AMS Overview

Prepared April 26, 2010

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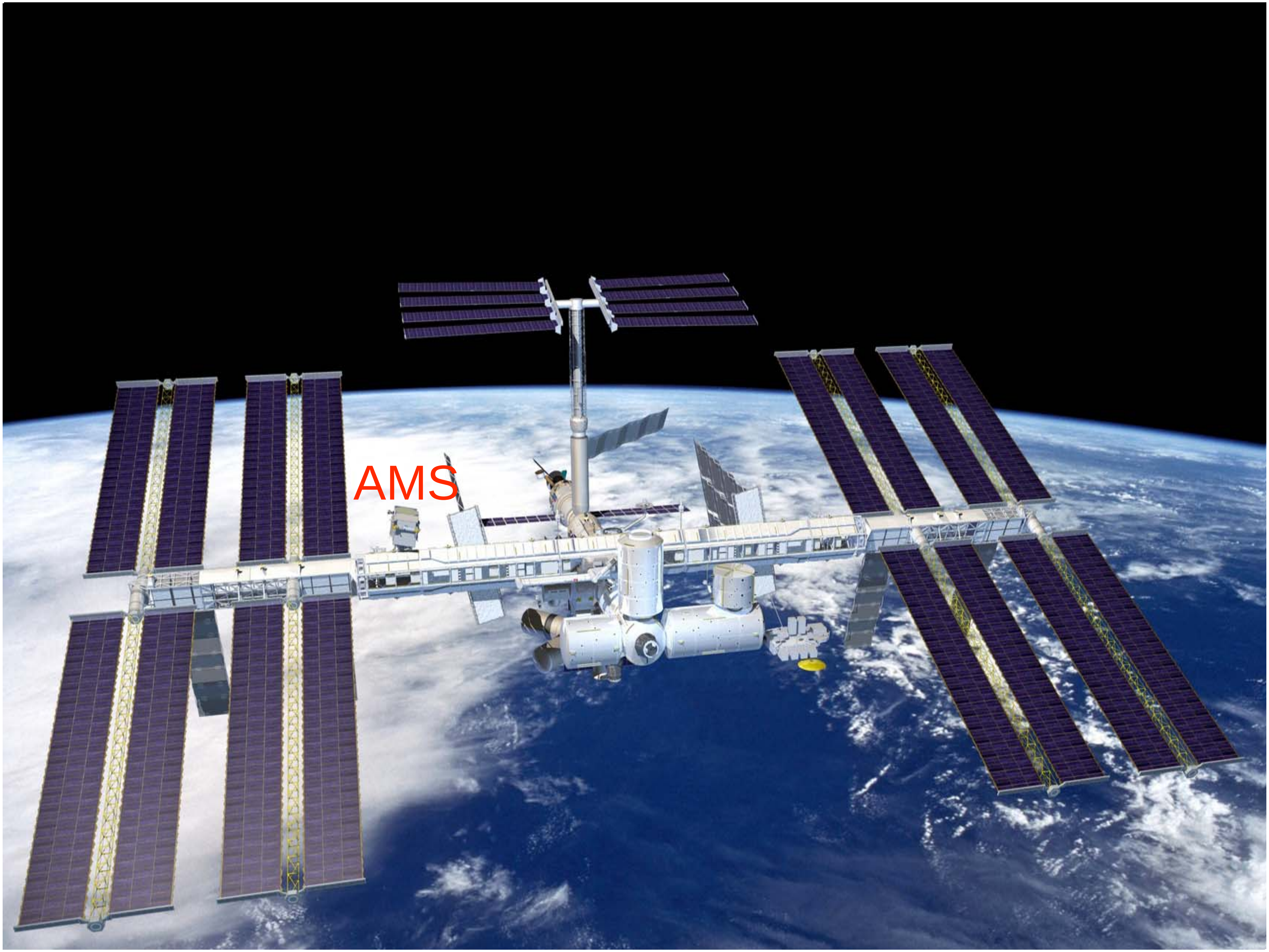
http://ams.nasa.gov
http://www.ams02.org

Alpha Magnetic Spectrometer

- Description
  - AMS-02 is a high energy physics experiment that employs a large permanent magnet to produce a strong, uniform magnetic field (~0.14 Tesla) combined with a state-of-the-art precision spectrometer to search for anti-matter (anti-helium and anti-carbon), dark matter, dark energy and to understand Cosmic Ray propagation.
    - As originally reviewed, AMS employed a superconducting magnet with a 0.8 Tesla magnetic field.
  - Although the payload cost is ~$2 Billion (not including launch costs), more than 95% of the funds come from foreign governments, institutes and companies
- Investigators:
  - The AMS team, led by Nobel laureate Prof. Samuel Ting/MIT, has approximately 500 physicists, engineers and technicians from multiple countries participating.
  - USA sponsorship by the U.S. Department of Energy.
  - Flown under a NASA / DOE interagency agreement for two flights: Engineering Test on Shuttle (STS-91) and 3 yr Science Mission on ISS.
  - NASA/JSC Engineering Directorate is assigned Project Management and Payload Integration task (AMS Project Office/JSC Engineering Directorate)

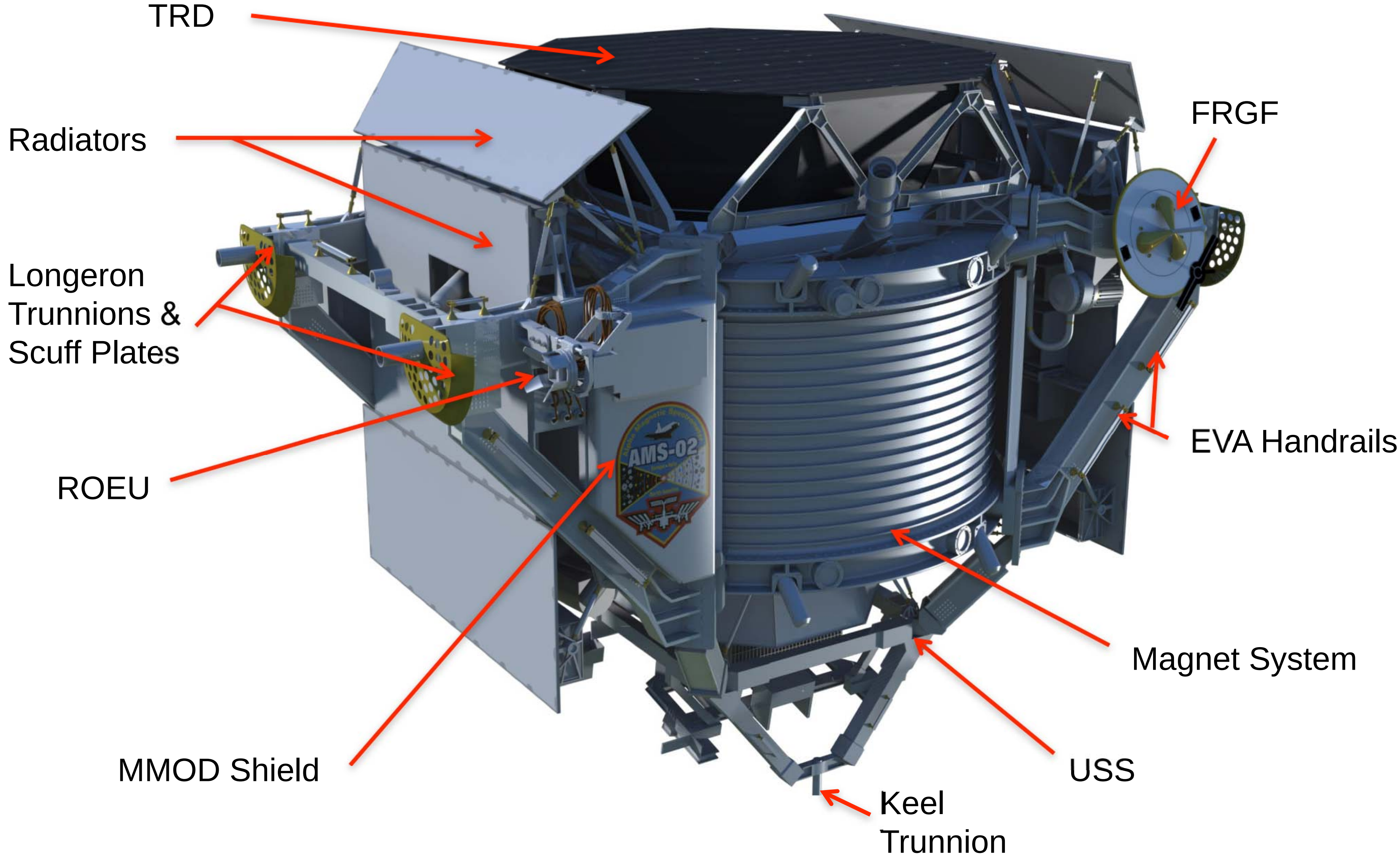

AMS

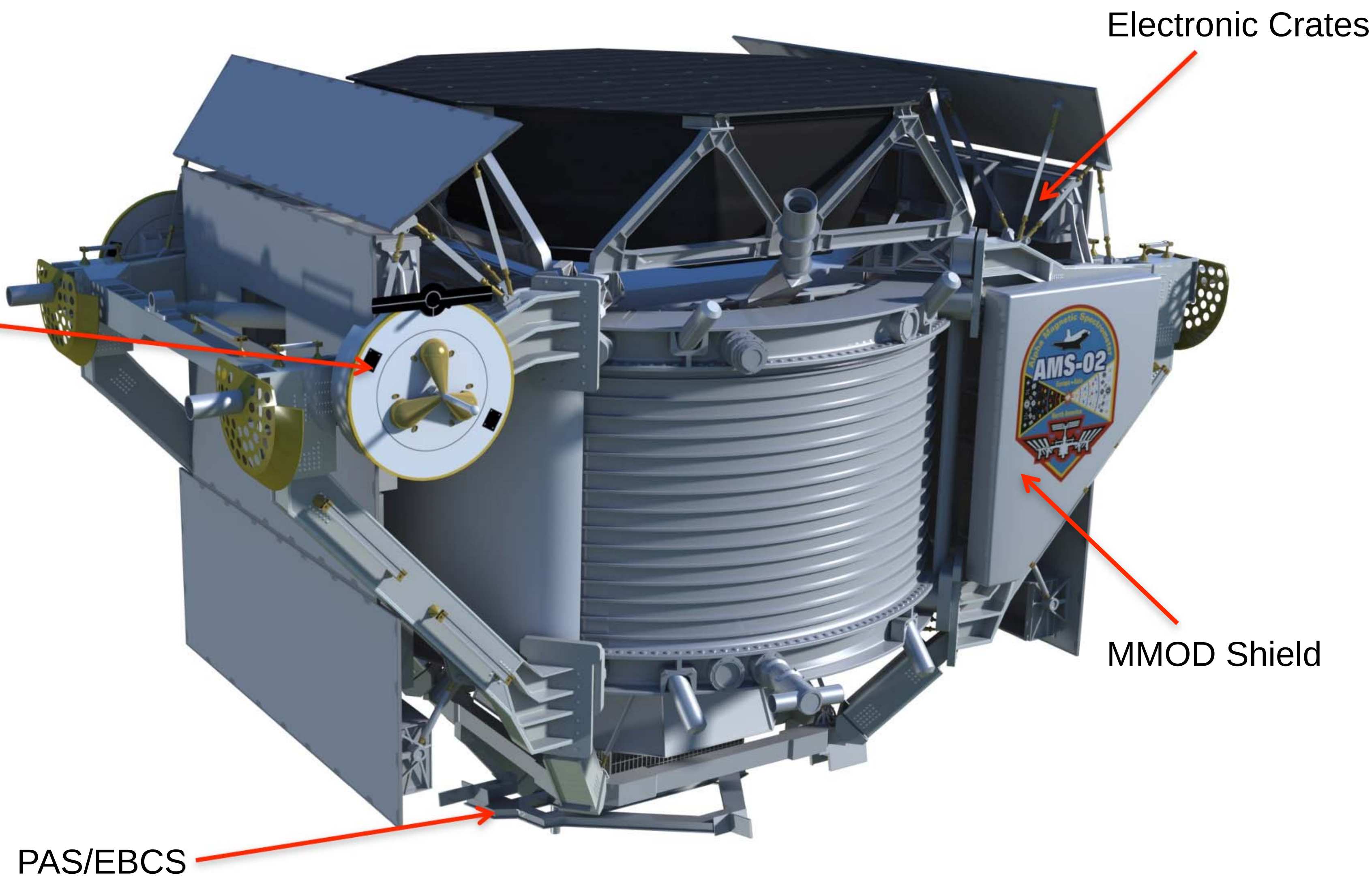
AMS Top Level Specifications

	AMS Unpressuriz	ISS Press	STS Cabin
Upmass	15,300 lbs	70 lbs	70 lbs
Volume	¼ Bay Payload	2 ft^3	2 ft^3
Power	2,400 W Cont. (ISS & STS)	60 W Cont.	60 W Cont.
High-rate Data	6 Mbps (can burst up to 40 Mbps)		6 Mbps
Crew Time	Robotic only during install	>10 Hrs Total	
Magnetic Field	1400 G Center of Magnet, 10 G Max Fringe Field at VC		

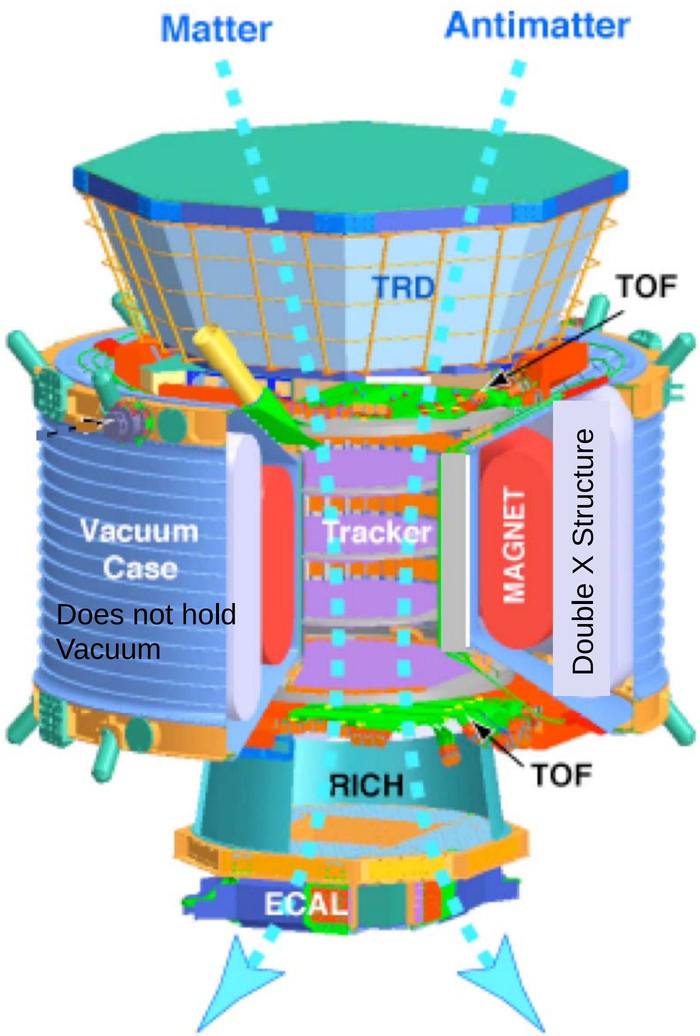
(8500 G Center of Magnet for superconducting magnet)


Superconducting Magnet
TOF
TRD
ACC
RICH
ECAL
Electronics
TCS
Tracker
Star Tracker
GPS
AMS on ISS
Launch to ISS
USS-02
Safety Responsibility
Vacuum Cases


TRD
Radiators
Longeron Trunnions & Scuff Plates
ROEU
MMOD Shield
FRGF
EVA Handrails
Magnet System
USS
Keel Trunnion


Electronic Crates
PVGF
MMOD Shield
PAS/EBCS
AMS-02

Each primary detector for AMS will provide a distinct measurement of different types of charged particles.



	e^-	P	Fe	e^+	$\bar{P}$	$\overline{He}$
TRD						
TOF						
Tracker + Magnet						
RICH						
ECAL						
Physics example	Cosmic Ray Physics Strangelets			Dark matter		Antimatter

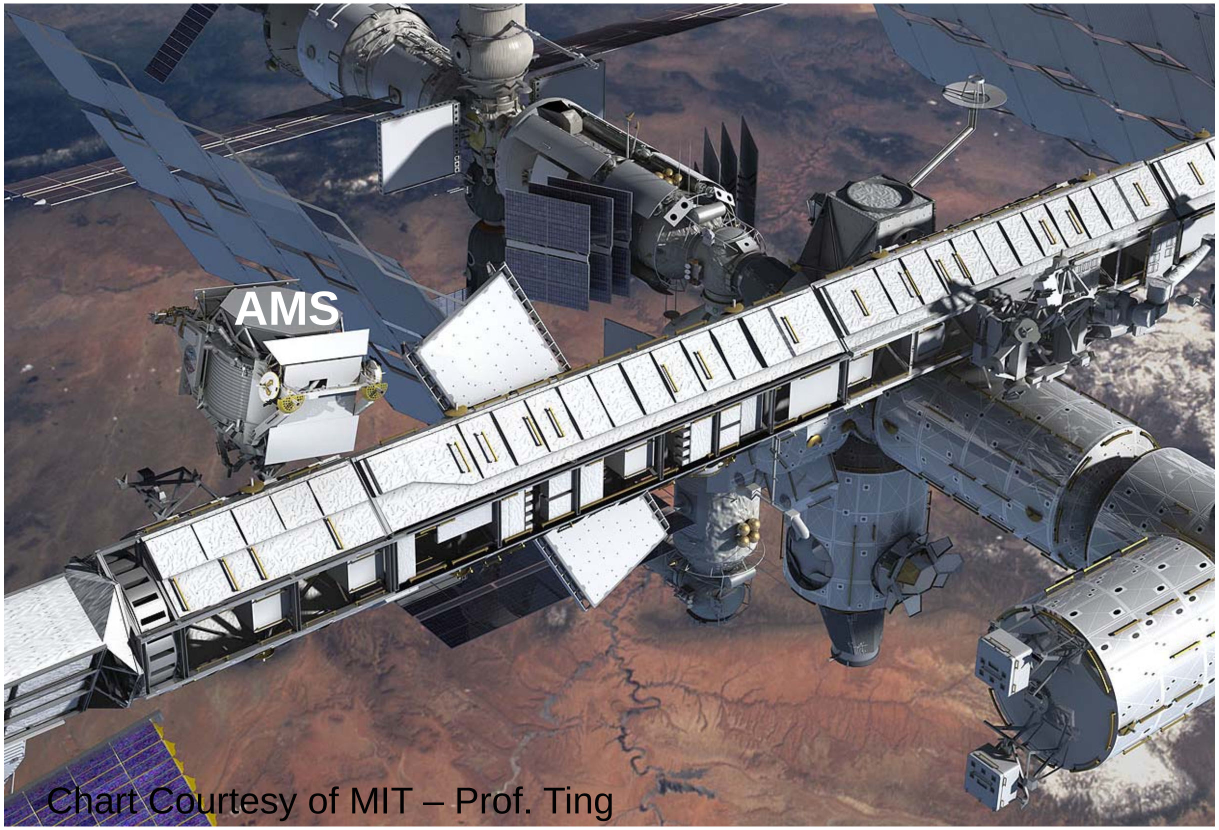
Chart Courtesy of MIT – Prof. Ting

Fundamental Science on the International Space Station (ISS)

There are two kinds of cosmic rays traveling through space

1- Light rays have been measured (e.g., Hubble) for over 50 years. Fundamental discoveries have been made (10 Nobel Prizes).

2- Charged cosmic rays: An unexplored region in science. Using a magnetic spectrometer (AMS) on ISS is the only way to measure high energy charged cosmic rays.

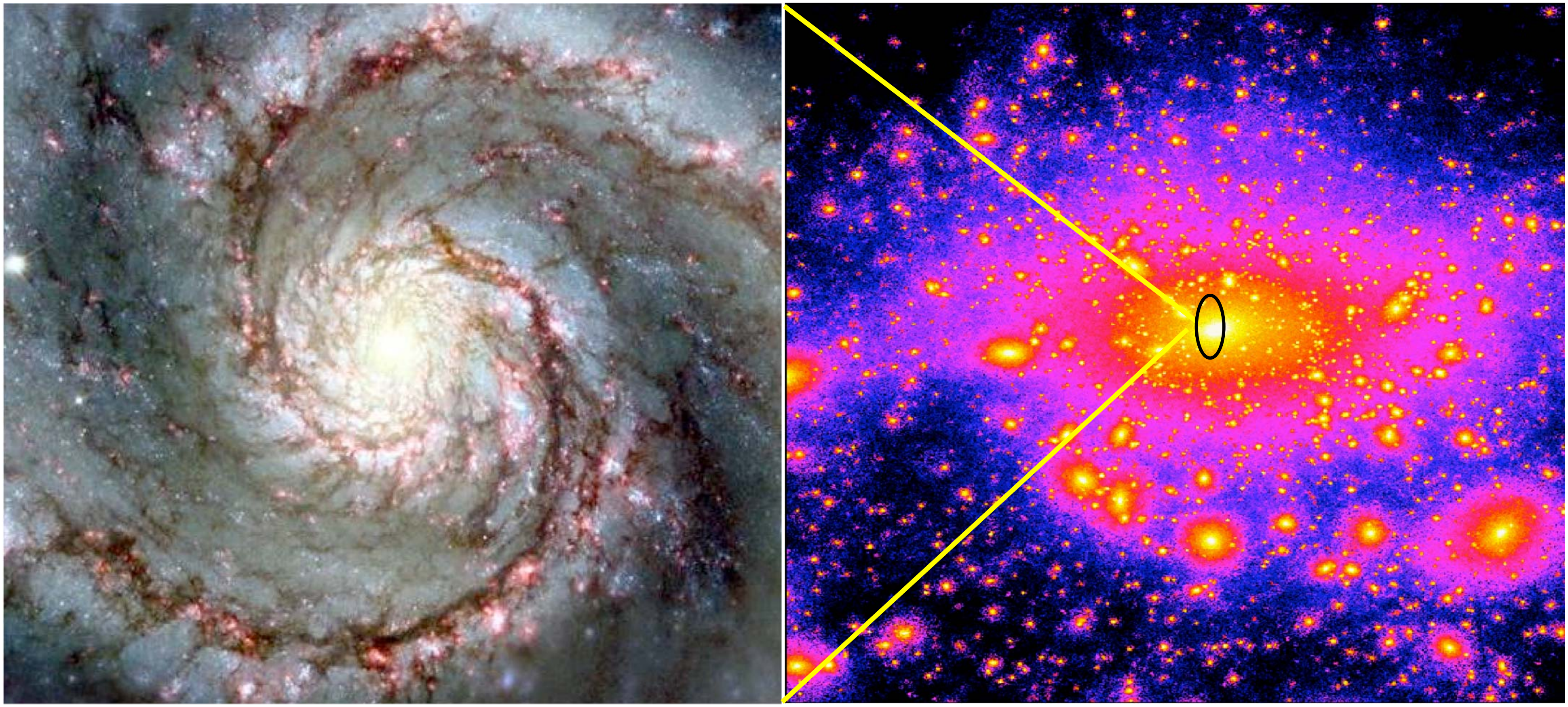


The major physical science experiment on the ISS .

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

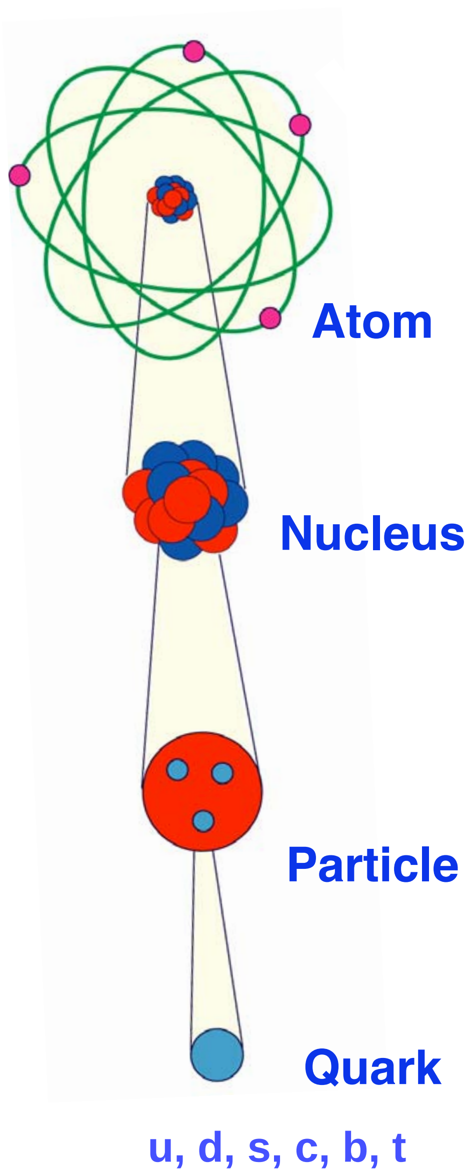


A Galaxy as seen by telescope

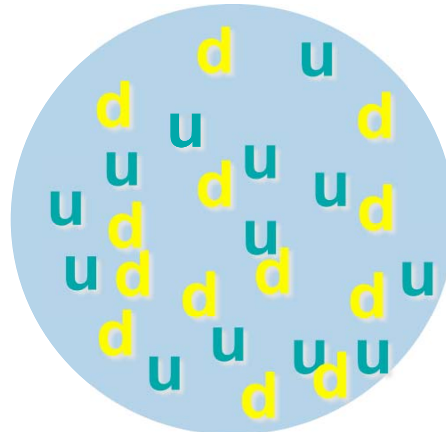
If we could see Dark Matter in the Galaxy

Chart Courtesy of MIT – Prof. Ting

Science Example: Strange Quark Matter – “Strangelets”

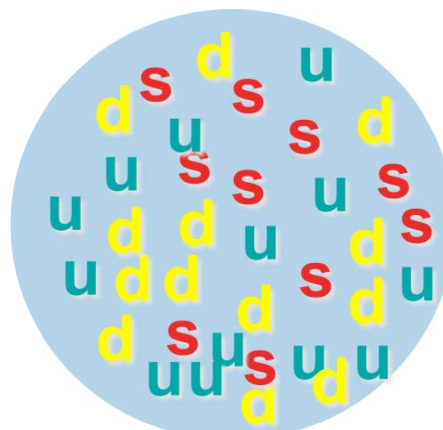


All the known material on Earth is made out of u and d quarks



Diamond

Is there material in the universe made up of u, d, & s quarks?



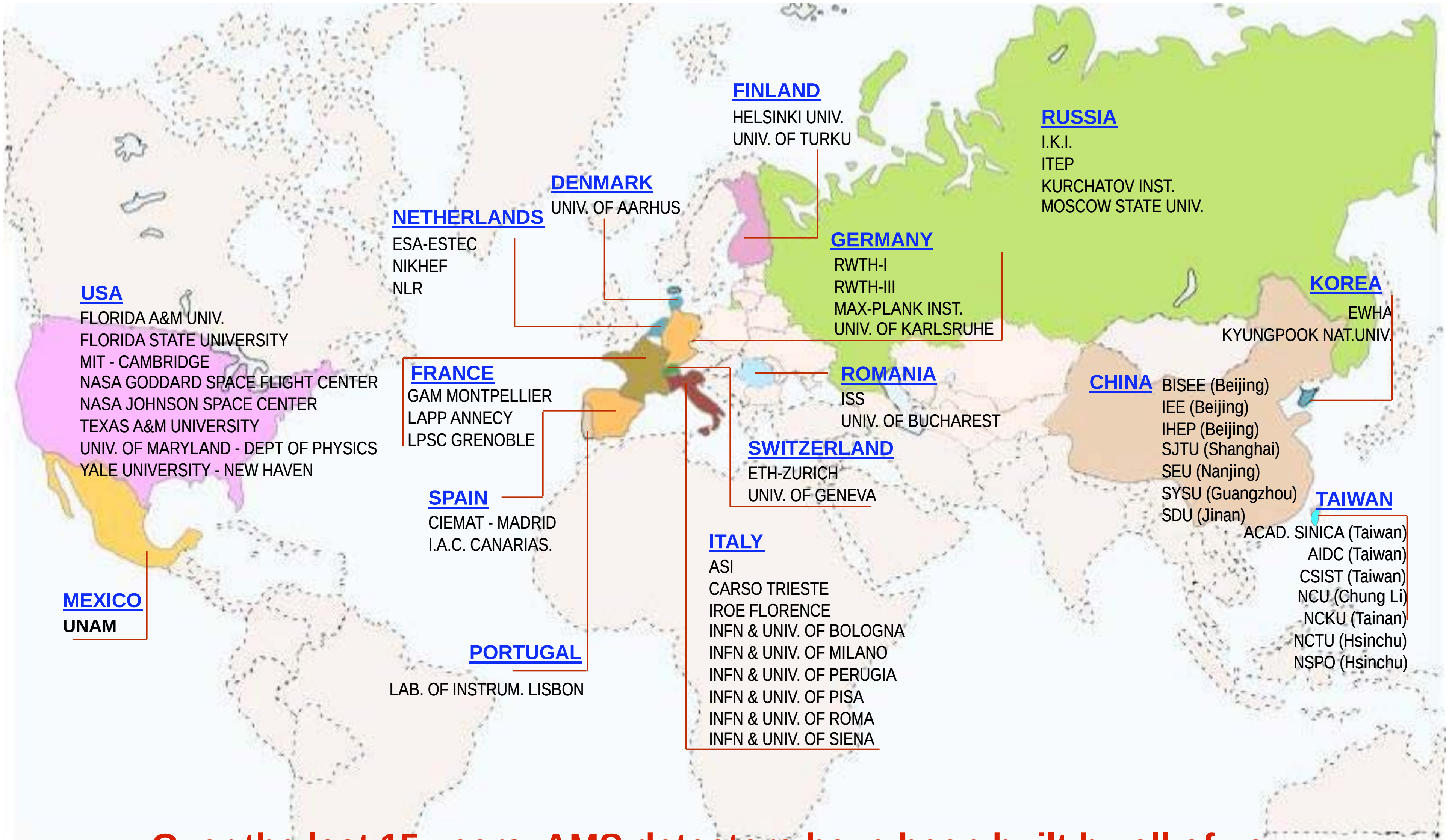
Strangelet

This can be answered definitively by AMS.

