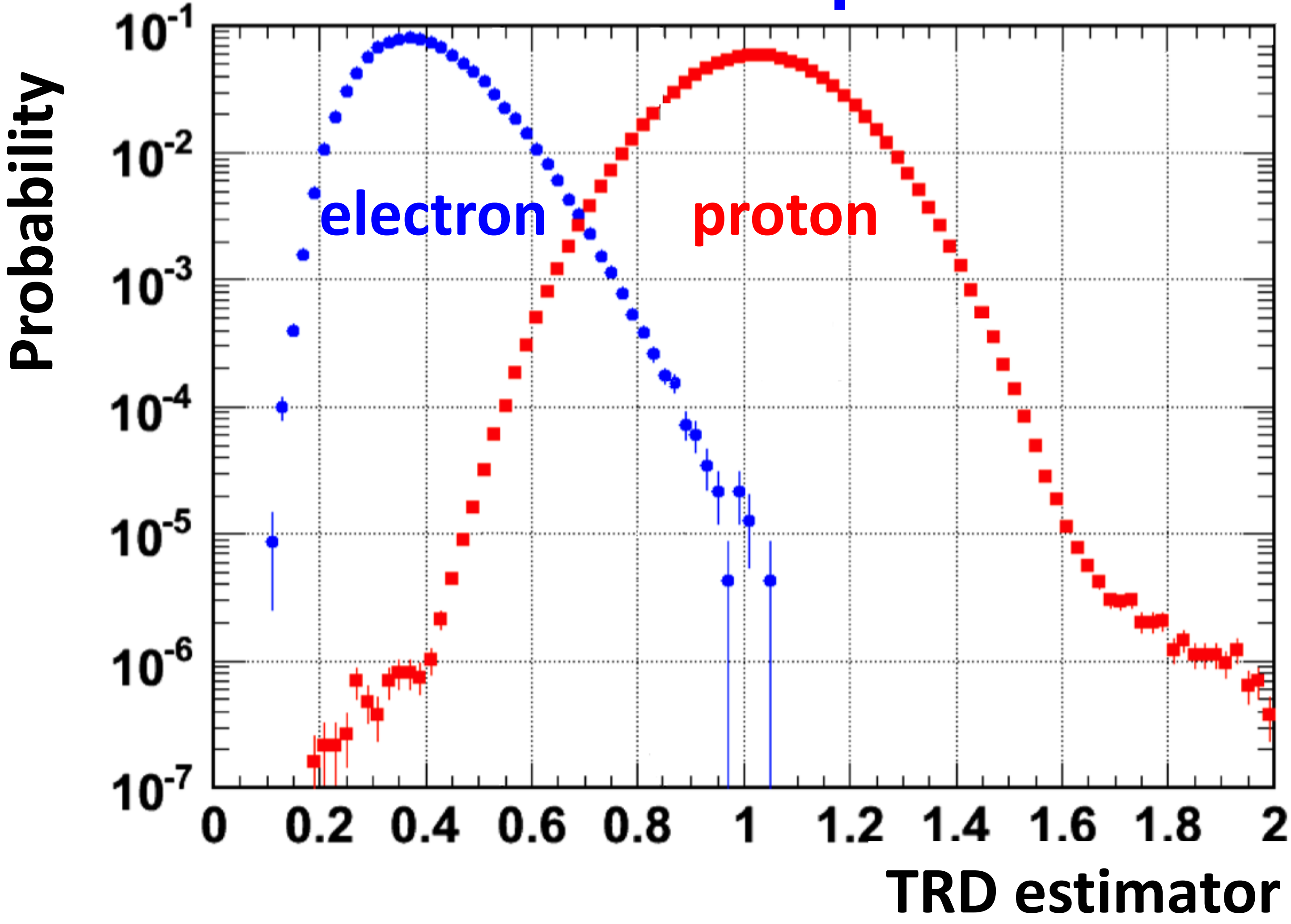
Systematic error on the positron fraction:
3. Bin-to-bin migration



Event migration effects are obtained by folding the measured spectra of positrons and electrons with the ECAL energy resolution.

