Alpha Magnetic Spectrometer (AMS) Experiment in Space

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Frontier Objects in Astrophysics and Particle Physics

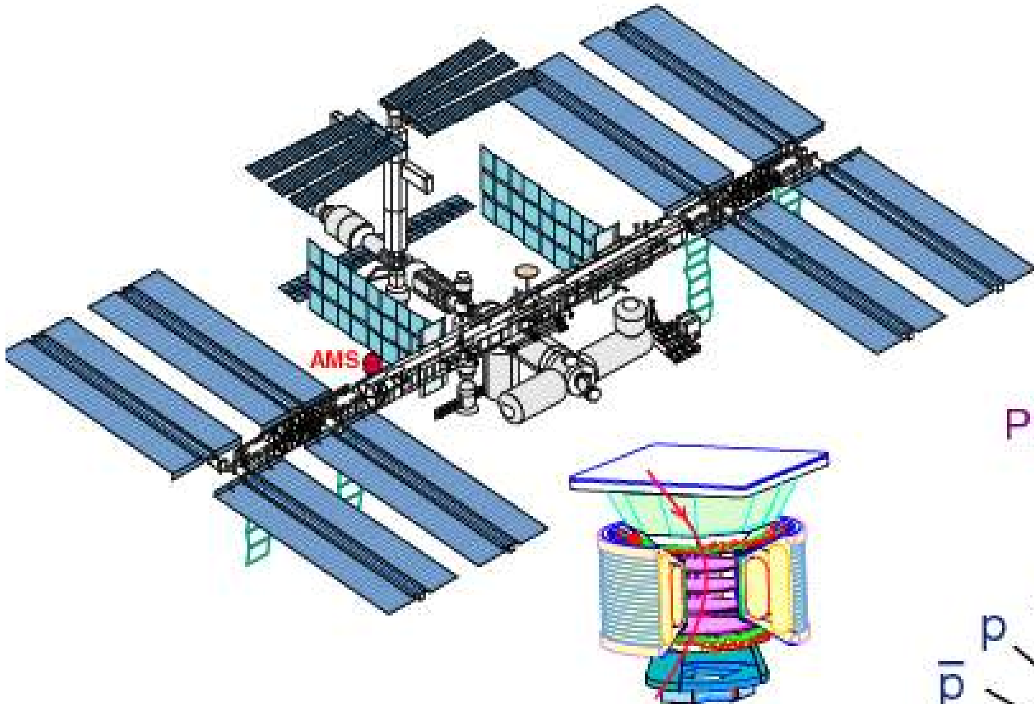
Vulcano (Italy) Workshop 22-27th May, 2006

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

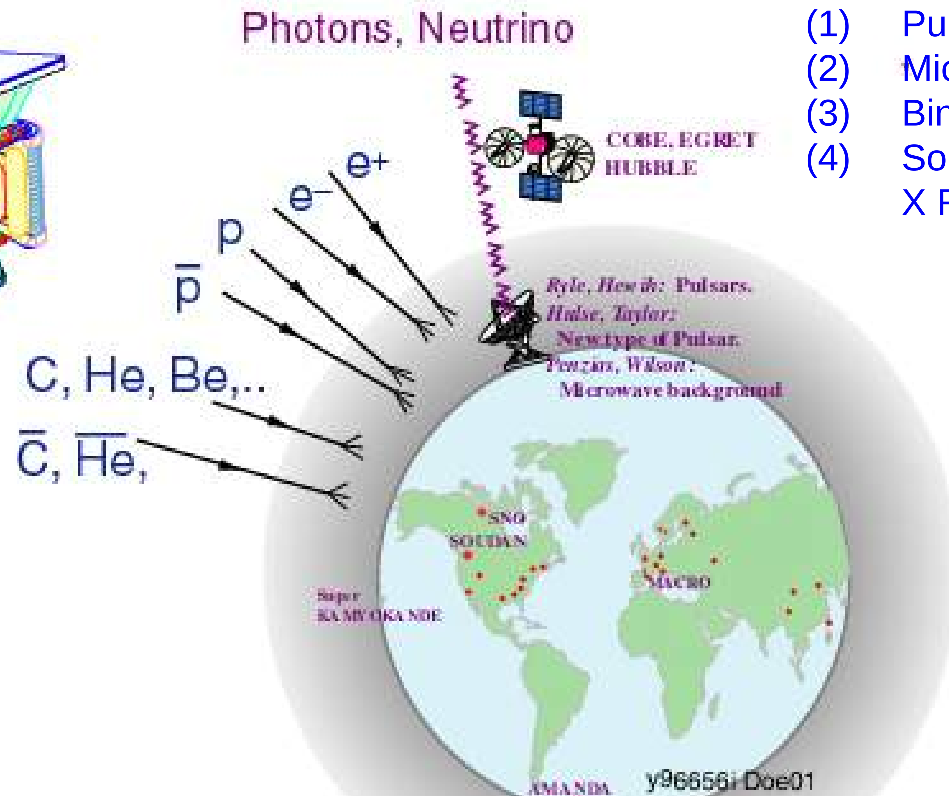
- energetic (>1 GeV) gamma rays.

AMS is a particle physics experiment:



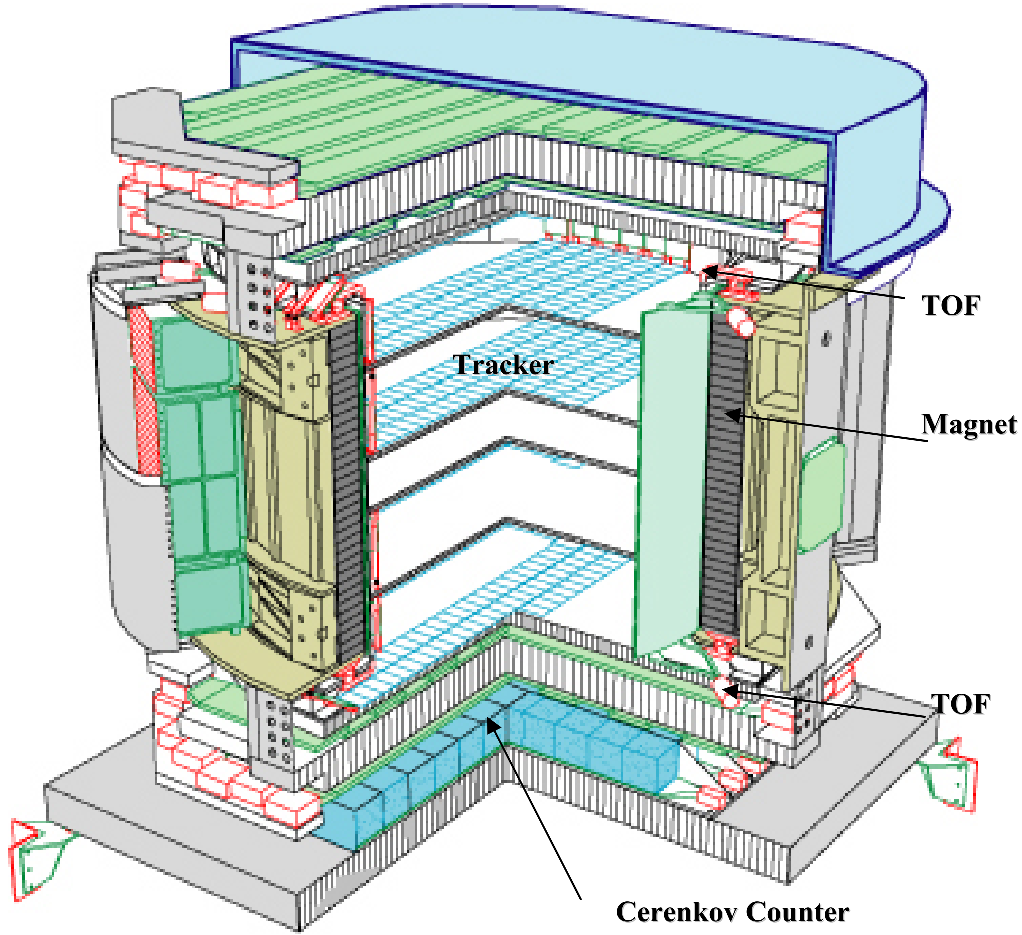
SUSY (Super Symmetry)
Grand Unified Theory
Baryon number violation
CP violation

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)



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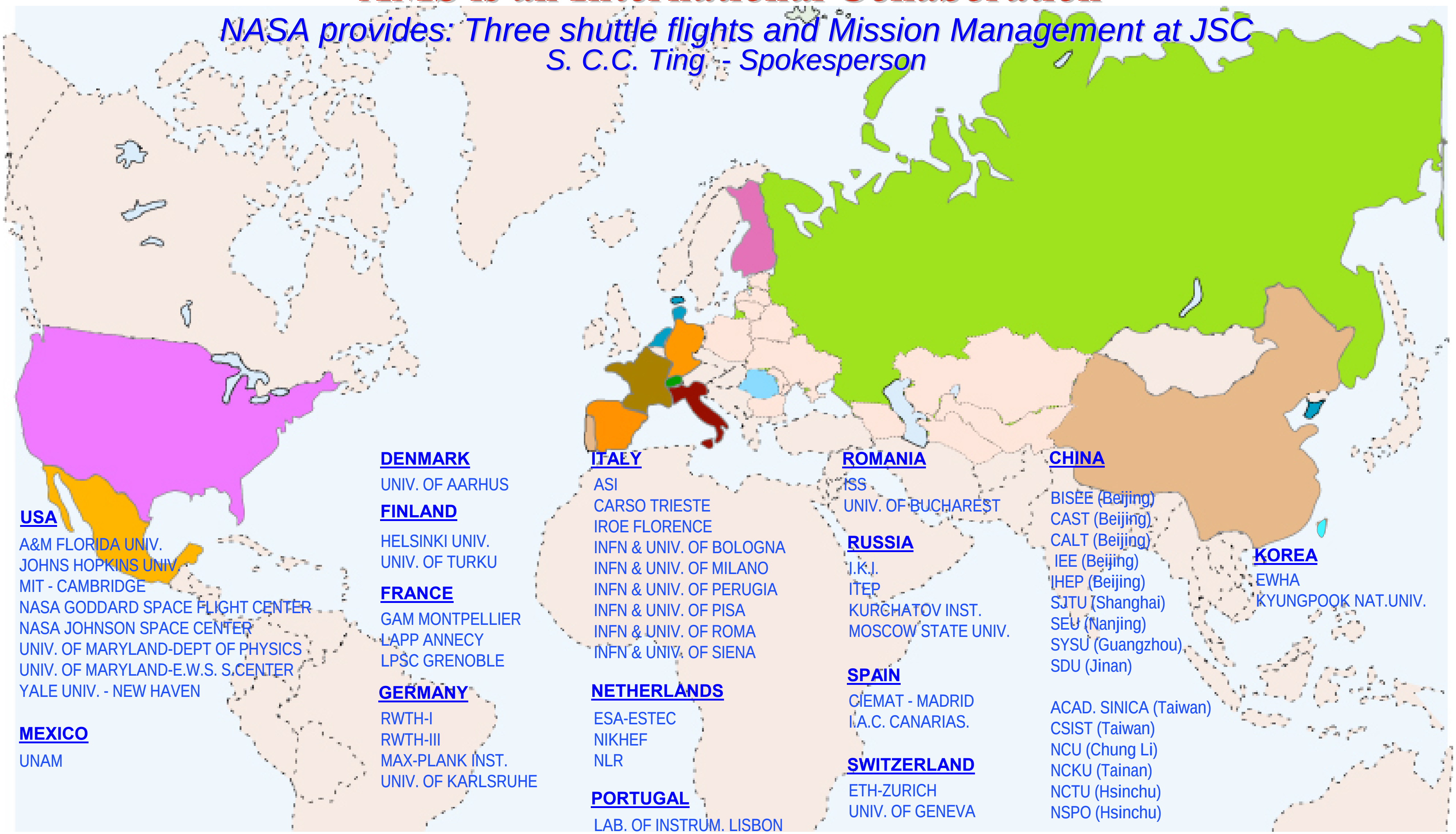
AMS is an International Collaboration

NASA provides: Three shuttle flights and Mission Management at JSC
S. C.C. Ting - Spokesperson



