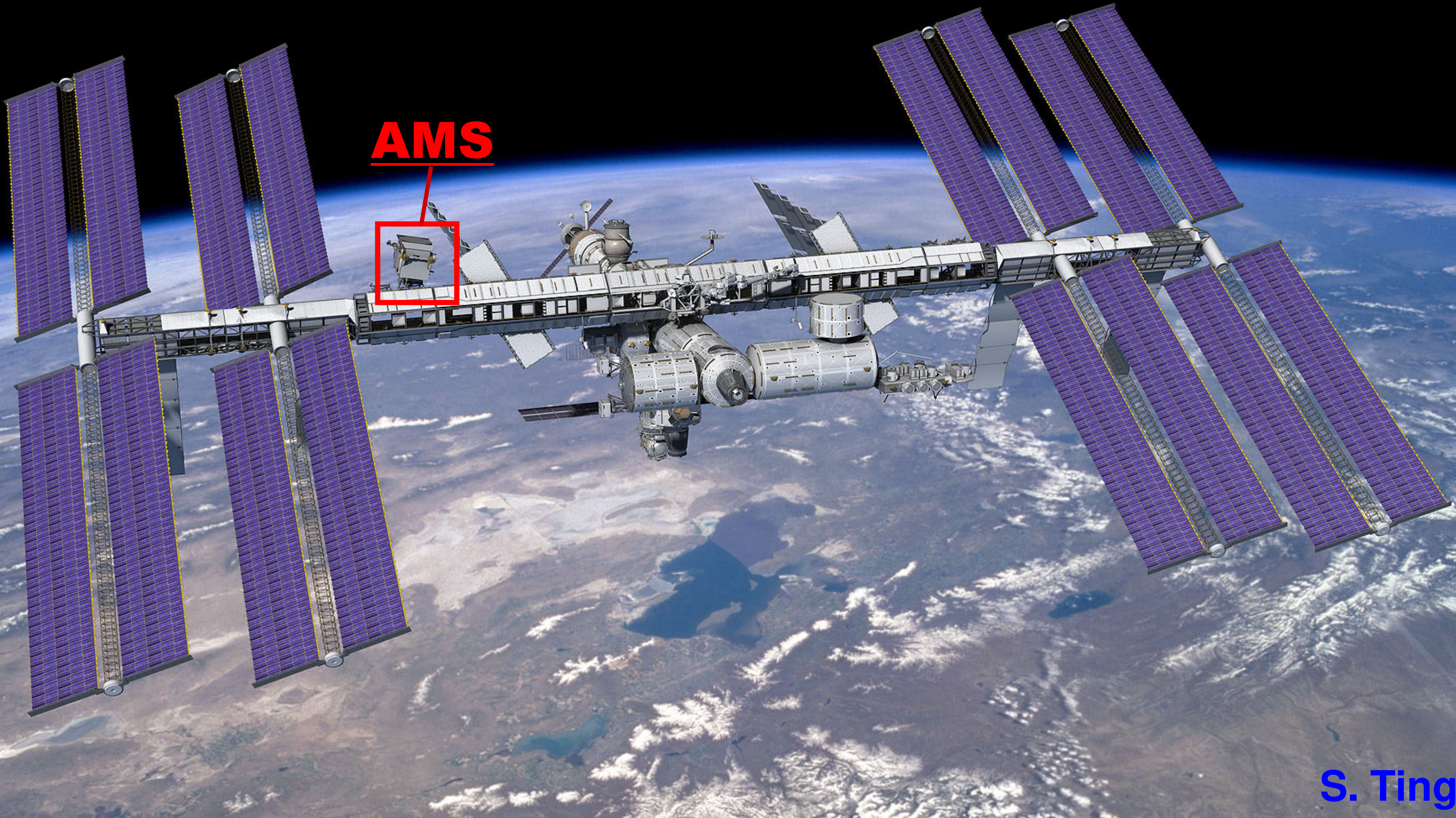
The Alpha Magnetic Spectrometer
on the
International Space Station



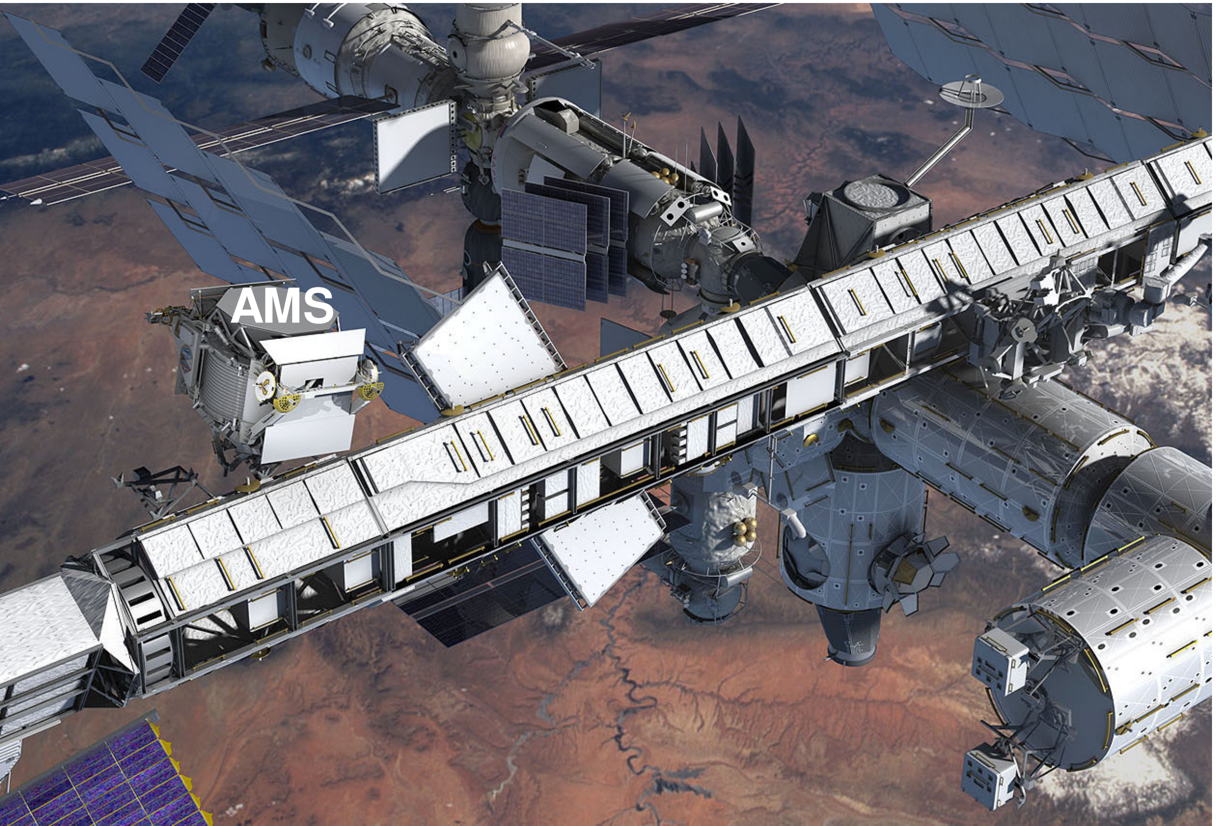
S. Ting

Fundamental Science on the International Space Station (ISS)

There are two kinds of cosmic rays traveling through space

1- Chargedless cosmic rays (light rays and neutrinos):
Light rays have been measured (e.g., Hubble) for over 50 years.
Fundamental discoveries have been made.

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

National Aeronautics and
Space Administration

Headquarters
Washington, DC 20546-0001

JUN 1 1994

ply to Attn of

Professor Samuel Ting
Massachusetts Institute of Technology
Laboratory for Nuclear Science
Cambridge, MA 02139

Dear Professor Ting:

Thank you for your May 9, 1994, presentation on a concept to search for the origin of mass using a magnetic spectrometer on the Space Station. The detection of antinuclei, heavier than hydrogen from cosmic sources, would indeed have a fundamental impact on science and the way we view the universe.

This letter is to inform you that we are taking some initial steps to assess the accommodations for fundamental physics experiments as external attached payloads on the Space Station using your concept as a model. We are assuming that your research group would provide the experimental package with non-NASA, primarily Department of Energy (DOE) funding, and that NASA would provide transportation to the Station and on-orbit accommodations including electrical power, operations, and delivery of data tapes or equipment.

……

Sincerely,

Wesley T. Huntress

Wesley T. Huntress, Jr.
Associate Administrator
for Space Science

FINAL of 3 SCIENTIFIC REVIEWS of AMS by the U.S. DOE (Sept 25, 06)

by the DOE AMS committee:

***Barry C. Barish*, Chair, Caltech**

***Elliott D. Bloom,* Stanford University**

***James Cronin*, University of Chicago**

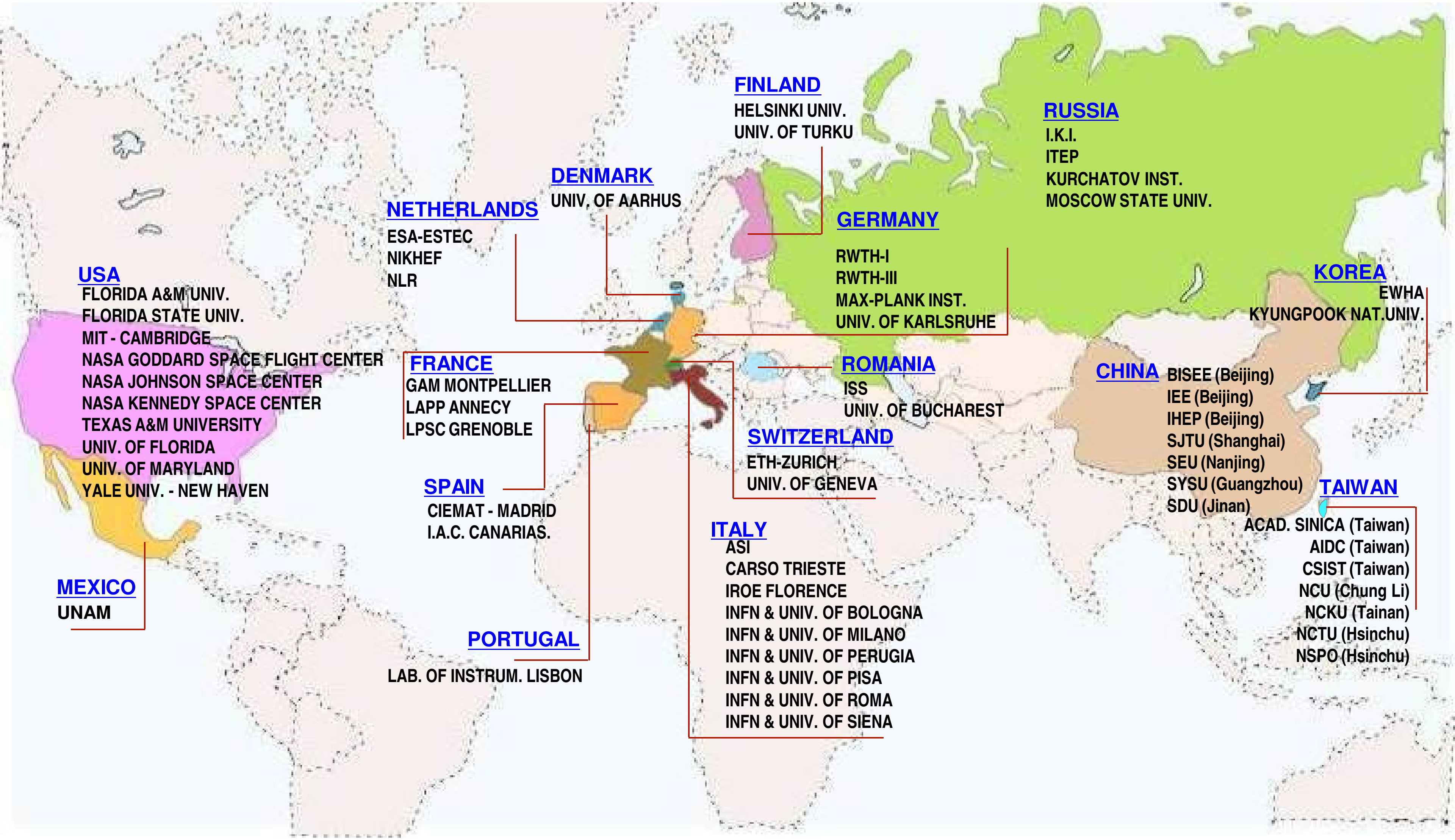
***Steve Olsen,* University of Hawaii**

***George Smoot*, L.B.N.L.**

***Paul J. Steinhardt,* Princeton University,**

***Trevor Weekes,* Harvard University**

AMS is an international collaboration of 16 countries, 60 institutes (10 U.S.) and 600 physicists.



USA
FLORIDA A&M UNIV.
FLORIDA STATE UNIV.
MIT - CAMBRIDGE
NASA GODDARD SPACE FLIGHT CENTER
NASA JOHNSON SPACE CENTER
NASA KENNEDY SPACE CENTER
TEXAS A&M UNIVERSITY
UNIV. OF FLORIDA
UNIV. OF MARYLAND
YALE UNIV. - NEW HAVEN

MEXICO
UNAM

NETHERLANDS
ESA-ESTEC
NIKHEF
NLR

DENMARK
UNIV. OF AARHUS

FINLAND
HELSINKI UNIV.
UNIV. OF TURKU

FRANCE
GAM MONTPELLIER
LAPP ANNECY
LPSC GRENOBLE

SPAIN
CIEMAT - MADRID
I.A.C. CANARIAS.

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LAB. OF INSTRUM. LISBON

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RWTH-III
MAX-PLANK INST.
UNIV. OF KARLSRUHE

SWITZERLAND
ETH-ZURICH
UNIV. OF GENEVA

ITALY
ASI
CARSO TRIESTE
IROE FLORENCE
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INFN & UNIV. OF MILANO
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UNIV. OF BUCHAREST

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ITEP
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MOSCOW STATE UNIV.

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IEE (Beijing)
IHEP (Beijing)
SJTU (Shanghai)
SEU (Nanjing)
SYSU (Guangzhou)
SDU (Jinan)

KOREA
EWHA
KYUNGPOOK NAT.UNIV.

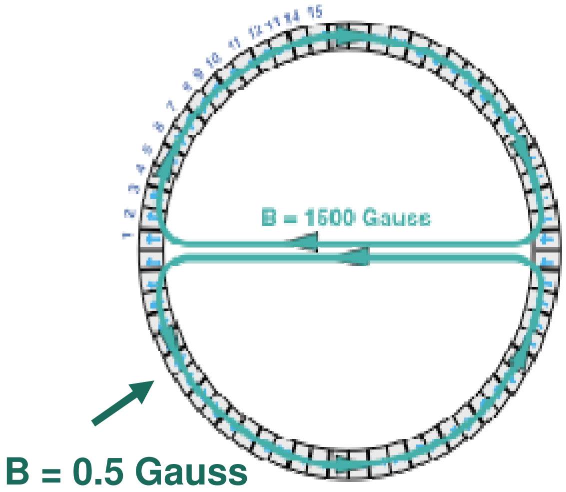
TAIWAN
ACAD. SINICA (Taiwan)
AIDC (Taiwan)
CSIST (Taiwan)
NCU (Chung Li)
NCKU (Tainan)
NCTU (Hsinchu)
NSPO (Hsinchu)

Acknowledgement

The CERN cryogenics, magnet, vacuum and accelerator groups have provided outstanding technical support which has kept AMS on schedule.

Many theoretical physicists at CERN, John Ellis, Alvaro De Rujula and others, have kept a continuous interest in AMS. They have contributed greatly in the formation of our data analysis framework.

There has never been a superconducting magnet in space due to the extremely difficult technical challenges



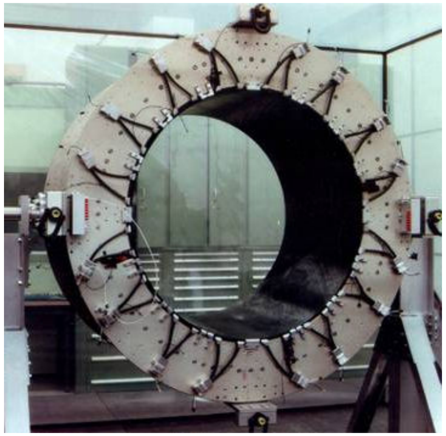
STEP ONE: AMS-01

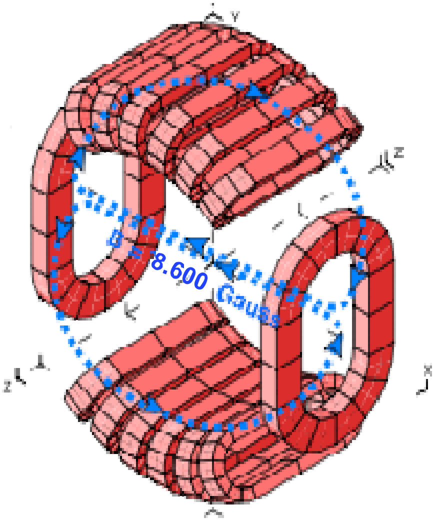
A Permanent Magnet to fly on the Shuttle

