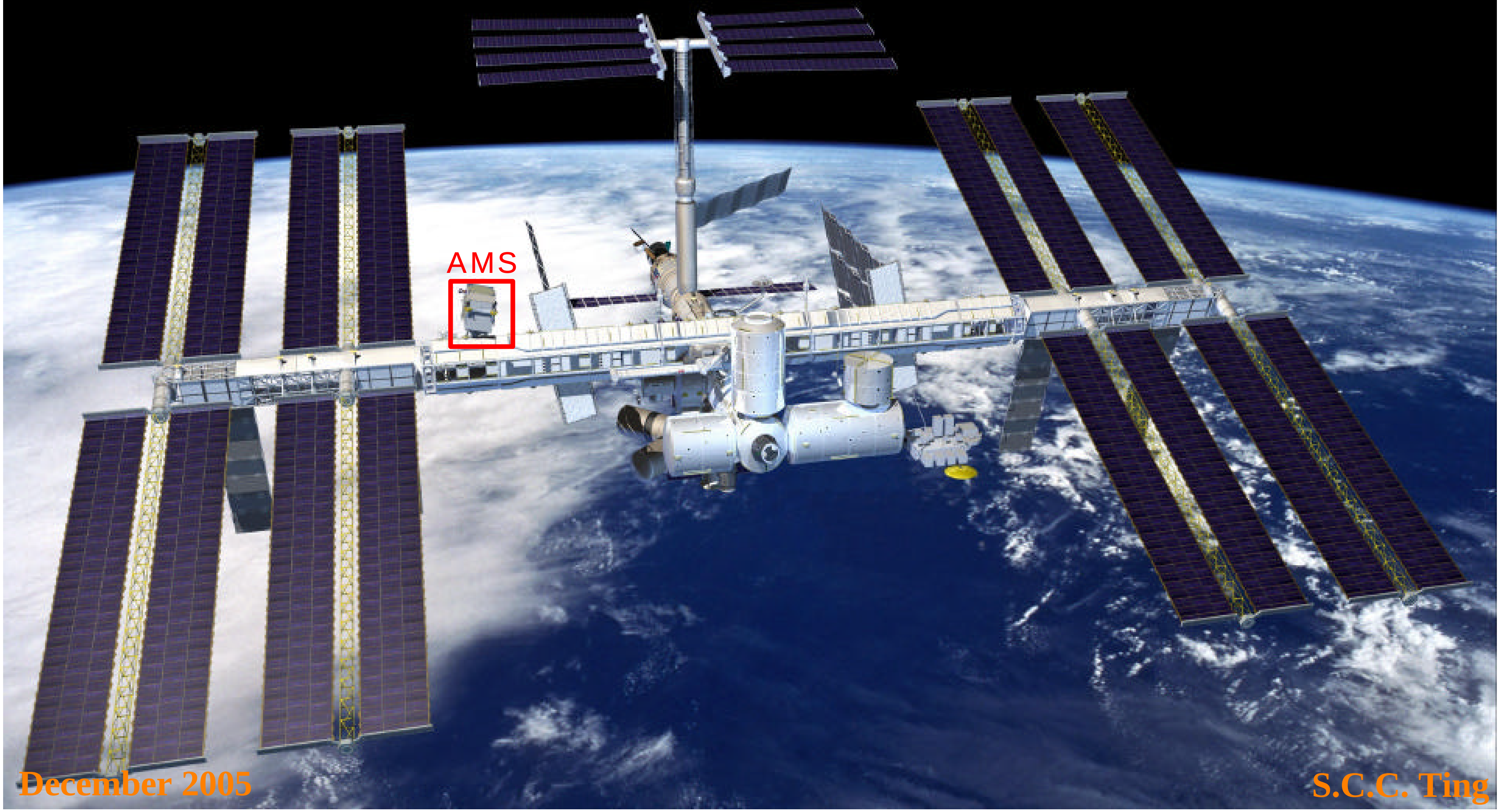
The Alpha Magnetic Spectrometer Experiment (AMS)



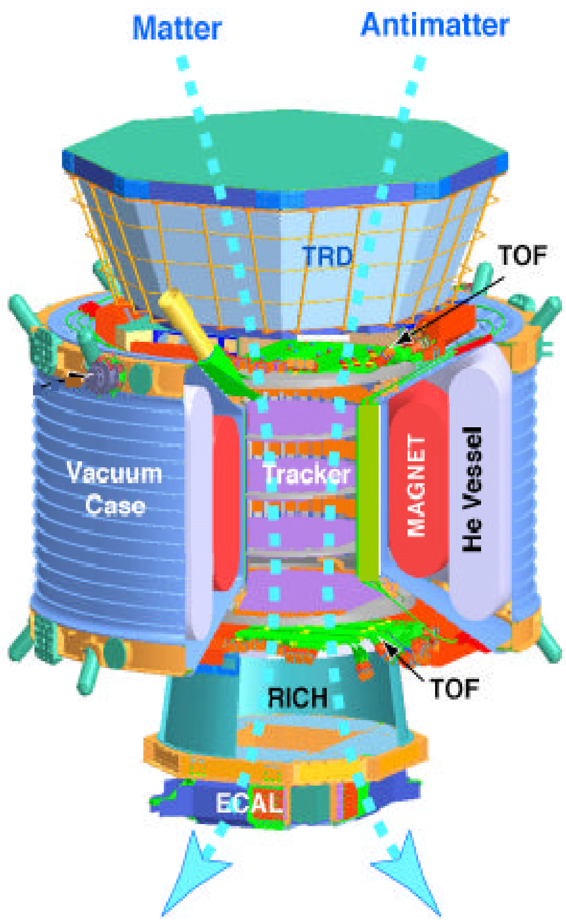
December 2005

S.C.C. Ting

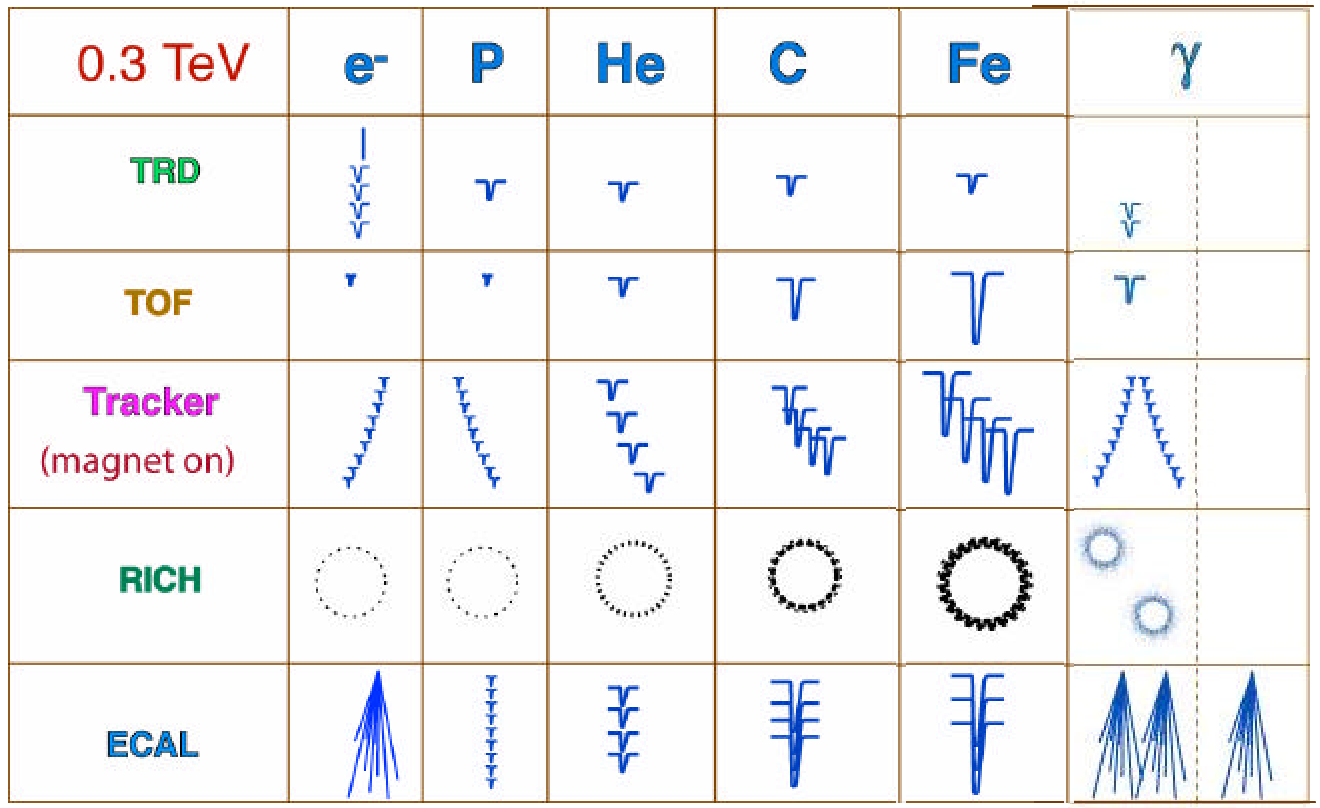
AMS: A TeV (10^{12} eV) Magnetic Spectrometer in Space

3m x 3m x 3m, 7t, ~ 0.5m^2 sr

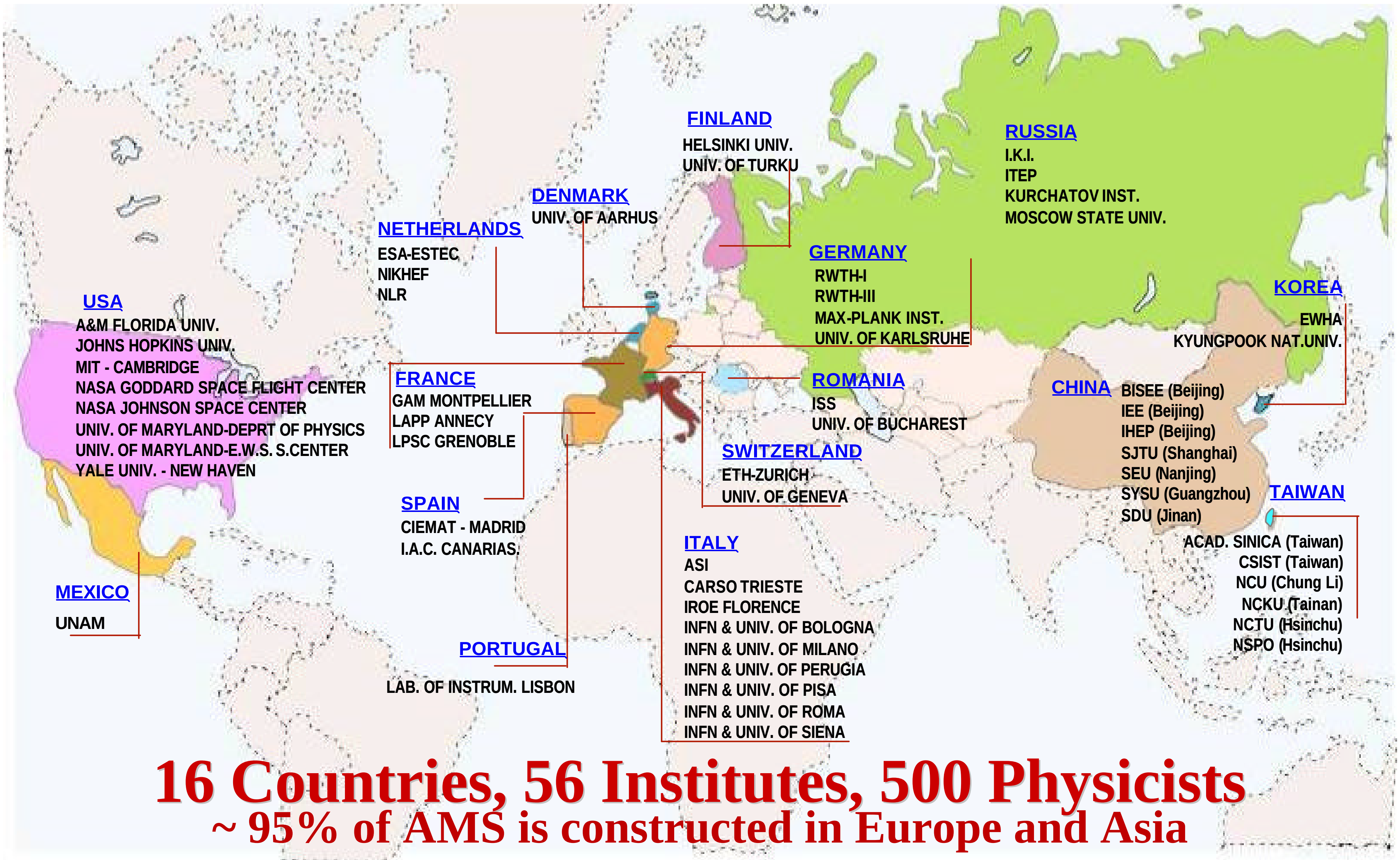
The AMS detector has been under construction for 10 years.



300,000 channels of electronics Δt = 100 ps, Δx = 10μm



International Participation in AMS



16 Countries, 56 Institutes, 500 Physicists

~ 95% of AMS is constructed in Europe and Asia

Italian National participation in AMS-02

Istituto Nazionale
Di Fisica Nucleare

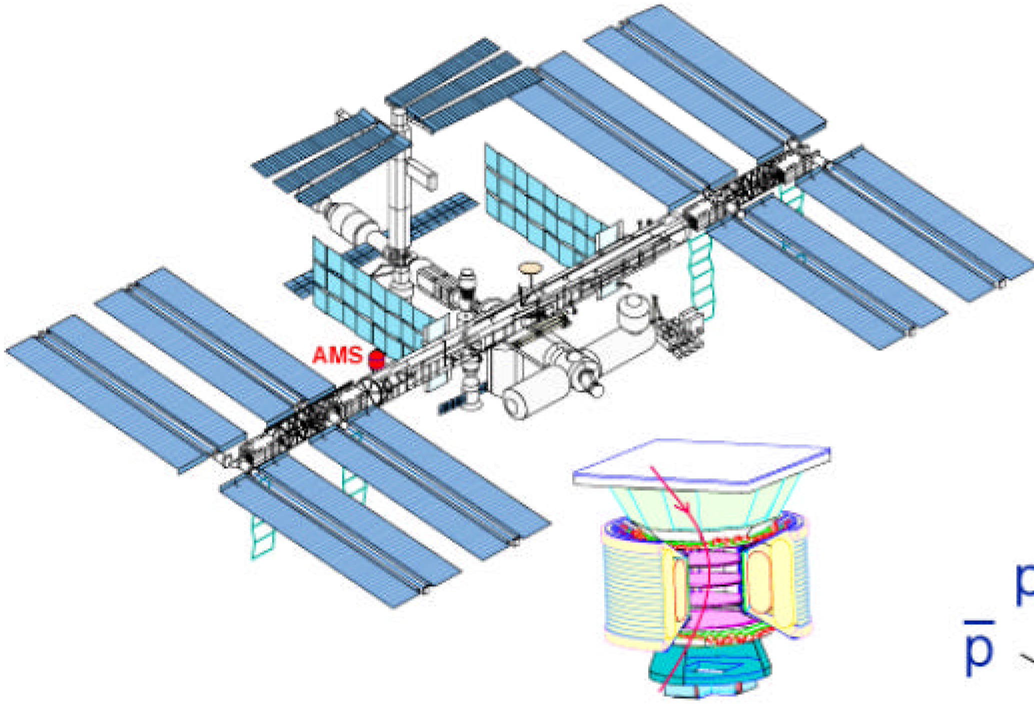
agenzia spaziale italiana

- Universities
- Space Industry

y97637_1ba.ppt

Coordinator: R. Battiston

Physics of AMS

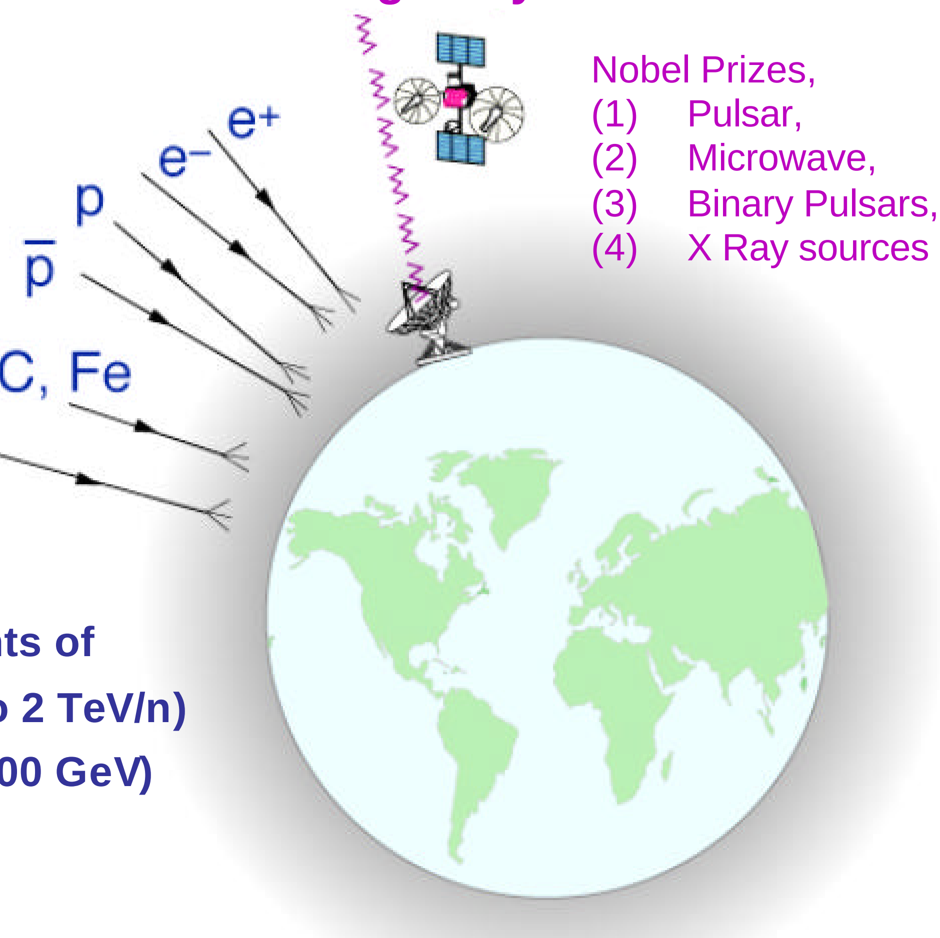


Cosmic rays

1- Neutral component:

Light rays and neutrinos

Nobel Prizes,
(1) Pulsar,
(2) Microwave,
(3) Binary Pulsars,
(4) X Ray sources



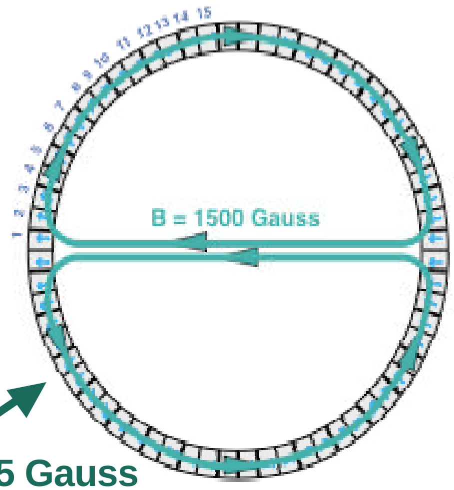
2- Charged component: He, Be, C, Fe

$\overline{He}$,

AMS will perform accurate measurements of energetic charged cosmic rays (0.2 GeV/n to 2 TeV/n) and high energy gamma rays (0.5 GeV to 300 GeV)

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

AMS-01



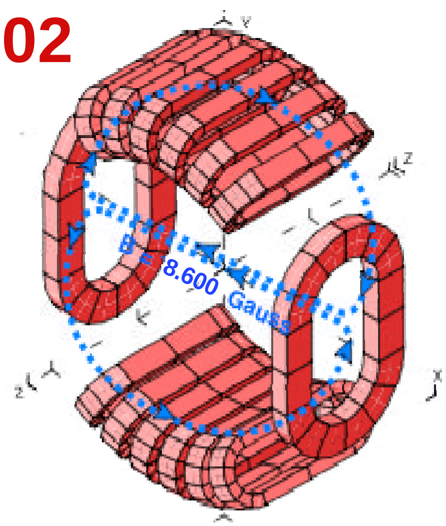
STEP ONE:
A Permanent Magnet to fly on STS-91

1- Stable: no influence from earth magnetic field

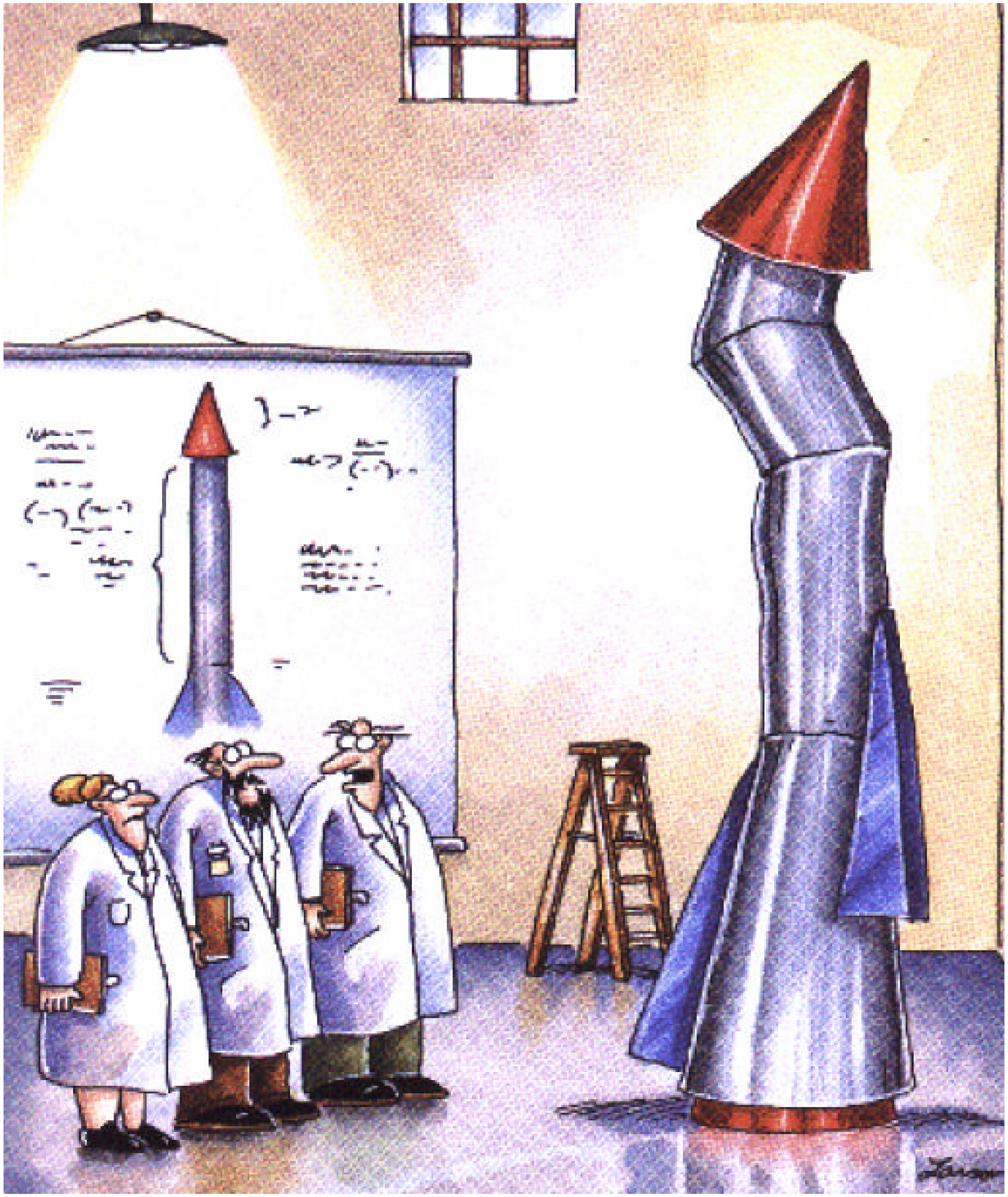
2- Safety for the astronauts: Minimum field leakage out of the magnet

3- Low weight: no iron

AMS-02



STEP TWO:
A Superconducting Magnet for ISS with the same field arrangement



"Its time we face reality,

my friends….

We're not exactly

rocket scientists."

