Operation and Performance of the AMS-02 Silicon Tracker

P. Saouter
Université de Genève, Switzerland
On behalf of the AMS Tracker Collaboration

17 September 2014

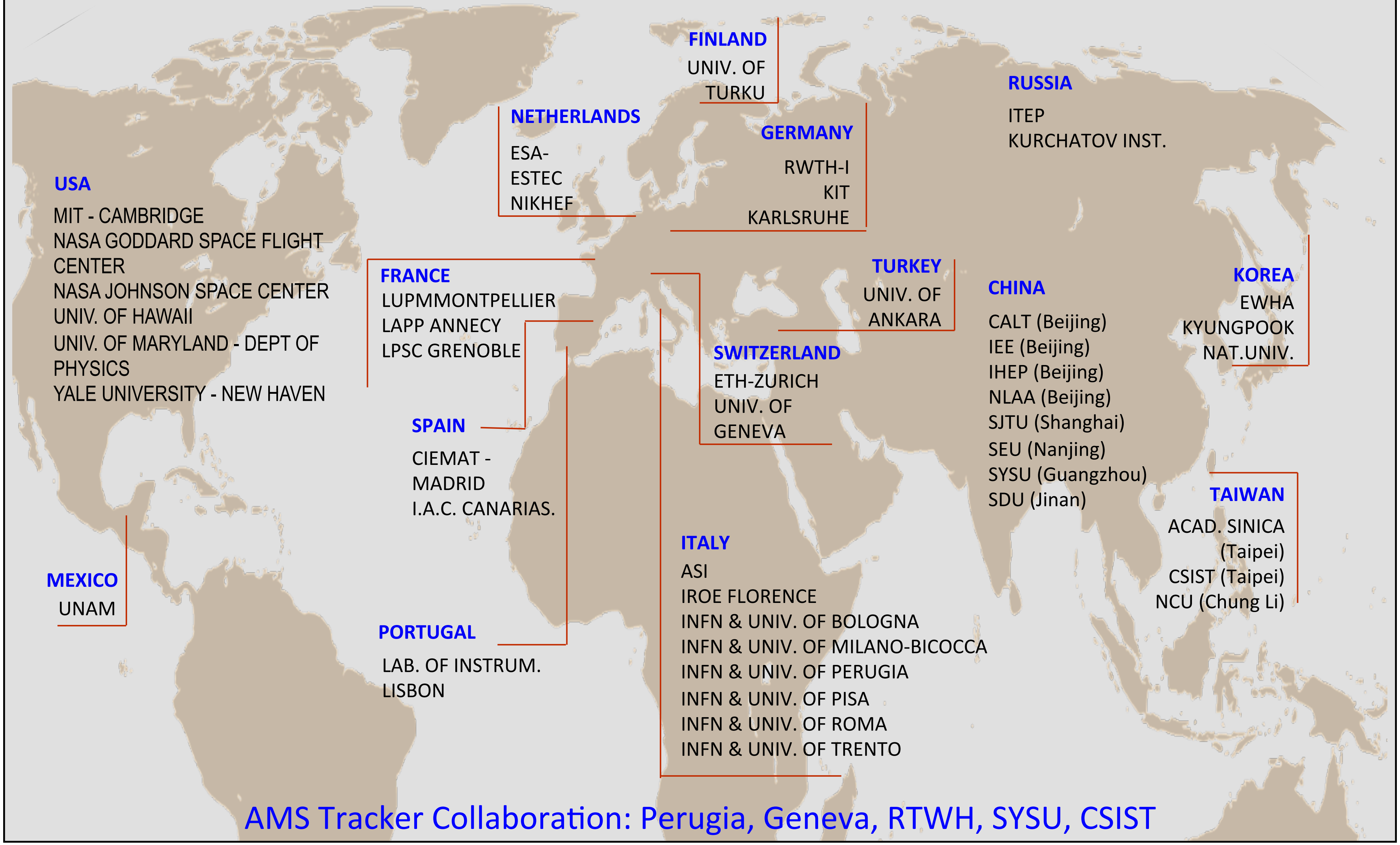
VERTEX 2014 Workshop

Outline

1. AMS-02 and its Silicon Tracker
2. Space Operation of the Silicon Tracker
3. Performances of the Silicon Tracker
4. Particle Charge Identification

The AMS-02 Collaboration

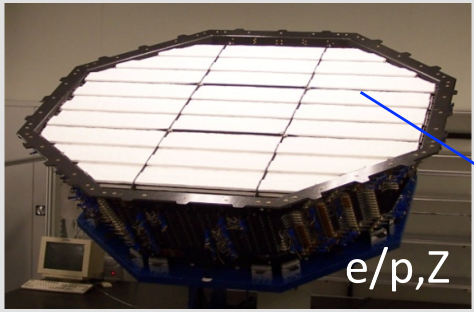
15 Countries, 44 institutions and more then 600 Physicists.



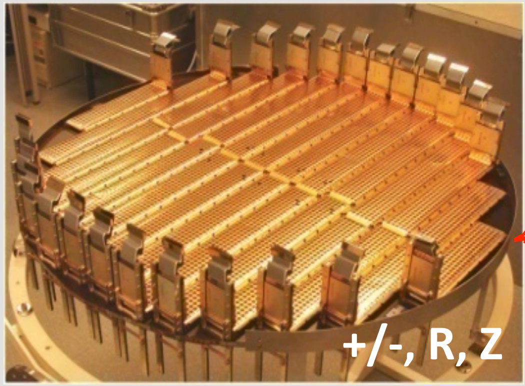
AMS Tracker Collaboration: Perugia, Geneva, RTWH, SYSU, CSIST

The Instrument

TRD

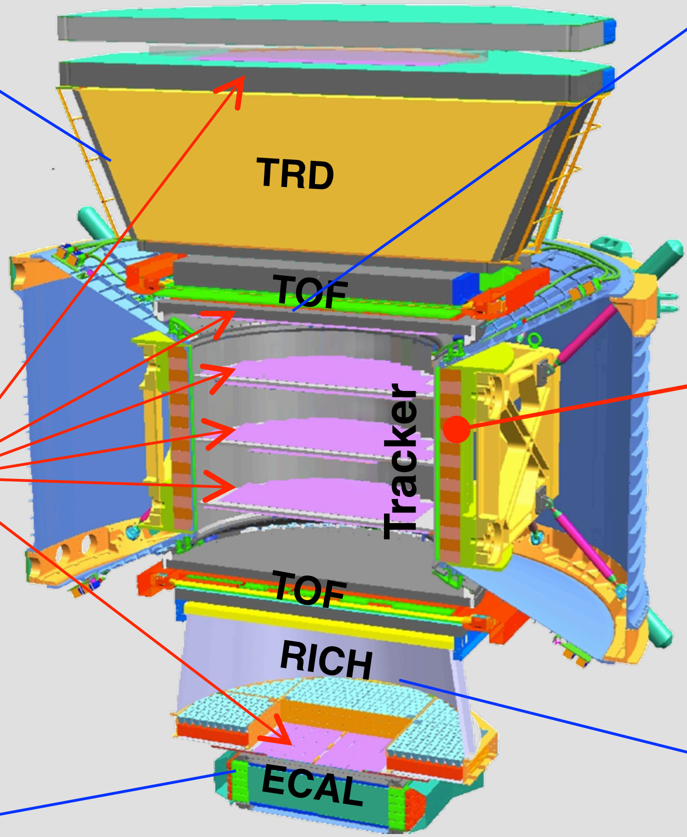


Silicon Tracker

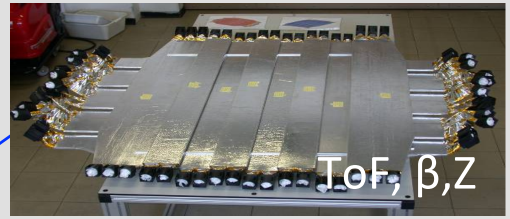


Calorimeter

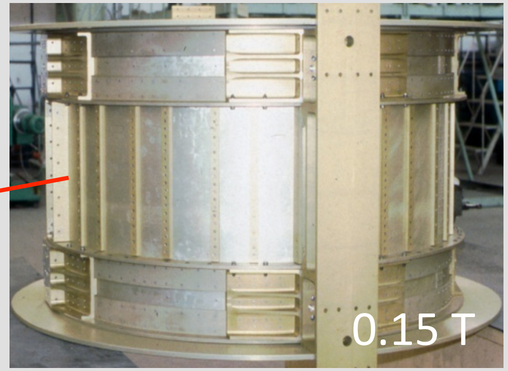
AMS Instrument



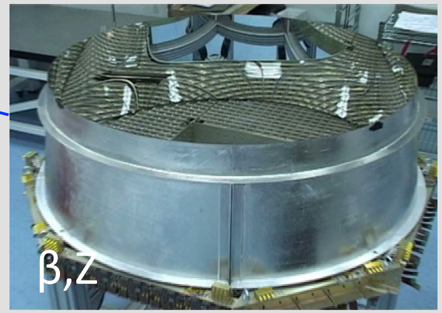
ToF



Magnet



RICH

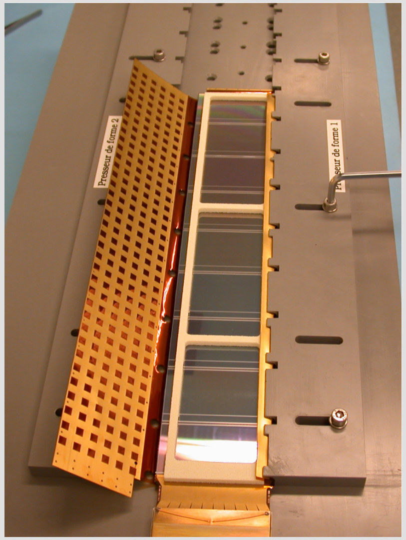


Goal : Cosmic Ray Properties from few GeV to few TeV

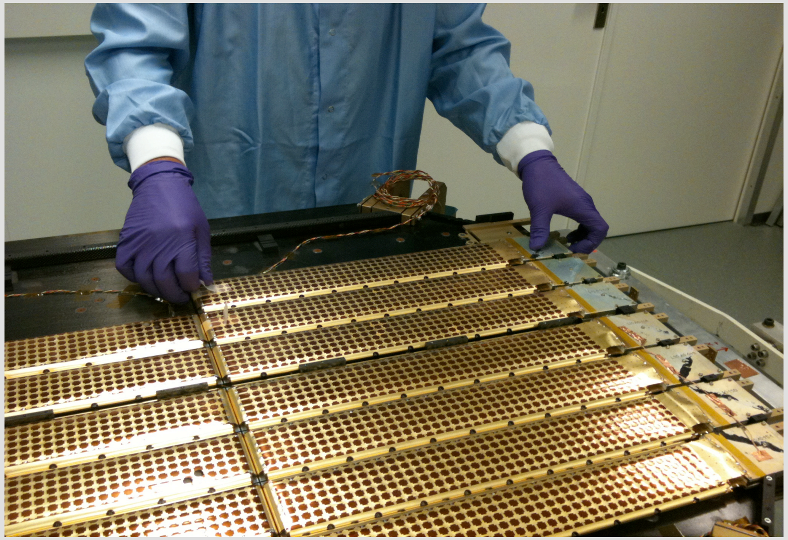
The Silicon Tracker

- 2284, 300μm thick, double-sided silicon micro-strip sensors (p+-n-n+)
- 7 to 15 sensors arranged in basic functional units (ladders)
- Intrinsic position resolution : 10 (30) μm in y(x) bending (non-bending)
- 6 honeycomb carbon fiber planes (0.04 X_0)
- 196k channels → 192 Watts
- 126 Watts cooled by Tracker Thermal Control System (2 phase CO_2)
- Operational temperature range : -10°C to 25 °C.

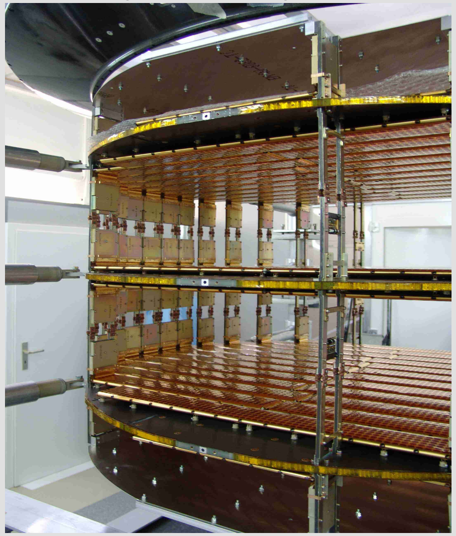
2284 sensors



192 ladders

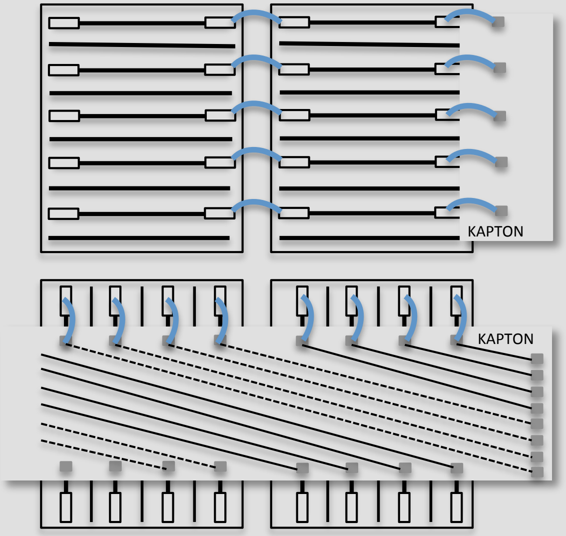


9 layers in 6 planes



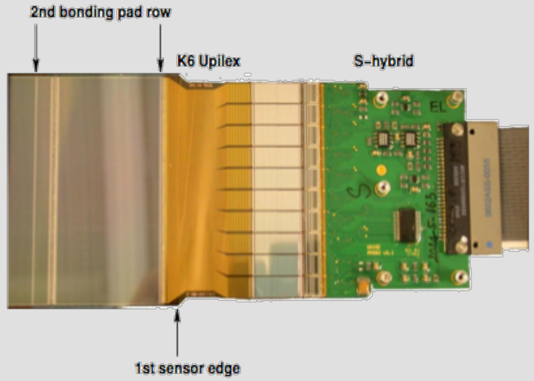
The Silicon Ladder Readout Chain

Y-side – p+ strips

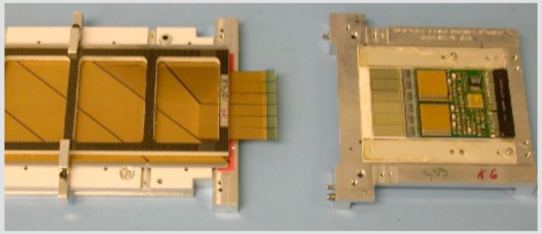


X-side – n+ strips

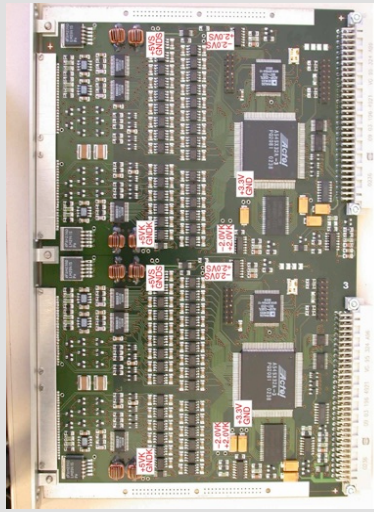
To Y-side Electronics →



To X-side Electronics →



To Digitizat. →



Sensors

- 300µm,72x41mm^2
- Srip pitch : 27.5 (104) for Y(X)
- reverse biased at 50 V
- Readout pitch : 110 (208)
- Capacitive coupling : 1 pF/cm
- Charge sharing

