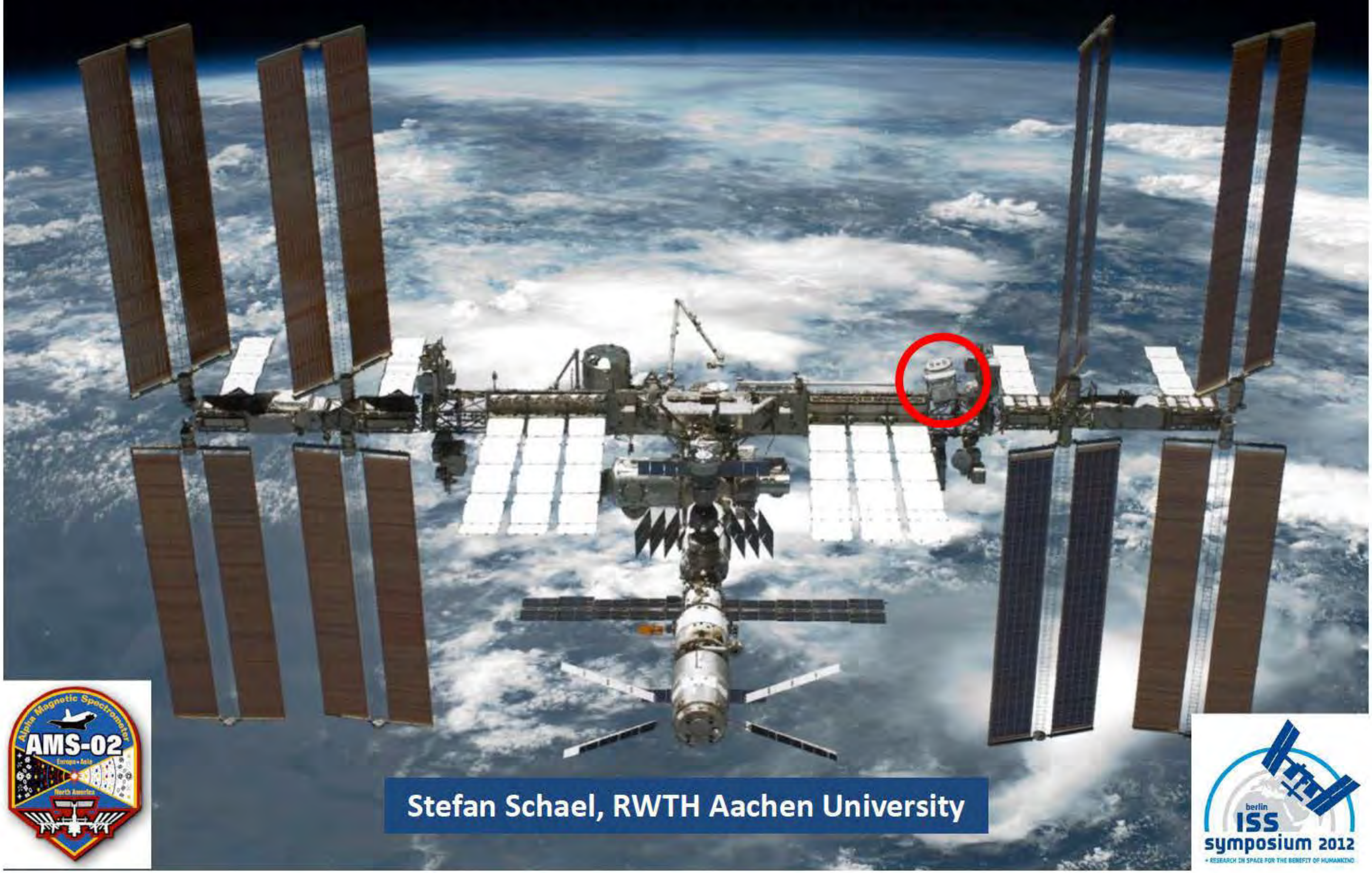
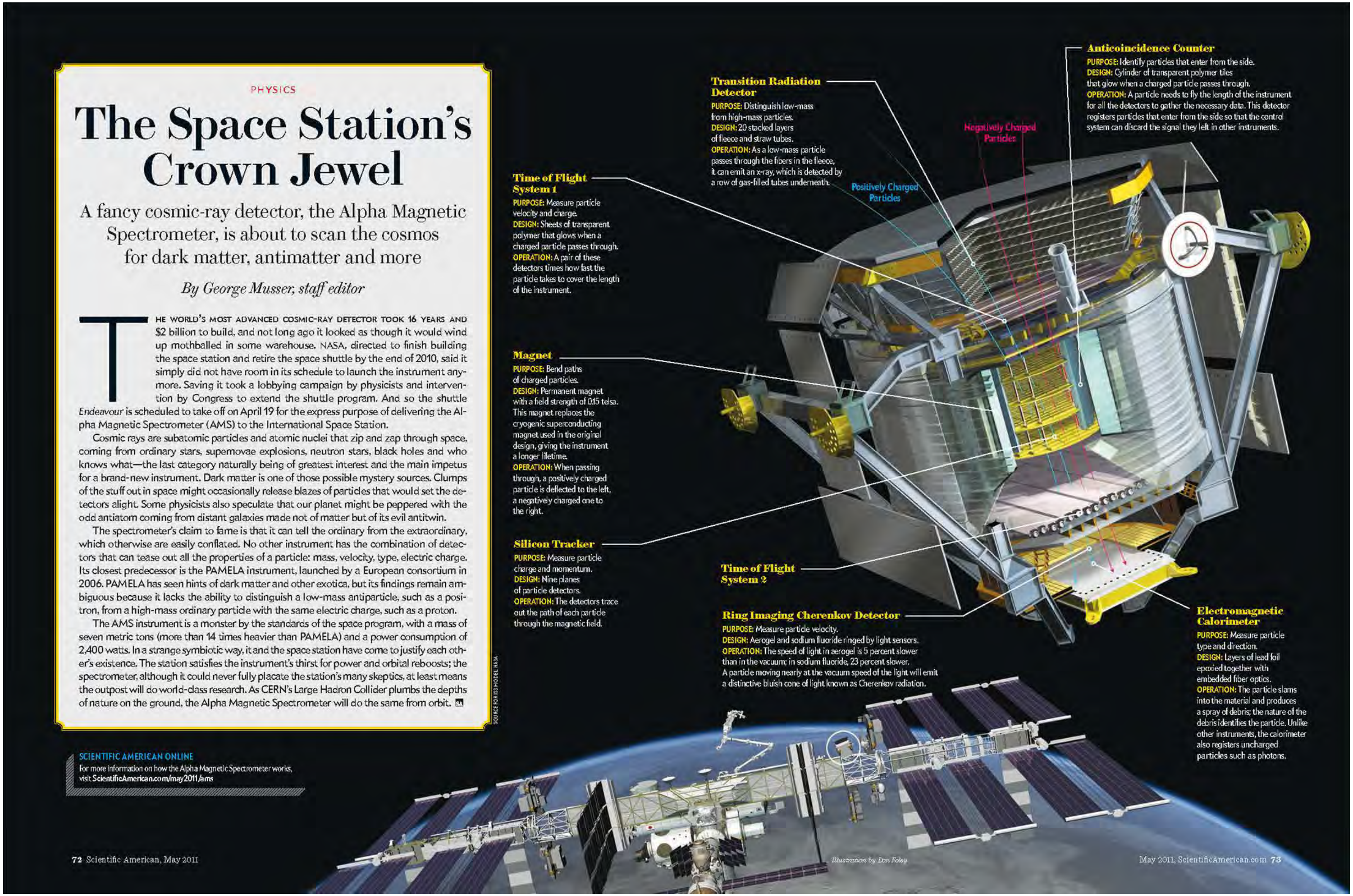
The Alpha Magnetic Spectrometer Experiment on ISS –
An endeavor for a Global Research Collaboration



Stefan Schael, RWTH Aachen University



PHYSICS

The Space Station's Crown Jewel

A fancy cosmic-ray detector, the Alpha Magnetic Spectrometer, is about to scan the cosmos for dark matter, antimatter and more

By George Musser, staff editor

THE WORLD'S MOST ADVANCED COSMIC-RAY DETECTOR TOOK 16 YEARS AND $2 billion to build, and not long ago it looked as though it would wind up mothballed in some warehouse. NASA, directed to finish building the space station and retire the space shuttle by the end of 2010, said it simply did not have room in its schedule to launch the instrument anymore. Saving it took a lobbying campaign by physicists and intervention by Congress to extend the shuttle program. And so the shuttle *Endeavour* is scheduled to take off on April 19 for the express purpose of delivering the Alpha Magnetic Spectrometer (AMS) to the International Space Station.

Cosmic rays are subatomic particles and atomic nuclei that zip and zap through space, coming from ordinary stars, supernovae explosions, neutron stars, black holes and who knows what—the last category naturally being of greatest interest and the main impetus for a brand-new instrument. Dark matter is one of those possible mystery sources. Clumps of the stuff out in space might occasionally release blazes of particles that would set the detectors alight. Some physicists also speculate that our planet might be peppered with the odd antiatom coming from distant galaxies made not of matter but of its evil antitwin.

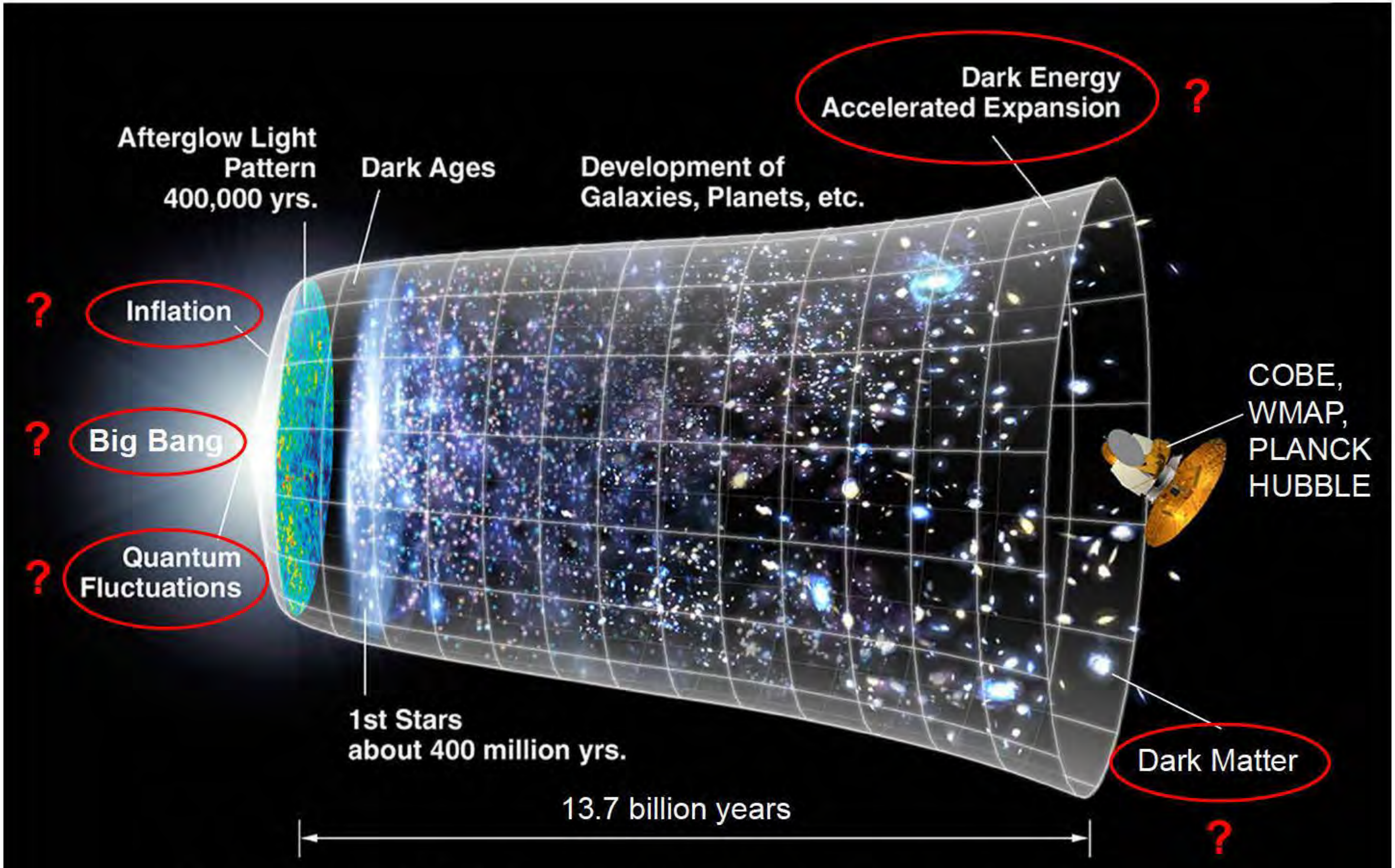
The spectrometer's claim to fame is that it can tell the ordinary from the extraordinary, which otherwise are easily conflated. No other instrument has the combination of detectors that can tease out all the properties of a particle: mass, velocity, type, electric charge. Its closest predecessor is the PAMELA instrument, launched by a European consortium in 2006. PAMELA has seen hints of dark matter and other exotica, but its findings remain ambiguous because it lacks the ability to distinguish a low-mass antiparticle, such as a positron, from a high-mass ordinary particle with the same electric charge, such as a proton.

The AMS instrument is a monster by the standards of the space program, with a mass of seven metric tons (more than 14 times heavier than PAMELA) and a power consumption of 2,400 watts. In a strange symbiotic way, it and the space station have come to justify each other's existence. The station satisfies the instrument's thirst for power and orbital reboosts; the spectrometer, although it could never fully placate the station's many skeptics, at least means the outpost will do world-class research. As CERN's Large Hadron Collider plumbs the depths of nature on the ground, the Alpha Magnetic Spectrometer will do the same from orbit.

SOURCE FOR ISS MODEL: NASA

SCIENTIFIC AMERICAN ONLINE
For more information on how the Alpha Magnetic Spectrometer works, visit ScientificAmerican.com/may2011/ams

From Scientific American, May 2011



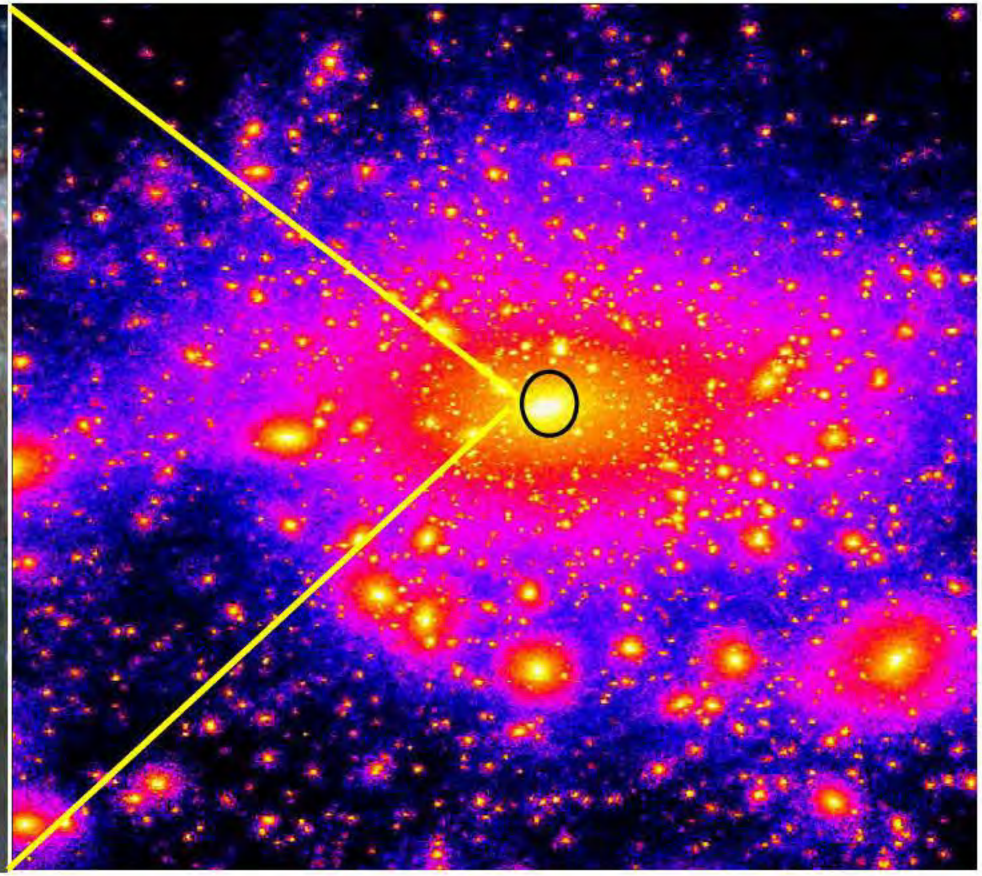
ISS Symposium 2012: „Research in space for the benefit of humankind“
Sustainable development of today's technologies is based
on continuous efforts in fundamental science

The scientific goals of AMS include:

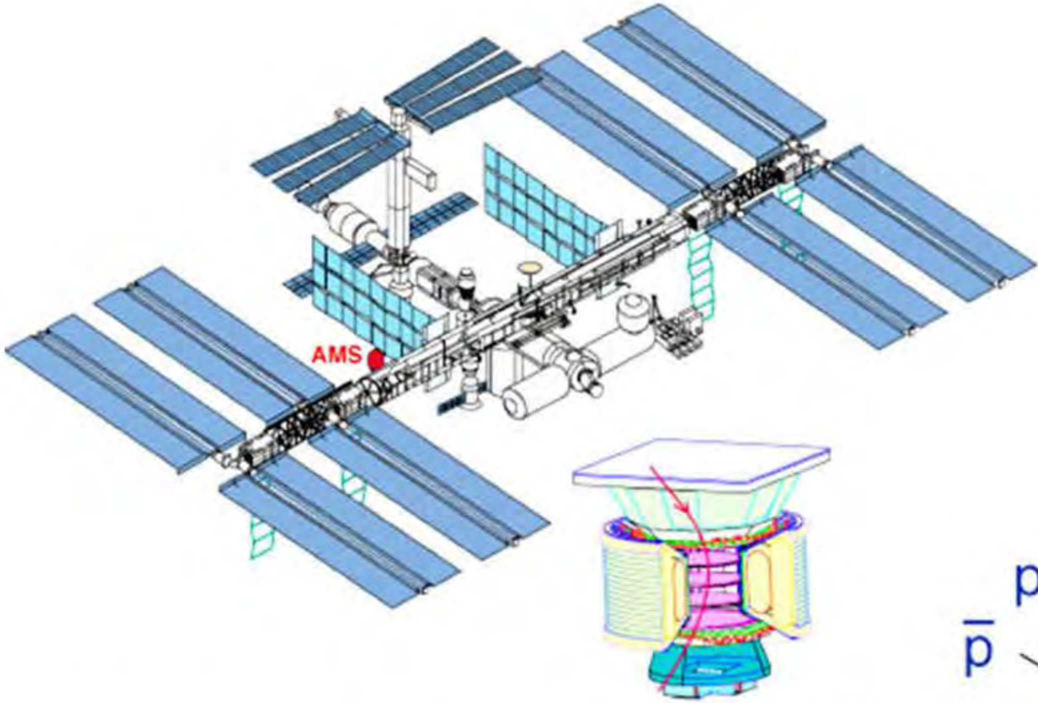
The Origin of Dark Matter

~ 90% 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

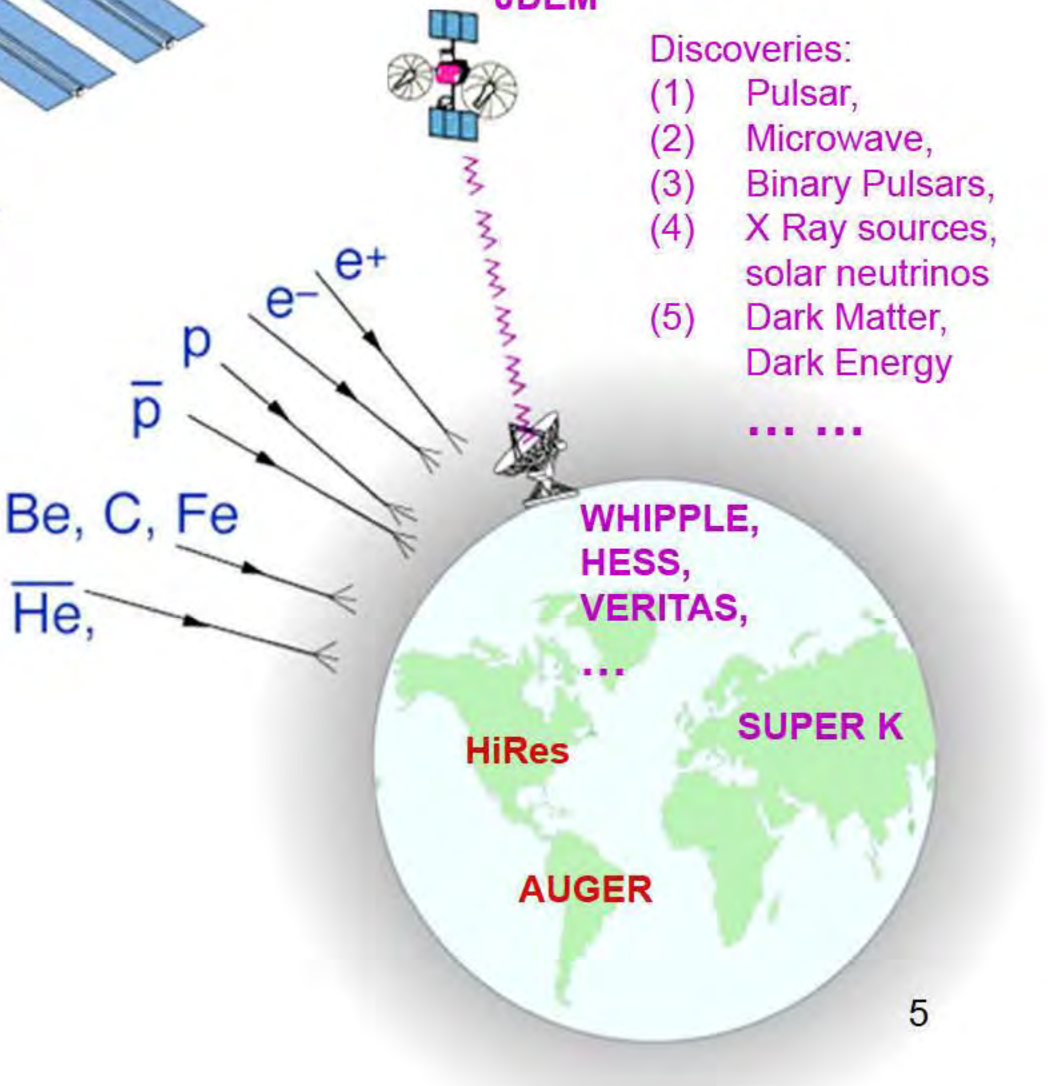


1- Neutral component:

γ, ν

Hubble, Chandra, GLAST, JWST, JDEM

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

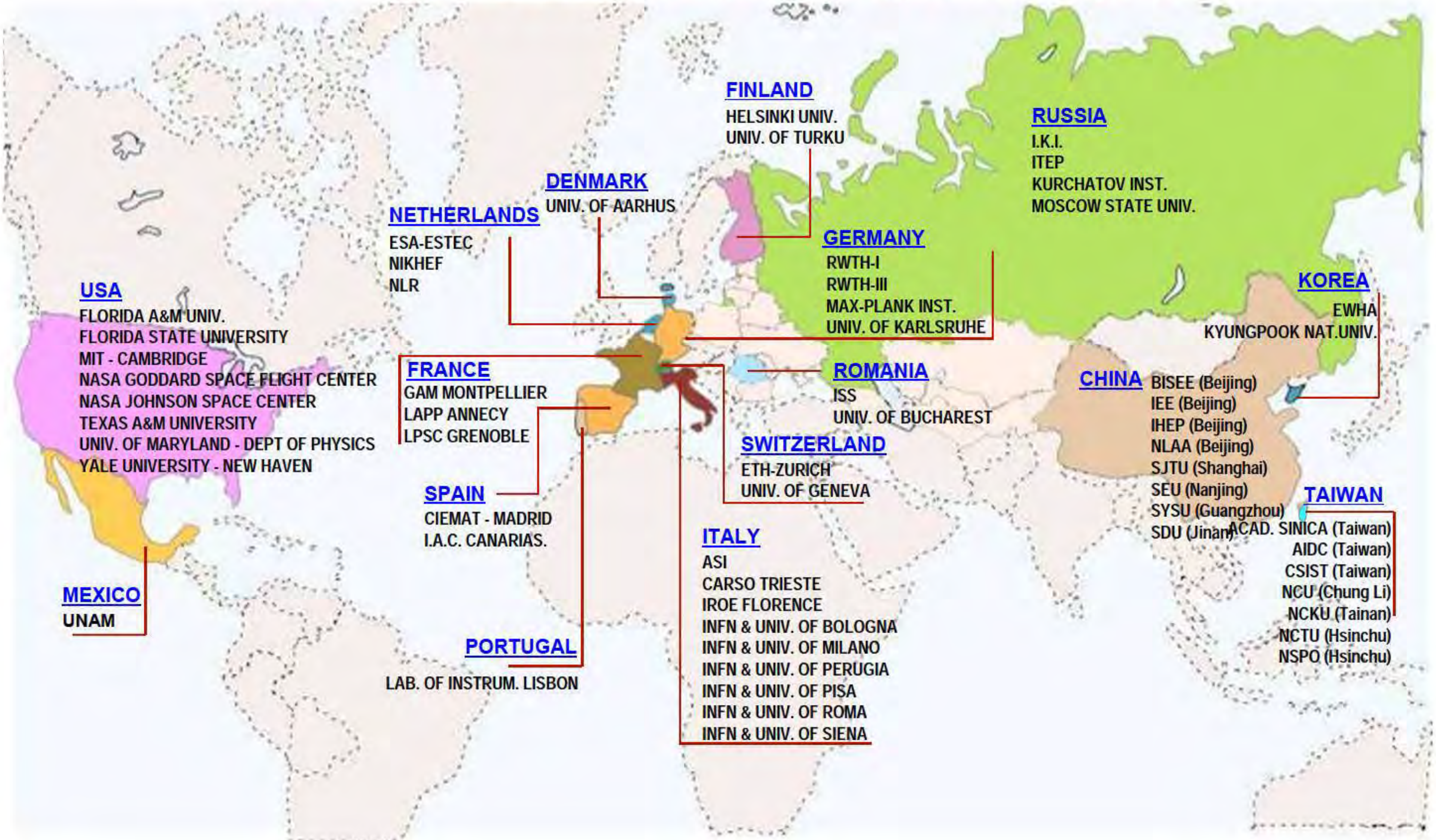


2- Charged component:

S. Ting, MIT

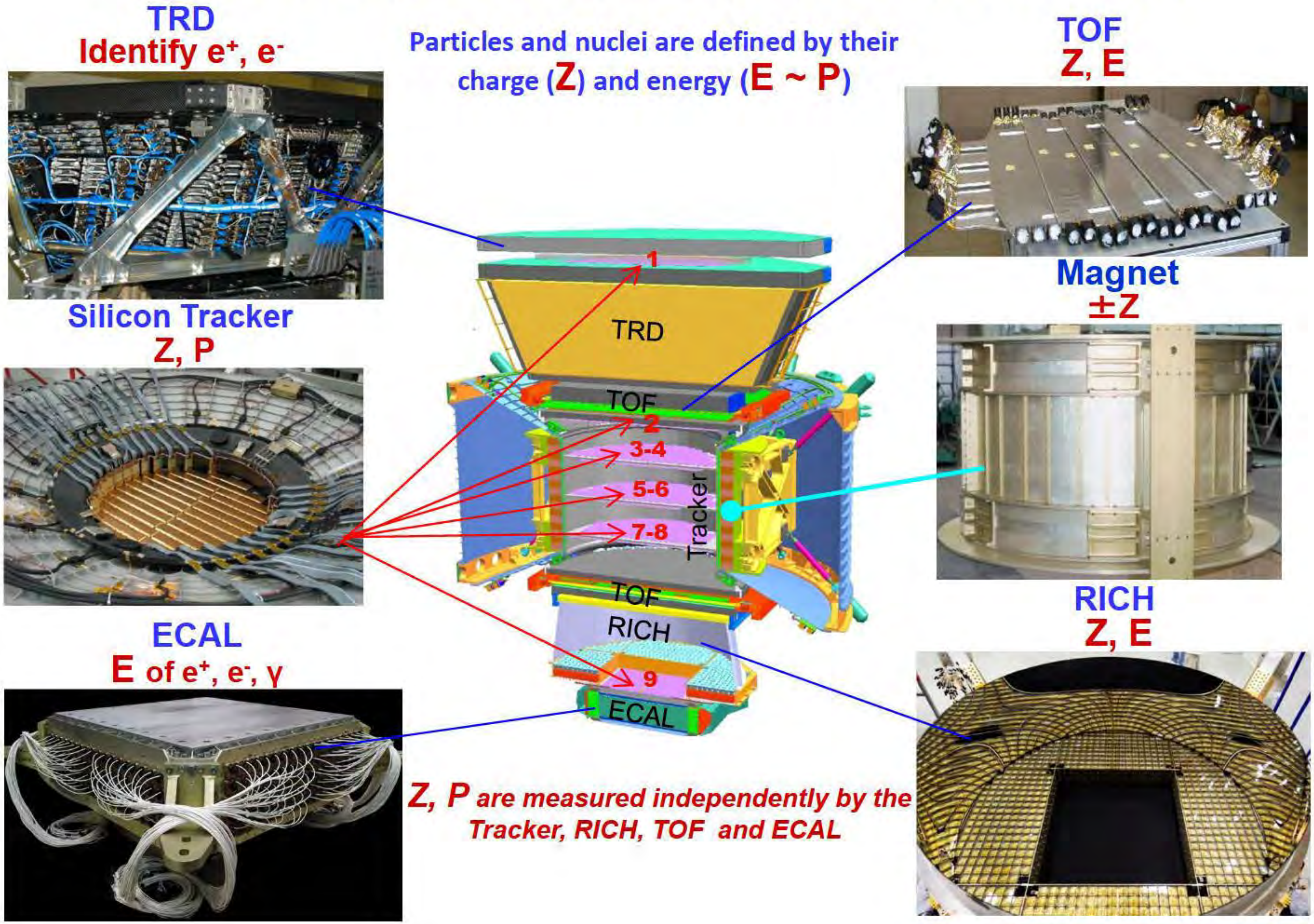
AMS is US Dept of Energy (DOE) led International Collaboration

16 Countries, 60 Institutes and 600 Physicists, 17 years

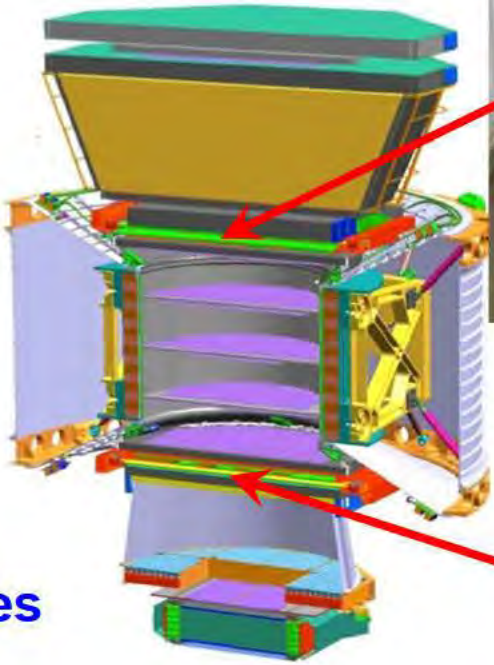


The detectors were built all over the world and assembled at CERN, near Geneva, Switzerland

AMS: A TeV precision, multipurpose spectrometer



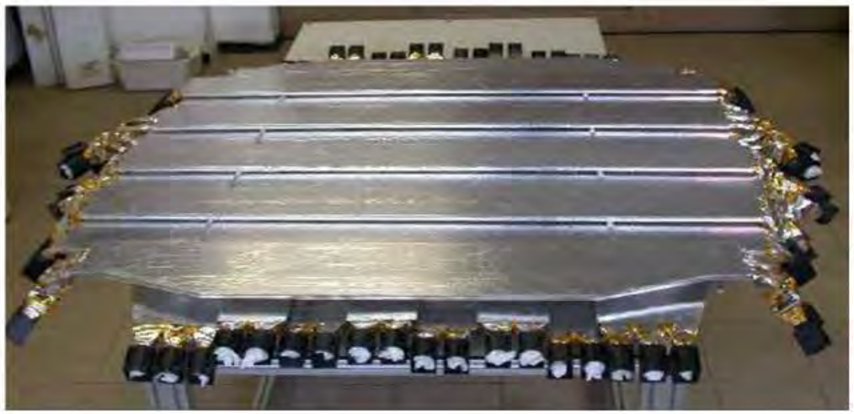
Time of Flight (TOF)

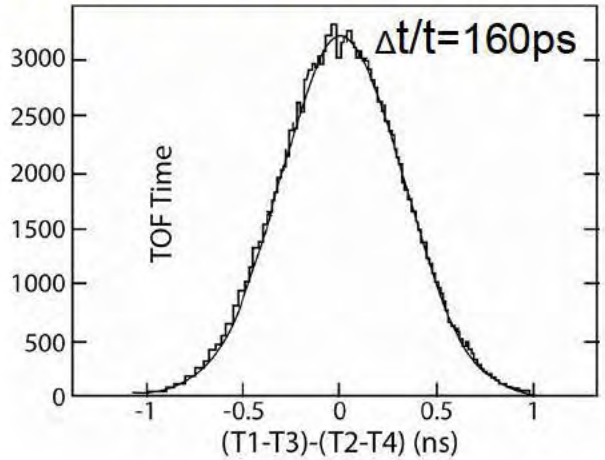


Provides trigger for charged particles

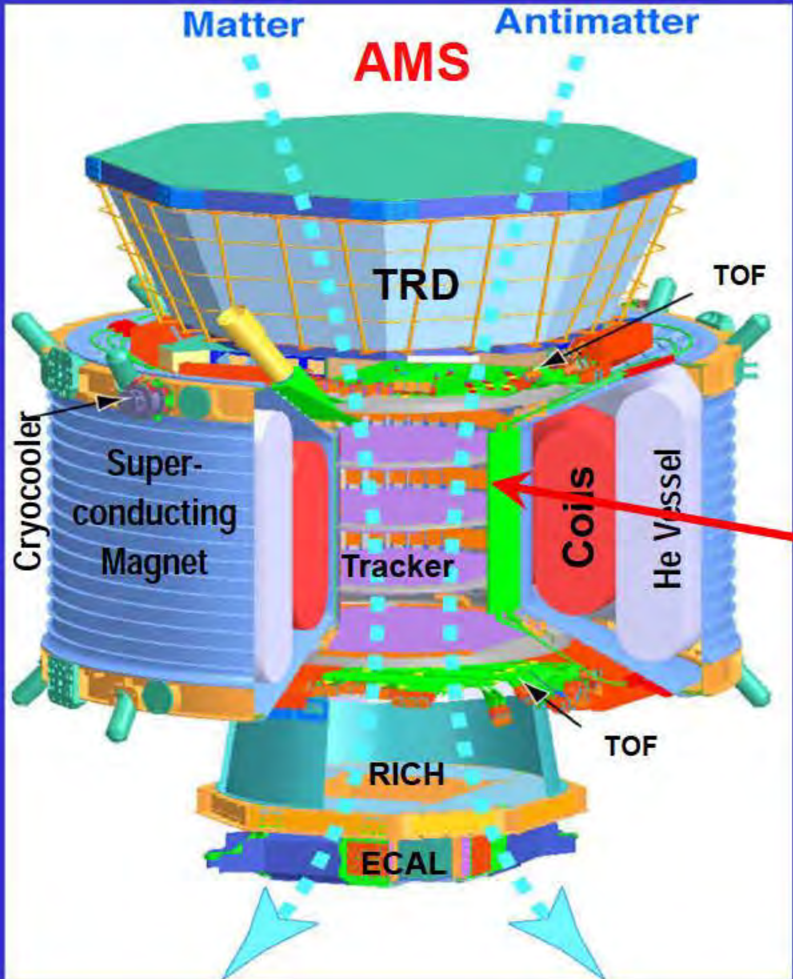
Trigger time is synchronized to UTC time to 1μs

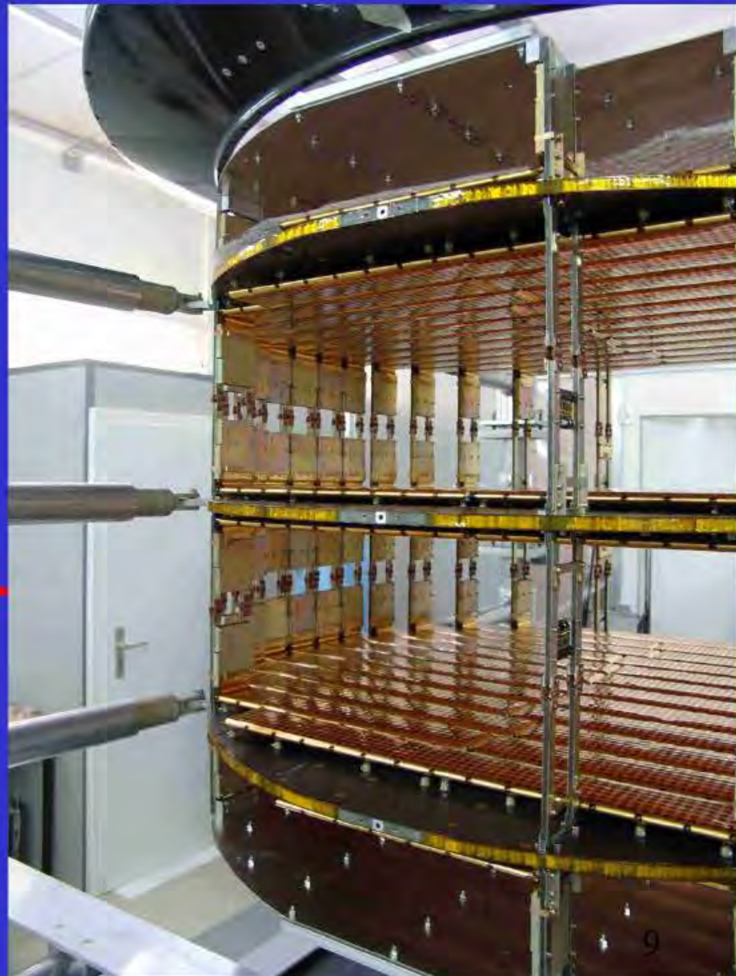
Measures the time of relativistic particles to 160 picoseconds



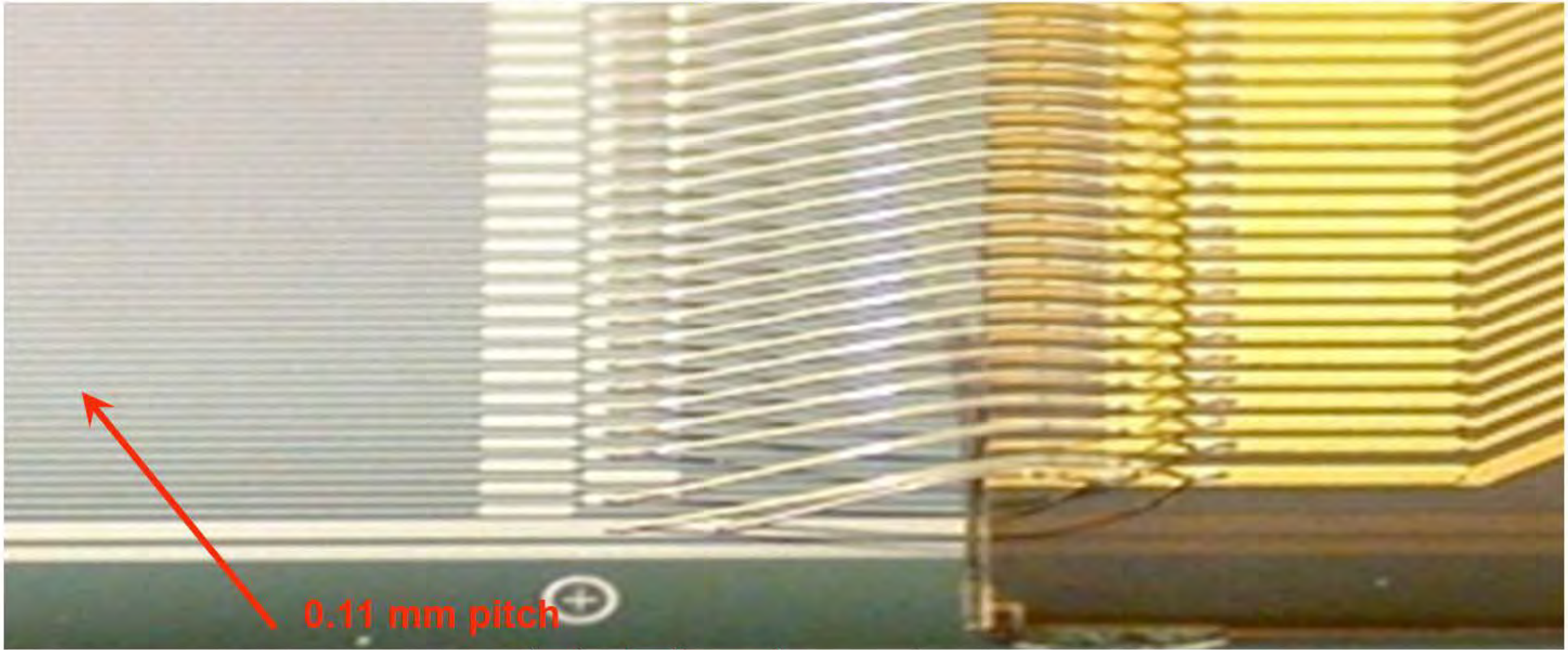


The AMS Silicon-Tracker





Silicon Tracker: 9 planes, 200,000 channels

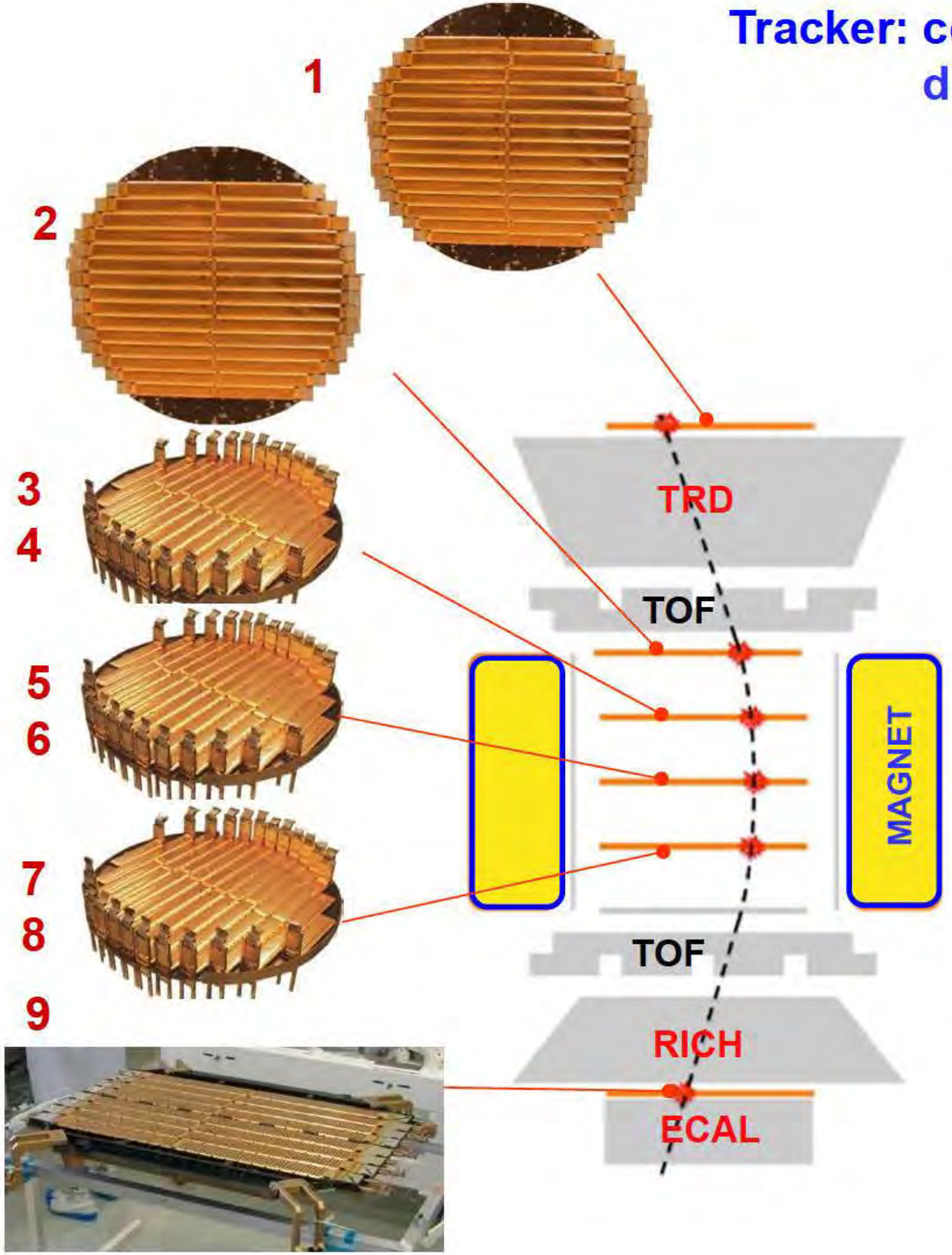


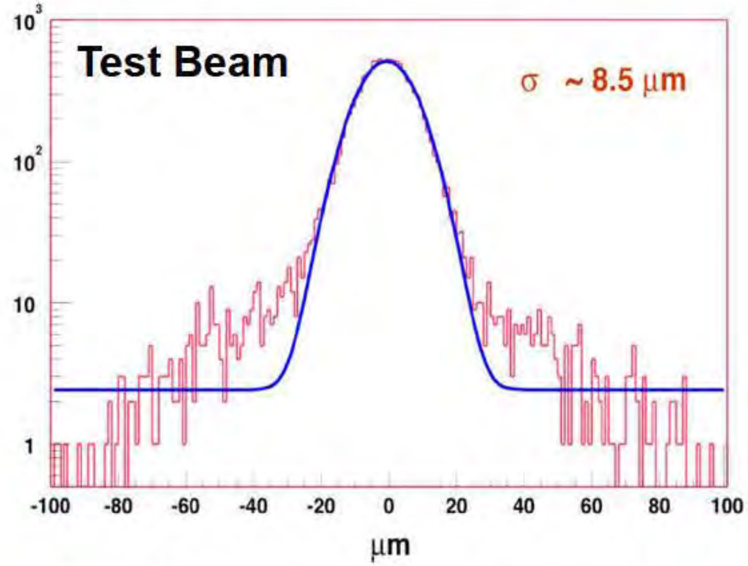
Construction:

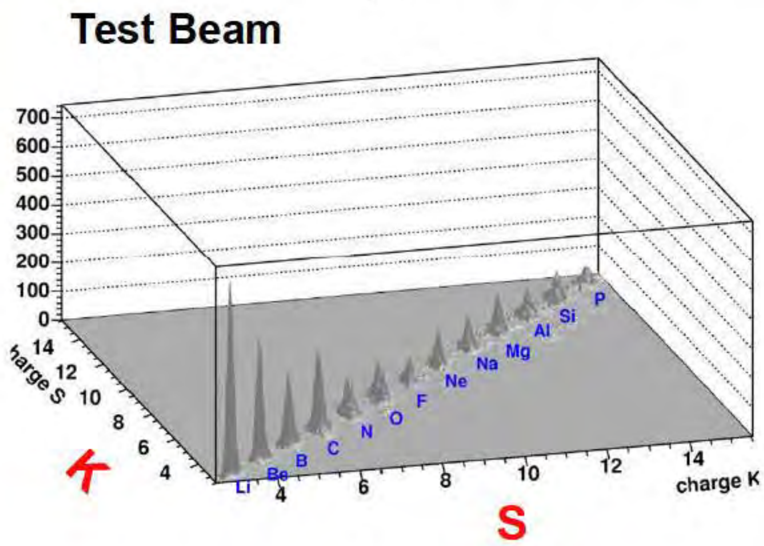
Mechanical: 50 engineers 3 yrs

Electronics: 10 yrs at CSIST

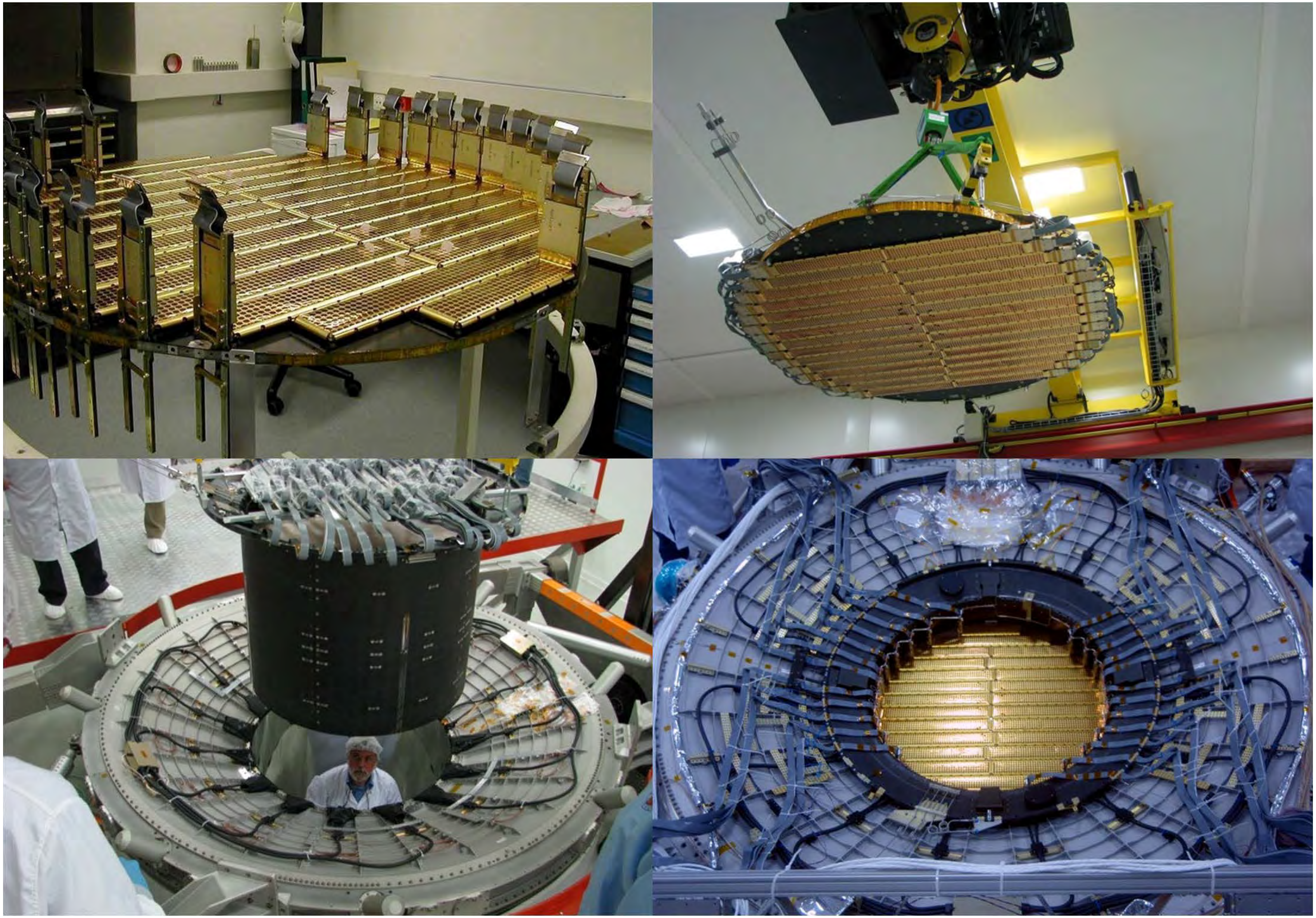
Tracker: coordinate resolution 0.010 μμ
dE/dX: identify nuclei



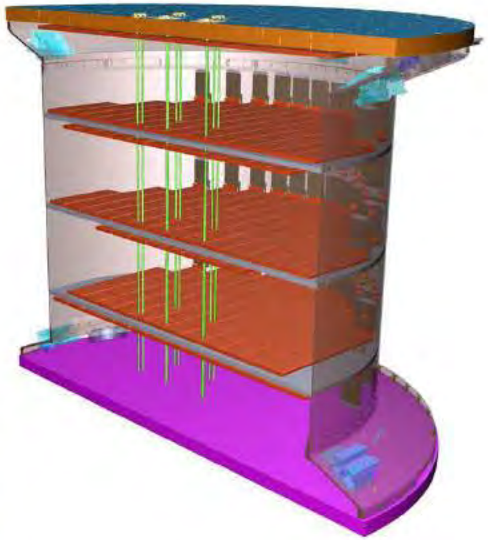




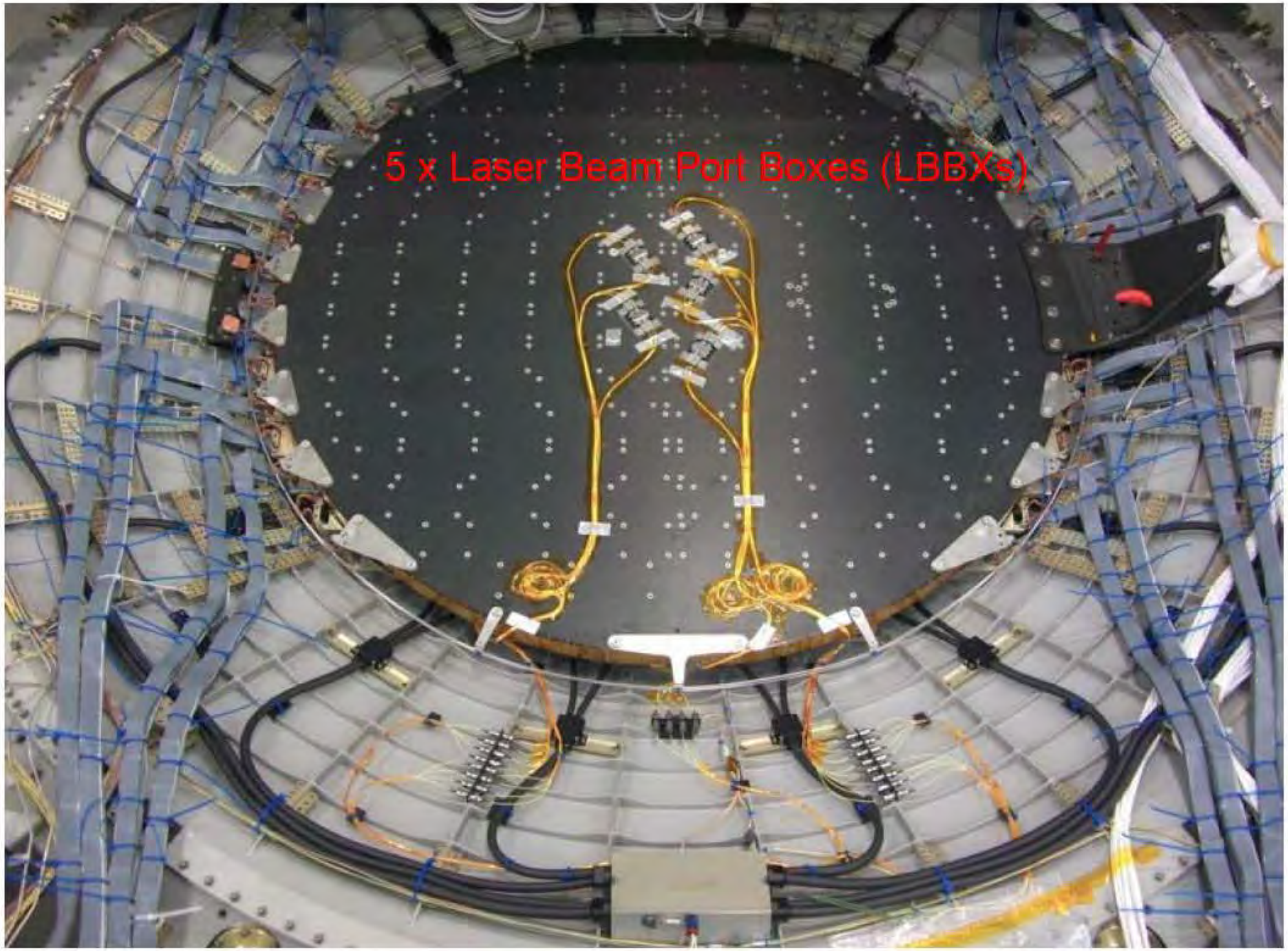
Assembly of the AMS Silicon Tracker in Geneva