***Jack Sandweiss,* Yale**

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

This large International Collaboration was made possible with the strong support of NASA, ASI, DLR, CDTI, CNES, ESA, US DoE, INFN, AS, CERN and others



Over the last 15 years, AMS detectors have been built by all of you.
This TIM is the summary of all detector tests results.

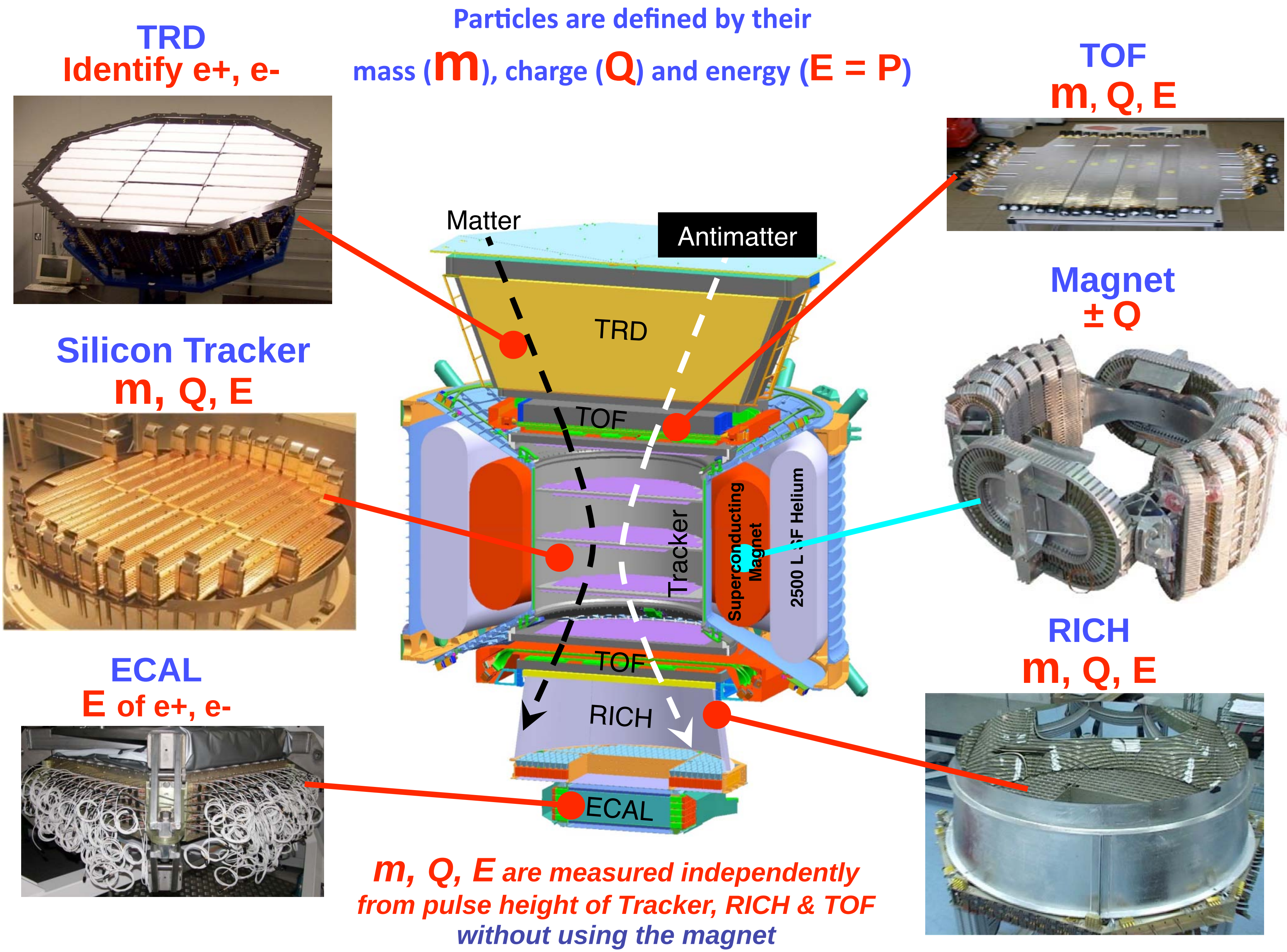
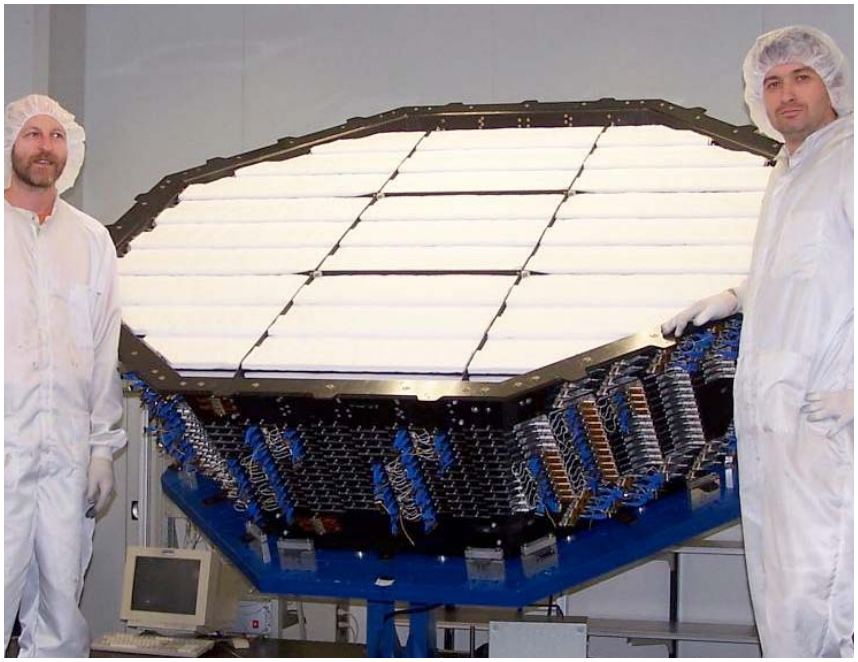
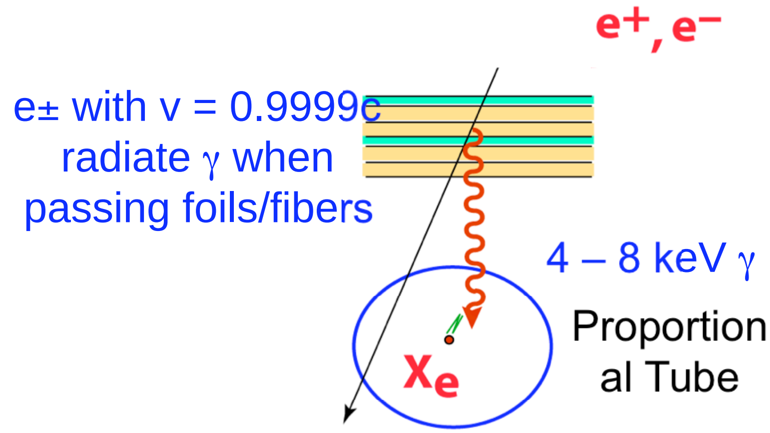


Chart Courtesy of MIT – Prof. Ting

TRD: Transition Radiation Detector: Identify electrons





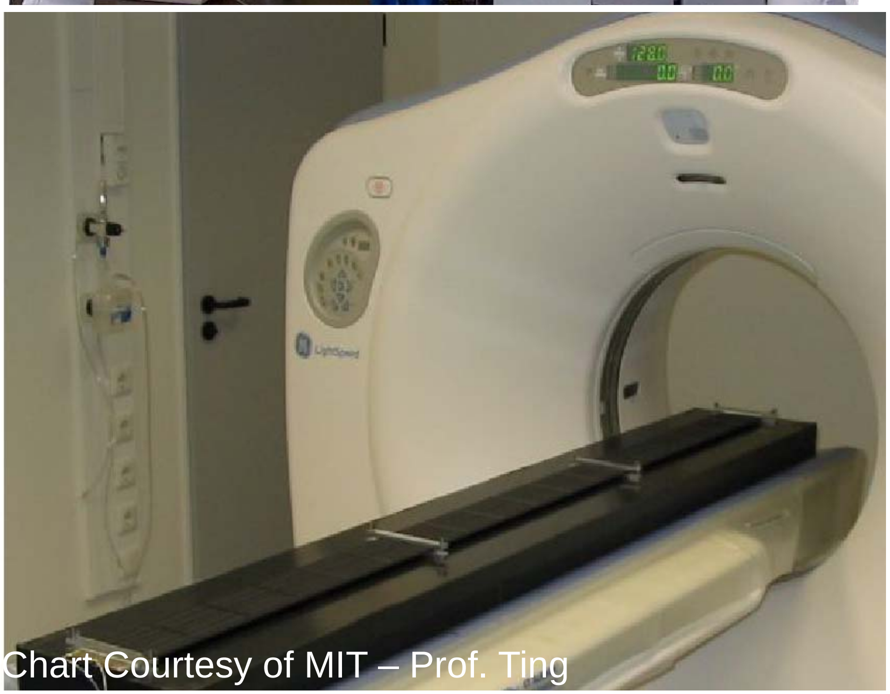
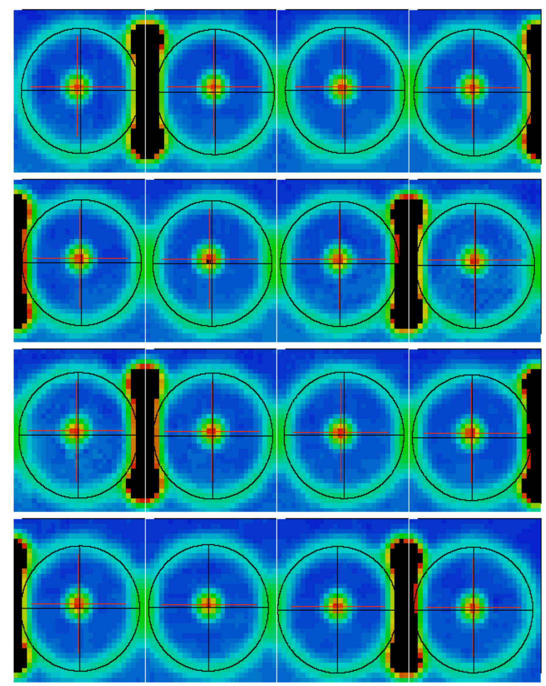


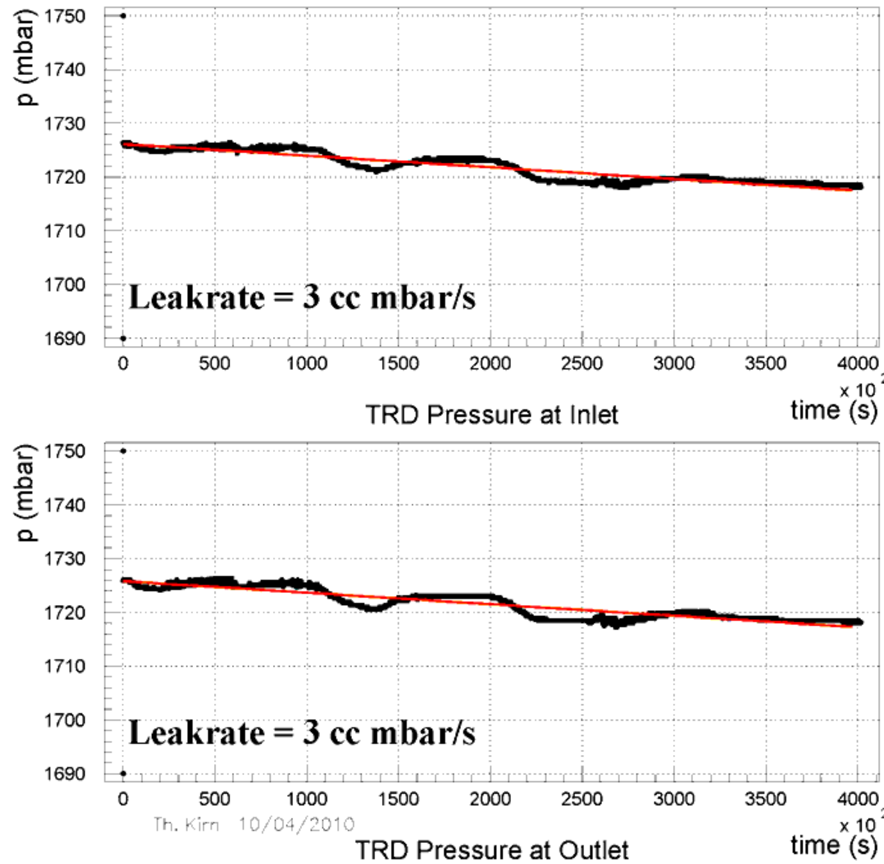
Chart Courtesy of MIT – Prof. Ting

5248 tubes
2 meter length
centered to 0.1mm



AMS02 – TRD: Gastightness

TRD with closed system and no flow



Leakrate q_{CO2}= 3 cc mbar/s ≈ $6 \cdot 10^{-3}$ **µ**g/s
TRD-CO2 –Storage: 5 kg

→ 24 years lifetime in space

Chart Courtesy of MIT – Prof. Ting

RWTH AACHEN
RHEINISCH-WESTFÄLISCHE TECHNISCHE HOCHSCHULE AACHEN
Physics AC-I

Veto System rejects random cosmic rays

AMS-02 Magnet with Veto Counters

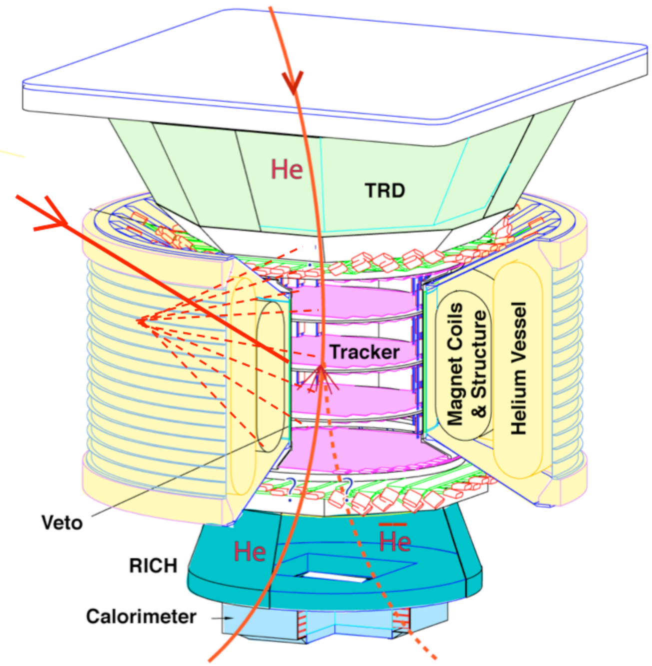
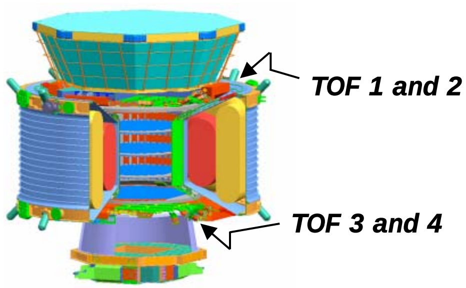
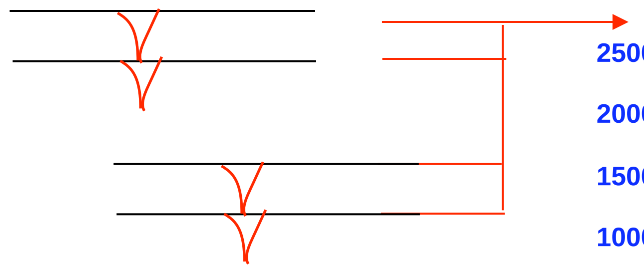


Chart Courtesy of MIT – Prof. Ting

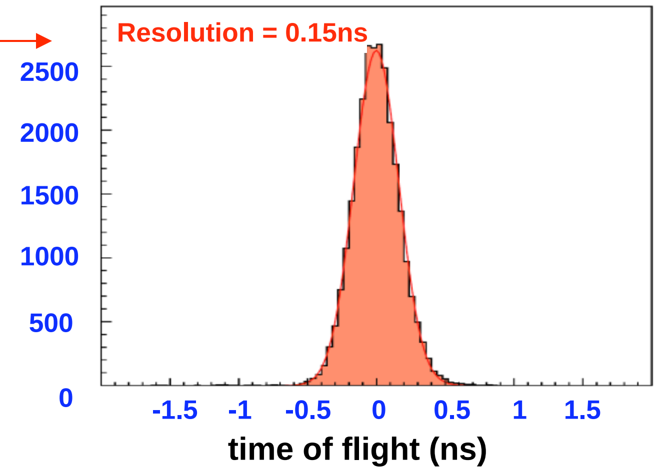
Time of Flight System

Measures Velocity and Charge of particles





Velocity = Distance / Time



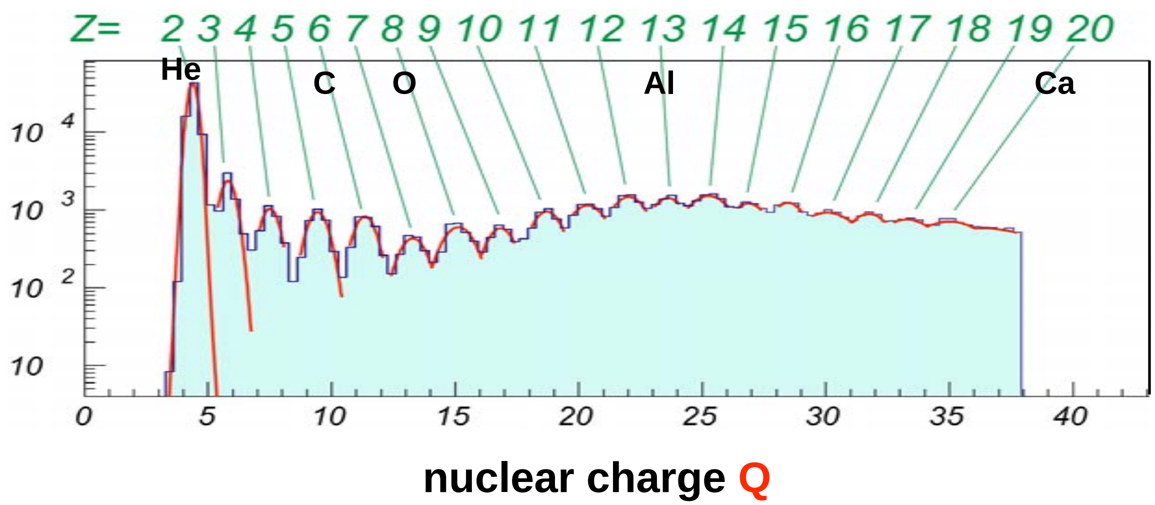
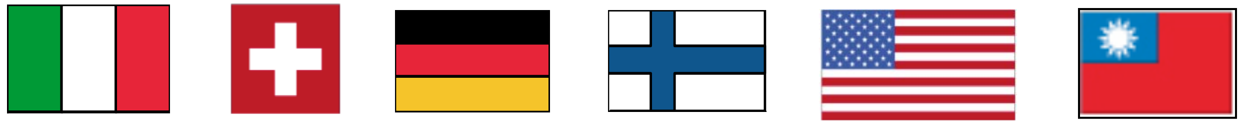
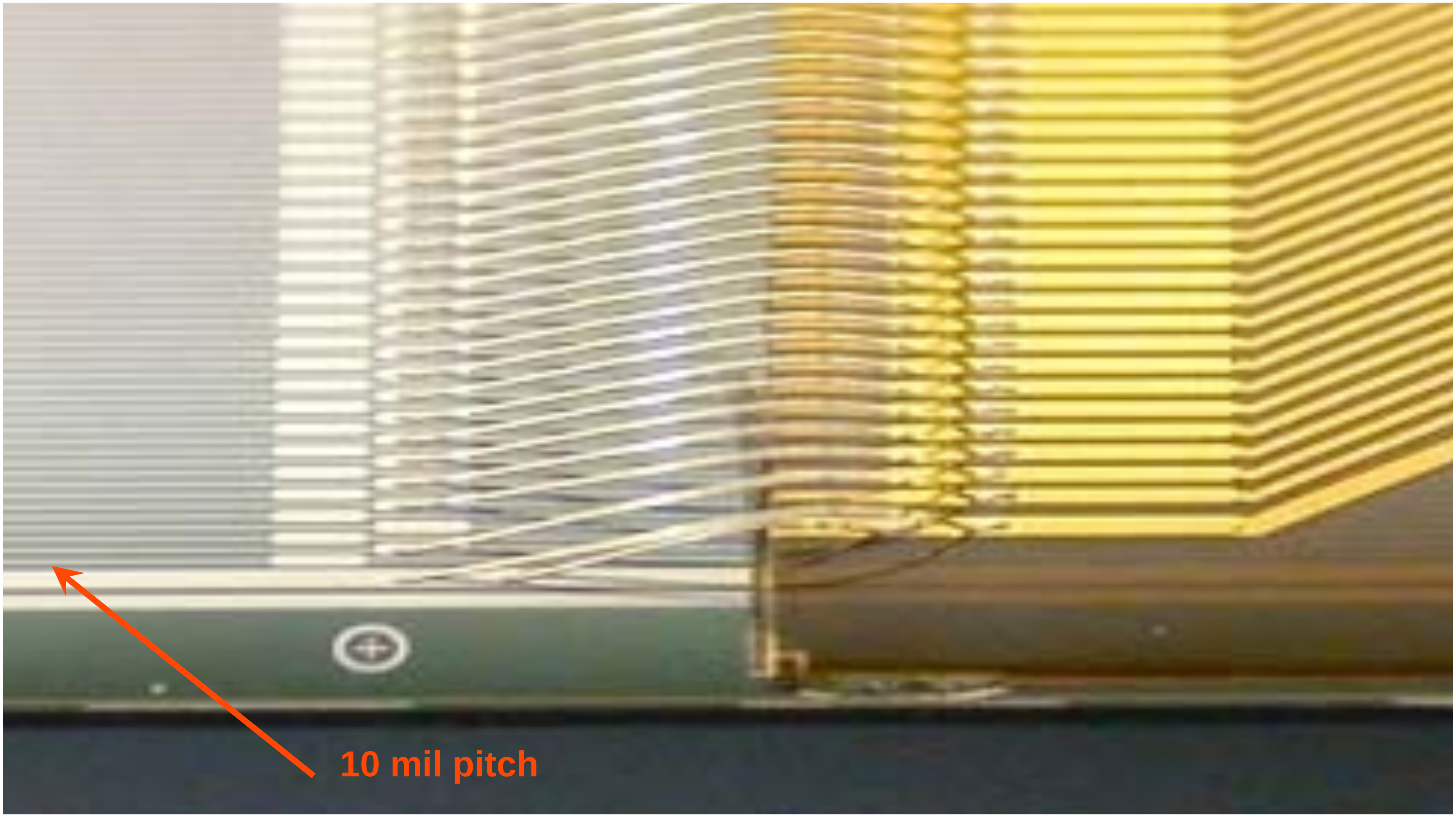


Chart Courtesy of MIT – Prof. Ting

Silicon Tracker





200,000 channels alignment 3 μ resolution: 10 μ

Chart Courtesy of MIT – Prof. Ting

Chart Courtesy of MIT – Prof. Ting

It took

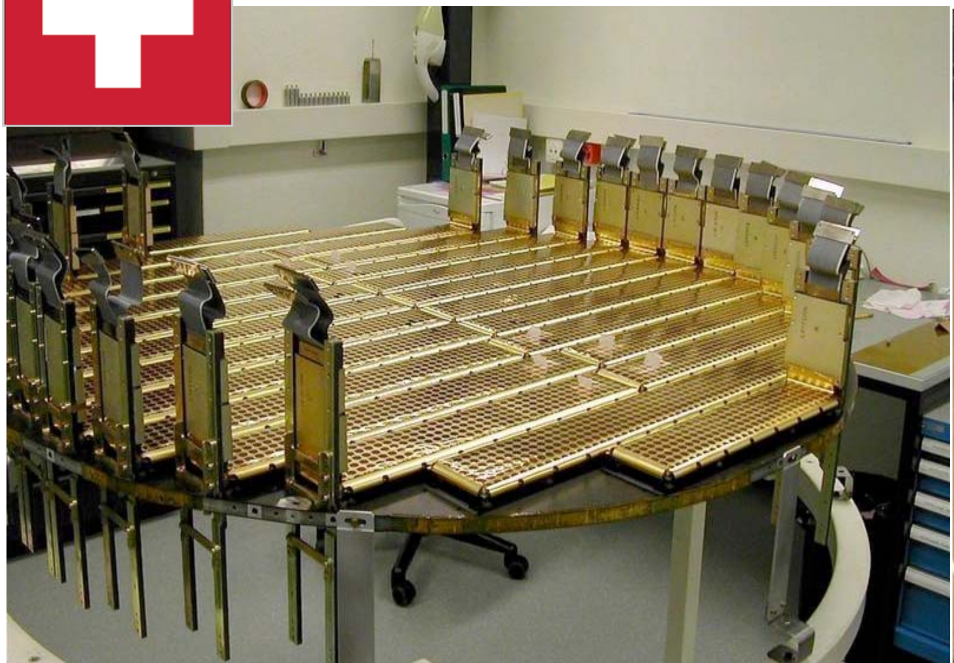
50 engineers

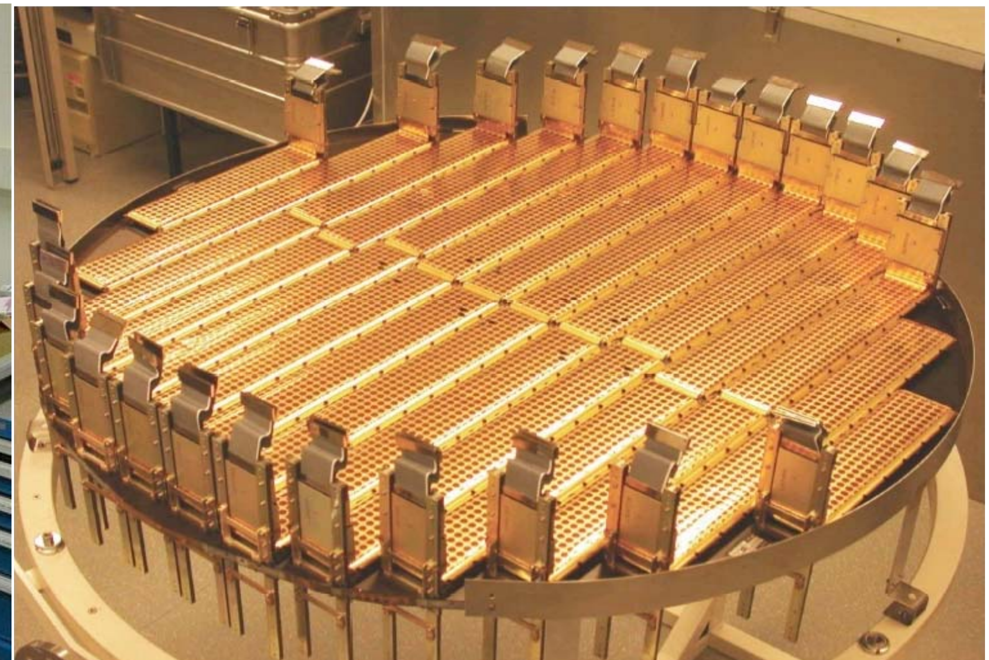
3 years

to complete

the detector

Silicon Tracker, 8 planes





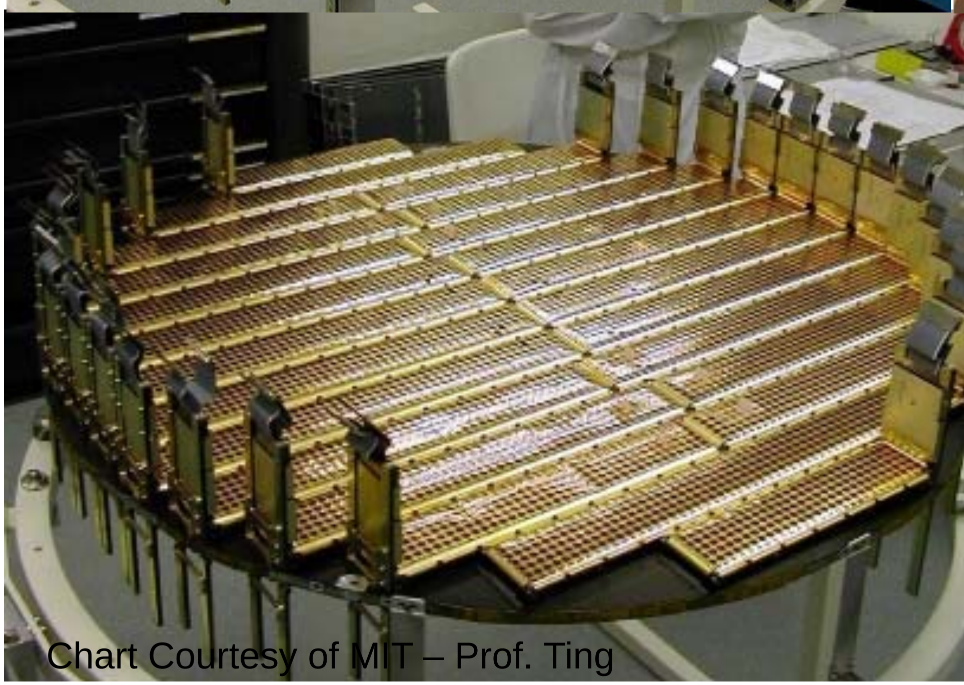
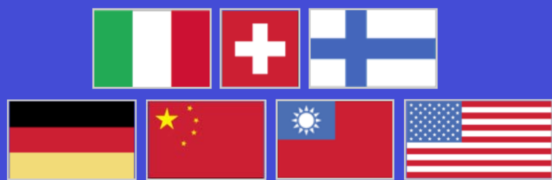
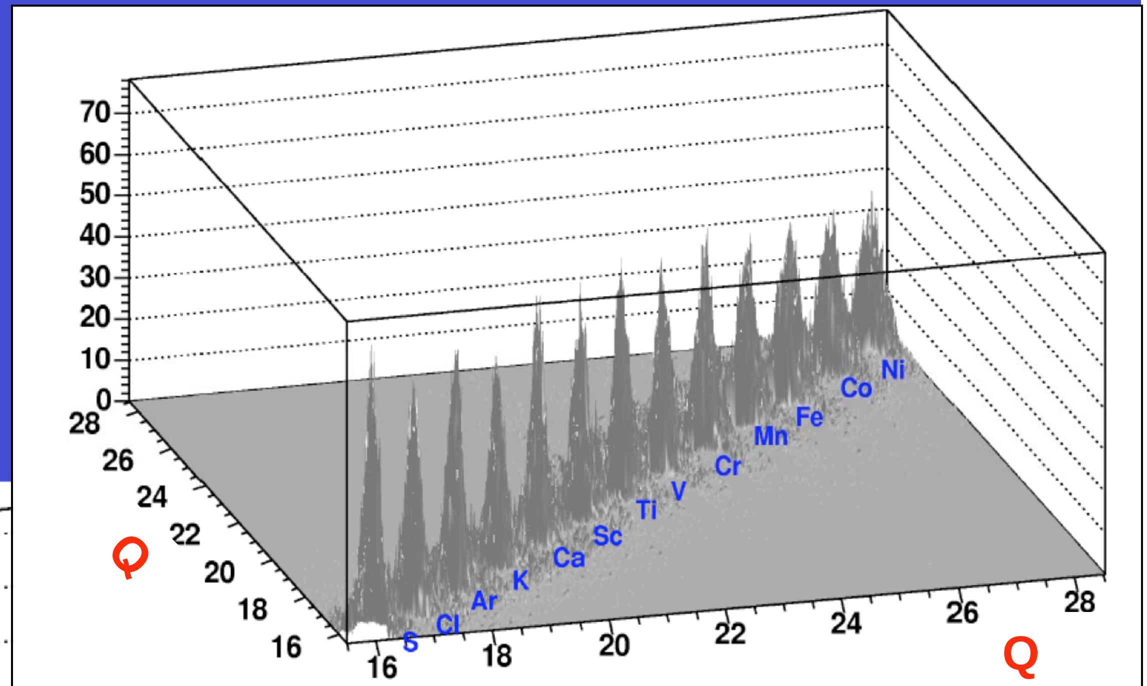


