Детекторы нового поколения

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Outline

1. Silicon Detectors for HEP experiments

2. Pixel detectors:
   a) Now
   b) Future

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

4. ALICE Pixel Detectors (ALPIDE family)

5. The ALPIDE characteristics studies

6. Detectors in Future Experiments

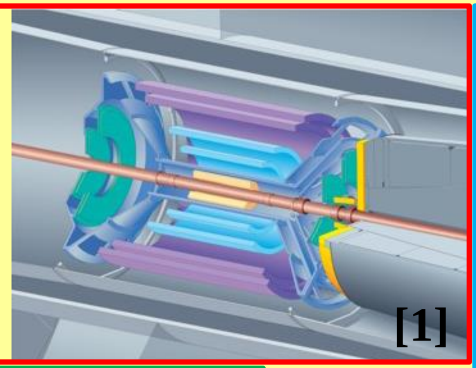
7. Industrial applications

8. Next planes

9. Conclusions

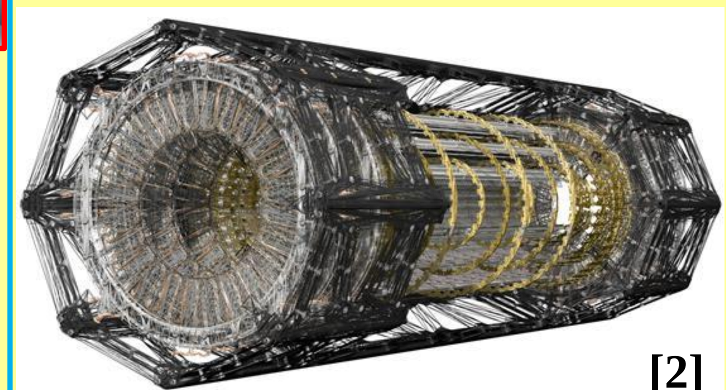
Silicon Detectors for HEP experiments

ALICE Pixel Detector
first two layers: tracking
ALICE Drift Detector
two middle layers: tracking+PID
ALICE Strip Detector
two outer layers: tracking+PID



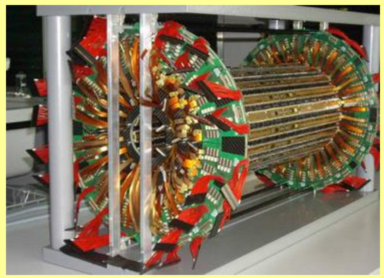
[1]

ATLAS Pixel Detector
80 million pixels
area: 1.7m^2
15 kW power consumption
Pixel size: 50 x 400μm^2

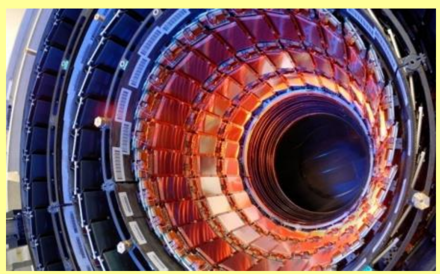


[2]

CMS Pixel Detector
65 million pixels.
Pixel size: 100×150 μm^2

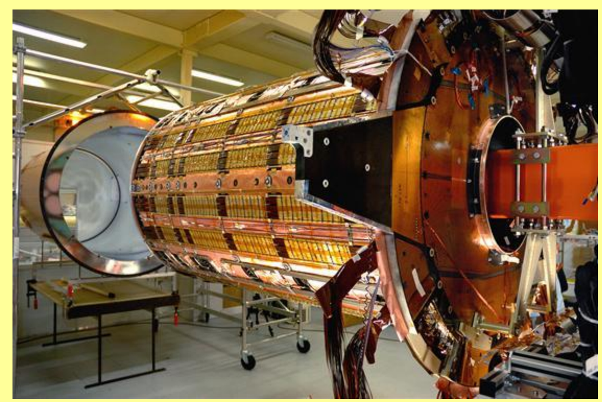


CMS Strip Tracker IB
First 4 layers (strips)
10 cm x 180 μm,
Next 6 layers (strips)
25 cm x 180 μm
10 million strips
The largest Si detector in the world. More 200 m^2



