NEW PIXEL DETECTORS FOR ALICE AT LHC AND FOR NICA EXPERIMENTS

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on behalf of the ALICE collaboration

Saint-Petersburg State University

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Outline

1. ALICE Inner Tracking System: current status and upgrade strategy

2. New pixel sensors for ALICE experiment: ALICE Pixel detectors (ALPIDE family)

3. Study of the characteristics of ALICE ITS pixel detectors

4. Pixel detectors for NICA experiments

5. Summary

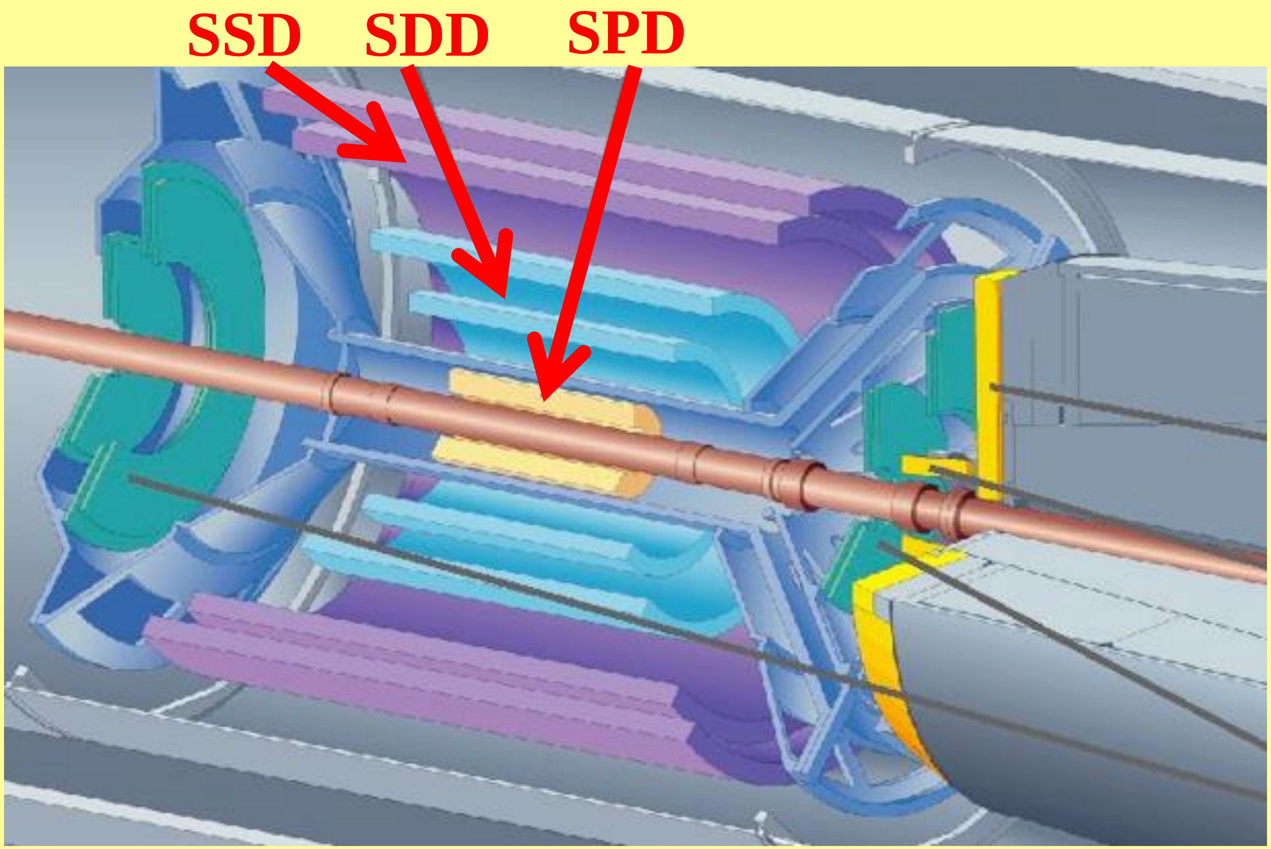
ALICE Inner Tracking System: current status and upgrade strategy

ALICE Pixel Detector : SPD
first two layers : tracking

ALICE Drift Detector: SDD
two middle layers: tracking+ particle identification

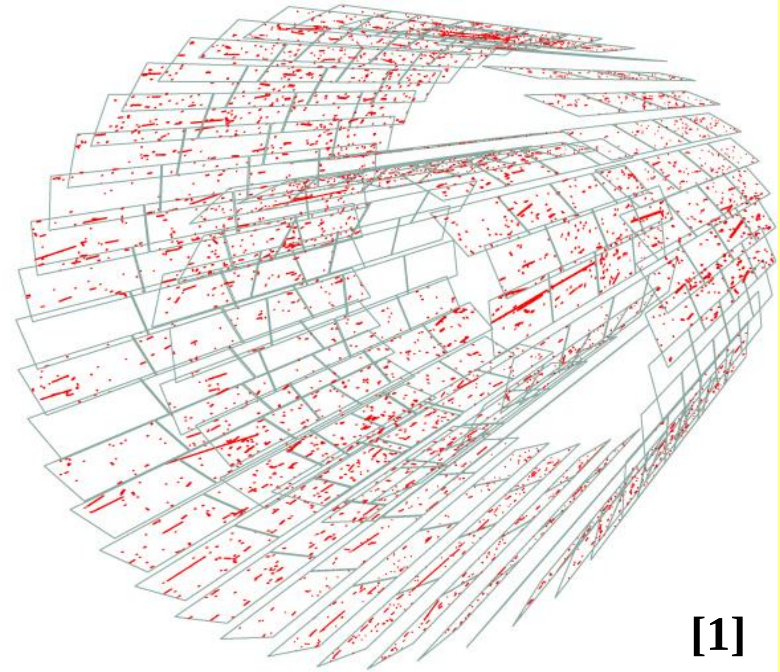
ALICE Strip Detector: SSD
two outer layers: tracking + particle identification

→ **6 cylindrical layers of Si detectors (placed coaxially around the beam pipe**



[1]

ALICE Inner Tracking System: current status and upgrade strategy



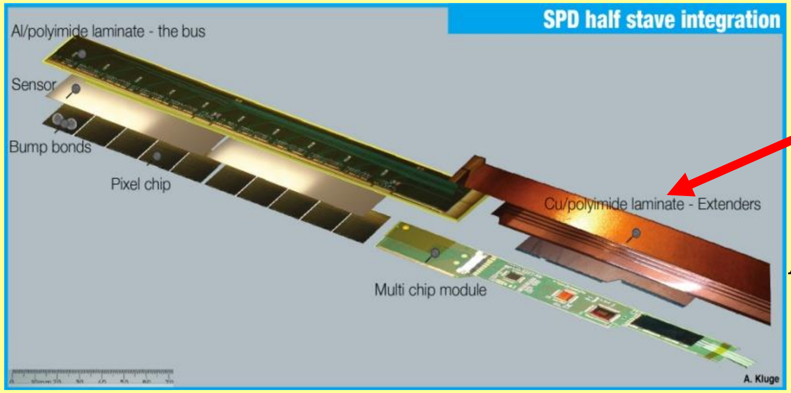
Advantages of the Pixel Detectors

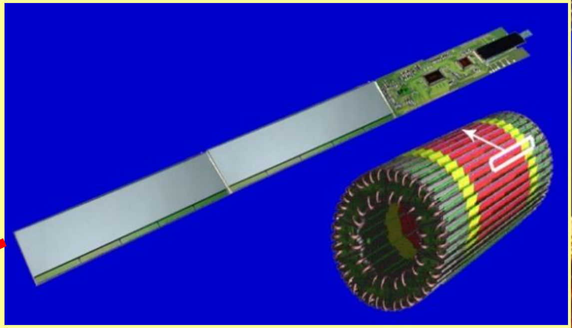
Good position resolution: Smaller pixels, Higher integration

Small pixels - low capacitance - better S/N - lower analog power

More pixels – More logic per pixel – high integration work at higher rates and high radiation levels

June 2008, ALICE Silicon Pixel detector registered muon tracks produced in the injection beam line of the LHC near Point 2





ALICE silicon pixel detector [1]

ALICE Inner Tracking System: current status and upgrade strategy

Limitations of current ITS:

1. **Read-out capabilities limited at 1kHz for Pb-Pb collisions;**

2. **Pointing resolution of the present ITS restricts the range of measurements. It is adequate for the study of charm and beauty mesons at p_T>1 GeV/c, but at lower p_T the statistical significance becomes insufficient for currently achievable data sets;**

3. **Vertices of charmed baryons are currently not feasible in Pb-Pb collisions. The mean proper decay length ~60 μm, which is lower than the pointing resolution of the current ITS in the p_T range of most of the $\Lambda^+_c \rightarrow p K^- \pi^+$ daughter particles (<1GeV/c);**

4. **For the same reasons study of beauty mesons, beauty baryons, and of hadrons with more than one heavy quark is beyond reach of the current detector.**

Motivations for upgrade:

1. **Increase vertex resolution**

2. **Improve tracking efficiency and p_T resolution at low p_T: allow improvement of the resolution of the track impact parameter by a factor of three or better (at p_T = 1 GeV/c) with respect to the present ITS**

3. **Increase readout rate capabilities: readout Pb-Pb interactions at > 100 kHz, readout pp interactions at >400 kHz**

ALICE Inner Tracking System: current status and upgrade strategy

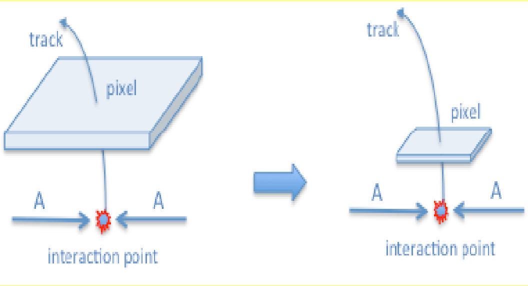
Upgrade strategy (main points)

1. Improve impact parameter resolution by a factor of ~3

a) First detection layer closer to the beam line: 39 mm → 22 mm

b) Reduction of material budget: the radiation length per layer (<u>for inner layers</u>) X: from 1.14 to 0.3 %X0

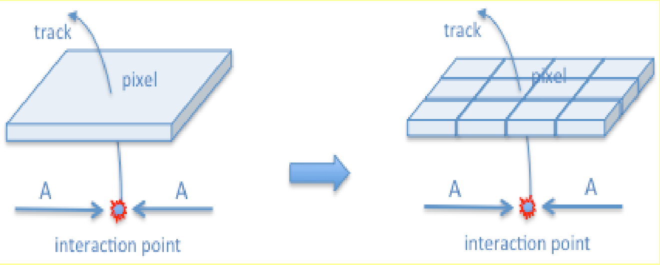
c) Reducing pixel size: 425 µm x 50 µm → 30 µm x 30 µm



[2]

2. Improve tracking efficiency and p_T resolution at low p_T

Increase in granularity (smaller pixels), number of layers: 6 → 7, silicon drift and strips → pixels



20 chan/cm^3 → 2000 pixel/cm^3

3. Fast readout
   readout Pb-Pb interactions at > 100 kHz
   (currently limited at 1kHz with full ITS)

<u>Also:</u>

a) lower power consumption and optimized scheme for the distribution of power and signals;

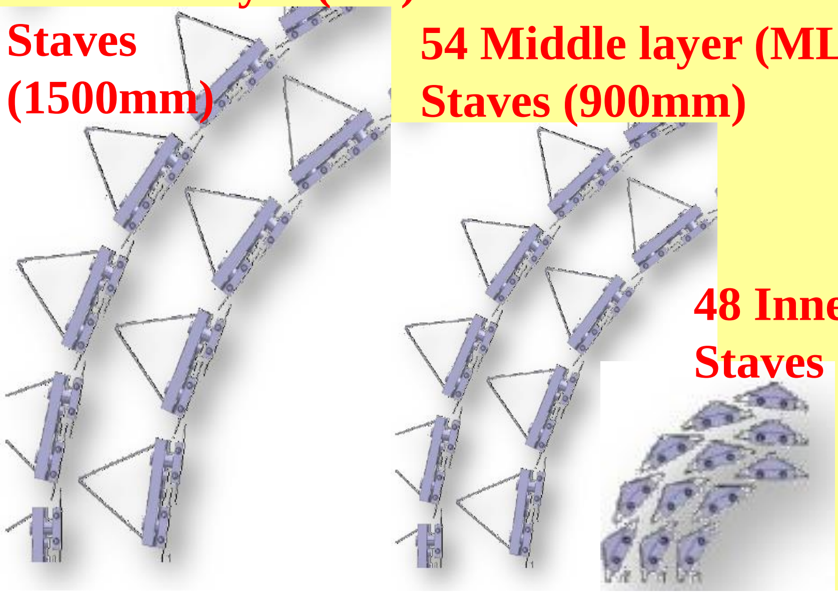
b) mechanics, cooling and other detector elements will be also improved: all services are connected on one side. This allows the extraction and reinsertion of the ITS, for maintenance purposes, during the yearly LHC shutdown.

ALICE Inner Tracking System: current status and upgrade strategy

90 Outer layer (OL) Staves (1500mm)

54 Middle layer (ML) Staves (900mm)

48 Inner layer (IL) Staves (290mm)

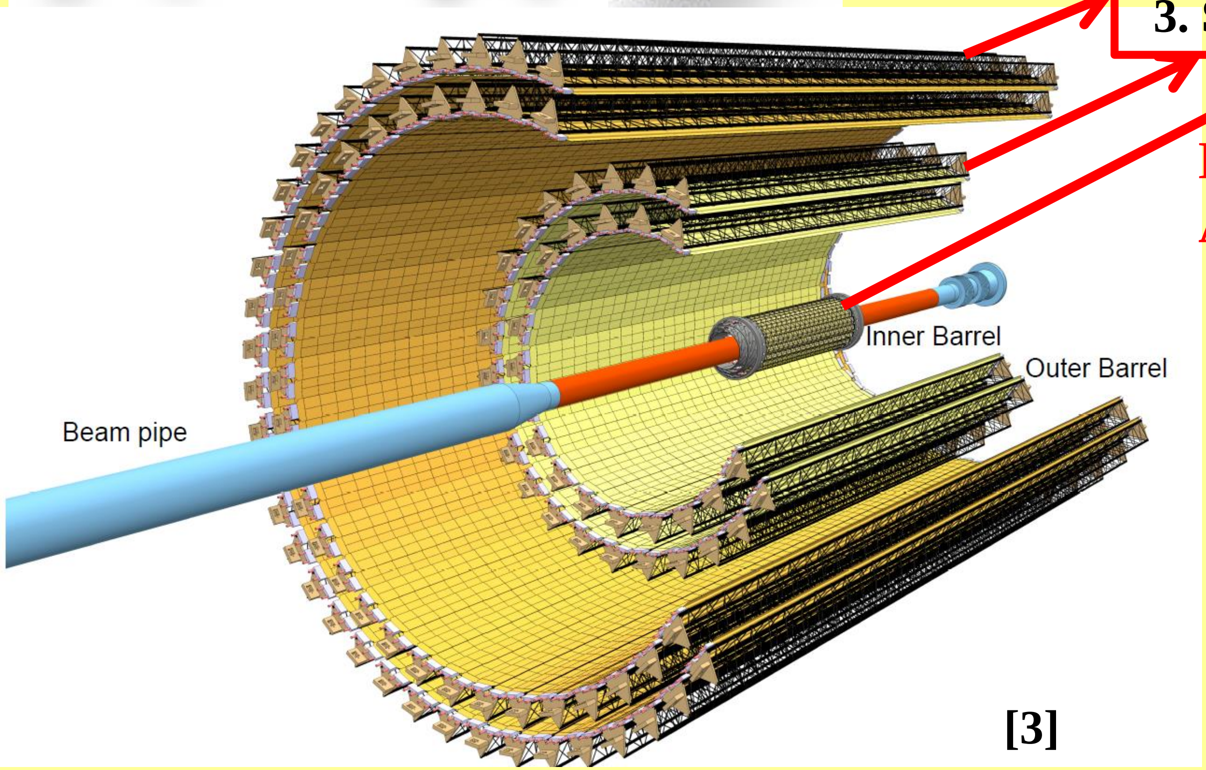


STAVES

Total – 144 staves:
48 (IL) – Inner Barrel
54(ML) and 90(OL) – Outer Barrel

Stave consists of :

1. Hybrid Integrated Circuit (HIC)
2. Cold plate
3. Space frame



Barrel: 7 layers of Monolithic Active Pixel Sensors (MAPS)

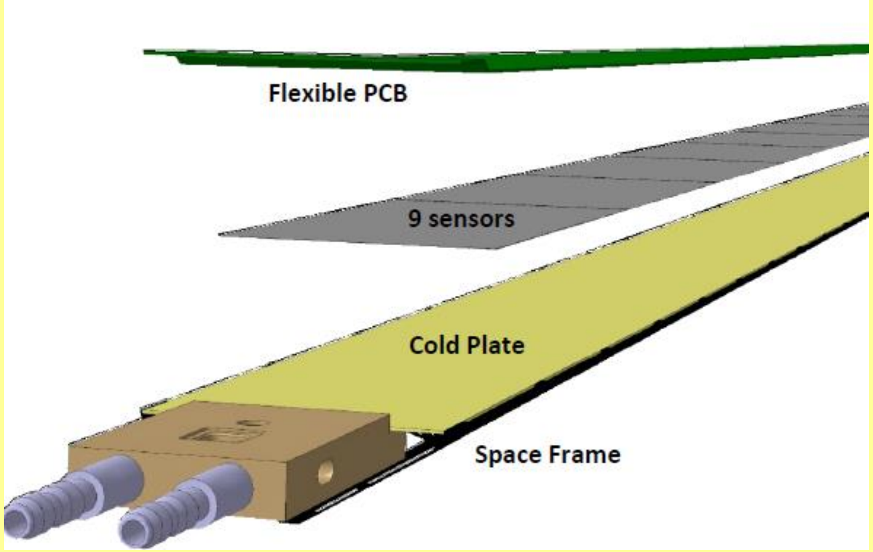
New ITS:

12.5 G pixels;

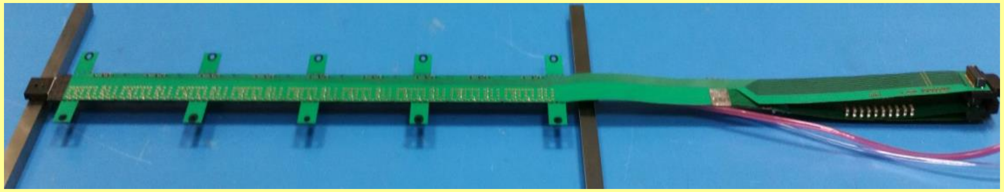
~ 10 m^2 silicon active area;

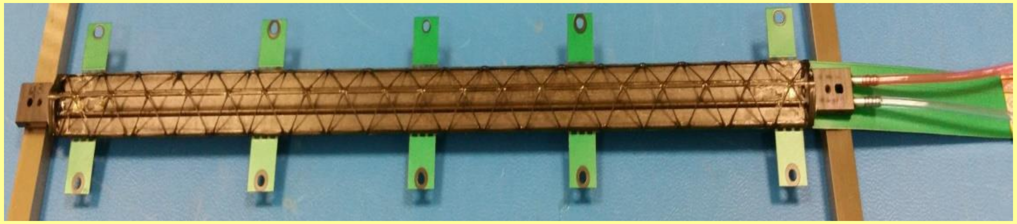
radial coverage 22 – 400 mm.