Chart Courtesy of MIT – Prof. Ting

Test results: measure nuclear charge Q simultaneously

Silicon Tracker





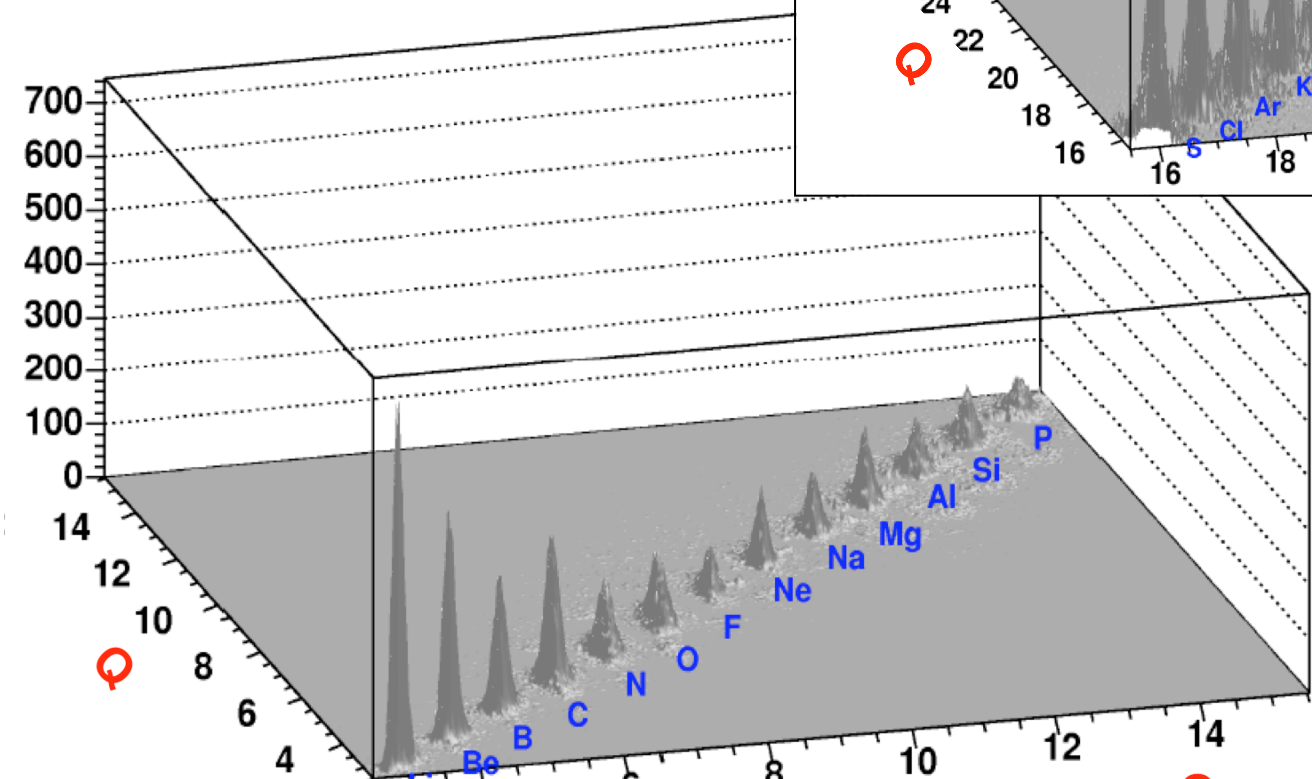
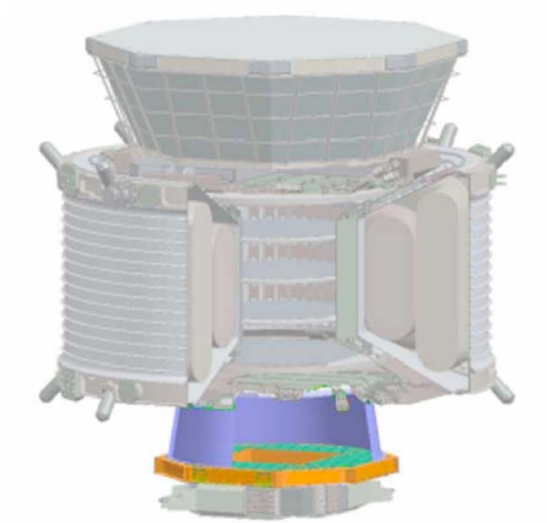
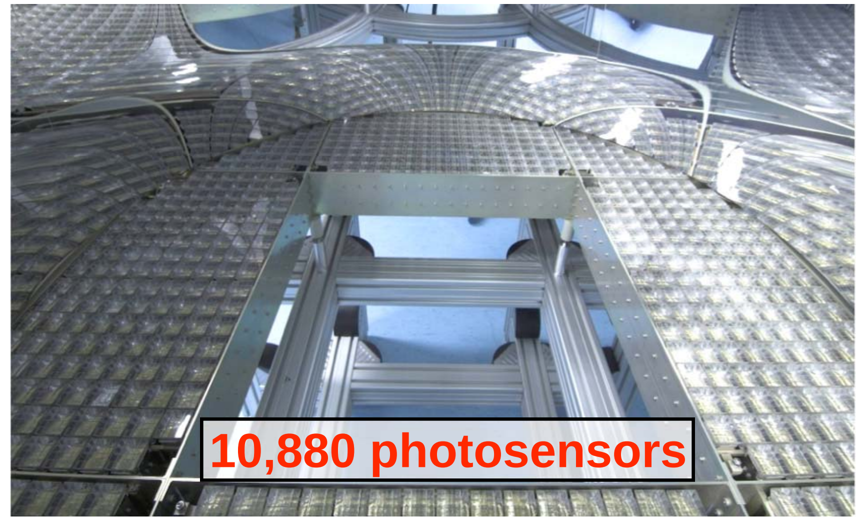


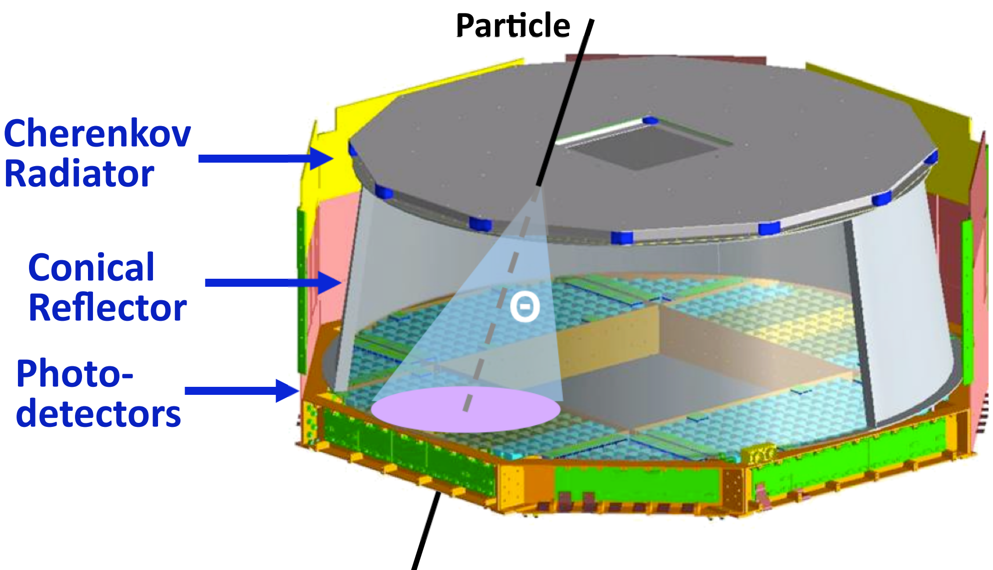
Chart Courtesy of MIT – Prof. Ting

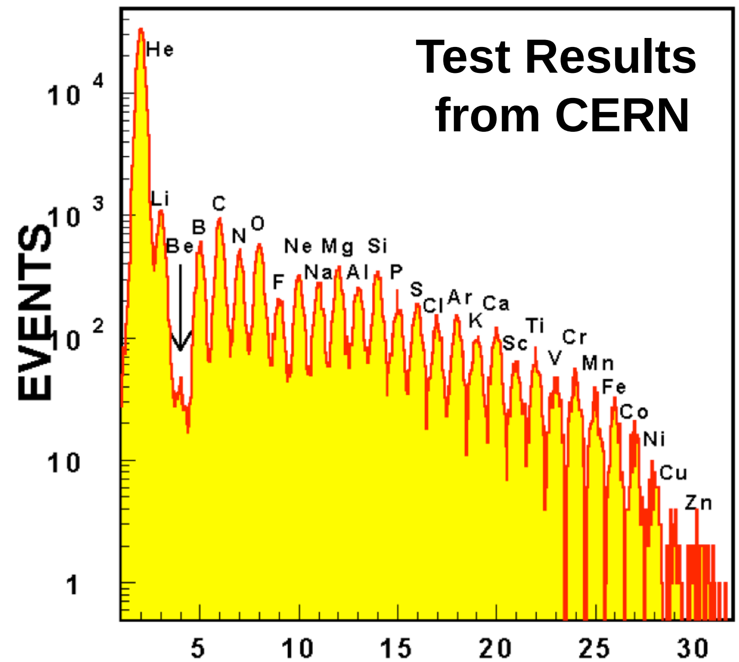
Ring Imaging CHerenkov (RICH)





Cherenkov radiation



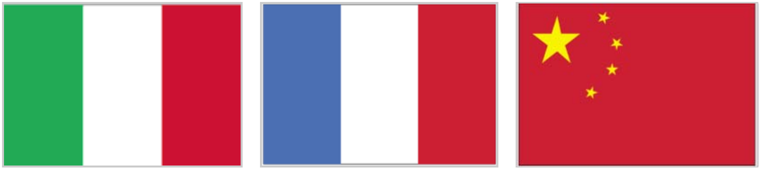


Intensity ∝ Nuclear Charge Q

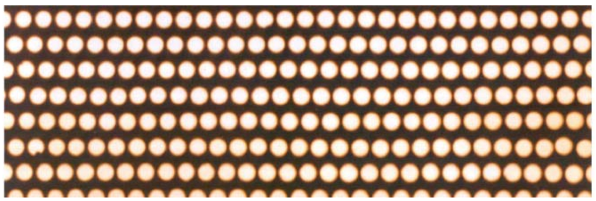
Θ ∝ Velocity

Nuclear Charge Q

Chart Courtesy of MIT – Prof. Ting

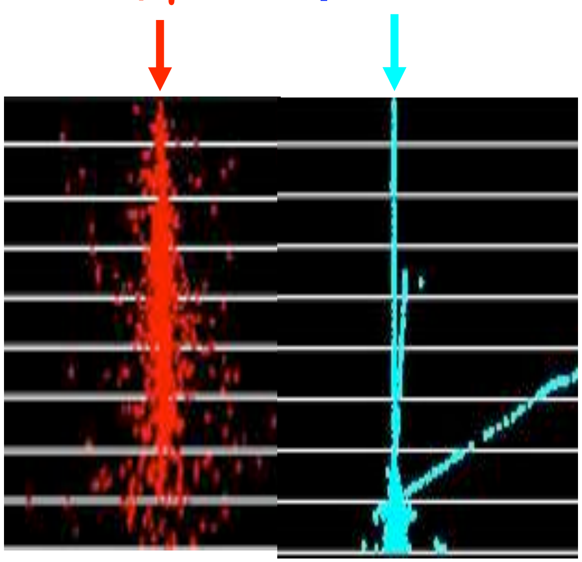


Calorimeter (ECAL)

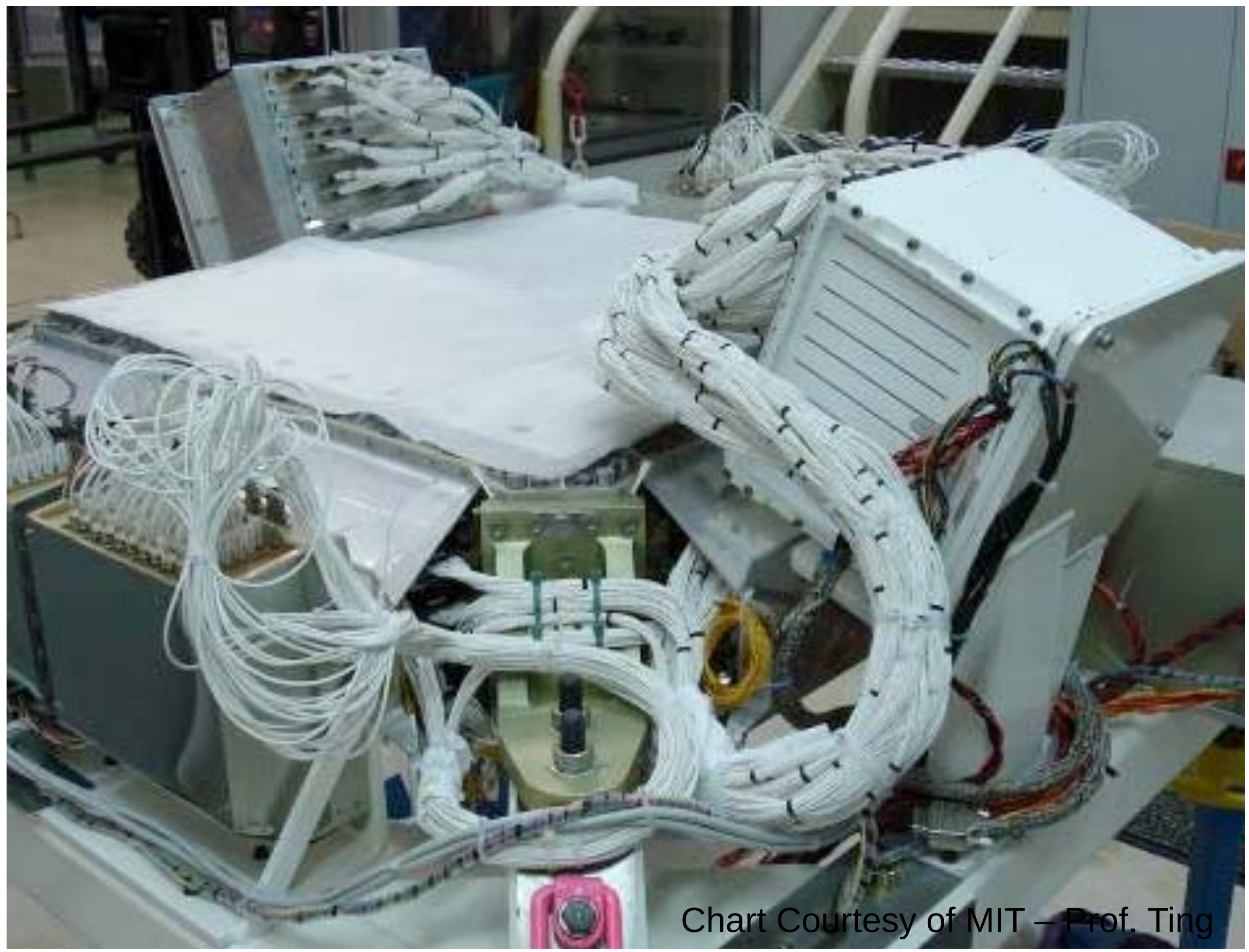


10 000 fibers, $\phi = 1$ mm distributed uniformly Inside 1,200 lb of lead

$e^{\pm}$, γ proton



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



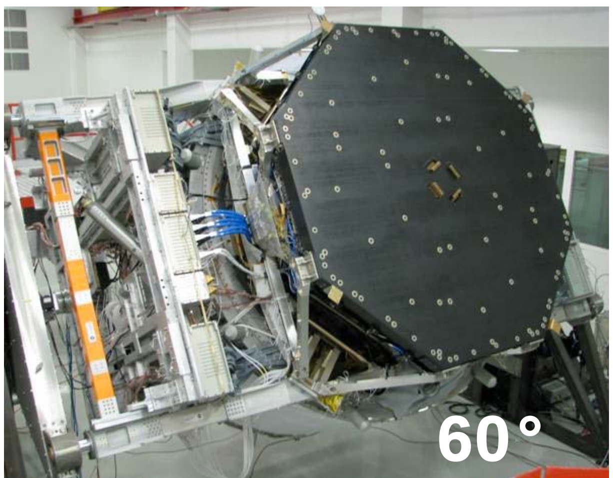
AMS-02

First INTEGRATION

COMPLETED

on

14 June 2008



Flight hardware

assembled on

Vacuum Case STA

for mechanics and electronics interfaces verification

DE-INTEGRATION

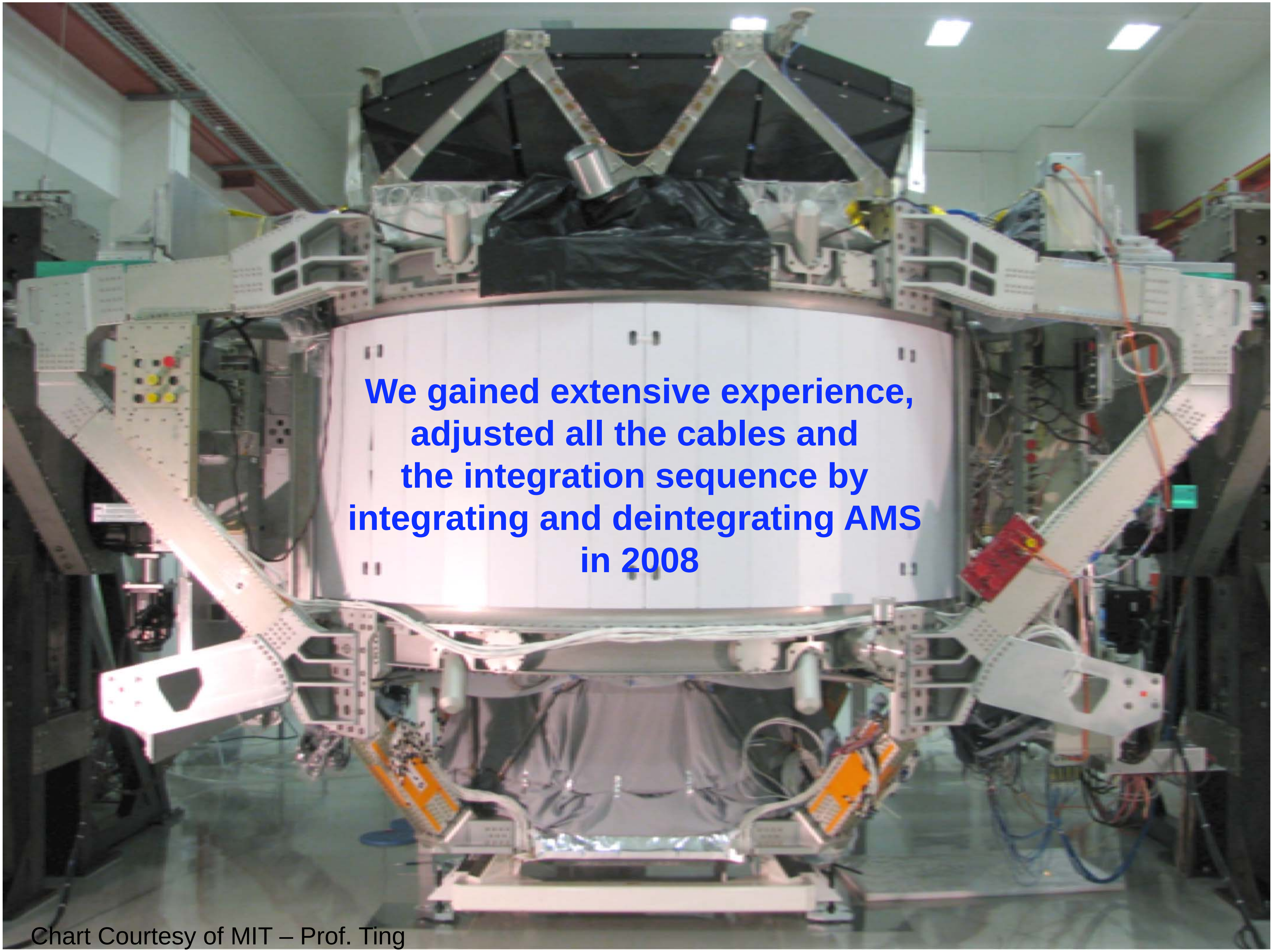
start

18 June 2008

end

18 July 2008

Chart Courtesy of MIT – Prof. Ting


We gained extensive experience,
adjusted all the cables and
the integration sequence by
integrating and deintegrating AMS
in 2008
Chart Courtesy of MIT – Prof. Ting

AMS FLIGHT INTEGRATION: STS-134 Astronauts Visit Detectors in the AMS Clean Room at CERN
13-16 Oct 2009

Flight Integration of AMS: installation of the Veto system

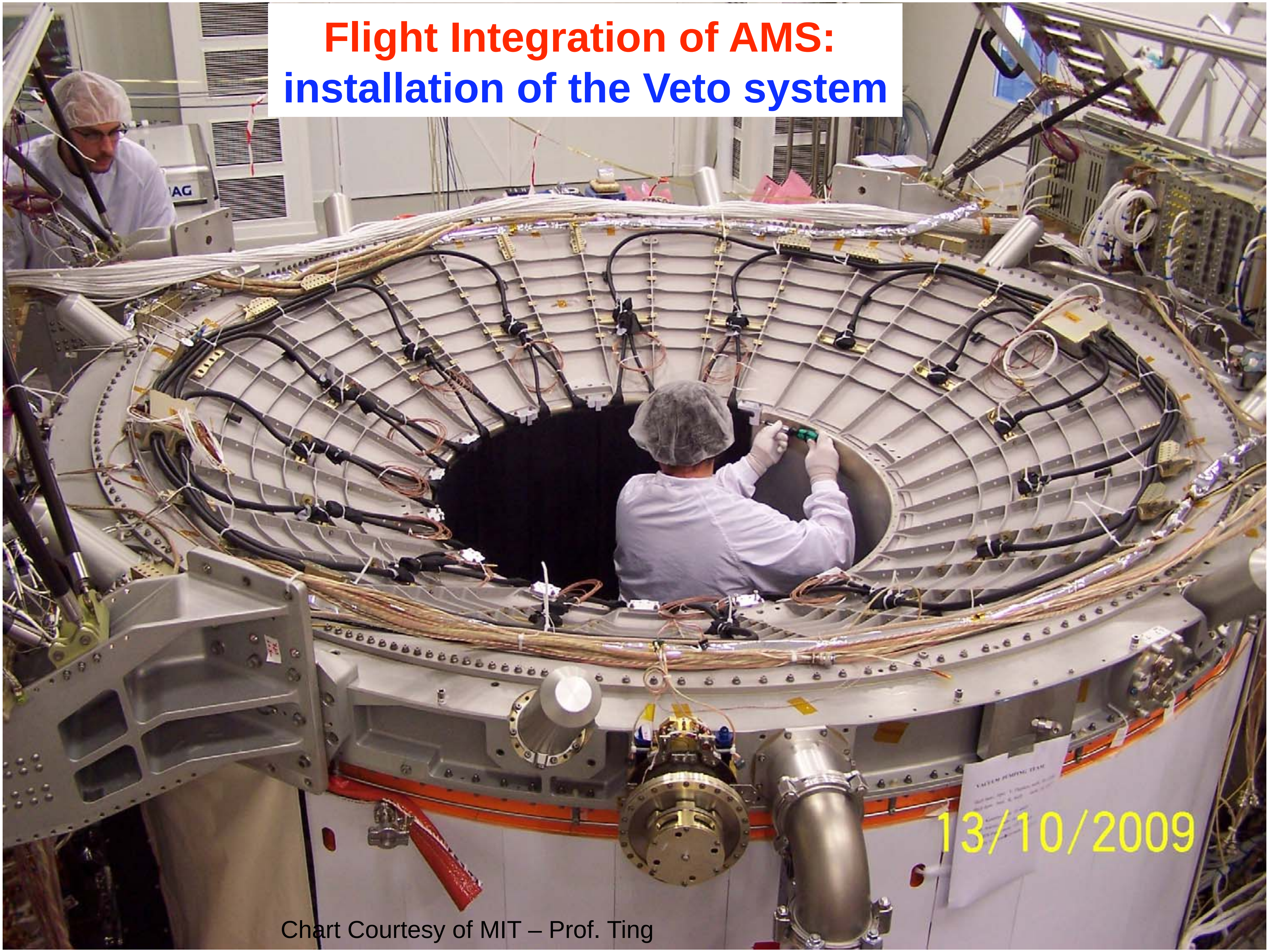
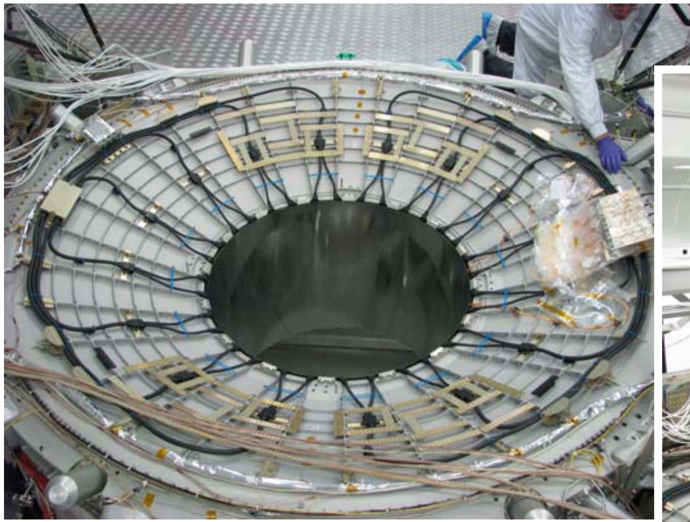