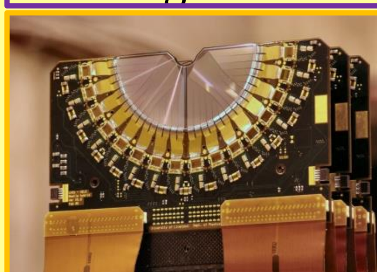
[4]

ATLAS Semiconductor Tracker (SCT)



[3]

A silicon microstrip tracker : 4,088 two-sided modules and over 6 million implanted readout strips



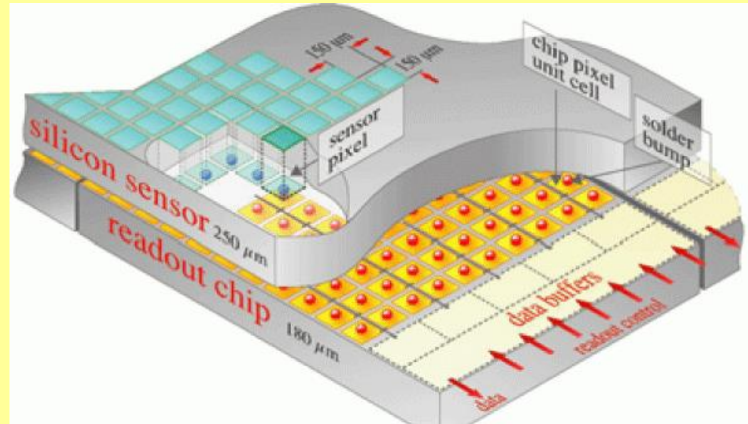
LHCb VELO
VErtex LOcator
silicon microstrip detector

[5]

Pixel detectors: Now

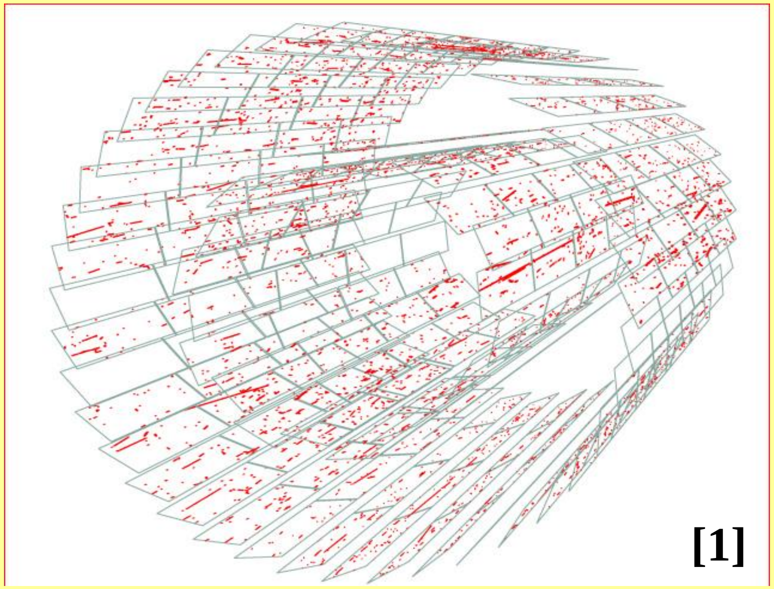
Hybrid Pixel Detectors in LHC:

