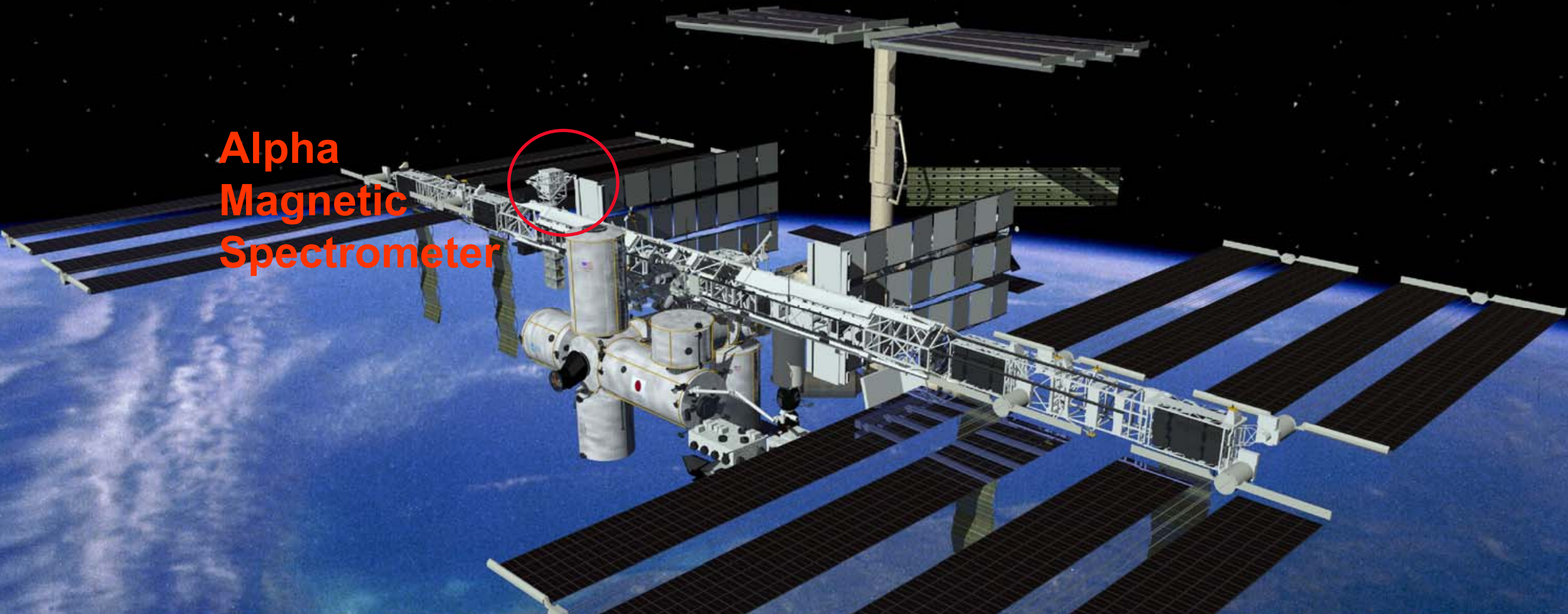
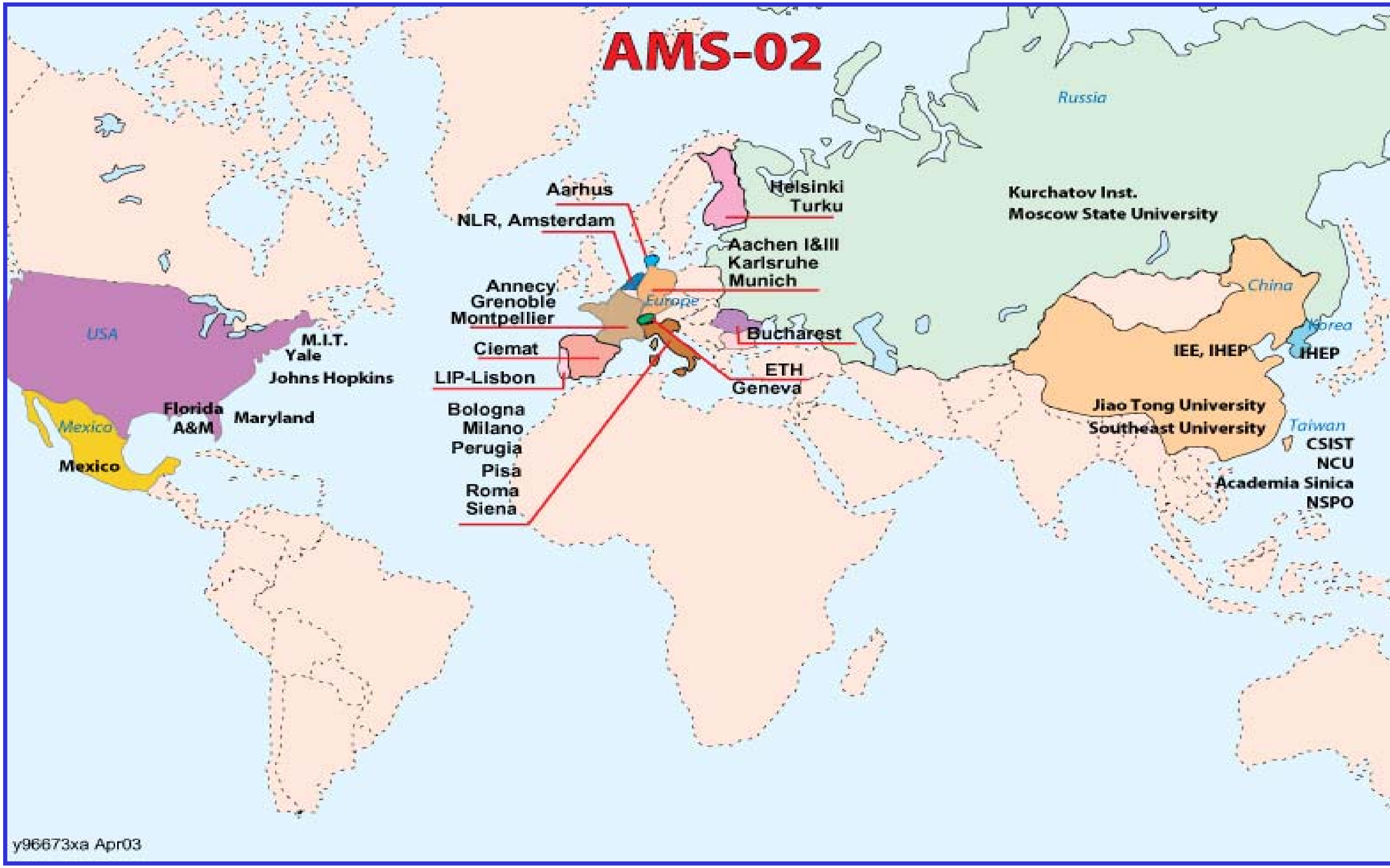
AMS : A COSMIC RAY OBSERVATORY



ON THE INTERNATIONAL SPACE STATION

Jean-Pierre VIALLE
LAPP/IN2P3/CNRS
for the AMS Collaboration
IPRD04 Siena

THE AMS-02 COLLABORATION: 15 COUNTRIES, 56 INSTITUTES



The Alpha Magnetic Spectrometer

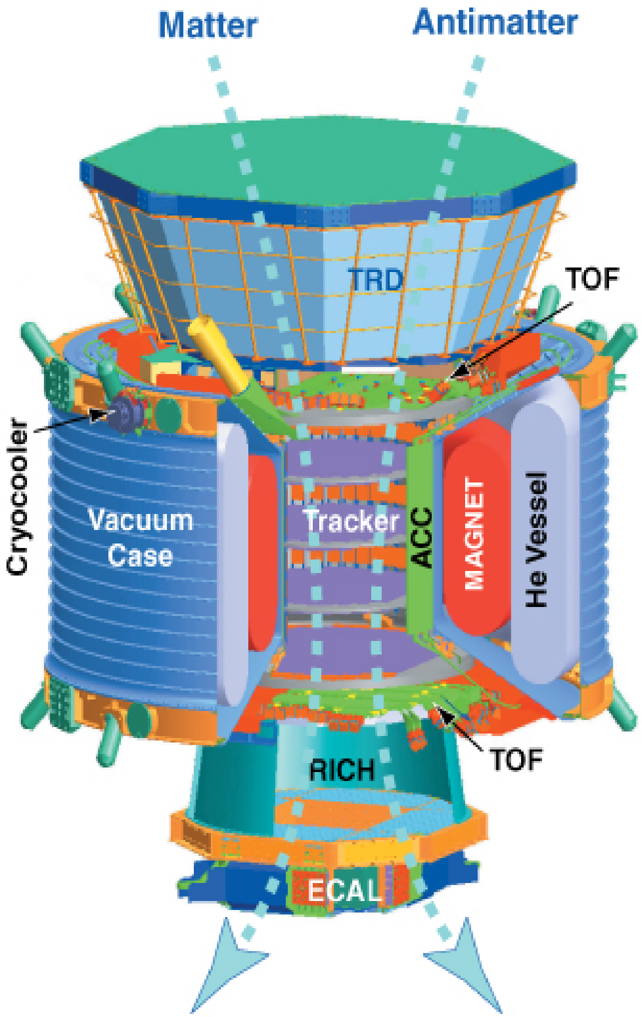
On the International Space Station as from 2007 for at least 3 years

PHYSICS GOALS

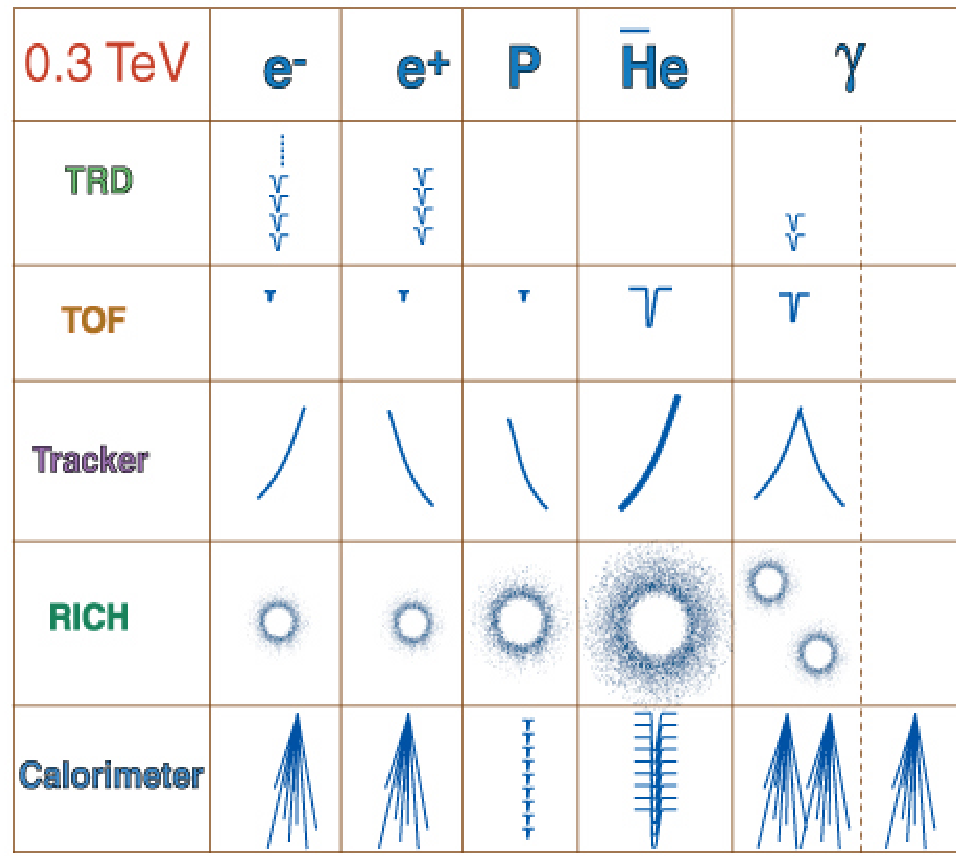
- Study of charged particles and nuclei in cosmic rays with high precision and high statistics in rigidity range 0.5 GV– few TV
- Direct search for antimatter (antihelium). Sensitivity 10^{-9} to antihelium/helium
- Indirect search for non-baryonic Dark Matter (neutralino $\chi + \chi \rightarrow e^+, \bar{p}, \gamma, +\ldots$)
- High energy cosmic gamma-rays physics.

Total statistics expected above 10^{10} events.

AMS: A TeV Magnetic Spectrometer in Space (3m x 3m x 3m, 7t)



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



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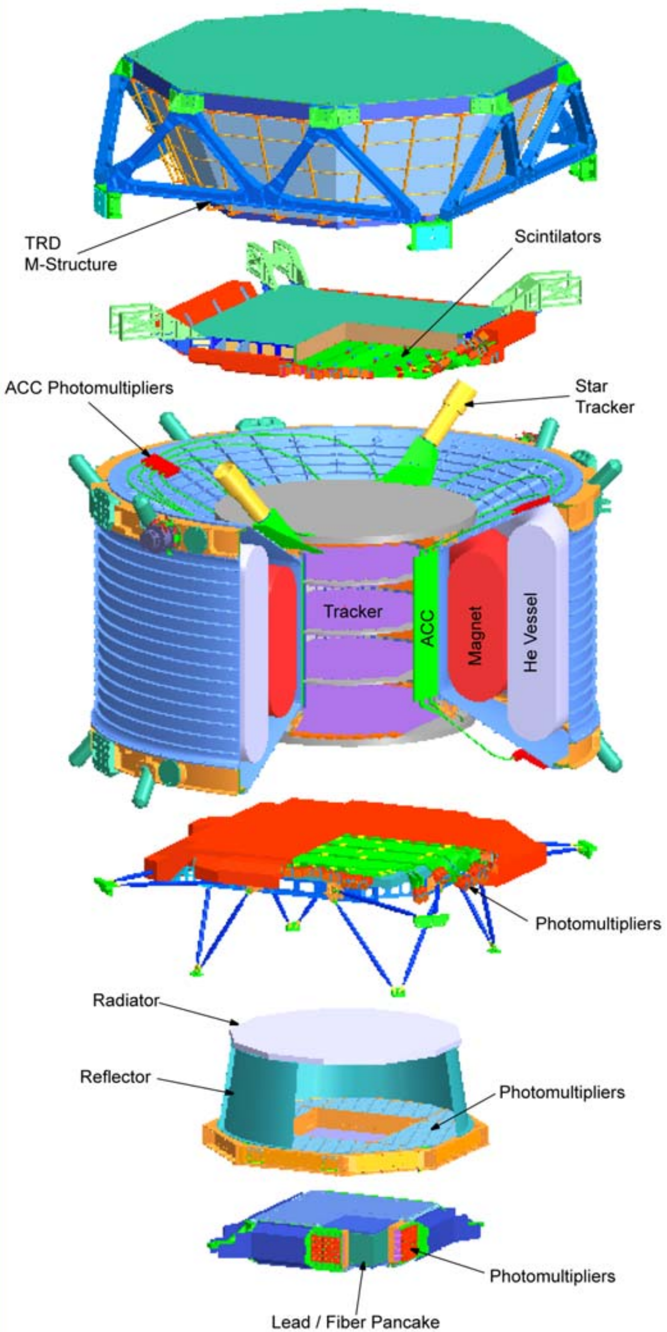


TRD:
Transition
Radiation
Detector

TOF: (s1,s2)
Time of Flight
Detector

MG:
Magnet

TR:
Silicon Tracker

ACC:
Anticoincidence
Counter

AST:
Amiga Star
Tracker

TOF: (s1,s2)
Time of Flight
Detector

RICH:
Ring Image
Cherenkov Counter

EMC;
Electromagnetic
Calorimeter

AMS *Alpha Magnetic Spectrometer*

- **Transition Radiation Detector. 20 planes**
- **Time of Flight. 4 planes of scintillating counters**
- **Double-sided Si strip tracker planes inside superconducting magnet. 8 Layers**
- **Rich: Ring Imaging Cerenkov detector**
- **3D Electromagnetic calorimeter**

MAIN DESIGN CHARACTERISTICS

- Minimum amount of matter (X_0) before ECAL
- Acceptance 0.5 m^2.Sr -> anti-He search
- Velocity measurement $\Delta\beta/\beta$ = 0.1 % to distinguish ^{9}Be,^{10}Be, ^{3}He,^{4}He isotopes.
- Rigidity R= pc/|Z|e (GV) proton resolution 20% at 0.5 TV and Helium resolution of 20% at 1 TV.
- Antihelium/Helium identification factor 10^{10}.

Multiple and independant measurements to reach performances required :

- |Z| measured from Tracker, RICH, TOF.
- Sign of charge Z measured from tracker (8 points).
- Velocity β measured from TOF, RICH.
- Hadron/electron separation from TRD, ECAL.