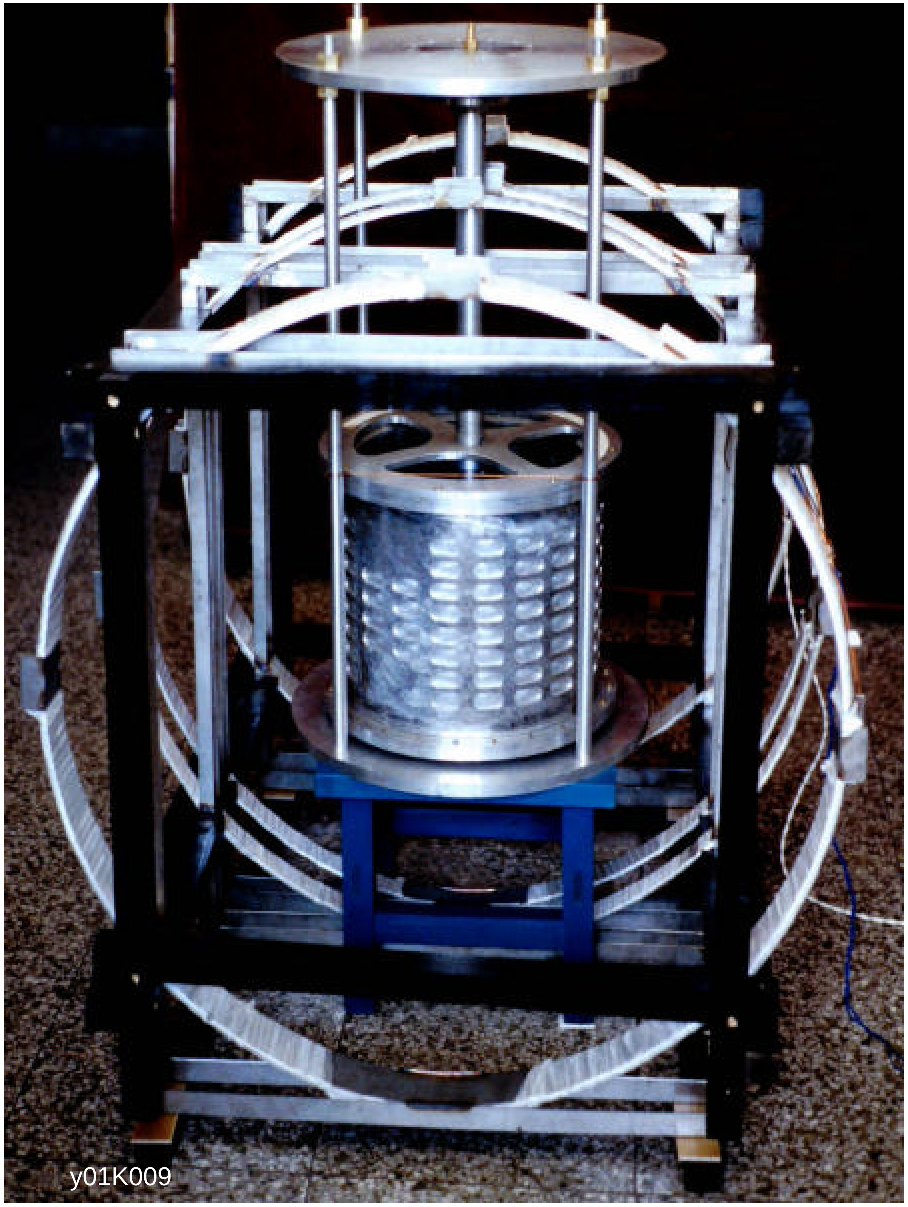
AMS-01: STS-91

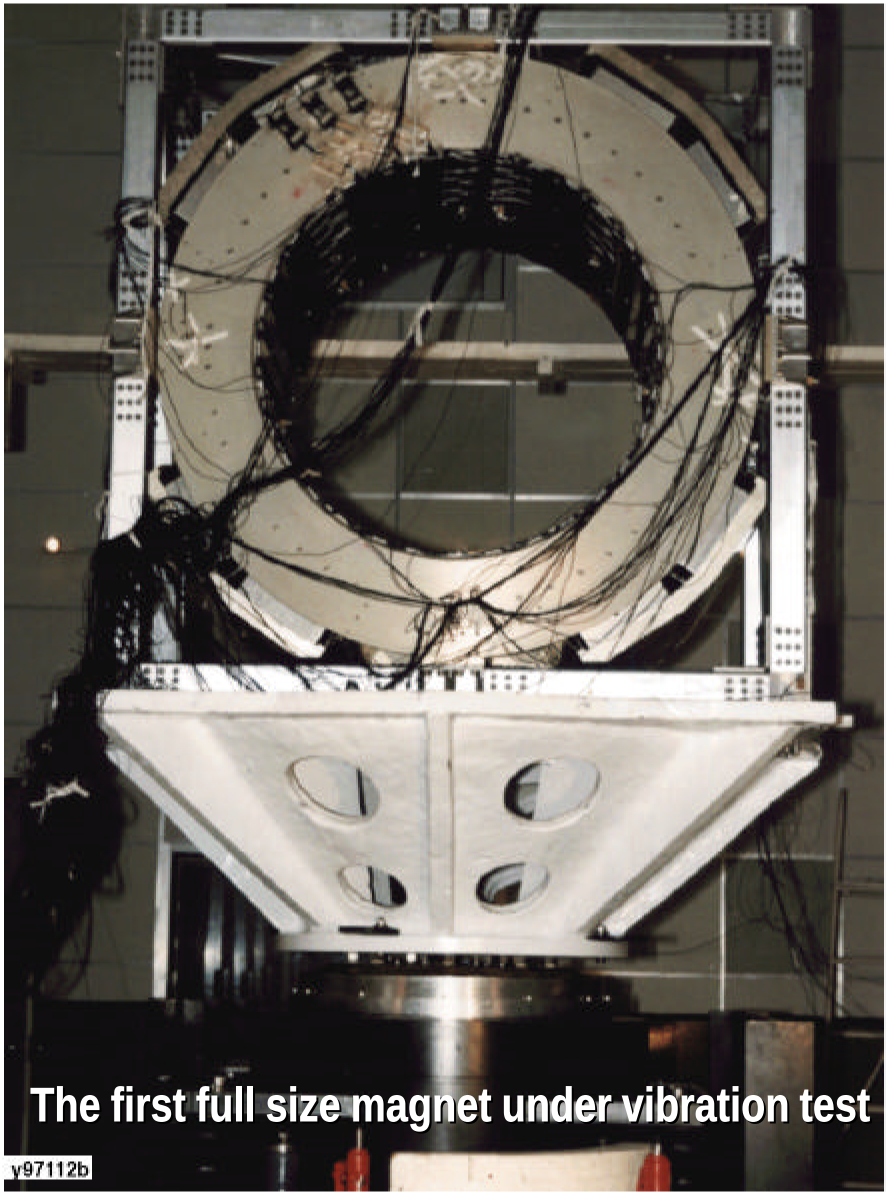
10 Magnets were made

7 to study Field Calculation, Field Leakage, Dipole moment

+

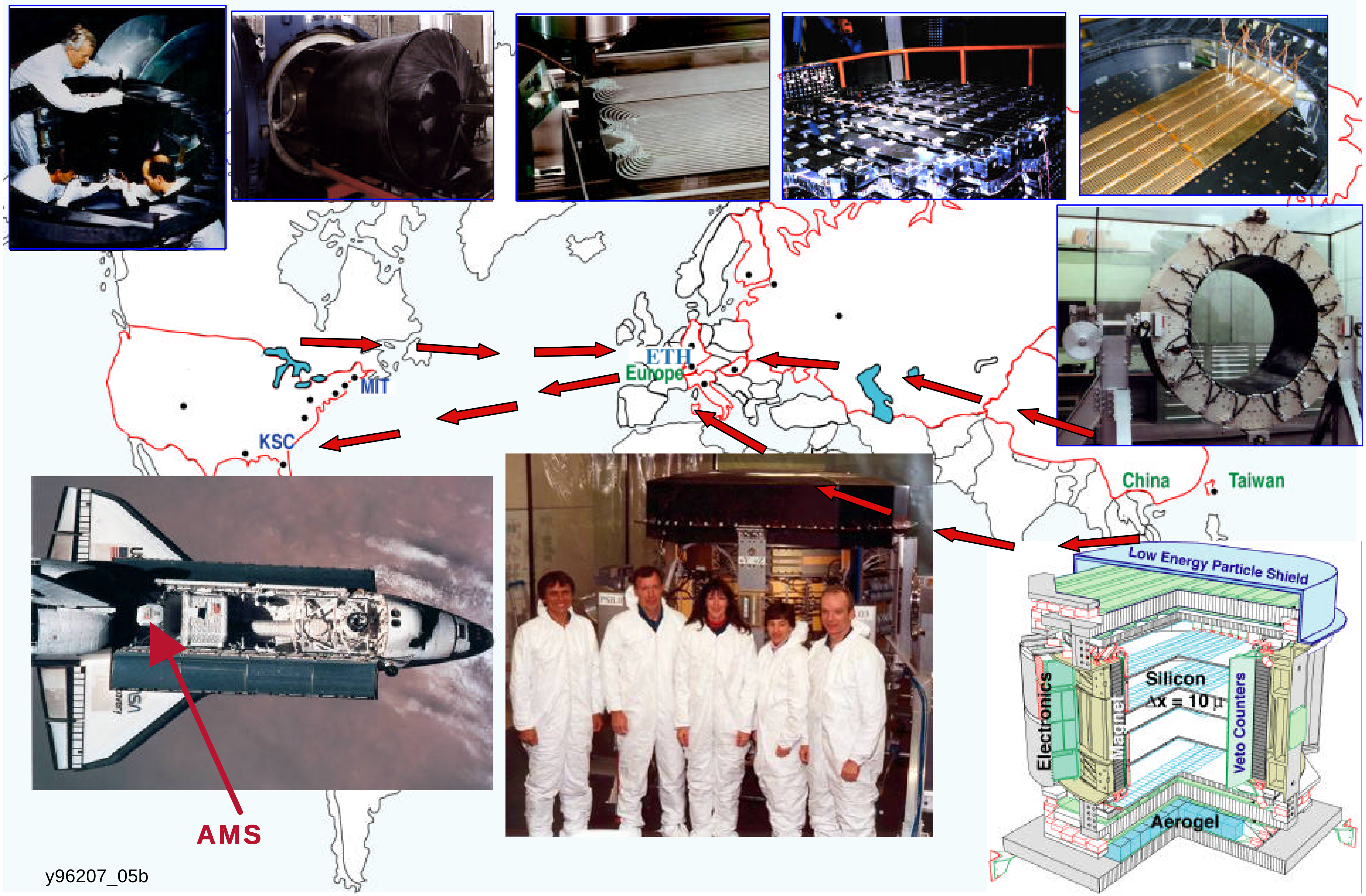
3 (full size) for Space Qualification, test to Destruction and Flight.

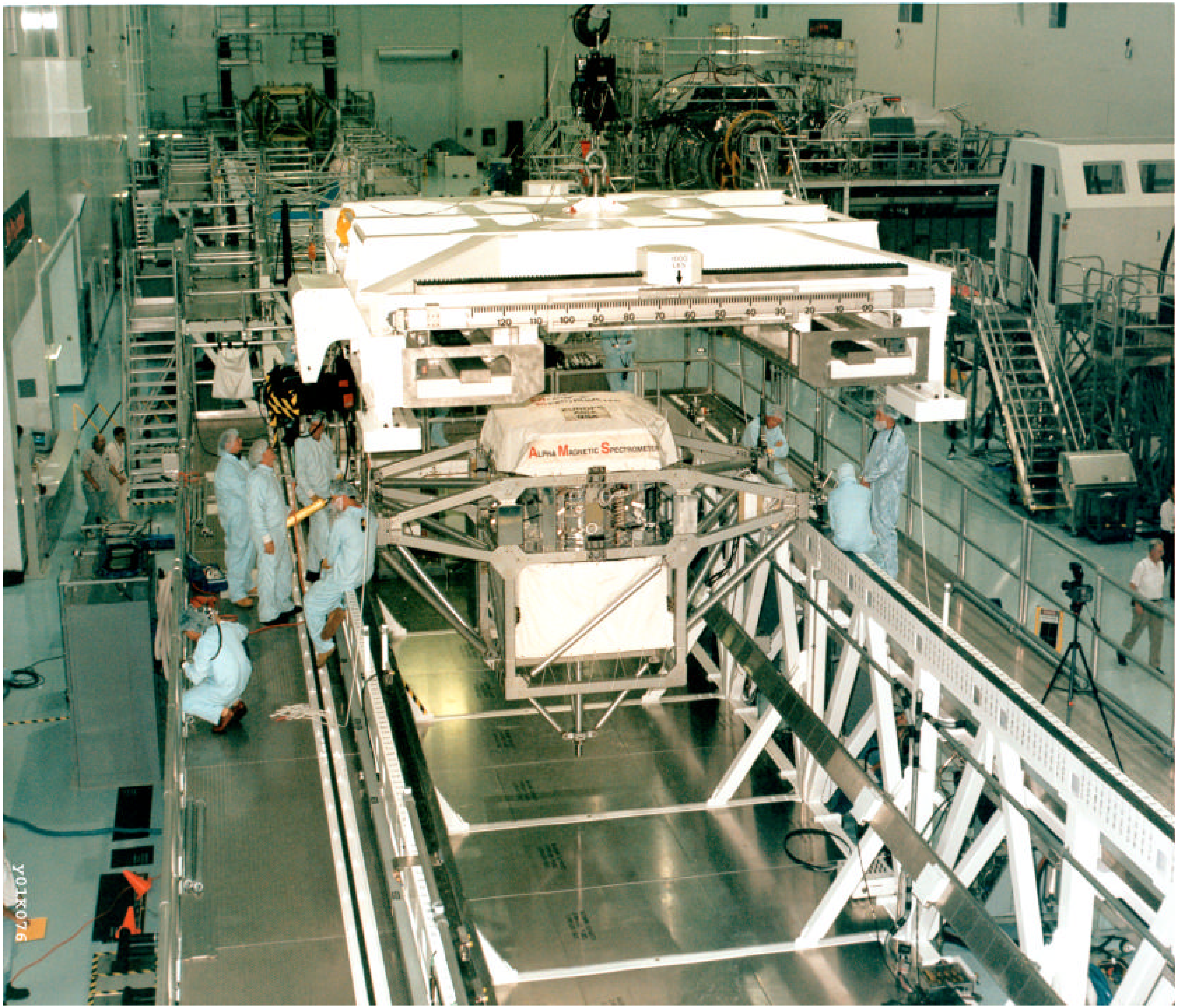


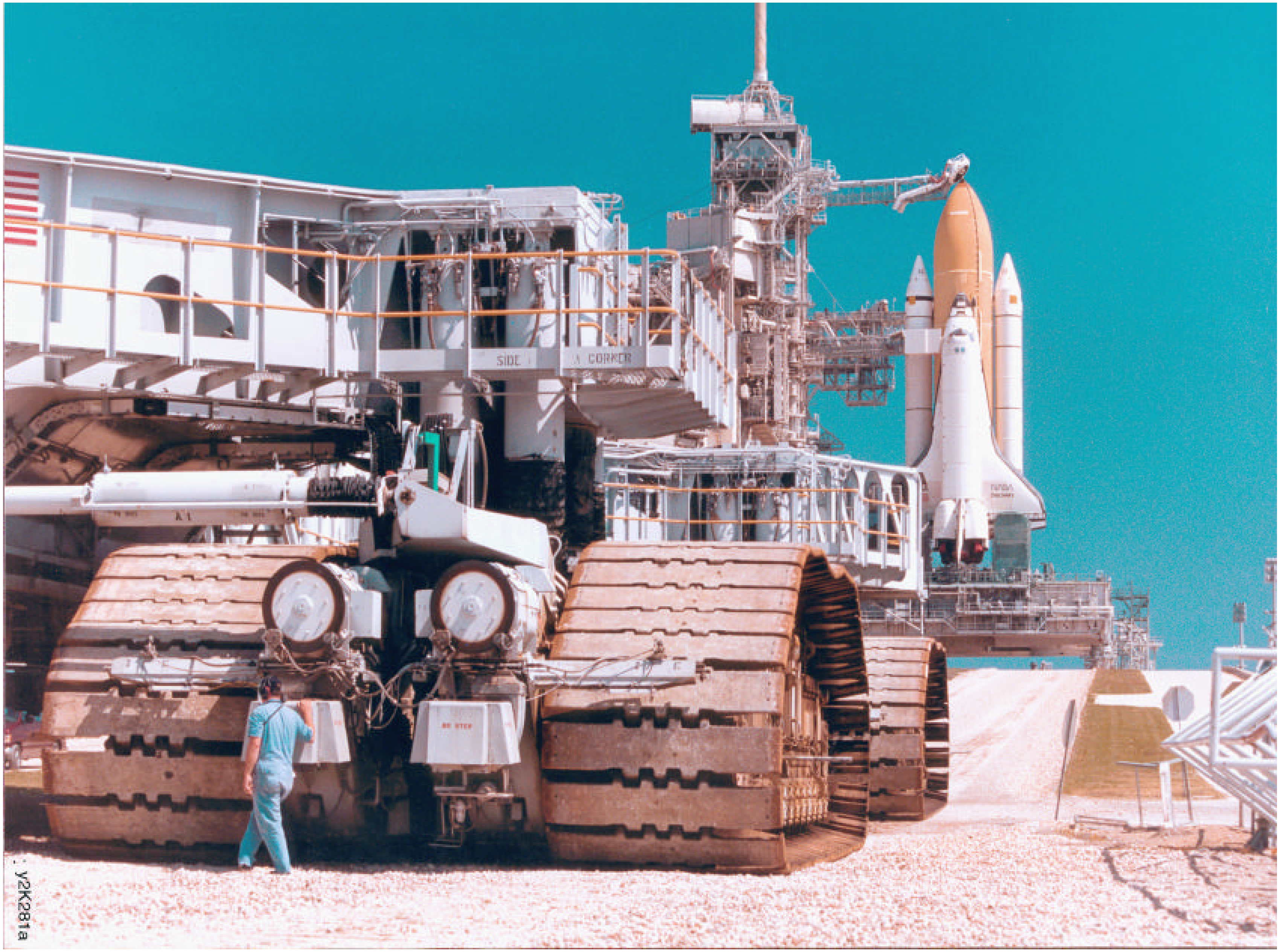


First flight AMS-01

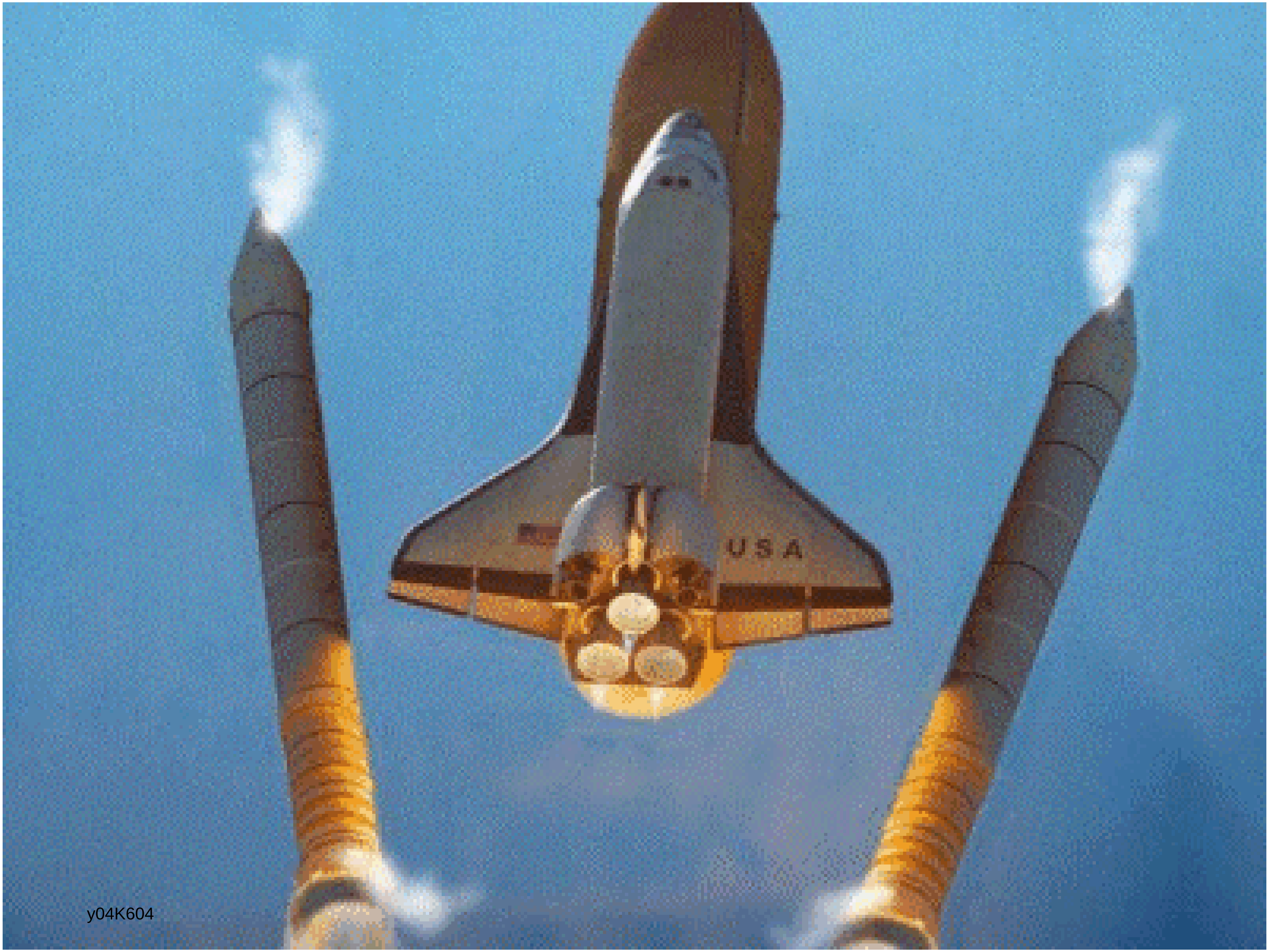
Approval: April 1995, Assembly: December 1997, Flight: June 1998




ALPHA MAGNETIC SPECTROMETER
Y01K076

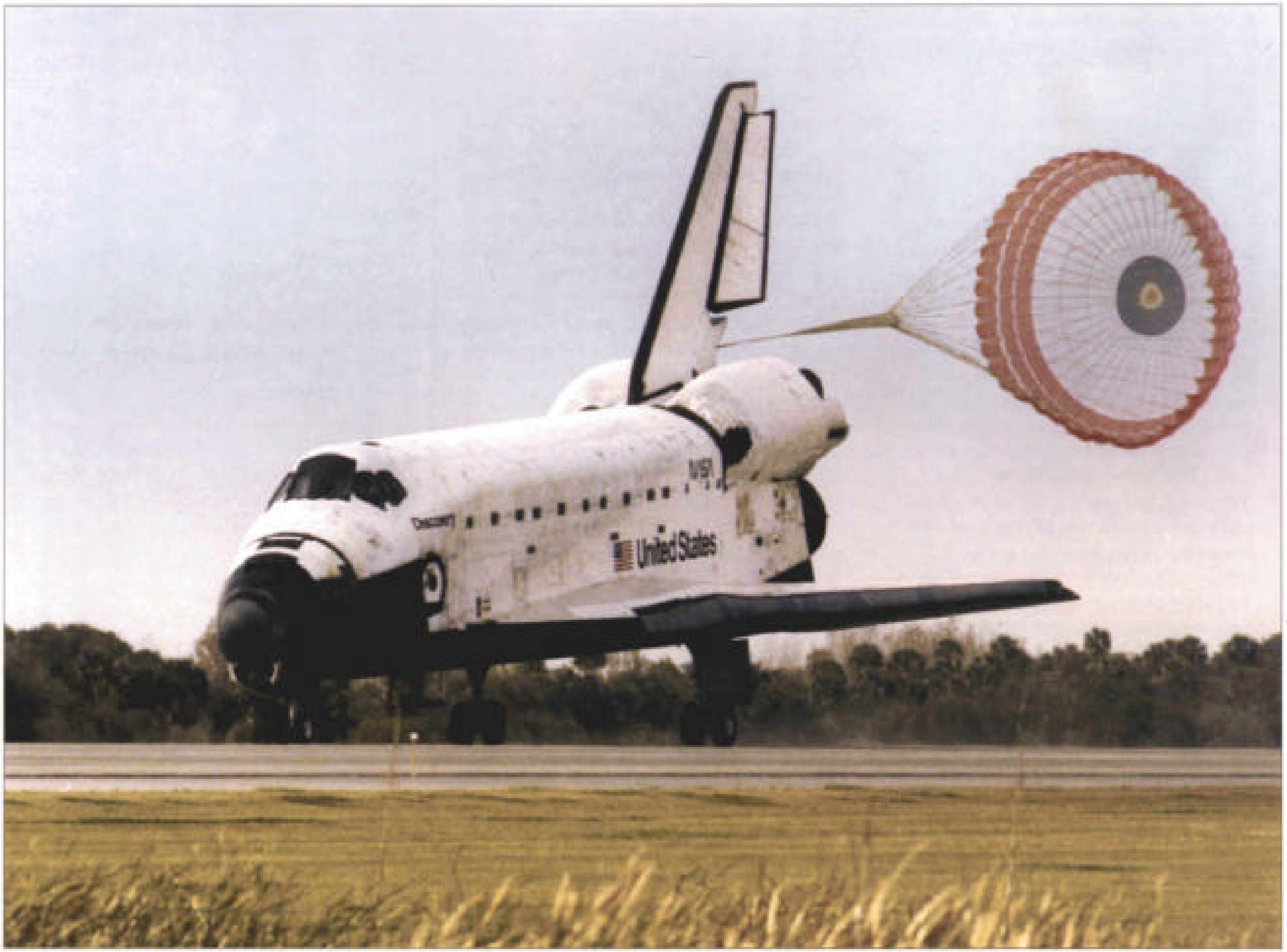

SIDE
A CORNER
y2K281a


USA
NASA
Atlantis


USA
y04K604

National Aeronautics and
Space Administration

Space Shuttle *Discovery* Returns from Space

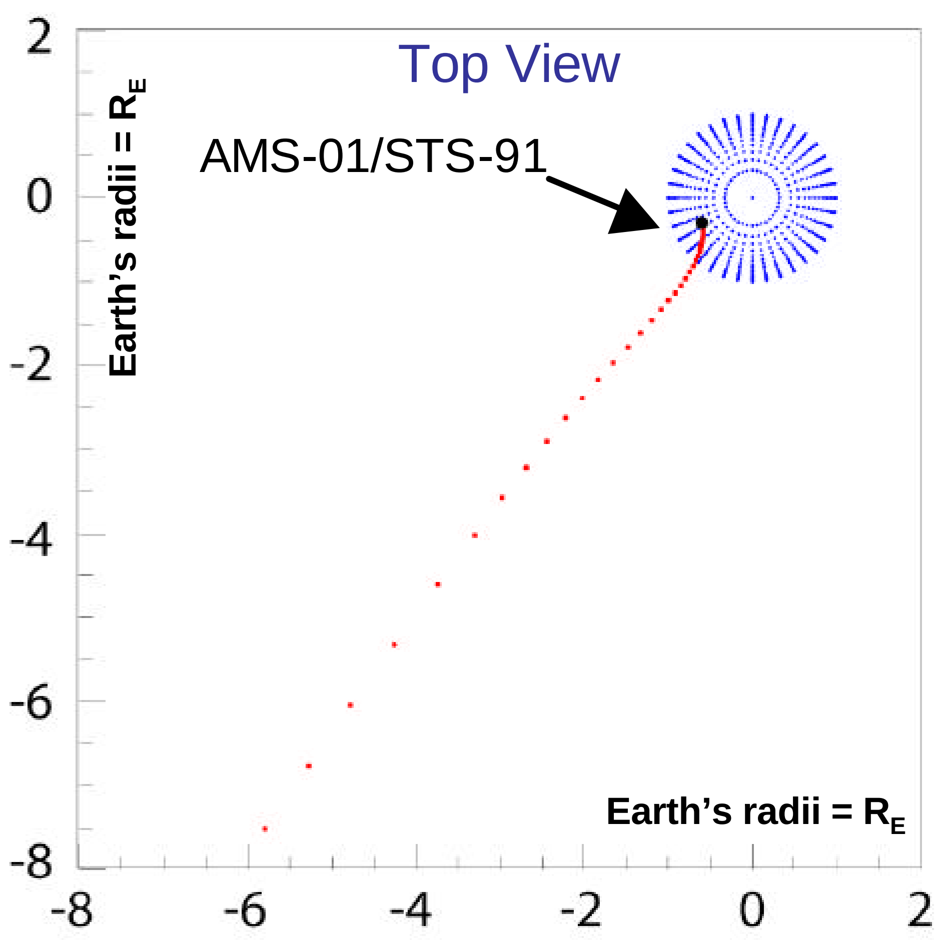


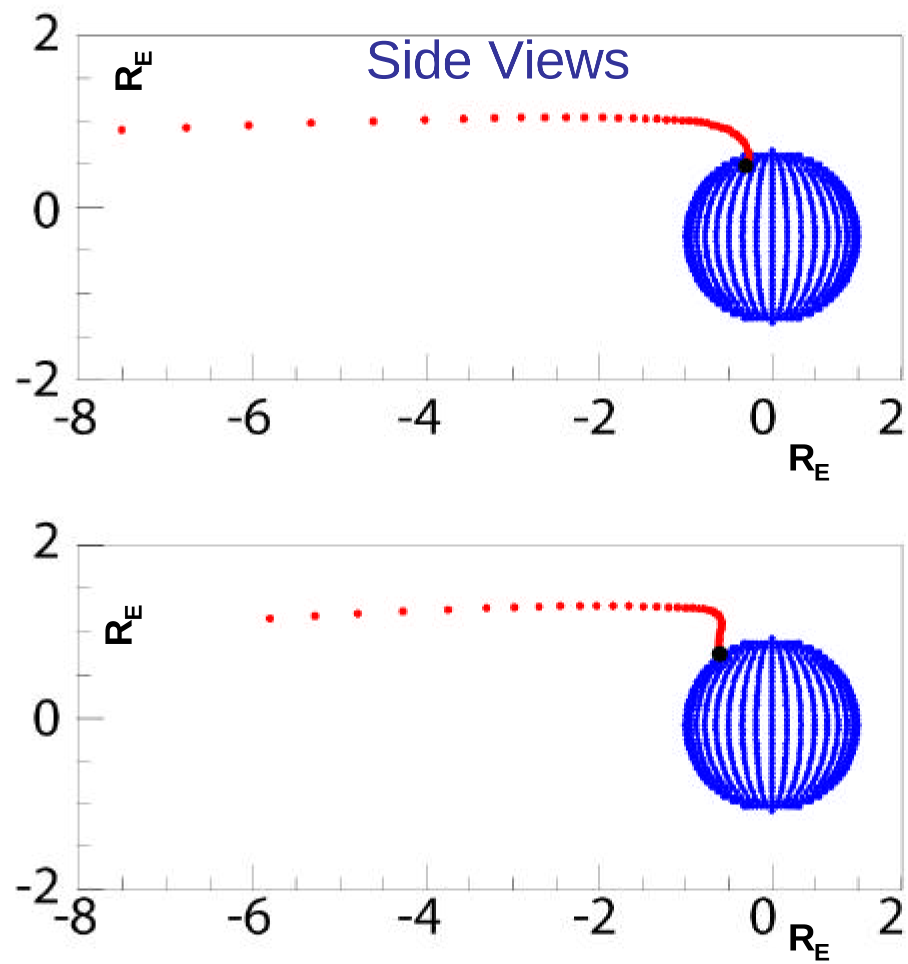
y97271c

AMS-01 Mission returns to K.S.C. - June 12 3 pm, 1998

Tracing the origin of cosmic rays from precision measurements of incident momentum vector and location