1- Minimum torque from Earth's magnetic field

2- Minimum field leakage

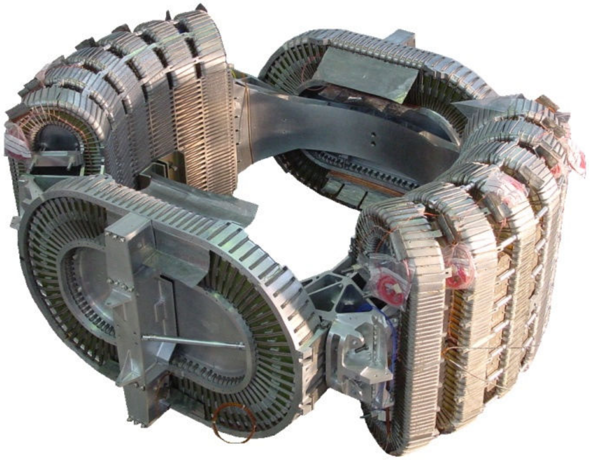
3- Minimum weight: no iron





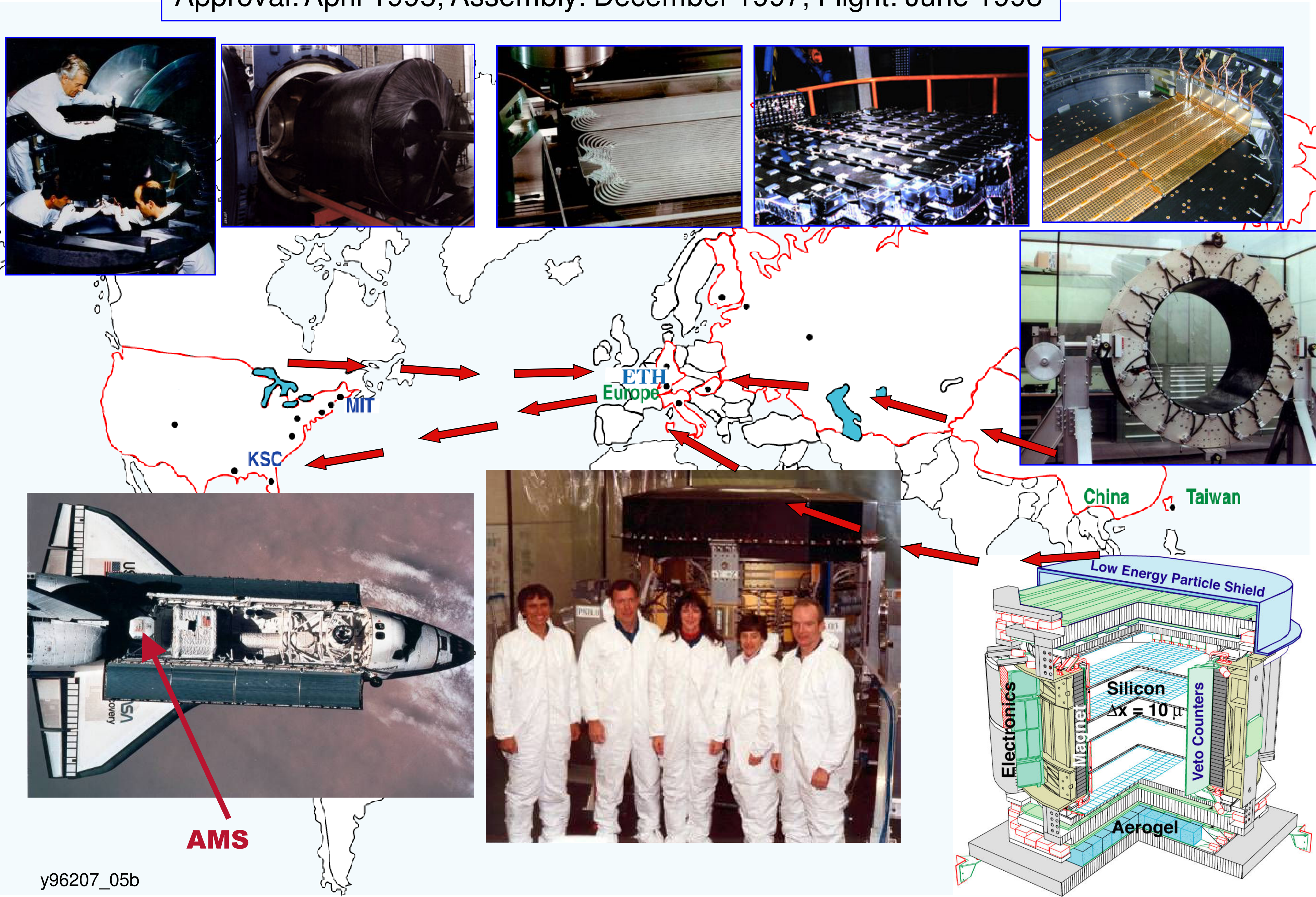
STEP TWO: AMS-02

A Superconducting Magnet
with the same field arrangement



First flight AMS-01

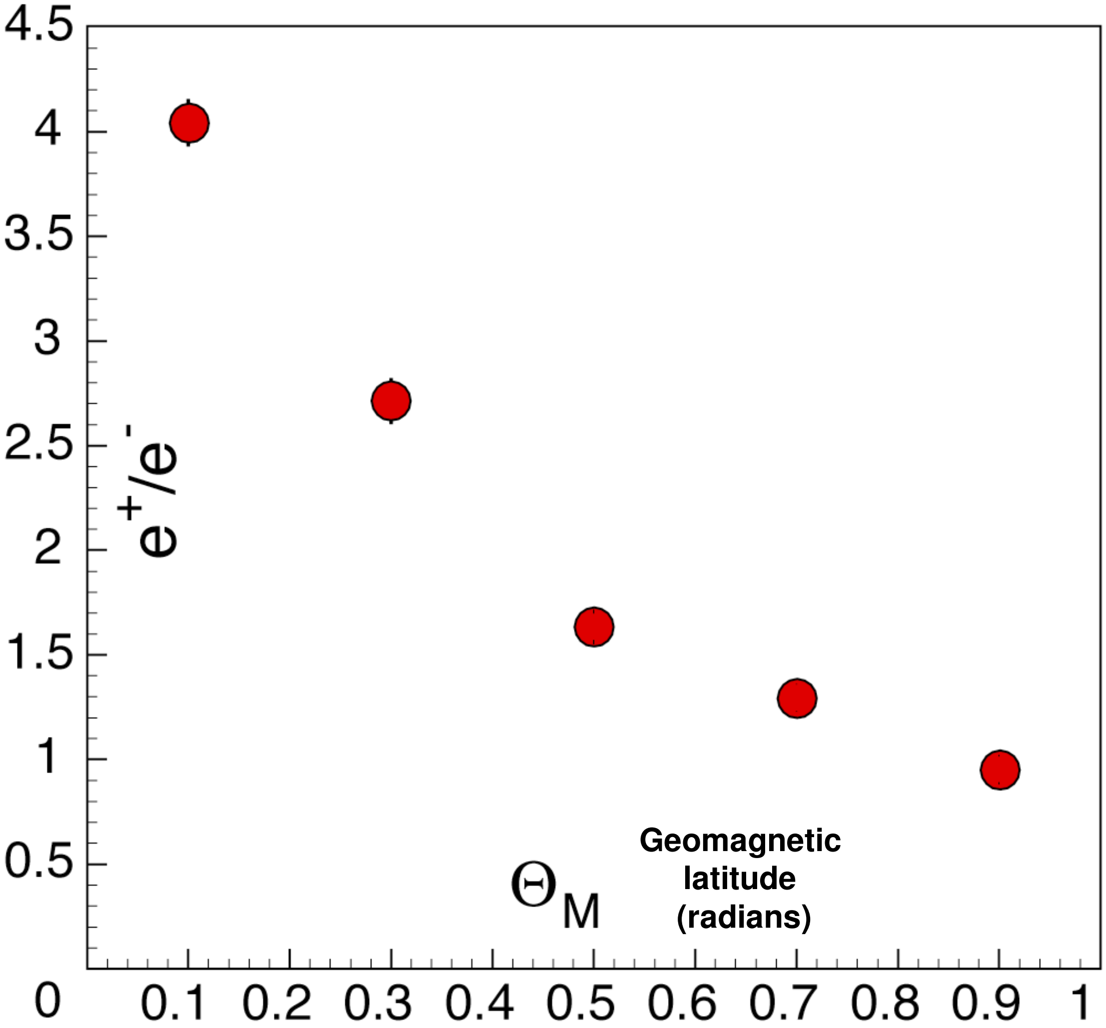
Approval: April 1995, Assembly: December 1997, Flight: June 1998



y96207_05b

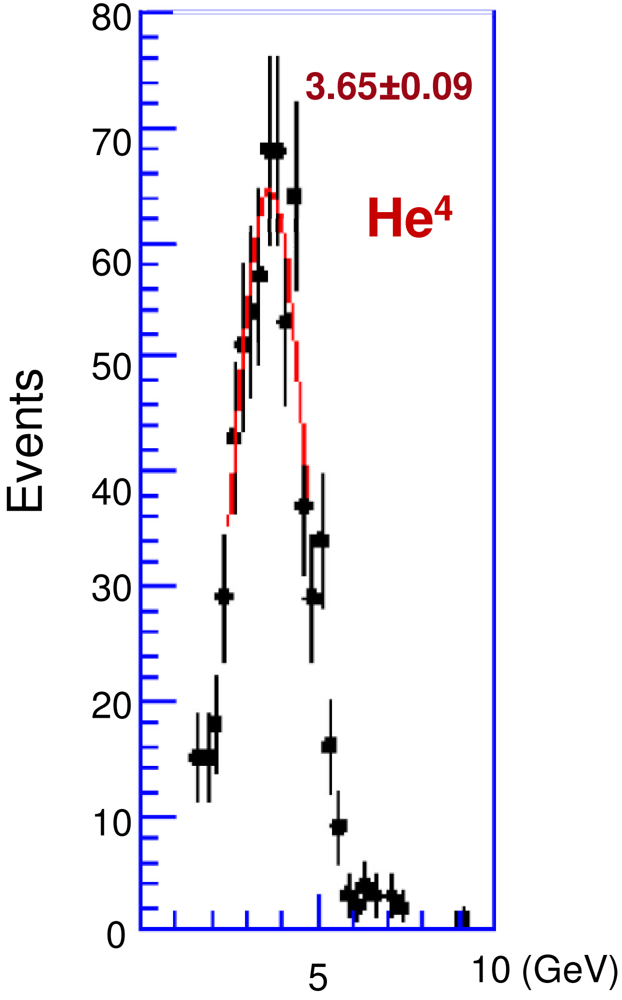
Unexpected results from first flight:

There are many more positrons (e^+) than electrons (e^-)

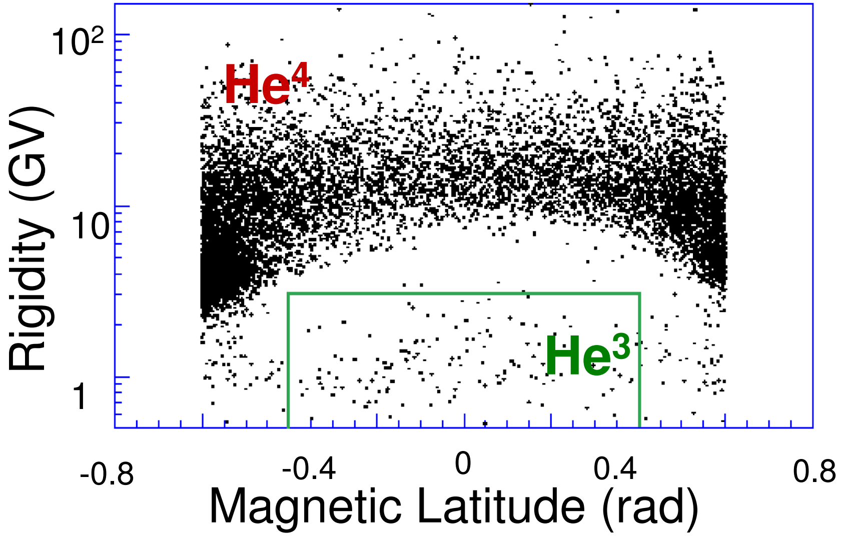


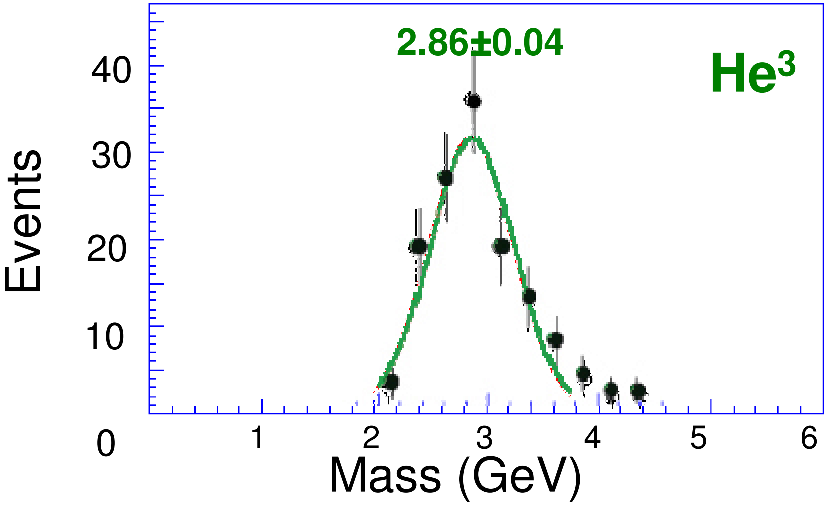
Phys. Lett. B484 (27 Jun 2000) 10-22

“Helium in Near Earth Orbit”



(Mass of He^4 = 3.7 GeV; He^3 = 2.8 GeV)





Physics Letters B vol.494 (3-4), p193.

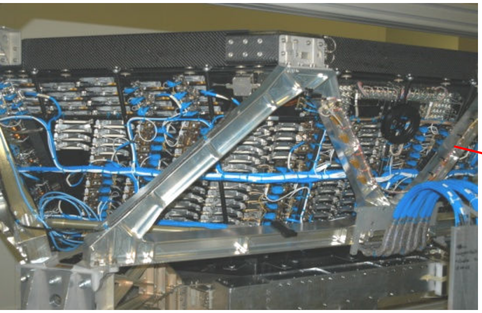
AMS-01 results were not predicted by any cosmic ray model

AMS on ISS

Particles are identified by their mass, charge and energy.

