A silicon array for cosmic-ray particle identification in space

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SIMONE BONECHI

OUTLINE

1) Charge identification using Silicon Matrix

2) Development of a Silicon Matrix Array for Cosmic Nuclei Identification in Space (we proposed this Array for Gamma-400 experiment)

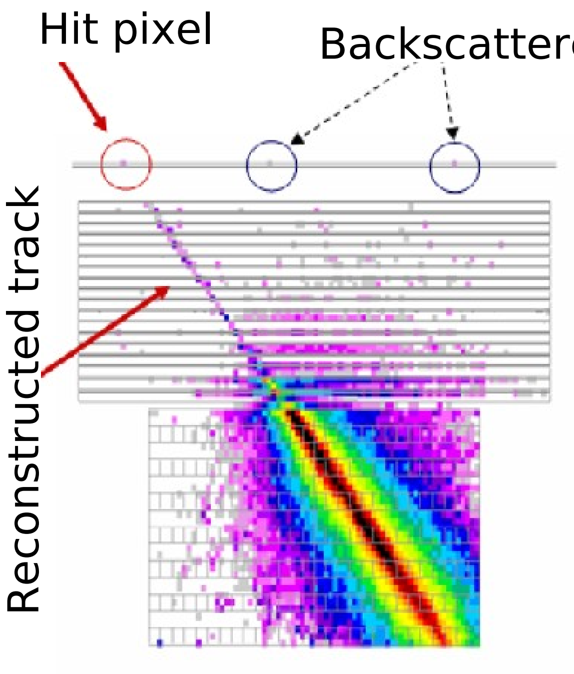
3) Test of Silicon Matrix and associated Front-end Electronics

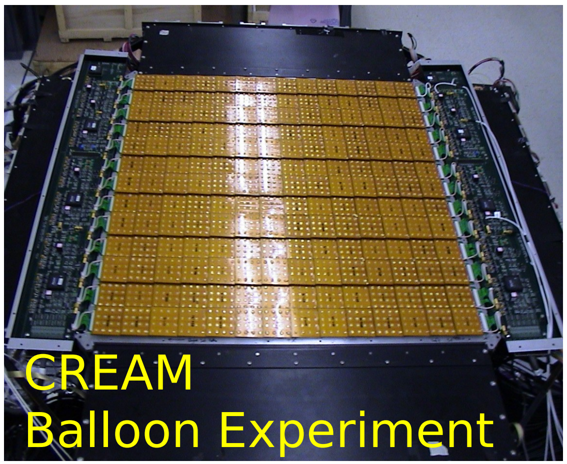
4) Test of the basic detector module prototype at Cern

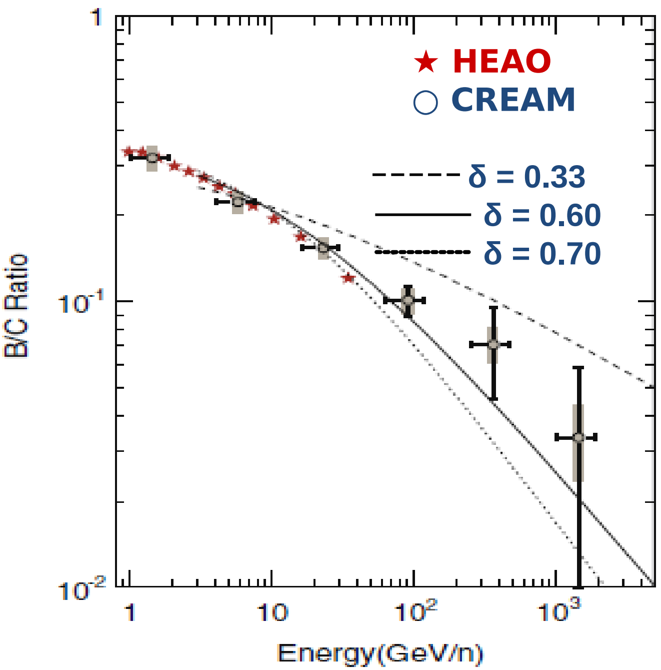
5) Data analysis of Beam test data

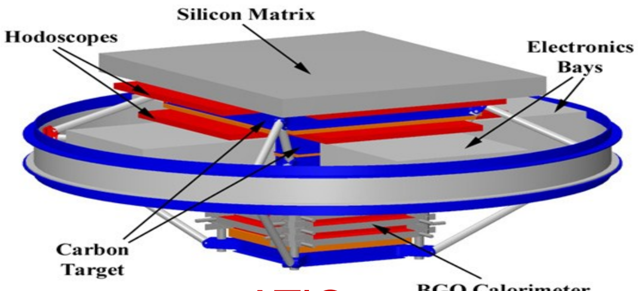
Examples of Silicon charge identifier

Exemples of experiments where the charge identification of primary cosmic rays is achieved by means of a Si detector with "large" pixels of order 1 cm².









ATIC
Balloon Experiment

Horizontal errors : systematic error in the overall energy scale
Vertical errors: statistical error of the ratio
Grey bars: the systematic uncertainty in the ratio.

Astroparticle Physics 30 (2008) 133–141 [CREAM]

Silicon Charge Detector - Sensor

From SINTEF - Norway

- **Pixel area: 1.125 × 1.125 cm²**
- **Thickness: 500 µm**
- **Matrix: 8 × 8 pixels**
- **Active area: 9.07 × 9.07 cm²**
- **Full area: 9.47 × 9.47 cm²**
- **Full depletion voltage: < 20V**
- **Breakdown voltage: > 200V**
- **Dark current per pixel: < ~ 1nA**
- **Junction capacitance per pixel : ~ 25pF**

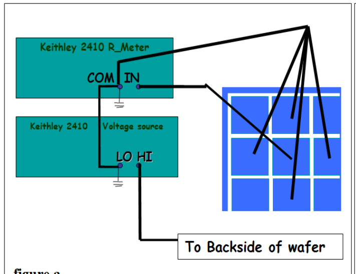


figure a

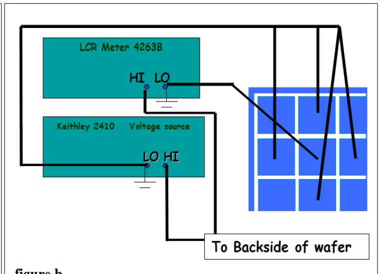
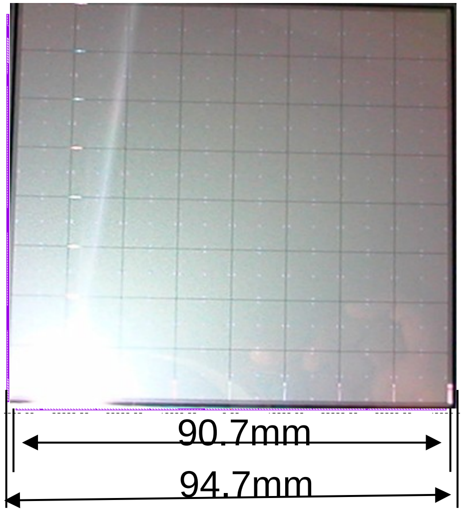
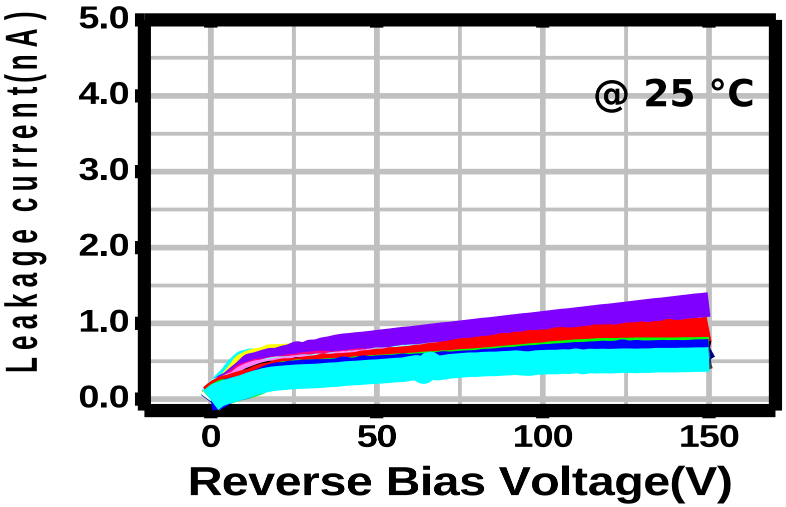