Run/Event: 897171331/310063 06-Jun-98 22:33:48 Lat/Long: 50N/27W

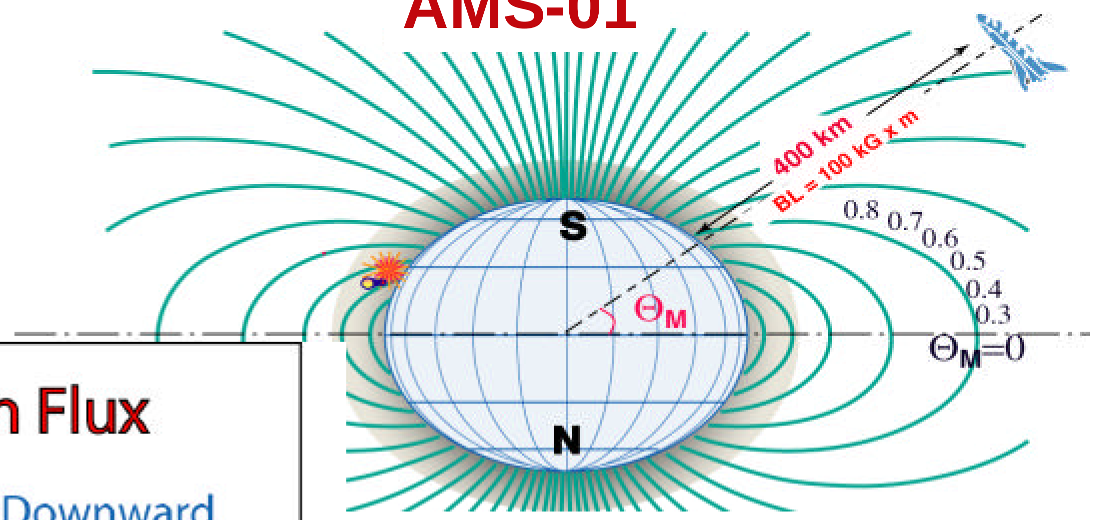


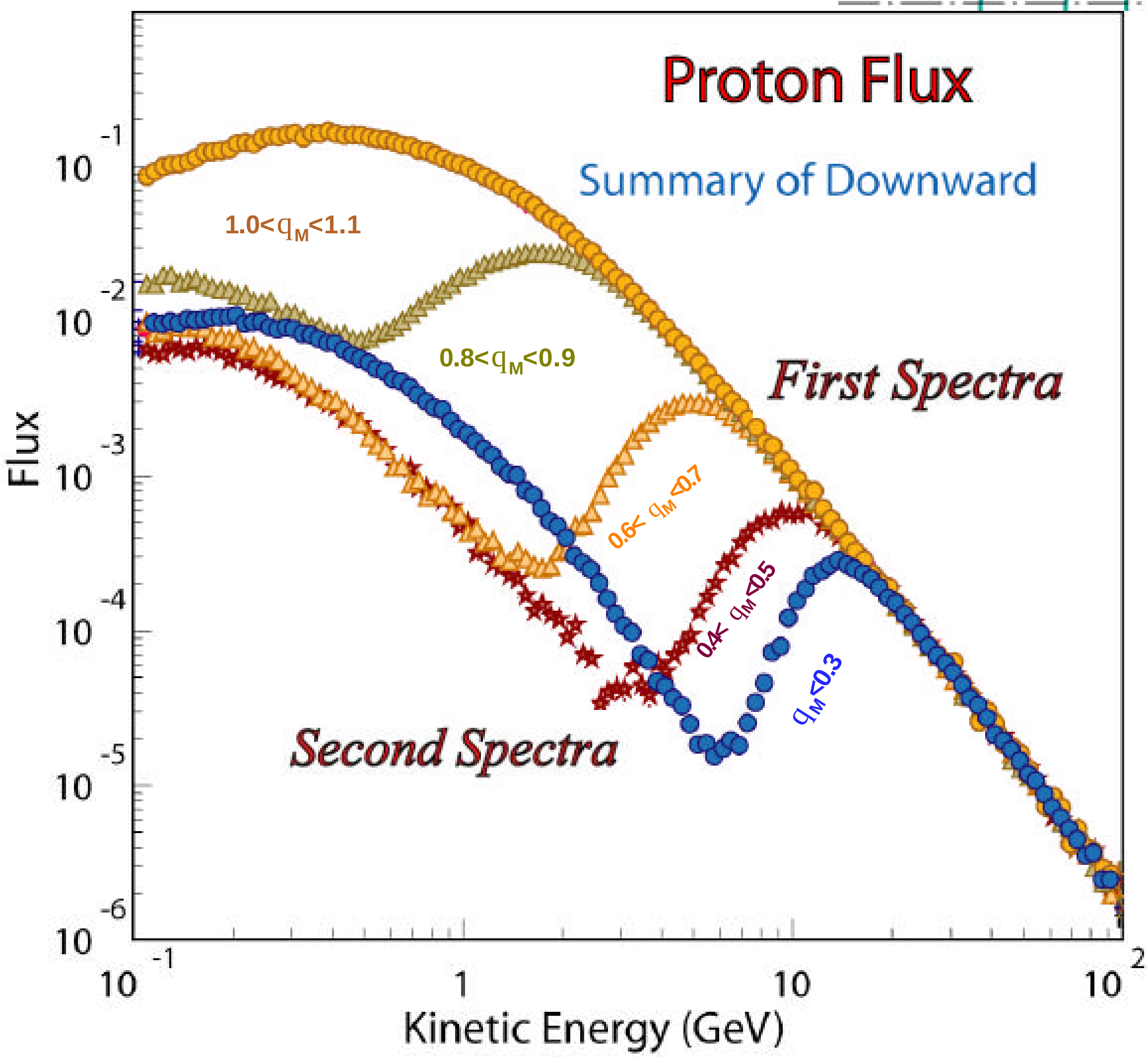


Primary proton, E_K = 516 MeV,

Measured at R_E = 1.06 , traced back to R_E > 8

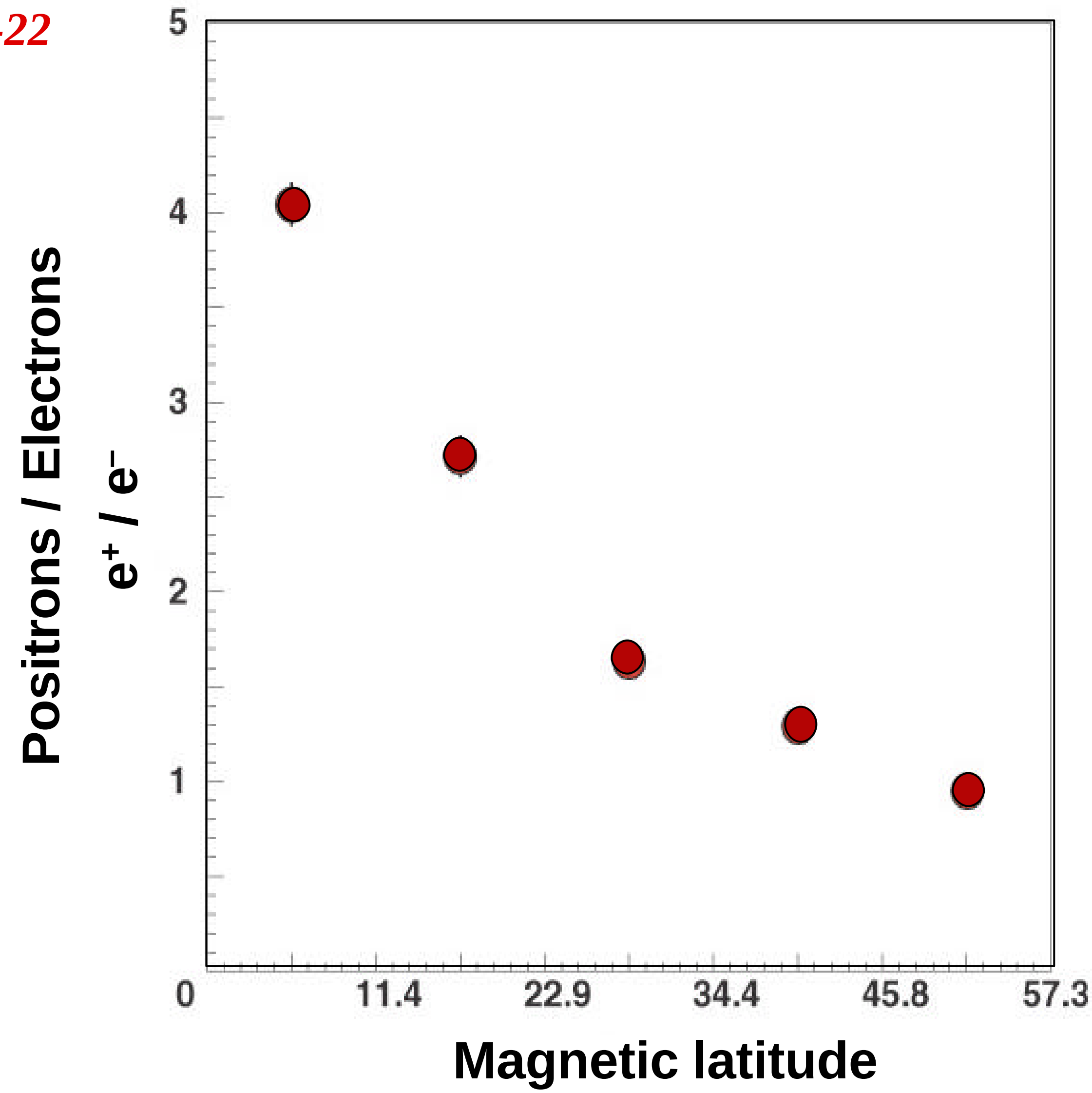
AMS-01


400 km
BL = 100 kG x m
S
N
Θ_M
0.8
0.7
0.6
0.5
0.4
0.3
Θ_M=0


Proton Flux
Summary of Downward
$1.0<q_M<1.1$
$0.8<q_M<0.9$
First Spectra
$0.6< q_M<0.7$
$0.4< q_M<0.5$
$q_M<0.3$
Second Spectra
Flux
Kinetic Energy (GeV)
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
1
10
10^{2}

AMS paper: "Leptons in Near Earth Orbit"

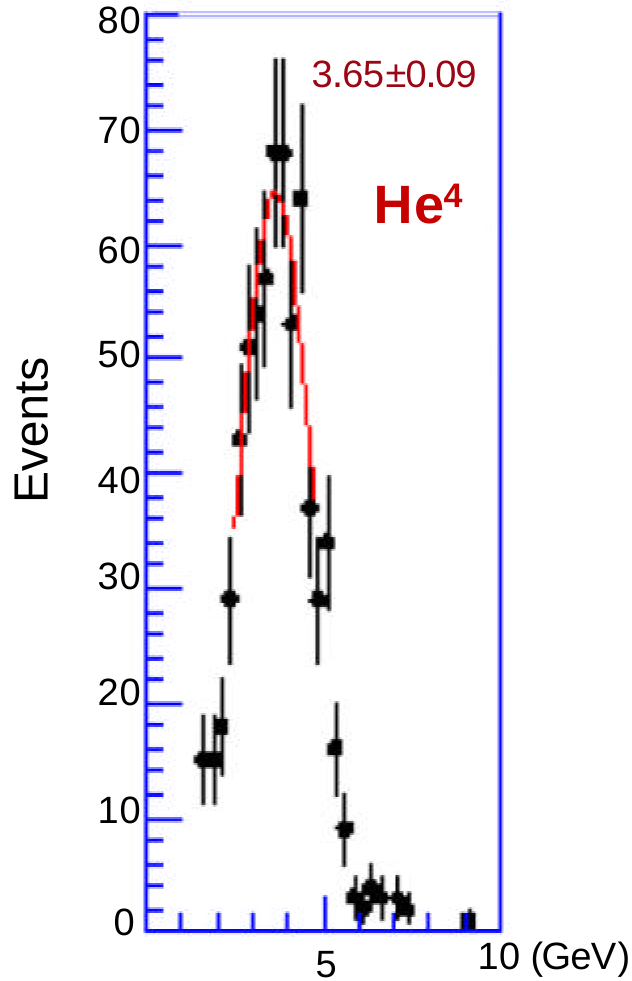
Physics Letters B 484 (2000) p. 10-22

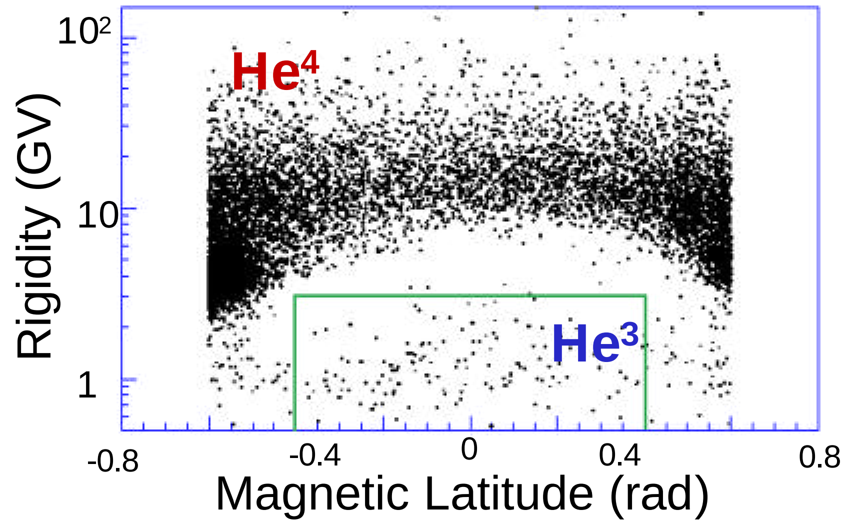


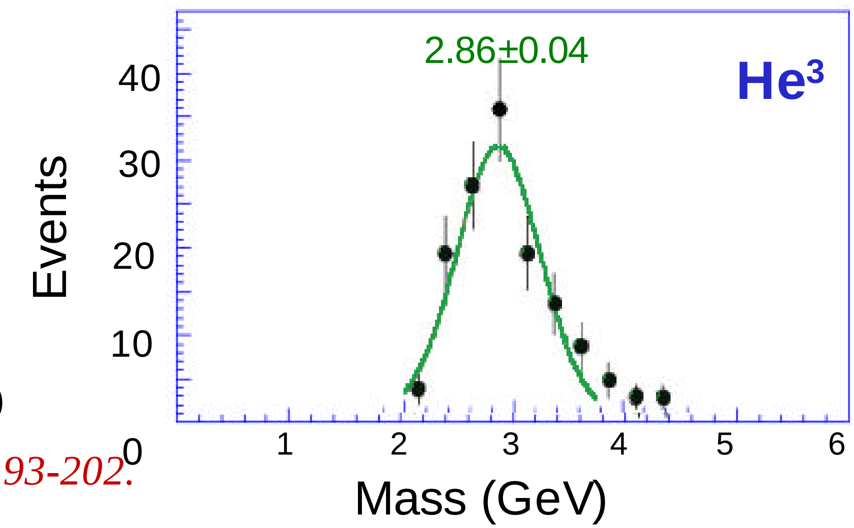
"Helium in Near Earth Orbit"

Helium spectrum

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



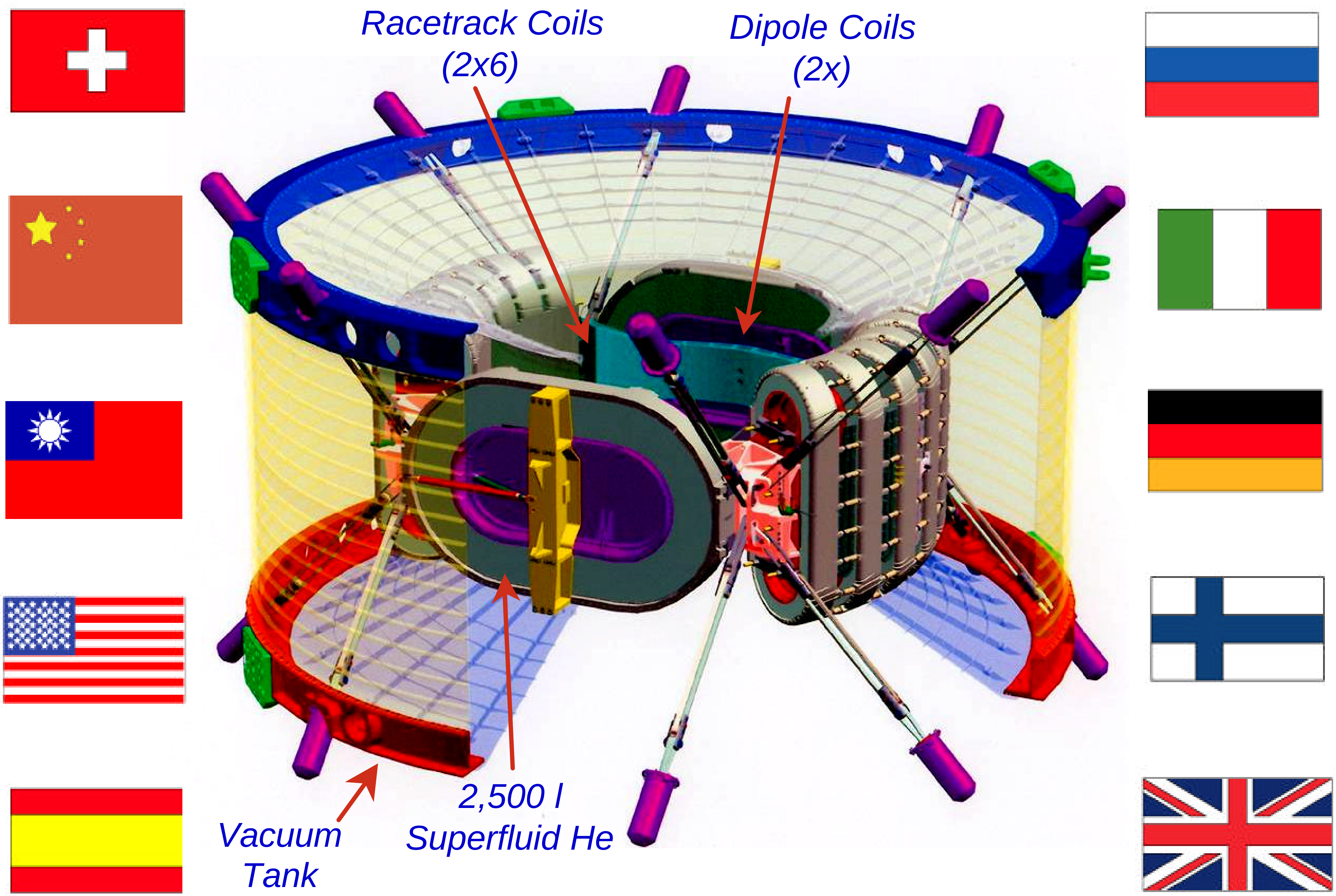




Physics Letters B vol.494 (3-4) (2000) p.193-202.

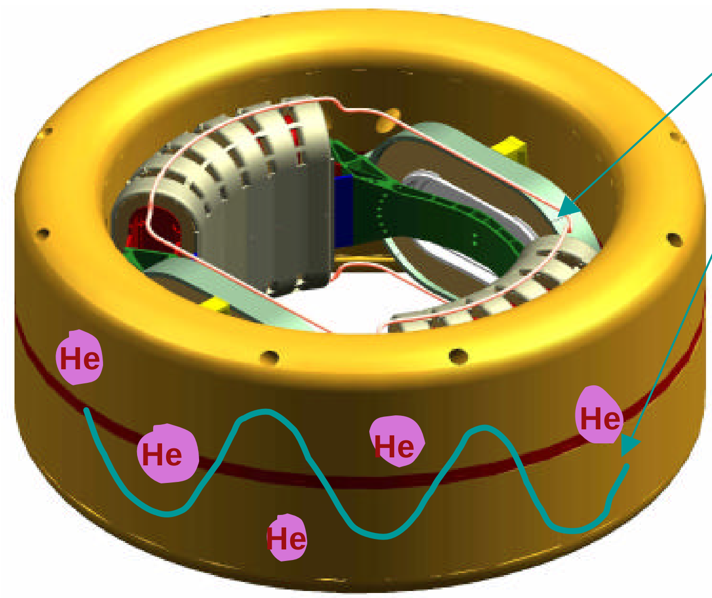
 AMS-01 results were not predicted by any cosmic ray model

Construction of the AMS-02 Superconducting magnet



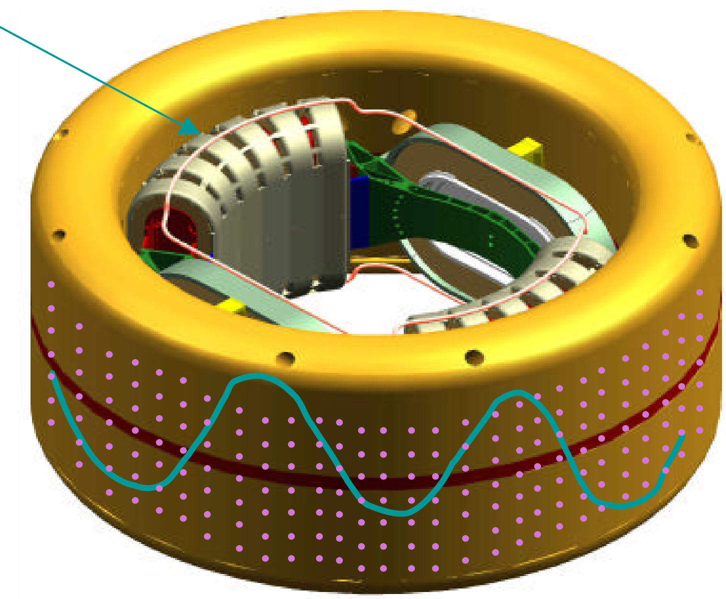
For a magnet with long duration without refill and light weight, use superfluid Helium

Indirect cooling with cold heat exchanger



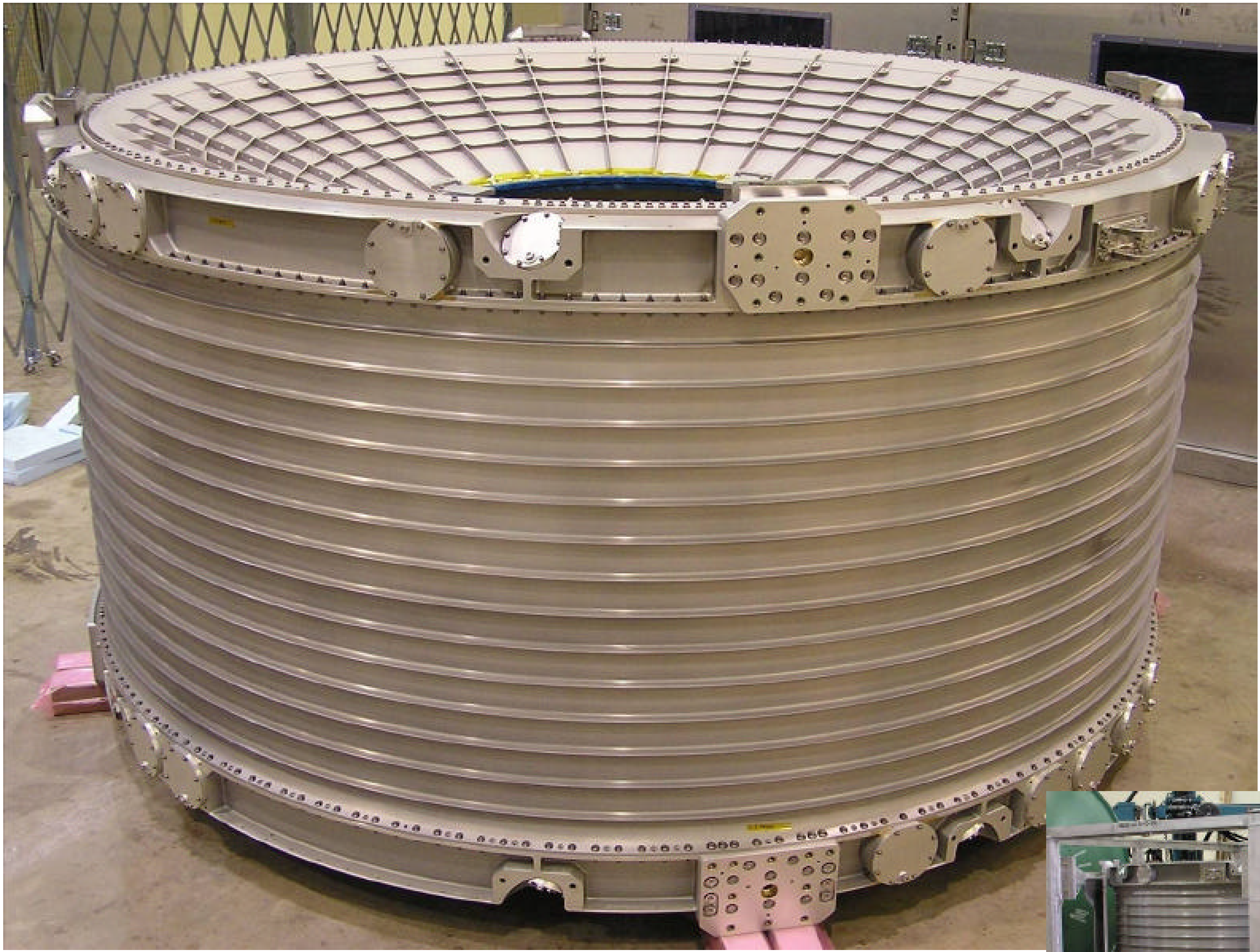
Normal liquid Helium:
4.2K

In Space: Cold Heat exchanger cannot be uniformly cooled



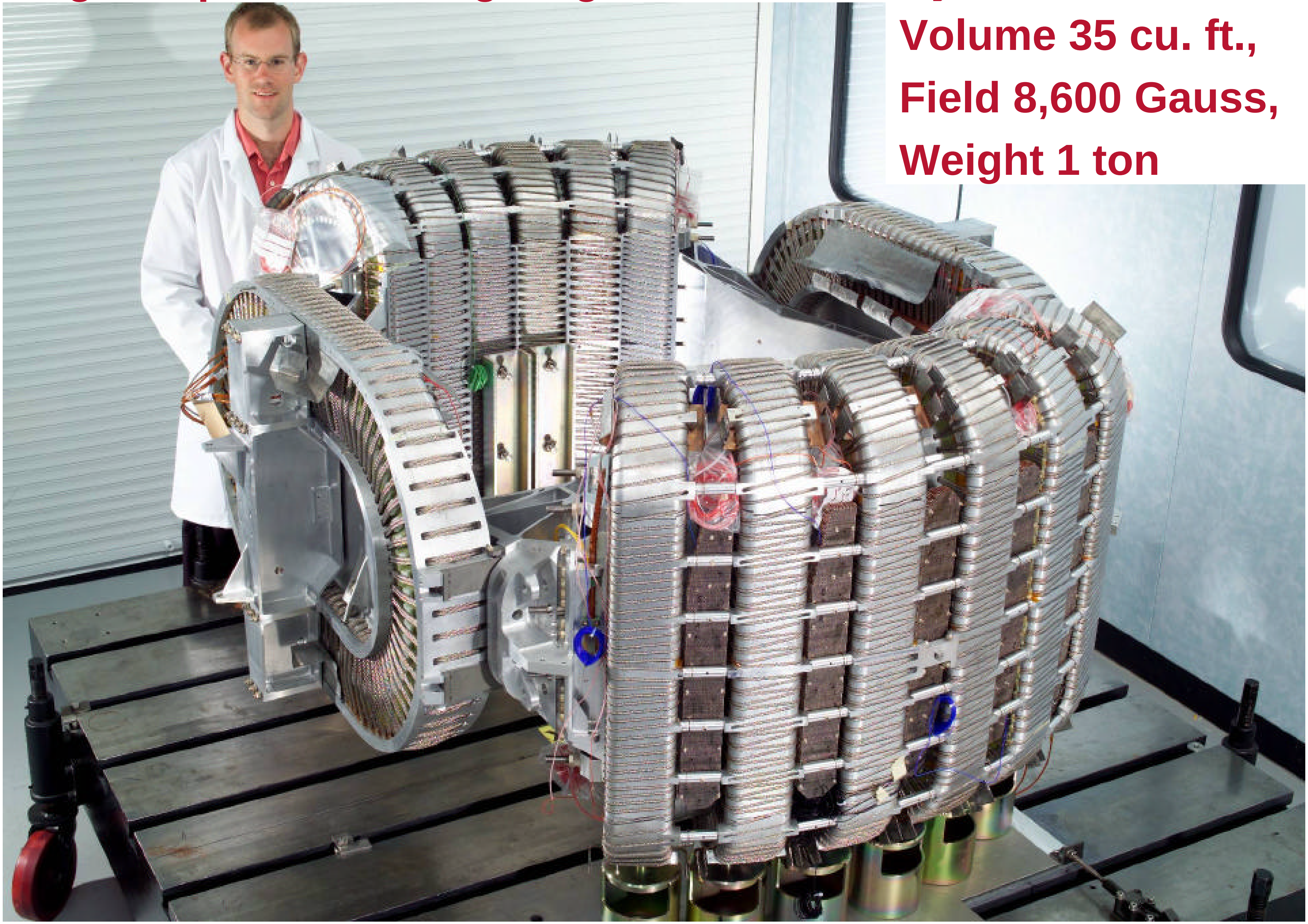
Superfluid Helium:
1.8K
film flow

In Space: Cold Heat exchanger is uniformly cooled



Flight Vacuum Case at JSC

Flight superconducting magnet coils are fully assembled:



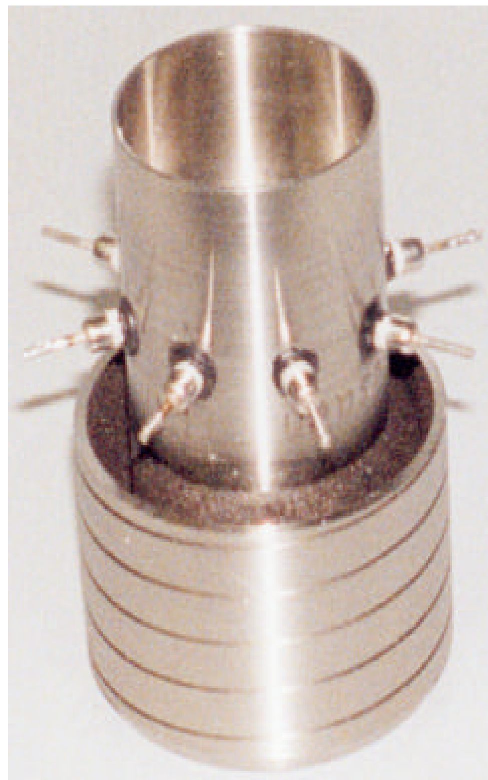
Volume 35 cu. ft.,

Field 8,600 Gauss,

Weight 1 ton

New Technology for superconducting magnet in space

Thermal Mechanical Pump transfers superfluid helium at zero gravity
in strong magnetic field.

