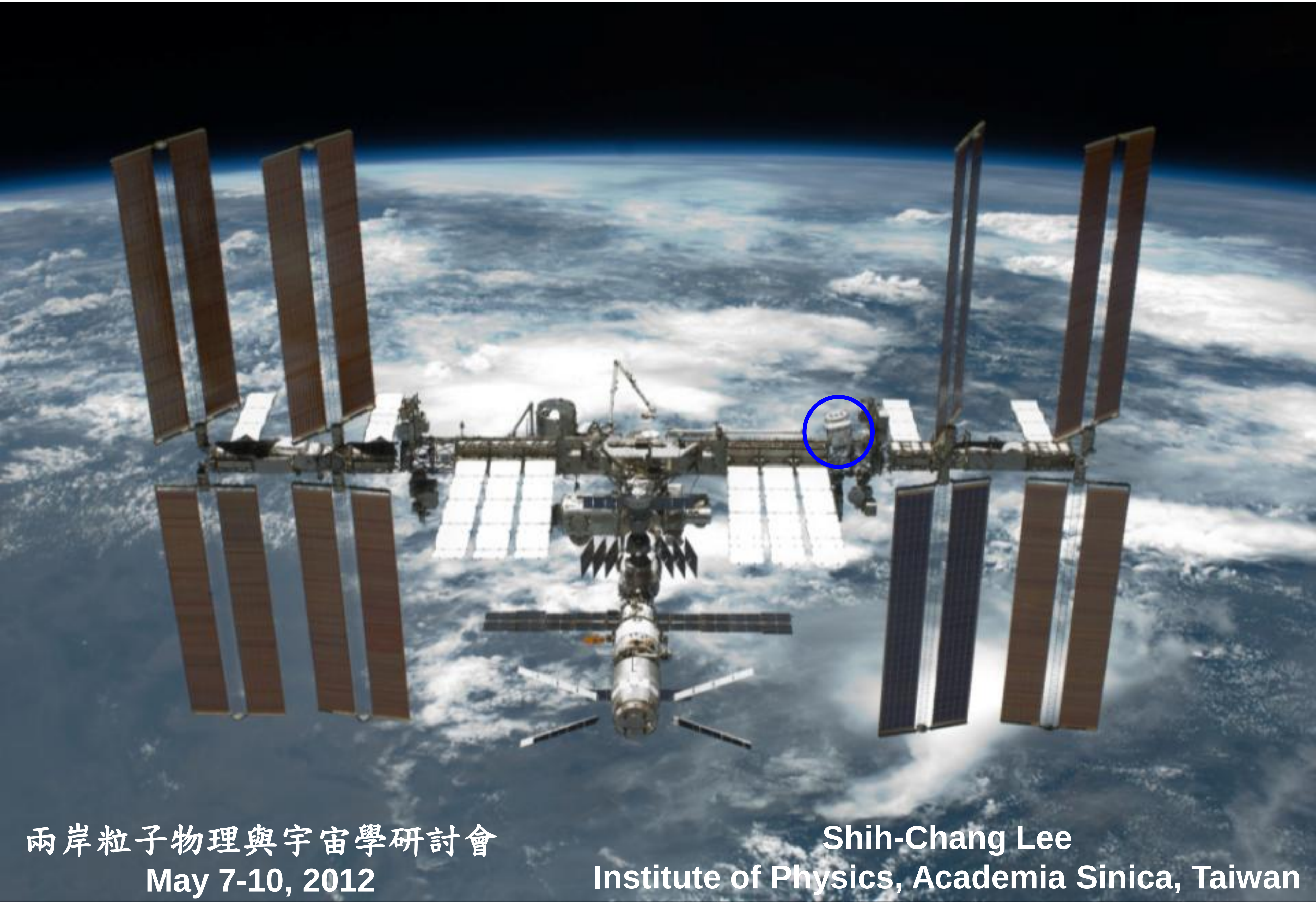
Status of the Alpha Magnetic Spectrometer Experiment

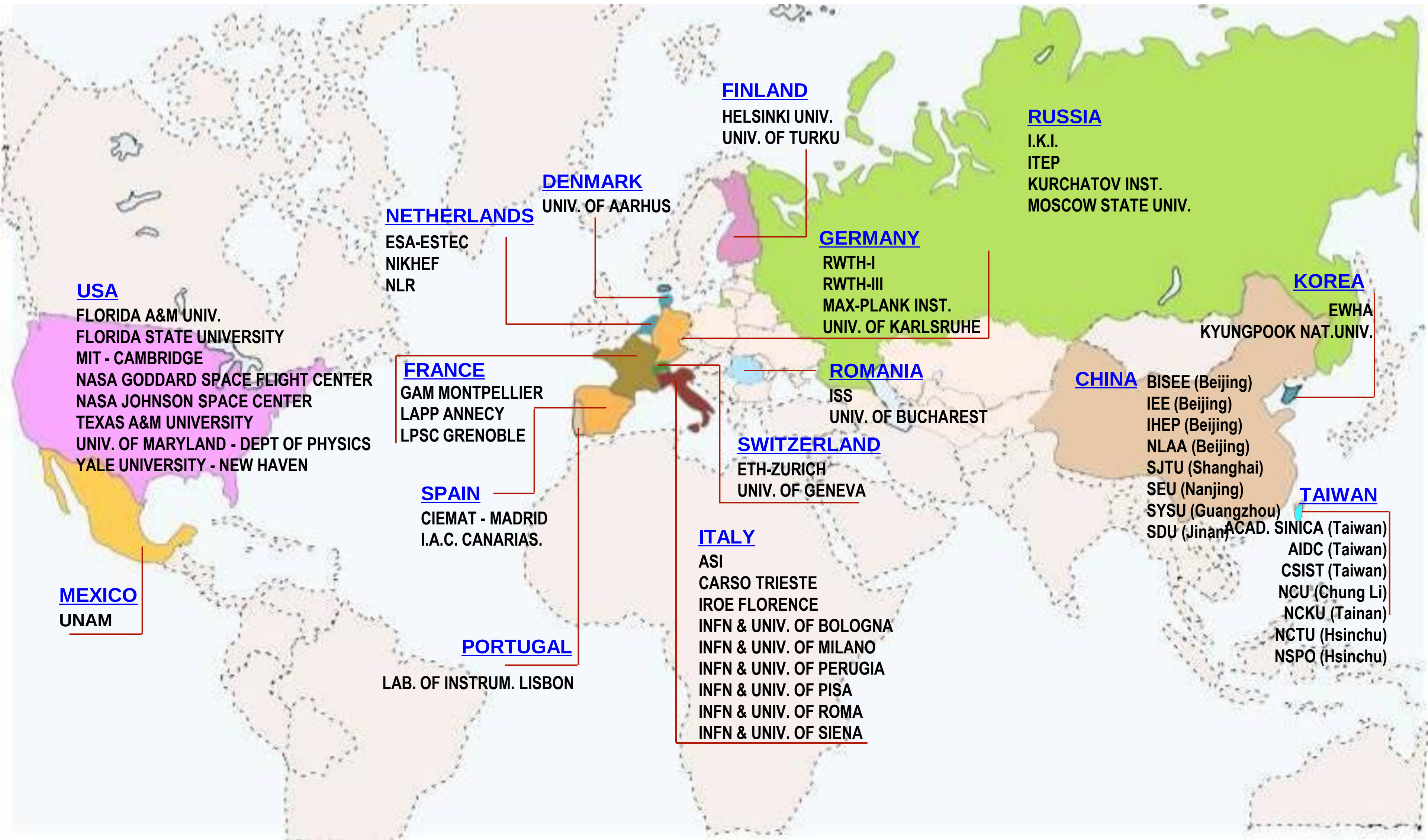


兩岸粒子物理與宇宙學研討會
May 7-10, 2012

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

AMS is an International Collaboration

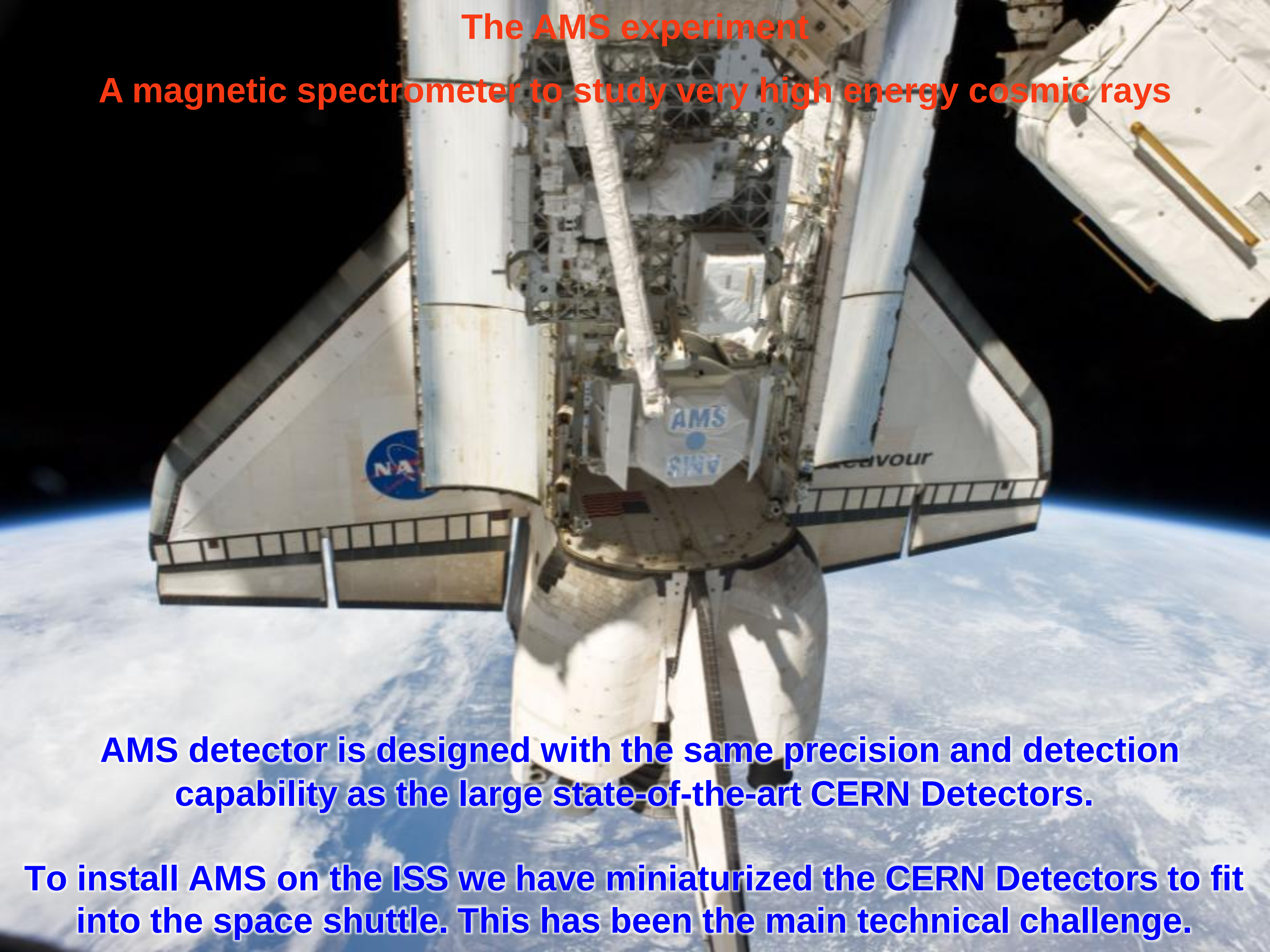
16 Countries, 60 Institutes and 600 Physicists, 17 years



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

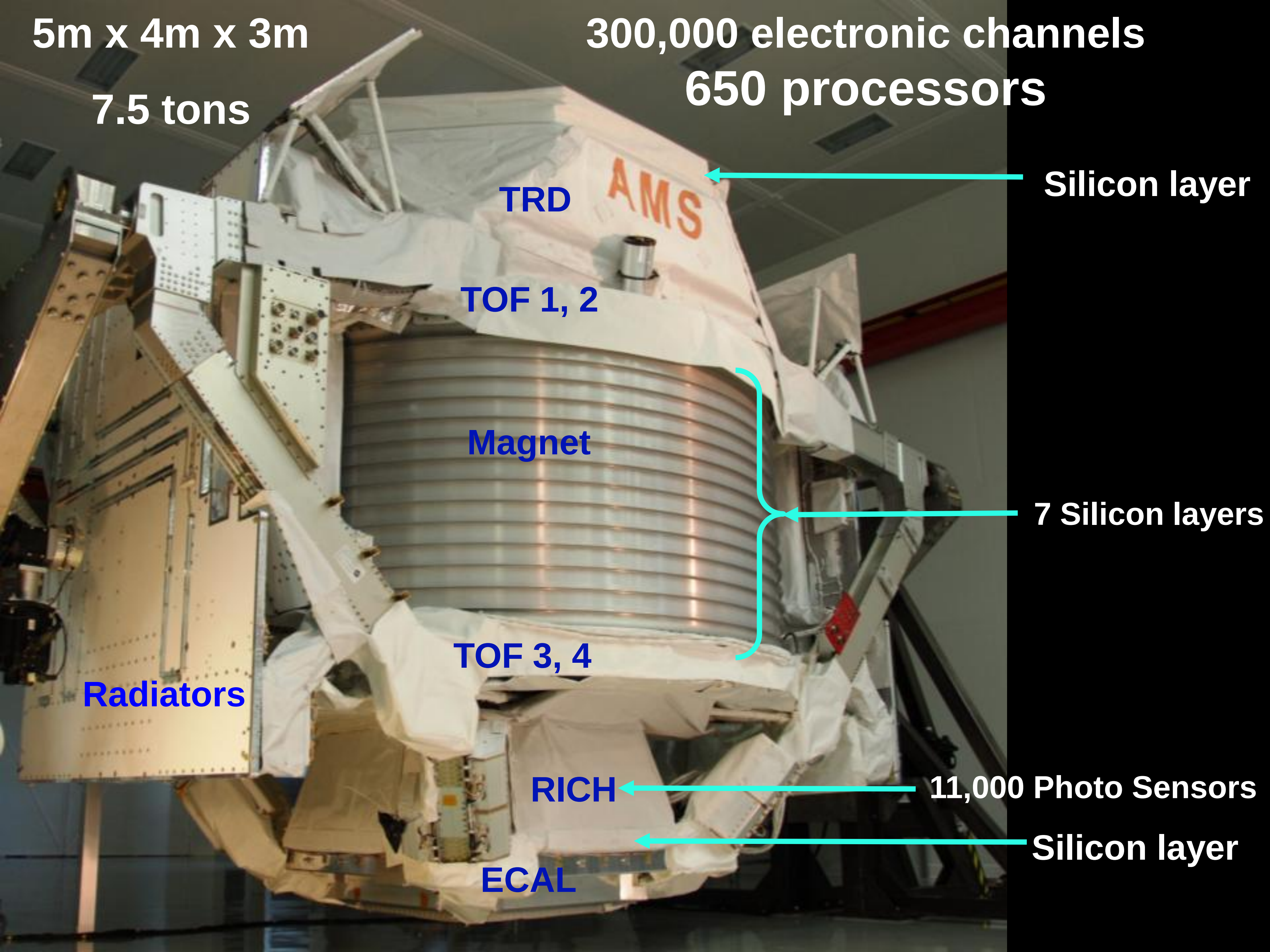
The AMS experiment

A magnetic spectrometer to study very high energy cosmic rays



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

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

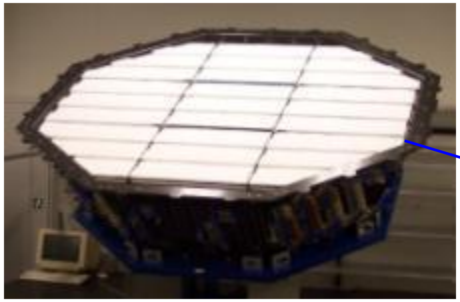

5m x 4m x 3m
7.5 tons
300,000 electronic channels
650 processors
Silicon layer
TRD
AMS
TOF 1, 2
Magnet
7 Silicon layers
TOF 3, 4
Radiators
RICH
11,000 Photo Sensors
Silicon layer
ECAL

AMS mated with the Payload Attach System simulator (A) during Space Station interface verification test

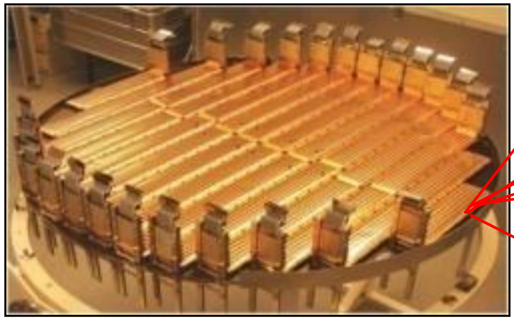
AMS: A TeV precision, multipurpose particle physics spectrometer in space.

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

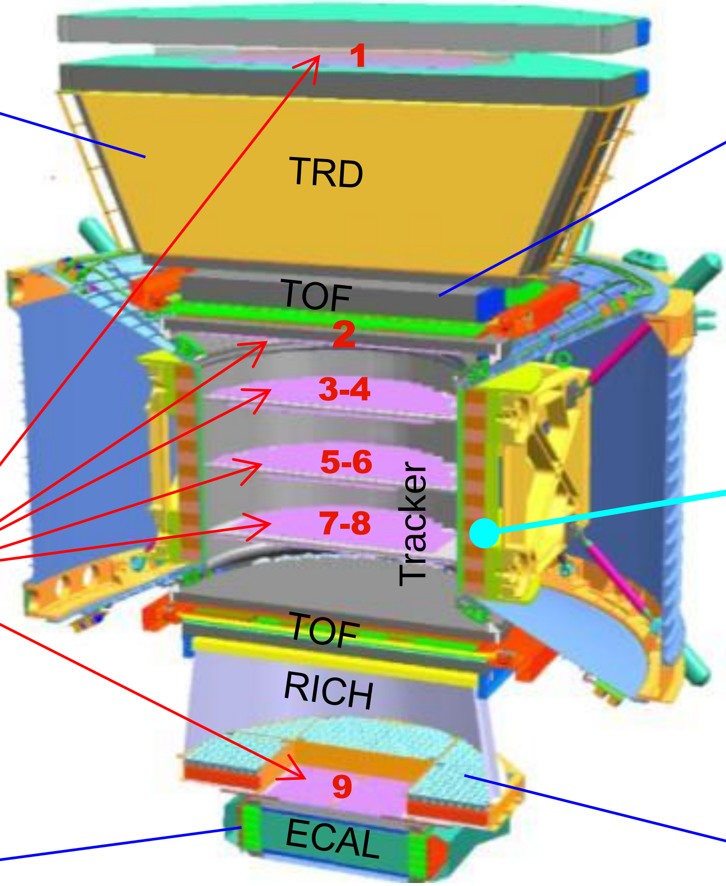
TRD
Identify e+, e-



Silicon Tracker
Z, P

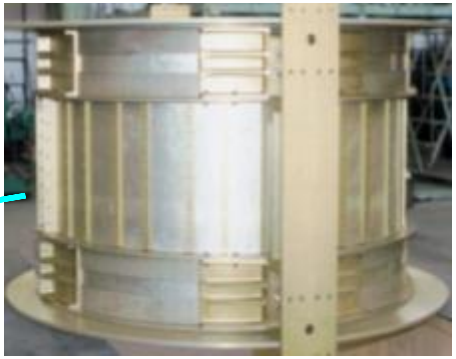


ECAL
E of e+, e-, γ

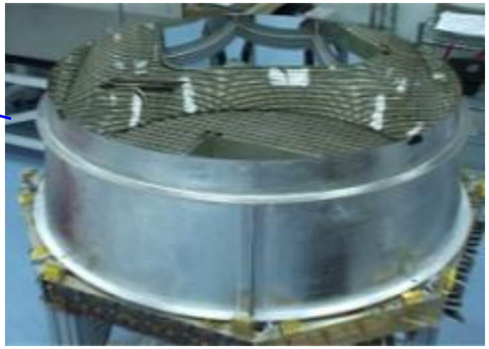


TOF
Z, E

Magnet
±Z



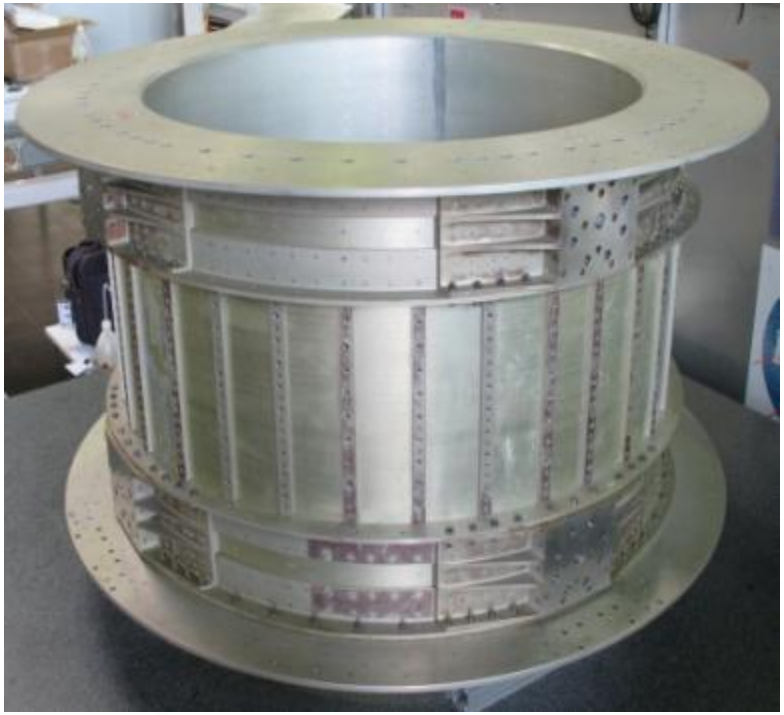
RICH
Z, E



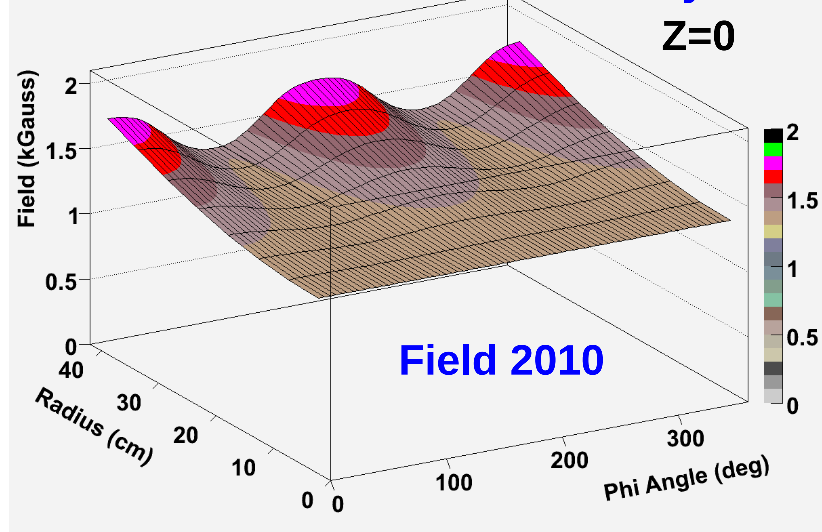
Z, P are measured independently by the Tracker, RICH, TOF and ECAL

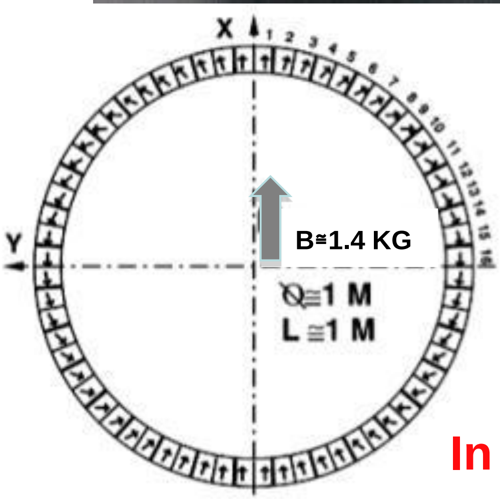
1. Stable: no torque
2. Safety : no field leak out of the magnet
3 . Low weight: no return iron

The Magnet



The detailed 3D field map (120k locations) was measured on 25-27 May 2010



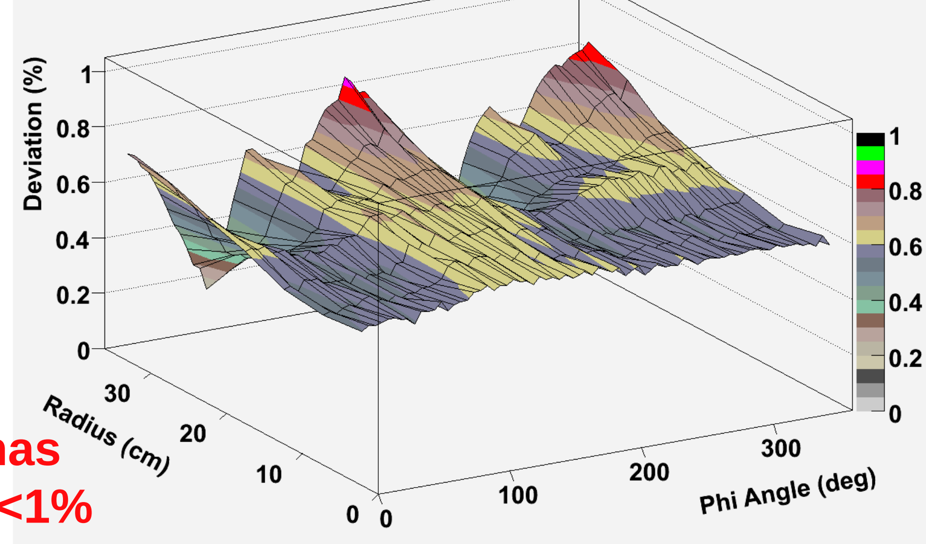


Permanent Magnet

$B_{max} \cong 0.14$ T

$BL^2 = 0.15$ Tm^2

Deviation from 1997 measurement



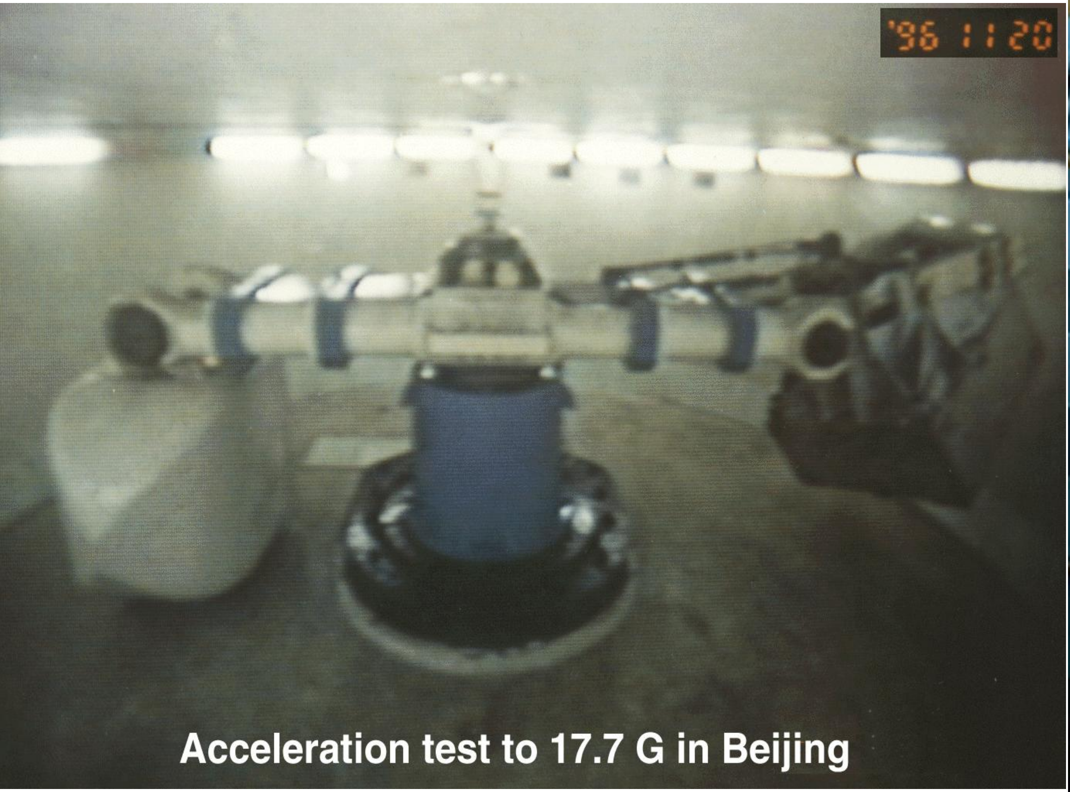
In 12 years the field has remained the same to <1%

The Permanent Magnet was manufactured at IEE, CAS

For AMS-01, 10 Magnets were made:

Seven magnets to understand
the field calculation, leakage and dipole moment

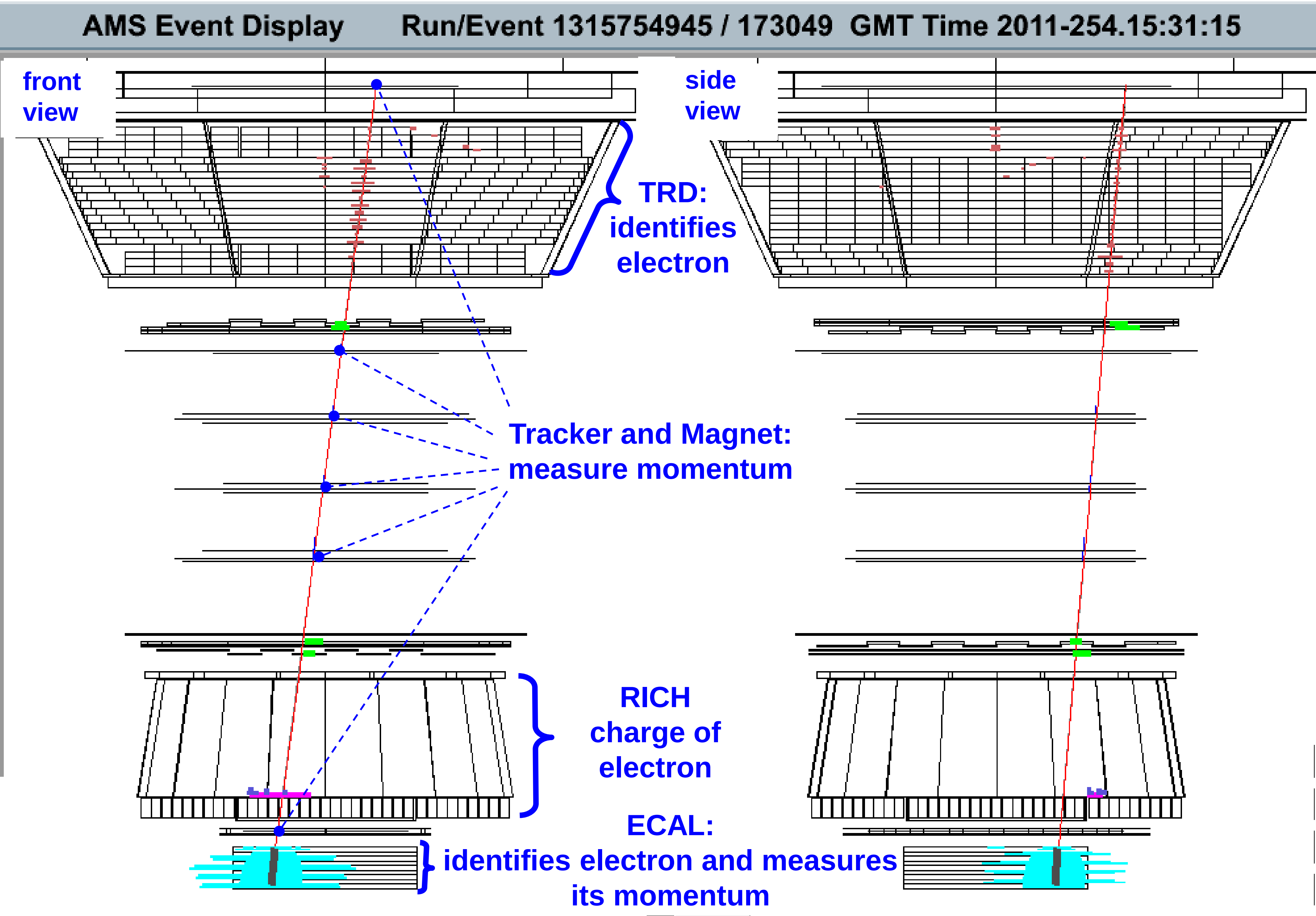
Three full-size magnets for
1) space qualification, 2) destructive testing and 3) flight



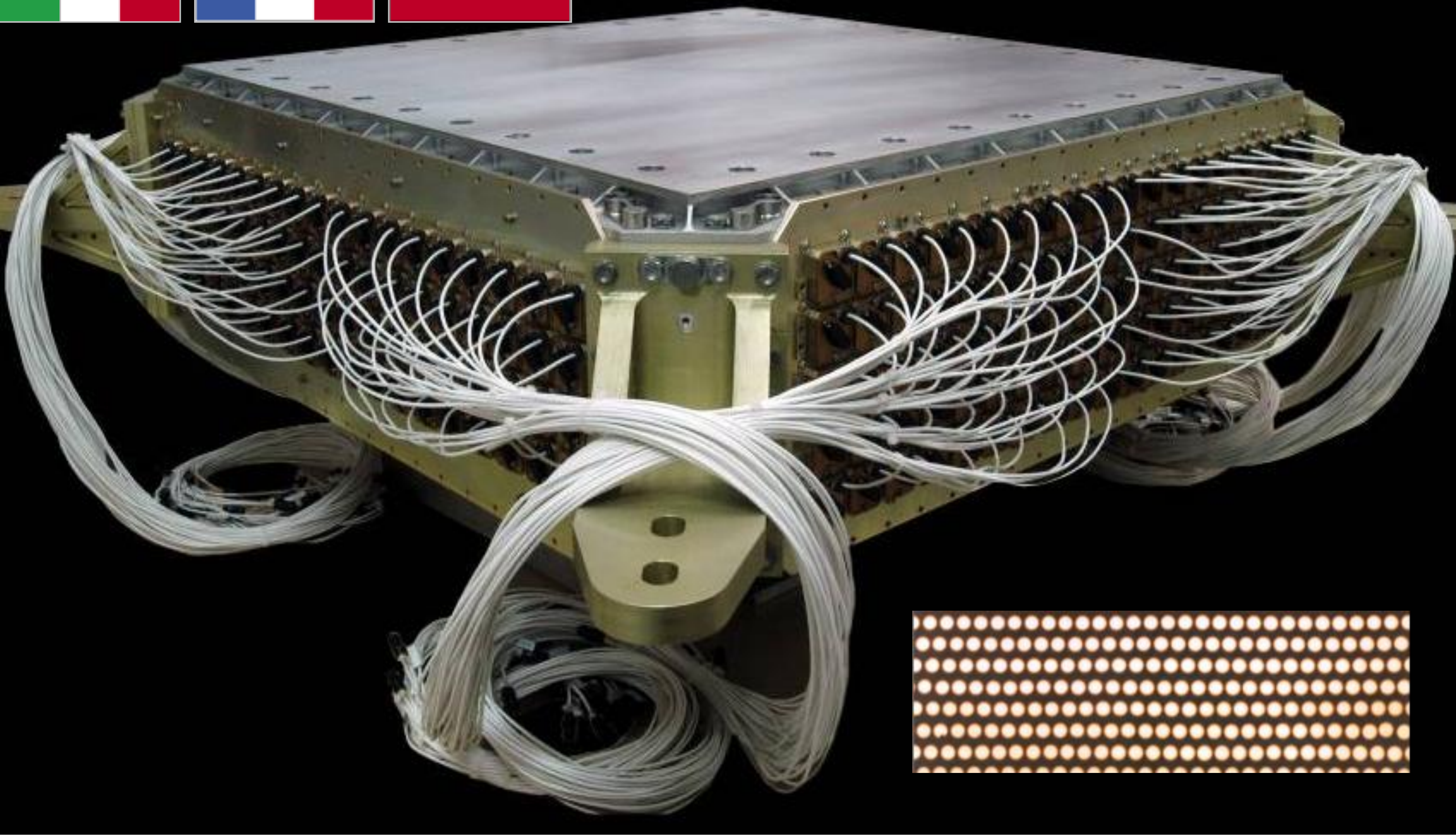
Acceleration test to 17.7 G in Beijing

Magnet vibration qualification
at CALT, Beijing

1.03 TeV electron

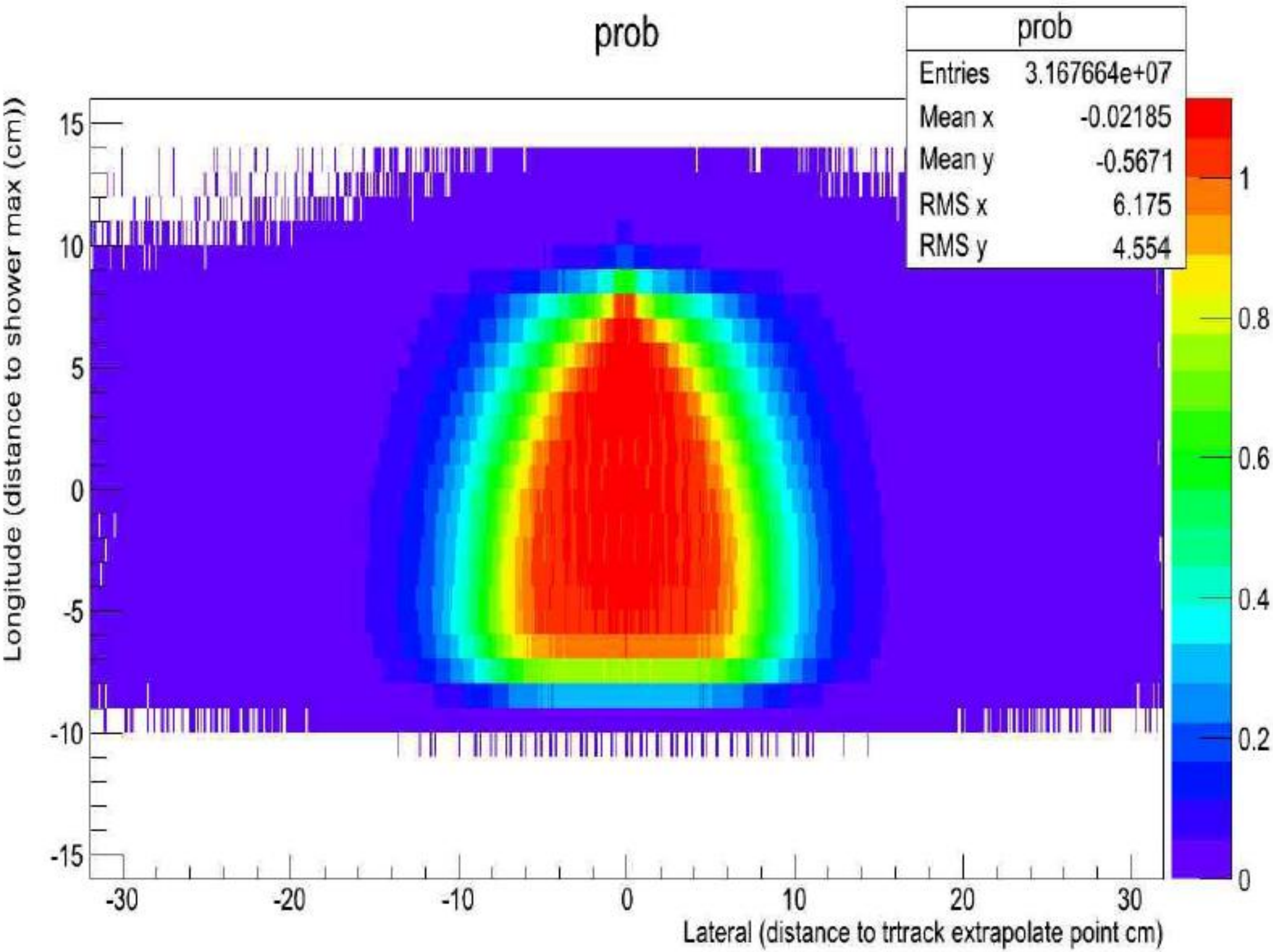


Calorimeter (ECAL)



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

Electron Shower Shape in ECAL



Kaiyuan Wu, private

Physics of AMS: Search for Antimatter Universe

AMS on ISS

The Universe began with the Big Bang.
After the Big Bang there were
equal amounts of matter and
antimatter.

It is known that the Milky Way and the galaxies around it are made of matter predominantly.
Where are the primordial antimatter in the Universe?

anti-Helium?
anti-Carbon?

Experimental work on Antimatter in the Universe

Direct search

AMS

Increase in sensitivity: x 10^3 – 10^6

Increase in energy to ~TeV

Search for Baryogenesis

New CP

BELLE

BaBar

(sin 2β= 0.672±0.023 consistent with SM)

FNAL KTeV

(Re(ε'/ ε) = (19.2±2.1)*10^{-4})

CERN NA-48

CDF, D0

LHC-b

ATLAS

CMS

Proton decay

Super K

(τ_p > 6.6 * 10^{33} years)

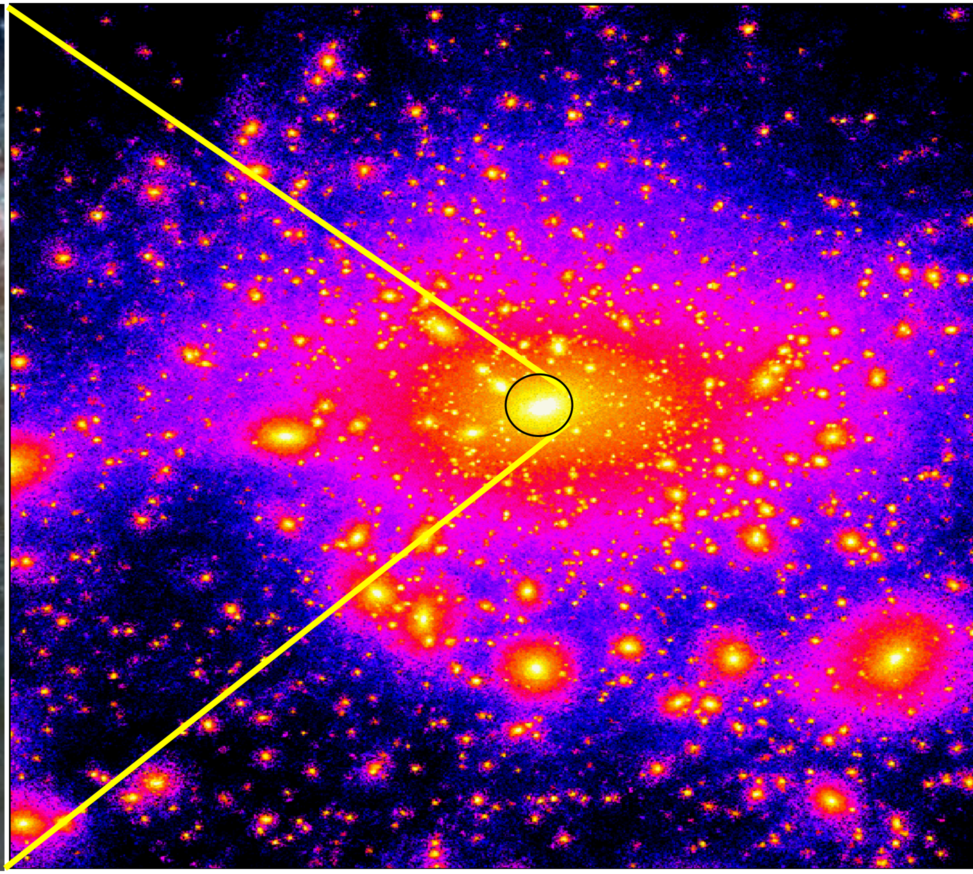
y06K299a

The physics of AMS include:

The Origin of Dark Matter

~ 90% of Matter in the Universe is not visible and is called Dark Matter

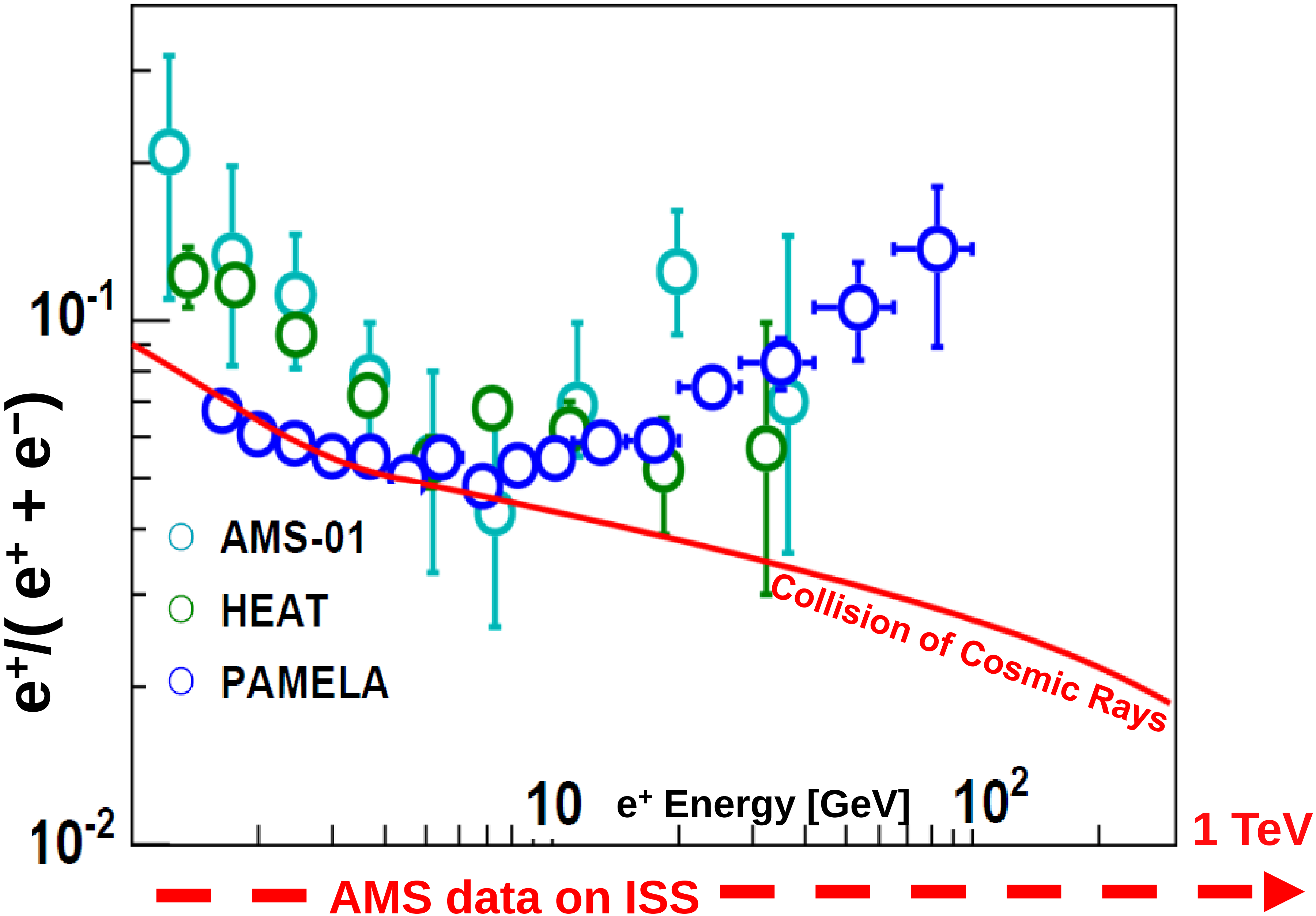
A Galaxy as seen by telescope



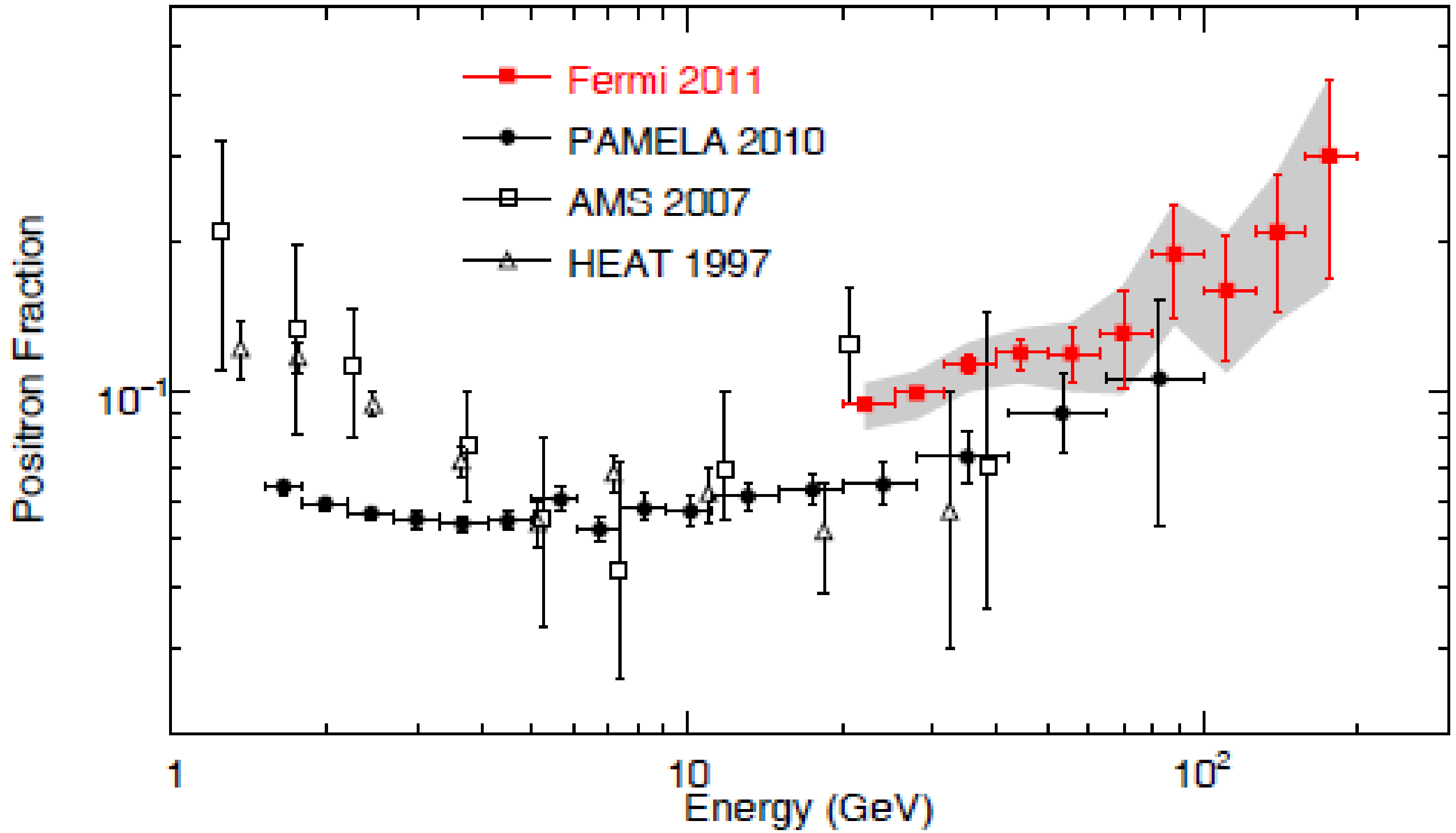
If we could see Dark Matter in the Galaxy

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

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



Measurement of Separate Cosmic-Ray Electron and Positron Spectra with the Fermi Large Area Telescope



Phys. Rev. Lett. 108, 011103 (2012)

FIG. 5: Positron fraction measured by the Fermi LAT and by other experiments [7, 14, 16]. The Fermi statistical uncertainty is shown with error bars and the total (statistical plus systematic uncertainty) is shown as a shaded band.

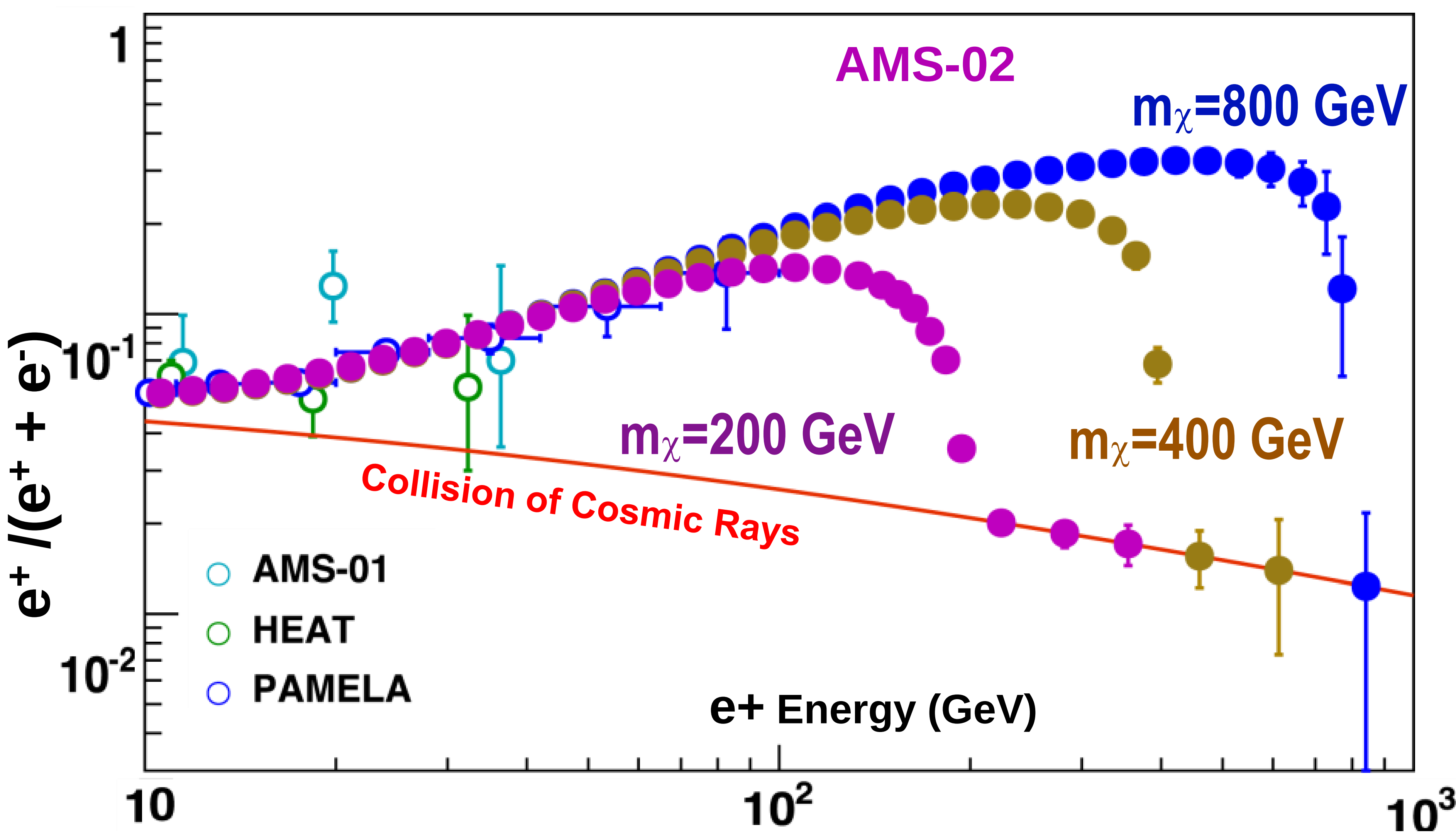
Science NOW UP TO THE MINUTE NEWS FROM SCIENCE

Cosmic Antimatter Excess Confirmed

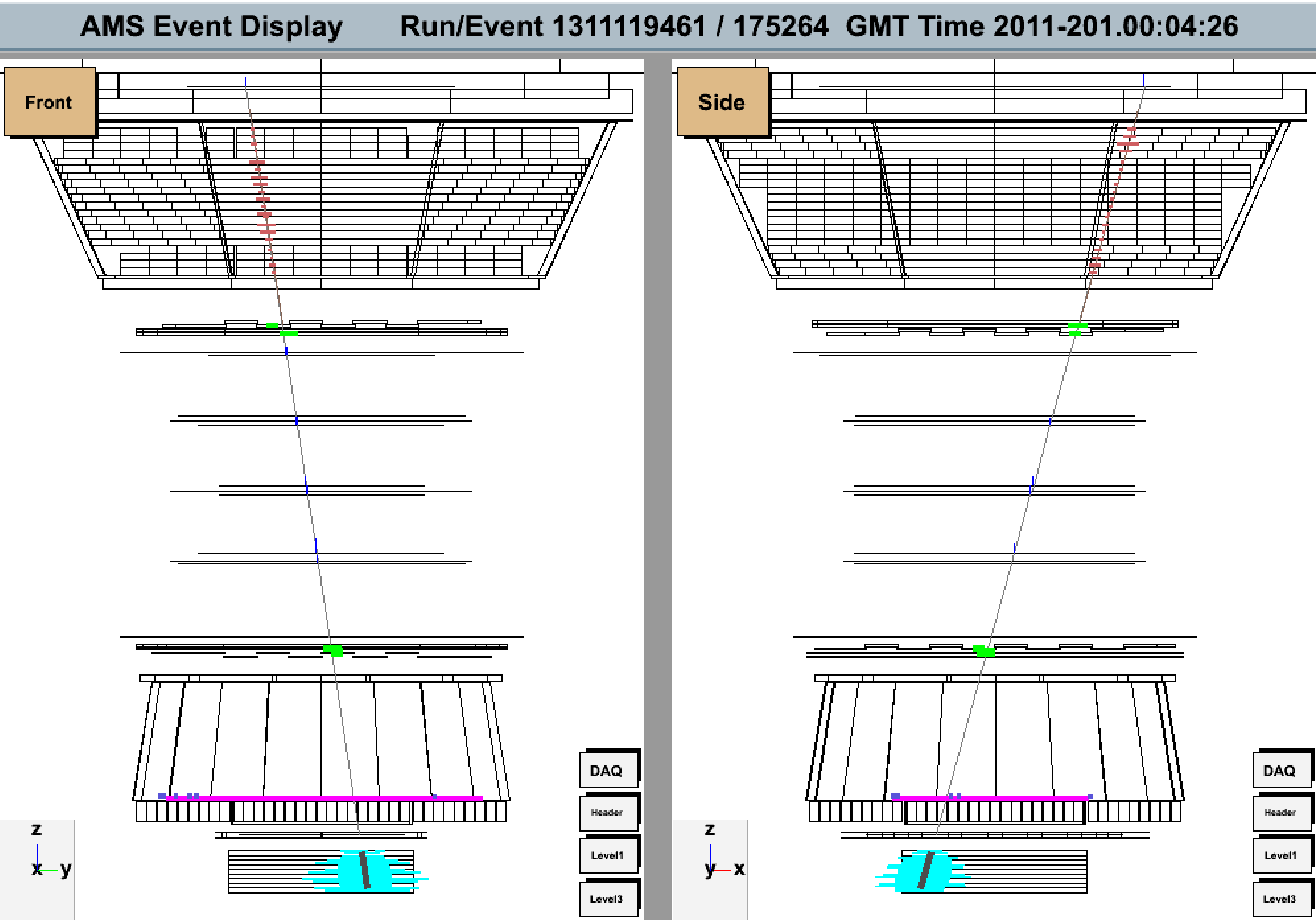
by Geoffrey Koch on 22 November 2011, 4:13 PM

The search for Turner's "smoking gun" is now counting on another detector, the $2.2 billion internationally funded Alpha Magnetic Spectrometer (AMS-02), which was carried to the International Space Station in May. AMS-02 includes a powerful magnet to parse cosmic rays and should be able to probe for the positron excess, and the sudden drop-off, at significantly higher energies than the Fermi telescope can manage. "AMS-02 should be able to make a final statement on this," Funk says. "This is something we are all eagerly awaiting."