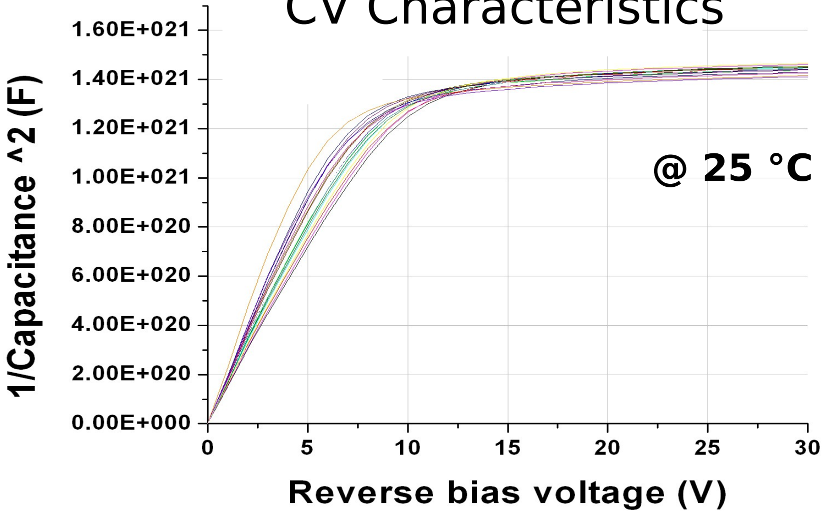
figure b



IV Characteristics

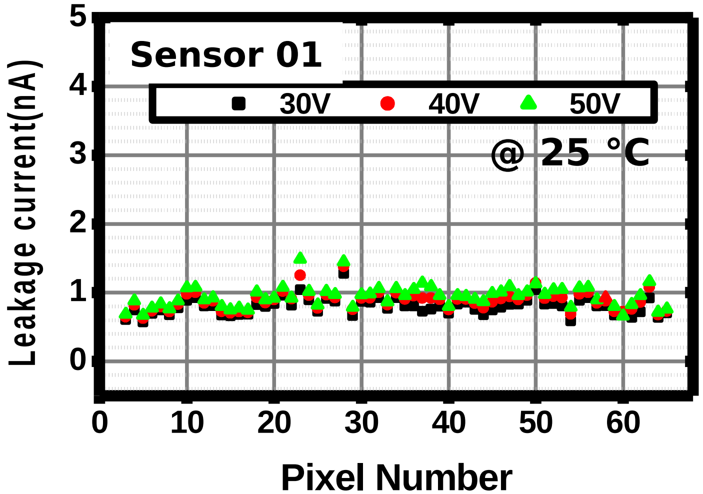


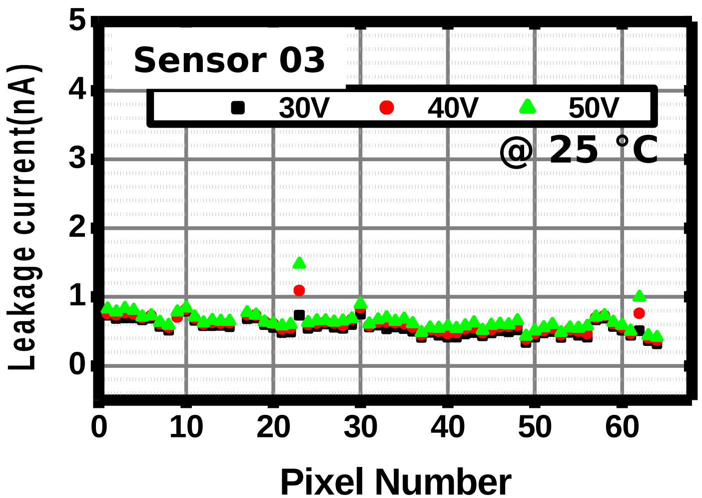
CV Characteristics



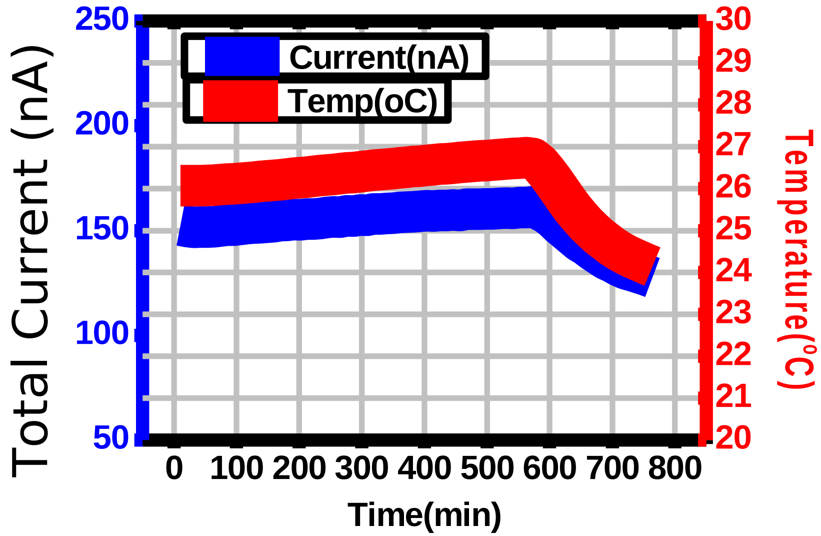
Silicon Charge Detector - Sensor

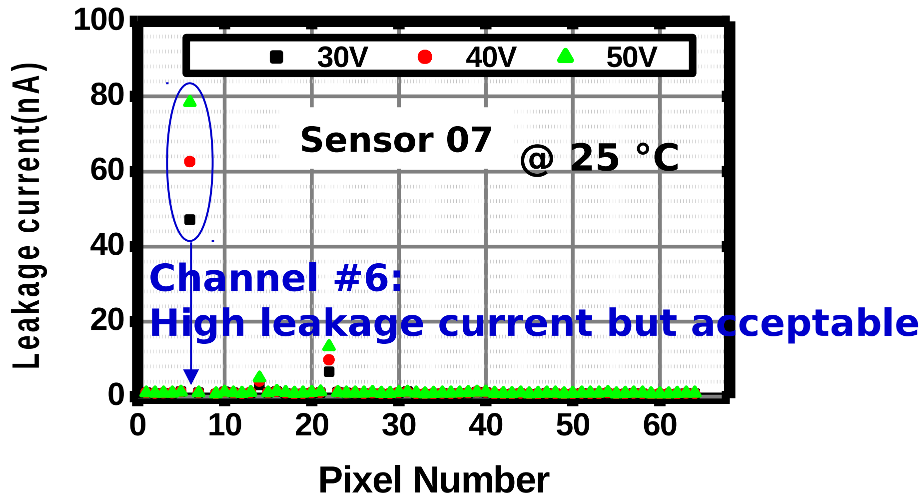
Leakage current distribution within a sensor





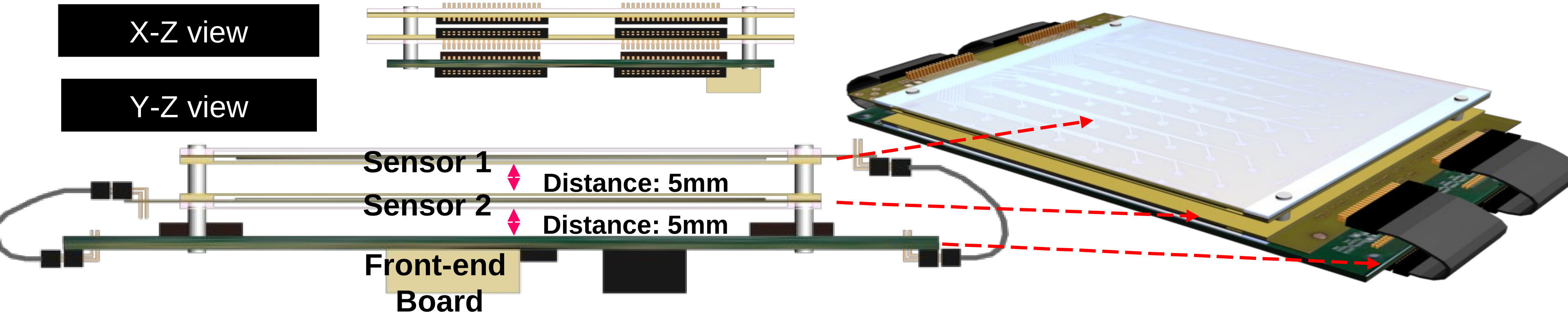
Leakage current Stability test during 12hours (sensor 07)

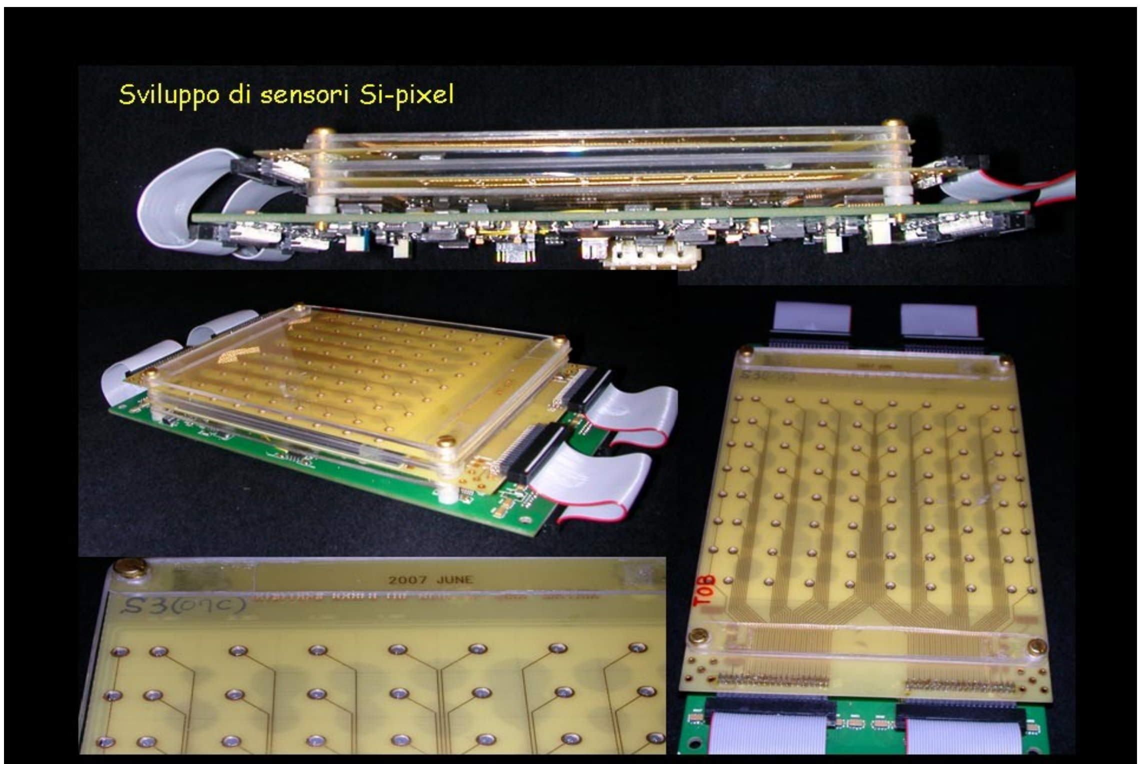




Silicon Charge Detector – Basic Detector Module

Basic module: one pair of aligned sensors + front-end (VAB) board



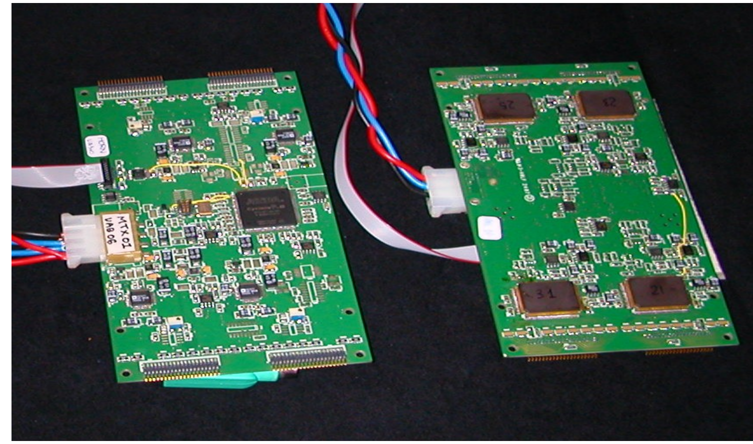


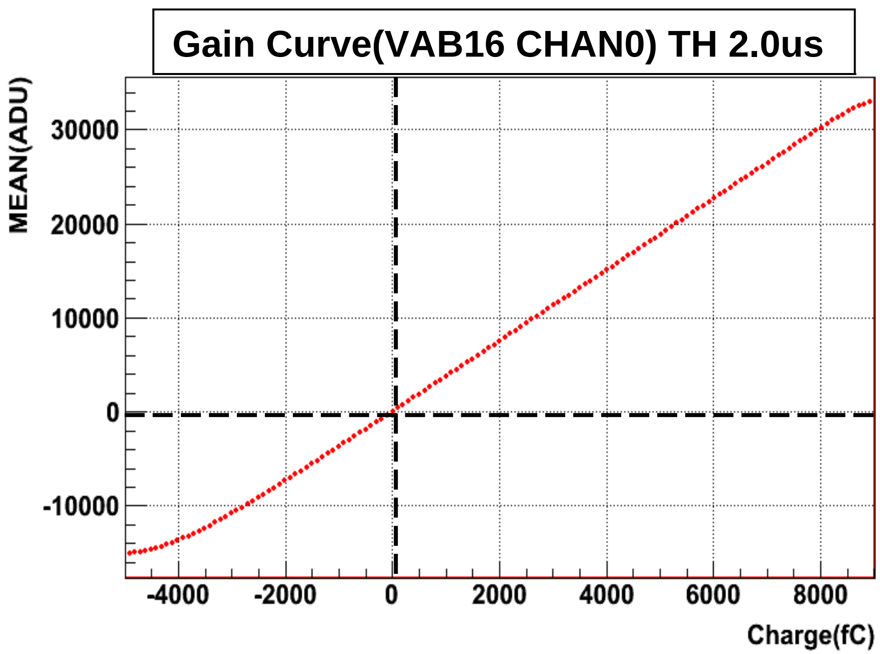
Basic Module tested at GSI in 2010 end at Cern in 2011,2012 and 2013

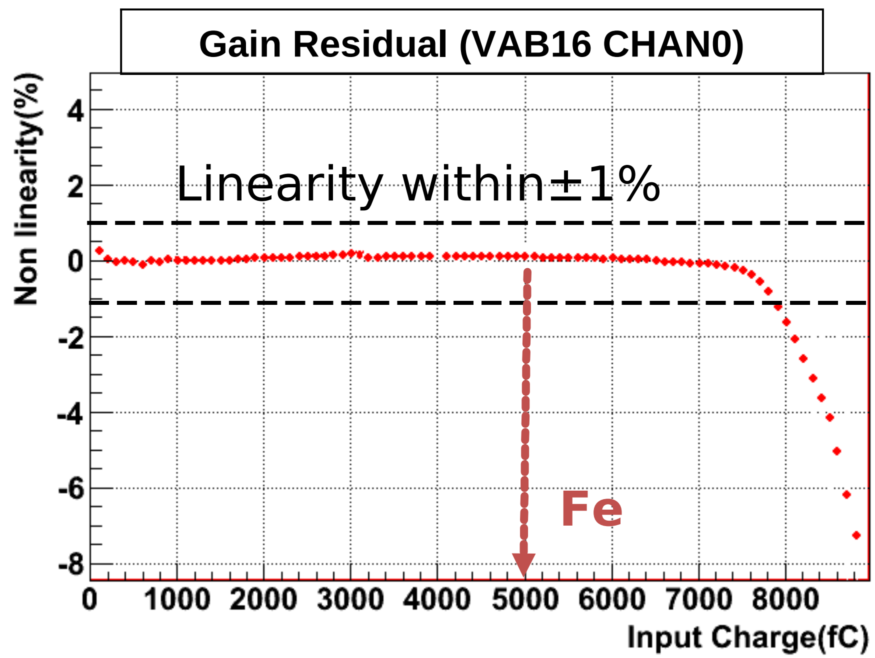
Silicon Charge Detector - Electronics

VA Board

- Large dynamic range (~1000 MIP)
- Low-noise : 0.13 MIP (Board level)
- Low-power consumption : 1W
- Number of channels : 128
- 16bit ADC
- Gain Distribution: 3.4 ± 0.2 ADU/1fC

