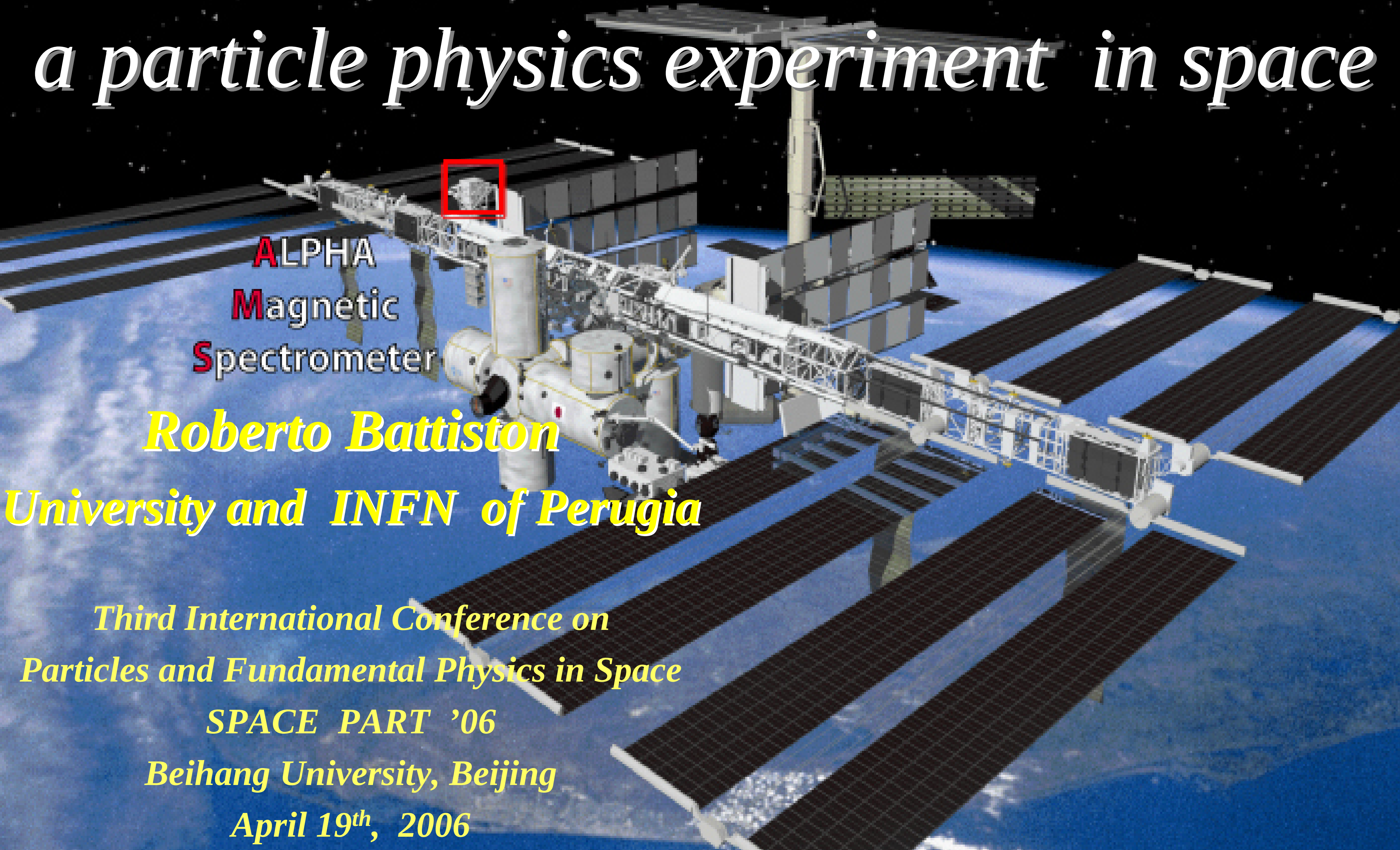
The AMS detector:
a particle physics experiment in space



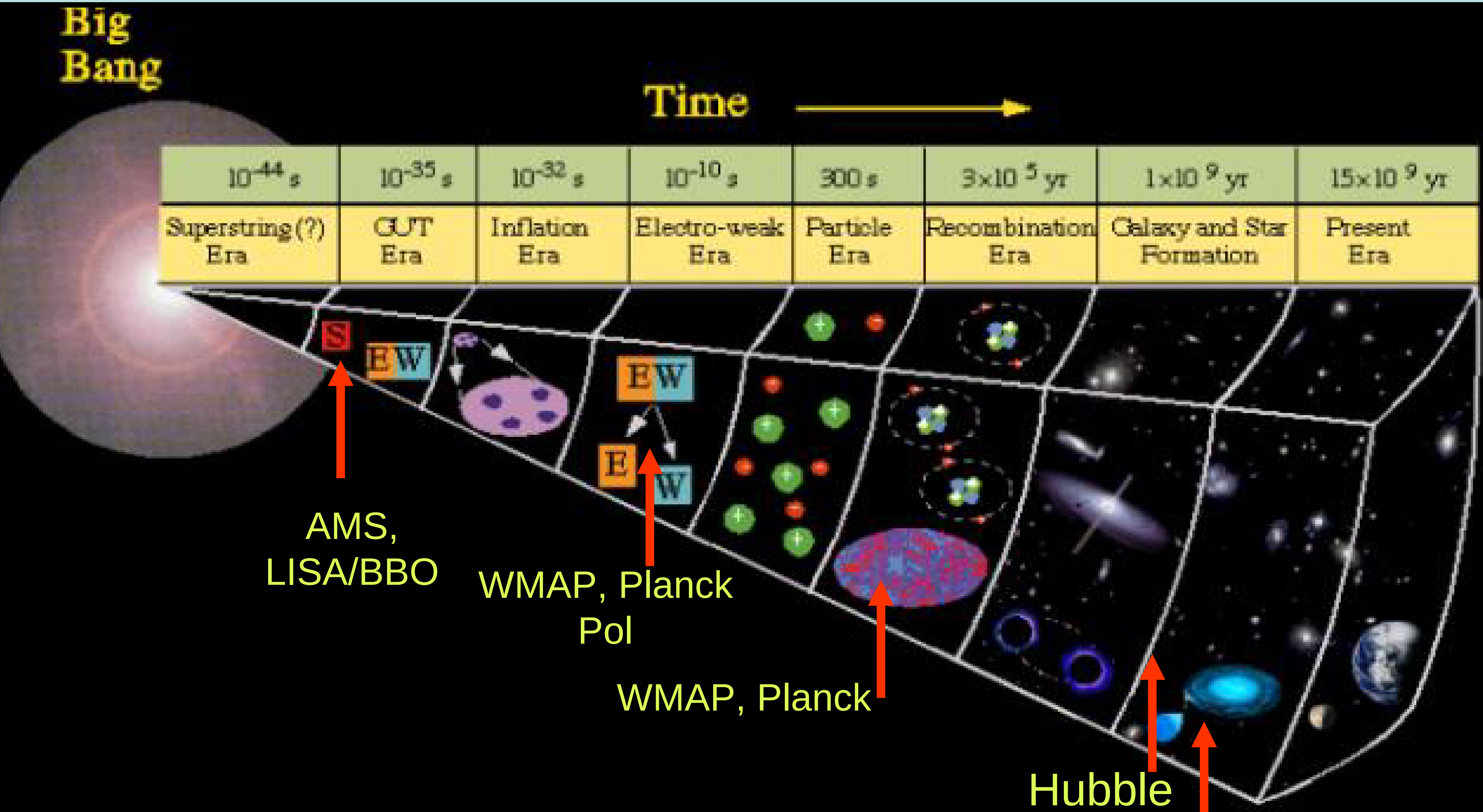
ALPHA
Magnetic
Spectrometer

Roberto Battiston

University and INFN of Perugia

Third International Conference on
Particles and Fundamental Physics in Space
SPACE PART ’06
Beihang University, Beijing
April 19th, 2006

The universe is the ultimate laboratory to study fundamental physics…….



10^{-44} s	10^{-35} s	10^{-32} s	10^{-10} s	300 s	3×10^{5} yr	1×10^{9} yr	15×10^{9} yr
Superstring(?) Era	GUT Era	Inflation Era	Electro-weak Era	Particle Era	Recombination Era	Galaxy and Star Formation	Present Era

AMS,
LISA/BBO

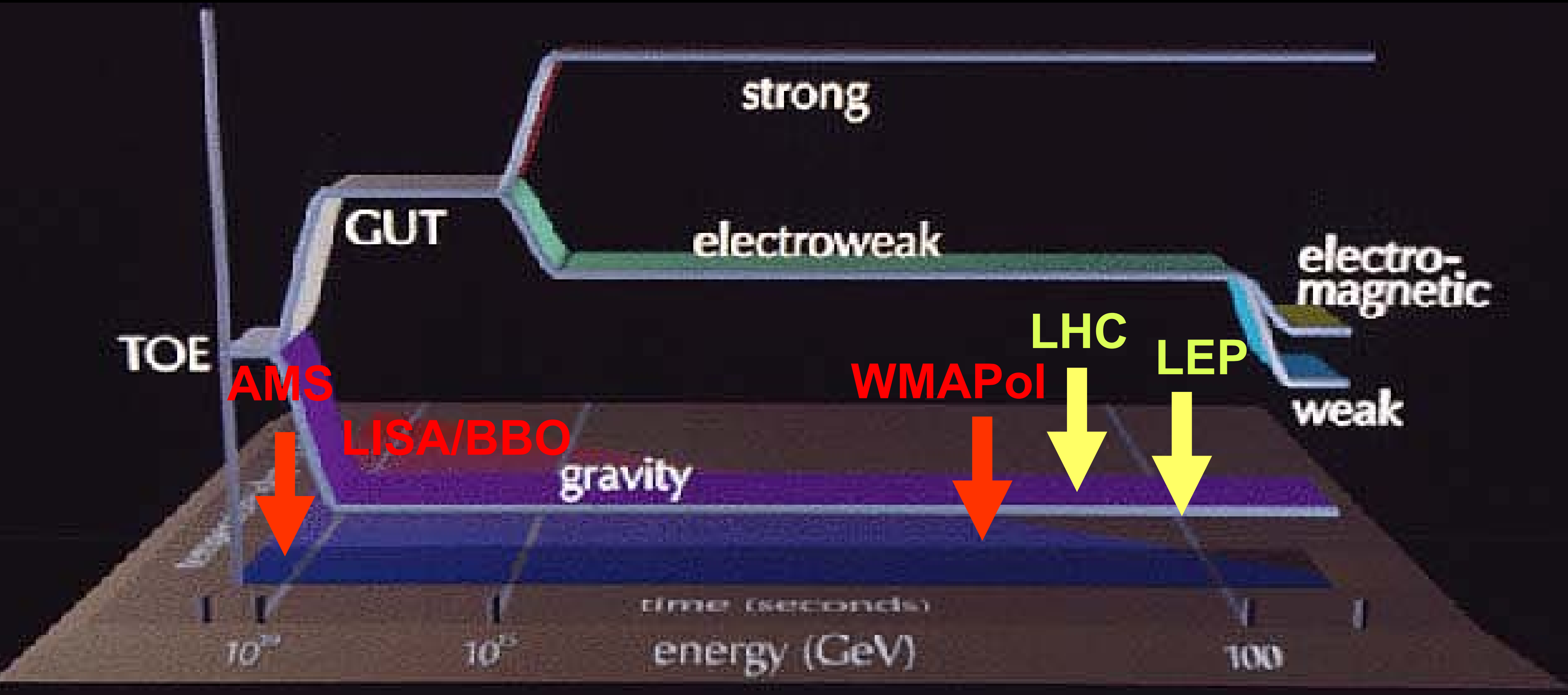
WMAP, Planck
Pol

WMAP, Planck

Hubble

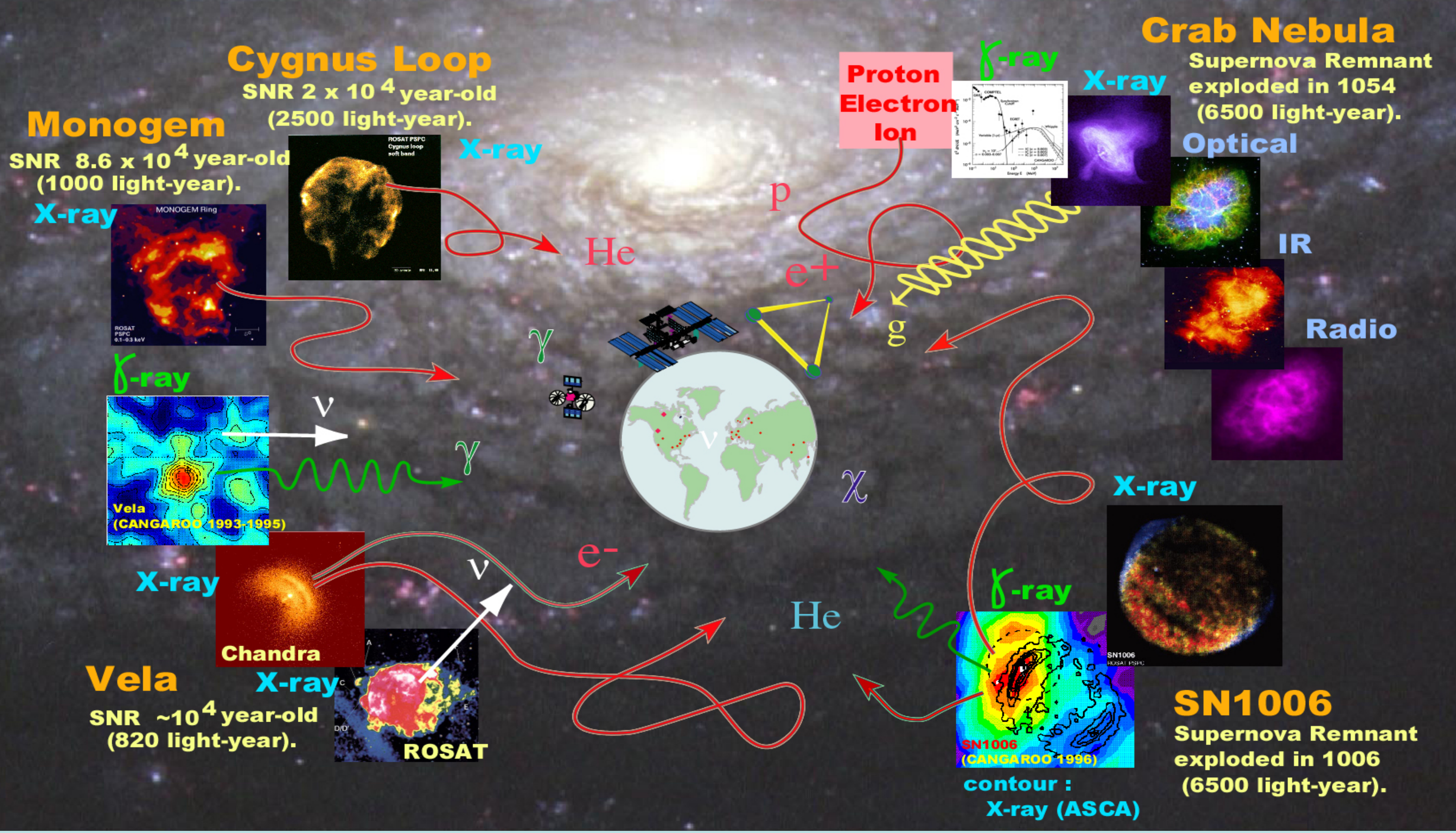
XMM, Swift, Chandra, LISA……

…….reaching energies which cannot be studied at accelerators………



10^{-44} s	10^{-35} s	10^{-32} s	10^{-10} s	300 s	
rstring (?) ra	GUT Era	Inflation Era	Electro-weak Era	Particle Era	F

High Energy Cosmic Rays in the Universe



Cygnus Loop
SNR 2 x 10 ^{4} year-old
(2500 light-year).

Monogem
SNR 8.6 x 10 ^{4} year-old
(1000 light-year).

Crab Nebula
Supernova Remnant
exploded in 1054
(6500 light-year).

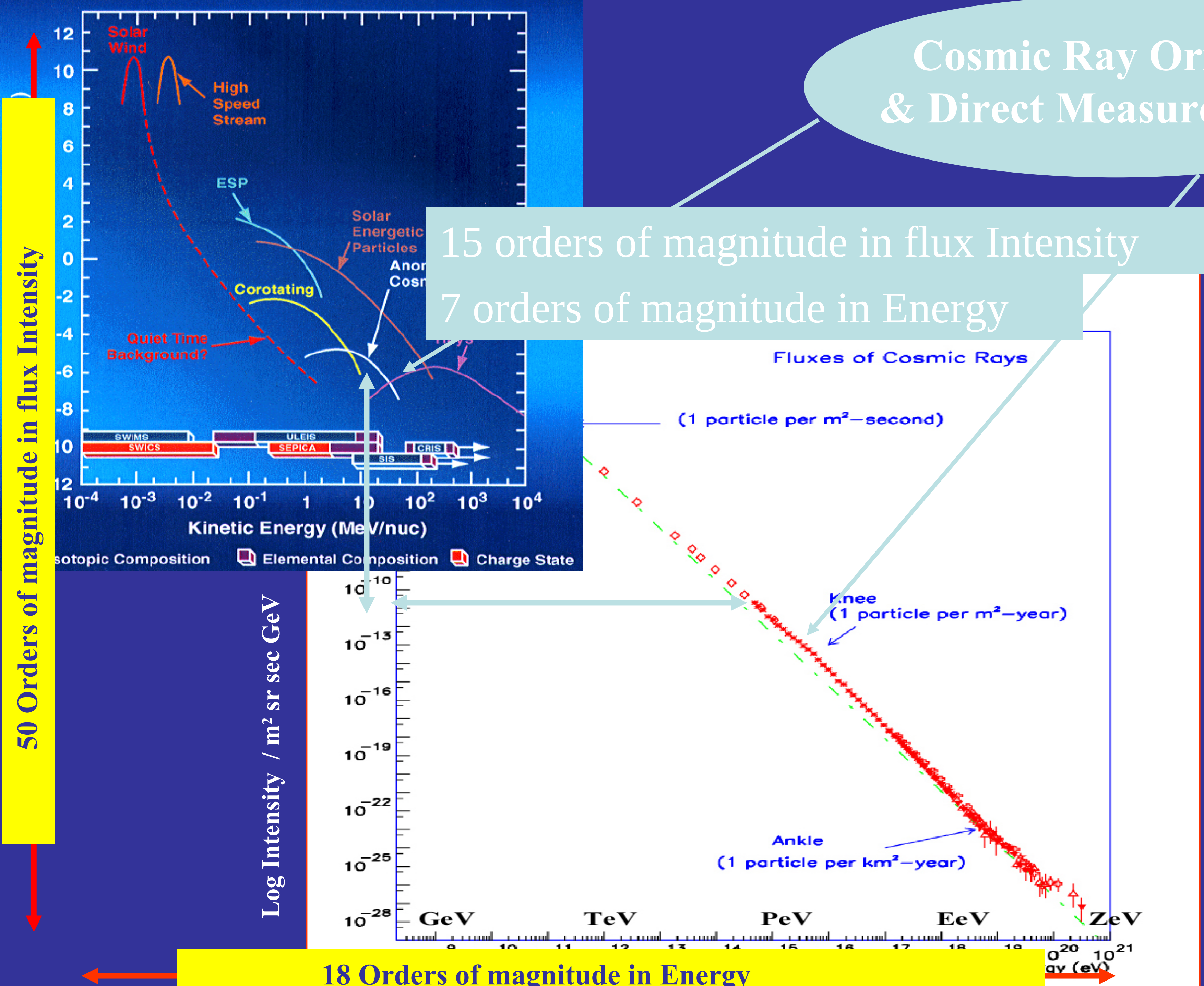
Vela
SNR ~10 ^{4} year-old
(820 light-year).

SN1006
Supernova Remnant
exploded in 1006
(6500 light-year).

contour :
X-ray (ASCA)

Messengers are photons, charged/neutral particles, gravitational waves…….

Cosmic Ray Origin & Direct Measurements



15 orders of magnitude in flux Intensity

7 orders of magnitude in Energy

50 Orders of magnitude in flux Intensity

Log Intensity / m² sr sec GeV

18 Orders of magnitude in Energy

The purpose of the AMS experiment is to perform accurate, high statistics, long duration measurements in space of

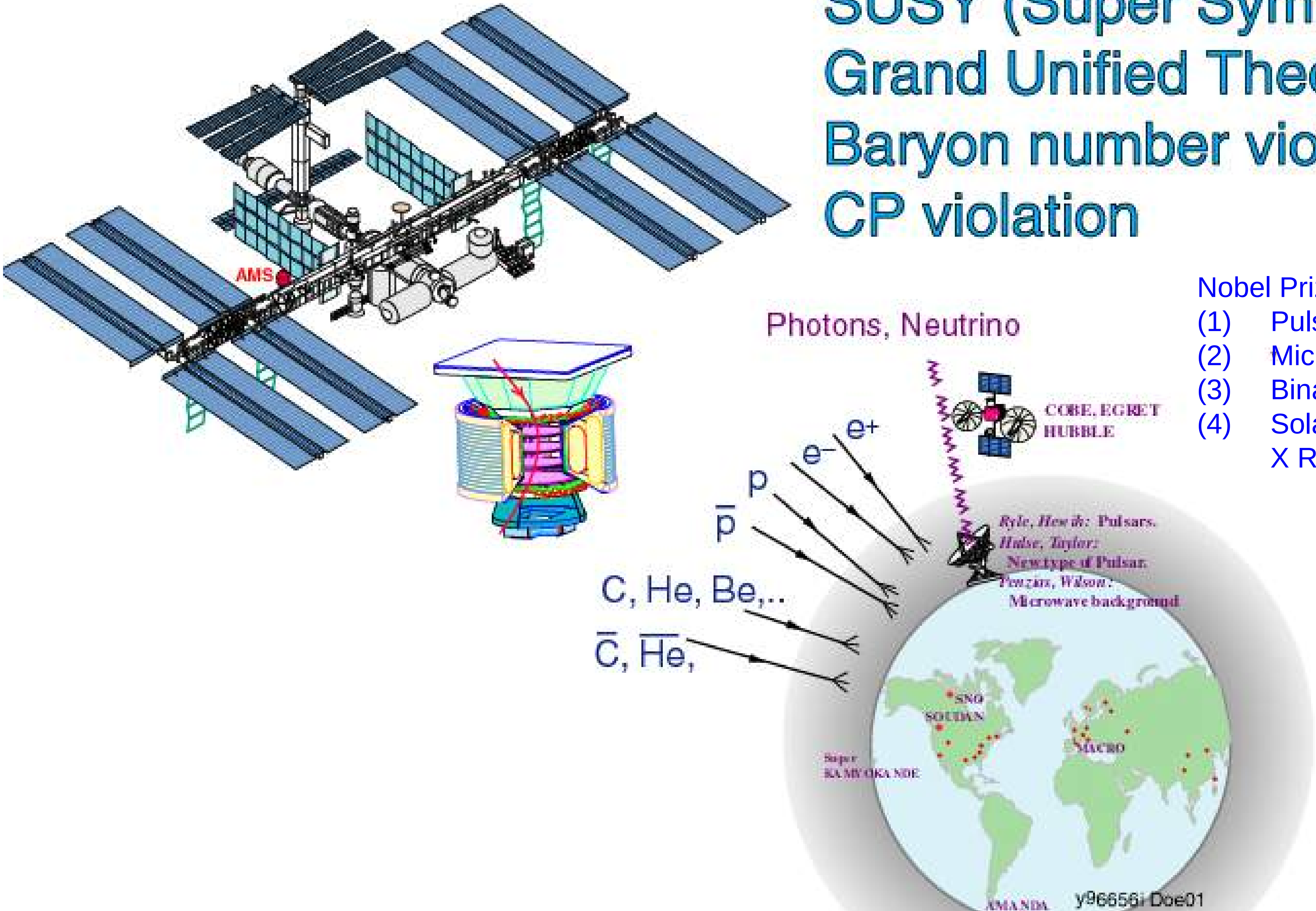
- **energetic (0.1 GV - few TV) charged CR**

- **energetic (>1 GeV) gamma rays.**

AMS is a particle physics experiment:

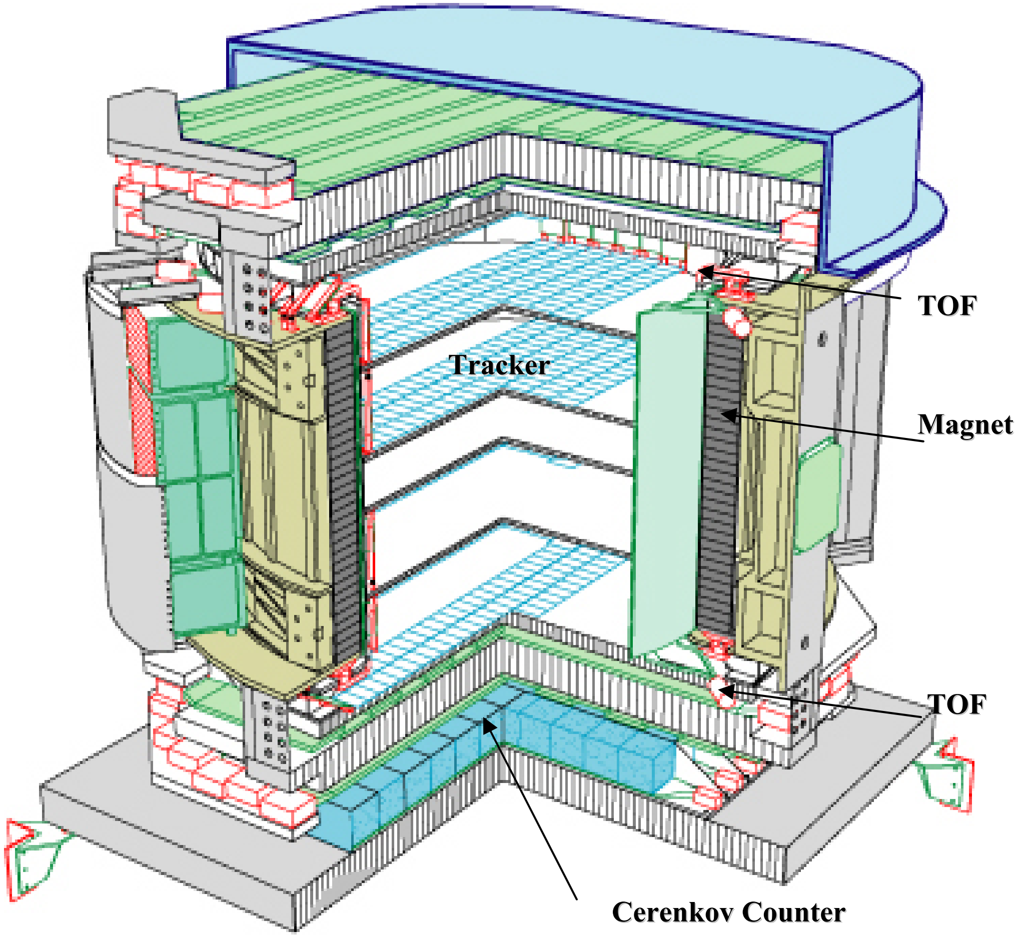
SUSY (Super Symmetry)
Grand Unified Theory
Baryon number violation
CP violation