TRD

Electrons

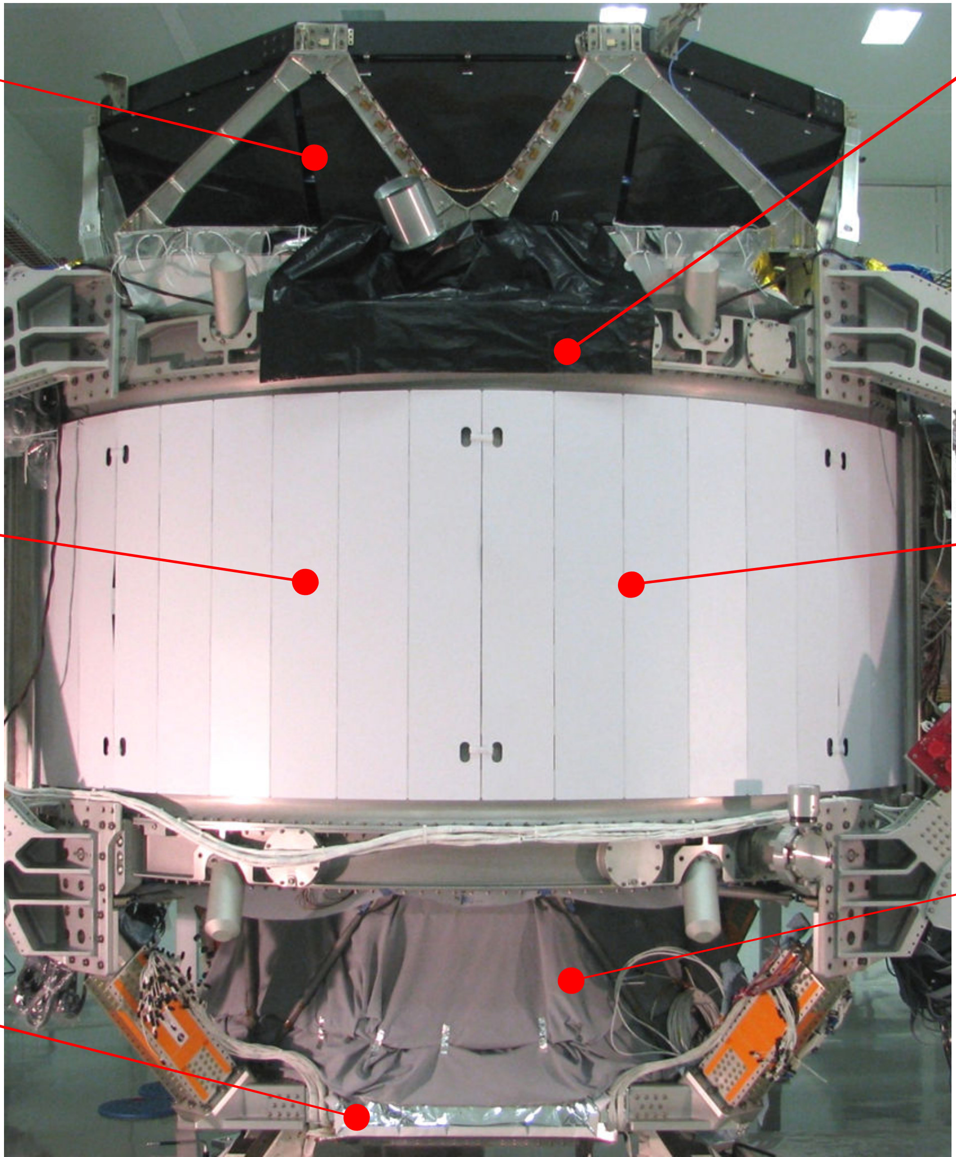


Silicon Tracker

Mass, Charge, Energy

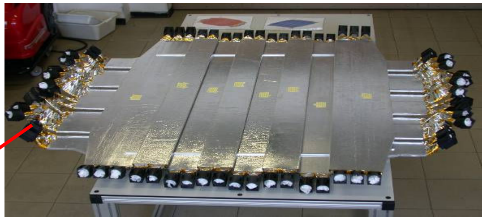
ECAL

Electrons, Gamma-rays



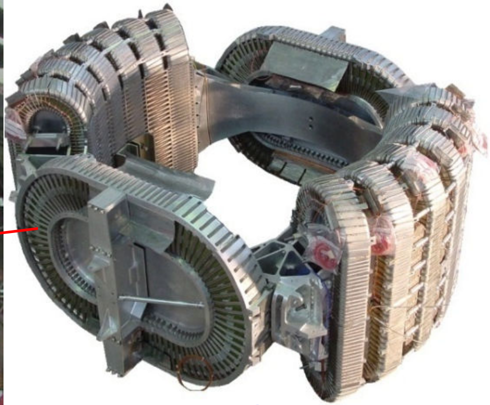
TOF

Mass, Charge, Energy



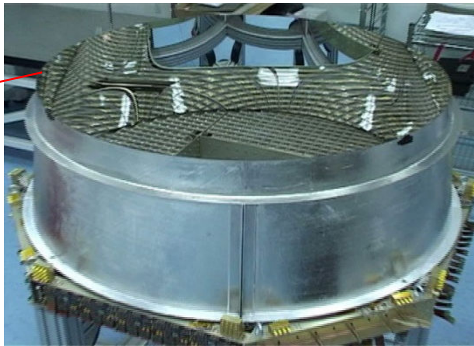
Magnet

Mass, ± Charge, Energy

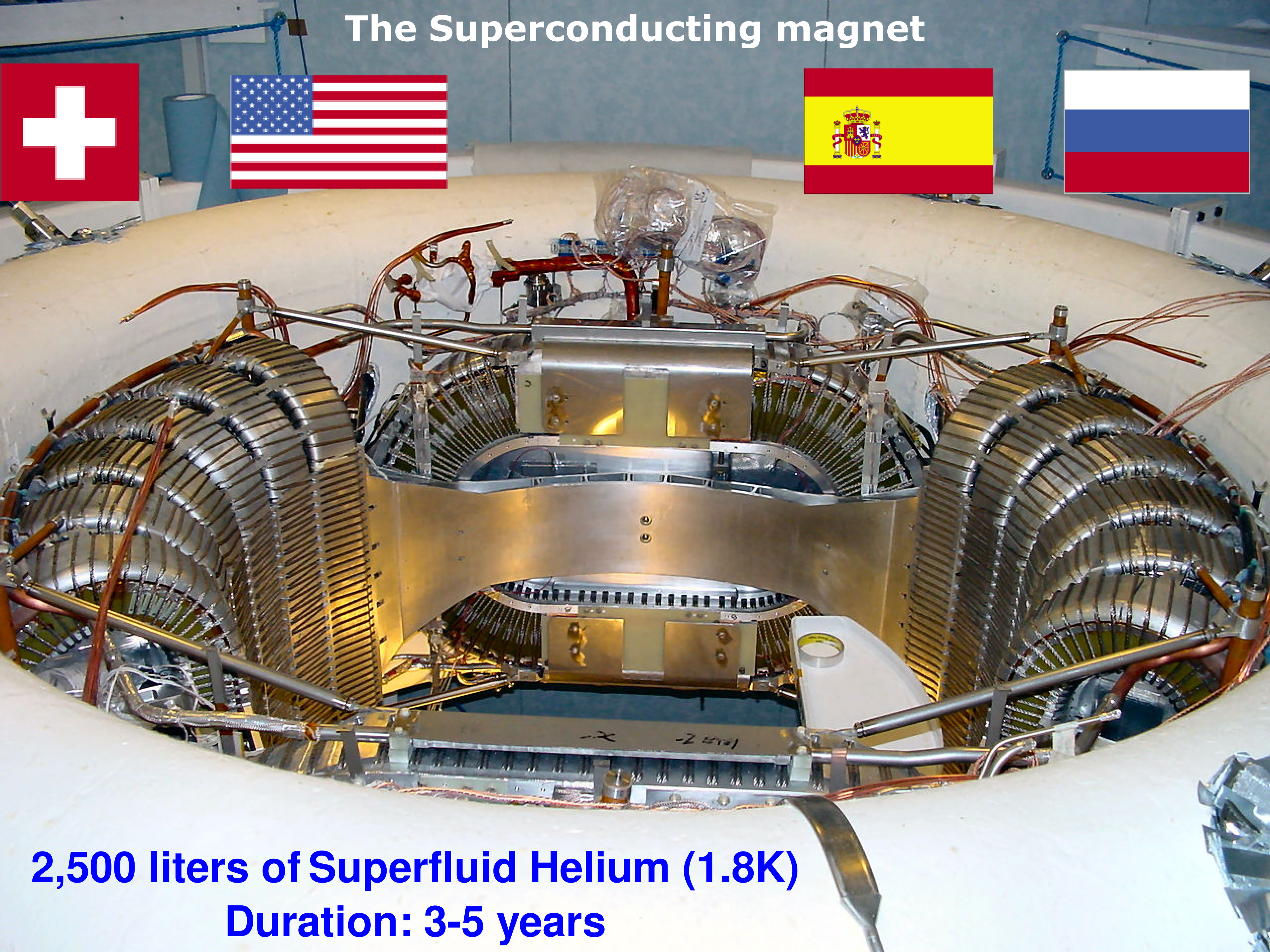


RICH

Mass, Charge, Energy



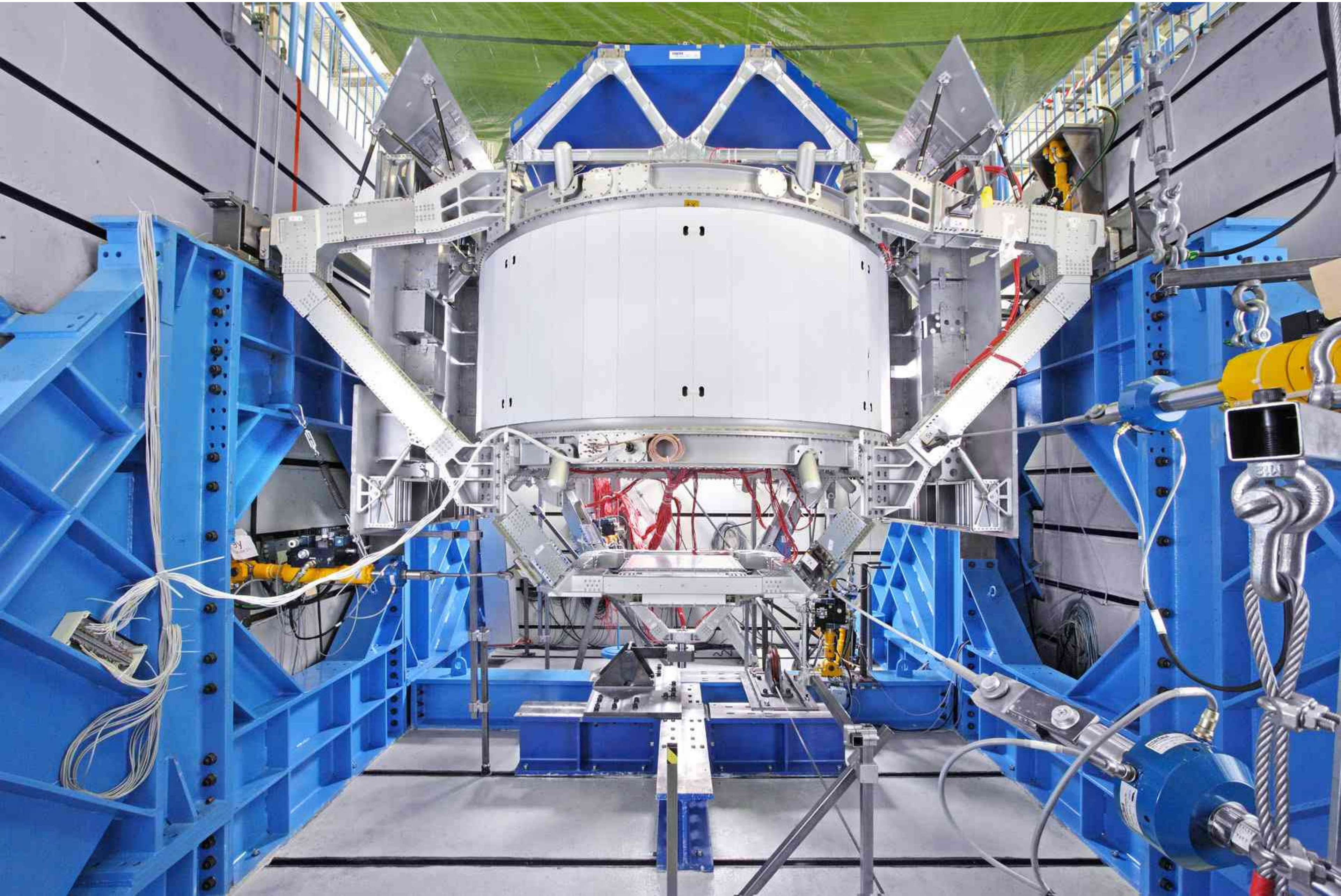
The Superconducting magnet



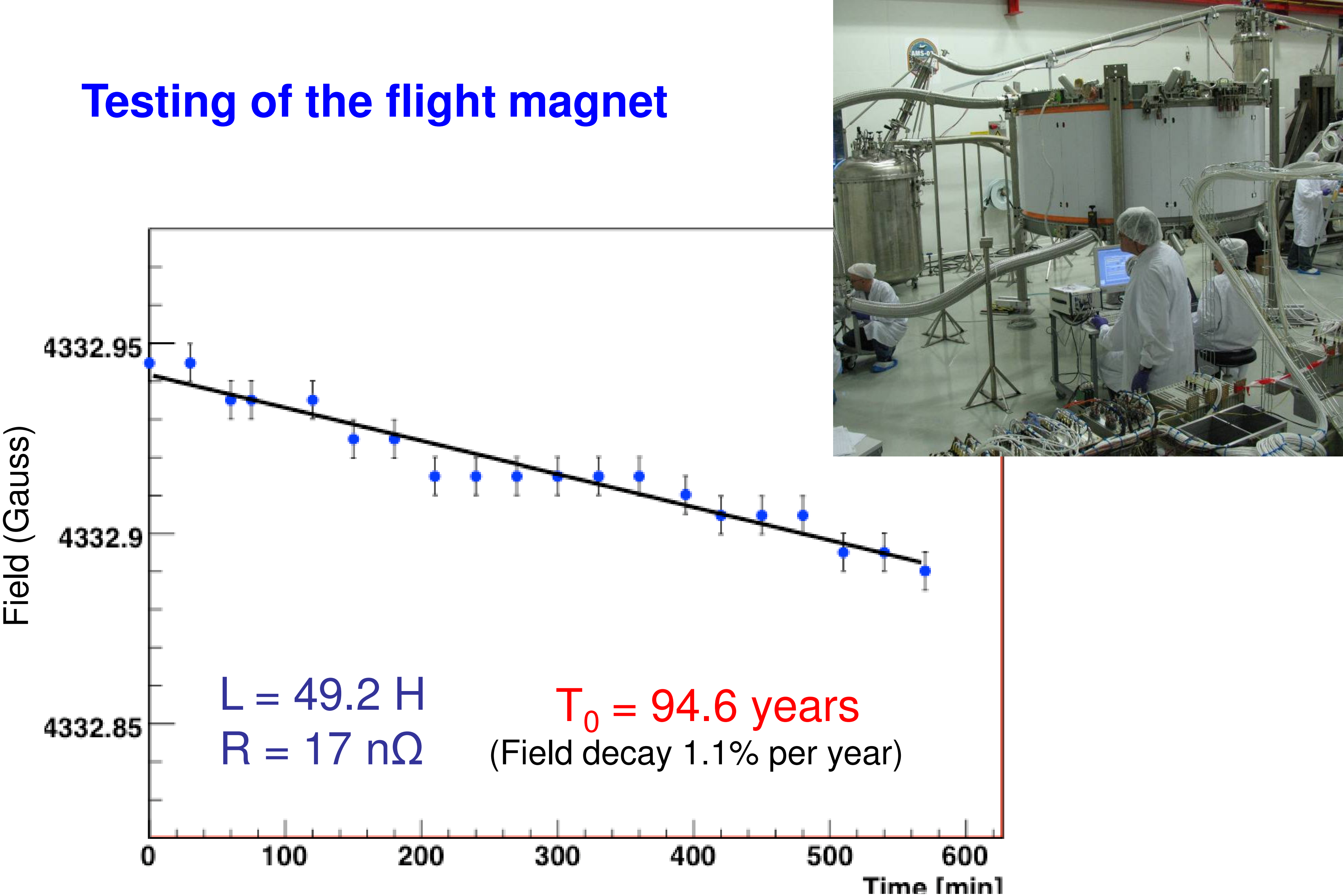
2,500 liters of Superfluid Helium (1.8K)

Duration: 3-5 years

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



Testing of the flight magnet

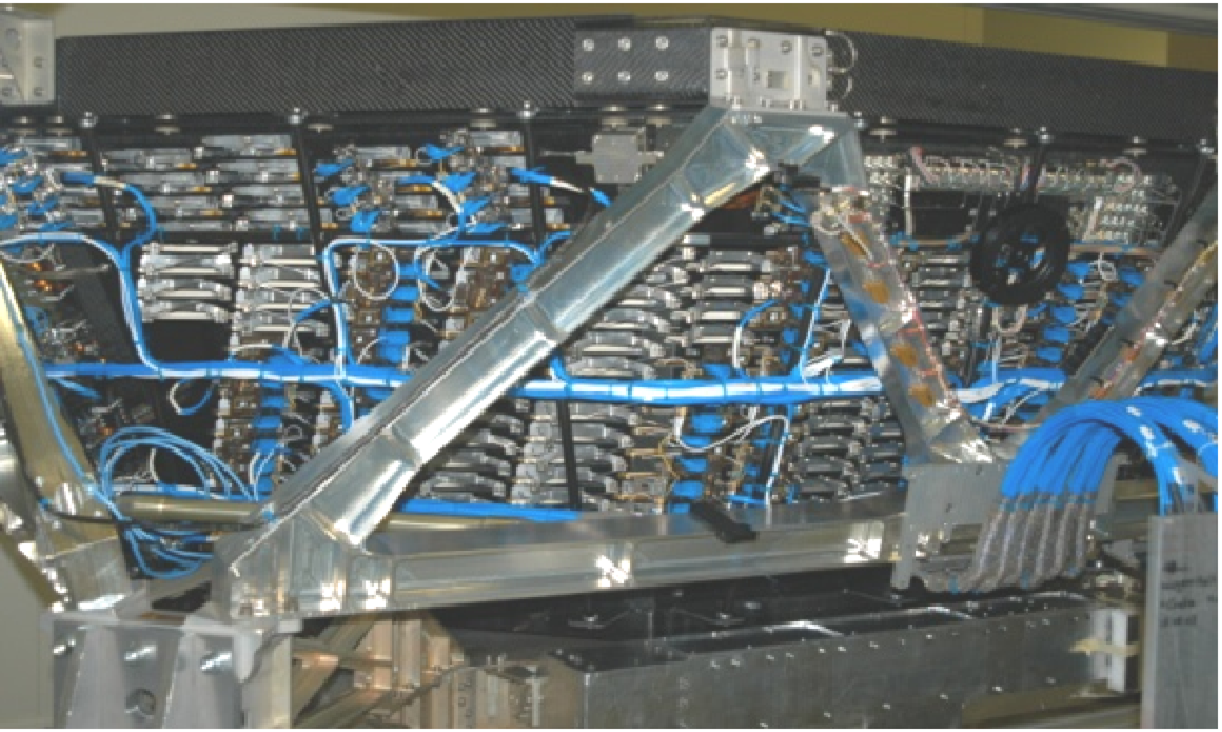


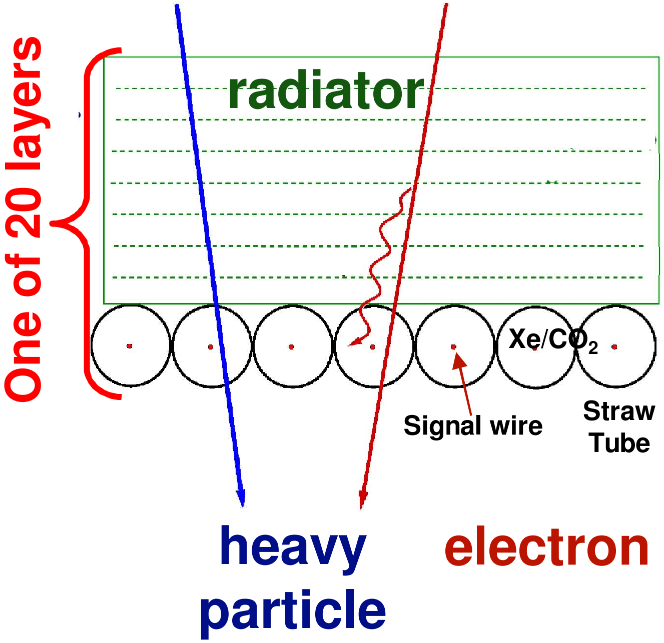
L = 49.2 H
R = 17 nΩ

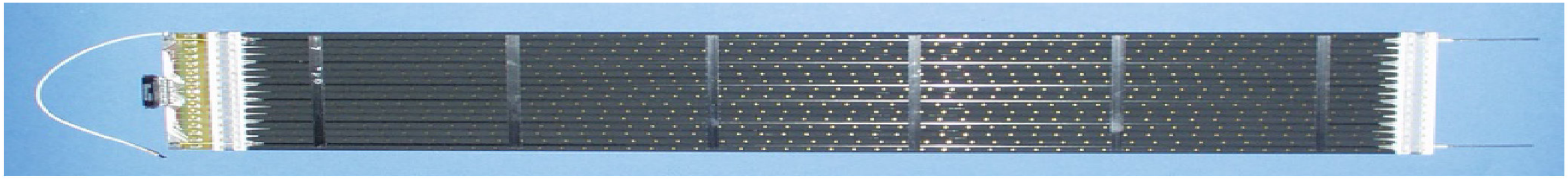
T_0 = 94.6 years
(Field decay 1.1% per year)

**Once charged, the magnetic field will decay ~5% in 5 years.
It will require no additional charge.**

Transition Radiation Detector (TRD) Identifies electrons





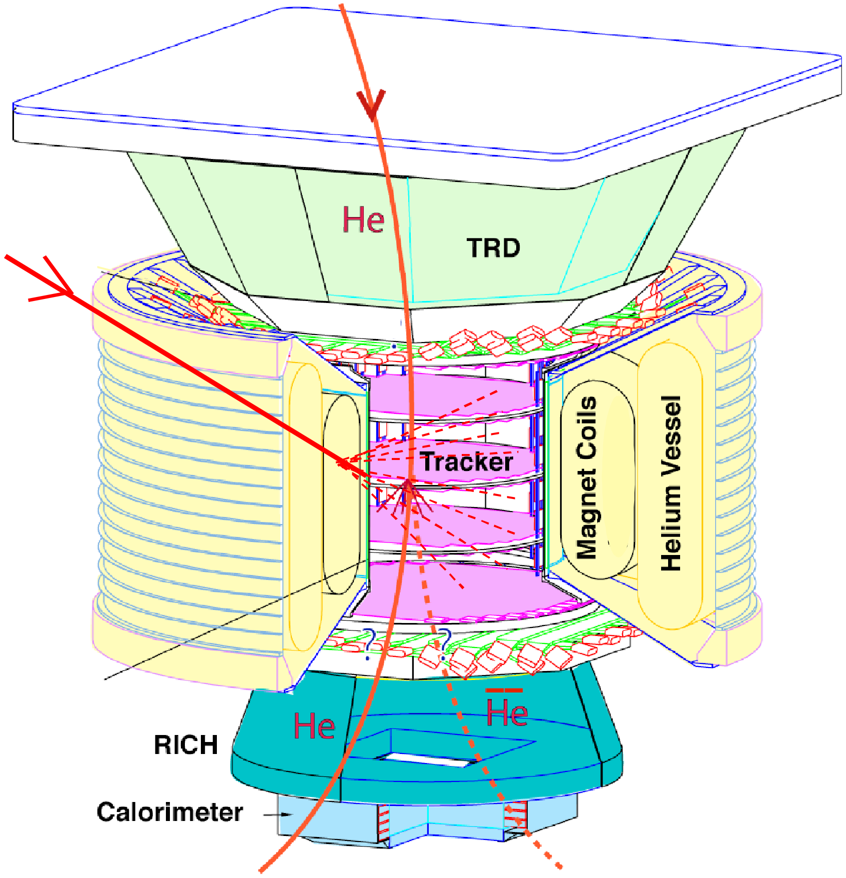


5248 tubes filled with Xe/CO$_2$, 2m length centered to 100 μm

Life time ~ 21 years

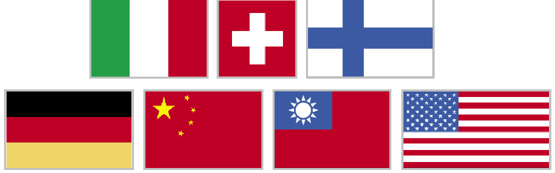
Veto System rejects random cosmic rays

AMS-02 Magnet with Veto Counters

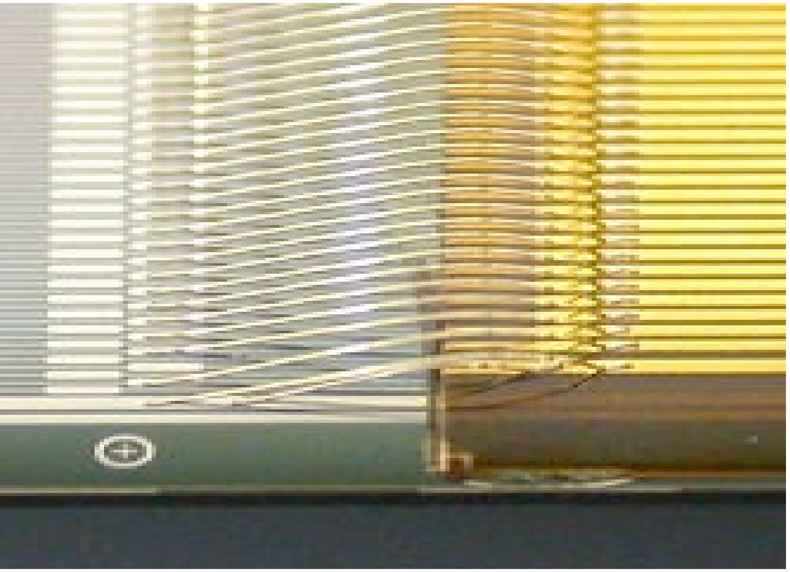


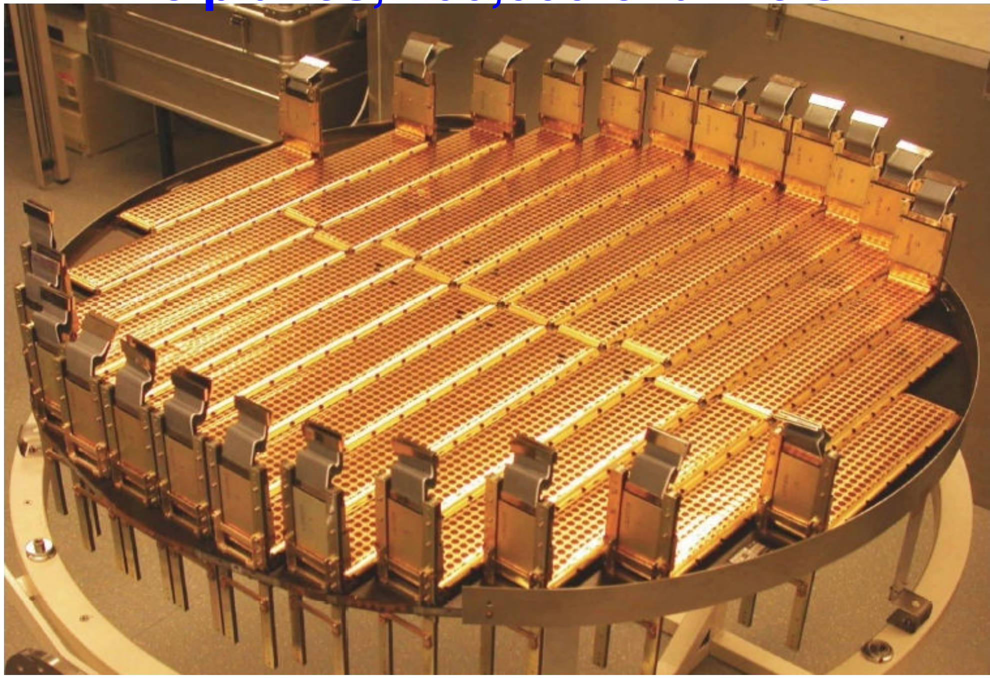
Measured veto efficiency better than 0.9999

