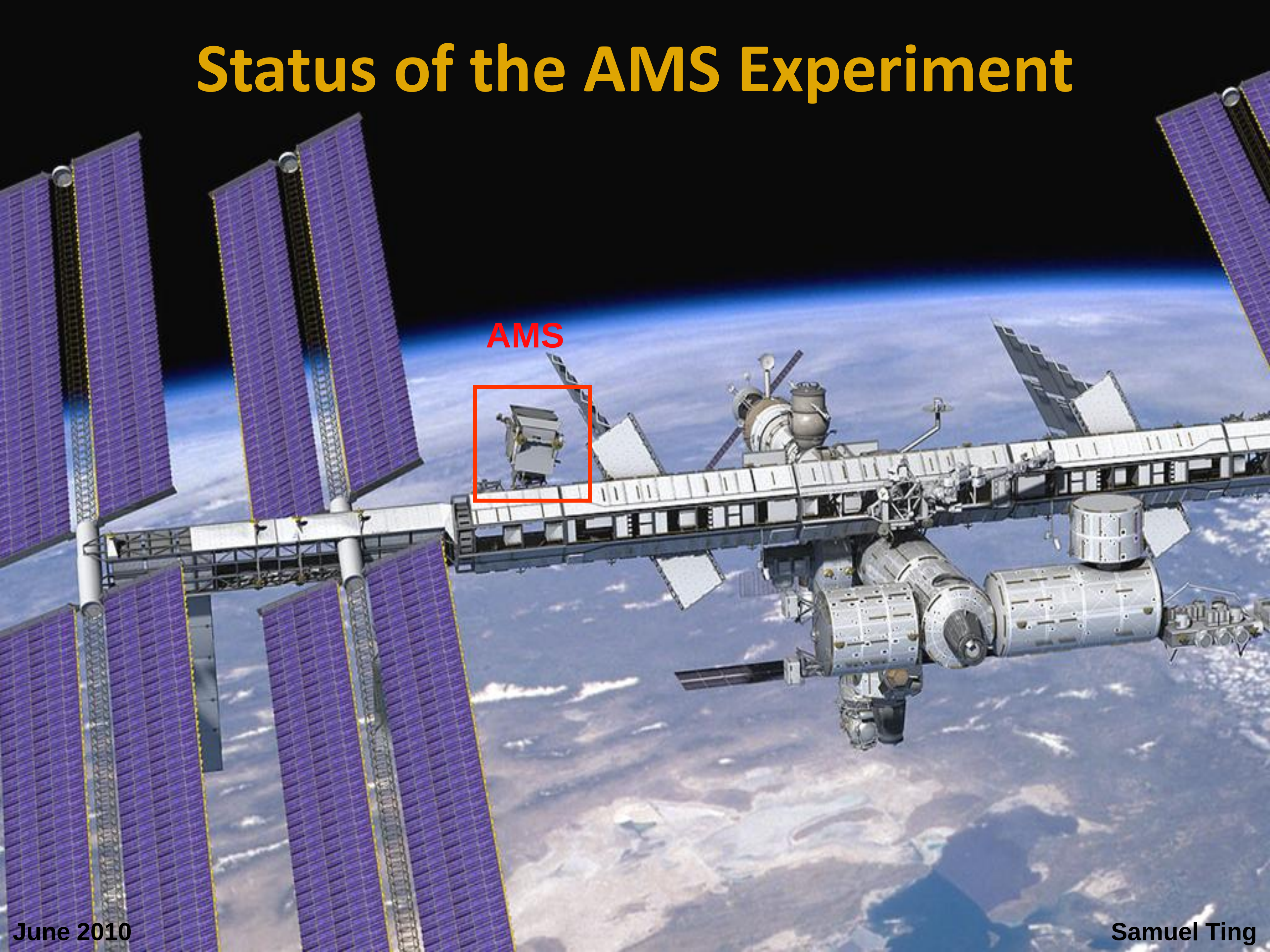
Status of the AMS Experiment



June 2010

Samuel Ting

STS-134 Mission Information

Image above: Pictured clockwise in the STS-134 crew portrait are NASA astronauts Mark Kelly (bottom center), commander; Gregory H. Johnson, pilot; Michael Fincke, Greg Chamitoff, Andrew Feustel and European Space Agency's Roberto Vittori, all mission specialists. Image credit: NASA

The STS-134 crew members are Commander Mark Kelly, Pilot Gregory H. Johnson and Mission Specialists Michael Fincke, Greg Chamitoff, Andrew Feustel and European Space Agency astronaut Roberto Vittori.

Endeavour will deliver spare parts including two S-band communications antennas, a high-pressure gas tank, additional spare parts for Dextre and micrometeoroid debris shields. This will be the 36th shuttle mission to the International Space Station.

Overview

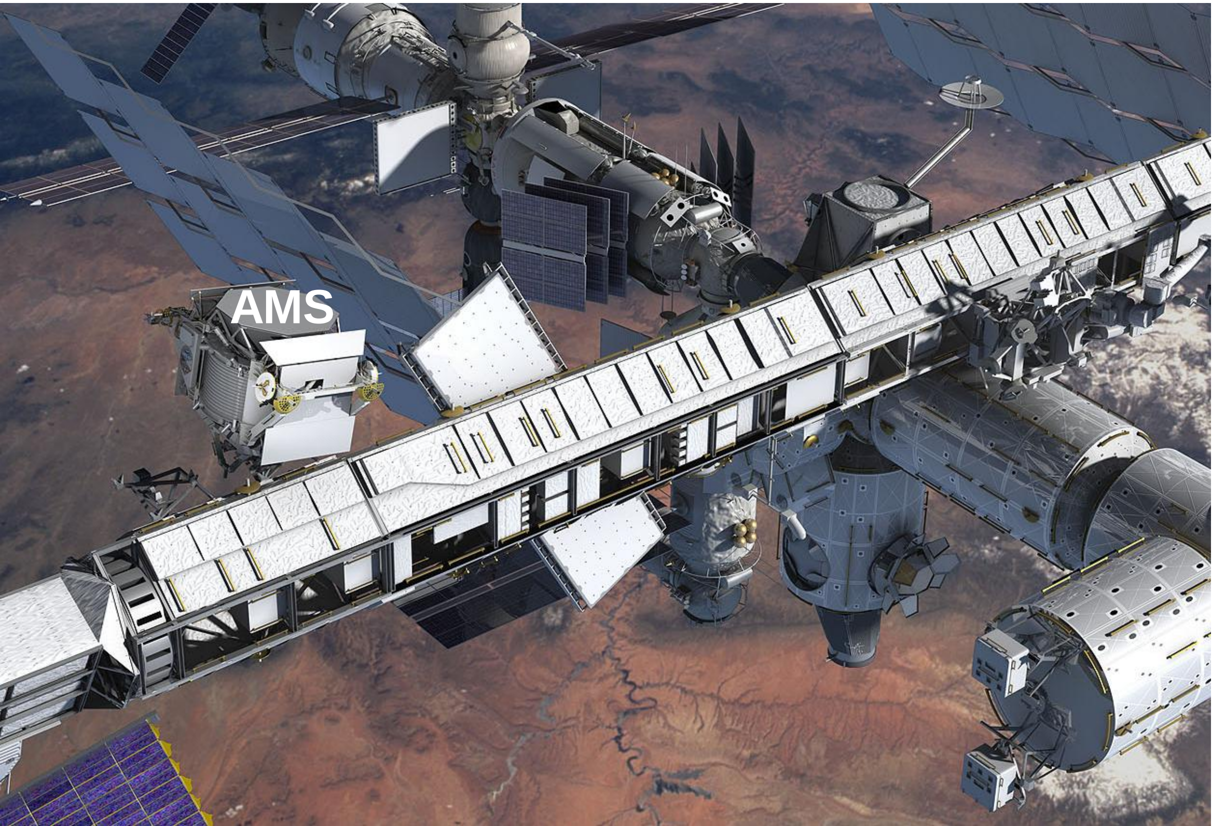
Launch Target:
Nov. 2010
Orbiter:
Endeavour
Mission Number:
STS-134
(134th space shuttle flight)
Launch Window:
10 minutes
Launch Pad:
39A
Mission Duration:
10 days
Landing Site:
KSC
Inclination/Altitude:
51.6 degrees/122 nautical miles
Primary Payload:
36th station flight (ULF6), EXPRESS Logistics Carrier 3 (ELC3), Alpha Magnetic Spectrometer (AMS)

Fundamental Science on the International Space Station (ISS)

There are two kinds of cosmic rays traveling through space

1- <u>Light rays</u> and neutrinos have been measured (e.g., Hubble) for over 50 years. Fundamental discoveries have been made .

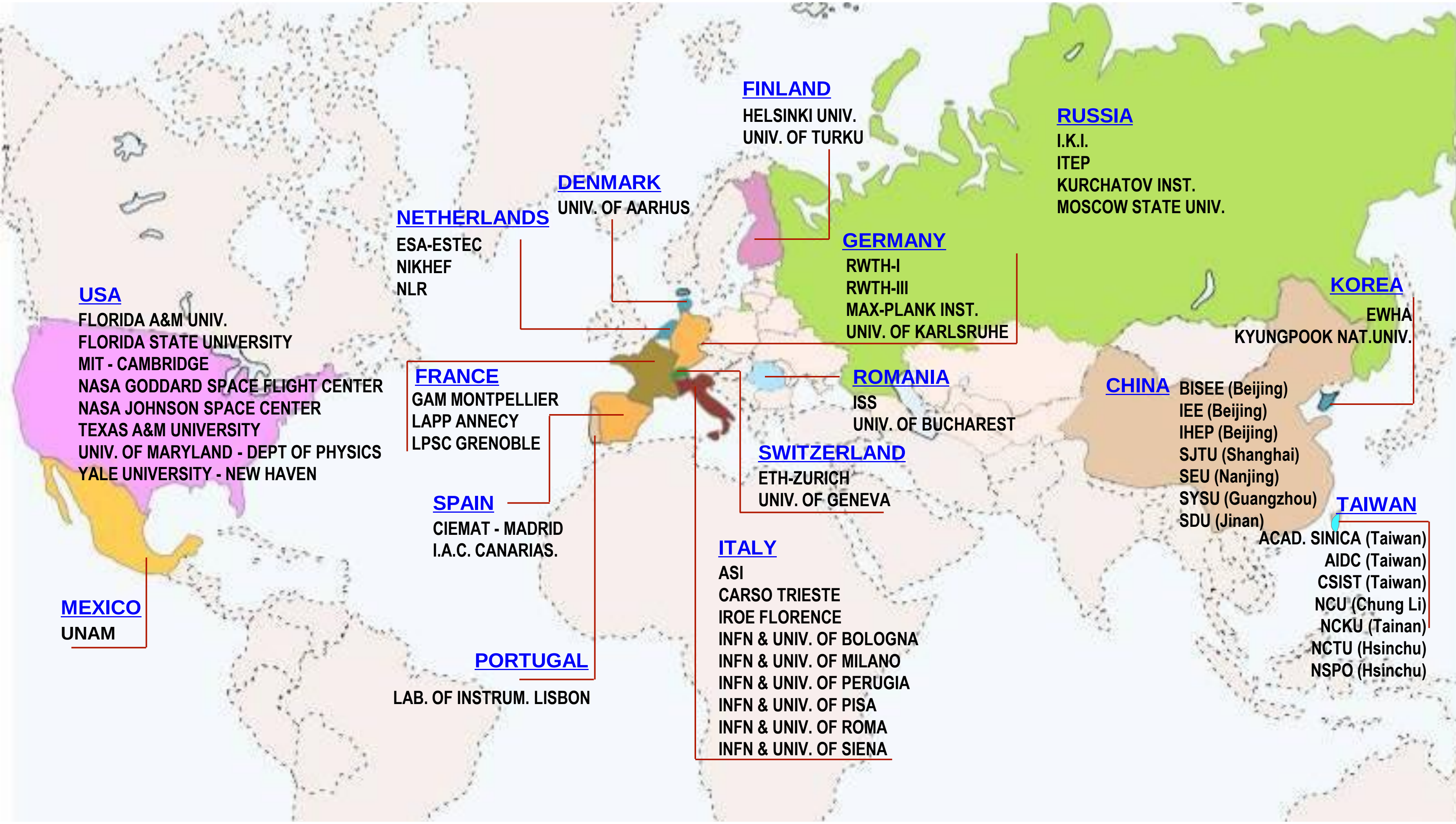
2- <u>Charged cosmic rays</u>: A large acceptance, multipurpose, magnetic spectrometer (AMS) on ISS is the only way to measure precisely high energy charged cosmic rays.



The major physical science experiment on the ISS .

AMS is a DOE sponsored International Collaboration

16 Countries, 60 Institutes and 600 Physicists



95% of the > $2.0B to build AMS has come from our international partners .

We acknowledge the continuous strong support from DOE (D. Kovar, S. Gonzalez)

FPAG(97)2
CERN, 18 February 1997

EUROPEAN SPACE AGENCY

FUNDAMENTAL PHYSICS ADVISORY GROUP

The Alpha Magnetic Spectrometer (AMS)

The AMS will be the first magnetic spectrometer in orbit, scheduled for flight on the Shuttle in 1998 and on the International Space Station (ISS) in 2001. One of the most challenging scientific objectives of this experiment is to search for antimatter ($\overline{He}$, $\overline{C}$) in space with a sensitivity of 10^4 to 10^5 better than current limits. Therefore, the AMS also belongs to the discipline of Fundamental Physics in Space.

Following a presentation by the AMS Principal Investigator, Prof. S.C.C. Ting, the FPAG, at its meeting on 17-18 February 1997 at CERN, reviewed the scientific objectives, experimental technique and international collaboration aspects of the AMS, and concluded that the AMS is a very important and presently unique experiment and that the strong European involvement in the AMS, which to a large extent is already in place, is highly desirable.

The FPAG noted that the preparation for the Shuttle flight was nearly complete but that further efforts for the full-scale Space Station experiment are still needed.

The remaining development work for the experiment on the ISS would greatly benefit from ESA's knowledge and expertise in space instrument qualification and mission and science operations. The FPAG therefore recommends that ESA should explore ways and means to make this expertise available to the AMS experiment.

y98150

AMS Referees — Switzerland

Research Council of the Swiss National Funds

Professor Hans BALSIGER	Bern
Professor Kurt BAUKNECHT	Zürich
Professor Willy BENOIT	Lausanne
Professor Klaus BERNAUER	Neuchâtel
Professor Maurice BOURQUIN	Geneva
Professor Jacques BUFFLE	Geneva
Professor Anton DEMARMELS	Zürich
Professor François DESCOEUDRES	Lausanne
Professor Erwin ENGELER	Zürich
Professor Martin FREY	Basel
Professor Hans Ulrich GUEDEL	Bern
Professor Piero MARTINOLI	Neuchatel
Professor Albert MATTER	Bern
Professor André MERBACH	Lausanne
Professor Heinz OCHSNER	Solothurn
Professor Albert RENKEN	Lausanne
Professor Hanspeter SCHELLING	Basel
Professor Paul SCHMIDHALTER	Brig
Professor Ingo SICK	Basel
Professor Pierre VOGEL	Lausanne
Professor Gérard WANDERS	Lausanne

AMS Referees — Germany

Professor K.U. GROSSMANN	Wuppertal
Professor Th. HENNING	MPG-AG, Iena
Professor E. JESSBERGER	MPI , Heidelberg
Dr E. KENDZIORRA	Tubingen
Professor F.J. LUBKEN	Bonn
Dr H. LUHR	Braunschweig
Professor H.P. ROSER	Berlin
Dr G. RUDIGER	Potsdam
Professor V. SCHONFELDER	Garching
Dr B. WILKEN	Katlenburg-Lindau

AMS Referees — Italy

Professor Enrico BELLOTTI	INFN Gran Sasso
Professor Sandro BOTTINO	Torino
Dr Marcello CORADINI	ESA, Paris
Professor G. FIORENTINI	Ferrara
Professor G. GIUBELLINO	Torino
Professor L. RICCATI	Torino

AMS Referees — Finland

Finish Academy of Sciences
and

Professor Axel BRANDENBURG	NORDITA
Professor Keijo KAJANTIE	Helsinki
Professor Pentti LAPPALAINEN	Oulu

AMS is a DOE sponsored International Collaboration

April 2 - 3, 1995 DOE-AMS Committee review with :

- **Robert K. Adair**
- **Barry C. Barish**
- **Stephen L. Olsen**
- **Malvin A. Ruderman**
- **David N. Schramm**
- **George F. Smoot**
- **Paul J. Steinhardt**

March 15, 1999 DOE-AMS Committee review with :

- **Robert K. Adair**
- **Barry C. Barish**
- **Stephen L. Olsen**
- **Malvin A. Ruderman**
- **George F. Smoot**
- **Paul J. Steinhardt**

March 27, 2001 Presentation to DOE HEPAP

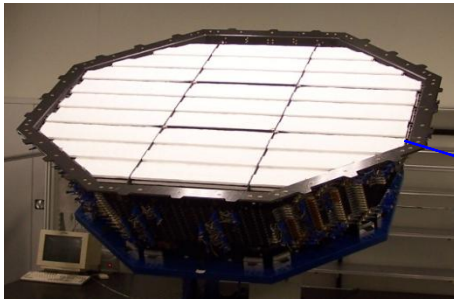
Sept 25, 2006 SCIENTIFIC REVIEW OF AMS with:

- **Barry C. Barish, Chair**
- **Elliott D. Bloom**
- **James Cronin**
- **Stephen L. Olsen**
- **George F. Smoot**
- **Paul J. Steinhardt**
- **Trevor Weekes**

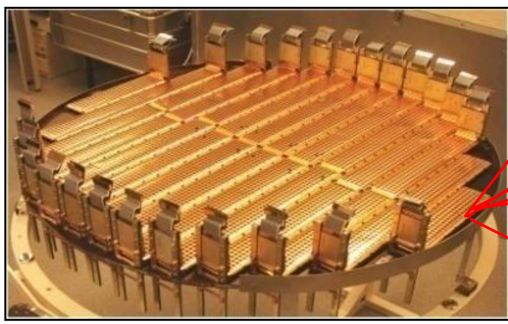
y01K083_07

AMS: A TeV precision, multipurpose spectrometer

TRD
Identify e+, e-

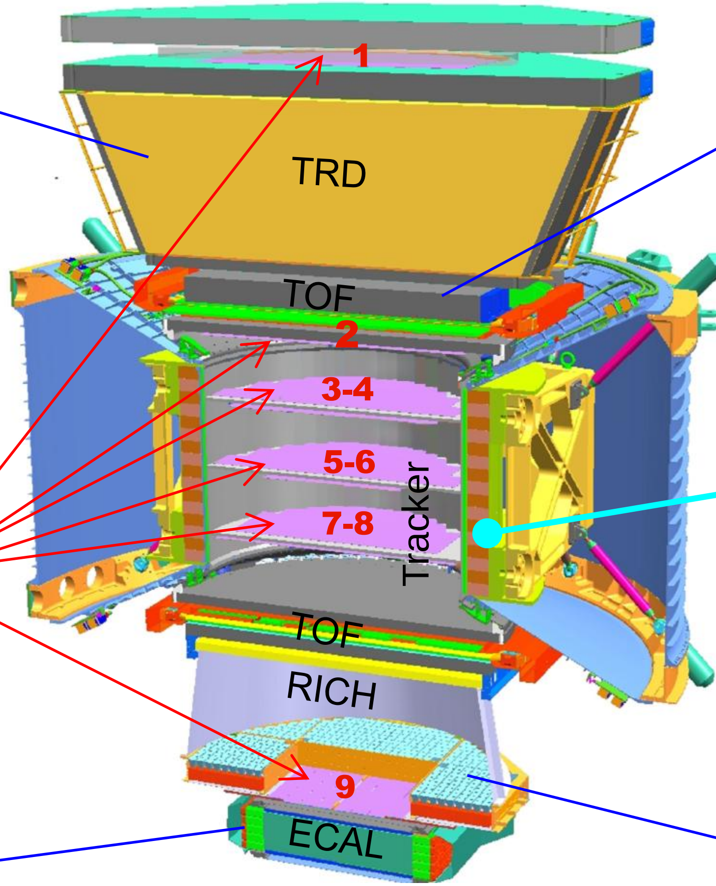


Silicon Tracker
Z, P



ECAL
E of e+, e-, γ

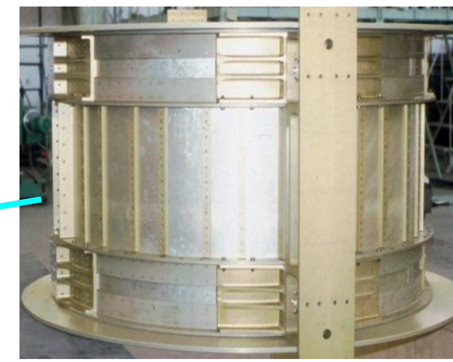
Particles and nuclei are defined by their charge (**Z**) and energy (**E ~ P**)



