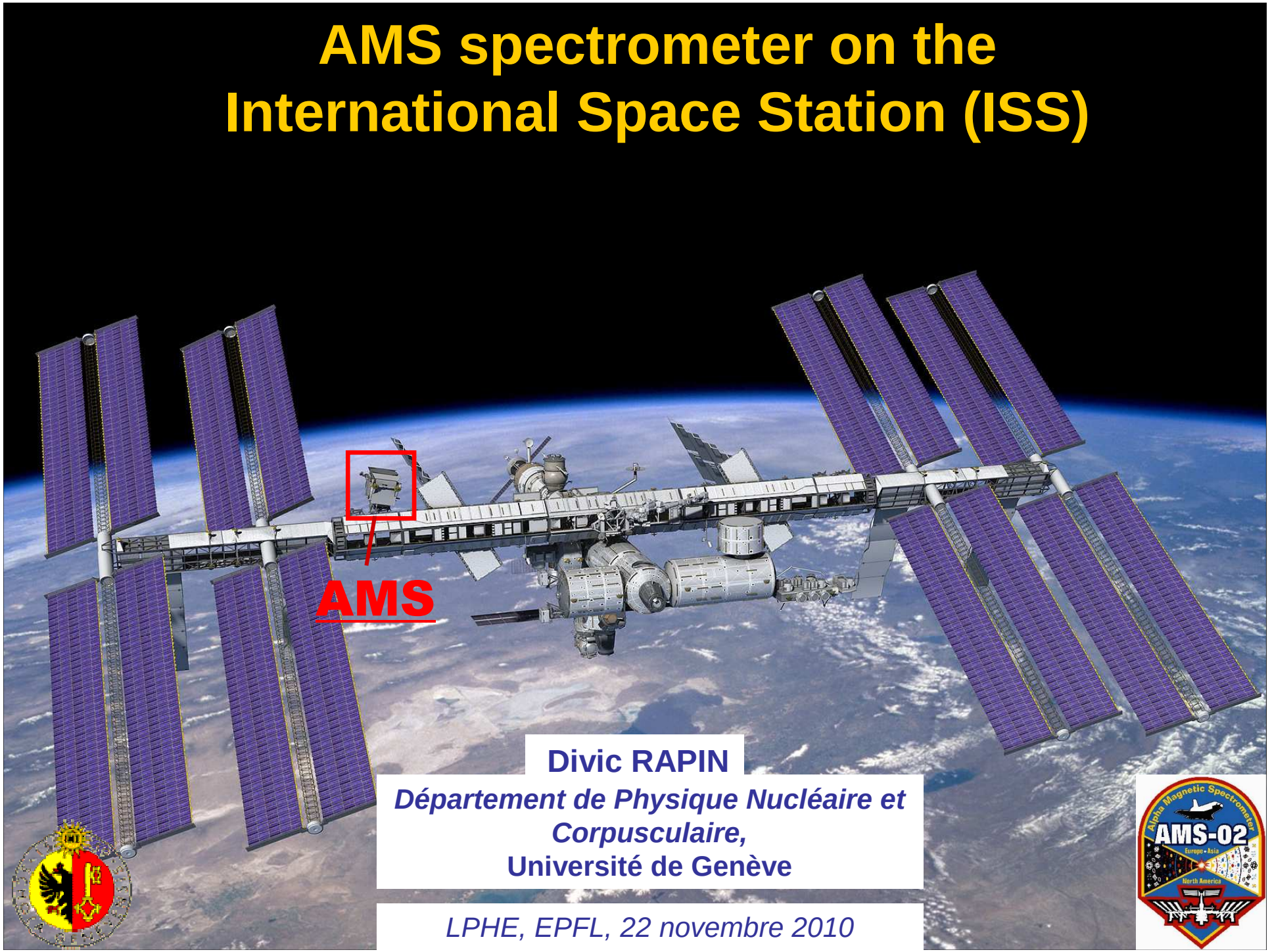
AMS spectrometer on the International Space Station (ISS)



Divic RAPIN

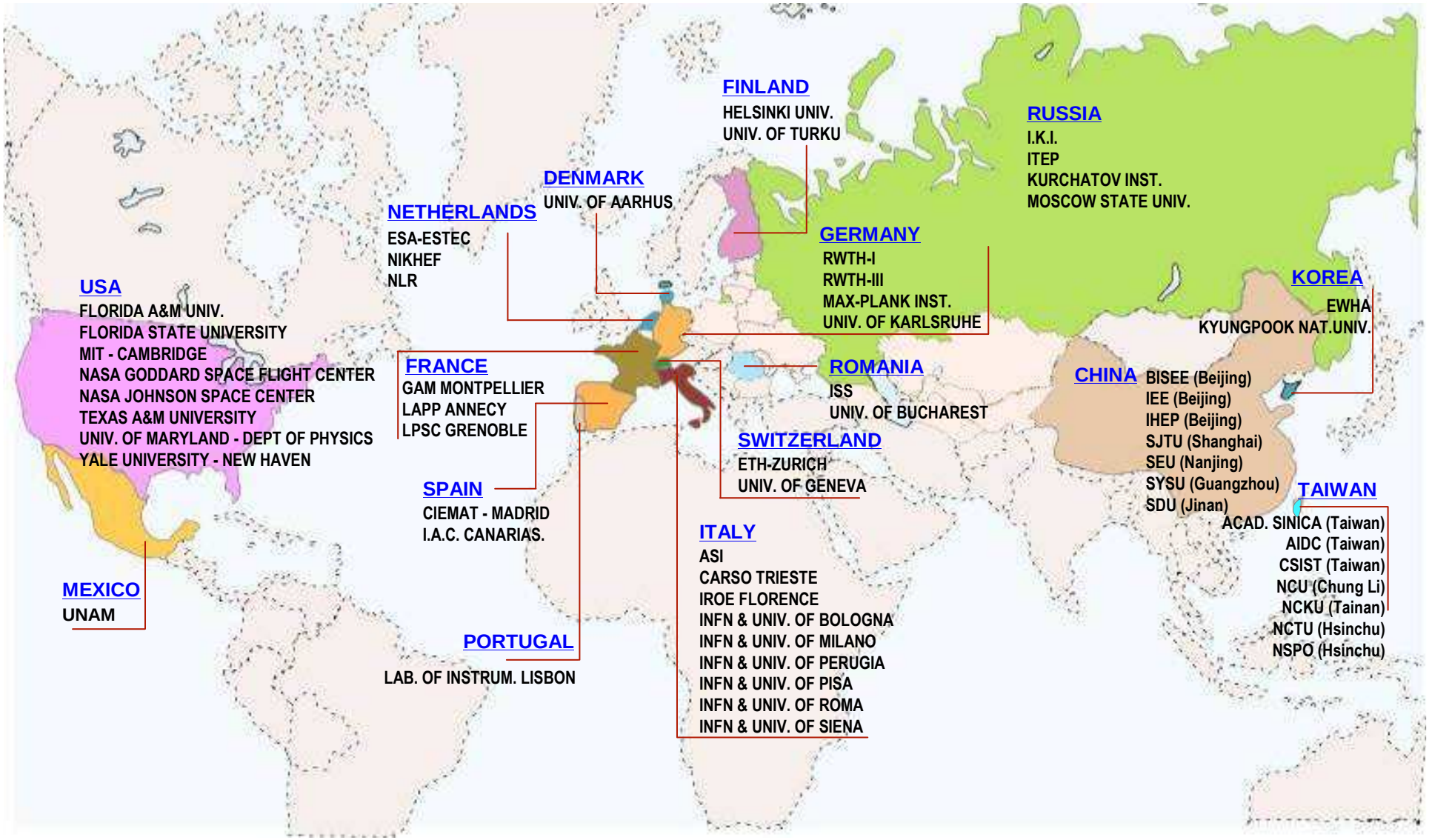
Département de Physique Nucléaire et Corpusculaire,

Université de Genève

LPHE, EPFL, 22 novembre 2010

AMS International Collaboration

16 Countries, 60 Institutes and 600 Physicists



Project and design based on NASA's commitment to deploy AMS on the ISS

Fundamental Science on the International Space Station

Messengers: 1- Neutral component:

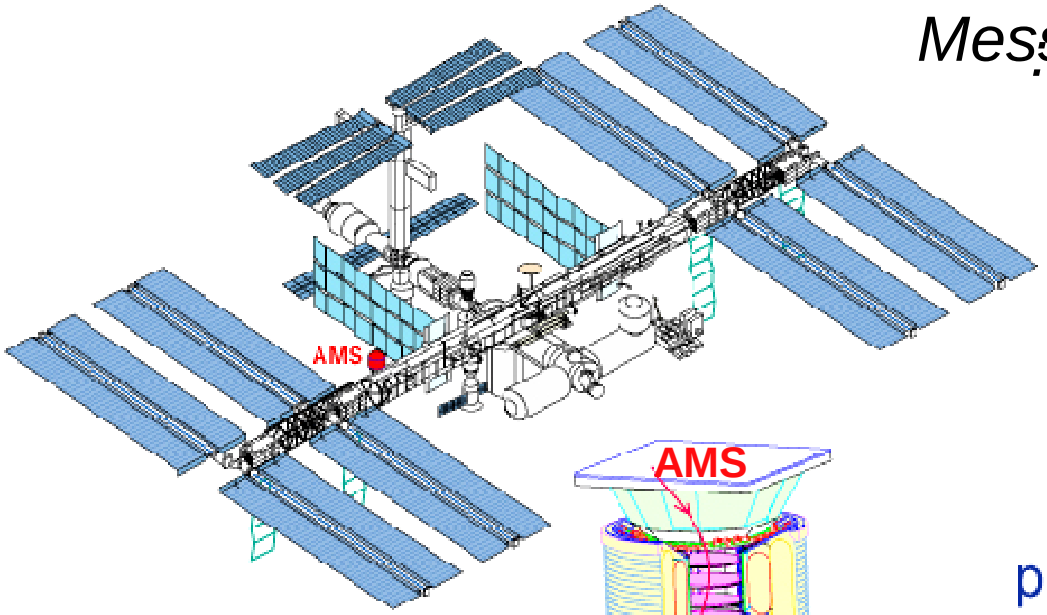
γ,ν

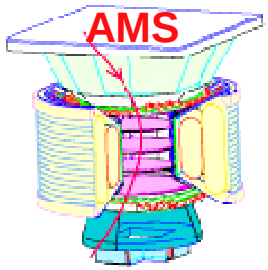
Hubble, Chandra, GLAST, JDEM, INTEGRAL

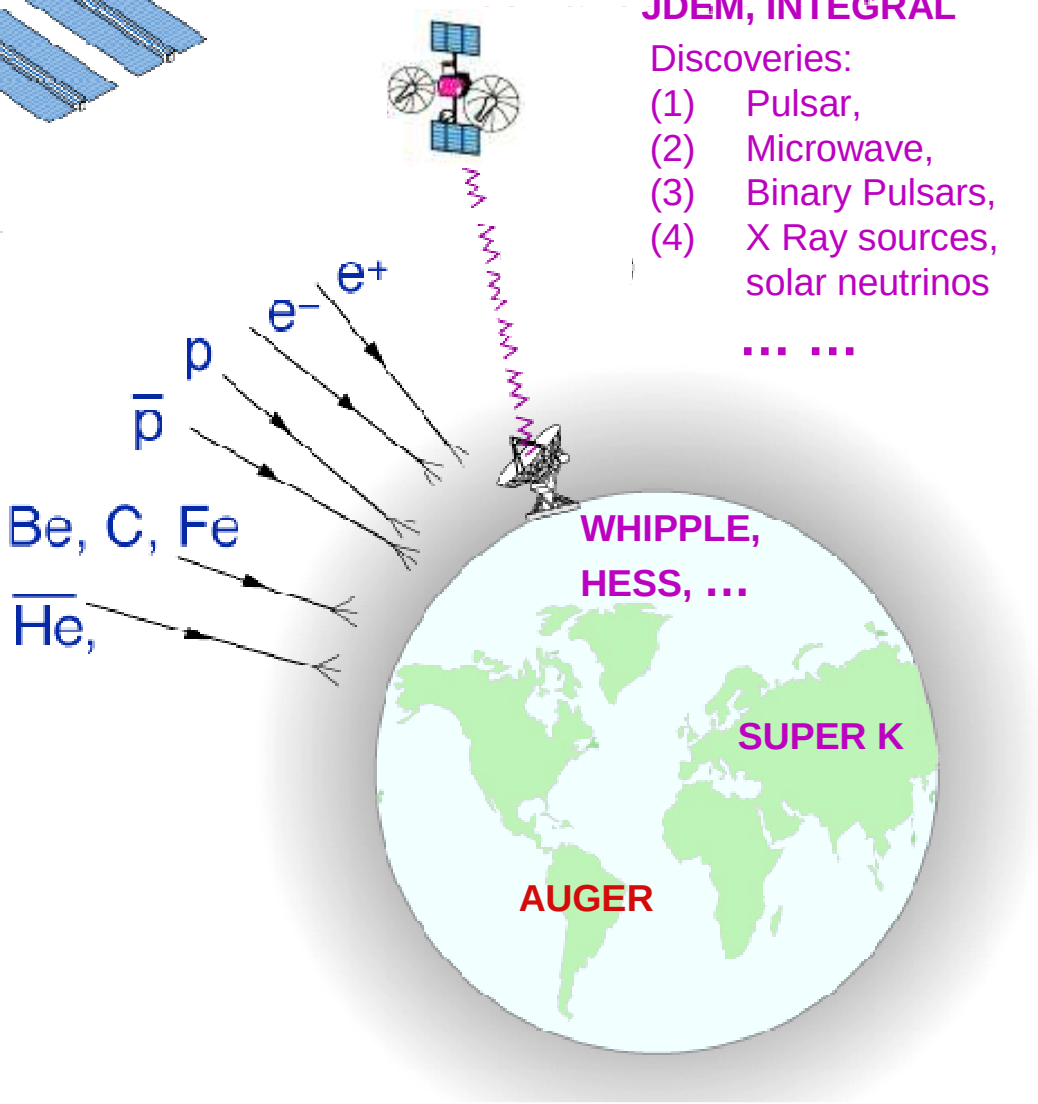
Discoveries:

(1) Pulsar,
(2) Microwave,
(3) Binary Pulsars,
(4) X Ray sources, solar neutrinos

… …





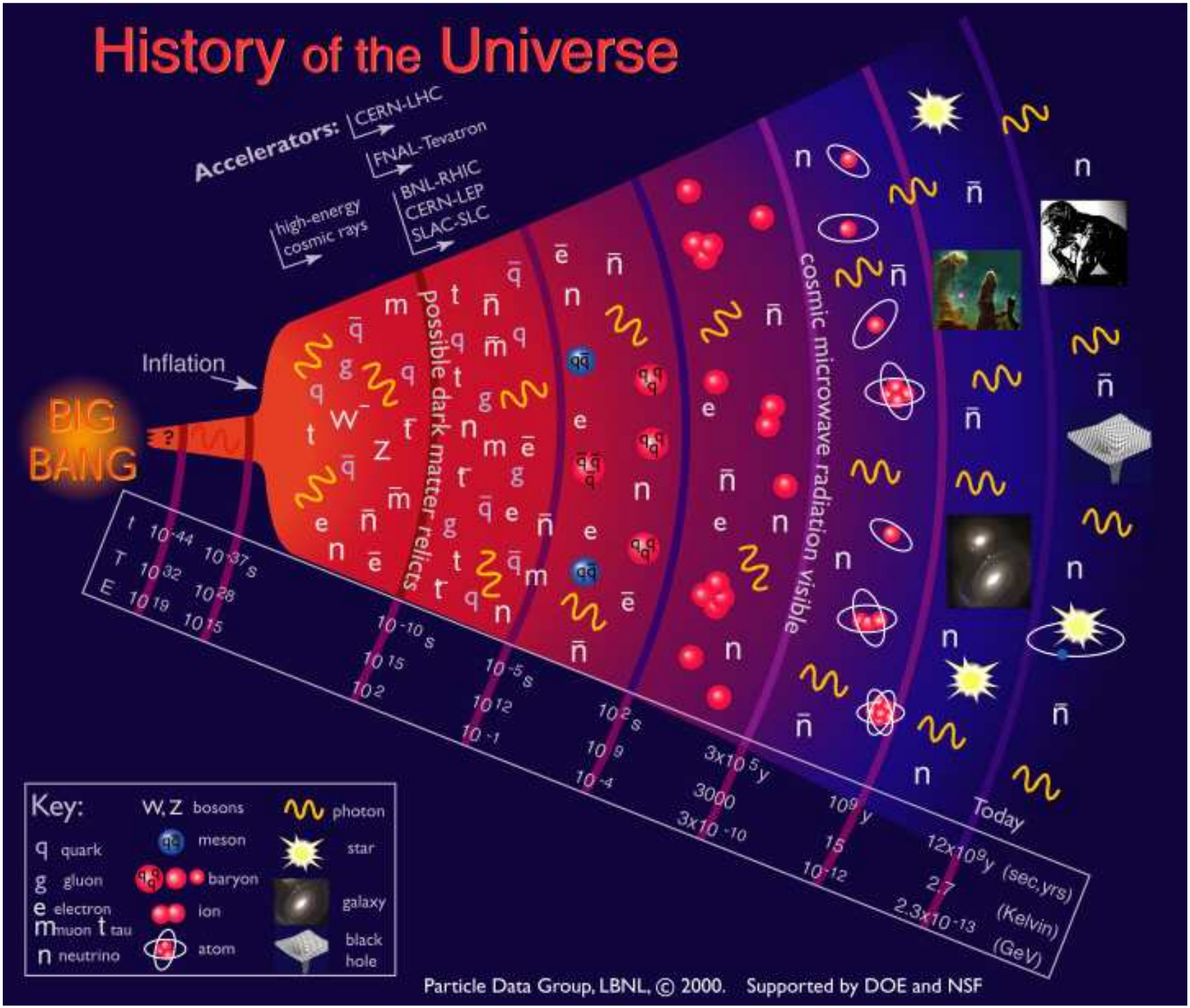


2- Charged component:

AMS is a particle physics experiment in space

- Anti-matter in Universe
- Precise study of Cosmic Ray
- Dark Matter
- Surprises ?

Où est l'anti-matière ?



Questions and problems:

- No signal of presence of antimatter in Universe is presently seen. (No annihilation signals of sufficient intensity)
- If antimatter existed, where is it? Very far?
- Are there relics in the local Universe?
- What is the limit of its non existence

Sakharov Conditions: for a baryogenesis (with no anti-baryons)

- Out of thermal equilibrium (***yes)***
- Violation of symmetries C ***(yes)*** and CP ***(too small)***
- Baryon number (nb of quarks) violation.***(no)***

The physics applying to the firsts instants of Big-Bang is not yet known.

AMS: Search for anti-nuclei in cosmic ray

Experimental work on Antimatter in the Universe

Direct search

Search for Baryogenesis

New CP

BELLE

BaBar

(sin 2β= 0.672±0.023 consistent with SM)

FNAL KTeV

($Re(\varepsilon'/\varepsilon) = (19.2\pm2.1)*10^{-4}$)

CERN NA-48

CDF, D0

Proton decay

Super K

($T_p > 6.6 * 10^{33}$ years)

AMS

Increase in sensitivity: x 10^3 – 10^6

Increase in energy to ~TeV

LHC-b

ATLAS

CMS

y06K299a

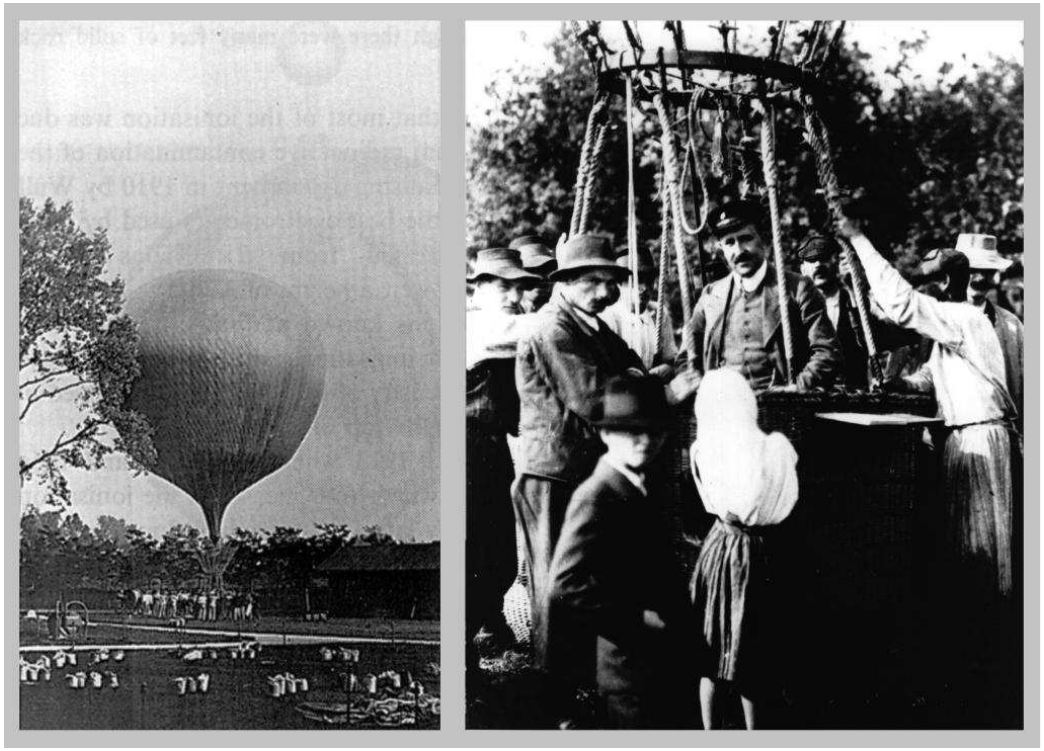
Les rayons cosmiques: *découverte*

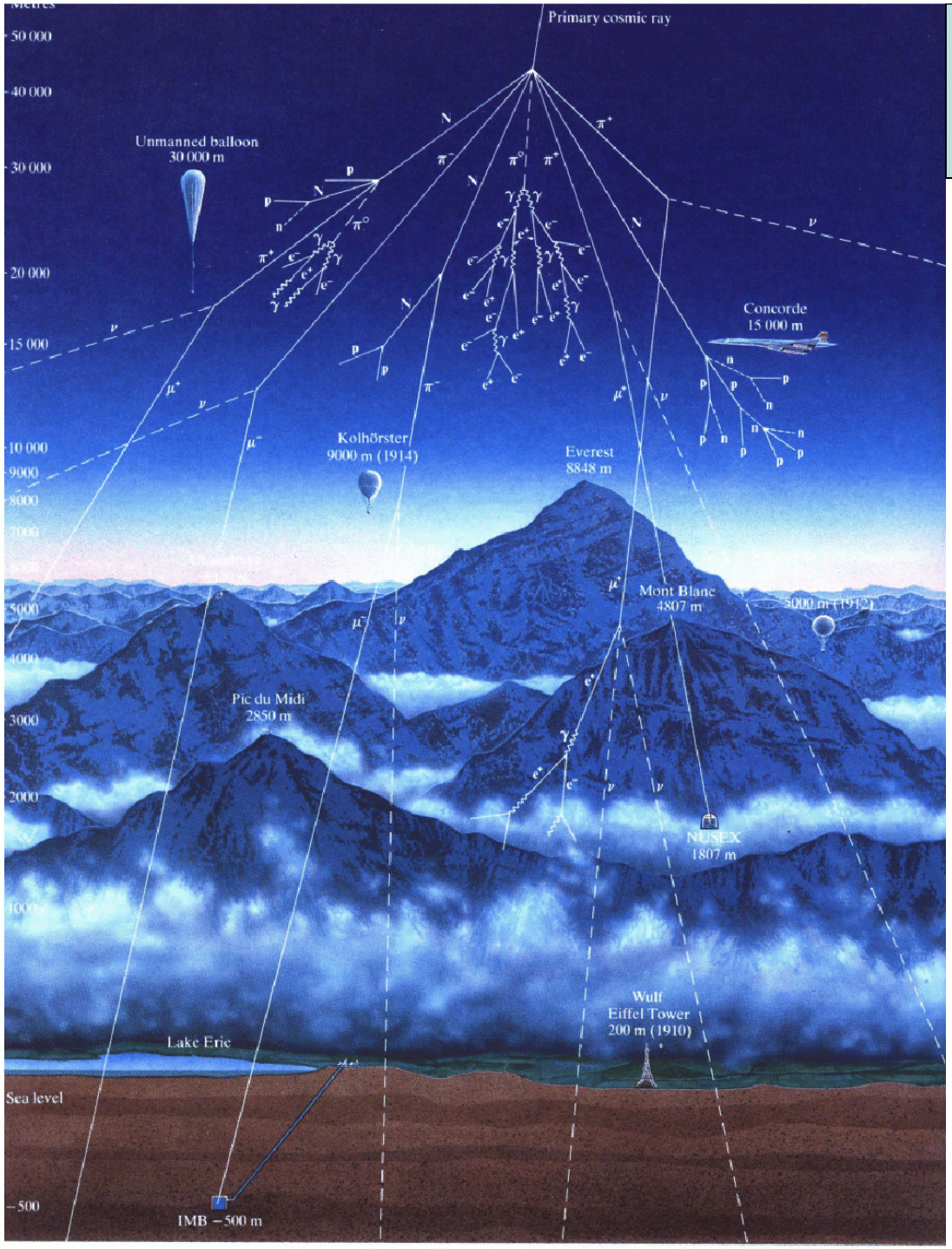
1910 Théodor Wulf sur la Tour Eiffel:

L'ionisation de l'air diminue avec l'altitude (ce qui s'explique très bien par la radio-activité naturelle qui vient du sol)

1912 Victor Hess en ballon:

- *Confirme Théodor Wulf* jusqu'à 700 m.
- *De 1500 à 5000 m, l'ionisation augmente, il y a un rayonnement ionisant qui vient du ciel.*
- *Découverte des rayons cosmiques*

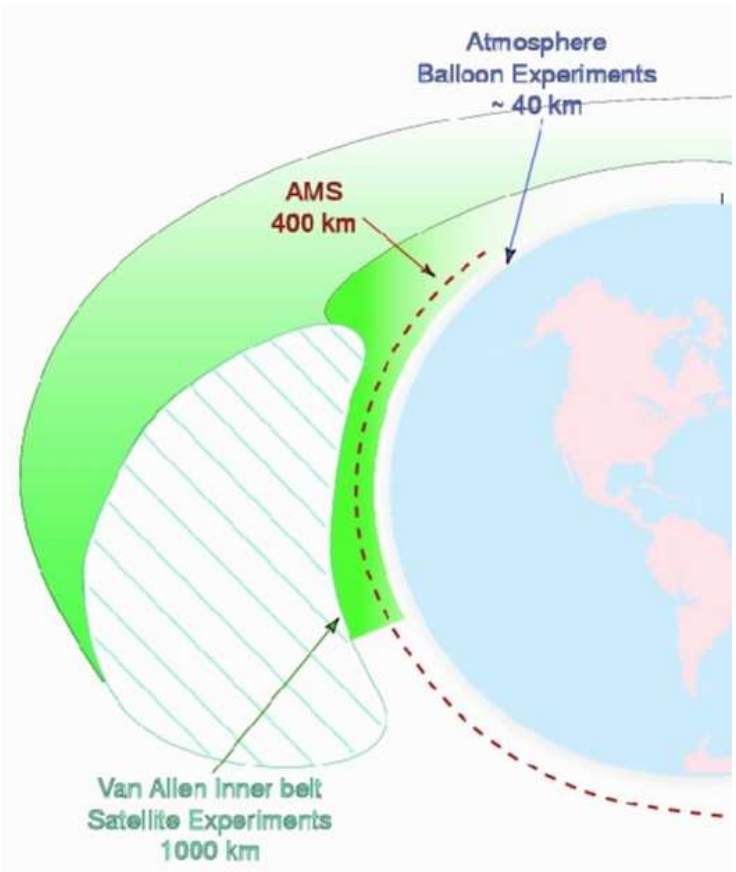


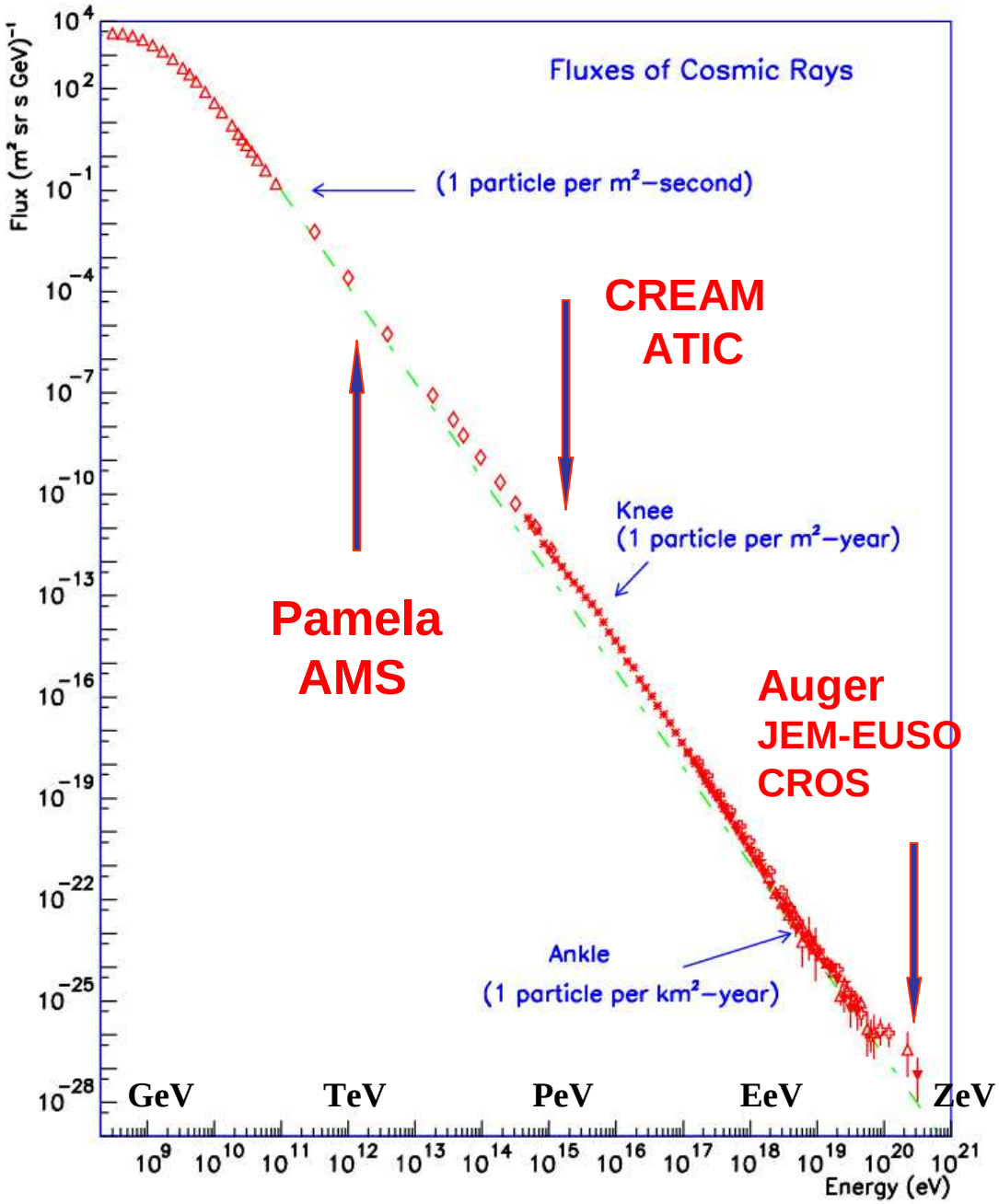


Cosmic Ray in atmosphere

- The thickness of atmosphere (1kg/cm²) corresponds to a 4 meter thick concrete shielding.
- Pratically, only muons can reach earth surface.
- Ballons can fly up to 35 km (5 g/cm^2) but with a limited exposure time (~20 days).
- Detectors in space can benefit of large exposure times (3-15 years).

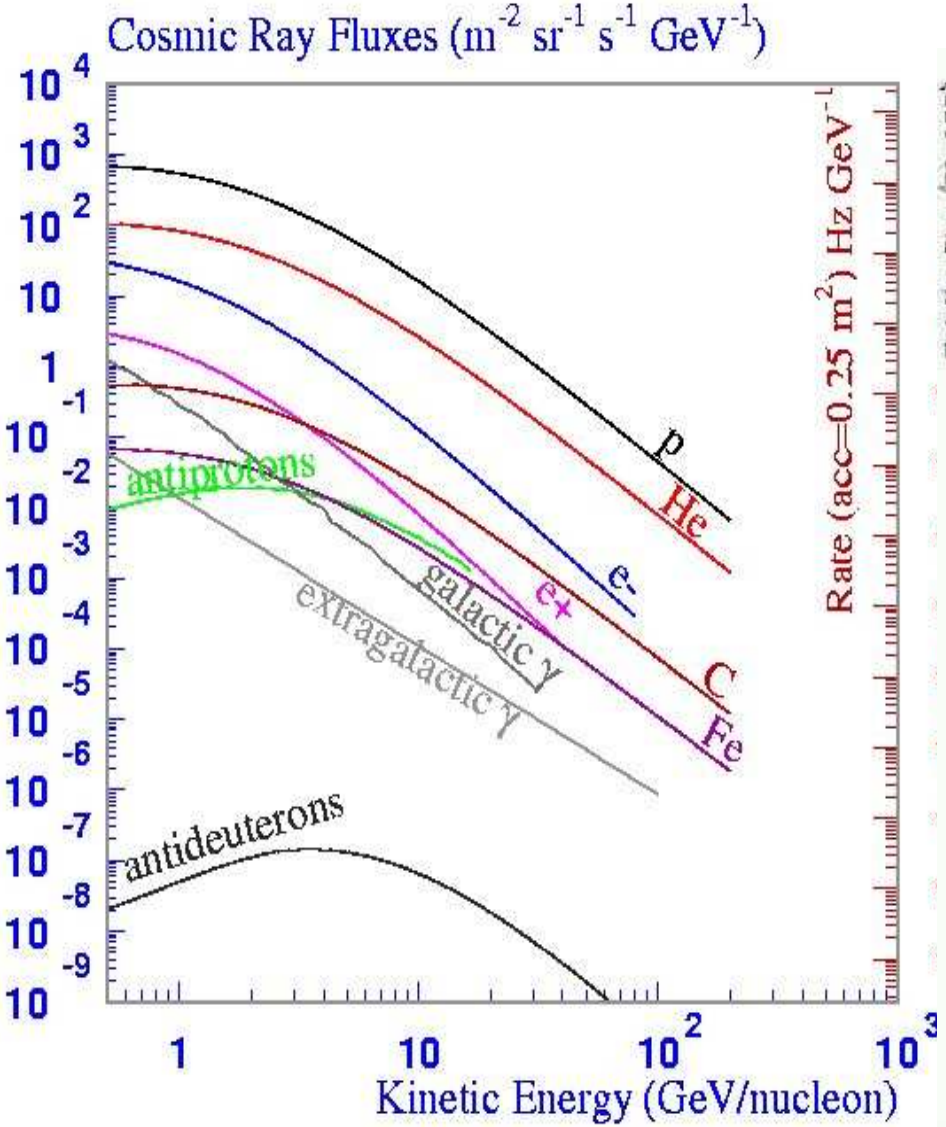
Large number of orders of magnitude in energies and intensities of CR

