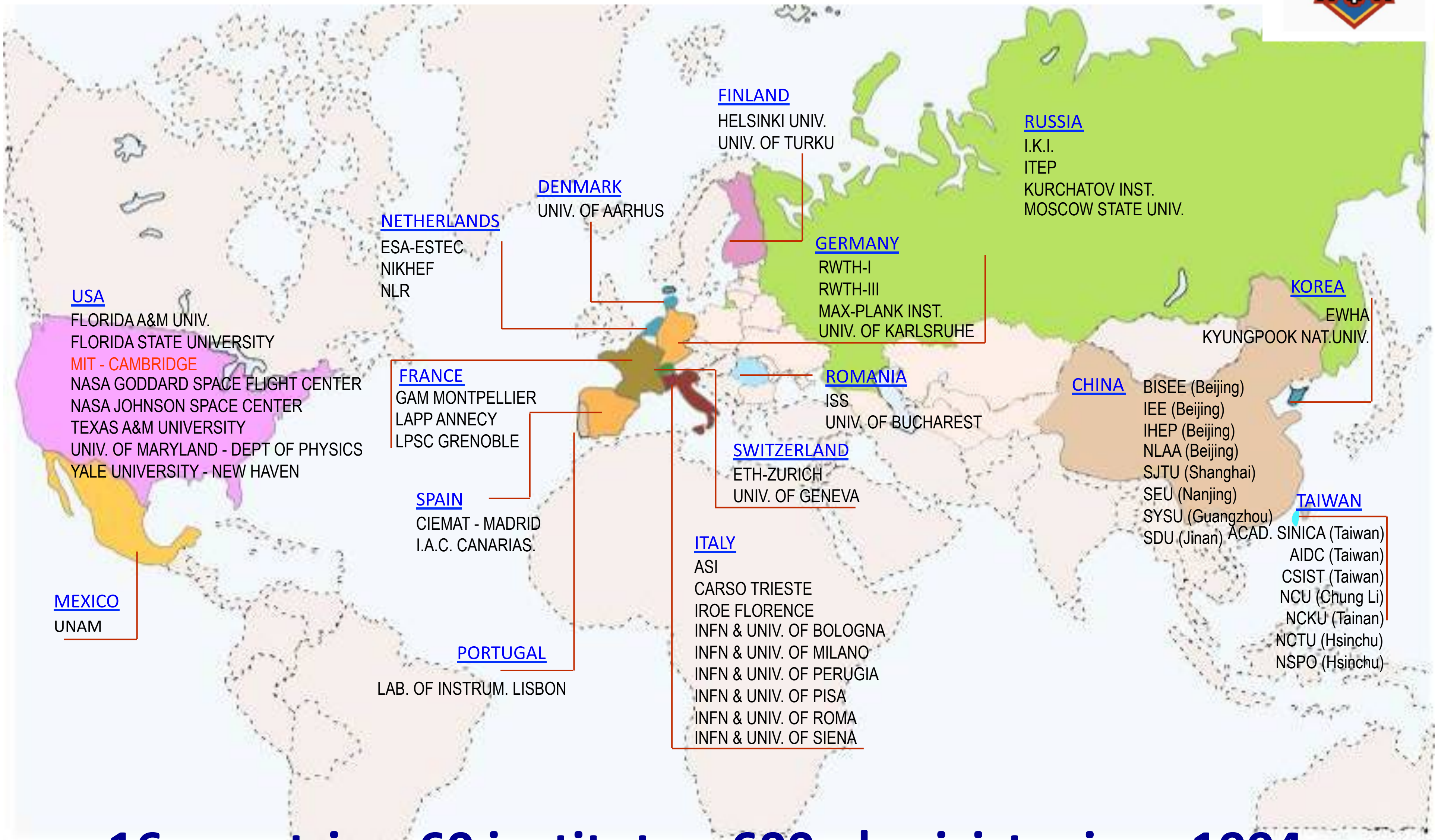
Status of AMS-02

S. Haino
INFN Perugia

ICRR seminar
14/Dec./2011

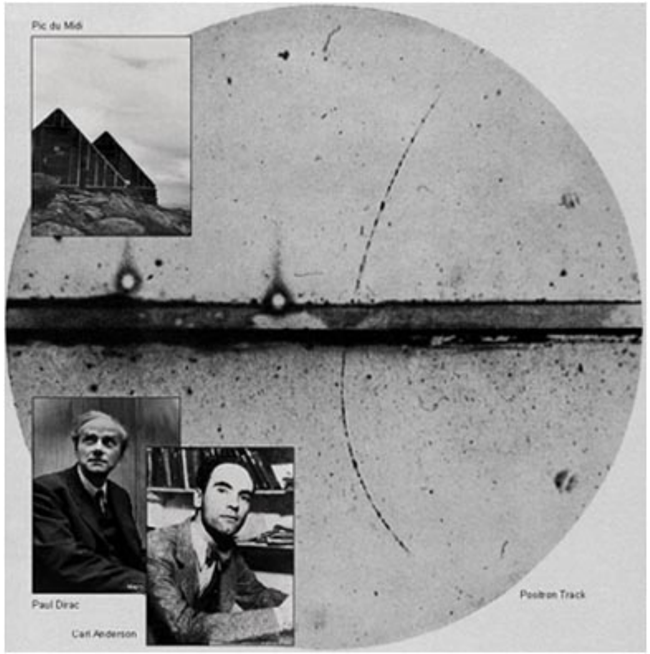
AMS-02 collaboration



16 countries, 60 institutes, 600 physicists since 1994

1911 – 2011 : a century of Cosmic Rays

Hess, Wulf, Wilson,
Anderson, Compton
Bothe, Kohlorster,
Millikan,
Blackett, Skobeltsyn,
Rochester,
Butler, Rossi, Pacini ,
Conversi, Powell,
Occhialini
……



Anti-Particle was discovered in Cosmic Rays !

The Nobel Prize in Physics 1936
Victor F. Hess, Carl D. Anderson

Biography

Victor Franz Hess was born on the 24th of June, 1883, in Waldstein Castle, near Peggau in Steiermark, Austria. His father, Vinzens Hess, was a forester in Prince Öttingen-Wallerstein's service and his mother was Serafine Edle von Grossbauer-Waldstätt.

He received his entire education in Graz: Gymnasium (1893-1901), and afterwards Graz University (1901-1905), where he took his doctor's degree in 1910.

He worked, for a short time, at the Physical Institute in Vienna, where Professor von Schweidler initiated him in recent discoveries in the field of radioactivity. During 1910-1920 he was Assistant under Stephan Meyer at the Institute of Radium Research of the Viennese Academy of Sciences. In 1919 he received the Lieben Prize for his discovery of the"ultra-radiation" (cosmic radiation), and the year after became Extraordinary Professor of Experimental Physics at the Graz University.

Hess's work which gained him the Nobel Prize, was carried out during the years 1911-1913, and published in the Proceedings of the Viennese Academy of Sciences. In addition he has published some sixty papers and several books, of which the most important were: "Die Wärmeproduktion des Radiums" (The heat production of radium), 1912; "Konvektionserscheinungen in ionisierten Gasen-Ionenwind" (Convection phenomena in ionized gas-ionwinds), 1919-1920; "The

arXiv:1002.2888v2 [physics.hist-ph] 16 Mar 2010

Domenico Pacini, the forgotten pioneer of the discovery of cosmic rays

A De Angelis[1], N. Giglietto[2] and S. Stramaglia[2]

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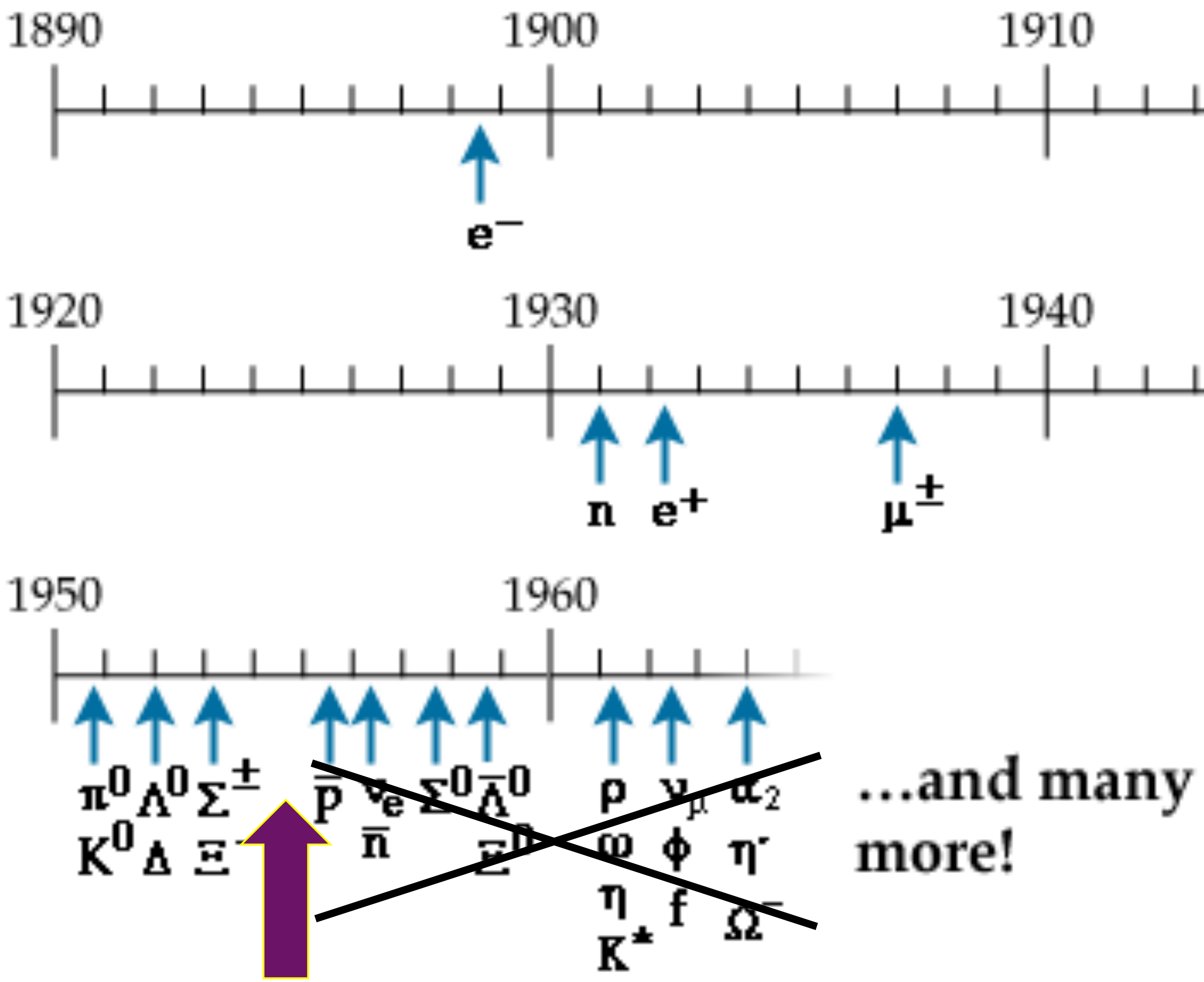
Abstract

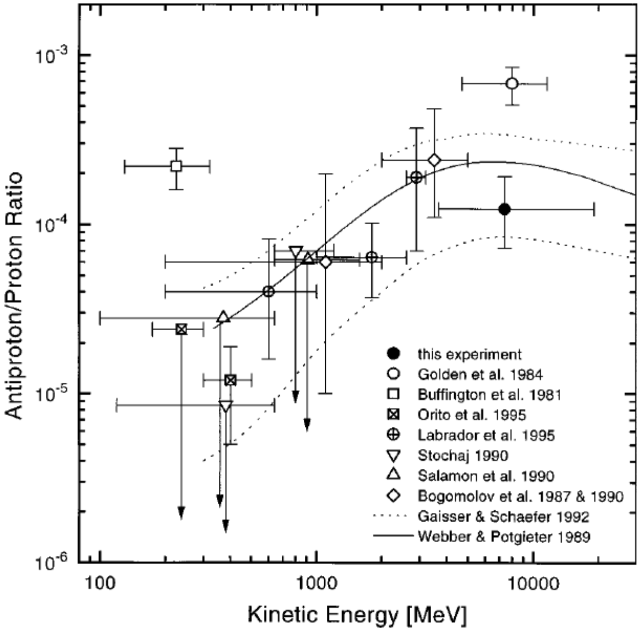
About a century ago, cosmic rays were identified as being a source of radiation on Earth. The proof came from two independent experiments. The Italian physicist Domenico Pacini observed the radiation strength to decrease when going from the surface to a few meters underwater (both in a lake and in a sea). At about the same time, in a balloon flight, the Austrian Victor Hess found the ionization rate to increase with height. The present article attempts to give an unbiased historical account of the discovery of cosmic rays – and in doing so it will duly account for Pacini's pioneering work, which involved a technique that was complementary to, and independent from, Hess'. Personal stories, and the pre- and post-war historical context, led Pacini's work to slip into oblivion.

CR & the Particle Physics connection

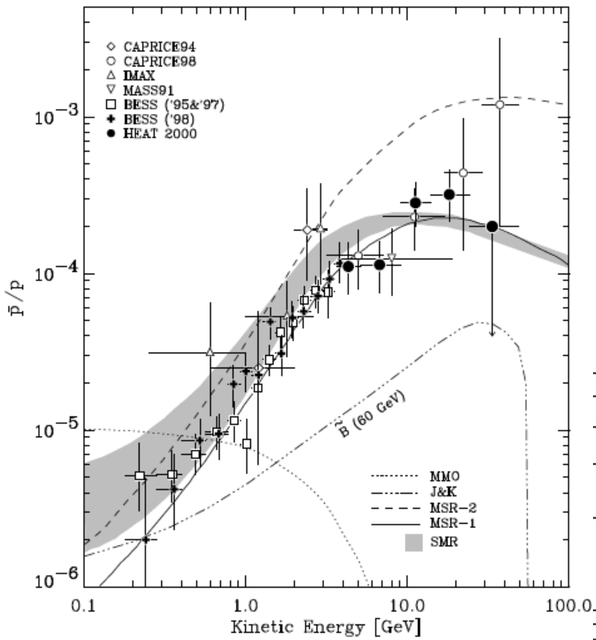


particle accelerators taking over (?)

Anti-protons by the balloon experiments

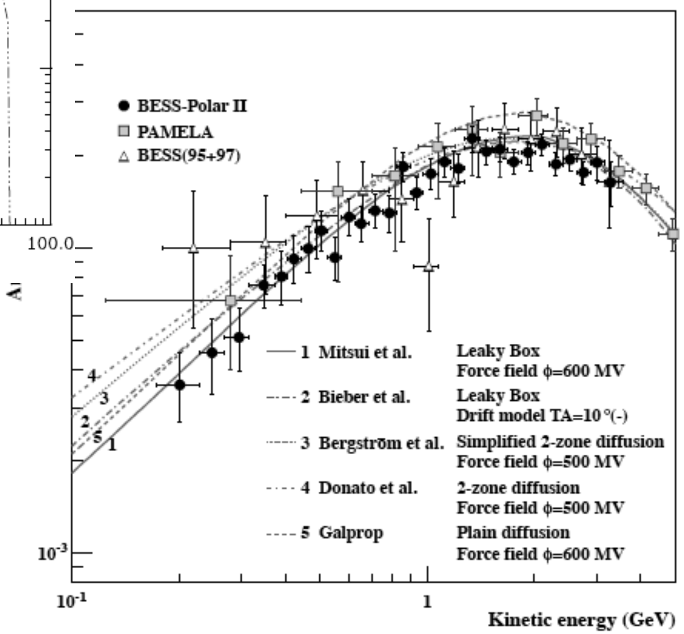


MASS 91 flight

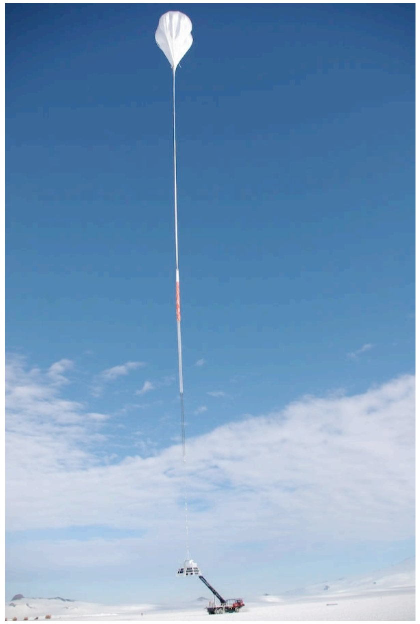


HEAT-PBAR

BESS/BESS POLAR-II

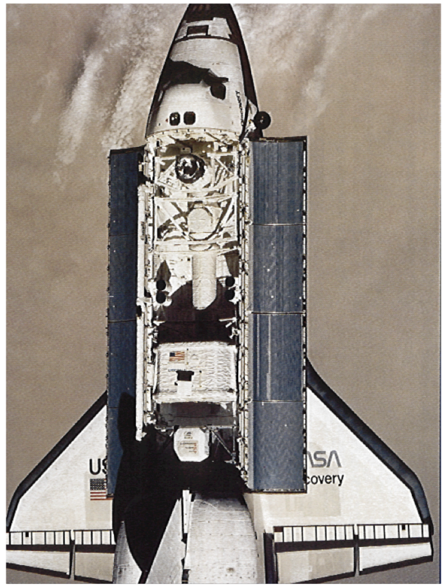


Anti-matter in space



The stratospheric balloon program:

- ☺ ☺ ☺ Easy to fly
- ☺ ☺ Large payloads/multiple flights
- ☹ Limited Time exposure
- ☹ Atmospheric background & TOA corrections



The space program

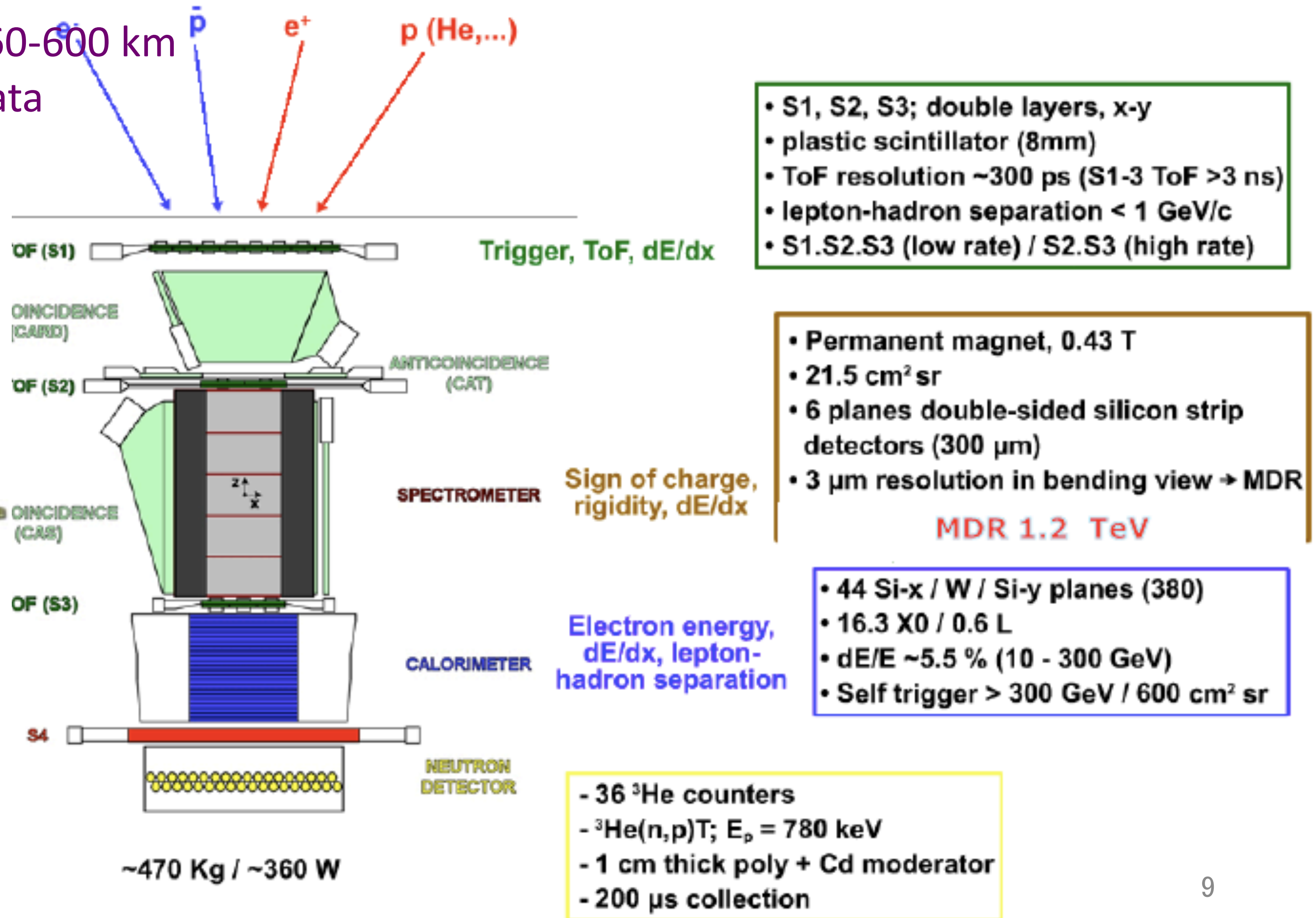
- ☹ ☹ ☹ Less opportunities/more expensive
- ☹ ☹ Hostile environment/no failure allowed
- ☺ ☺ No atmospheric background
- ☺ ☺ ☺ Long exposure times

PaMeLa

a Payload for Antimatter Matter Exploration and Light-nuclei Astrophysics

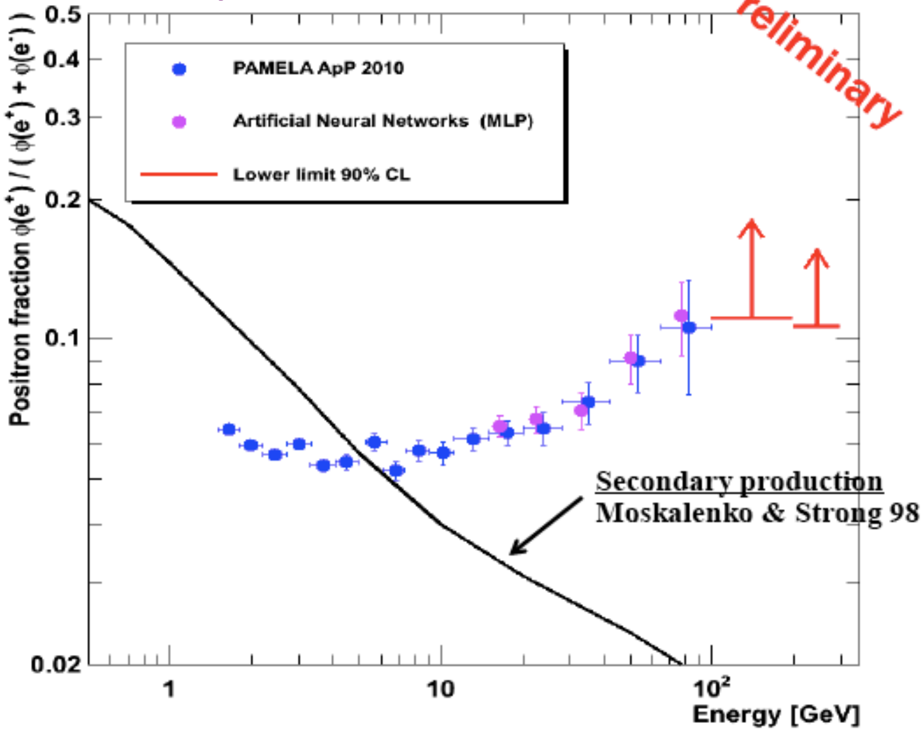
On orbit since 06/2006 on the Russian Satellite RESURS DK1:

- ✓ 10^9 triggers collected
- ✓ 70° elliptical orbit at 360-600 km
- ✓ 20 TB of downlinked data

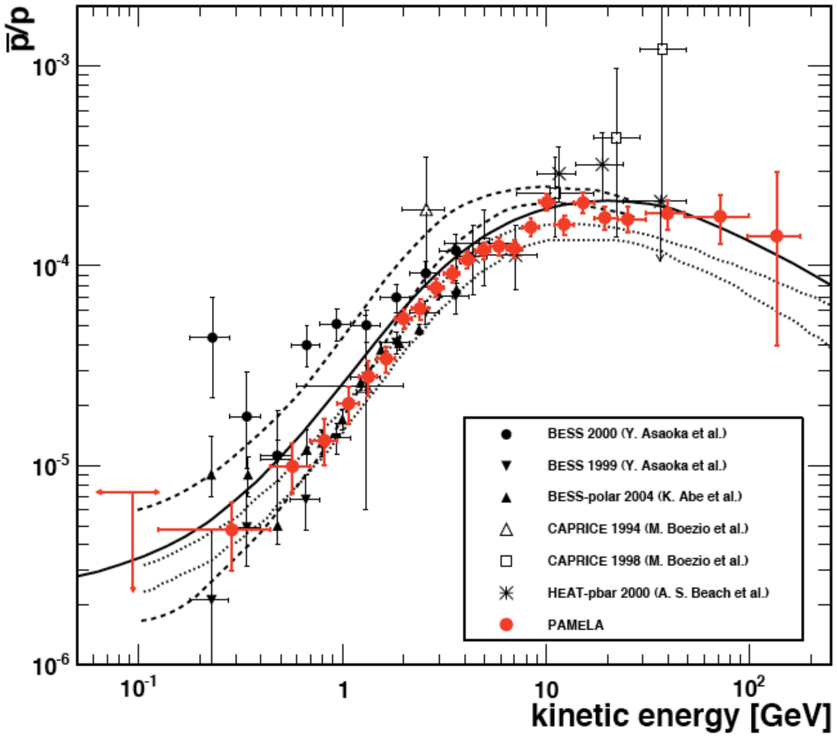


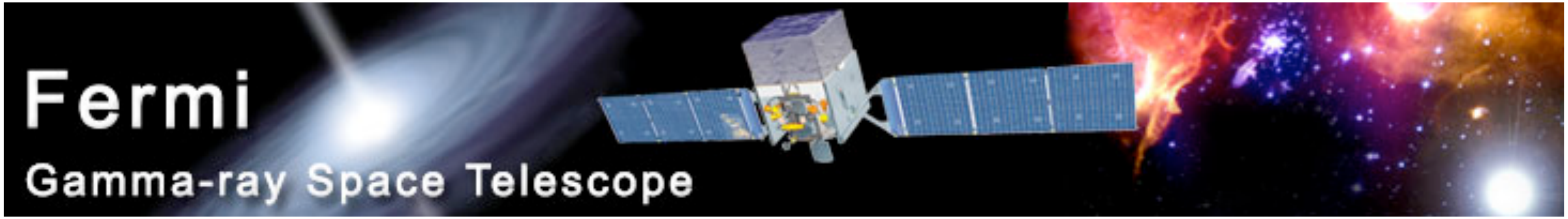
a Payload for Antimatter Matter Exploration and Light-nuclei Astrophysics

The positron fraction

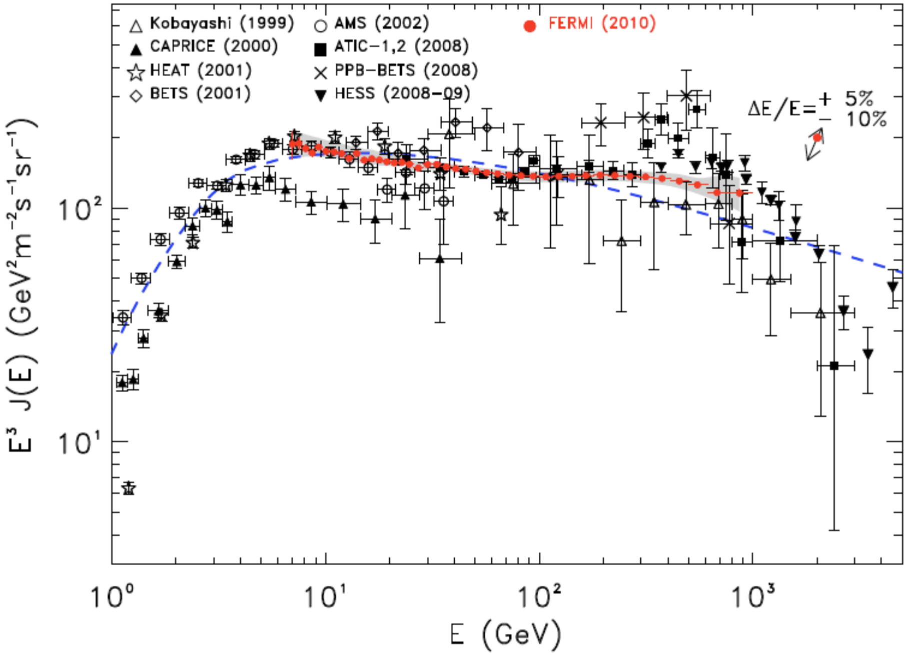


The anti-proton fraction

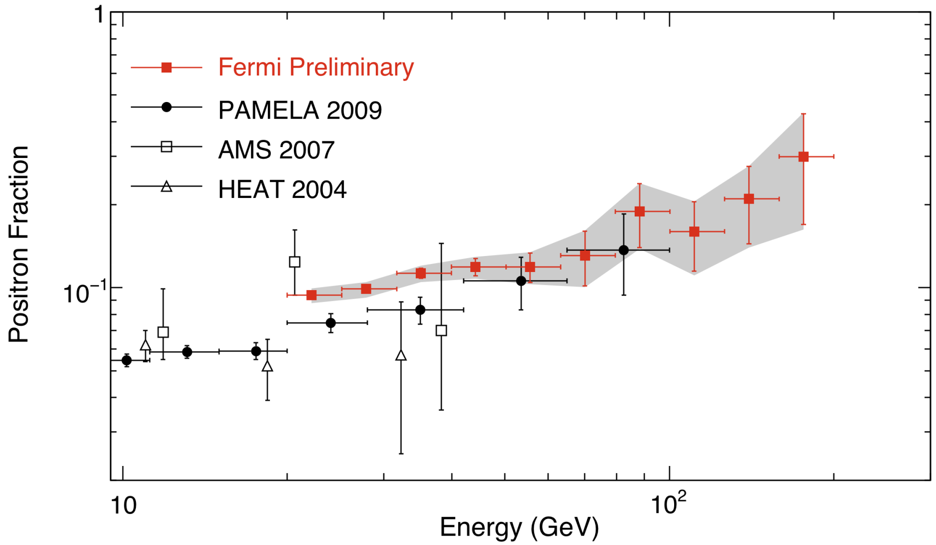




The all electron flux:

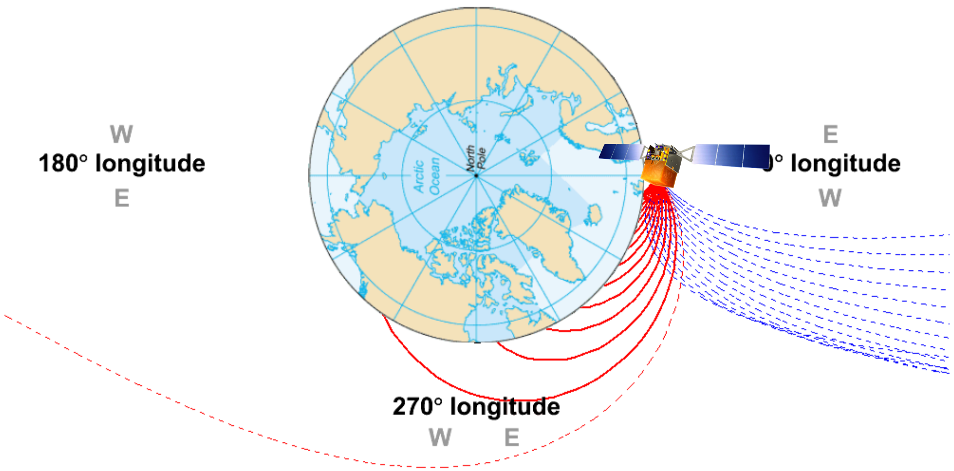


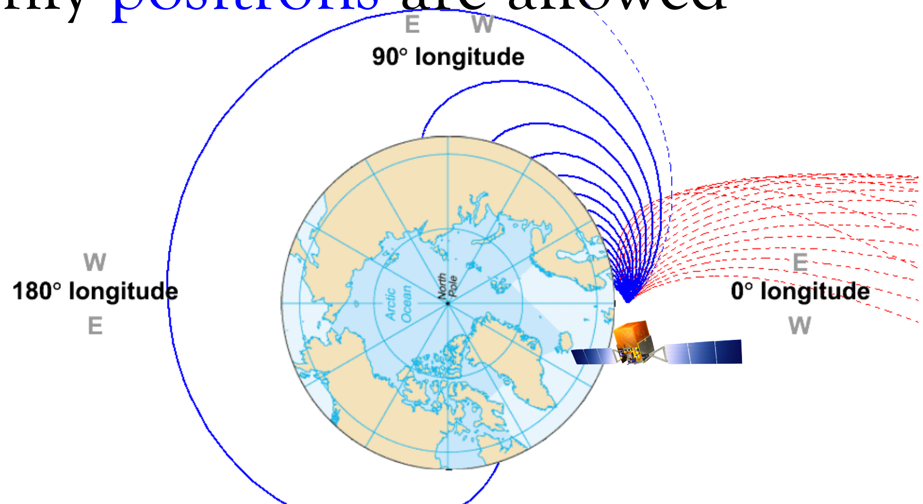
The positron fraction



Geomagnetic field + Earth shadow = directions from which only electrons or only positrons are allowed

events arriving from West:
e^+ allowed, e^- blocked



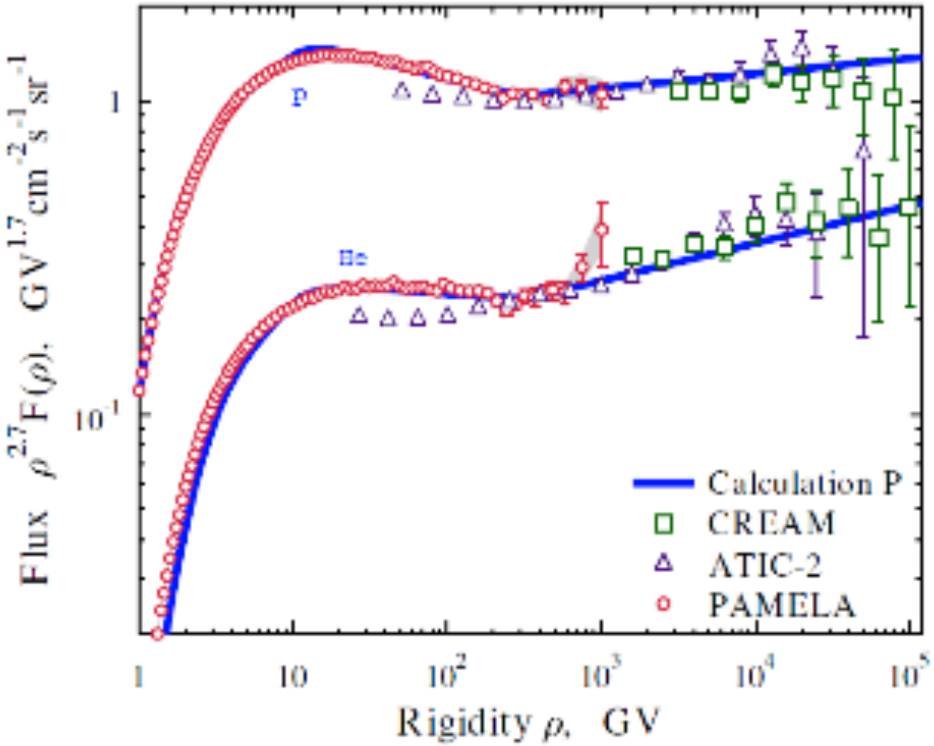


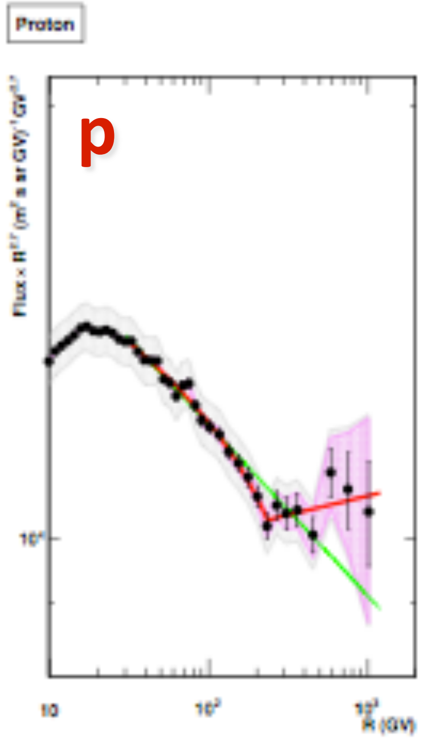
events arriving from East:
e^- allowed, e^+ blocked

