Results from the AMS experiment

B.Bertucci
Perugia University & INFN

Perugia
INFN
Istituto Nazionale
di Fisica Nucleare

UNIVERSITÀ DEGLI STUDI
DI PERUGIA

From Mickey Mouse…

Mickey Mouse n.2859
September 14, 2010

MEGLIO RIPASSARE UN PÒ!

Intanto, l'astronauta italiano Roberto Vittori e i quattro colleghi con cui partirà non si annoiano: hanno così tante cose da imparare (già, guidare un'astronave non è semplice!), che qualche mese in più per ripassare tutto gli farà comodo! Così arriveranno perfettamente preparati alla missione che li aspetta: portare sulla Stazione Spaziale Internazionale l'AMS-02, complesso macchinario indispensabile per rispondere a una fondamentale domanda: l'universo è davvero vuoto come sembra?

VITTORI È DIRETTO SU QUESTO TECNOLOGICO LABORATORIO DI RICERCA CHE RUOTA ATTORNO ALLA TERRA, CIRCA 350 CHILOMETRI SOPRA LE NOSTRE TESTE, TRATTENUTO DALLA FORZA DI GRAVITÀ

E mentre gli astronauti ripassano, ingegneri, meccanici, fisici mettono a punto gli ultimi dettagli dello Space Shuttle, la complessa navetta spaziale che porterà Roberto Vittori fino alla Stazione Spaziale Internazionale.

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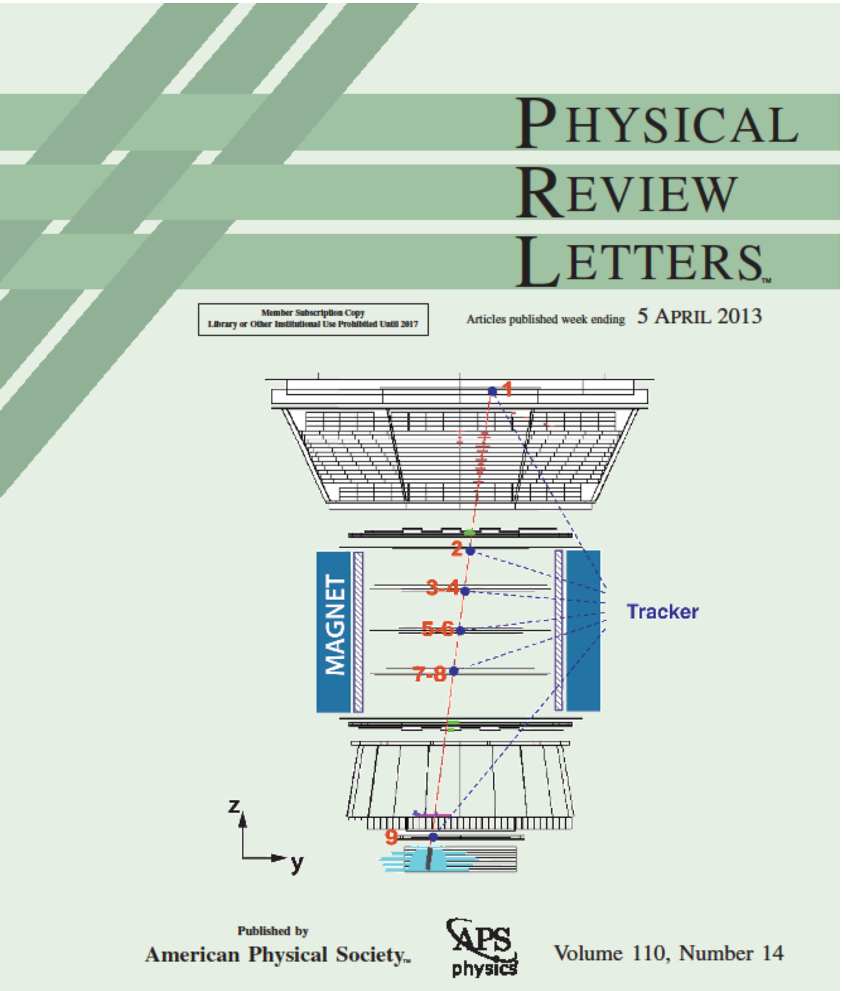
....to PRL



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. 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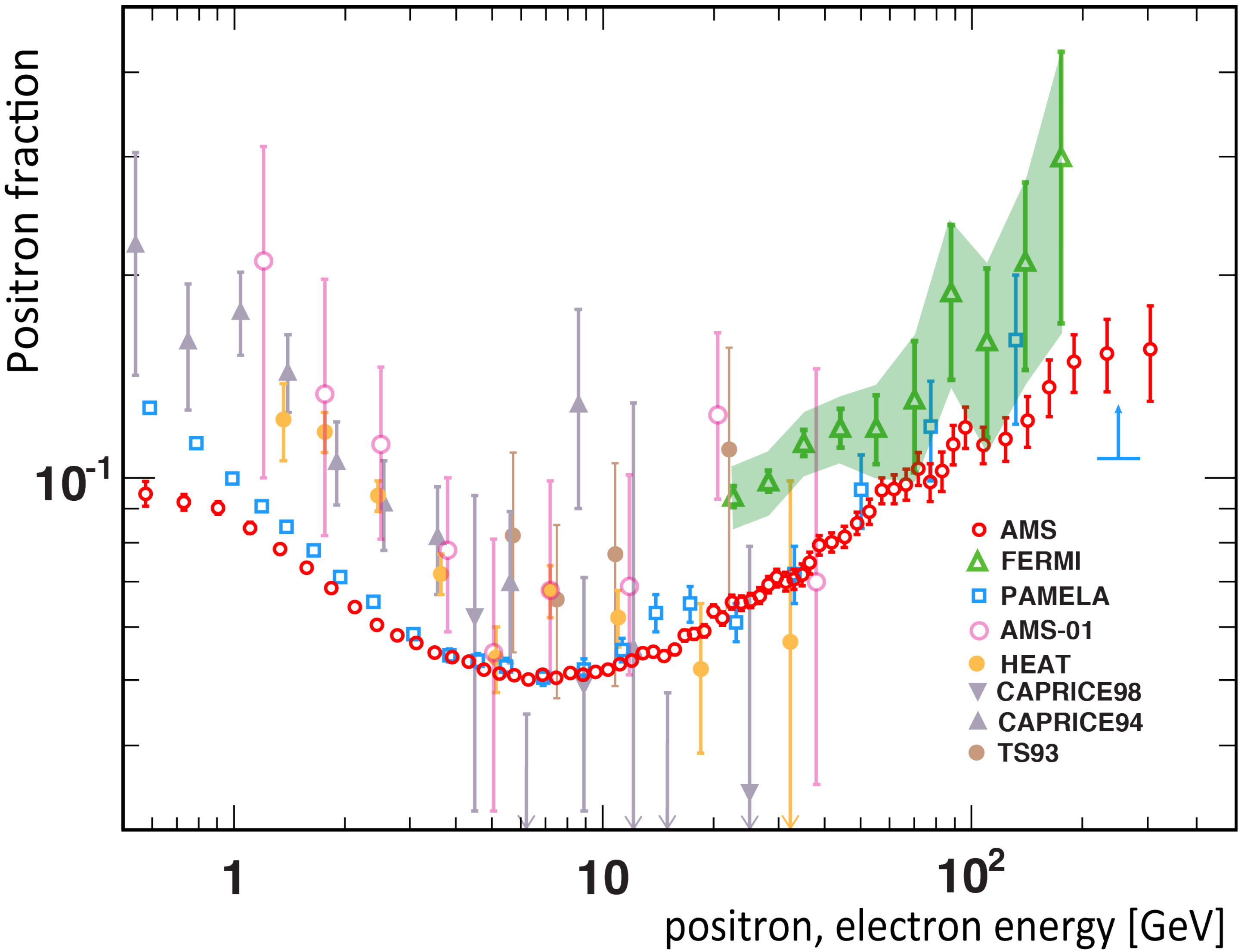
Liu,[52] H. Liu,[40] T. Lomtadze,[44] Y. S. Lu,[8] S. Lucidi,[42] K. Lübelsmeyer,[1] J. Z. Luo,[40] W. Lustermann,[54] S. Lv,[23] J. Madsen,[2] R. Majka,[41] A. Malinin,[14] C. Mañá,[32] J. Marín,[32] T. Martin,[25] G. Martínez,[32] F. Masciocchi,[21] N. Masi,[9,10] D. Maurin,[22] A. McInturff,[15] P. McIntyre,[15] A. Menchaca-Rocha,[33] Q. Meng,[40] M. Menichelli,[42] I. Mereu,[42,43] M. Millinger,[1] D. C. Mo,[23] M. Molina,[§] P. Mott,[25] A. Mujunen,[27] S. Natale,[1,52] P. Nemeth,[25] J. Q. Ni,[23] N. Nikonov,[28] F. Nozzoli,[42,19] P. Nunes,[30] A. Obermeier,[28] S. Oh,[49] A. Oliva,[42,43,32] F. Palmonari,[9,10] C. Palomares,[32] M. Paniccia,[5,21] A. Papi,[42] W. H. Park,[16] M. Pauluzzi,[42,43] F. Pauss,[54] A. Pauw,[17] E. Pedreschi,[44] S. Pensotti,[36,37] R. Pereira,[30] E. Perrin,[21] G. Pessina,[36,37] G. Pierschel,[1] F. Pilo,[44] A. Piluso,[42,43] C. Pizzolotto,[42,19] V. Plyaskin,[11] J. Pochon,[5,29] M. Pohl,[21] V. Poireau,[5] S. Porter,[25] J. Pouxe,[22] A. Putze,[1] L. Quadrani,[9,10] X. N. Qi,[23] P. G. Rancoita,[36] D. Rapin,[21] Z. L. Ren,[52] J. S. Ricol,[22] E. Riihonen,[53] I. Rodríguez,[32] U. Roeser,[54] S. Rosier-Lees,[5] L. Rossi,[35,20] A. Rozhkov,[11] D. Rozza,[36,37,20] A. Sabellek,[28] R. Sagdeev,[13] J. Sandweiss,[41] B. Santos,[30] P. Saouter,[21] M. Sarchioni,[42] S. Schael,[1] D. Schinzel,[11] M. Schmanau,[28] G. Schwering,[1] A. Schulz von Dratzig,[1] G. Scolieri,[42] E. S. Seo,[14] B. S. Shan,[6] J. Y. Shi,[40] Y. M. Shi,[51] T. Siedenburg,[1] R. Siedling,[1] D. Son,[16] F. Spada,[47] F. Spinella,[44] M. Steuer,[11] K. Stiff,[15] W. Sun,[11] W. H. Sun,[40] X. H. Sun,[23] M. Tacconi,[36,37] C. P. Tang,[23] X. W. Tang,[8] Z. C. Tang,[8] L. Tao,[5] J. Tassan-Viol,[5] Samuel C. C. Ting,[11] S. M. Ting,[11] C. Titus,[11] N. Tomassetti,[42,43] F. Toral,[32] J. Torsti,[53] J. R. Tsai,[26] J. C. Tutt,[25] J. Ulbricht,[54] T. Urban,[25] V. Vagelli,[28] E. Valente,[47] C. Vannini,[44] E. Valtonen,[53] M. Vargas Trevino,[22] S. Vaurynovich,[11] M. Vecchi,[12] M. Vergain,[11] B. Verlaat,[3] C. Vescovi,[22] J. P. Vialle,[5] G. Viertel,[54] G. Volpini,[34,35] D. Wang,[26] N. H. Wang,[50] Q. L. Wang,[7] R. S. Wang,[51] X. Wang,[11] Z. X. Wang,[23] W. Wallraff,[1] Z. L. Weng,[23,52] M. Willenbrock,[11] M. Wlochal,[1] H. Wu,[40] K. Y. Wu,[6,52] Z. S. Wu,[23] W. J. Xiao,[23] S. Xie,[51] R. Q. Xiong,[40] G. M. Xin,[50] N. S. Xu,[23] W. Xu,[8] Q. Yan,[8] J. Yang,[49] M. Yang,[8] Q. H. Ye,[51] H. Yi,[40] Y. J. Yu,[7] Z. Q. Yu,[8] S. Zeissler,[28] J. G. Zhang,[40] Z. Zhang,[23] M. M. Zhang,[23] Z. M. Zheng,[6] H. L. Zhuang,[8] V. Zhukov,[1] A. Zichichi,[9,10] P. Zuccon,[42,11] and C. Zurbach[38]

(AMS Collaboration)

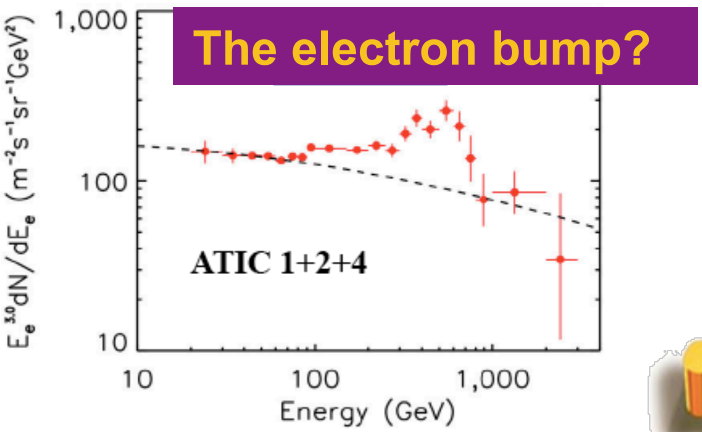
Viewpoint: Positrons Galore

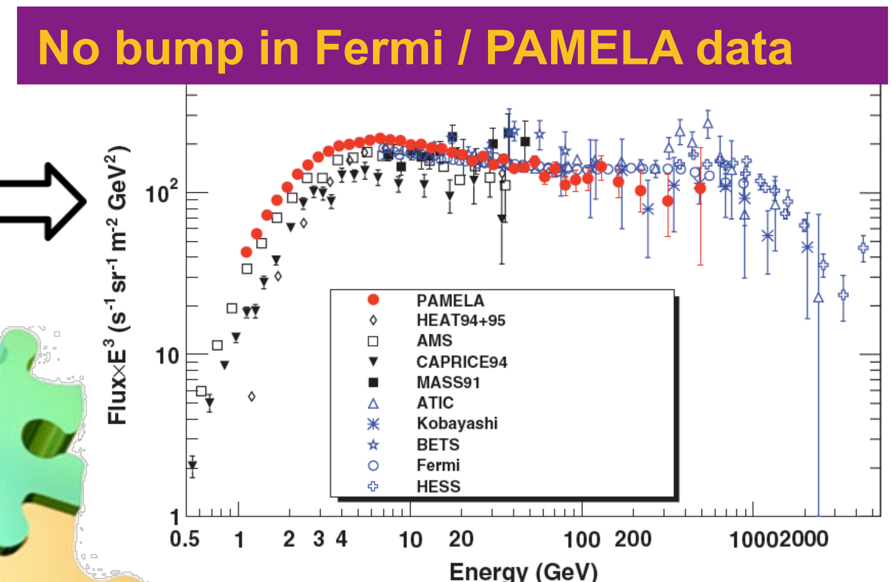
PRL 110, 141102 (2013)

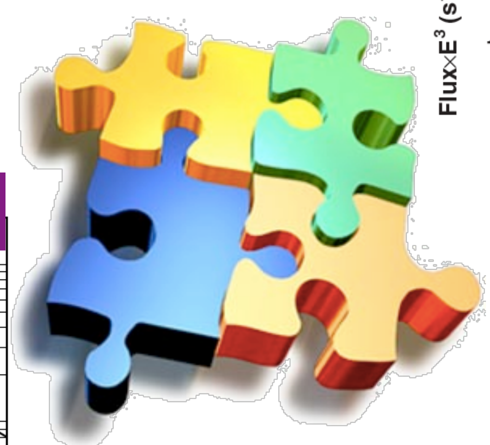


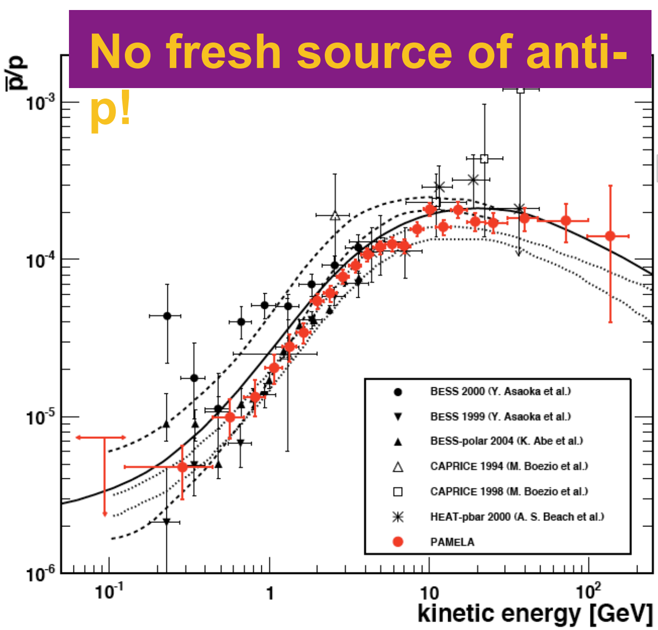
Accurate Measurement of the positron fraction in cosmic rays up to 350 GeV based on unprecedented collected statistics:
6.8 Million electrons collected in space