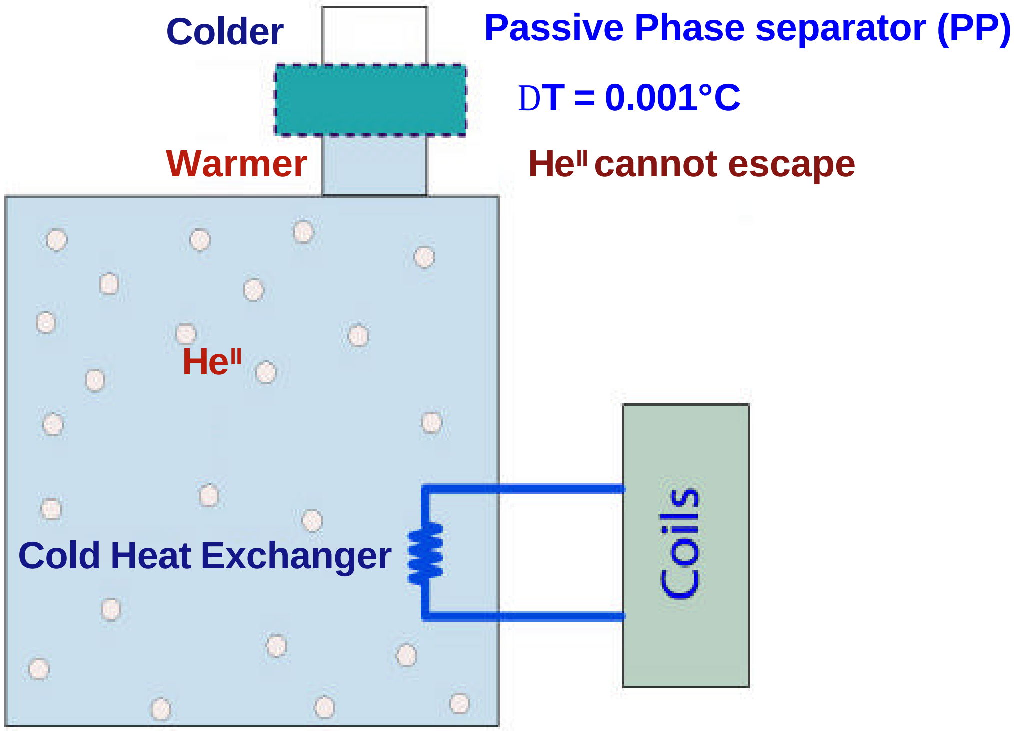


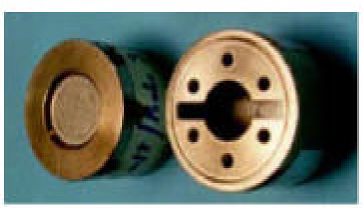
↑ He^{2}

Heater $\frac{\text{warmer}}{\text{colder}}$ $\Delta = 0.01°C$

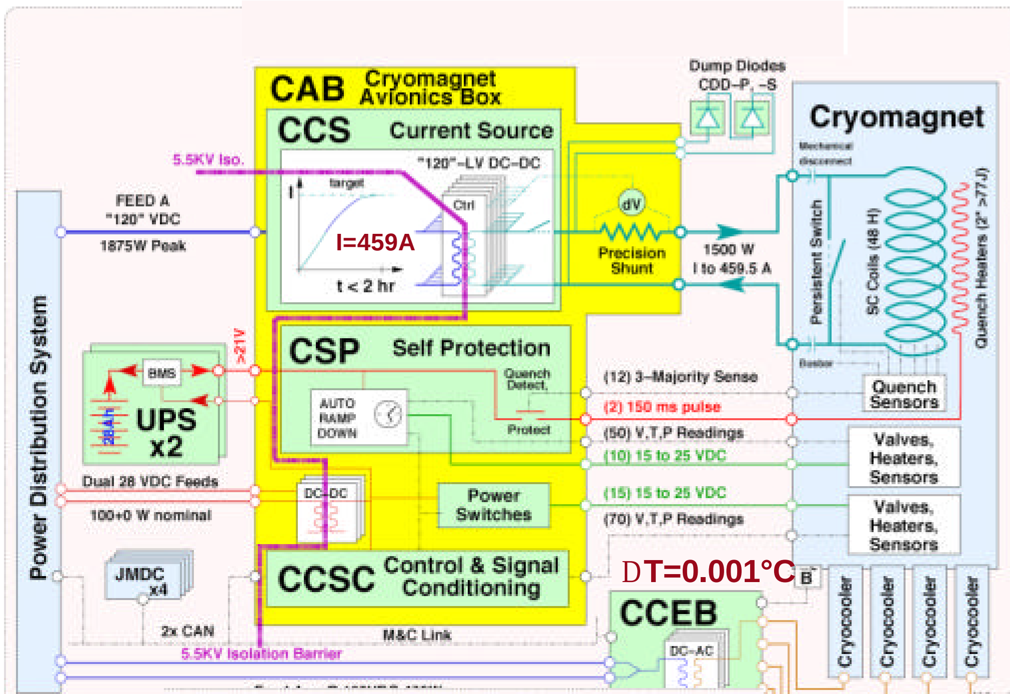
New Technology for superconducting magnet in space

A passive phase separator in a strong magnetic field at 1.8K and zero gravity to remove helium gas from superfluid He tank

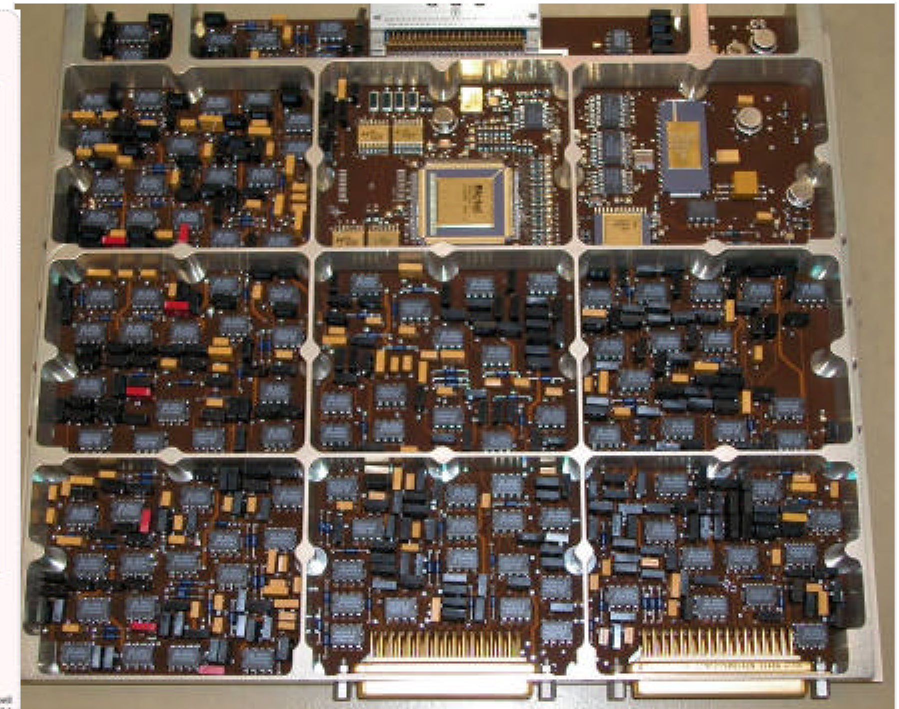


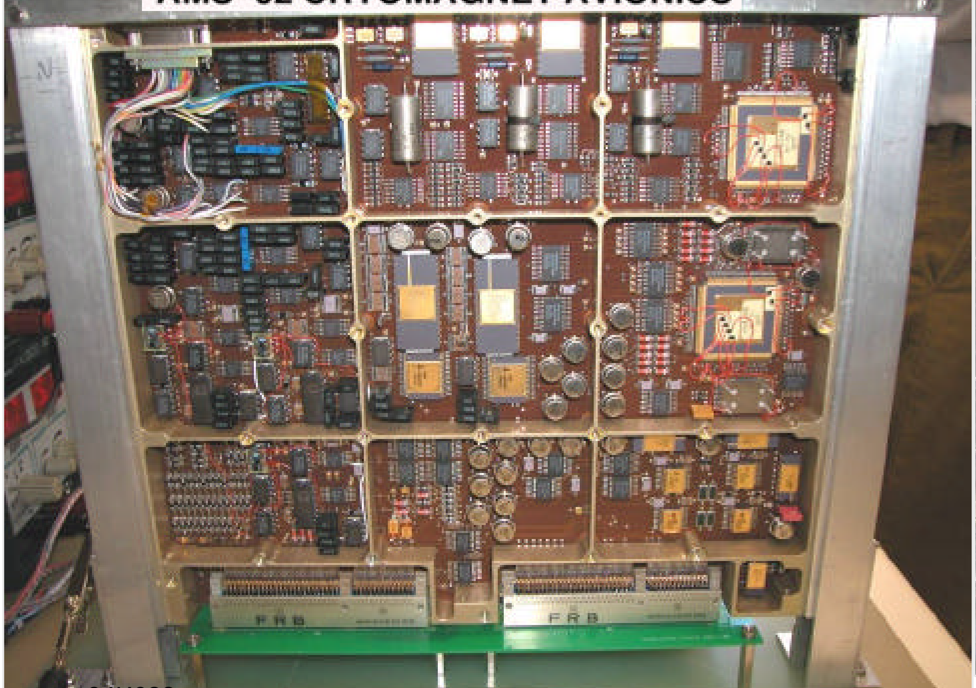


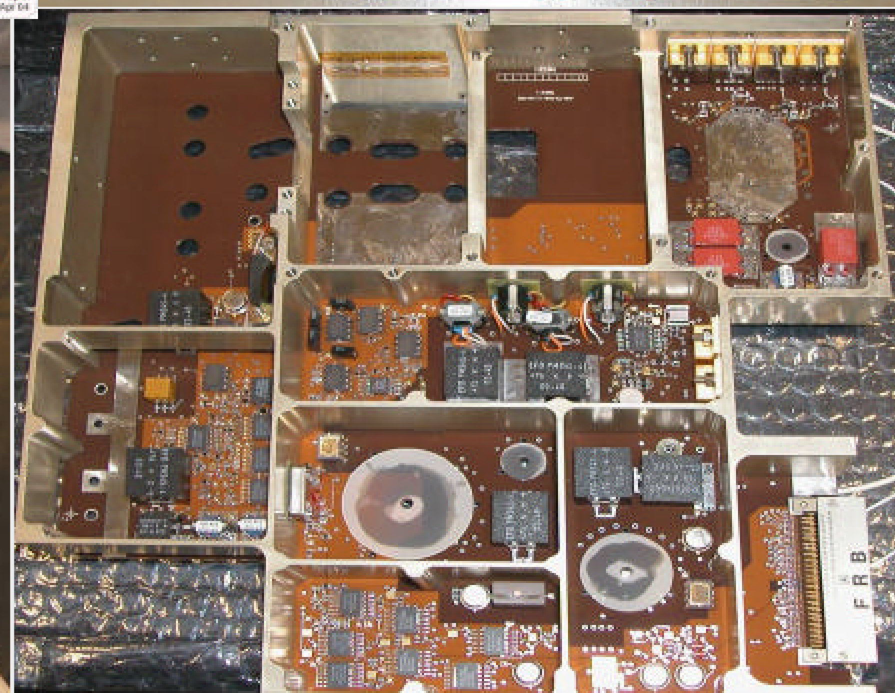
Flight Hardware



AMS–02 CRYOMAGNET AVIONICS

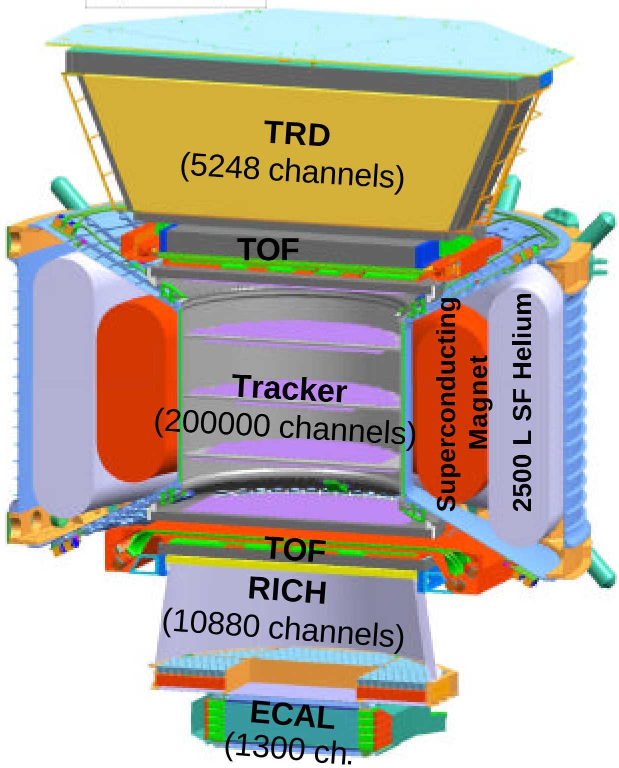


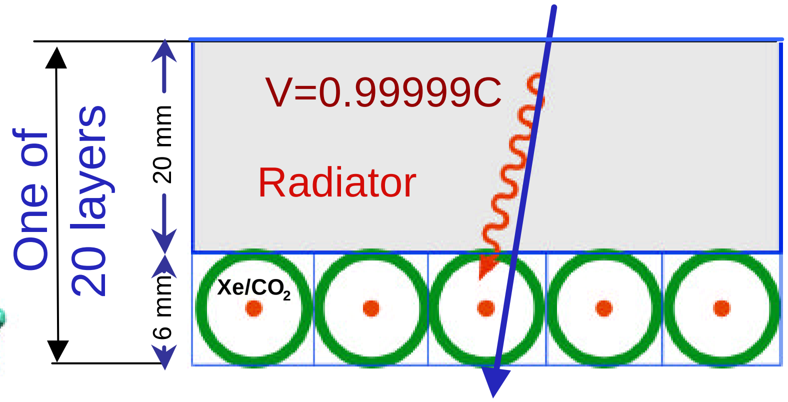


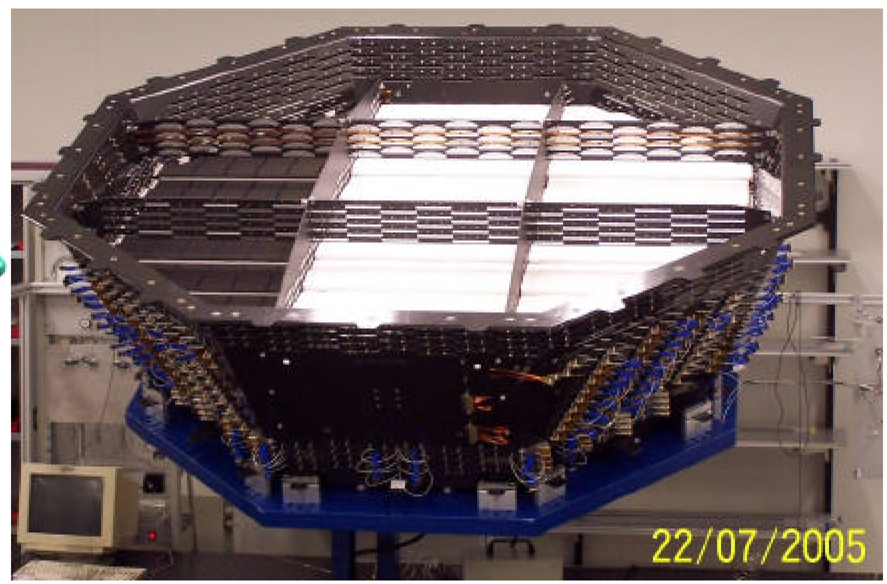


Transition Radiation Detector (TRD)

Distinguishes electrons and positrons from all other particles





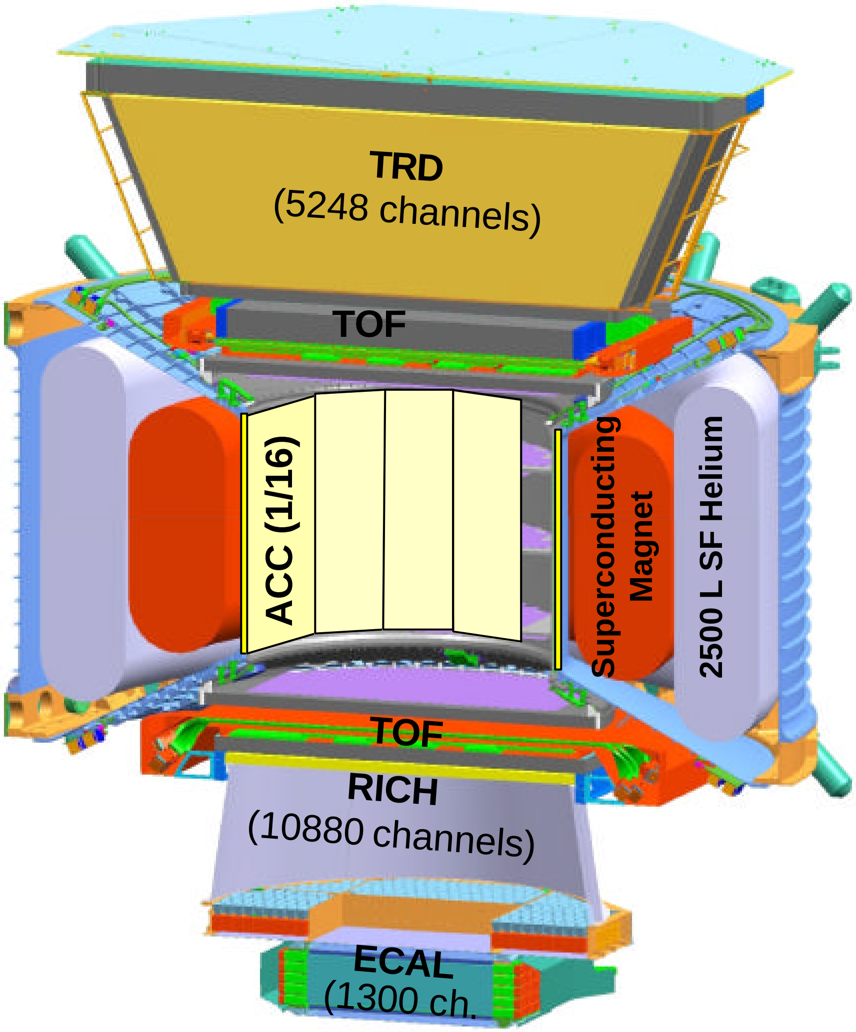


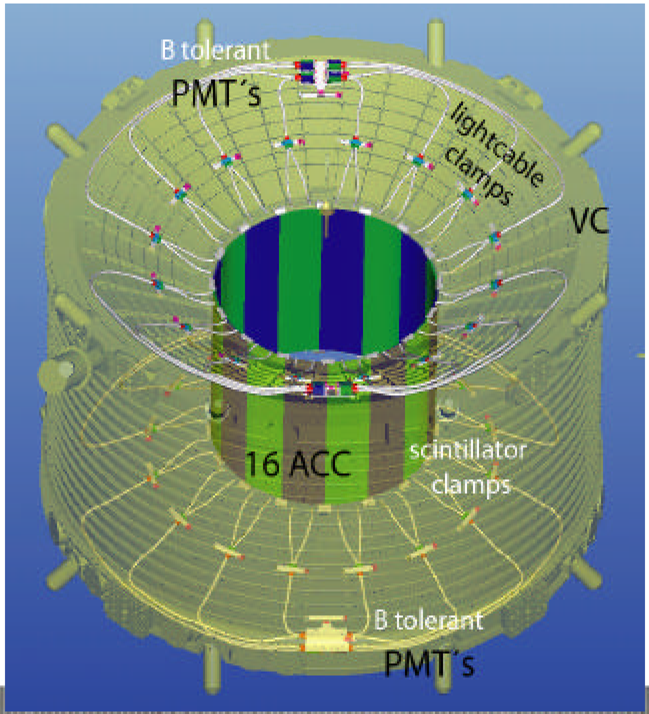
5248 tubes
L(max) = 1.8m

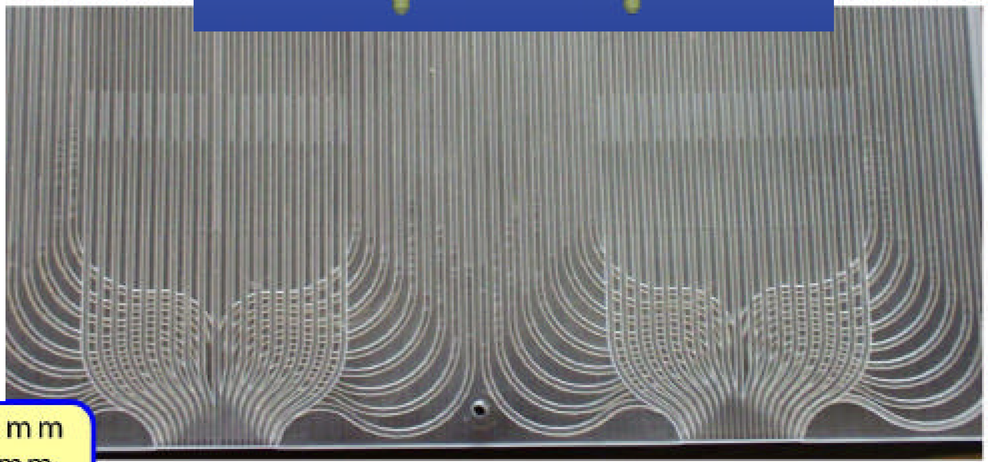
All Flight Hardware Modules produced. Assembly complete in 2005.