Z, P *are measured independently from Tracker, RICH, TOF and ECAL*

TOF
Z, E

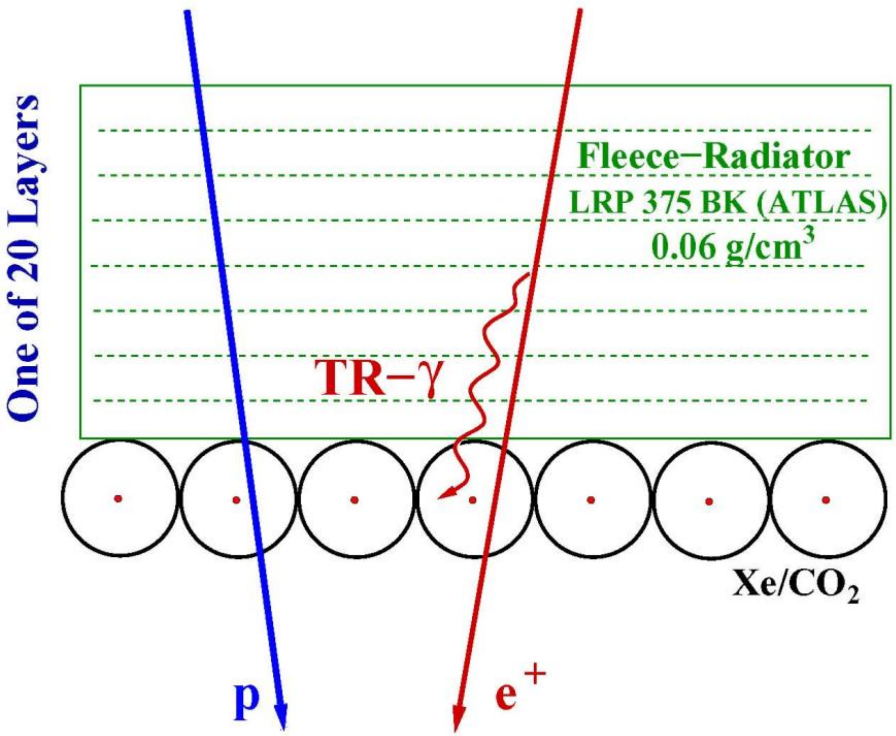
Magnet
±Z

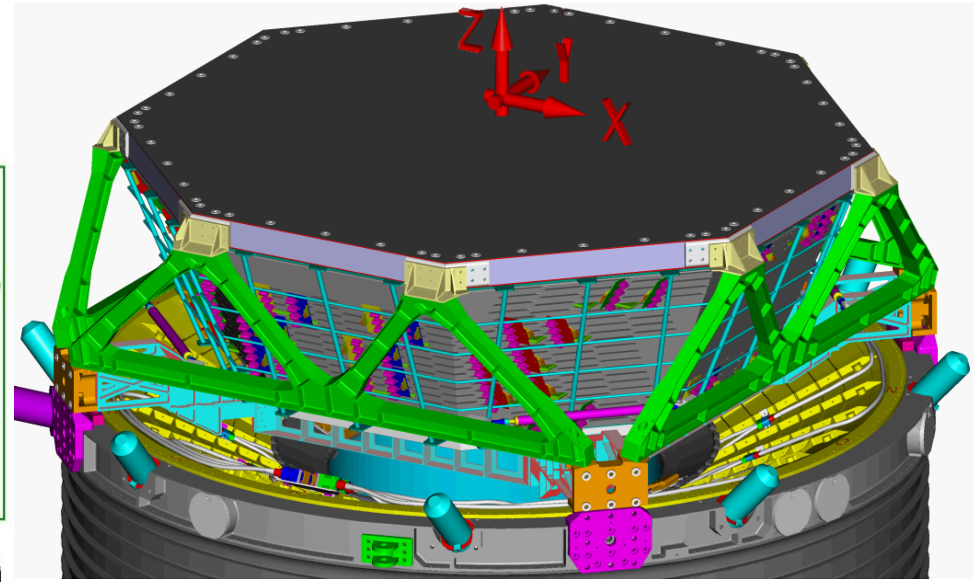


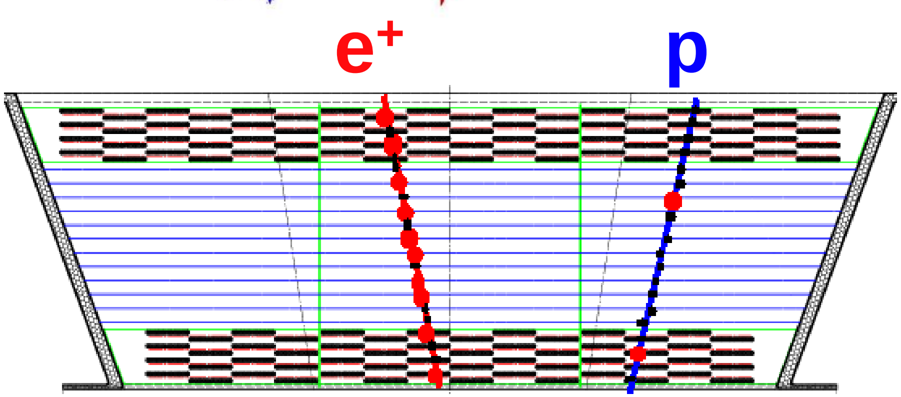
RICH
Z, E

Transition Radiation Detector: TRD

Identify e^+, reject P



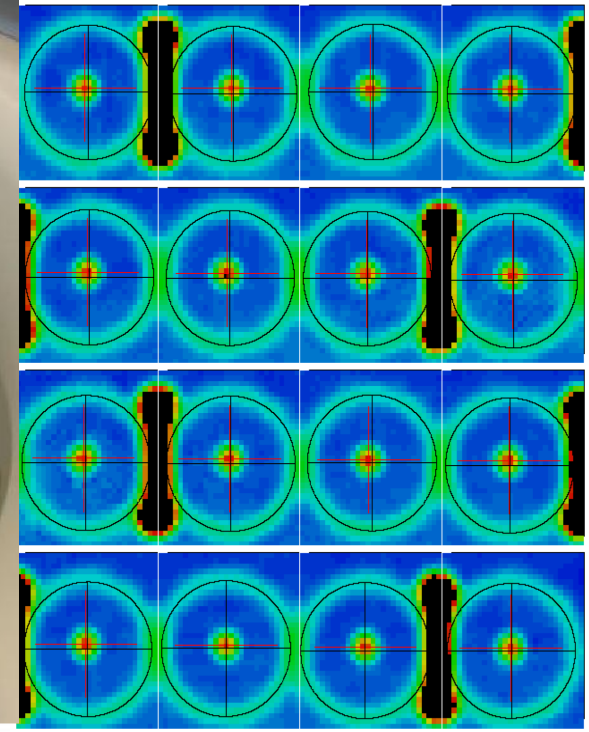




20 layers

5248 selected from 9000,

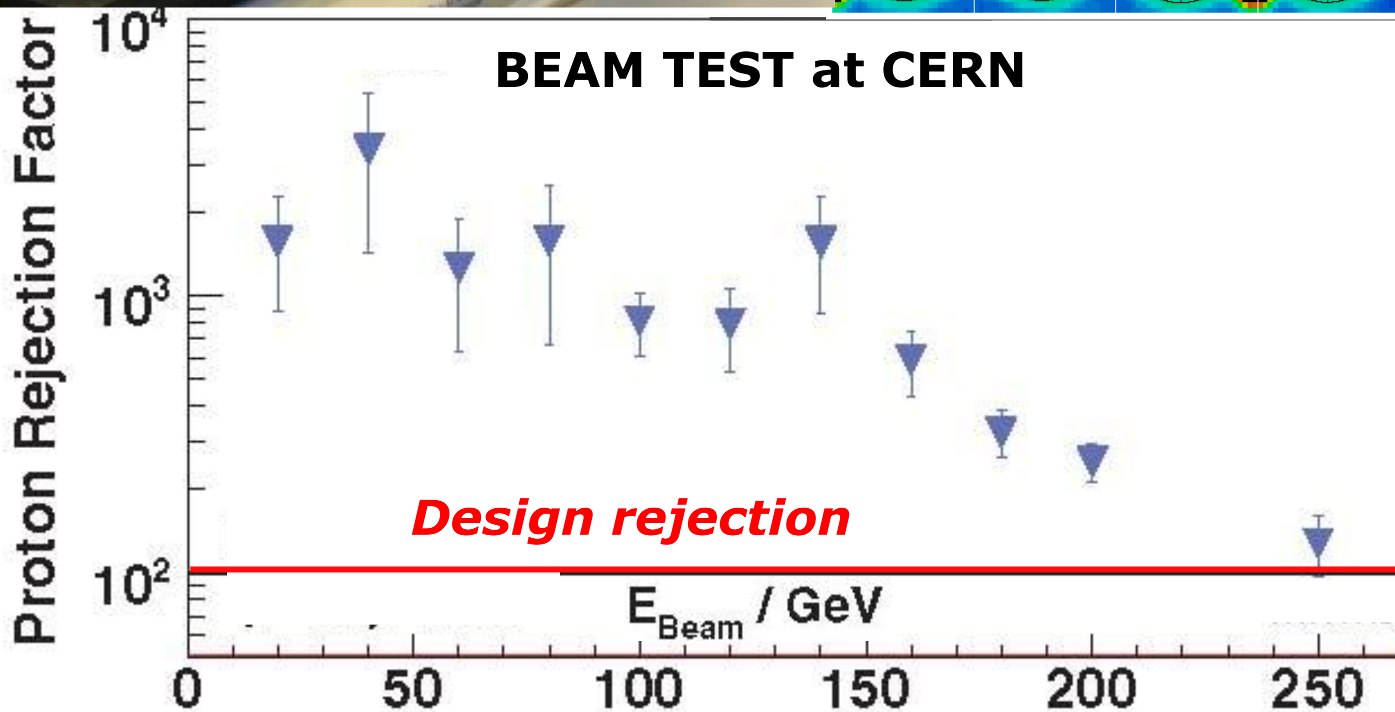
2 m length centered to 100μm



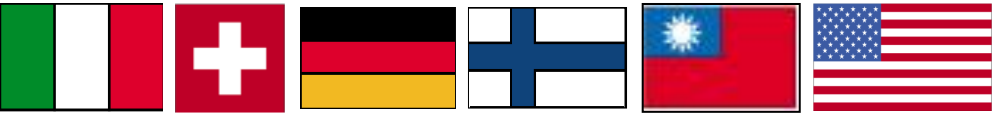
Leakrate: CO_2 ≈ 6 μg/s

Storage: 5 kg

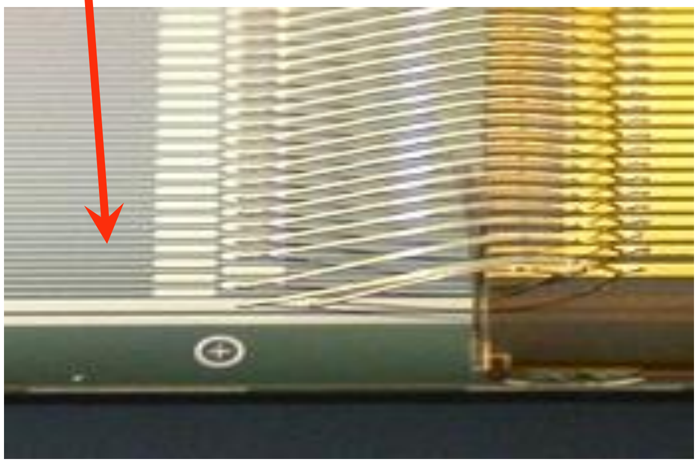
24 years lifetime

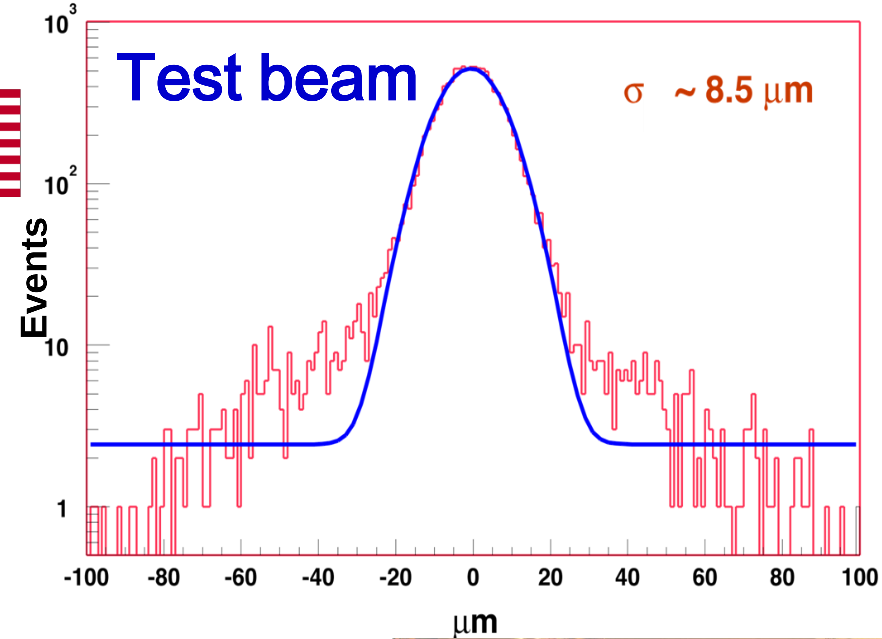


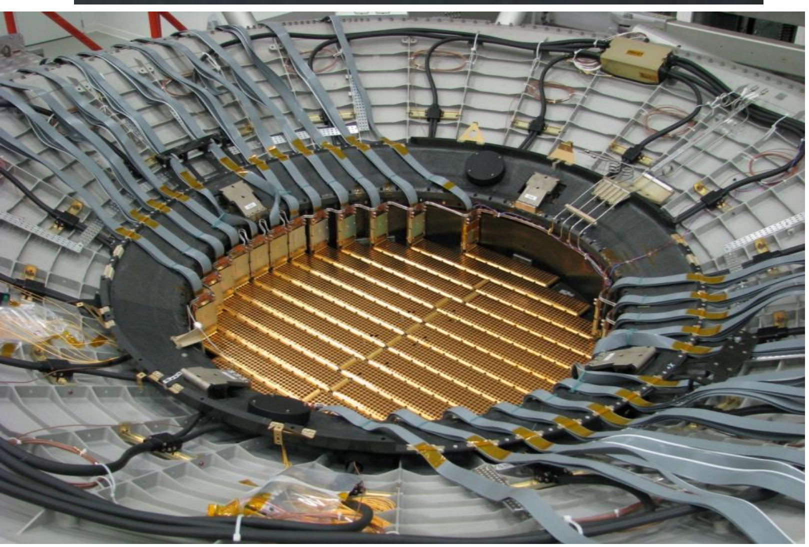
Silicon Tracker



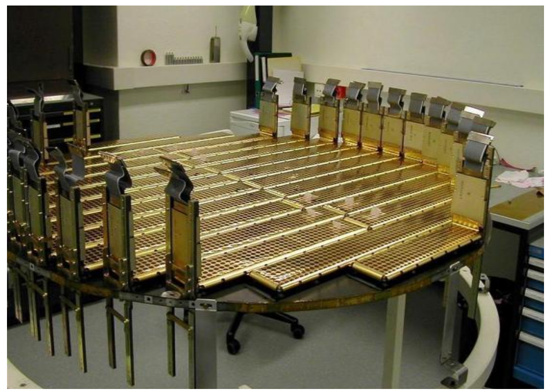
10 mil pitch; 200,000 channels; alignment 3 μm

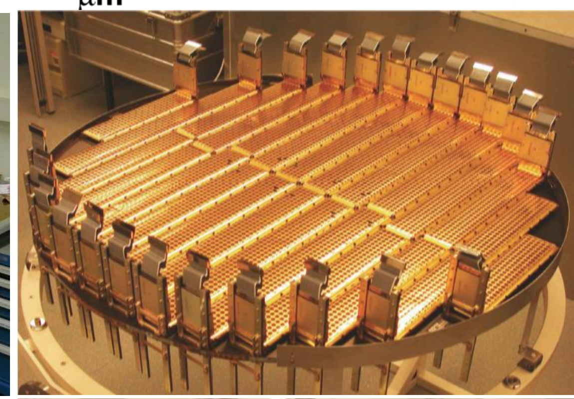


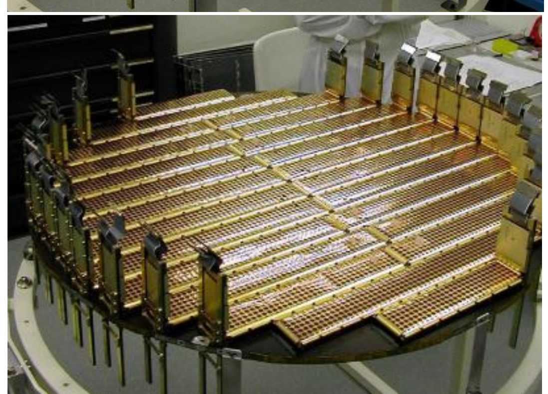




8 planes

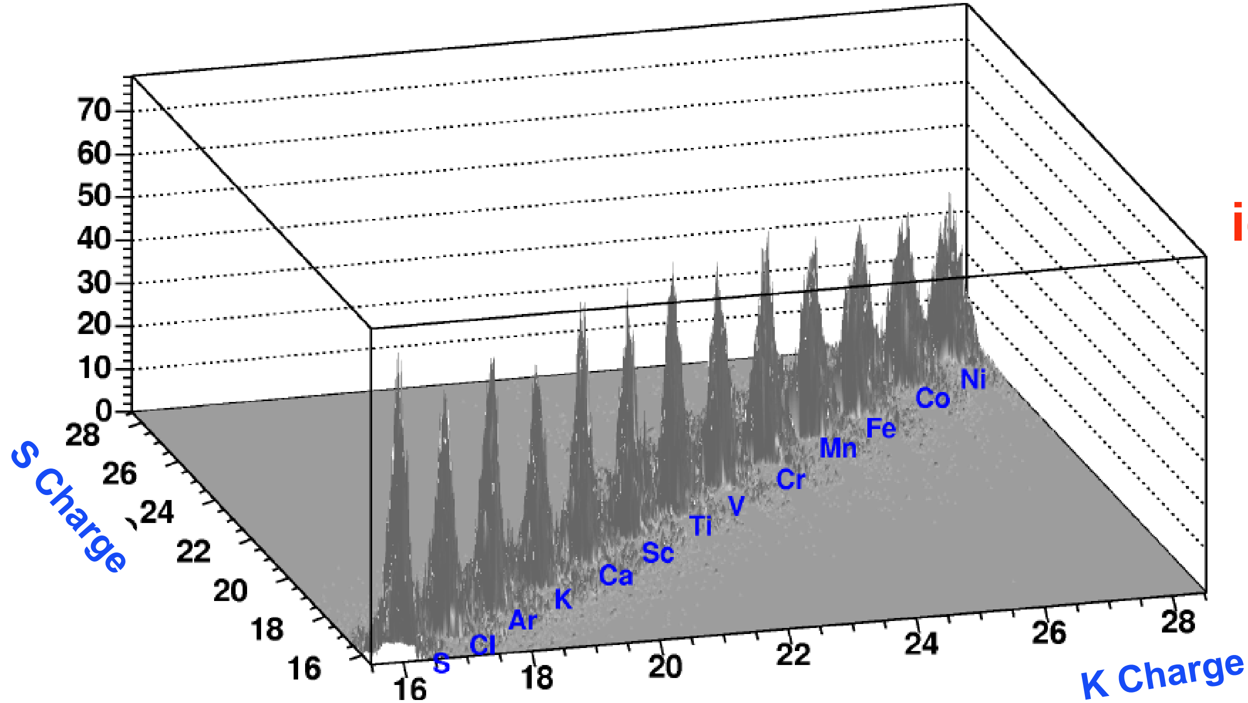


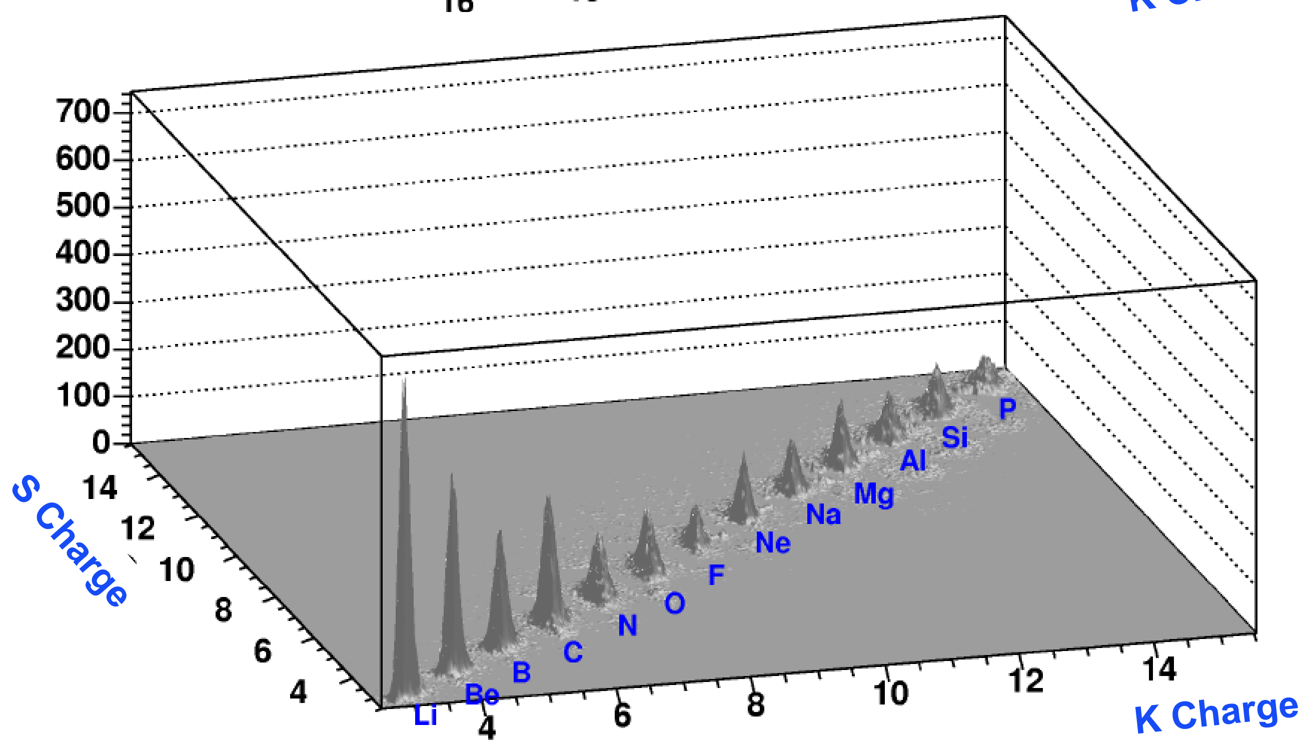




Test beam 158 GeV/n

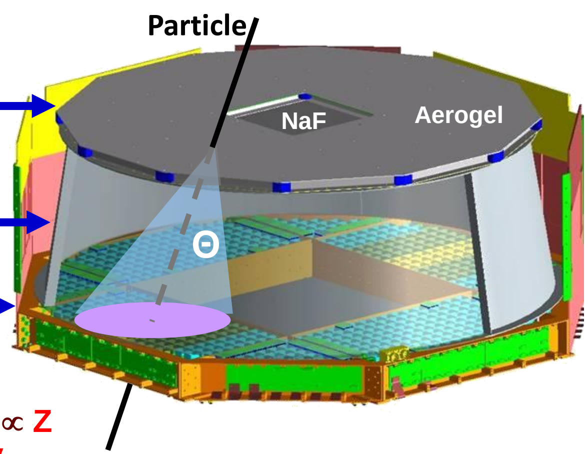
identify all nuclei simultaneously

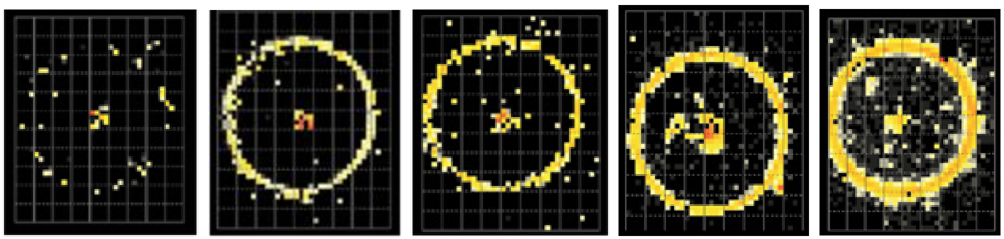




Ring Imaging CHerenkov (RICH)

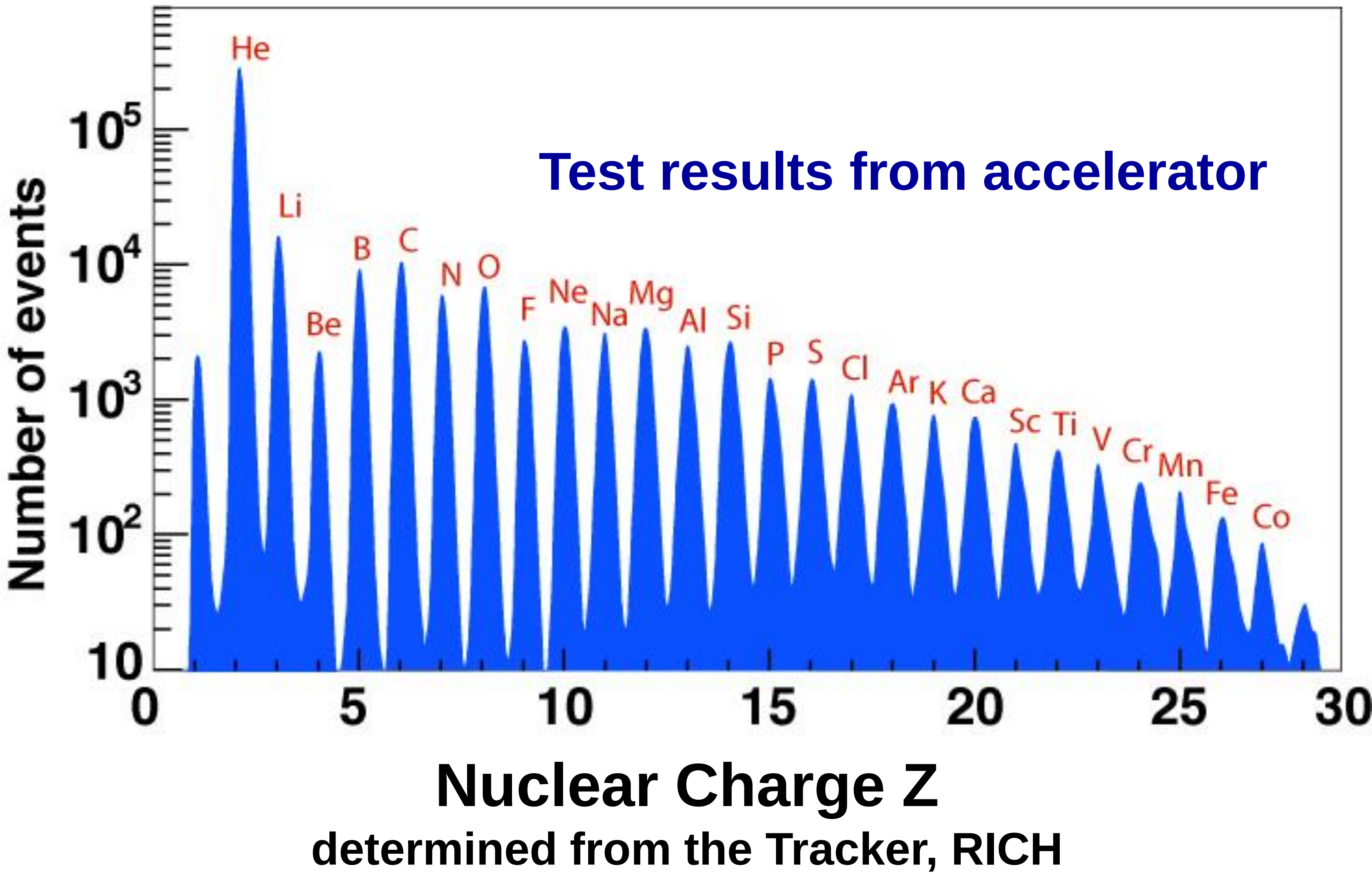
10,880 photosensors





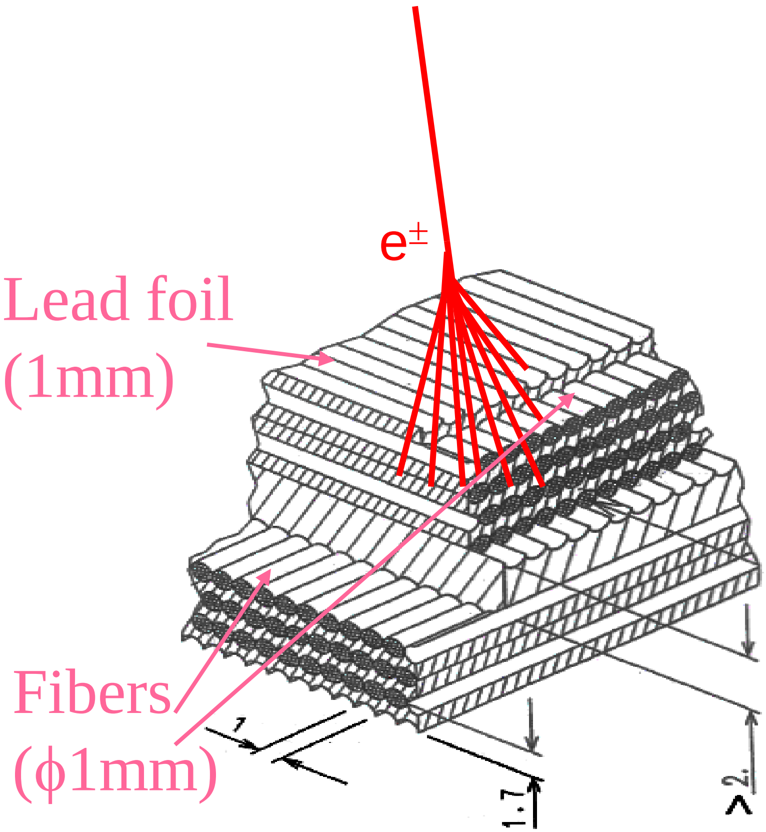
Single Event Displays

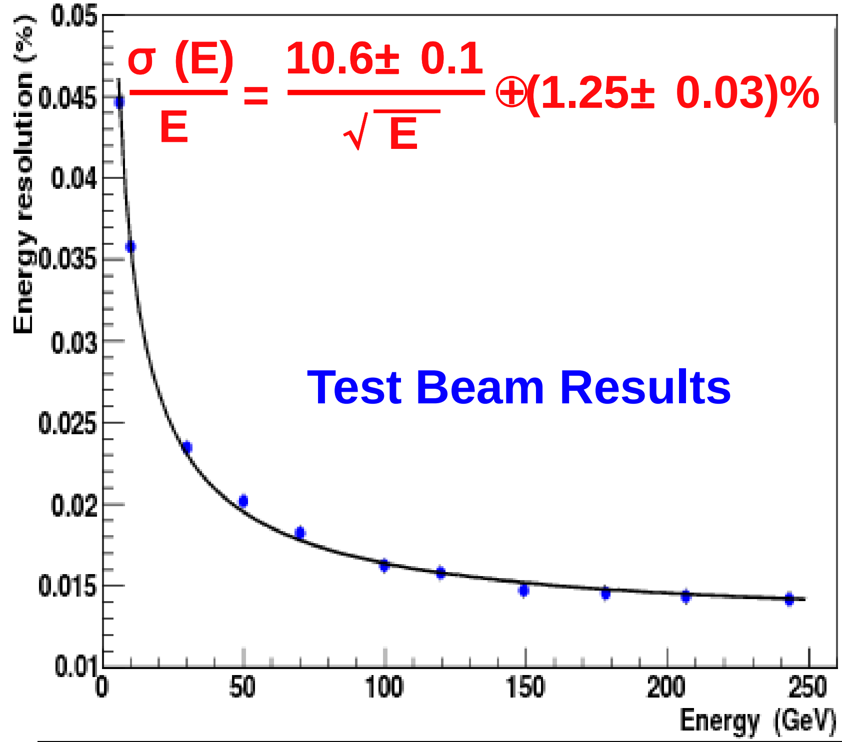
RICH test beam E=158 GeV/n

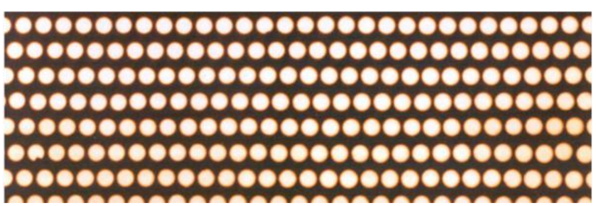

Test results from accelerator
Number of events
10
10^2
10^3
10^4
10^5
0
5
10
15
20
25
30
He
Li
Be
B
C
N
O
F
Ne
Na
Mg
Al
Si
P
S
Cl
Ar
K
Ca
Sc
Ti
V
Cr
Mn
Fe
Co
Nuclear Charge Z
determined from the Tracker, RICH

Calorimeter (ECAL)

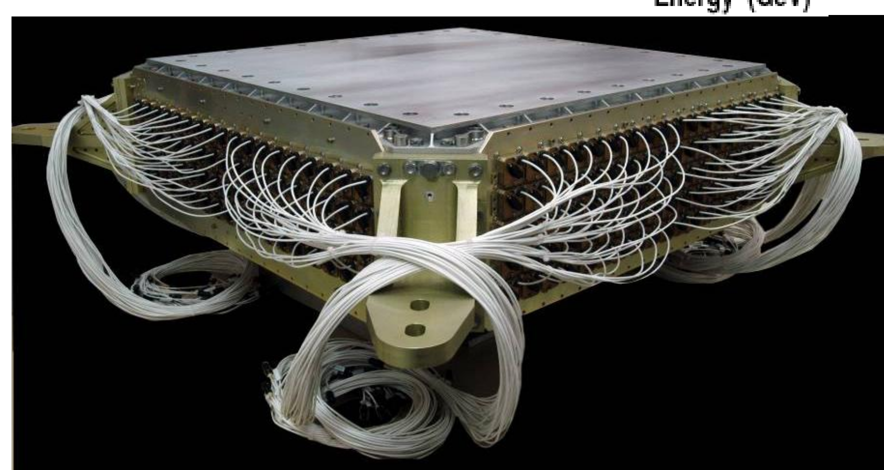
A precision, 17 X_0, 3-dimensional measurement of the directions and energies of light rays and electrons







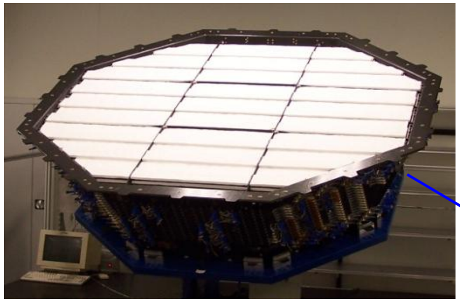
10 000 fibers, ϕ = 1 mm
distributed uniformly
Inside 1,200 lb of lead




THE END
SSRMS places AMS on S3 Upper Inboard Payload Attach Site
2009: AFTER 9000 hrs of TVT…THE END OF SUB-SYSTEM TESTS

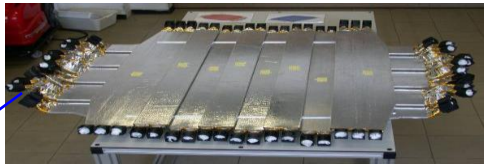
AMS: A TeV precision, multipurpose spectrometer

TRD
Identify e+, e-

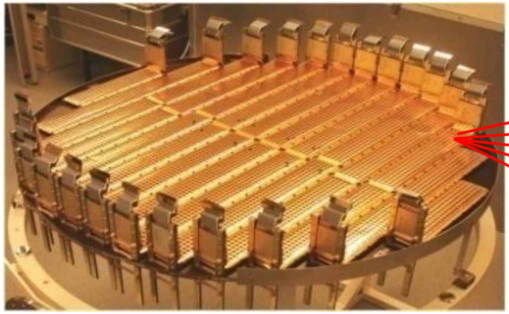


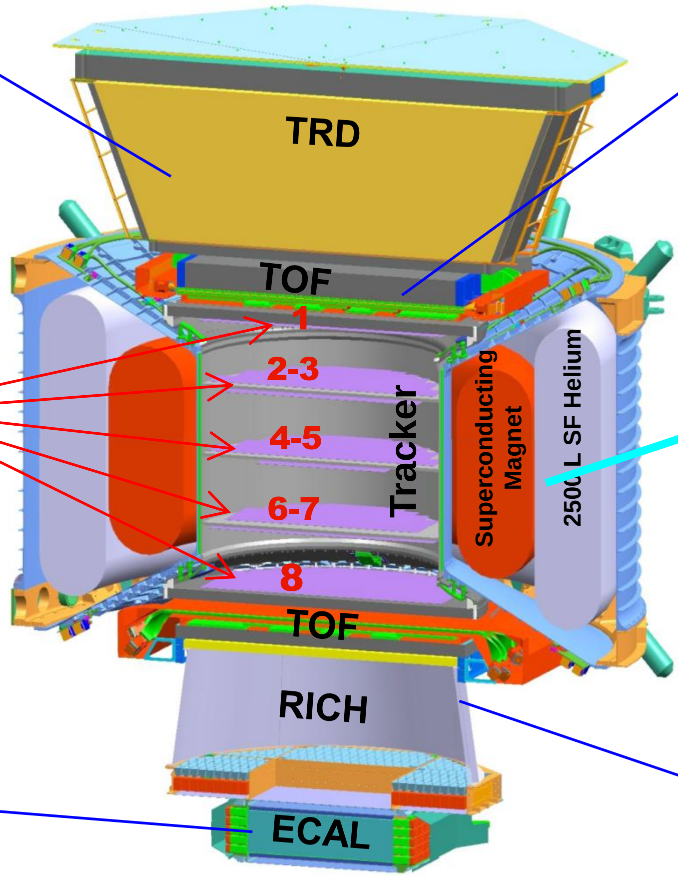
Particles and nuclei are defined by their charge (**Z**) and energy (**E ~ P**)