Front-Ends

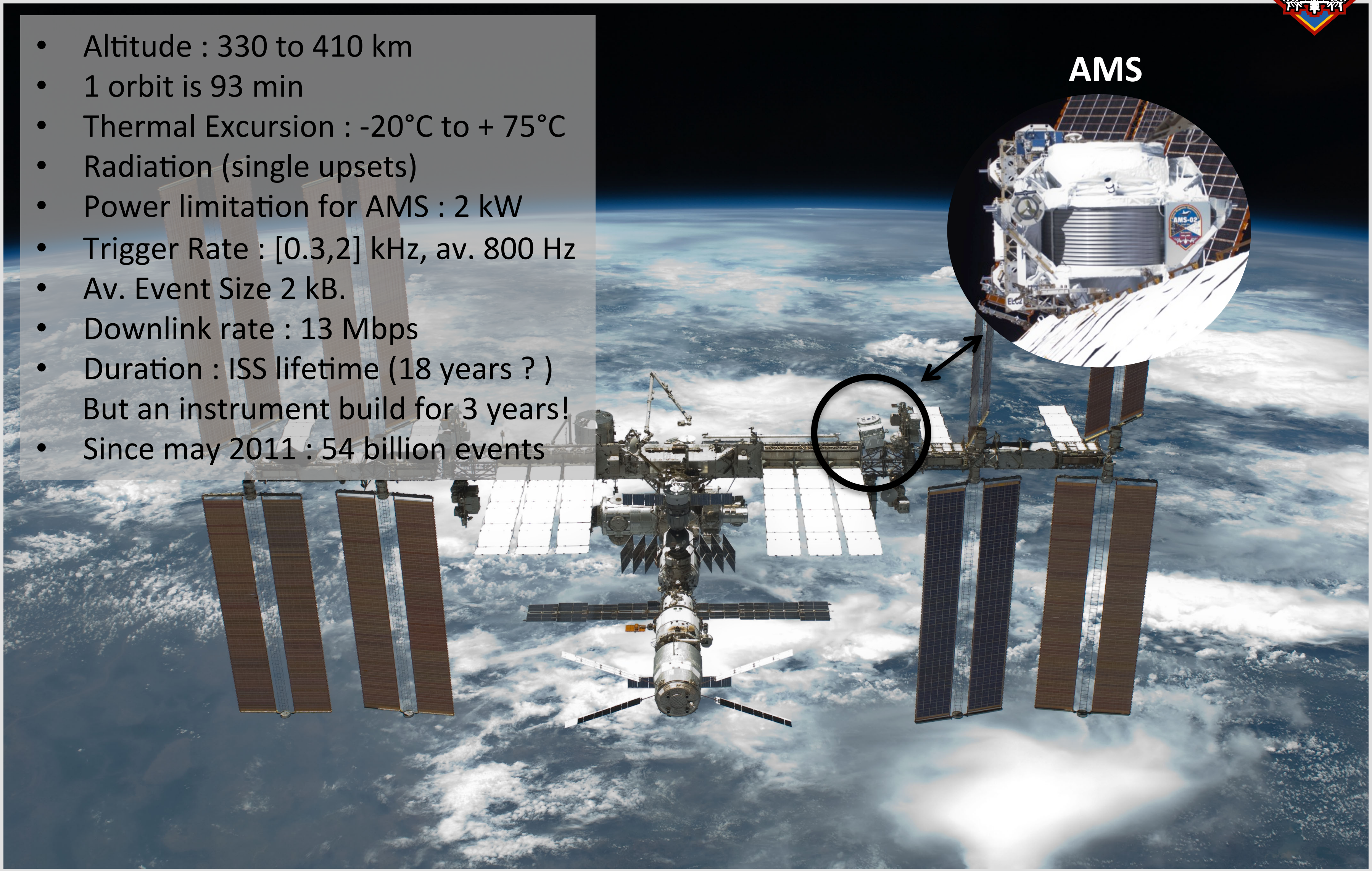
- 10 (6) VAs Y (X)
- Amplification (100 MIP)
- Shaping (~ 4 µs)
- Sample-and-Hold
- 0.7 mW / channel

Data Reduction

- Three 12 bits ADC
- Pedestal/Noise Eval.
- Common Noise Subtraction
- Cluster Search
- Compression (1000)

AMS on the ISS (since 19 may 2011)

- Altitude : 330 to 410 km
- 1 orbit is 93 min
- Thermal Excursion : -20°C to + 75°C
- Radiation (single upsets)
- Power limitation for AMS : 2 kW
- Trigger Rate : [0.3,2] kHz, av. 800 Hz
- Av. Event Size 2 kB.
- Downlink rate : 13 Mbps
- Duration : ISS lifetime (18 years ?)
  But an instrument build for 3 years!
- Since may 2011 : 54 billion events

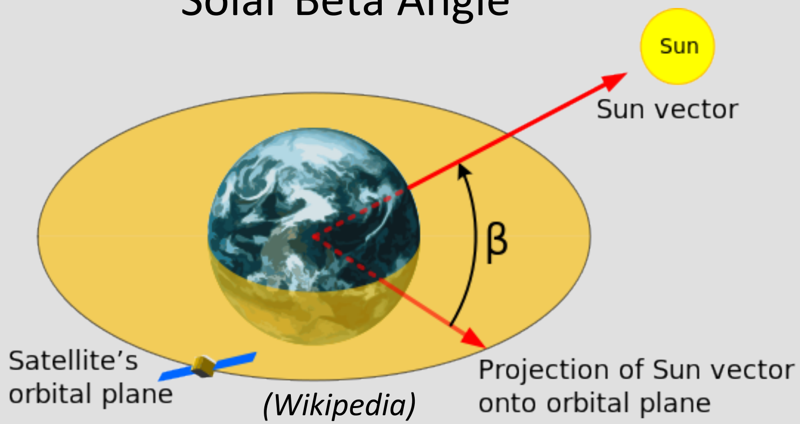


Thermal challenges for on-orbit operations

Thermal environment variables:

- Orbital properties, day/night
- Solar beta angle
- Radiator and solar panel positions
- Space craft attitude, visiting vehicles, re-boost
- Time scales: Months, days, hours, minutes

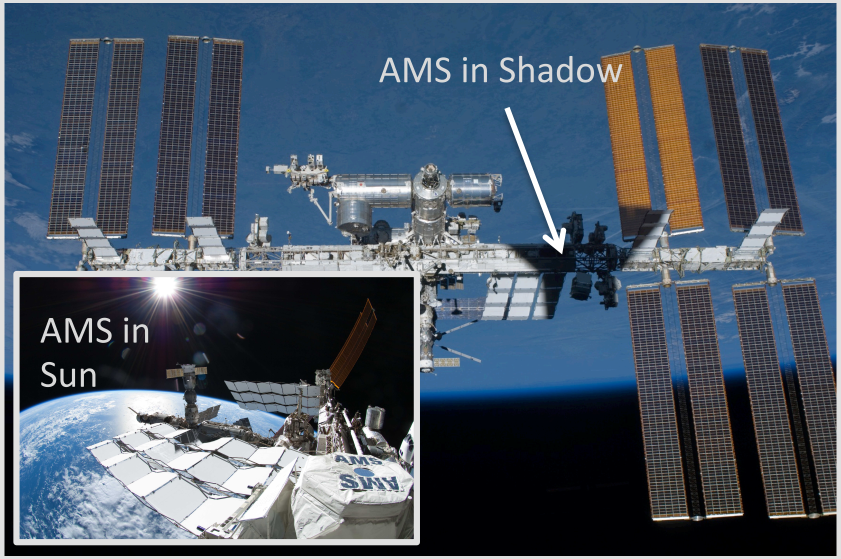
Solar Beta Angle



(Wikipedia)

Results of thermal environment:

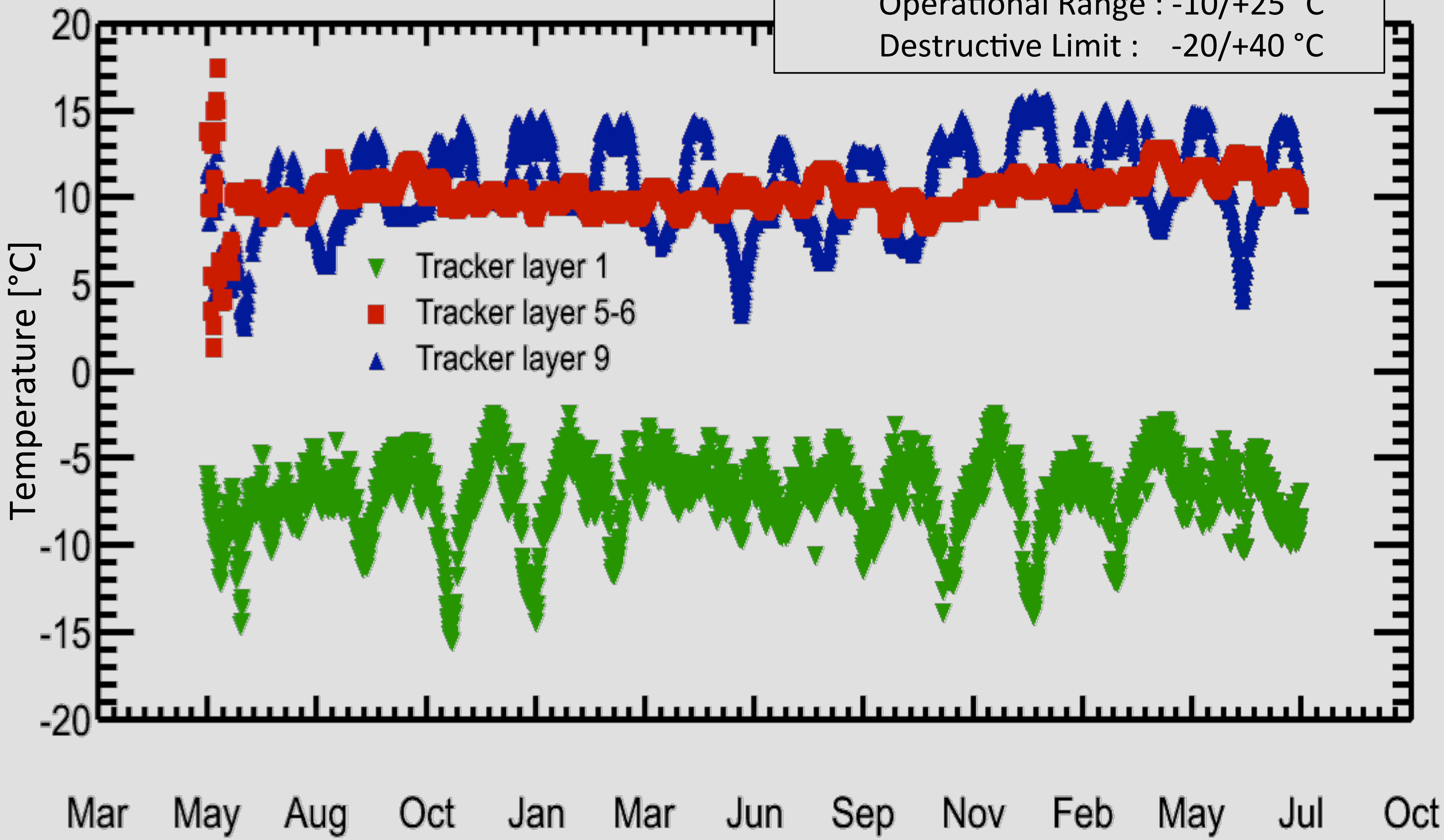
- Thermo-mechanical deformations
- Noise level and gain shift in electronic components
- Damaging effects outside survival or operational temperature range



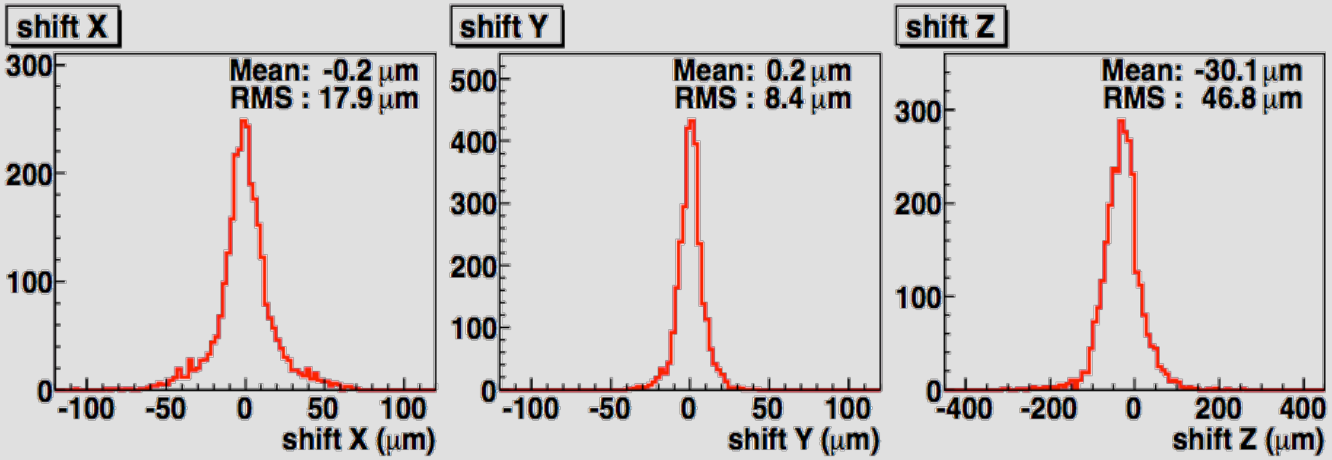
Tracker Temperatures

Only passive thermal control for external layers.