Silicon Tracker



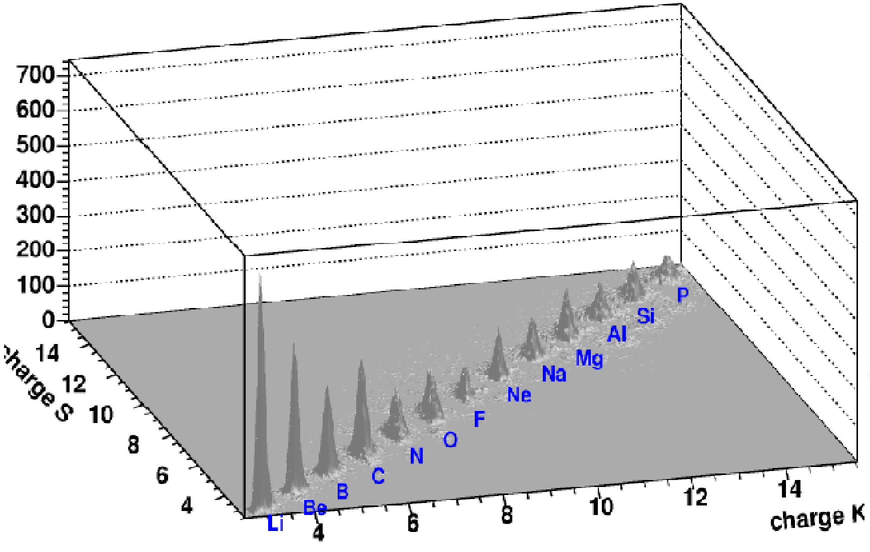
8 planes, 200,000 channels

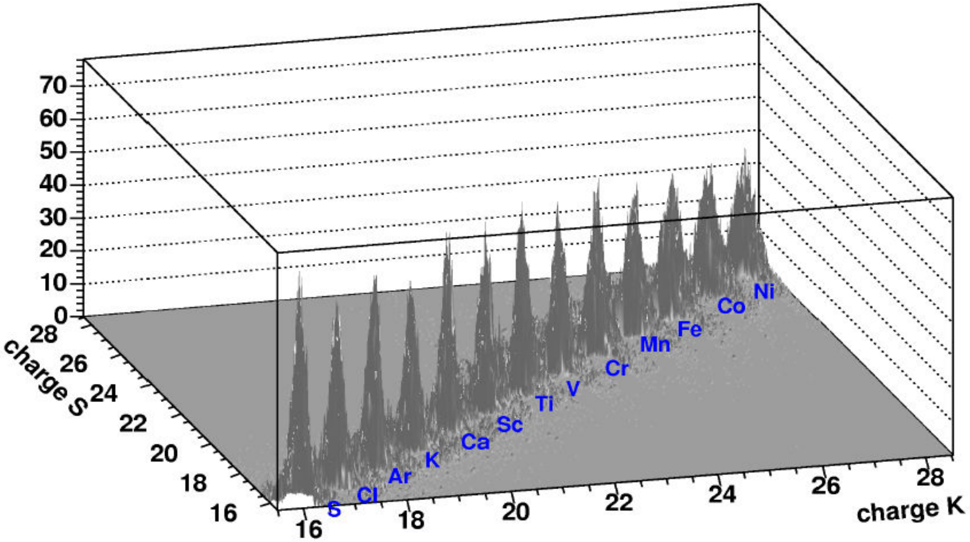




Resolution: 10 μm

Test results: measure all nuclei simultaneously

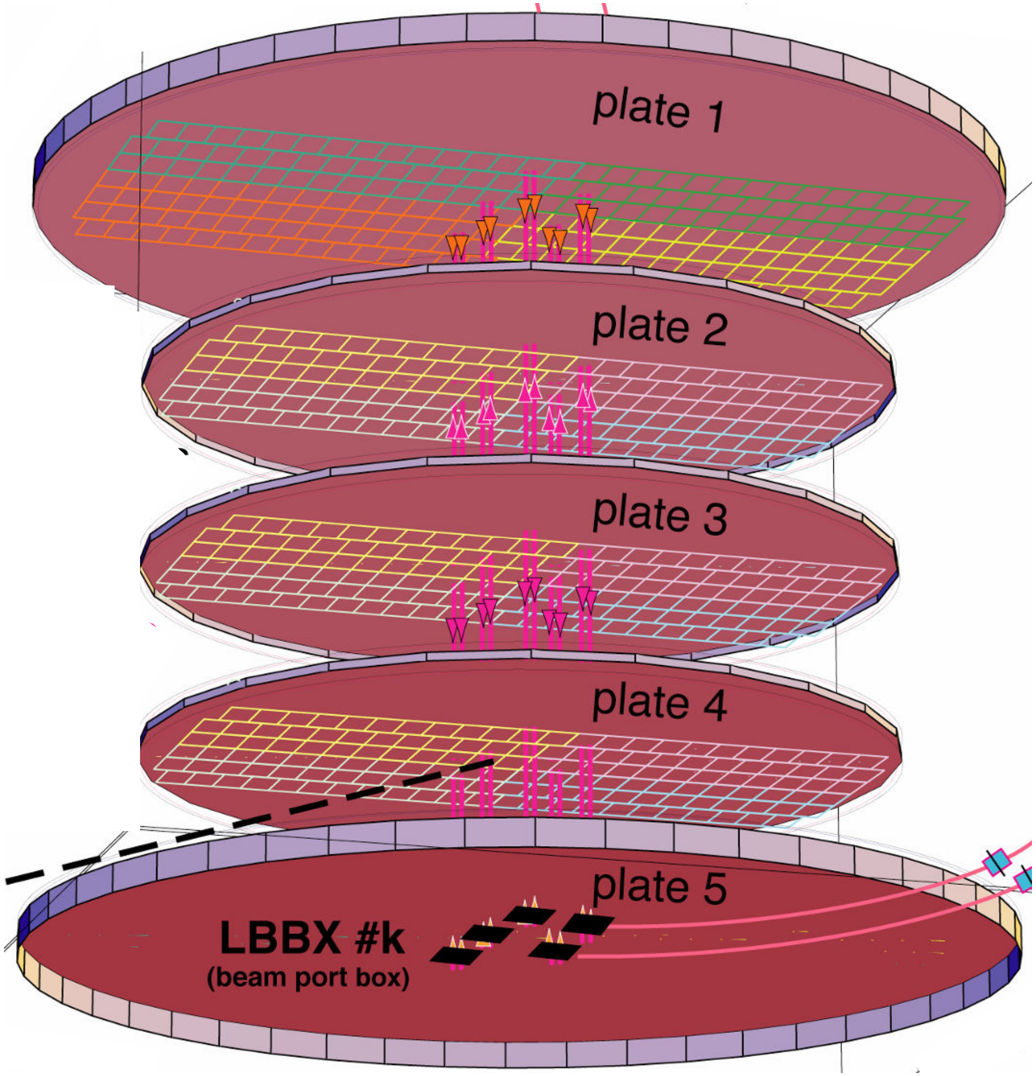


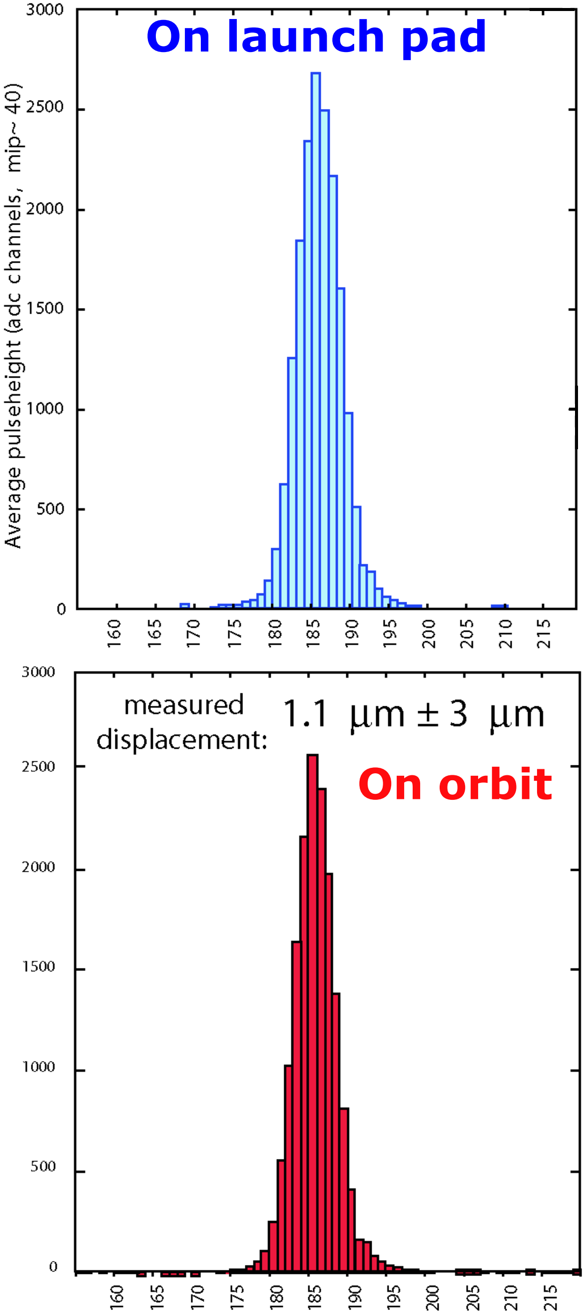


Tracker alignment

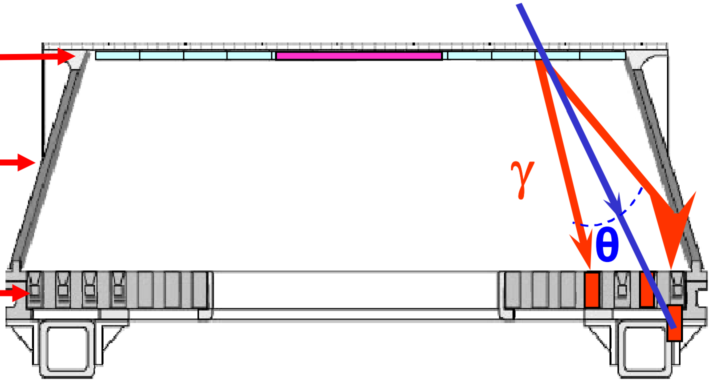
AMS-01

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





Ring Imaging Cerenkov Counter (RICH)

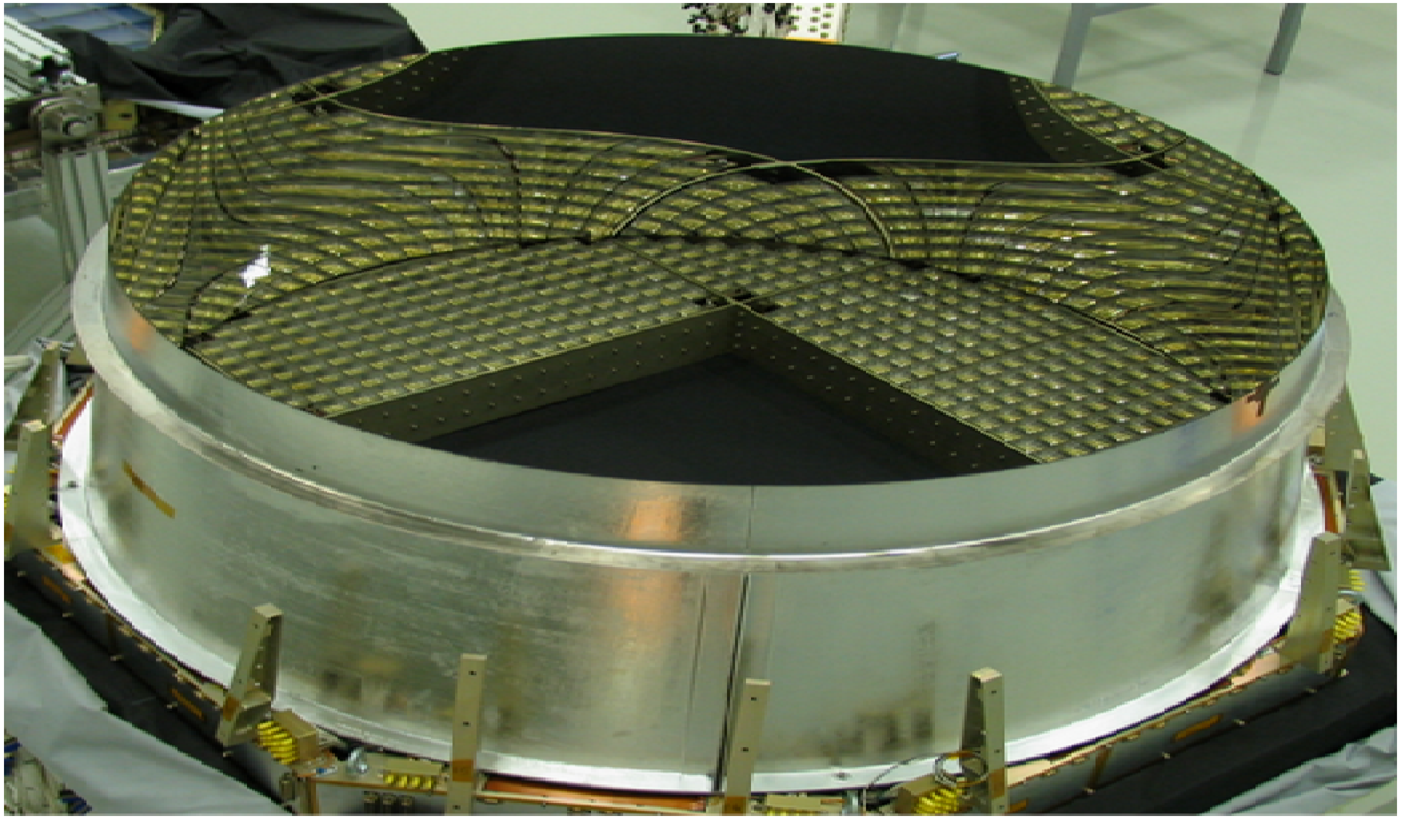


Particle: Velocity(θ), Charge(Intensity)

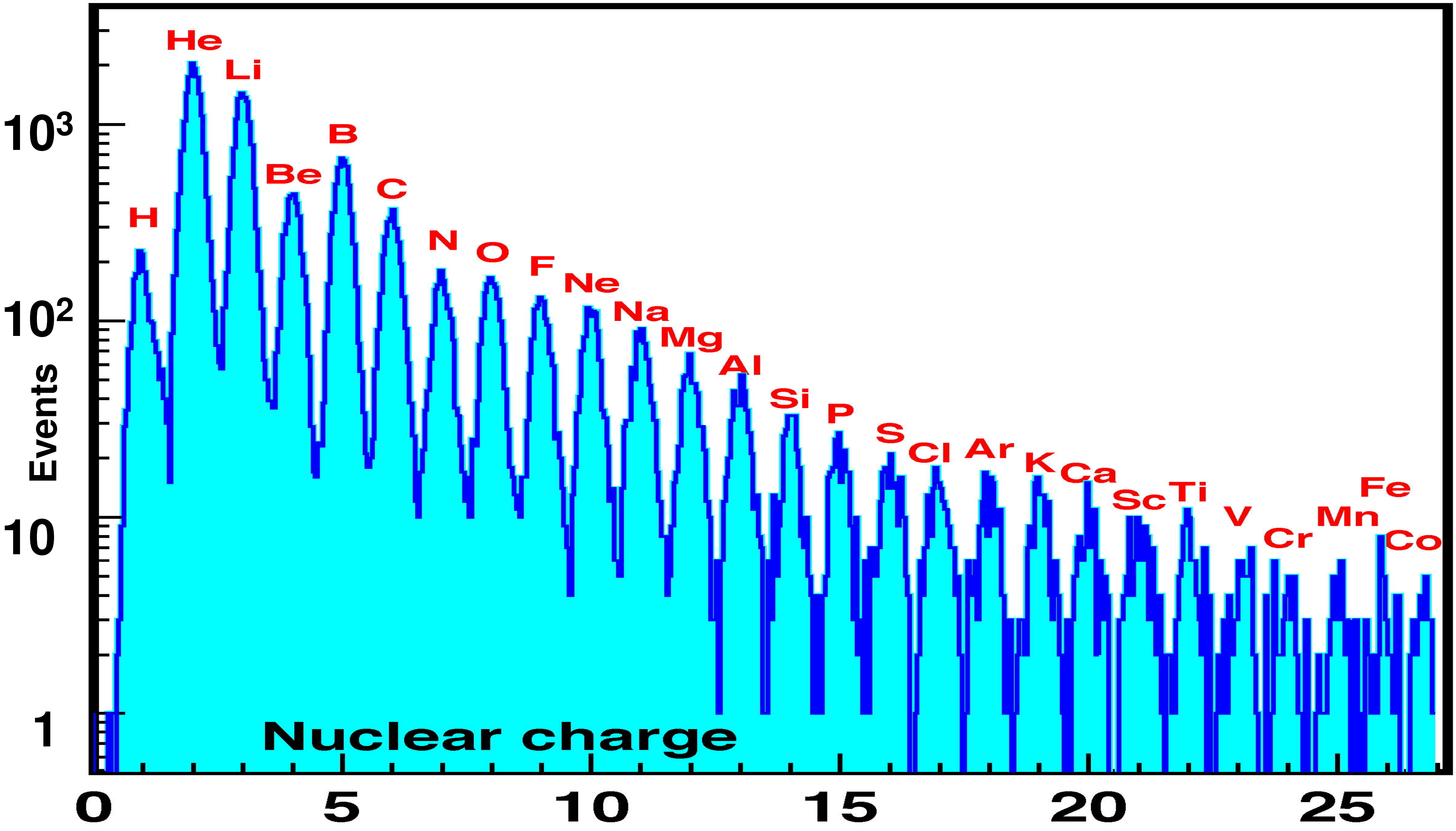
Radiator

Reflector

10,880 Photodetectors

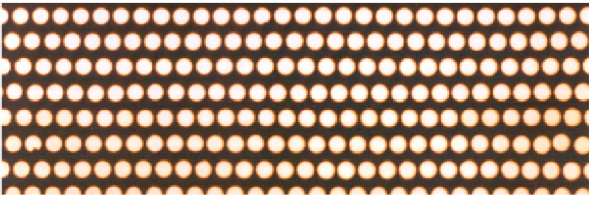


Tests with Accelerator at E=158 GeV/n

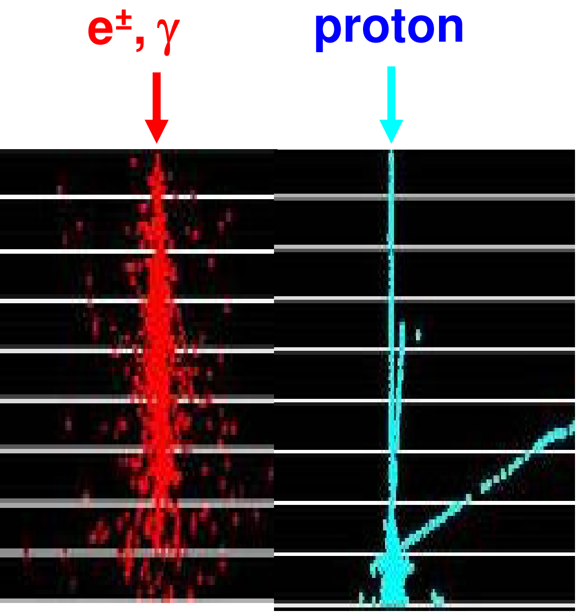


RICH has no consumables: AMS on ISS can study high energy cosmic ray spectra indefinitely