Anti-Coincidence Counters

Coordinator: W.Wallraff, RWTH-Aachen





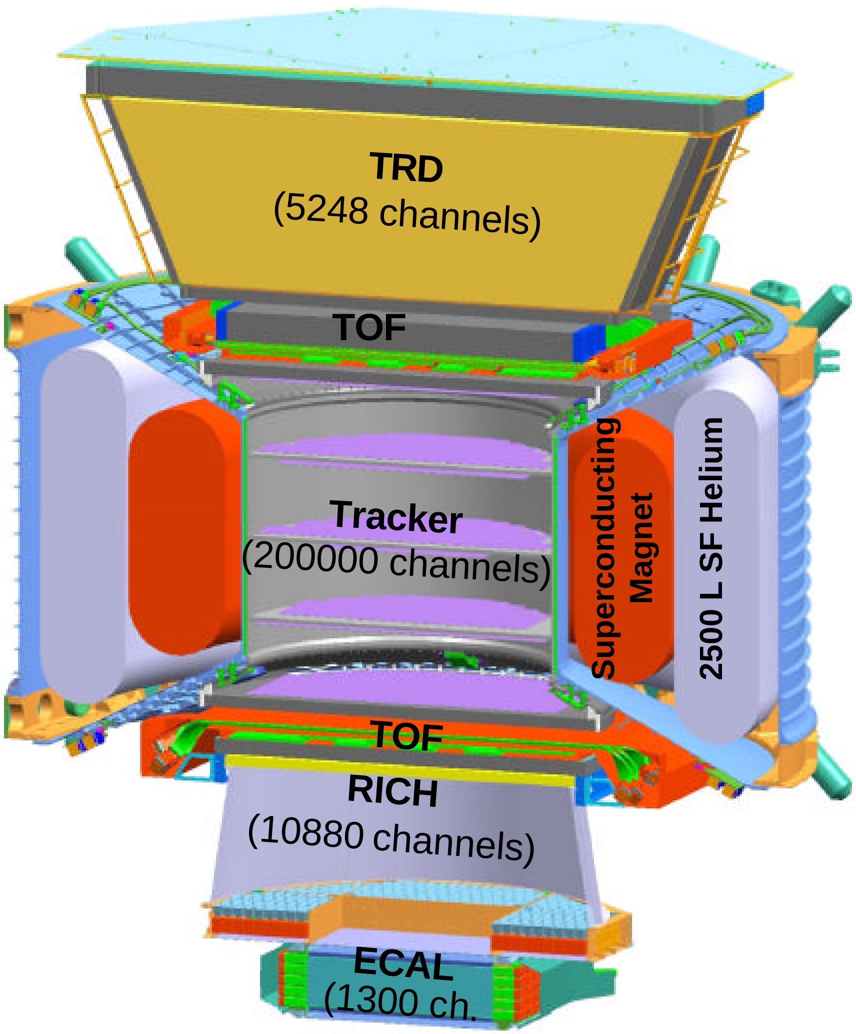


Thickness=8 mm
Length=830 mm
Width=220 mm
Fiber pitch=2.9 mm
Fiber diam.=1.0mm
2× 37 fibers

Precision milling of wave length fiber grooves

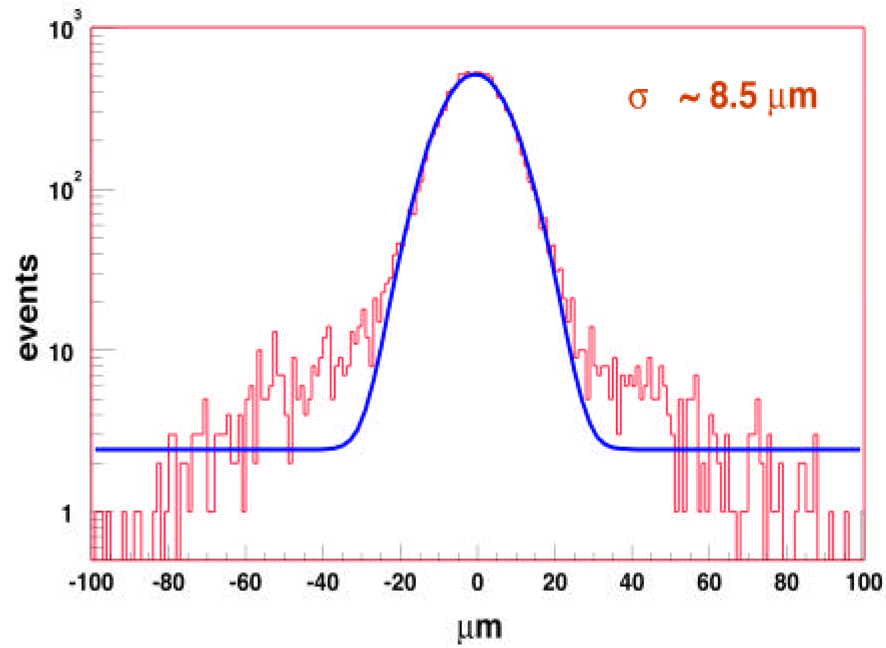
to PMT   to PMT

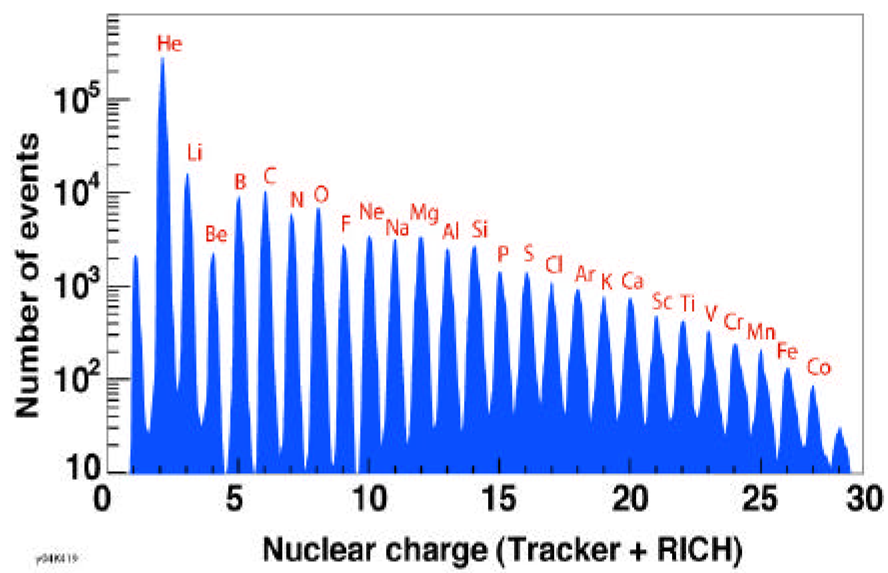
Silicon Tracker



8 planes 6.6 m^2:
Largest Silicon Detector
with 10 mm accuracy

Production completed. Test results from accelerator.



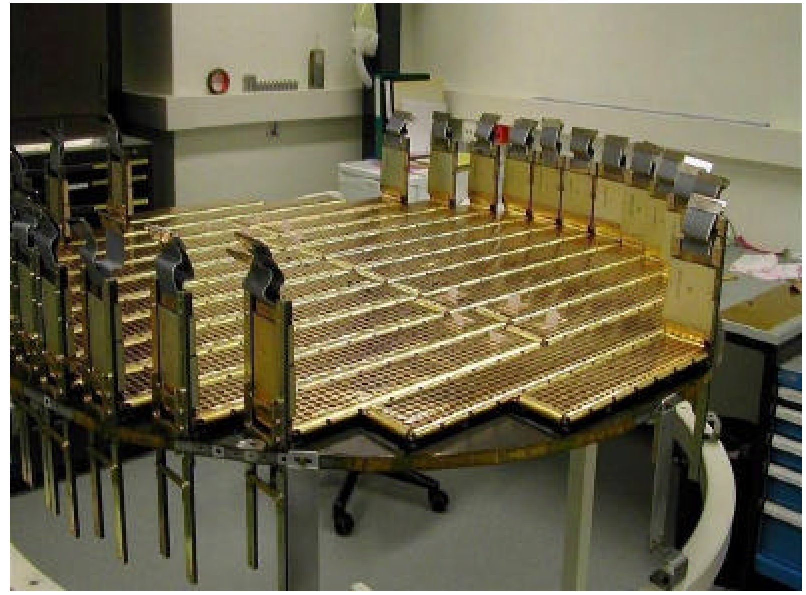


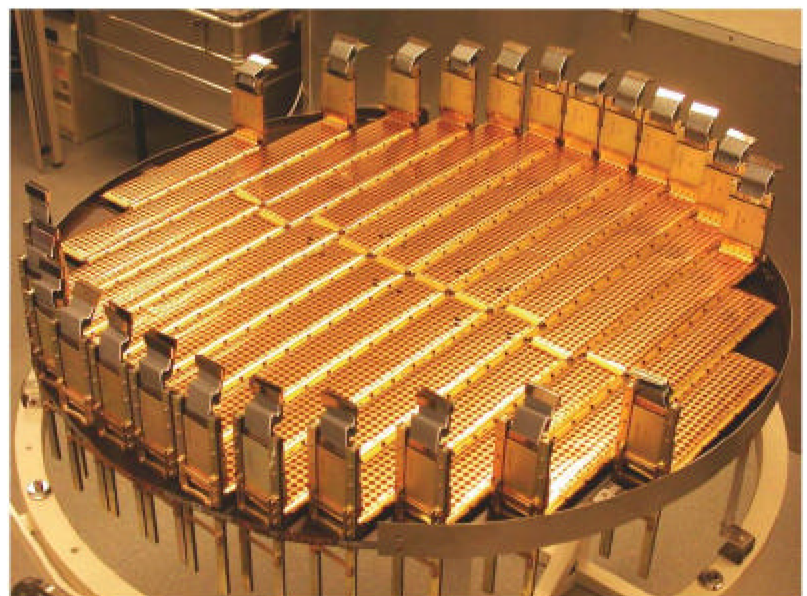
Silicon Tracker Flight Hardware

All 8 planes (200,000 channels) have been produced

Sensor positioning (Geneva)

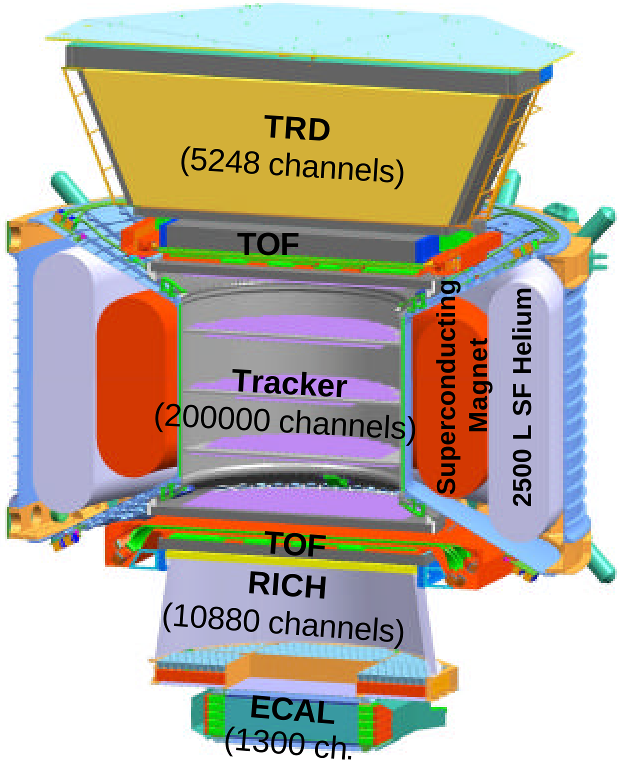
Ultrasonic wire bonding (ETH-Z)



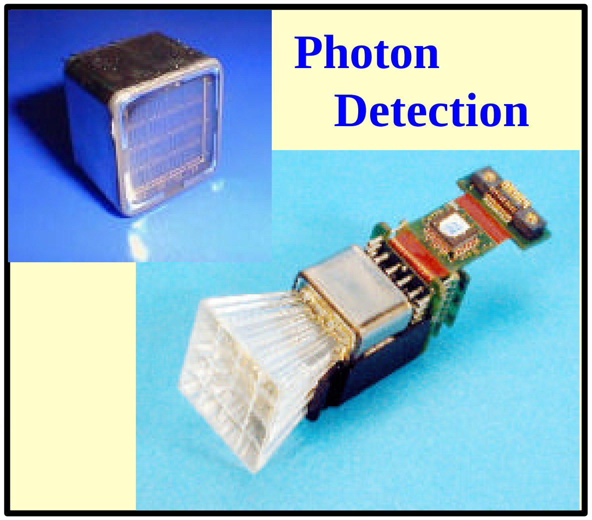


Ring Imaging Cerenkov Counter (RICH)

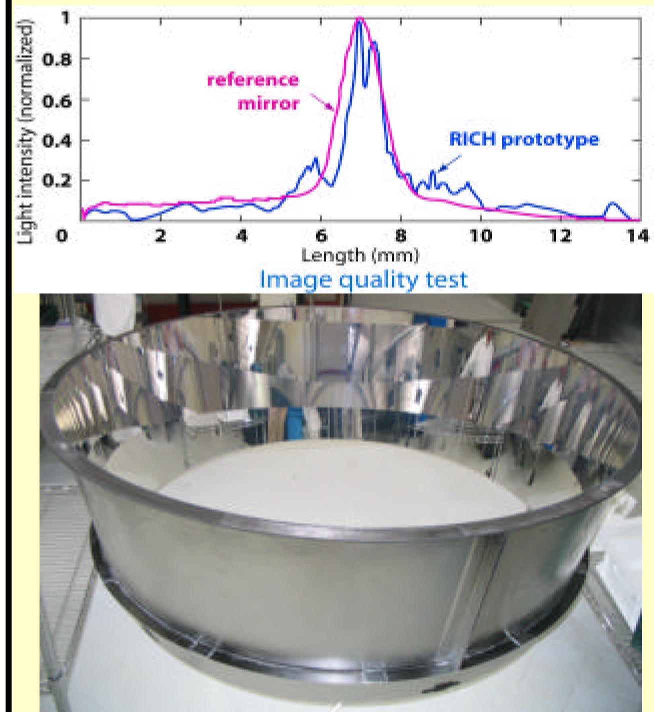
Coordinator: G.Laurenti, INFN-Bologna

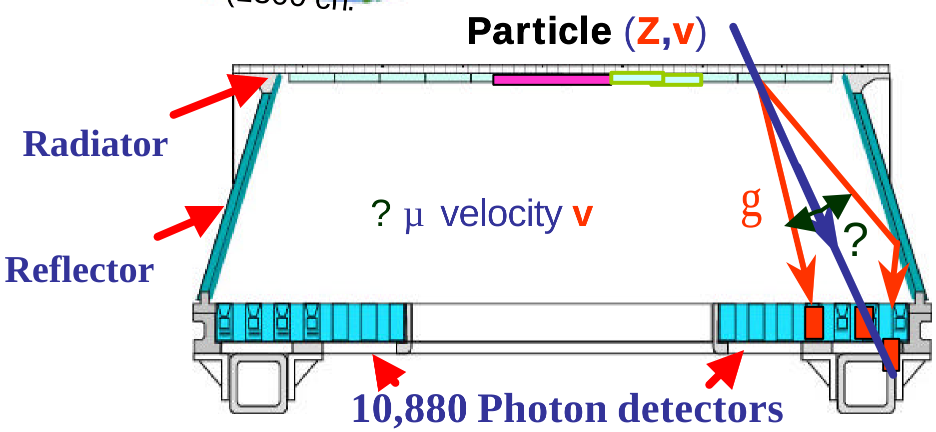


Photon Detection

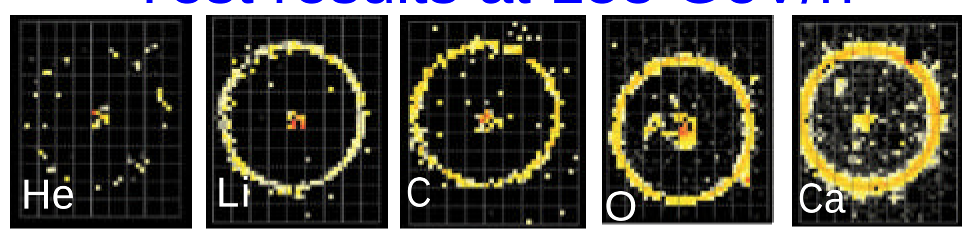


Reflector



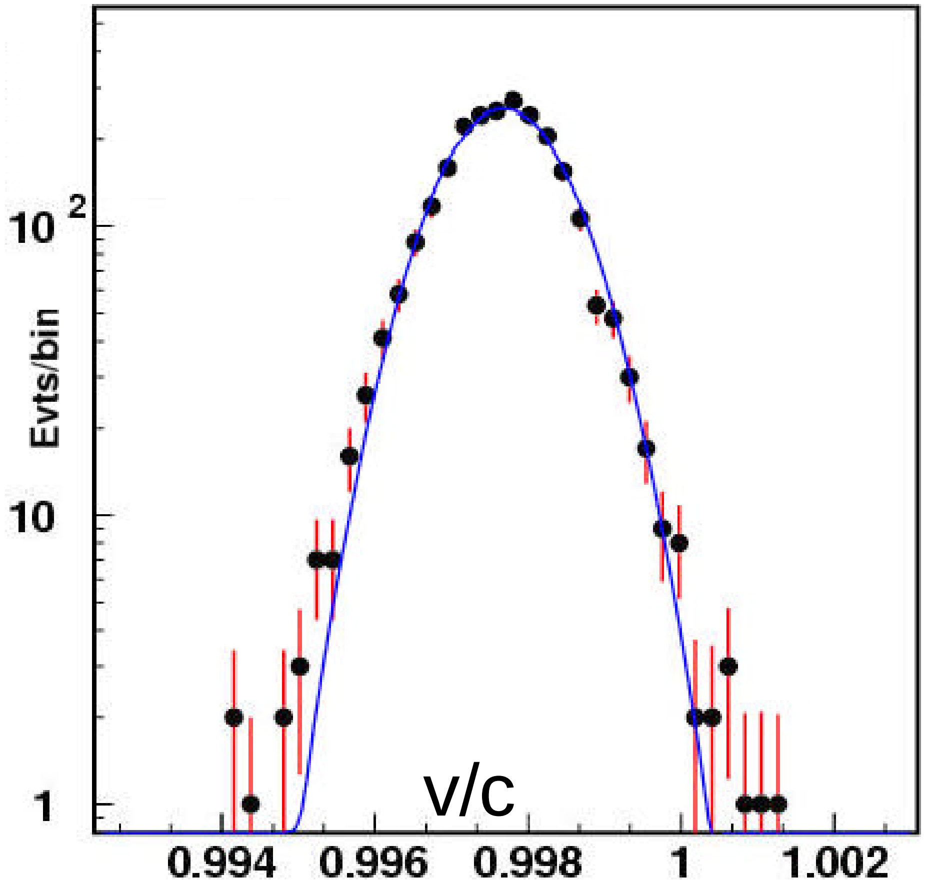


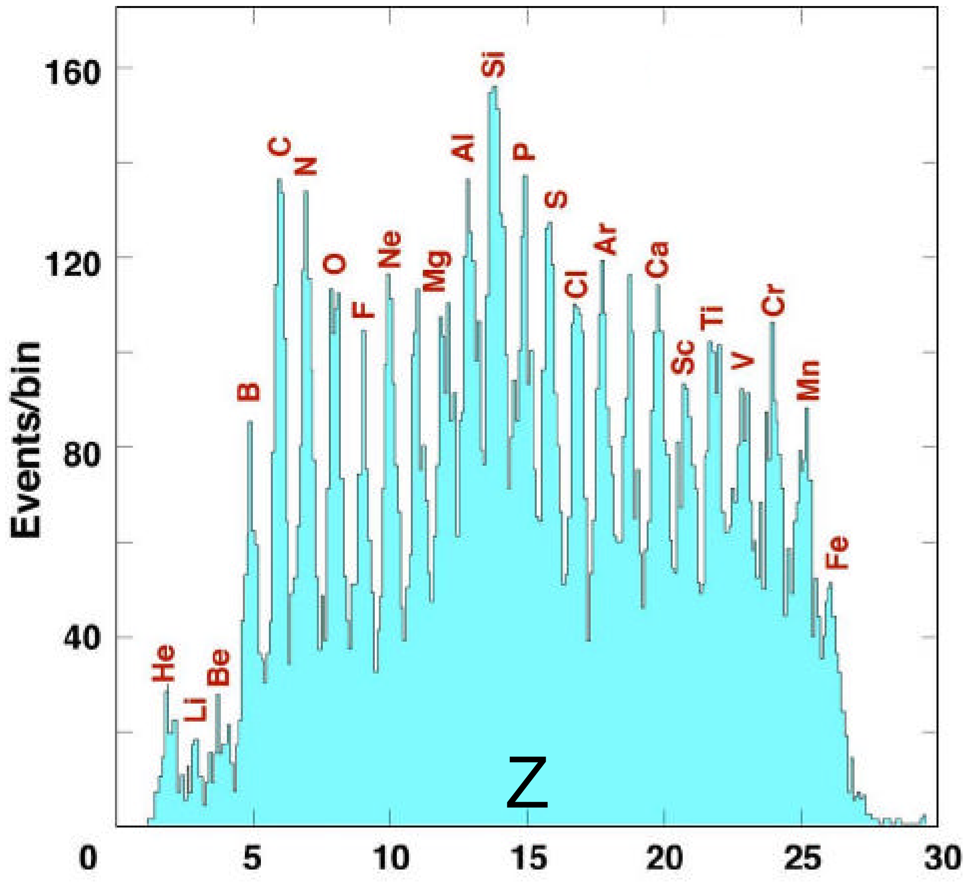
Test results at 158 GeV/n



Light (g) intensity µ Z^2

RICH Test Beam Results E = 158 GeV/n



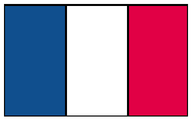


Velocity resolution = 0.1%

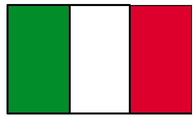
Charge measured up to Z = 26 (Fe)