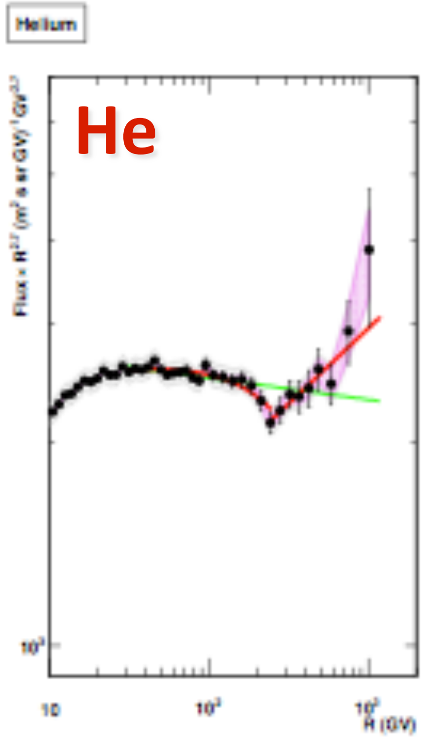
- For some directions, e^- or e^+ forbidden
- Pure e^+ region looking West and pure e^- region looking East
- Regions vary with particle energy and spacecraft position
- To determine regions, use code by Don Smart and Peggy Shea (numerically traces trajectory in geomagnetic field)
- Using International Geomagnetic Reference Field for the 2010 epoch

a Payload for Antimatter Matter Exploration and Light-nuclei Astrophysics

Break ? in p and He spectra

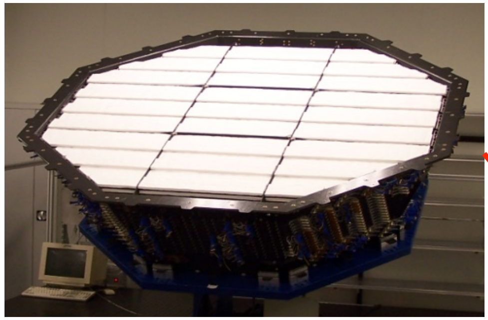






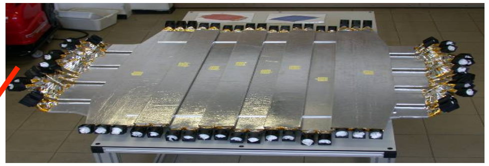
Alpha Magnetic Spectrometer

TRD e/p separation

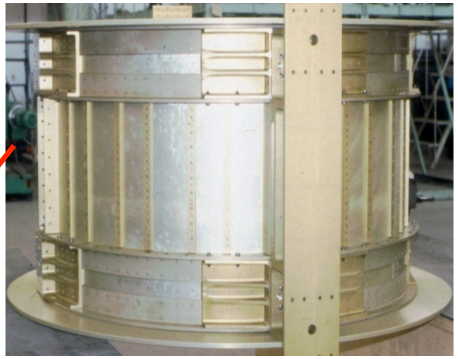


Particles/nuclei ID by
- Charge Z
- Rigidity $R = p/Ze$
- Energy E
- Velocity $v = \beta c$

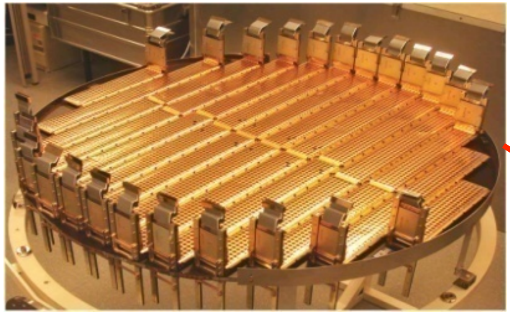
TOF v, Z

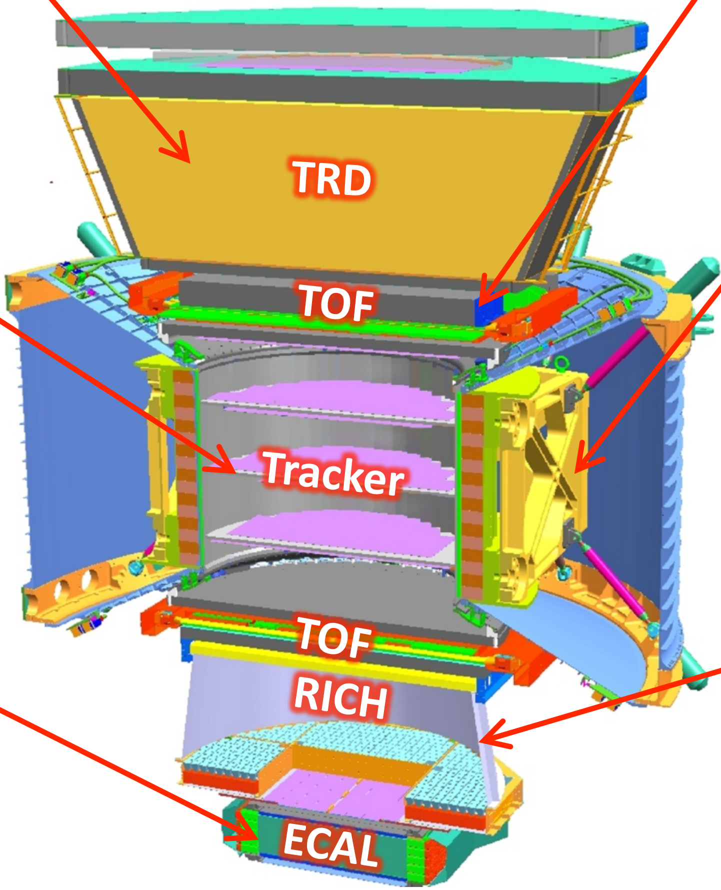


Magnet

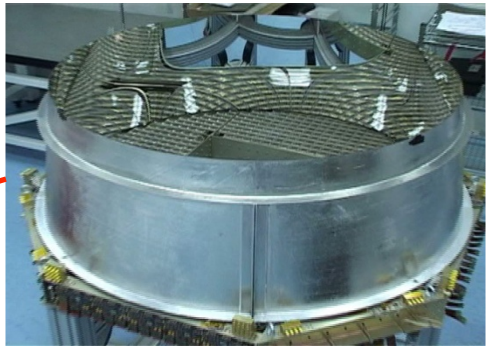


Silicon Tracker Z, $\pm R$





RICH v, Z



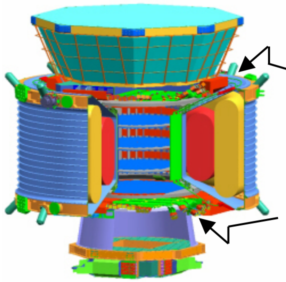
ECAL E ($e+/e^-$, γ)

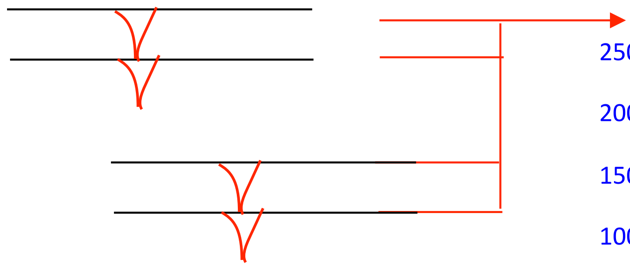
Particle signals

	e^-	p	He,Li,Be,..Fe	γ	e^+	$\bar{p}$, $\bar{d}$	$\overline{He}$, $\bar{C}$
TRD							
TOF							
Tracker							
RICH							
ECAL							
Physics example	Cosmic Ray Physics				Dark matter		Antimatter

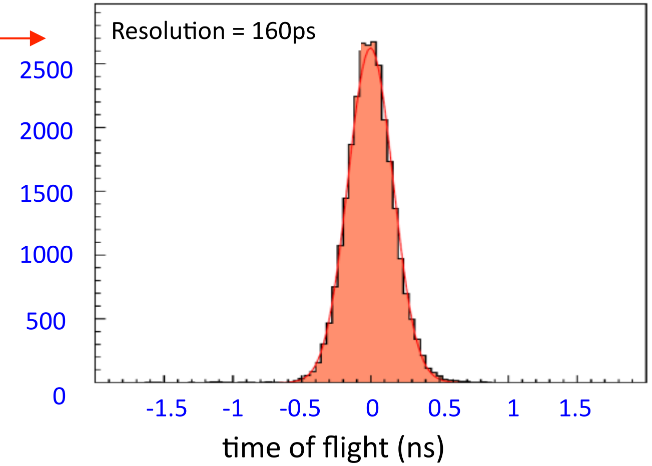
Time of Flight System

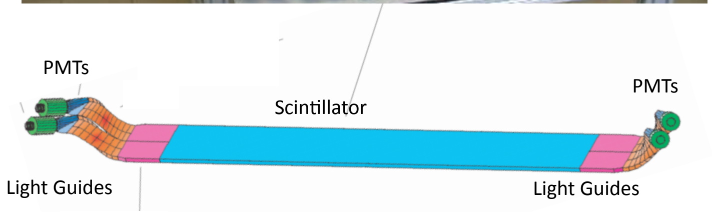
Measures Velocity and Charge of particles

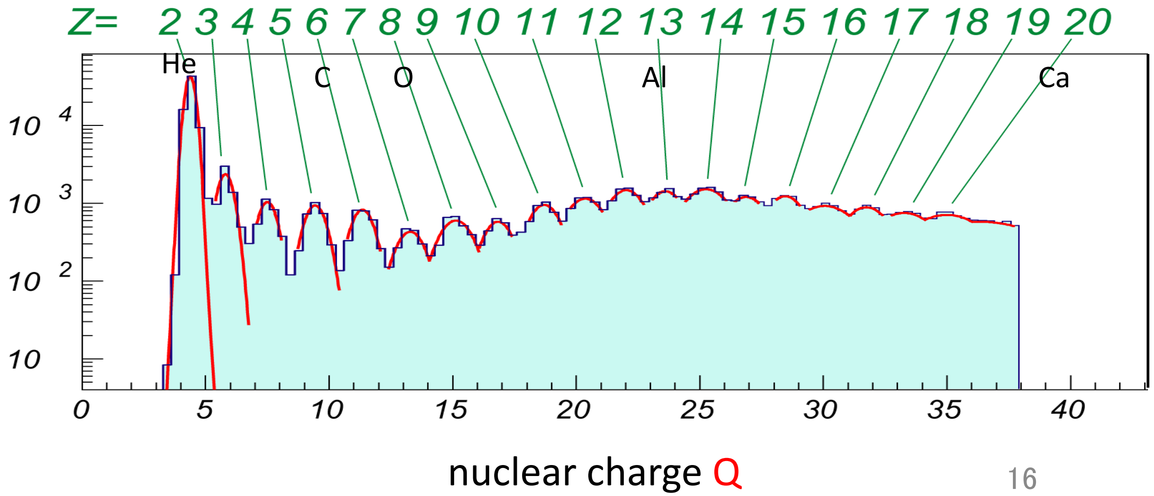




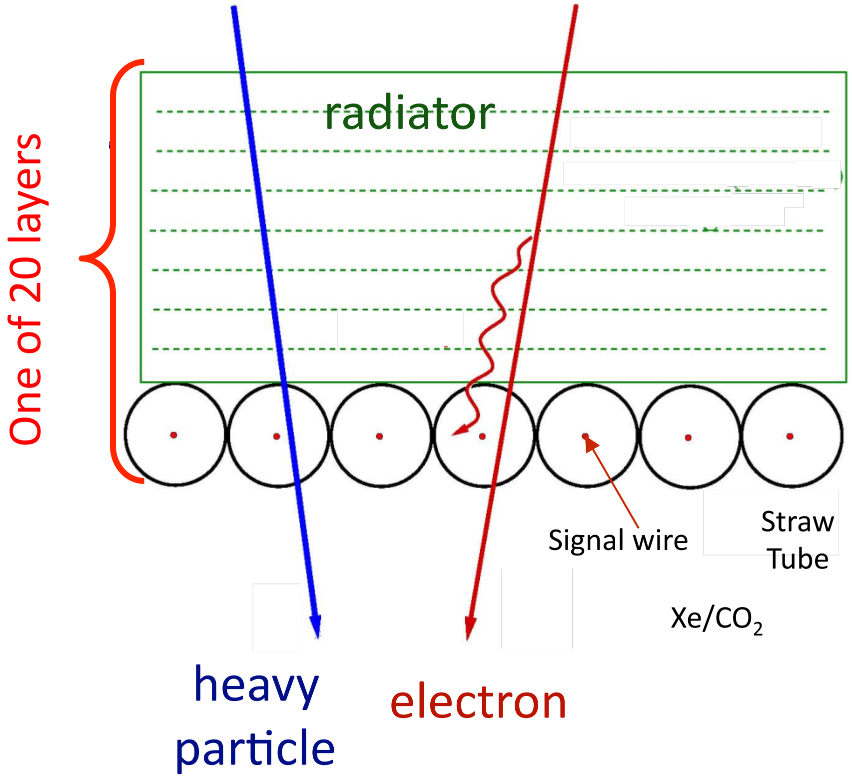
Velocity = Distance / Time

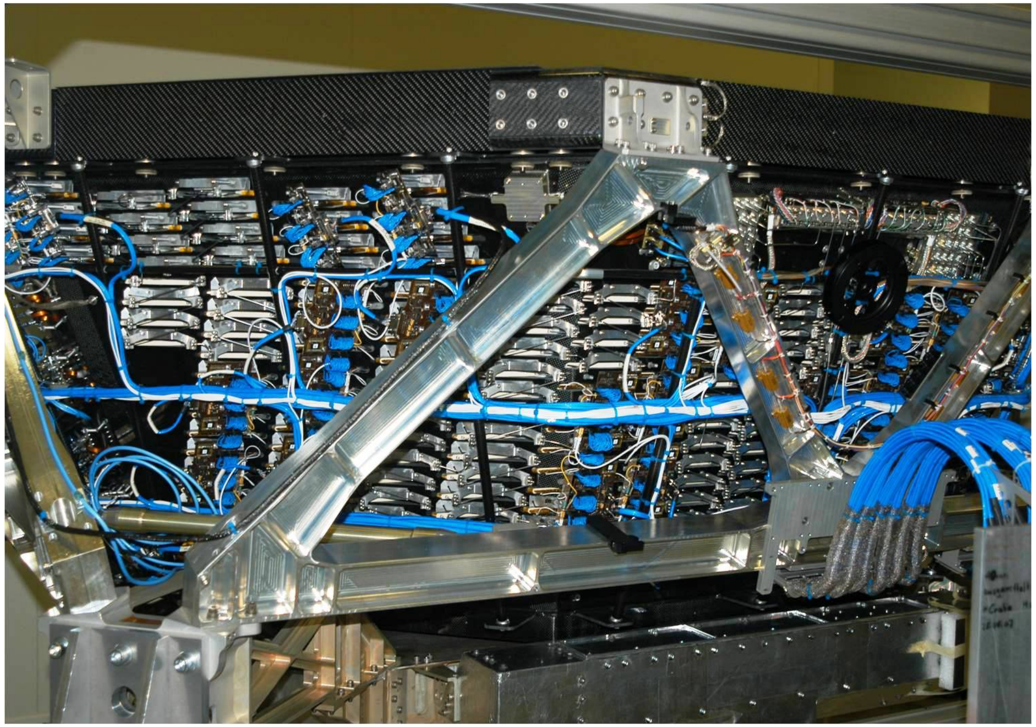


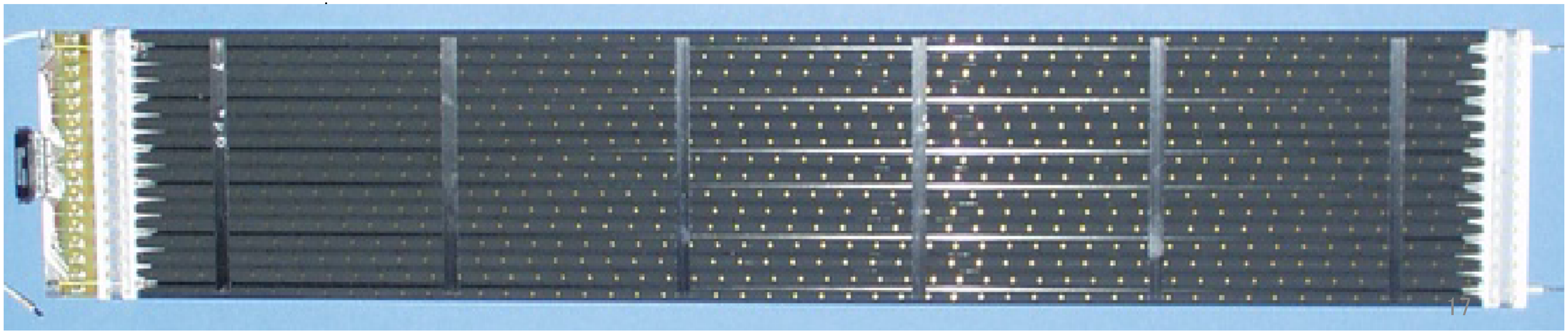




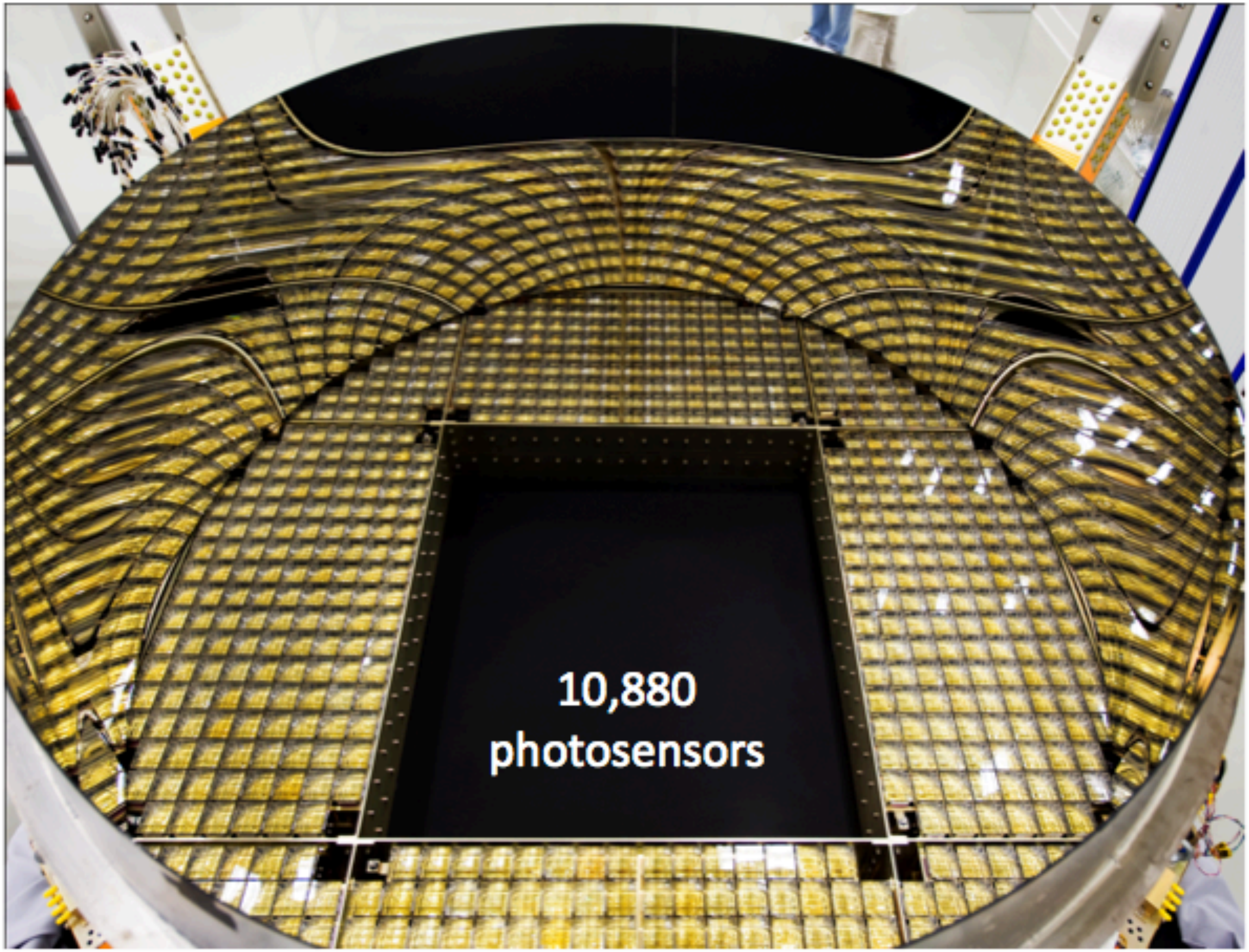
Transition Radiation Detector (TRD): identifies Positrons and Electrons



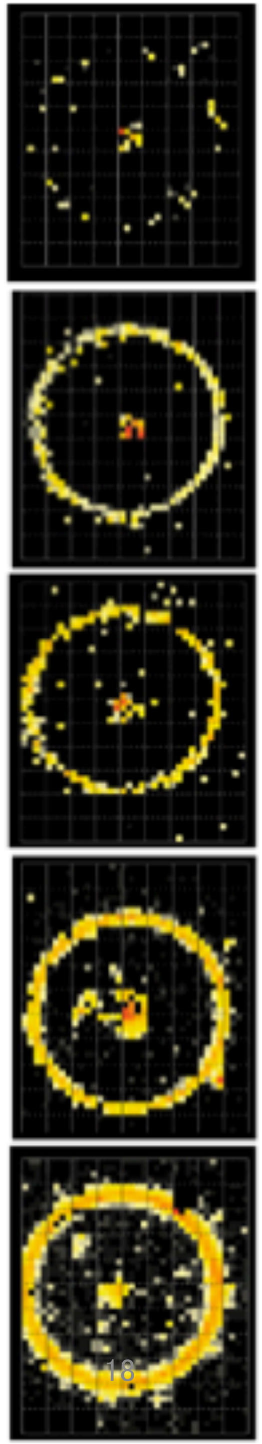




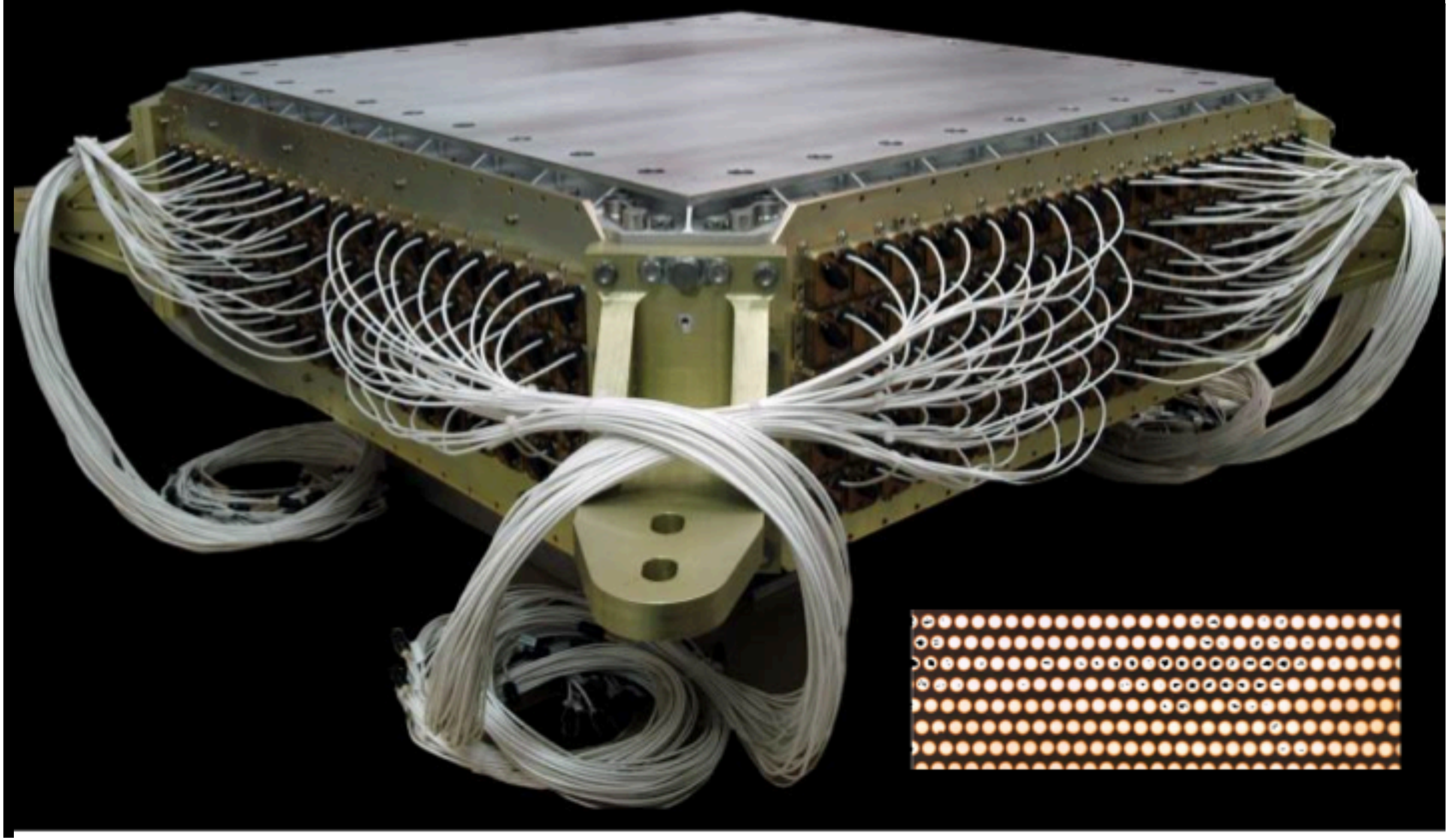
Ring Imaging CHerenkov (RICH)



160 Gv

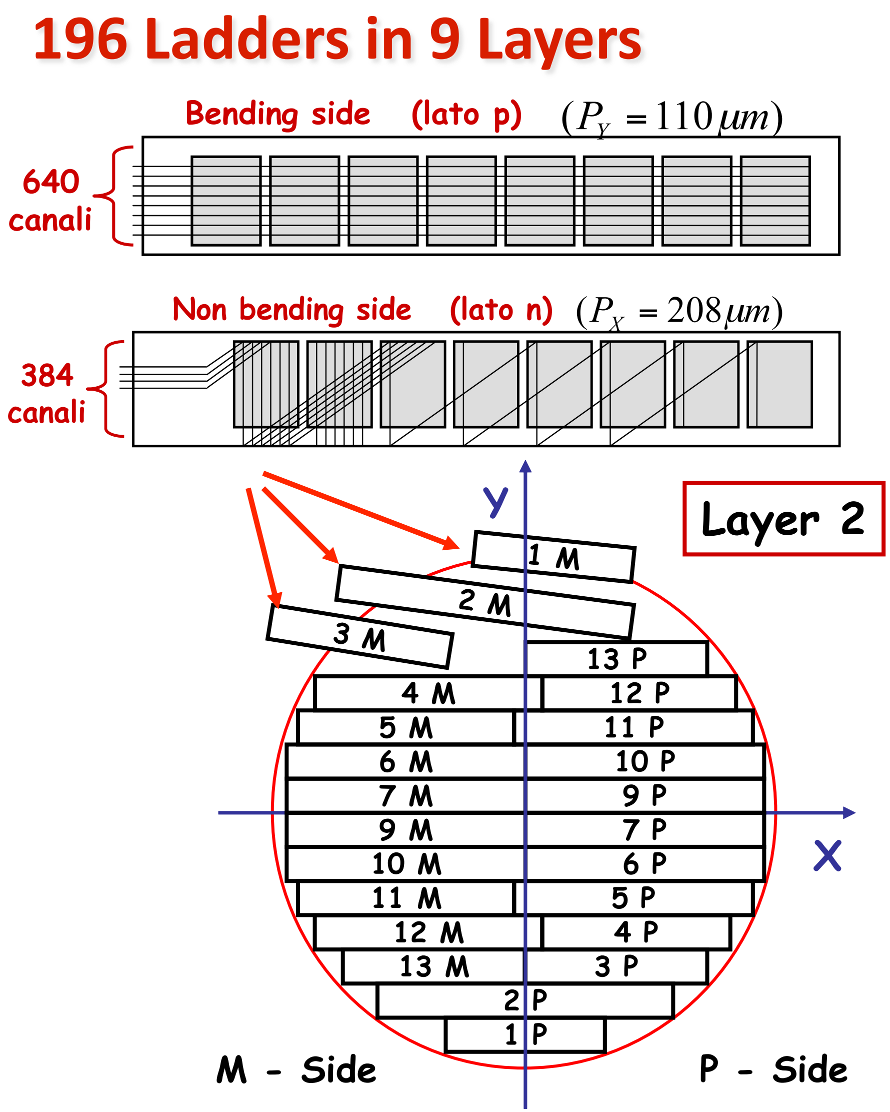


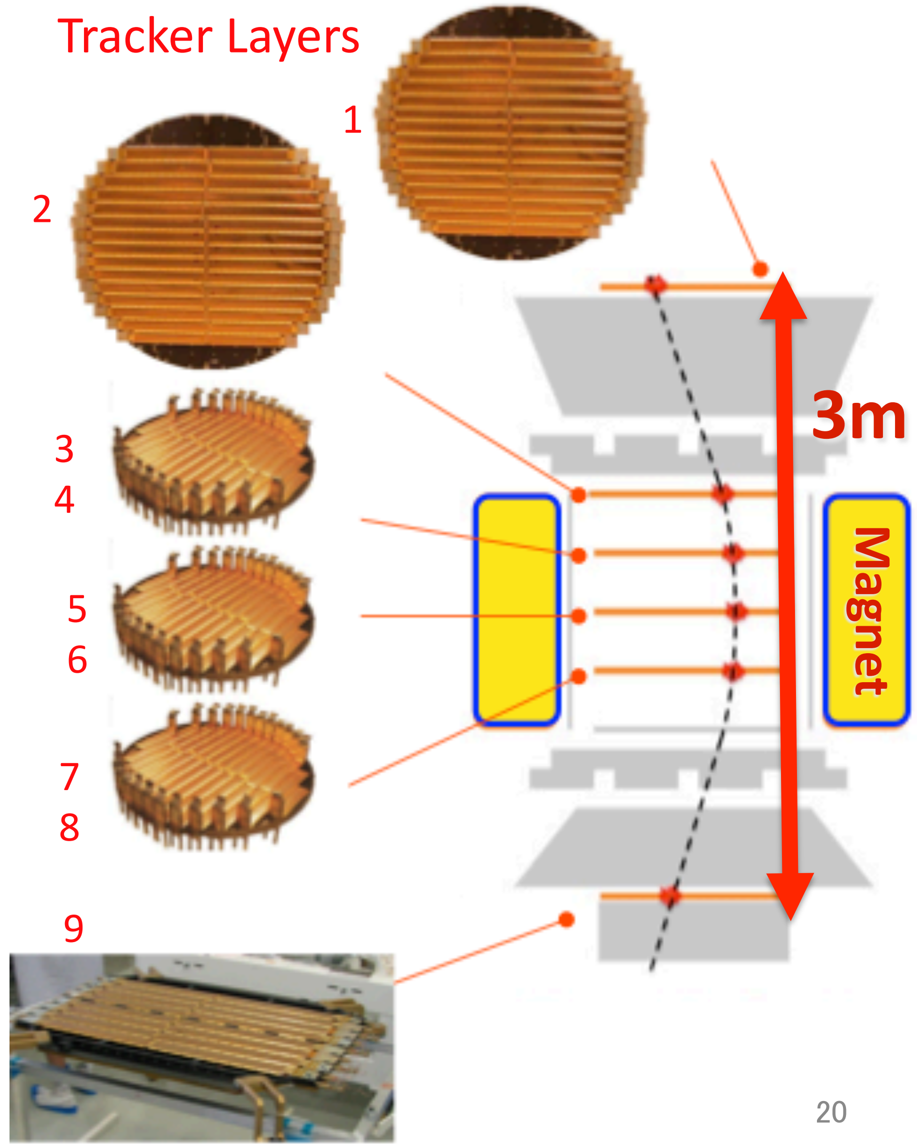
Calorimeter (ECAL)



50,000 fibers, ϕ =1mm, distributed uniformly inside 1,200 lb of lead
which provides a precision, 3-dimensional, $17X_0$ measurement
of the directions and energies of light rays and electrons up to 1 TeV