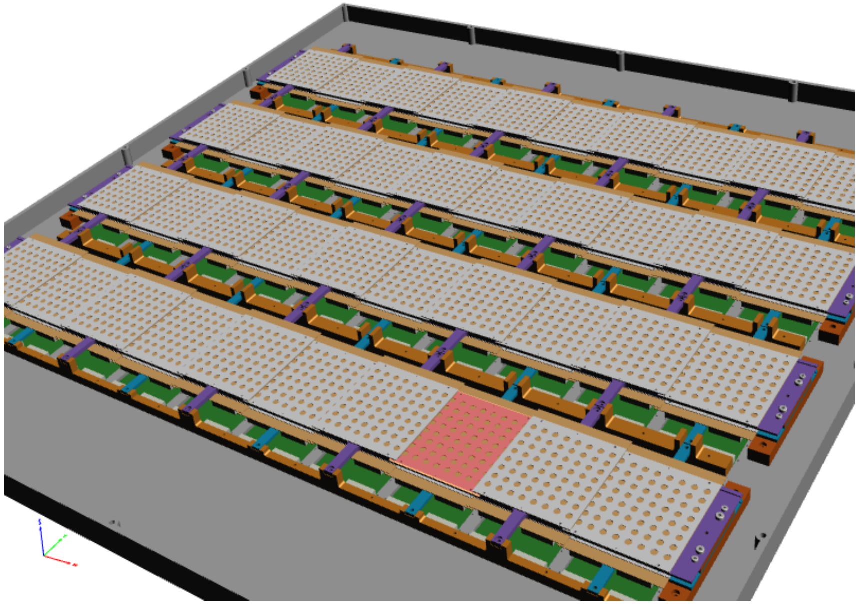




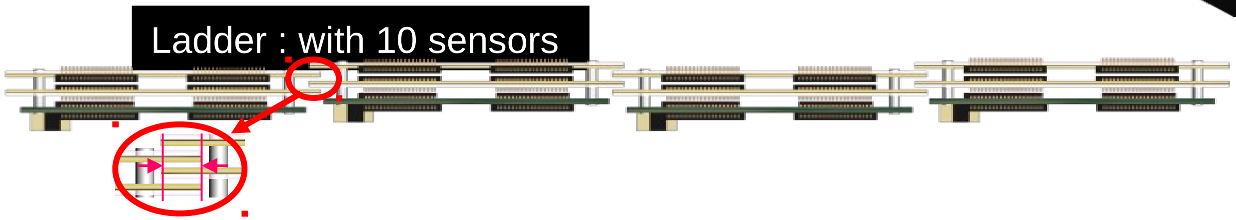


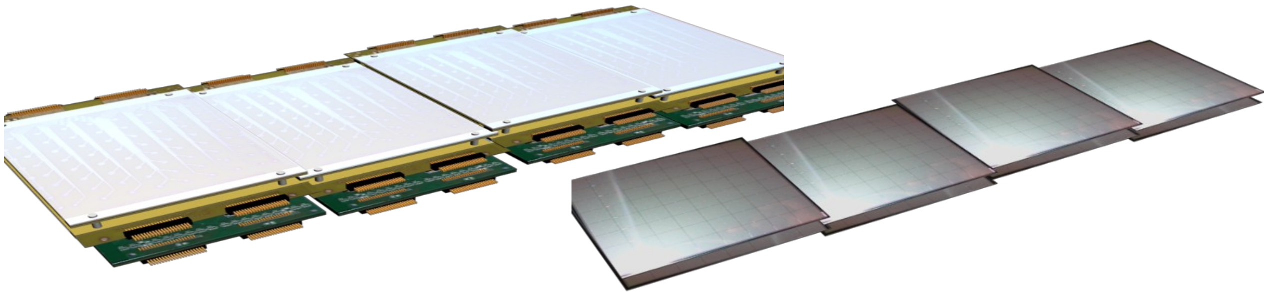
A LAYER structure for Gamma400 experiment (concept study)

The GAMMA-400 space mission is included in the long term Russian Federal program for space. The Goal is the observation of high energy gamma rays and the high energy electrons and positrons. But it can be used to measure also the nuclei flux using a charge identification



Lower layer with odd numbered ladders.
The upper layer is a complementary structure containing the even numbered ladders. The upper layer is mounted upside-down.
We obtain a seamless structure with no dead zones.

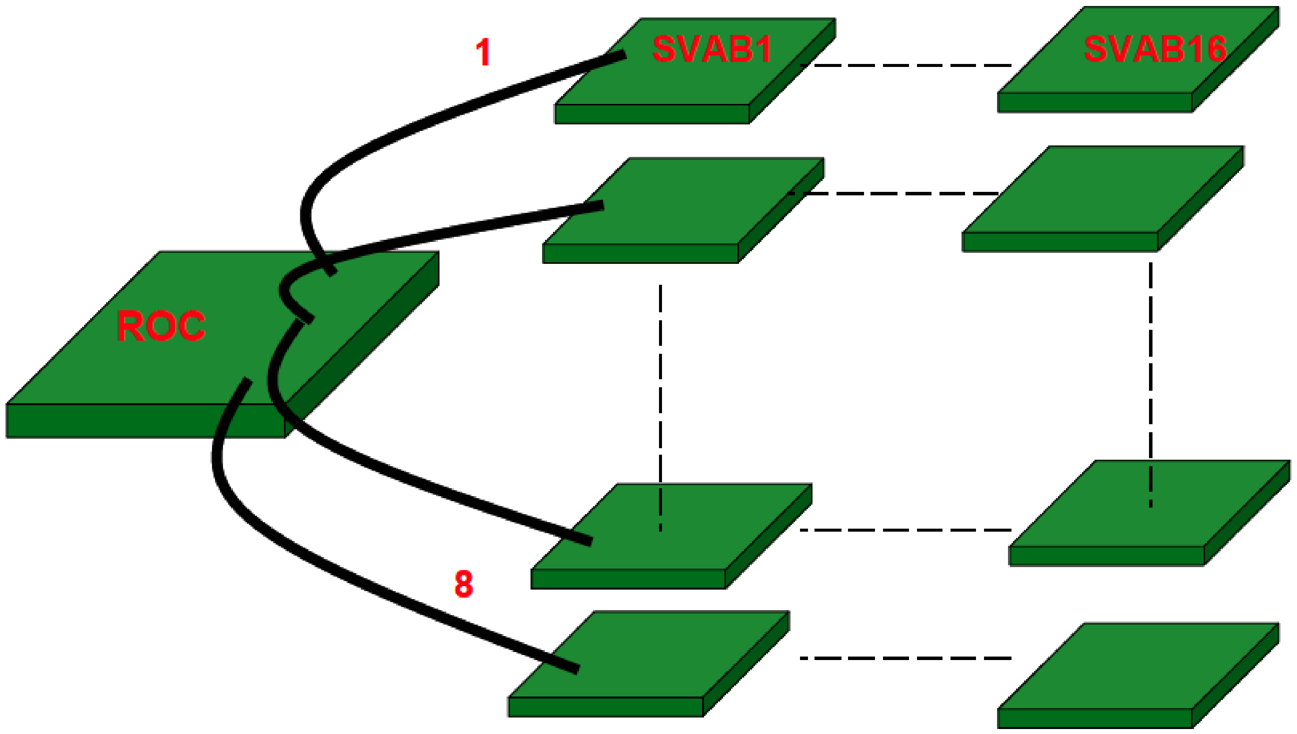




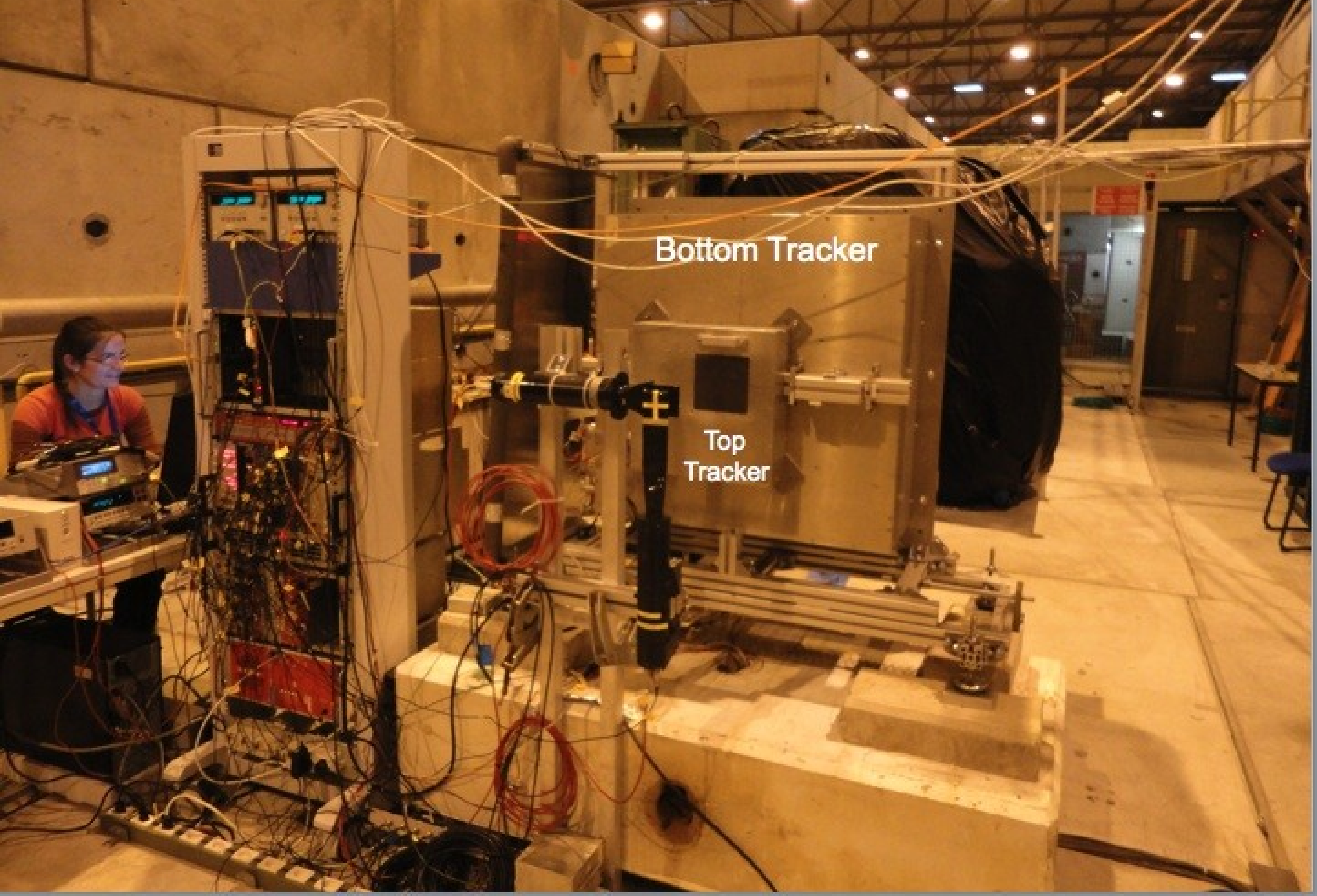
Silicon Array Readout Concept

ROC = ReadOut Controller: interface to main DAQ and trigger; reads up to 8 ladders

SVAB (Space VA Board) ROC board (up to 16 units in a ladder).

