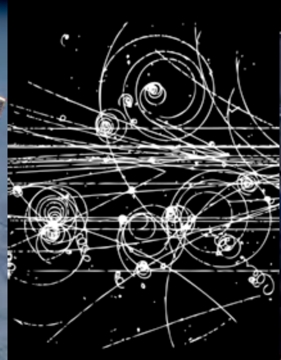
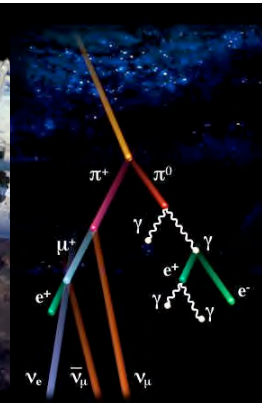
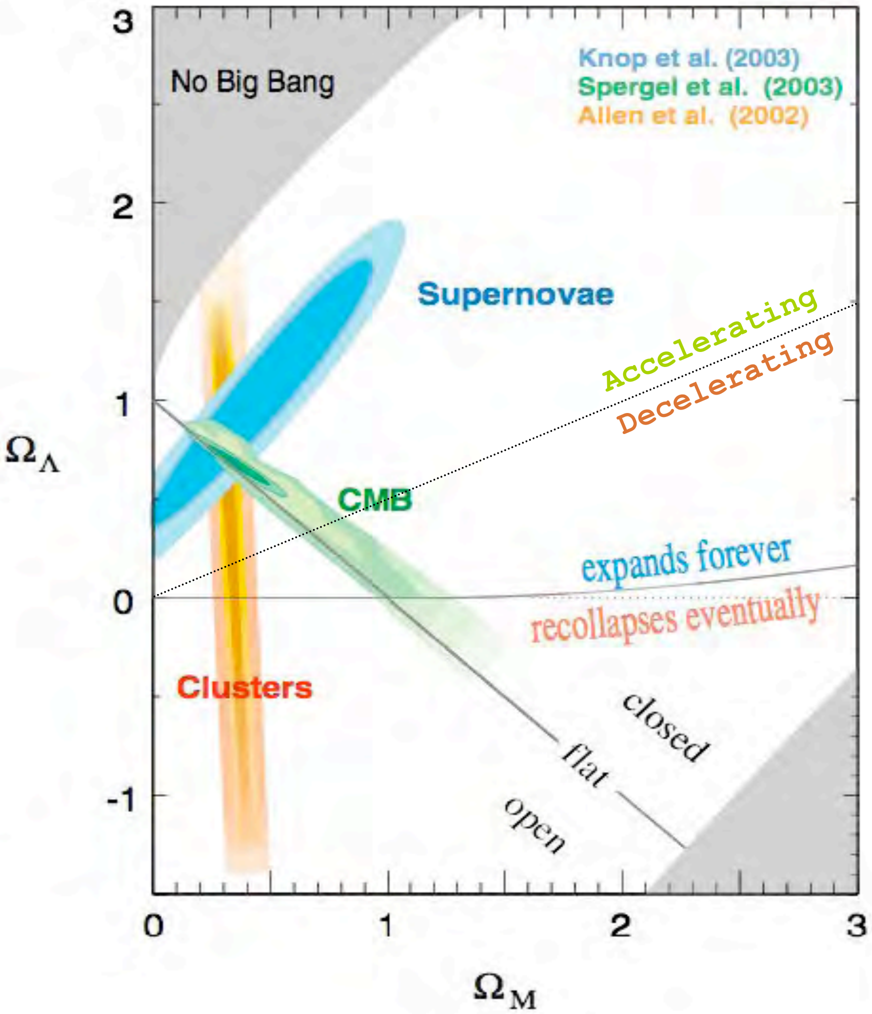




AMS-02 on the International Space Station

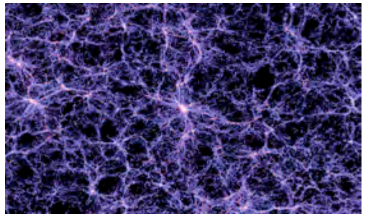
Francesca Spada
Dip. di Fisica – Roma
3-6-2010

A “Precision Cosmology”



Large scale structures

Ω_m = 0.25 – 0.30

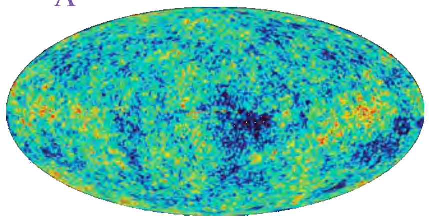


Cosmic MW background

Flat universe – $\Omega_{tot} = 1$

$\Omega_b \approx 0.04$

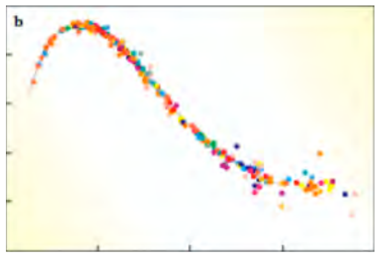
$\Omega_m \approx 0.25 \rightarrow \Omega_\Lambda > 0$



Type-Ia Supernovae

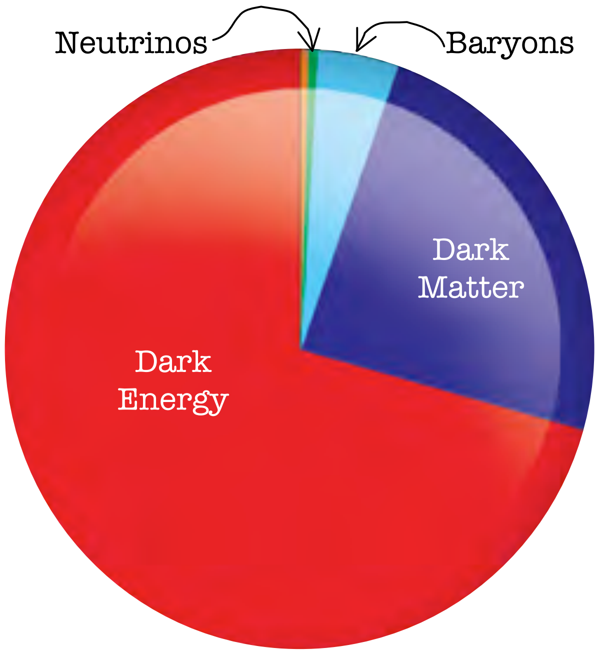
Accelerated expansion

$\Omega_\Lambda > 0$



A "Precision Cosmology"

Ordinary matter and radiation	4 %
Cold Dark matter	23 %
Dark energy	73 %
Antimatter	$< 10^{-6}$ matter



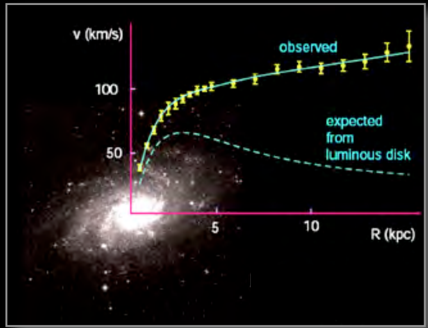
The Physics of AMS-02

- Dark Matter search
- Antimatter search
- New matter types
- Cosmic rays physics

Evidence for Dark Matter

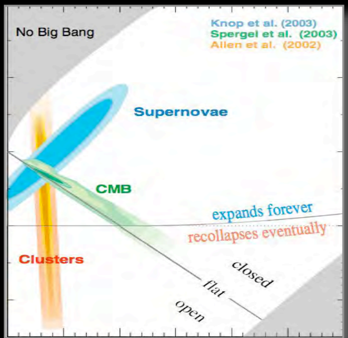
Clusters of galaxies, *and the Bullet cluster*

$\Omega_m \approx 0.2 \div 0.4$



Rotation curves of galaxies

$\Omega_m > 0.1$



Precision cosmology

$\Omega_m = 0.23 \pm 0.05$

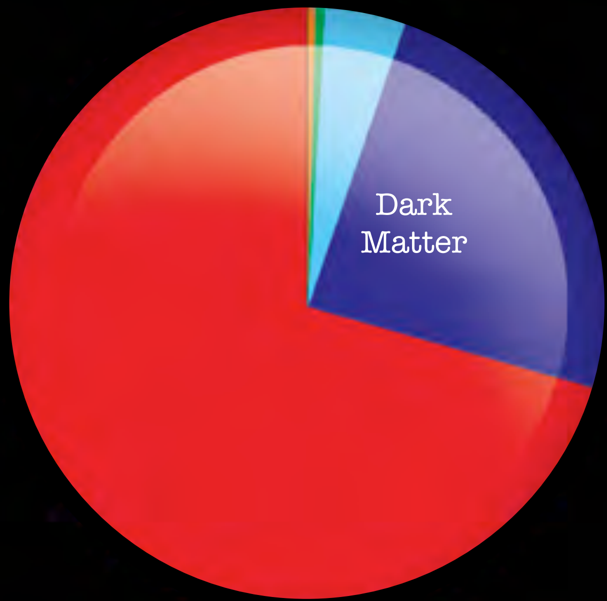
- DM consists of a “weakly” interacting particle
- Permeates galactic haloes

Nature of Dark Matter

CDM candidate masses vary on many orders of magnitude (from few eV to stars)

SUSY neutralino χ is a heavy, stable particle

- Couples with weak interactions
- Thermal relic from the early universe with the correct abundance
- Decoupled at non-relativistic energies (CDM)
- Mass at the TeV scale



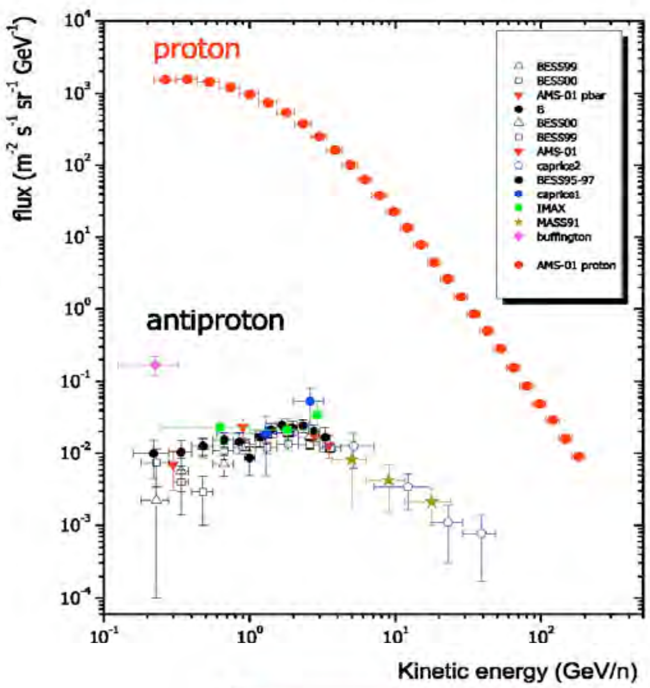
$\chi\chi$ annihilations can produce:

- Neutrinos
- e^+
- Photons
- $\bar{p}$

Channels accessible to AMS

Origin of Antimatter

- In the Big Bang theory **matter** and **antimatter** are created with **equal abundances**
- The disappearance of antimatter requires **barion number** violation and **another source of CP violation**



Antiparticles are produced in collisions between high energy particles and are observed in Cosmic Rays

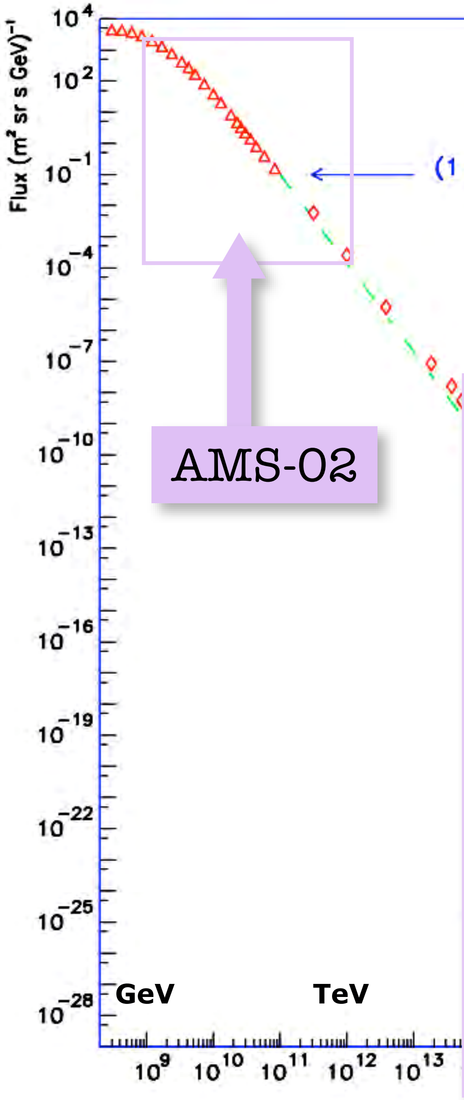
$\phi(e^+)/\ \phi(e^-) \sim 10^{-1}$ at 10 GeV

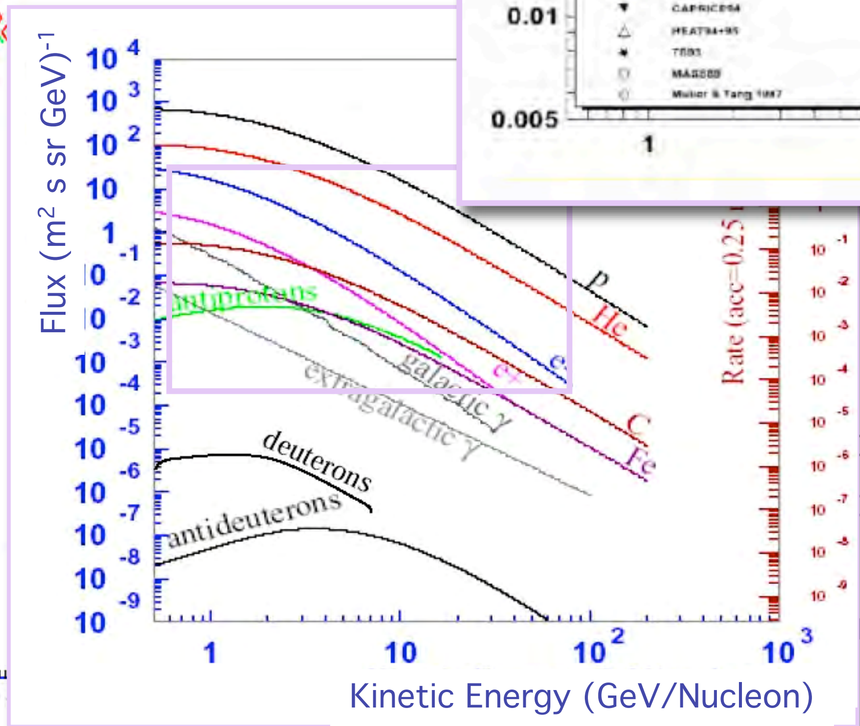
$\phi(\bar{p})\ /\ \phi(p) \sim 10^{-5}$ at 10 GeV

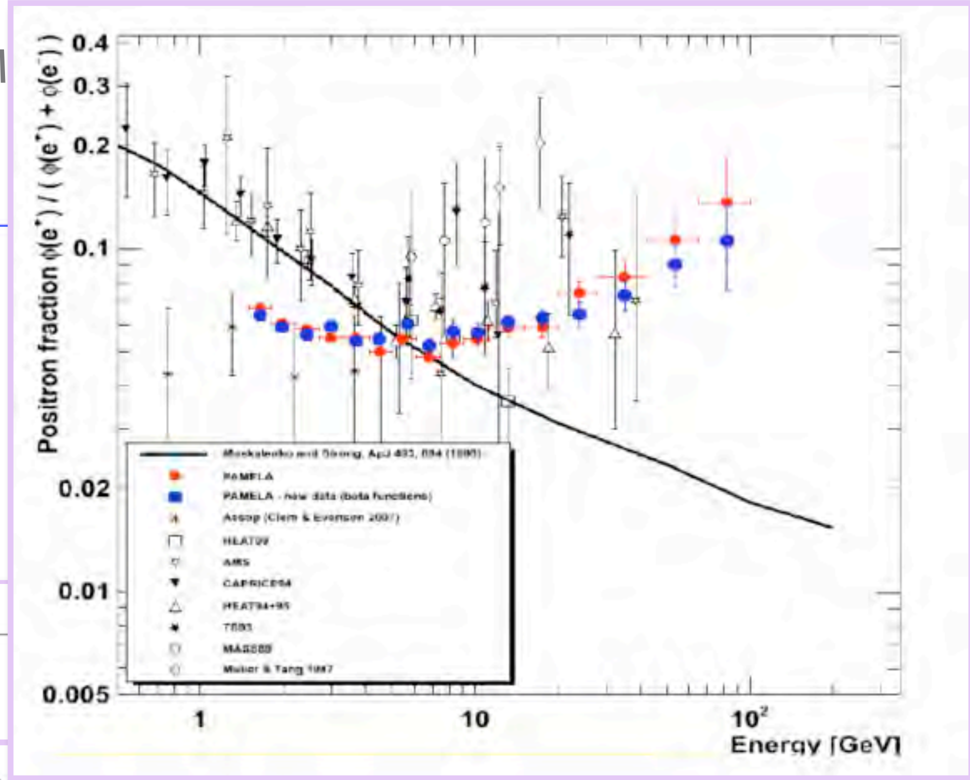
An **antihelium nucleus** has very low probability of being produced in collisions

→ detection of antinuclei indicates the existence of antistellar nucleosynthesis in an **antimatter domain** somewhere in the Universe

The spectrum of Cosm







AMS-02

...nce, long exposure time

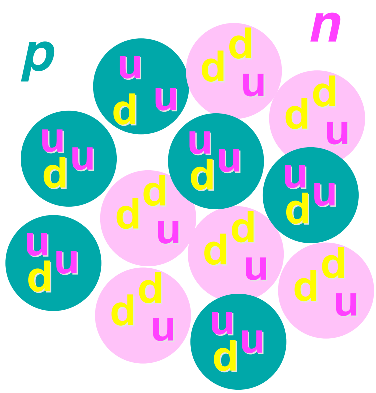
...ics

...nvironmental background

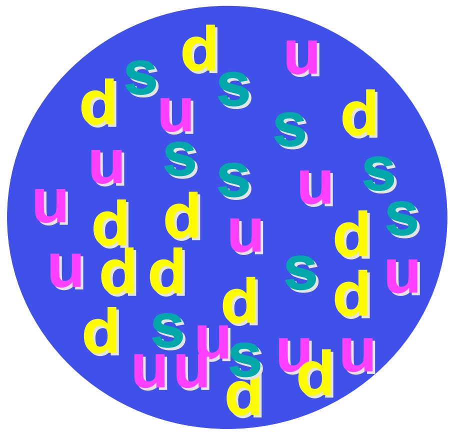
Search for New Matter

Strangelets are a not-yet observed stable matter type containing a strange quark (***u***, ***d***, ***s***).
They could exist in the Cosmos.
A strangelet can be seen as a single super-nucleon, with very small Z/A ratio.

Carbon Nucleus



Strangelet



“Neutron” stars may be one big strangelet.

AMS-02 on the International Space Station

The International Space Station

The ISS is a USA/Russia/ESA/Japan/Canada collaboration

Mainteinance at least until 2020, evaluating extention to 2028

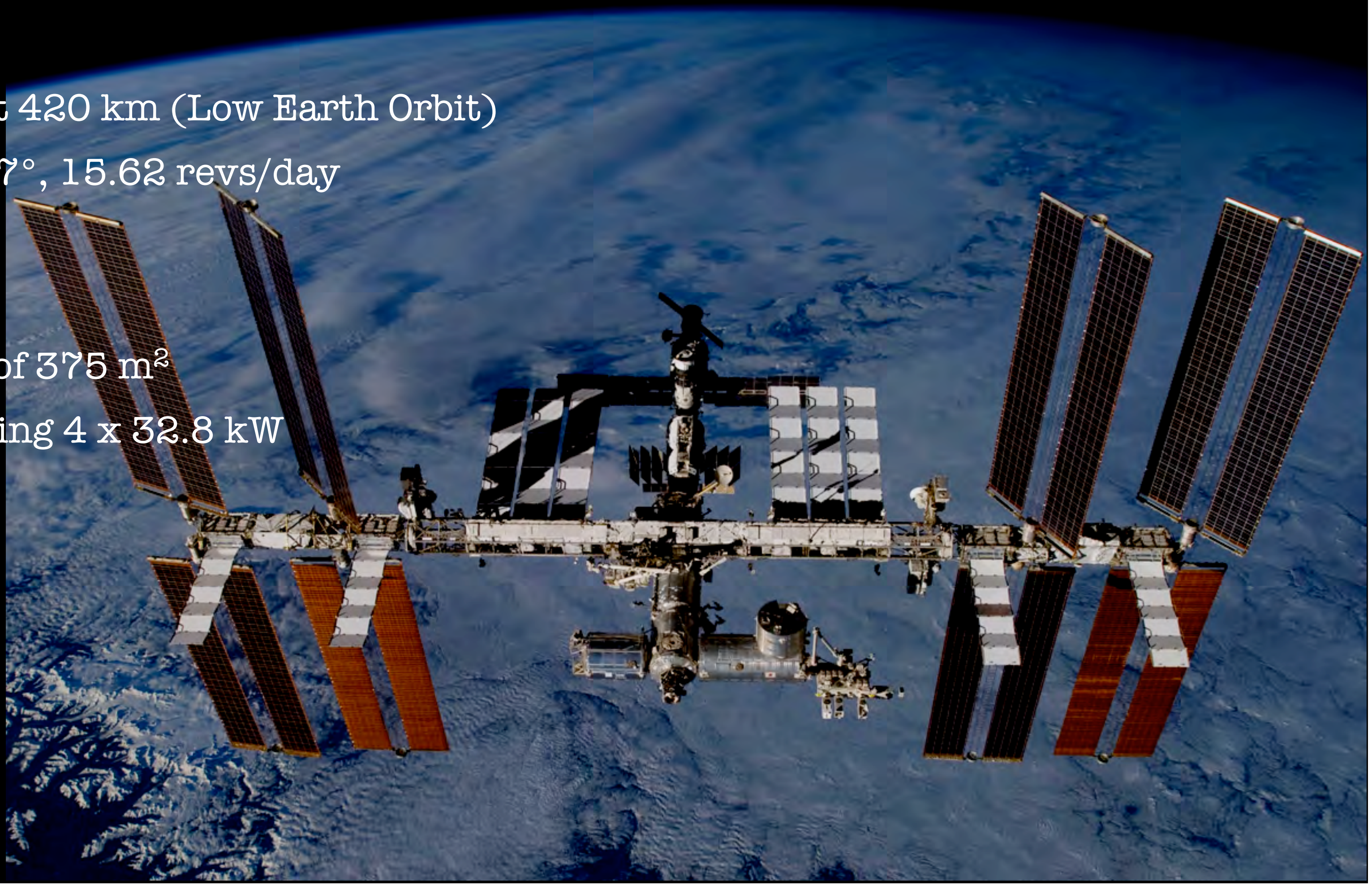
Orbit: elliptical at 420 km (Low Earth Orbit)