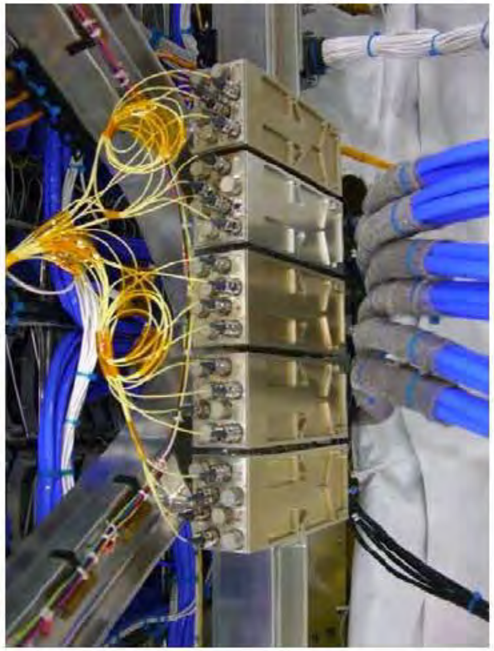
Tracker Alignment System



accuracy: 0.003 μμ with 20 UV lasers



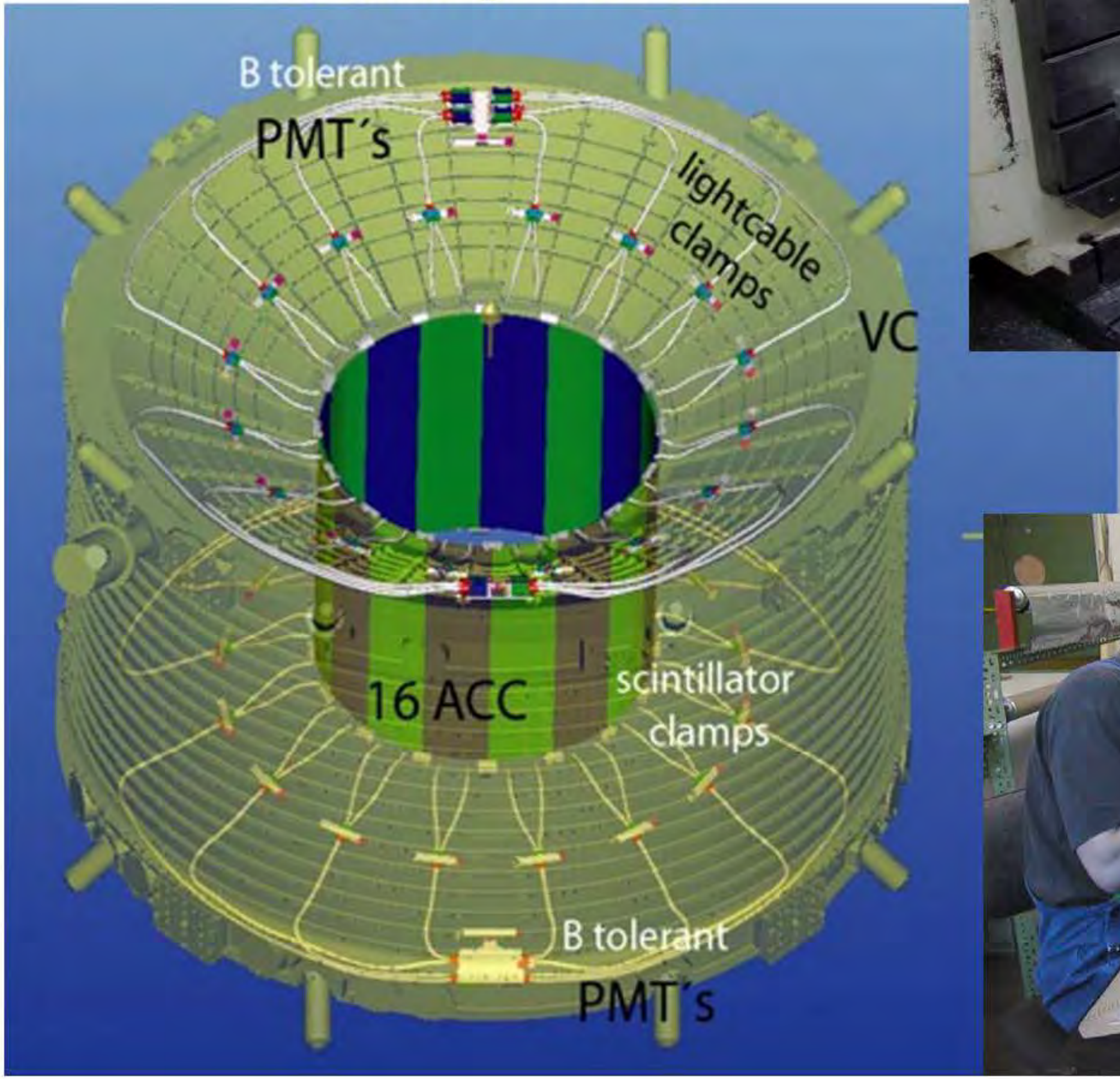
1080 nm

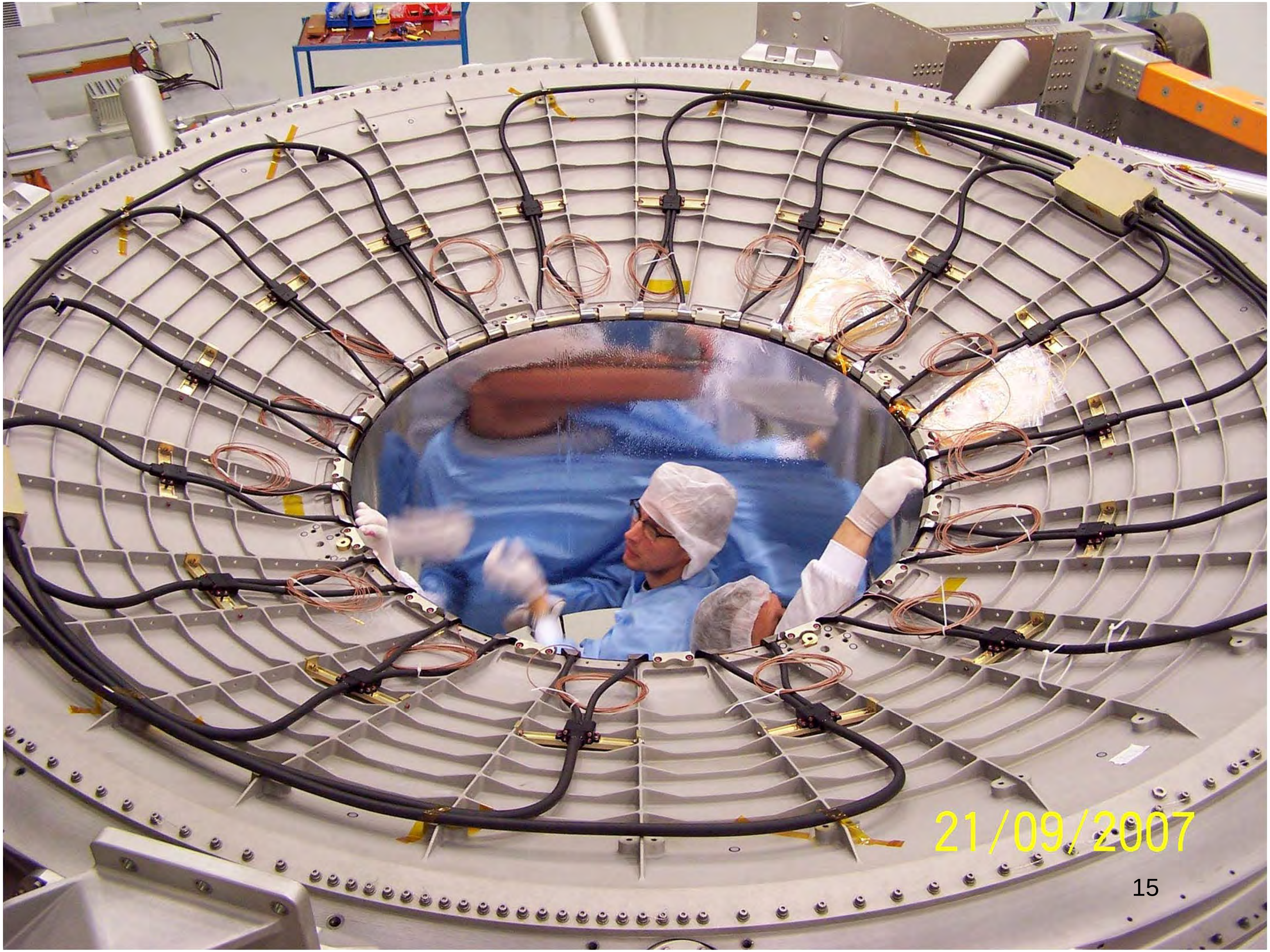


Laser Fiber Couplers

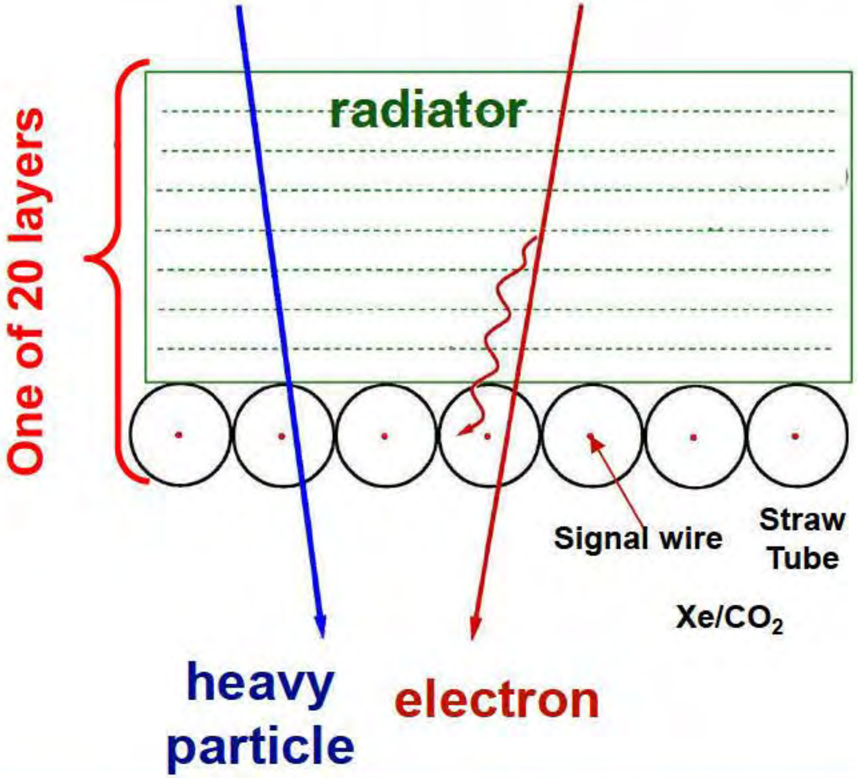
Anti-Coincidence Counter

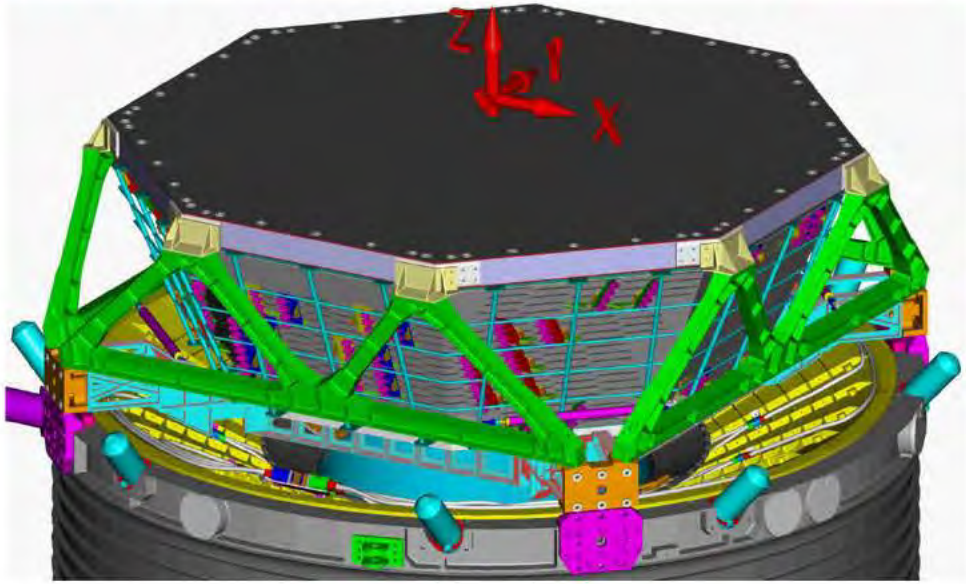
Efficieny >99.99%

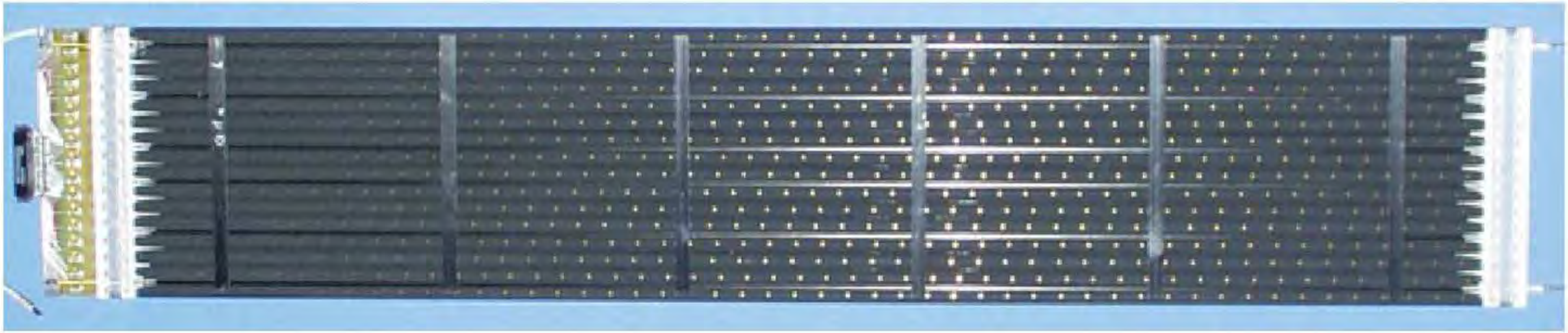



21/09/2007

Transition Radiation Detector (TRD): identifies Positron and Electron

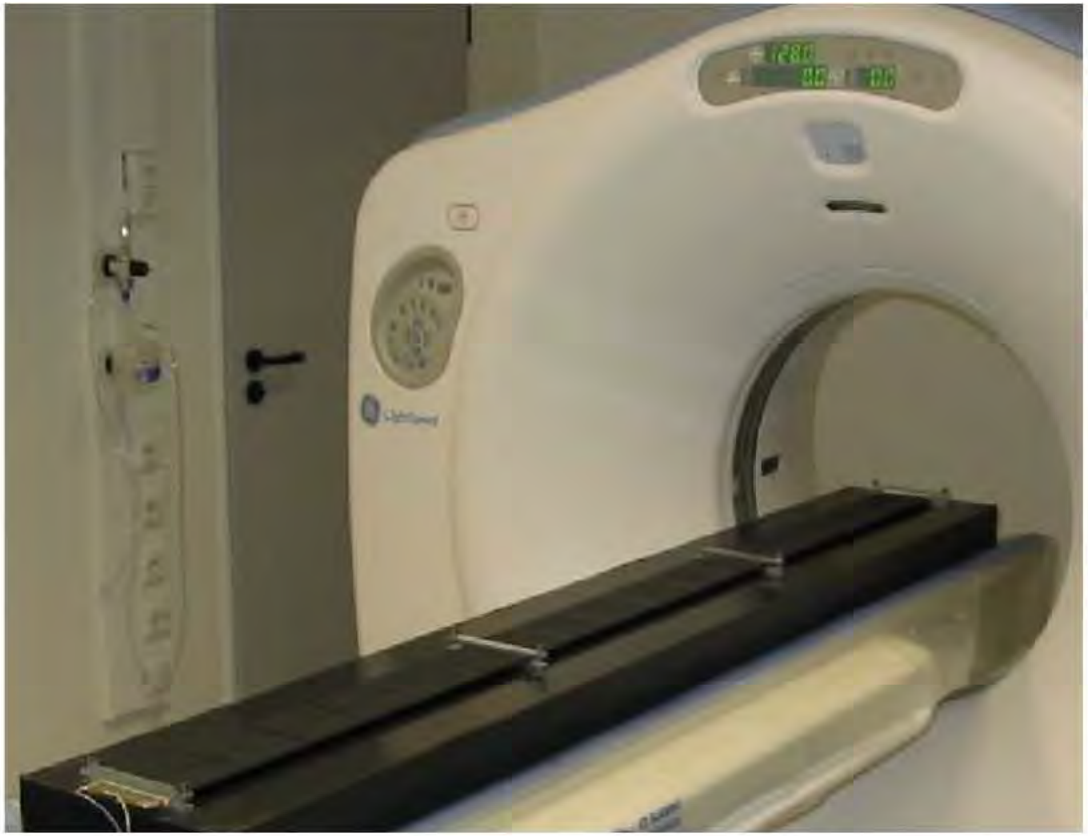


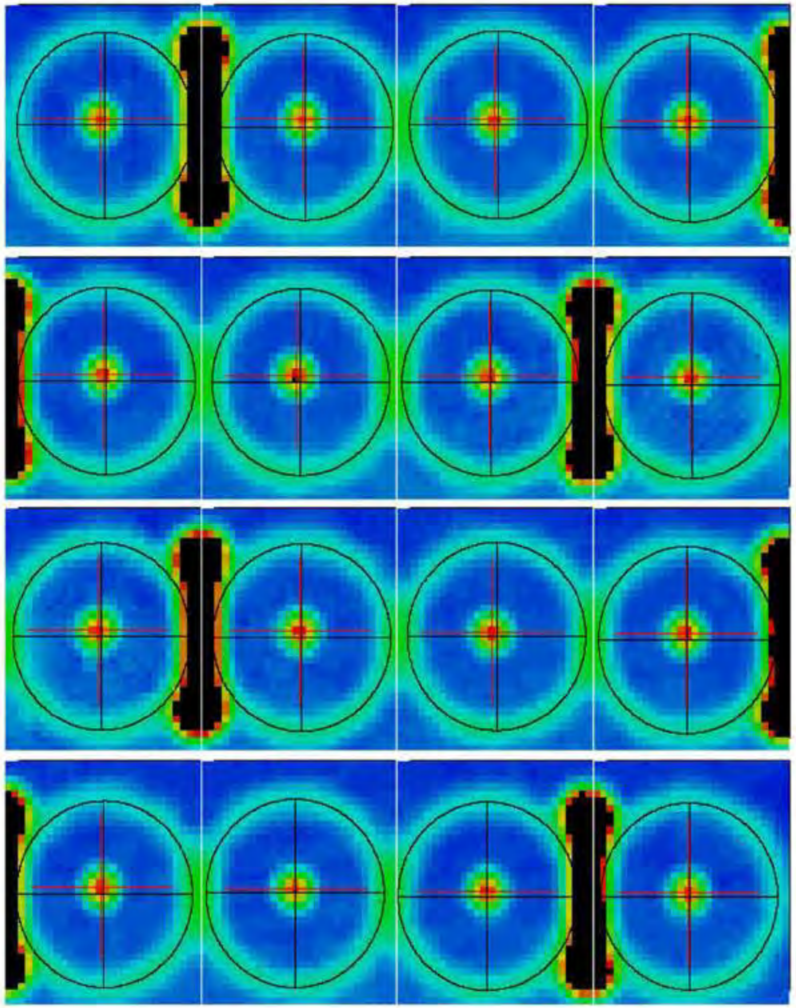




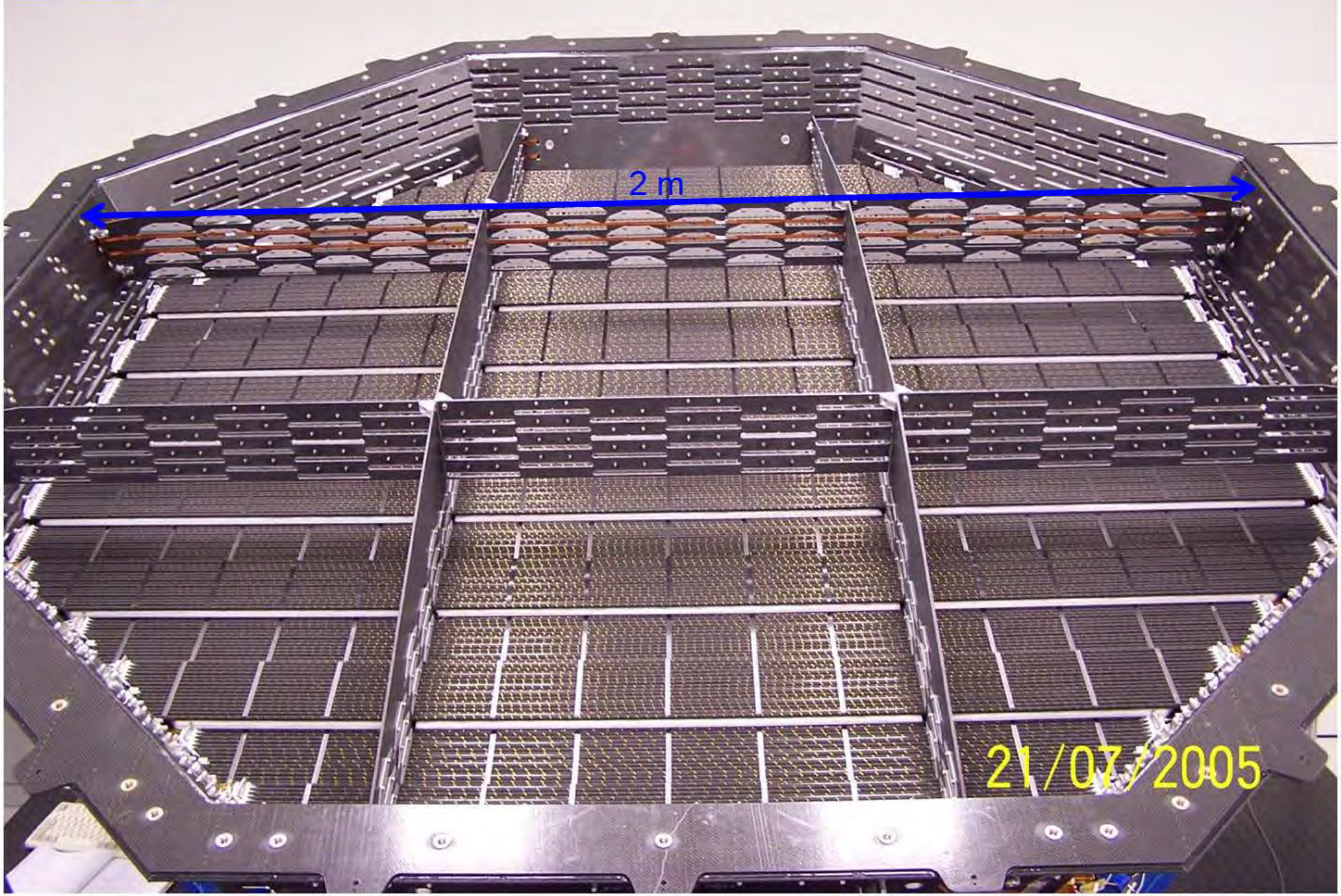
9,000 Straw Tube Detector Manufactured

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





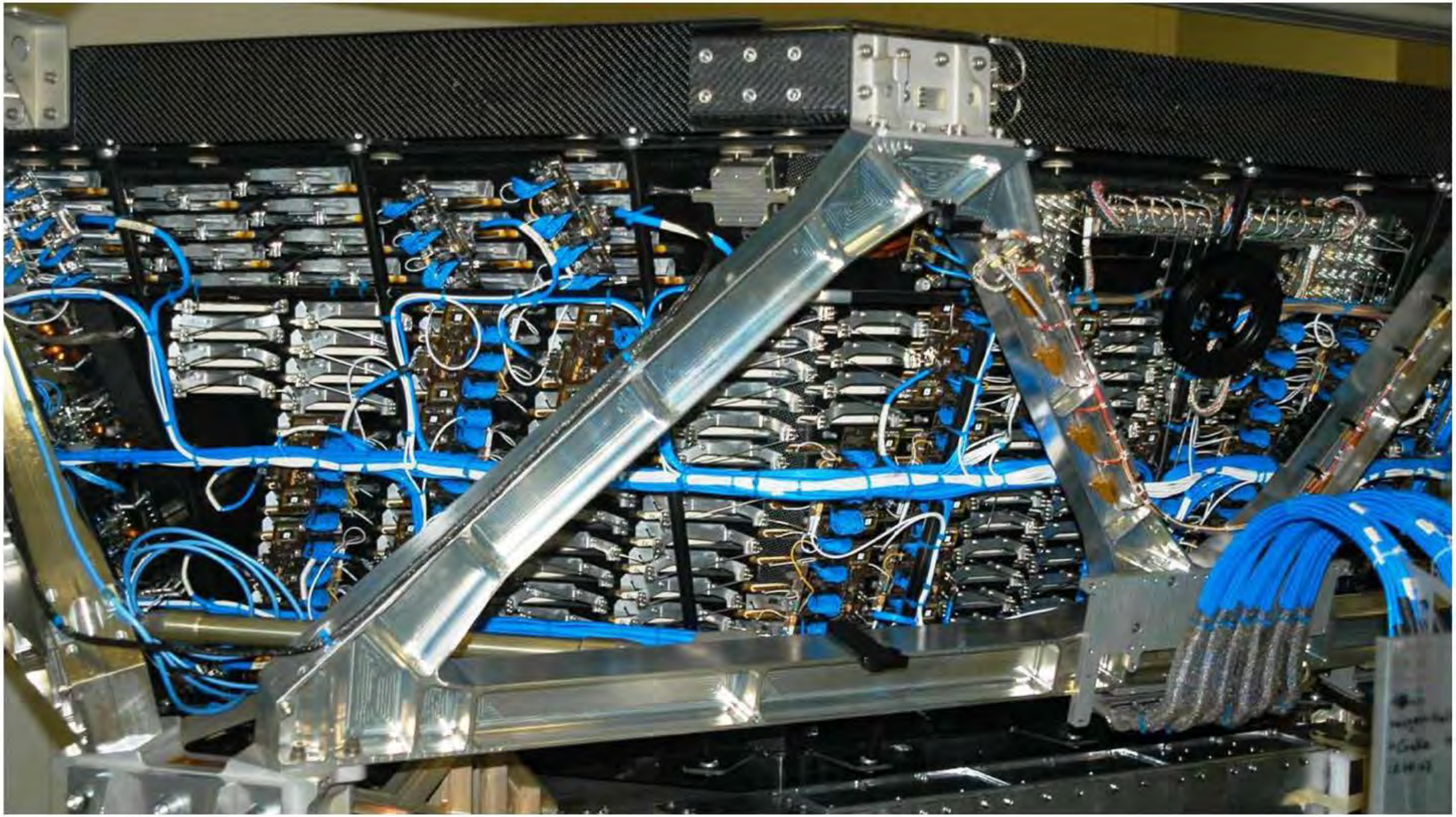
AMS-02 Transition Radiation Detector



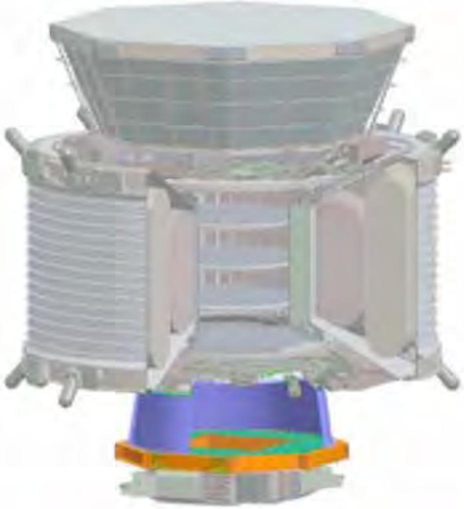
TRD: 5,248 Pulse Heights

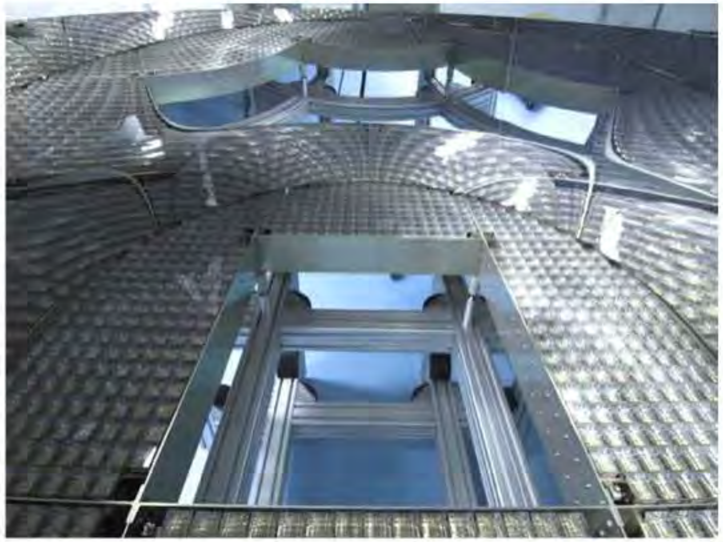
Precision TRD Gas System: 482 Temperature Sensors, 24 Heaters 8 Pressure Sensors ensures pulse height stability