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NASA JOHNSON SPACE CENTER
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UNIV. OF MARYLAND-E.W.S. S.CENTER
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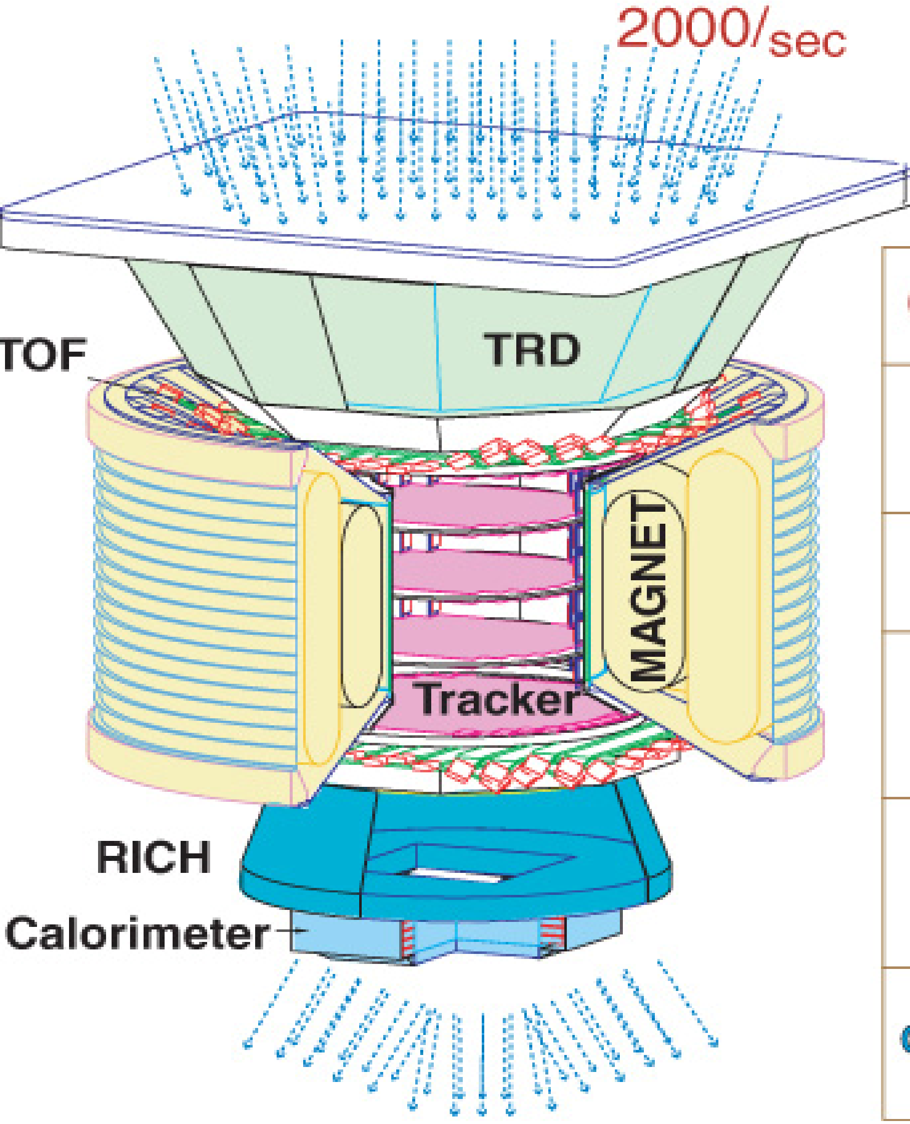
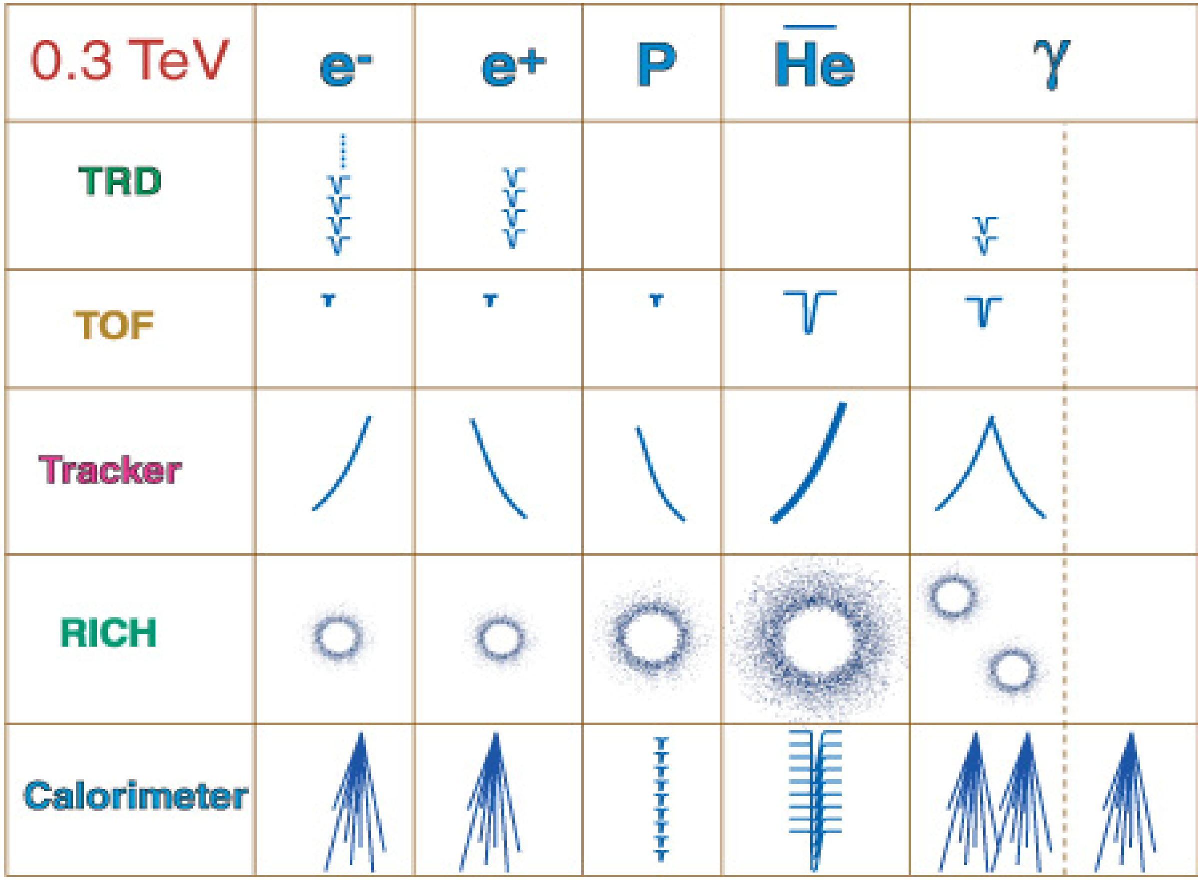
AMS: A TeV Magnetic Spectrometer in Space



G.F. 5000 cm^2 sr
Exposure > 3 yrs



dP/P^2 ~ 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:

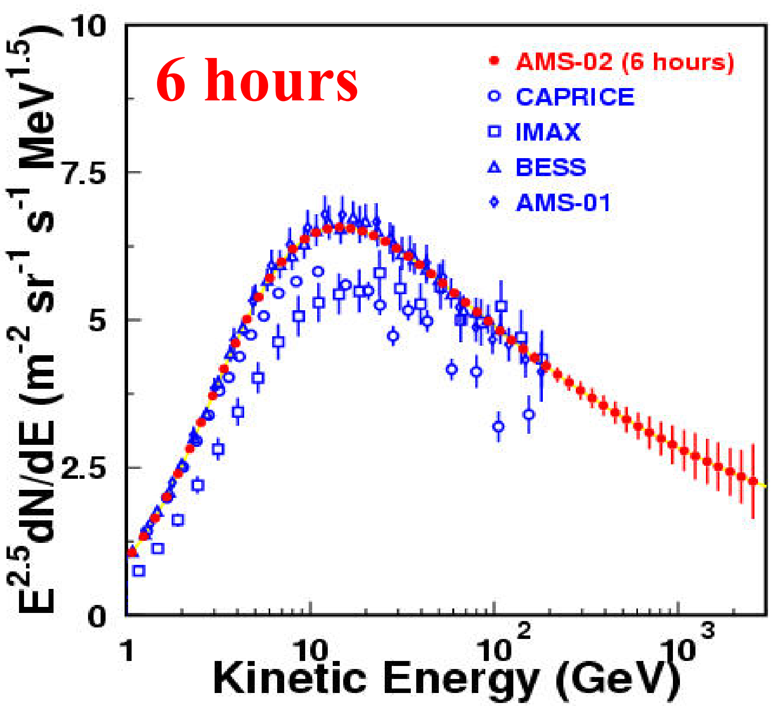
- **p for E < 1 TeV with unprecedented precision**
- **e+ for E < 300 GeV and e– for E < 1 TeV (unprecedented precision)**
- **Light Isotopes for E < 10 GeV/n**
- **Individual elements up to Z = 26 for E < 1 TeV/n**

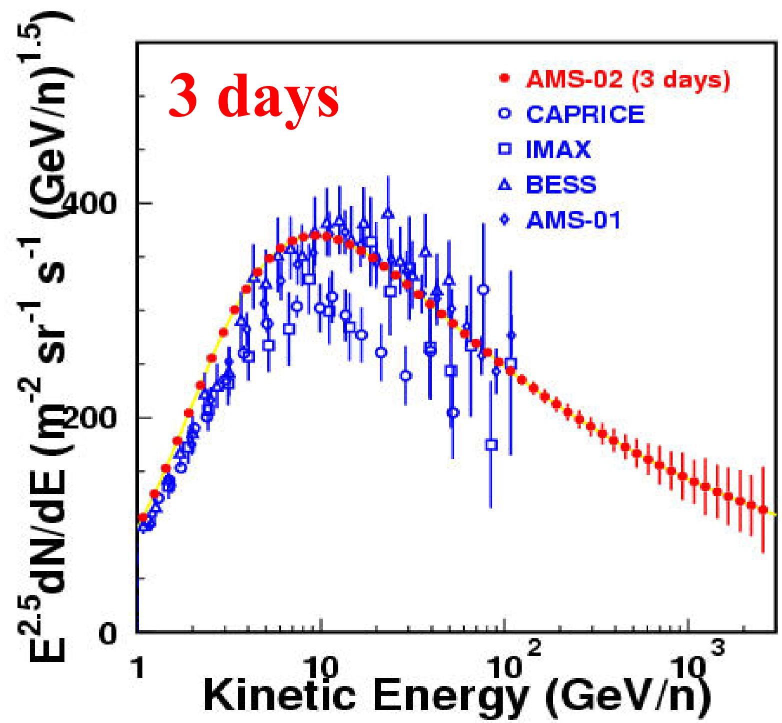
Absolute fluxes and spectrum shapes of protons and helium are important for calculation of atmospheric neutrino fluxes

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

Protons and helium

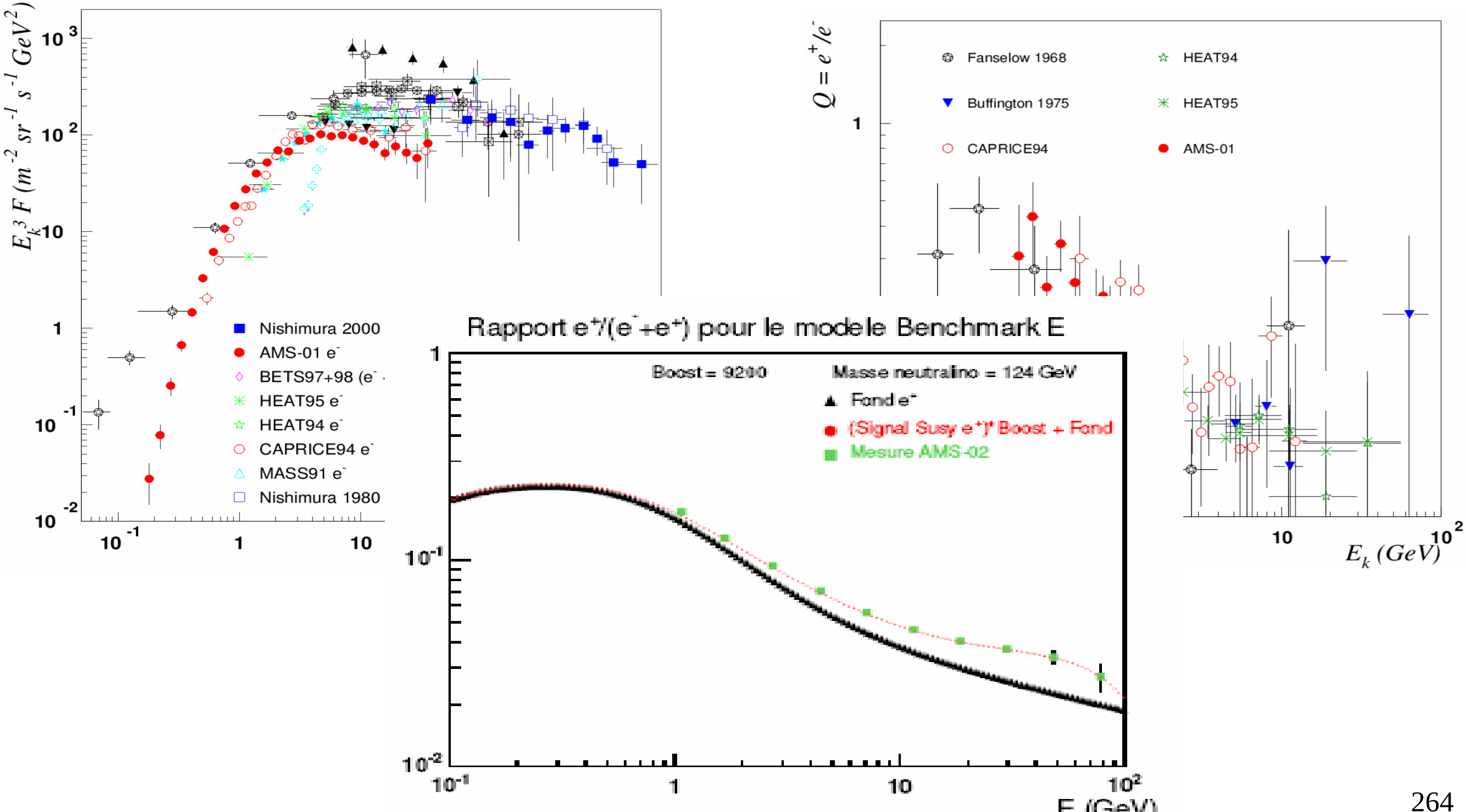
- AMS will measure H & He fluxes for E < 1 TeV
- after 3 years will collect ≈10^8 H with E > 100 GeV
- and ≈10^7 He with E > 100 GeV/n





Electrons and positrons

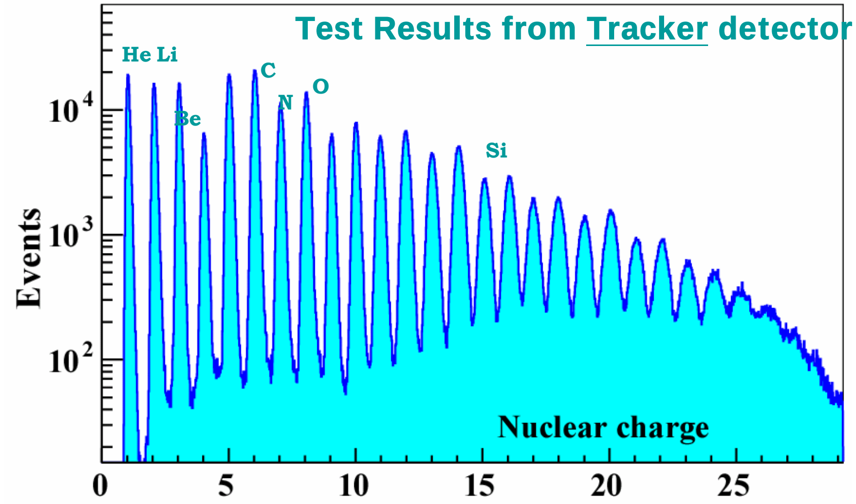
Energetic e+/e– cannot diffuse more than few kpc: they are sensitive probes of the Local Bubble and its neighbourhood.