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

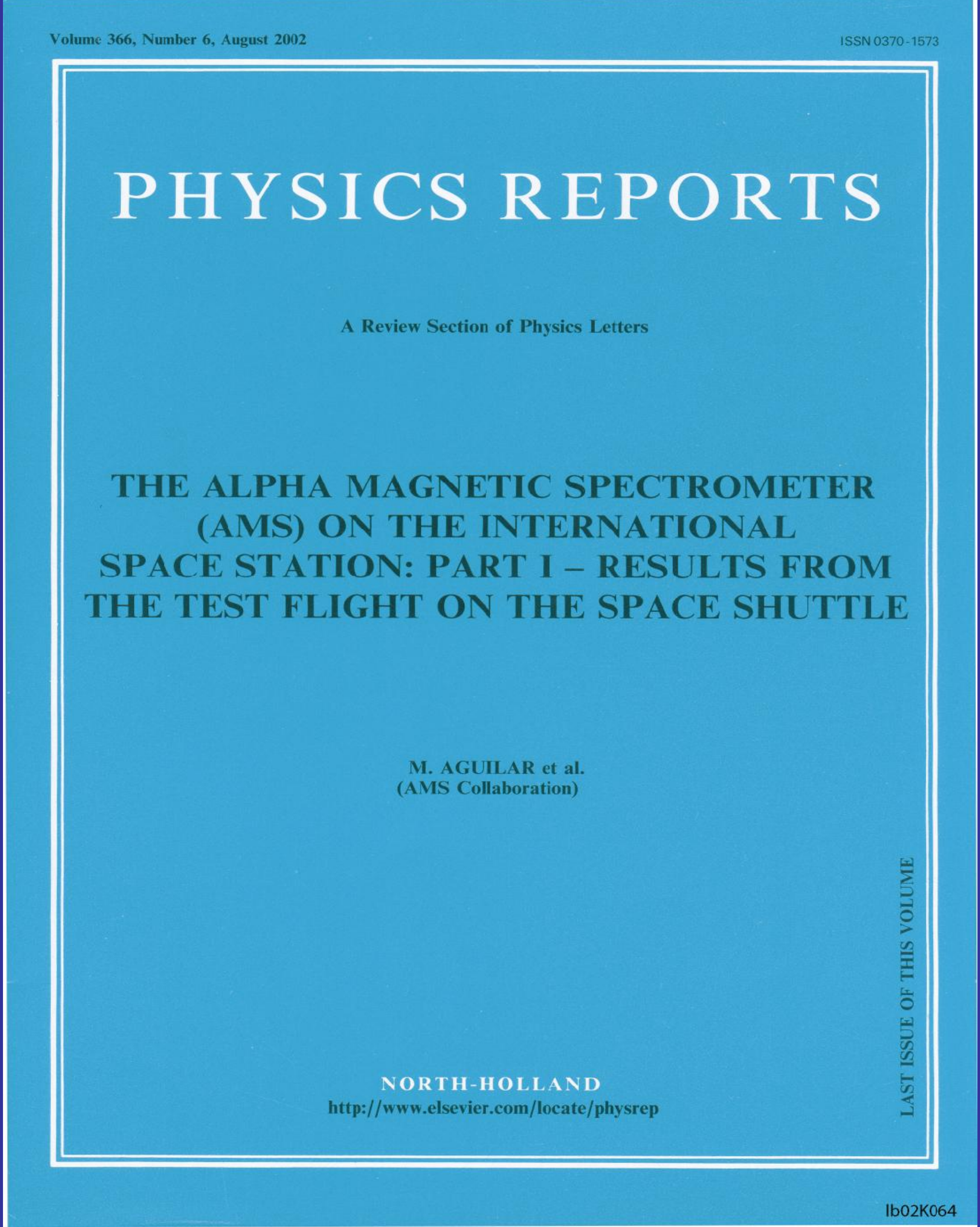


Alpha Magnetic Spectrometer - AMS-01

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



y99163_04c.ppt



Volume 366, Number 6, August 2002
ISSN 0370-1573

PHYSICS REPORTS

A Review Section of Physics Letters

THE ALPHA MAGNETIC SPECTROMETER (AMS) ON THE INTERNATIONAL SPACE STATION: PART I – RESULTS FROM THE TEST FLIGHT ON THE SPACE SHUTTLE

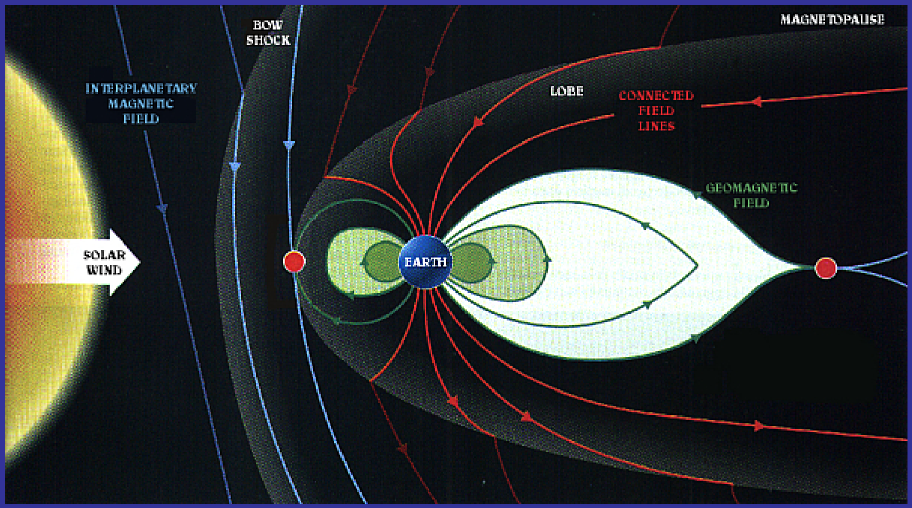
M. AGUILAR et al.
(AMS Collaboration)

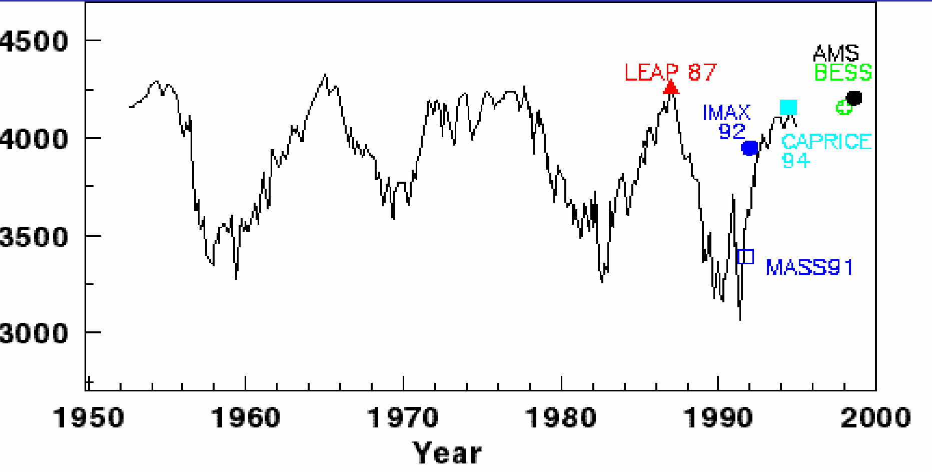
LAST ISSUE OF THIS VOLUME

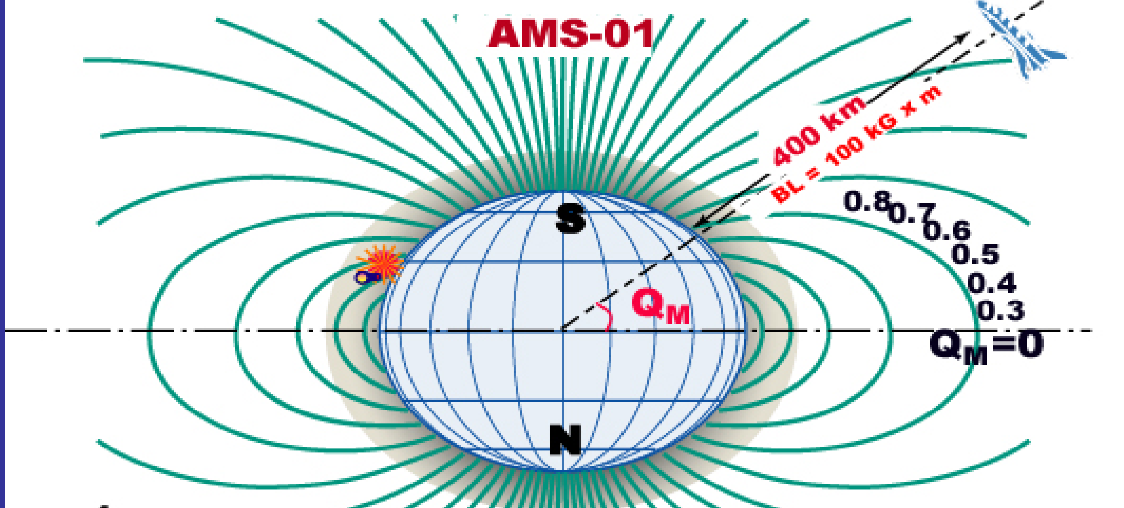
NORTH-HOLLAND
http://www.elsevier.com/locate/physrep

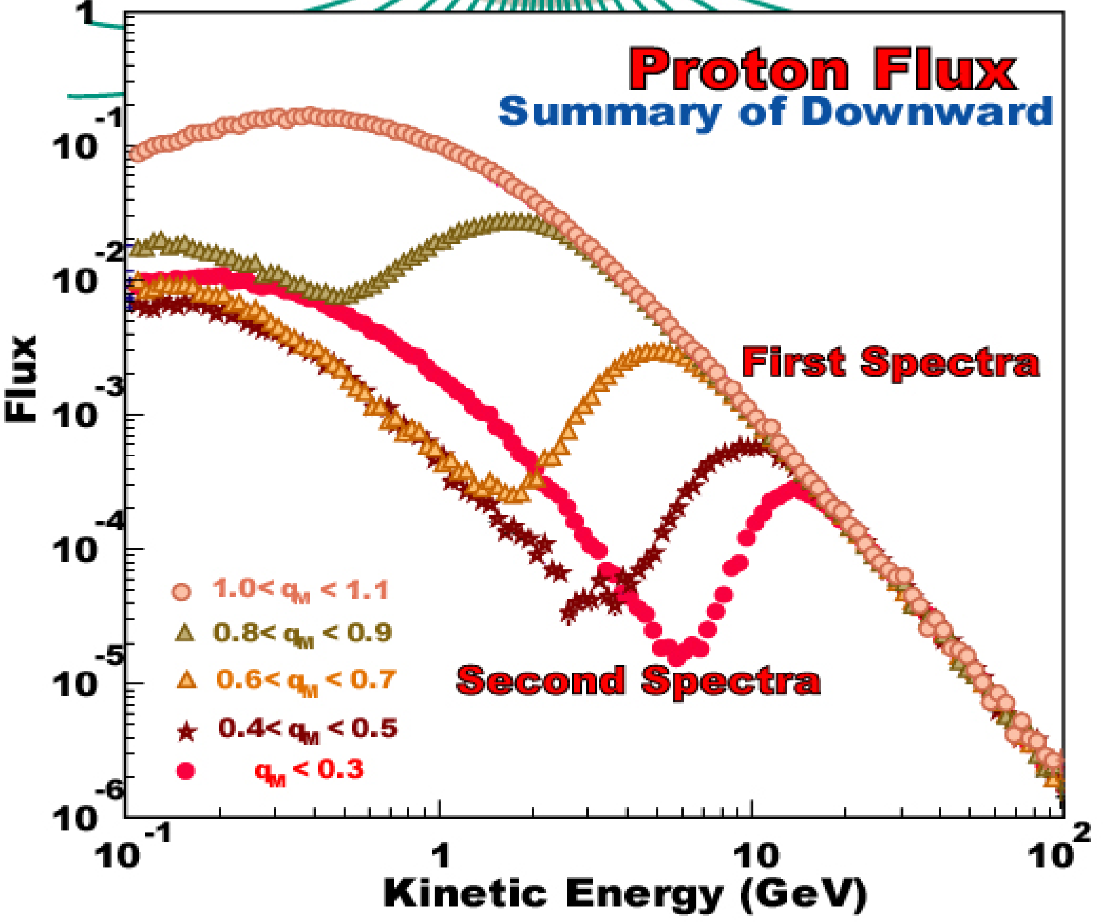
Ib02K064

Magnetosphere effects





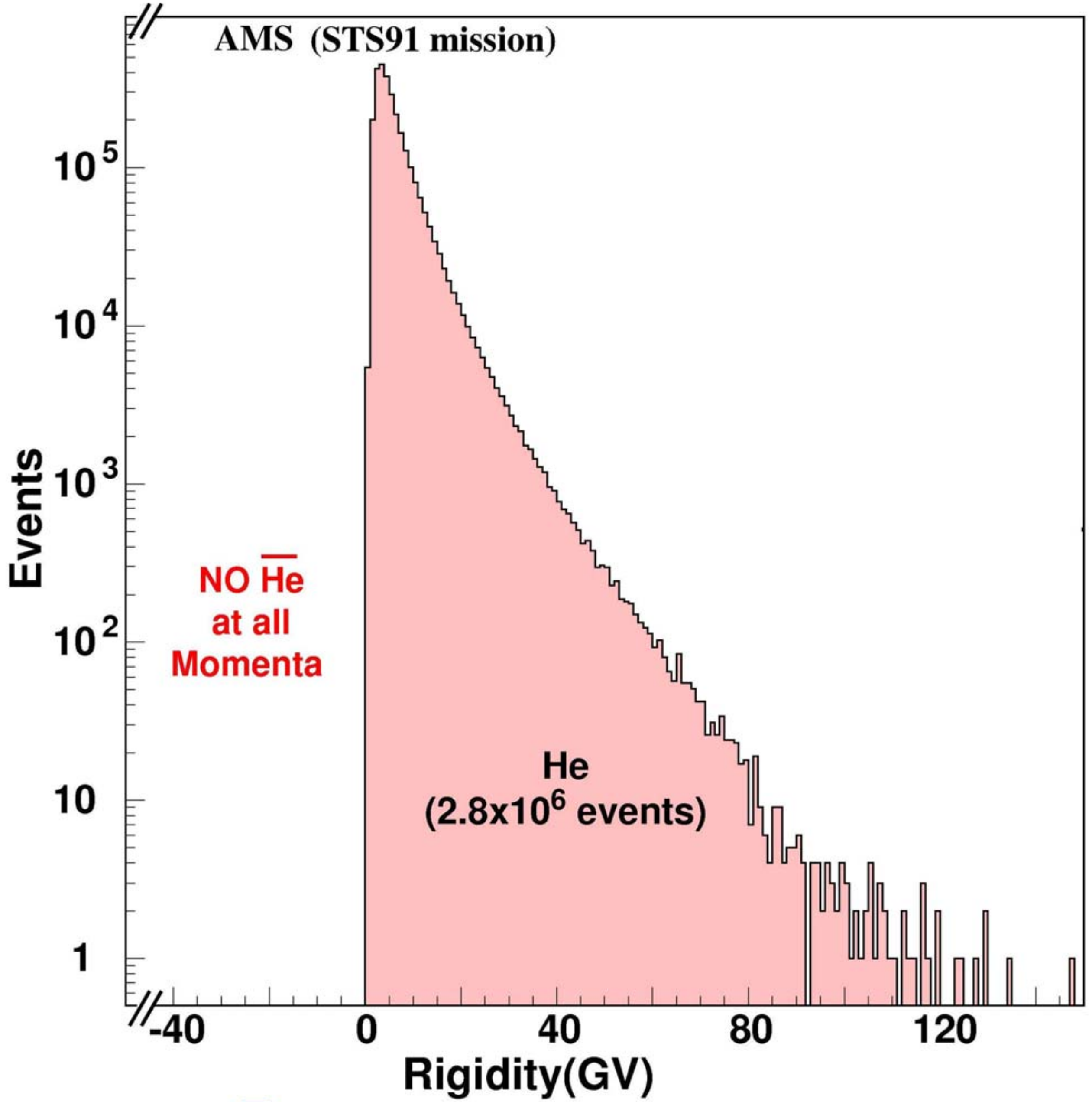




AMS has flown in space during a period of solar maximum

At low energy (below cutoff, up to R ~ 15 GeV) latitude dependence and solar modulation influence the spectra

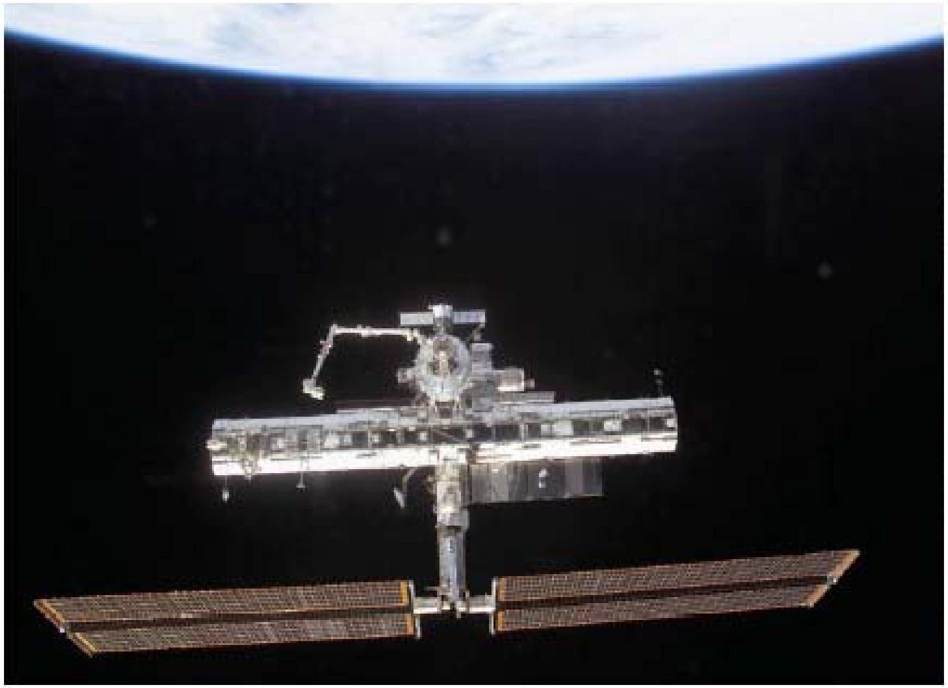
At high energy (above R~ 20 GeV) the measurement of the primary flux should give the same result in experiments performed at similar solar activities (LEAP, IMAX, CAPRICE, BESS, AMS)



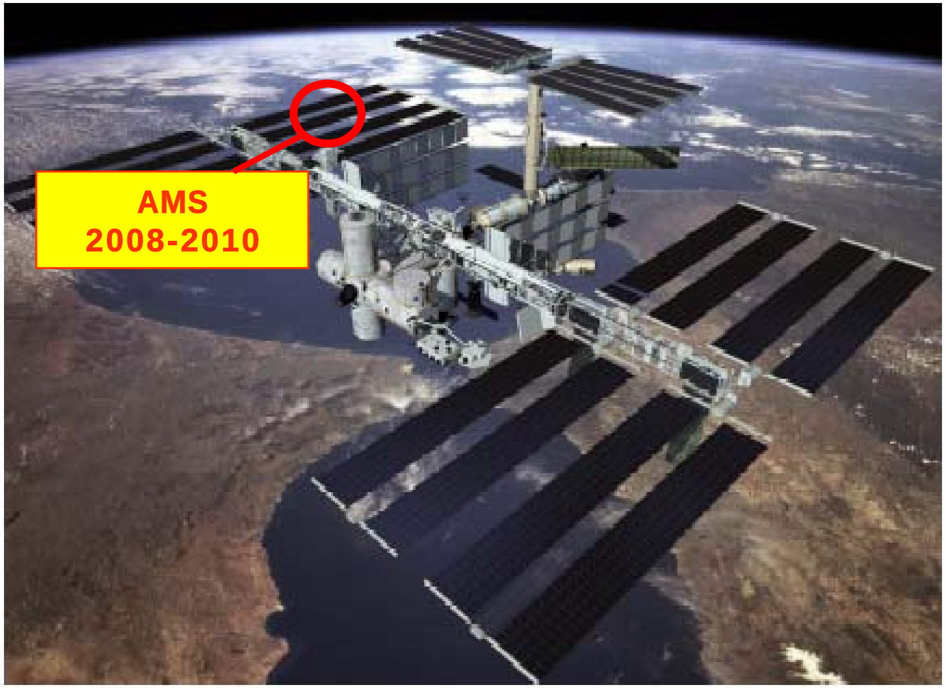
Assume $\overline{\text{He}}$ and He have the same spectrum up to 140 GV then $\overline{\text{He}}$ / He is < ~ 1.1 10^{-6}

International Space Station

February 2006
August 2005



Final configuration

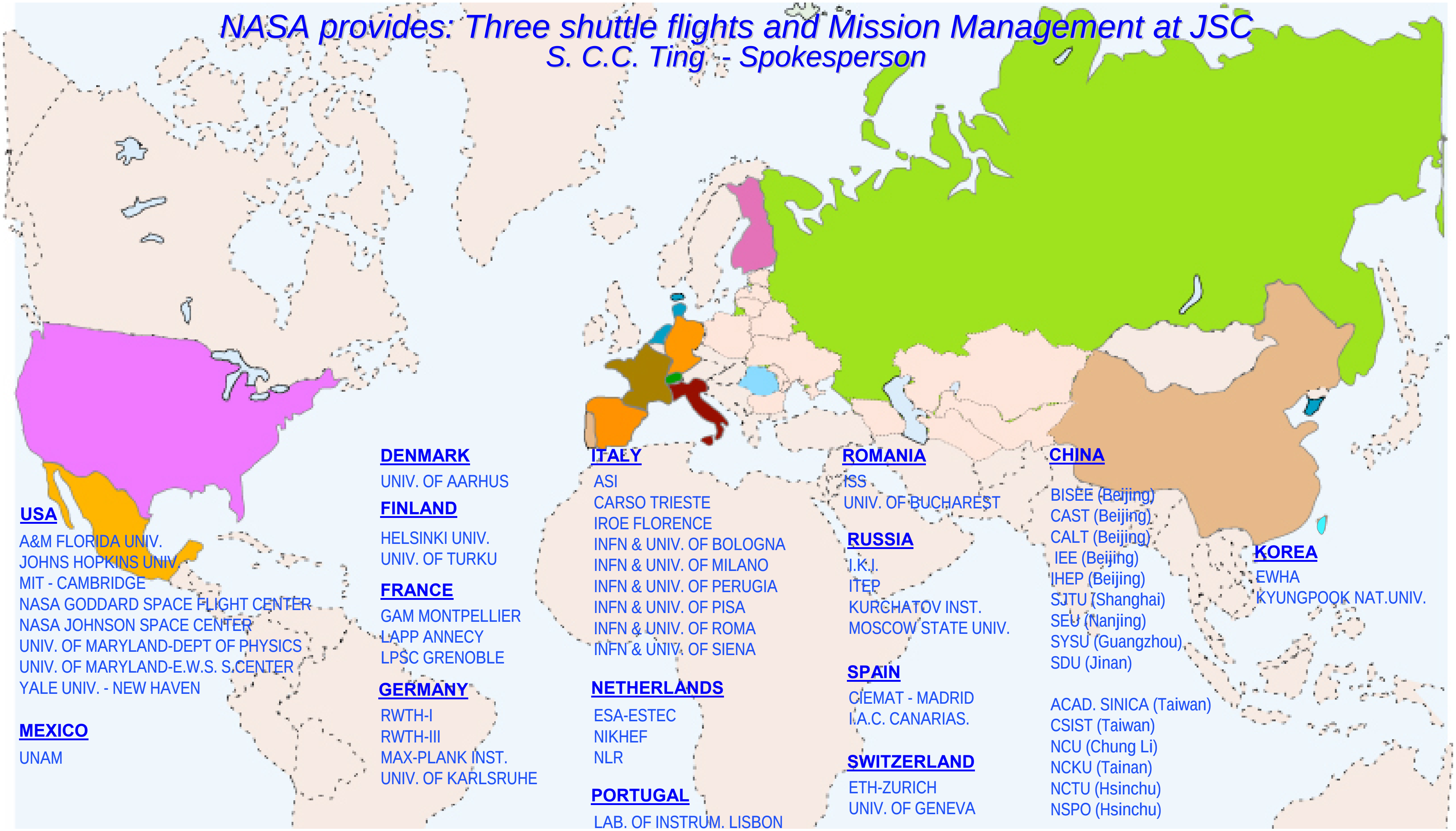


AMS
2008-2010

AMS is an International Collaboration

NASA provides: Three shuttle flights and Mission Management at JSC

S. C.C. Ting - Spokesperson



USA

A&M FLORIDA UNIV.
JOHNS HOPKINS UNIV.
MIT - CAMBRIDGE
NASA GODDARD SPACE FLIGHT CENTER
NASA JOHNSON SPACE CENTER
UNIV. OF MARYLAND-DEPT OF PHYSICS
UNIV. OF MARYLAND-E.W.S. S.CENTER
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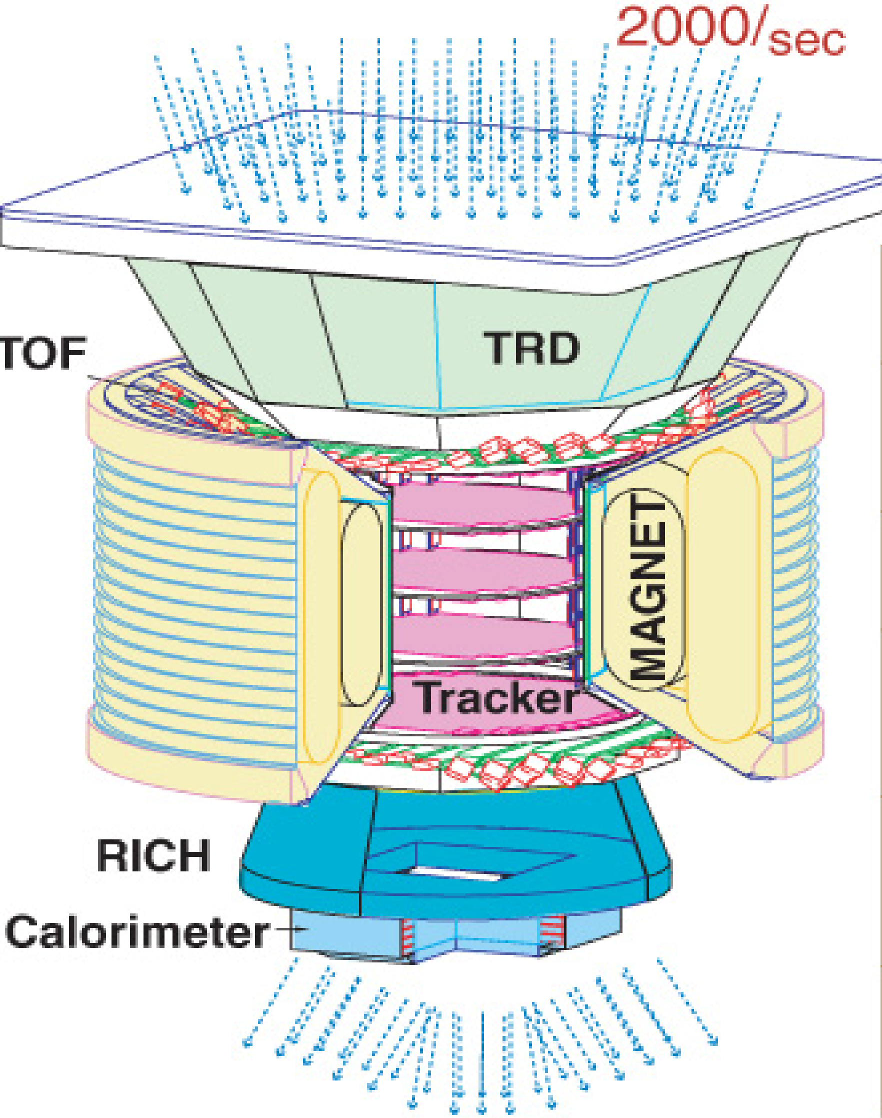
KOREA

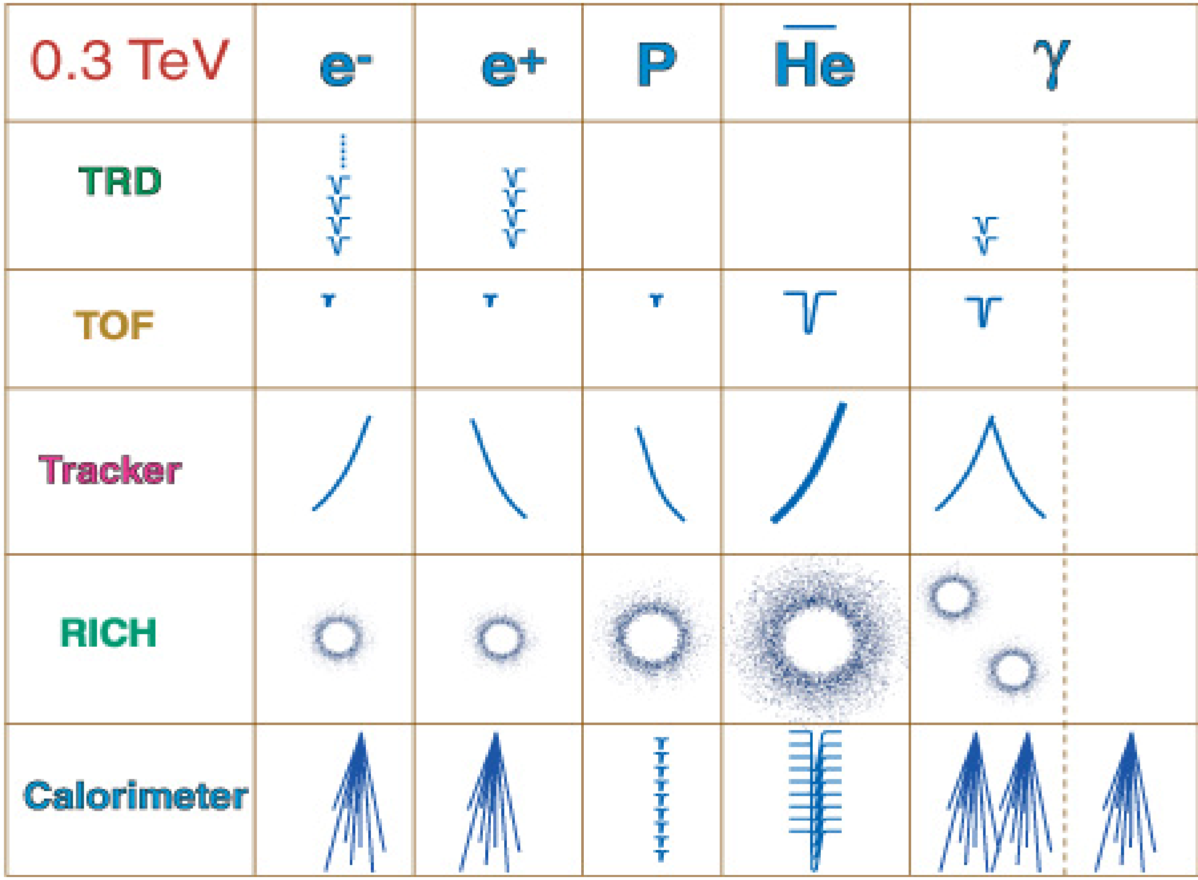
EWHA
KYUNGPOOK NAT.UNIV.