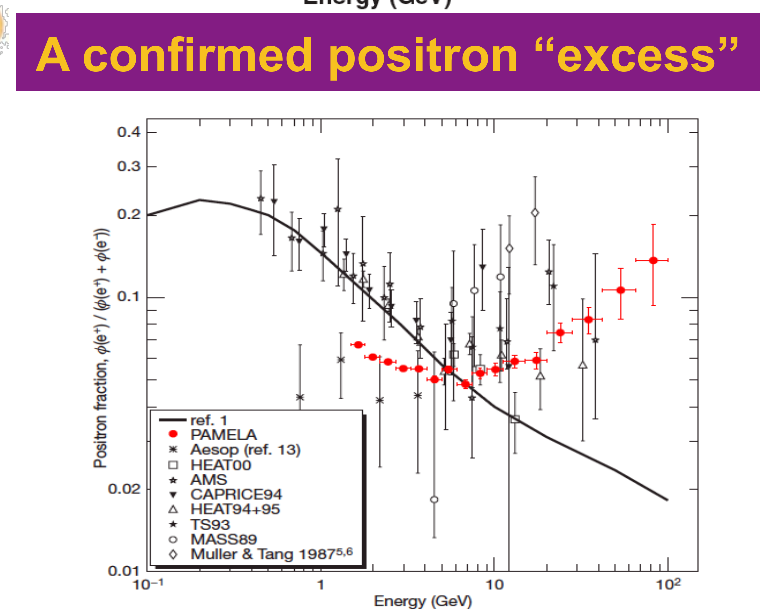
The origin of “excess positrons”?

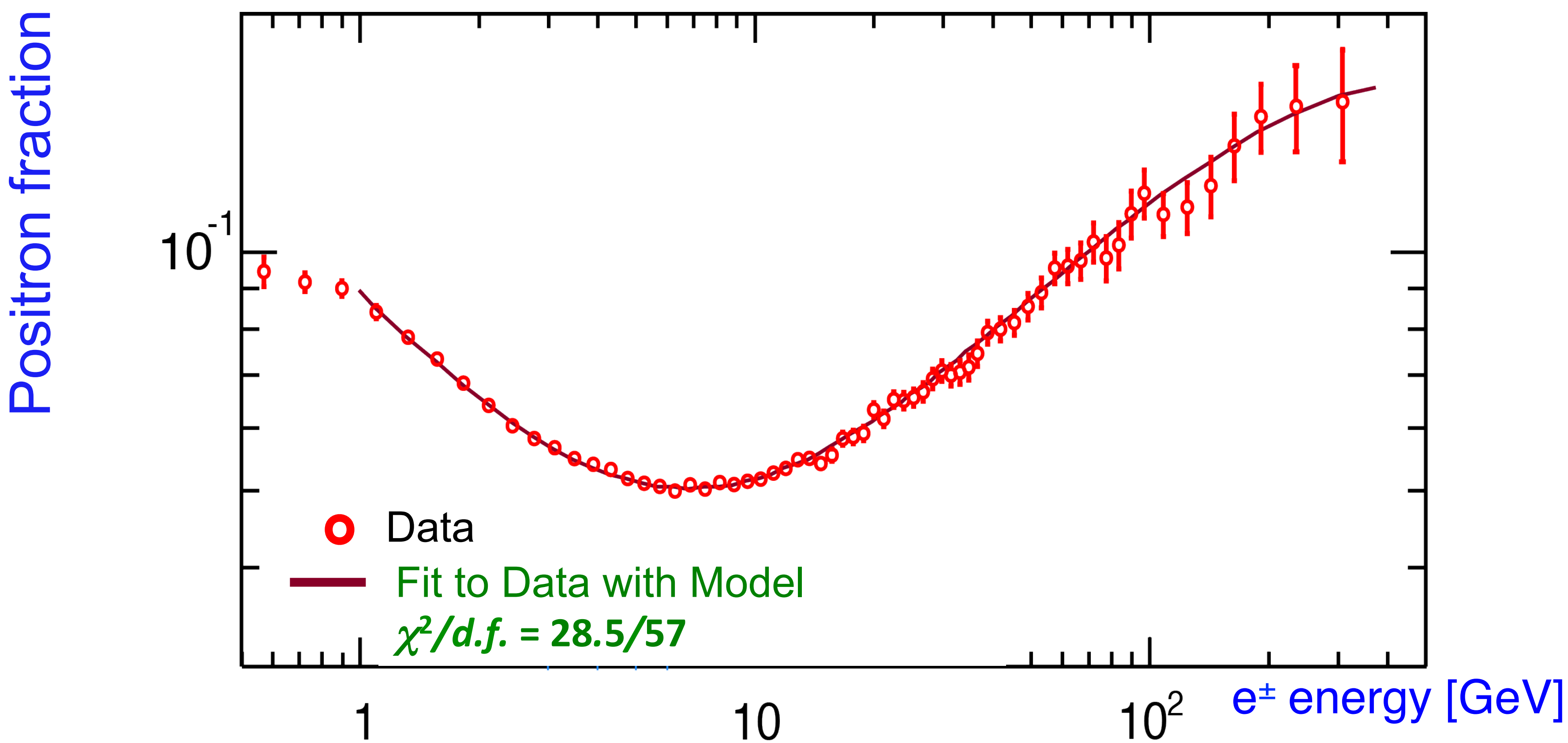












Describe electron and positron fluxes as a sum of a **diffuse component** and a **common source** with a cutoff energy :

$$\Phi_{e^+} = C_{e^+} E^{-\gamma_{e^+}} + C_s E^{-\gamma_s} e^{-E/E_s}$$

$$\Phi_{e^-} = C_{e^-} E^{-\gamma_{e^-}} + C_s E^{-\gamma_s} e^{-E/E_s}$$

→

$\gamma_{e-} - \gamma_{e+}$

$\gamma_{e-} - \gamma_s$

C_{e+}/C_{e-}

C_s/C_{e-}

$1/E_s$

A fit to the data in the energy range 1 to 350 GeV yields a $\chi^2/d.f. = 28.5/57$ and:

$\gamma_{e-} - \gamma_{e+} = -0.63 \pm 0.03$, *i.e.*, the diffuse positron spectrum is less energetic than the diffuse electron spectrum;

$\gamma_{e-} - \gamma_{S} = 0.66 \pm 0.05$, *i.e.*, the source spectrum is more energetic than the diffuse electron spectrum;

$C_{e+}/C_{e-} = 0.091 \pm 0.001$, *i.e.*, the weight of the diffuse positron flux amounts to ~10% of that of the diffuse electron flux;

$C_{S}/C_{e-} = 0.0078 \pm 0.0012$, *i.e.*, the weight of the common source constitutes only ~1% of that of the diffuse electron flux;

$1/E_s = 0.0013 \pm 0.0007\ \mathrm{GeV}^{-1}$,

corresponding to a cutoff energy of 760^{+1000}_{-280} GeV.

The origin of the excess …

…is there any privileged arrival direction?

Analysis of possible deviation of the measured ratio as a function of the arrival direction in galactic coordinates (b,l)

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

Power spectrum from the coefficient of the spherical armonics:

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

Compatible with isotropy in the dipolar mode $\delta = 3\sqrt{C_1/4\pi}$,

δ ≤ 0.036 at the 95% confidence level

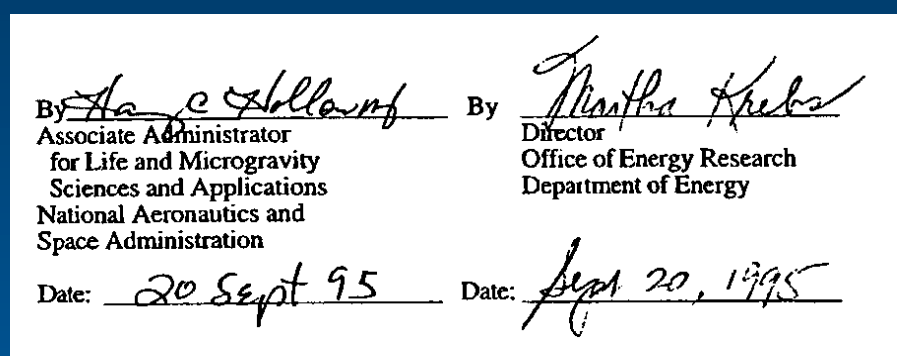
How did we arrive to this??

The origin....1994/1995

- Proposed in 1994
- Signed agreement DOE/NASA in 1995 :

AMS-01 :… precursor flight to test technology

AMS-02: the real experiment…



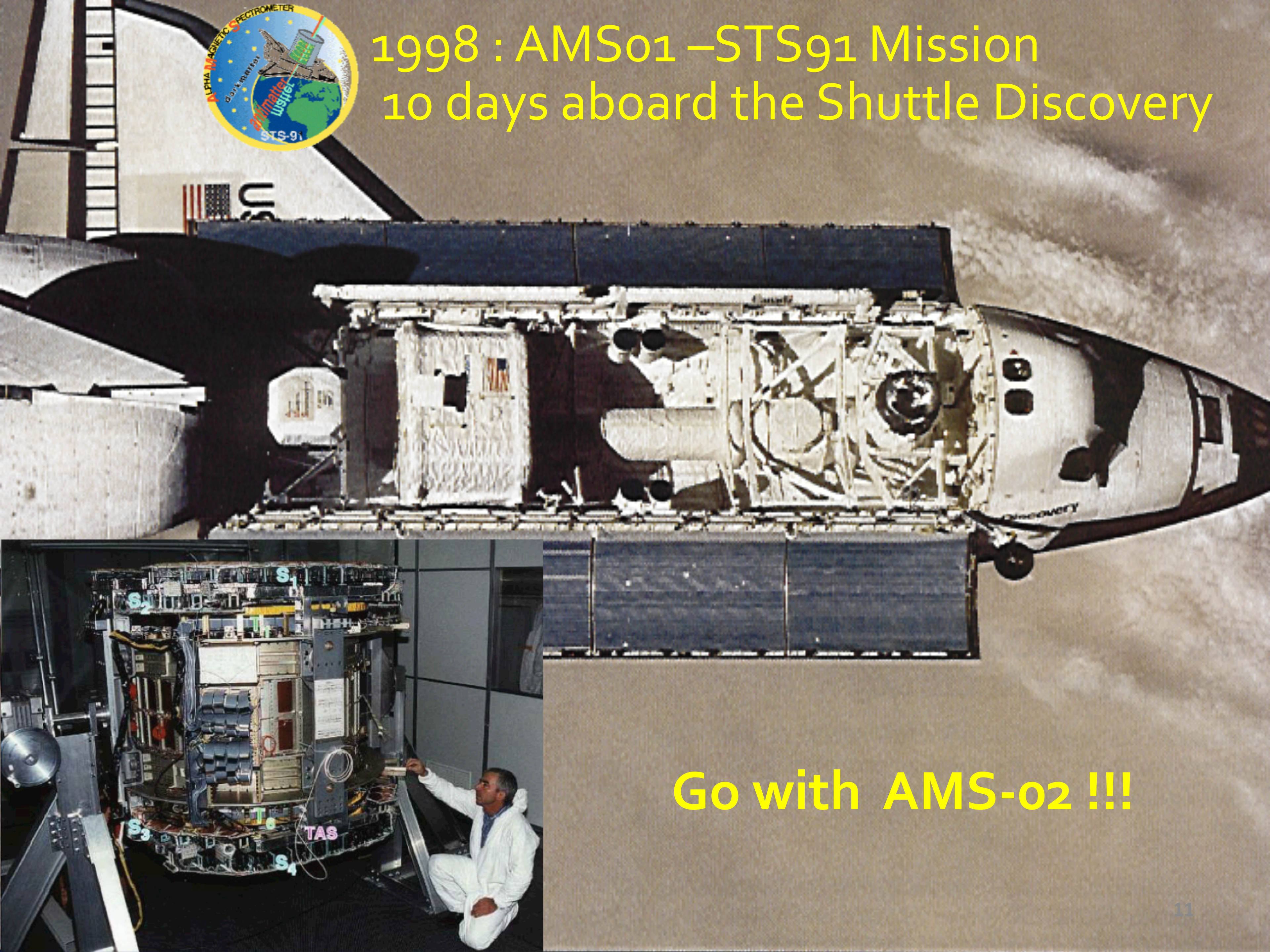
By
Associate Administrator
for Life and Microgravity
Sciences and Applications
National Aeronautics and
Space Administration

Date: 20 Sept 95

By
Director
Office of Energy Research
Department of Energy

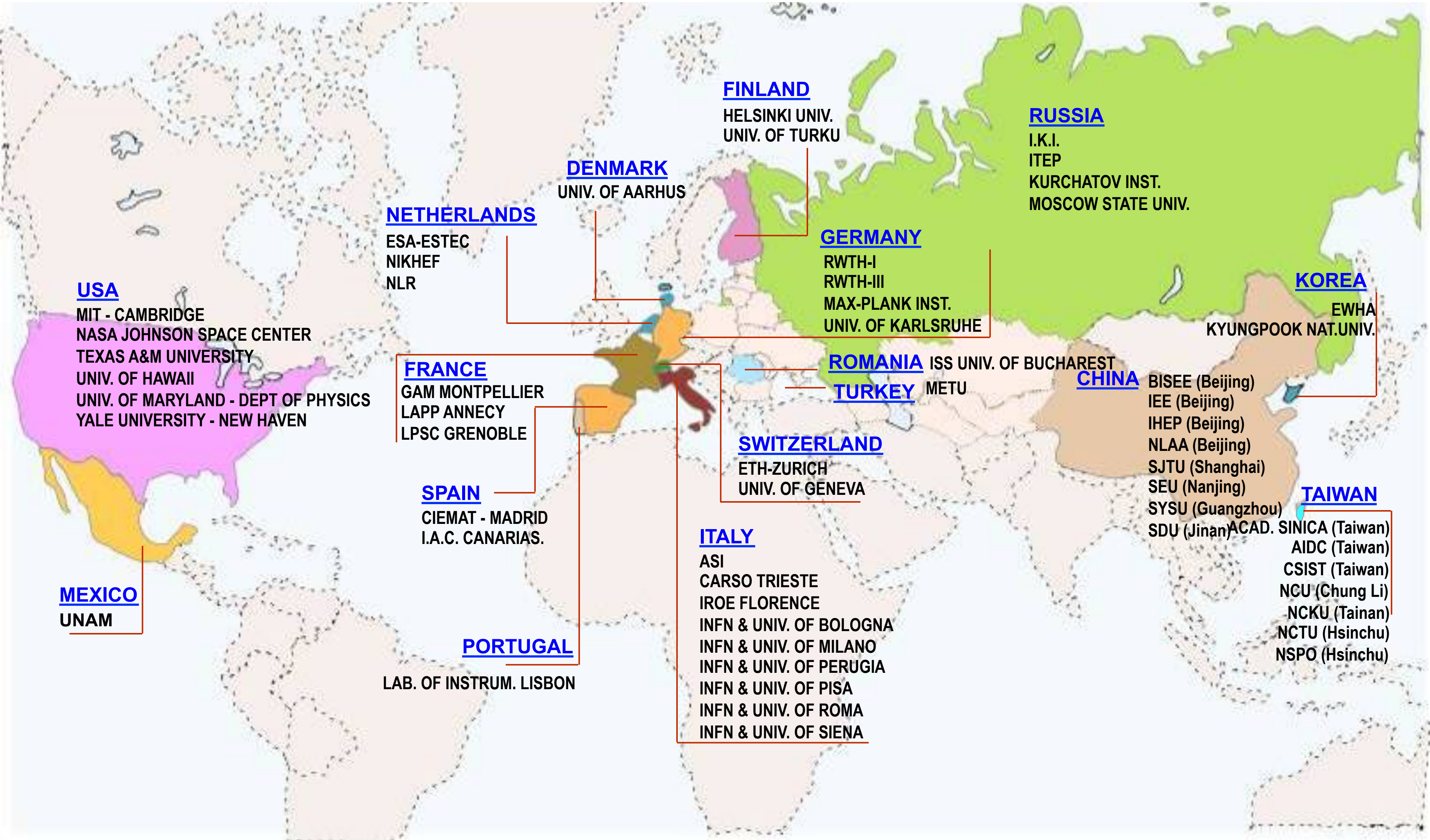
Date: Sept 20, 1995

1998 : AMS01 –STS91 Mission
10 days aboard the Shuttle Discovery



Go with AMS-02 !!!