Onboard processing: 30 computers

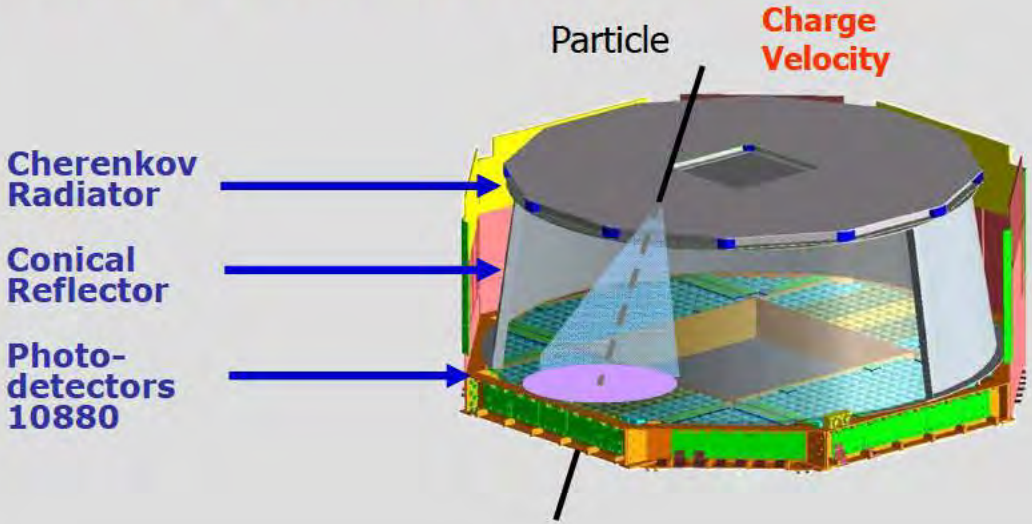


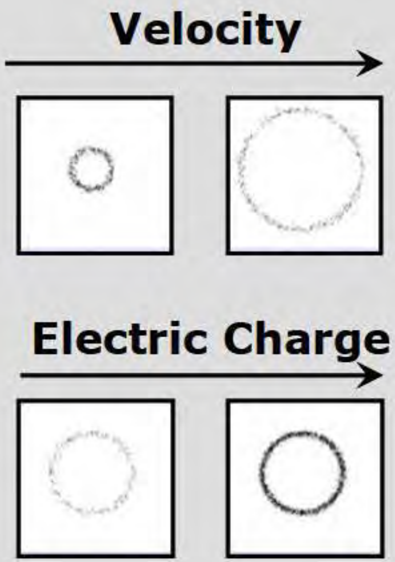
AMS Ring Imaging CHerenkov (RICH)

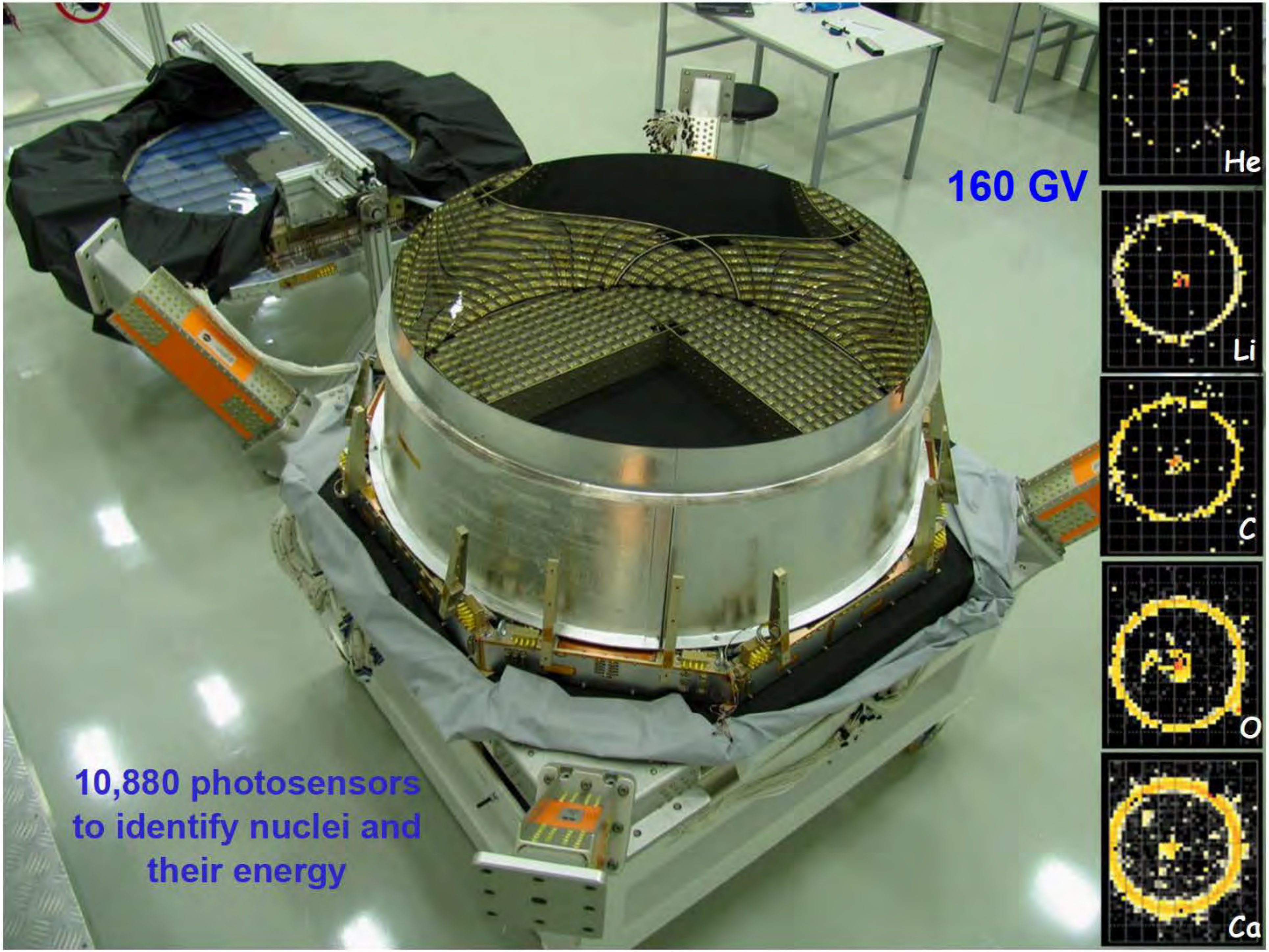




Cherenkov radiation

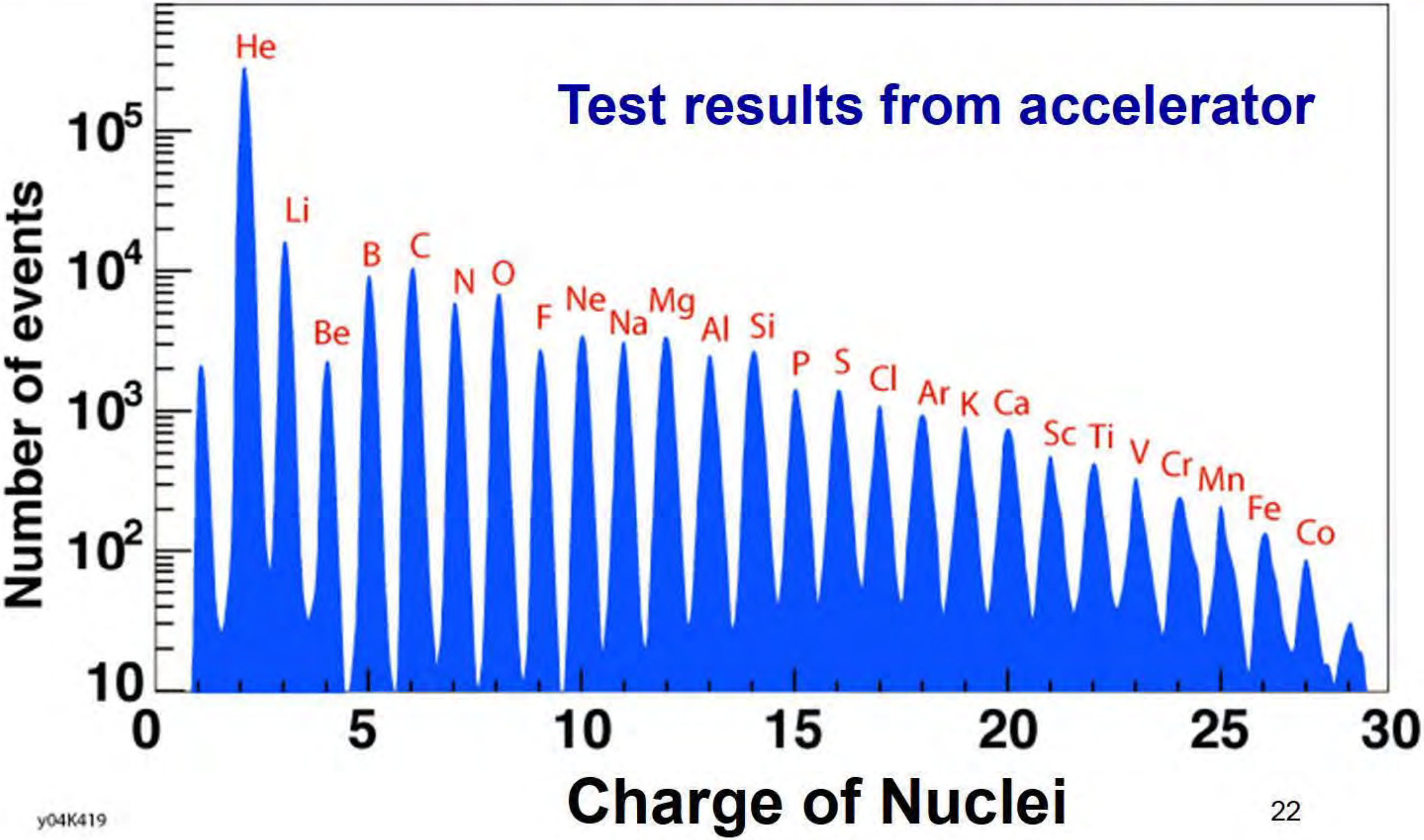






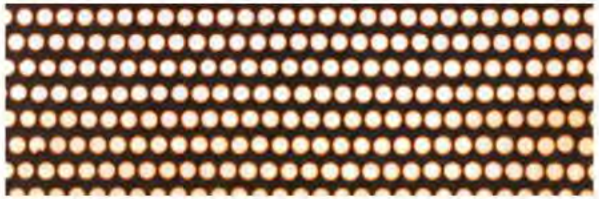
160 GV
He
Li
C
O
Ca
10,880 photosensors
to identify nuclei and
their energy

On the ISS, AMS will measure the composition of high energy Cosmic Rays with extraordinary accuracy

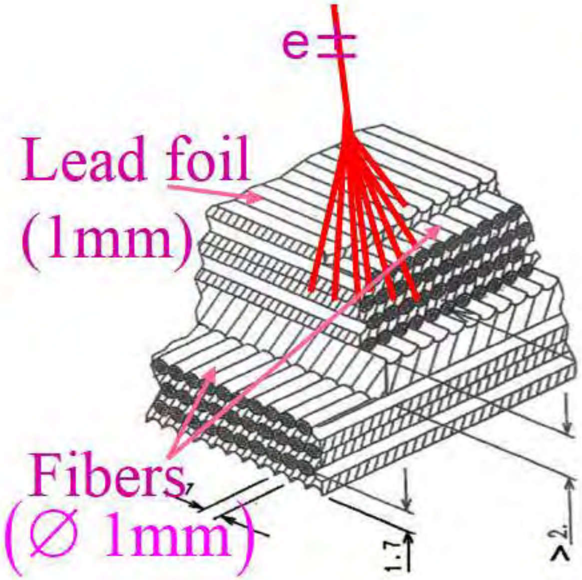


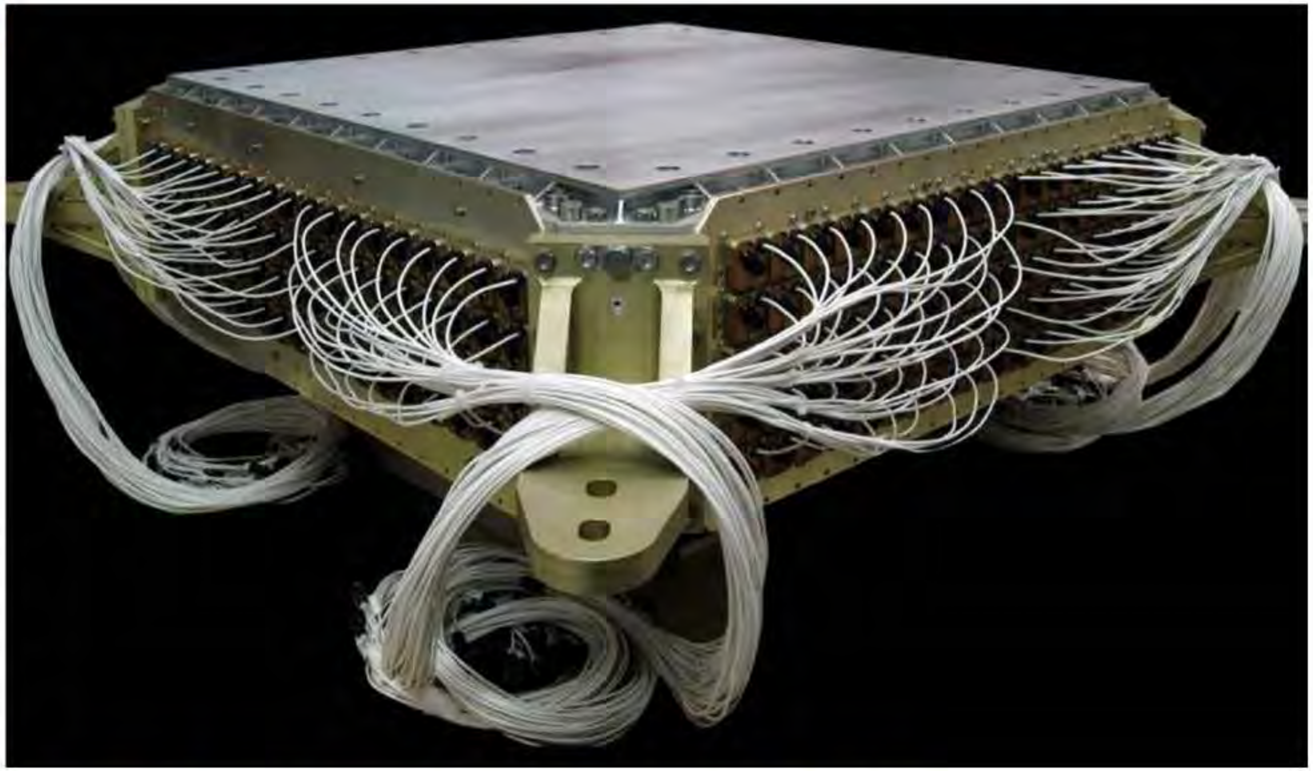
y04K419

Electromagnetic Calorimeter (ECAL)

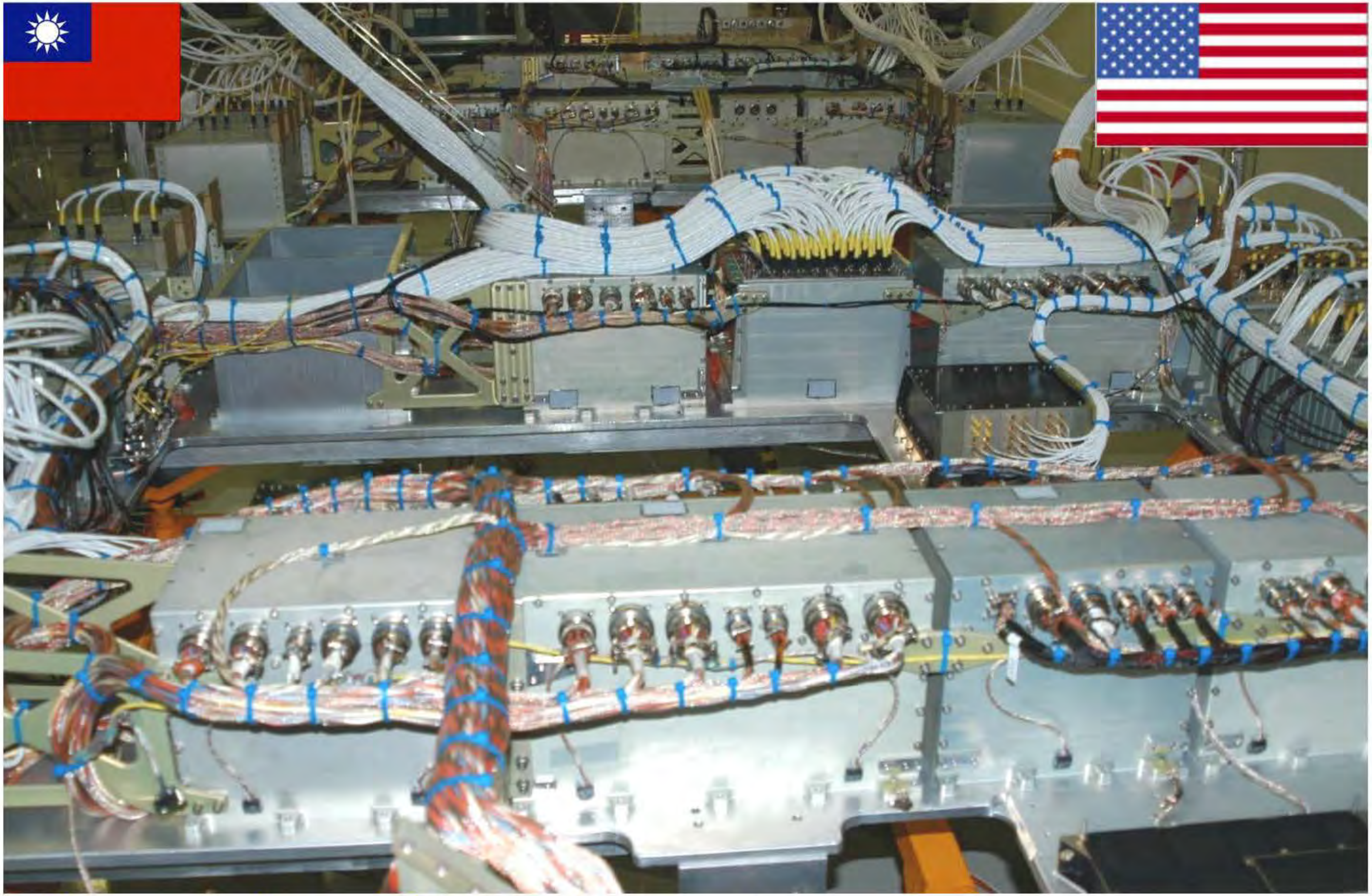


A precision 3-dimensional measurement of the directions and energies of light rays and electrons





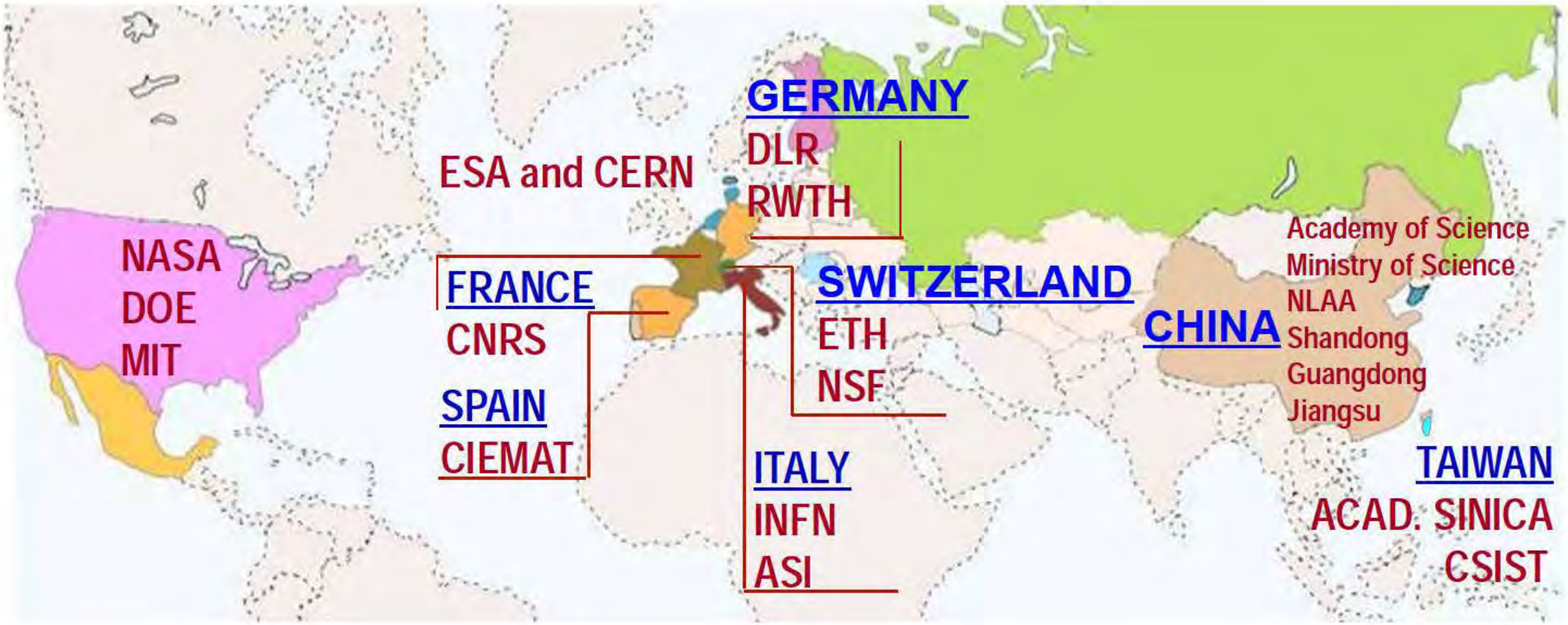
50,000 fibers, δ =1mm, distributed uniformly inside 1,200 lb of lead which provides a precision, 3-dimensional, $17X_0$ measurement of the directions and energies of light rays and electrons up to 1 TeV



The completed flight electronics
(650 microprocessors, 300,000 channels)

AMS was suddenly removed from the Shuttle Manifest in October 2005. It was ultimately restored in January 2009 because of:

1. Strong endorsement of the AMS science from reviews by the world's leading scientists
2. Unanimous support from the US Senate and House
3. Major worldwide support from (ESA (J. J. Dordain), DLR (J-D. Woerner), ASI (E. Saggesi), DOE, CERN,…)



Visit of Senator Bill Nelson to AMS - March 16, 2008

Dr. B. Accoyer, M.D. , ***President, French National Assembly***

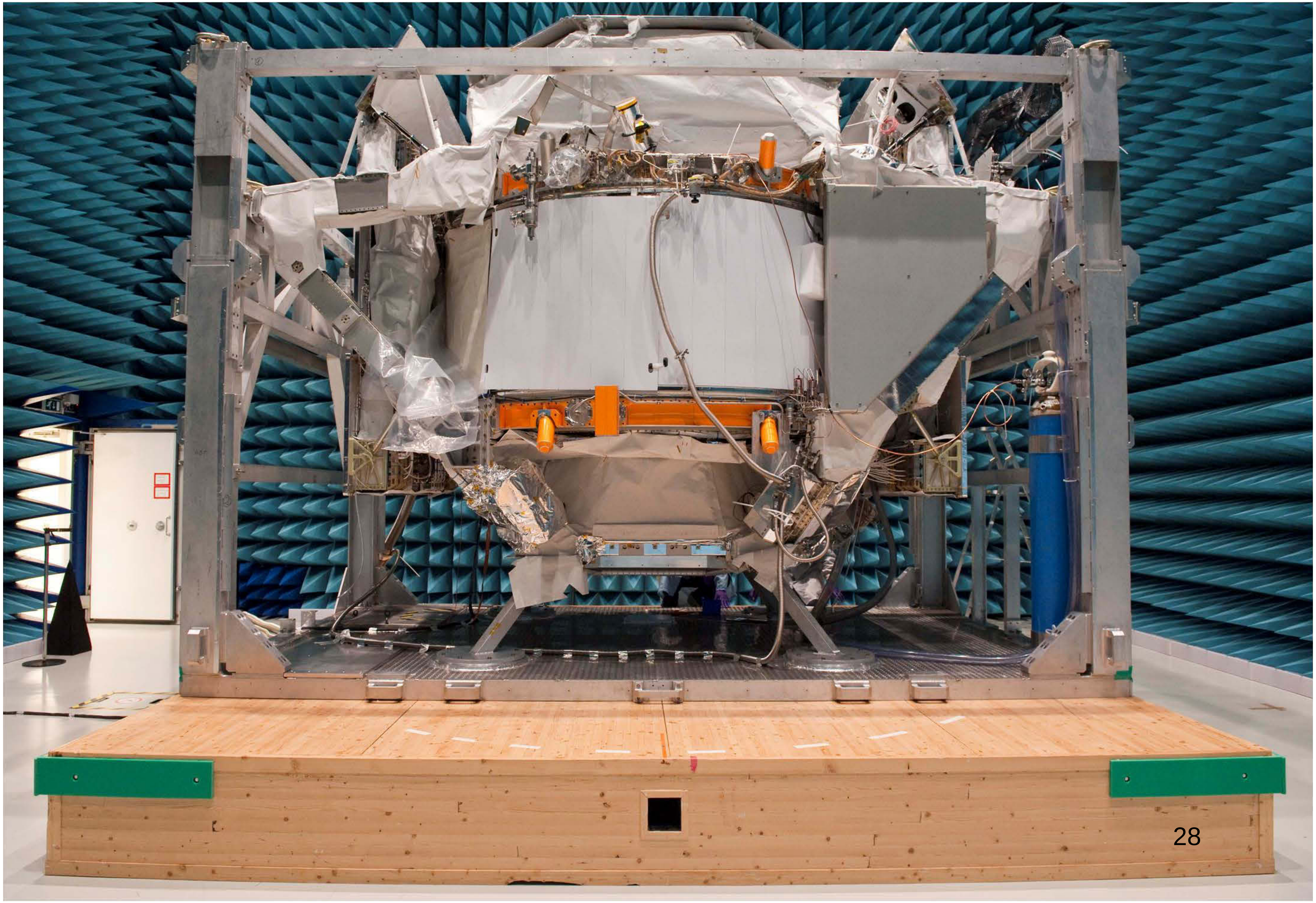
Professor G. Bignami, ***President, Italian Space Agency (ASI)***