Constraints on design due to launch and space

- Vibration (6.8 G rms) and G-Forces (17G)

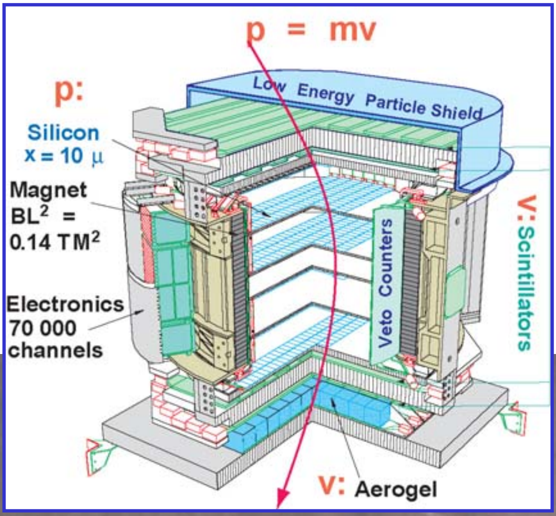
- Thermal Environment (day/night: $\Delta T \sim 100^oC$)
- Vacuum: < 10^{-10} Torr
- Radiation: Ionizing Flux ~1000 $cm^{-2}s^{-1}$
- Orbital Debris and Micrometeorites

- Limitation : Weight (14 809 lb) and Power (2000 W)
- Reliable for more than 3 years – Redundancy
- Must operate without services and human Intervention

ALPHA MAGNETIC SPECTROMETER AMS01 MISSION

STS91 flight on Discovery 2-12 June 1998

10 days in space. 10^8 cosmic ray triggers

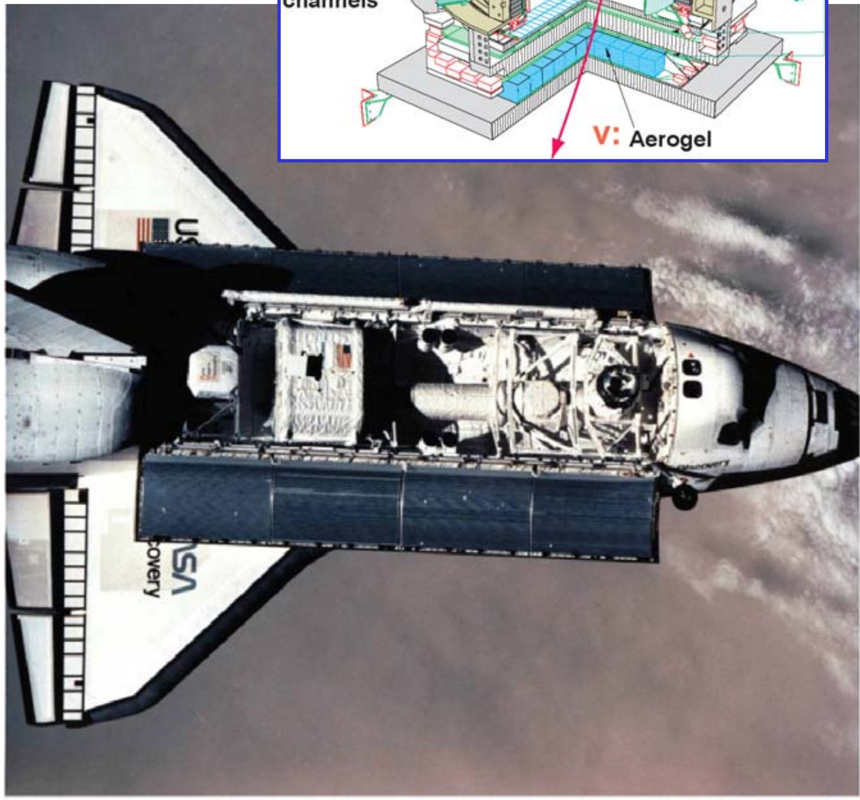


Several important physics results published
(Overview in Physics Reports 366 (2002))

Limit on primordial antimatter :
Search for antihelium in C.R. PL B461 (1999)

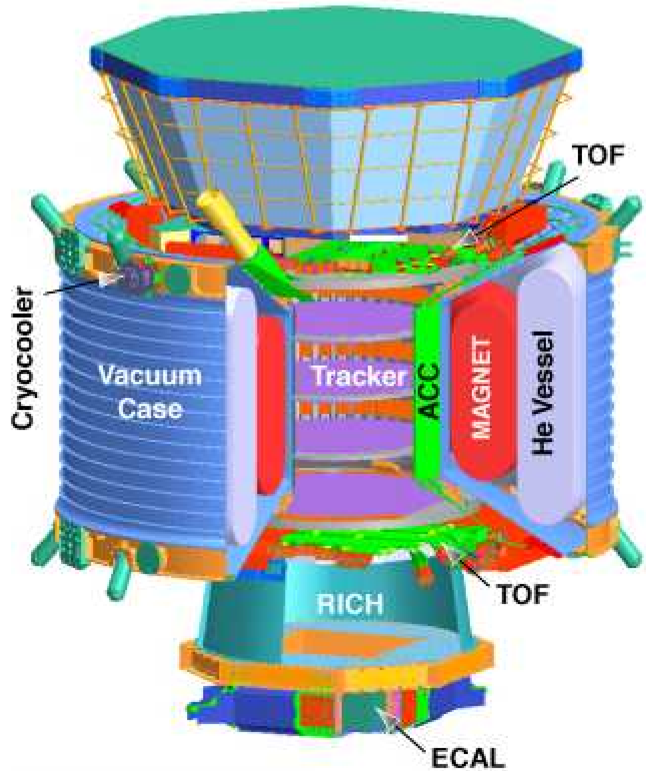
Measurement of primary fluxes p, He, e-, e+, ..., detection of secondary fluxes, geomagnetic field effect and particles trapping:
Protons in near earth orbit PL B472 (2000)
Leptons in near earth orbit PL B484 (2000)
Cosmic protons PL B490 (2000)
Helium in near earth orbit PL B494 (2000)

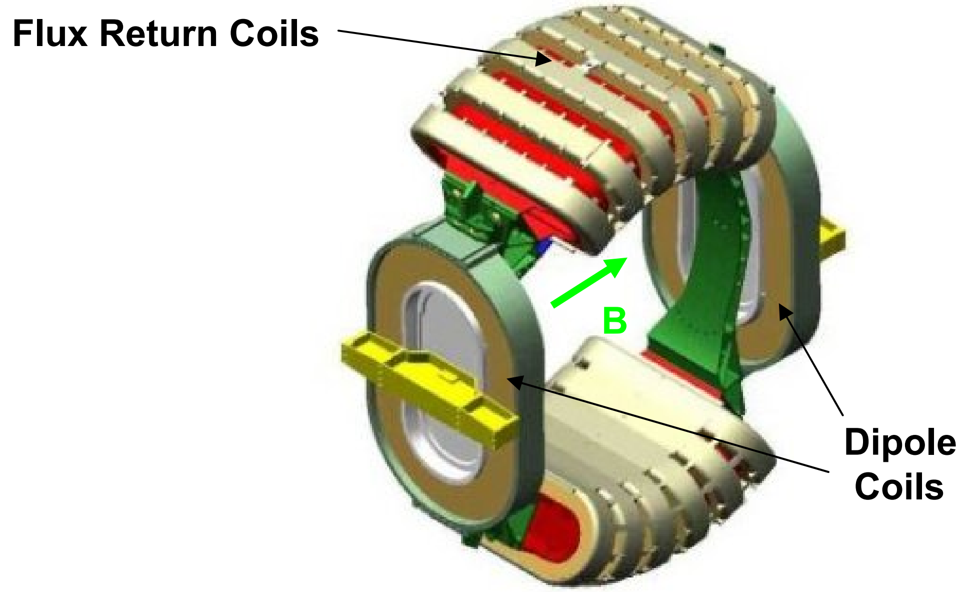
Use of results for other fluxes calculations:
A 3D simulation of atmospheric neutrinos PRD68 (2003)

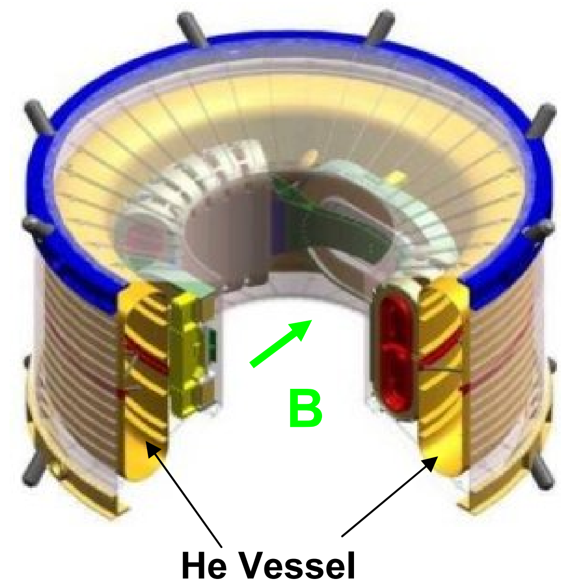


AMS01 SEEN FROM MIR IN THE CARGO BAY OF DISCOVERY

AMS02 Superconducting Magnet







- 3000 Liters Superfluid He
- cryocoolers
- $BL^2 = 0.8\ TM^2$
- Dipole field inside, no Dipole moment

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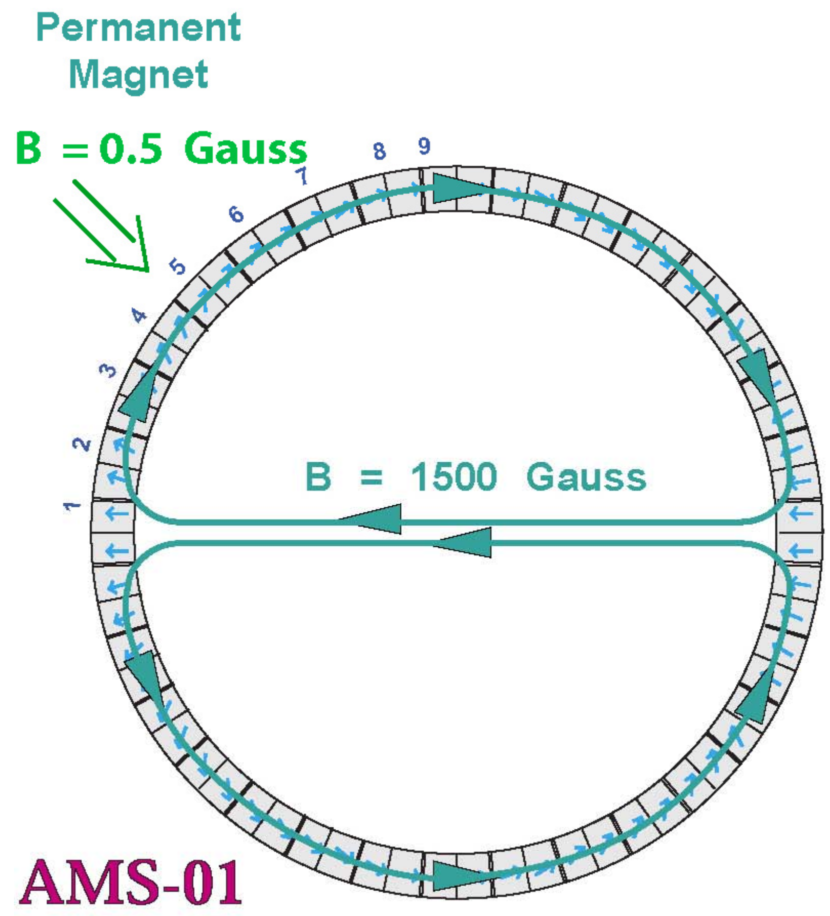
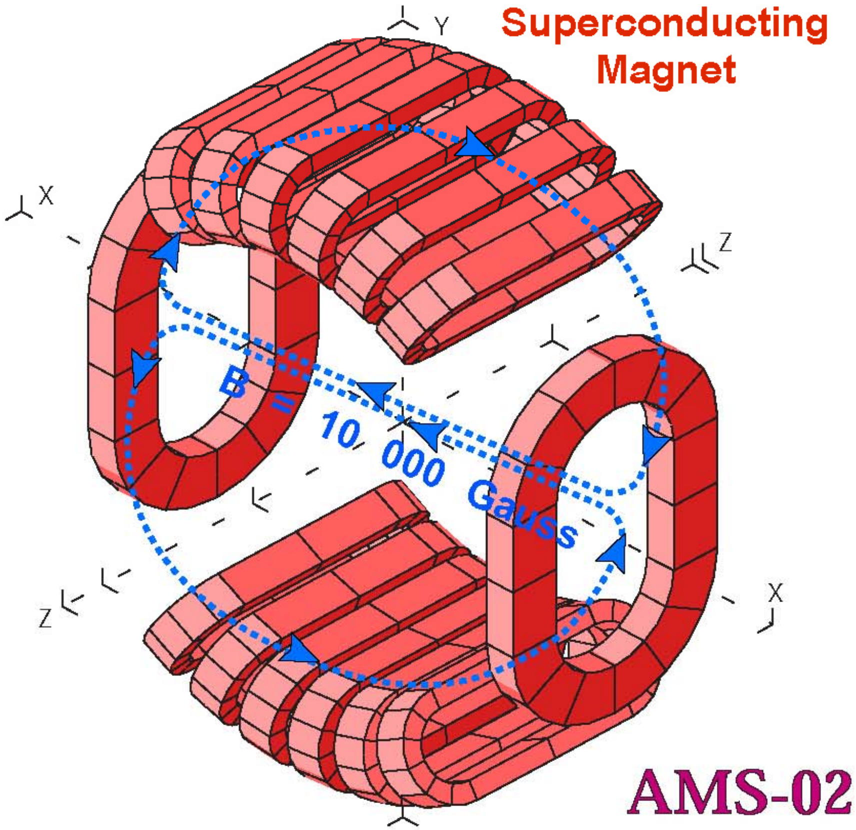
Identical configuration between AMS-01 and AMS-02

1. Same large volume (Φ = 3', h = 3')
2. No Dipole momentum (no rotation in earth mag. field)
3. No quench





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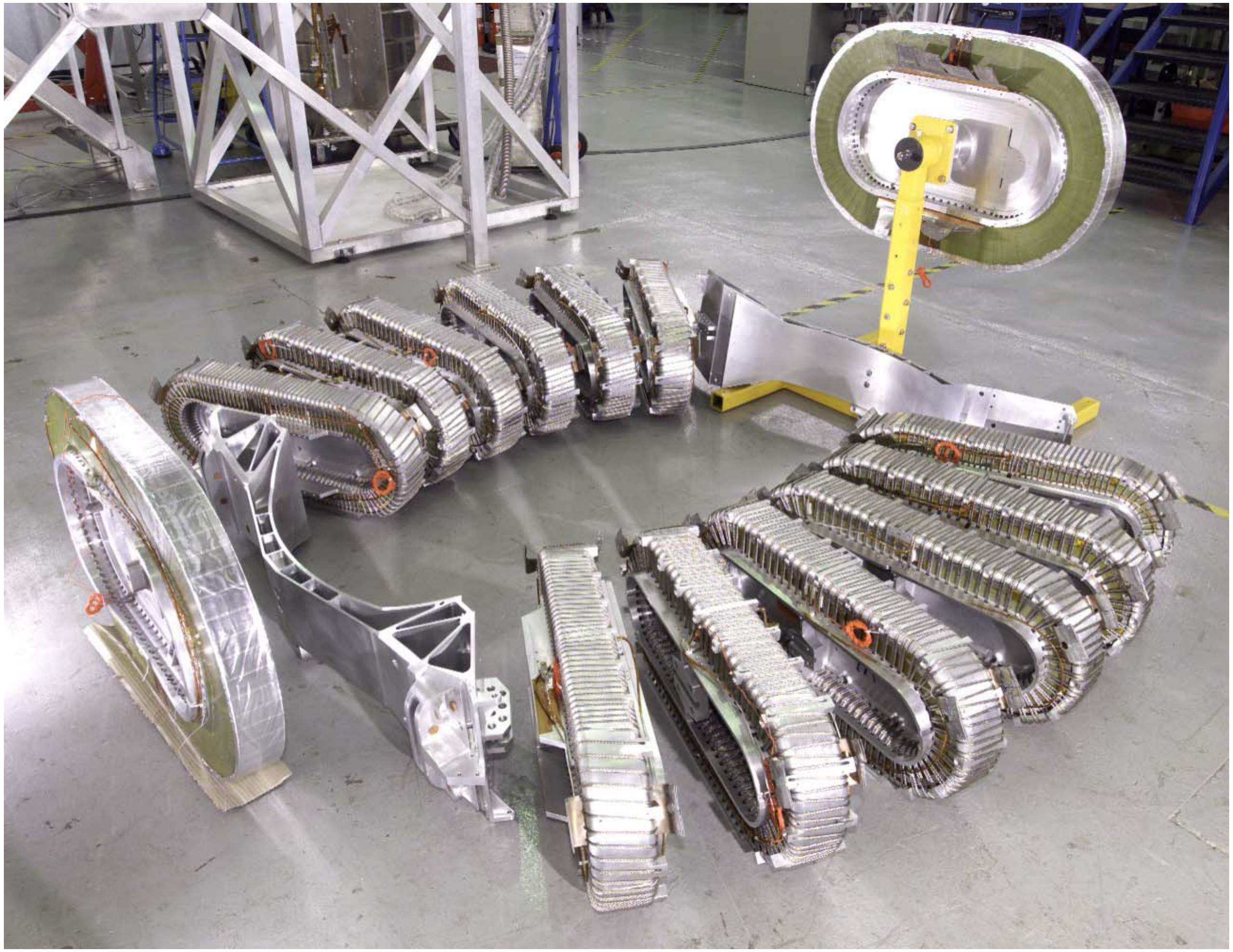
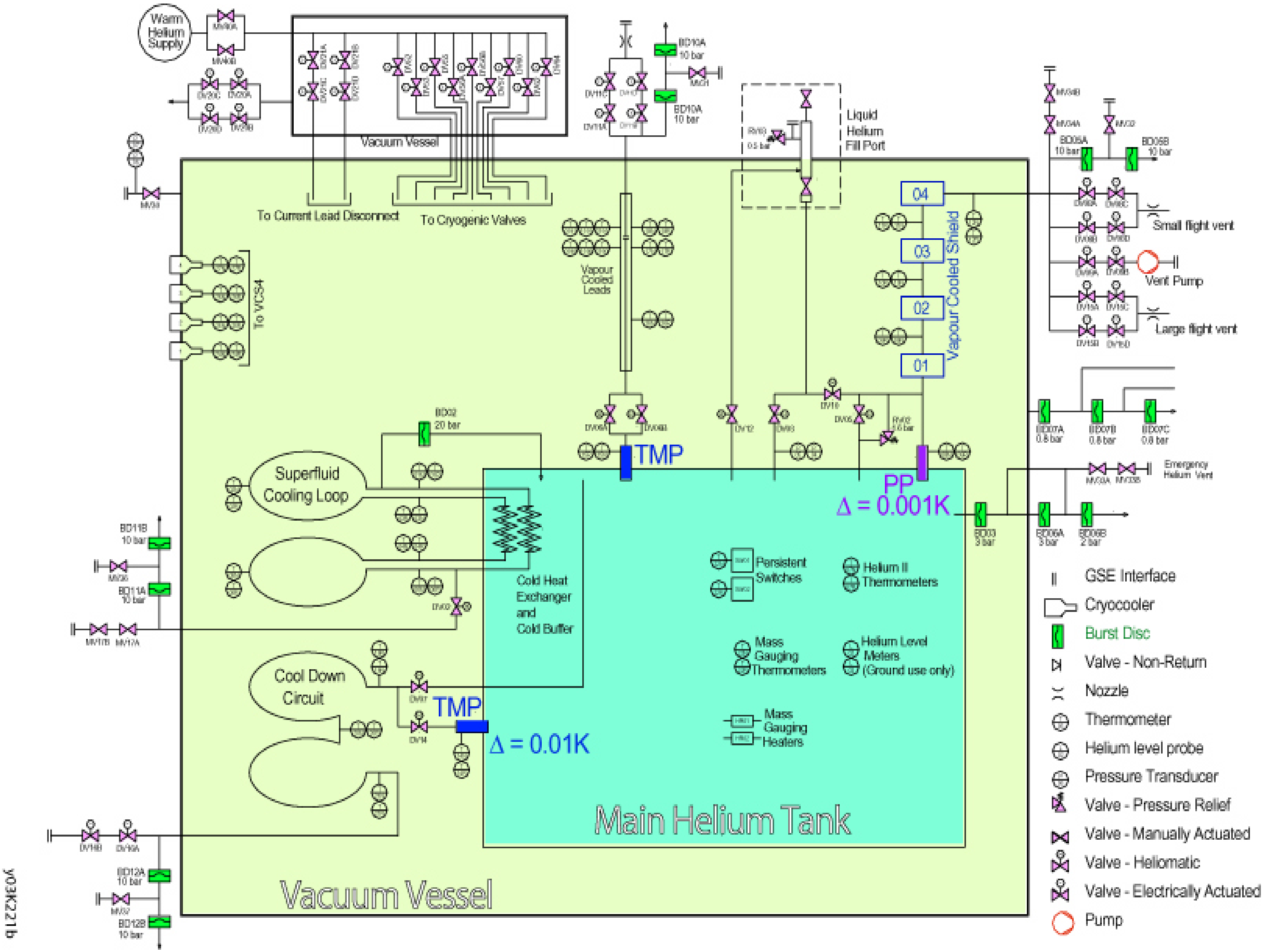
AMS02 Superconducting Magnet
2 Dipoles coils and 12 racetrack coils



ALL THE COILS ARE BUILT AND TESTED.