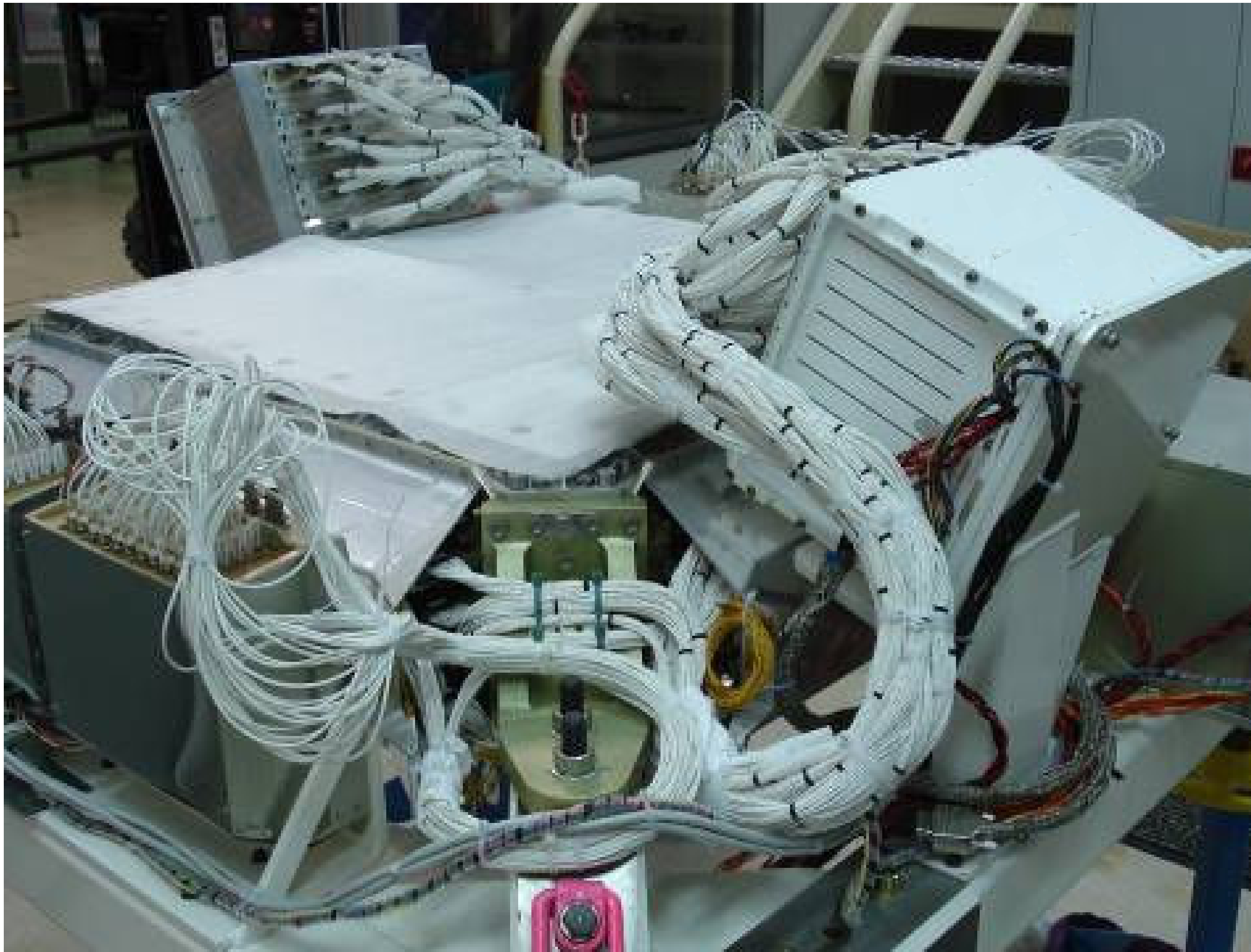
Calorimeter (ECAL)

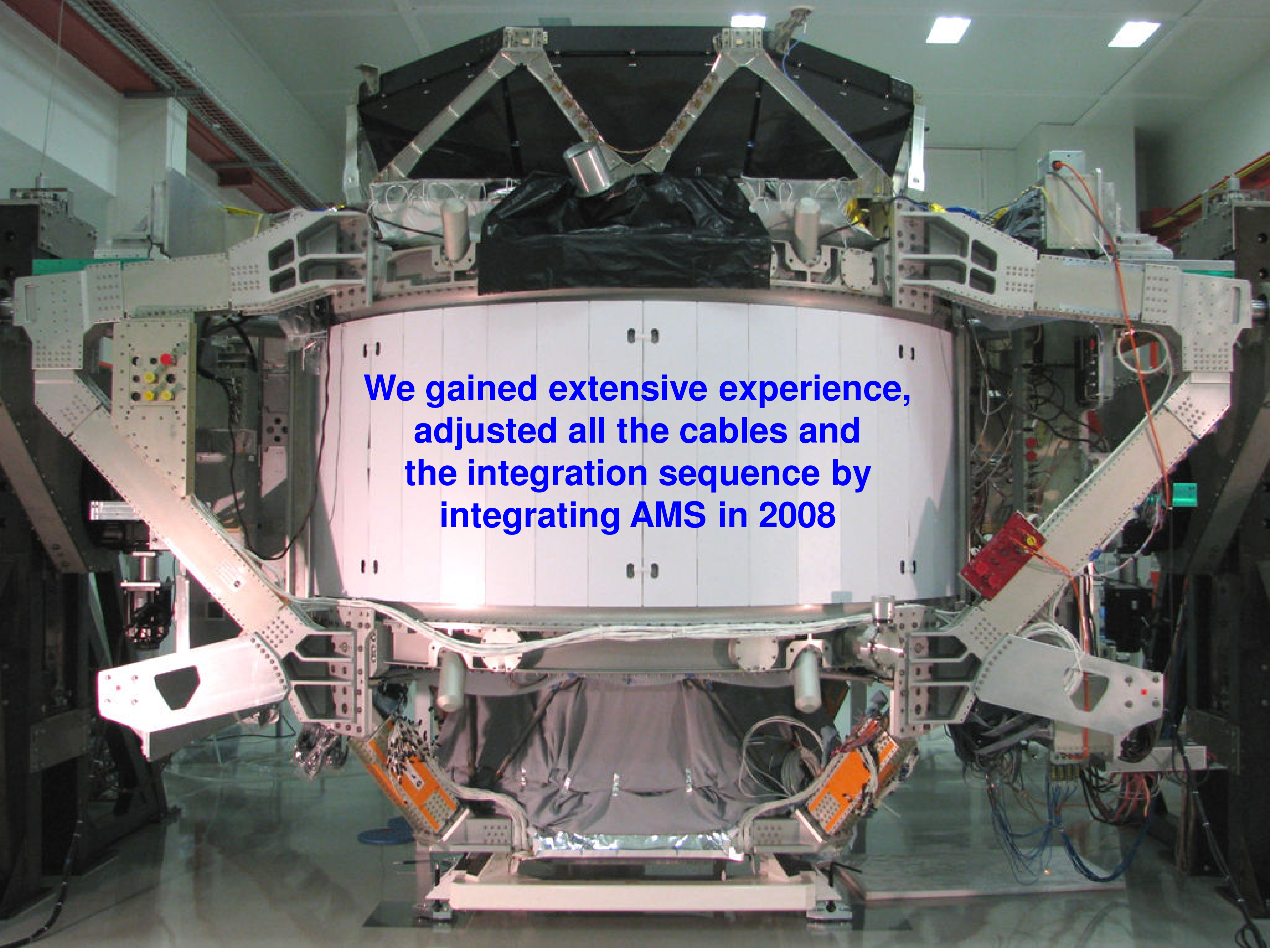


10 000 fibers, $\phi = 1$ mm
distributed uniformly
Inside 1,200 lb of lead



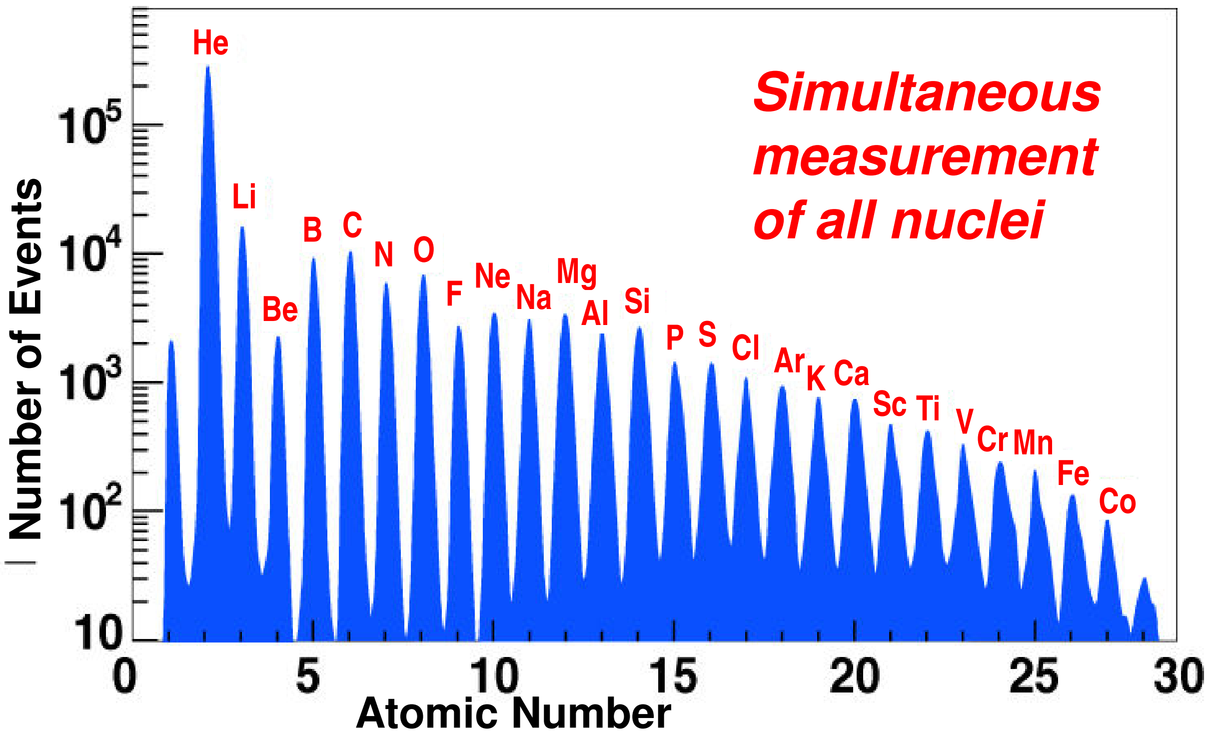
A precision 3-dimensional measurement of the directions and energies of light rays and electrons

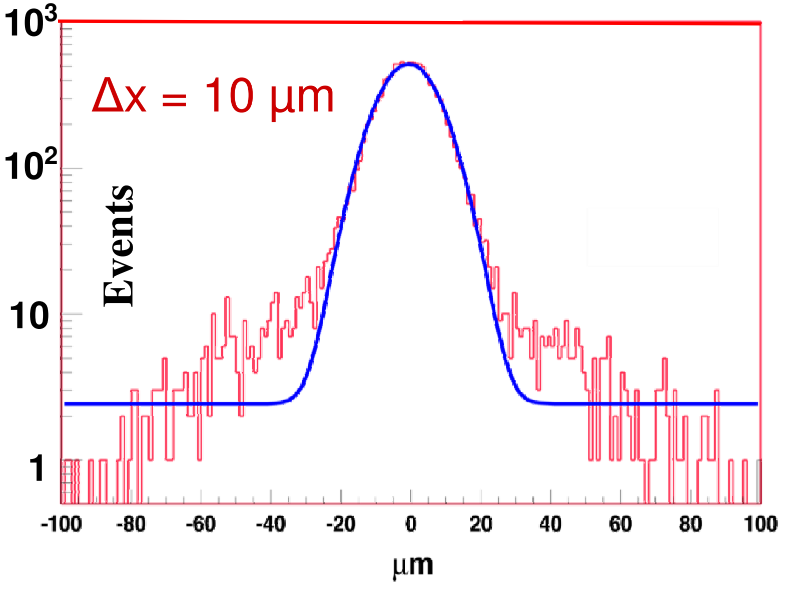


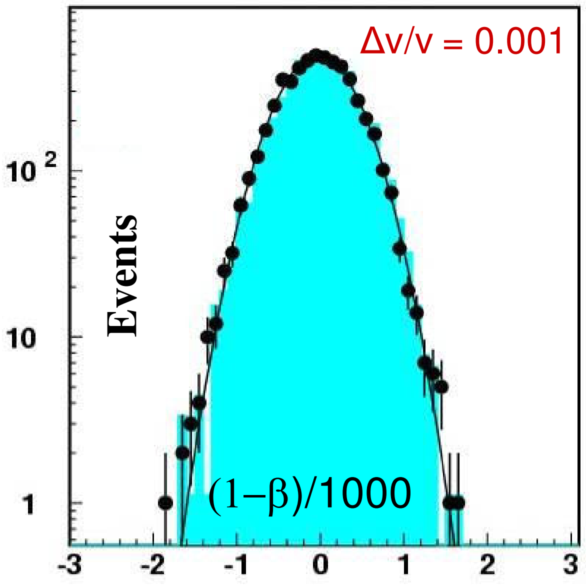


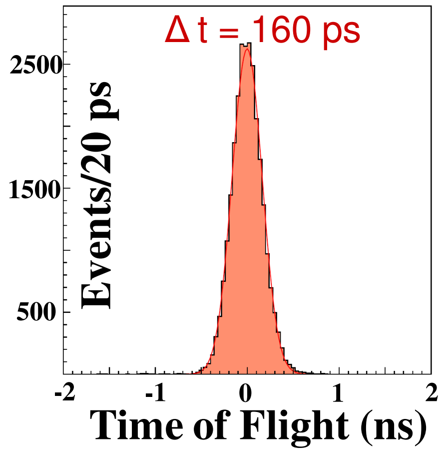
We gained extensive experience, adjusted all the cables and the integration sequence by integrating AMS in 2008

Test results from accelerator









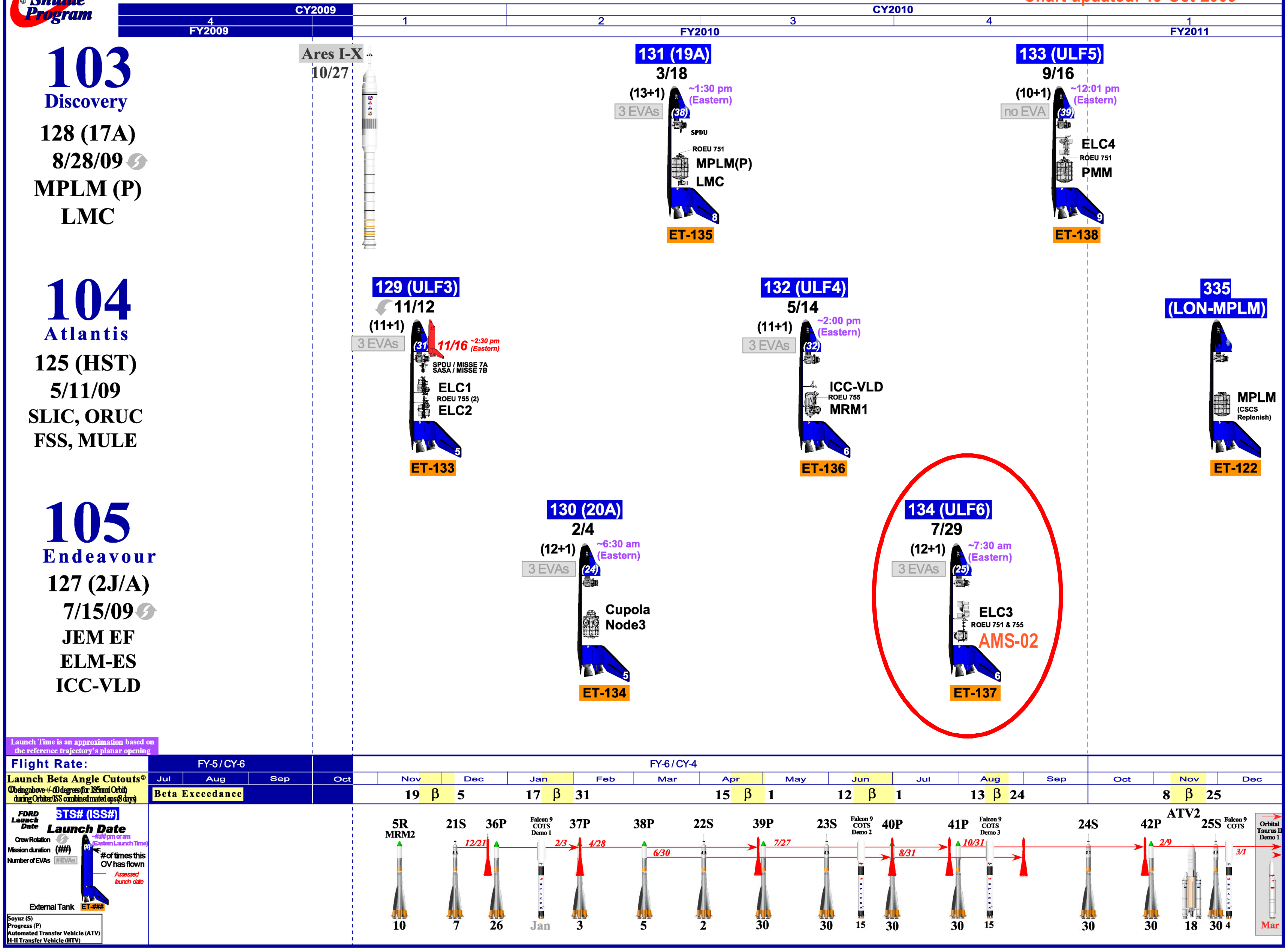
y04K513_05

Space Shuttle Program (SSP) Manifest

Space Shuttle Program

NASA Official: John Coggeshall
USA Project Lead: Barton K. Gibson

Chart updated: 19-Oct-2009



CY2009 | CY2010

FY2009: 4 | FY2010: 1, 2, 3, 4 | FY2011: 1

103
Discovery

128 (17A)
8/28/09
MPLM (P)
LMC

Ares I-X
10/27

131 (19A)
3/18
(13+1) ~1:30 pm (Eastern)
3 EVAs (38)
SPDU
ROEU 751
MPLM(P)
LMC
8
ET-135

133 (ULF5)
9/16
(10+1) ~12:01 pm (Eastern)
no EVA (39)
ELC4
ROEU 751
PMM
9
ET-138

104
Atlantis

125 (HST)
5/11/09
SLIC, ORUC
FSS, MULE

129 (ULF3)
11/12
(11+1)
3 EVAs (31)
11/16 ~2:30 pm (Eastern)
SPDU / MISSE 7A
SASA / MISSE 7B
ELC1
ROEU 755 (2)
ELC2
5
ET-133

132 (ULF4)
5/14
(11+1) ~2:00 pm (Eastern)
3 EVAs (32)
ICC-VLD
ROEU 755
MRM1
6
ET-136

335 (LON-MPLM)
MPLM
(CSCS Replenish)
ET-122

105
Endeavour

127 (2J/A)
7/15/09
JEM EF
ELM-ES
ICC-VLD

130 (20A)
2/4
(12+1) ~6:30 am (Eastern)
3 EVAs (24)
Cupola
Node3
5
ET-134

134 (ULF6)
7/29
(12+1) ~7:30 am (Eastern)
3 EVAs (25)
ELC3
ROEU 751 & 755
AMS-02
6
ET-137

Launch Time is an approximation based on the reference trajectory's planar opening

Flight Rate: FY-5 / CY-6 | FY-6 / CY-4

Launch Beta Angle Cutouts①
① being above +/- 60 degrees (for 185nmi Orbit) during Orbiter/ISS combined mated ops (8 days)

Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Beta Exceedance				19 β	5	17 β	31		15 β	1	12 β	1	13 β 24			8 β	25

FDRD Launch Date
STS# (ISS#)
Launch Date
Crew Rotation
Mission duration (##)
Number of EVAs #EVAs
~#:## pm or am (Eastern Launch Time)
(#) #of times this OV has flown
Assessed launch date
External Tank ET-###

Soyuz (S)
Progress (P)
Automated Transfer Vehicle (ATV)
H-II Transfer Vehicle (HTV)