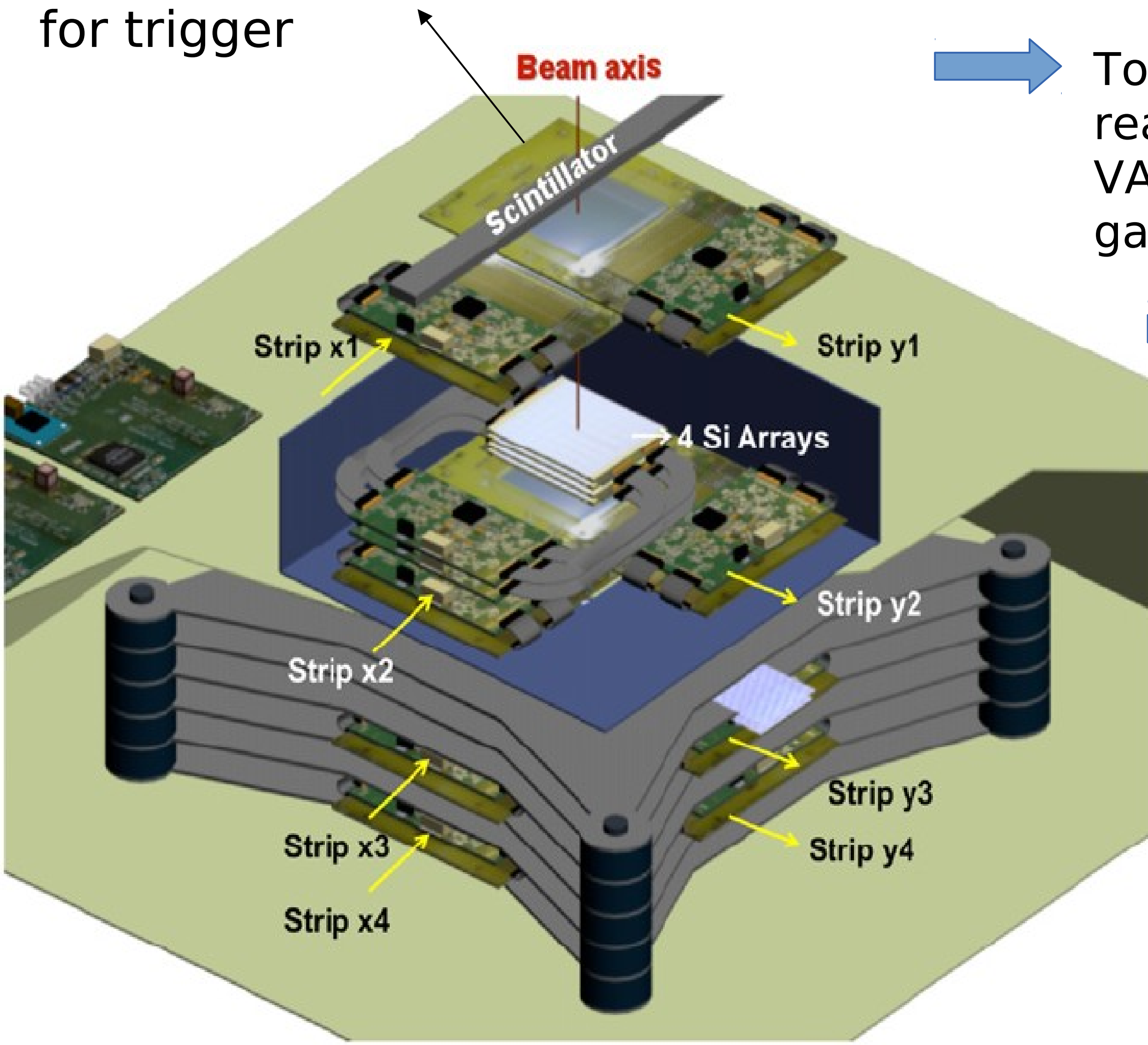


Beam Test Experimental Set Up at Cern



Beam tracker layout– CERN 2013

Coincidence of 2 scintillators for trigger

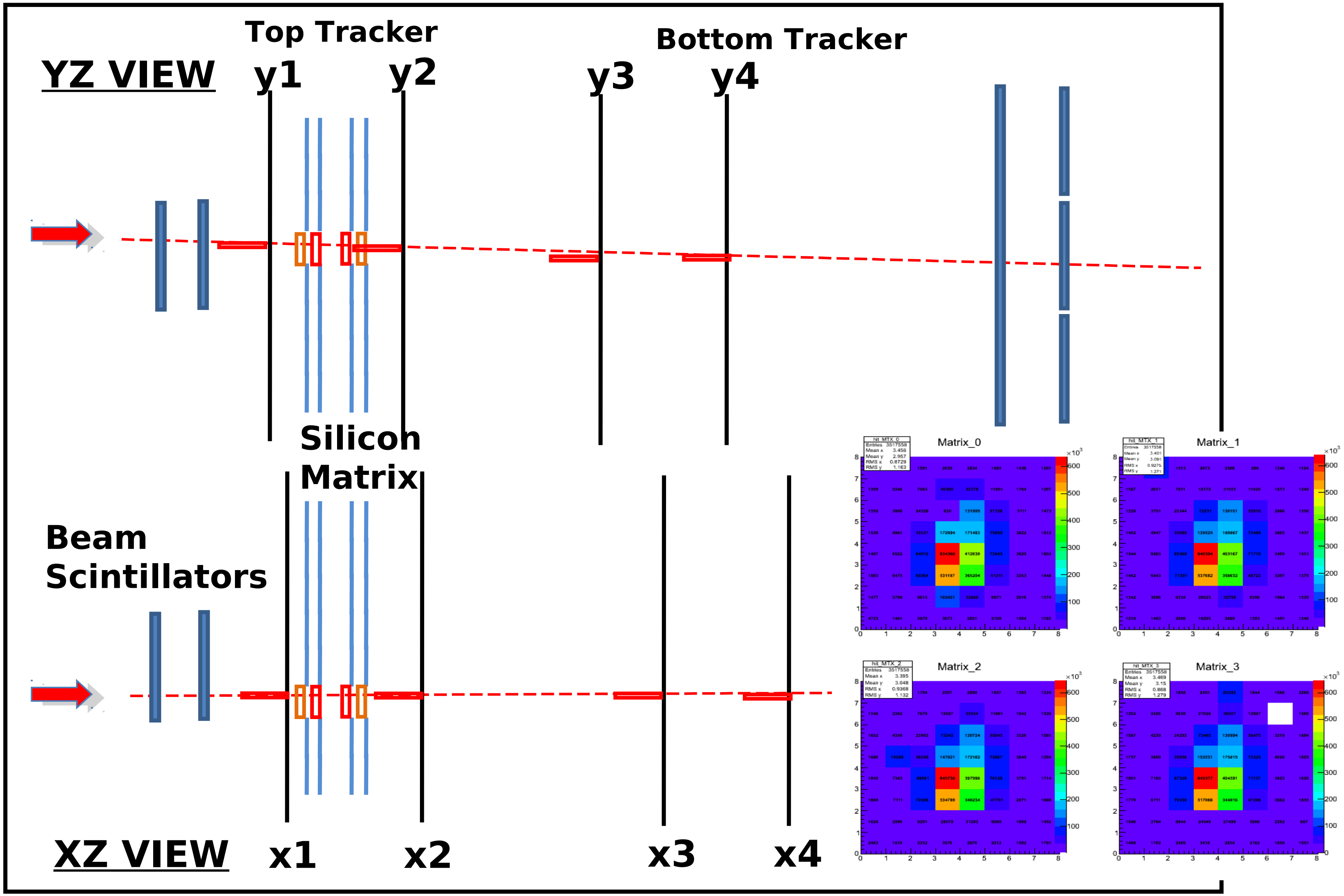


- 8 layers of strip sensors to measure 4 (x,y) coordinate
- To reduce the number of readout channel for matching VA Board, every 4 strips are ganged to a readout channel
- The original pitch of the strip is 183μm and the final pitch is 732μm whereby the position resolution is close to 200 micron.
- 4 Matrix sensors are placed consecutively to obtain a good charge identification.

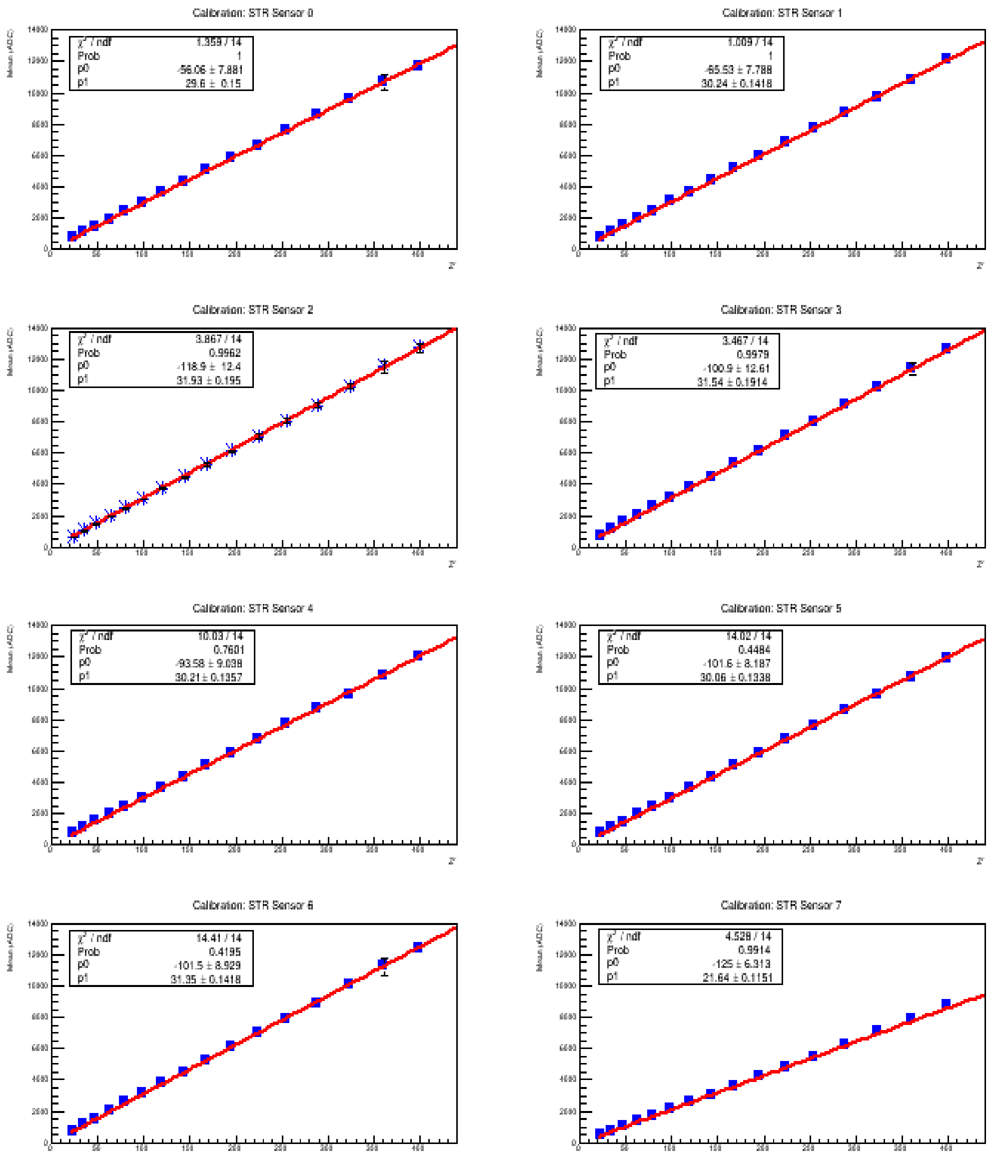
Analysis of Beam Tracker data – CERN 2013

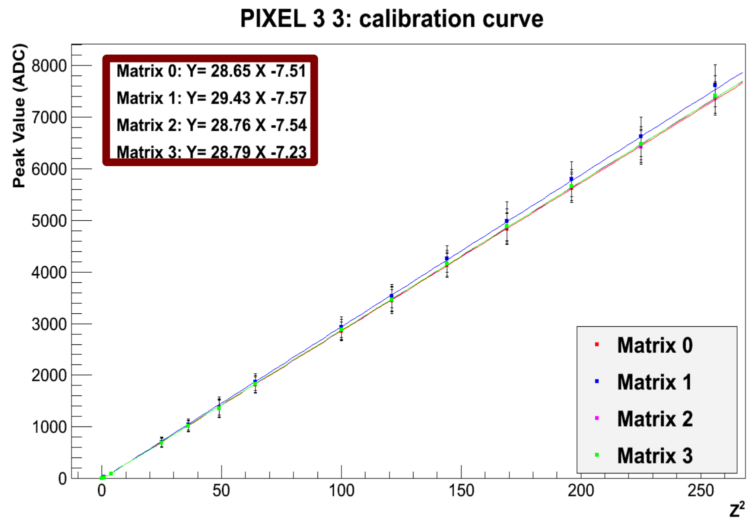
- **Tracking**:
  - Internal tracker alignment between strip sensors
  - Chi-square cut on track reconstruction
- **Rejection of interactions in the beam tracker:**
  - Average of 1° and 2° (before MTX) vs. average of 7° and 8° strip layers
- **Charge tagging**:
  - After calibration: use all available dE/dx measurements (up to 4 MTXs + 8 STRIPS)

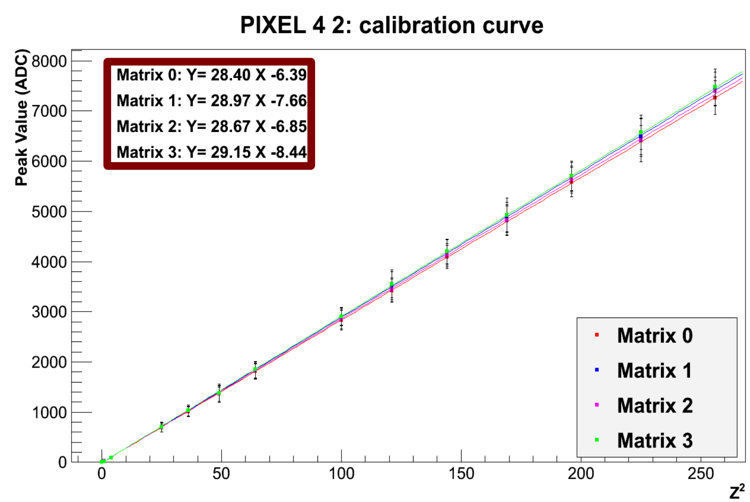
TRACKER LAYOUT at the CERN Jan-Feb 2013: ion beam test (H8)



CALIBRATIONS OF MATRIX AND SILICON STRIPS

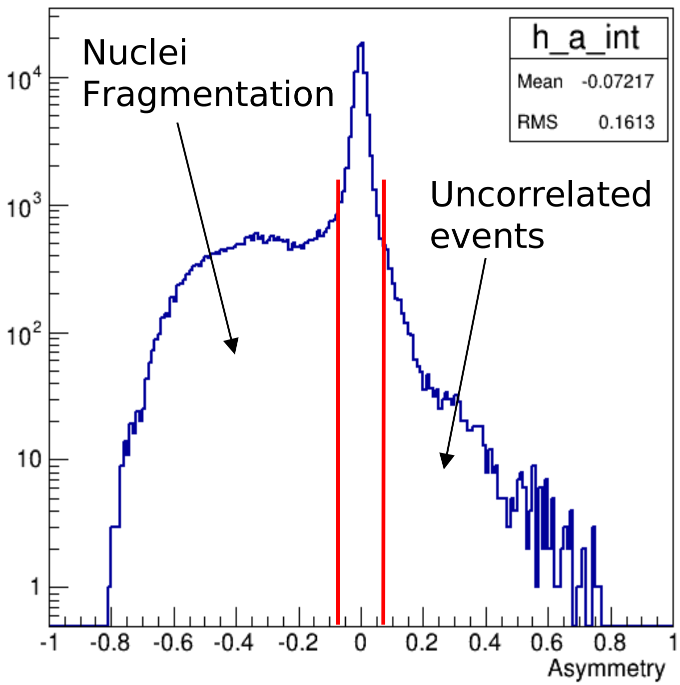






Rejection of the interactions taking place in the beam tracker

T = average of 1° and 2° strip layers(before MTX);
B = average of 7° and 8° strip layers (after MTX);