ALICE Inner Tracking System: current status and upgrade strategy

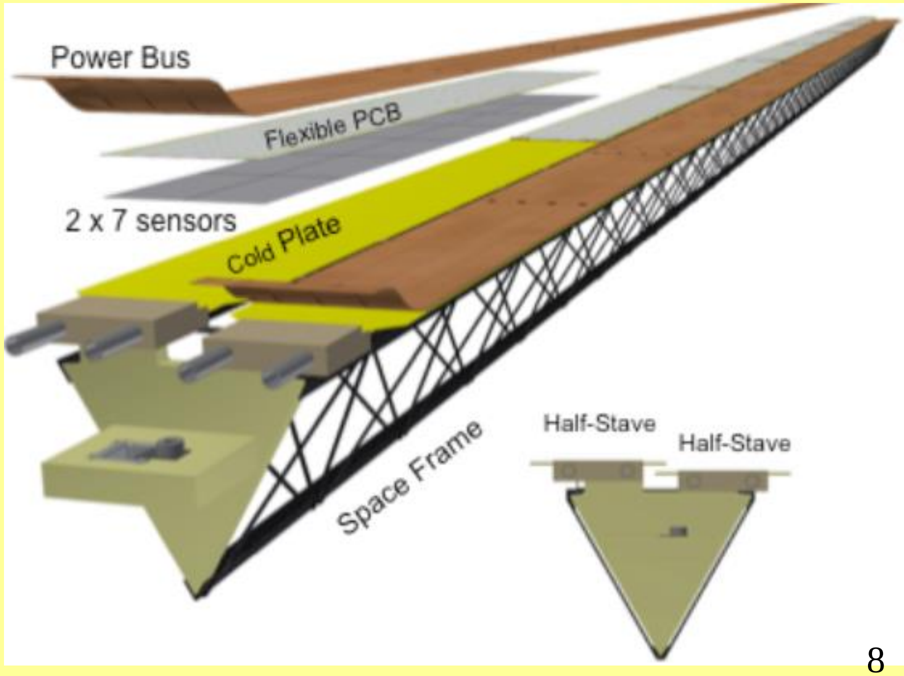


Inner Barrel Stave

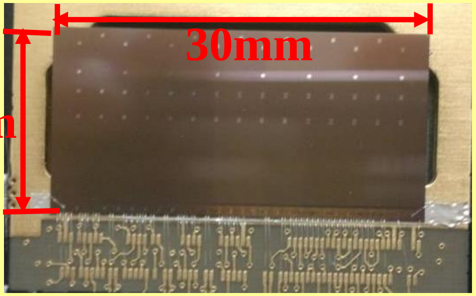




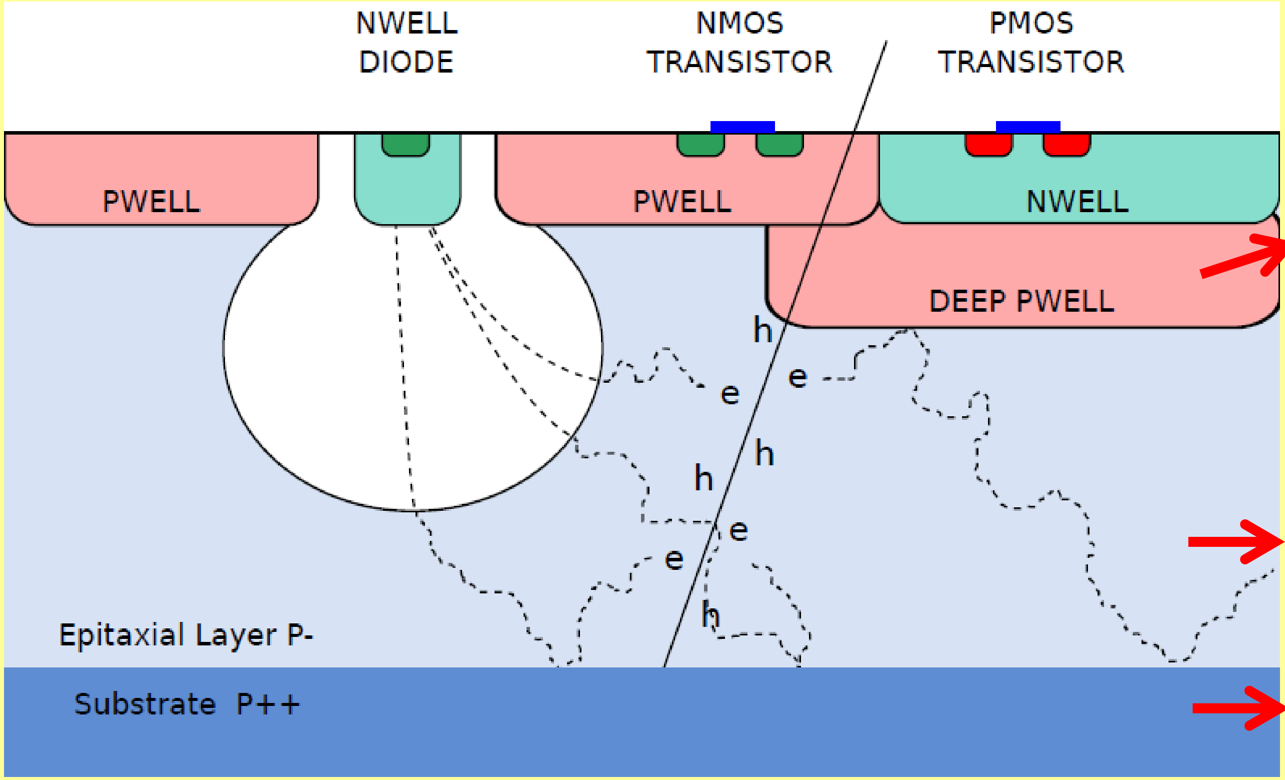
Outer Barrel Stave



New pixel sensors for ALICE experiment:
ALICE Pixel detectors (ALPIDE family)



MAPS using TowerJazz 180nm CMOS Imaging Process



Shields the other nwells different from the collection electrode, preventing these from collecting signal charge which then would be lost for readout. Full CMOS within the pixel

High resistivity(> 1kΩ ·cm) p-type epitaxial layer (25µm)

low-resistivity p-type substrate

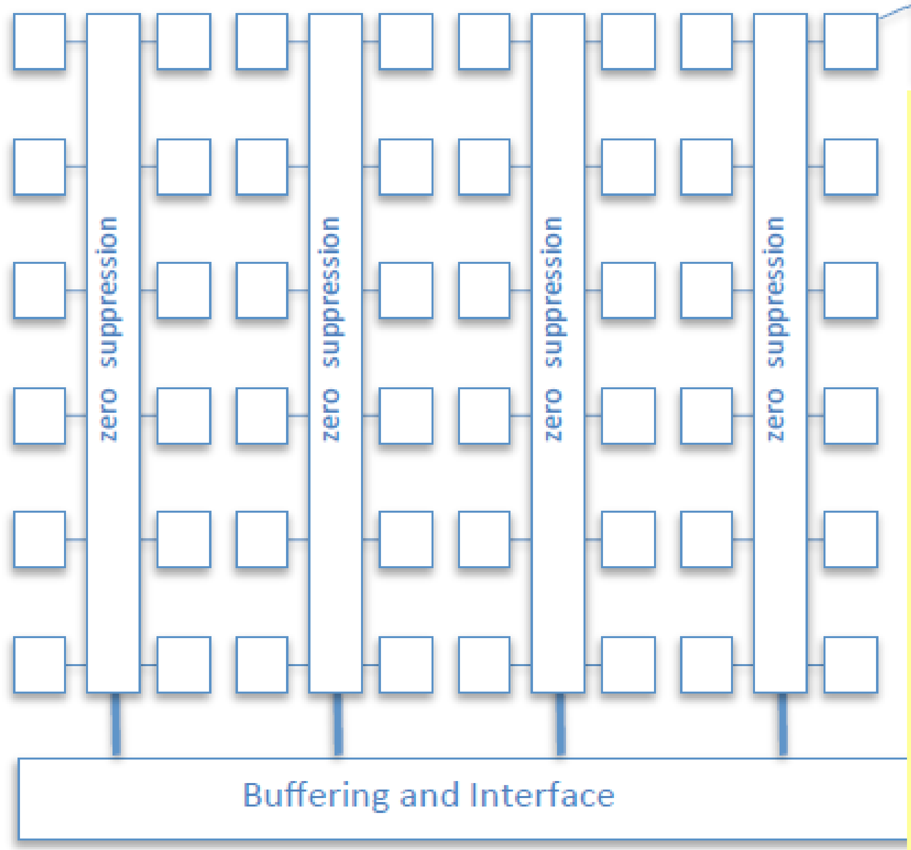
Small n-well diode (2-3 µm diameter), ~100 times smaller than pixel →low capacitance

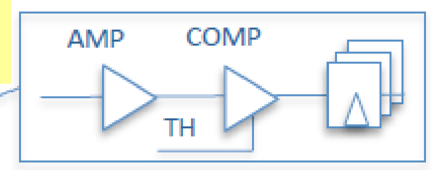
The gate oxide thickness of 3 nm → robustness to Total Ionizing Dose

Possibility to apply back bias to the substrate can be used to increase depletion zone around NWELL collection diode: S/N ratio increases, higher efficiency

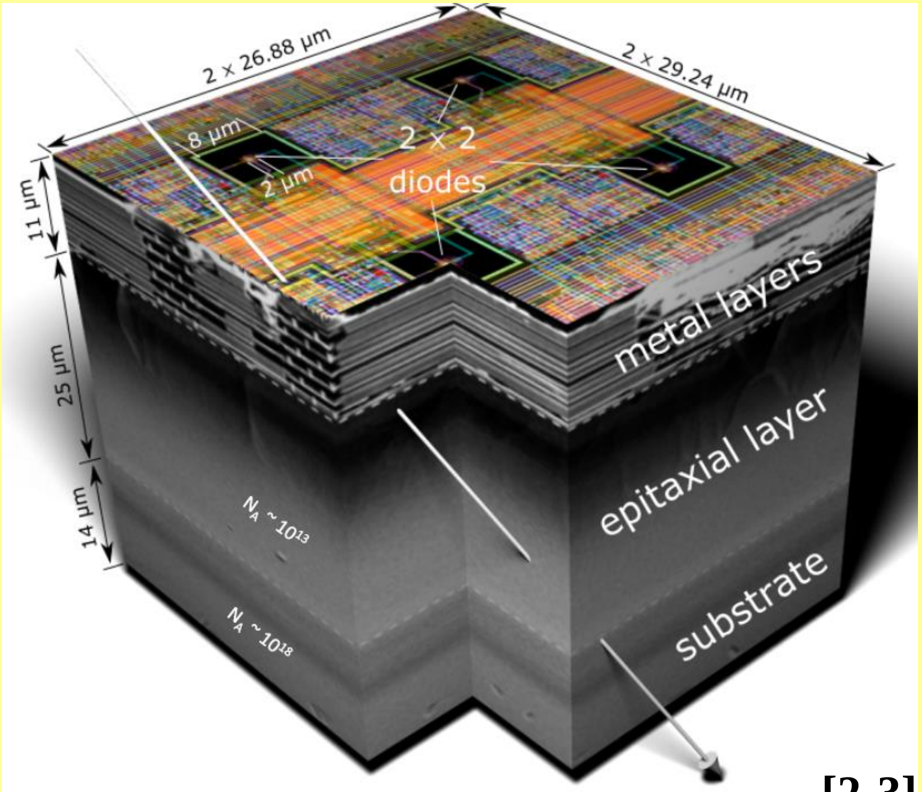
New pixel sensors for ALICE experiment: ALICE Pixel detectors (ALPIDE family)

ALPIDE chip architecture





In-pixel amplification
In-pixel discrimination
In-pixel (multi-) hit buffer



[2-3]

The zero suppression is performed within the matrix. Address-Encoder Reset-Decoder circuit is employed. It can either be controlled by an external trigger signal or operated in continuous acquisition mode.

Power consumption 40 mW/cm^2

Contains a matrix of 512 × 1024 sensitive pixels

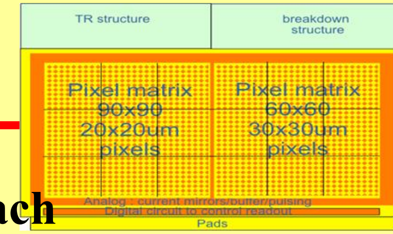
New pixel sensors for ALICE experiment: ALICE Pixel detectors (ALPIDE family)

Pixel detector general requirements (from ALICE TDR [3])

Parameter	**Inner Barrel (IB)**	**Outer Barrel (OB)**	**ALPIDE Performance**
Silicon thickness	50 μm	100 μm	
Chip dimension	15 mm x 30 mm	15 mm x 30 mm	
Spatial resolution	5 μm	10 μm	5 μm (IB), 5 μm (OB)
Power density	< 300 mW/cm^2	< 100 mW/cm^2	40 mW/cm^2 (IB), 30 mW/cm^2 (OB)
Max. integration time	30 μs	30 μs	10 μs
Detection efficiency	>99%	>99%	>99% **Upper limit!**
Fake-hit rate	$<10^{-5}$(TDR),$<10^{-6}$* /event/pixel for IB and OB		$<<<10^{-6}$ /event/pixel
Total Ionizing Dose	270 krad 2.7 Mrad*	10 krad, 100 krad*	Up to 500 krad
Non-Ionizing Energy Loss (1 MeV n_{eq}/cm^2)	1.7 x 10^{12} (TDR), 1.7 x 10^{13}*	1.7 x 10^{11} (TDR), 1.7 x 10^{12}*	Up to 1.7 x 10^{13}

radiation load integrated over the approved program (~ 6 years of operation)
*revised numbers with respect to ALICE TDR (factor 10)

New pixel sensors for ALICE experiment: ALICE Pixel detectors (ALPIDE family)



2012 — Explorer

Explorer-1,2

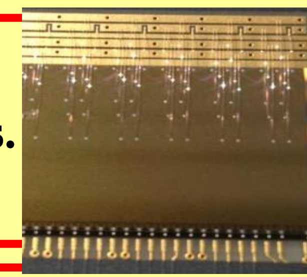
Two submatrices: 90x90 array of 20 x 20µm pixels and 60x60 array of 30x30µm pixels. Each sub-matrix is divided into 9 sectors with one variant of collection electrode(analogue readout). Investigations: pixel geometry, starting material, sensitivity to radiation.

2013 — pALPIDEss

Matrix with 64 columns x 512 rows of 22µm x 22µm pixels. (in-pixel discrimination and buffering). Study priority encoder and the front-end electronics

May-2014 — pALPIDE-1

Full-scale prototype to study system effects: 1024 columns x 512 rows of 28µm x 28µm pixels. 4 sectors with different pixels.



May-2015 — pALPIDE-2

4 sectors with different pixels. Optimization of several circuit blocks. Allows integration into ITS modules

Oct-2015 — pALPIDE-3

8 sectors with different pixels. Final interfaces, more features including 1.2 Gbit/s output serial link.

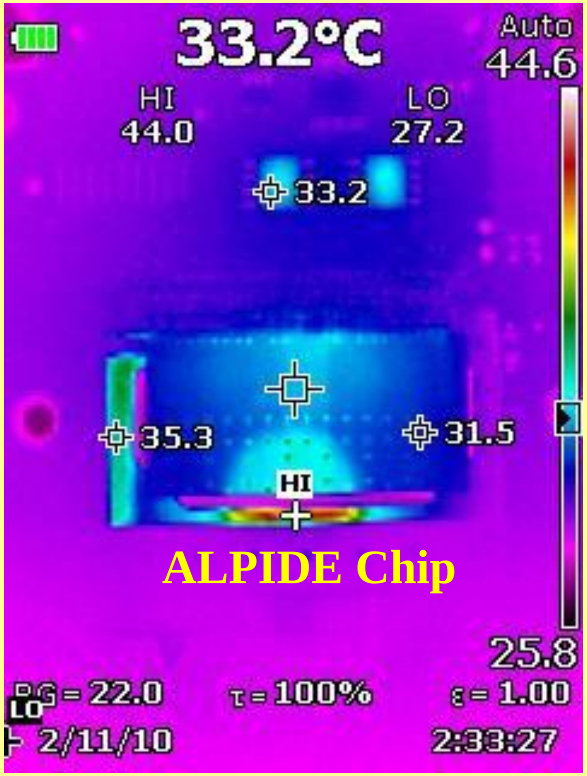
Jul - 2016

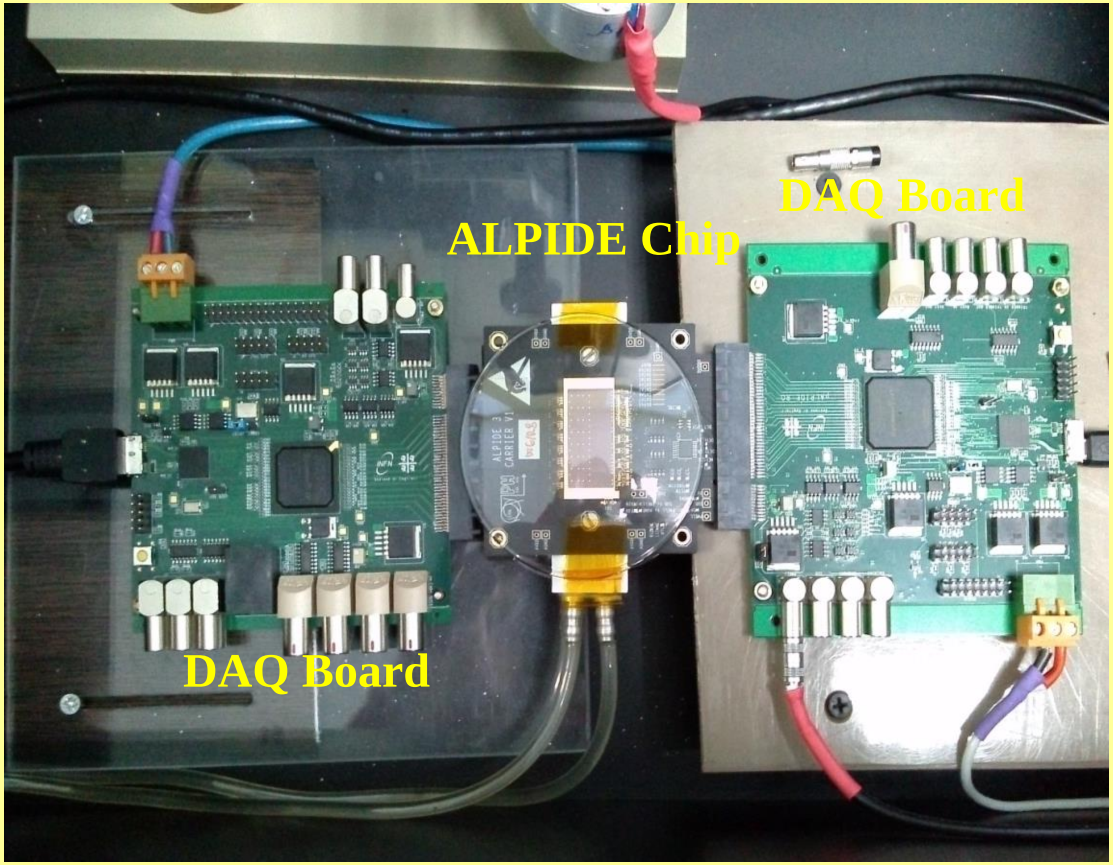
ALPIDE – Final Version

Study of the characteristics of ALICE ITS pixel detectors

1. Two different chip types (telescope geometry) with own DAQ boards were installed.
2. Detector Power supply(current control).
3. Dark box with electrical earthing inside. Temperature control inside the box.
4. Radioactive source (γβ) positioning system.
5. The water cooling(heating) system was implemented.
6. Thermo-camera for detector heating investigations.

Experimental set-up: I





All generations of ALPIDE chip: pALPIDE-1,2,3 and final version were studied

Characterization and tests

1. **Electrical tests:**

   a) **On-chip Digital-Analogue Converter Test.** The output of the on-chip DACs is connected to monitoring pins of the detector and measured by ADCs on the DAQ board.

   b) **Digital Scan.** Scan generates a digital pulse in a number of pixels and reads the hits out. The number of injections per pixel and the group of pixels can be set.

   c) **Analogue Scan.** A programmable charge is injected into the preamplifier. The values of the injected charge, as well as the number of injections per pixel and the groups of pixels can be set.

   d) **Threshold Scan.** Scan performs analogue injections, looping over the charge ranging from 7 to 350 electrons. The values of the threshold can be set.

2. **Noise characteristics of the sensor and its temperature dependence were studied**
   The scan gives a selectable number of random triggers and returns the number of hits. The values of threshold current (ITHR) and threshold voltage (VCASN) and also chip temperature can be set.

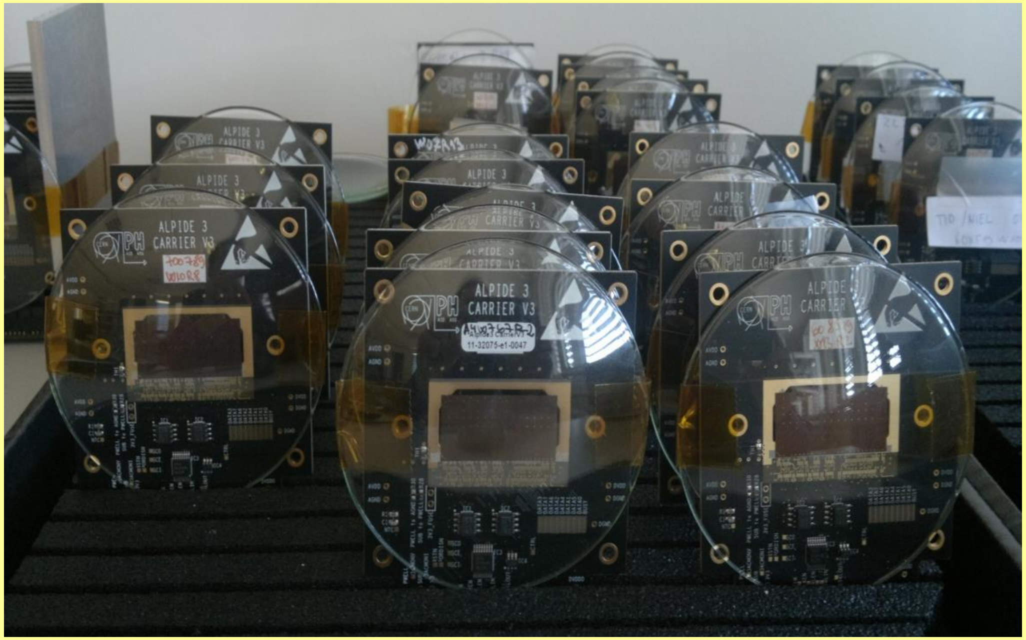
3. **Studies with a variety of gamma and beta sources were carried out**
   The scan gives the number of hits using the selectable number of random triggers. Radioactive source measurements are needed to study the uniformity of hit-maps and to evaluate cluster shape and size. The noise mask is prepared before the scan and can then be used in measurements.

All results for pALPIDE-3 see in Back up slides

Study of the characteristics of ALICE ITS pixel detectors

The performance of irradiated sensors at different temperatures, including cryogenic temperatures

Detectors ALPIDE (final version)



Detectors were irradiated by:

X-rays (from X-ray machine)

Chip W8R22 – 60 krad (low dose)

Chip W7R12 – 300 krad (high dose)

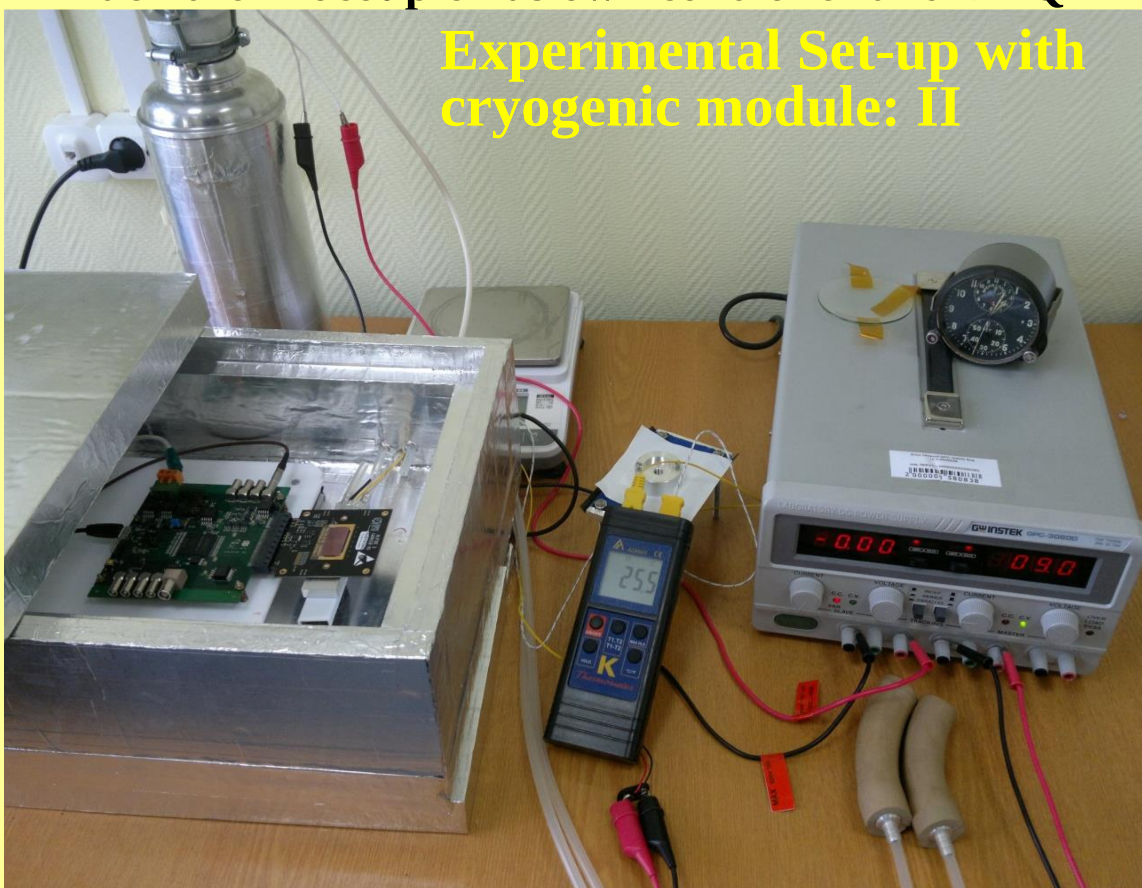
Before irradiation Chip W7R12 was measured at lab.