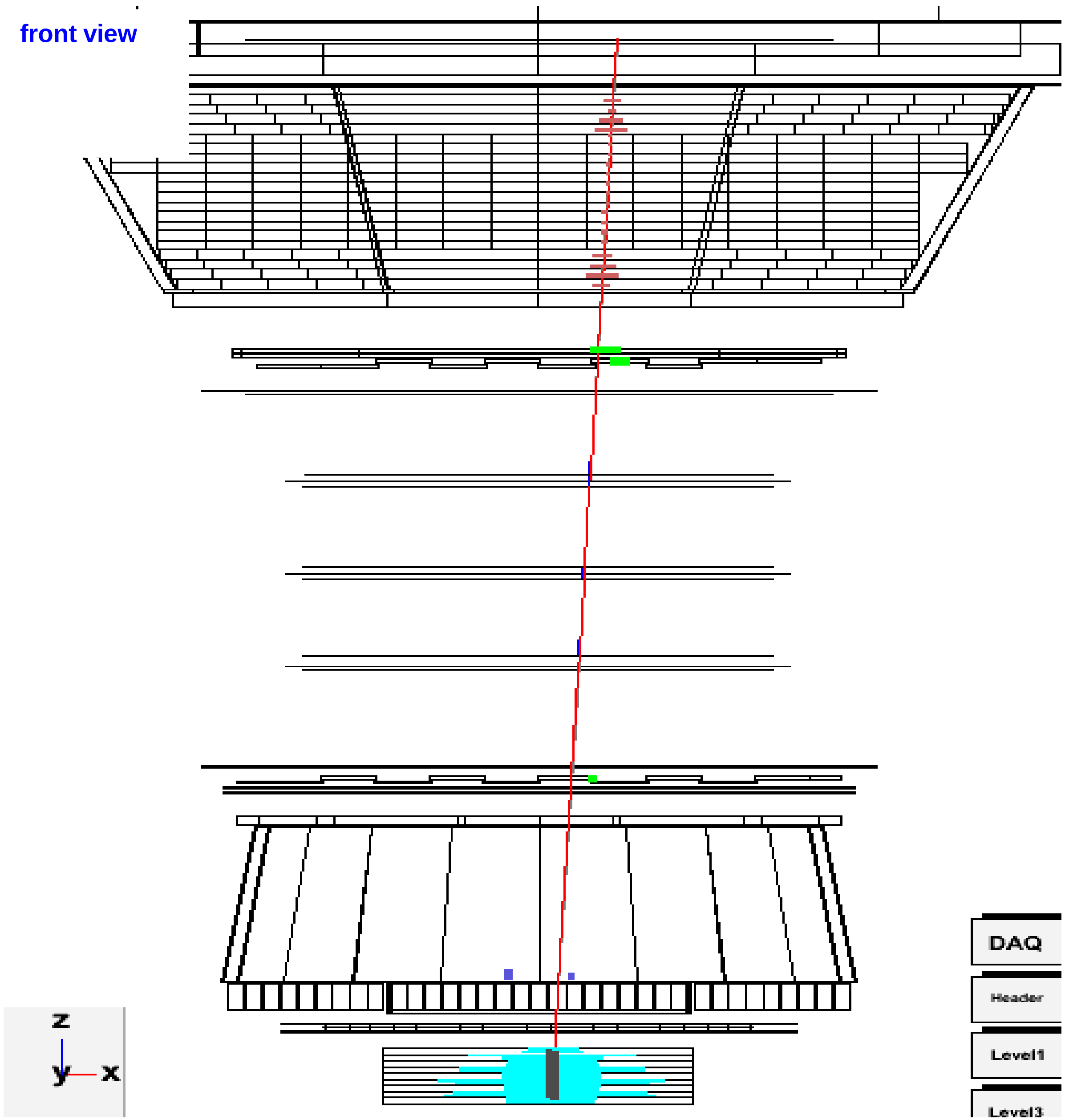
Detection of High Mass Dark Matter from ISS



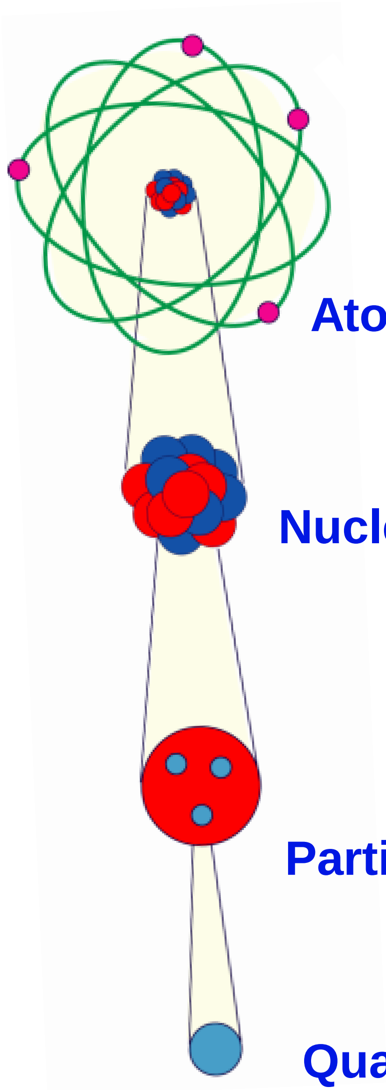
205 GeV positron



424 GeV positron

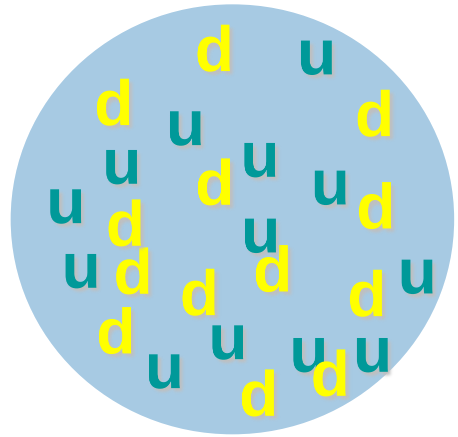


Science Example: Strange Quark Matter – "Strangelets"



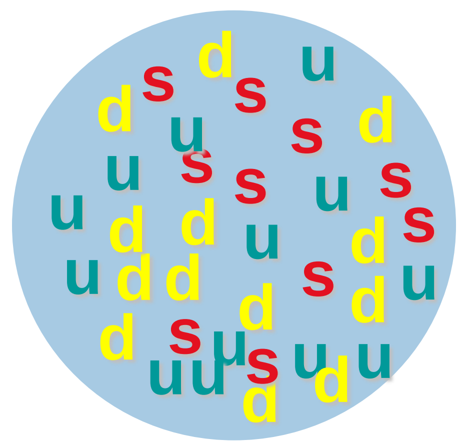
u, d, s, c, b, t

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**

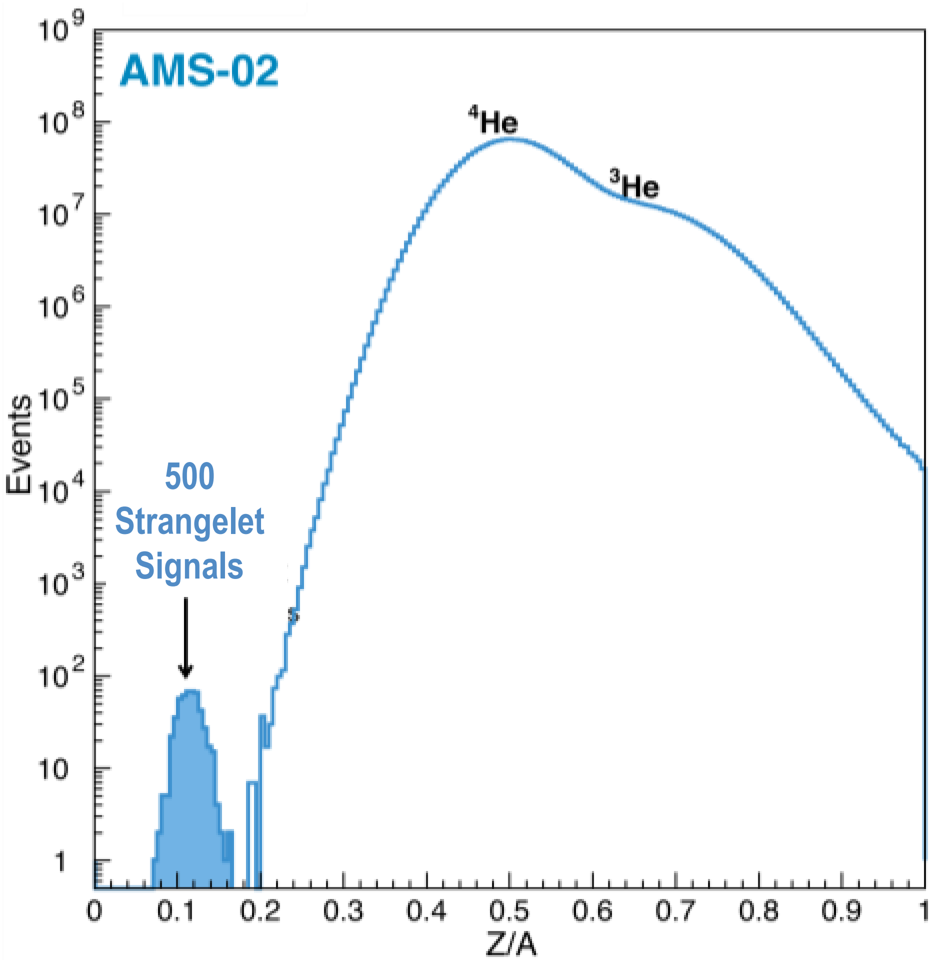
Strangelets

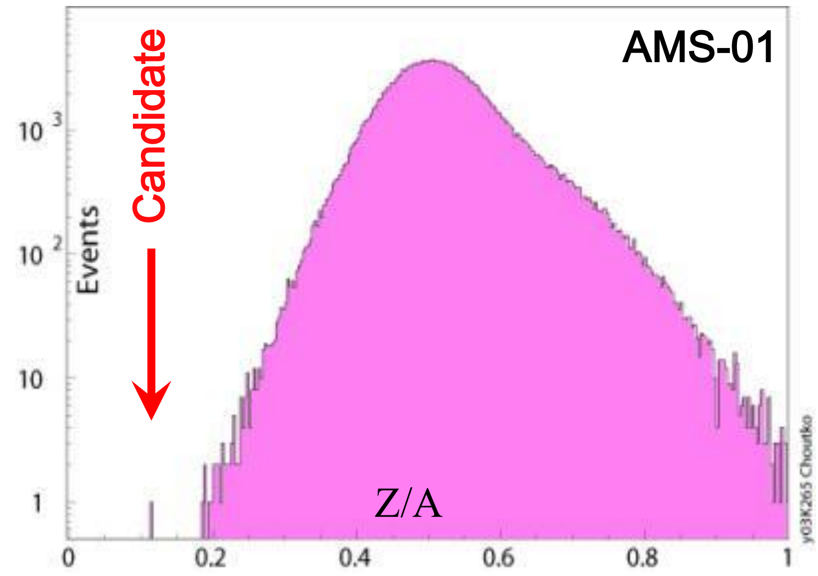
E. Witten, Phys. Rev. D,272-285 (1984)

All the known material on Earth is made out of u and d quarks.
Is there material in the universe made up of u, d, & s quarks?

Z/A~0.1

Candidate observed with AMS-01 5 June 1998 11:13:16 UTC

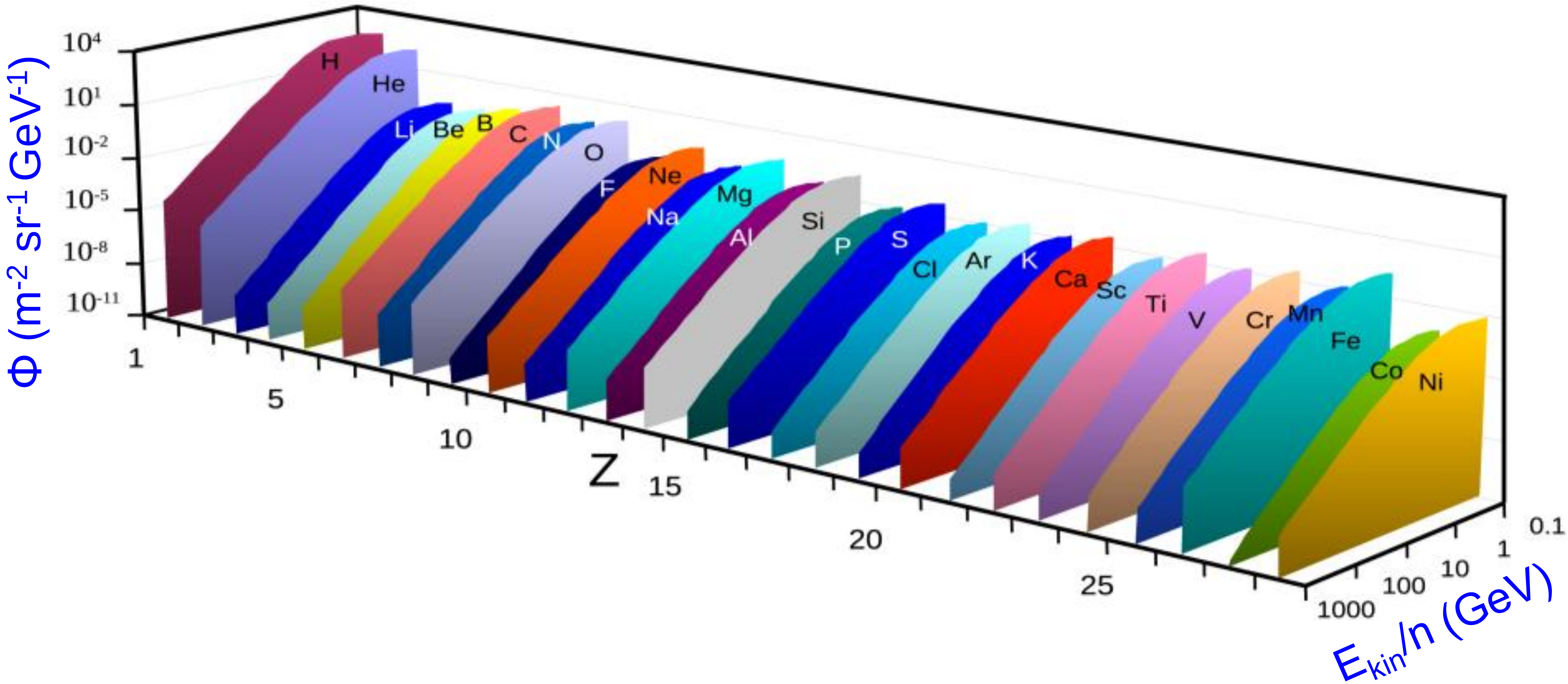




$$\Phi_{strangelets} = 5x10^{-10}(cm^2 s\ sr)^{-1}$$

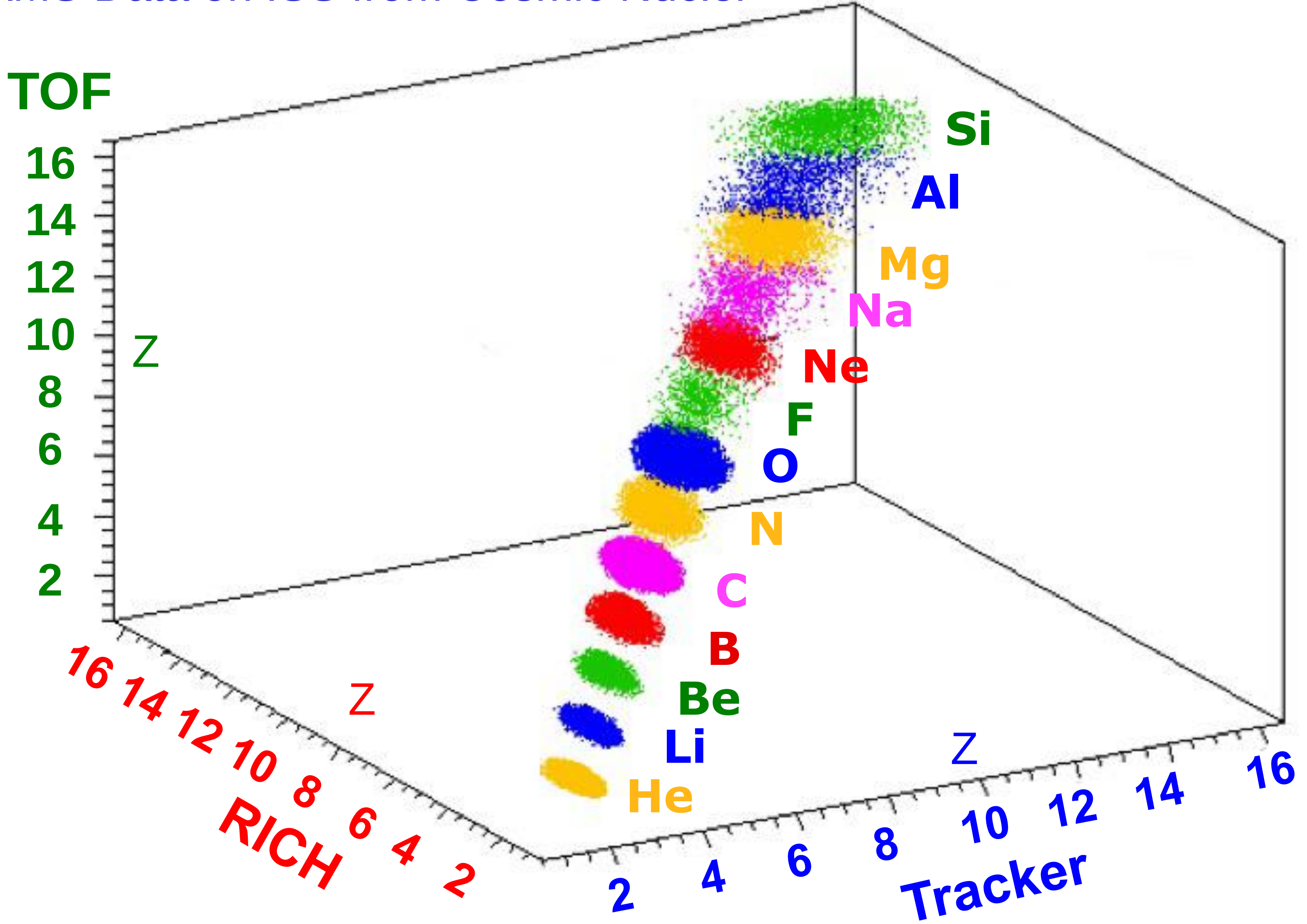
Physics of AMS: Nuclear Abundances Measurements

For energies from 100 MeV to 1 TeV
with 1% accuracy over the 11-year solar cycle.

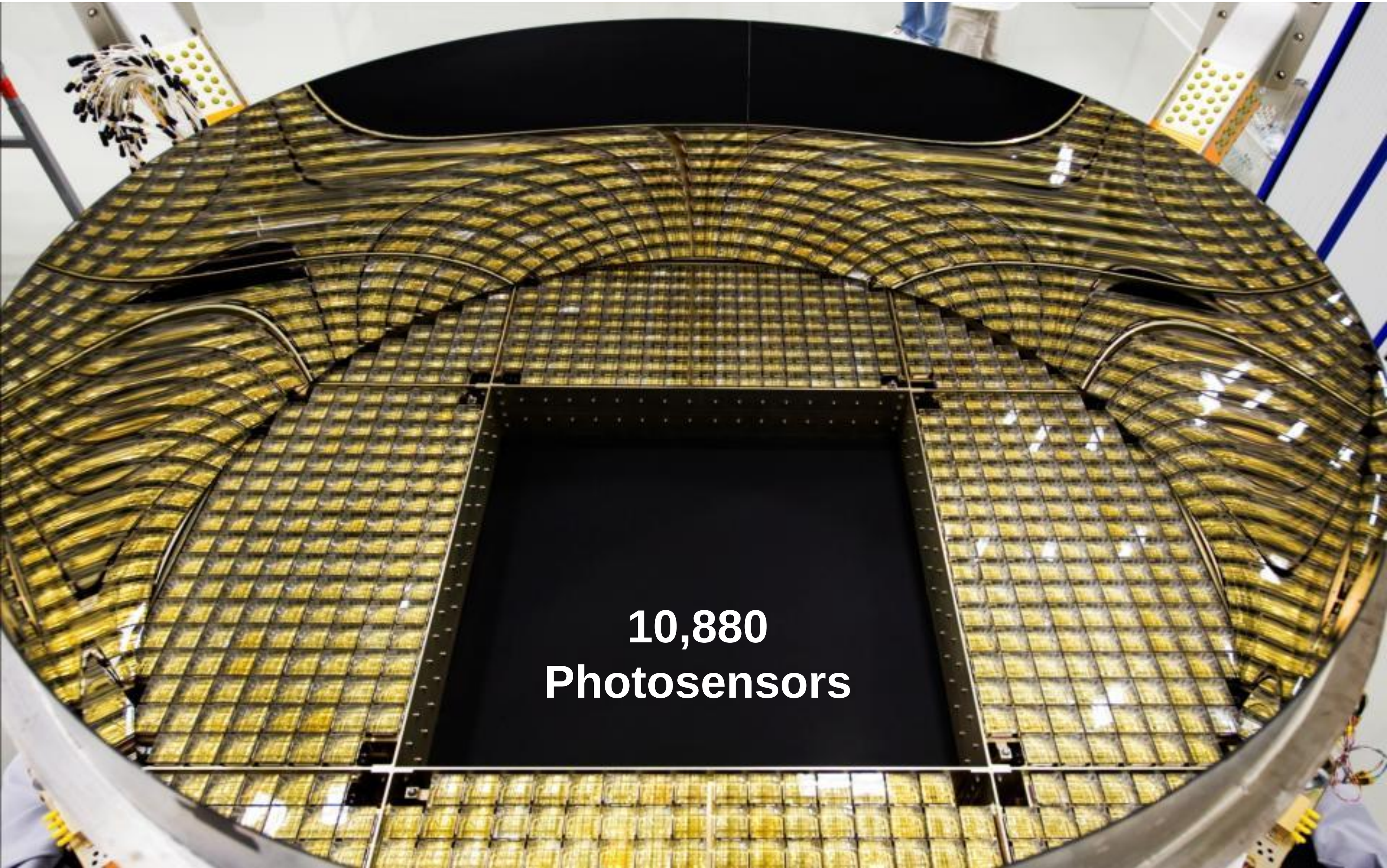


These spectra will provide experimental data that go into calculating the background in the Search for Dark Matter,
i.e., p + C →e^+, …

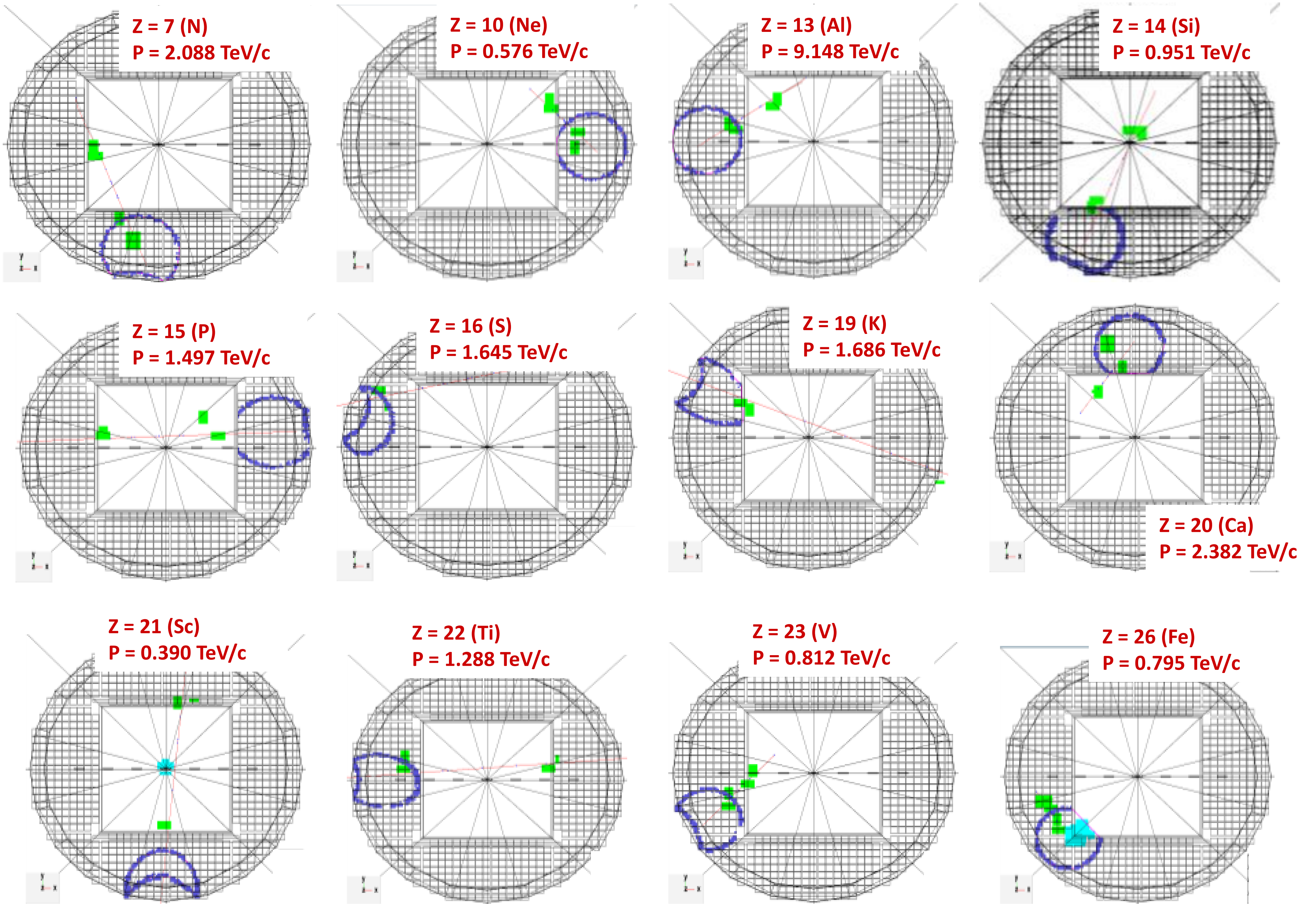
AMS Data on ISS from Cosmic Nuclei



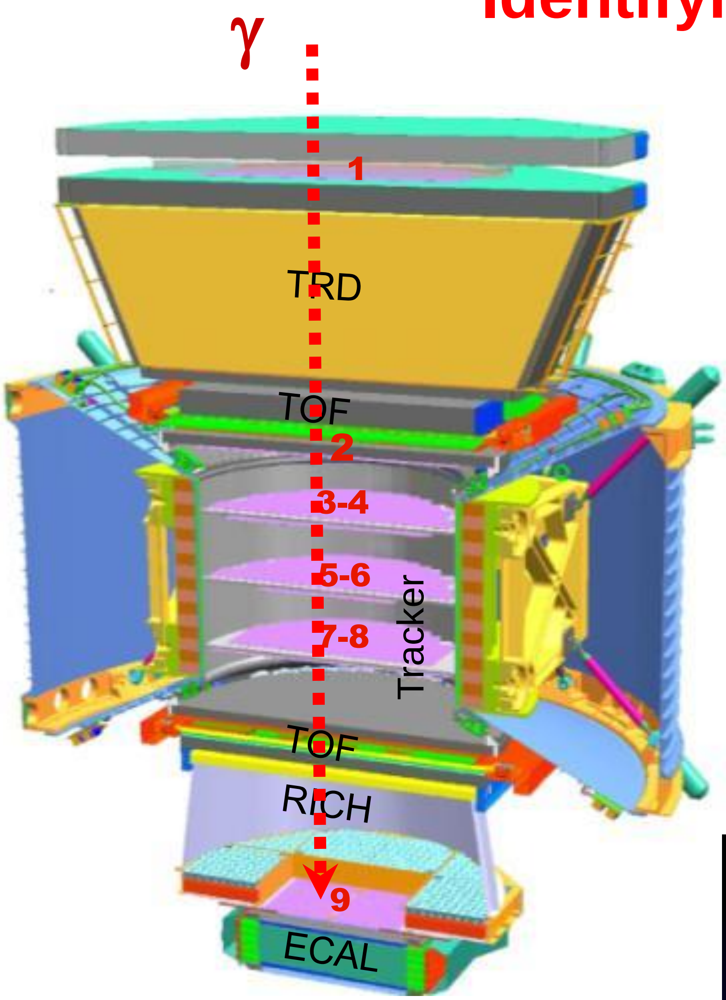
RICH: 21,760 Pulse Heights (low and high gain)
Onboard processing: 28 computers



AMS data: Nuclei in the TeV range



Identifying γ Sources with AMS



Example: Pulsars in the Milky Way

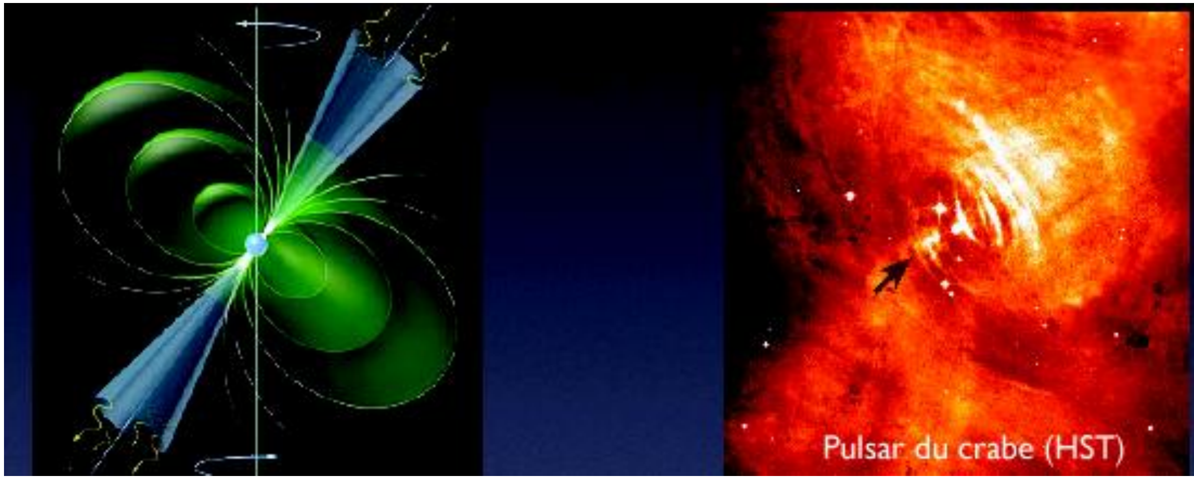
Neutron star sending radiation in a periodic way.

Currently measured to energies of ~ GeV with precision of a millisec.