Inclination: 51.57°, 15.62 revs/day

ΔT: -60 ÷ +40 °C

Power: 4 arrays of 375 m^2

solar panels giving 4 x 32.8 kW



The Space Shuttle

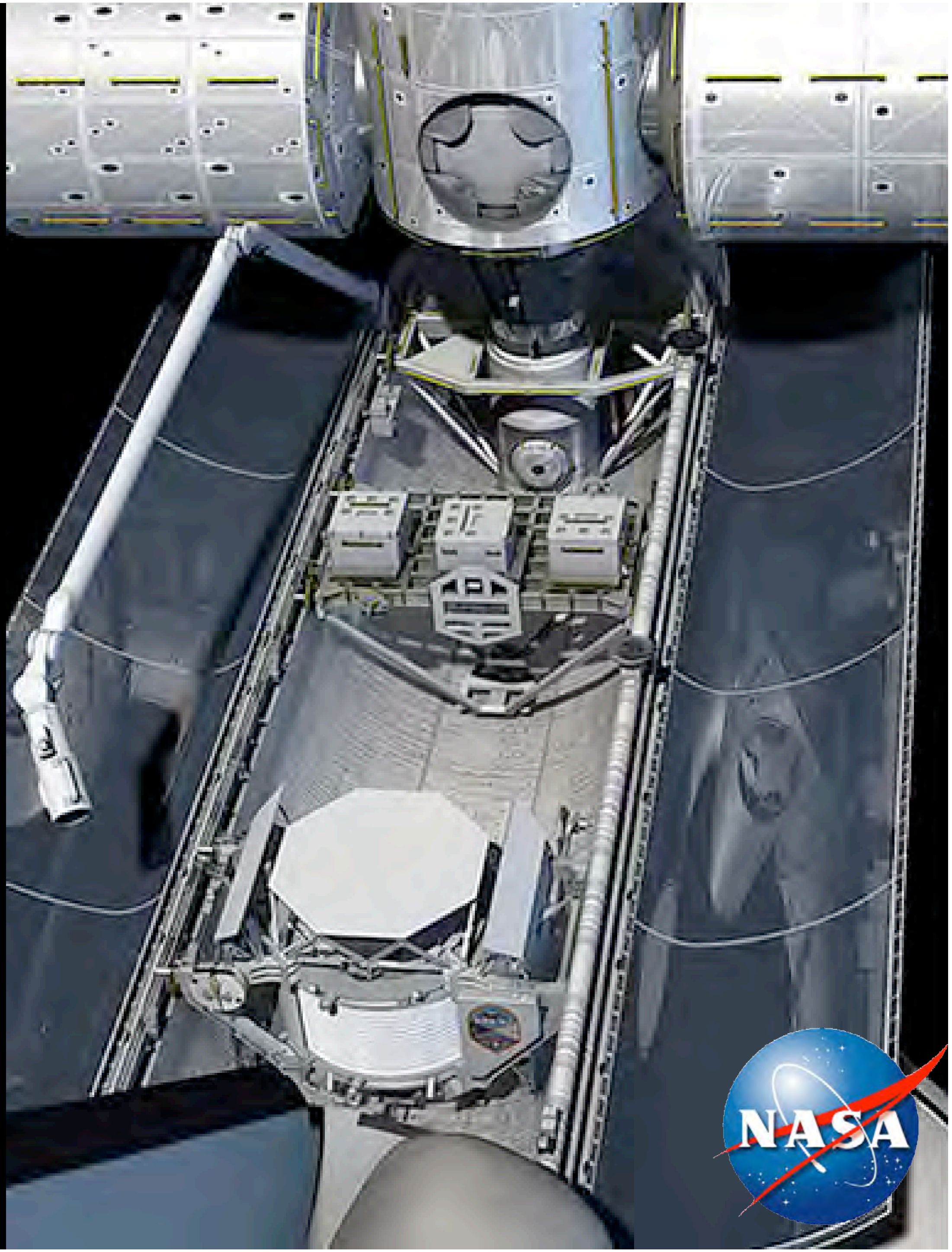
The Shuttles are launched from Kennedy Space Center (Florida)

Orbital velocity: 27,600 Km/h (Mach 23)

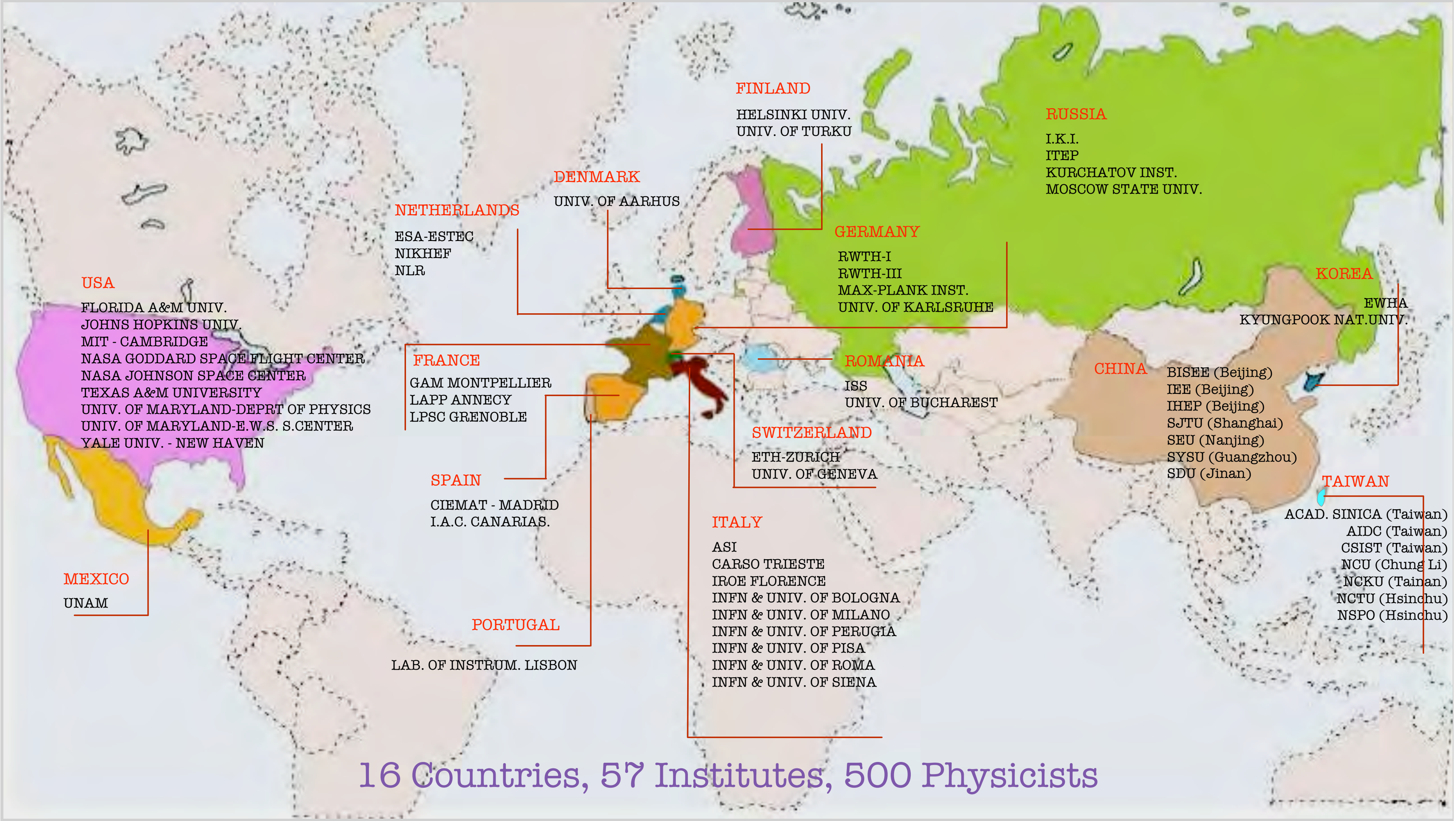
Launch acceleration: -3 g

Launch vibrations: >3 g RMS

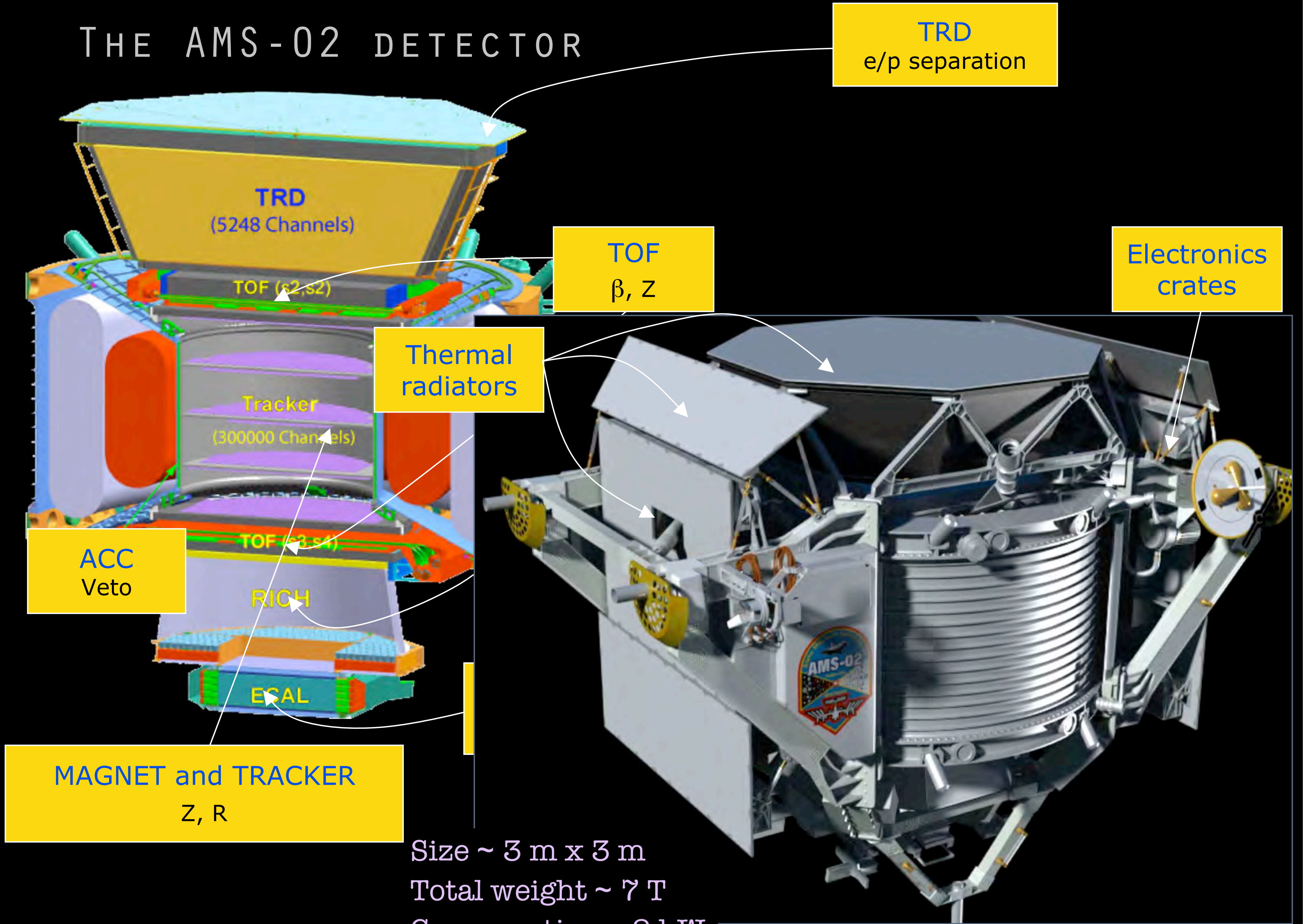
Cargo bay: 4.5 m Ø x 14.6 m



The AMS-02 Collaboration

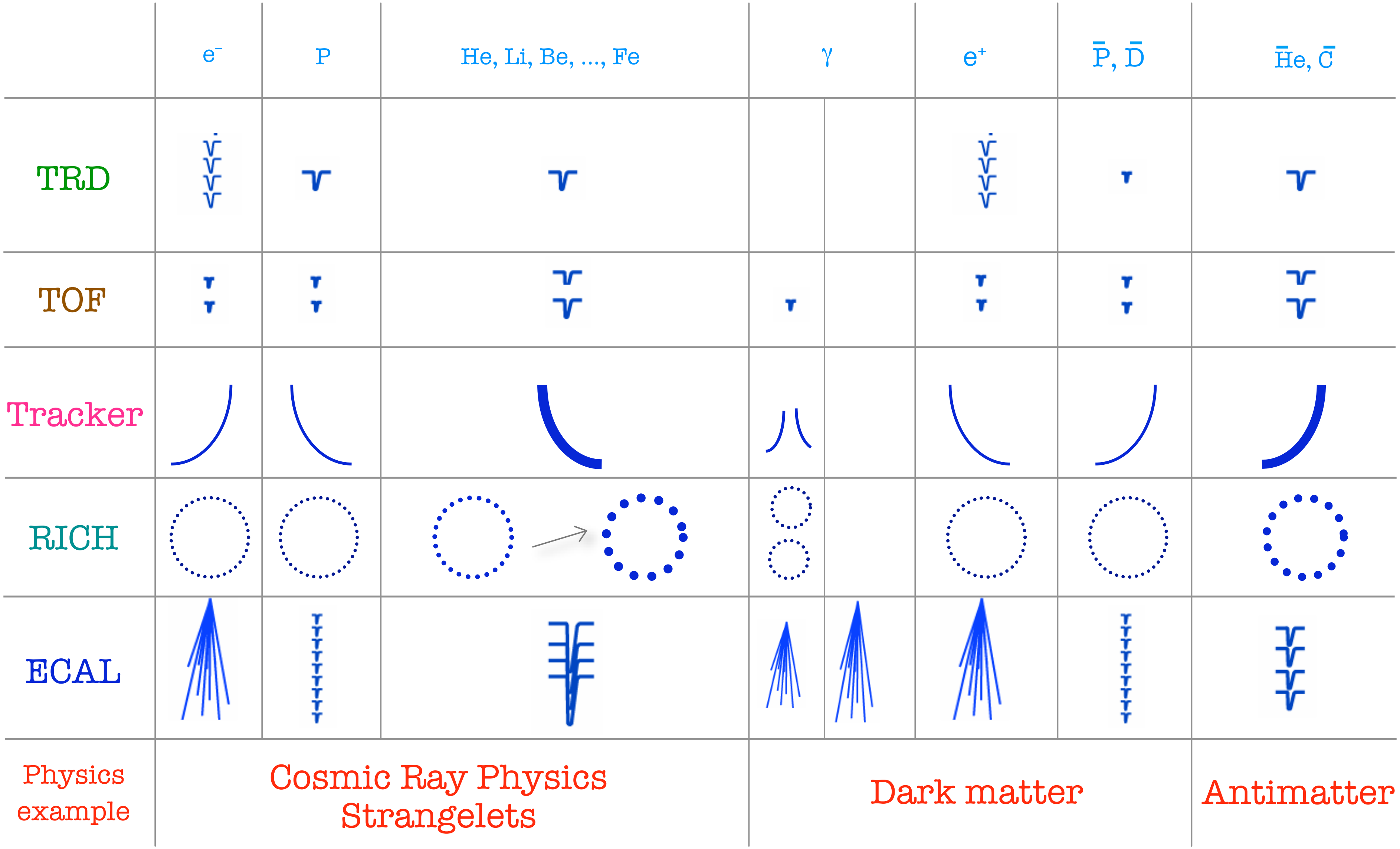


The AMS-02 detector



Size ~ 3 m x 3 m
Total weight ~ 7 T
Consumption ~ 2 kW

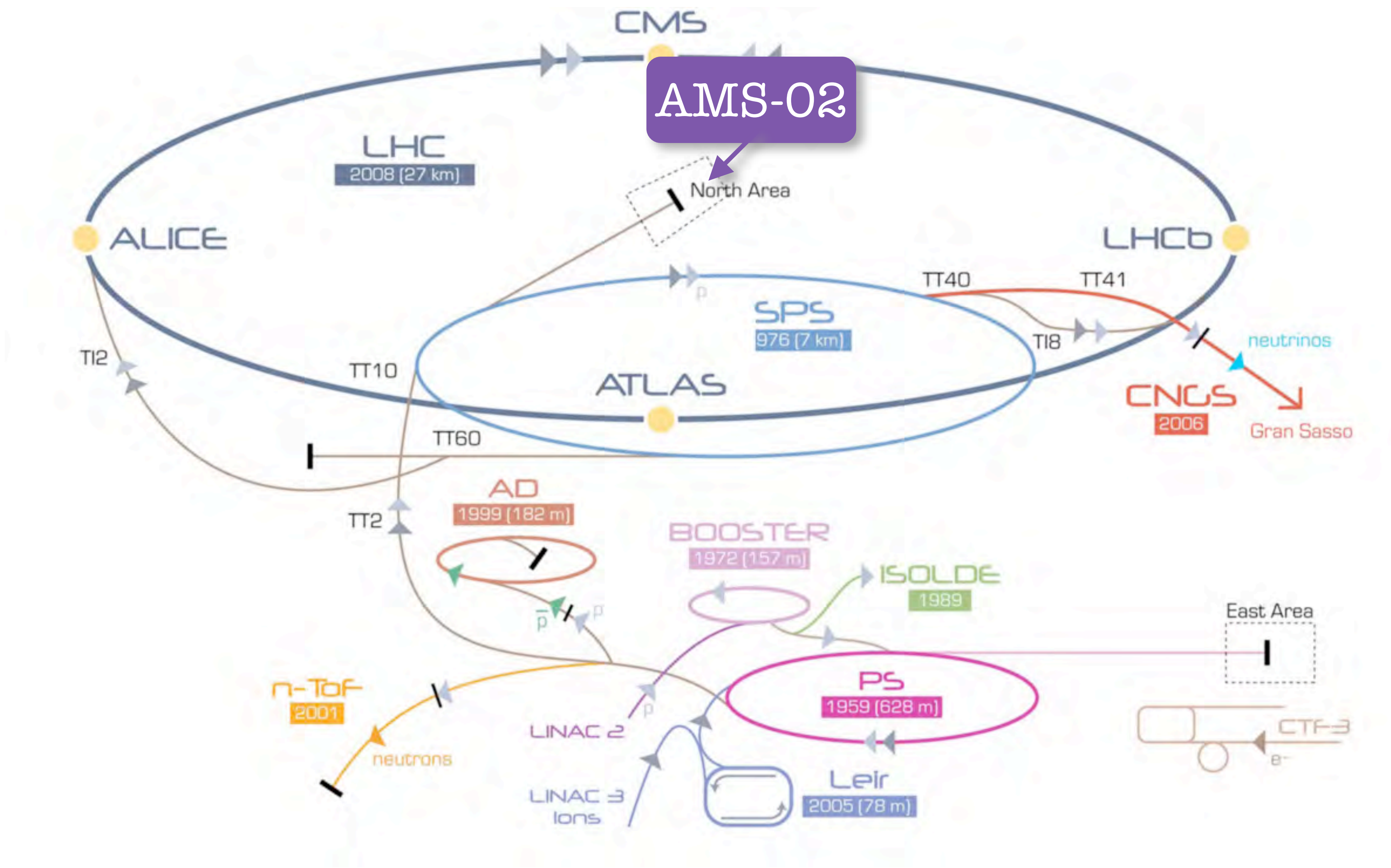
Signatures


e⁻
P
He, Li, Be, ..., Fe
γ
e⁺
P̄, D̄
H̄e, C̄
TRD
TOF
Tracker
RICH
ECAL
Physics example
Cosmic Ray Physics
Strangelets
Dark matter
Antimatter

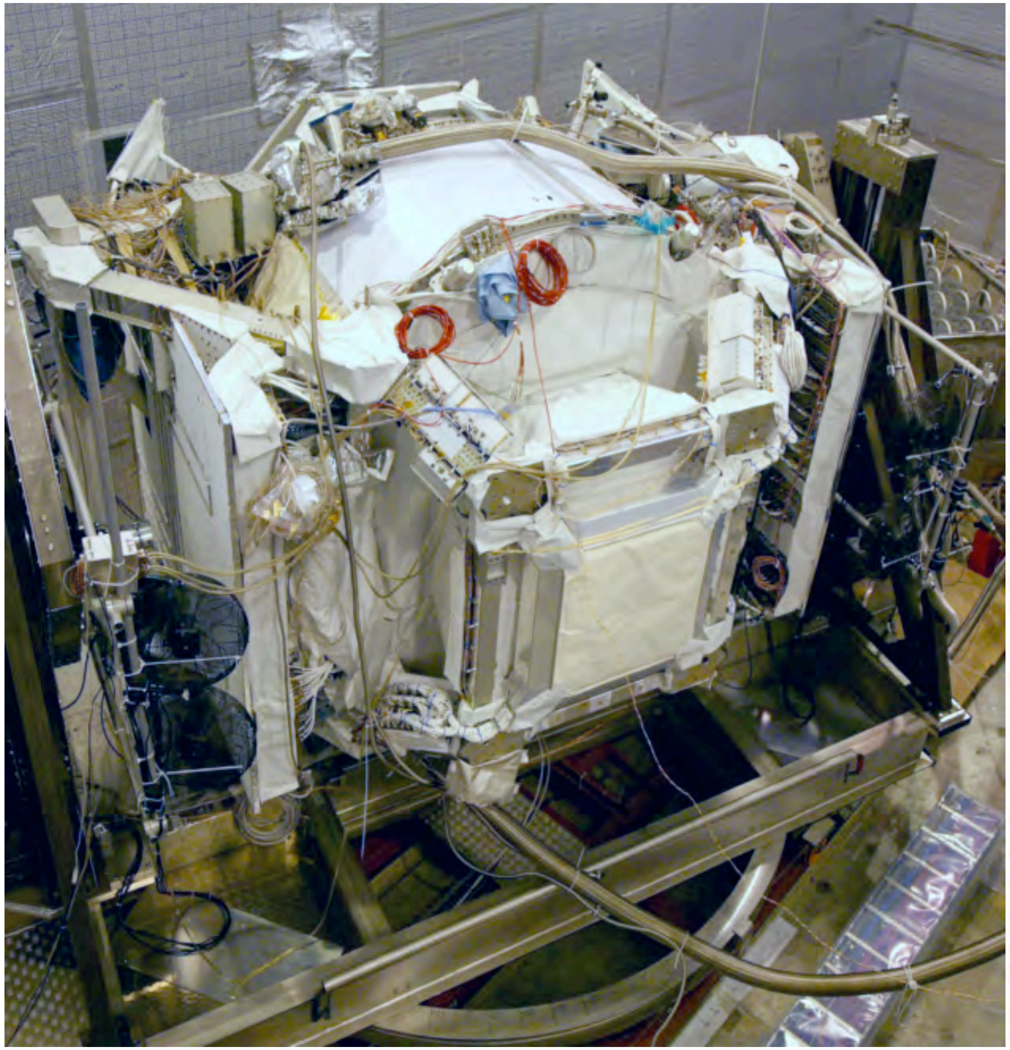
Oct 2009	Detector integrated with the 0.8T Superconducting magnet
Feb 2010	Test-beam
Feb-Apr 2010	Electromagnetic compatibility & Thermo-vacuum test

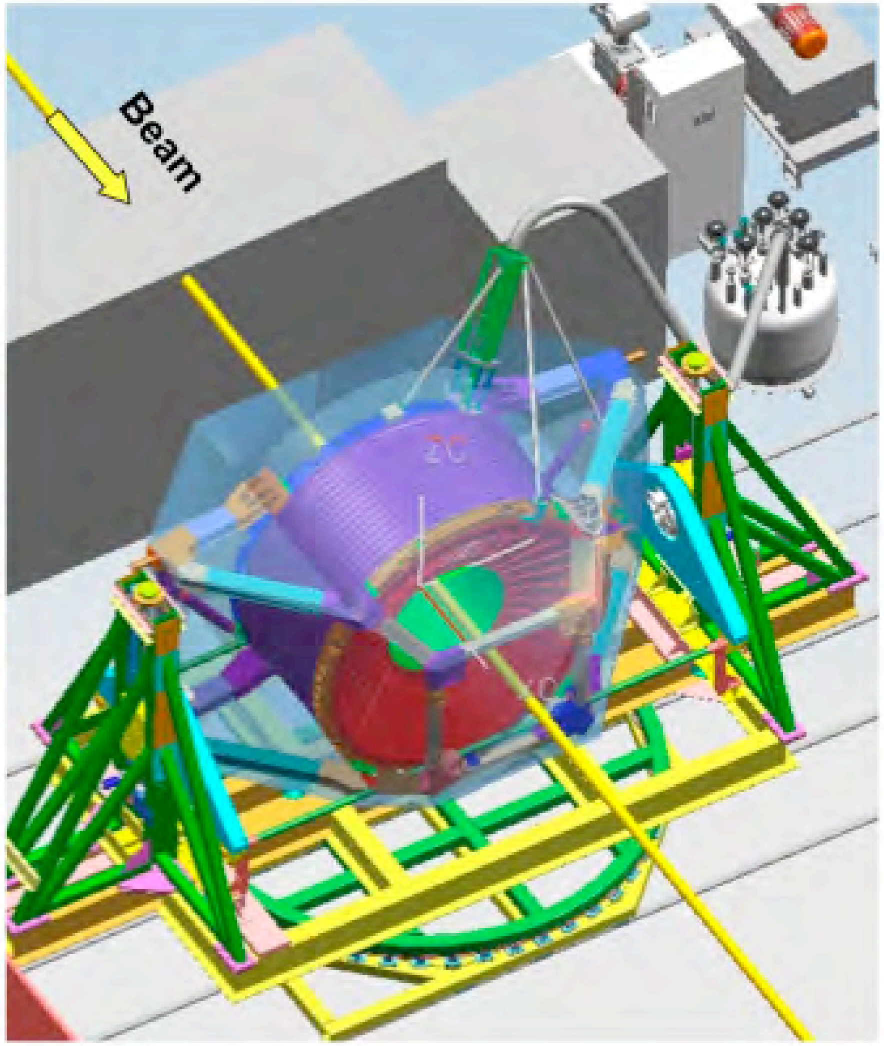
Test Beam Results
(CERN - feb. 2010)