- ATLAS
- CMS
- ALICE



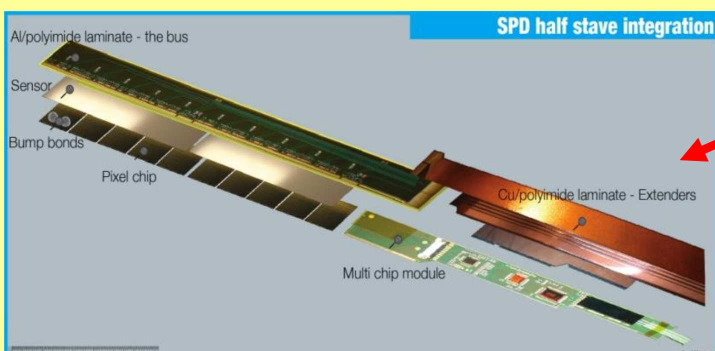
CMS silicon pixel detector [4]

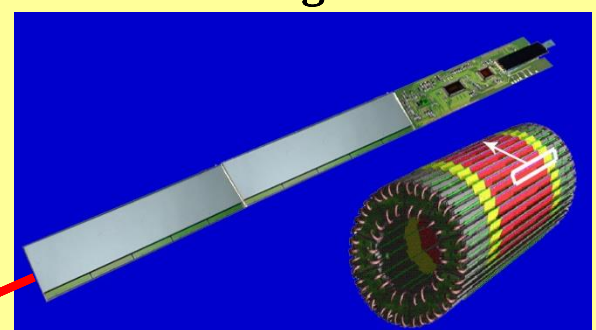
- Good position resolution: Smaller pixels, Higher integration
- Small pixels - low capacitance - better S/N - smaller analog power
- More pixels – More logic per pixels – high integration
- Work at higher rates and high radiation level



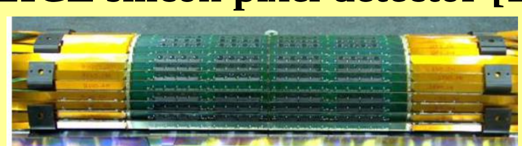
[1]