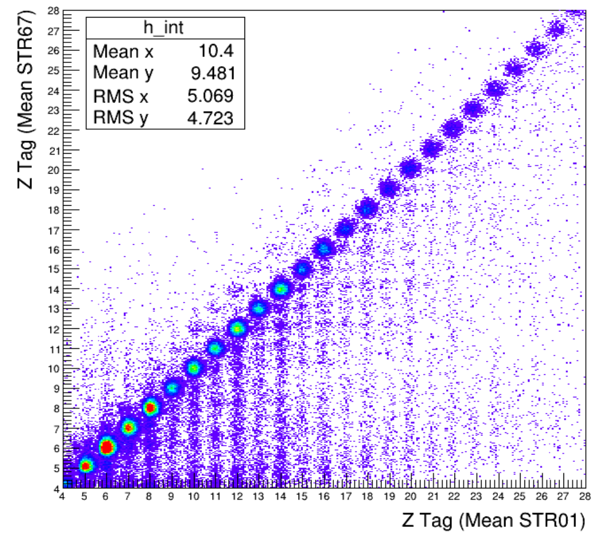


Cut on the asymmetry
A = (B-T)/(T+B)

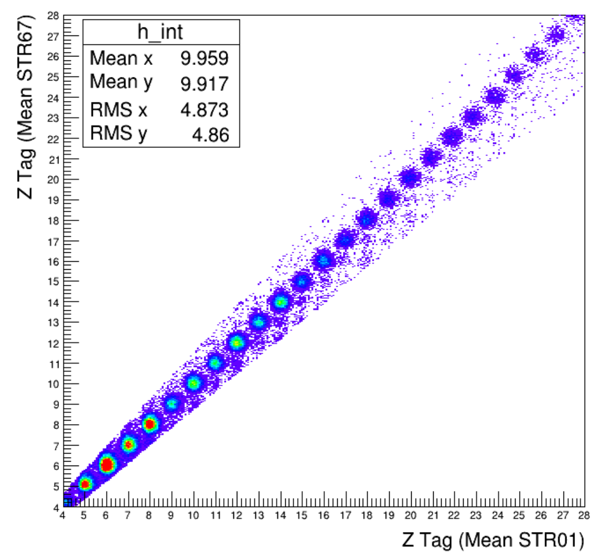
Non interacting nuclei have A = 0

This cut involves ONLY silicon STRIP layers

BEFORE CUT



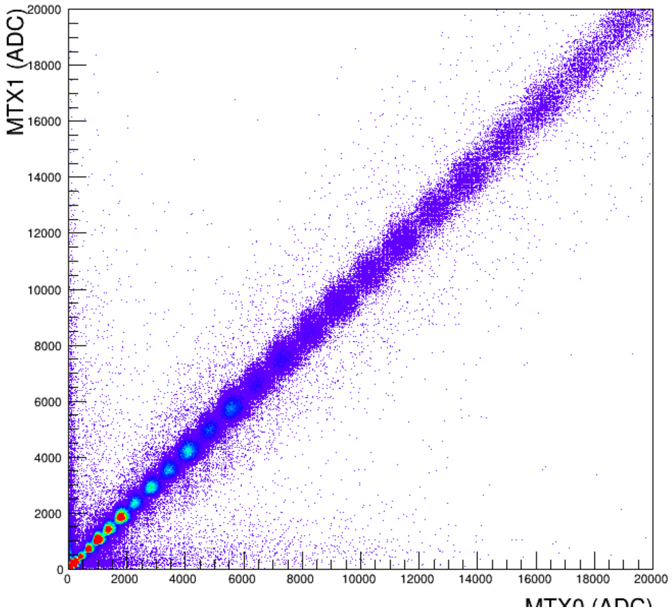
AFTER CUT



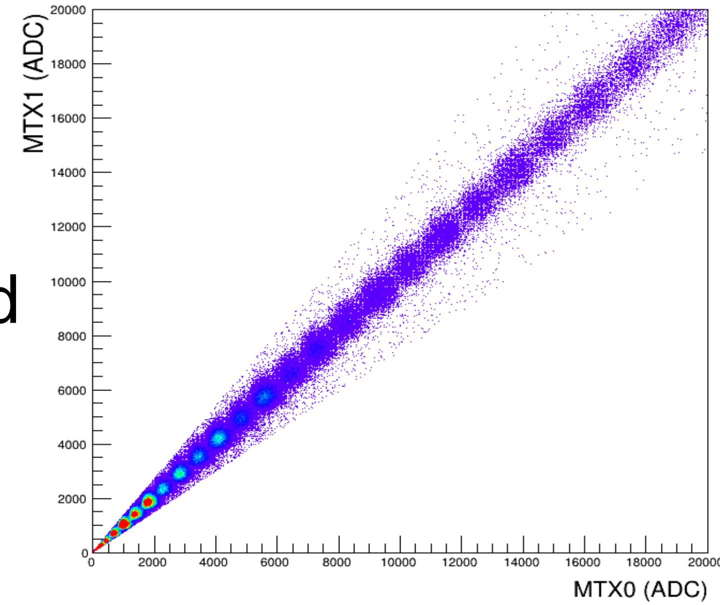
Selected events between -0.07 to 0.07

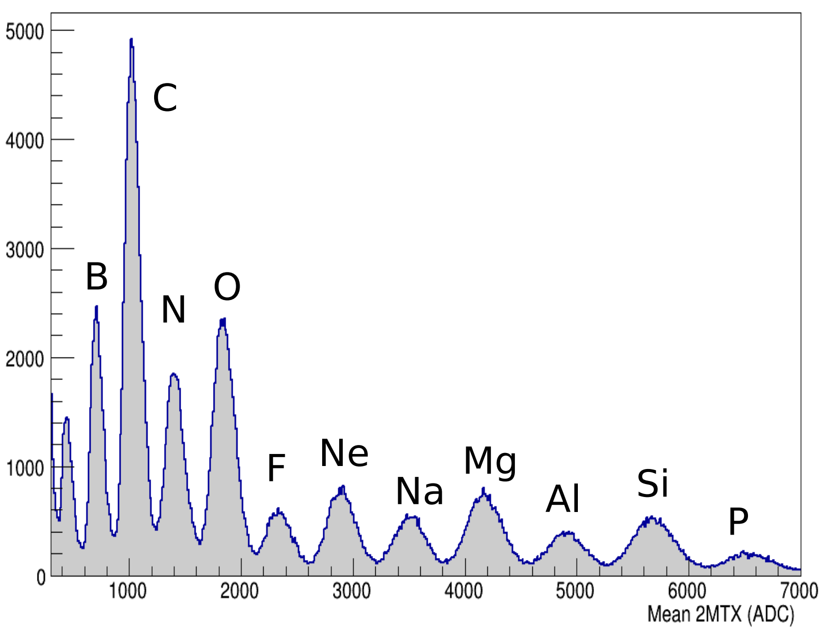
<u>Efficiency of the cut in the tracker selection:</u>
0.731