The CERN Test Beam Area



AMS-02 in the CERN North Area



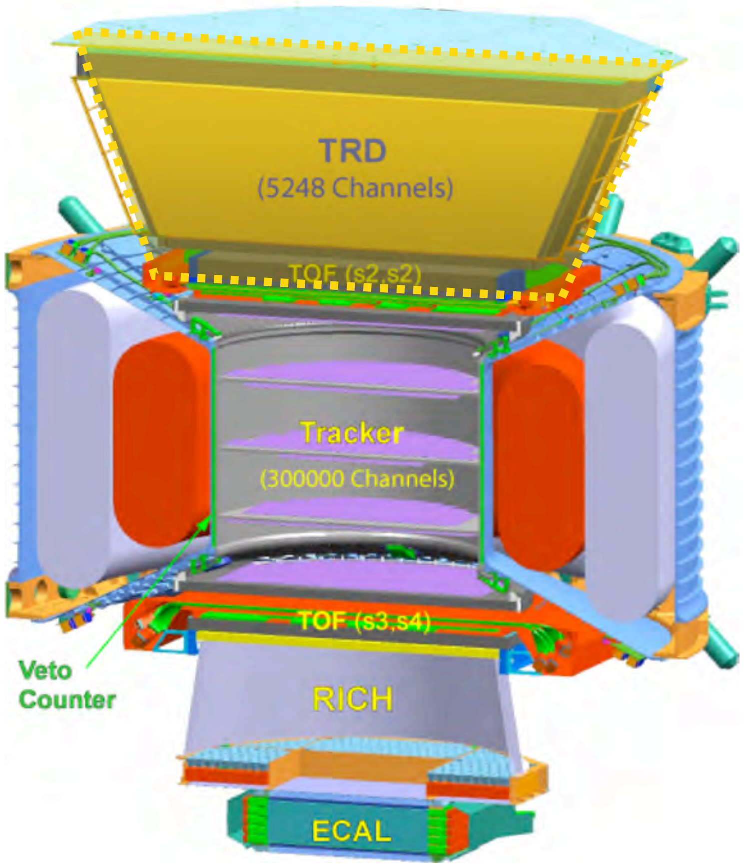


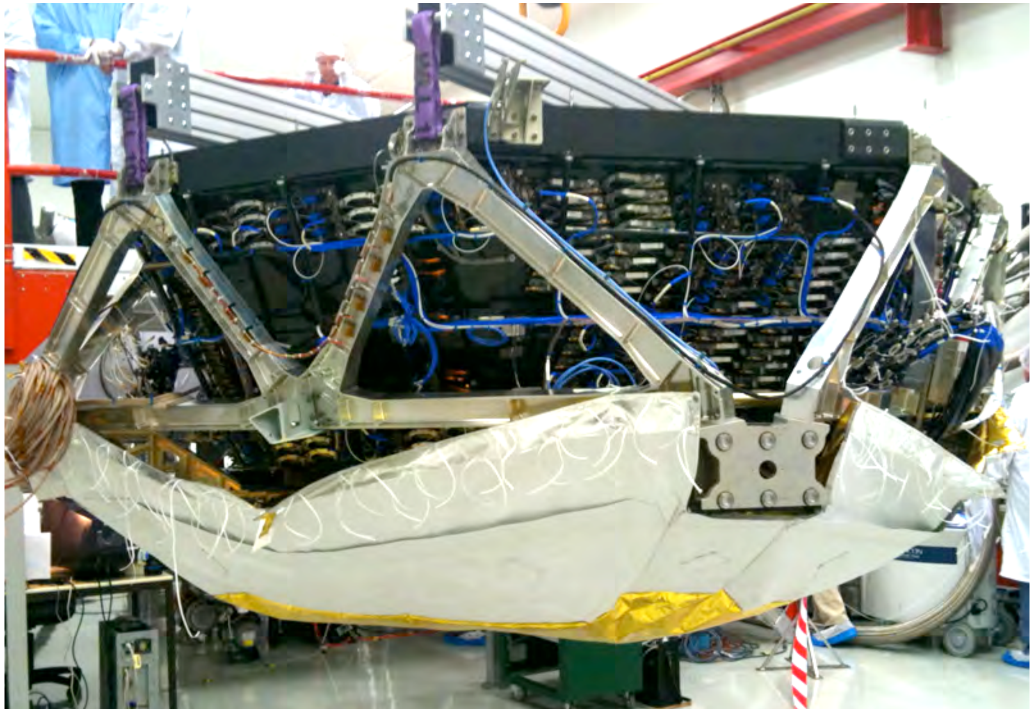
Transition Radiation Detector

Fleece radiator + straw tubes (Xe:CO_2)

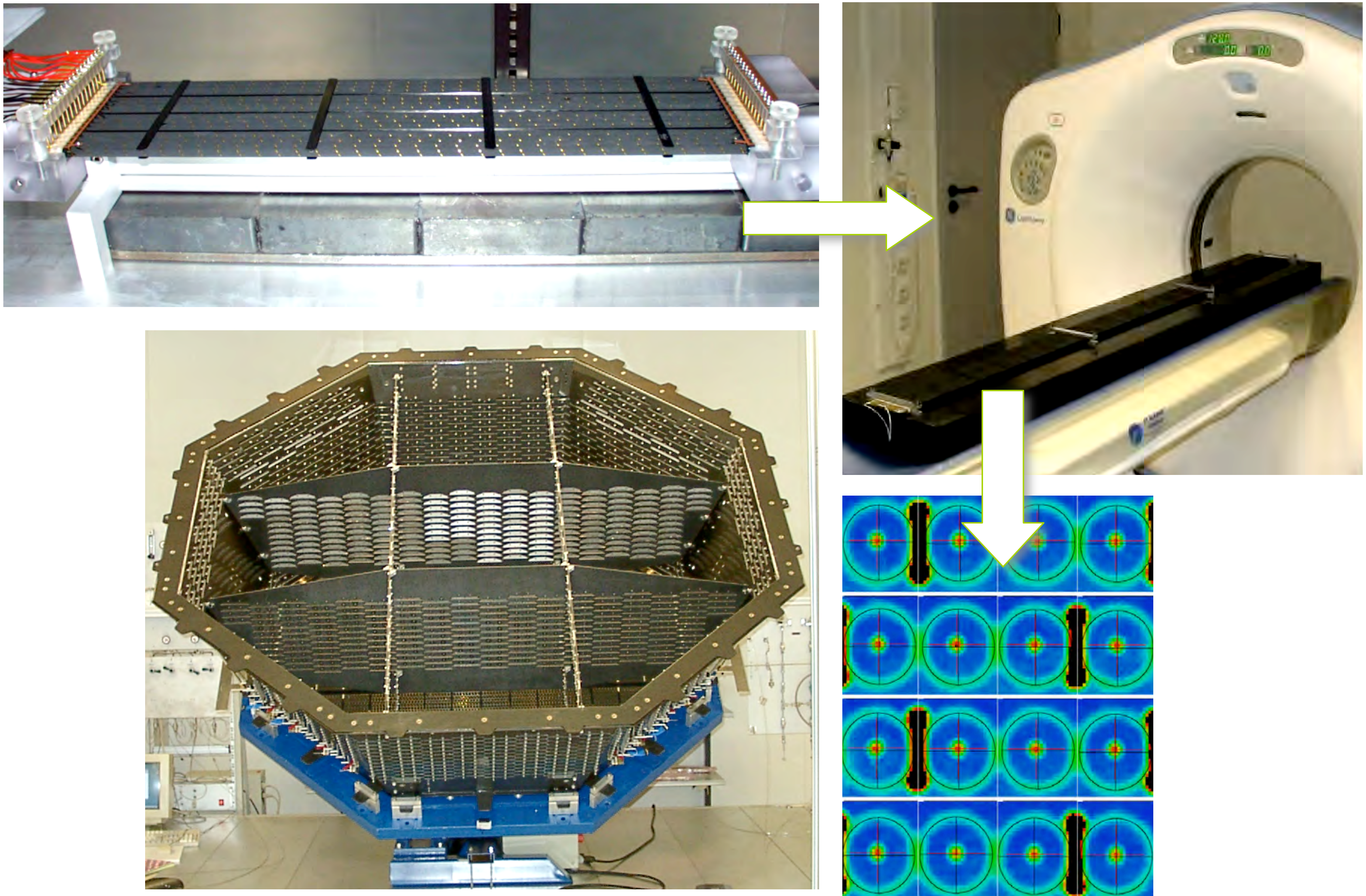
e/p separation

3D-tracking



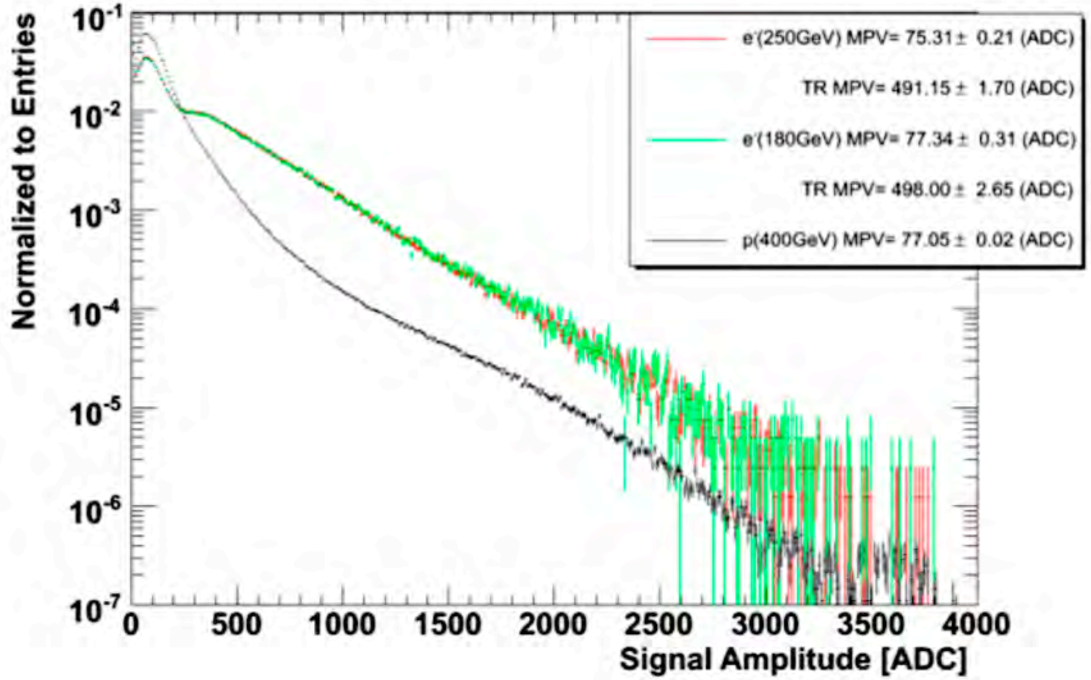


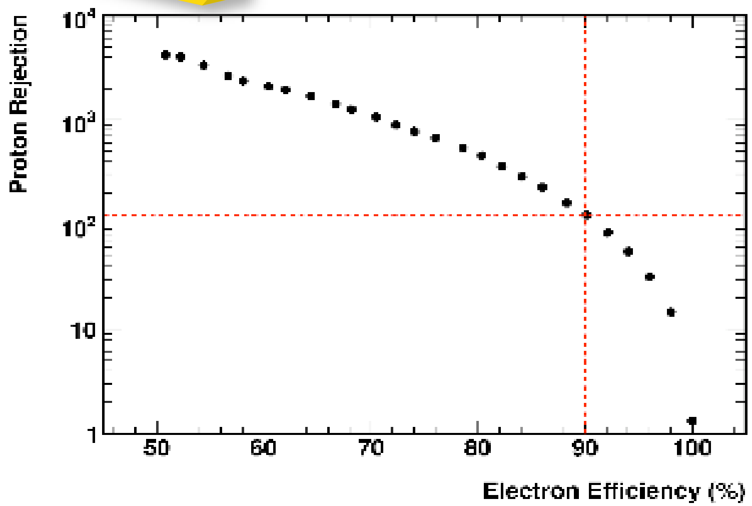
Transition Radiation Detector

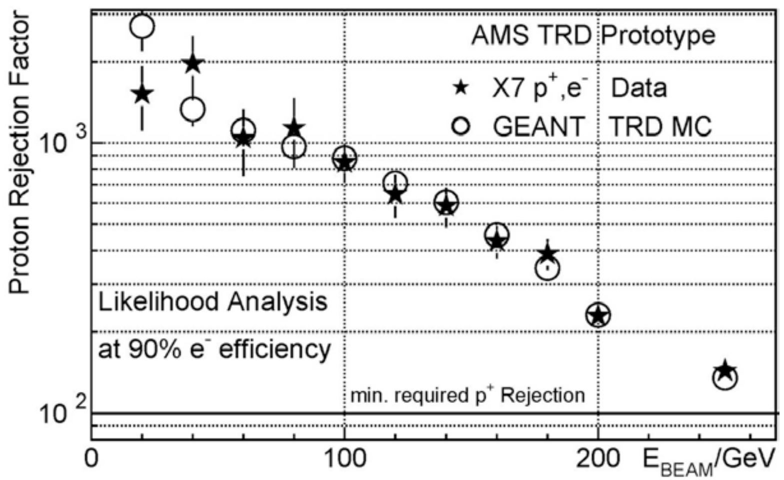


TRD Response to 400 GeV Protons and 180÷250 GeV Electrons

Feb 2010 Test Beam

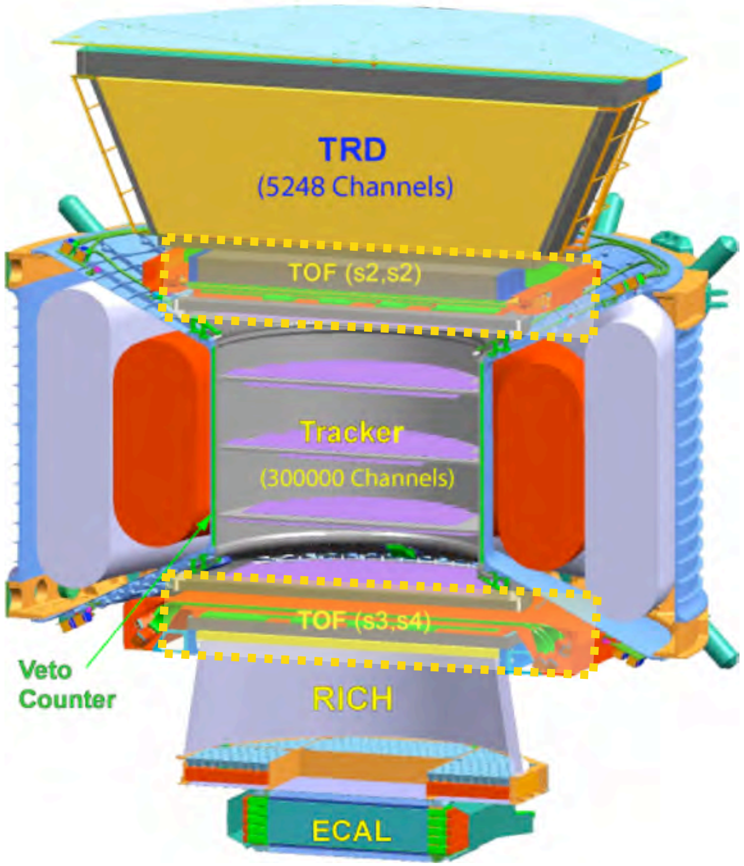






e/p separation > 10^2 up to 400 GeV

Time of Flight

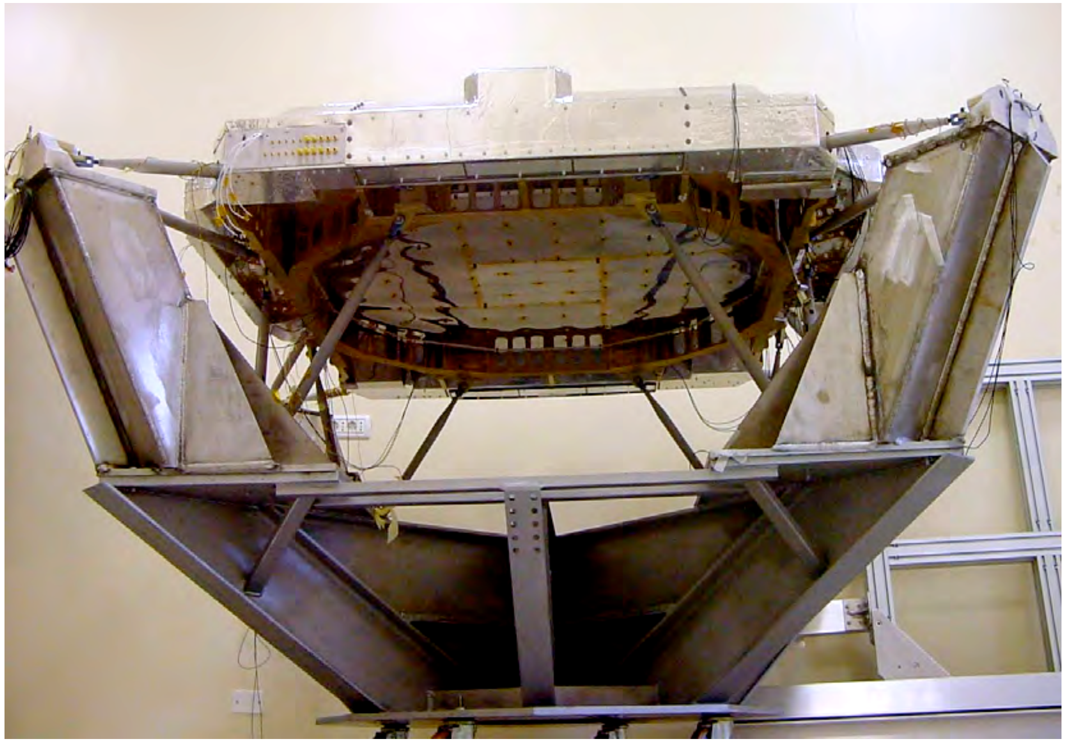


2+2 layers of scintillators

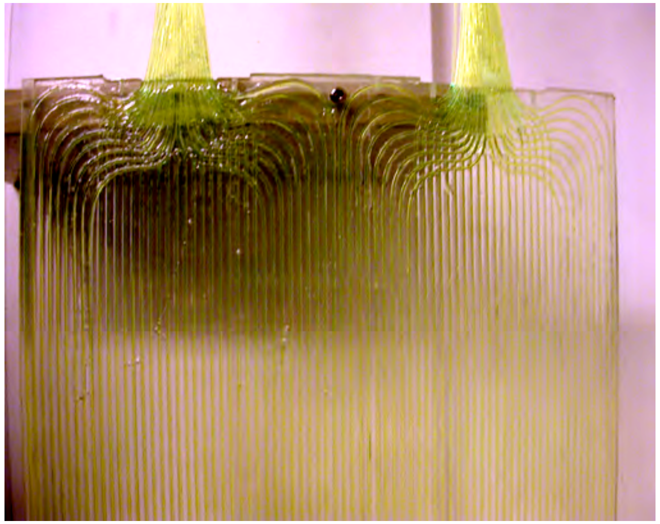
Main Trigger (up to 2 kHz)

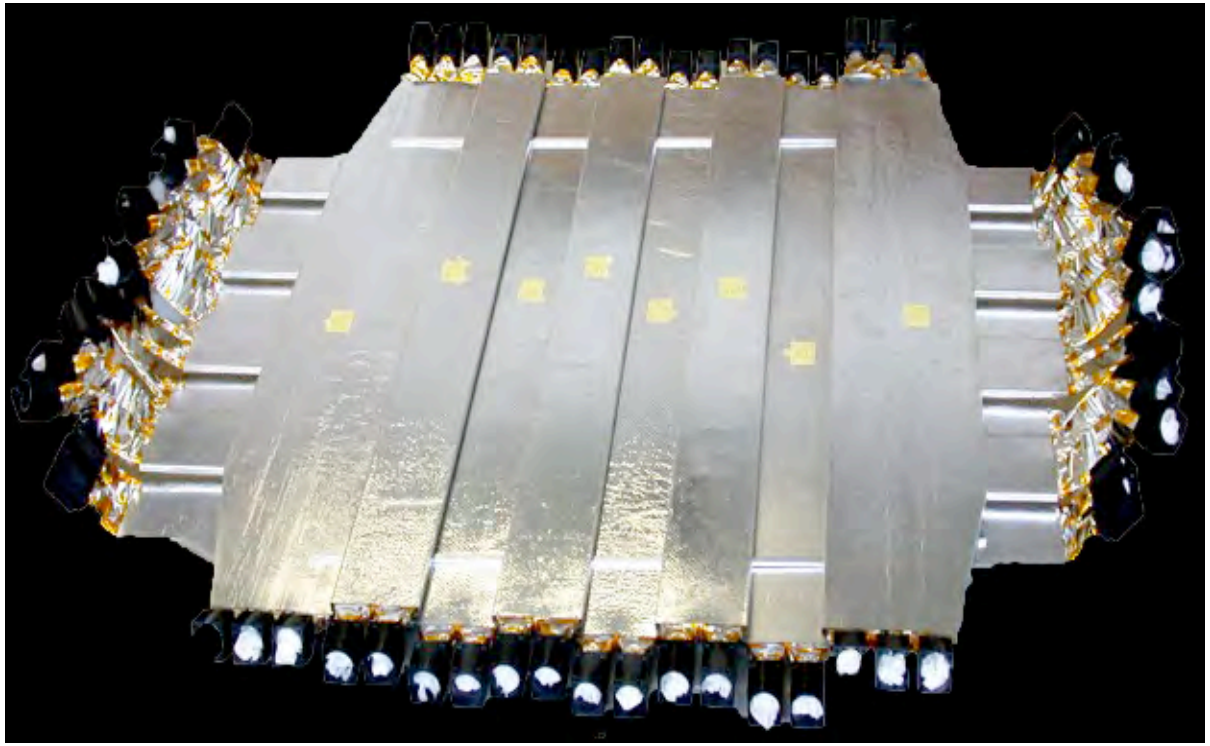
Z separation

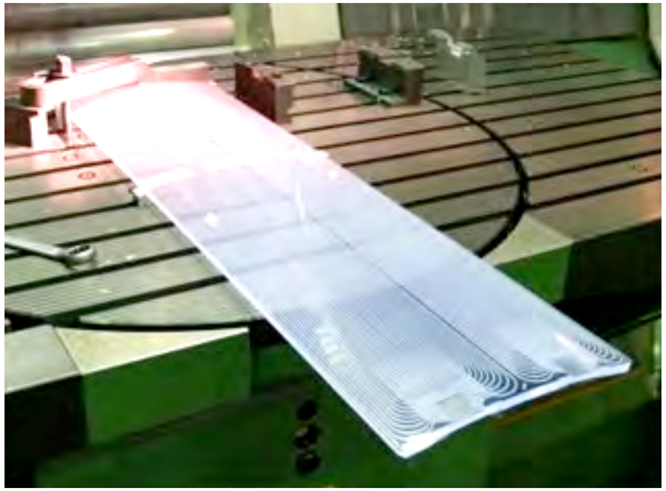
β with few % precision



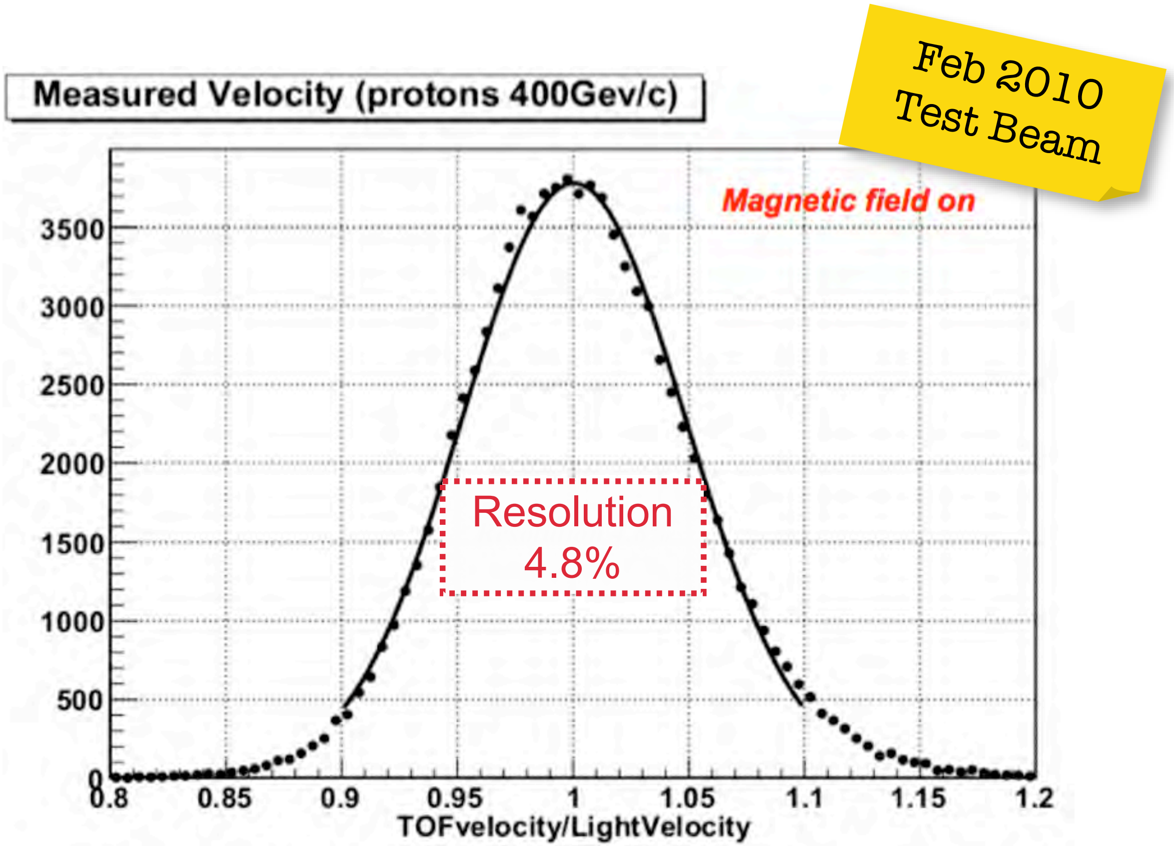
Time of Flight







TOF Response to 400 GeV Protons



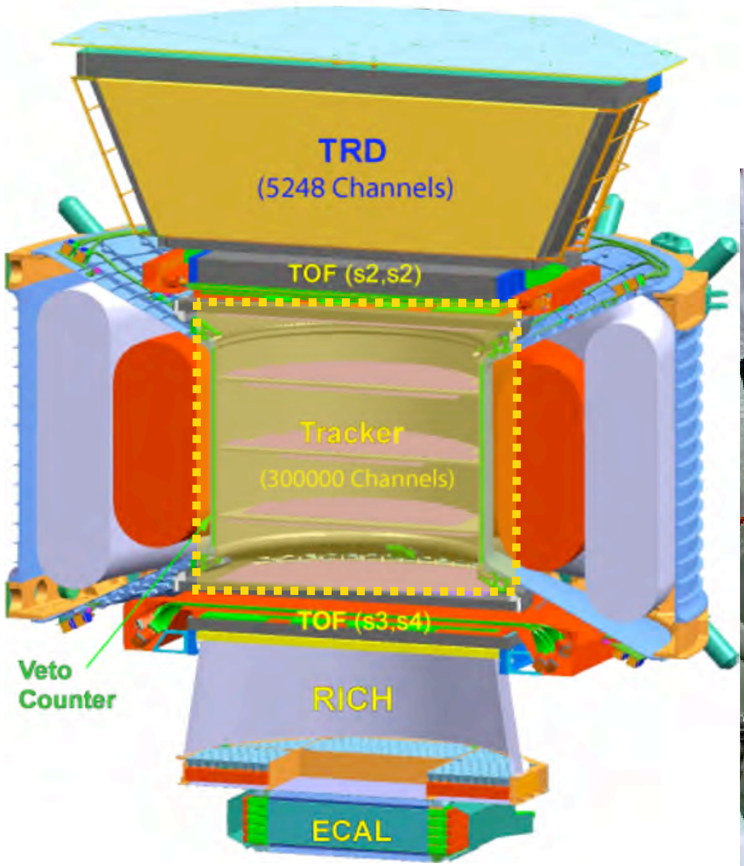
$\Delta t \sim 160$ ps

Silicon Tracker

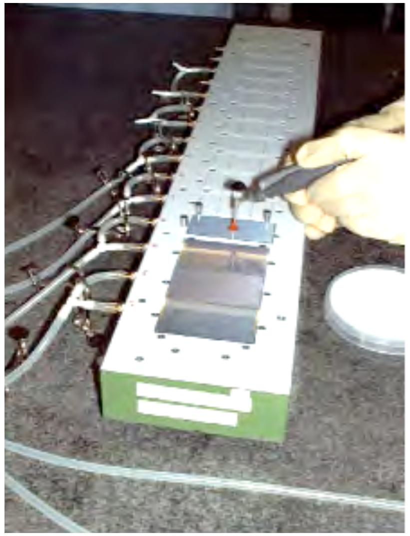
8 layers double-sided
silicon microstrip detector