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

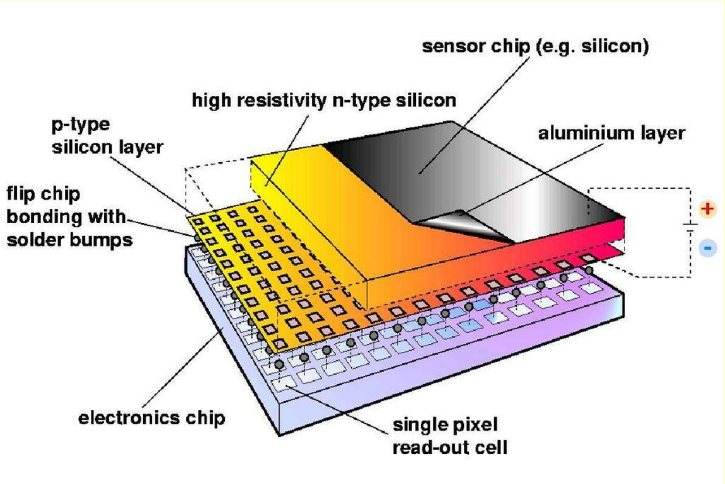




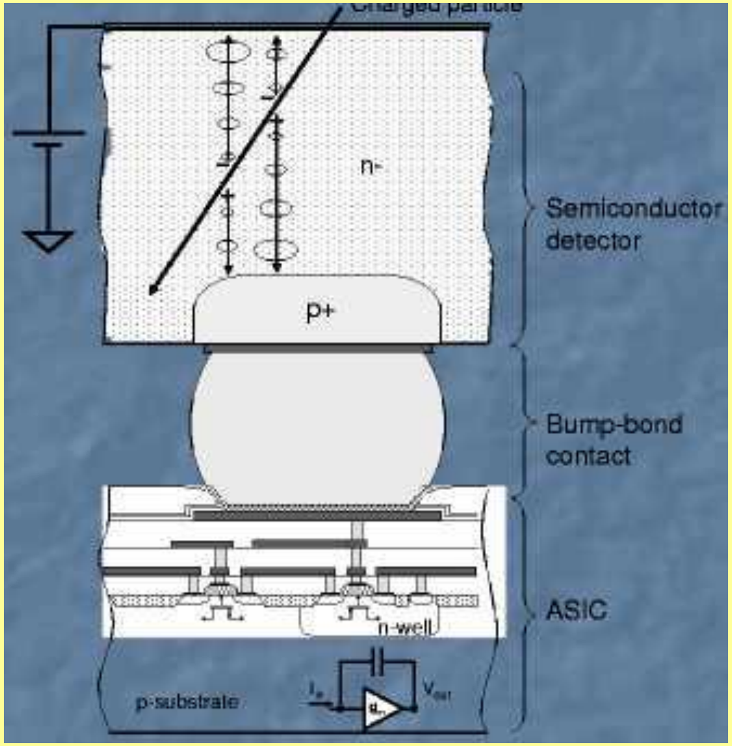
ALICE silicon pixel detector [1]

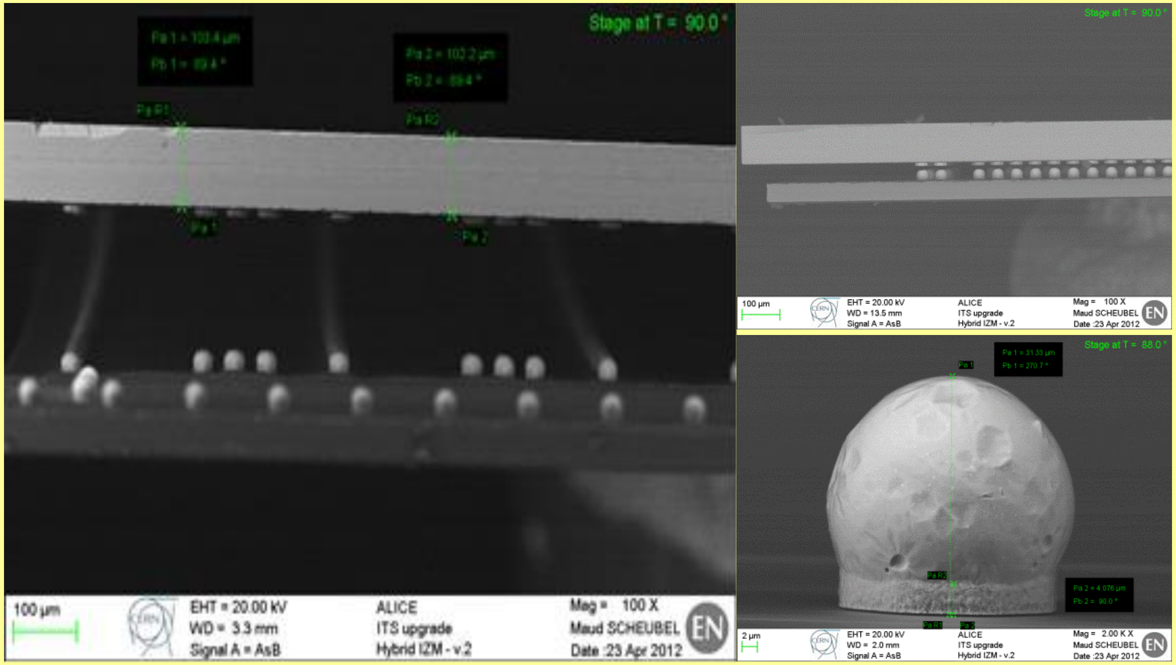


Pixel detectors: Now. Hybrid Pixel Detectors



1. Sensor and readout chip (ASIC) are independent modules
2. Interconnection needed to connect each pixel in the sensor to a readout cell in the ASIC - Bump bonding ASIC and detector (very complicated technologies)
3. Thick detector units: radiation length 1 – 3 % X_0
4. Sensor and electronics optimized for very high radiation (hit rate)