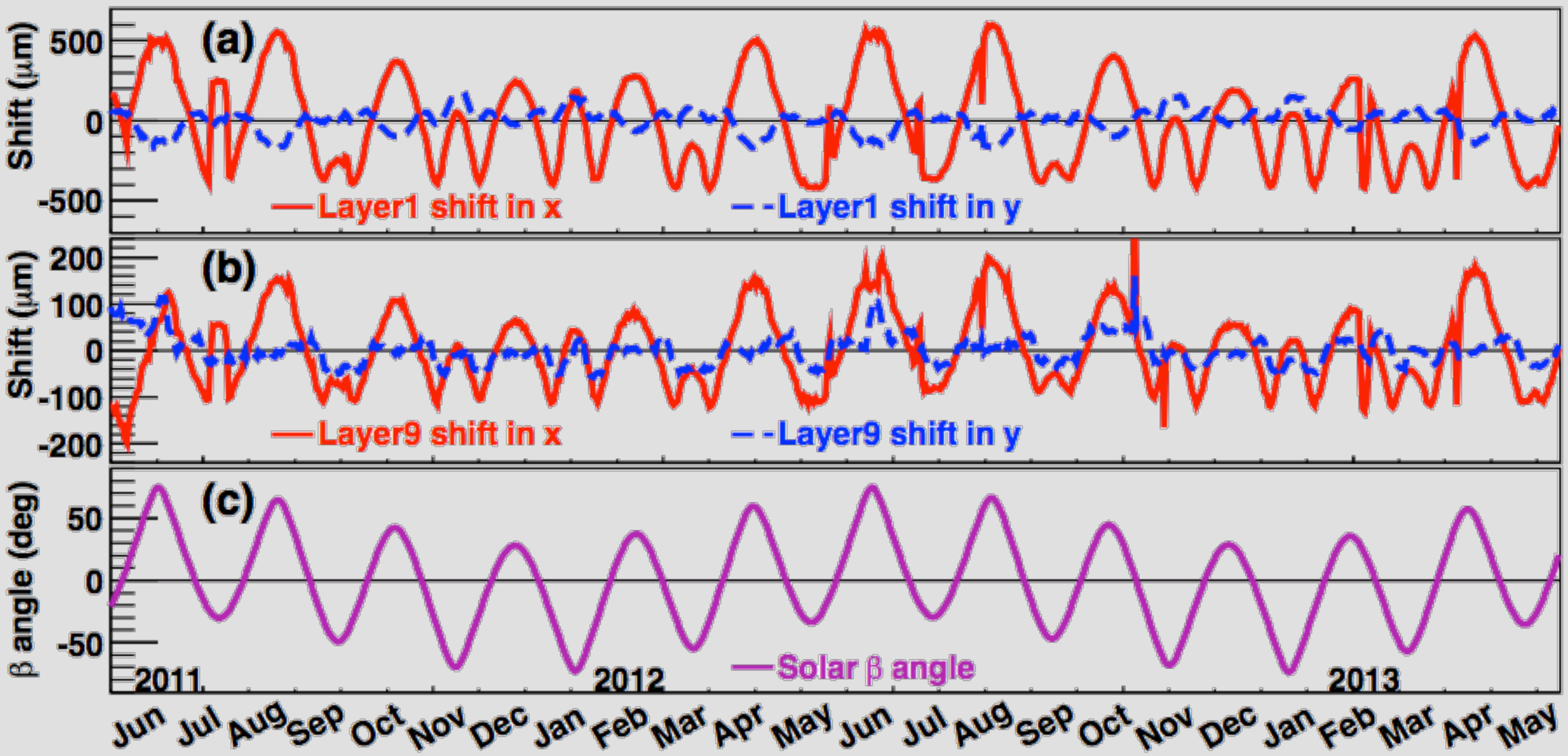
Operational Range : -10/+25 °C
Destructive Limit : -20/+40 °C



Thermal Excursions : Effects



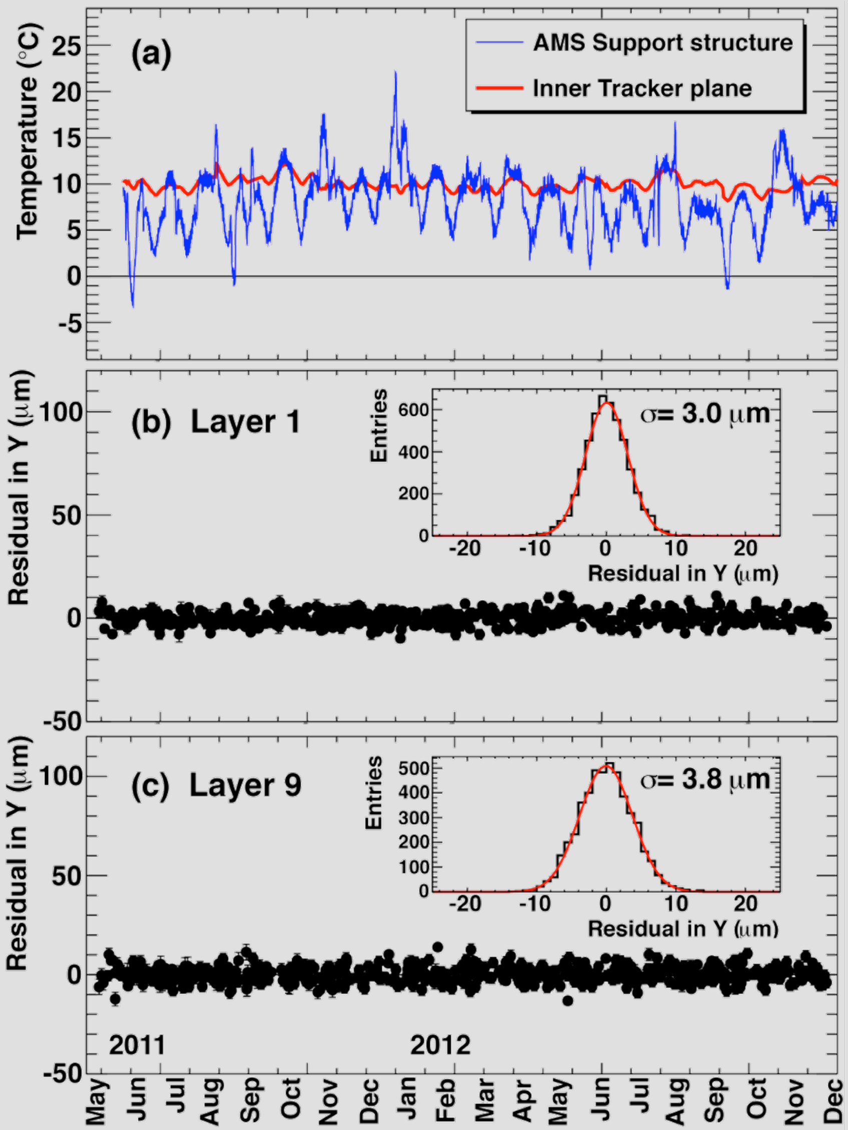
Relative Shifts
of Inner Tracker Sensors
between Test Beam
and ISS Data.
→ **Static Alignment**



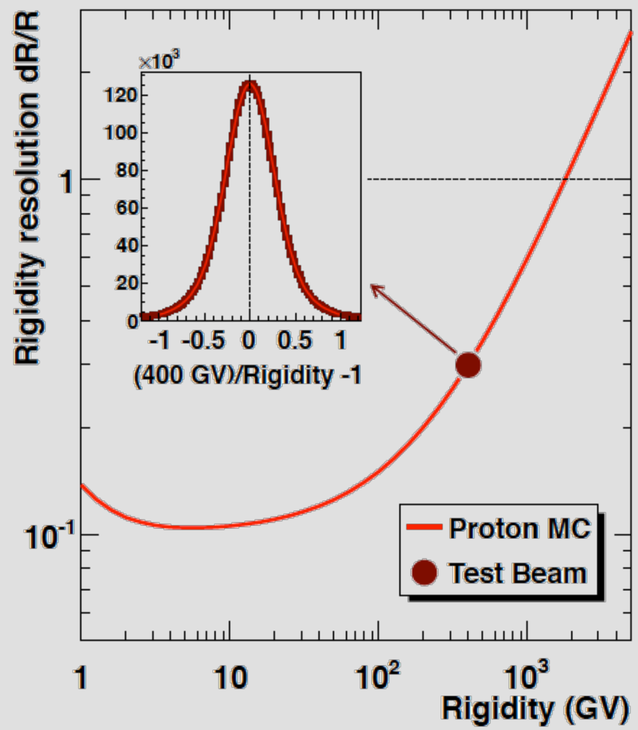
Movement of tracker layers with time <u>before alignment</u>.
→ **Dynamic Alignement**

(Delgado, ICRC 2013))

Alignment of the Silicon Tracker (Stability in Time)



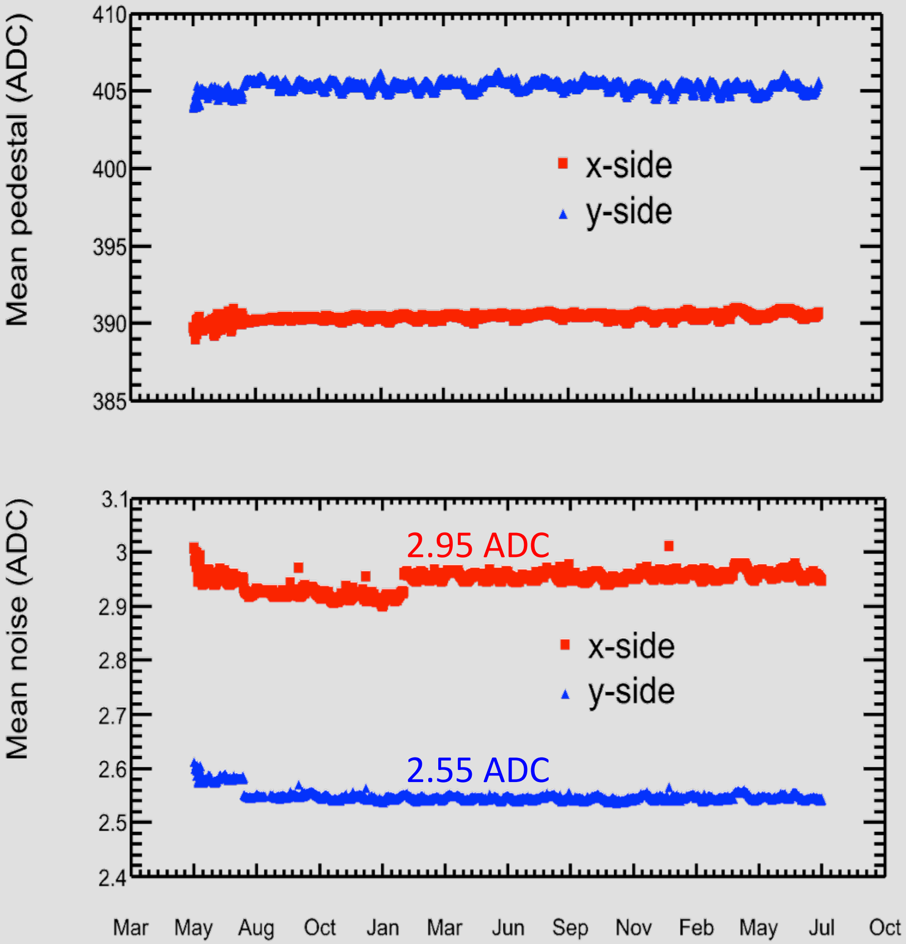
- Static Alignment Inner Tracker
- Dynamic Alignment External Layers
- Alignment error : 7 μm.
- Rigidity resolution at 10% at 10GV
- **MDR for protons is ~1.8 TV**



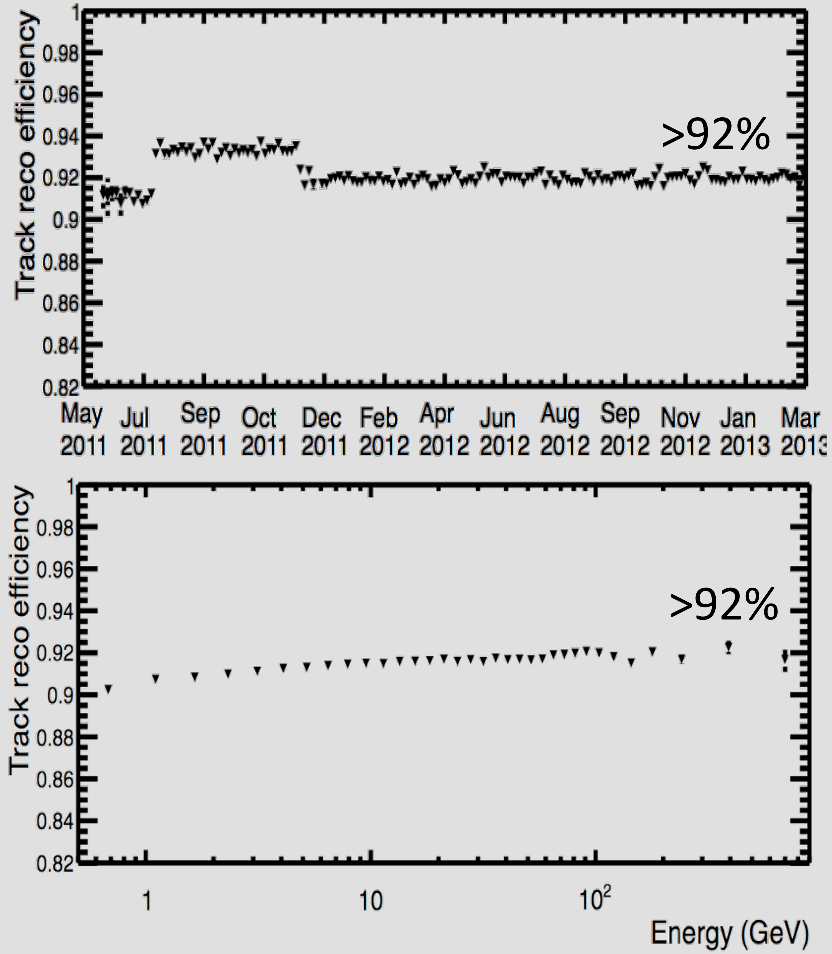
Tracker Calibration Stability

Calibration (< 1 minute) twice per orbit to account for temperature variations.

