GeV to Multi-TeV Cosmic Rays: AMS-02 and PEBS Status & Future Prospects

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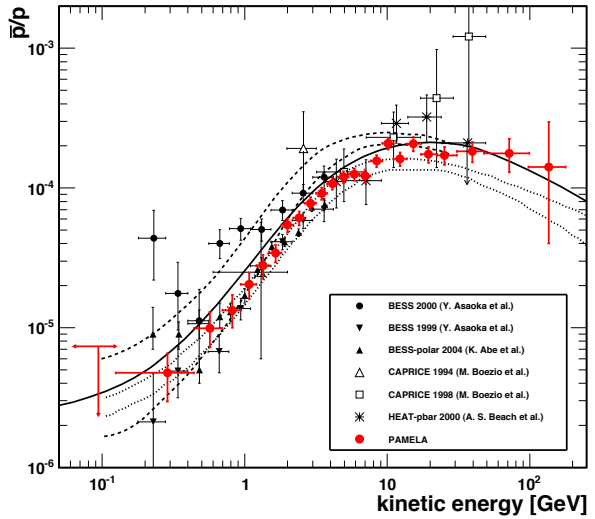
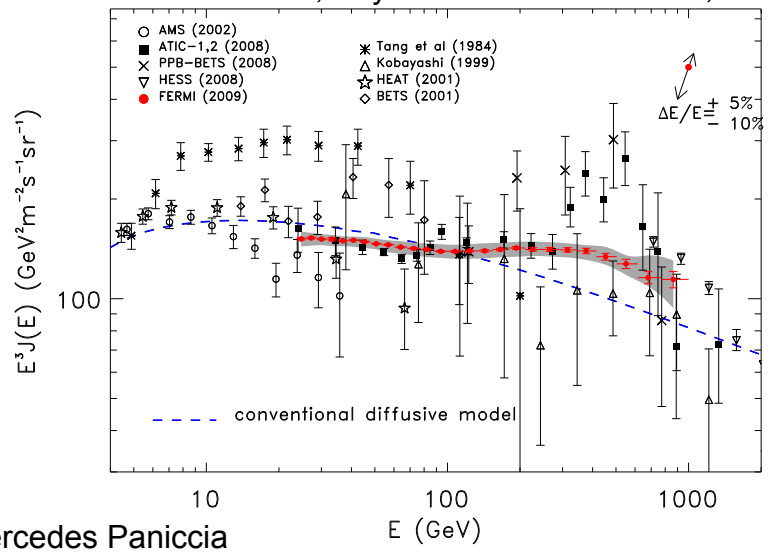
Renewed Interest in Galactic CR

- Antiproton spectrum compatible with secondary production
- Positron and (e^++e^-) spectra show unusual shape
- HEAT (2001), AMS-01 (2002), ATIC (2008), Pamela (2009), Fermi-LAT (2009), H.E.S.S. (2010)
- Astrophysical or DM source?

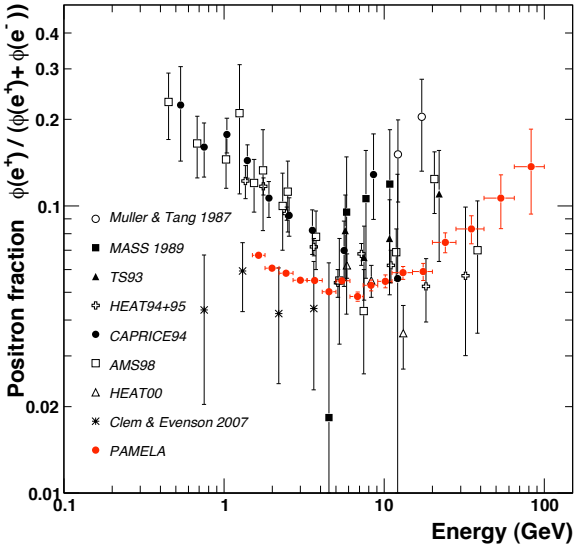
O. Adriani et al., arXiv:1007.0821 (2010)



A.A. Abdo et al., Phys.Rev.Lett.102:181101,2009.

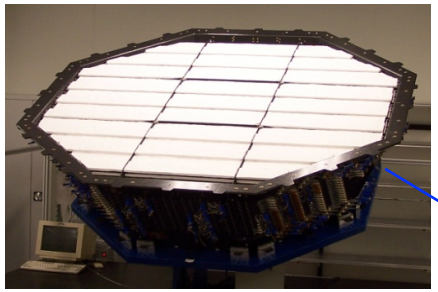


O Adriani *et al. Nature* **458**, 607-609 (2009)

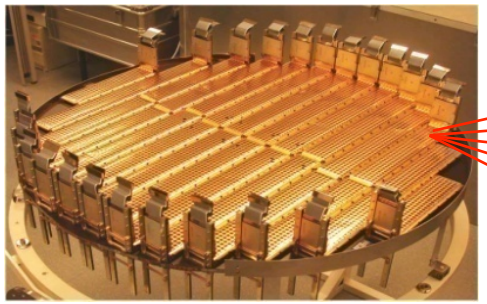


AMS-02 with Superconducting Magnet

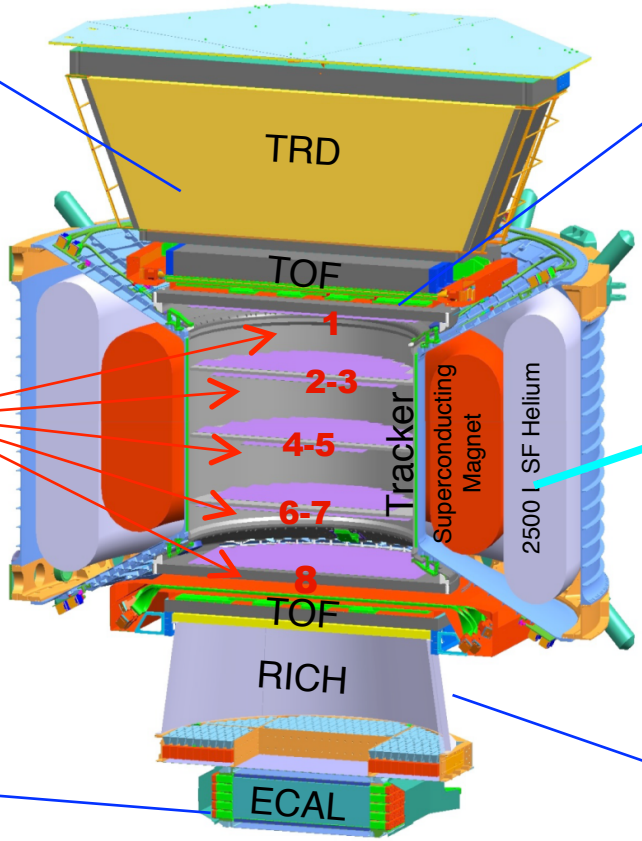
TRD
Identify e+, e-



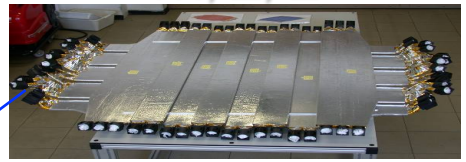
Silicon Tracker
m, Z, P



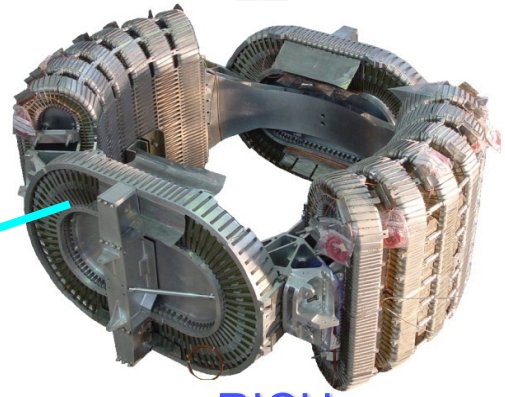
ECAL
E of e+, e-, γ



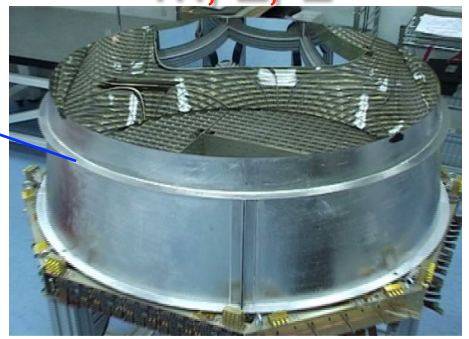
TOF
m, Z, E



Magnet
±Z

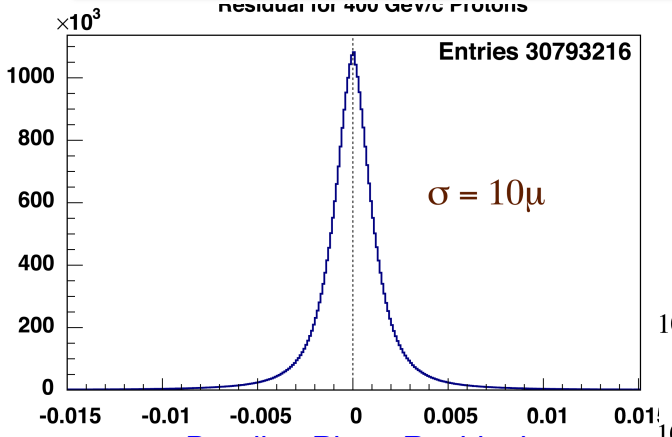


RICH
m, Z, E



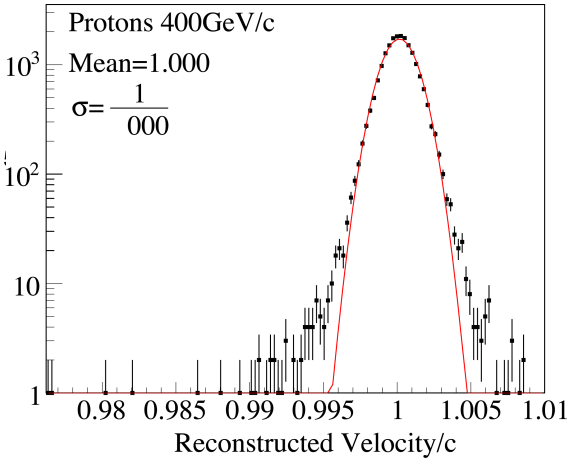
m, Z, E are measured independently from Tracker, RICH, TOF and ECAL

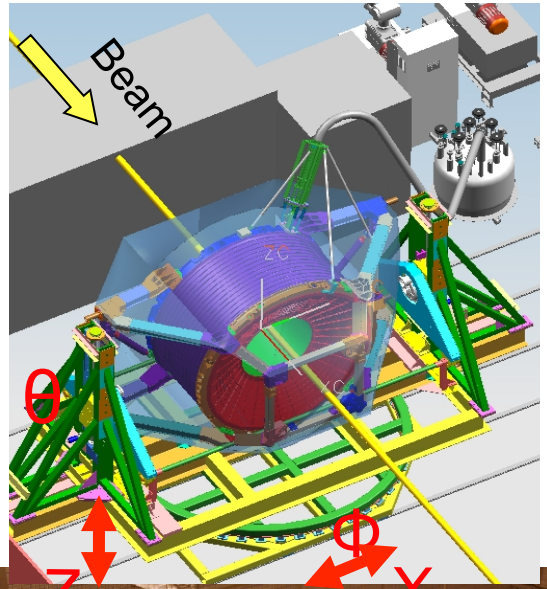
AMS in CERN SPS Test Beam, Feb 4-8, 2010

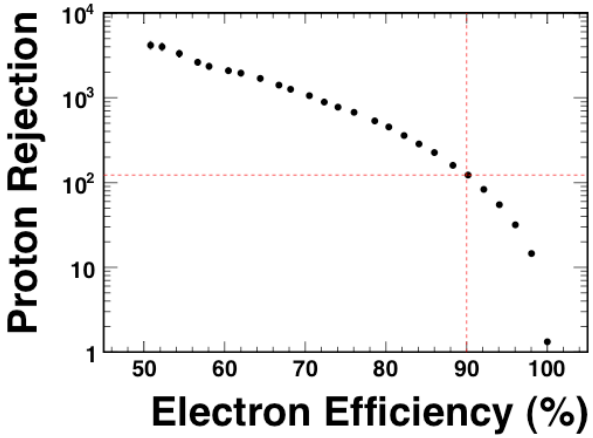


Bending Plane Residual (cm)