Chip 50 μm and sensor 100 μm; sensor matrix 256x160 cells; pixel size: 50 μm x 425 μm **[6]**

Pixel detectors: Future

For HEP experiments. For future trackers

Excellent resolution - More channels - Higher integration

Low mass tracking system – Minimum materials (cables, cooling, services) - Low power consumptions

Radiation tolerance – work at high radiation doses

For electronics: acquire more data at higher rate - high speed data processing, low error rates (FPGA based trigger systems, CPU based DAQs)

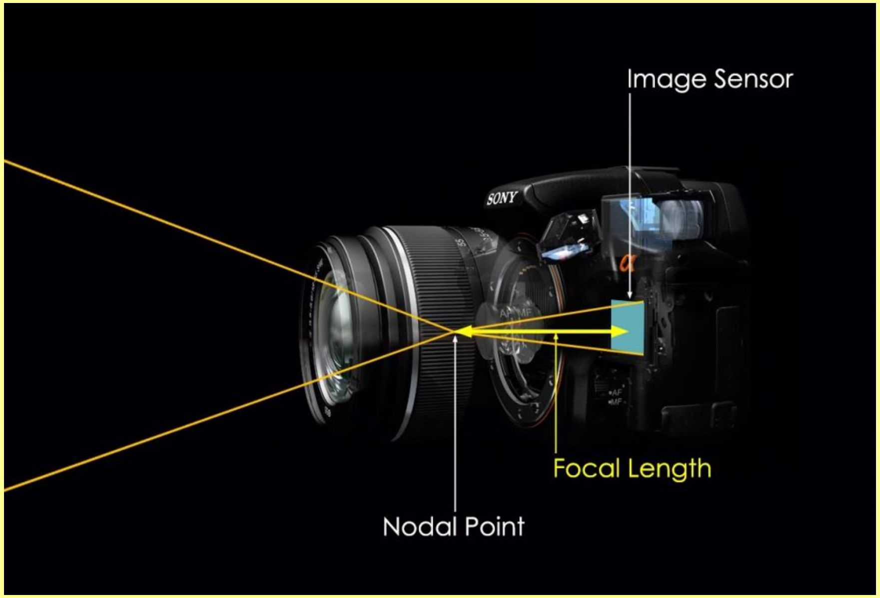
We will built Large and complicated systems
acceptable cost!

Pixel detectors: Future

Monolithic Active Pixel Sensors (MAPS)

Idea from CMOS Active Image Pixel Sensors

Advantages of CMOS imaging sensors (camera-on-chip) in industry: low power, compact devises (digital cameras) due to electronics – on a chip, reduced the number of components