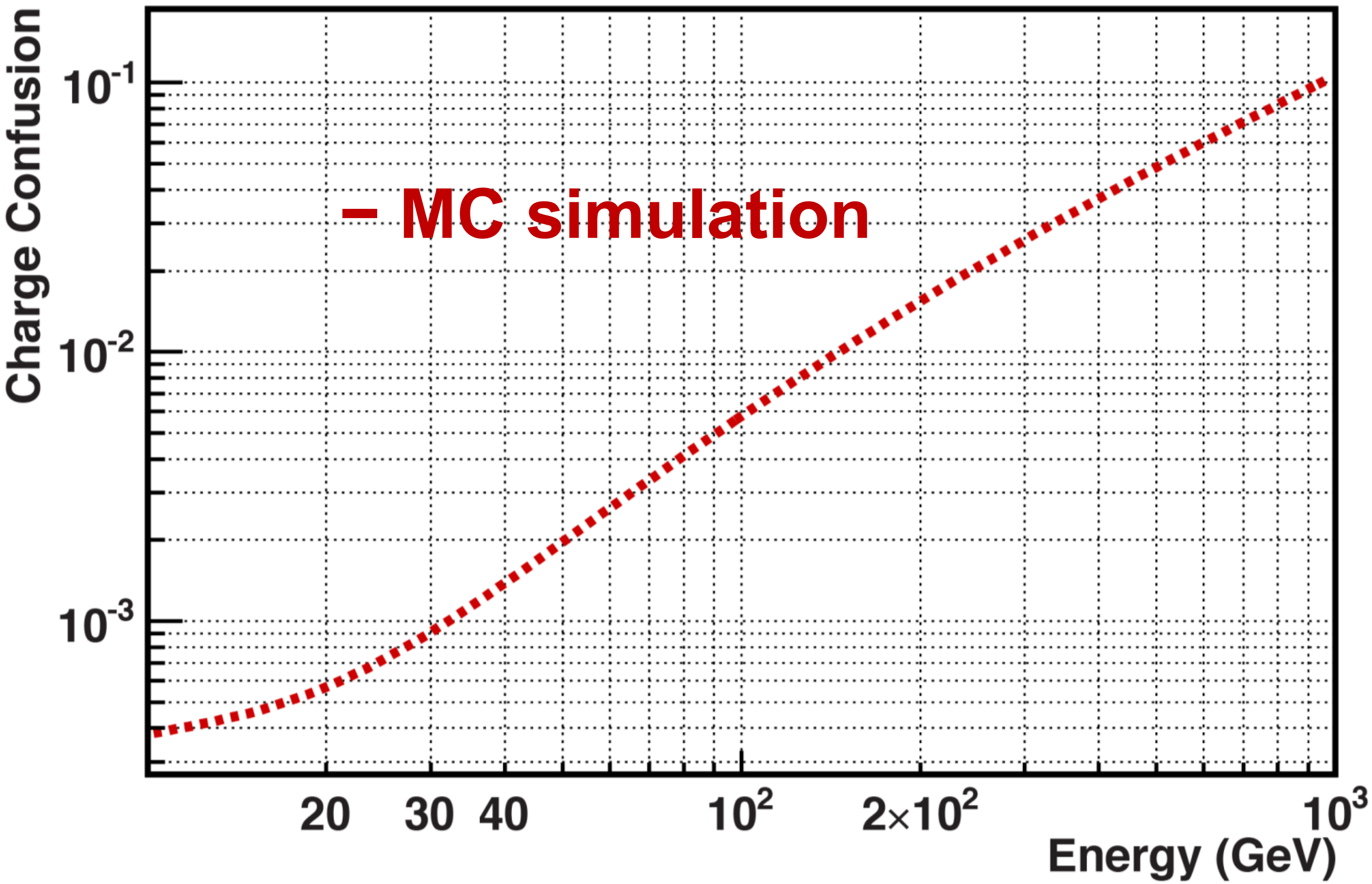
Bin width: 2σ at 5 GeV; 4σ at 50 GeV; 8σ at 100 GeV; 19σ at 300 GeV.

Systematic error on the positron fraction: 4. Reference spectra



Definition of the reference spectra is based on pure samples of electrons and protons of finite statistics.