TOF
Z , E

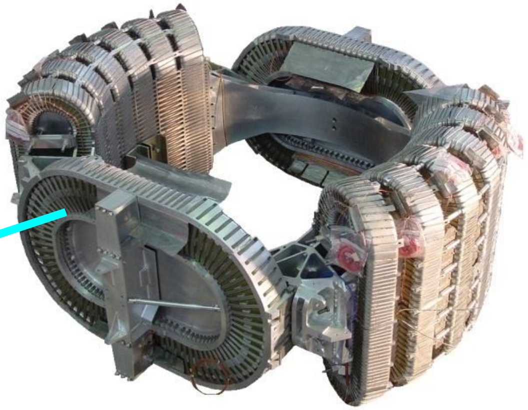


Silicon Tracker
Z , P



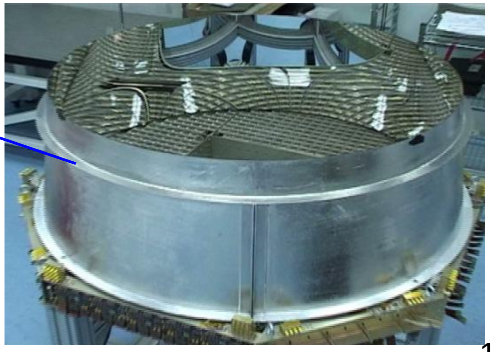


Magnet
±Z



ECAL
E of e+, e-, γ

RICH
Z , E

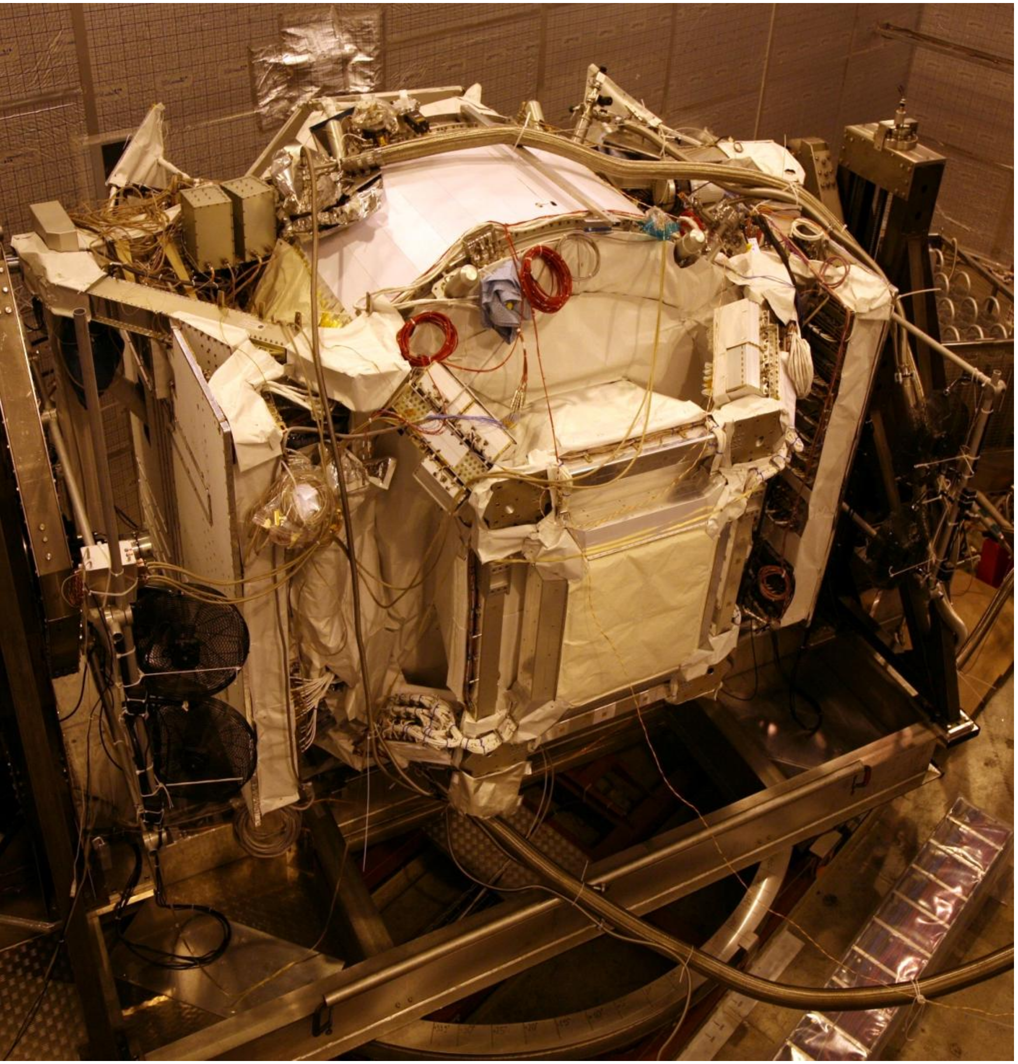


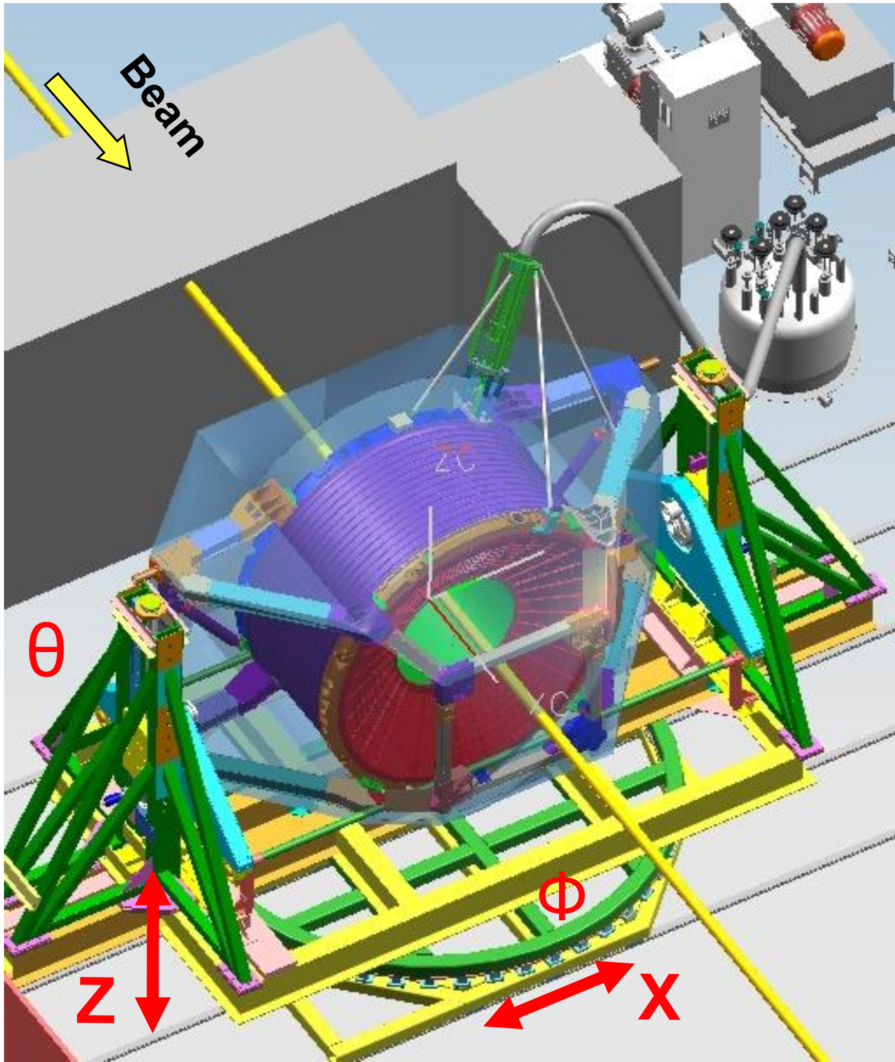
***Z, E* are measured independently from Tracker, RICH, TOF and ECAL**

AMS in Test Beam, Feb 4-8, 2010

Tests were performed with the superconducting magnet charged to its design current of 400A and to 80A corresponding to the field of the AMS-01 permanent magnet.

TRD, Tracker, RICH, TOF and ECAL performance was not affected by the change of magnetic field





From: Steve Myers Sent: Mon 2/8/2010 7:58 AM To: Dimitri Delikaris; Dietrich Schinzel

Dear Dimitri,

There is a decision from the Directorate level to give the maximum possible amount of help to AMS.

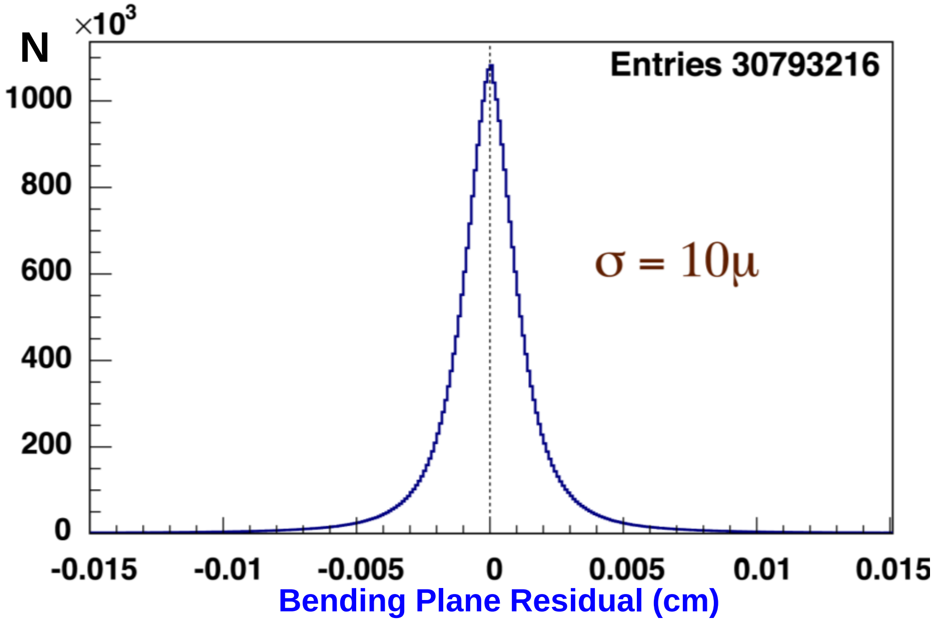
I really appreciate your aid. If there are any “legal” problems please let me know right away.

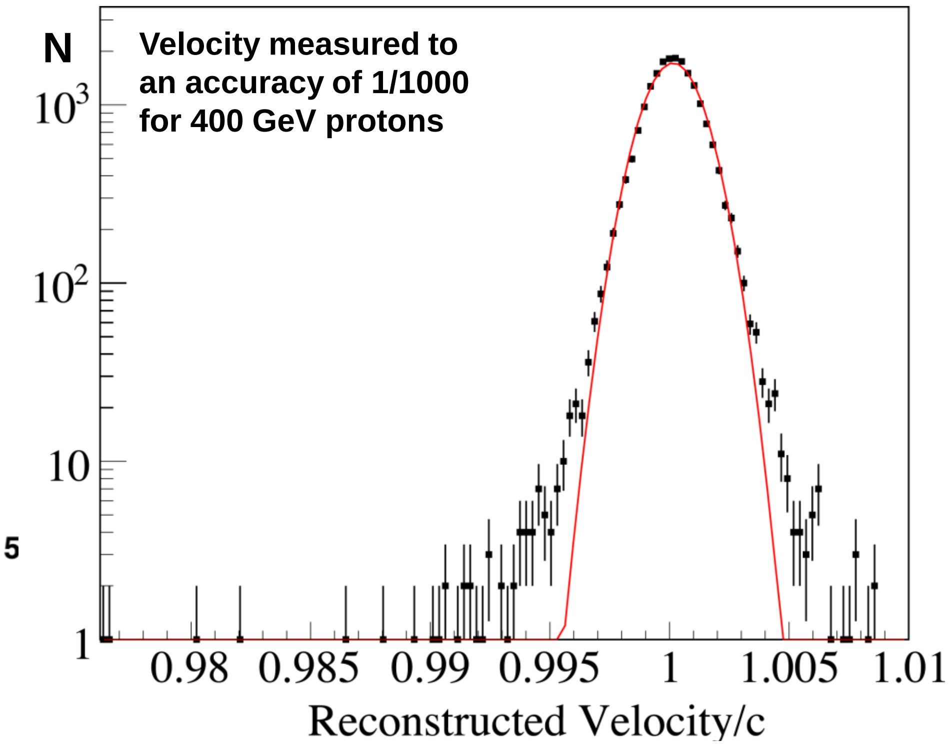
Regards,

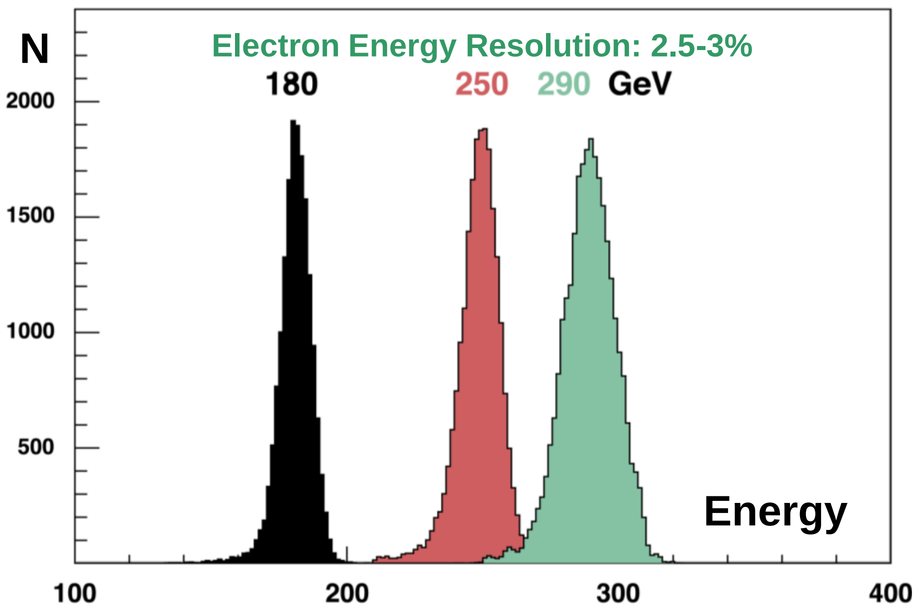
Steve

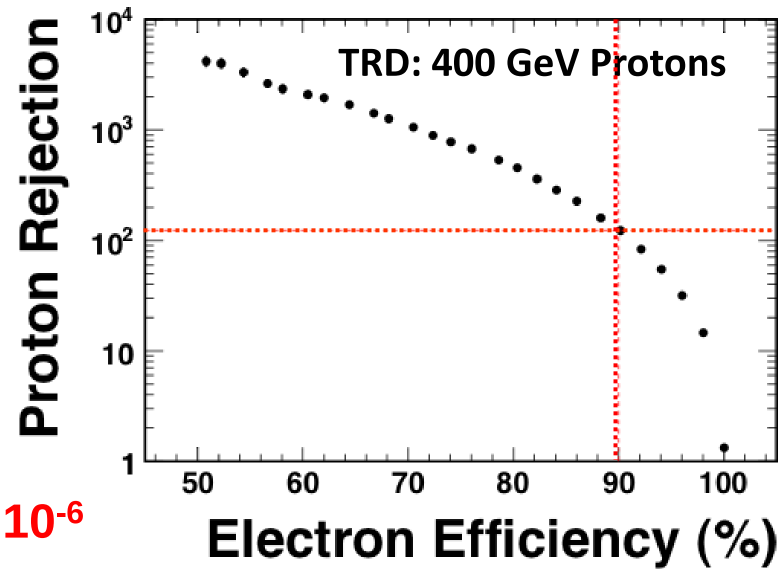
Steve Myers
Director of Accelerators and Technology
European Organisation for Nuclear Research (CERN)
CH-1211 Geneva 23
Switzerland

Test Beam Results of integrated detector









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

THE DIRECTOR GENERAL

DG/146

Paris, 3 February 2010

Samuel C.C. Ting
CERN, Physics Department
CH-1211 GENEVA 23

Ref. My letter DG/137 dated 29 January 2010

Dear Professor Ting,

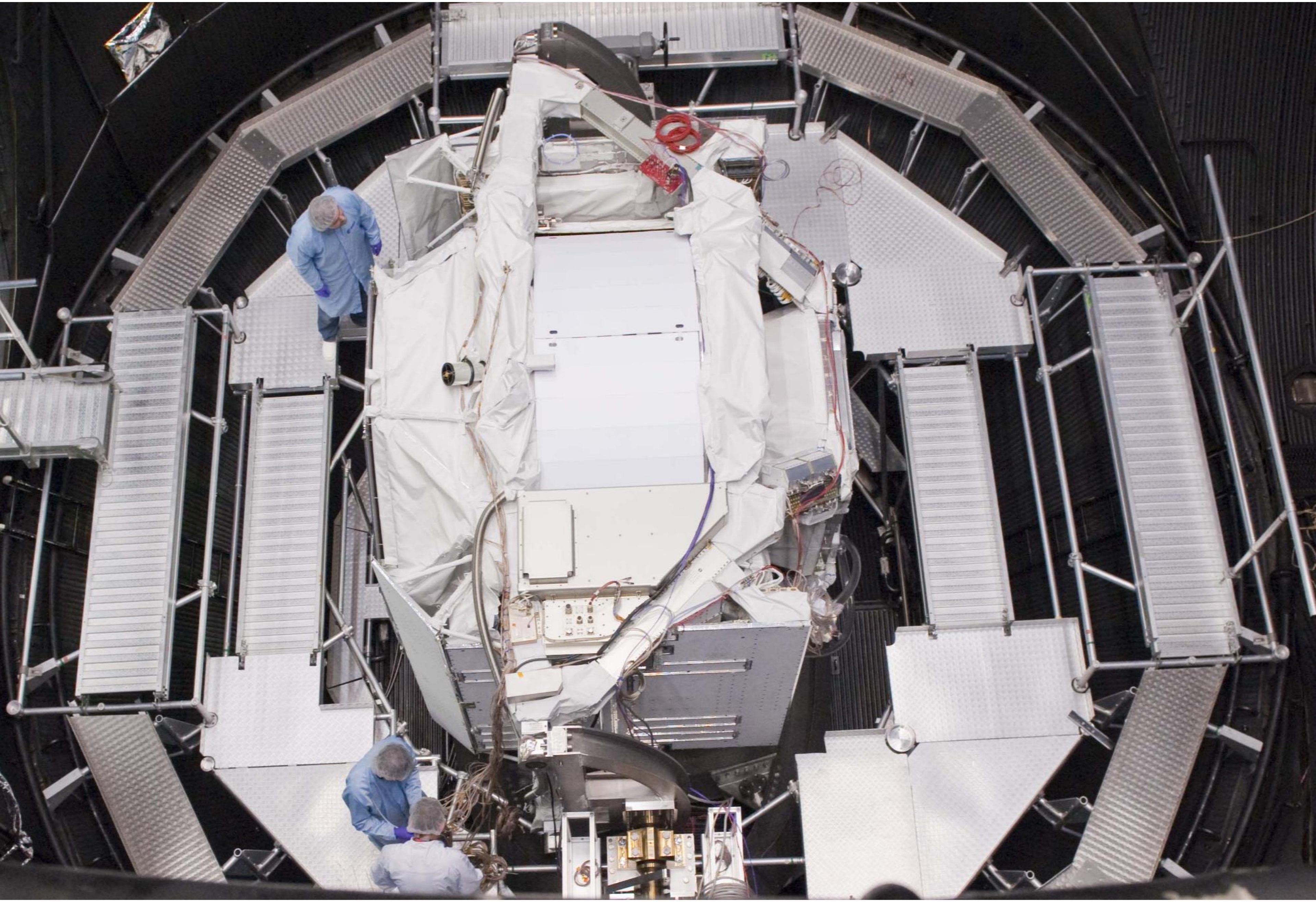
A I wrote to you in my referenced letter, and following the positive outcome from the visit of the ESA team at CERN to evaluate the readiness of AMS-02, I confirm that I grant the highest priority to AMS-02 in providing it access to the ESTEC Test Centre as soon as possible in order that you meet your targeted launch date.

....

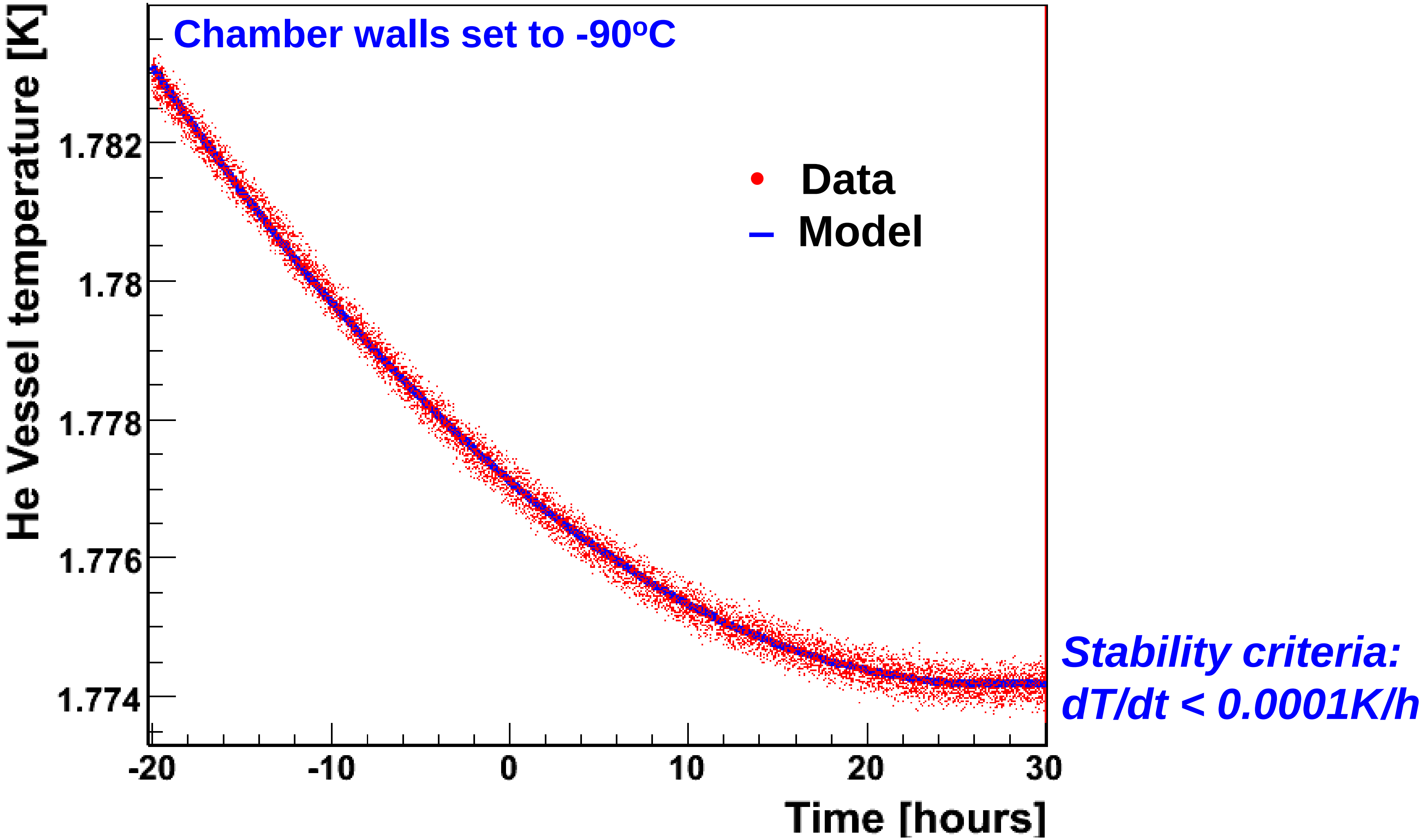
Yours sincerely,

Jean-Jacques Dordain

AMS in the ESA TVT Chamber



Stabilization of the He Vessel

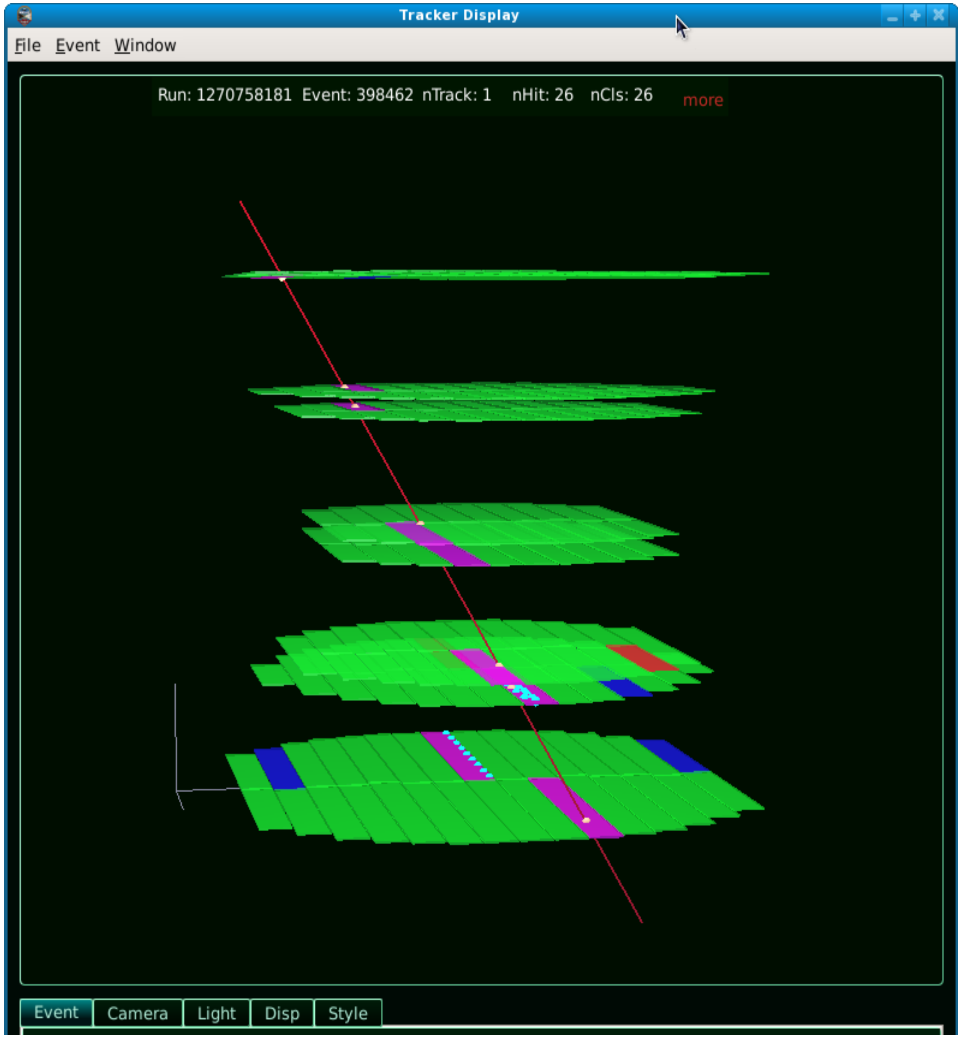


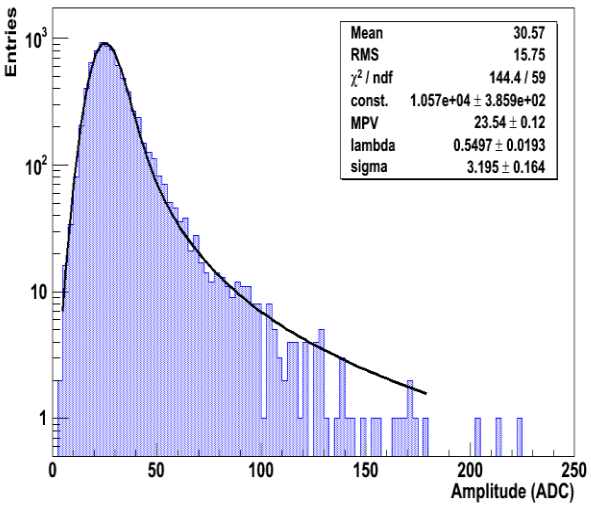
Expected life time of the AMS Cryostat on ISS:

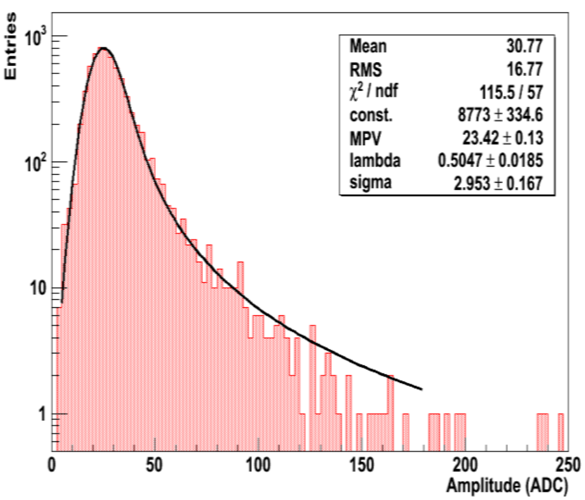
20±4 months with M87 cryocoolers (1999)

28±6 months with GT cryocoolers (2010)

TRACKER PERFORMANCE at -90ºC and 10^{-7} mbar: a cold muon track & mip signal in silicon







All detectors performed nominally in the TVT test

Characteristics of AMS

AMS was constructed with emphasis on

a) Precision: δx=10μm, δt =150 ps, $\delta v/v$ =1/1000, $\delta E/E=10^{-2}$, $e^{+}/p=10^{-6}$.

b) Redundancy: 200% to 400%.

c) Reliability: Each detector was tested in specially built space simulation facilities in Italy, Germany, Spain, Taiwan. The entire AMS detector was then tested at ESA-ESTEC, Holland. The AMS-01 detectors have been operating for over ten years to study cosmic rays at SEU, China.

d) Lifetime: TRD consumables will last more than 20 years.

e) Readily assembled, disassembled for modification before lift-off:

2008

1st integration – 6 months

1st de-integration – 1 month

2009

2nd integration – 1 month

IMPLEMENTING ARRANGEMENT
BETWEEN
THE DEPARTMENT OF ENERGY
AND
THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
REGARDING THE
ALPHA MAGNETIC SPECTROMETER IN SPACE PROGRAM

…

I. PROGRAM DESCRIPTION

The AMS is a state-of-the-art particle physics detector containing a large permanent magnet that will be designed constructed and tested by an international team organized under DOE sponsorship and that will use the unique environment of space to advance knowledge of the universe and lead potentially to a clearer understanding of the origin of the universe. Specifically, the science objectives of the AMS are to search for cosmic sources of anti-matter (i.e., anti-helium or heavier elements) and dark matter.

… On the second flight, NASA will launch the AMS on the Shuttle and transfer and install it onto the International Space Station (ISS). The AMS then will be operated as an externally attached payload on the ISS for a nominal three-year period, after which NASA will detach the AMS from the ISS, transfer it to a Space Shuttle, and return it to Earth. …

By Harry C. Holloway
Associate Administrator
for Life and Microgravity
Sciences and Applications
National Aeronautics and
Space Administration

Date: 20 Sept 95

By Martha Krebs
Director
Office of Energy Research
Department of Energy

Date: Sept 20, 1995

Michael Braukus
Headquarters, Washington
202-358-1979
michael.j.braukus@nasa.gov

March 11, 2010

RELEASE : 10-063

Heads of Agency International Space Station Joint Statement

TOKYO -- The heads of the International Space Station (ISS) agencies from Canada, Europe, Japan, Russia, and the United States met in Tokyo, Japan, on March 11, 2010, to review ISS cooperation.