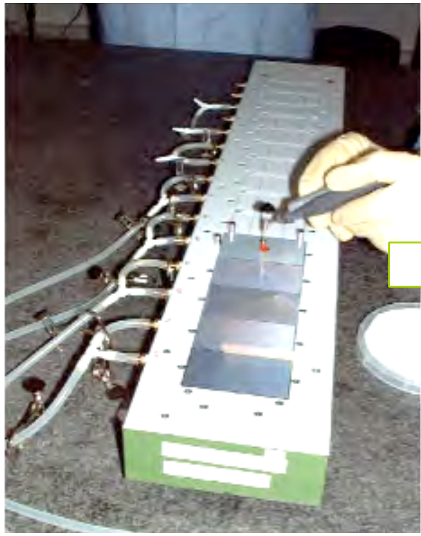
R up to 2 TeV

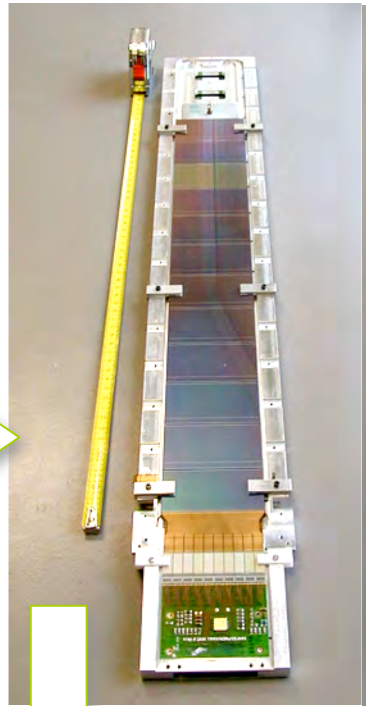
Z separation

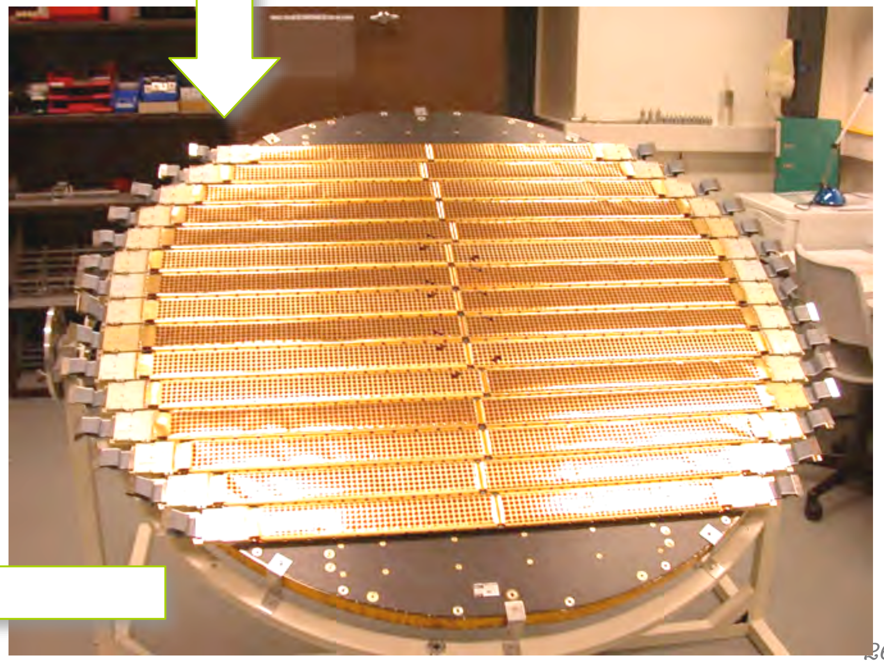


Silicon Tracker



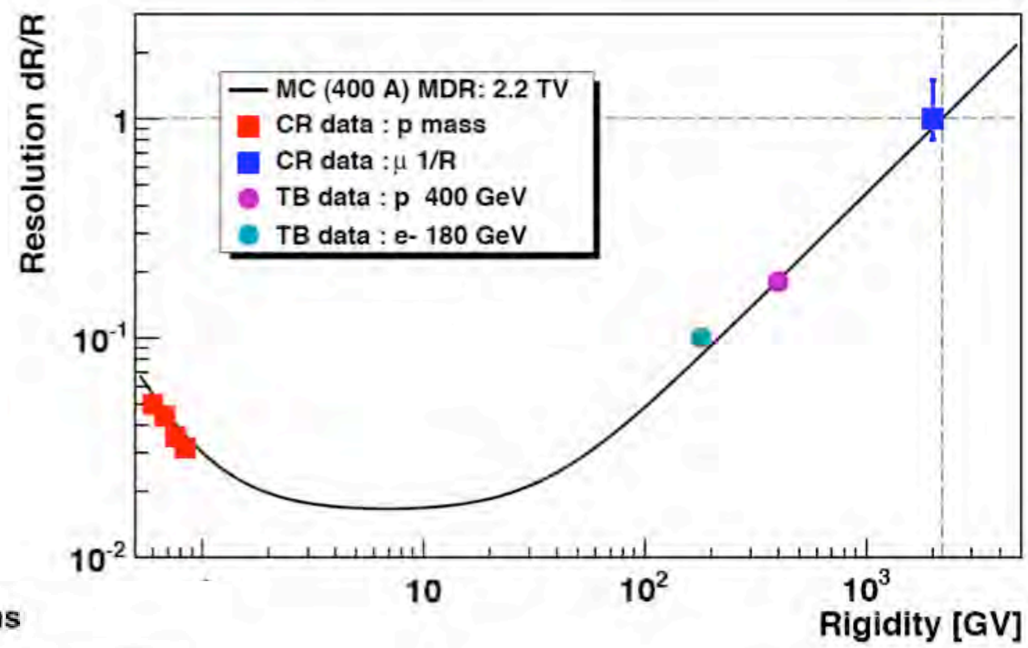


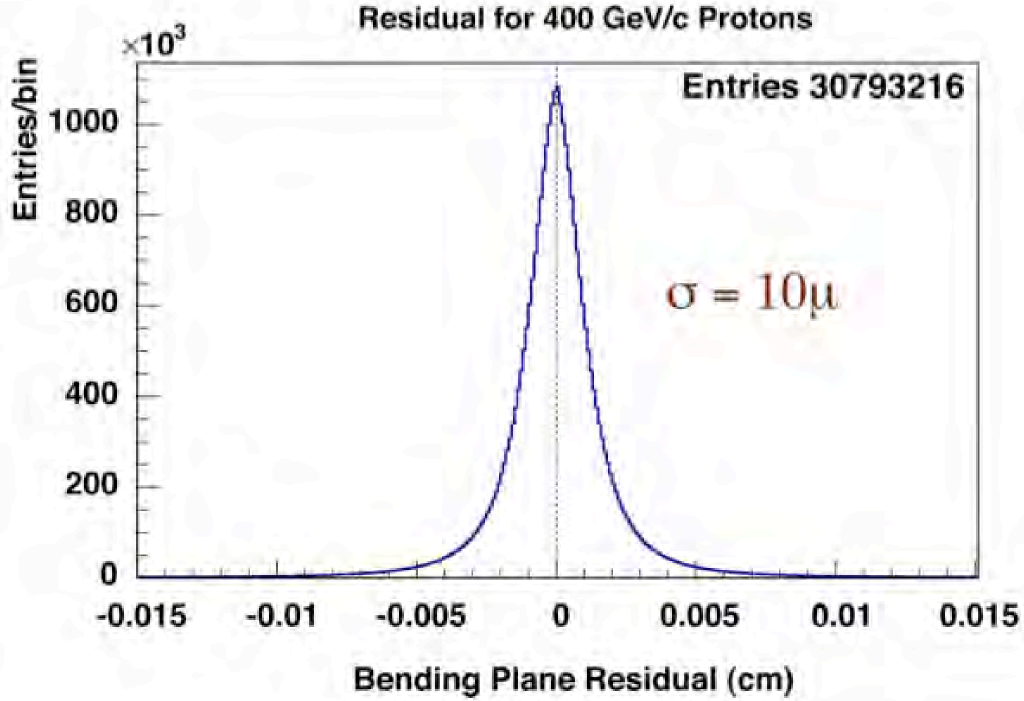




Silicon Tracker

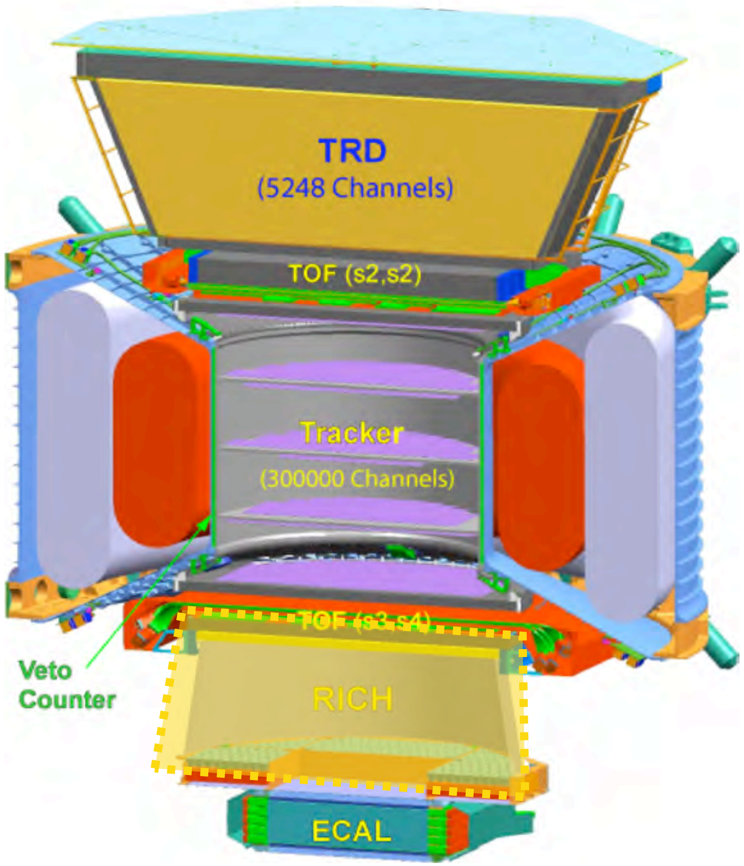
Feb 2010
Test Beam





$\sigma_R < 2\%$ for $R < 10$ GeV

Ring Imaging CHerenkov

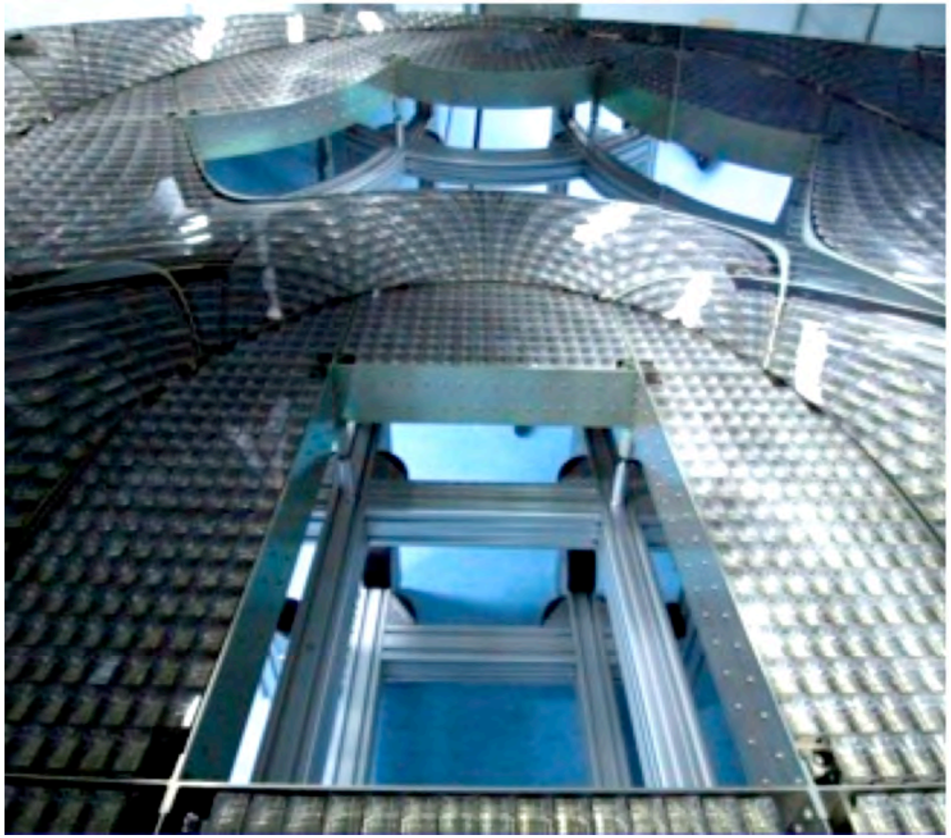


2 Radiators: NaF (center),
Aerogel (elsewhere)

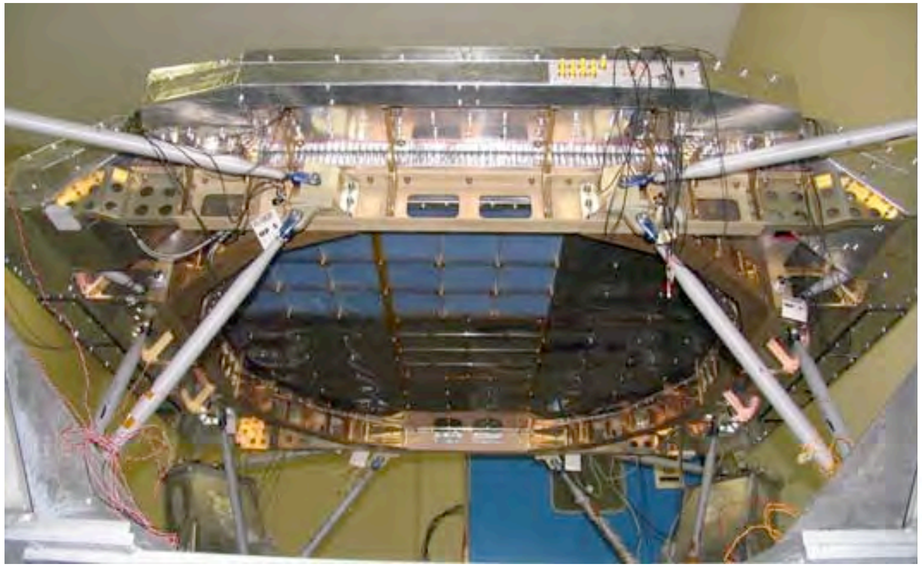
β with few ‰ precision

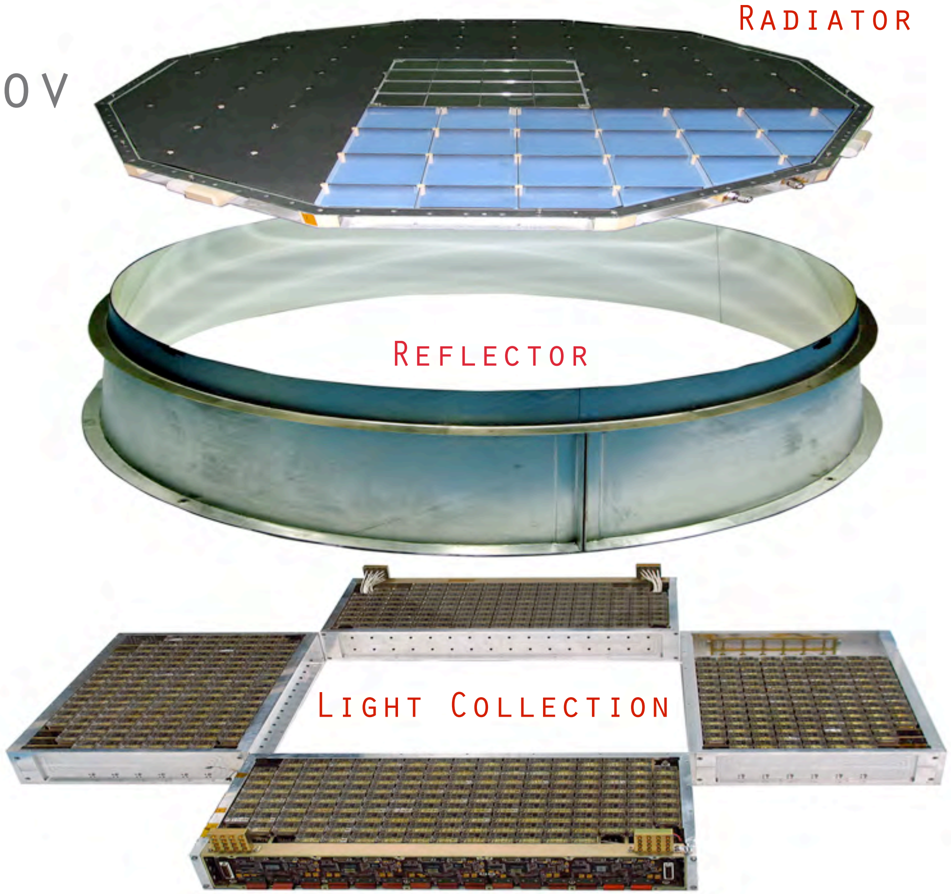
Z and isotopes separation

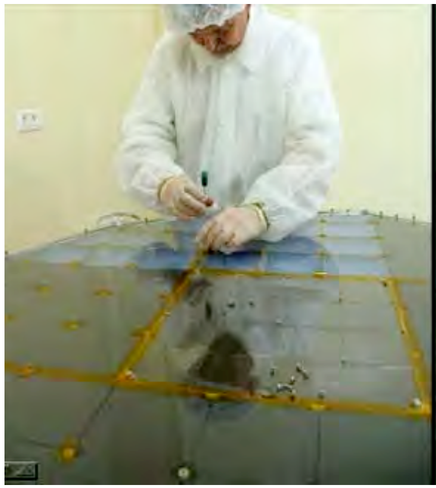
σ_{mass} = 2% below 10 GeV/n

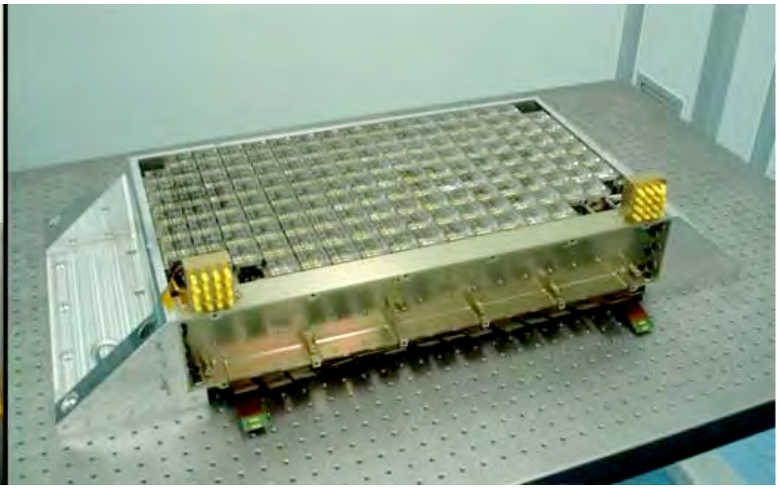


Ring Imaging CHerenkov

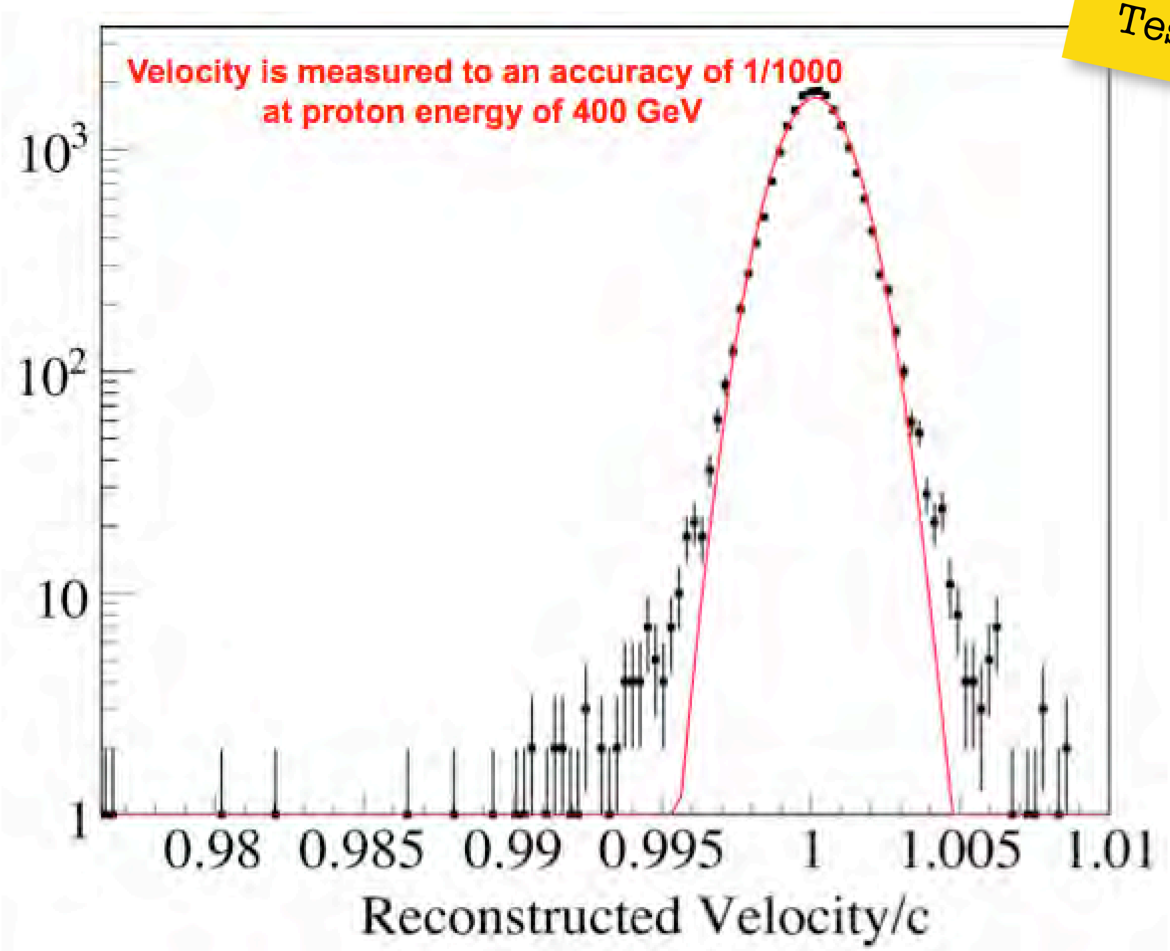






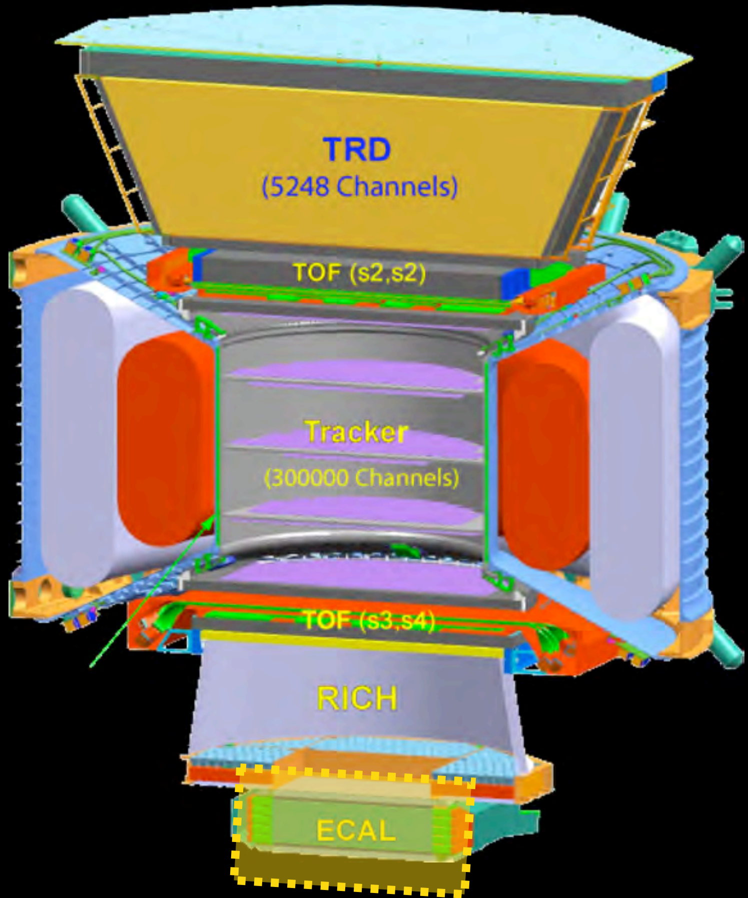


RICH Velocity Measurement



Feb 2010
Test Beam