Systematic error on the positron fraction: 5. Charge confusion

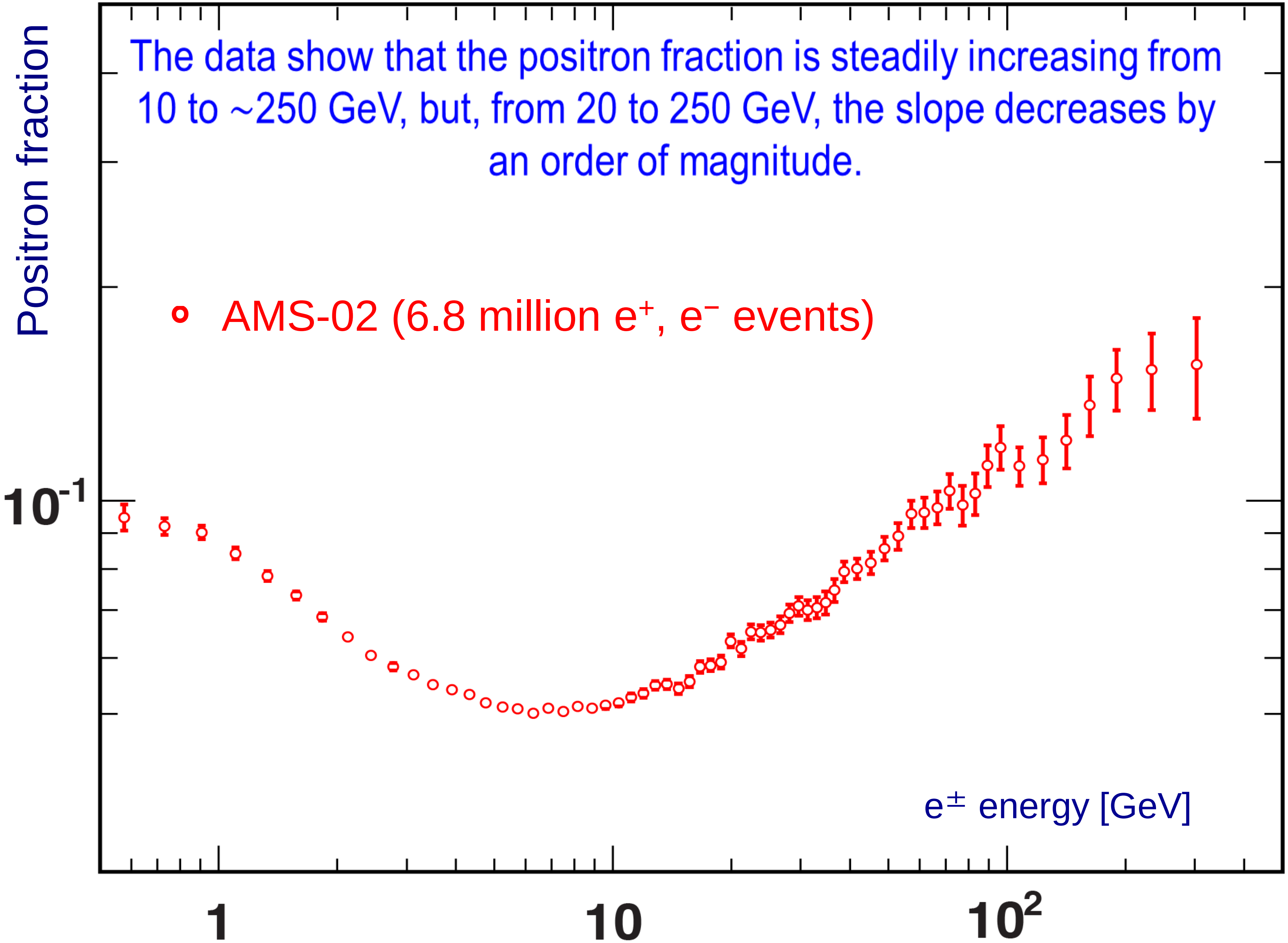


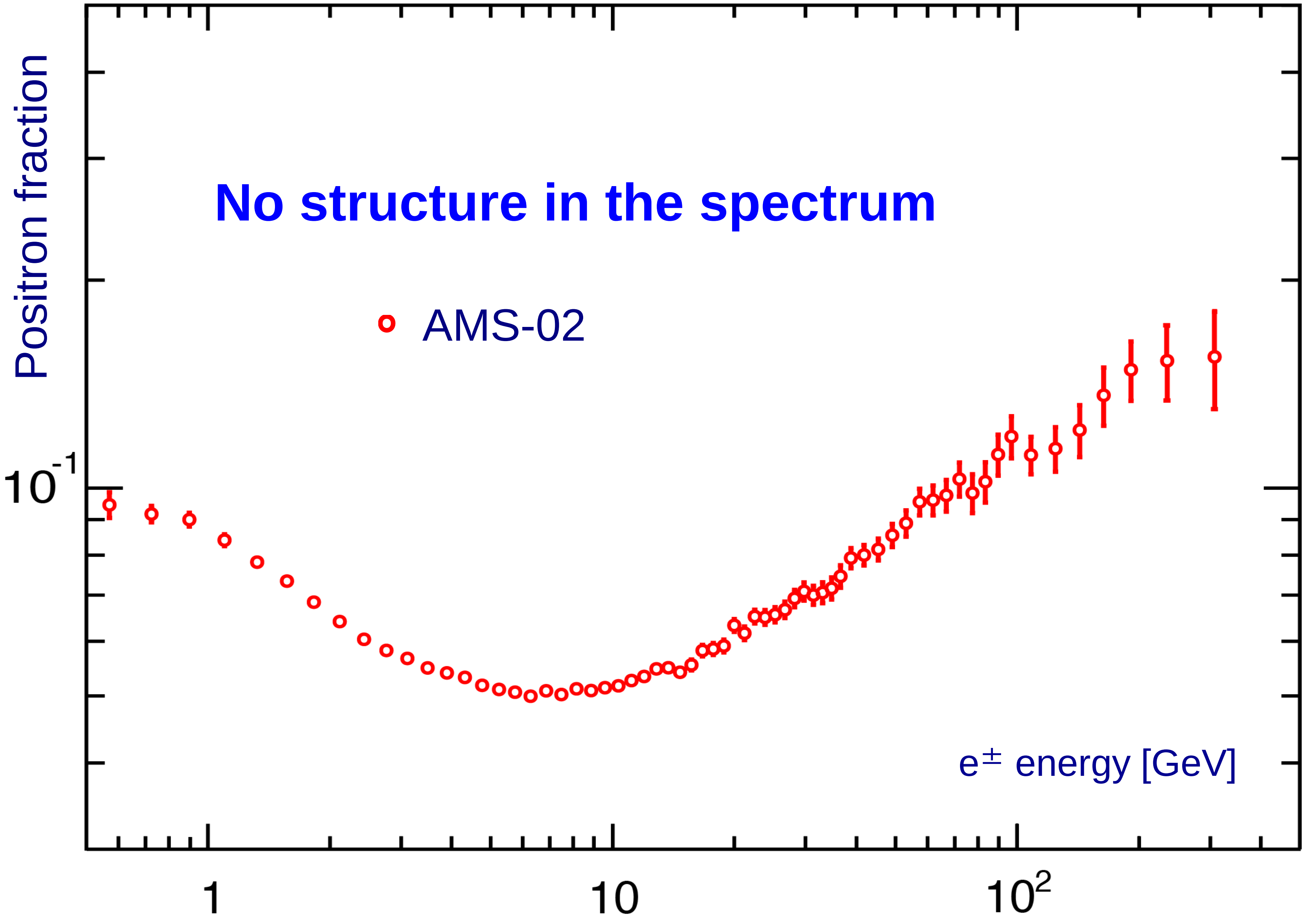
Two sources: large angle scattering and production of secondary tracks along the path of the primary track. Both are well reproduced by MC. Systematic errors correspond to variations of these effects within their statistical limits.