Prof. Dr.-Ing. J-D Woerner, ***President, German Space Agency (DLR)***

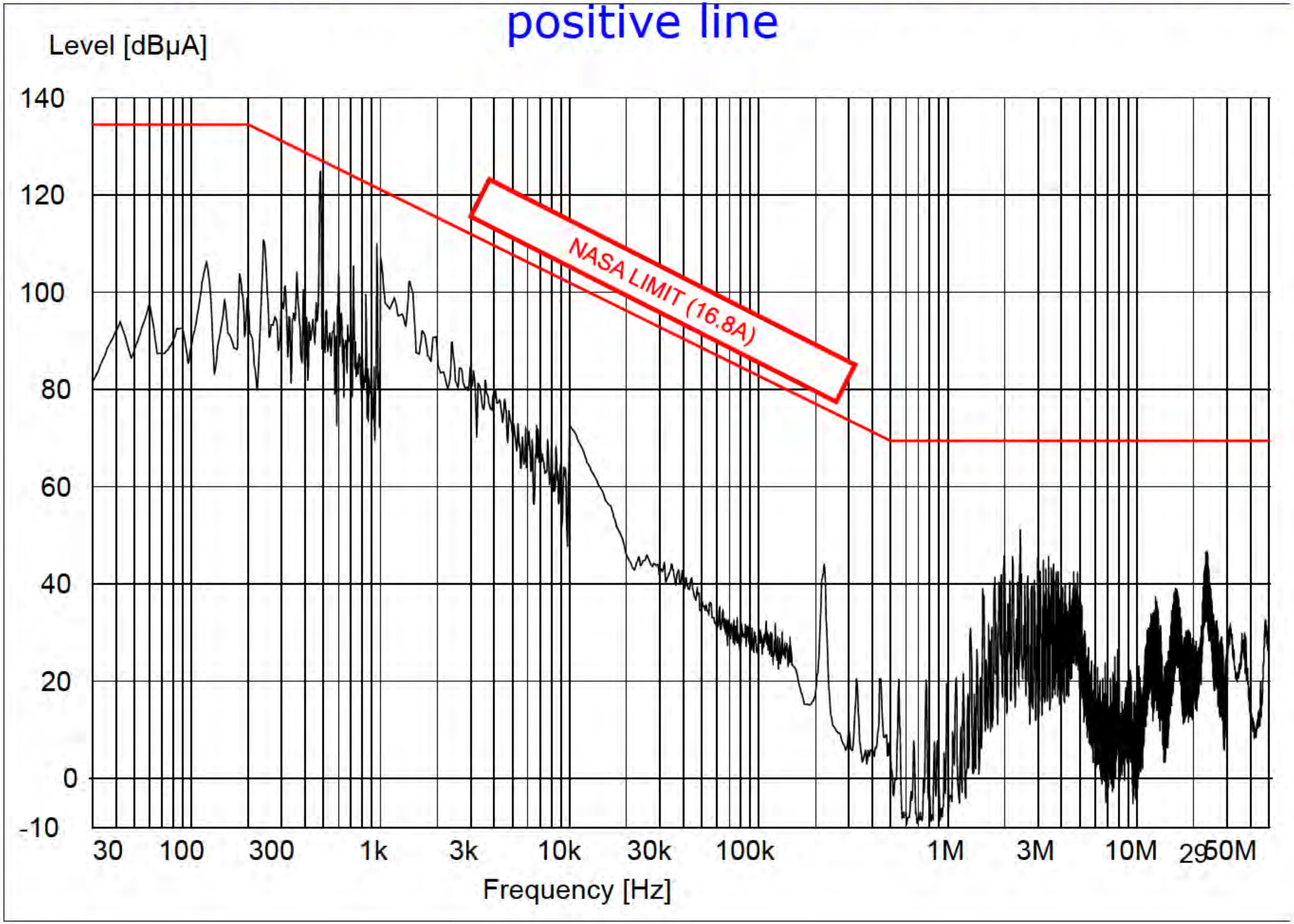
Dr. M. Serrano, ***Head, Spanish Space Program (CDTI)***

12.February 2010 - 16. Febrauary 2010:
AMS-02 Transport from CERN, Geneva to ESTEC, Noordwijk

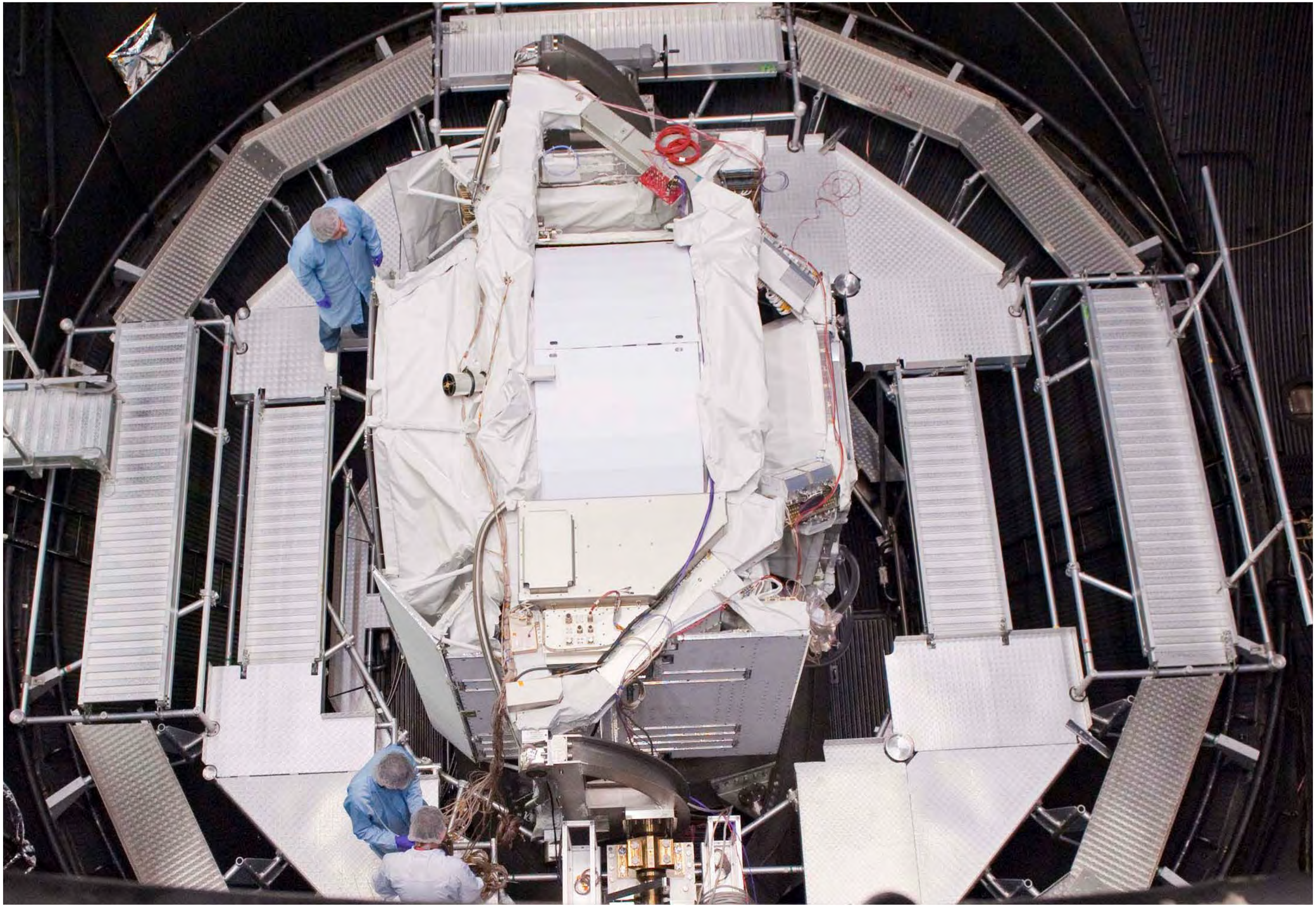
AMS in the Maxwell EMI chamber at ESTEC



AMS Conductive Emissions (CE01, CE03) Measurement – positive line



AMS in the ESA Thermal Vacuum Chamber, Noordwijk, the Netherlands



Michael Braukus
Headquarters, Washington
202-358-1979
michael.j.braukus@nasa.gov

March 11, 2010

RELEASE : 10-063

Heads of Agency International Space Station Joint Statement

TOKYO -- The heads of the International Space Station (ISS) agencies from Canada, Europe, Japan, Russia, and the United States met in Tokyo, Japan, on March 11, 2010, to review ISS cooperation.

With the assembly of the ISS nearing completion and the capability to support a full-time crew of six established, they noted the outstanding opportunities now offered by the ISS for on-orbit research and for discovery including the operation and management of the world's largest international space complex. In particular, they noted the unprecedented opportunities that enhanced use of this unique facility provides to drive advanced science and technology. This research will deliver benefits to humanity on Earth while preparing the way for future exploration activities beyond low-Earth orbit. The ISS will also allow the partnership to experiment with more integrated international operations and research, paving the way for enhanced collaboration on future international missions.

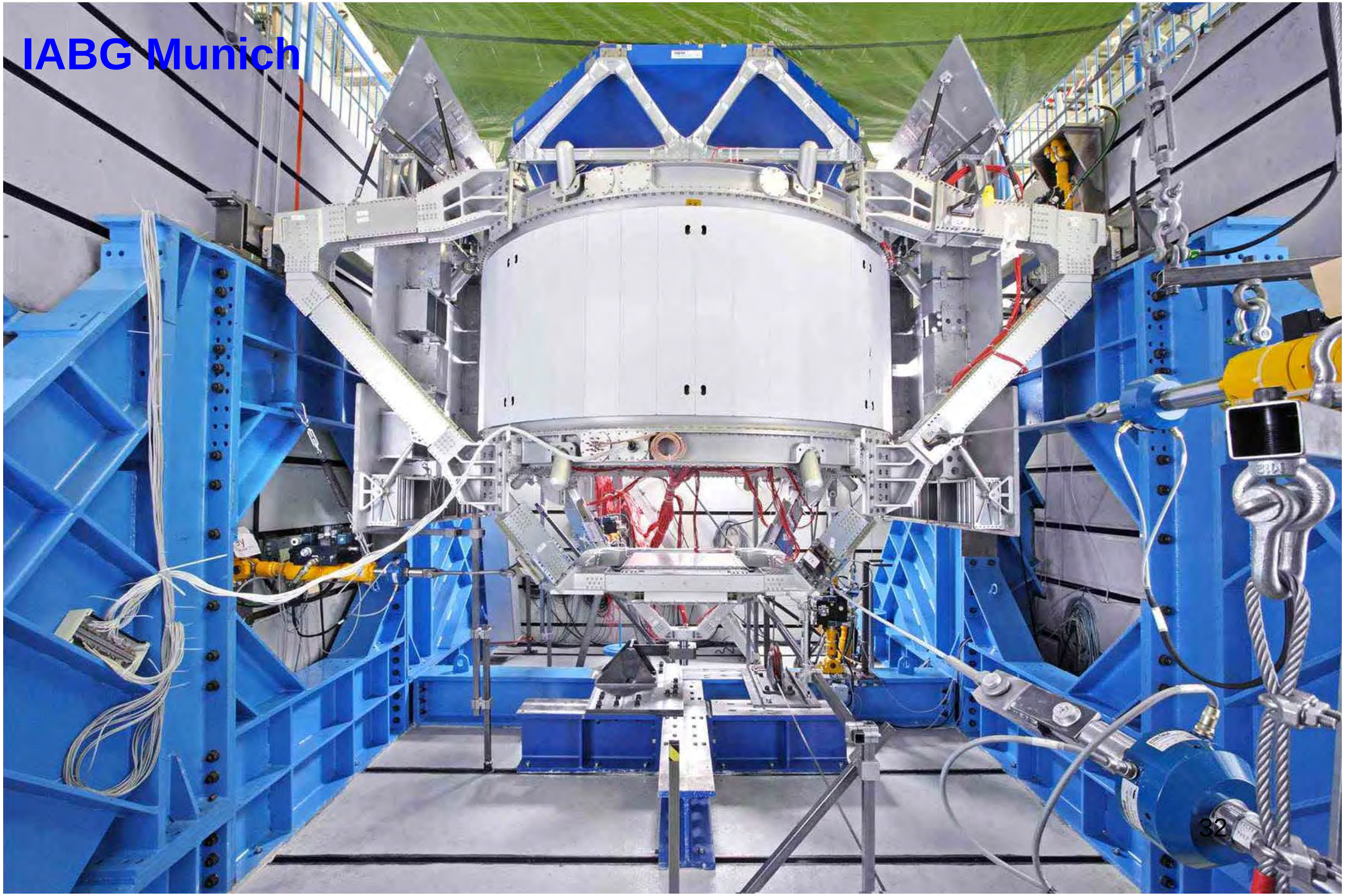
The heads of agency reaffirmed the importance of full exploitation of the station's scientific, engineering, utilization, and education potential. They noted that there are no identified technical constraints to continuing ISS operations beyond the current planning horizon of 2015 to at least 2020, and that the partnership is currently working to certify on-orbit elements through 2028. The heads of agency expressed their strong mutual interest in continuing operations and utilization for as long as the benefits of ISS exploitation are demonstrated. They acknowledged that a U.S. fiscal year 2011 budget consistent with the U.S. administration's budget request would allow the United States to support the continuation of ISS operations and utilization activities to at least 2020. They emphasized their common intent to undertake the necessary procedures within their respective governments to reach consensus later this year on the continuation of the ISS to the next decade.

In looking ahead, the heads of agency discussed the importance of increasing ISS utilization and operational efficiency by all possible means, including finding and coordinating efficiencies across the ISS Program and assuring the most effective use of essential capabilities, such as space transportation for crew and cargo, for the life of the program.

For the latest about the International Space Station, visit the Internet at: http://www.nasa.gov/station

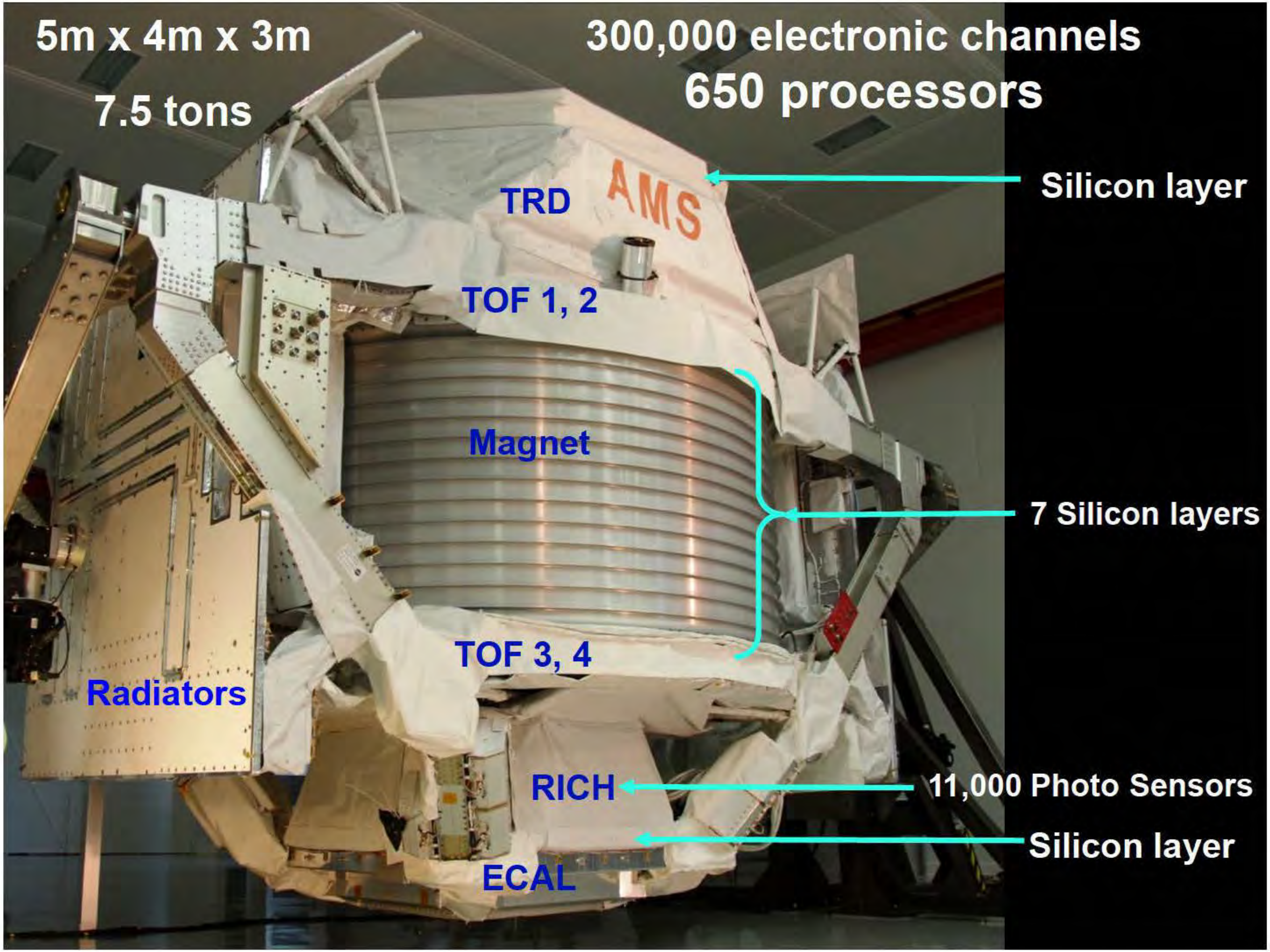
- end -

For AMS-02, Two Magnets were built:
One for Space Qualification Tests in Germany and Italy

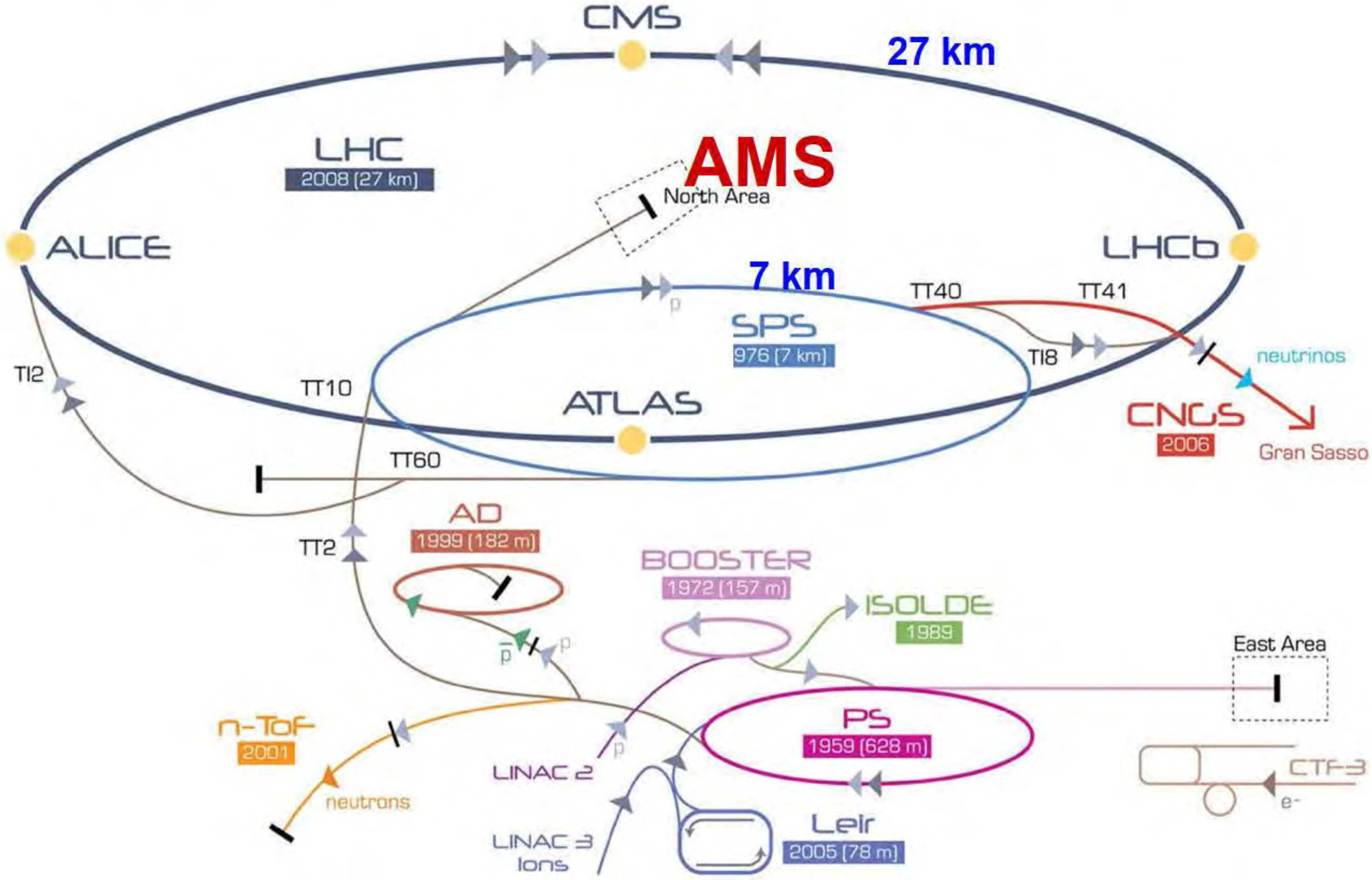


NASA Associate Administrator for Space Operations William Gerstenmaier visited AMS on 19 June 2010 and reviewed the progress.

Other visits:
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
300,000 electronic channels
650 processors
Silicon layer
TRD
AMS
TOF 1, 2
Magnet
7 Silicon layers
TOF 3, 4
Radiators
RICH
11,000 Photo Sensors
Silicon layer
ECAL

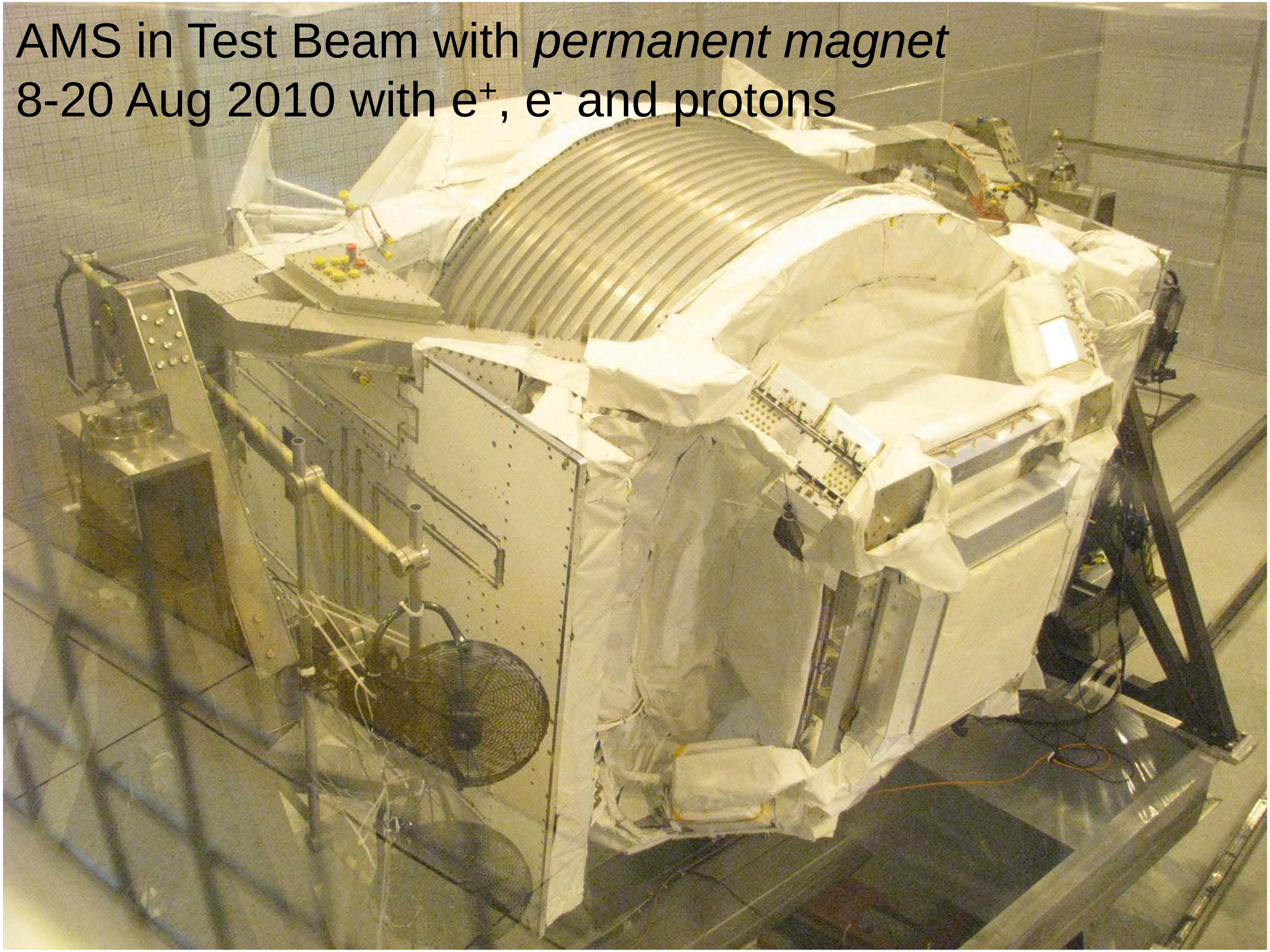
Test at CERN
AMS in accelerator test beam Aug 8-20, 2010