AMS: energy spectrum up to 1 TeV and pulsar periods measured with μsec precision

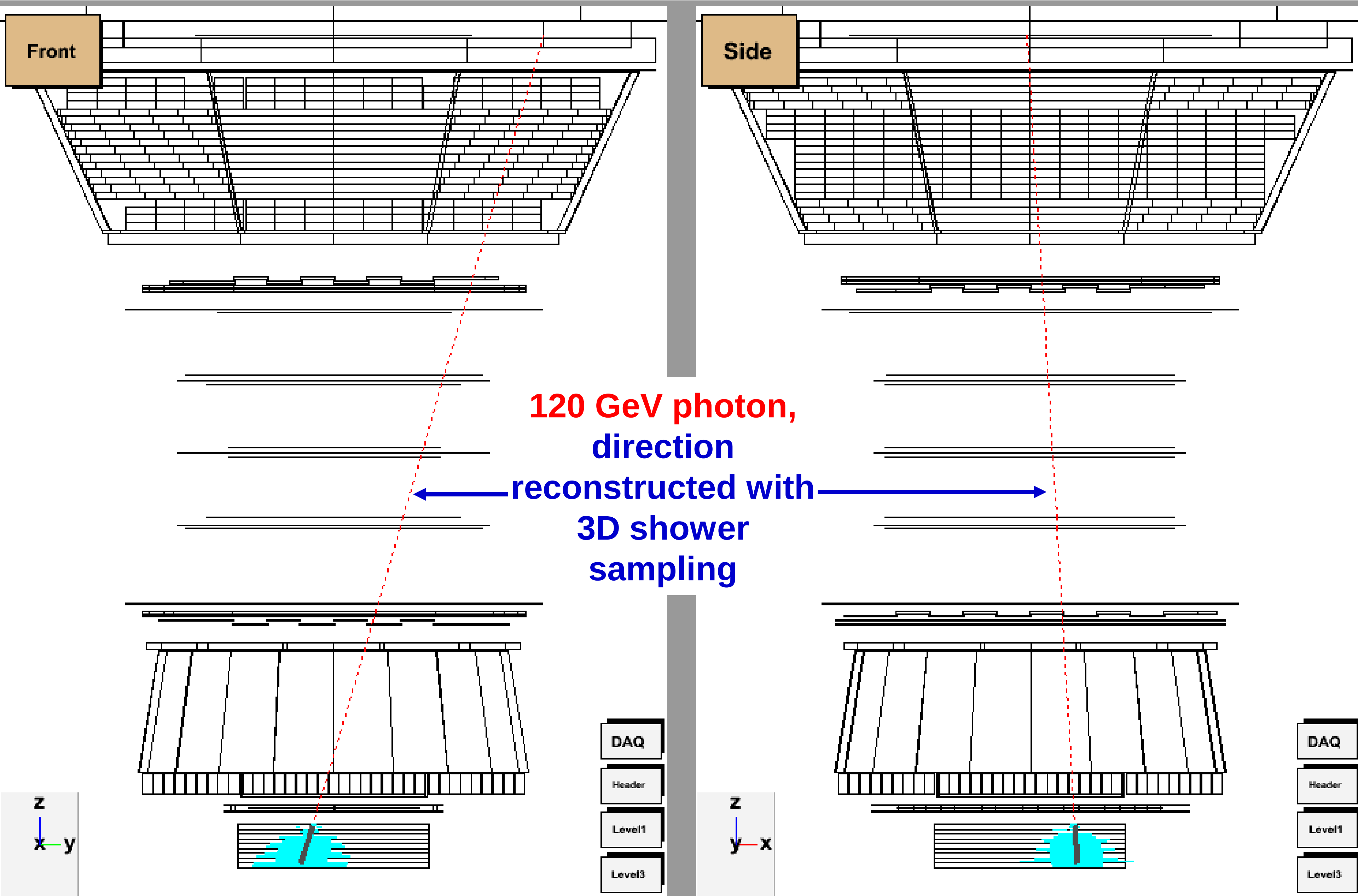
A factor of 1,000 improvement in Energy and Time

Unique Features:
17 X_0, 3D ECAL,
Measure γ to 1 TeV,

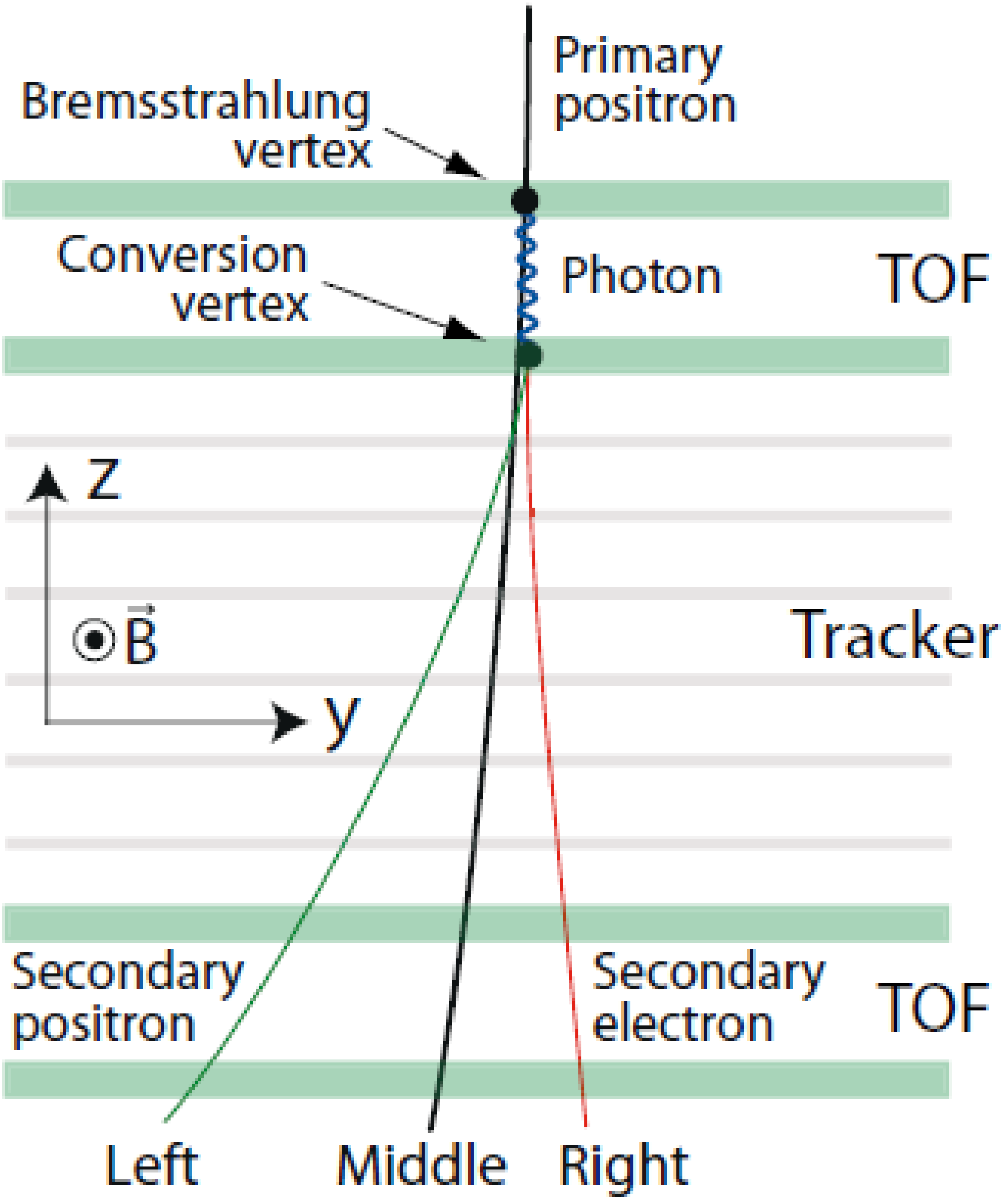


Physics of AMS: Measuring photons

Unique Features: 17 X_0, 3D ECAL, measure γ to 1 TeV, time resolution of 1μsec



AMS is capable of measuring polarizations of high energy photons.



AMS-01 Collaboration
Phys.Lett.B646:145-154,2007

Figure 1: Schematic view of a converted bremsstrahlung event caused by a positron going top-down.

Possible Experimental Determination of Whether the Neutral Meson is Scalar or Pseudoscalar

C. N. Yang
Institute for Advanced Study, Princeton, New Jersey
January 16, 1950

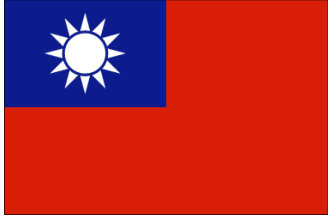
NEUTRAL mesons with a mass of ∼300 Mev which decay into two photons have been reported.[1] It can be proved[2,3] on general grounds of rotation-inversion invariance that a particle which dematerializes into two photons cannot have spin 1.

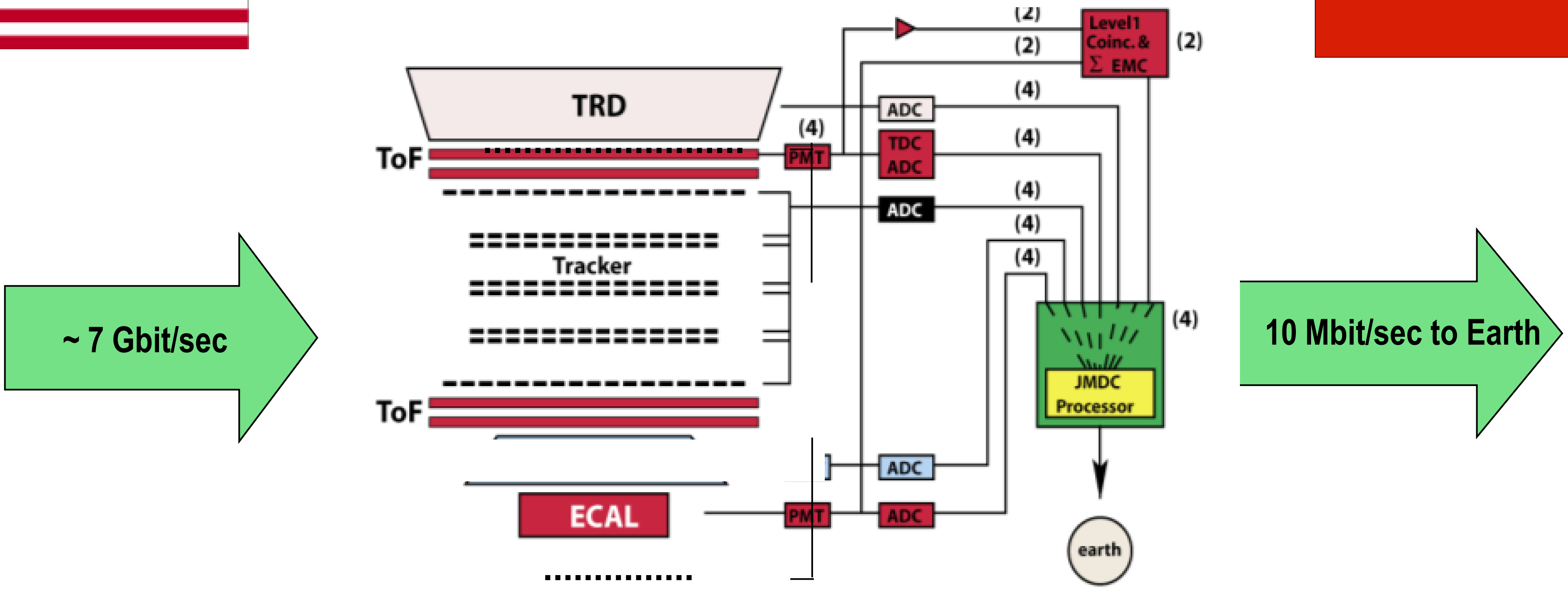
Detection of Gamma-Ray Polarization by Pair Production*

G. C. Wick
Radiation Laboratory, University of California, Berkeley, California
December 12, 1950

IT has been pointed out by Yang,[1] that pair production may provide a method for detecting the polarization of γ-rays in the high energy range: $h\nu \gg mc^2$ (m being the electron mass) where the usual Compton recoil method becomes insensitive. The idea is to utilize the azimuthal dependence of the pair production cross section $d\sigma$, the azimuth ϕ being measured around the direction $\mathbf{k}$ of the incident quantum and from the plane containing $\mathbf{k}$ and the electric polarization vector $\boldsymbol{\varepsilon}$ of the quantum. Actually, of course, one must consider two azimuths ϕ_+ and ϕ_- for the positive and negative electron respectively. Berlin and

AMS-02 Electronics





The level of redundancy is shown in parenthesis.

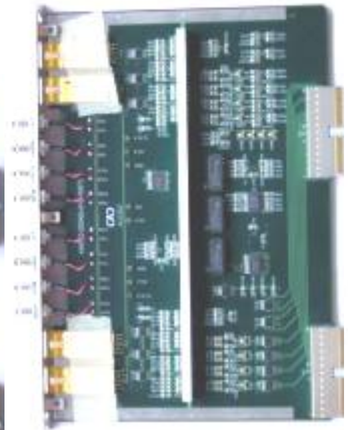
AMS electronics are based on accelerator physics technologies.

They are ~ 10 times faster than commercial space electronics.

They were manufactured at the
Chung Shan Institute of Science and Technology (CSIST)
under the leadership of General Jinchi Hao
with the support of the Director Generals of CSIST


JSBC


JIM-CAN

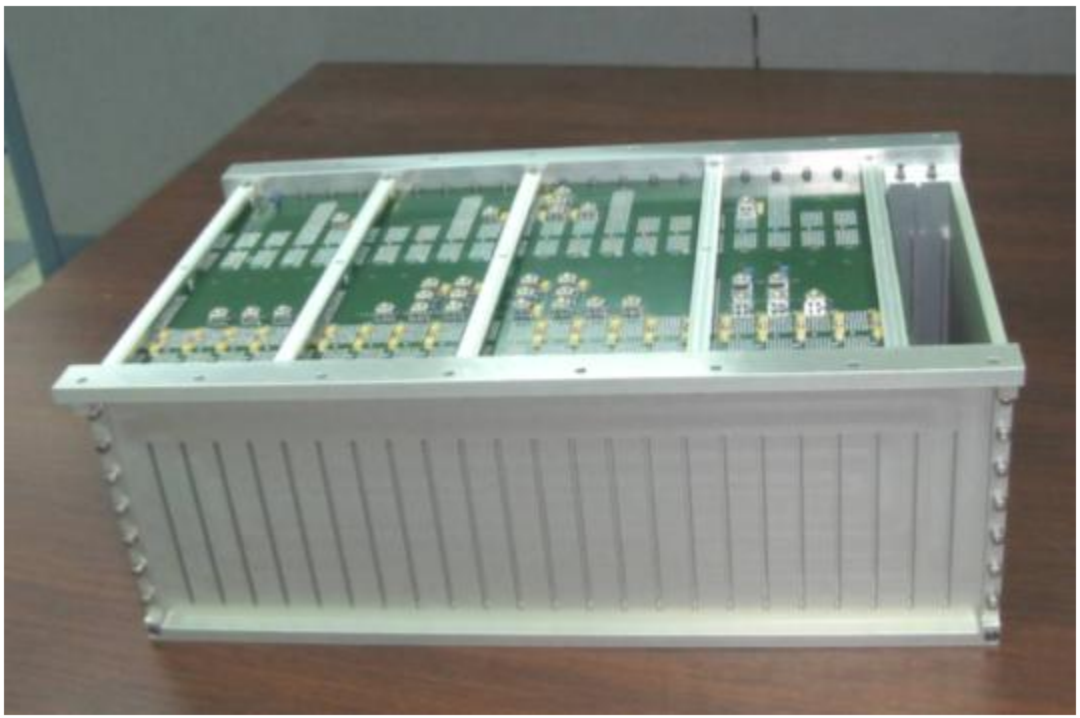

JHIF


JIM-AMSW&1553

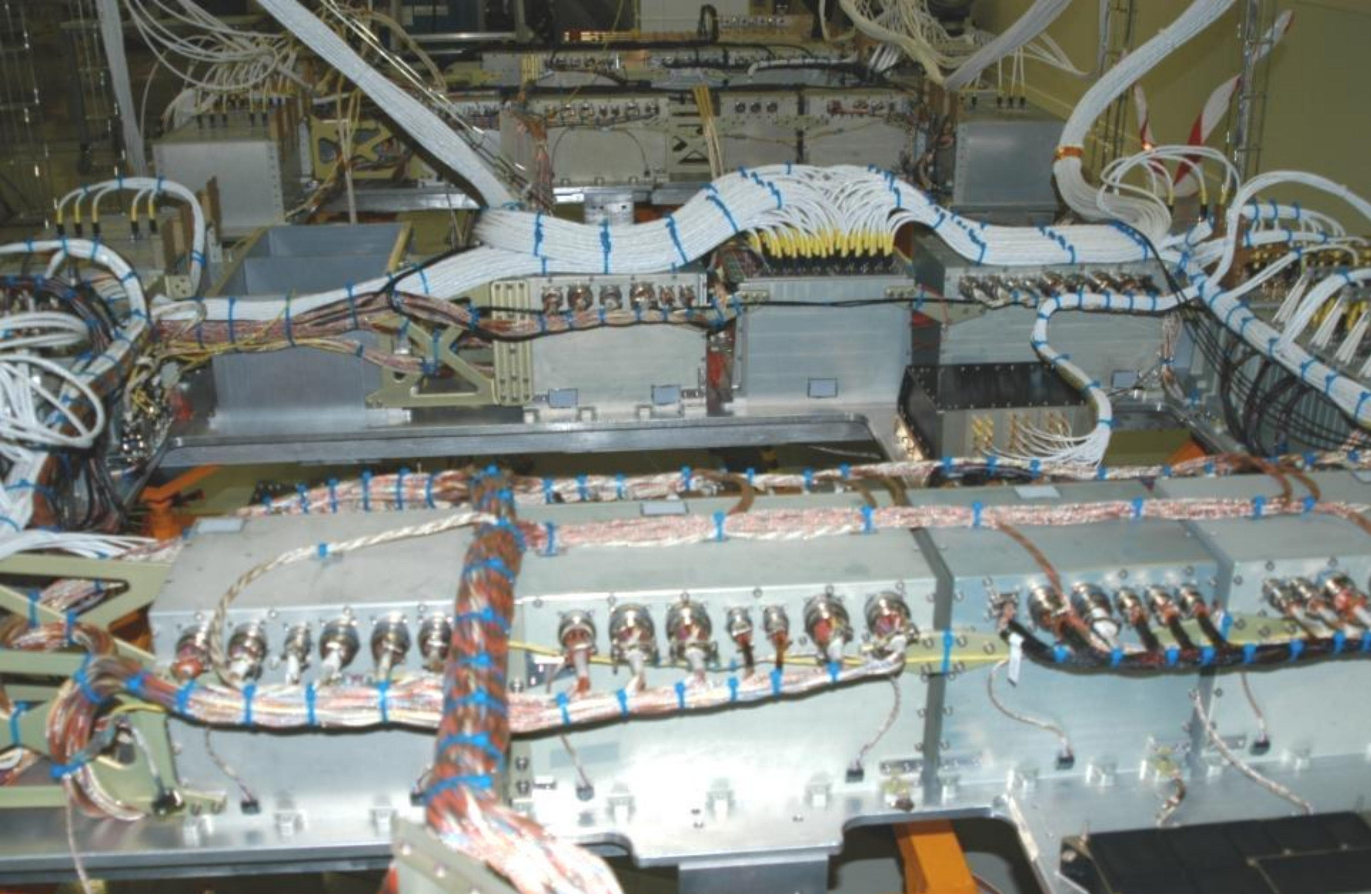

JBU


JIM-HRDL

Total 650 micro-processors
48 crates



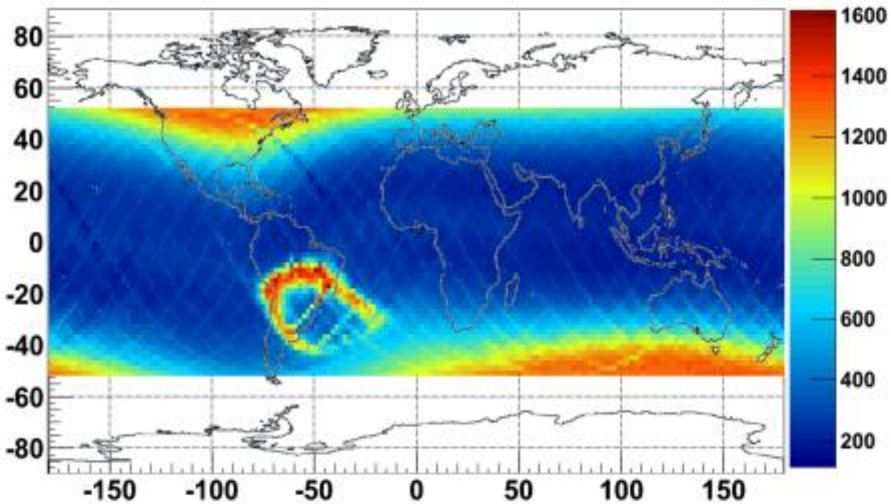
General Hao Jinchi and the AMS CSIST Electronics experts



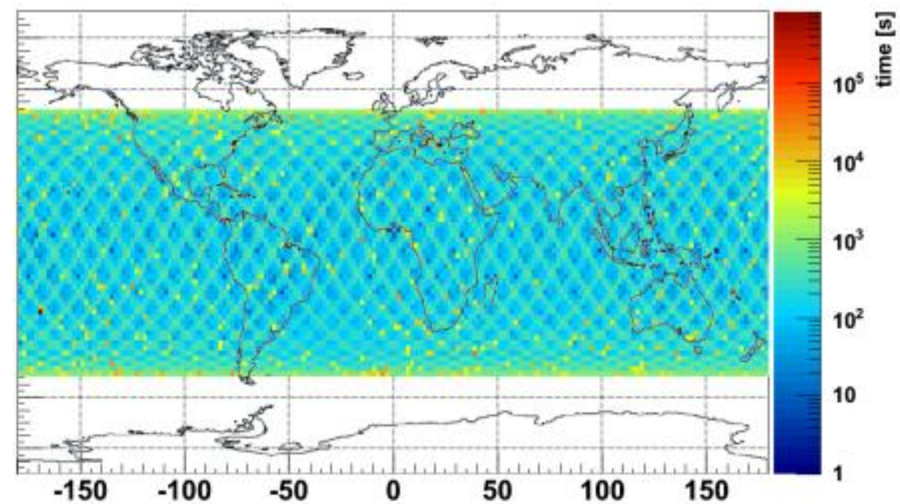
The completed flight electronics
(650 microprocessors, 300,000 channels)

Orbital DAQ parameters

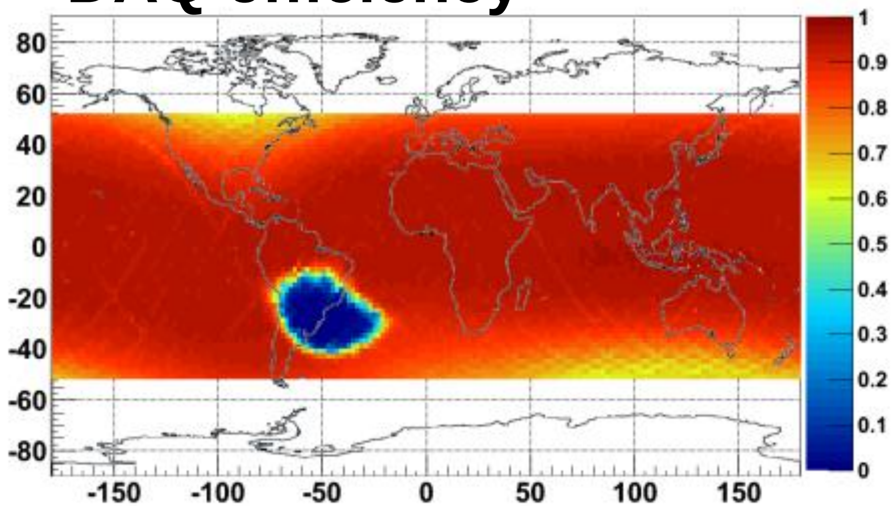
Acquisition rate [Hz]



Time at location [s]



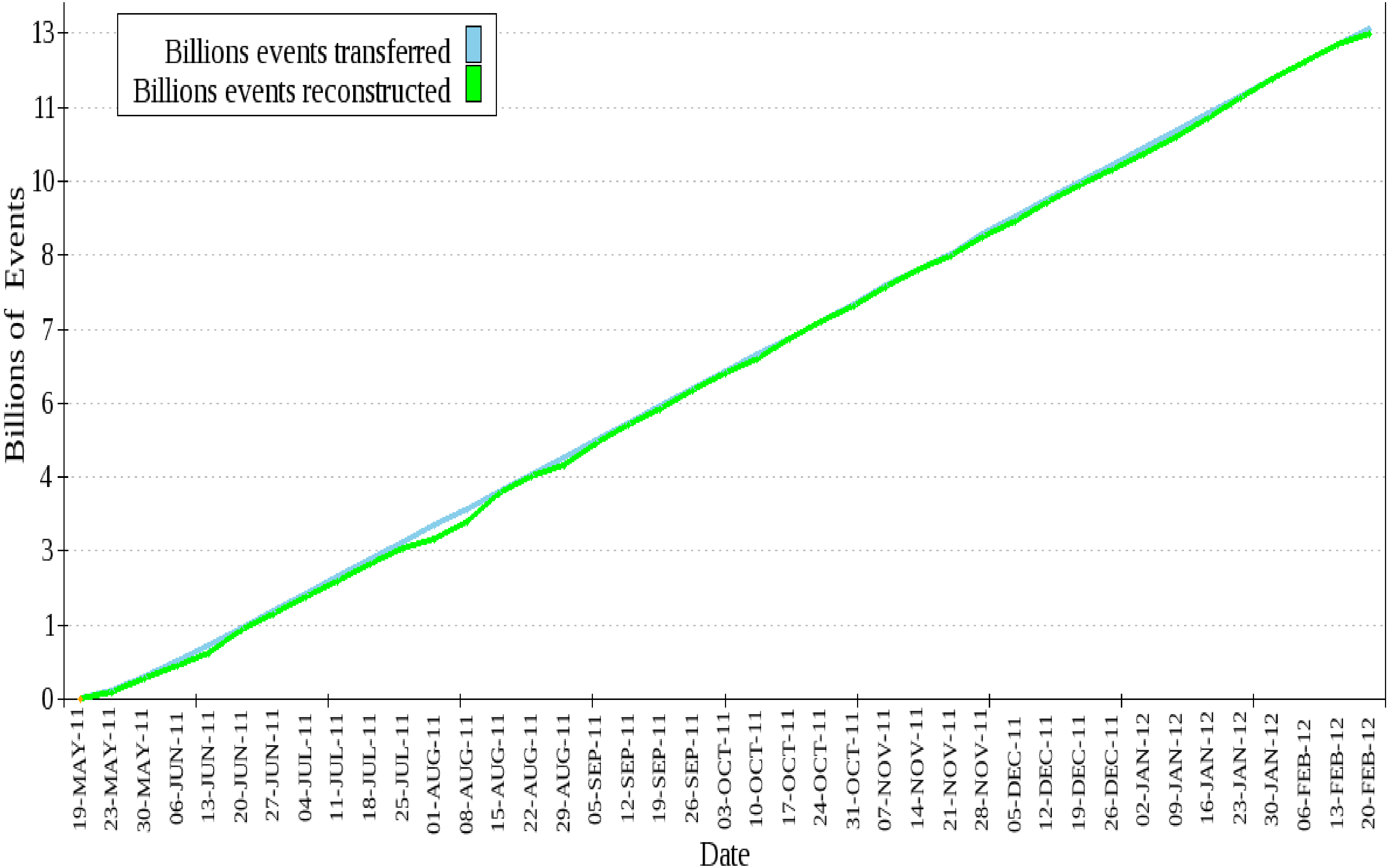
DAQ efficiency



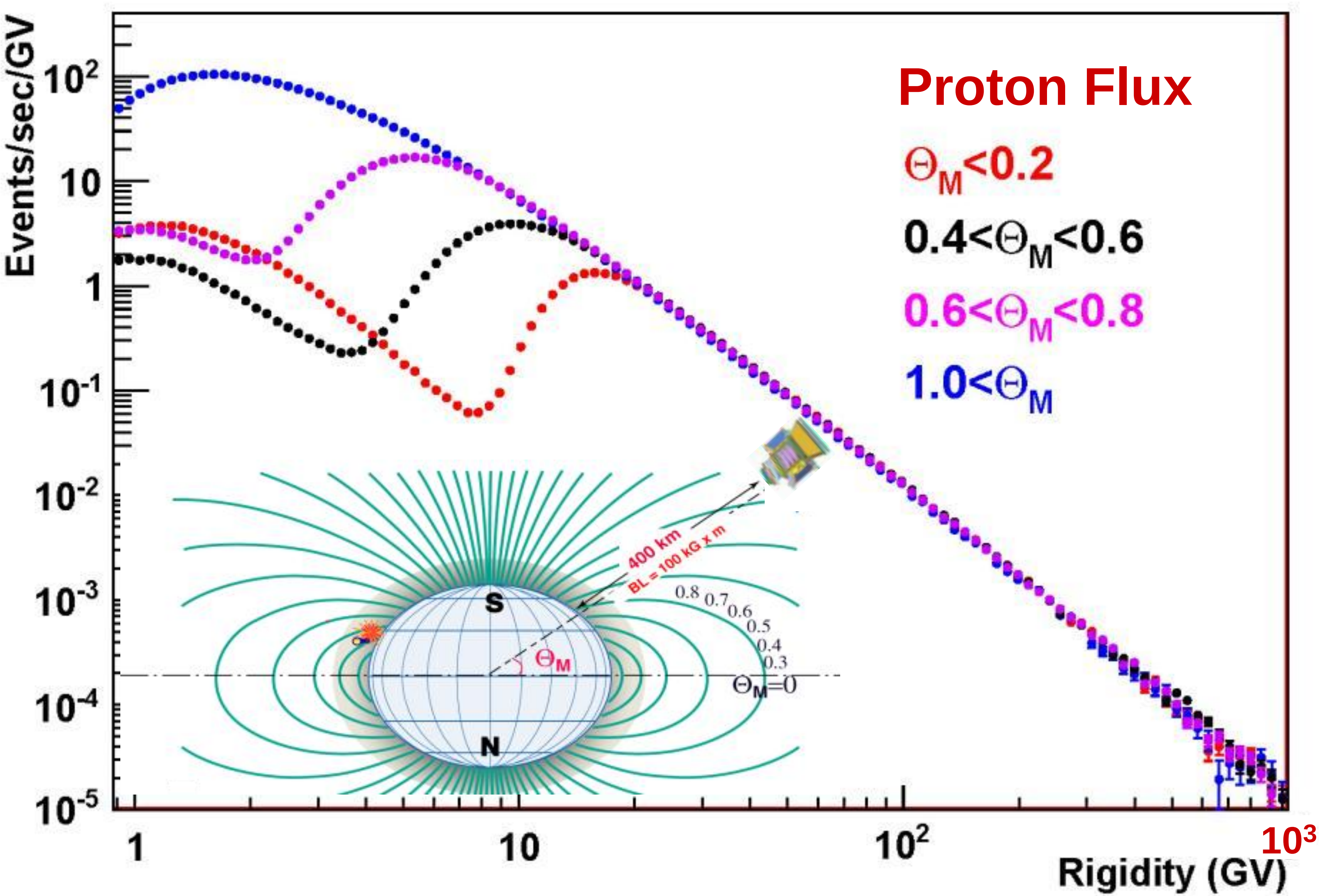
Particle rates vary from 200 to 2000 Hz per orbit