Positron events, positron fraction in each energy bin				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	$\sigma_{stat.}$	$\sigma_{acc.}$	$\sigma_{sel.}$	$\sigma_{mig.}$	$\sigma_{ref.}$	$\sigma_{c.c.}$	$\sigma_{syst.}$
0.50–0.65	822	0.0947	0.0034	0.001	0.0016	0.0005	0.0002	0.001	0.0022
0.65–0.81	3,045	0.0919	0.0016	0.0007	0.0014	0.0007	0.0002	0.0008	0.0019
0.81–1.00	6,504	0.0902	0.0011	0.0006	0.0012	0.0009	0.0002	0.0006	0.0017
1.00–1.21	9,335	0.0842	0.0008	0.0005	0.0009	0.0008	0.0001	0.0005	0.0014
1.21–1.45	12,621	0.0783	0.0007	0.0004	0.0007	0.0006	0.0001	0.0005	0.0011
1.45–1.70	15,189	0.0735	0.0006	0.0003	0.0005	0.0004	0.0001	0.0003	0.0008
1.70–1.97	18,400	0.0685	0.0005	0.0003	0.0005	0.0003	0.0001	0.0003	0.0007
1.97–2.28	23,893	0.0642	0.0004	0.0002	0.0005	0.0002	0.0001	0.0002	0.0006
2.28–2.60	22,455	0.0605	0.0004	0.0002	0.0005	0.0001	0.0001	0.0002	0.0006
2.60–2.94	21,587	0.0583	0.0004	0.0001	0.0005	0.0001	0.0001	0.0002	0.0006
2.94–3.30	21,158	0.0568	0.0004	0.0001	0.0004	0.0000	0.0001	0.0002	0.0005
3.30–3.70	20,707	0.0550	0.0004	0.0001	0.0003	0.0000	0.0001	0.0002	0.0004
3.70–4.11	19,429	0.0541	0.0004	0.0001	0.0002	0.0000	0.0001	0.0002	0.0003
4.11–4.54	18,370	0.0533	0.0004	0.0001	0.0001	0.0000	0.0001	0.0002	0.0003
4.54–5.00	17,064	0.0519	0.0004	0.0001	0.0001	0.0000	0.0001	0.0002	0.0003
5.00–5.50	16,385	0.0512	0.0004	0.0001	0.0001	0.0000	0.0001	0.0002	0.0003
5.50–6.00	14,244	0.0508	0.0004	0.0001	0.0000	0.0000	0.0001	0.0002	0.0002
6.00–6.56	13,880	0.0501	0.0004	0.0001	0.0000	0.0000	0.0001	0.0002	0.0002
6.56–7.16	13,153	0.0510	0.0004	0.0001	0.0000	0.0000	0.0001	0.0002	0.0002

Positron events, positron fraction in each energy bin				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	$\sigma_{stat.}$	$\sigma_{acc.}$	$\sigma_{sel.}$	$\sigma_{mig.}$	$\sigma_{ref.}$	$\sigma_{c.c.}$	$\sigma_{syst.}$
7.16–7.80	11,747	0.0504	0.0005	0.0001	0.0000	0.0000	0.0001	0.0002	0.0002
7.80–8.50	10,910	0.0513	0.0005	0.0001	0.0000	0.0000	0.0001	0.0002	0.0002
8.50–9.21	9,110	0.0510	0.0005	0.0001	0.0000	0.0000	0.0001	0.0002	0.0002
9.21–9.95	7,501	0.0515	0.0006	0.0001	0.0000	0.0000	0.0001	0.0002	0.0002
9.95–10.73	7,161	0.0519	0.0006	0.0001	0.0000	0.0000	0.0001	0.0002	0.0002
10.73–11.54	6,047	0.0528	0.0007	0.0001	0.0000	0.0000	0.0001	0.0001	0.0002
11.54–12.39	5,246	0.0535	0.0007	0.0001	0.0000	0.0000	0.0001	0.0001	0.0002
12.39–13.27	4,787	0.0549	0.0008	0.0001	0.0000	0.0000	0.0001	0.0001	0.0002
13.27–14.19	4,166	0.0551	0.0008	0.0001	0.0000	0.0000	0.0001	0.0001	0.0002
14.19–15.15	3,698	0.0543	0.0009	0.0001	0.0001	0.0000	0.0001	0.0001	0.0002
15.15–16.15	3,326	0.0556	0.0010	0.0001	0.0001	0.0000	0.0001	0.0001	0.0002
16.15–17.18	3,007	0.0583	0.0011	0.0001	0.0001	0.0000	0.0001	0.0002	0.0003
17.18–18.25	2,663	0.0586	0.0011	0.0001	0.0001	0.0000	0.0001	0.0002	0.0003
18.25–19.37	2,410	0.0592	0.0012	0.0001	0.0001	0.0000	0.0001	0.0002	0.0003
19.37–20.54	2,322	0.0634	0.0013	0.0001	0.0001	0.0000	0.0001	0.0002	0.0003
20.54–21.76	2,052	0.0618	0.0014	0.0001	0.0001	0.0000	0.0001	0.0002	0.0003
21.76–23.07	1,992	0.0653	0.0015	0.0001	0.0001	0.0000	0.0001	0.0002	0.0003
23.07–24.45	1,788	0.0651	0.0016	0.0001	0.0001	0.0000	0.0001	0.0002	0.0003
24.45–25.87	1,642	0.0657	0.0016	0.0001	0.0001	0.0000	0.0001	0.0002	0.0003
25.87–27.34	1,447	0.0668	0.0018	0.0001	0.0001	0.0000	0.0001	0.0003	0.0003
27.34–28.87	1,260	0.0694	0.0020	0.0001	0.0001	0.0000	0.0001	0.0003	0.0003
28.87–30.45	1,137	0.0710	0.0021	0.0001	0.0002	0.0000	0.0001	0.0003	0.0004
30.45–32.10	1,094	0.0701	0.0022	0.0001	0.0002	0.0000	0.0001	0.0003	0.0004
32.10–33.80	888	0.0707	0.0024	0.0001	0.0002	0.0000	0.0001	0.0004	0.0005