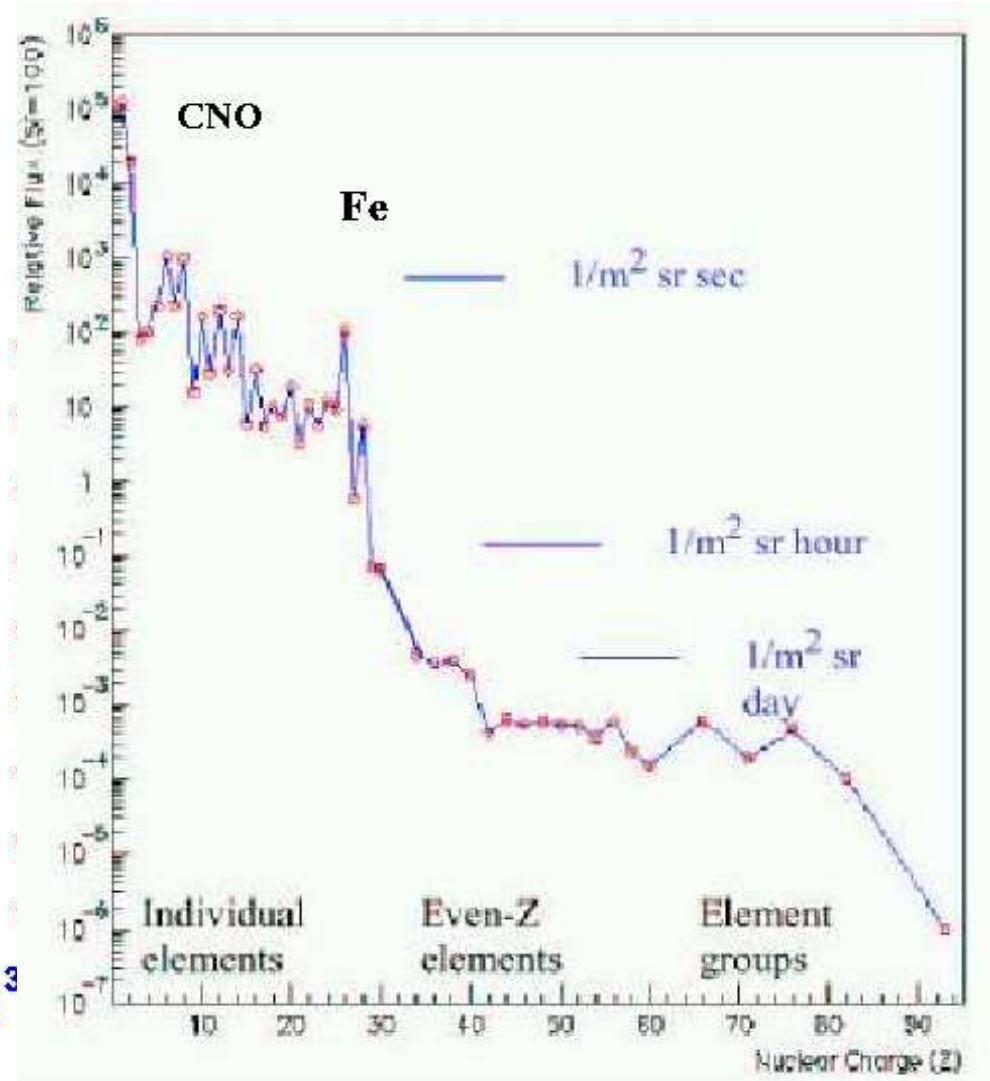




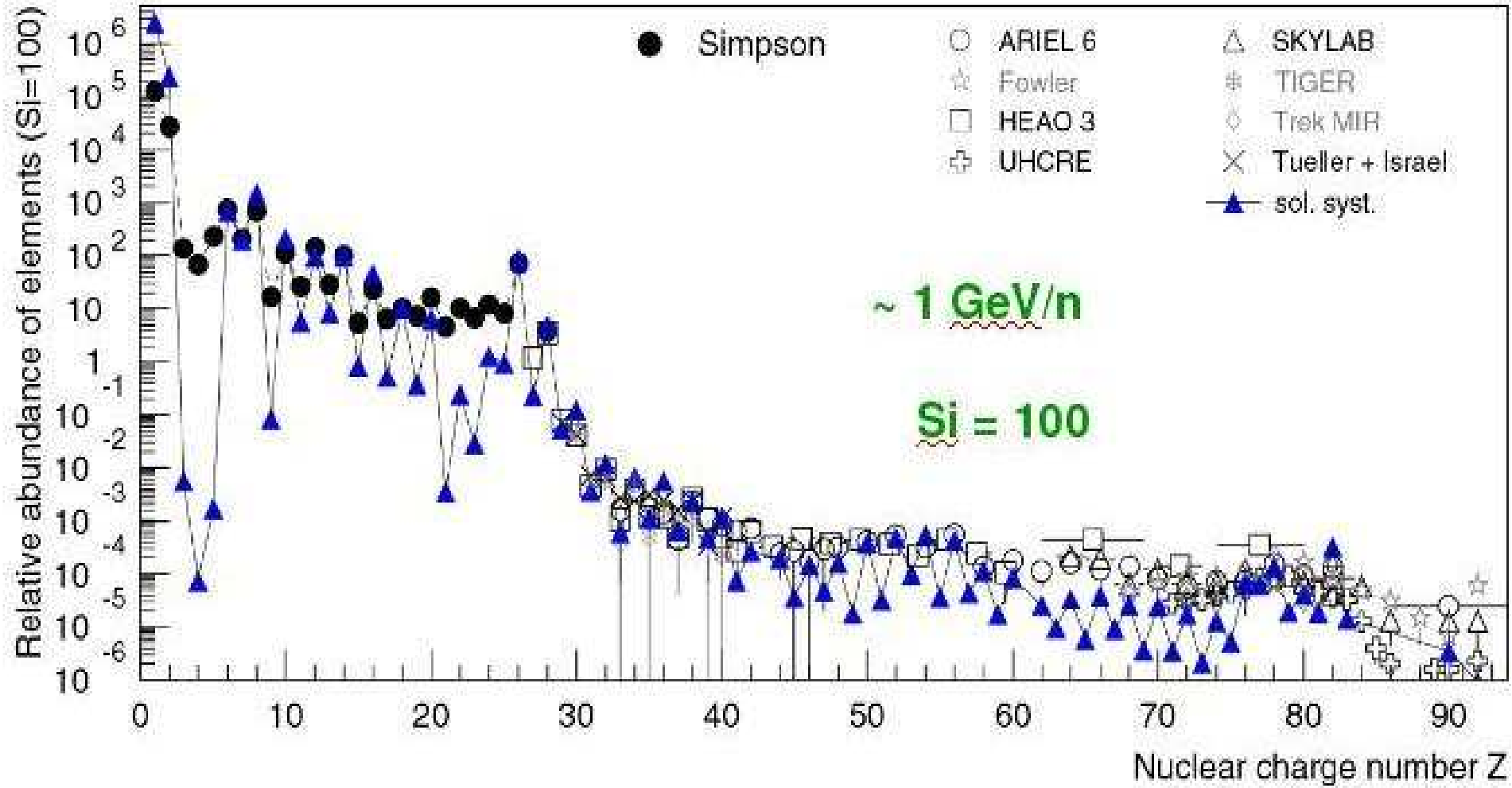
Abundances of various particles (➔ *identification)*

Abundance of various nuclei (elements) in CR





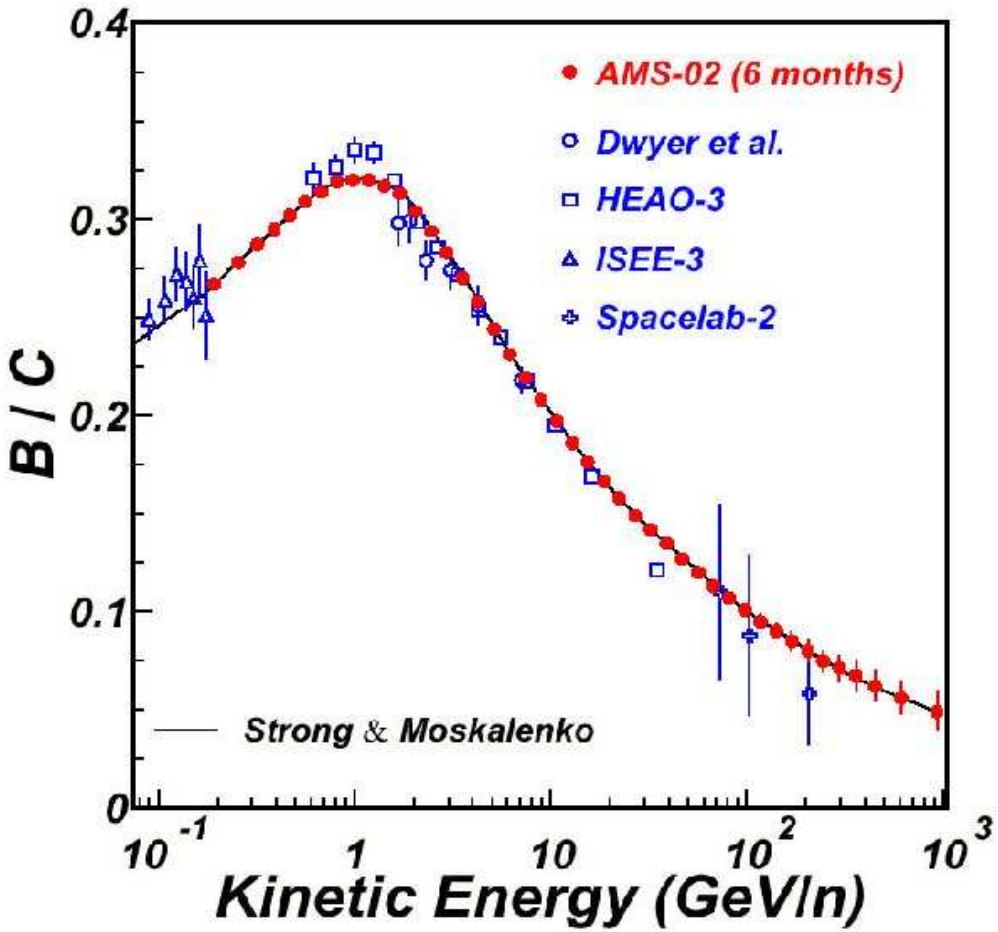
Relative abundance of elements in CR and in solar system

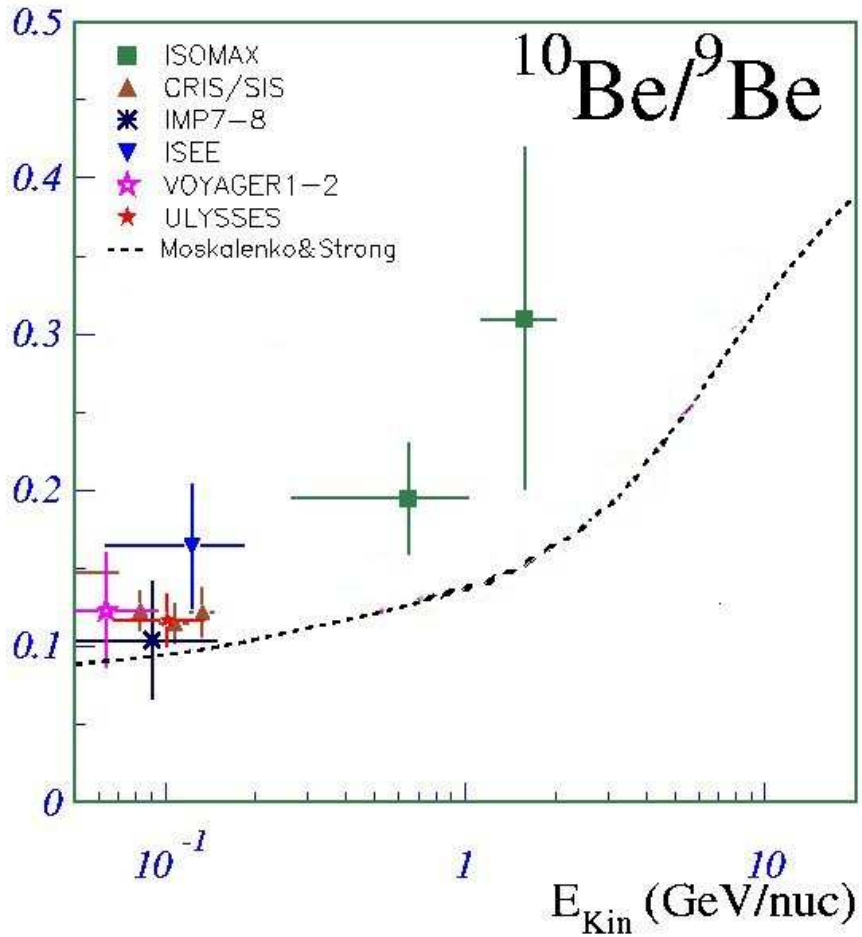


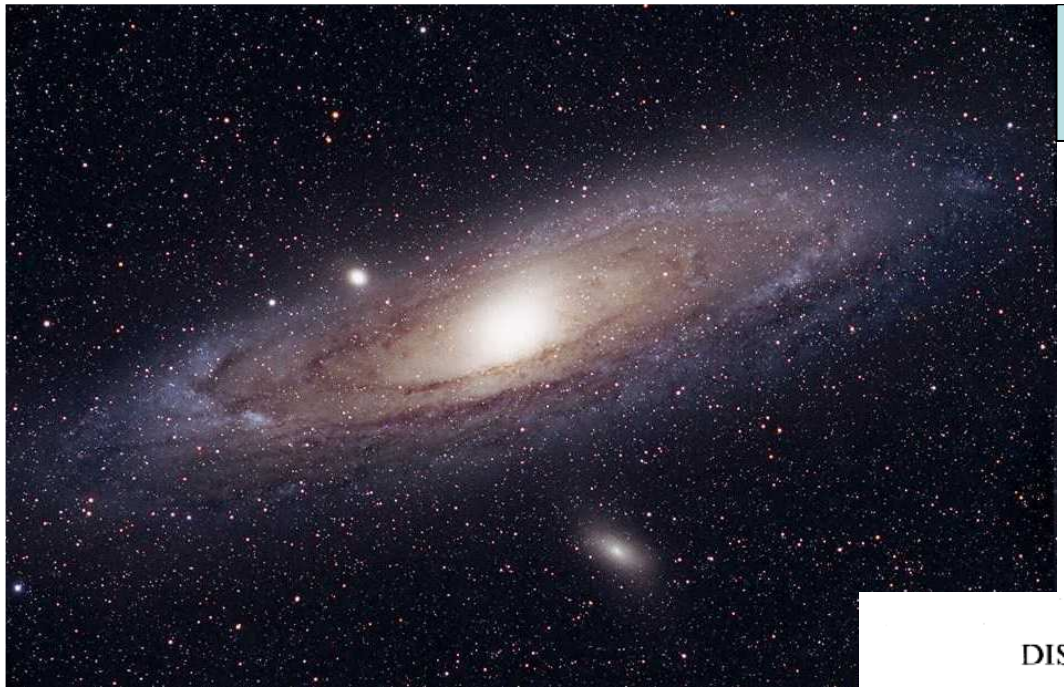
➔ Interaction des RC avec le milieu interstellaire par fragmentation ➔ temps de confinement

Tests of CR propagation models using secondaries and ratios

Li, Be, B nuclei come from CNO spallation. Radio-active secondary nuclei like ^{10}Be ($\tau = 2 \times 10^6$ y) are *cosmic clocks.* Chemical composition and isotope ratios depend on cosmic ray confinement time and density of the interstellar medium.





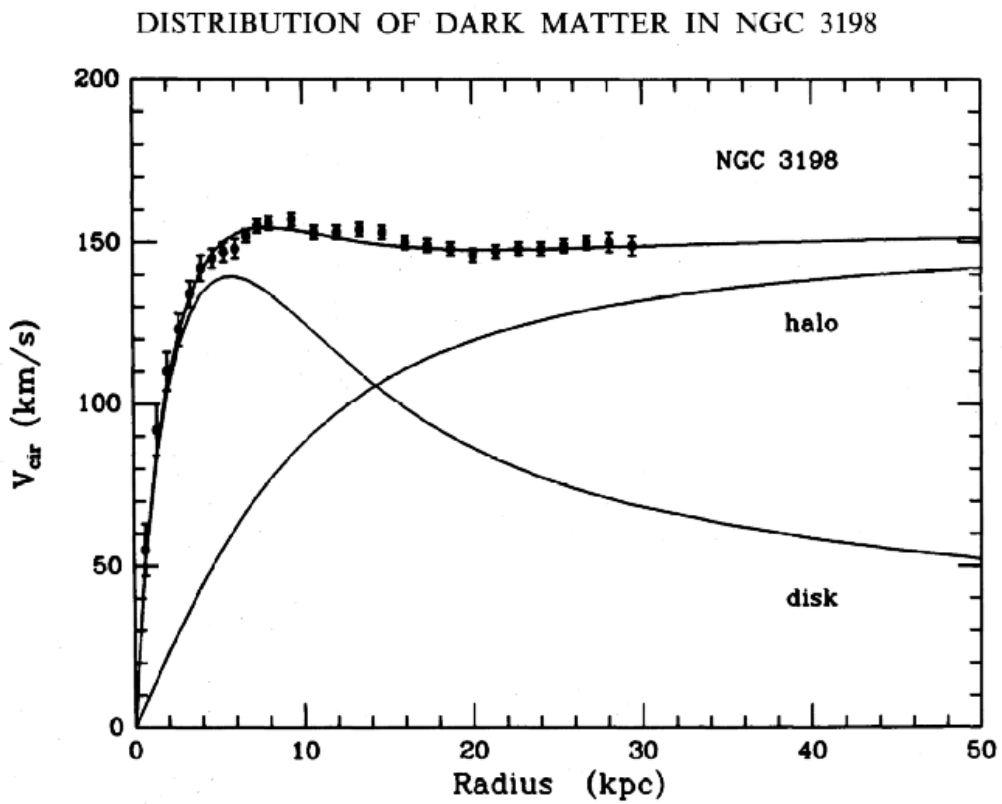


Dark Matter

Dark Matter manifests its existence through its gravitational effects:

-Rotational velocities of stars at the edge of the disk galaxies.

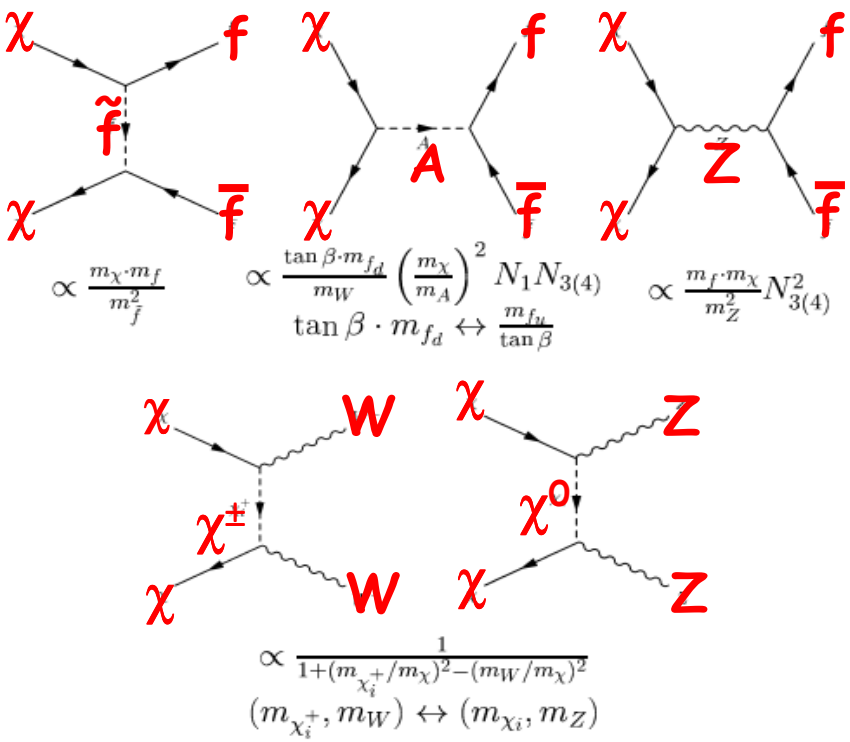
-Gravitational lensing

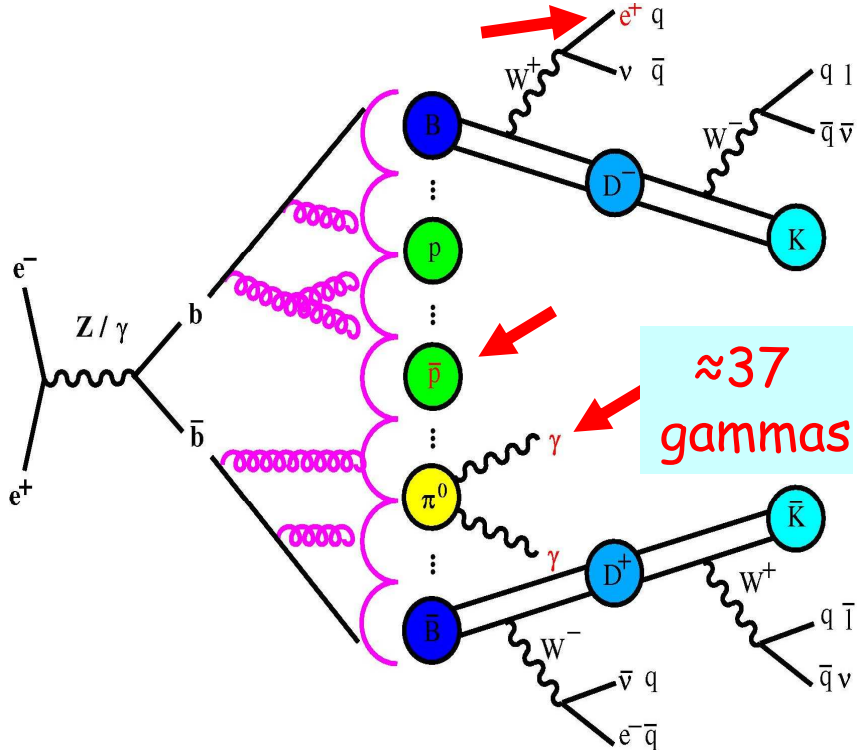


From the many hypothesis on the nature of DM, two are related to particle physics:

- Supersymmetric particles χ_0
- Kaluza-Klein Boson (B)

DM Annihilation in Supersymmetry



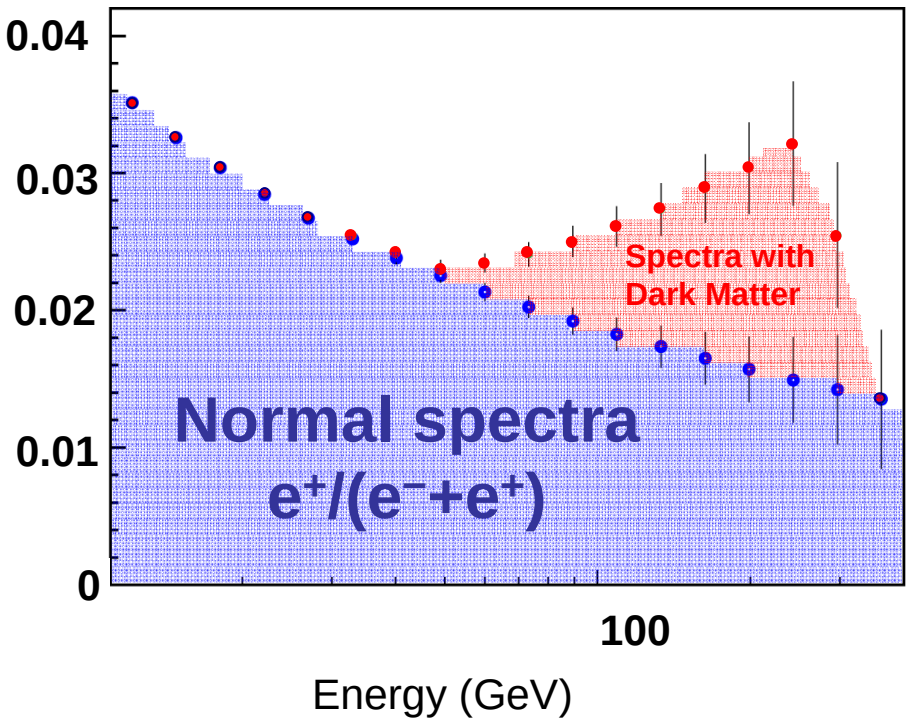


Dominant
$\chi + \chi \Rightarrow A \Rightarrow$ b bbar quark pair

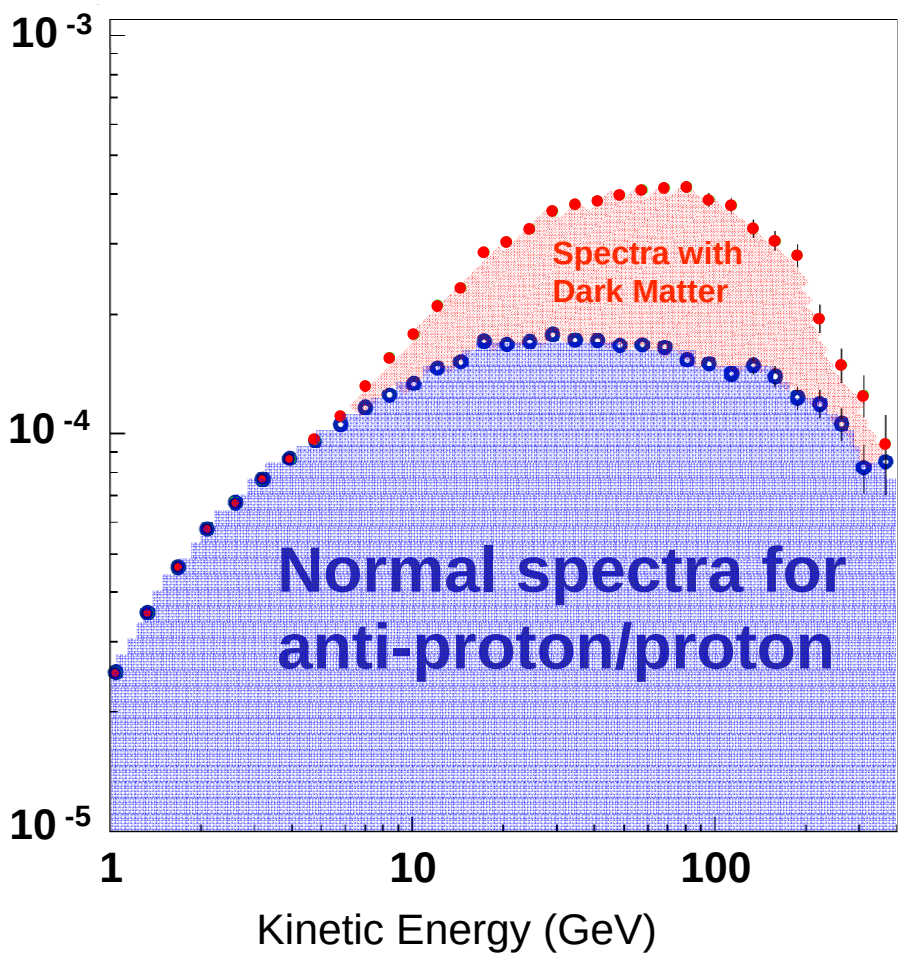
B-Fragmentation known!
Hence Spectra of Positrons, Gammas and Antiprotons known!

Two leading theoretical candidates

Dark Matter is a Kaluza-Klein Boson (B) - assumes extra dimensions - with a typical mass of M_B = 300GeV

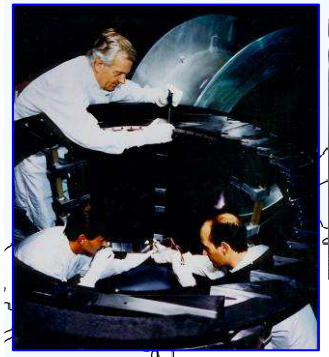


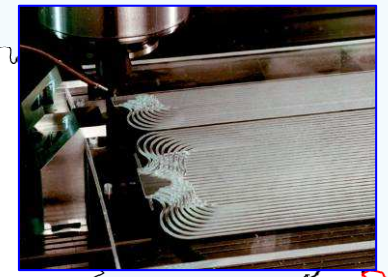
Dark Matter is a supersymmetric particle with M_χ = 840 GeV. This is not accessible to the next accelerator (LHC)

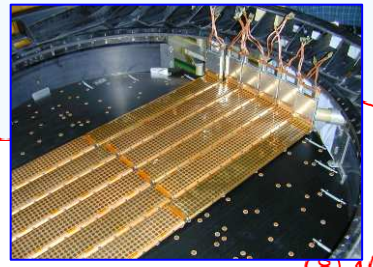


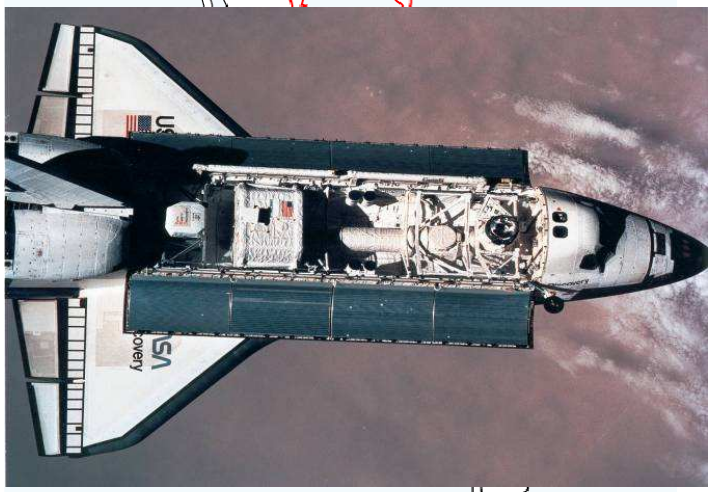
First flight AMS-01 (STS-91 Docking to MIR)

Approval: April 1995, Assembly: December 1997, Flight: 10 days in June 1998

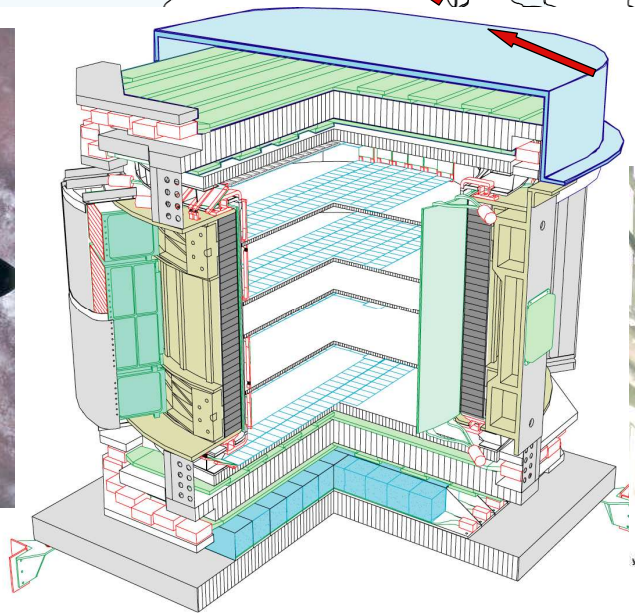






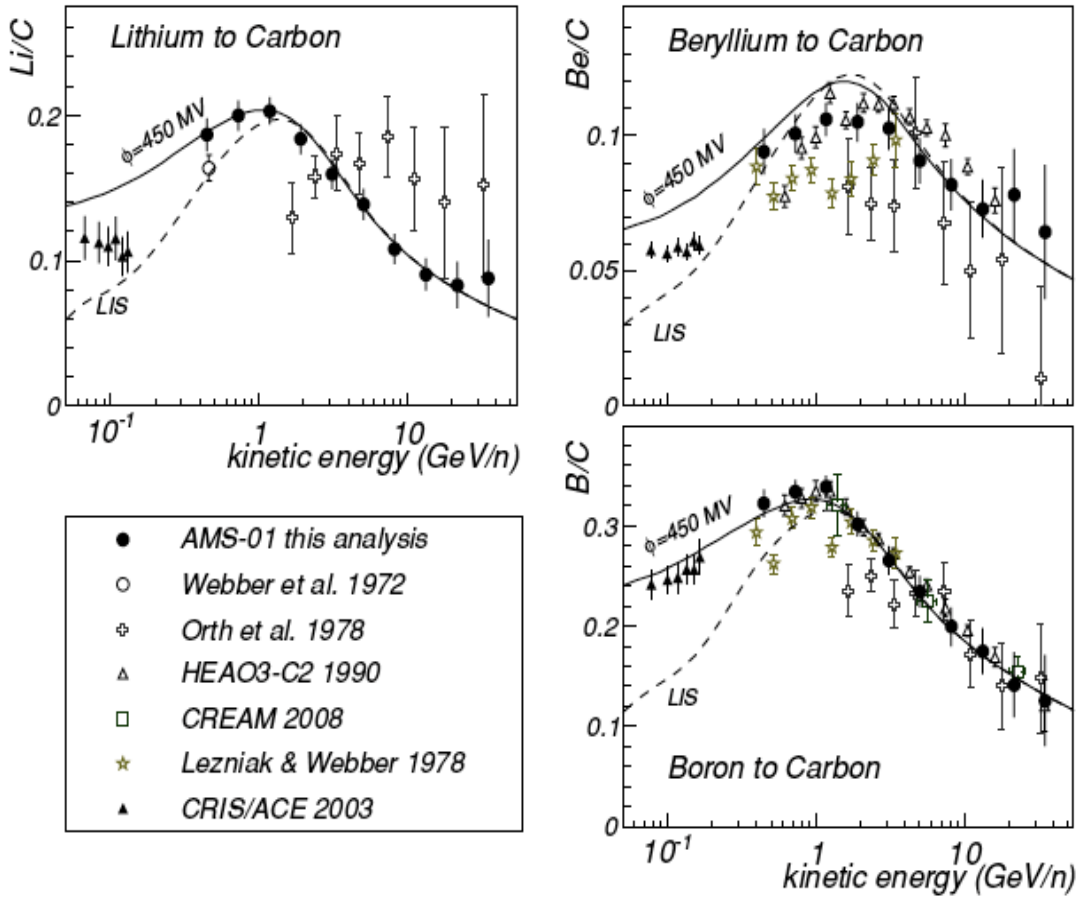


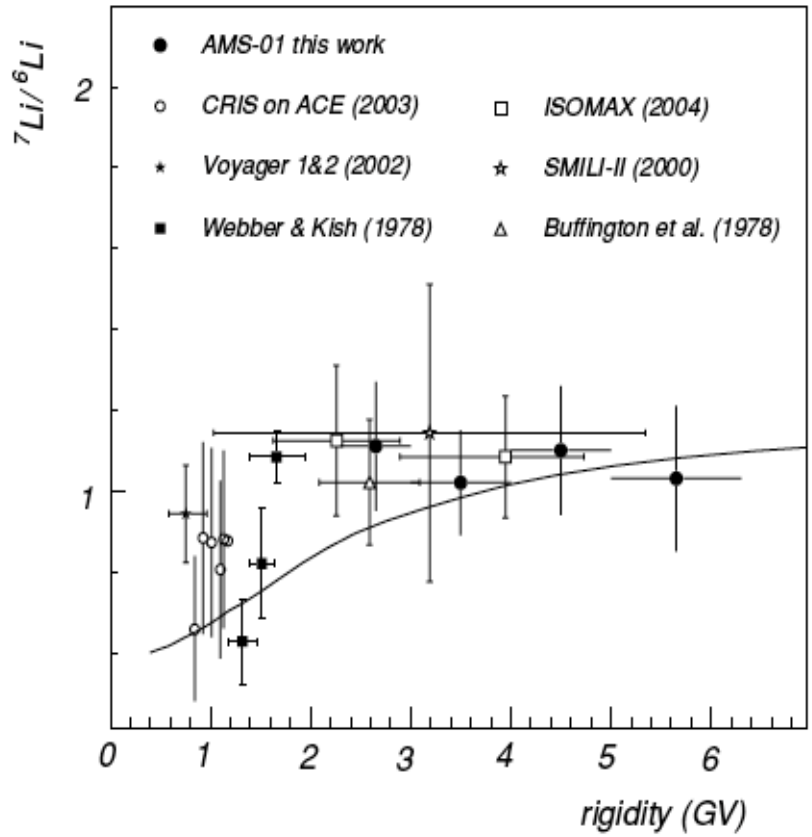
AMS



y96207_05b

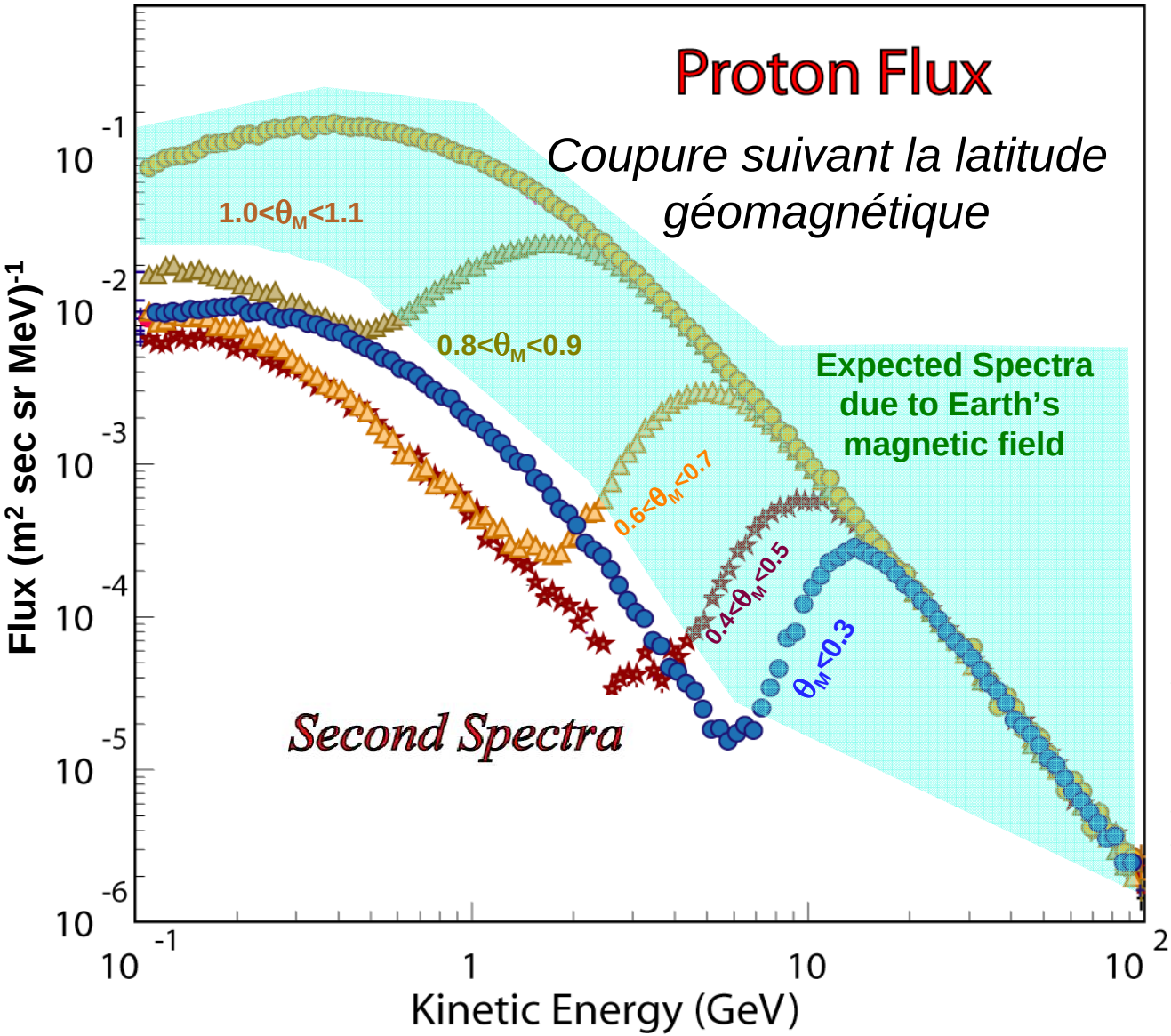
Elements and Isotopes Ratios measured by AMS-01

