Investigation of silicon pixel sensors for the ALICE Inner Tracking System upgrade project

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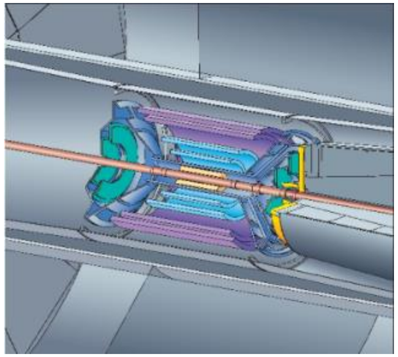
OUTLOOK

- ALICE ITS Upgrade
- ALPIDE silicon sensors
- Beam test at CERN PS
- Radiation hardness test at the cyclotron U120-M in Rez
- Development software for the setup at the cyclotron

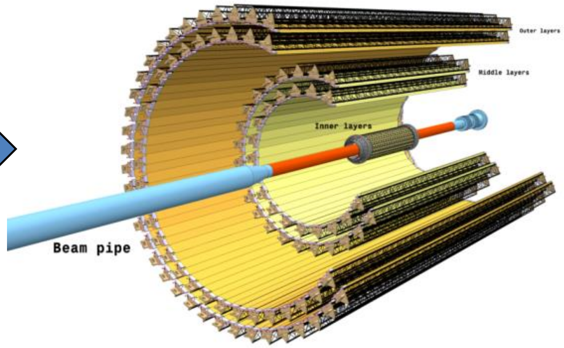
ALICE ITS Upgrade

By 2019-2020 ALICE plans to upgrade its Inner Tracking System detector, the purpose of this upgrade is:

- Improve impact parameter of the resolution of tracks by a factor of 3(5)
  - First layer closer to interaction point: 39 mm→23 mm
  - 6 layers → 7 layers
  - All layers are made of pixel detectors ALPIDE (based on MAPS tech.)
  - Reduction of material budget 1.14% X0 → 0.3% X0 for the three innermost layers
- Increase readout speed from 1 kHz up to 50 kHz (Pb-Pb) and 100 kHz(p-p)
- Fast insertion/removal for yearly maintenance



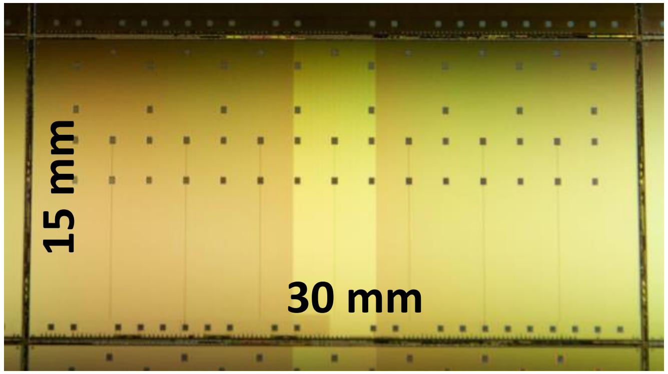
Current ITS



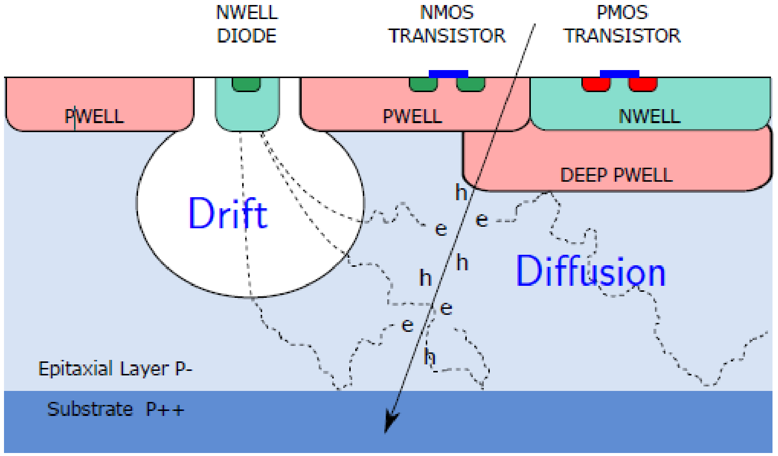
Modified ITS

Specification of ALPIDE

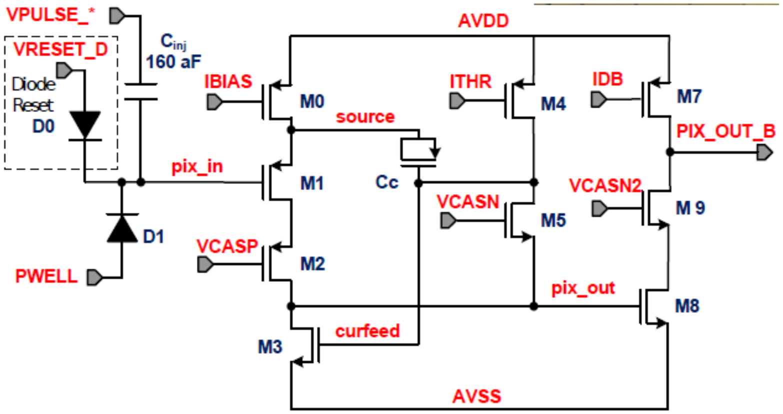
- Large silicon sensor (15 mm × 30 mm)
- 512 × 1024 pixels
- Pixel 27 μm × 29 μm
- Digital readout with priority encoder



Matrix of ALPIDE detector



Scheme of MAPS sensor



Scheme of Front- End circuit

Tasks for thesis

Based on PS CERN DATA **pALPIDE-3**

1. Analysis of beam test data, taken at PS CERN using inclined tracks:

   Comparison of cluster size, cluster shape for different pion energies and inclination angles.

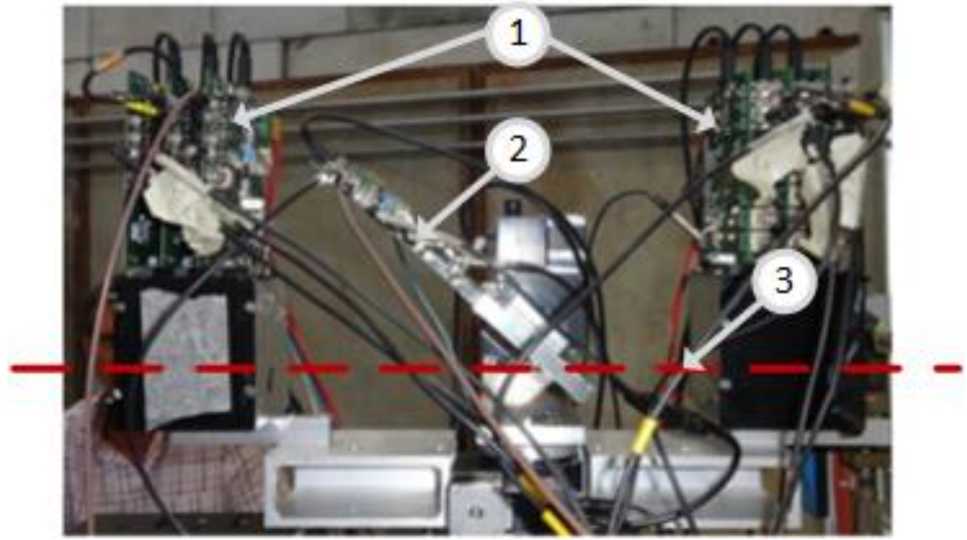
Based on cyclotron U-120M DATA **Final prototype ALPIDE**