Electromagnetic CALorimeter



9 superlayers of Lead + Scintillating Fibers

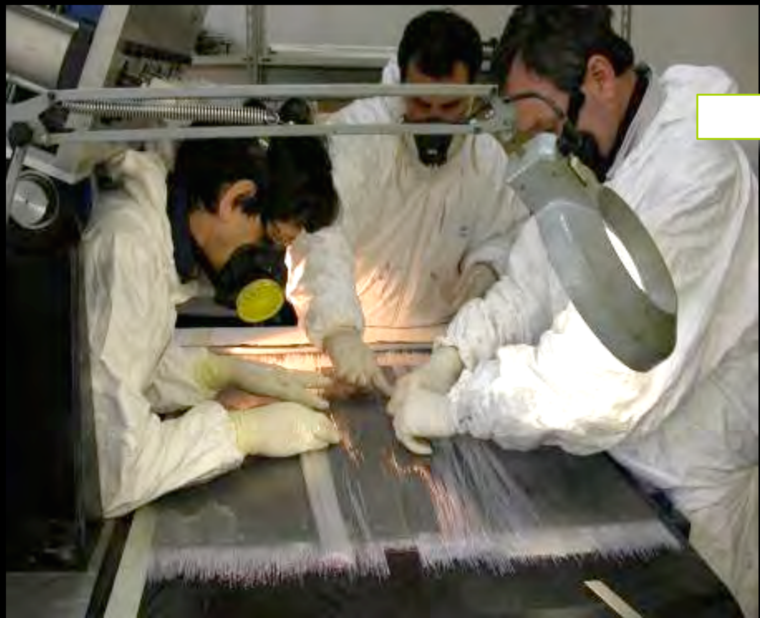
e/p separation

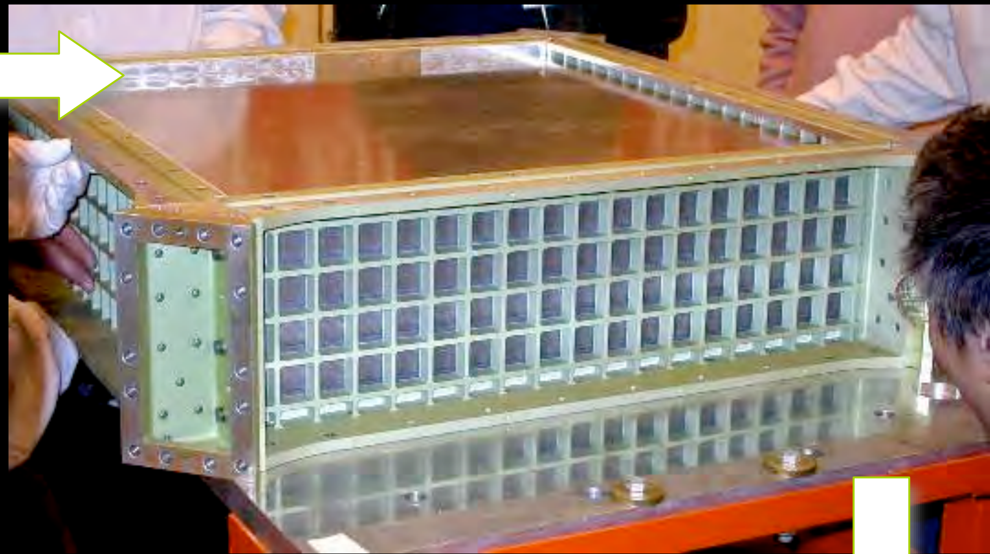
γ detection

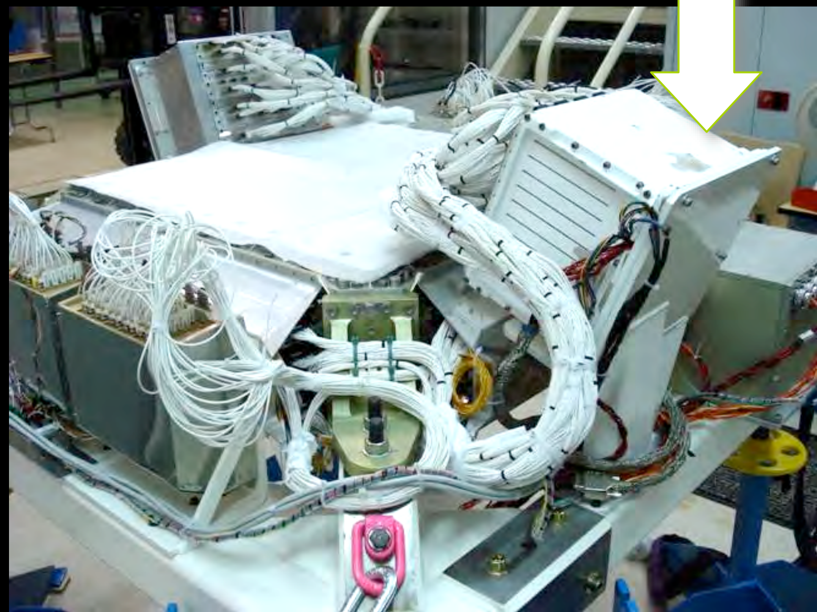
3D-imaging with 1° precision

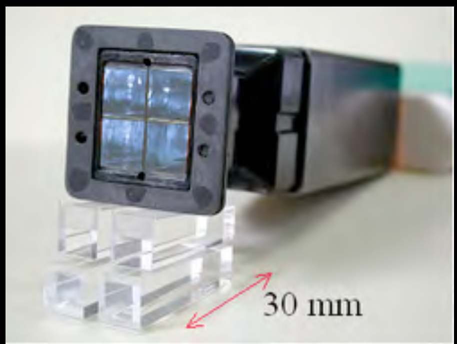
Standalone Trigger

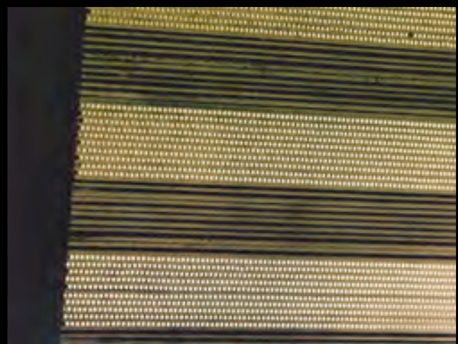
Electromagnetic CALorimeter



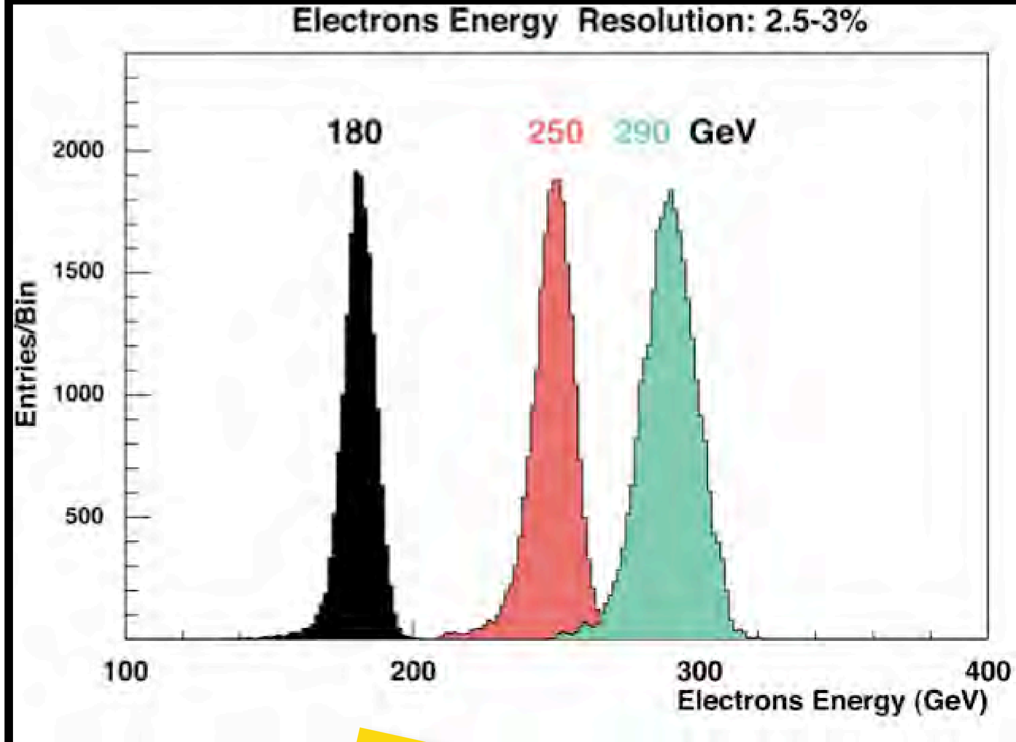


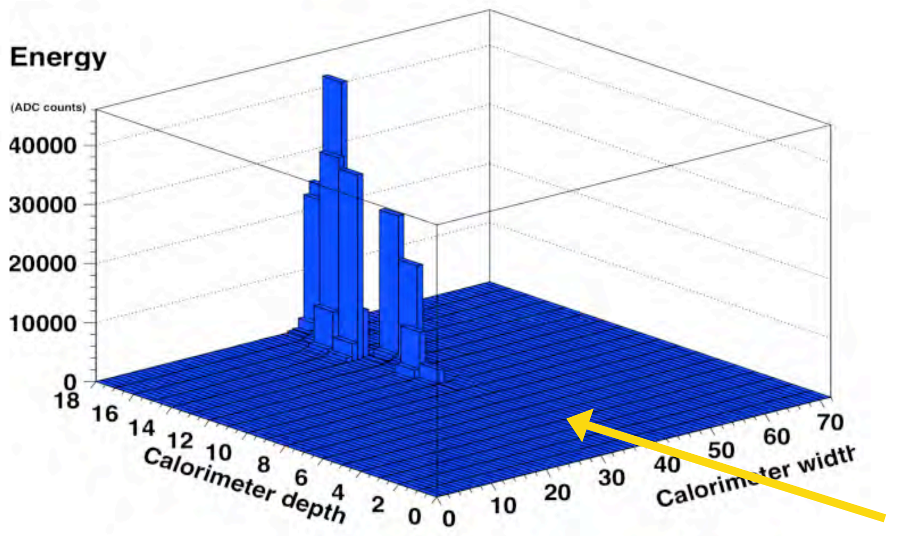


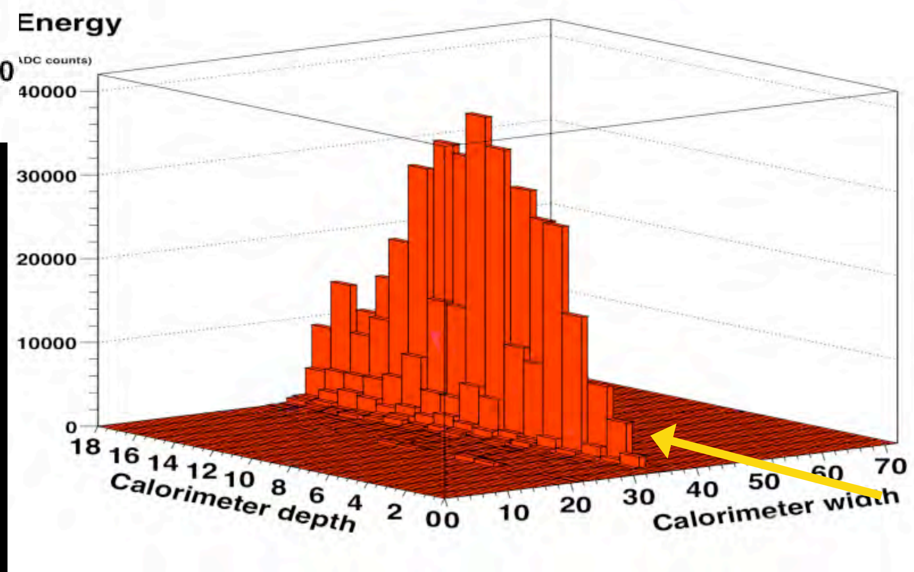




ECAL Response to Electrons and Protons

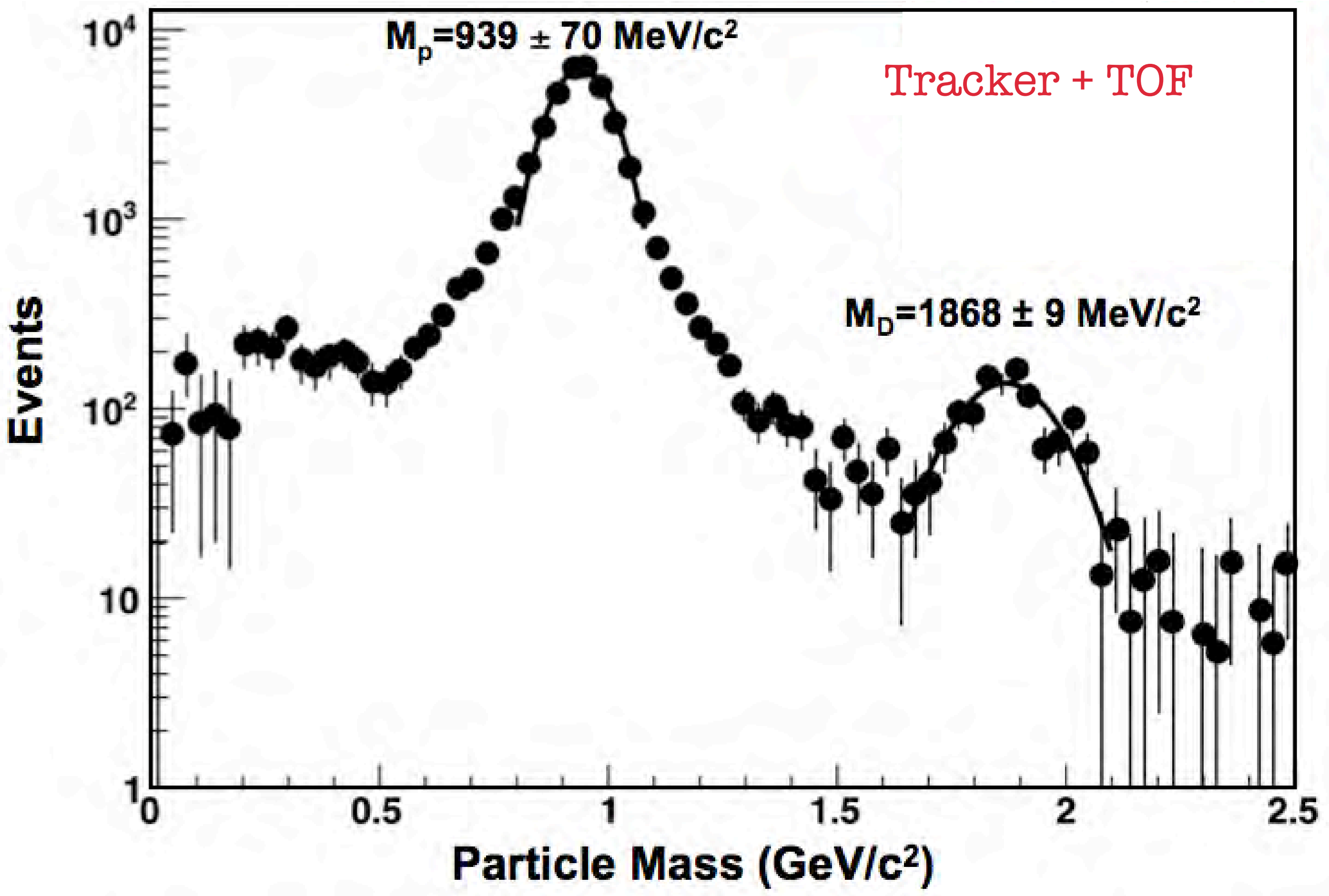






Feb 2010
Test Beam

AMS Mass Measurement



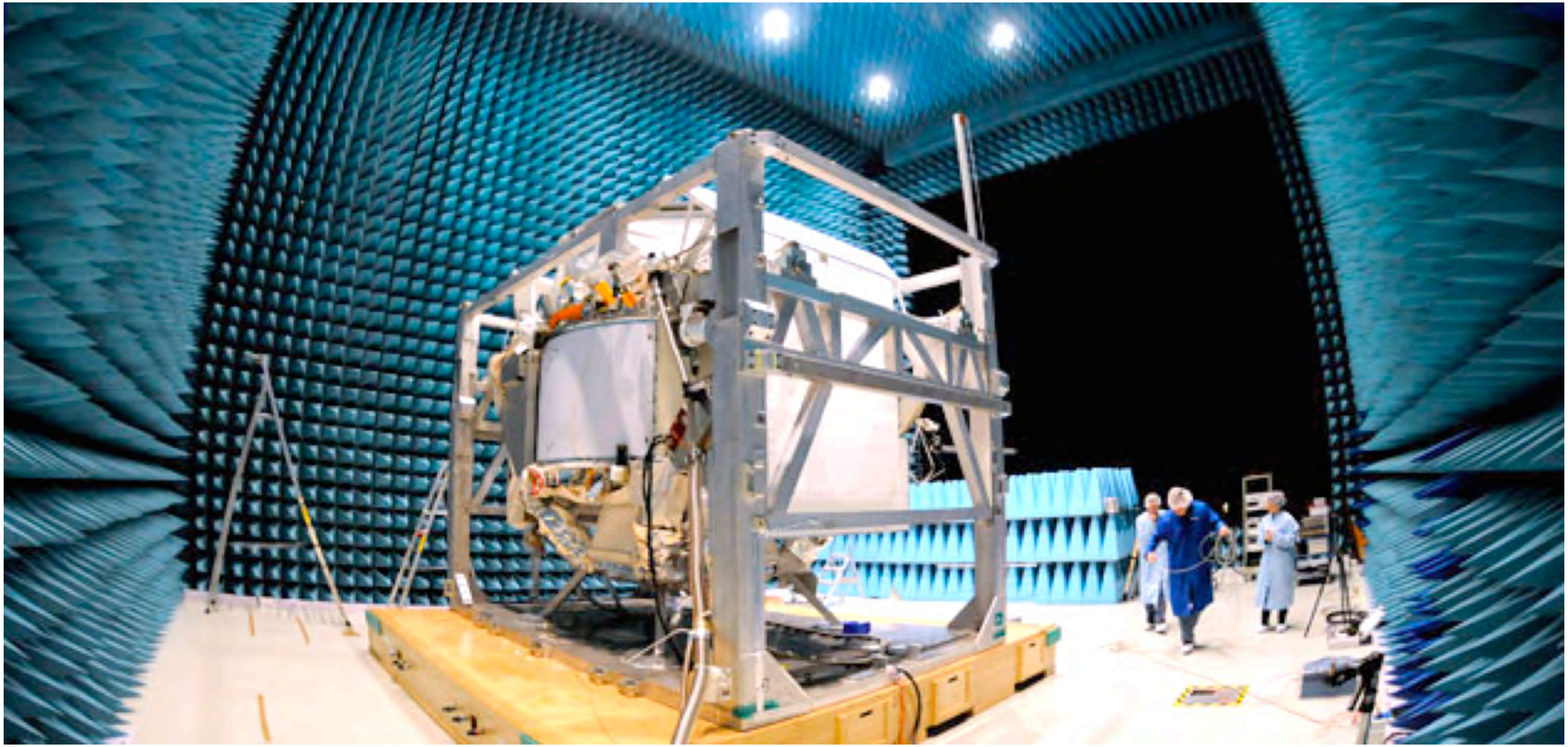
Test of AMS-02 at ESA/ESTEC (Feb-Apr 2010)

- Electromagnetic Compatibility
- Thermo-vacuum Test

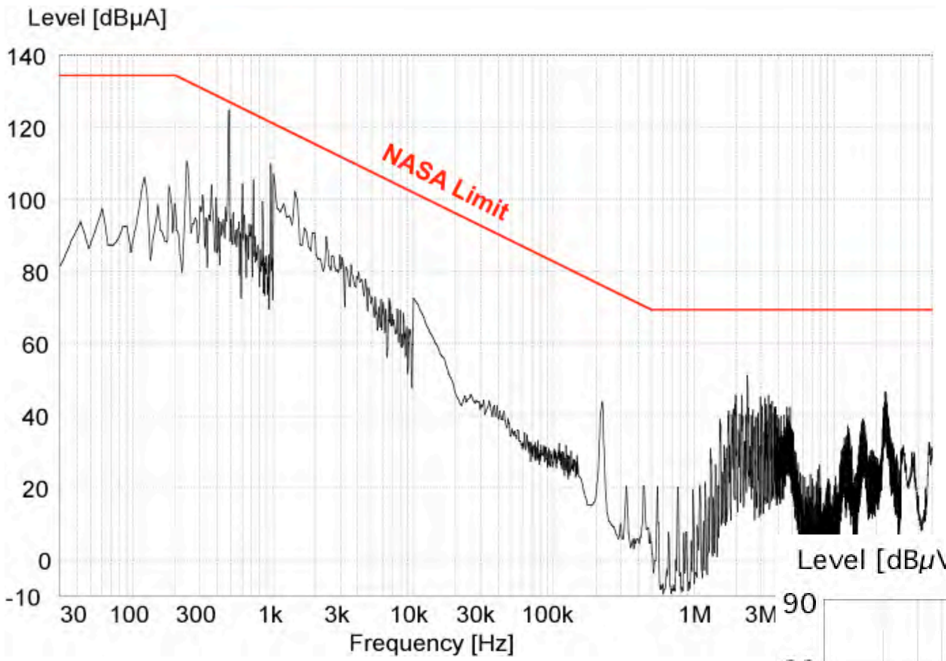
AMS-02 leaves CERN for ESTEC on 12/2/2010

... and arrives at ESTEC after a 6-days trip...