AMS02 Superconducting Magnet cooling system



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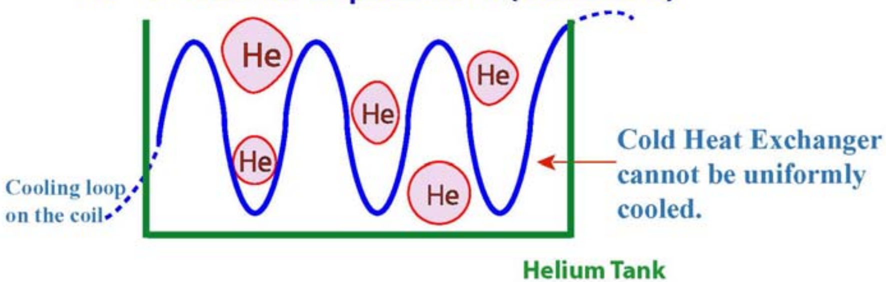
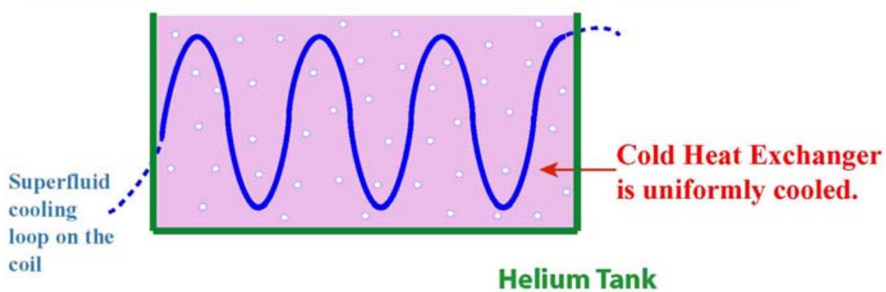
COOLING WITH SUPERFLUID HELIUM

Liquid Helium in Space

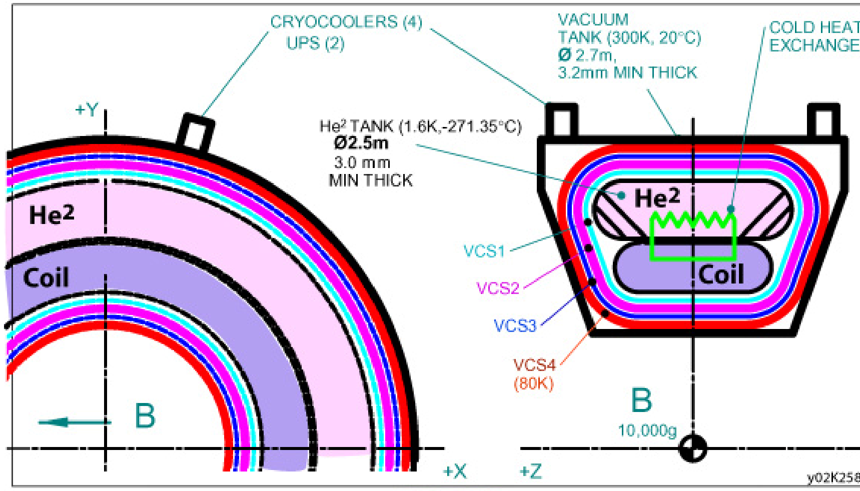
He¹ : Normal Liquid: 4.3 K (-268.85 C)

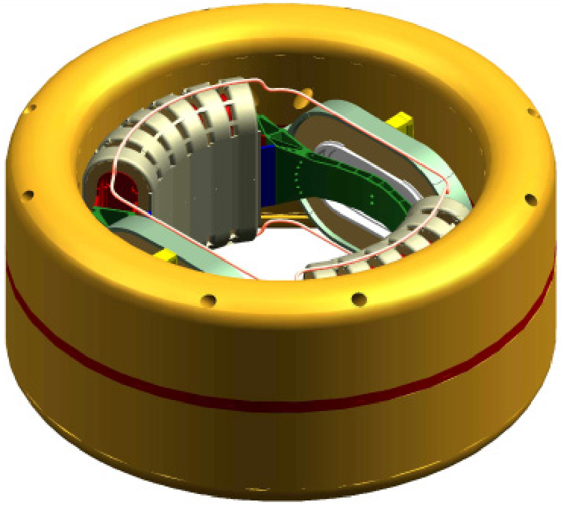


He² : Superfluid Helium: 1.6 K (-271.35 C) is a Bose-Einstein Liquid; it has no surface tension



Superfluid helium vessel





A puncture in the tank would result in expanding the volume from 2500 litres to 1.9×10^6 litres (six times the volume of the shuttle cargo bay) with extremely serious consequences.

y02K121gHarrison

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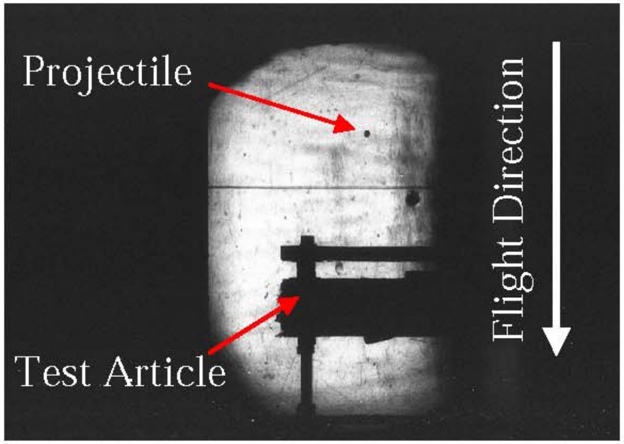
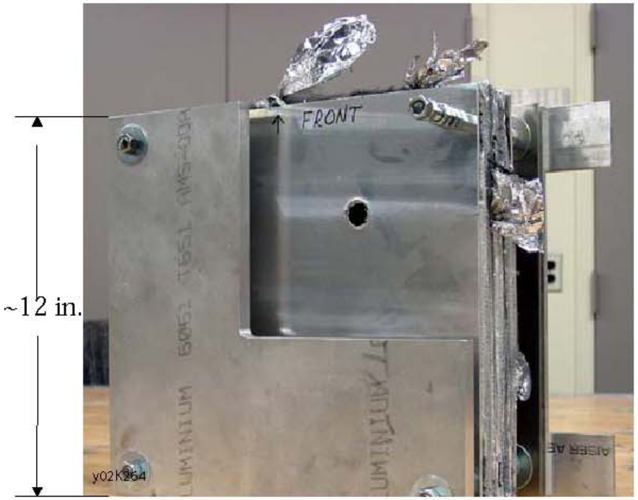
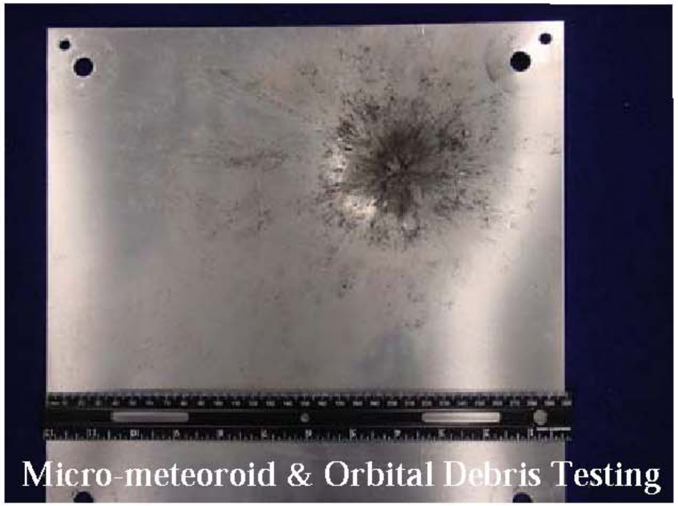
Micro-meteroid & Orbital debris testing



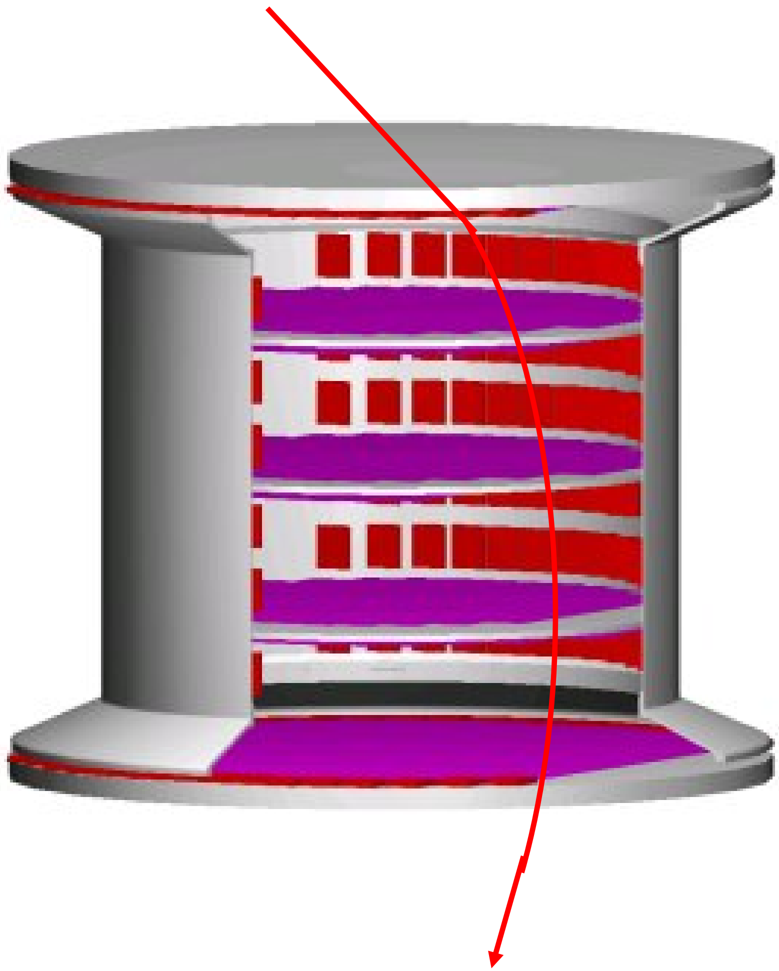


Hole made in
Vacuum Case Layer
from 5mm Aluminum
Orbital Debris Particle
shot at ~ 15,000 mph



Damage to
SFHe tank due to
5 mm Al
Orbital Debris Particle.
Tank not punctured

Silicon Tracker



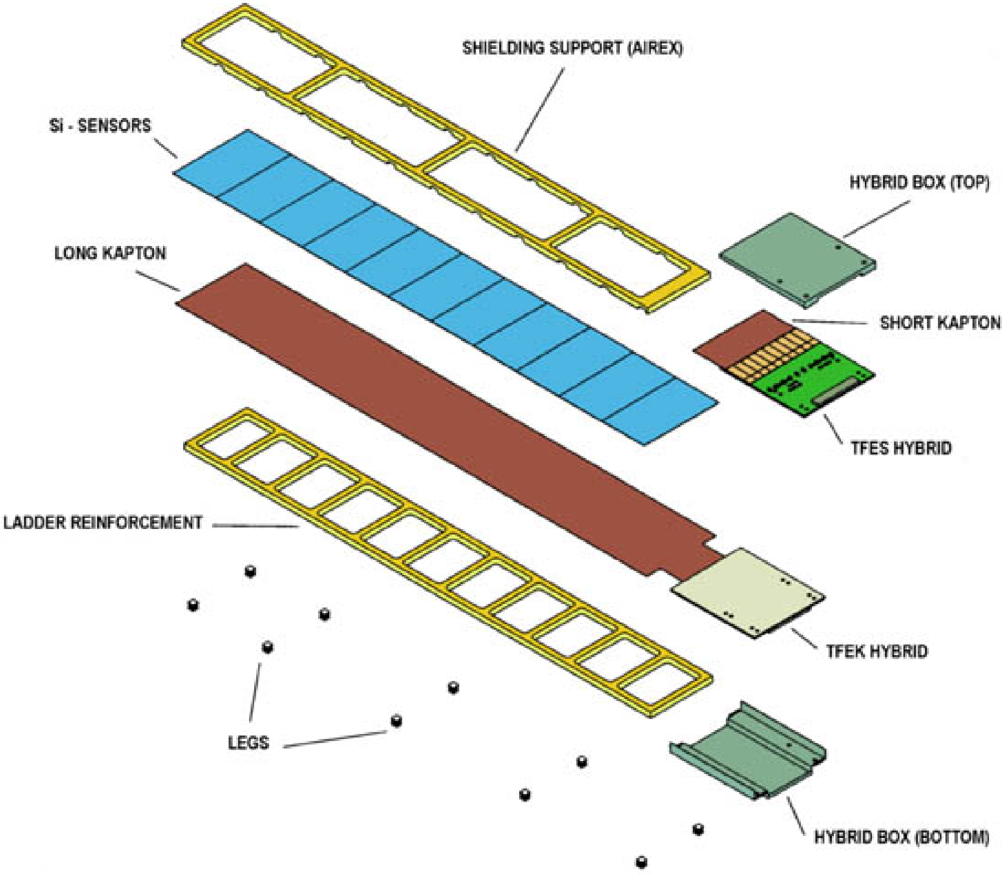
- 8 Double-sided planes, ~6m^2
- Pitch:

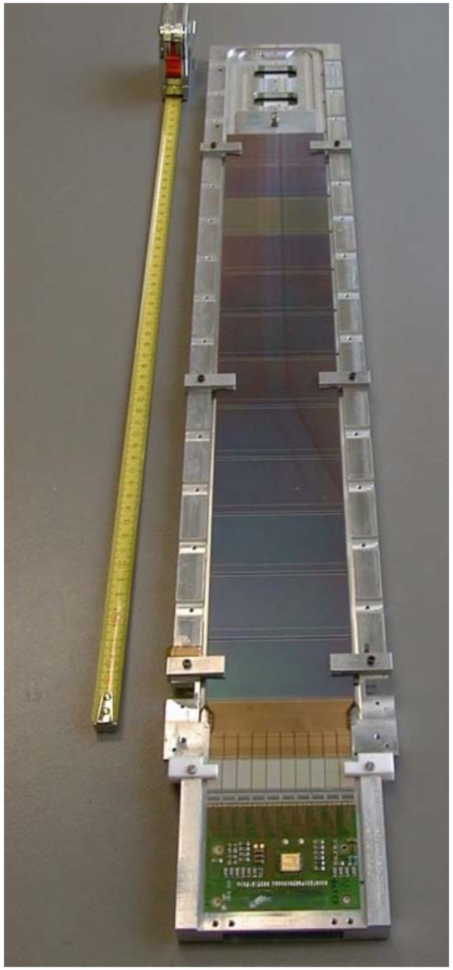
  Bending 27.5 μm (coord res 10 μm)

  Non-Bending 104 μm (coord res 30 μm)
- Rigidity: *dR/R* ≈ 2%

  for 1-10 GeV protons with magnet
- Signed Charge (*dE/dx*)

Silicon Tracker Ladder





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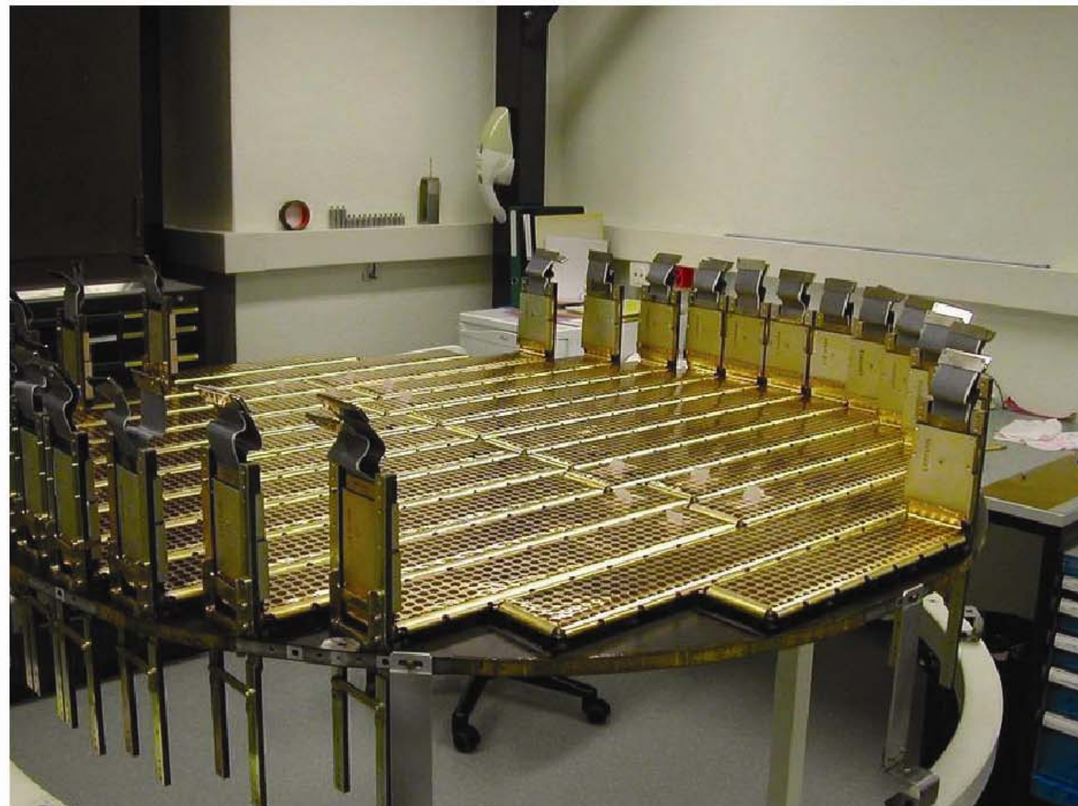
Silicon Tracker Construction