On average:
DAQ efficiency 85%
DAQ rate ~700Hz

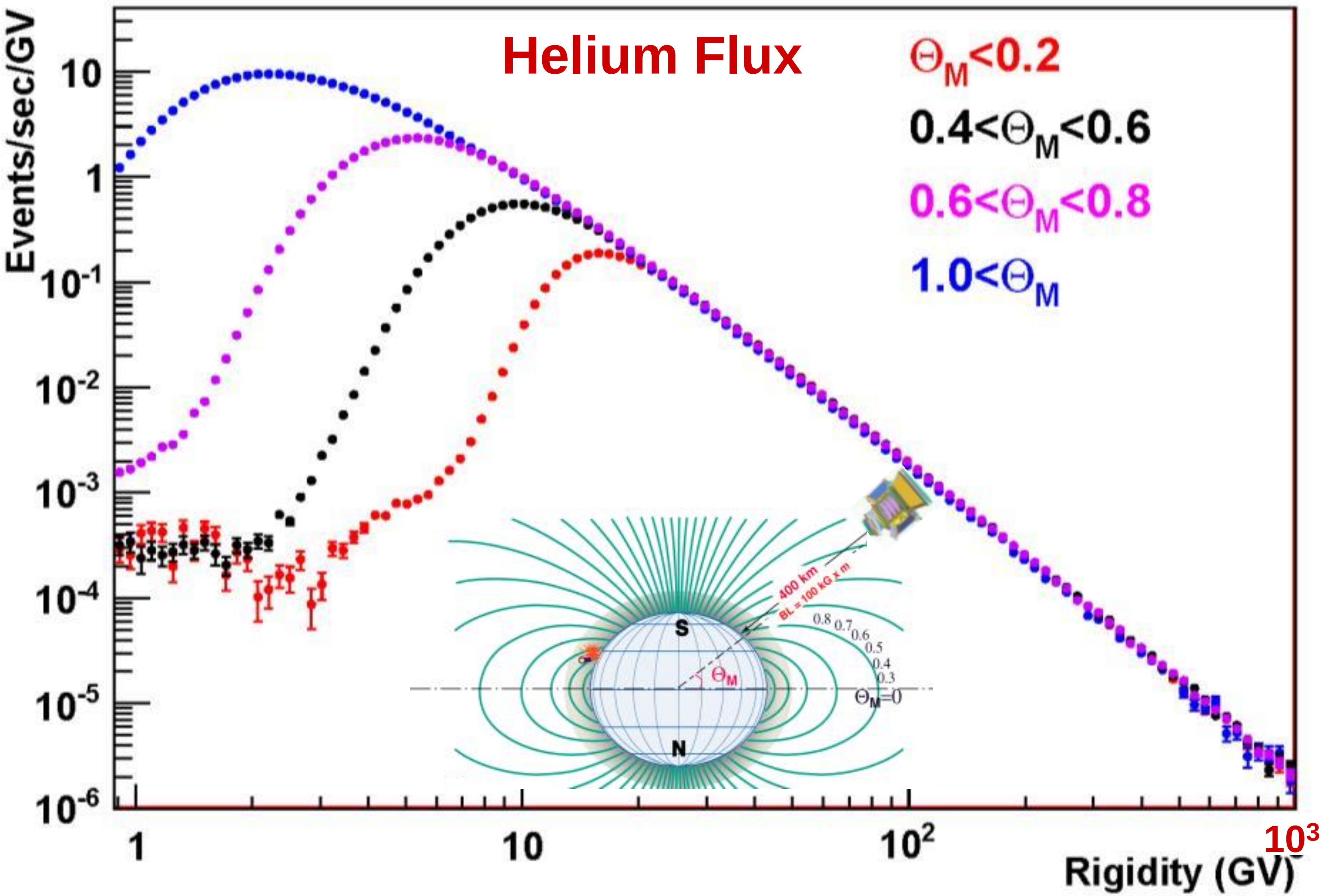
AMS collected over 8 billion events for the first 6 months



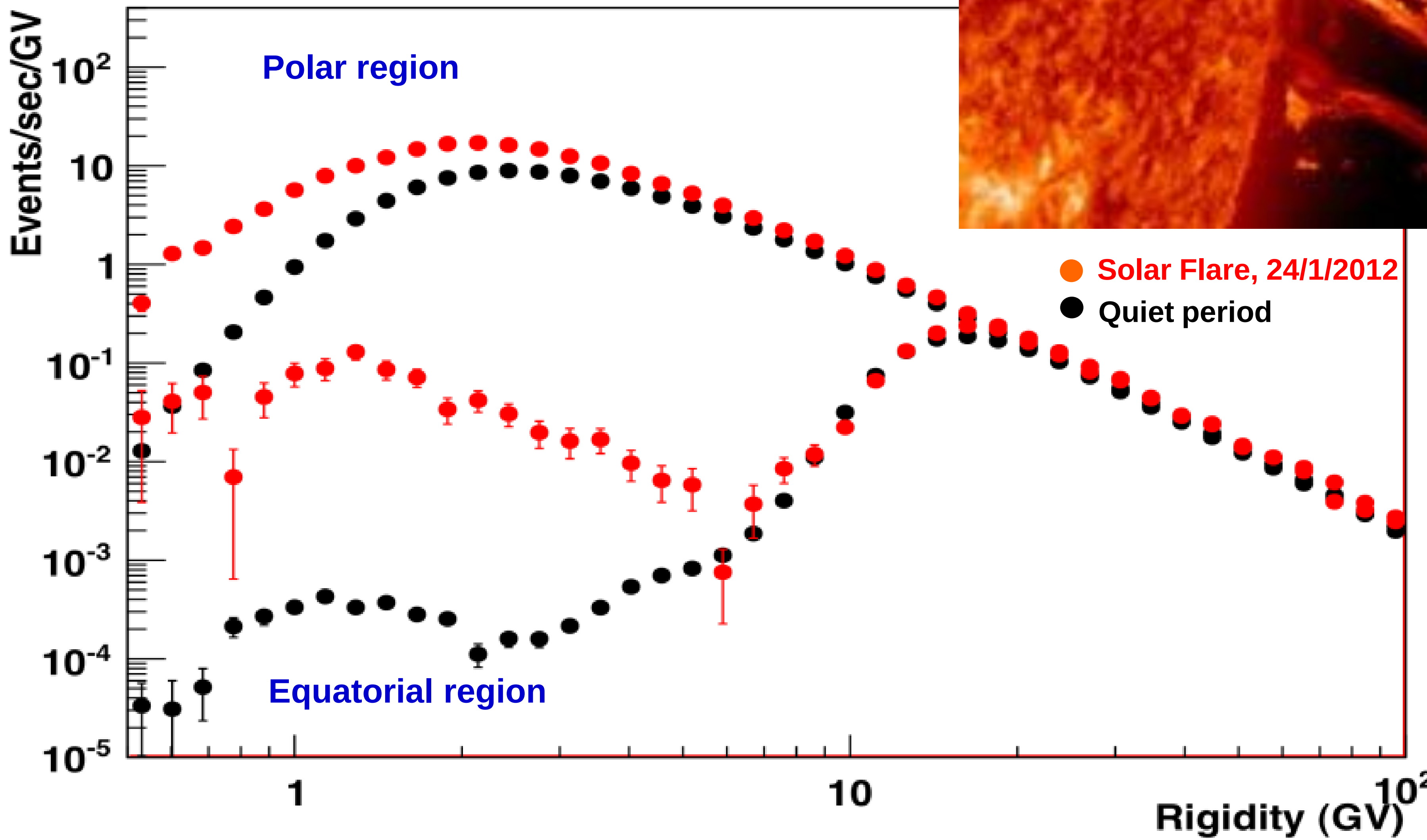
Data from AMS on ISS



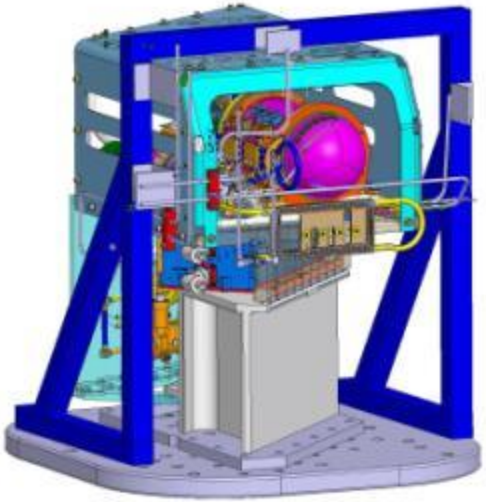
Data from AMS on ISS



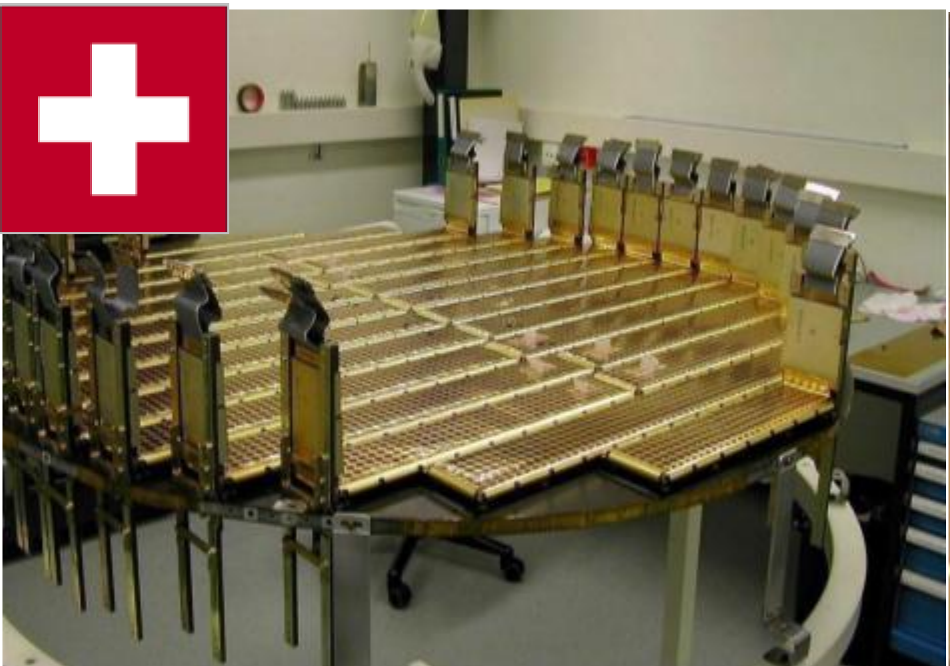
AMS data: He rate and Solar Flare

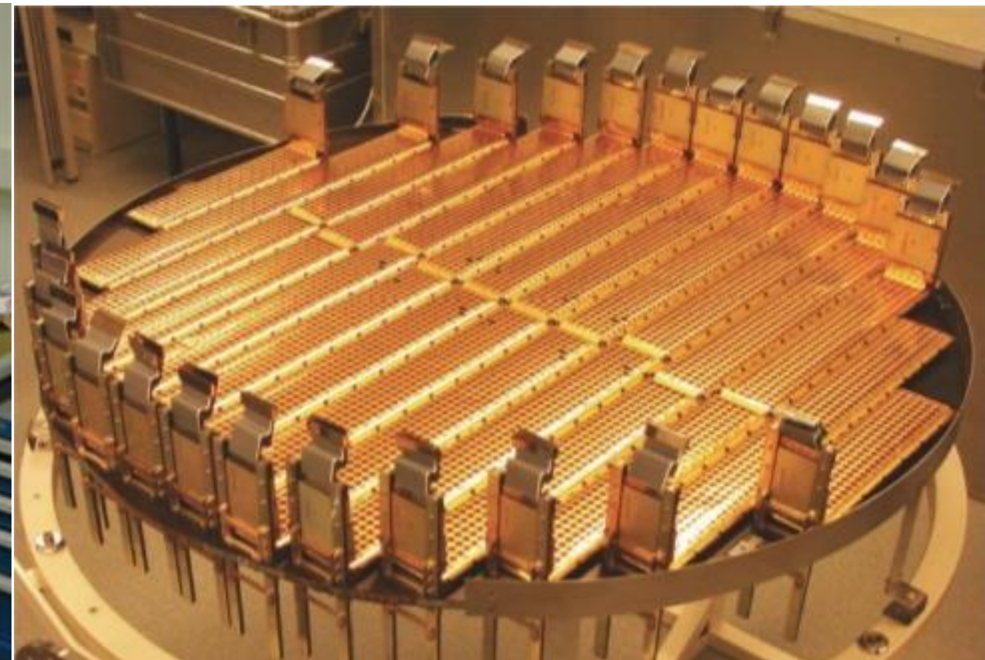


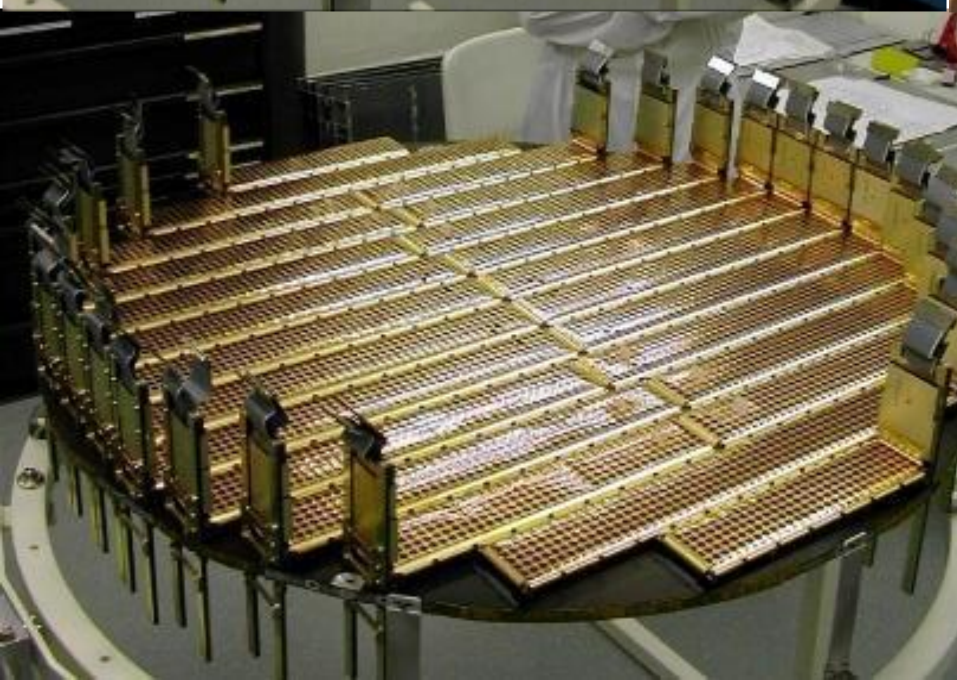
3 TTCS Boxes



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

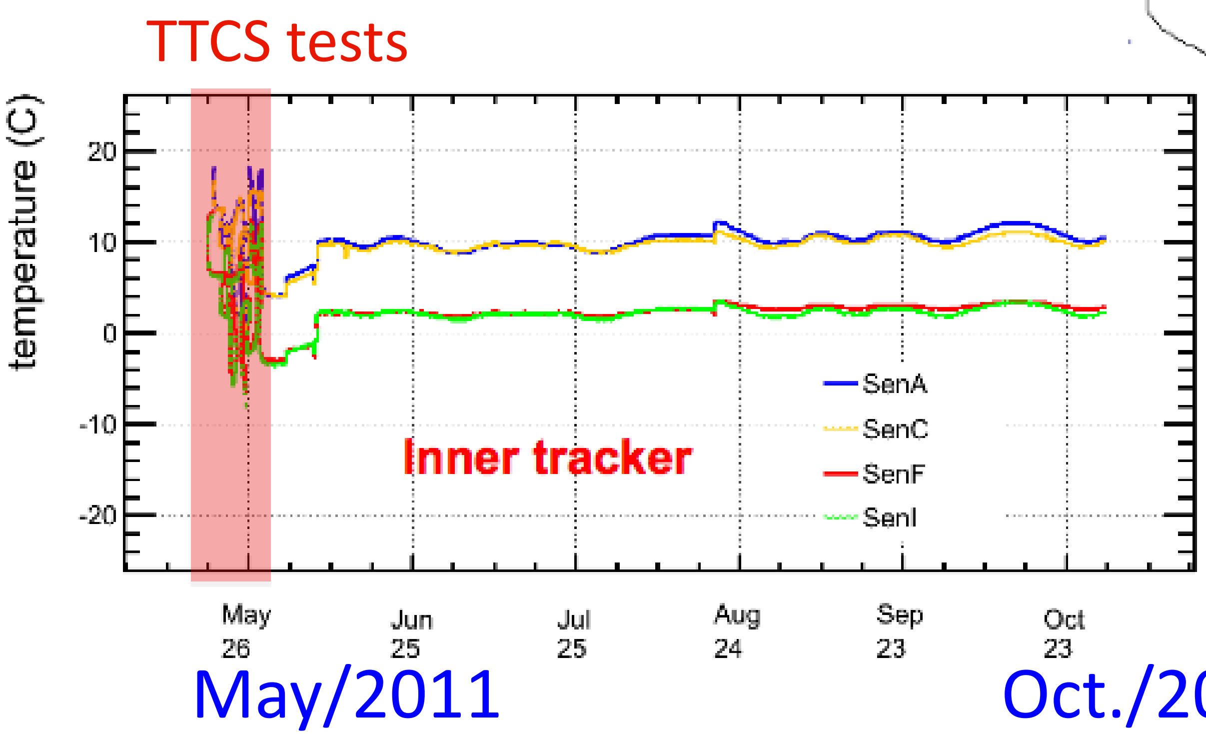


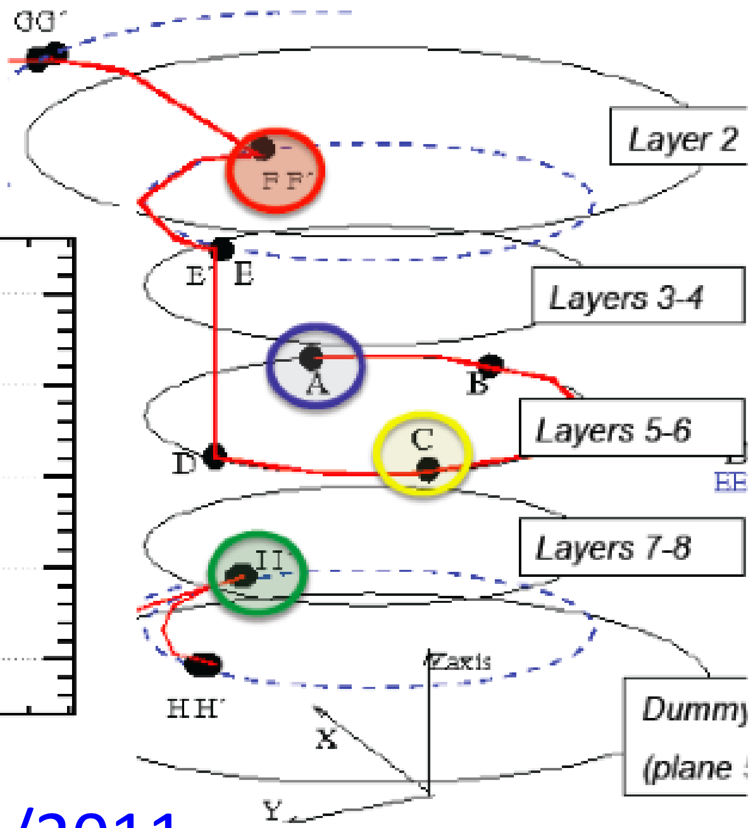




Inner Tracker Temperatures

Inner tracker temperature is kept under control by the TTCS





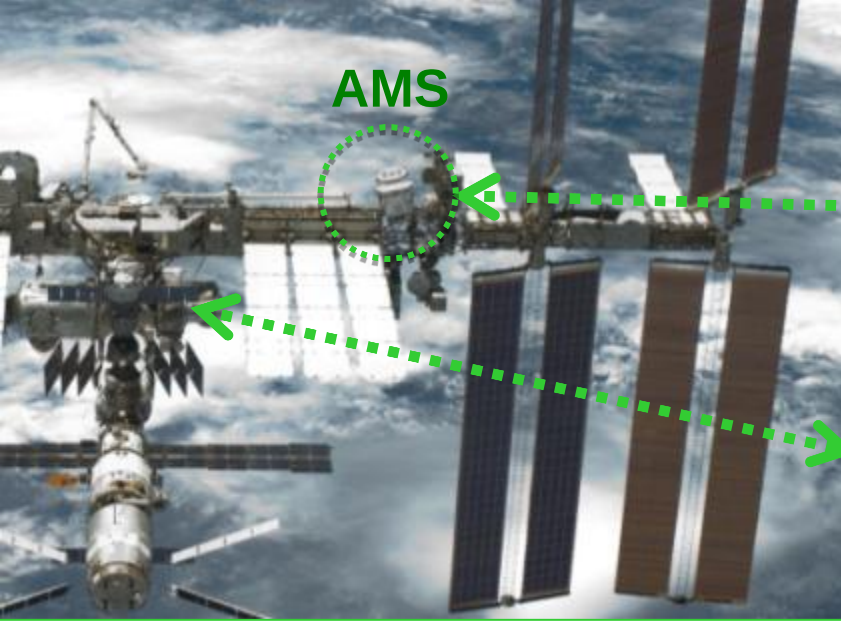
Manufacturing of the main radiator panel

Test of the Tracker Radiator Panel

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

May 19: AMS installation completed at 5:15 CDT, start taking data 9:35 CDT
During the first week, we collected 100 million cosmic rays

AMS Operations



TDRS Satellites

Astronaut at ISS AMS Laptop

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

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

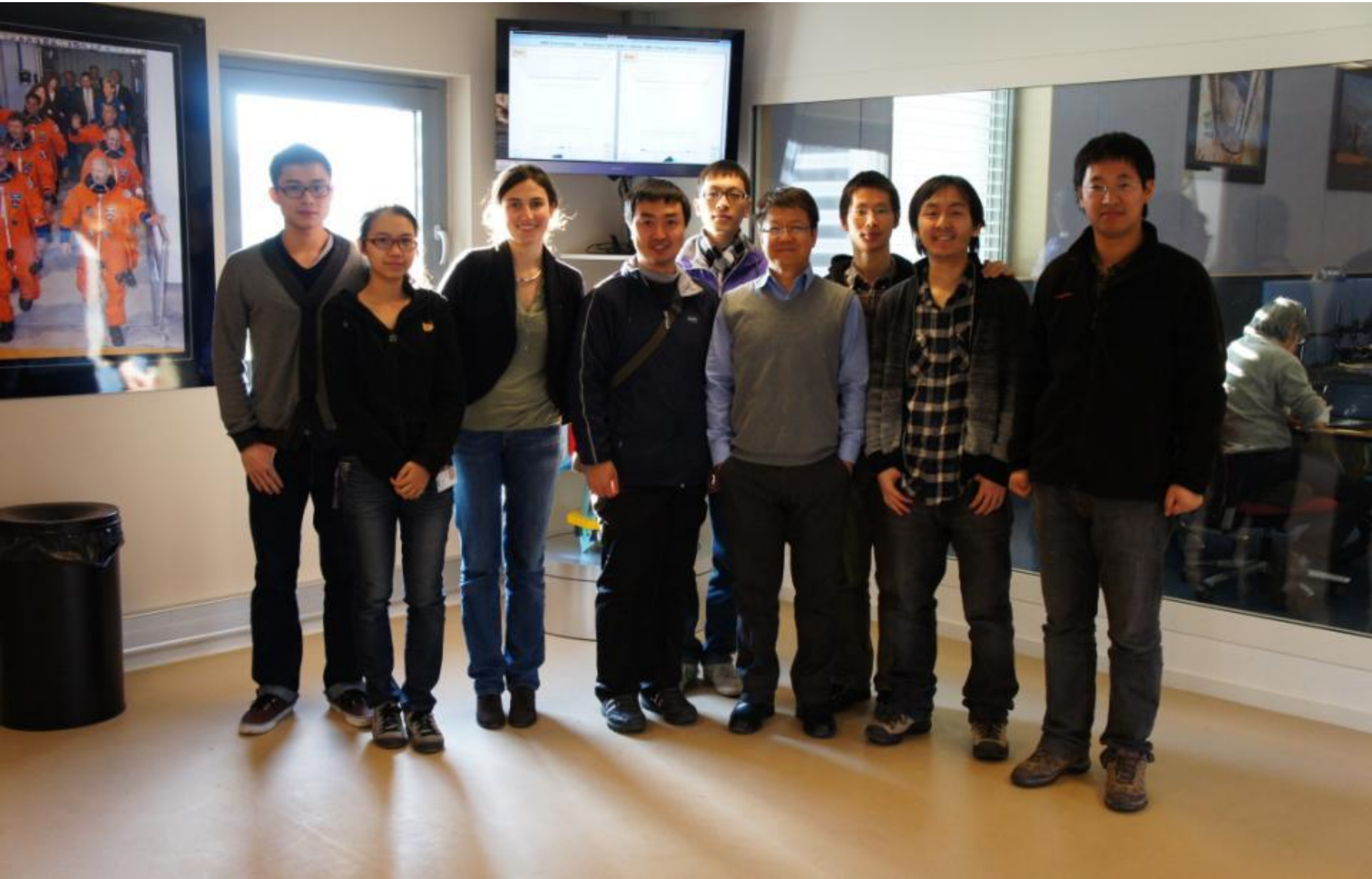
AMS Payload Operations Control and Science Operations Centers (POCC, SOC) at CERN

AMS Computers at MSFC, AL

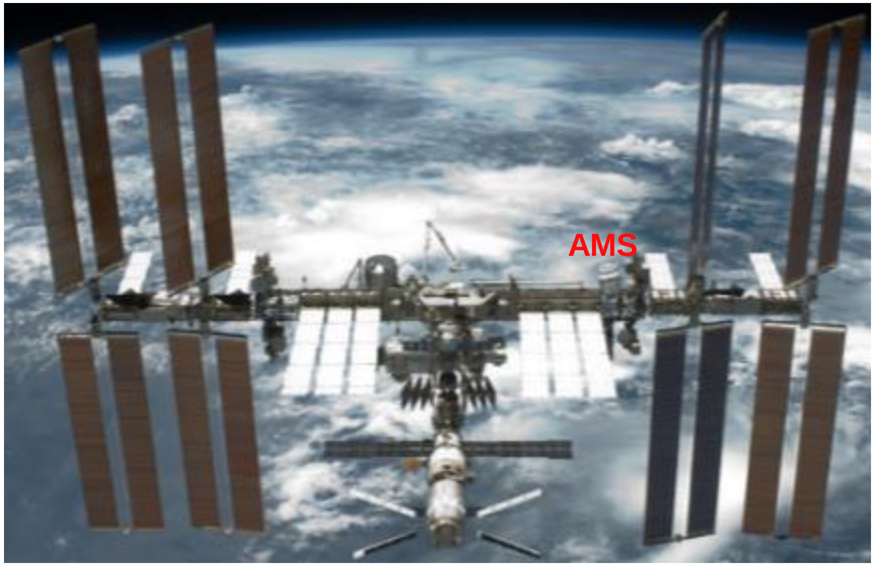
White Sands Ground Terminal, NM

We are collaborating with MIT and Perugia on TRD, Tracker and ECAL Commissioning.

Undergraduate students from China work with our groups at CERN for their senior theses.