AMS-02 Calorimeter

Measuring energy of electrons and g rays

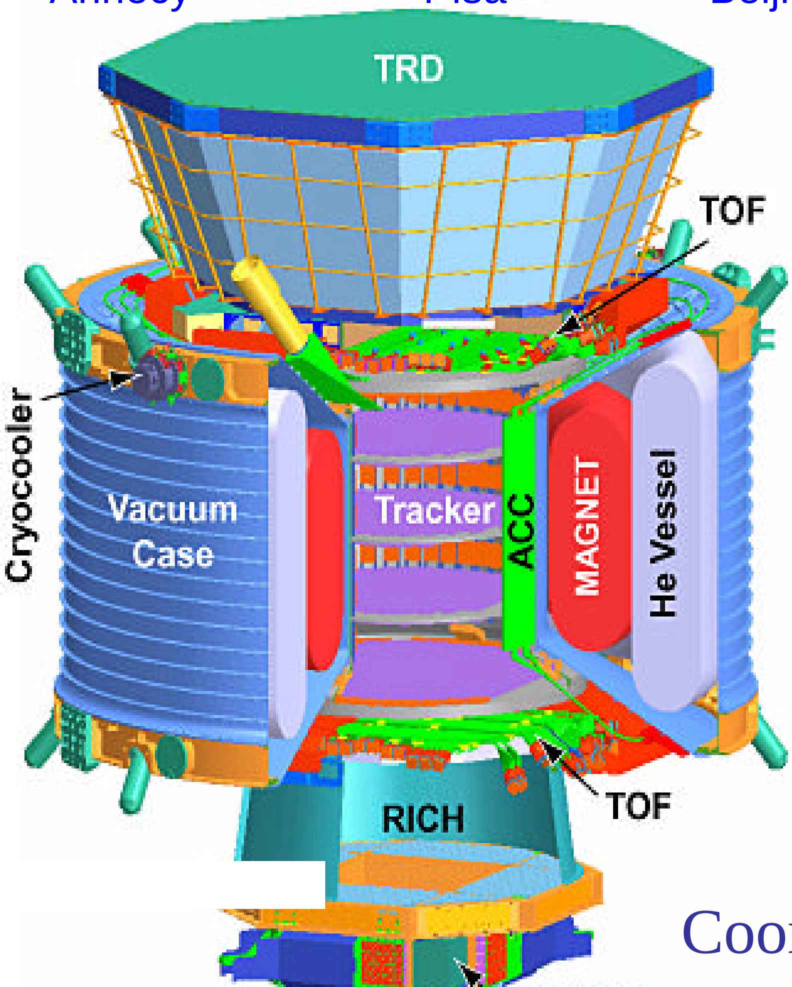


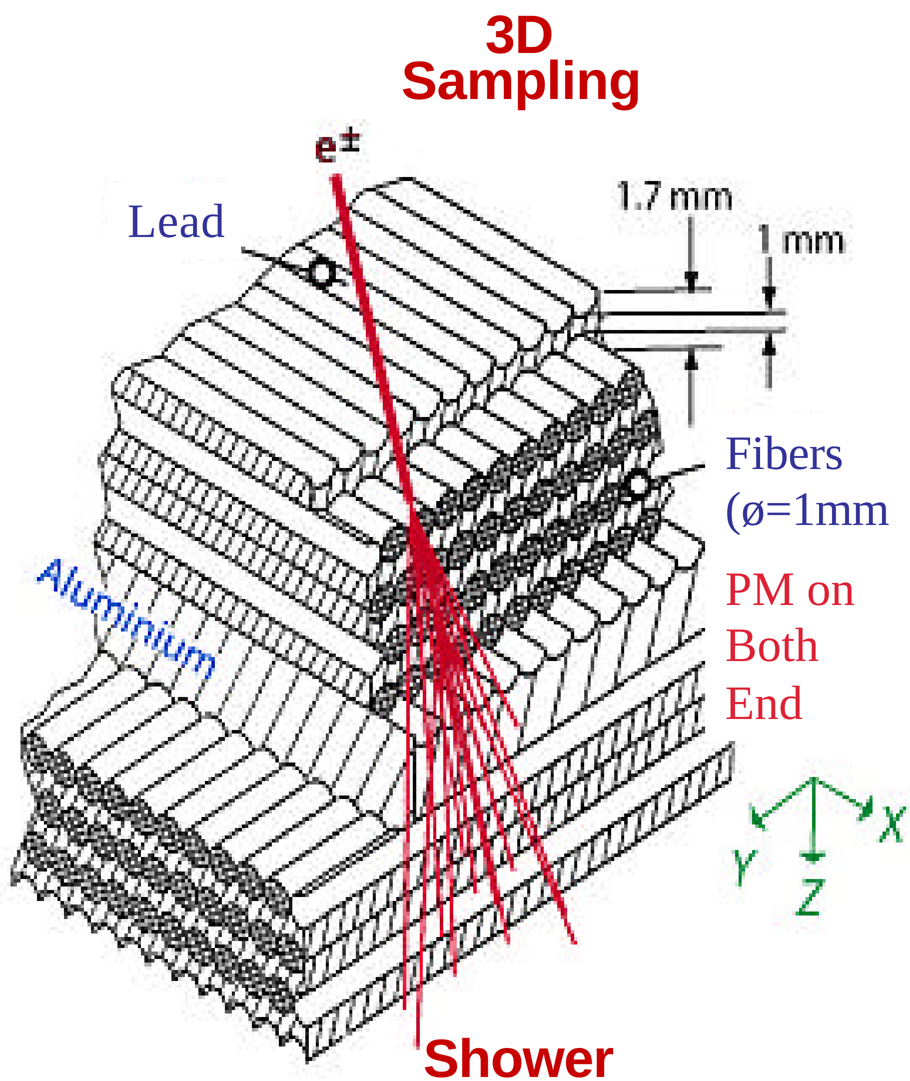
J.P. Vialle
LAPP
Annecy



F. Cervelli
INFN
Pisa

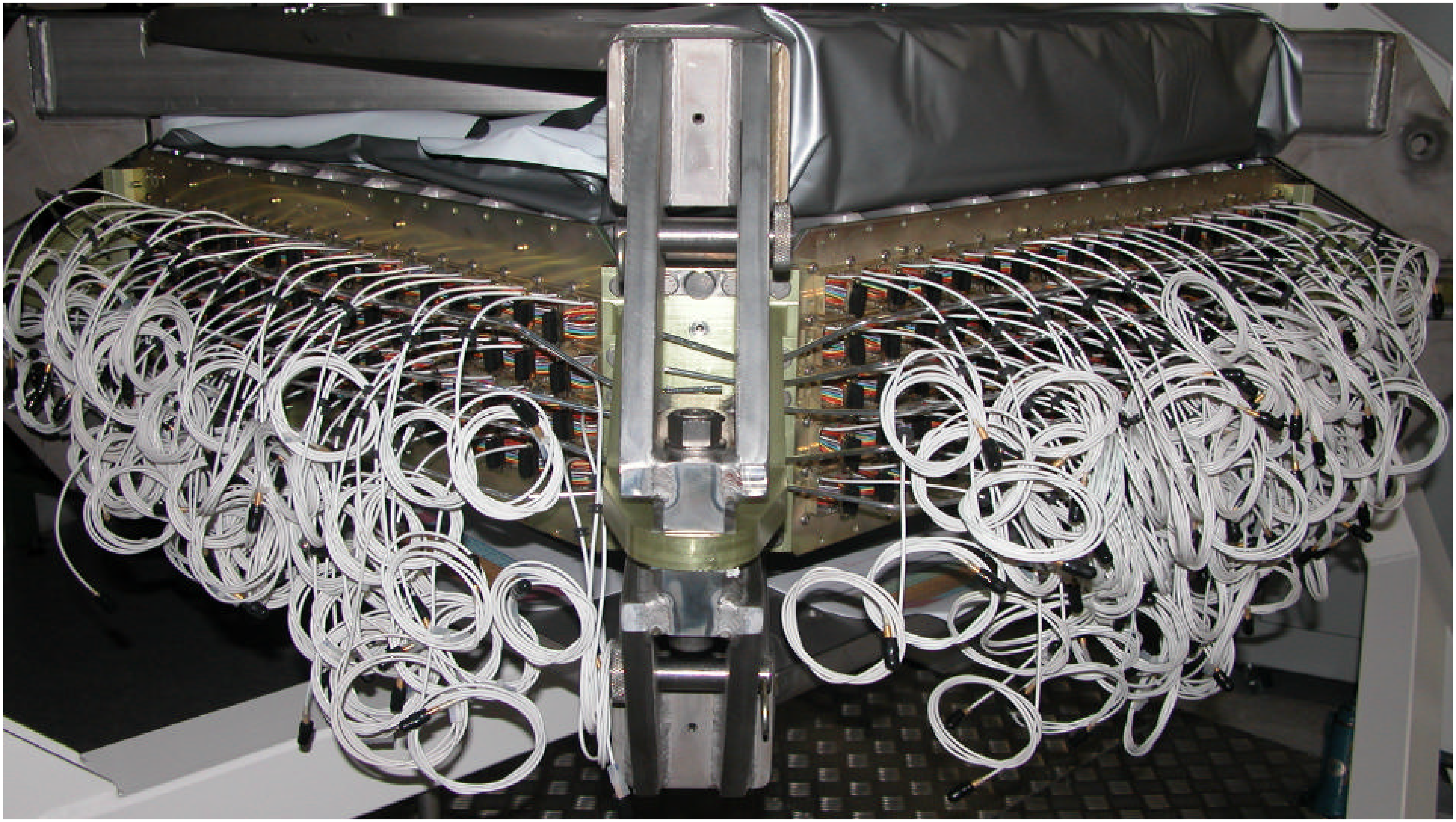
H.S. Chen
IHEP
Beijing



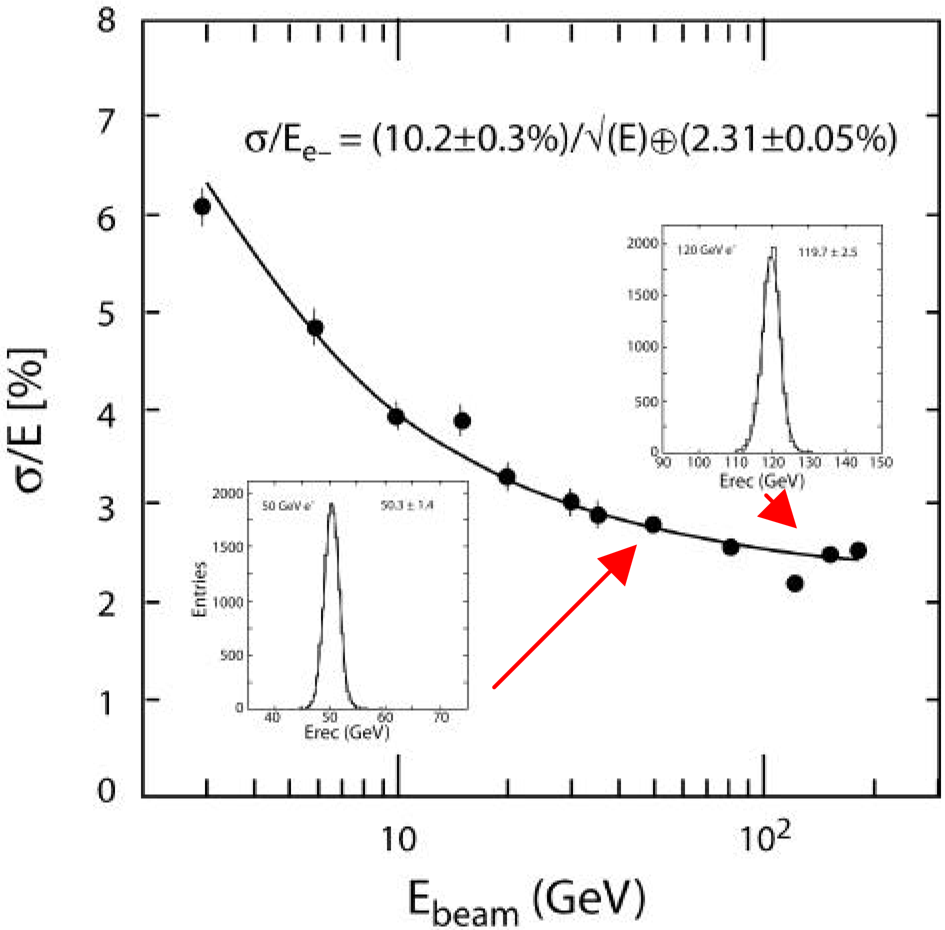


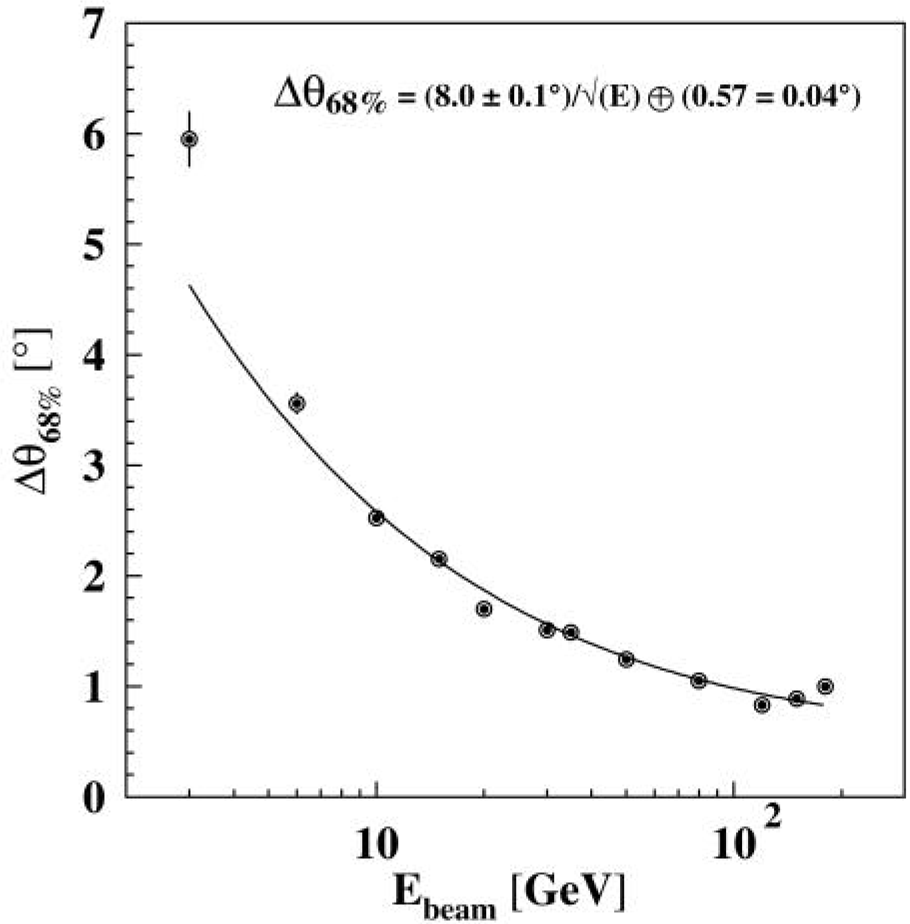
Coordinator: F. Cervelli

ECAL Flight Module

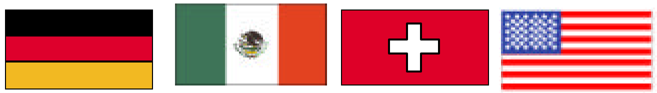


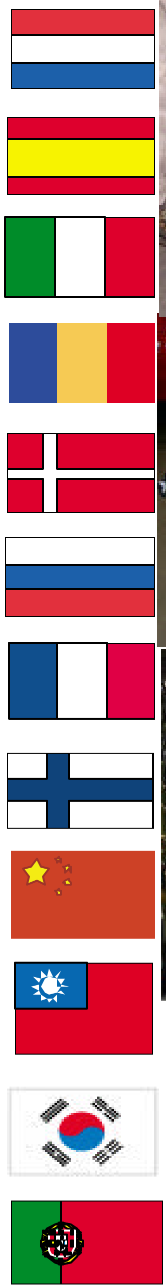
Energy and Angular Resolution of ECAL from test beam measurements

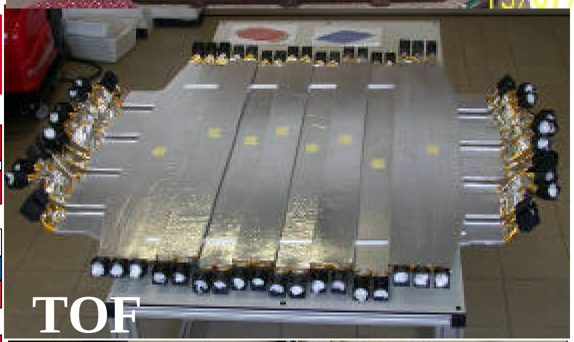


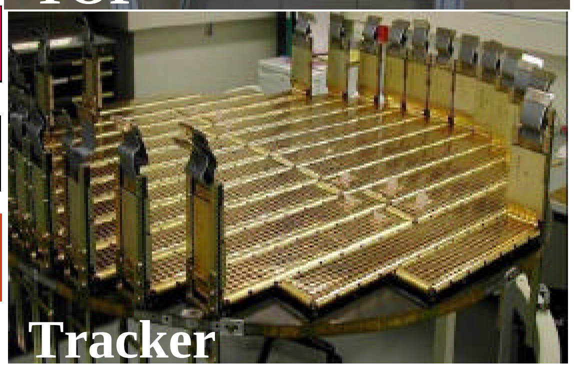


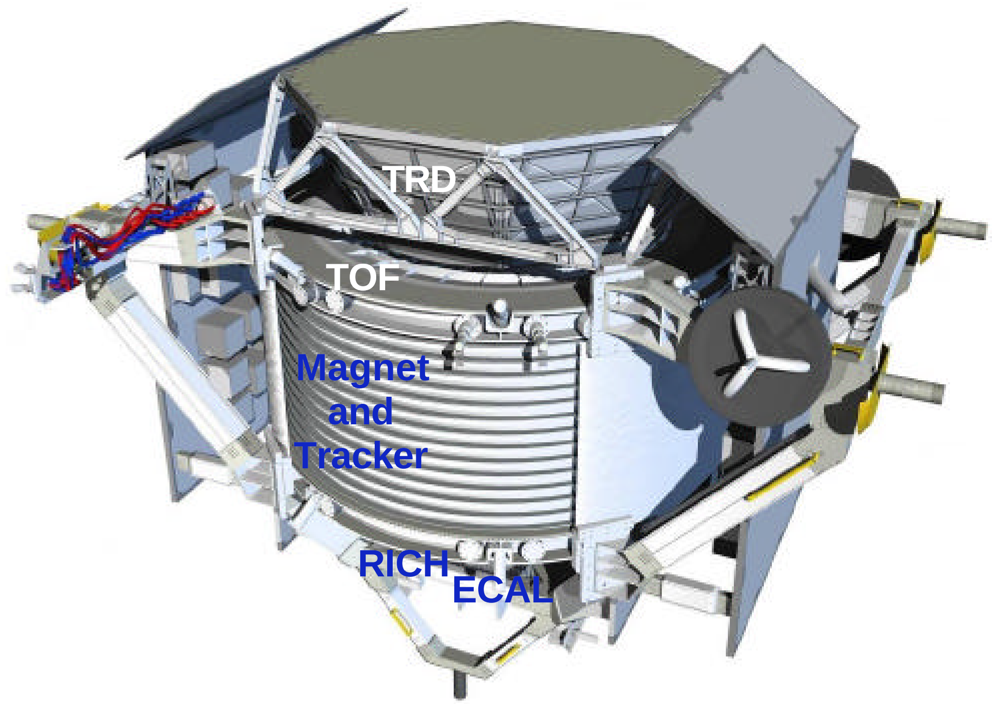
2005 - 2006
Assembly of all Flight Hardware onto the Superconducting Magnet

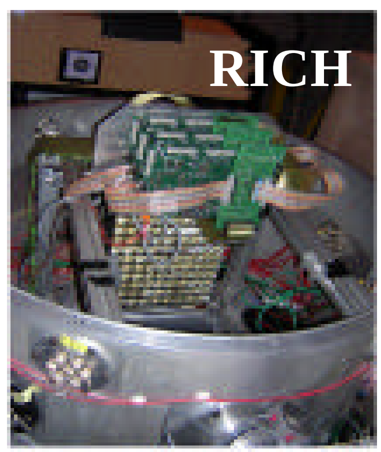






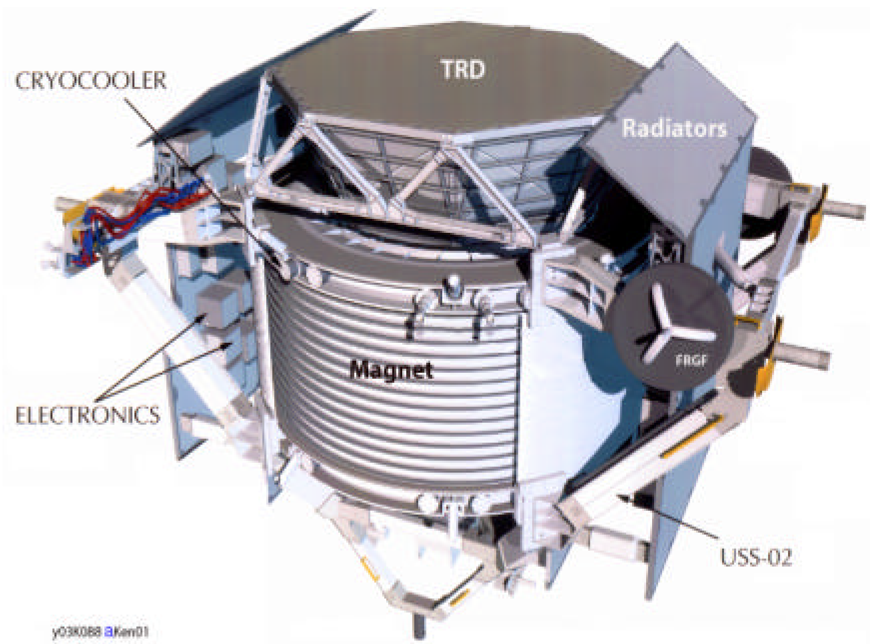






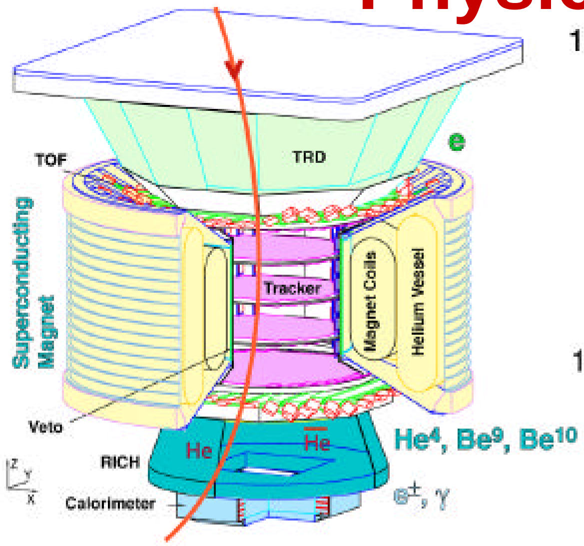
The 650 fast microprocessors

Thermal system



- **Thermal-Vacuum Test at ESA** *(Noordwijk)*

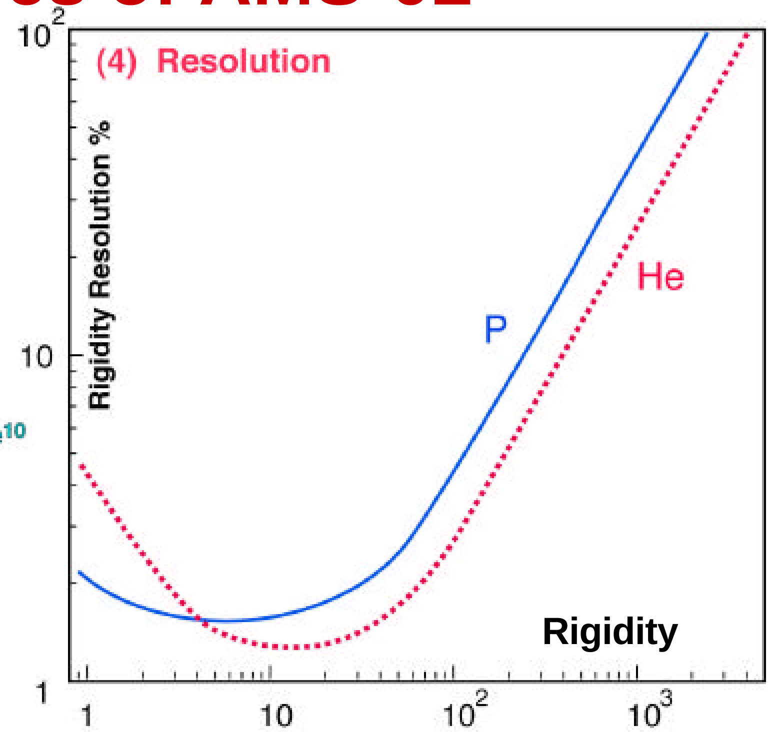
Physics of AMS-02

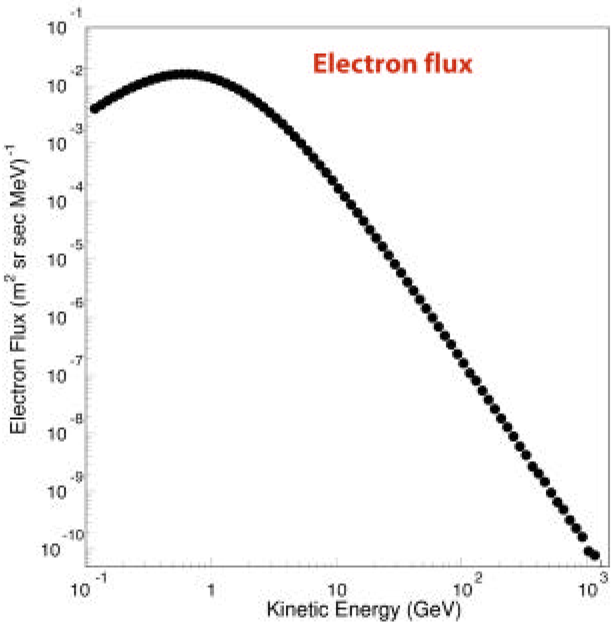


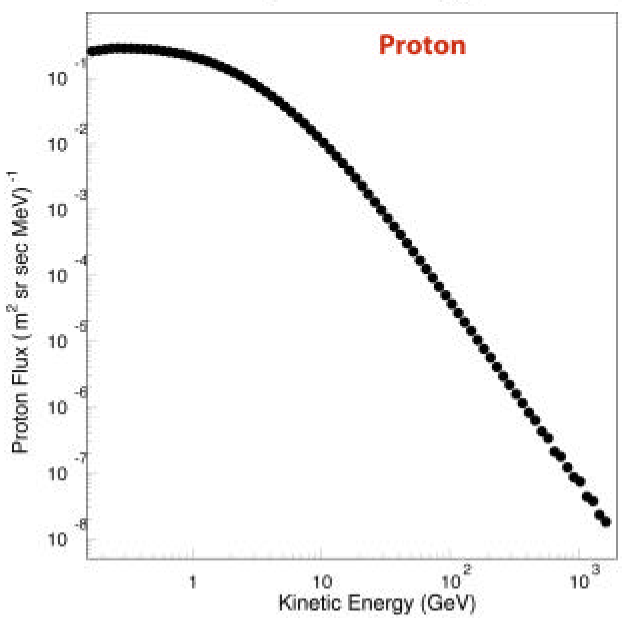
(1) 0.5 m^2 sr

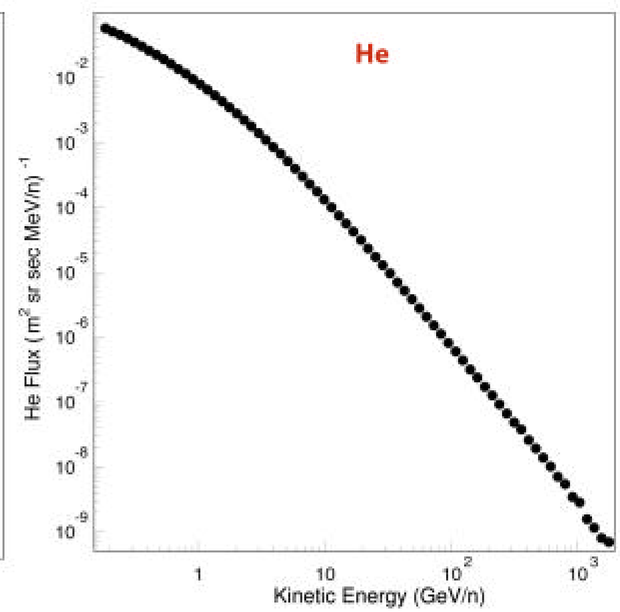
(2) h/e$^+$ > 10^6

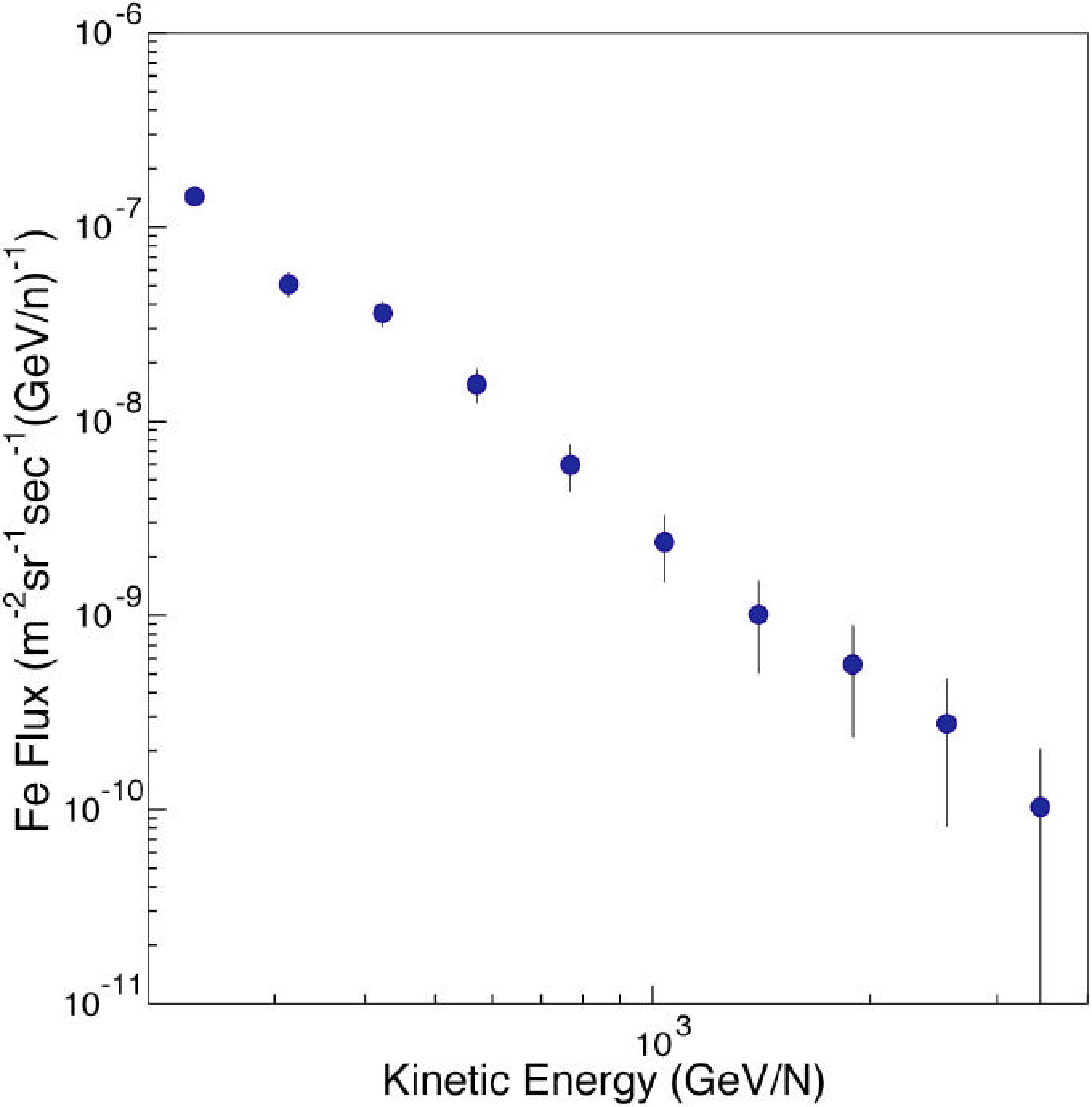
(3) $\Delta\beta/\beta$ = 0.1%









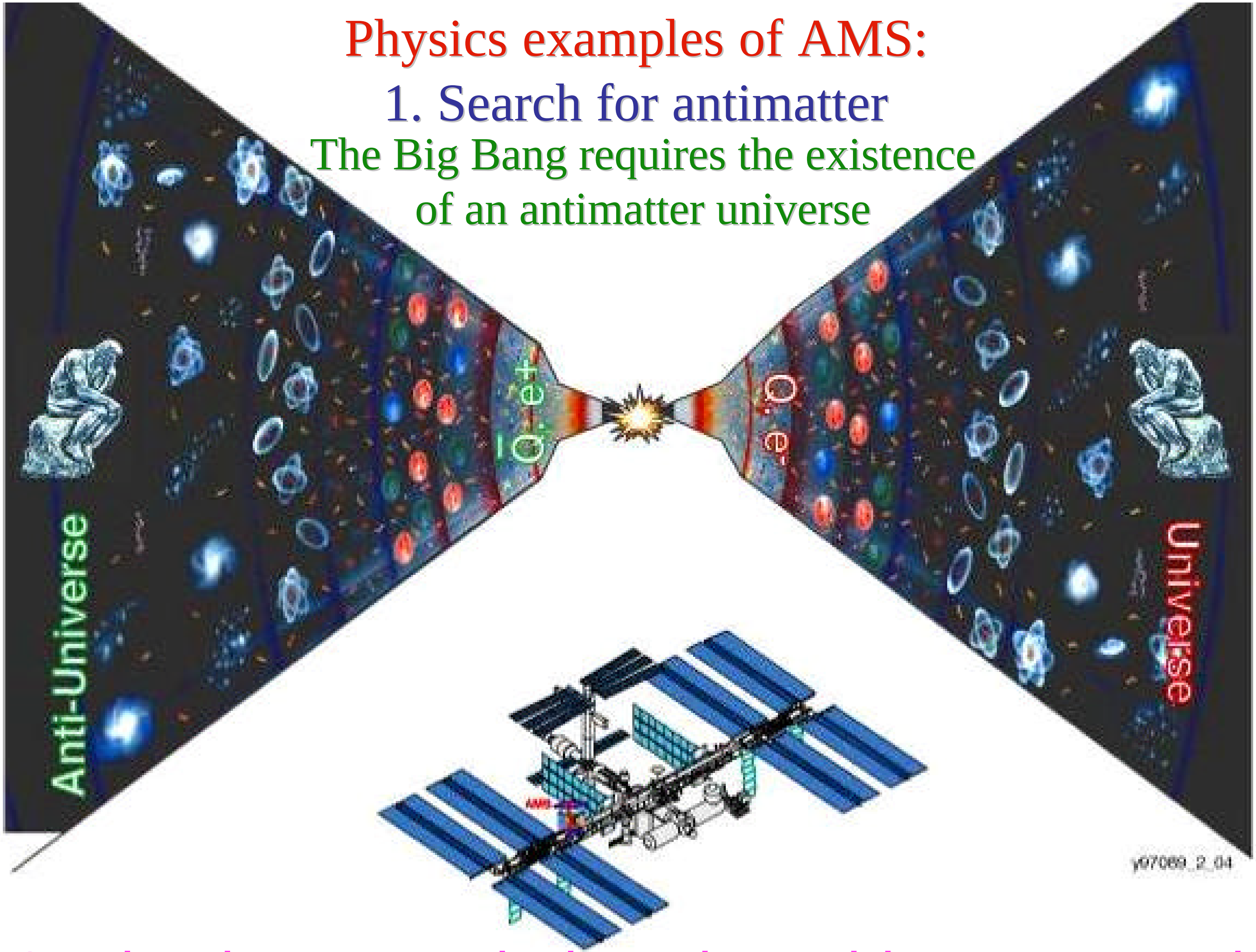


Fe Flux (m^{-2}sr^{-1}sec^{-1}(GeV/n)$^{-1}$)
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-11}
10^{3}
Kinetic Energy (GeV/N)