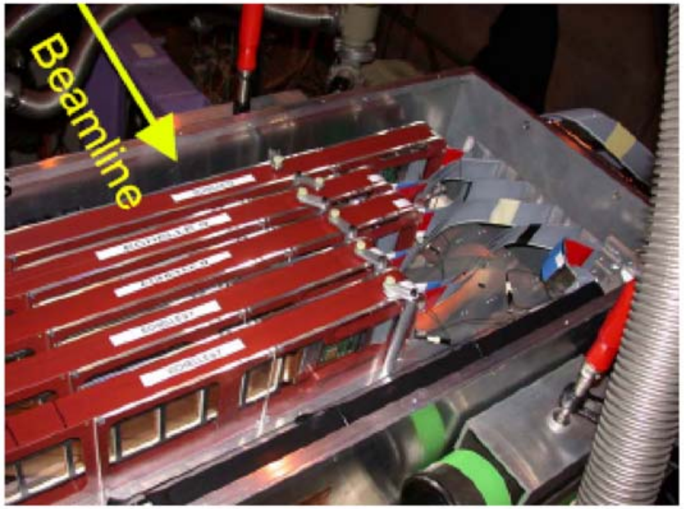
Sensor Positioning to a few μ accuracy

Bonding and inspection of ladders

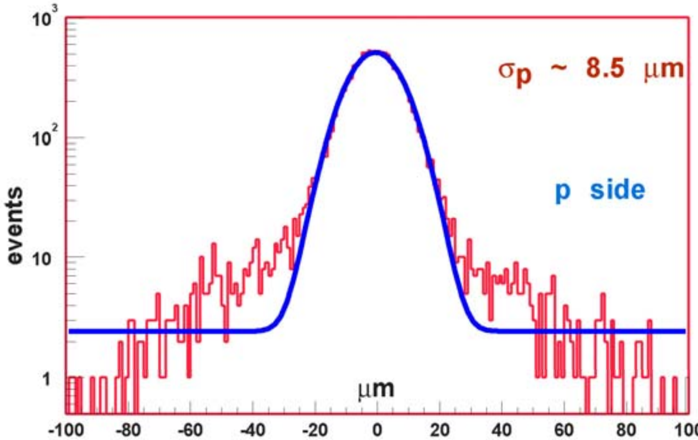


Tracker integration : layer L2 on plane P2

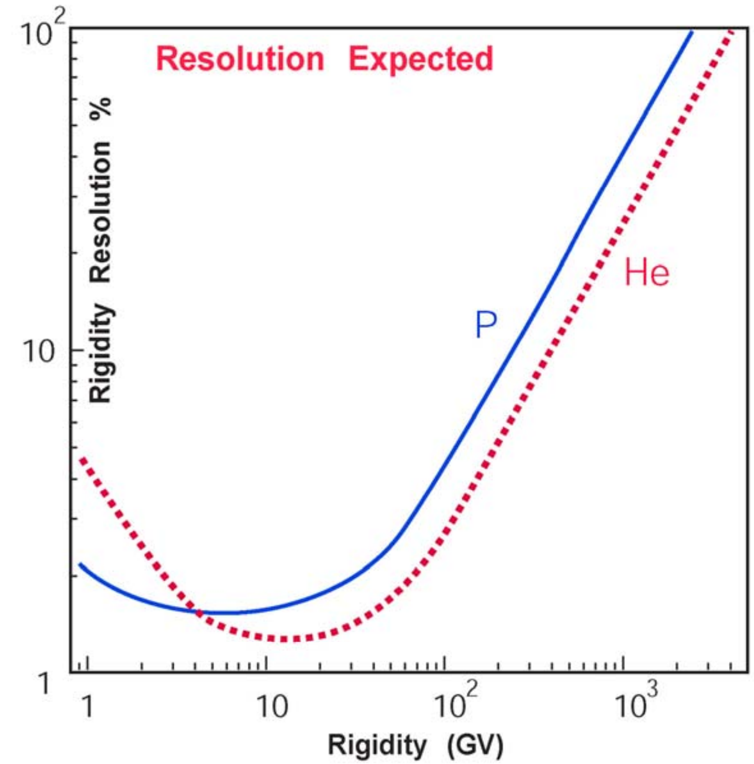
Performances of the Silicon tracker



Ladders in a test beam at CERN

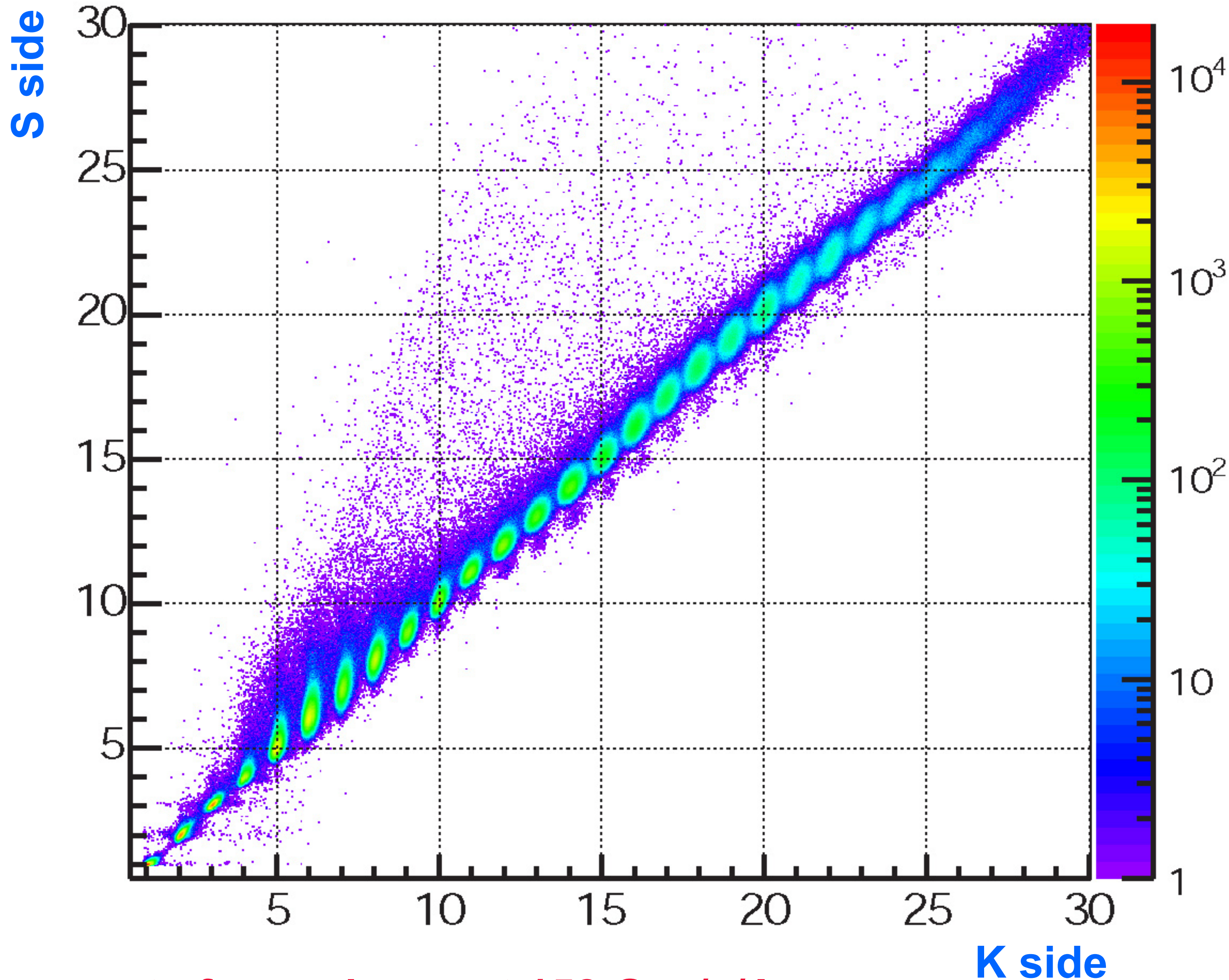


Test of ladders in a 120 GeV/c muon beam.
Hits with respect to the position from the beam



Calculated Rigidity resolution for p and He

Charge Measurement with Silicon Tracker



Fragments from a beam at 158 Gev/c/A

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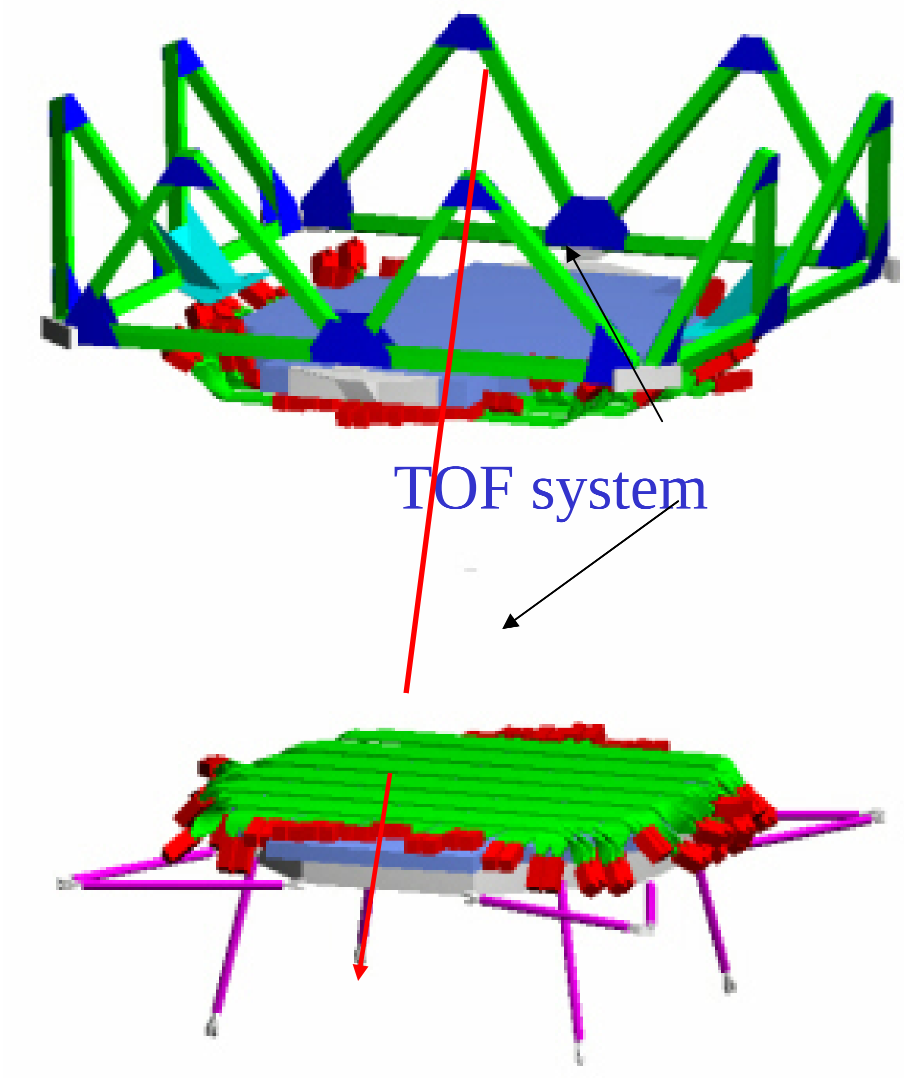
Time-of-flight system

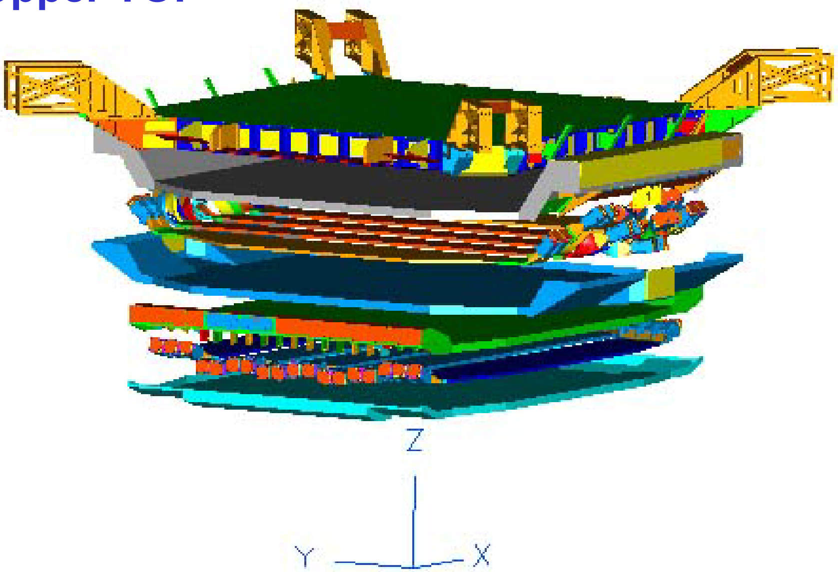
(See talk C.Sbarra, this conf.)

- •Time-of-flight (velocity).
- •Charge Determination (dE/dx)
- • Fast Trigger
- •Up/Down Separation
- •Scintillator Paddles With Phototubes at Both Ends
- •120 ps Time Resolution
- •8 m^2 Total Area
- •4 Planes (2 upper, 2 lower)



STRUCTURE OF THE TOF COUNTERS

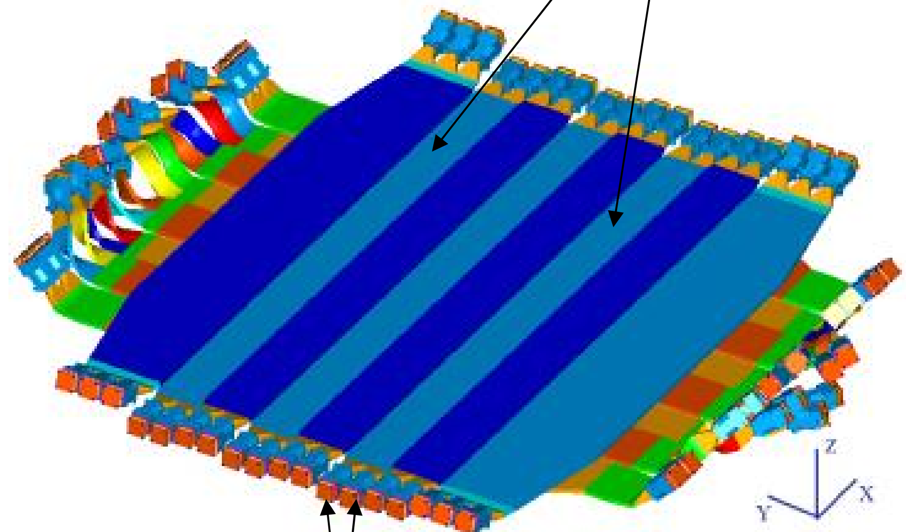
Upper TOF



Lower TOF

Complicated light guides structure to cope with high magnetic field

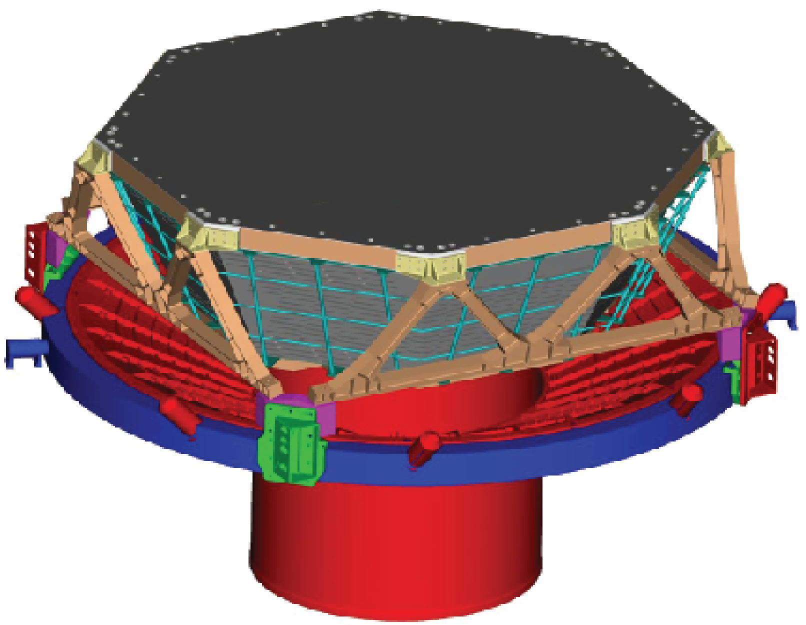
Scintillator Paddles



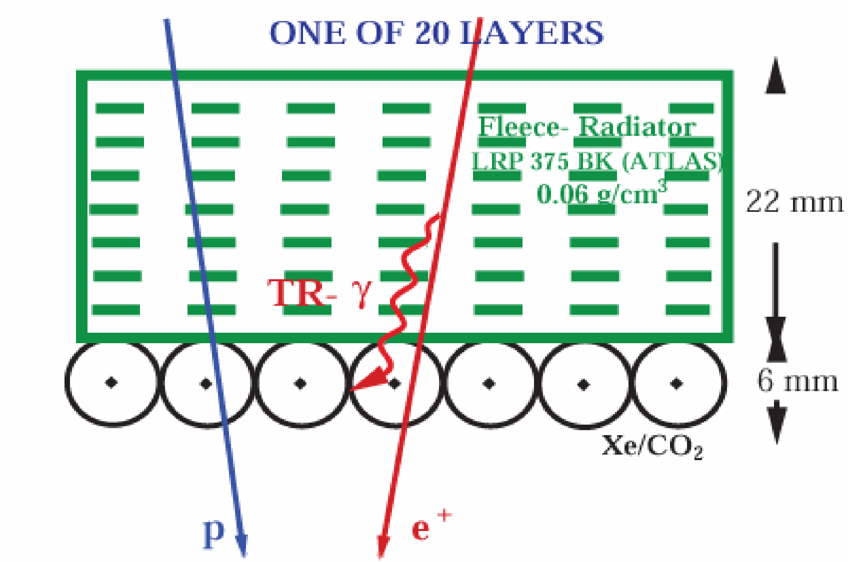
Dual Photomultipliers for Redundancy and time resolution

Transition Radiation Detector (TRD)

(See talk by T. Siedenburg. This conf.)