AMS Control Centers (POCC)



NASA channels

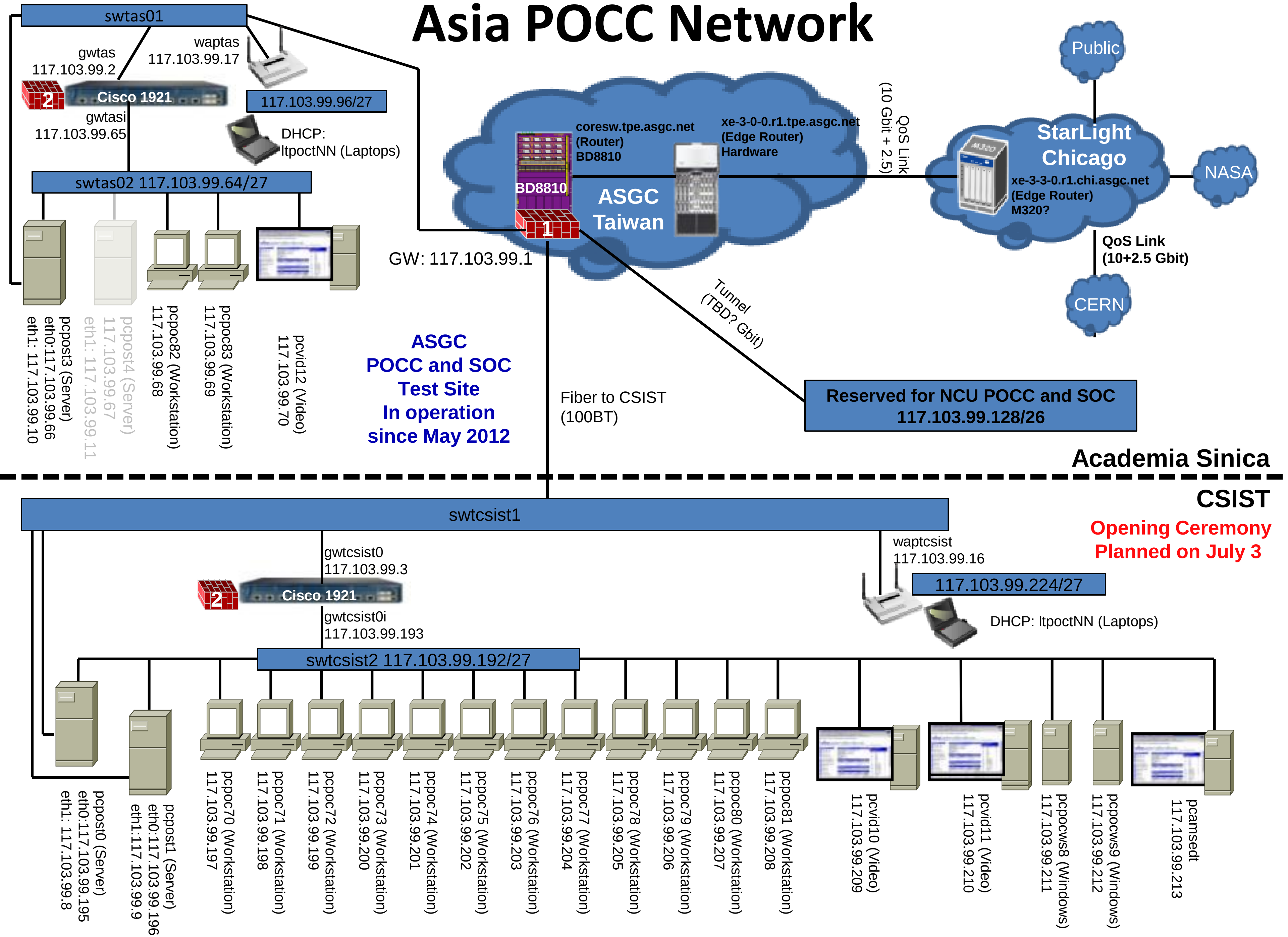
MSFC POIC, AL
AMS GSC Center

Taiwan
(June 2012)

JSC, TX
Back up POCC

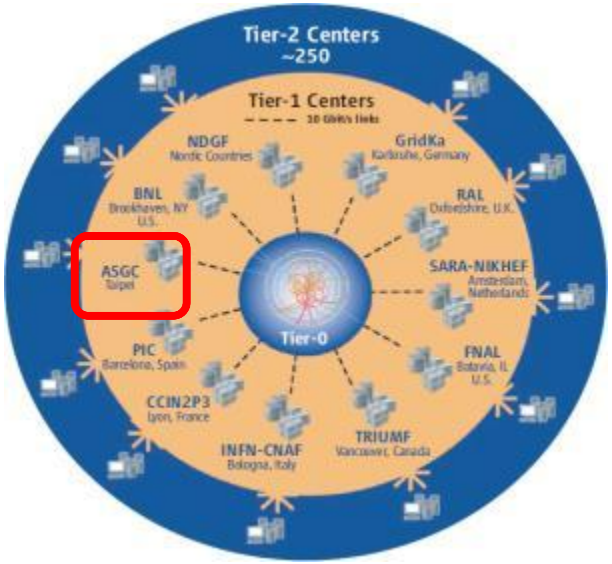
CERN, Geneva
AMS POCC

Asia POCC Network



ASGC Computing Center

Executive Officer S.-C. Lee



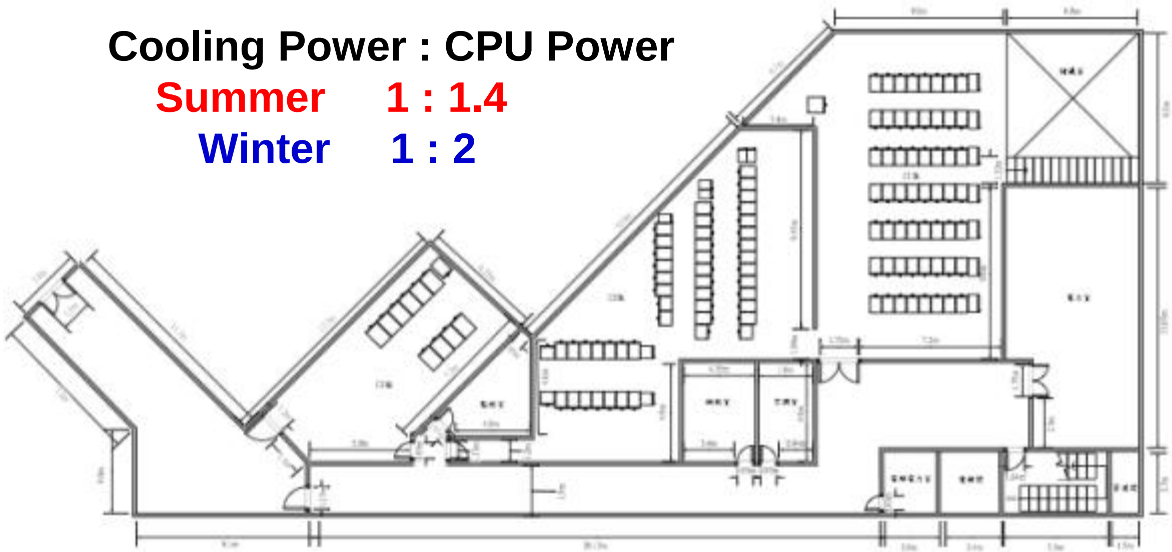
5 SEPTEMBER 2008 VOL 321 SCIENCE

ASGC is a Tier-1 Center of World-Wide Grid

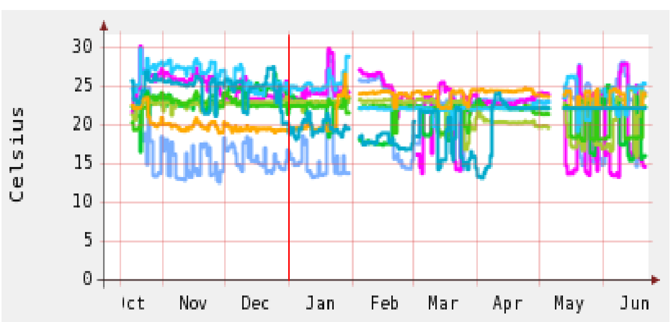
Cooling Power : CPU Power

Summer 1 : 1.4

Winter 1 : 2



- **Total Capacity**
  - **2MW, 400 tons AHUs**
  - **93 racks**
  - **~ 800 m^2**
- **Current Resources**
  - **15,000 CPU Cores**
  - **6 PB Disk**
  - **5 PB Tape**

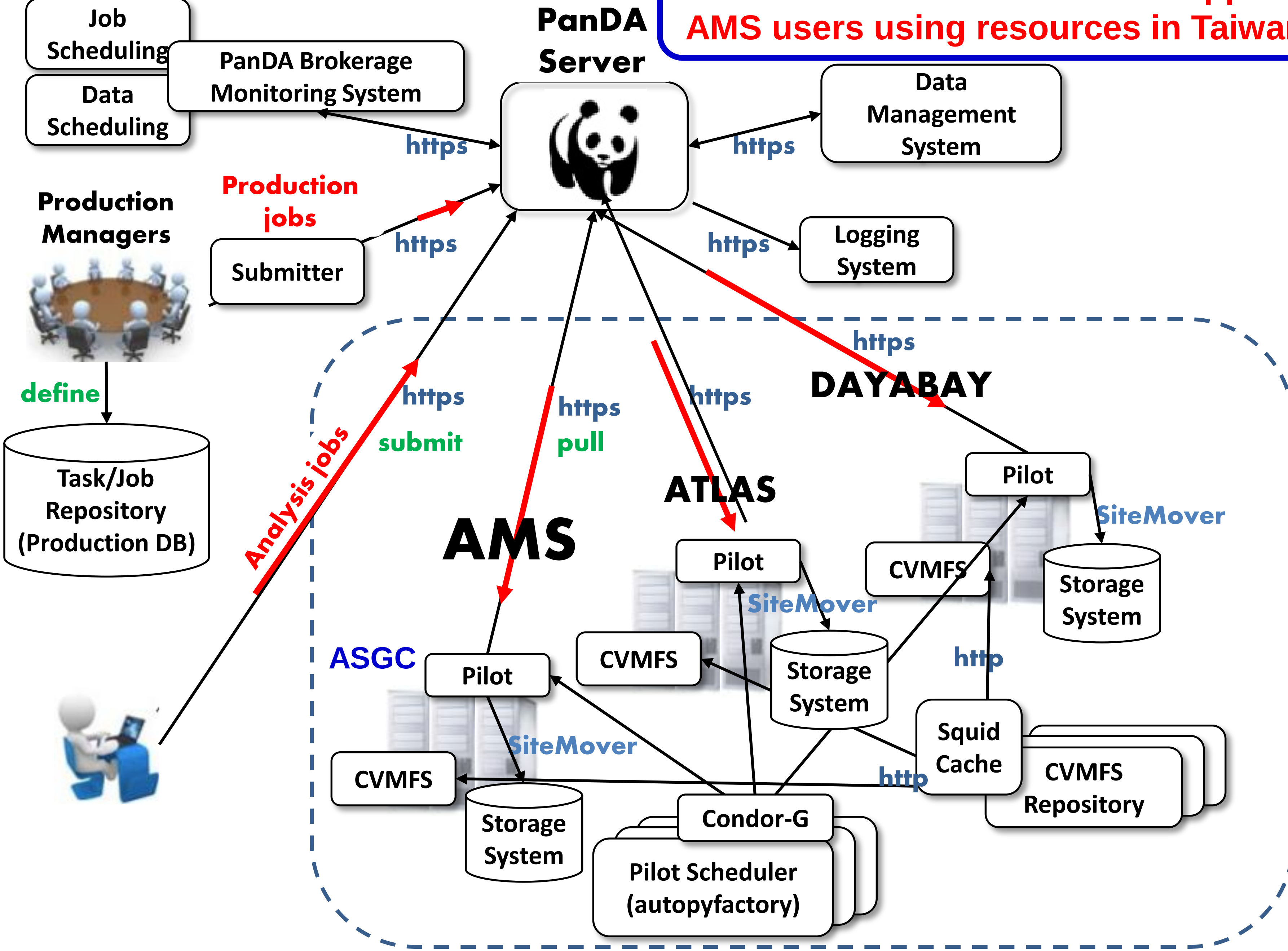


Monitoring the power consumption and temperature of every piece of equipment every 10 seconds.

Data Center is a restricted access area. It is 24-hour monitored by video surveillance.

PanDA: Production and Distributed Analysis System

We adopt grid software developed by BNL and CERN for ATLAS to support AMS users using resources in Taiwan.



Thermal Control is the most challenging task in the operation of AMS

The thermal environment on ISS is constantly changing due to:

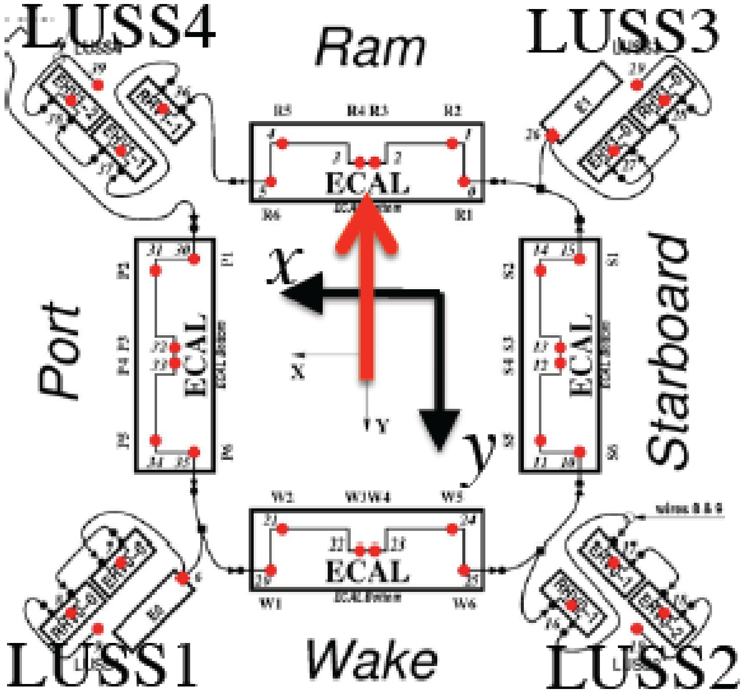
- **Solar Beta Angle (β)**
- **Position of the ISS Radiators and Solar Arrays**
- **ISS Attitude**

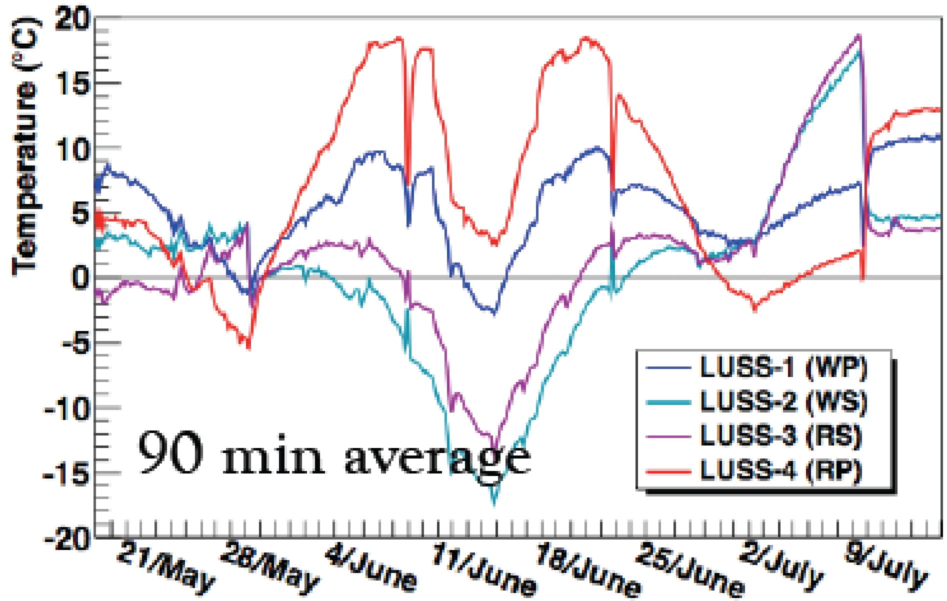
Over 1,100 temperature sensors are monitored around the clock in the AMS POCC to assure components stay within thermal limits.

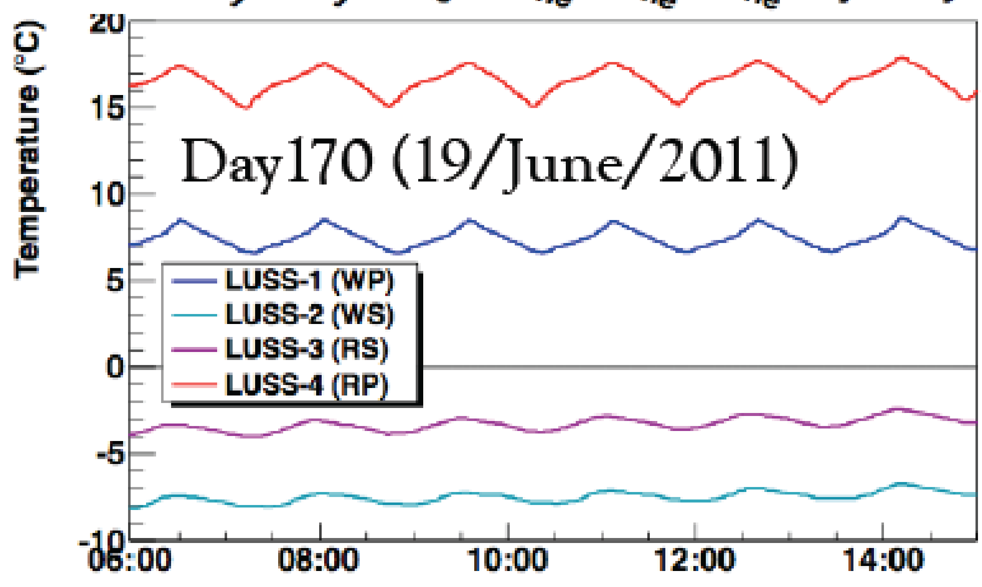
AMS temperatures are in a constant transient.

Several subsystems (e.g. TRD Gas, TOF, TTCS) have operated near their limits, requiring AMS operational workarounds or ISS actions to avoid damage.

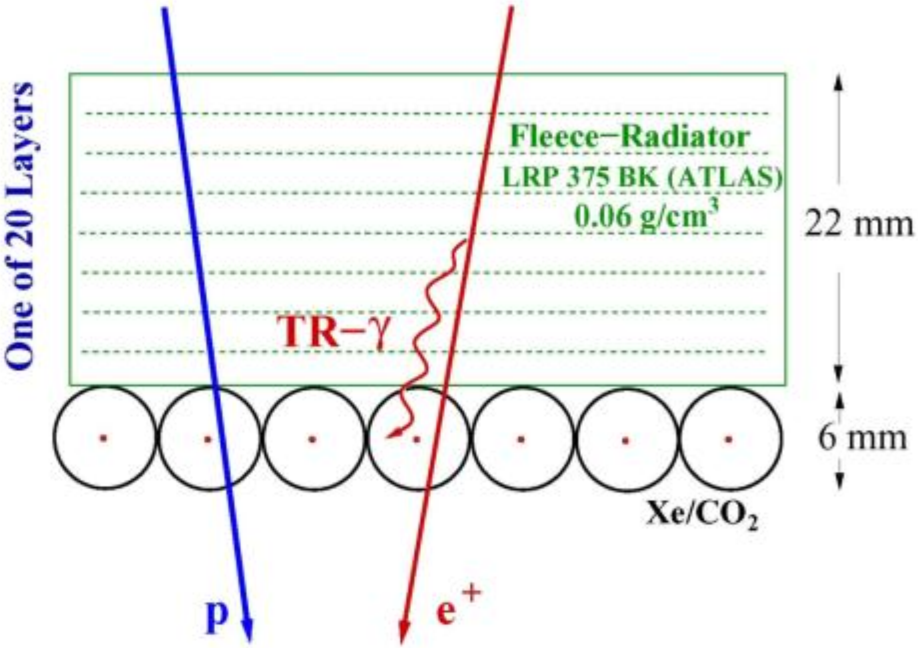
Temperatures on LUSS

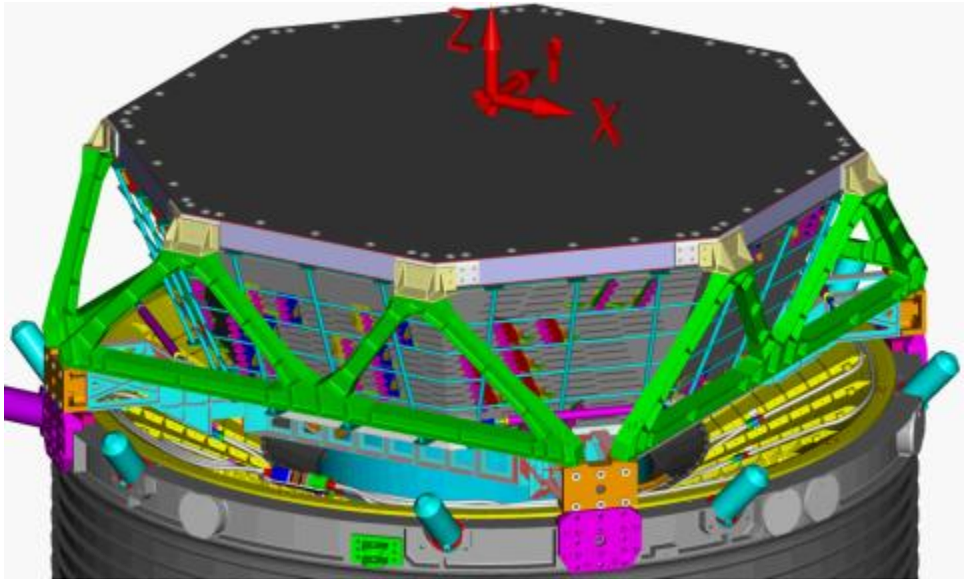






Example: TRD Alignment

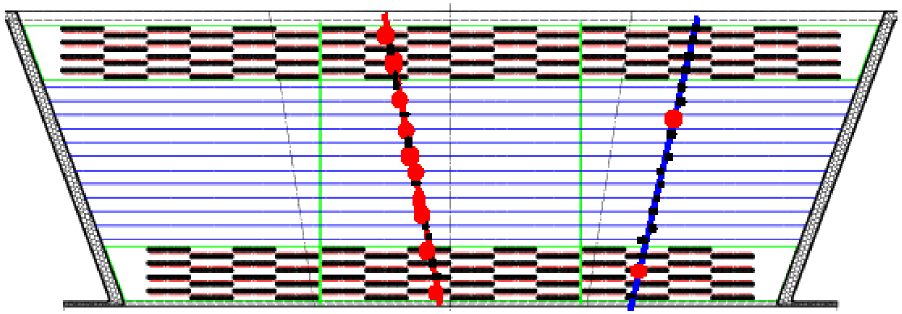




12 layers in the bending plane
2 x 4 layers in the non-bending plane

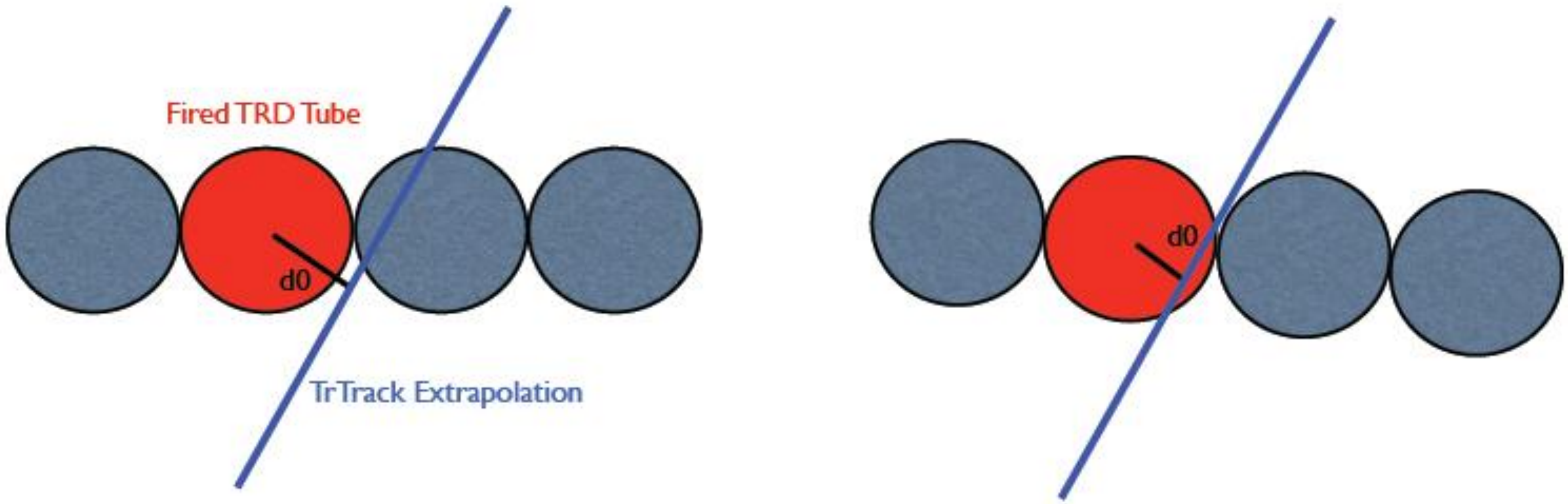
Chosen configuration for 60 cm height:
20 Layers each existing of:

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



large acceptance: 0.5m²sr

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

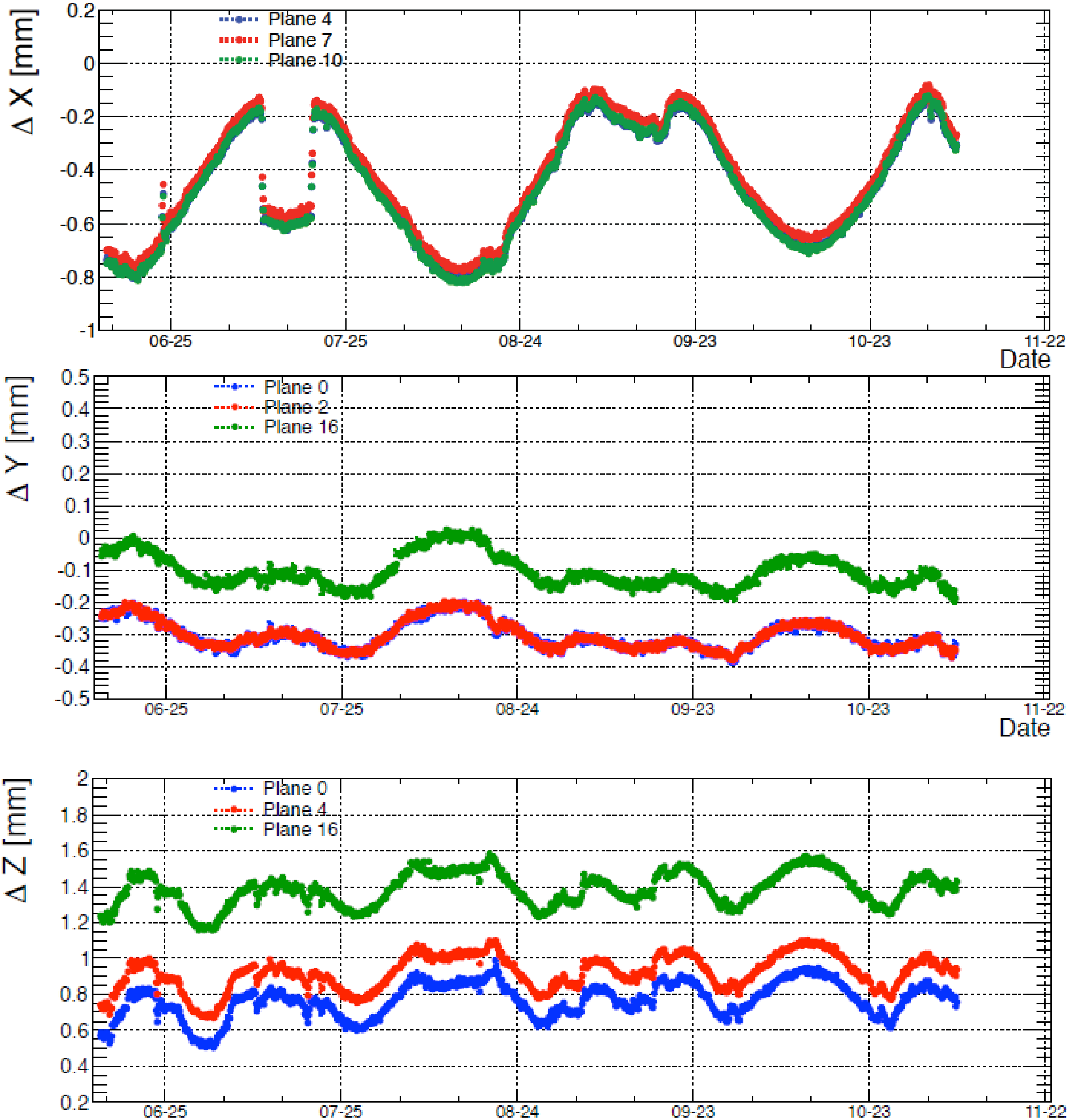


Extrapolate inner tracker tracks to TRD. Minimize the impact parameter to determine the position of a TRD module relative to the inner tracker.

TRD Alignment -- long term variation

3 hr per point

All planes vary in the same way indicating that TRD is a rigid body.



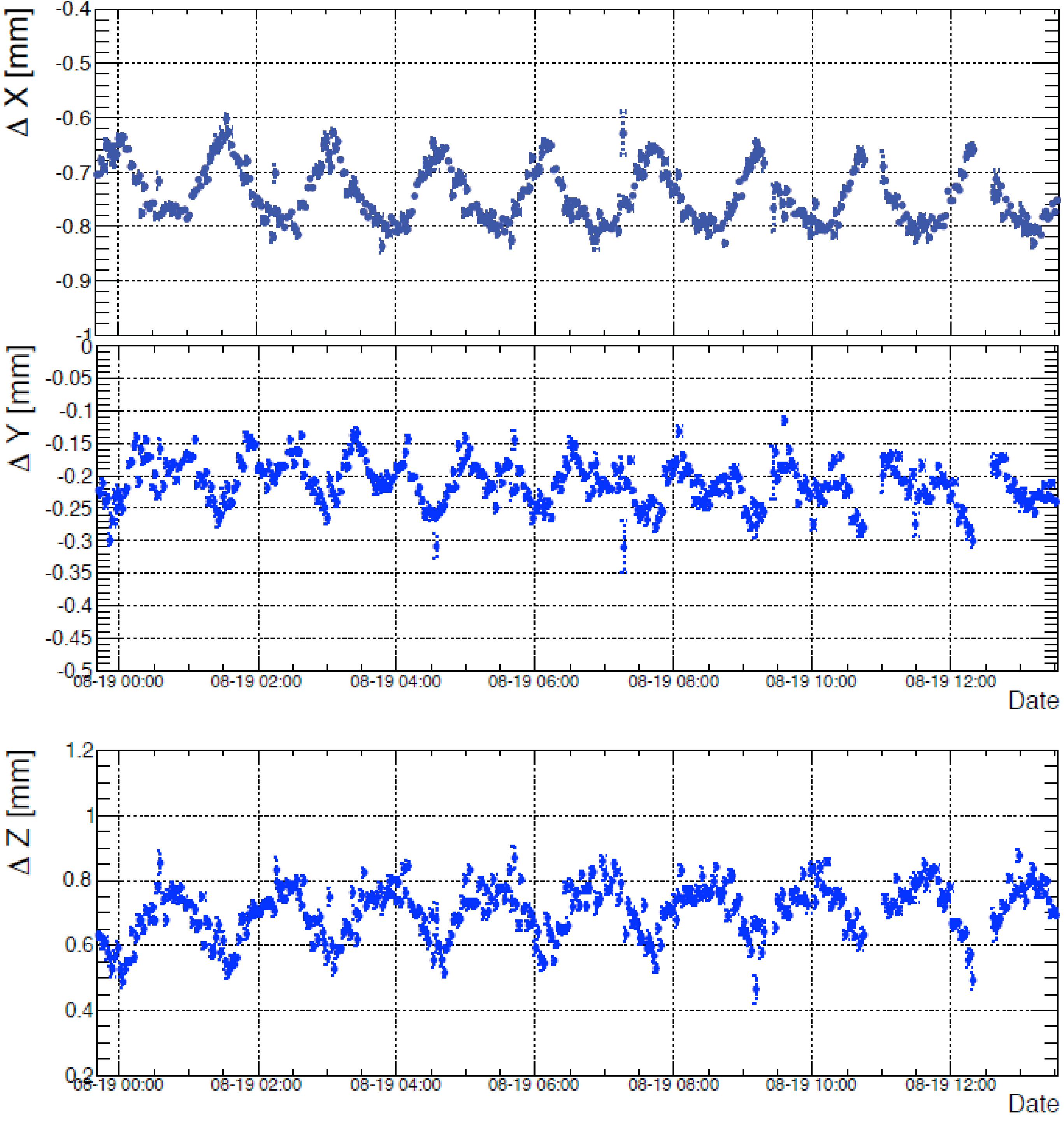
Zhili Weng, private

TRD Alignment

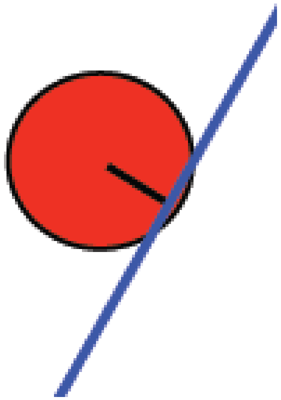
-- short tem variation

2 min per point

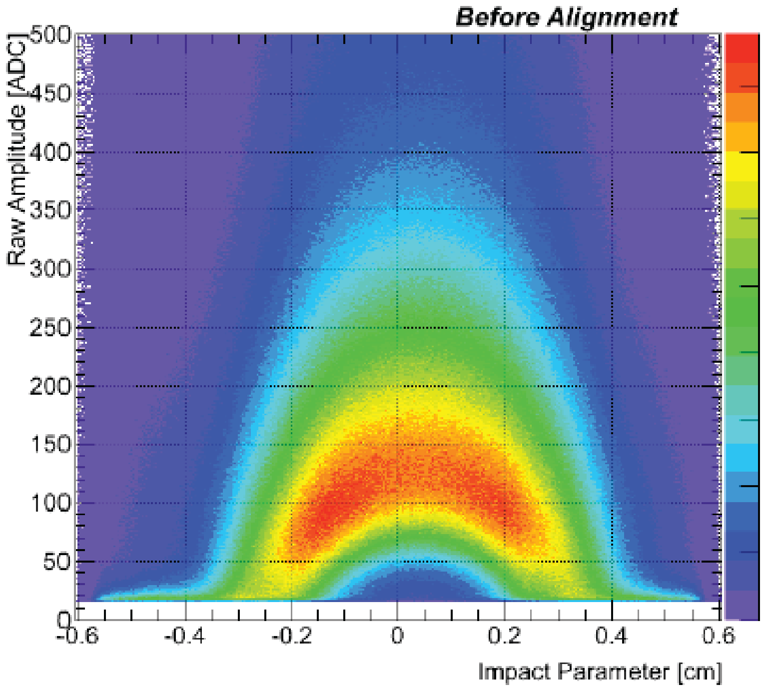
Shows the orbital variation.