AMS: A TeV Magnetic Spectrometer in Space



G.F. 5000 cm^2 sr

Exposure > 3 yrs



$dP/P^2 \sim 0.004$ → MDR = 2.5 TV, $h/e = 10^{-6}$ (ECAL +TRD)

AMS-02 goals and capabilities

Cosmic rays spectra and chemical composition up to 1 TeV

Search for Antimatter in Space

Search for Dark Matter

AMS will identify and measure the fluxes for:

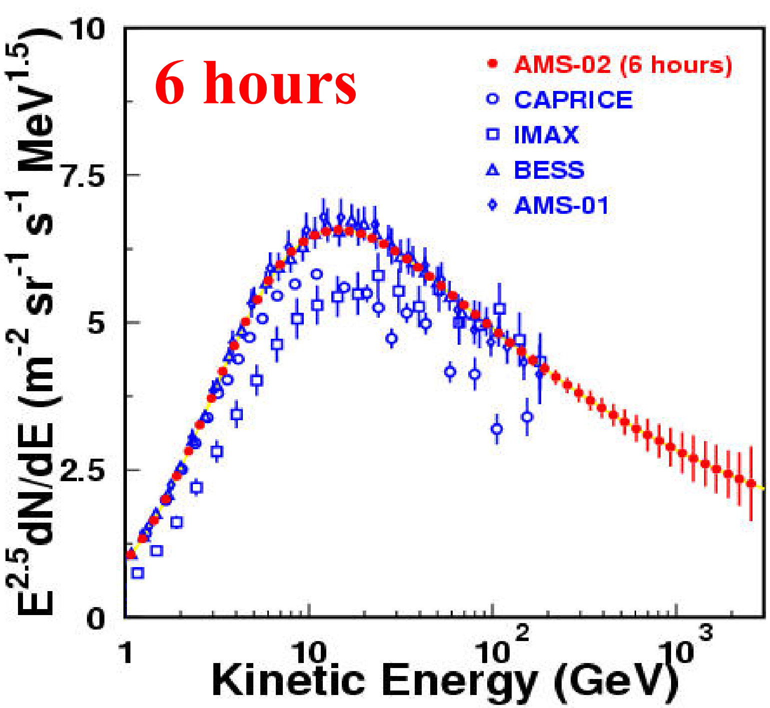
- **p for E < 1 TeV with unprecedented precision**
- **e+ for E < 300 GeV and e– for E < 1 TeV (unprecedented precision)**
- **Light Isotopes for E < 10 GeV/n**
- **Individual elements up to Z = 26 for E < 1 TeV/n**

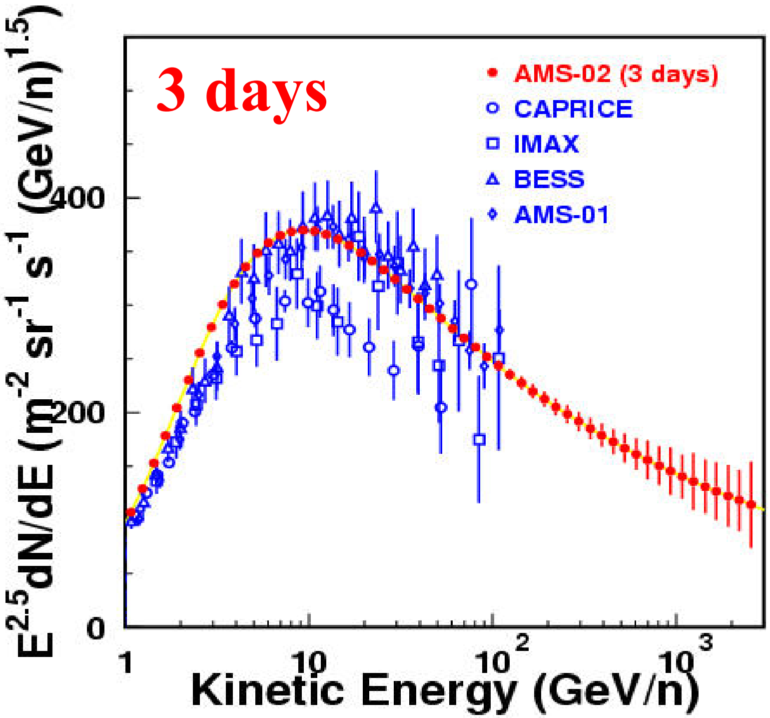
Absolute fluxes and spectrum shapes of protons and helium are important for calculation of atmospheric neutrino fluxes

Composition and spectra are important to constraint propagation, confinement, ISM density

Protons and helium

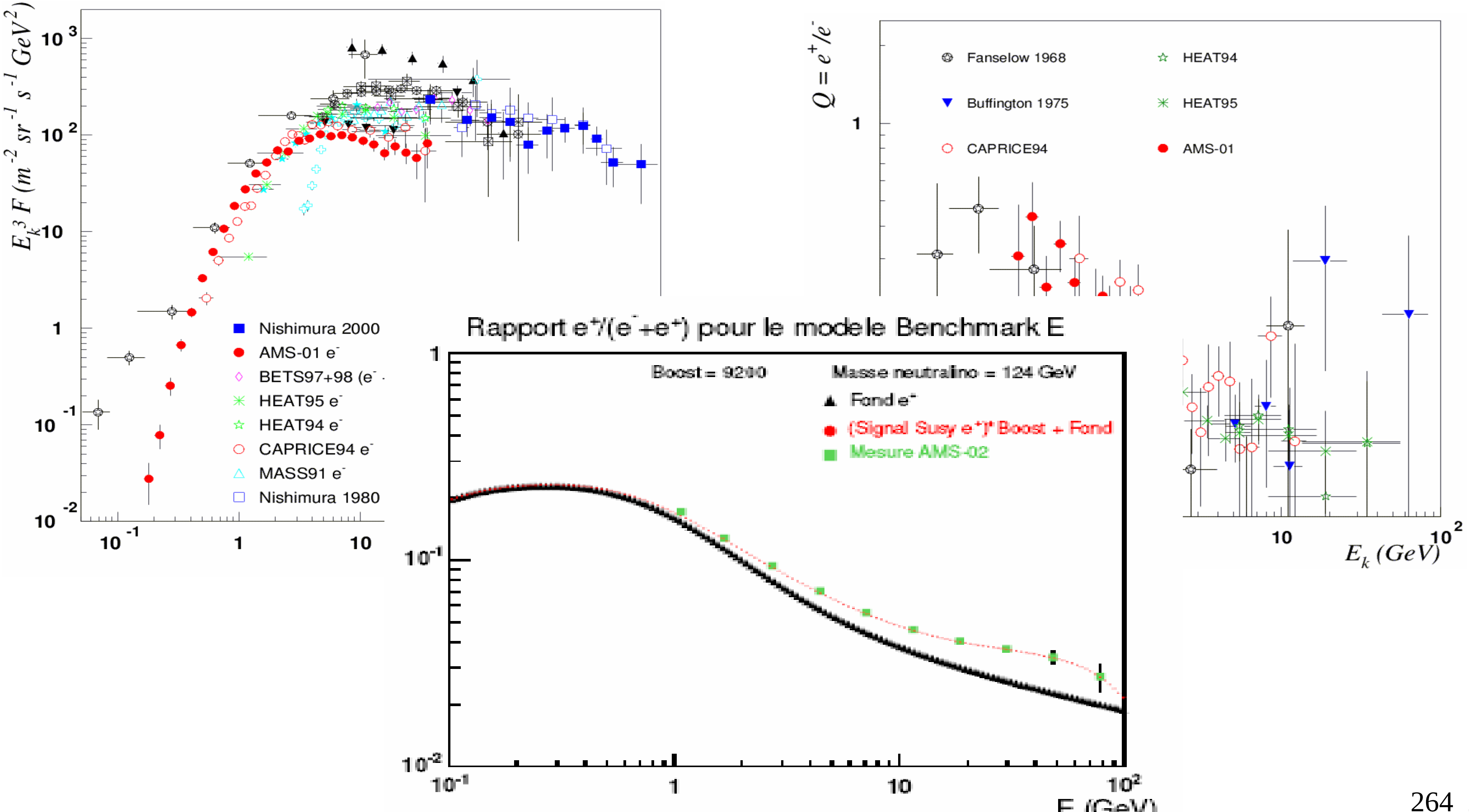
- **AMS will measure H & He fluxes for E < 1 TeV**
- **after 3 years will collect ≈10^8 H with E > 100 GeV**
- **and ≈10^7 He with E > 100 GeV/n**





Electrons and positrons

Energetic e+/e– cannot diffuse more than few kpc: they are sensitive probes of the Local Bubble and its neighbourhood.

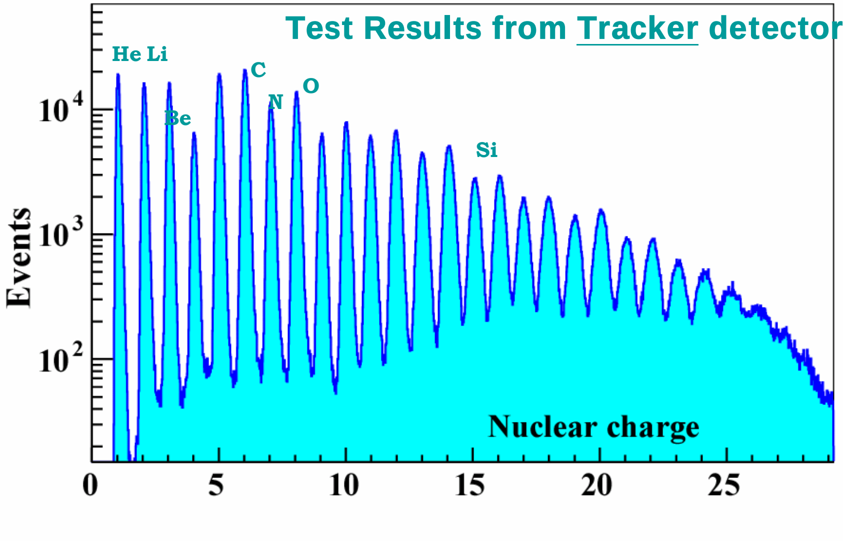


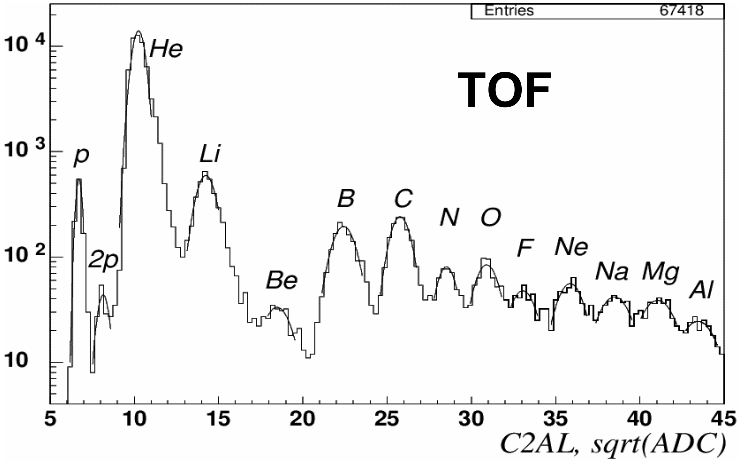
Nuclei separation

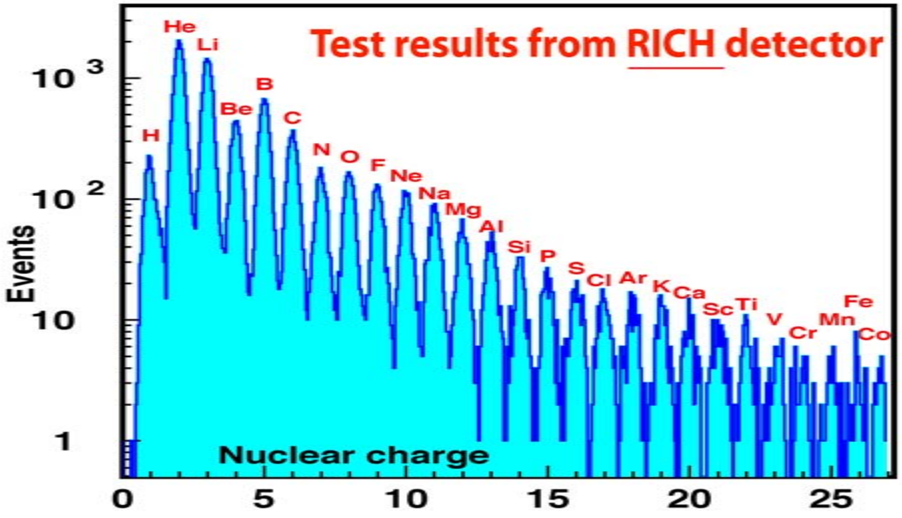
Charge measurement:

TOF, Tracker and RICH

Verified by heavy ion beam tests at CERN & GSI.


Test Results from Tracker detector

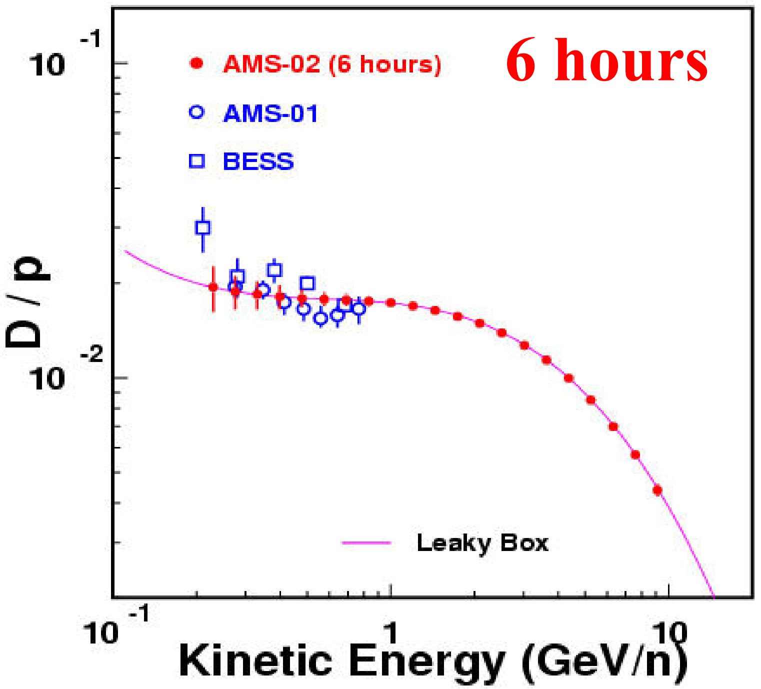

TOF

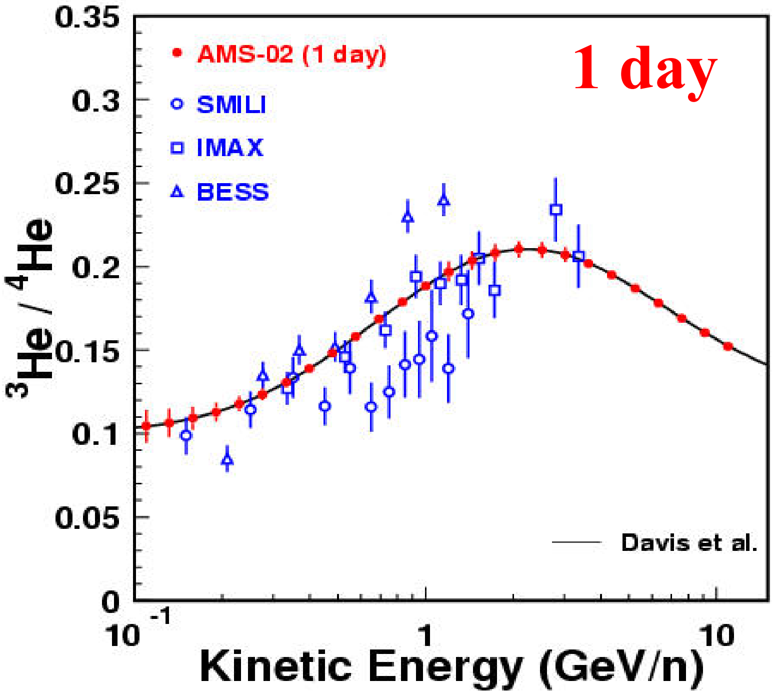

Test results from RICH detector

Light isotopes

Hydrogen and helium isotopes (deuterium and ^{3}He) are important tests of Big Bang nucleosynthesis which is their main source.

AMS-02 will identify D and ^{3}He up to 10 GeV/n


6 hours

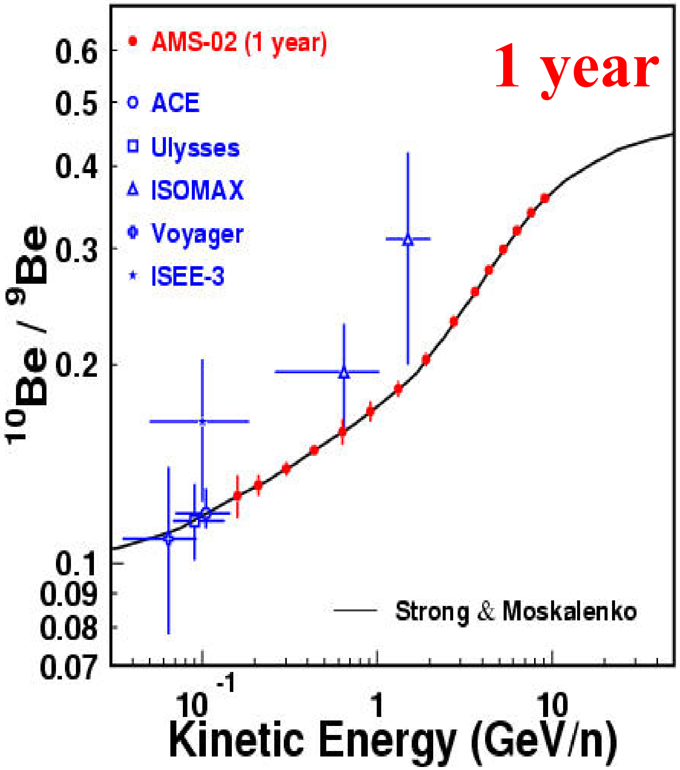

1 day

After 3 years AMS-02 will collect about 10^8 D and ^{3}He

^{10}Be/^{9}Be – radioactive clock

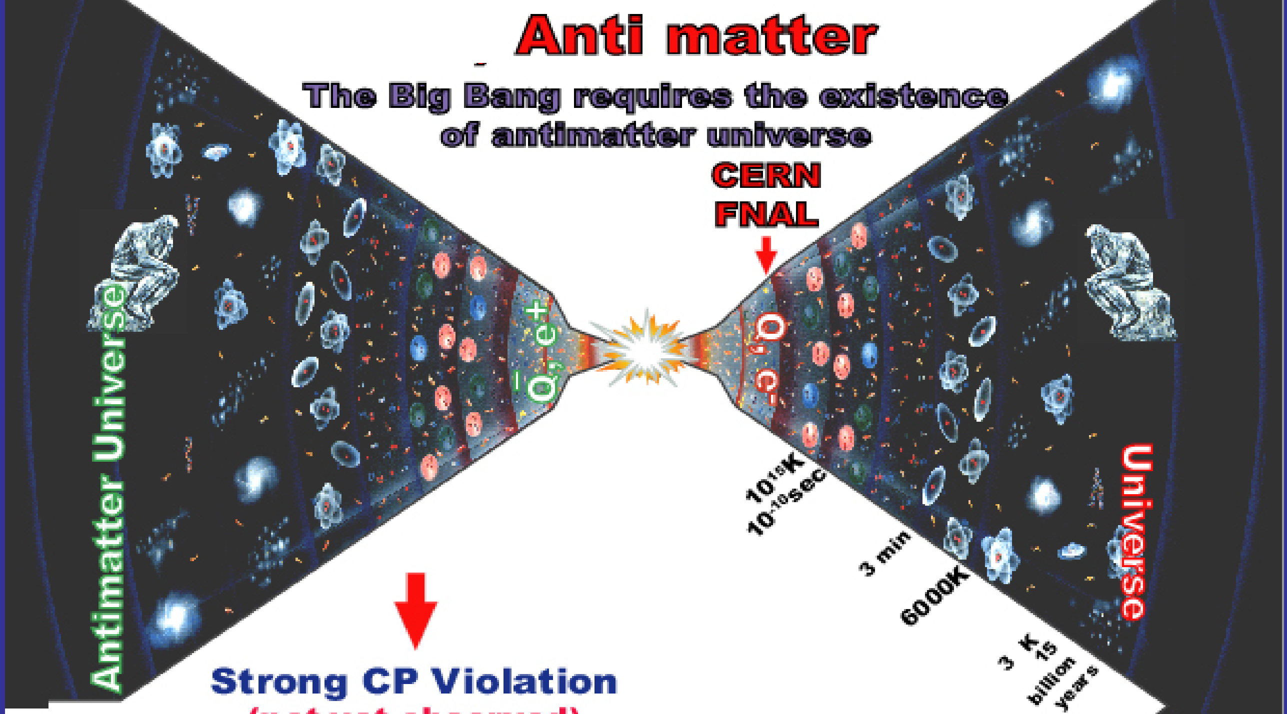
- **^{10}Be ($t_{1/2}$ = 1.51 Myr) is the lightest β-radioactive secondary isotope having a half-life comparable with the CR confinement time in the Galaxy.**
- **In diffusion models, the ratio ^{10}Be/^{9}Be is sensitive to the size of the halo and to the properties of the local interstellar medium**

AMS will separate ^{10}Be from ^{9}Be for
0.15 GeV/n $< E <$ 10 GeV/n
after 3 years will collect ≈10^5 ^{10}Be



Anti matter

The Big Bang requires the existence of antimatter universe



Strong CP Violation

(not yet observed)

and

Baryon Number Violation

(Proton decay not yet observed)

Then

Grand Unified Theories

or

Electroweak Theories

predicts

Magnetic Monopole

or

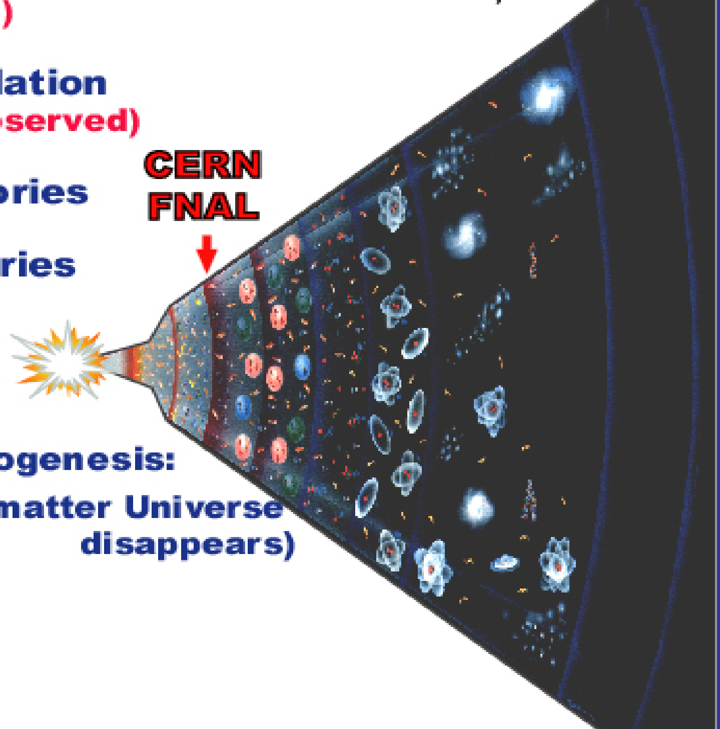
Light Higgs

or

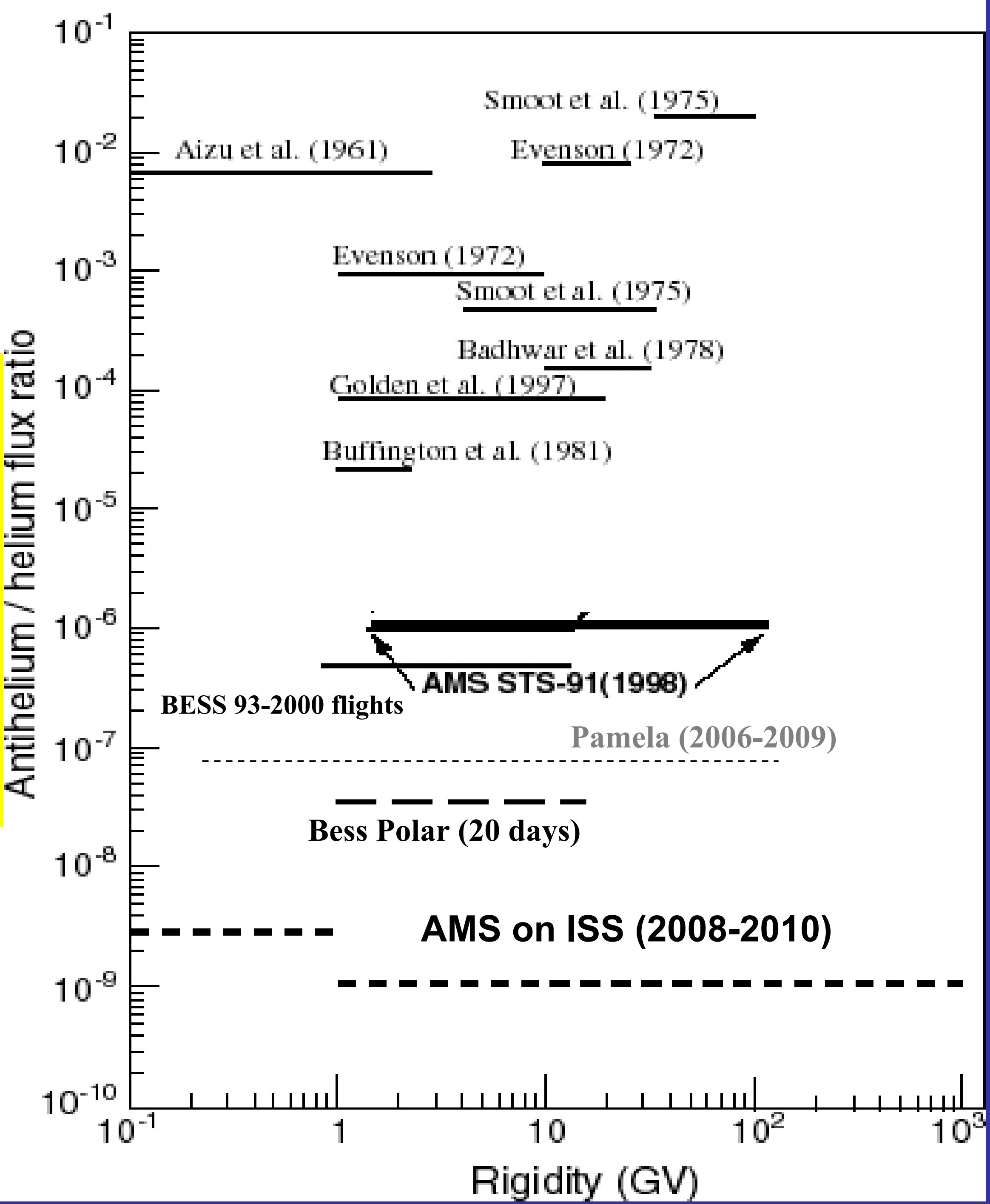
Massive neutrinos

Baryogenesis:

(Antimatter Universe disappears)

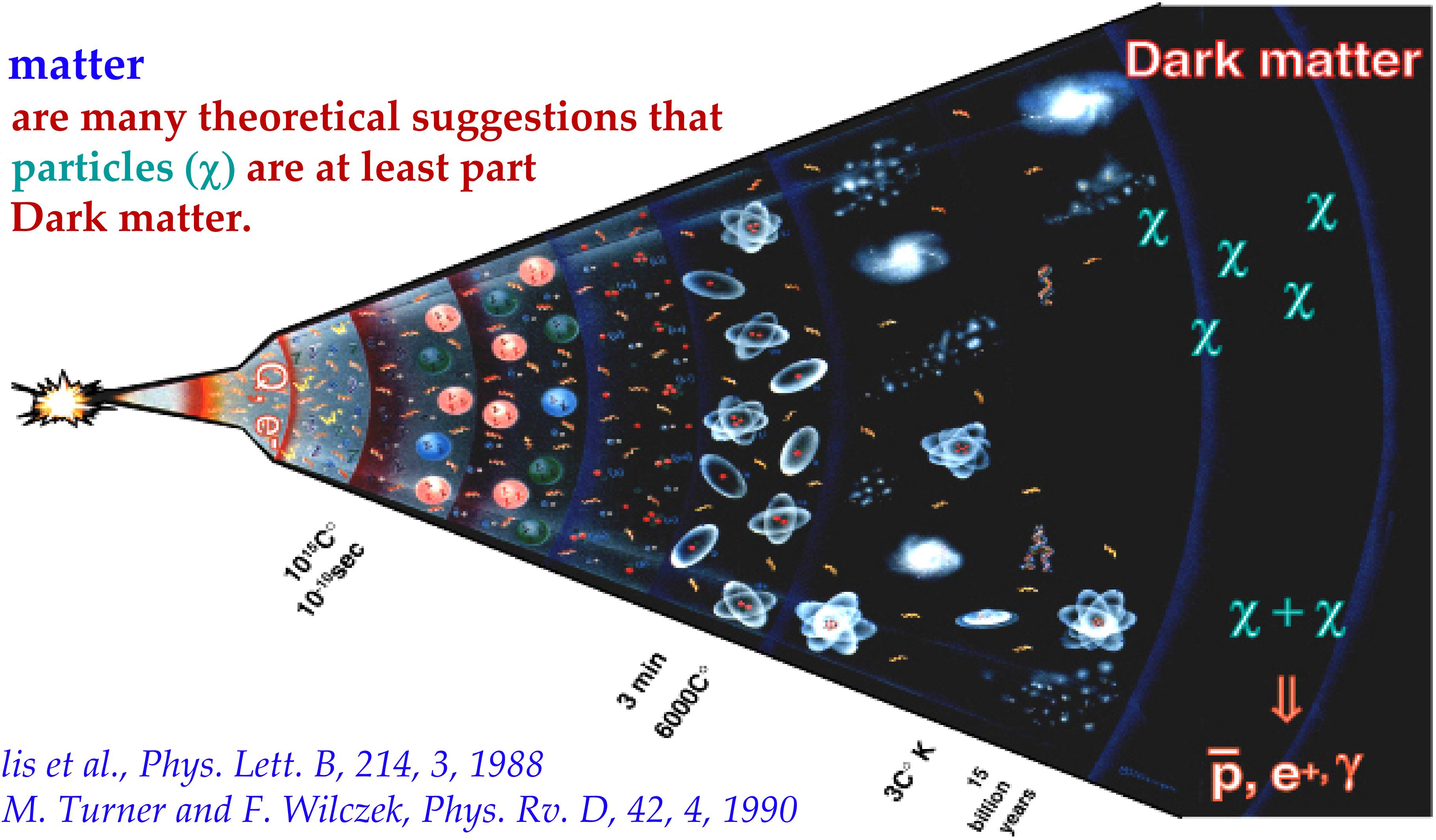


Search for antimatter at the 10^{-9} level of sensitivity with AMS-02 on the ISS

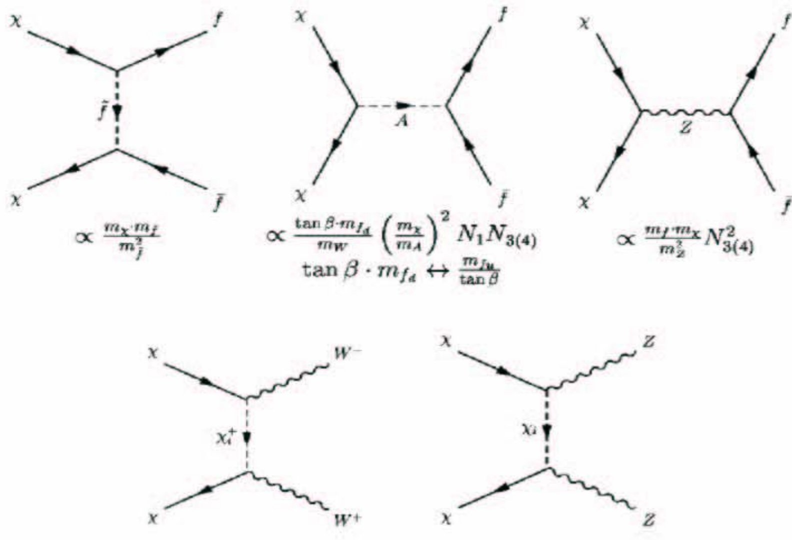


Dark matter

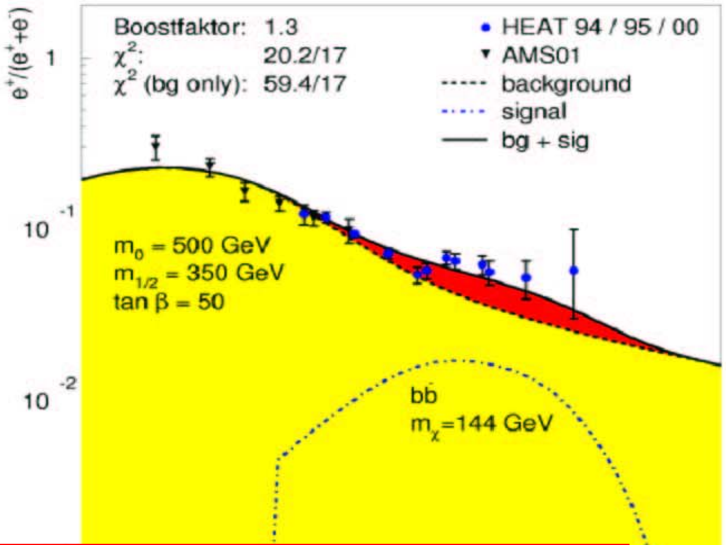
There are many theoretical suggestions that SUSY particles (χ) are at least part of the Dark matter.



J. Ellis et al., Phys. Lett. B, 214, 3, 1988
and M. Turner and F. Wilczek, Phys. Rv. D, 42, 4, 1990
E.A. Baltz, J. Edsjo, P.R. D59, 23511, 1999

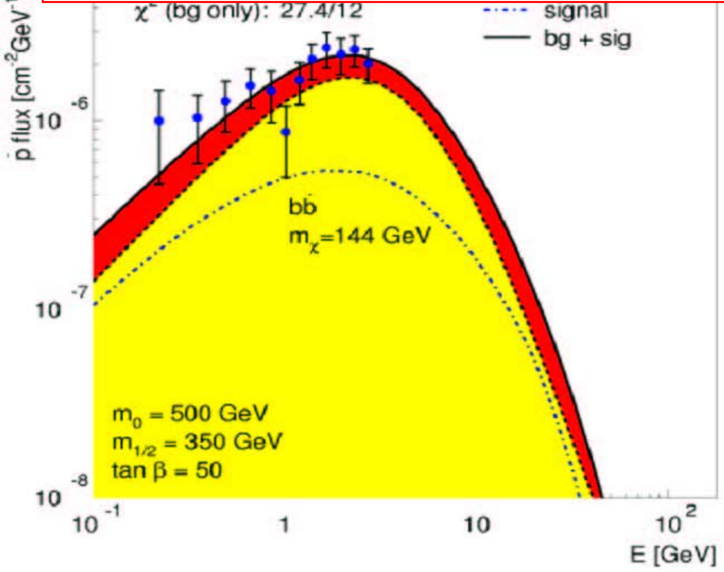


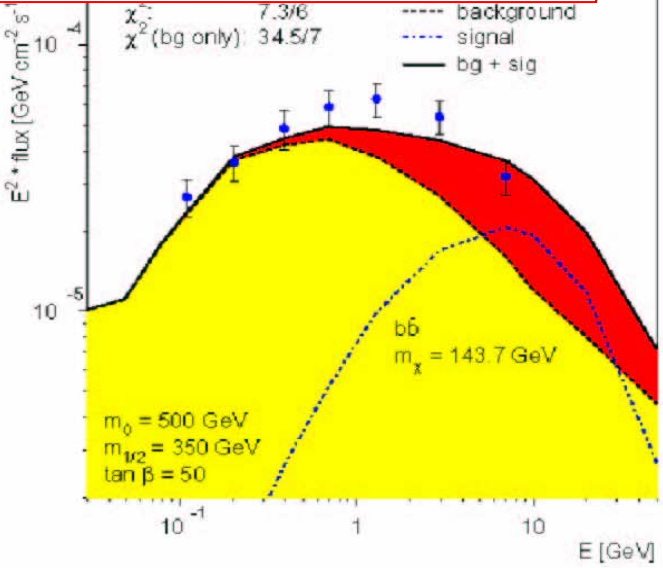
Unique Feature of AMS



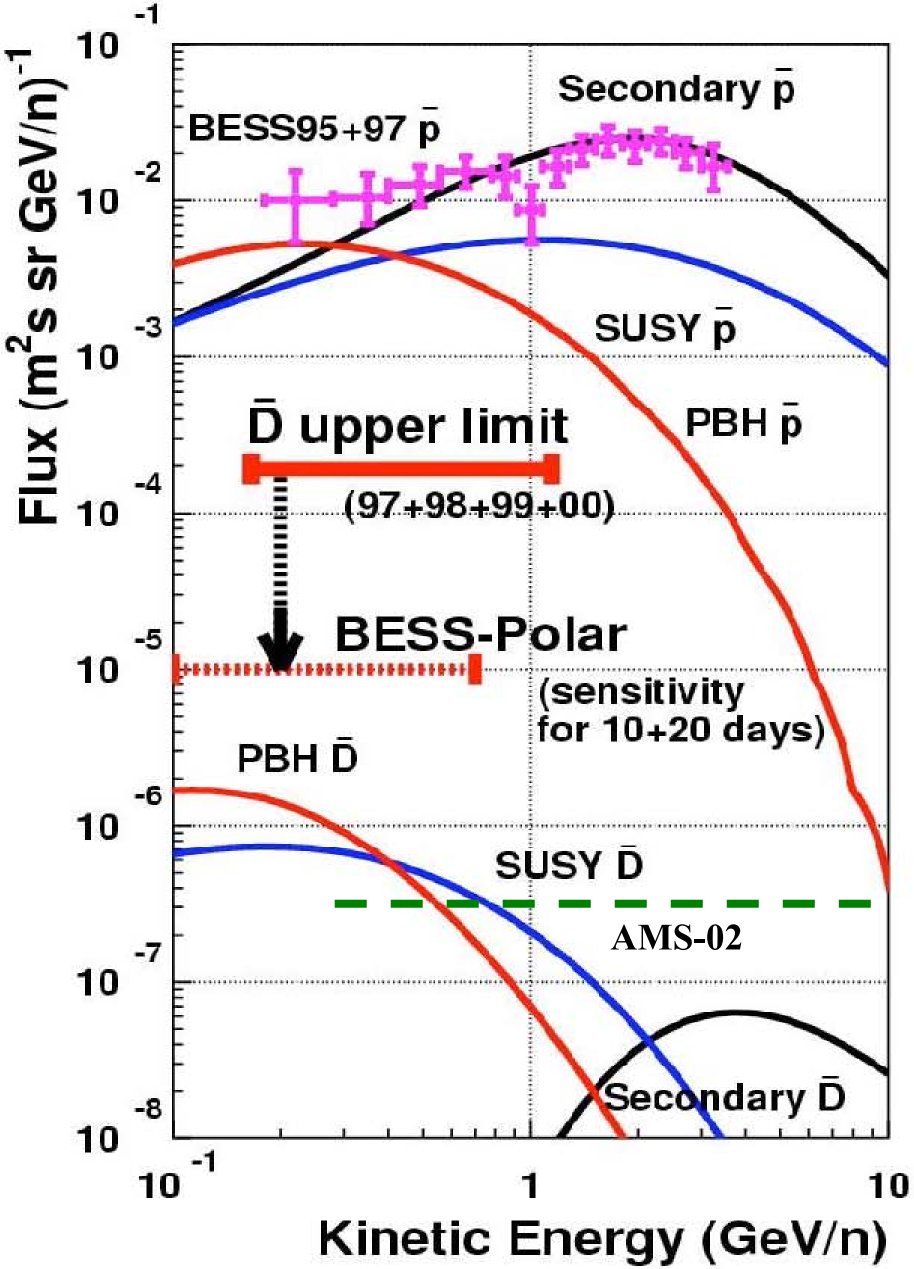
Combining searches in different channels could give (much) higher sensitiviy to SUSY DM signals

Wim de Boer et al., EPS867

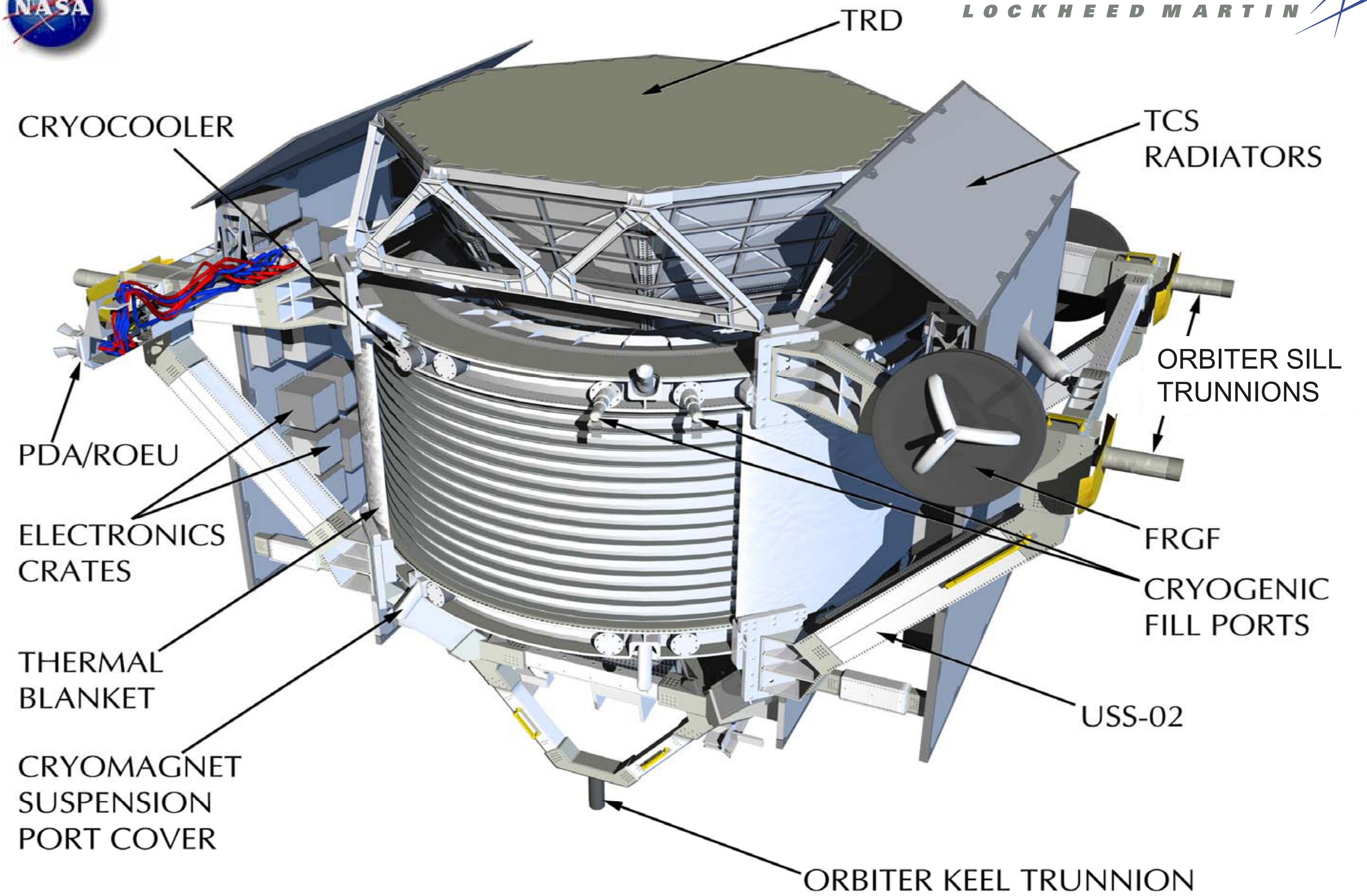


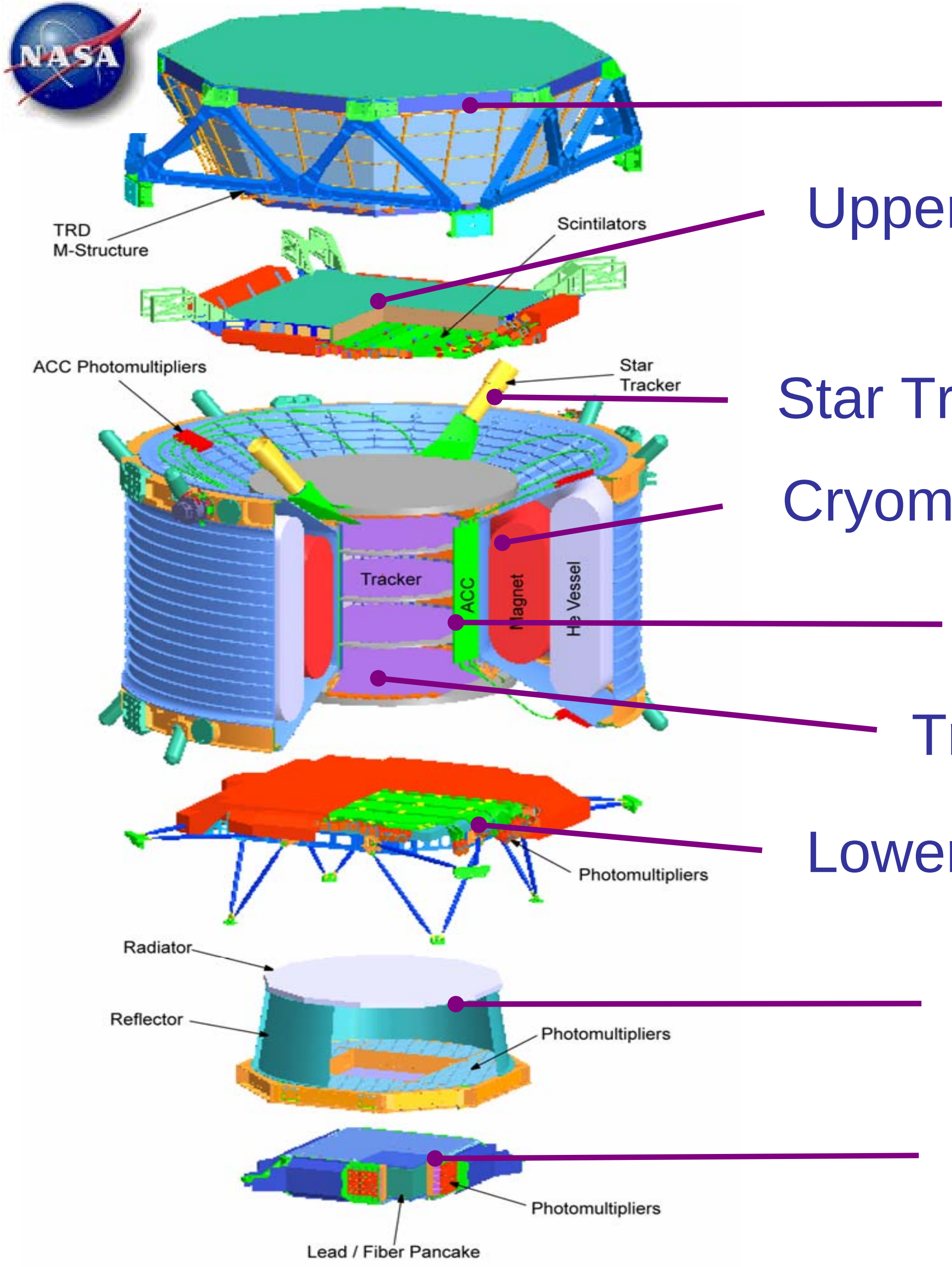


AMS sensitivity to anti D

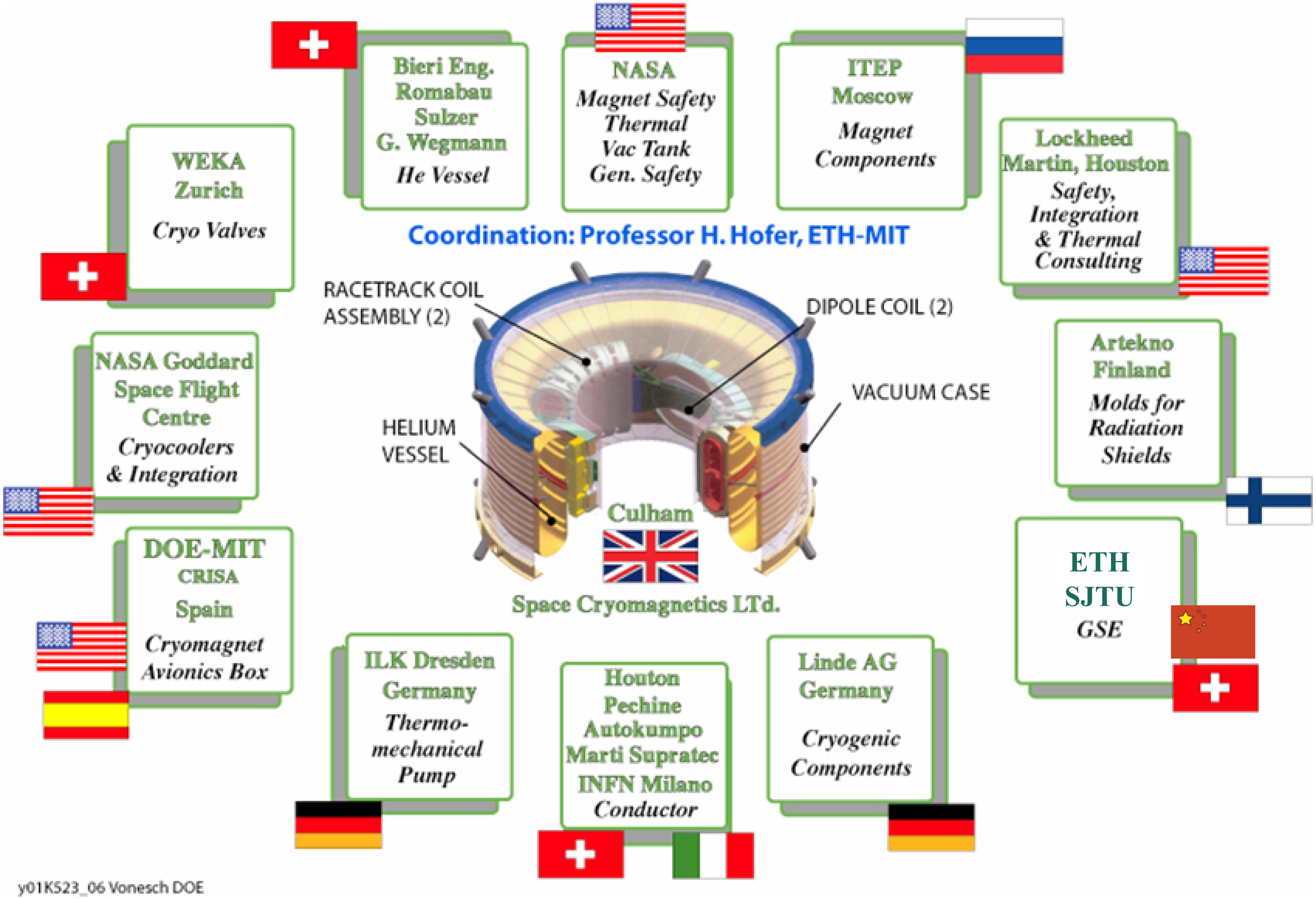


LOCKHEED MARTIN





TRD	🇩🇪 🇺🇸 🇮🇹	In Assembly
Upper TOF	🇮🇹	In Assembly
GPS	🇫🇷	In Design
Star Tracker	🇮🇹	In Assembly
Cryomagnet	🇨🇭 🇬🇧 🇺🇸 🇩🇪 🇮🇹 🇹🇼 🇫🇮 🇷🇺 🇨🇳 🇪🇸	In Design, Manufacturing & Assembly
ACC	🇩🇪	In Assembly
Tracker	🇮🇹 🇨🇭 🇩🇪 🇫🇷 🇷🇴 🇳🇱 🇨🇳 🇫🇮 🇷🇺	In Assembly
Lower TOF	🇮🇹	In Assembly
RICH	🇮🇹 🇪🇸	In Manufacturing & Assembly
ECAL	🇮🇹 🇨🇳 🇫🇷	In Testing



Coordination: Professor H. Hofer, ETH-MIT

WEKA
Zurich
Cryo Valves

Bieri Eng.
Romabau
Sulzer
G. Wegmann
He Vessel

NASA
Magnet Safety
Thermal
Vac Tank
Gen. Safety

ITEP
Moscow
Magnet
Components

Lockheed Martin, Houston
Safety,
Integration
& Thermal
Consulting

NASA Goddard Space Flight Centre
Cryocoolers
& Integration

Artekno
Finland
Molds for
Radiation
Shields

Culham
Space Cryomagnetics LTd.

