Alpha Magnetic Spectrometer
AMS-02 の現状報告

灰野禎一
台湾國立中央大學

2013年4月5日

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國立中央大學
National Central University

AMS collaboration

= 16 Countries, 60 Institutes and 600 Physicists
from Asia, Europa, and USA

Taiwan in AMS

Coordinator:
Prof. S.C. Lee
中央研究院
李世昌院士

AMS is the only project supported by Academia Sinica, National Science Council as well as the defense and the space agencies, all with the highest priority

中央大學 (NCU)

交通大學 (NCTU)

漢翔公司 (AIDC)

成功大學 (NCKU)

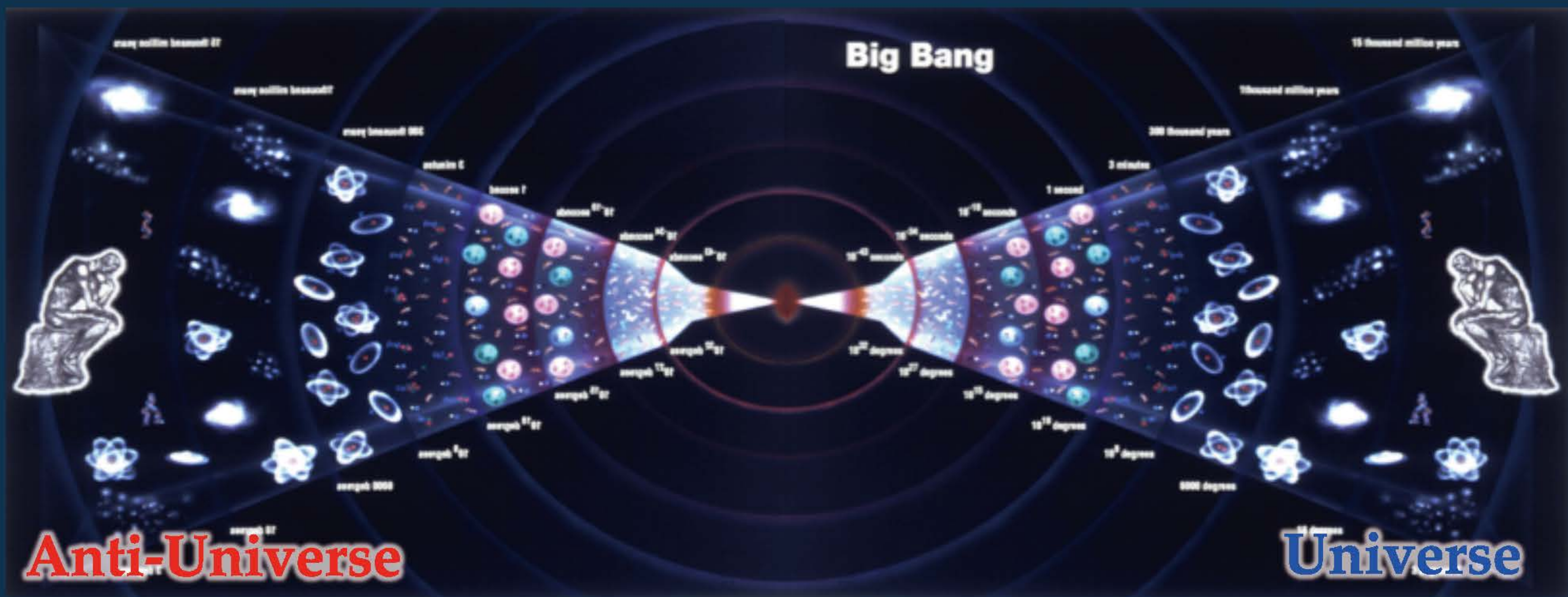
中央研究院 (Academia Sinica)

中山科學研究院 (CSIST)

國家太空中心 (NSPO)

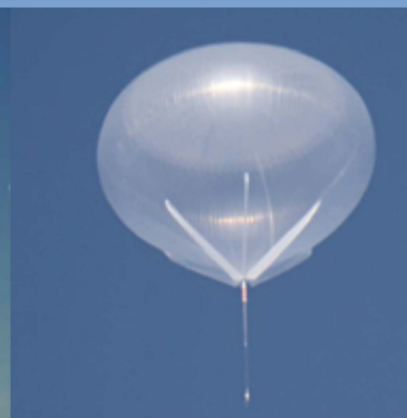
AMS is Anti-Matter Spectrometer

- Apparent asymmetry of matter and antimatter is one of the fundamental problems in cosmology
- Detection of anti-nuclei in Cosmic Rays will be a strong evidence of primordial Anti Matter



Pioneering works by balloons

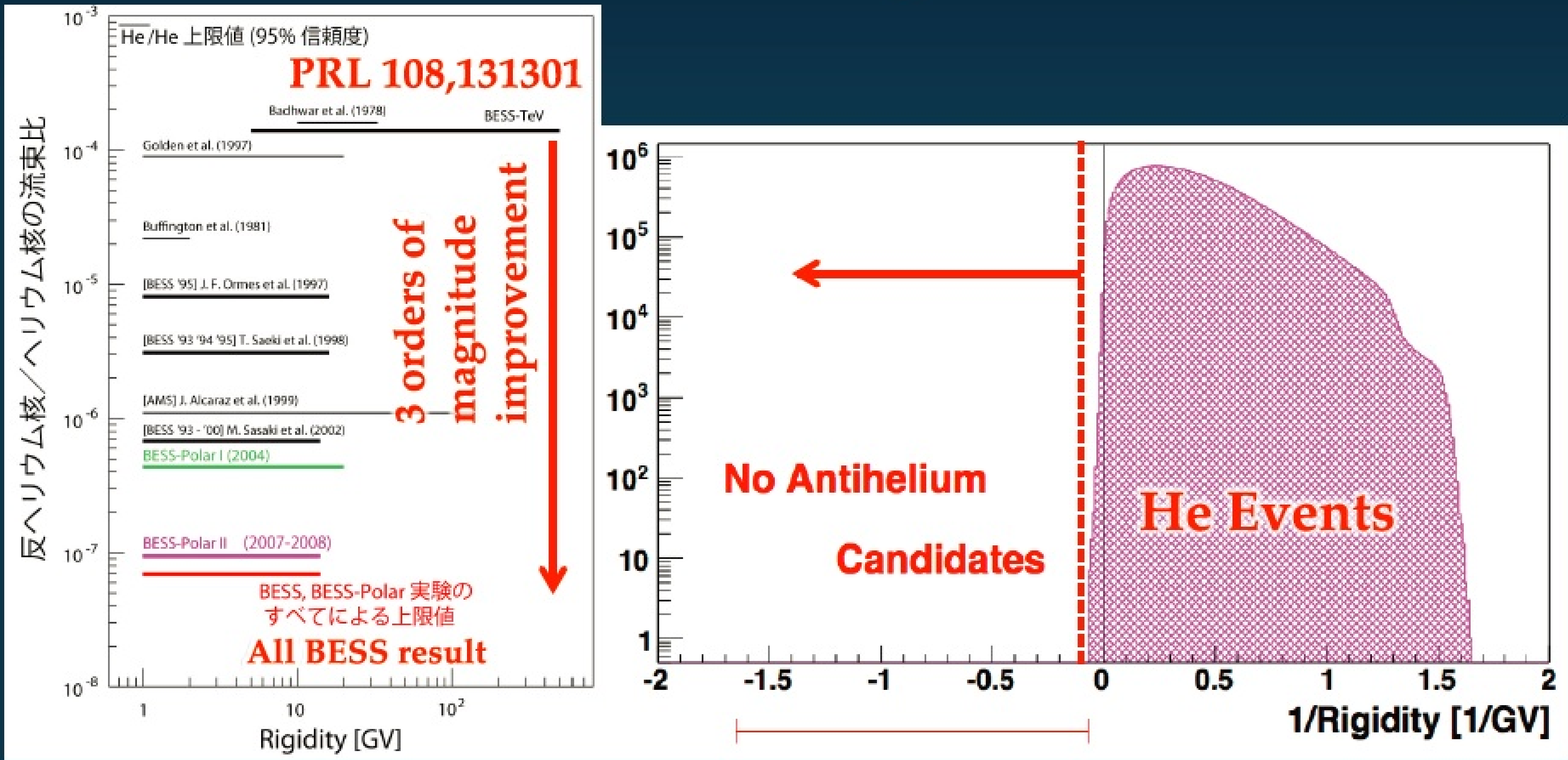
- BESS, Balloon-borne Experiment
  with a Superconducting Spectrometer
  (Japan- US collaboration)



Most stringent limit by BESS so far

- $\overline{He}/He < 6.9 \times 10^{-8}$, ~$10^3$ better than before BESS
- AMS : ~10^2 further sensitivity (down to 10^{-10} level)

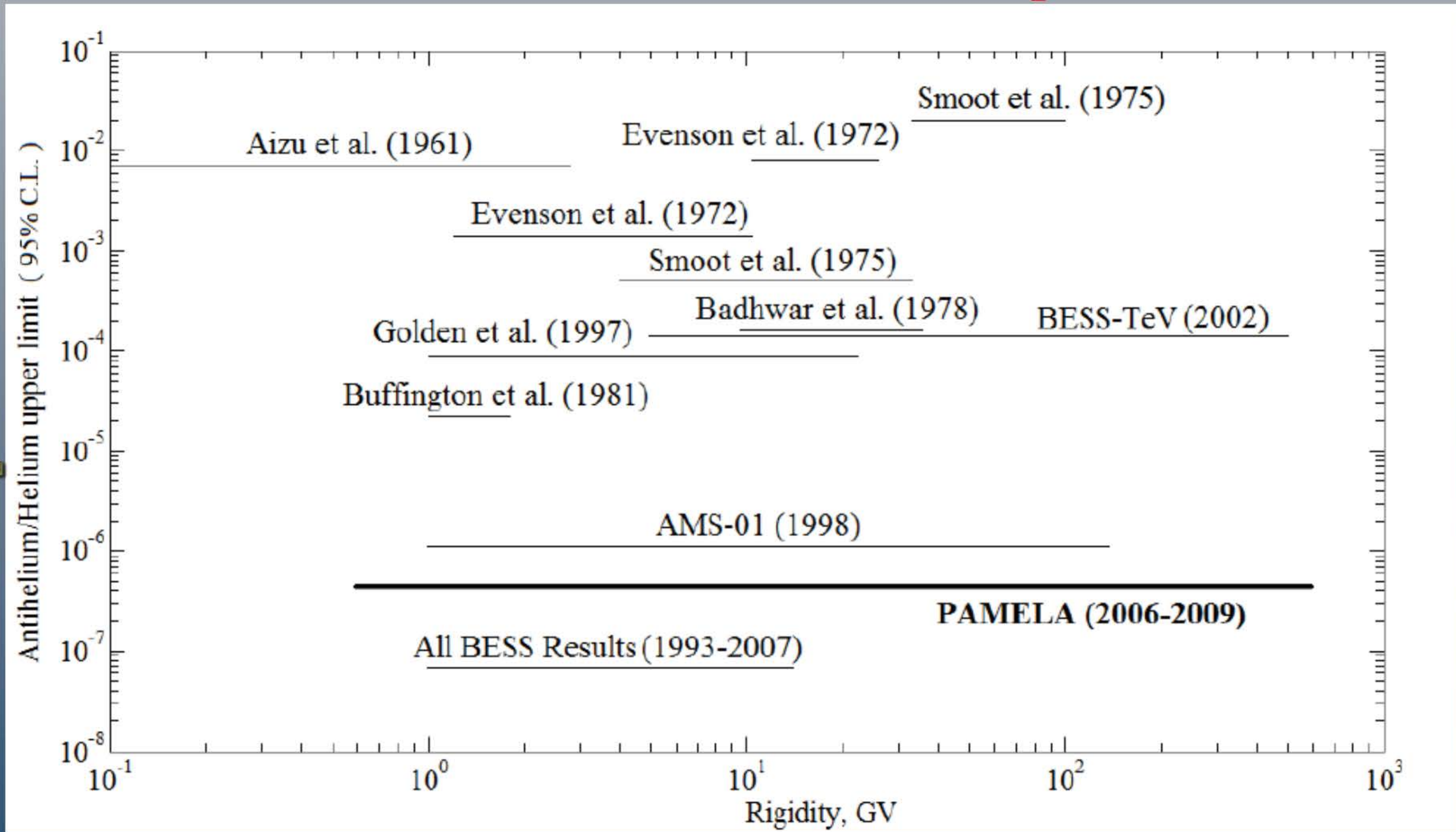
Anti-He/He flux ratio



a Payload for Antimatter Matter Exploration and Light-nuclei Astrophysics

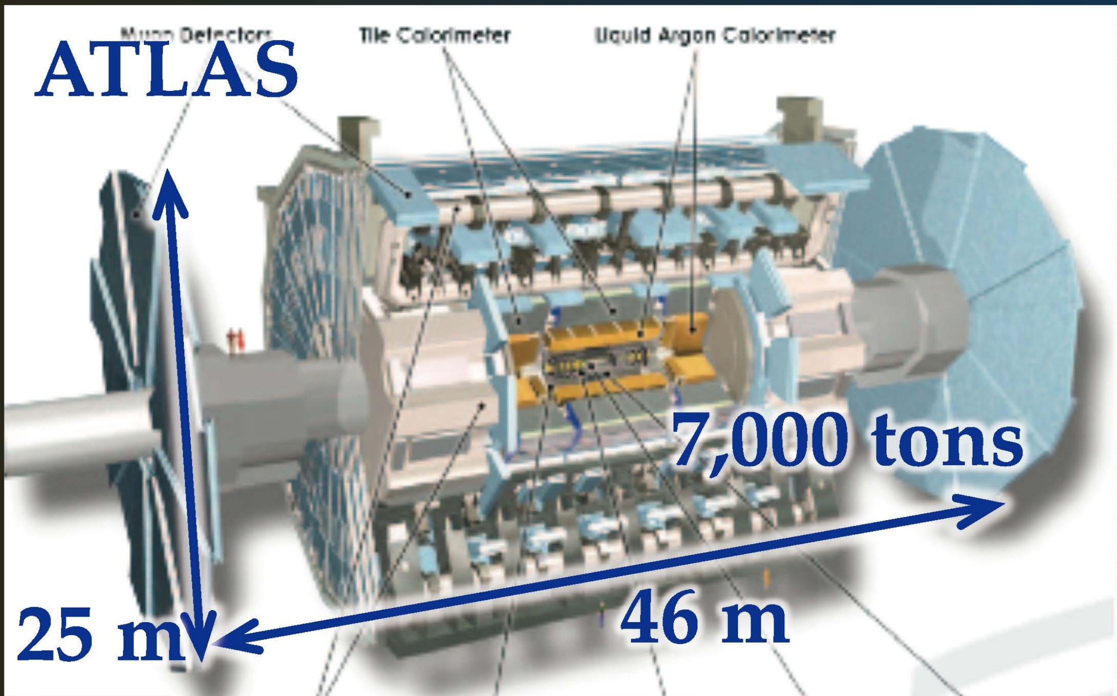
• $\overline{He}/He$ upper limit in wide energy range

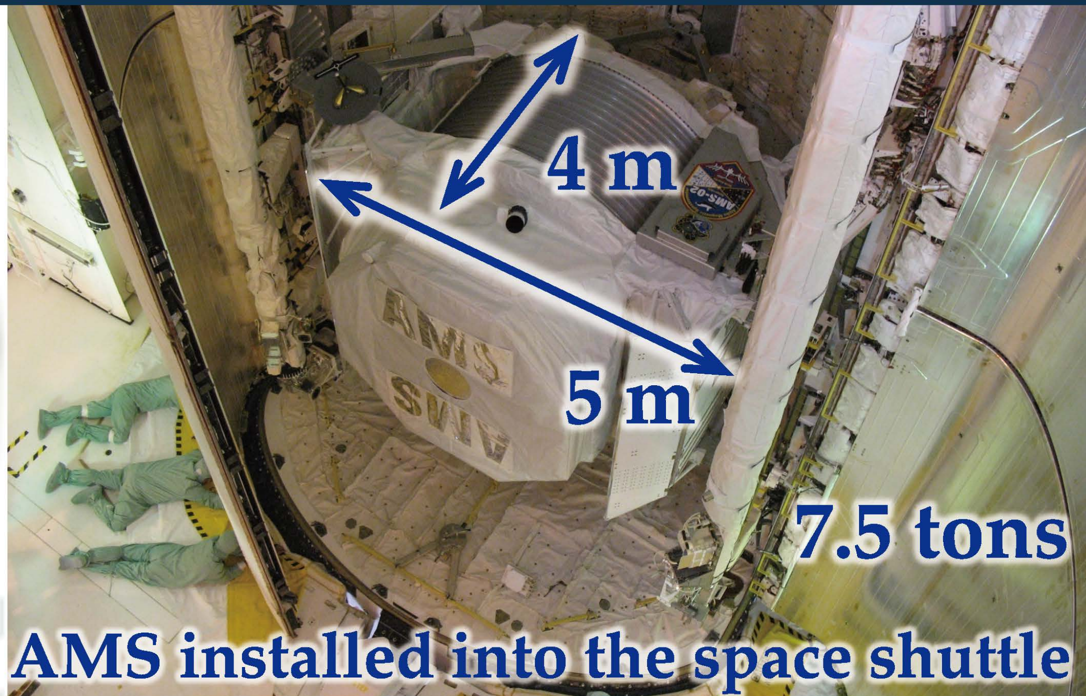
P. Picozza SpacePart 2012



Technical challenge

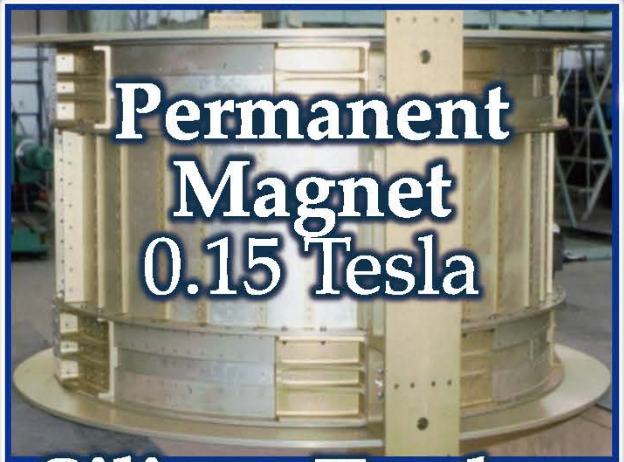
- AMS is designed with the same capability as state-of-art CERN-LHC detectors
- AMS needs to work for 20 years in extreme space enviroment without access nor repair