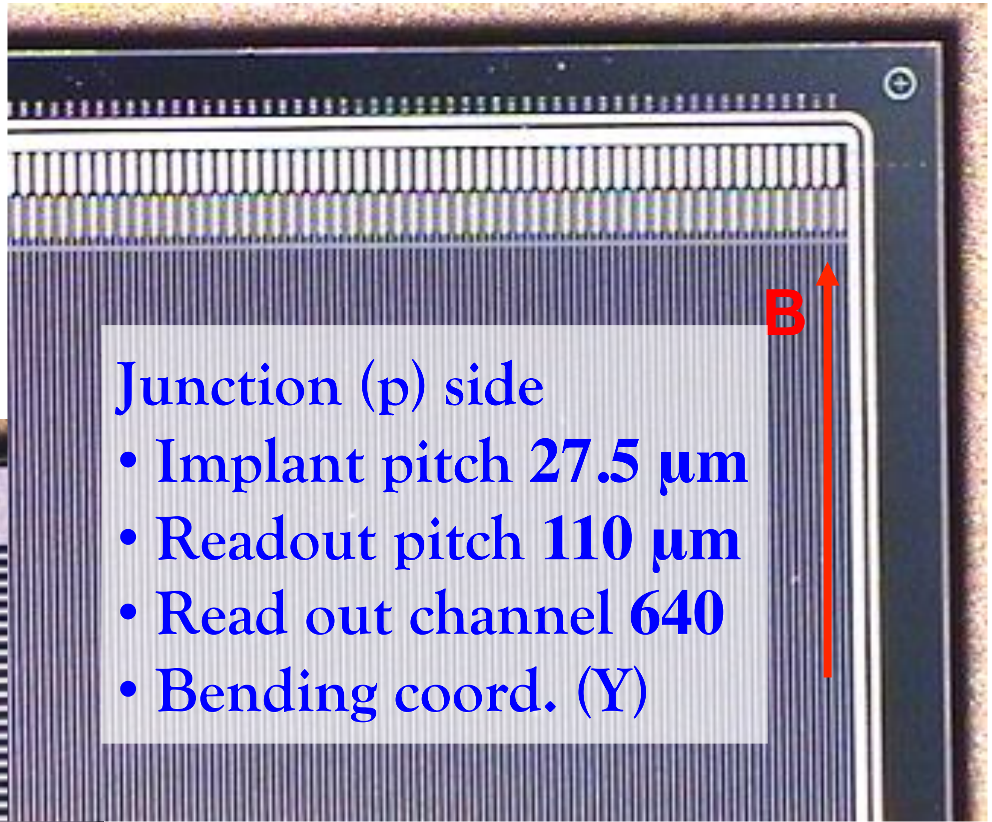
Silicon Tracker



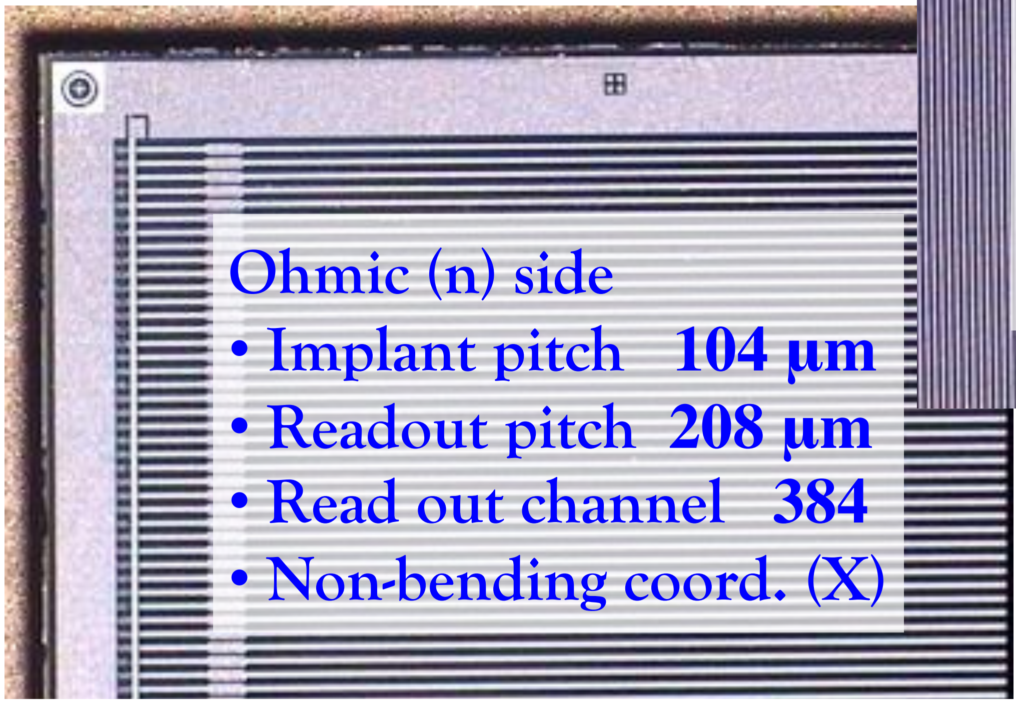


Silicon sensor

Wafer
- Thickness **300 μm**
- Size **7×4 cm^2**
- Total number **2264**
- Total area **6.75 m^2**



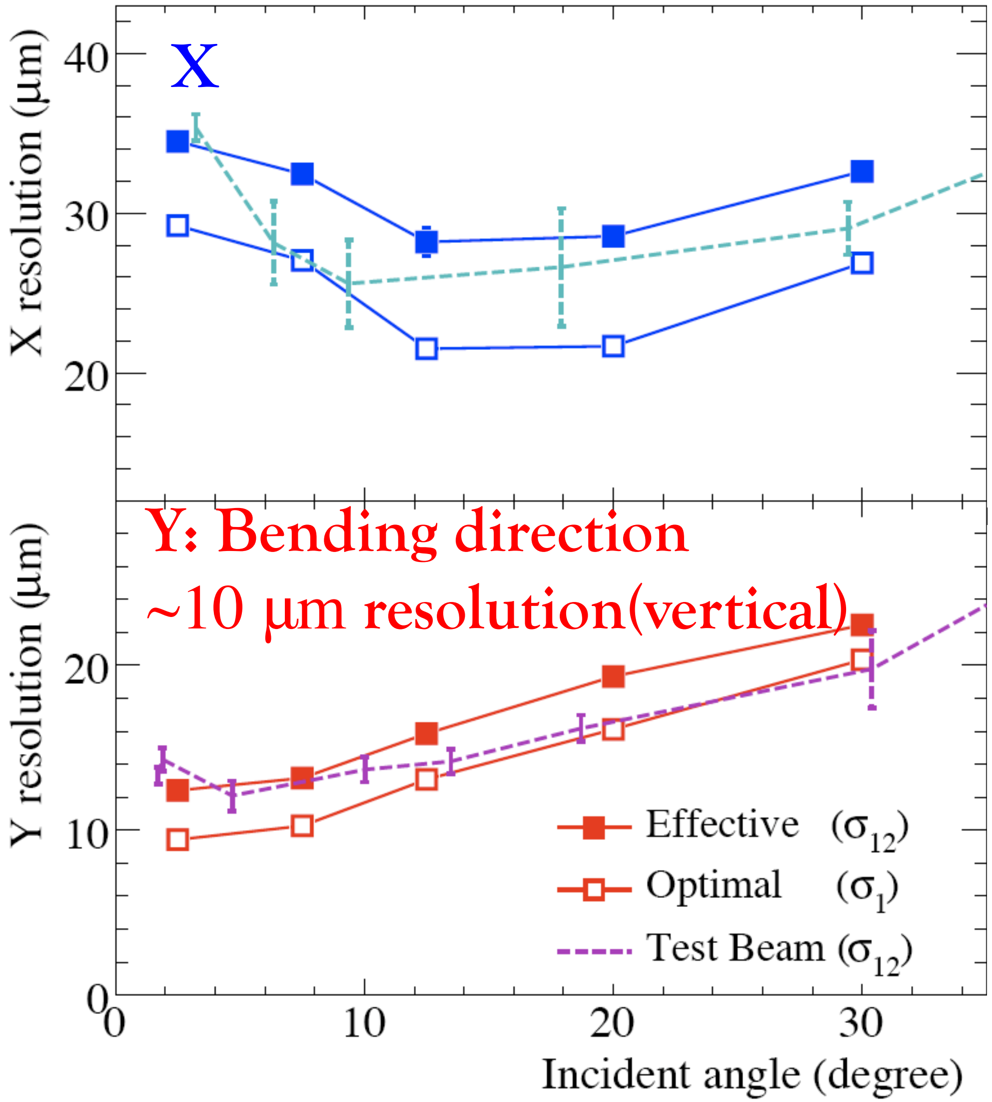
Junction (p) side
- Implant pitch **27.5 μm**
- Readout pitch **110 μm**
- Read out channel **640**
- Bending coord. (Y)

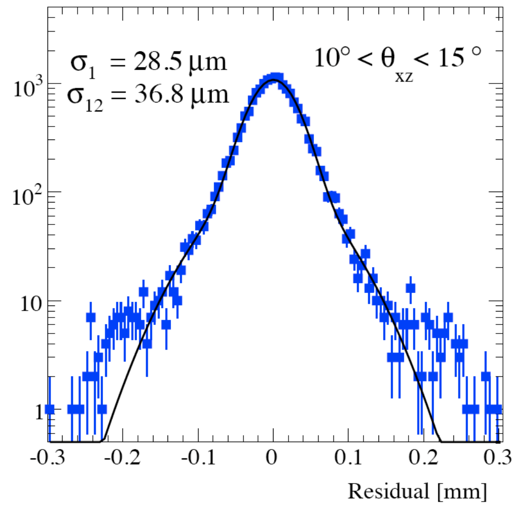


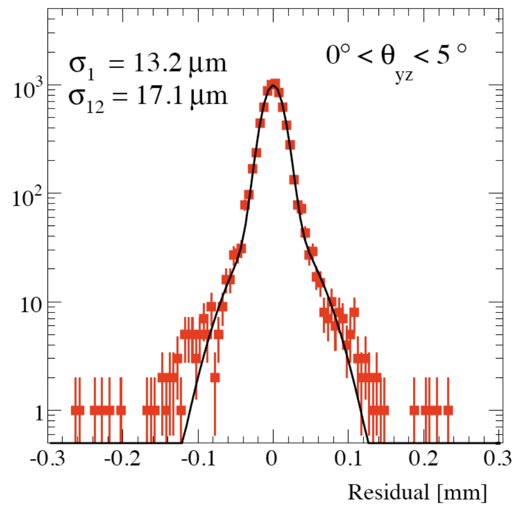
Ohmic (n) side
- Implant pitch **104 μm**
- Readout pitch **208 μm**
- Read out channel **384**
- Non-bending coord. (X)

Resolution VS angle (Muons on ground)

NIM A 613 (2010) 207







Magnetic Rigidity

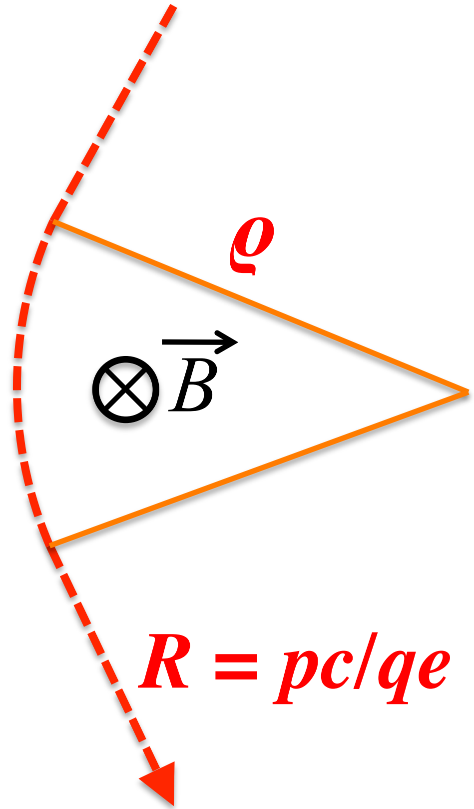
Relation between the curvature and momentum or Rigidity

$p \quad = qe\varrho B \quad [\mathrm{eV}/c]$

$R \quad = c\varrho B \quad (R = pc/qe \ [\mathrm{V}])$

$R/\mathrm{GV} \approx 0.3 \ (\varrho/\mathrm{m}) \ (B/\mathrm{Testa})$

$q < 0$ ➔ $R < 0$



e.g.

$p = 1$ GeV/c, $q = 1$ ($R = 1$ GV),

$B = 1$ Tesla ➔ $\varrho \approx 3.3$ m

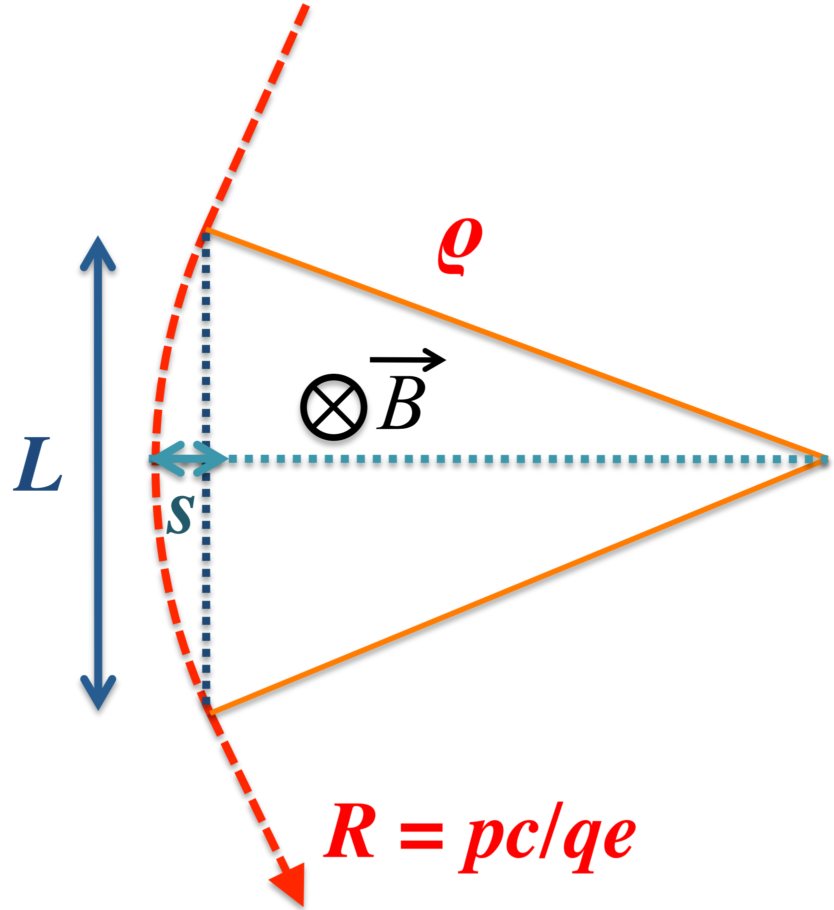
Sagitta

$$s = \varrho - \sqrt{\varrho^2 - (L/2)^2}$$

$$\approx \varrho - \varrho(1 - (L/\varrho/2)^2/2)$$

$$= L^2/\varrho/8 = \frac{0.3BL^2}{8R}$$

$$\sqrt{1-x} \approx 1 - x/2 \quad (x \ll 1)$$



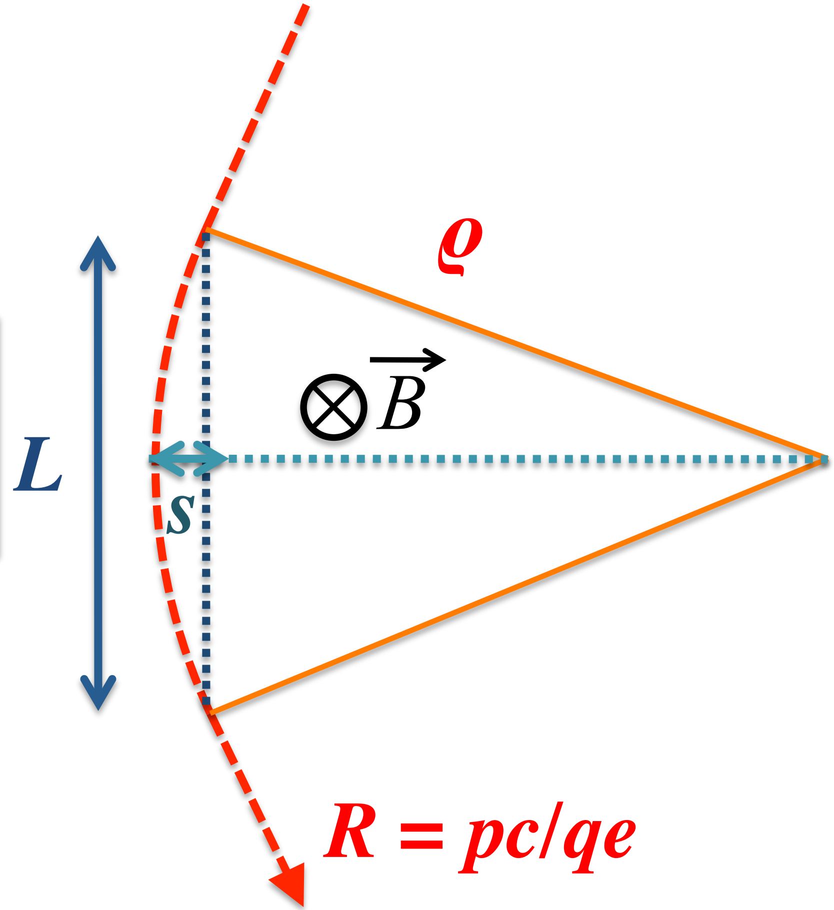
e.g.

$R = 1$ GV, $B = 1$ Tesla, $L = 1$ m ➔ $s \approx 38$ mm

Rigidity resolution

$$s \approx \frac{0.3BL^2}{8R}$$

$$\Delta(1/R) = \frac{\Delta R}{R^2} \approx \frac{8\Delta s}{0.3BL^2}$$



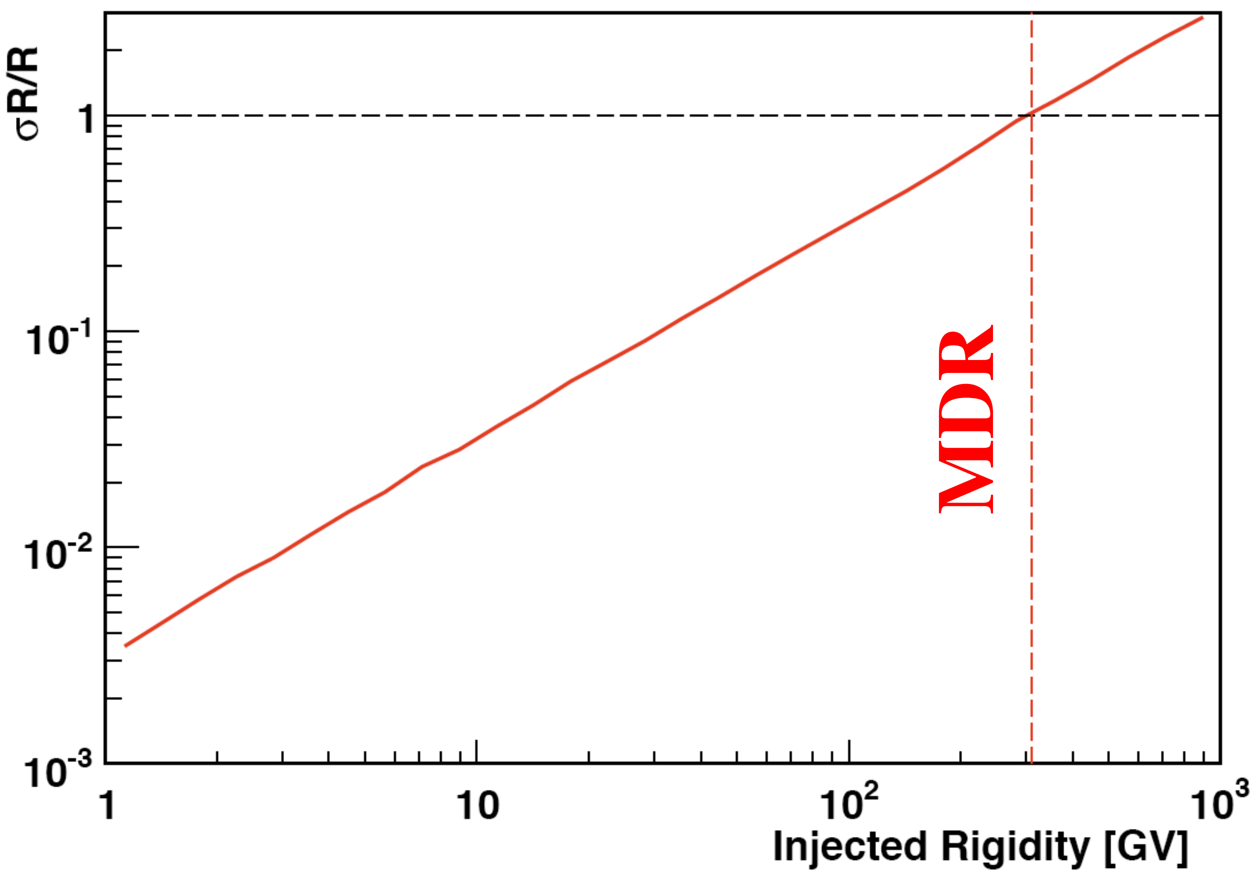
$e.g.$

$B = 1$ Tesla, $L = 1$ m, $\Delta s = 0.1$ mm

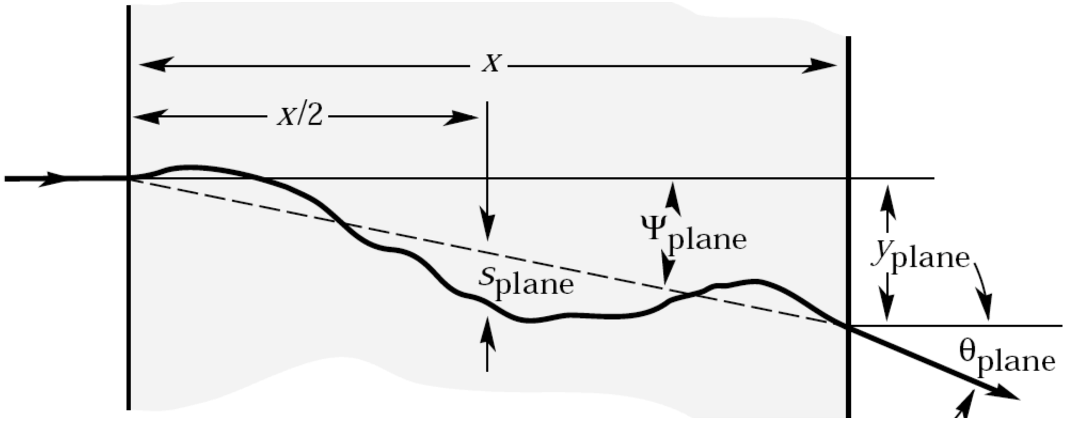
➔ $\Delta R/R \approx 2.7$ % ($R = 10$ GV)

Maximum Detectable Rigidity

$$\frac{\Delta R}{R} = \frac{8\Delta s}{0.3BL^2} R = 1 \rightarrow R_{\mathrm{MD}} = \frac{0.3BL^2}{8\Delta s}$$



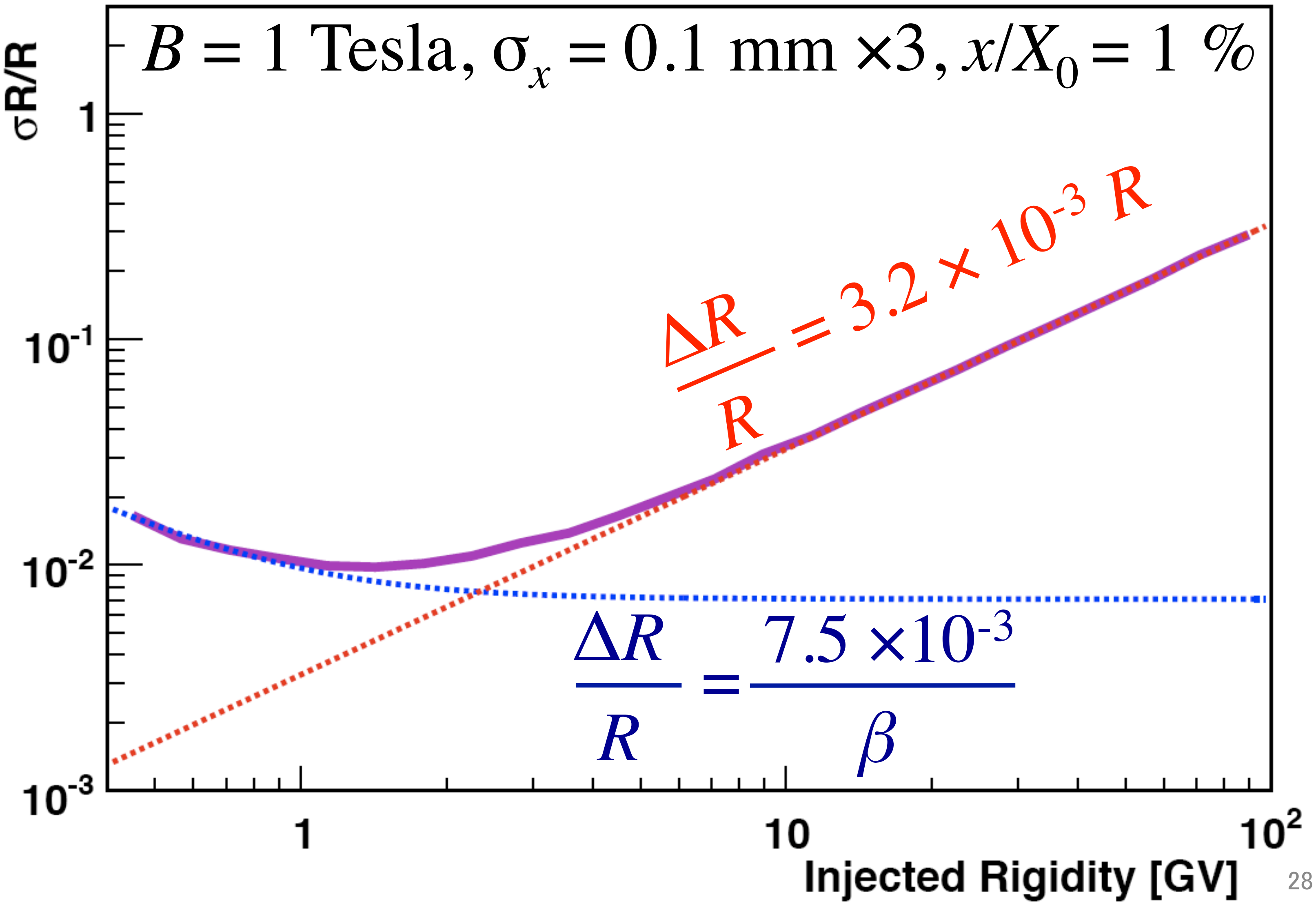
Multiple scattering



$$\theta_0 = \frac{13.6\ \mathrm{MeV}}{\beta c p}\ z\ \sqrt{x/X_0}\Big[1 + 0.038\ln(x/X_0)\Big]$$

- x/X_0 : Thickness in *radiation length*
- *e.g.*
  $x/X_0 = 1\ \%$ ➔ $\theta_0 = 1.1\times10^{-3}$ rad $/\beta R$

Simulation with scattering

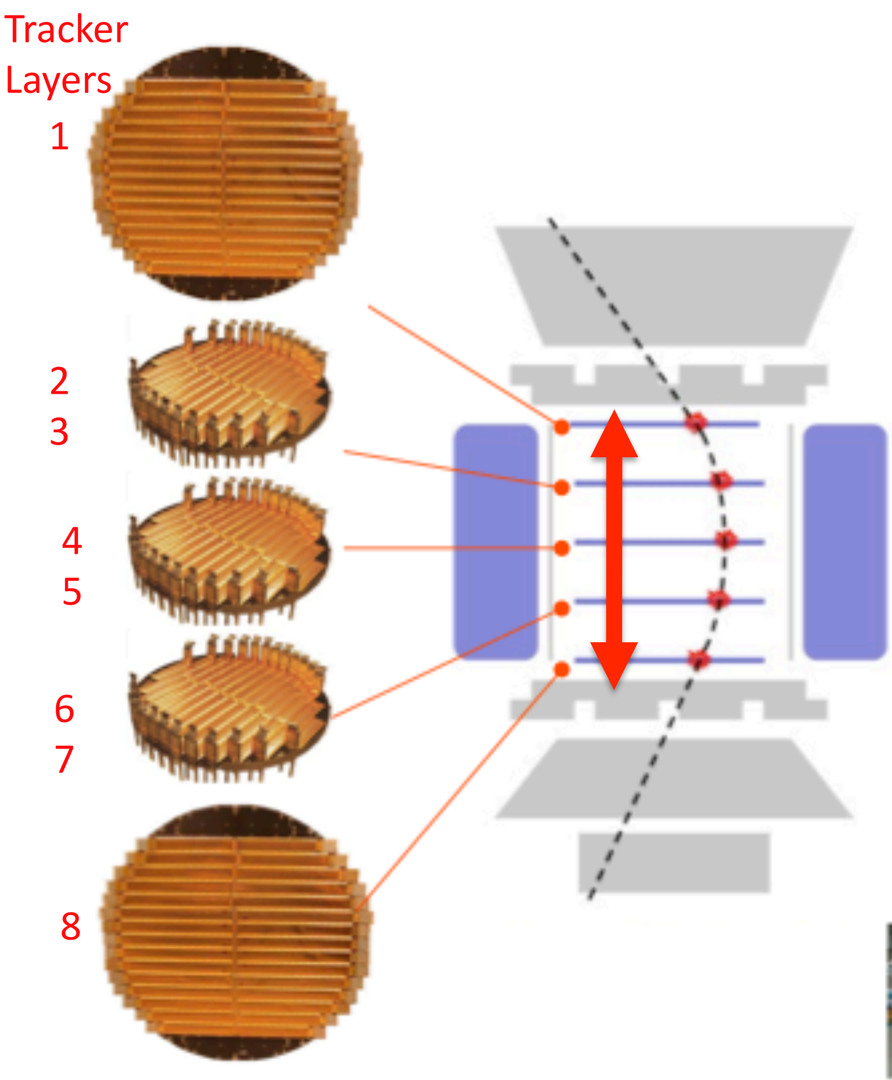


AMS-02 : Timeline 2009~2011

Oct-Dec	2009	Spectrometer integration at CERN
Feb	2010	Beam test at CERN
Mar-Apr	2010	Space qualification tests at ESTEC
Apr-Jul	2010	Reconfiguration with Perm.Magnet
Aug	2010	Beam test at CERN
Sep-Dec	2010	Payload integration at KSC
May	2011	Launch Start the mission on the ISS