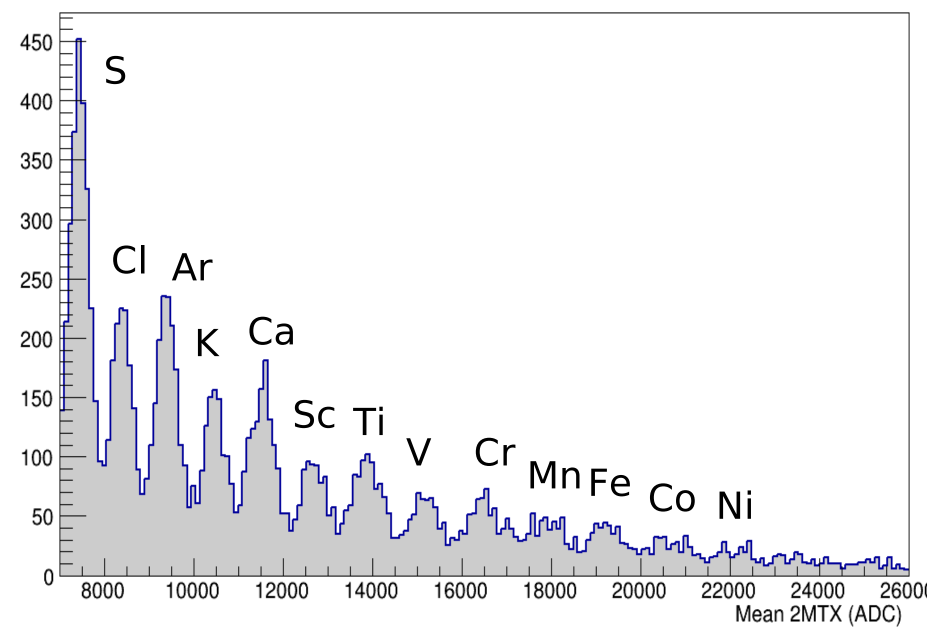
Analysis using 2 Matrix sample



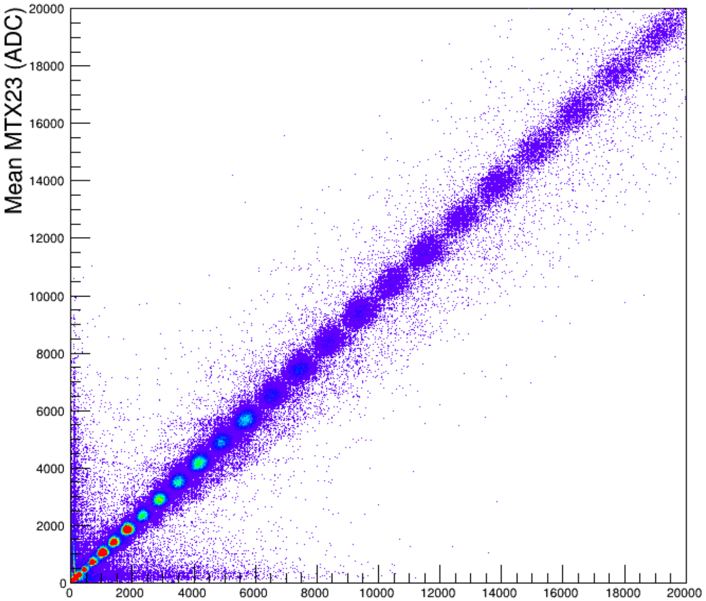
Remove of uncorrelated events



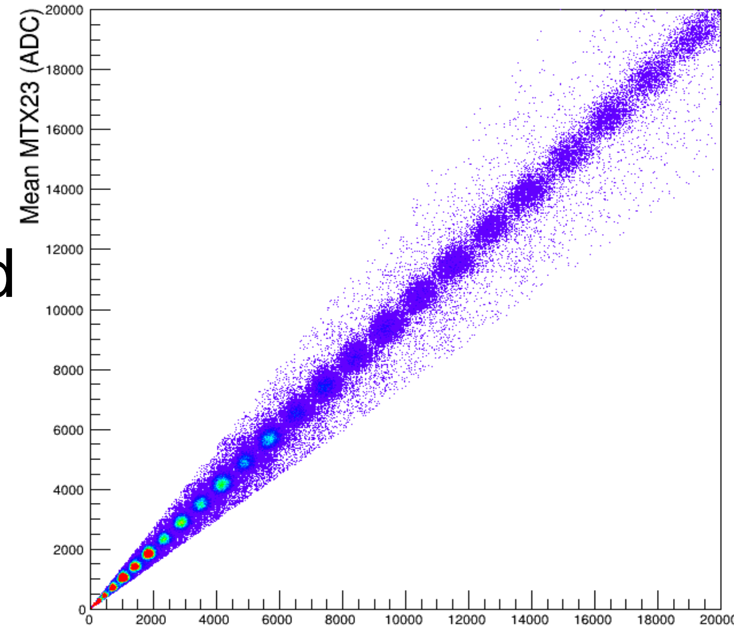


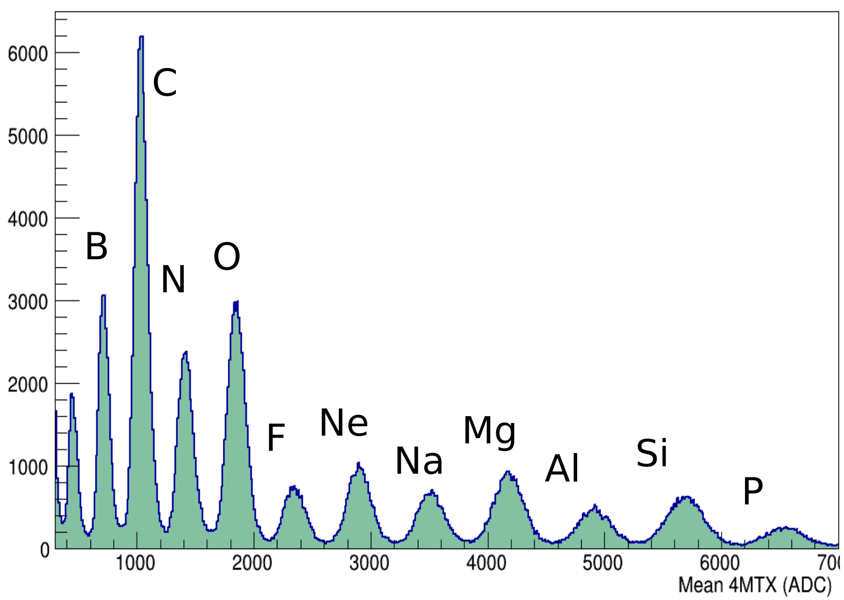


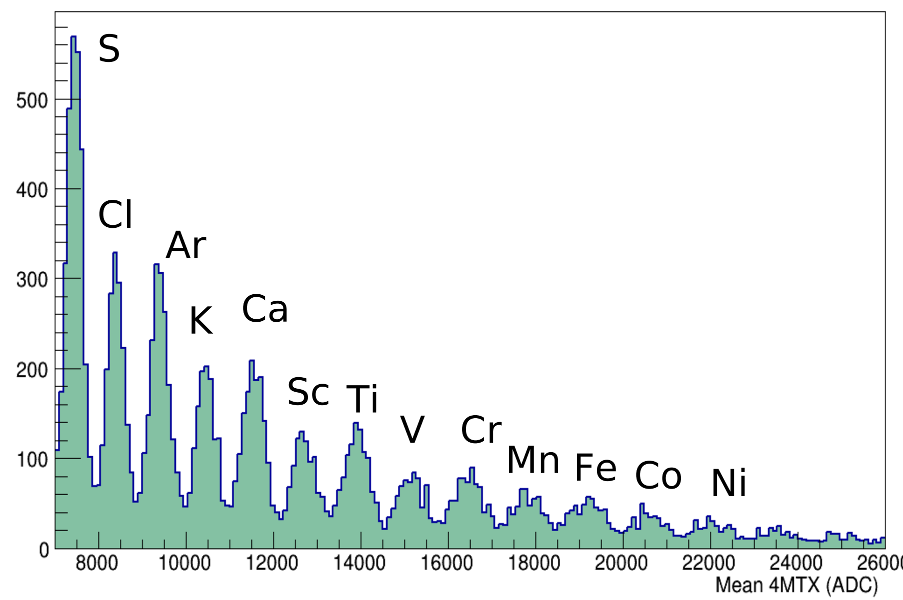
Analysis using 4 Matrix sample



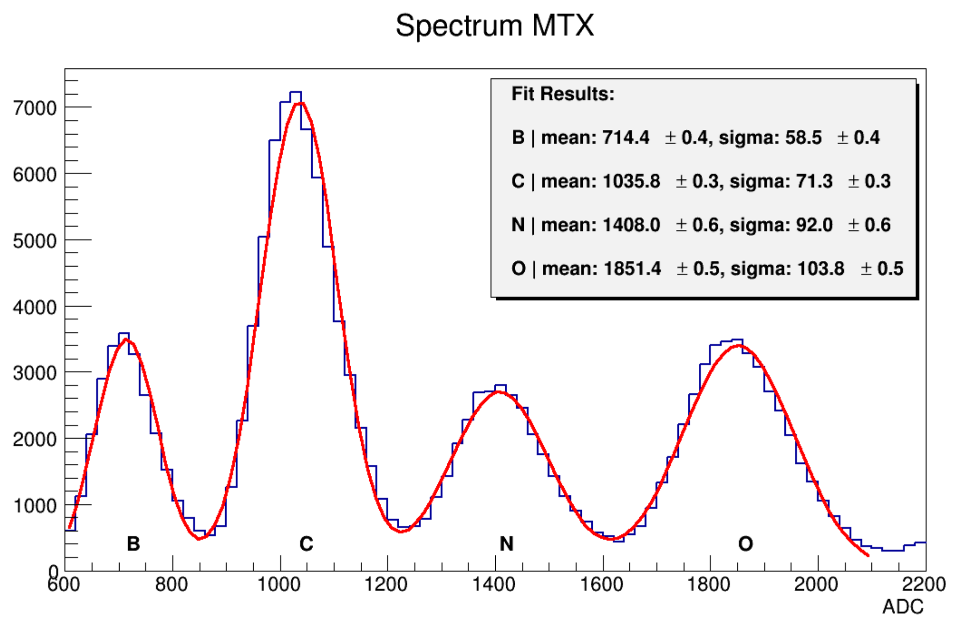
Remove of uncorrelated events







Charge resolution at BCNO group



Mean of 2 Matrix

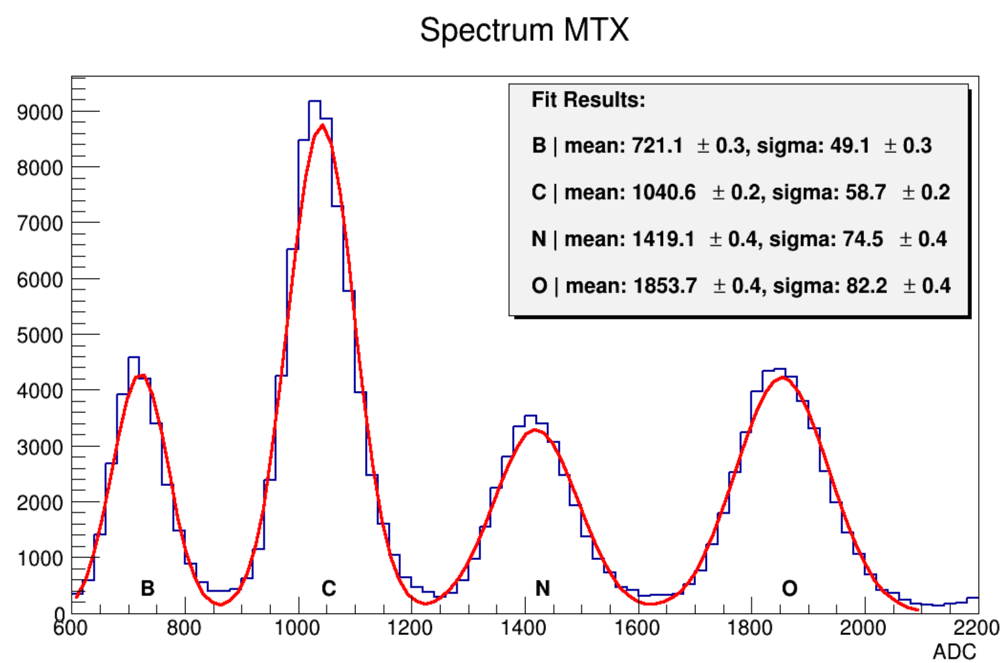
Charge Resolution

$$\Delta Z = \frac{\sigma_Z}{\mu_{Z+1} - \mu_Z}$$

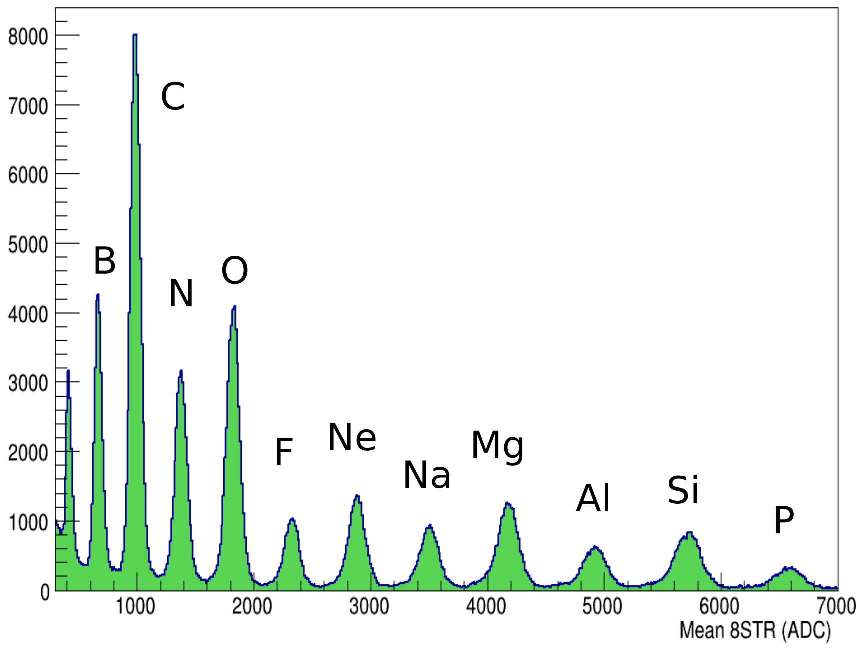
Δz at B ≃ 0.18

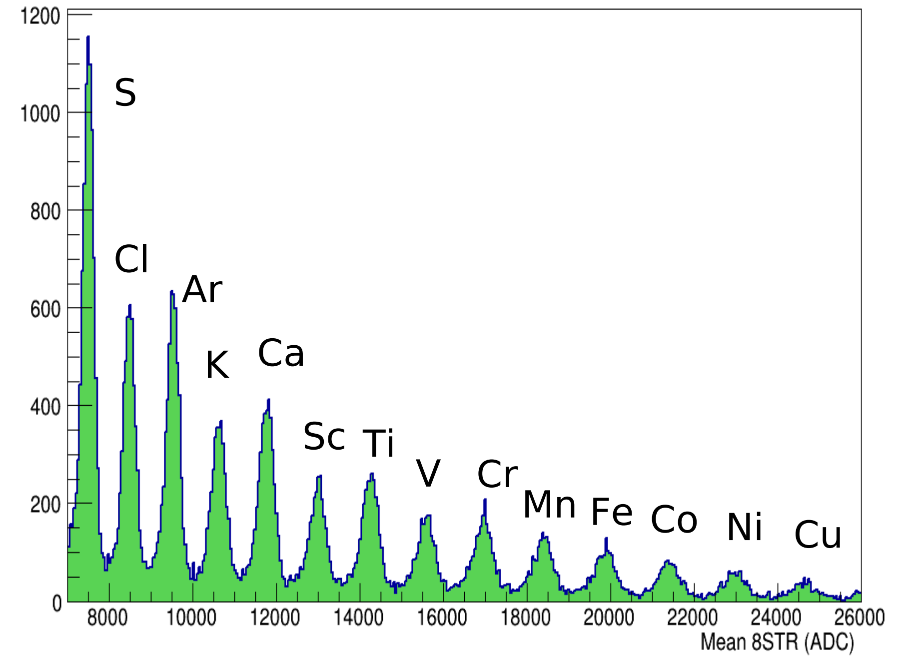
Mean of 4 Matrix

Δz at B ≃ 0.15



Beam tracker charge selection based **only on 8** silicon strip dE/dx samples