With the assembly of the ISS nearing completion and the capability to support a full-time crew of six established, they noted the outstanding opportunities now offered by the ISS for on-orbit research and for discovery including the operation and management of the world's largest international space complex. In particular, they noted the unprecedented opportunities that enhanced use of this unique facility provides to drive advanced science and technology. This research will deliver benefits to humanity on Earth while preparing the way for future exploration activities beyond low-Earth orbit. The ISS will also allow the partnership to experiment with more integrated international operations and research, paving the way for enhanced collaboration on future international missions.

The heads of agency reaffirmed the importance of full exploitation of the station's scientific, engineering, utilization, and education potential. They noted that there are no identified technical constraints to continuing ISS operations beyond the current planning horizon of 2015 to at least 2020, and that the partnership is currently working to certify on-orbit elements through 2028. The heads of agency expressed their strong mutual interest in continuing operations and utilization for as long as the benefits of ISS exploitation are demonstrated. They acknowledged that a U.S. fiscal year 2011 budget consistent with the U.S. administration's budget request would allow the United States to support the continuation of ISS operations and utilization activities to at least 2020. They emphasized their common intent to undertake the necessary procedures within their respective governments to reach consensus later this year on the continuation of the ISS to the next decade.

In looking ahead, the heads of agency discussed the importance of increasing ISS utilization and operational efficiency by all possible means, including finding and coordinating efficiencies across the ISS Program and assuring the most effective use of essential capabilities, such as space transportation for crew and cargo, for the life of the program.

For the latest about the International Space Station, visit the Internet at: http://www.nasa.gov/station

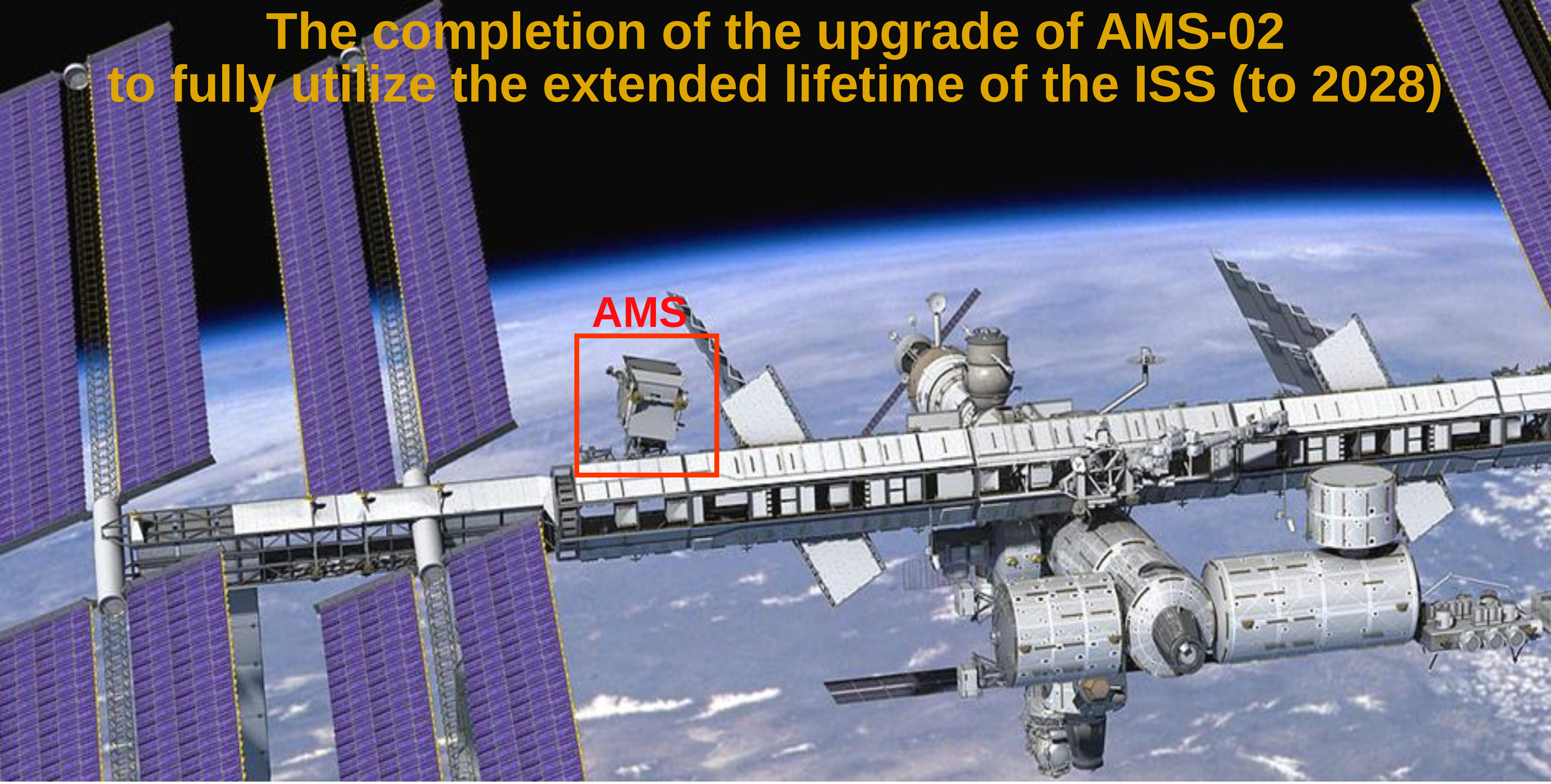
- end -

A superconducting magnet was ideal for a three year stay on ISS as originally planned for AMS.

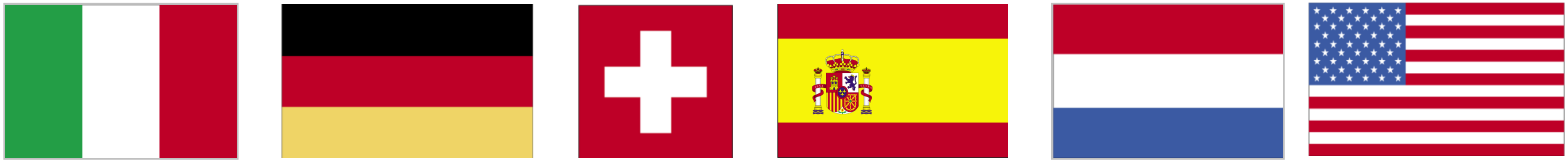
The ISS lifetime has been extended to 2020 (2028), the Shuttle program will be terminated, thus eliminating any possibility of returning and refilling AMS.

A superconducting magnet is no longer the ideal choice.

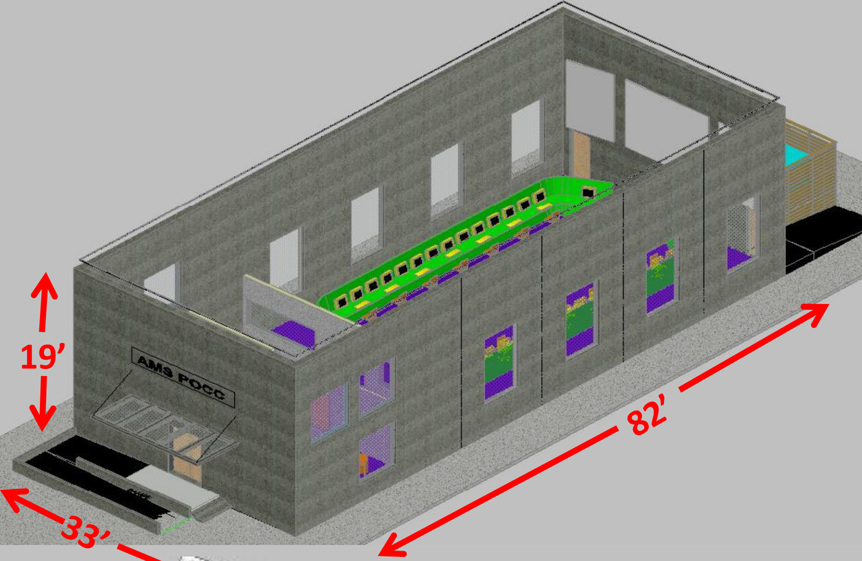
The completion of the upgrade of AMS-02 to fully utilize the extended lifetime of the ISS (to 2028)

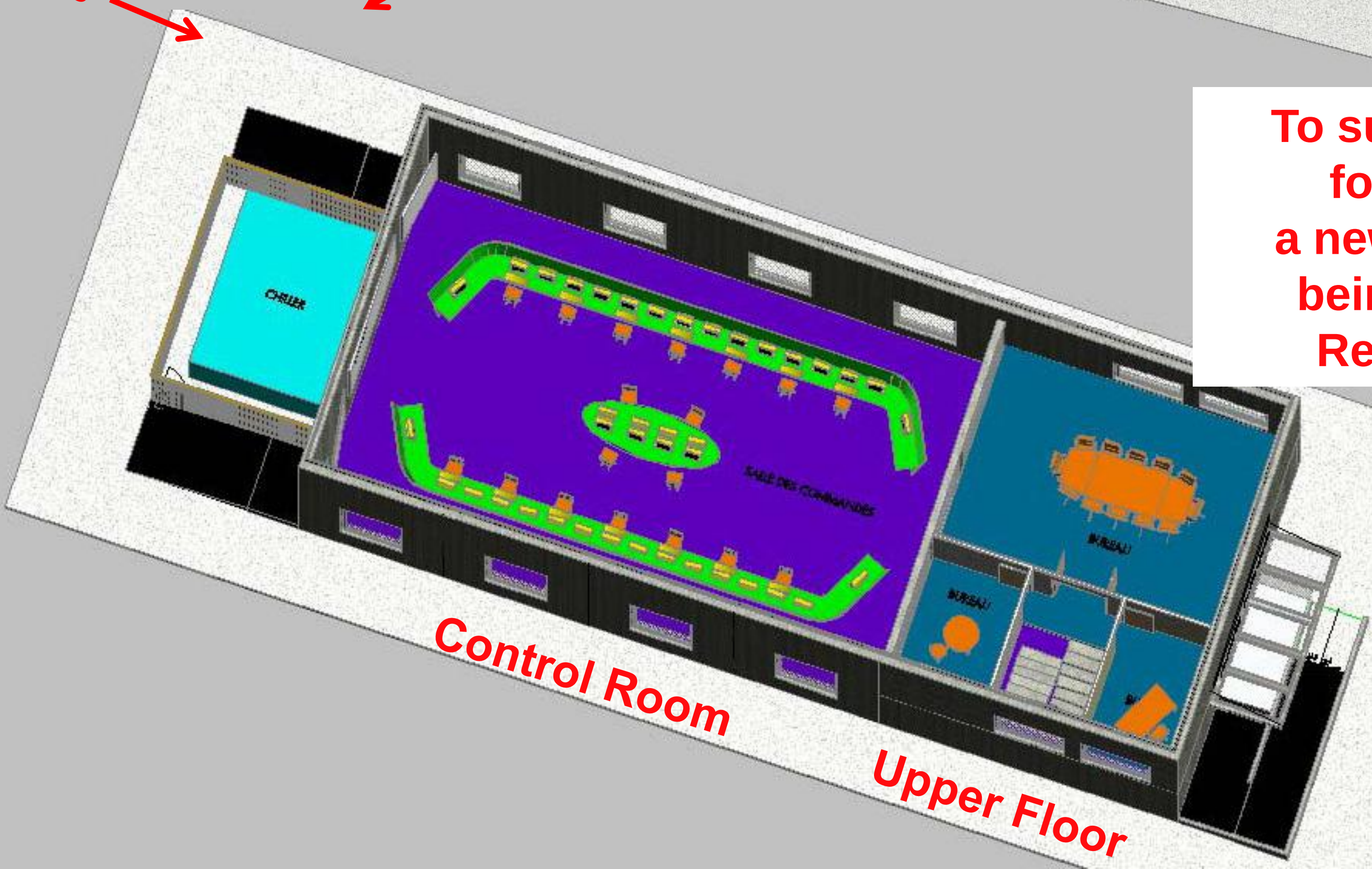


This upgrade has been supported by agencies from
Italy, Germany, Switzerland, Spain and the Netherlands and U.S.A.



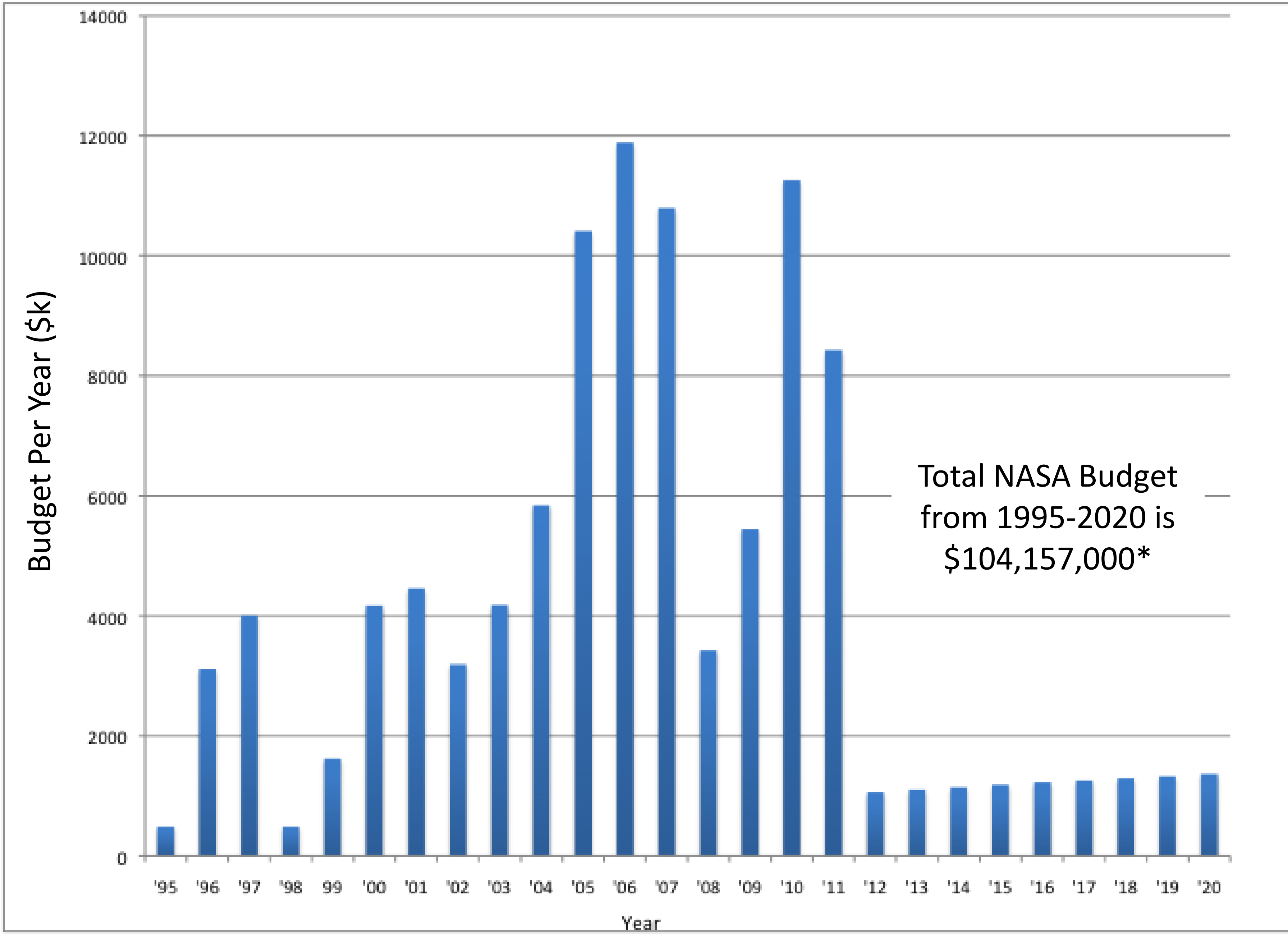
The European science community realizes the importance of full exploitation of the potential of ISS, to which they have contributed greatly.





To support AMS on ISS for 10 to 18 years, a new control center is being built by CERN. Ready 15 Nov 2010

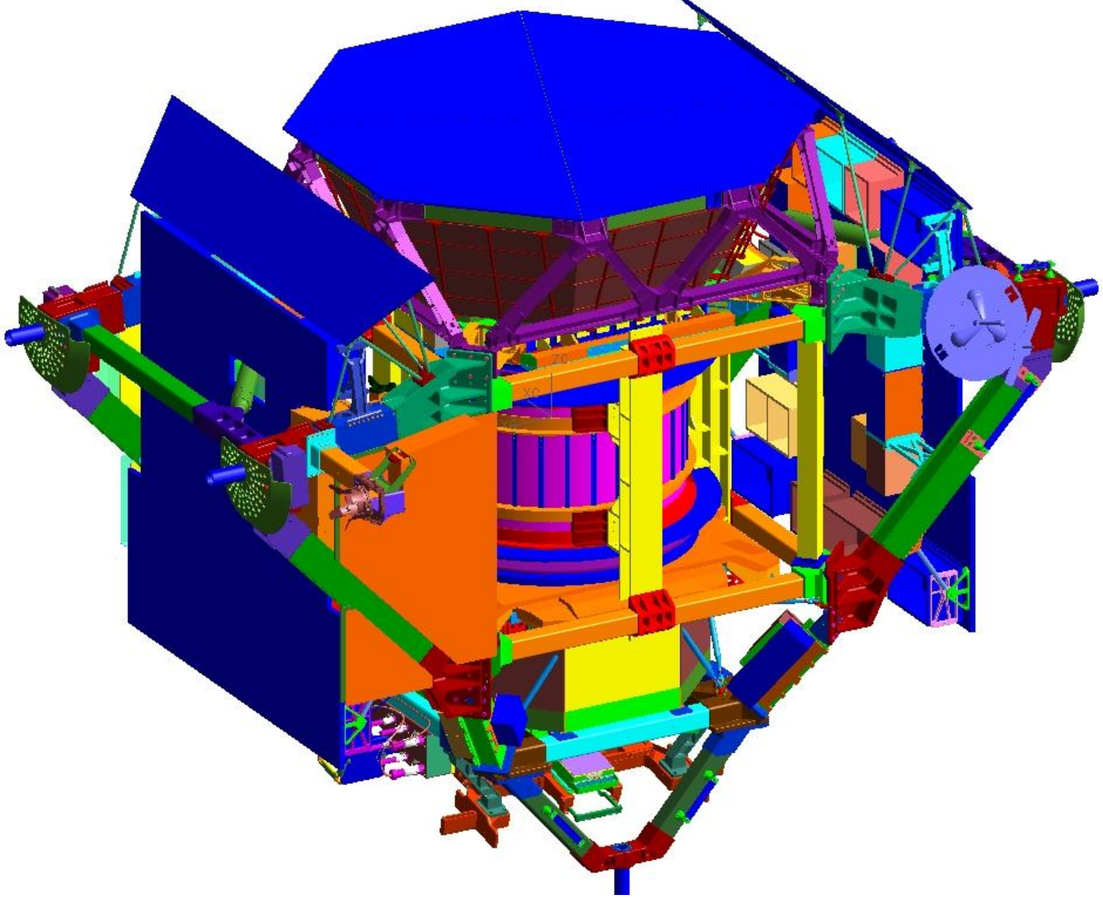
NASA AMS Project Office Budgets for AMS-01 and AMS-02



* Budget does not include launch costs

During the past ten years the AMS-01 Permanent Magnet has been kept as an alternative for AMS-02, and has been reviewed regularly by the Collaboration.

AMS Group Meeting, CERN - 30Jan.-3 Feb. 2006

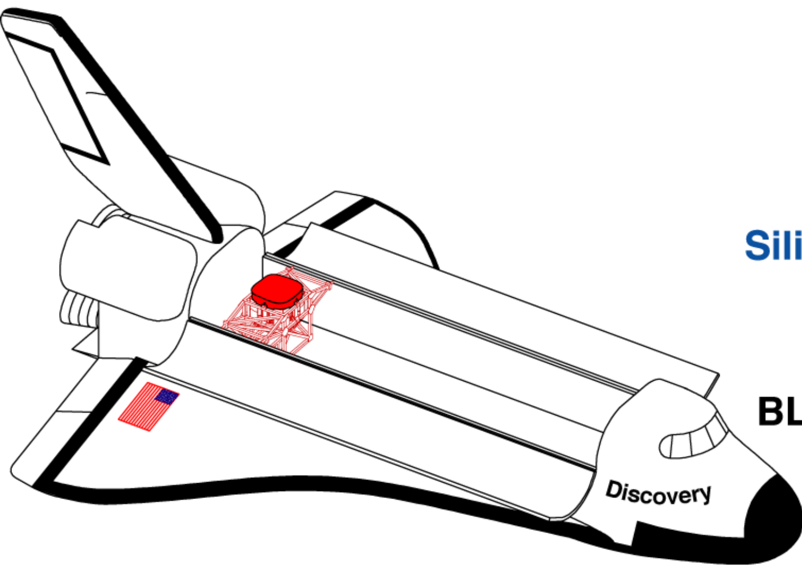


AMS-02 with a permanent magnet

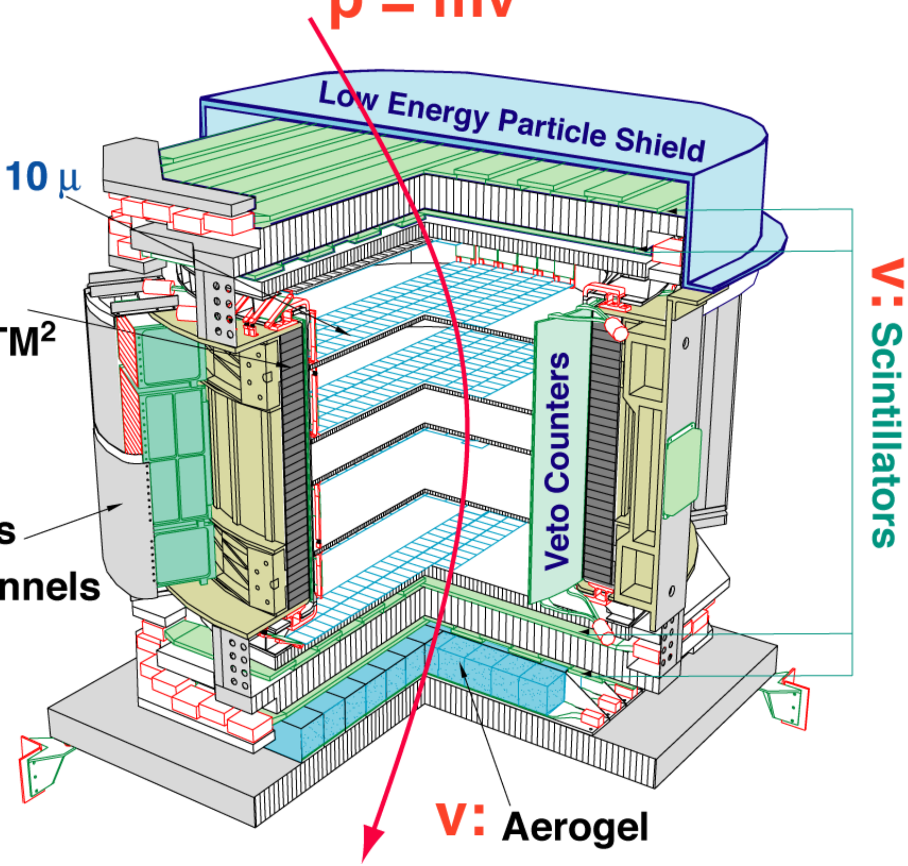
Alpha Magnetic Spectrometer

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

AMS-01



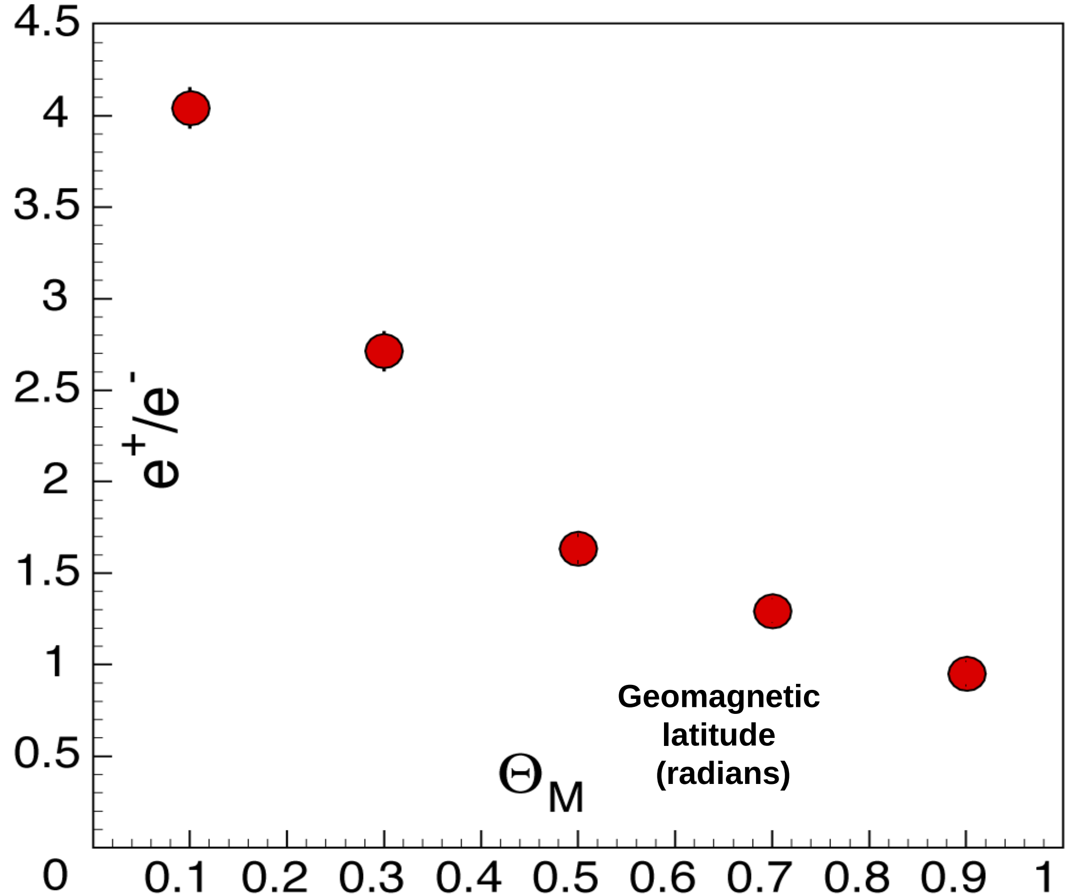
Construction of AMS-01



y99163_1AmsSts91Detect

Unexpected results from first flight:

There are many more positrons (e^+) than electrons (e^-)



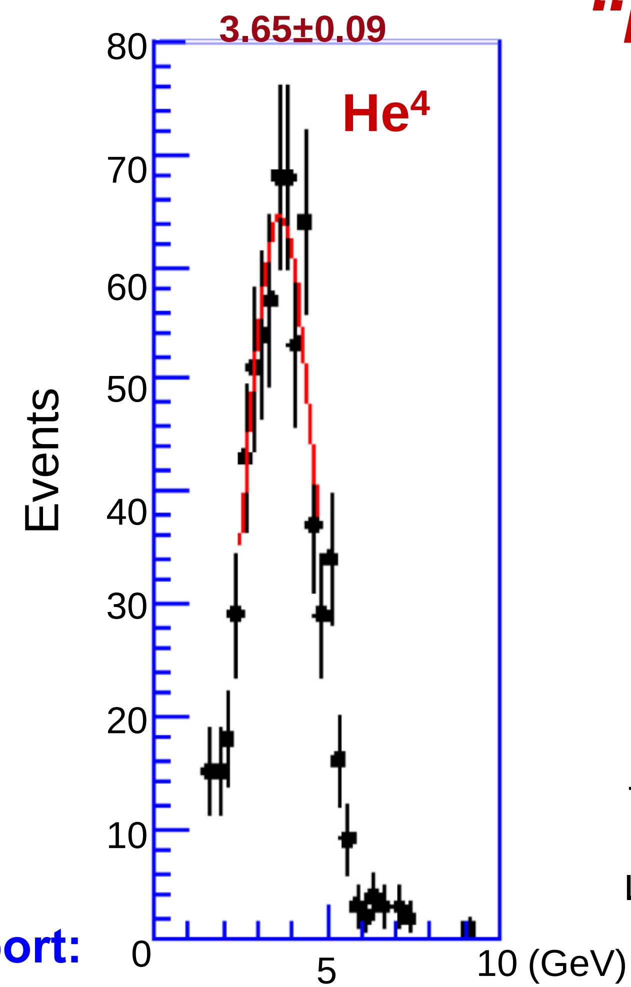
Referee's report:

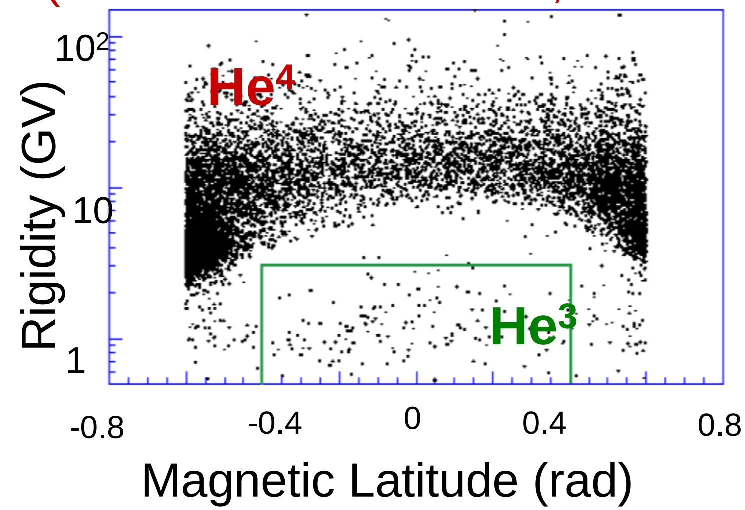
Phys. Lett. B484 (27 Jun 2000) 10-22

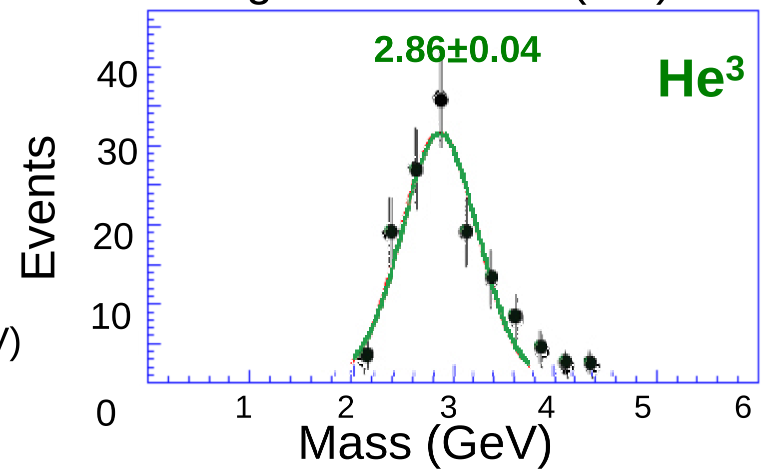
"This paper supplies entirely new data of the highest quality on electrons and positrons of cosmic rays …"

“Helium in Near Earth Orbit”

(Mass of He^4 = 3.7 GeV; He^3 = 2.8 GeV)







Referee’s report:

Physics Letters B vol.494 (3-4), p193

“This paper is an exciting and important paper ...”