AMS: a worldwide collaboration



17 years, 16 Countries, 60 Institutes and 600 Physicists

AMS Objectives

- **Fundamental physics & Antimatter :**
  - Primordial origin (anti-nuclei ?)
  - Exotic sources (positrons, anti-p, anti-D?)
- **The CR composition and energy spectrum**

  (how to understand the beam)
  - Sources & acceleration : Proton and He
  - Propagation in the ISM: (B/C, isotopic composition)

→ DESIGN : state of the art detectors providing redundant measurements of particle properties

→ TEST: test and calibration on ground

→ MONITORING on ISS : calibration on flight

AMS Objectives according to some blogs…

http://www.rumormillnews.com/cgi-bin/archive.cgi?read=204750

…Shuttle Endeavor's official mission is to haul a deliberately-mislabeled "Alpha Magnetic Spectrometer" (AMS-02) to the International Space Station and install it. NASA claims that the AMS-02 is a state-of-the-art particle physics detector. In actuality the AMS-02 is an advanced extreme-energy neutral-particle-beam space weapon intended to shoot down Star Visitor craft (UFOs). And instead of the International Space Station, Shuttle Endeavor will deliver the AMS-02 Star Wars weapon to a secret military space station, also in orbit….

….

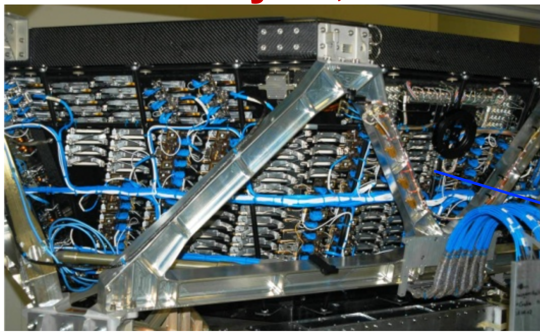
You are invited to join in a Joint Psychic Exercise to address these problems.

…

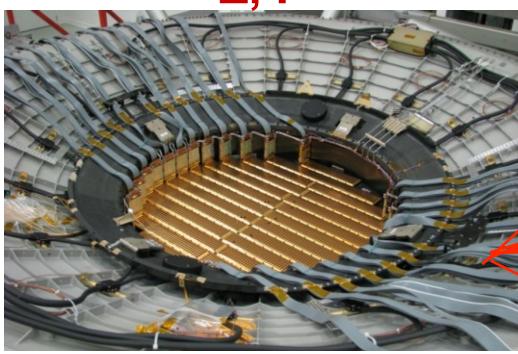
We will focus on one or both of two things. First is to direct telekinetic, electrical-pulse, disruptive-magnetic, and/or other energies to deactivate the AMS-02 neutral-particle-beam weapon and render it inoperative. Thus there will be nothing useful to deliver to the military space station.

AMS: A TeV precision, multipurpose spectrometer on the ISS

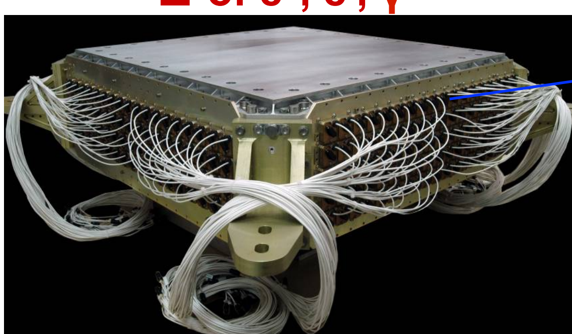
TRD
Identify e^+, e^-



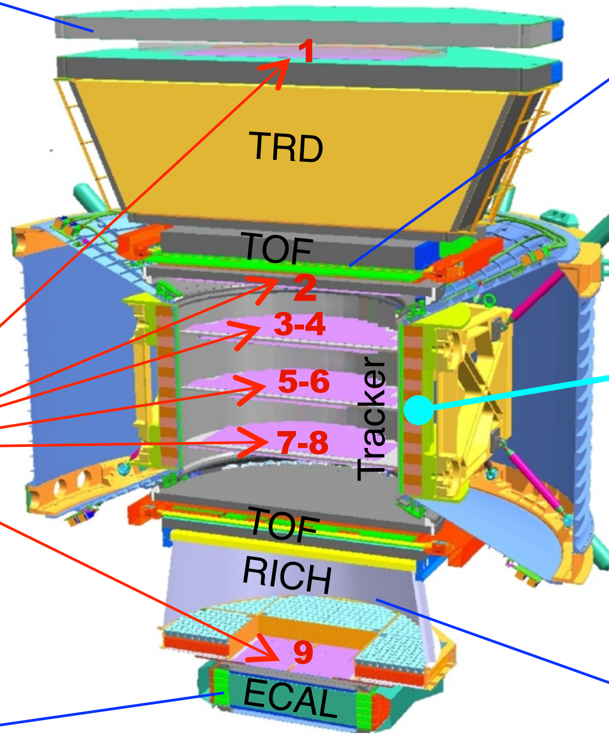
Silicon Tracker
Z, P



ECAL
E of e^+, e^-, γ



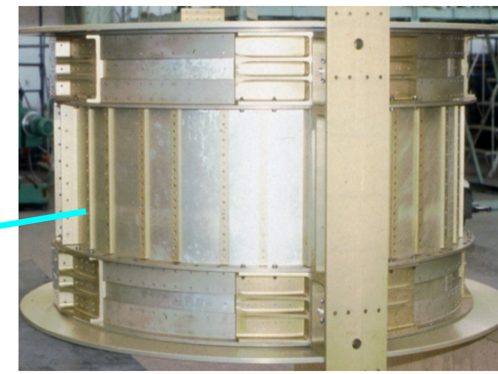
Particles and nuclei are defined by their charge (Z) and energy (E ~ P)



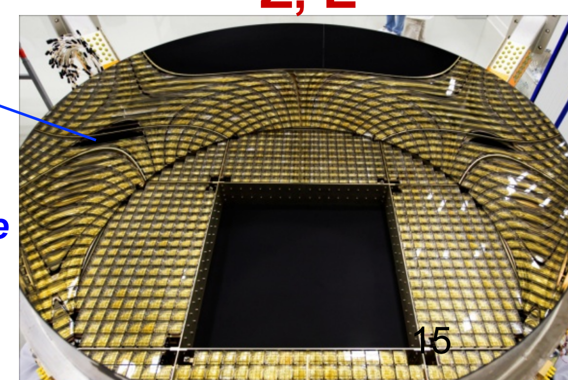
***Z, P* are measured independently by the Tracker, RICH, TOF and ECAL**

TOF
Z, E

Magnet
±Z



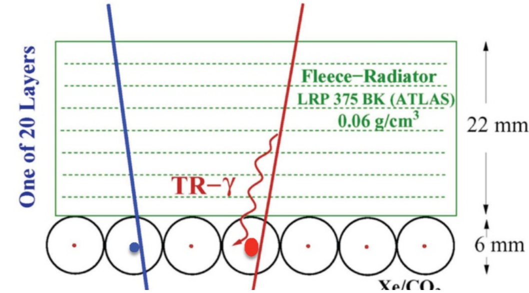
RICH
Z, E



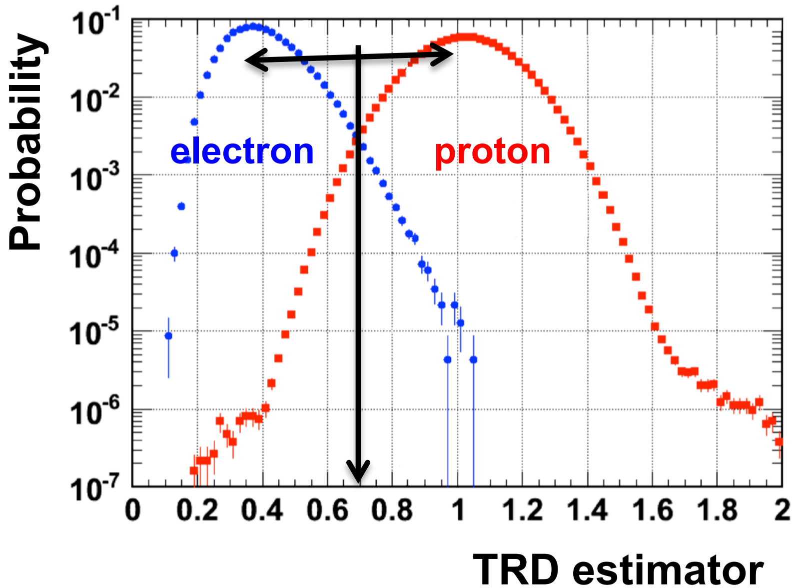
AMS- Detectors in a nutshell

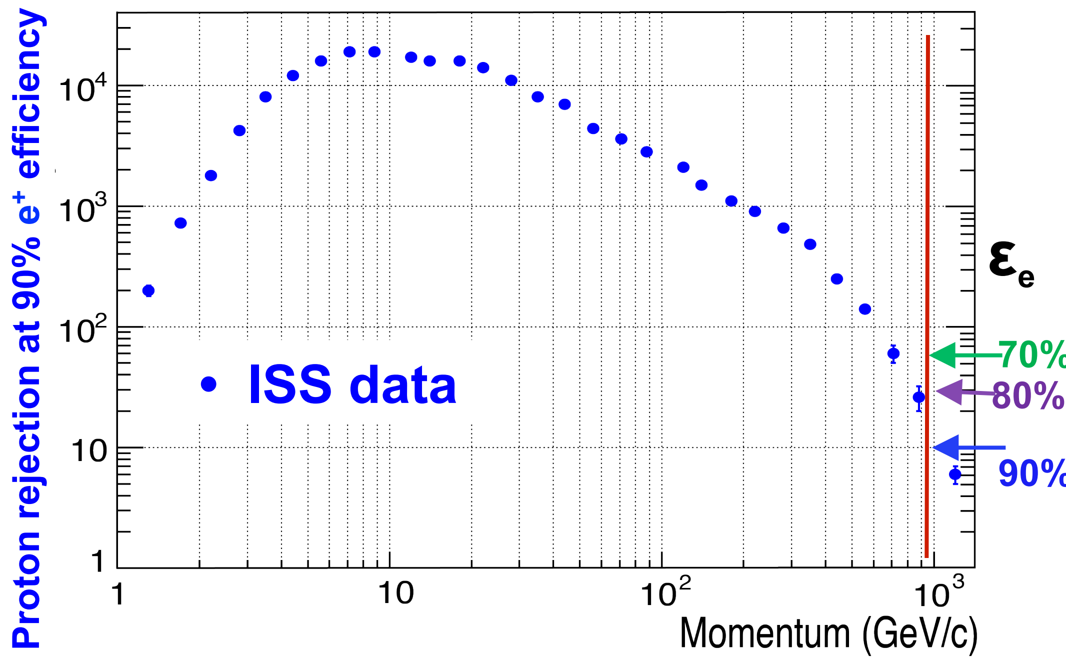
TRD

20 layers of fiber fleece radiators interleaved with 80/20 Xe/Co2 straw tubes. e/p separation > 10^2



TRD estimator = $-\ln(P_e/(P_e+P_p))$



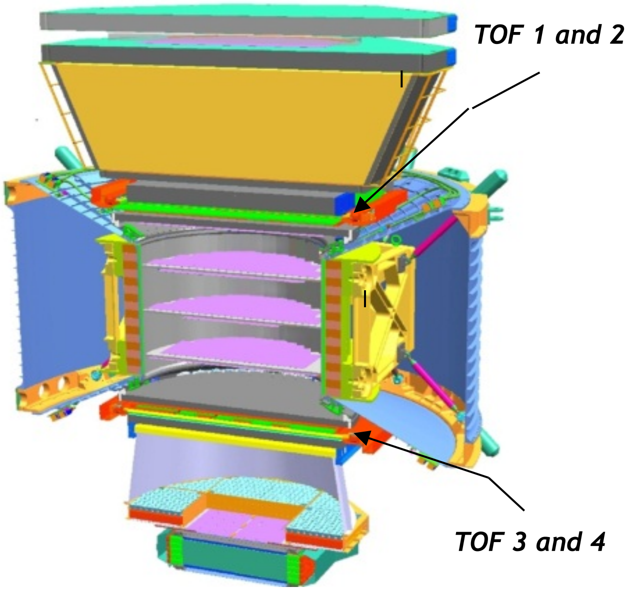


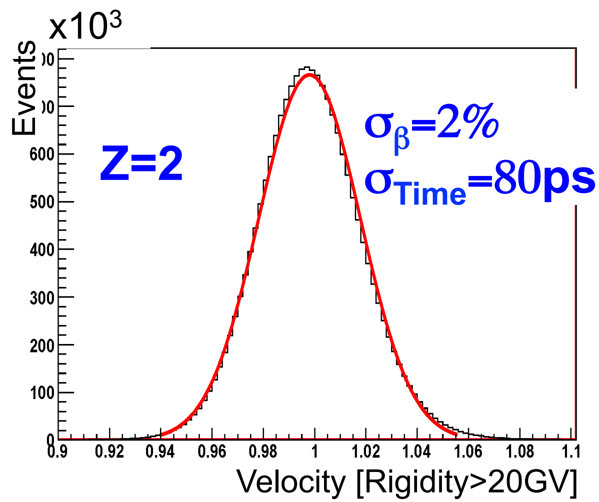
Normalized probabilities P_e and P_p

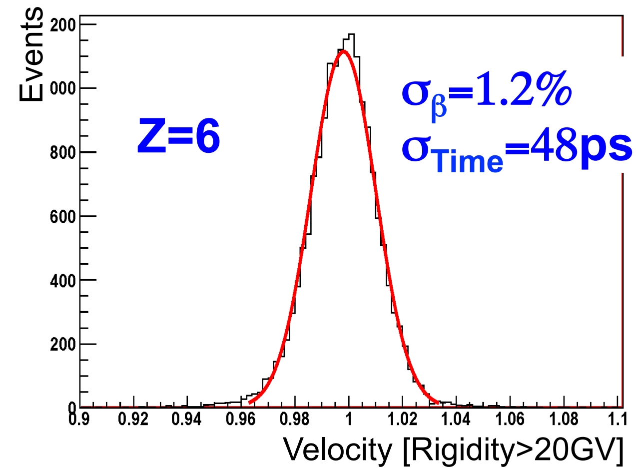
$$P_e = \sqrt[n]{\prod_i^n P_e^{(i)}(A)} \qquad P_p = \sqrt[n]{\prod_i^n P_p^{(i)}(A)}$$