Chart Courtesy of MIT – Prof. Ting



Tracker FLIGHT INTEGRATION

19-29 October 2009

Chart Courtesy of MIT – Prof. Ting

Flight Integration of AMS: cabling of the inner tracker

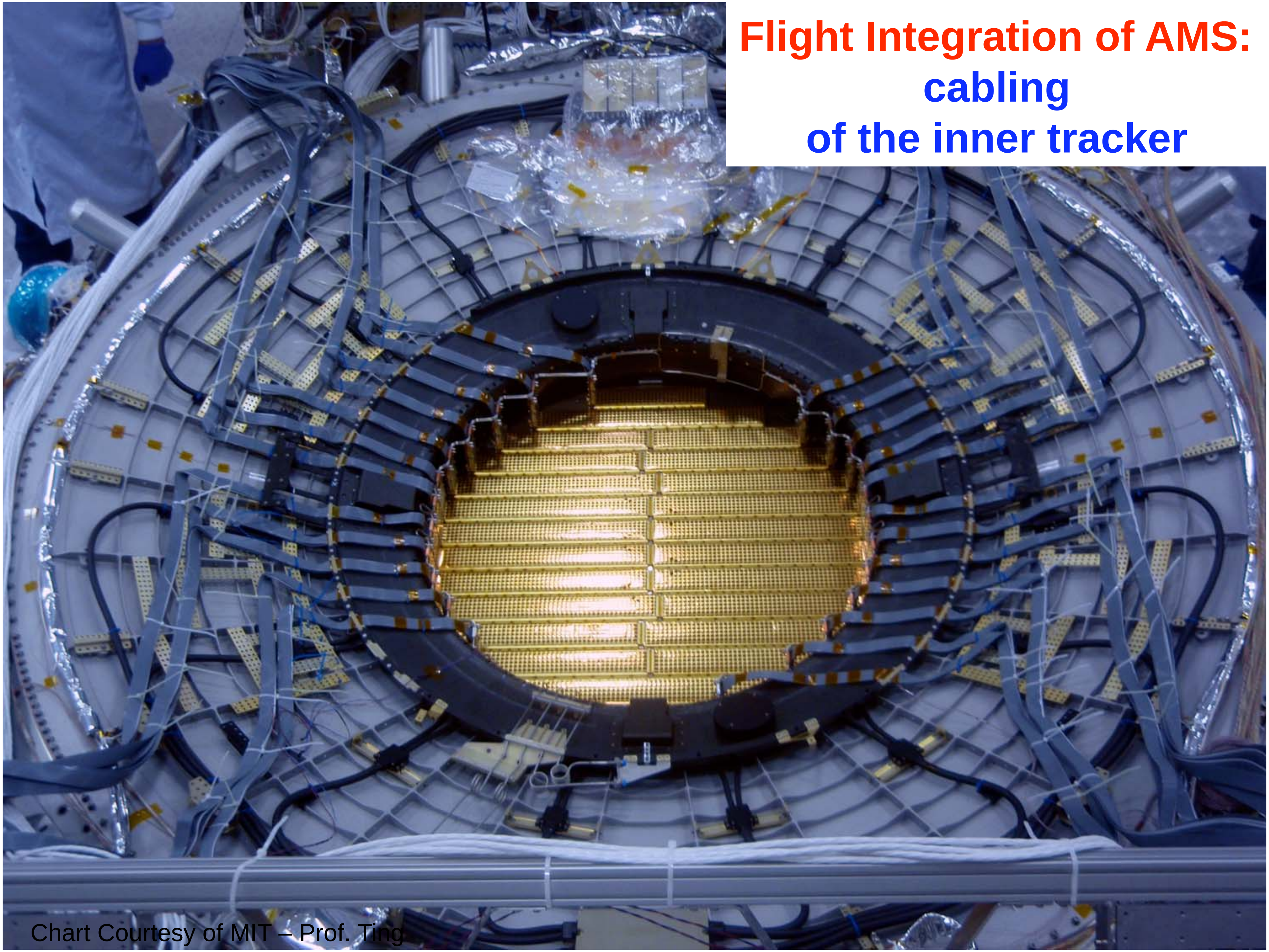


Chart Courtesy of MIT – Prof. Ting

Tracker

FLIGHT INTEGRATION

19-29 October 2009

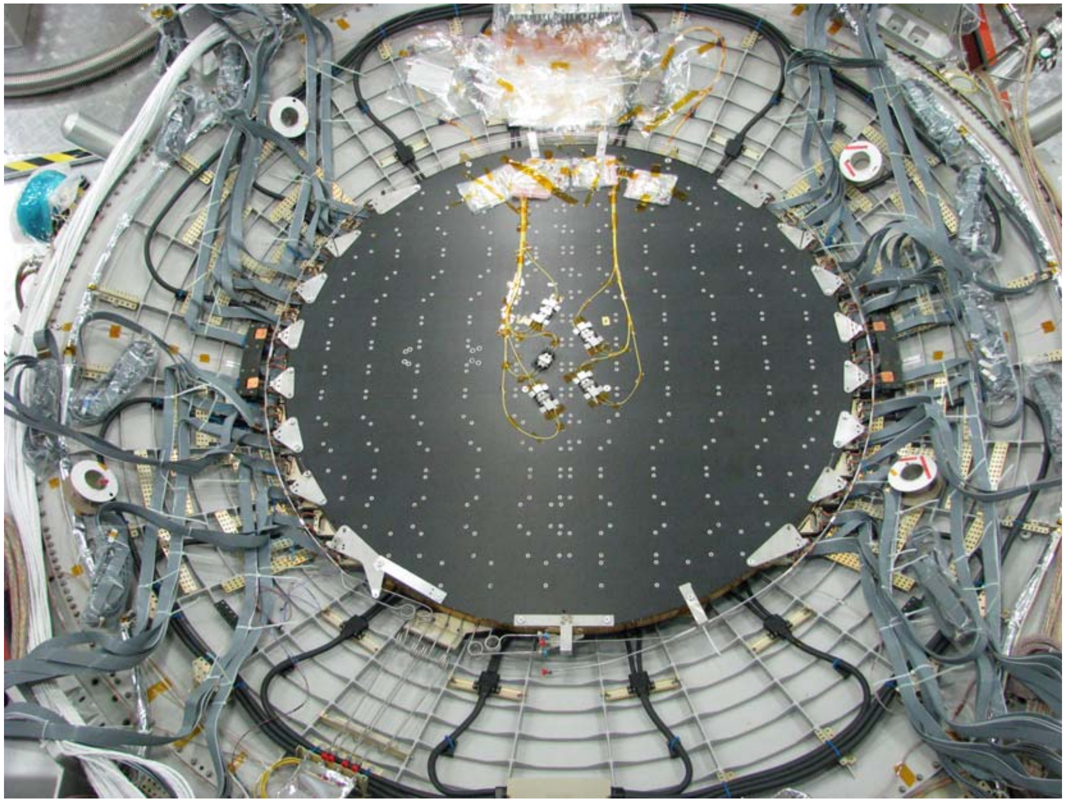
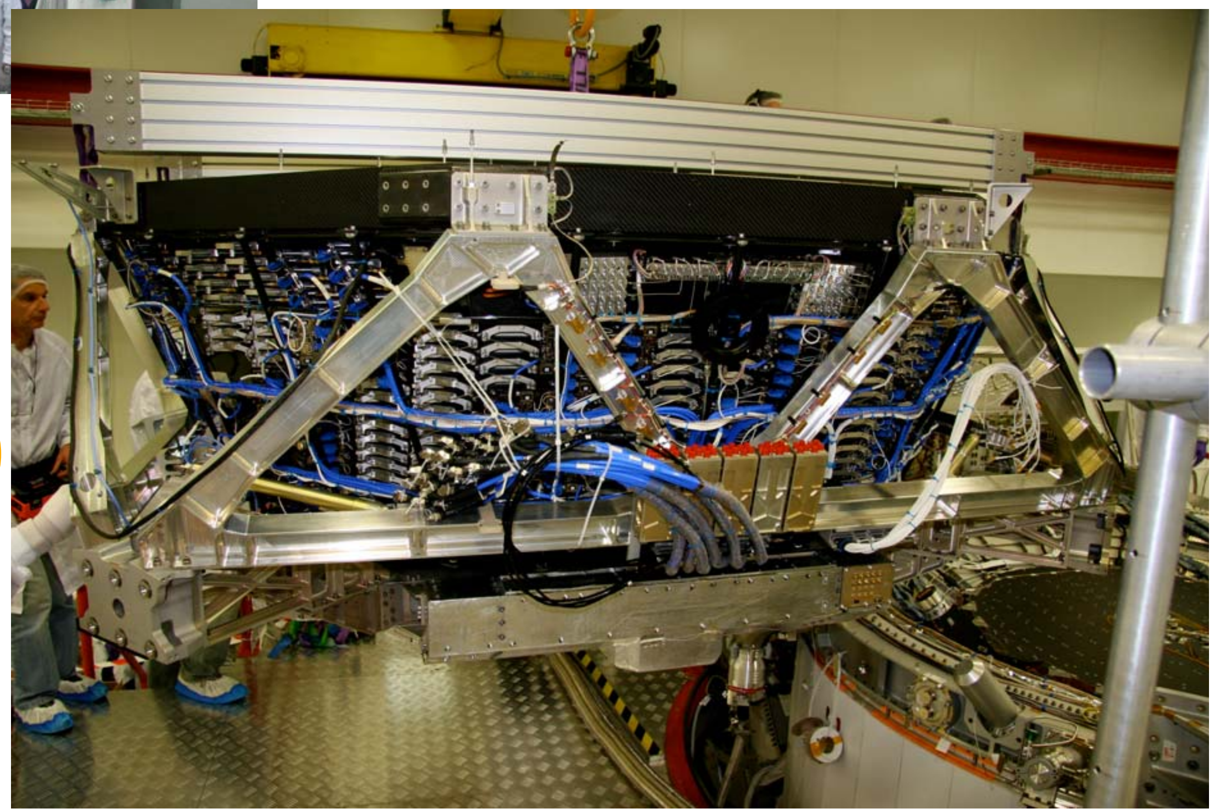


Chart Courtesy of MIT – Prof. Ting



TRD AND TOF
FLIGHT INTEGRATION

29-30 October 2009

Chart Courtesy of MIT – Prof. Ting

Cryo-system

installation of the TOF, RICH & ECAL

30-31 October 2009

Chart Courtesy of MIT – Prof. Ting

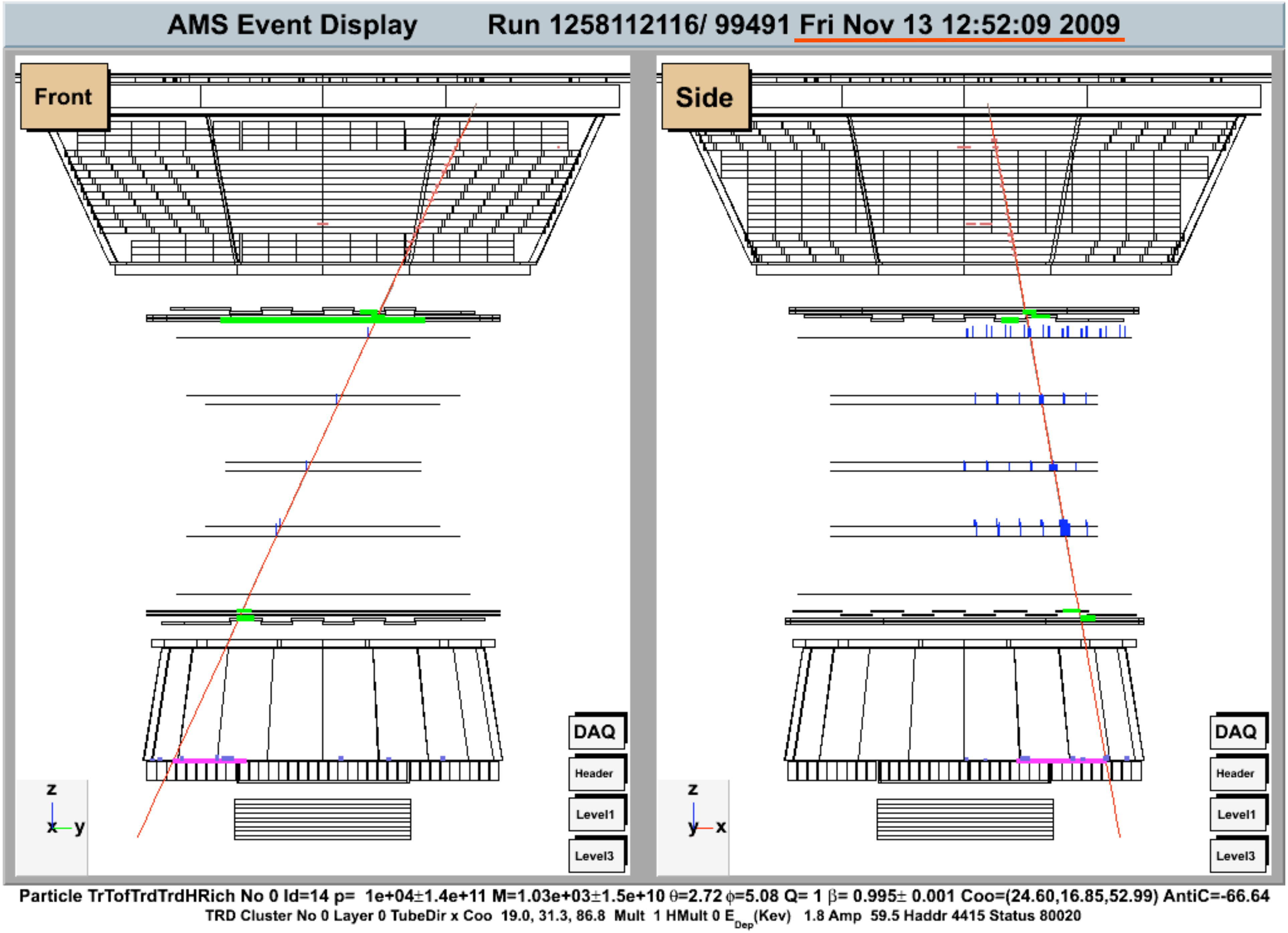


Chart Courtesy of MIT – Prof. Ting

AMS Mass measurement

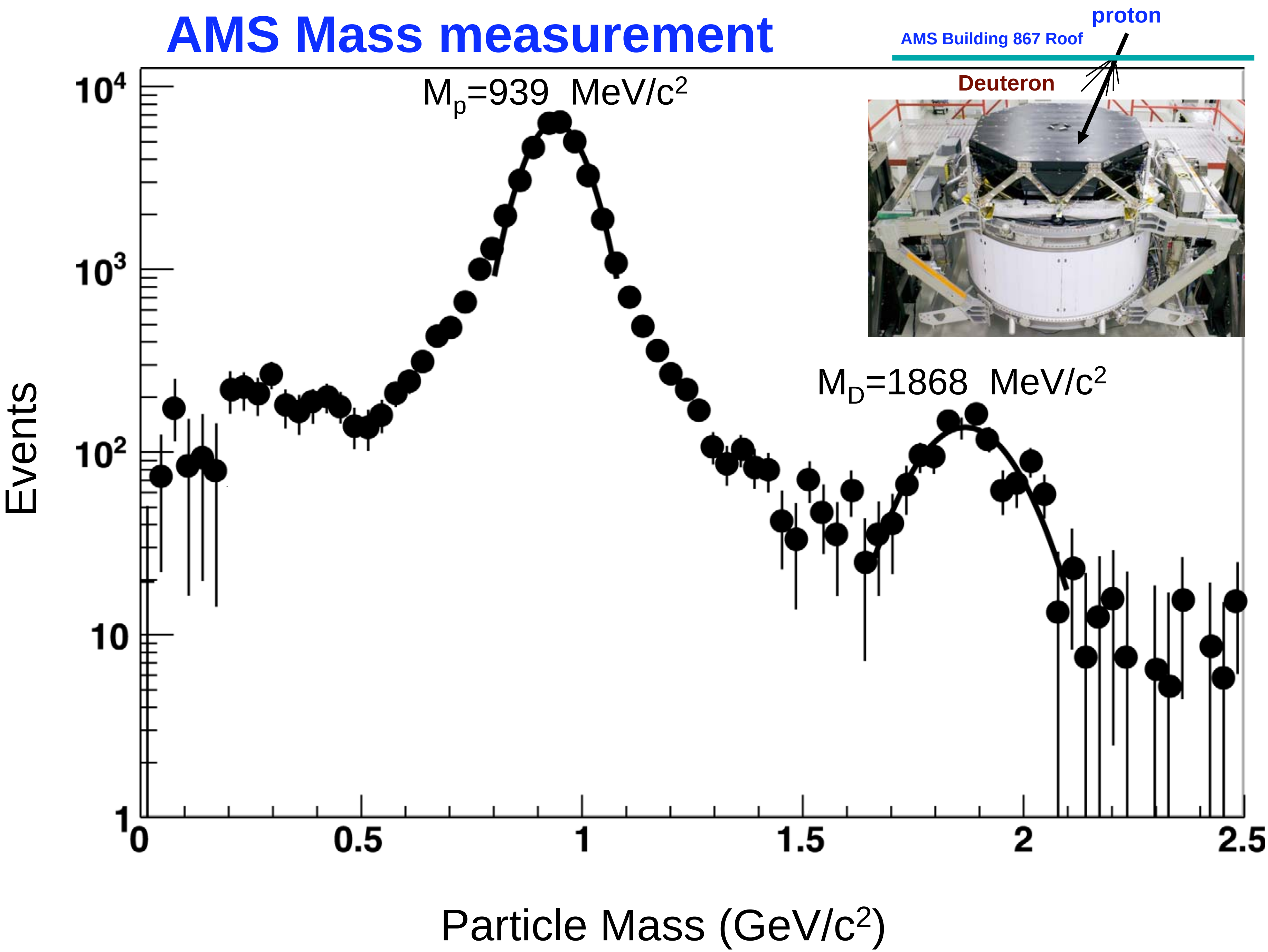


Chart Courtesy of MIT – Prof. Ting

Experience on Integration of AMS-02

From assembly of the detector elements, electronics, and cabling until data taking:

2008

1st integration – 6 months

1st de- integration– 1 month

2009

2nd integration – 1 month

(with cryo-system)

Chart Courtesy of MIT – Prof. Ting

Test at CERN
AMS in accelerator test beam Feb 4-8, 2010
(was scheduled Feb 4-15)

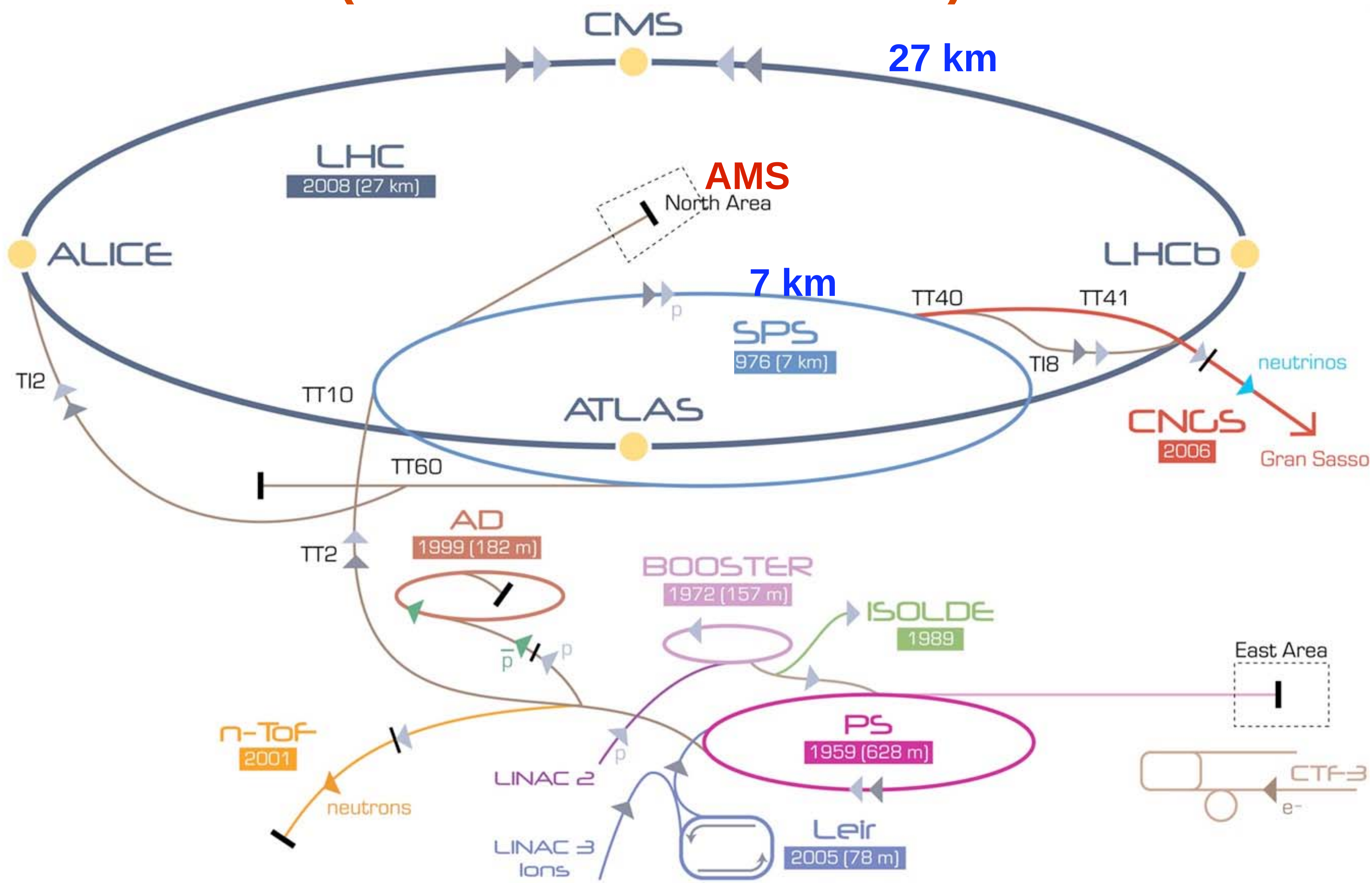
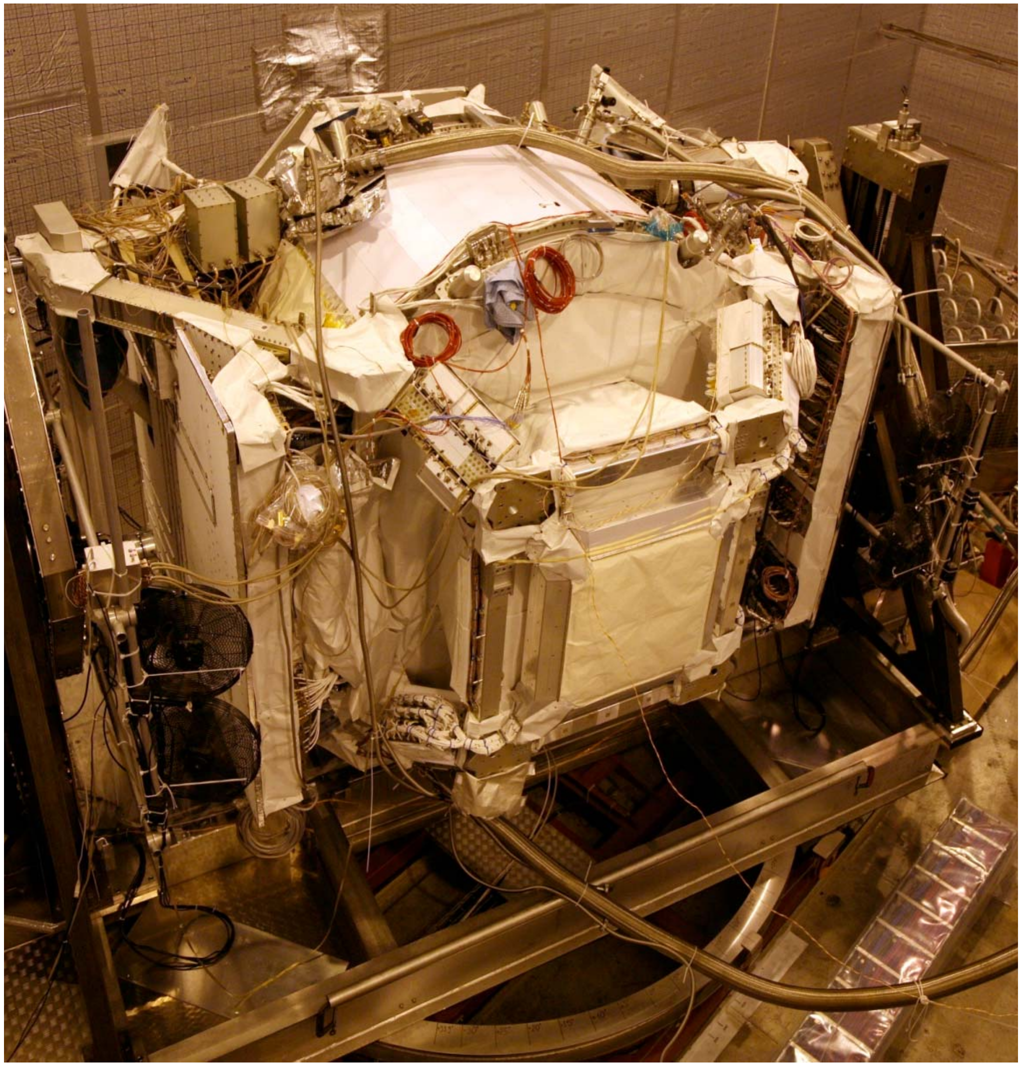