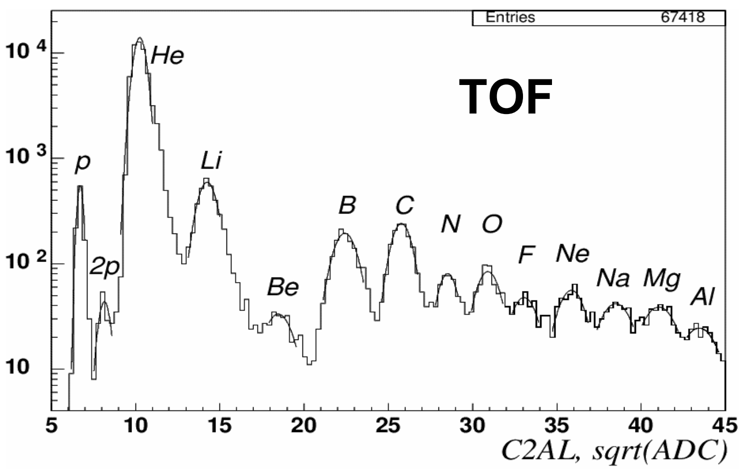
Nuclei separation

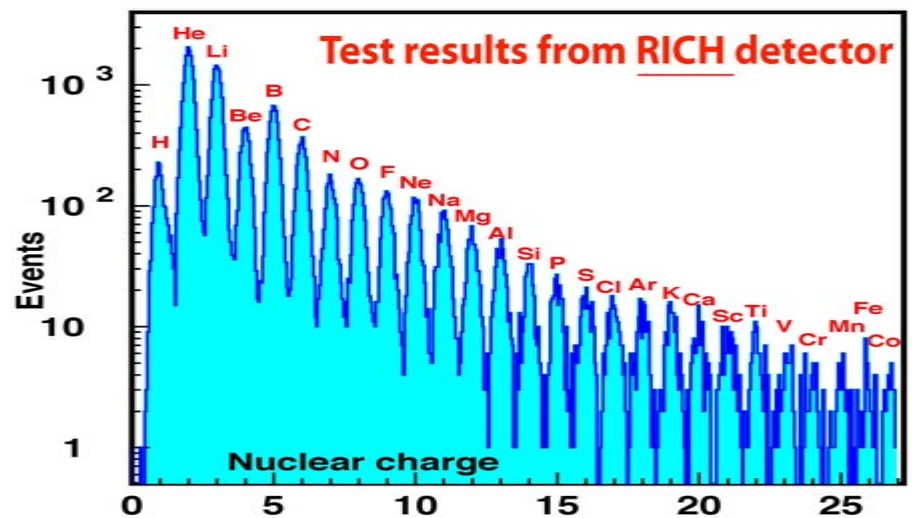
Charge measurement:

TOF, Tracker and RICH



Verified by heavy ion beam tests at CERN & GSI.