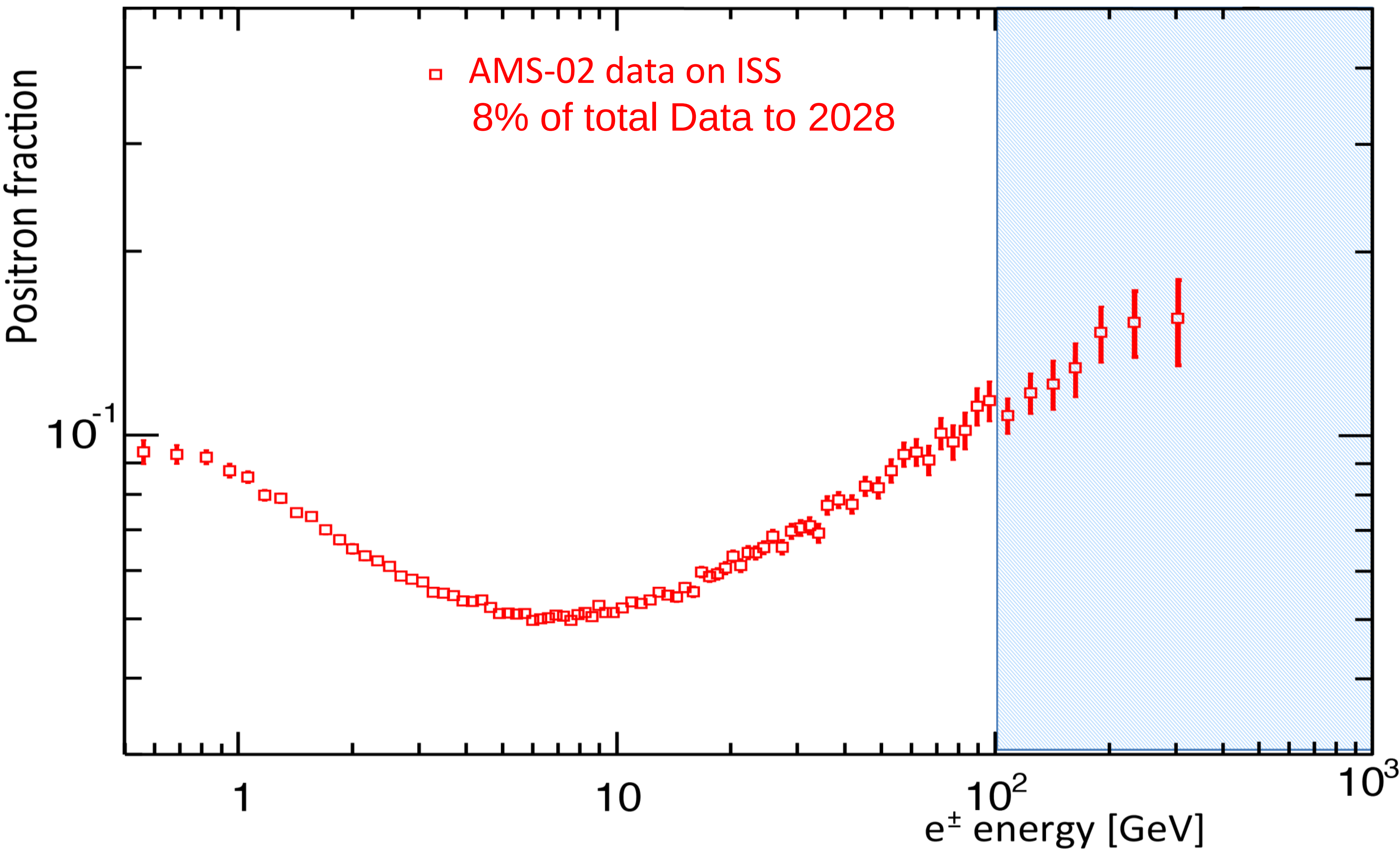
Positron events, positron fraction in each energy bin				Systematic Errors					
Energy [GeV]	N_{e+}	Fraction	statistical error	acceptance asymmetry	event selection	bin-to-bin migration	reference spectra	charge confusion	total systematic uncertainty
Energy[GeV]	N_{e+}	Fraction	$\sigma_{stat.}$	$\sigma_{acc.}$	$\sigma_{sel.}$	$\sigma_{mig.}$	$\sigma_{ref.}$	$\sigma_{c.c.}$	$\sigma_{syst.}$
33.80 – 35.57	807	0.0718	0.0026	0.0001	0.0003	0.0000	0.0001	0.0004	0.0005
35.57 – 37.40	787	0.0747	0.0027	0.0001	0.0003	0.0000	0.0001	0.0004	0.0005
37.40 – 40.00	982	0.0794	0.0026	0.0002	0.0004	0.0000	0.0001	0.0004	0.0006
40.00 – 43.39	976	0.0802	0.0026	0.0002	0.0005	0.0000	0.0001	0.0004	0.0007
43.39 – 47.01	856	0.0817	0.0029	0.0002	0.0005	0.0000	0.0001	0.0004	0.0007
47.01 – 50.87	739	0.0856	0.0032	0.0002	0.0006	0.0000	0.0001	0.0004	0.0008
50.87 – 54.98	605	0.0891	0.0038	0.0002	0.0006	0.0000	0.0001	0.0004	0.0008
54.98 – 59.36	558	0.0957	0.0041	0.0002	0.0008	0.0000	0.0001	0.0005	0.0010
59.36 – 64.03	448	0.0962	0.0047	0.0002	0.0009	0.0000	0.0002	0.0006	0.0011
64.03 – 69.00	392	0.0978	0.0050	0.0002	0.0010	0.0000	0.0002	0.0007	0.0013
69.00 – 74.30	324	0.1032	0.0057	0.0002	0.0010	0.0000	0.0002	0.0009	0.0014
74.30 – 80.00	276	0.0985	0.0062	0.0002	0.0010	0.0000	0.0002	0.0010	0.0014
80.00 – 86.00	232	0.1023	0.0067	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
92.50 – 100.0	226	0.1189	0.0081	0.0002	0.0011	0.0000	0.0003	0.0012	0.0017
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