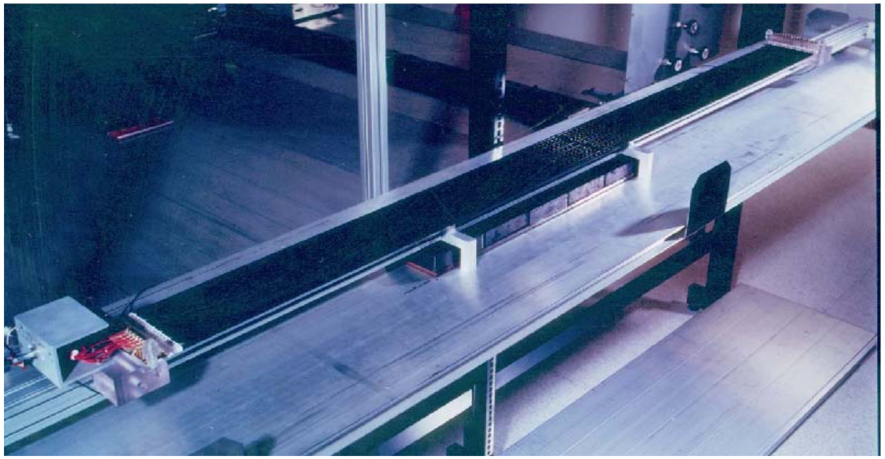


20 layers
328 modules each consisting of :
- 22mm fleece
- 16 - 6 mm straw tubes
- (Xe/CO_2 – 80/20)

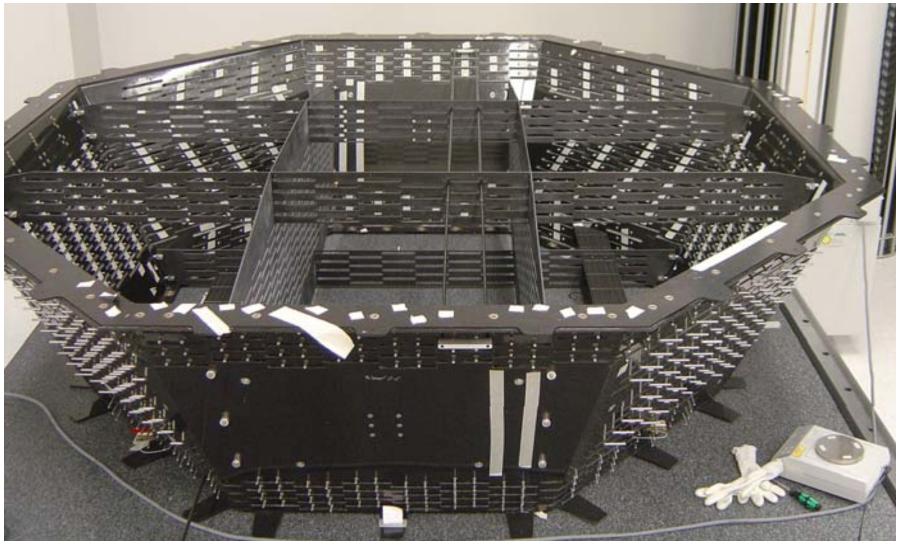


- e+/e- rejection 10^2 – 10^3 in 1.5 – 300 GeV range
- with ECAL: e+/p rejection >10^6

Transition Radiation Detector Construction

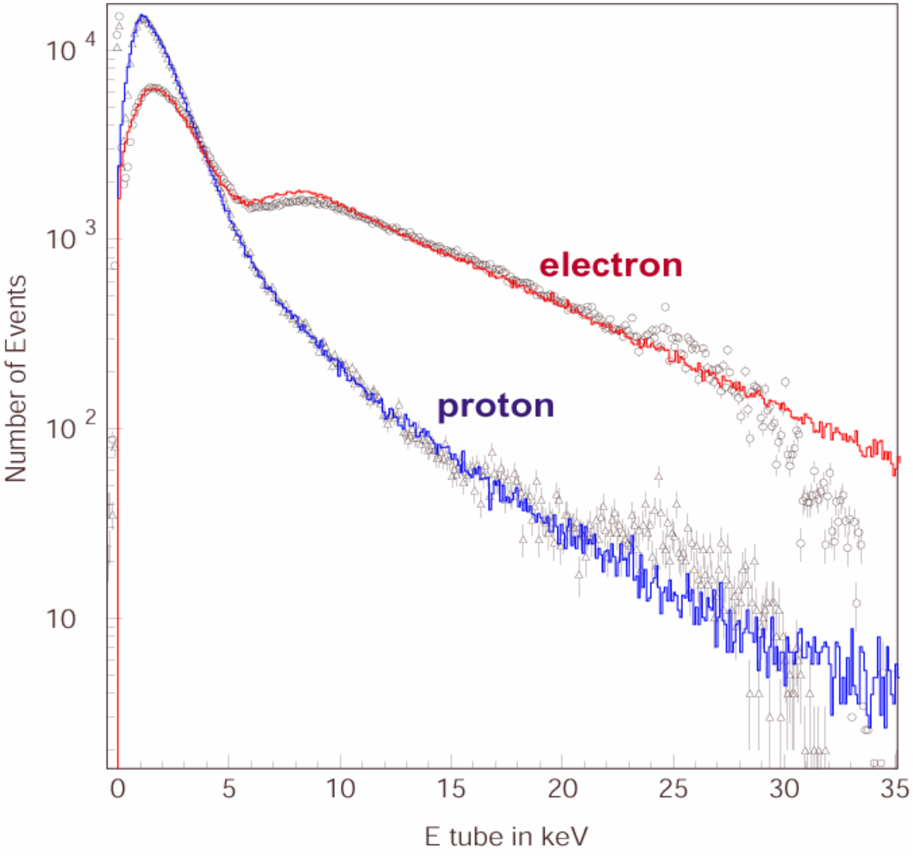


1.5 meter module on assembly jig



Carbon fiber composite/Aluminum Honeycomb
Mechanical support structure

Test at CERN with protons and electrons
in 5 to 250 GeV range



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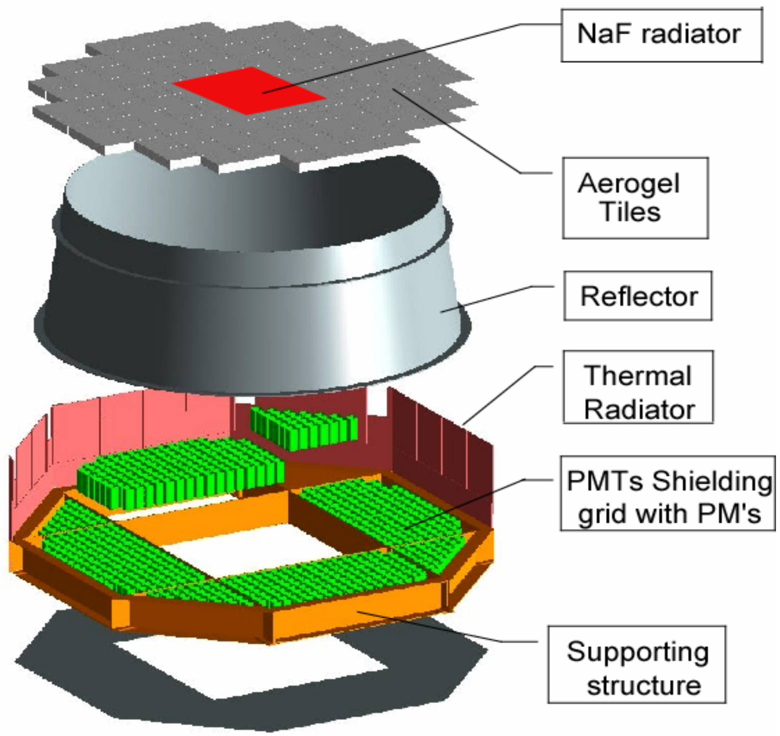
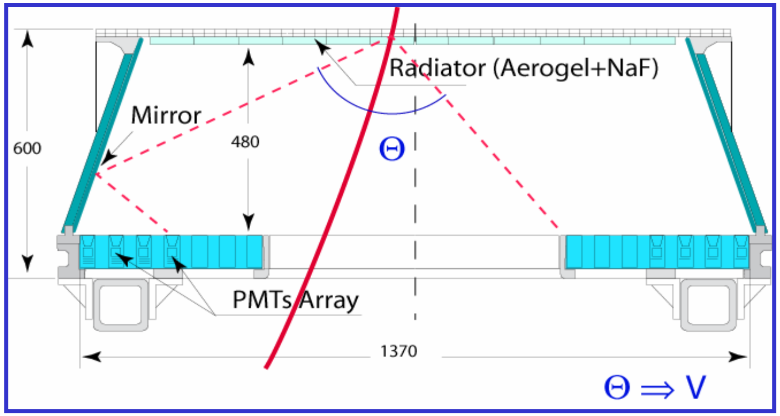
Ring Imaging Čerenkov Counter

- Z measurement
- Precise measurement of velocity $\delta\beta/\beta \sim 0.1\%$ from čerenkov cone opening angle
- Combined with p from tracker, allow isotopic separation of nuclei up to A<25 and p<12 GeV/c/N
- Albedo rejection

- Dual solid radiator configuration Aerogel (n=1.035, 3cm thick, threshold 3 GeV/c) and NaF (n=1.33, 0.5cm thick, threshold 1 GeV/c) to extend energy range
- High accuracy mirror to improve light collection
- 680 PMT's multianodes (16 pixels). Granularity $(8.5mm)^2$





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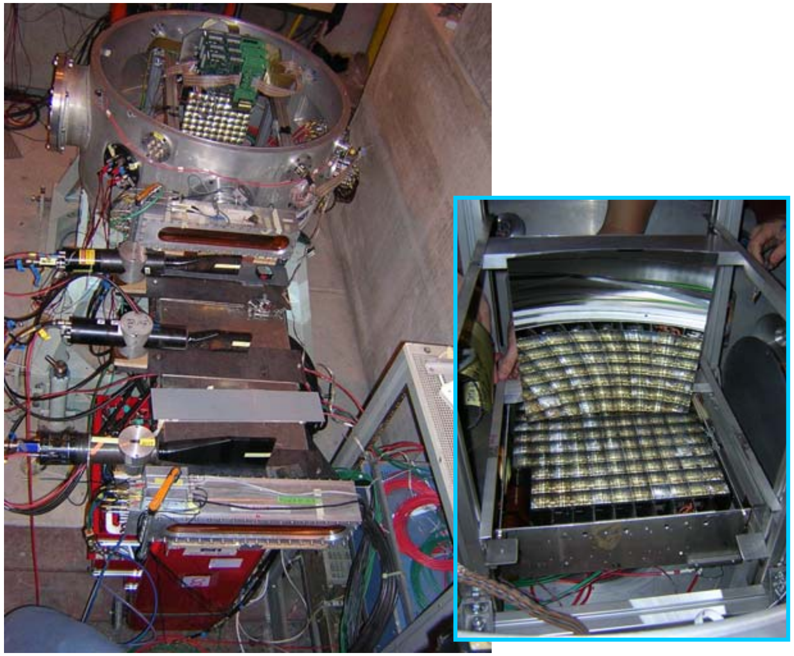
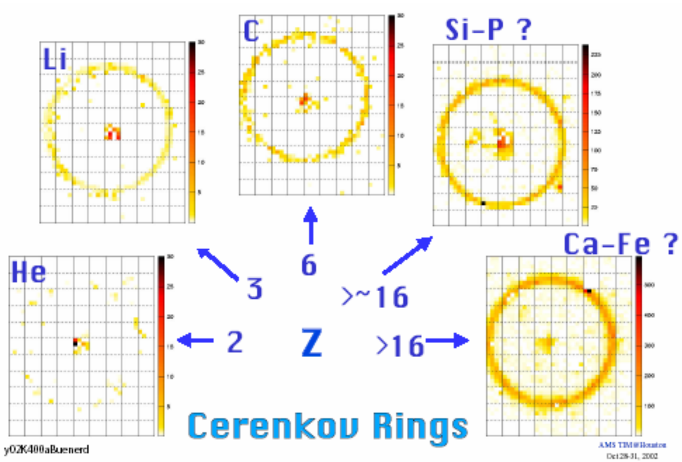
RICH PERFORMANCES (TEST BEAM)

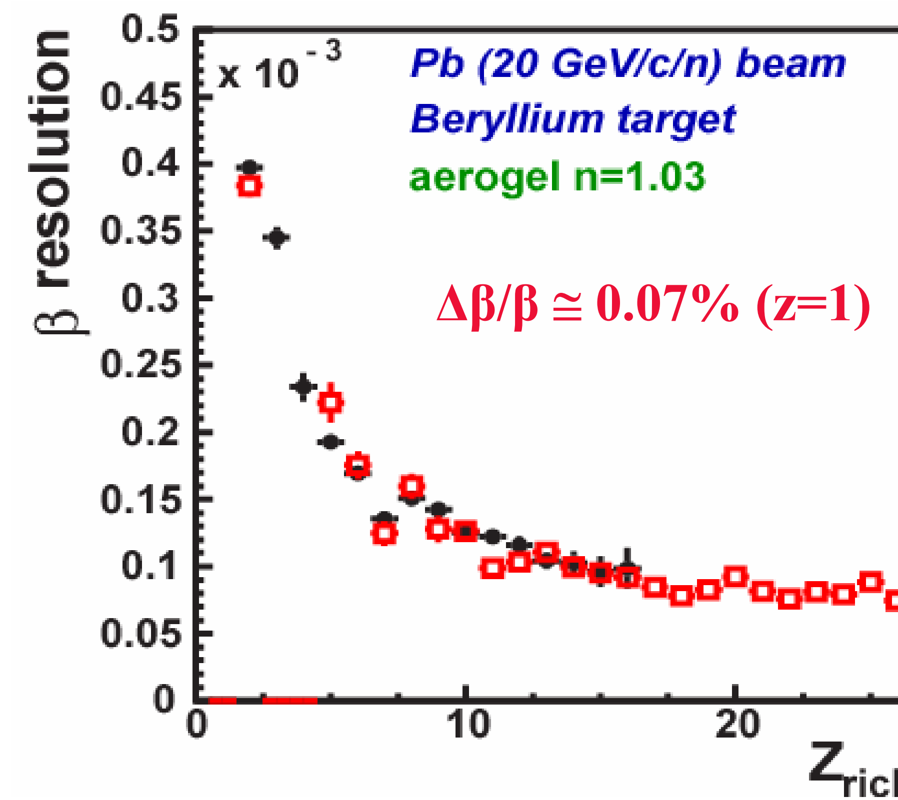


Experimental Setup in the Test beam and closeup view of the mirror system and PM's



Raw data from test beam

Resolution on velocity for nuclei up to Z=25



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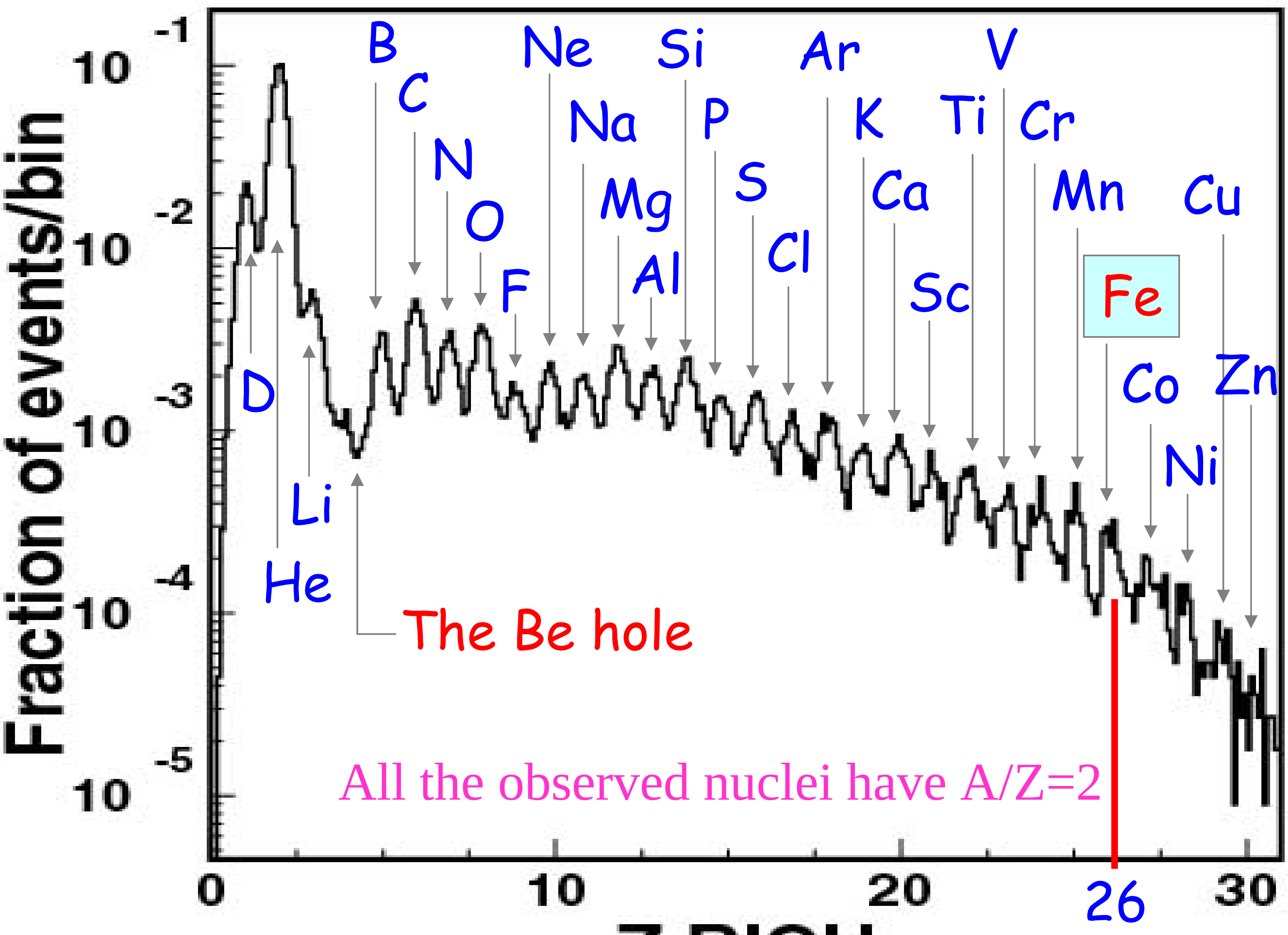
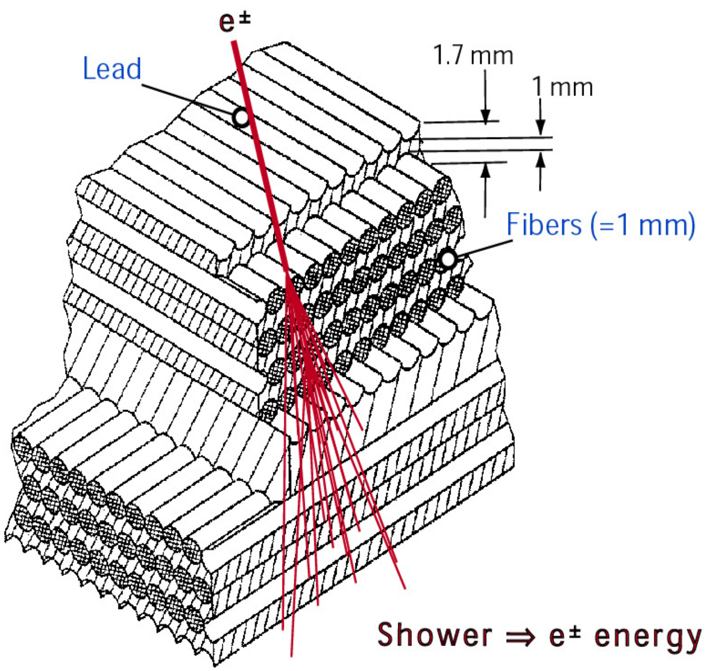
RICH reconstructed charge spectrum