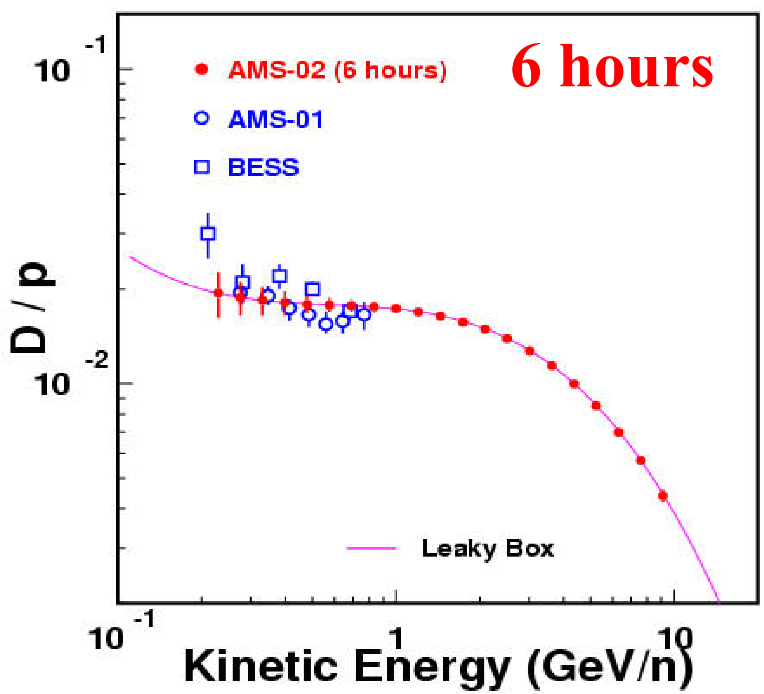


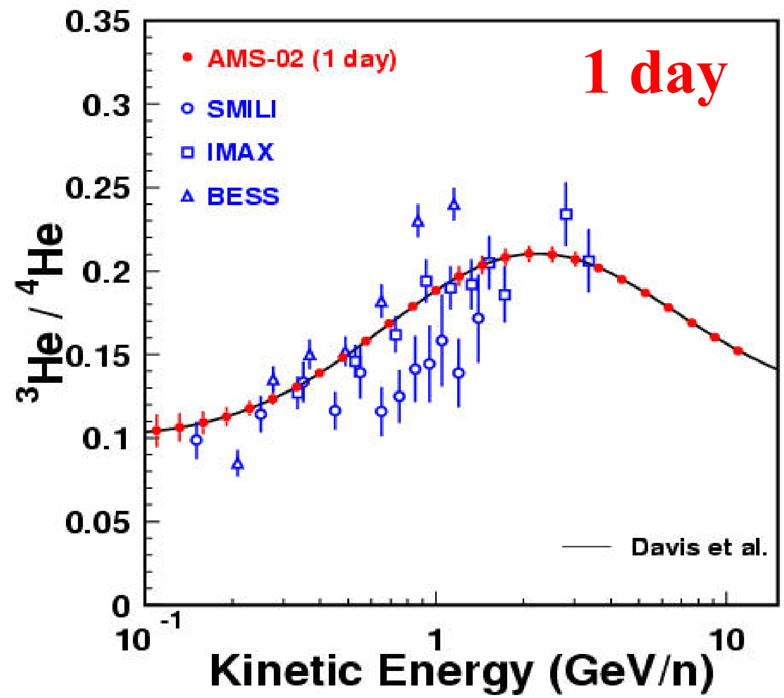


Light isotopes

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

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



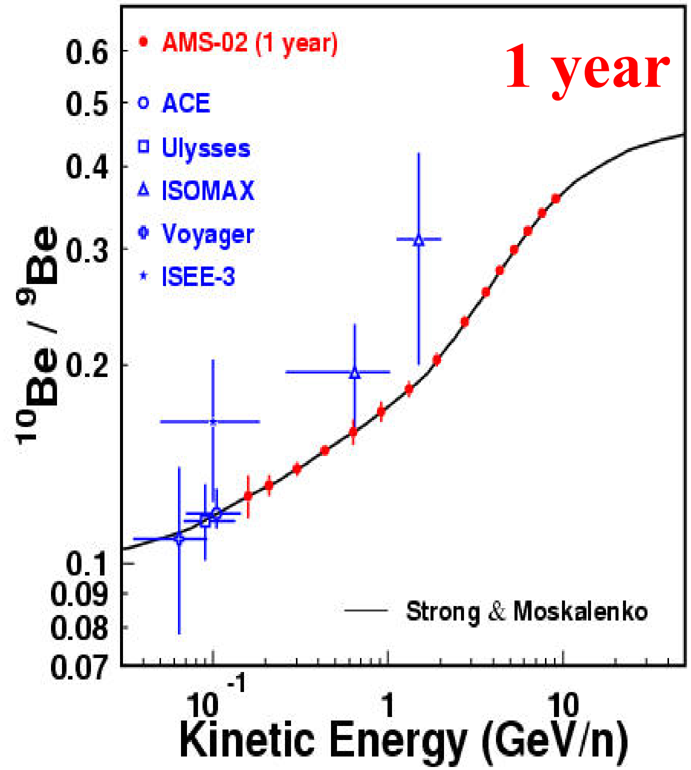


After 3 years AMS-02 will collect about 10^8 D and ^3He

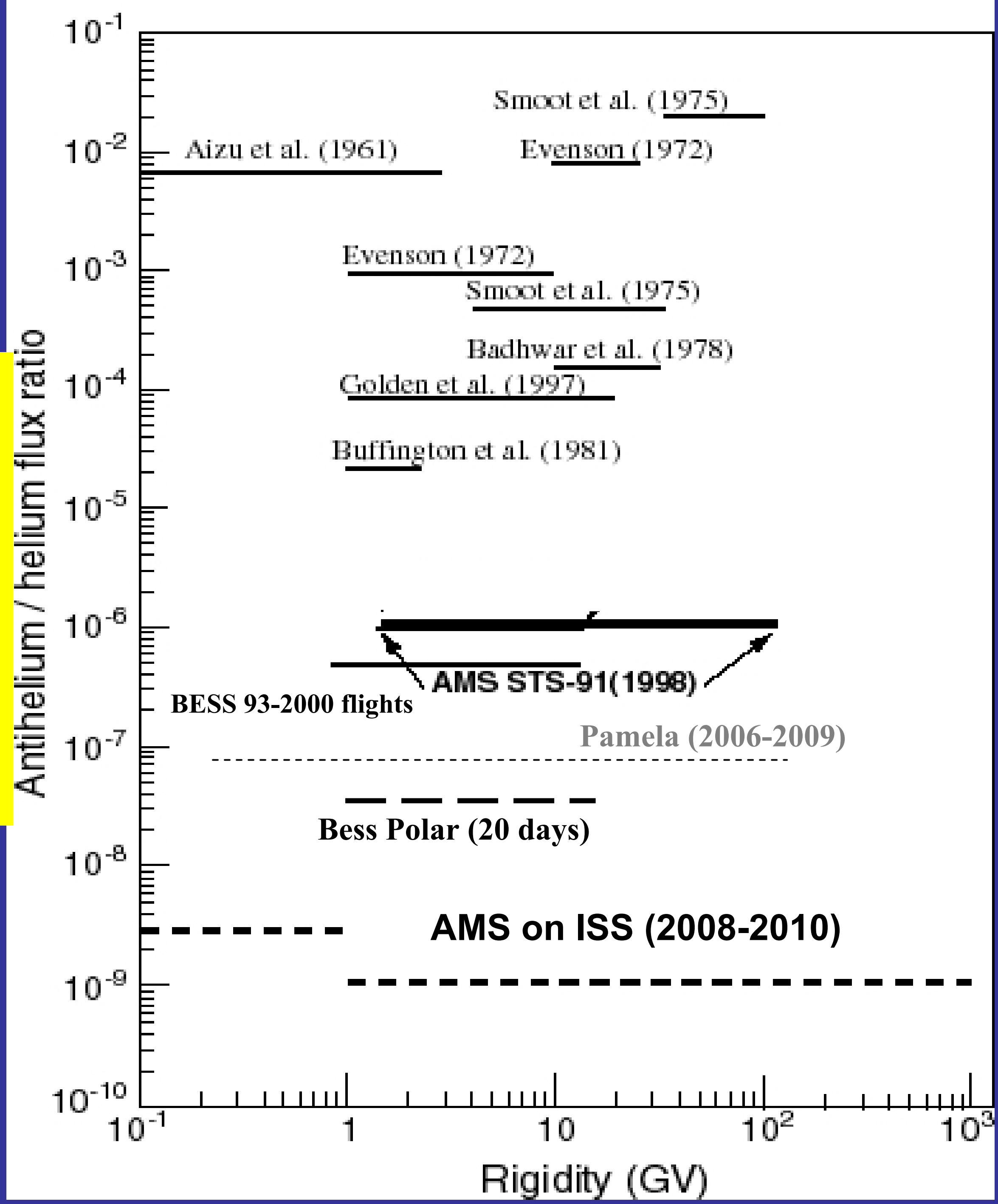
$^{10}Be/^{9}Be$ – radioactive clock

- **^{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

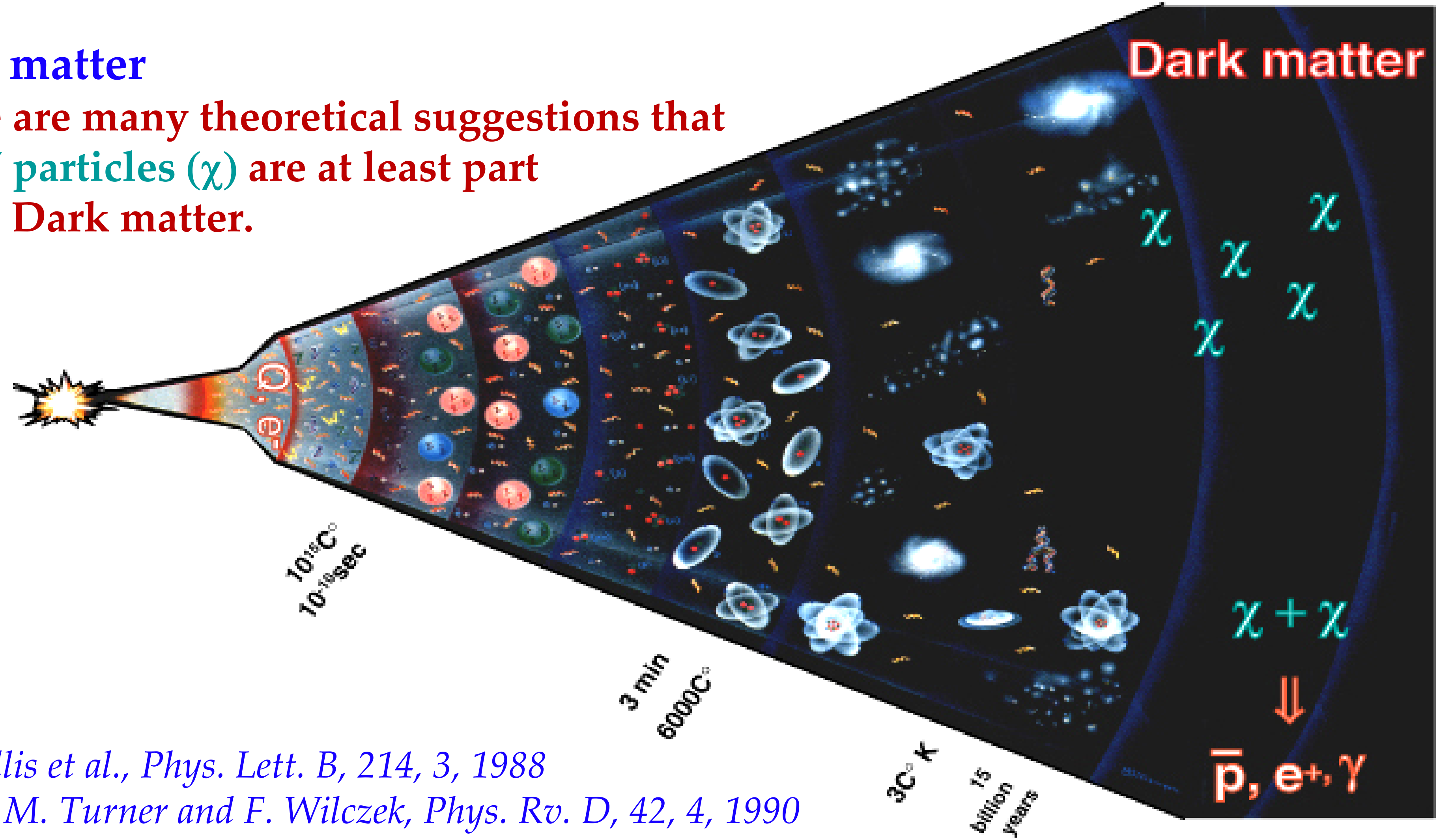


Search for antimatter at the 10^{-9} level of sensitivity with AMS-02 on the ISS

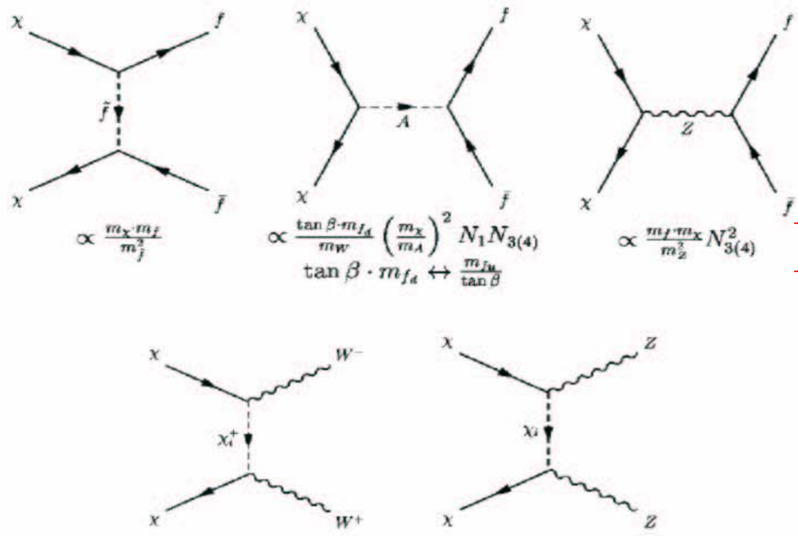


Dark matter

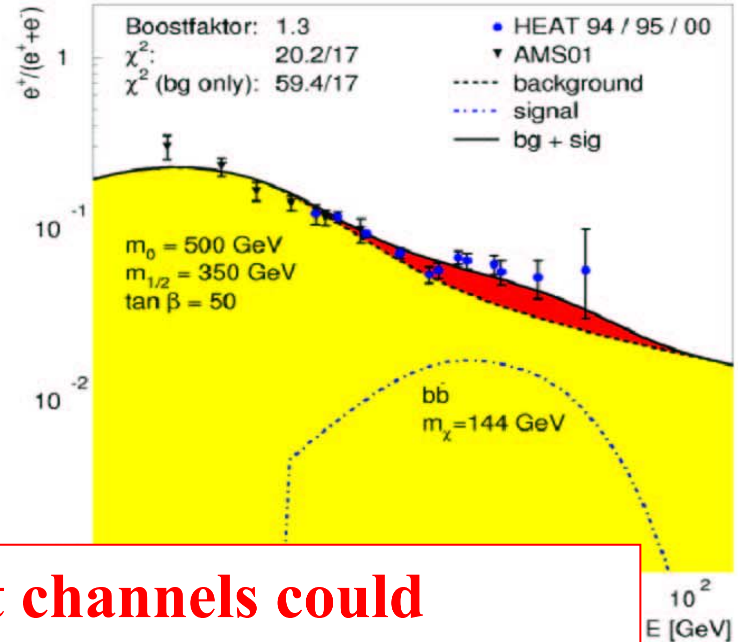
There are many theoretical suggestions that SUSY particles (χ) are at least part of the Dark matter.



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

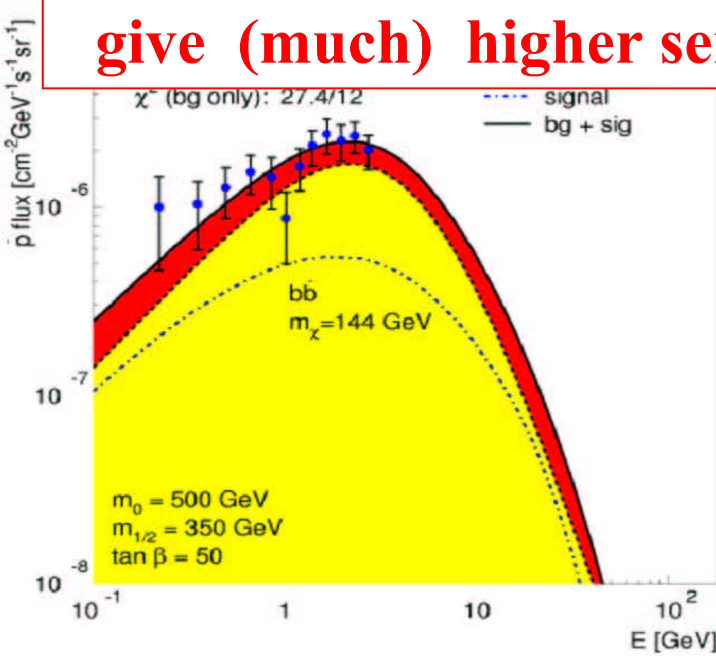


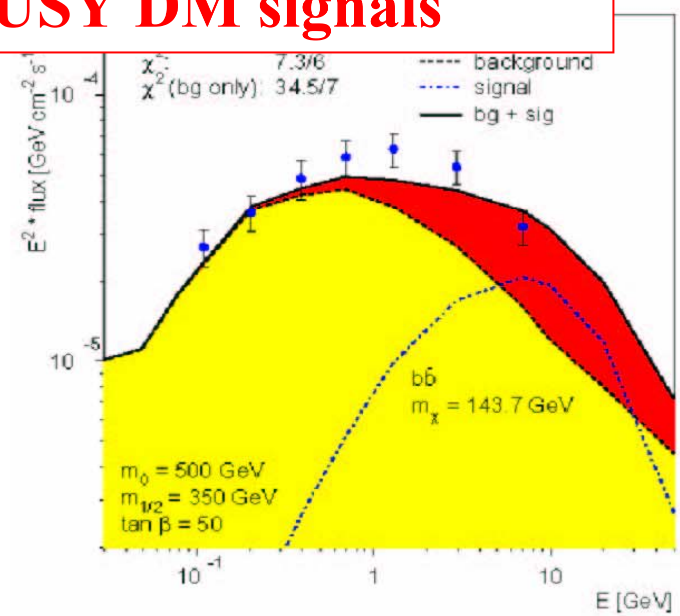
Unique Feature of AMS

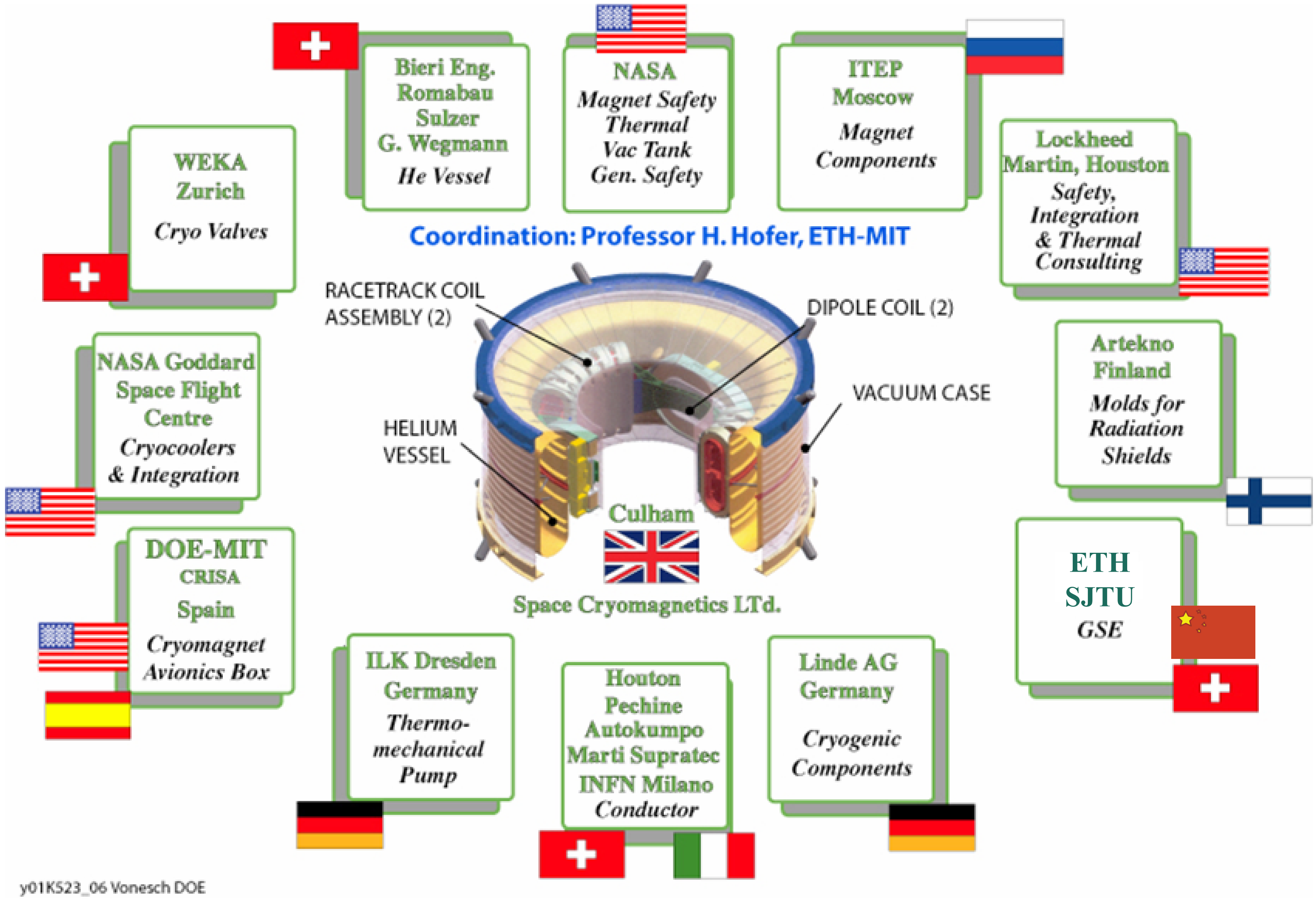


Combining searches in different channels could give (much) higher sensitiviy to SUSY DM signals

Wim de Boer et al., EPS867



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Romabau
Sulzer
G. Wegmann
He Vessel
NASA
Magnet Safety
Thermal
Vac Tank
Gen. Safety
ITEP
Moscow
Magnet
Components
WEKA
Zurich
Cryo Valves
Lockheed
Martin, Houston
Safety,
Integration
& Thermal
Consulting
Coordination: Professor H. Hofer, ETH-MIT
RACETRACK COIL
ASSEMBLY (2)
DIPOLE COIL (2)
VACUUM CASE
HELIUM
VESSEL
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
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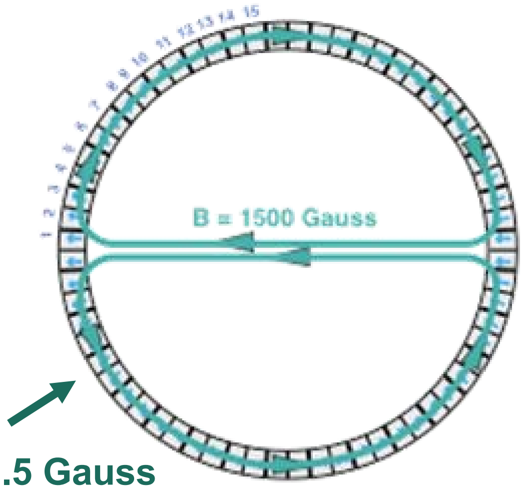
mechanical
Pump
Houton
Pechine
Autokumpo
Marti Supratec
INFN Milano
Conductor
Linde AG
Germany
Cryogenic
Components
y01K523_06 Vonesch DOE