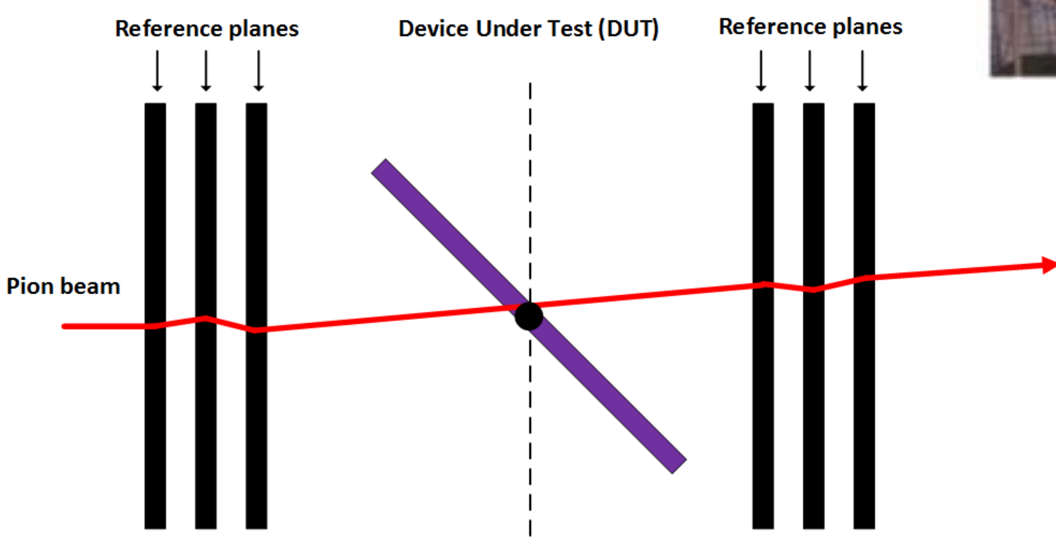
2. Characterization of irradiated ALPIDEs

3. Development of software for the setup at the cyclotron U-120M, Rez

1. Beam test at PS CERN

- Several pion beam campaigns with energies 250 MeV - 6 GeV for inclined track studies
- Tracking is done by a telescope consisting of 3+DUT+3 layers
- Readout and analysis is done using the Eudaq+EUTelescope framework



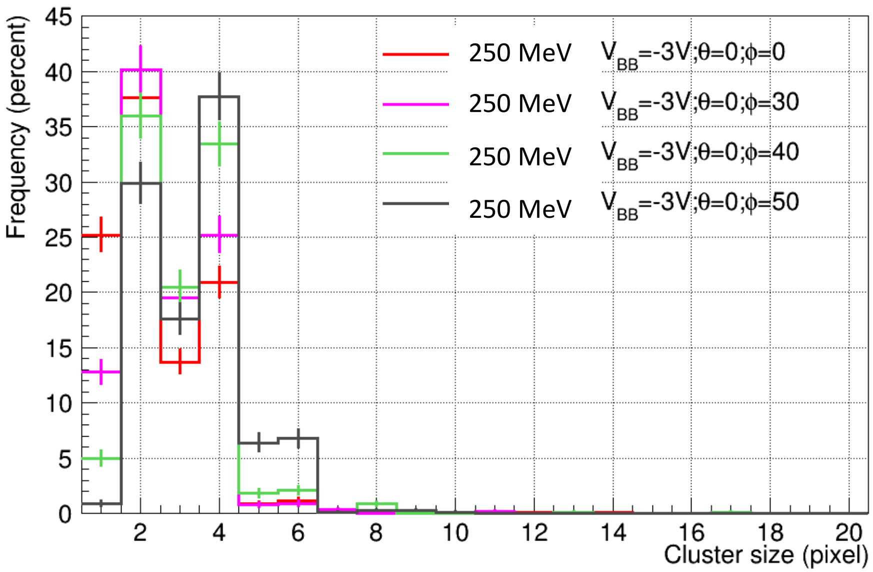


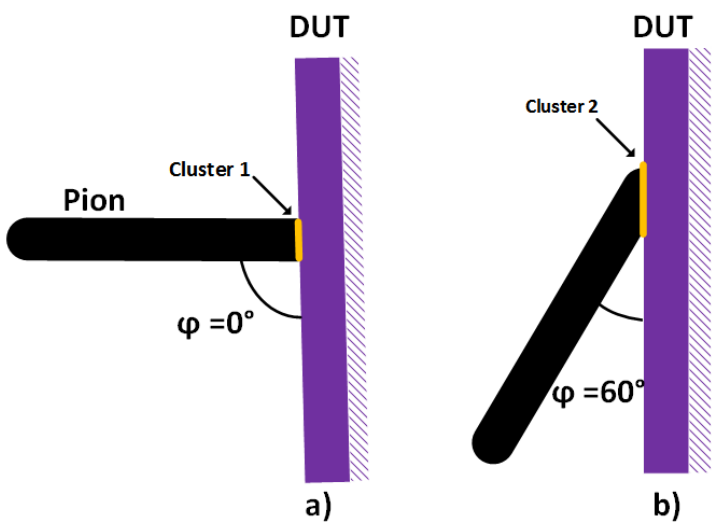
Telescope settings
1 – Reference planes (pALPIDE v2)
2 – Device under test (pALPIDE v3)
3 – Beam

1.1. Comparison of Cluster size 250 MeV vs. 6 GeV

Inclination angle	Mean of cluster size in pixels	
	Energy of the particles, 6 GeV	Energy of the particles 250 MeV
θ=0°, φ=0°	2.39	2.41
θ=0°, φ=30°	2.67	2.67
θ=0°, φ=50°	3.4	3.43

Normalized histograms of cluster size in pixels for 250 MeV π





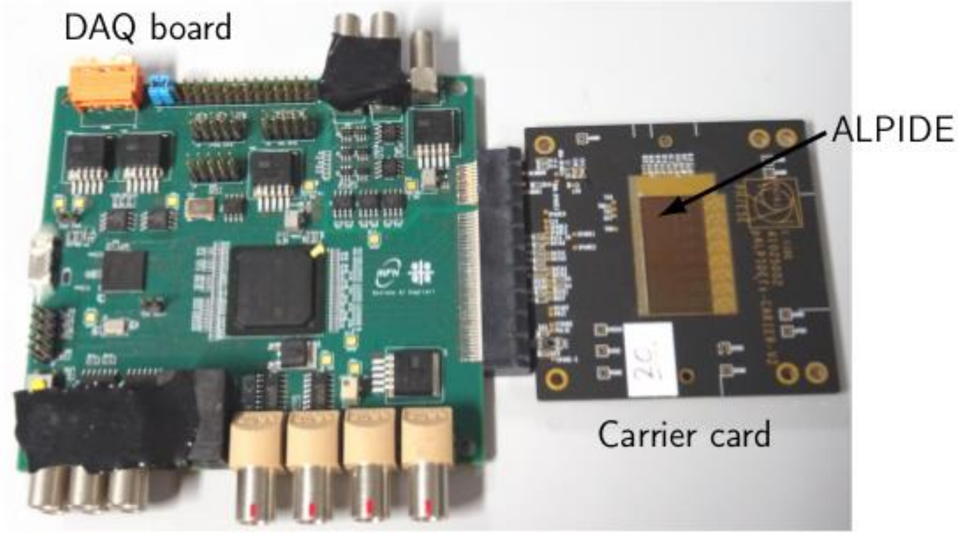
Cluster 2>Cluster 1

2. Study of radiation hardness of the ALPIDE chip

1. ALPIDE is irradiated at the cyclotron U-120M to study how properties of the chip change, when it is irradiated by given TID (Total Ionization Dose).