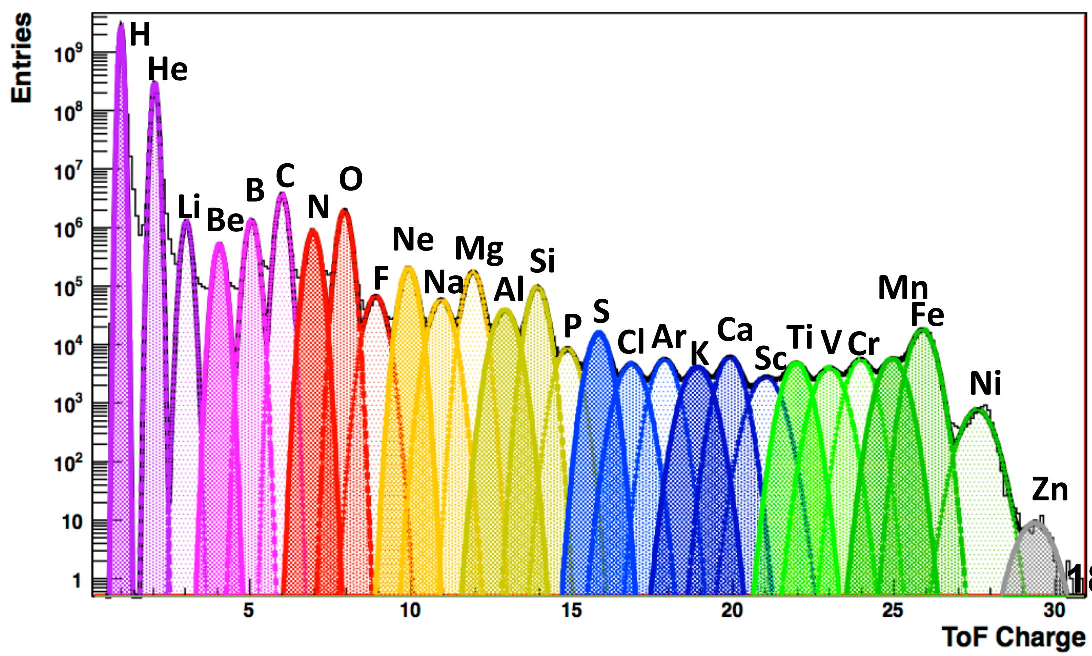
Time of Flight System

Measures Velocity and Charge of particles

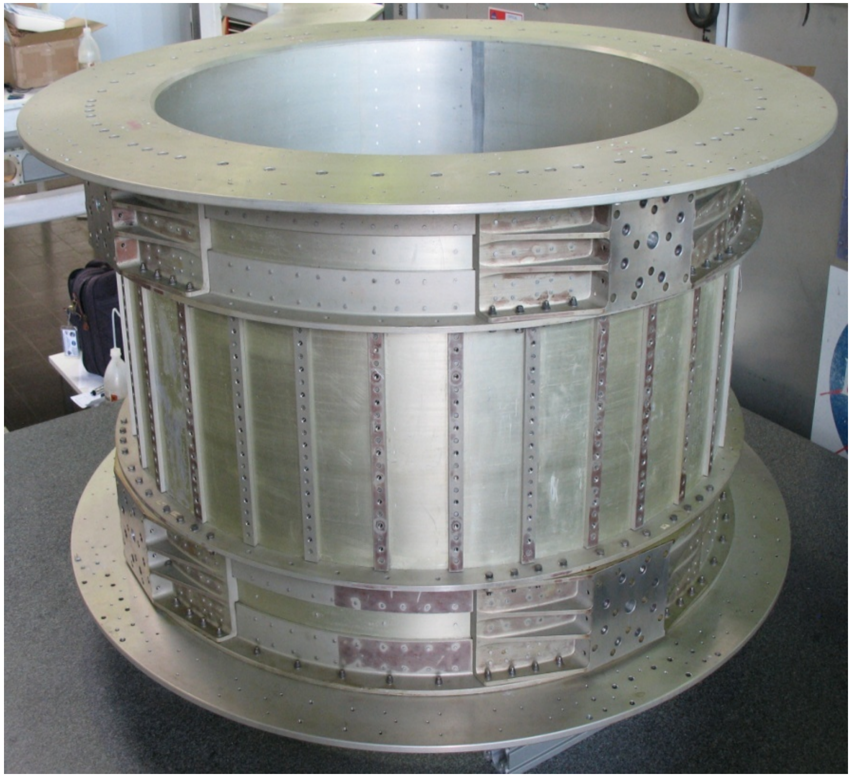


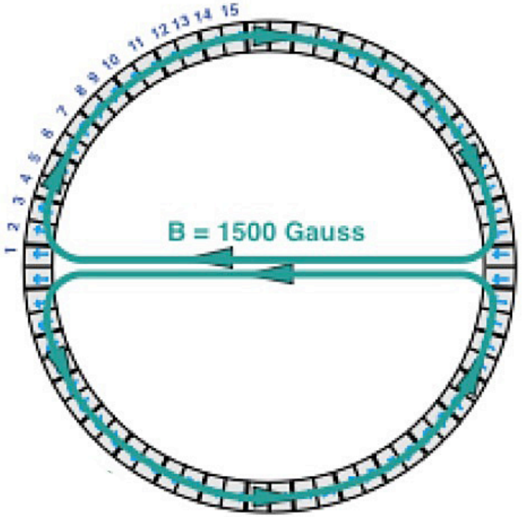






The Magnet

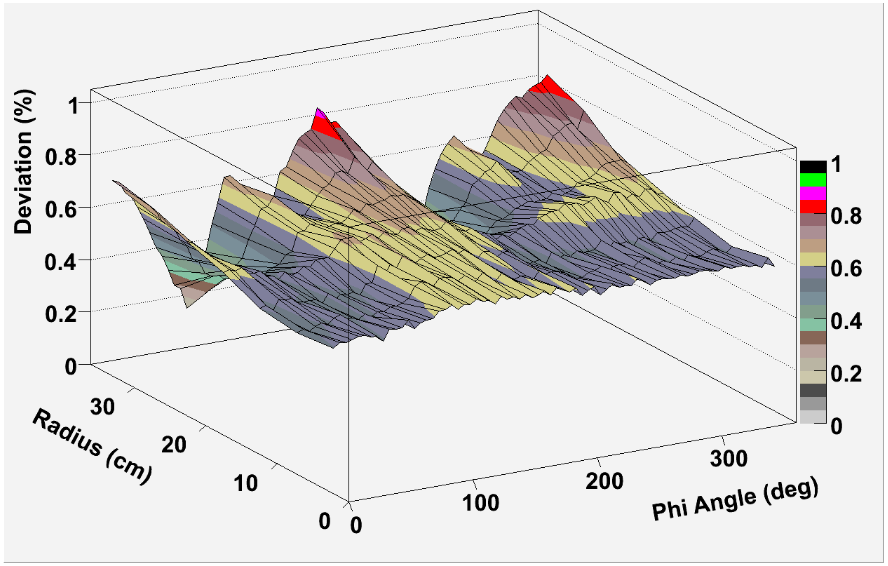




1. Stable: no torque
2. Safety : no field leak out of the magnet
3 . Low weight: no iron

The detailed 3D field map (120k locations) was measured in May 2010

It was found that the deviation from the 1997 measurement had remained the same to <1%



Tracker:

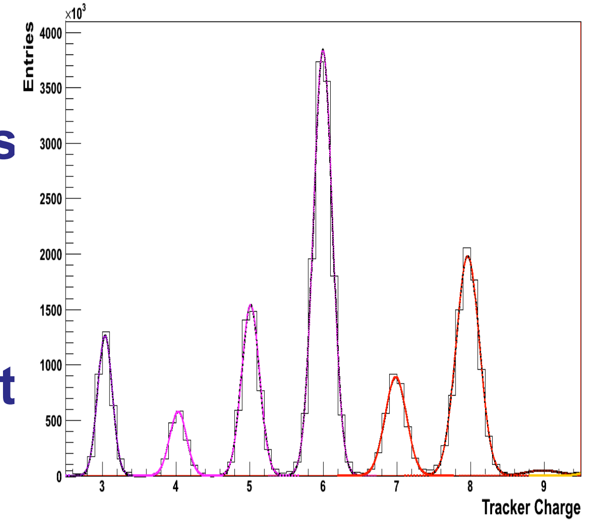
9 layers of double sided silicon microstrip detectors

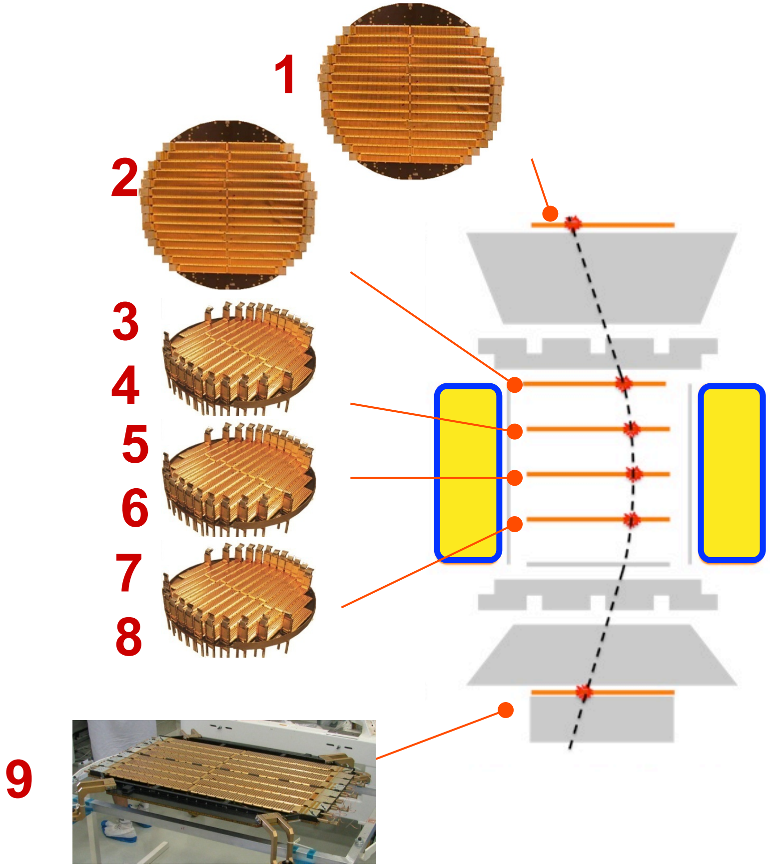
192 ladders / 2598 sensors/ 200k readout channels

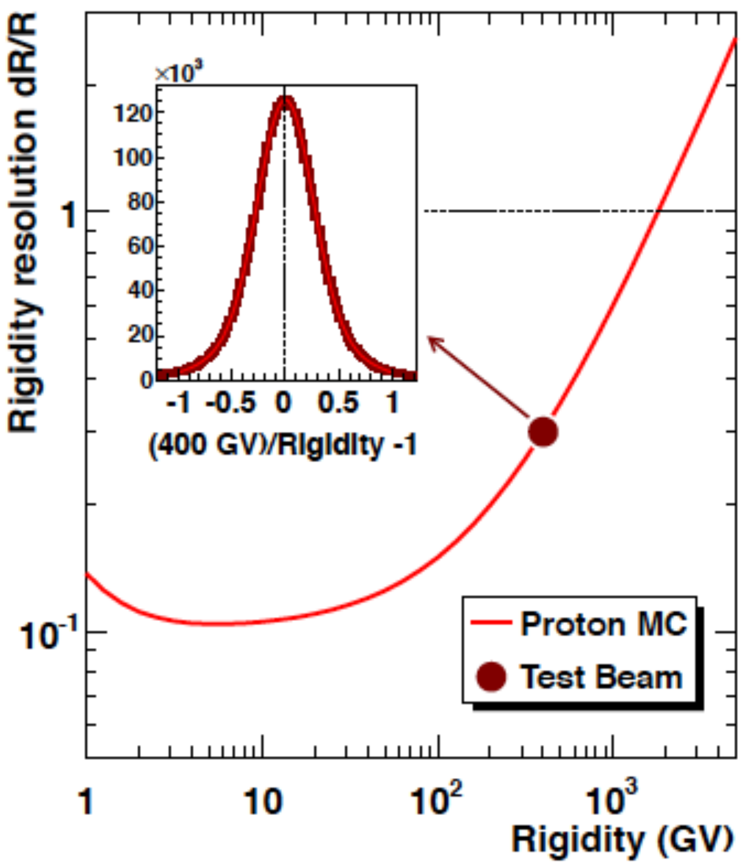
Coordinate resolution 10 μ

→ 20 –UV Lasers to monitor inner tracker alignment

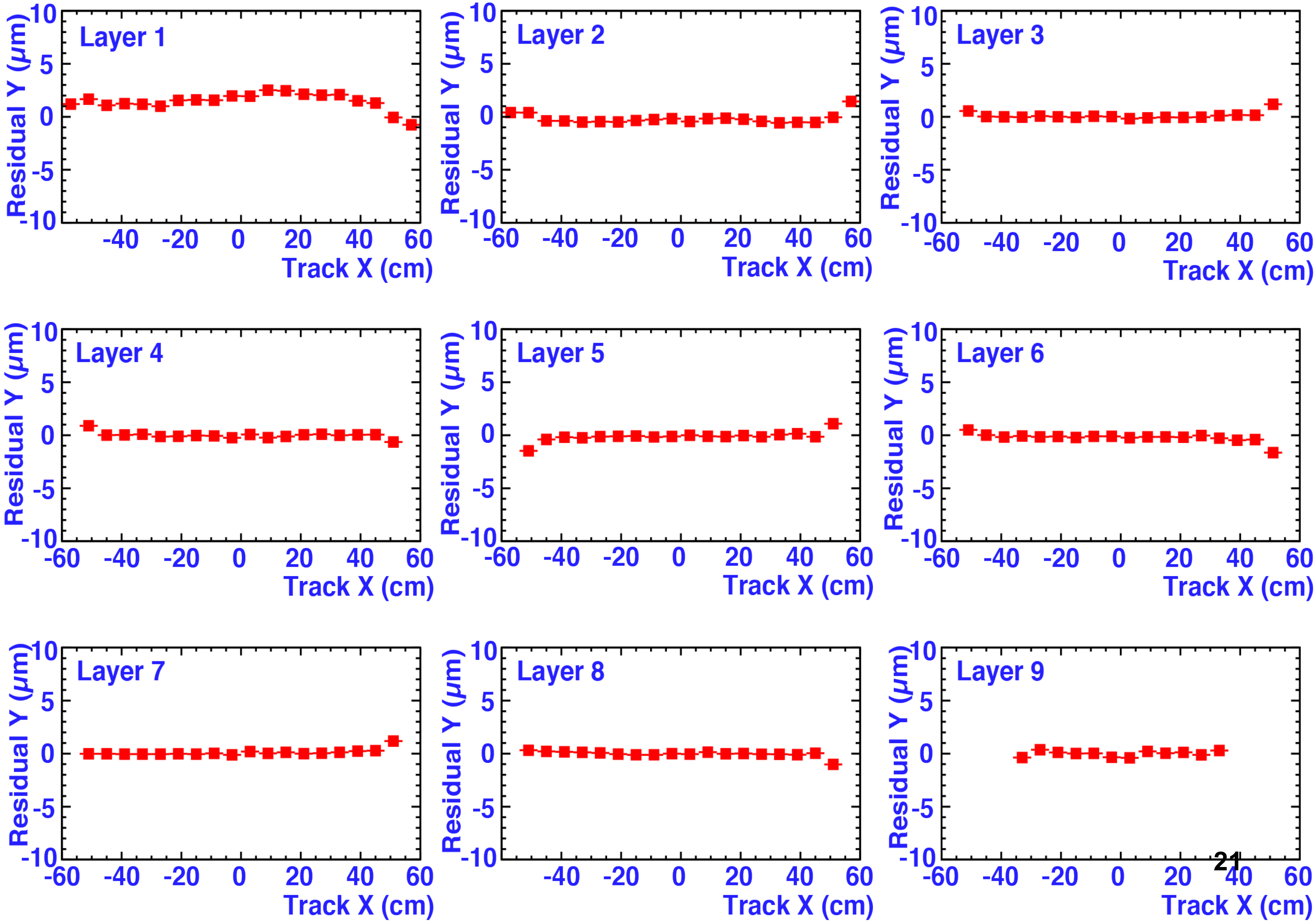
→ Cosmic rays to monitor outer tracker alignment