Velocity measured to an accuracy of 1/1000 for 400 GeV protons

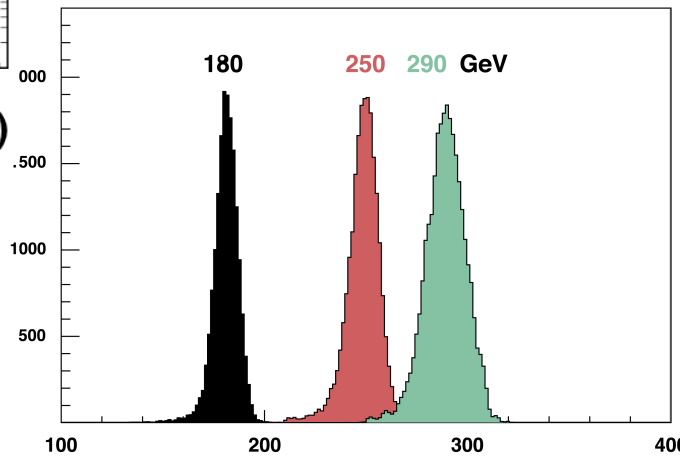


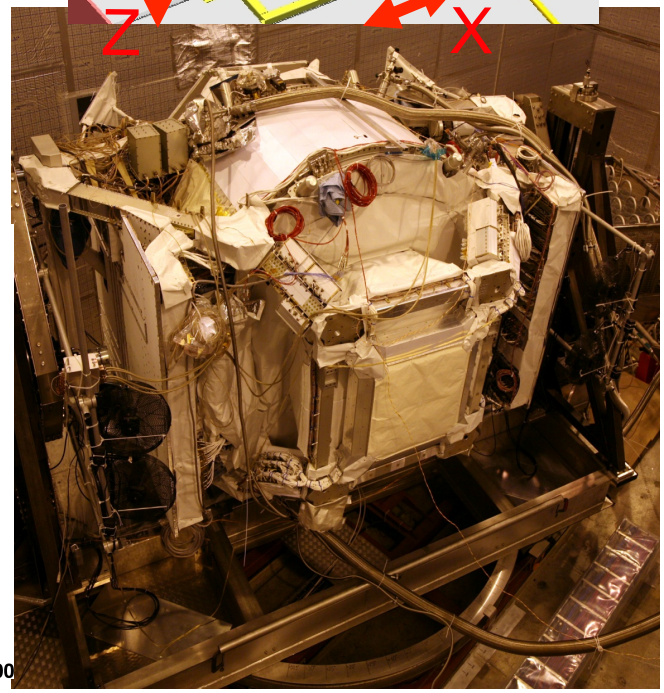




Combined rejection power at 400 GeV: $e^+/p = 10^{-6}$

Electron Energy Resolution: 2.5-3%





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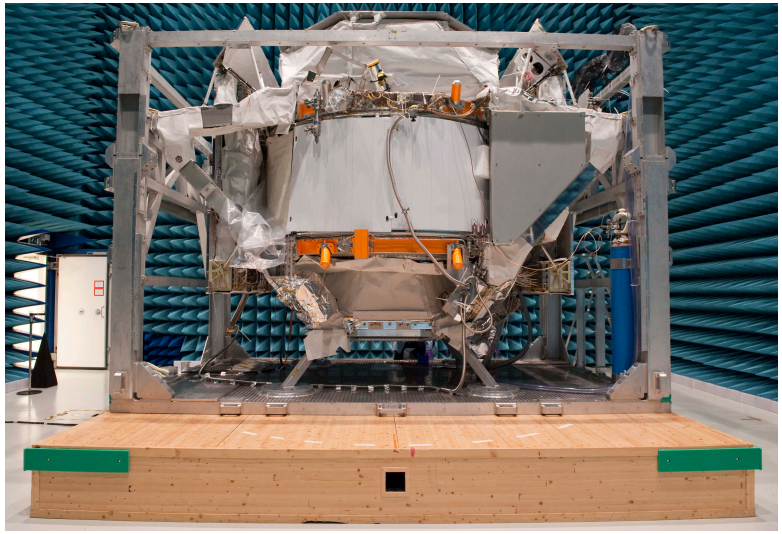
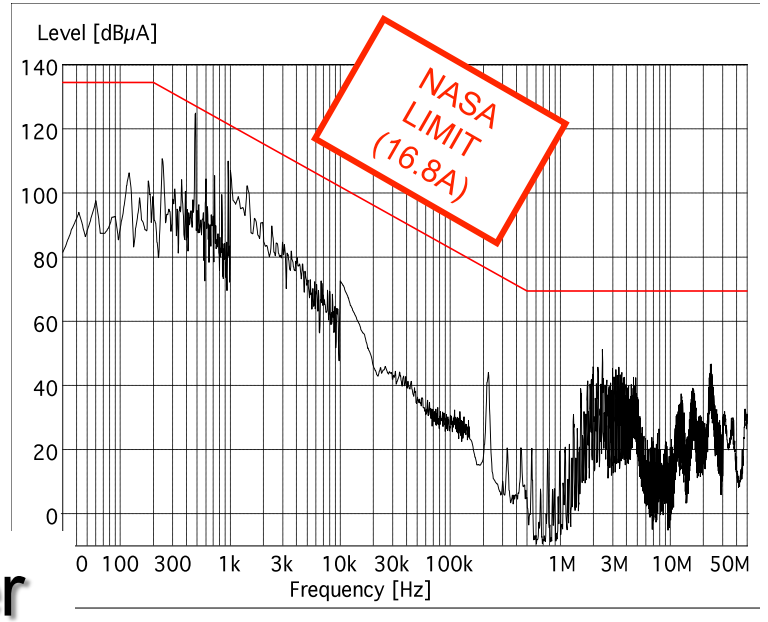
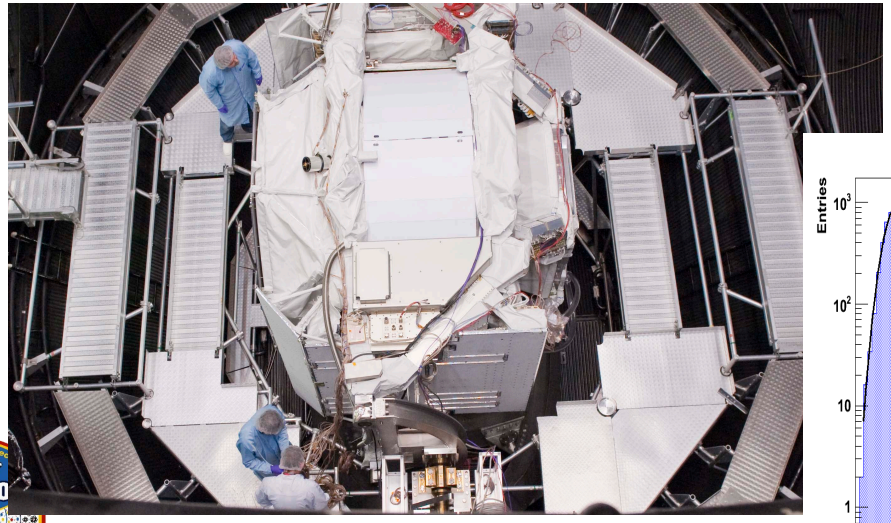
AMS in the Maxwell EMI chamber at ESTEC

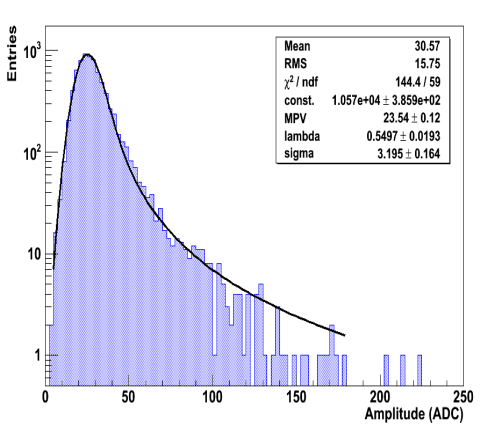


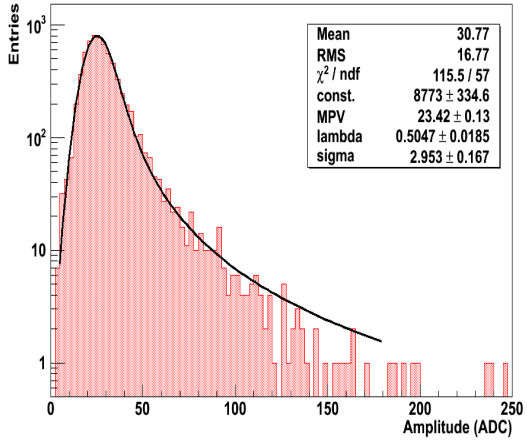


AMS in the ESA TVT Chamber



Tracker performance at −90°C: muon track & mip signal





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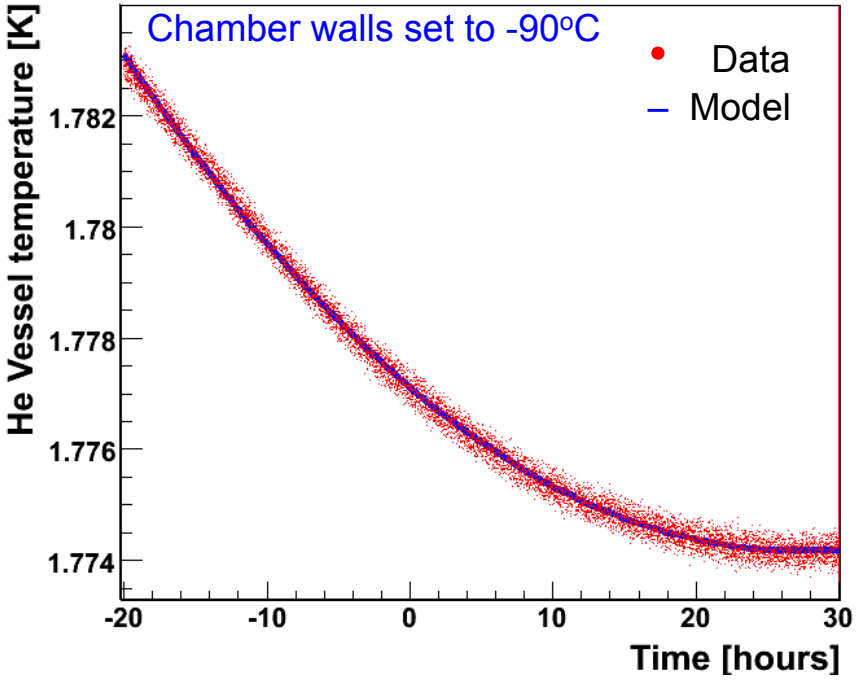
Stabilization of the He Vessel



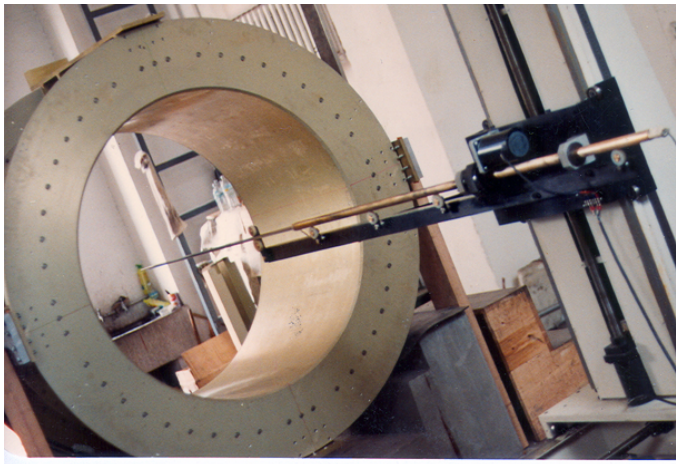
Stability criteria:
dT/dt < 0.0001K/h

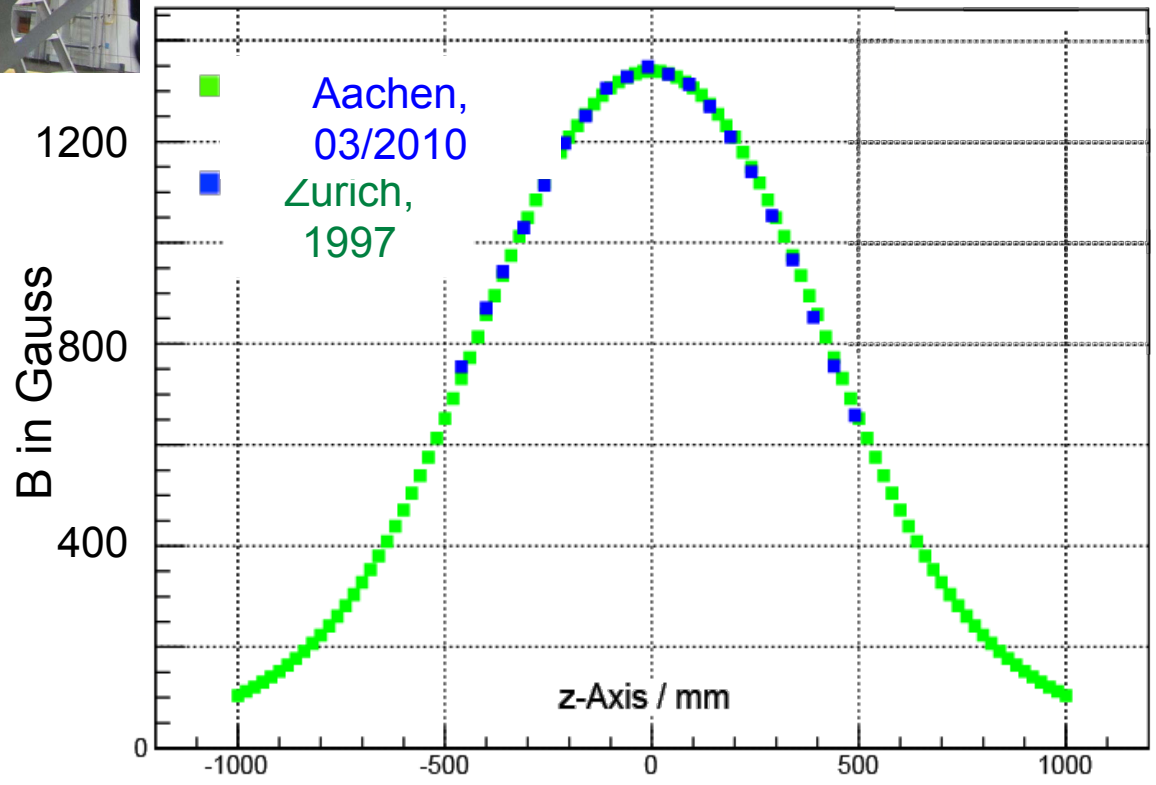
Expected life time of the AMS Cryostat on ISS:
20±4 months with M87 cryocoolers (1999)
28±6 months with GT cryocoolers (2010)

ISS Lifetime Extension

- The ISS lifetime has been extended from 2015 to 2020 (or even 2028).
- The Shuttle program will be definitely terminated, thus eliminating any possibility of returning and refilling AMS.
- A superconducting magnet was ideal for a three year stay on ISS as originally planned for AMS.
- With the extended ISS life, the super-conducting magnet is no longer the optimum choice.
- AMS-02 with the permanent magnet from AMS-01 will have 10-18 years time to collect data, providing much more sensitivity to search for new phenomena.