Pedestal and Noise

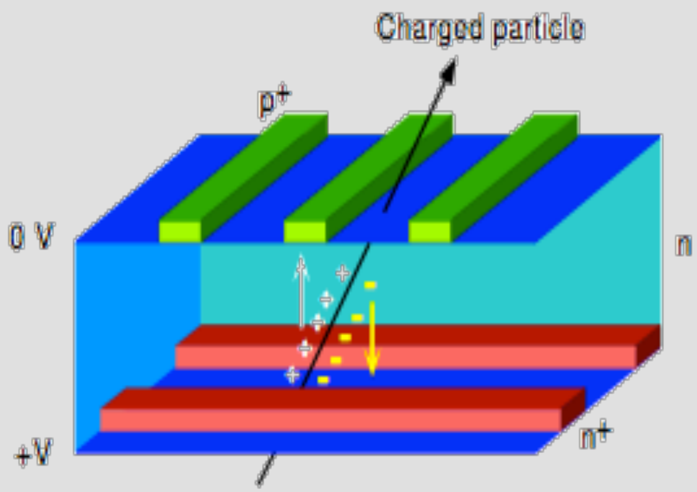


Tracking Efficiency (using ToF)



(J. Bazao, 2013 ICRC)

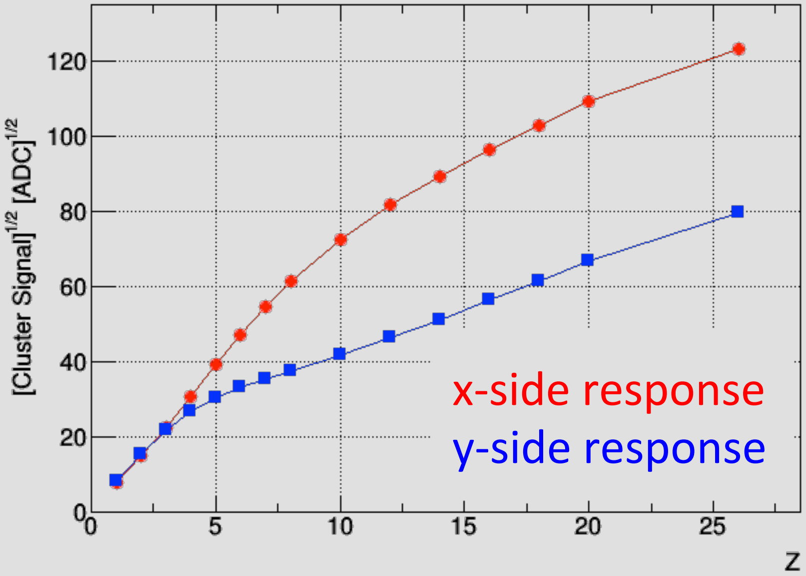
Charge Measurement



$I \propto Z^2$

(Bethe-Bloch)

Tracker Response



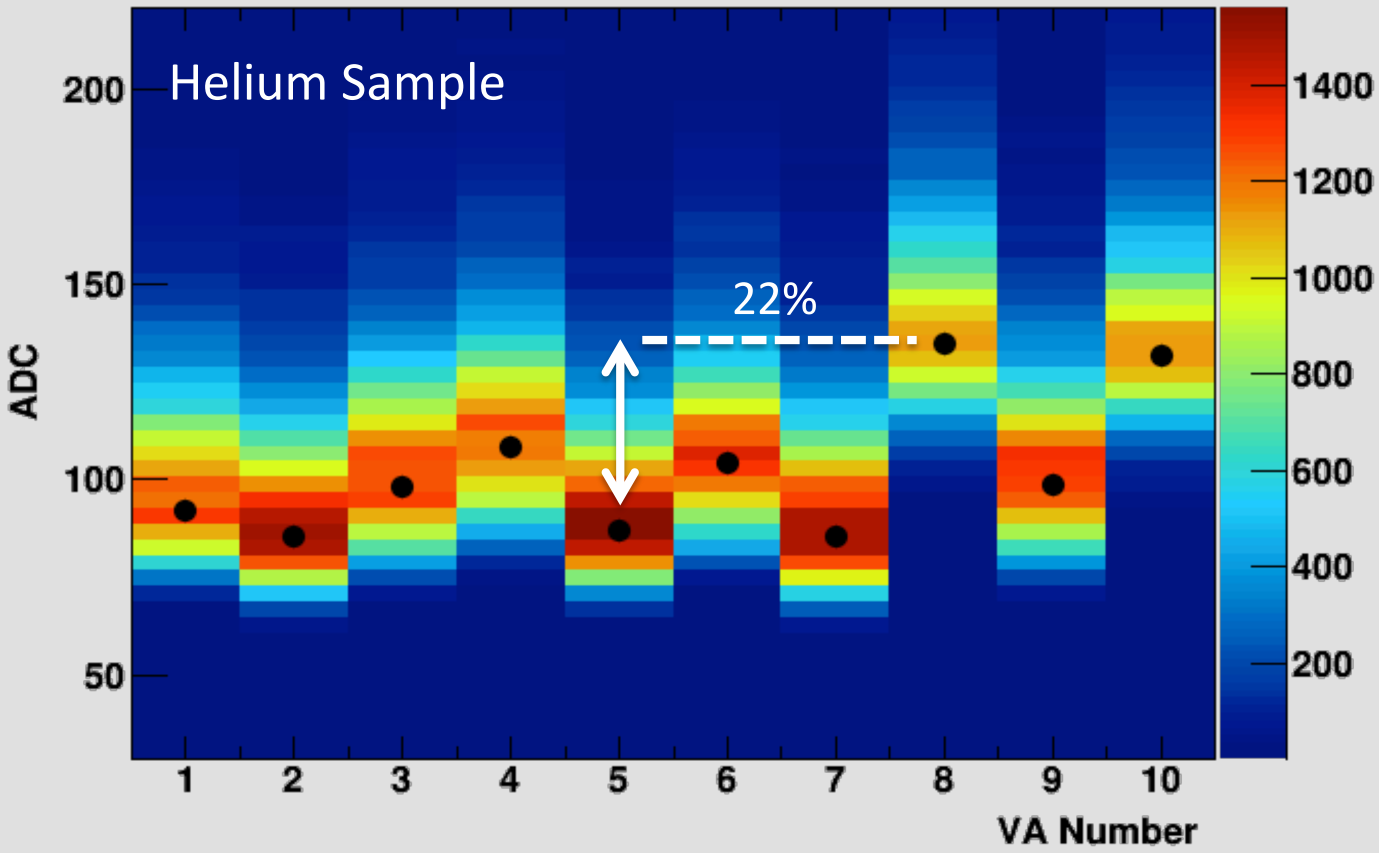
Detector response degraded by variety of effects…

VA Equalization
Collection Efficiency
Energy Dependence

Construct a single energy independent tracker charge estimator

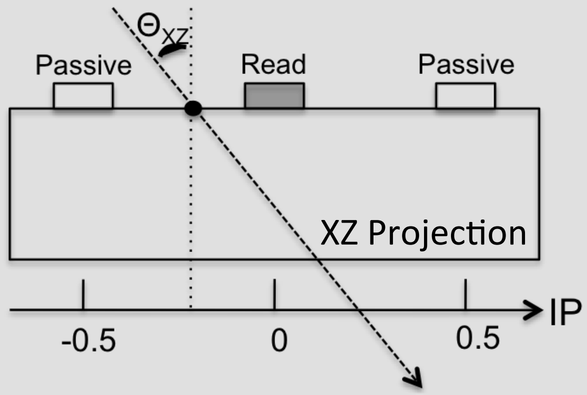
VA Gain Differences

10 y-side VAs of single ladder



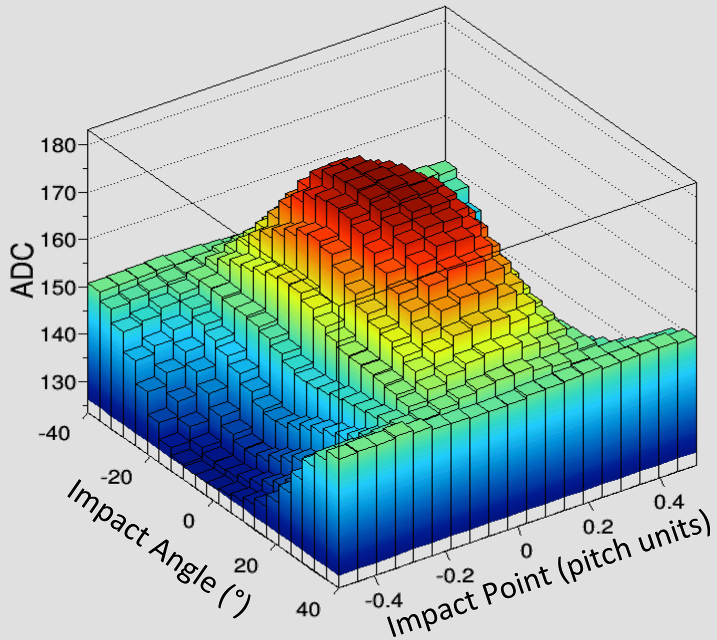
MPV of Landau convoluted with Gaussian used as main estimator of the gain of a given VA.

Charge Measurement

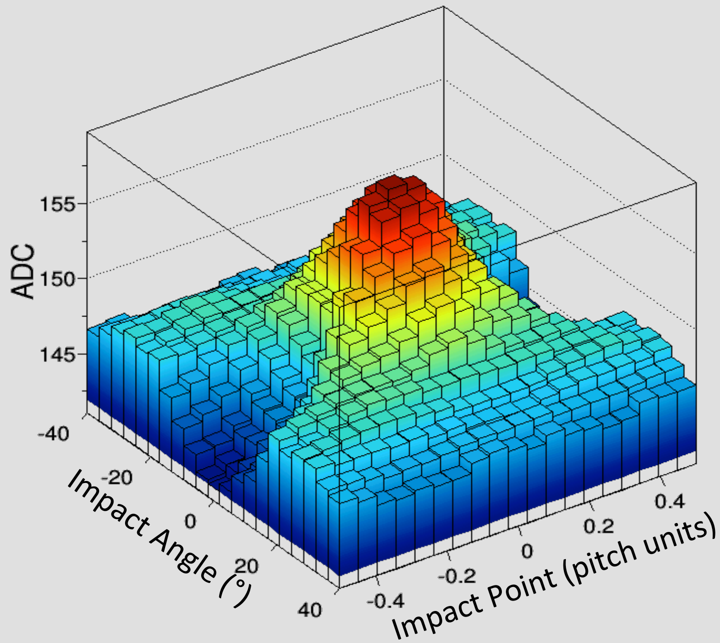


- Ip = 0, θ=0 : max collection
- |Ip| = 0.5, θ=0 : min collection
- Up to 30% difference in peak position
- Equalization procedure in each bin