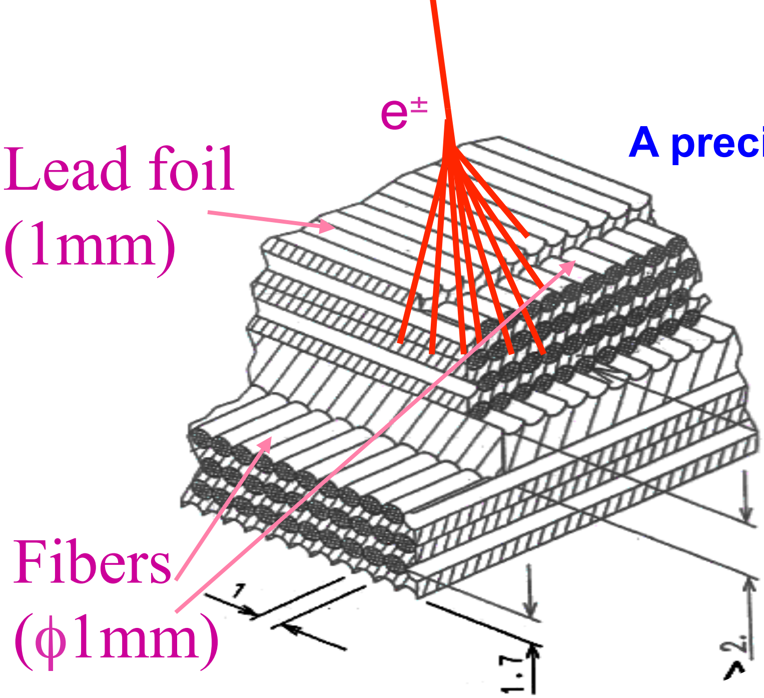


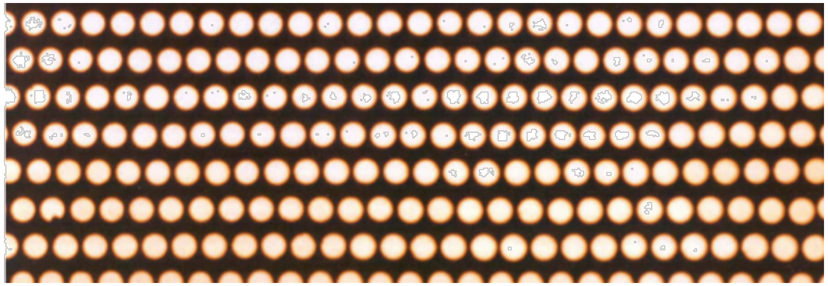
Alignment accuracy of the 9 Tracker layers over 18 months



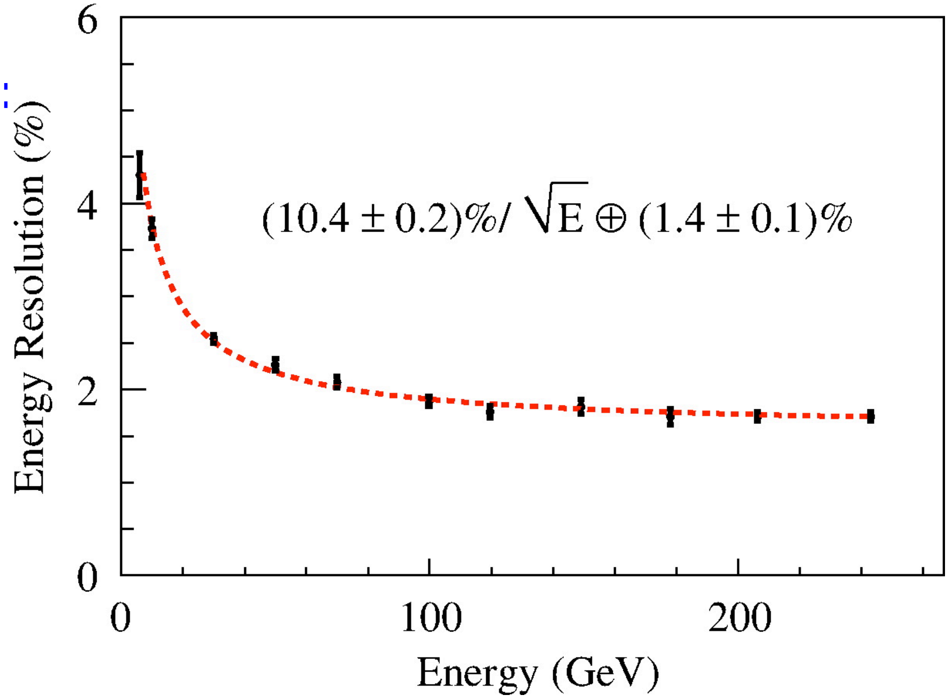
Calorimeter (ECAL)

A precision, 3-D measurement of the directions and energies of gammas and electrons up to 1 TeV

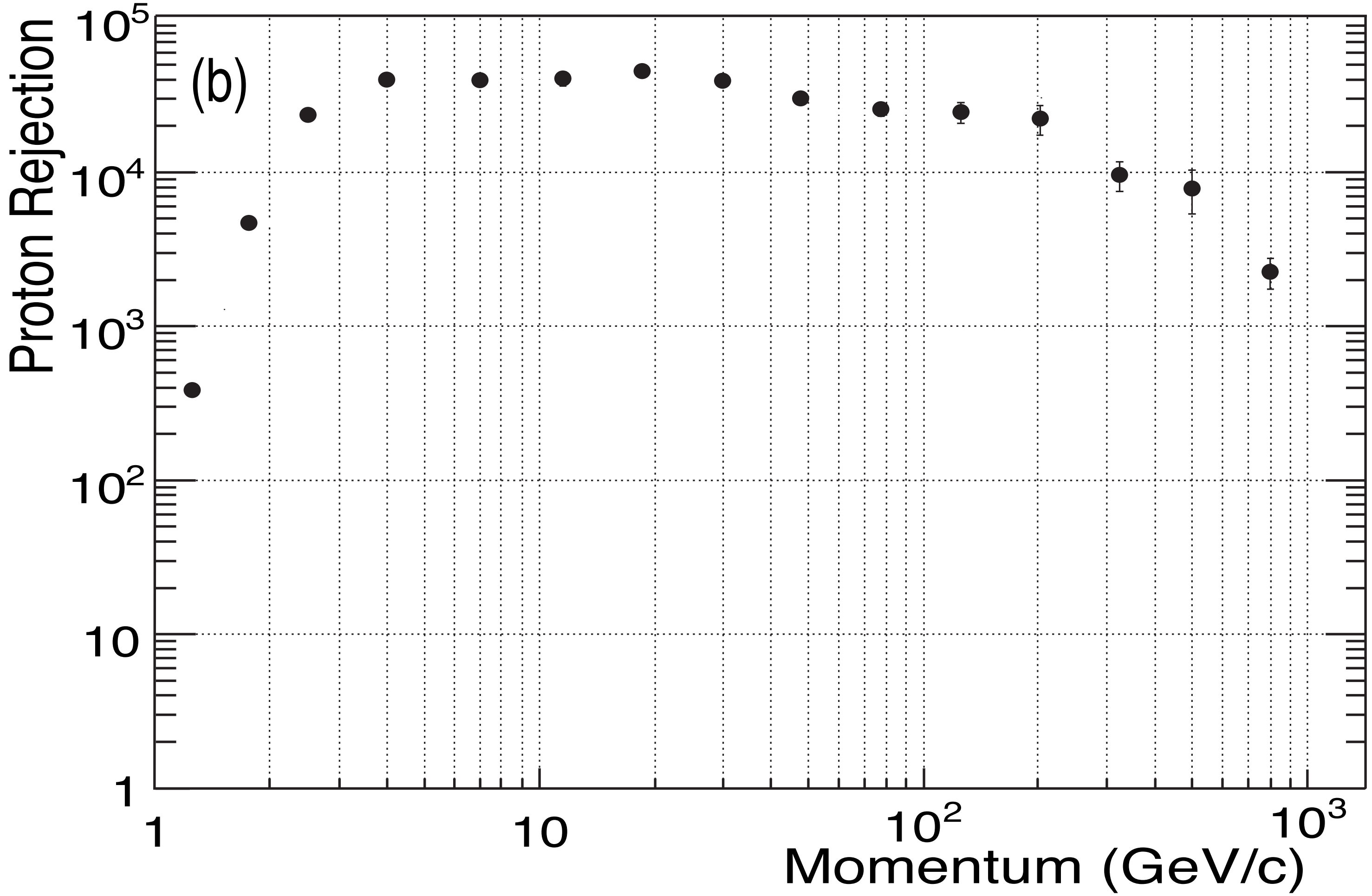




50,000 fibers, ϕ = 1 mm
distributed uniformly Inside 600 kg of lead:



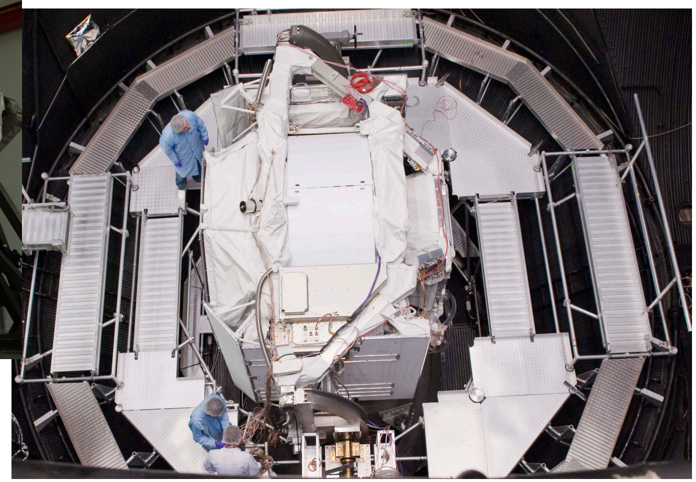
e/p separation with ECAL+trk

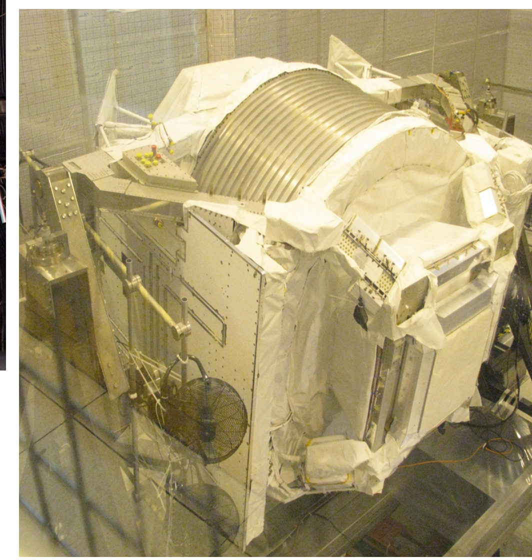


For all detectors:

Before assembly : Beam test, Thermal, Vibration, TVT,EMI
After assembly : EMI, TVT, Beam Test

5m x 4m x 3m
7.5 tons





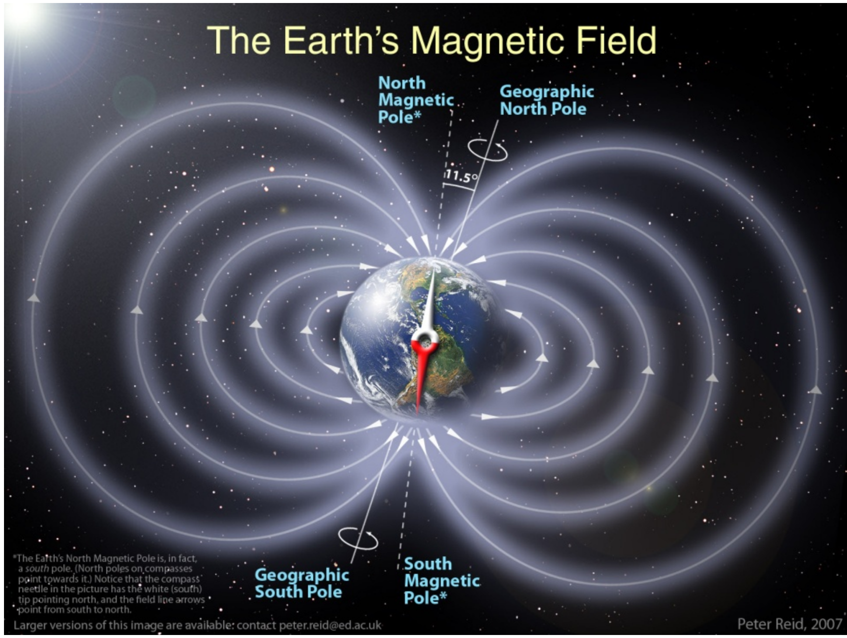
May 19, 2011: AMS installation completed.

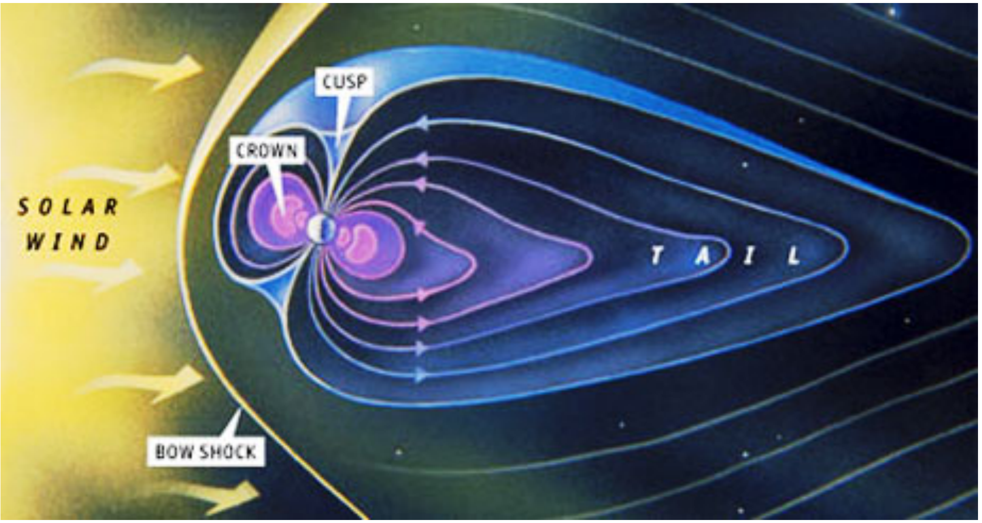
33 billion events in 2 years
≈80 TB of raw data
≈ 400 TB of reconstructed data

The environment

The Geomagnetic Field

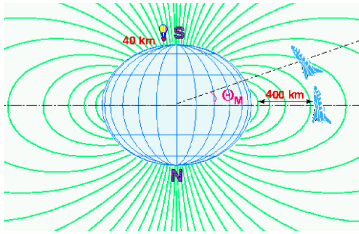
The Earth magnetic field can roughly be considered as a dipole, whose axis is tilted with respect to the rotation axis and whose center is shifted with respect to the Earth's center.