AMS-01 Permanent Magnet in Aachen Germany, April/May 2010





- SC: B_{max} = 0.87T
- PM: B_{max} = 0.14T

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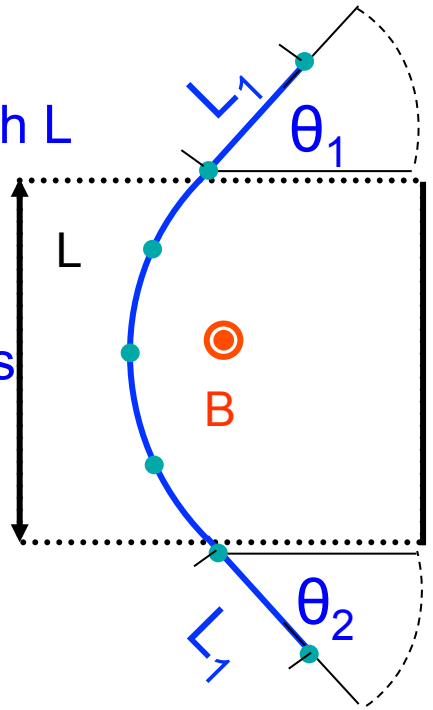
The momentum resolution ($\Delta p/p$) is the sum of two contributions:

1. Measurement inside the magnet with an effective length L

$$(Q/p)\cdot(\Delta p/p) \alpha\ 1/BL^2$$

2. Measurement of the incident (θ_1) and exit (θ_2) angles which depend on the length L_1

$$(Q/p)\cdot(\Delta p/p) \alpha\ 1/BLL_1$$



For both magnets, L ~ 80 cm,
but in the permanent magnet B is 5 times smaller
to maintain the same $\Delta p/p$ we increase L1 from ~15 cm
(Superconducting Magnet) to ~125 cm (permanent magnet)

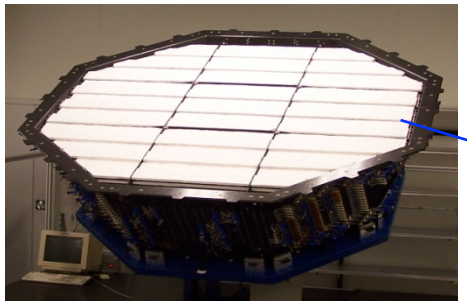
AMS-02 with Permanent Magnet

Acceptance

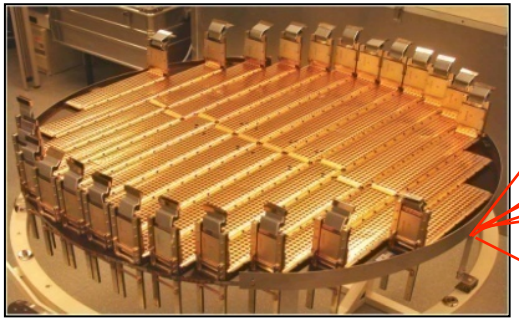
e^+ 950 cm^2sr

p, He, He, … 4,500 cm^2sr

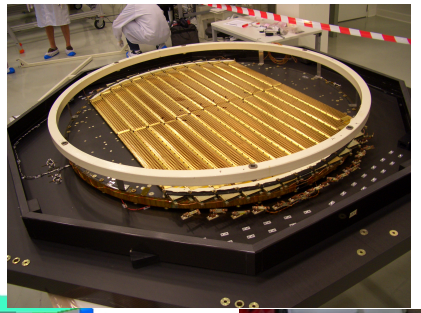
TRD



Silicon Tracker

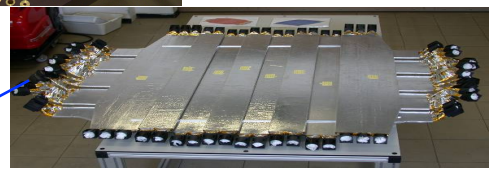


ECAL

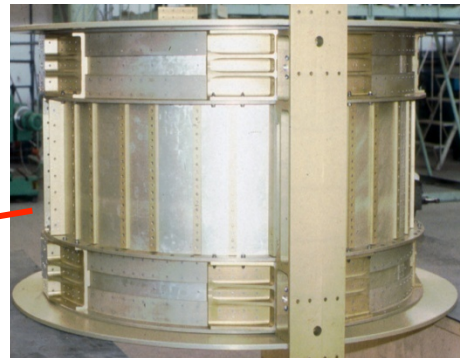


One Silicon layer displaced to top

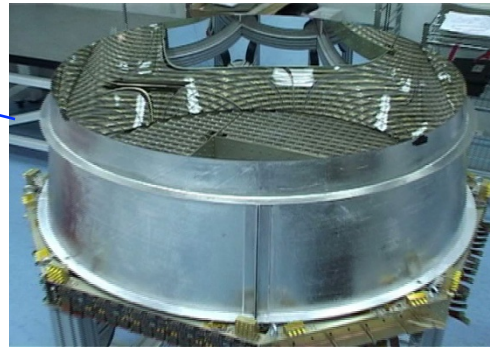
TOF

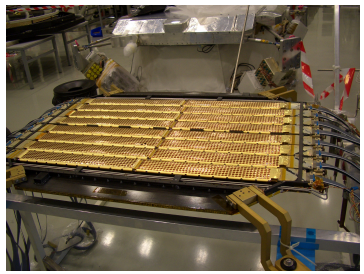


Permanent Magnet

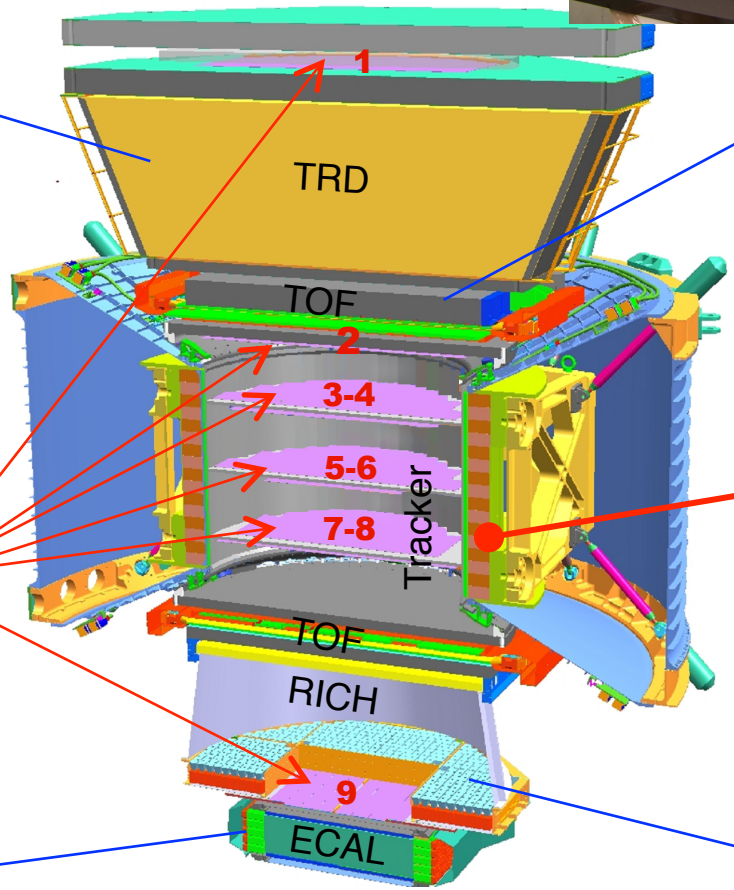


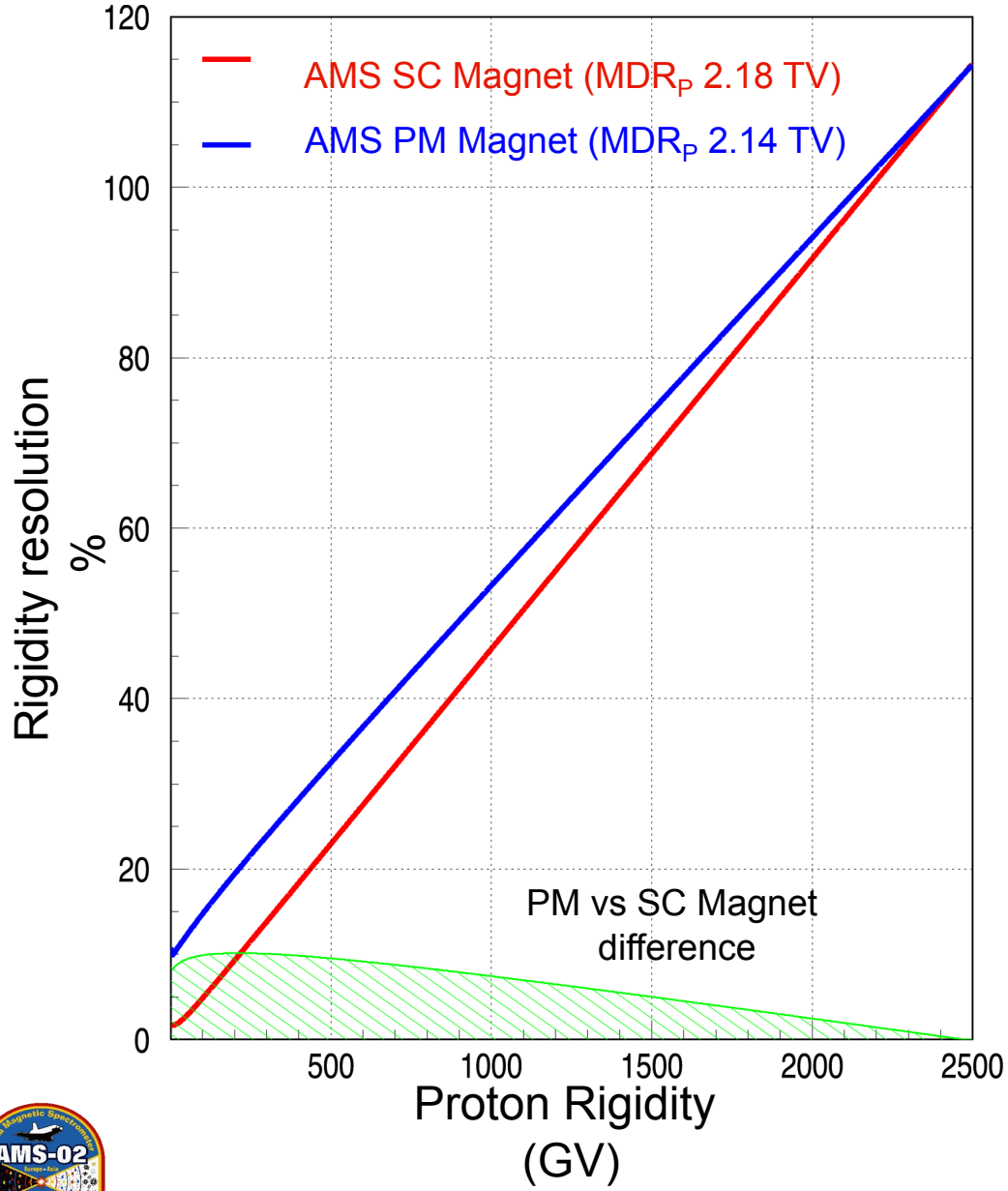
RICH





One additional silicon layer on bottom

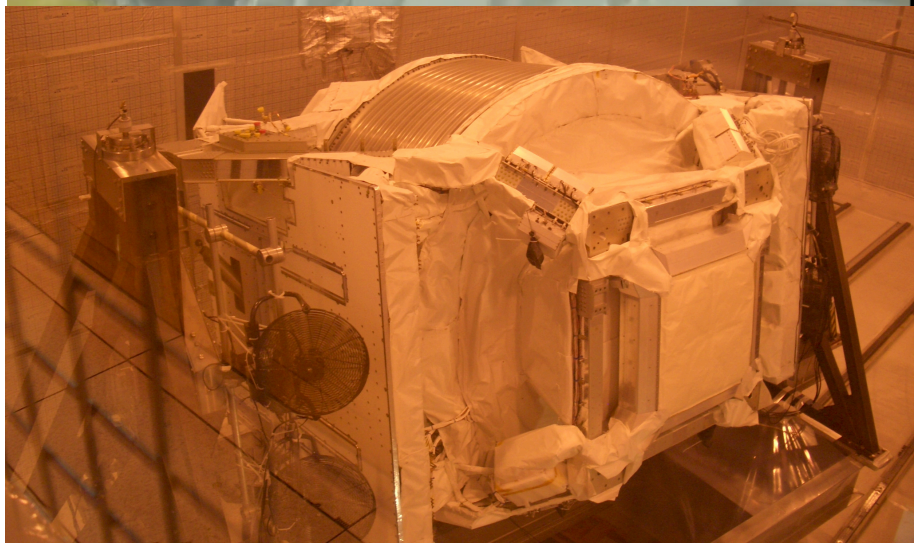




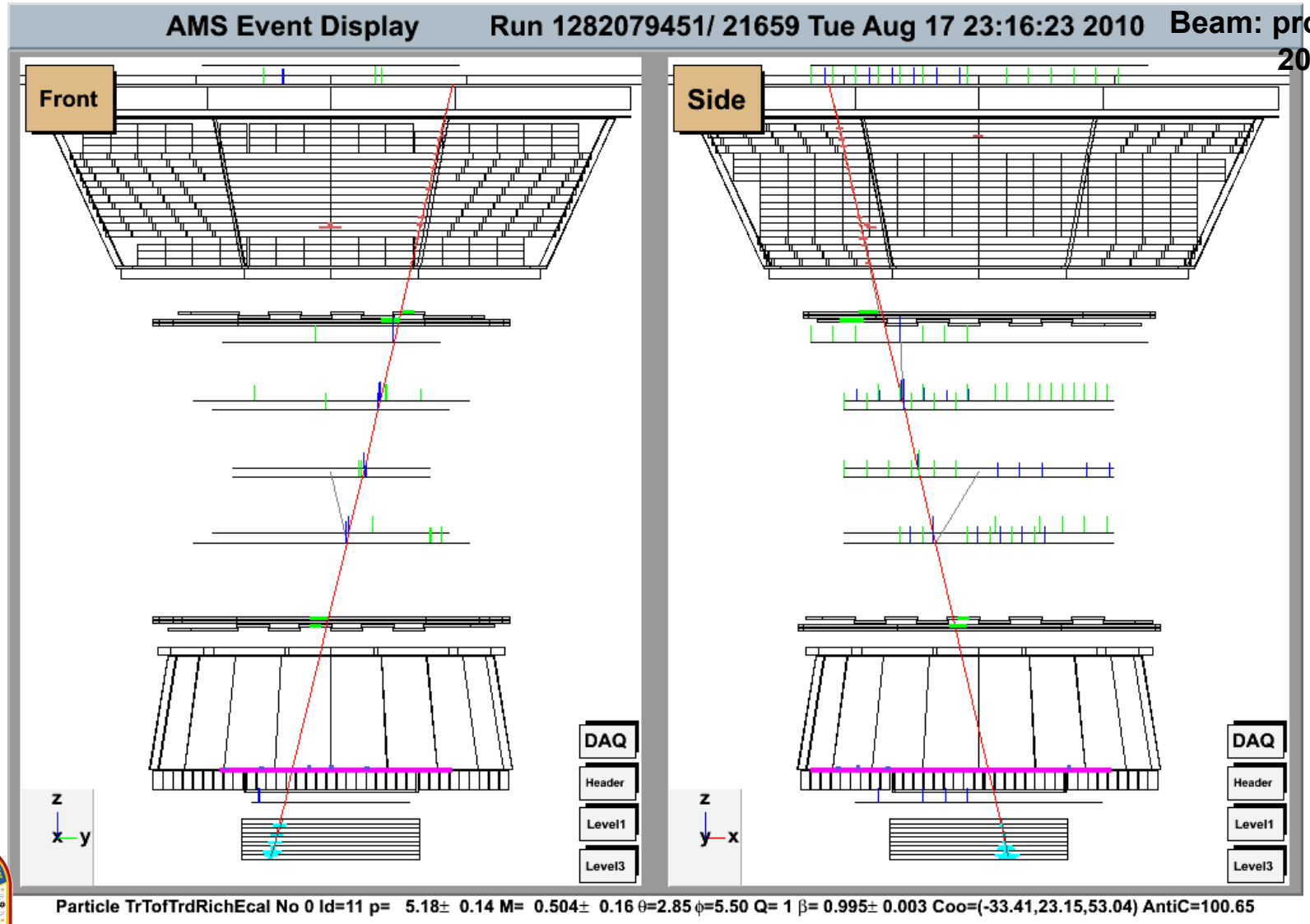
- With 9 tracker planes in the new configuration, the rigidity resolution of AMS with the permanent magnet is equal (within 10%) to that of the superconducting magnet.
- For helium nuclei, the MDR for the permanent magnet is 3.75 TV.
- Alignment will be done with 10'000 CR tracks per minute in orbit.