The 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.
AMS-02 (6.8 million e+, e− events)
Positron fraction
e± energy [GeV]
10-1
1
10
102


Positron fraction
No structure in the spectrum
AMS-02
e± energy [GeV]
10-1
1
10
10²

AMS will be on ISS for 20 years.

The data to ~1 TeV will be presented when there are sufficient events.



On the origin of excess positrons

If the excess has a particle physics origin, there should be no anisotropy.

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

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

where $r_e(b, l)$ denotes the positron ratio at (b, l); $< r_e >$ 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

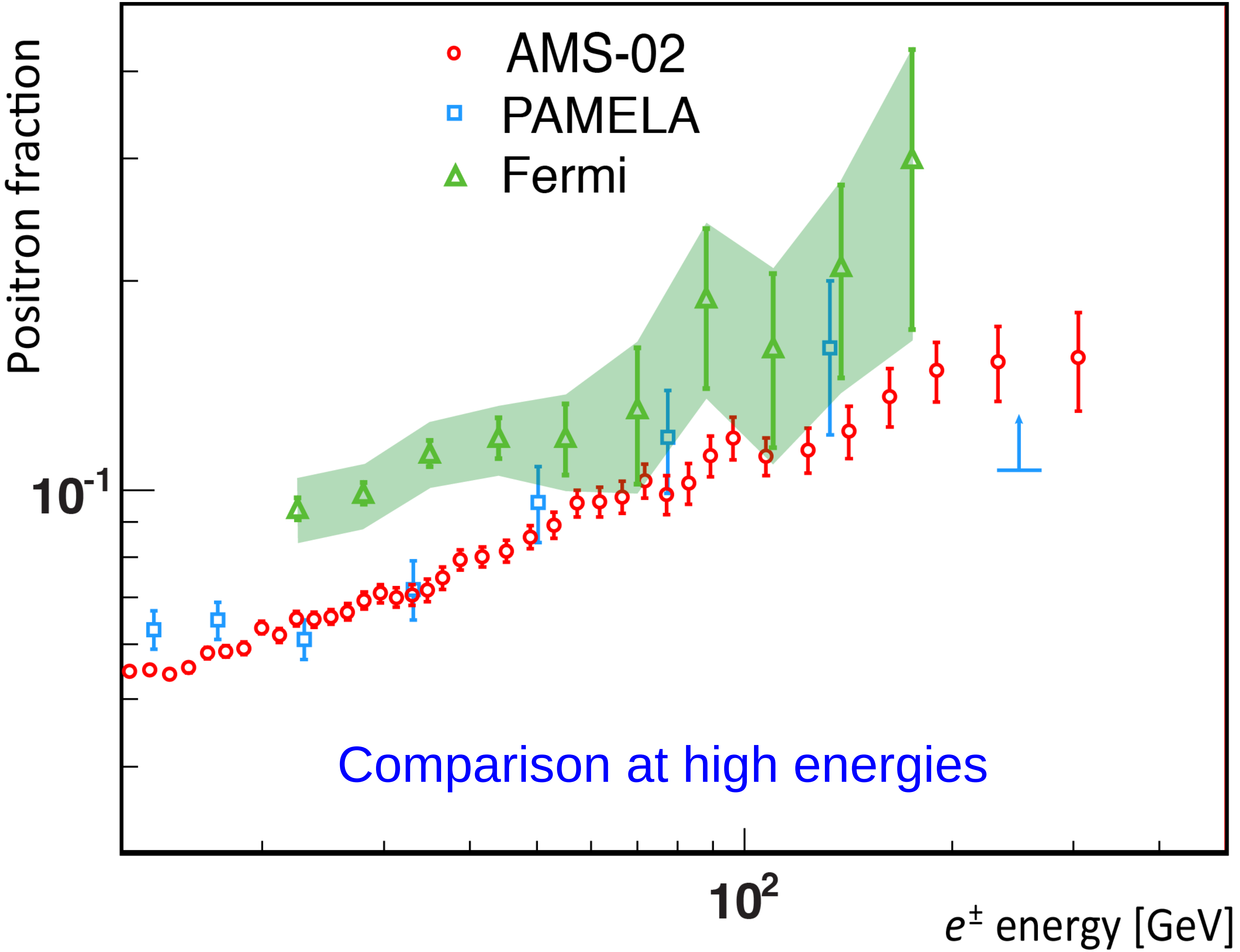
$$C_\ell = \frac{1}{2\ell+1} \sum_{m=-\ell}^{\ell} |a_{\ell m}|^2.$$