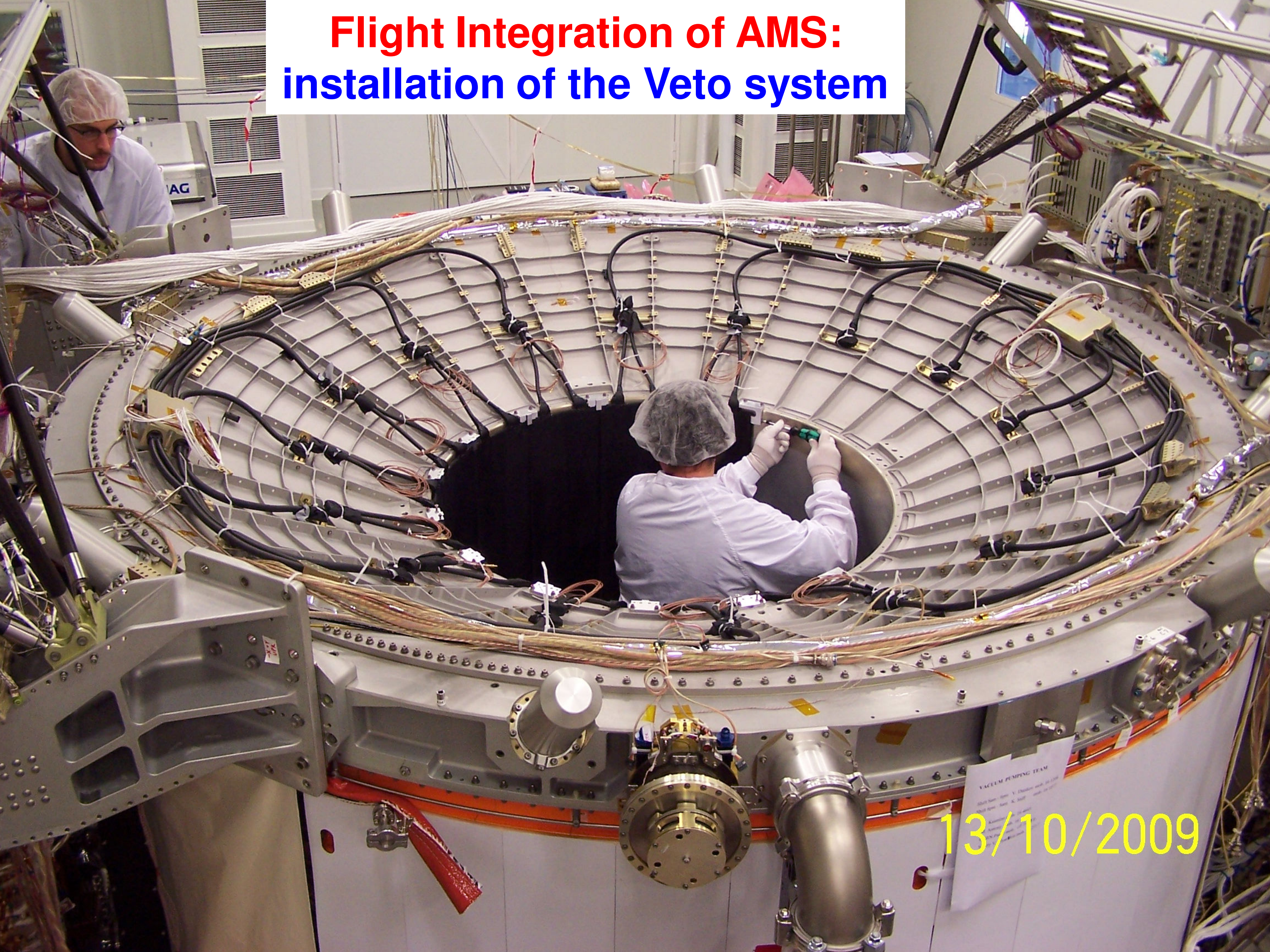
5R MRM2	21S	36P	Falcon 9 COTS Demo 1	37P	38P	22S	39P	23S	Falcon 9 COTS Demo 2	40P	41P	Falcon 9 COTS Demo 3	24S	42P	ATV2	25S	Falcon 9 COTS	Orbital Taurus II Demo 1
10	7	26	Jan	3	5	2	30	30	15	30	30	15	30	30	18	30	4	Mar

12/21
2/3
4/28
6/30
7/27
8/31
10/31
2/9
3/1

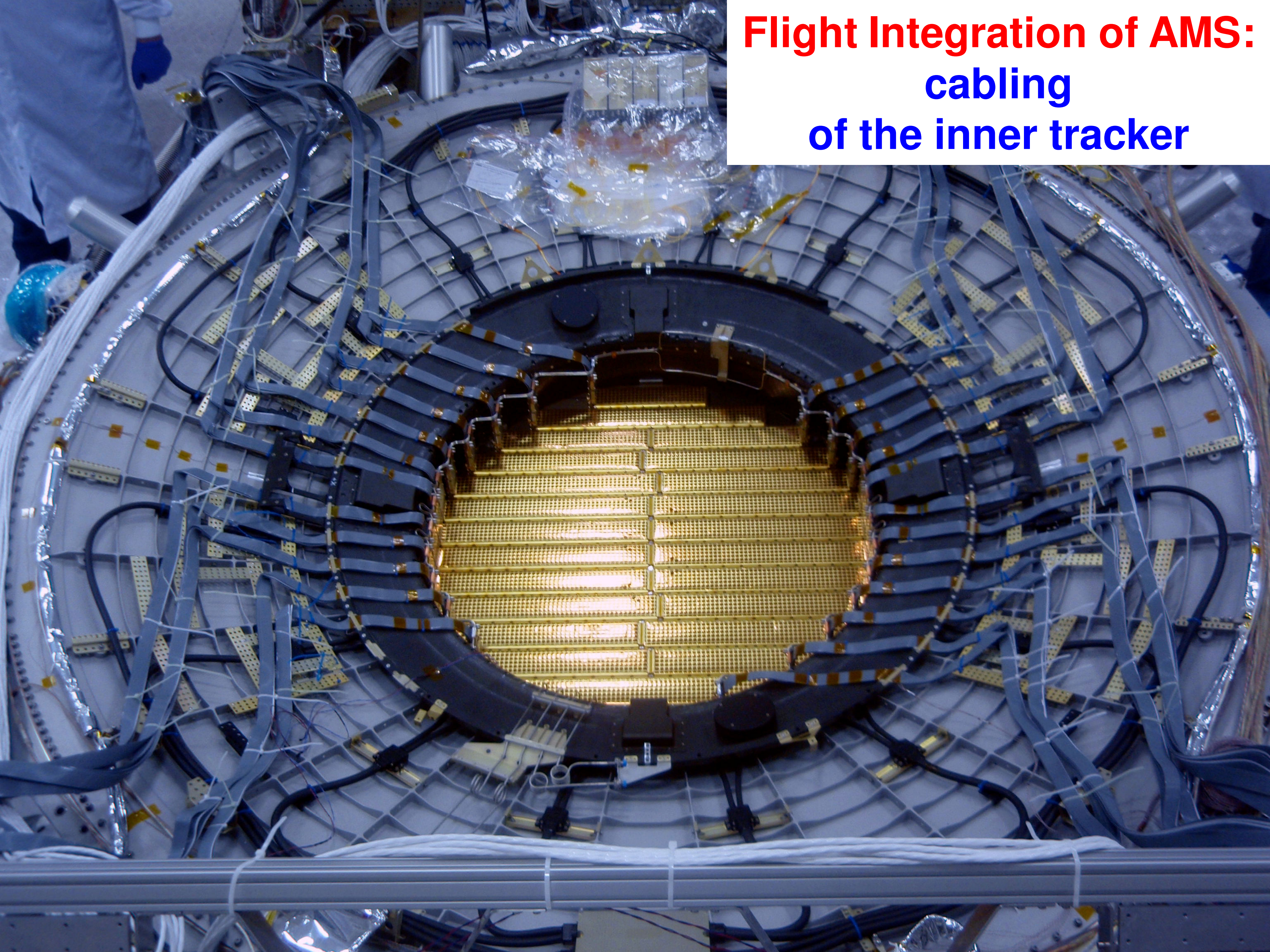
AMS Astronauts with AMS detectors 13-16 Oct 2009

The astronauts strongly urged us to study the on-orbit refill capability so that AMS will continue to produce unique science

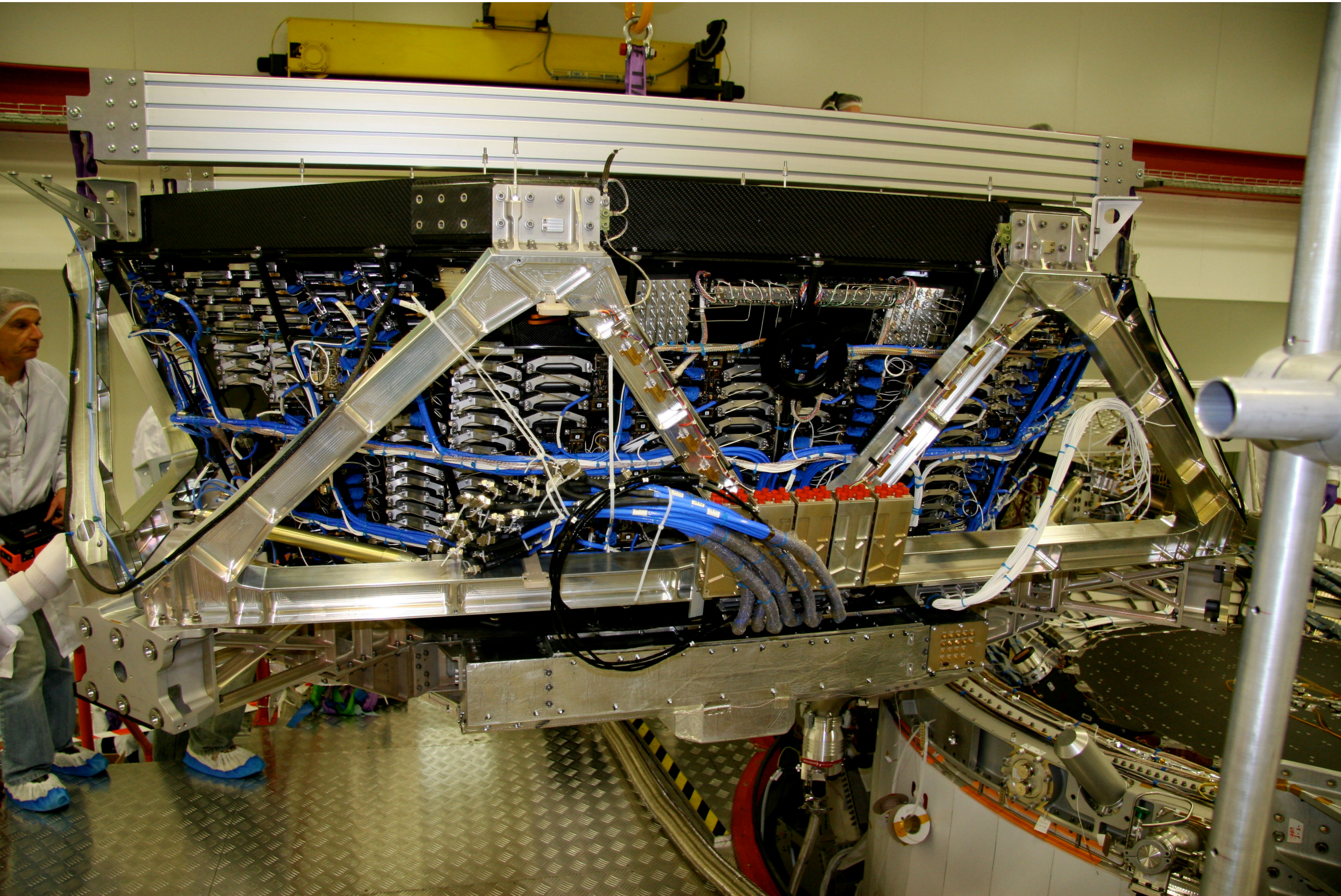
Flight Integration of AMS: installation of the Veto system



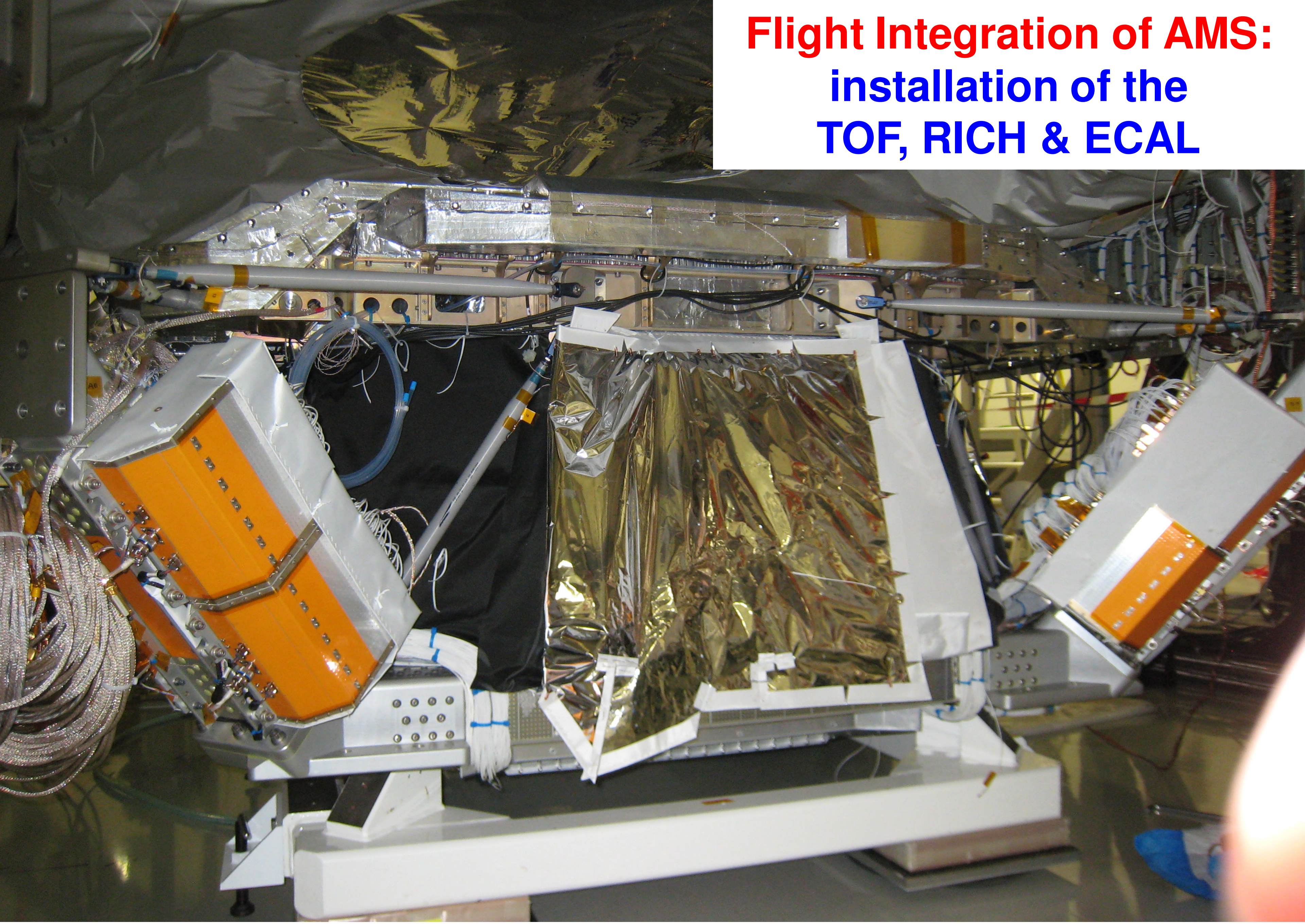
Flight Integration of AMS:
cabling
of the inner tracker



Flight Integration of AMS: mounting of the TRD and TOF

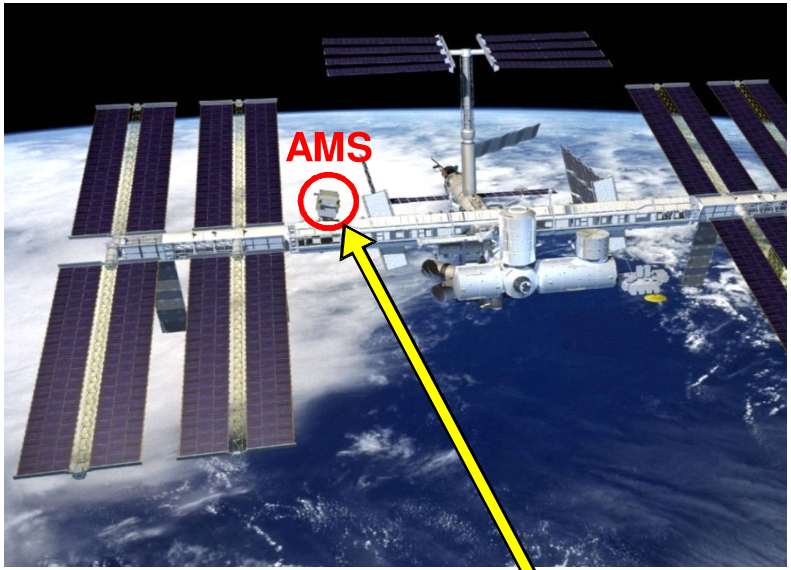


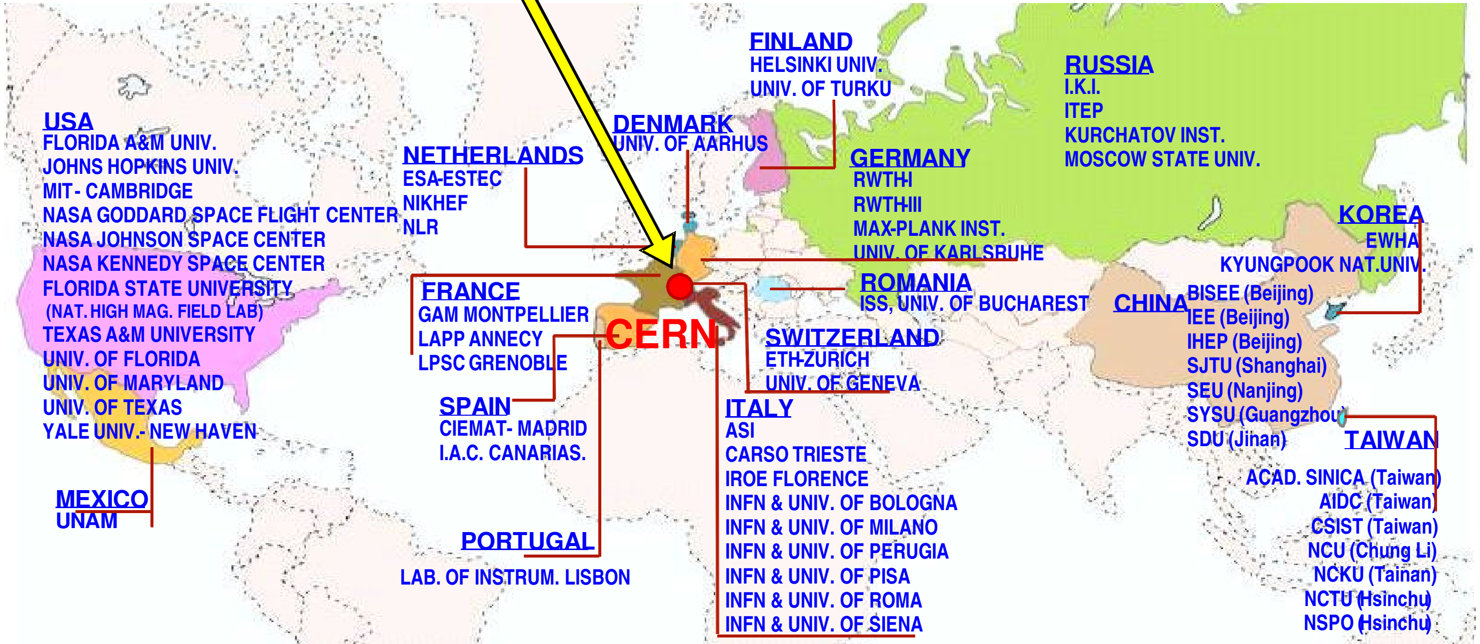
Flight Integration of AMS: installation of the TOF, RICH & ECAL



All of the detectors have been re-integrated and functionally tested

The AMS Science Operation and Data Analysis Center at CERN





USA
FLORIDA A&M UNIV.
JOHNS HOPKINS UNIV.
MIT - CAMBRIDGE
NASA GODDARD SPACE FLIGHT CENTER
NASA JOHNSON SPACE CENTER
NASA KENNEDY SPACE CENTER
FLORIDA STATE UNIVERSITY
(NAT. HIGH MAG. FIELD LAB)
TEXAS A&M UNIVERSITY
UNIV. OF FLORIDA
UNIV. OF MARYLAND
UNIV. OF TEXAS
YALE UNIV.- NEW HAVEN

MEXICO
UNAM

NETHERLANDS
ESA-ESTEC
NIKHEF
NLR

FRANCE
GAM MONTPELLIER
LAPP ANNECY
LPSC GRENOBLE

SPAIN
CIEMAT- MADRID
I.A.C. CANARIAS.