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

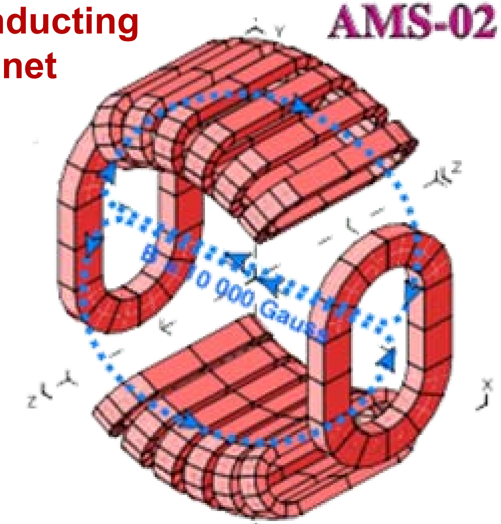
1- Stable: no influence from earth magnetic field

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

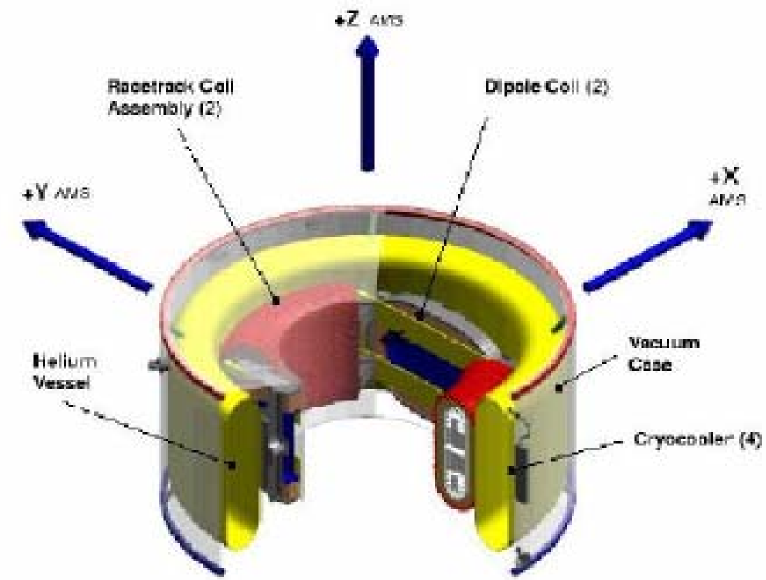
With the same field arrangement as the permanent magnet:

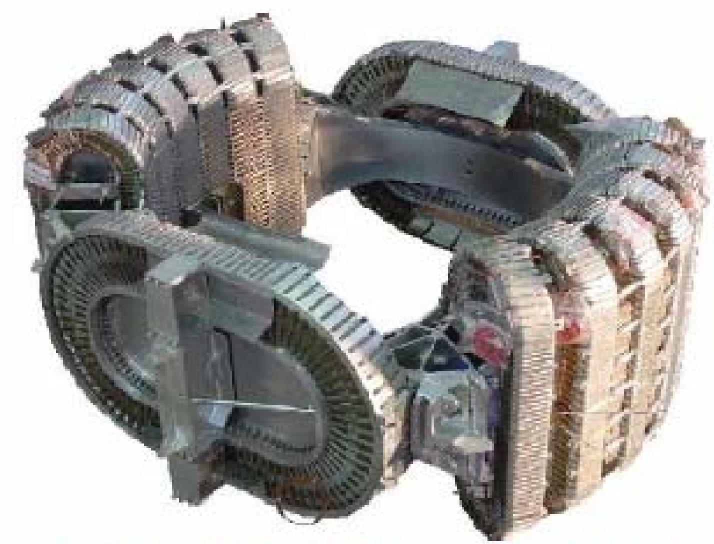
Except it has 10,000 Gauss field = 1 T

AMS-02: Superconducting Magnet

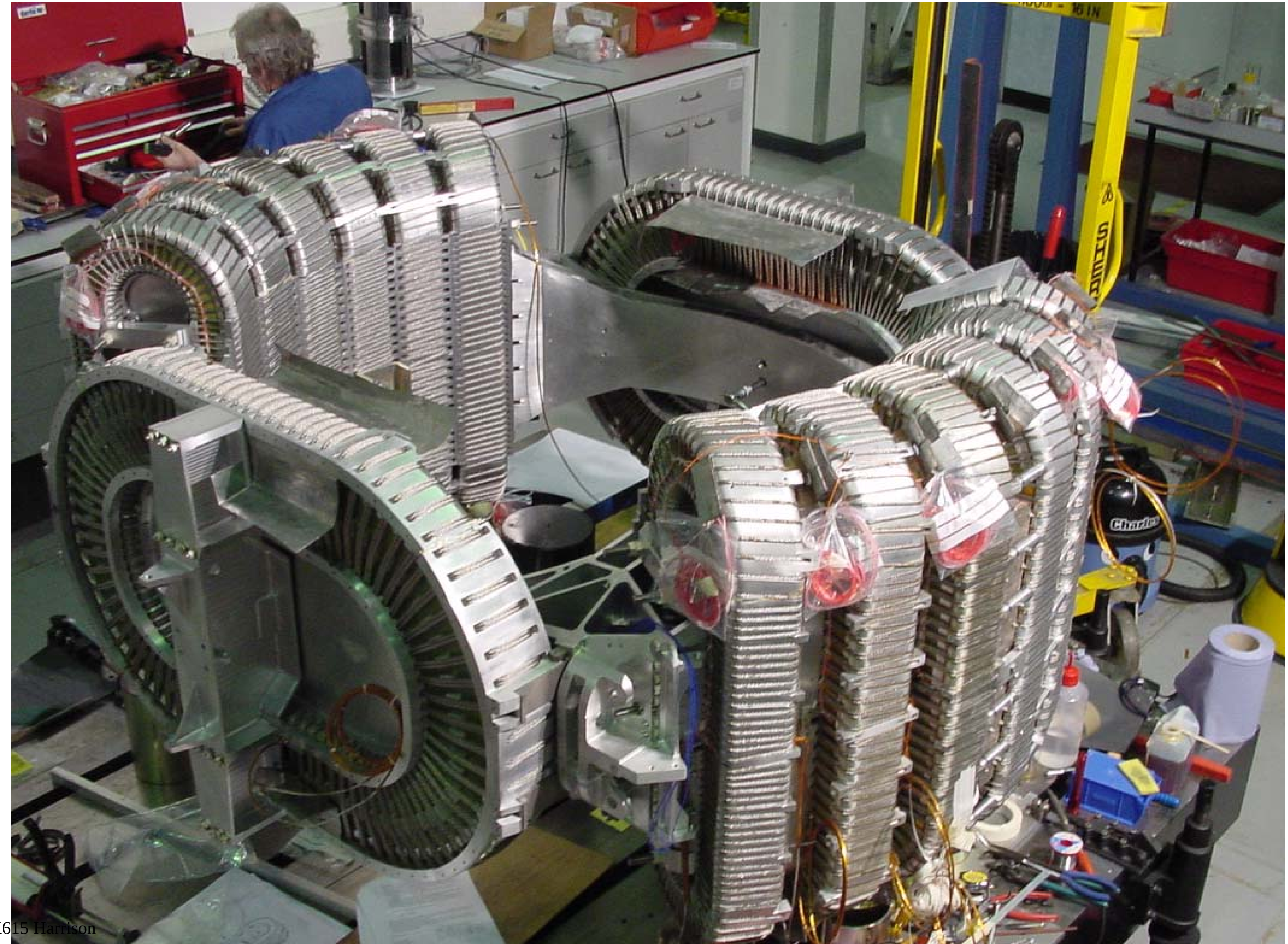
- 14 superconducting coils
- Geometrical configuration to ensure a null magnetic dipole moment
- Indirect cooling system based on superfluid helium
- Helium vessel: 2500 liters
- Dimensions: inner diameter 1.1m, weight: 2360 Kg
- an intense magnetic field: ~ 0.9 T
- a large bending power: ~ 0.8 T.m^2

▷ 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

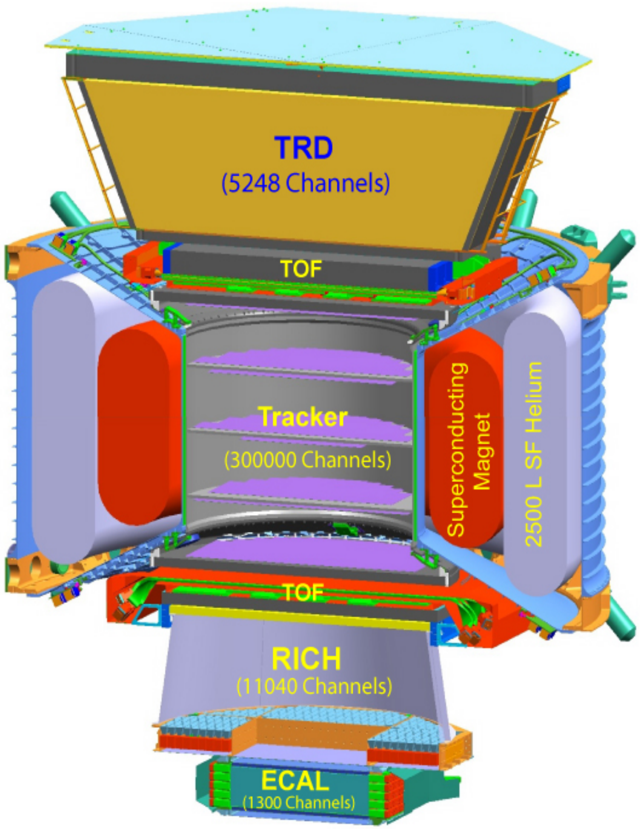


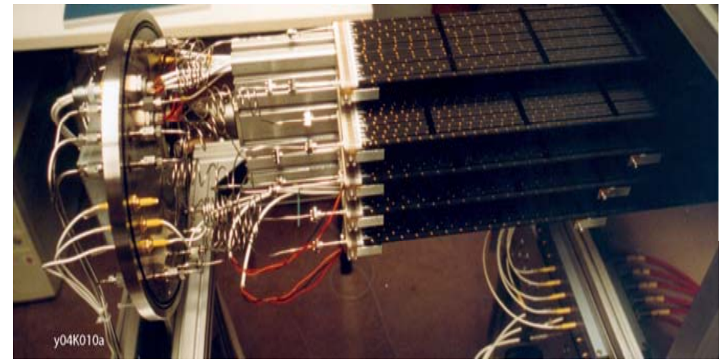


R.H. MacMahon he-24


Charles

Transition Radiation Detector (TRD)





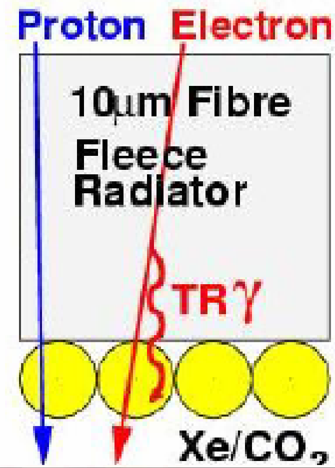
Functional tests of TRD

All modules have been produced

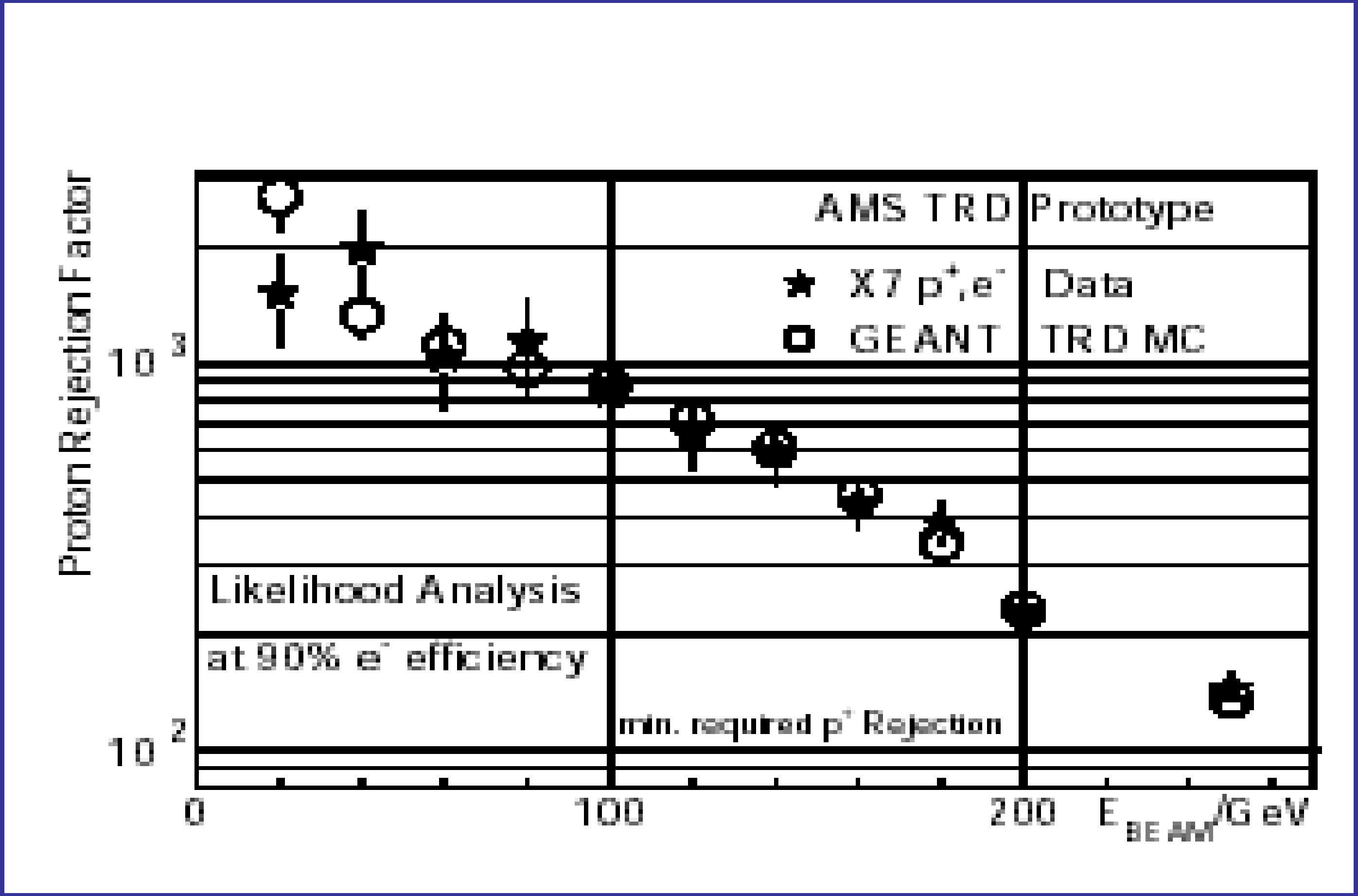
AMS-02: Transition Radiation Detector

- 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 $\bar{\text{p}}$/p up to 300 GeV