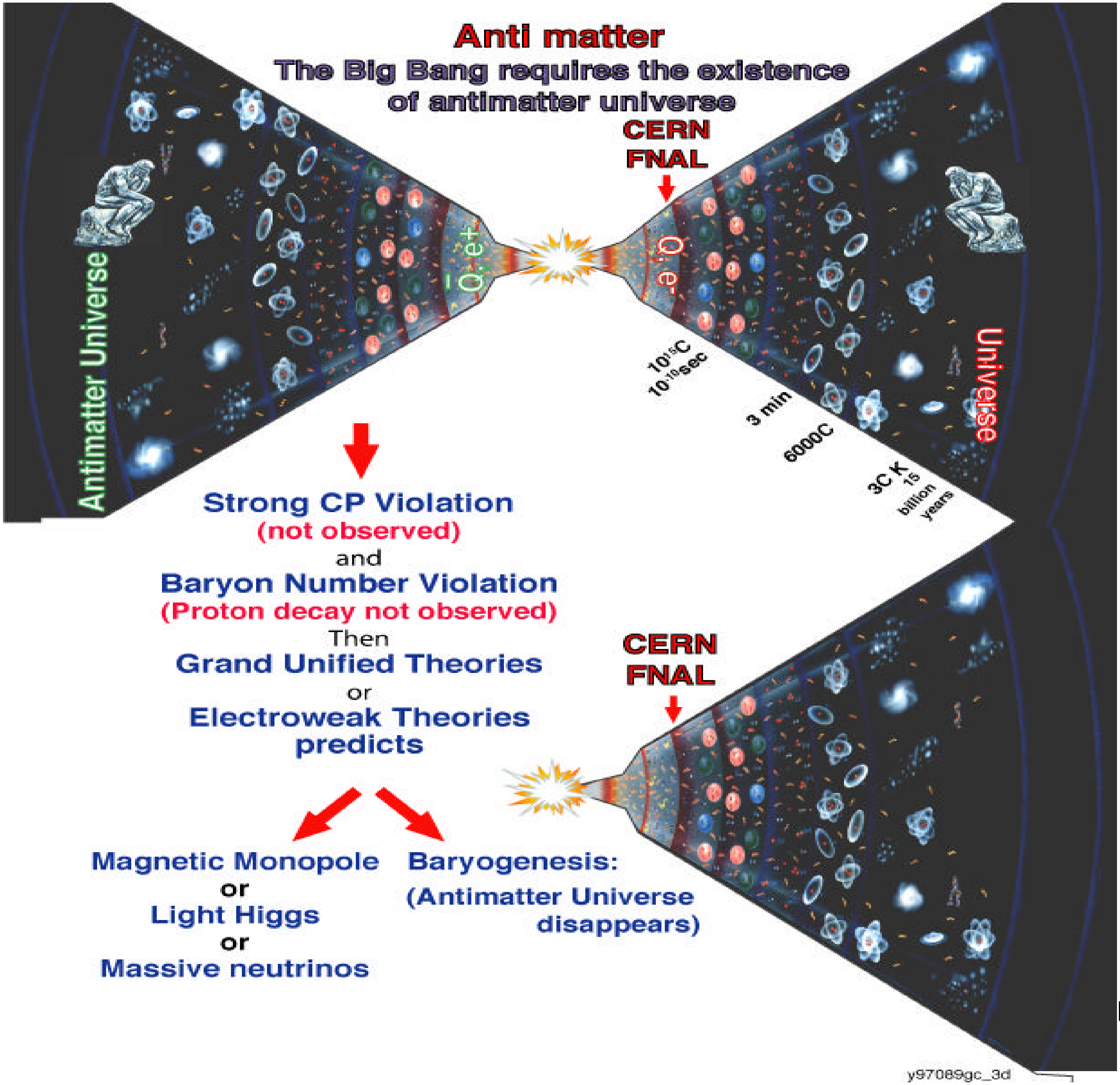
Physics examples of AMS:

1. Search for antimatter

The Big Bang requires the existence of an antimatter universe



Cosmic antimatter cannot be detected on earth because matter and antimatter will annihilate each other in the atmosphere


Anti matter
The Big Bang requires the existence
of antimatter universe
CERN
FNAL
Antimatter Universe
Q̄, e+
Q, e-
Universe
10^{15}C
10^{-10}sec
3 min
6000C
3C K
15
billion
years
Strong CP Violation
(not observed)
and
Baryon Number Violation
(Proton decay not observed)
Then
Grand Unified Theories
or
Electroweak Theories
predicts
Magnetic Monopole
or
Light Higgs
or
Massive neutrinos
Baryogenesis:
(Antimatter Universe
disappears)
CERN
FNAL
y97089gc_3d

Baryon Number Violation

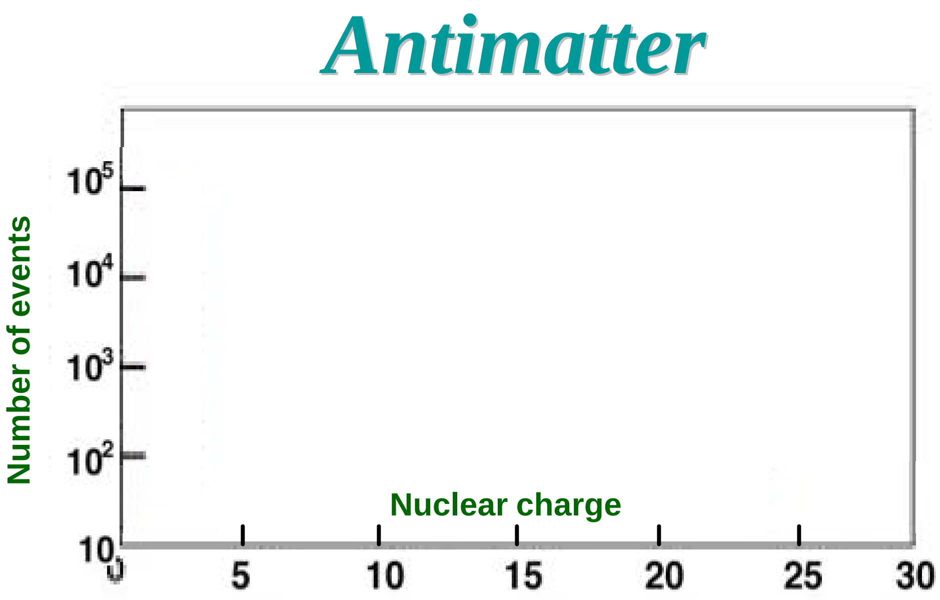
No data from accelerator or proton decay has yet provided evidence for baryon number violation.

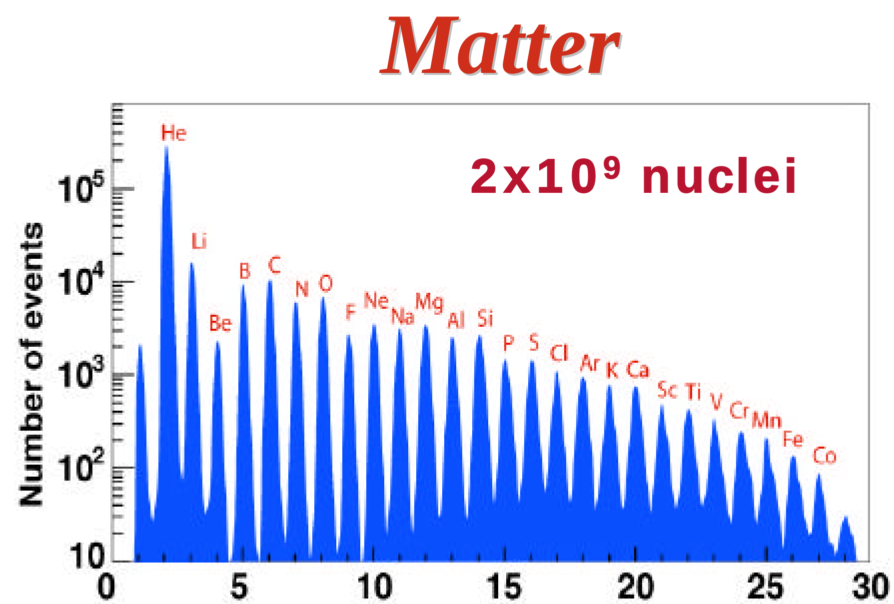
$\tau > 1.6 \times 10^{33}$ Y ($e^+ \pi^o$ mode)

CP-violation

Has been observed in K_L and B only. Both results are in agreement with the Standard Model.

Need new type of CP-violation for Baryogenesis.





If no antimatter is found => there is no antimatter to the edge (1000 Mpc) of universe.

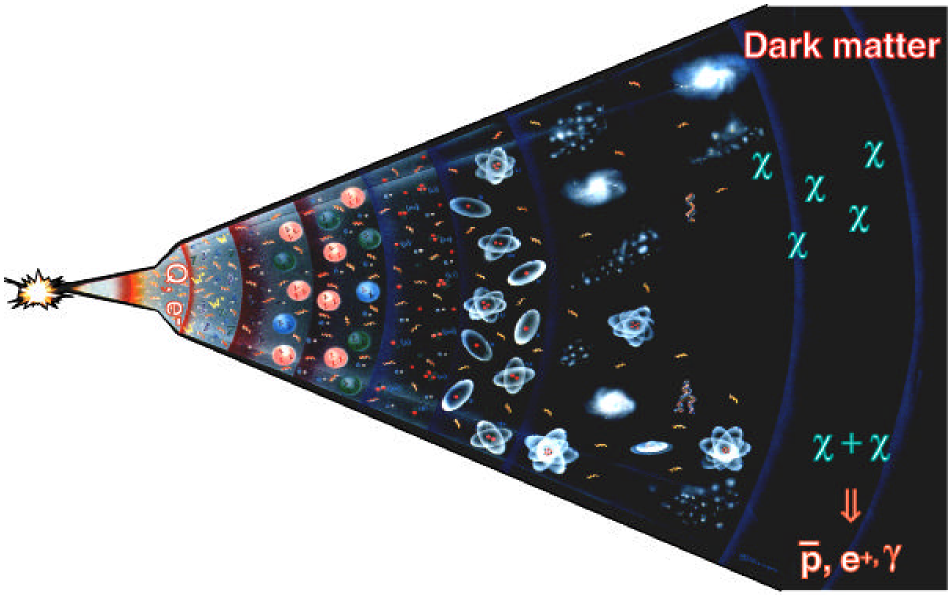
The physics of antimatter in the universe is based on:

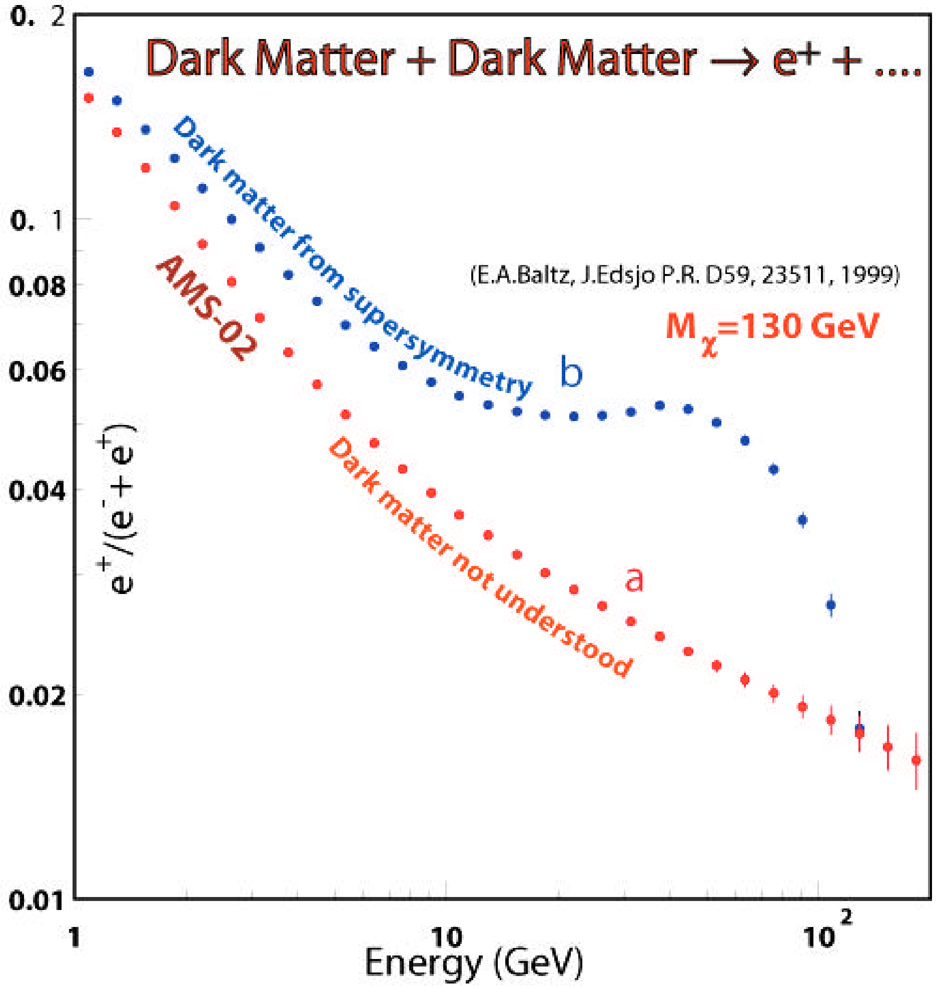
the existence of a strong Time Reversal Violation
the existence of Baryon Number Violation (proton decay)
Grand Unified Theory
Electroweak Theory

This is the main research topic for the current and next generation of accelerators world wide

2. Dark matter

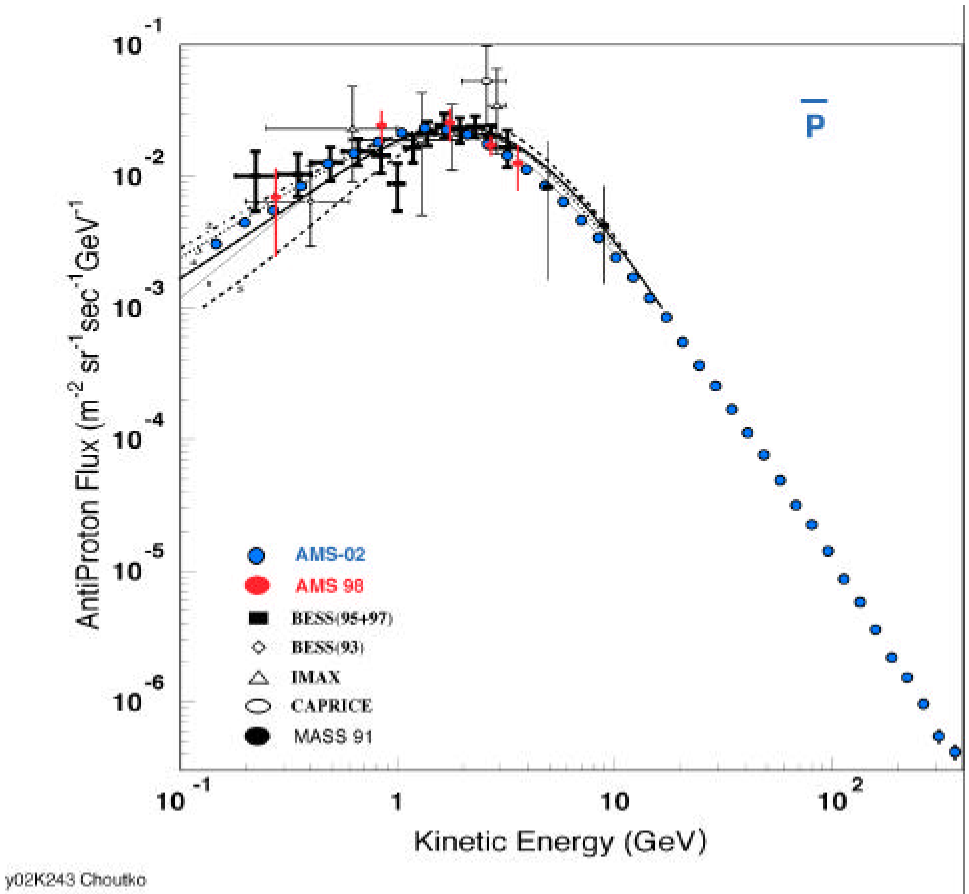
There are many theoretical suggestions that SUSY particles (c) are at least part of the Dark matter.

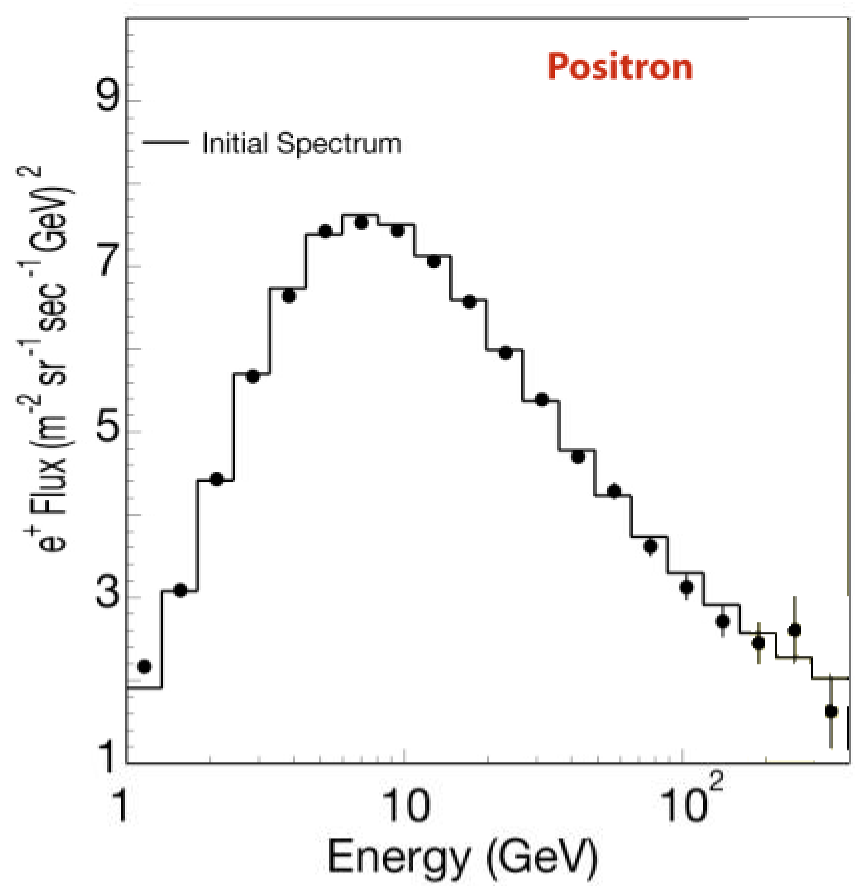




AMS and Dark Matter

The fluxes of antiprotons and positrons may be sensitive to dark matter



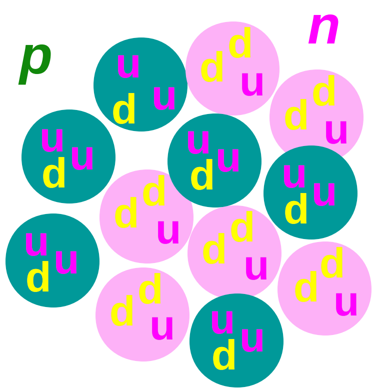


3. Strange Quark Matter – "Strangelets"

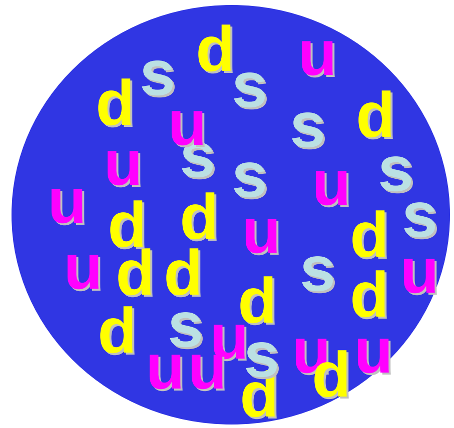
Known quarks: u, d, s, c, b, t

Carbon Nucleus

Z/A ~ 0.5



Strangelet



Z/A < 0.12

Strangelets: a single "super nucleon" with many u, d & s

- **Stable for masses A > ~10, with no upper limit**
- **"Neutron" stars may be composed of one big strangelet**

Searches

with terrestrial samples – low sensitivity.

with lunar samples – limited sensitivity.

in accelerators – cannot be produced at an observable rate.

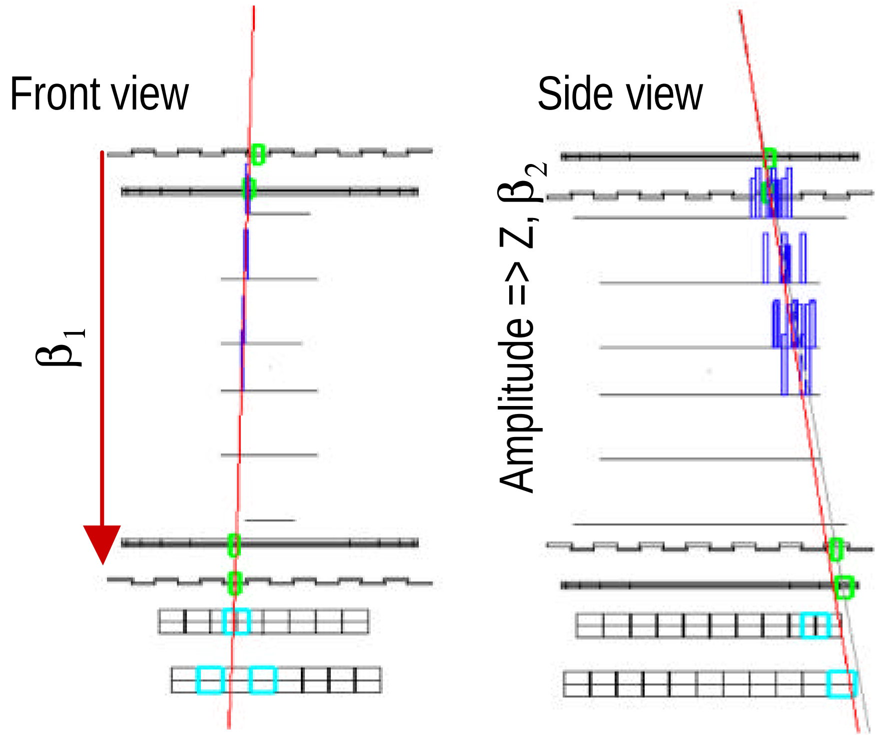
in space – candidates…

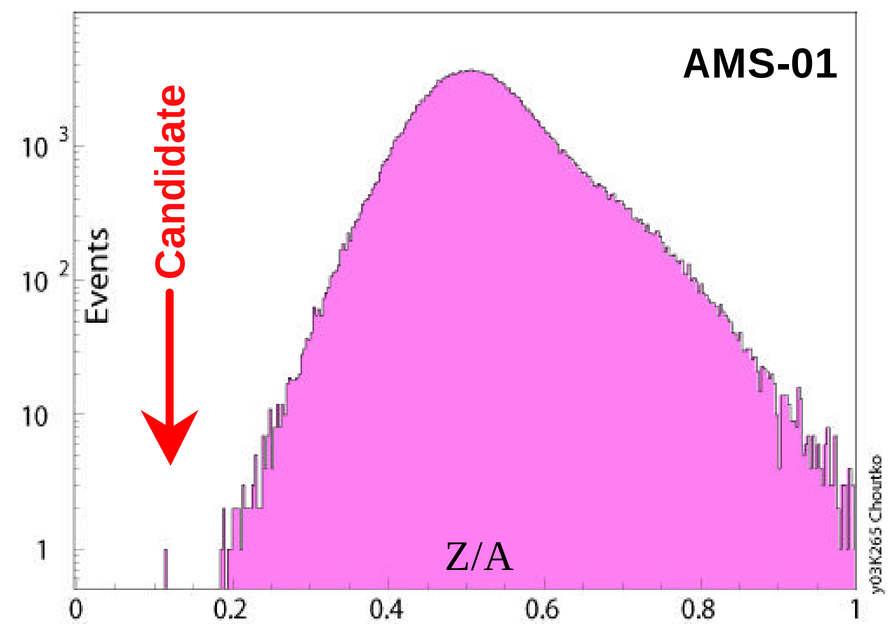
***Jack Sandweiss,* Yale**

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

$b_1 = b_2$ **= 0.462 ± 0.005**

Mass = 16.45±0.15 GeV/c²

Z/A = 0.114 ± 0.01

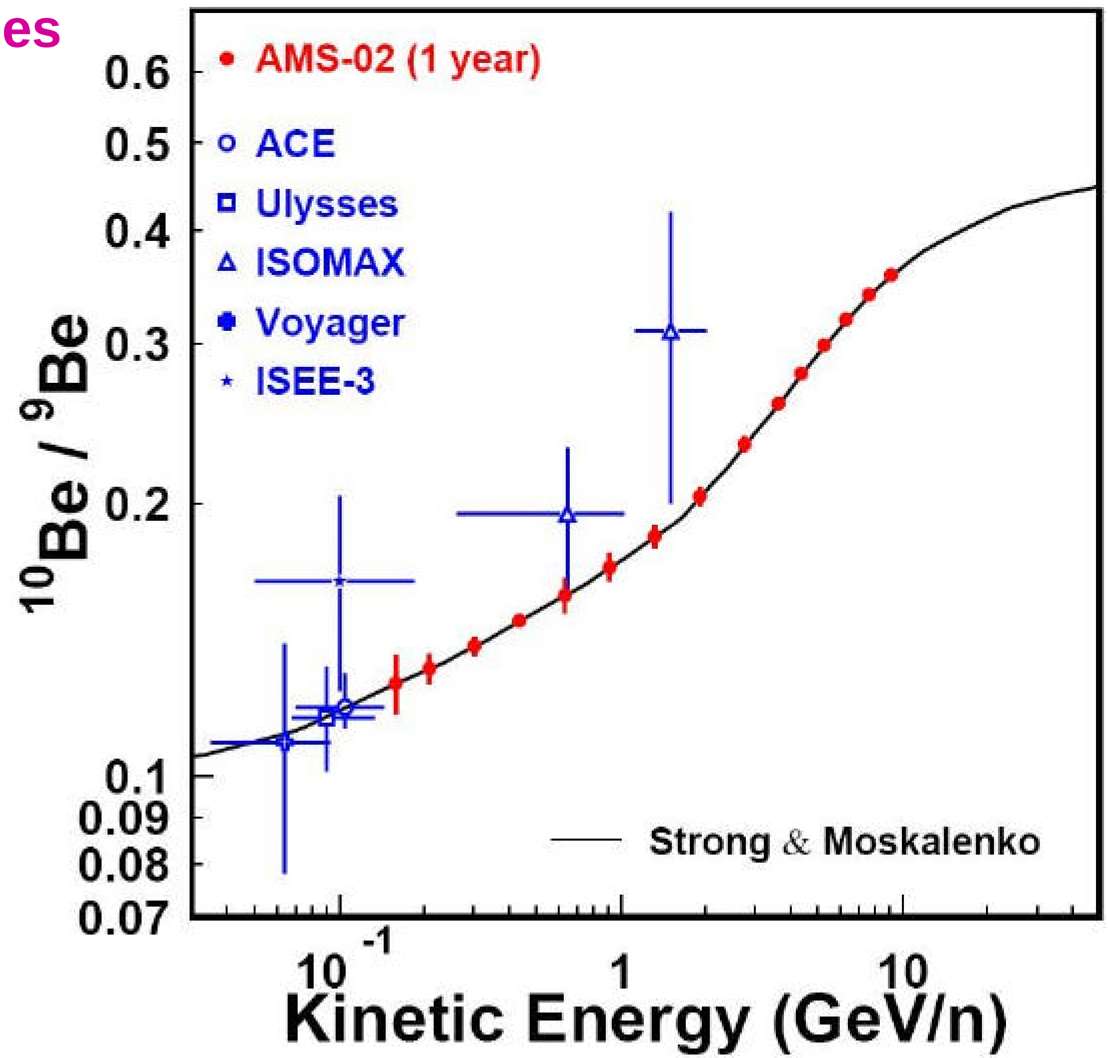
Flux (1.5 < E_K < 10 GeV) = 5×10^{-5} (m^2 sr sec)$^{-1}$

Background probability < 10^{-3}

4. The ratio ^{10}Be / ^{9}Be determines

i) the cosmic ray confinement time in the galaxy, and

ii) the mean density of interstellar material traversed by cosmic rays.