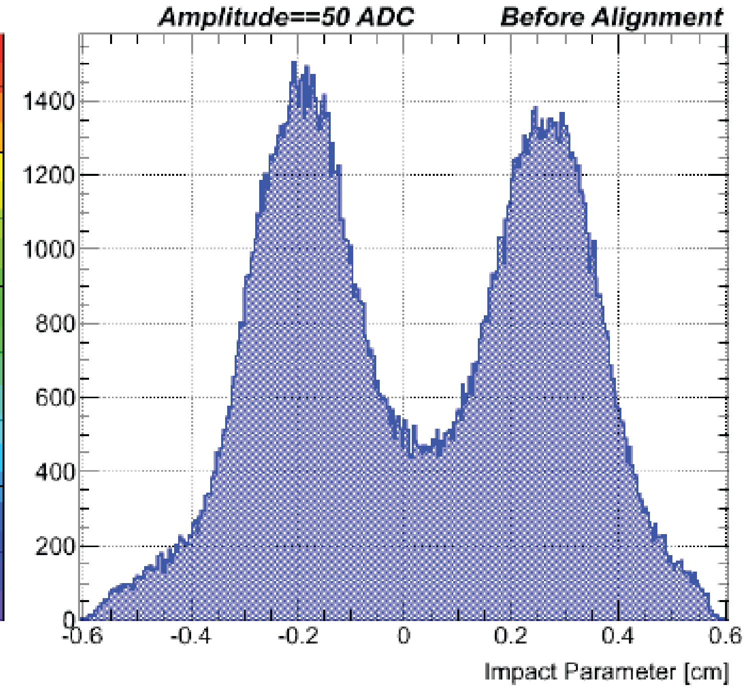


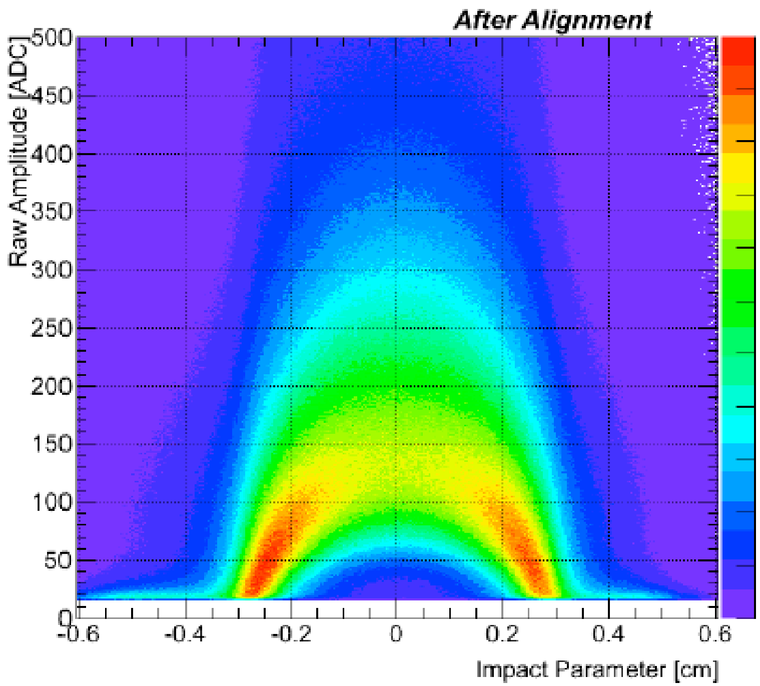
Zhili Weng, private

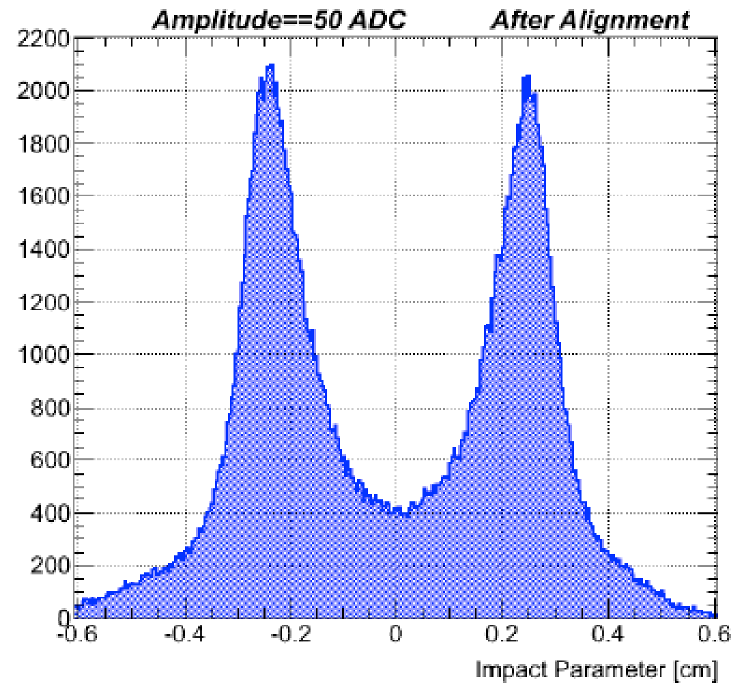


Alignment affect gain calibration

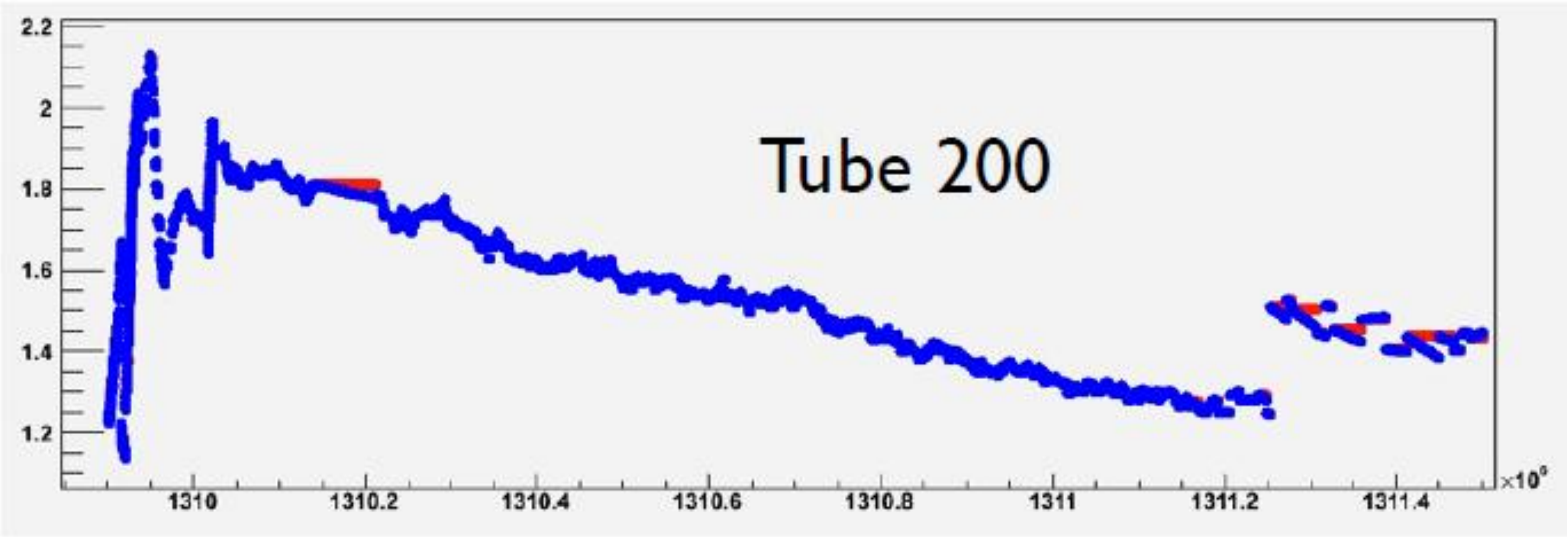


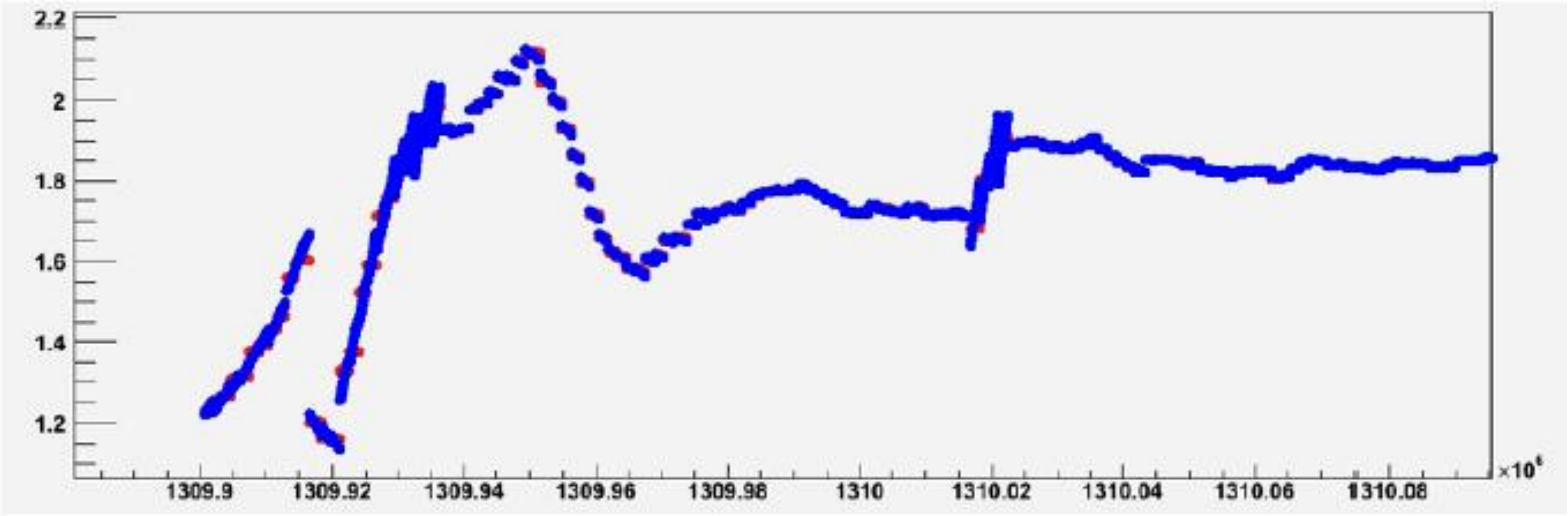






TRD Gain Calibration During Refill





Zhli Weng, private

Conclusion

AMS is working well.

All subdetectors are performing as expected.

Electronics and thermal systems built in Taiwan have been doing outstanding jobs.

We are still optimizing the performance of AMS.

We expect exciting results to be unveiled soon.

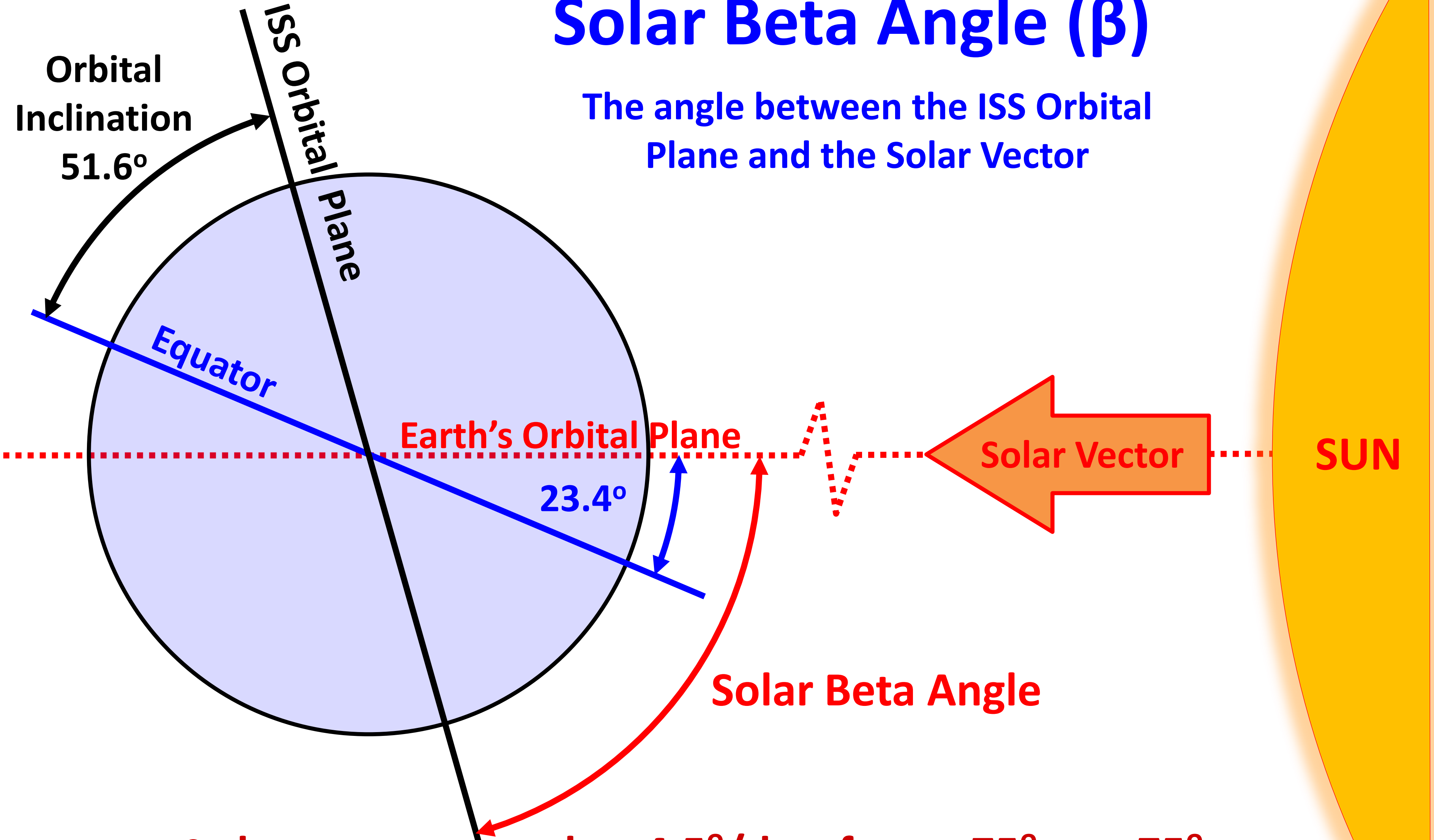
Discoveries in Physics

Facility	Original purpose, Expert Opinion	Discovery with Precision Instrument
30 GeV Proton Accelerator (1960's) CERN	Nuclear force	Neutral Currents -> Z, W
30 GeV Proton Accelerator (1960's) Brookhaven	Nuclear force	2 types of neutrinos Break down of time reversal symmetry New form of matter
400 GeV Proton Accelerator (1970's) FNAL	Neutrino physics	*5th and 6th types of quark*
Electron Positron Collider (1970's) SLAC Spear	Properties of quantum electricity	Quark inside protons 4th family of quarks 3rd kind of electrons
Electron Positron Collider (1980's) PETRA	6th kind of quark	*Gluon*
Large Underground Cave (2000) Super Kamiokande	Proton life time	Neutrino has mass
Hubble Space Telescope (1990's)	Galactic survey	*Curvature of the universe, dark energy*
AMS on ISS	Dark Matter, Antimatter,…	*?*

Exploring a new territory with a precision instrument is the key to discovery.

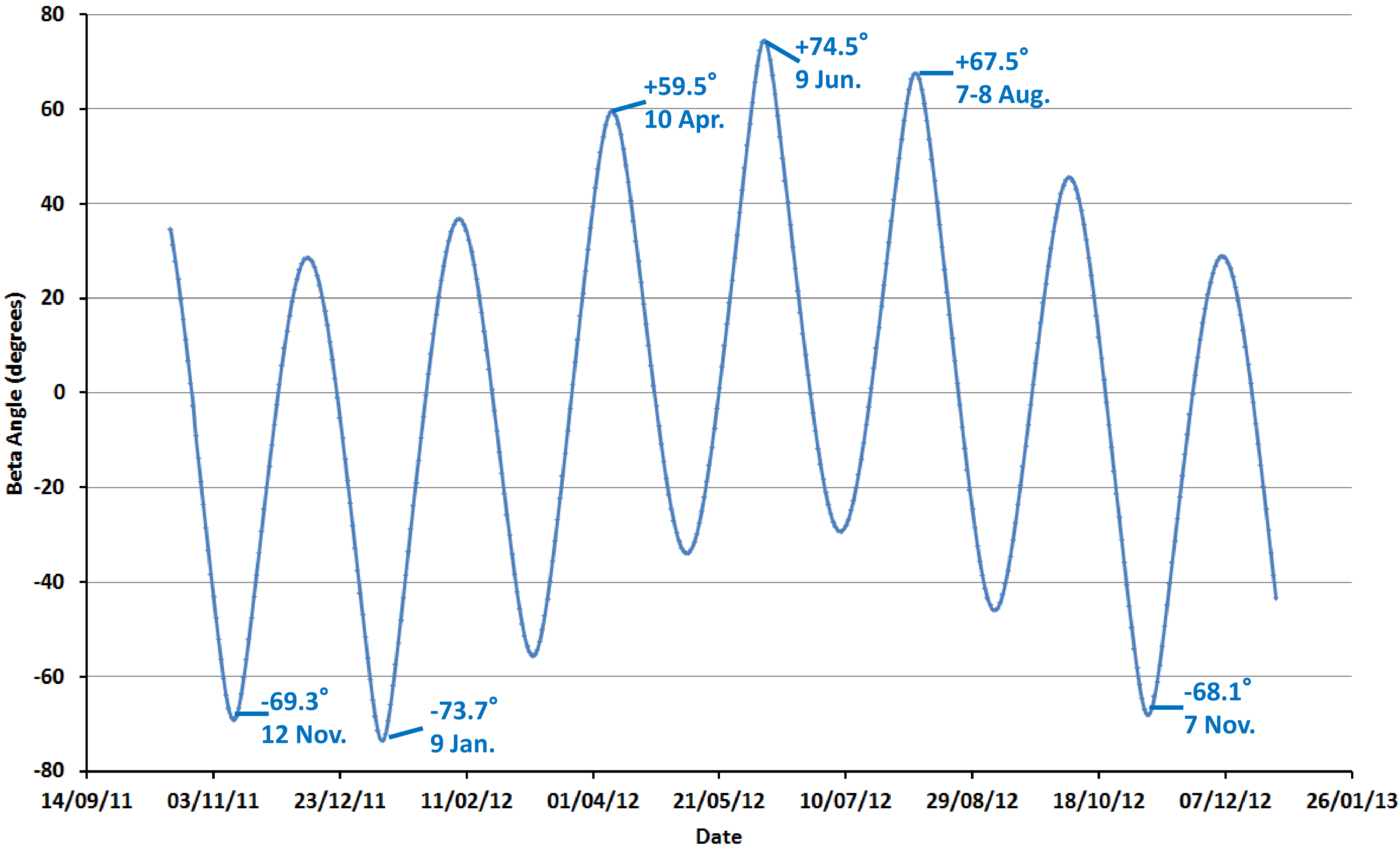
Solar Beta Angle (β)

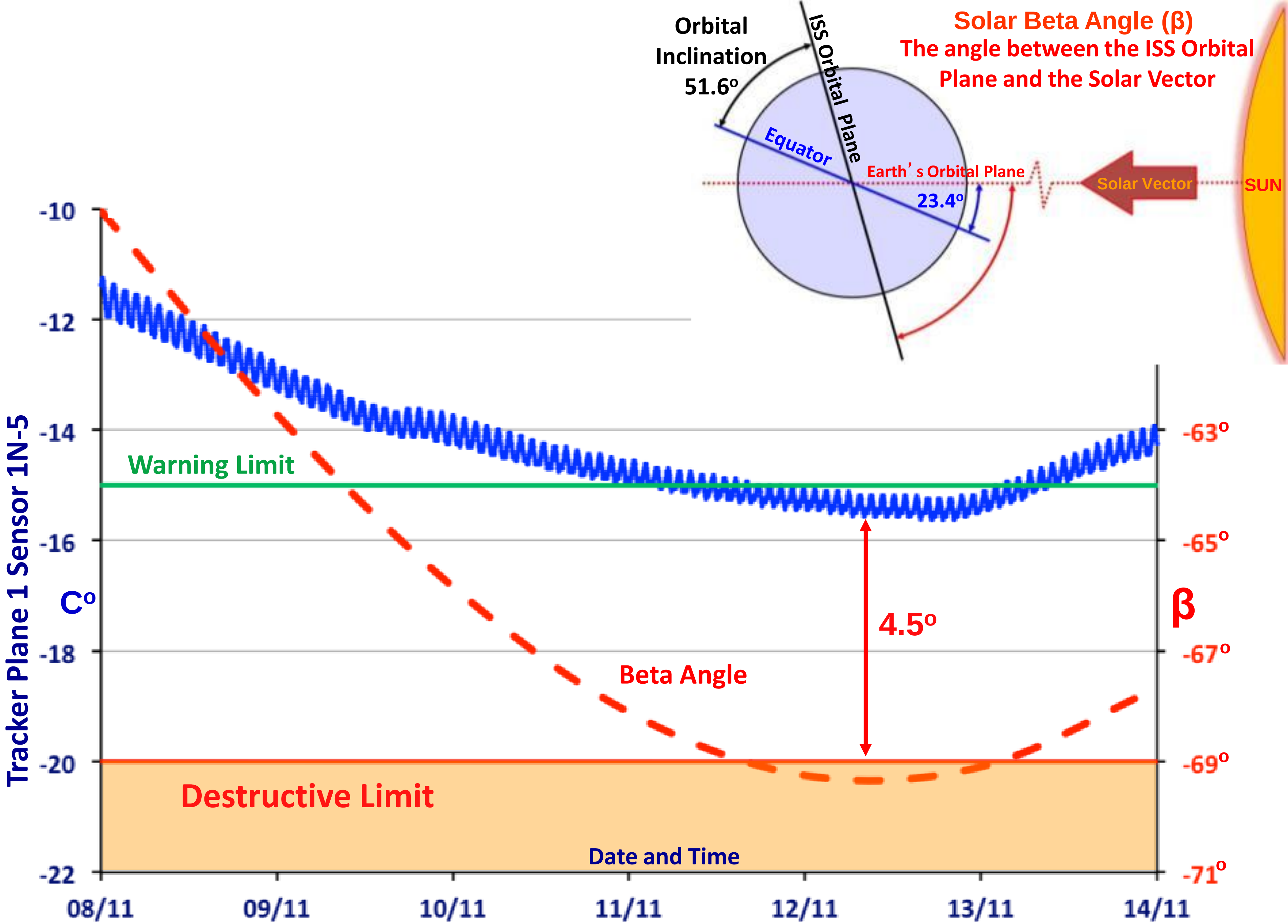
The angle between the ISS Orbital Plane and the Solar Vector



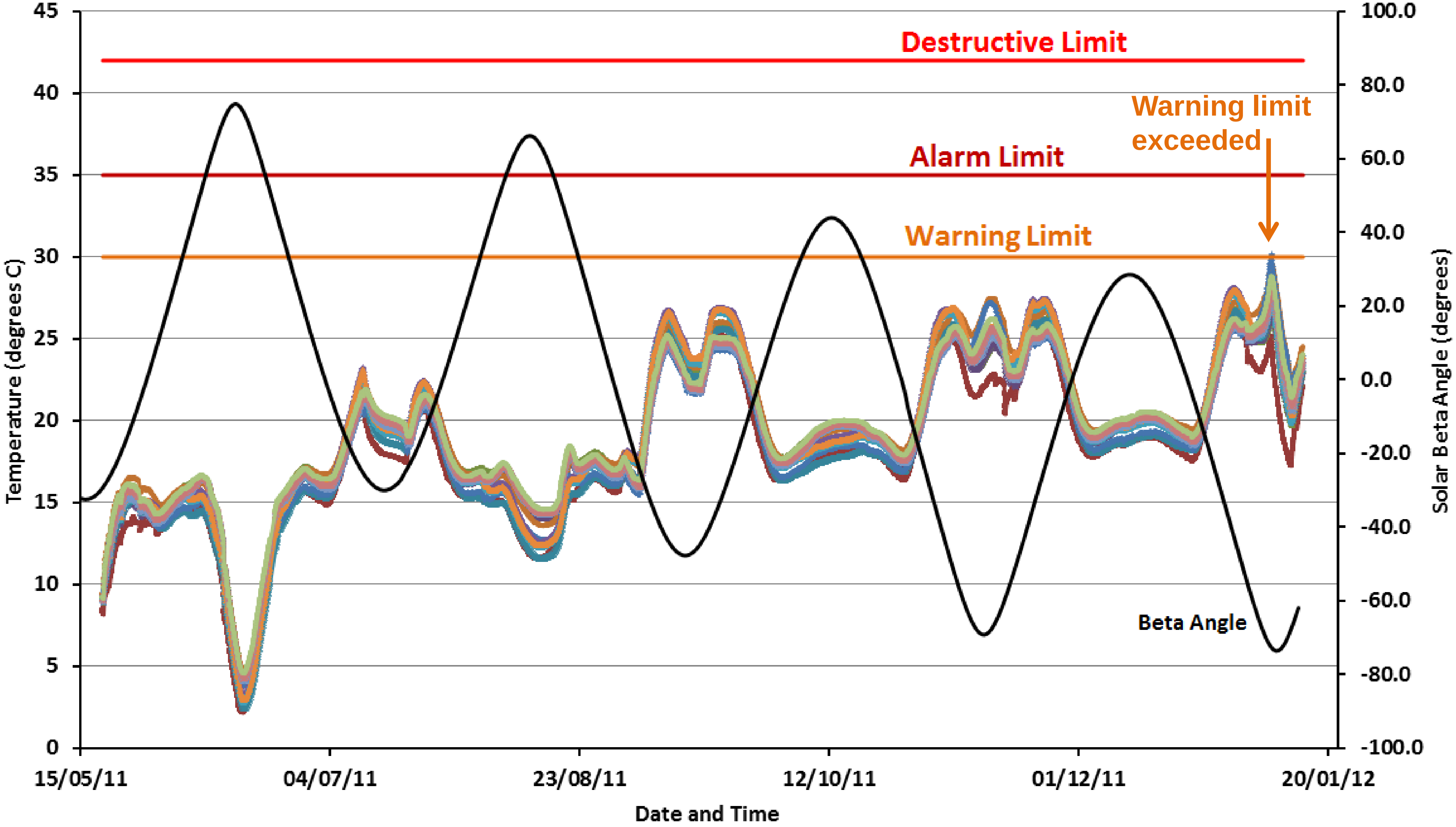
β changes constantly, ~4.5°/day, from −75° to + 75°, due to the precession of the ISS's orbit and the rotation of the Earth about the Sun

Evolution of the beta angle through 2012, with dates of extreme values
At large positive values, the port side of AMS is hot and the starboard side cold.
Vice-versa for large negative beta angles




Orbital
Inclination
51.6°
ISS Orbital Plane
Equator
Earth's Orbital Plane
23.4°
Solar Vector
SUN
Solar Beta Angle (β)
The angle between the ISS Orbital
Plane and the Solar Vector
Tracker Plane 1 Sensor 1N-5
C°
-10
-12
-14
-16
-18
-20
-22
Warning Limit
Beta Angle
4.5°
Destructive Limit
Date and Time
β
-63°
-65°
-67°
-69°
-71°
08/11
09/11
10/11
11/11
12/11
13/11
14/11