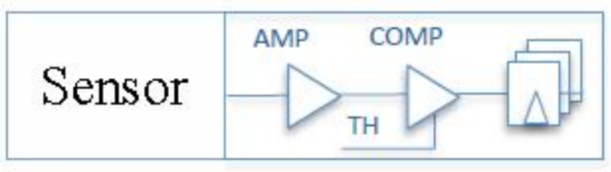


Era of digital photography

Era of mobile photography

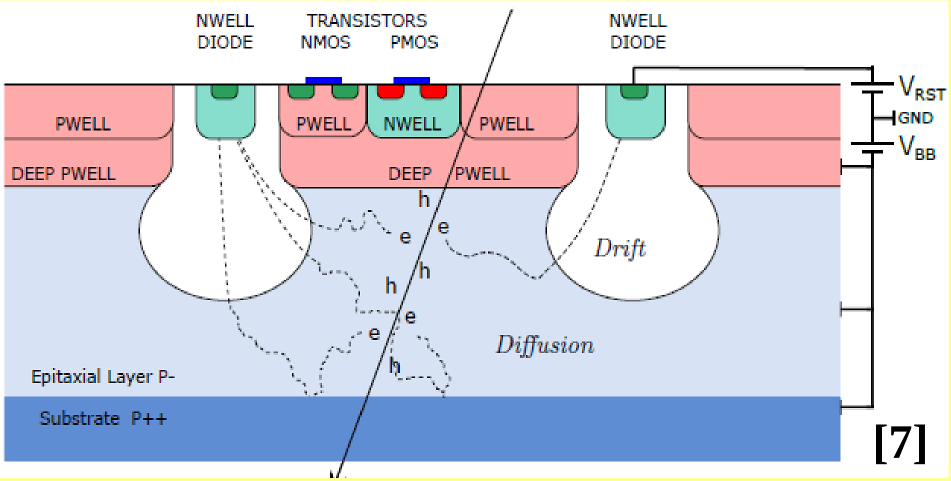
Pixel detectors: Future

Monolithic Active Pixel Sensors (MAPS)



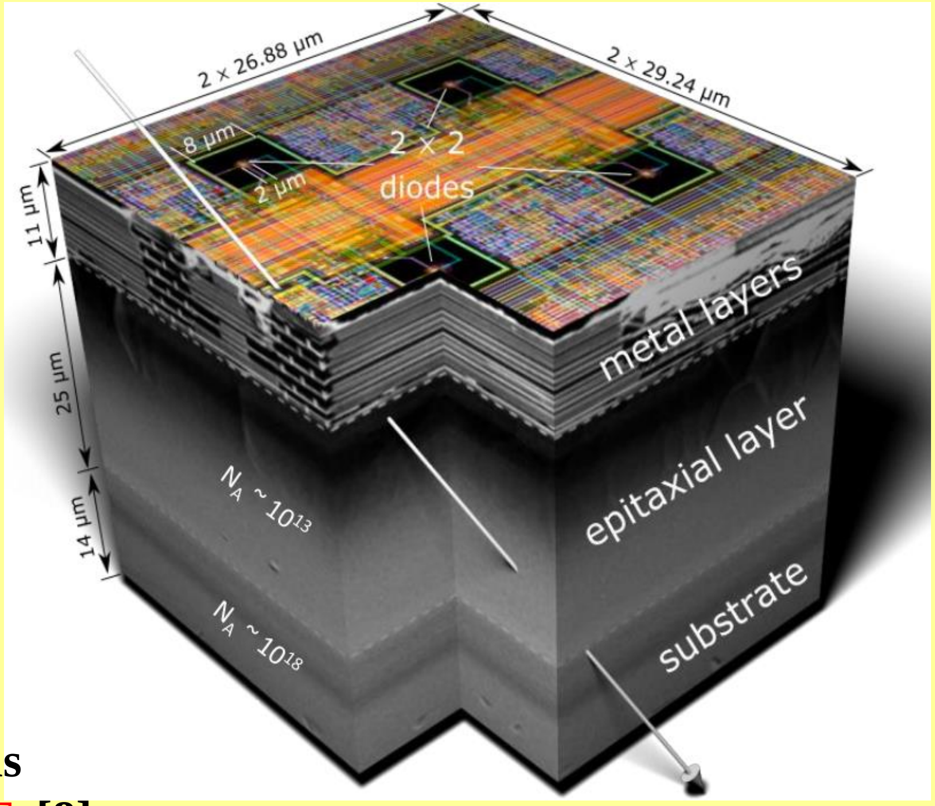
Active volume of the detector integrated into the ASIC
In one pixel we have detector +front-end electronics

Thin monolithic CMOS sensor, on-chip digital readout architecture



[7]

Optimized for highest hit rates and also work in high radiation environment



Small pixel and thin detectors: for new ALICE ITS size of one pixel is 28x28 µm^2 and total radiation length of 0.3% X0 per layer

Cost: cheaper than other.