2. During processes of irradiation and regeneration following tests are done:

- Noise and threshold measurements
- Internal DAC scanning
- Analog and digital current supply



2.2. Parameters of cyclotron test

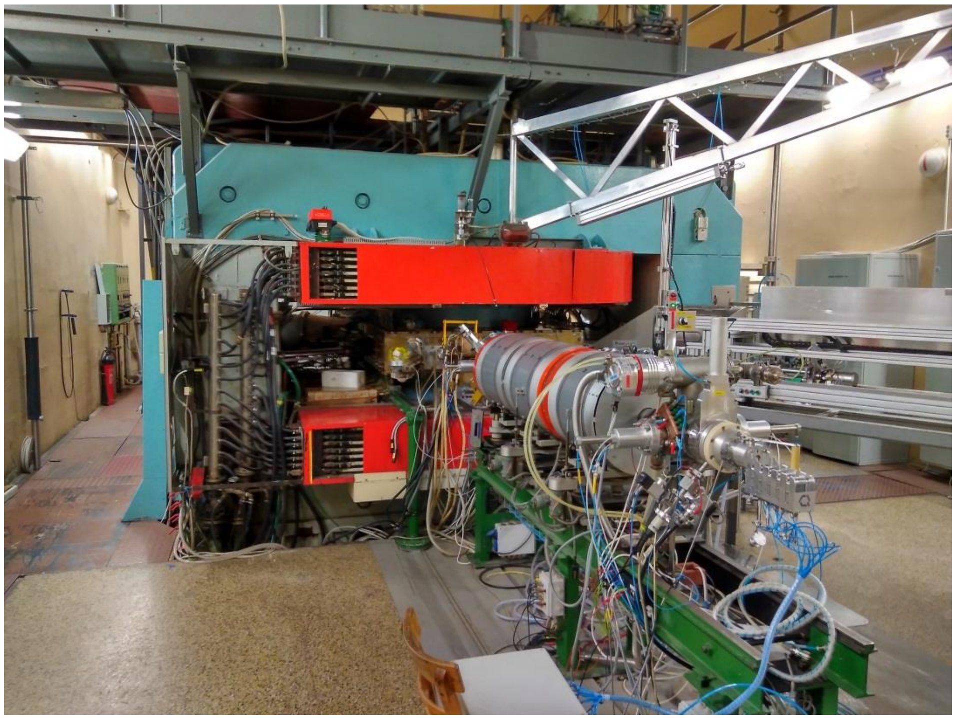
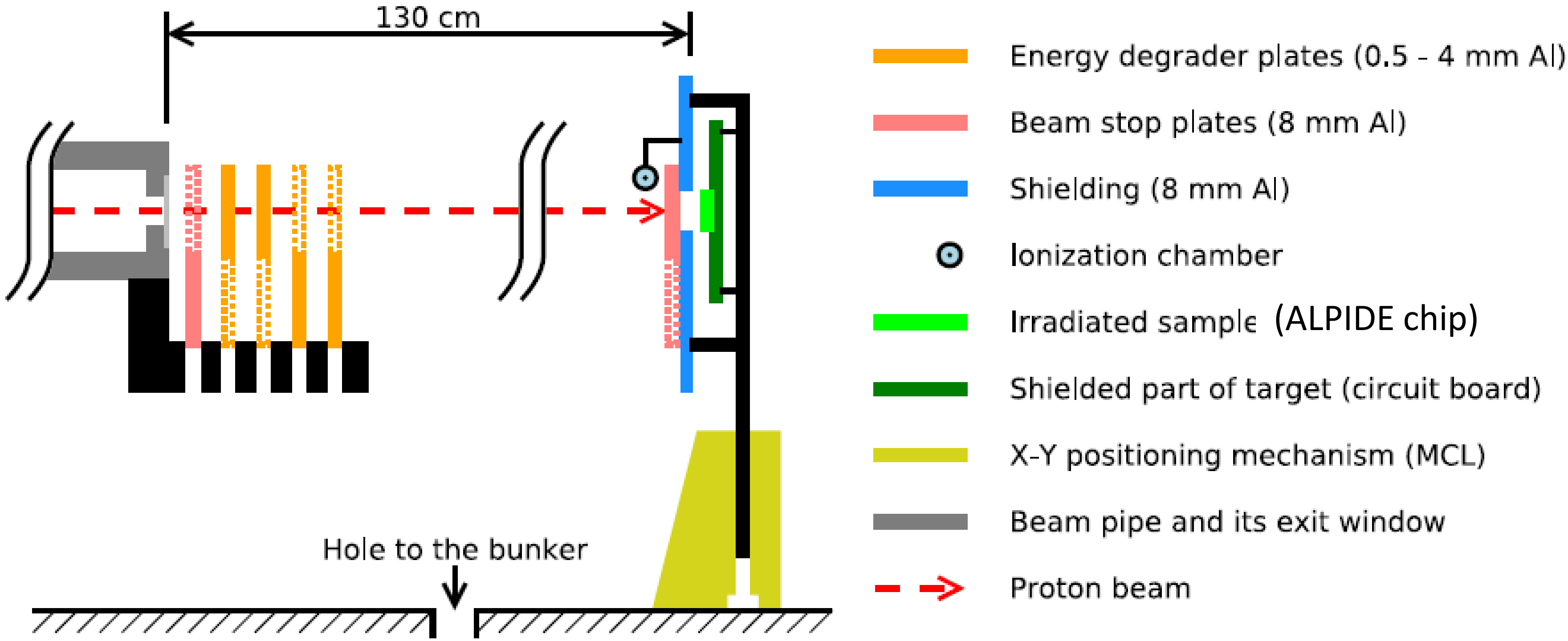


Photo of cyclotron U-120M

Cyclotron settings used during radiation hardness tests of ALPIDE chip:

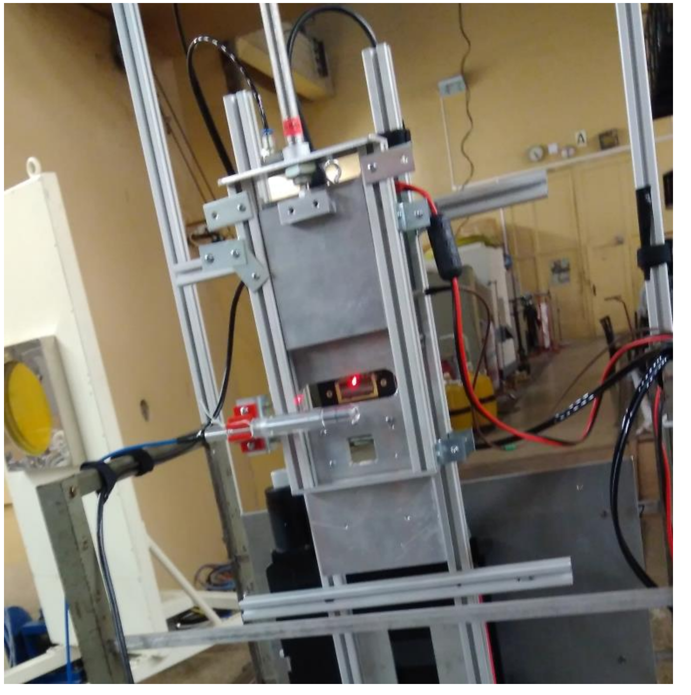
- Negative injection mode
- Energy of proton beam ~35 MeV
- Flux ~1×10^{8} $cm^{-2}sec^{-1}$