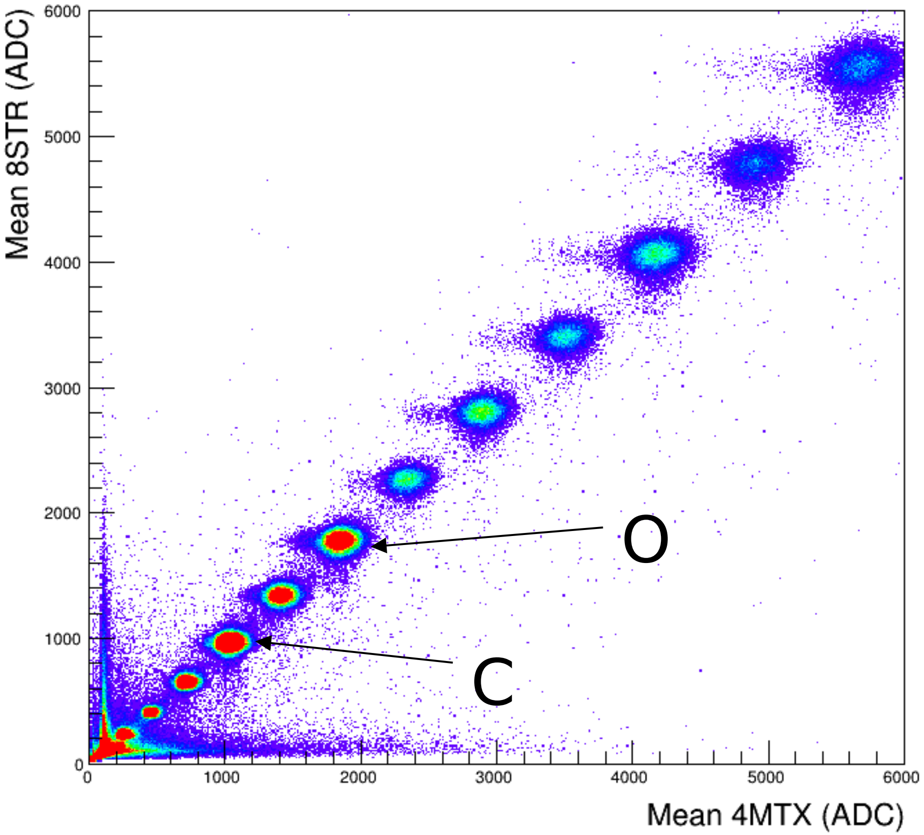


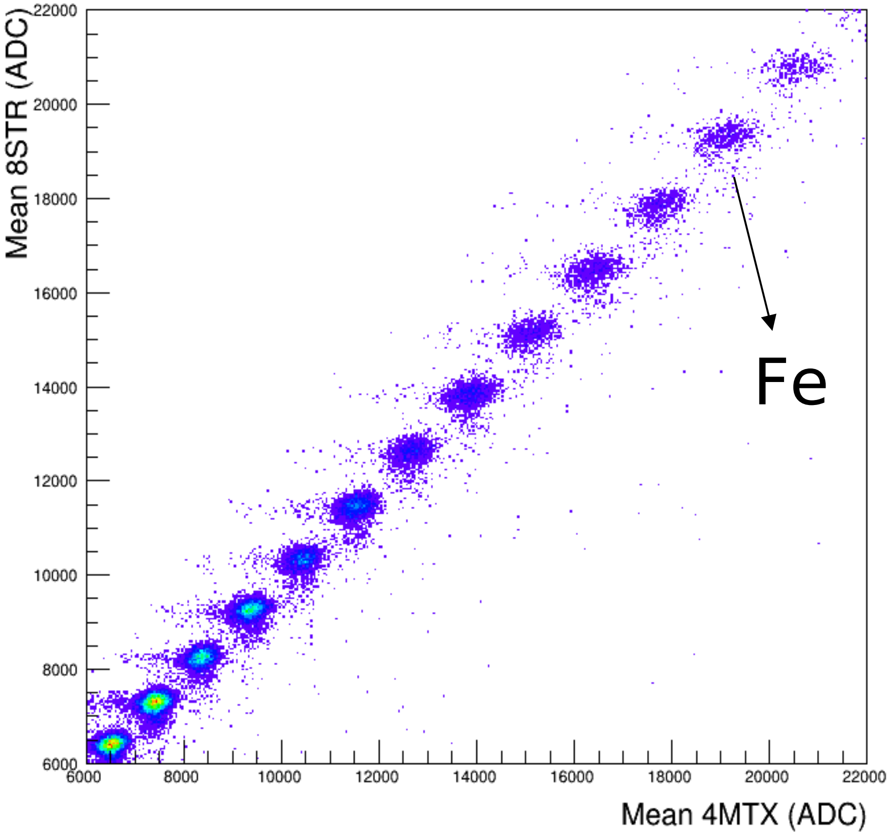
After a cluster reconstruction in STRIP, for each strip plane we get the maximum cluster truncated (max ± 1 strip)

Using 8 dE/dX we obtain a good charge resolution up to Ni demonstrating that Silicon Strips are not useful only for tracking but also for charge identification

BEAM TRACKER CHARGE TAGGING

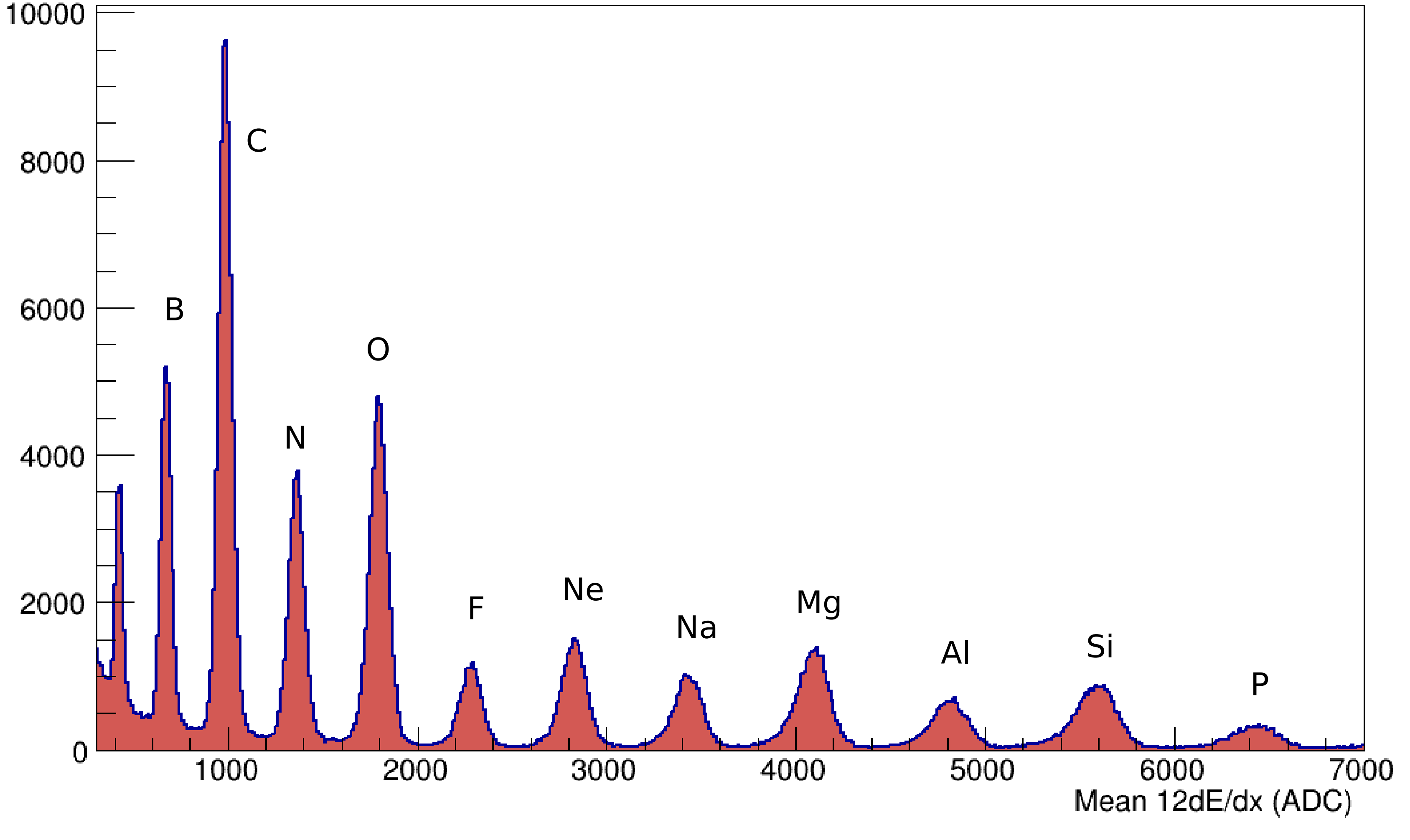
Average of 8 dE/dx measurements with STRIPS vs.
Average of 4 dE/dx measurements with silicon MATRIX



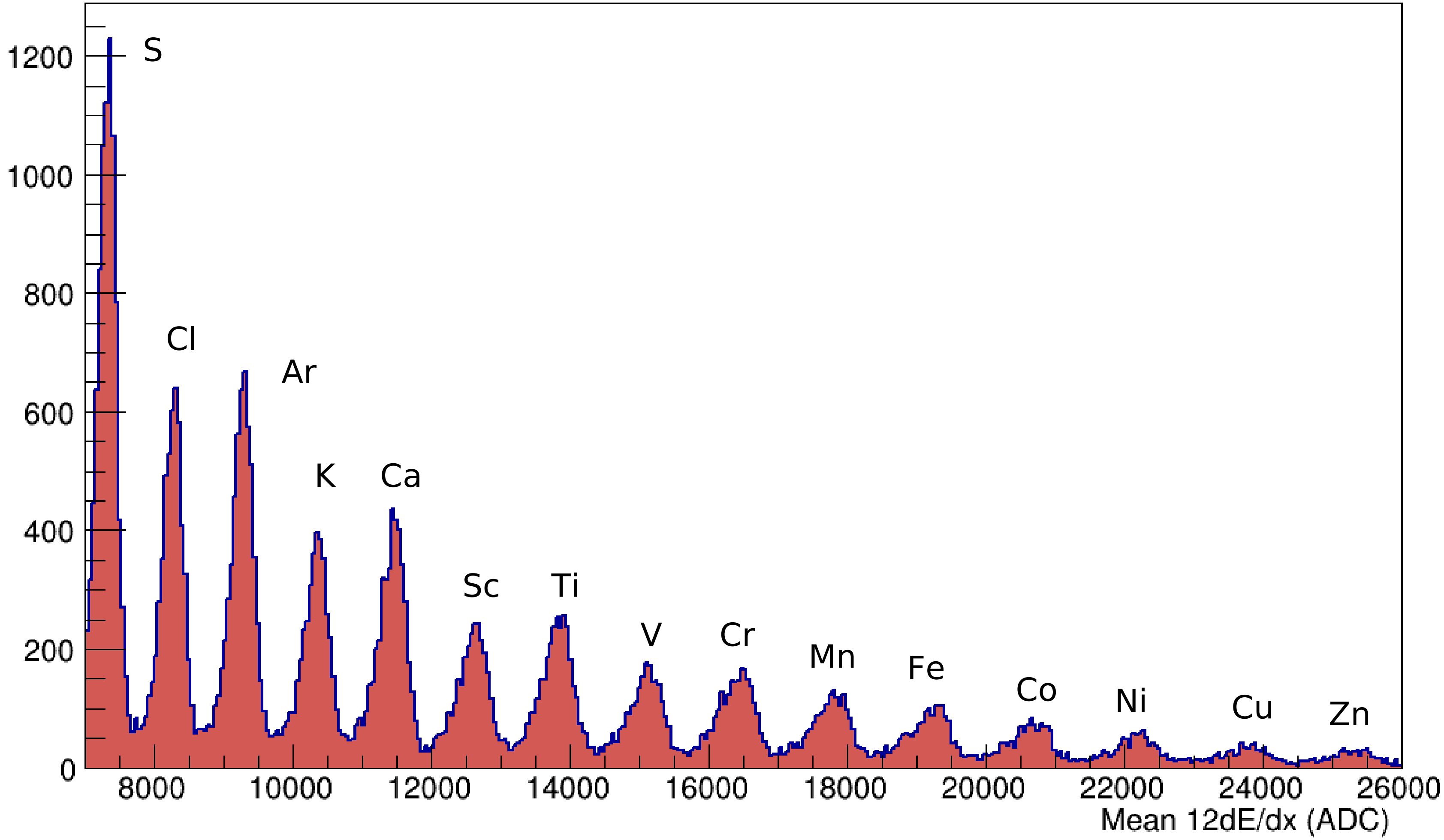


Using correlation between STR and MTX we obtain a good separation between nuclei

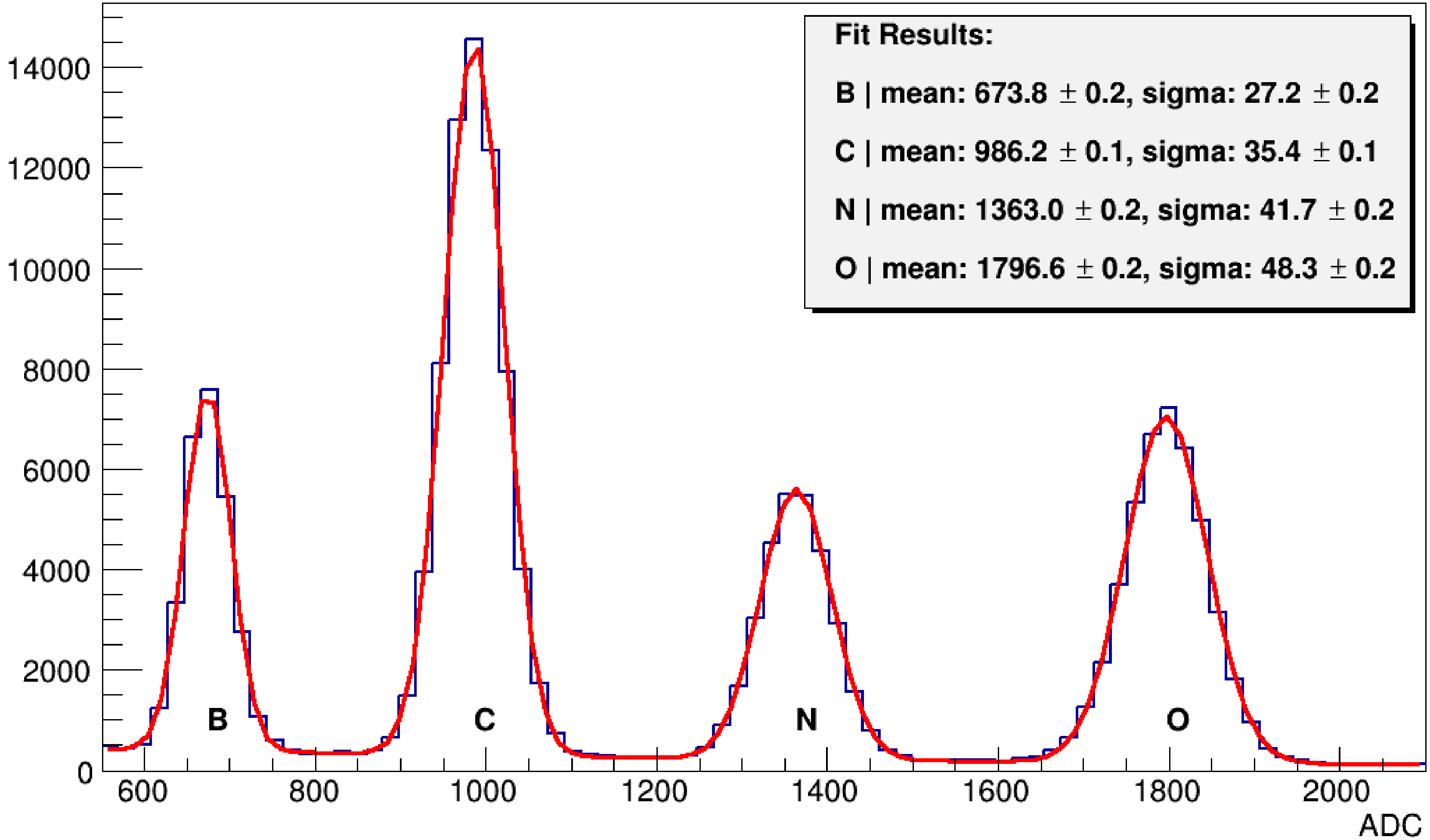
Beam tracker charge selection based on **8 silicon strip + 4 MTX** pixels dE/dx samples