PORTUGAL
LAB. OF INSTRUM. LISBON

DENMARK
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IROE FLORENCE
INFN & UNIV. OF BOLOGNA
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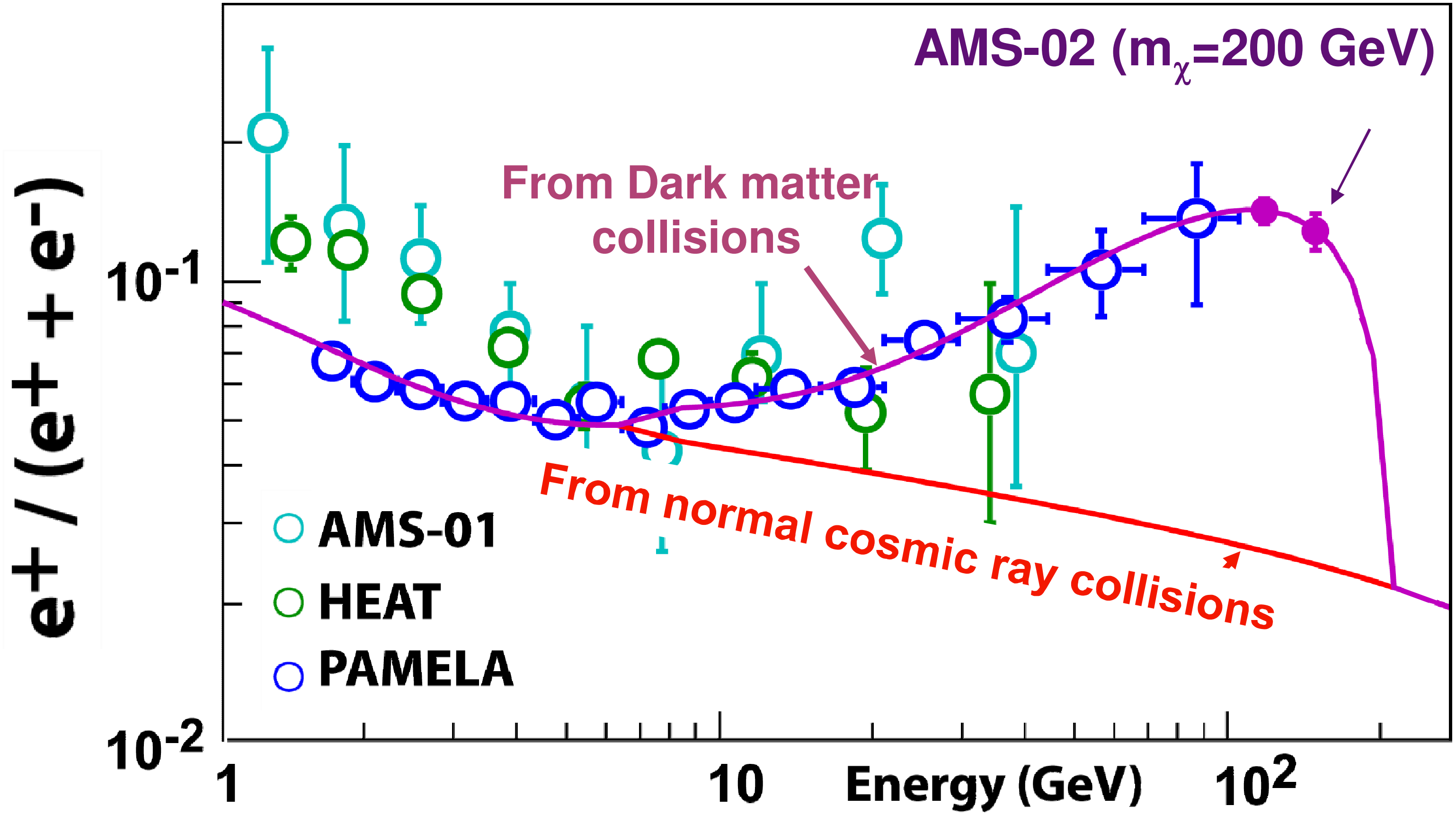
NCTU (Hsinchu)
NSPO (Hsinchu)

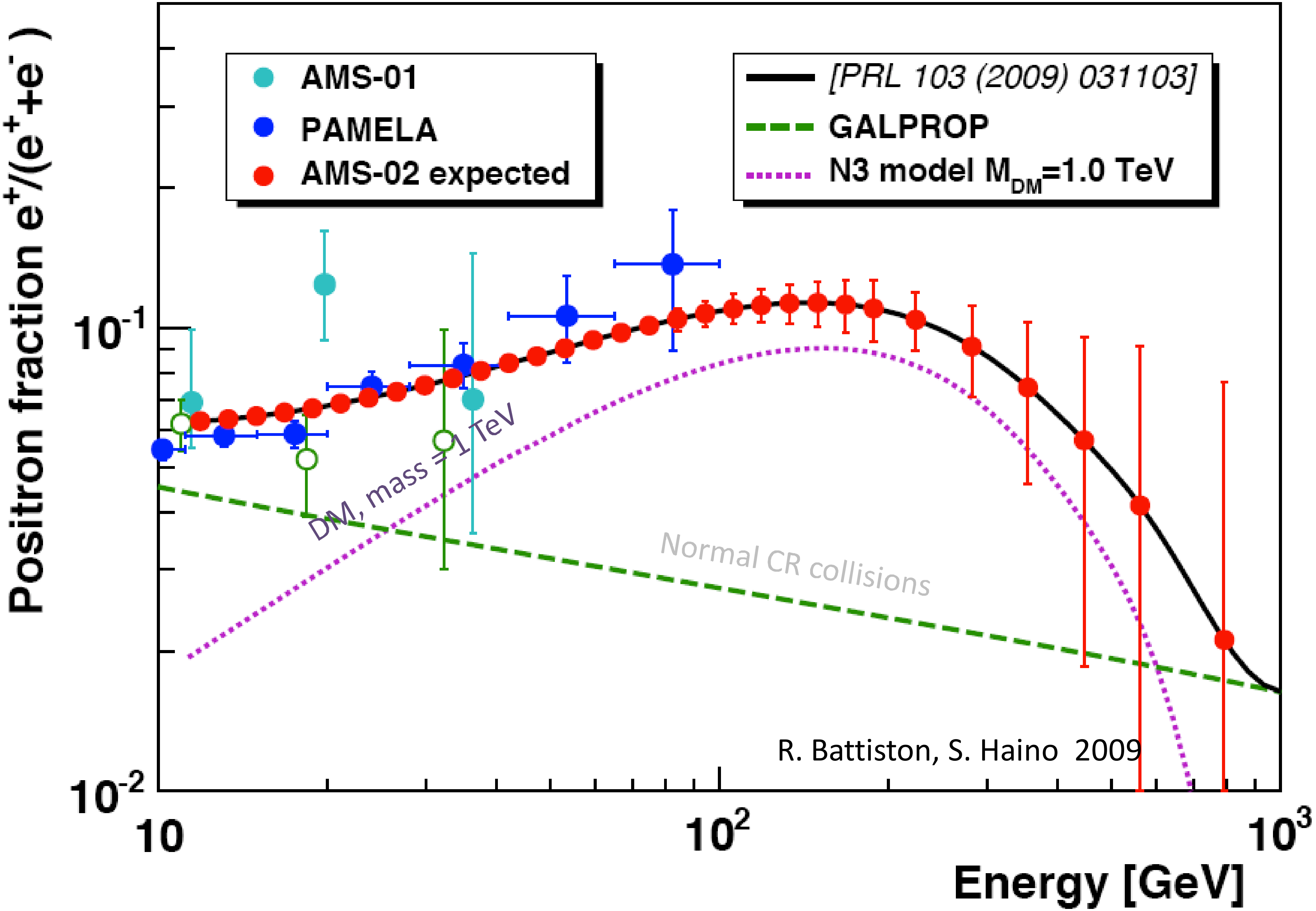
Physics example

Search for Cold Dark Matter: χ^0

Collisions of χ^0 will produce excesses in the spectra of $e^+, e^-, \bar{p}$ different from known cosmic ray collisions



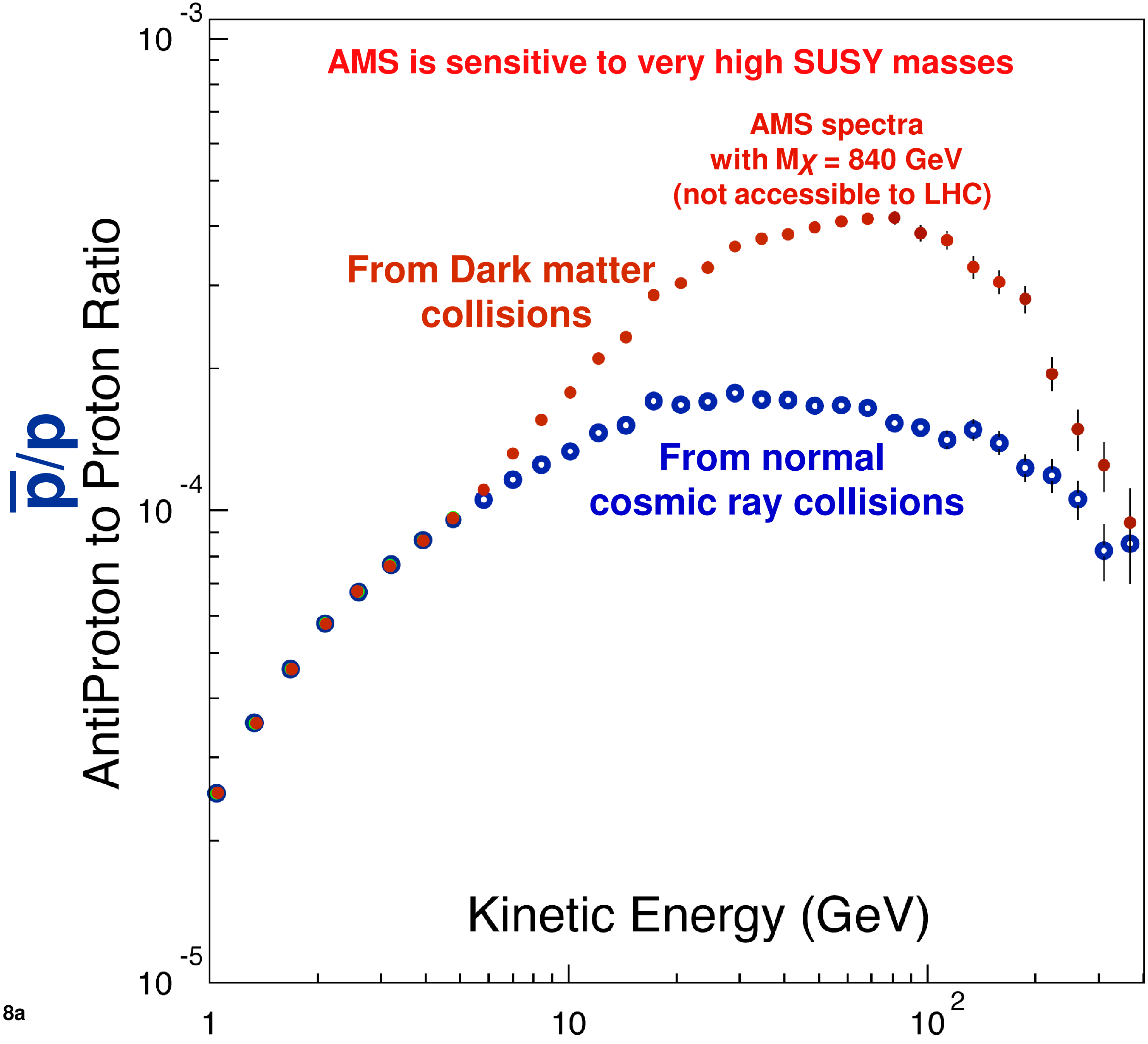
The spectra of all types of cosmic rays will be measured by AMS simultaneously



DM, mass = 1 TeV

Normal CR collisions

R. Battiston, S. Haino 2009

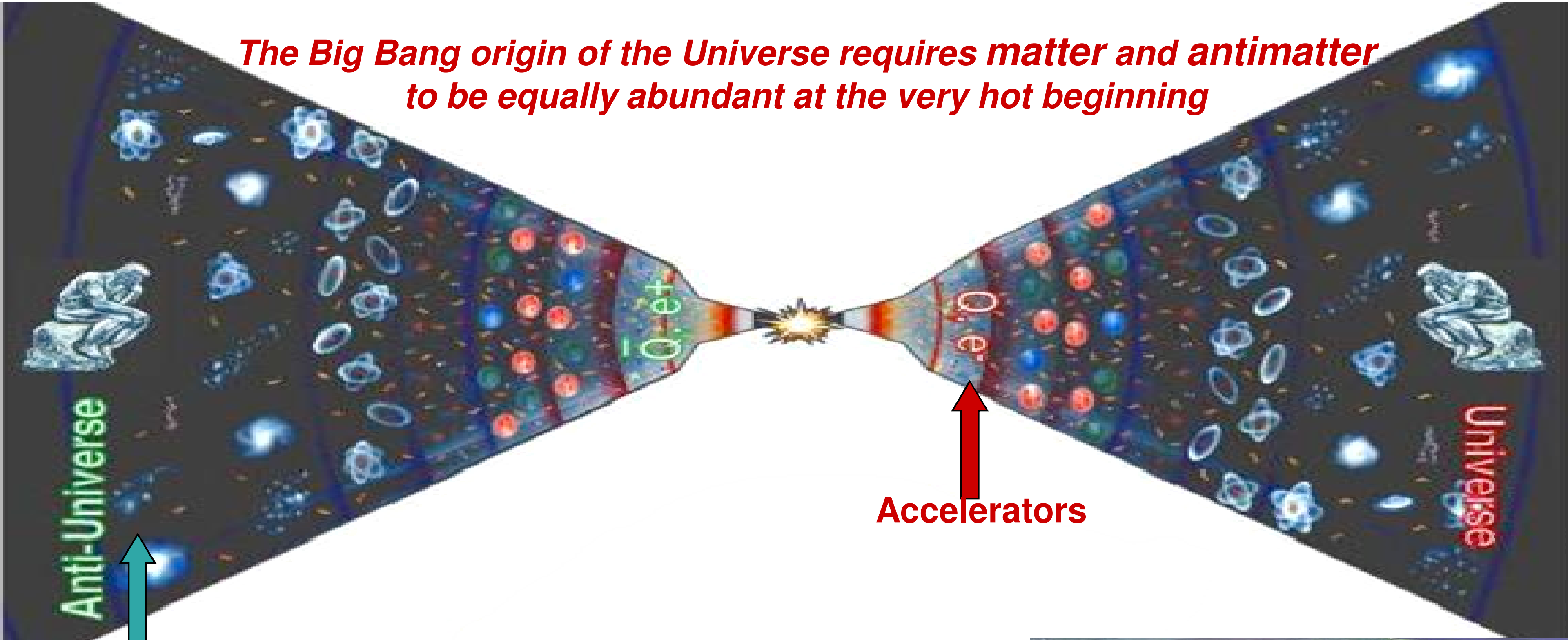


AMS is sensitive to very high SUSY masses

y06K318a

Physics examples

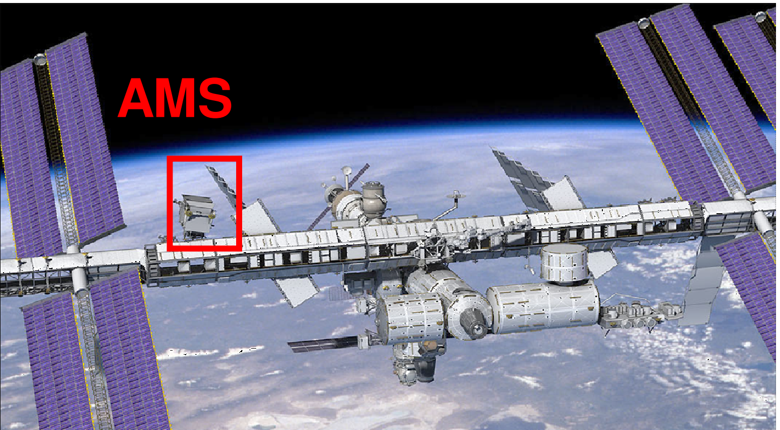
Search for the existence of Antimatter in the Universe

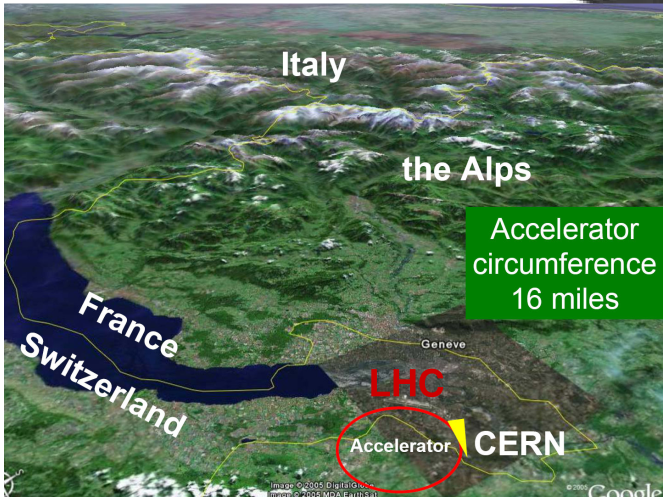


The Big Bang origin of the Universe requires ***matter*** *and* ***antimatter*** *to be equally abundant at the very hot beginning*