DOE-MIT
CRISA
Spain
Cryomagnet
Avionics Box

ETH
SJTU
GSE

ILK Dresden
Germany
Thermo-
mechanical
Pump

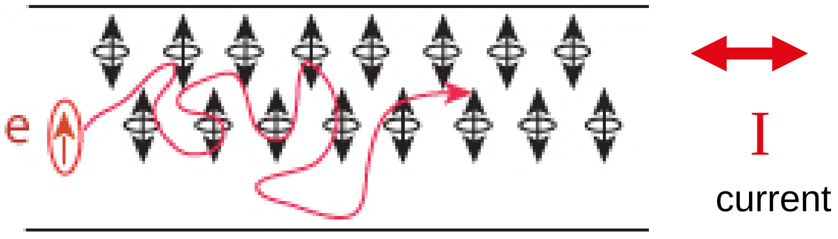
Houton
Pechine
Autokumpo
Marti Supratec
INFN Milano
Conductor

Linde AG
Germany
Cryogenic
Components

y01K523_06 Vonesch DOE

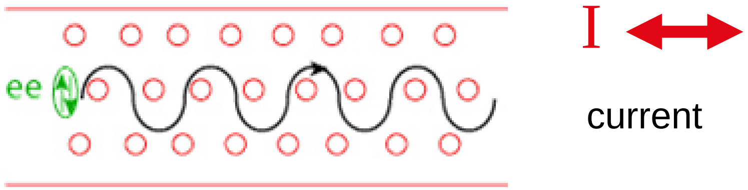
100 Years of Super Conductivity

Normal conduction Wire



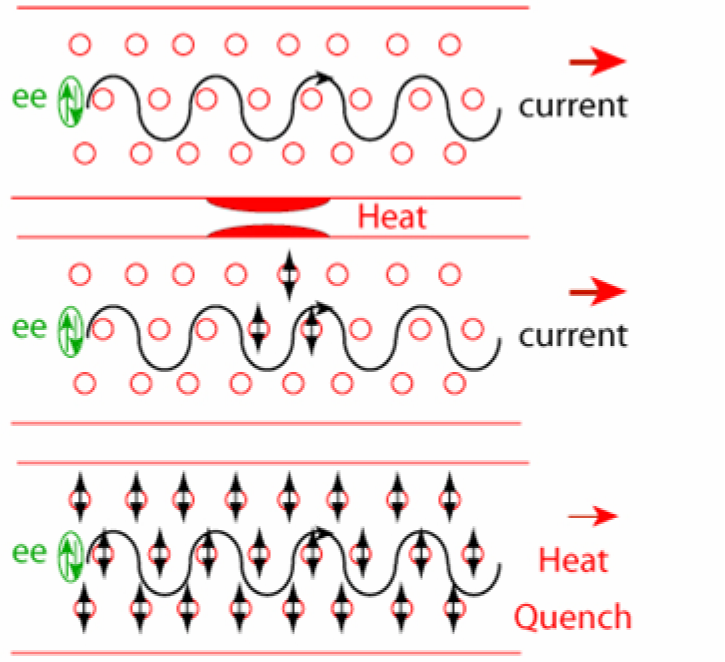
Metal atoms oscillate ⇒ cause friction ⇒ HEAT

Super-Conduction at -270° C
(Kammerlingh-Onnes 1911)



Metals: Pb, Nb, Ti ⇒ Atoms rest, Cooper pairs of electrons move frictionless (Quantum Mech.)

Quench: loss of superconductivity due to relative motion of wire => friction => heat



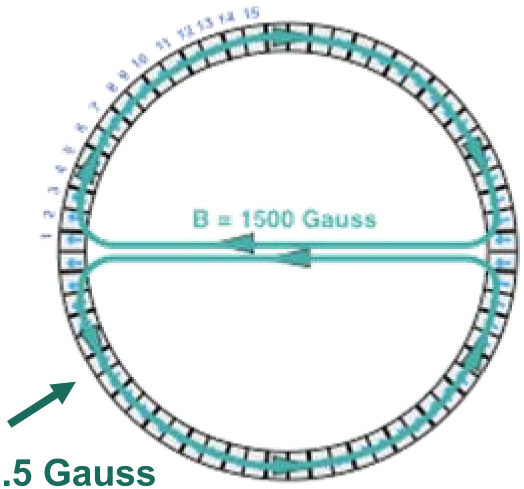
Nobel Prizes in:

1913	H. Kammerlingh-Onnes *Discovery of Superconductivity*
1972	J. Barden, L.Cooper, J.Schrieffer *Theory of Superconductivity*
1987	G.Bednorz, A.Müller *High temperature Superconductivity*
2003	A.A. Abrikosov, V.L. Ginzburg, A.J. Leggett *Theory of superconductors and superfluids*

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

Permanent Magnet

AMS-01



B = 0.5 Gauss

STEP ONE: Develop a Permanent Magnet in Space

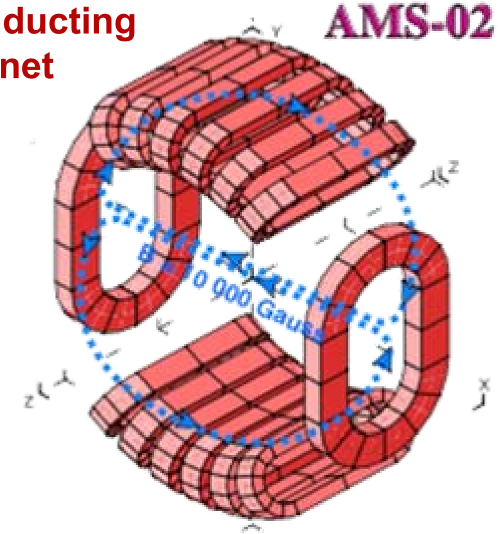
1- Stable: no influence from earth magnetic field

2- Safety for the astronauts:
No field leak out of the magnet

3- Low weight: no iron

Superconducting Magnet

AMS-02



STEP TWO: Develop a Superconducting Magnet in Space

With the same field arrangement as the permanent magnet:

Except it has 10,000 Gauss field = 1 T

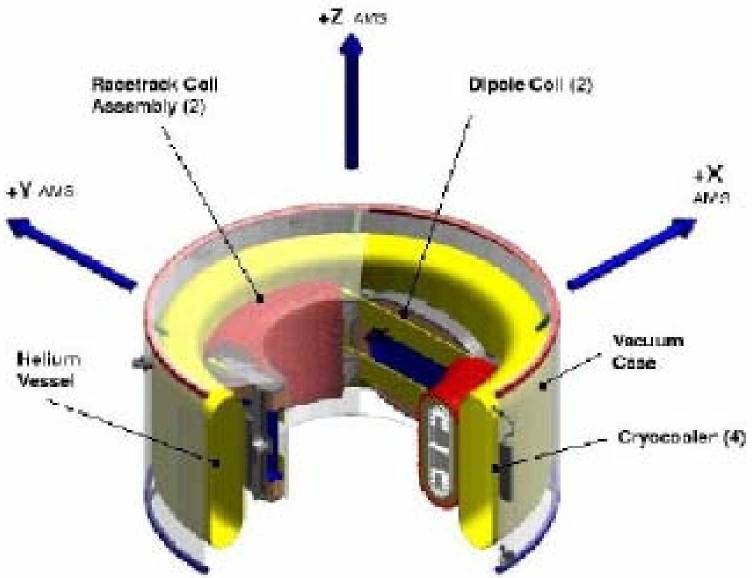
AMS-02: Superconducting Magnet

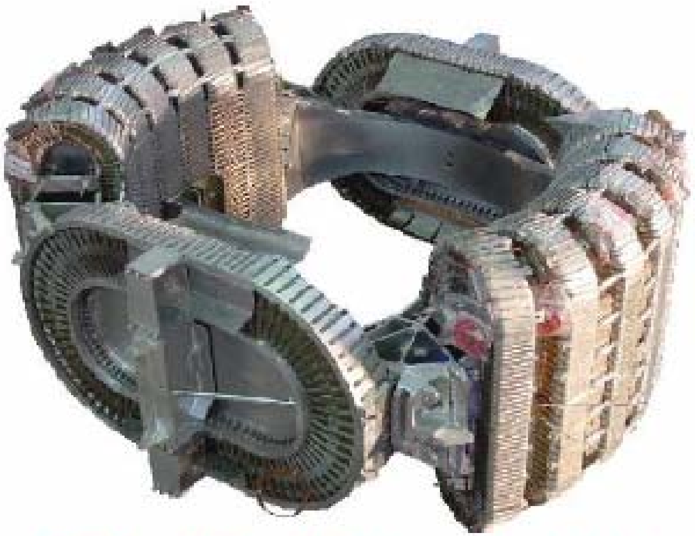
- 14 superconducting coils
- Geometrical configuration to ensure a null magnetic dipole moment
- Indirect cooling system based on superfluid helium
- Helium vessel: 2500 liters
- Dimensions: inner diameter 1.1m, weight: 2360 Kg
- an intense magnetic field: ~ 0.9 T
- a large bending power: ~ 0.8 T.m^2

▷ All coils are produced, tested individually at 1.8 K and assembled

▷ Vacuum vessel is completed

▷ Magnet delivered to CERN where the integration will start in 2006

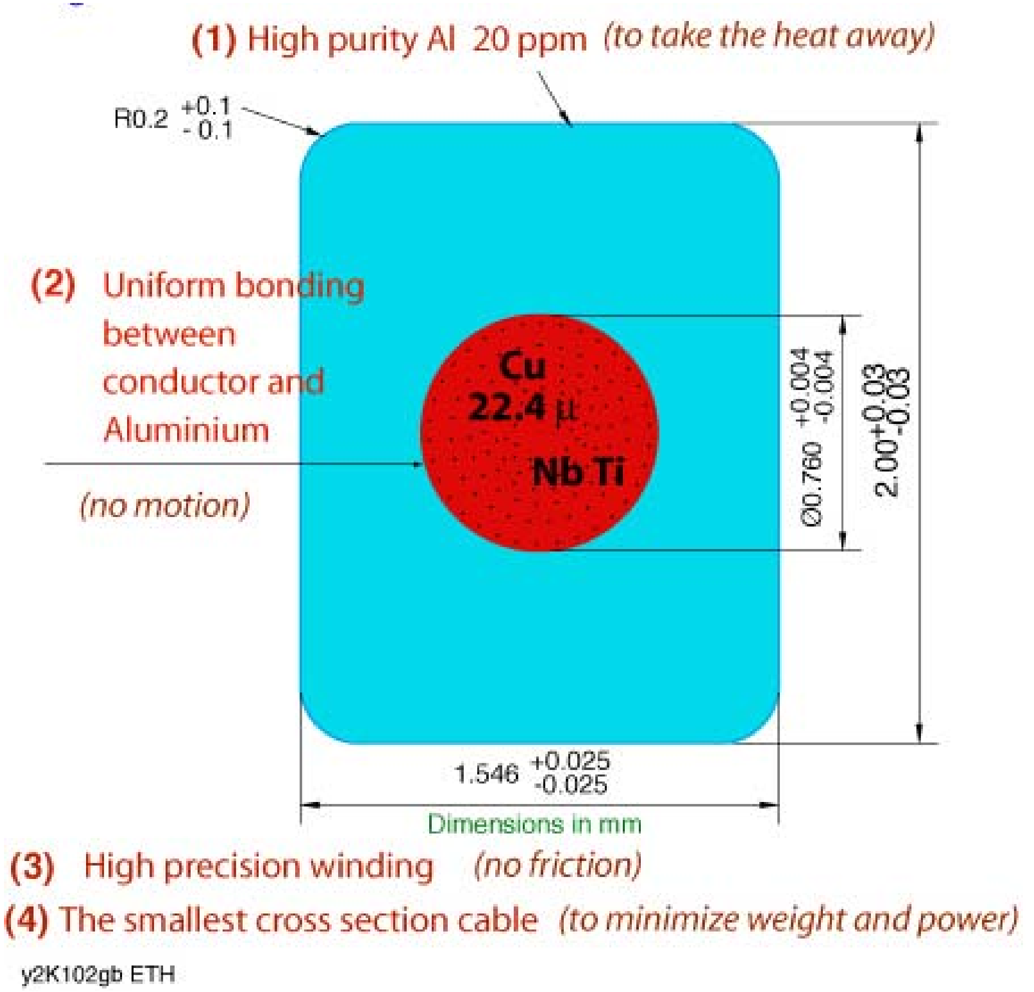




R.H. MacMahon he-24

Technical achievement to eliminate quench for AMS-02

It is not possible to quench the coils except by outside heating



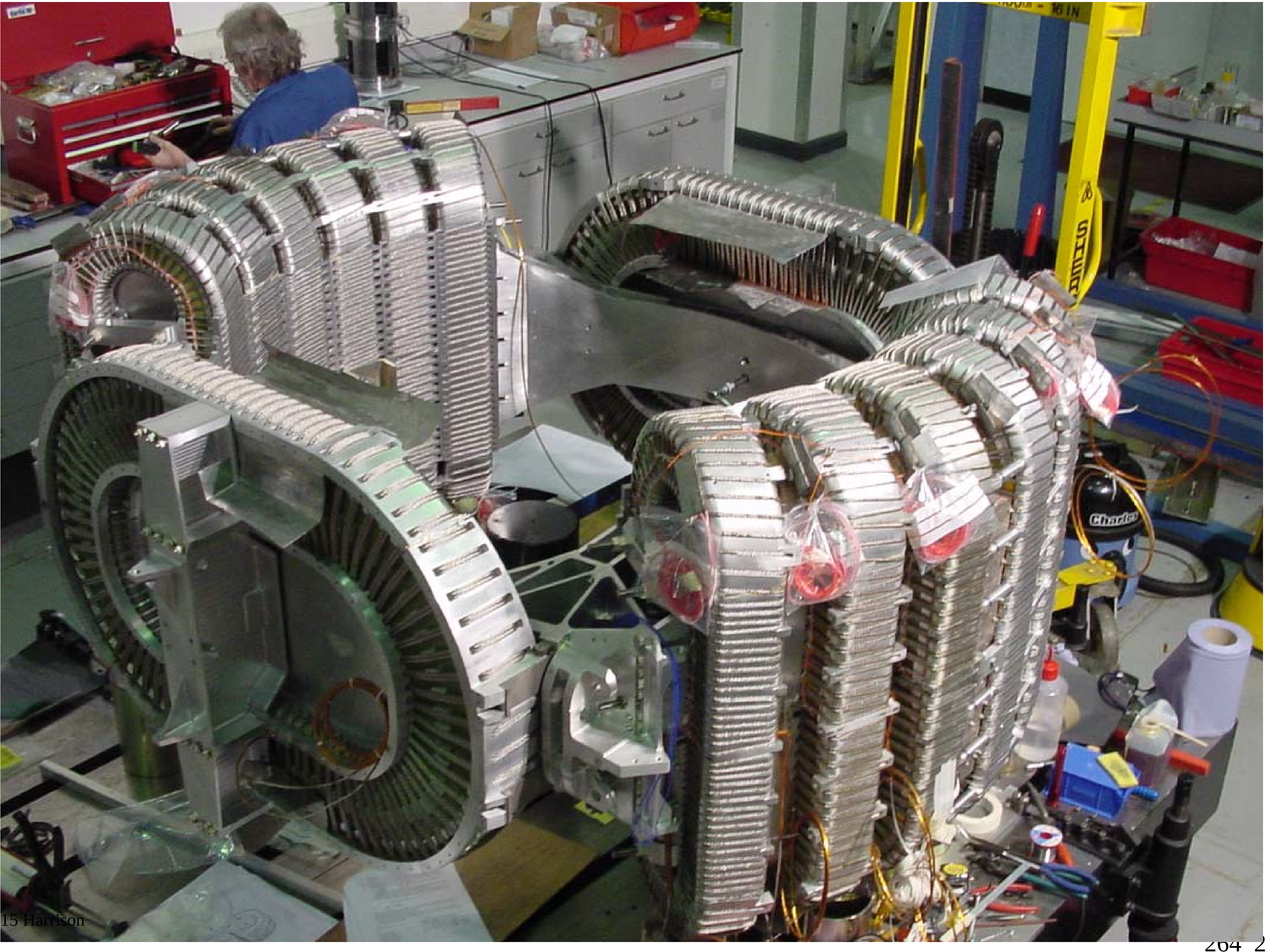
(1) High purity Al 20 ppm *(to take the heat away)*

(2) Uniform bonding between conductor and Aluminium *(no motion)*

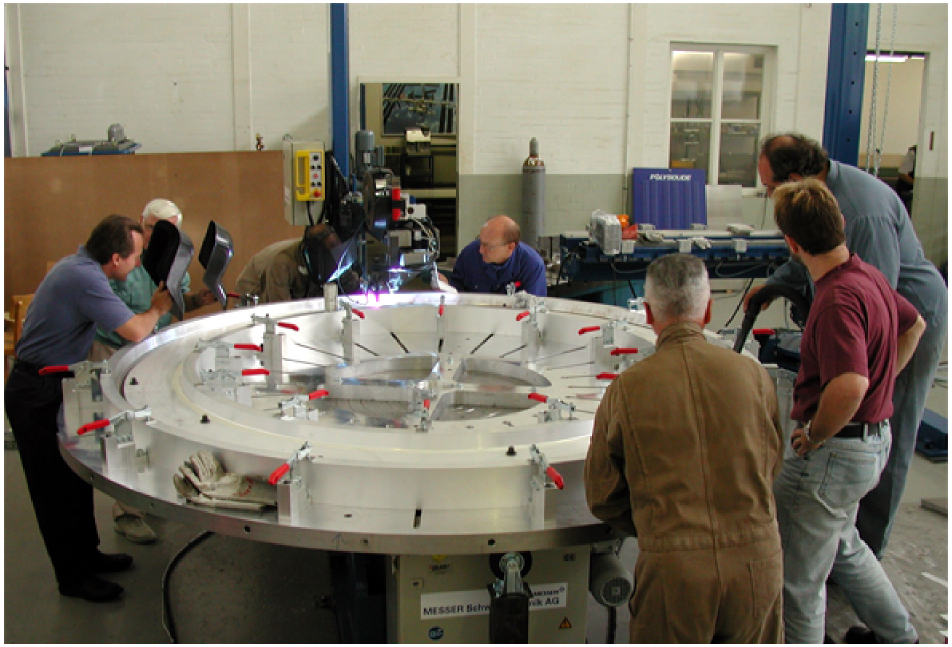
(3) High precision winding *(no friction)*

(4) The smallest cross section cable *(to minimize weight and power)*

y2K102gb ETH



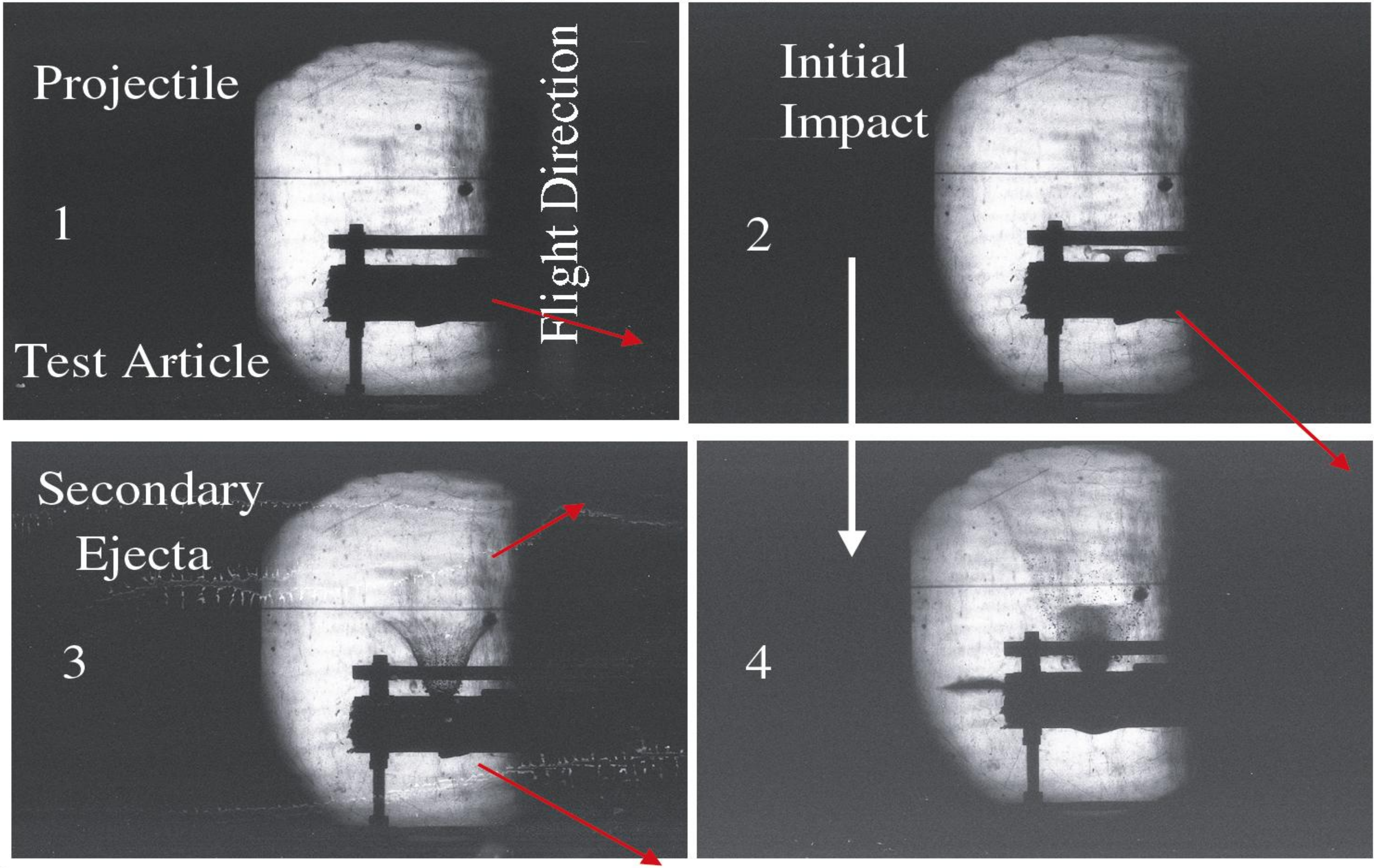
Welding of the He tank

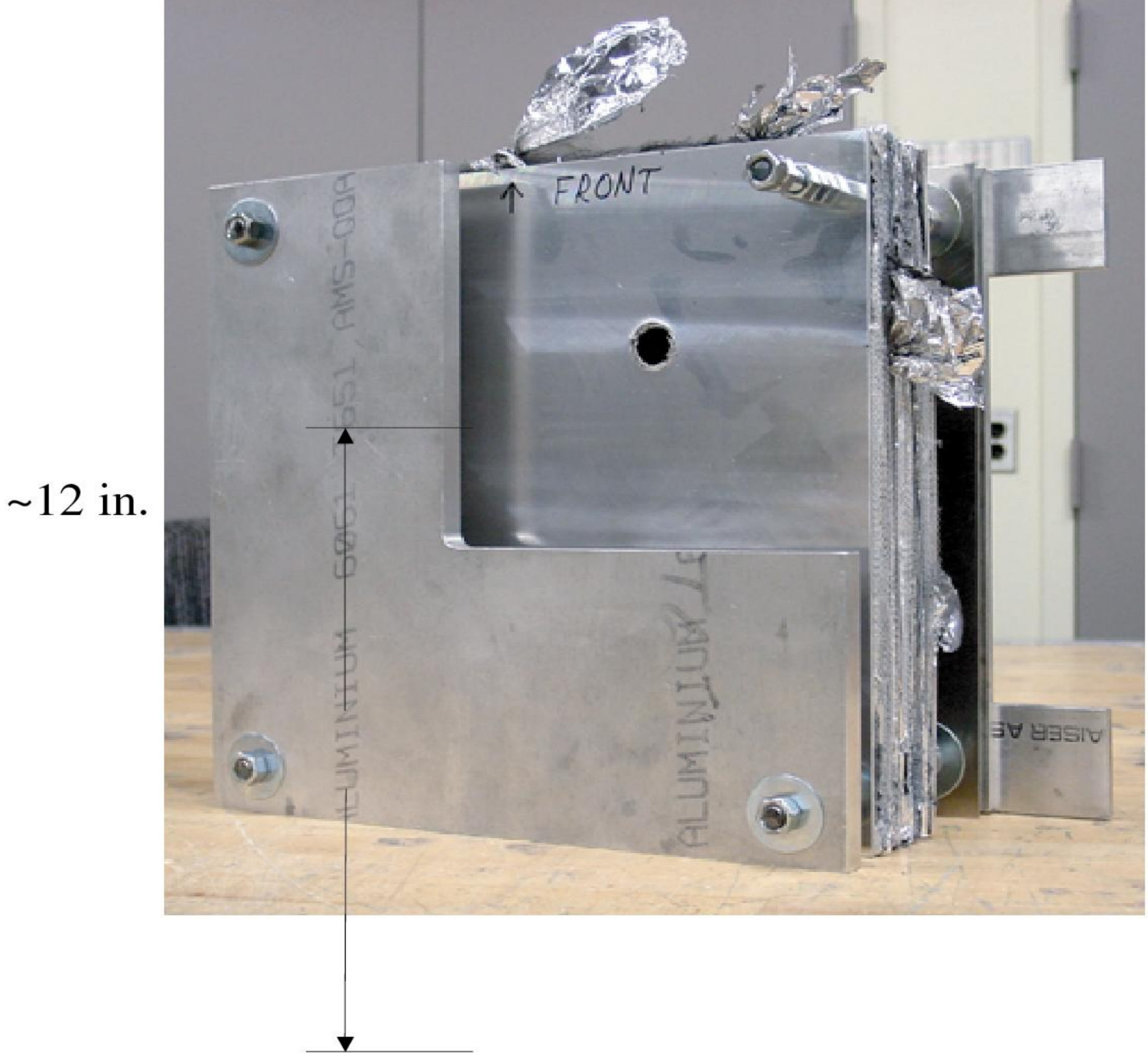


Radiation Shield

Vacuum Case

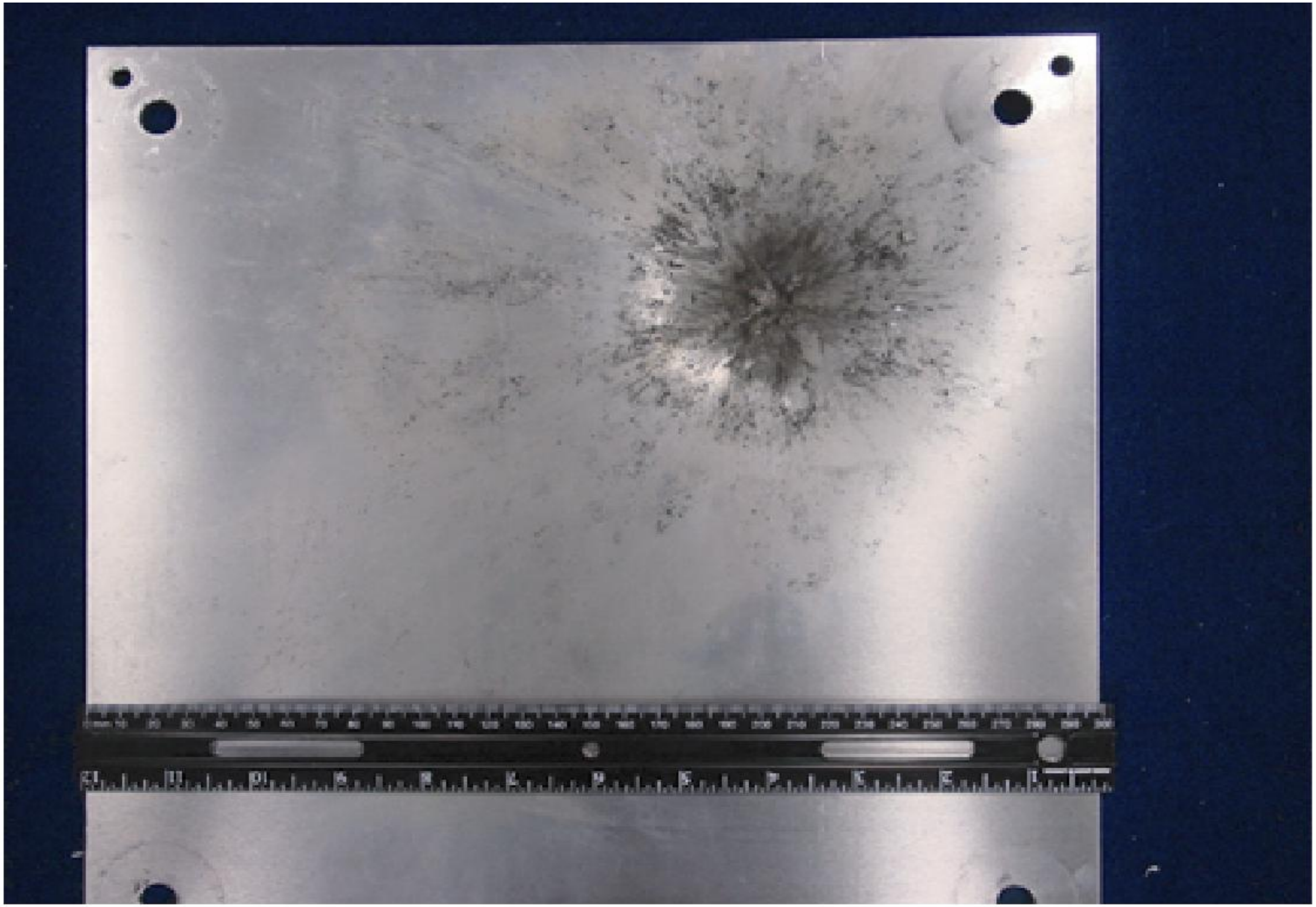
AMS-02 VC/SFHe Tank Micrometeoroid & Orbital Debris Hypervelocity Impact Test Photos