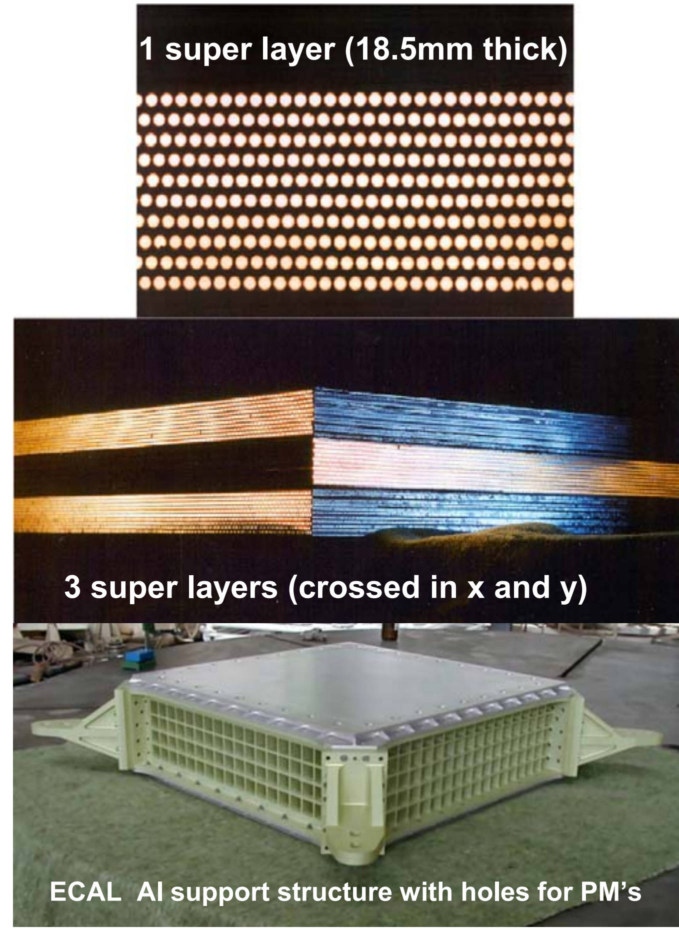
3D IMAGING ELECTROMAGNETIC CALORIMETER (ECAL)

Lead/fibers sandwich
9 super layers
(size 65.8x65.8cm^2, thick 18.5mm each)

16.5 Xo (Xo ≅ 1 cm)
18 samplings in depth
Lateral granularity 0.9 cm
(0.5 moliere radius)

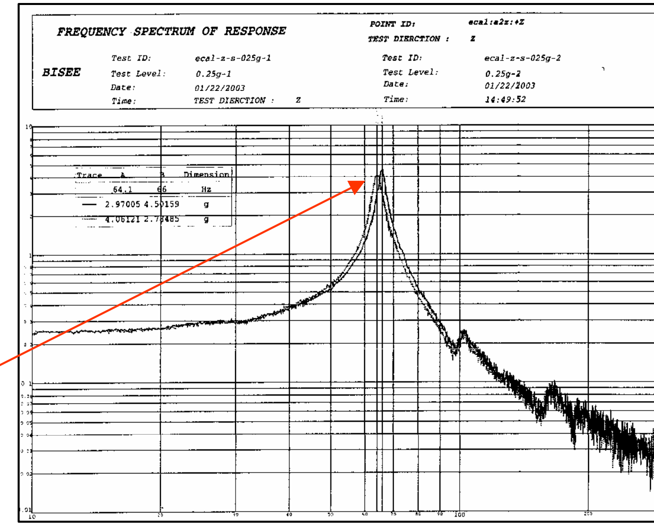


Measures energy and angle of γ, e+,e- from 1 GeV up to a few TeV



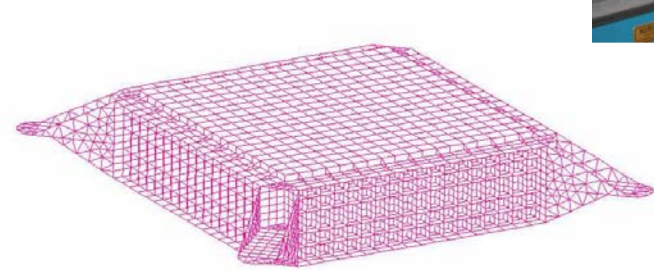
10^{-3} p$^{\pm}$ Rejection at 95% e$^{\pm}$ Efficiency Via Shower Profile

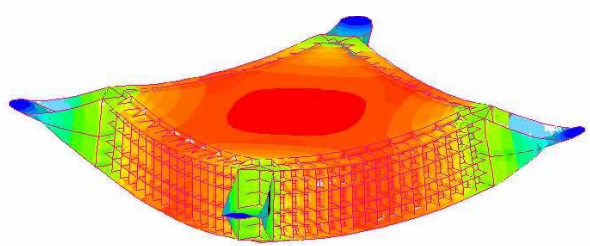
SPACE QUALIFICATION TESTS. BEIJING. 01/2003



First eigenfrequency
At 65 Hz

FEA Model

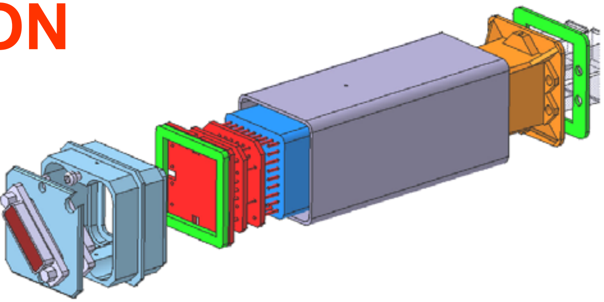




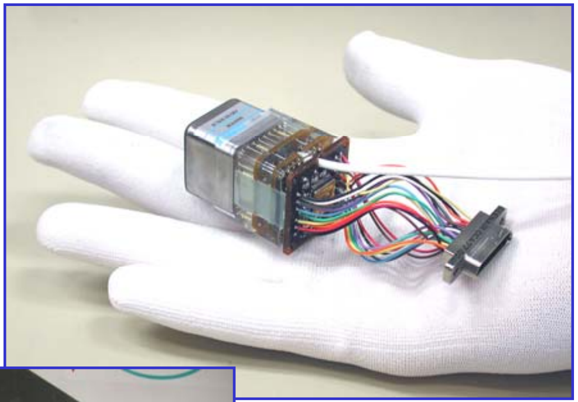
Calculation :
1st vibration mode at 69 Hz

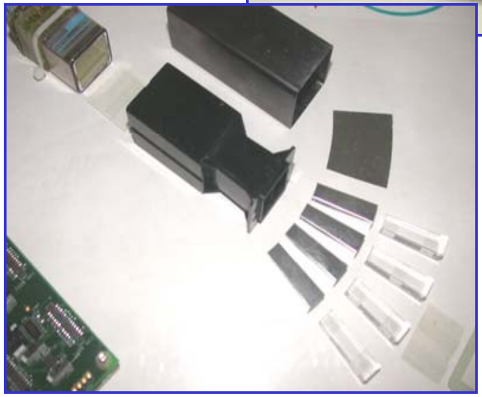
ECAL AND MODEL VALIDATED

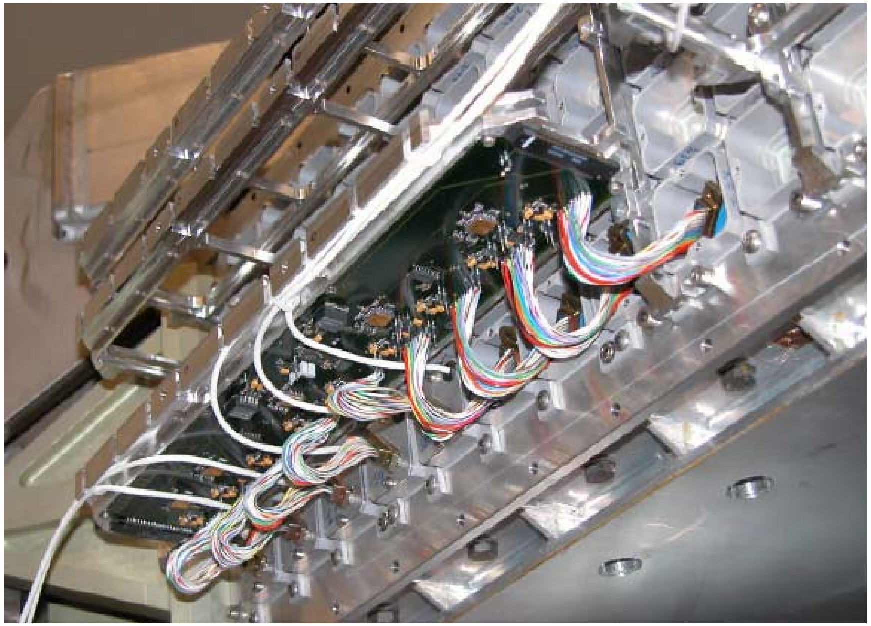
ECAL INSTRUMENTATION



- Fibers read by 324 4-pixels pmt's
- FE readout electronics with ASIC 60 000 dynamic range
- Stand alone γ trigger for physics of high energy cosmic gamma rays



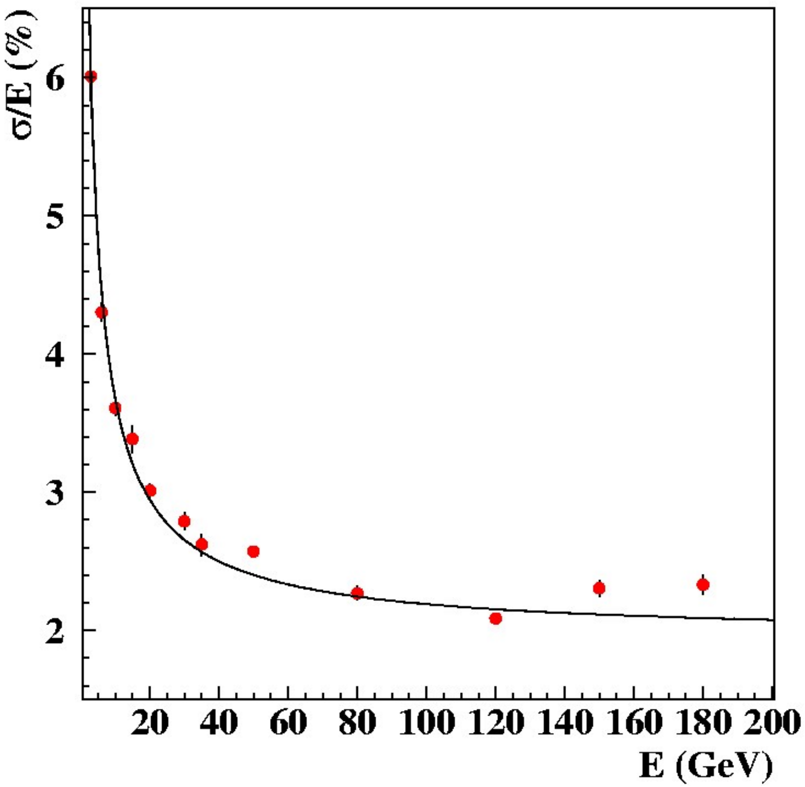


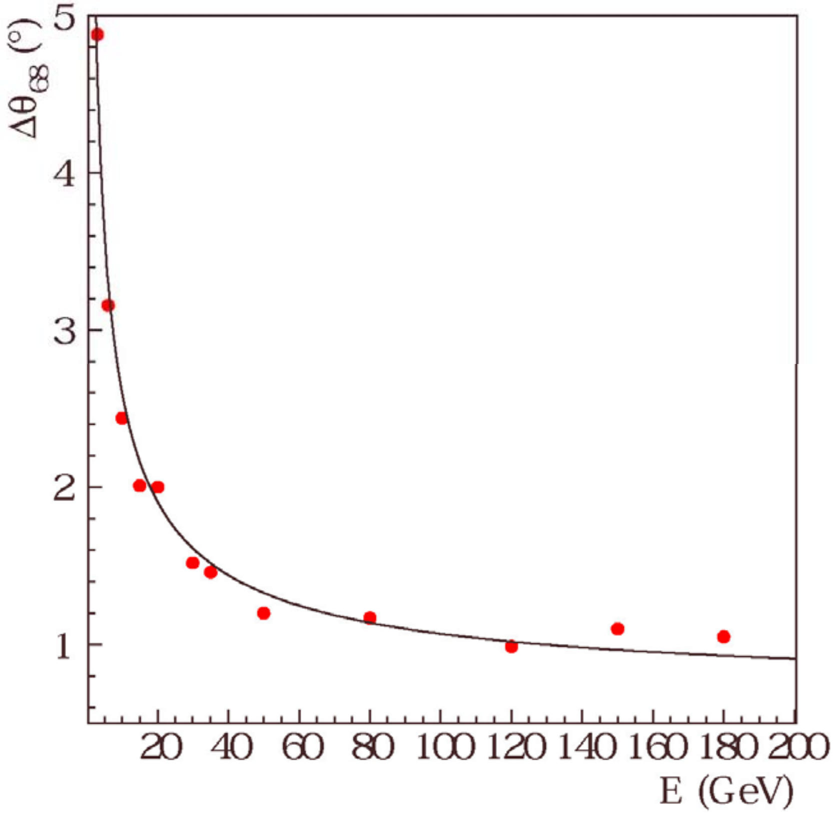


Light collection system with
Front end electronics

ECAL equipped for test beam
Space qualification in Terni

ECAL ENERGY AND ANGULAR RESOLUTION (FROM BEAM)





$\sigma/E = (10.89 \pm 0.28)/\sqrt{E} \oplus (2.48 \pm 0.05)$ %

$\Delta\theta_{68} = (8.06 \pm 0.11)/\sqrt{E} \oplus (0.60 \pm 0.04)^{\circ}$ (at 68 % c.l.)

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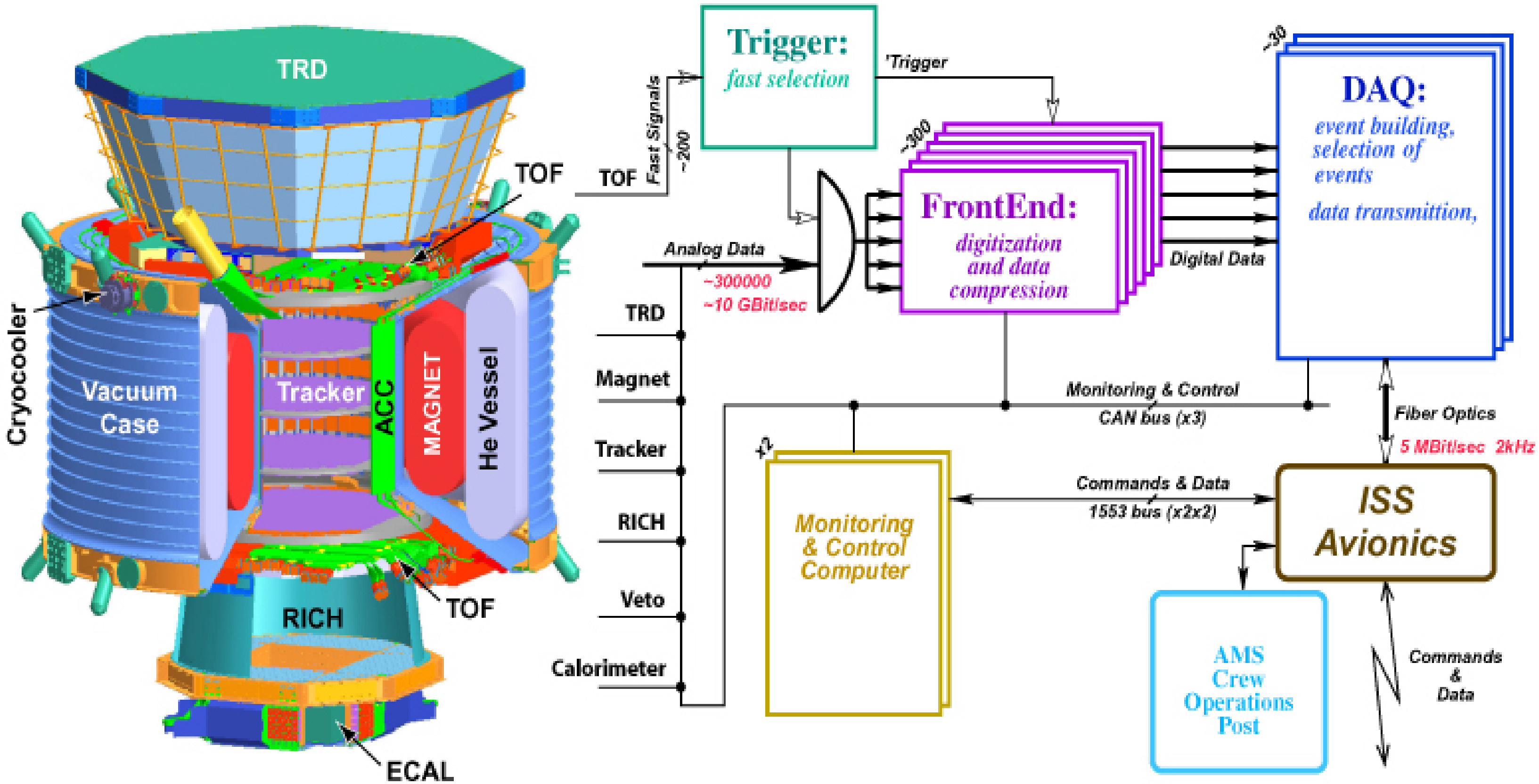
Overview of AMS-02 Electronics on the ISS