All measurements were done at back bias voltage Vbb = -3V

Study of the characteristics of ALICE ITS pixel detectors

1. Cryo-box.
2. Irradiated ALPIDE chip + DAQ board.
3. Chip was mounted on cooled platform.
4. Three thermocouples (1 copper-constantan, 2 chromel-alumel) mounted on cooled platform. Each thermocouple has own controller and DAQ

Experimental Set-up with cryogenic module: II



5. Dewar vessel with heater system.
6. Source holder.
7. Analytical balance

Second Experimental Set-up with cryogenic module

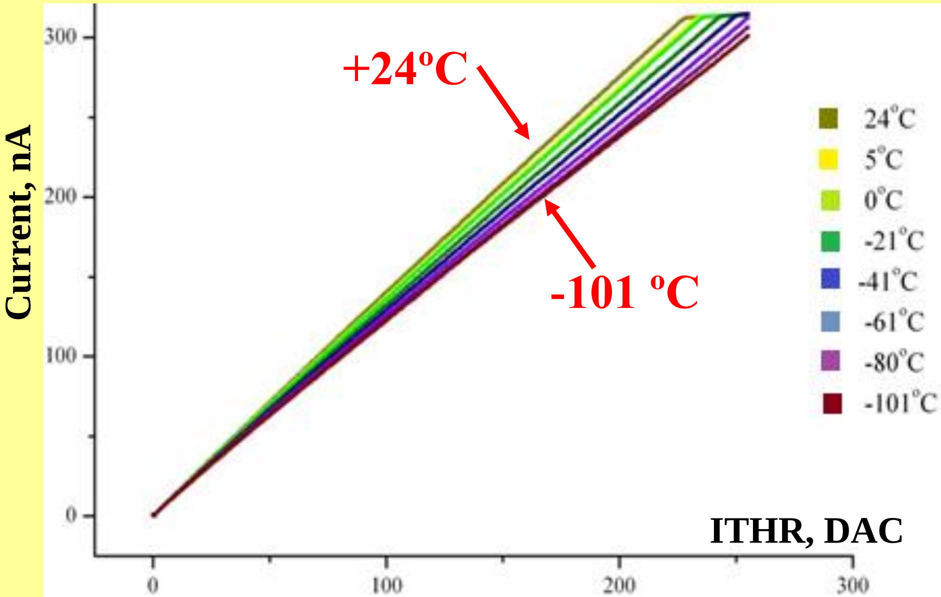
Two different modes of the cooling process:

1. **Cooling and heating with the chiller (alcohol-containing mixture), range: from +65 °C to -20 °C.**
   To protect a chip against frost the nitrogen was supplied in a cryo-box.

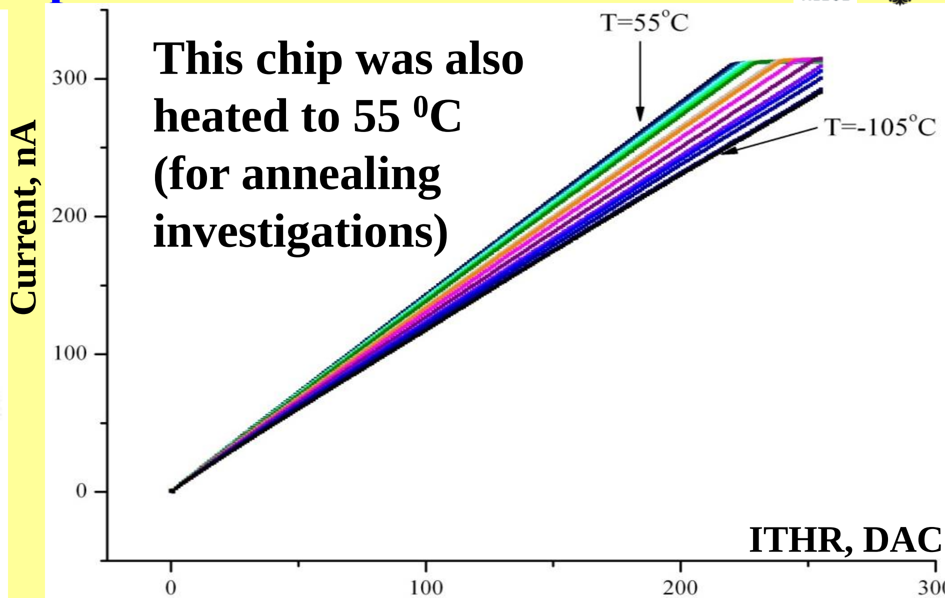
2. **Cooling with liquid nitrogen through evaporation.**
   The liquid nitrogen was heated by nichrome heater mounted inside the Dewar vessel. Cold gas is then flowing through platform (inside platform).
   We can regulate the nitrogen flow, by powering the nichrome heater (different currents up to 6 A).
   We can also control the volume of the liquid nitrogen by weighing the Dewar vessel.
   Temperature control:
   a) 3 thermocouples
   b) on-chip temperature sensor. This sensor works only up to -80 °C.

A temperature of -115 °C has been reached

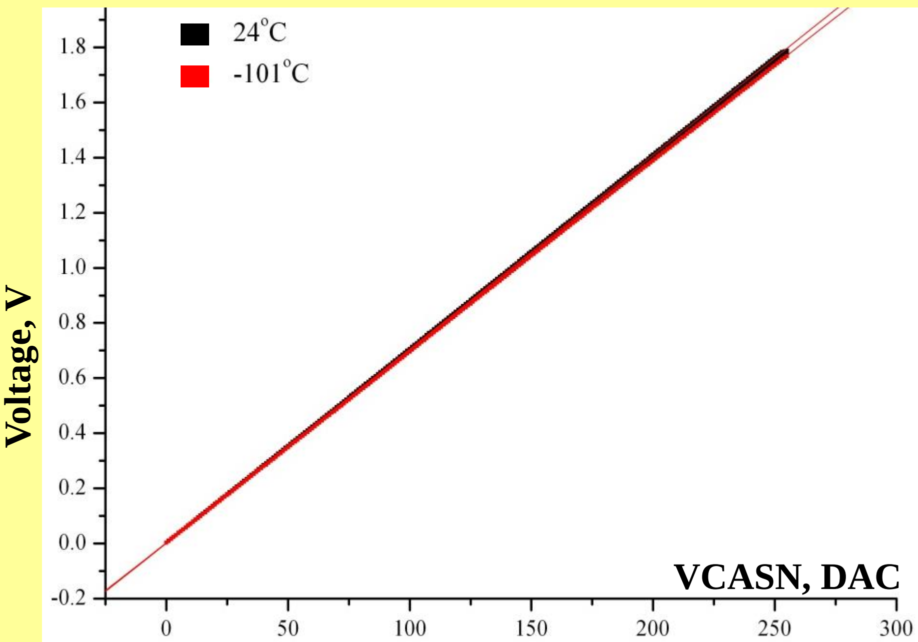
Study of the characteristics of ALICE ITS pixel detectors

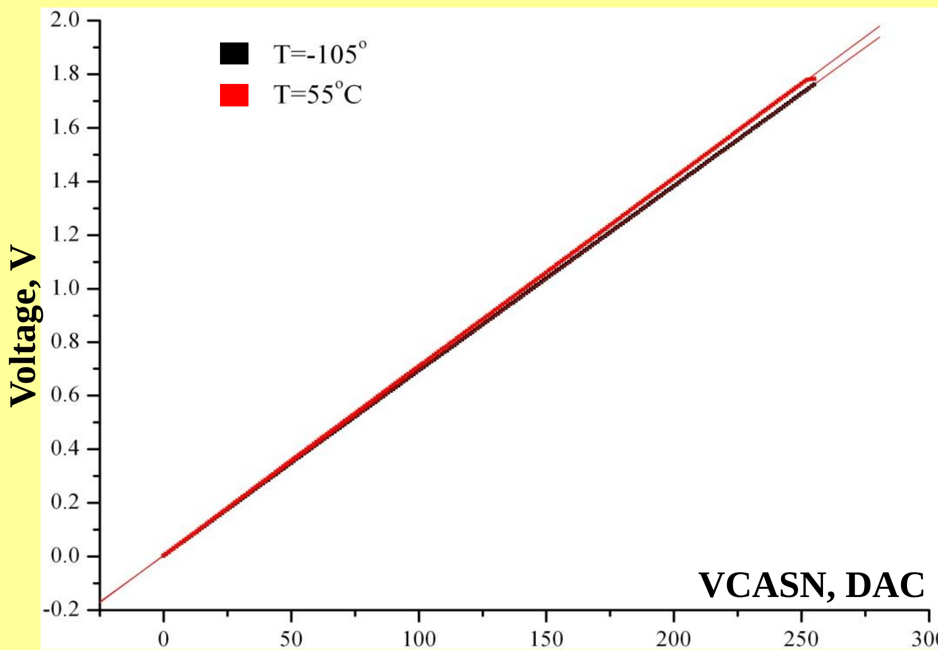


DAC Scan Chip W8R22 (low dose)

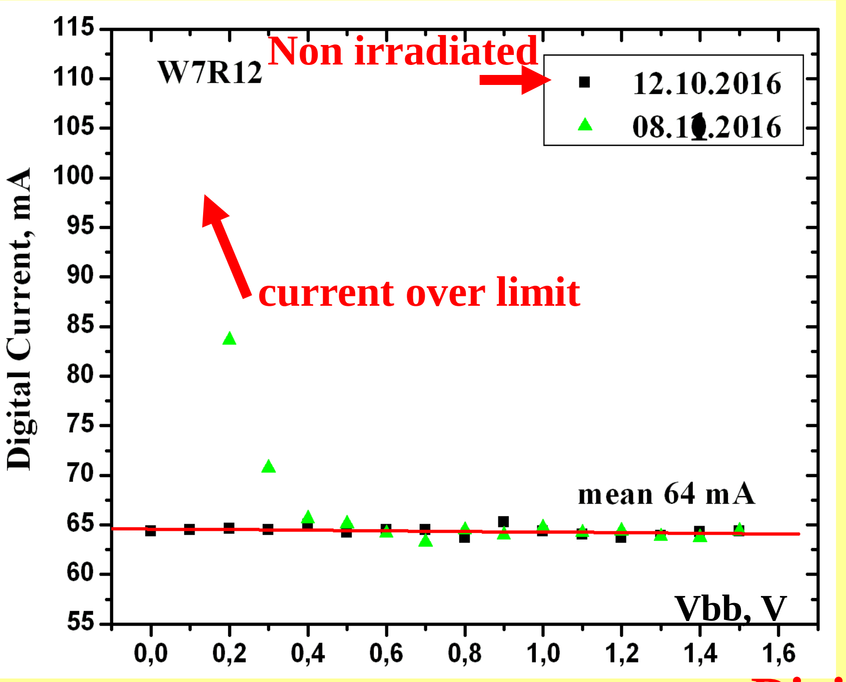


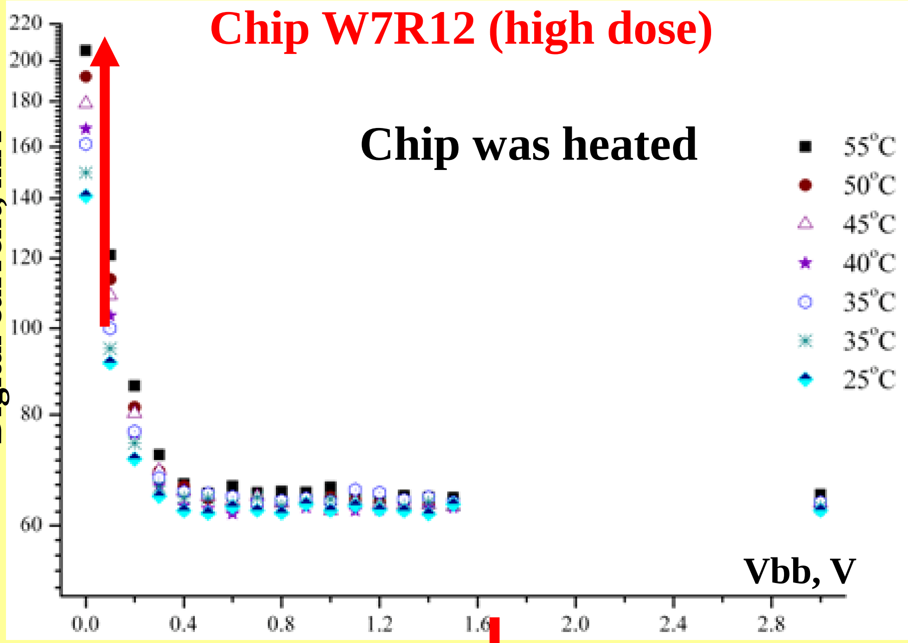
DAC Scan Chip W7R12 (high dose)



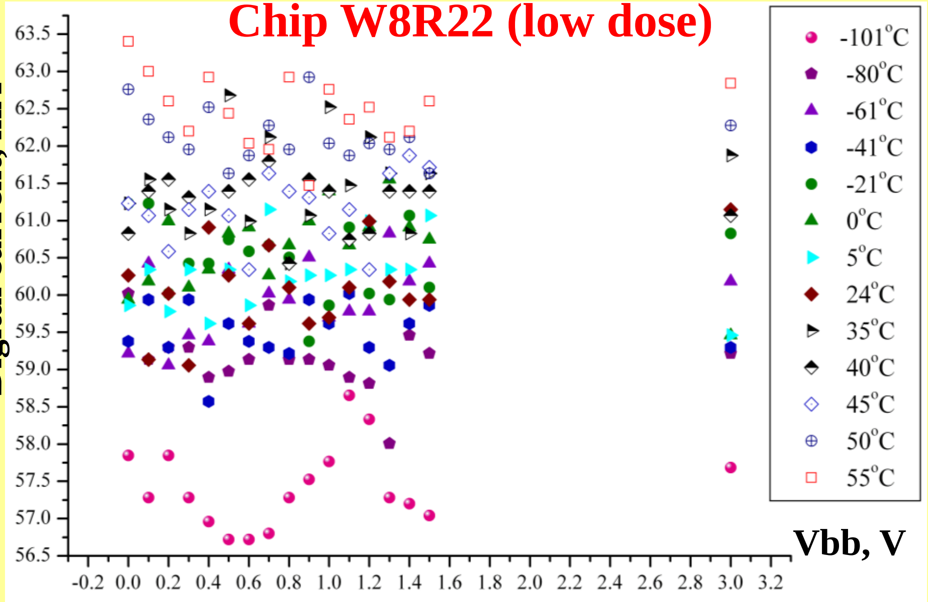


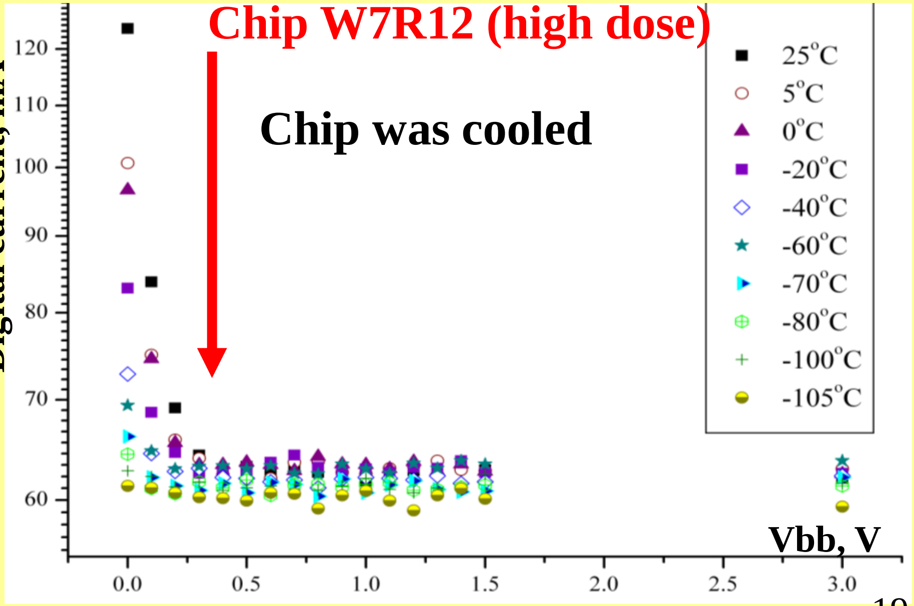
Study of the characteristics of full-scale Pixel Detector prototypes





Digital Currents



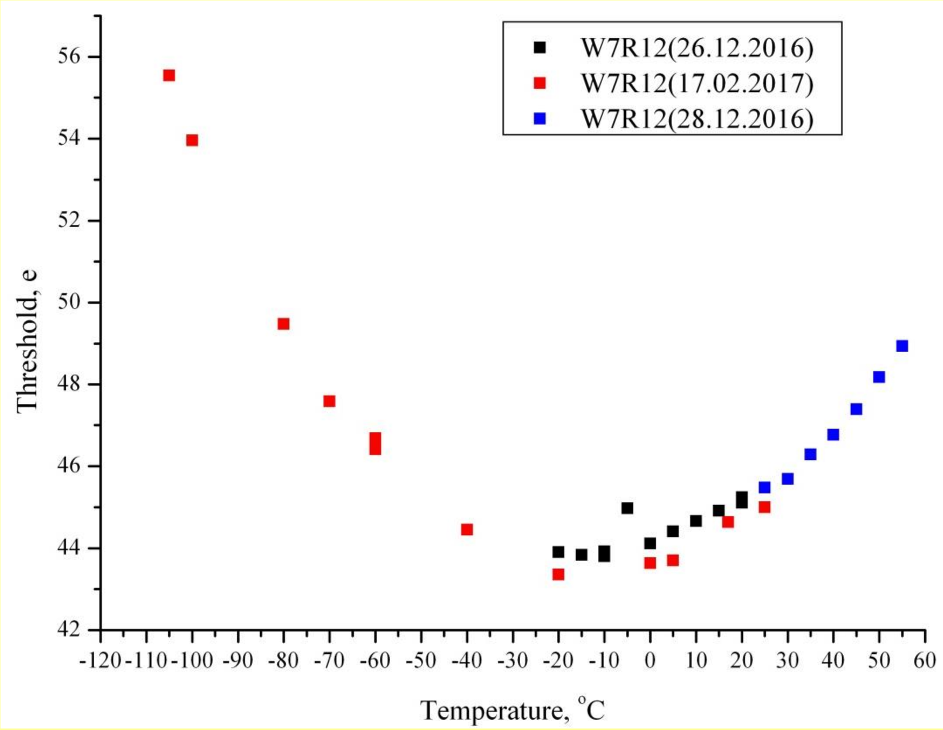


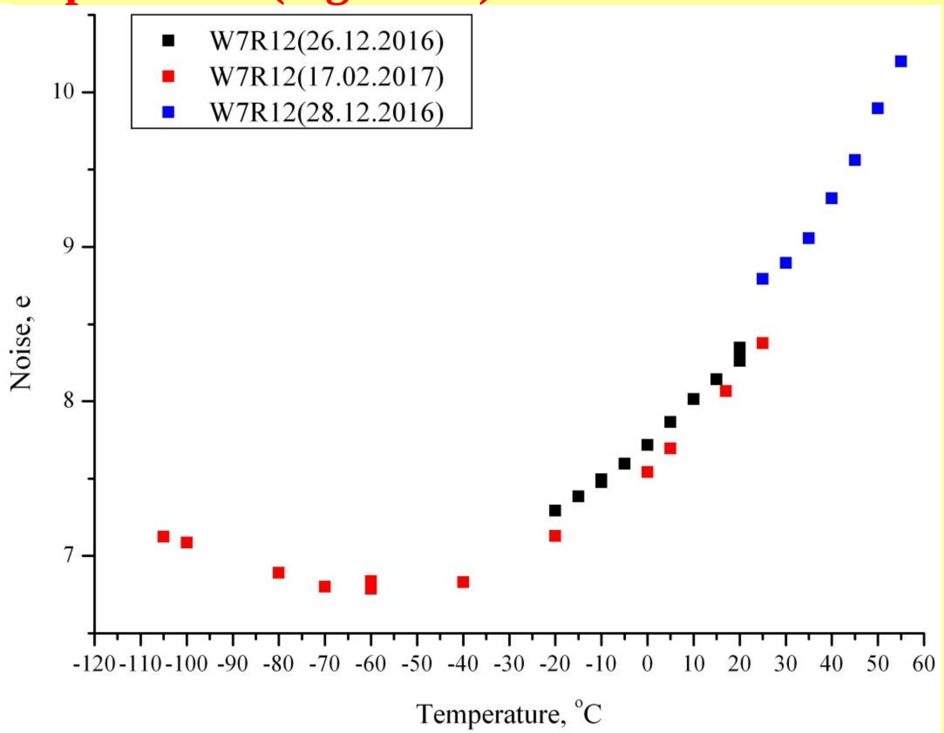
Study of the characteristics of ALICE ITS pixel detectors

Threshold Scan

Results for high dose irradiated chip

Chip W7R12 (high dose)





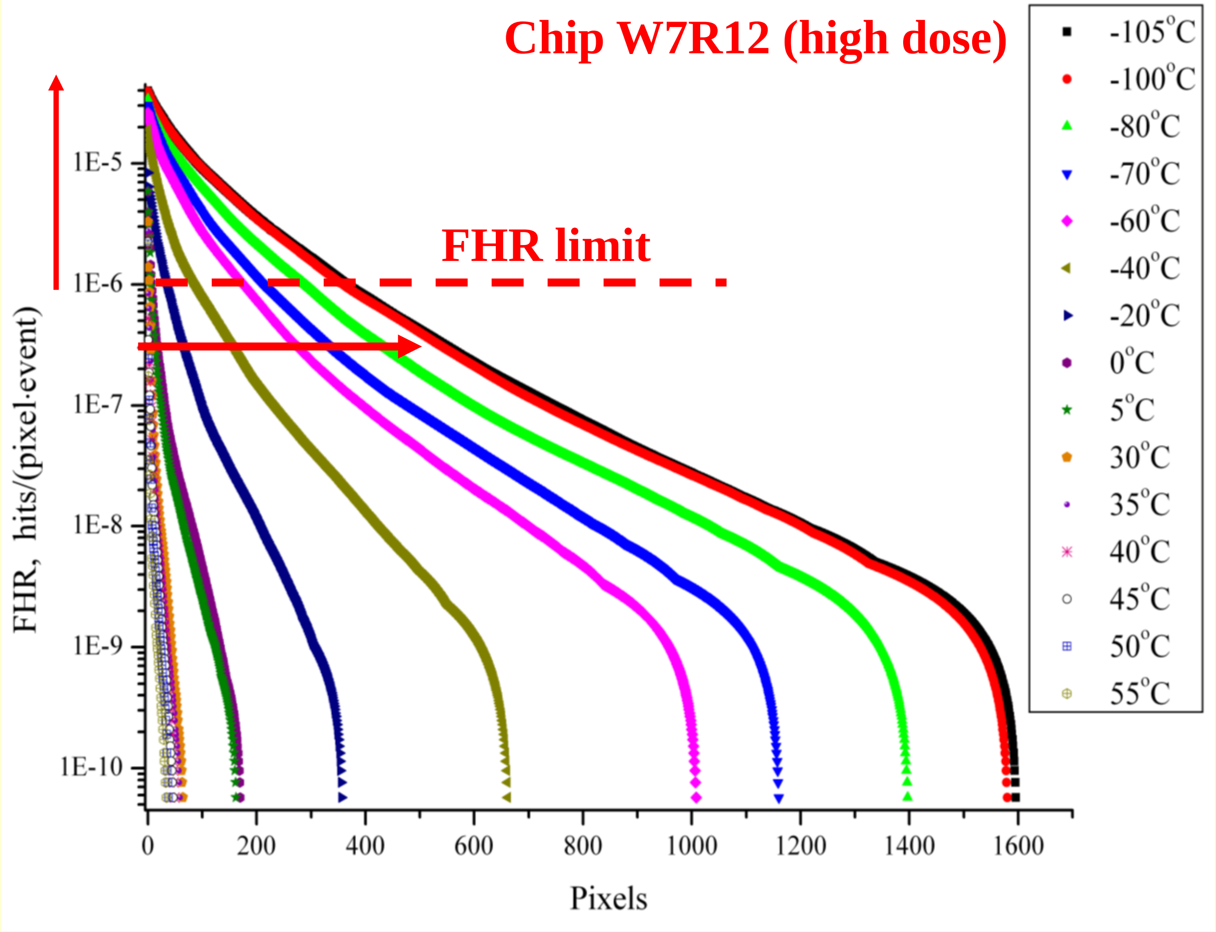
Before irradiation the threshold was ~ 85 e, after irradiation (300 krad) the threshold was ~ 45-50 e

Before irradiation the noise was ~ 6 e, after irradiation (300 krad) the noise was ~ 14 e

The threshold goes up both with increasing temperature and with lowering temperature, but initial value (before irradiation) of the threshold is not reached.