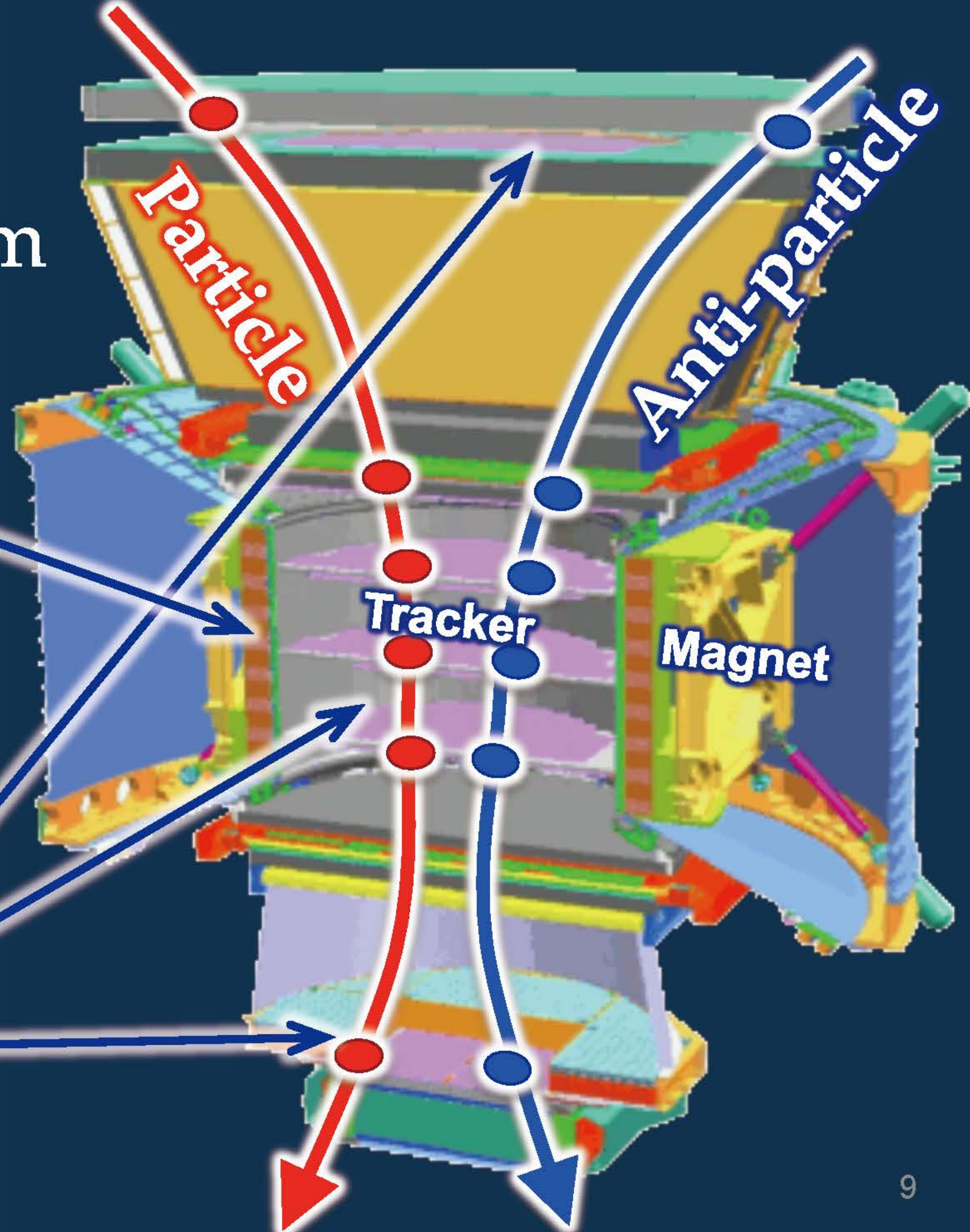




Magnet and Tracker

- Determine charge sign and measure momentum

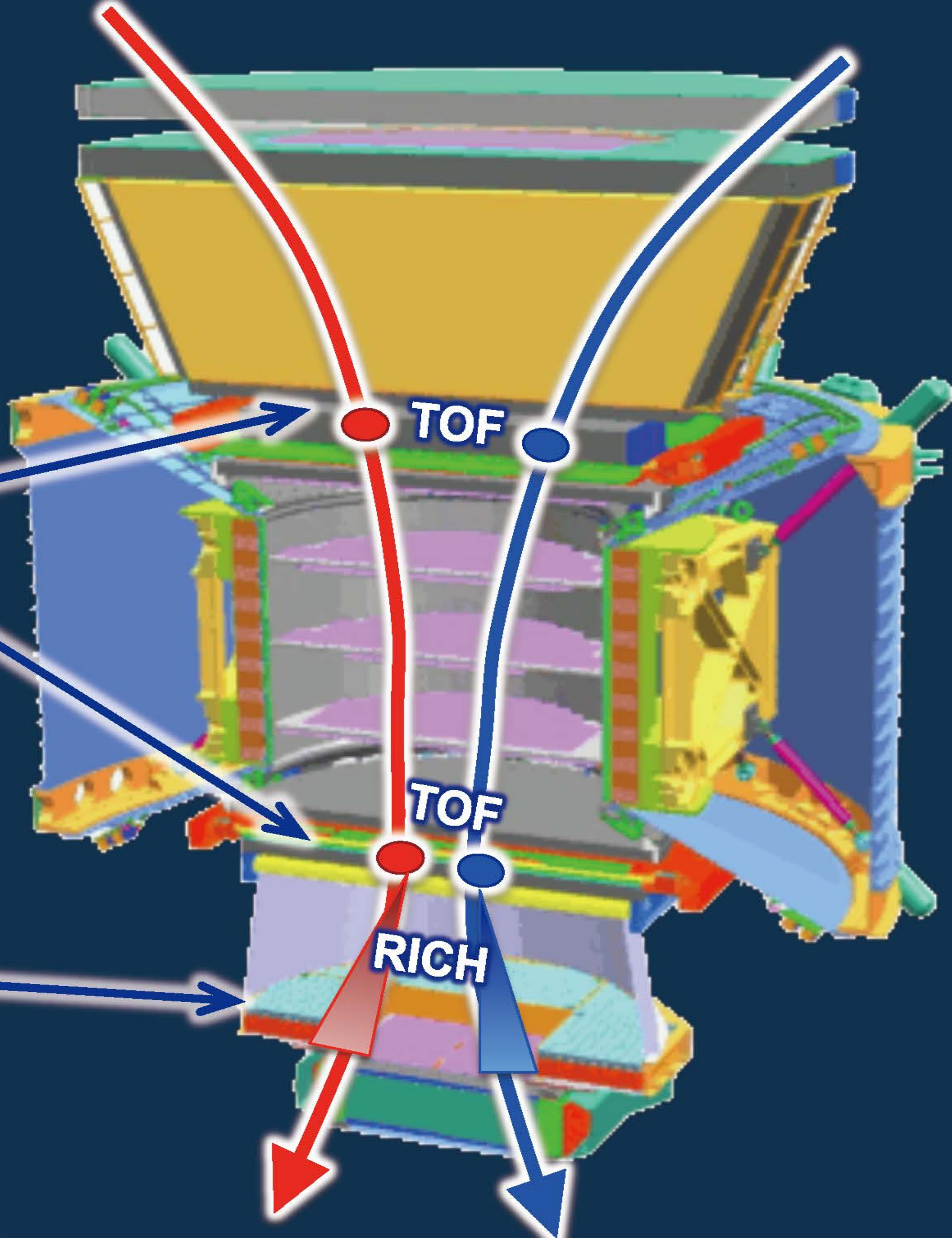




TOF and RICH

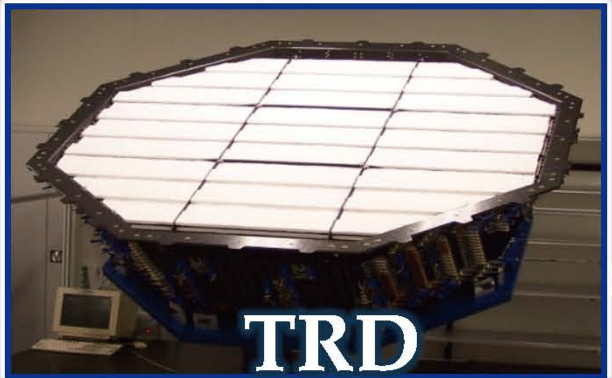
- Determine direction and mesure velocity

Time Of Flight



TRD and Ecal

- Distinguish e+ / e- from proton backgrounds

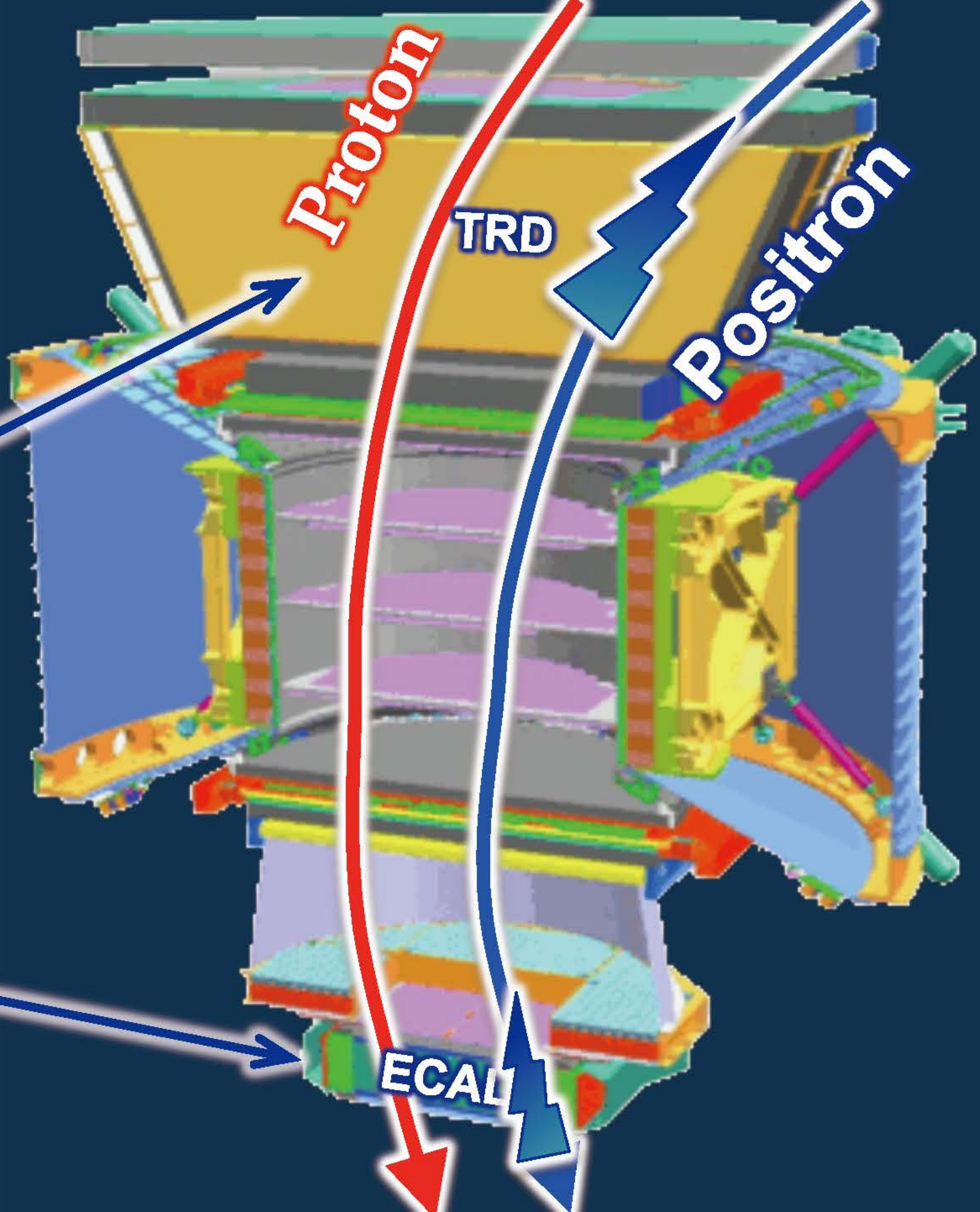


TRD

p Rejection > 10^2

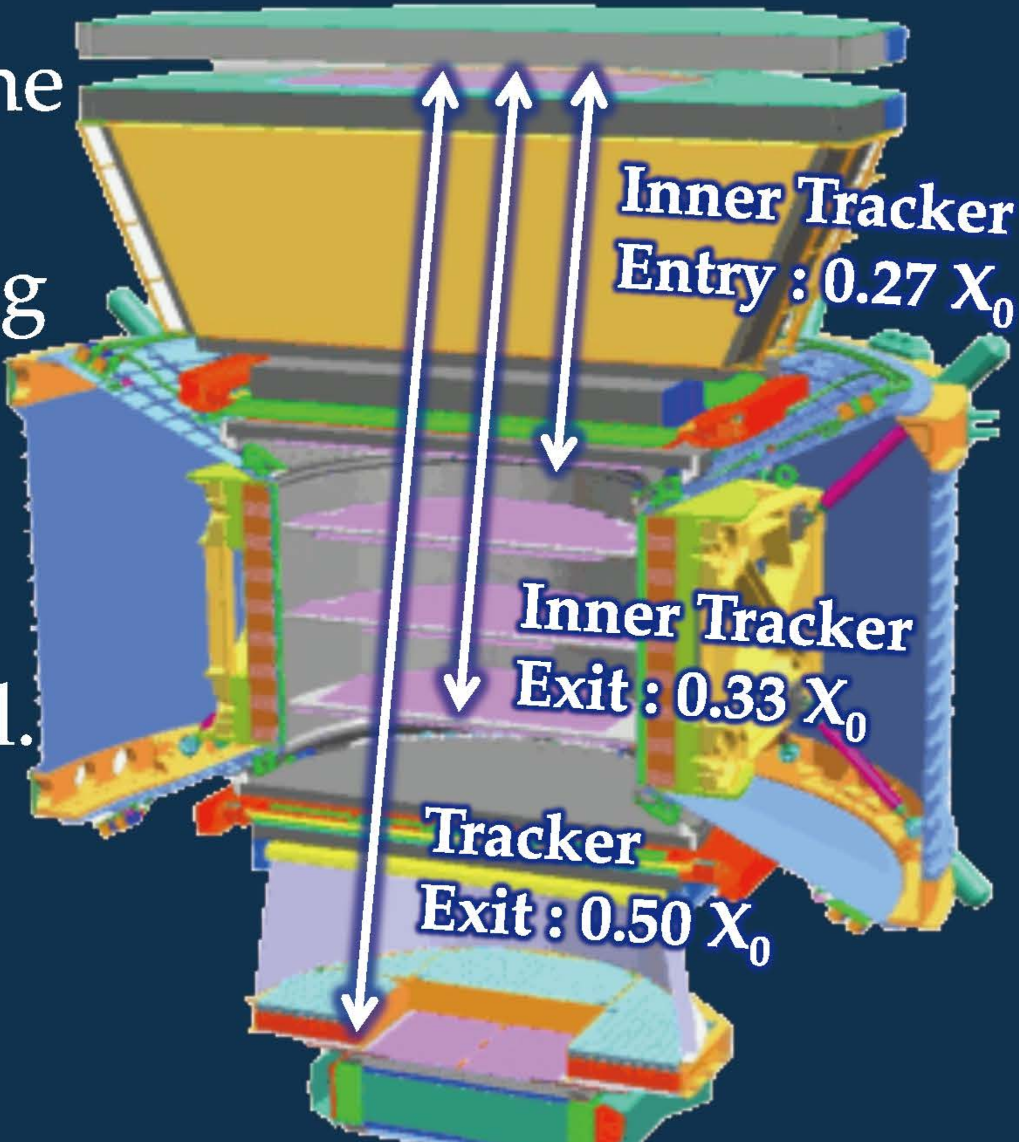
ECAL ($17\ X_0$)

p Rejection > 10^4



Minimal material and Repetitive measurements

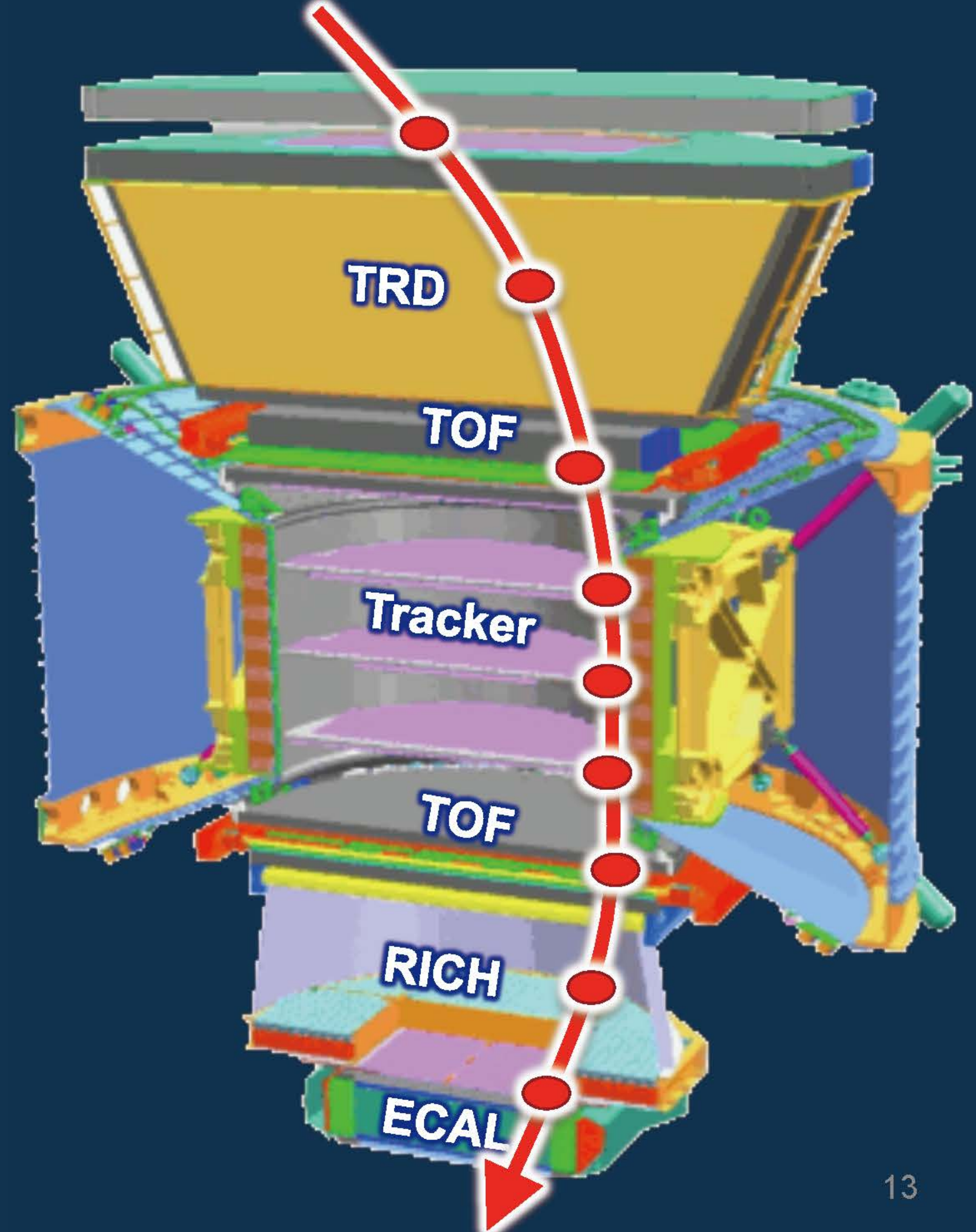
- Detector does not become a source of background nor large angle scattering
- To ensure that particles with large angle scattering are not confused with the signal.
- Matching of Tracker momentum and Ecal energy measurements



Multiple charge measurements

Charge resolution ΔZ (au) for Carbon (Z=6)

- Tracker plane 1 : 0.30
- TRD : 0.33
- Upper TOF : 0.17
- Inner plane 2-8 : 0.15
- Lower TOF : 0.20
- RICH : 0.32
- Tracker plane 9 : 0.30



Brief history of AMS

1994 Idea of antimatter spectrometer in space

1998 Test flight AMS-01

Construction and qualification of detectors

2009 Integration of AMS at CERN

2010 Space qualification tests at ESA/ESTEC

Beam test at CERN

2011 Launch of Space Shuttle Endeavor

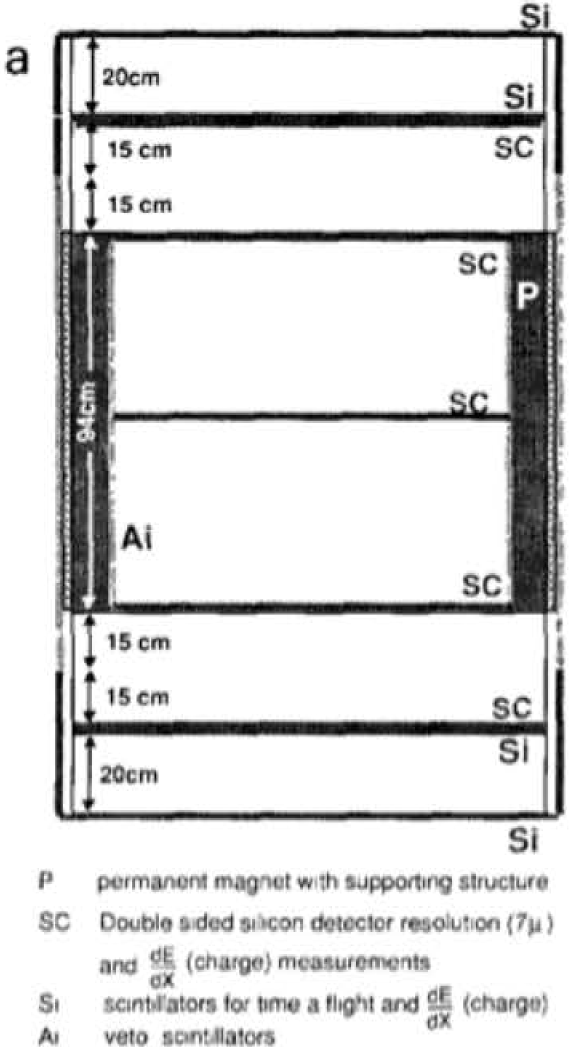
Installation on the International Space Station

Nuclear Instruments and Methods in Physics Research A 350 (1994) 351–367
North-Holland

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH
Section A

An antimatter spectrometer in space

Antimatter Study Group



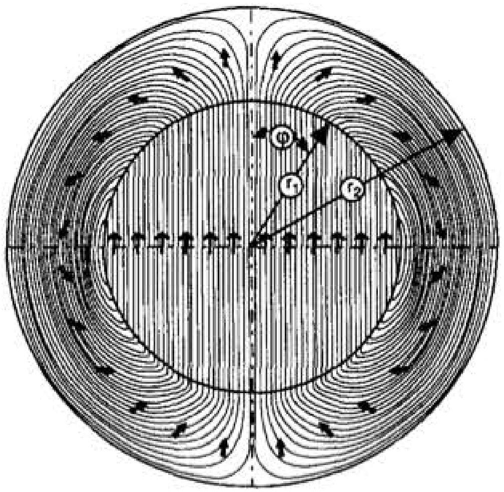


Fig. 6. Magnetic field distribution at a cross-section of the center of the magnet.