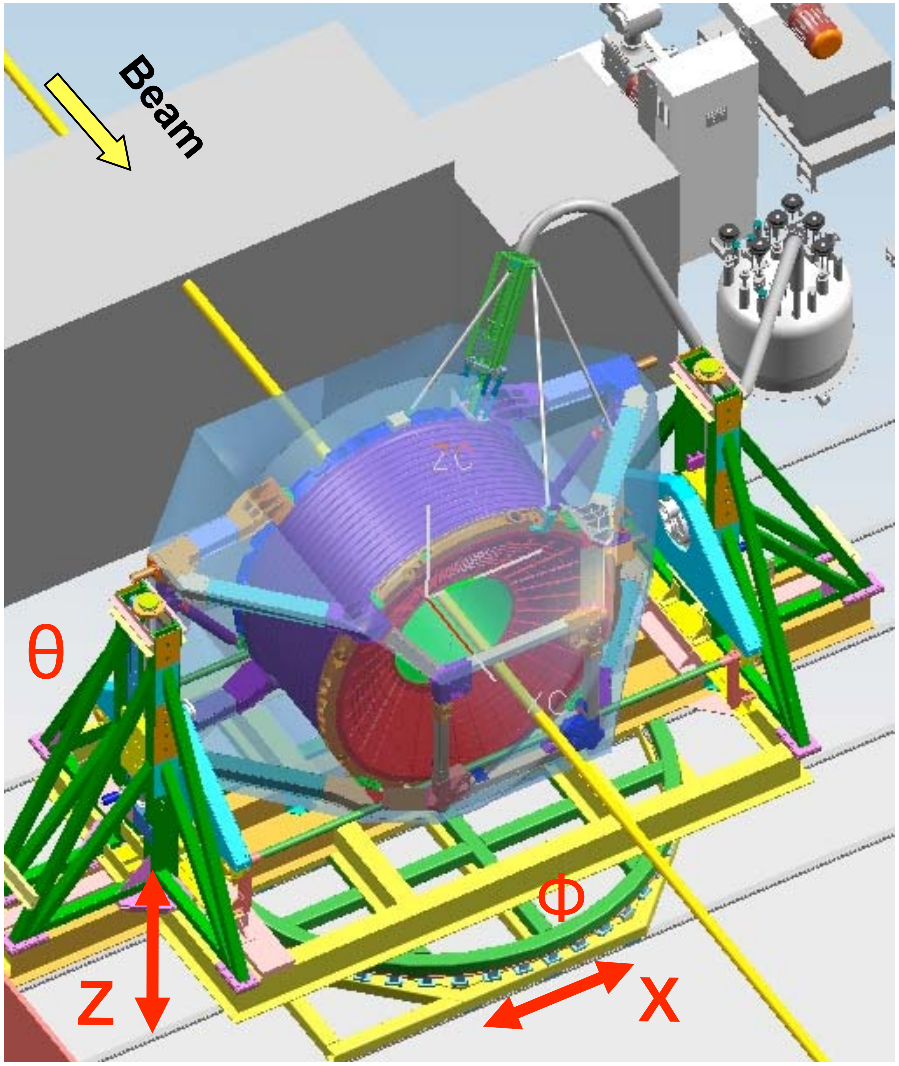
Chart Courtesy of MIT – Prof. Ting

CERN Accelerator Complex

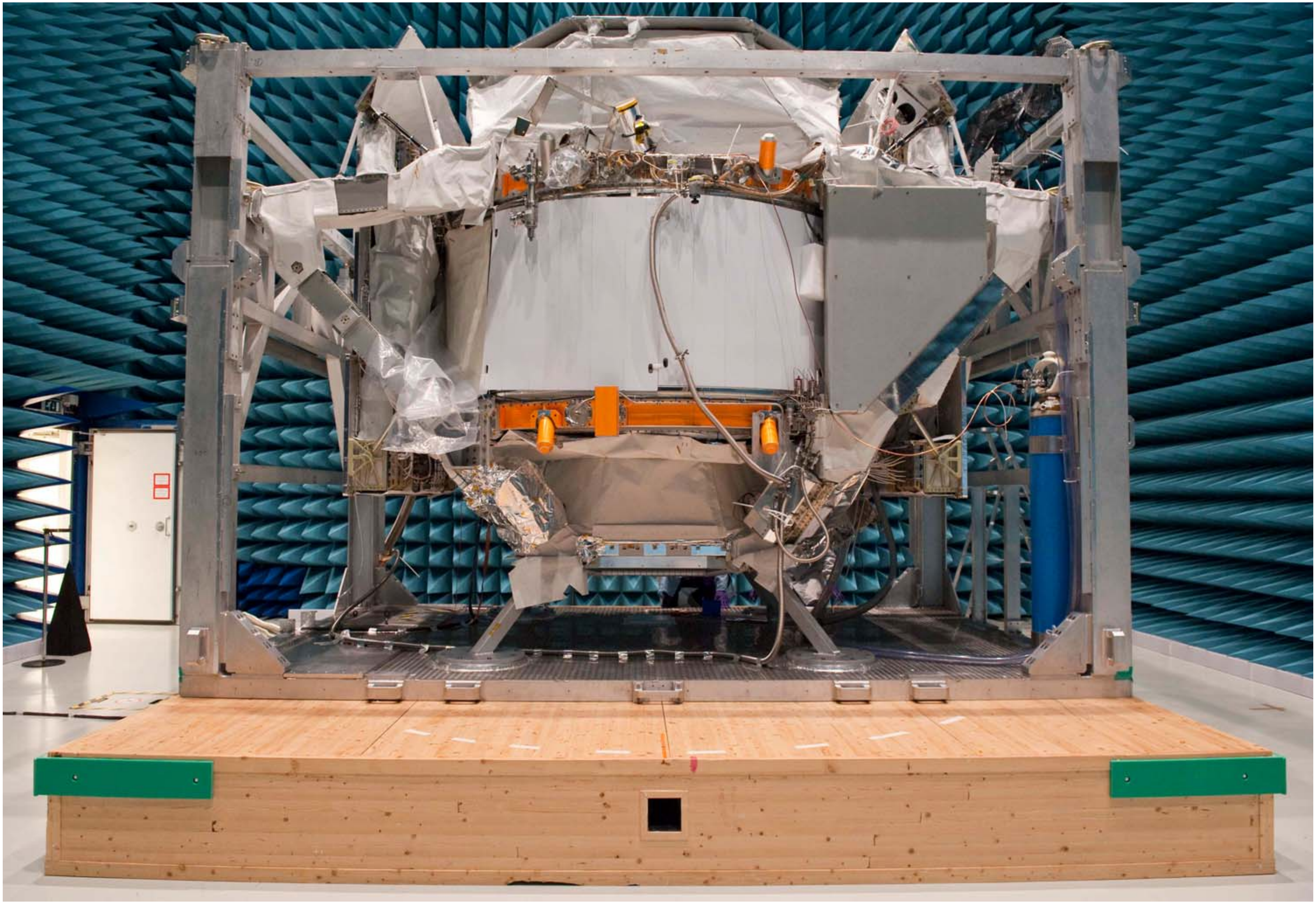
AMS in Test Beam

Feb 4-8, 2010

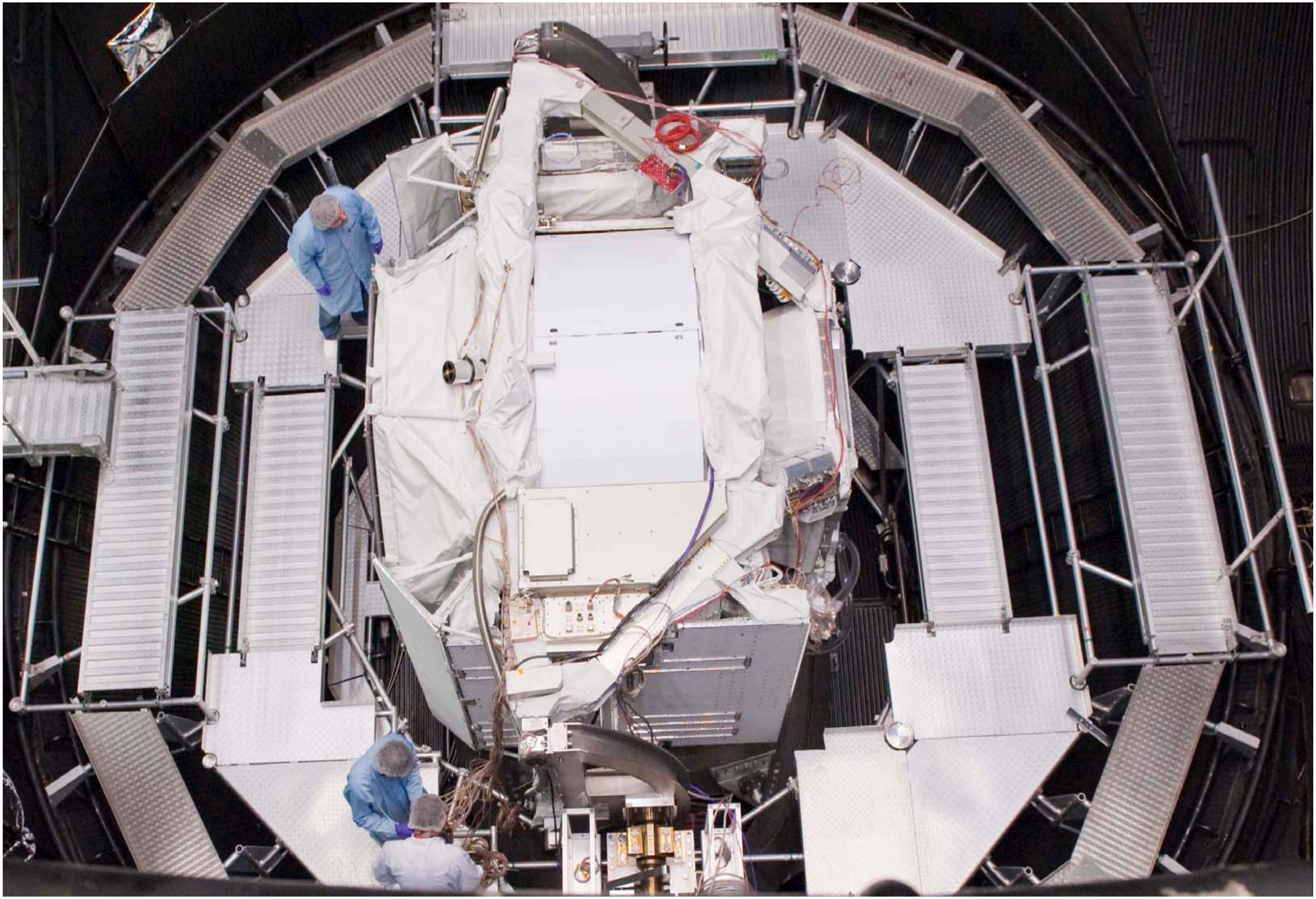




AMS in the Maxwell EMI chamber at ESTEC



AMS in the ESA TVT Chamber in the horizontal position



The Magnet Switch

- On April 16, after the thermal vacuum test, the AMS Collaboration made a decision to replace the superconducting magnet with the AMS-01 permanent magnet
- The permanent magnet presents the collaboration with the opportunity to gather science for a longer duration
- In addition, the superconducting magnet presented additional risks that the collaboration chose not to accept

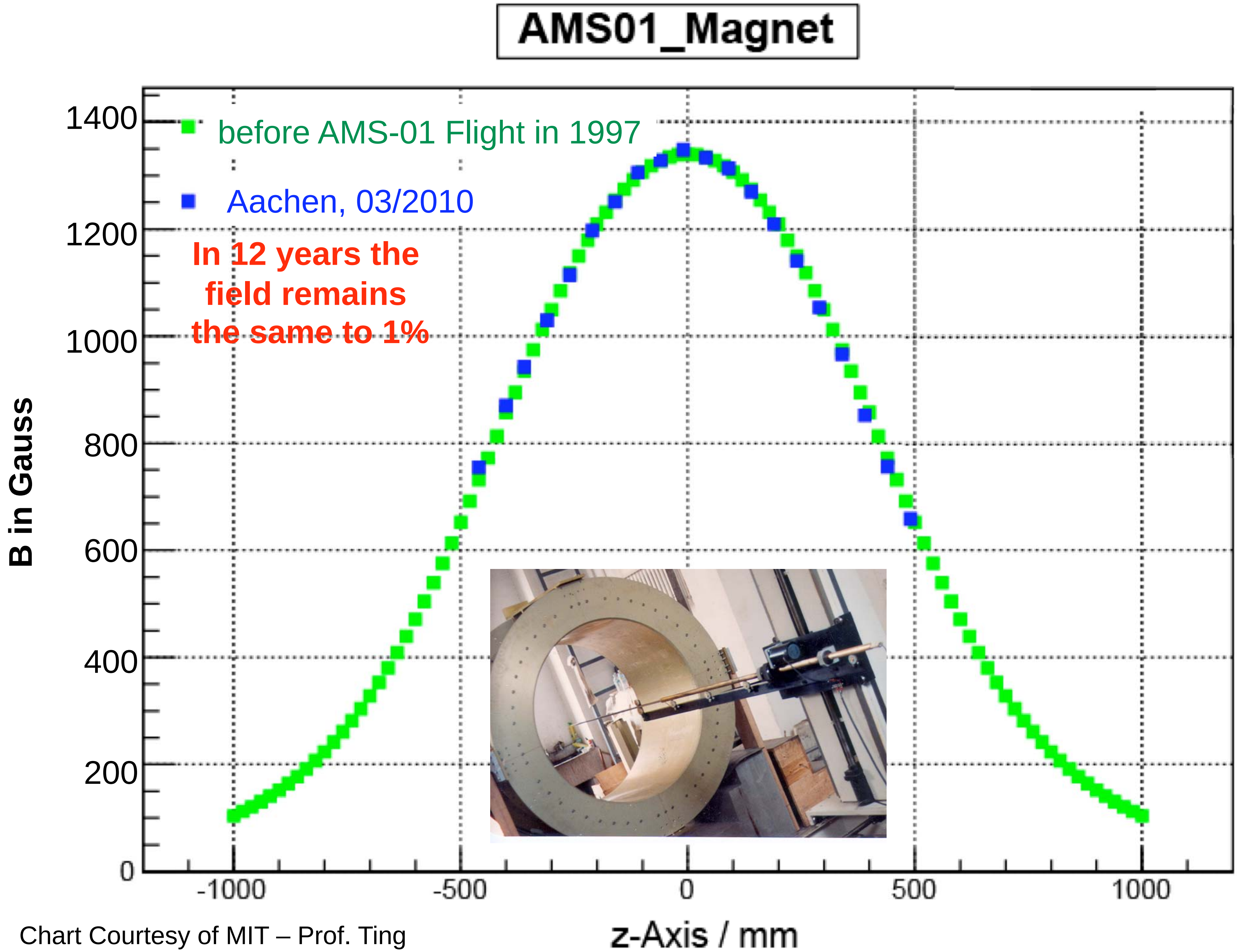
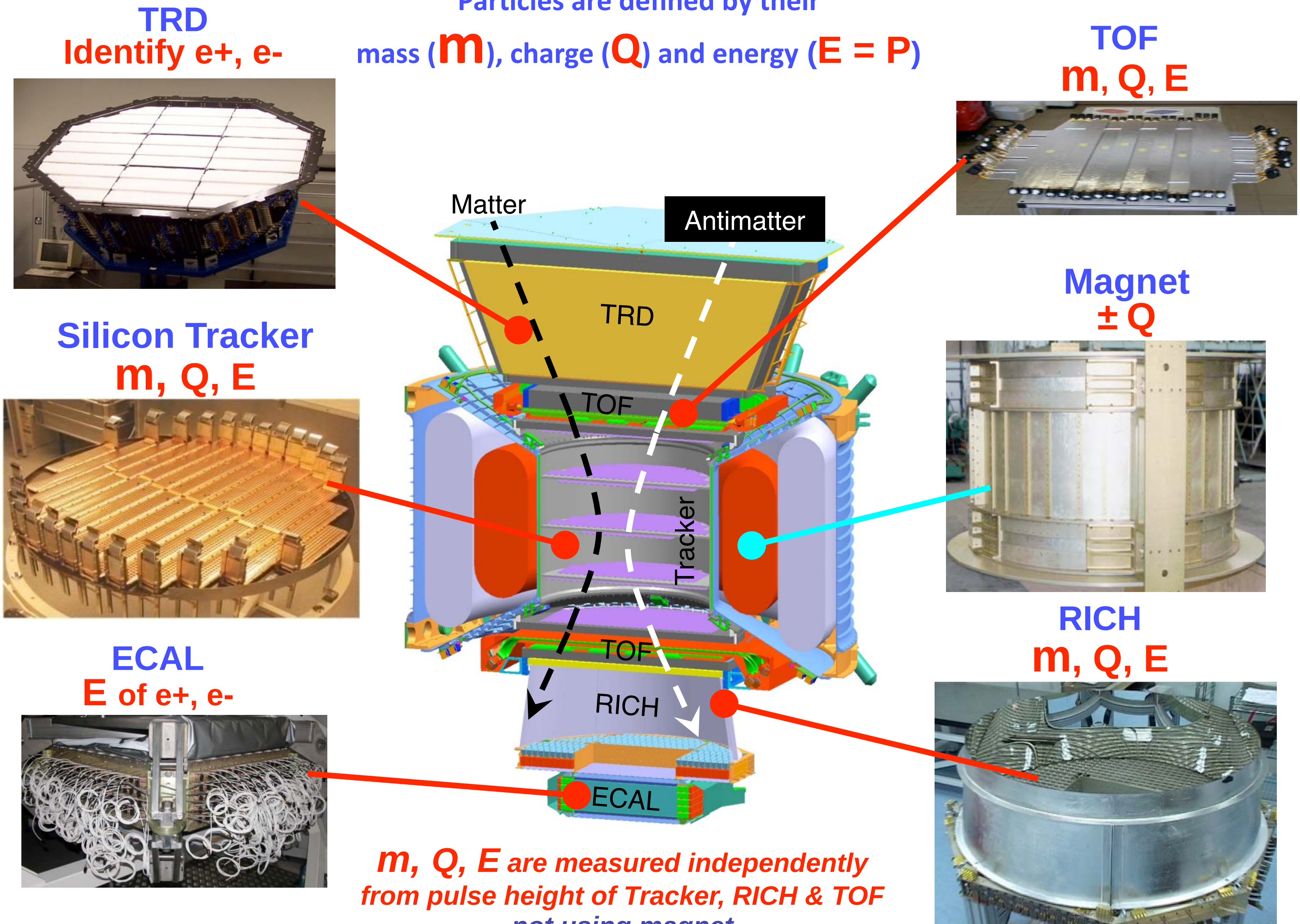


Chart Courtesy of MIT – Prof. Ting

Particles are defined by their mass (m), charge (Q) and energy (E = P)



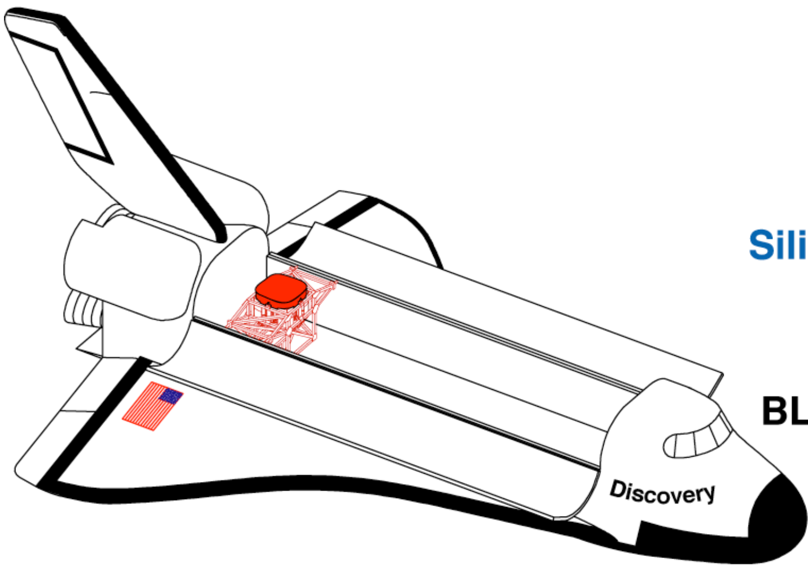
***m, Q, E* are measured independently from pulse height of Tracker, RICH & TOF not using magnet**

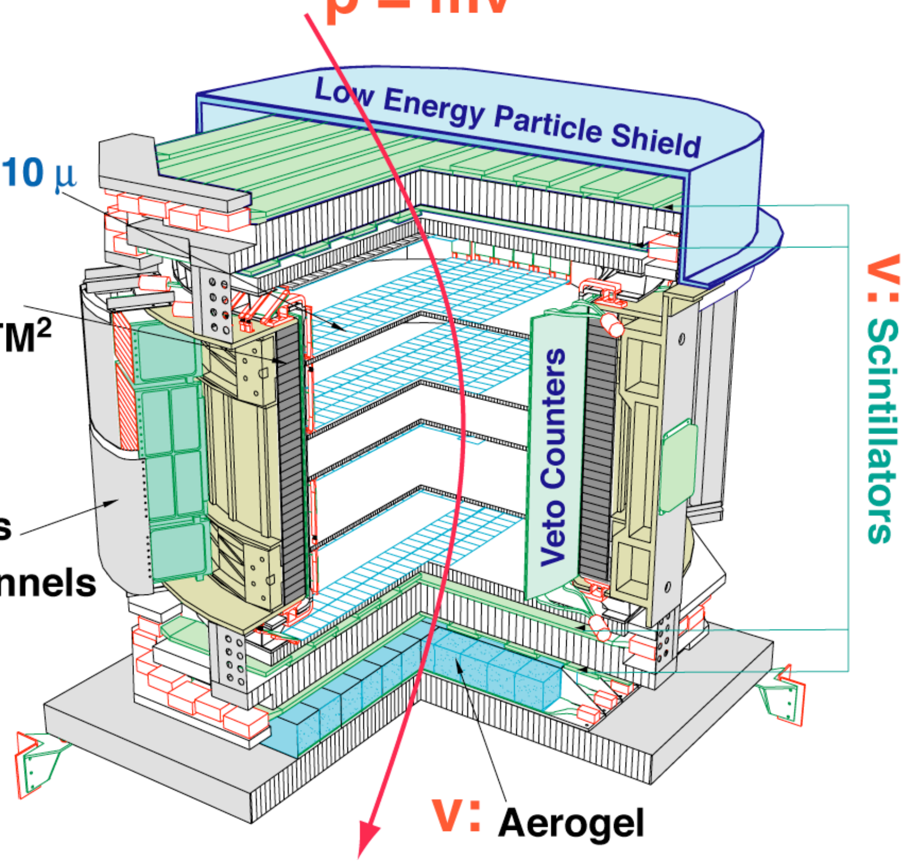
Chart Courtesy of MIT – Prof. Ting

Alpha Magnetic Spectrometer

First flight, STS-91, 2 June 1998 (10 days)

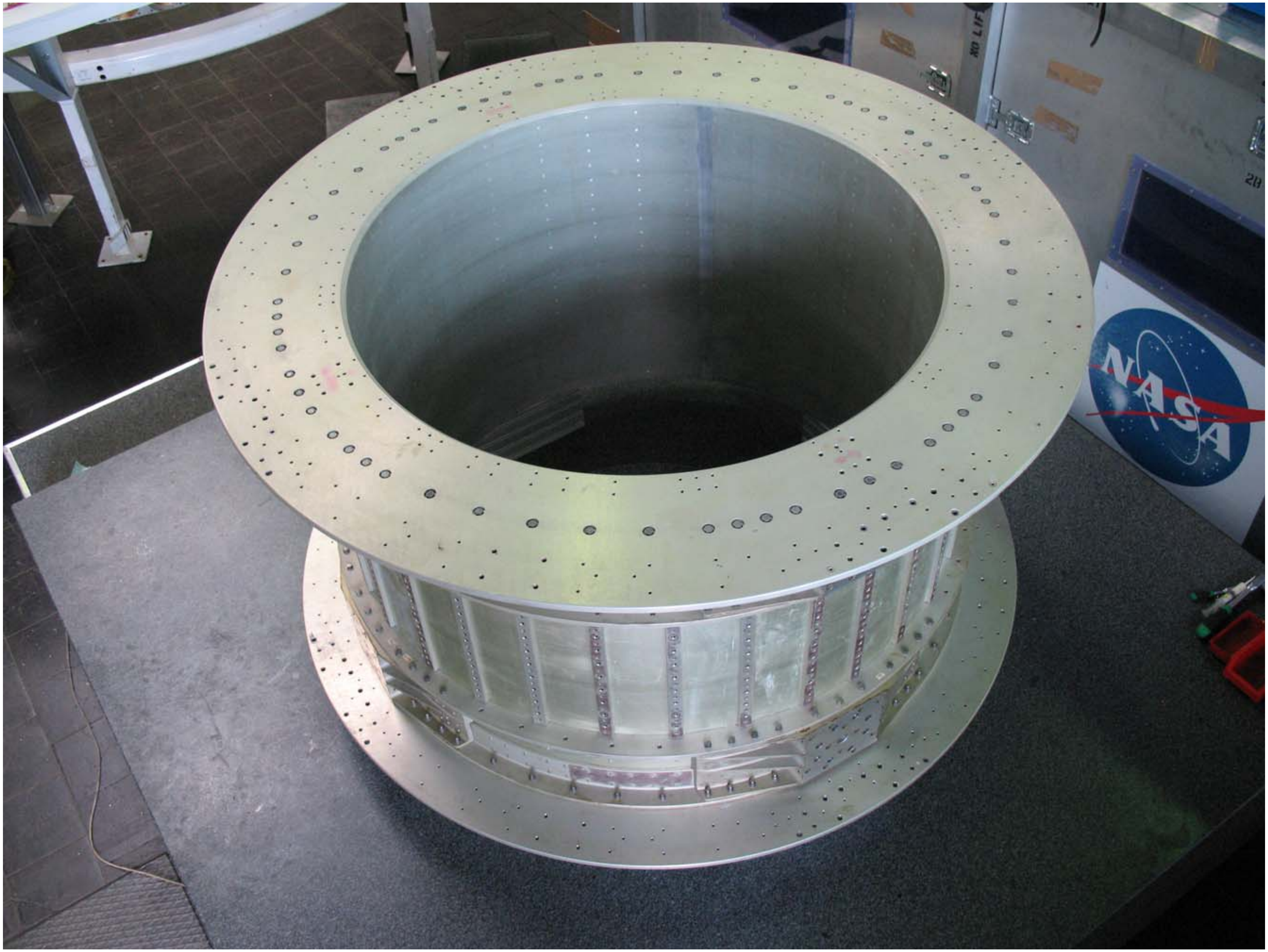
AMS-01





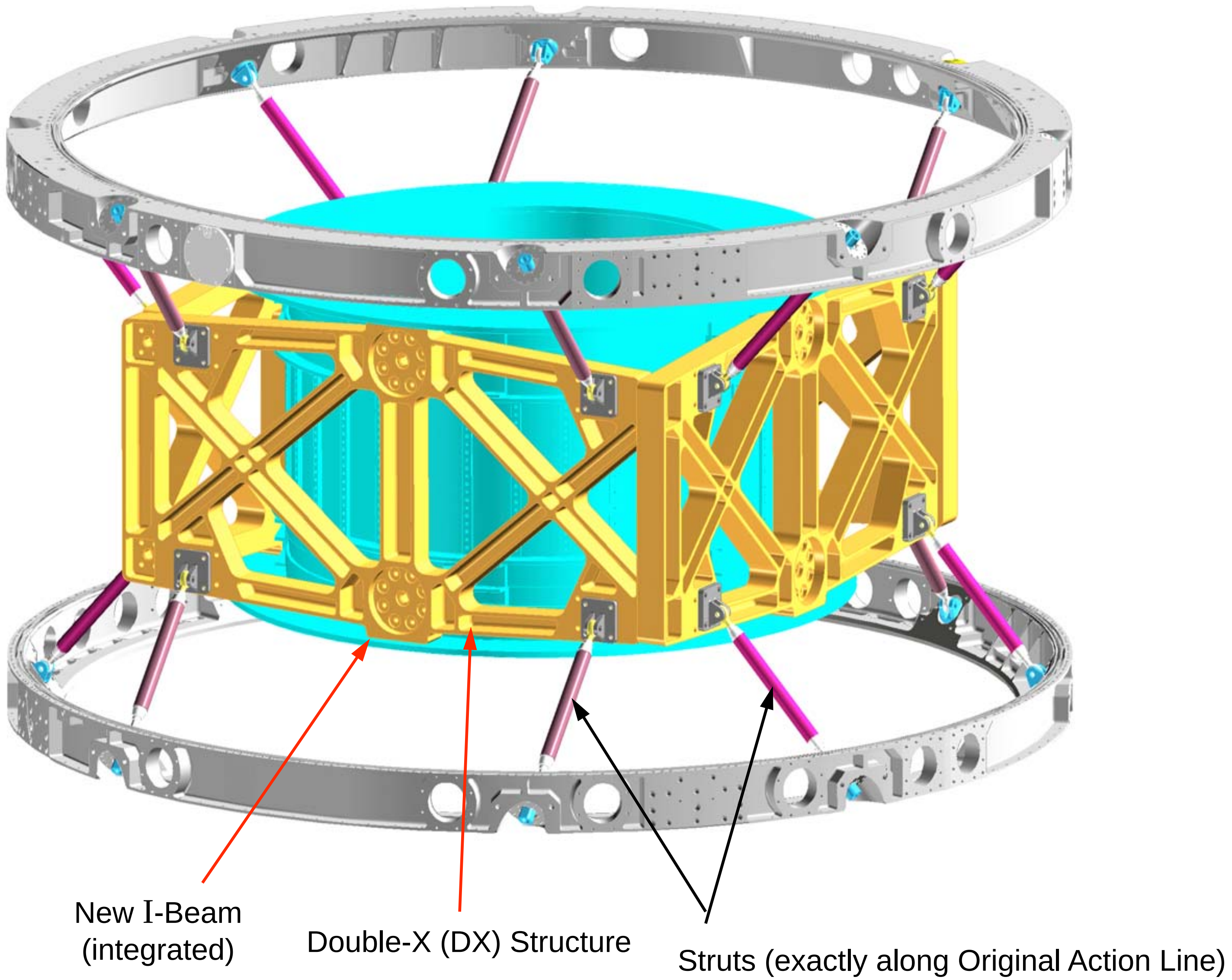
y99163_1AmsSts91Detect

Chart Courtesy of MIT – Prof. Ting



Ken Bollweg will present the details of the flight permanent magnet

Work began January 25, 2010



Outer Support Structure (Only Outer Rings of VC shown)

Double X Structure after Machining

AMS02: Permanent Magnet
to be fit into the Vacuum Case

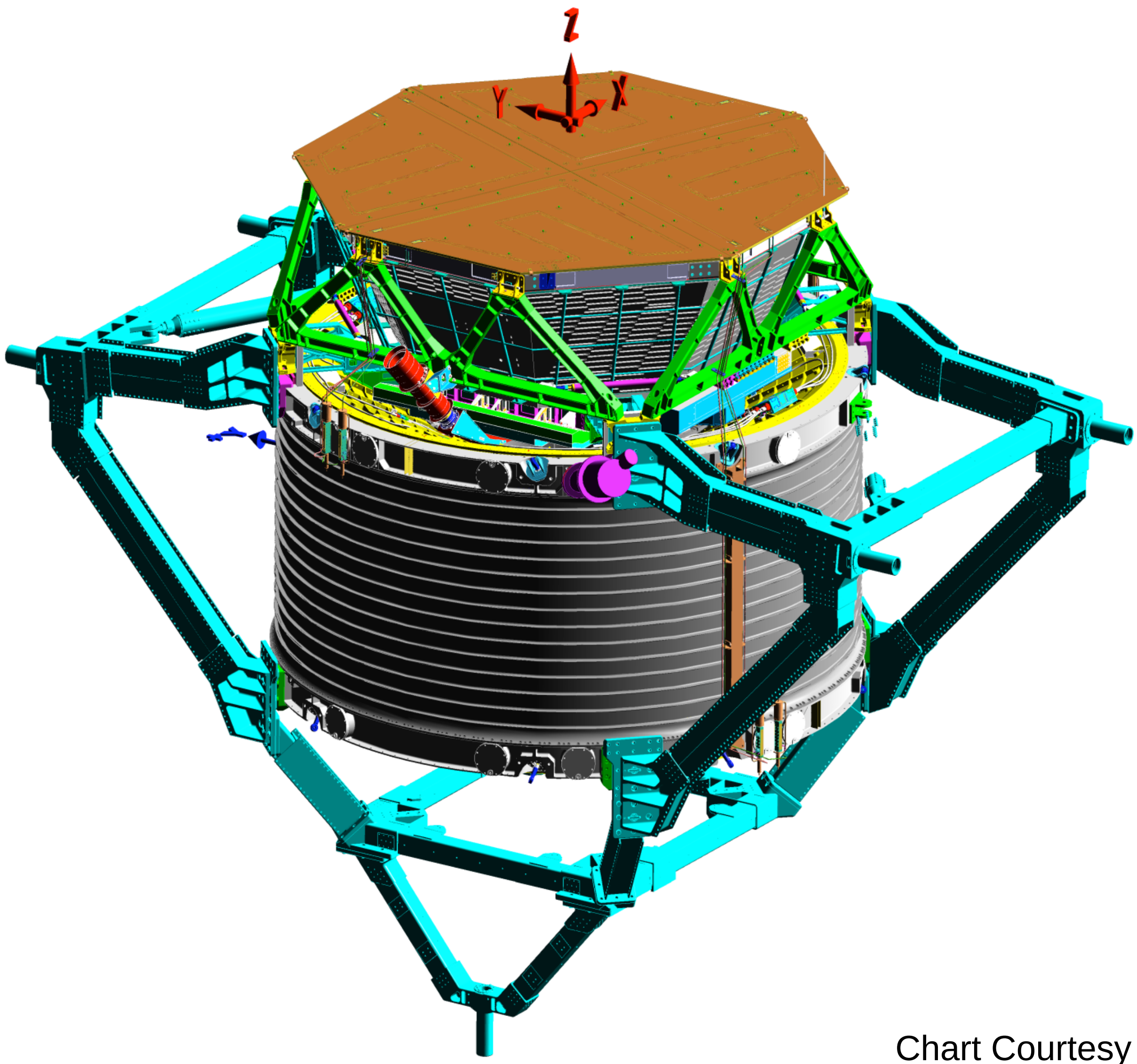


Chart Courtesy of MIT – Prof. Ting

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

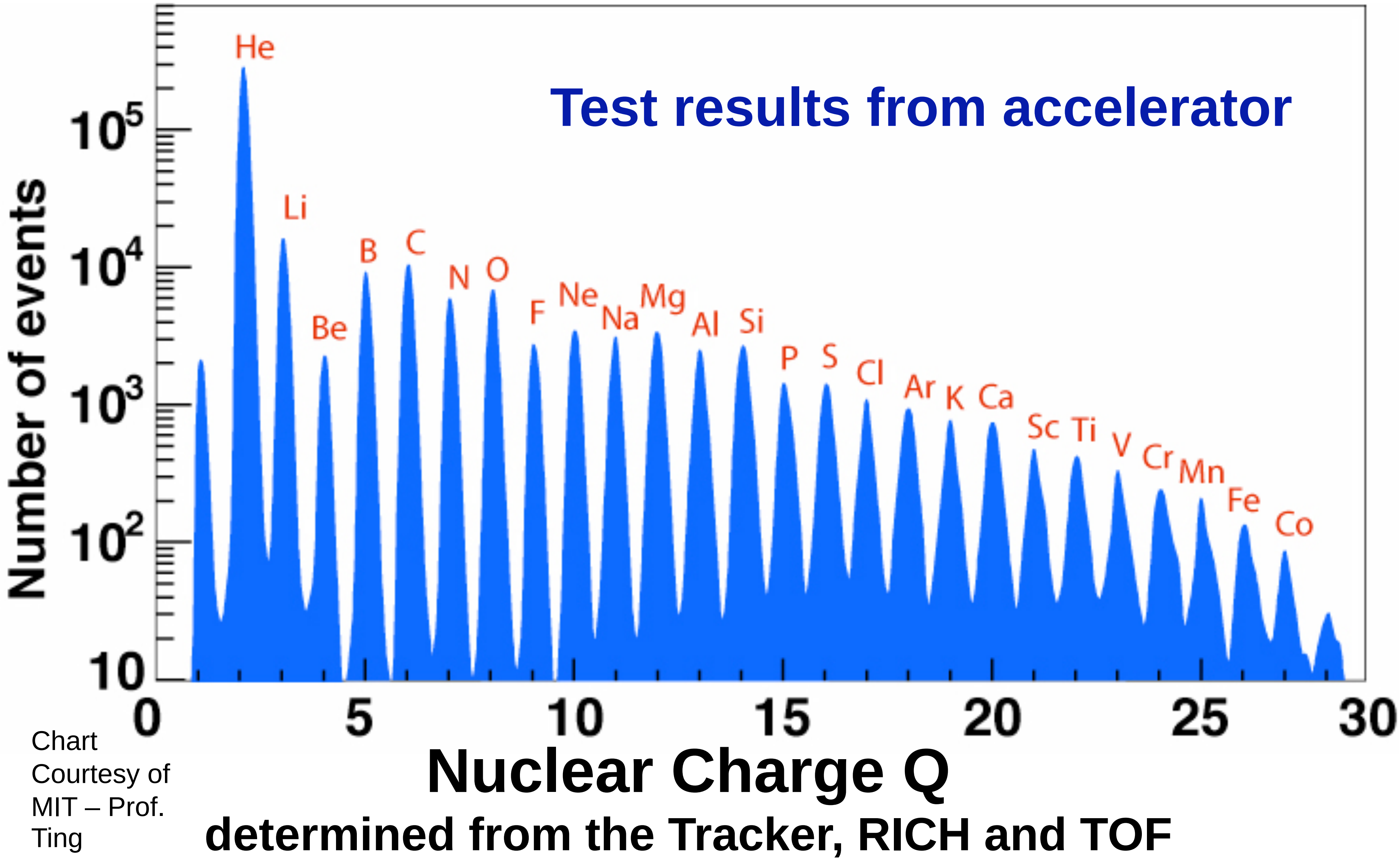
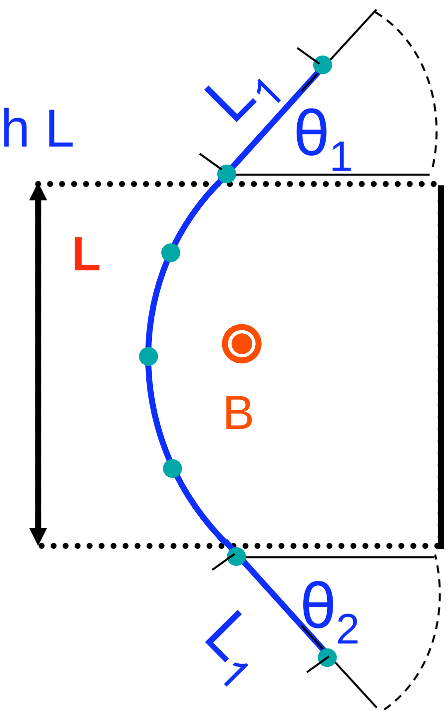


Chart Courtesy of MIT – Prof. Ting

The function of the magnet is to measure the sign of the charge (±) and the momentum (P) of charged particles.