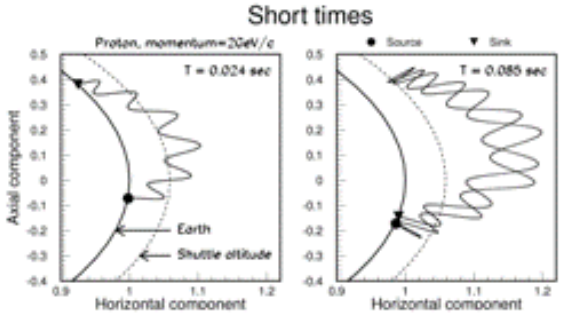


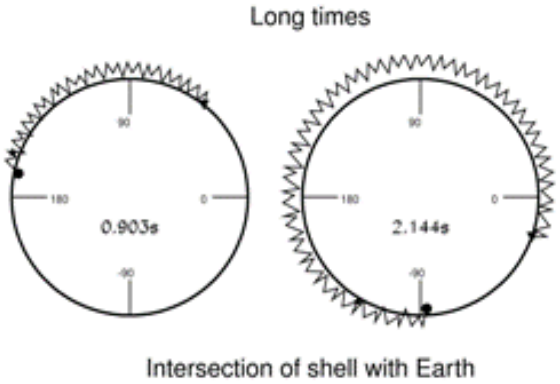


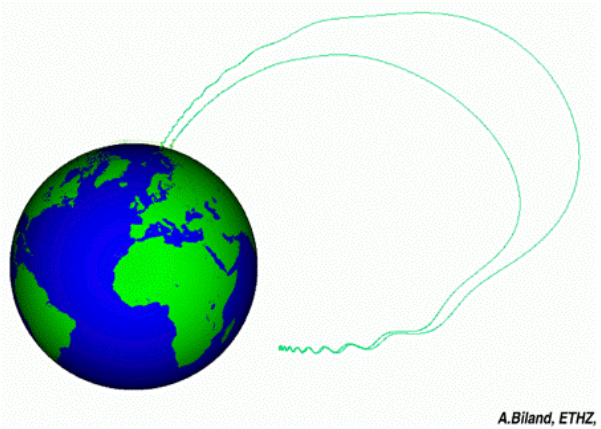
Unexpected results from first flight:

1- the existence of two Spectra in proton flux



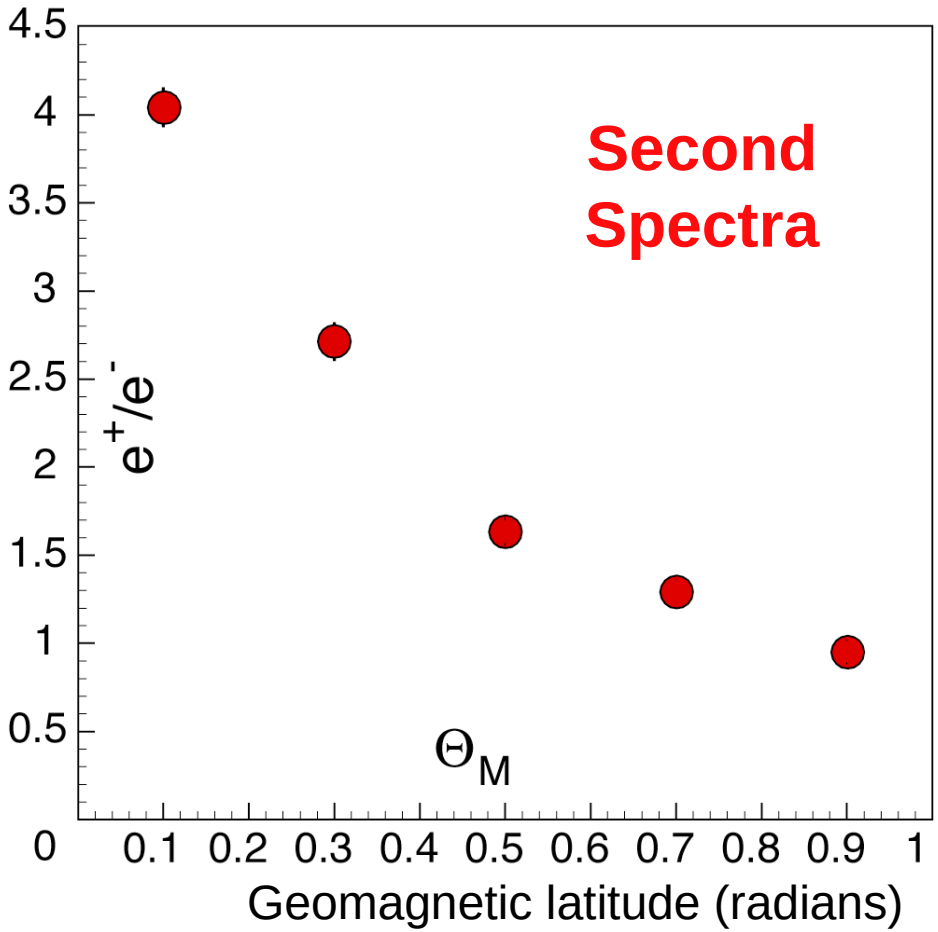




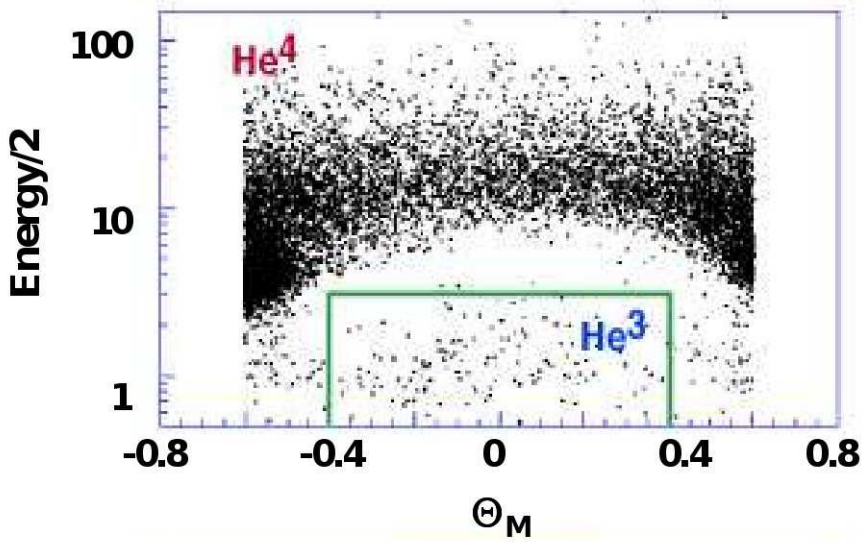


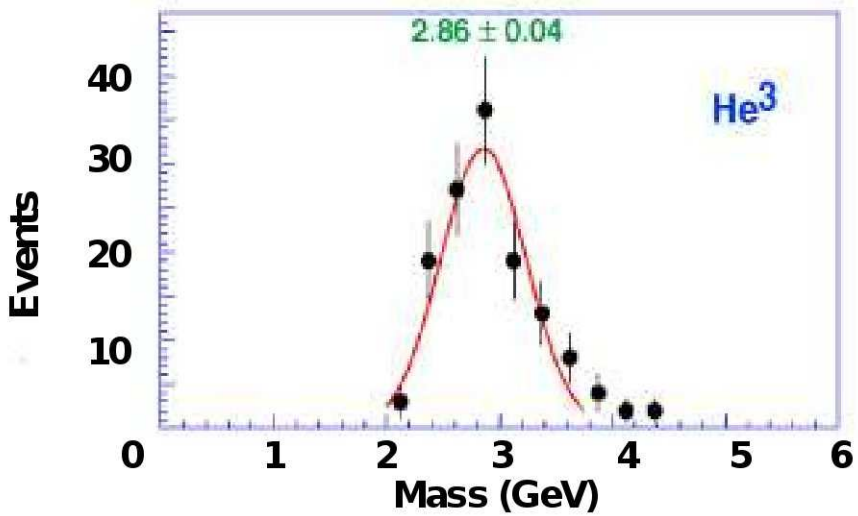
Unexpected results from first flight:

2- Under the geomagnetic cut, there are many more positrons (e^+) than electrons (e^-)

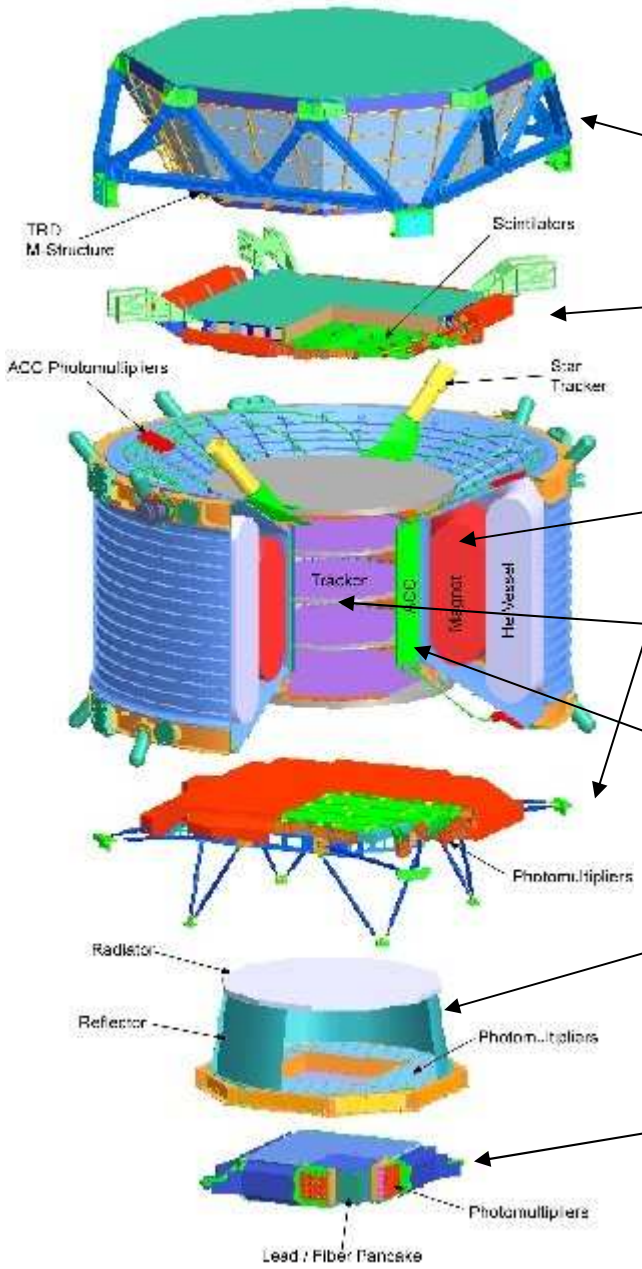


3- He^4 and He^3 isotopes are completely separated in space





AMS-02 detector

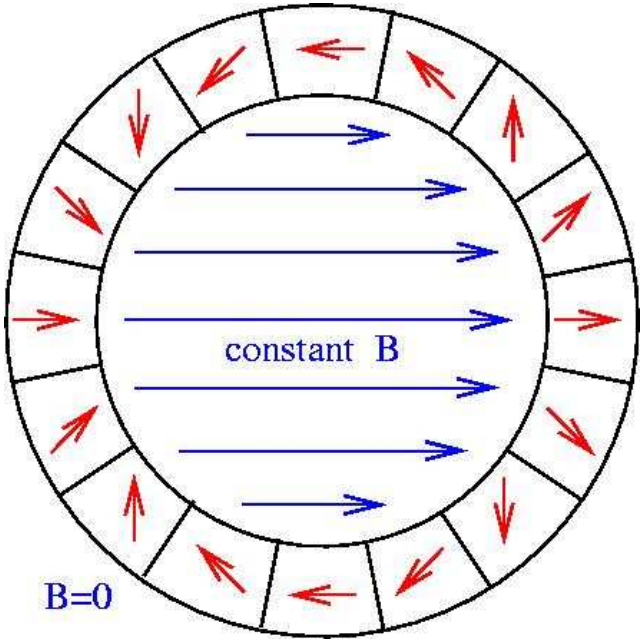


- *TRD*: *Transition Radiation Detector*
- *TOF*: *Two double layers of scintillators paddles for trigger and time of flight. (+/-)*
- *Magnet (with field perpendicular to cylinder)*
- *Silicon microstrip Tracker (8 XY planes)*
- *Anti-counters*
- *RICH: (proximity focusing with Aerogel and NaF radiators)*
- *ECAL: Electromagnetic Calorimeter with ~17* X_0 *to identify* $e^{\pm}$, γ *and energy measurement*

AMS-01 permanent magnet

Torques are forbidden on spacecrafts

➔ The total magnetic moment MUST BE ZERO



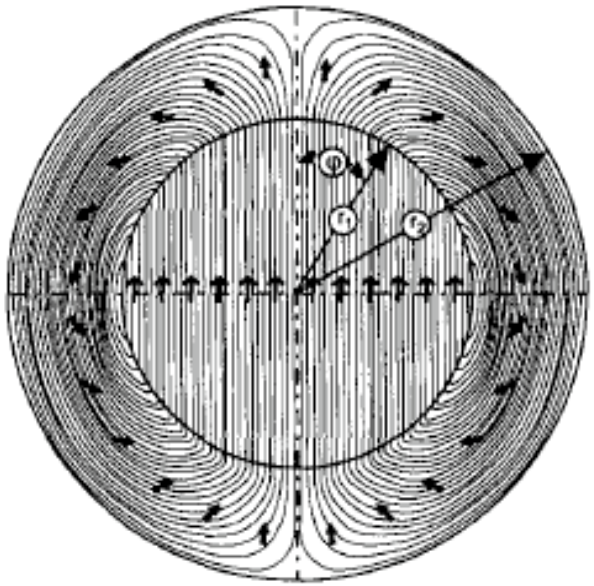


Fig. 6. Magnetic field distribution at a cross-section of the center of the magnet.

B=0.13 T

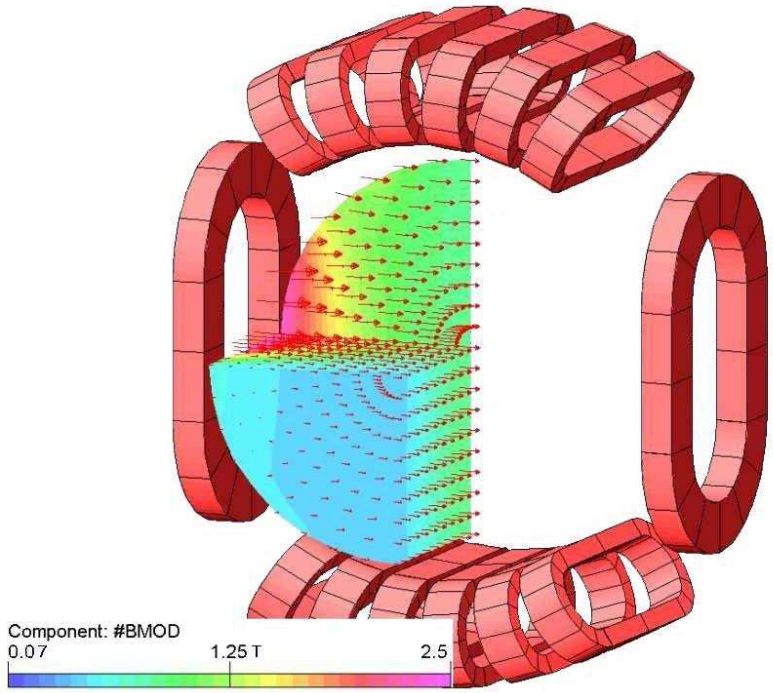
L= 1 m

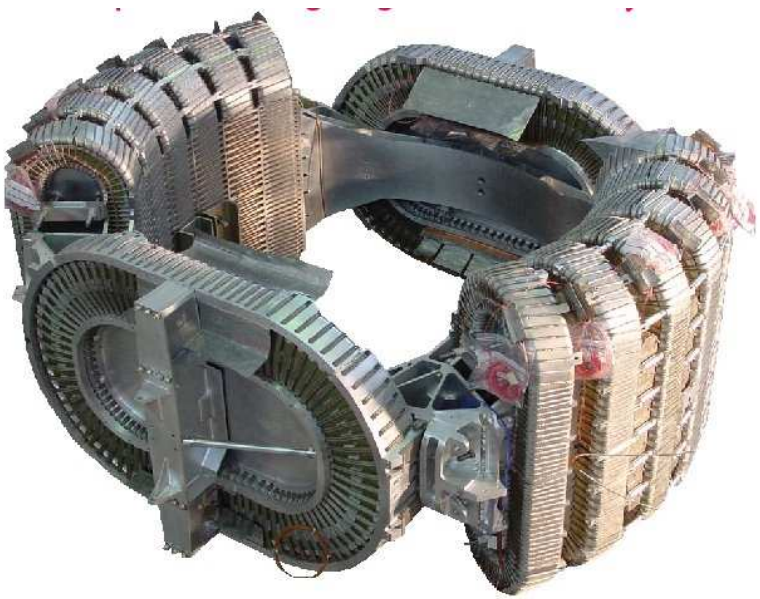
Superconducting Magnet

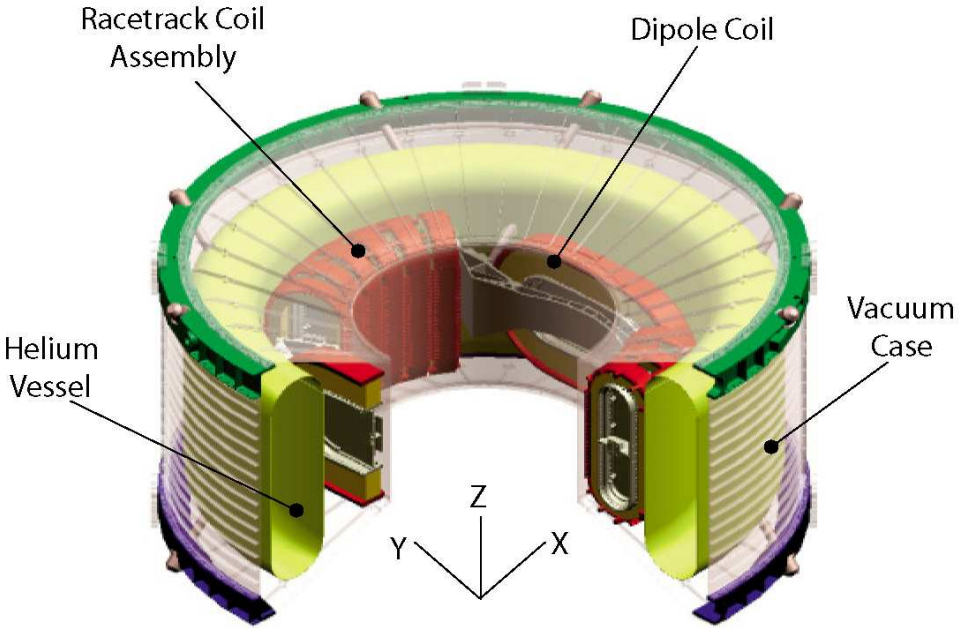
- *Cooled with superfluid Helium.*
- *2500 liters He for 3 years operation*

B=0.7 T

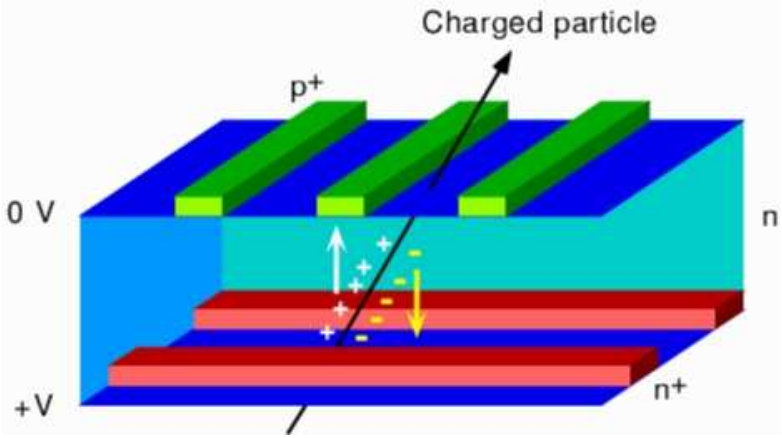
L= 1 m



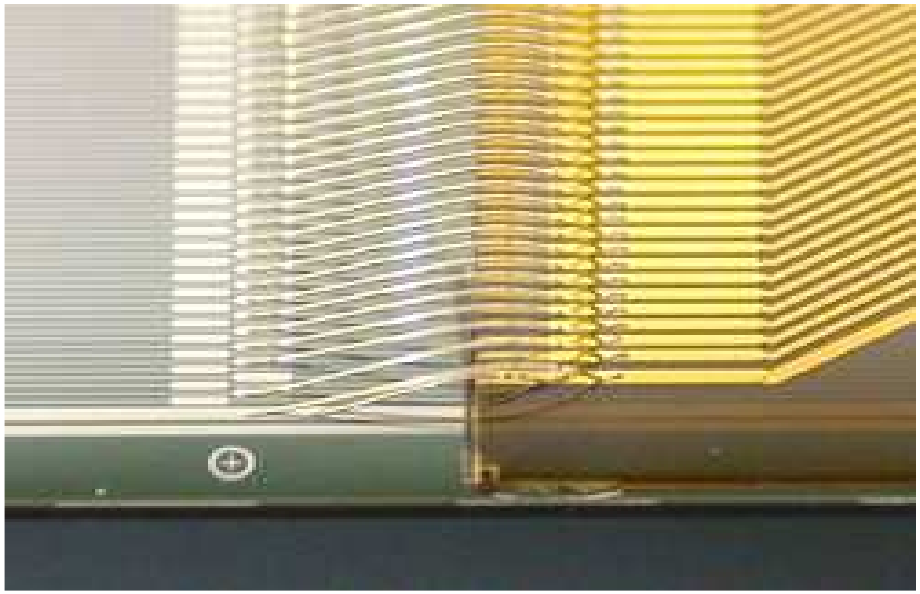


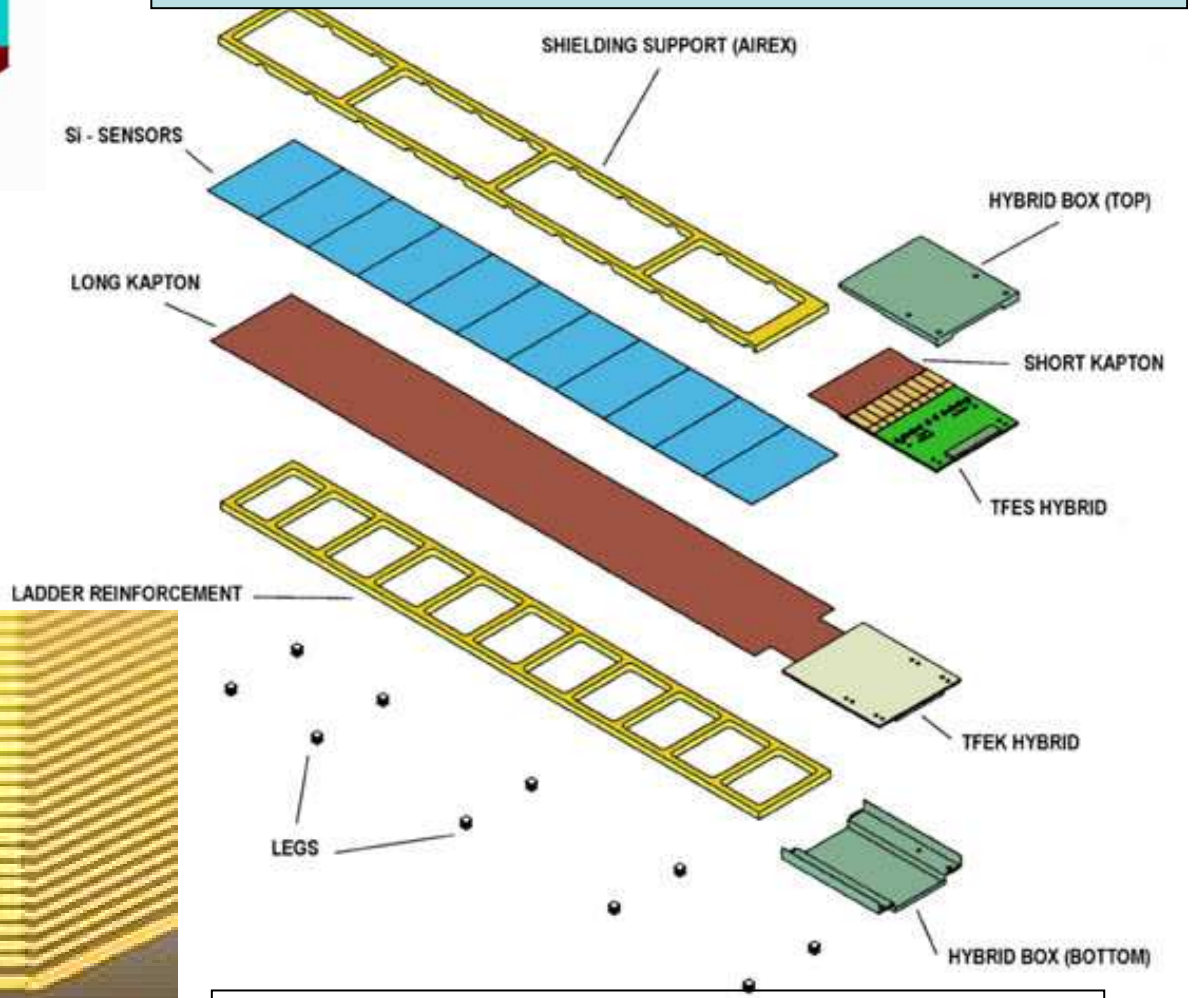


Silicon microstrip Tracker

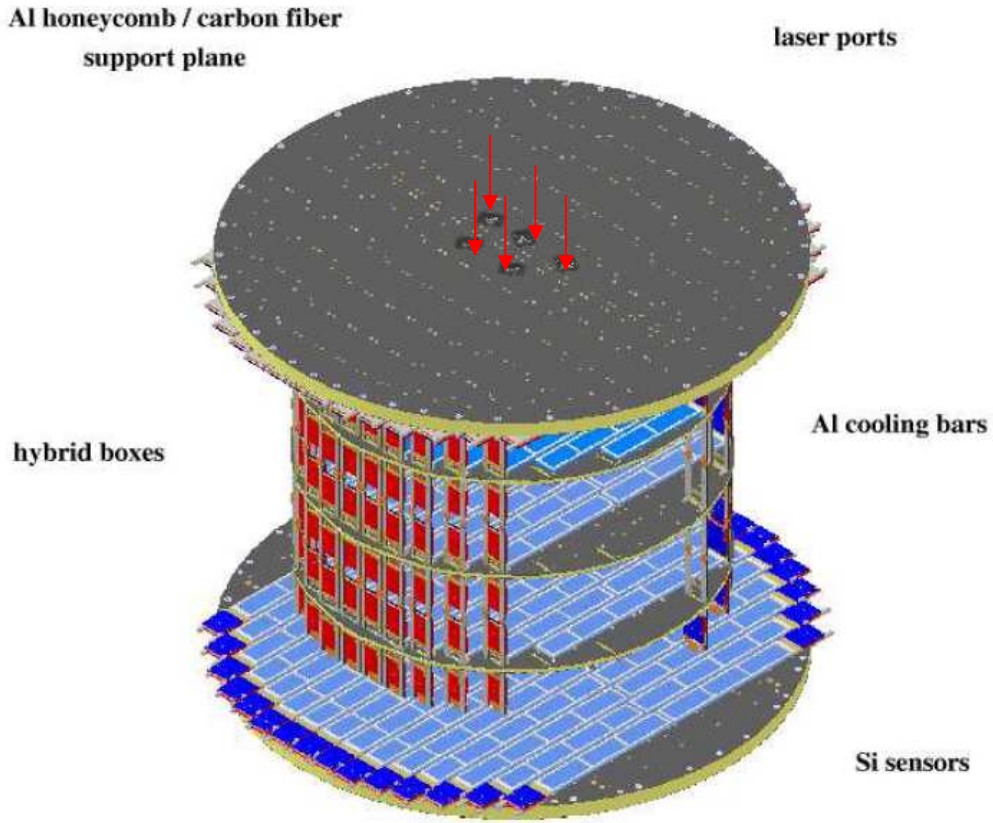


- Thickness: 300 µm
- Strip every 25 µm
- Read-out 1 strip/4: 100 µm
- Total 200'000 channels
- Spatial resolution (σ) ~8µm

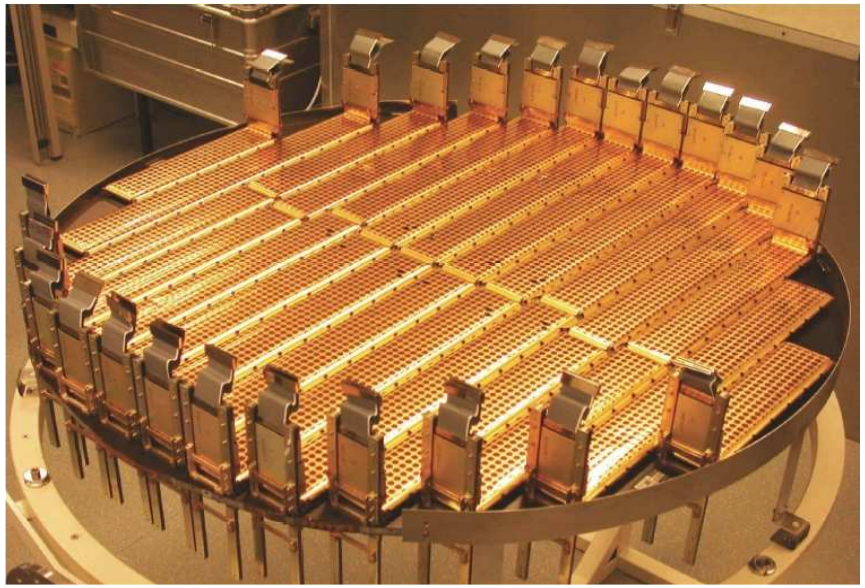


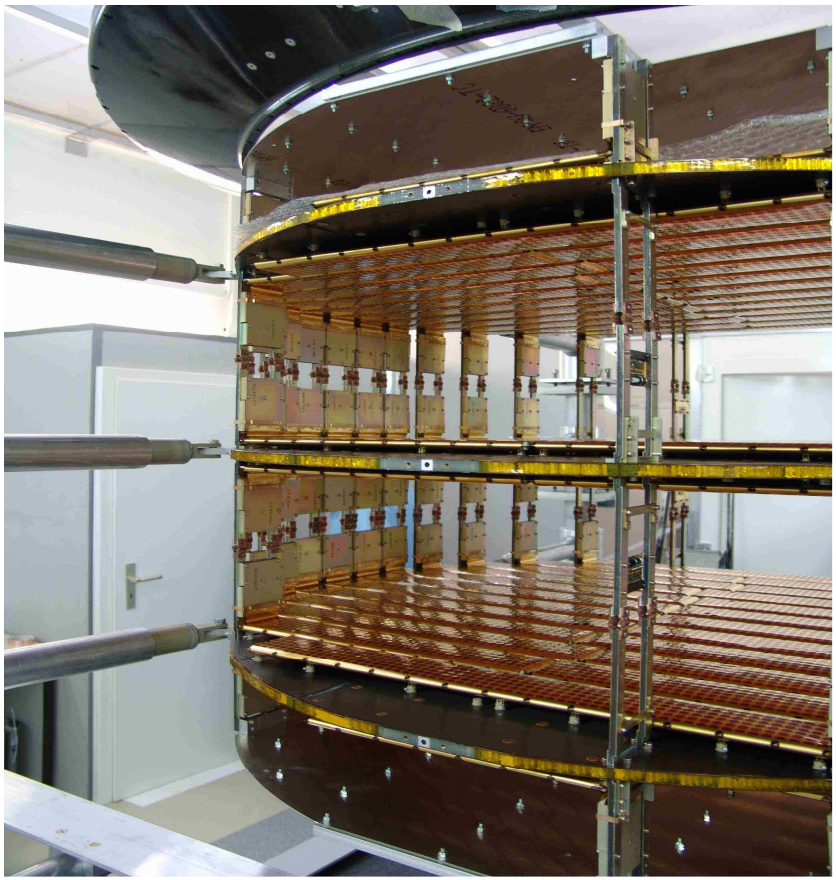


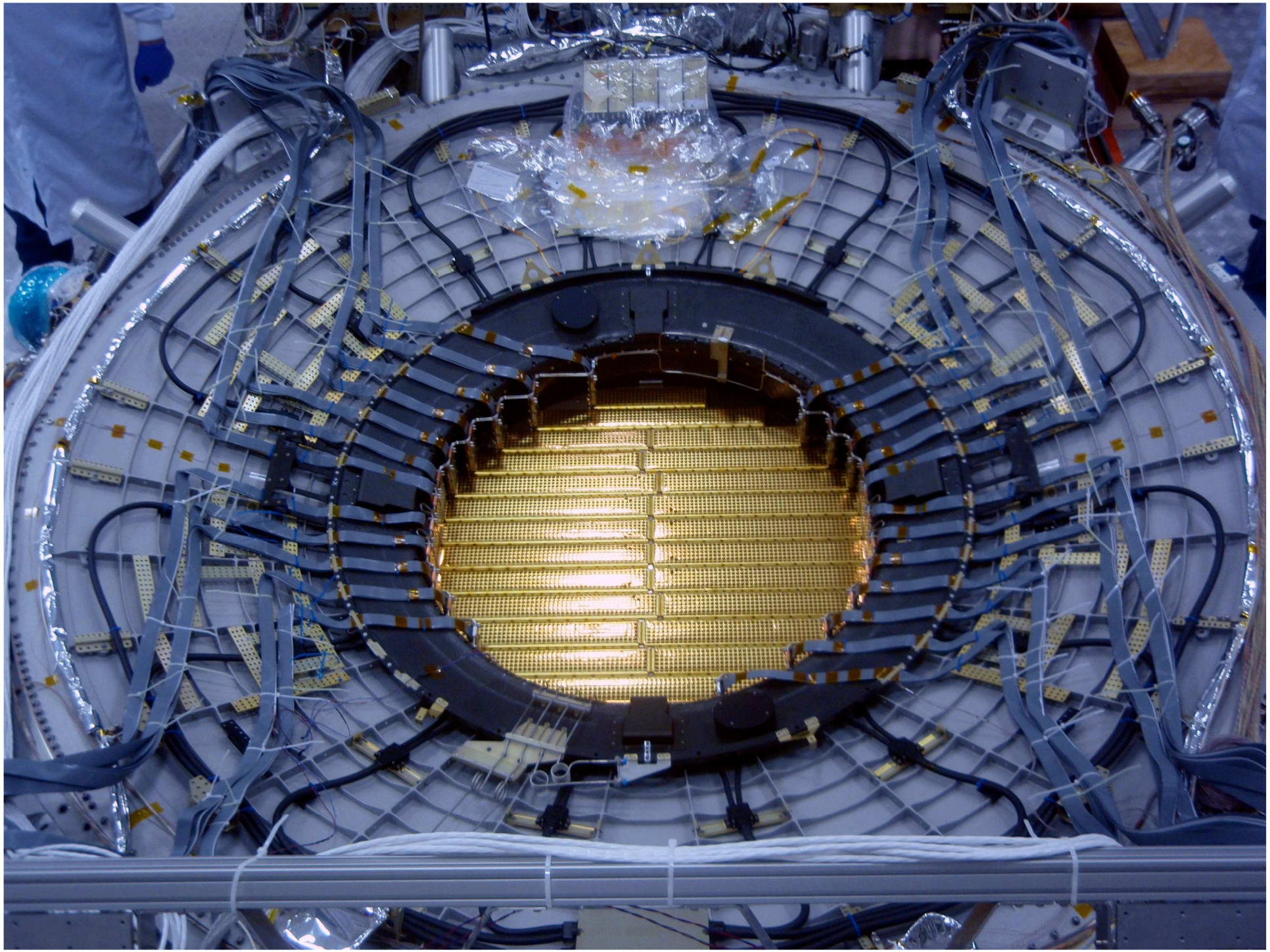
Mesures *position and charge*
(large dynamic range)



- 8 layers of XY sensors on 5 rigid planes (7 m² total)
- 10 laser beams for survey of movements
- Cooling of the front-end electronics by *thermal bars* and two phases CO2 circuit at 50 bar pressure.