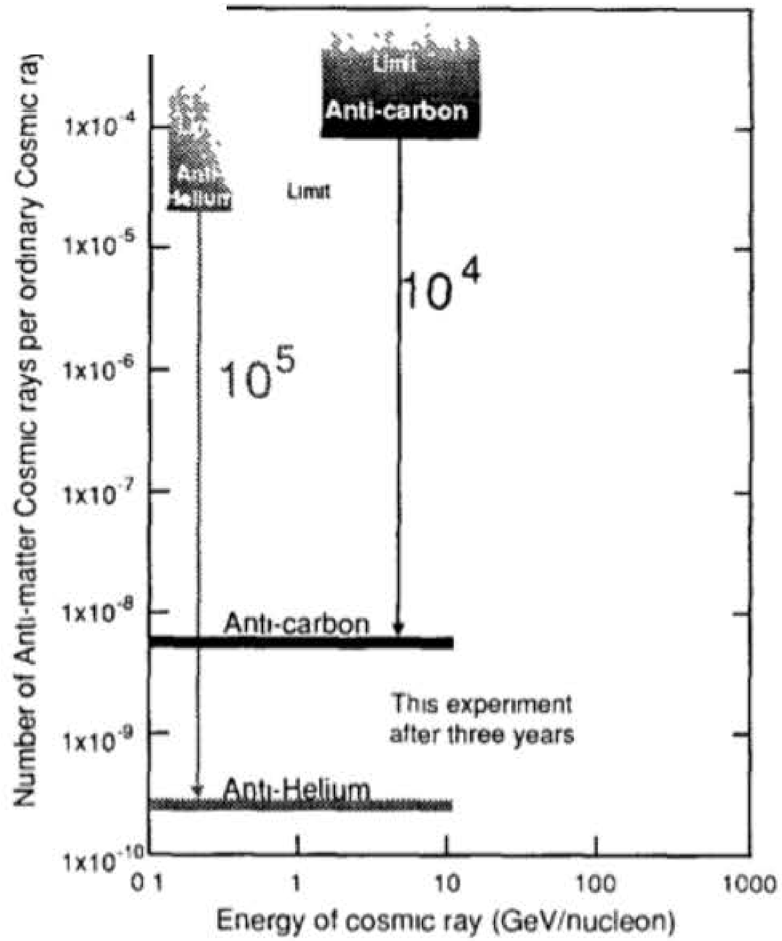
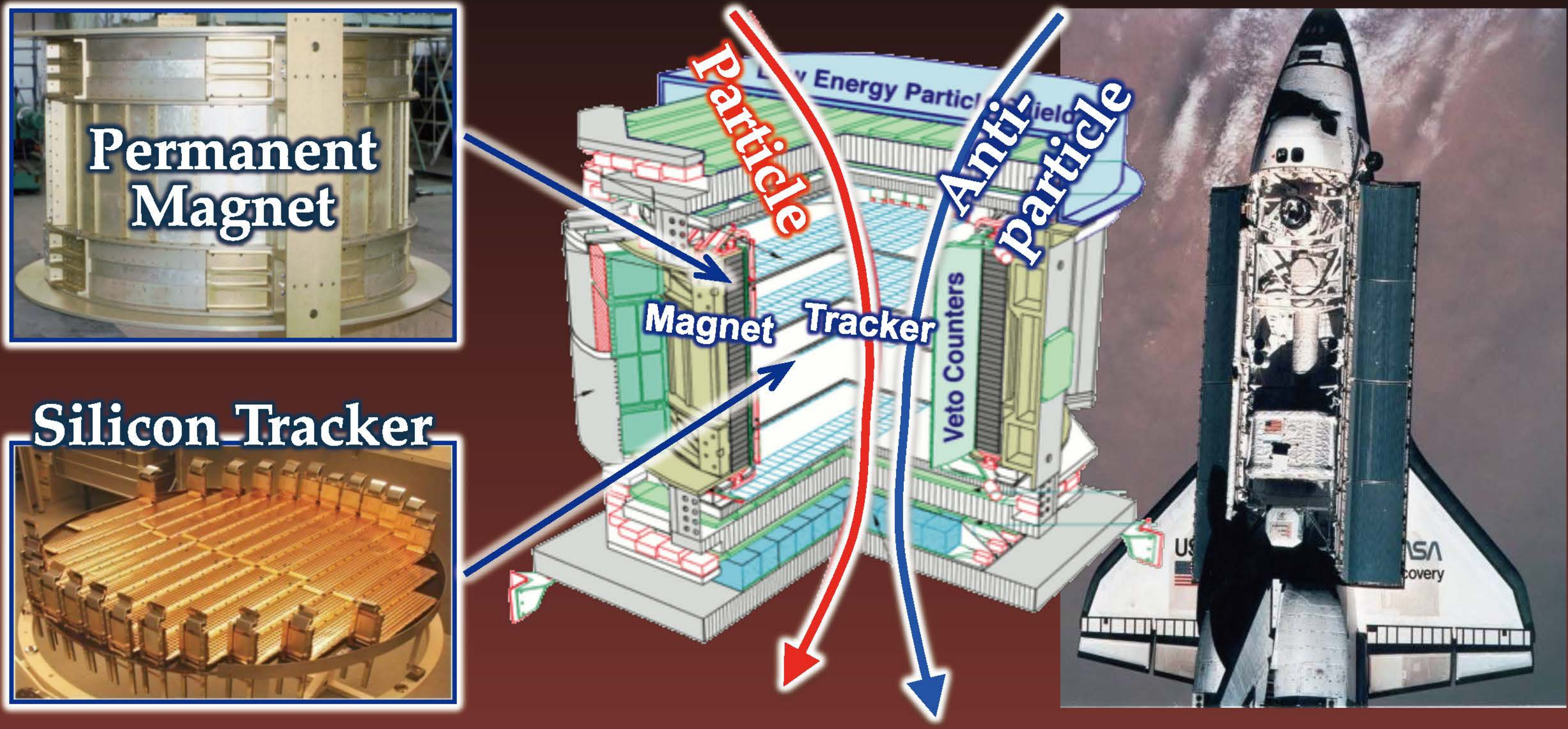


Fig. 30. Current limits and sensitivity of this experiment for antimatter. In addition to the search for antimatter, our detector could be easily modified (particularly for options 2 and 4) to explore the search of $\overline{p}$ and e^+.

AMS-01

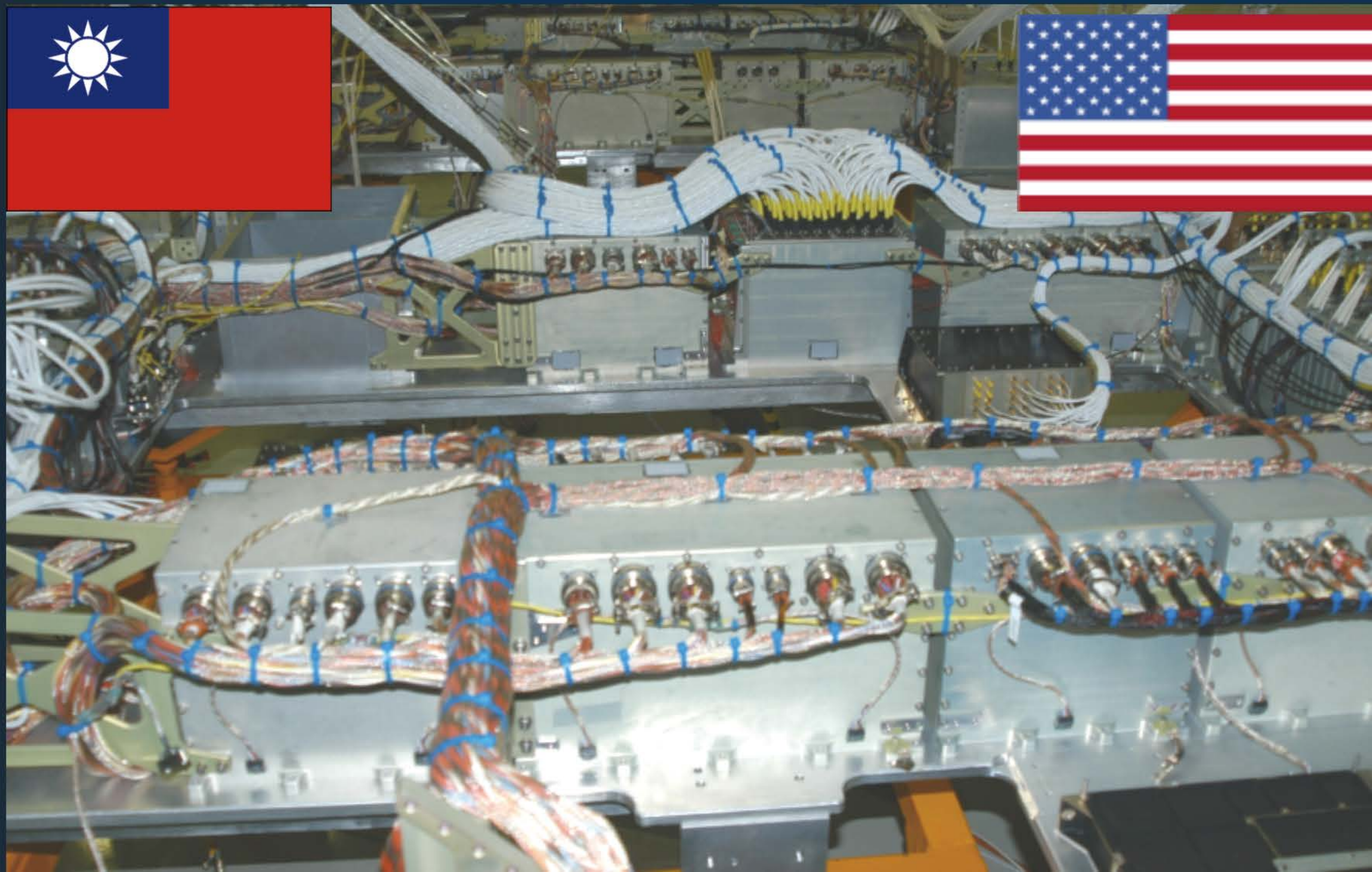
- Test flight in 1998 on space shuttle Discovery with the same magnet



Construction of electronics

2000~2008

- 650 microchips and 300,000 electric channels
- Led by Taiwan and USA (MIT)

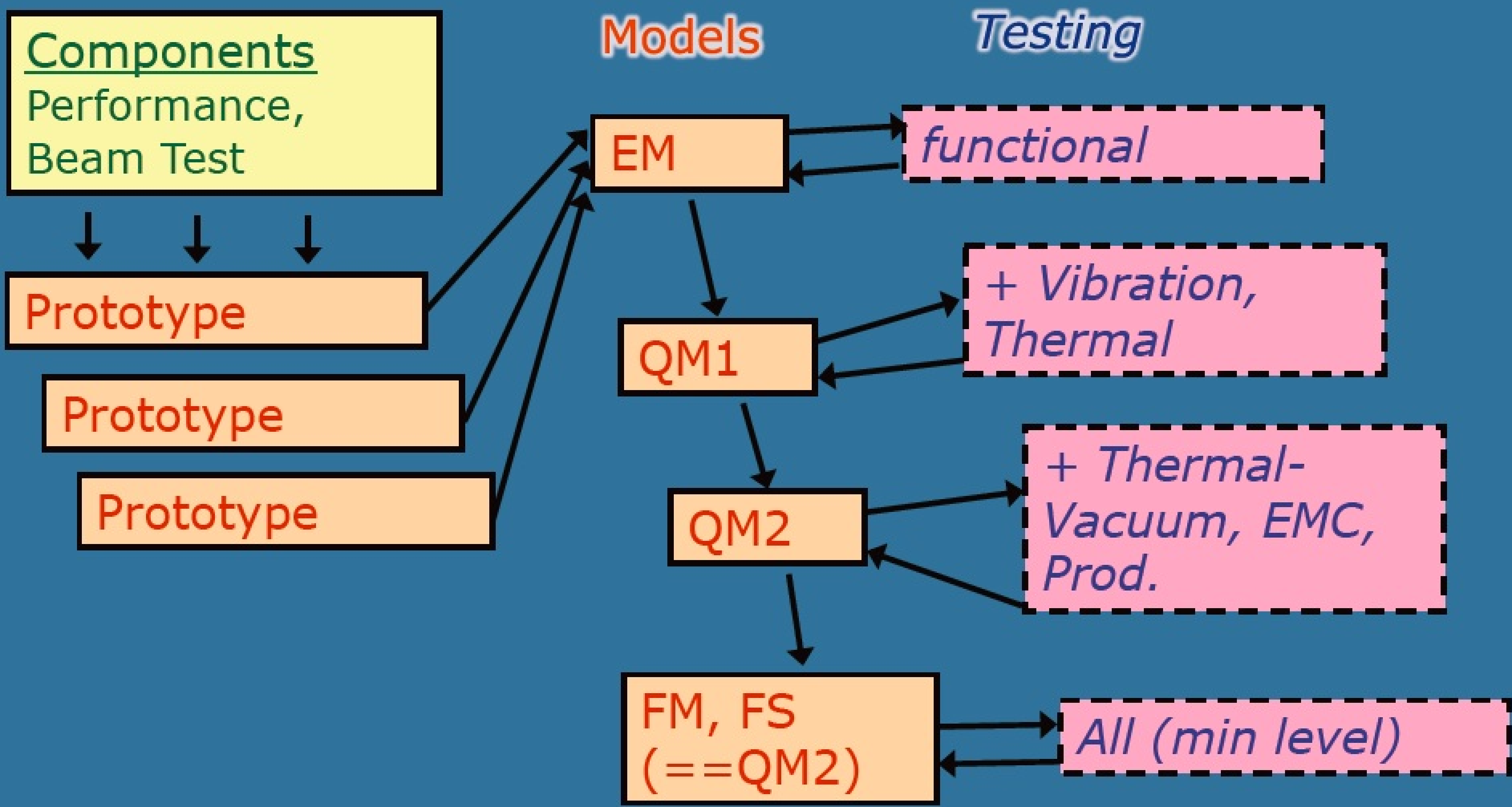


Qualification tests of subsystems

~2008

- Led by Italy (INFN Perugia)

Models of subsystems



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Beam test at CERN

2011 Launch of Space Shuttle Endeavor

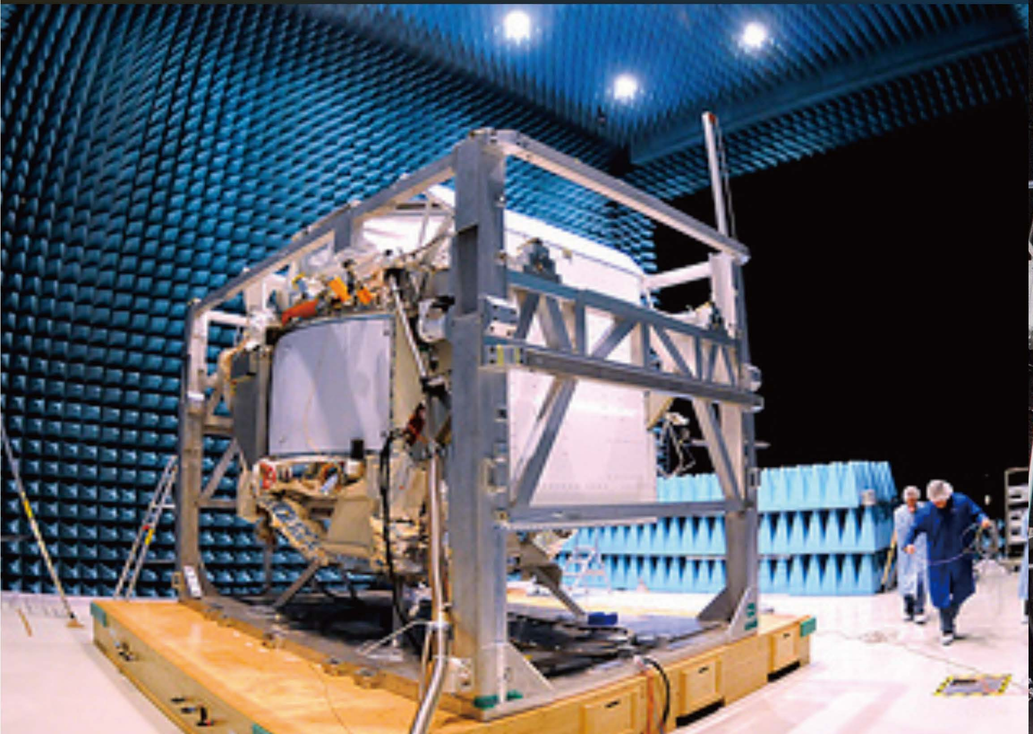
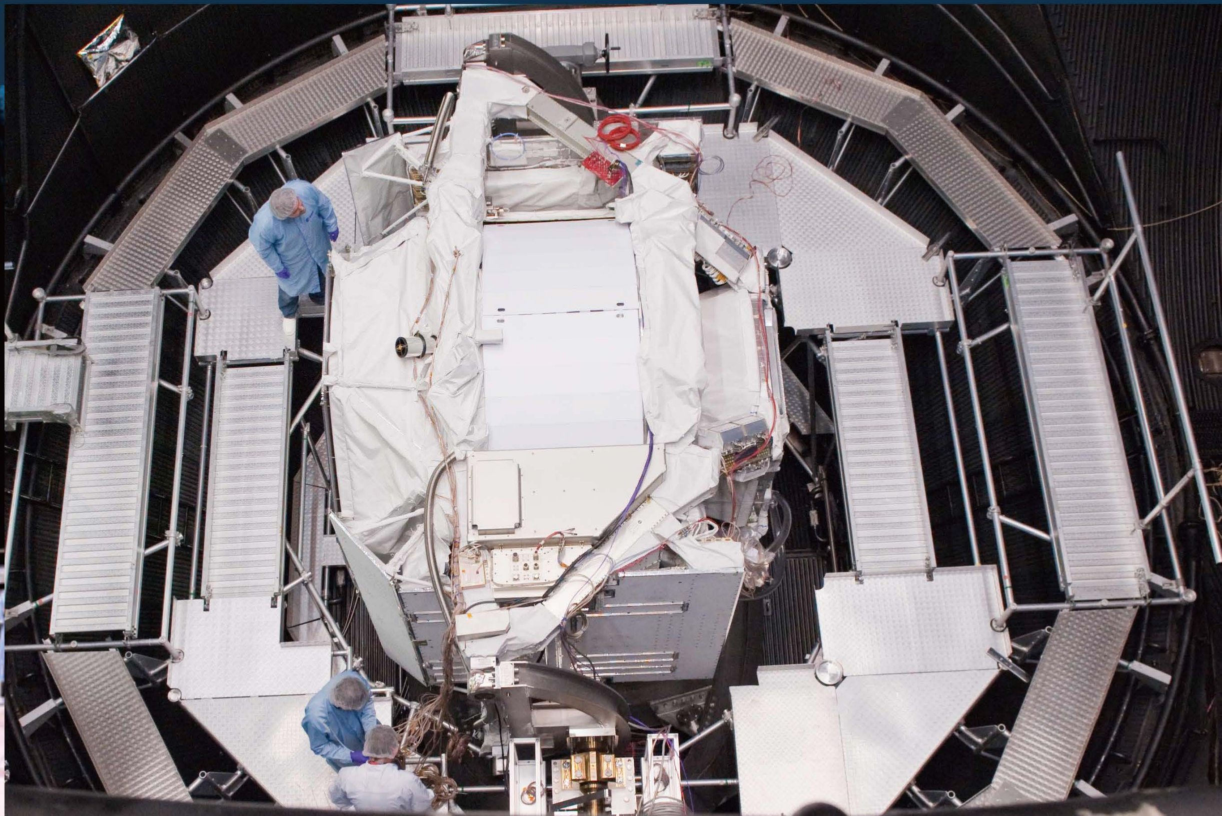
Installation on the International Space Station

Space qualification at ESA

Mar~Apr/2010

- EMI (Electro Magnetic Interference) test
- Thermal Vacuum test

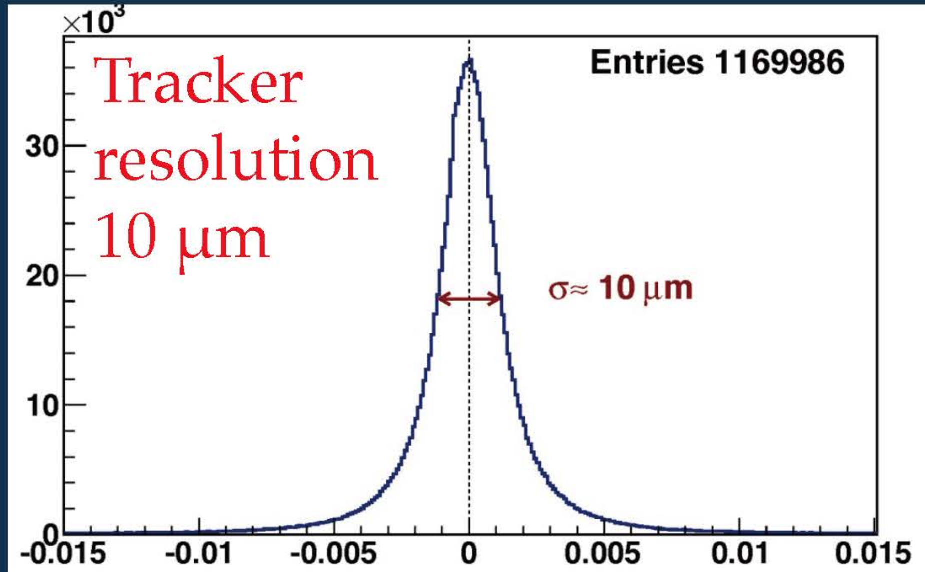
  Pressure < 10^{-9} bar, Temperature -40 ~ +90 °C

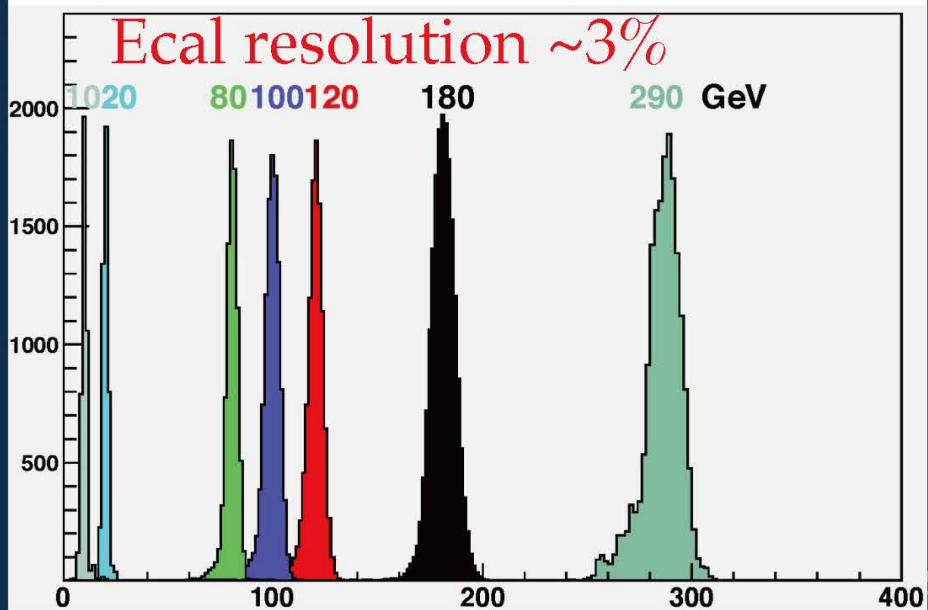



Particle beam Tests at CERN

Aug. / 2010

- Proton 400 GeV / c
- e+, e- 80 ~ 290 GeV





Shipping to U.S.