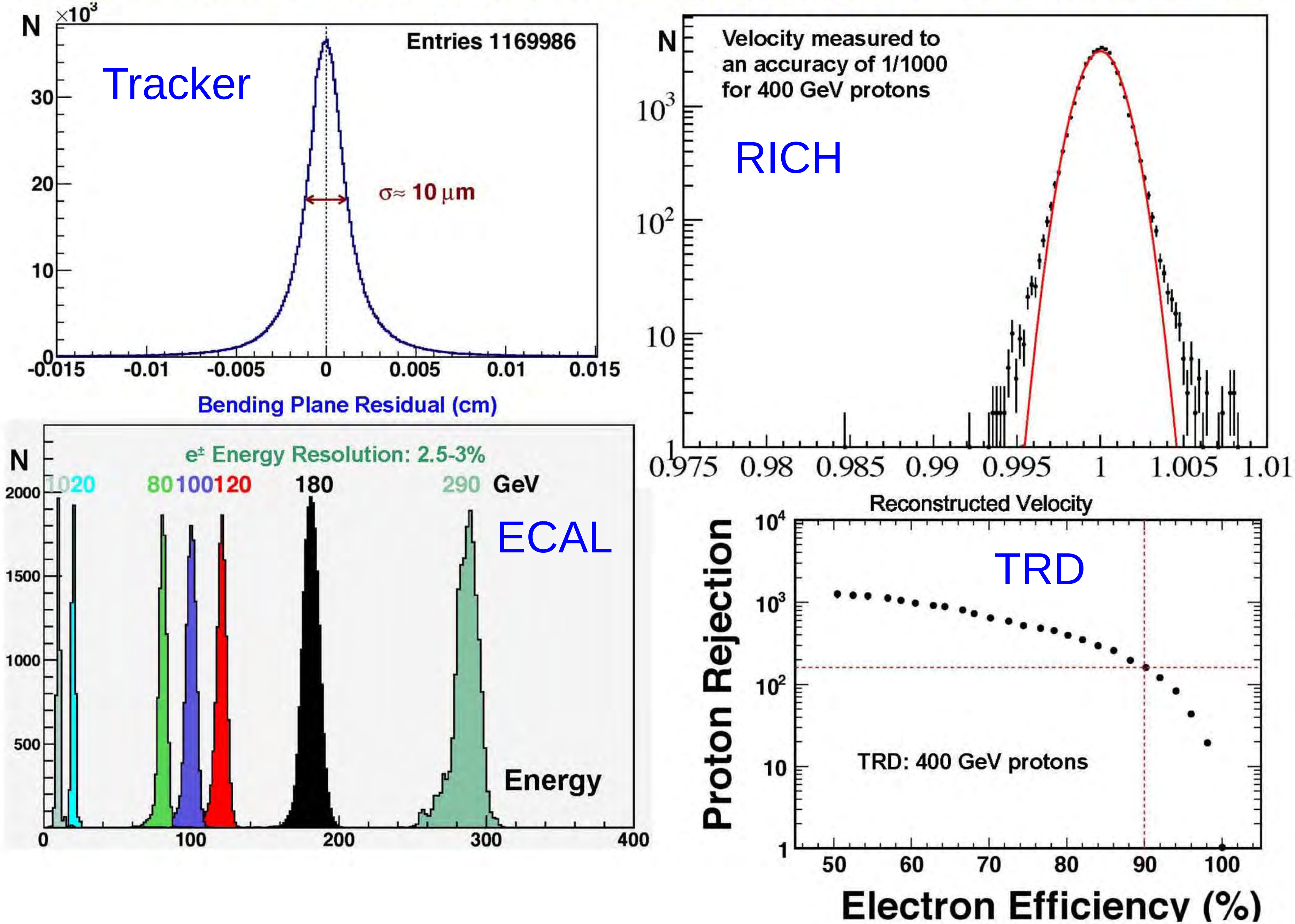
CERN Accelerator Complex

AMS in Test Beam with *permanent magnet*

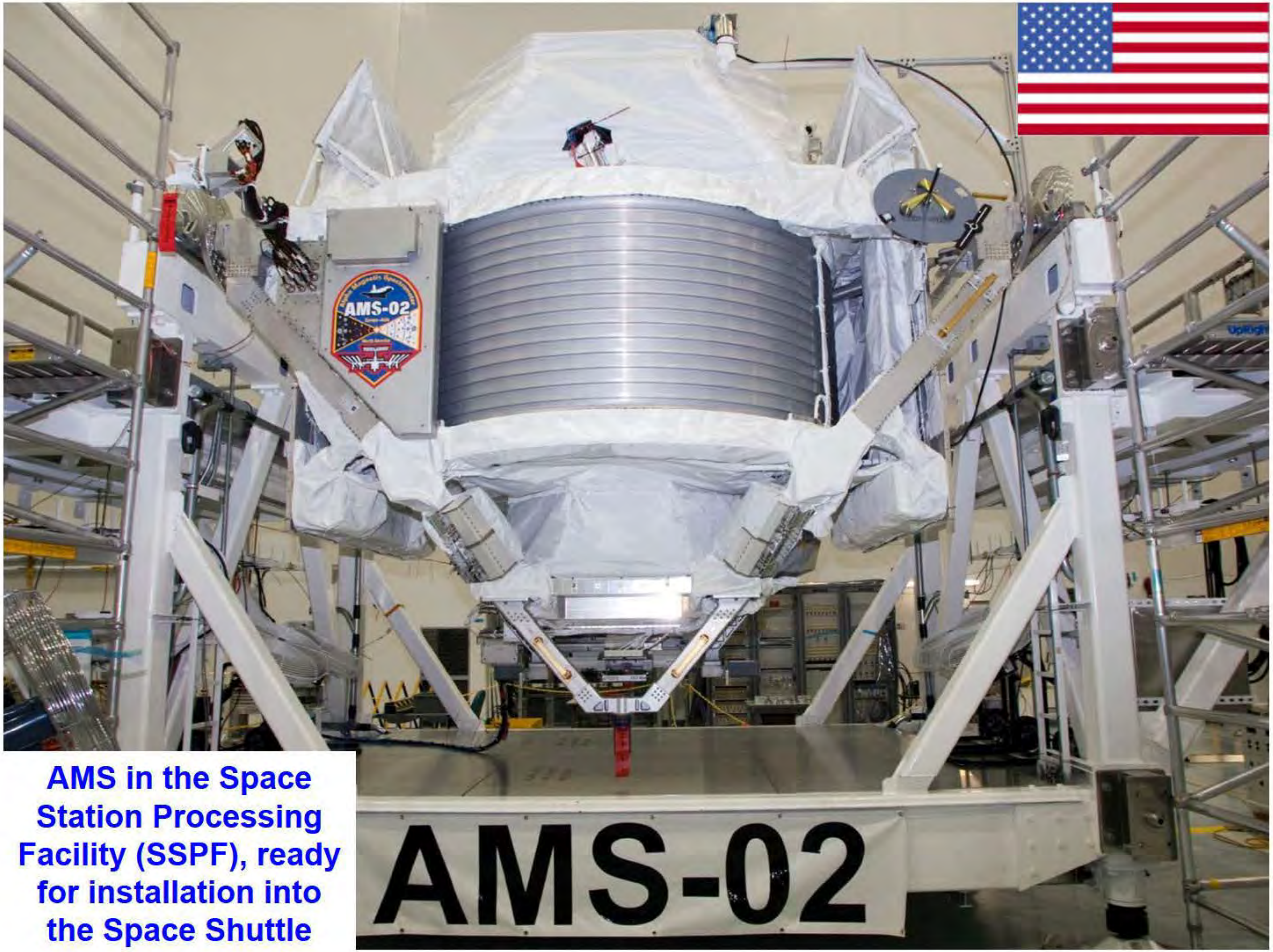
8-20 Aug 2010 with e^+, e^- and protons



Test Beam Results with permanent magnet – 8-20 Aug 2010



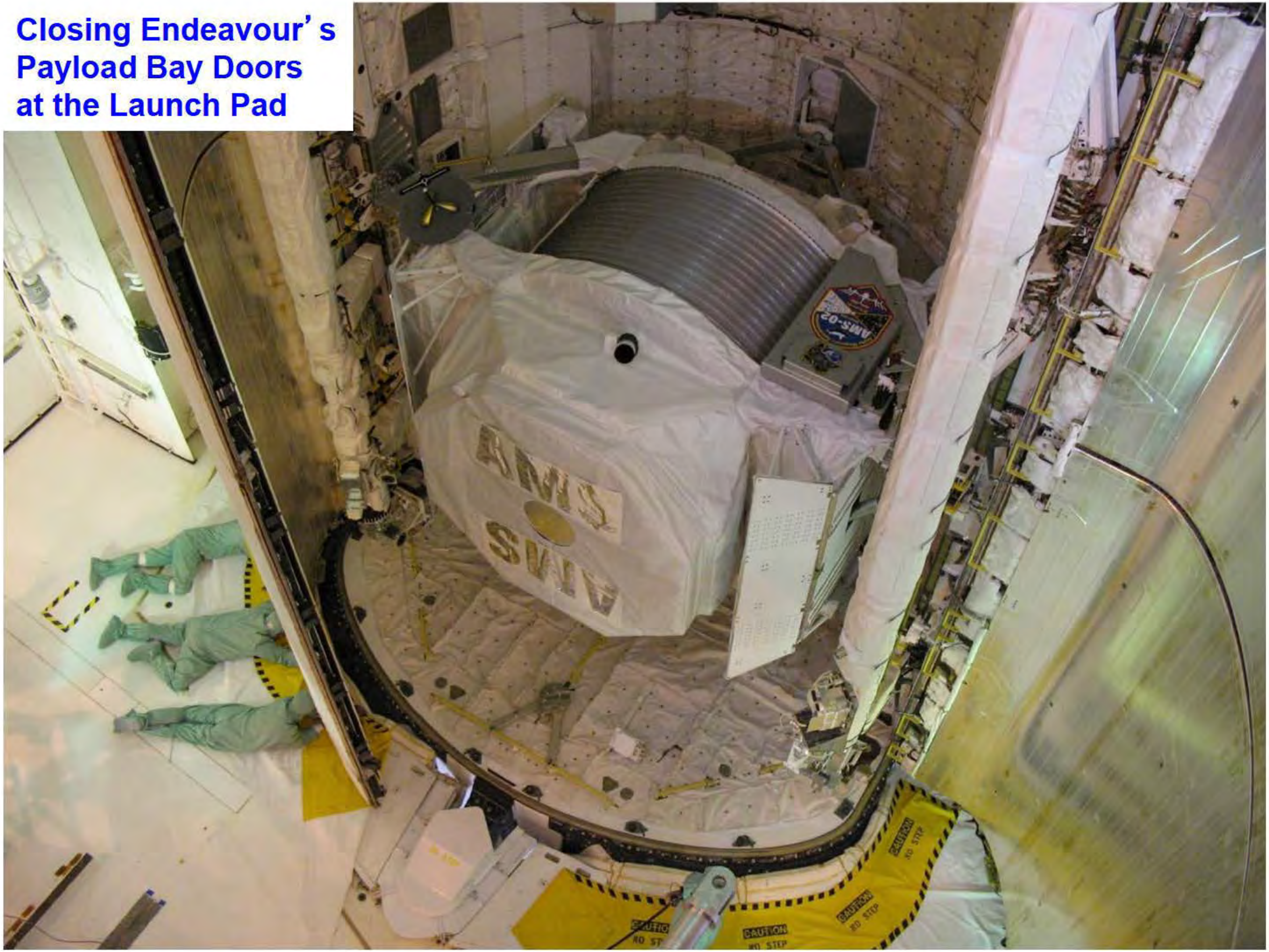
A US Air Force C-5 Galaxy
has been used for transport
from Geneva to KSC
25. August 2010

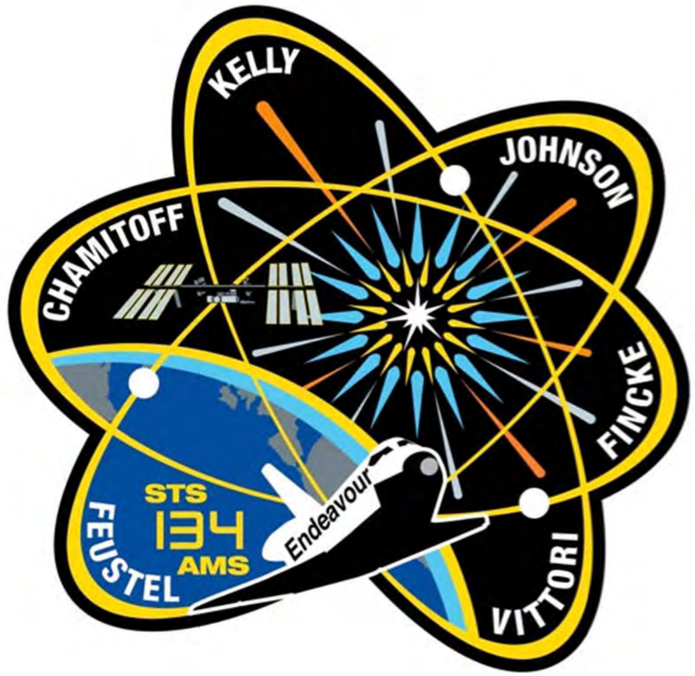


AMS in the Space Station Processing Facility (SSPF), ready for installation into the Space Shuttle


AMS

Closing Endeavour's Payload Bay Doors at the Launch Pad

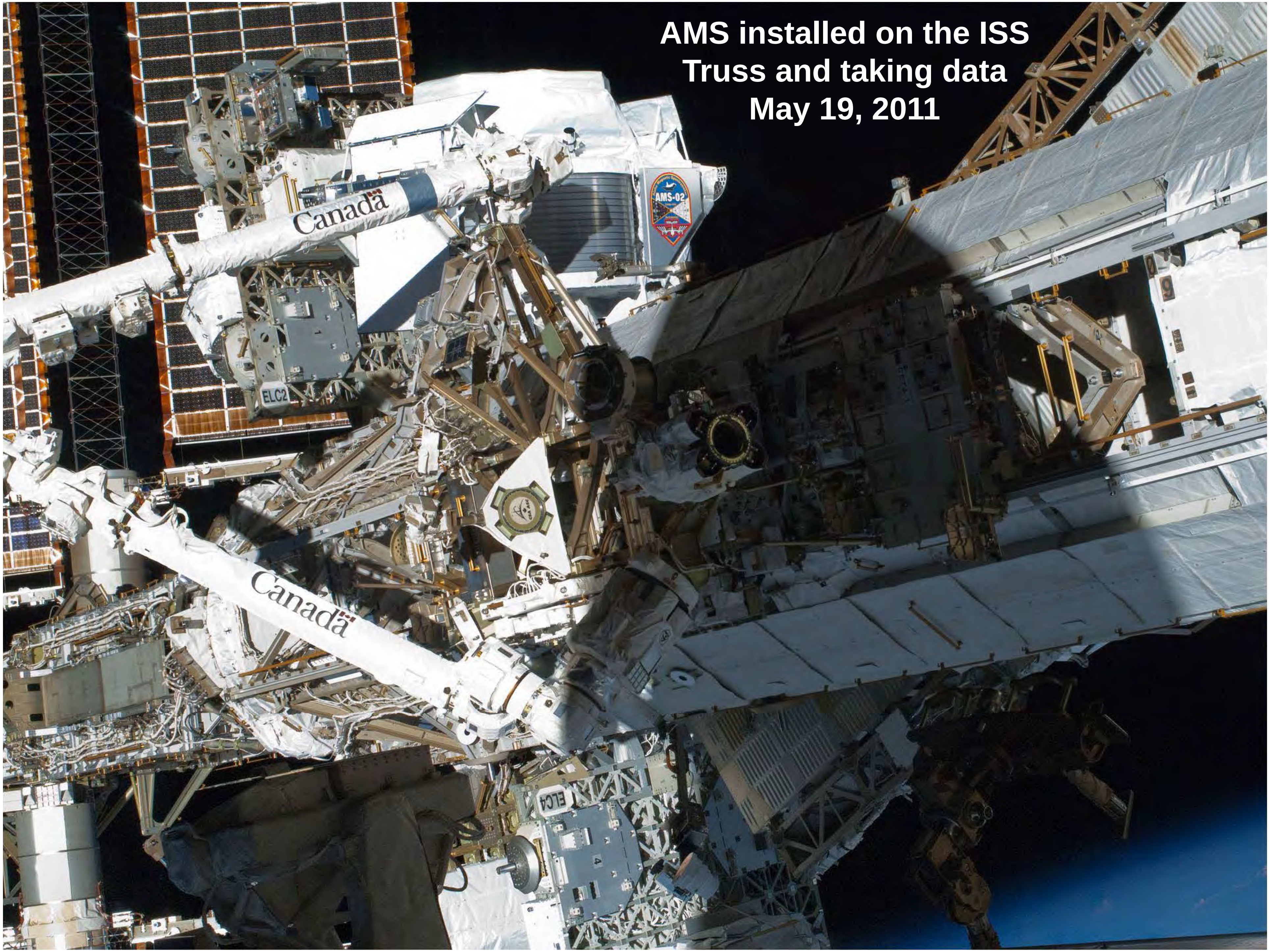




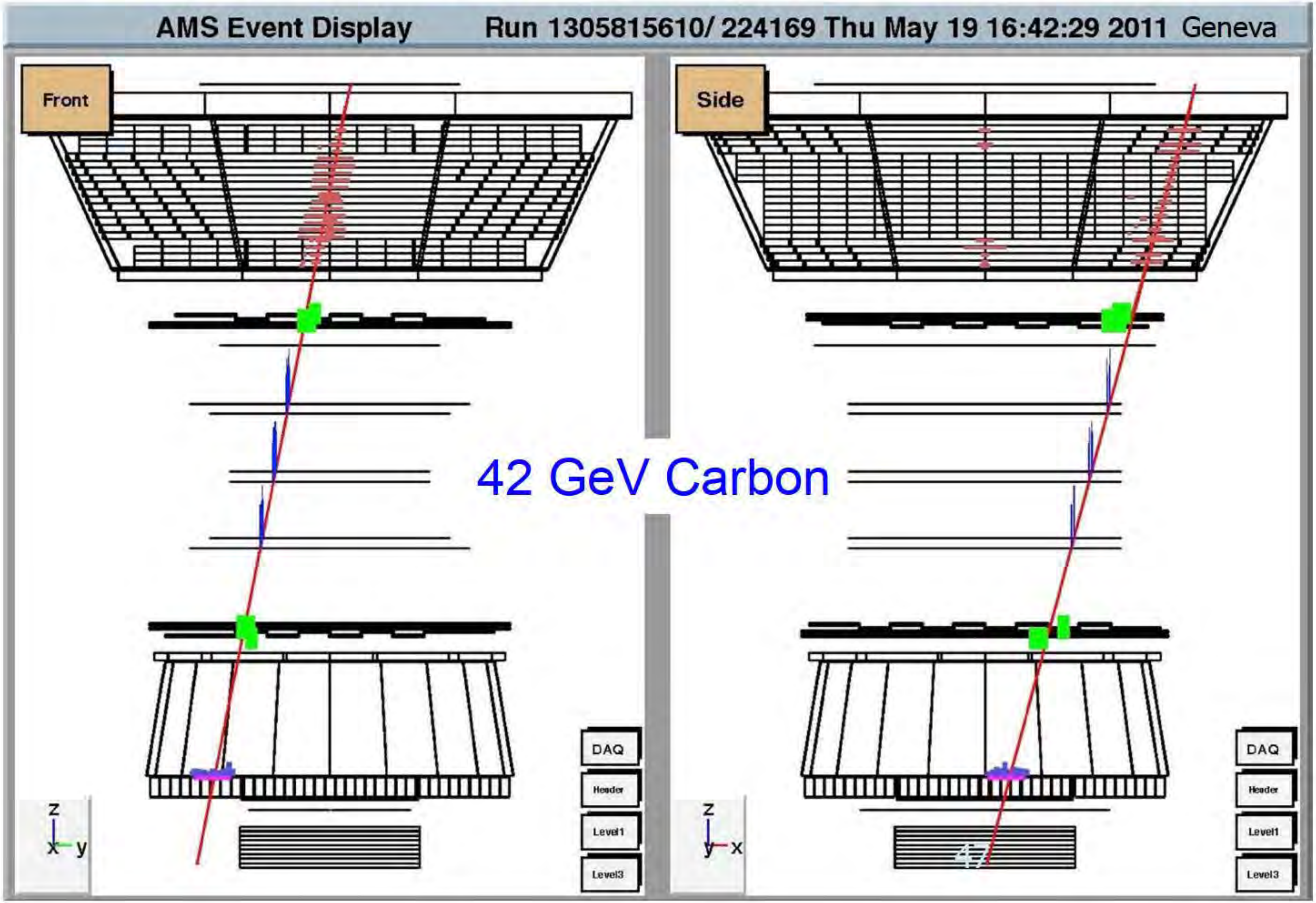
The STS-134 crew leaves the Operations & Checkout building on their way to the Launch Pad, May 16, 2011


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

Endeavour approaches the International Space Station

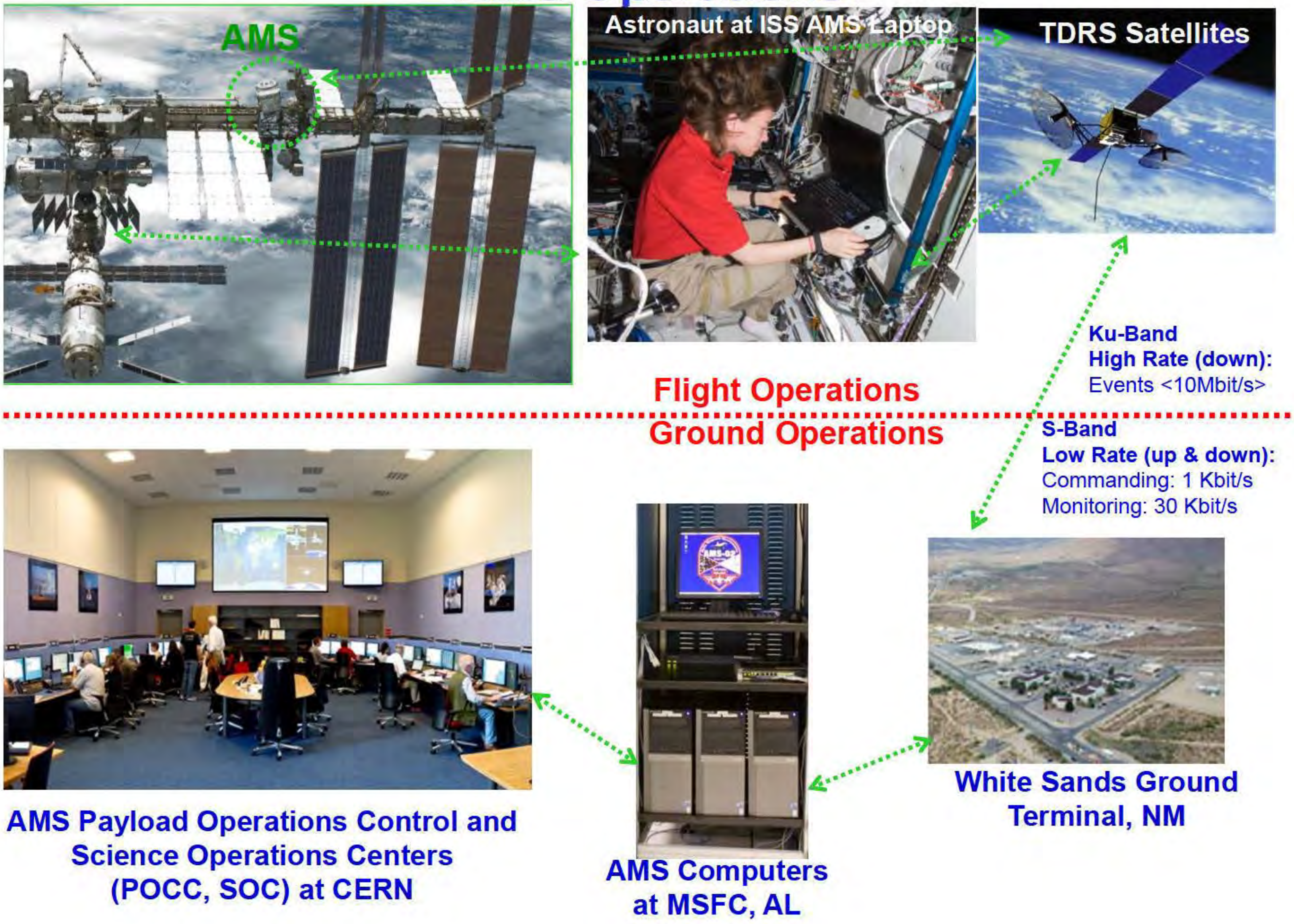

AMS installed on the ISS
Truss and taking data
May 19, 2011
Canada
Canada
AMS-02
ELC2

May 19: AMS installed on ISS 5:15 CDT, start taking data 9:35 CDT



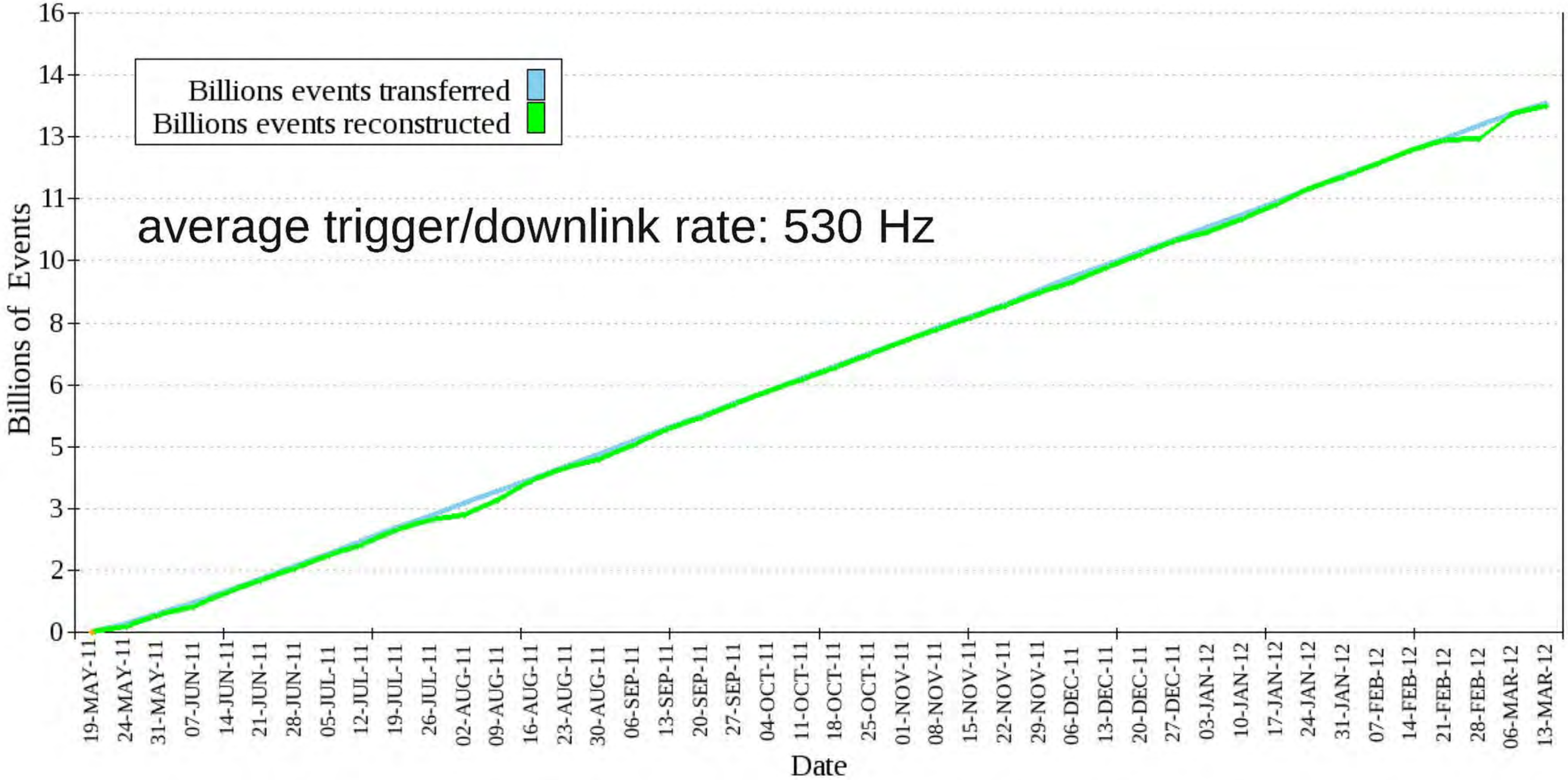
JSC, May 19th 2011

AMS Operations



General Charles Bolden, NASA Administrator, inaugurated AMS Payload Operations Control Center (POCC), June 23, 2011

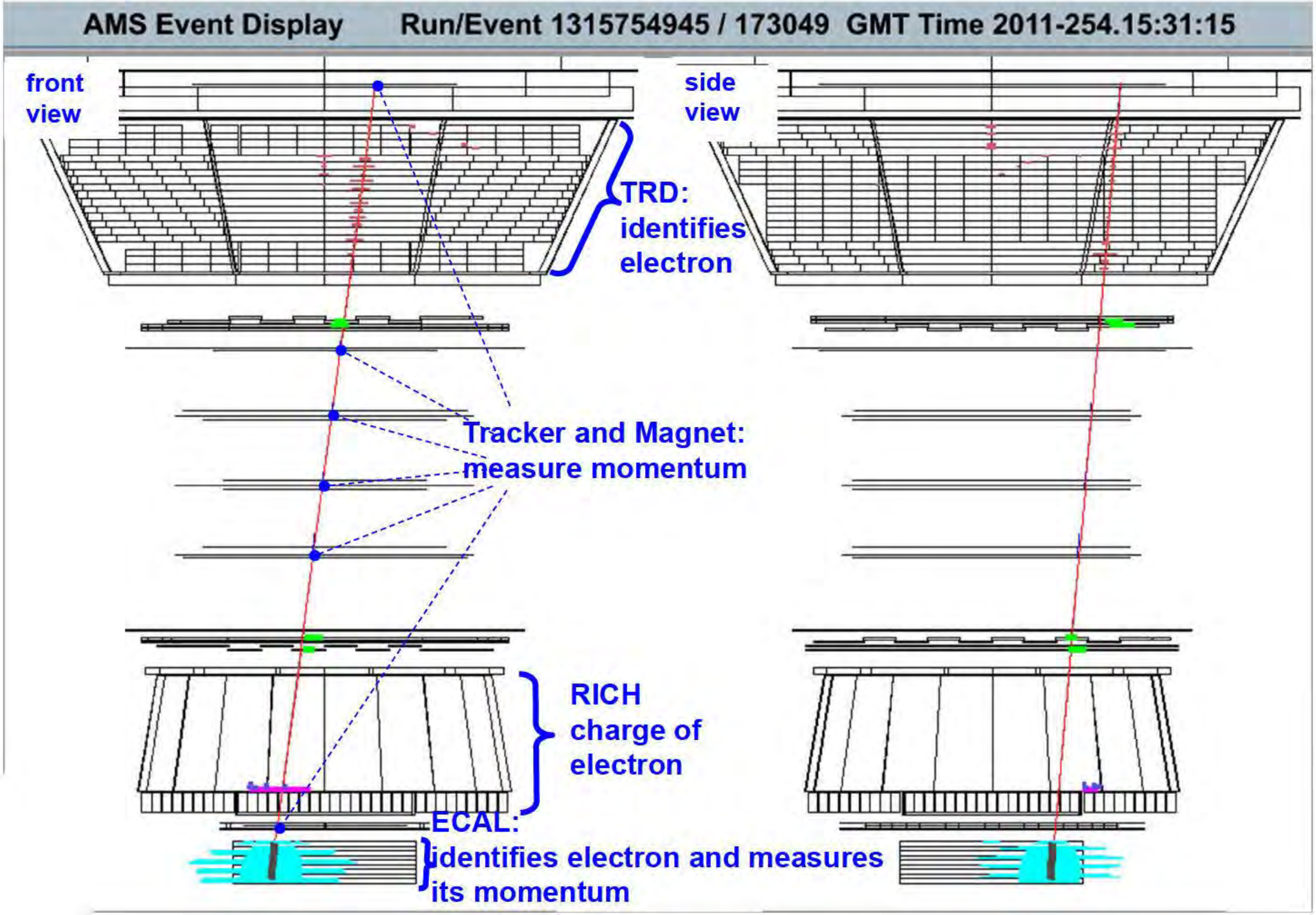
- **The detectors function exactly as designed**
- AMS collected over 13 billion events over the first 10 months
- Data taking has been continuously active except a few hours.