Lower Time of Flight Phototube temperatures during entire time of AMS on ISS

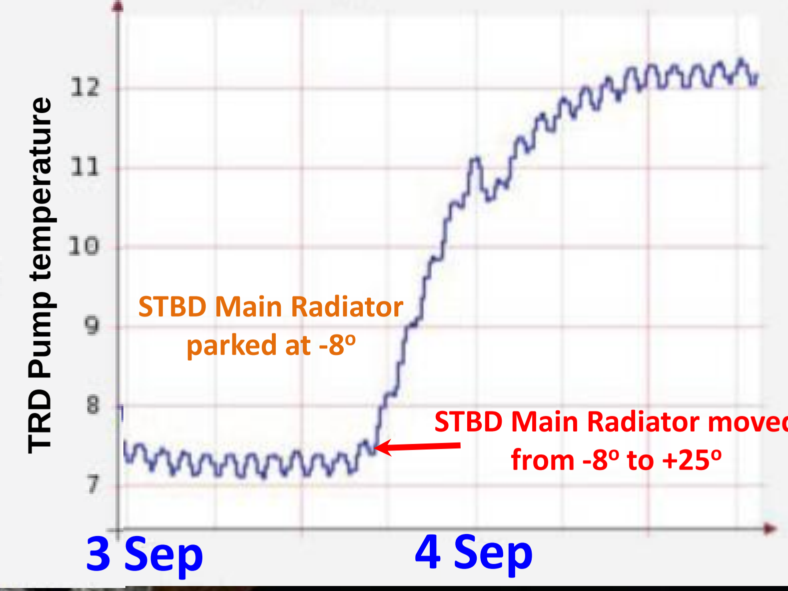


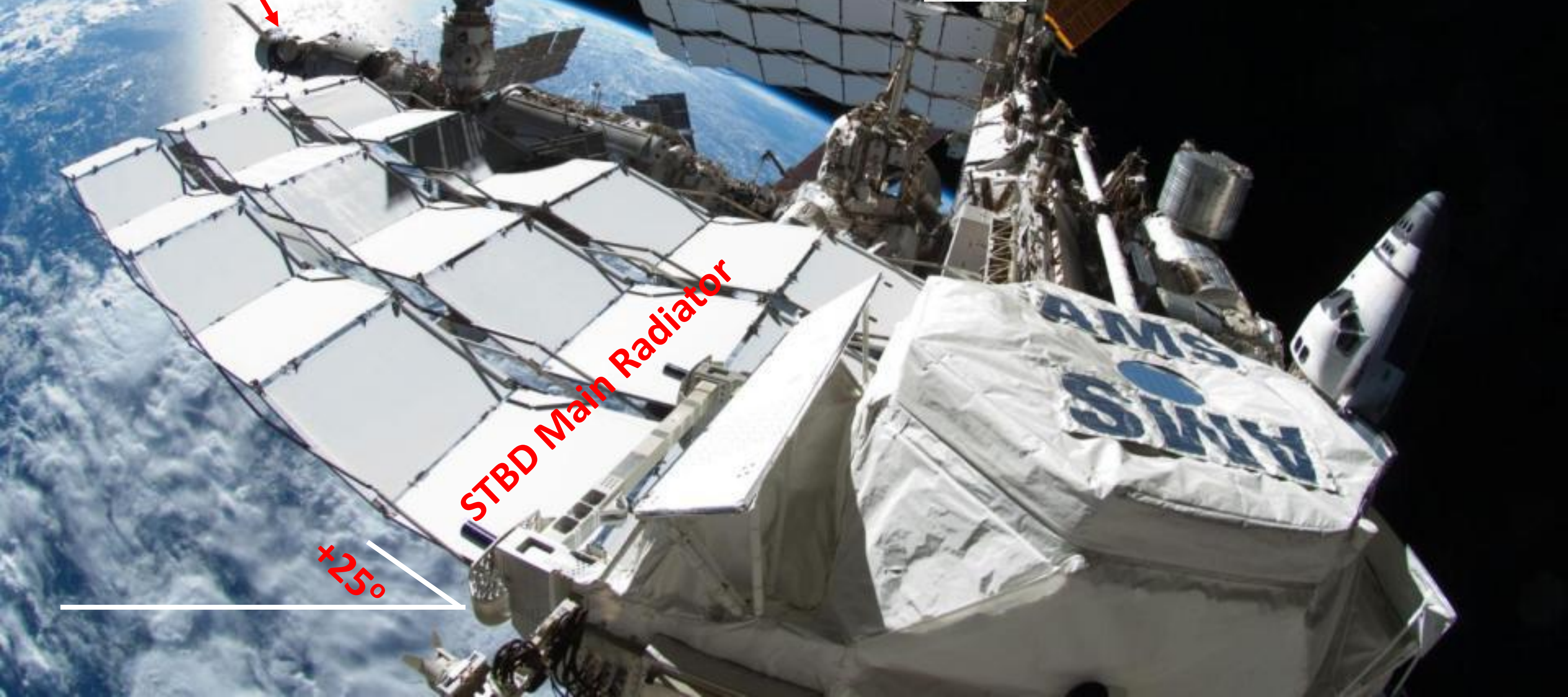
Highest LTOF PM temperatures increased in successive low beta periods due to increasingly extreme beta angles, changing solar constant (earth is closest to sun on Jan. 4) and five day period of no eclipse in January

Completion of installation of the AMS on the Space Station

Thermal variables:

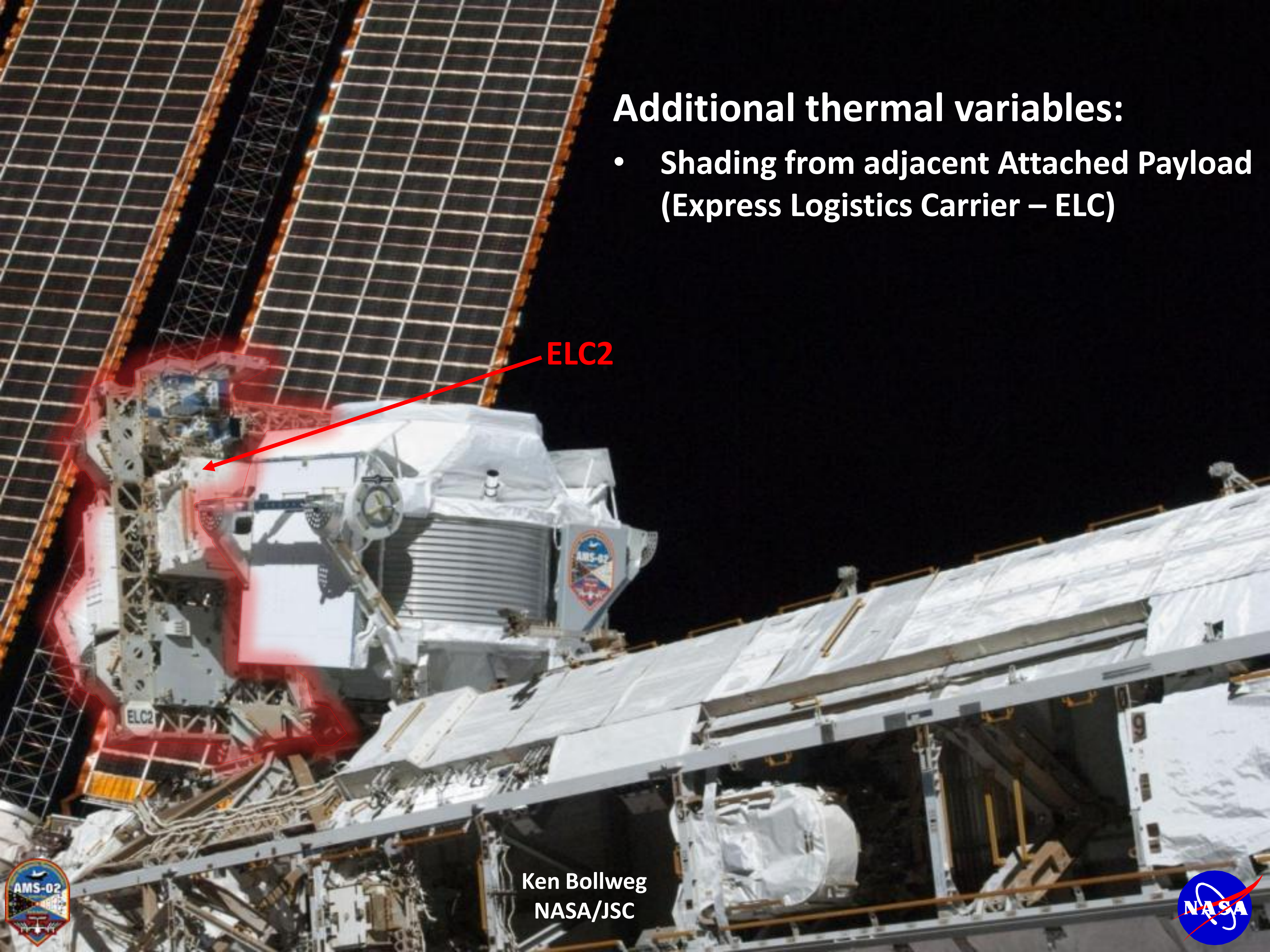
- ISS Radiator positions
- ISS attitude changes (primarily for visiting vehicles)





Additional thermal variables:

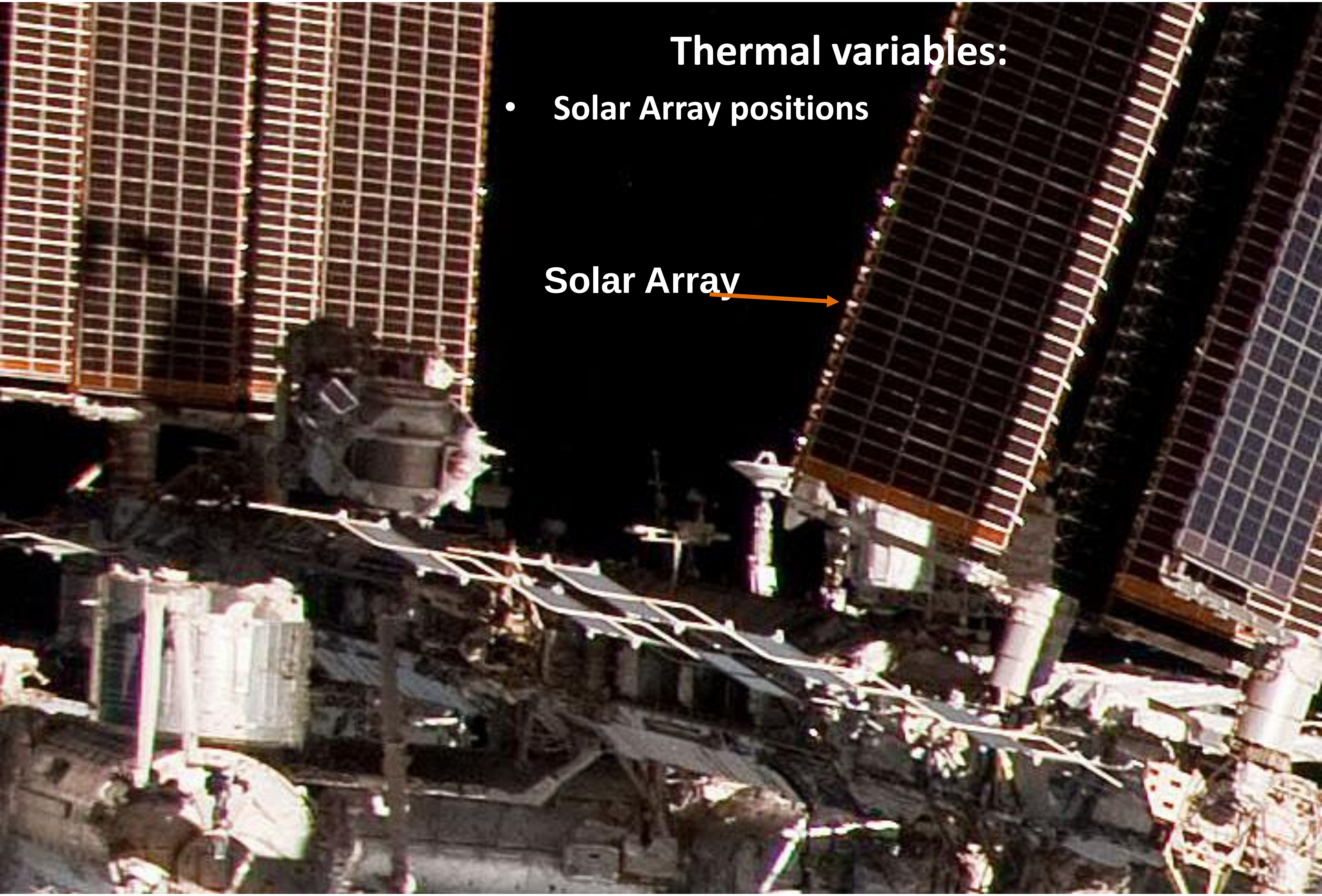
- Shading from adjacent Attached Payload (Express Logistics Carrier – ELC)



Ken Bollweg
NASA/JSC

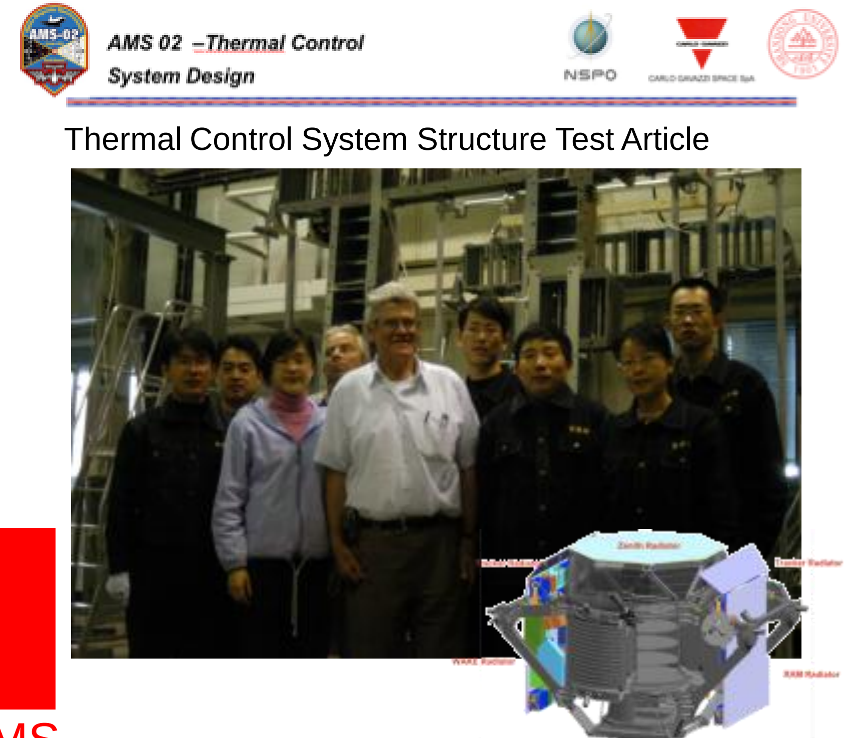
Thermal variables:

- Solar Array positions



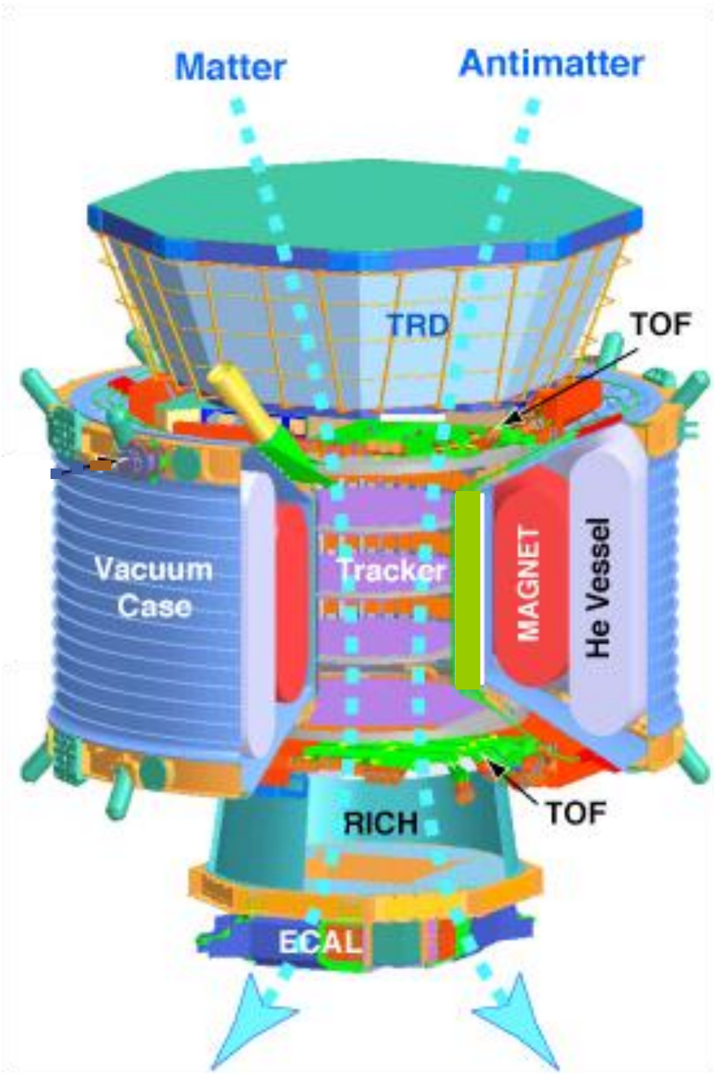
IHEP participated in the design and manufacturing of ECAL

China in AMS



Evaporator of TTCS: SYSU participated in the design, prototyping and qualification of TTCS

To distinguish matter from anti-matter, a magnet is needed.



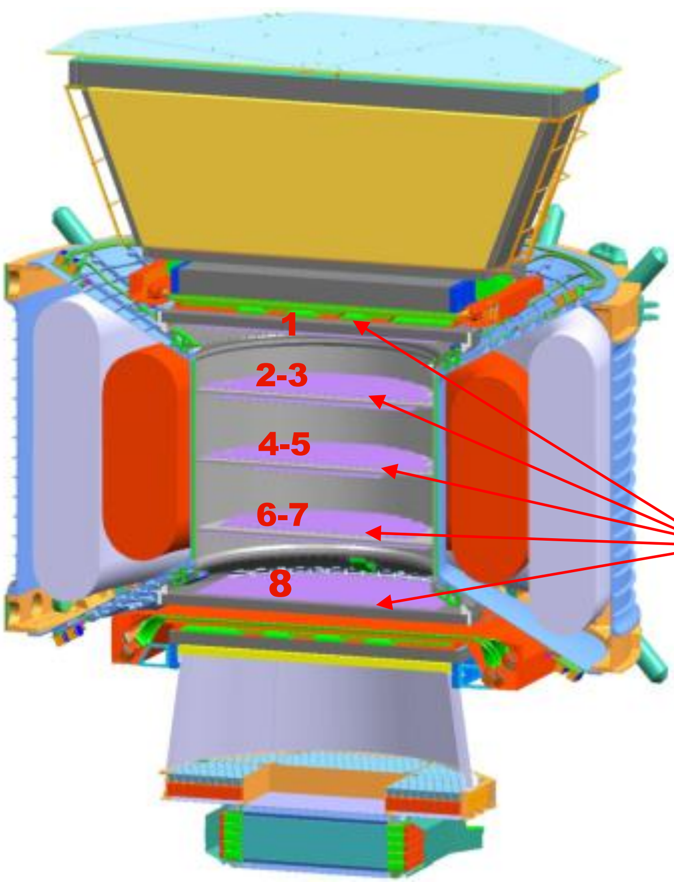
	e^-	P	Fe	e^+	$\bar{P}$	$\overline{He}$
TRD						
TOF						
Tracker + Magnet						
RICH						
ECAL						
Physics example	Cosmic Ray Physics Strangelets			Dark matter		Antimatter

AMS-02

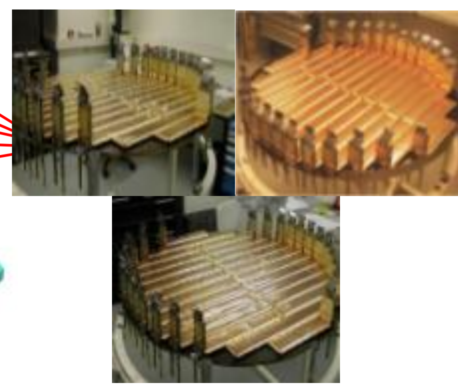
(3 yrs)
with SC Magnet
8 layers of Silicon

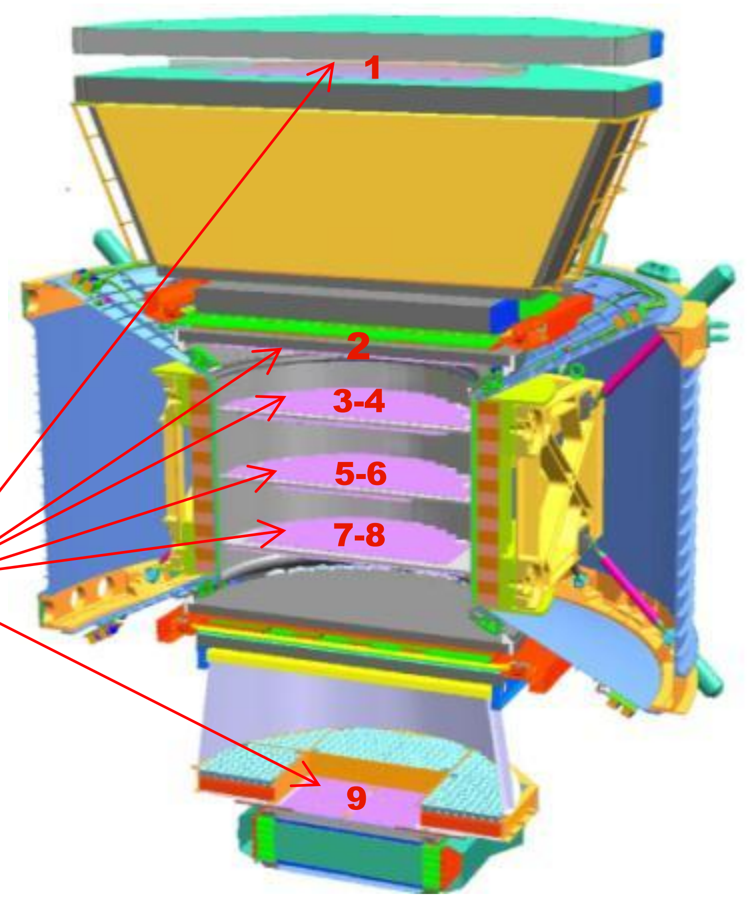
AMS-02

with Permanent Magnet
9 layers of Silicon



Silicon layers





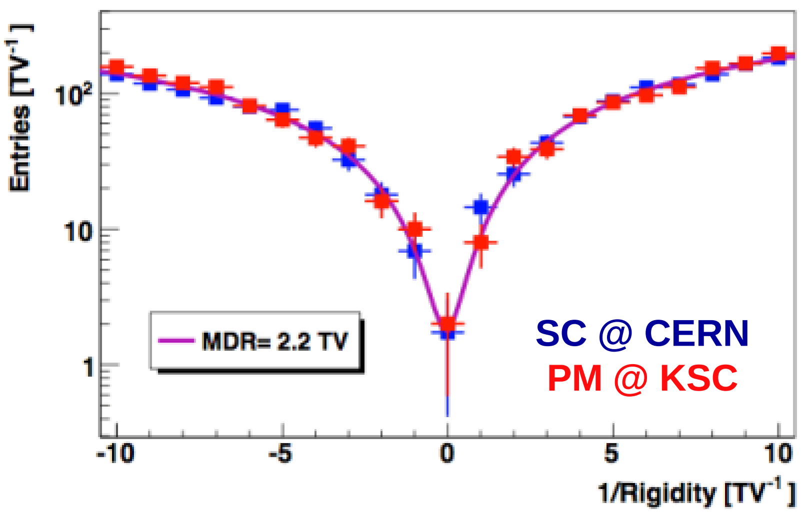
Layers 1 and 9 are far away from the magnet to extend the lever arm.

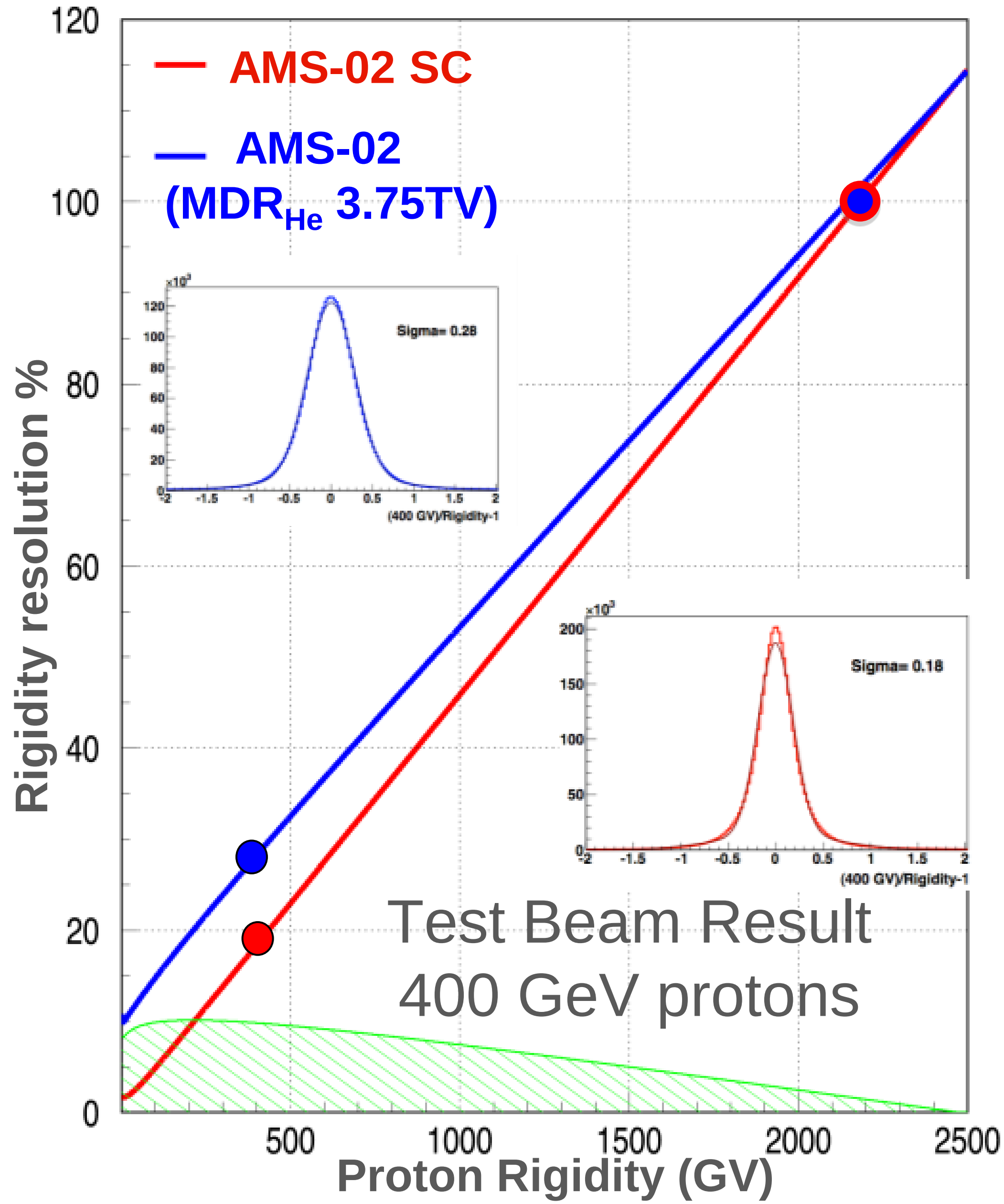
Rigidity resolution

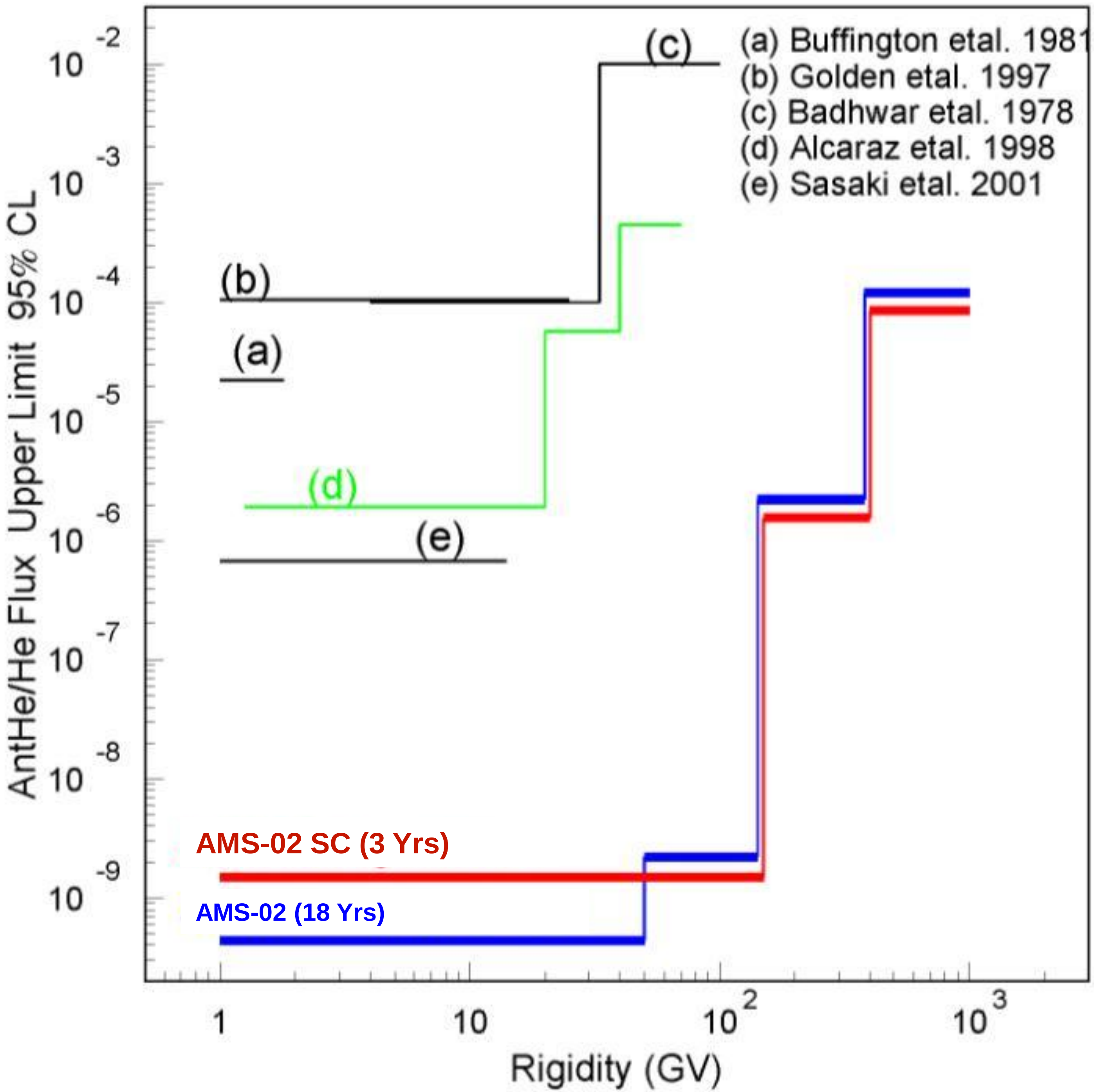
Maximum detectable Rigidity:

- **2.14 TV for protons**
- **3.75 TV for He**

Calibration with muons





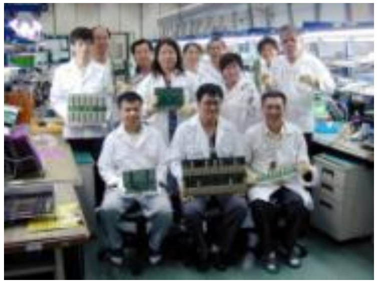


(a) Buffington etal. 1981
(b) Golden etal. 1997
(c) Badhwar etal. 1978
(d) Alcaraz etal. 1998
(e) Sasaki etal. 2001
(a)
(b)
(c)
(d)
(e)
AMS-02 SC (3 Yrs)
AMS-02 (18 Yrs)
AntHe/He Flux Upper Limit 95% CL
Rigidity (GV)

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.

Examples of our early work include:

Scientists from 15 countries come to Taiwan every 3 months for a Technical Exchange Meeting on electronics.



They also come to work with local scientists to test and qualify *every piece* of electronics equipment produced.

Milan-Thermal

Indiana-Beam

Scientists fromTaiwan go to U.S. and Europe to work with AMS partners.

Milan-Power

Germany -Beam

Planned Asia POCC -- in Preparation at CSIST

POCC at CERN in control of AMS since 19 June 2011

AMS Science Centers were established at all the participating universities in China. They contribute greatly to the computing needs of AMS.