- Integration of AMS-02 with the long lifetime permanent magnet has been completed last July
- The reconfigured detector has been extensively tested:
  - Cosmic rays: July 10 to August 5
  - Test Beam at CERN SPS H8 line August 9 to 21 with hadrons and electrons at different energies and with more than 1000 different detector orientations
    - Tracker Alignement :
      protons 400 and 180 Gev ,
    - RICH Calibration: protons 180 GeV
    - AntiCounter Efficiency: protons 180 GeV
    - DAQ Performance: protons 180 GeV
    - ECAL, TRD, Tracker Performance at different energies:
      positrons 20,80,120,180,300 GeV
      protons/pions 20,60,80,100,120 GeV
      electrons 100,120,180,300 GeV

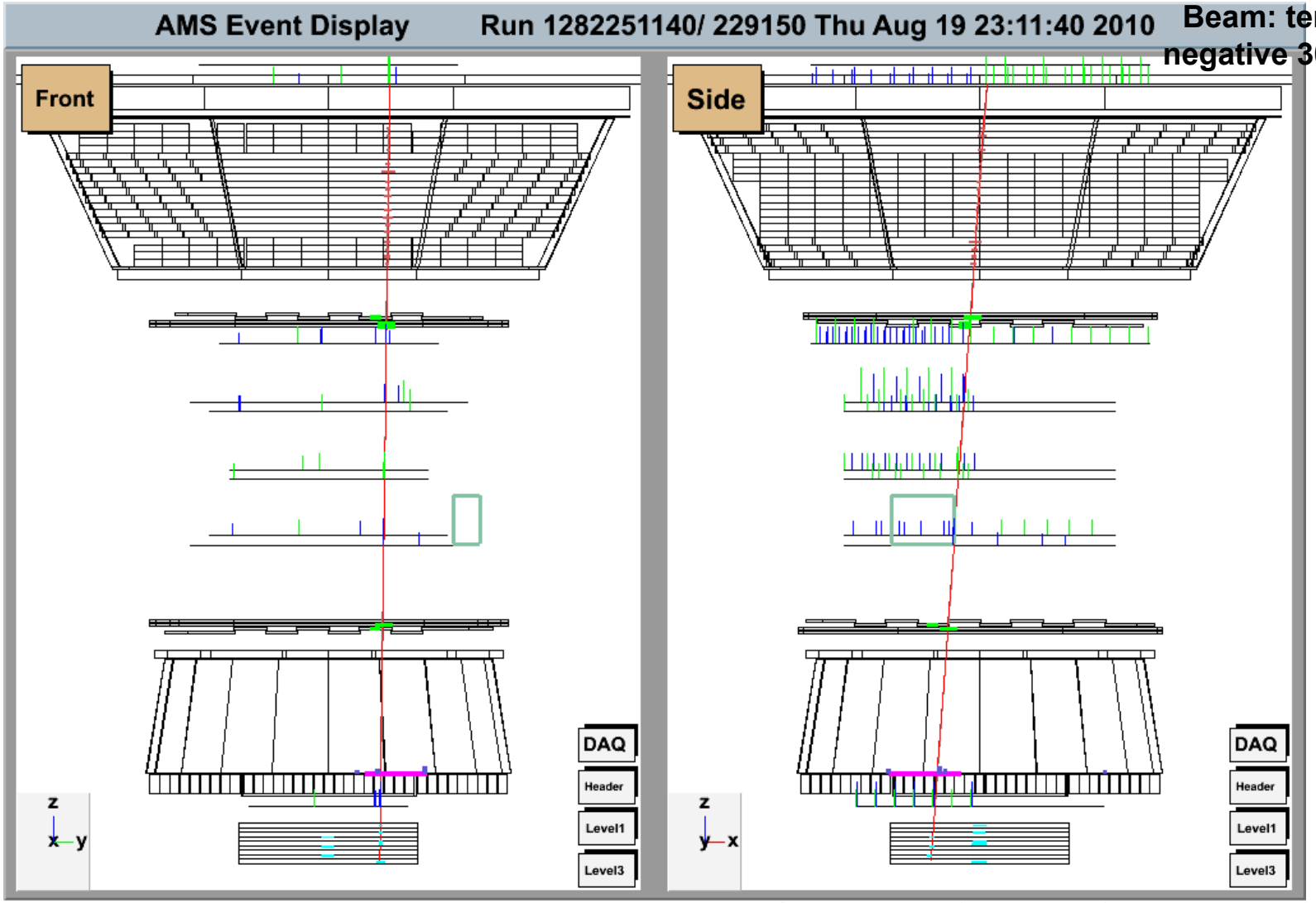
AMS02 fully integrated at the CERN cleanroom


AMS02 in the Rotation Stand at the SPS H8 Beam Line

Test at CERN SPS H8 beam line, August 9-21 2010

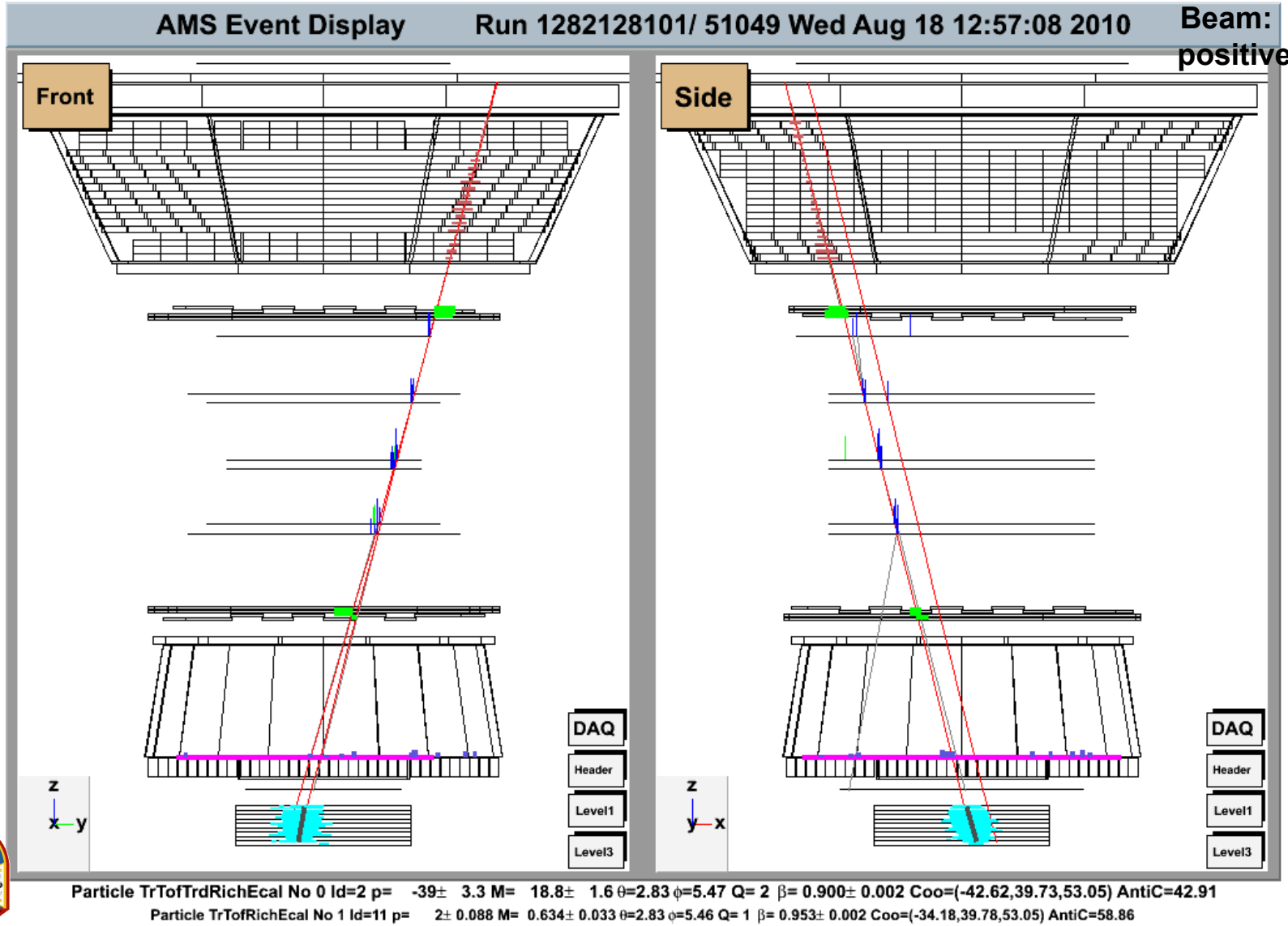


Test at CERN SPS H8 beam line, August 9-21 2010



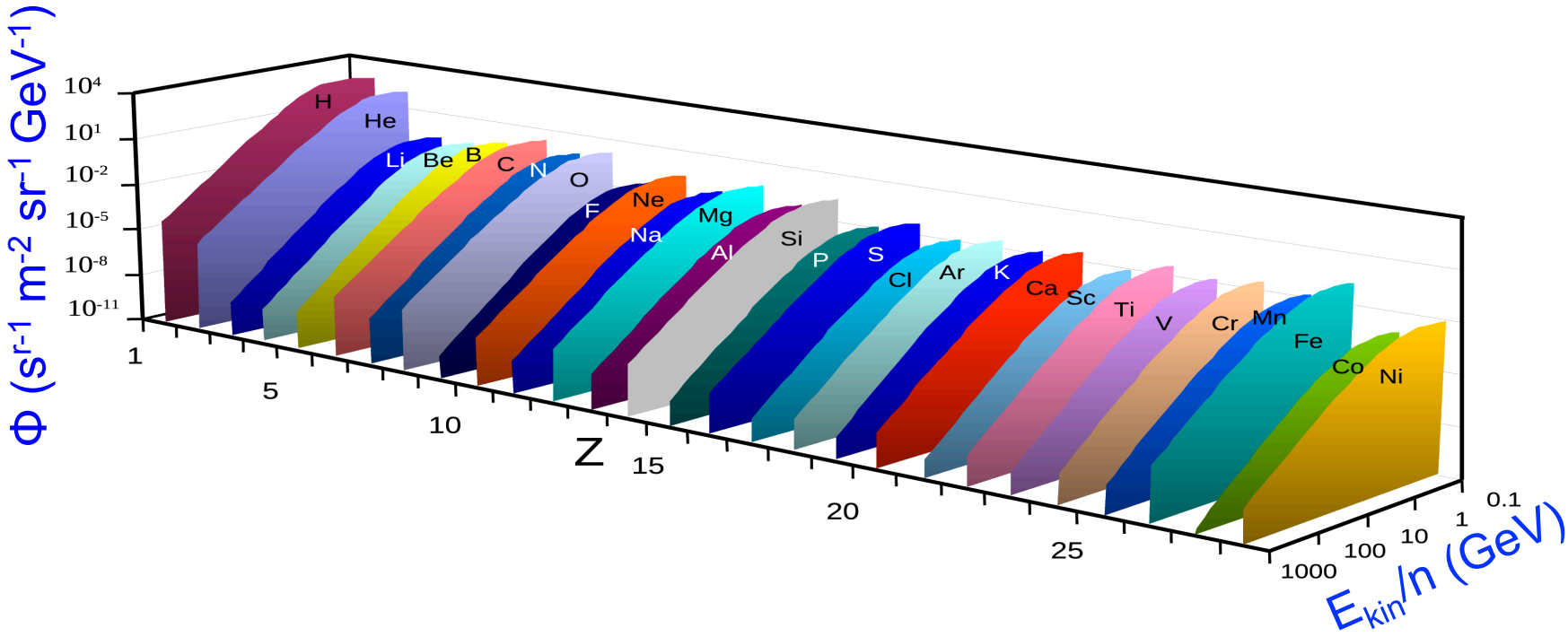
Beam: tertiary negative 300 GeV

Test at CERN SPS H8 beam line, August 9-21 2010



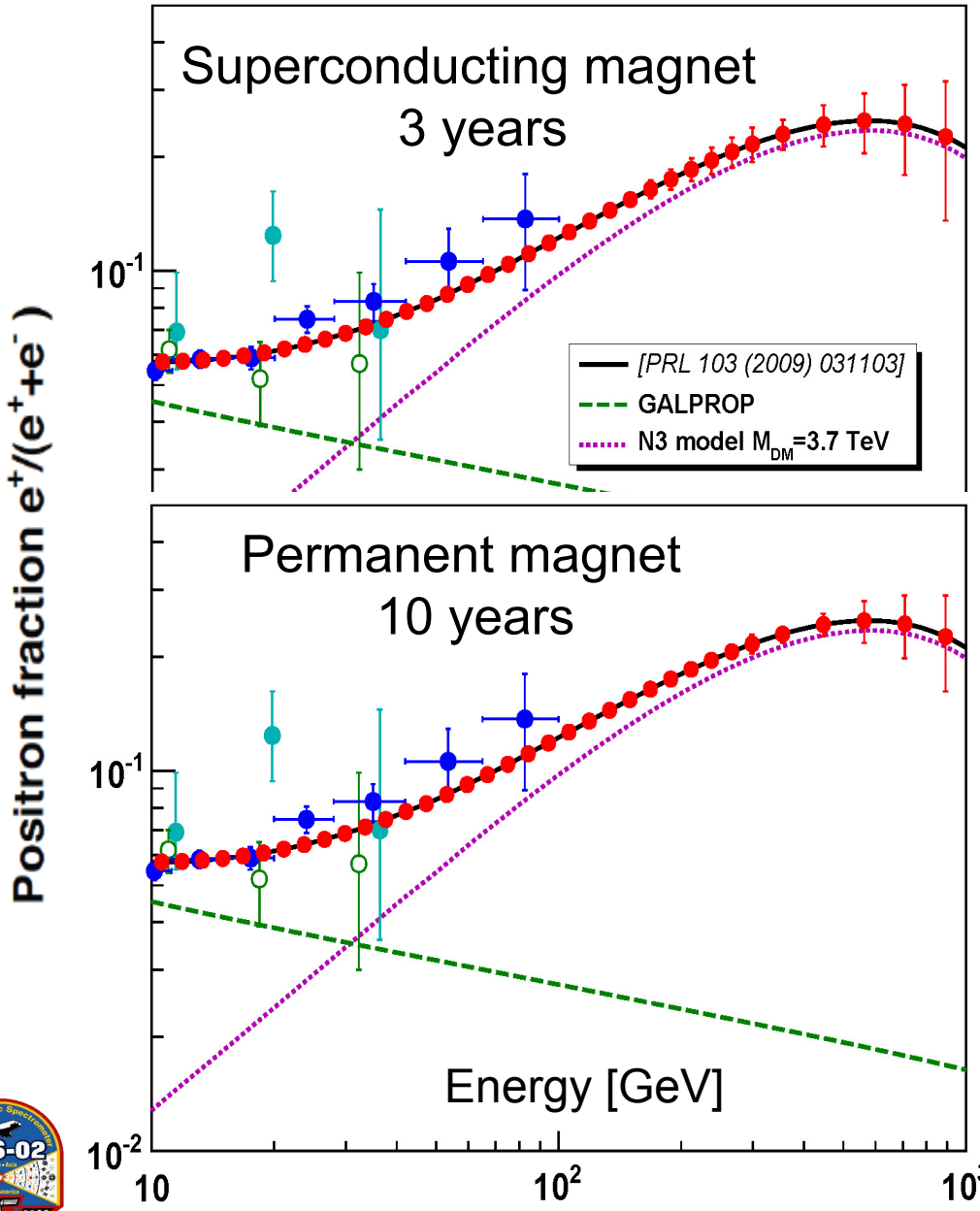
Beam: tertiary positive 20 GeV

Physics of AMS: Nuclear Abundances Measurements



AMS will measure of cosmic ray spectra for nuclei, for energies from 500 MeV to 2 TeV to 1% over the 11-year solar cycle.