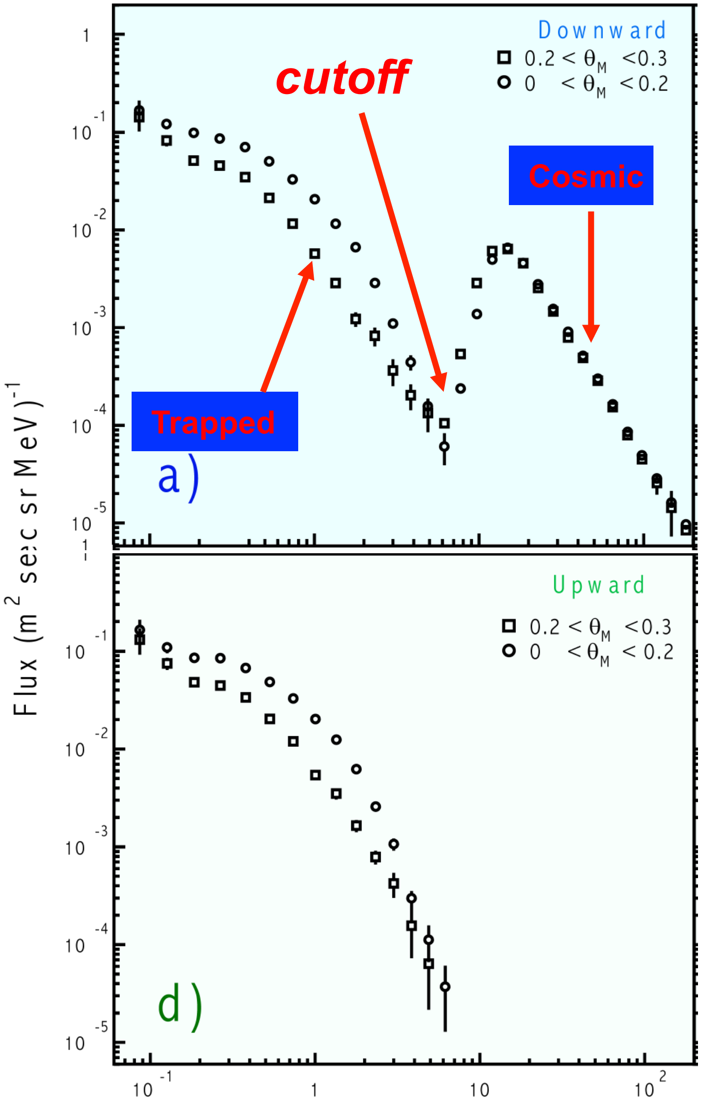


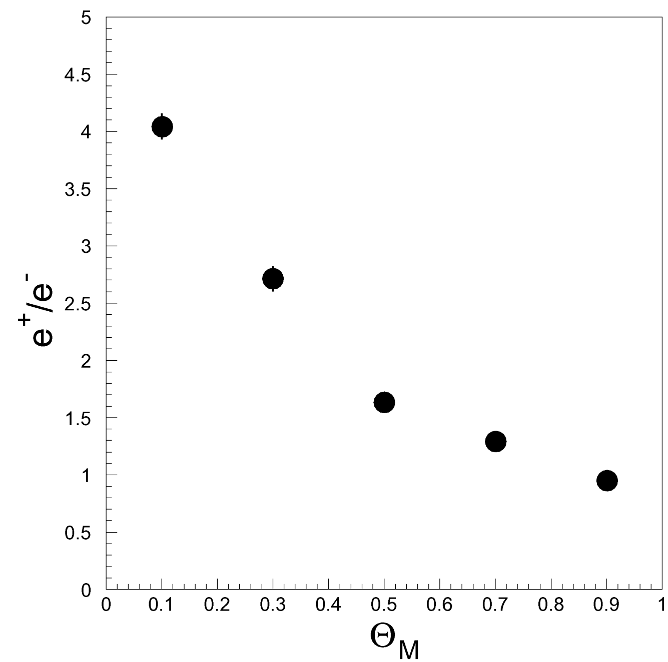
Due to the compression of the solar wind it becomes widely asymmetric with a long tail opposite to the Sun

Magnetospheric effects on CR: The cutoff



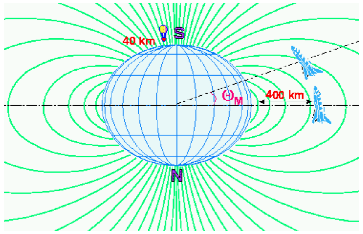
M. Aguilar et al. / Physics Reports 366 (2002) 331–405

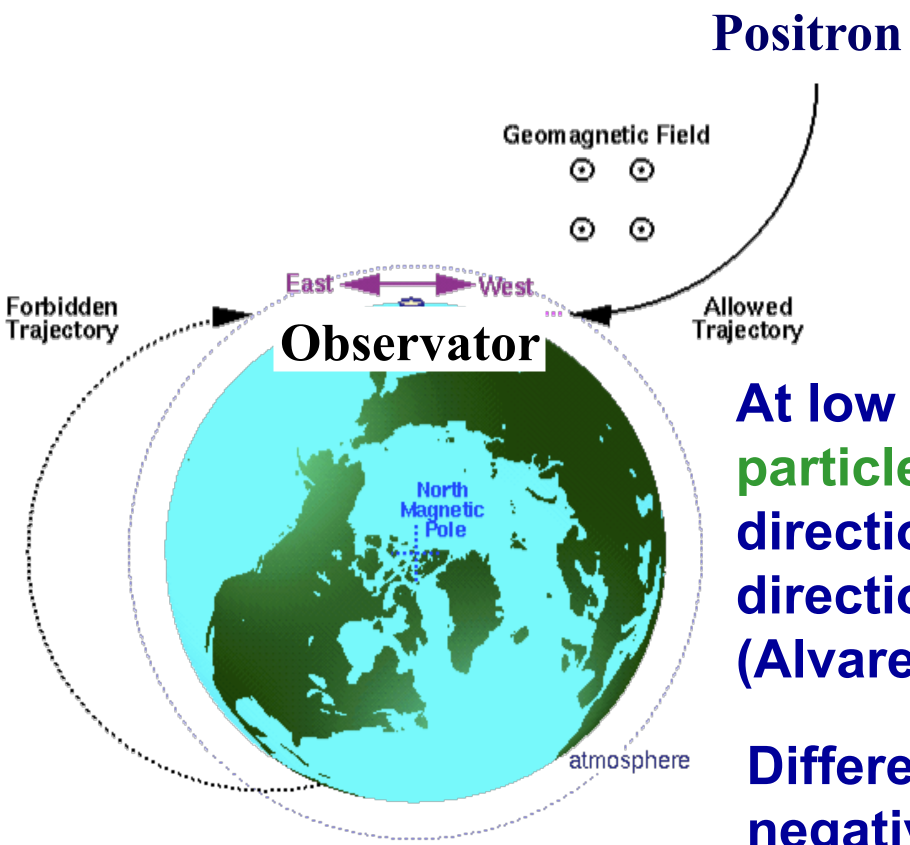




In all analyses primary and secondary particles need to be separated as a function of the position of AMS in the earth's magnetic field

Magnetospheric effects on CR: The east-west effect





Due to magnetic field, for a given detector position not all trajectories are allowed for primary particles
The effect is more and more important at low rigidities.

At low Rigididies (<20 GV) positive particles arrives mainly from West direction. Negative particle from East direction.
(Alvarez & Compton, 1934, Rossi, 1934)

Different "exposures" to positive and negative charged particles as a function of detector position → need to carefully model these effects.

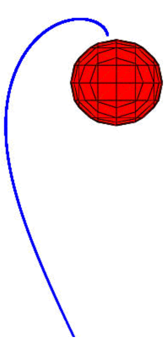
Evaluation/correction for Magnetospheric effects in AMS

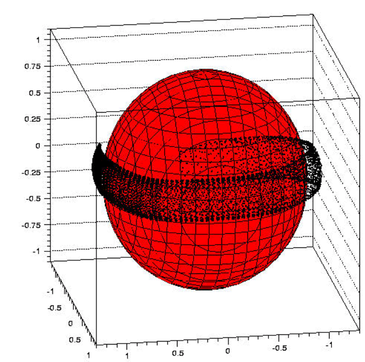
- ✓ **Geomagnetic model implementation**
- ✓ **Definition of Geomagnetic Coordinates**
- ✓ **Evaluation of Geomagnetic Cutoff for each particle**
- ✓ **Evaluation of maximum geomagnetic cutoff for positive/negative particles as a function of position and FOV.**

Based on Stoermer dipole approach

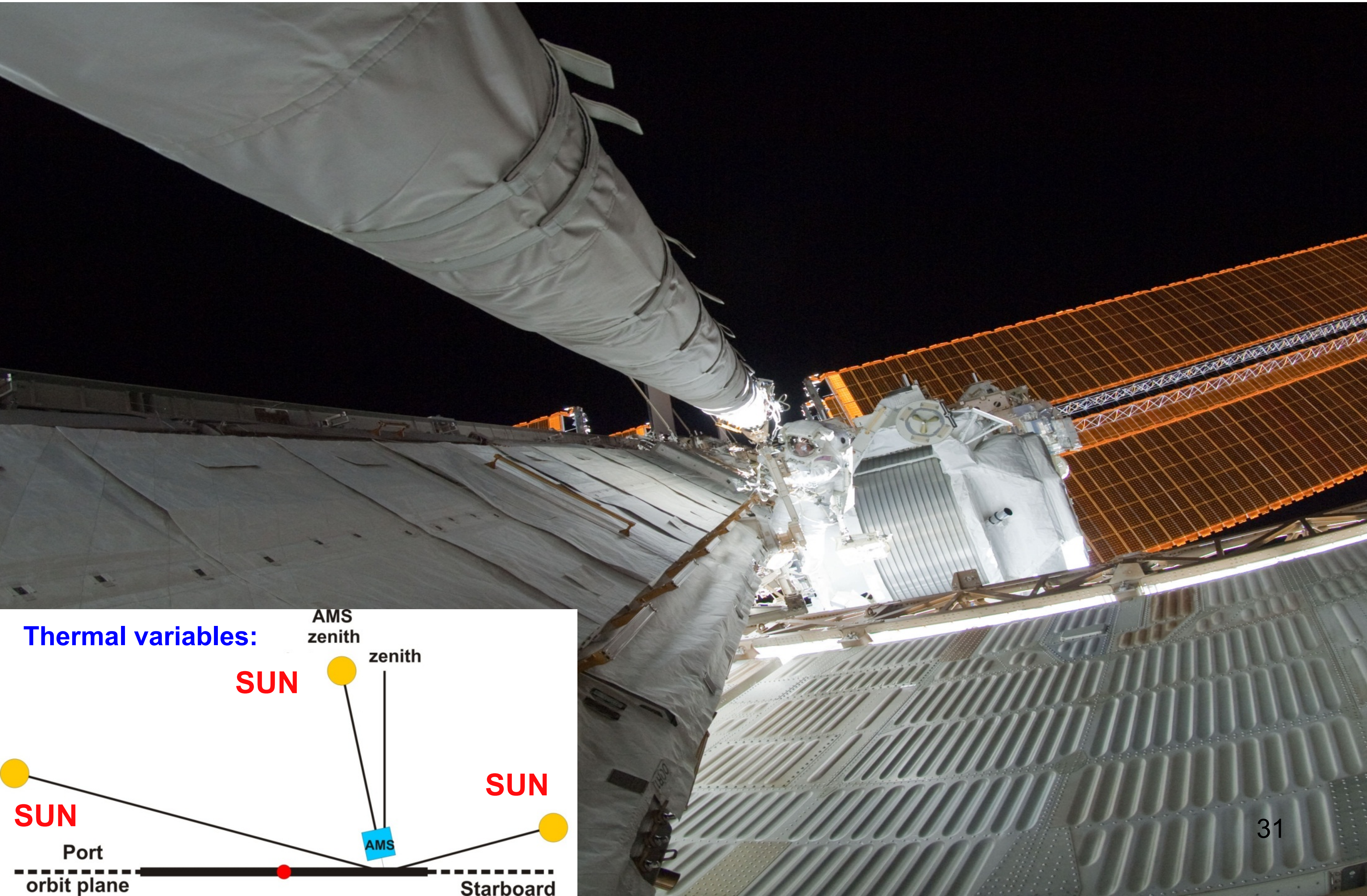
$$R_{cut} = \frac{M}{R_E^2}\left[\frac{1-\sqrt{1-\sin\vartheta\cos^3\lambda_{geo}}}{\sin\vartheta\cos\lambda_{geo}}\right]^2$$

Backtracing of individual particle trajectories



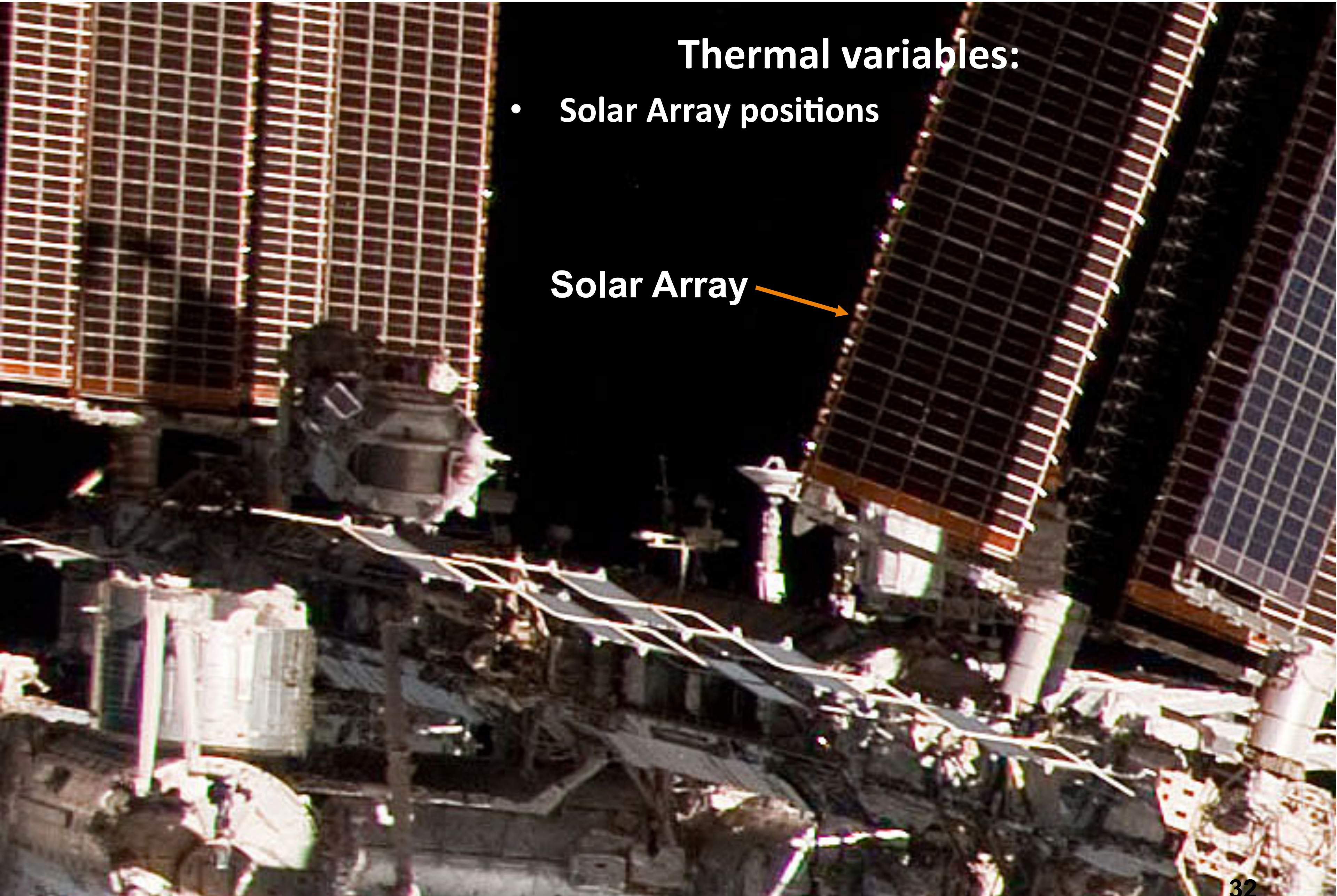


The Thermal environment



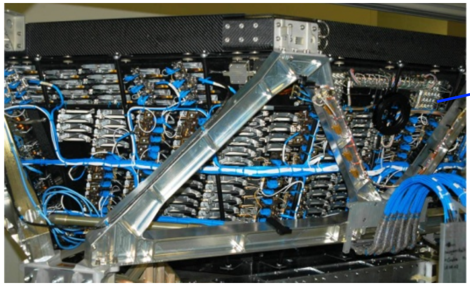
Thermal variables:

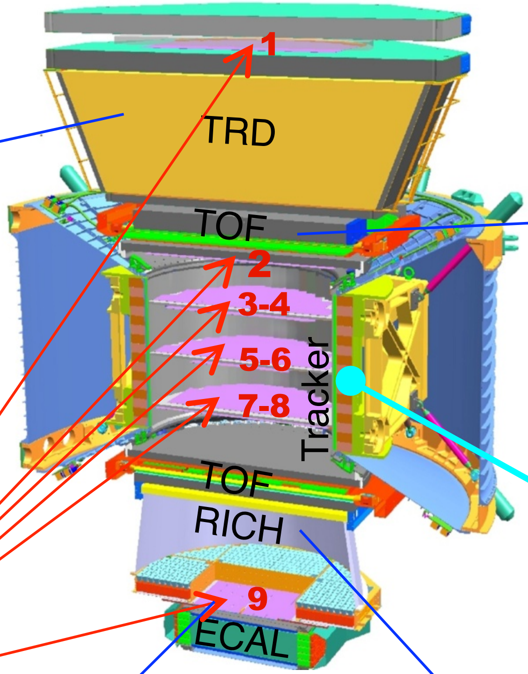
- Solar Array positions



AMS Flight Electronics for Thermal Control

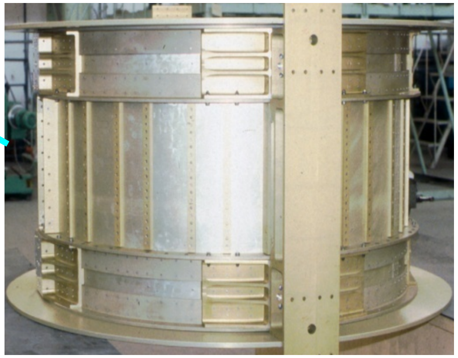
TRD
24 Heaters
8 Pressure Sensors
482 Temperature Sensors