Beam tracker charge selection based on **8 silicon strip + 4 MTX** pixels dE/dx samples

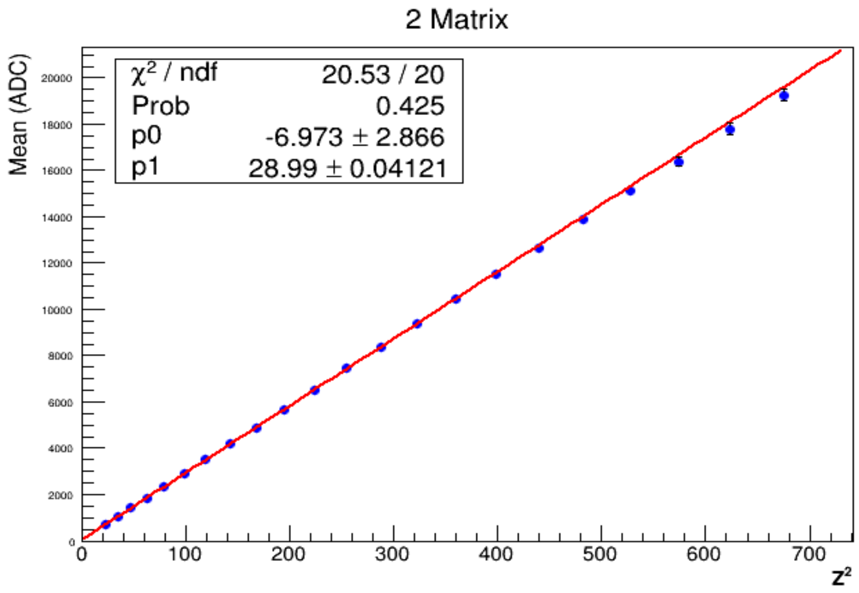


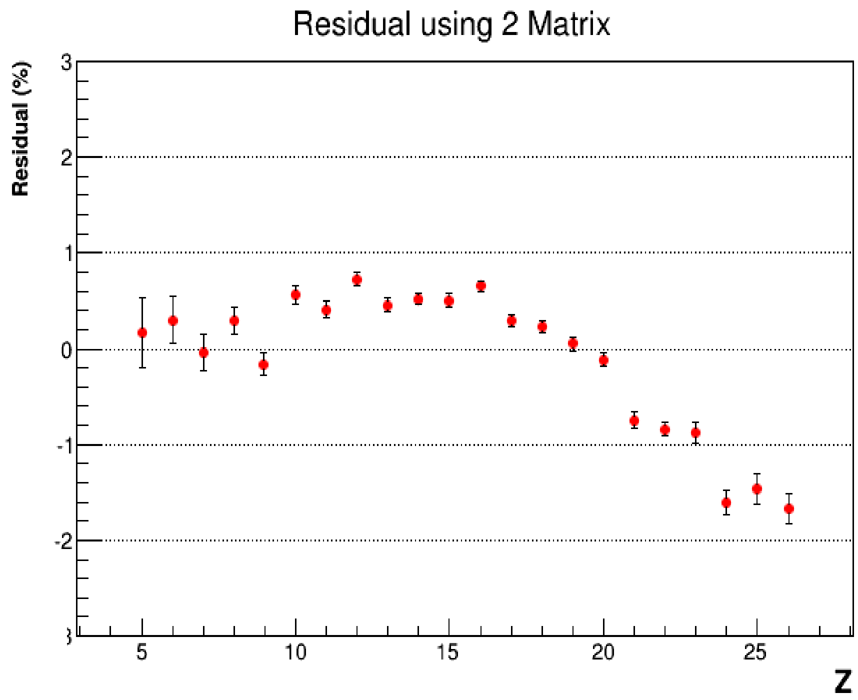
Charge measurement **from the tracker** using 12 dE/dx samples = 8 strips + 4 pixels

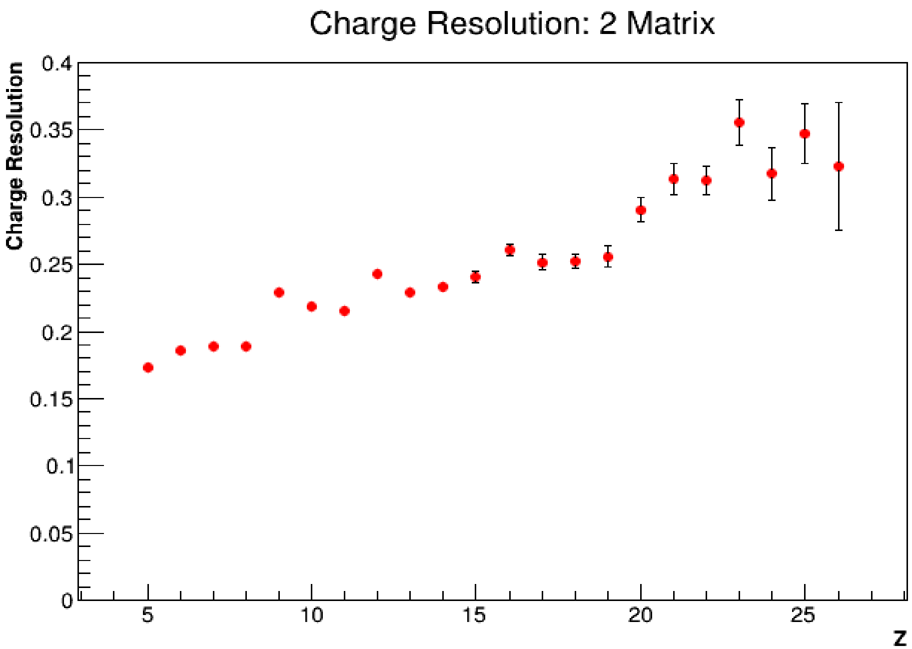


Δz at B $\backsimeq$ 0.09

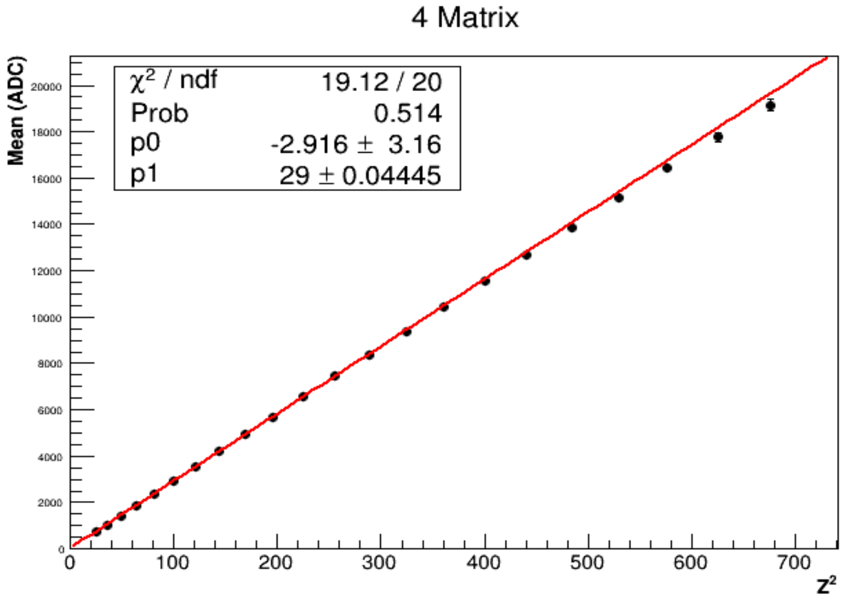
MATRIX RESULTS USING 2 MATRIX DETECTORS

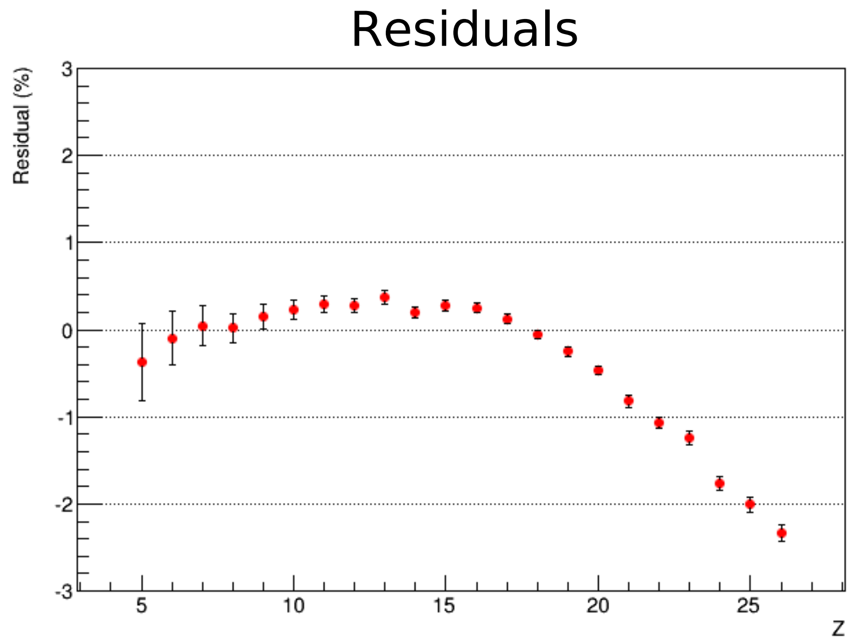


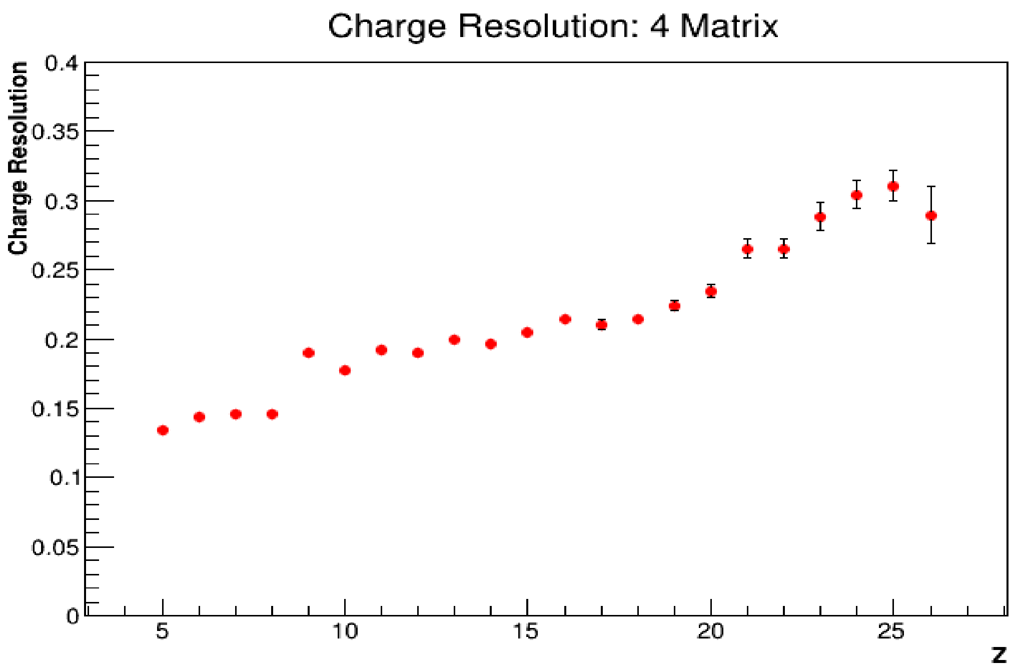




MATRIX RESULTS USING 4 MATRIX DETECTORS







SUMMARY

1) The instrument prototype and associated electronics were capable to provide an excellent charge identification of relativistic nuclei.

2) The dynamic range of the front-end electronics was properly dimensioned to allow a linear response of the system up to the largest charges under test.

3) The correlation of the signals from two layers of Si arrays, placed at different depths in the telescope, is proved to be a powerful tool to identify nuclei interacting in the detector material and allowed to reject them in the data analysis.

4) Moreover – by combining the response of two separate layers of a Si array – an excellent charge resolution in the range of 0.18–0.30 was achieved from Boron to Carbon