Aug./2010

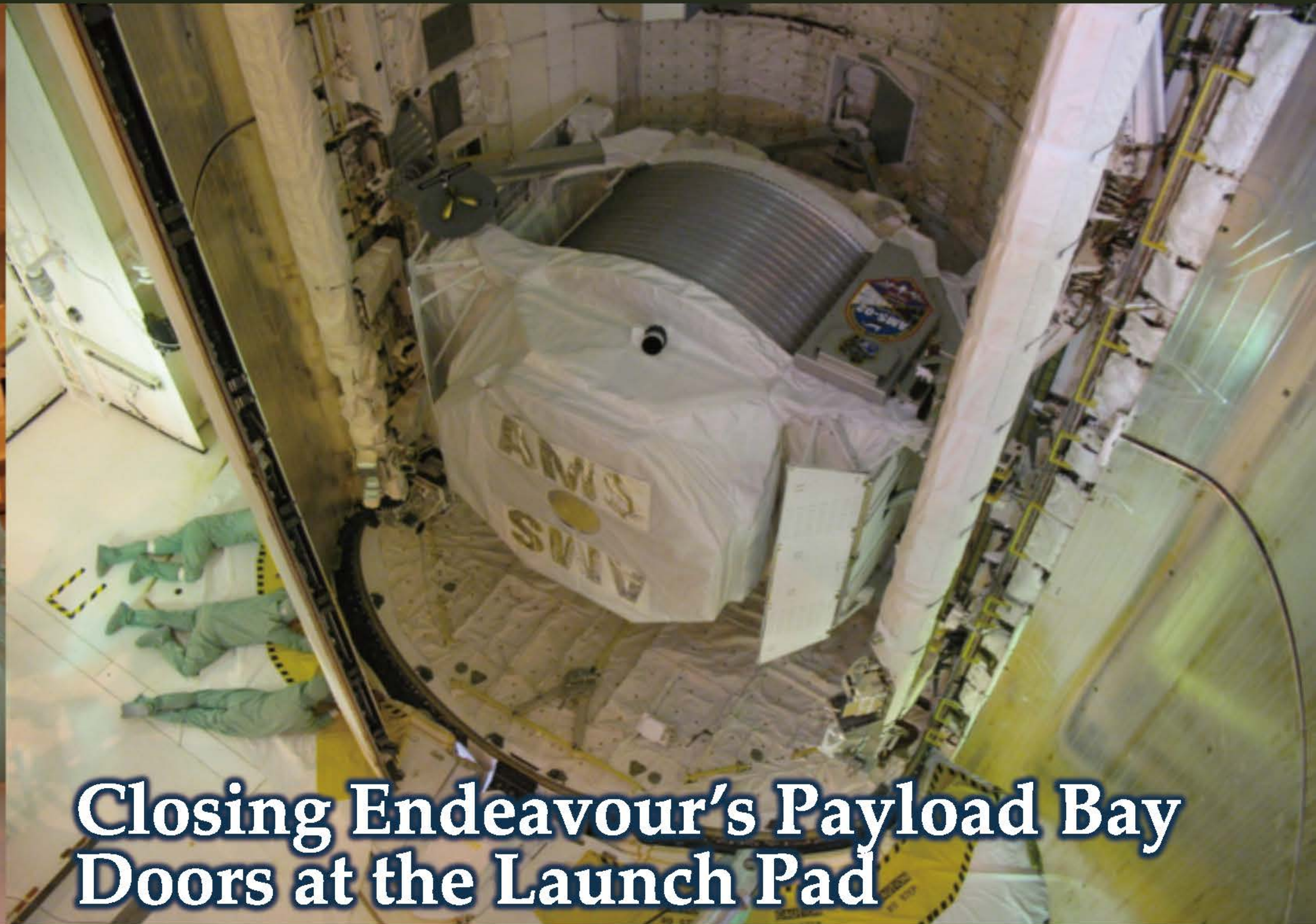
US Air Force C5

Loading AMS Geneva

AMS installed in Space Shuttle

2010~2011

Final inspection
by S. Ting



Closing Endeavour's Payload Bay
Doors at the Launch Pad

STS-134 Launch (Last flight of Endeavor)

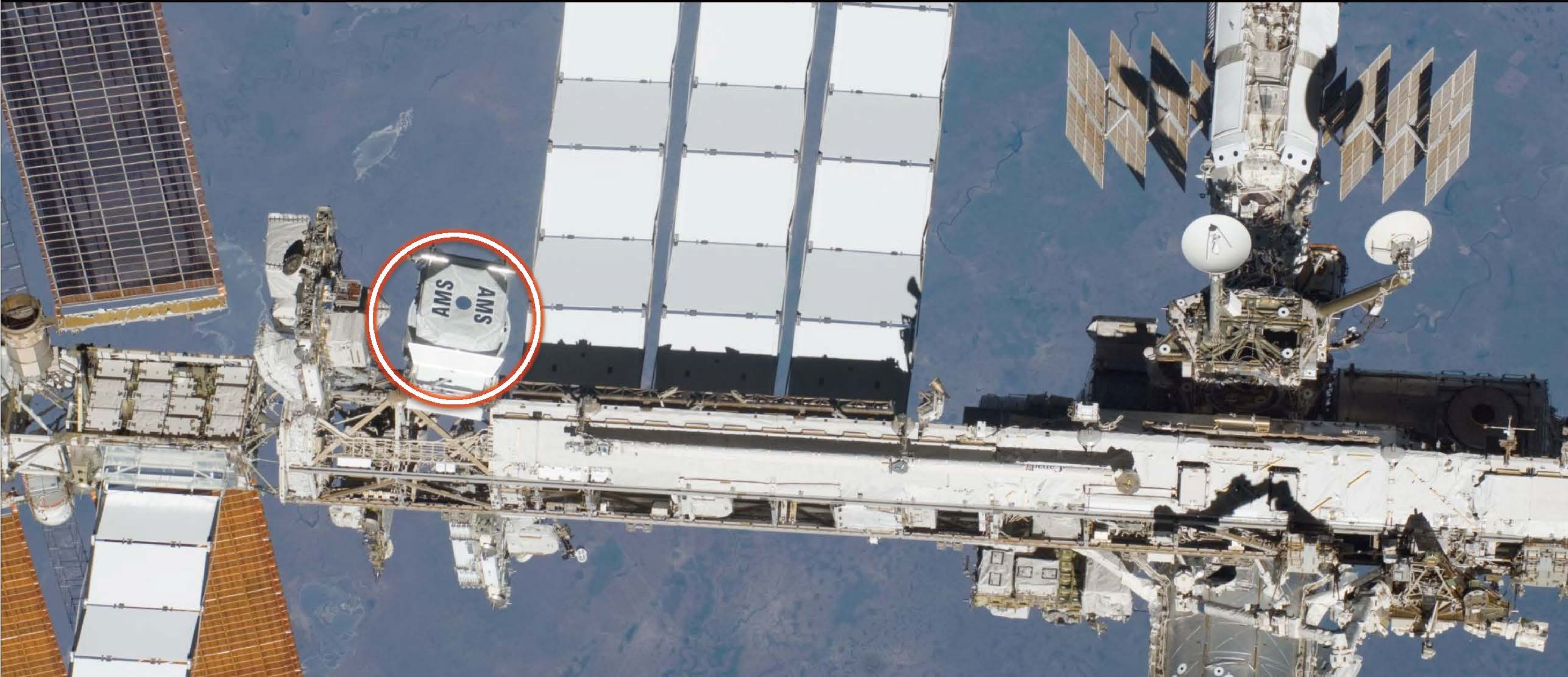
May 16, 2011 8:56 EDT

AMS : 7.5 t
Space Shuttle : 110 t
External tak : 756 t
Solid rocket boosters : 1,142 t

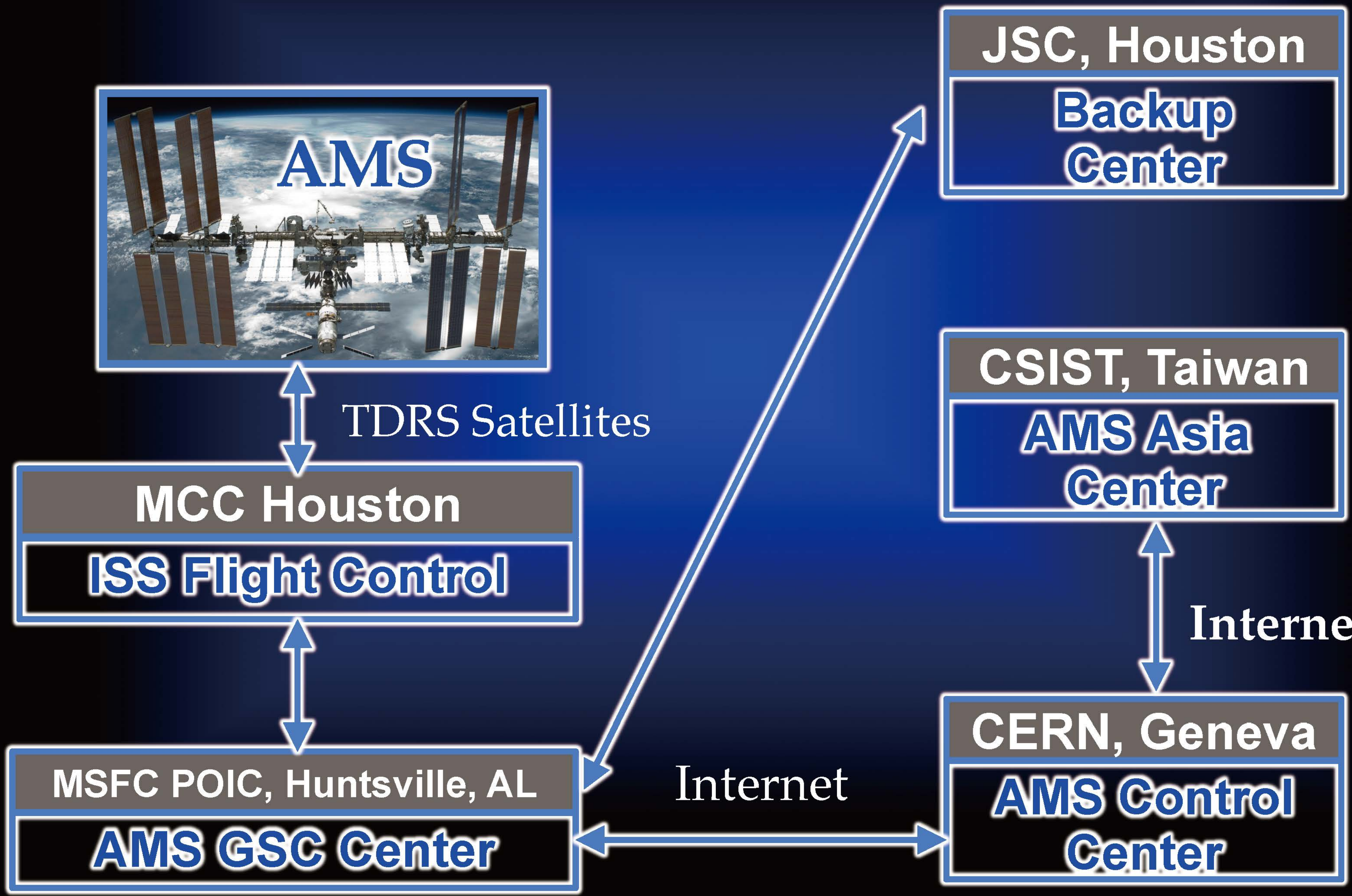
Total weight : 2,008 t

AMS installed on the ISS

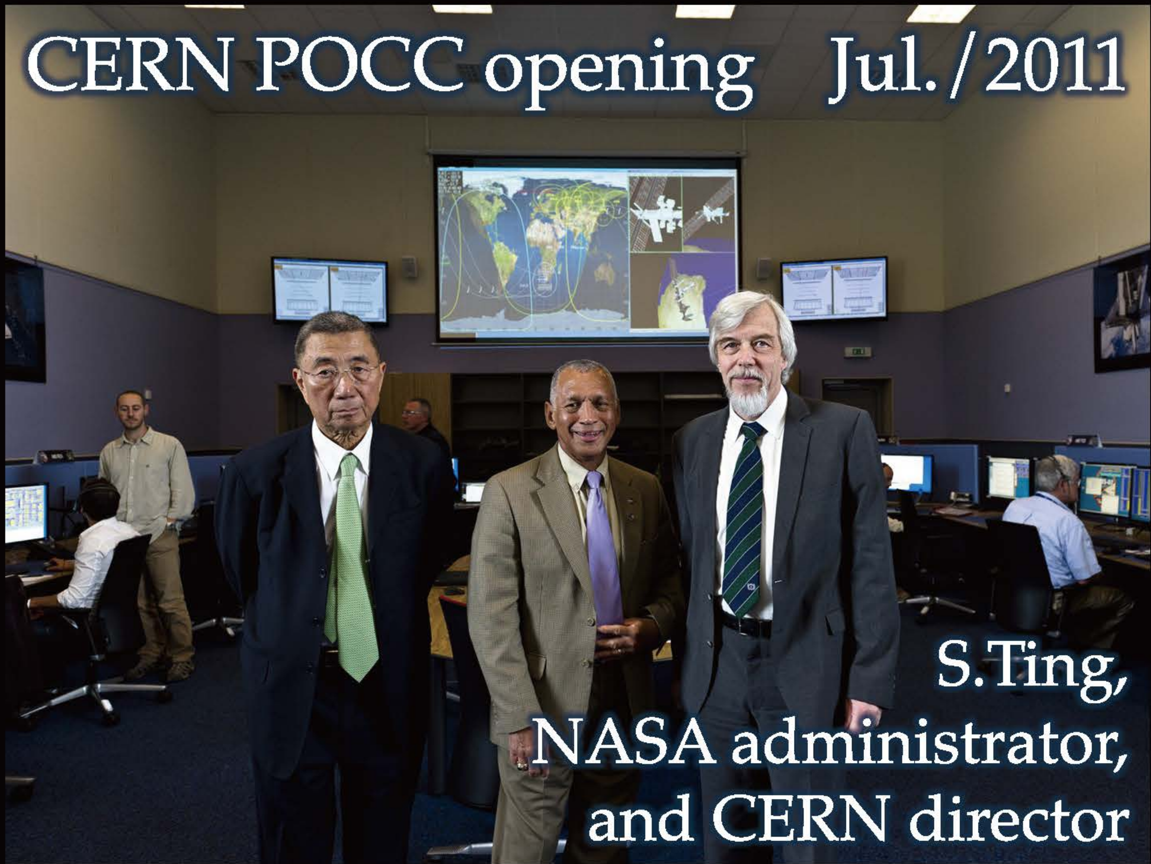
- May 19, 2011 5:15 CDT
- Start taking data 9:35 CDT