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

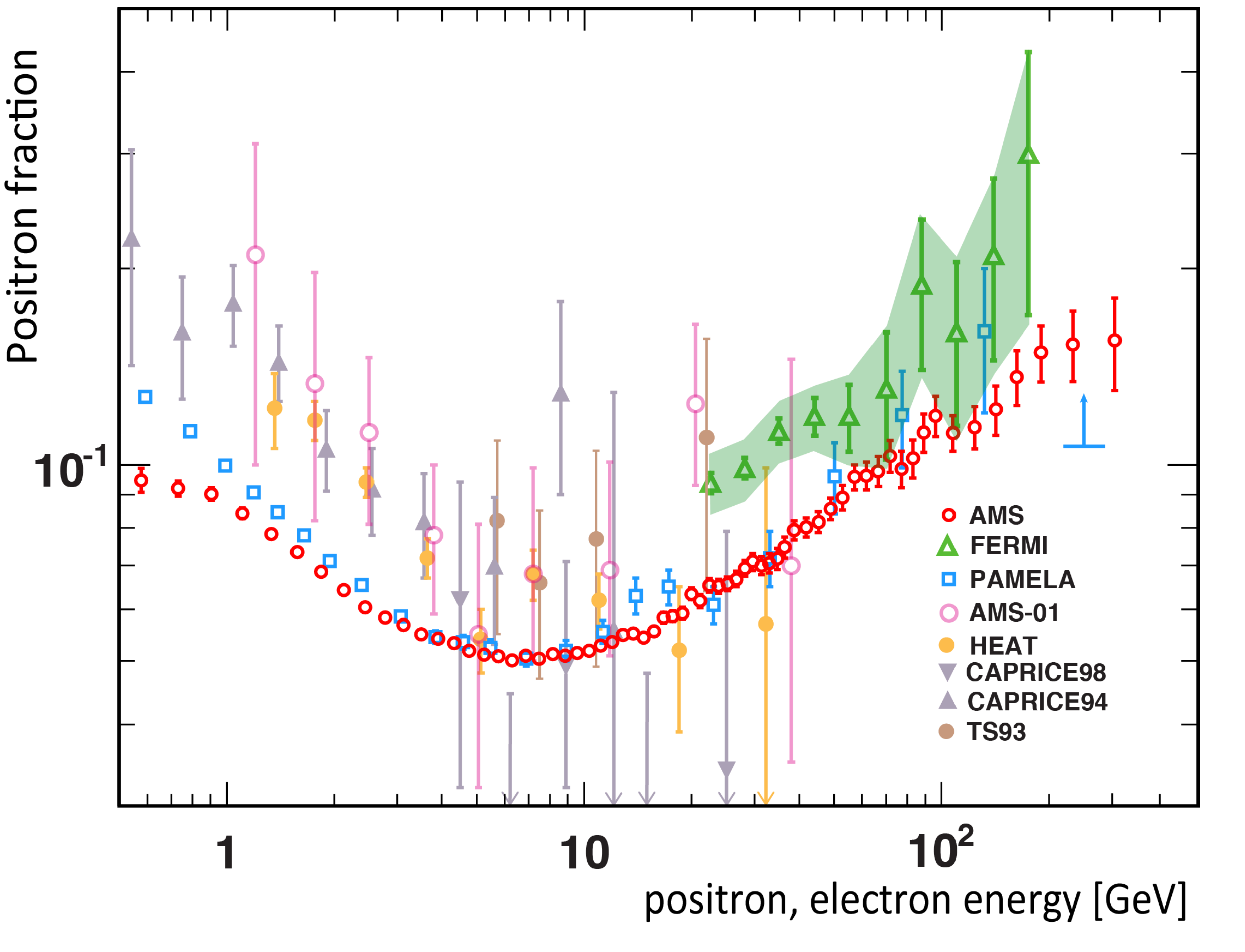
$$\delta = 3\sqrt{C_1/4\pi} \leq 0.036 \quad (95\%\ C.L.)$$

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

$\delta \leq 0.036$ at the 95% confidence level



AMS-02
PAMELA
Fermi
Positron fraction
10^{-1}
10^{2}
$e^{\pm}$ energy [GeV]
Comparison at high energies



Positron fraction
10⁻¹
1
10
10²
positron, electron energy [GeV]
AMS
FERMI
PAMELA
AMS-01
HEAT
CAPRICE98
CAPRICE94
TS93

An Example:
Comparing AMS data with a minimal model.

In this model the e^+ and e^- fluxes, Φ_{e+} and Φ_{e-}, are parameterized as the sum of individual diffuse power law spectra and the contribution of a single common source of $e^{\pm}$:

$$\Phi_{e^+} = C_{e^+} E^{-\gamma_{e^+}} + C_s E^{-\gamma_s} e^{-E/E_s} \qquad \text{Eq(1)}$$

$$\Phi_{e^-} = C_{e^-} E^{-\gamma_{e^-}} + C_s E^{-\gamma_s} e^{-E/E_s} \quad (E \text{ in GeV}) \qquad \text{Eq(2)}$$

Coefficients C_{e+} and C_{e-} correspond to relative weights of diffuse spectra for positrons and electrons.

C_s is the weight of the source spectrum.

γ_{e+}, γ_{e-} and γ_s are the corresponding spectral indexes.

E_s is a characteristic cutoff energy for the source spectrum.

With this parametrization the positron fraction depends on 5 parameters.