Example: new ALICE ITS

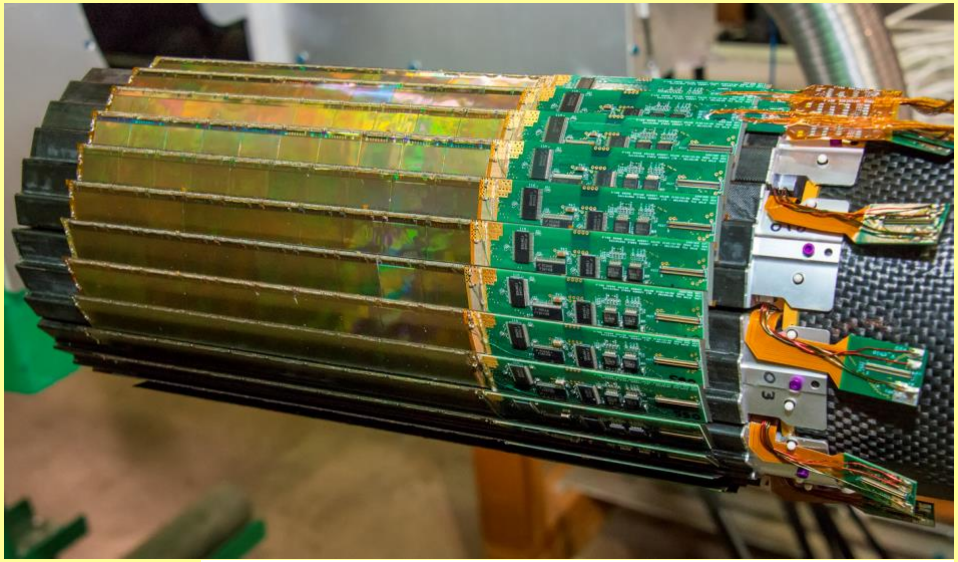
1. **Option 1: 7 layers of MAPS – 14 000 kCHF**
2. **Option 2: 3 innermost layers of hybrid pixels and 4 outermost layers of strips - 20 000 kCHF [8]**

Pixel detectors: Future. Monolithic Active Pixel Sensors (MAPS)

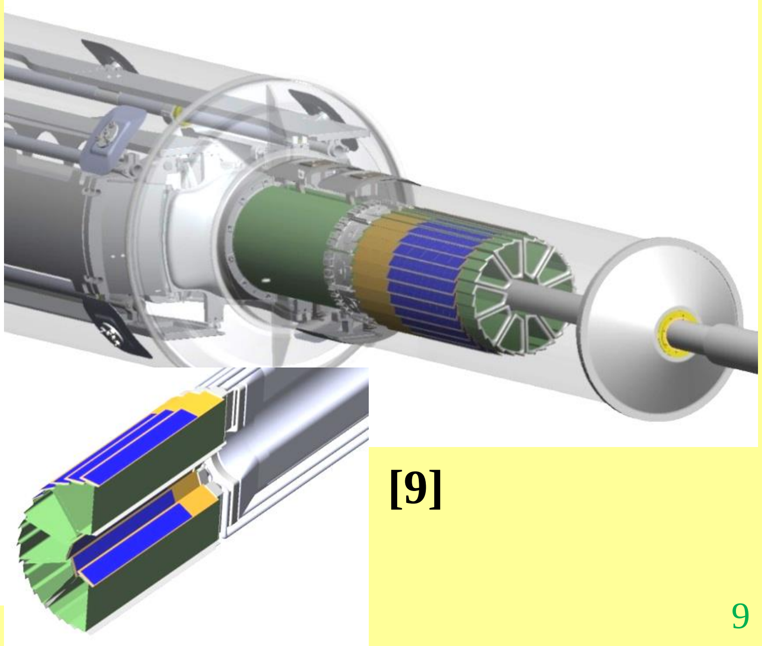
First using: STAR Heavy Flavour Tracker.
First MAPS based vertex tracker at a collider experiment.