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



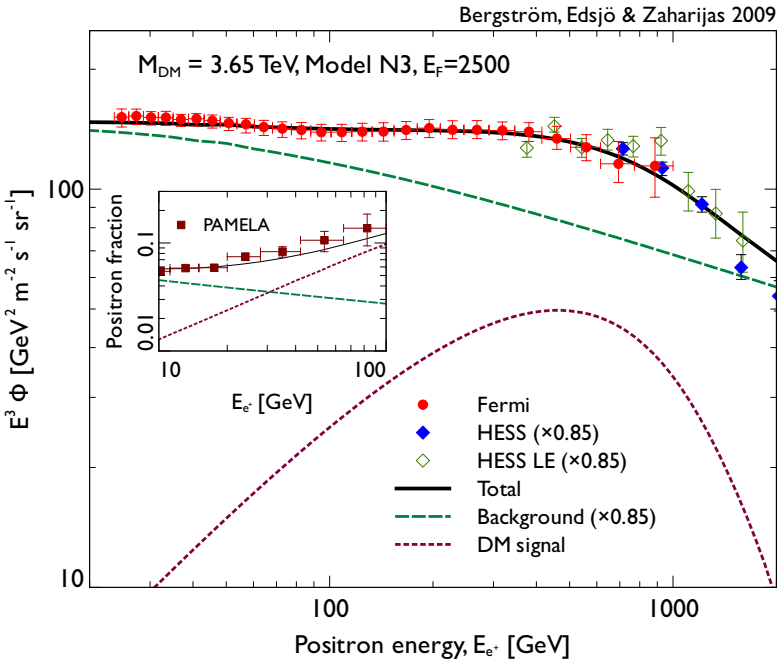
Bergström, Edsjö, Zaharias 2009

Fit to Pamela, Fermi-LAT, HESS

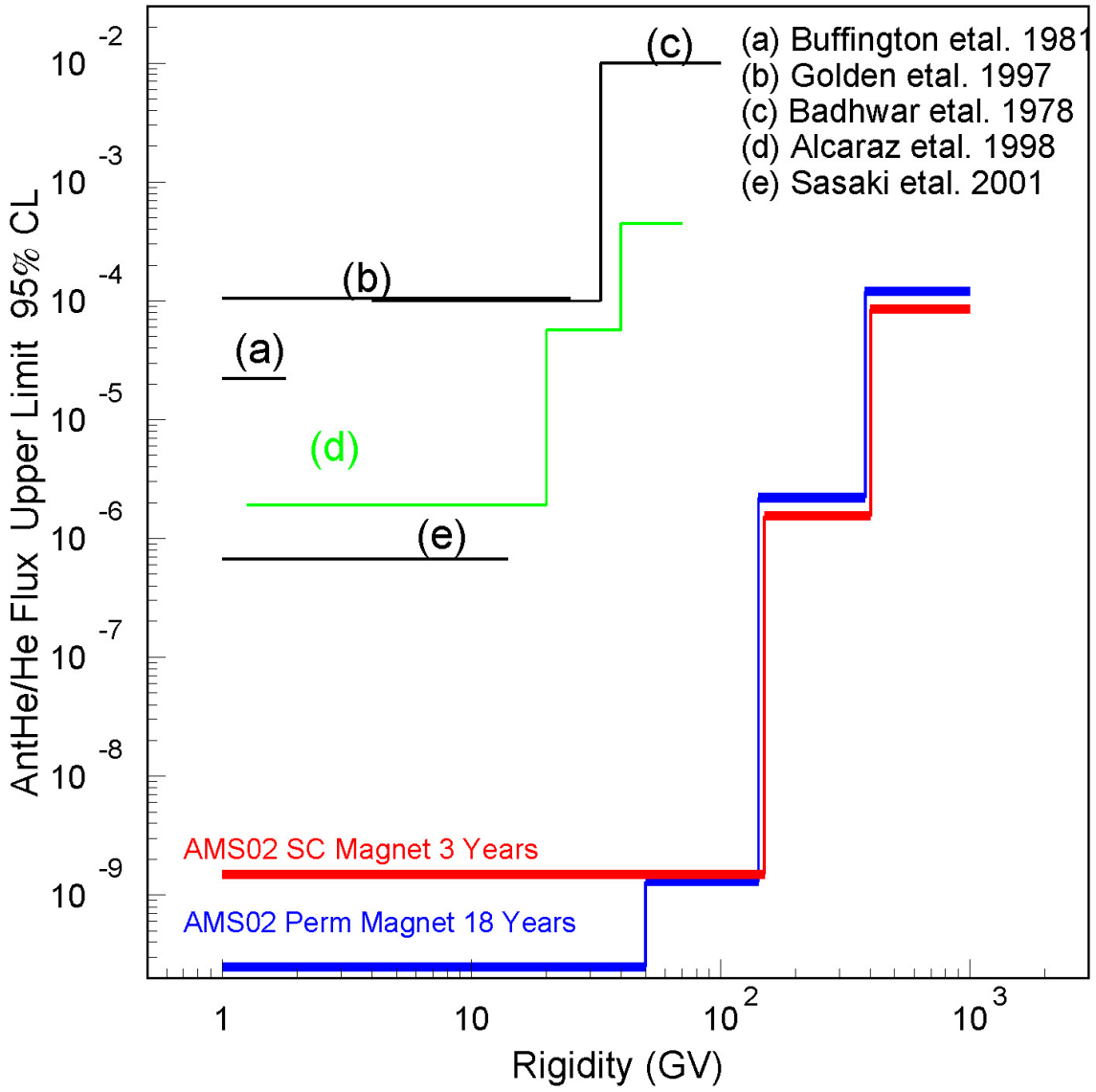
Nomura-Thaler model N3

M_{DM} = 3.65 TeV

$E_F \approx 2500$



Search for Residual Antimatter



AMS: Conclusions

- AMS-02 has successfully been integrated with the long lifetime permanent magnet, to match the extended ISS lifecycle.
- The experiment performance at high energies is preserved.
- Schedule:
  - CERN test beam in final configuration from August 8 to 21, 2010 has confirmed expected detector performances.
  - US Air Force C5 will take us on August 26 to Kennedy Space Center, Florida.
  - On flight STS-134, scheduled for Feb. 26, 2011, space shuttle Endeavour will take us to the ISS.

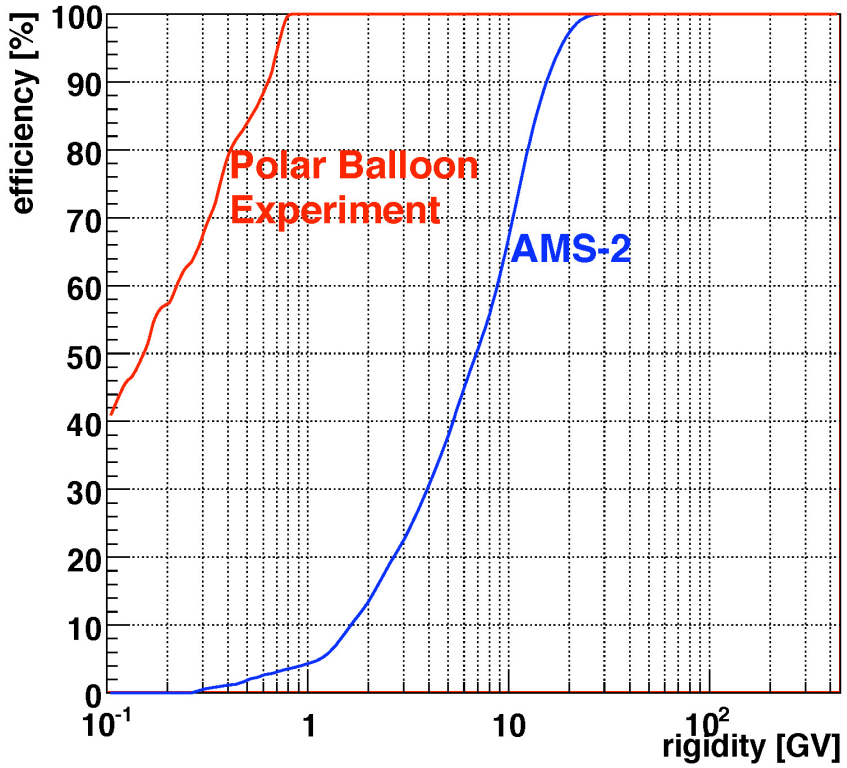
Positron Electron Balloon Spectrometer (PEBS)

- Flux measurement of cosmic charged particle at an altitude of 40 km with a magnetic spectrometer launched by a stratosphere balloon making circular flights around north and/or south pole
- Collaboration: CH: EPFL, ETHZ ; CN: Tsinghua Univ.; DE: Aachen; US: Chicago, Ohio
- Why using a balloon not a satellite, since a balloon flight provide a shorter measurement period (up to ~40 days)?
  - Typically, the size of a balloon detector can be much larger, compensating the shorter data taking period
  - Easier conditions for the launch and operation of the detector and the detector can be launched faster
    ⇒can benefit from the latest detector technology
  - Multiple launch possible with the same or upgraded detector
    ⇒the experimental programme can evolve with the technological and scientific development

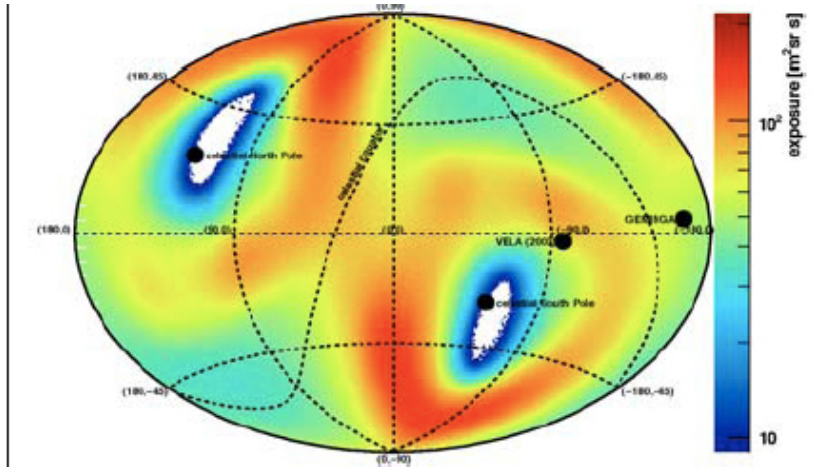
Courtesy of Prof. T. Nakada EPFL

PEBS complementary coverage

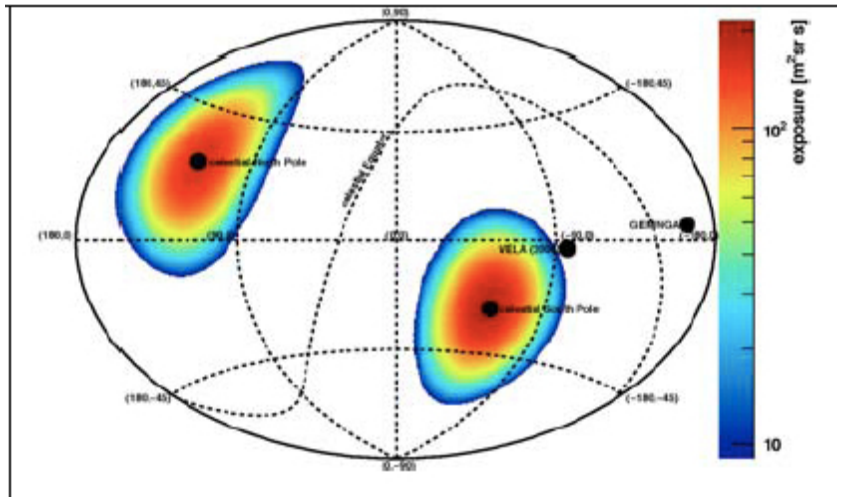
Momentum cut-off



AMS-2 sky coverage



PEBS sky coverage



Courtesy of Prof. T. Nakada EPFL

- PEBS will be launched in the framework of the NASA balloon programme (informal information: will be approved for the 2011-2015 programme)
- First flight: 2014 north pole
- Second longer flight: 2015 south pole

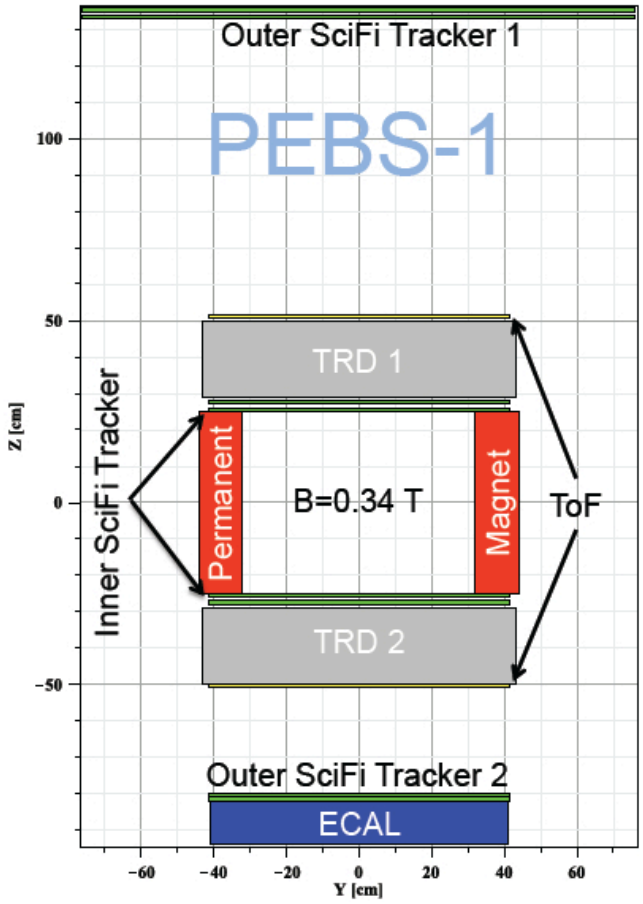
PEBS-1 with the basic configuration:

Scintillating fiber tracker
Tungsten-scintillator calorimeter with fiber readout
ToF/trigger scintillator

} SiPMT photon detector

TRD a la AMS-2
Permanent dipole magnet

- Acceptance e^+, e^-: 1200 cm^2 sr
- Acceptance e^++e^-: 6000 cm^2 sr
- Weight: ~2000 kg
- Power: ~900 W
- $\sigma_p/p = 0.001 \times p \oplus 0.038$
- Miss ID(p→e) = 10^{-6}
- e^+ identification up to 600 GeV



Courtesy of Prof. T. Nakada EPFL

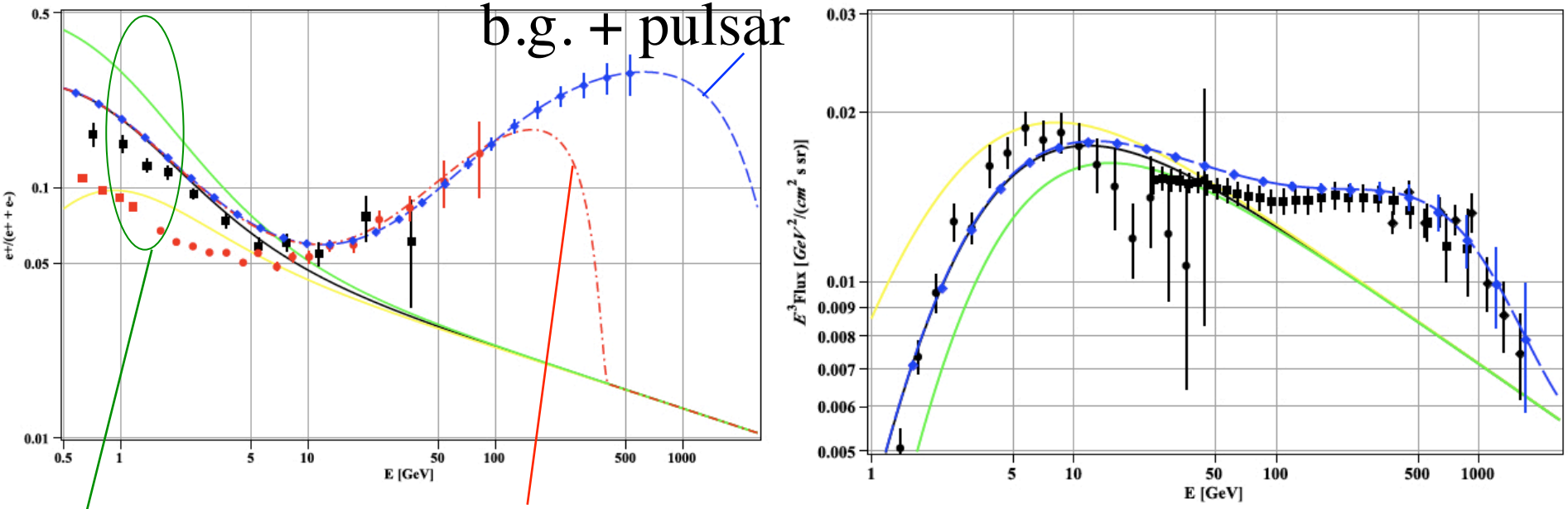
PEBS expected performance

PEBS-1 20 days flight

together with already existing measurements

e^+ flux

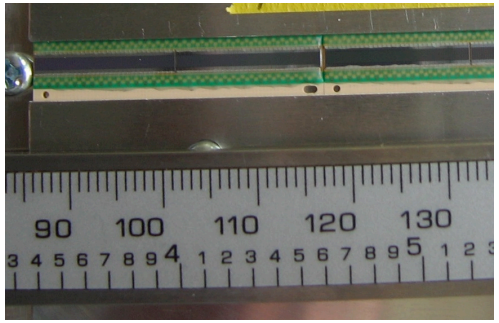
$e^+ + e^-$ flux

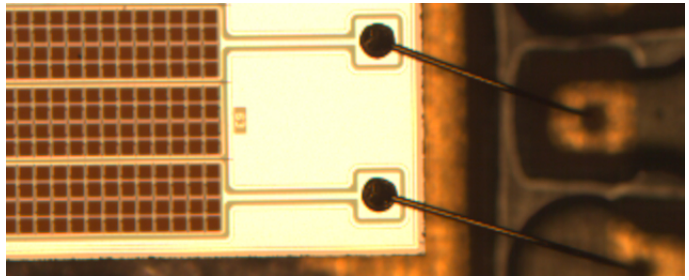


Courtesy of Prof. T. Nakada EPFL

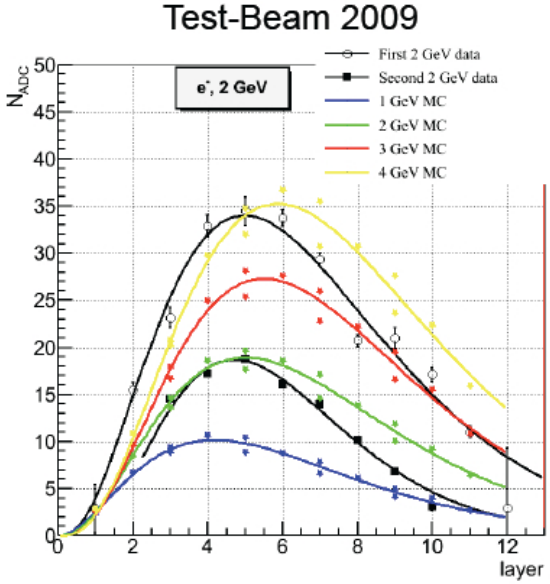
PEBS CH Contribution

- Electromagnetic Calorimeter
  - Tungsten-Scintillator sandwich electromagnetic calorimeter readout by WLS fibres (ϕ = 1 mm)
  - SiPMT (MPPC) photon detector, modified from a commercial (HPK) single channel device
  - SPIROC readout chip, originally developed for ILC
- 128 channel SiPMT, for the tracker, custom development with HPK
- DAQ electronics





128 channel SiPMT

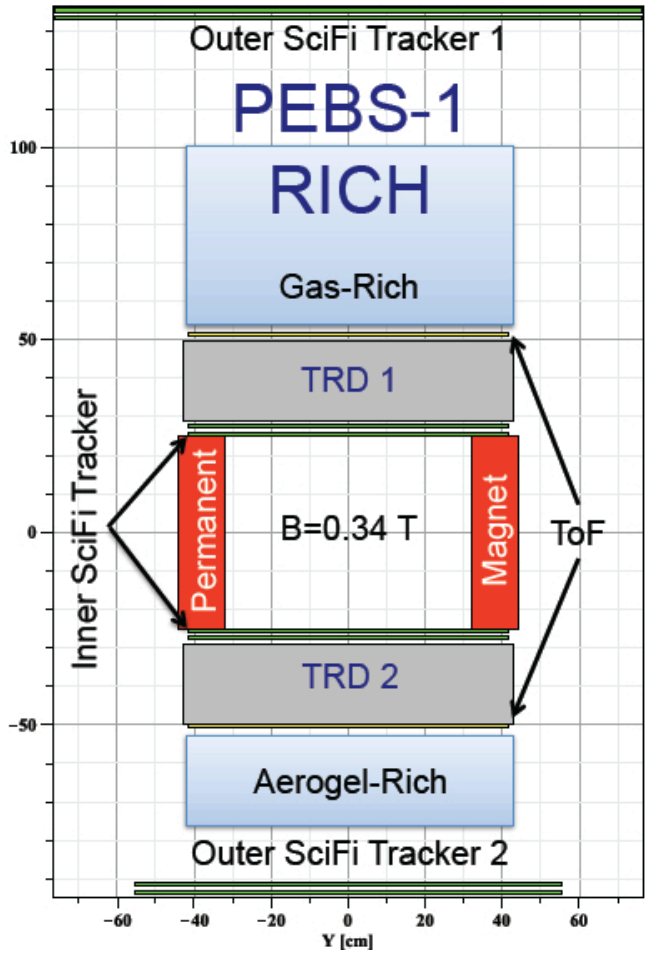


E-cal prototype test

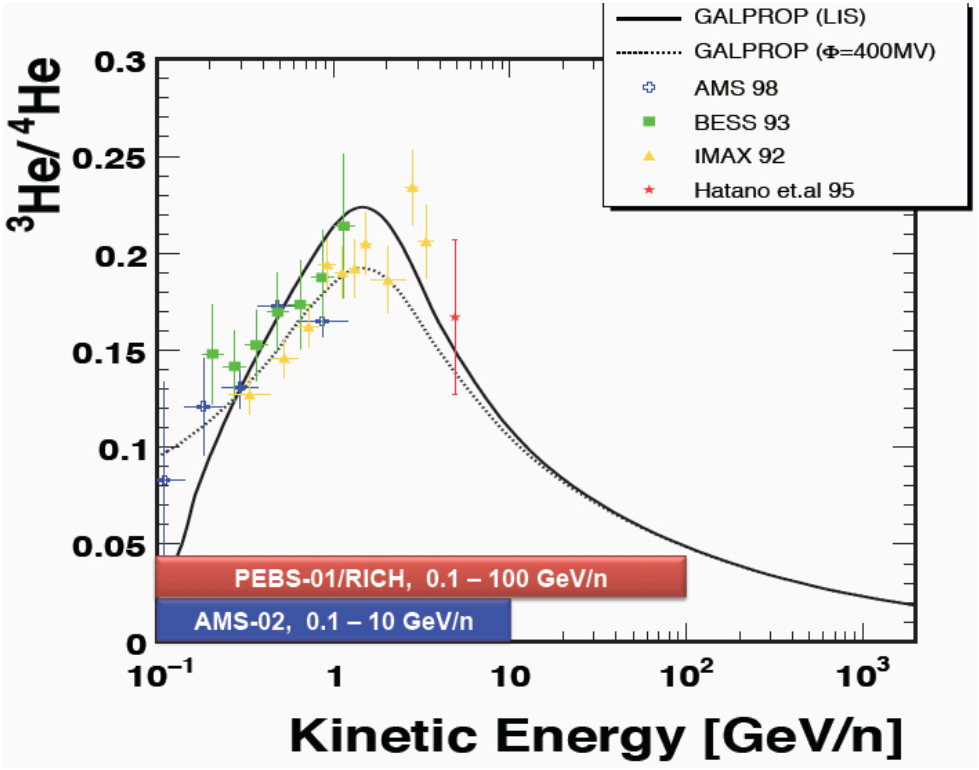
Courtesy of Prof. T. Nakada EPFL

PEBS-1 variant

- As a second phase RICH could be added to PEBS-1



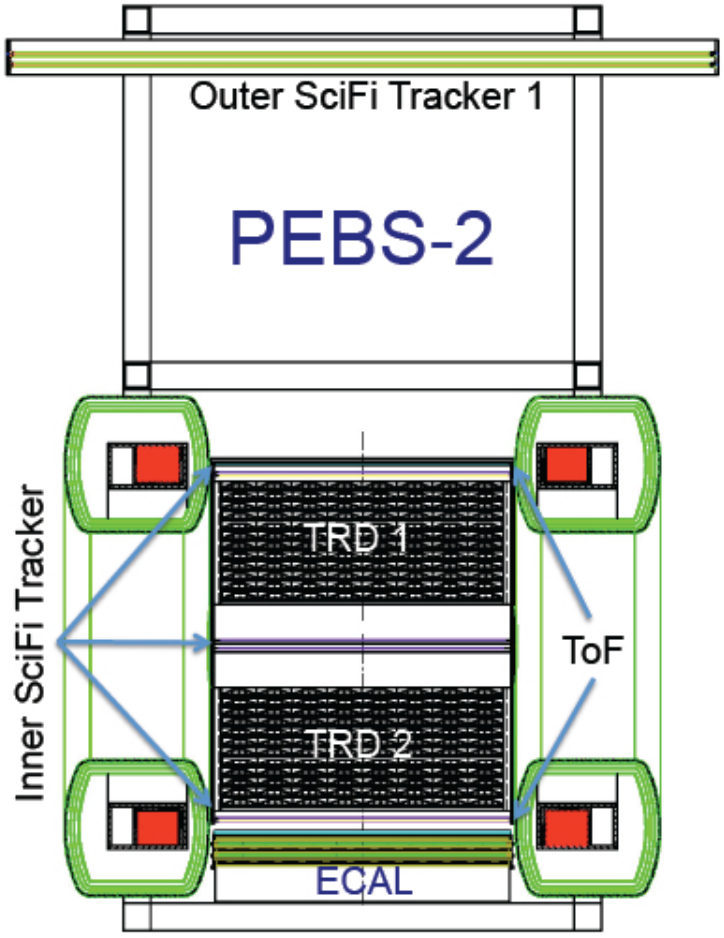
Courtesy of Prof. T. Nakada EPFL



To test different theoretical flux calculations

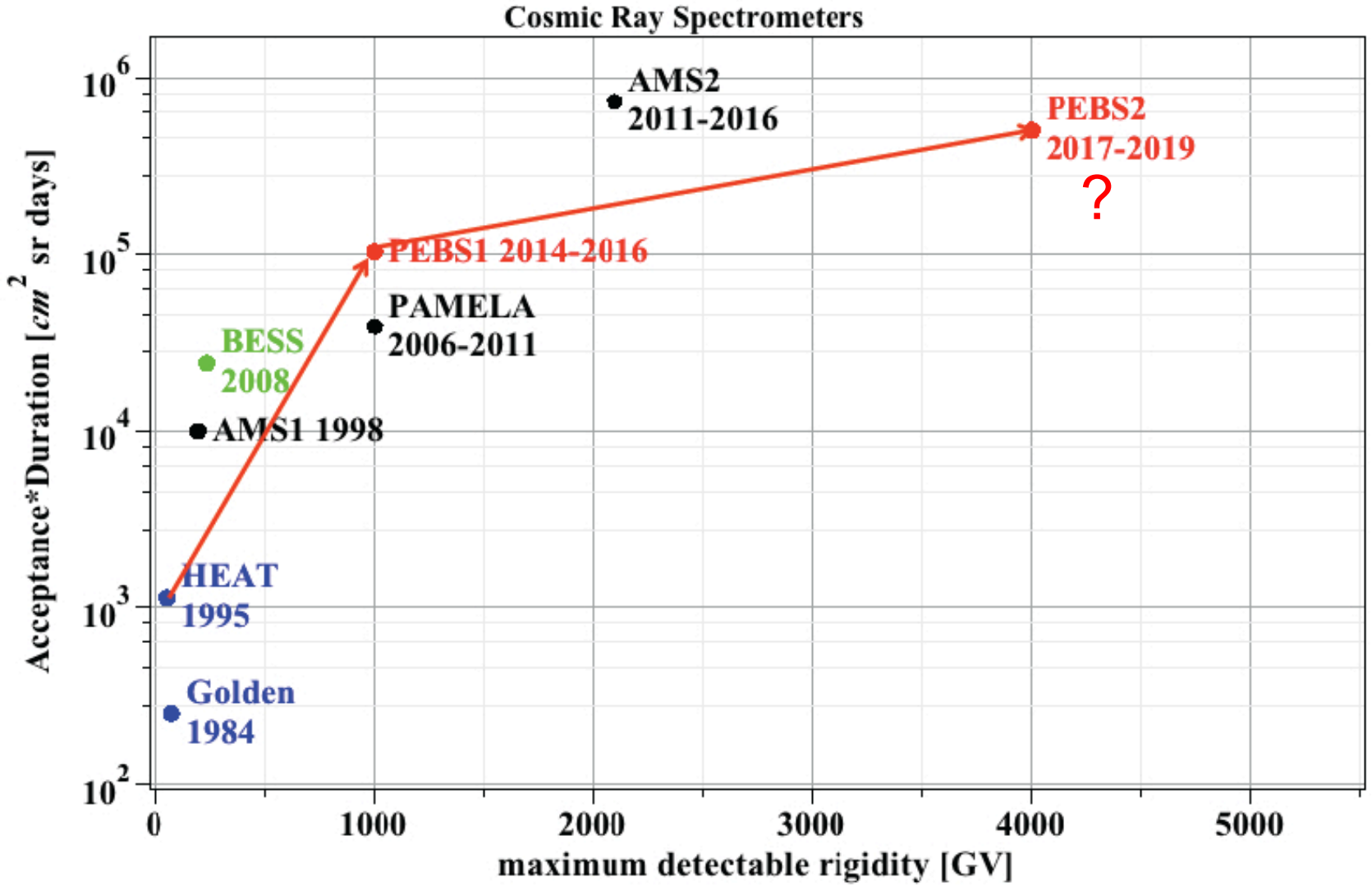
PEBS-2

- Further upgrade of PEBS with a superconductive magnet for e^+ identification 1 TeV with a larger acceptance
  - B field = 0.9T
  - e^+ ID up to ~1.5 TeV
  - acceptance 2500 cm^2 sr
  - Cost ~2 MCHF