A fit to the data in the energy range 1 to 350 GeV yields a $\chi^2/d.f. = 28.5/57$ and:

$\gamma_{e-} - \gamma_{e+} = -0.63 \pm 0.03$, *i.e.*, the diffuse positron spectrum is less energetic than the diffuse electron spectrum;

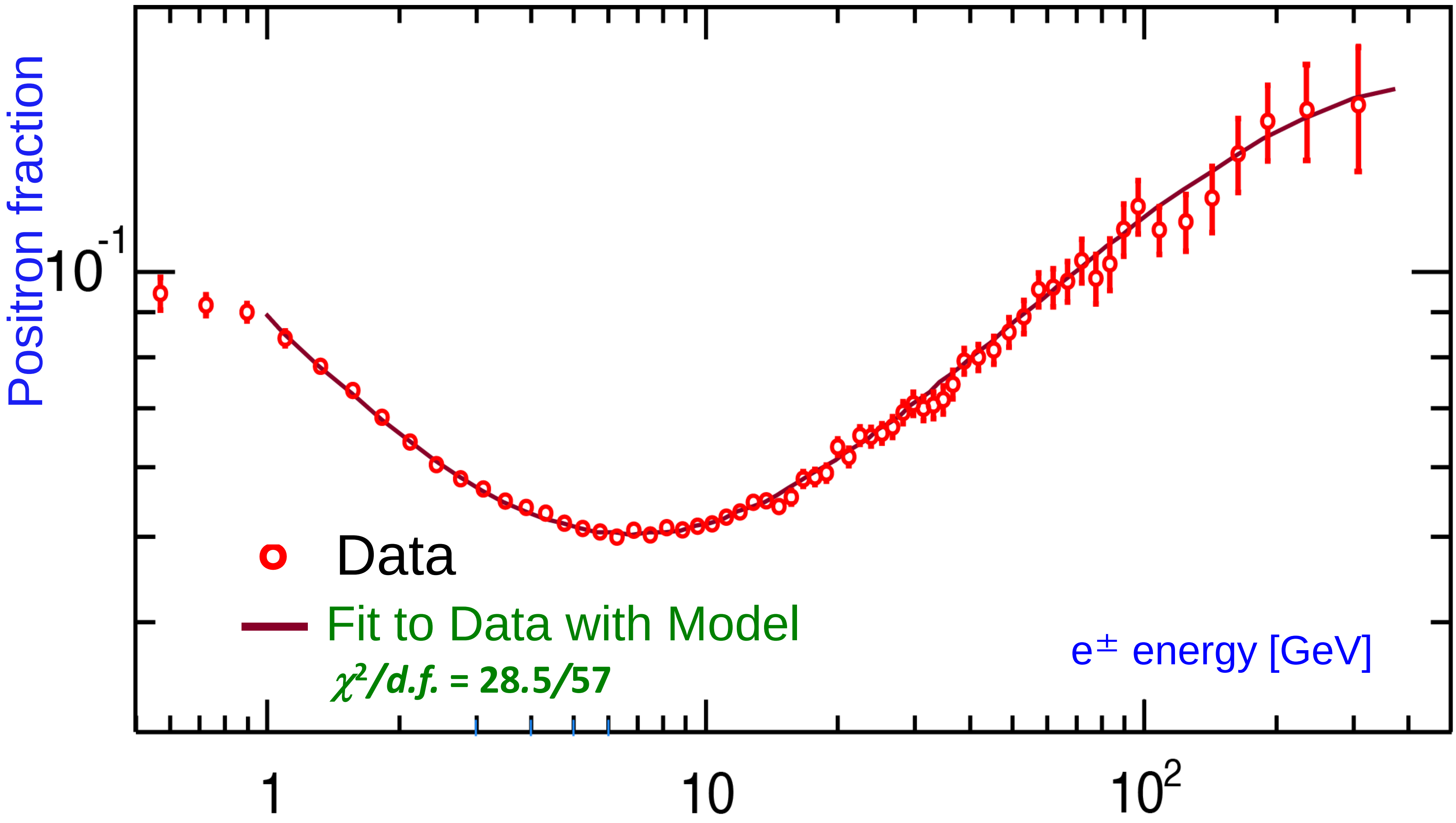
$\gamma_{e-} - \gamma_{S} = 0.66 \pm 0.05$, *i.e.*, the source spectrum is more energetic than the diffuse electron spectrum;

$C_{e+}/C_{e-} = 0.091 \pm 0.001$, *i.e.*, the weight of the diffuse positron flux amounts to ~10% of that of the diffuse electron flux;

$C_S/C_{e-} = 0.0078 \pm 0.0012$, *i.e.*, the weight of the common source constitutes only ~1% of that of the diffuse electron flux;

$1/E_s = 0.0013 \pm 0.0007$ GeV^{-1},

corresponding to a cutoff energy of 760^{+1000}_{-280} GeV.



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

In conclusion, the first 6.8 million primary positron and electron events collected with AMS on the ISS show:

i.At energies < 10 GeV, a decrease in the positron fraction with increasing energy.

ii. A steady increase in the positron fraction from 10 to ~250 GeV.

iii. The determination of the behavior of the positron fraction from 250 to 350 GeV and beyond requires more statistics.

iv. The slope of the positron fraction versus energy decreases by an order of magnitude from 20 to 250GeV and no fine structure is observed. 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.

v. The positron to electron ratio is consistent with isotropy; $\delta \leq 0.036$ at the 95% *C.L.*

These observations show the existence of new physical phenomena, whether from a particle D3 physics or an astrophysical origin.

The excess of antimatter (positrons) has been observed for more than twenty years and has aroused much interest.

AMS is the first experiment to probe in detail the nature of this excess with its high sensitivity and precision.

We have observed many new phenomena in this positron spectrum. Soon, the origin of this excess will be understood.

It is very difficult in accelerators to do a 1% accuracy experiment. To do so in space is extremely challenging. It is the effort of the entire AMS collaboration with the support of NASA and CERN which is making this possible.