2.1. Scheme of the experiment on the cyclotron



2.1. Scheme of the experiment on the cyclotron

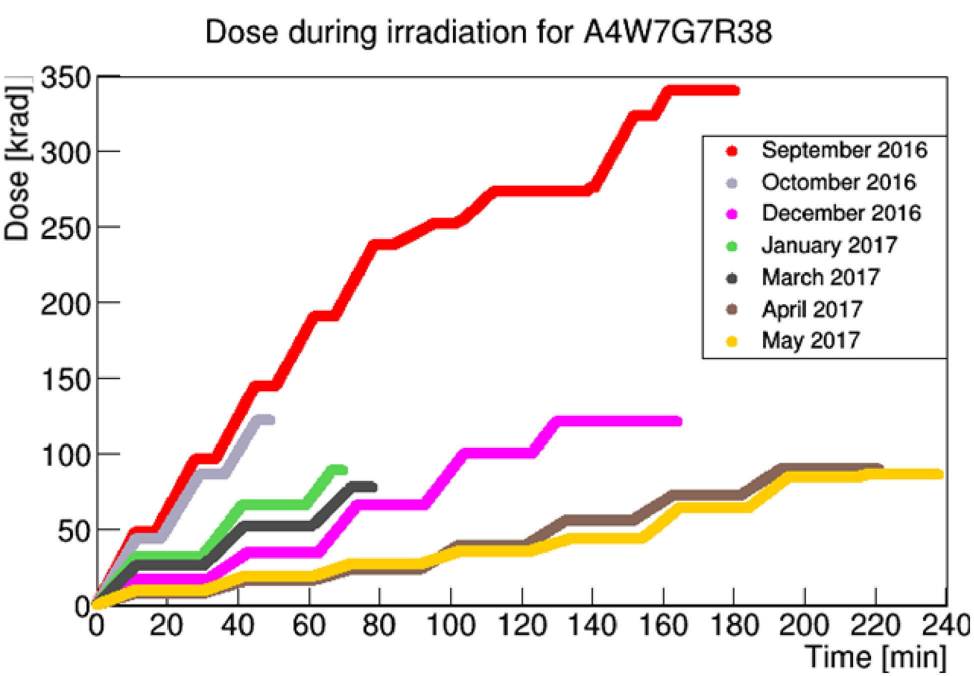
Photo of the system of degrader plates



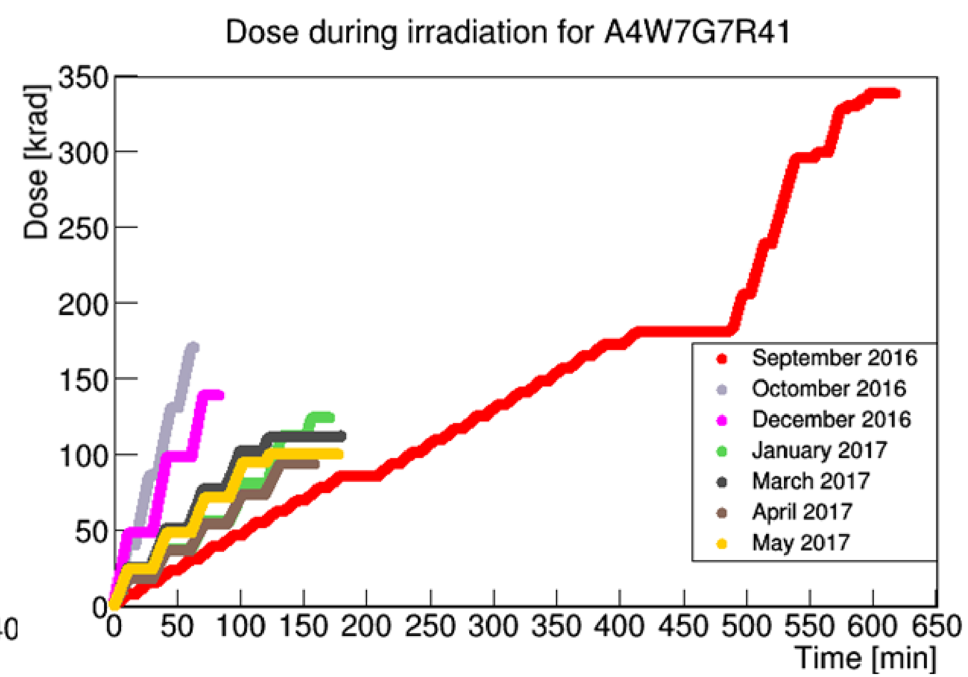
Positioning stage with connected ALPIDE chip

2.2. Graph of the absorbed dose during tests

	Inner Barrel	Middle and Outer Barrel
TID radiation in 4 years	**2700 krad**	100 krad
NIEL radiation in 4 years	1.7×10^{13} 1MeV n eq/cm^2	1×10^{12} 1MeV n eq/cm^2



Total absorbed dose, 927 krad



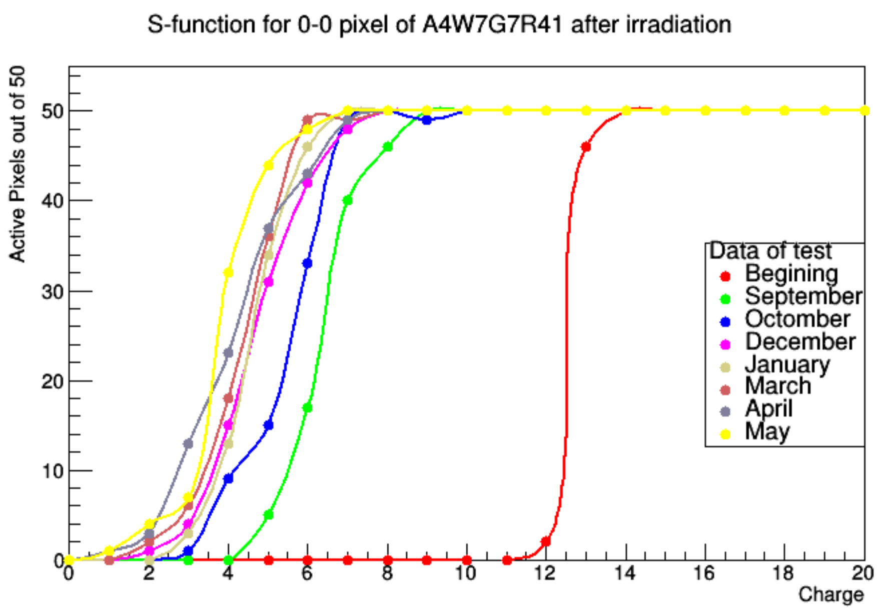
Total absorbed dose, 1078 krad

2.3. Threshold test

Activation function (S-function) of the pixel can be described by error function:

$$f(q_{inj}) = \frac{1}{2}\left[1 + erf\left(\frac{q_{inj} + \mu}{\sqrt{2}\sigma}\right)\right]$$

Where q_{inj} — injected charge, μ — average charge for activation pixel, σ — value of temporal noise