Micro-meteoroid
and Orbital
Debris Testing
of AMS
Cryomagnet
System

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

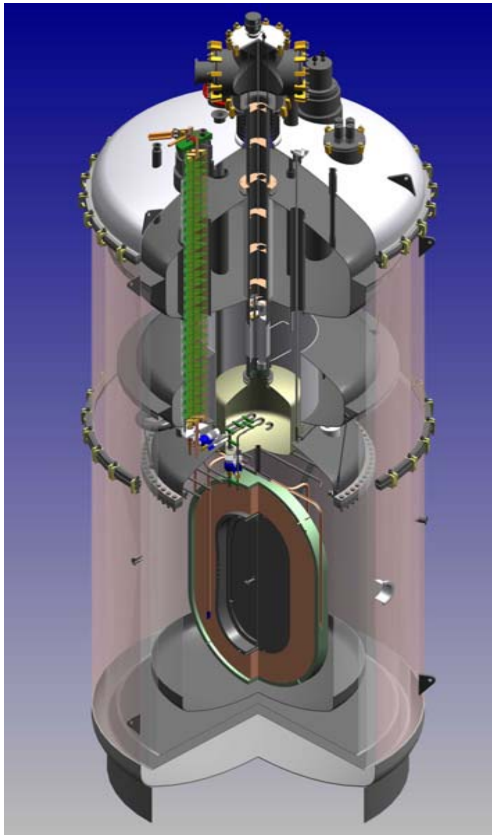


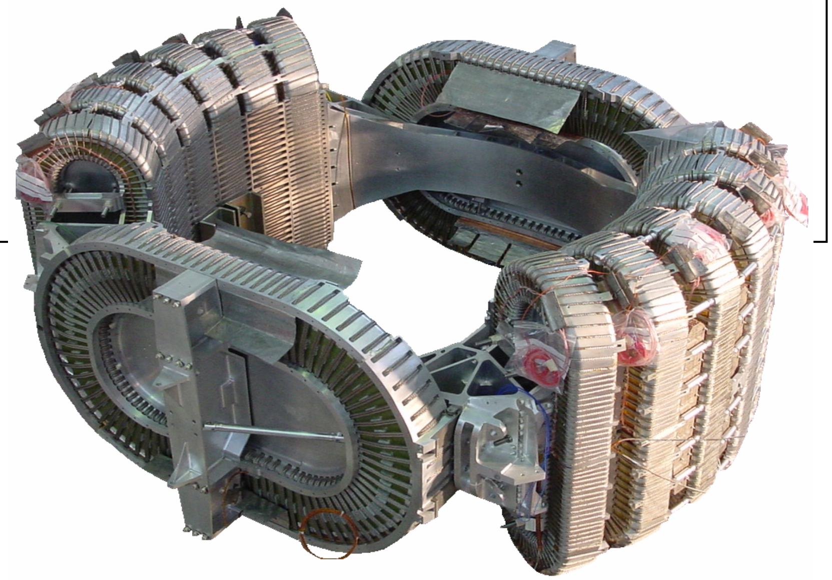
Micro-meteoroid & Orbital Debris Testing

Shows damage to SFHe tank do to 5 mm Aluminum Orbital Debris Particle – Tank not punctured

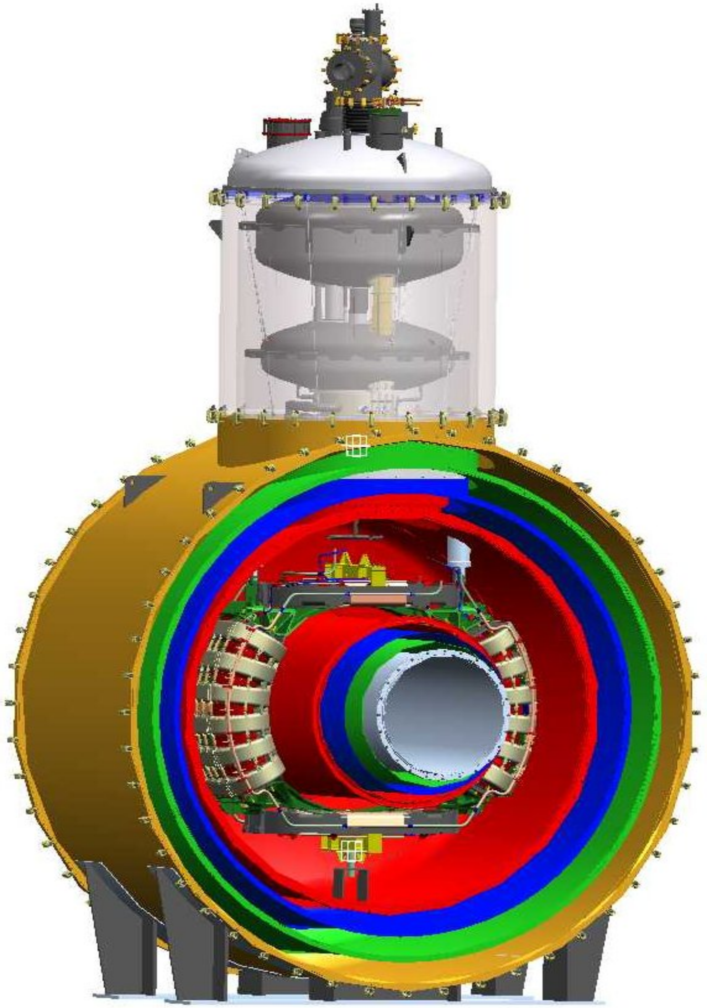
Status

- All coils have been individually tested.
- Magnet assembly is complete.





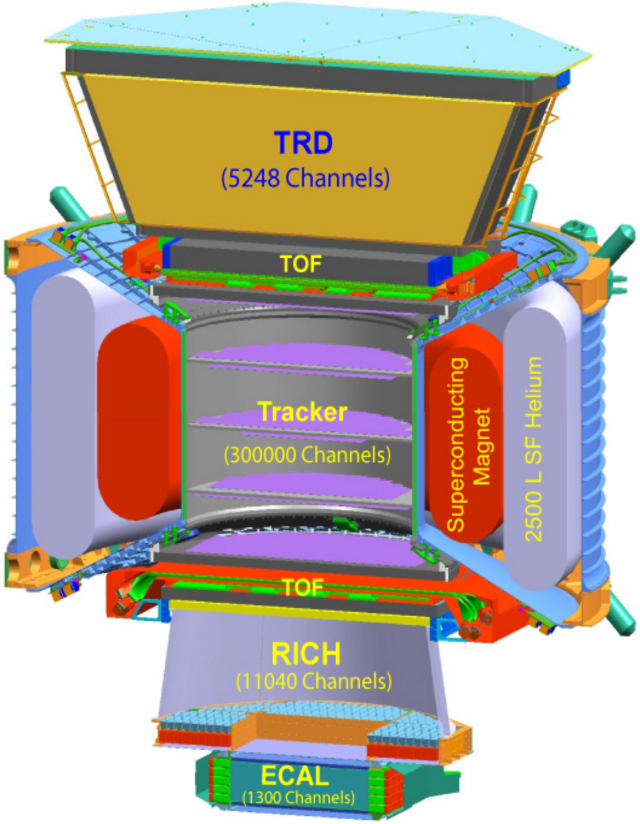
Magnet test facility

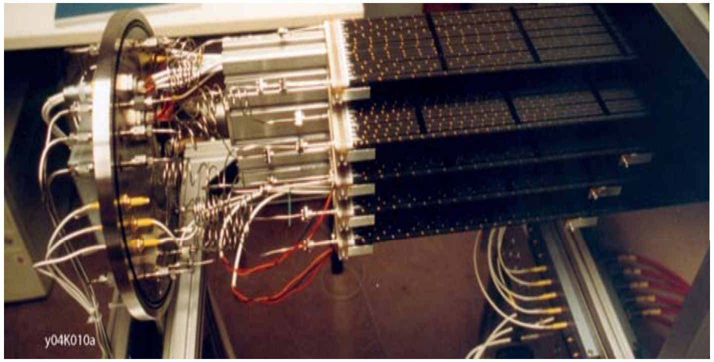


- Magnet test facility design is nearing completion.

SJTU (Shangai)

Transition Radiation Detector (TRD)





Functional tests of TRD

All modules have been produced

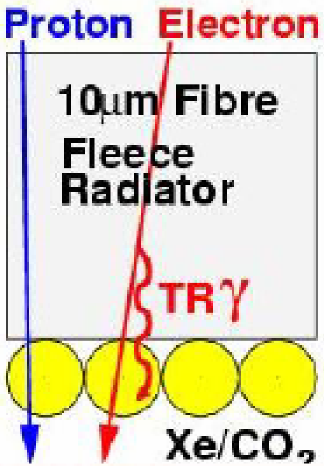
AMS-02: Transition Radiation Detector

- Modules (328) made of fleece radiator and straw tubes
  - $E_\gamma \sim \gamma$(eV)
  - Emission probability small (10^{-2}) $N_\gamma \sim \alpha N_{transitions}$
  - TRD photons detected in proportional straw tubes Xe/CO_2
- 20 layers assembled in an octogonal shape structure
- Separation of e^-/e^+ from $\bar{p}/p$ up to 300 GeV

▷ All modules produced

▷ 14 layers with 220 modules inserted in supporting structure

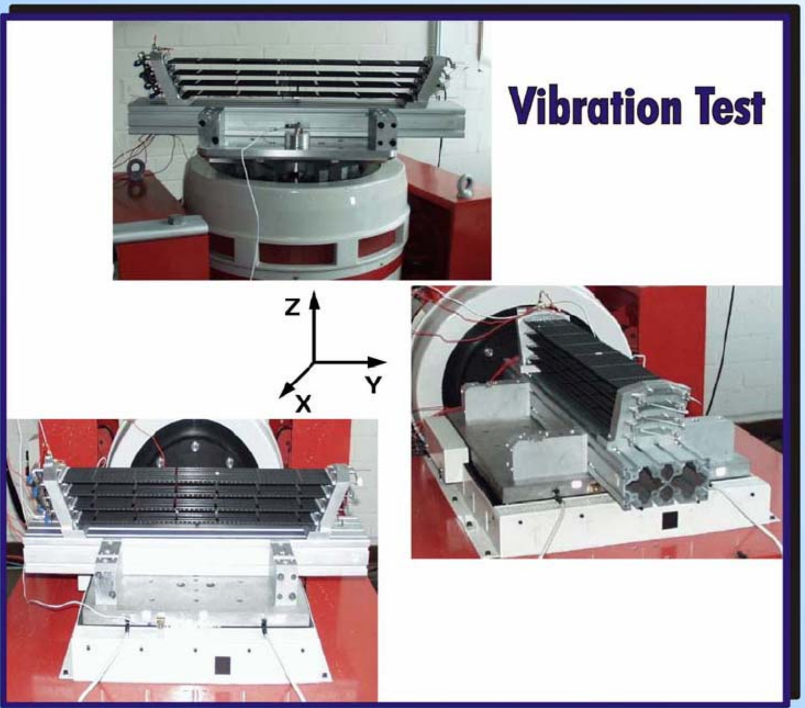
▷ Detector finished in Spring 2006



Transition Radiation Detector (TRD)

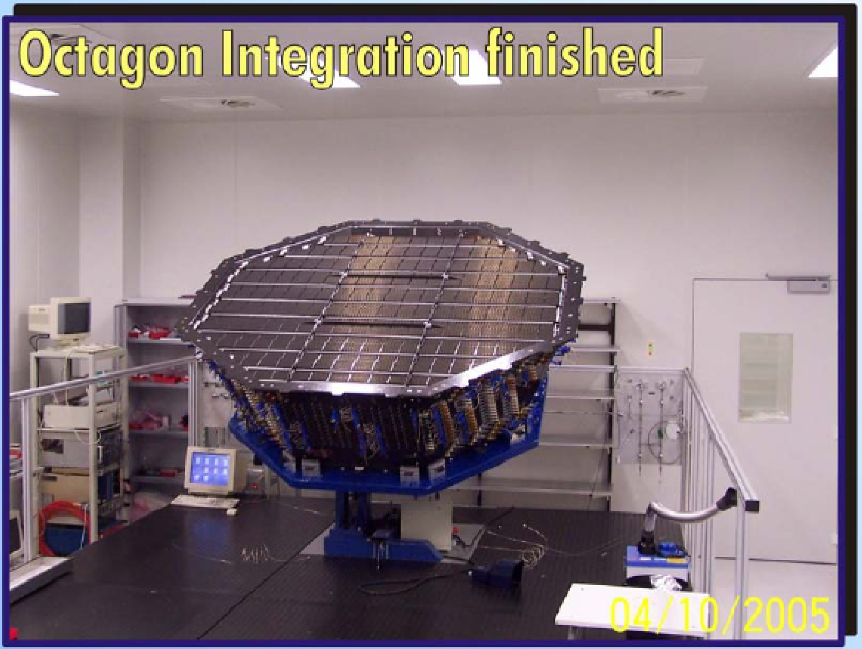

Electromagnetic Interference Test


Thermo Vacuum Test


Vibration Test


M-Support Structure


Octagon Support Structure


Octagon Integration finished

04/10/2005


1 out of 328 Straw Module

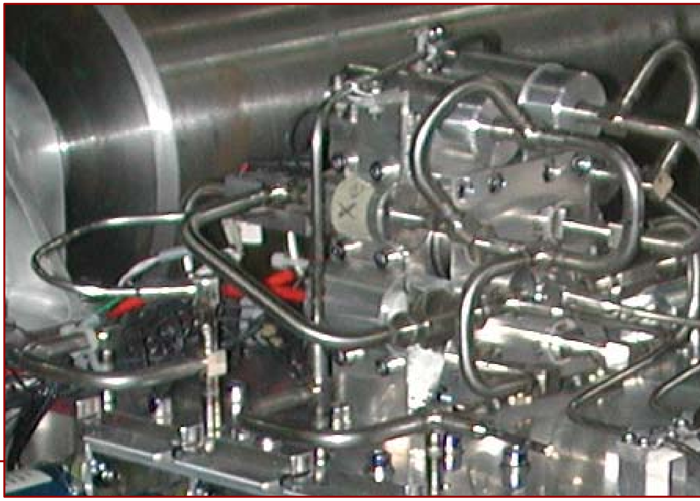
“Box S” Assembly & Test

CO2 tank

Tank weight 1,85 kg filled with 4.5kg Isopropyl alcohol

MV197 valves assembly

weight 2,5kg



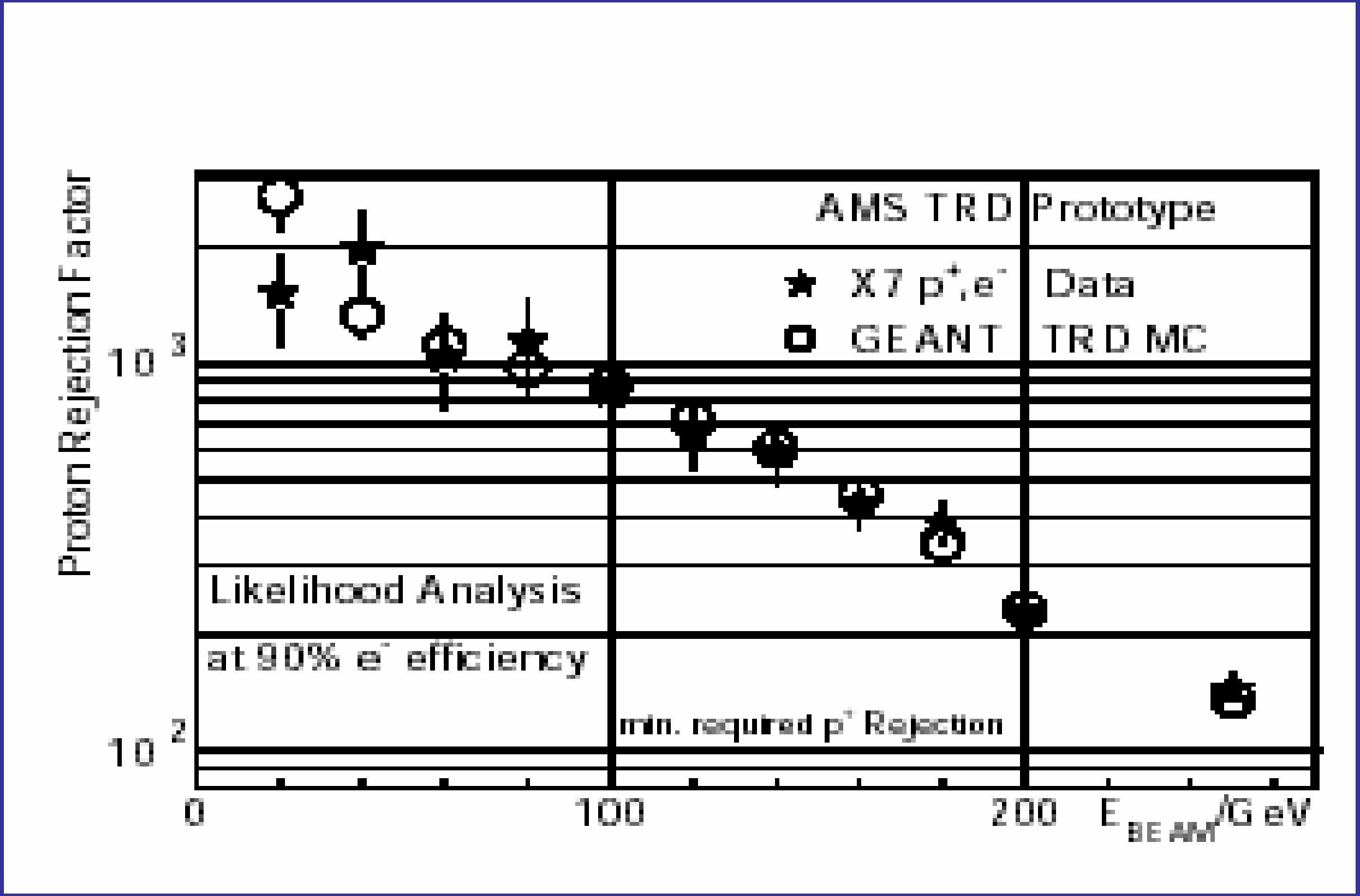
Two Marotta valves assemblies

weight 0,75 kg each

Four Marotta valves assembly

weight 2.95 kg

TRD Performances



20 layer prototype tested with

e^-, μ^-, π^+, p^+

Proton rejection >10^2

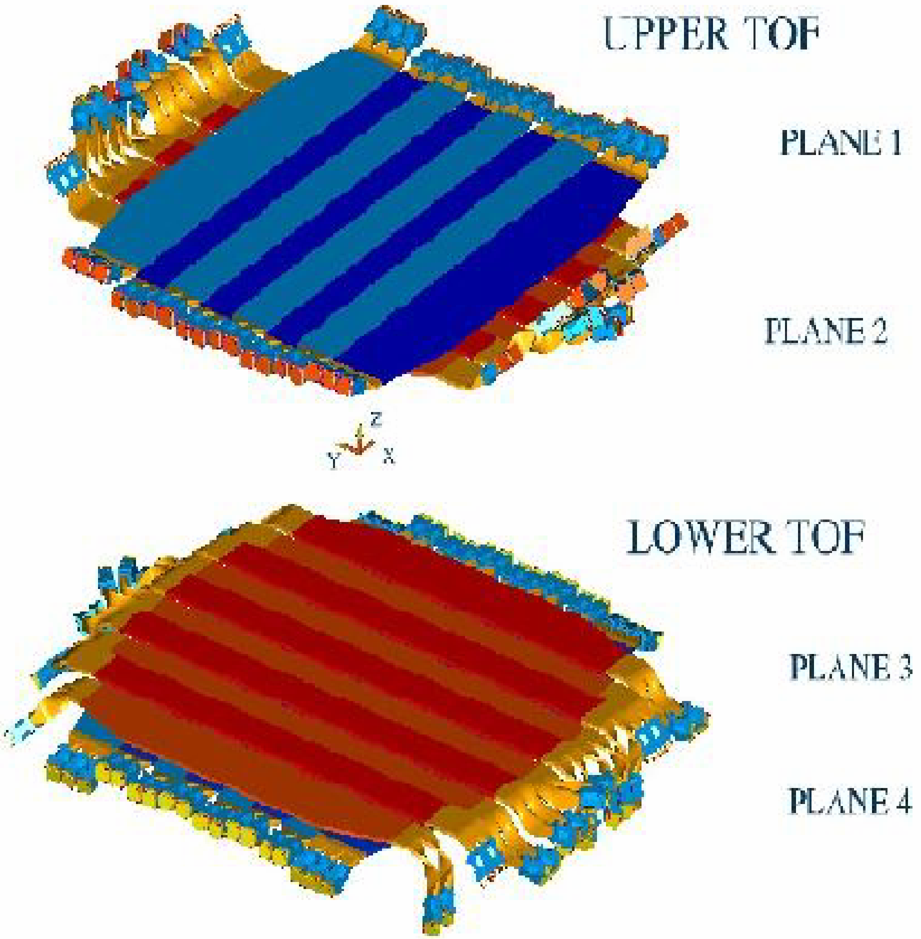
reached up to 250GeV with 90% electron efficiency

AMS-02: Time-of-Flight Detector

- 4 scintillator planes
- A total of 34 crossed scintillator paddles, 1.6 m^2/plane
- Light guides twisted/bent and photo-tubes aligned with $\vec{B}$
- Principle trigger detector for charged particles
- Upgoing/downgoing particle separation
- Velocity measurement with $\Delta\beta/\beta \sim 3\%$ for protons
- Absolute charge measurement (up to $Z \sim 20$)

▷ All scintillator paddles produced

▷ Ready for integration in 2006

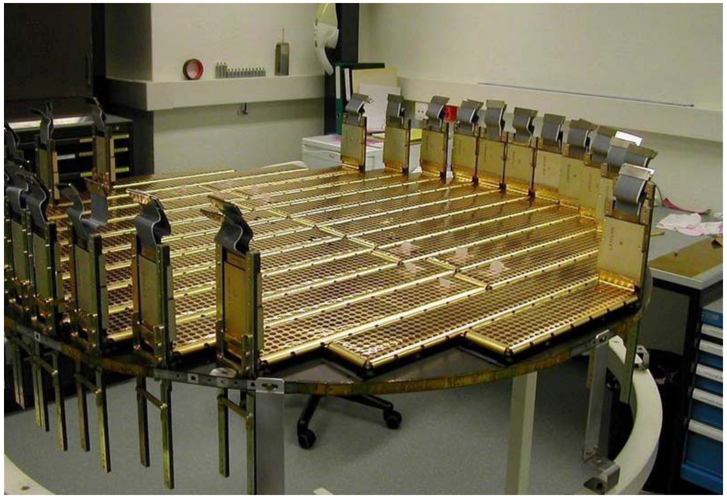


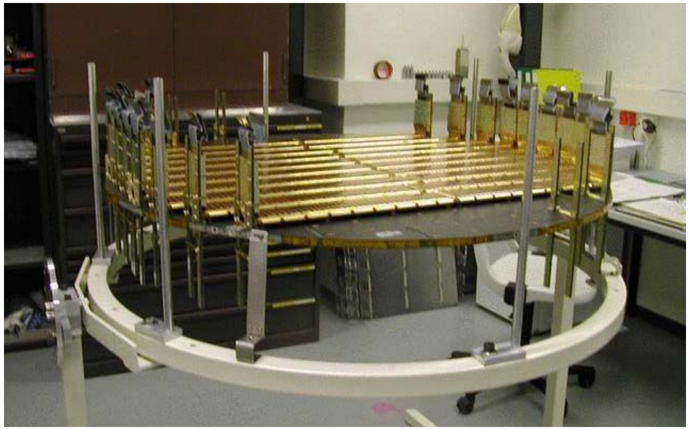
F. Giovacchini he-21
V. Bindi he-15
L. Quadrani he-21

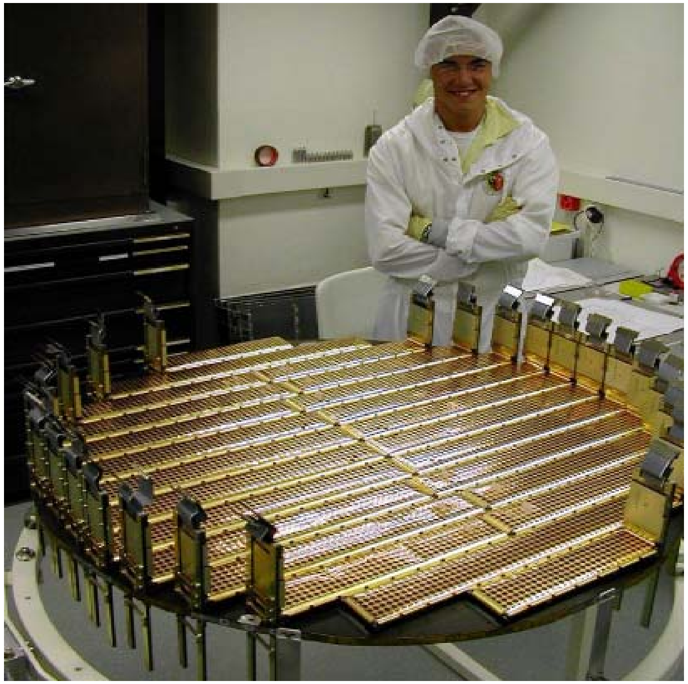
TOF assembly - Test mounting of Lower TOF

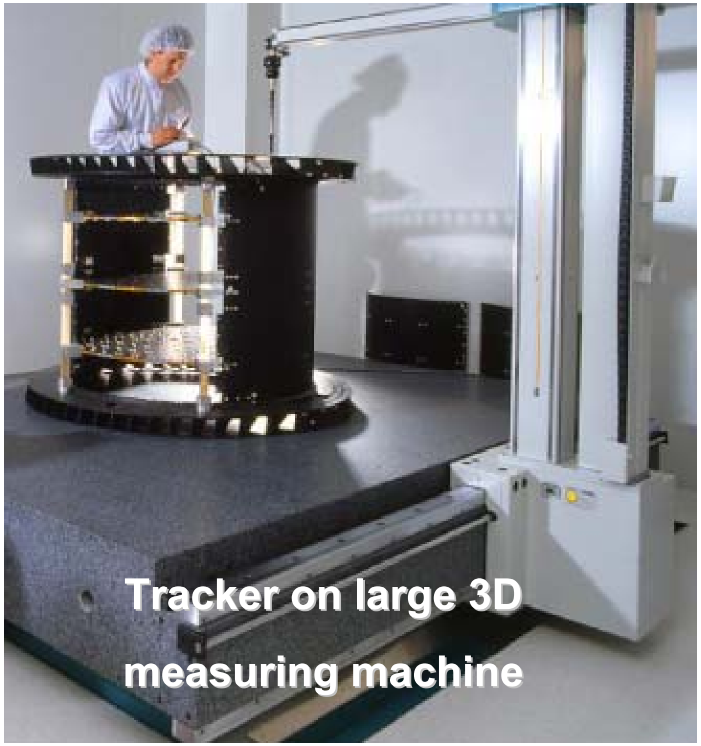
Silicon Tracker

All 8 planes, 300,000 channels have been produced









Tracker on large 3D measuring machine

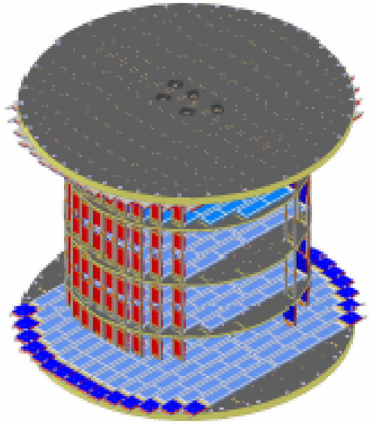
AMS-02 Spectrometer: Silicon Tracker

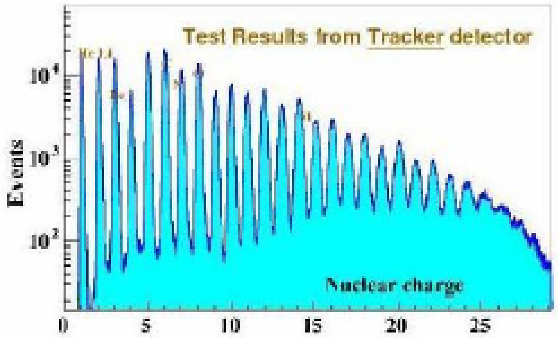
- Precise localisation of charged particles by double sided silicon sensors
- 8 layers of ~ 0.8 m^2 on five ultra-light supporting planes
- Total of ~2500 silicon sensors
- 8 independent position measurements of a particle with $\sim 10\mu$m resolution in bending direction, $\sim 30\mu$m orthogonal
- Particle rigidity $R = \frac{\mathrm{pc}}{|Z|\mathrm{e}}$ up to a few TV
- Electric charge (Z) from energy loss dE/dx. Identification of elements up to iron possible
- Direction and energy of converted photons