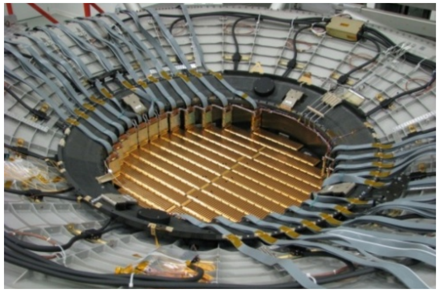


TOF & ACC
64 Temperature Sensors

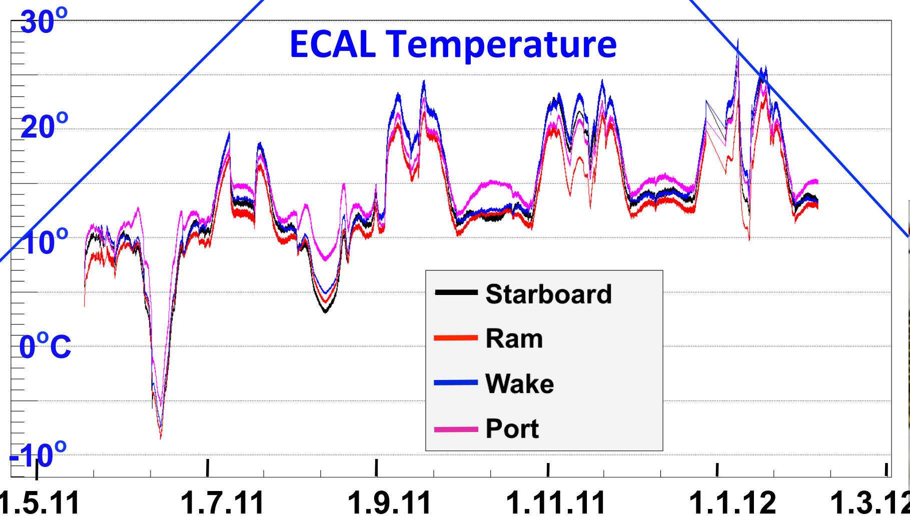
Magnet
68 Temperature Sensors



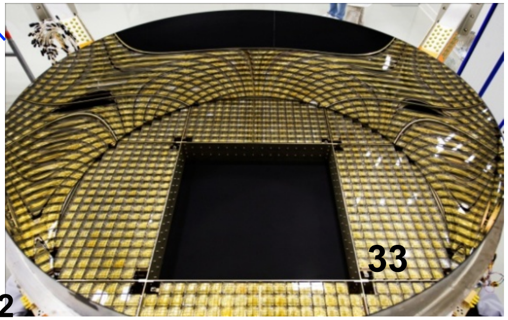
Silicon Tracker
4 -Pressure Sensors
32 Heaters
142 Temperature Sensors



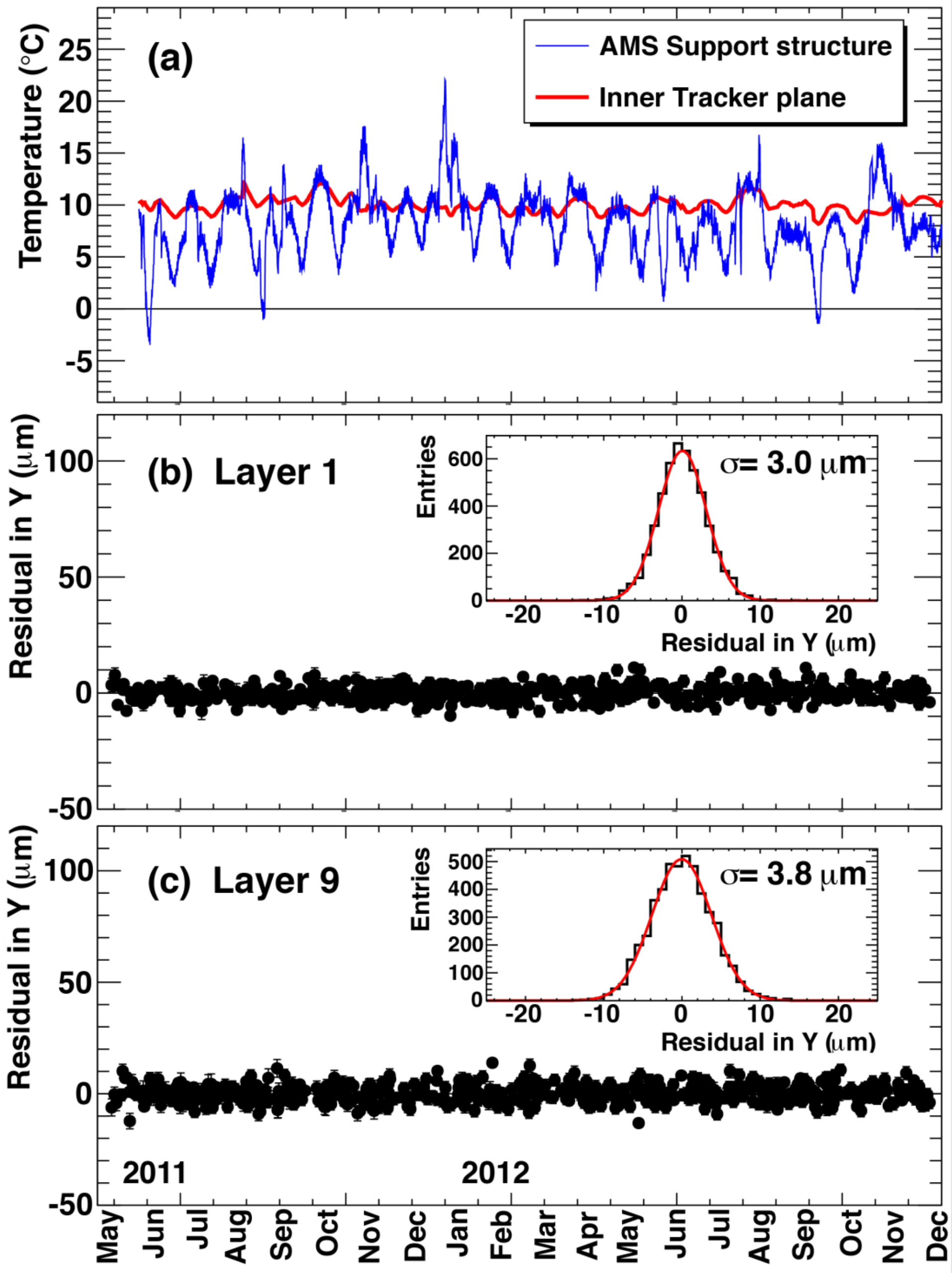
ECAL
80 Temperature Sensors



RICH
96 Temperature Sensors

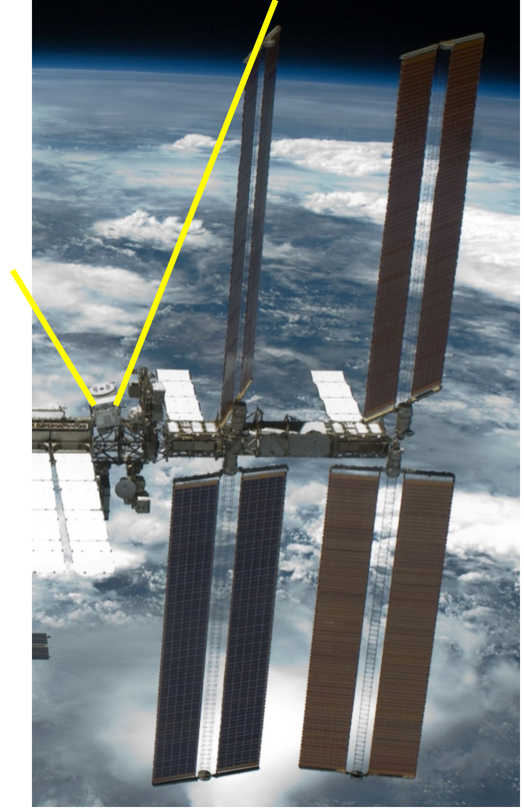


Stability of the alignment on Tracker plane 1 & 9



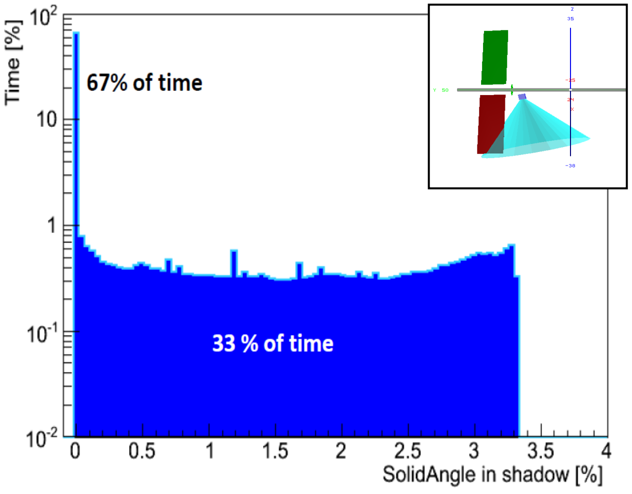
The Solar Panel Shadow

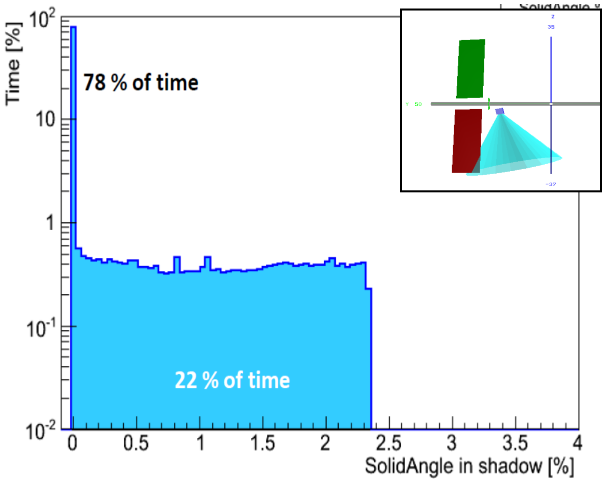
Two ISS Solar Arrays are close to the AMS position on ISS: even though the AMS zenith angle is tilted of 12° wrt zenith rotation of the SA over the orbit/or in parking position may shadow the AMS FOV .

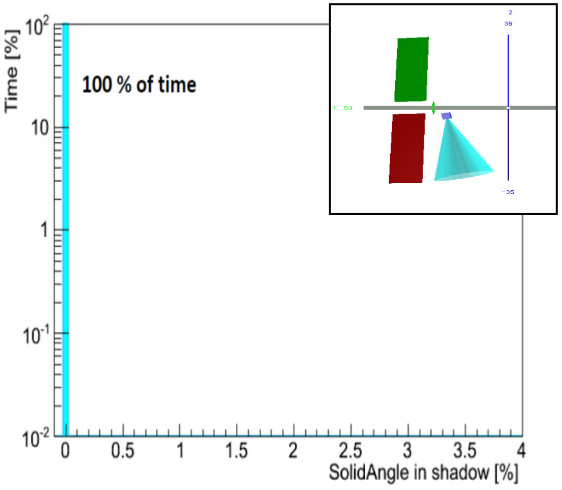


- **Study the fraction of time the SA are within the AMS FOV**
- **Verify the size of the shadow**