Helium x-side

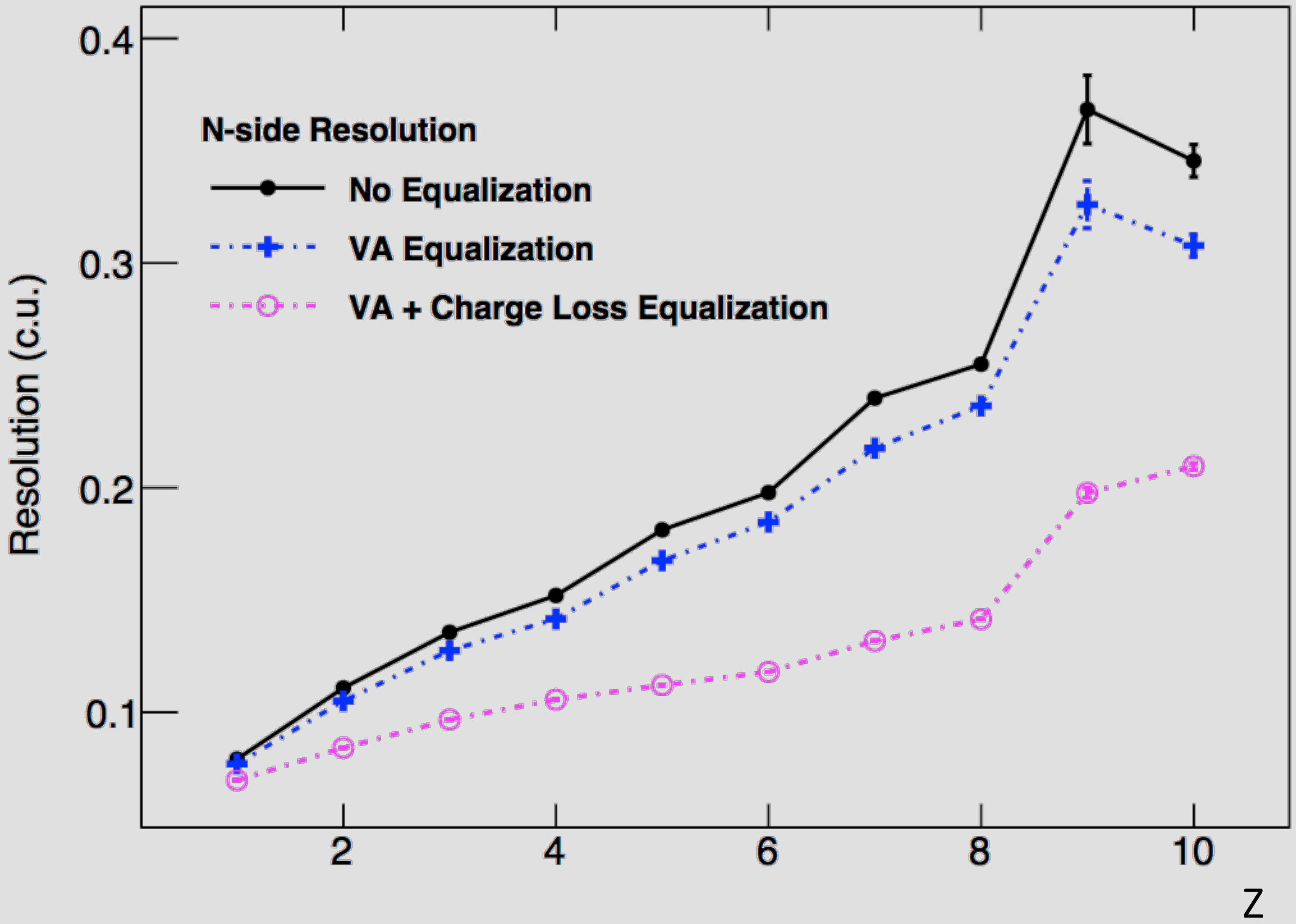


Helium y-side



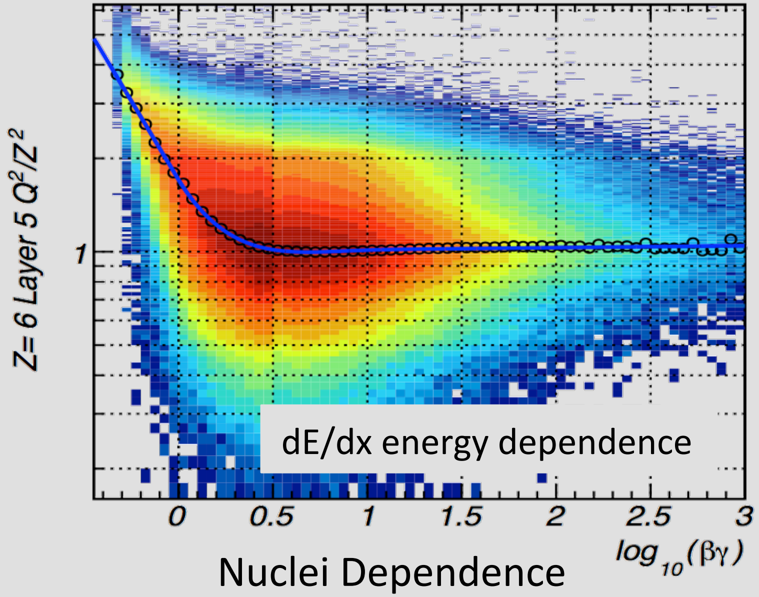
Resolution Improvement n-side

Using multi-Gaussian fit to extract resolution measurement.

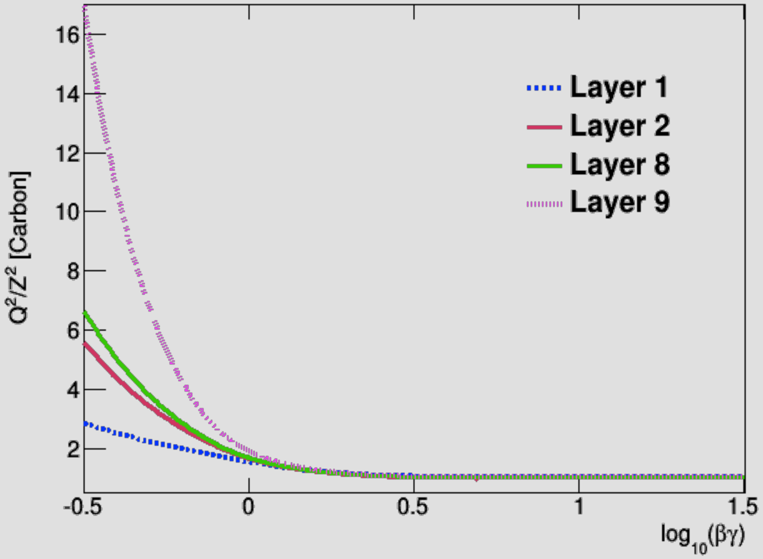


Energy Loss β Dependence

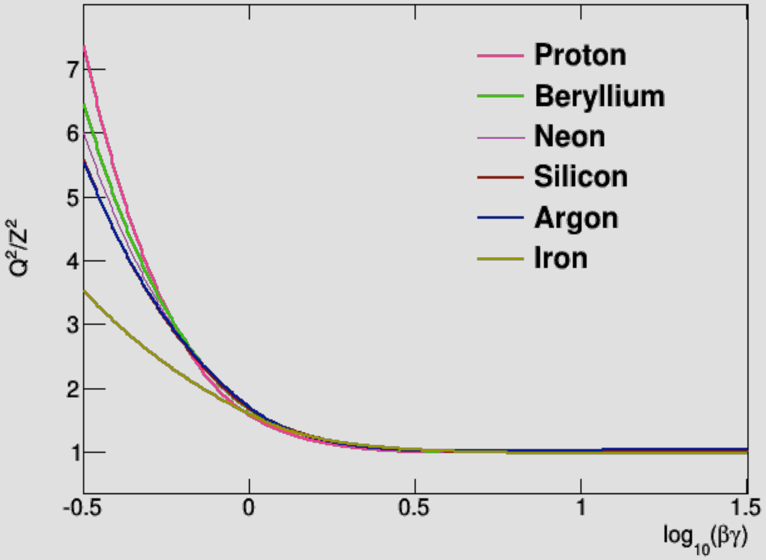
Parameterization



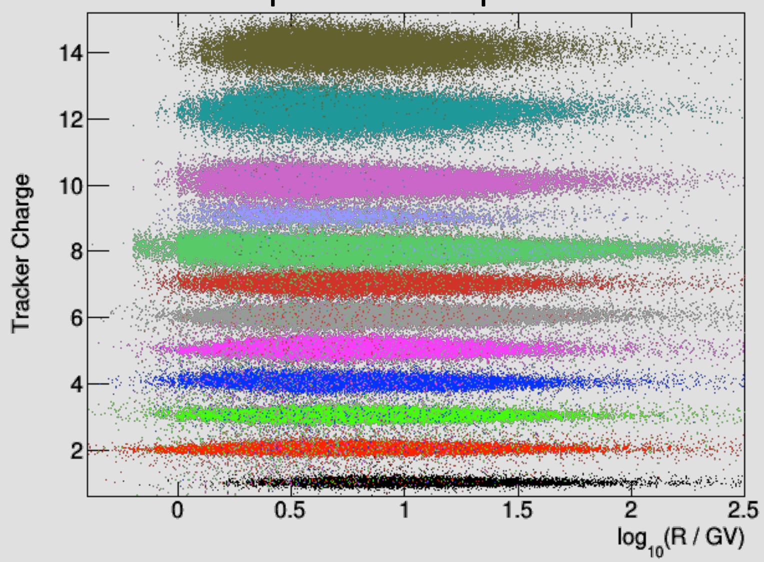
Layer Dependence



Nuclei Dependence



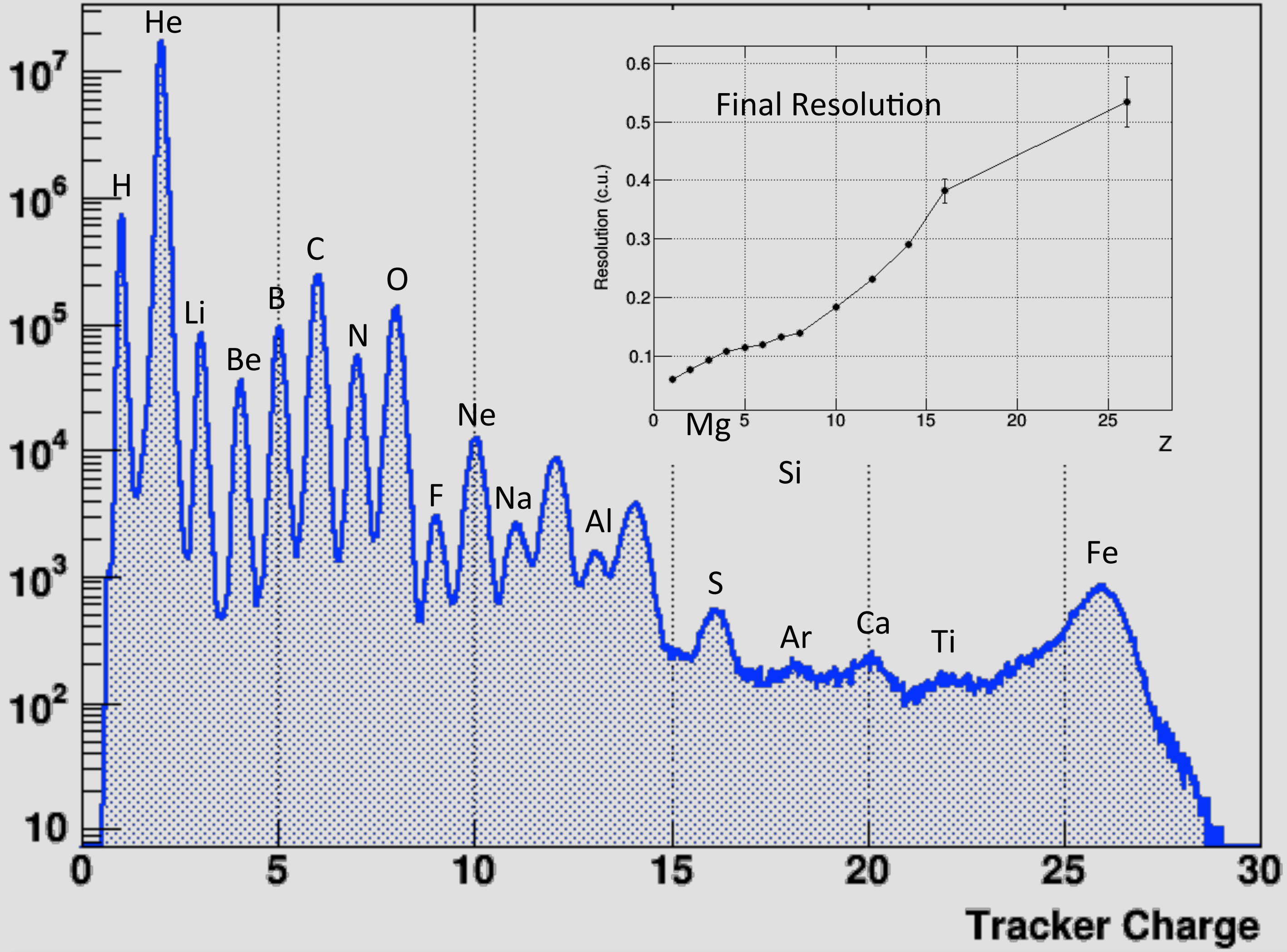
Equalized Response



Final Calibration Results

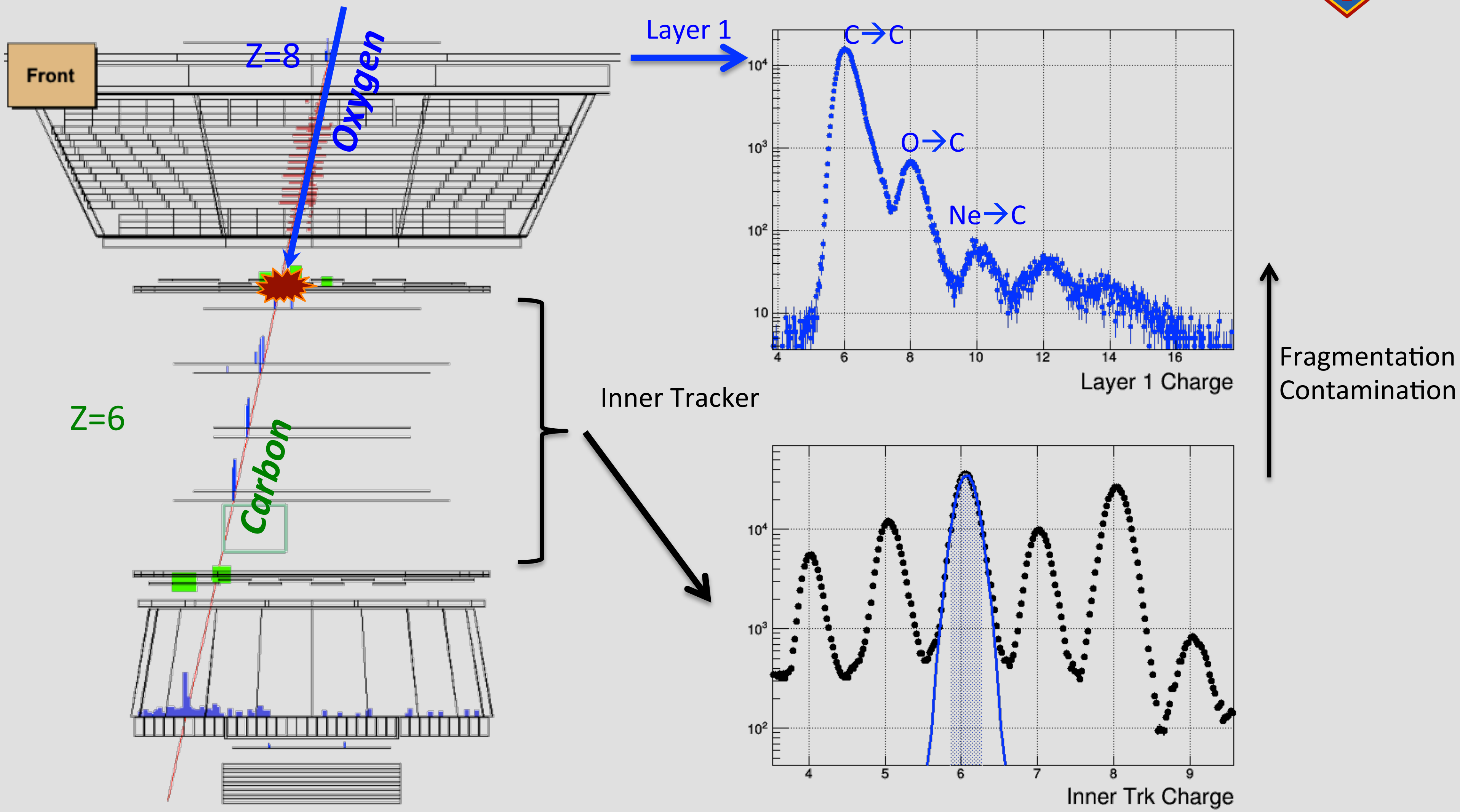
$$Q = \frac{Q_n w_n + Q_p w_p}{w_n + w_p} \qquad w_i = \frac{1}{\sigma^2(n_{pts})}$$

Carbon misid. prob. at 99% selection efficiency is < 10^{-4}



Contribution of H, He is pre-scaled in this plot.