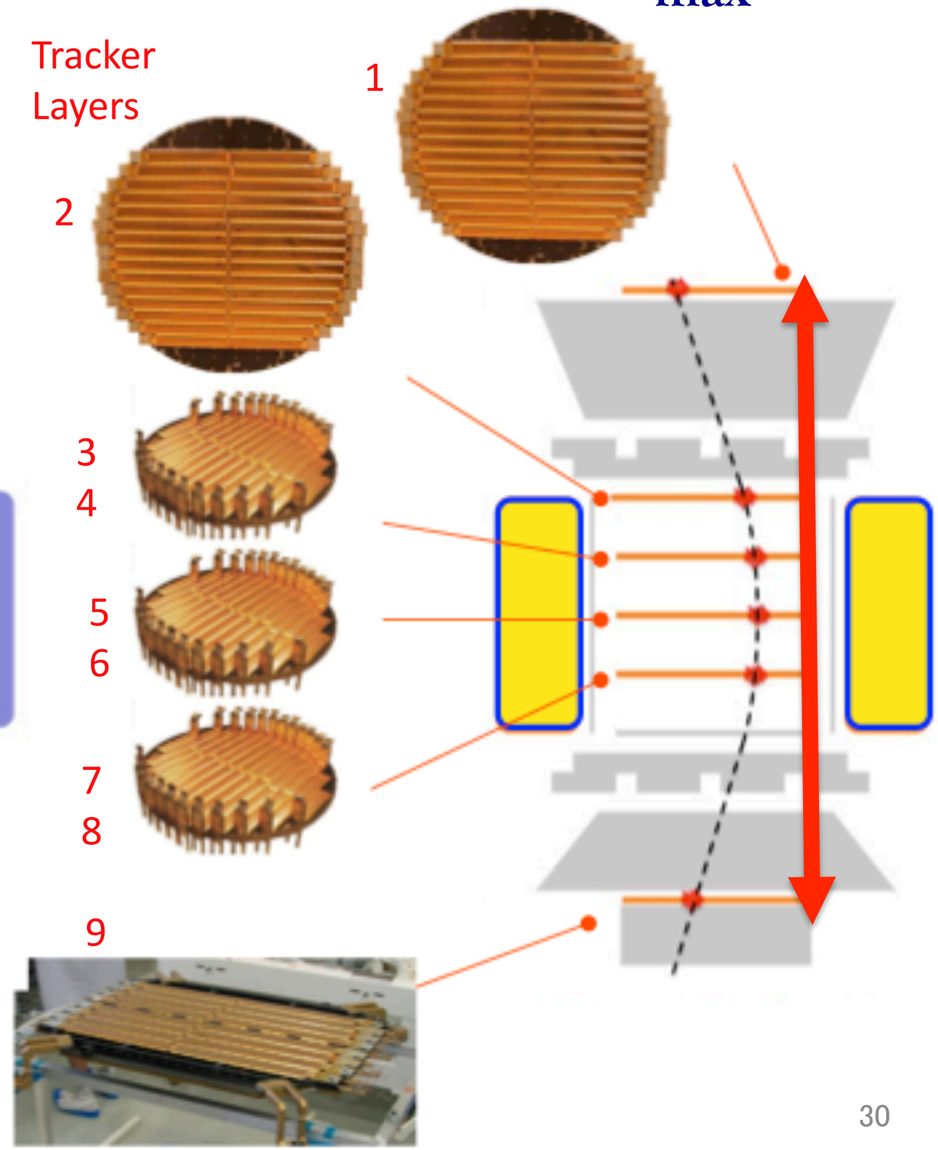
AMS-SC

B = 0.8 T, L = 1 m

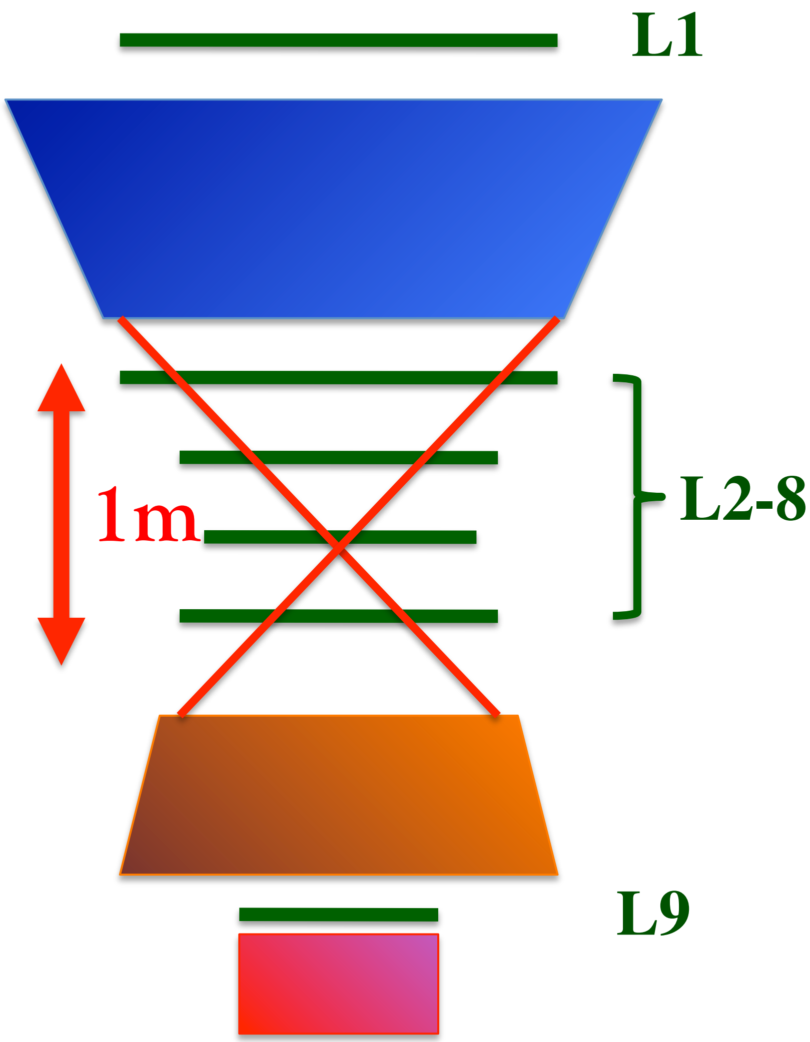


AMS-PM

B= 0.15 T, L_{max}= 3m



Exposures VS Resolution



MC estimation

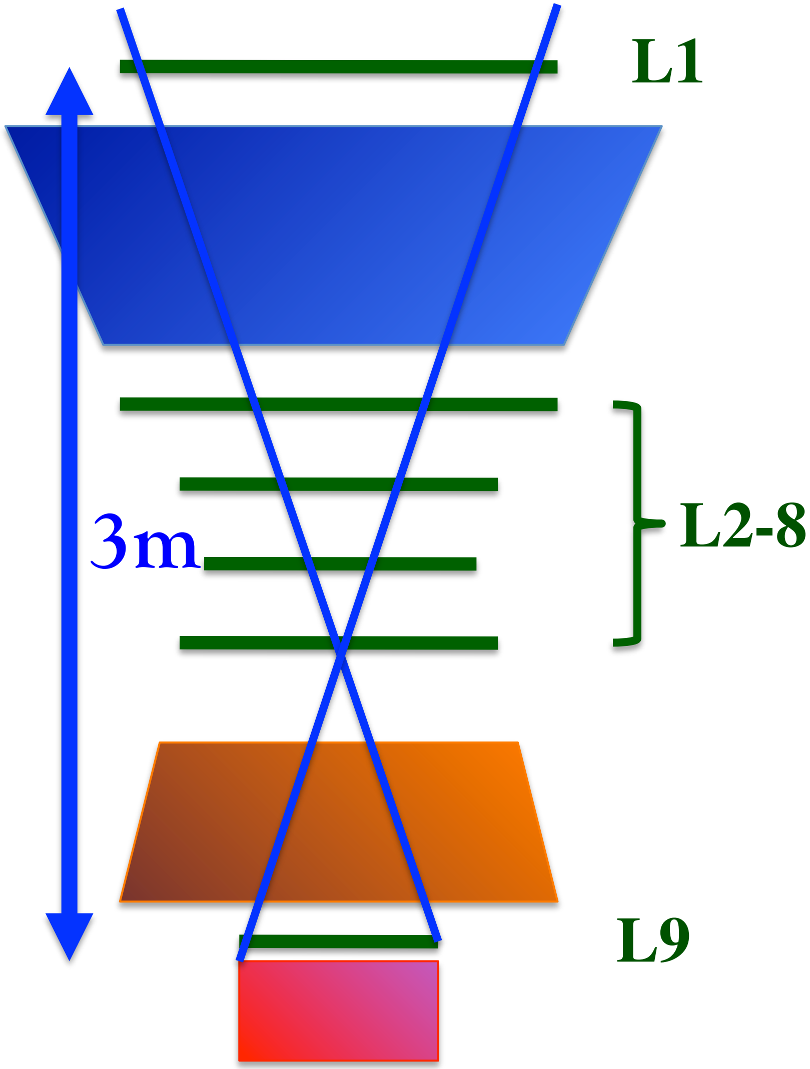
Inner only (L2-8)
4500 cm^{2}sr, MDR 0.2 TV

L2-8 + L1
1600 cm^{2}sr, MDR 0.6 TV

L2-8 + L9
950 cm^{2}sr, MDR 0.8 TV

L2-8 + L1 + L9 (Max Span)
300 cm^{2}sr, MDR 2.0 TV

Exposures VS Resolution



MC estimation

Inner only (L2-8)

4500 cm^{2}sr, MDR 0.2 TV

L2-8 + L1

1600 cm^{2}sr, MDR 0.6 TV

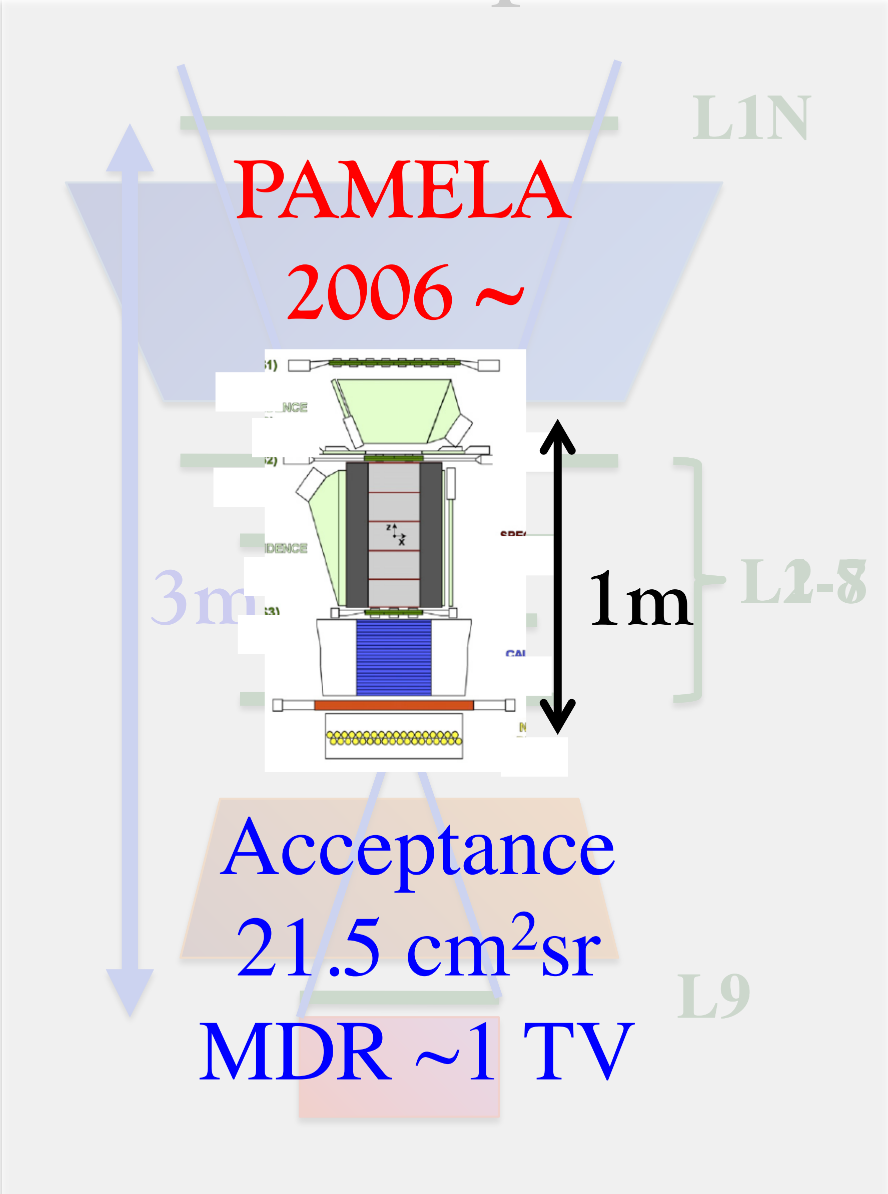
L2-8 + L9

950 cm^{2}sr, MDR 0.8 TV

L2-8 + L1 + L9 (Max Span)

300 cm^{2}sr, MDR 2.0 TV

Exposures VS Resolution



MC estimation

Inner only (L2-8)

4500 cm^{2}sr, MDR 0.2 TV

L2-8 + L1

1600 cm^{2}sr, MDR 0.6 TV

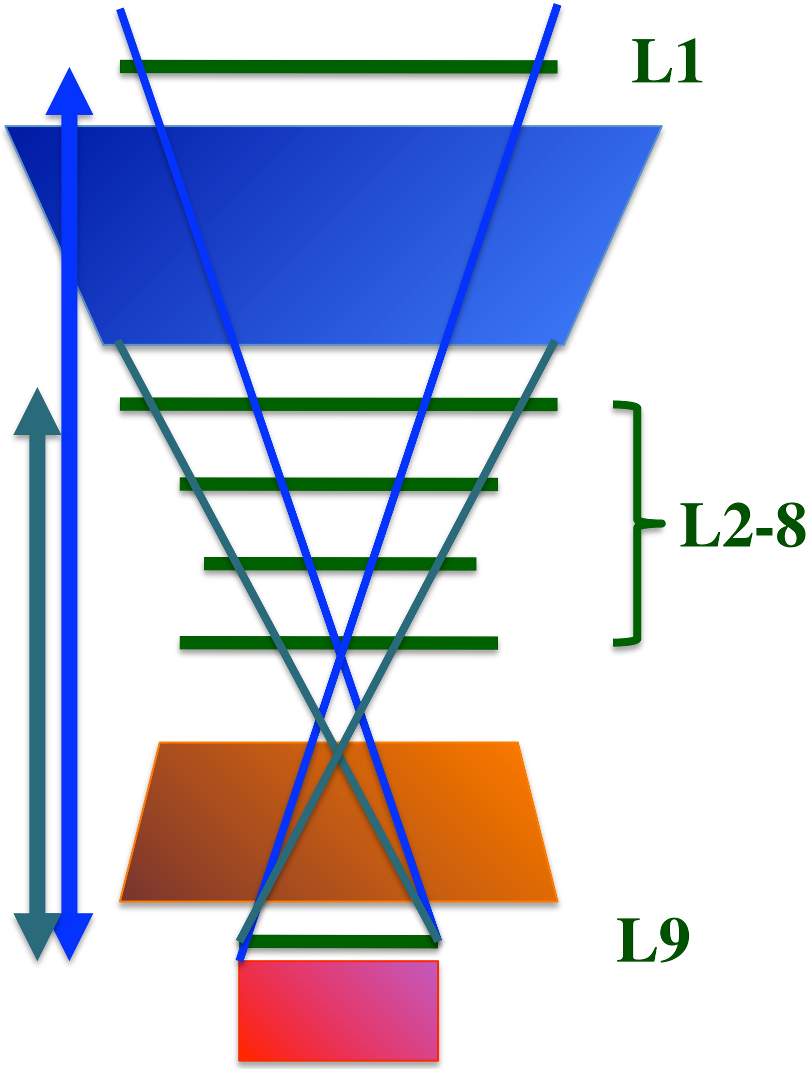
L2-8 + L9

950 cm^{2}sr, MDR 0.8 TV

L2-8 + L1 + L9 (Max Span)

300 cm^{2}sr, MDR 2.0 TV

Exposures for positrons



AMS-PM

L2-8 + L9

950 cm^2sr, MDR 0.8 TV

L2-8 + L1 + L9 (Max Span)

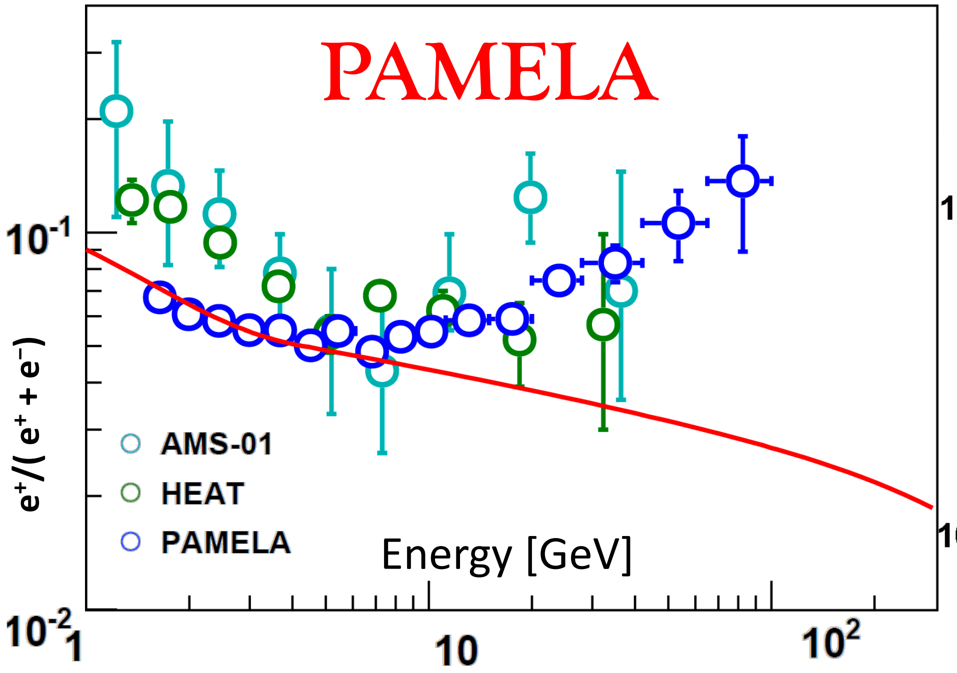
300 cm^2sr, MDR 2.1 TV

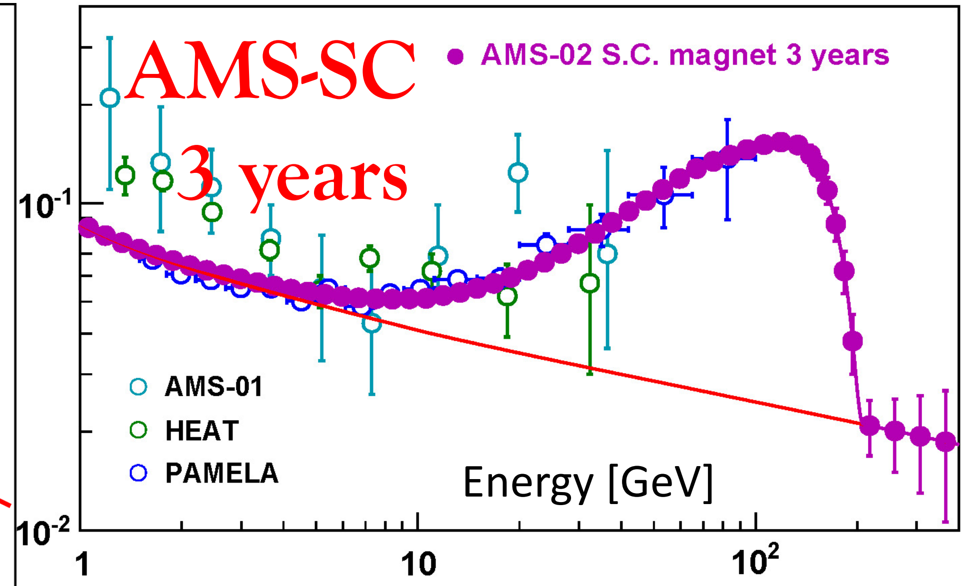
AMS-SC

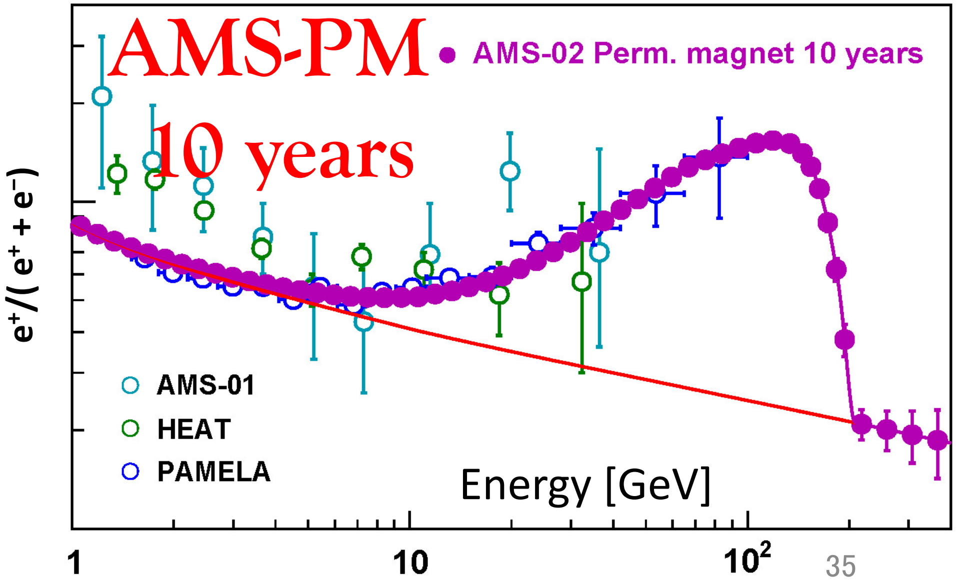
L1-8 + Ecal

950 cm^2sr, MDR 2.2 TV

Dark Matter Candidate $\chi^0 \chi^0 \rightarrow e^+e^-$ for $m\chi^0 = 200$ GeV







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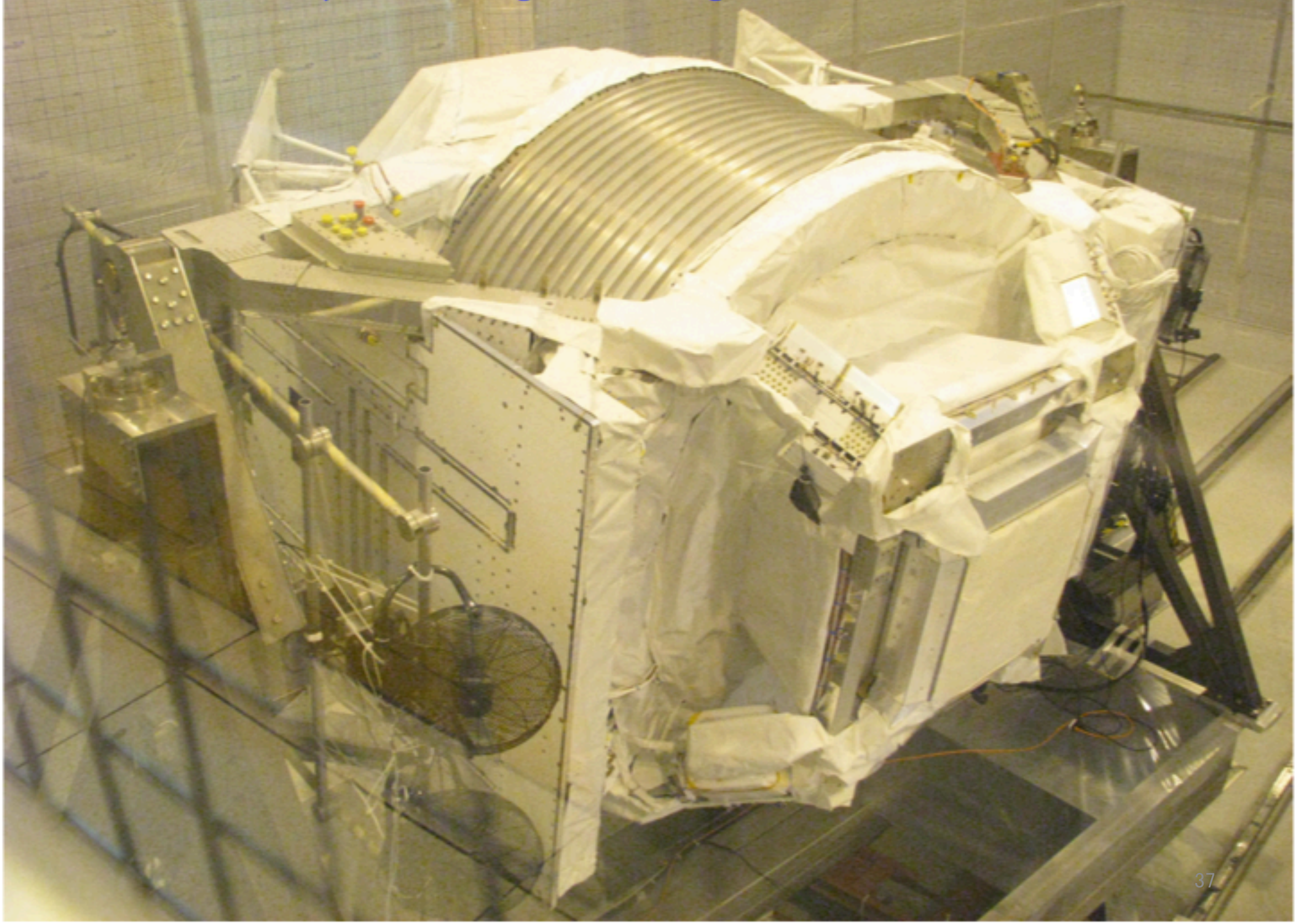
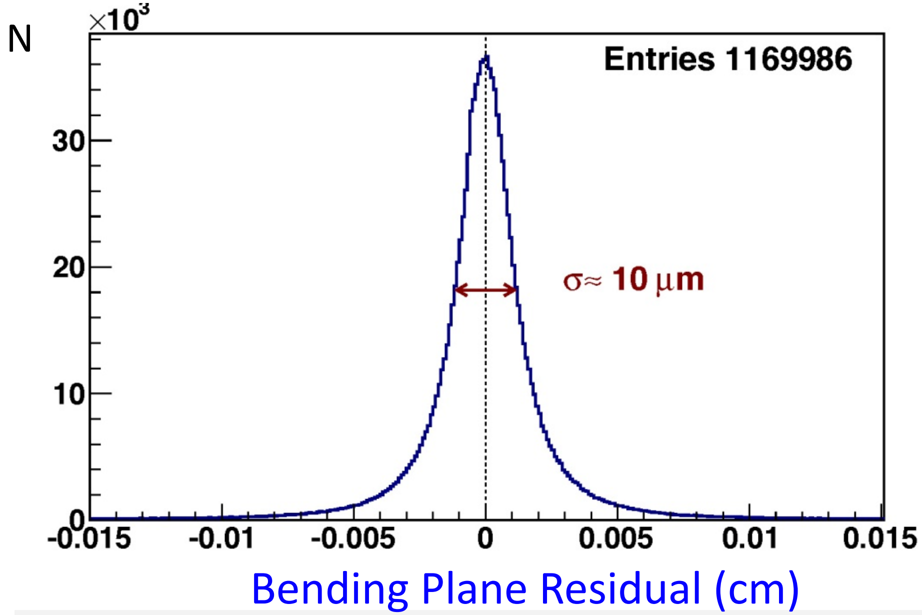
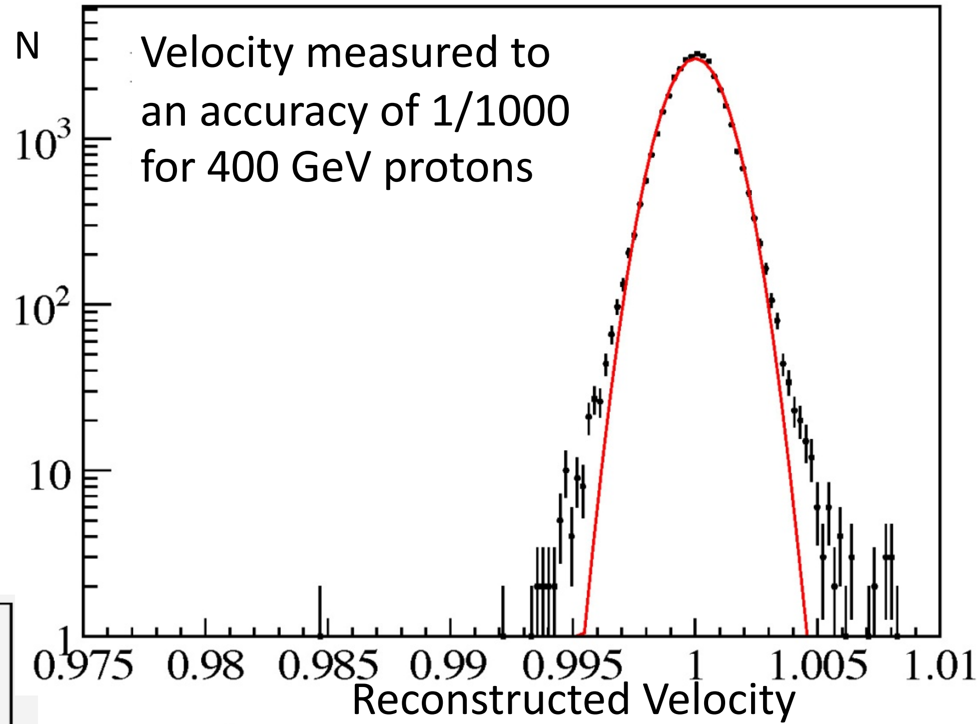
May	2011	Launch Start the mission on the ISS

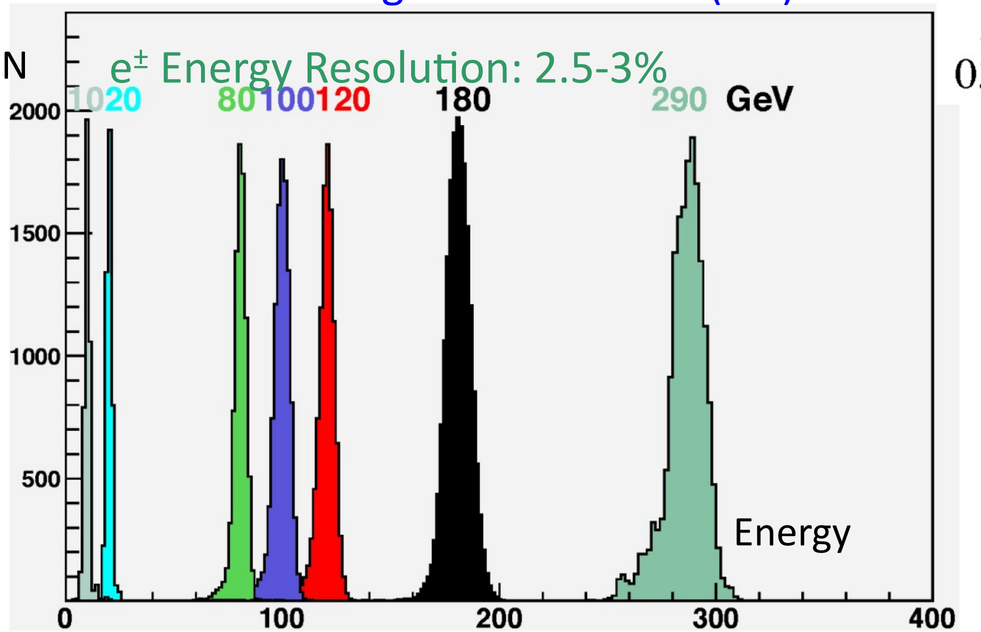
AMS in Test Beam with permanent magnet – 8-20 Aug 2010

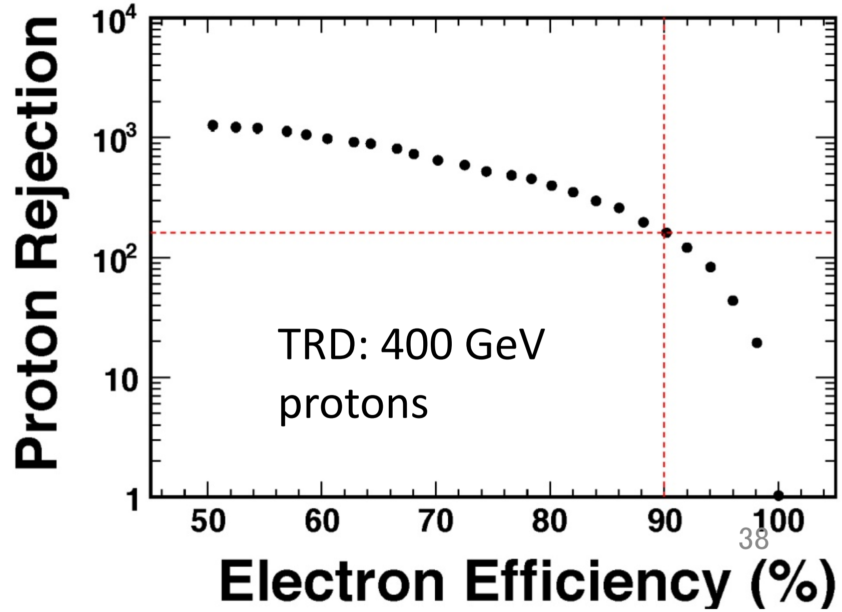


Test Beam Results with permanent magnet – 8-19 Aug 2010



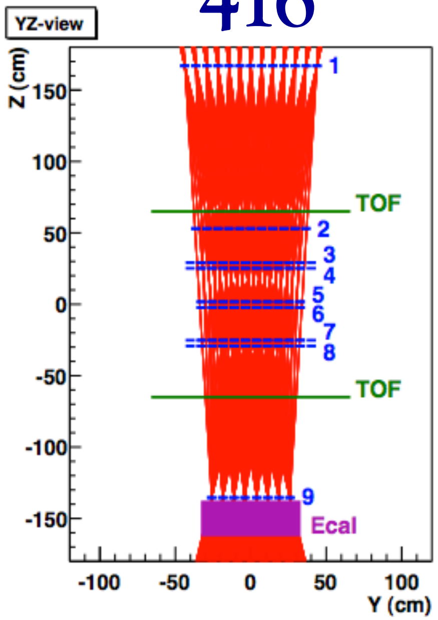




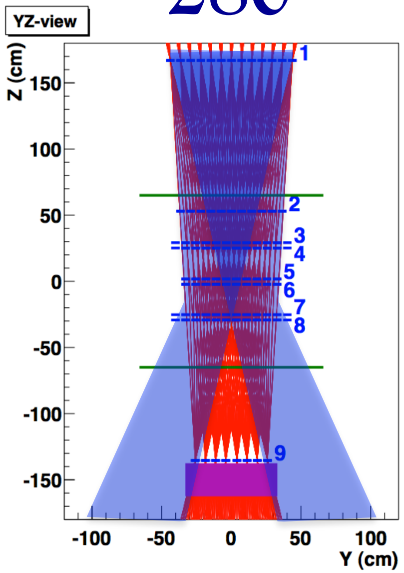


Tracker alignment ~900 beam positions

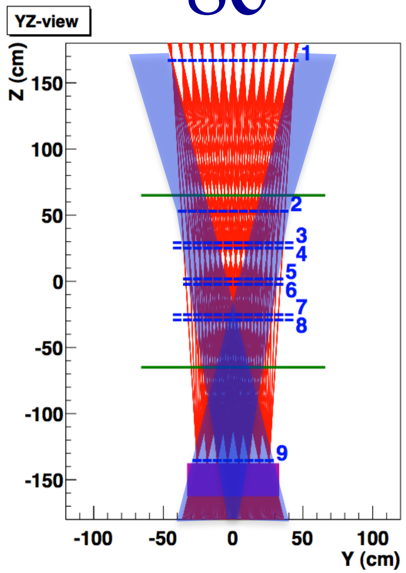
416



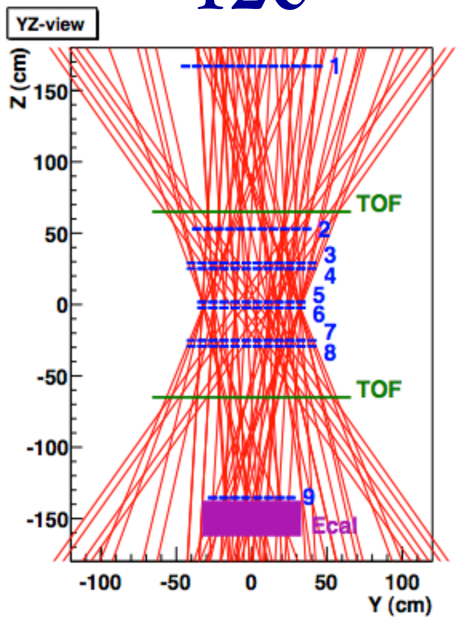
280



80



120



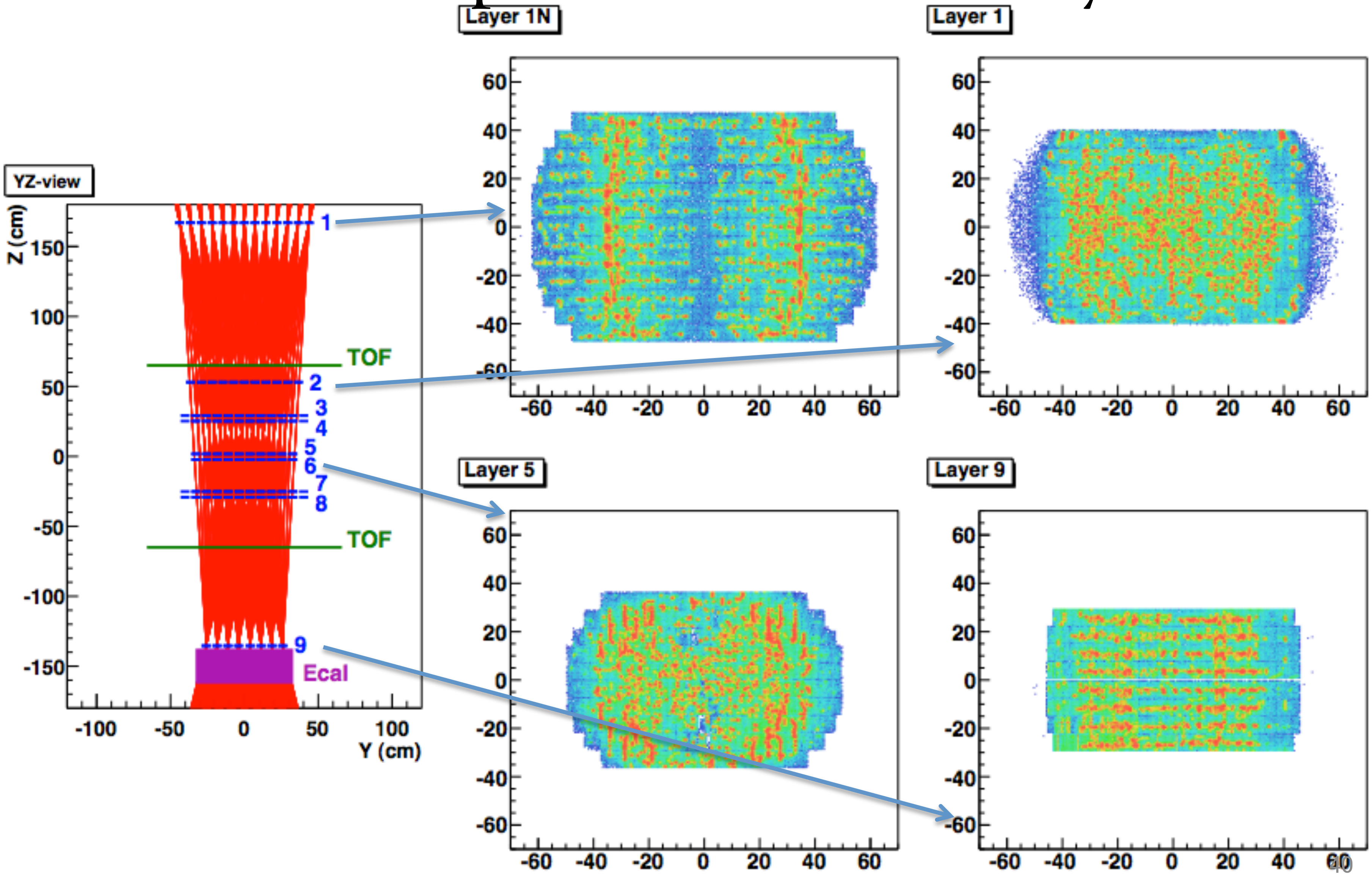
Proton 400 GeV (primary beam)