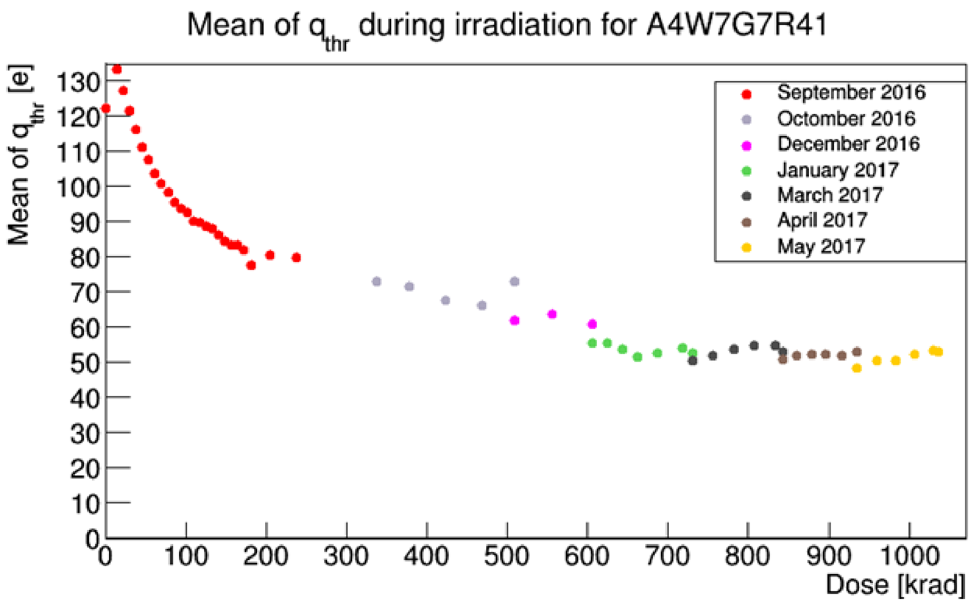


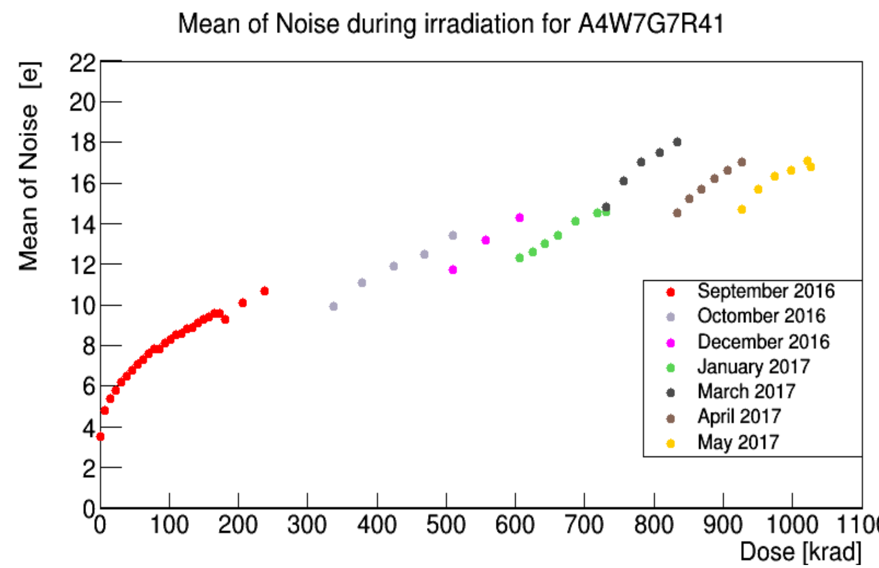
S-function with growth of the Dose:

- Shifting to the left → reduction of activation charge

2.3. Threshold test

Graph of the mean of *threshold* and *noise* vs. total accumulated dose

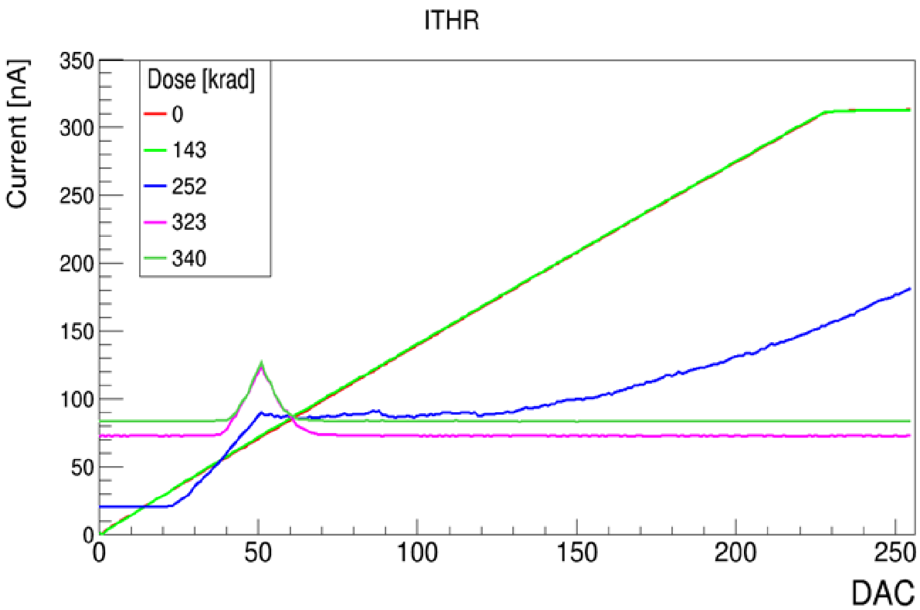


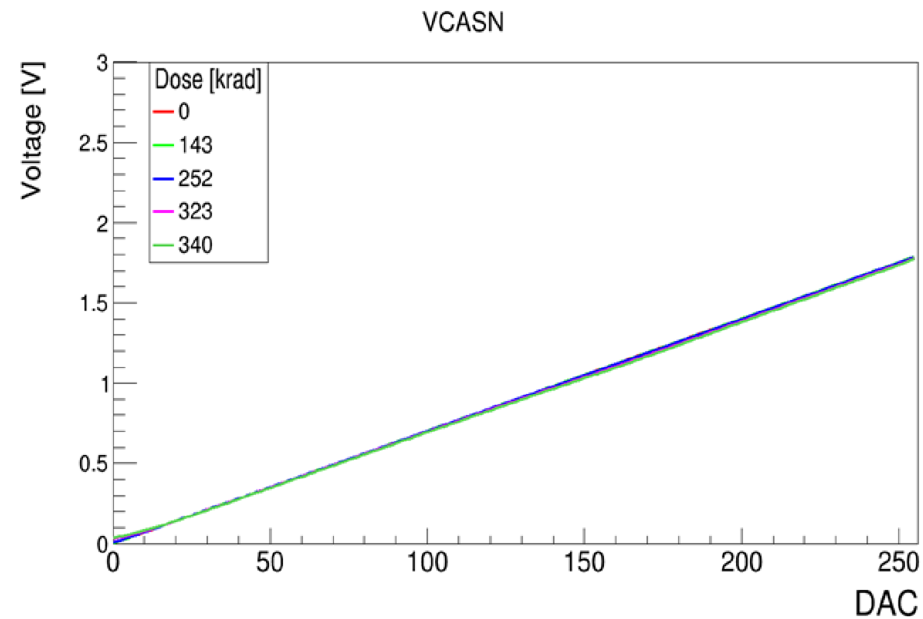


- Decrease of *threshold* with growth of total absorbed dose (Not recovering)
- Increase of *noise* with growth of total absorbed dose (Recovering)

2.4. DAC scan test

DAC (Digital Analog Converter) scan during September 2016 irradiation for A4W7G7R38 chip