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

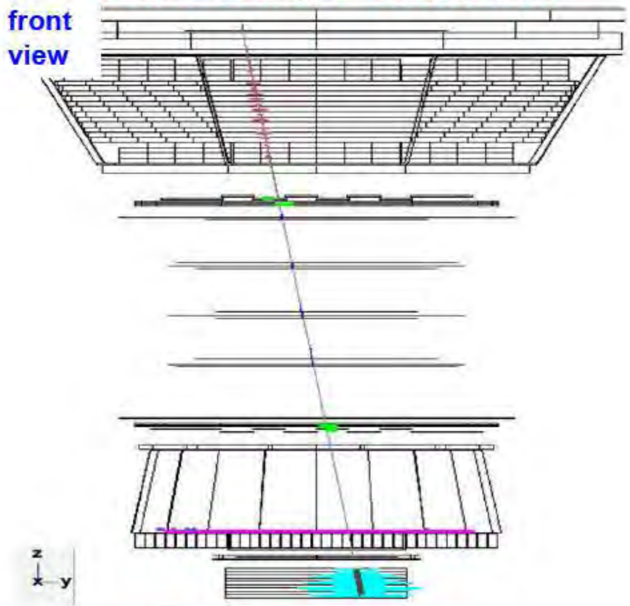
This will provide unprecedented sensitivity to search for new physics.

1.03 TeV electron

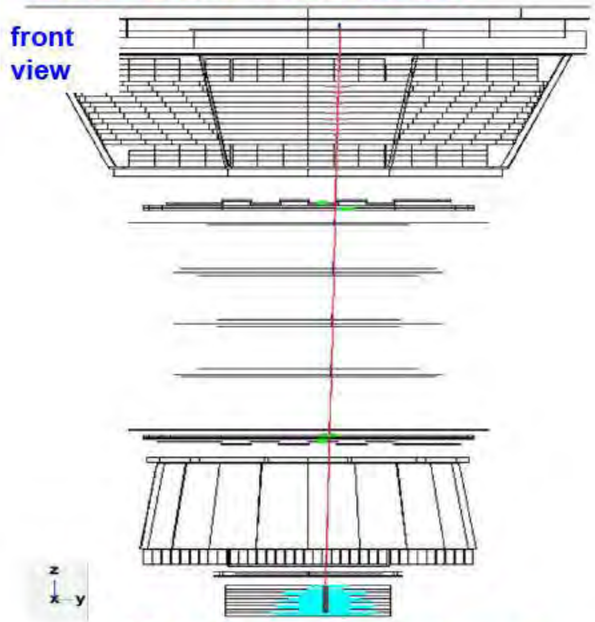


AMS data: High energy e$^{\pm}$

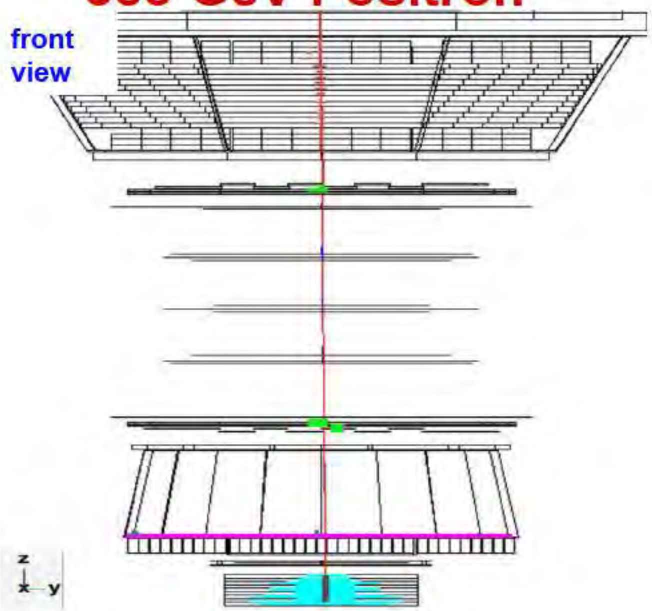
205 GeV Positron



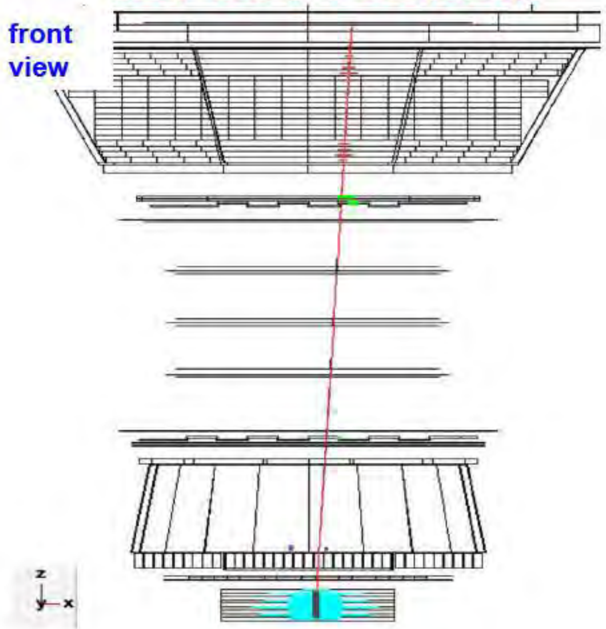
369 GeV Positron



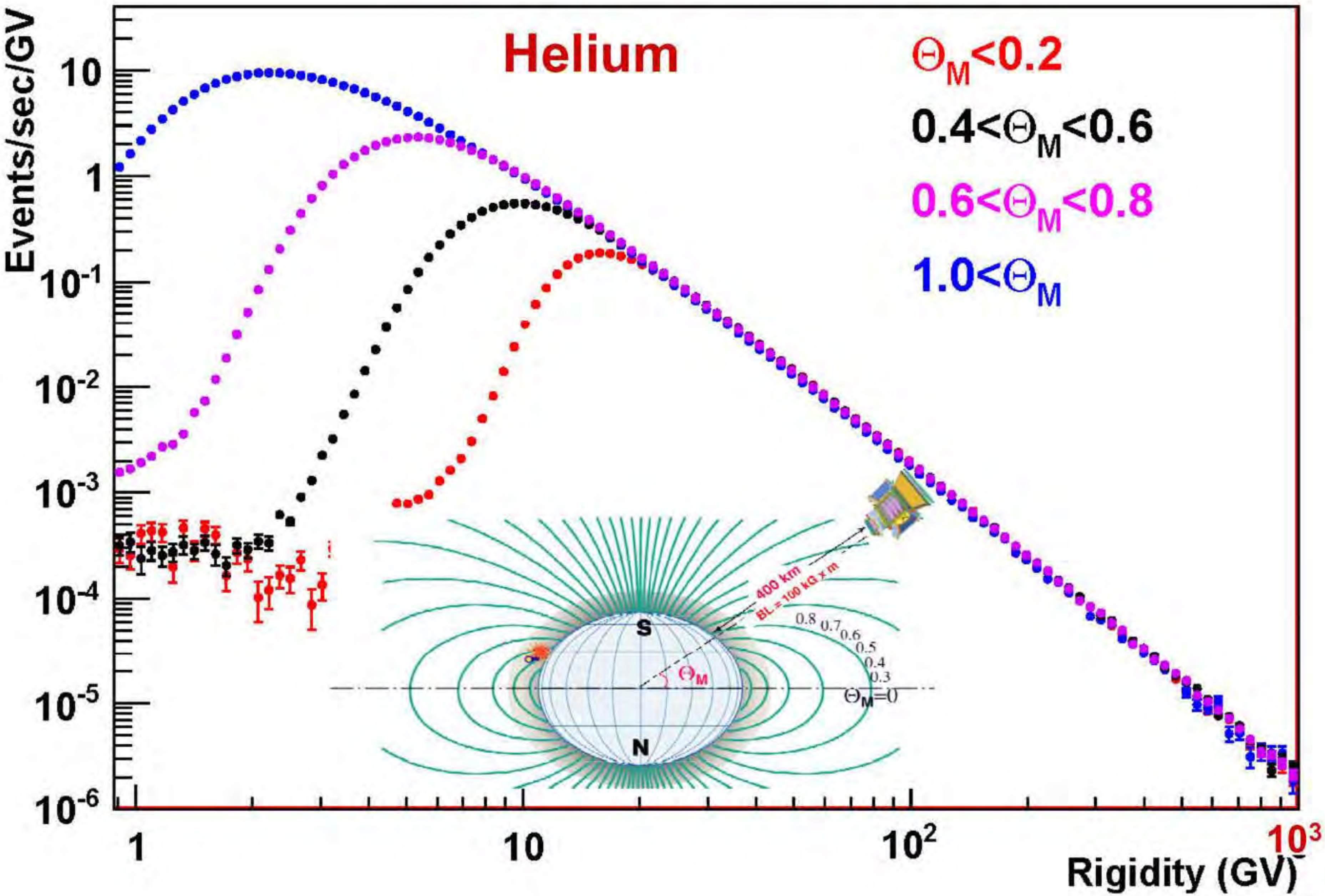
388 GeV Positron



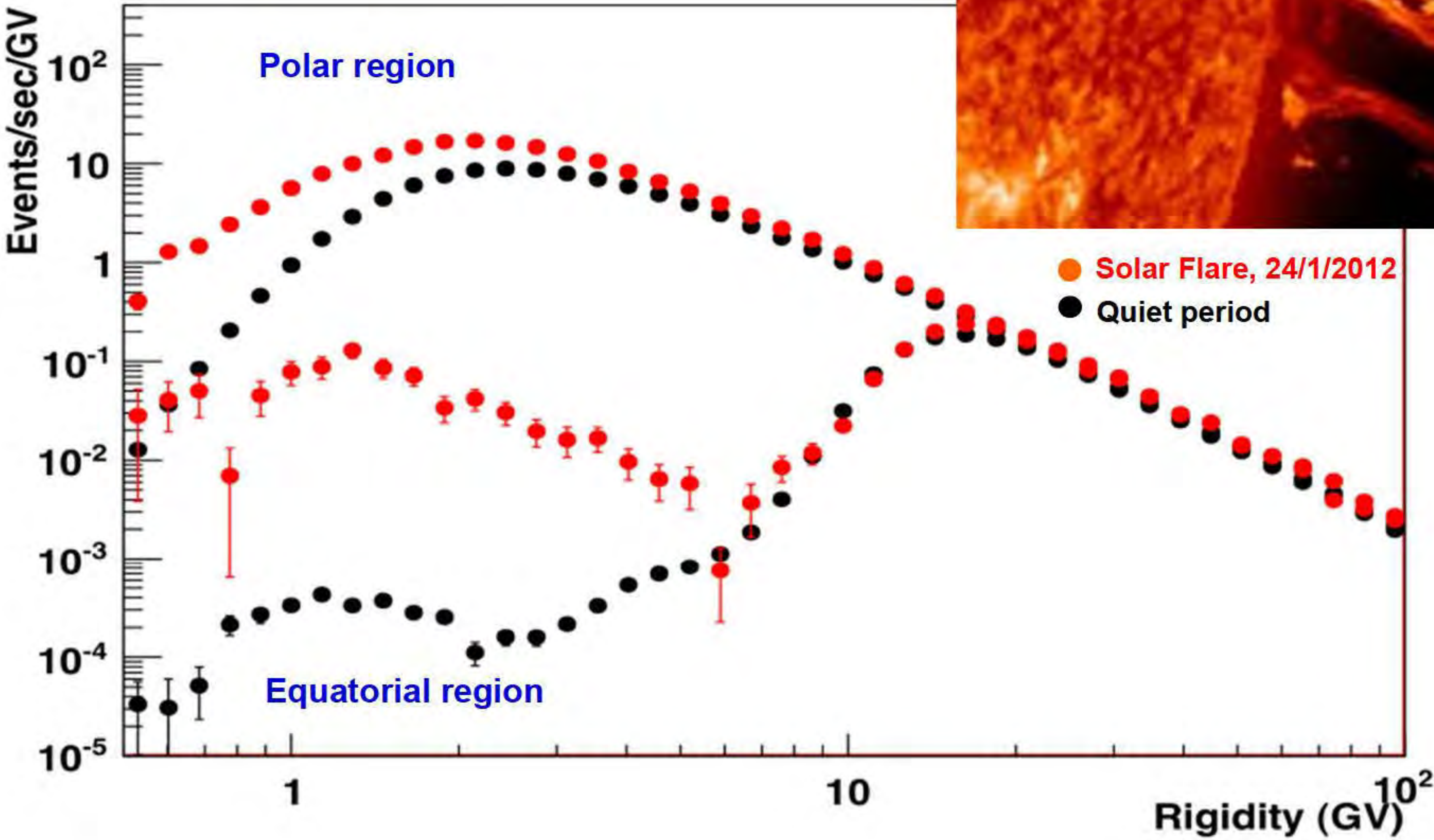
424 GeV Positron

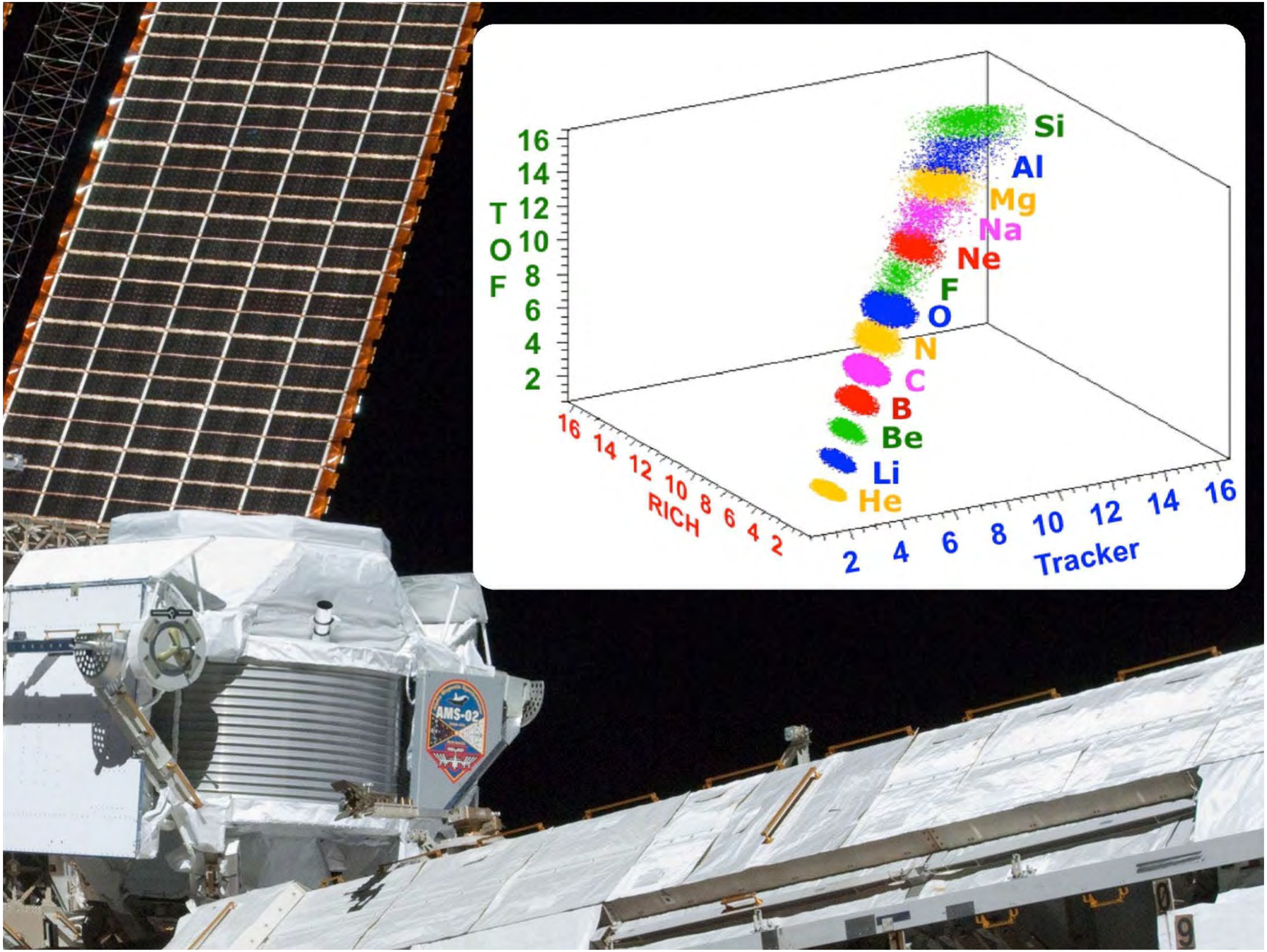


Data from AMS on ISS



AMS data: He rate and Solar Flare





Si
Al
Mg
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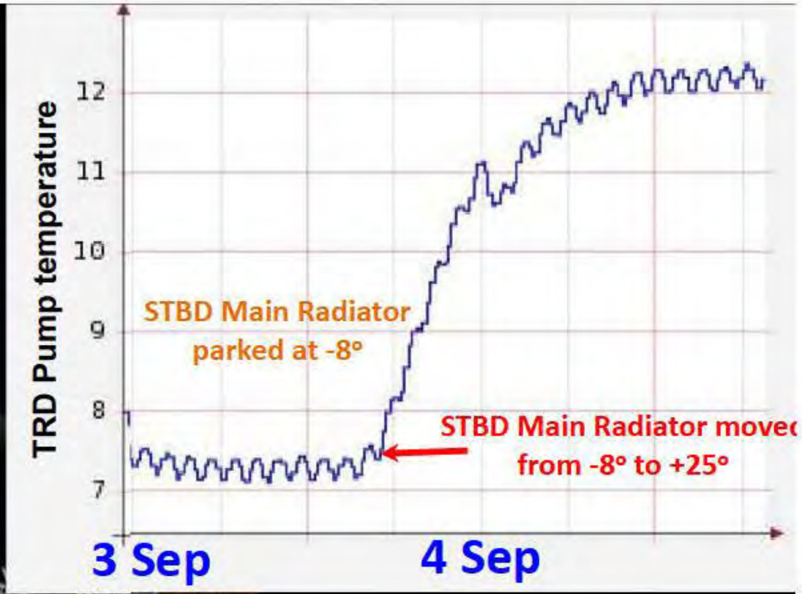
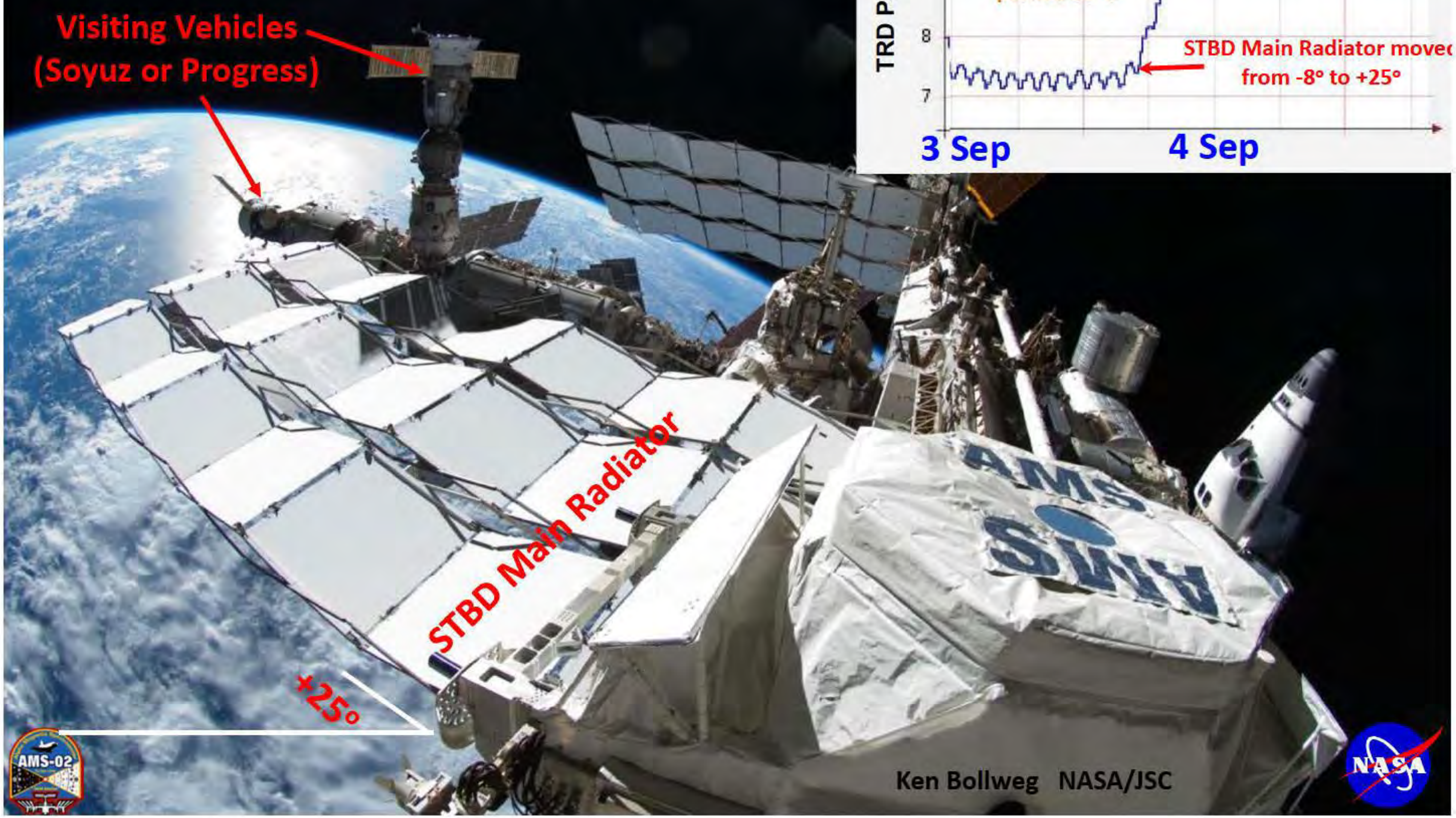
O
N
C
B
Be
Li
He
TOF
16 14 12 10 8 6 4 2
RICH
16 14 12 10 8 6 4 2
Tracker
2 4 6 8 10 12 14 16
AMS-02

Thermal variables:

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

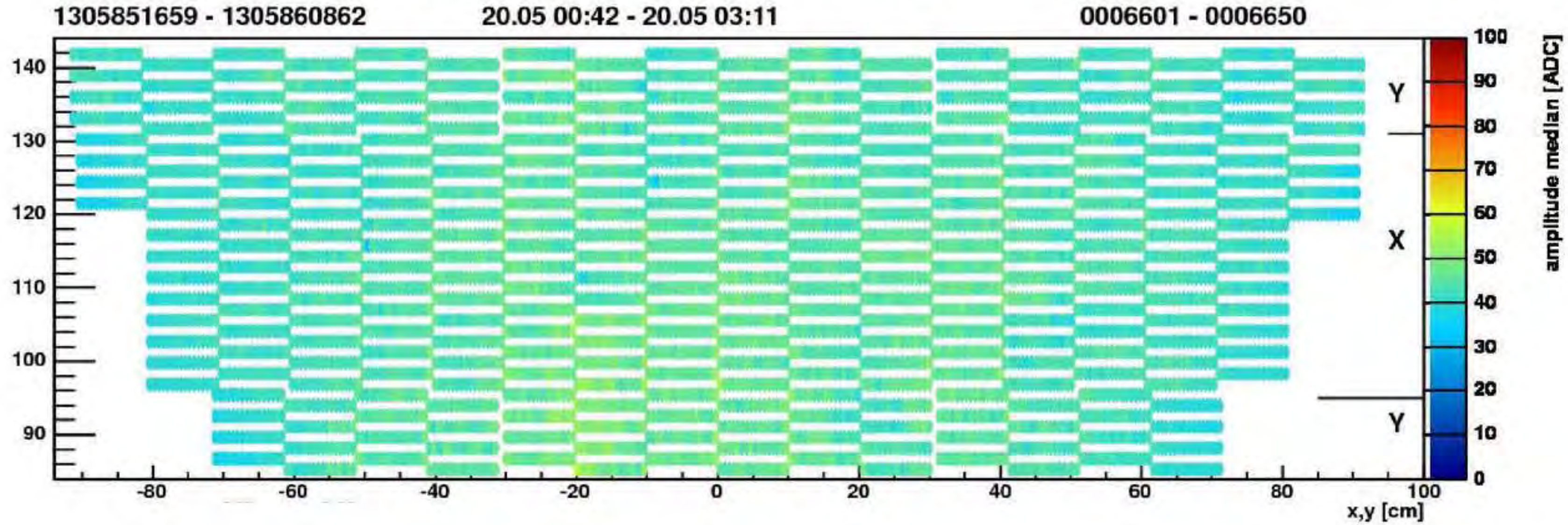




TRD Operation on ISS

All 5248 TRD channels operational

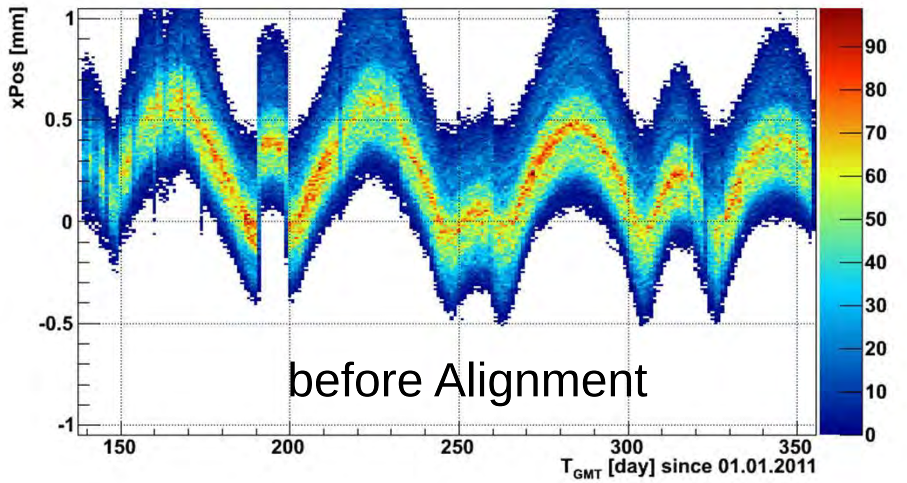
TRD-Straw Amplitudes for hits on particle track:

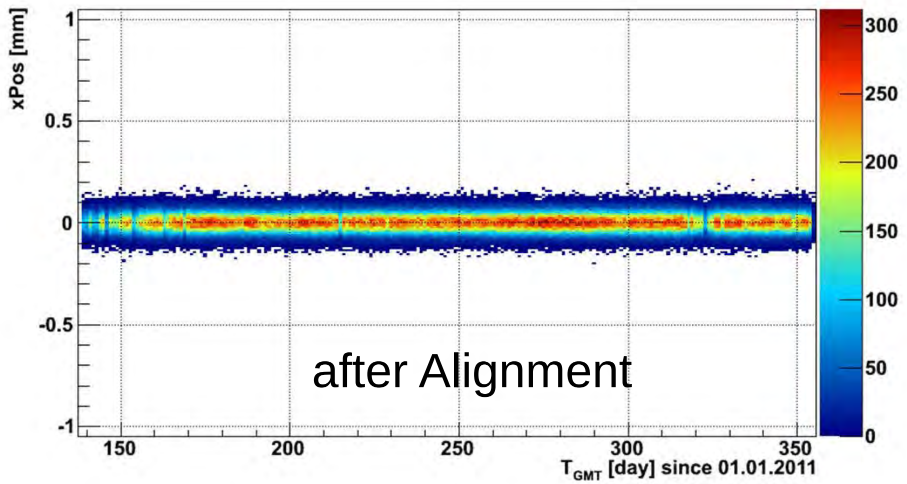


Gas-Losses: 4.2 mbar/d

CO_2 Storage: 5 kg: Sufficient for more than 17 years

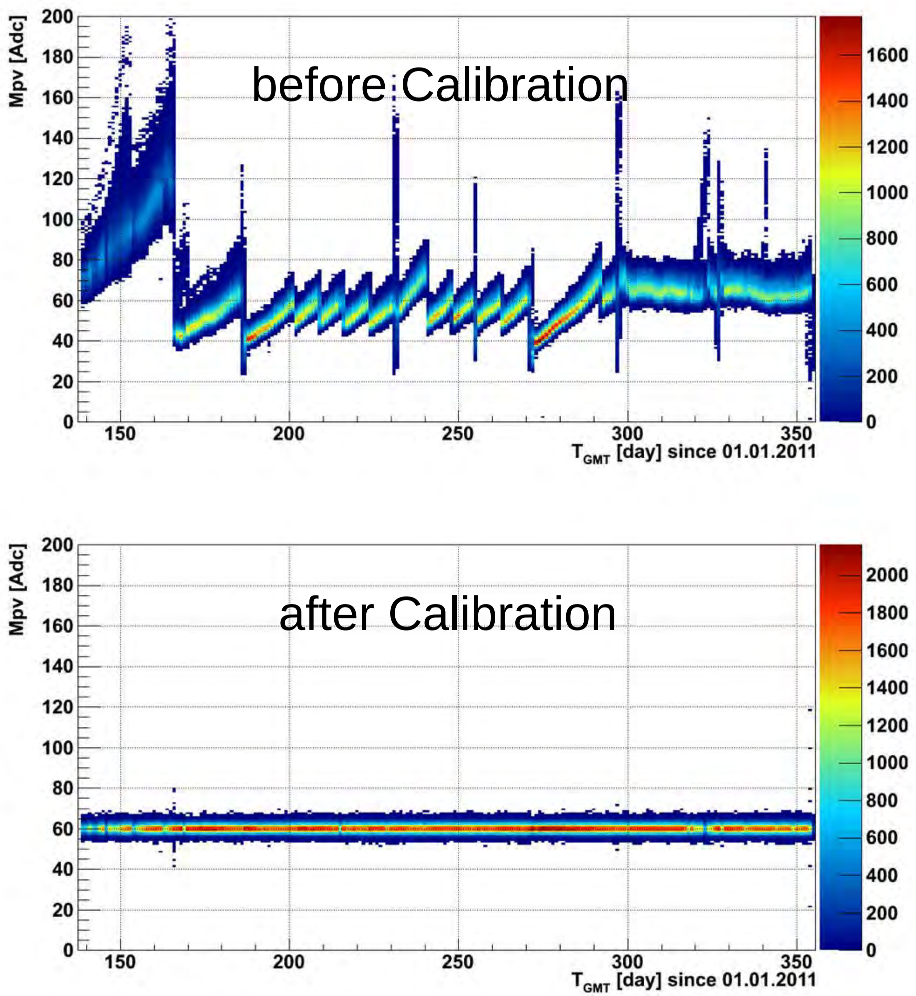
- **Due to temperature variations the TRD is moving on top of the inner tracker by up to 1 mm.**
- **We can use protons for alignment to an accuracy of 0.04 mm for each straw module.**



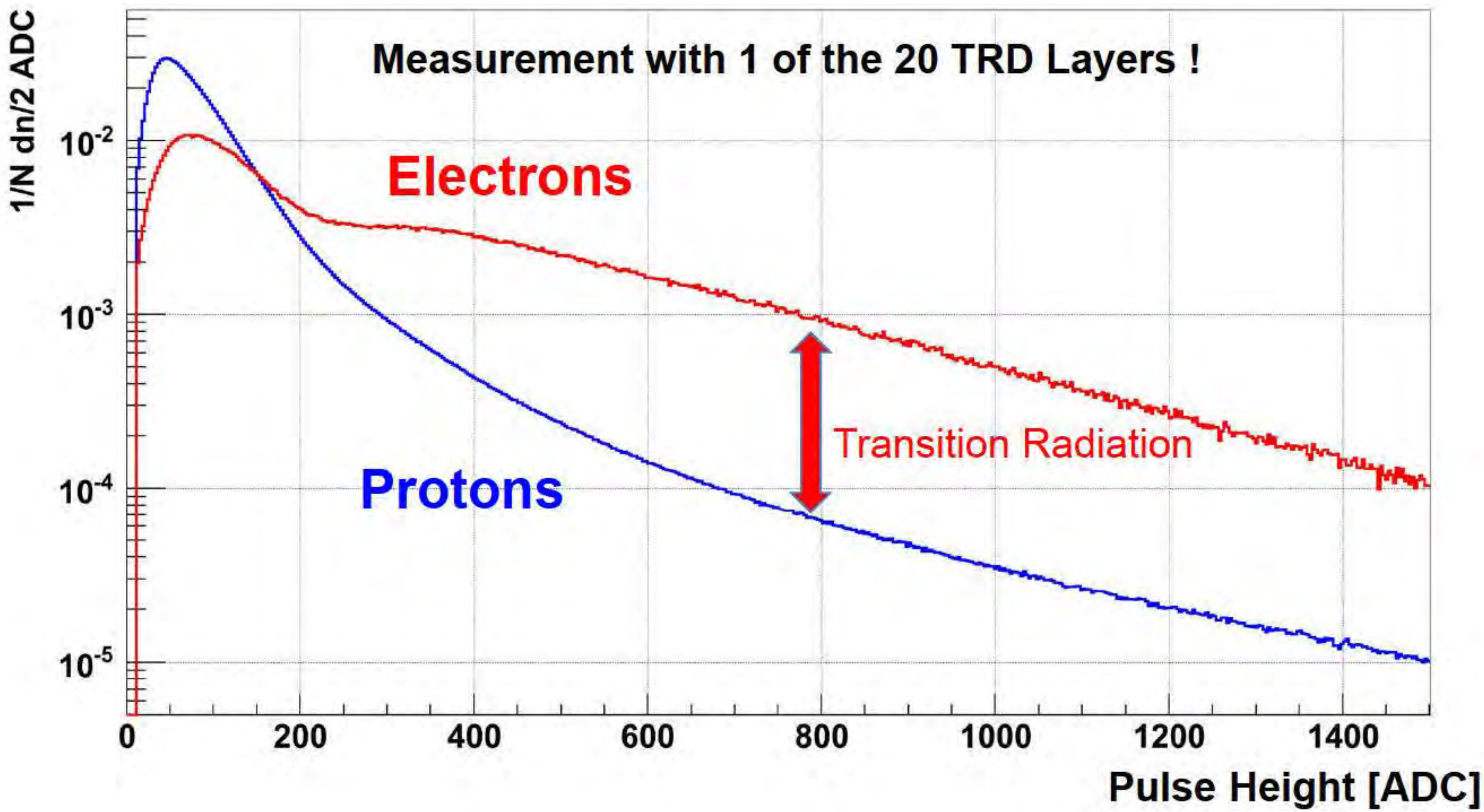


- **Due to temperatue, pressure, gas composition and HV changes the TRD detector response is changing**

- **We can use cosmic ray protons to calibrate the detector response to 3% accurary.**



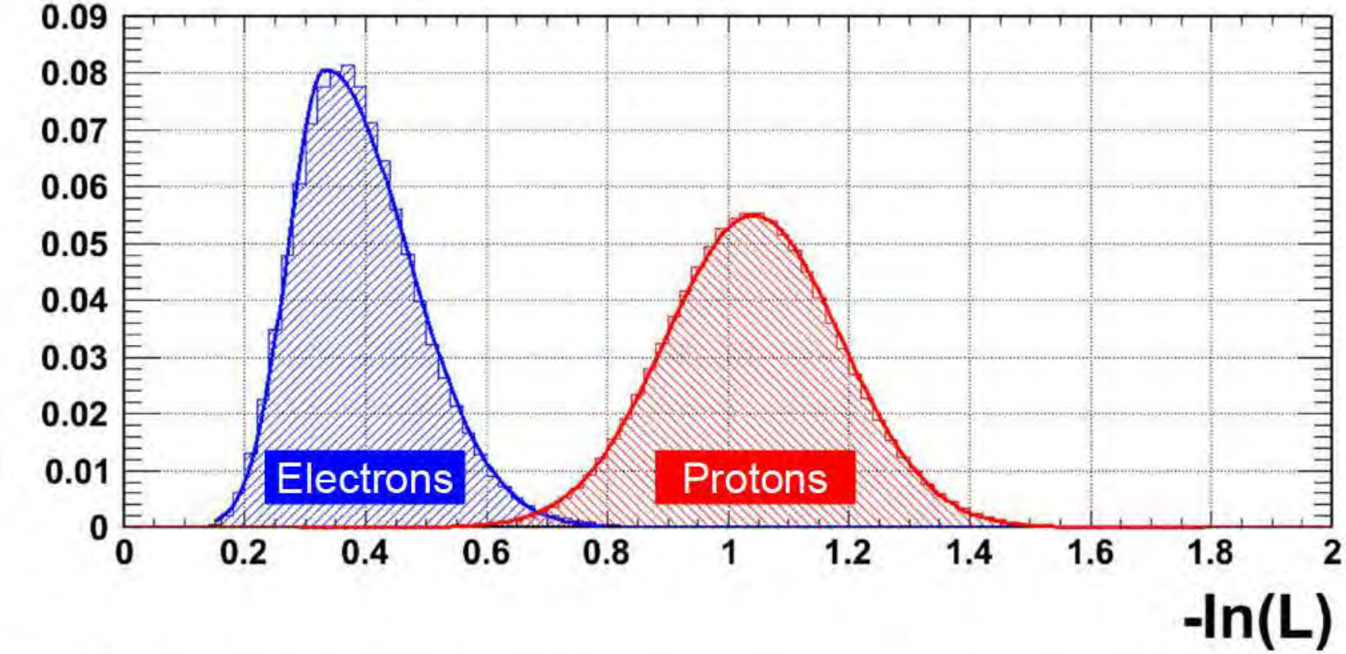
- Use the AMS Tracker and Electromagnetic Calorimeter to define a clean Electron and Proton sample.
- Study the TRD response in Space and determine the particle identification power from space data directly !

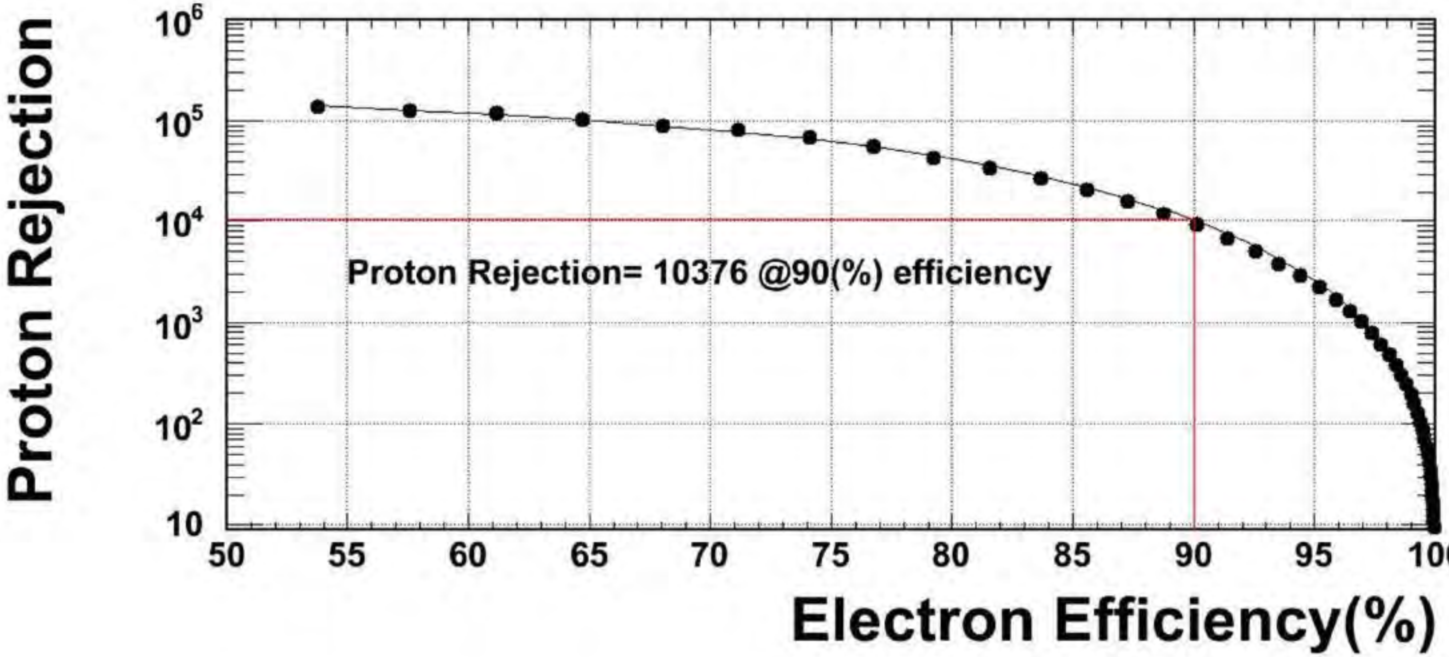


AMS TRD Data on ISS

$$\bar{P}_{e/p} = \sqrt[n]{\prod_{i}^{n} P_{e/p}^{(i)}(E)}$$

$$L = \frac{\bar{P}_e}{\bar{P}_p + \bar{P}_e}$$





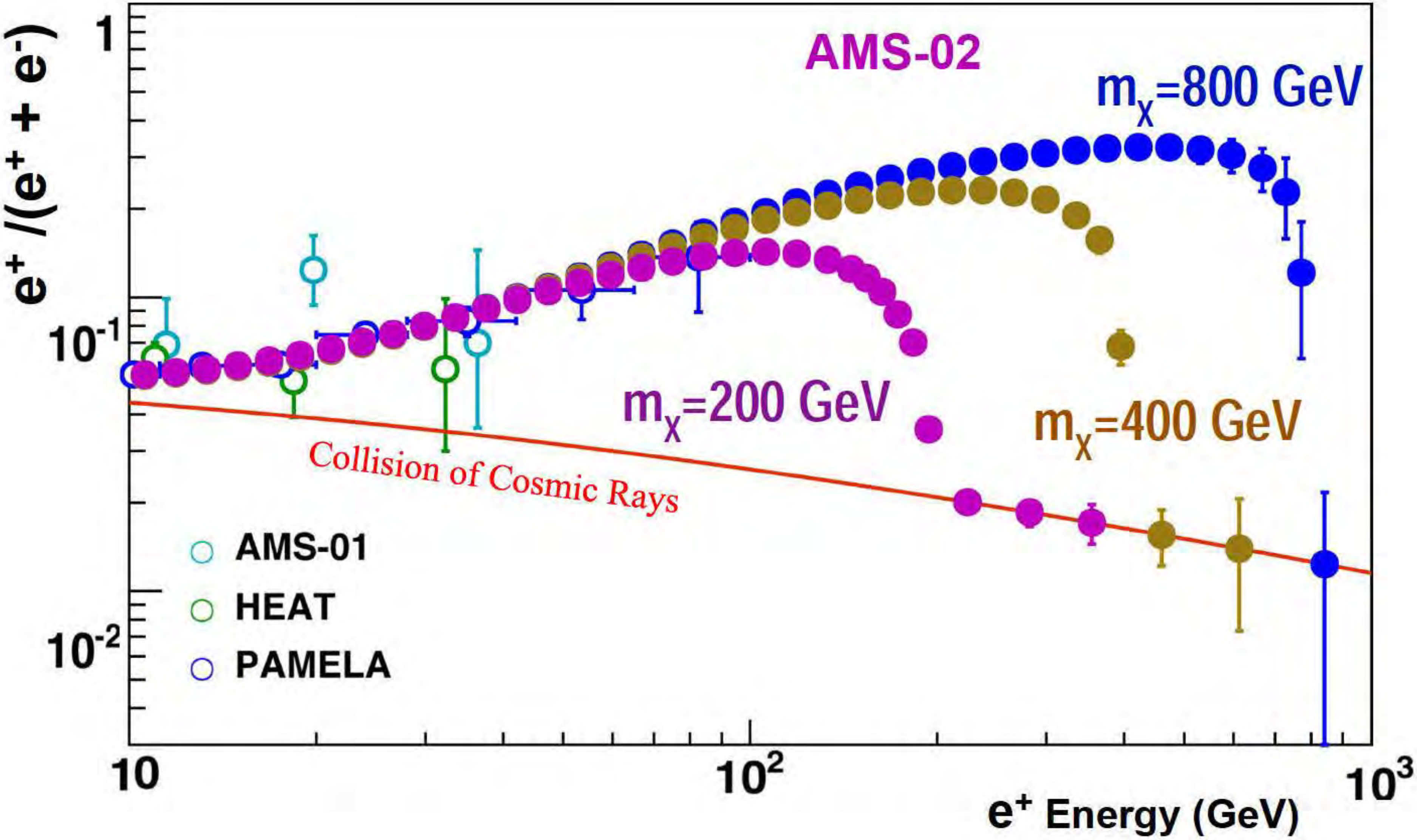
AMS Physics Potential

- **Searches for primordial antimatter:**
  - Anti-nuclei: **$\overline{\text{He}}$, …**
- **Dark Matter searches:**
  - **e^+, $e^\pm$, $\bar{p}$, …**
  - simultaneous observation of several signal channels.
- **Searches for new forms of matter:**
  - **strangelets, …**
- **Measuring CR spectra – refining propagation models;**
- **Identification of local sources of high energy photons (~TeV):**
  - **SNR, Pulsars, PBH, …**
- **Study effects of solar modulation on CR spectra over 11 year solar cycle**
- **…**

"The most exciting objective of AMS is to probe the unknown;
to search for phenomena which exist in nature
that we have not yet imagined nor had the tools to discover."

S. Ting

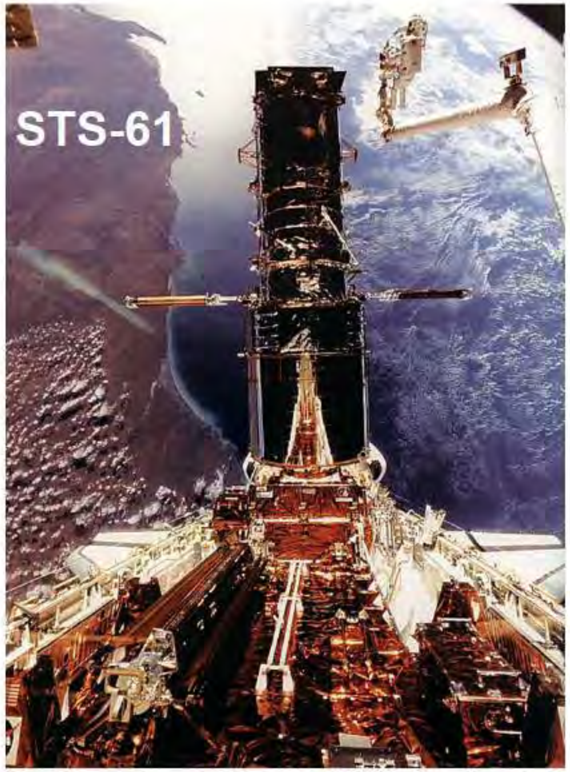
What can we expect from AMS ?



Hubble Space Telescope ⇔ AMS

Wide Field Planetary Camera 1

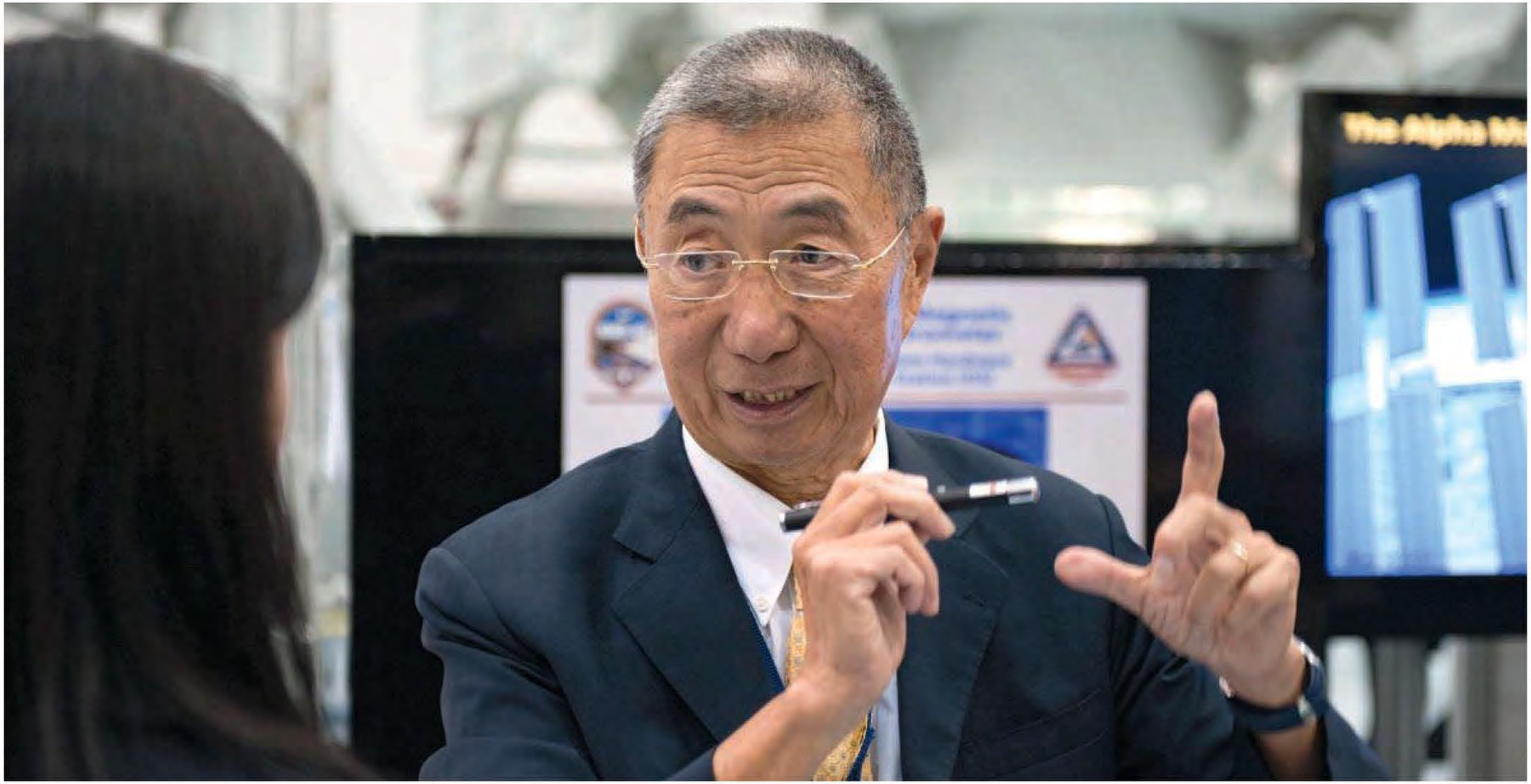
Wide Field Planetary Camera 2



Could we imagine upgrades for AMS which would enhance the scientific program in a similar way ?

	Start	SM1	SM2	SM3A	SM3B	SM4
Datum	Apr 1990	Dez 1993	Feb 1997	Dez 1999	Mar 2002	Mai 2009
Mission	STS-31	STS-61	STS-82	STS-103	STS-109	STS-125
Shuttle	Discovery	Endeavour	Discovery	Discovery	Columbia	Atlantis
Bahnhöhe	618 km	590 km	596 km	603 km	577 km	567 km
Reboost		+ 8 km	+ 15 km		+ 6	
Instr. 1	WF/PC	WFPC2				WFC3
Instr. 2	GHRS		STIS			STIS (R)
Instr. 3 (axiale Pos.)	HSP	COSTAR				COS
Instr. 4	FOC				ACS	ACS (R)
Instr. 5	FOS		NICMOS		NICMOS Kühler	
Gyroskope	6	4 (R)	2 (R)	6 (R)	2 (R)	6 (R)
Photovoltaik	SA1	SA2			SA3	

AMS - An endeavor for a Global Research Collaboration, but …



Undeniable. By sheer determination, Samuel Ting kept the project alive, all agree.

22 APRIL 2011 VOL 332 **SCIENCE** www.sciencemag.org

The Cosmos is the Ultimate Laboratory.

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