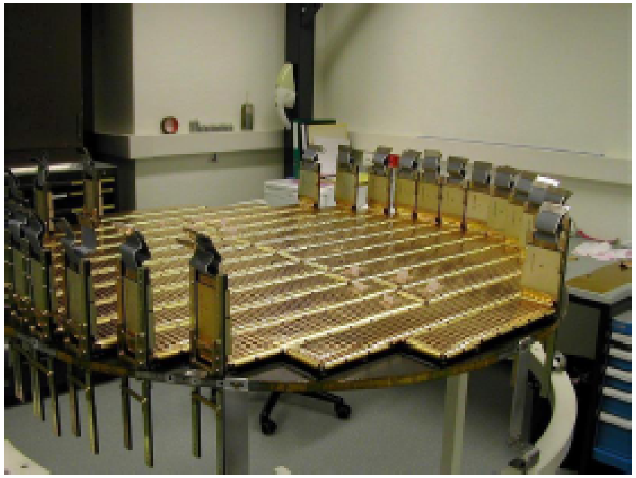
▷ 100 % of sensors mounted

▷ 4 layers completely equipped

▷ All 8 layers equipped by December 2005

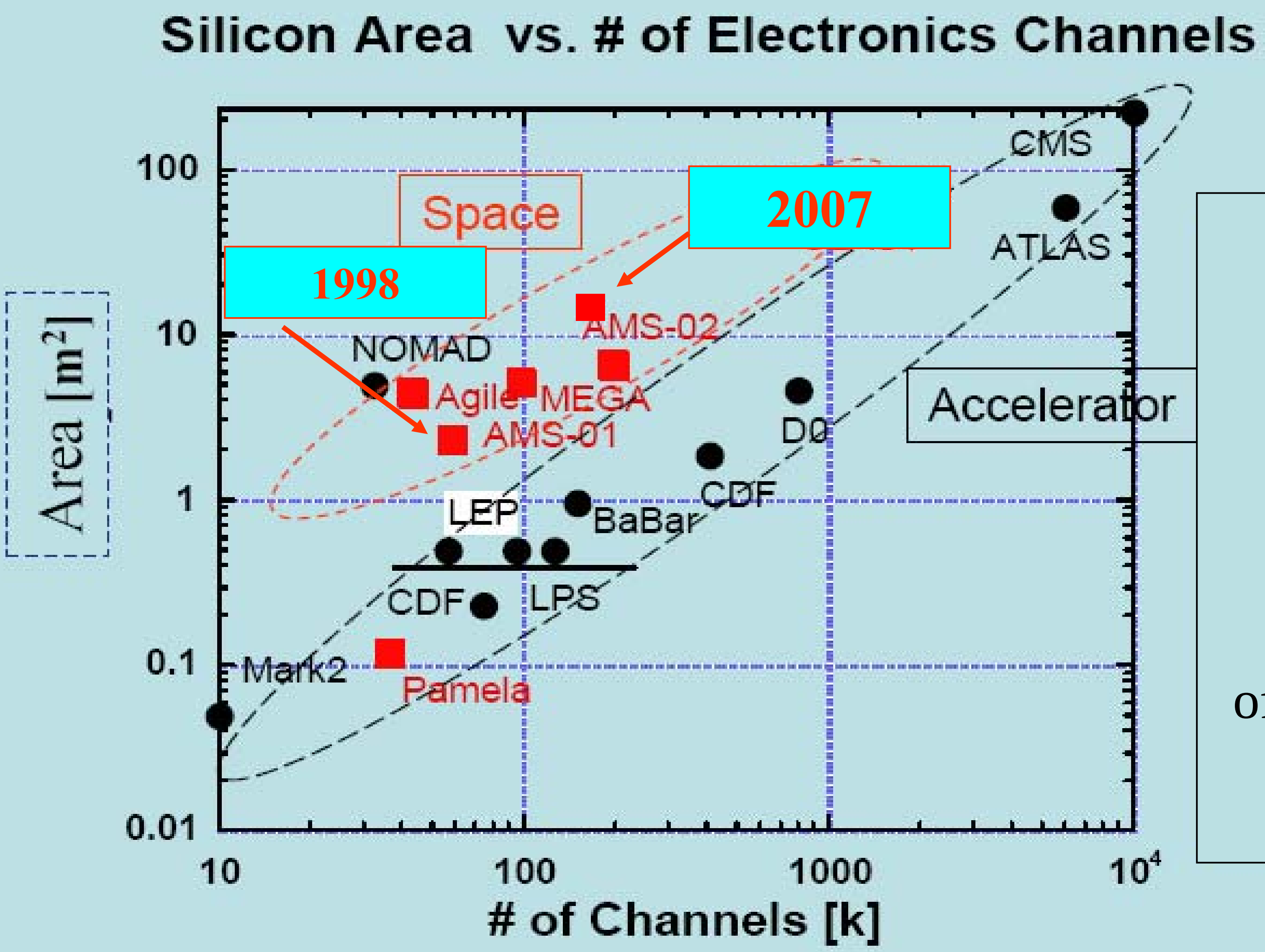






P. Zuccon he-24

Trends in applications of silicon sensors in tracking detectors



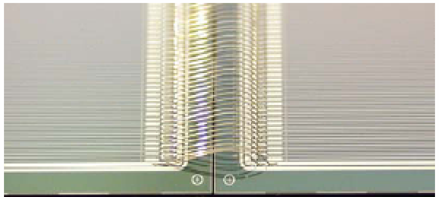
AMS
Silicon Tracker
has pioneered
in 1998
large
scale utilization
of microstrip silicon
detectors in space

Construction of the Silicon Tracker

Step 1

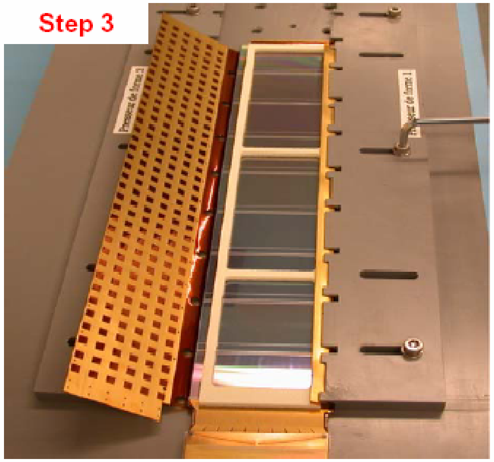
Assembling sensors on vacuum jig

Step 2



Ultrasonic wire-bonding, 50 µm pitch

Step 3



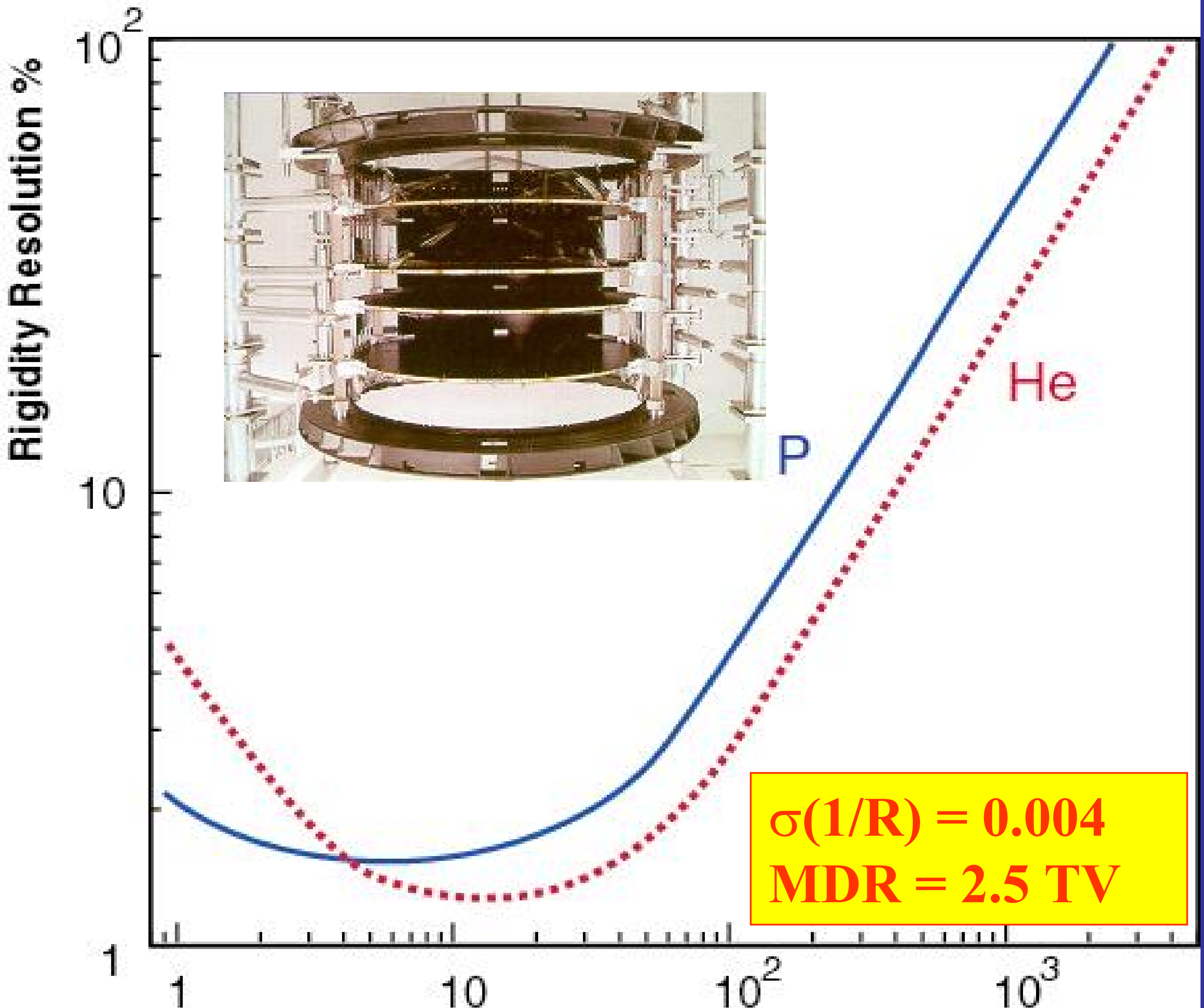
EMI Shielding

Step 5

Step 4

Storage in N_2 gas

AMS-02 Silicon Spectrometer Rigidity Resolution/

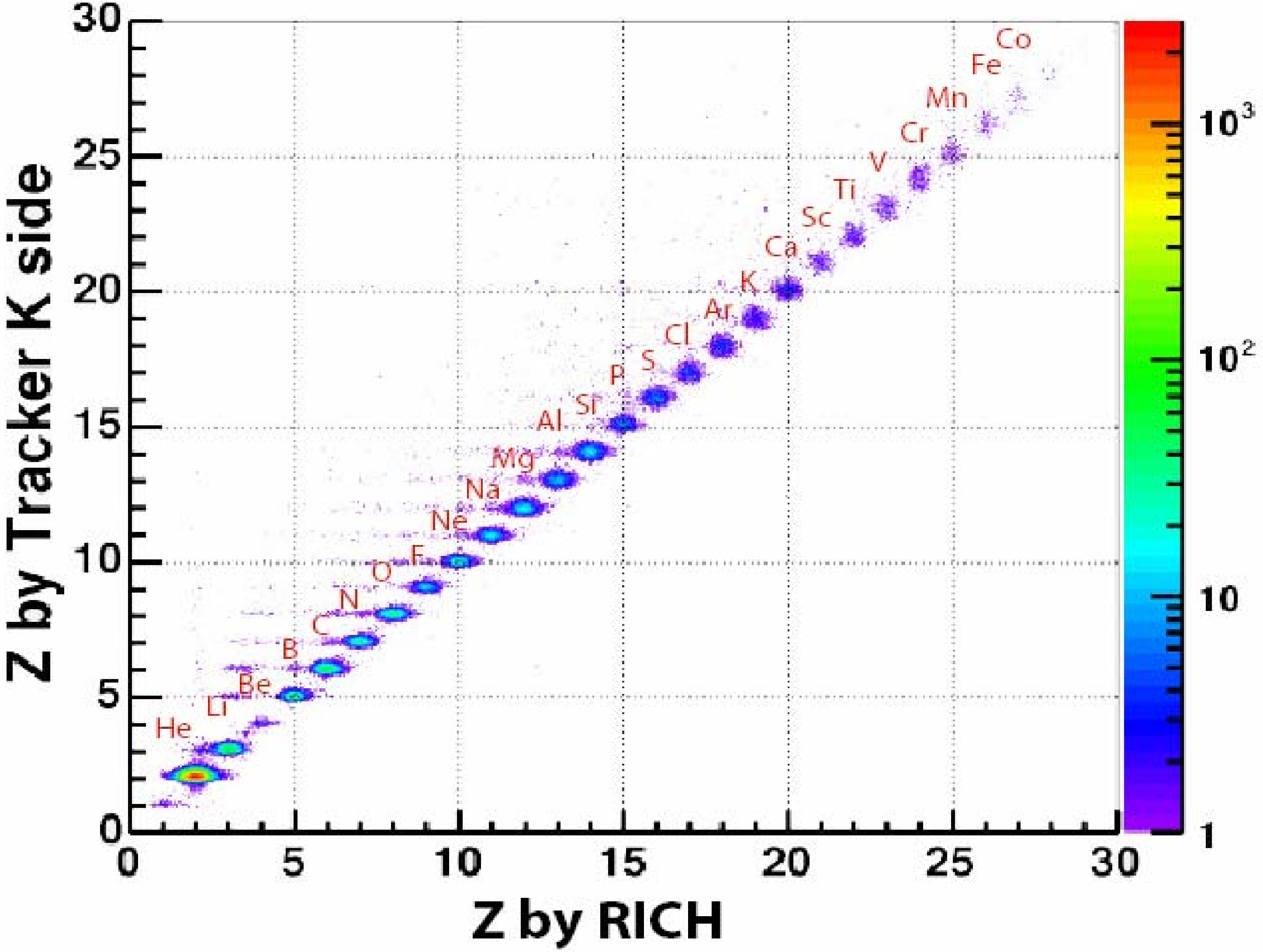


σ(1/R) = 0.004
MDR = 2.5 TV

Rigidity (GV)

Accurate measurement of cosmic radiation for all atomic nuclei

Test results from accelerator using both RICH and Tracker 158 GeV/N



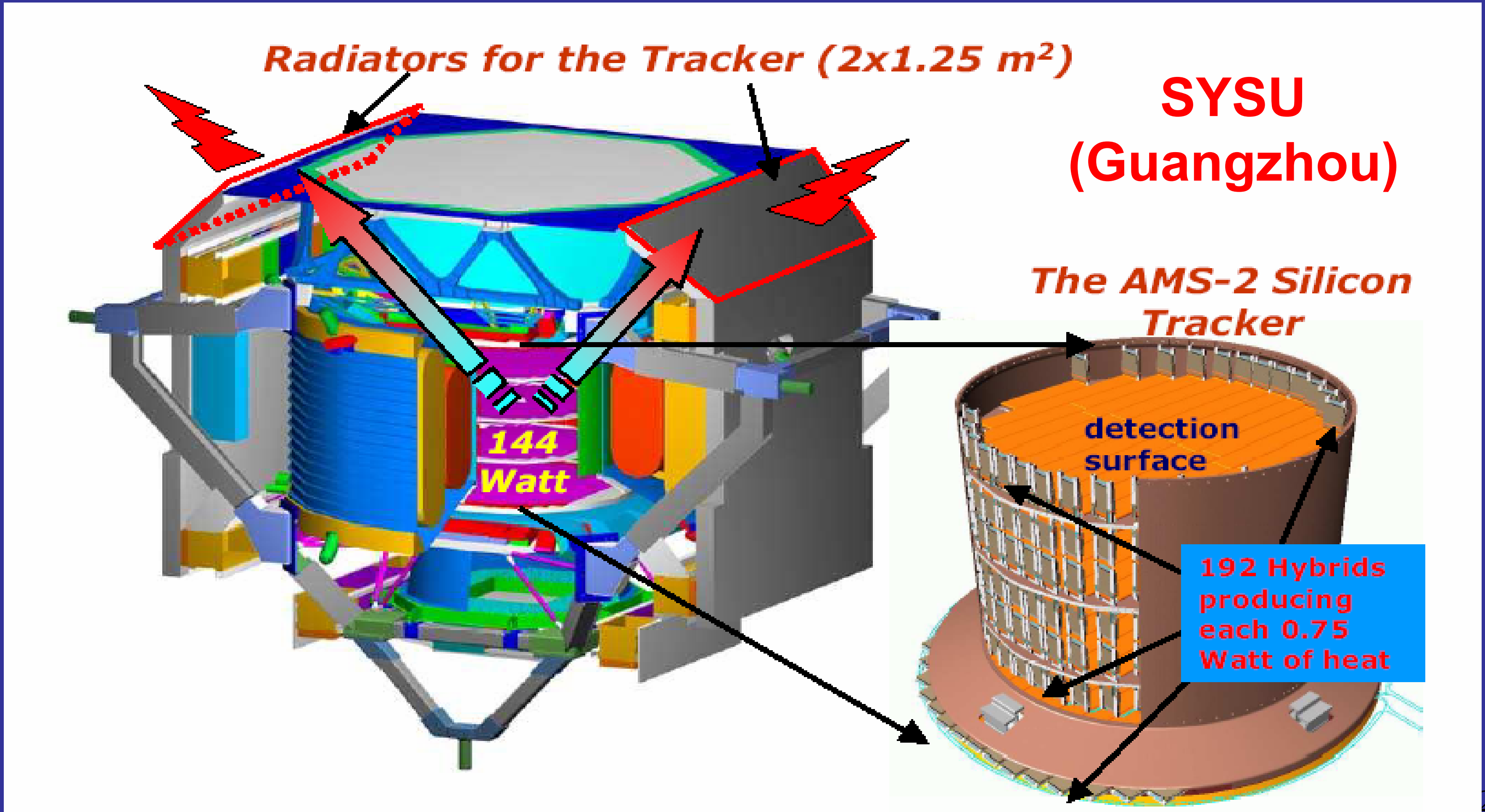
y04K335c TKvsR.ai

Tracker Thermal Control System

Two-phase pumped CO_2 loops

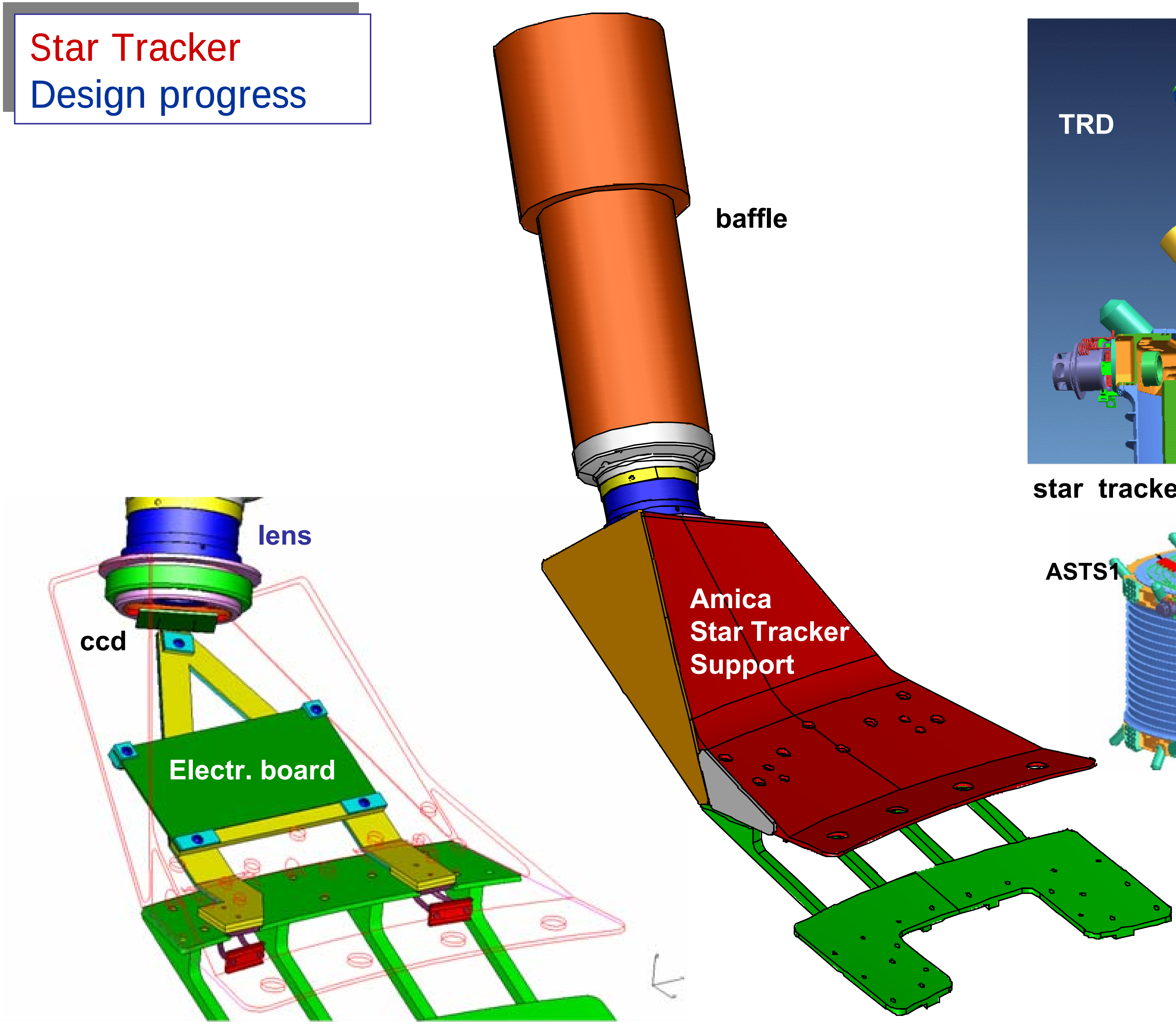
The most advanced cooling technology for space

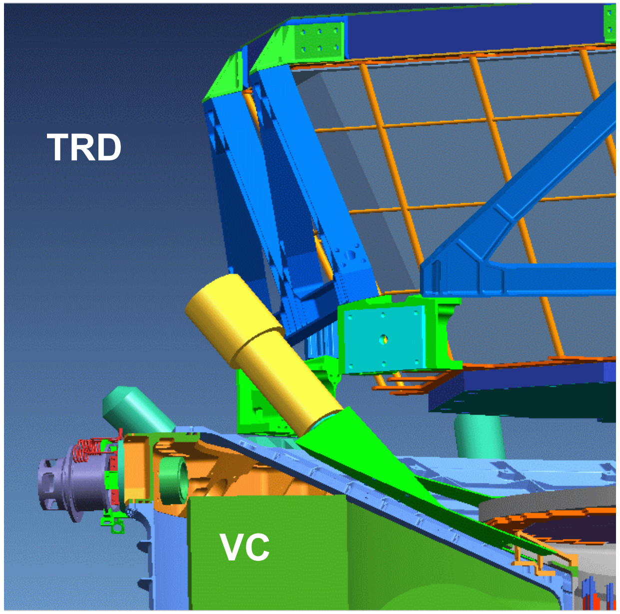
Key technology for robotic or manned space exploration



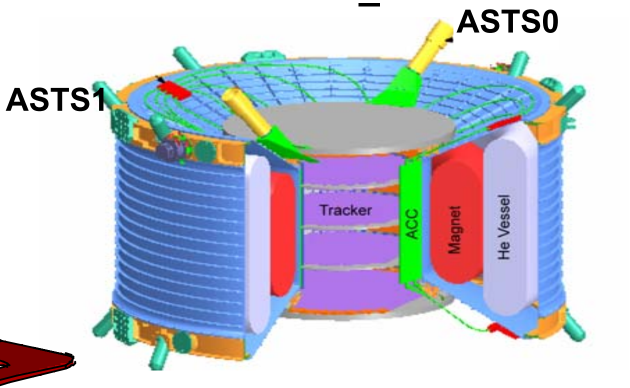
SYSU (Guangzhou)

Star Tracker
Design progress





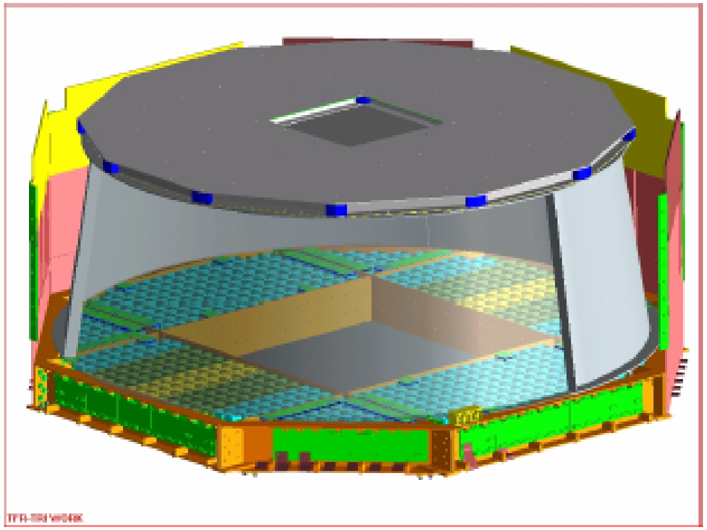
star trackers in AMS_02

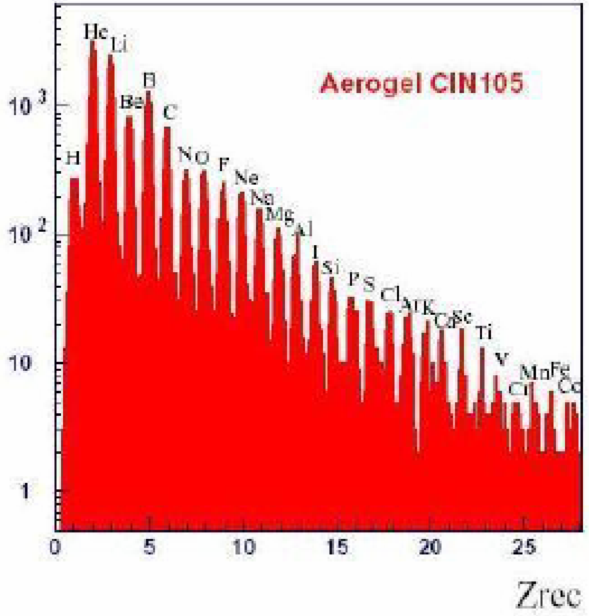


AMS-02: Ring Imaging Cherenkov Detector

- Proximity focusing Ring Imaging Detector
- 2 different radiators:
  Aerogel, n=1.05, 2.7 cm thickness
  Sodium fluoride, n=1.336, 0.5 cm thickness
- Conical reflector
- Photomultiplier matrix (680)
- velocity measurement from emission angle
  $\Delta\beta/\beta \sim 0.1\%$ for single charge particles
- Number of photo-electrons measures Z
  ΔZ $\simeq$0.2-0.25 up to Fe
- directional sensitivity