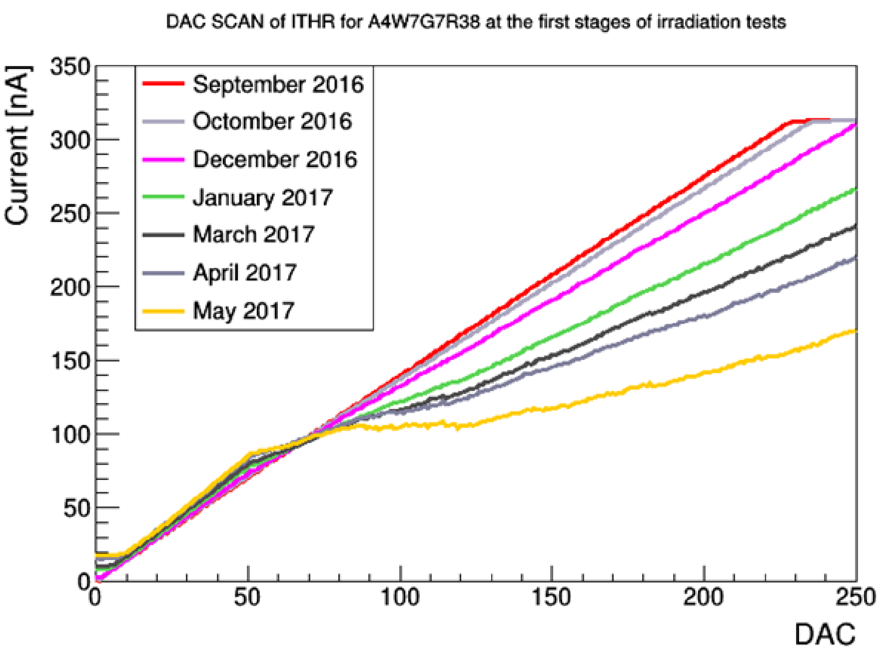


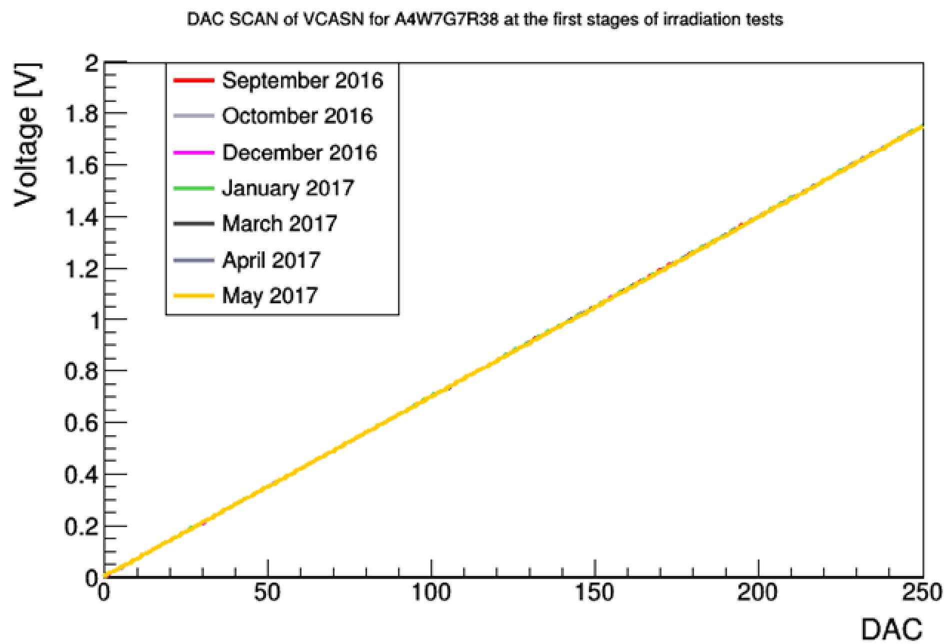


- Voltage DAC — not changed with increase of dose
- Current DAC — degradates with increasing of dose

2.4. DAC scan test

DAC scan for the end of each recovering period for A4W7G7R38 chip





- Current DAC — processes of recovering
- Recovery is reducing with growth of total absorbed dose

3. Development software for the installation for the cyclotron test

Current software for the installation for the cyclotron test does not fully meet requirements on performance.

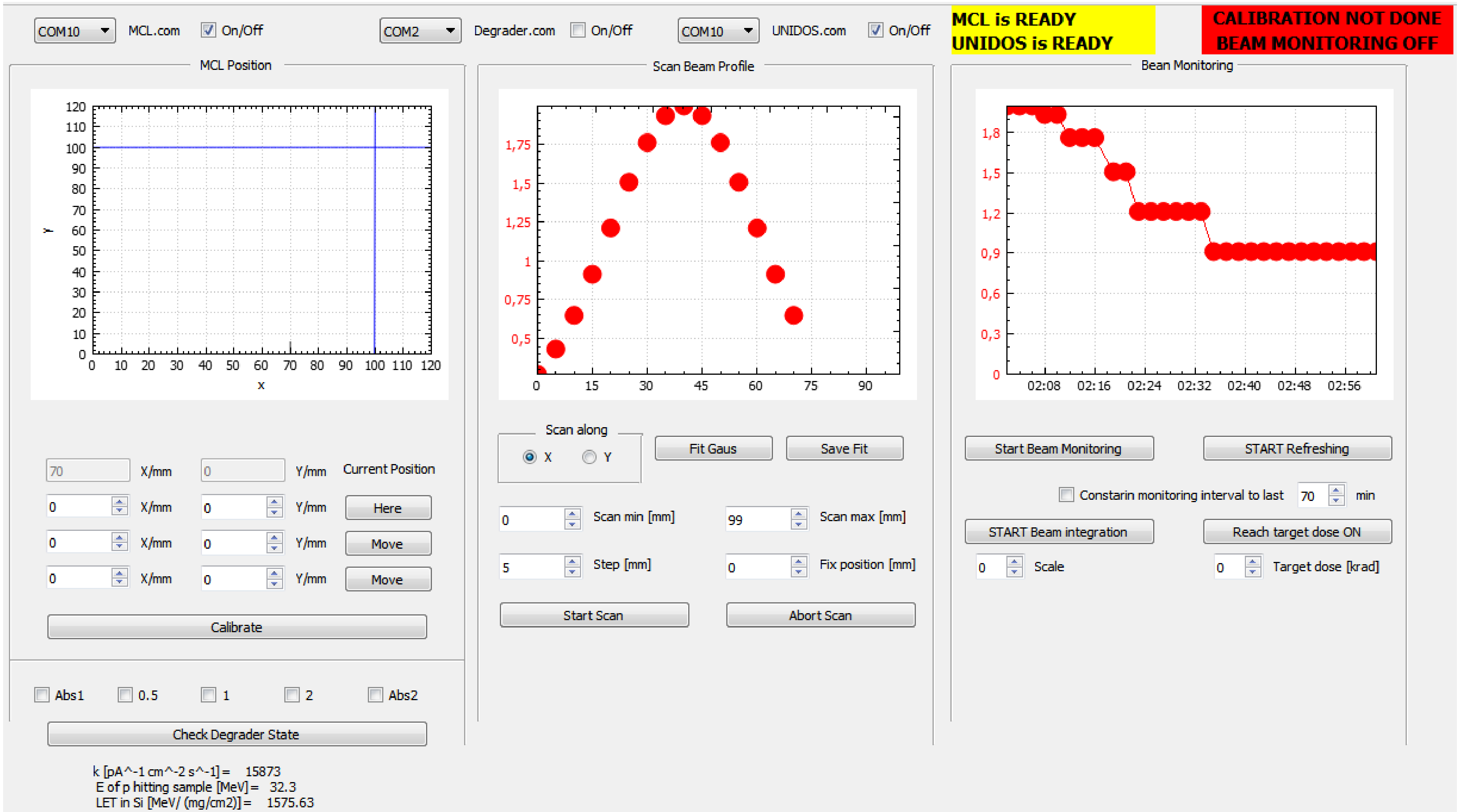
Needs to design new multithread software for installation with the same functions as previous software, such as:

- Controlling MCL moving table
- Reading value of current from UNIDOS ionization chamber
- Controlling system of degrader plates
- Perform logging experimental data
- Perform primary data processing (fitting beam profile, calculation of dose and flux)

Also new software should allow extension in the next measurements

3. Development software for the installation for the cyclotron test

3.1 Screenshot of software



Conclusion

Investigation of the ALPIDE chip for ALICE ITS upgrade:

- Parameters of clusters depend on energy of pions and inclination angle
- Radiation hardness of ALPIDE chips at cyclotron U120-M
- 1Mrad chips are still operational
- Effects of degradation and regeneration are observed (drop of threshold, current DACs)

Results were presented at CERN meetings

New software for controlling setup for cyclotron tests.