A charged particle passing through a magnetic field (B) experiences a bending. The amount of the bending depends on the value of the charge, Q, and momentum, p. The direction of the bending depends on the sign of the charge (±) .

The momentum resolution (Δp/p) is a measure the detectors ability to distinguish the sign of the charge and the accuracy of the momentum. It is the sum of two contributions:



1. Measurement inside the magnet with an effective length L

$$(Q/p)\cdot(\Delta p/p) \propto 1/BL^2$$

2. Measurement of the incident (θ_1) and exit (θ_2) angles which depend on the length L_1

$$(Q/p)\cdot(\Delta p/p) \propto 1/BLL_1$$

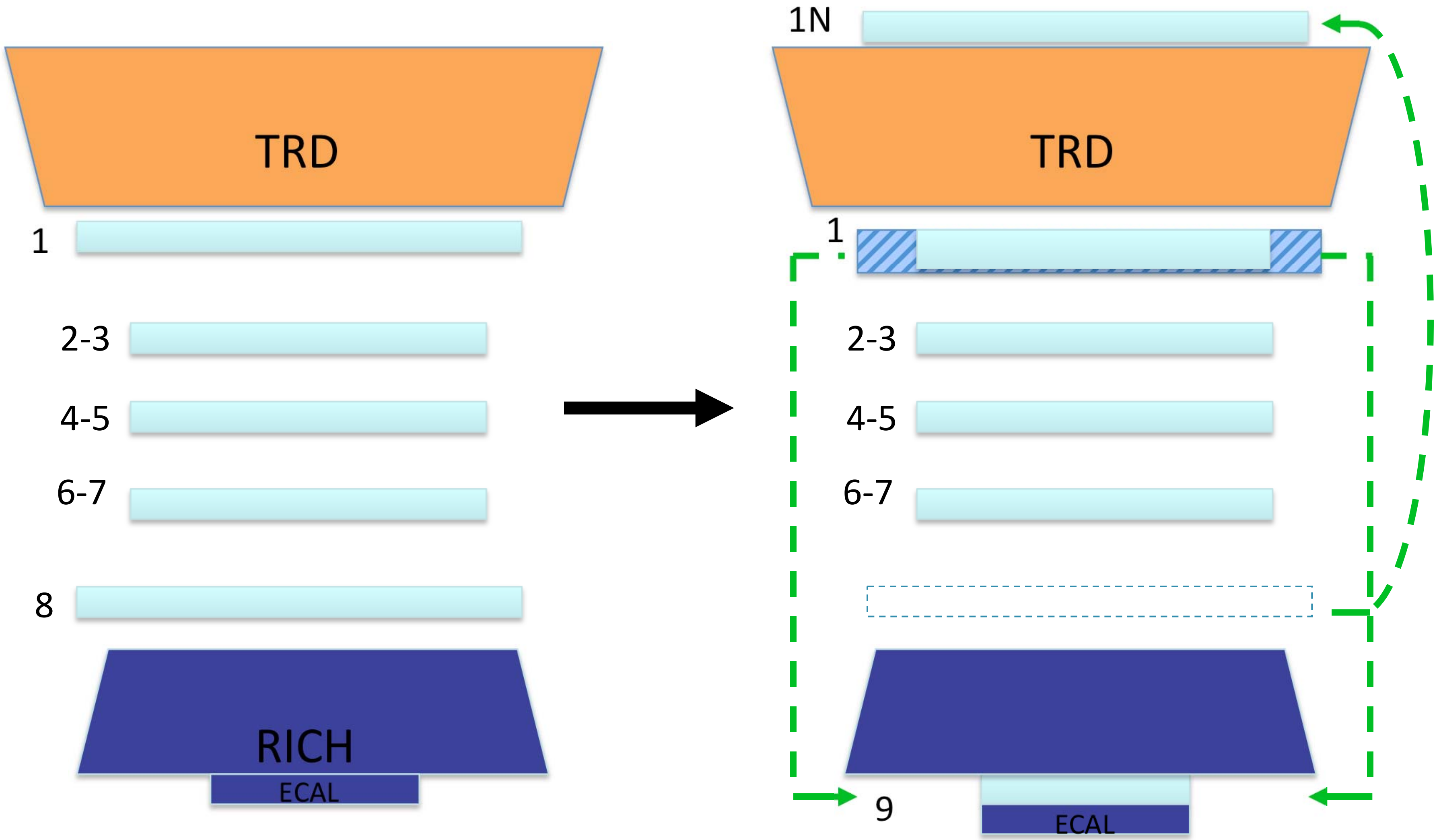
For both magnets, L ~ 80 cm,
but in the permanent magnet B is 5 times smaller

to maintain the same Δp/p we increase L1 from ~15 cm (Superconducting Magnet) to ~125 cm (permanent magnet)

Chart Courtesy of MIT – Prof. Ting

AMS-02 Superconducting Magnet Silicon Tracker Layers

AMS-02 Permanent Magnet Silicon Tracker Layers



Layer 9 comes from moving the ladders at the edge of the acceptance from layer 1. The layer 8 is moved on top of the TRD to become 1N.
No new silicon and no new electronics are required.

THE AMS SILICON TRACKER

we have built a state of the art Tracking Detector based on 8 thin layers of Silicon Detectors, with a spatial accuracy better than 10 micron

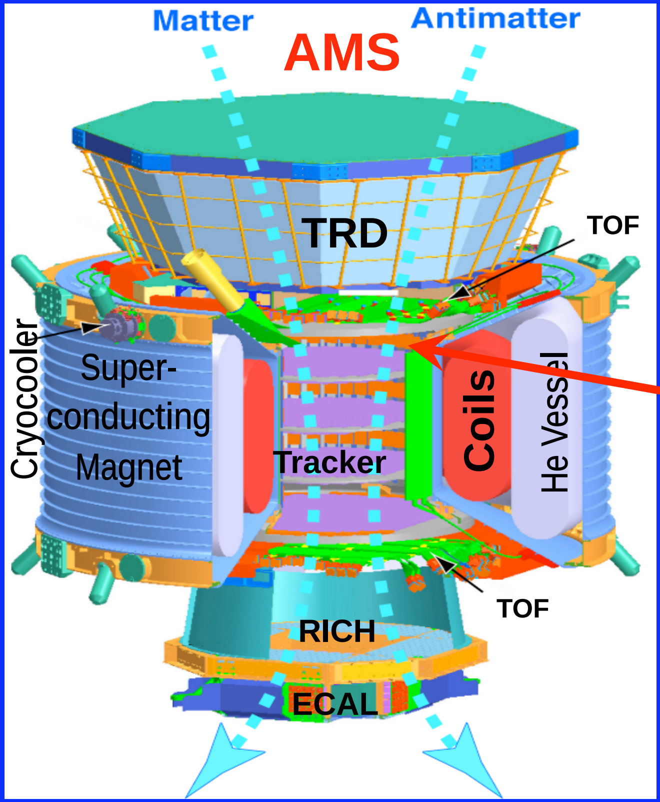


Chart Courtesy of MIT – Prof. Ting

Silicon Tracker planes are movable

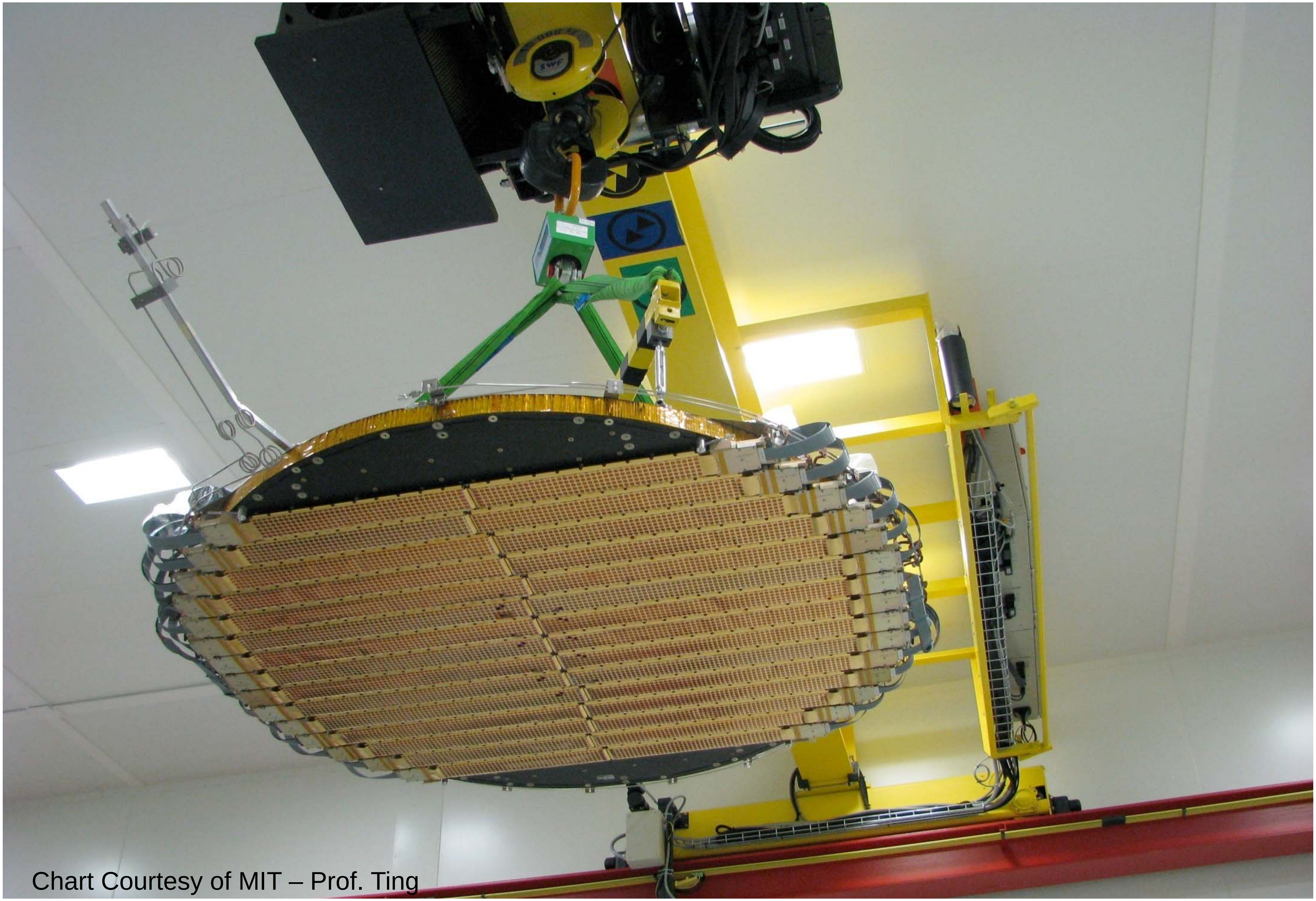


Chart Courtesy of MIT – Prof. Ting

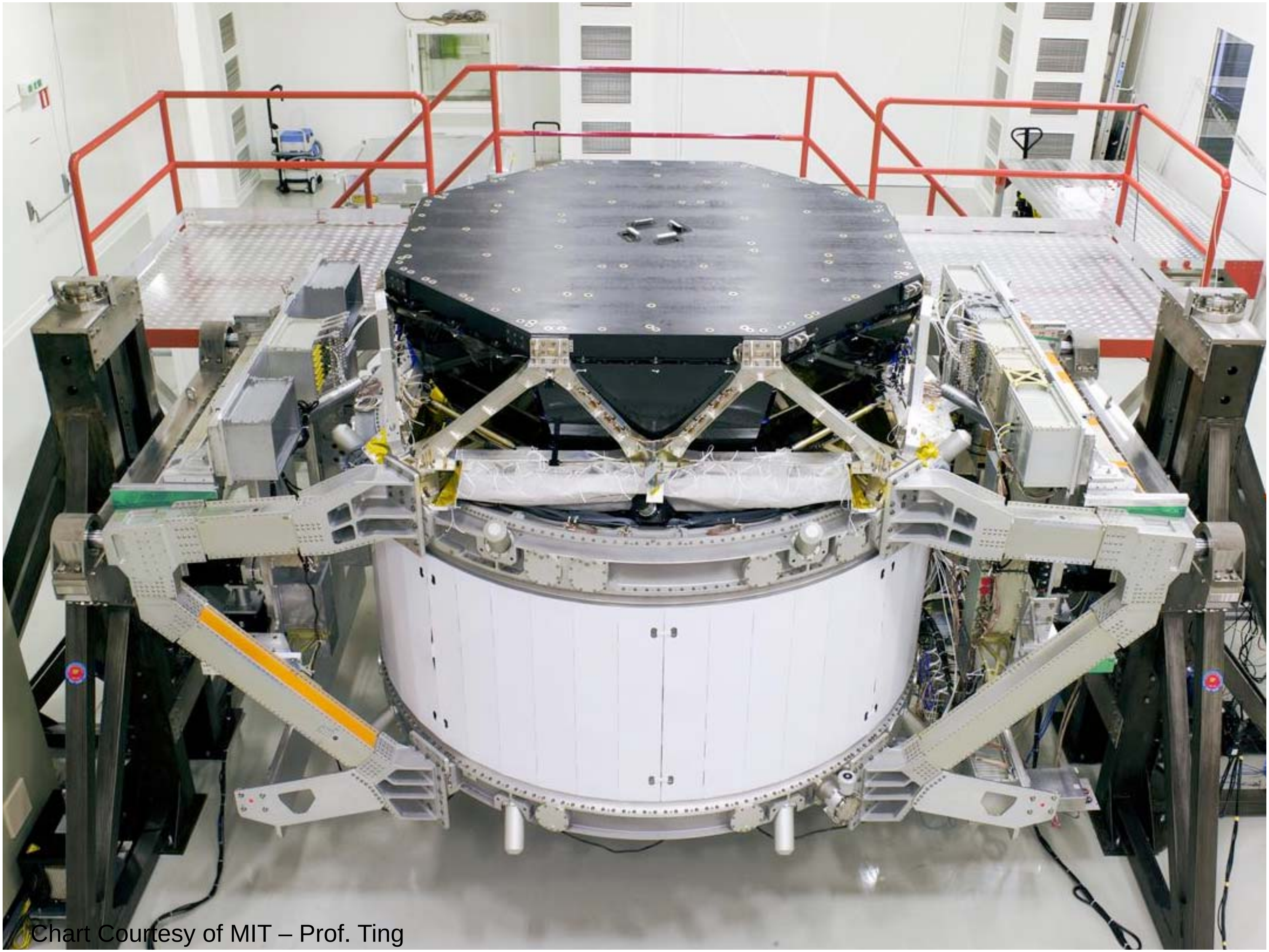


Chart Courtesy of MIT – Prof. Ting

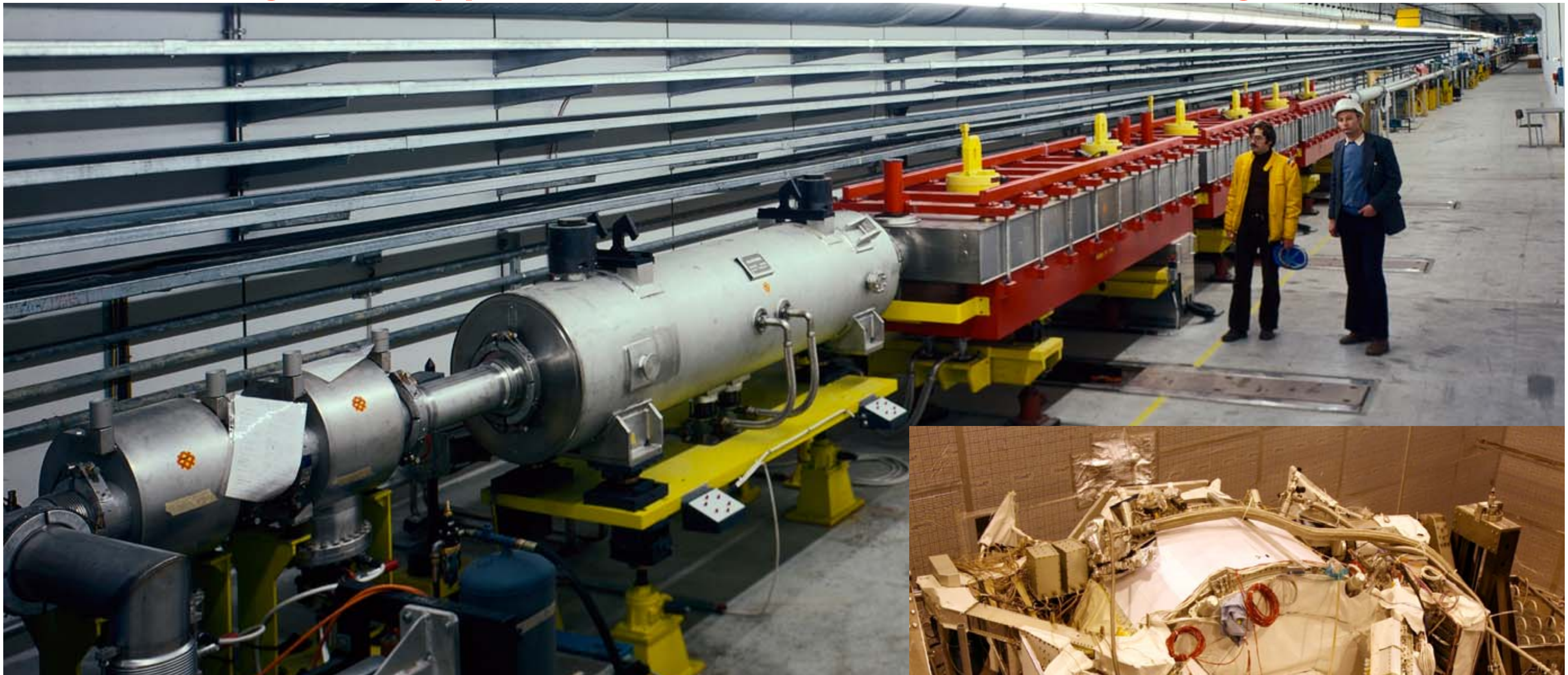
Independent Alignment Systems of the AMS Tracker Planes

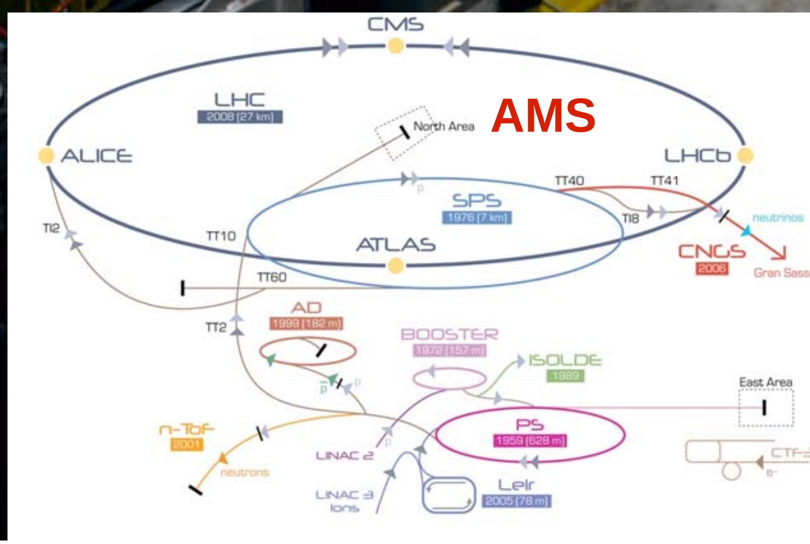
1. Alignment with CERN Test beam on 24-25 Aug 2010 using the highest energy protons (Energy = 400 Billion Electron Volts).

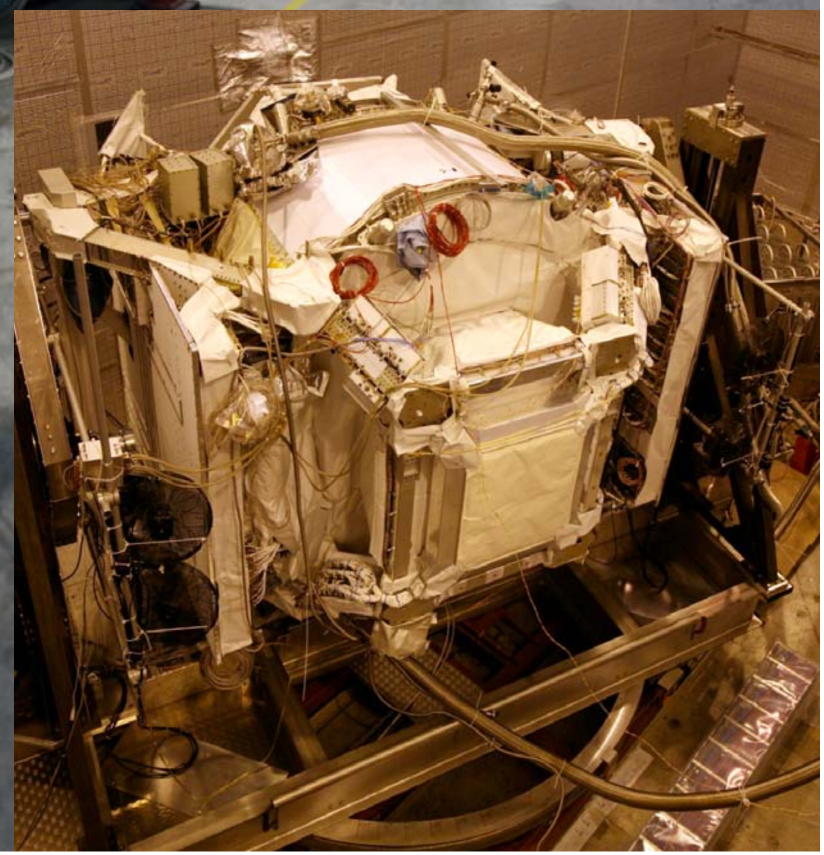
2. Alignment with 10,000 cosmic rays every minute in every orbit

Chart Courtesy of MIT – Prof. Ting

Alignment (1) : with accelerator test beam 7-14 Aug 2010







Alignment (2): with Cosmic Rays

The effects of thermal movements of the top and bottom tracker planes in the (x, y) directions were studied.

The thermal model predicts the movement in x and y are both less than 150 μ.

The plane thermal movement of 1 mm per orbit was simulated.

Reconstruction was then done via propagation of the tracks obtained by the 7 inner tracker planes to the top and bottom planes.

By comparing the simulated and reconstructed plane positions the residual misalignment was estimated.

The plane thermal movement of 1 cm per orbit was also simulated.

Chart Courtesy of MIT – Prof. Ting

Tracker alignment

In space, the tracker alignment of 3 μm will be continuously monitored by 40 Laser beams.

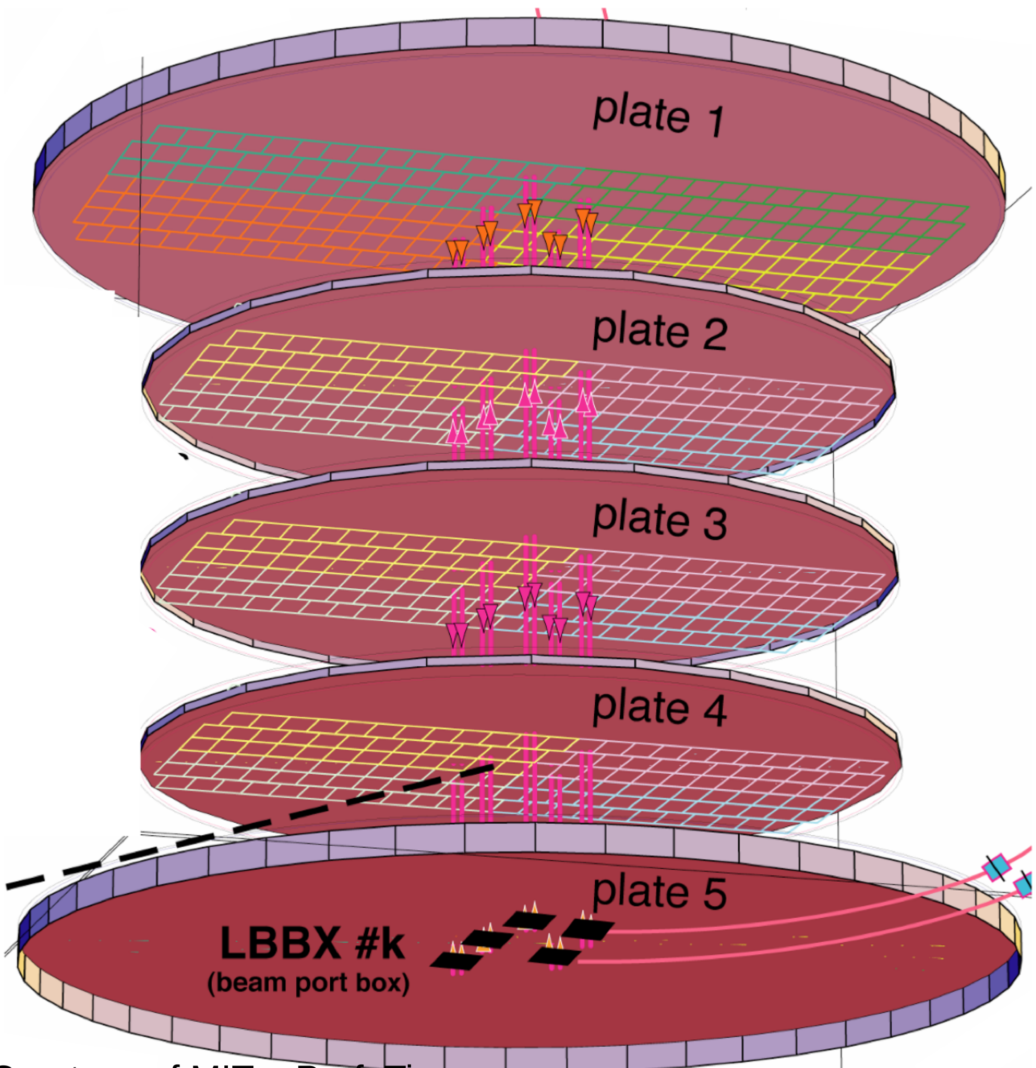
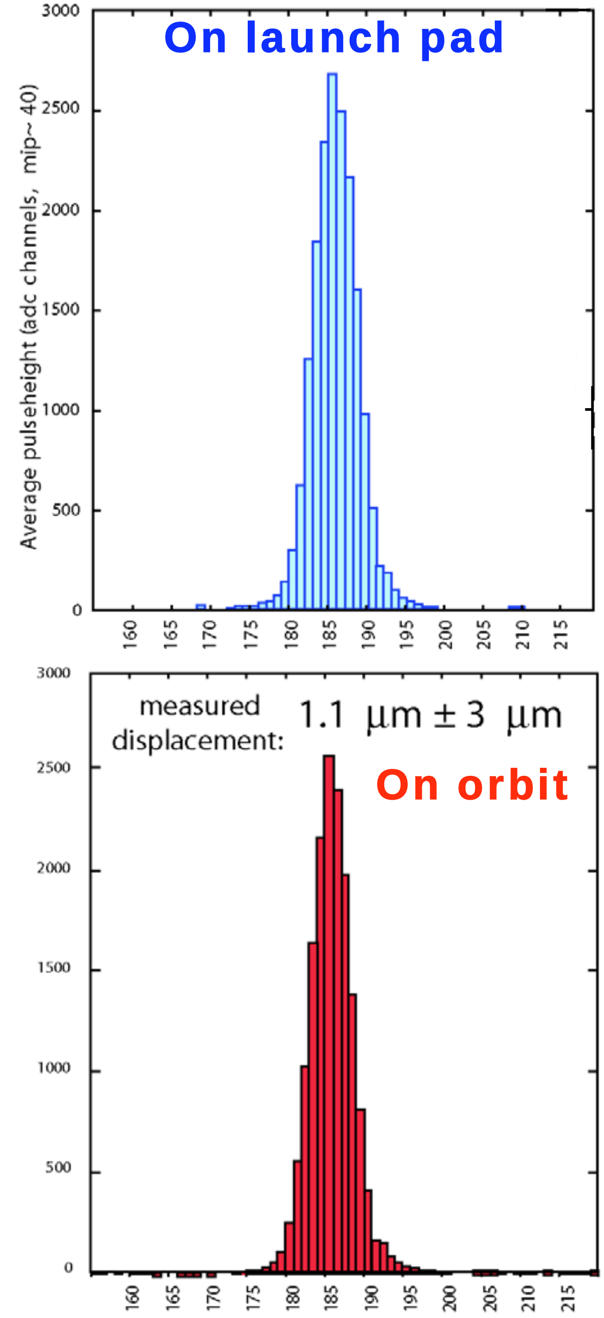