AMS-01 results were not predicted by any cosmic ray model

CONSIDERATIONS TO UPGRADE AMS-02

Tests of the detectors show their performance exceeds expectations and all the detectors have a lifetime of more than 20 years.

We have maintained 2 magnet options:

1. The original AMS-01 permanent magnet and
2. A superconducting magnet.

Two identical support structures were provided by NASA.

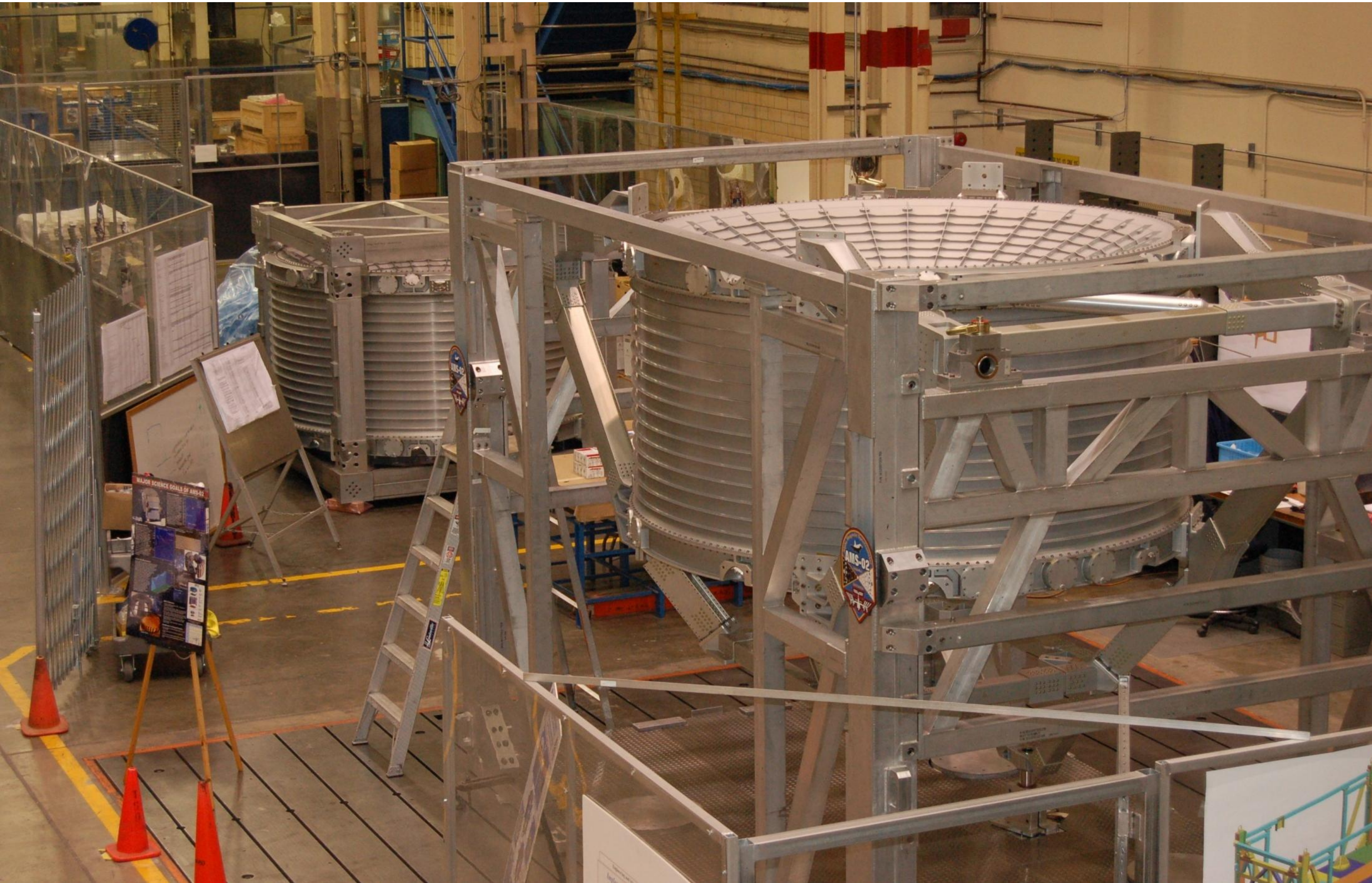
The detectors are compatible with both options.

The two options have comparable momentum resolutions and ranges.

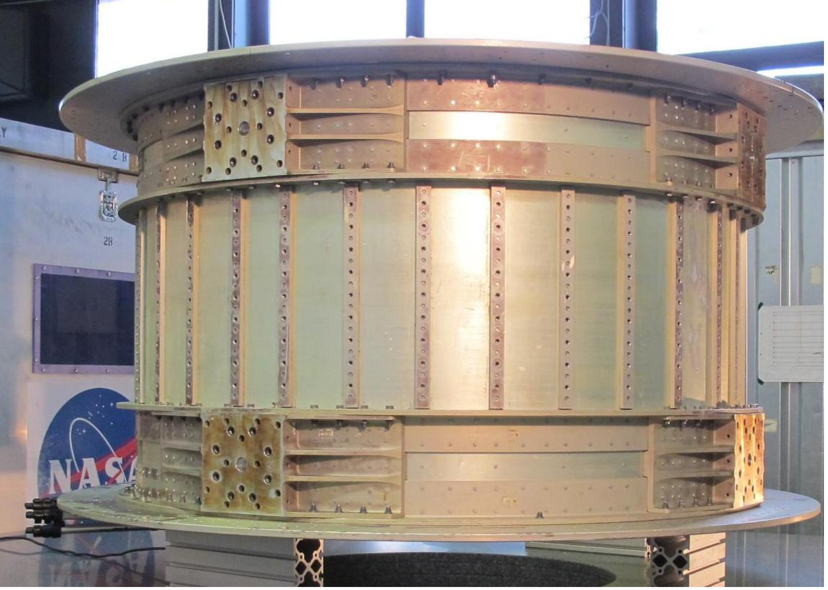
Most importantly, the permanent magnet option will have 10-18 years time to collect data, providing much more sensitivity to search for new phenomena.

Two identical vacuum cases

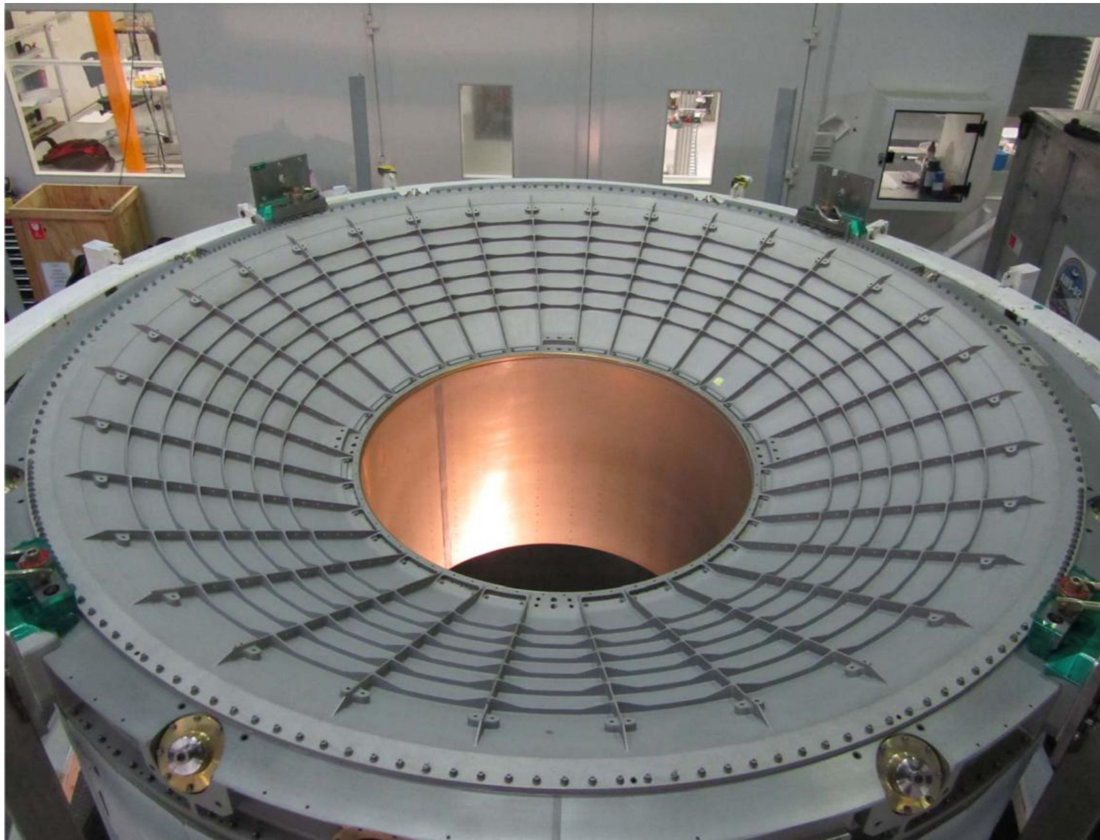
One to support the permanent and one for the superconducting magnet

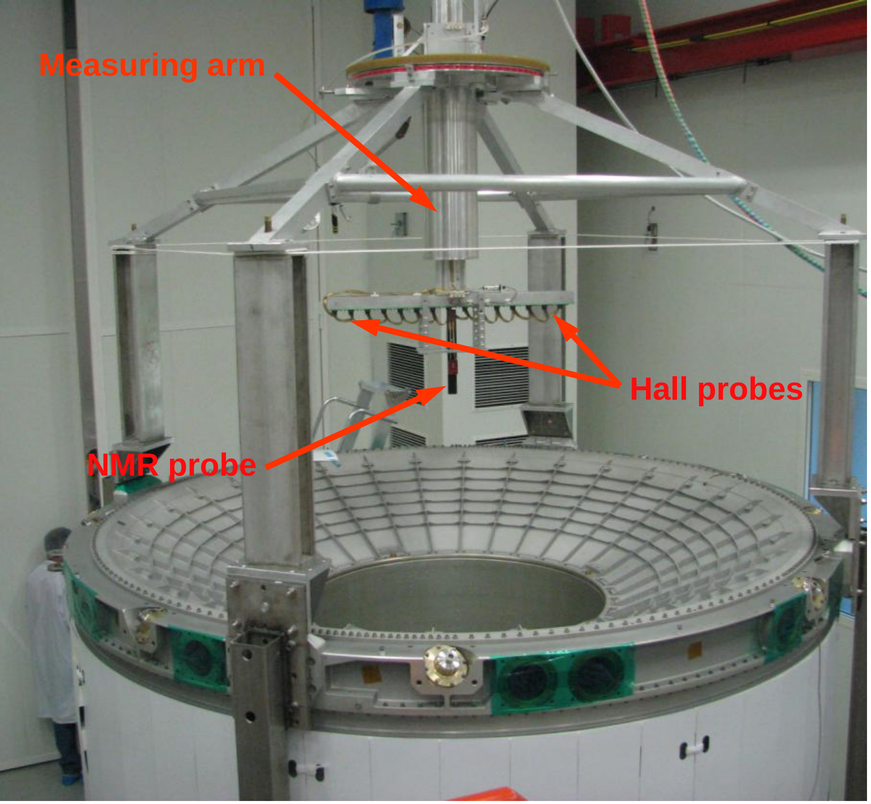


RWTH Aachen, I. Physics Institute Workshop



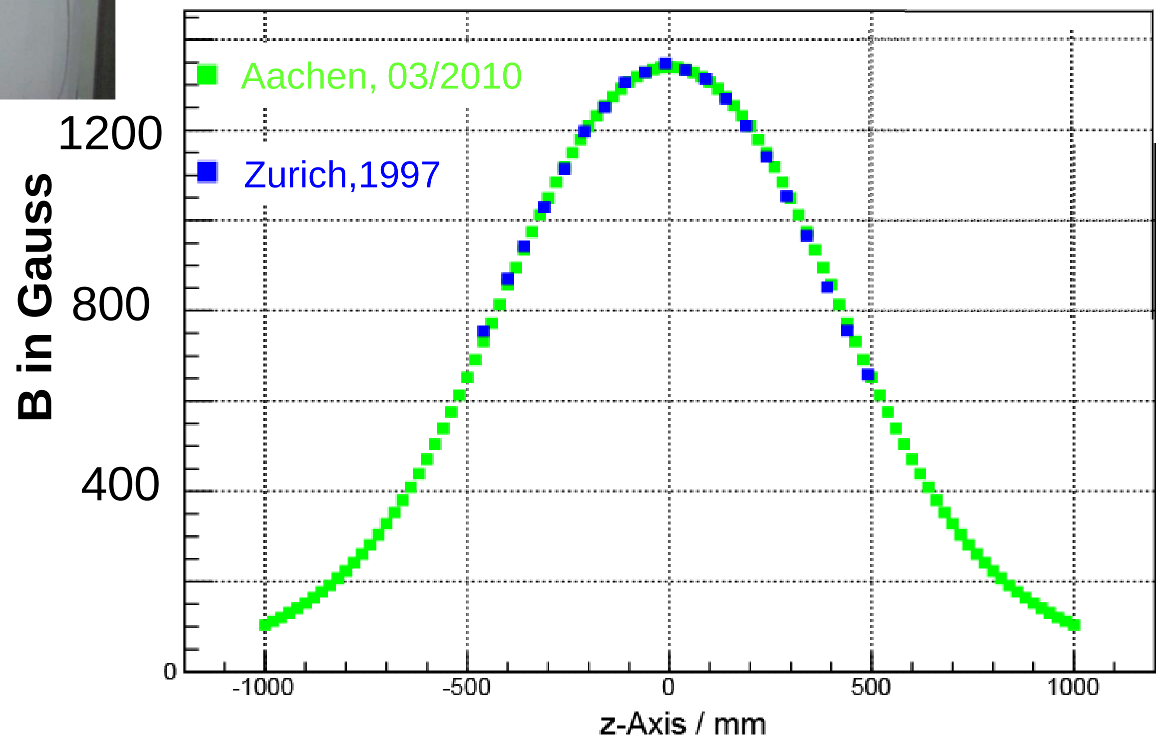
Permanent Magnet installation in the vacuum case,
12 May 2010, RWTH, Aachen, Germany





In 12 years the field has remained the same to <1%

The detailed 3D field map (18000 locations) was measured at CERN on 25-27 May 2010



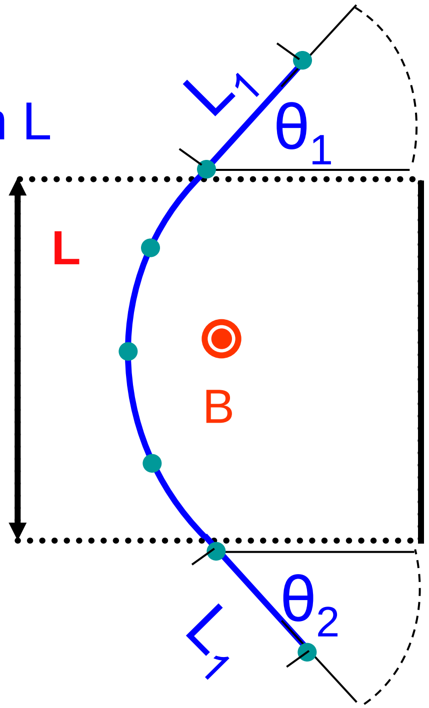
The momentum resolution (Δp/p) is the sum of two contributions:

1. Measurement inside the magnet with an effective length L

$$(z/p)\cdot(\Delta p/p) \propto 1/BL^2$$

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

$$(z/p)\cdot(\Delta p/p) \propto 1/BLL_1$$

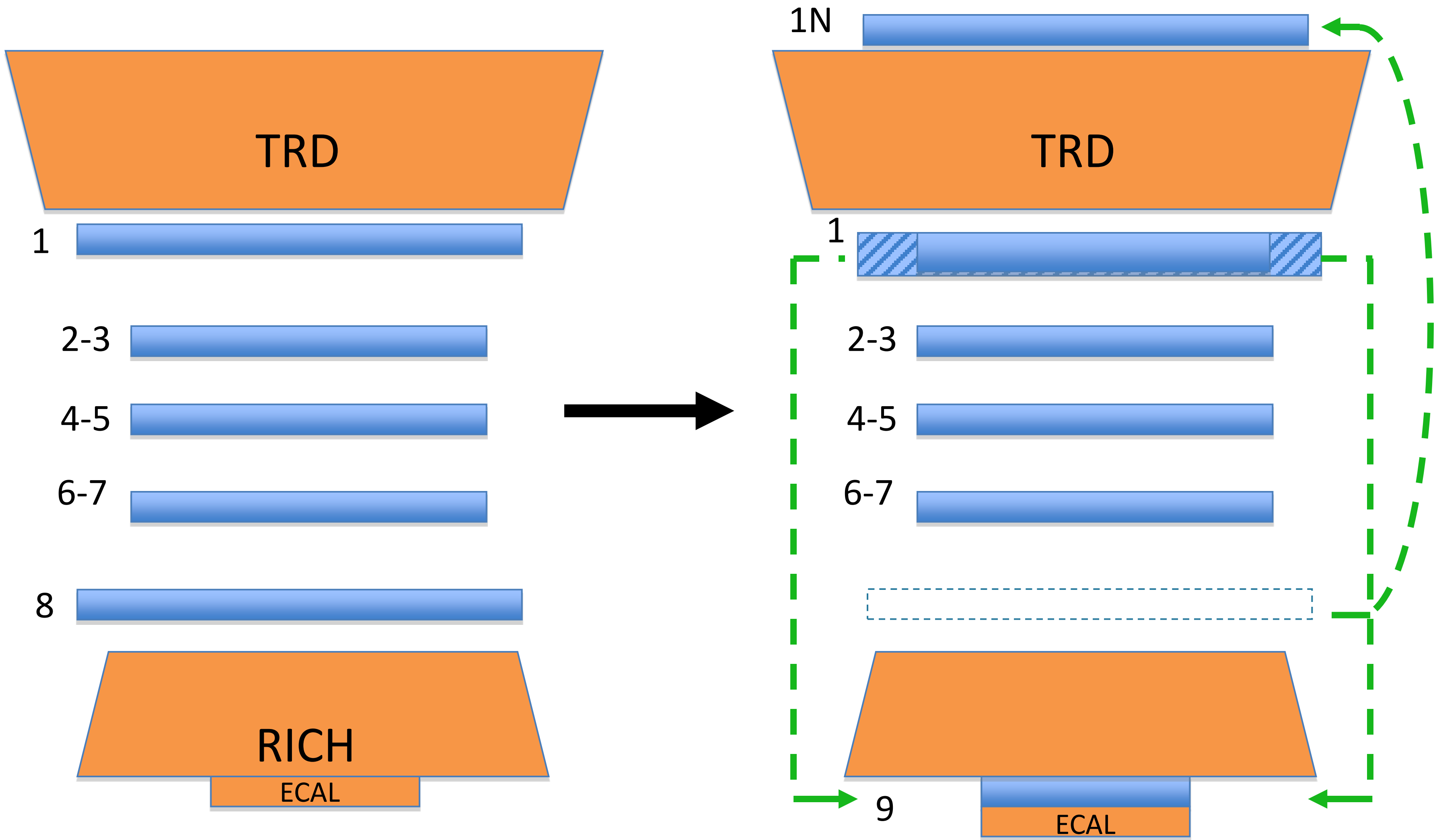


For both magnets, L ~ 80 cm,
but in the permanent magnet B is 5 times smaller

to maintain the same Δp/p we increase L1 from ~15 cm (Superconducting Magnet) to ~125 cm (permanent magnet)

AMS-02 SC (3Yrs)
Silicon Tracker Layers

AMS-02 (10 - 18 Yrs)
Silicon Tracker Layers



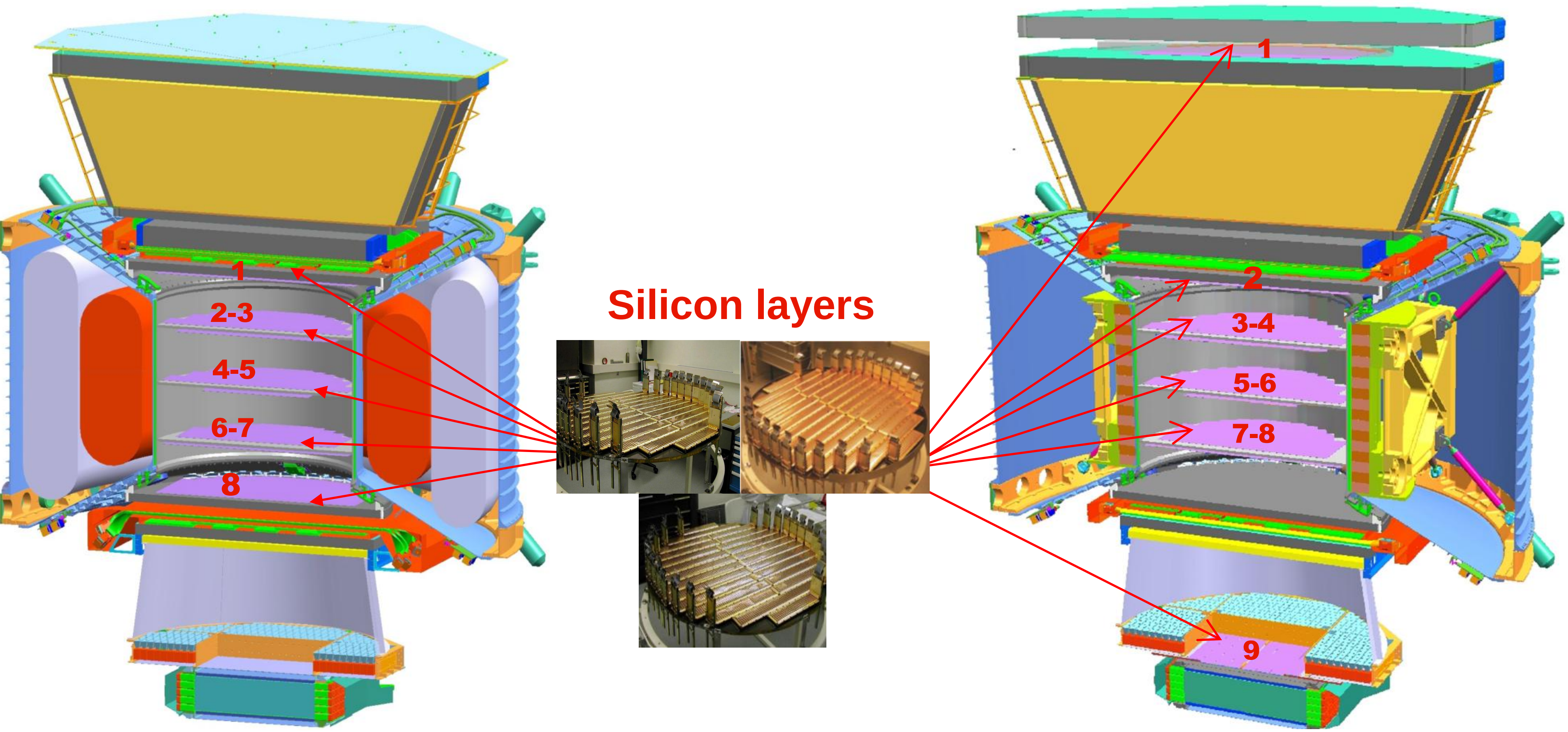
Layer 9 comes from moving the ladders at the edge of the acceptance from layer 1. The layer 8 is moved on top of the TRD to become 1N.
No new silicon and no new electronics are required.

AMS-02

(3 yrs)
with SC Magnet

AMS-02

(10 Yrs to 18 yrs)
with Permanent Magnet
9 layers of Silicon

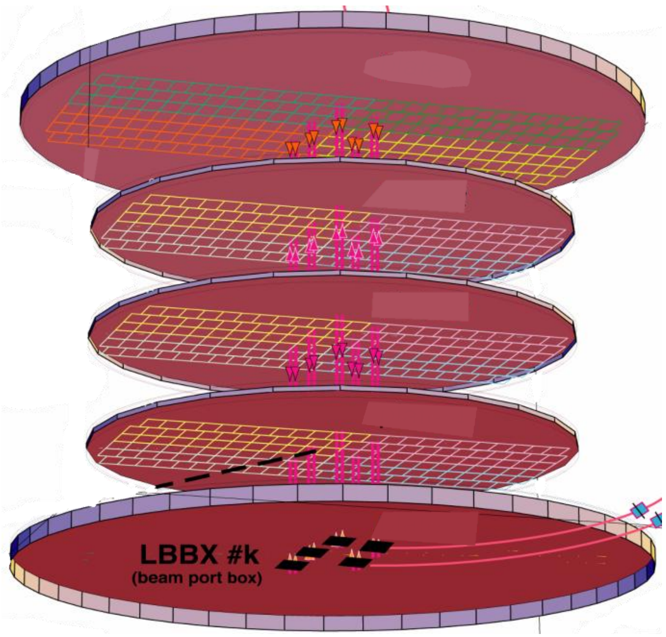


Layers 1 and 9 are far away from the magnet.

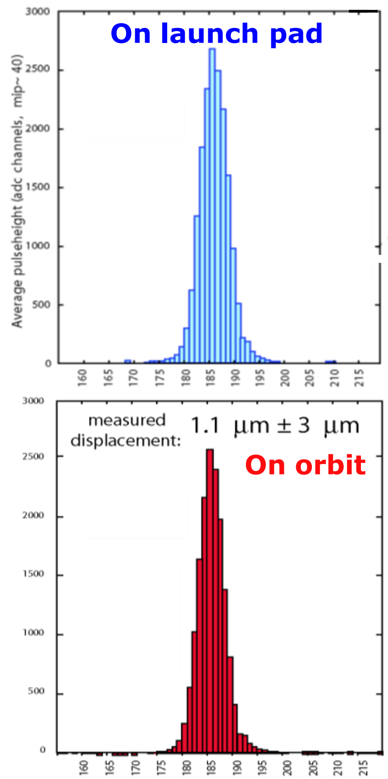
Alignment of the entire Tracker System

Inner tracker alignment

In space, the inner tracker alignment of 3 μm will be continuously monitored by 20 Laser beams.



AMS-01



Alignment of the entire System

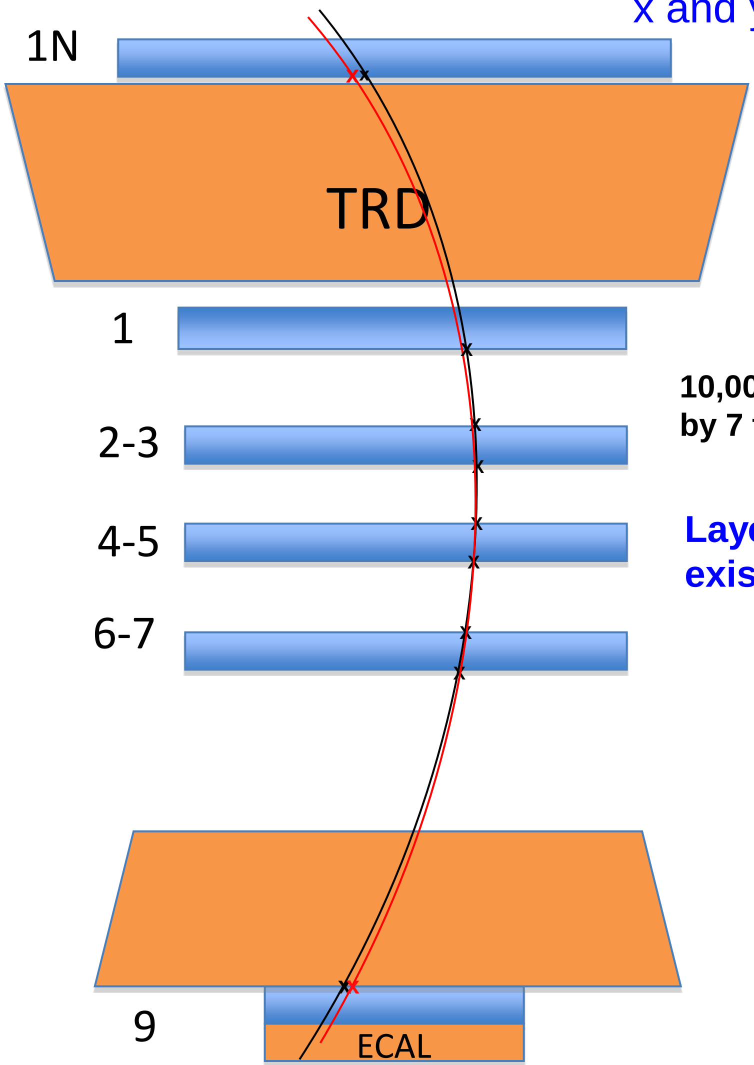
1. **With CERN Test beam on 7-14 Aug 2010 using 400 GeV protons.**

2. **With 10,000 cosmic rays every minute in every orbit**

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.