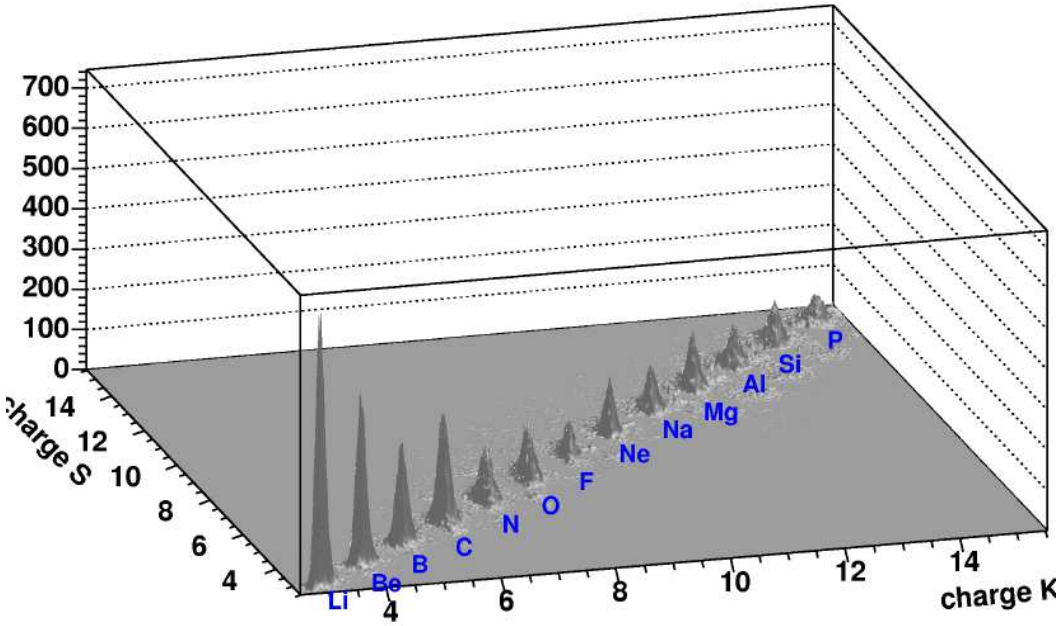


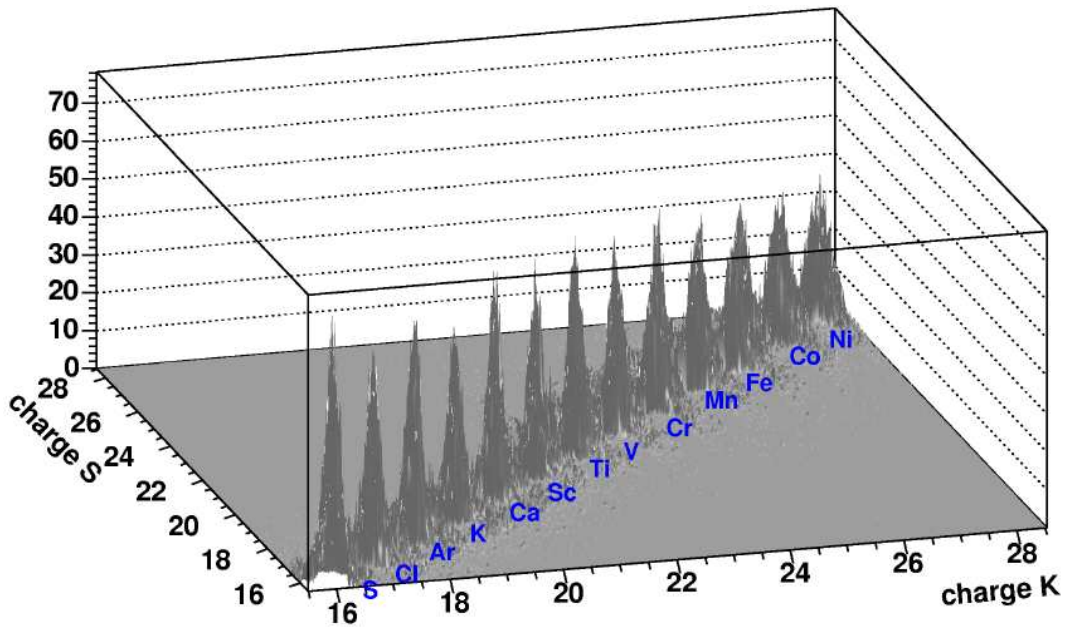


Tracker performance

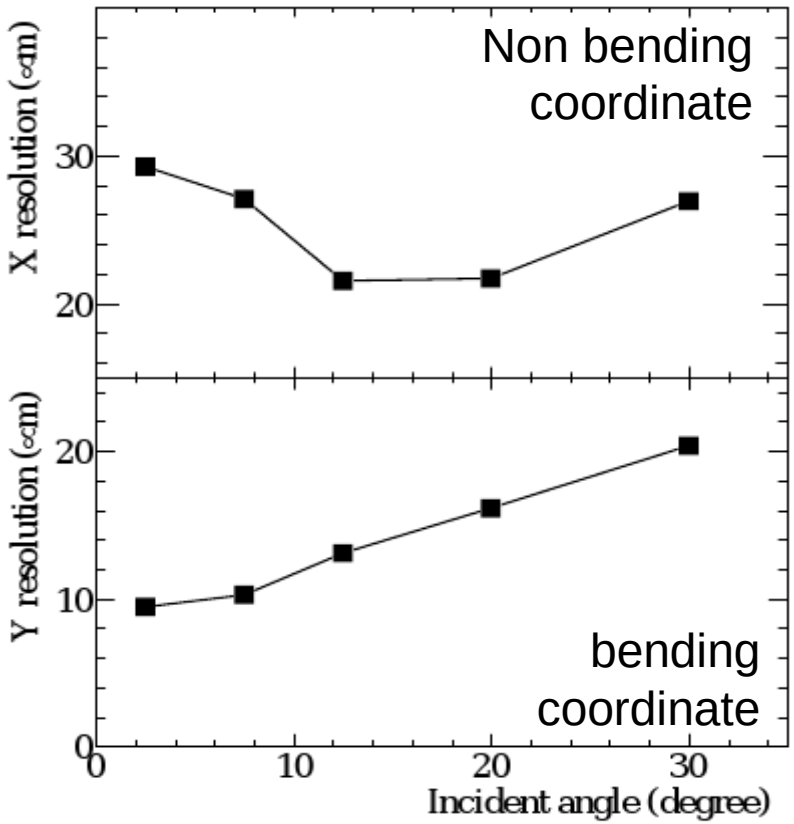
Test beam 158 GeV/n (fragmentation)

Charge (Z) identification



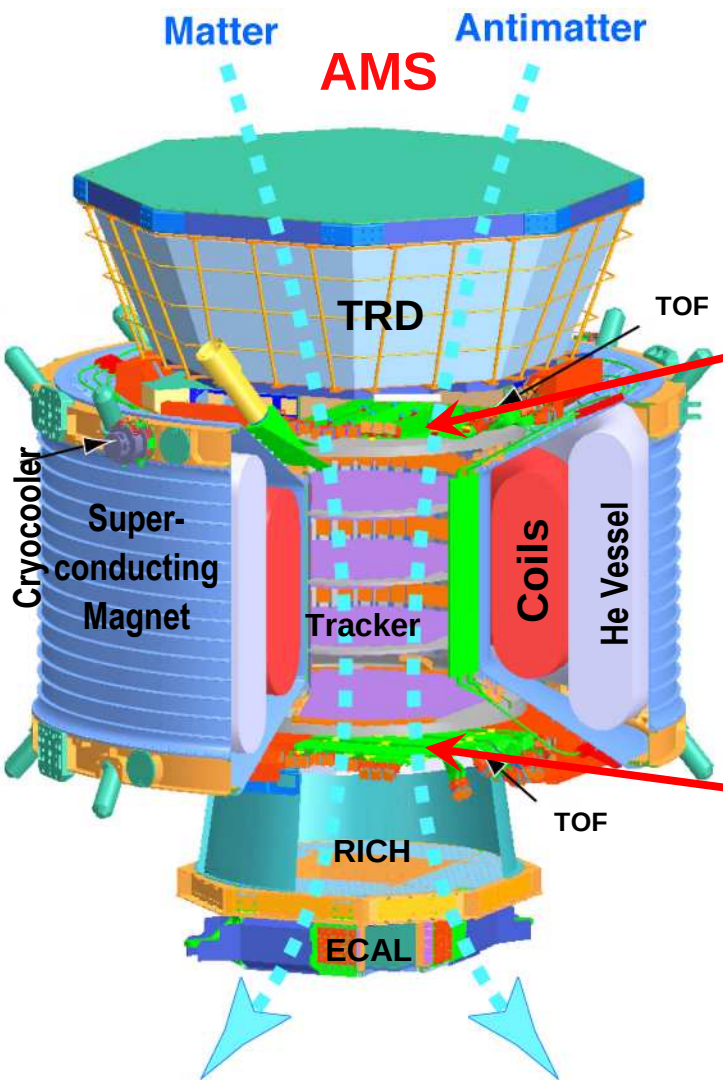


Spatial resolution (MIPs) versus incident angle



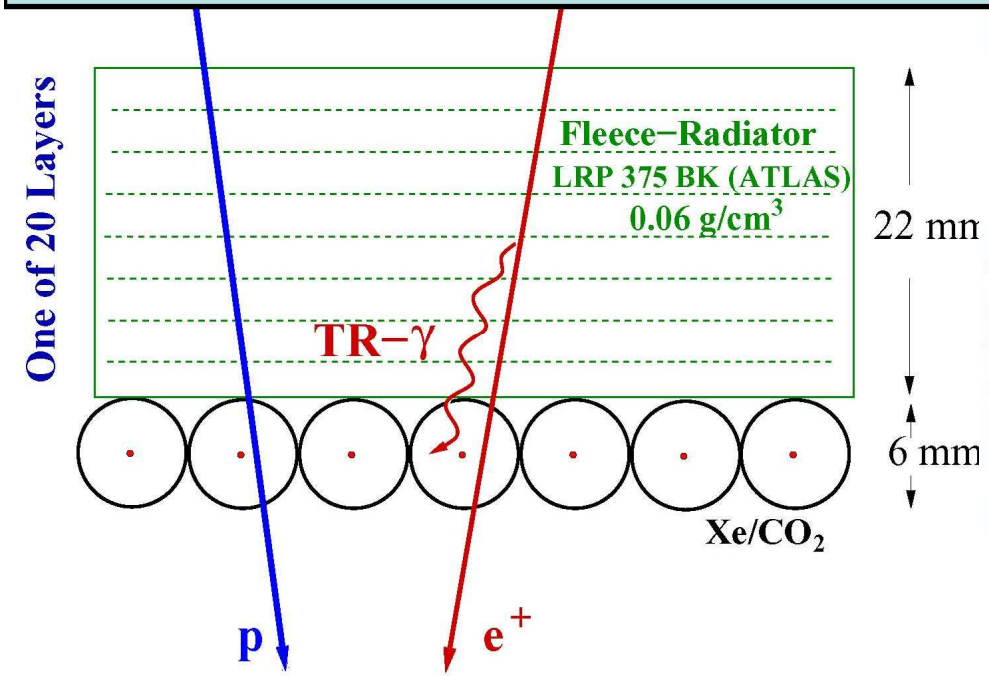
Time of Flight (TOF)

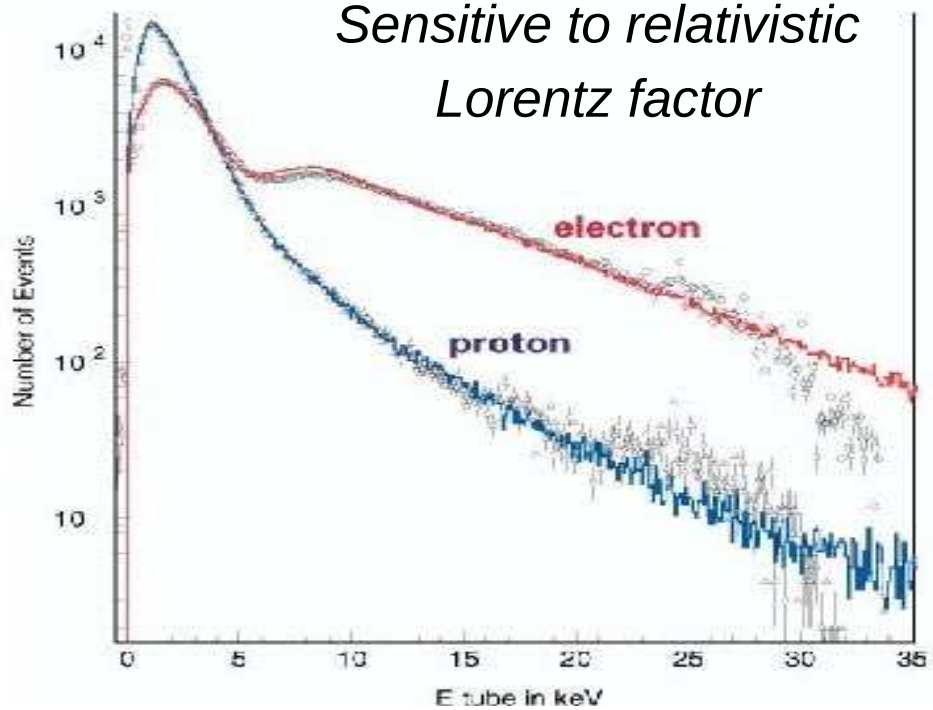
Measures the time of particles to ~ 100 picoseconds

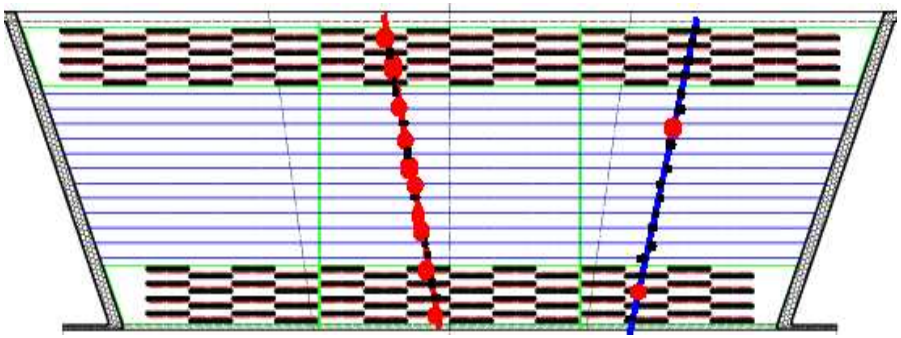


Transition Radiation Detector: TRD

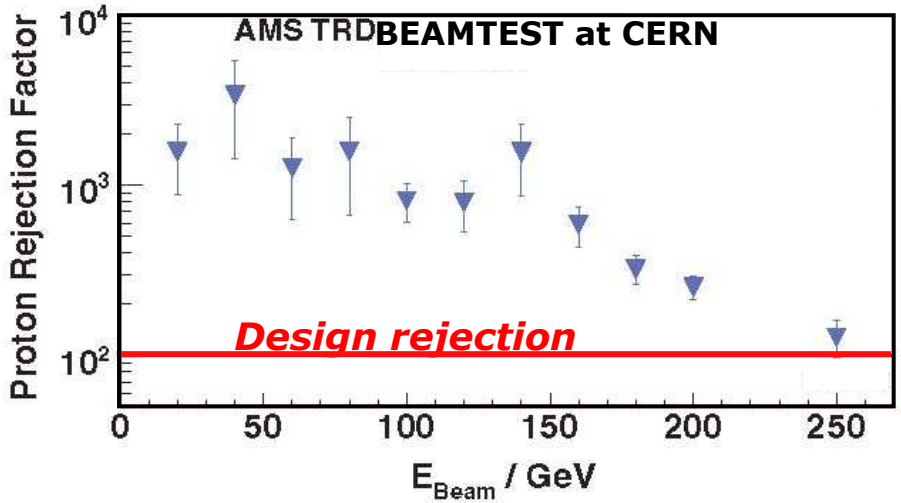
Identify electrons/positron



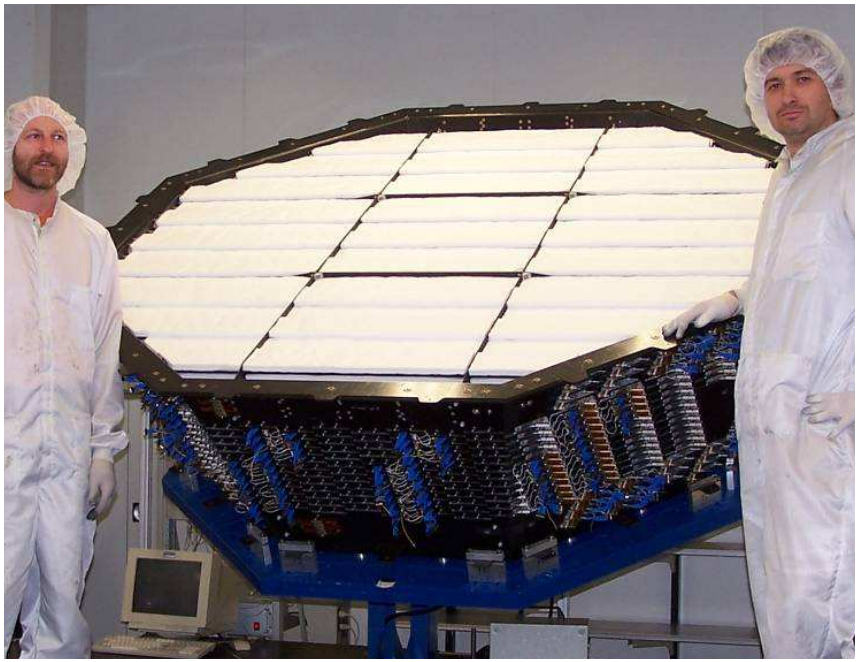


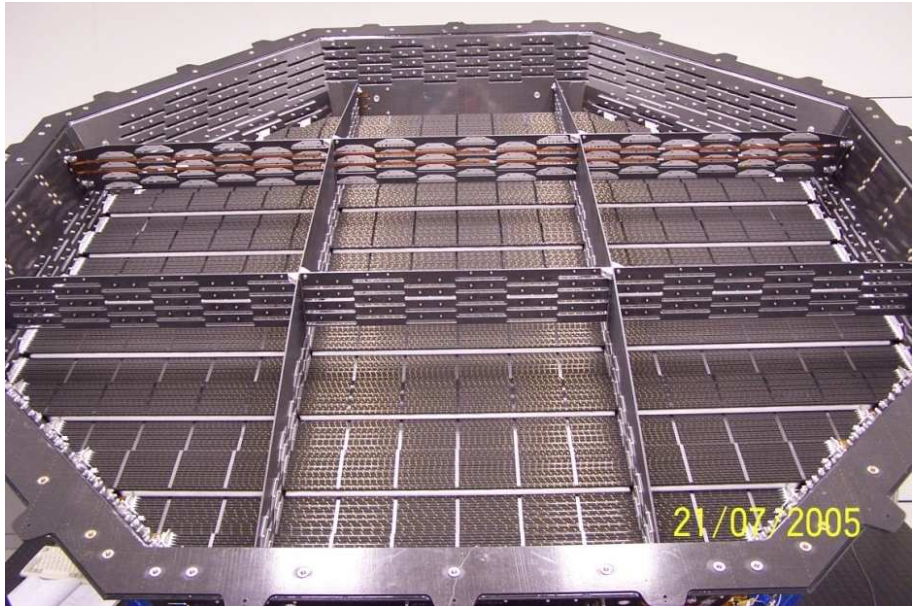


12 layers in the bending plane
8 layers in the non-bending plane

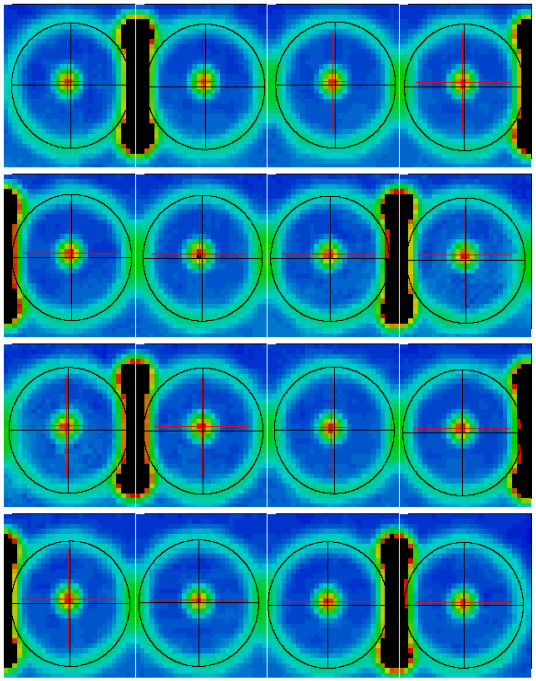


Transition Radiation Detector: TRD

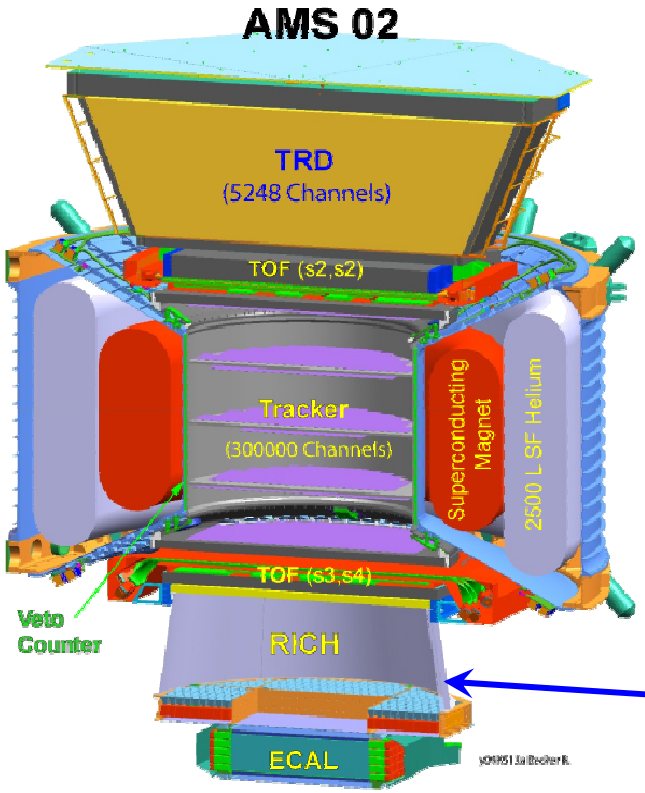


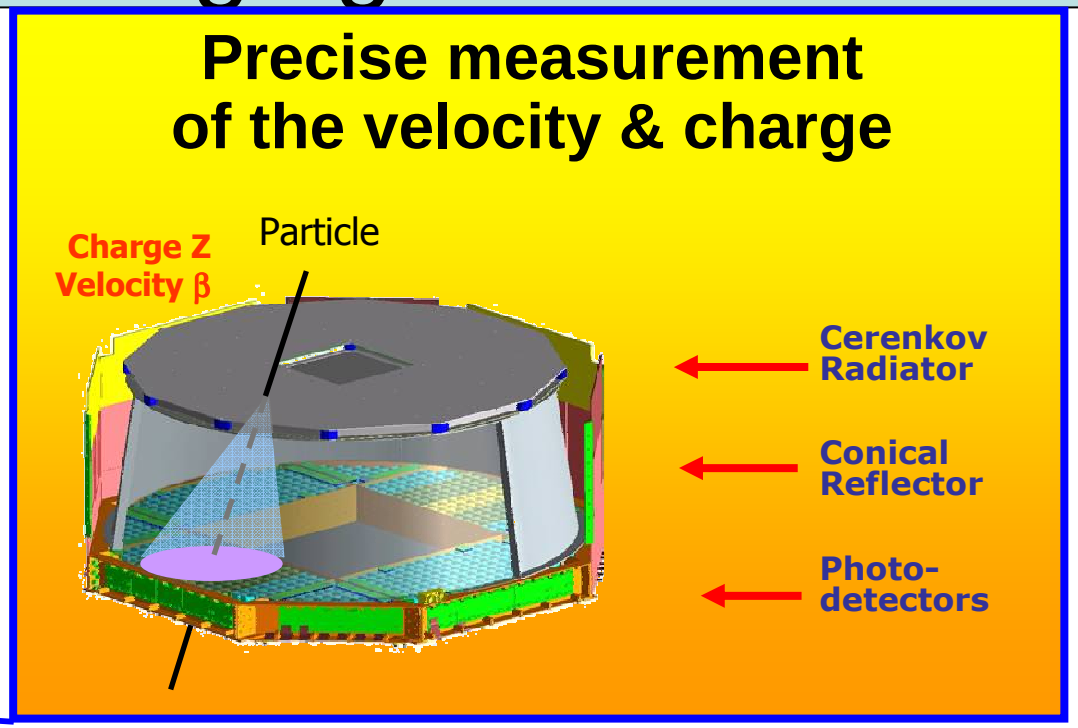


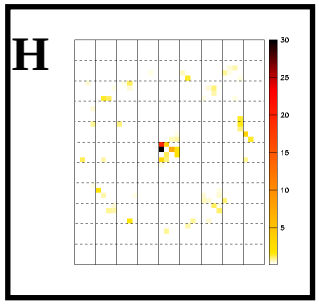
5248 tubes
2 meter length
centered to 0.1mm

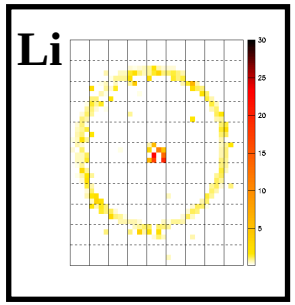


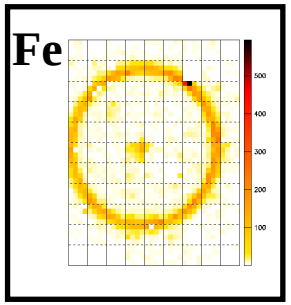
RICH: Ring Imaging CHerenkov







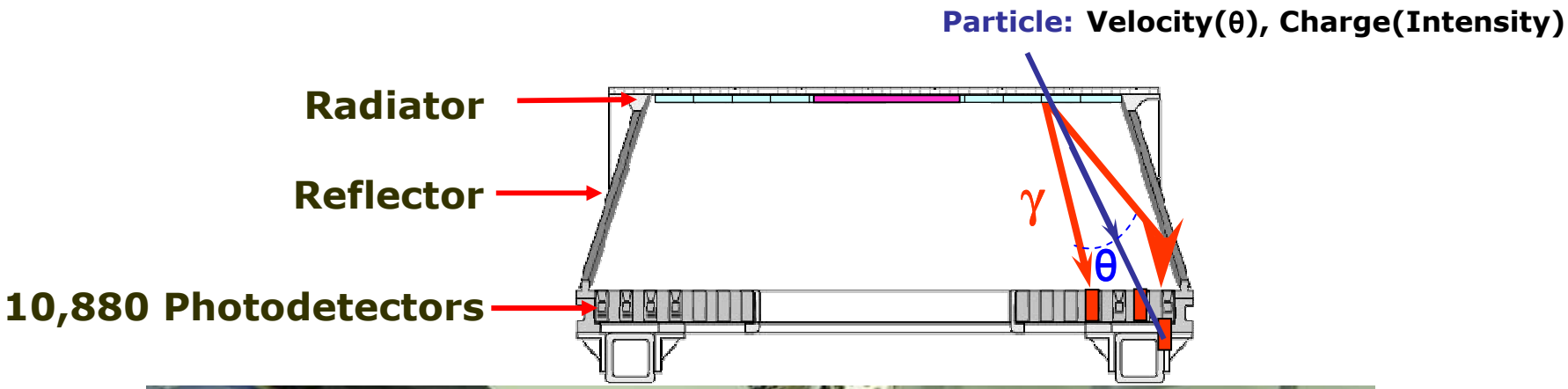


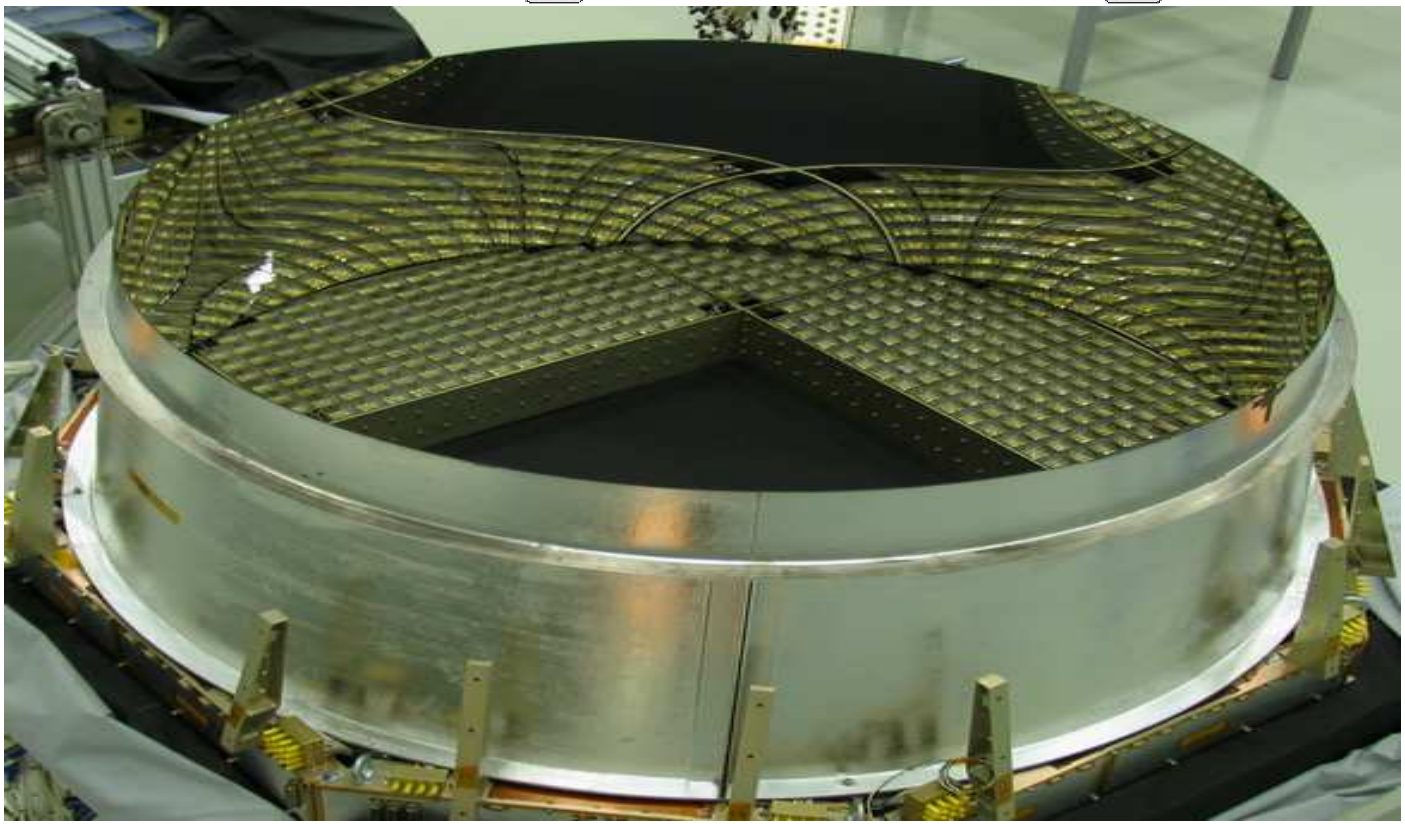


Two radiators:

- Aerogel, 2.5 cm ***(n=1.05)***
- NaF, 0.5 cm ***(n=1.336)***
- $\Delta\beta/\beta \sim 0.1\%$ (for Z=1)
- Photo-multiplier matrix of 680 x 4 x 4 channels

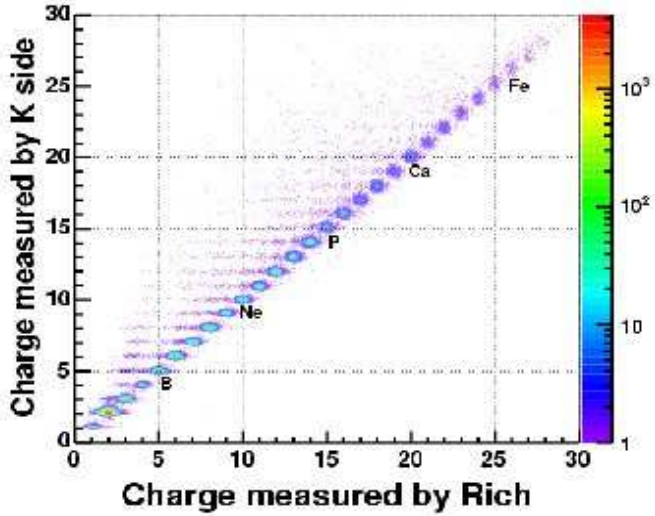
Ring Imaging Cerenkov Counter (RICH)



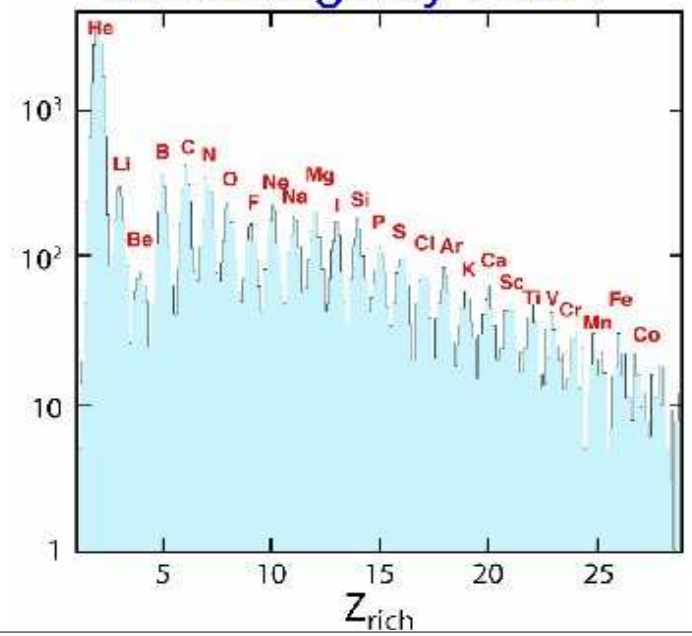


Redundancy of charge (Z) measurement (TOF,Tracker,RICH)

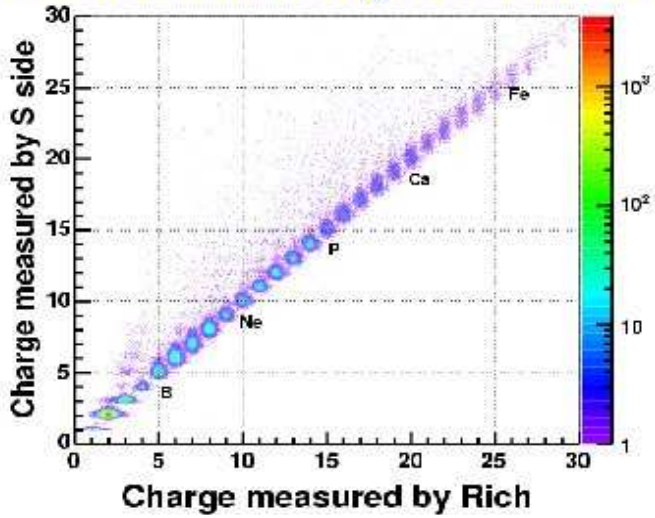
RICH vs Tracker (ohmic side)

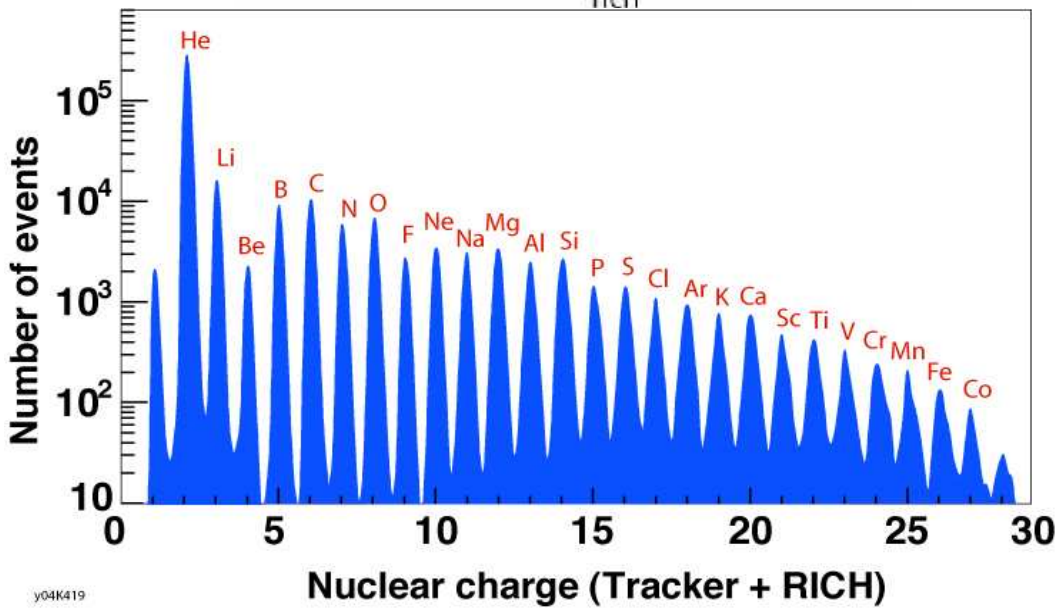


Ion Charge by RICH

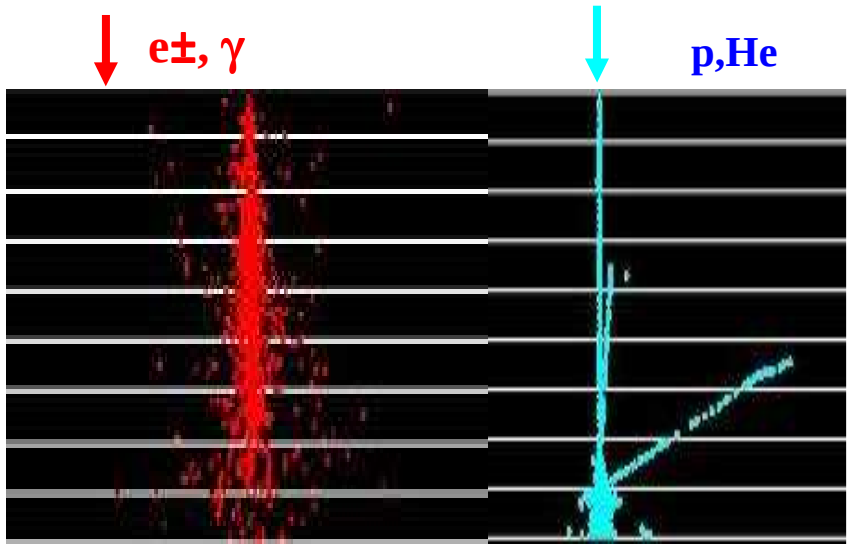


RICH vs Tracker (junction side)