Redundant Charge Measurement



Crucial for nuclei flux measurements and secondary to primary nuclei ratios.

Summary

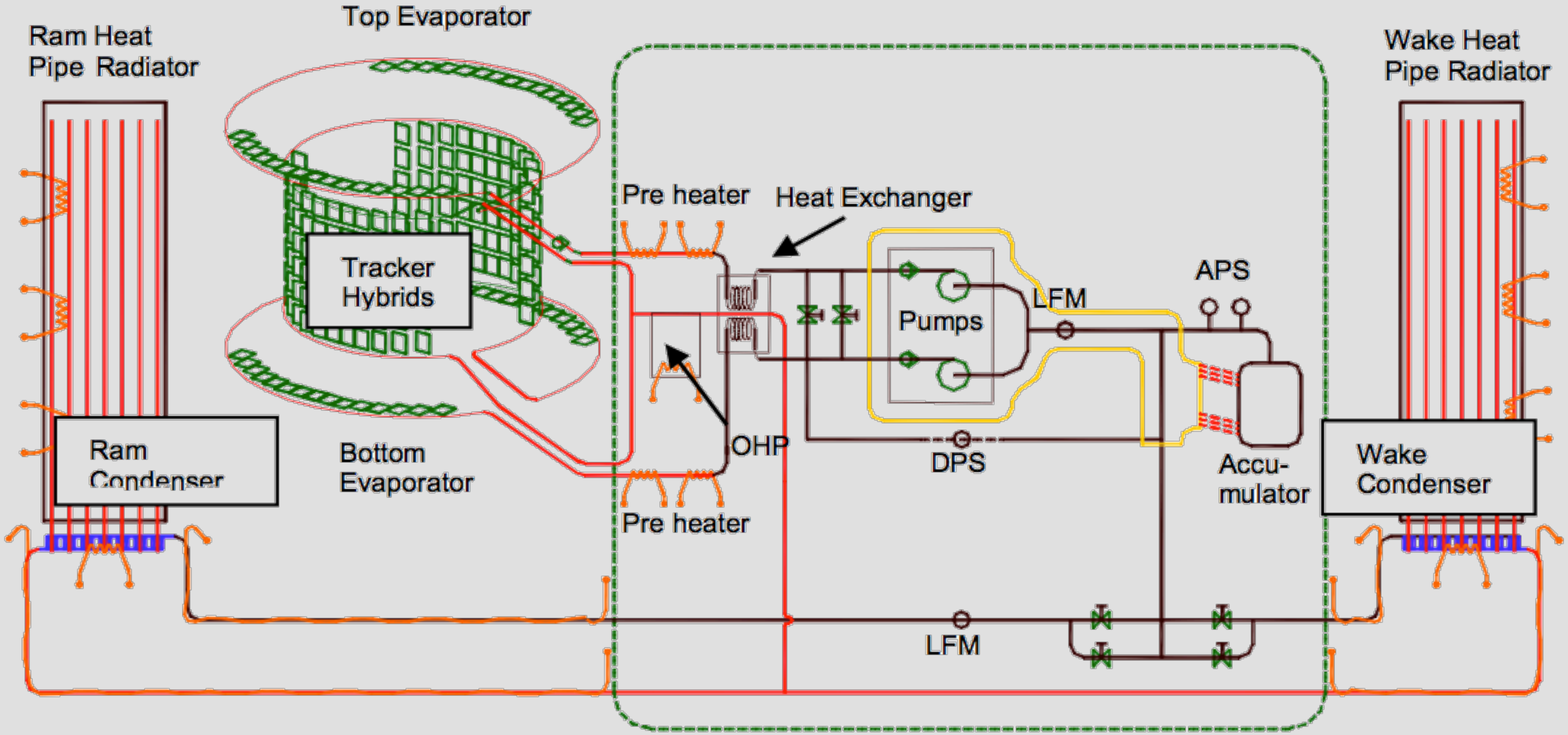
- Silicon Tracker operation in space most challenging due to the harsh thermal conditions.
- Precise control and detailed on-orbit calibration of the tracker allows best performances in terms of tracking efficiency and rigidity measurement.
- An accurate charge calibration of the tracker has been developed, resulting in a misidentification probability for carbon at the level of 10^{-4}. Good identification capability up to Iron.
- The charge measured by individual tracker layers are essential tools to control fragmentation in the detector.

Thank you for your attention…

BackUp Slides

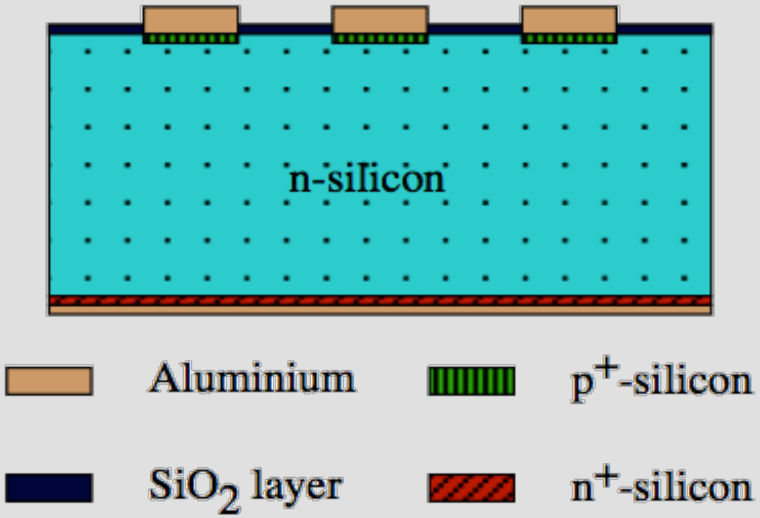
Tracker Thermal Control System (TTCS)

- TTCS is a 2 phases CO_2 pumped loop (first pumped CO_2 system in space).
- TTCS can remove 125 W from layer 2 to layer 9.
- Layer 1, facing deep space, only needs a heater.

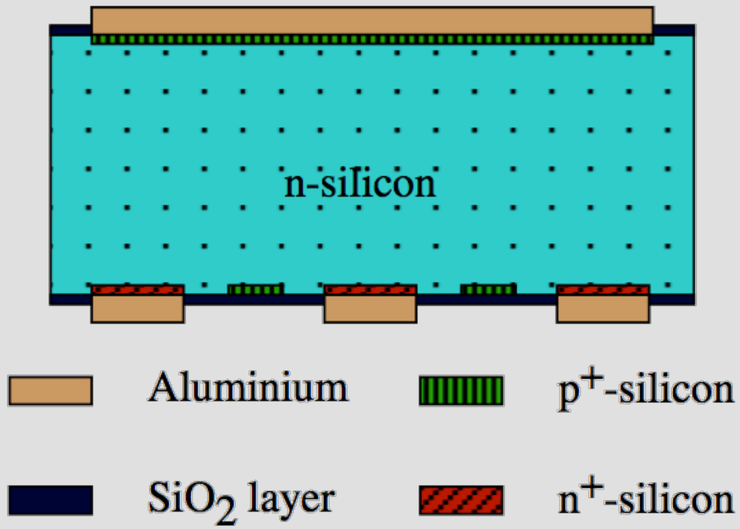


Silicon Sensor Design (P. Azzarello, 2004)

p-side slice



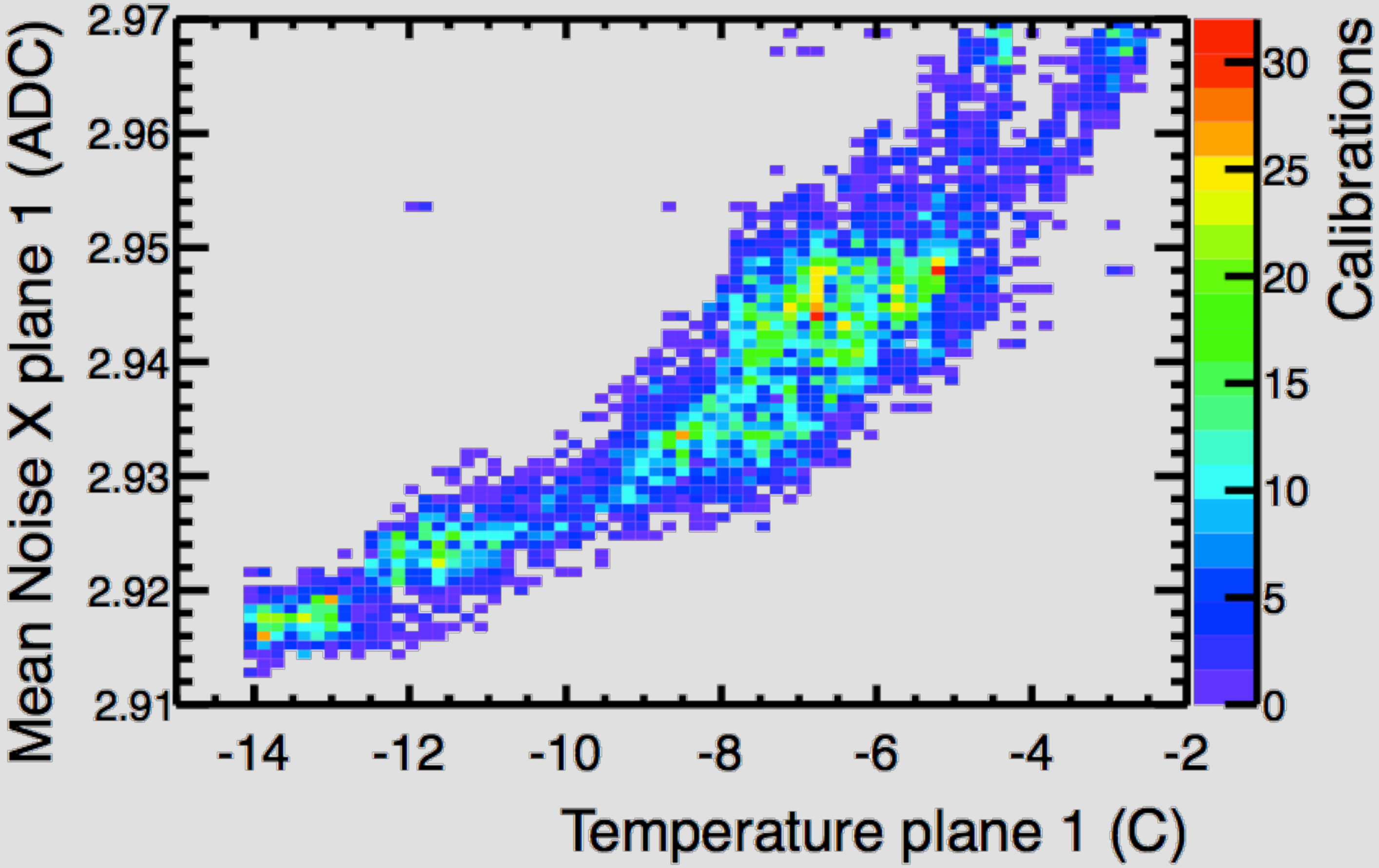
n-side slice



Max. depletion voltage	50 V
Max. total leakage current	2 μA
p-side hot strip definition	$I_{strip} > 2$ nA
n-side hot strip definition	$I_{strip} > 20$ nA
Max. number of p-side hot strips	6
Max. number of n-side hot strips	4

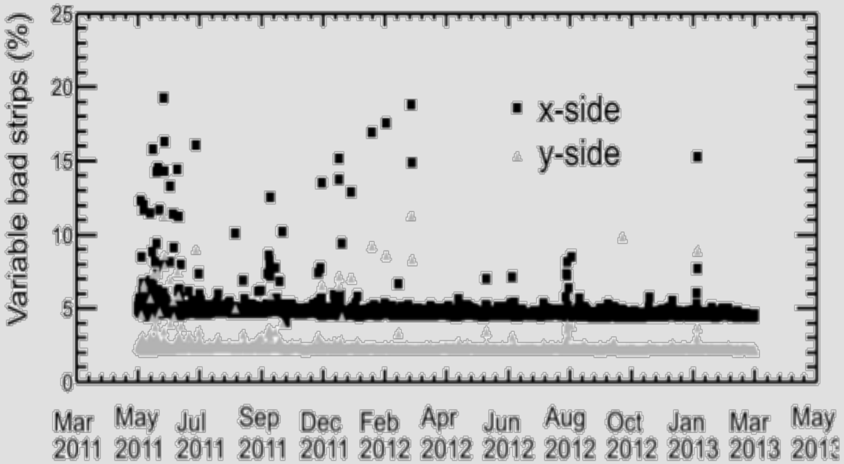
Table 3.1: Selection criteria applied to the AMS-02 silicon microstrip detectors [49].