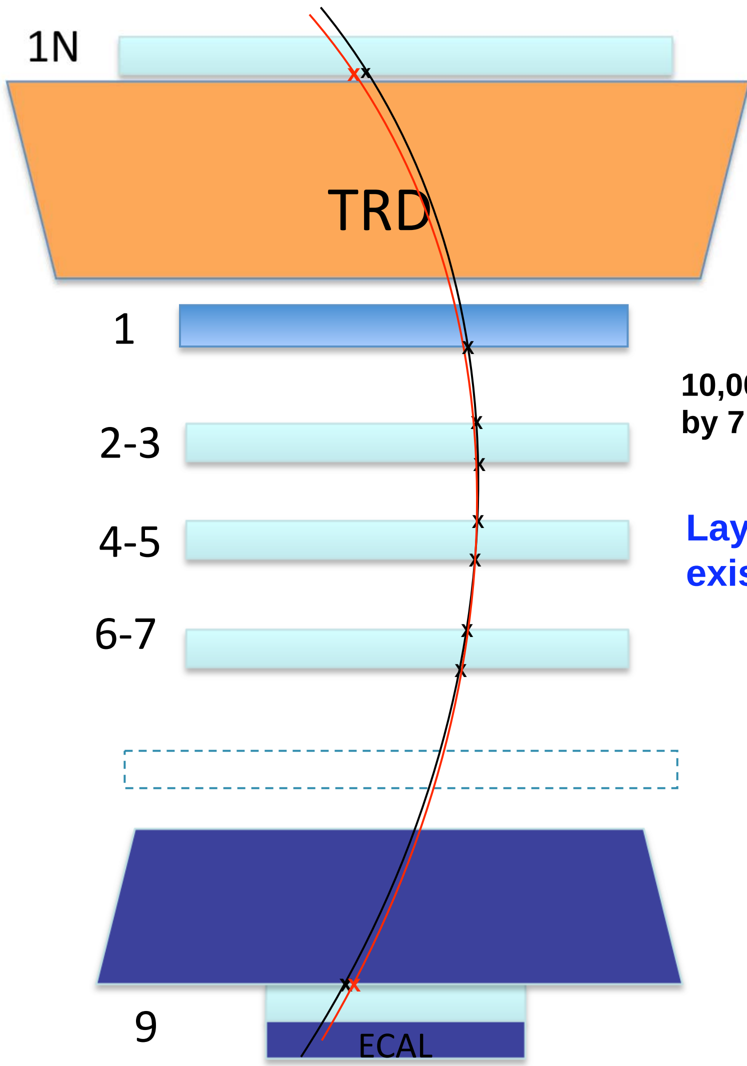
Chart Courtesy of MIT – Prof. Ting

AMS-01



AMS-02 Permanent Magnet:
Silicon Tracker Alignment with Cosmic protons

Extrapolated track from 7 measurements inside the magnet

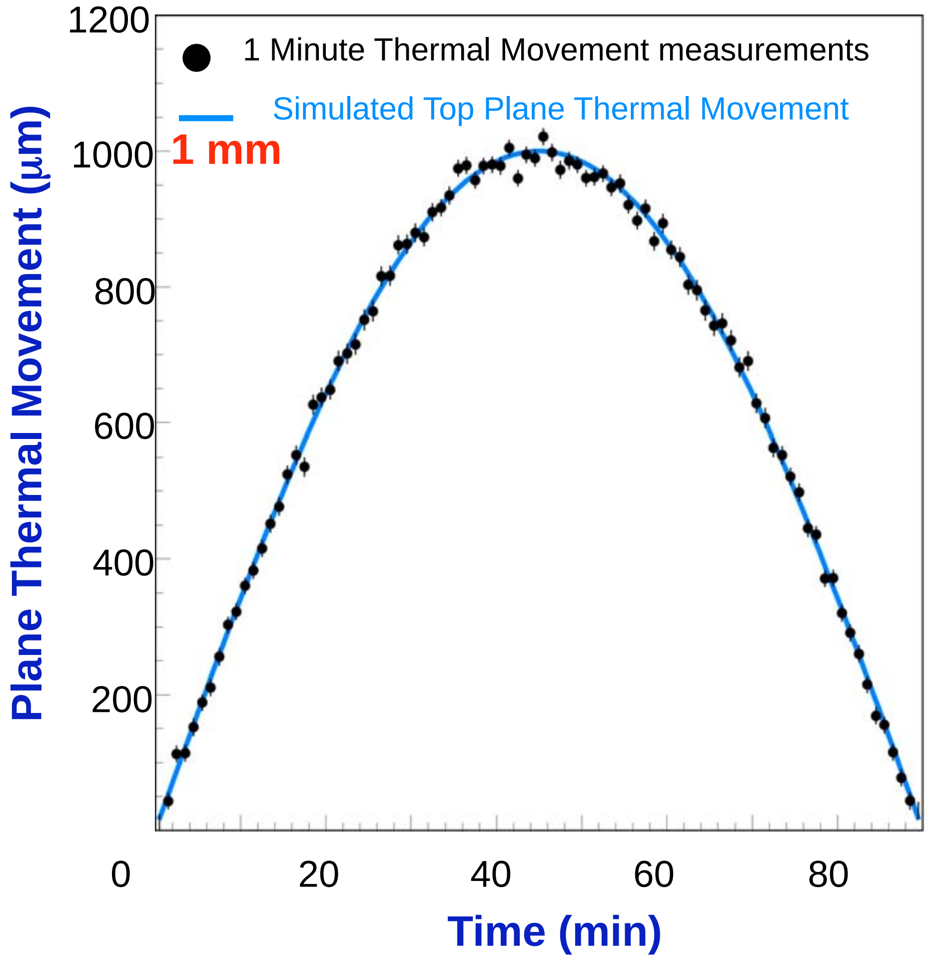


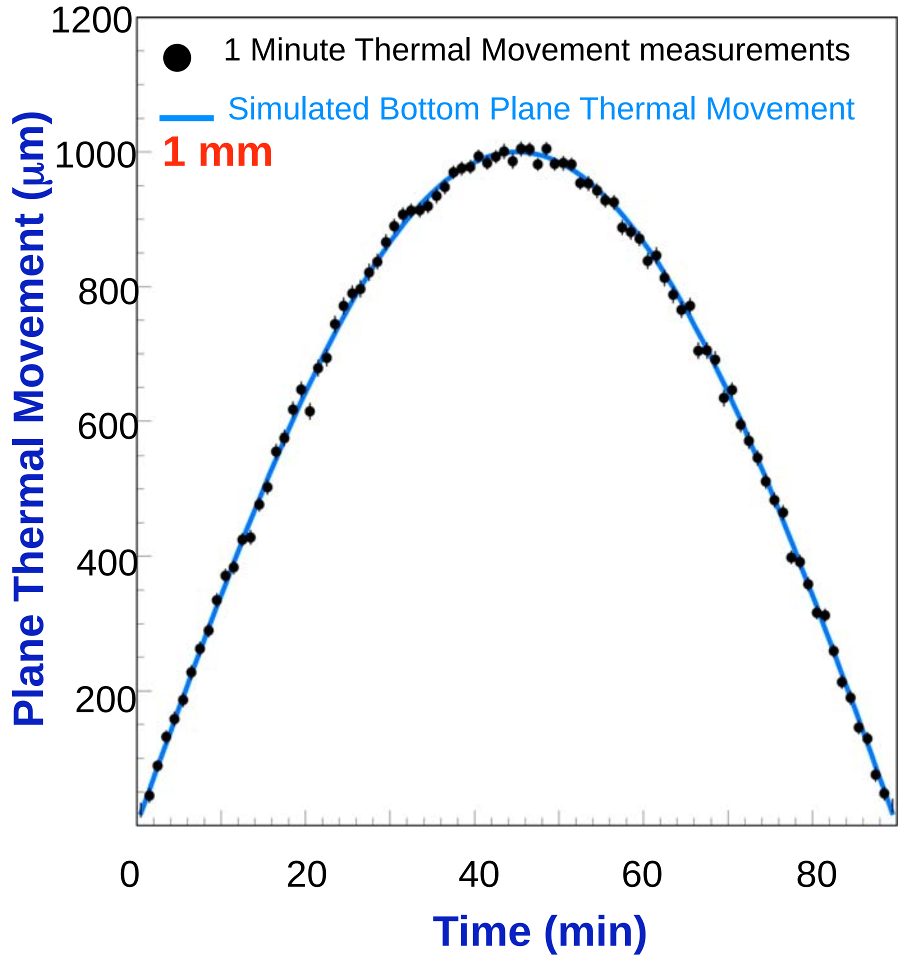
10,000 cosmic protons / min measured by 7 tracker layers in the magnet

Layers 1 to 7 are aligned with existing laser system

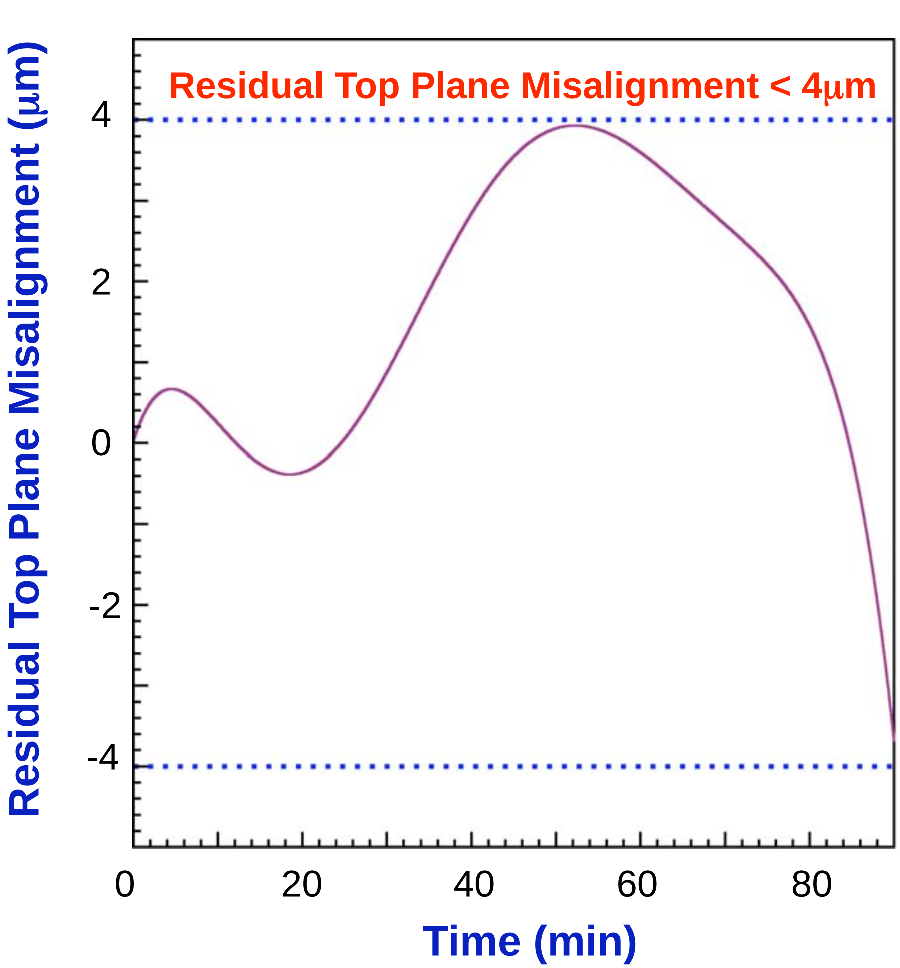
Extrapolated track from 7 measurements inside the magnet

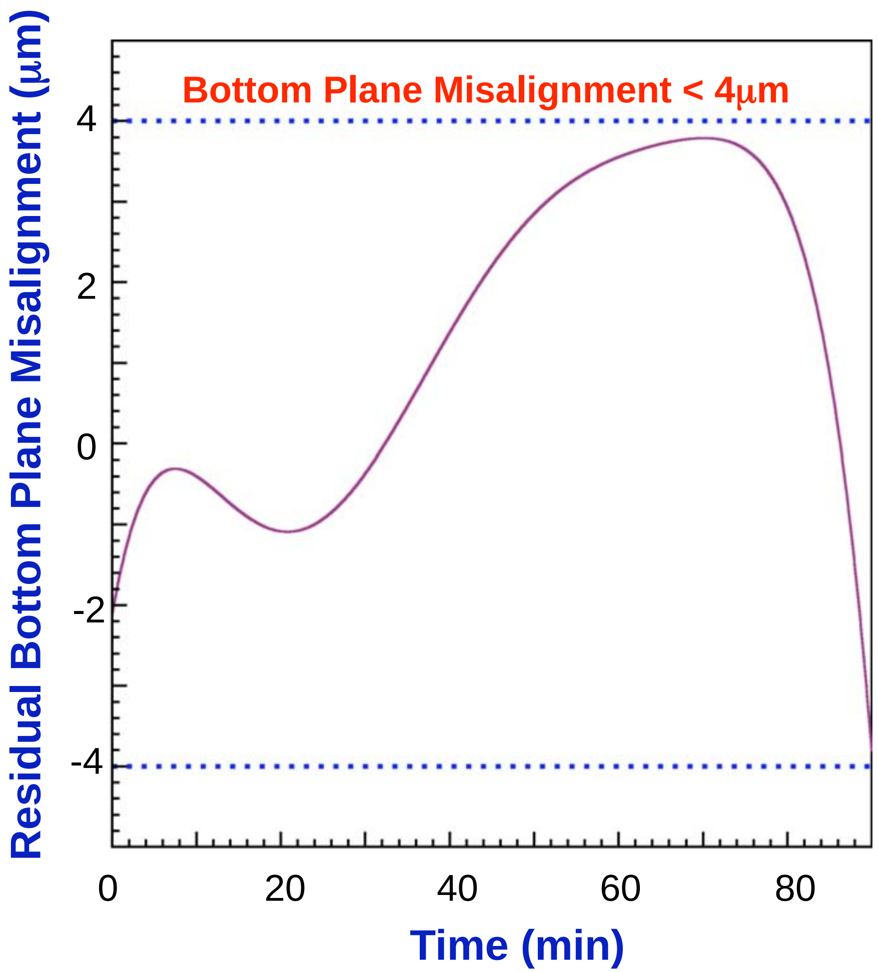
External Plane Alignment with Cosmic Rays   Minute by Minute

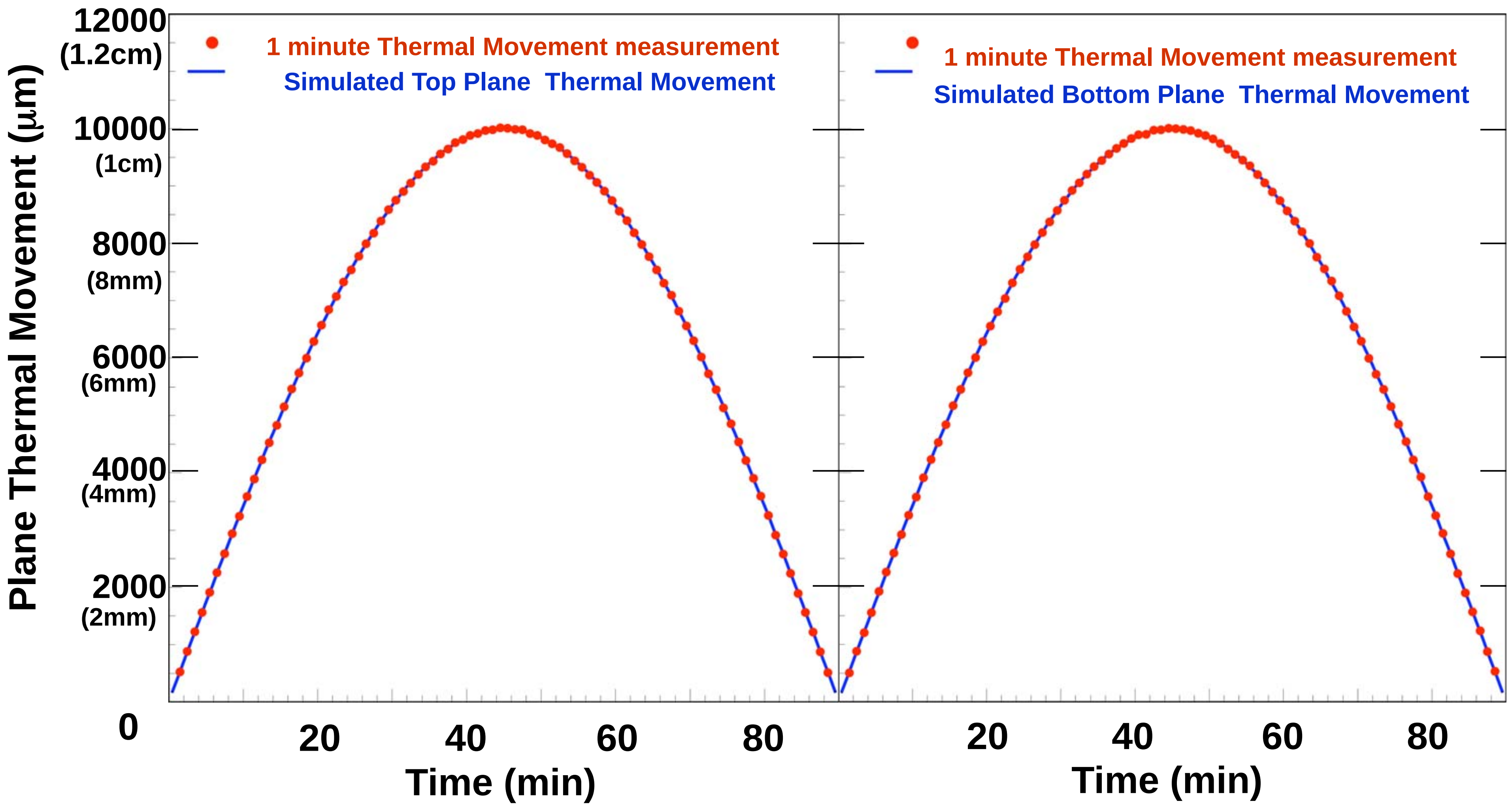




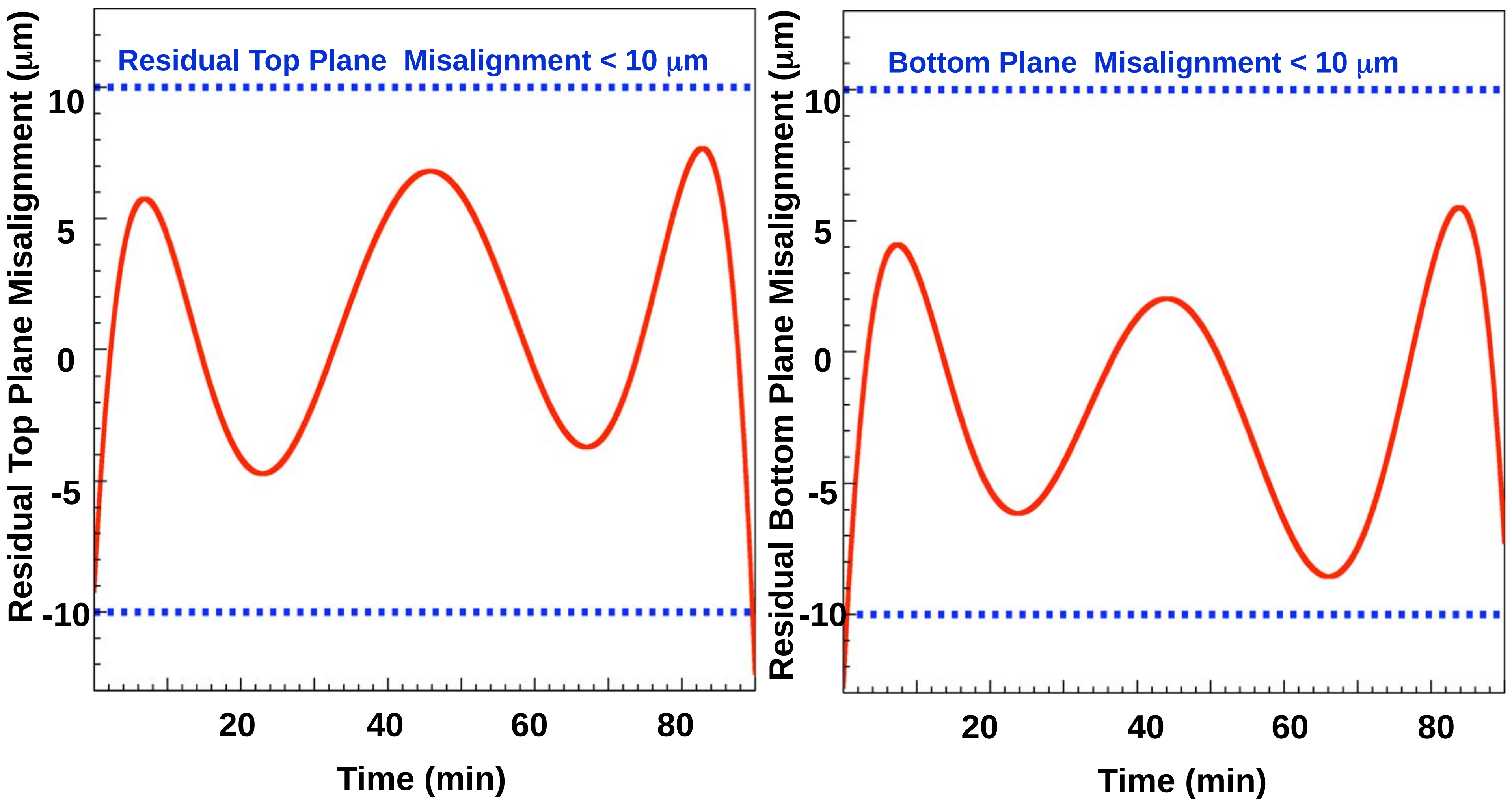
External Planes Alignment Studies



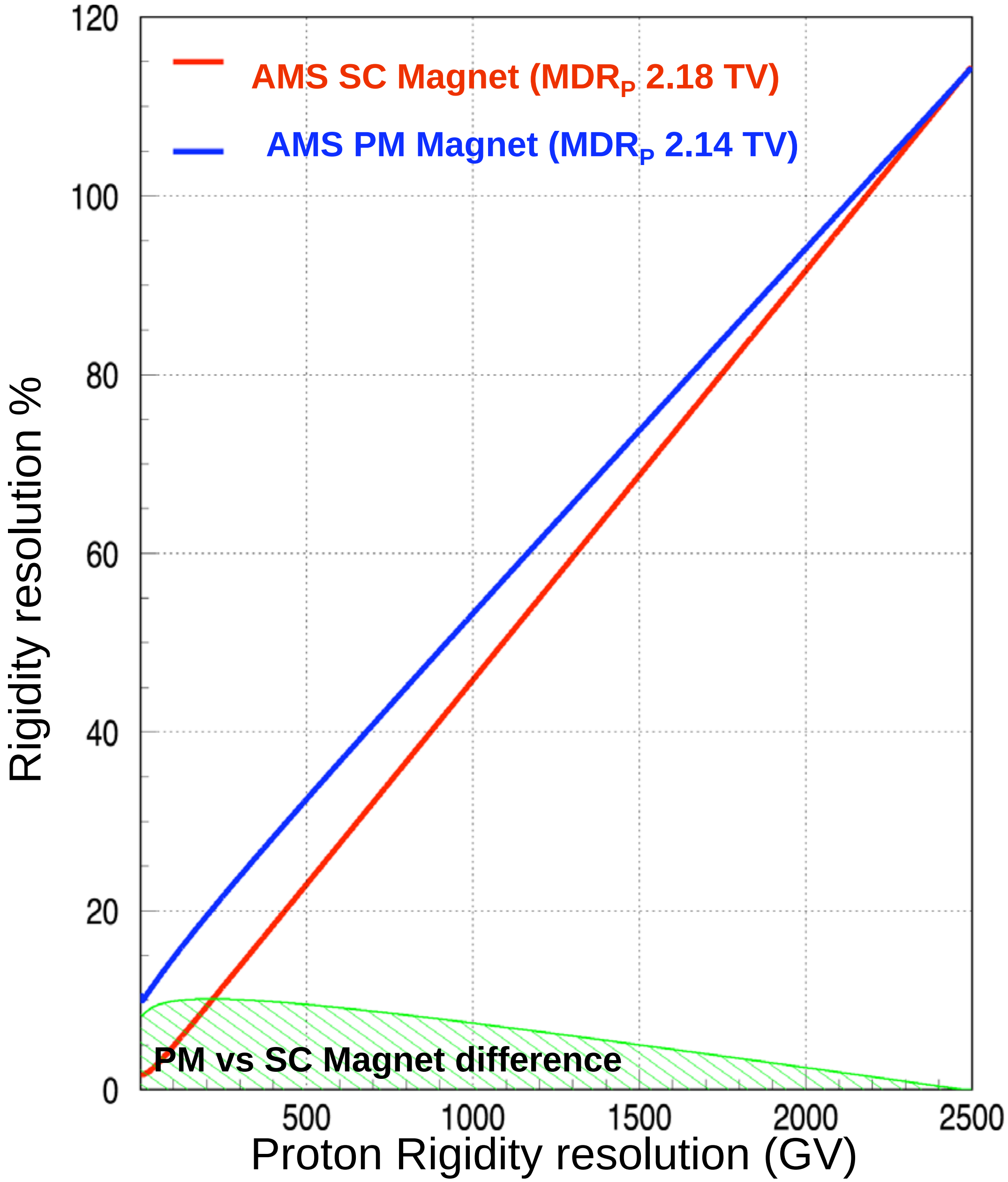




12000
(1.2cm)
10000
(1cm)
8000
(8mm)
6000
(6mm)
4000
(4mm)
2000
(2mm)
0
Plane Thermal Movement (μm)
1 minute Thermal Movement measurement
Simulated Top Plane Thermal Movement
20
40
60
80
Time (min)
1 minute Thermal Movement measurement
Simulated Bottom Plane Thermal Movement
20
40
60
80
Time (min)



Residual Top Plane Misalignment < 10 µm
Residual Top Plane Misalignment (µm)
10
5
0
-5
-10
20
40
60
80
Time (min)
Bottom Plane Misalignment < 10 µm
Residual Bottom Plane Misalignment (µm)
10
5
0
-5
-10
20
40
60
80
Time (min)



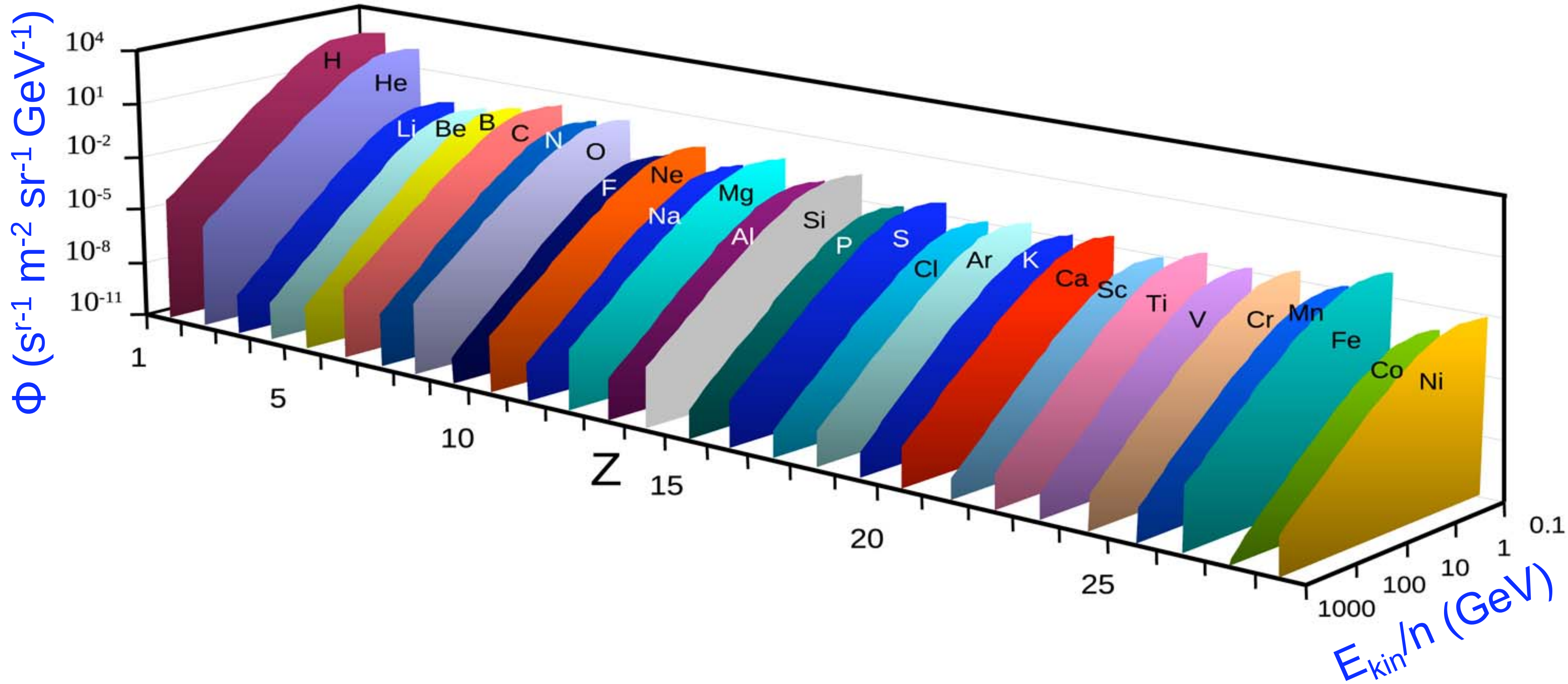
With 9 tracker planes, the resolution of AMS with the permanent magnet is equal (to 10%) to that of the superconducting magnet, but with the permanent magnet AMS will be active for the duration of the ISS.