AMS Control Centers

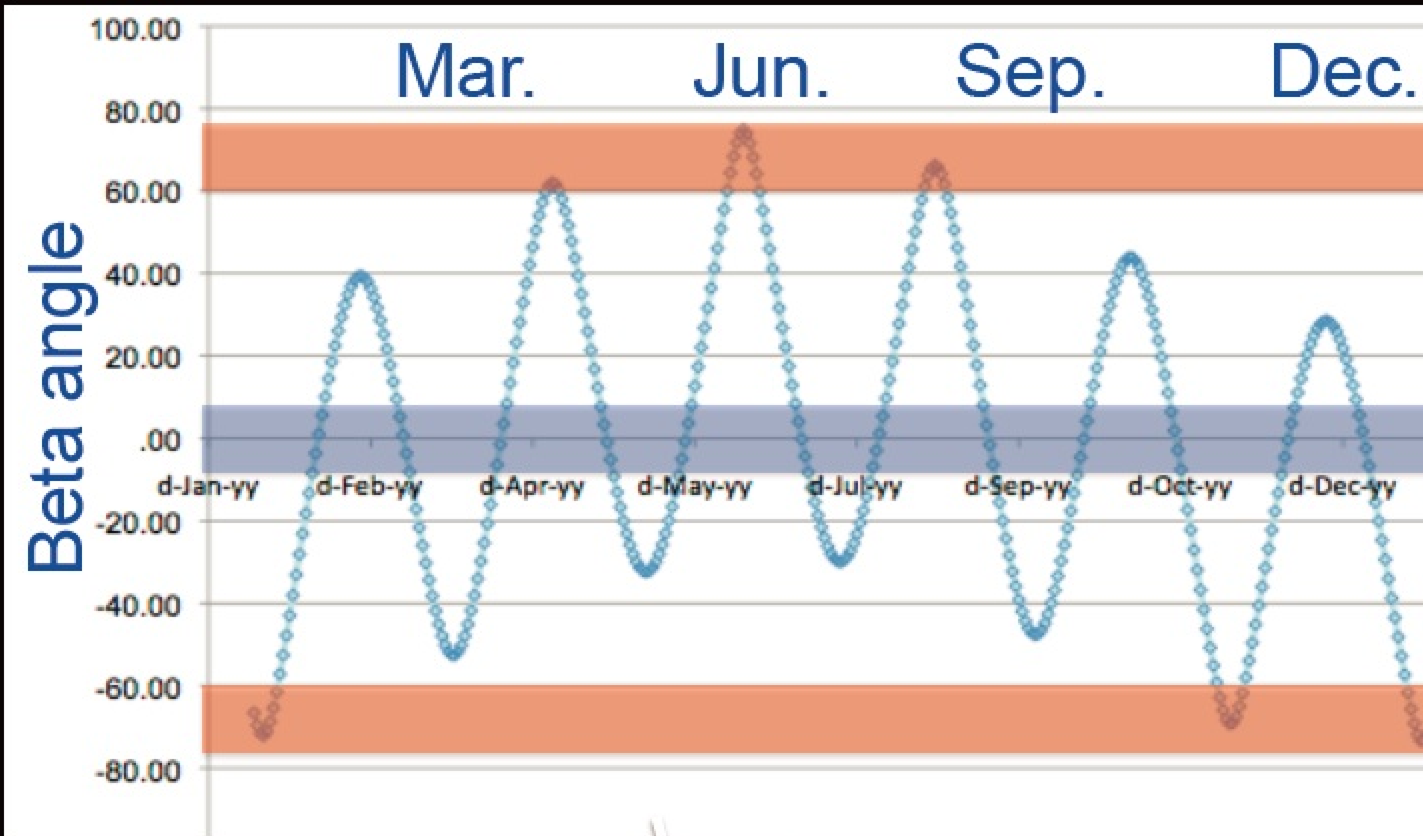


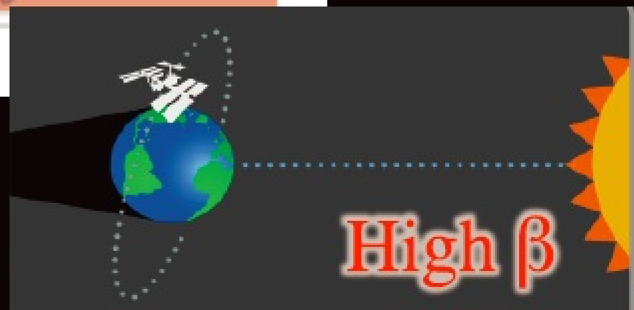
Payload Operations Control Centers

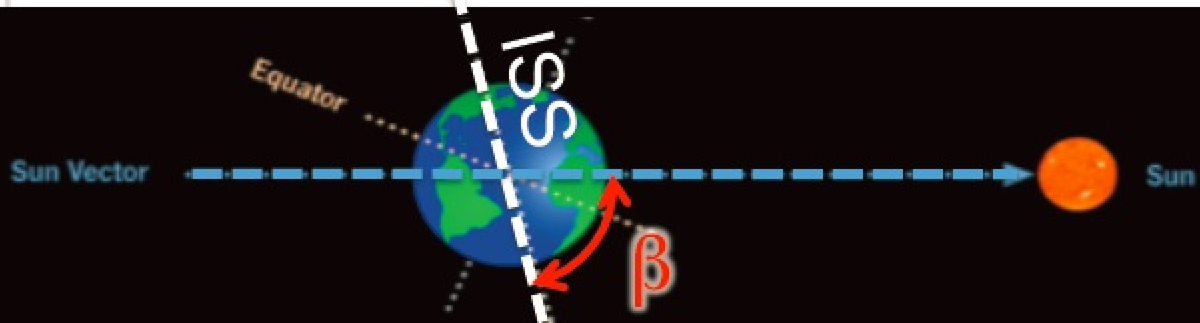


馬英九總統（圖中）與研發太空磁譜儀監控中心的日籍中大教授灰野楨一（右）握手致意，諾貝爾獎得主丁肇中（左）在旁陪同。（記者沈繼昌攝）

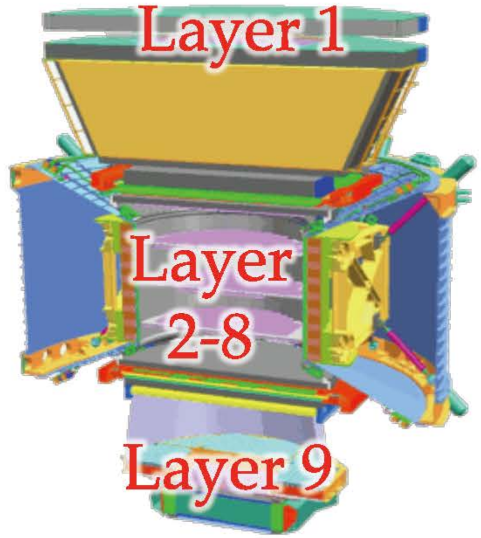
Solar beta angle



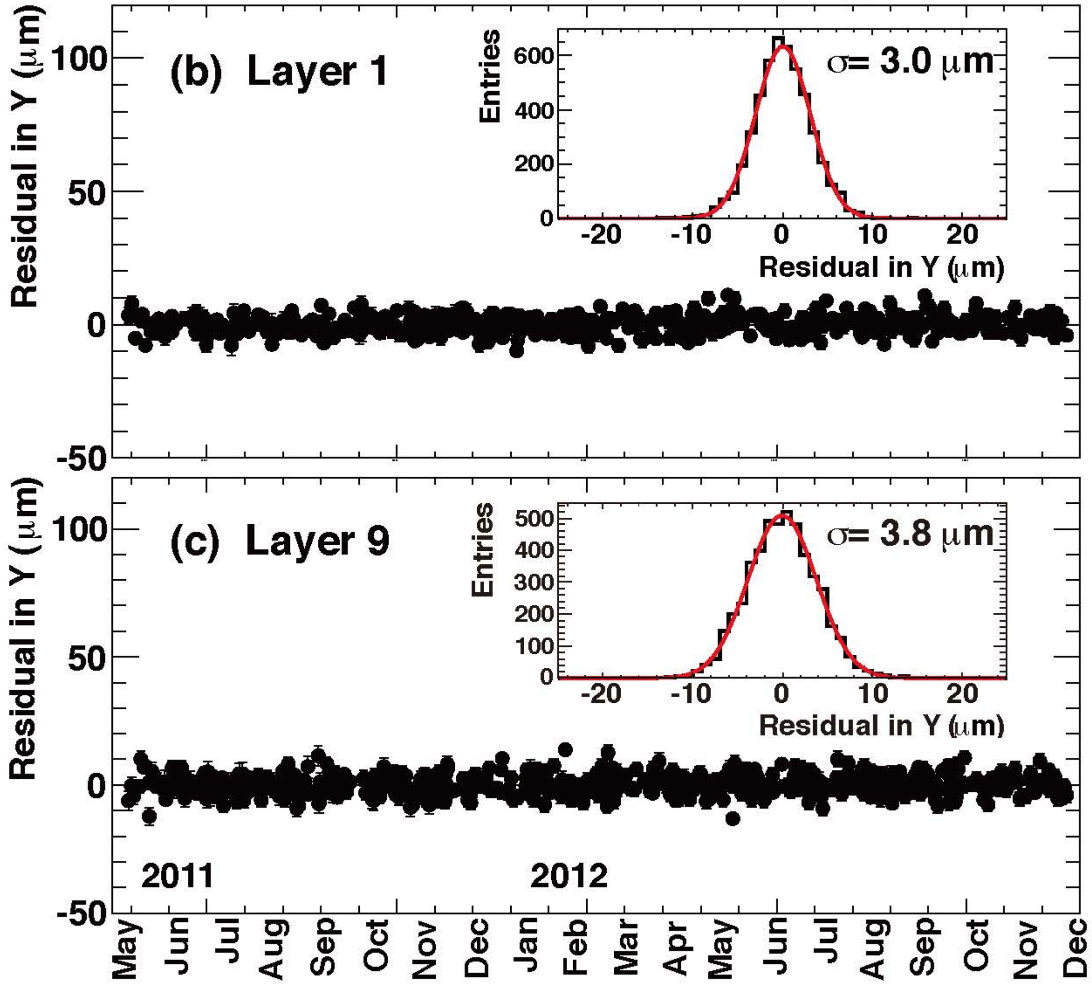


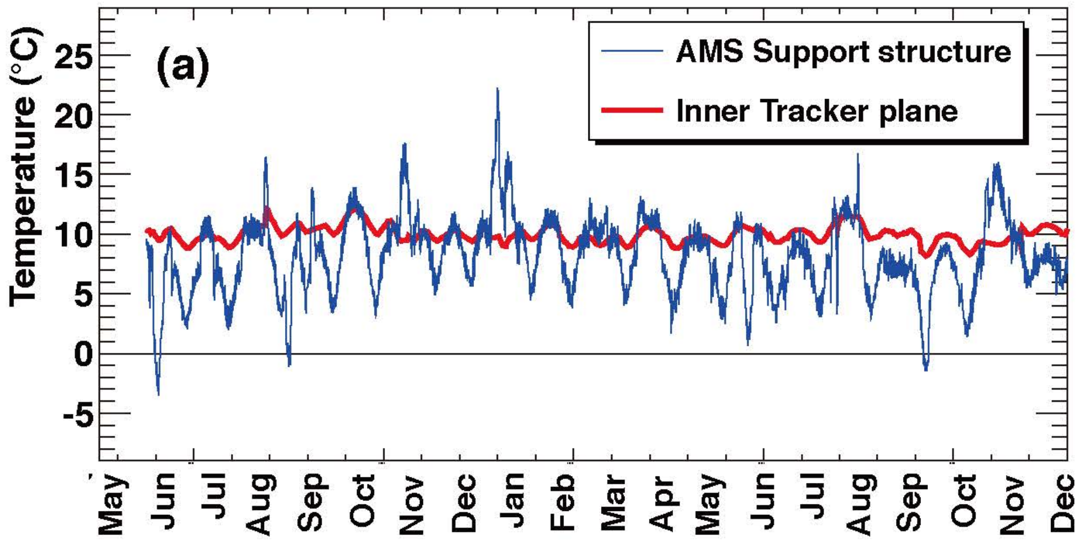


Stability of Tracker layers



- Temperature of inner layers (2-8) are kept stable
- Outer layers (1,9) are aligned with ISS data





For more details...

- 高エネルギーニュース４月号、研究紹介

305

■研究紹介

Alpha Magnetic Spectrometer (AMS)

- 様々な困難を乗り越え，遂にファーストリザルトへ -

台湾中央大學

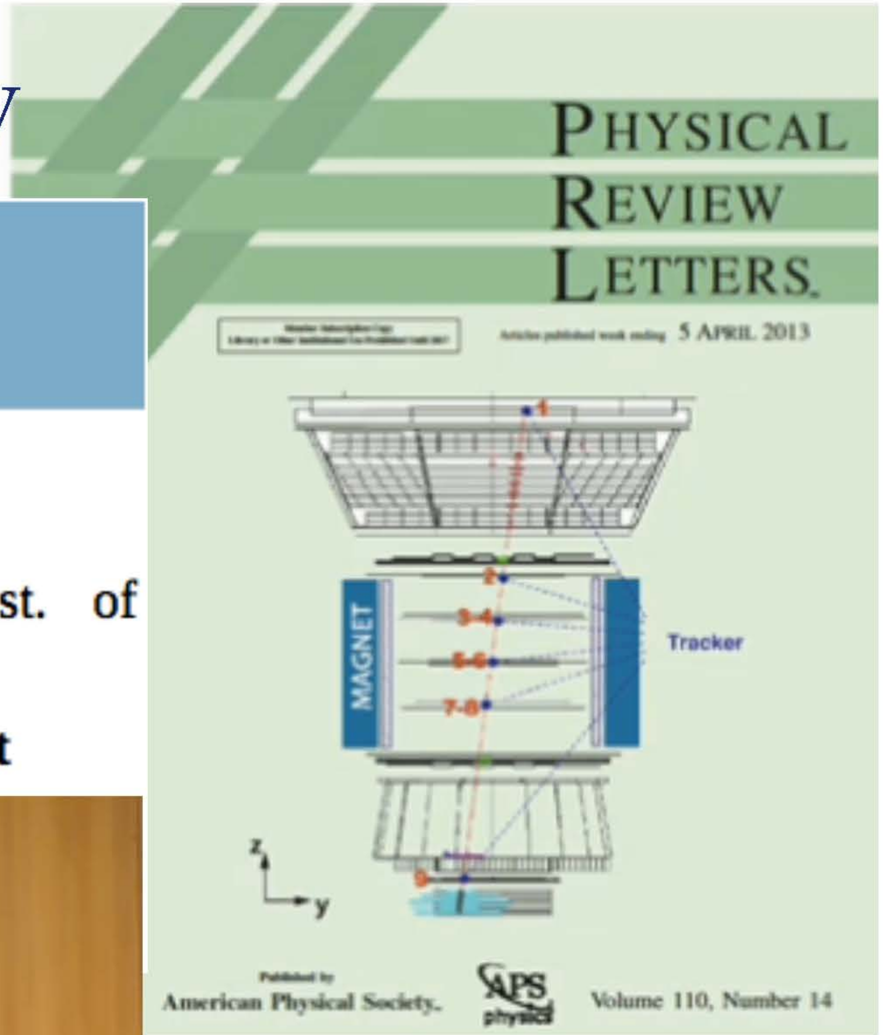
灰 野　禎 一

Sadakazu.Haino@cern.ch

2013年2月28日

First results of AMS

Positron fraction in 0.5~350 GeV



5 April, 2013

EP Seminar

SPEAKER: Prof. Samuel Ting (Massachusetts Inst. of Technology (US))

TITLE: **Recent results from the AMS experiment**

DATE: Wed 03/04/2013 17:00

PLACE: Main Auditorium

First results of AMS

Selected for a Viewpoint in *Physics*
PRL **110**, 141102 (2013) PHYSICAL REVIEW LETTERS week ending 5 APRIL 2013

First Result from the Alpha Magnetic Spectrometer on the International Space Station: Precision Measurement of the Positron Fraction in Primary Cosmic Rays of 0.5–350 GeV

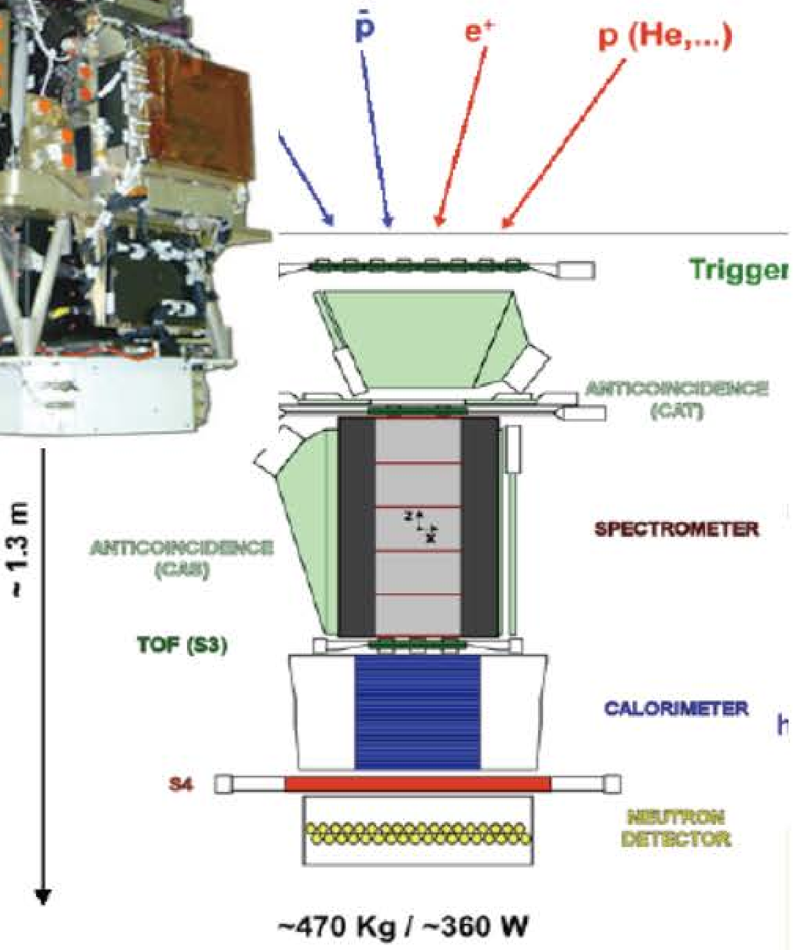
M. Aguilar,[32,20] G. Alberti,[42,43] B. Alpat,[42] A. Alvino,[42,43] G. Ambrosi,[42] K. Andeen,[28] H. Anderhub,[54] L. Arruda,[30] P. Azzarello,[42,21,*] A. Bachlechner,[1] F. Barao,[30] B. Baret,[22] A. Barrau,[22] L. Barrin,[20] A. Bartoloni,[47] L. Basara,[5] A. Basili,[11] L. Batalha,[30] J. Bates,[25] R. Battiston,[42,43,46] J. Bazo,[42] R. Becker,[11] U. Becker,[11] M. Behlmann,[11] B. Beischer,[1] J. Berdugo,[32] P. Berges,[11] B. Bertucci,[42,43] G. Bigongiari,[44,45] A. Biland,[54] V. Bindi,[24] S. Bizzaglia,[42] G. Boella,[36,37] W. de Boer,[28] K. Bollweg,[25] J. Bolmont,[38] B. Borgia,[47,48] S. Borsini,[42,43] M. J. Boschini,[36] G. Boudoul,[22] M. Bourquin,[21] P. Brun,[5] M. Buénerd,[22] J. Burger,[11] W. Burger,[43] F. Cadoux,[5,21] X. D. Cai,[11] M. Capell,[11] D. Casadei,[9,10] J. Casaus,[32] V. Cascioli,[42,43] G. Castellini,[18] I. Cernuda,[32] F. Cervelli,[44] M. J. Chae,[49] Y. H. Chang,[12] A. I. Chen,[11] C. R. Chen,[26] H. Chen,[11] G. M. Cheng,[8] H. S. Chen,[8] L. Cheng,[50] N. Chernoplyiokov,[39] A. Chikanian,[41] E. Choumilov,[11] V. Choutko,[11] C. H. Chung,[1] C. Clark,[25] R. Clavero,[29] G. Coignet,[5] V. Commichau,[54] C. Consolandi,[36,24] A. Contin,[9,10] C. Corti,[24] M. T. Costado Dios,[29] B. Coste,[22] D. Crespo,[32] Z. Cui,[50] M. Dai,[7] C. Delgado,[32] S. Della Torre,[36,37] B. Demirkoz,[4] P. Dennett,[11] L. Derome,[22] S. Di Falco,[44] X. H. Diao,[23] A. Diago,[29] L. Djambazov,[54] C. Díaz,[32] P. von Doetinchem,[1] W. J. Du,[50] J. M. Dubois,[5] R. Duperay,[22] M. Duranti,[42,43] D. D'Urso,[42,20] A. Egorov,[11] A. Eline,[11] F. J. Eppling,[11] T. Eronen,[53] J. van Es,[17] H. Esser,[1] A. Falvard,[38] E. Fiandrini,[42,43] A. Fiasson,[5] E. Finch,[41] P. Fisher,[11] K. Flood,[11] R. Foglio,[22] M. Fohey,[25] S. Fopp,[1] N. Fouque,[5] Y. Galaktionov,[11] M. Gallilee,[11] L. Gallin-Martel,[22] G. Gallucci,[44] B. García,[32] J. García,[32] R. García-López,[29] L. García-Tabares,[32] C. Gargiulo,[47,11] H. Gast,[1] I. Gebauer,[28] S. Gentile,[47,48] M. Gervasi,[36,37] W. Gillard,[22] F. Giovacchini,[32] L. Girard,[5] P. Goglov,[11] J. Gong,[40] C. Goy-Henningsen,[5] D. Grandi,[36] M. Graziani,[42,43] A. Grechko,[39] A. Gross,[1] I. Guerri,[44,45] C. de la Guía,[32] K. H. Guo,[23] M. Habiby,[21] S. Haino,[42,12]

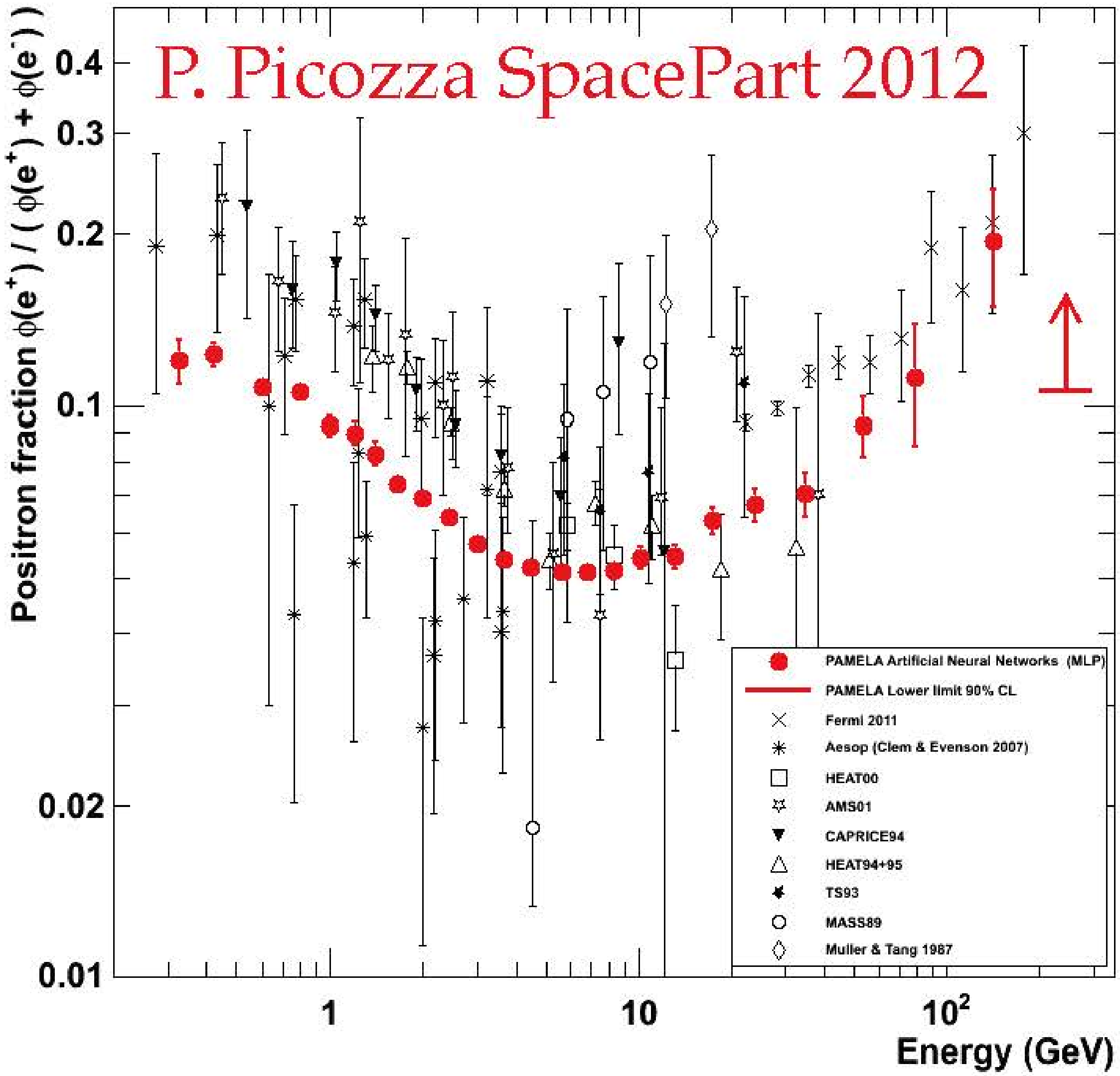
First results

- ISS data for 18 months (May/2011~Dec./2012) have been analysized by independent groups
- 6.4×10^6 e- and 4×10^5 e+ identified among 2.5×10^{10} cosmic ray events triggerd AMS
- The largest number of energetic antiparticles directly measured in space
- Positron fraction, $e^+/(e^+ + e^-)$ is precisely measured in 0.5 ~ 350 GeV