Study of the characteristics of ALICE ITS pixel detectors

Results for high dose irradiated chip **Noise Occupancy Scan**



1. **The number of pixels to be masked to achieve certain fake-hit rate increases with the lowering of temperature.**
2. **FHR also increases with temperature decreasing**

3. **For low dose irradiated chip and non irradiated chip fake-hit rate DID NOT change over the full temperature range: from -115 to +30 °C**

Study of the characteristics of ALICE ITS pixel detectors

Source test + Cluster analysis

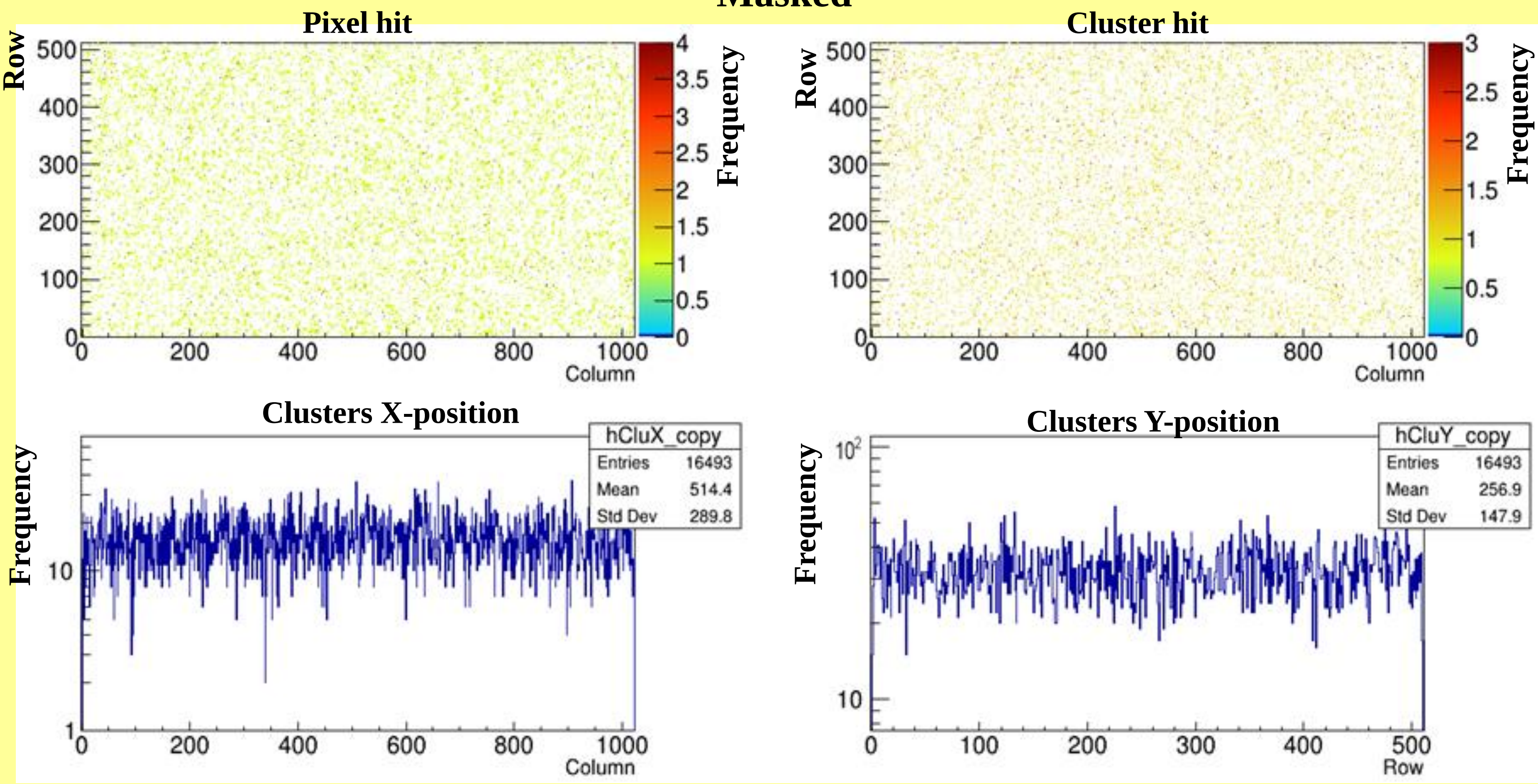
Results for high dose irradiated chip

Chip W7R12

Triggers: 2000000

Vbb = -3V

Masked



Source: ^{133}Ba, chip temperature: -115 °C

Gamma: 5.64 keV

Study of the characteristics of ALICE ITS pixel detectors

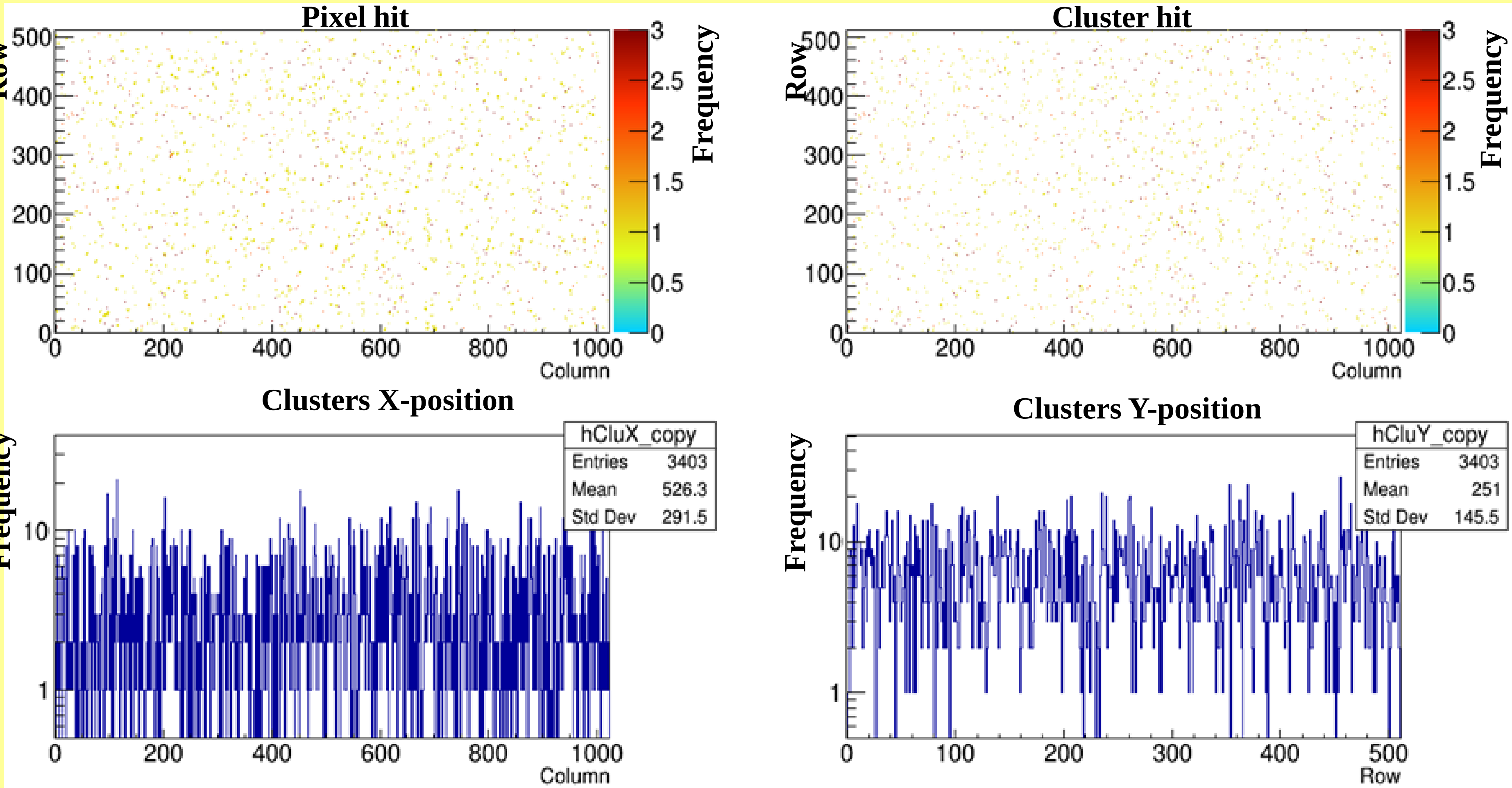
Source test + Cluster analysis

Chip W7R12

Triggers – 2000000
Vbb = -3V

Results for high dose irradiated chip

Masked

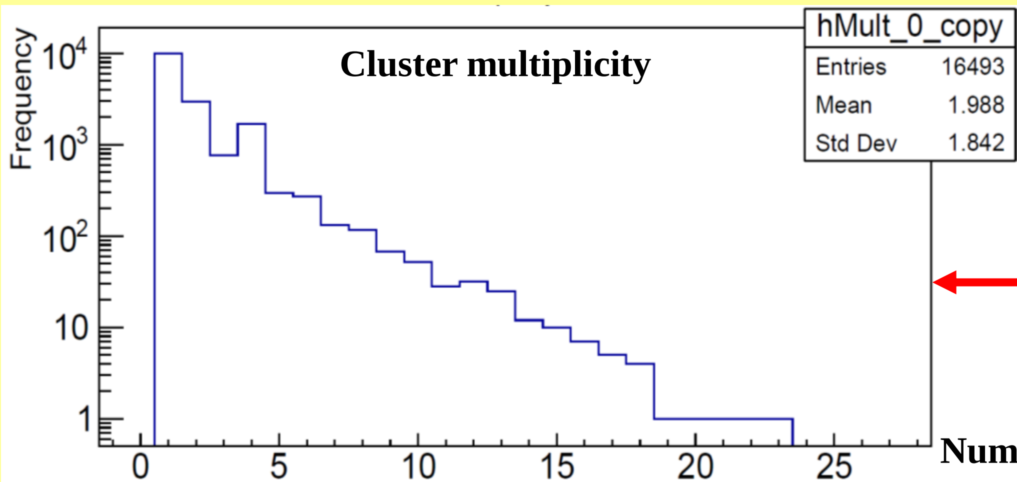


Source: ^{14}C, chip temperature: -100 ^{o}C
beta: 156 keV

for another beta source Sr-Y see Back-up

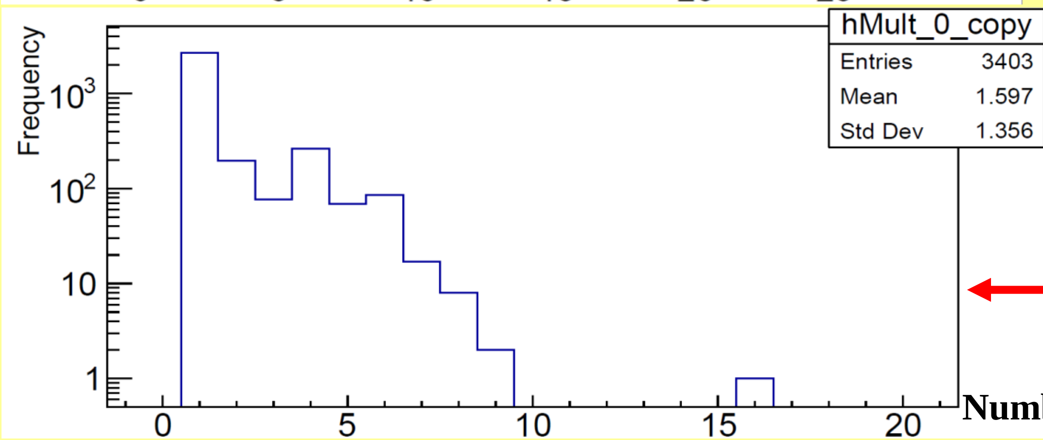
Source test + Cluster analysis

Chip W7R12 (high dose)



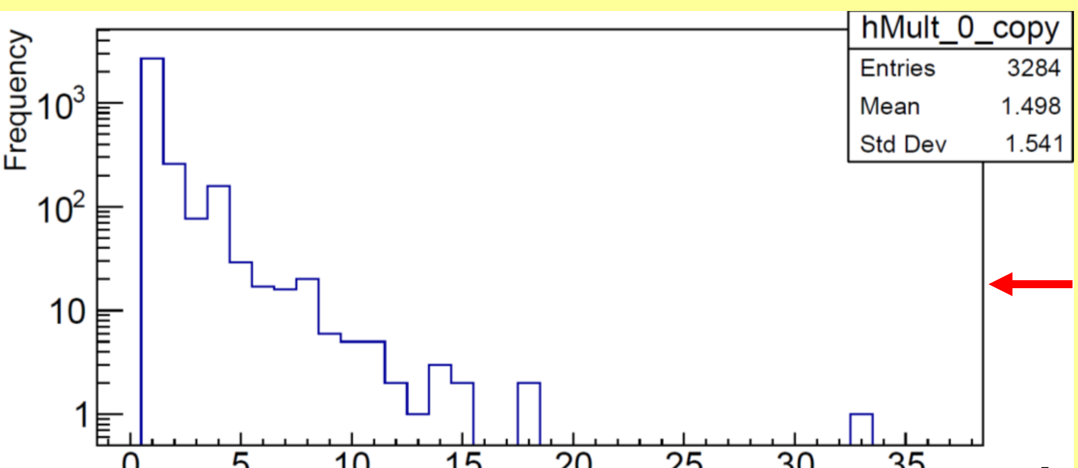
^{133}Ba, chip temperature -115 ºC

Number of pixels in cluster



^{14}C, chip temperature -100 ºC

Number of pixels in cluster



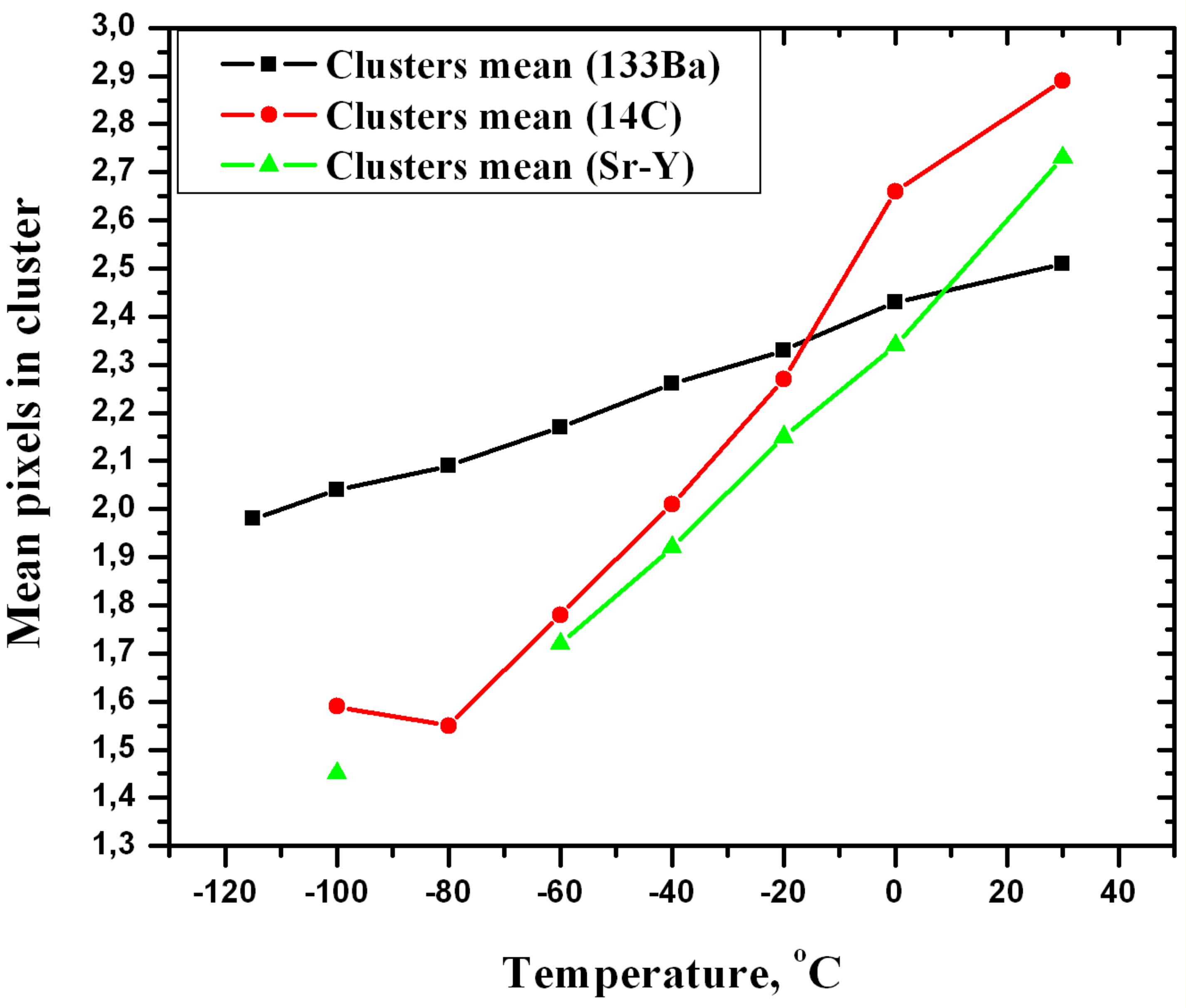
Sr-Y, chip temperature -100 ºC

Number of pixels in cluster

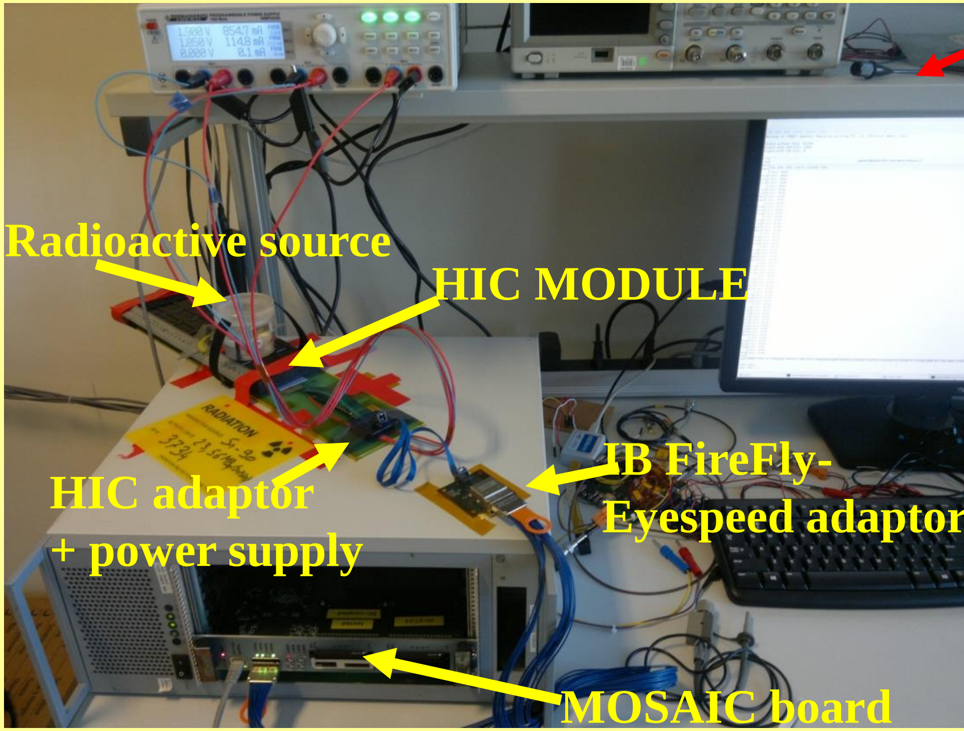
Study of the characteristics of ALICE ITS pixel detectors