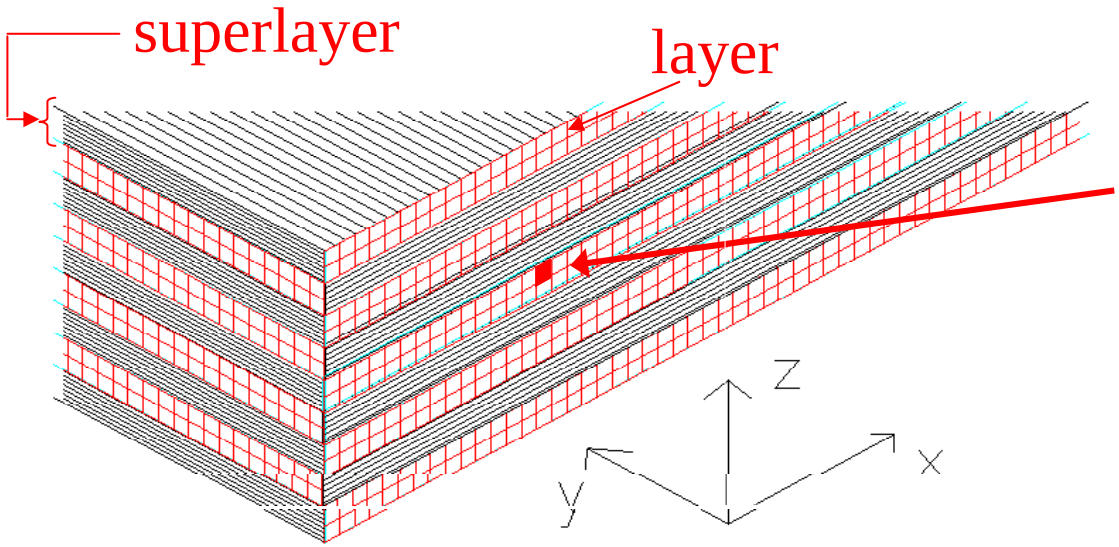


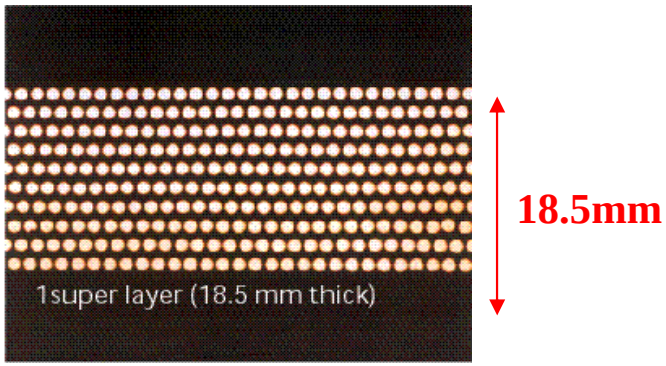


ECAL: electromagnetic calorimeter

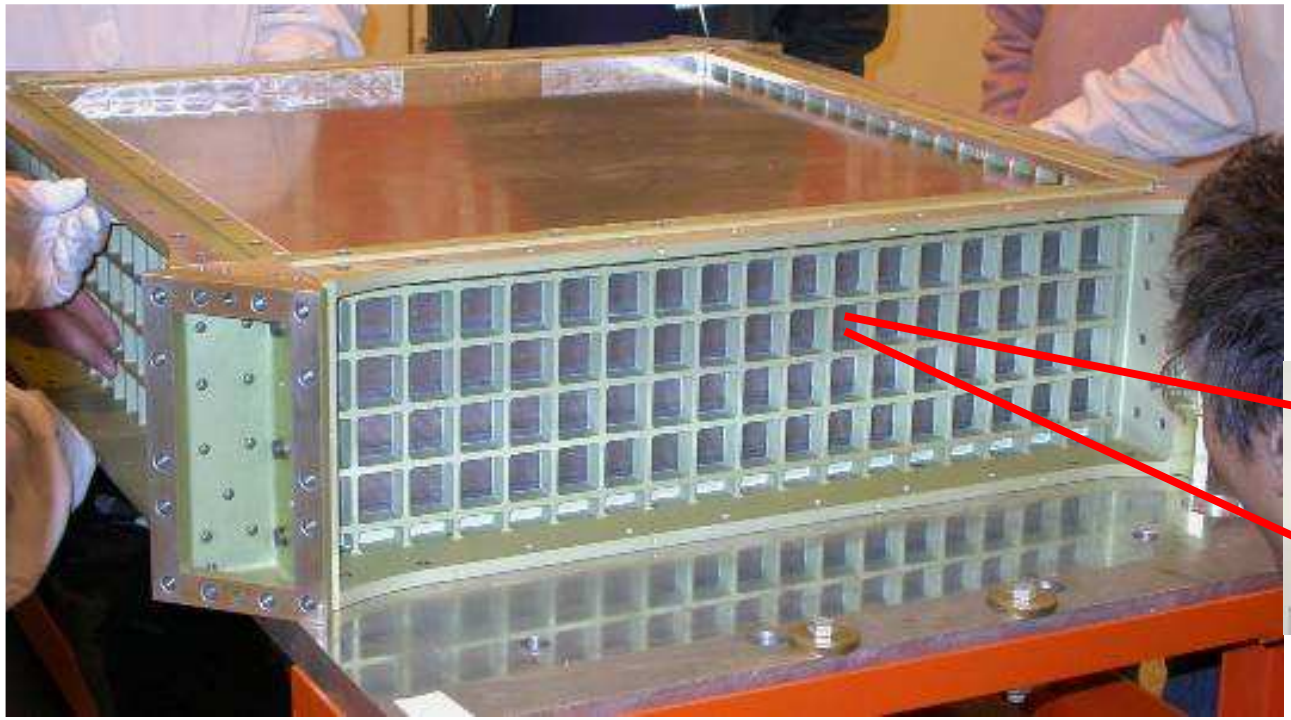


- Pb/scintillating fibers sandwich (640 kg) with 3D sampling by 9 crossed superlayers (18 layers, 5 pairs in X, 4 pairs in Y)
- Segmentation: *long:~ 1 X_0, lat: ~ 0.5 R_M*
- Length: ***~ 17 X_0 ,≈ 1 λ_R .***
- Angular resolution: *~1°*
- ΔE/E = *10%/√E + 2.6%*
- Proton suppression up to 10^4 at 500 GeV. (10^6 with TRD)

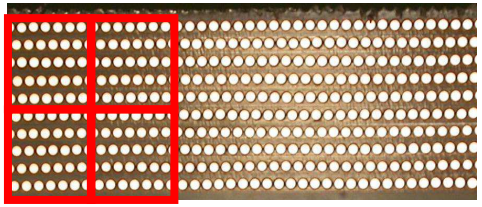




Imagerie 3D



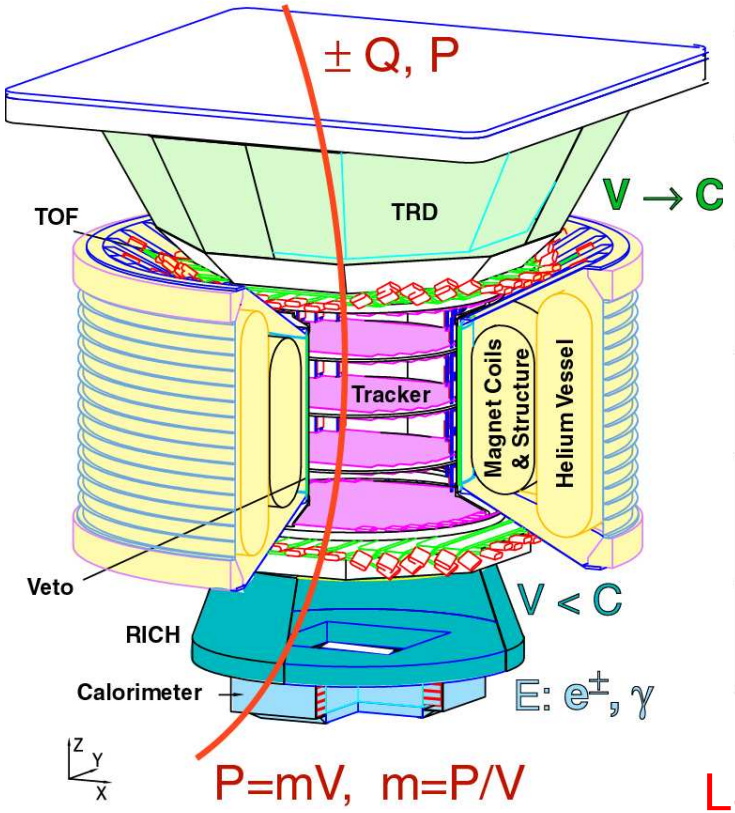
Superlayer

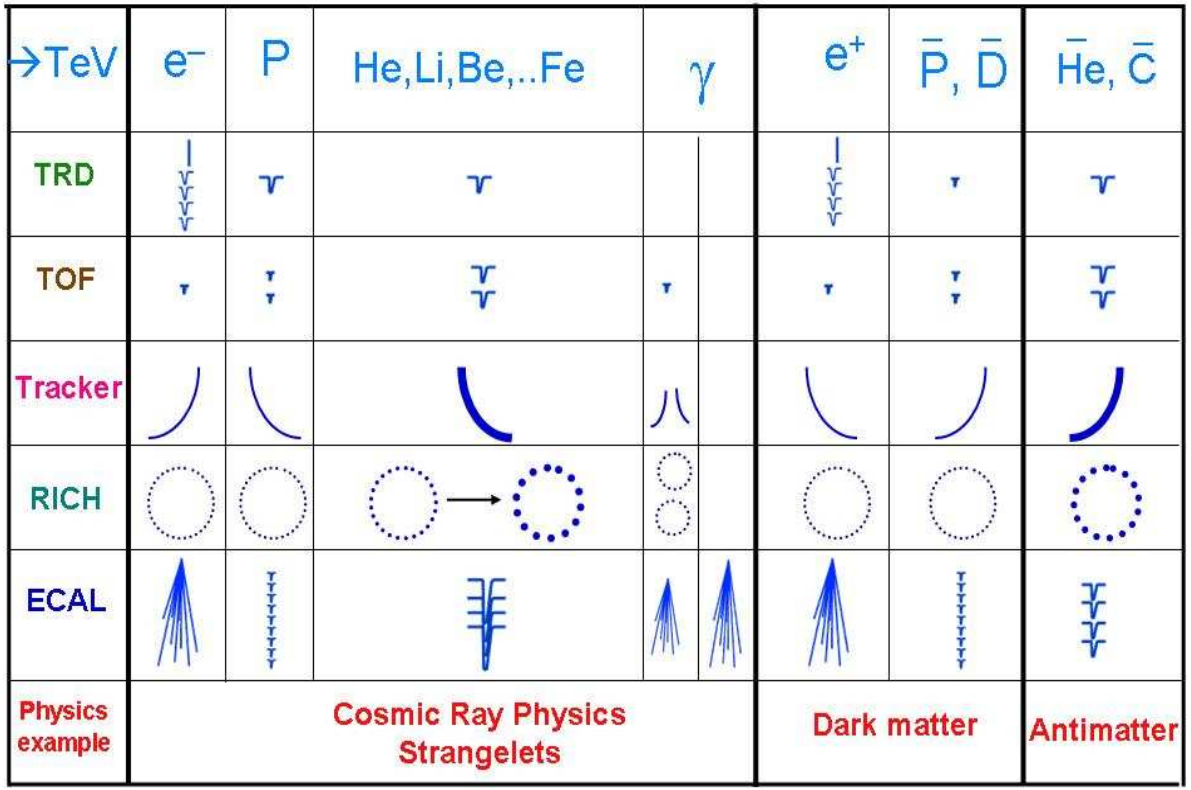


1 cell = 35 fibers

324 PMs x 4 cells

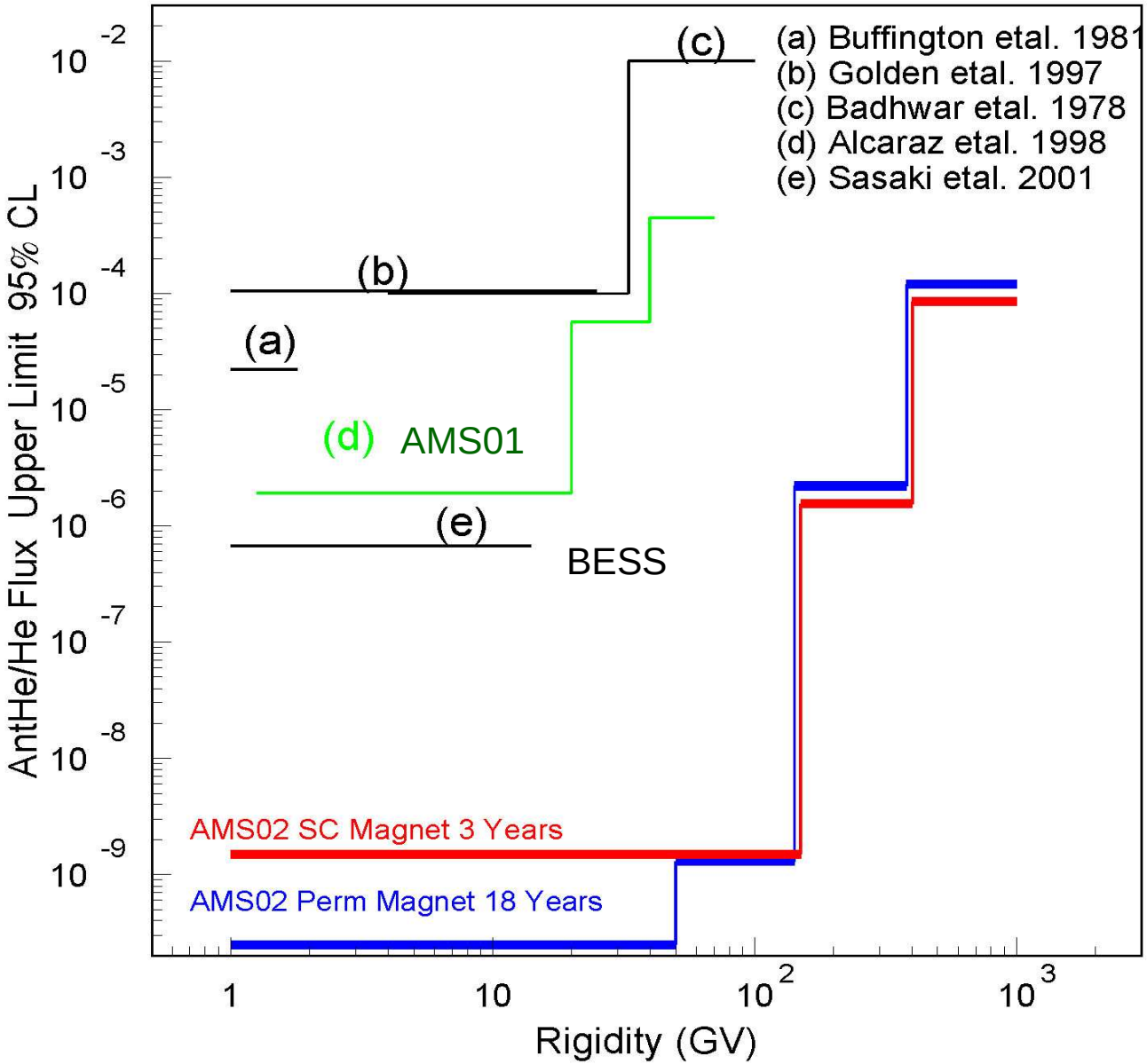
Identification grâce à la combinaison de la réponse des sous-détecteurs



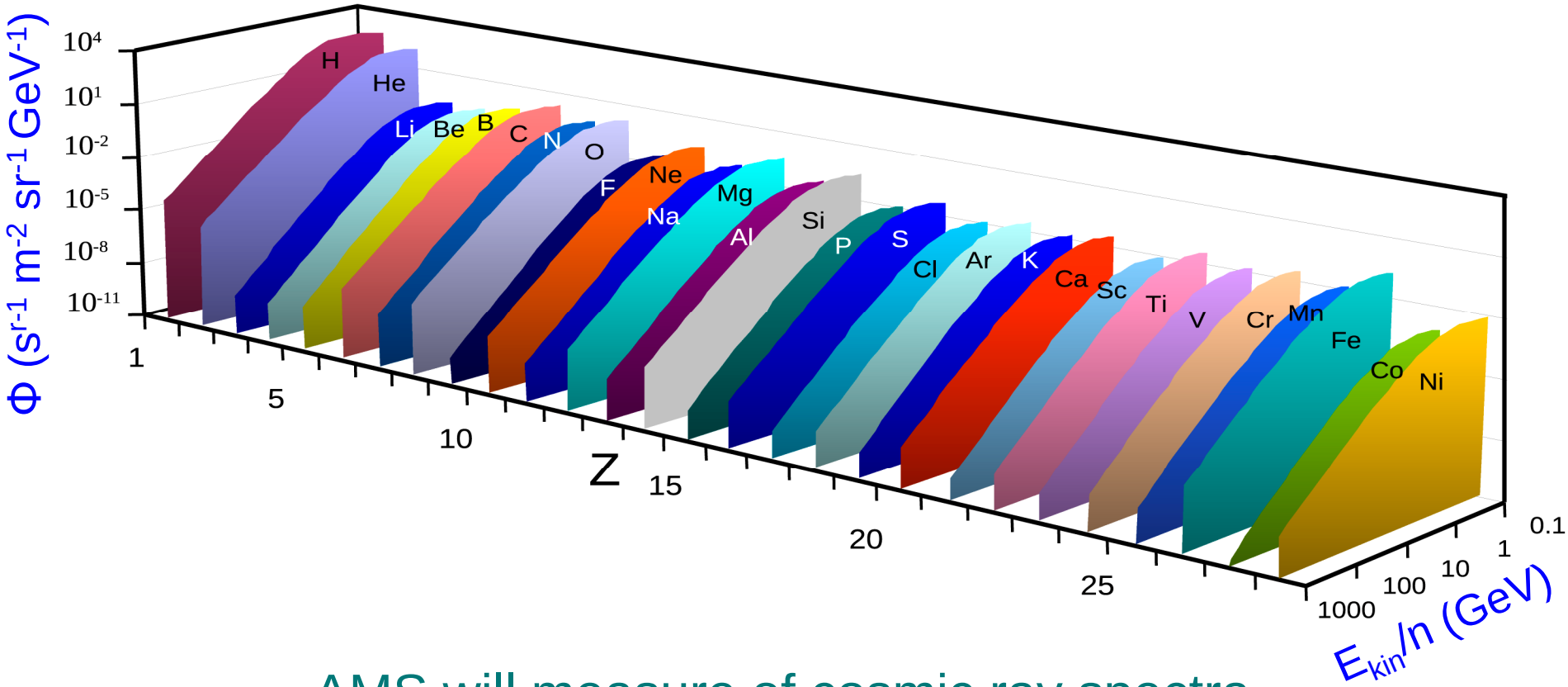


La redondance est importante pour identifier des événements rares

AMS goal: Limits on anti-Helium in cosmic rays



Physics of AMS: Nuclear Abundances Measurements

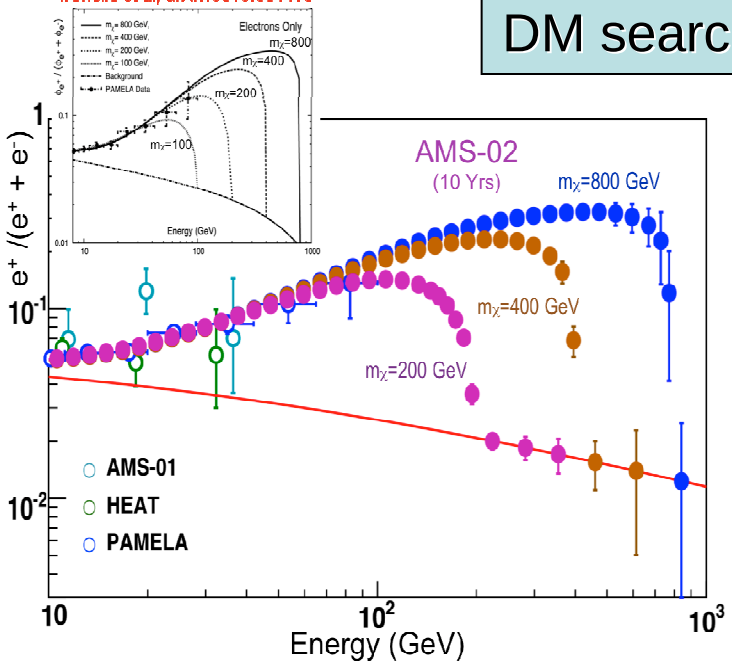


AMS will measure of cosmic ray spectra
for nuclei, for energies from 100 MeV to 2 TeV
with 1% accuracy over the 11-year solar cycle.

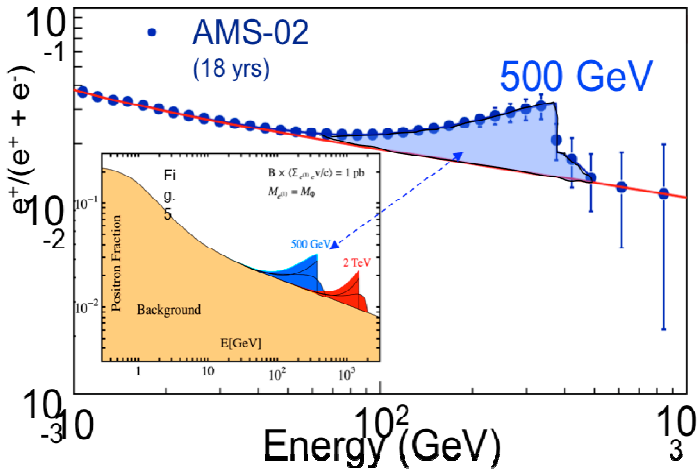
These spectra will provide experimental measurements of the assumptions that go into calculating the background in searching for Dark Matter, i.e., $p + C \rightarrow e^+, \bar{p}, \ldots$

DM searches with AMS-02

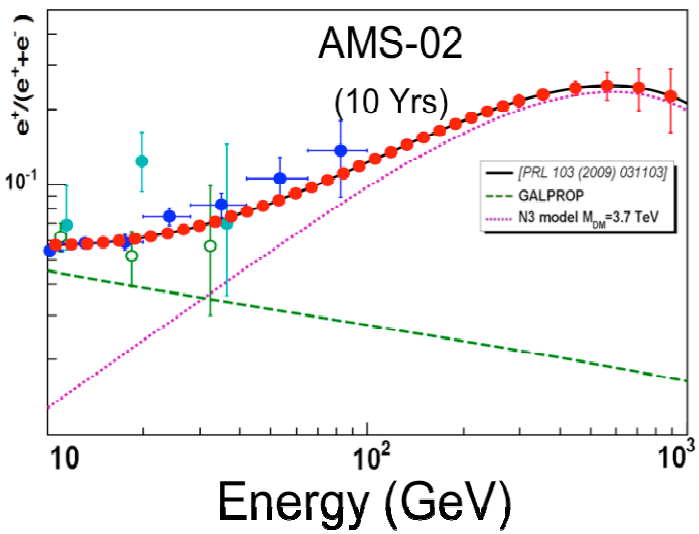
I.Cholis et al, arXiv:0810.5344v3



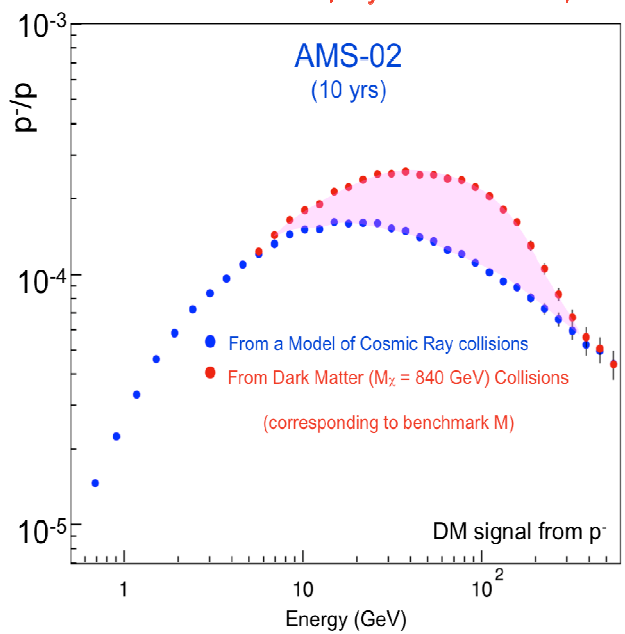
E. Pontón & L. Randall: arXiv:



L.Bergstrom et al, PRL 103 (2009) 031103

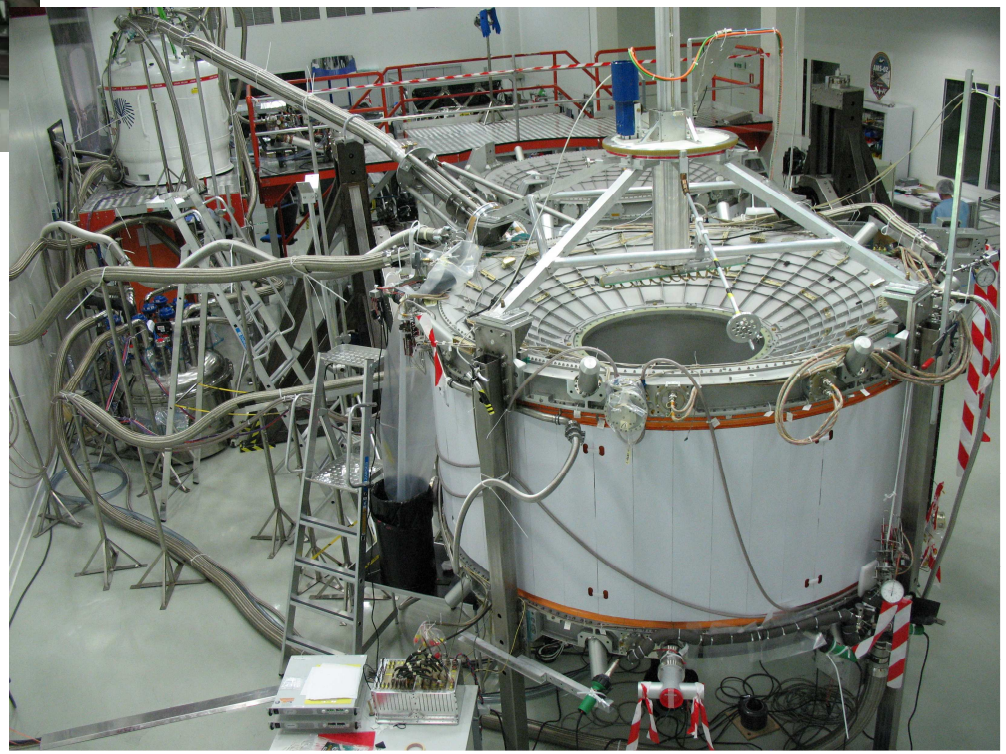


P. Brun, Phys.Rev.D76:083506, 2007



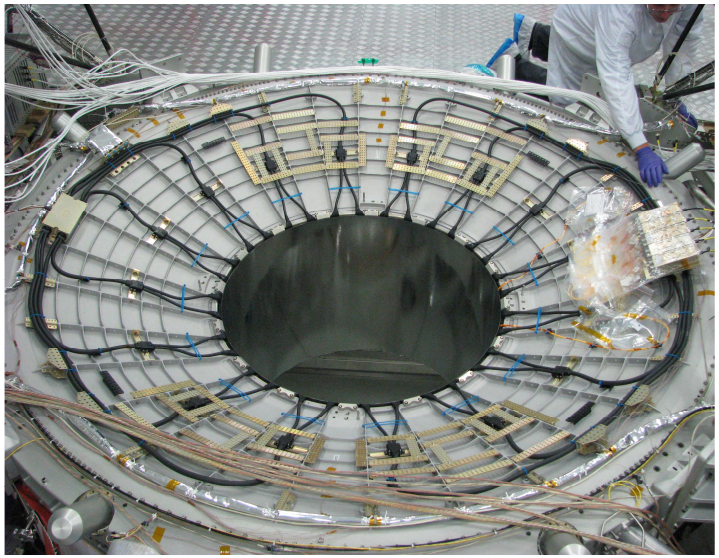
Integration of AMS: at CERN in a new clean room

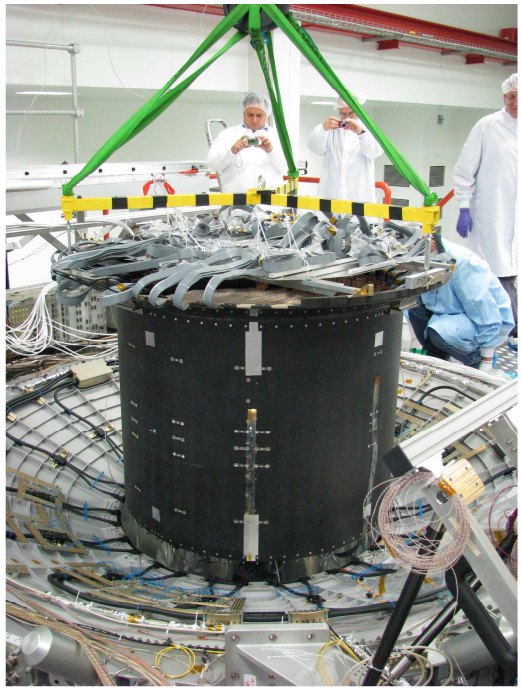
- 2007-08: pre-integration with spare vacuum case (waiting for the magnet)
- mid 2008: de-integration

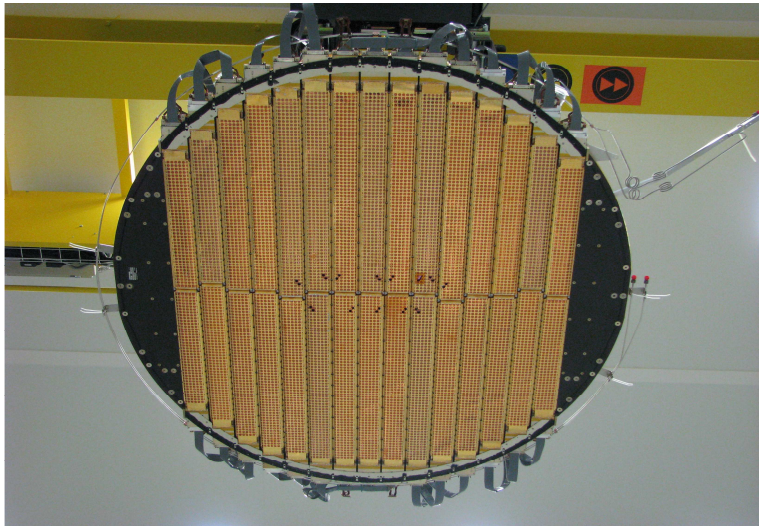


- Dec 2008: arrival of magnet
- Tests, cooling, operation of the magnet and measurement of its field → september 2009

Sub-detector *final* ***integration (19-31 octobre 2009)***







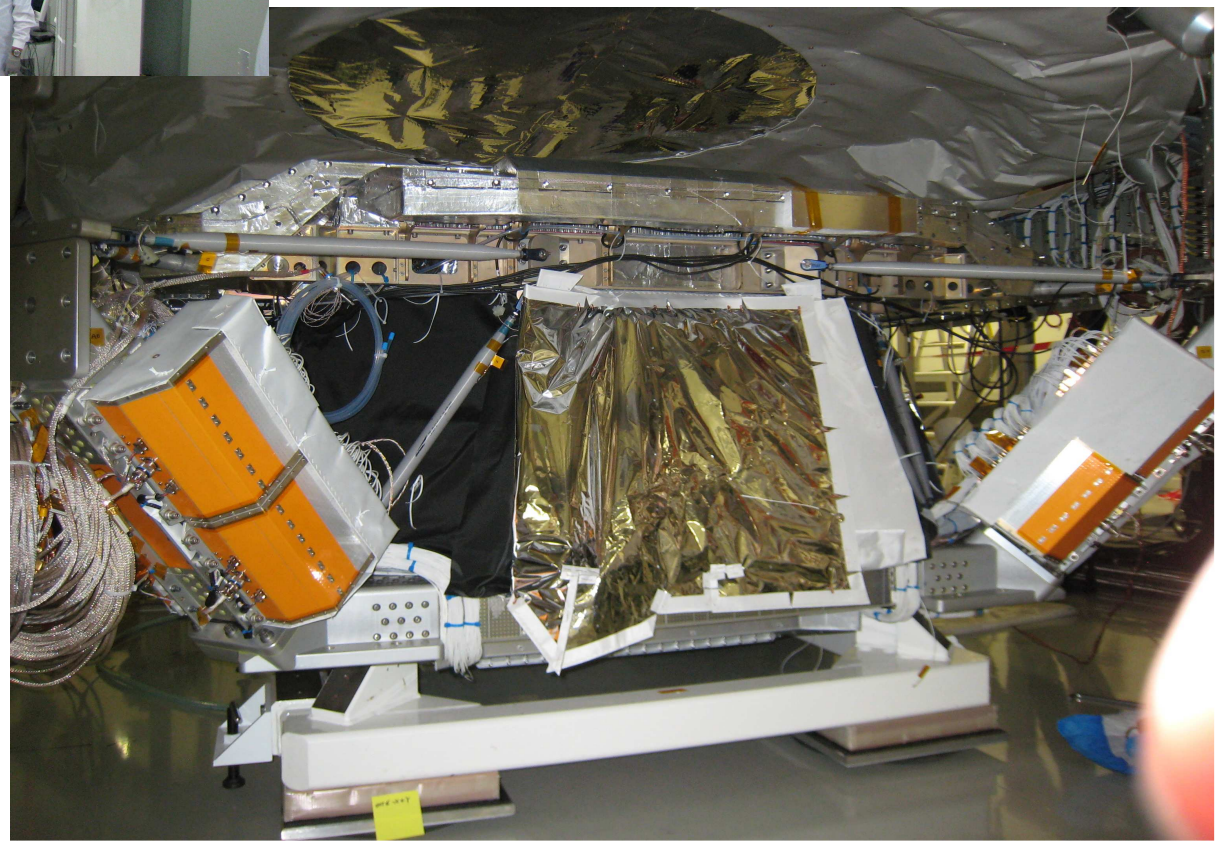
Tracker integration and cabling

October 19-29, 2009

TRD + UpperTOF

0ctober 29-31, 2009

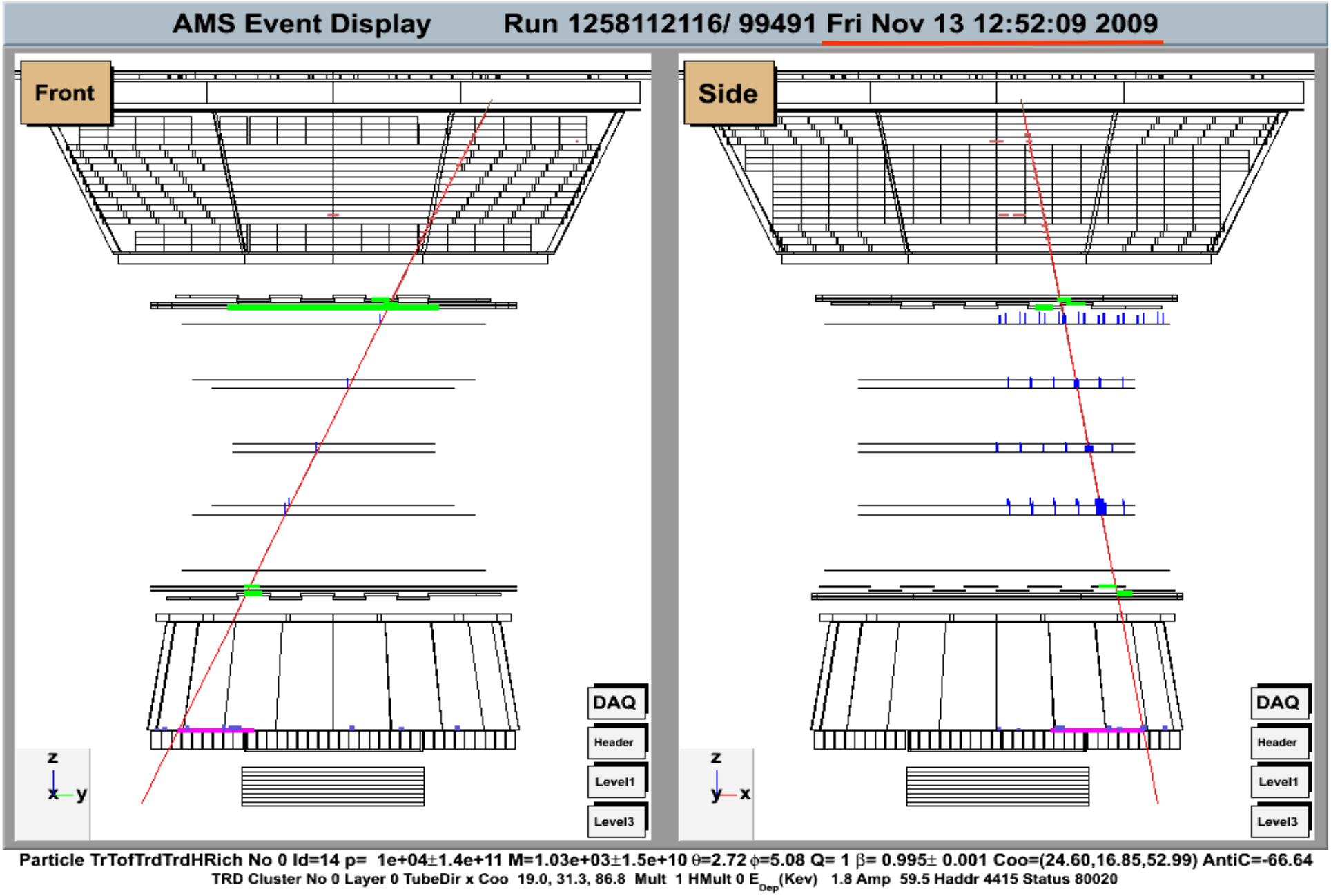
LowerTOF + RICH + ECAL



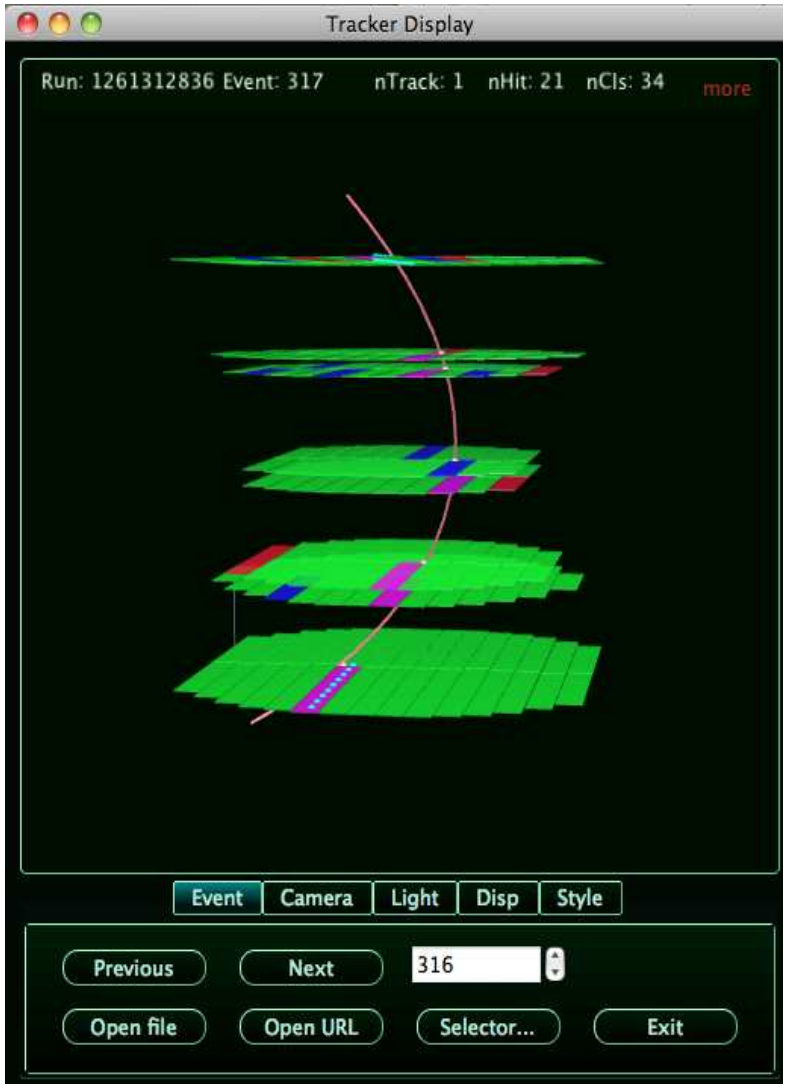
Nov/Dec 2009:

- end of cabling
- tests with cosmics
- cooling installation (radiators, piping)
- commissioning of magnet cryostat

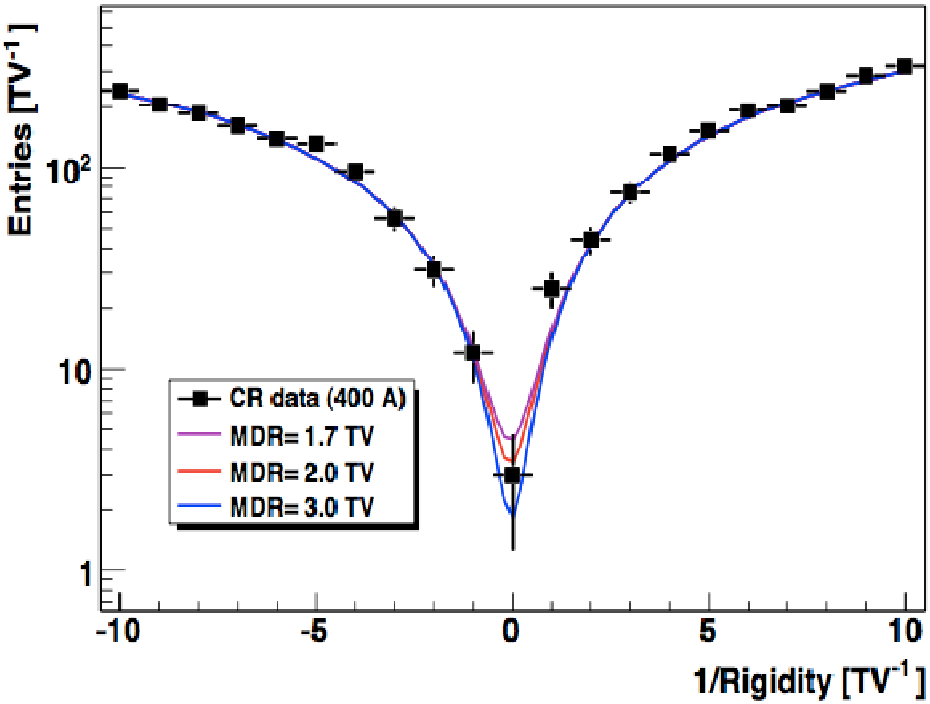
Tests and alignment with cosmics during magnet commissioning



20 Dicembre 2009 : run stabile con carica del magnete @ 400 A

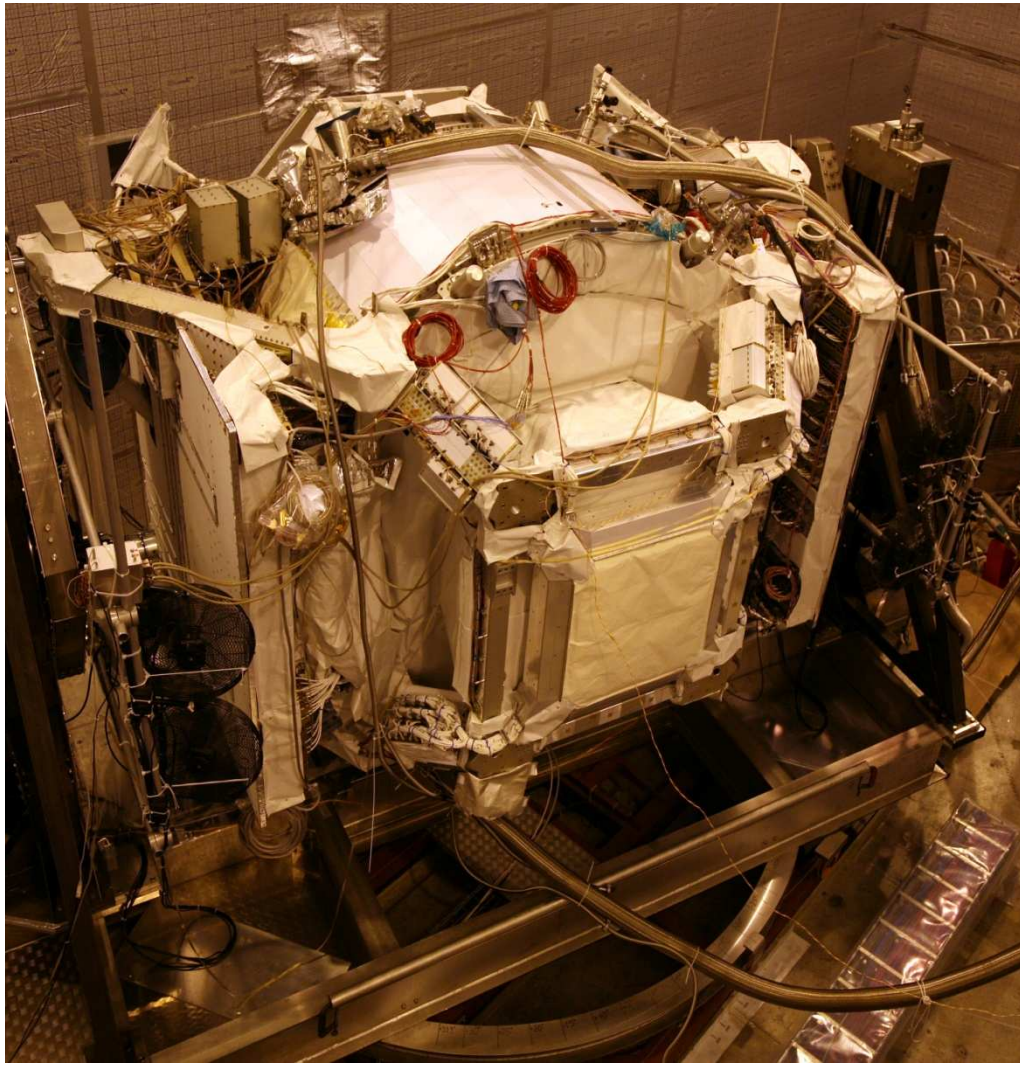


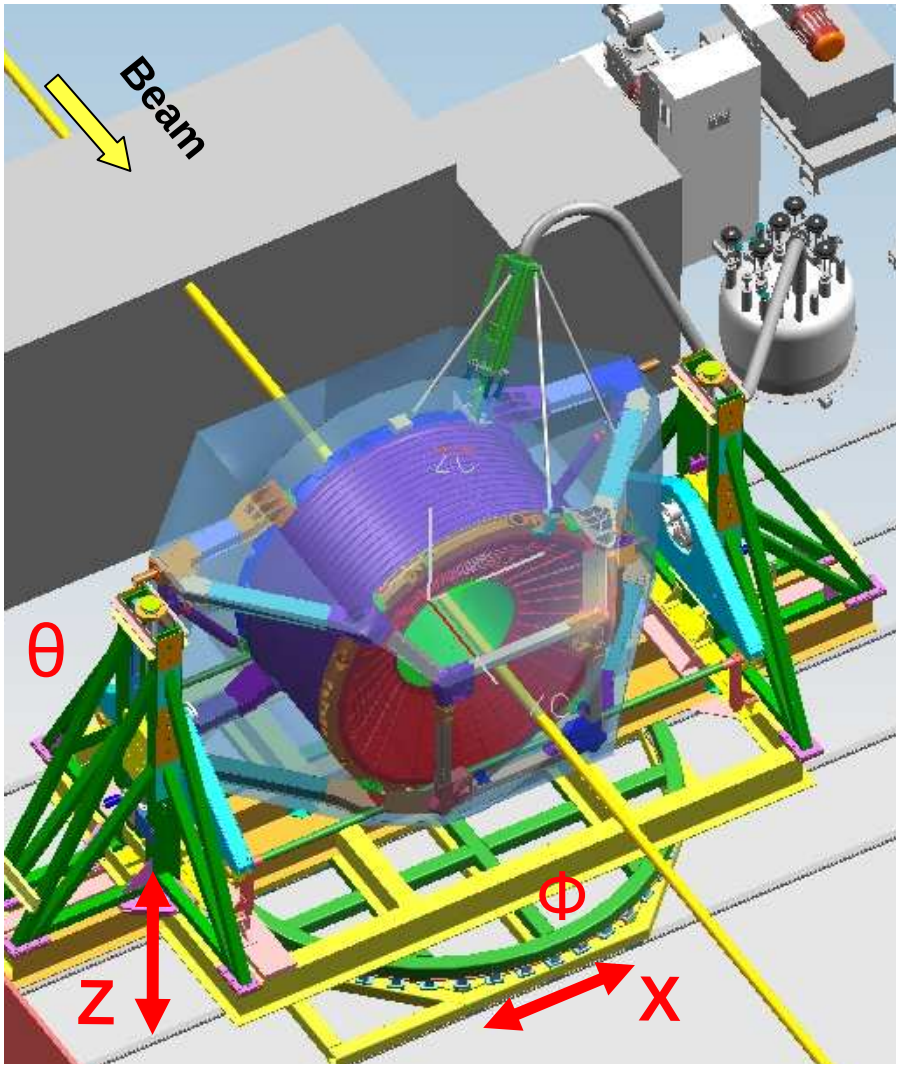
Cosmic muons



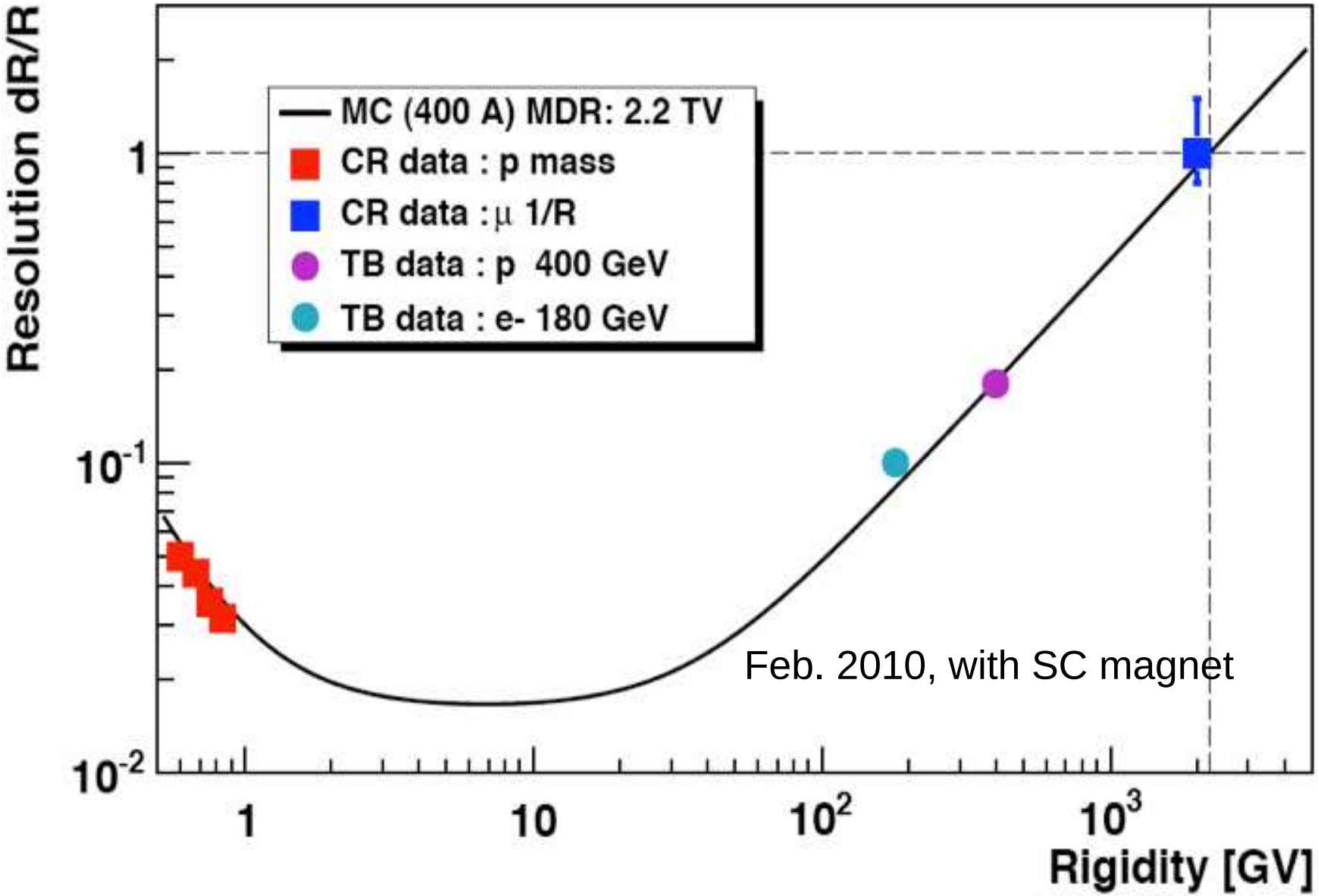
AMS in Test Beam (CERN)

Feb 4-8, 2010

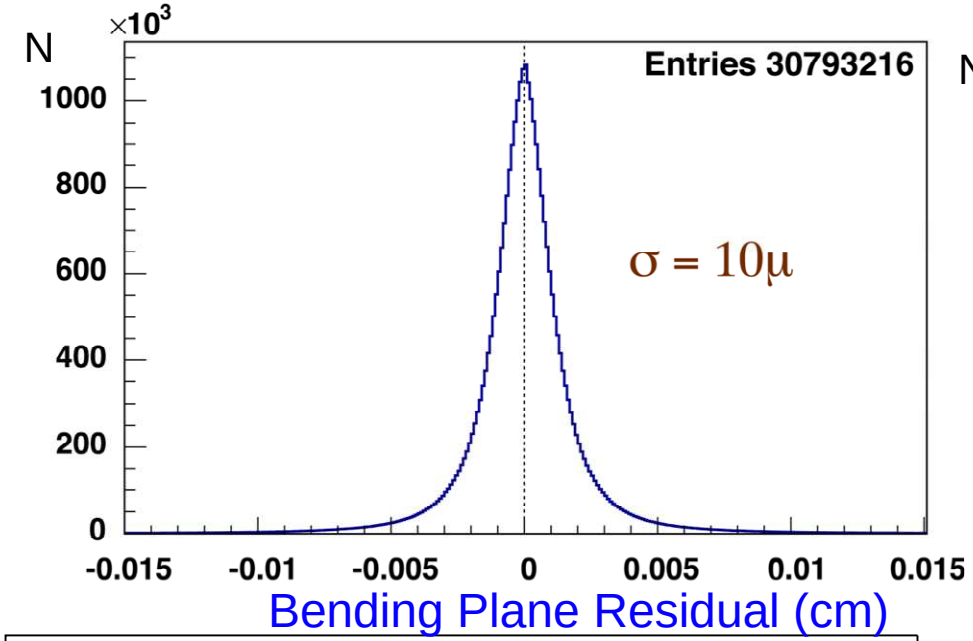


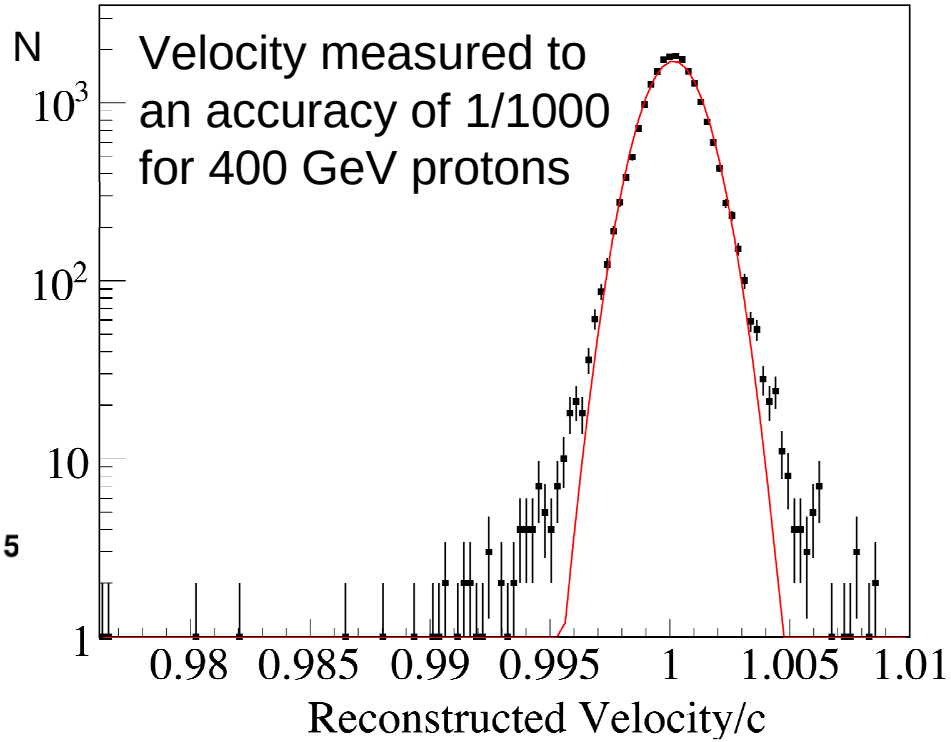


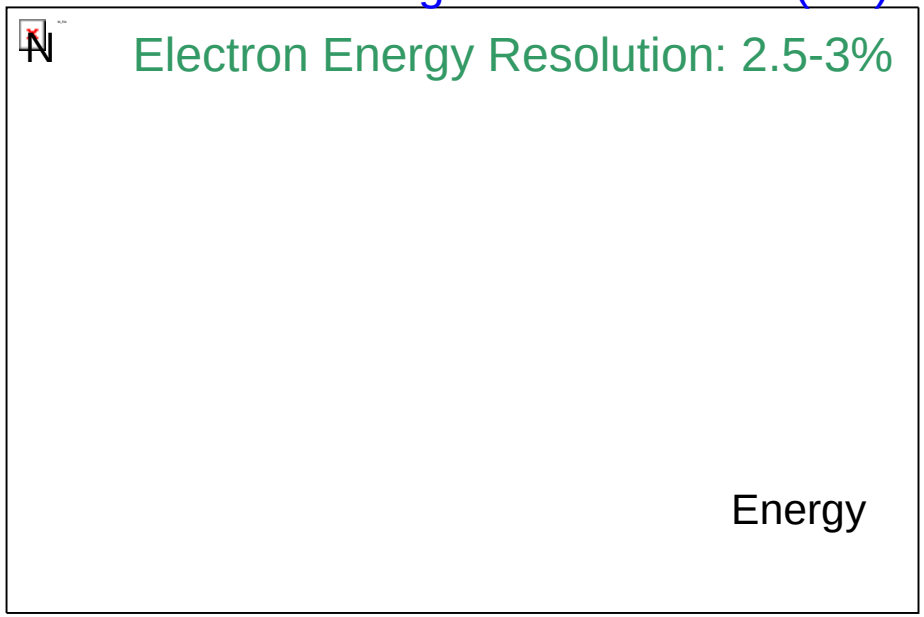
Test Beam 2010 : momentum resolution of the spectrometer

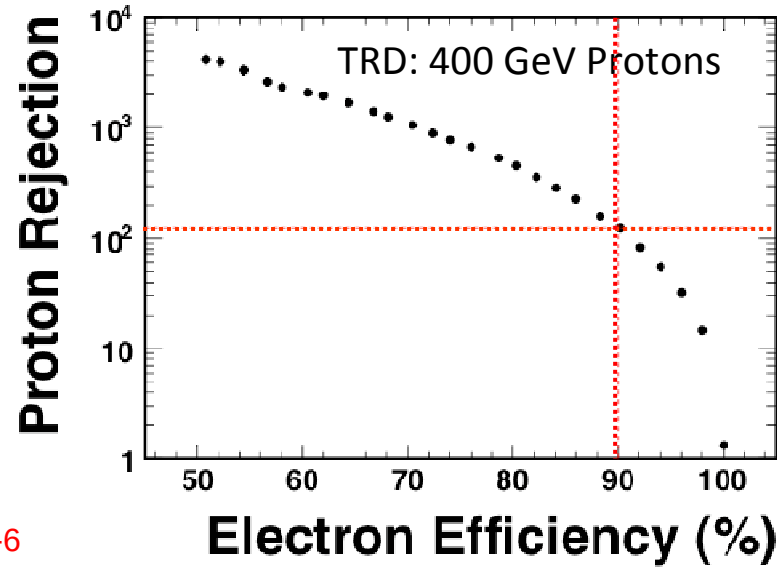


Test Beam Results with superconducting magnet – Feb 2010





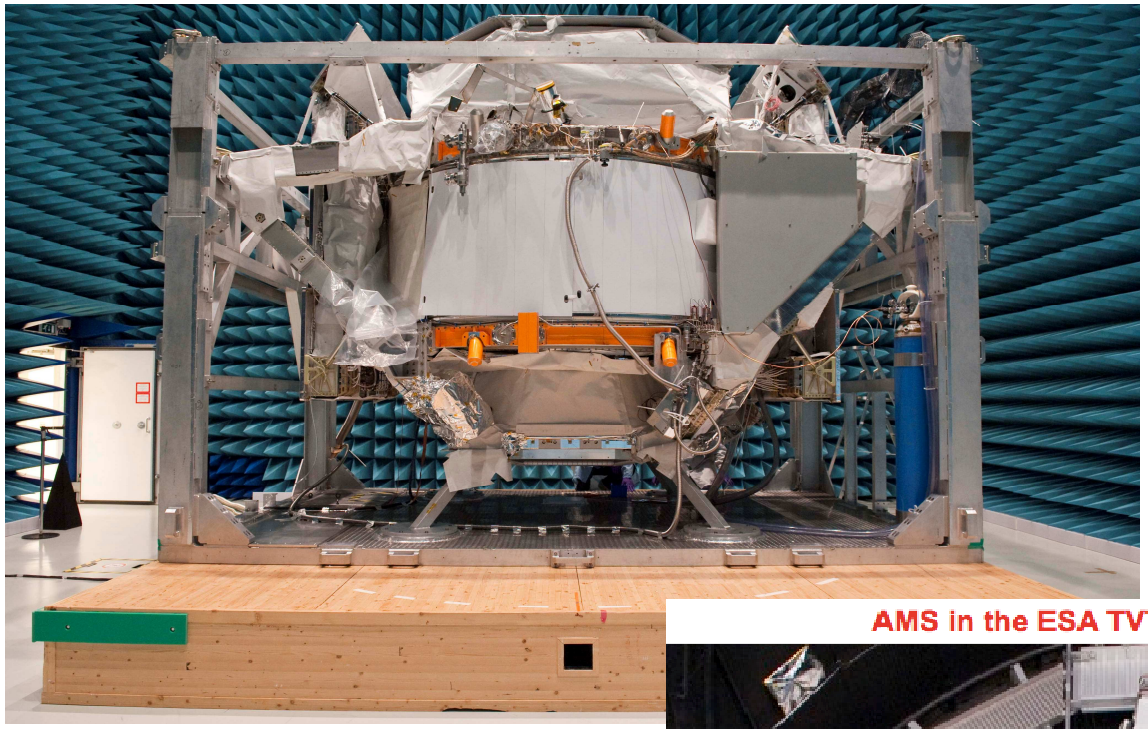




Measured combined rejection power at 400 GeV: $e^+/p = 10^{-6}$

Journey from CERN to ESTEC

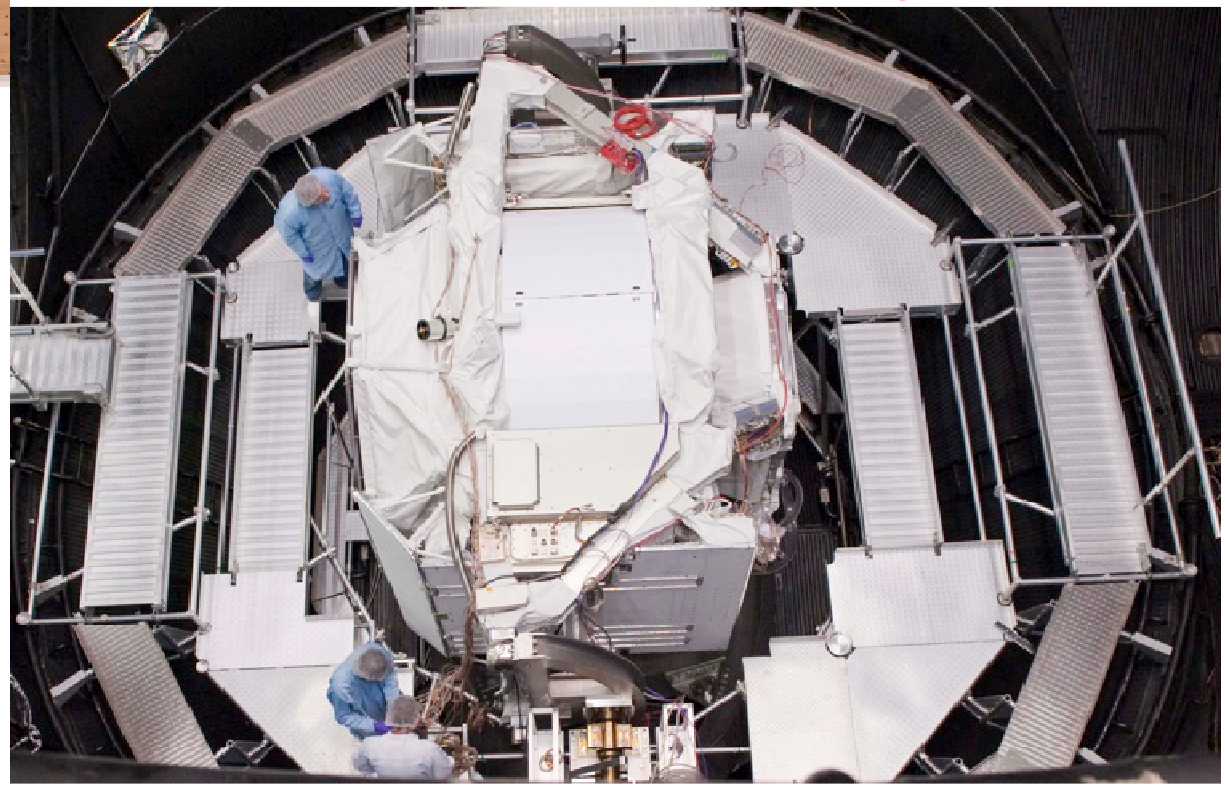
(ESA center at Noordwijk, NL)



AMS in Maxwell EMI test chamber at ESTEC

AMS in TVT chamber at ESTEC

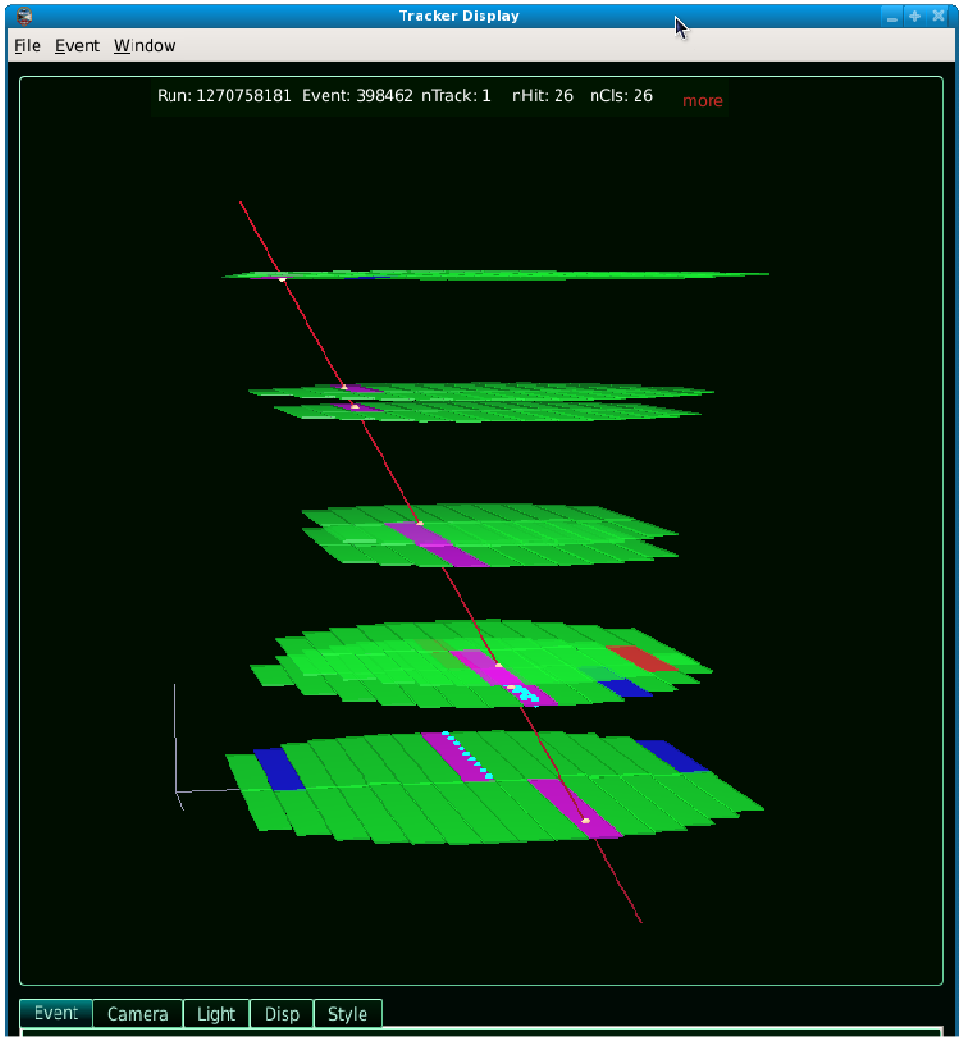
AMS in the ESA TVT Chamber in the horizontal position

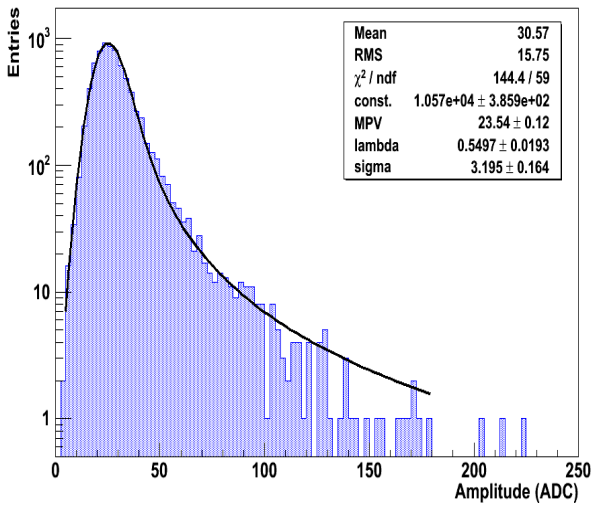


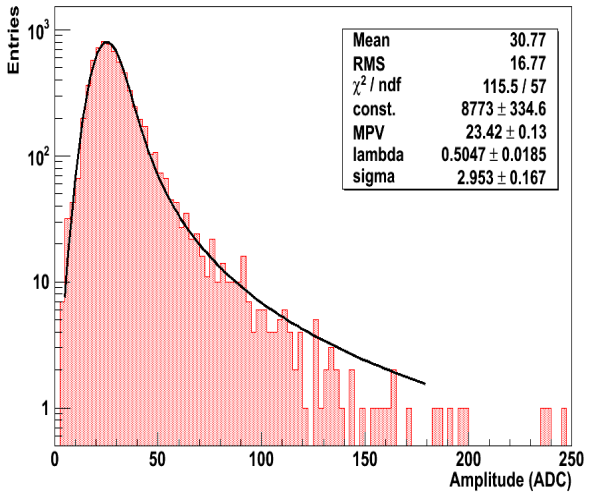
Simulation of space conditions (vacuum, tempetrature and solar radiation)

Feb, March 2010

TRACKER PERFORMANCE at −90°C: a muon track & mip signal in silicon

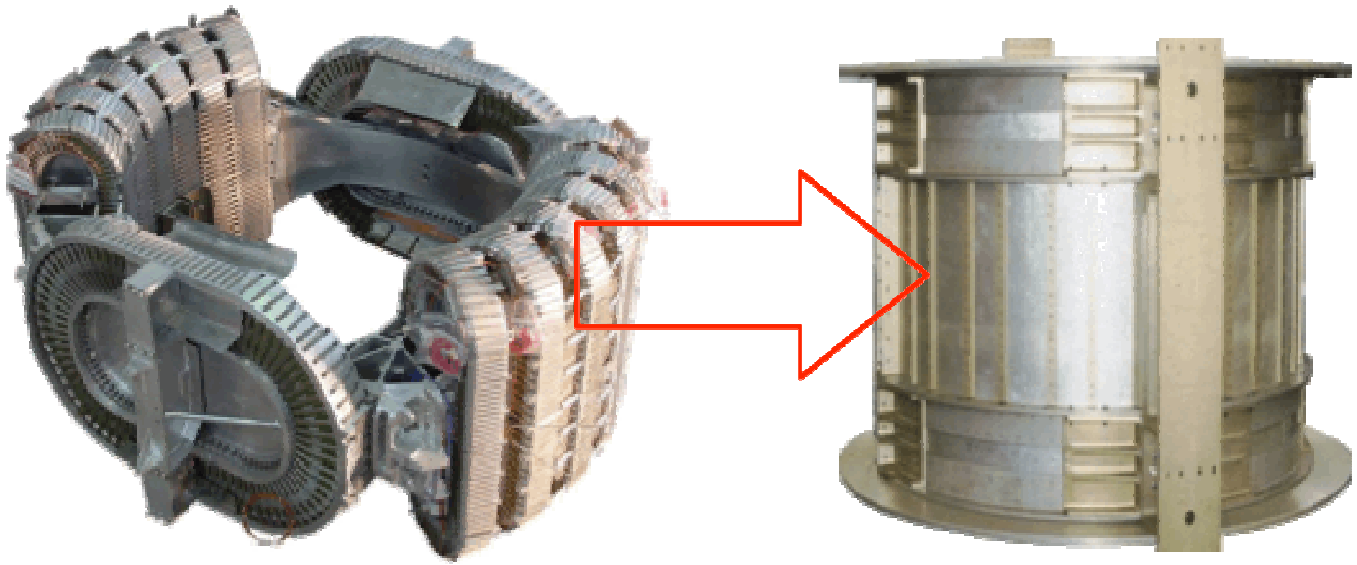






Change of Strategy after test at ESTEC *(april 16, 2010)*

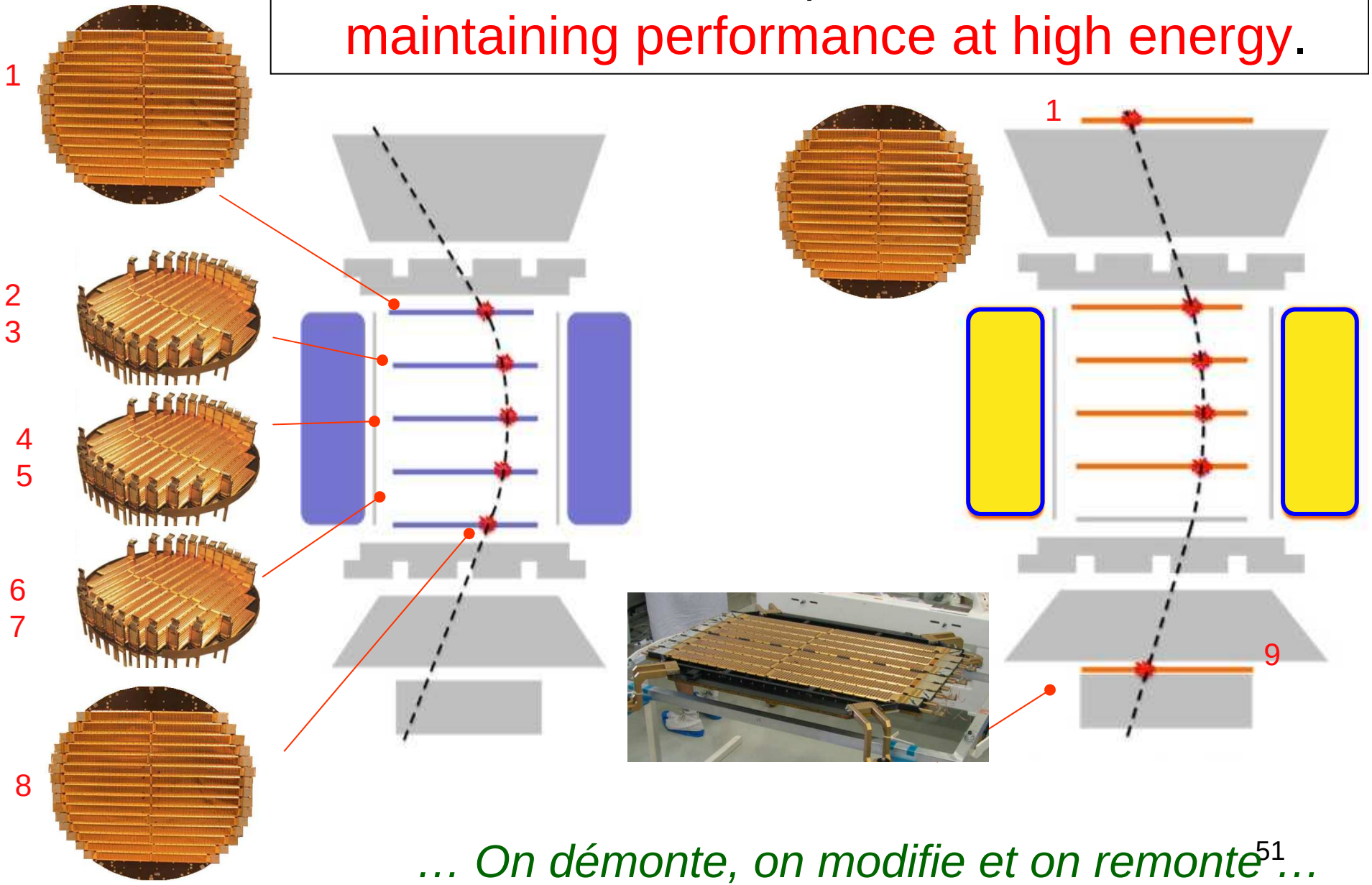
- Measured Helium consumption: → 20 ±4 months of SC magnet operation
- Refilling is not an option (AMS will stay on ISS)
- ISS life and operation time is extended (→ 2020, 2028 ?)
- Availability of a 2nd cylindrical support (spare vacuum tank) + AMS-1 magnet
- → The exposure time can be multiplied by a large factor.