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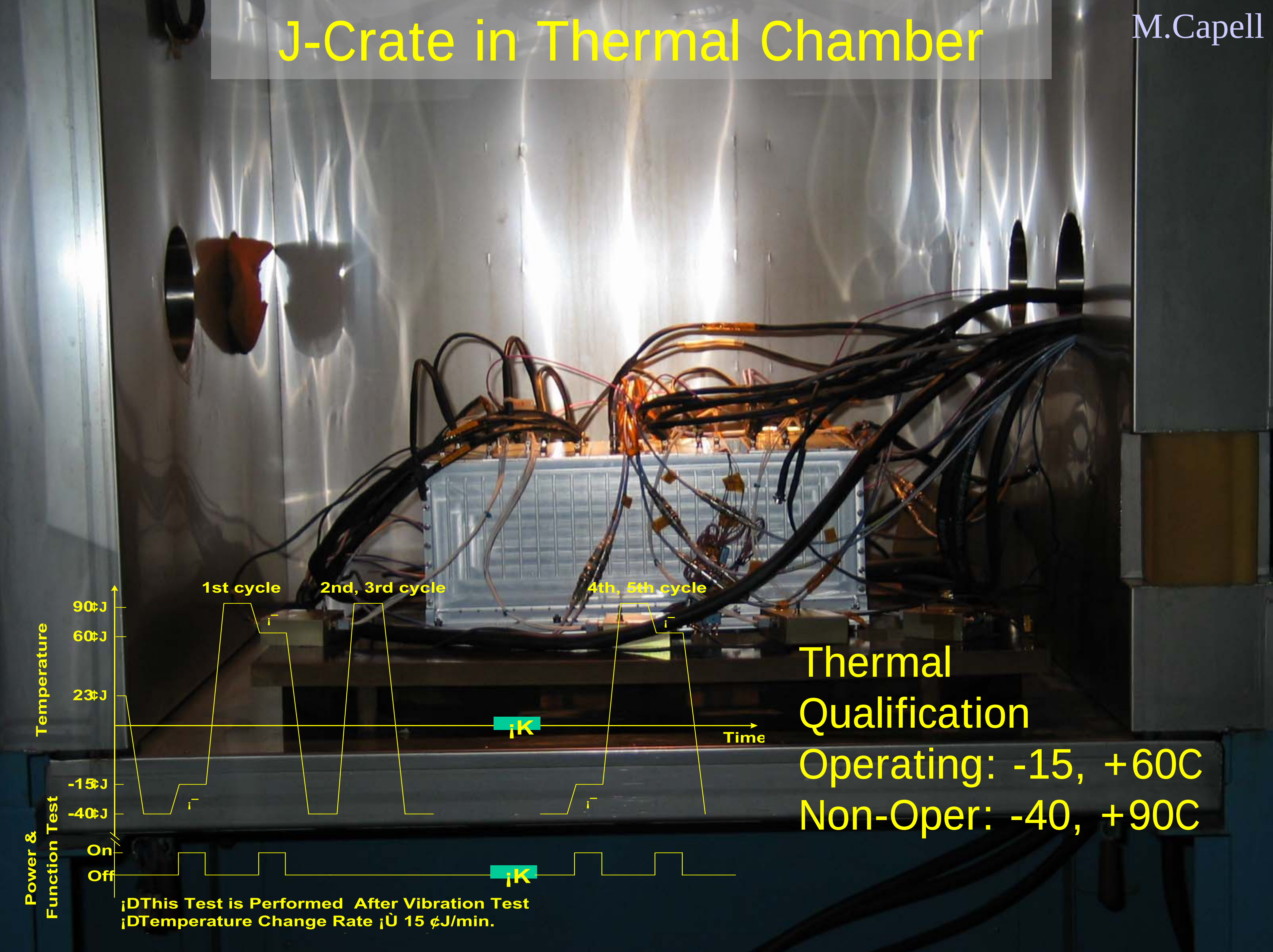
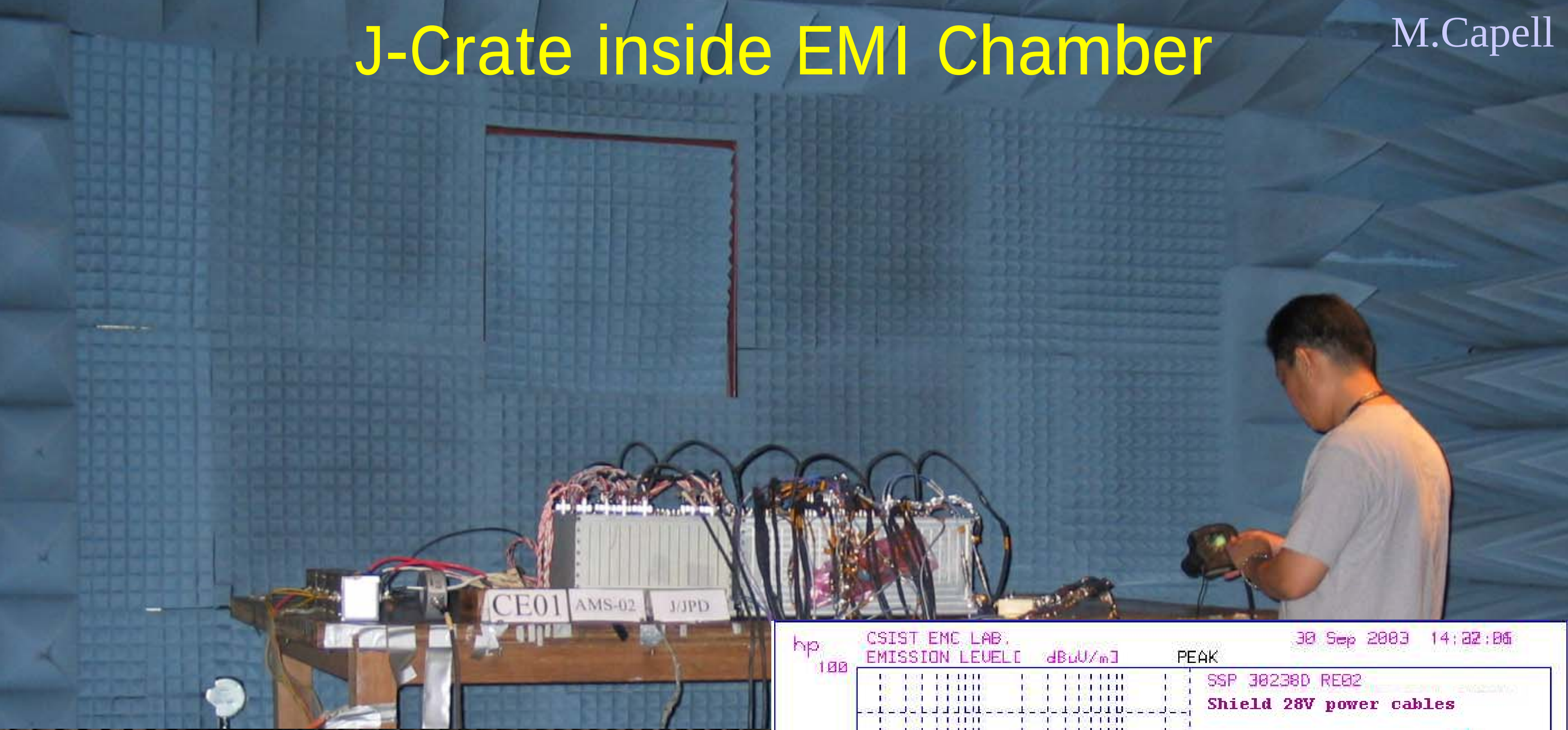
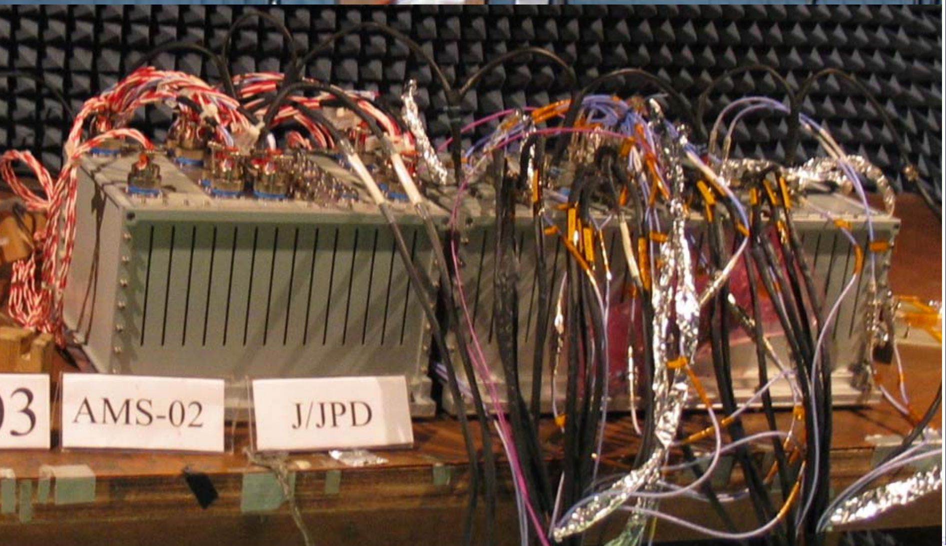
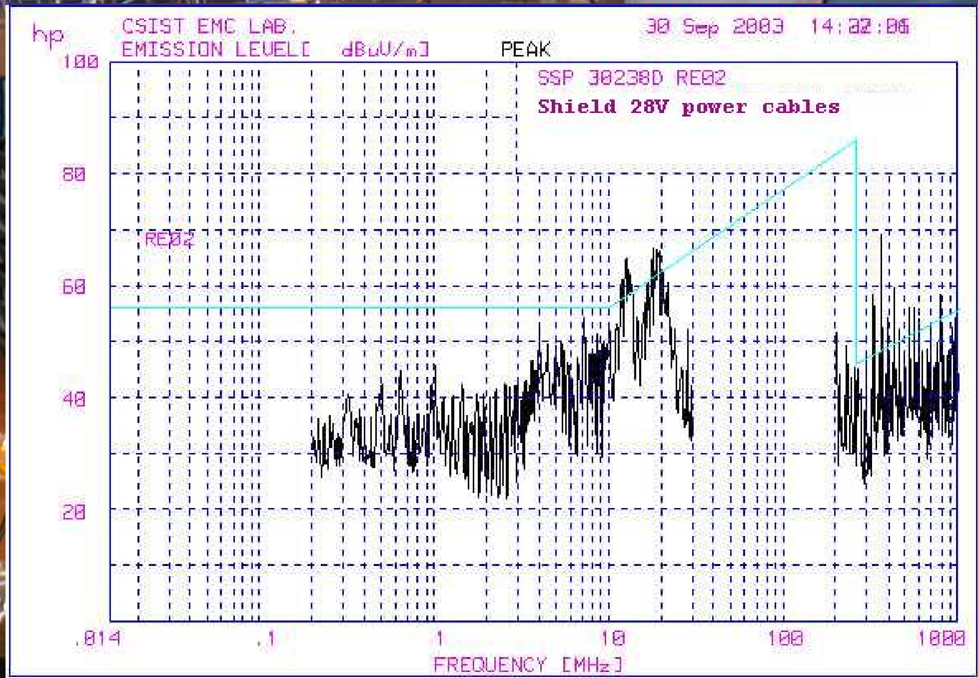

J-Crate in Thermal Chamber
M.Capell
1st cycle
2nd, 3rd cycle
4th, 5th cycle
90¢J
60¢J
23¢J
-15¢J
-40¢J
Temperature
Time
¡K
Power &
Function Test
On
Off
¡K
Thermal
Qualification
Operating: -15, +60C
Non-Oper: -40, +90C
¡DThis Test is Performed After Vibration Test
¡DTemperature Change Rate ¡Ù 15 ¢J/min.

J-Crate inside EMI Chamber

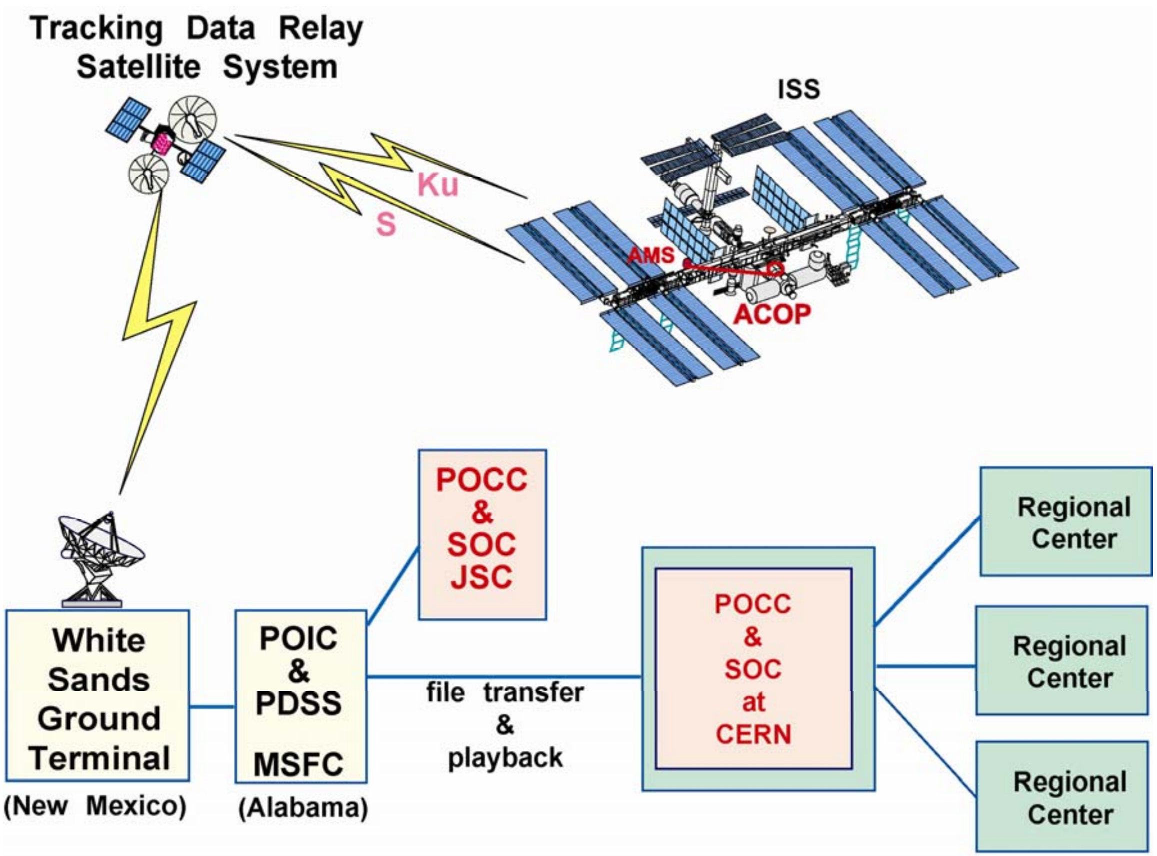
M.Capell







AMS DATA TRANSFER AND PROCESSING



2 Mbits/sec average science data downlink rate

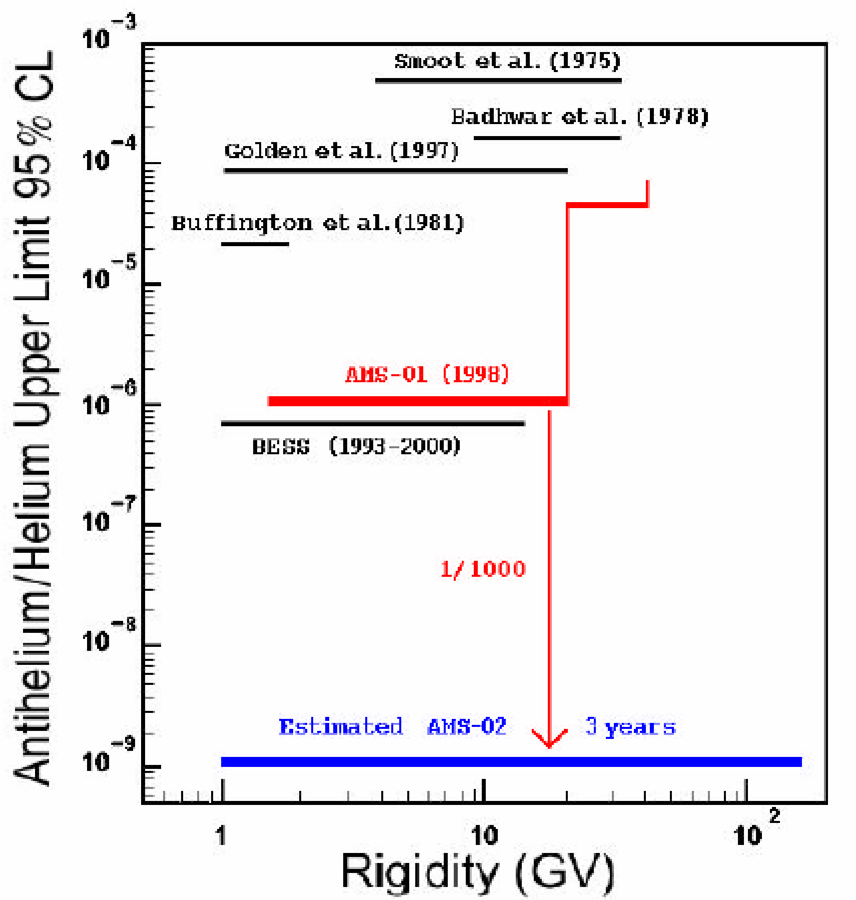
ACOP (AMS Crew Operation Post) allows ISS local storage and backup of data when downlink is off.