416 positions: 2 external layers (Full Span)

280+80 positions: At least 1 external layers (Half Span)

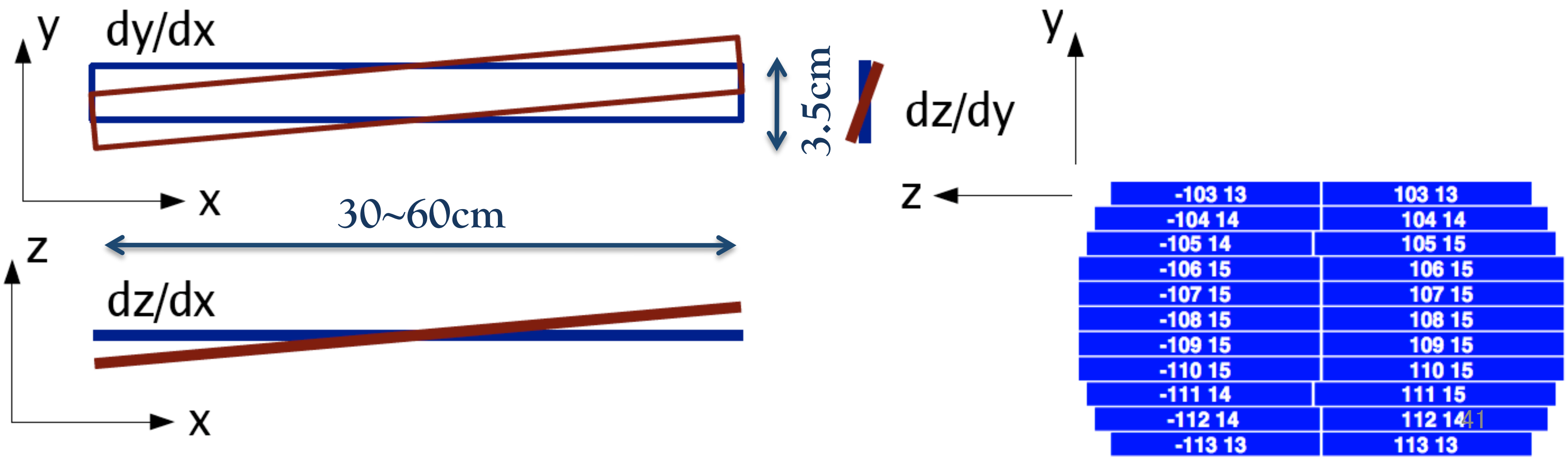
120 positions: Internal layers

Beam profile on each layer

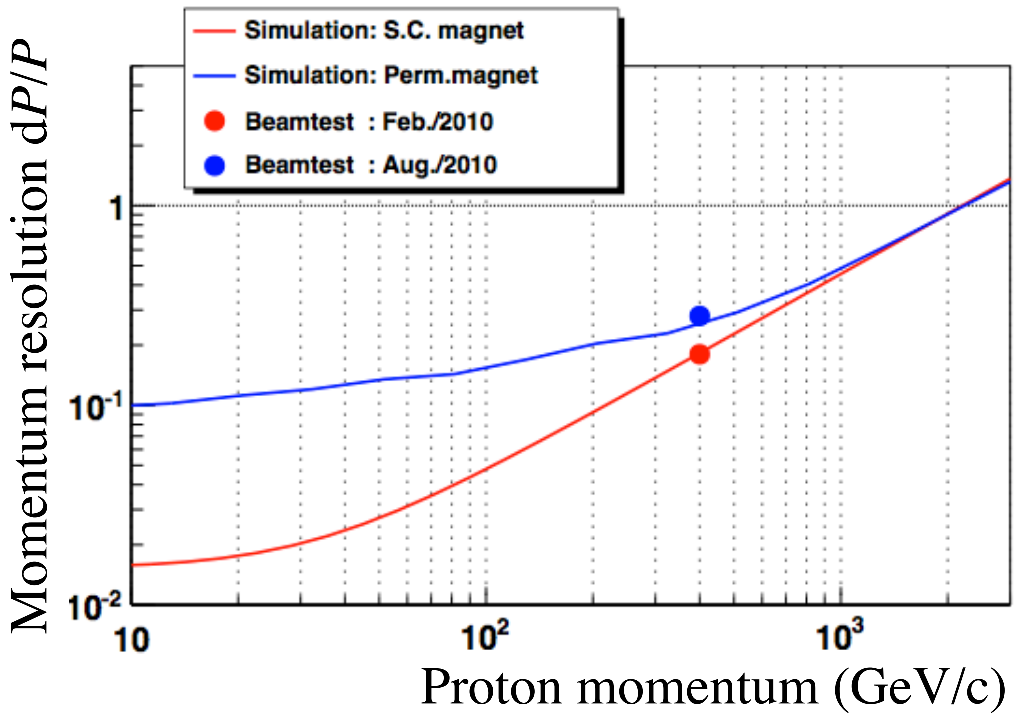


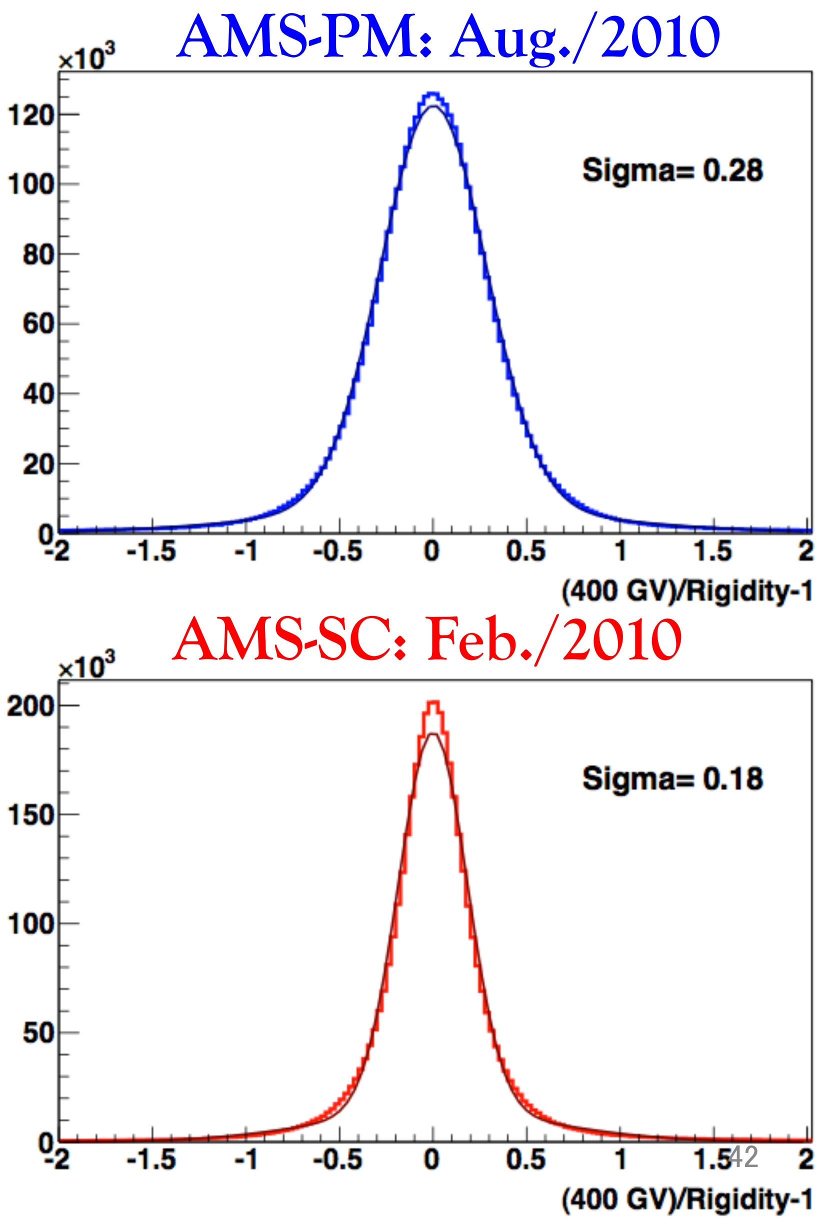
Ladder alignment

- 5 parameters for each ladder have been determined from residual in the track fitting with fixed momentum (5×192 = 960 in total)
  - Translation (dx, dy, dz)
  - Rotation (dx/dy, dz/dx, dz/dy)



Momentum resolution





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Aéroport de Cointrin. Un des plus gros avions-cargos du monde attend sur le tarmac. Il est le seul capable de transporter au-dessus de l'Atlantique le Spectromètre magnétique Alpha (AMS). (LAURENT GUIRAUD)

Vol spécial pour l'aimant chasseur d'antimatière

PHYSIQUE Assemblé au CERN, l'AMS quitte Cointrin pour la Floride d'où il doit être lancé dans l'espace en février.

ANNE-MURIEL BROUET

C'est un monstre obèse, comme avachi sur ses trains d'atterrissage. La gueule ouverte, le Super Galaxy de l'US Air Force, un des plus gros avions-cargos du monde, attend sur le tarmac de l'aéroport de Cointrin. Il est le seul capable de transporter au-dessus de l'Atlantique le Spectromètre magnétique Alpha (AMS), fruit de quinze ans de travail de 600 physiciens en Europe, aux Etats-Unis, en Chine, à Taïwan et en Corée. Cet instrument unique, assemblé au CERN, l'Organisation européenne pour la recherche nucléaire, traquera, depuis l'espace, l'antimatière et la matière noire soupçonnée de constituer à 90% de la masse de l'Univers.

Le chargement dans la soute a eu lieu hier. Le mastodonte a devait décoller ce matin entre 6 et 7 heures, en direction du Centre spatial Kennedy en Floride. C'est de là que le précieux instrument partira, en principe en février, pour sa destination finale, la Station spatiale internationale.

Principal et unique instrument de physique sur l'ISS, AMS devrait y fonctionner durant une vingtaine d'années. Les données récoltées seront transmises, via Houston, au CERN où se trouve le centre de contrôle du détecteur.

Soixante universités et instituts, dont l'Université de Genève et l'EPFZ en Suisse, ont contribué à la réalisation de ce détecteur de 7,5 tonnes, haut de 4 mètres et large de 5, qui ne rentre pas dans des avions-cargos standard. Sa valeur totale atteint 2 milliards de dollars.

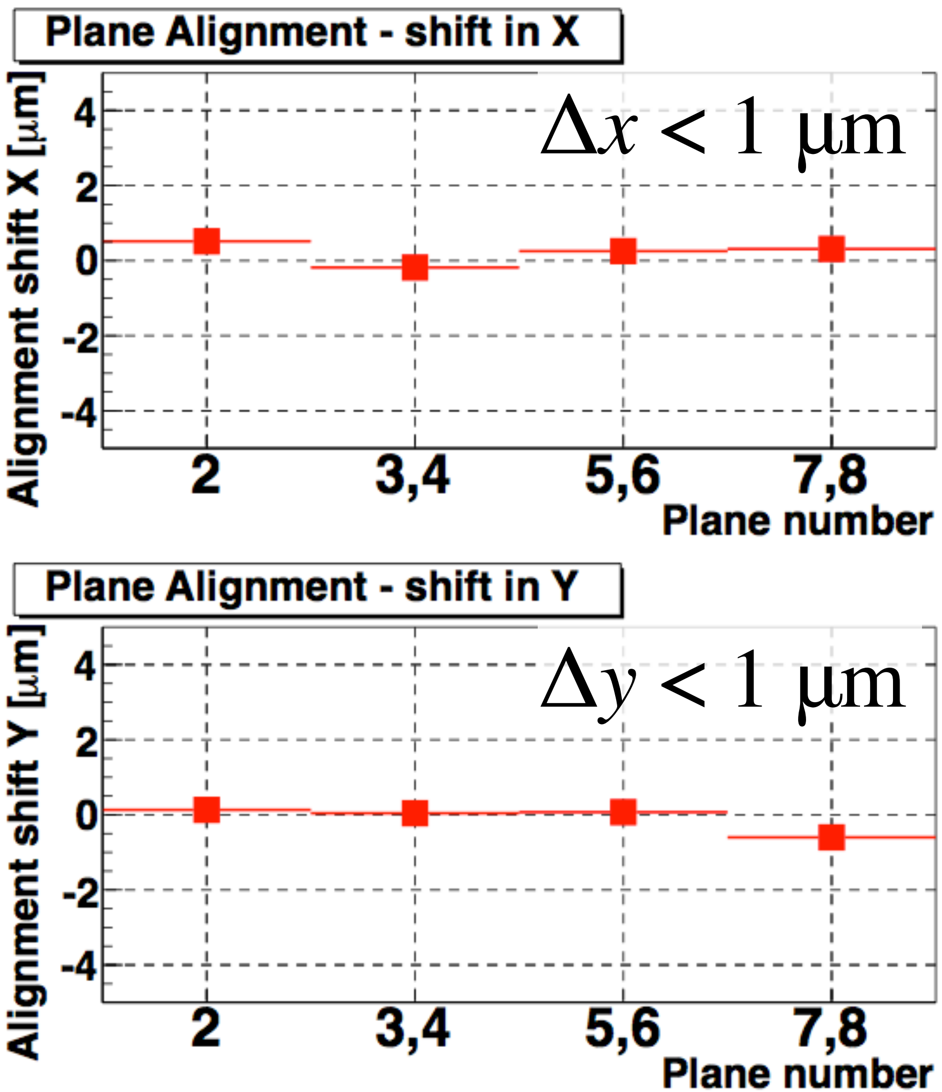
Bouquet de surprises

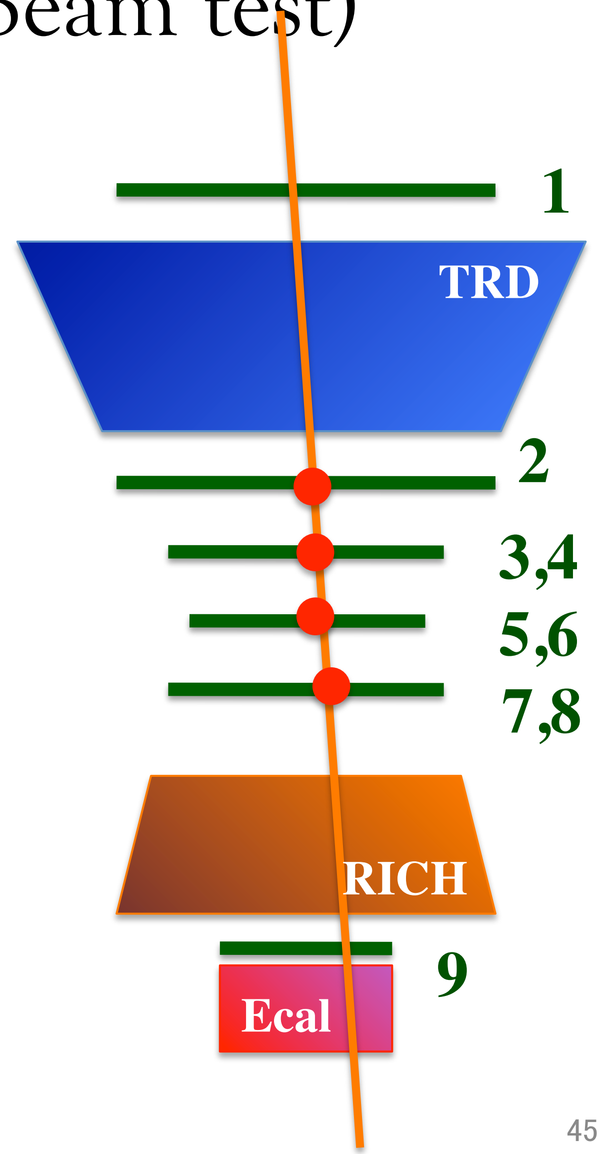
Qu'en attendent les physiciens? «Des surprises», a déclaré hier au cours de la conférence de presse le porte-parole de l'expérience et Prix Nobel Samuel Ting. «Le plus souvent les découvertes n'ont rien à voir avec le but premier de l'expérience.» Toutefois, l'idée de base est de profiter de l'énergie gigantesque des particules dans l'espace. Si le grand accélérateur de particules du CERN, le LHC, peut pousser les particules à une énergie de 7 TeV, dans le cosmos celle-ci peut atteindre 100 millions de TeV. L'intérêt d'être à 400 kilomètres de nos têtes est donc d'échapper aux brouillages de l'atmosphère.

Une quantité appréciable d'antimatière détectée depuis l'ISS serait une preuve qu'une source d'antimatière serait encore active dans le cosmos. Outre l'antimatière primordiale, AMS analysera la composition des rayons cosmiques galactiques et extragalactiques, et recherchera également la matière noire.

Le Spectromètre magnétique Alpha (AMS). Il traquera, depuis l'espace, l'antimatière et la matière noire soupçonnée de constituer 90% de la masse de l'Univers. (LAURENT GUIRAUD)

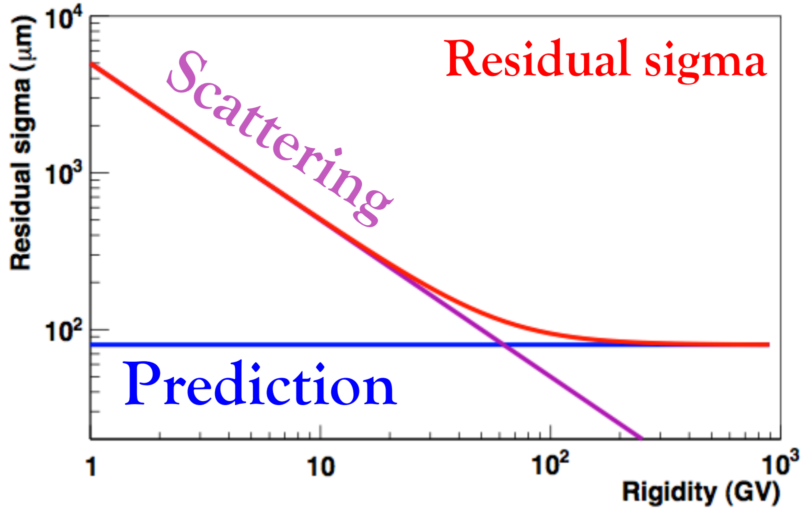
Planes alignment check with muons @ KSC (w.r.t. CERN Beam test)

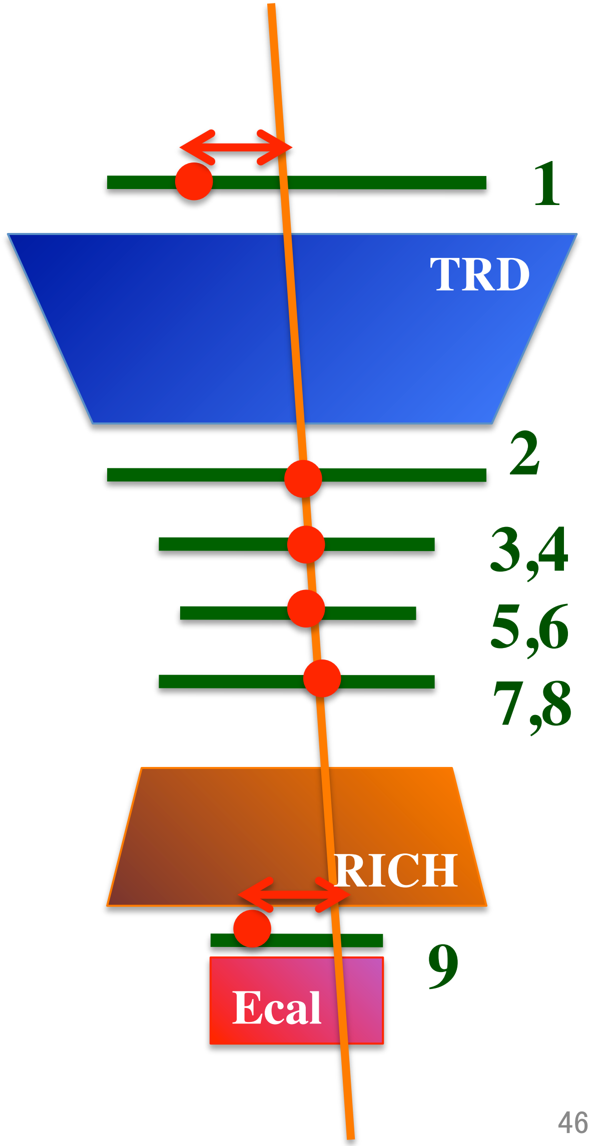




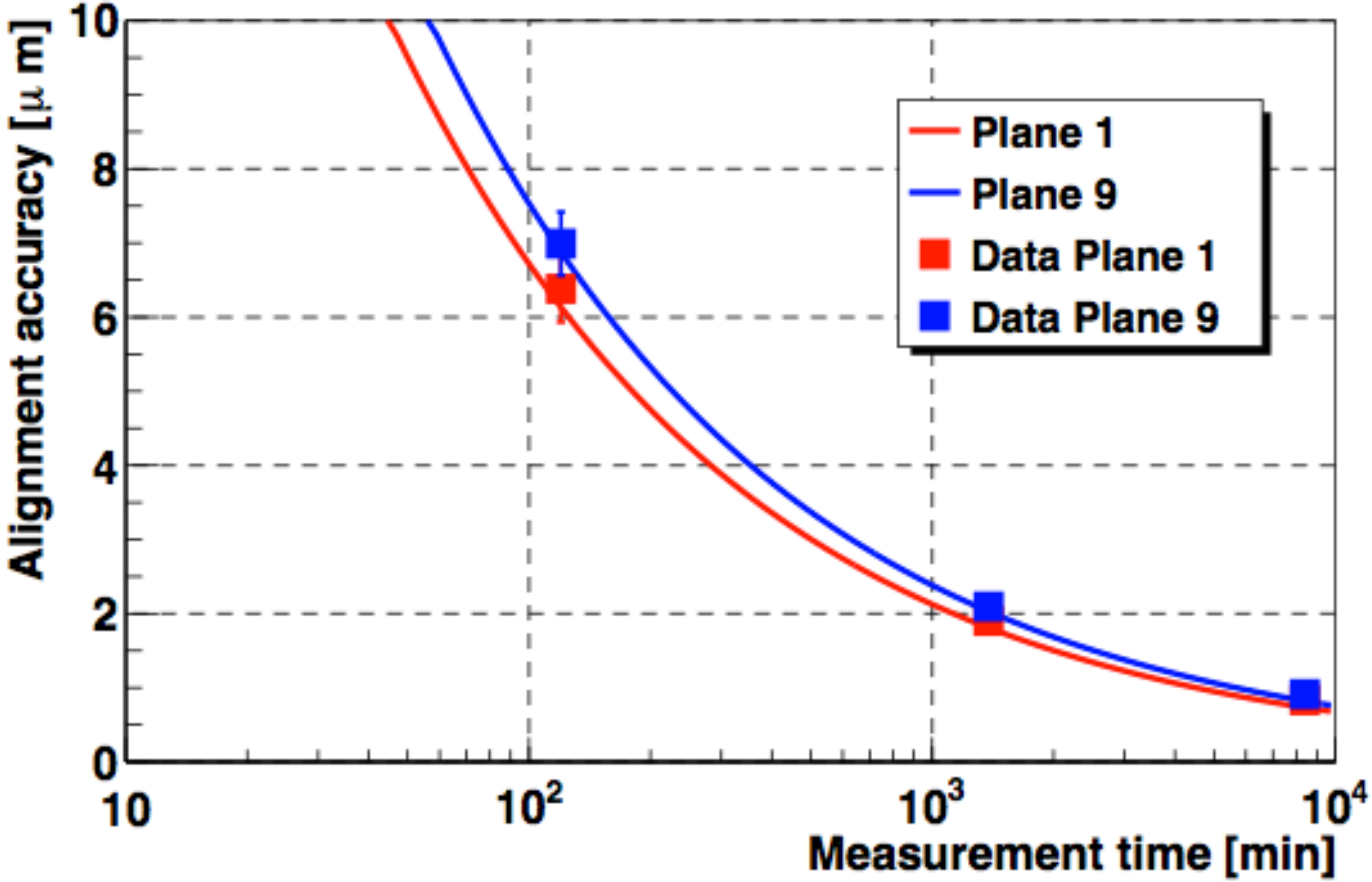
External planes alignment

- Fitting residuals :
  Prediction of Inner tracker
  Multiple scattering
  Hit resolution
  Alignment shift

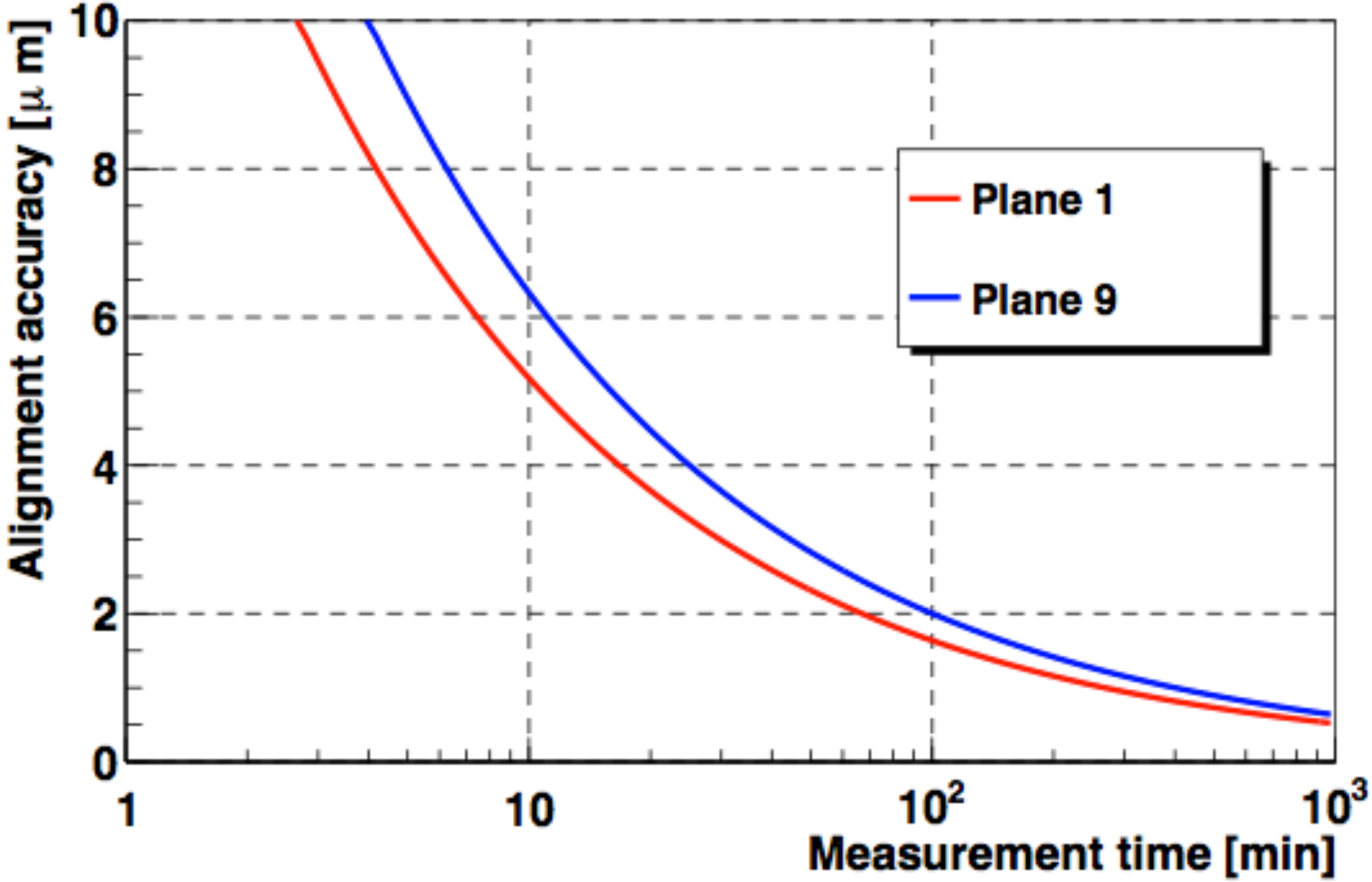




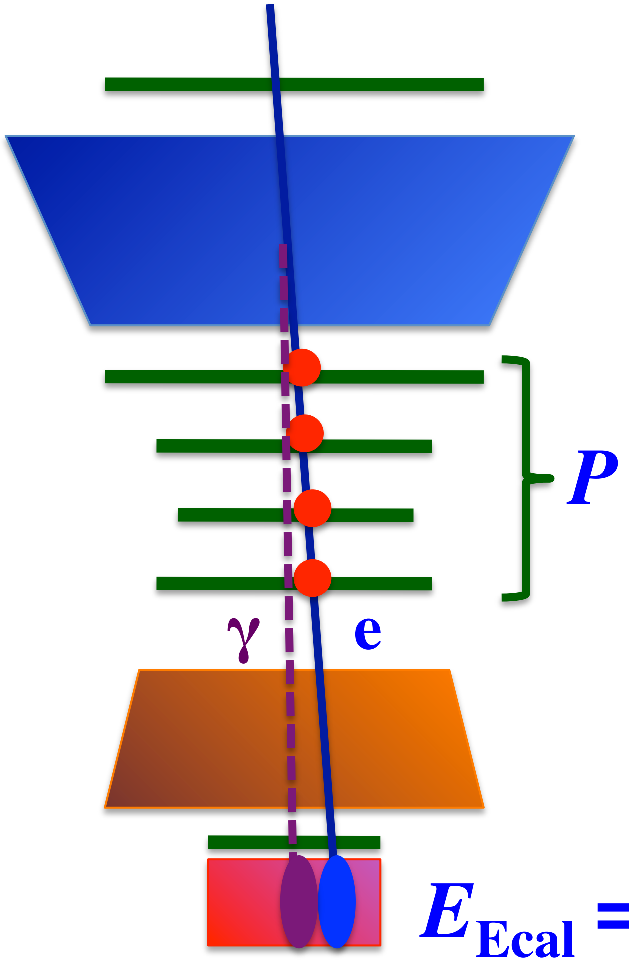
Alignment Accuracy VS statistics Measured with muons on ground