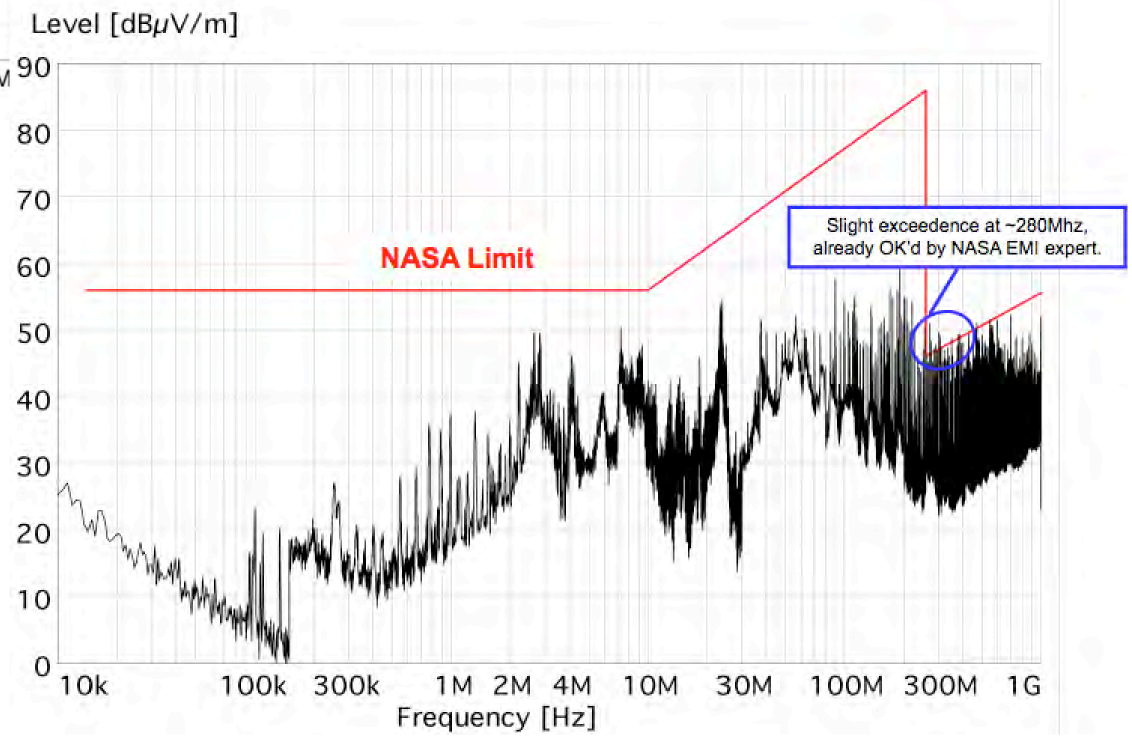
AMS-02 in the ESTEC Maxwell EMI-chamber



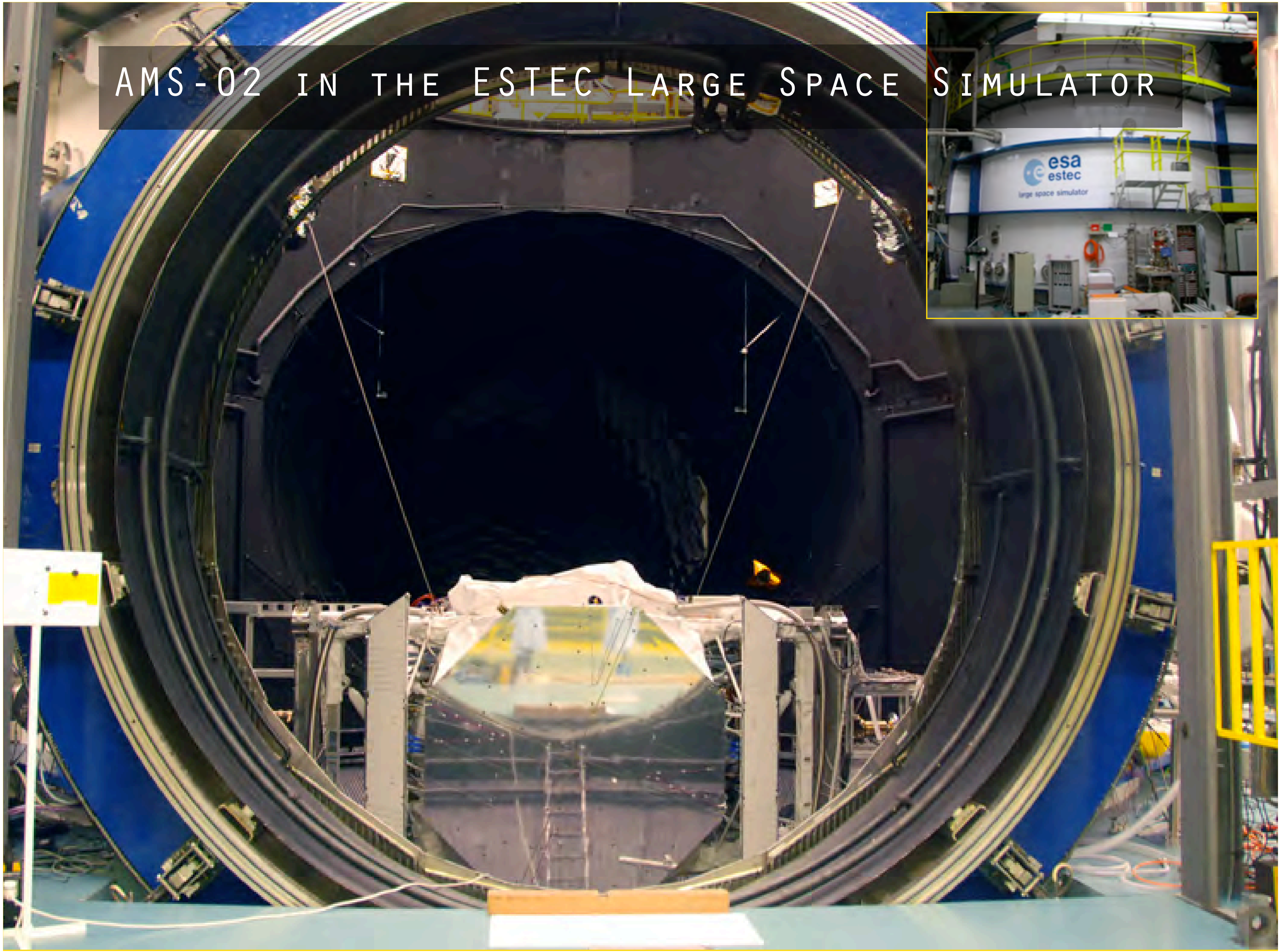
EMI typical Test results



Conducted Emission
(CE01, CE03)



Radiated Emission
(RE02)


AMS-02 in the ESTEC Large Space Simulator
esa
estec
large space simulator

Thermo-Vacuum Test

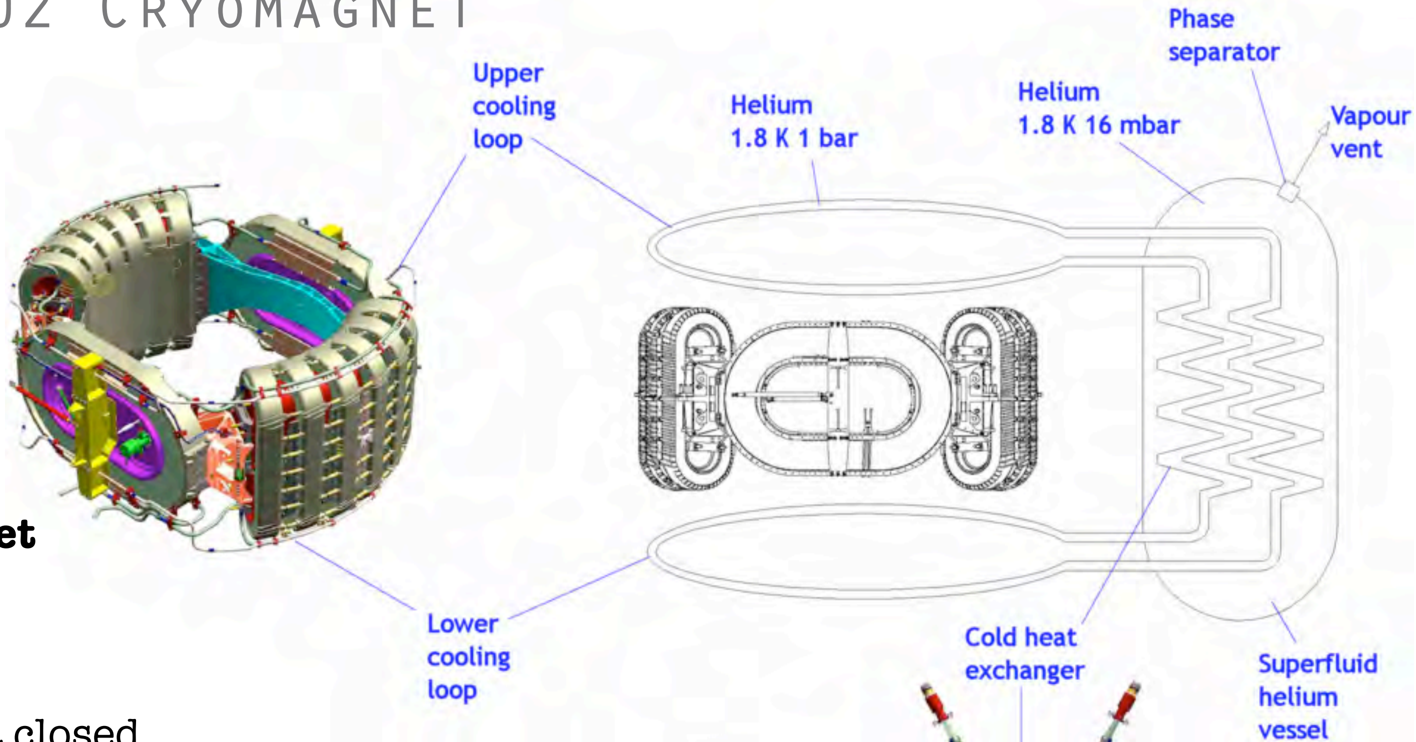
Pressure in LSS ~10^{-7} mbar
Shroud temperature -90°C to +40°C

Aim of the test:

- Verify the detector thermal model
- Check that the subdetectors work correctly in a space-like environment
- Test the cryogenic system of the superconducting magnet

- All subdetectors worked as expected
- Subdetectors thermal models were validated
- A measurement of the helium mass dissipated by the magnet cryogenic system in flight conditions was estimated

The AMS-02 Cryomagnet



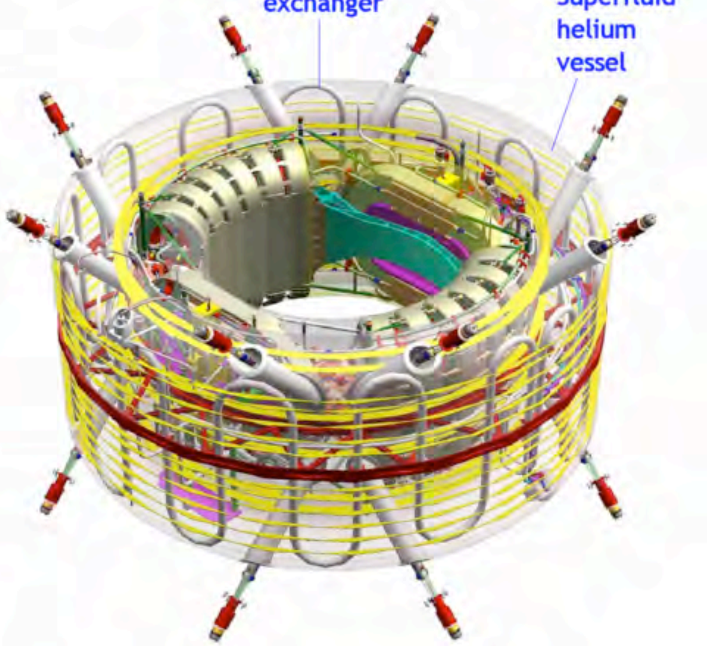
AMS has a **dry magnet**

Heat leaking into the magnet is moved by a closed **superfluid helium cooling loop** into the superfluid helium tank and removed by evaporation.

100 mW leak

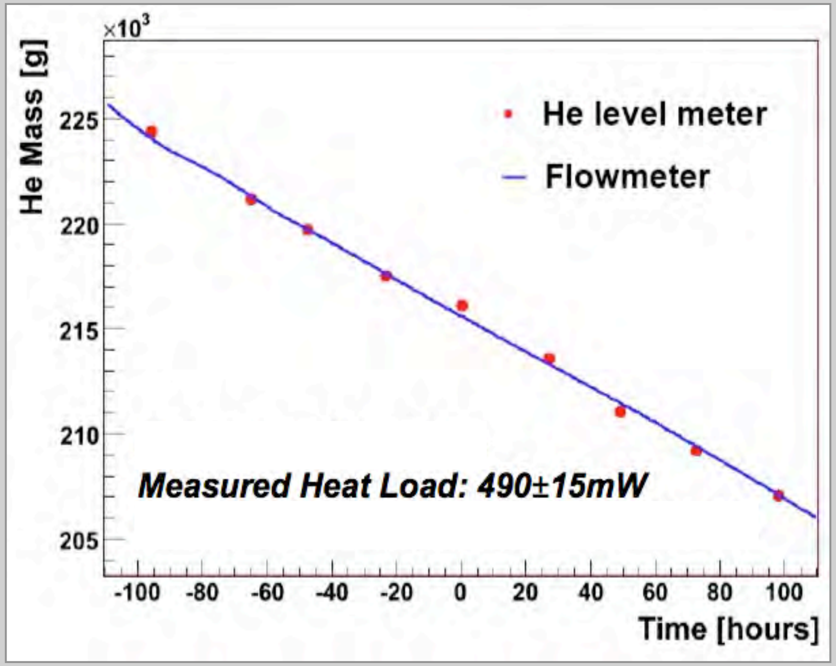
↓

3 years endurance



The cold mass is suspended onto a vacuum tank by 16 composite straps.

Cryomagnet Endurance measurement

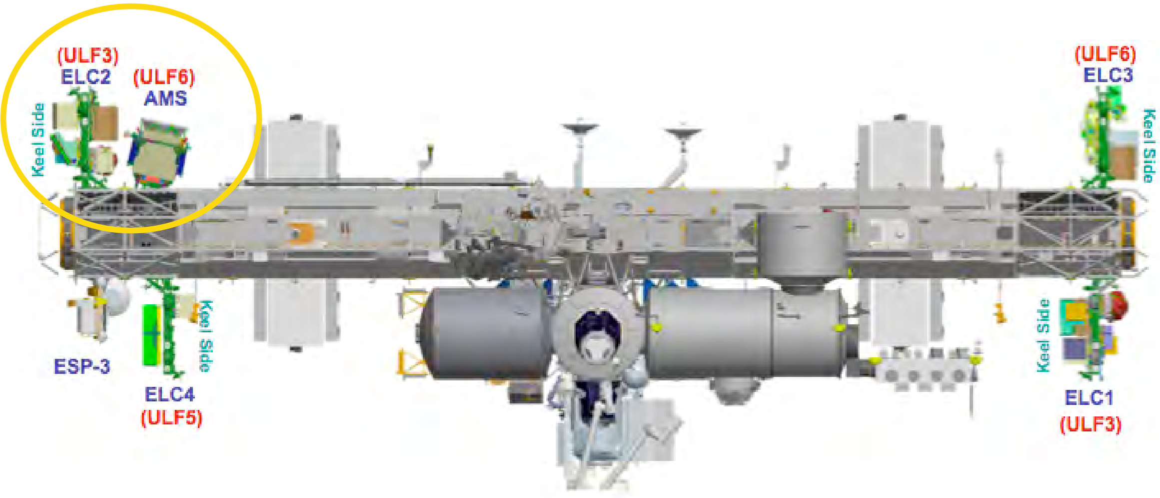


	Room T	ESTEC TVT	ISS
Total heat load	*720 mW*	*490 mW*	*180 mW*

Expected cryomagnet endurance = 20 ± 4 months

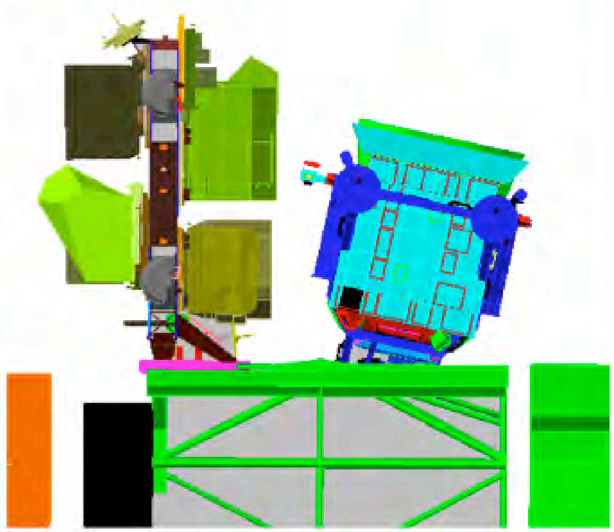
Uncertainties	
Accuracy of heat load estimate	15%
Nearby payloads on ISS	9%
Waiting time on the launch pad	8%
ISS attitude control	6%

An unexpected thermal concern on the ISS



ELC-2 affects the AMS thermal behaviour due to **solar reflection**.

ELC-2 also **radiates 2.7 kW** one meter away from AMS.



Comments

- The activity and maintainance of the ISS has been extended to 2020, with the possibility of extension to 2028 under evaluation at the Space Operations Directorate of NASA

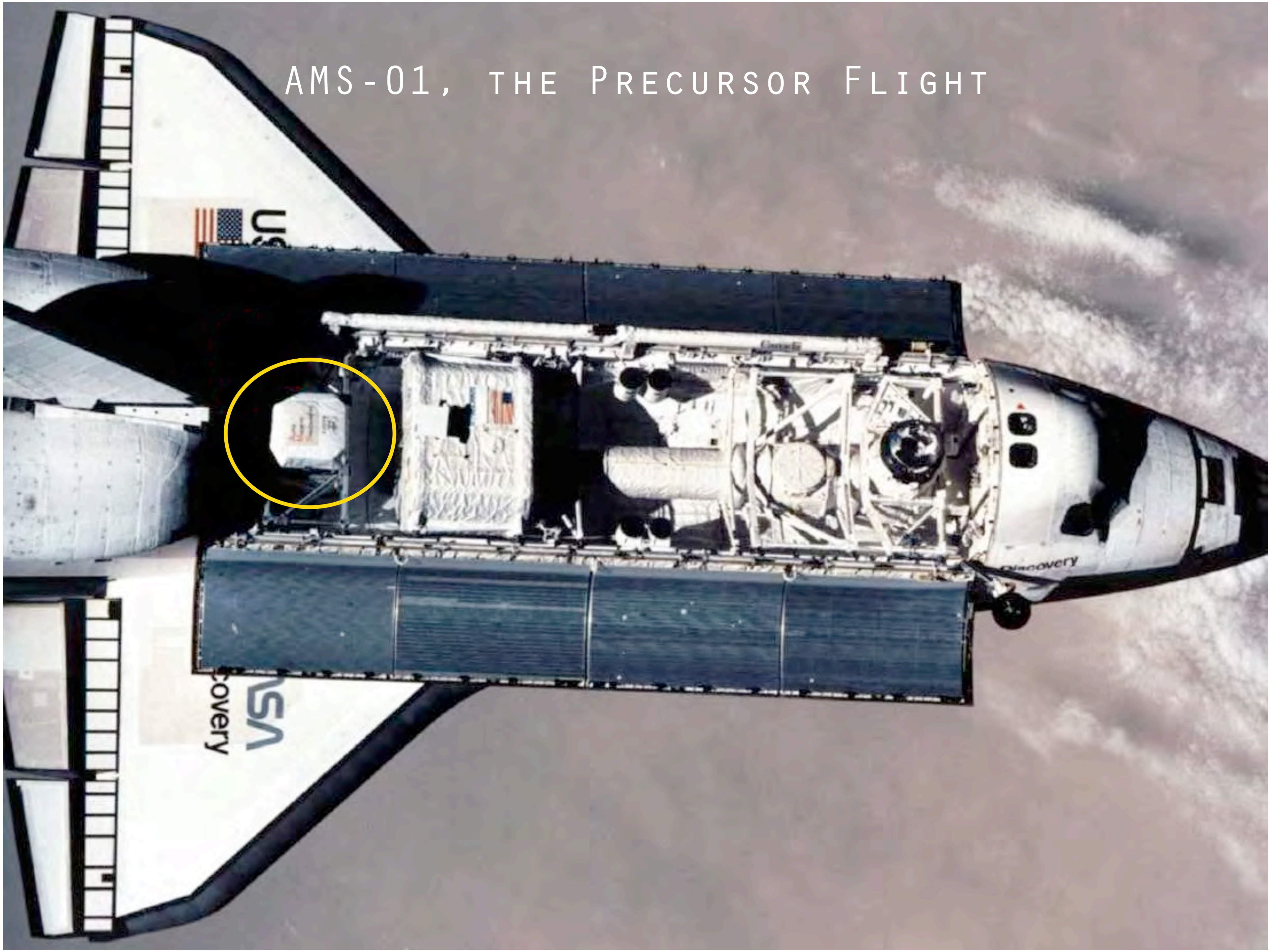
- The estimated SC magnet's lifetime is 20 ± 4 months with uncertainties (e.g. radiation from nearby payloads, waiting time on the launchpad, ...)
- There is no easy way to extend the lifetime: to upgrade the cryogenic system would take about 8 months

- The last shuttle flight is forseen at the end of 2010

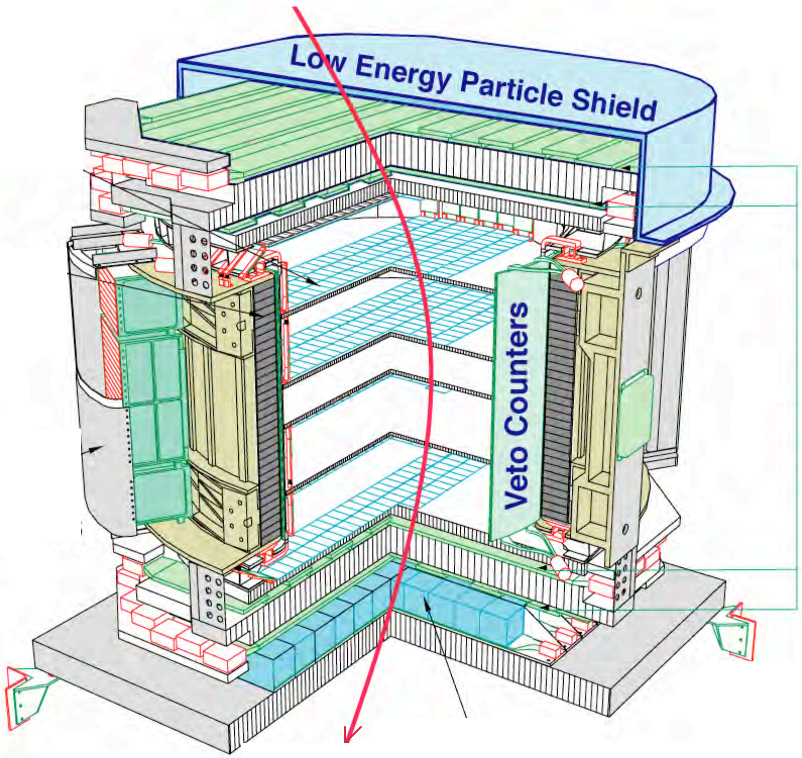
⟶ **AMS decided for the Permanent Magnet technology**

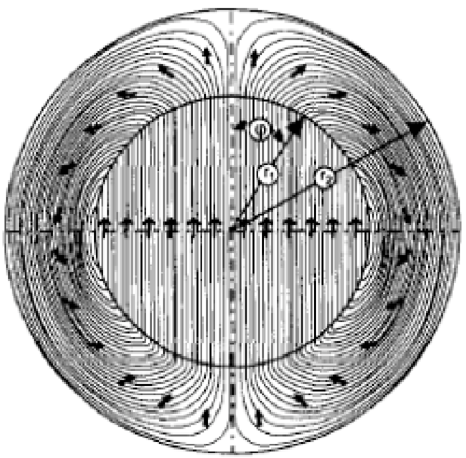
- Some phyisics items are affected by the lower resolution at low energy, most items benefit from the higher statistics