▷ All modules produced
▷ 14 layers with 220 modules inserted in supporting structure
▷ Detector finished in Spring 2006



TRD Performances



20 layer prototype tested with

e^-, μ^-, π^+, p^+

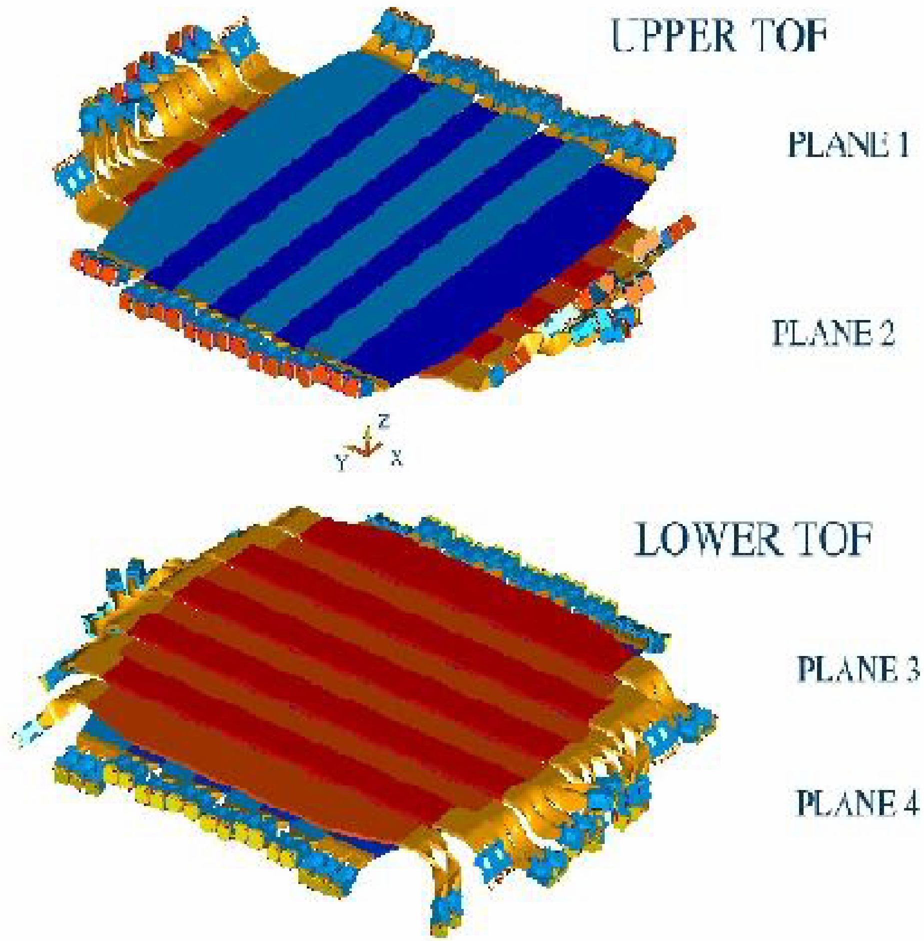
Proton rejection >10^2

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

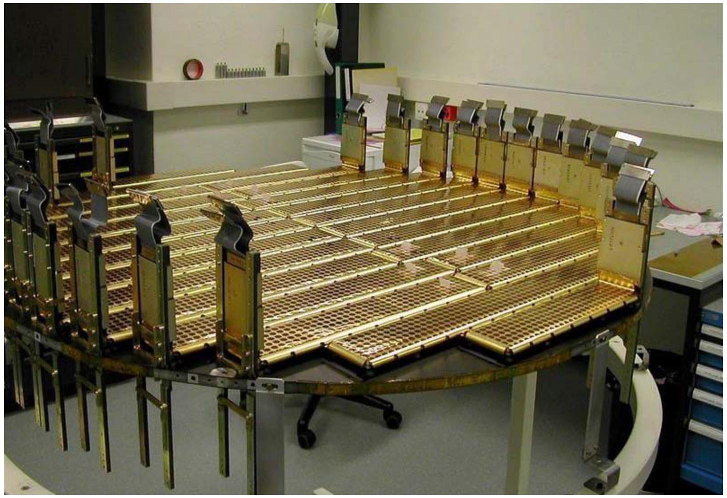


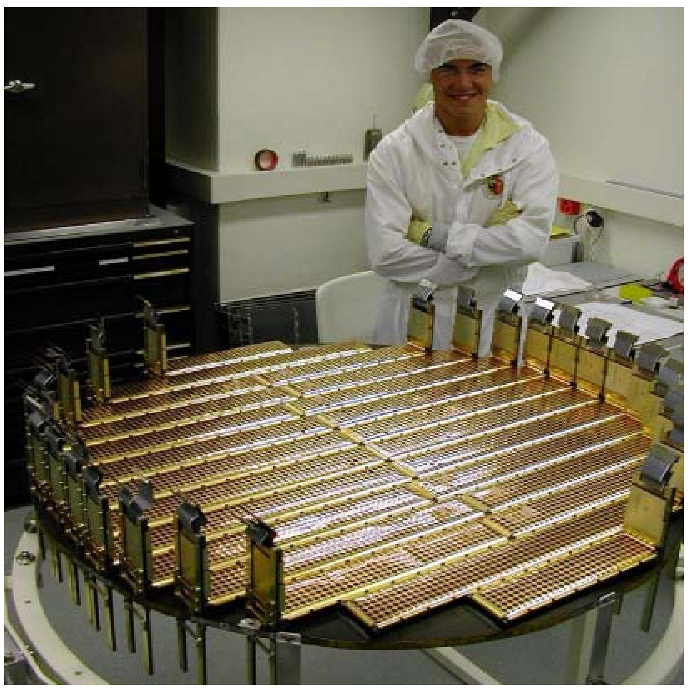
F. Giovacchini he-21
V. Bindi he-15
L. Quadrani he-21

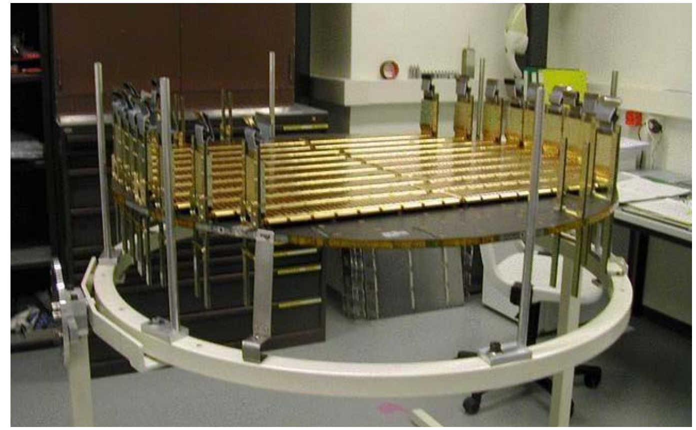
TOF assembly - Test mounting of Lower TOF

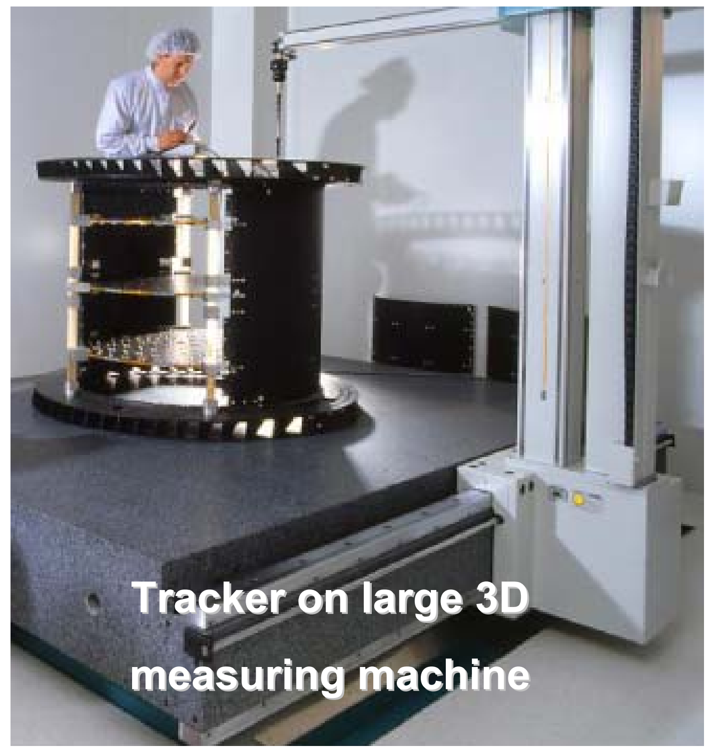
Silicon Tracker

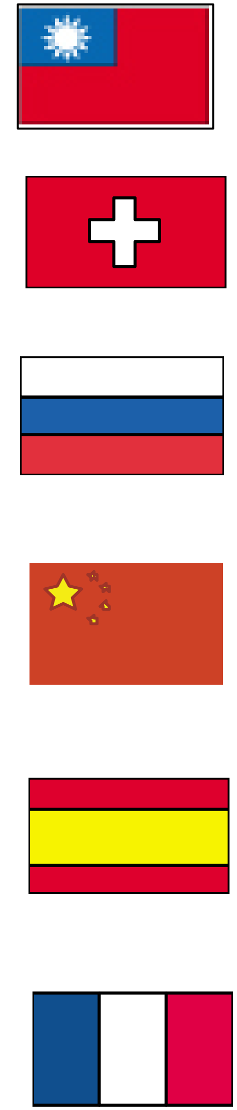
All 8 planes, 300,000 channels have been produced







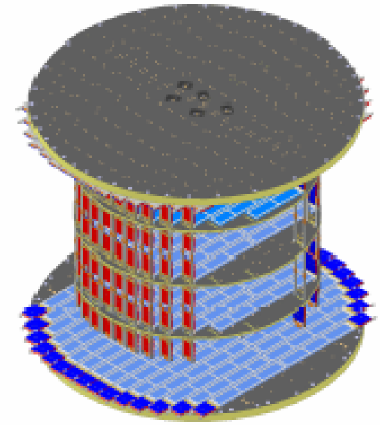


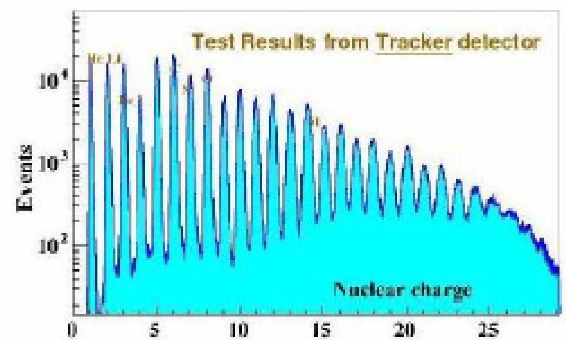


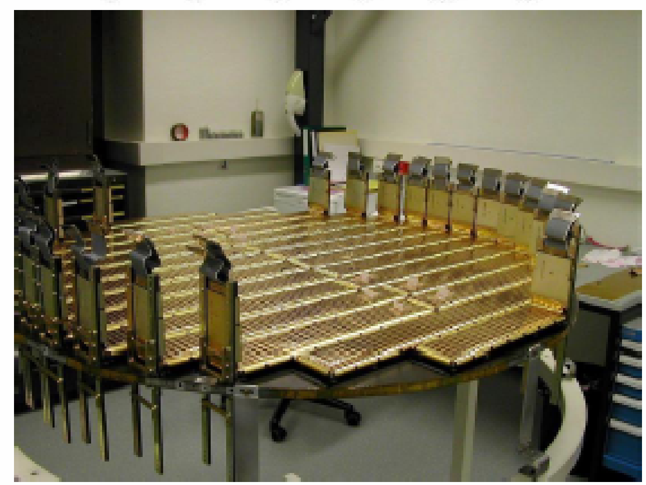
AMS-02 Spectrometer: Silicon Tracker

- 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 $R = \frac{\text{pc}}{|Z|\text{e}}$ 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