Alignment Accuracy VS statistics Estimation for protons on the ISS

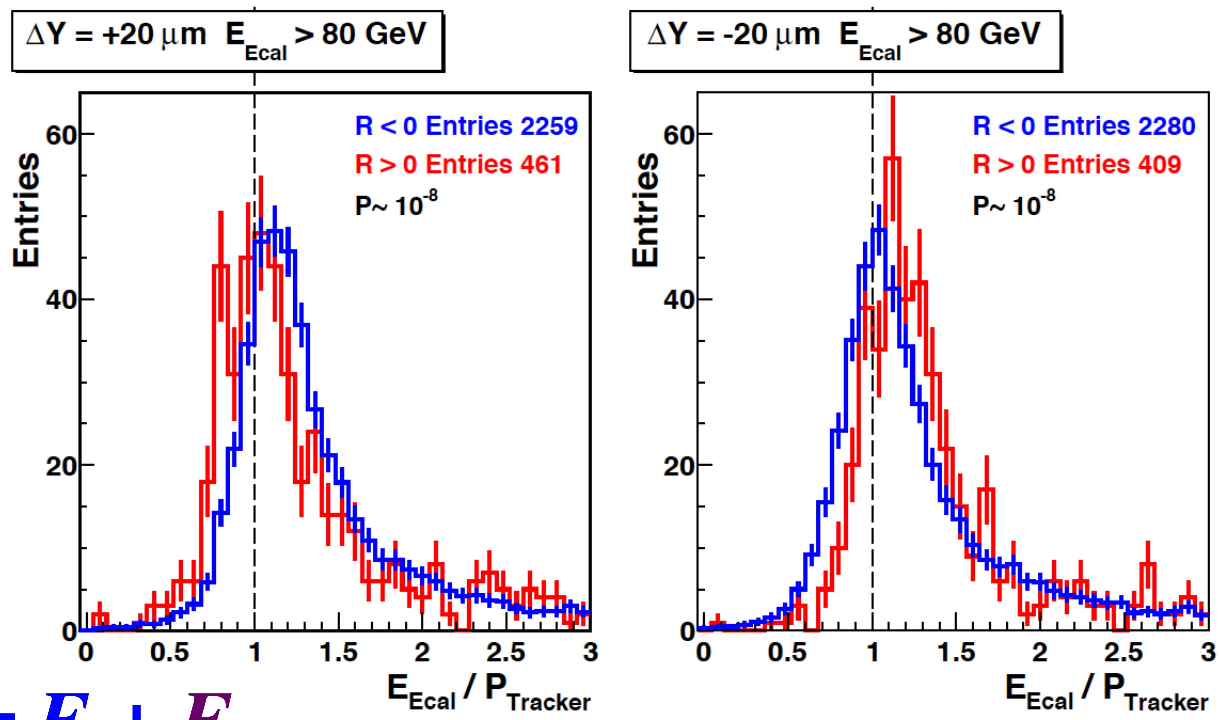


Alignment check with $E_{Ecal}/P_{Tracker}$ using e^{+} and e^{-} sample

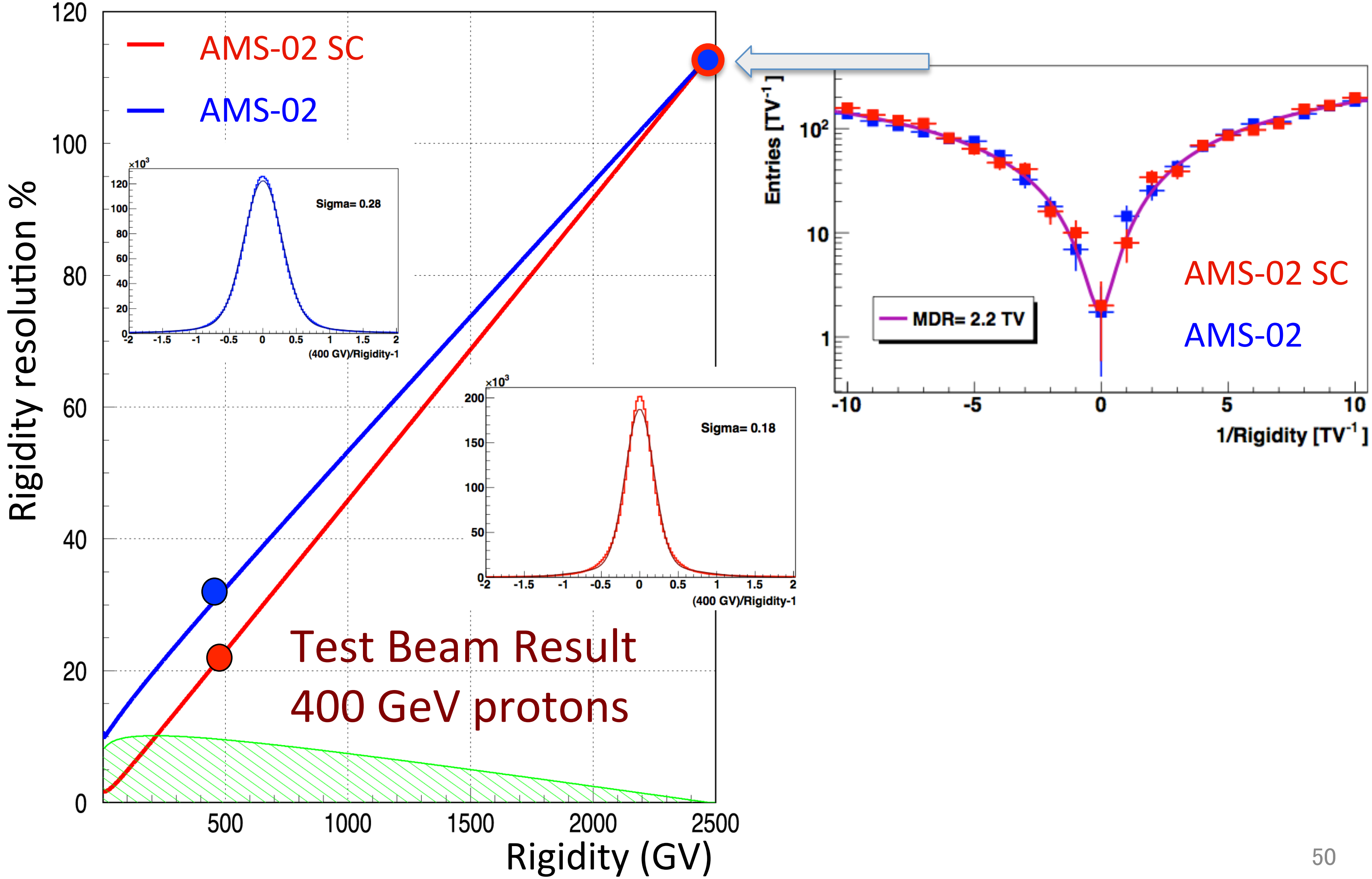


$$E_{Ecal} = E_e + E_\gamma$$

Simulation



MDR extimated with muons @ KSC



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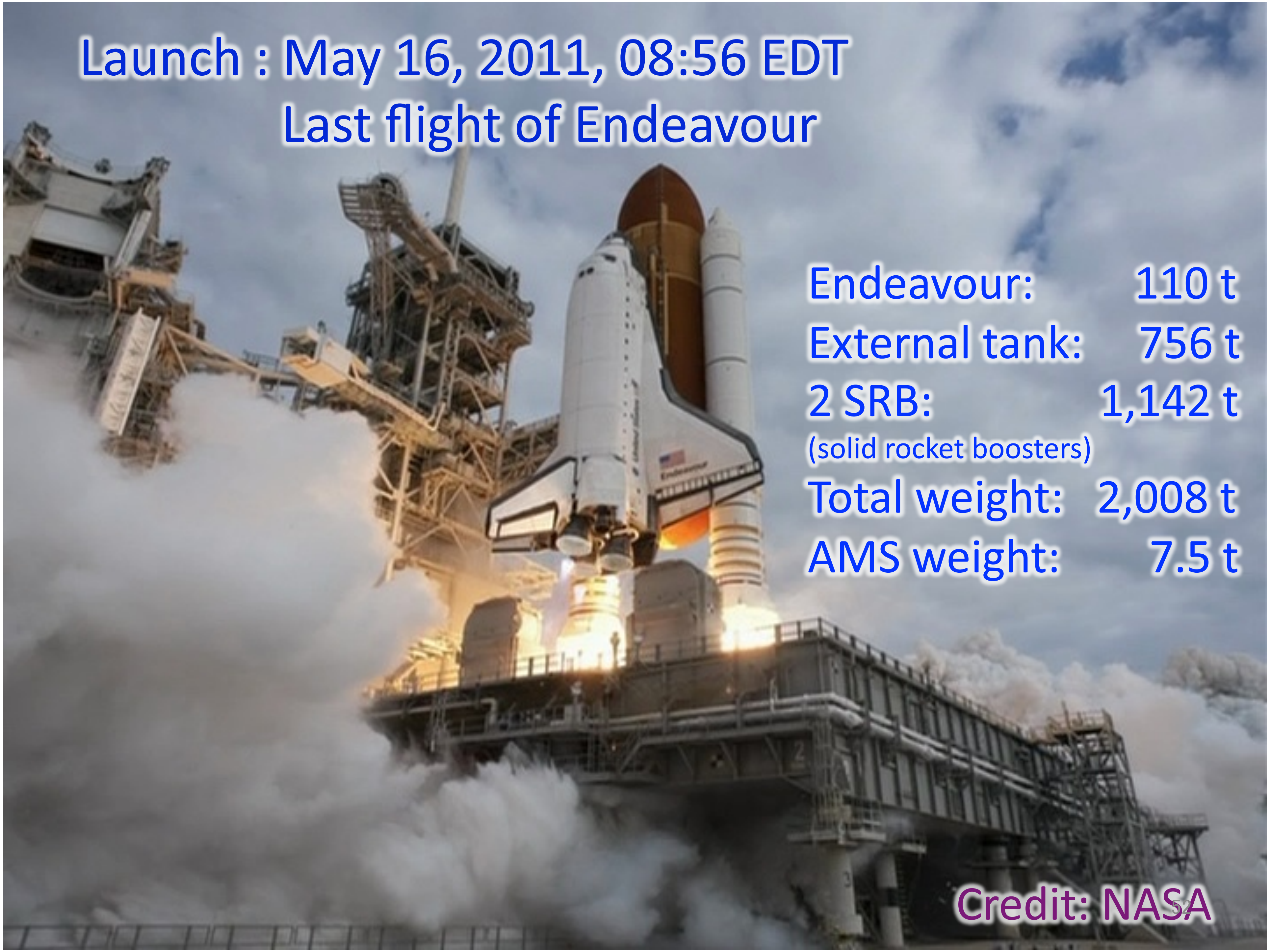
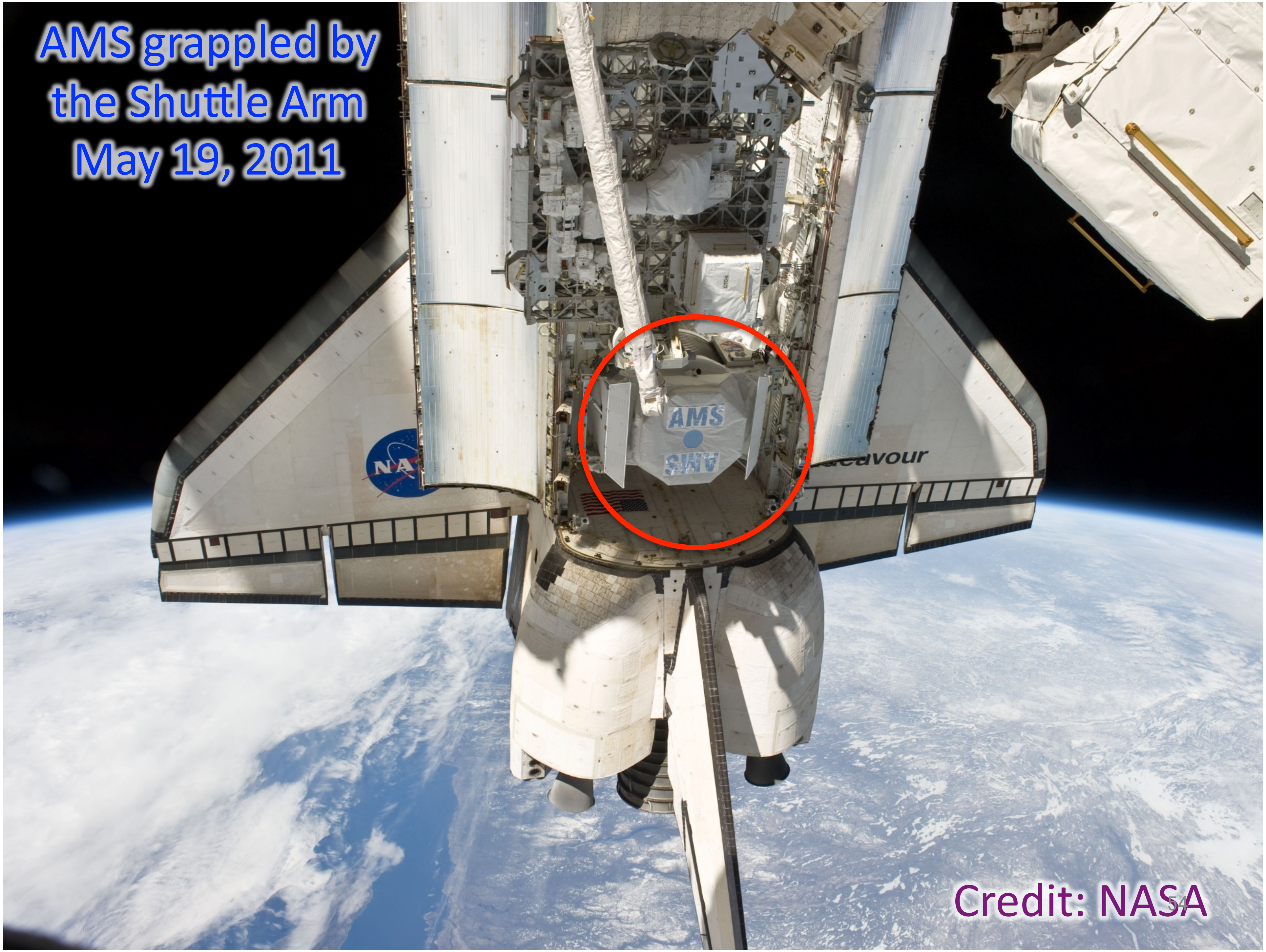
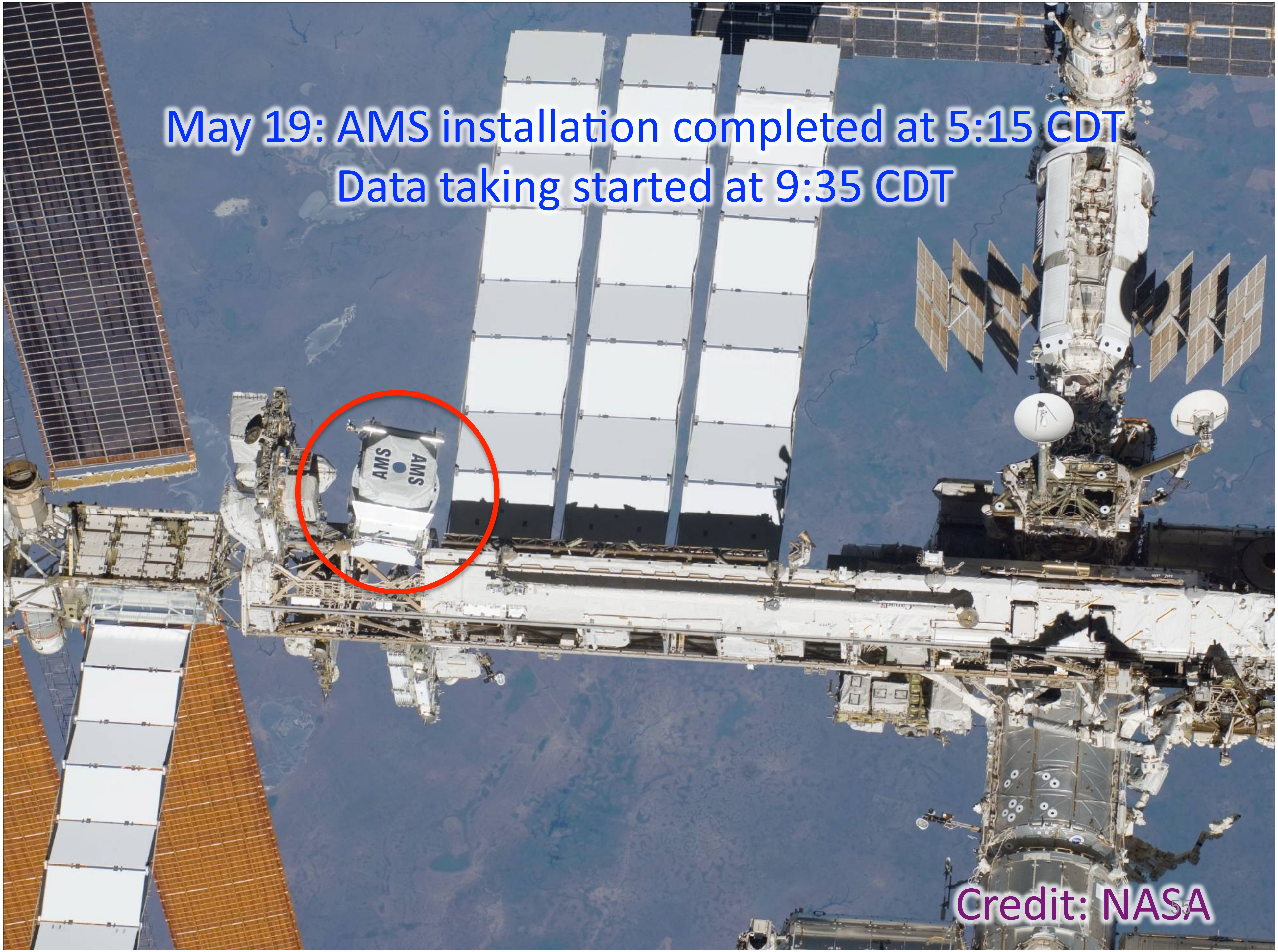

Launch : May 16, 2011, 08:56 EDT
Last flight of Endeavour
Endeavour: 110 t
External tank: 756 t
2 SRB: 1,142 t
(solid rocket boosters)
Total weight: 2,008 t
AMS weight: 7.5 t
Credit: NASA


After 123 seconds,
1,000 tons of fuel
is spent.
Photographed from a STA
(Shuttle Training Aircraft)
Credit: NASA

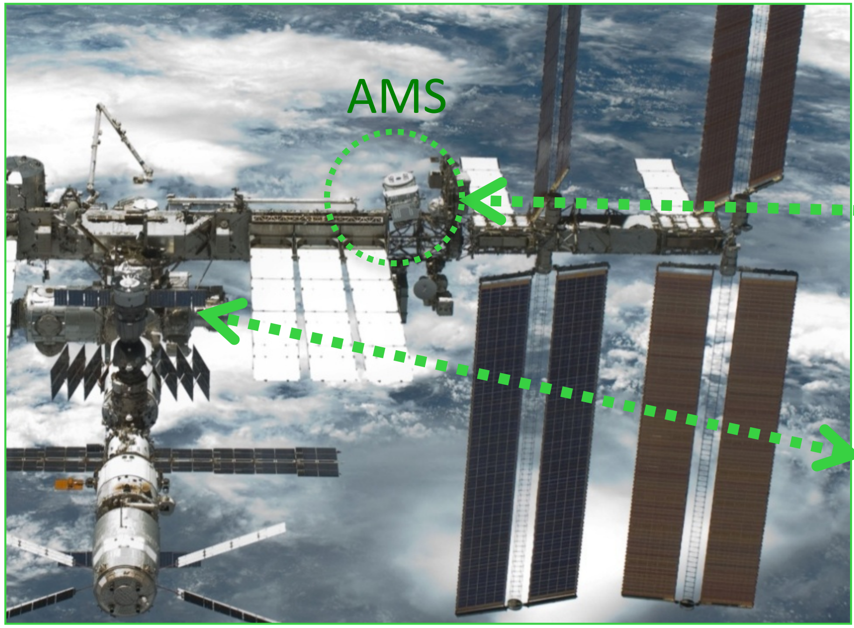
AMS grappled by the Shuttle Arm
May 19, 2011



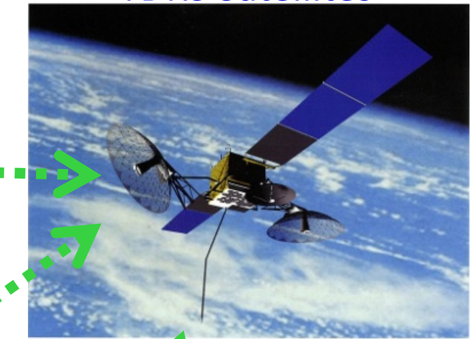
Credit: NASA


May 19: AMS installation completed at 5:15 CDT
Data taking started at 9:35 CDT
AMS
AMS
Credit: NASA

AMS Operations



TDRS Satellites



Astronaut at ISS AMS Laptop

Ku-Band
High Rate (down):
Events <10Mbit/s>

S-Band
Low Rate (up & down):
Commanding: 1 Kbit/s
Monitoring: 30 Kbit/s

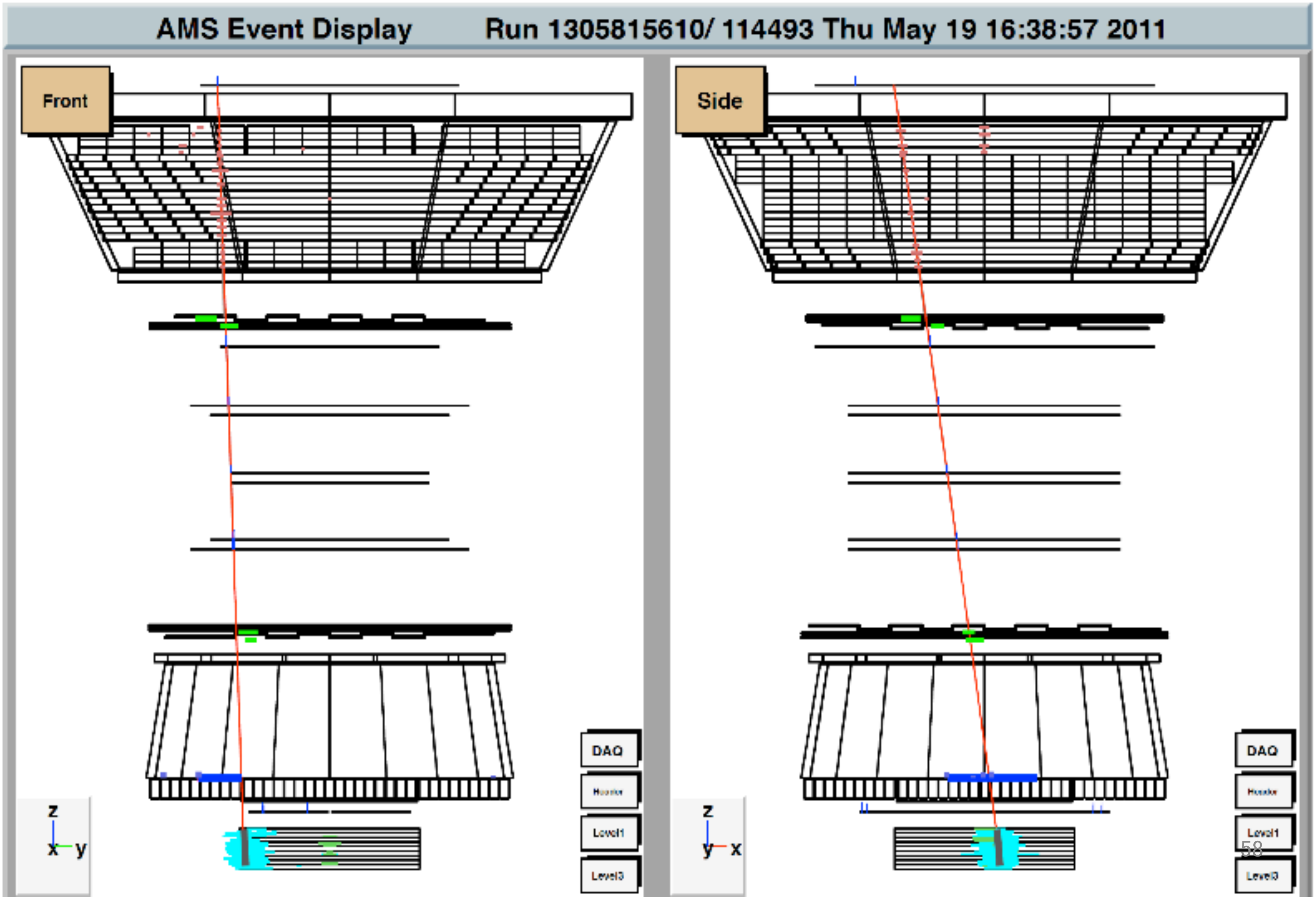
AMS Payload Operations Control and Science Operations Centers (POCC, SOC) at CERN

AMS Computers at MSFC, AL

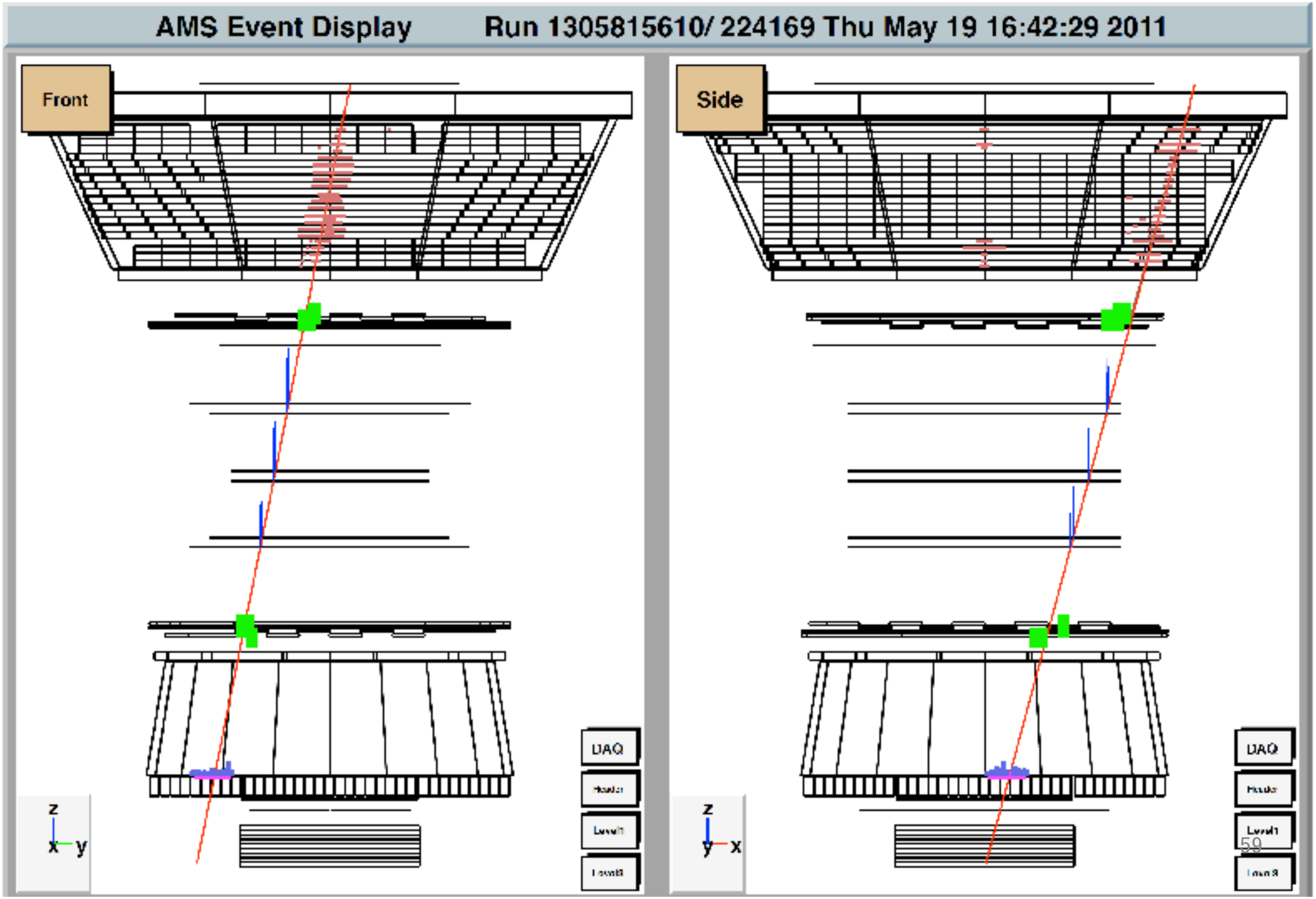
White Sands Ground Terminal, NM

General Charles Bolden, NASA Administrator, inaugurated AMS Payload Operation Control Center at CERN, June 23, 2011

Event from the first minutes: e- 20 GeV

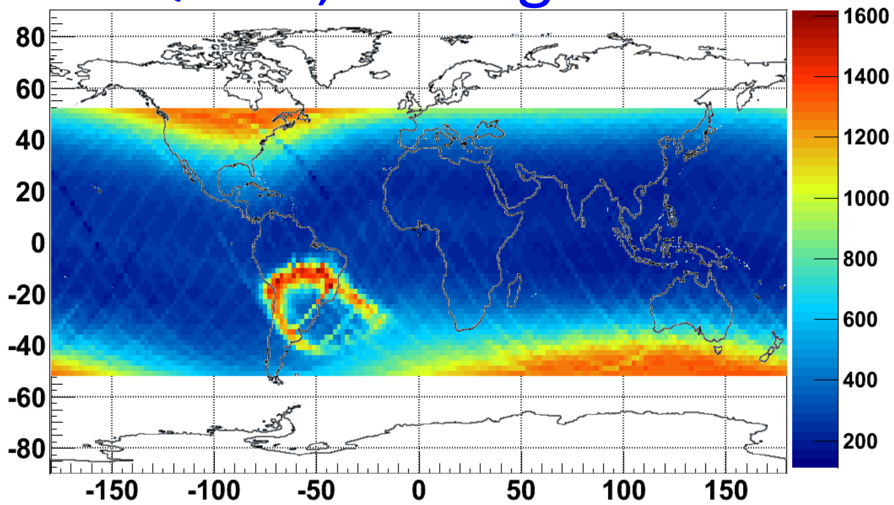


Event from the first minutes: Carbon 40 GeV/c

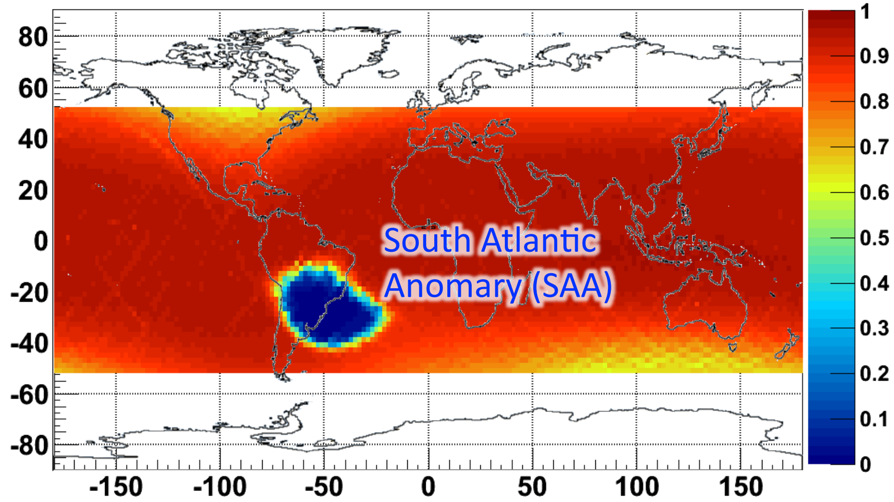


Orbital DAQ Parameters

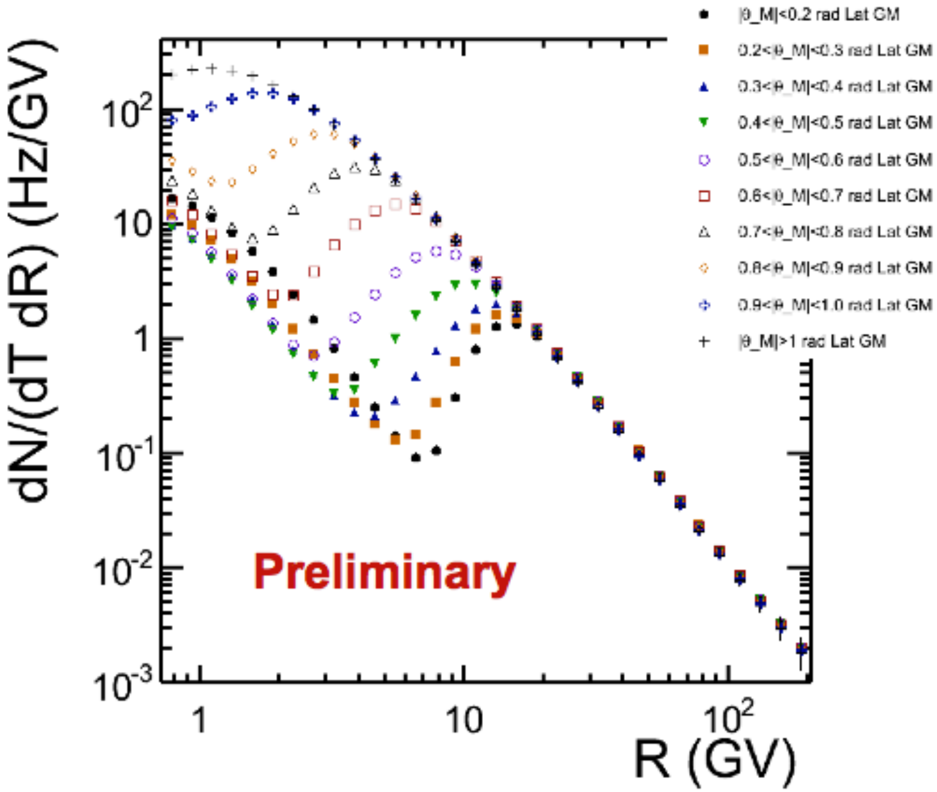
DAQ rate, average 700 Hz



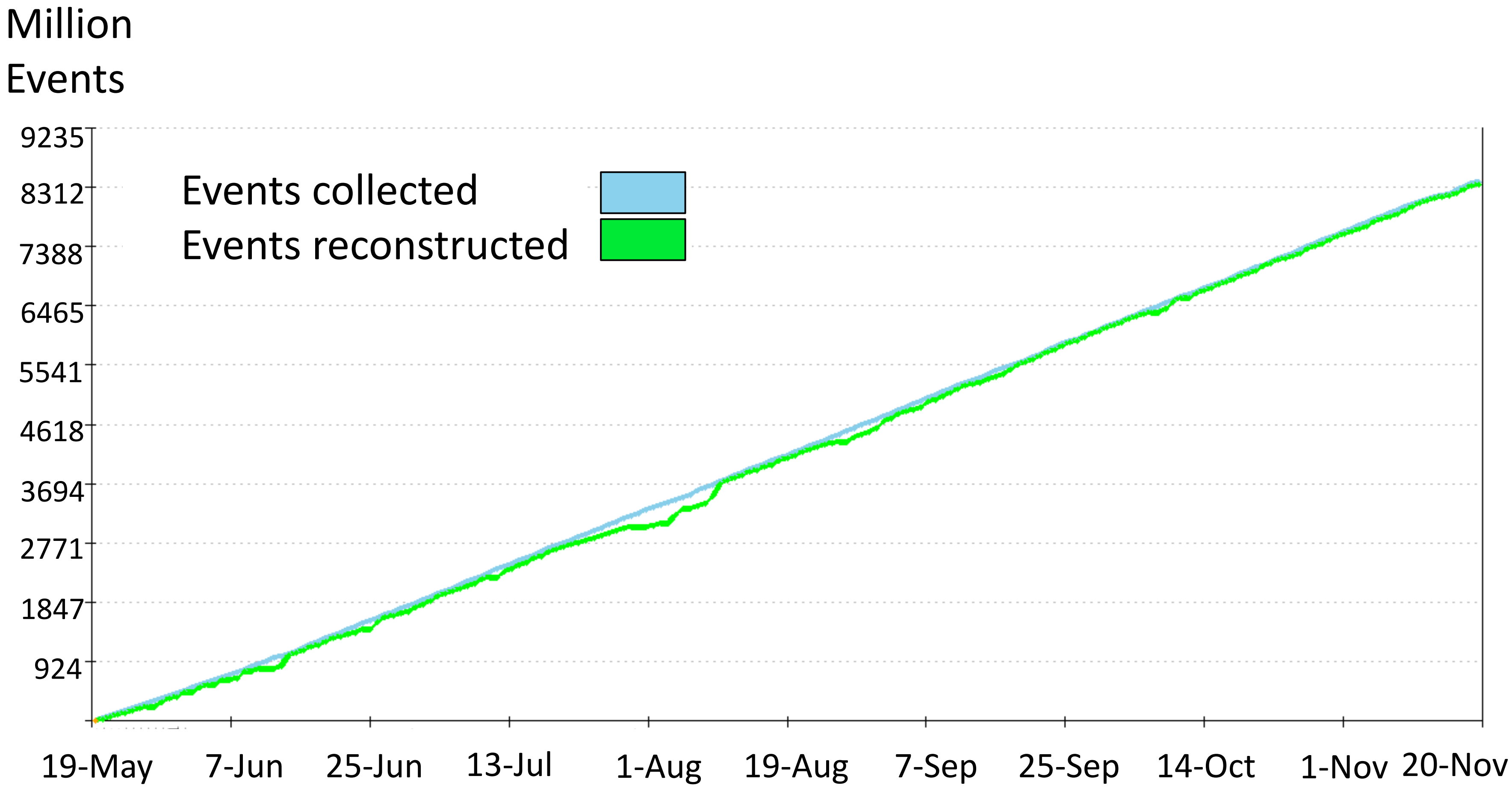
DAQ efficiency, average 85%



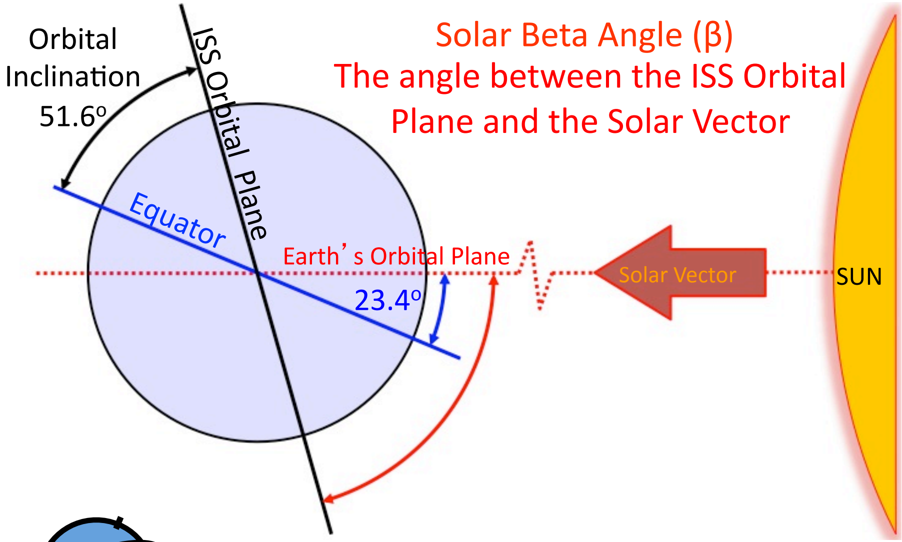
Proton rates at several geomagnetic latitudes