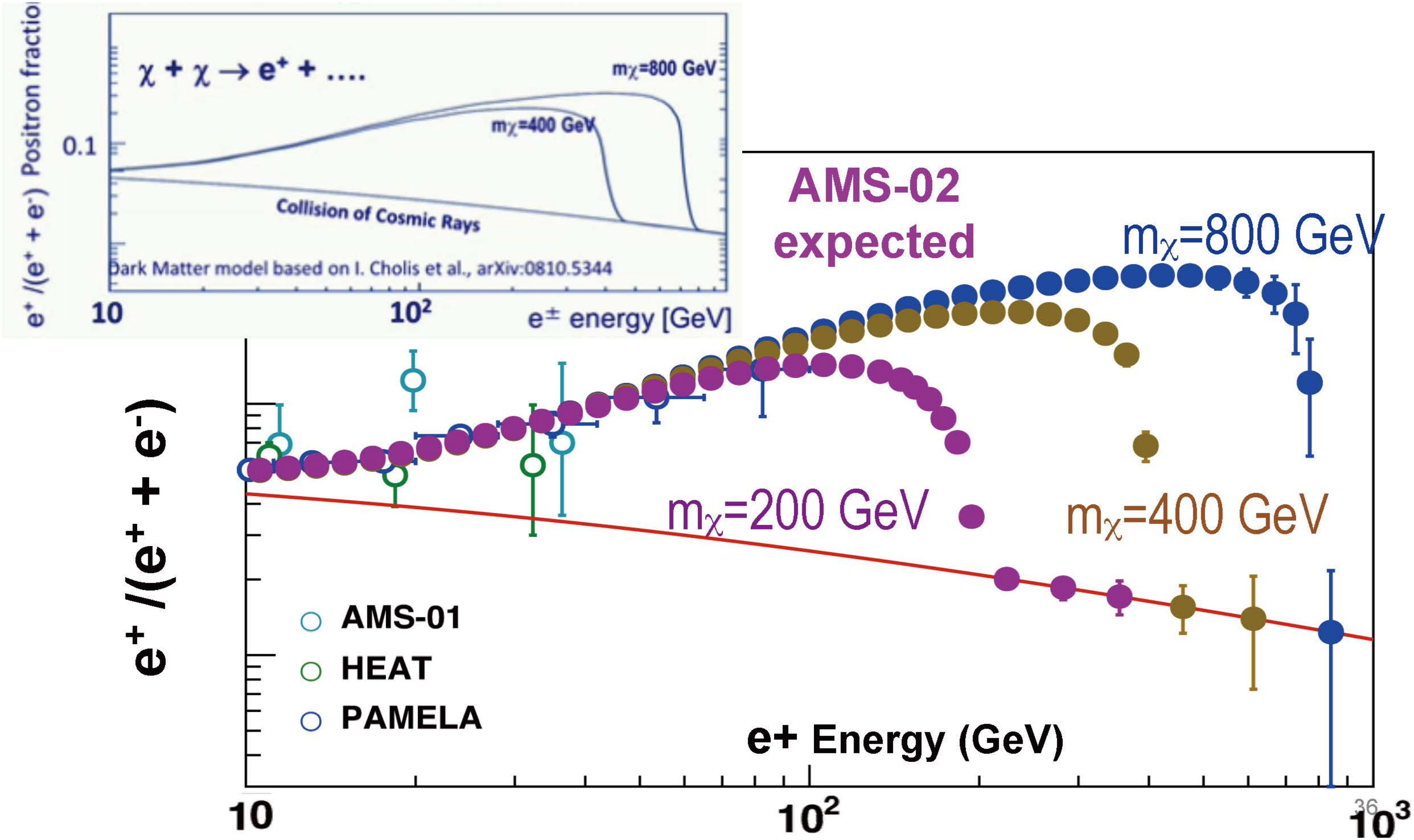
PaMeLa

a Payload for Antimatter Matter Exploration and Light-nuclei Astrophysics

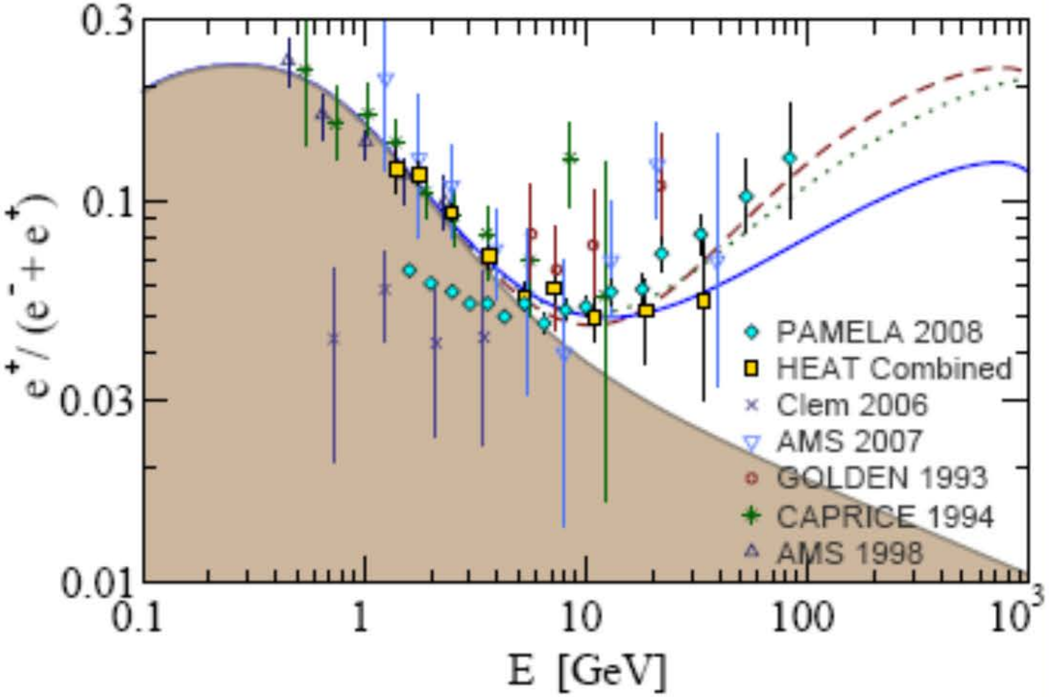




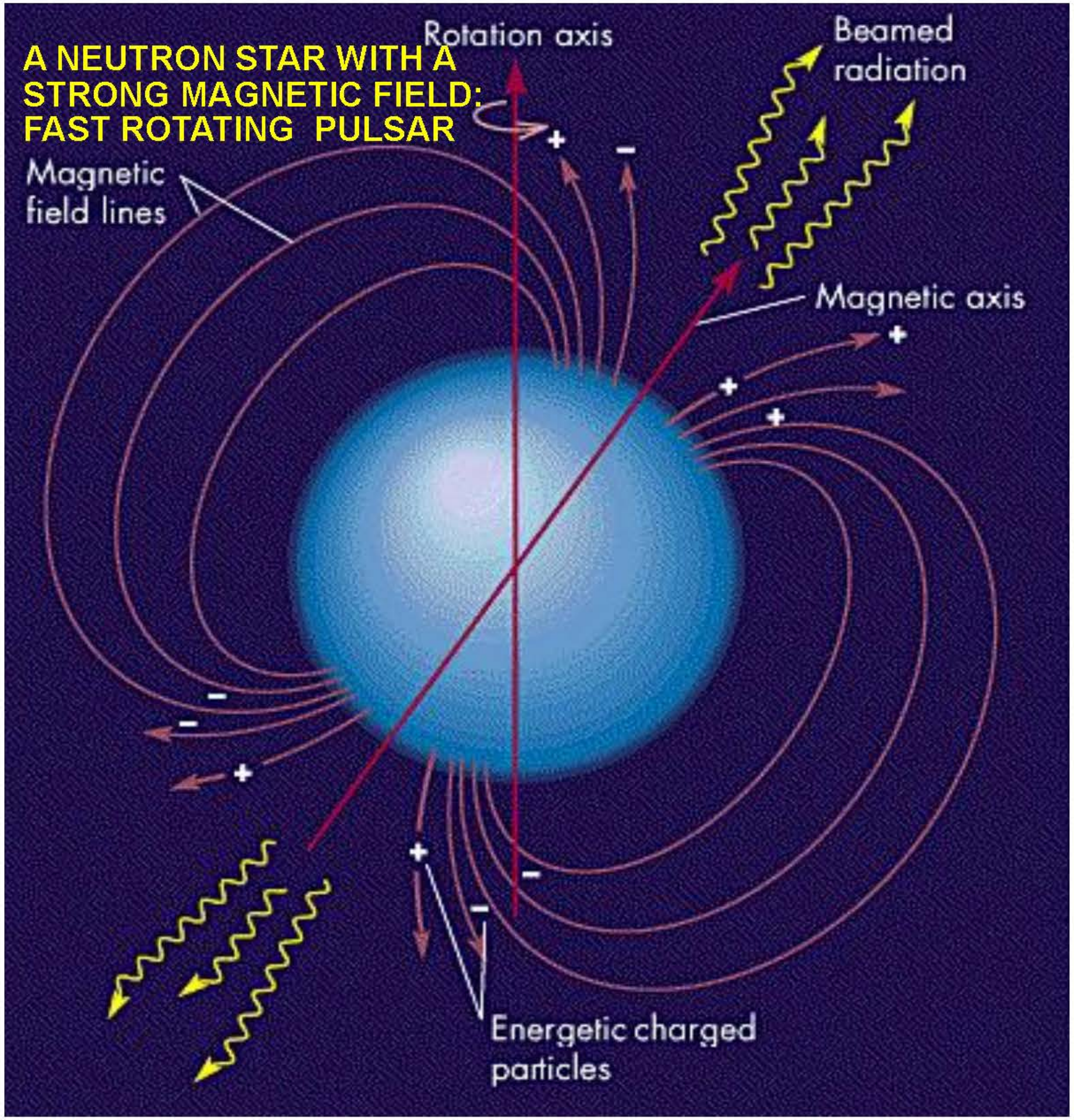
Indirect search for Dark Matter



Astrophysical origin : e.g. pulsars



H. Yüksak et al., arXiv:0810.2784v2
Contributions of e- & e+ from Geminga assuming different distance, age and energetic of the pulsar

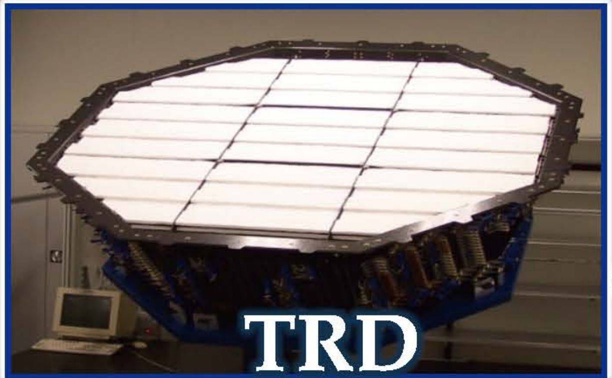


Positron excess - issues

- Make sure proton backgrounds (10^4~10^5) rejection is under control
- The positron fraction continuously increases ? or drops suddenly or slowly ?
- Any structures in the spectrum ?
- Any preferred direction of positrons ? or isotropic ?

TRD and Ecal

- Distinguish e+/e- from proton backgrounds

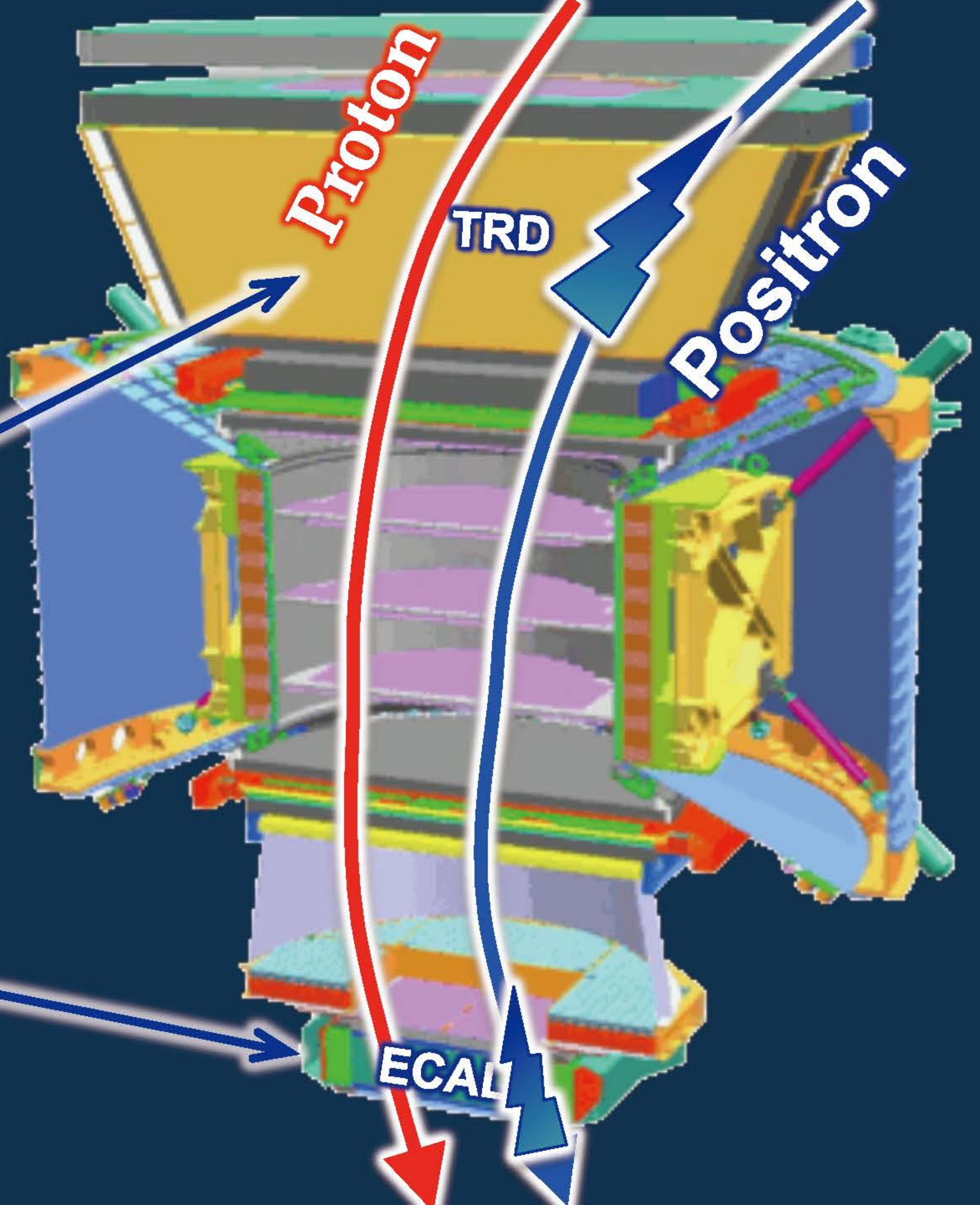


TRD

p Rejection > 10^2

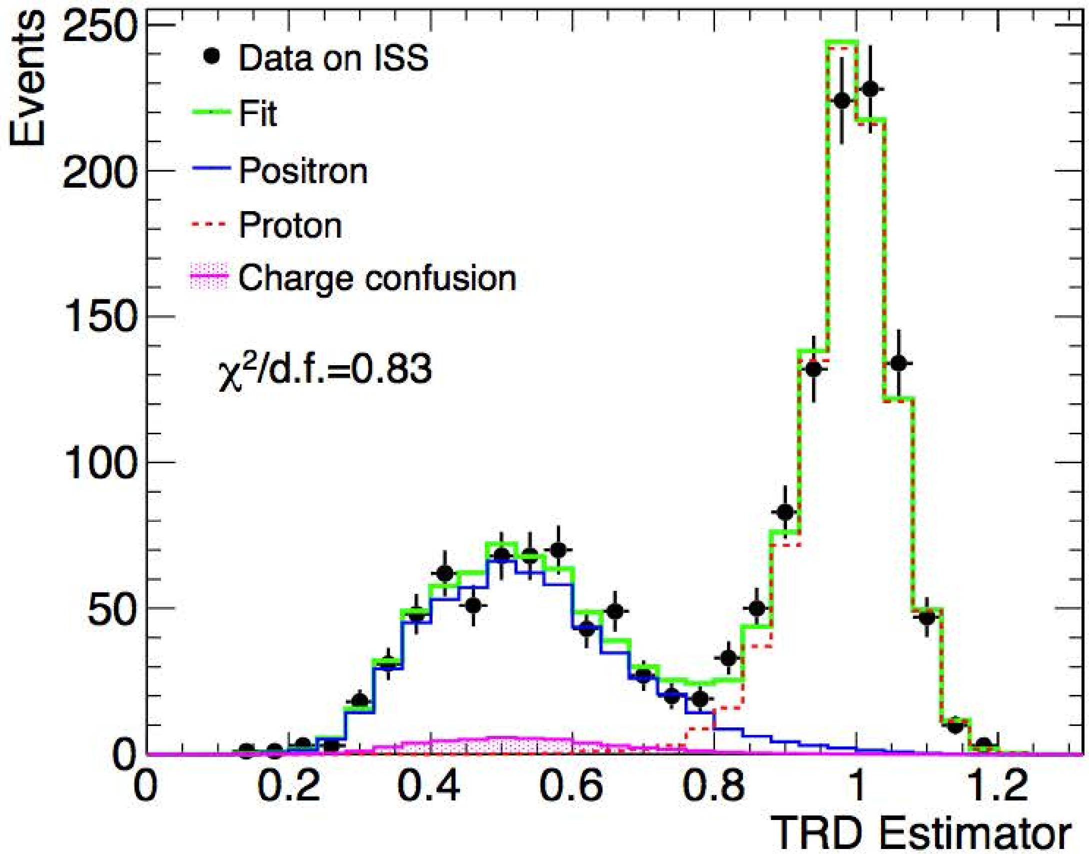
ECAL ($17\ X_0$)