Nuclear Abundances Measurements

AMS Physics examples

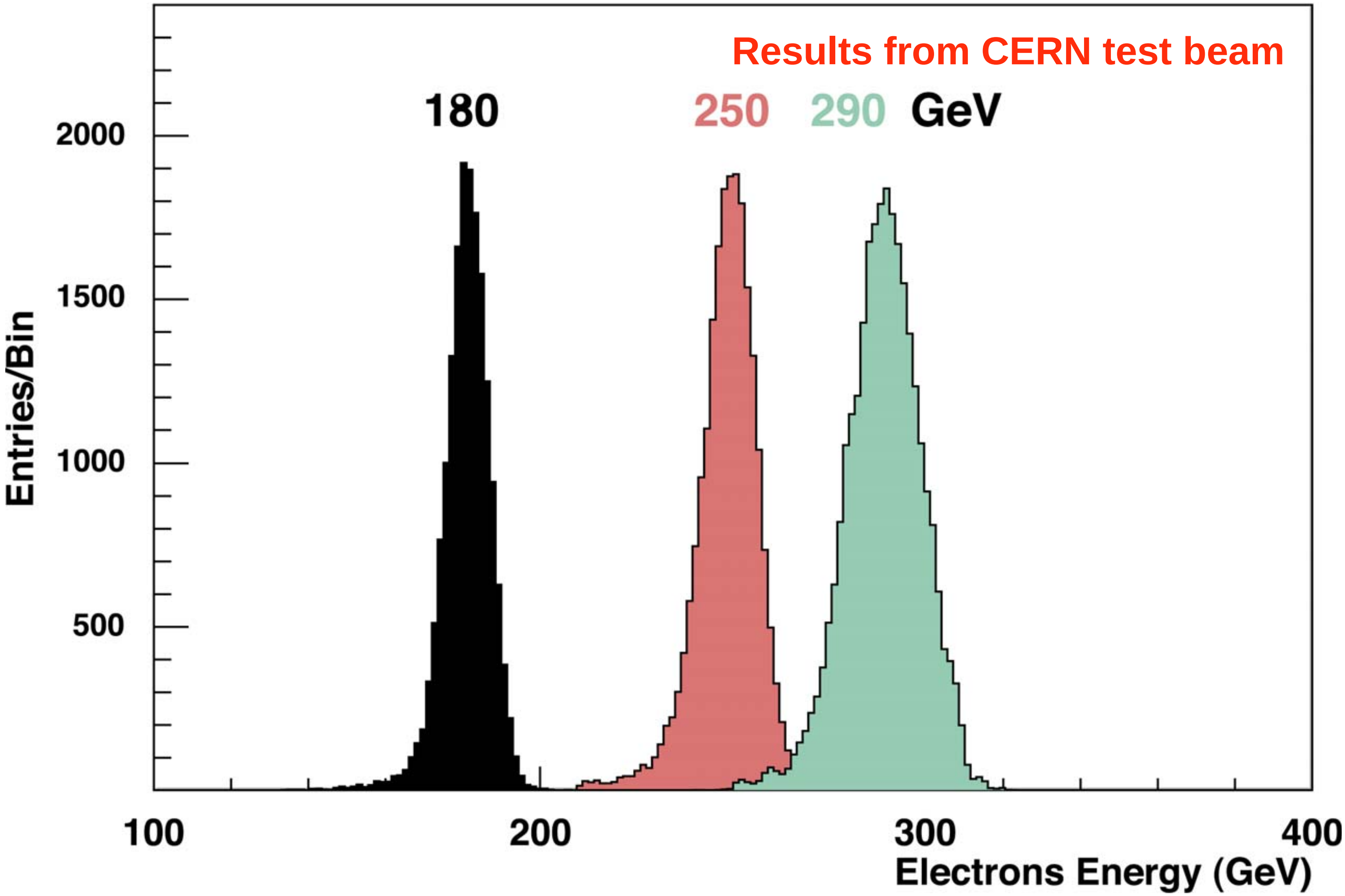
Precision study of the properties of Cosmic Rays

Composition at different energies (1 GeV, 100 GeV, 1 TeV)
continuously over eleven year solar cycle

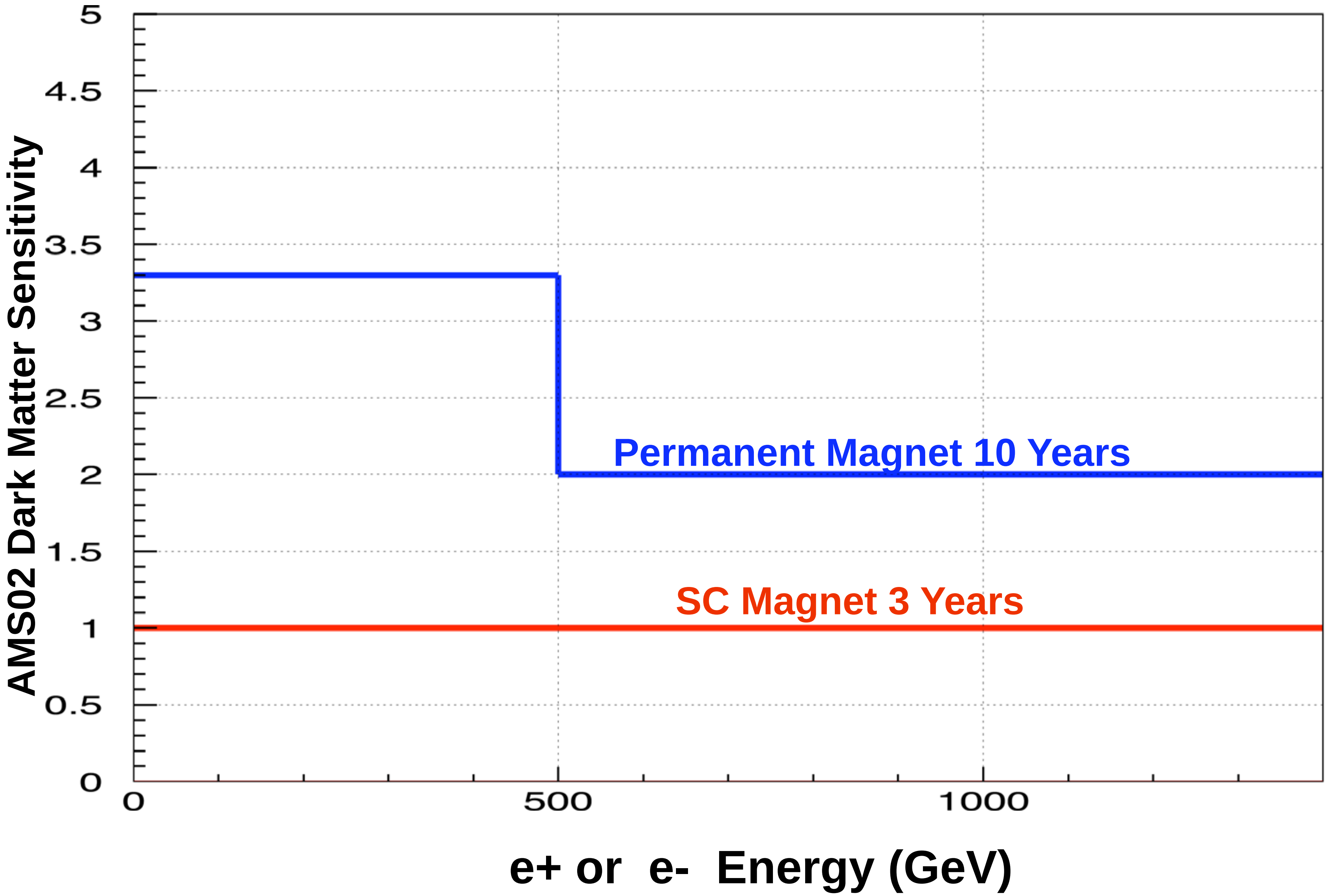


Due to the nearly equal charge separation there will be no difference in measuring nuclear abundances.

With the AMS-01 permanent magnet the resolution for e^+ and e^- remains the same as the superconducting magnet because the energies of e^+ and e^- are measured by the Electromagnetic Calorimeter (ECAL).
The magnetic field is used to determine the sign of the charge.



Dark Matter Searches

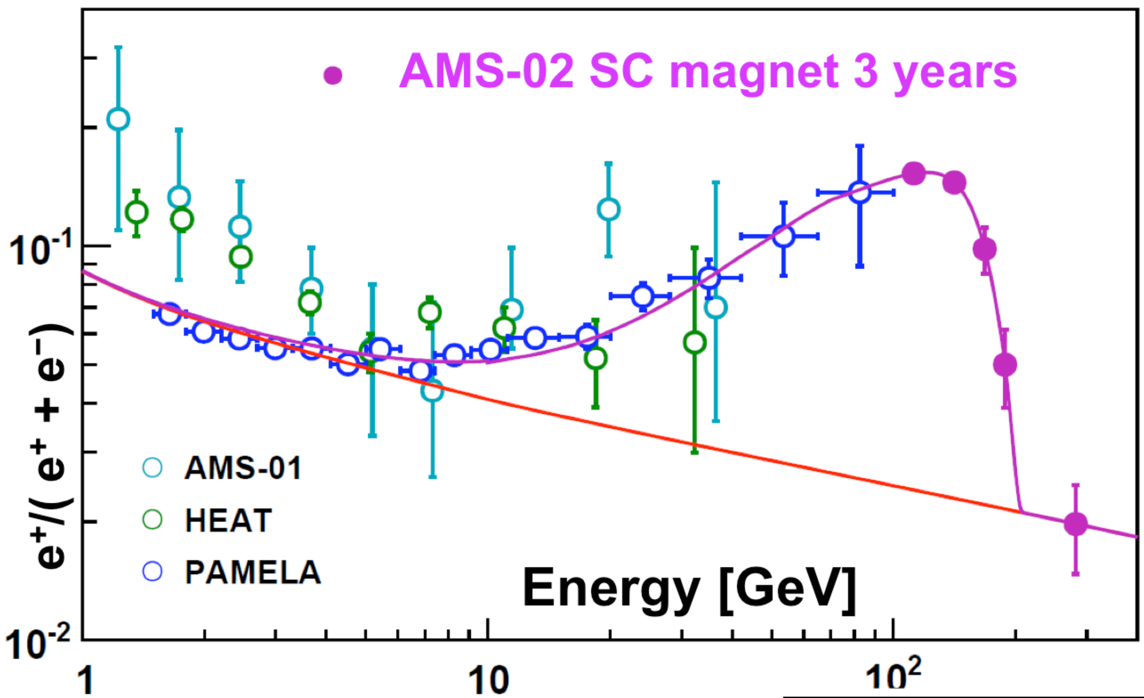


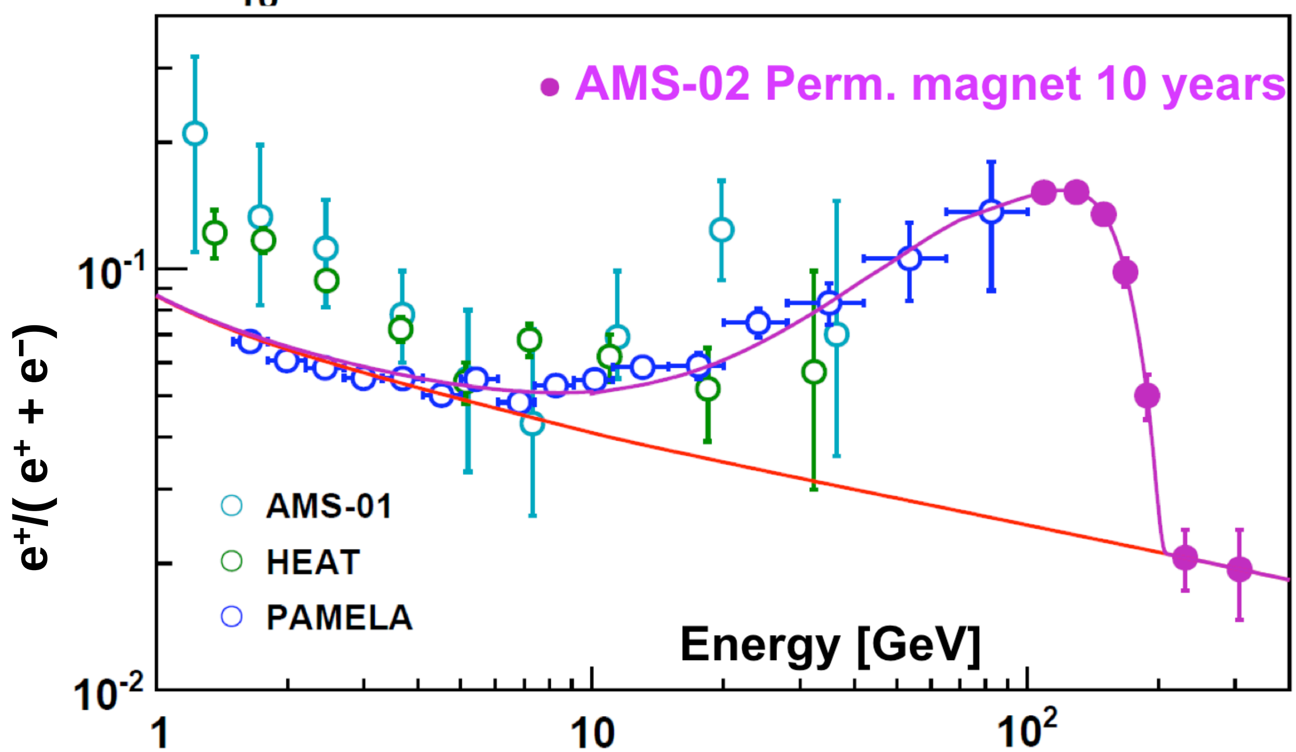
Permanent Magnet

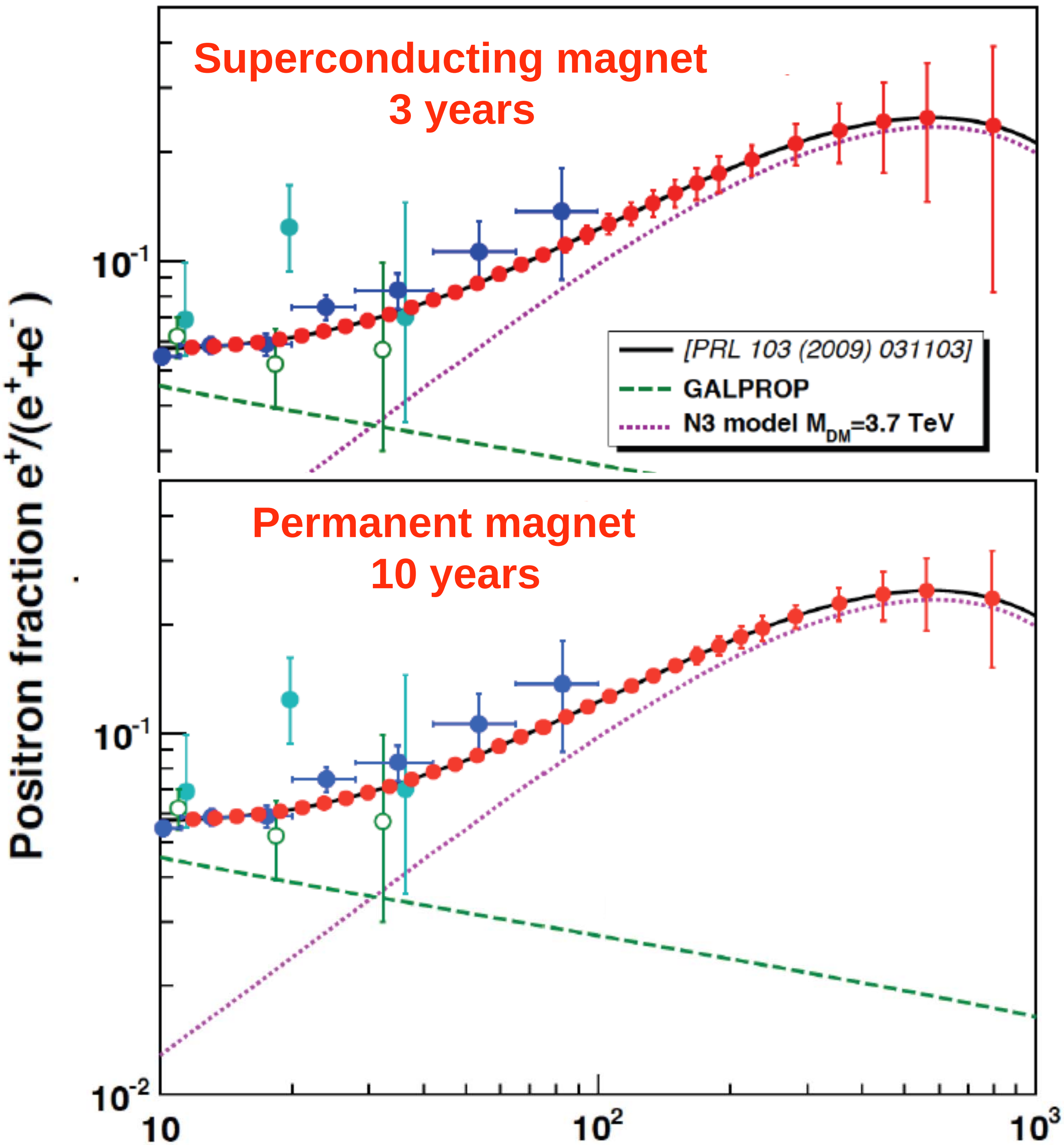
Physics example

Search for Cold Dark Matter: χ^0

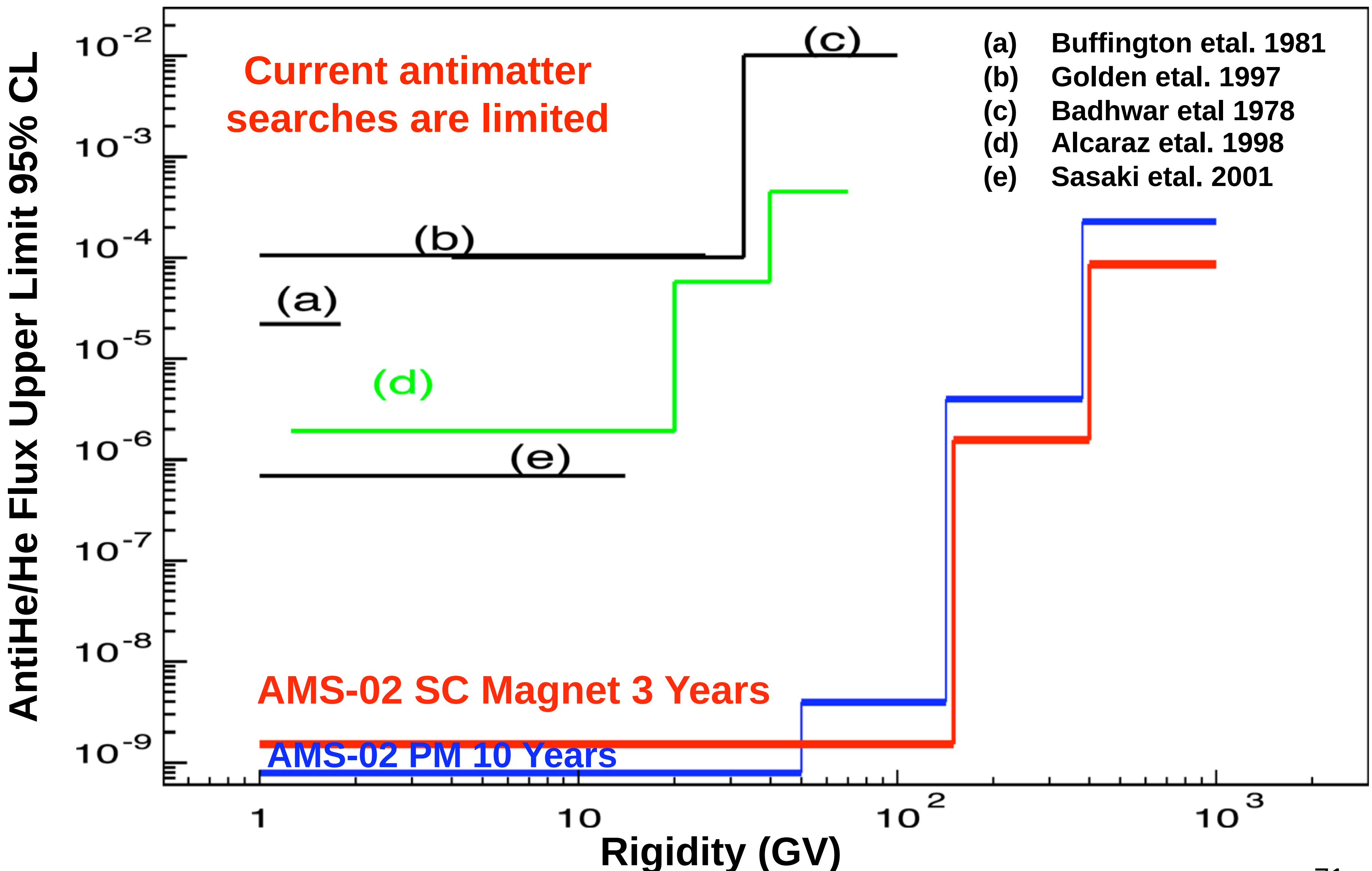
$$\chi 0 + \chi 0 \rightarrow e^+ + \dots$$



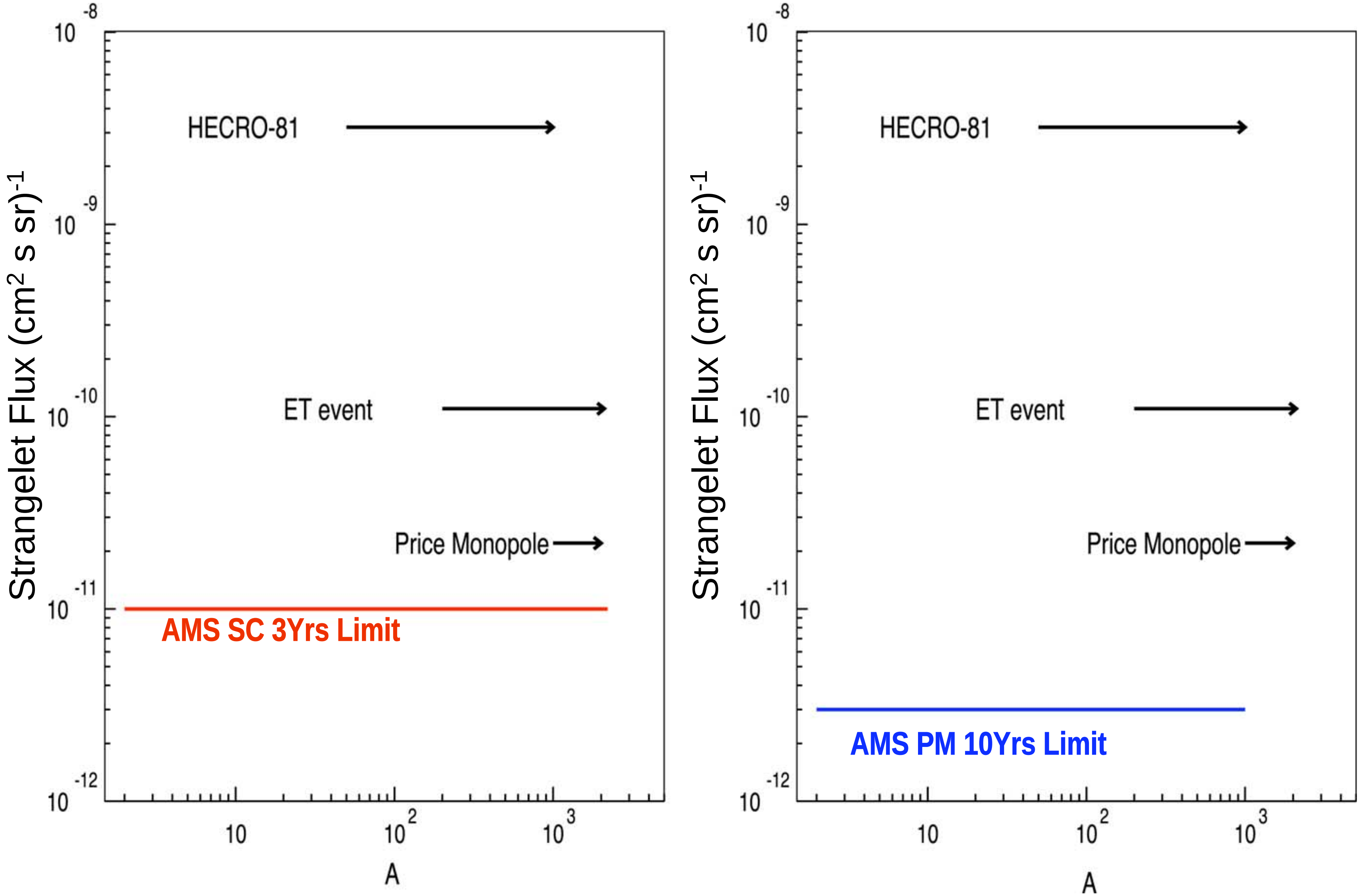



Superconducting magnet
3 years
Permanent magnet
10 years
Positron fraction e+/(e++e-)
[PRL 103 (2009) 031103]
GALPROP
N3 model M_DM=3.7 TeV
10^-1
10^-2
10
10^2
10^3

AMS-02 Antihelium Limits



Strangelets



Baseline Nominal Operations

Prelaunch – Payload Bay

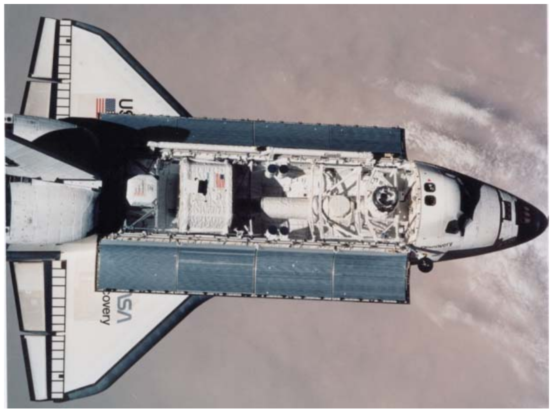
- T0 Umbilical power for Critical monitoring functions & J Crate
- T0 interface will be dead-faced prior to LCC time frame

Ascent

- Launch – T0 Disconnect
- No power required during ascent

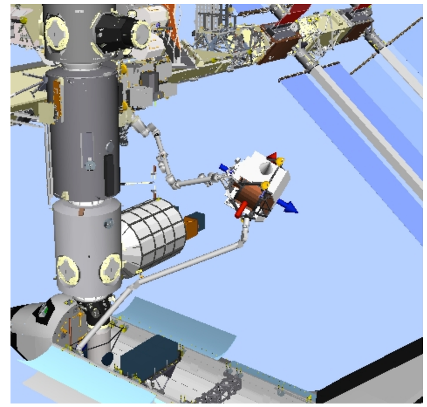
Baseline Nominal Operations

On-Orbit STS Operations



- Power up experiment (Max – 2.4kW)
- Activate and thermally condition experiment
- Dock to ISS on MET Day 3

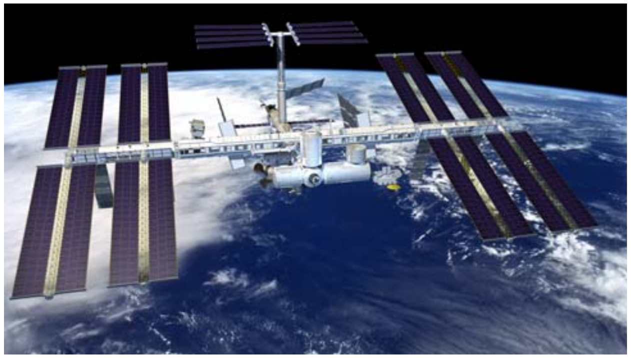
Transfer



- Grapple AMS FRGF with SRMS
- Disconnect Remotely Operated Electrical Umbilical (ROEU)
- Release longeron and keel trunnions
- Remove AMS from payload bay
- Handoff from SRMS (FRGF) to SSRMS (PVGF)
- Place AMS on S3 Upper Inboard Payload Attach Site using External Berthing Cues System (EBCS)
- Attach AMS mechanically with PAS and electrically with UMA

Baseline Nominal Operations

On-Orbit ISS Operations



- Activate Experiment
- 10 Years of Continuous Operations
- Primary control from ground (JSC POCC or CERN POCC)
- AMS will de-orbit with the ISS

Design Change Goals

- In summary, the AMS team realizes that the proposed changes will be difficult, so we have been driven by the following goals
  1. Only make changes that are absolutely necessary. This includes design and operations changes.
  2. Do not change any electronics unless it means completely eliminating systems associated with the superconducting magnet.
  3. Minimize changes that require documentation changes.
  4. For new mechanical construction, either utilize existing designs or design with extremely high factors and margins of safety because additional scheduled does not easily accommodate additional structural testing