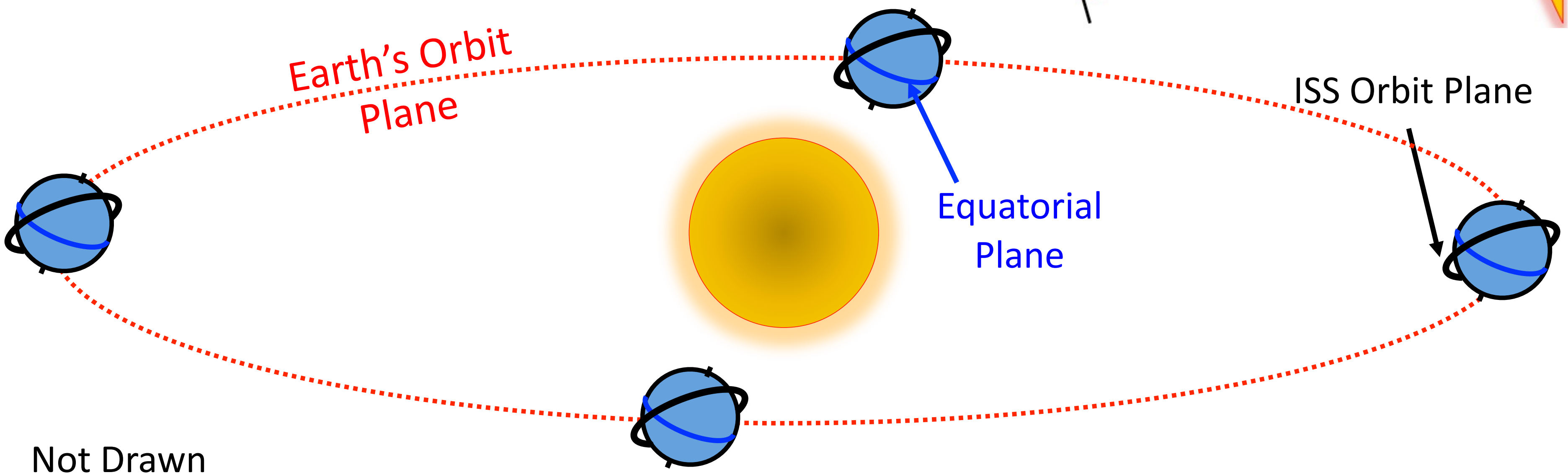


AMS collected over 8 billion events for the first 6 months



Solar Beta Angle (β)





Not Drawn to Scale

The Earth's Orbit around the Sun changes the Solar Beta Angle ~1º per day

Ken Bollweg NASA/JSC

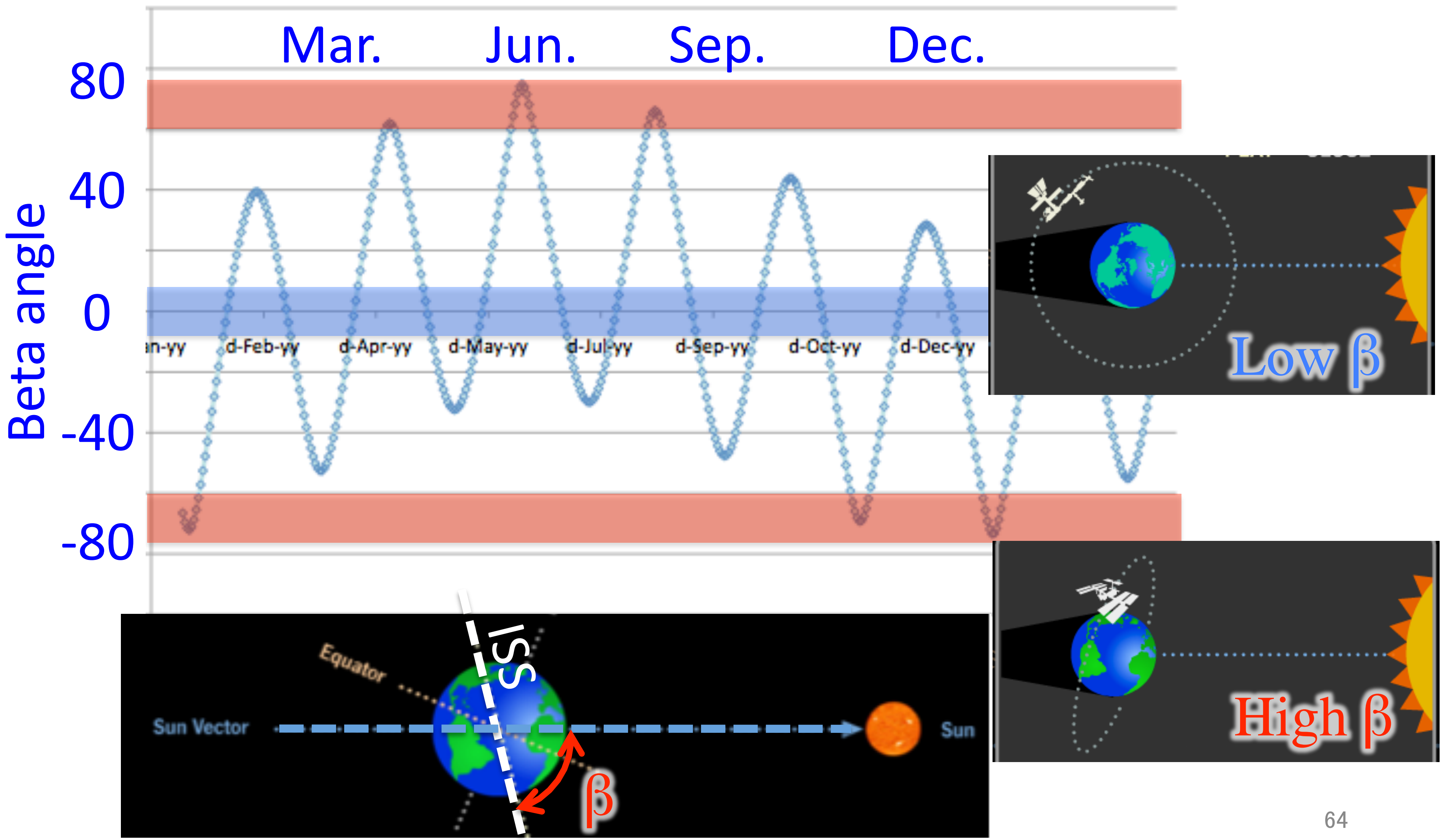
ISS orbit parameters

- i= 51.6° (Baikonur latitude is ~46°)
- $d\Omega/dt$= 6°/day
- h= 320-400 km
- T= ~90 min.

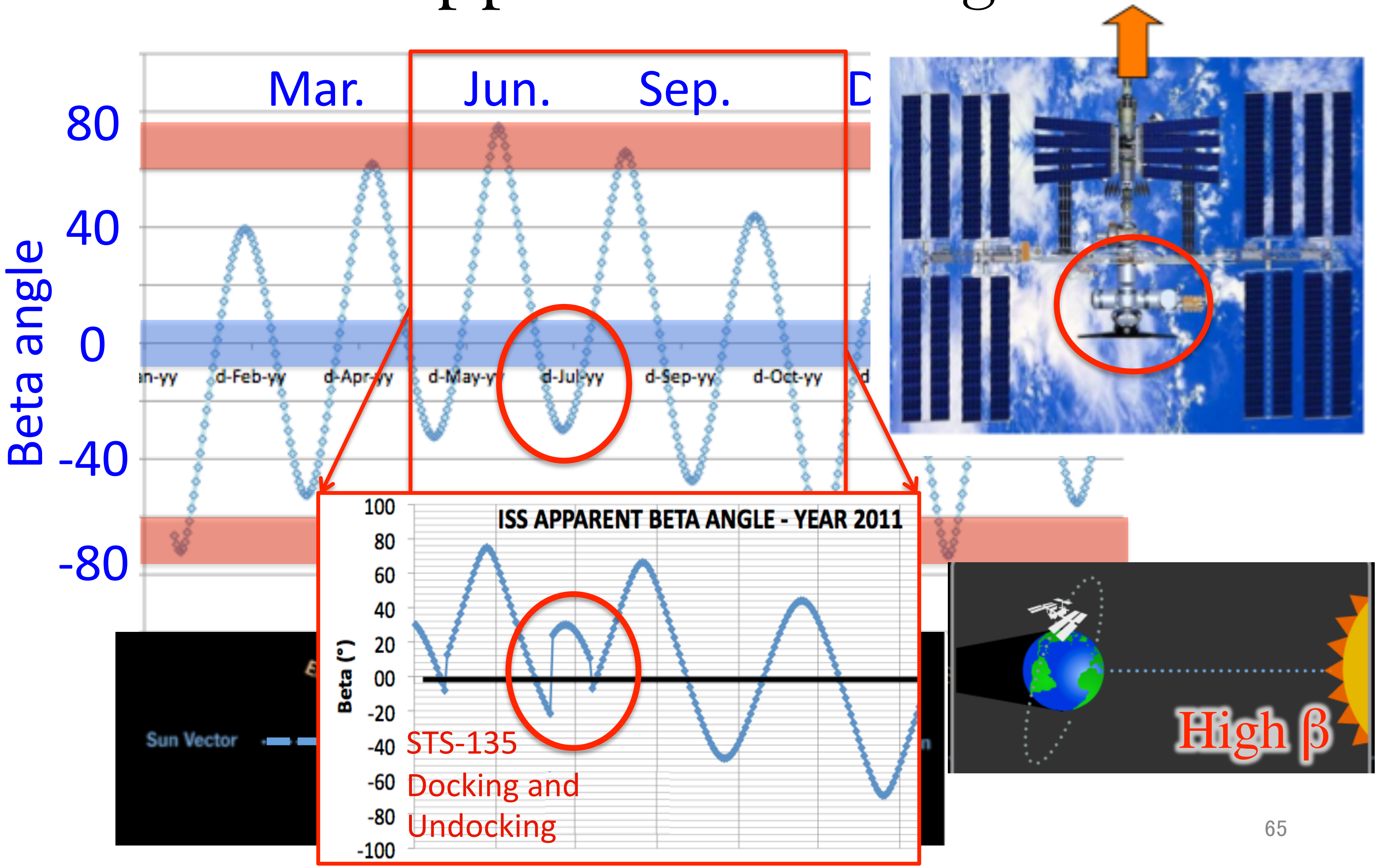
$$\frac{d}{dt}\Omega := \frac{-3 \cdot n \cdot J_2 \cdot R^2 \cdot \cos(i)}{2a^2\left(1 - e^2\right)^2}$$

Ω ~ Longitude of the ascending node;
R~ Mean equatorial radius
J_2 ~ Zonal coeff.(for earth = 0.001082)
n ~ mean motion (sqrt(GM/a^3)), a~ semimajor axis

Solar beta angle

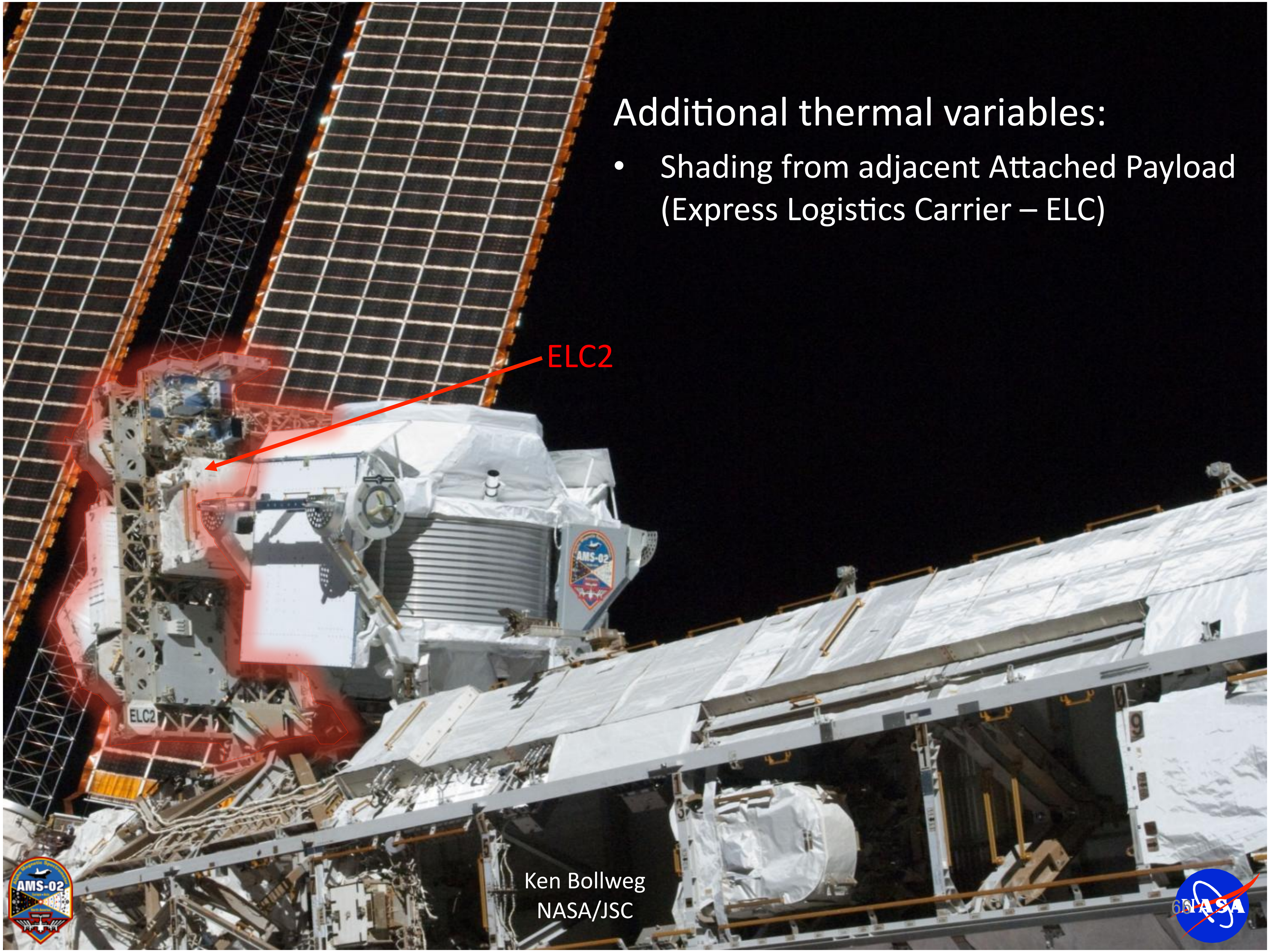


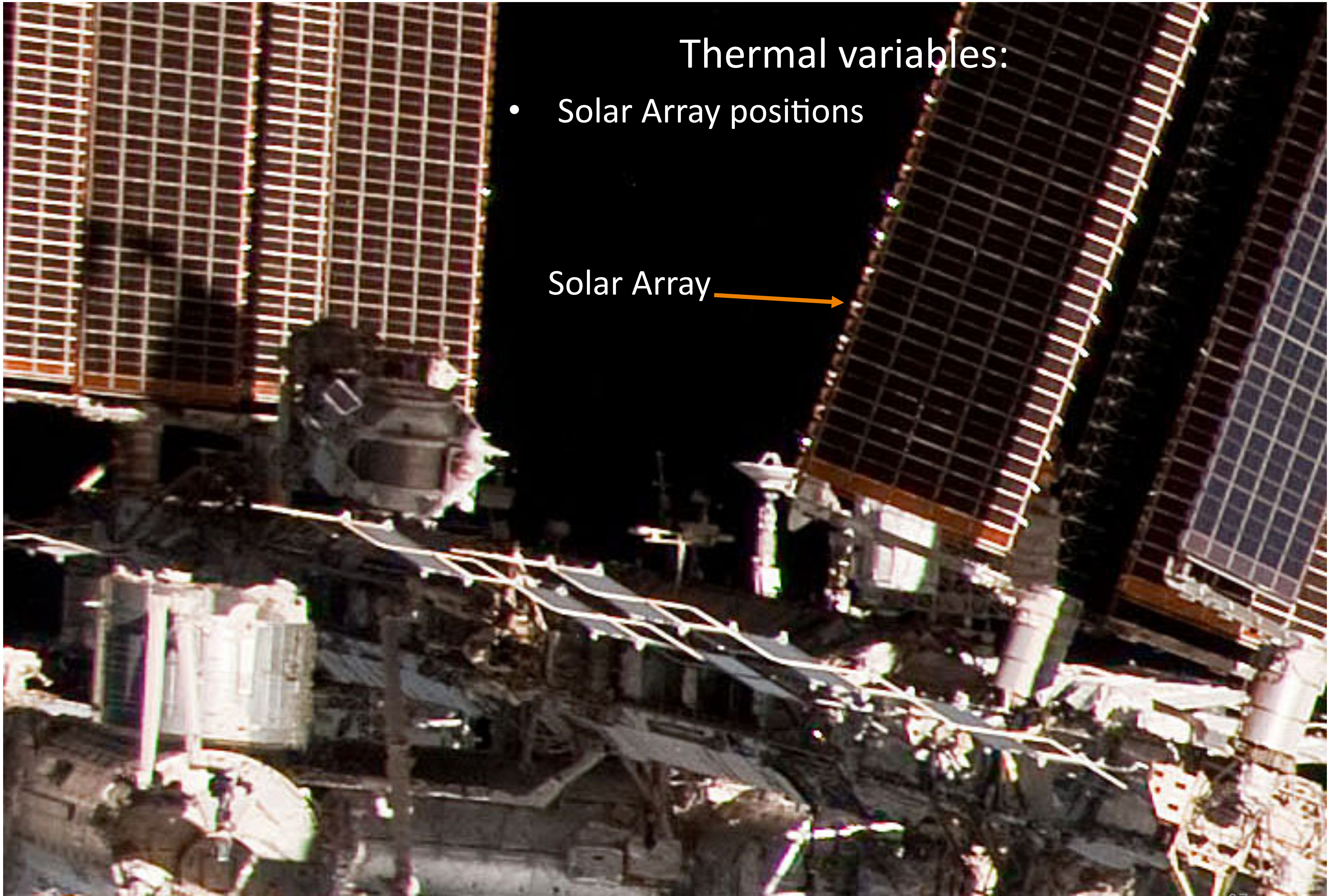
Apparent beta angle



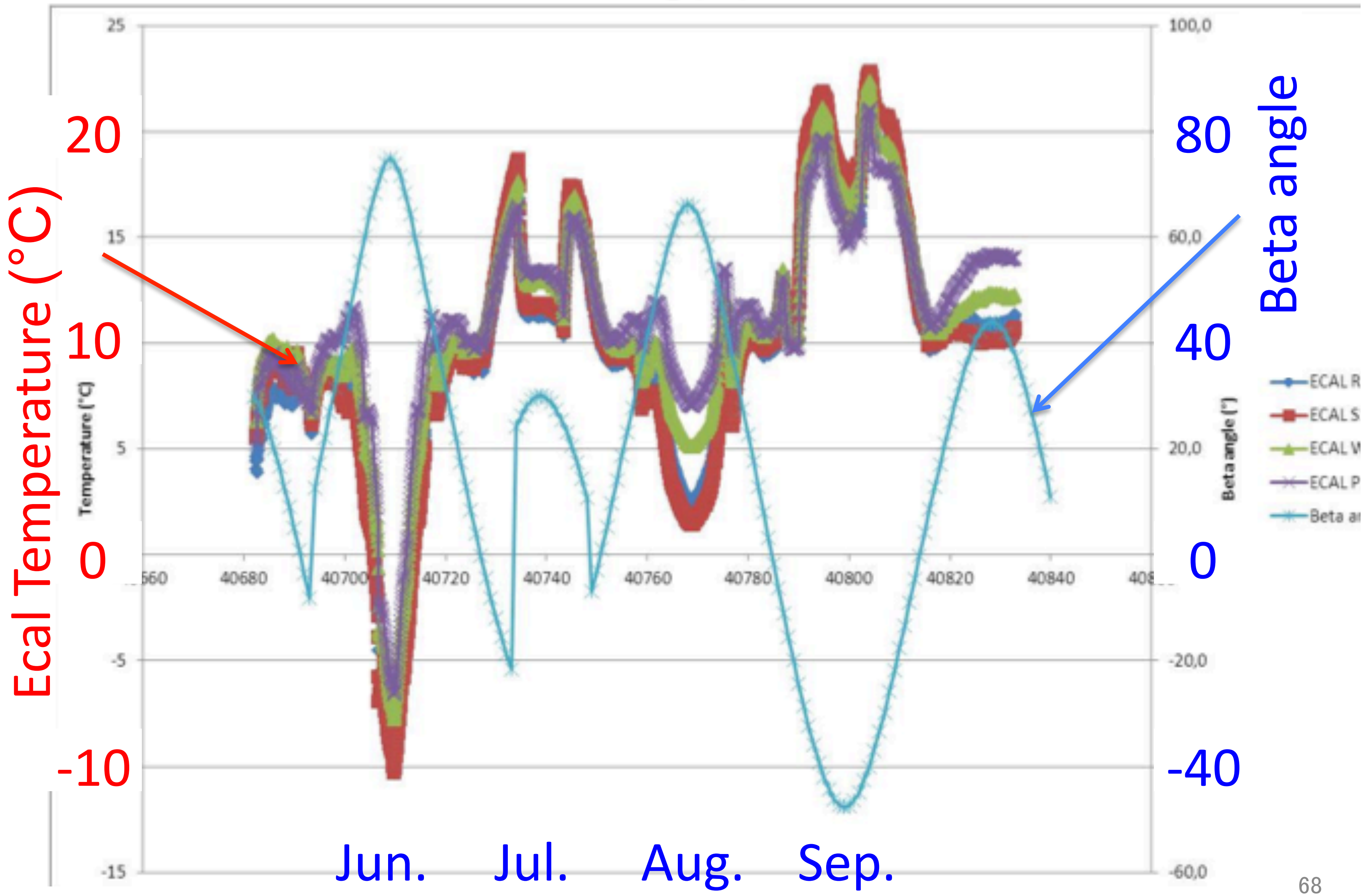
Additional thermal variables:

- Shading from adjacent Attached Payload (Express Logistics Carrier – ELC)




Thermal variables:
• Solar Array positions
Solar Array

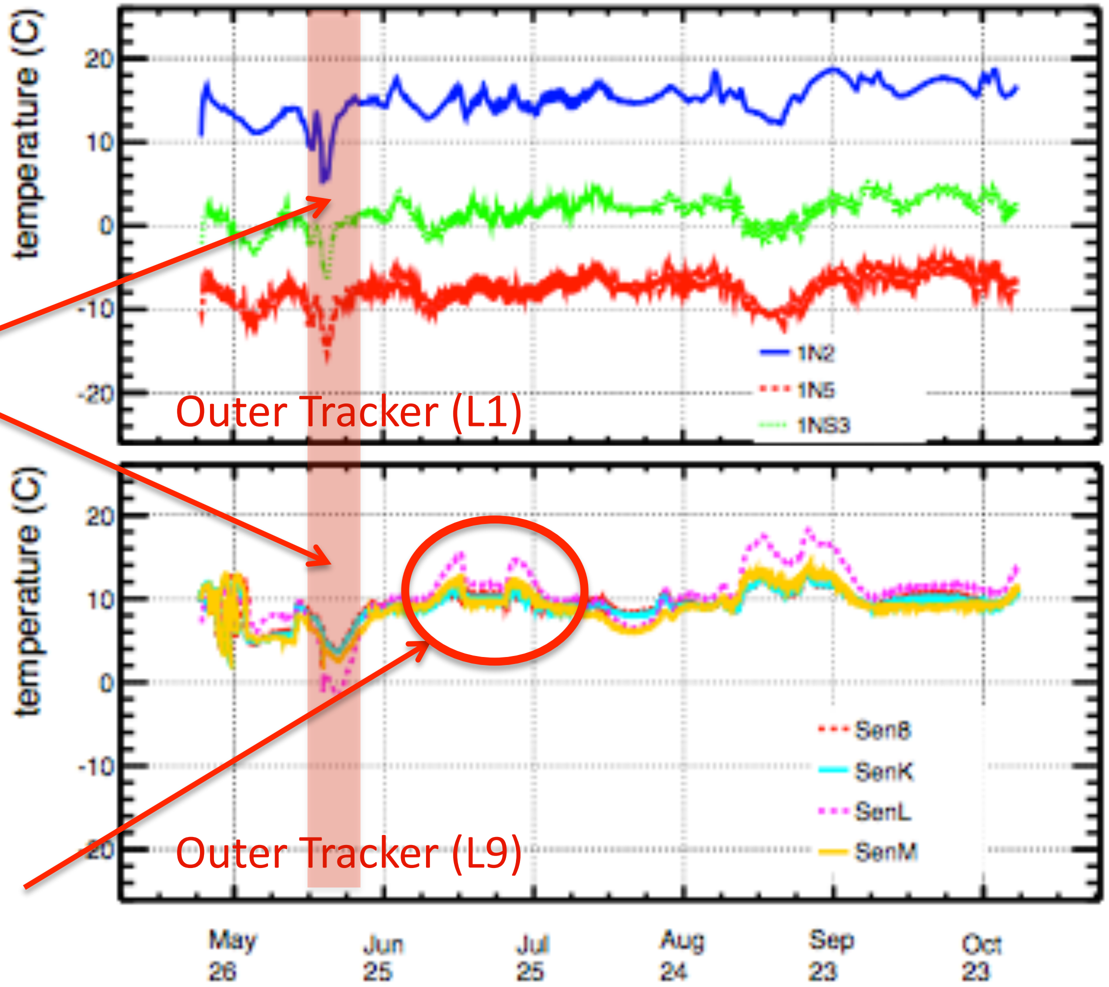
ECAL



25
20
15
10
5
0
-5
-10
-15
Temperature (°C)
Ecal Temperature (°C)
100,0
80
60,0
40
20,0
0
-20,0
-40
-60,0
Beta angle (°)
Beta angle
40680
40700
40720
40740
40760
40780
40800
40820
40840
Jun.
Jul.
Aug.
Sep.