Noise versus Temperature

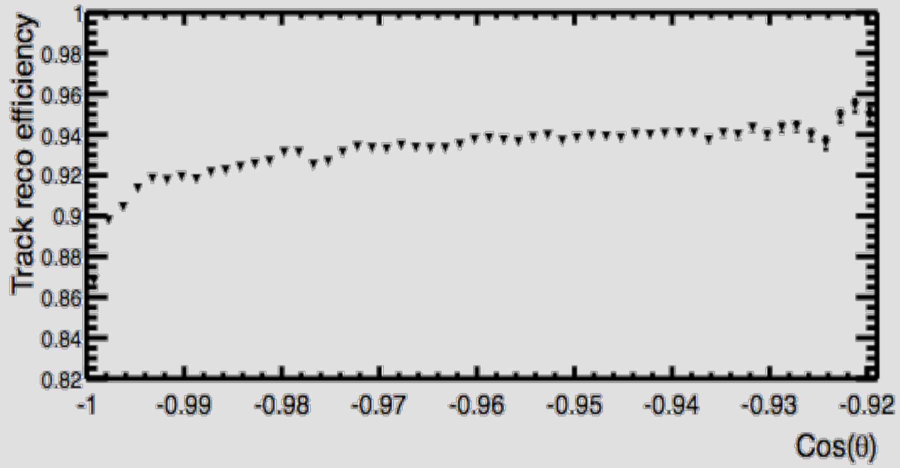


Tracker Performance

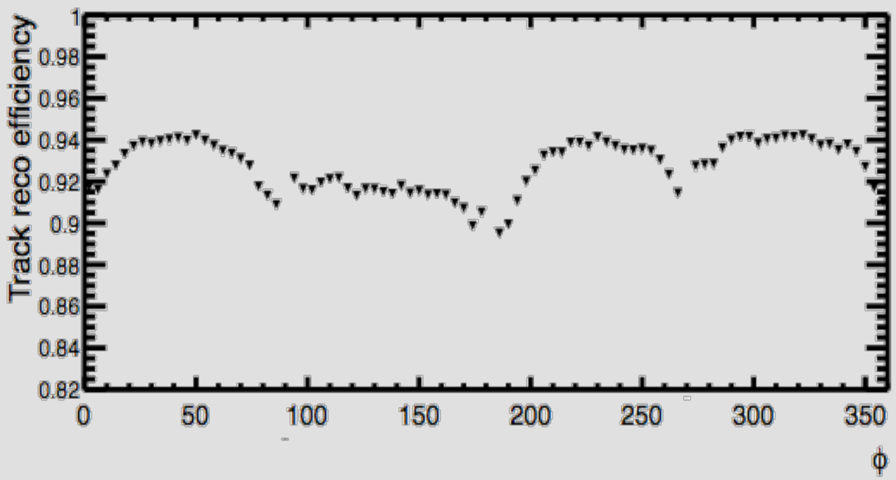
Perentage Bad Strips vs Time



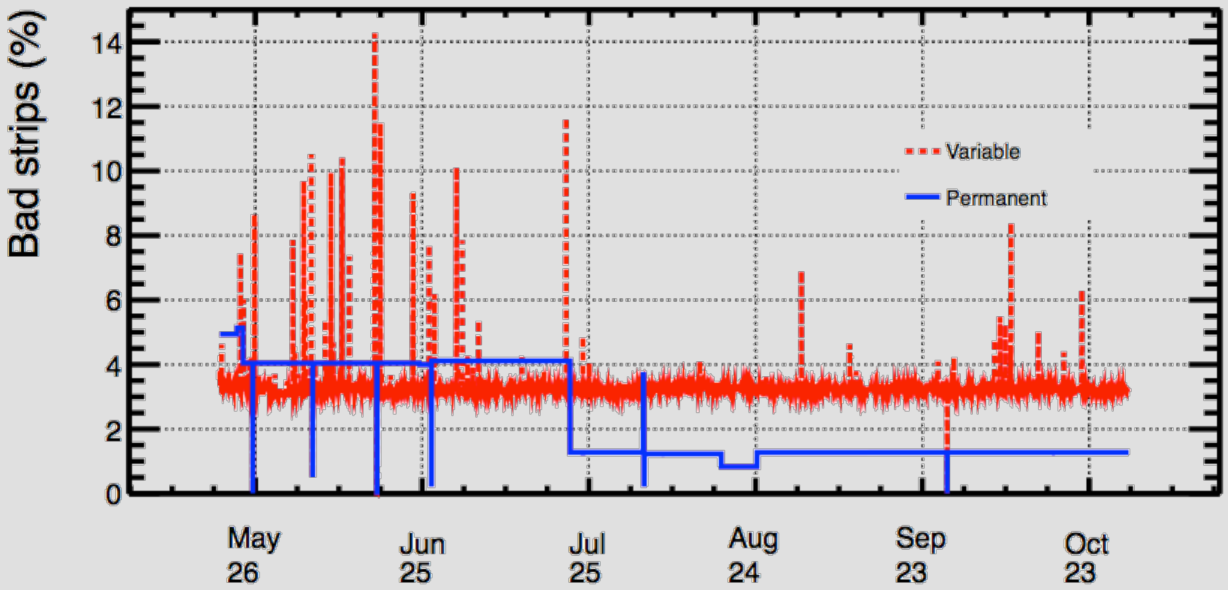
Track Efficiency vs Incident Angle

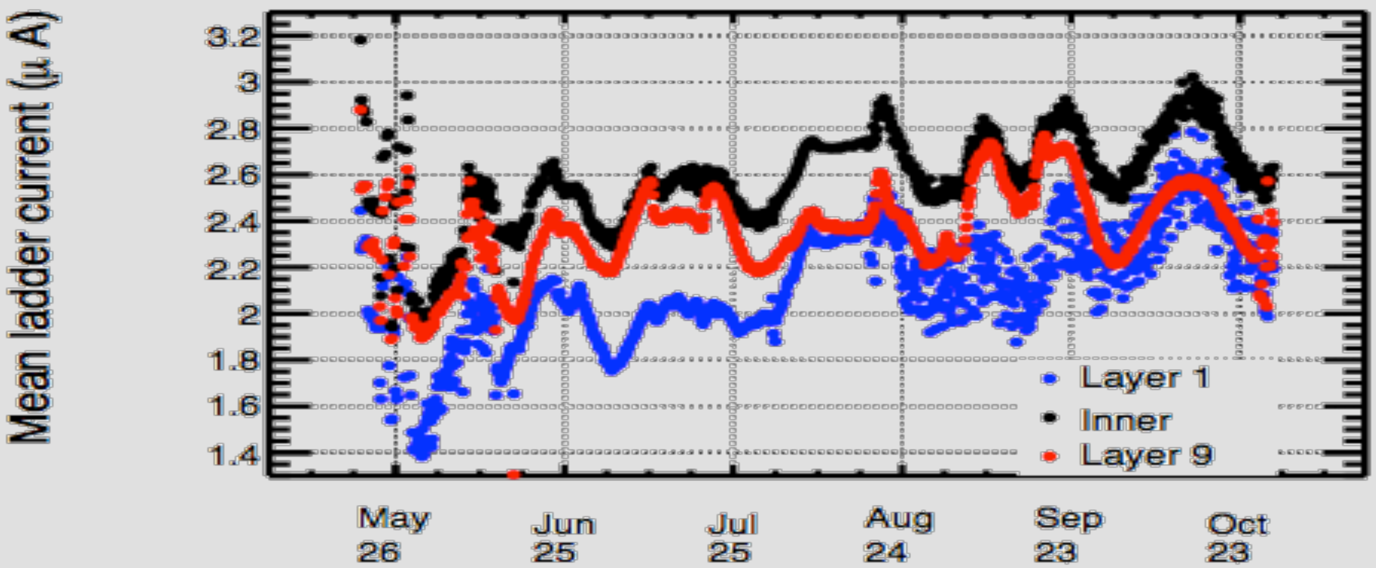


Track Efficiency vs Azimuthal



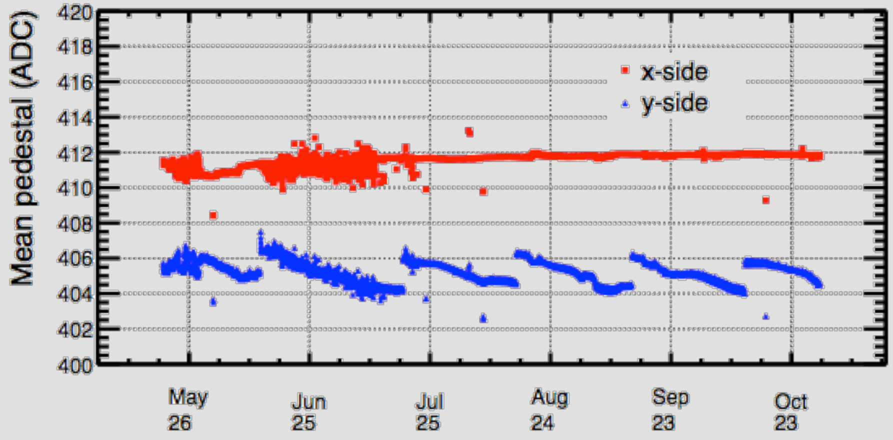
Noise versus Time



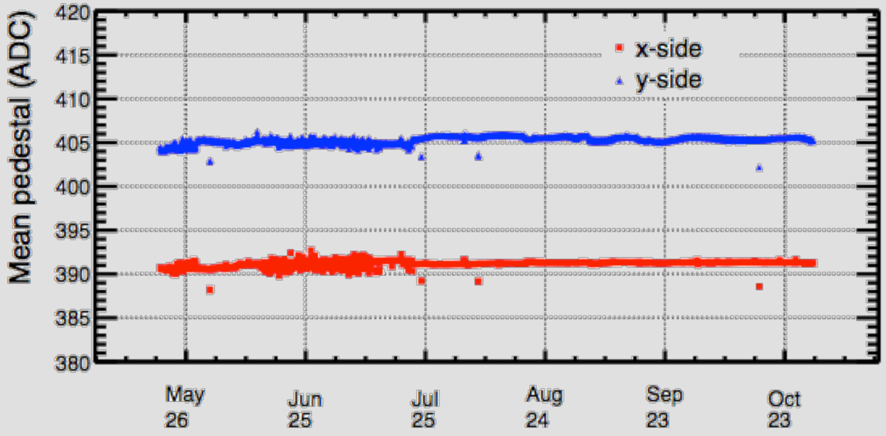


Pedestal Behavior

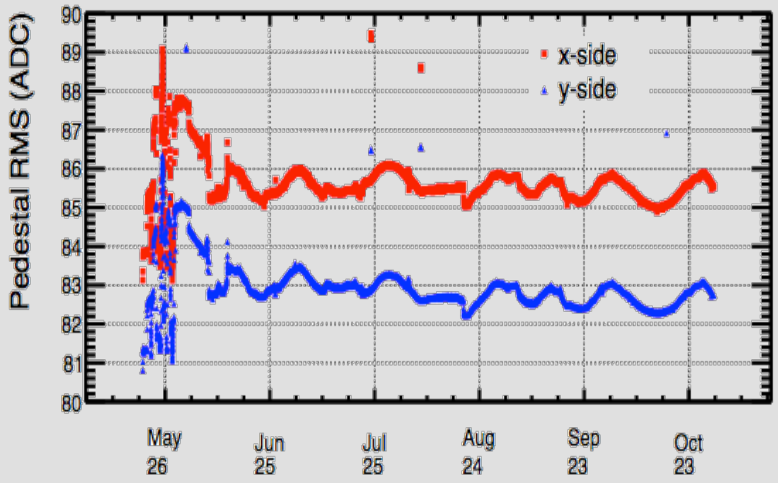
Mean Pedestal



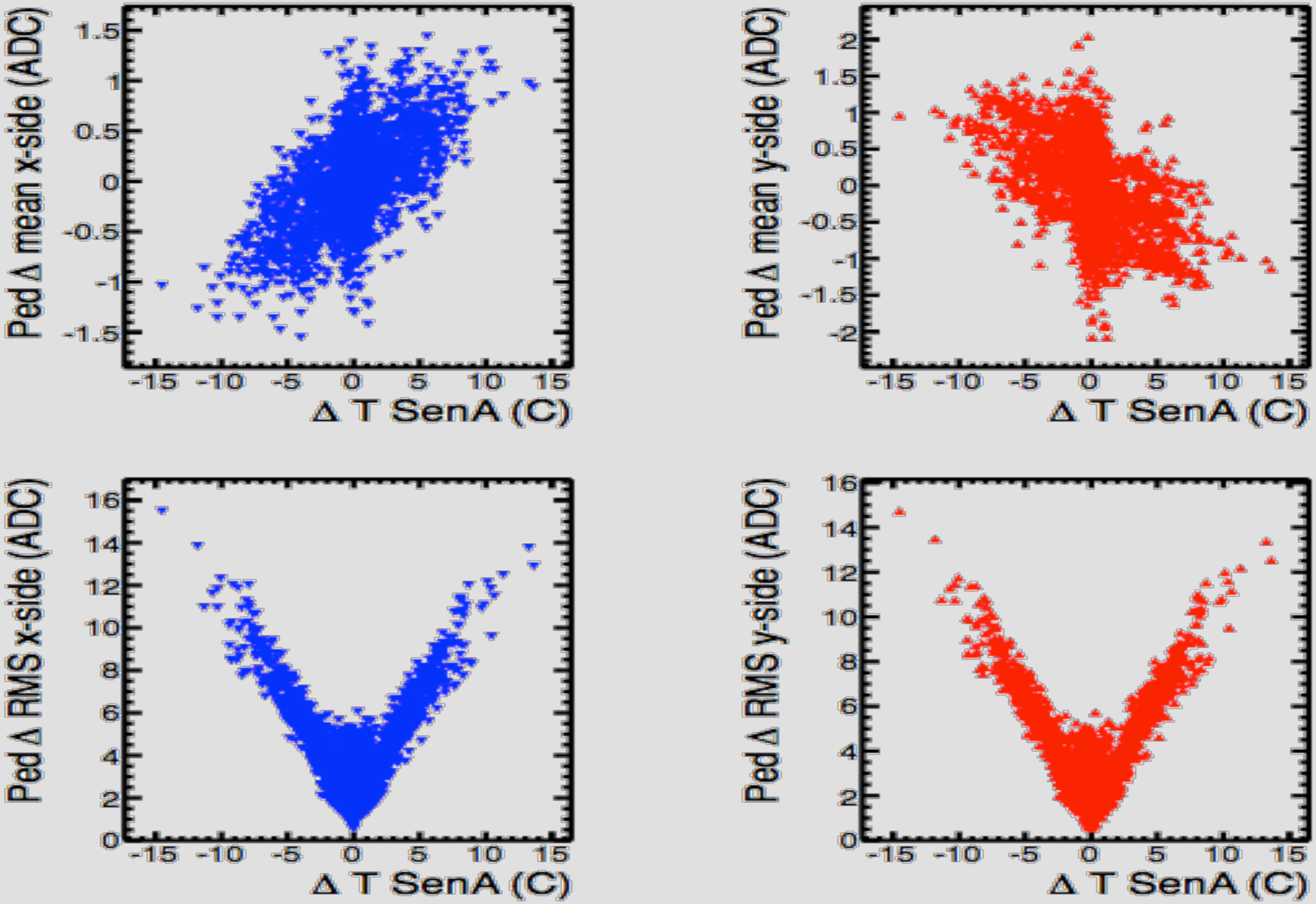
removing permanent bad strips and pathological ladder