Courtesy of Prof. T. Nakada EPFL

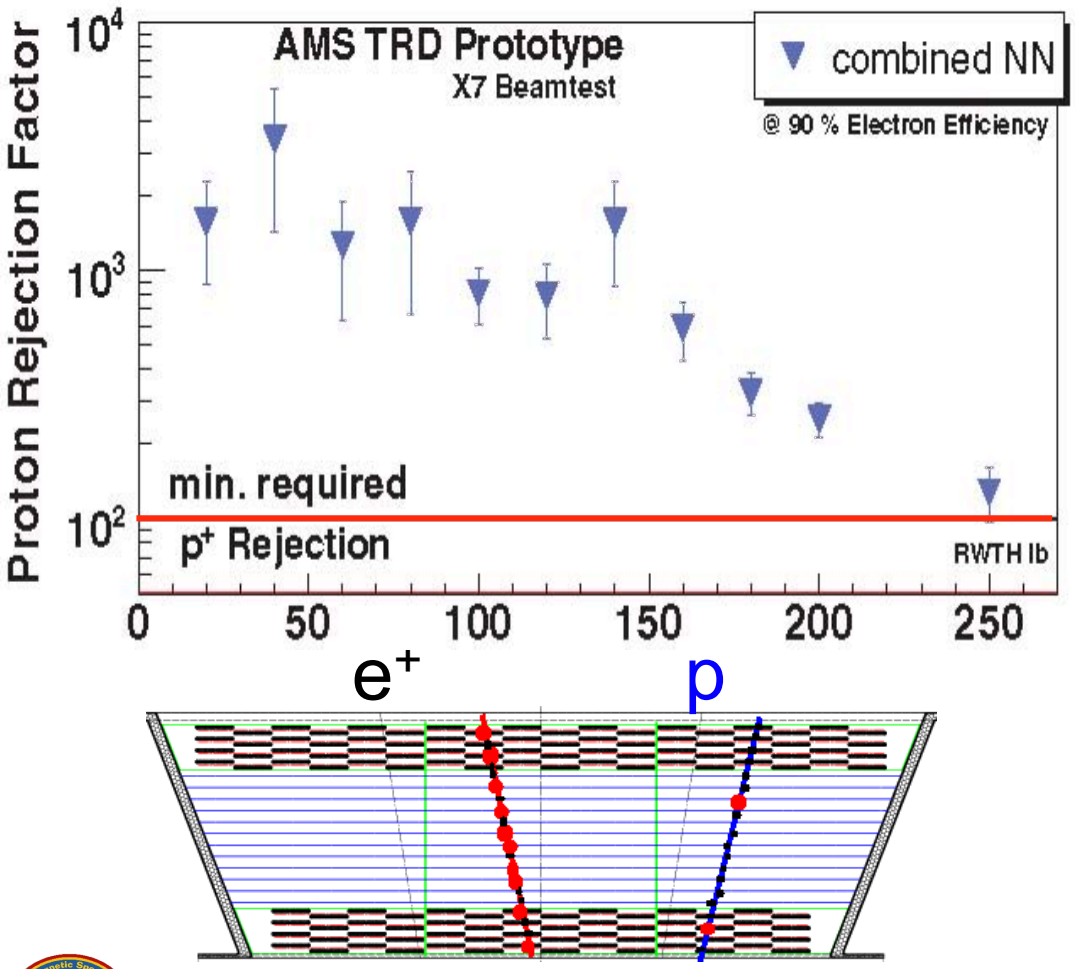
Cosmic Ray Spectrometers Overview and PEBS evolution



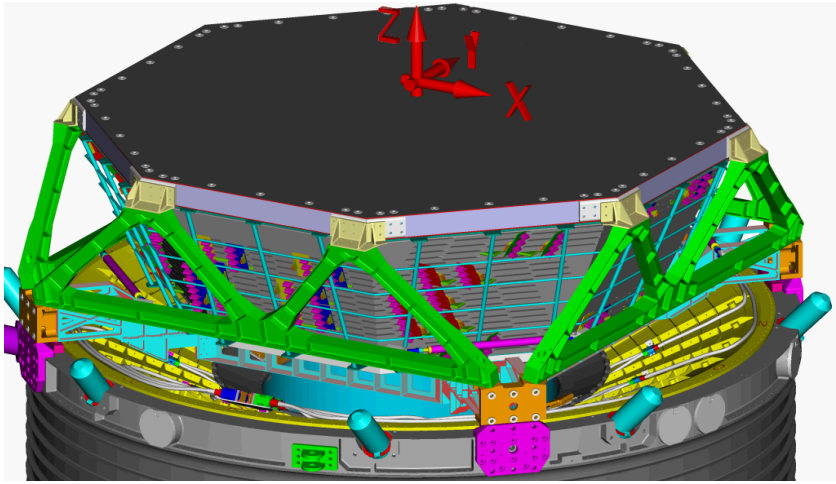
Courtesy of Prof. T. Nakada EPFL

BACKUP SLIDES

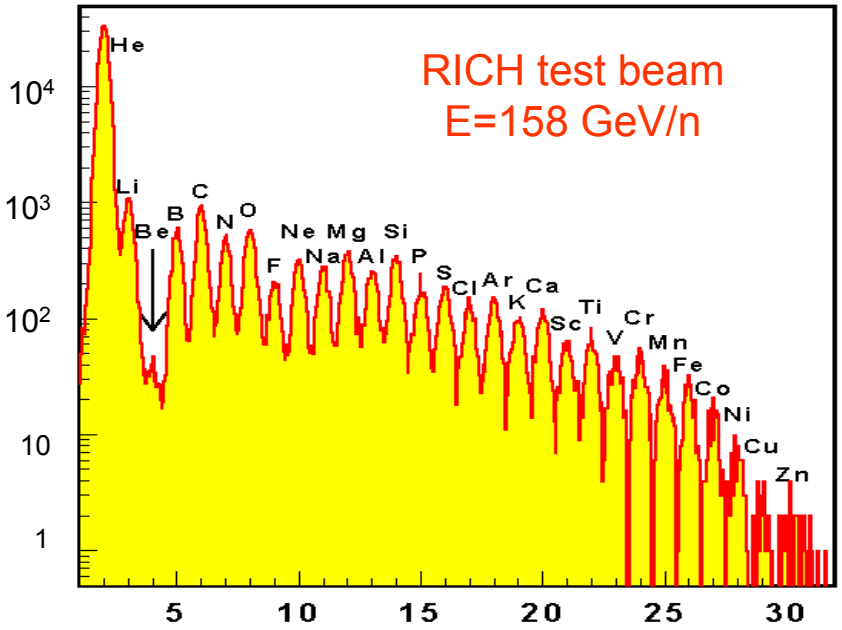
Transition Radiation Detector (TRD)

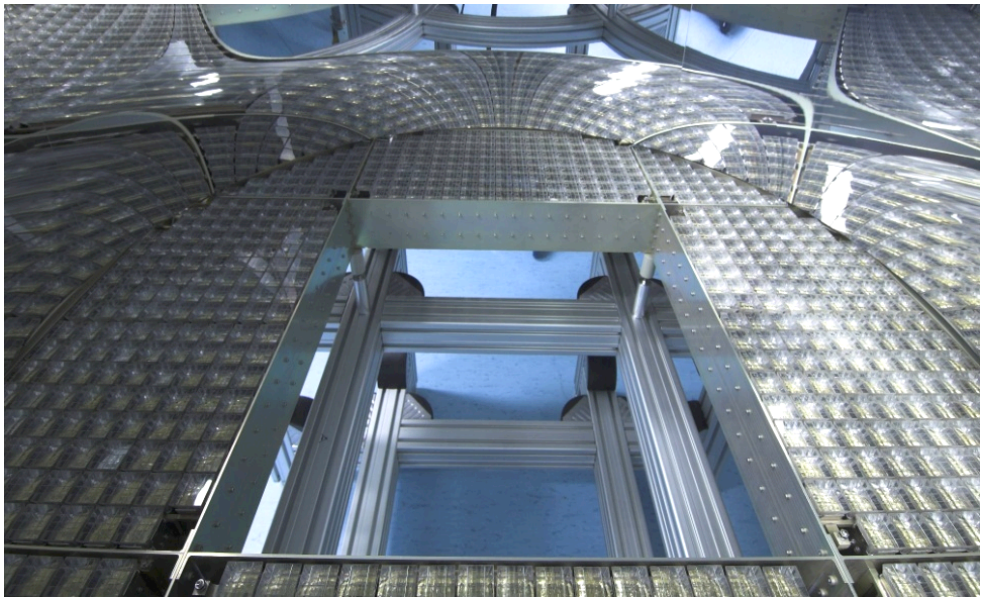


20 layers

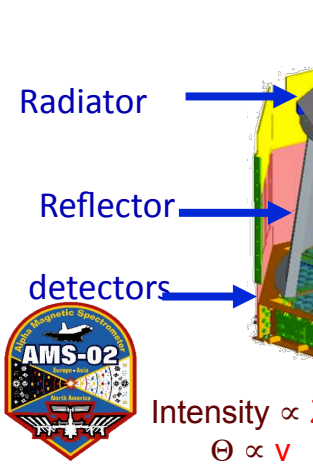


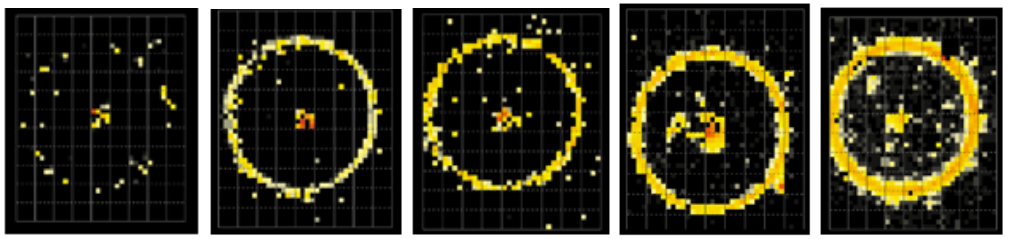
Ring Imaging Cherenkov (RICH)





10,880 photosensors

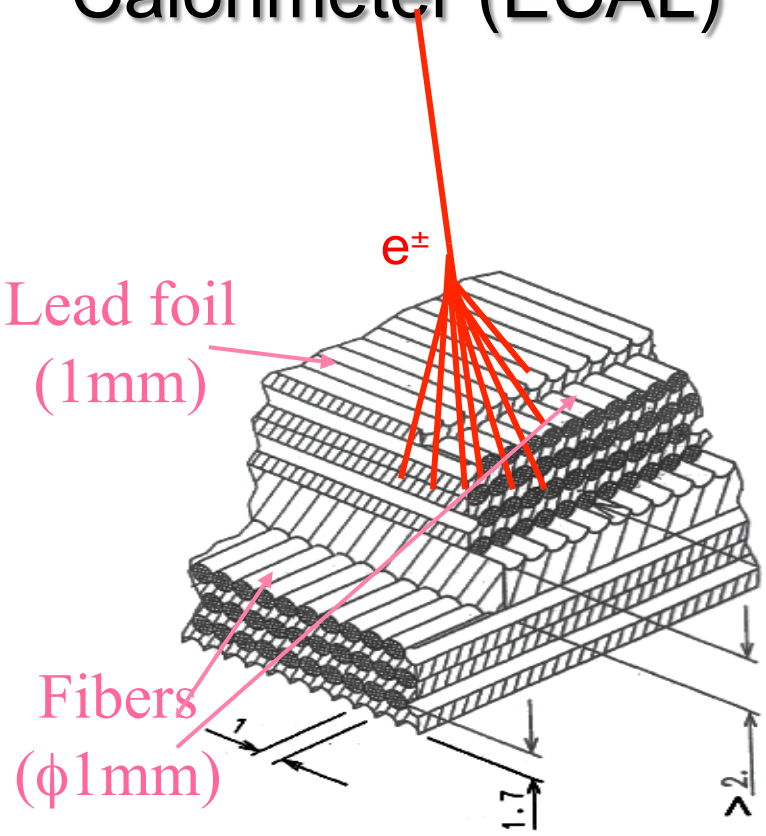


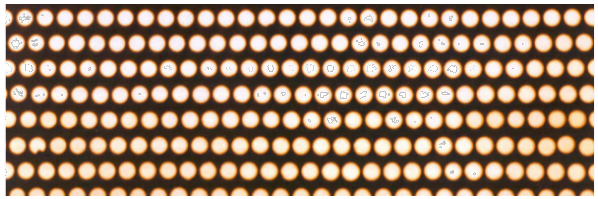


He Li C O Ca

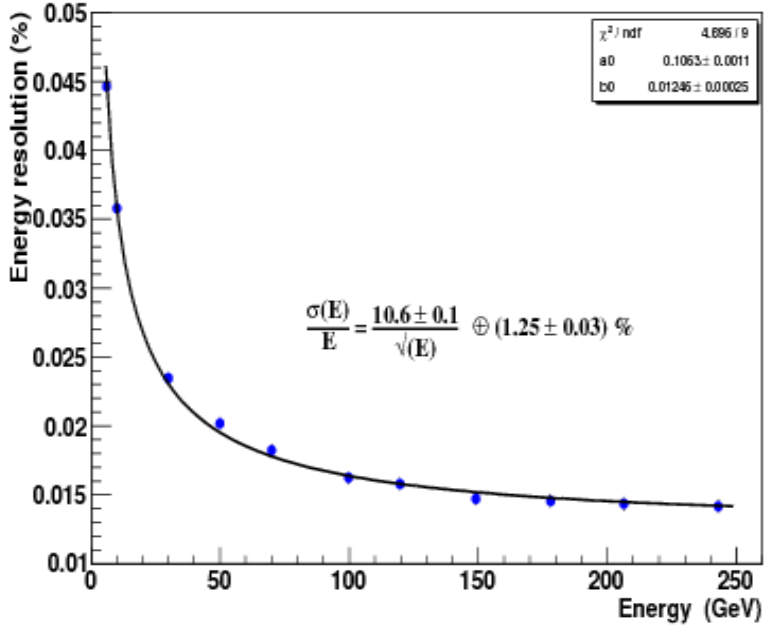
Single Event Displays
RICH test beam E=158 GeV/n