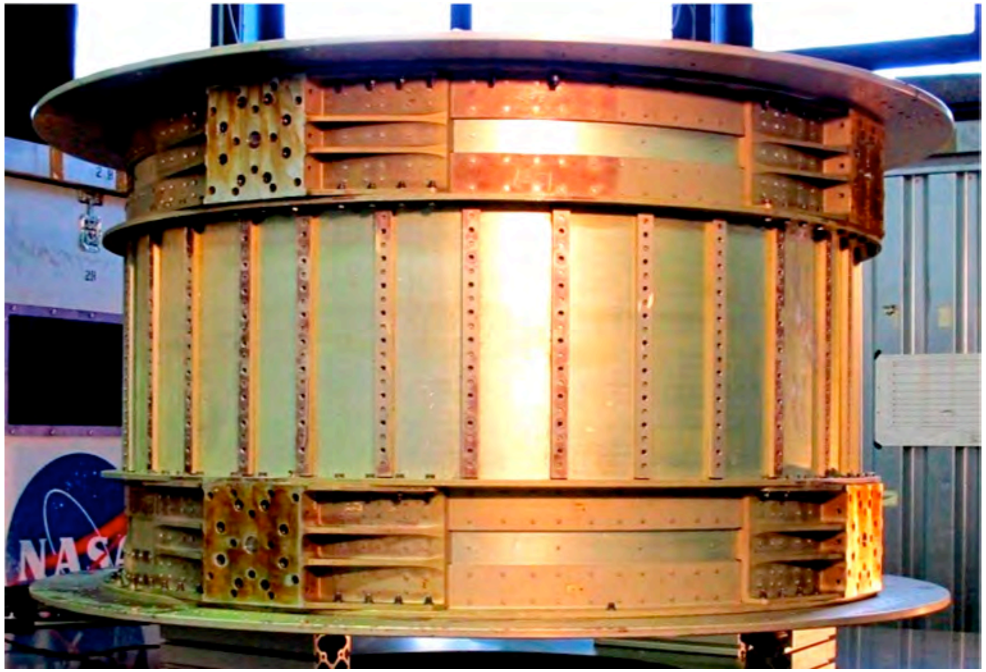
AMS-01, the Precursor Flight



AMS-01 and the Permanent Magnet





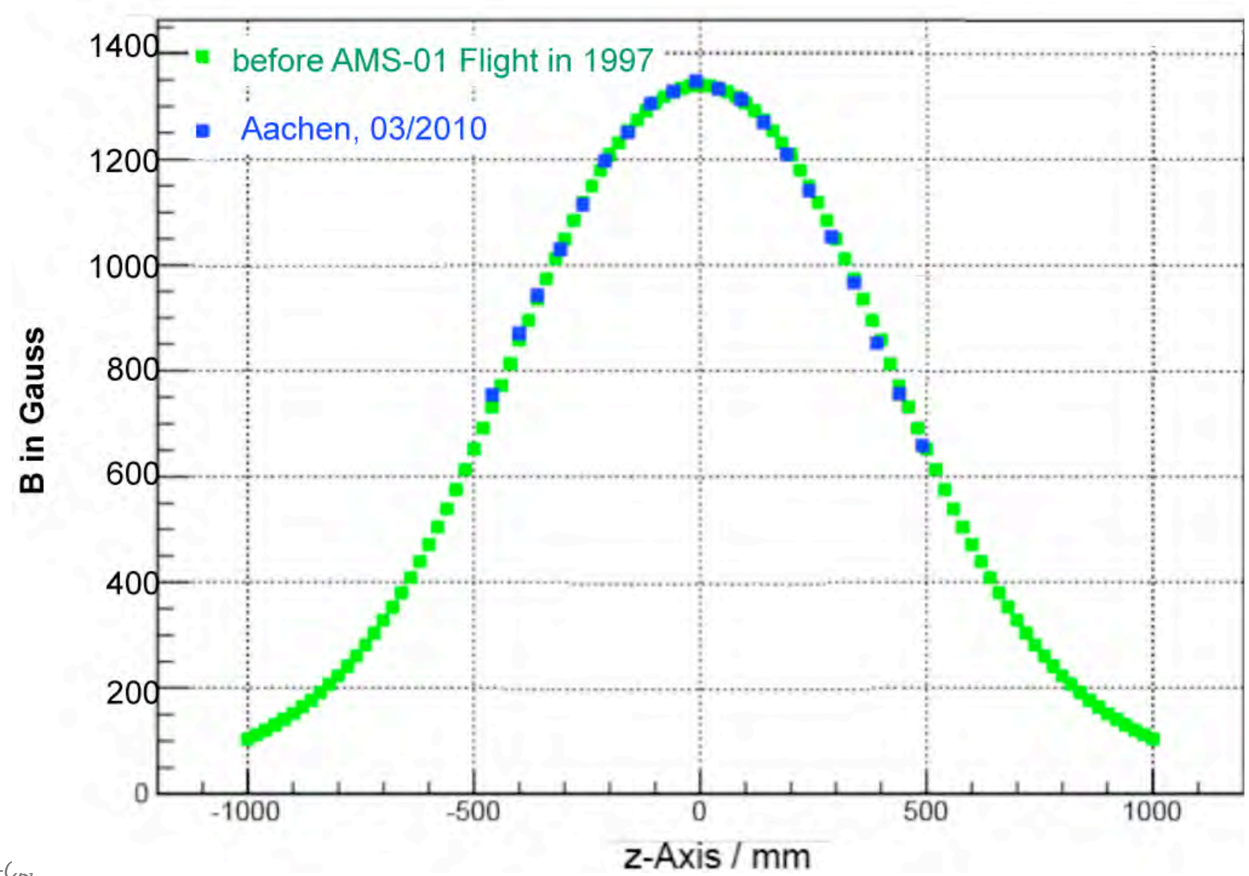


$BL^2 = 0.14\ Tm^2$

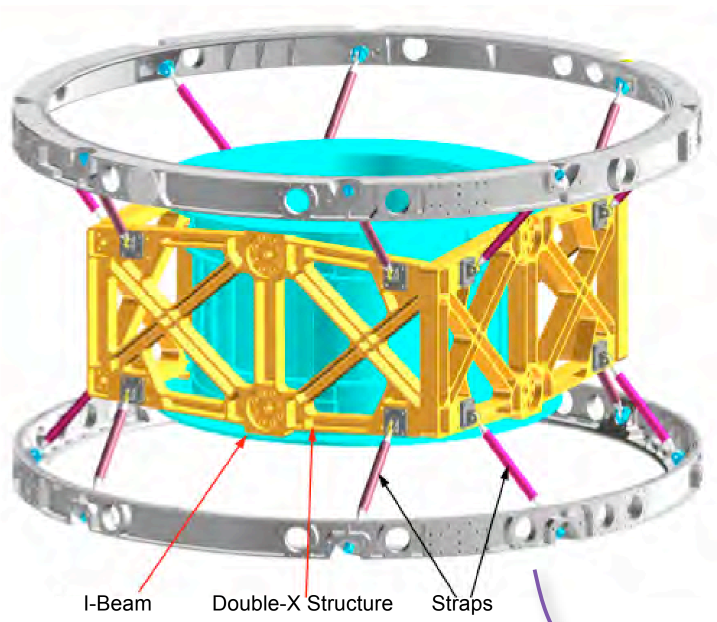
Permanent Magnet Field

- After the de-integration of AMS-01 in 1998 the magnet was kept in a clean room in Taiwan. It was sento to Aachen, Germany in Mar 2010

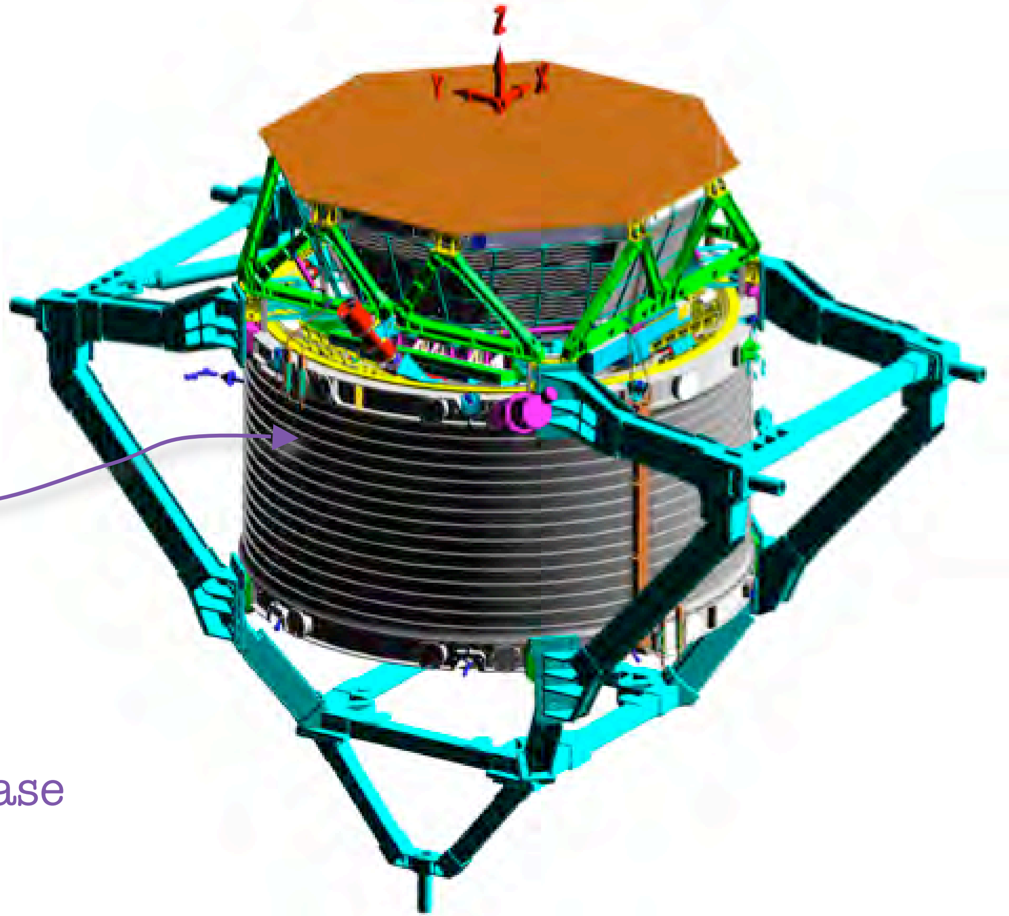
- The magnetic field of the Permanent Magnet was remeasured in Mar 2010 and it was unchanged within 1% since 1997



Permanent Magnet integration



All AMS subdetectors, in particular the Tracker and the Anti-Coincidence Counters, are structurally compatible with both SC and Permanent Magnet

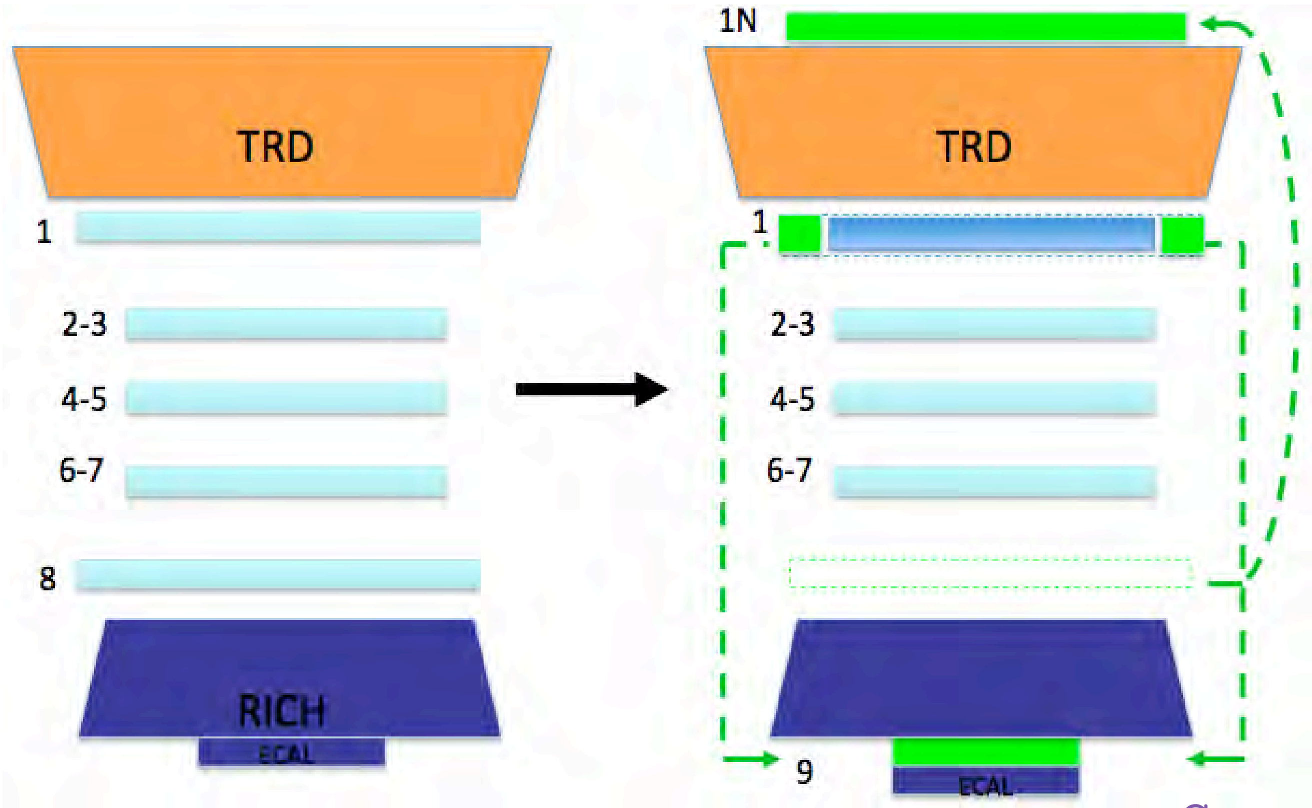


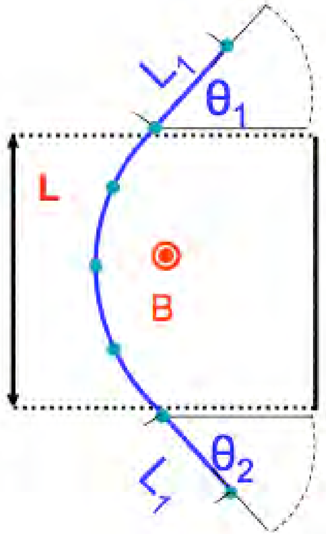
To minimize structural changes the (smaller) permanent magnet is housed in the Spare Vacuum Case

Tracker modification

B is 5 times smaller
L_1 has to be increased correspondingly

All tracker planes are independently movable

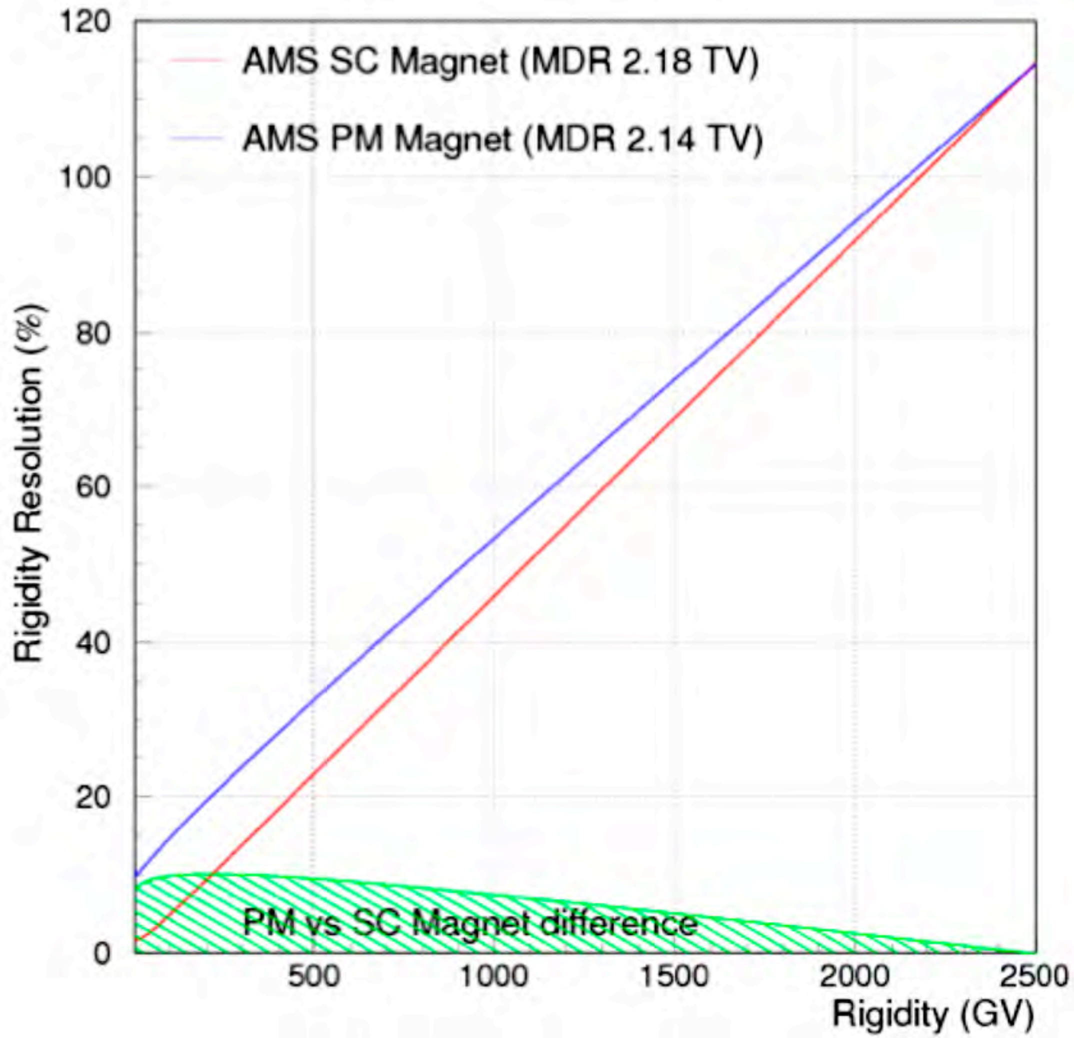




No new silicon,
no new electronics
are needed

Geometrical acceptance
0.1 m^2 sr

Resolution on Rigidity



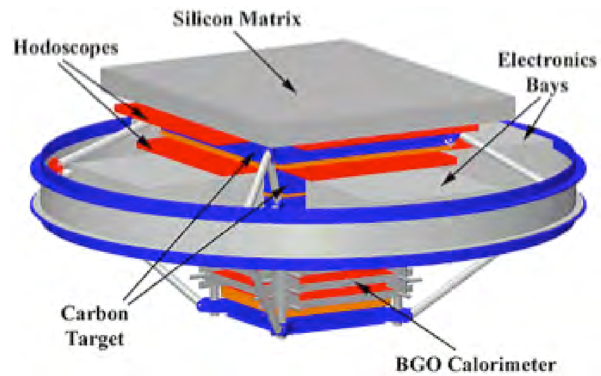
With 9 tracker planes, the resolution with the Permanent Magnet differs at most by 10% to that with the Superconducting Magnet

but AMS will be active for all the duration of the ISS - at least 10 y

Impact on the Physics

- Dark Matter
- Antimatter
- New matter types
- Cosmic rays physics

ATIC, FERMI, PAMELA

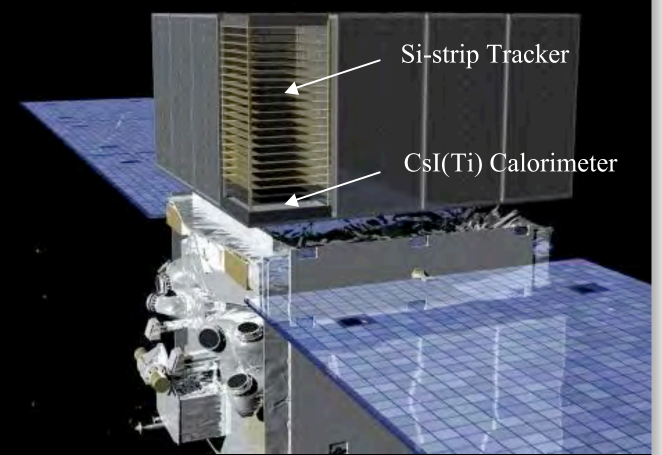


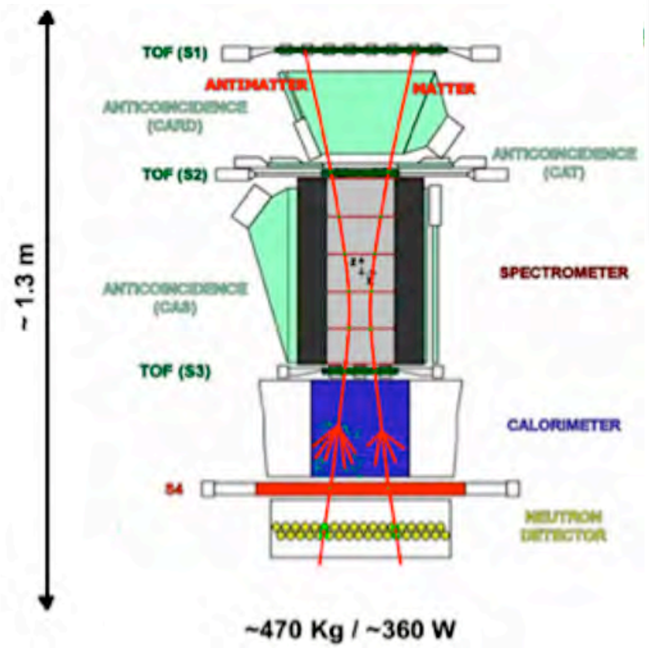
ATIC

Balloon experiment
50 GeV to 100 TeV
No charge sign

FERMI-LAT

Satellite experiment
20 MeV to 300 GeV
20% sky field of view
No charge sign





Pamela

Satellite experiment
Geom. Acceptance 21.5 cm² sr
Z_{max} = 8
MDR ≈ 700 GeV
Sign of charge

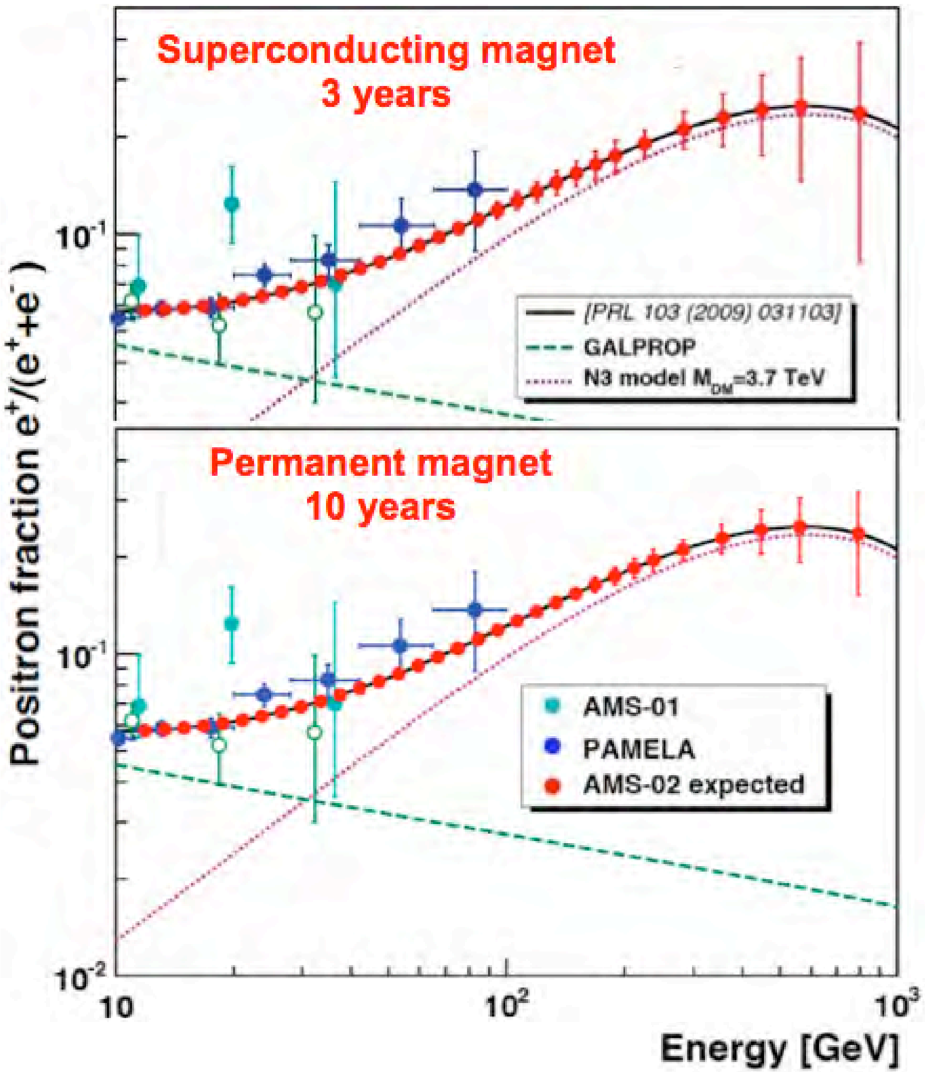
AMS

1000 cm² sr
Z_{max} = 26
MDR ≈ 2 TeV

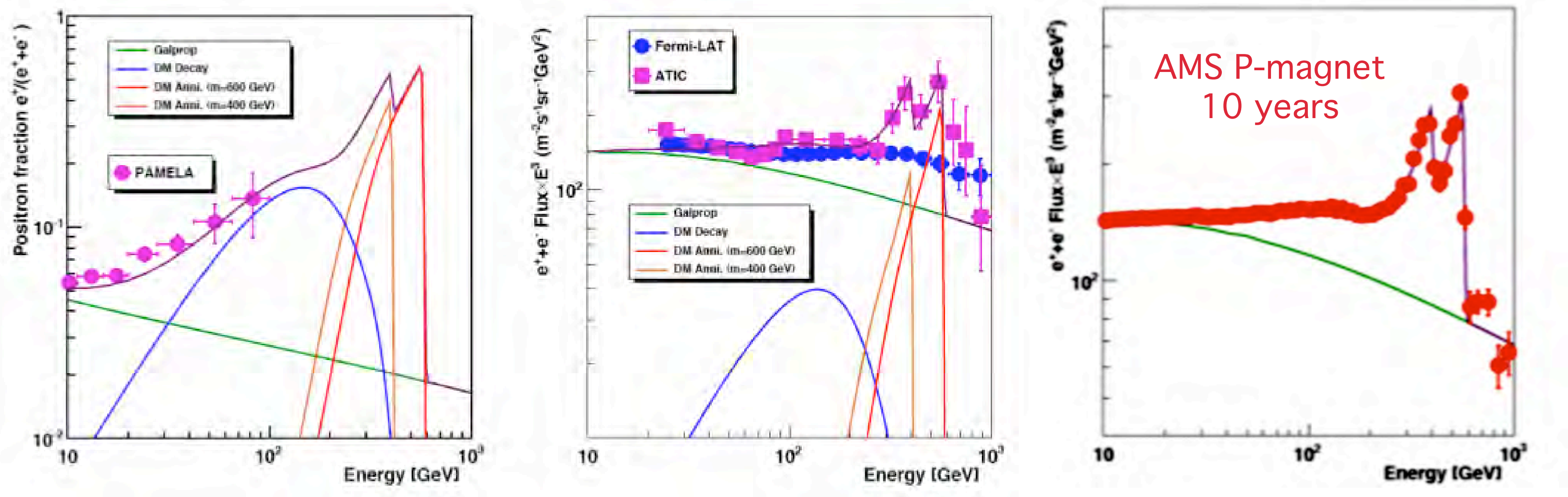
DM Search in the e^+ Channel

Error comes from the statistics
→ decreases with a Permanent Magnet as the experiment lifetime increases

Energy resolution on e^+ and e^- depends on the ECAL only
→ unaffected



Expected $(e^{+} + e^{-})$ Flux



AMS-02 extends both Pamela and Fermi/ATIC energy ranges

⟶ solve the ATIC disagreement wrt to Fermi data.