Extrapolated track from 7 measurements inside the magnet

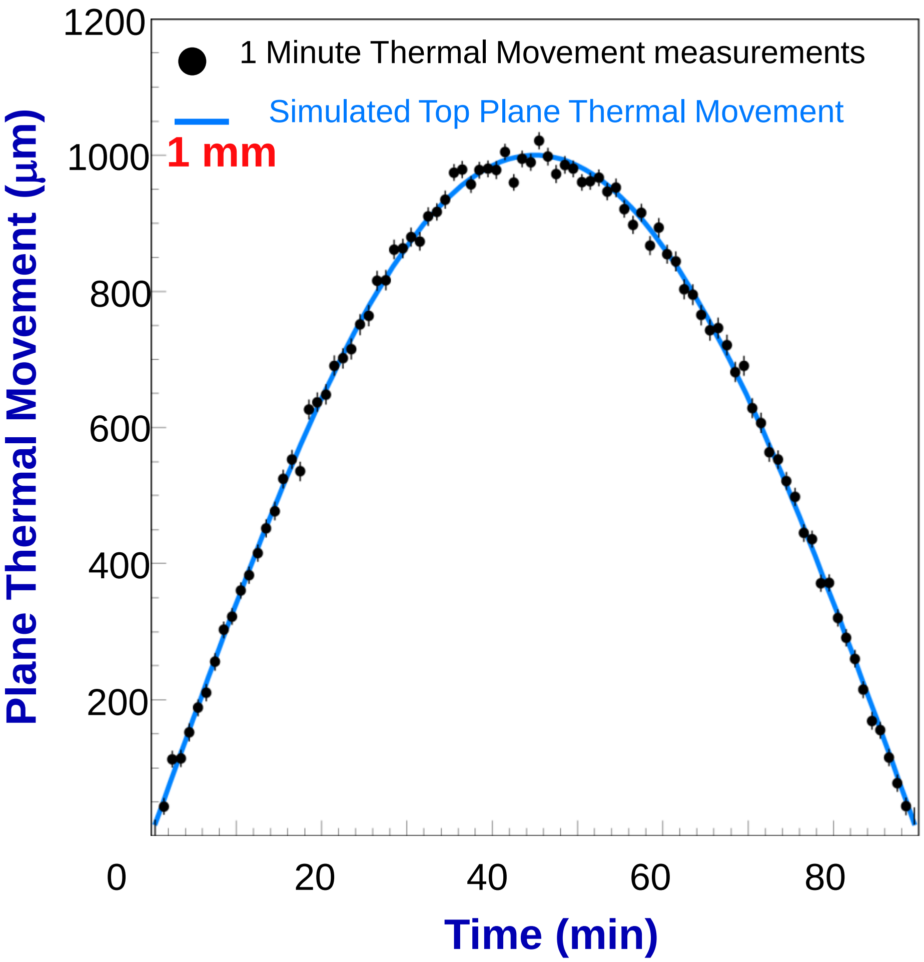


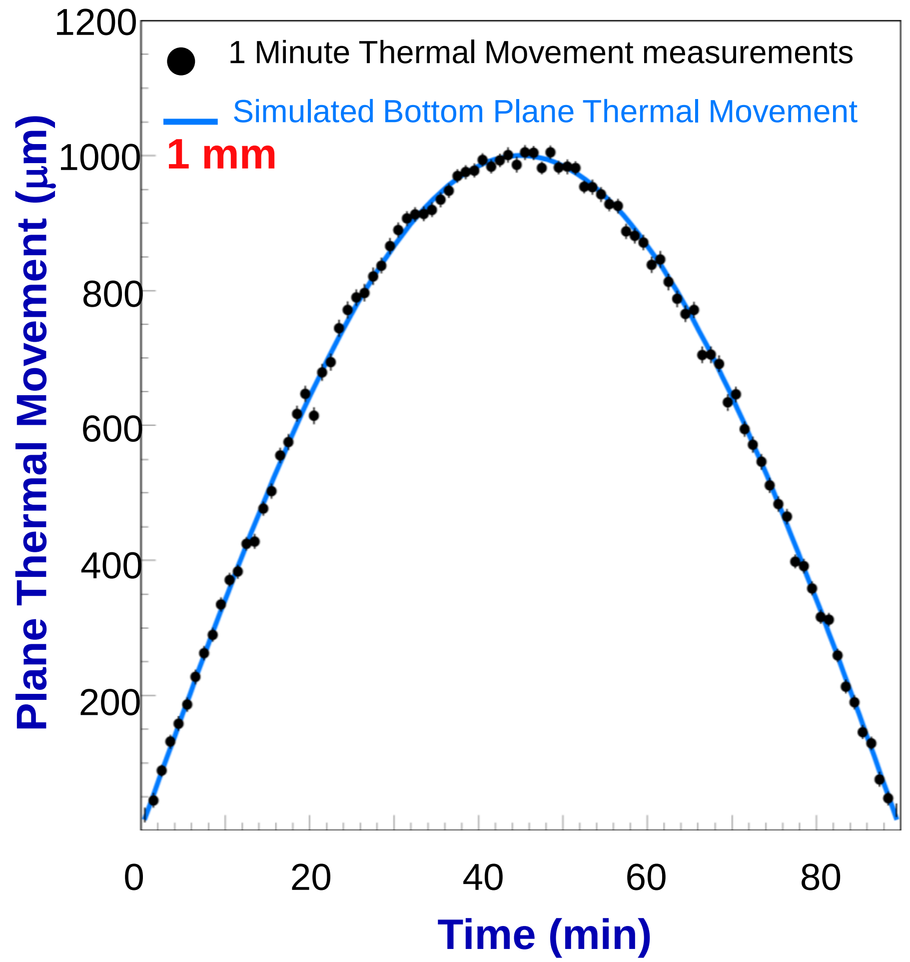
10,000 cosmic protons / min measured by 7 tracker layers in the magnet

Layers 1 to 7 are aligned with existing laser system

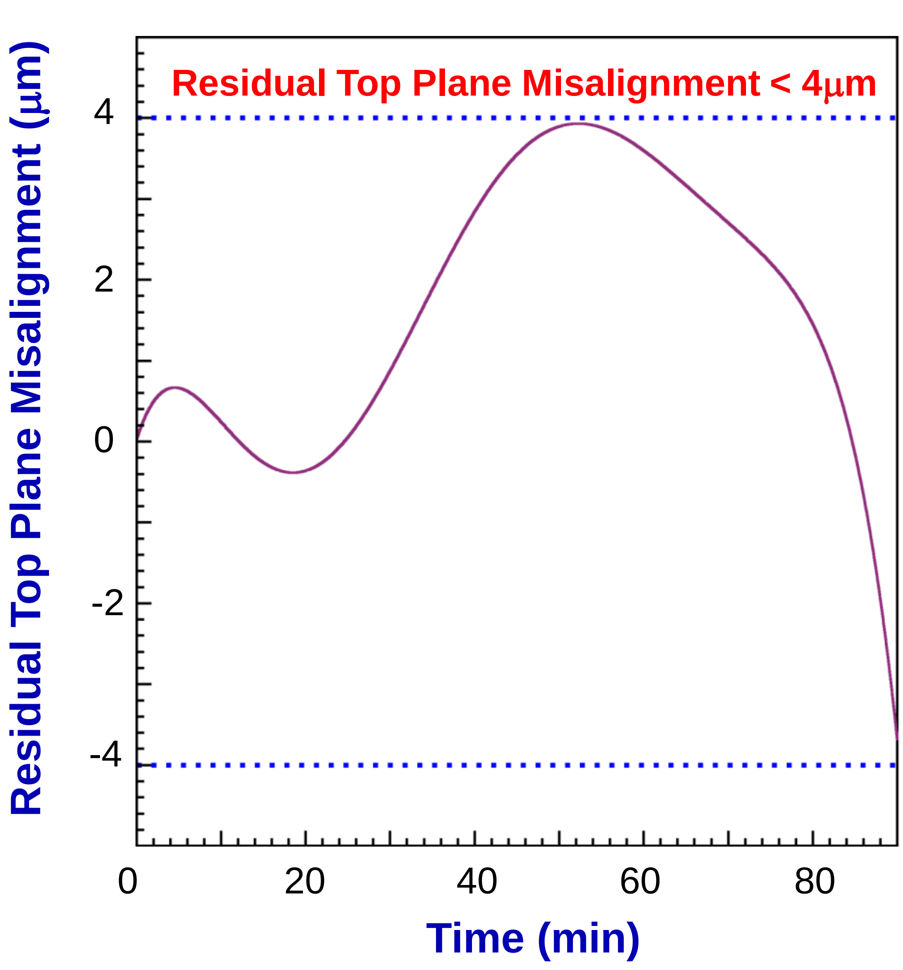
Extrapolated track from 7 measurements inside the magnet

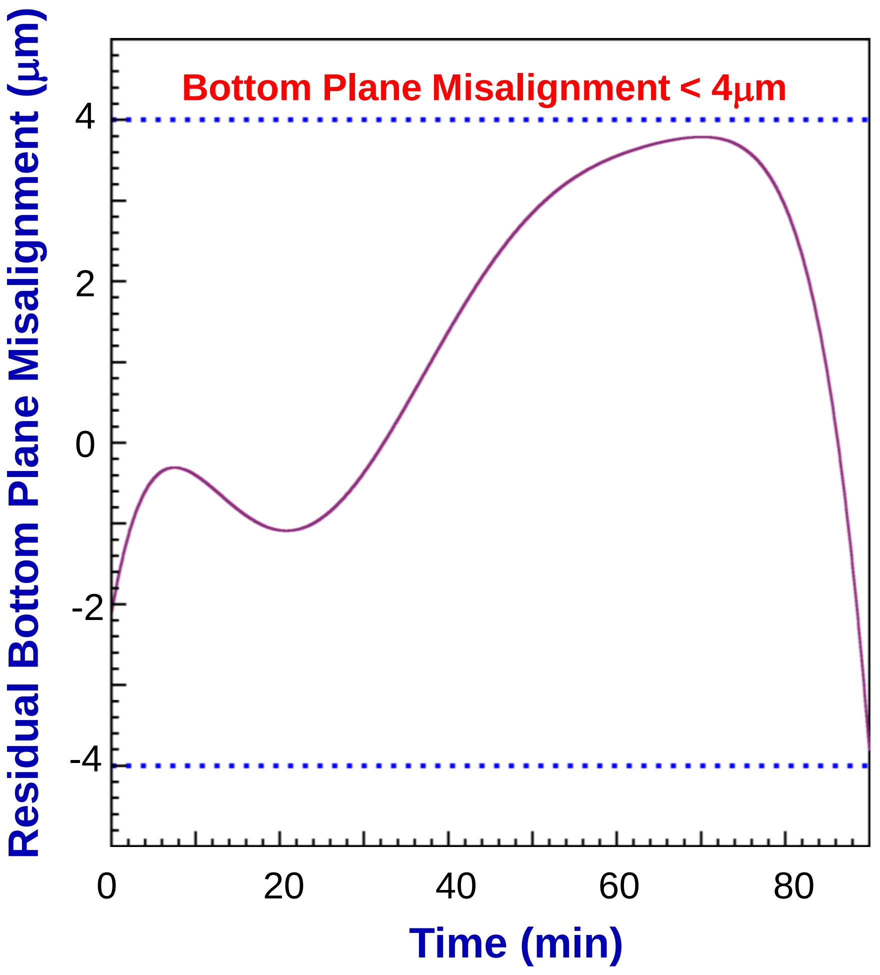
External Plane Alignment with Cosmic Rays Minute by Minute





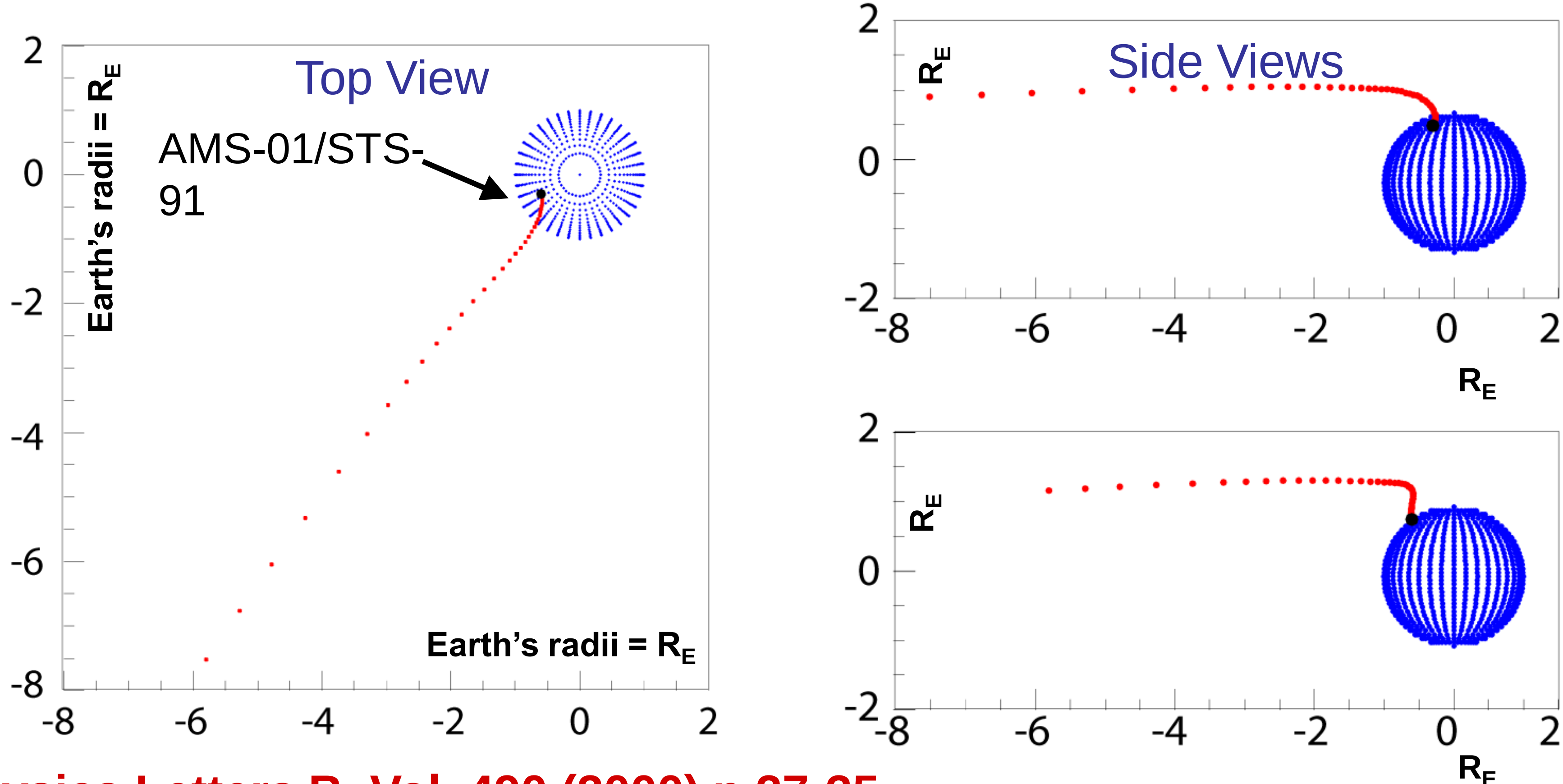
External Planes Alignment Studies





AMS-01: Tracing the origin of cosmic rays from measurements with 6 tracker layers

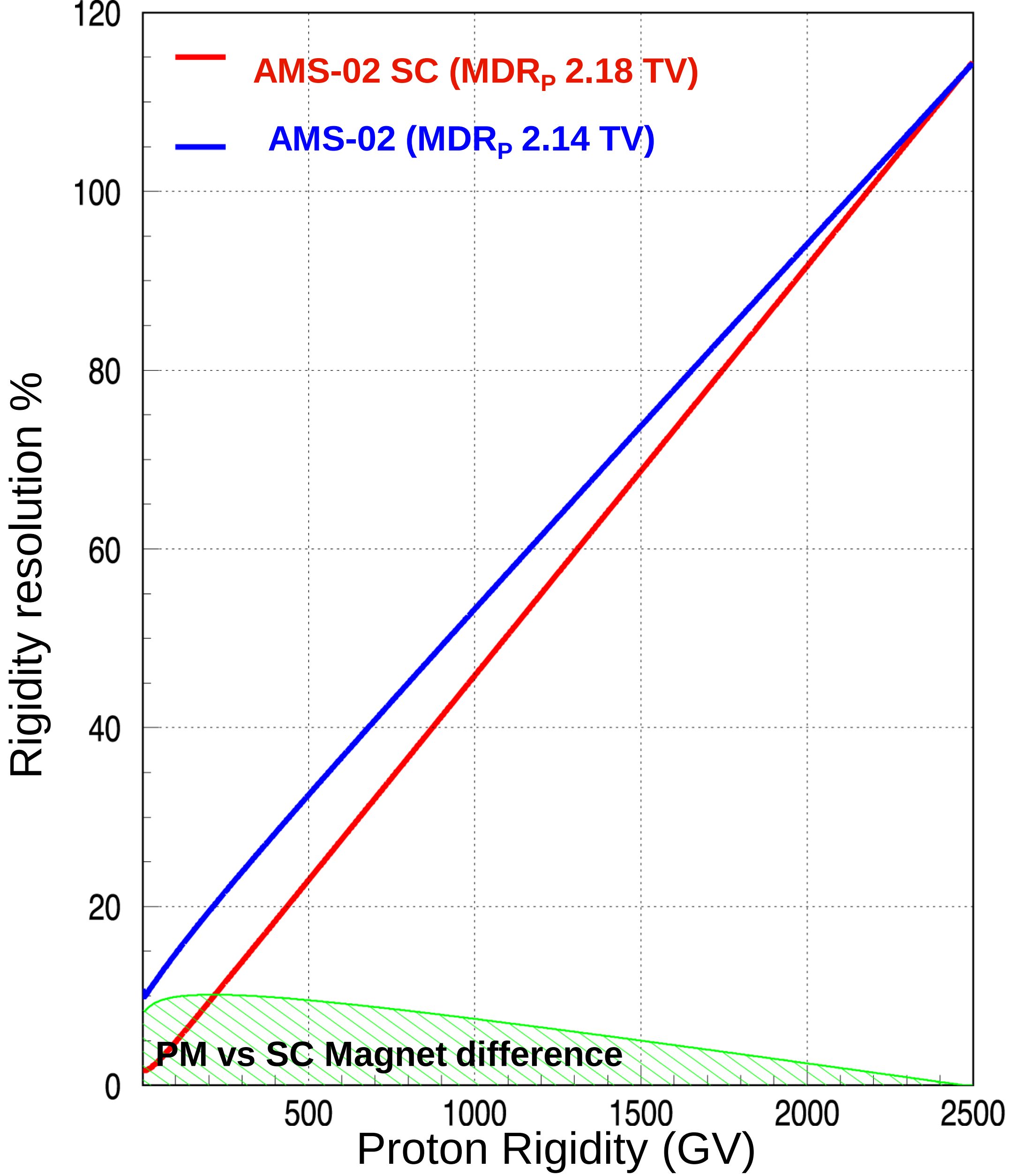
Run/Event: 897171331/310063 06-Jun-98 22:33:48 Lat/Long: 50N/27W



Physics Letters B, Vol. 490 (2000) p.27-35

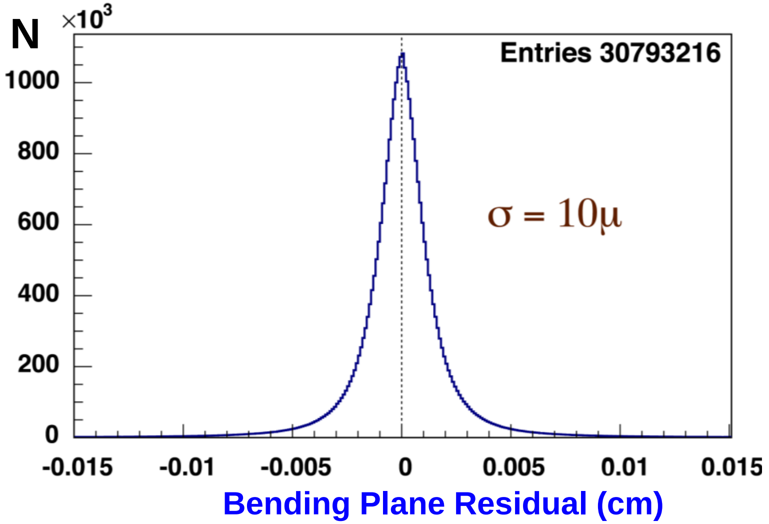
Referee's report:

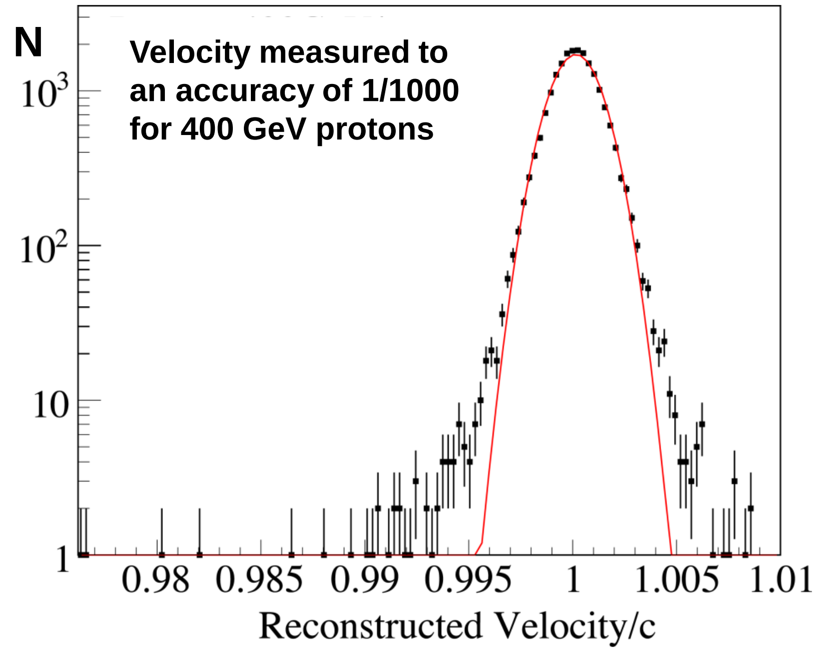
"This paper is very important and highly relevant…"

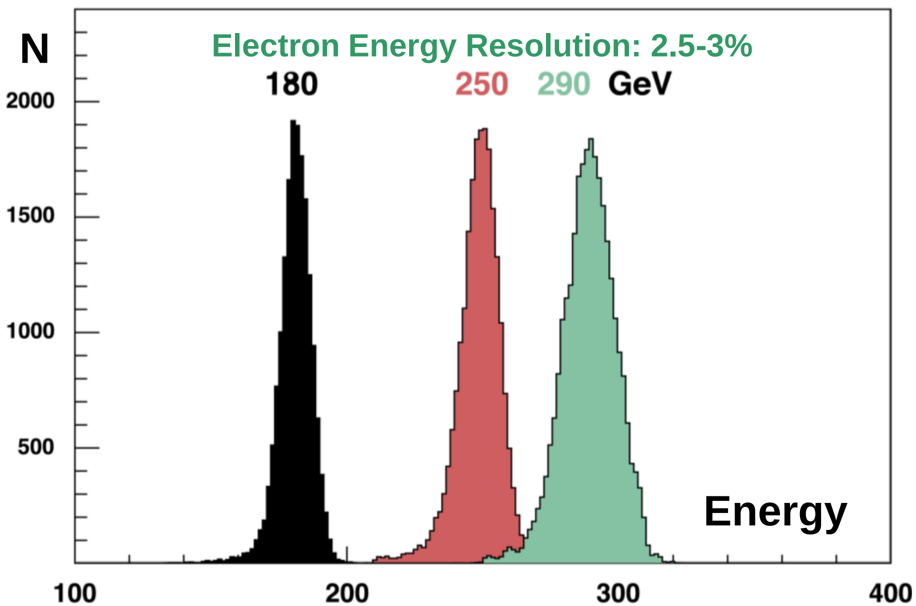


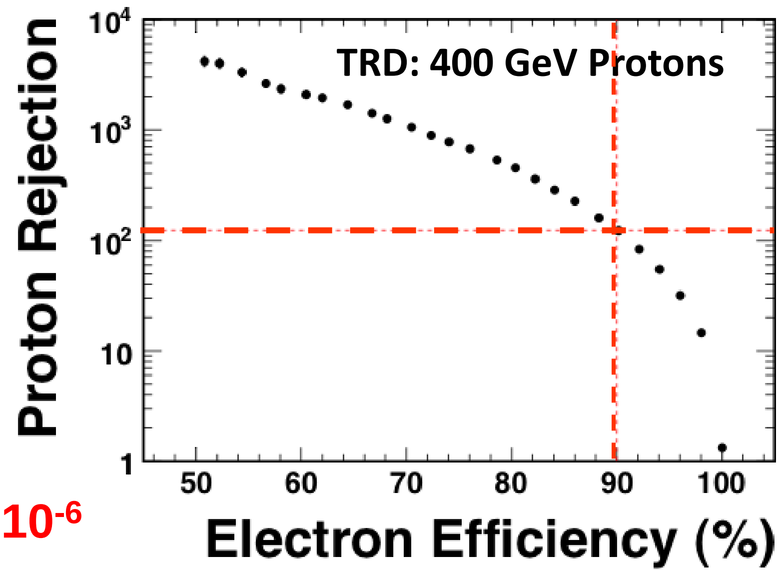
With 9 tracker planes, the resolution of AMS with the permanent magnet is equal (to 10%) to that of the superconducting magnet.
For helium, the MDR for the permanent magnet is 3.75 TV.

With the permanent magnet the properties of the detectors remain the same as with the superconducting magnet.
The magnetic field is used to determine the momentum and the sign of the charge.



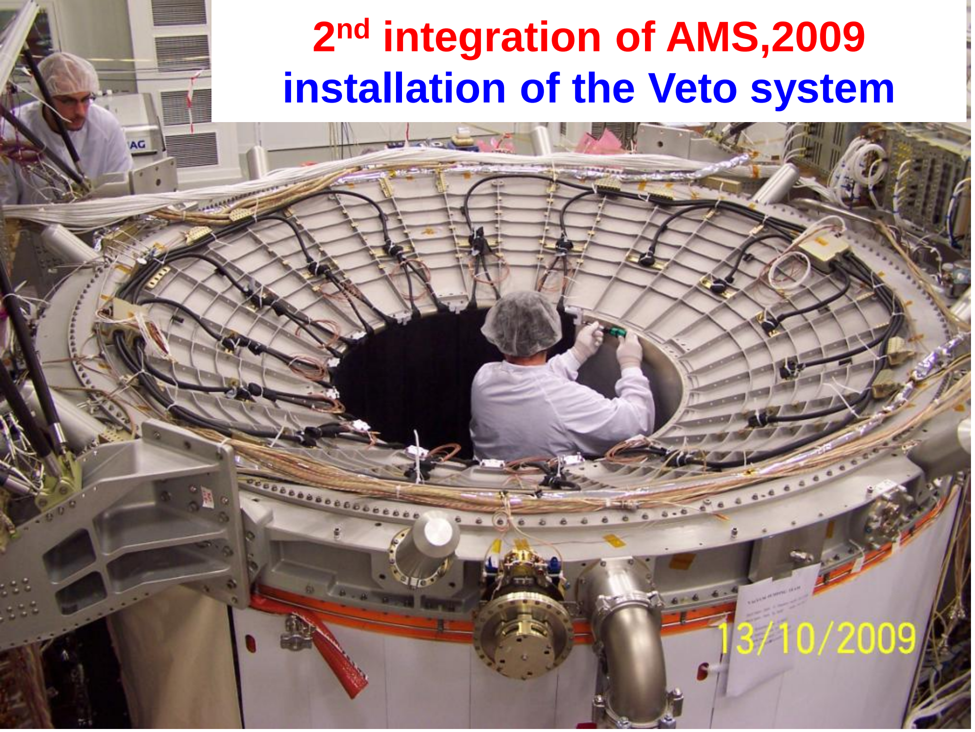


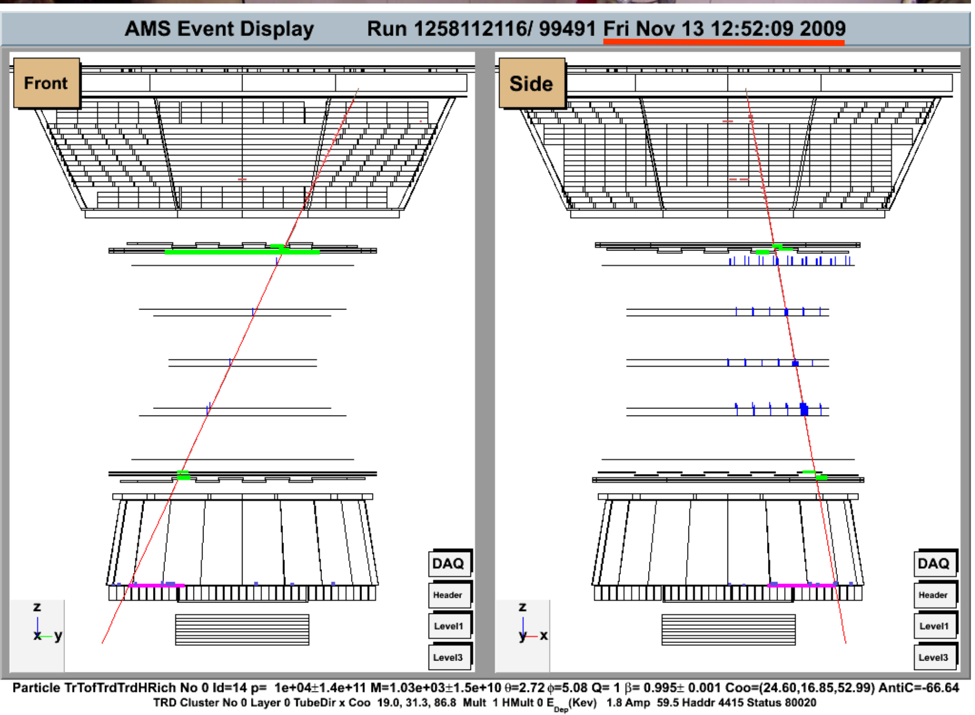




Measured combined rejection power at 400 GeV: $e^+/p = 10^{-6}$

2nd integration of AMS,2009
installation of the Veto system





Flight integration, 2010:

begins 7 June,
with installation of veto system

The Permanent Magnet version of AMS is ready for reintegration two days ahead of schedule. Photo taken on 3 June 2010