Accelerators

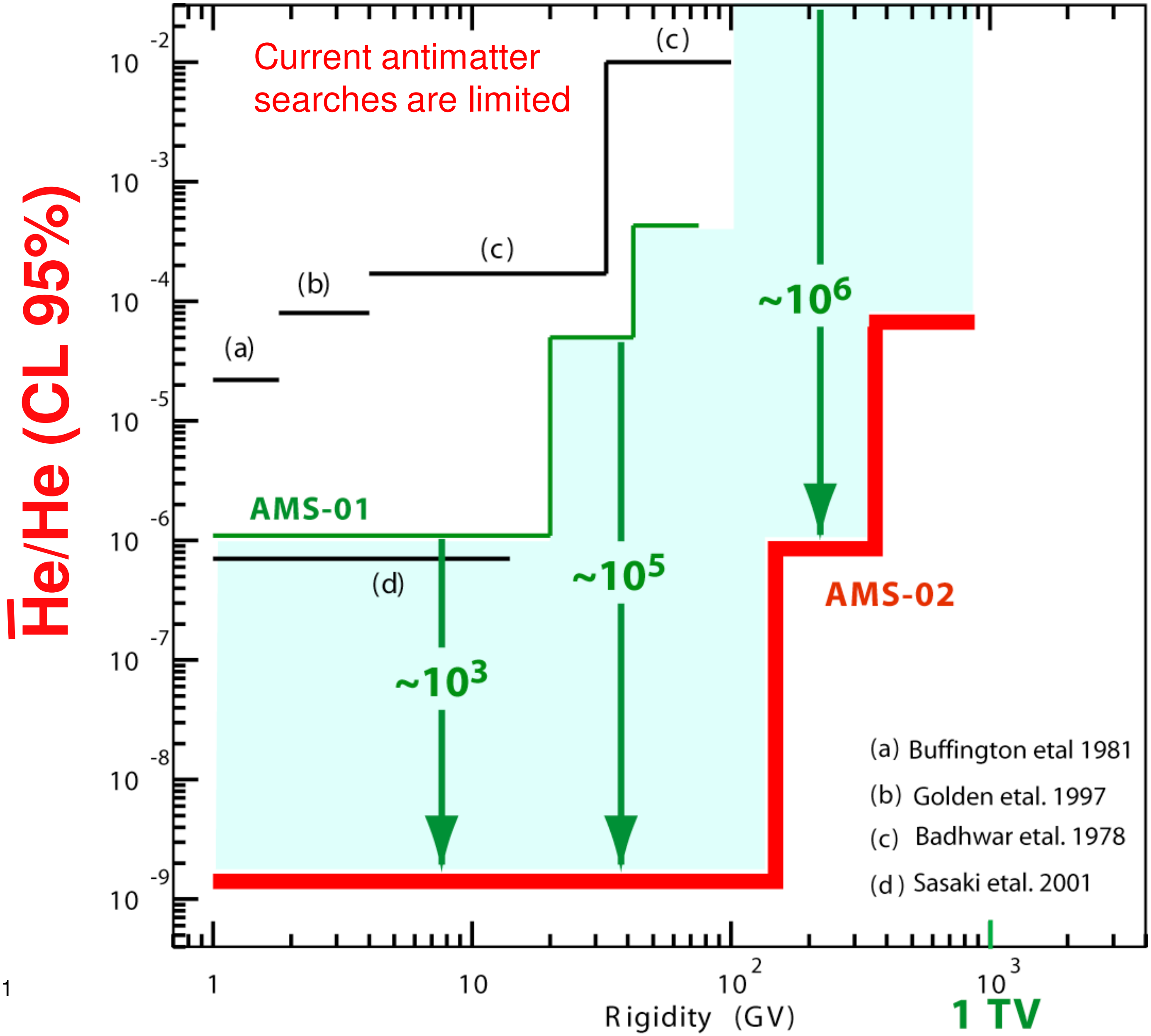
AMS in Space





Accelerator circumference 16 miles

AMS-02 Antihelium Limits



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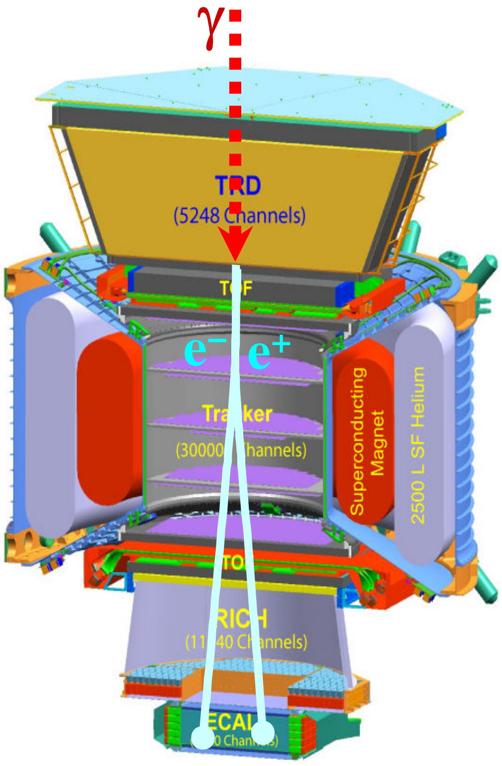
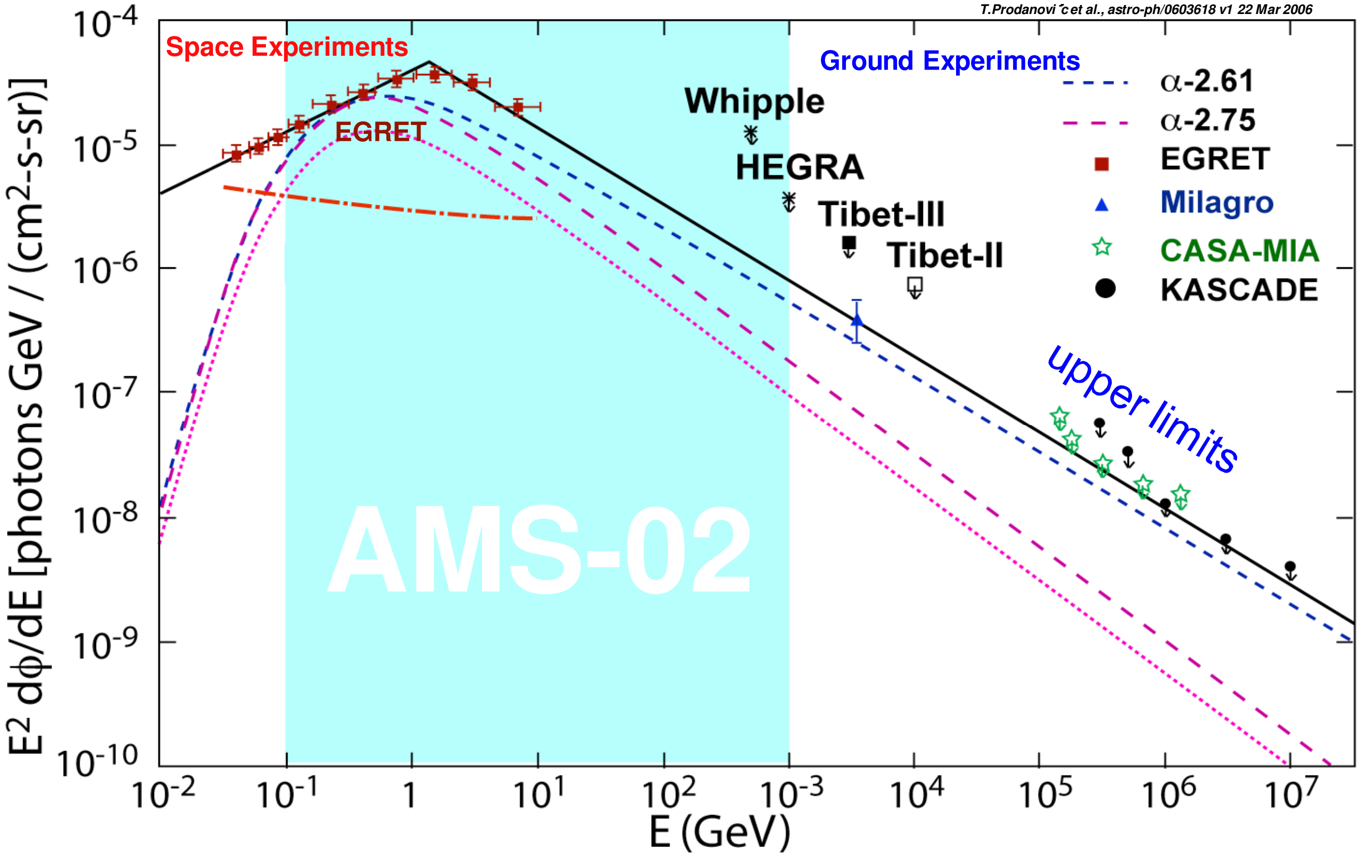
AMS Physics example

Study of high energy (0.1 GeV – 1 TeV) diffuse gammas





T.Prodanovi ́c et al., astro-ph/0603618 v1 22 Mar 2006

The diffuse gamma-ray spectrum of the Galactic plane

40° < 1 < 100°, |b| < 5°

1. **Pointing precision of 2 arcsec**
2. **UTC time (from GPS, µsec accuracy) allows to relate AMS measurements with other missions**

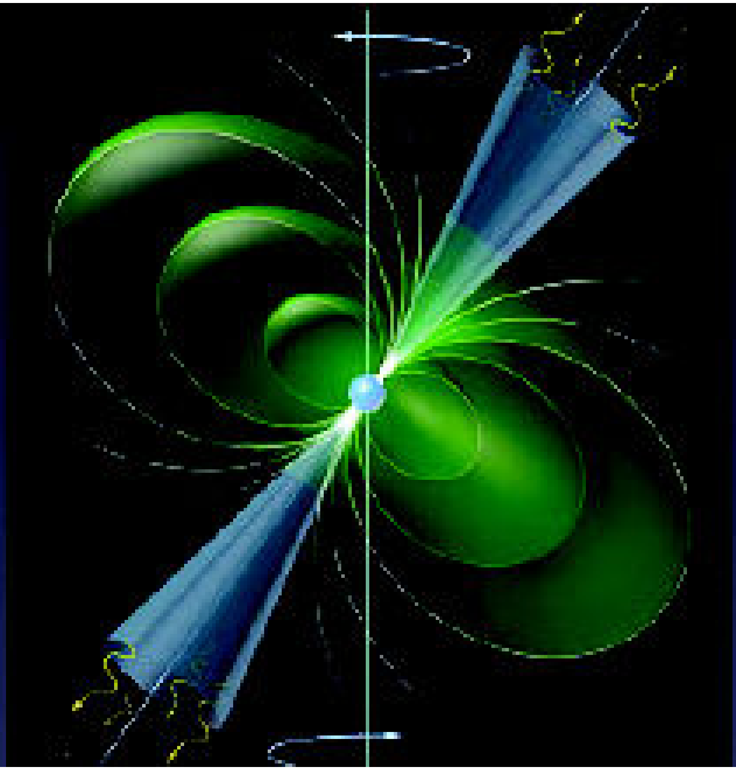
Pulsars in the Milky Way:

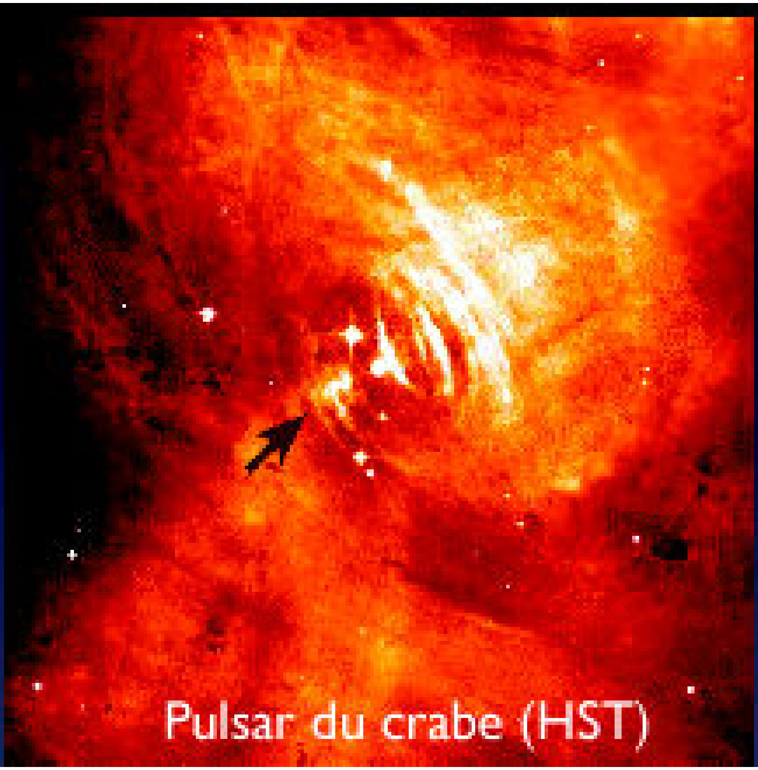
Pulsar:

Neutron star sending radiation in a periodic way, currently measured with millisec accuracy.

Emission in radio, visible, X- and gamma rays currently measured up to ~1 Gev.

AMS: pulsar periods measured with μsec time precision and
energy spectrum for pulsars measured to 1 TeV
(a factor of 1,000 improvement in time and energy).





Similar studies can be made for Blazers and Gamma Ray Bursters

Physics Example

Search for New Matter in the Universe

Jack Sandweiss, Yale University

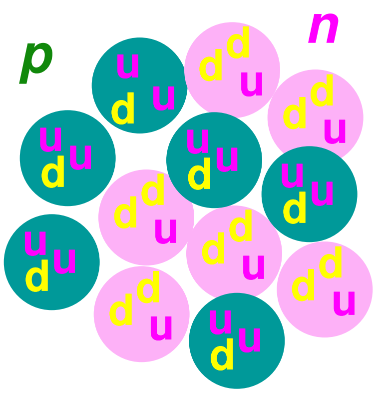
There are six types of Quarks found in accelerators (u, d, s, c, b, t).

All matter on Earth is made out of only two types (u, d) of quarks.

"Strangelets" are new types of matter composed of three types of quarks (u, d, s) which should exist in the cosmos.

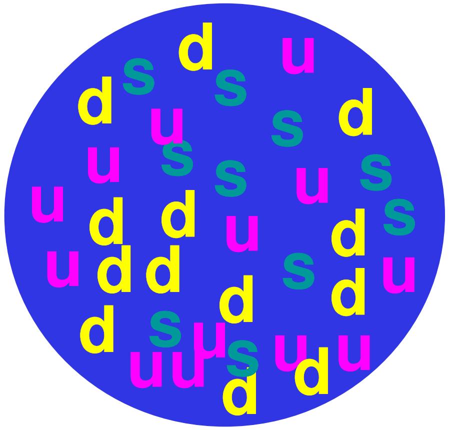
Carbon Nucleus

Z/A ~ 0.5



Strangelet

Z/A ~ 0.1



i. A stable, single "super nucleon" with three types of quarks

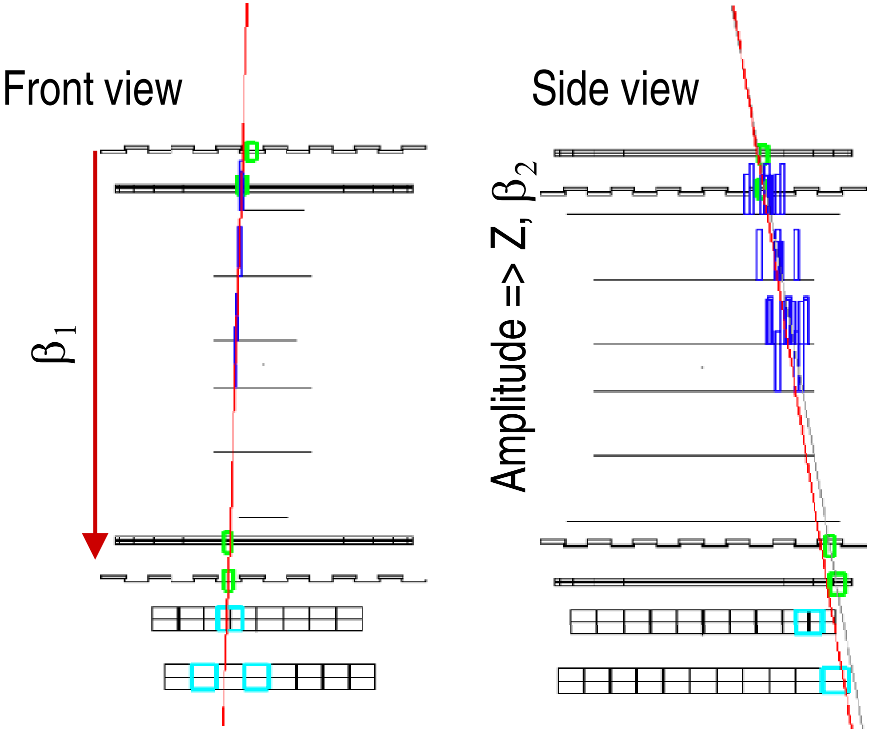
ii. "Neutron" stars may be one big strangelet

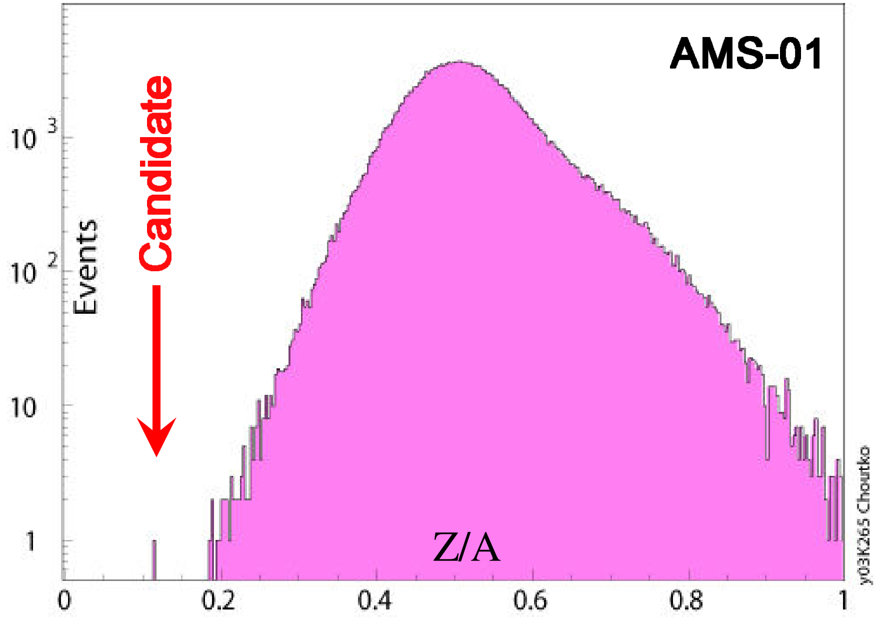
AMS will provide a definitive search for this new type of matter.

Strangelet candidate from AMS-01

Observed 5 June 1998 11:13:16 UTC

Lat/Long= -44.38°/+23.70°, Local Cutoff 1.95±0.1 GV, Angle= 77.5° from local zenith





Rigidity = 4.31 ± 0.38 GV

Charge Z = 2

$\beta_1 = \beta_2$ = 0.462 ± 0.005

Mass = 16.45±0.15 GeV/c^2

Z/A = 0.114 ± 0.01

Flux ($1.5 < E_K < 10$ GeV) = 5×10^{-5} (m^2 sr sec$)^{-1}$

Background probability $< 10^{-3}$

Discoveries in Physics

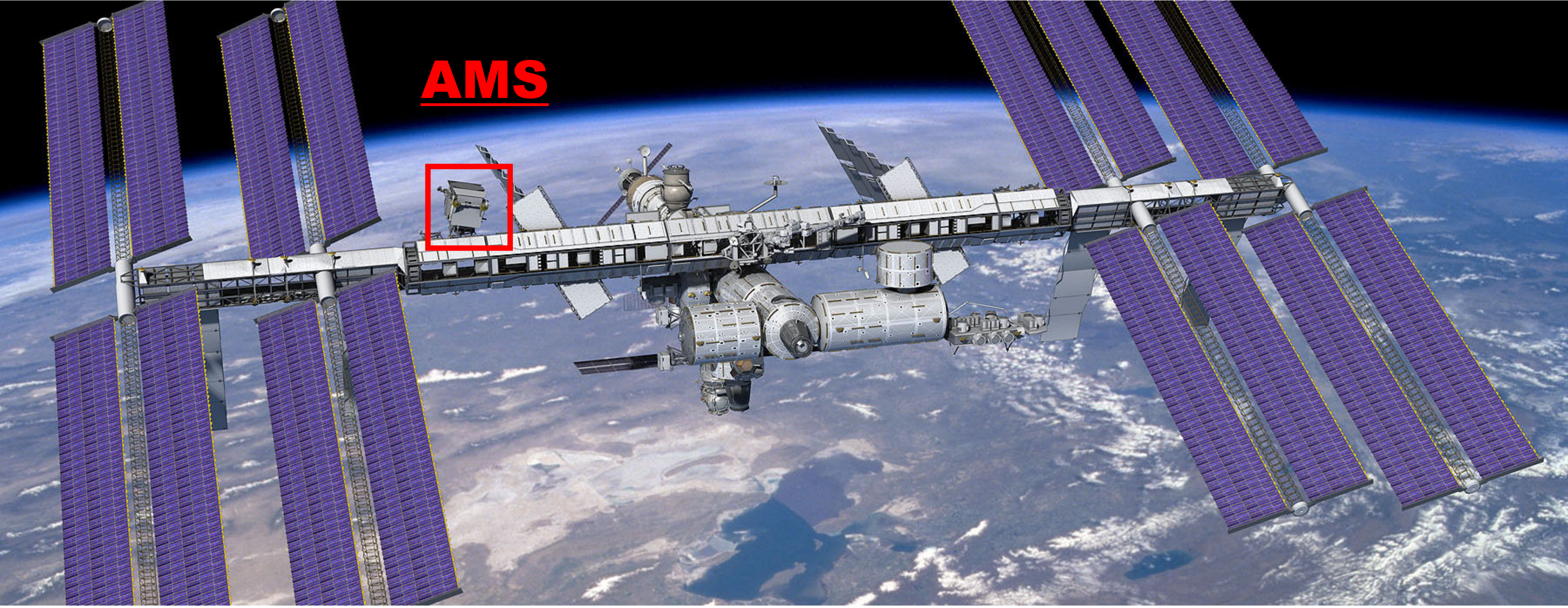
Facility		Original purpose, Expert Opinion	Discovery with Precision Instrument
P.S. CERN	(1960's)	π N interactions	Neutral Currents -> Z, W
Brookhaven	(1960's)	π N interactions	ν_e, ν_μ CP violation, J
FNAL	(1970's)	Neutrino physics	*b, t quarks*
SLAC Spear	(1970's)	ep, QED	Scaling, Ψ, τ
PETRA	(1980's)	t quark	*Gluon*
Super Kamiokande	(2000)	Proton decay	Neutrino oscillations
Hubble Space Telescope	(1990's)	Galactic survey	*Curvature of the universe, dark energy*
AMS on ISS		Dark Matter, Antimatter Strangelets,…	?

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

The Cosmos is the Ultimate Laboratory.

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

The issues of antimatter in the universe and the origin of Dark Matter probe the foundations of modern physics.



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.