Calorimeter (ECAL)

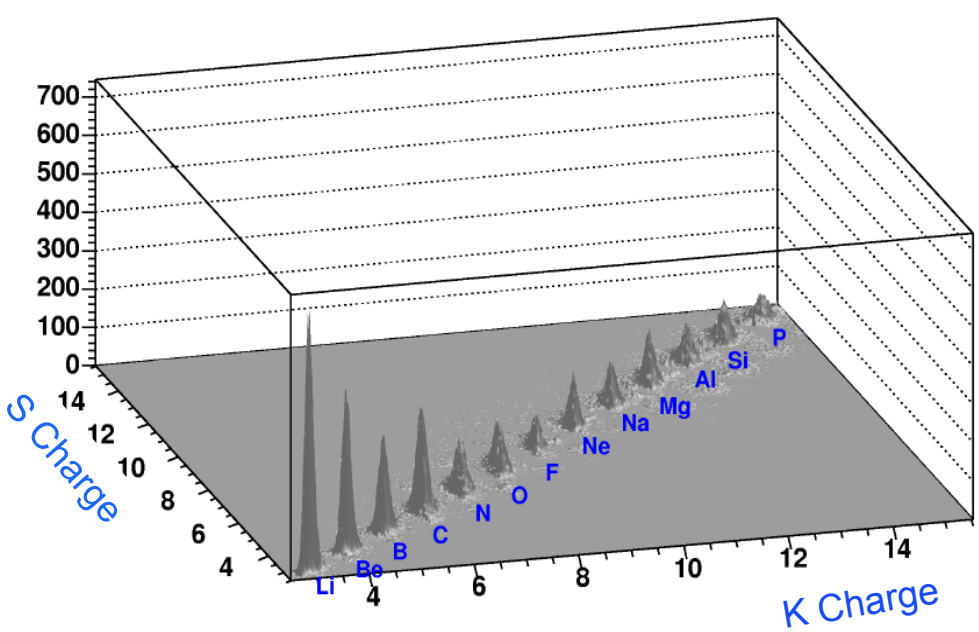


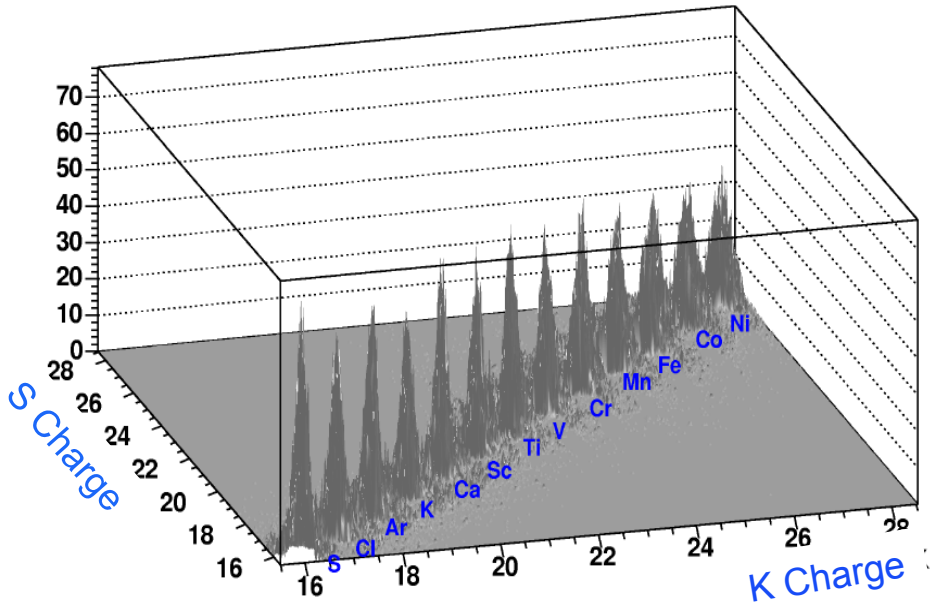


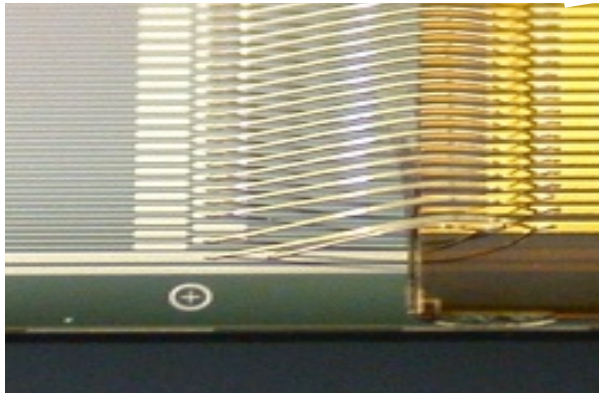
10 000 fibers, ϕ = 1 mm
distributed uniformly
inside 1,200 lb of lead

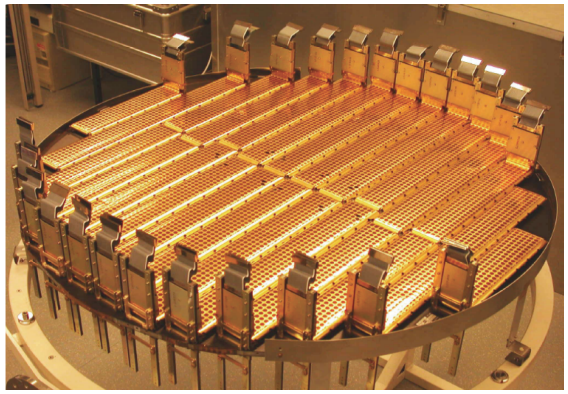


Silicon Tracker: Rigidity and Charge



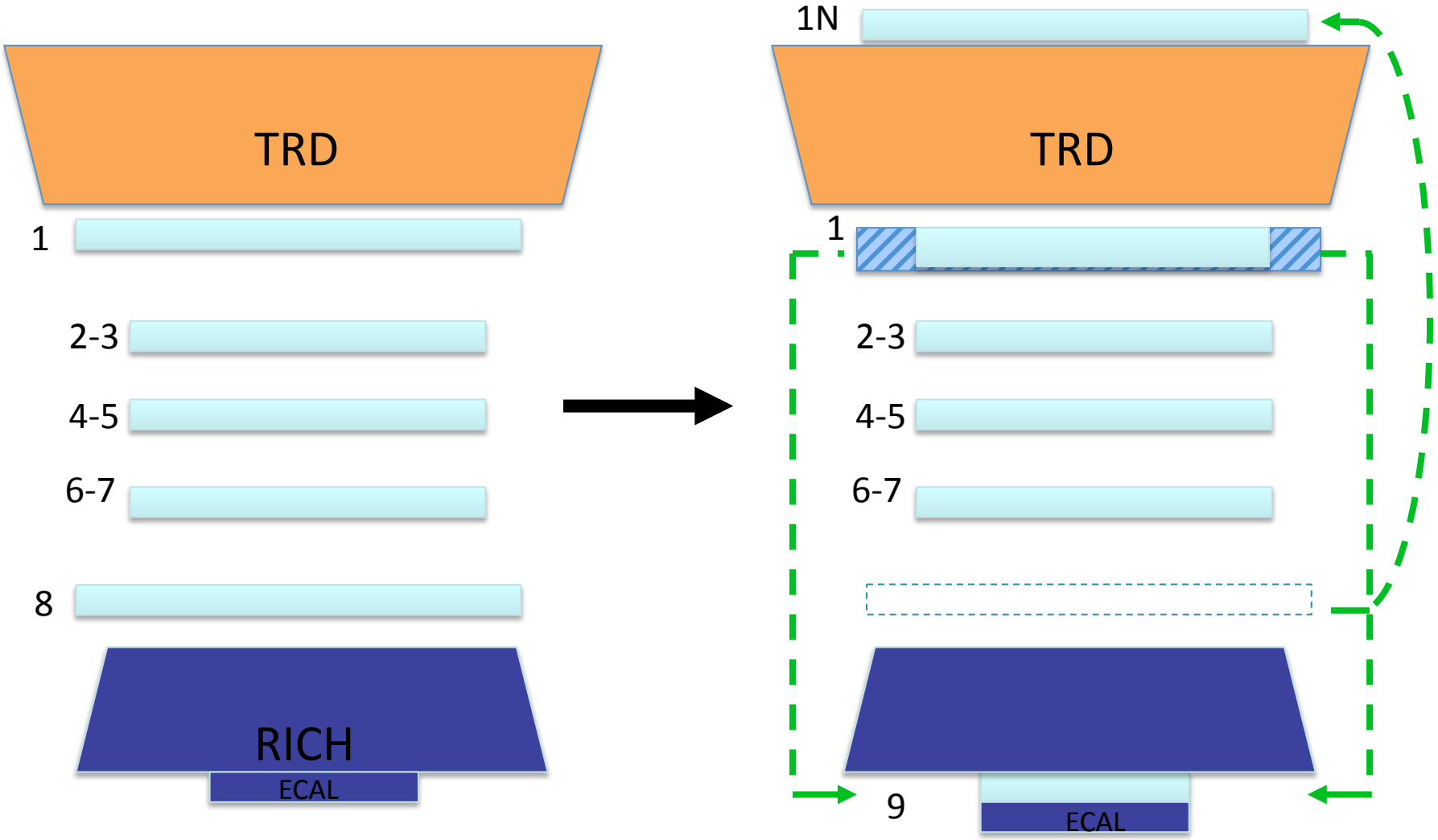




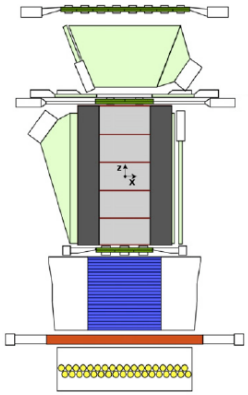


AMS-02 Superconducting Magnet
Silicon Tracker Layers

AMS-02 Permanent Magnet
Silicon Tracker Layers



Layer 9 comes from moving the ladders at the edge of the acceptance from layer 1. The layer 8 is moved on top of the TRD to become 1N.
No new silicon and no new electronics are required.



PAMELA

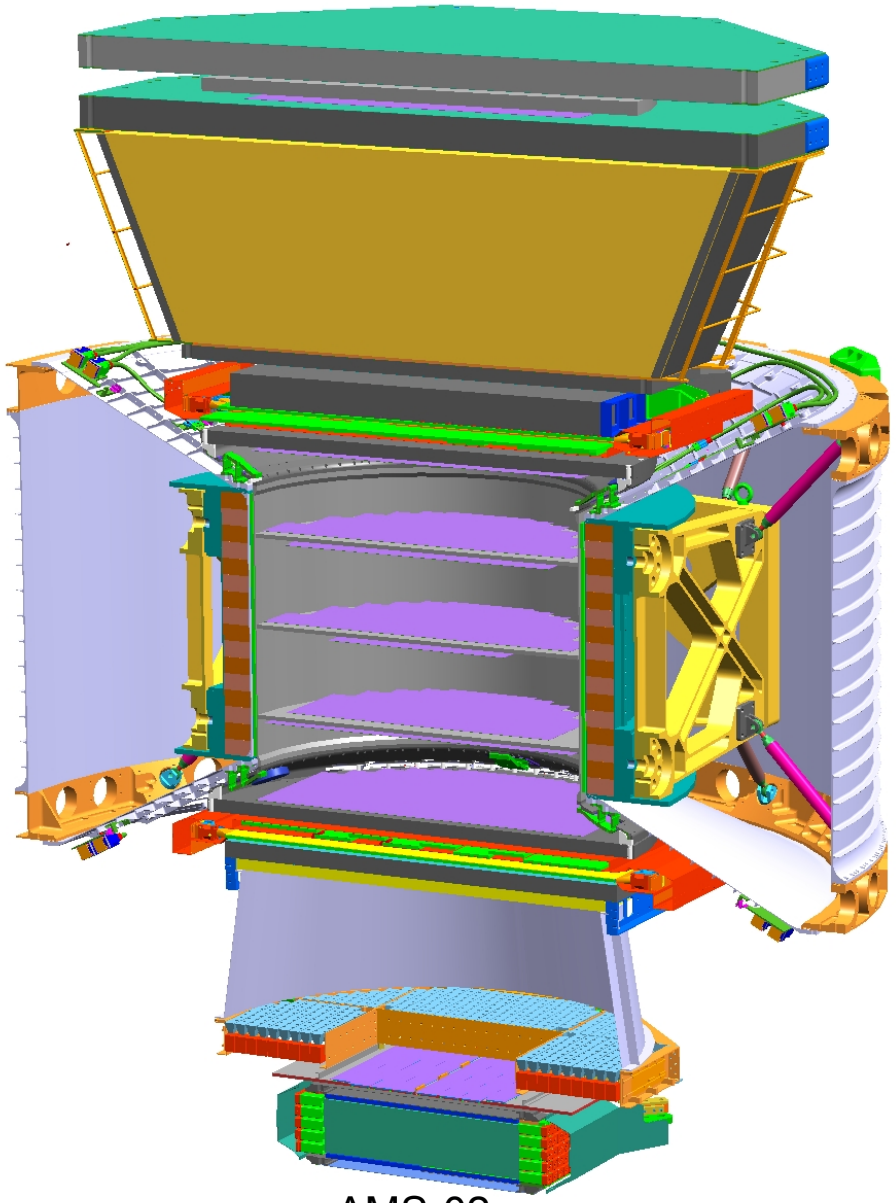
<u>Acceptance</u>

20.5 cm^2sr

<u>Exposure</u>

2006-2011

1m



AMS-02

<u>Acceptance</u>

e^+ 950 cm^2sr

$\bar{p}$, He, $\overline{He}$, … 4,500 cm^2sr

<u>Exposure</u>

2010-2020 (2028)