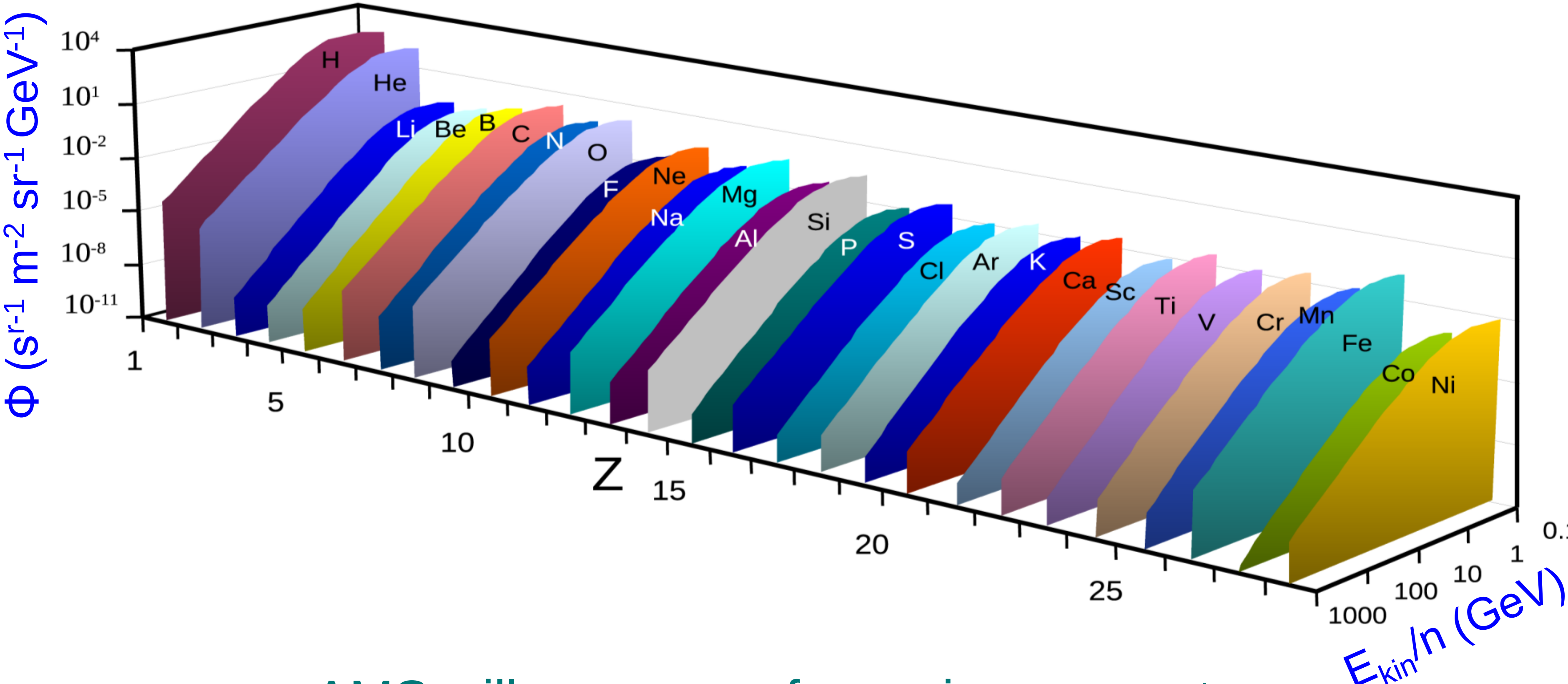
Completion – 7 August

Test beam: 7-14 August

Transport to KSC: 25-31 August

Launch to ISS: Nov 2010

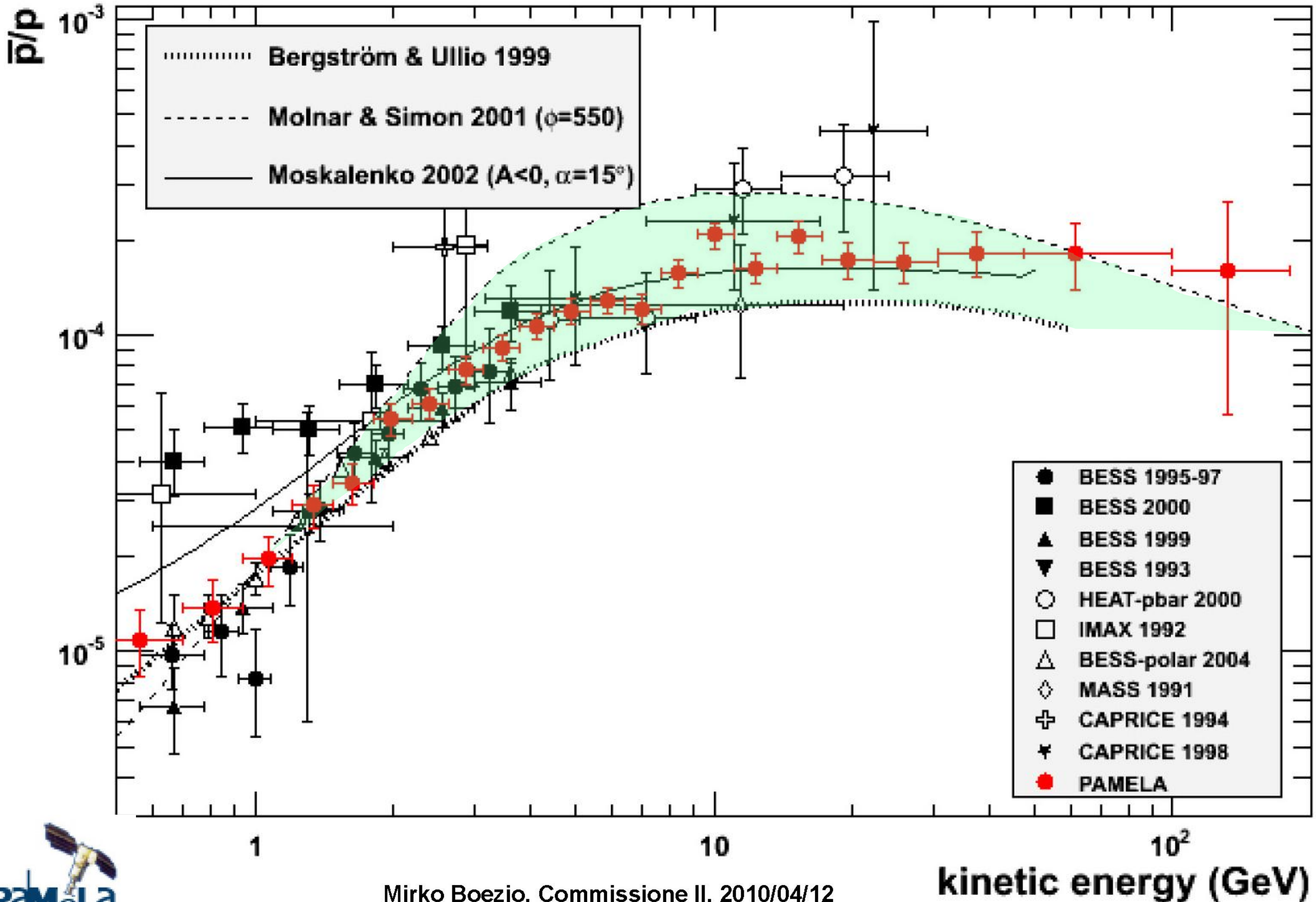
Physics of AMS: Nuclear Abundances Measurements



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 →e^+, $\bar{p}$, …

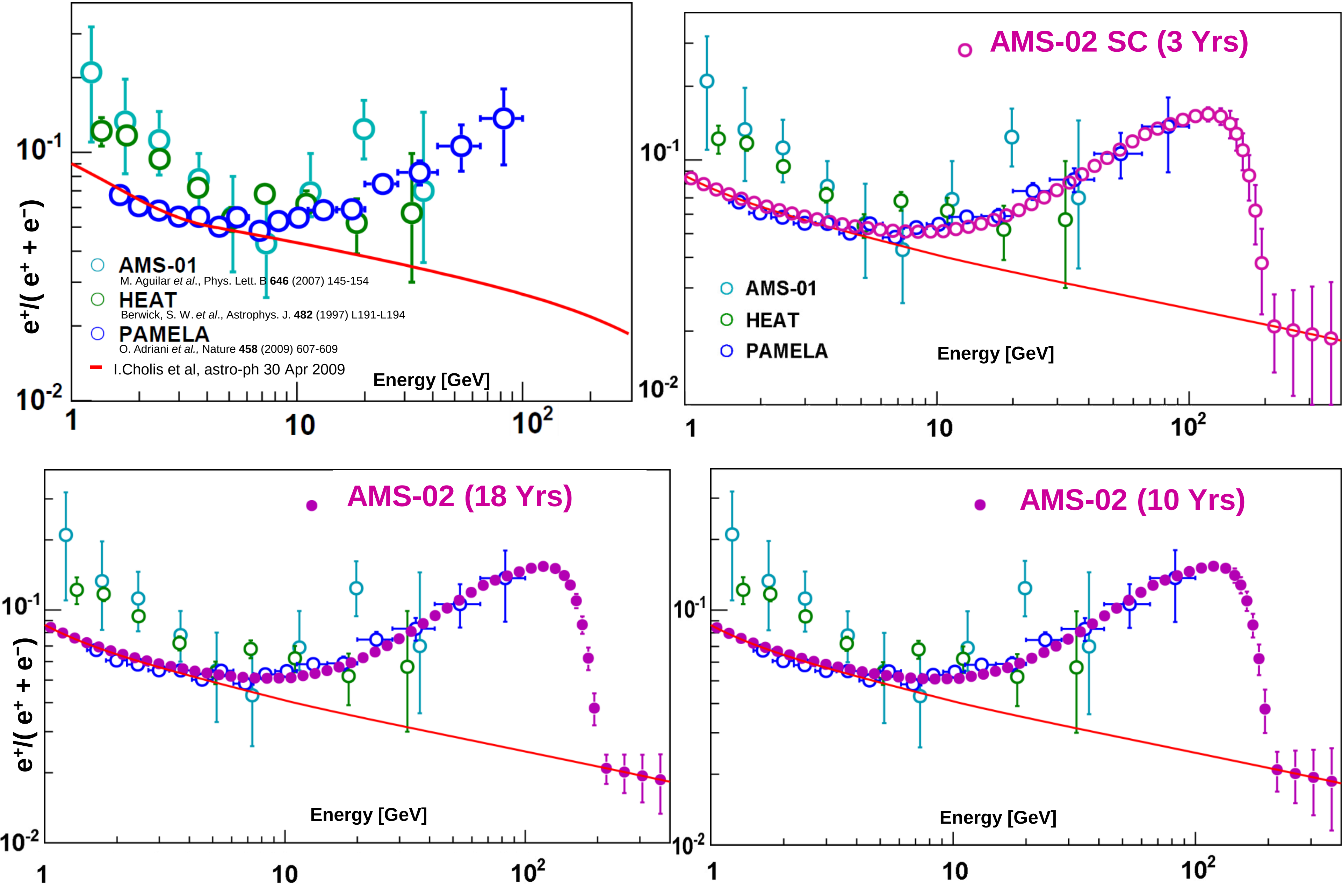
Rapporto Antiprotoni



Sensitivity in Dark Matter searches: large acceptance, long duration

$\chi^0 \chi^0 \rightarrow e^+, e^-$ for $m\chi^0 = 200$ GeV

I.Cholis et al, astro-ph 30 Apr 2009

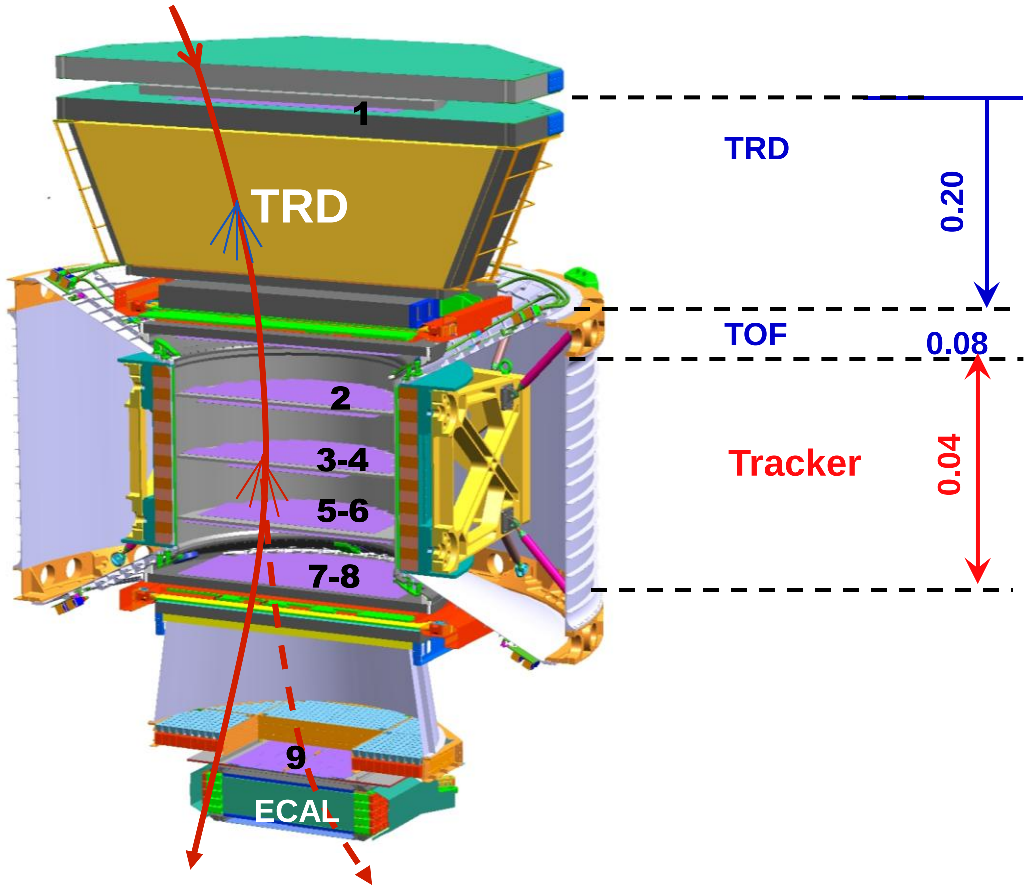


AMS goals: $\overline{He}/He = 1/10^{10}$, $e^+/p = 1/10^6$ & Spectra to 1%

$e^+/p = 10^{-2}$

Magnet

$e^+/p = 10^{-4}$



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

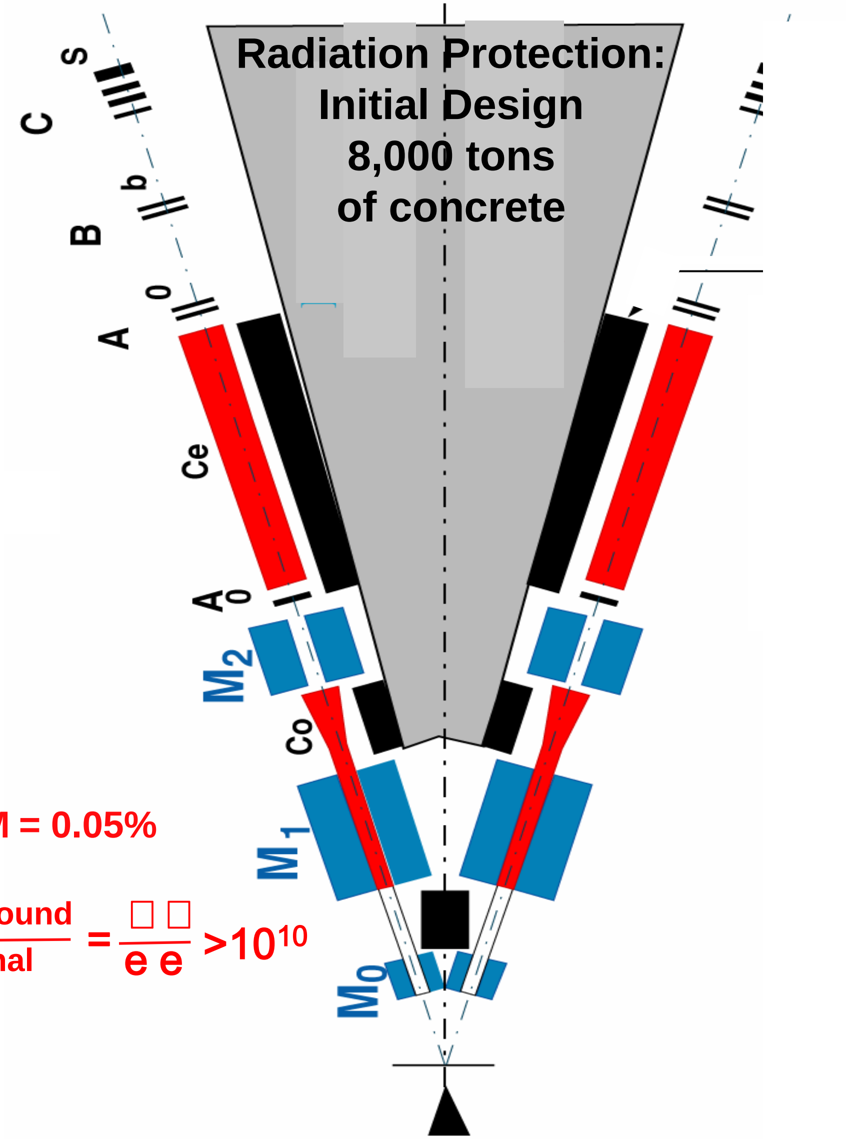
b) Repetitive measurements of momentum , to ensure that particles which had large angle scattering are not confused with the signal.

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 $e^+/p = 10^{-6}$

Discovery of a New Kind of Matter

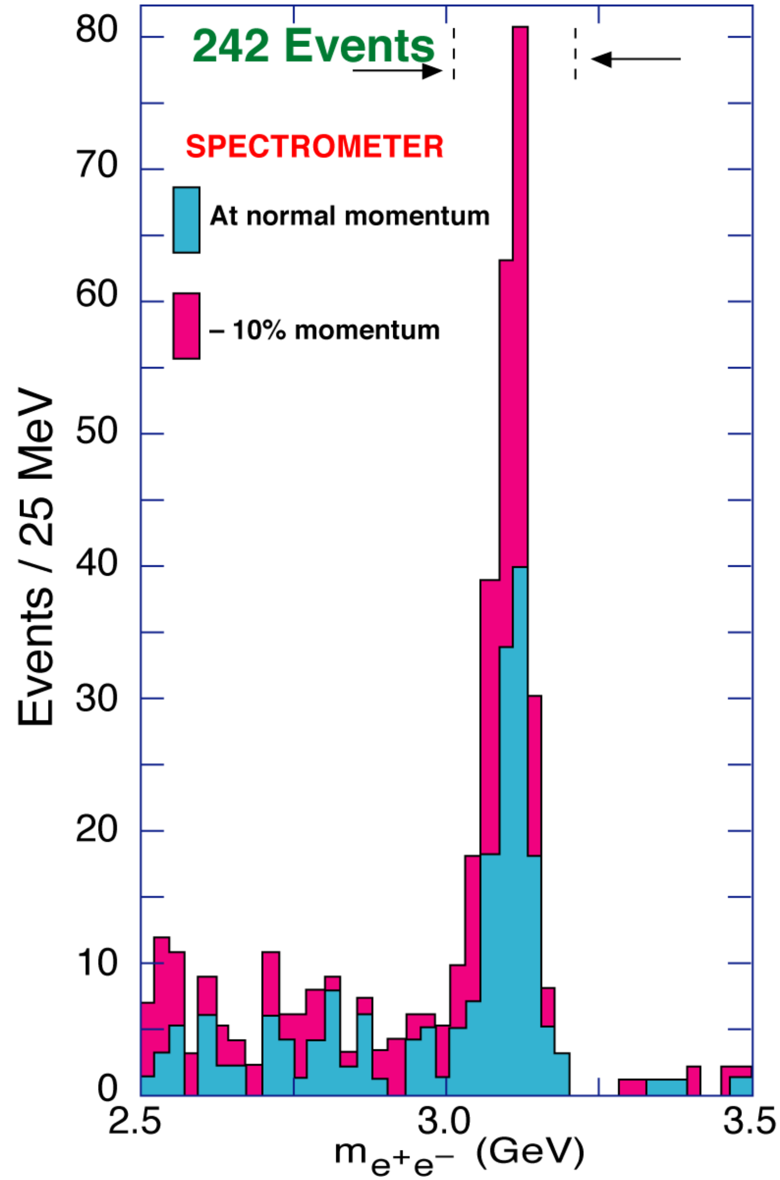
Brookhaven National Laboratory, NY



$\Delta M/M = 0.05\%$

$\frac{\text{Background}}{\text{Signal}} = \frac{\square\square}{e\,e} > 10^{10}$

10^{12} p/sec



Discovery of "J"

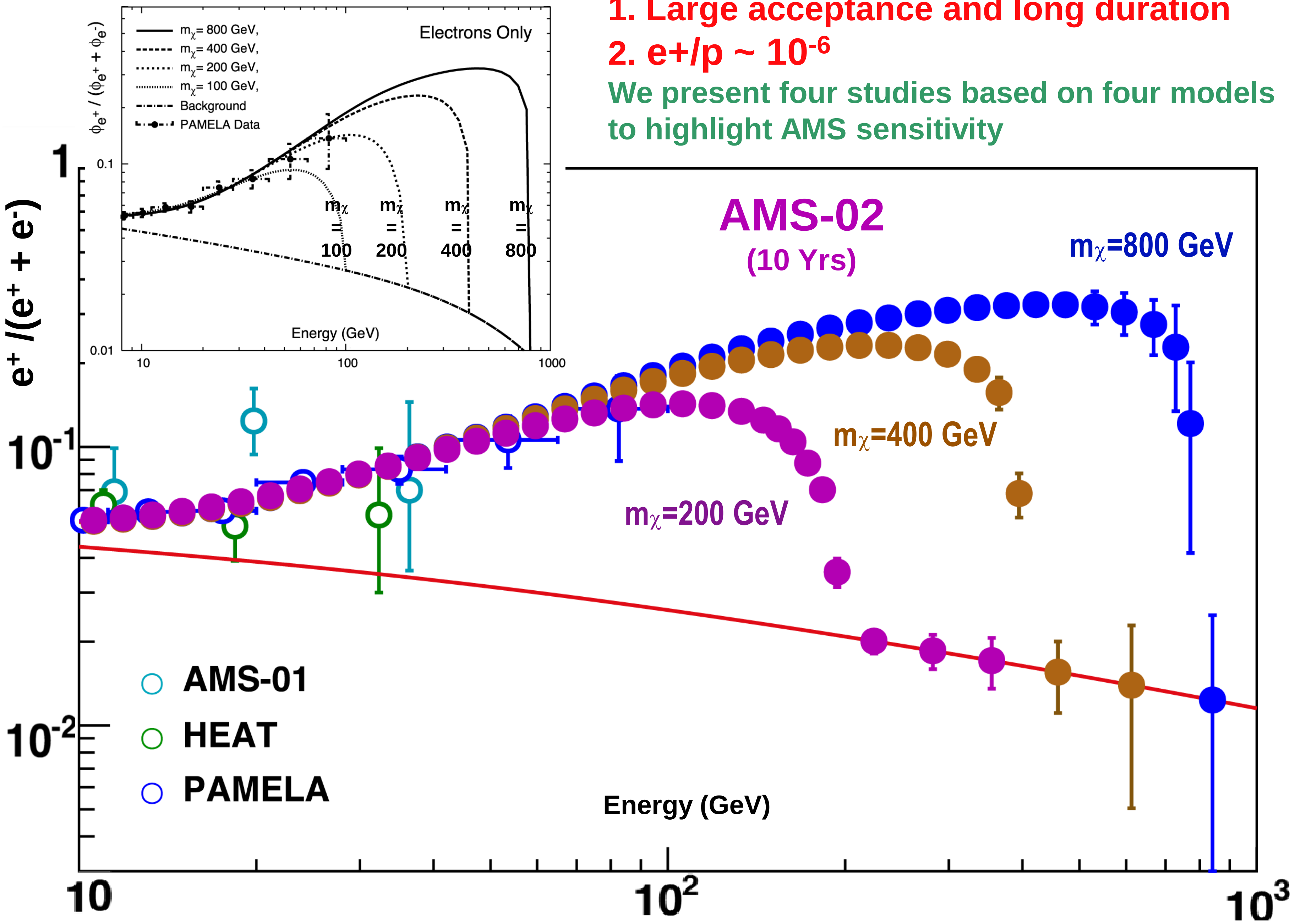
case 1

I.Cholis et al, arXiv:0810.5344v3

AMS – search for DM:

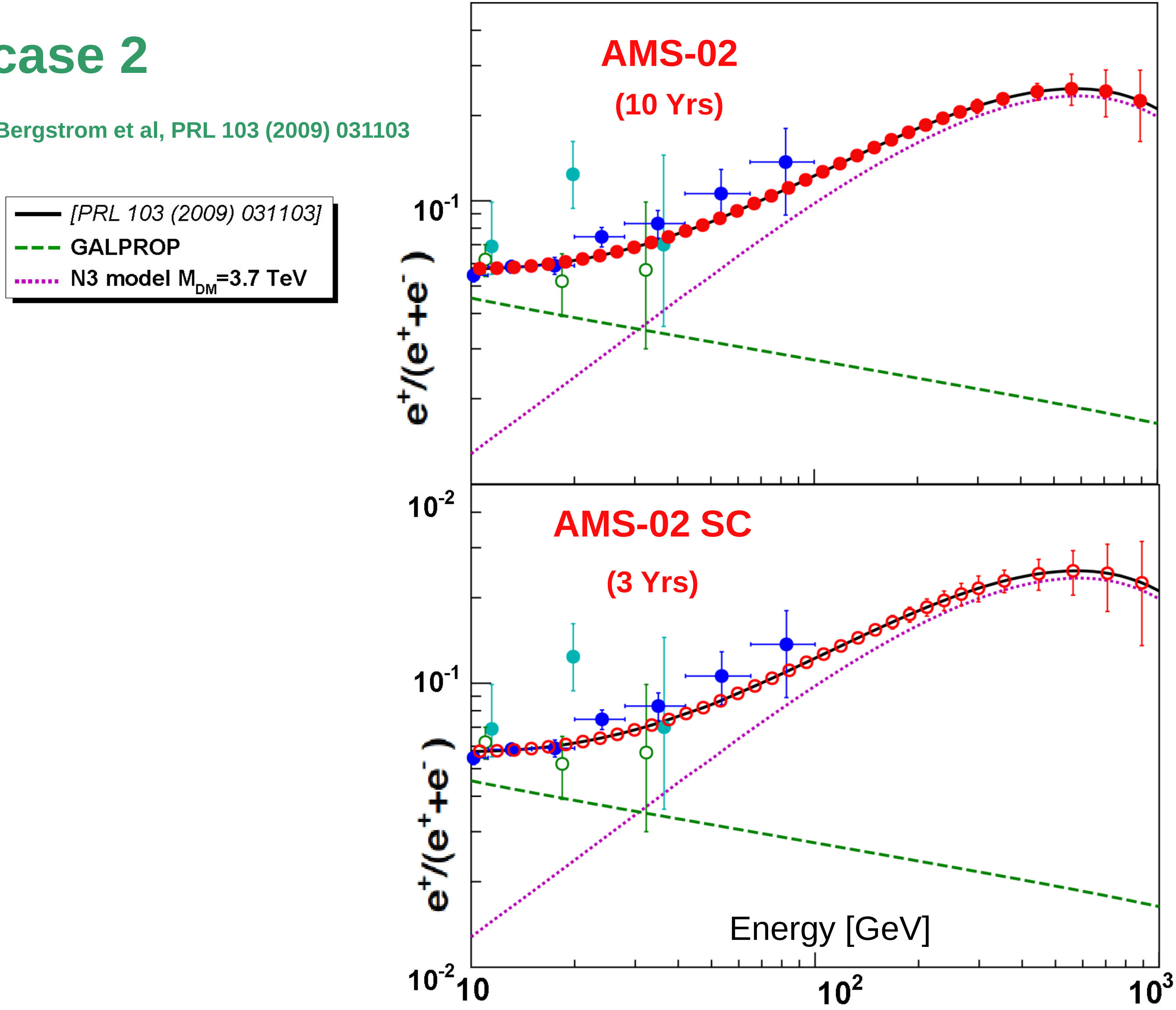
1. Large acceptance and long duration
2. e+/p ~ 10^{-6}