Thank you for your attention

Requirements for the upgrade of the ITS

	Inner Barrel	Middle and Outer Barrel
TID radiation in 4 years	2700 krad	100 krad
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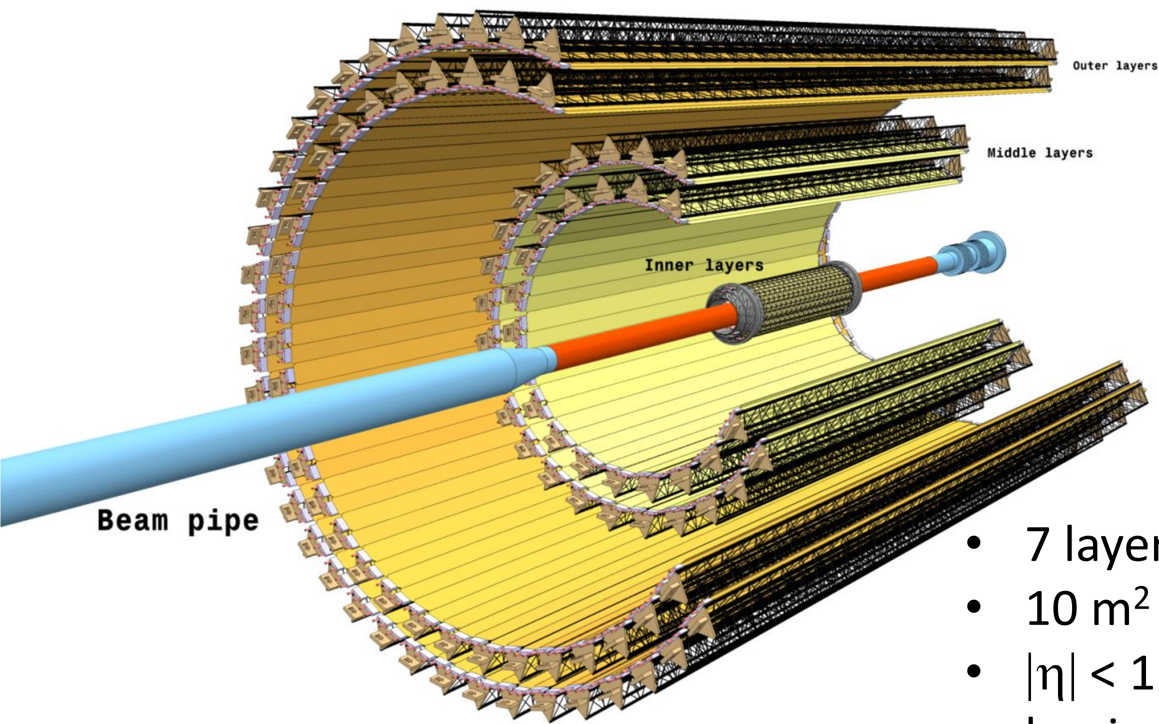
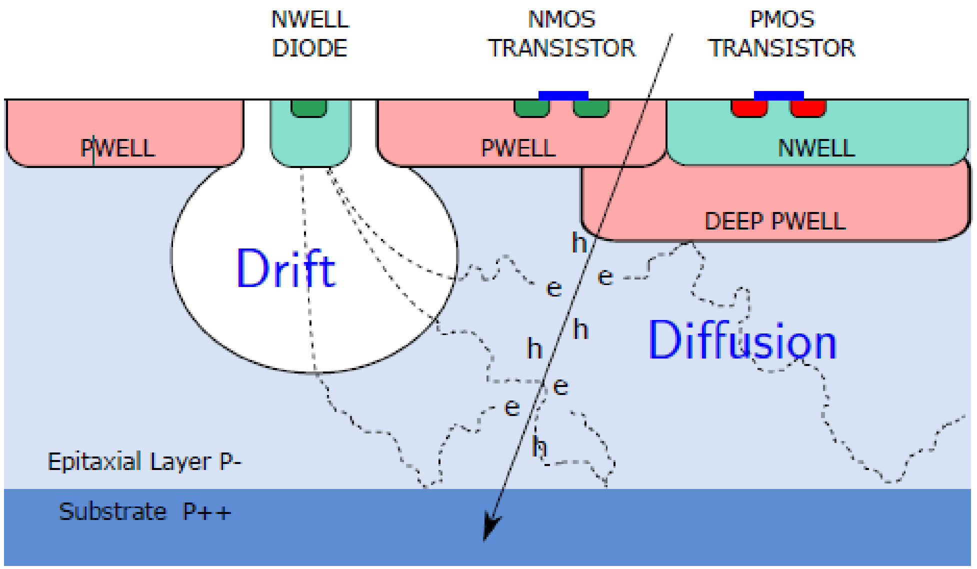


- 7 layers of pixel sensors (r = 23 - 400 mm)
- 10 m^2 of silicon with 12.5 Gpixels
- $|\eta| < 1.22$ for tracks from 90% of the most luminous region

Choice of sensor technology

Monolithic Active Pixel Sensors (MAPS)

- Using TowerJazz 0.18 μm CMOS imaging process
- High-resistivity (> 1kΩ cm) epitaxial layer on p-type substrate
- Deep PWELL shields NWELL of PMOS transistors
  - Allows full CMOS circuitry in active area
- Moderate reverse substrate biasing possible -> Larger depletion volume

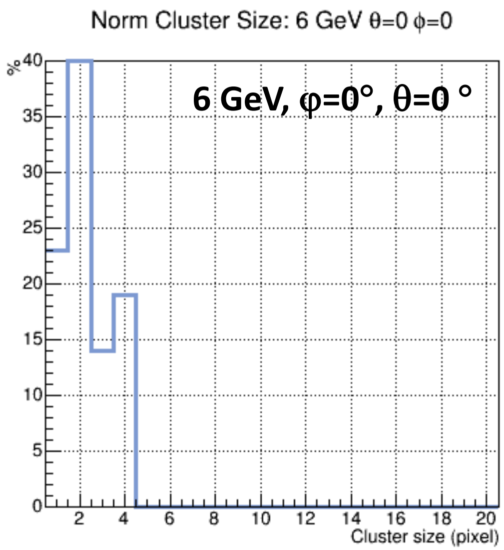


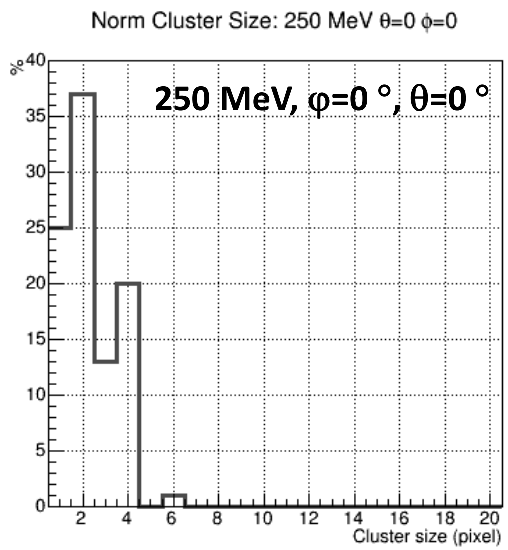
1.1. Comparison of Cluster size 250 MeV vs. 6 GeV