Source test + Cluster analysis

Chip W7R12 (high dose)



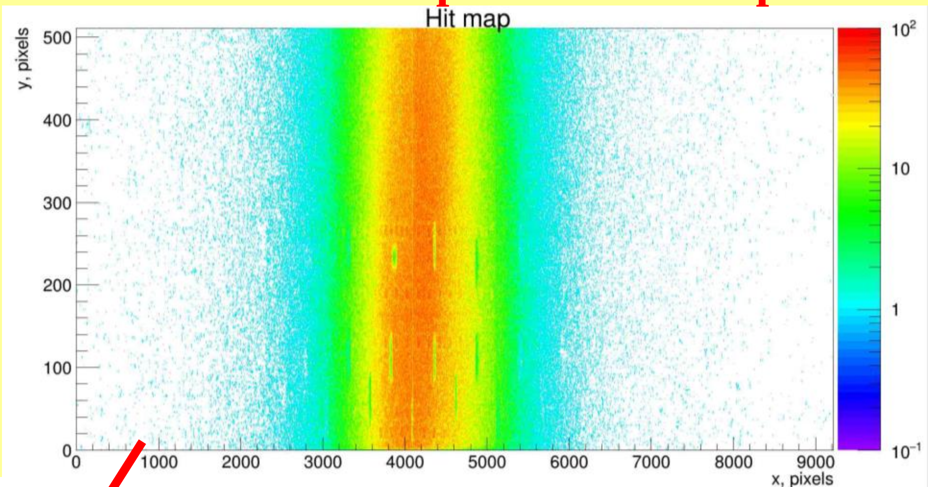
Study of the characteristics of ALICE ITS pixel detectors

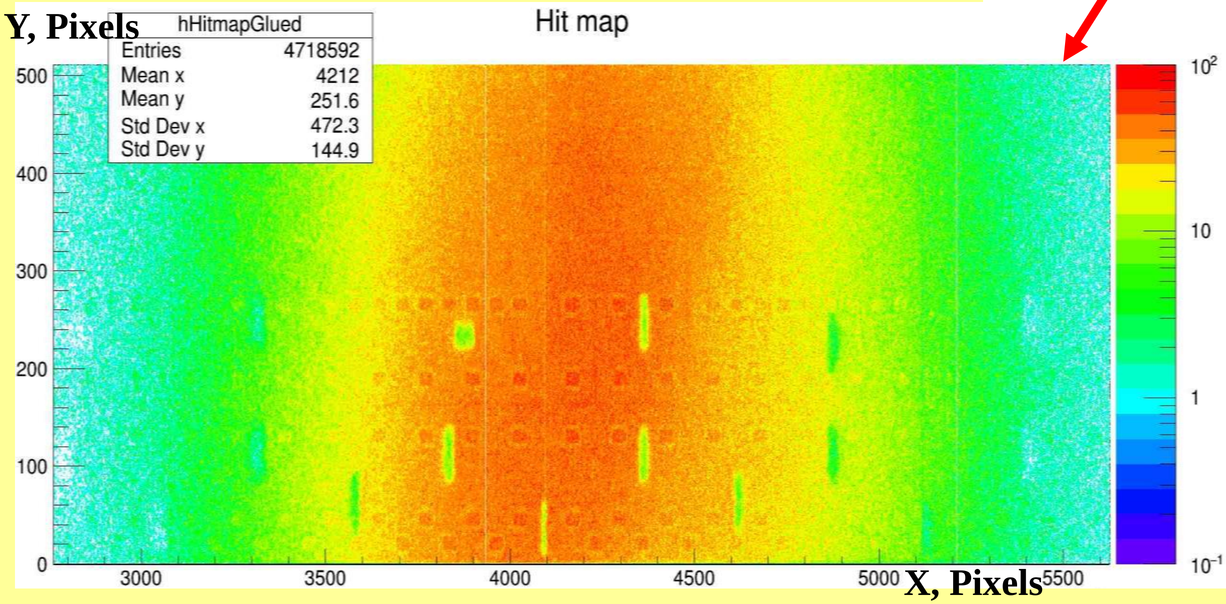


HIC – Hybrid Integer Circuit consists of 9 ALPIDE chips

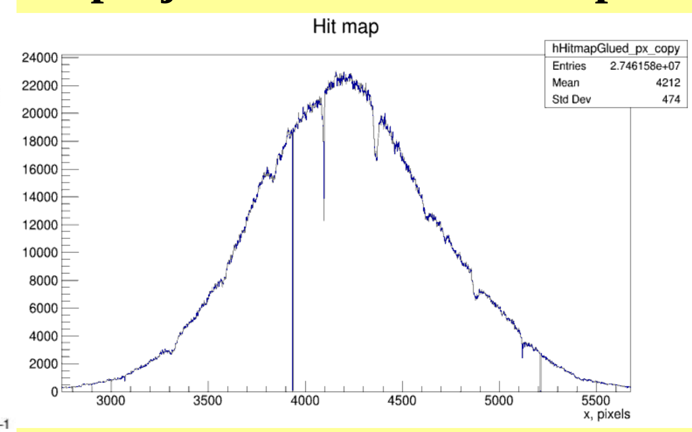
MOSAIC - MOdular System for Acquisition Interface and Control

Beam spot between chip 3-4



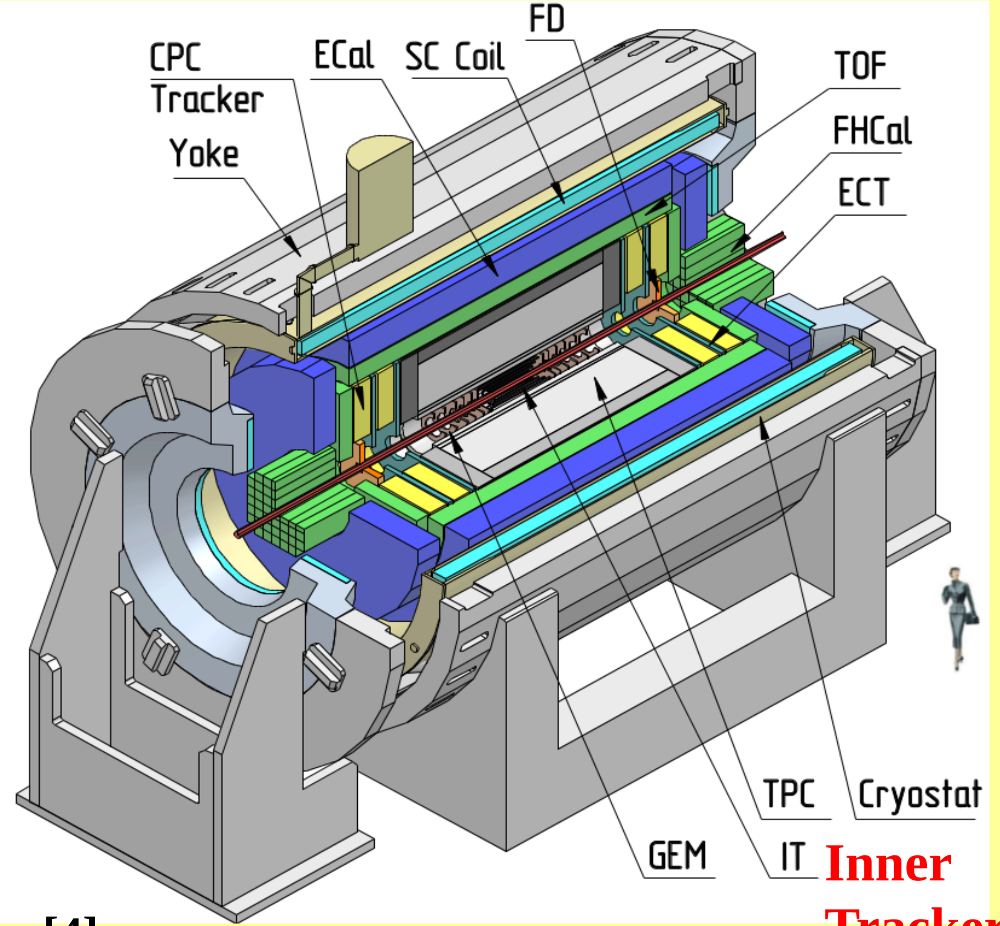


Hit projection on X-axis: chip 3-4



Pixel detectors for NICA experiments

NICA MPD



Inner Tracker

[4]

High vertex resolution

Fast readout (for Au-Au collisions the luminosity will be 10^{27} $cm^{-2}s^{-1}$)

Low material budget

Parameter	**ALPIDE Performance**
Silicon thickness	50 μm
Chip dimension	15 mm x 30 mm
Spatial resolution	5 μm
Power density	40 mW/cm^2
Max. integration time	10 μs
Detection efficiency	>99%
Fake-hit rate	<<<10^{-6} /event/pixel
Total Ionizing Dose	Up to 500 krad

One of the possible solutions:

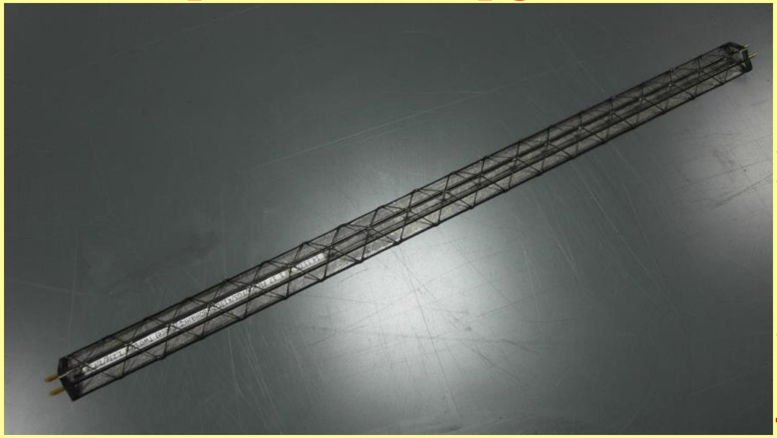
1. Use ALICE MAPS – ALPIDE

2. Use carbon ultra-lightweight support and cooling structures developed for the upgrade of ALICE at the LHC

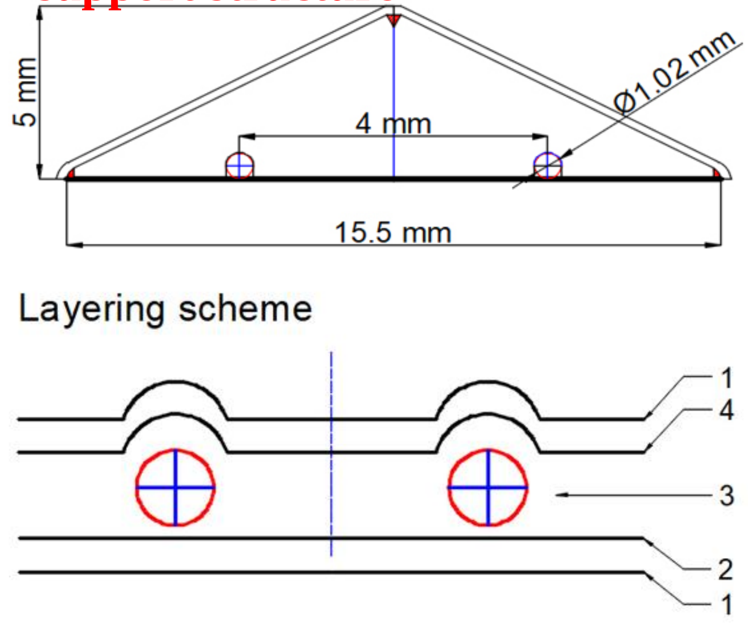
Pixel detectors for NICA experiments

NICA MPD

2. Use carbon ultra-lightweight support and cooling structures developed for the upgrade of ALICE at the LHC

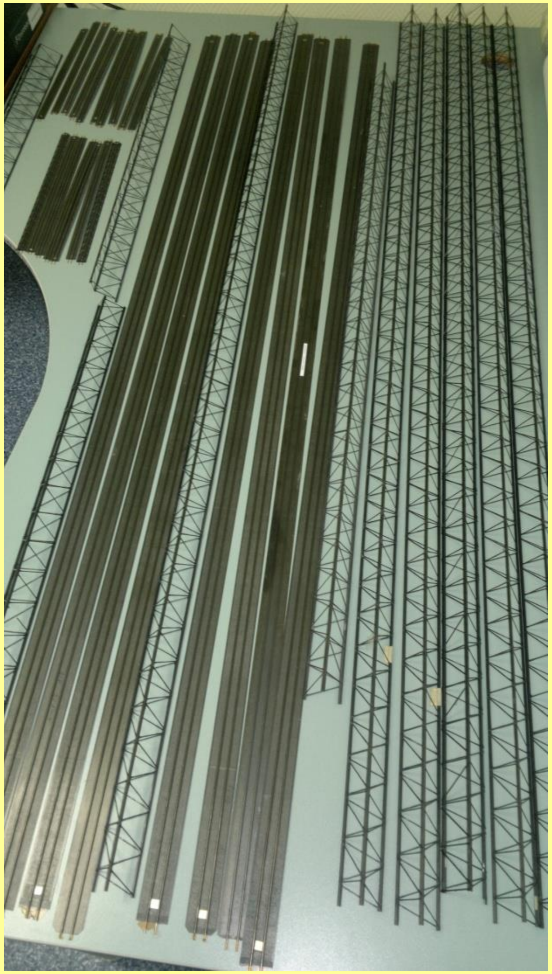


ALICE Inner barrel carbon support structure [5]



But for MPD Inner Tracker detailed simulations of the geometry and requirements to all detector modules <u>should be done!</u>

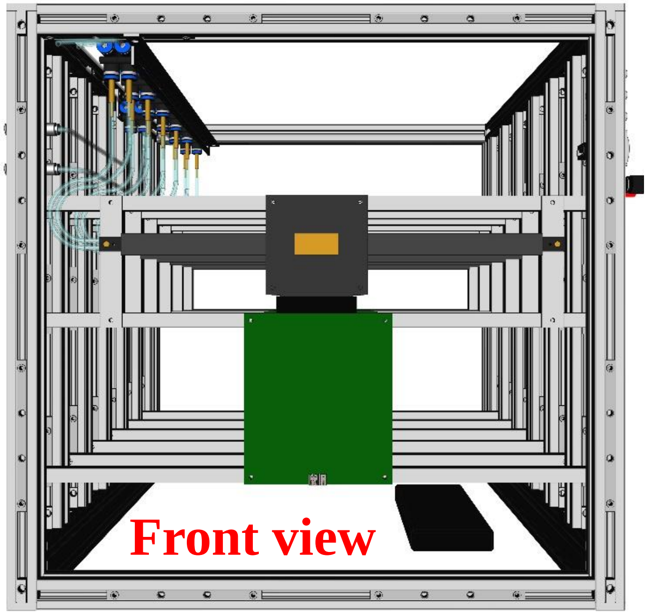
The same for NICA SPD experiment

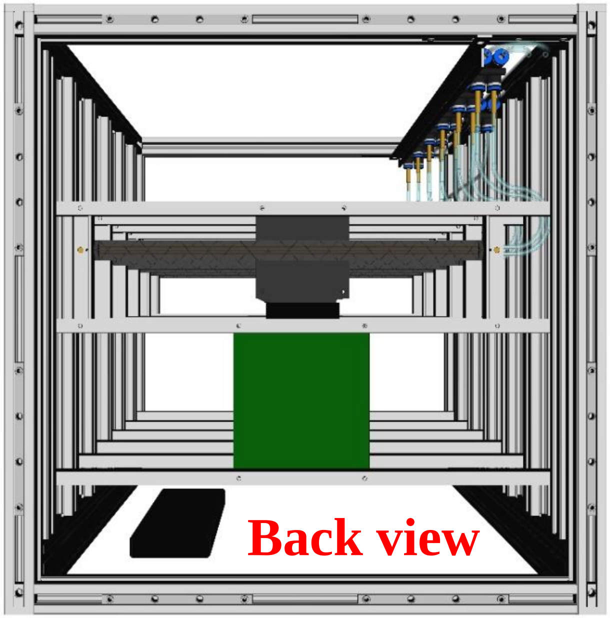


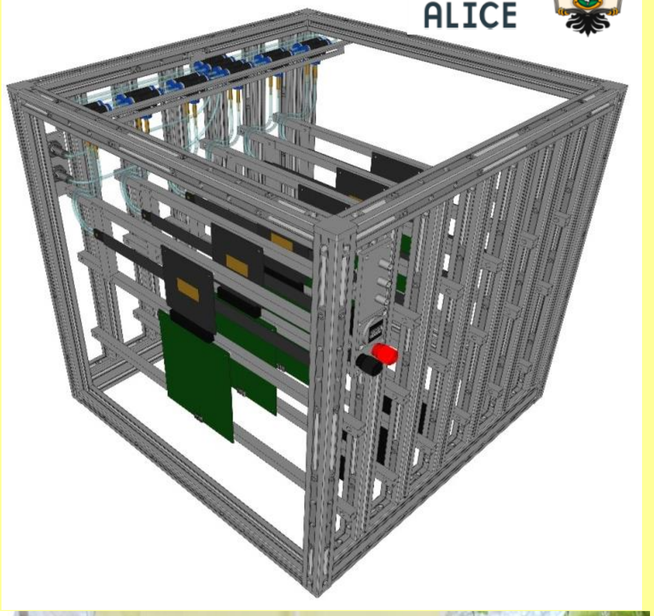
1. **Carbon-fiber fleece 20 µm (down and top);**
2. **Carbon-fiber plate 18 mm wide, 70 µm;**
3. **Round polyimide tubes, diameter 1.02 mm;**
4. **Carbon paper, 30 µm.**

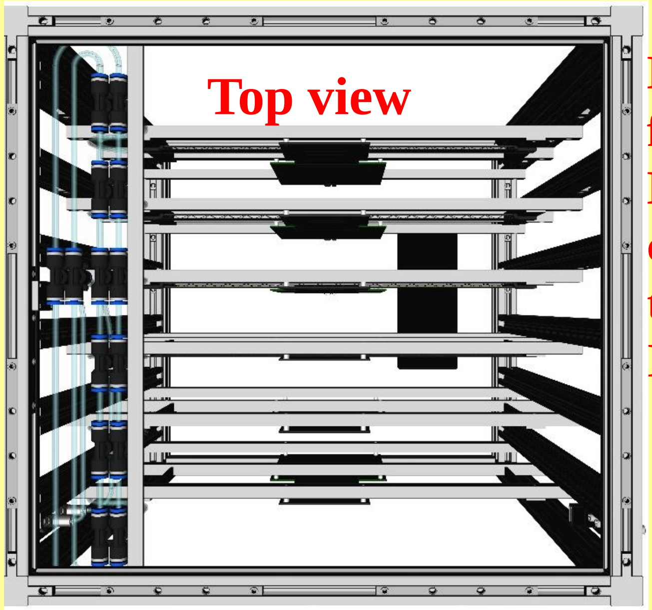
Pixel detectors for NICA experiments

NICA MPD

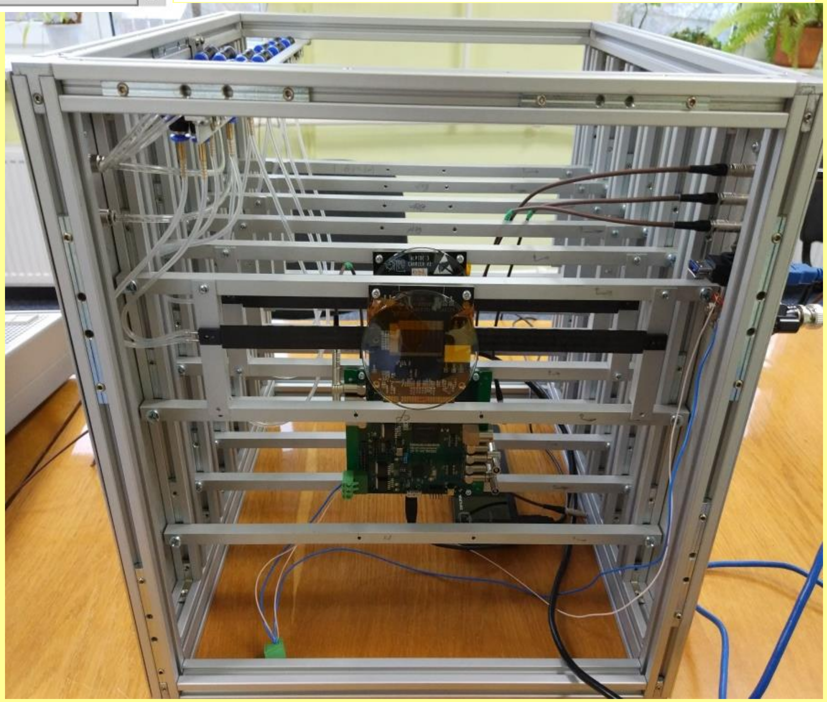








Experimental set-up for the ALPIDE MAPS characterization for the NICA MPD Inner Tracker: VT-1



Summary

1. The overview of ALICE ITS upgrade in detector context. New MAPS detectors.
2. Two test stations (based on the chip, DAQ board and software, cryogenic module) were constructed within the ITS upgrade project for the characterization and tests of the ALPIDE detectors.
3. To investigate the main characteristics of the pixels, electrical tests and comprehensive studies with a variety of gamma and beta sources were carried out.
4. The studies of irradiated sensors at different temperatures, including cryogenic temperatures, were also carried out.
5. Ideas of how the ALICE technology could be applied for MPD or SPD experiments

Experimental set-up for the future characterization of ALPIDE MAPS for the NICA MPD Inner Tracker: VT-1 has been developed, constructed and tested.

Next plans

1. Modernization of VT-1 for the beam measurements.
2. Studies of the ALPIDE characteristics using electron beams and NUCLOTRON beams in JINR
3. Investigation of characteristics of ALPIDE (Final Version of the detector) and Hybrid Integrated Circuit (with 9 ALPIDE chips).

Literature

1. ALICE: http://cdsweb.cern.ch/collection/ALICE%20Photos?ln=ru

2. L.Musa, ECFA High Luminosity LHC Experiments Workshop, Aix-Les Bains, 3-6 October 2016 and F. Reidt, PIXEL2016 , 05.09.2016 - 09.09.2016.