- **No effect (< 0.6% of the events on the FOV edge)**



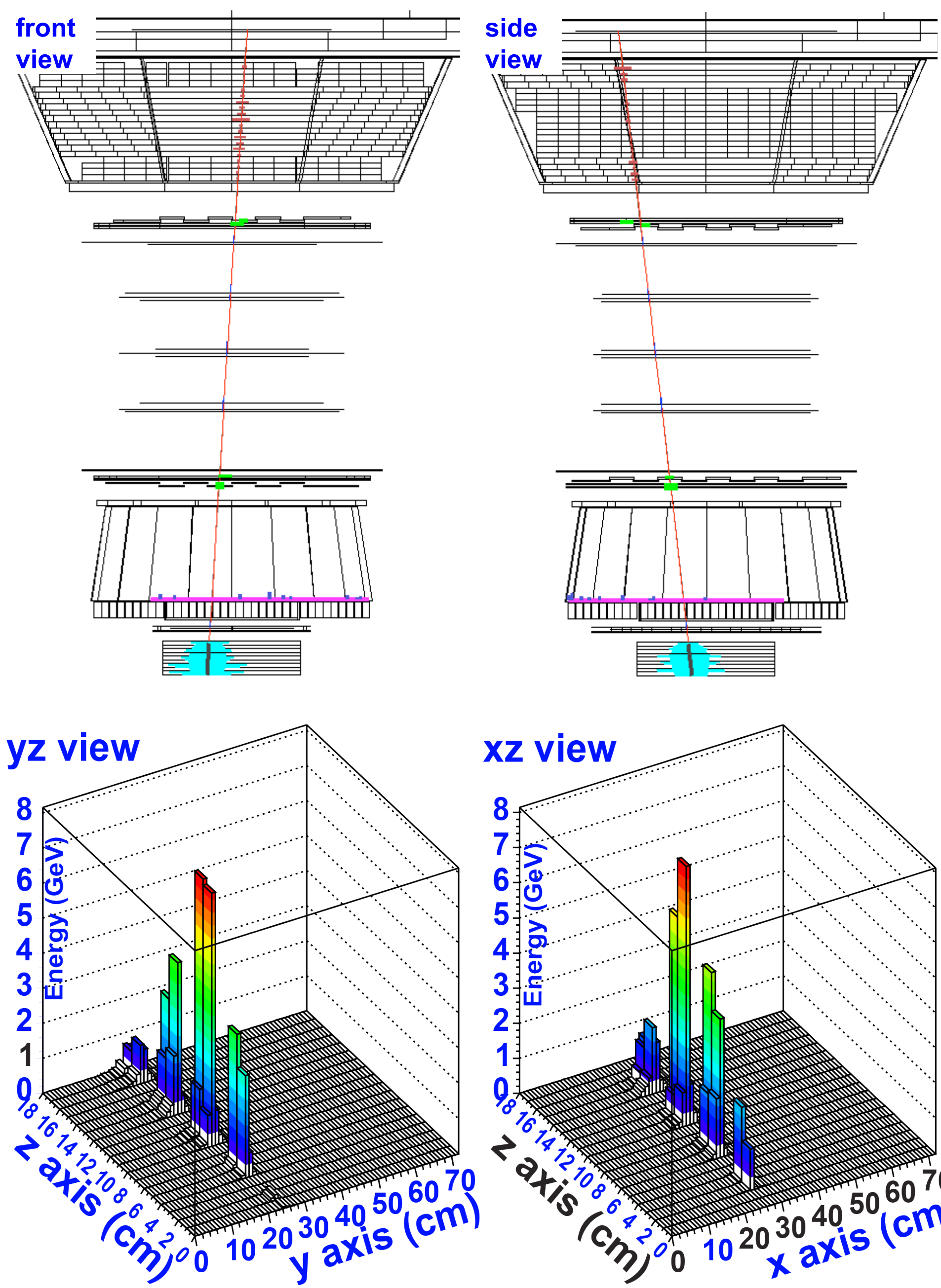




The measurement

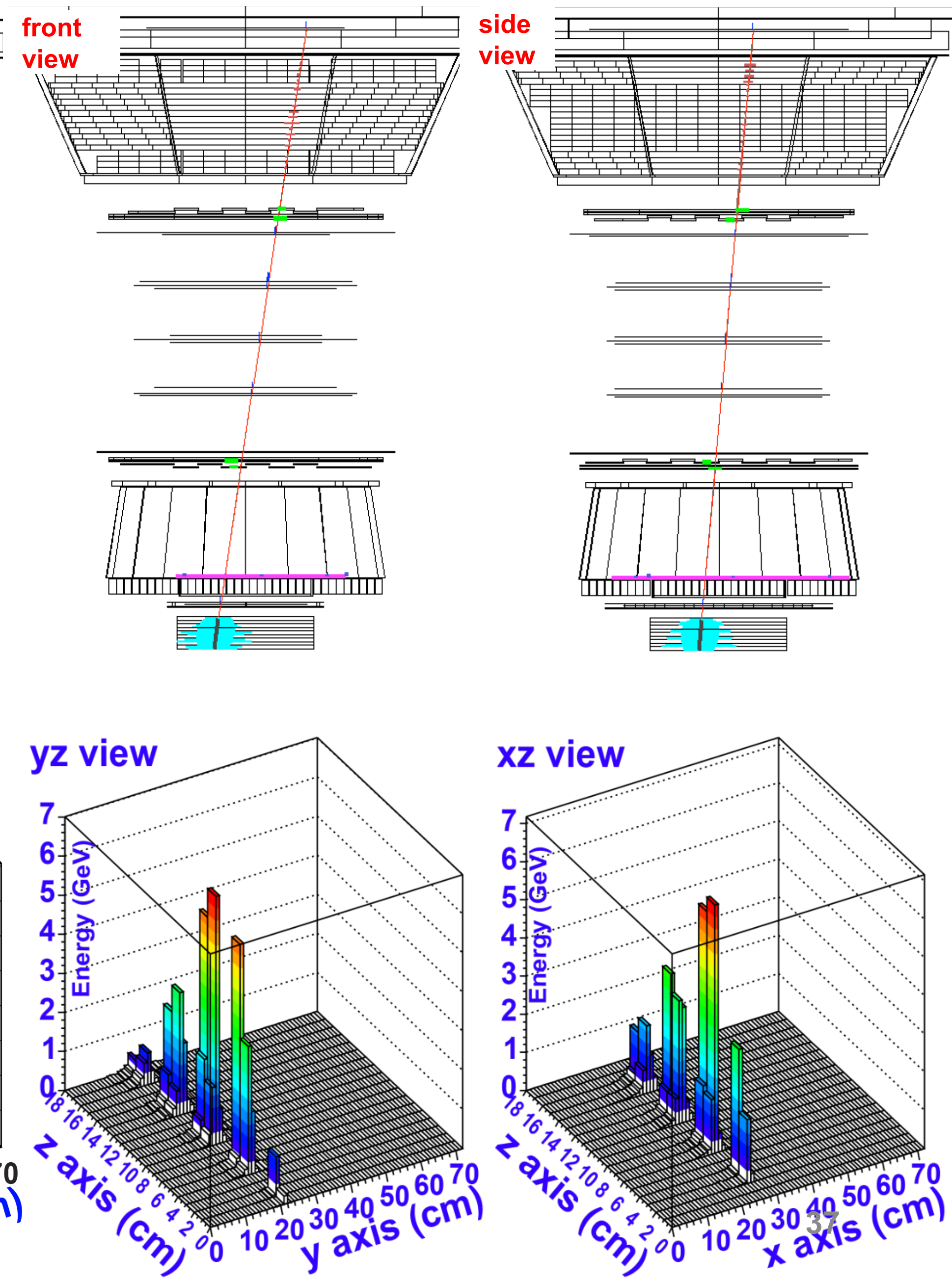
Electron E=99 GeV

Run/Event 1318944028/ 505503



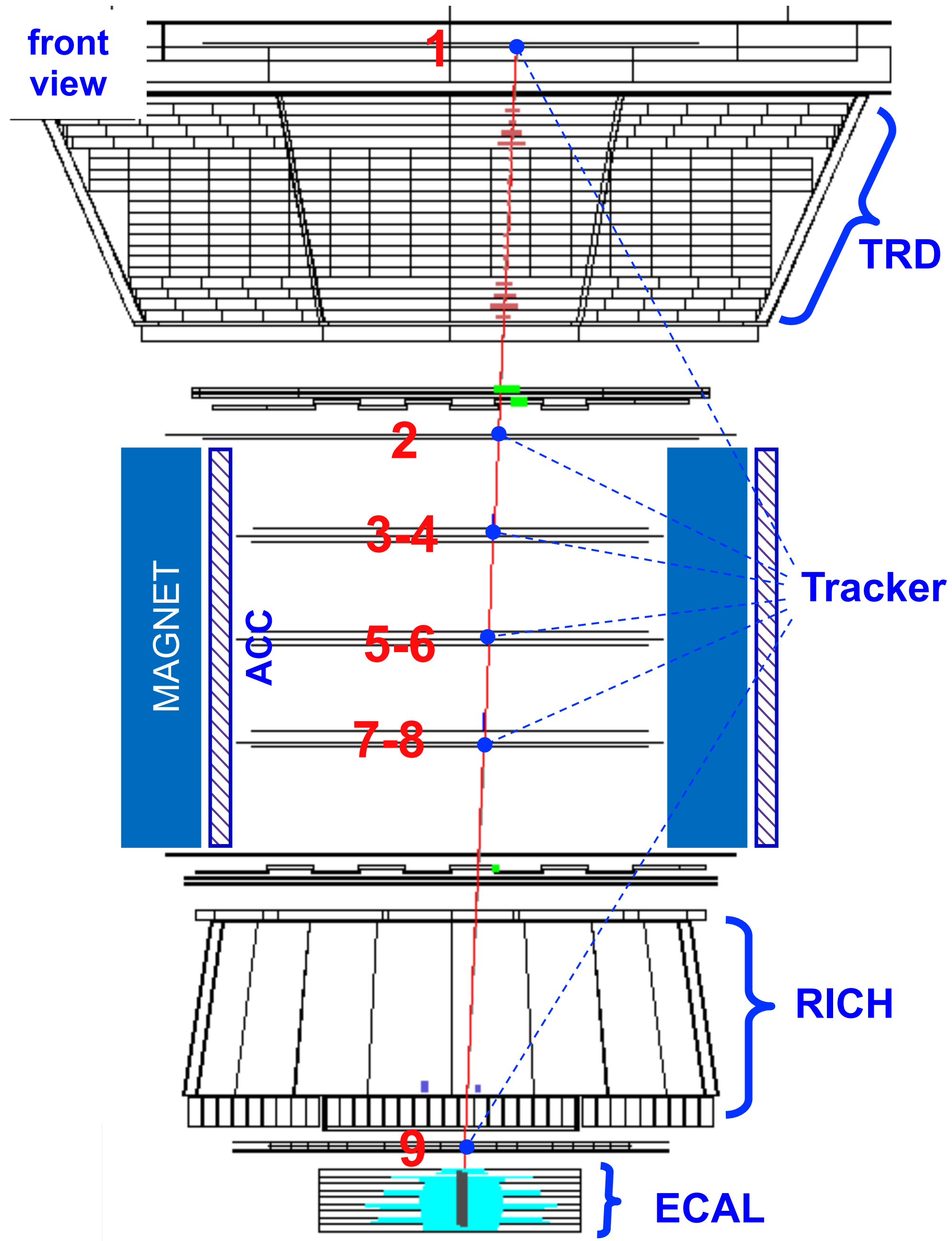
Positron E=100 GeV

Run/Event 1334274023/ 338433



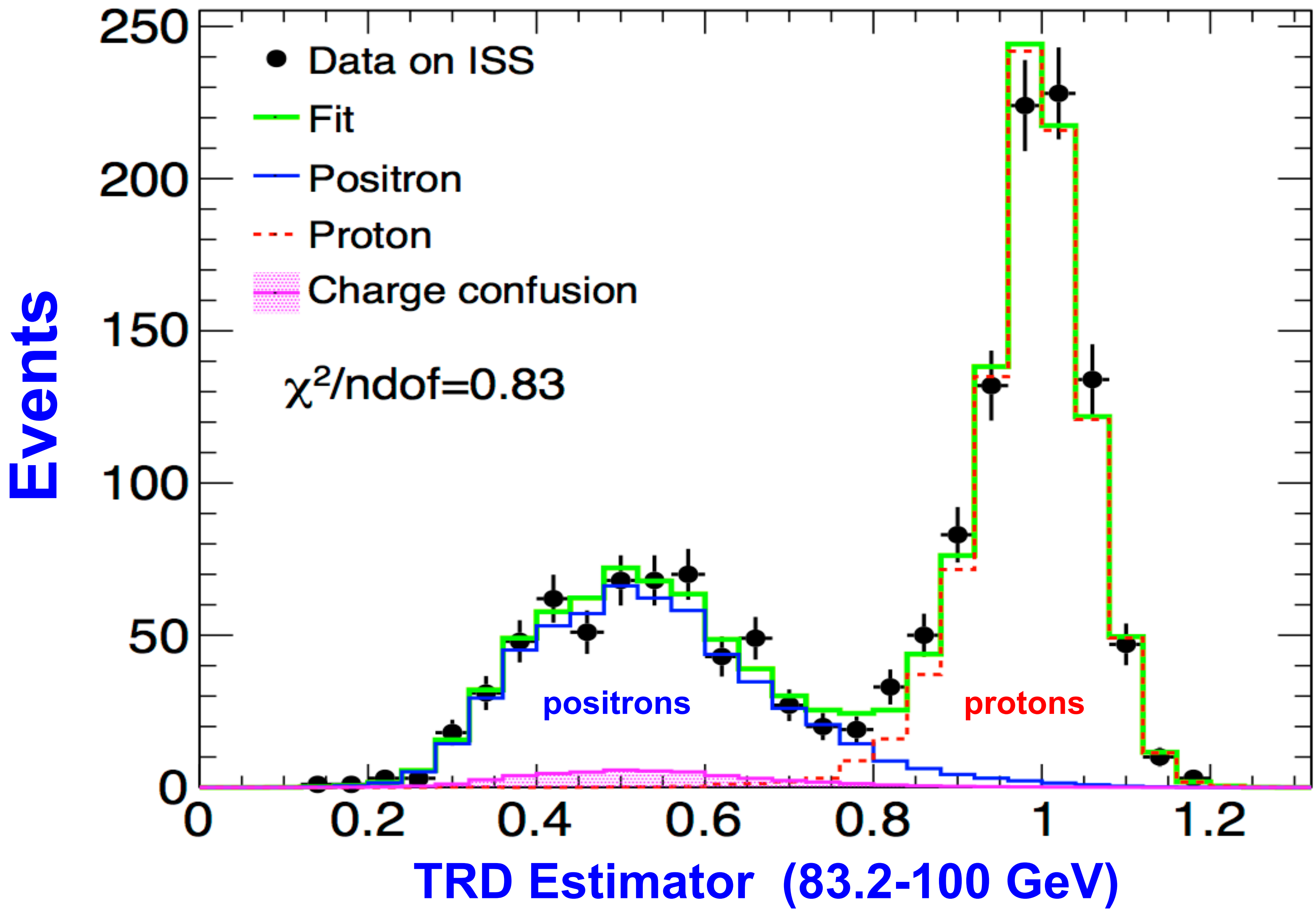
Event selection.

Tracker
A track in the Tracker containing at least one hit in planes 1 or 2 or 9 and hits in planes (3 or 4), (5 or 6) and (7 or 8). In addition, the projected track must pass within 3 cm in x and 10 cm in y of the center of gravity of the ECAL shower.
The relative error on the curvature (inverse of the rigidity) value from the track fit is less than 50 %, which ensures that tracks have rigidities well below their Maximum Detectable Rigidity.
The detector livetime exceeded 50 %, which excludes, for example, the South Atlantic Anomaly.
TOF
The particle velocity measured by TOF $\beta > 0.8$.
The value of the absolute charge is required to be between 0.8 and 1.4.
TRD
At least 15 TRD hits on the Tracker track traced through the TRD.
ECAL
A shower axis within the ECAL fiducial volume.
The ECAL shower has electromagnetic shape



Example of Positron Selection:

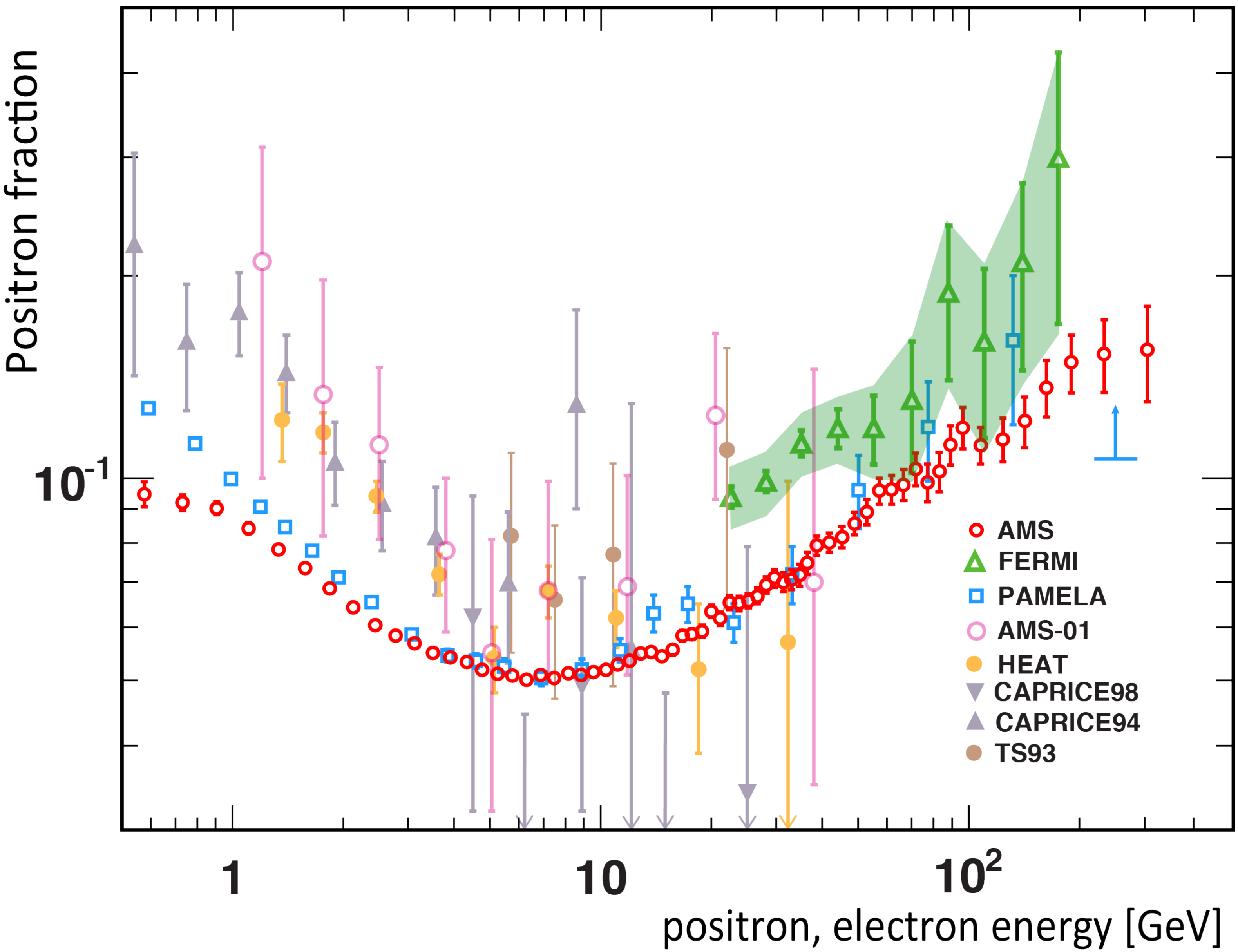
The TRD Estimator shows clear separation between protons and positrons with a small charge confusion background



Systematic errors to positron fraction

1. **Acceptance asymmetry**
   - Difference between positron and electron acceptance due to known minute tracker asymmetry : @ E< 0.6 GeV, < permille
2. **Selection dependence**
   - Dependence of the result on the cut values: change the cut and verify the stability < < % all the energy range
3. **Migration bin-to bin**
   - Migration of electron and positron events from the neighboring bins affects the measured fraction: @ E<5 GeV < %
4. **Reference spectrum**
   - Definition of the signal templates is based on pure samples of electrons and protons of finite statistics : @ high energy, < %
5. **Charge confusion**
   - Two sources: large angle scattering and production of secondary tracks along the path of the primary track. Both are well reproduced by MC. Systematic errors correspond to variations of these effects within their statistical limits. @ E>200 GeV, O(%)

Back to the beginning ….



It is very difficult in accelerators to do a 1% accuracy experiment. To do so in space is extremely challenging. It is the effort of the entire AMS collaboration with the support of NASA and CERN which is making this possible.

Thanks for attention!