Pedestal RMS

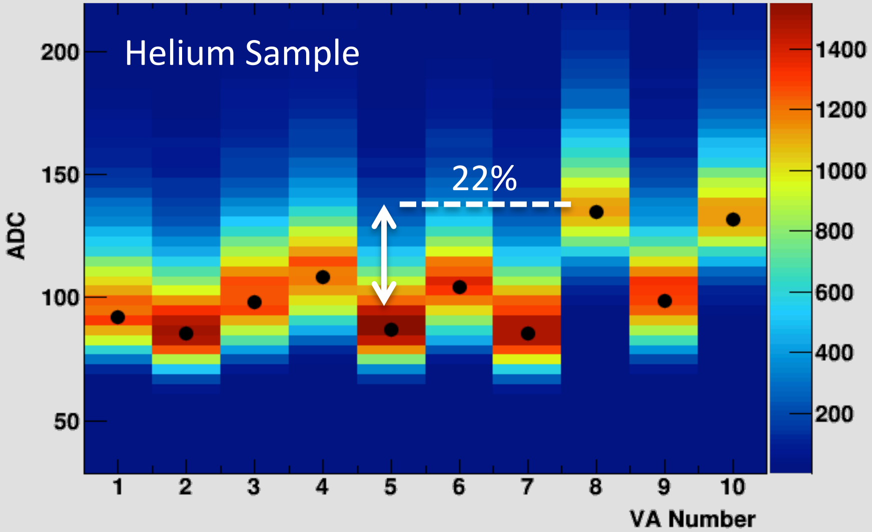


Pedestal Dependence on Temperature

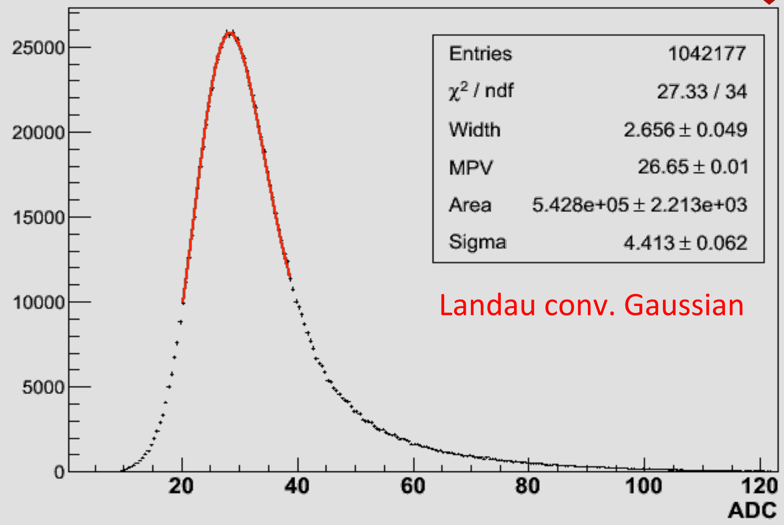


VA Equalization

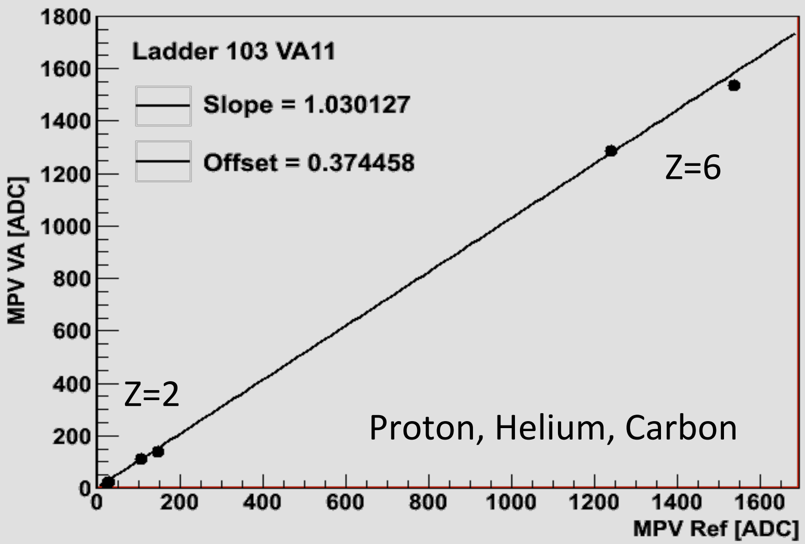
10 p-side VAs of single ladder



Single VA ADC distribution



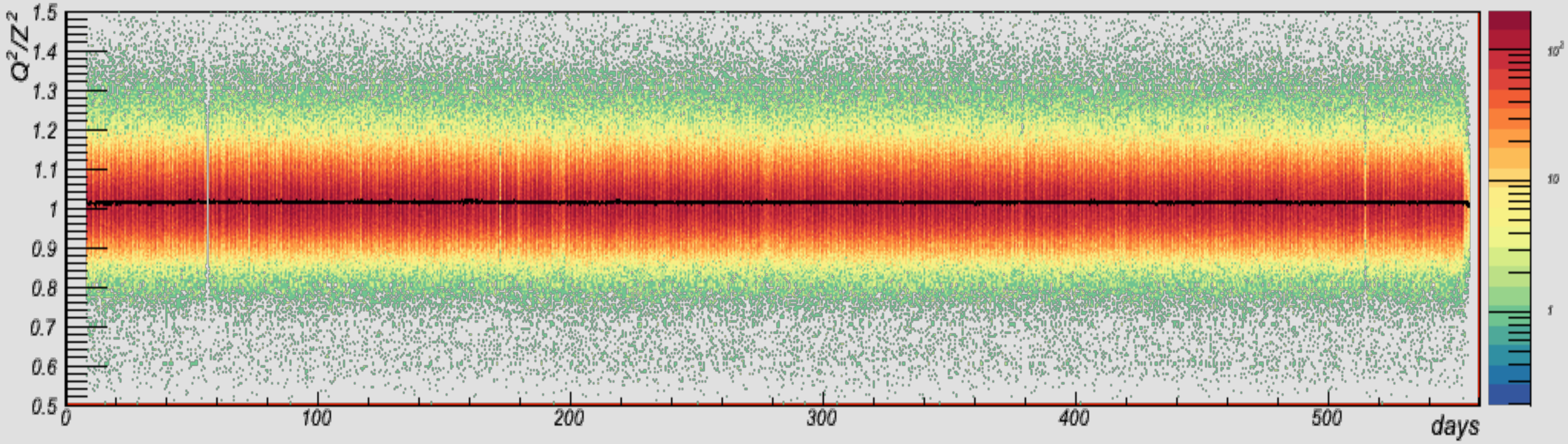
MPV (VA) versus MPV (Ref.)



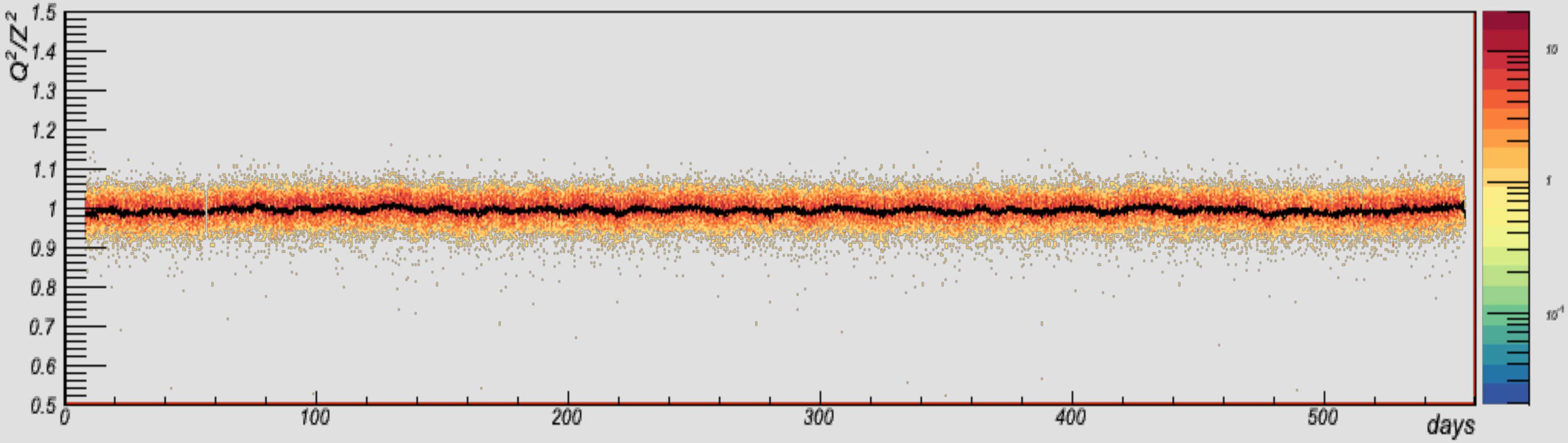
$$ADC_{Corr} = \frac{1}{slope}(ADC_{Meas} - offset)$$

Time Stability of the Tracker Measurement

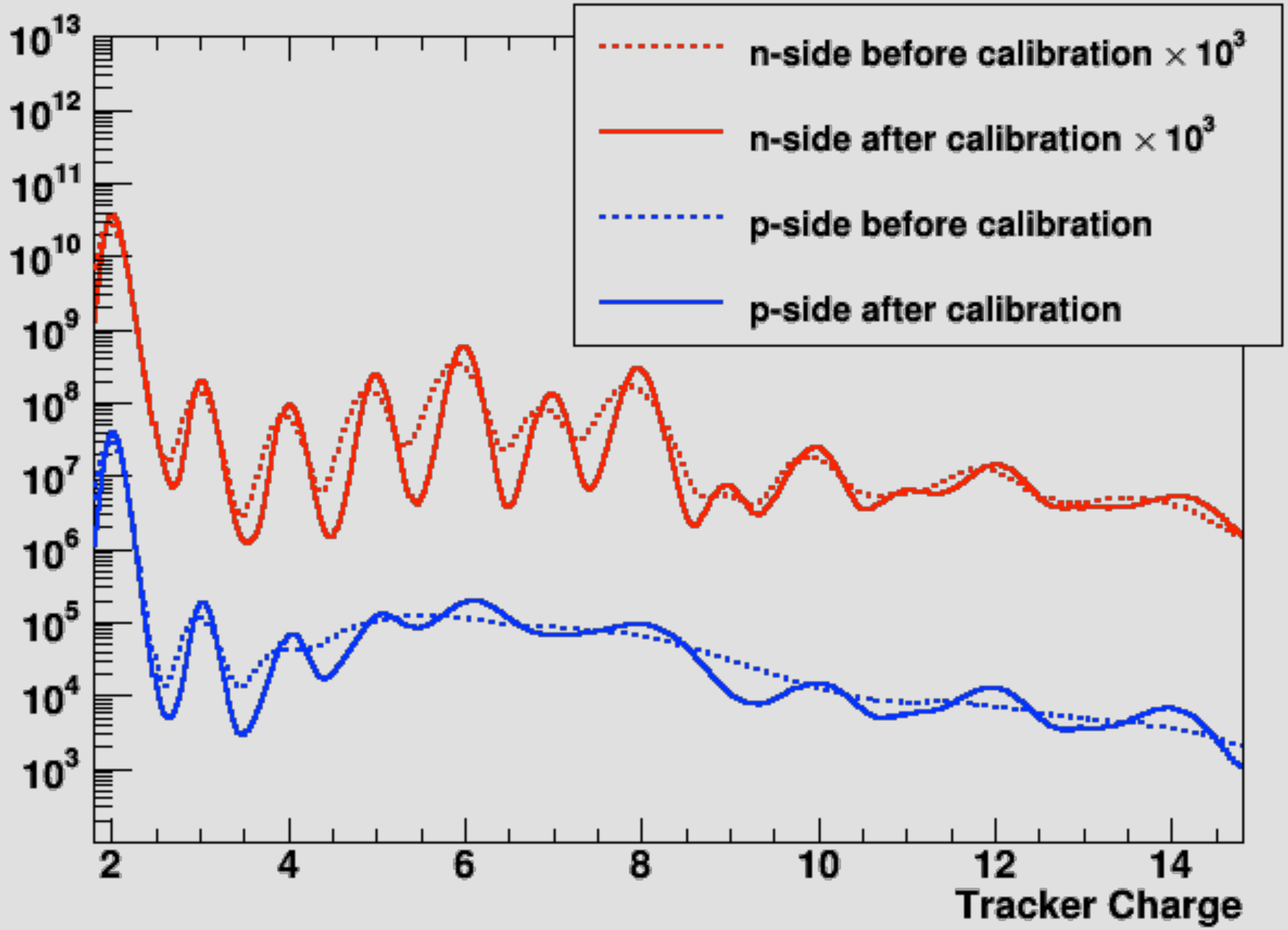
X-Side Z=1



Y-Side Z=26



Final Calibration Results



Boron to Carbon Ratio

Important measurement to constrain Cosmic Ray propagation models.