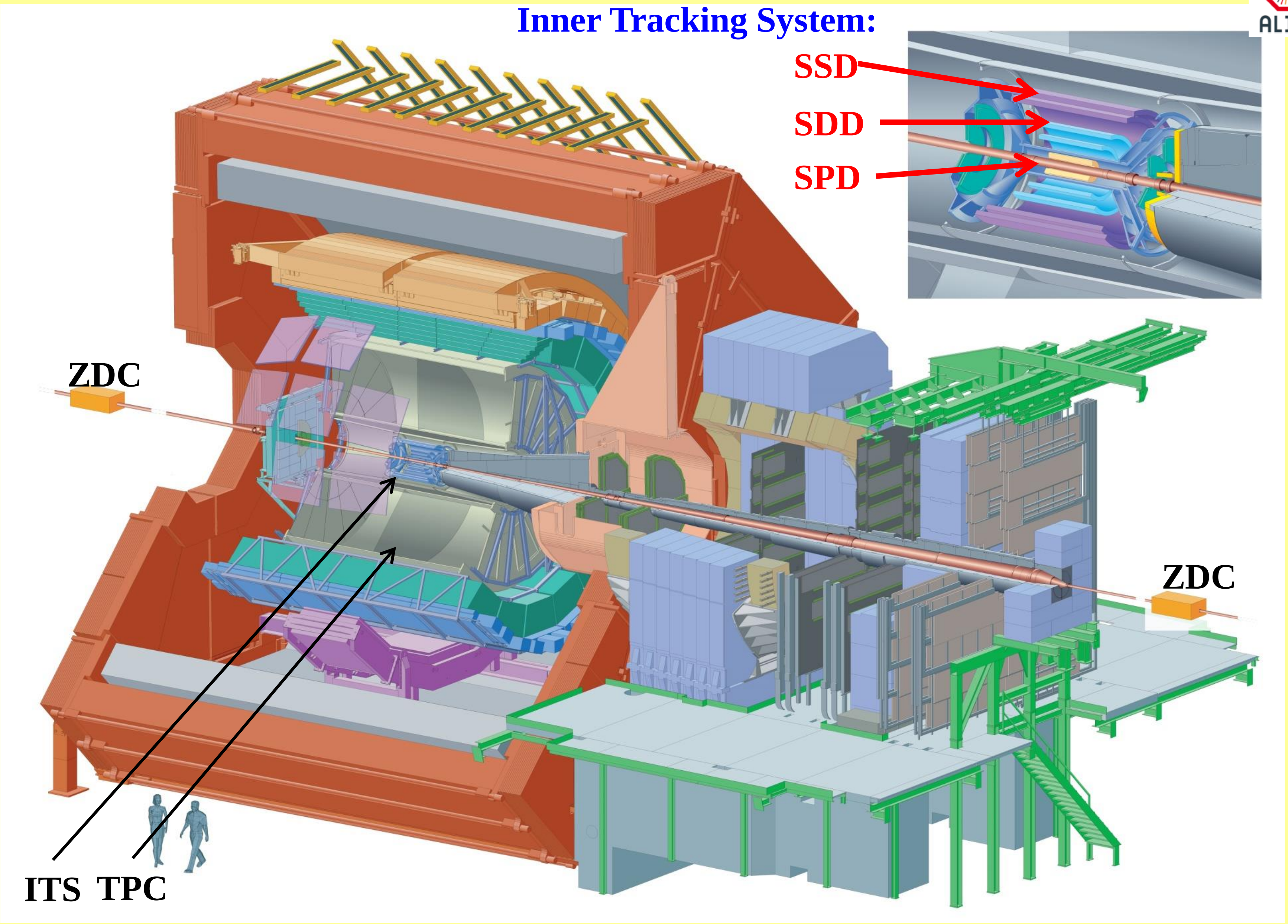
3. The ALICE Collaboration. “Technical Design Report for the Upgrade of the ALICE Inner Tracking System”. In: J. Phys. G41 (2014), p. 087002.

4. V.D. Kekelidze, on behalf of the NICA Collaboration, JINST 12 C06012, 2017.

5. V.I. Zherebchevsky, I.G. Altsybeev, G.A. Feofilov, A. Francescon, C. Gargiulo, S.N. Igolkin et al., JINST 13 T08003, 2018.

BACK-UP SLIDES

ALICE Inner Tracking System (current status)



Current ALICE set-up with its main detectors [1]

Physics

Heavy- flavour measurements with largely improved tracking and read-out rate capabilities

Two main open questions concerning heavy-flavour interactions with the QGP medium are:

1. Thermalisation and hadronisation of heavy quarks in the medium. Measuring the heavy-flavour baryon/meson ratio, the strange/non-strange ratio for charm, the azimuthal anisotropy for charm and beauty mesons, and the possible in-medium thermal production of charm quarks

2. Heavy-quark in-medium energy loss and its mass dependence.

Also detailed measurement of low-mass dielectrons (low material budget and the improved tracking precision and efficiency of the new ITS):

Thermal radiation from the QGP, via real and virtual photons detected as dielectrons

Also production measurement of hypernuclear states

Physics

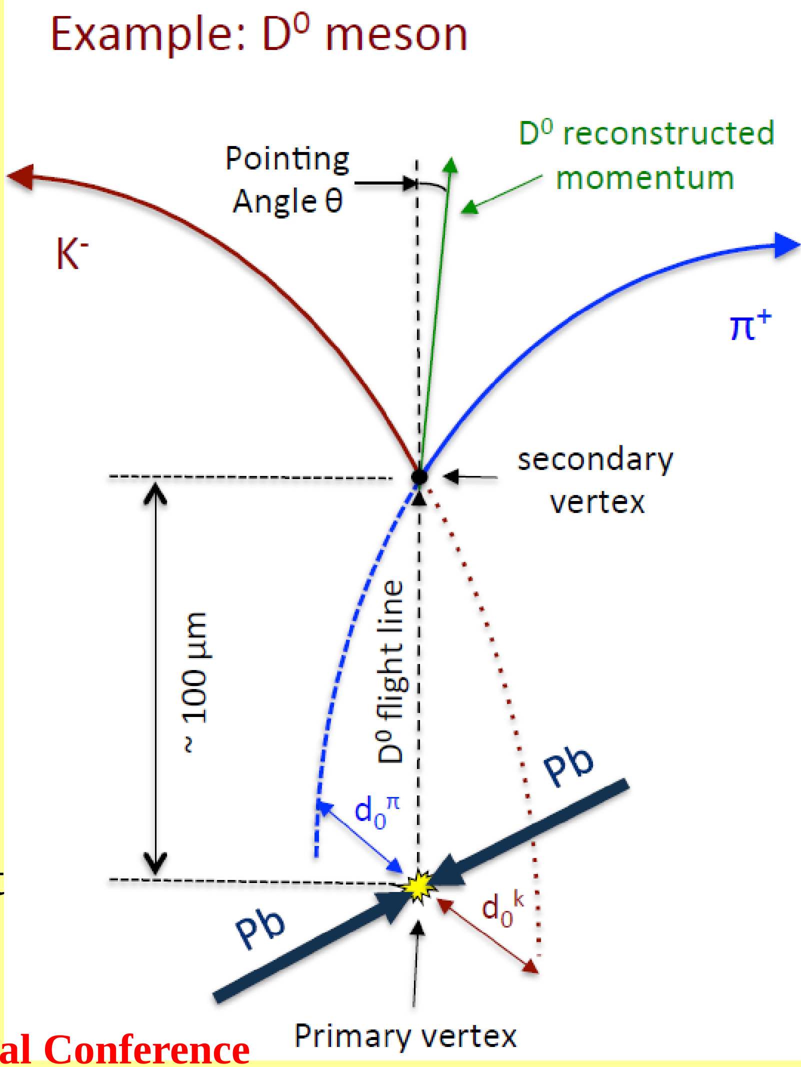
Improve primary vertex reconstruction, momentum and impact parameter Resolution

Reconstruction of secondary vertices from c and b decays with high resolution

Particle	Decay Channel	c·τ (μm)
Λ_c^+	$pK^-\pi^+$	60

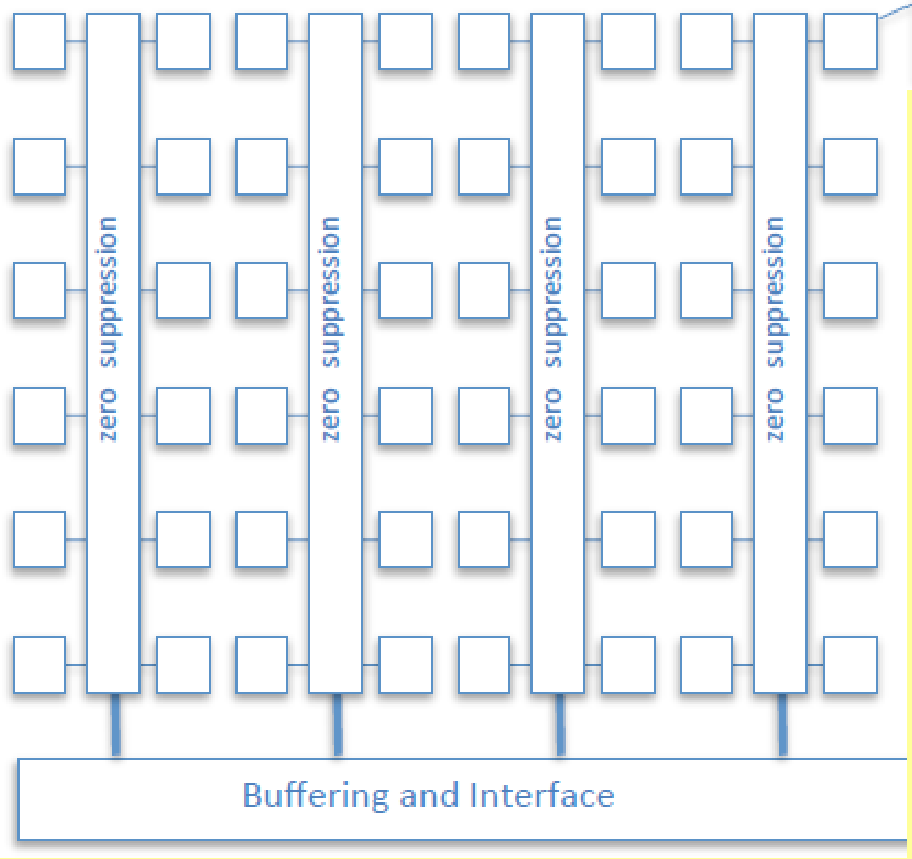
Current ITS Impact Parameter Resolution ~ 70 μm at p_t=1GeV/c

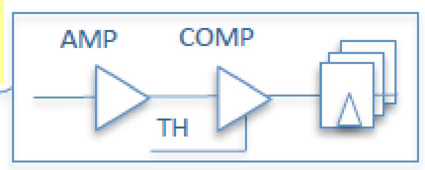
Secondary vertex determination



New pixel sensors for ALICE experiment: ALICE Pixel detectors (ALPIDE family)

ALPIDE chip architecture





In-pixel amplification
In-pixel discrimination
In-pixel (multi-) hit buffer

The zerosuppression is performed within the matrix. Address-Encoder Reset-Decoder circuit is employed. It can either be controlled by an external trigger signal or operated in continuous acquisition mode.

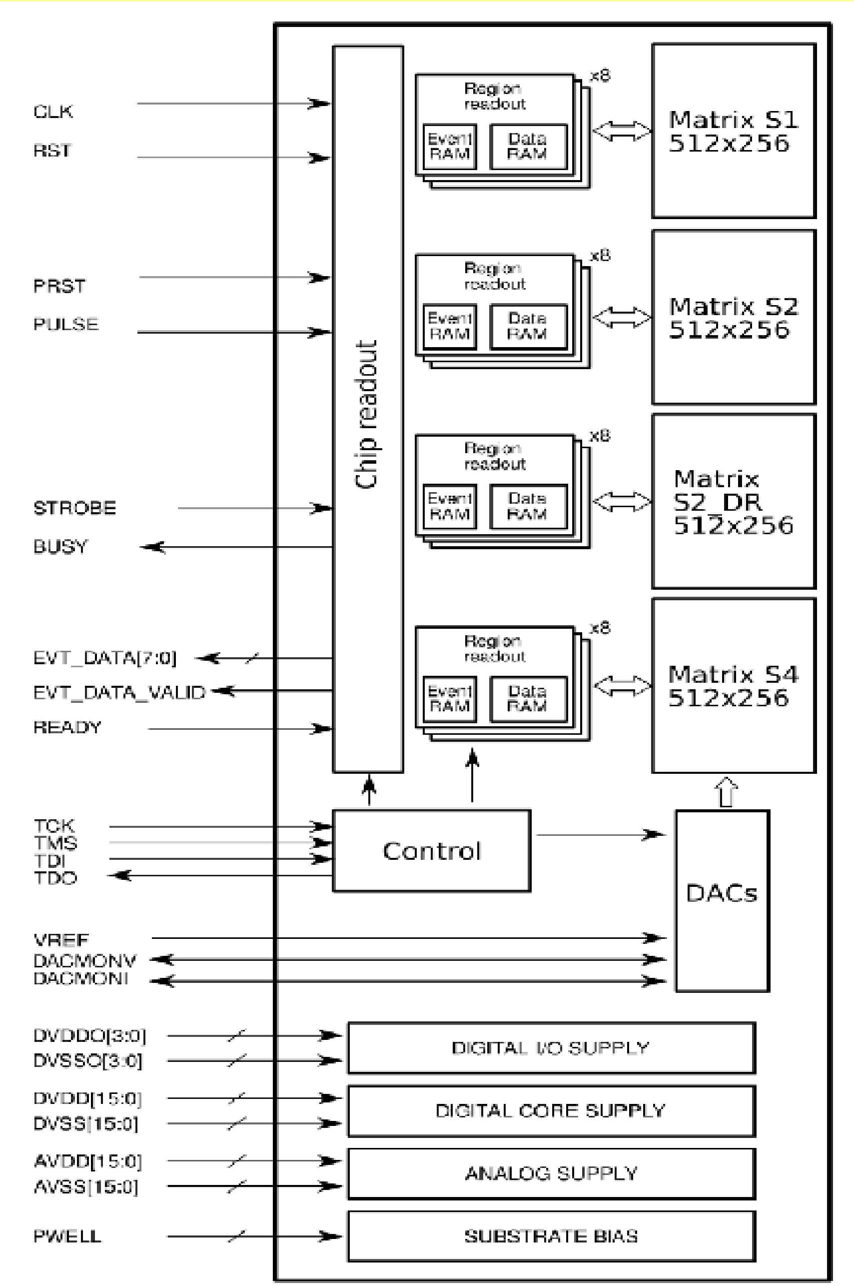
Advantages

1. Analog signal is no longer driven over the column lines → reduce power consumption and increase readout speed.

2. The realization of in-pixel discriminators: opportunity of readout, in which the digital outputs of the pixels are scanned by an encoder circuit that directly produces the address of hit pixels as output.

3. The circuit works in a way that the pixel hit register is reset after the read operation and the circuit will move on to the next hit pixel to encode its address. The procedure is iterated until the full pixel matrix is read out.

New pixel sensors for ALICE experiment: ALICE Pixel detectors (ALPIDE family)



A general block diagram of pALPIDE-1,2

All the analogue signals required by the front-ends are generated by a set of 11 (for pALPIDE-1,2) and 14 (pALPIDE-3) on-chip digital-to-analog converters (DACs).

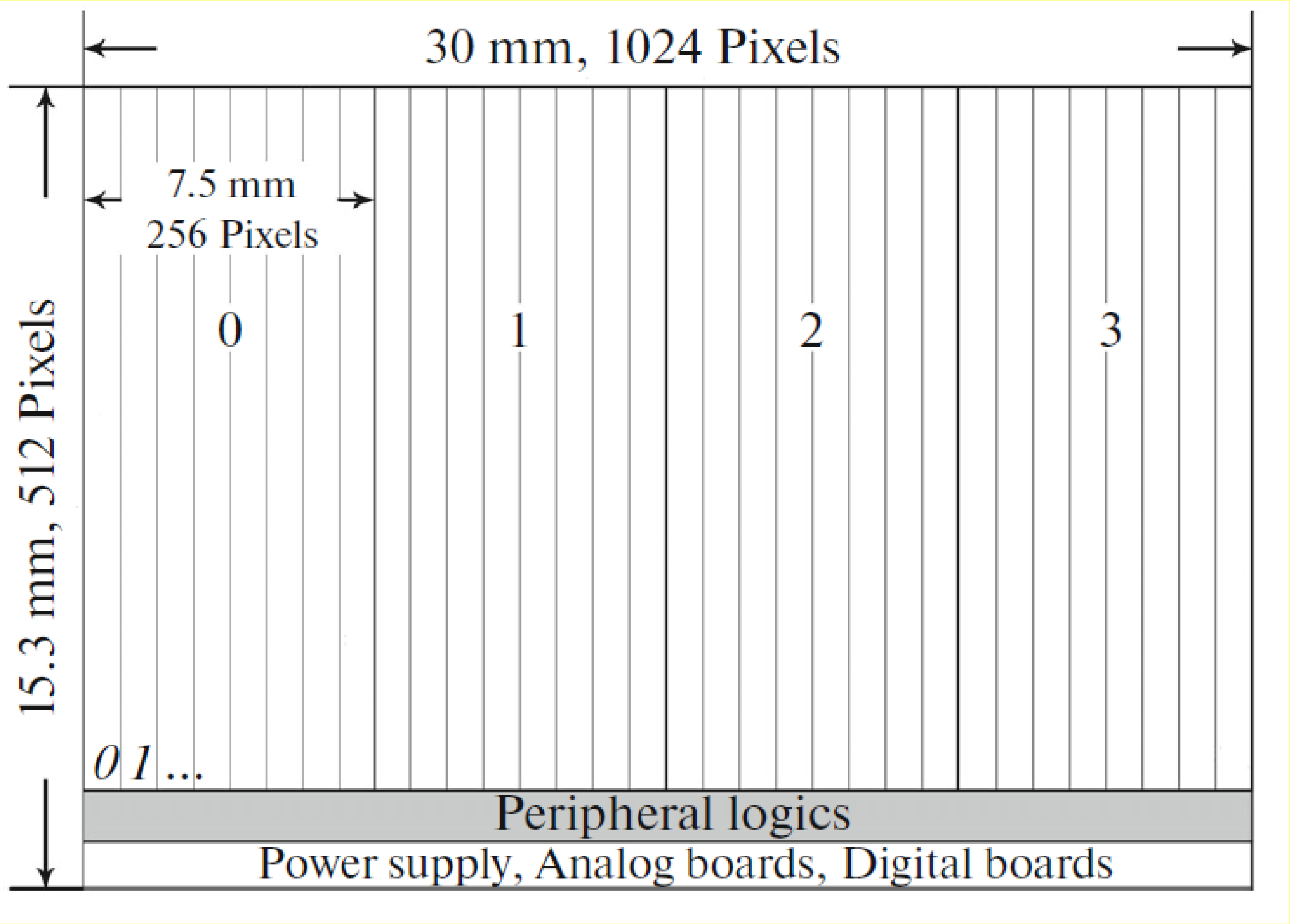
The region readout units contain multi-event storage SRAM memories.

Hit data from the 32 region readout blocks are combined and transmitted on a parallel 8-bit output data port.

A top-level Control block provides full access to the control and status registers of the chip.

New pixel sensors for ALICE experiment: ALICE Pixel detectors (ALPIDE family)

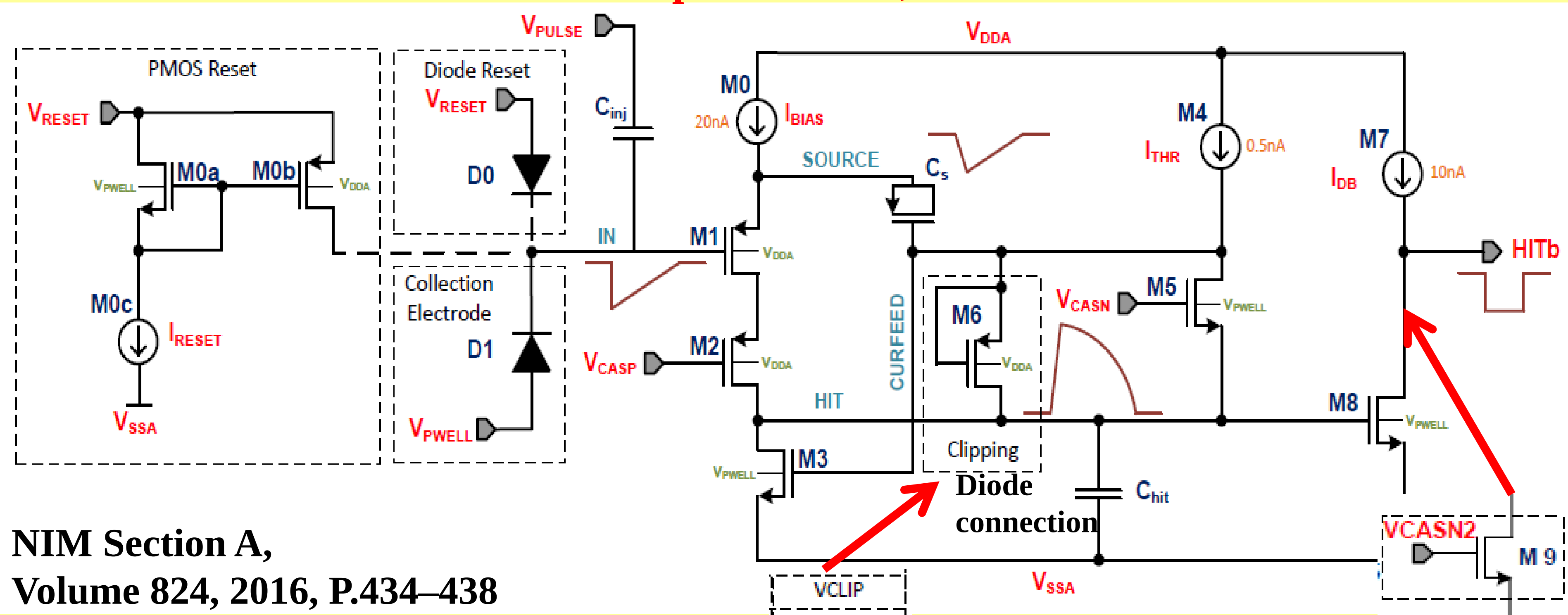
Pixel matrix of pALPIDE-1,2



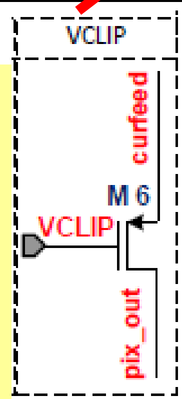
The pixel matrix is divided into 32 regions arranged in sectors. Each sector includes 8 double columns (0, 1, 2..). In the space between each pair of double columns is a priority encoder circuit (Address-Encoder Reset-Decoder) that performs the asynchronous reading of a signal from the pixels in these columns.