▷ RICH is currently being assembled
▷ will be integrated in AMS in June 2006

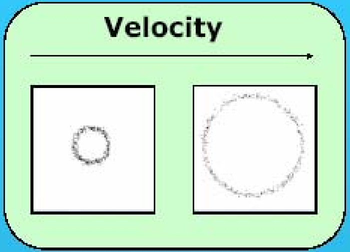


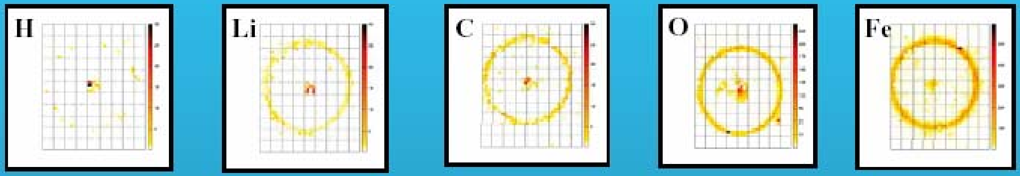


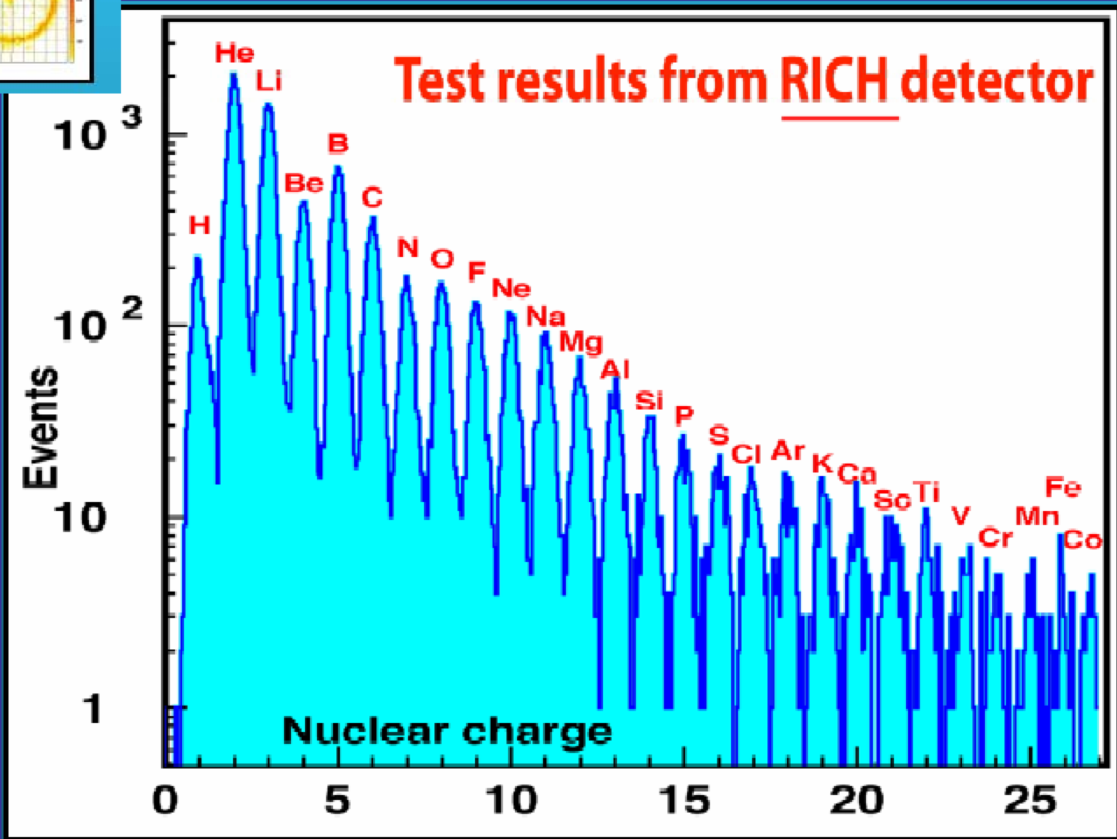
F. Barao og-15

Test from Accelerator

Measurements of Cosmic Nuclei

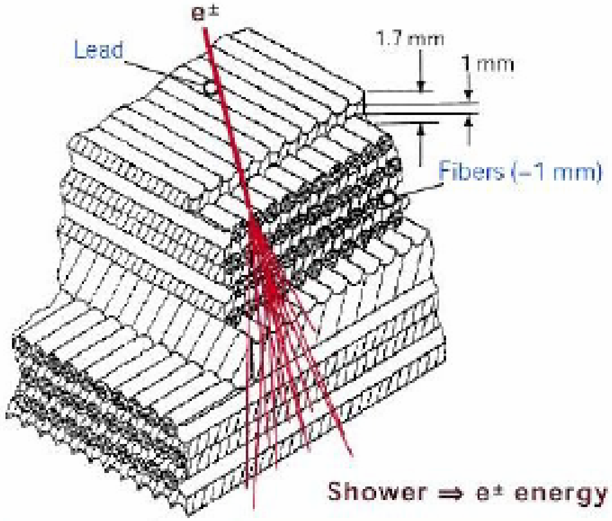


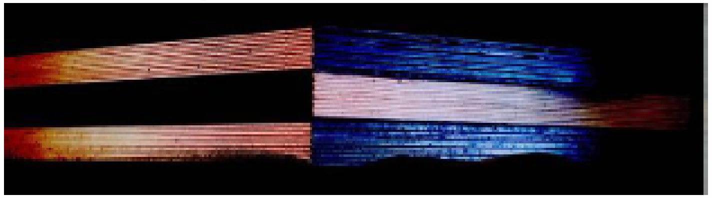


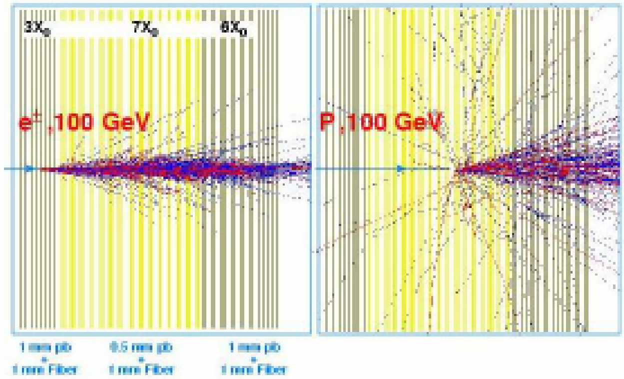

Test results from RICH detector

AMS-02: Electromagnetic Calorimeter

- Lead scintillating fiber sandwich (640 kg), 3D sampling by crossed layer
- $\sim 17X_o$ radiation lenghts
- 9 superlayers piled up disposed along Y and X alternately
- Energy resolution (GeV) $\Delta E/E \simeq 10.1\%/\sqrt{E} \oplus 2.6\%$
- Distinction between hadrons and e/γ by shower shape
- Protons supressed by 10^{-4} up to 500 GeV. Together with TRD, rejection of hadrons/electrons $\geq 10^6$
- Independent γ detector, angular resolution $\sim 2^\circ$, γ independently triggered



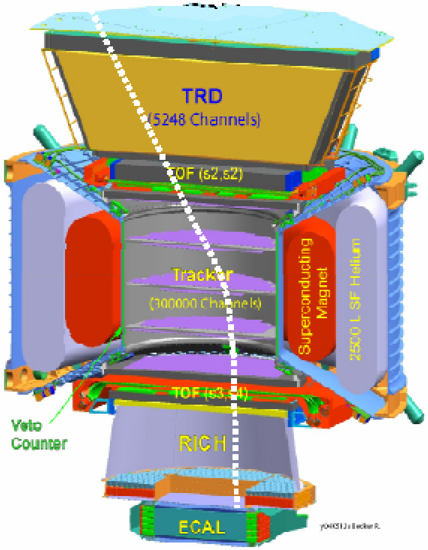




IHEP Beijing

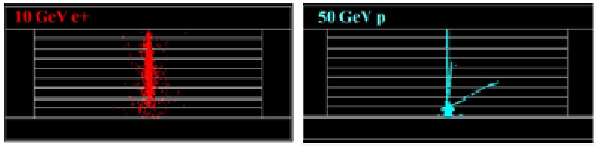
▷ All superlayers installed in mechanical structure

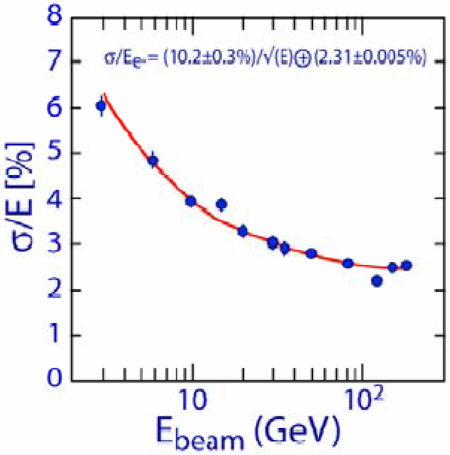
▷ Final calibration in e^- test beam in 2006

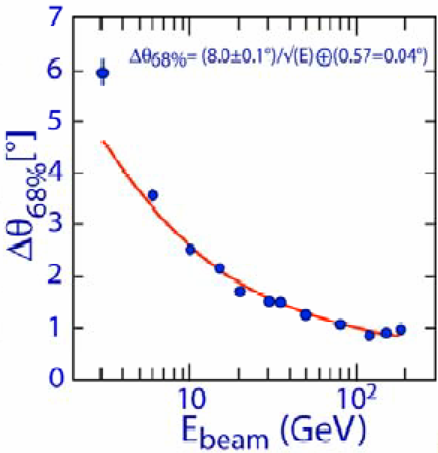


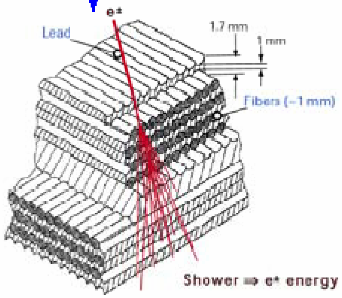
Measure the energy and identify cosmic particles

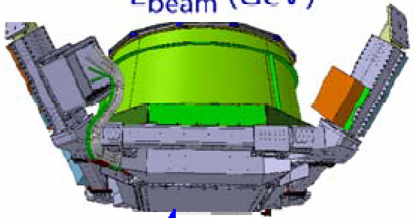
The shape of the shower in the ECAL allows
to identify the nature of the particle traversing it



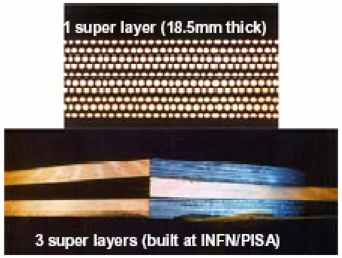


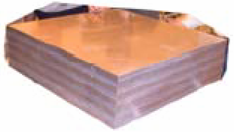




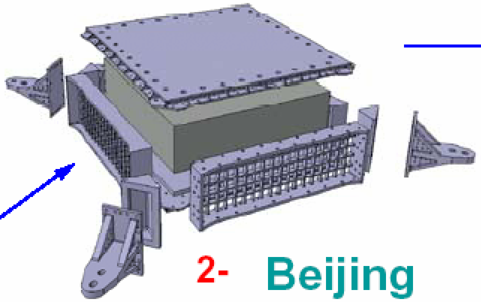


1- Pisa

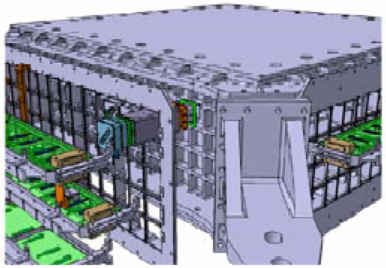


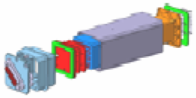


2- Beijing



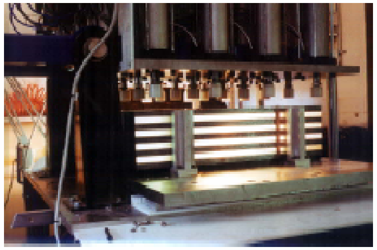
3- Annecy





1- Italy

Fibers and Lead foils are piled up and glued together to form a module



9 Modules are glued together to form a superlayer

2- Beijing

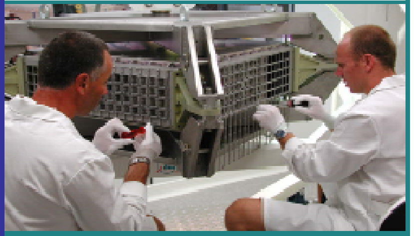
The superlayers are inserted in the mechanical support structure.

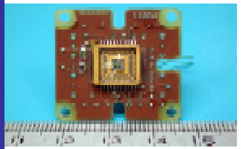
Space qualification in Beijing

3- Annecy

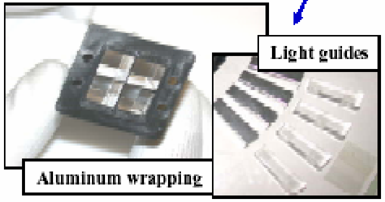
Instrumentation

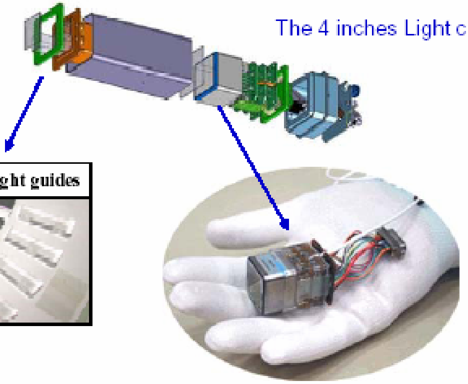
Preparation of assembly in clean room





Integrated circuit



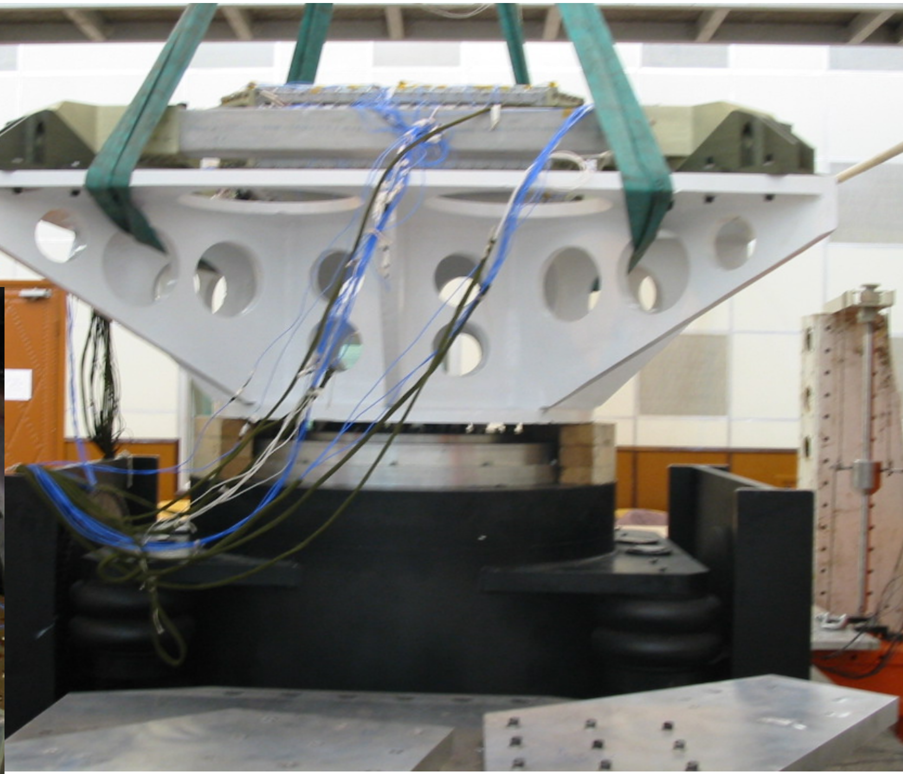


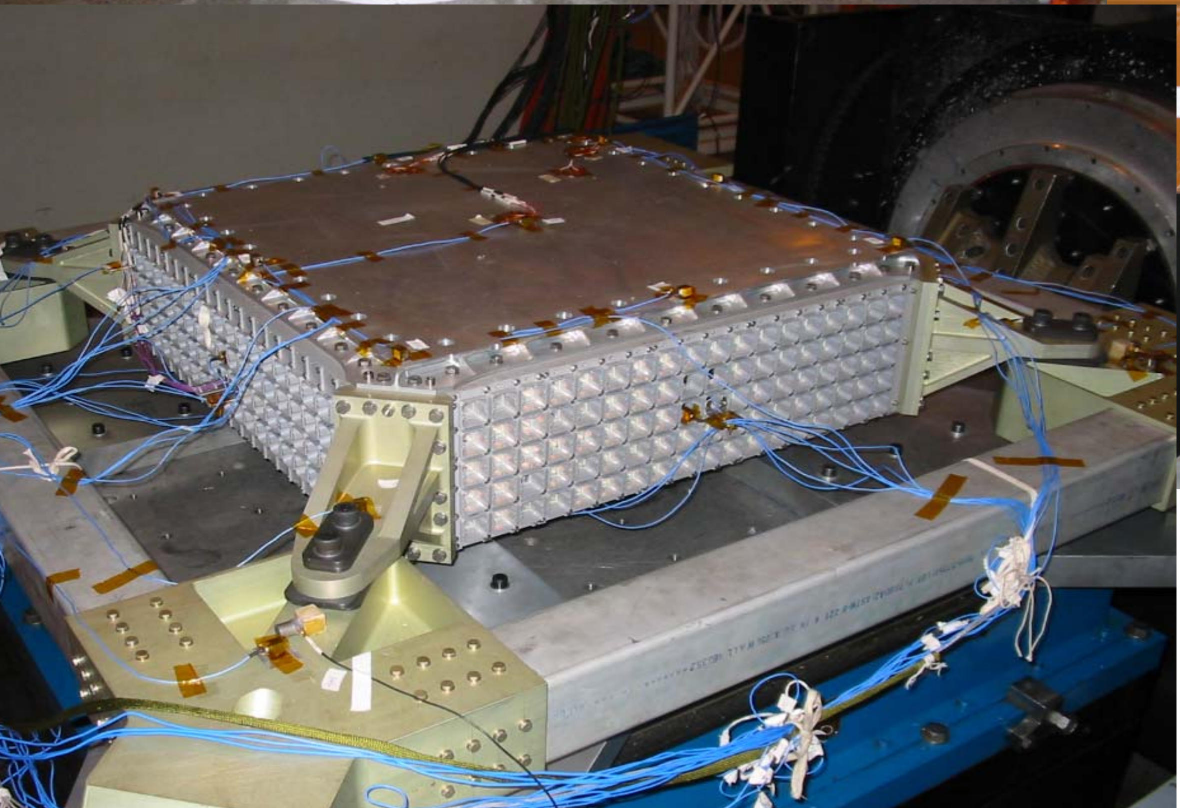
The 4 inches Light collection block

Assembly of Light collection blocks

Complete calorimeter

ECAL Structural Testing

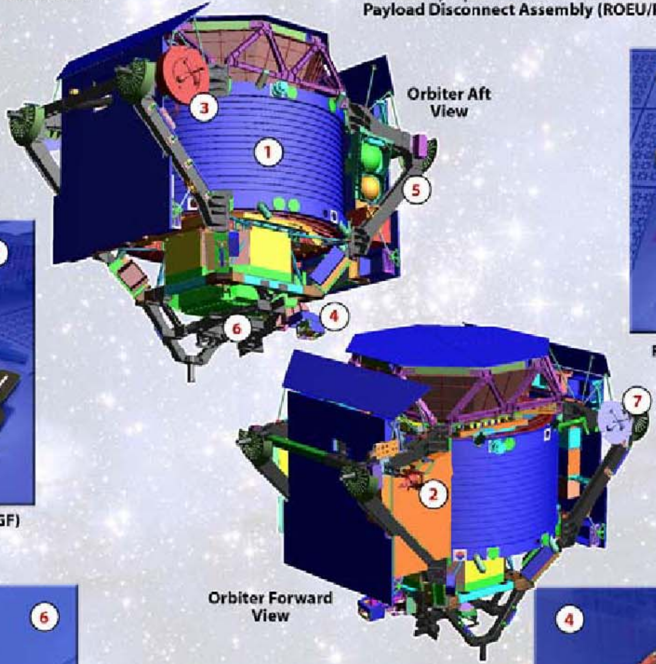




IHEP
CALT
(Beijing)

Vacuum Case

Remotely Operated Electrical Umbilical/
Payload Disconnect Assembly (ROEU/PDA)



Power Video Grapple Fixture (PVGF)

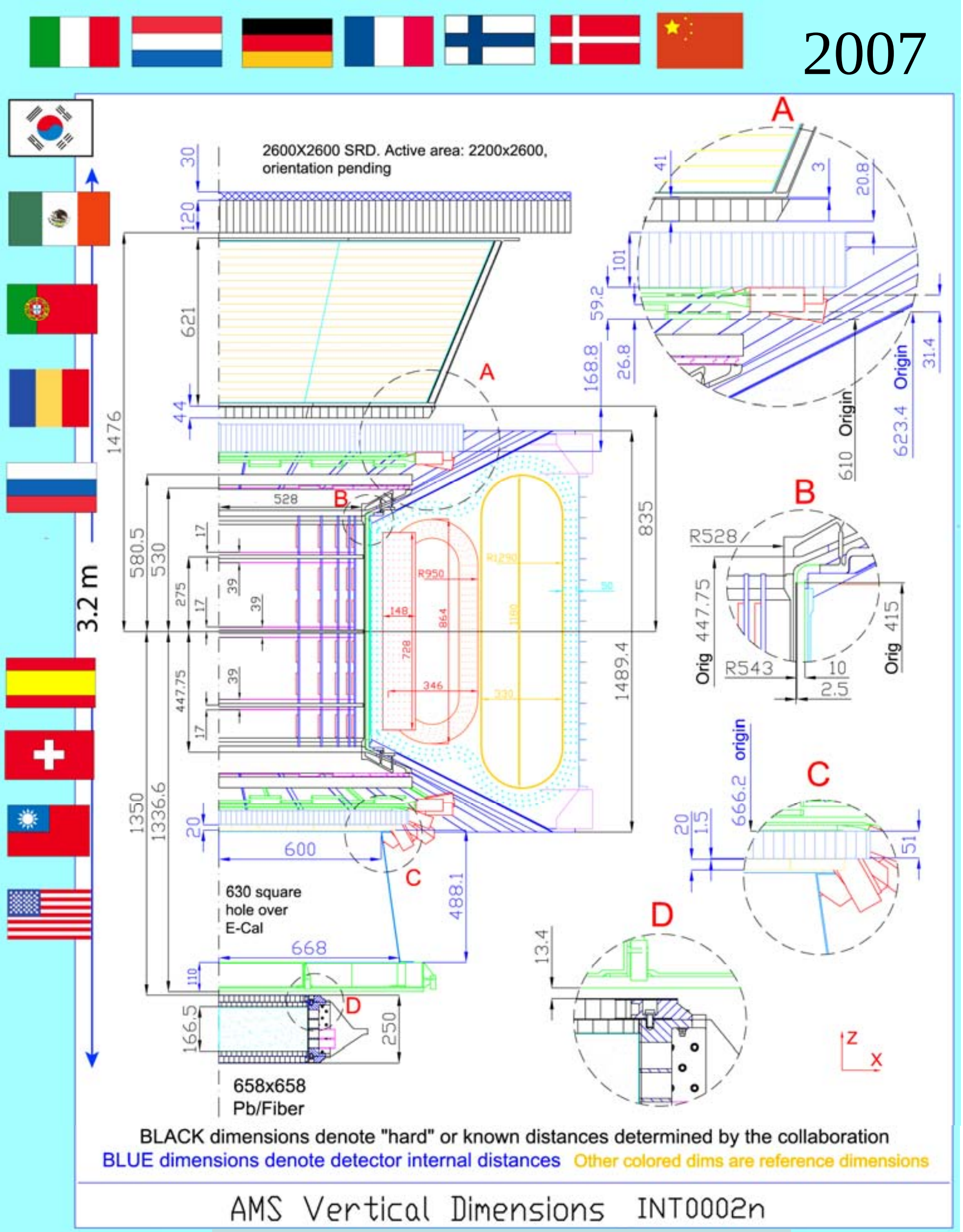
Flight Releasable Grapple Fixture (FRGF)

Passive Payload Attach System (PAS)

Unique Support Structure (USS)

Passive Umbilical Mechanism Assembly (UMA)

2007



2600X2600 SRD. Active area: 2200x2600, orientation pending

630 square hole over E-Cal

658x658 Pb/Fiber

BLACK dimensions denote "hard" or known distances determined by the collaboration

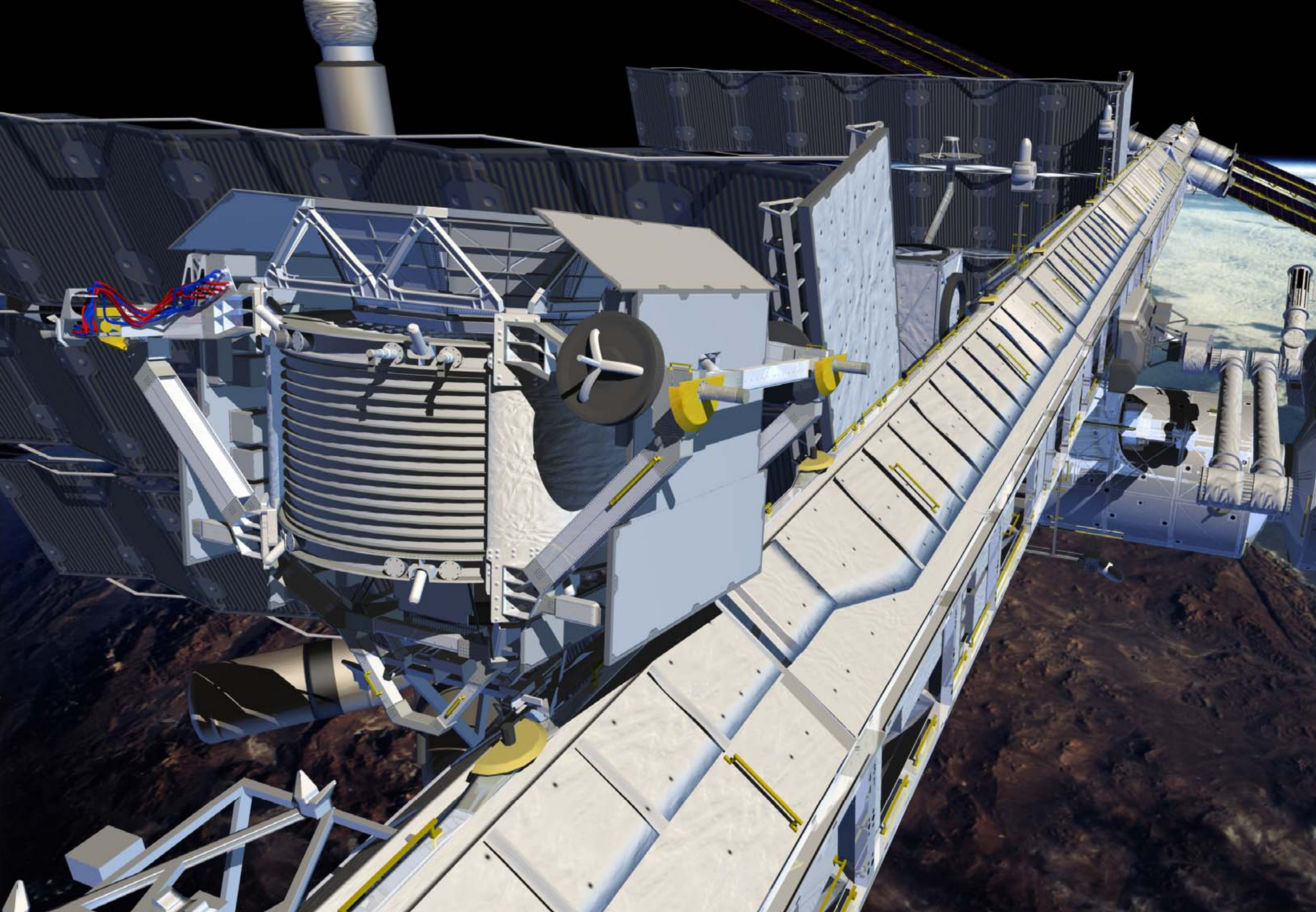
BLUE dimensions denote detector internal distances Other colored dims are reference dimensions

AMS Vertical Dimensions INT0002n

2007 Assembly at CERN

2008

Thermal vacuum test at ESA, Holland



Conclusions

- Cosmic Rays carry important informations about the non thermal universe
- AMS-02 has been designed to measure with ppb accuracy primary CR composition up the TeV region
- These accurate measurements will allow to undertand propagation and confinement mechanisms in our Galaxy
- The study of the rare components would allow to search for new phenomena (Dark Matter, strangelets) or to better constrain fundamental issues like the existence of primordial antimatter

Addressing fundamental questions aiming for a breakthrough

Accelerator	Original purpose	Discovery
AGS Brookhaven (1960)	π N interactions	2 kinds of neutrinos, Breakdown of time reversal symmetry, 4-th Quark
FNAL Batavia (1970)	neutrino physics	5-th Quark, 6-th Quark
SLAC Spear (1970)	ep, QED	Partons, 4-th Quark, 3rd electron
PETRA Hamburg (1980)	6-th Quark	Gluons
Super Kamiokande (2000)	Proton Decay	Neutrino Oscillation
Hubble Space Telescope	Galactic Survey	Curvature of the universe
AMS on ISS	Dark Matter Antimatter	?