Magnete superconduttore
B = 0.8 T

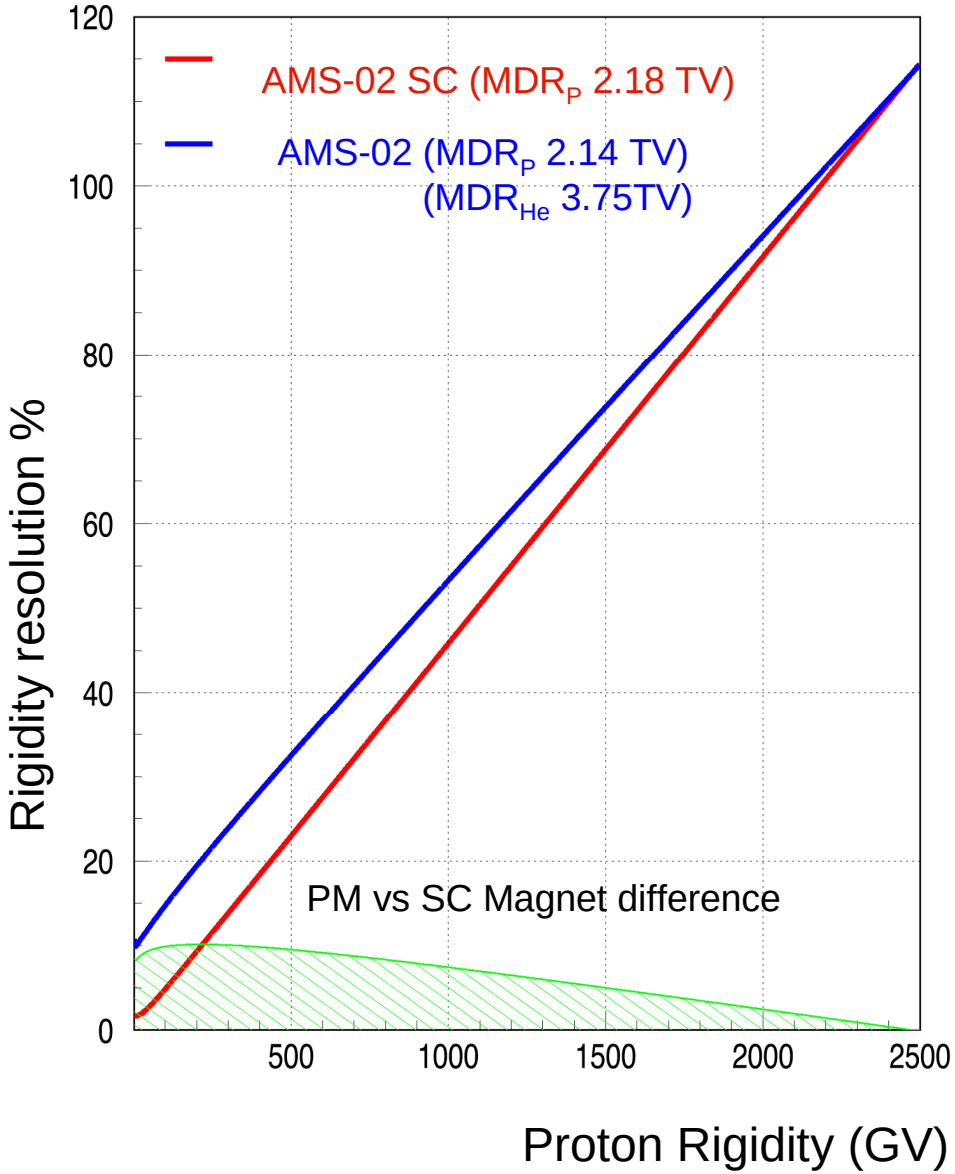
Magnete permanente
B = 0.13 T

Tracker geometry is modified in order to increase the lever arms to compensate the lower field, maintaining performance at high energy.

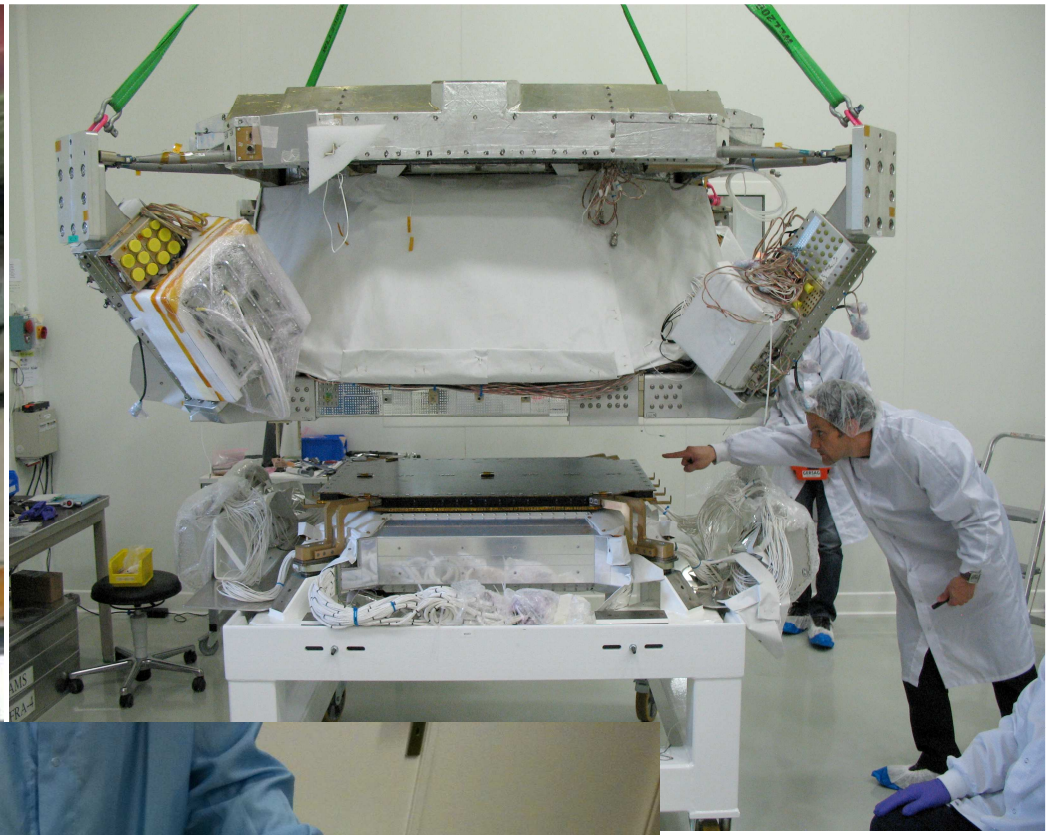


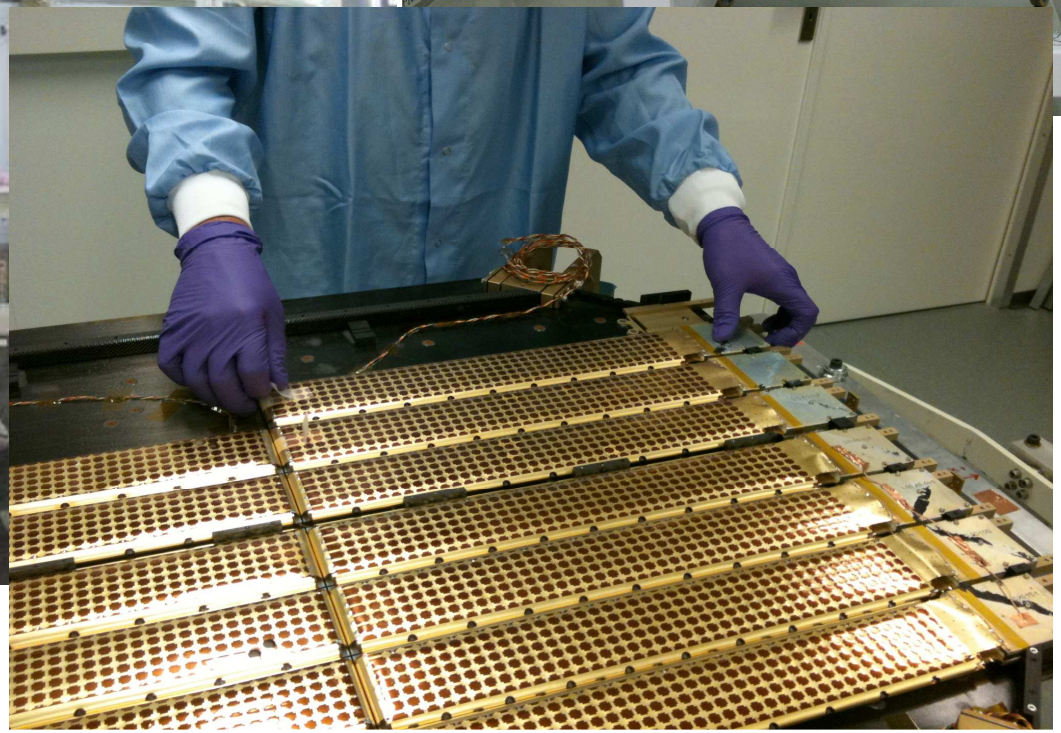
… On démonte, on modifie et on remonte…

Design curves for SC and PM tracker resolution ….



Real curves after beam test final analysis and muon data taking

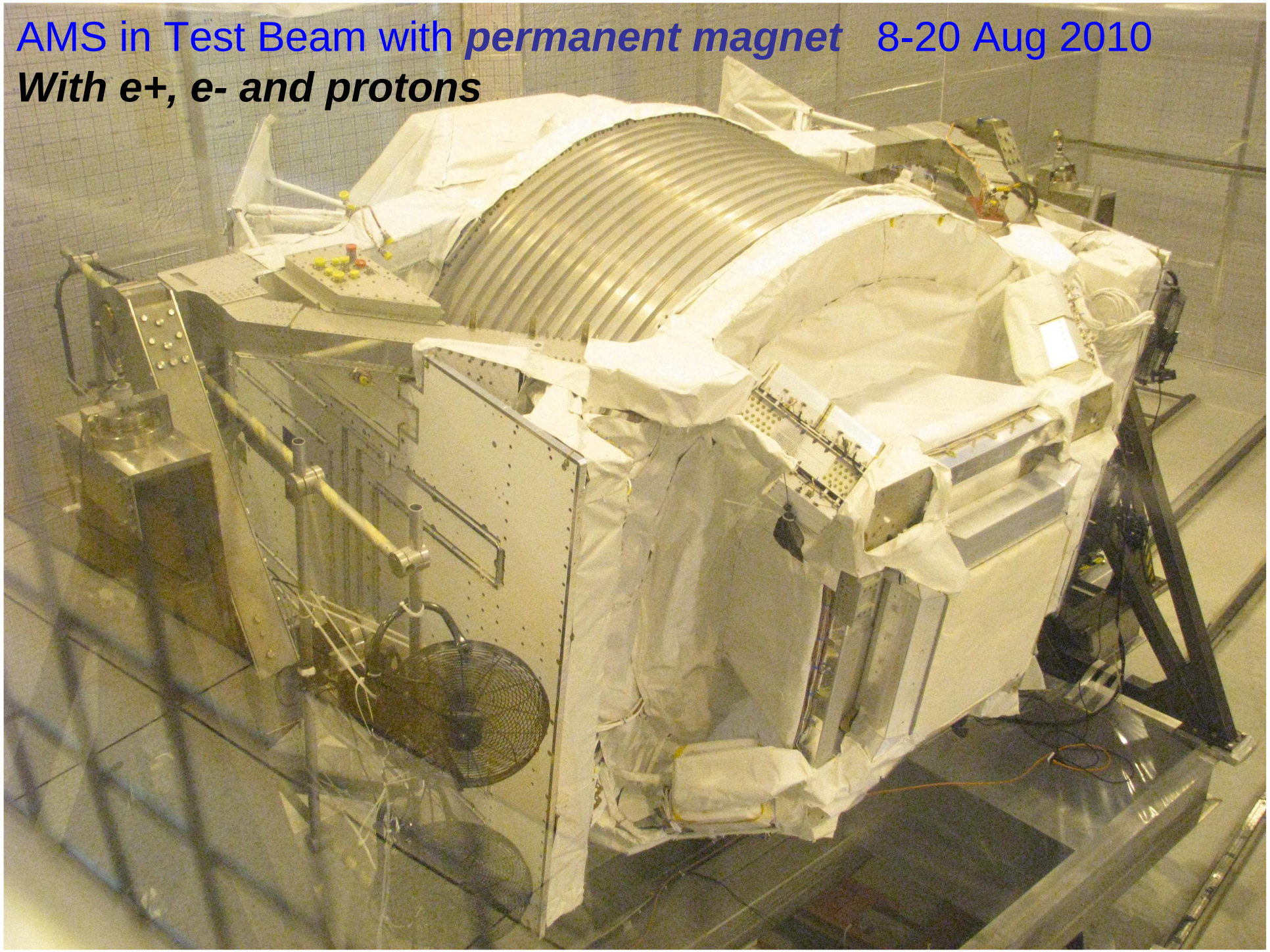





7 août 2010
AMS

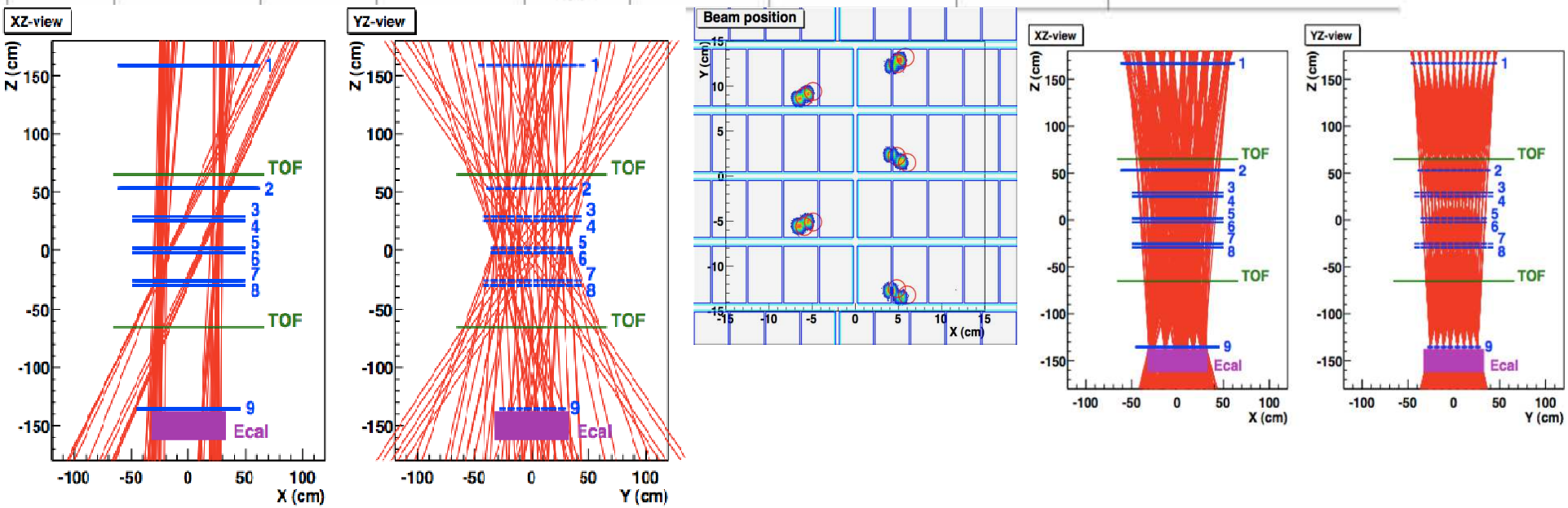
AMS in Test Beam with ***permanent magnet*** 8-20 Aug 2010

With e+, e- and protons

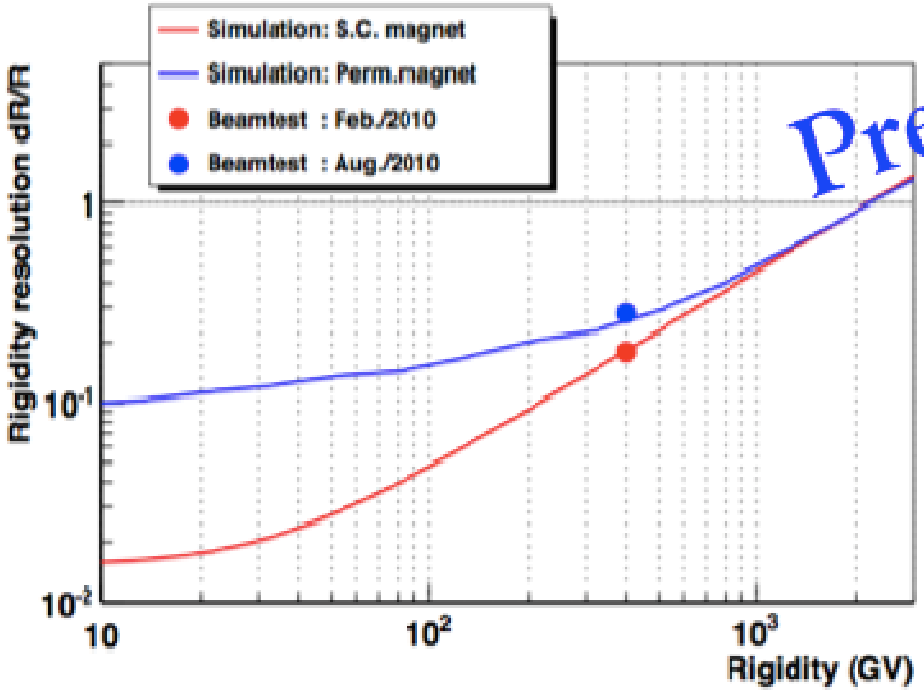


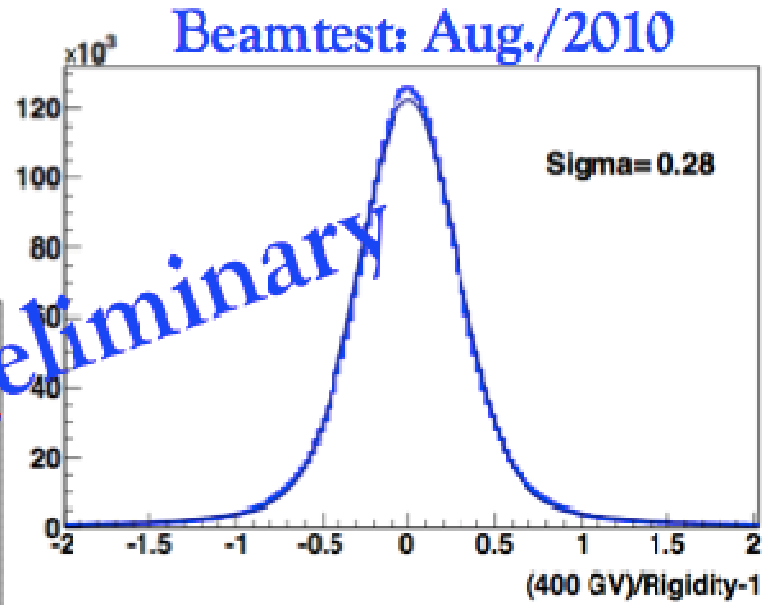
Calibrazione con p a 400 GeV

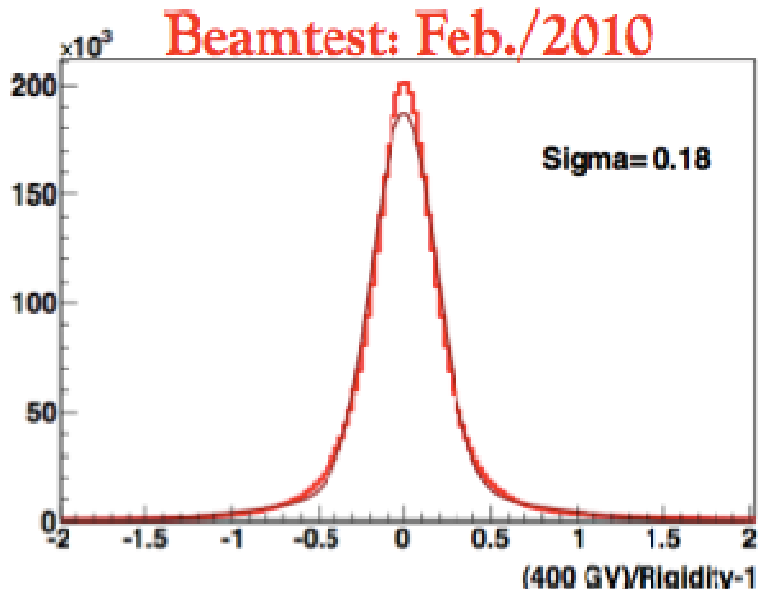
Particle	Momentum	C1/C2 Pr (Bar)	Min Events Per Pos	Spills Per Pos	Time (hrs) Total	Positions	Rate (p/sp) Expected	Comment
Protons	400 GeV	2/2	10^6	75	1	Center, 5°	20k	Initial Setup
Protons	400 GeV	2/2	10^4	3	5	TRACKER60	20k	Inner Tracker Alignment
Protons	400 GeV	2/2	10^4	7	1	TRACKER10	20k	Laser Correlation
Protons	400 GeV	2/2	10^4	3	30	TRACKER416	20k	Layers 1/9 Alignment
Protons	400 GeV	2/2	10^4	3	6	TRACKER80	20k	Layers 2/9 Alignment
Protons	400 GeV	2/2	10^4	3	24	TRACKER280	20k	Layers 1/8 Alignment
				67				



Risultati preliminari : TRACKER

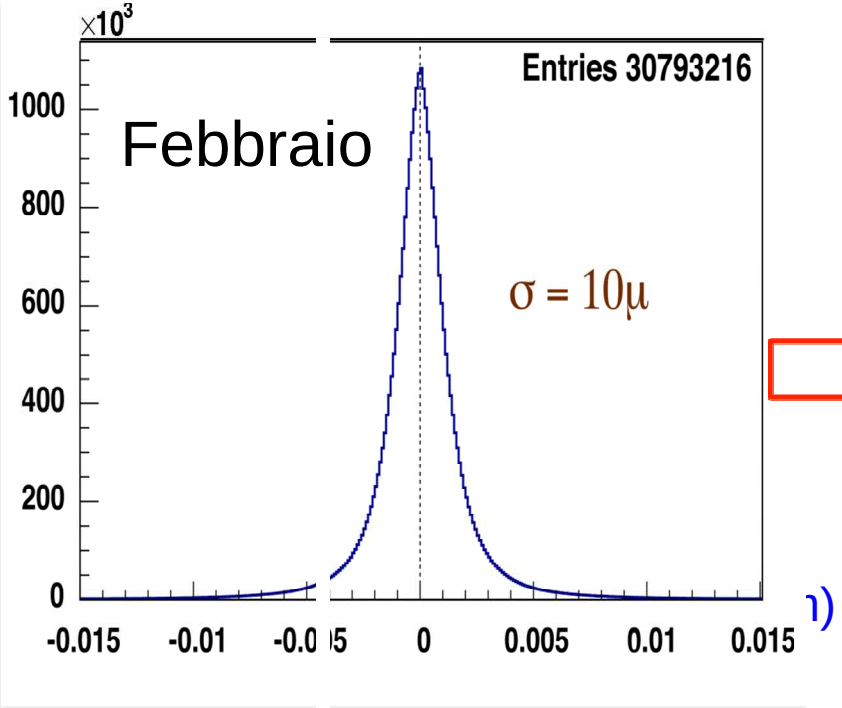


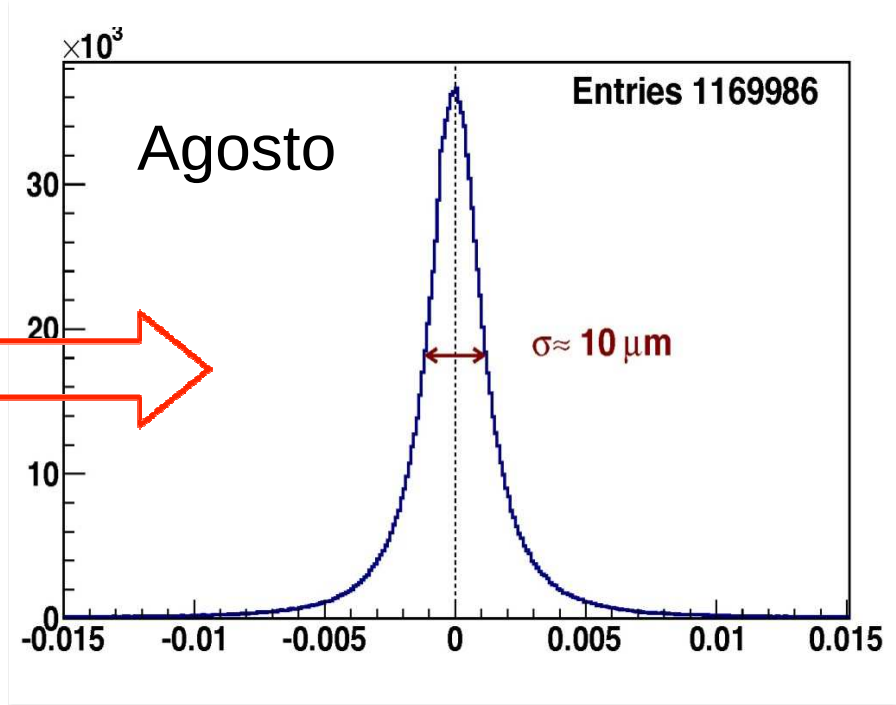


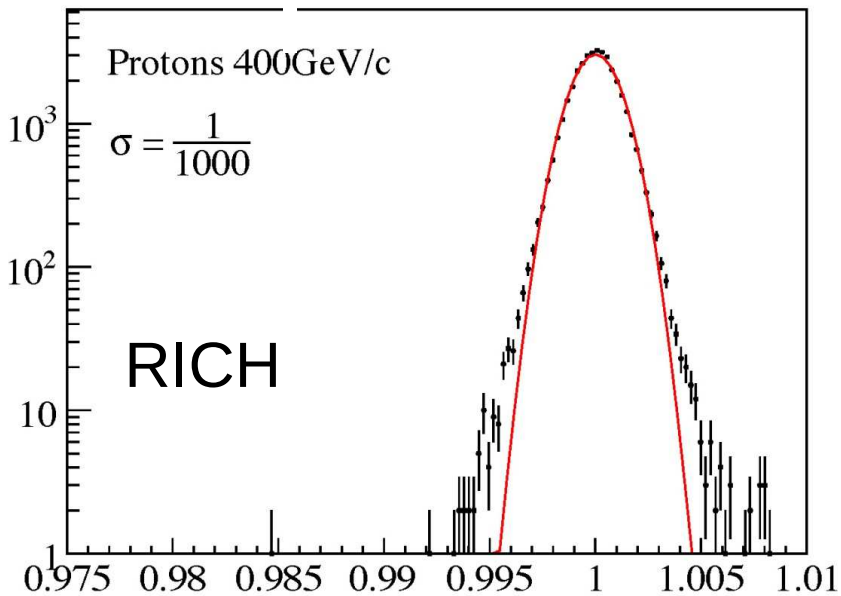


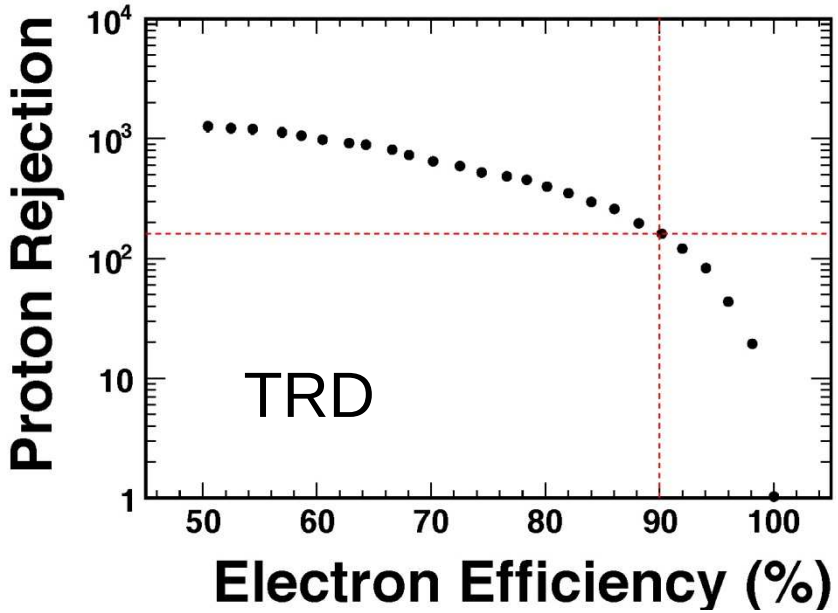
Preliminary

Les performances des autres détecteurs n'ont pas changé


×10³
Entries 30793216
Febbraio
σ = 10μ
1000
800
600
400
200
0
-0.015
-0.01
0
0.005
0.01
0.015


×10³
Entries 1169986
Agosto
σ≈ 10 μm
30
20
10
0
-0.015
-0.01
-0.005
0
0.005
0.01
0.015


Protons 400GeV/c
σ = 1/1000
RICH
10³
10²
10
1
0.975
0.98
0.985
0.99
0.995
1
1.005
1.01


Proton Rejection
TRD
10⁴
10³
10²
10
1
50
60
70
80
90
100
Electron Efficiency (%)

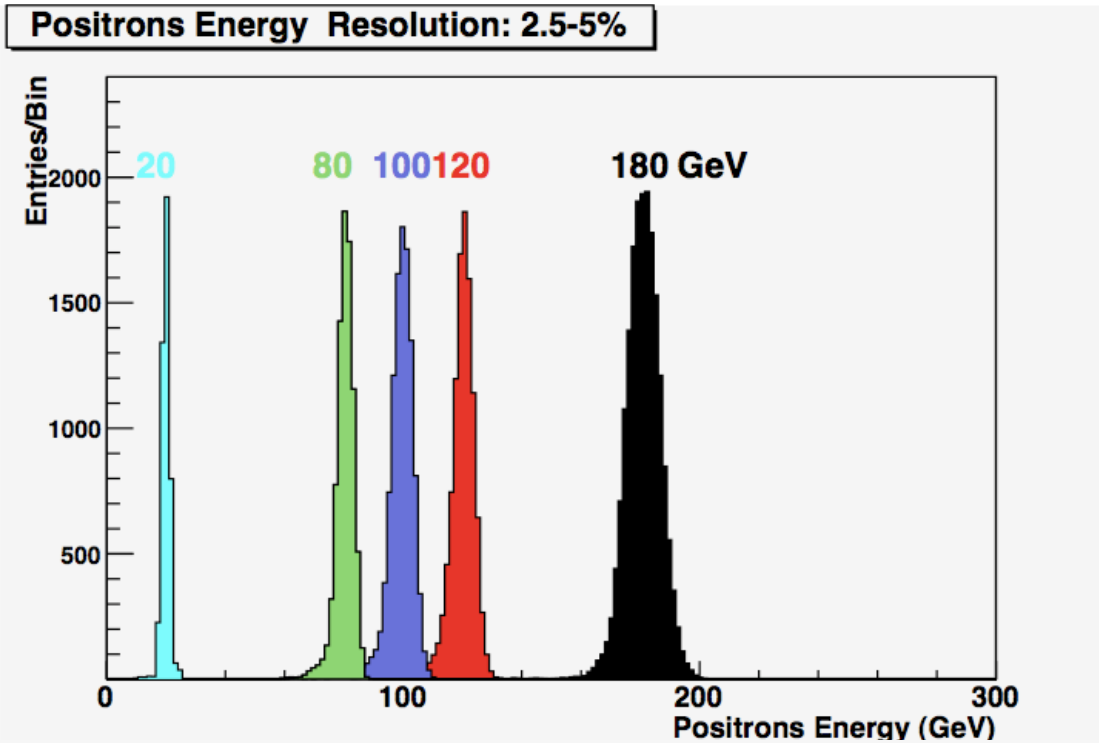
ECAL

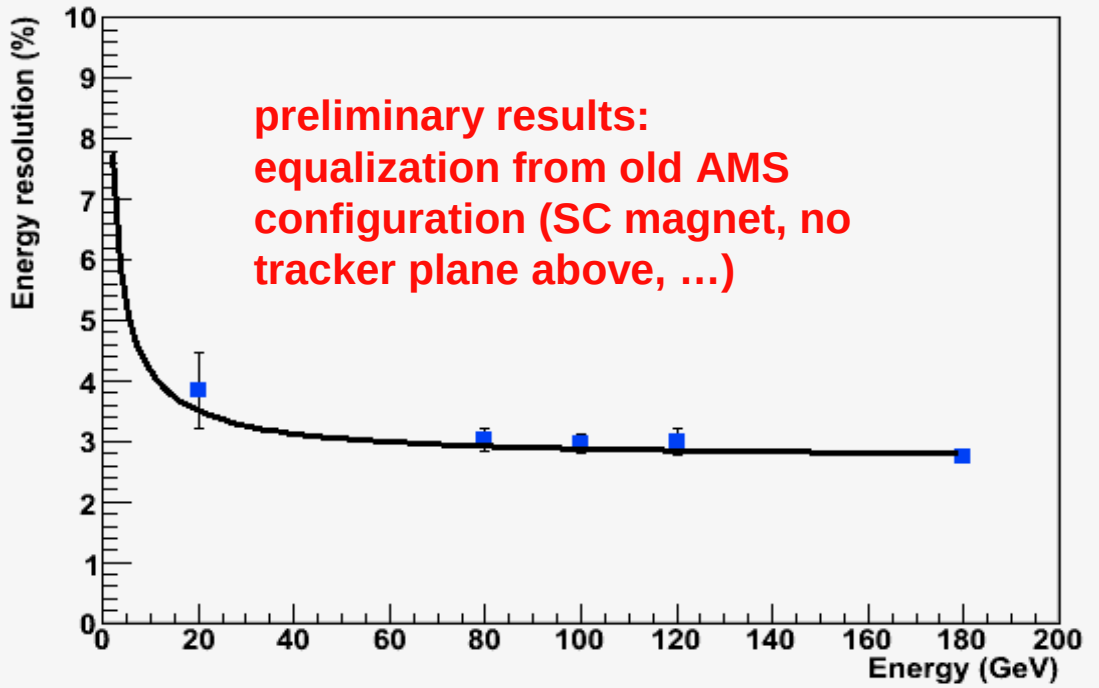
Preliminary energy resolution

$e^{\pm}$ data collected:

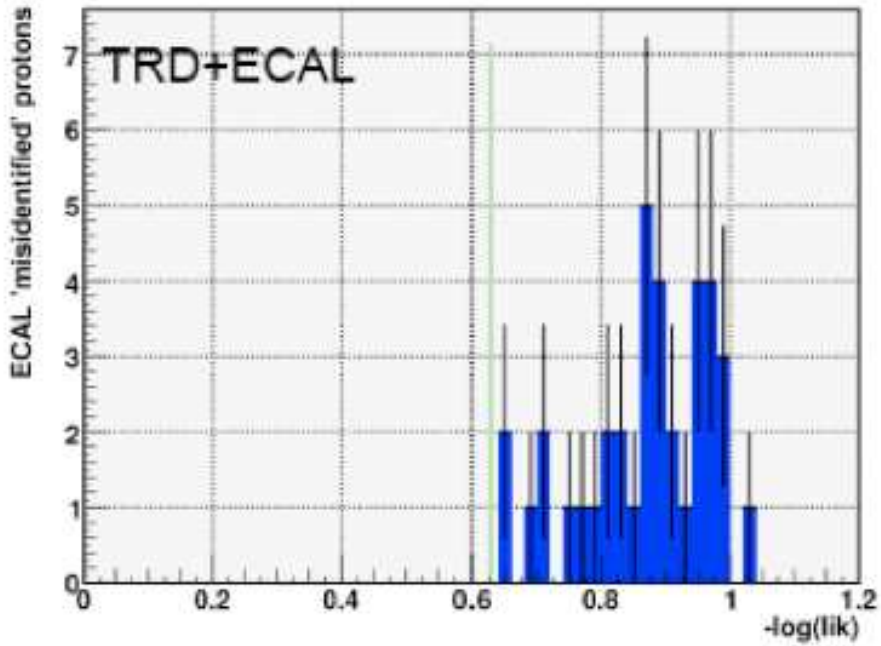
Positrons: 10, 20, 80, 100, 120, 180 GeV

Electrons: 100, 120, 180, 300 GeV





Preliminary AMS rejection



all 36 events which survive ECAL and E/p matching cuts are tagged as protons by TRD

- 400GeV protons:
- ECAL+TRACKER+TRD rejection:
  - $R_p < 1.2 \cdot 10^{-6}$ (0 out of 1.96e6)

23-24 août 2010: departure from CERN to GVA airport and loading in a C5-Galaxy airplane

- August 24: landing at KSC on the space shuttles runway
- Mechanical and electrical interfacing activities.
- Communication and control procedures are presently defined and tested between CERN, JSC and KSC

AMS astronauts

Mark E. Kelly
(Captain, USN)

Gregory H. Johnson
(Colonel, USAF, Ret.)