A comprehensive scheme for the pixel front-end circuit
Including all possible variations

For pALPIDE-1,2



NIM Section A,
Volume 824, 2016, P.434–438



For pALPIDE-3
for sectors: 3,4,5,7
add VCLIP

For pALPIDE-3
for sectors: 0,3,4,5,7
add VCASN-2 (M9)

New pixel sensors for ALICE experiment: ALICE Pixel detectors (ALPIDE family)

Each sector implements a different front-end electronics

pALPIDE-1

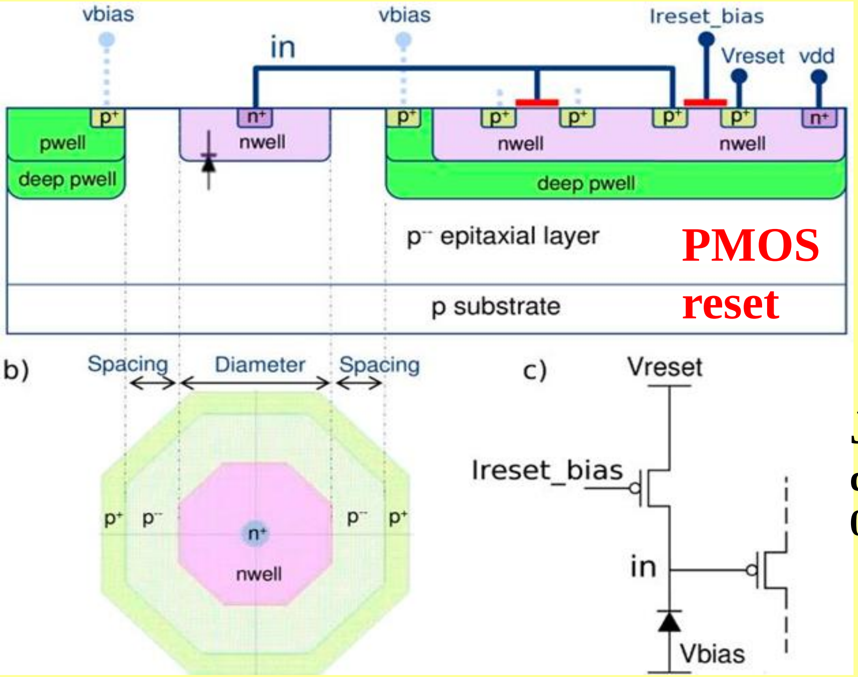
Sector	N-well diameter	Spacing	Reset type
0	2 um	1 um	PMOS
1	2 um	2 um	PMOS
2	2 um	2 um	Diode
3	2 um	4 um	PMOS

pALPIDE-2

Sector	N-well diameter	Spacing	Reset type
0	2 um	2 um	PMOS
1	2 um	2 um	PMOS
2	2 um	4 um	PMOS
3	2 um	4 um	Diode

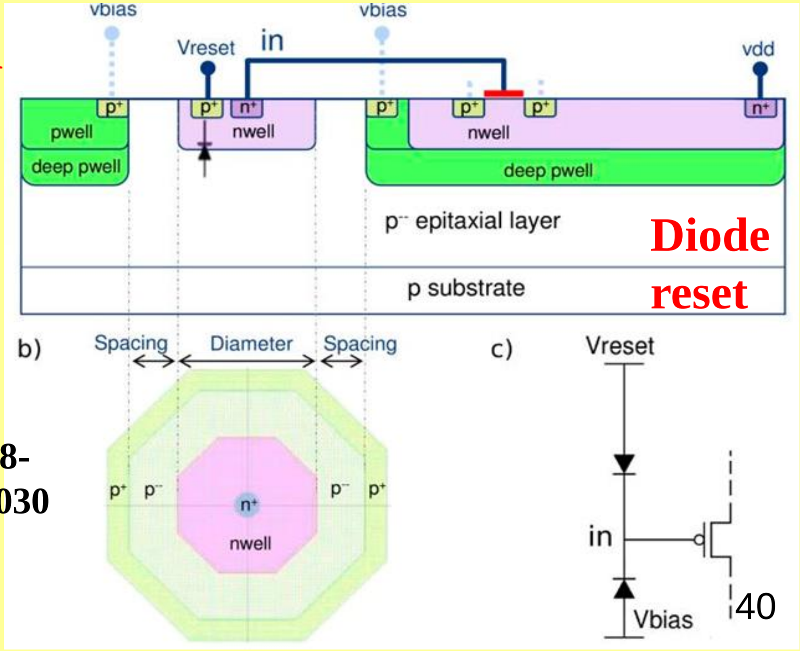
ALPIDE →

Sector	N-well	Spacing	Reset type
1	2 um	3 um	Diode



PMOS reset

Collection electrode

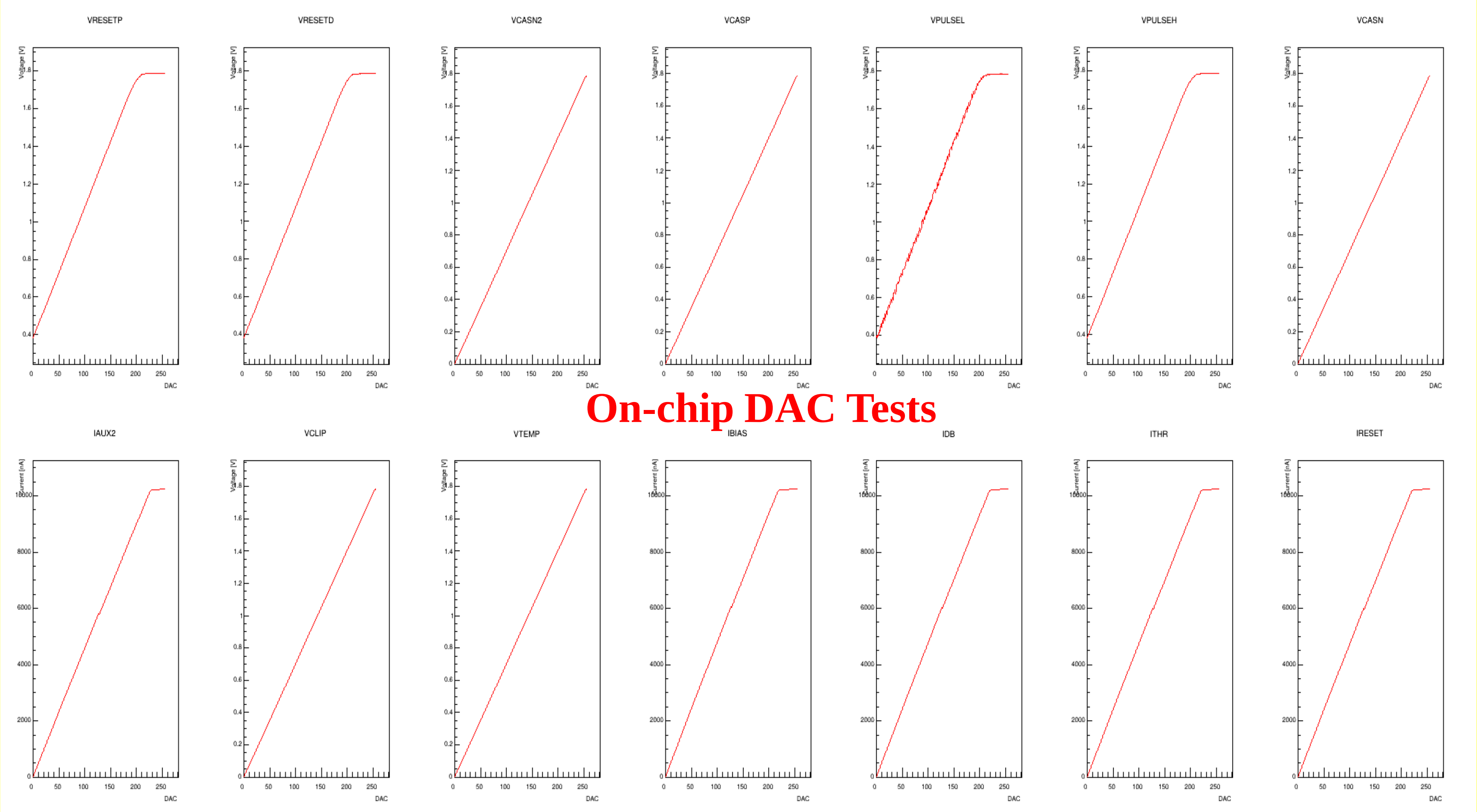


Diode reset

JINST doi:10.1088/1748-0221/10/03/C03030

Study of the characteristics of ALICE ITS pixel detectors

All next experimental results are presented for pALPIDE-3 chip



On-chip DAC Tests

Good linearity of voltage and current settings has been observed. The linear fit demonstrates the same slopes for all parameters for the present chip at different temperatures.

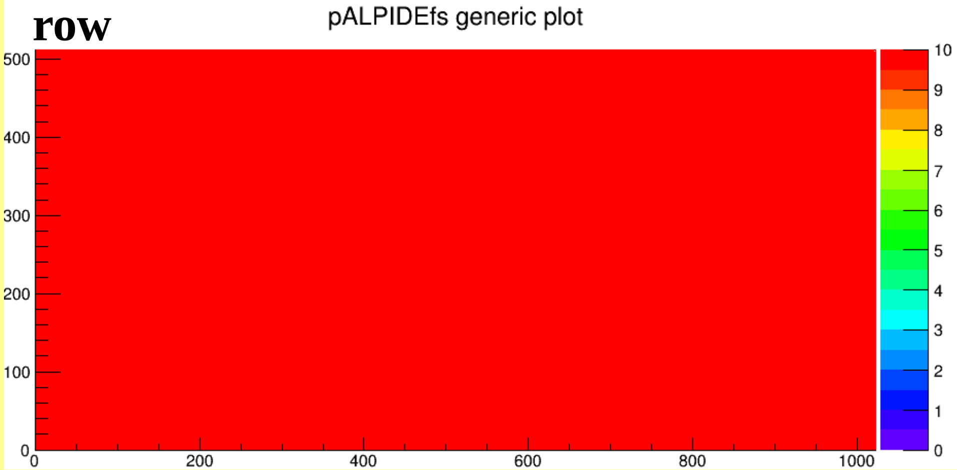
Study of the characteristics of ALICE ITS pixel detectors

Digital and Analogue scans. Scans generate digital or analog pulses in a number of pixels and read the hits out

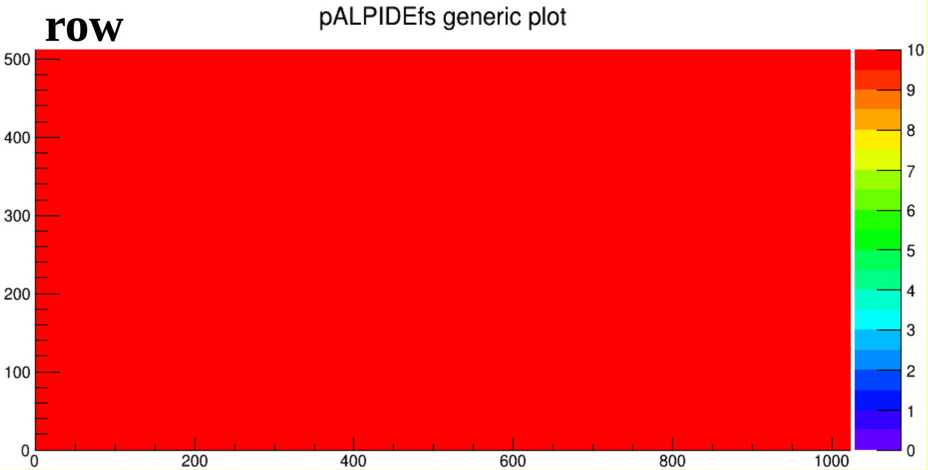
For both tests common parameters: 10 (number of injections per pixel) and test 100 % of the pixels

For analogue test an additional parameter the charge equal 350 e^- was used.

Digital Scan



Analogue Scan



Column

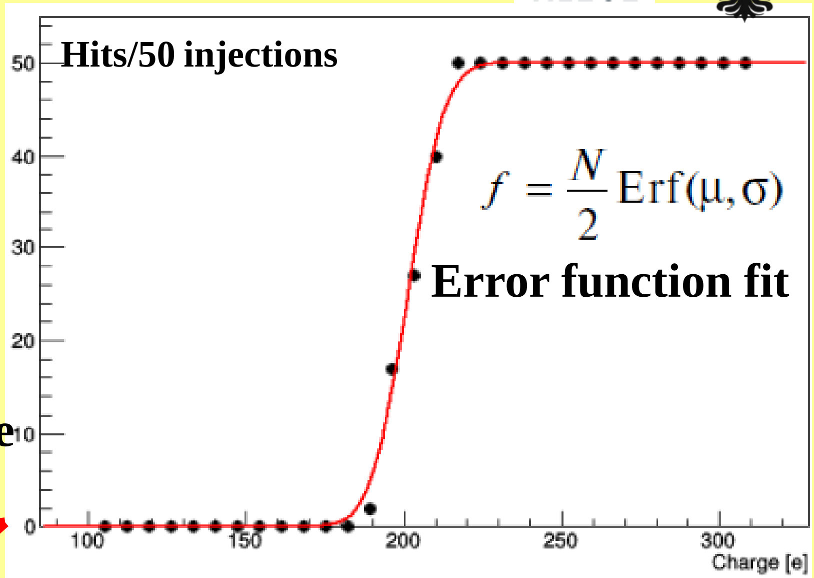
Good homogeneity of the pixel maps for both scans has been observed.

Study of the characteristics of ALICE ITS pixel detectors

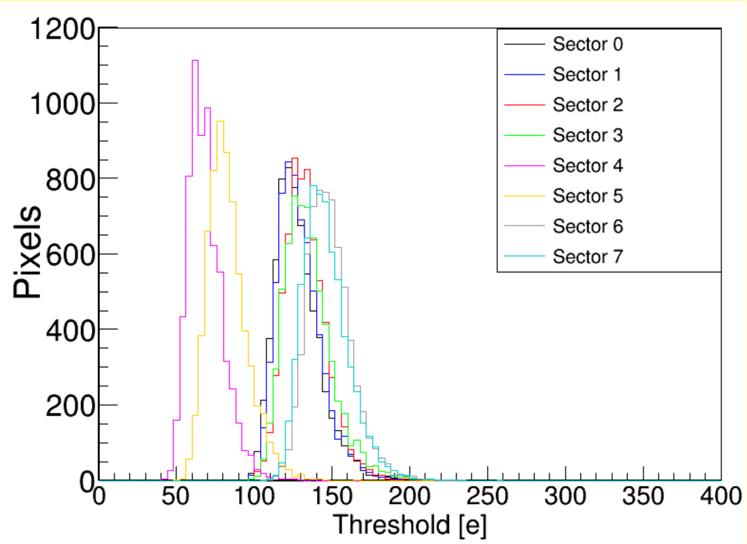
Threshold Scan

The operational thresholds for a certain set of detector's pixels depending on the charge delivered to the chosen pixels was determined

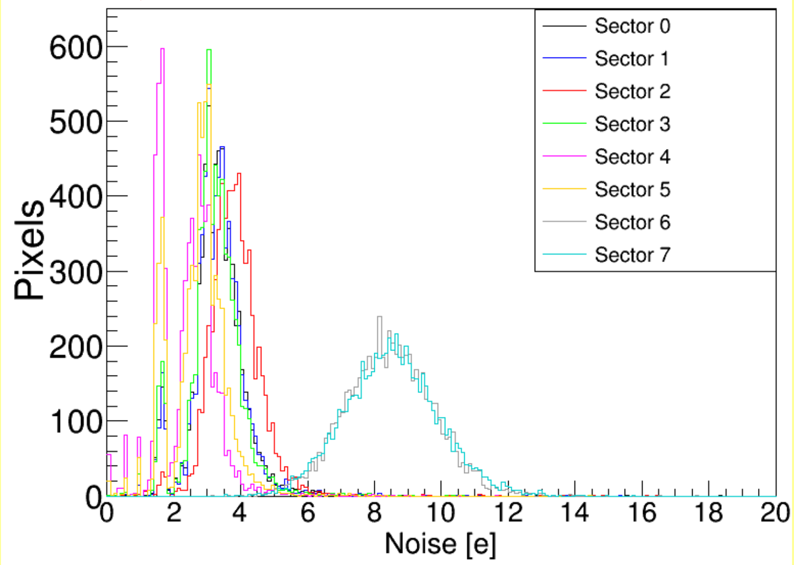
In order to extract threshold a number of charge injections with different amplitude are performed (50 points with 50 injections per point). A probability distribution of fired pixels measuring a pixel response (S-curve) has been obtained.



N - number of injections, μ - threshold value
σ- temporal noise value (threshold dispersion)



Pixel threshold distribution for 8 sectors

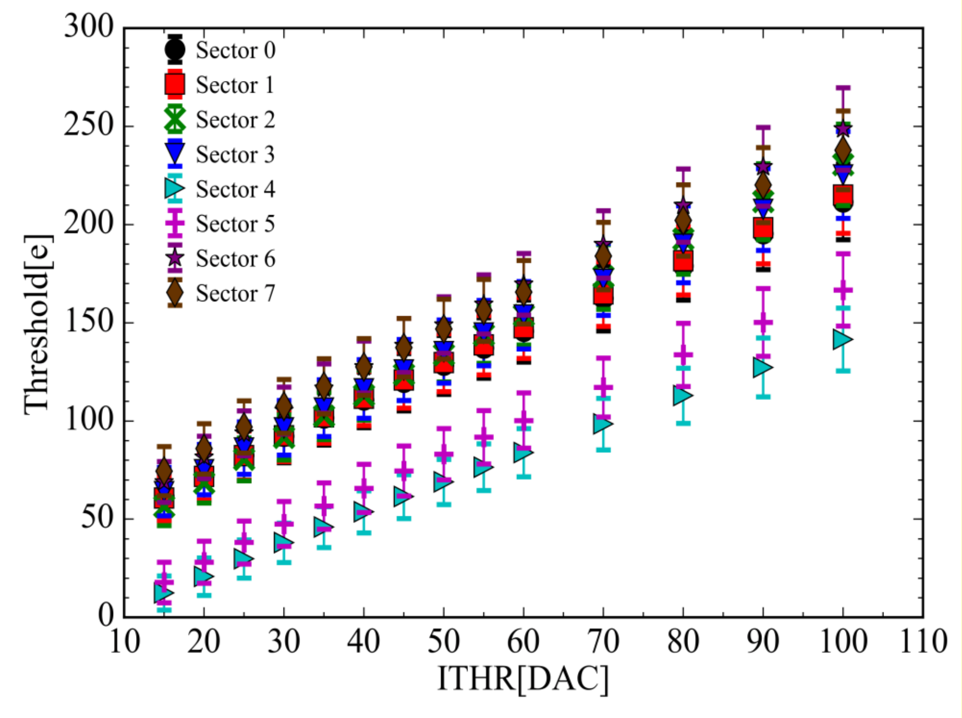


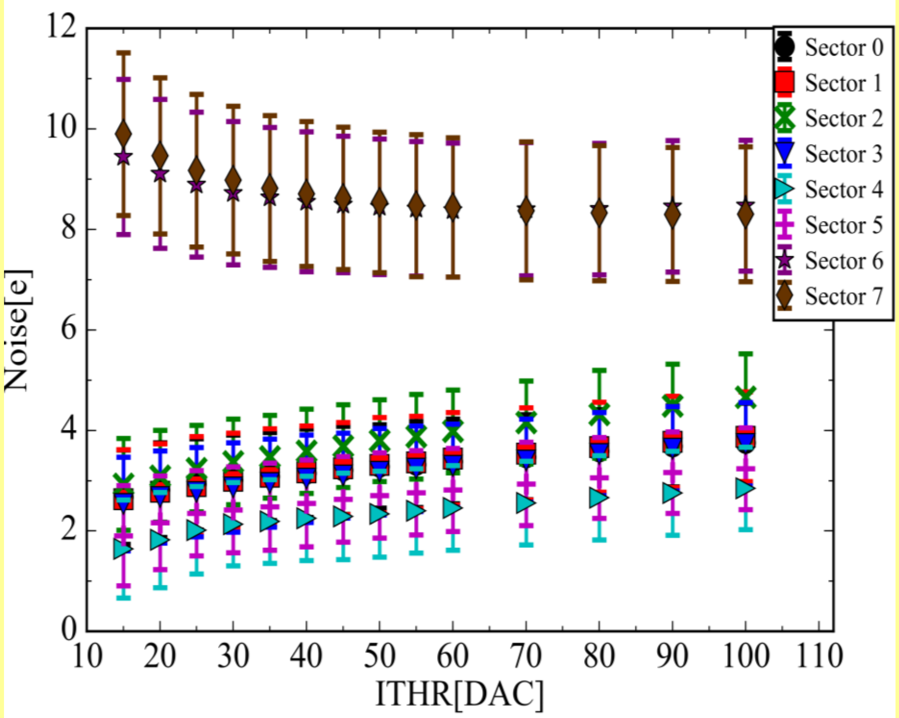
Temporal noise values for the pixels for 8 sectors

Study of the characteristics of ALICE ITS pixel detectors

Threshold Scan

1. Investigations of threshold and noise, depending on the magnitude of the I_{THR} current fed to the control transistor of a sensor at a fixed VCASN value





The linear dependence of the threshold values vs. Ithr has been observed for all sectors.