Main processing center at CERN

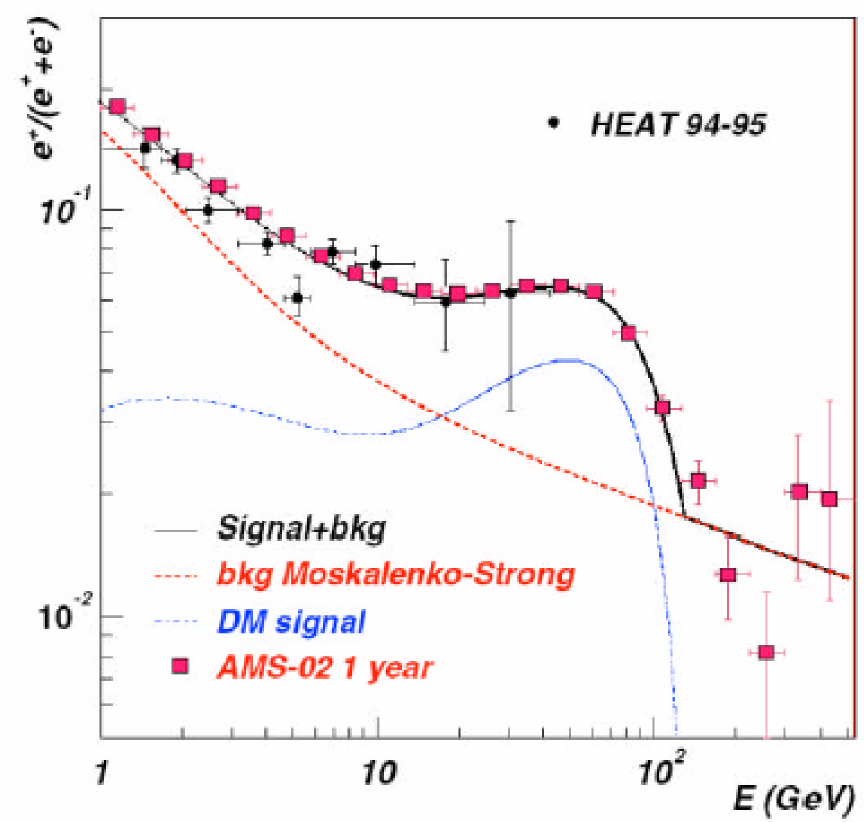
ACOP	AMS Crew Operation Post
POCC	Payload Operation Control Center
SOC	Science Operation Center
MSFC	Marshall Space Flight Center (Al)
JSC	Johnson Space Flight Center (Tx)

Physics performances of AMS-02

PRIMORDIAL ANTIMATTER
Limit on antihelium
1 year data taking



DARK MATTER
Positron spectra with neutralino
of mass 130.3 GeV/c2
1 year data taking



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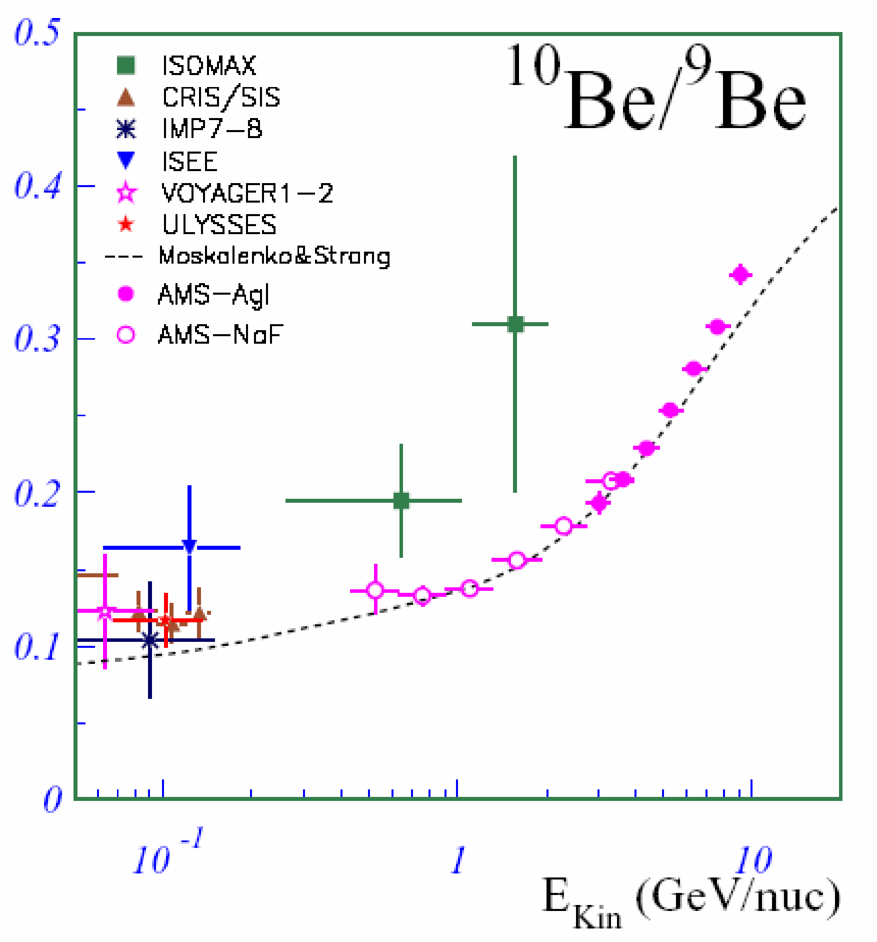
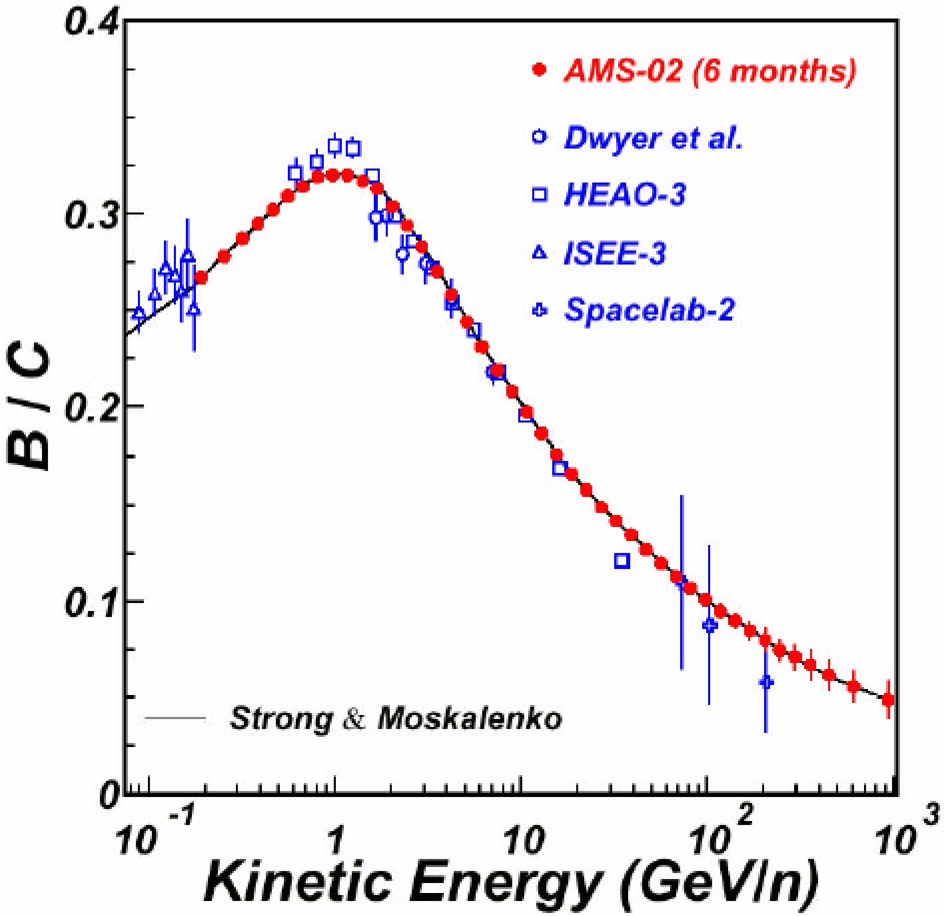
Measurement of Nuclei with AMS-02

Ratio $^{10}Be/^{9}Be$
1 year of data taking



Ratio B/C
6 months of data taking



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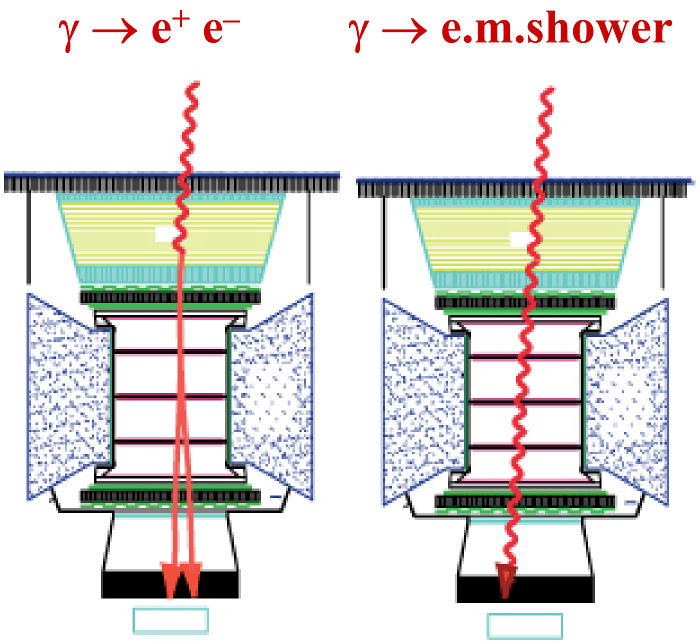
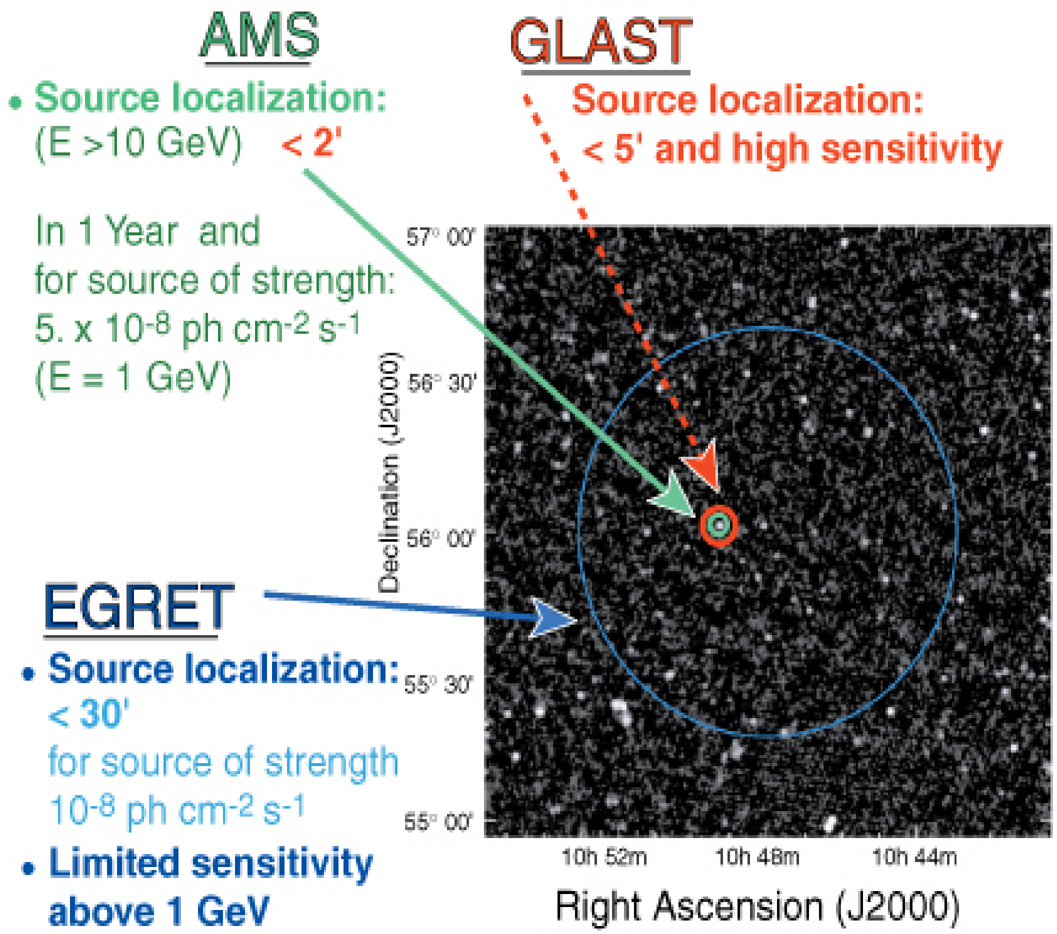
Unidentified Sources with AMS





AMS has a very high intrinsic resolution. Comprises a star tracker and a GPS for precise reference system

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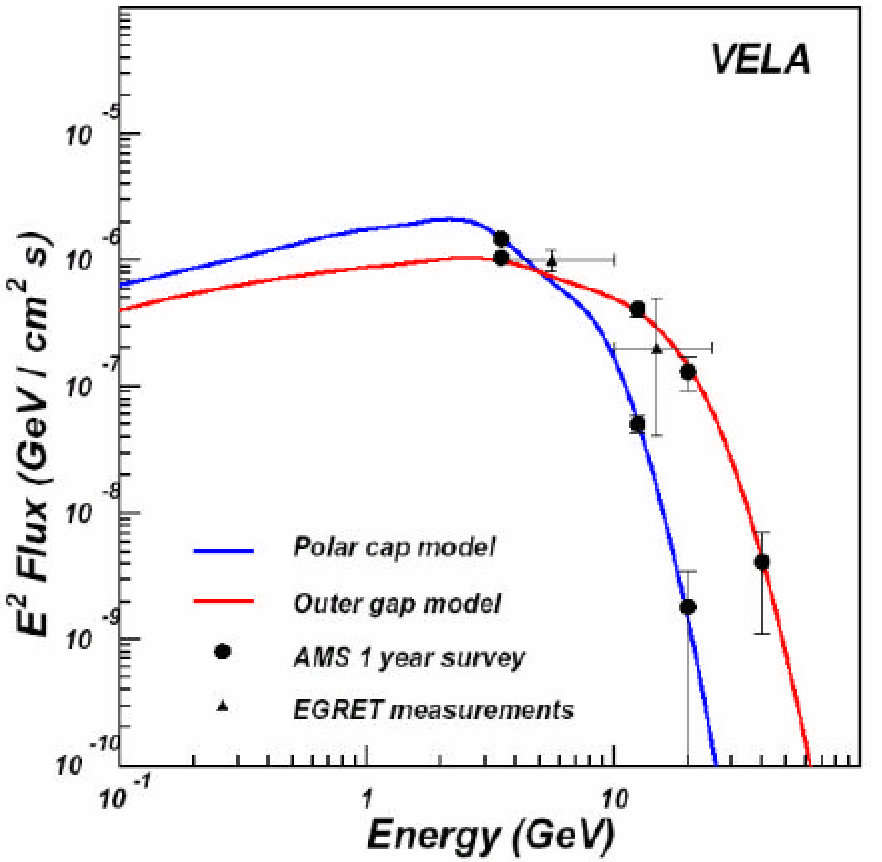
Gamma ray sources

COMPARISON OF PERFORMANCES
Complementarity between GLAST and AMS

Variable	EGRET	GLAST	AMS
Energy range	20MeV - 30GeV	20MeV - 300GeV	1GeV - 1TeV
Peak effective area (cm2)	1500	10 000	2 200
Energy Resol. (%)	10	<10	<3
Single photon Angular res.	2-3° (>1GeV)	<0.15 ° (>10GeV)	TRK : <0.8 ° (1GeV) <0.02 ° (100GeV)
F.o.V.	0.5Sr	3Sr	2Sr

EXEMPLE OF THE VELA PULSAR
1 year data taking
Allows to decide between polar cap and outer gap models



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CONCLUSIONS

- **Most of the sub-detectors will be ready by end 2004**
- **Detector integration in 2005**
- **Global Thermal-Vacuum test at ESA (Nordwijk, NL) end 2005 / beg. 2006**
- **Then AMS is ready for launch**

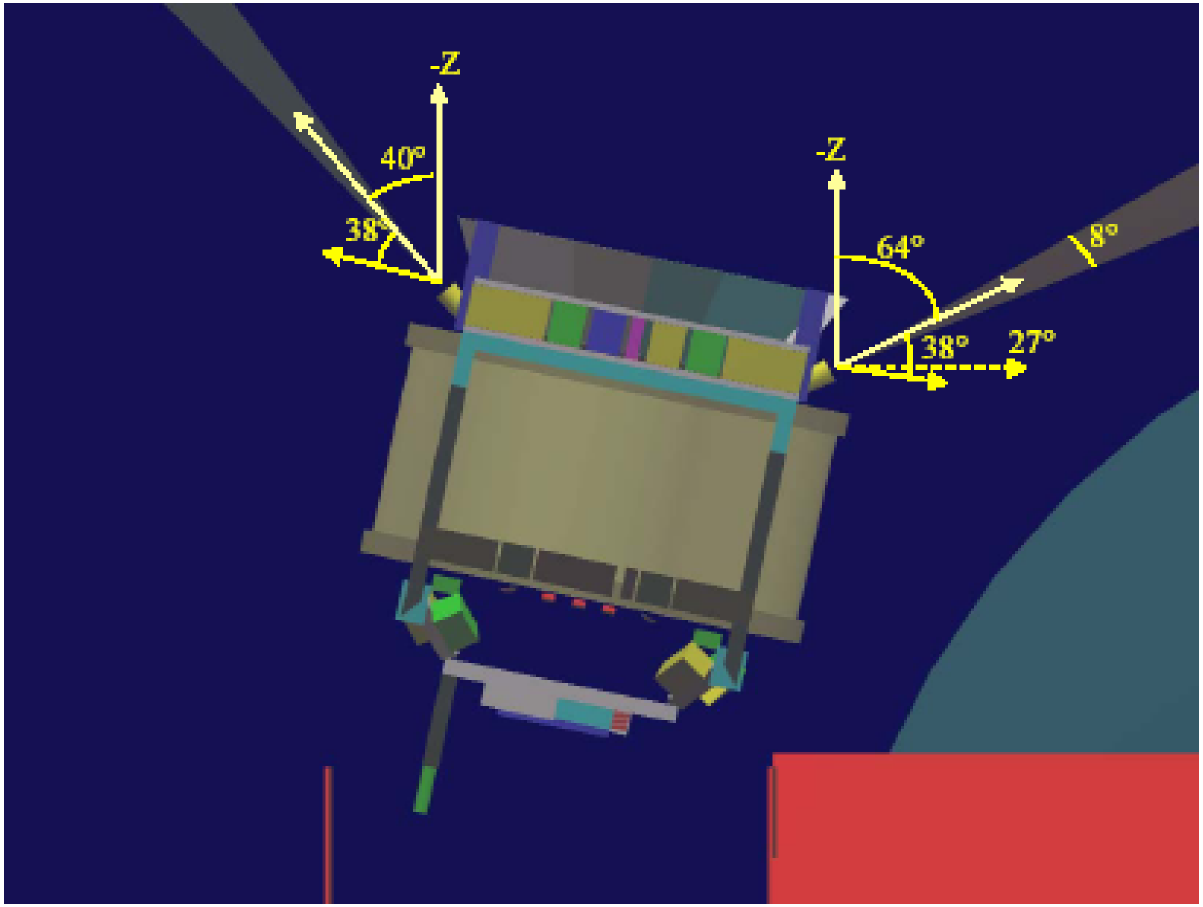
- **AMS02 will measure charged cosmic rays up to TV rigidity for 3 to 5 years on the International Space station as from 2007.**

  To search for:
  - **Antimatter**
  - **Dark Matter**
  - **Cosmic Ray Fluxes and propagation**
  - **High Energy γ sources**

- **All the physics channels are measured in the same conditions and simultaneously, which will give a strong constraint on models and increase the potential of discovery.**

AMS-02 on ISS (ARTIST VIEW)

Star Tracker



Angular resolution

30 arcsec

2 CCD Camera at 90°