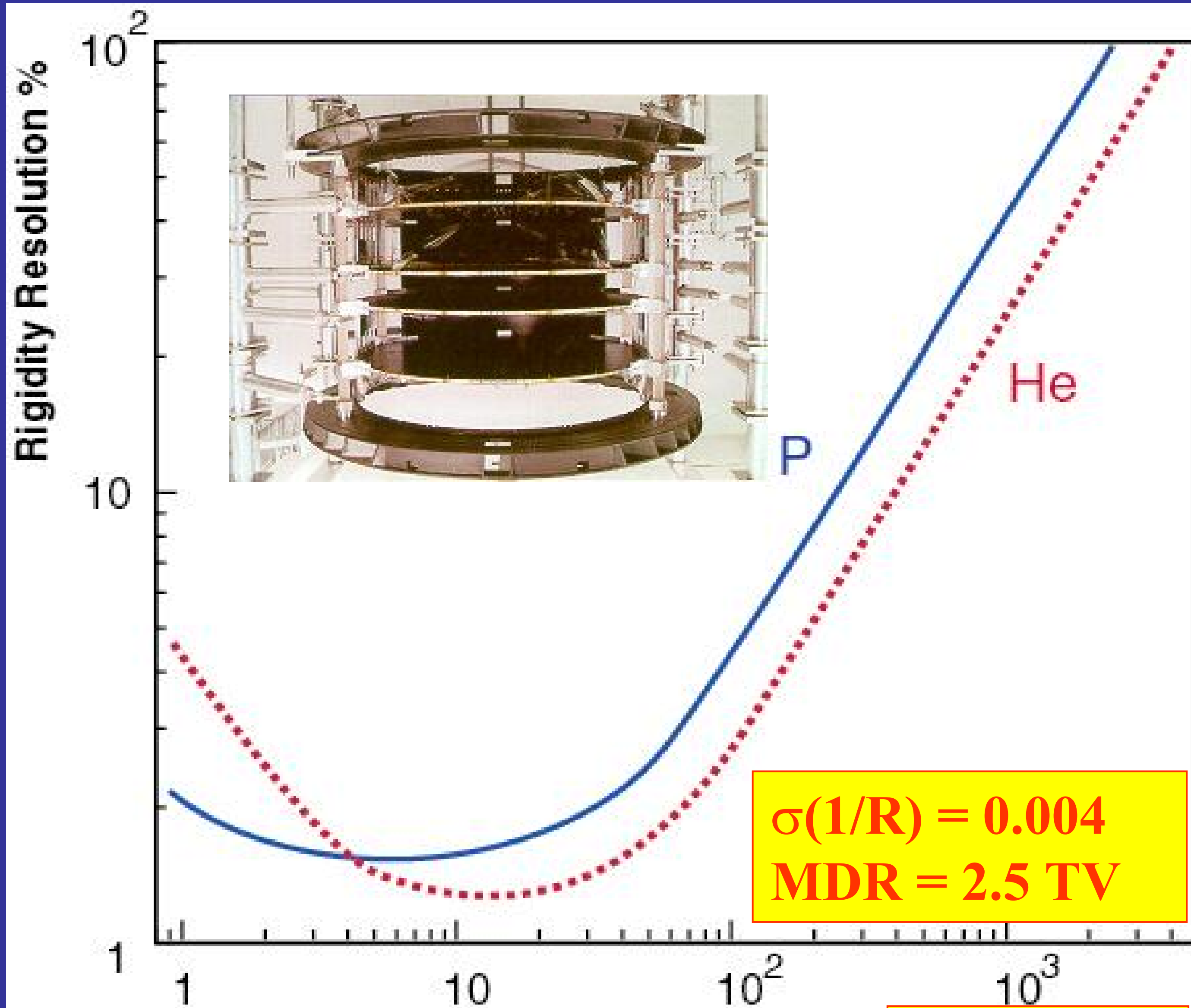






P. Zuccon he-24

AMS-02 Silicon Spectrometer Rigidity Resolution/

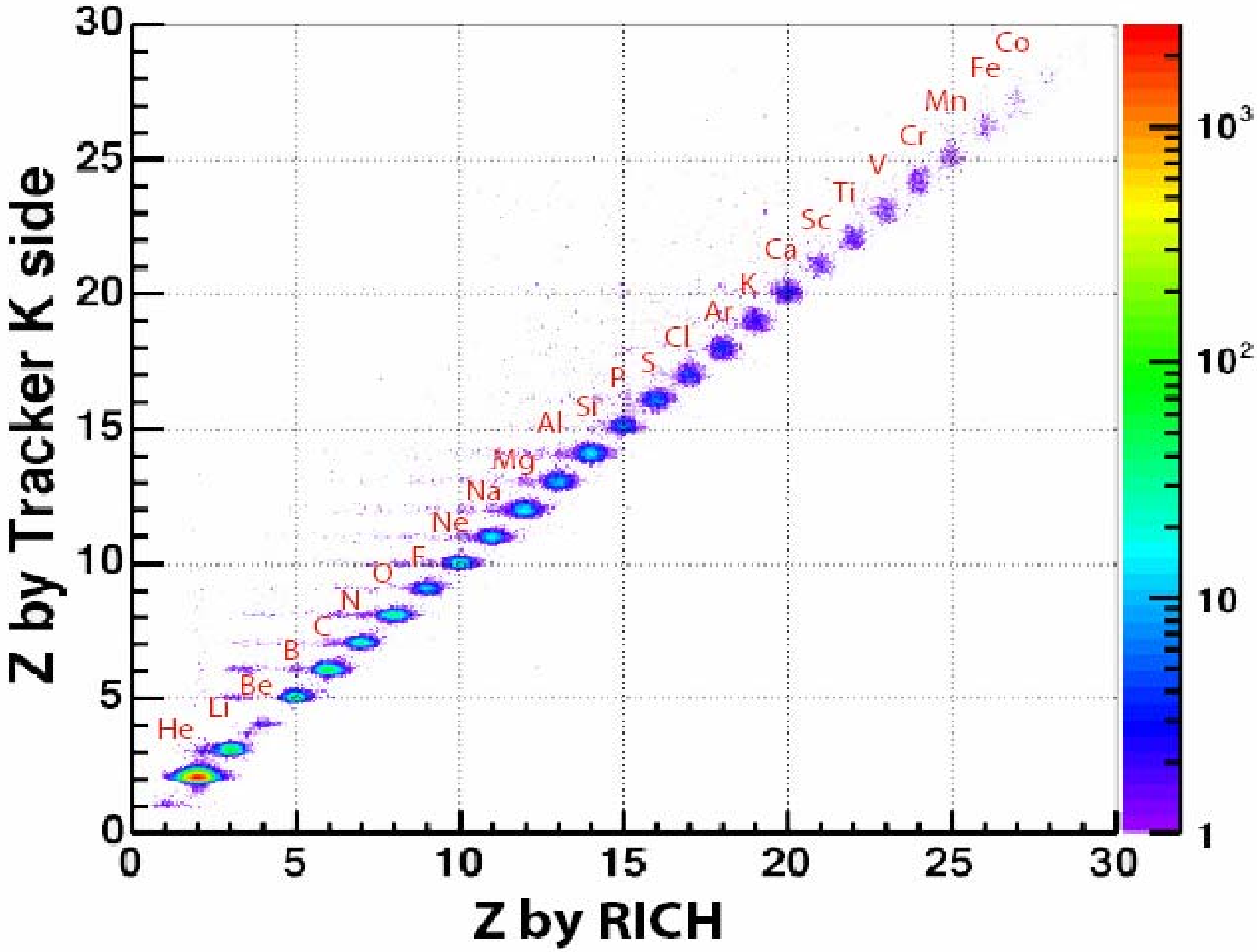


$\sigma(1/R) = 0.004$
MDR = 2.5 TV

Rigidity (GV)

Accurate measurement of cosmic radiation for all atomic nuclei

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



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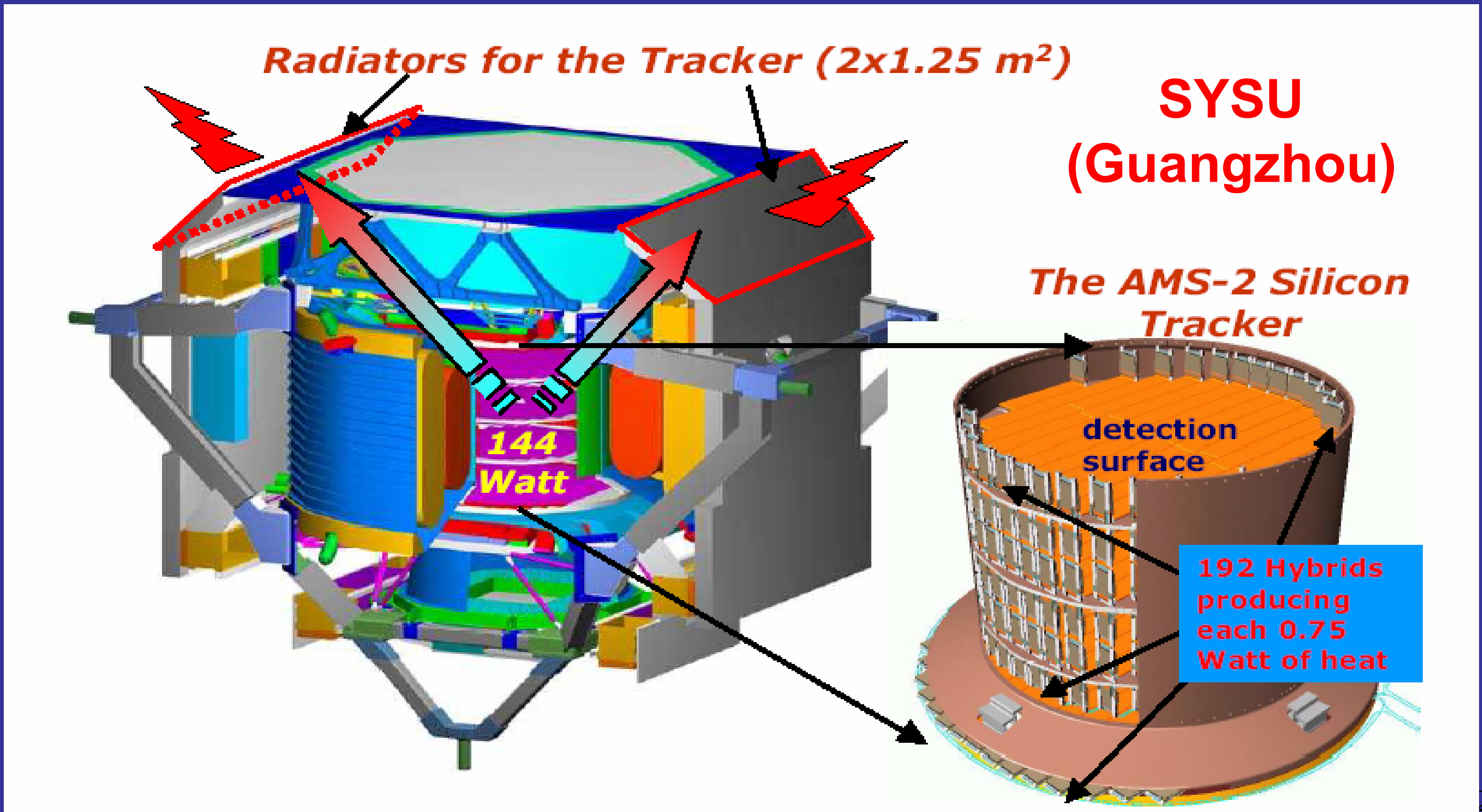
Tracker Thermal Control System