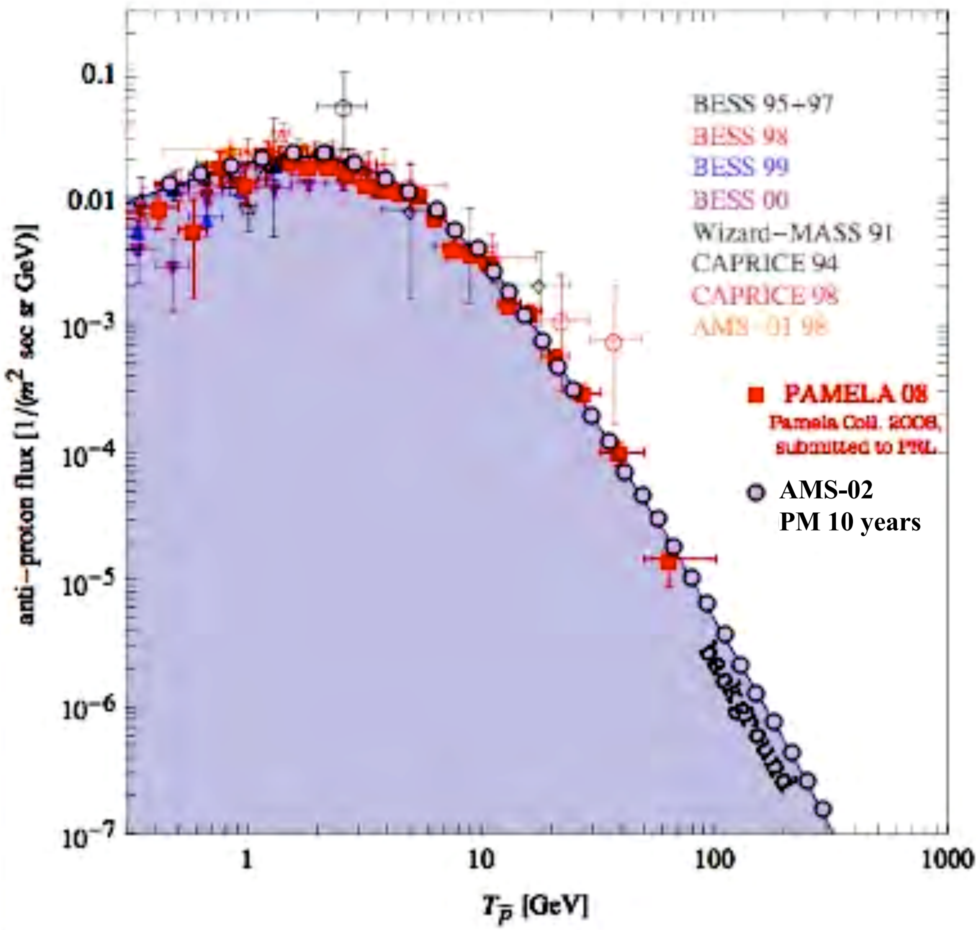
DM Search in the $\overline{p}$ Channel

Low energy Spectrum is well explained by secondary production

Expected signal at high energy (10 – 300 GeV) partially excluded by Pamela

→ very important to verify at higher energy and higher statistics

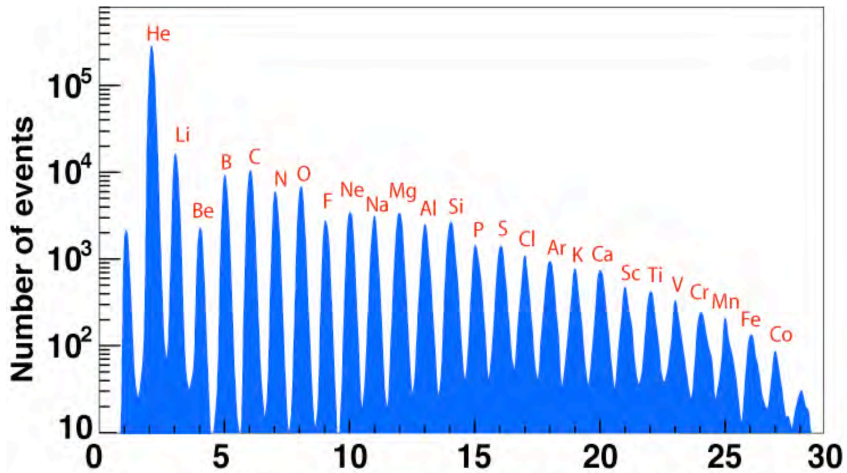
- Conventional $\overline{p}$ flux
- Statistical errors

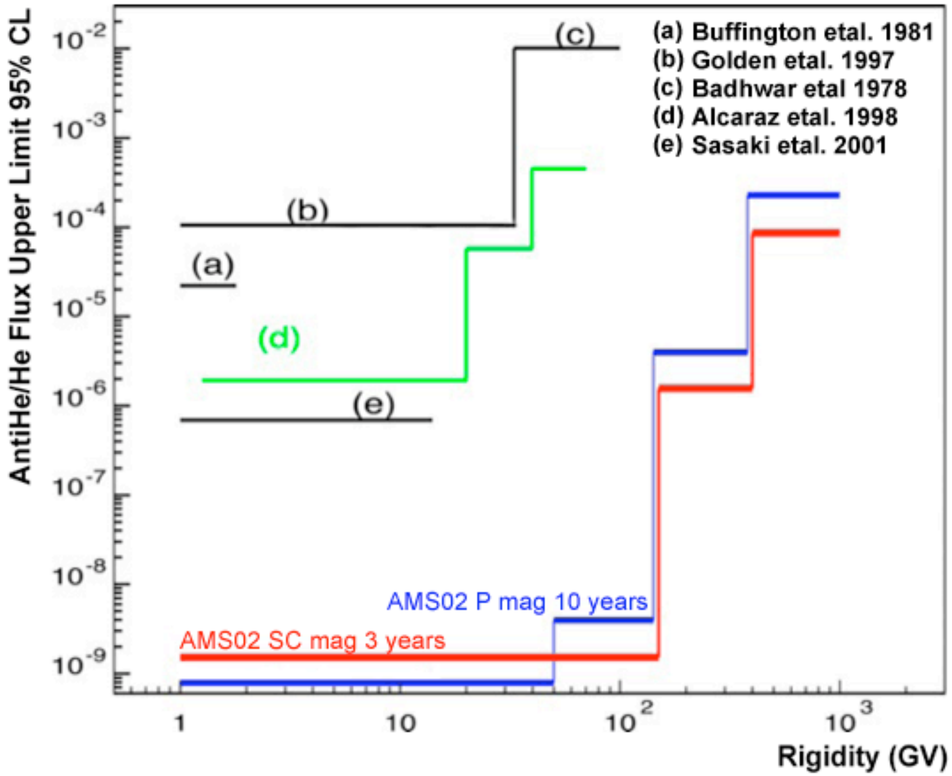


Expected limits on Antihelium

AMS will collect >10^9 nuclei with energies up to 2 TeV
In the same time ~10^{-7} $\overline{\text{He}}$ nuclei from secondary production are expected

Charge sensitivity up to anti-Iron, magnet-independent



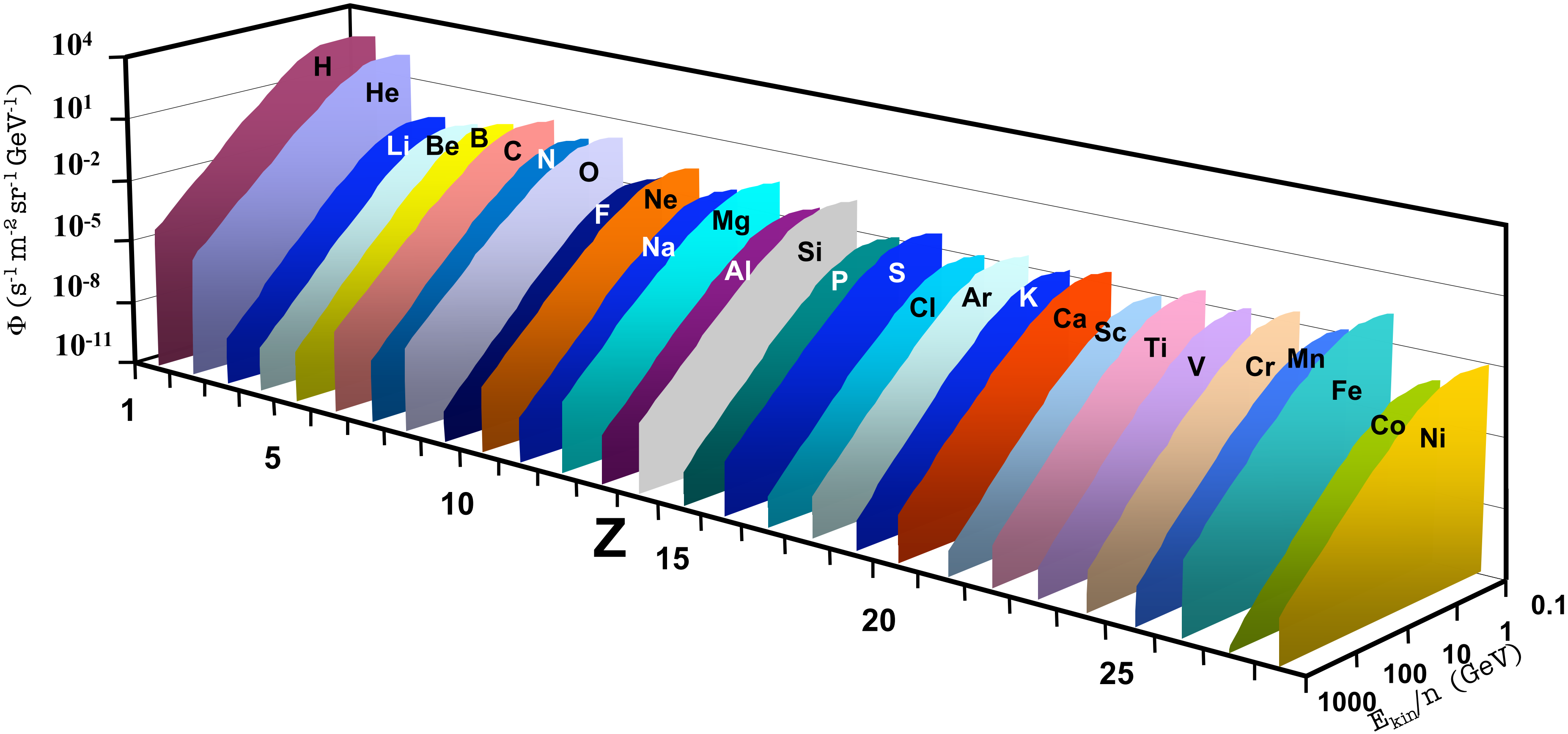


The $\overline{\text{He}}$ limit put by precursor flight AMS-01 will be increased of a factor 10^3

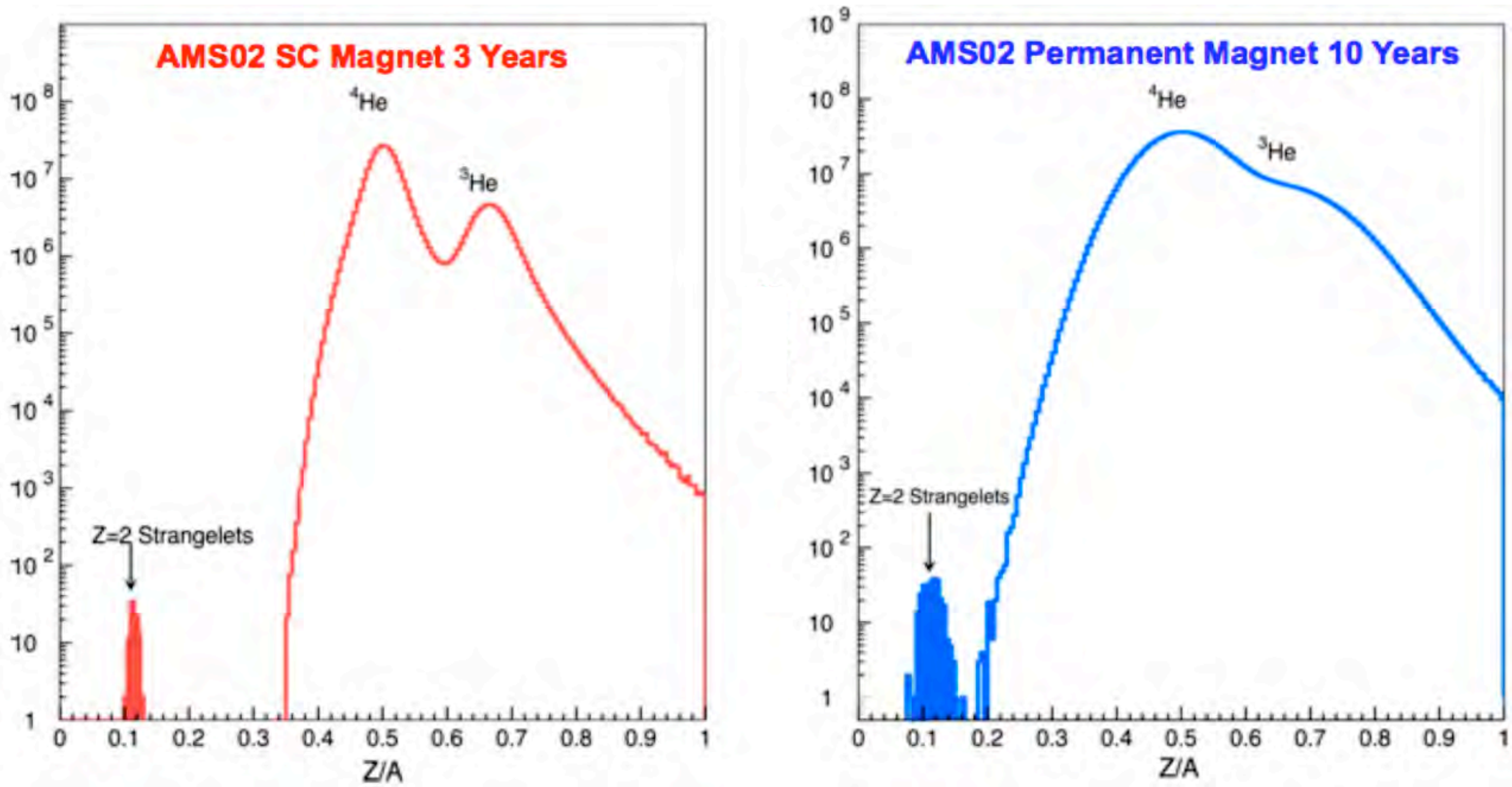
Loss of sensitivity at higher energies due to lower acceptance

Precision Cosmic Rays physics

Composition at different energies (1 GeV, 100 GeV, 1 TeV)
continuously over a 11-years solar cycle



Strangelets Search



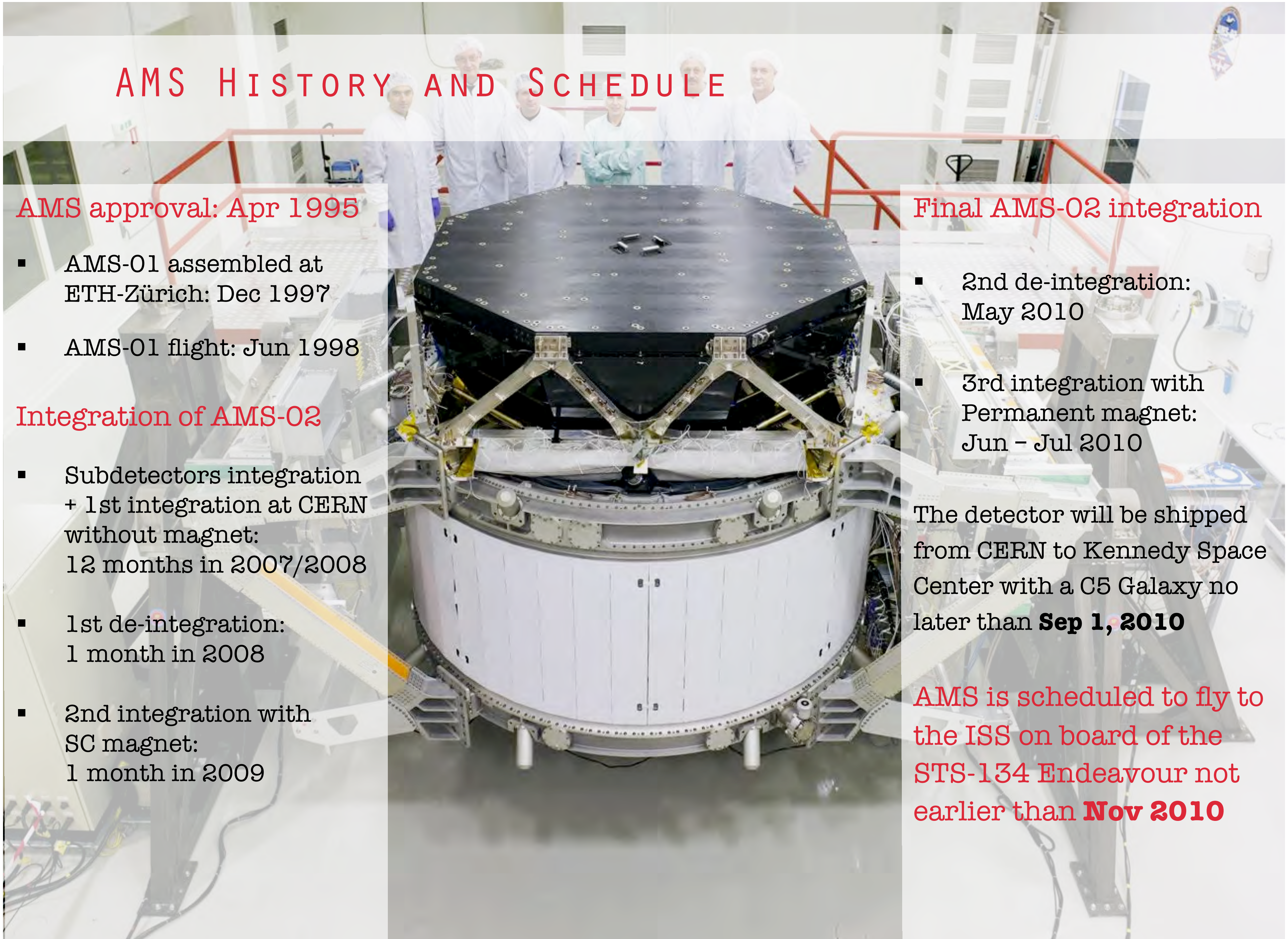
$\Phi_{strangelets} = 5x10^{-10}\ (cm^2\ s\ sr)^{-1}$

$Z_{strangelets} = 2$

Schedule

- Integration
- Launch

AMS History and Schedule



AMS approval: Apr 1995

- AMS-01 assembled at ETH-Zürich: Dec 1997
- AMS-01 flight: Jun 1998

Integration of AMS-02

- Subdetectors integration + 1st integration at CERN without magnet: 12 months in 2007/2008
- 1st de-integration: 1 month in 2008
- 2nd integration with SC magnet: 1 month in 2009

Final AMS-02 integration

- 2nd de-integration: May 2010
- 3rd integration with Permanent magnet: Jun – Jul 2010

The detector will be shipped from CERN to Kennedy Space Center with a C5 Galaxy no later than **Sep 1, 2010**

AMS is scheduled to fly to the ISS on board of the STS-134 Endeavour not earlier than **Nov 2010**

AMS-02 is scheduled on STS134 Endeavour

Commander

Mark Kelly

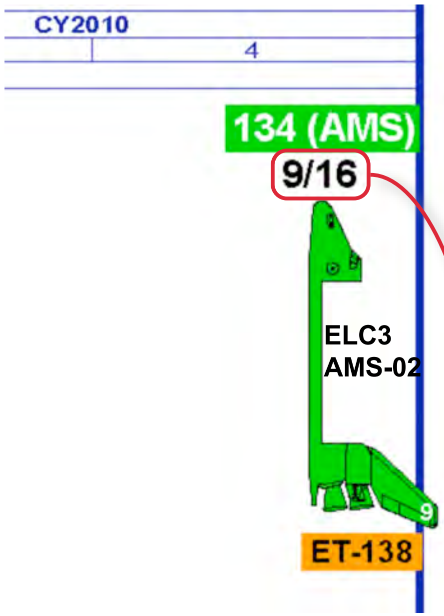
Pilot

Gregory H. Johnson

Mission Specialists

Michael Fincke (US)
Greg Chamitoff (US)
Andrew Feustel (US)
Roberto Vittori (ESA/Italy)

AMS-02 on the Shuttle Launch Manifest



International Space Station

Launch Schedule

Consolidated Launch Manifest

Launch Target	Assembly Flight	Launch Vehicle	Element(s)
April 28, 2010	37P	ISS Progress 37	• Logistics and resupply
May 14, 2010	ULF4	Atlantis STS-132	• Integrated Cargo Carrier (ICC) • Mini Research Module (MRM1)
June 2010	ATV2	Ariane 5	• European Automated Transfer Vehicle 2
June 16, 2010	23S	Soyuz TMA-19 Expedition 24	• Crew transport
June 28, 2010	38P	ISS Progress 38	• Logistics and resupply
Aug. 31, 2010	39P	ISS Progress 39	• Logistics and resupply
Sept. 16, 2010	ULF5	Discovery STS-133	• EXPRESS Logistics Carrier 4 (ELC4) • Permanent Multi-Purpose Module (PMM)
Sept. 29, 2010	24S	Soyuz TMA-20 Expedition 25	• Crew transport
Oct. 27, 2010	40P	ISS Progress 40	• Logistics and resupply
Nov. 2010	ULF6	Endeavour STS-134	• EXPRESS Logistics Carrier 3 (ELC3) • Alpha Magnetic Spectrometer (AMS)
Dec. 27, 2010	41P	ISS Progress 41	• Logistics and resupply
Dec. 2011	3R	Russian Proton	• Multipurpose Laboratory Module with European Robotic Arm (ERA)

Conclusions

- The **Permanent Magnet option** implies that AMS will be a unique physics detector in space for the lifetime of the ISS (until 2020, maybe 2028?)

- AMS-02 will be able to measure spectra of particles and nuclei up to Iron in the **GeV-TeV range**
- ***Accurate study of CR composition and energy spectrum***
- ***Search of new types of matter (strangelets)***

- ***Dark matter indirect search:***
- Measure **simultaneously** and with unprecedented precision the rates and spectra of *positrons*, *photons*, *antiprotons*

- ***Antimatter search:***
- If no antinucleus is observed the hypothesis of *barion asymmetry* will be strongly favoured as no antimatter areas are present in the observable universe

- Currently assembling the permanent magnet into AMS at the CERN Clean Room
- The launch is scheduled on Endeavour flight STS134 in **November 2010**


USA
GRAZIE!