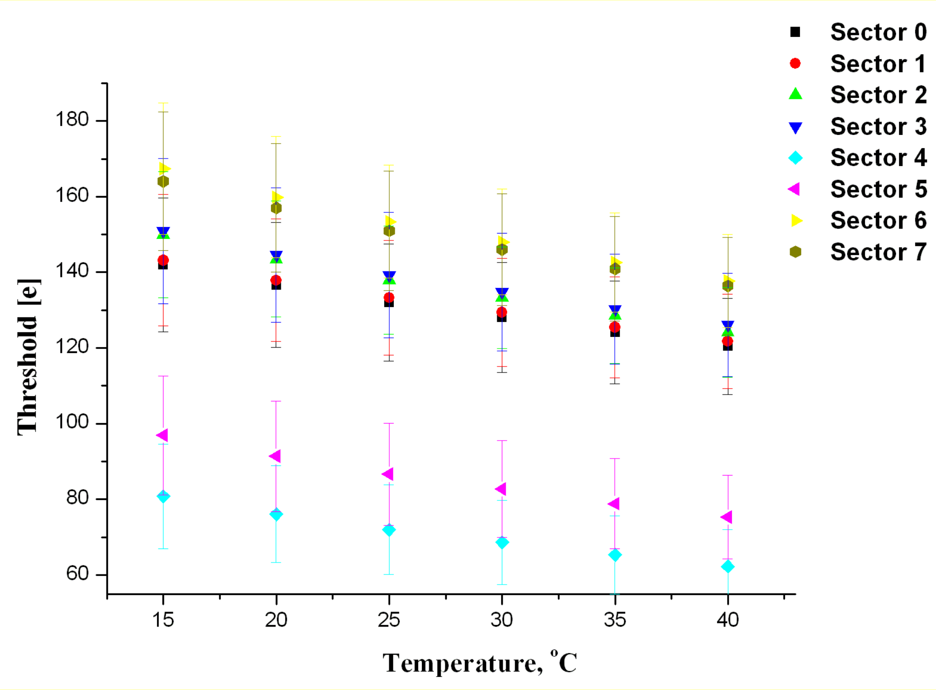
The threshold noise distributions are constant in the Ithr region: 40 - 60 DAC.

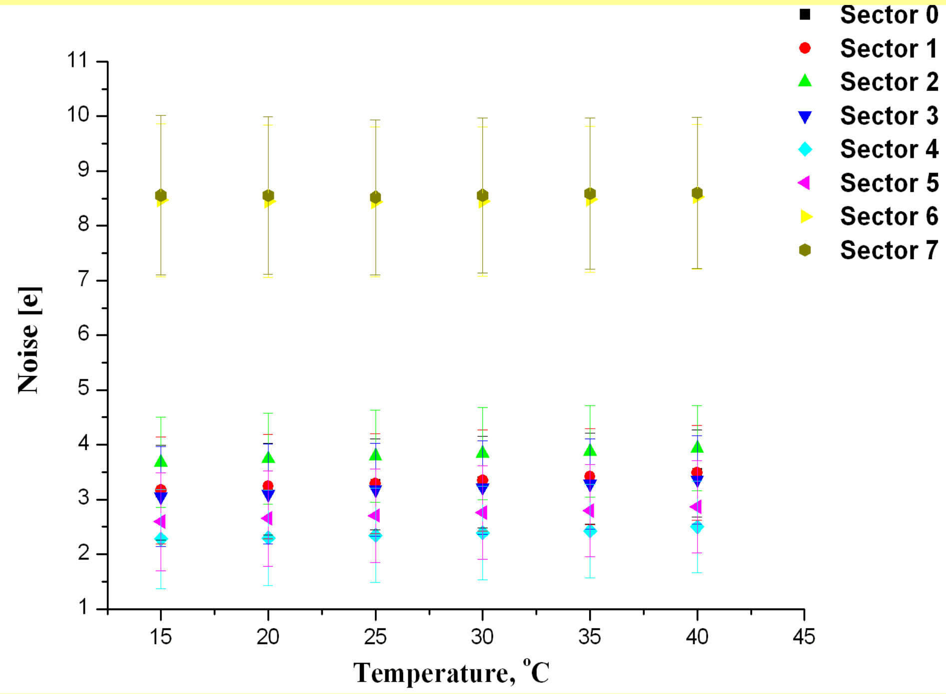
The thresholds in sectors 6-7 are bigger than in other sectors.

Study of the characteristics of ALICE ITS pixel detectors

Threshold Scan

1. Investigations of threshold and noise, depending on chip temperature

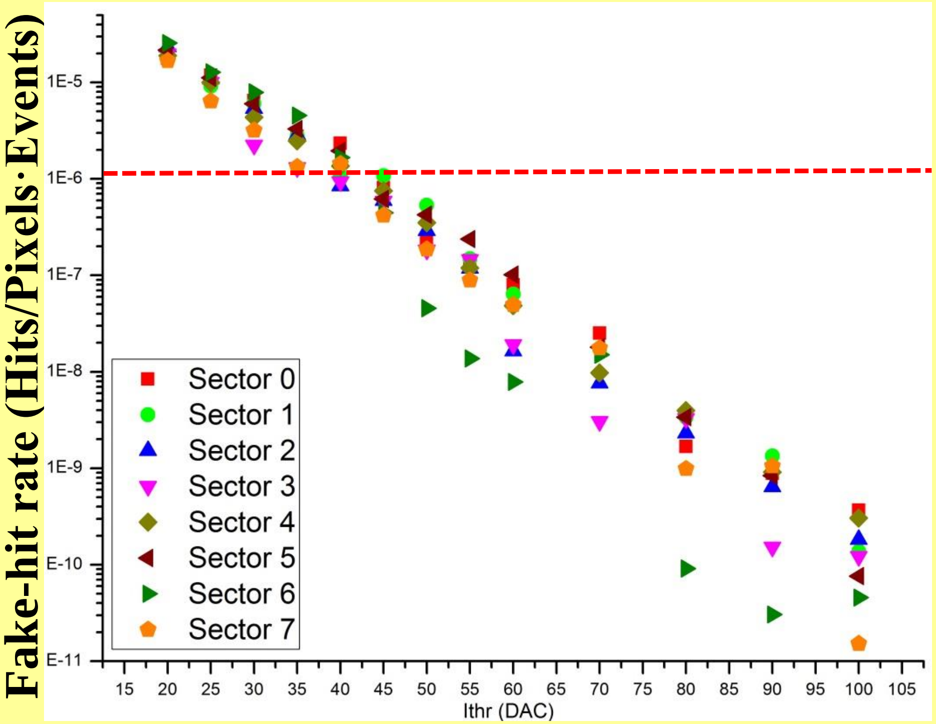


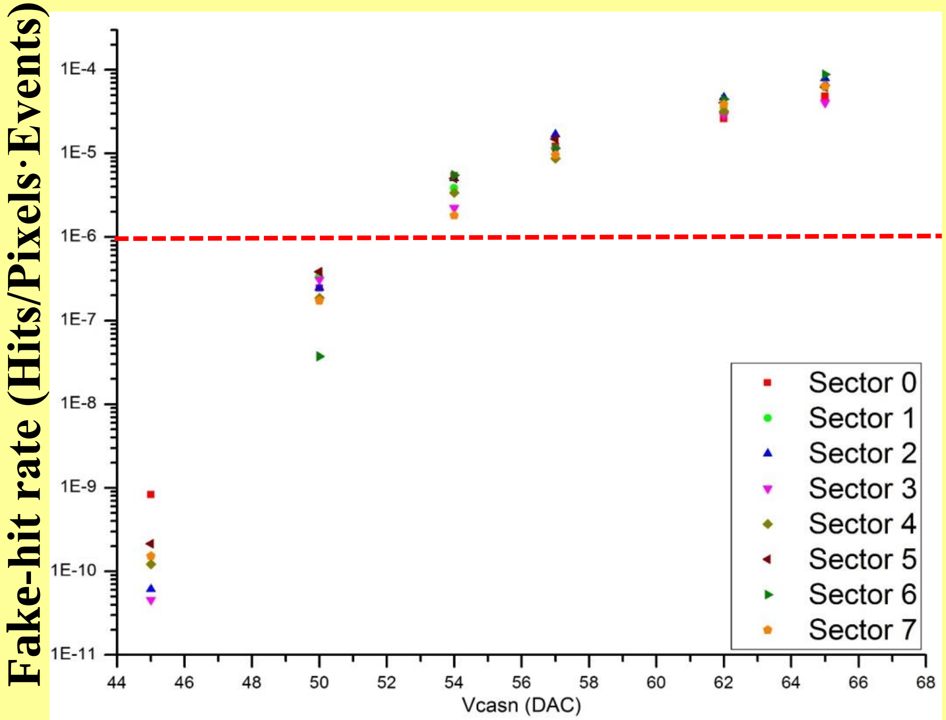


The threshold goes down slowly with the increasing of Temperature for all sectors.

The threshold noise distributions are constant within the entire temperature range.

Noise characteristics of the sensor

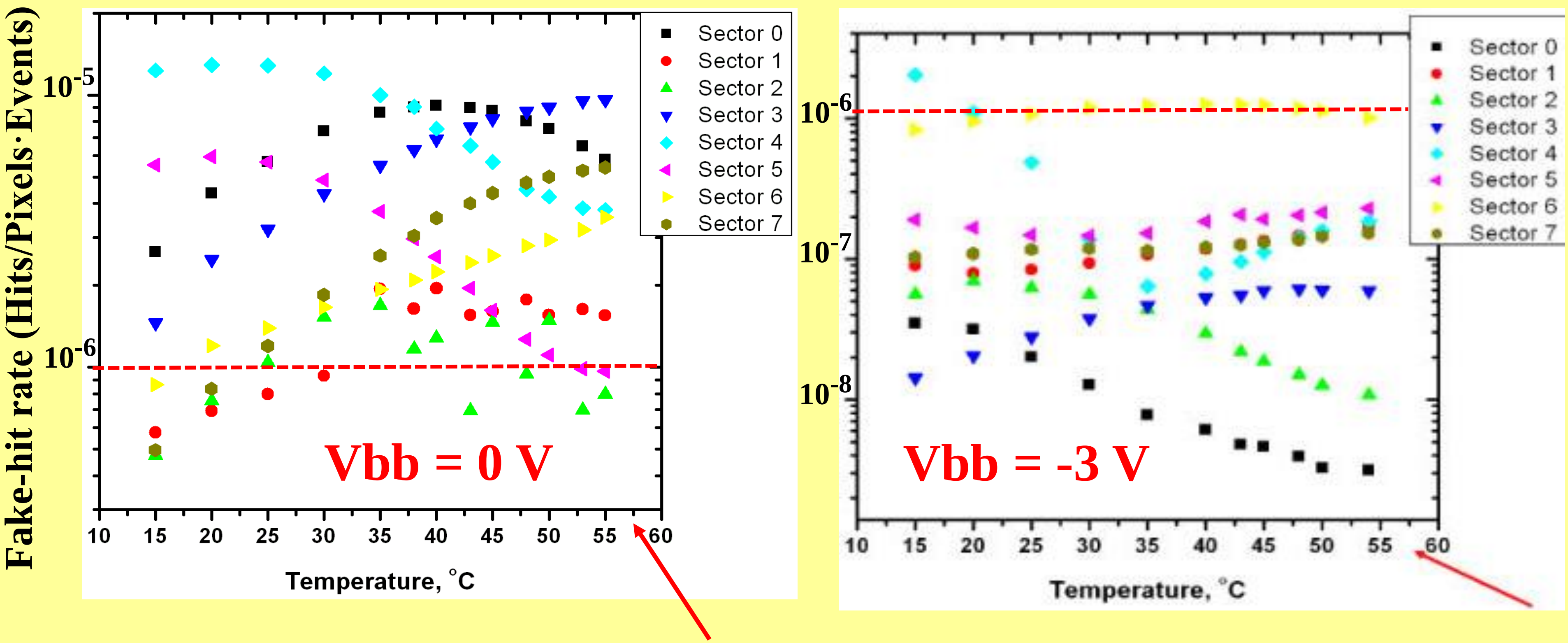




Noise occupancy strongly depends on the main detector settings I_{TH} and V_{CASN}
The values of these parameters which does not exceed the acceptable level of Fake hits per pixel per event (upgrade requirements) have been found.

Study of the characteristics of ALICE ITS pixel detectors

Noise characteristics of the sensor and its temperature dependence



Temperature limit has been reached: 56 °C

Noise occupancy strongly depends on temperature

After applying Vbb the acceptable level of Fake hits per pixel per event (upgrade requirements) has been reached.

Study of the characteristics of ALICE ITS pixel detectors

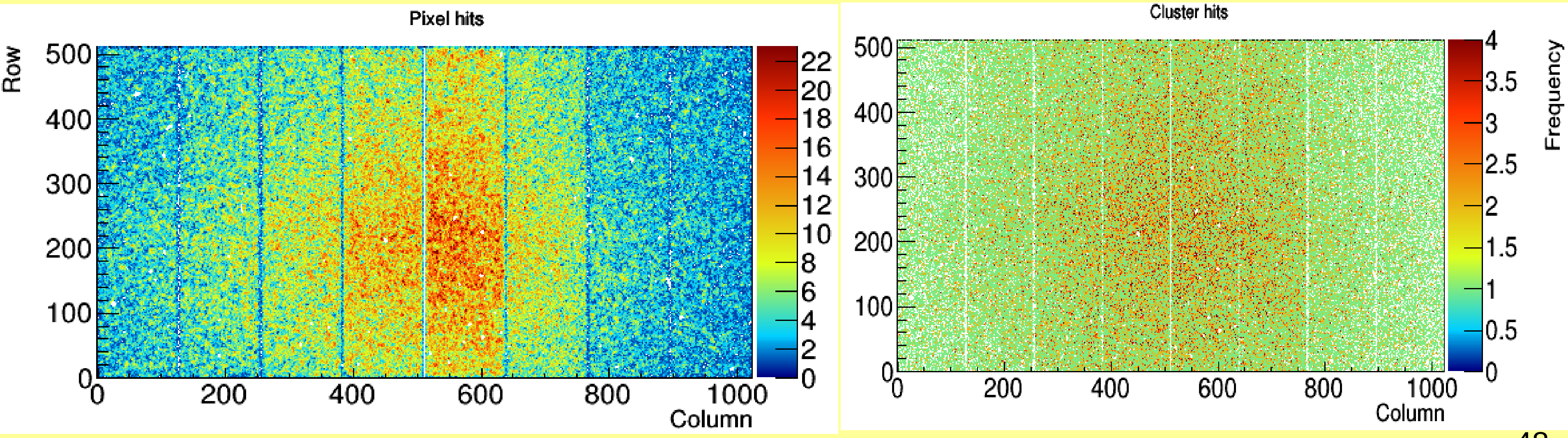
Studies with gamma and beta sources. Cluster analysis

Gamma sources: 241Am (13.9 keV), 133Ba (5.64 keV), 152 Eu (4.29), 55Fe (5.9 keV)
Beta sources: 14C, 90Sr-Y

A cluster is considered to be an area of a pixel matrix with a certain number of neighboring fired pixels. The number of pixels determines the cluster size.

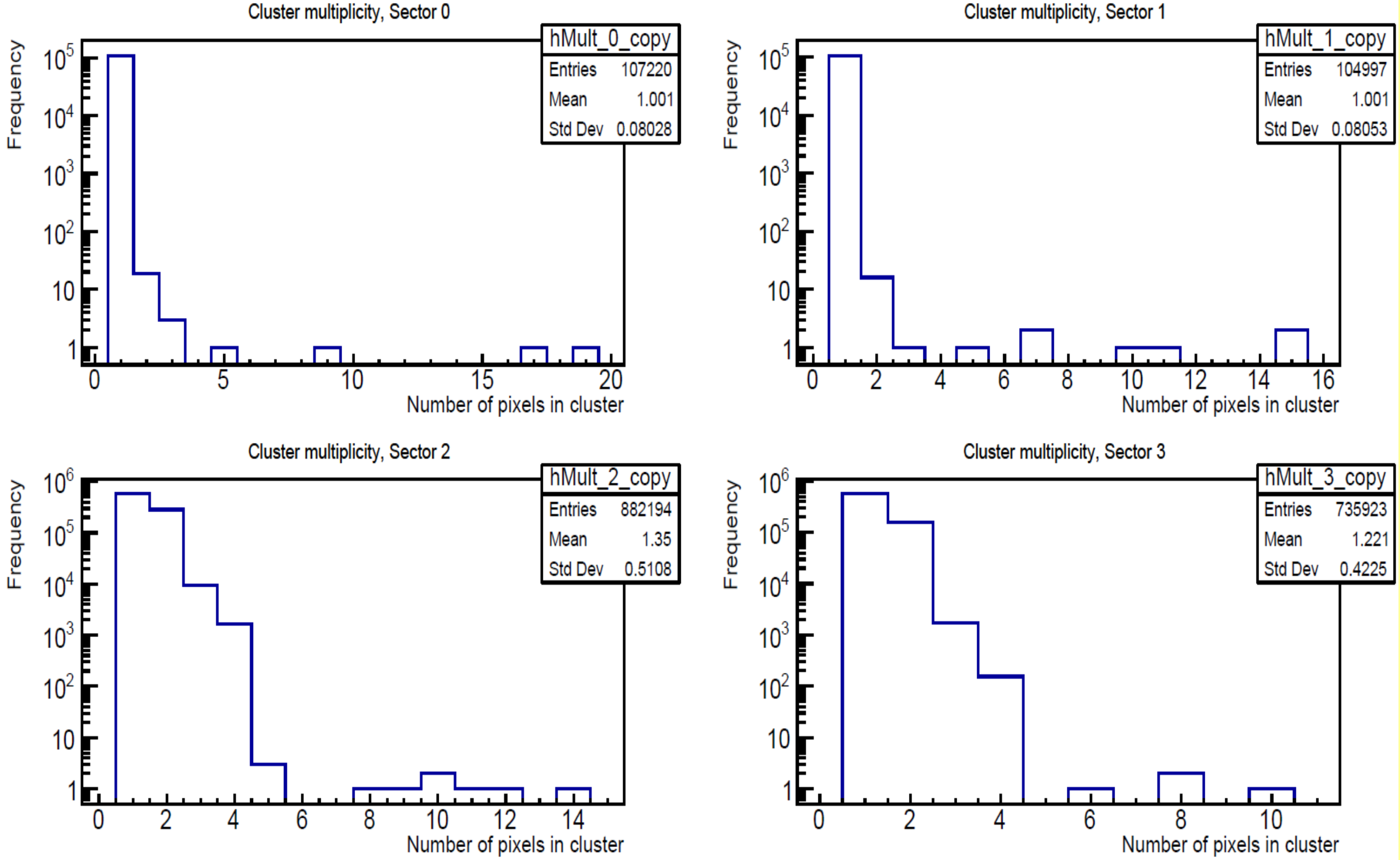
The clusters with cluster multiplicity = 1 have been included. Because in source test the noise mask (excluded hot pixels) has been applied.

Pixel and cluster hits for 152Eu



Study of the characteristics of ALICE ITS pixel detectors

Cluster multiplicity in different sectors for 55Fe



No large clusters. Average cluster multiplicity no more 1.35

Study of the characteristics of ALICE ITS pixel detectors

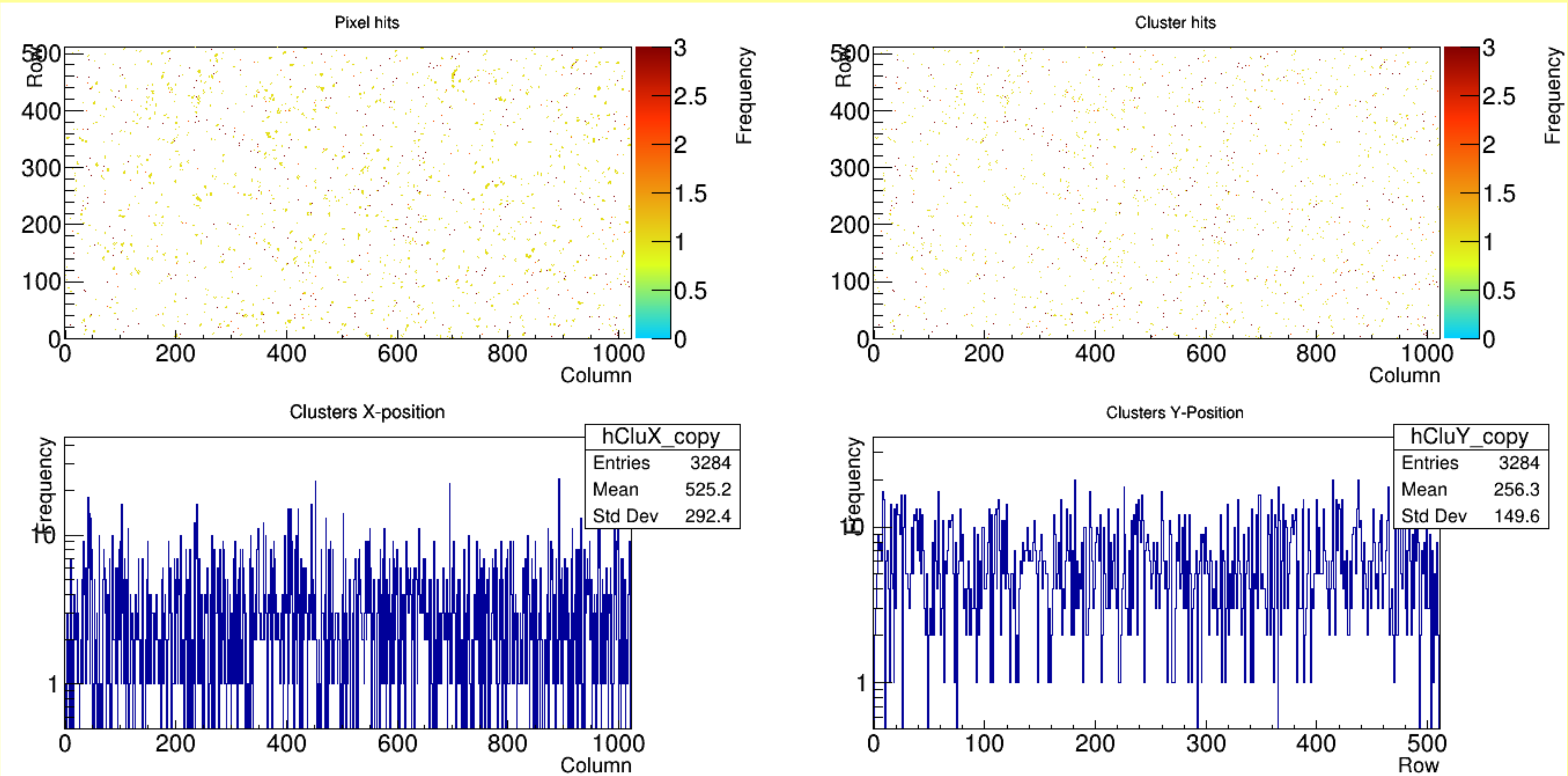
Source test + Cluster analysis

Chip W7R12

Triggers – 2000000
Vbb = -3V

Results for high dose irradiated chip

Masked



Source: Sr-Y, chip temperature -100 ºC