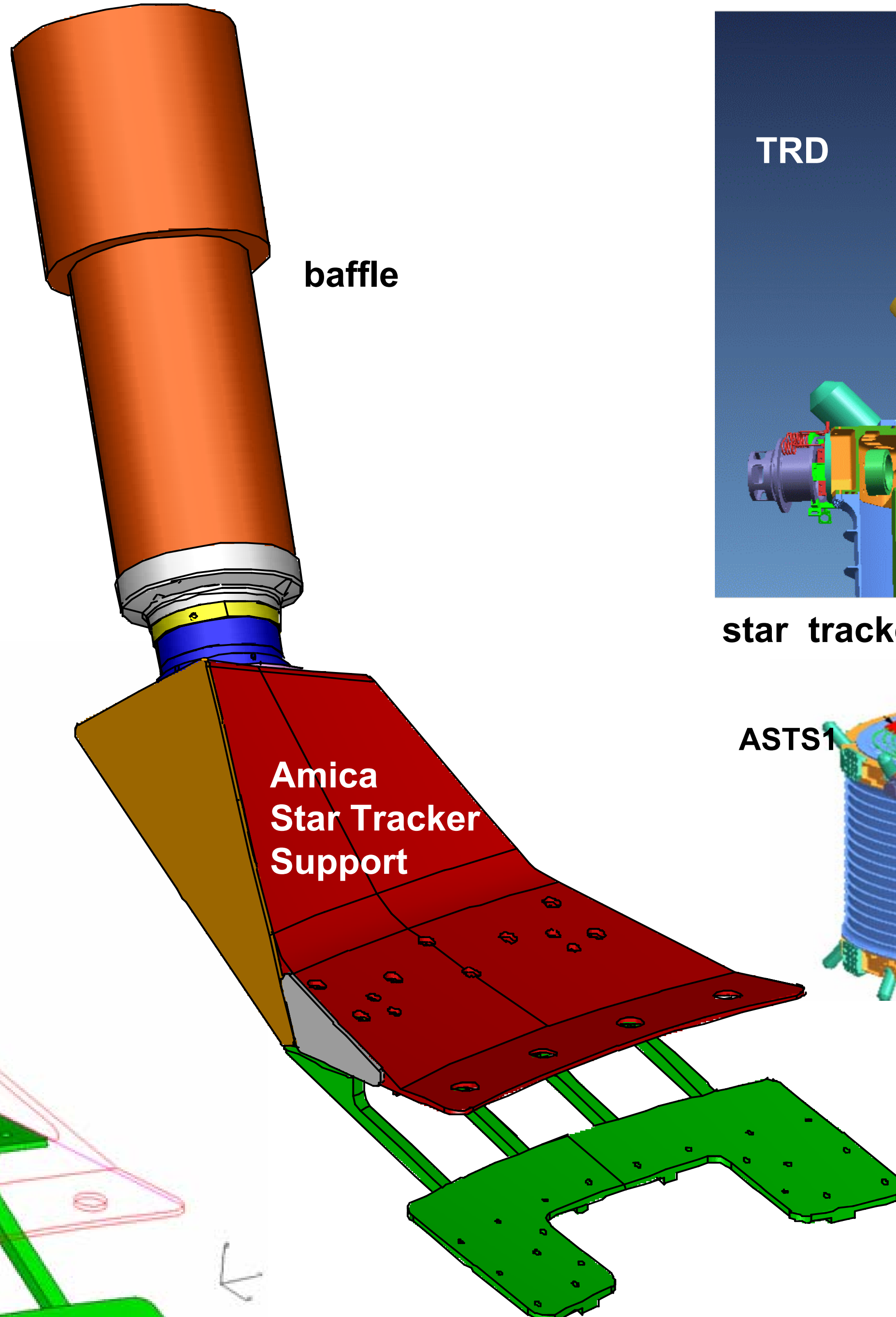
Two-phase pumped CO_2 loops

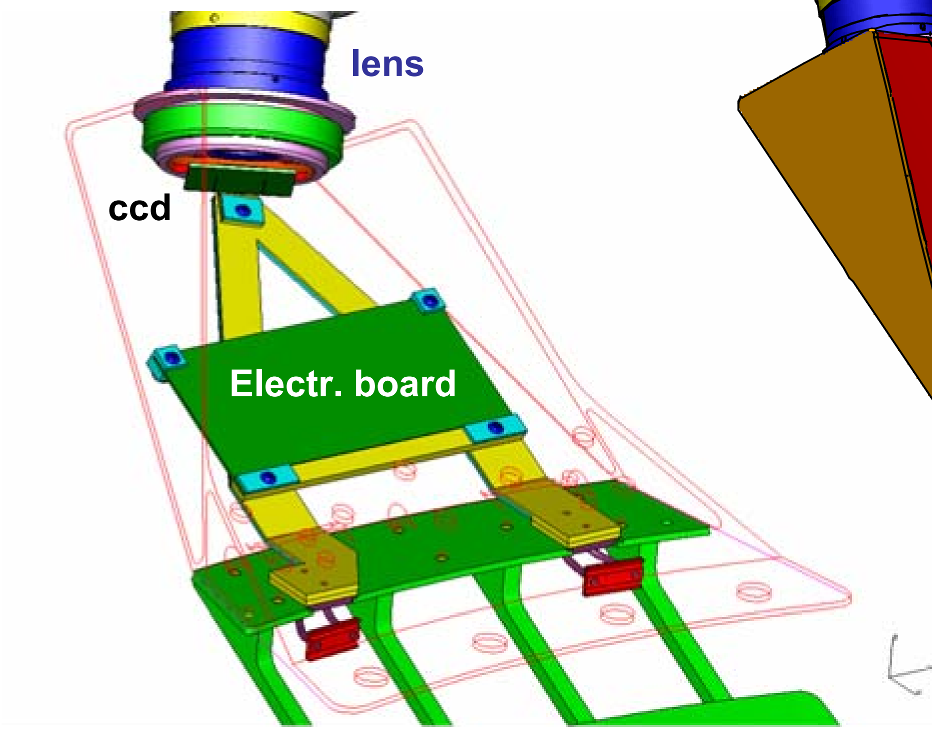
The most advanced cooling technology for space

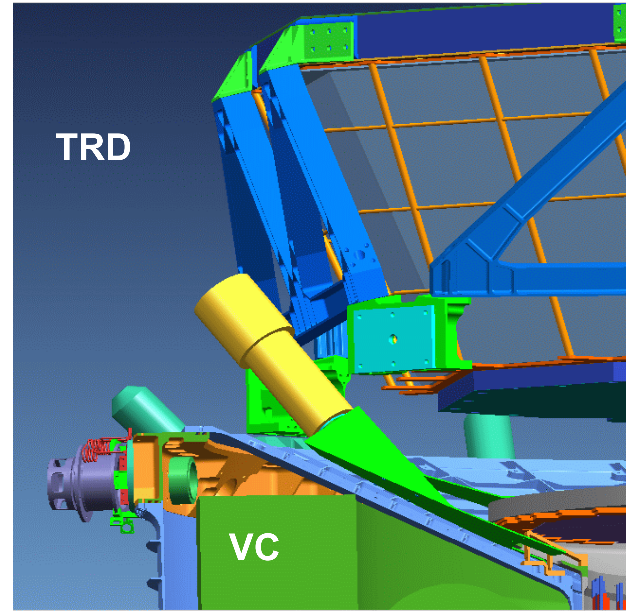
Key technology for robotic or manned space exploration



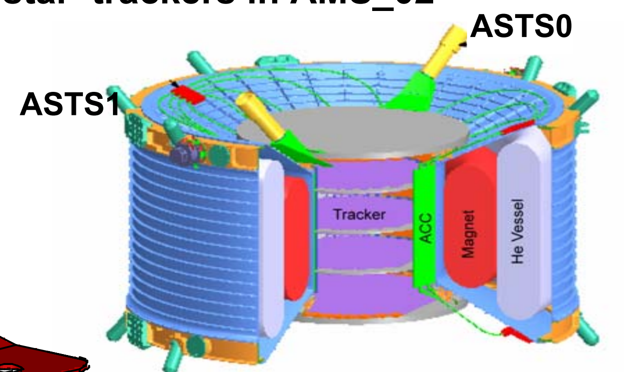
Star Tracker
Design progress







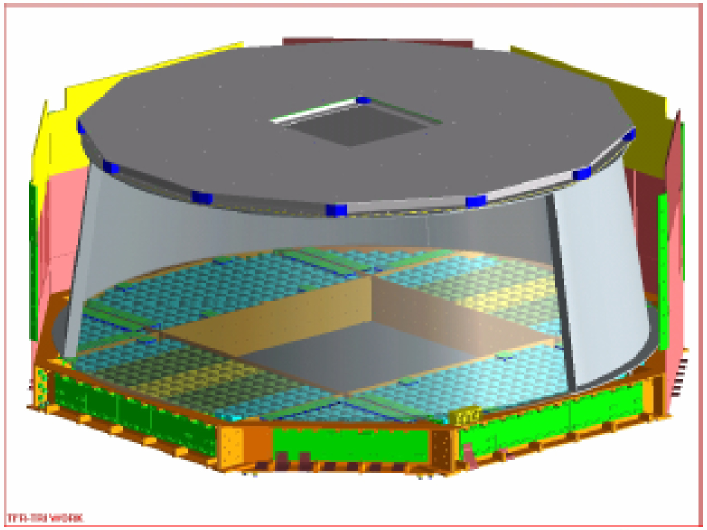
star trackers in AMS_02

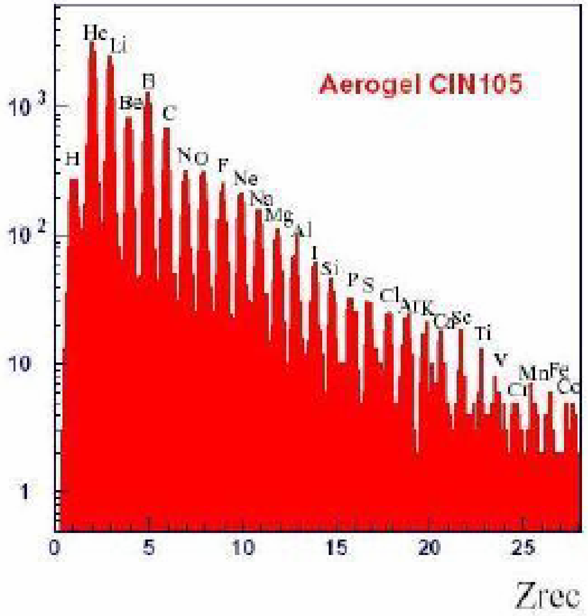


AMS-02: Ring Imaging Cherenkov Detector

- 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

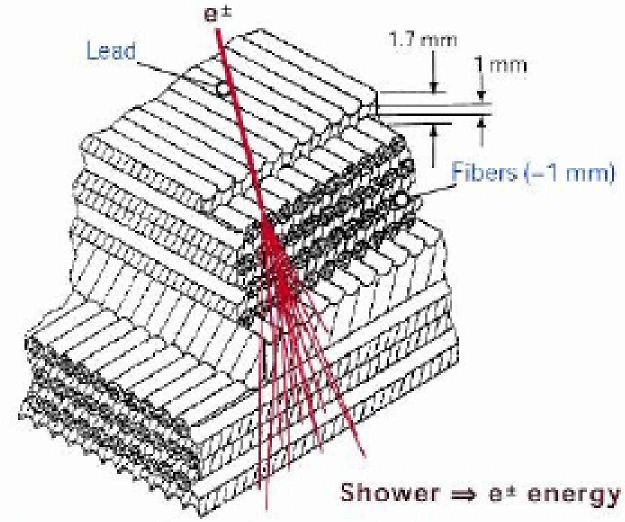


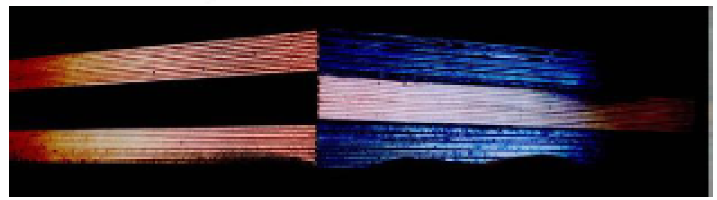


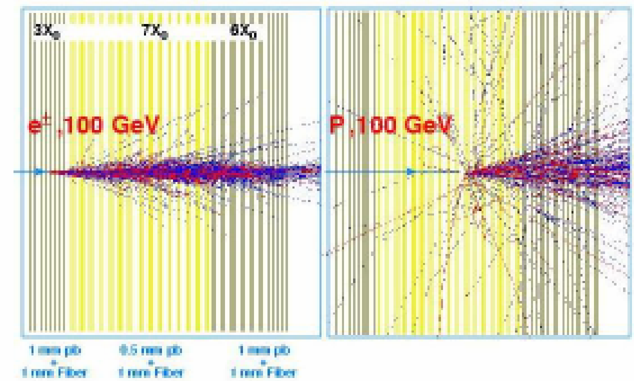
F. Barao og-15

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 $\sim 2°$, γ independently triggered



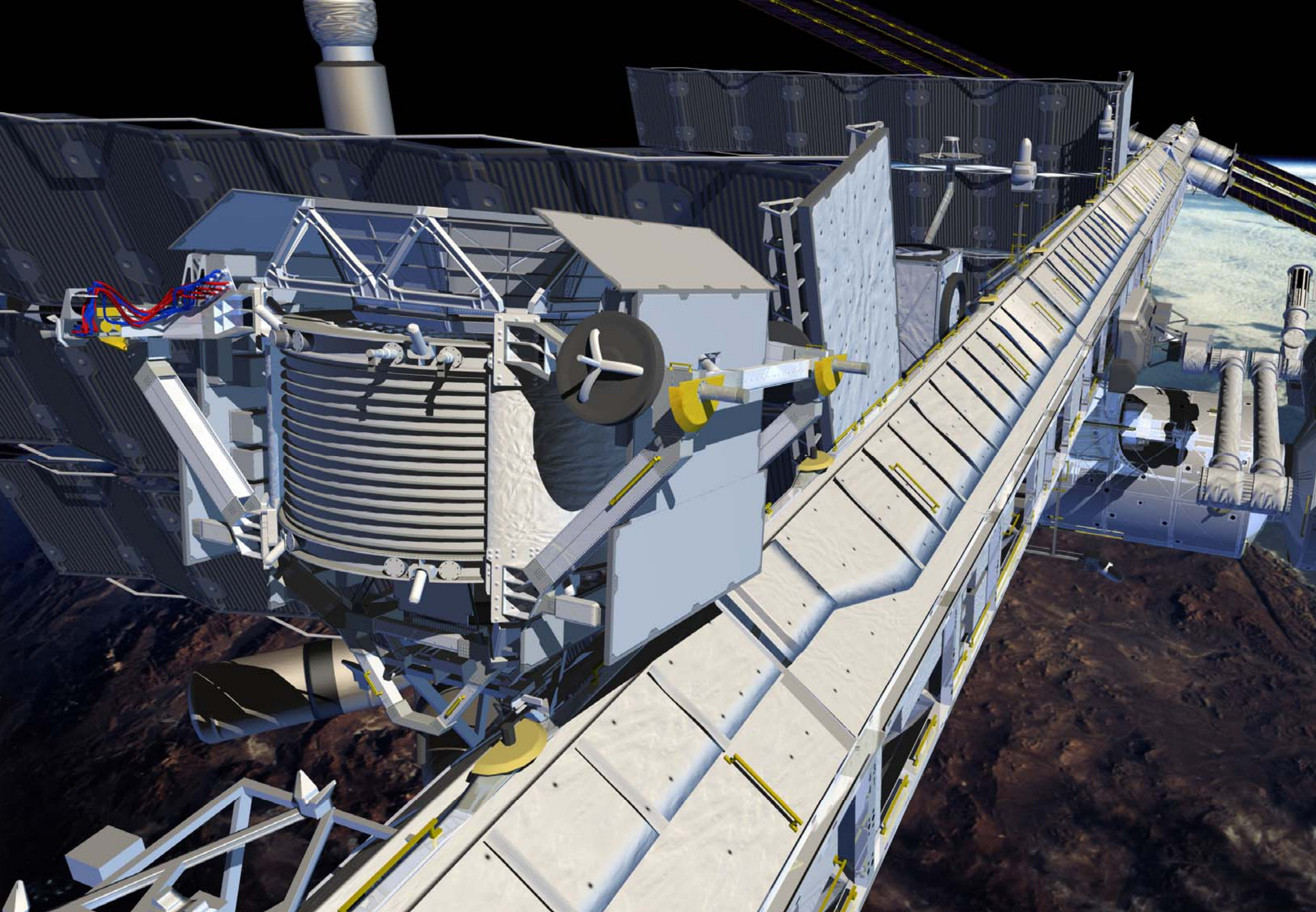




IHEP Beijing

▷ All superlayers installed in mechanical structure

▷ Final calibration in e^- test beam in 2006



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