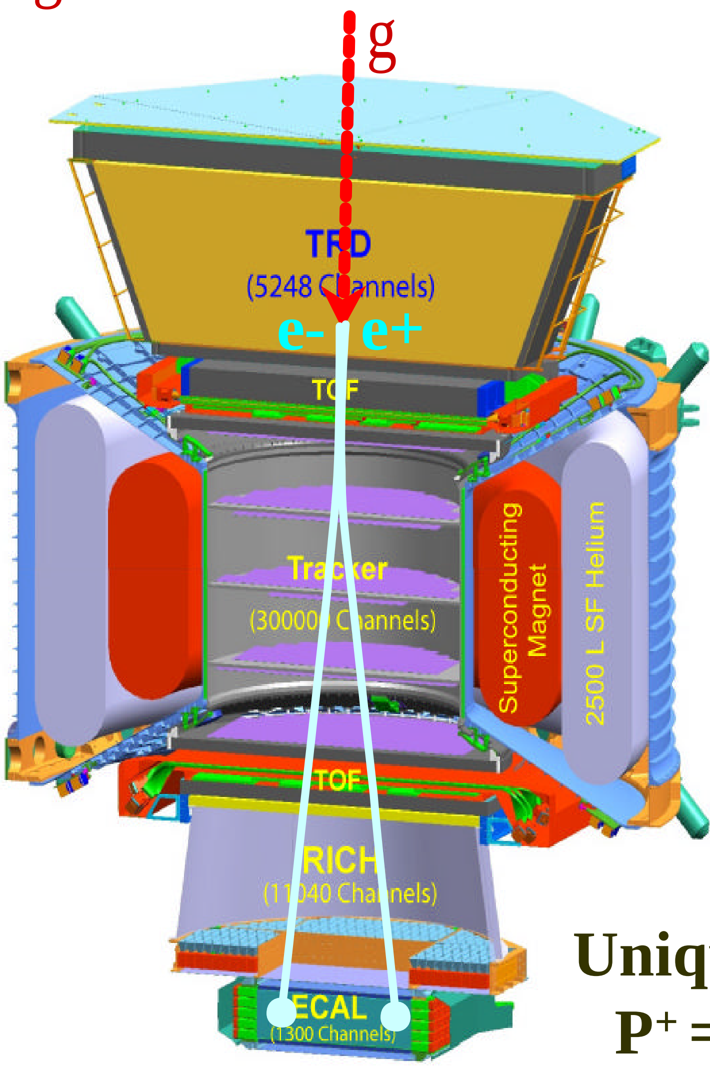


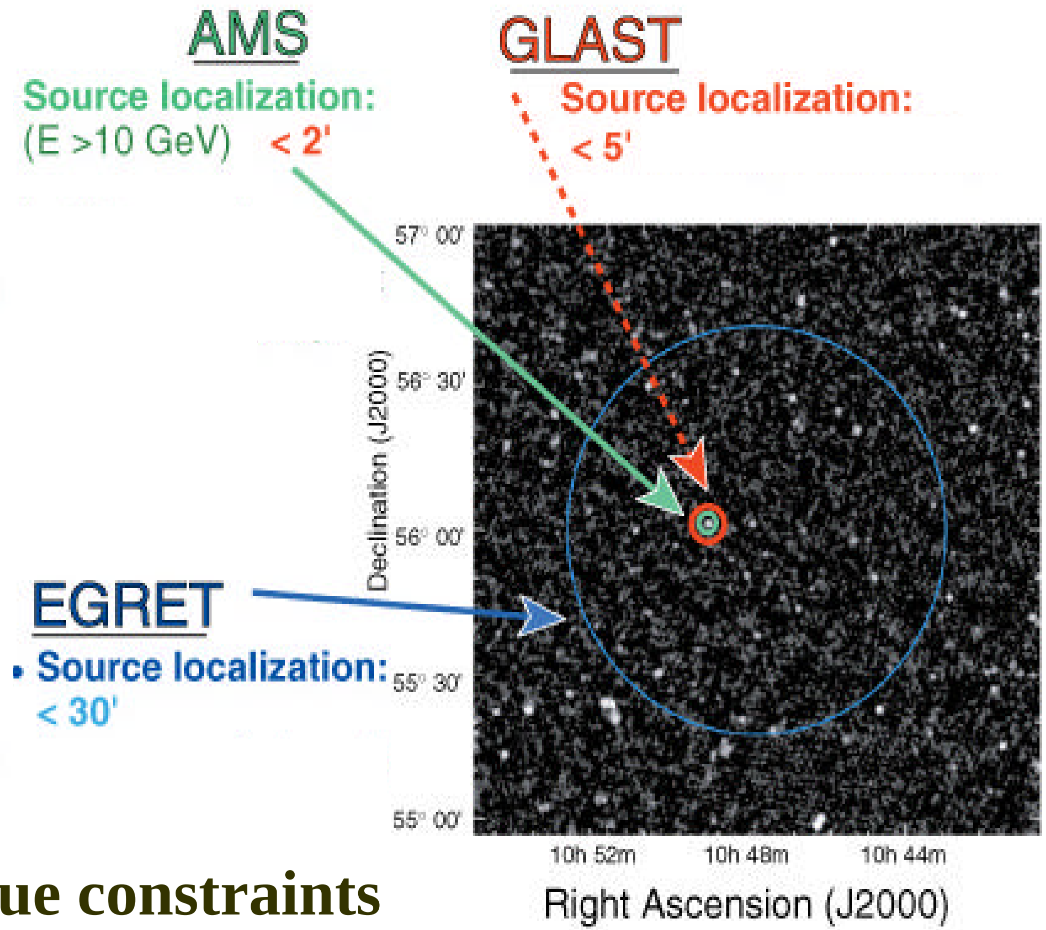
One of the most important measurements in cosmic ray physics

For additional physics examples, see Appendix 2

Identify g Sources with AMS

g ® $e^+ e^-$





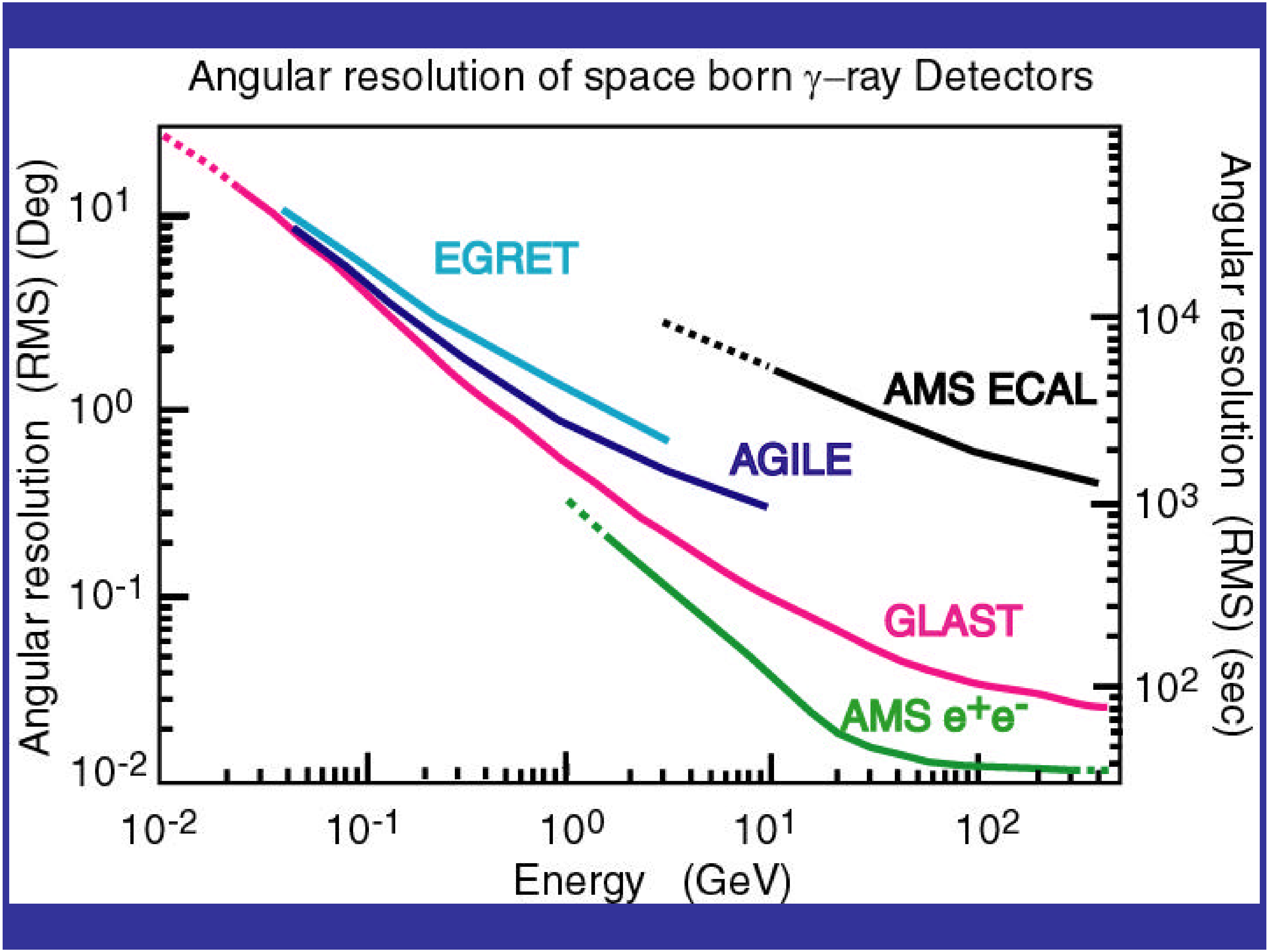
y01K062_2a

Unique constraints

$P^+ = E^+ = P^- = E^-$

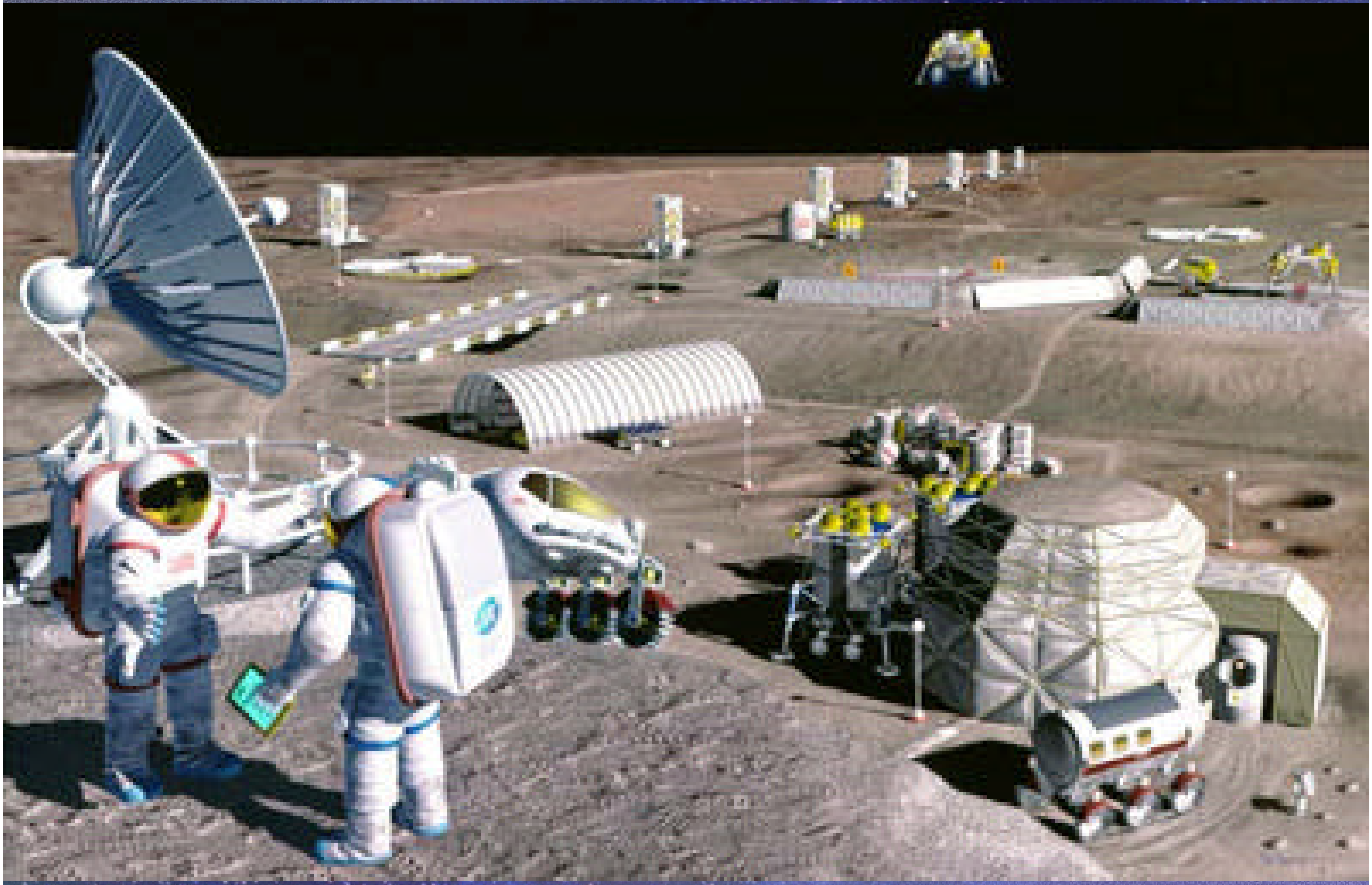
$?^+ \sim ?^-$

y01K062_03.ppt

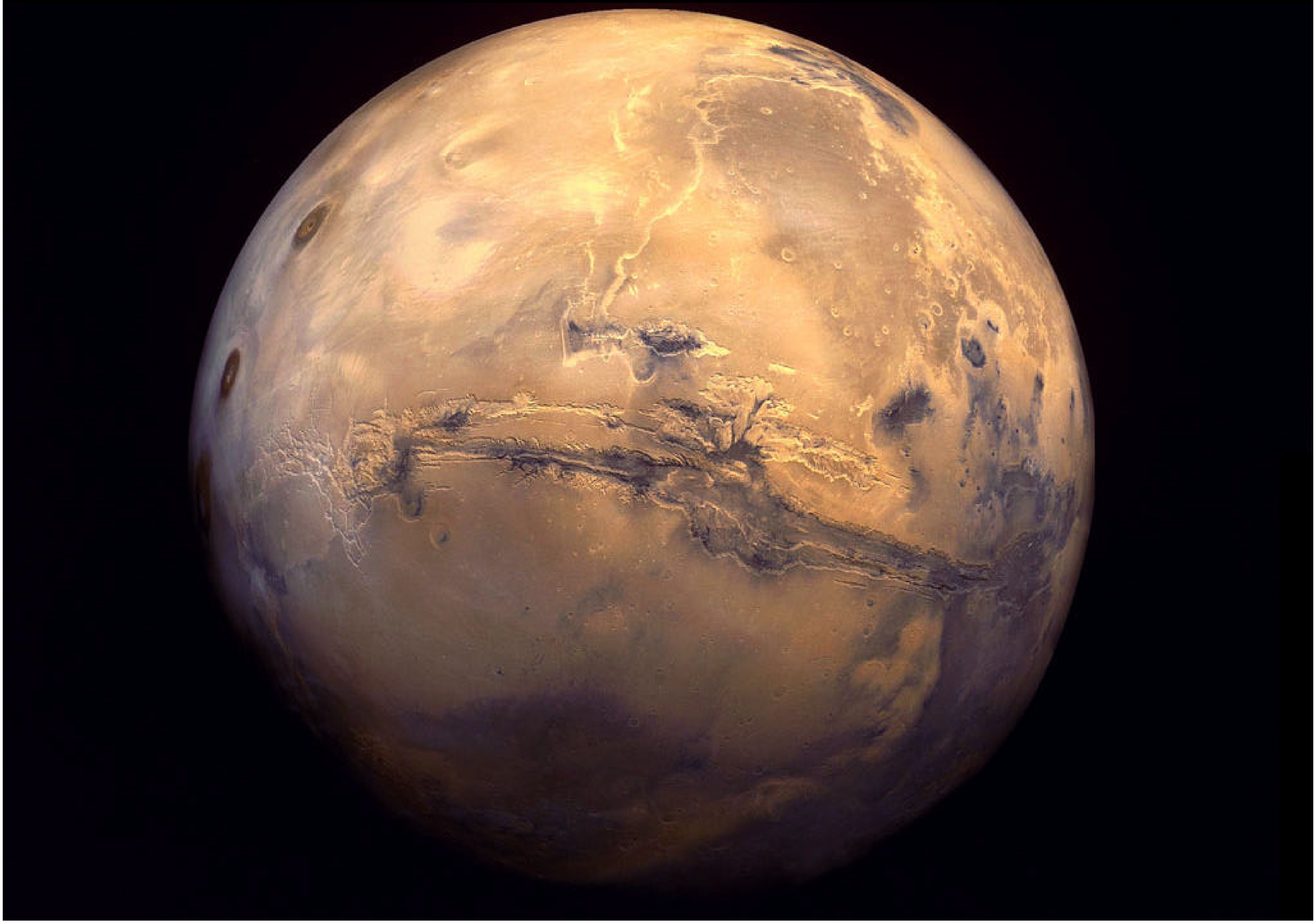


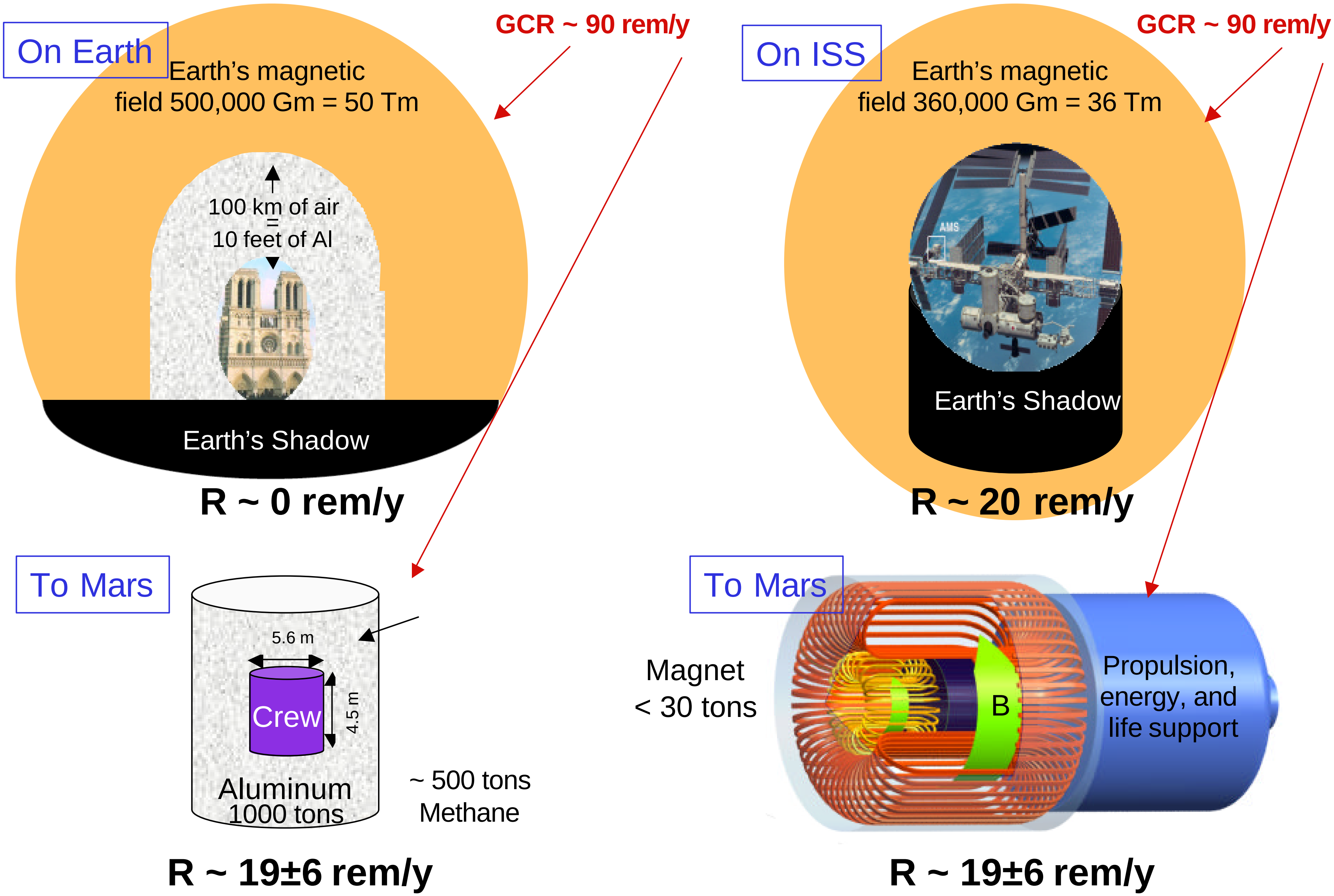
Angular resolution of space born γ–ray Detectors
Angular resolution (RMS) (Deg)
Angular resolution (RMS) (sec)
Energy (GeV)
10^1
10^0
10^-1
10^-2
10^4
10^3
10^2
10^-2
10^-1
10^0
10^1
10^2
EGRET
AGILE
GLAST
AMS ECAL
AMS e+e-

NASA Exploration: Establish a base on the Moon



Future NASA Exploration: Manned mission to Mars

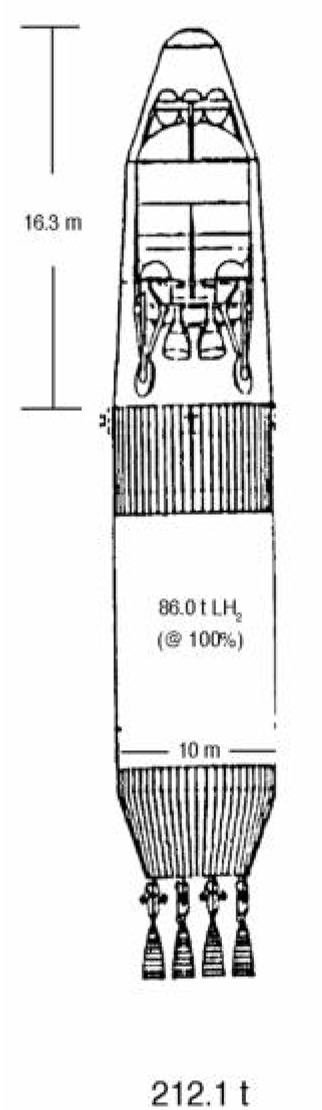




Of the 26892 man-days spent in space only 303 have been in Apollo Mission outside the magnetosphere (1.1%)

Mars reference design: weight estimates

2009 Piloted Mission 1
Surface Hab with Crew Lander



Exploration payload (Earth-Return Habitat Element):

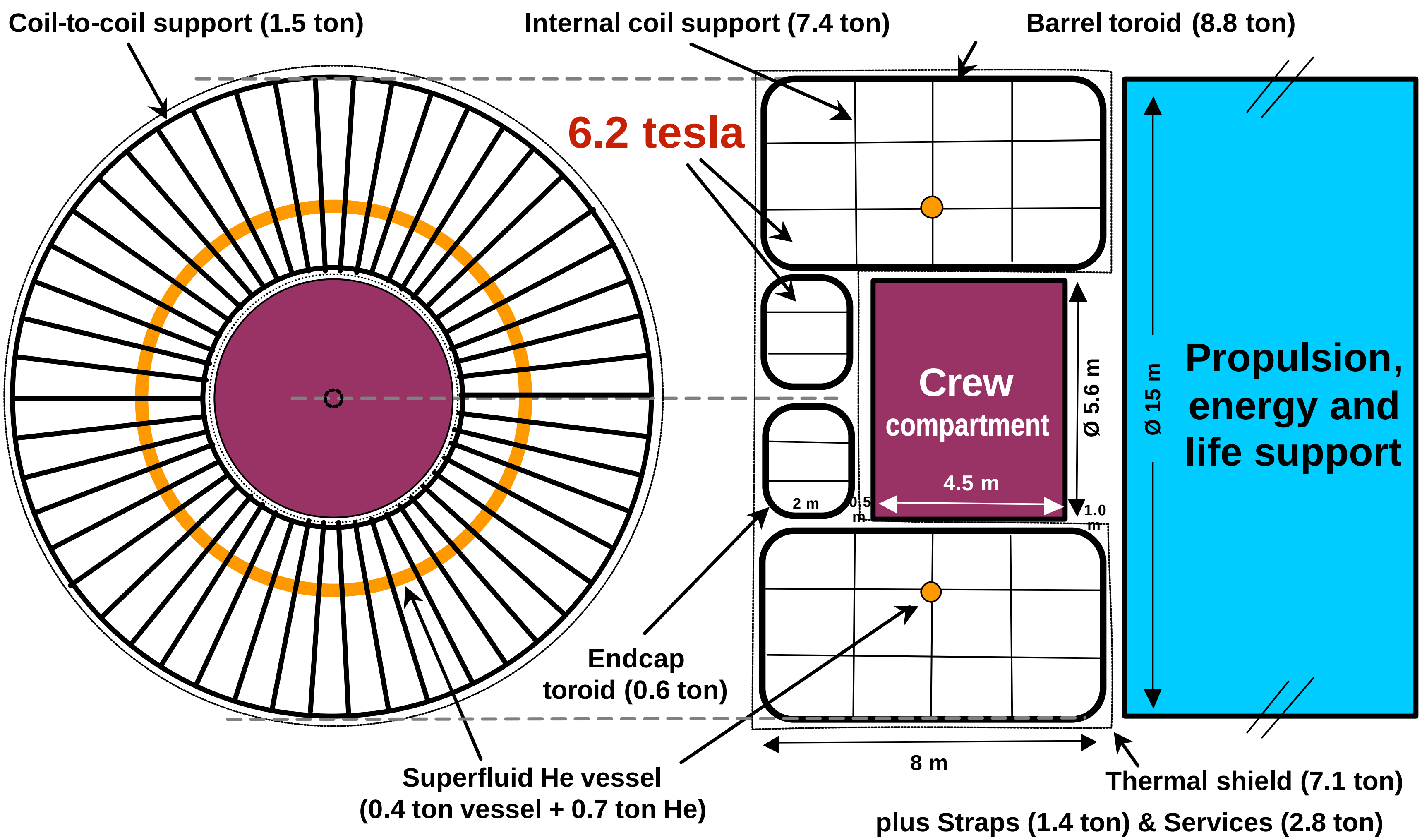
Subsystem	Subsystem Mass (tonnes)	Consumables Subtotal (tonnes)	Dry Mass Subtotal (tonnes)
Physical/chemical life support	6.00	3.00	3.00
Plant growth	0.00	0.00	0.00
Crew accommodations	22.50	17.50	5.00
Health care	2.50	0.50	2.00
Structures	10.00	0.00	10.00
EVA	4.00	3.00	1.00
Electrical power distribution	0.50	0.00	0.50
Communications and information management	1.50	0.00	1.50
Thermal control	2.00	0.00	2.00
Power generation	0.00	0.00	0.00
Attitude control	0.00	0.00	0.00
Spares/growth/margin	3.50	0.00	3.50
Radiation shielding	0.00	0.00	0.00
Science	0.90	0.00	0.90
Crew	0.50	0.50	0.00
Total estimate	**53.90**	**24.50**	**29.40**


YANKEE GO HOME!
MARS FOR MARTIANS

Magnetic radiation protection system for Mars mission

by B. Blau, V.Choutko, S. Harrison, A. Herve, S. Horvarth, H. Hofer,
H.P. Marti, I. Vetlitskiy, et al, (CERN, ETH, MIT, SCL)

with AMS technology



Weight of complete system: 30.7 ton

Major International Commitments to NASA

Discoveries in Physics

Facility	Original purpose, Expert Opinion	Discovery with Precision Instrument
P.S. CERN (1960)	π N interactions	Neutral Currents -> Z, W
AGS Brookhaven (1960)	π N interactions	2 kinds of neutrinos, Time reversal non-symmetry, New form of matter (4th Quark)
FNAL Batavia (1970)	Neutrino physics	*5th Quark, 6th Quark*
SLAC Spear (1970)	ep, QED	Partons, 4th Quark, 3rd electron
ISR CERN (1980)	PP	*Increasing PP Cross section*
PETRA Hamburg (1980)	6th Quark	*Gluon*
Super Kamiokande (2000)	Proton decay	Neutrinos have mass
Hubble Space Telescope	Galactic survey	*Curvature of the universe, dark energy*

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