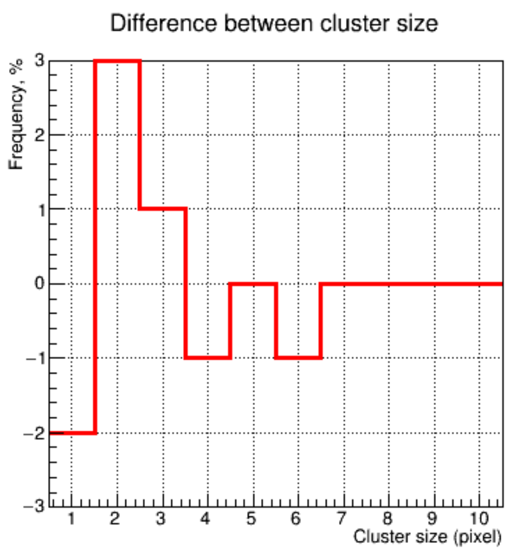
Mean of cluster size in pixels for particles with different energy and inclination angle

Inclination angle	Energy of the particles, 6 GeV	Energy of the particles 250 MeV
θ=0°, φ=0°	2.39	2.41
θ=0°, φ=30°	2.67	2.67
θ=0°, φ=50°	3.4	3.43

Comparison of cluster size in pixels for particles 250 MeV vs. 6 GeV, θ=0°, φ=0°

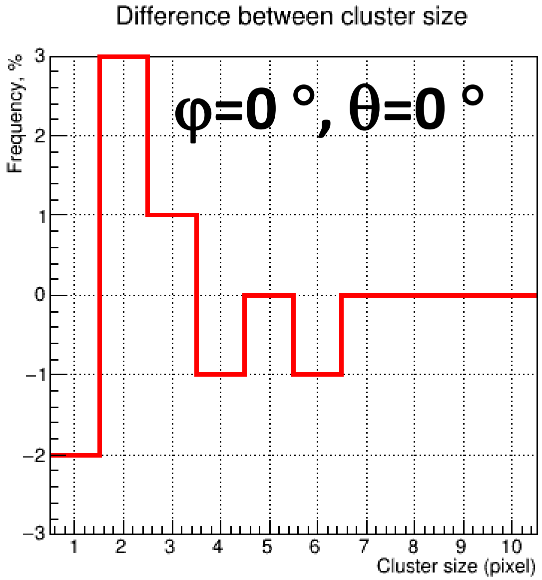


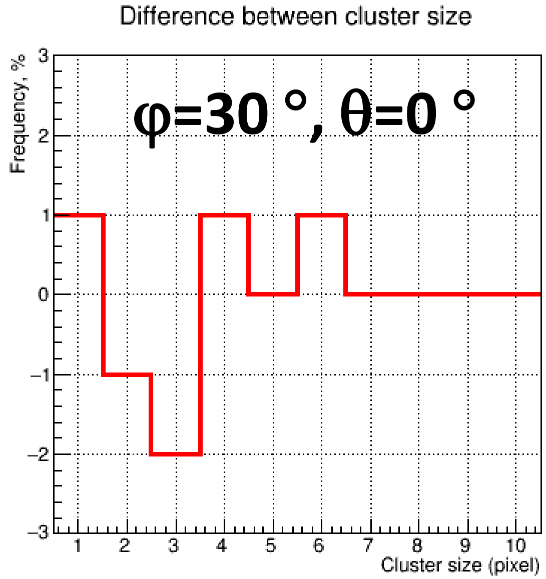


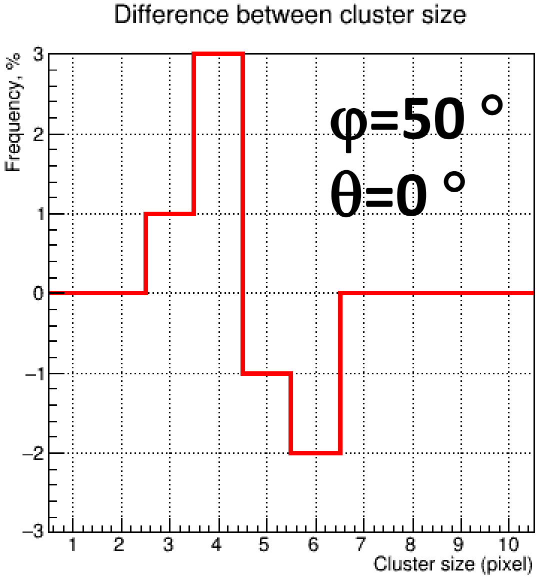


1.1. Comparison Cluster size 250 MeV vs. 6 GeV

Difference between cluster size for particles 250 MeV vs. 6 GeV.







There is no any dependency between difference of cluster size for particles 250 MeV and 6 GeV

2.1. Scheme of the experiment on the cyclotron

1 – Short beam line

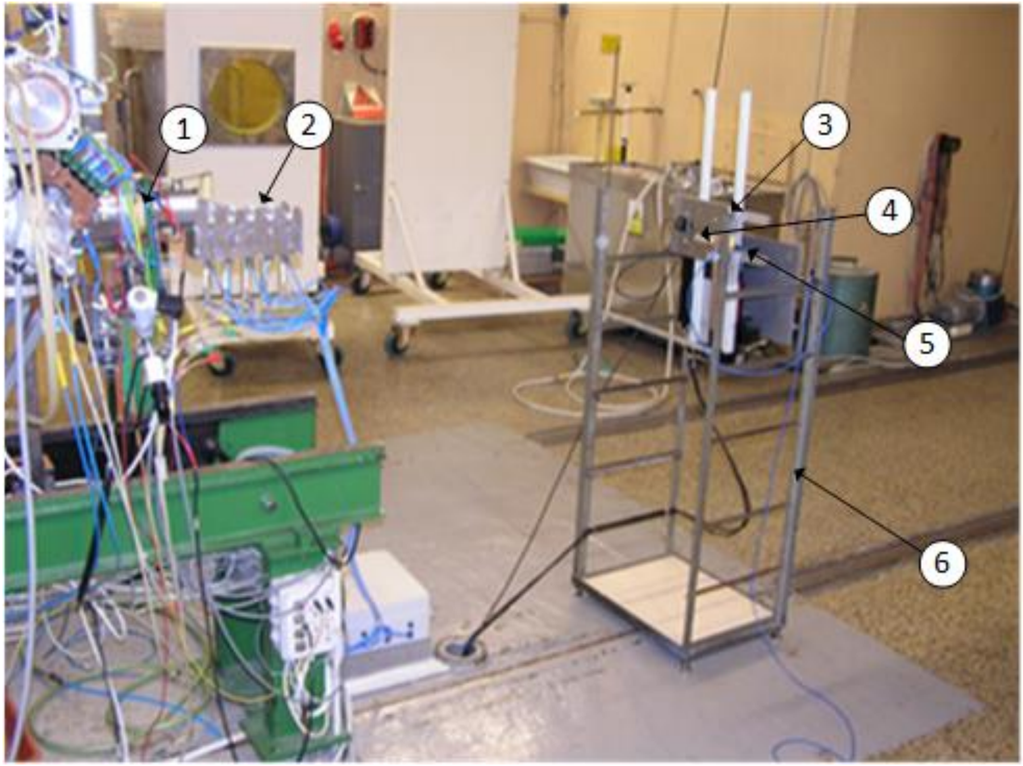
2 – System of degrader plates

3 – Protective shutter

4 – Sensitive element of the ionization chamber

5 – ALPIDE chip

6 – 2D Positioning table



2.4. Test of analog current