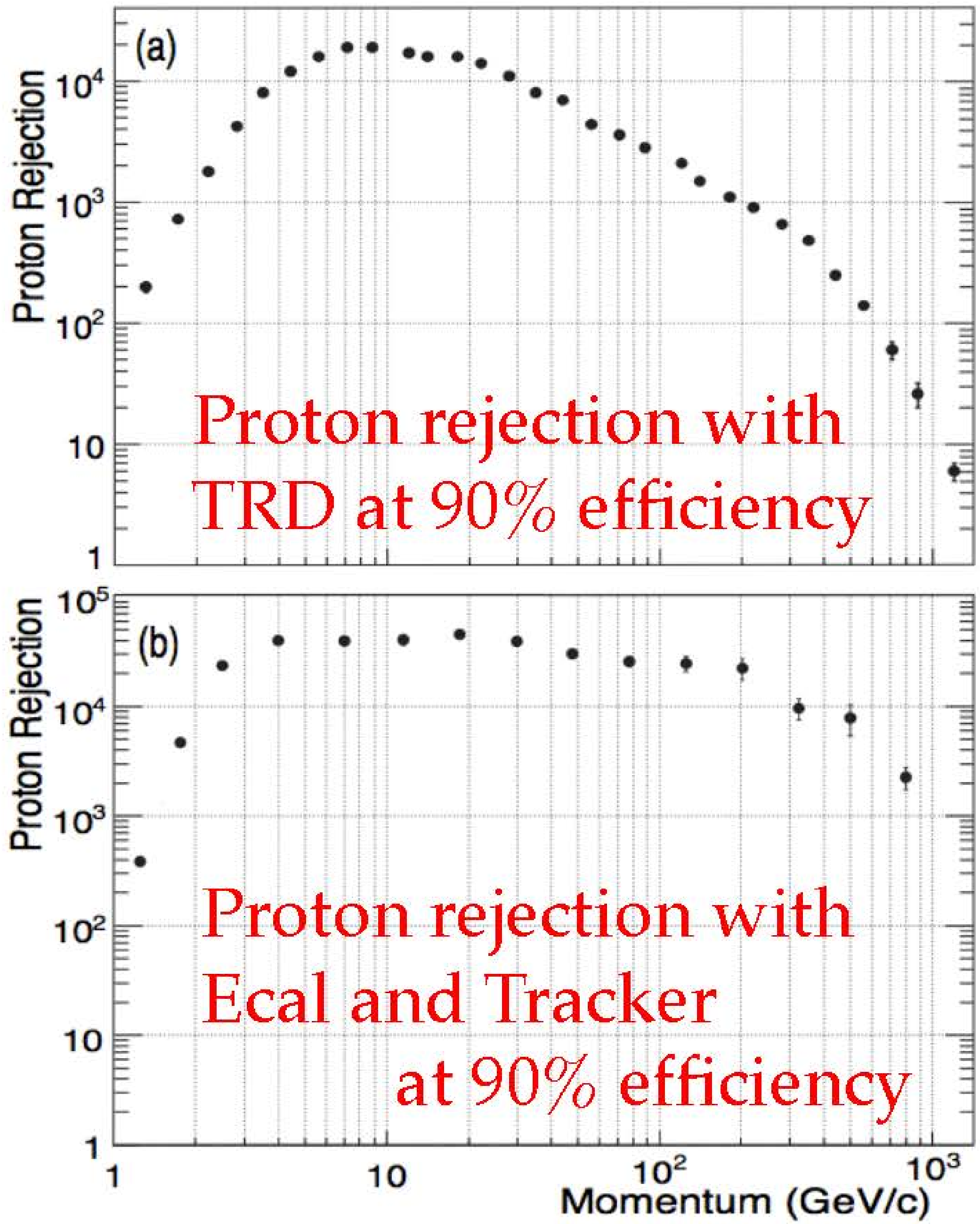
p Rejection > 10^4



Positron identification

Positive ISS data in 83-100 GeV



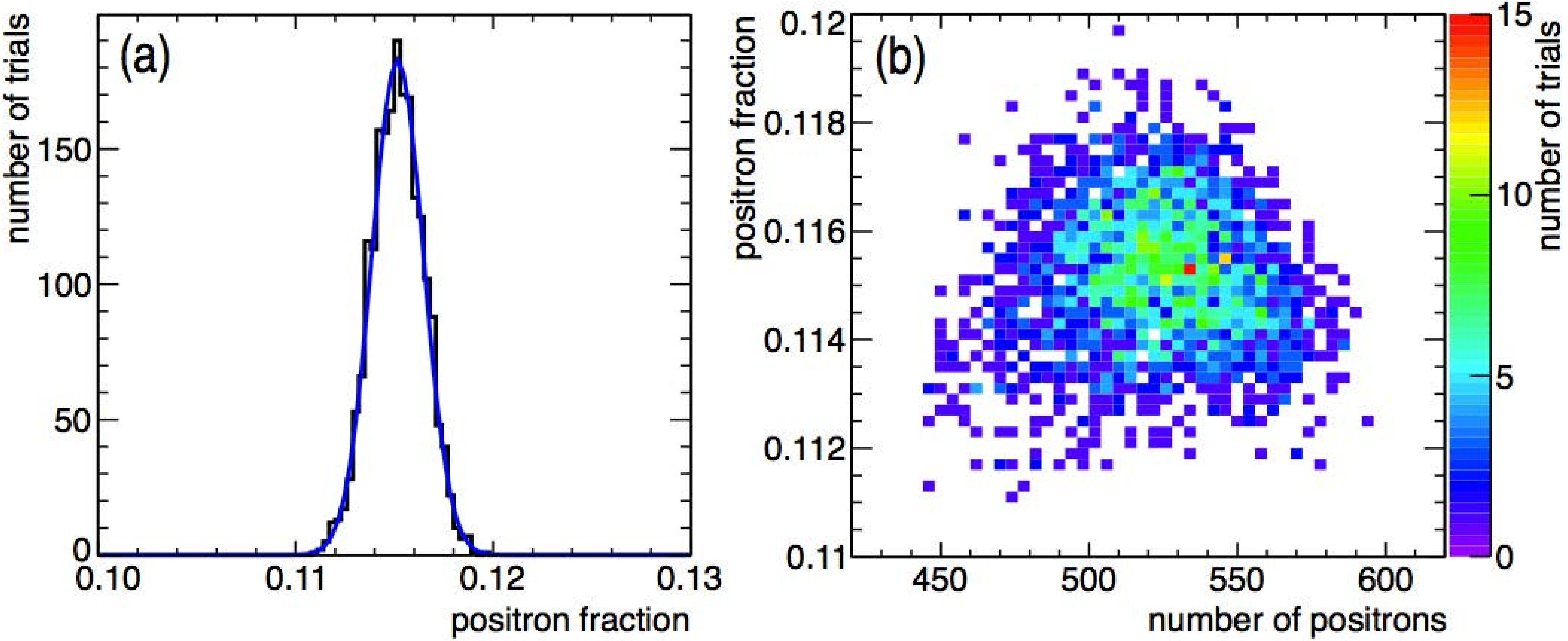


Systematic errors

- Acceptance asymmetry (E < a few GeV)
  due to small known tracker asymmetry
- Selection dependence on the cut values
- Migration bin-to-bin due to finite resolution
- Reference spectrum due to the statistics
  of pure proton and electron sample
- Charge confusion due to large angle scattering
  and production of secondary tracks,
  both of which are well reproduced by simulation

Selection dependence

ISS data in 83-100 GeV

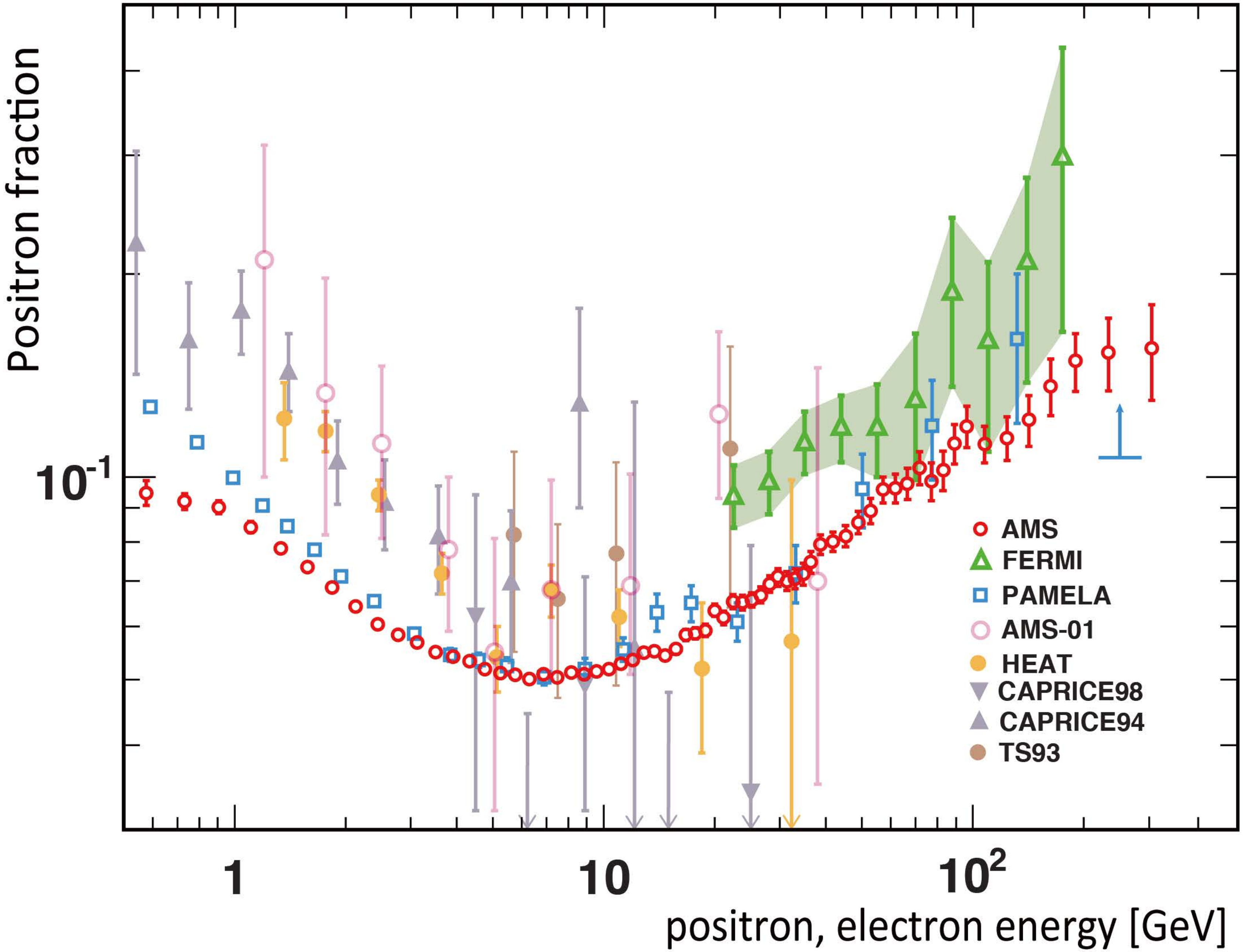


Data table (highest points)

- ~1,100 e+ identified above 100 GeV
- Syst. errors are always smaller than stat. errors, both of which are kept within ~10 % level

Energy [GeV]	N_{e^+}	**Fraction**	σ_{stat}	$\sigma_{acc.}$	$\sigma_{sel.}$	$\sigma_{mig.}$	$\sigma_{ref.}$	$\sigma_{c.c.}$	$\sigma_{syst.}$
100.0 - 115.1	304	0.1118	0.0066	0.0002	0.0015	0.0000	0.0003	0.0015	0.0022
115.1 - 132.1	223	0.1142	0.0080	0.0002	0.0019	0.0000	0.0004	0.0019	0.0027
132.1 - 151.5	156	0.1215	0.0100	0.0002	0.0021	0.0000	0.0005	0.0024	0.0032
151.5 - 173.5	144	0.1364	0.0121	0.0002	0.0026	0.0000	0.0006	0.0045	0.0052
173.5 - 206.0	134	0.1485	0.0133	0.0002	0.0031	0.0000	0.0009	0.0050	0.0060
206.0 - 260.0	101	0.1530	0.0160	0.0003	0.0031	0.0000	0.0013	0.0095	0.0101
260.0 - 350.0	72	0.1550	0.0200	0.0003	0.0056	0.0000	0.0018	0.0140	0.0152

Positron fraction



An example: Minimal model

- Positron fraction = $\dfrac{\Phi_{e+}}{\Phi_{e+} + \Phi_{e-}}$

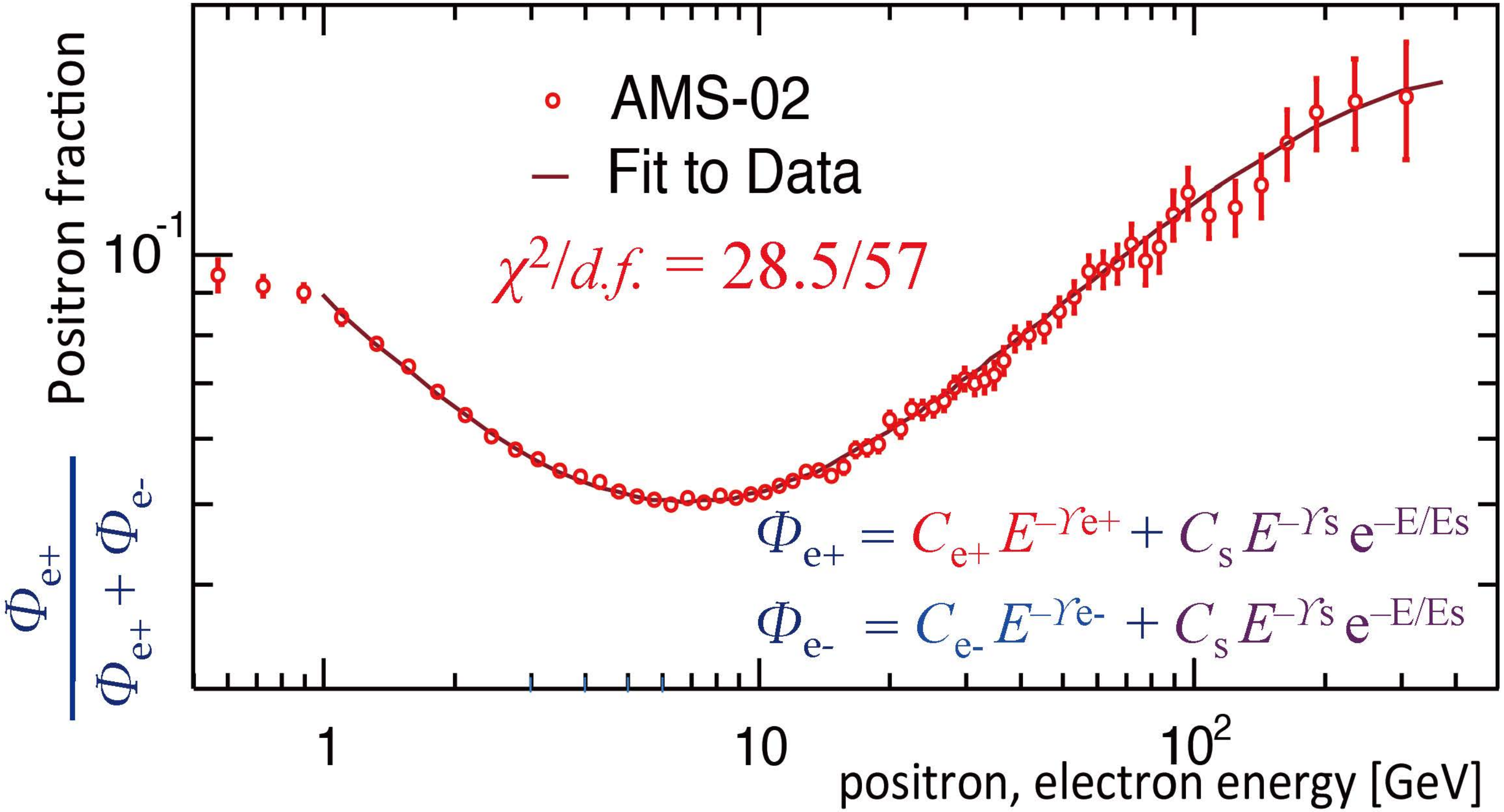
where $\Phi_{e+} = \underbrace{C_{e+} E^{-\gamma_{e+}}}_{\text{e+ diffuse}} + \underbrace{C_s E^{-\gamma_s} e^{-E/E_s}}_{\text{common source}}$

$\Phi_{e-} = \underbrace{C_{e-} E^{-\gamma_{e-}}}_{\text{e- diffuse (and primary)}} + \underbrace{C_s E^{-\gamma_s} e^{-E/E_s}}_{\text{common source}}$

Fit with minimal model

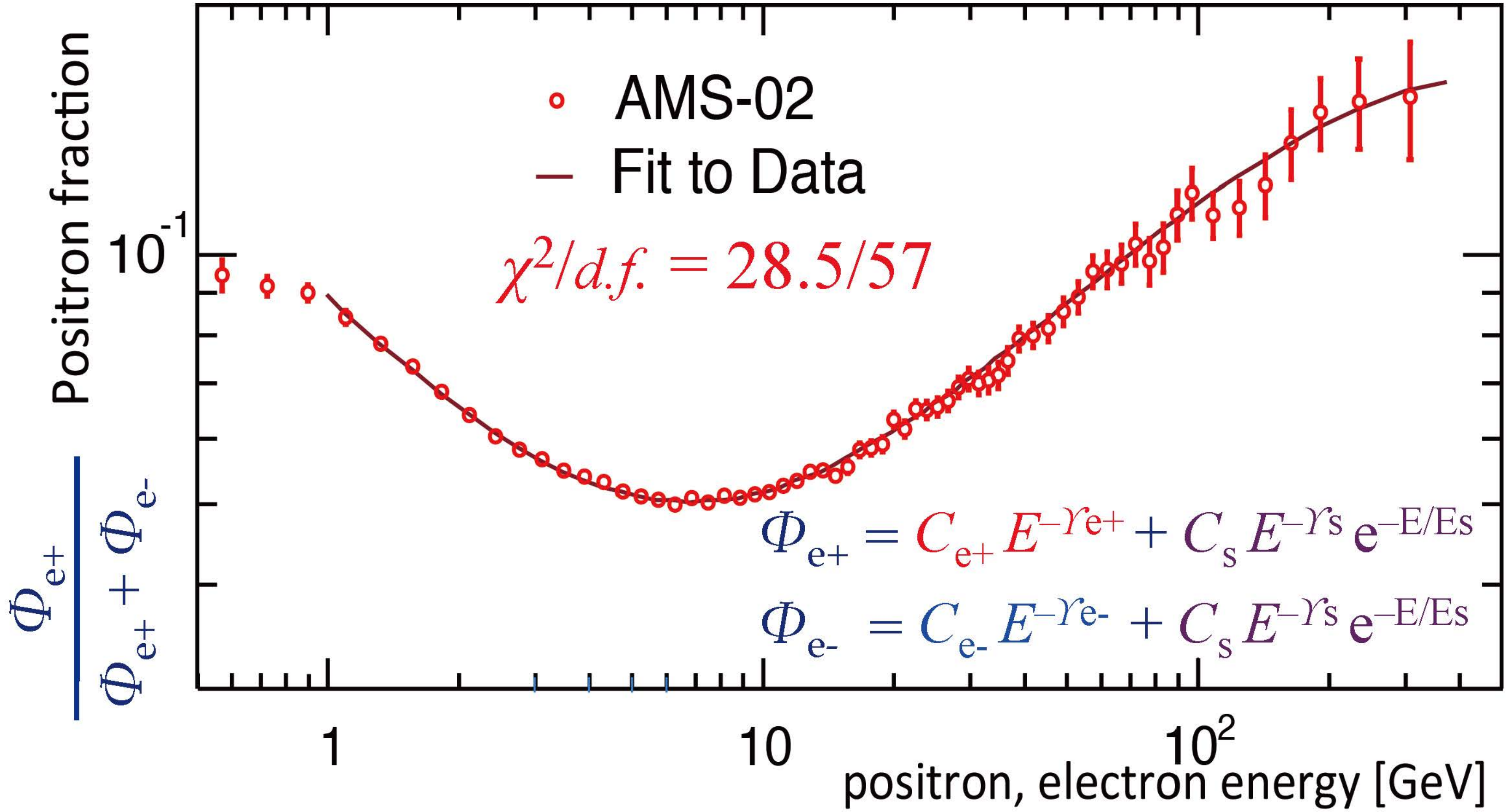
$\Upsilon_{e-} - \Upsilon_{e+} = -0.63 \pm 0.03$ Diffuse e+ is less energetic than e-

$\Upsilon_{e-} - \Upsilon_{s} = 0.66 \pm 0.05$ Source is more energetic than diffuse e-



Fit with minimal model

$C_{e+} / C_{e-} = 0.091 \pm 0.001$
$C_s / C_{e-} = 0.0078 \pm 0.0012$
$1/E_s = 0.0013 \pm 0.0007 \text{ GeV}^{-1}$ (Cutoff energy 760^{+1000}_{-280} GeV)



Anisotropy study

Arrival directions of electrons and positrons are used to build a sky map in galactic coordinates, (b, l), containing the number of observed positrons and electrons in a given energy range. The fluctuations of the observed positron ratio are described using a spherical harmonic expansion

$$\frac{r_e(b,l)}{< r_e >} - 1 = \sum_{\ell=0}^{\infty} \sum_{m=-\ell}^{\ell} a_{\ell m} Y_{\ell m}(\pi/2 - b, l),$$

where $r_e(b,l)$ denotes the positron ratio at (b,l); $< r_e >$ is the average ratio over the sky map; $Y_{\ell m}$ are spherical harmonic functions and $a_{\ell m}$ are the corresponding weights. The coefficients of the angular power spectrum of the fluctuations are defined as

$$C_\ell = \frac{1}{2\ell+1} \sum_{m=-\ell}^{\ell} |a_{\ell m}|^2.$$

They are found to be consistent with the expectations for isotropy at all energies and upper limits to multipole contributions are obtained. A limit on the amplitude of dipole anisotropy on the positron to electron ratio, $\delta = 3\sqrt{C_1/4\pi}$ for any axis in galactic coordinates is obtained by integrating the ratio above 16 GeV yielding a limit of $\delta(E > 16\,\text{GeV}) \leq 0.036$ at the 95% confidence level.