Outer Tracker Temperatures

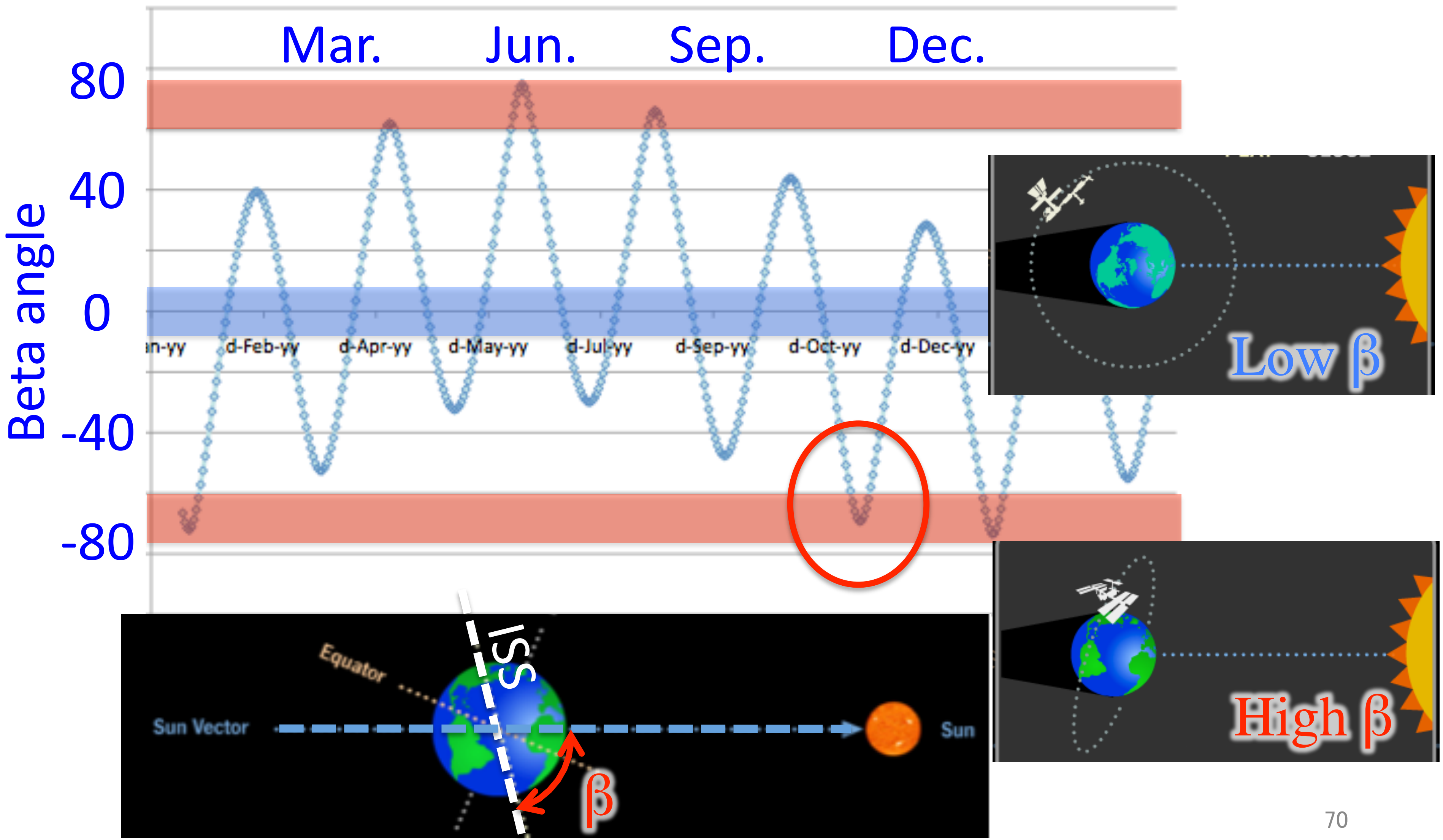
High beta
+ shadow
by solar array

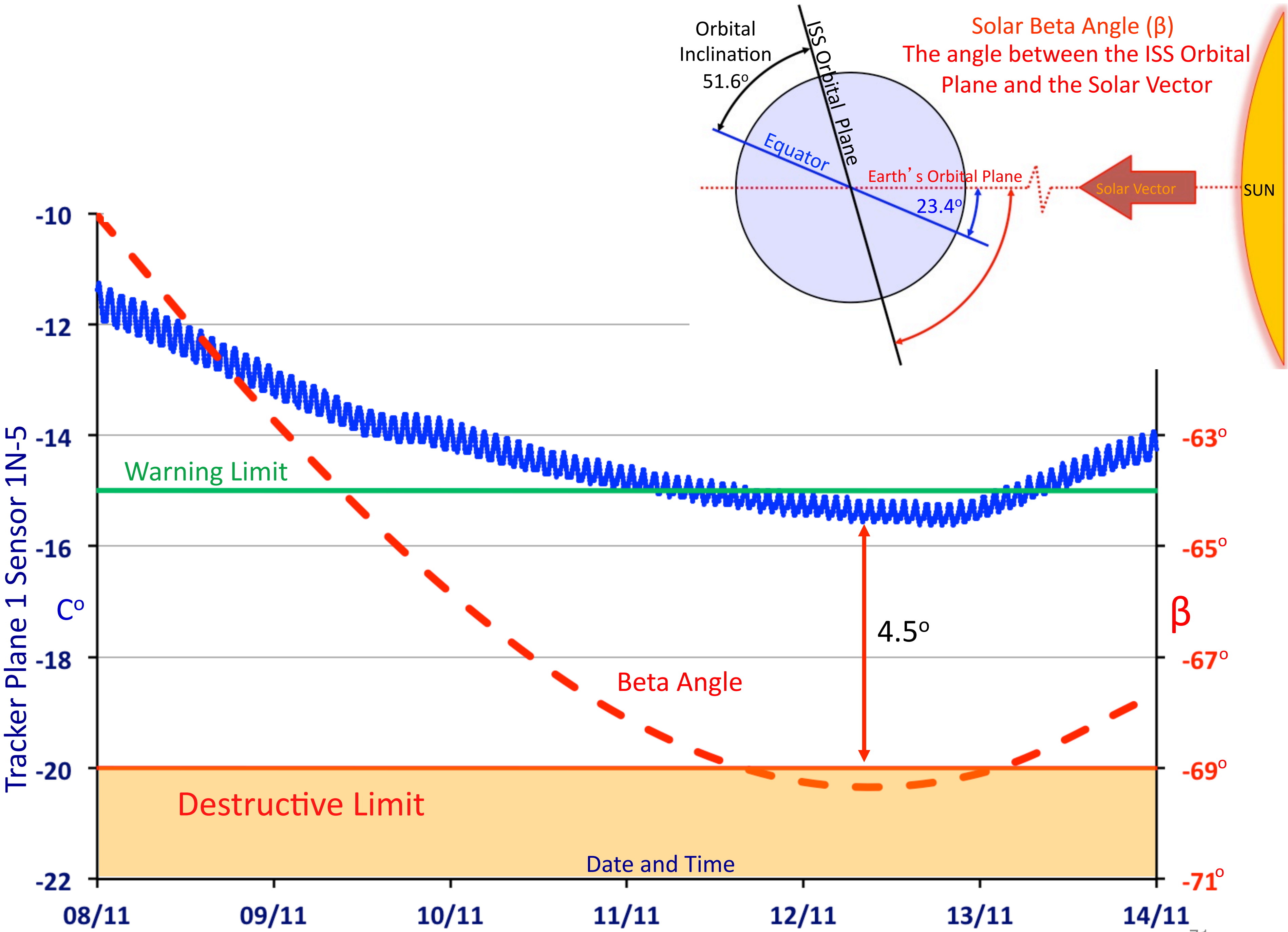


STS-135
Docking and
Undocking

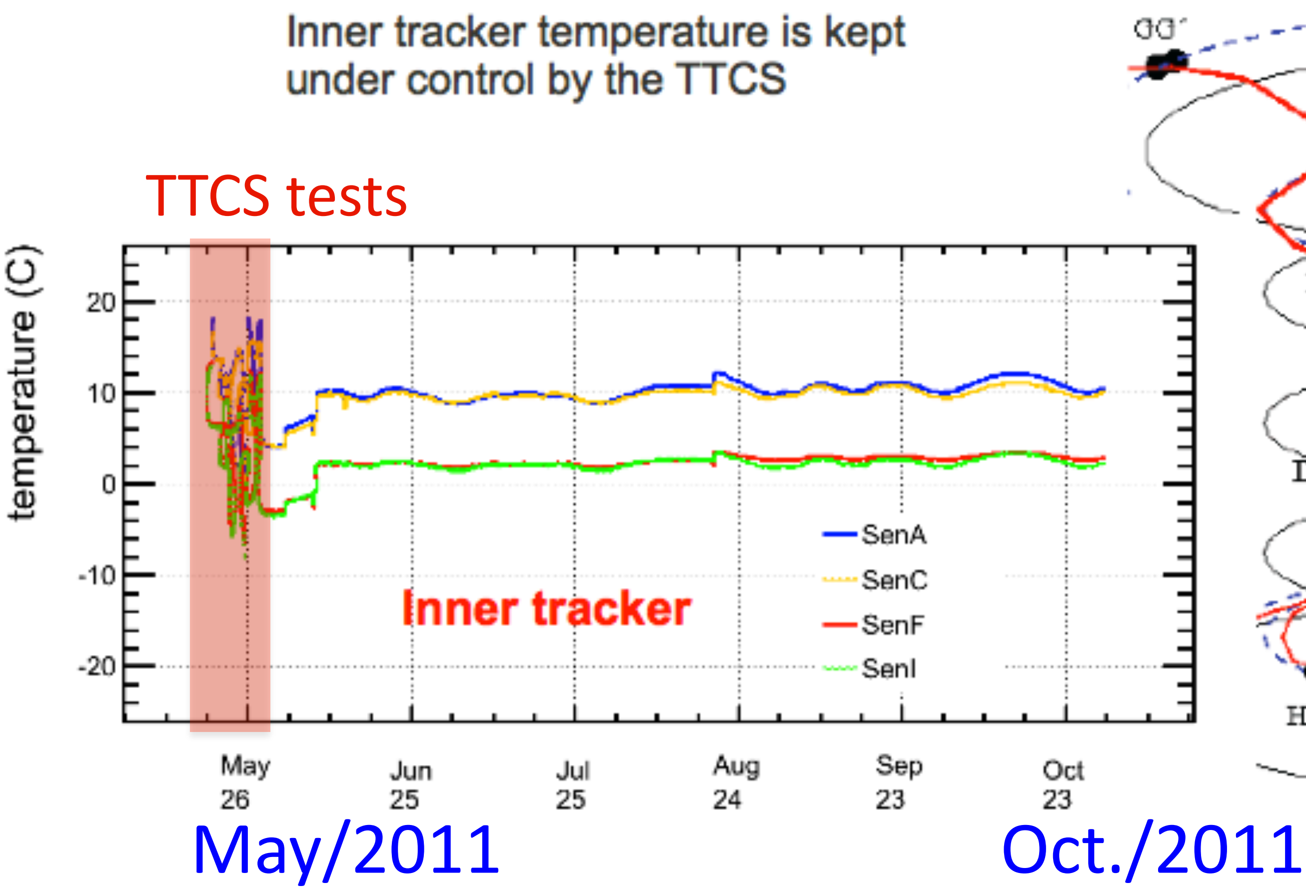
May/2011 Oct./2011

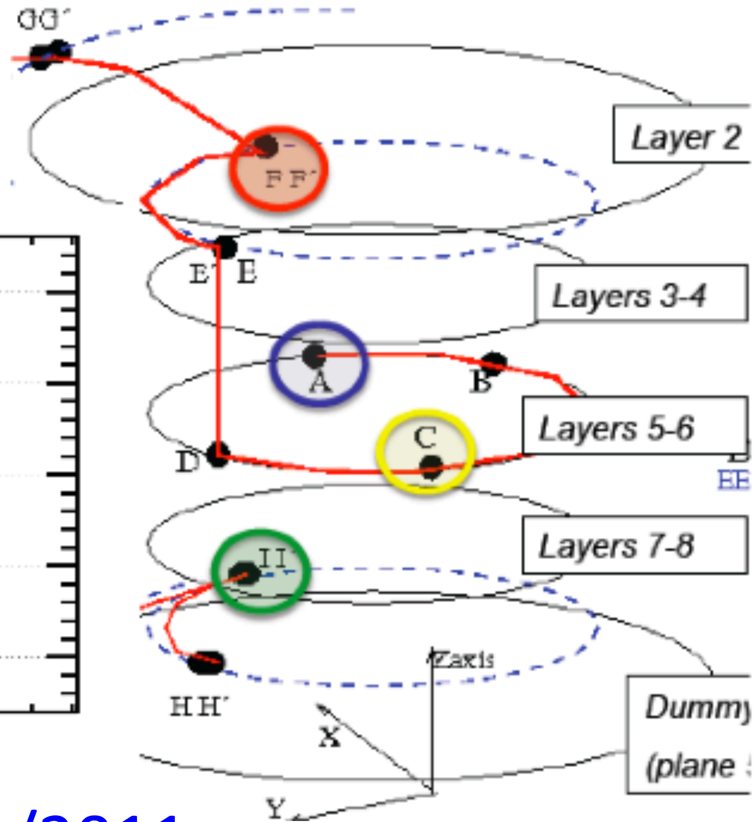
Solar beta angle



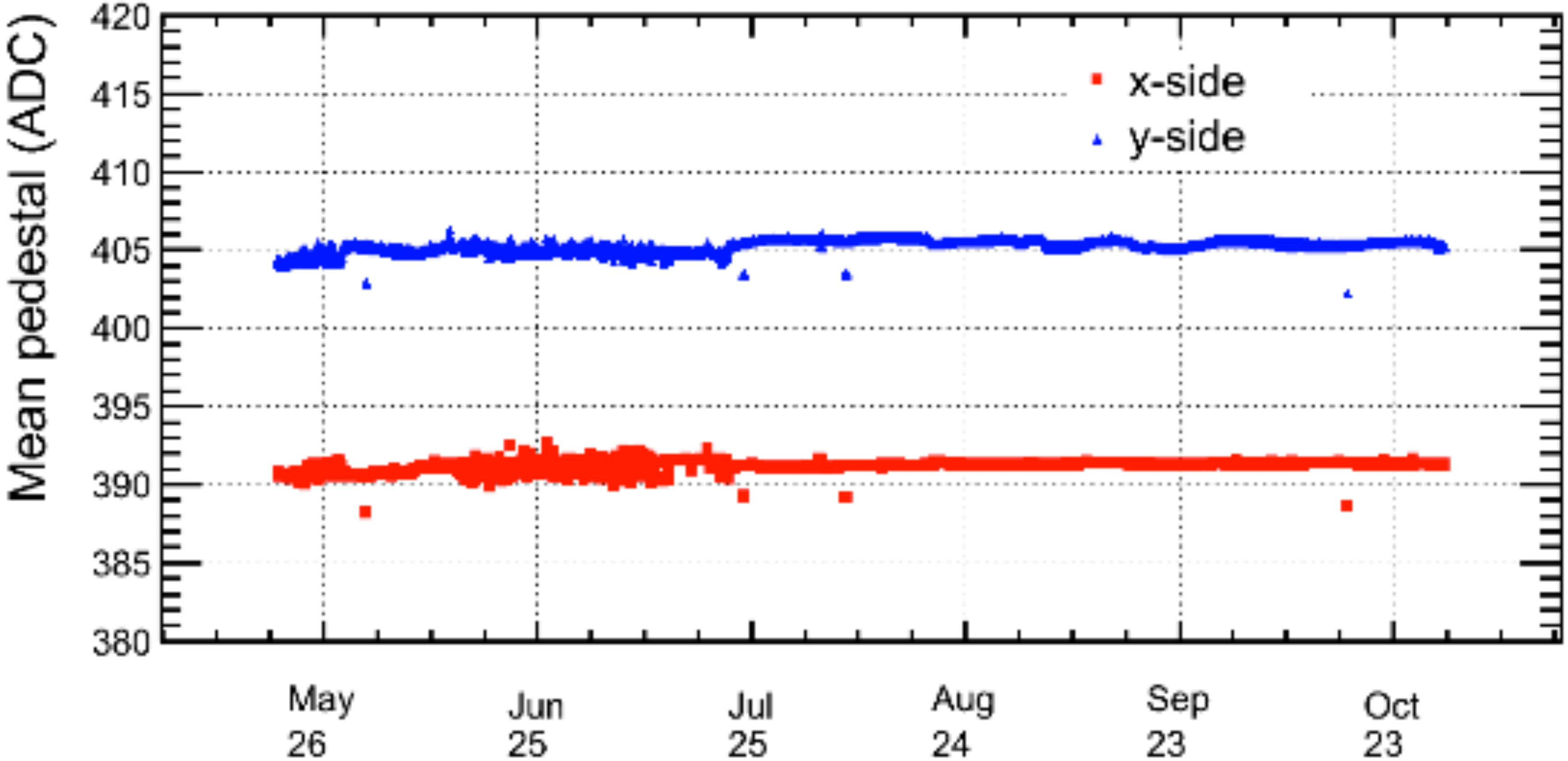

Orbital Inclination 51.6º
ISS Orbital Plane
Equator
Earth's Orbital Plane
23.4º
Solar Vector
SUN
Solar Beta Angle (β)
The angle between the ISS Orbital Plane and the Solar Vector
Tracker Plane 1 Sensor 1N-5
Cº
β
Warning Limit
Beta Angle
4.5º
Destructive Limit
Date and Time
-10
-12
-14
-16
-18
-20
-22
-63º
-65º
-67º
-69º
-71º
08/11
09/11
10/11
11/11
12/11
13/11
14/11

Inner Tracker Temperatures



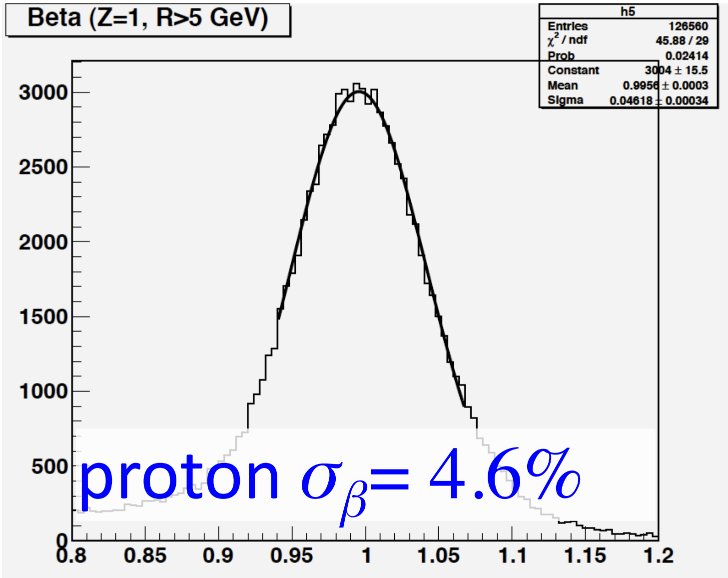


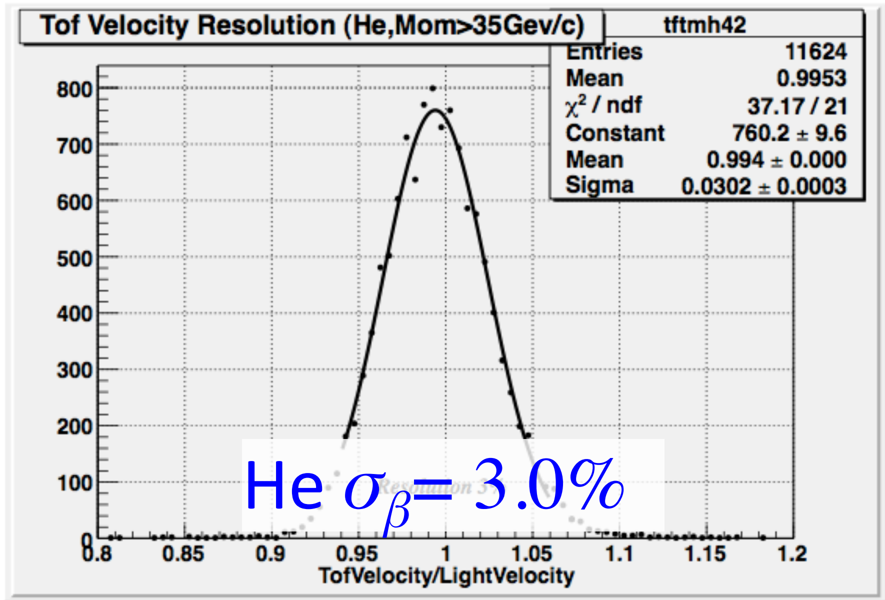
ADC Mean pedestals

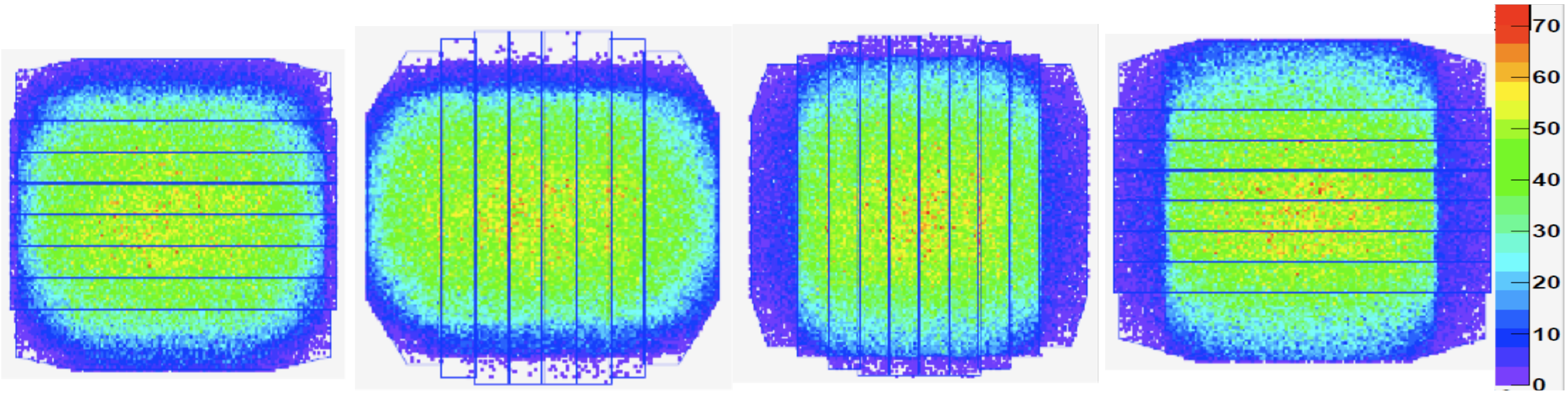


May/2011 Oct./2011

AMS-02 in flight experience: TOF

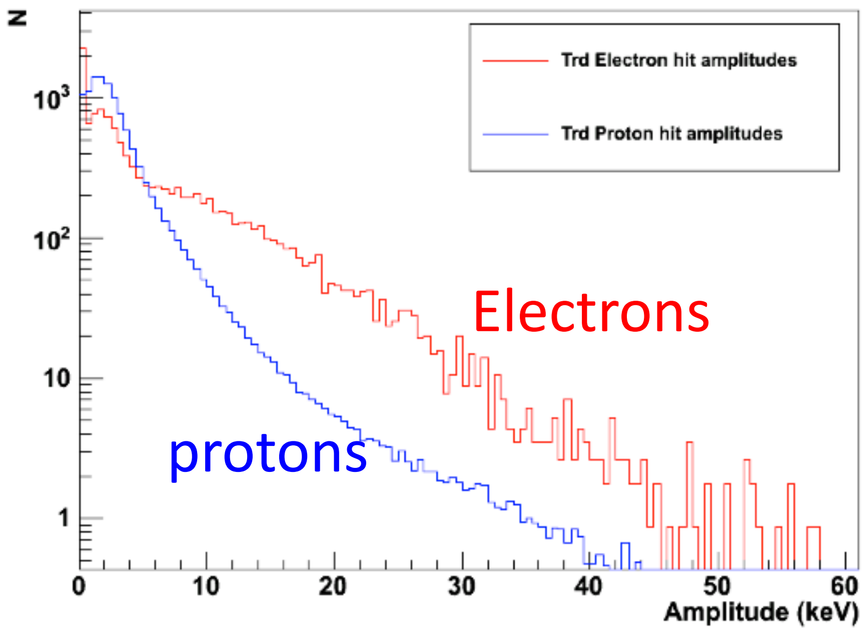




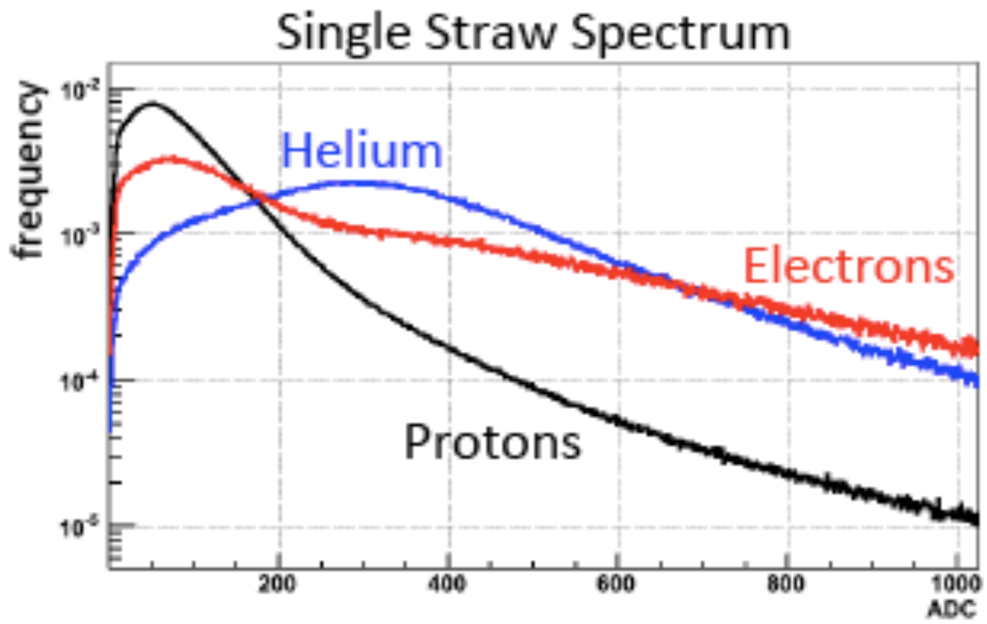


TOF 1 TOF 2 TOF 3 TOF 4

AMS-02 in flight experience: TRD



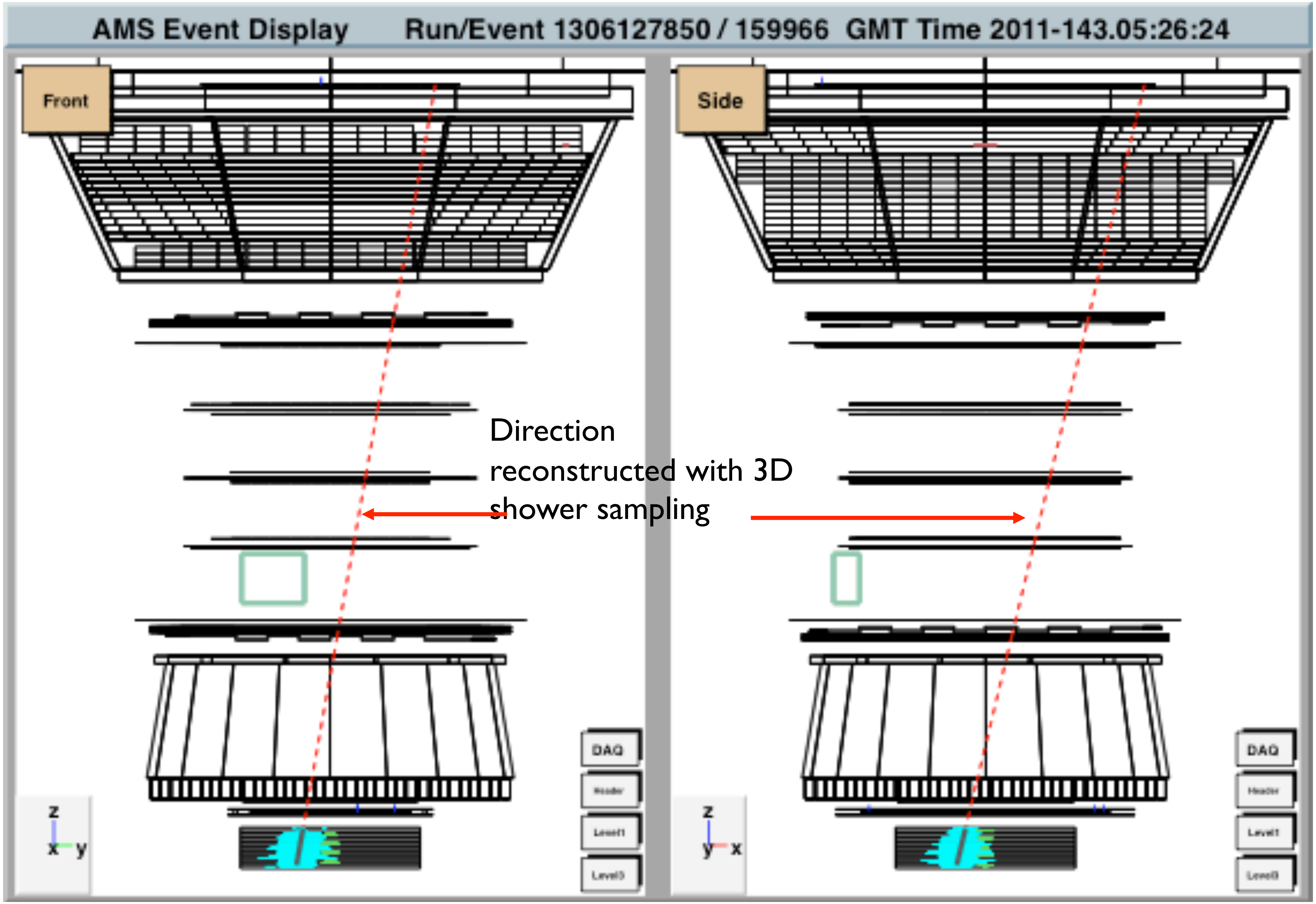
Test Beam data



ISS data

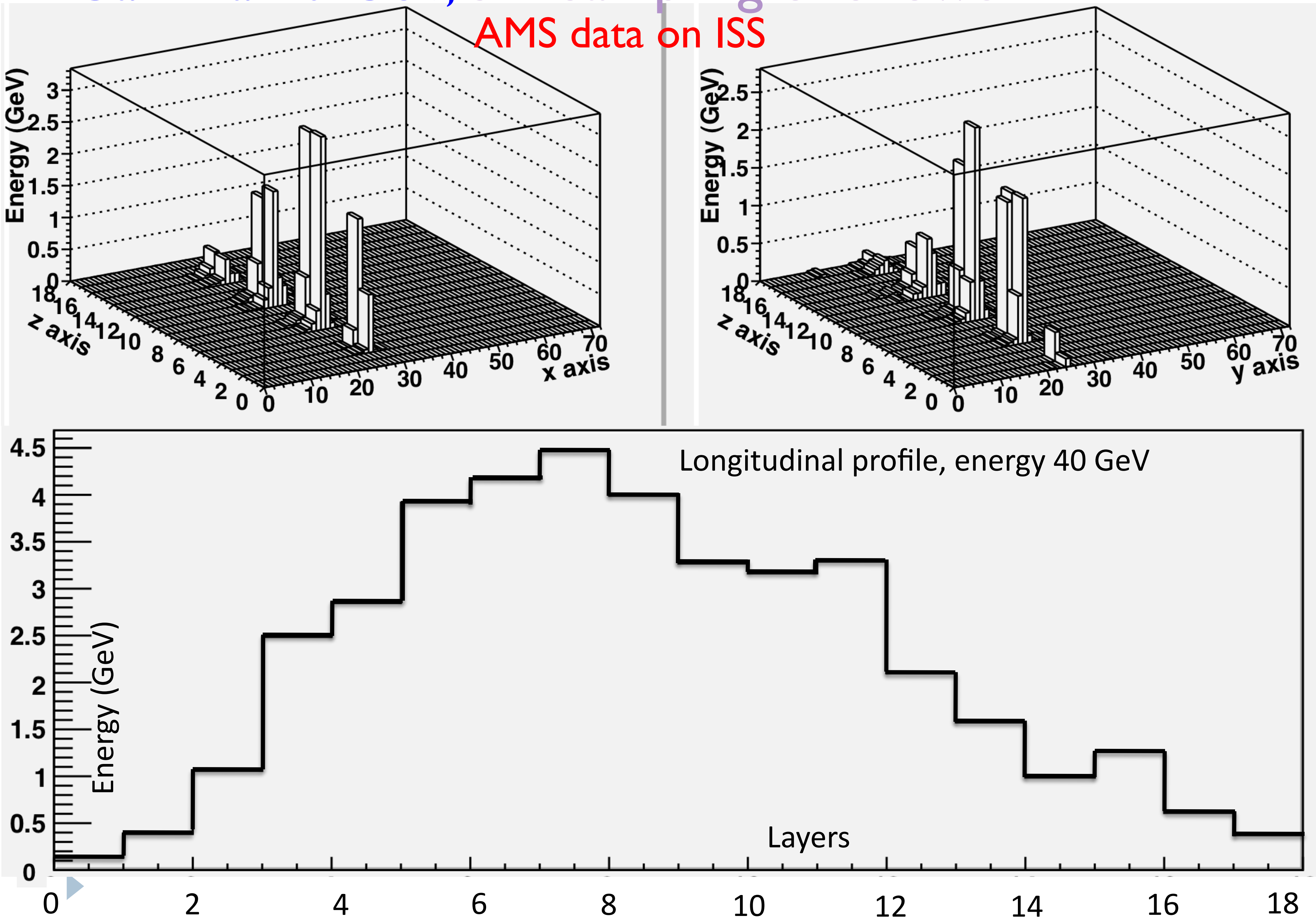
AMS data on ISS

Photon 40 GeV, 23 May

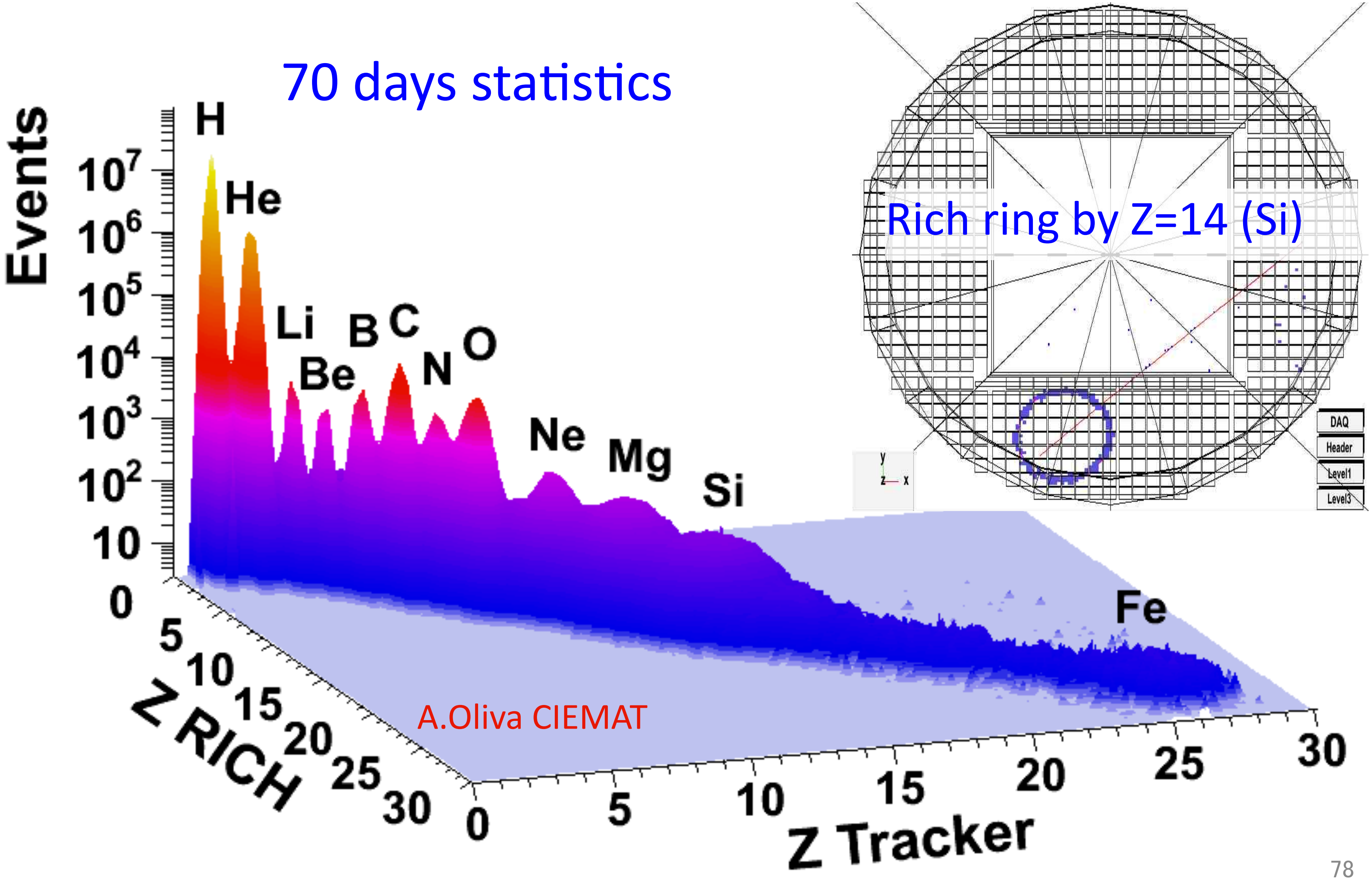


Gamma 40 GeV, 3D Sampling of Shower

AMS data on ISS

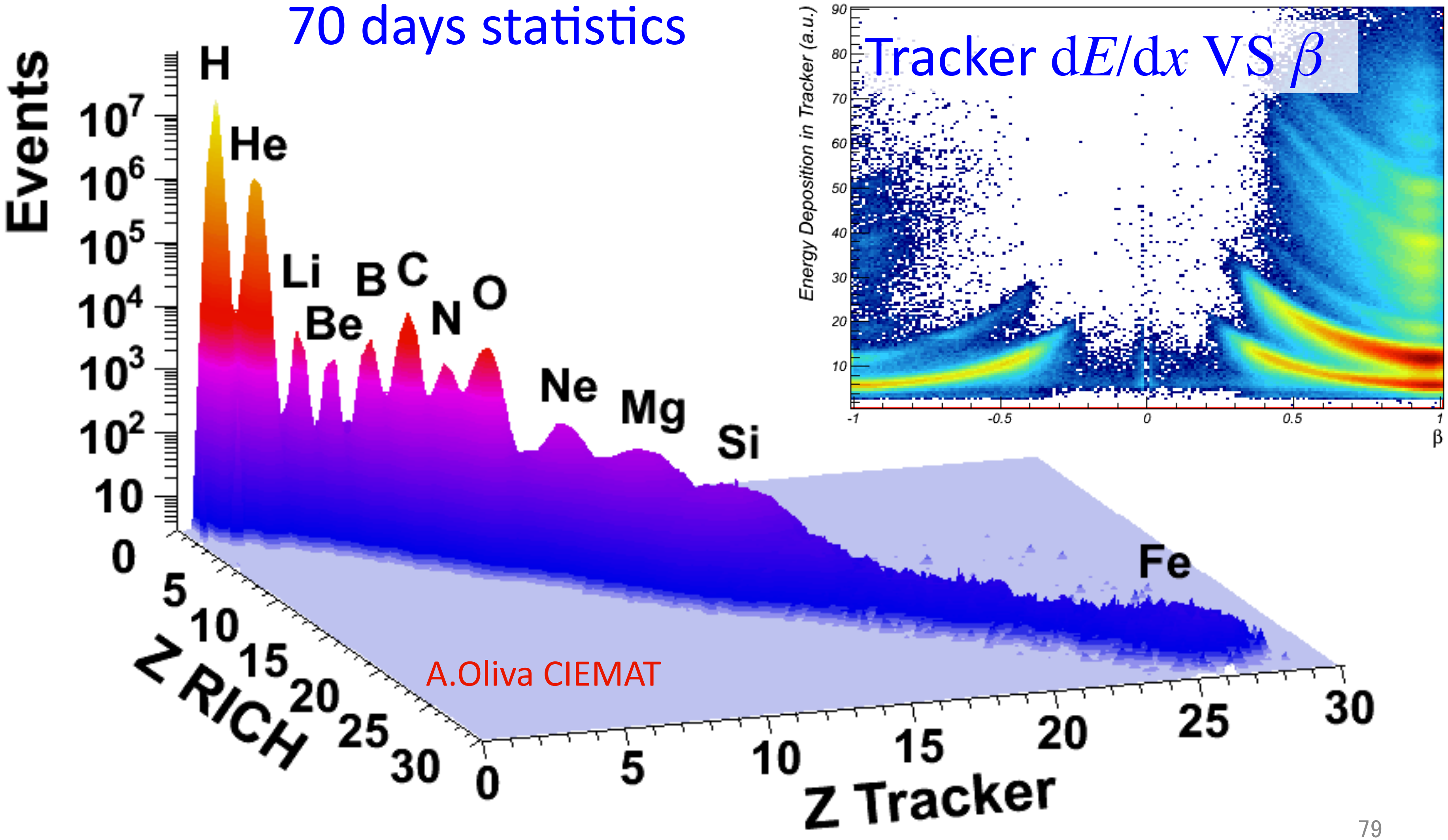


Charge measurement



Charge measurement

70 days statistics



Conclusions

- **AMS mission started on 19/May/2011 after successful launch and installation onto ISS**
- **All the detectors are fully operational with the expected performance**
- **Data calibration (e.g. Tracker alignment, e/p separation study, etc…) is on going**
- **Expecting data taking for more than 10 years**