E. M. "Mike"Fincke
(Colonel, USAF)

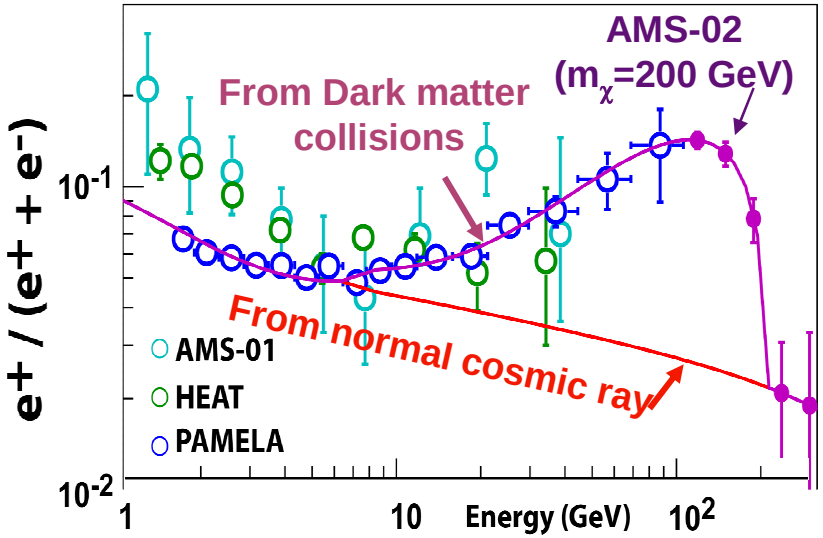
Roberto Vittori
(Italian Air Force Colonel)

Andrew J. Feustel
(Ph.D.)

Gregory Errol Chamitoff
(Ph.D.)

We will be ready for the journey to the ISS foreseen Feb. 27,2011 with the *Endeavour* space shuttle.

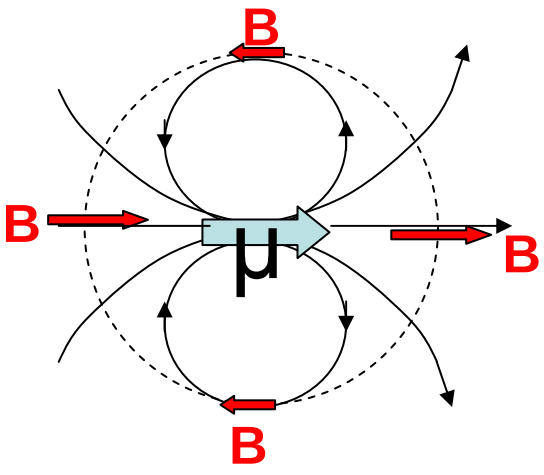
Mission duration: → 2020 (2028 ?)

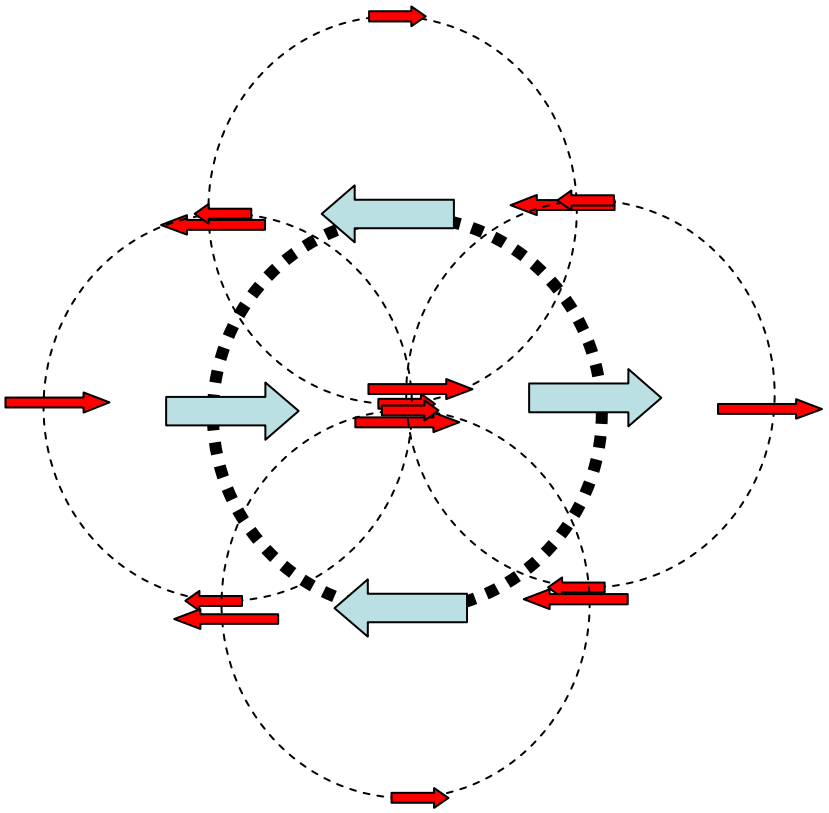


Les résultats de Pamela seront-ils confirmés ?

L'aimant d'AMS

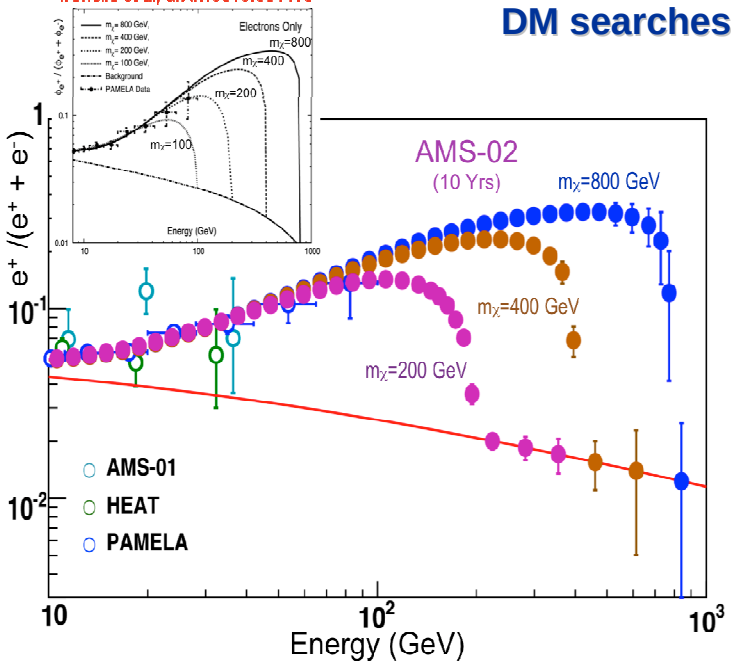
Addition des champs et des moments magnétiques



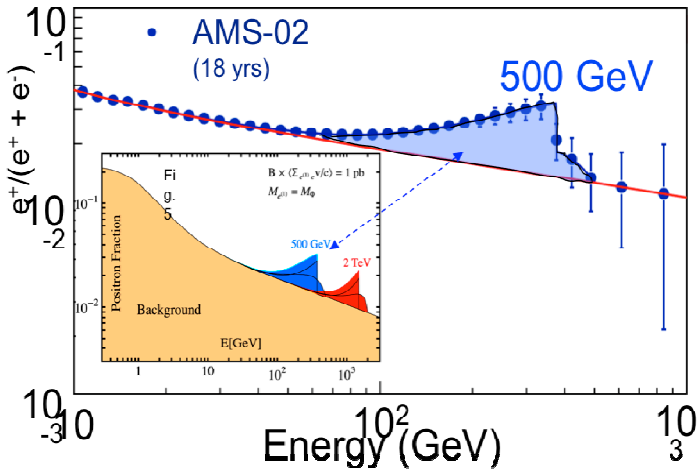


DM searches with AMS-02

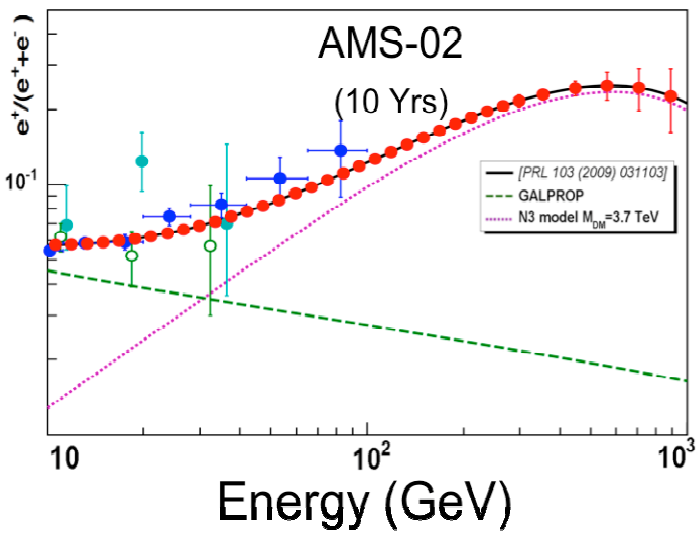
I.Cholis et al, arXiv:0810.5344v3



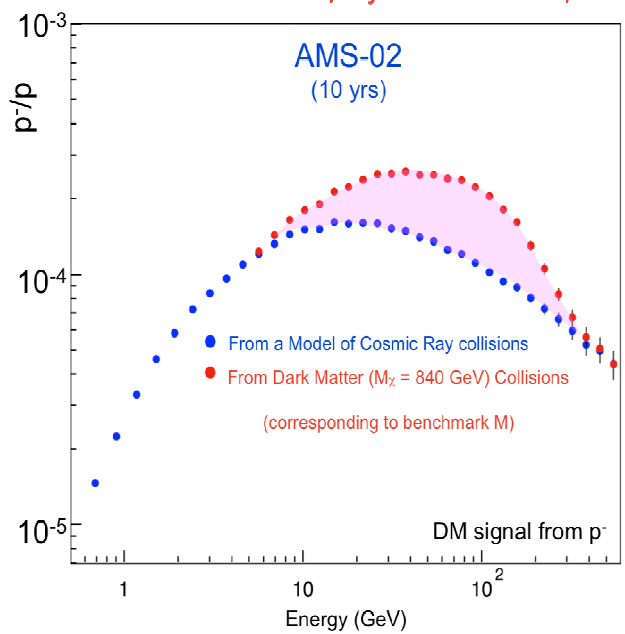
E. Pontón & L. Randall: arXiv:



L.Bergstrom et al, PRL 103 (2009) 031103

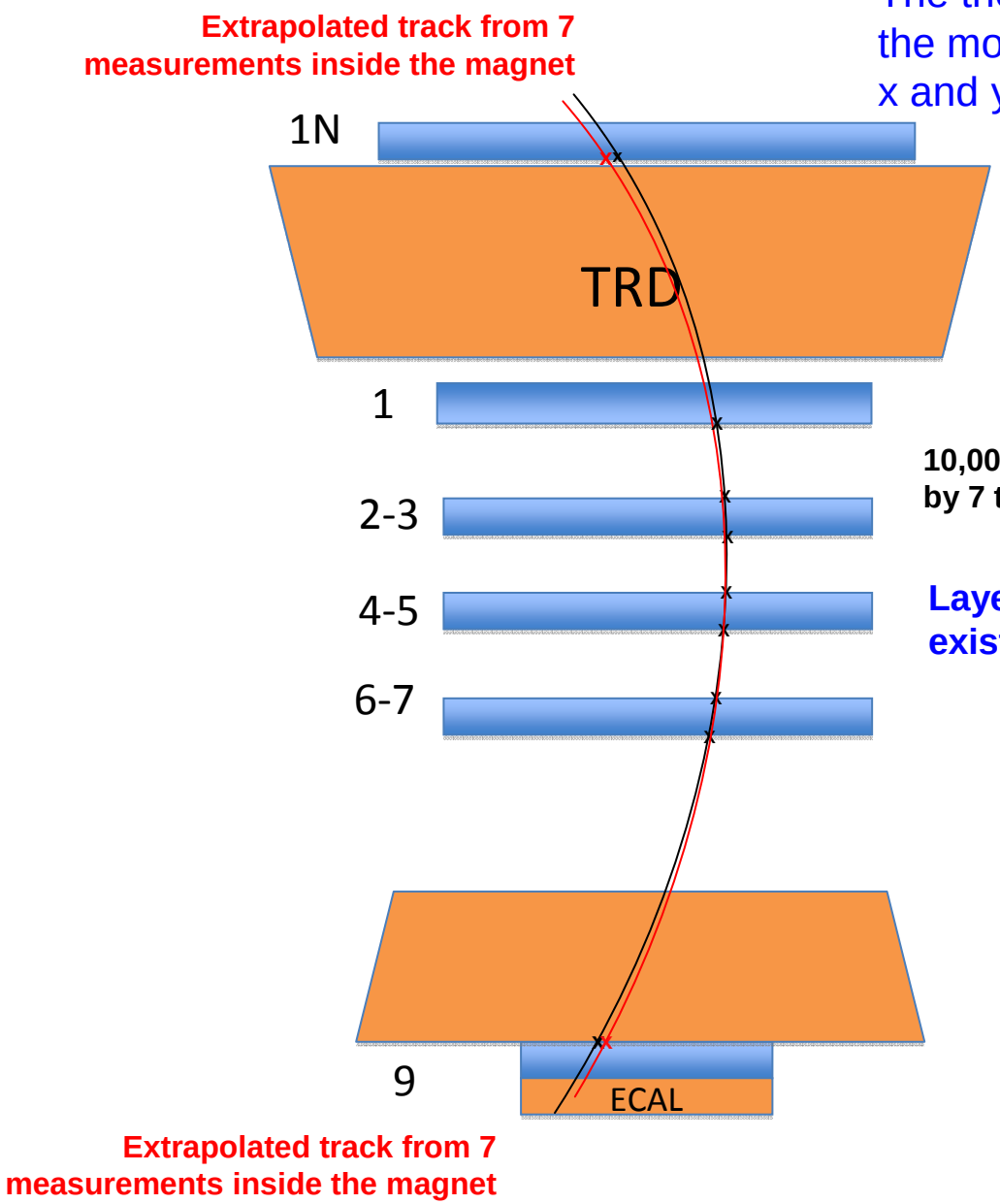


P. Brun, Phys.Rev.D76:083506, 2007



AMS-02 (10 to 18 Yrs)
Silicon Tracker Alignment with Cosmic protons

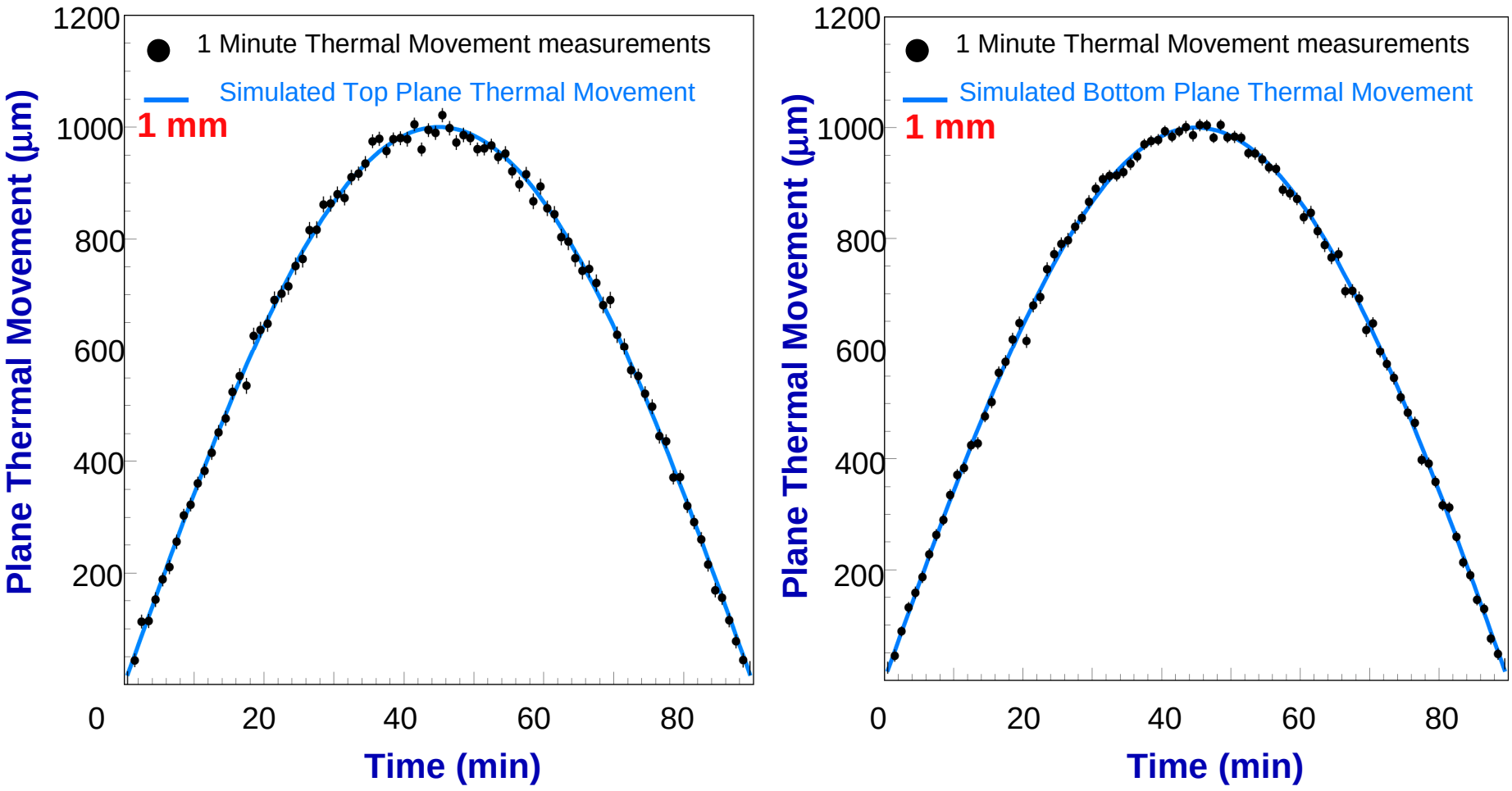
The thermal model predicts the movement of 1N and 9 in x and y are both less than 150 μm.



10,000 cosmic protons / min measured by 7 tracker layers in the magnet

Layers 1 to 7 are aligned with existing laser system

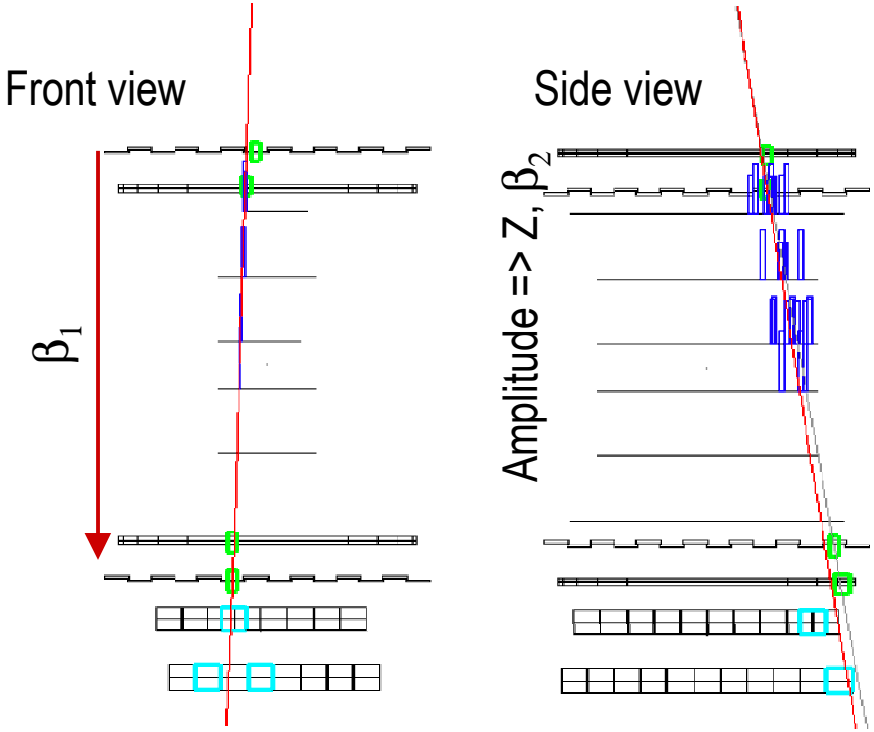
External Plane Alignment with Cosmic Rays Minute by Minute

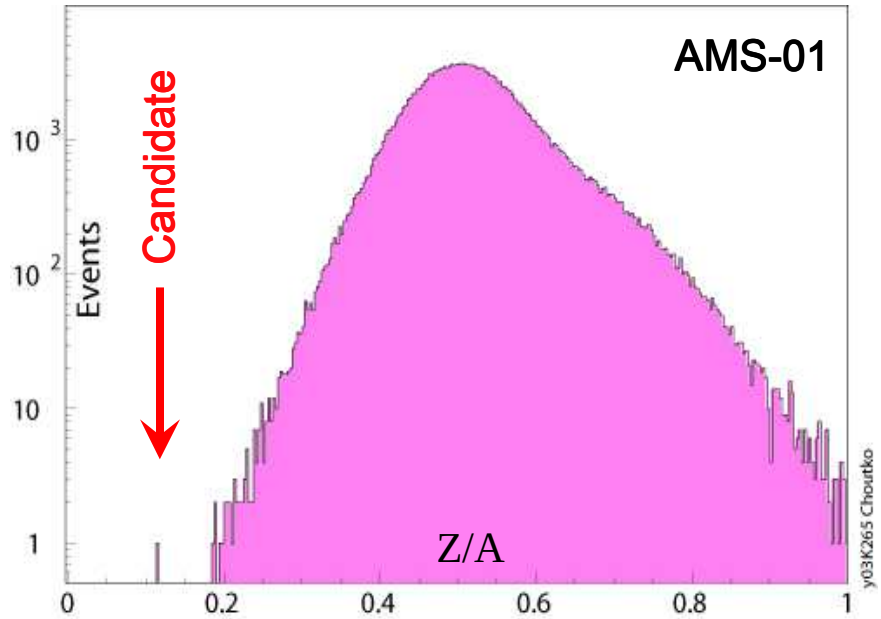


Strangelet candidate from AMS-01

Observed 5 June 1998 11:13:16 UTC

Lat/Long= -44.38°/+23.70°, Local Cutoff 1.95±0.1 GV, Angle= 77.5° from local zenith





Rigidity = 4.31 ± 0.38 GV

Charge Z = 2

$\beta_1 = \beta_2$ = 0.462 ± 0.005

Mass = 16.45±0.15 GeV/c^2

Z/A = 0.114 ± 0.01

Flux (1.5 < E_K < 10 GeV) = 5x10^{-5} (m^2 sr sec)$^{-1}$

Background probability < 10^{-3}

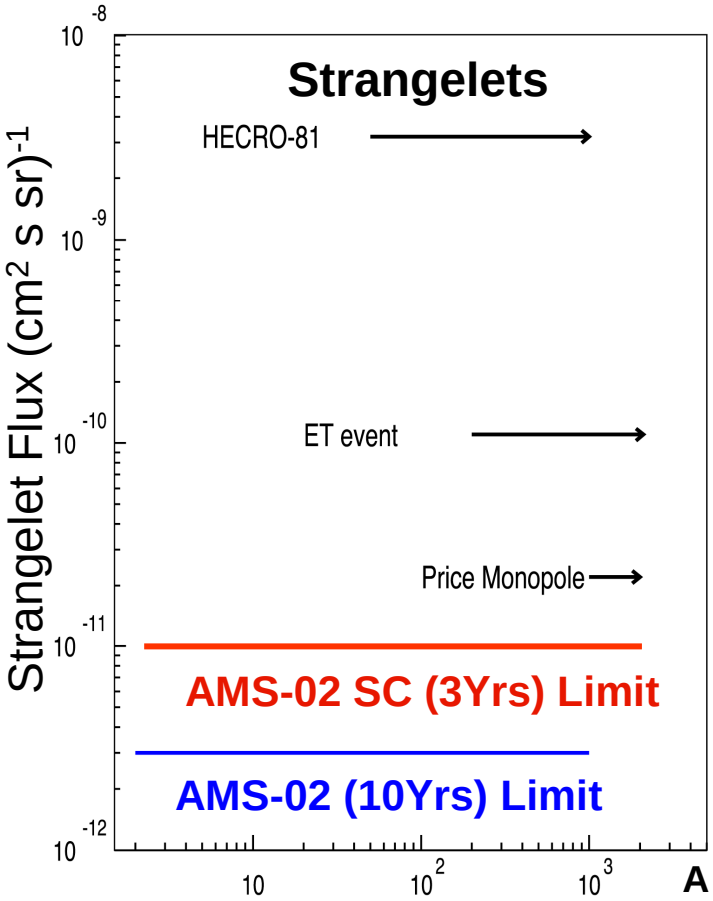
Strangelets

E. Witten, Phys. Rev. D,272-285 (1984)

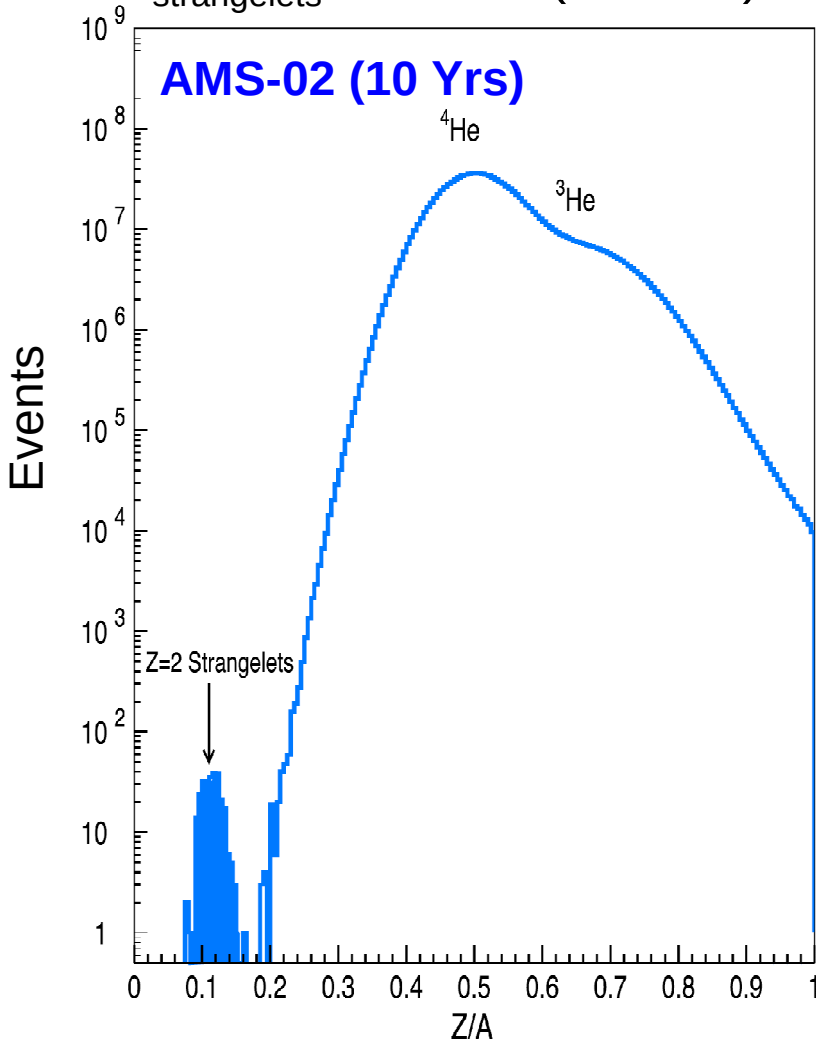
All the known material on Earth is made out of u and d quarks

Is there material in the universe made up of u, d, & s quarks?

Z/A~0.1



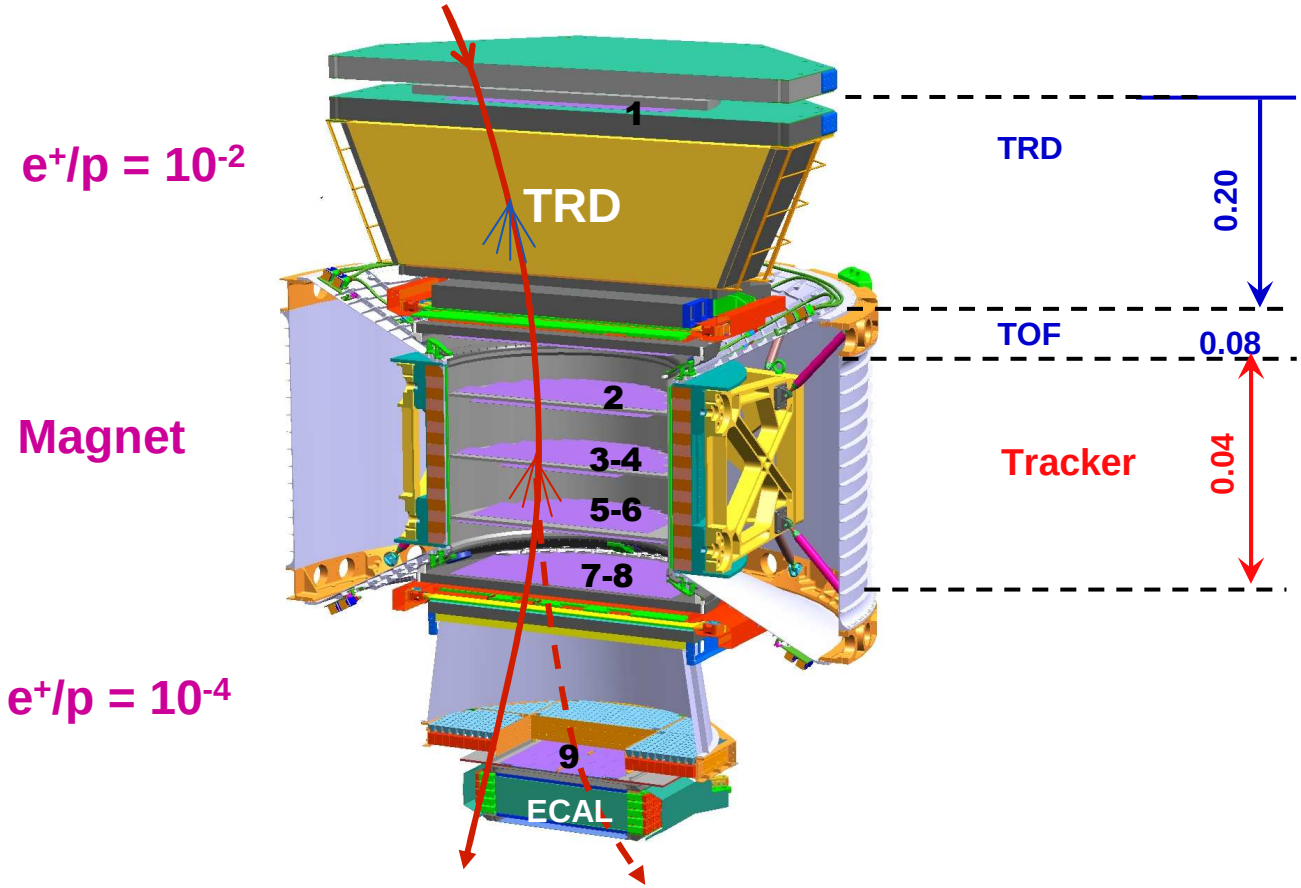
$\Phi_{strangelets} = 5x10^{-10}(cm^2 s\ sr)^{-1}$



This can be answered definitively by AMS.

***Jack Sandweiss*, Yale**

AMS goals: $\overline{He}/He = 1/10^{10}$, $e^+/p = 1/10^6$ & Spectra to 1%

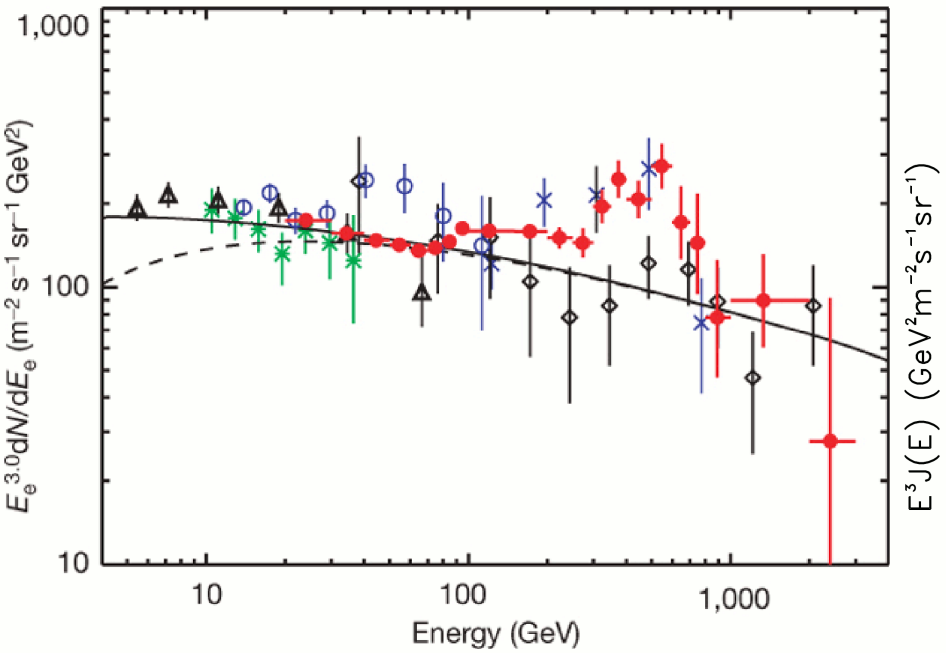


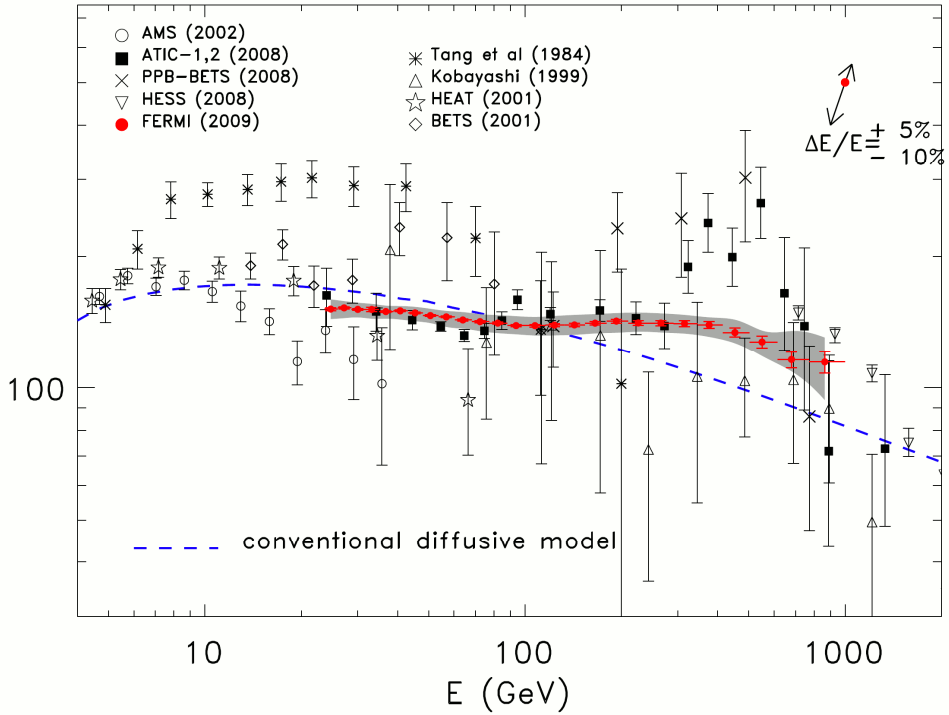
a) Minimal material in the tracker, so that it does not become a source of background nor of large angle scattering

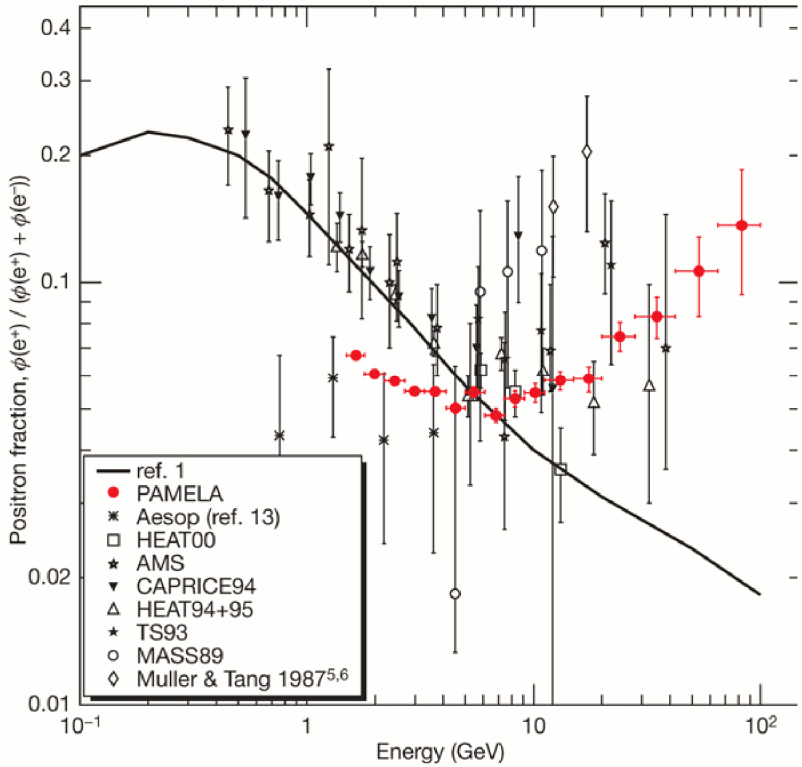
b) Repetitive measurements of momentum , to ensure that particles which had large angle scattering are not confused with the signal.

c) $e^{\pm}$ detectors are separated by magnetic field, so that particles from TRD do not enter into ECAL.

Measured rejection at 0.4 TeV $e^+/p = 10^{-6}$


1,000
100
10
10
100
1,000
Energy (GeV)
$E_e^{3.0}dN/dE_e$ ($m^{-2}s^{-1}sr^{-1}GeV^2$)


AMS (2002)
ATIC−1,2 (2008)
PPB−BETS (2008)
HESS (2008)
FERMI (2009)
Tang et al (1984)
Kobayashi (1999)
HEAT (2001)
BETS (2001)
ΔE/E = ± 5% − 10%
conventional diffusive model
100
10
100
1000
E (GeV)
$E^3J(E)$ ($GeV^2m^{-2}s^{-1}sr^{-1}$)


0.4
0.3
0.2
0.1
0.02
0.01
10^{-1}
1
10
10^2
Energy (GeV)
Positron fraction, $\phi(e^+) / (\phi(e^+) + \phi(e^-))$
ref. 1
PAMELA
Aesop (ref. 13)
HEAT00
AMS
CAPRICE94
HEAT94+95
TS93
MASS89
Muller & Tang 1987[5,6]