Positron fraction - conclusions

The first 6.8 million primary e+ and e- events show :

- Decrease below ~10 GeV
- Steady increase in 10~ 250 GeV with its slope decreasing by an order of magnitude
- No fine structure is observed consistent with sum of diffuse spectrum and a single common power law source
- Positron to electron ratio is consistent with isotropy: $\delta < 0.036$ at the 95 % *C.L.*

Positron fraction - conclusions

- These observations show the existence of new physical phenomena, whether from Dark Matter or astrophysical origin
- The determination of the behavior in 250~350 GeV and beyond requires more statistics
- AMS will be on ISS for 20 years the data to ~1 TeV will be presented when sufficient data are collected

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PAMELA Measurements of Cosmic-Ray Proton and Helium Spectra

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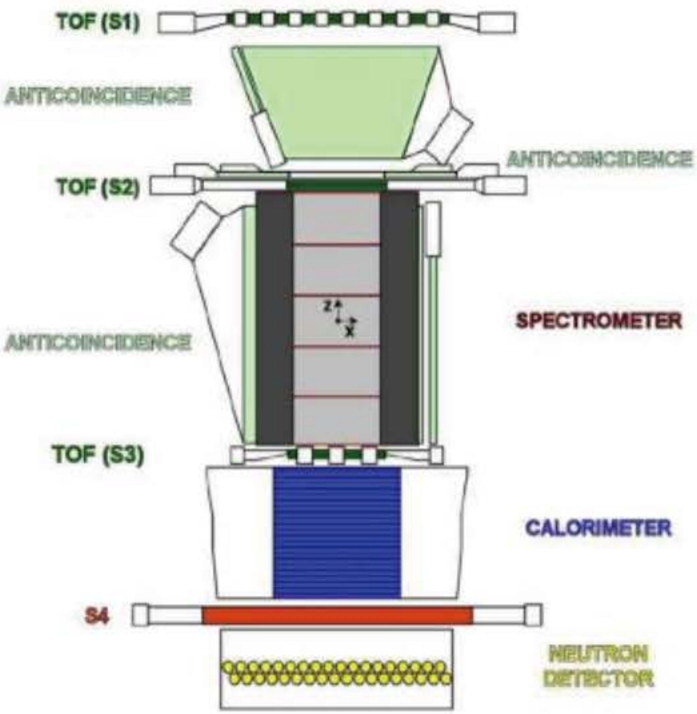


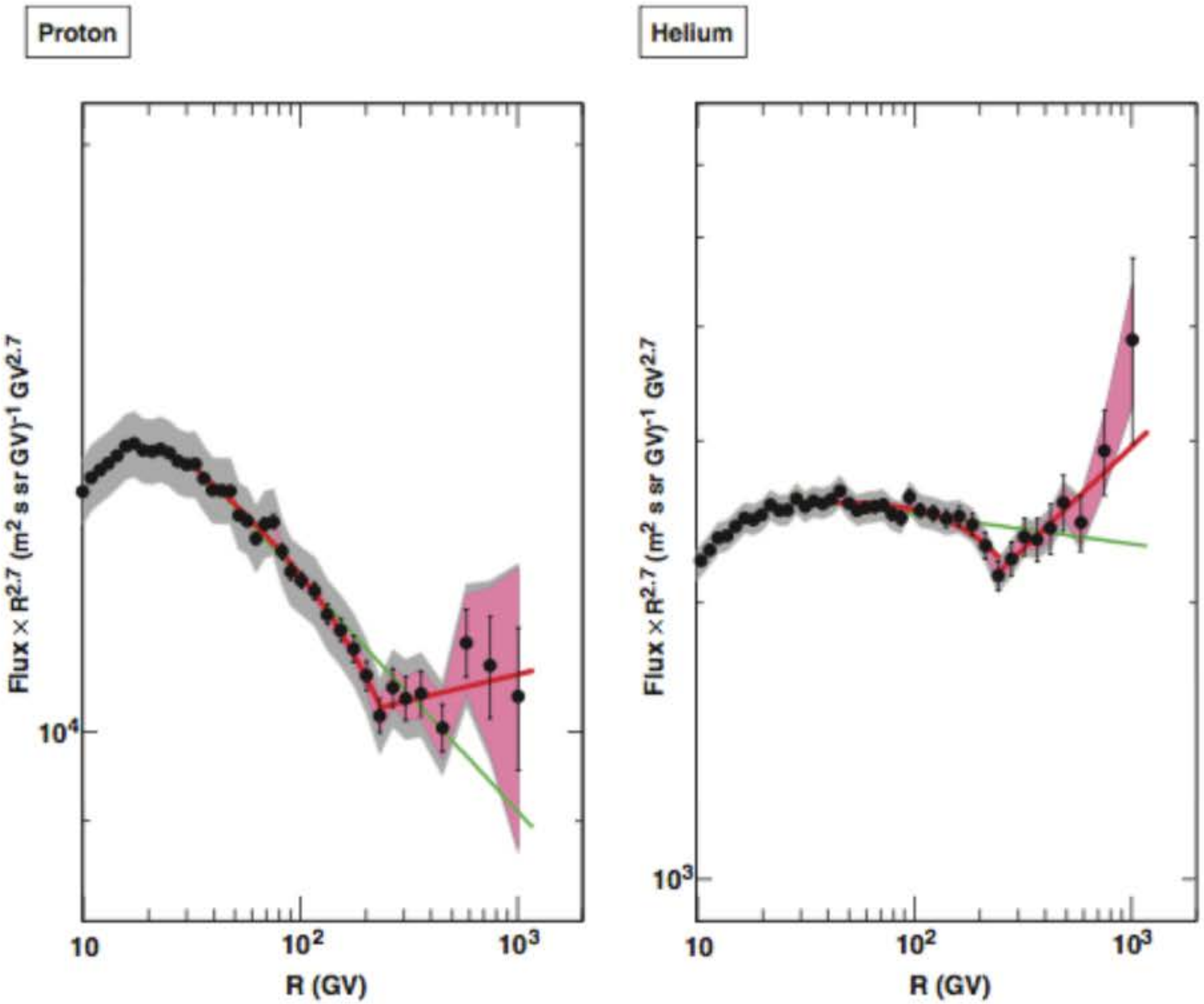
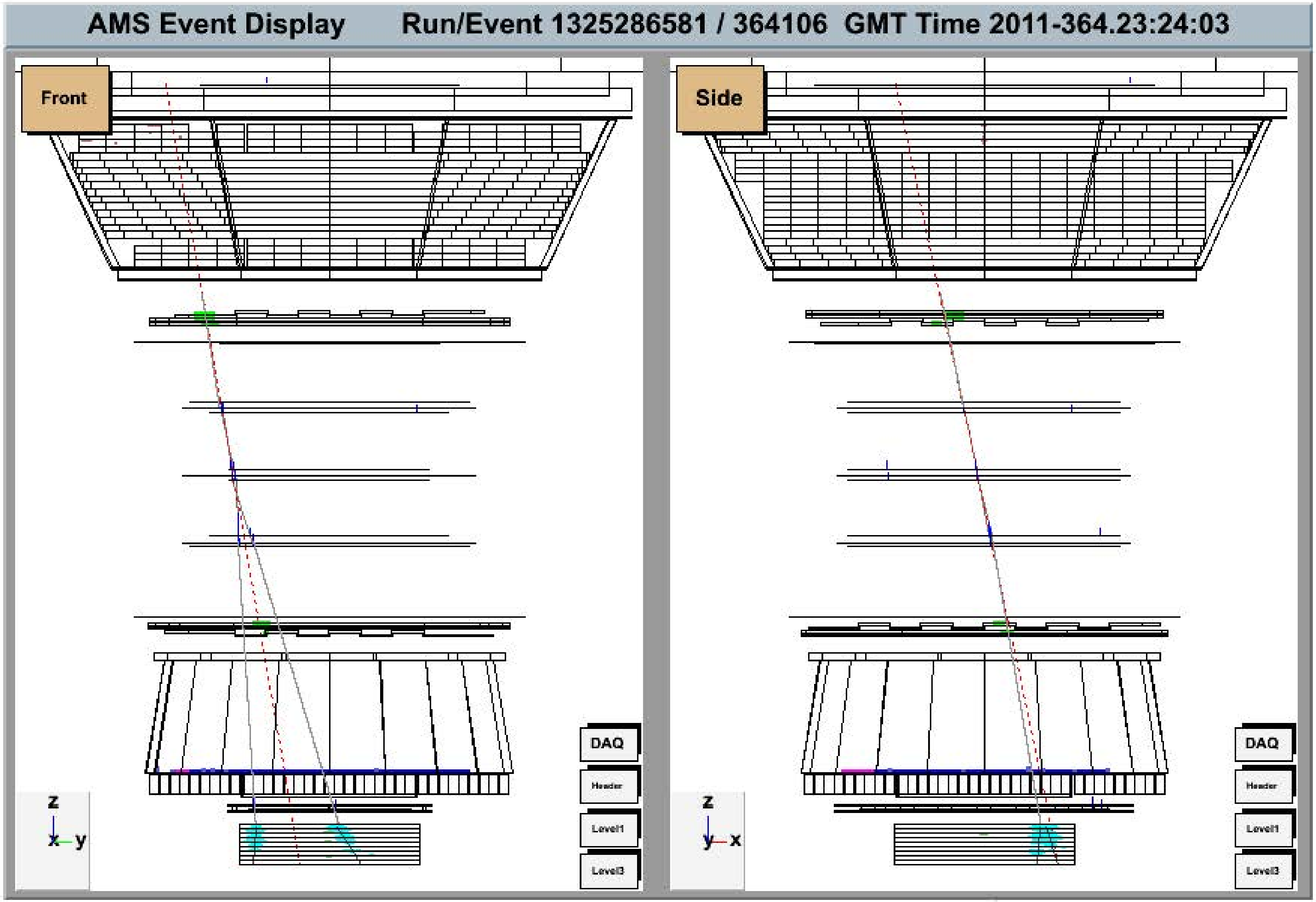


Fig. 4. Proton (**left**) and helium (**right**) spectra in the range 10 GV to 1.2 TV. The gray shaded area represents the estimated systematic uncertainty, and the pink shaded area represents the contribution due to tracker alignment. The green lines represent fits with a single power law in the rigidity range 30 to 240 GV. The red curves represent the fit with a rigidity-dependent power law (30 to 240 GV) and with a single power law above 240 GV.

Photon event - ISS data

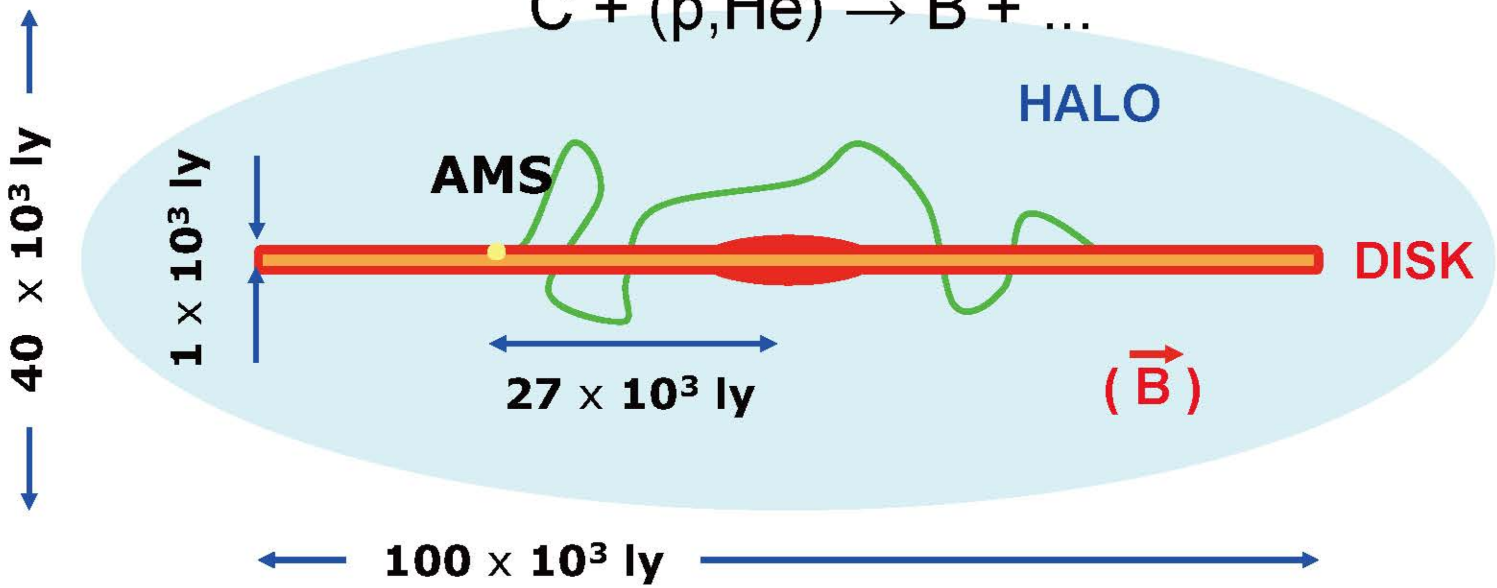


B/C ratio upto 1 TeV

Precise measurement provides information on Cosmic Ray Interactions and Propagation

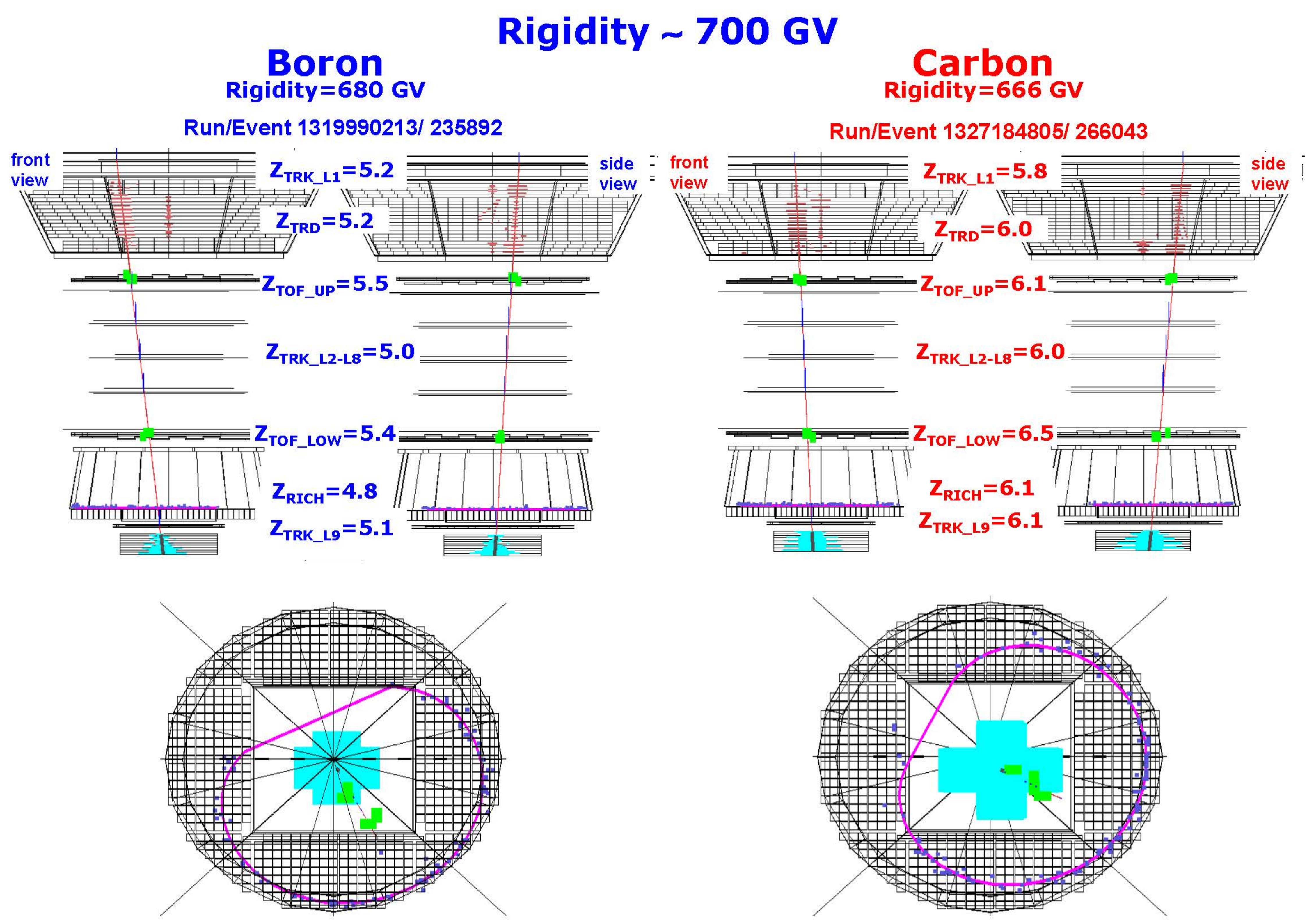
Interactions with the Interstellar Medium:

C + (p,He) → B + ...



Diffusion
Convection
Reacceleration

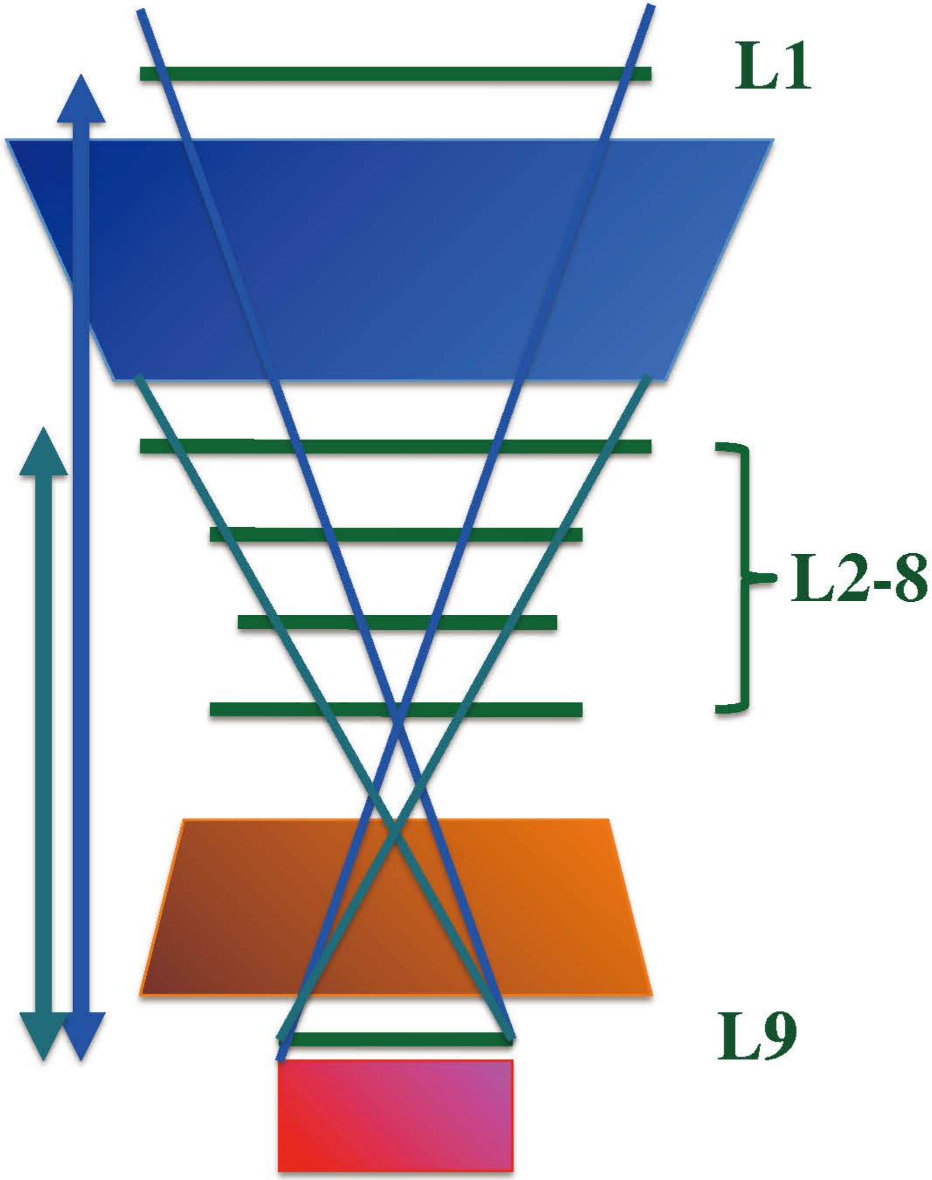
Interactions with the Interstellar Medium
Fragmentation
- Secondaries
- Energy loss



Rigidity ~ 700 GV
Boron
Rigidity=680 GV
Run/Event 1319990213/ 235892
front view
side view
Z_{TRK_L1}=5.2
Z_{TRD}=5.2
Z_{TOF_UP}=5.5
Z_{TRK_L2-L8}=5.0
Z_{TOF_LOW}=5.4
Z_{RICH}=4.8
Z_{TRK_L9}=5.1
Carbon
Rigidity=666 GV
Run/Event 1327184805/ 266043
front view
side view
Z_{TRK_L1}=5.8
Z_{TRD}=6.0
Z_{TOF_UP}=6.1
Z_{TRK_L2-L8}=6.0
Z_{TOF_LOW}=6.5
Z_{RICH}=6.1
Z_{TRK_L9}=6.1


To be continued ...

Exposures for positrons



AMS-PM

L2-8 + L9

950 cm^2sr, MDR 0.8 TV

L2-8 + L1 + L9 (Max Span)

300 cm^2sr, MDR 2.1 TV

AMS-SC

L1-8 + Ecal

950 cm^2sr, MDR 2.2 TV