We present four studies based on four models to highlight AMS sensitivity



case 2

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

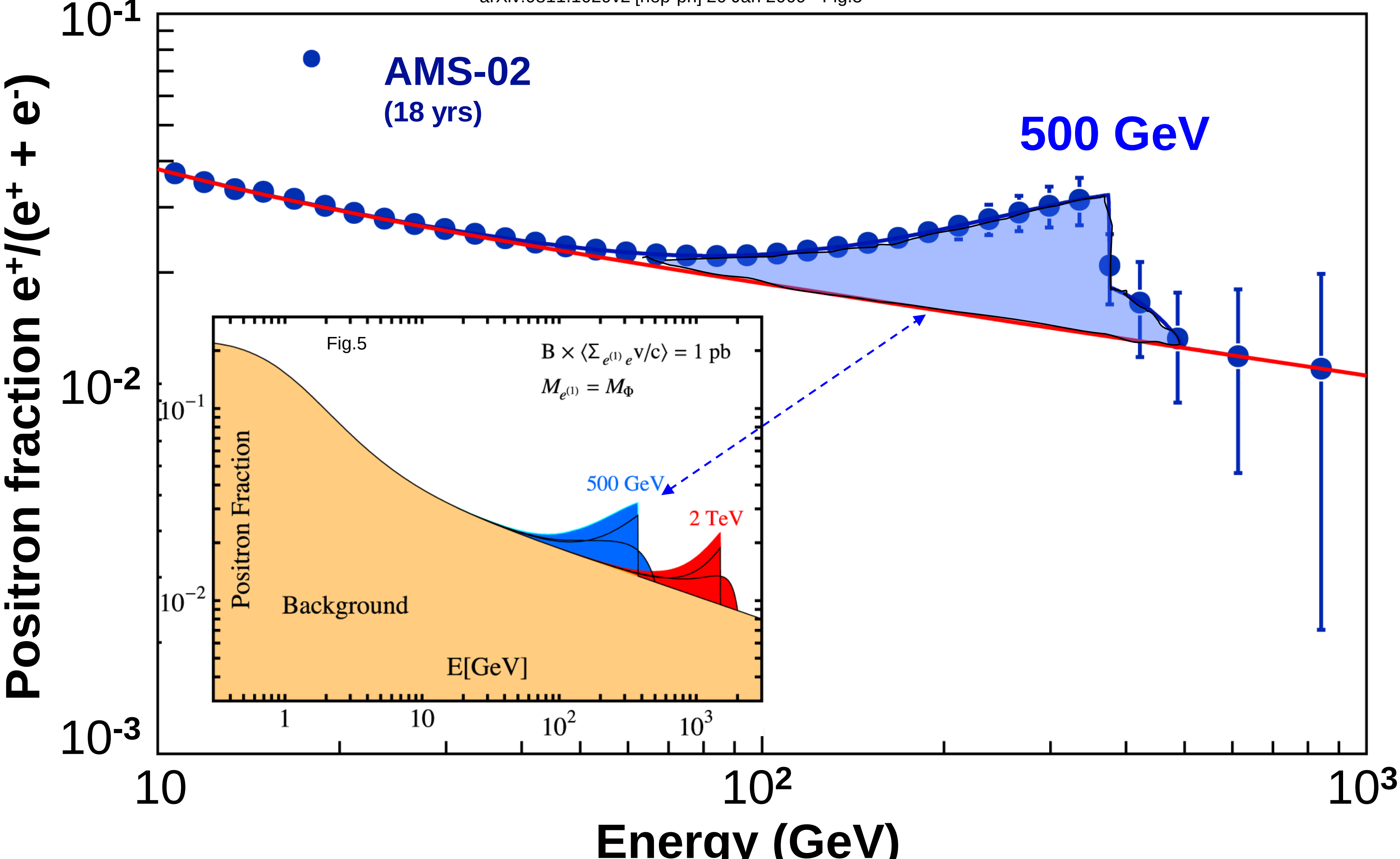


Kaluza-Klein Bosons are also Dark Matter candidates

case 3 TeV Scale Singlet Dark Matter

Eduardo Pontón and Lisa Randall

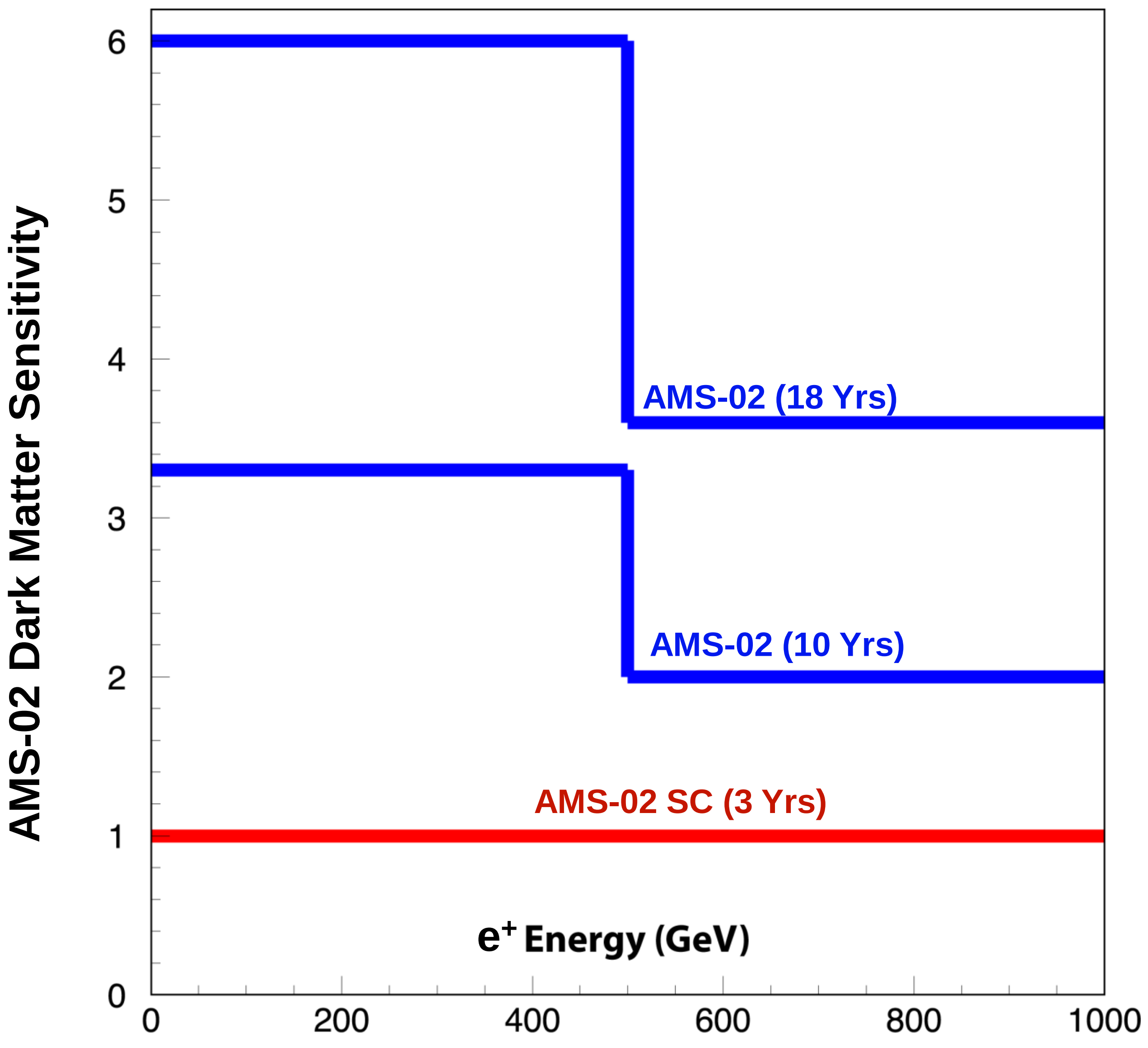
arXiv:0811.1029v2 [hep-ph] 20 Jan 2009 - Fig.5



sdm_500_18Yb

Dark Matter Searches

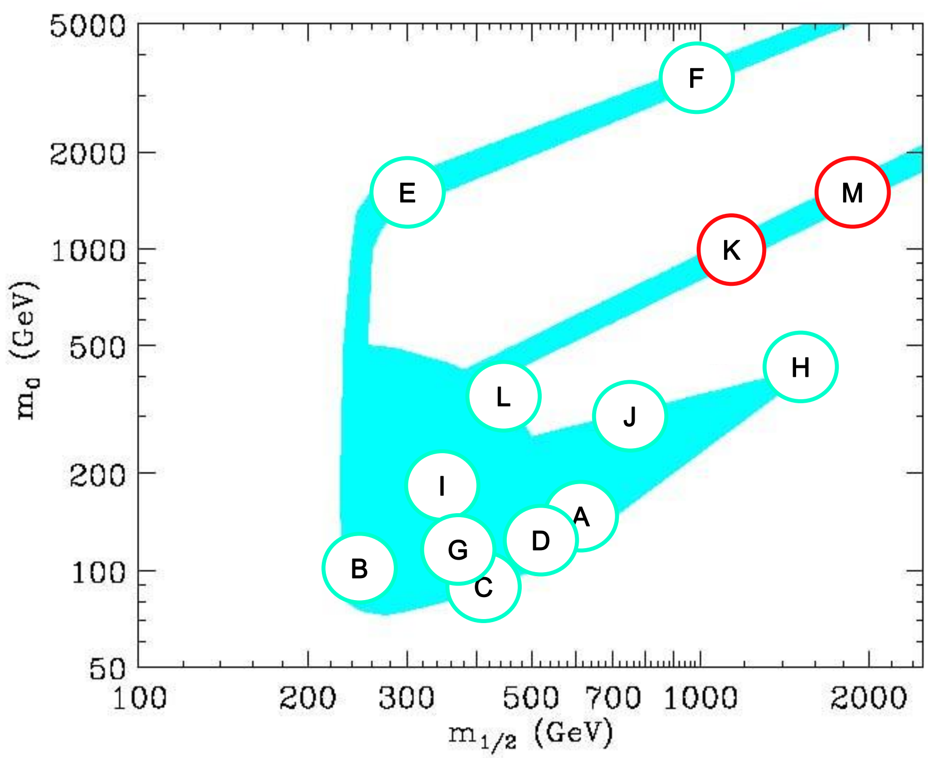
normalized to the sensitivity of AMS with superconducting magnet on ISS for 3 years



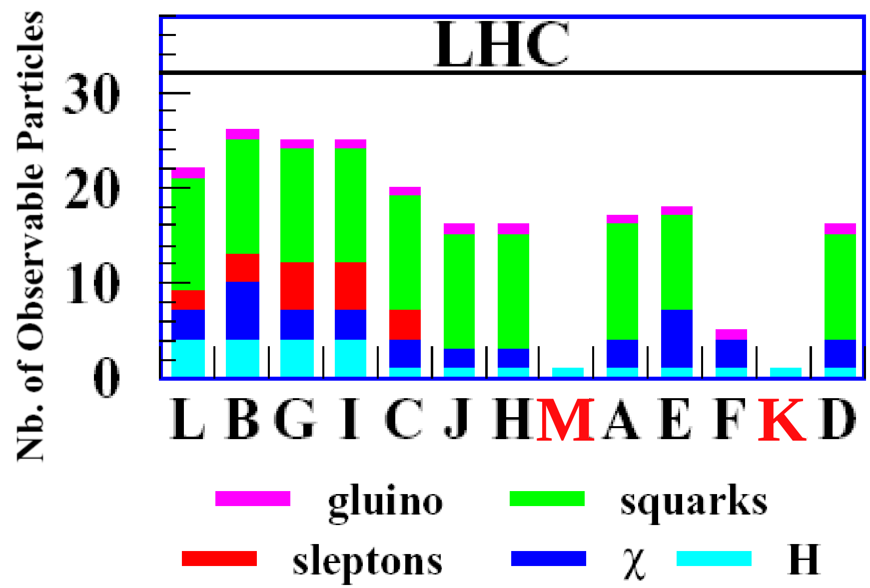
As seen, the permanent magnet upgrade of AMS has a 600-200% improvement in sensitivity in the search for Dark Matter.

AMS is sensitive to SUSY parameter space that is difficult to study at LHC (large m_0, $m_{1/2}$ values)
J.Ellis, private communication

Shaded region allowed by WMAP, etc.



Post-WMAP Benchmarks

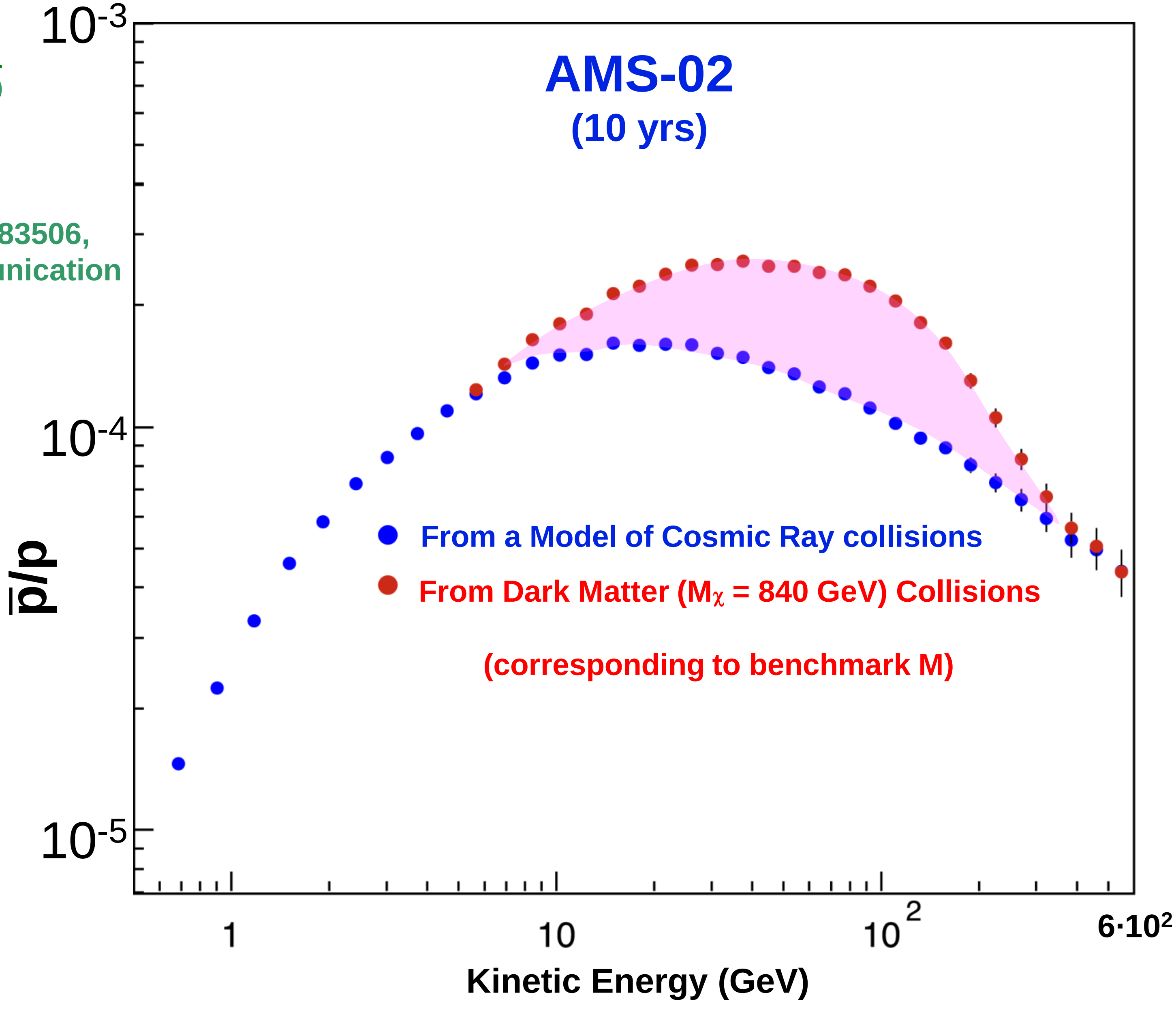


At benchmarks "K" & "M" Supersymmetric particles are not visible at the LHC.

M. Battaglia et al., hep-ph/0112013
M. Battaglia et al., hep-ex/0106207
M. Battaglia et al., hep-ph/0306219
D.N. Spergel et al., astro-ph/0603449

case 4:
DM signal from $\bar{p}$

P. Brun, Phys.Rev.D76:083506, 2007 and private communication



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(ε'/ ε) = (19.2±2.1)*10^{-4})

CERN NA-48

CDF, D0

LHC-b

ATLAS

CMS

Proton decay

Super K

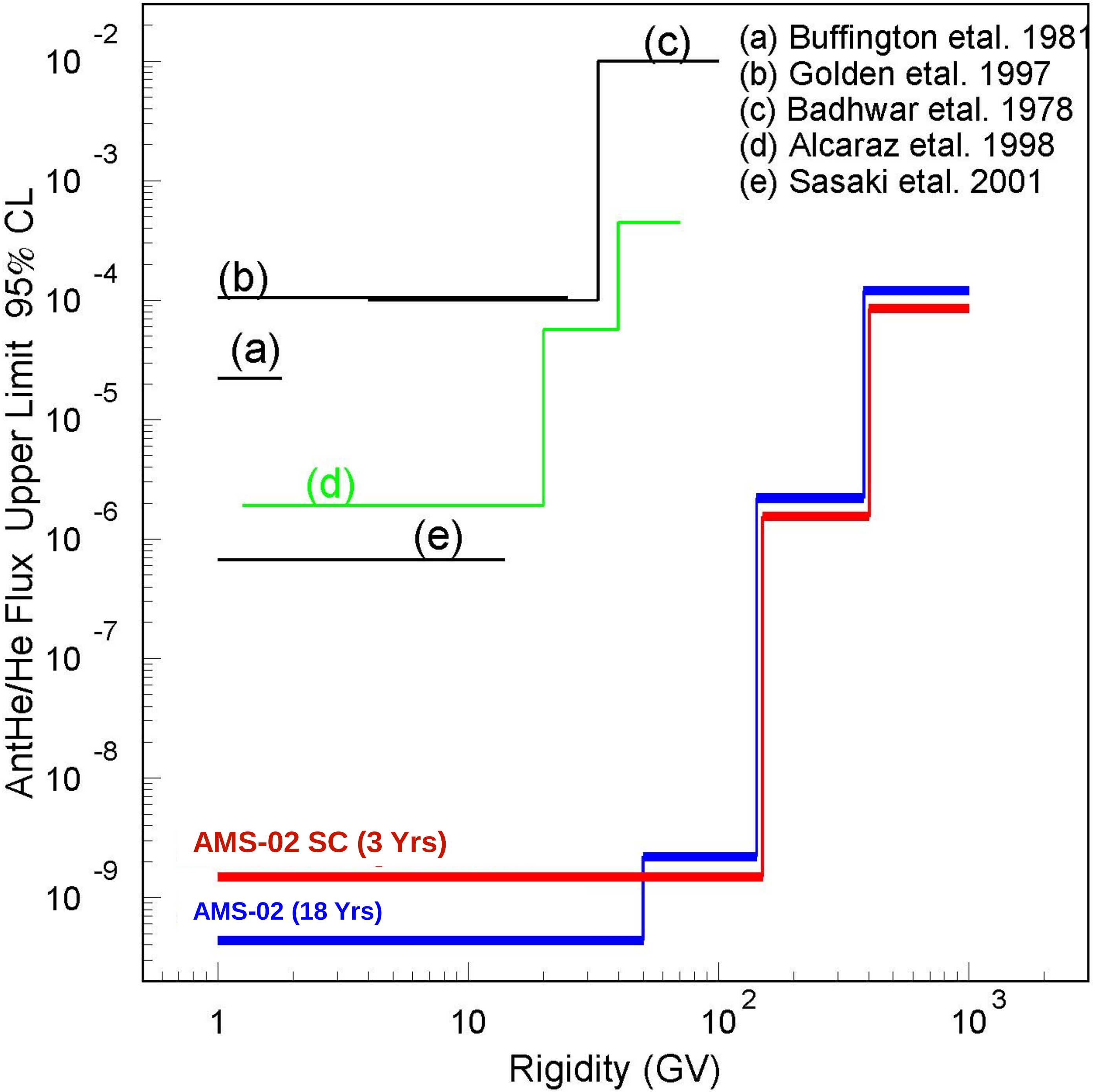
(τ_p > 6.6 * 10^{33} years)

AMS

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

Increase in energy to ~TeV

y06K299a



(a) Buffington etal. 1981
(b) Golden etal. 1997
(c) Badhwar etal. 1978
(d) Alcaraz etal. 1998
(e) Sasaki etal. 2001
(a)
(b)
(c)
(d)
(e)
AMS-02 SC (3 Yrs)
AMS-02 (18 Yrs)
AntHe/He Flux Upper Limit 95% CL
Rigidity (GV)

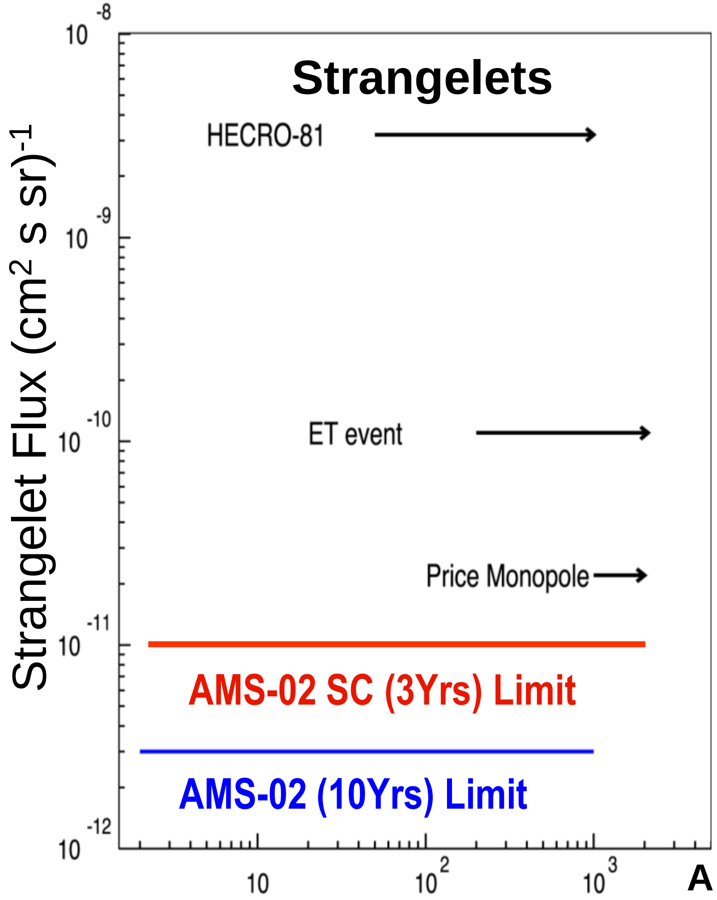
Strangelets

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

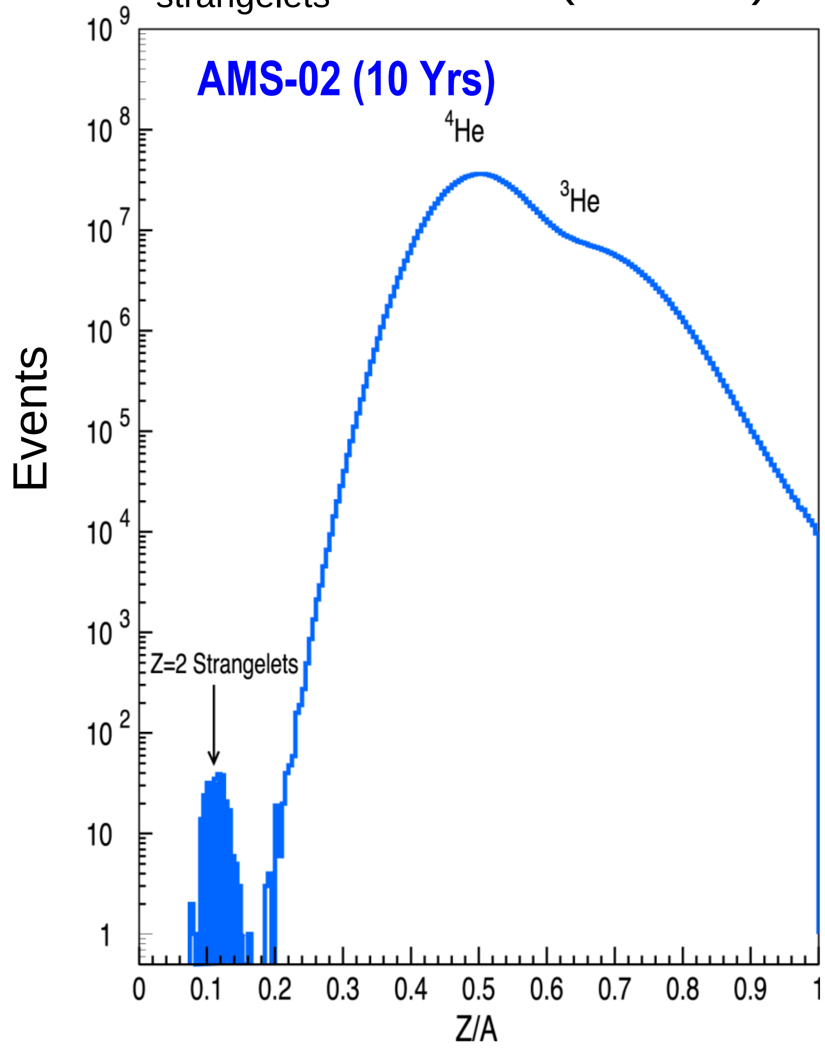
All the known material on Earth is made out of u and d quarks

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

Z/A~0.1



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



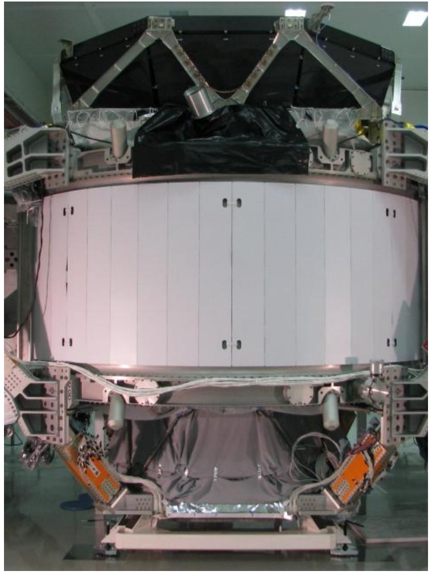
This can be answered definitively by AMS.

Discoveries in Physics

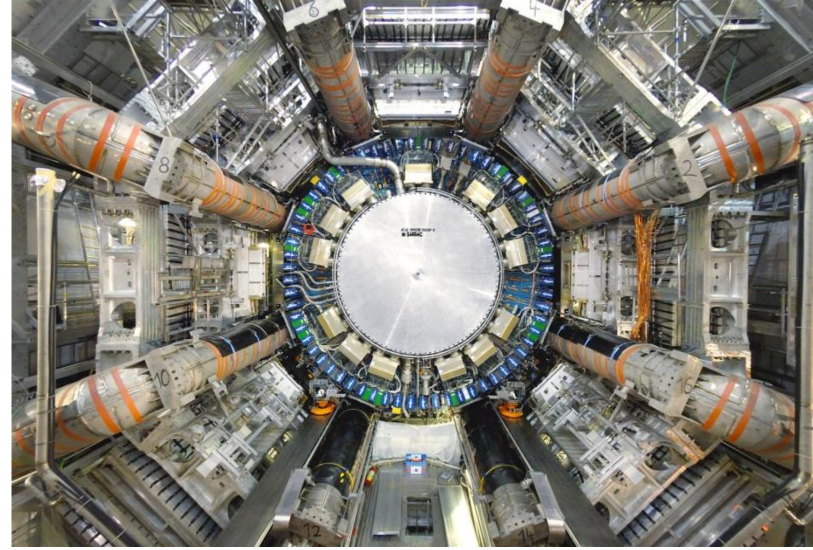
Facility	Original purpose, Expert Opinion	Discovery with Precision Instrument
P.S. CERN	π N interactions	Neutral Currents -> Z, W
Brookhaven	π N interactions	ν_e, ν_μ CP violation, J
FNAL	Neutrino physics	*b, t quarks*
SLAC Spear	ep, QED	Scaling, Ψ, τ
PETRA	t quark	*Gluon*
Super Kamiokande	Proton decay	Neutrino oscillations
Hubble Space Telescope	Galactic survey	*Curvature of the universe, dark energy*
AMS on ISS	Dark Matter, Antimatter Strangelets,…	***?***

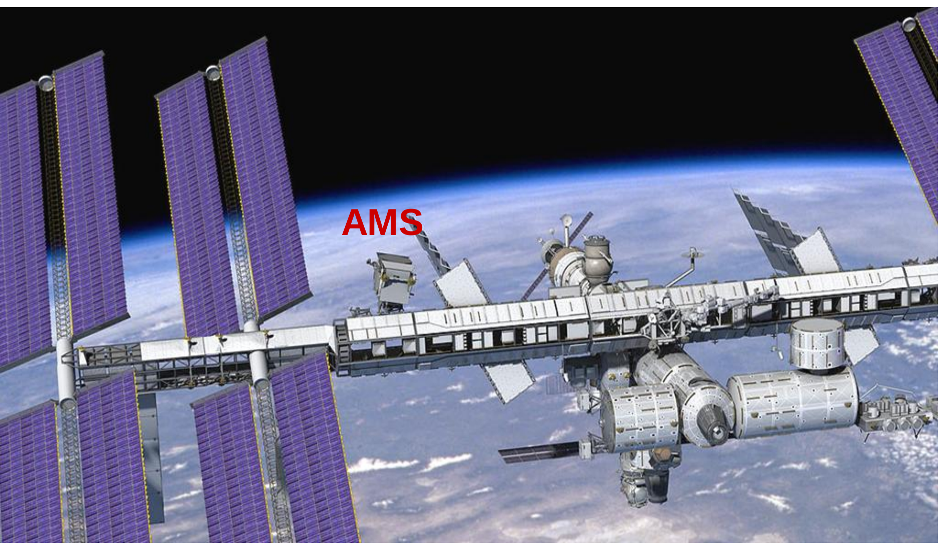
Exploring a new territory with a precision instrument is the key to discovery.

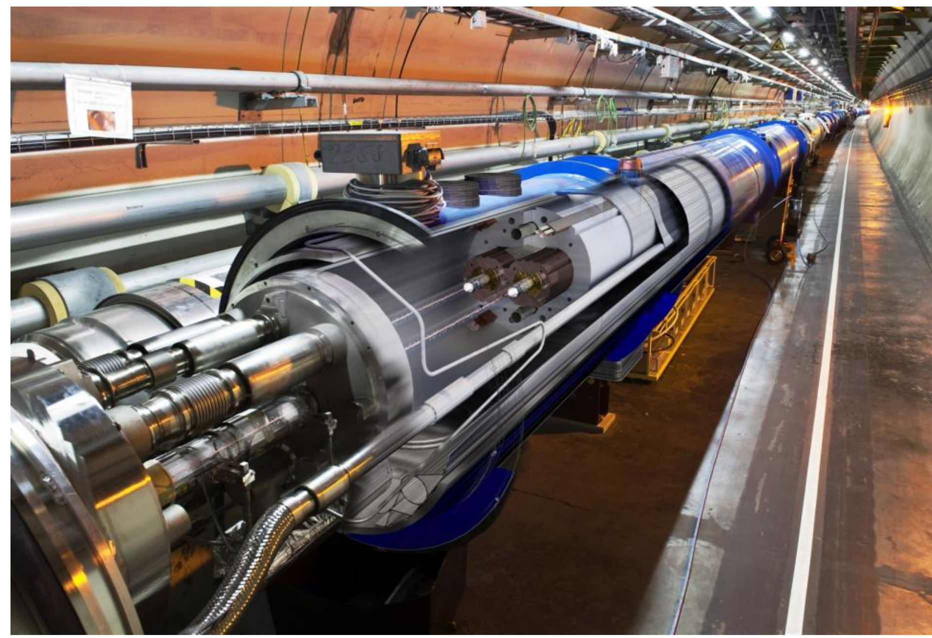
AMS



ATLAS, CMS,
ALICE & LHCb







ISS cost = ~10 LHC.
LHC has 4 big experiments.
ISS only has AMS.