1. Two layers of detectors
2. Pixel size - 20.7 x 20.7 um
3. Radiation length - ~0.5% X0
4. Number of pixels - 360M
5. Integration time 185.6 us
6. Radiation dose: 20 to 90 kRad / year

350 nm CMOS technology

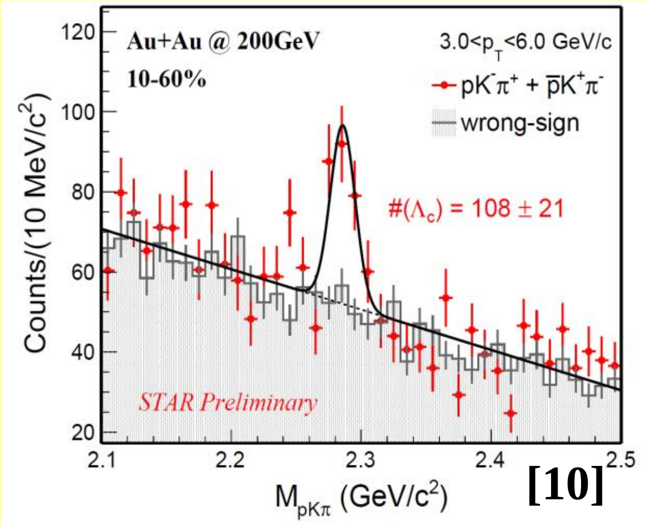


First measurements of Λ_c production in central Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV.
The invariant yield of Λ_c for $3<p_T<6$GeV/c was measured in 10-60%.



[9]

Invariant mass spectra of Kπp pairs. The data points are the Λc signals.
The grey histogram depicts the background distribution (scaled by 1/3)



[10]

ALICE Inner Tracking System: current status and upgrade strategy

Limitation:

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. Detection of charmed baryons is 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 $\Lambda^+_c \to p K^- \pi^+$ 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

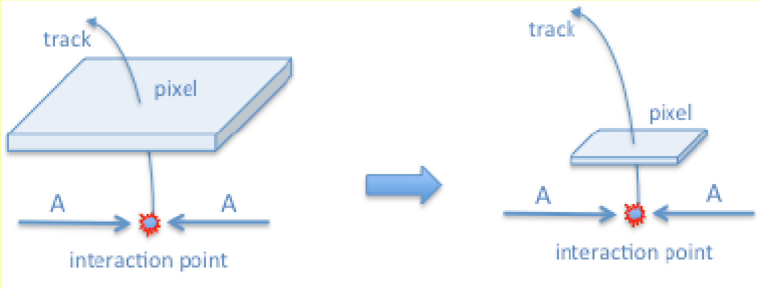
2. Improve tracking efficiency and p_T resolution at low p_T:
   allow improvement of the resolution of the track impact parameter by a factor of three or better (at p_T = 1 GeV/c) with respect to the present ITS

3. Increase readout rate capabilities:
   readout Pb-Pb interactions at >100 kHz, readout p-p interactions at >400 kHz,
   (currently limited at 1kHz with full ITS)

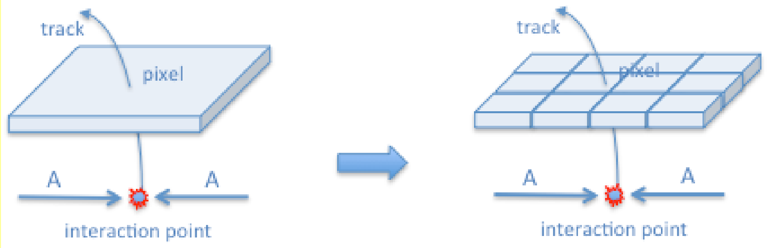
ALICE Inner Tracking System: current status and upgrade strategy

Upgrade strategy (main points):

1. **Improve impact parameter resolution by a factor of ~3**
   a) **First detection layer closer to the beam line: radius from 39mm to 23 mm**
   b) **Reduction of material budget: the radiation length per layer (for inner layer) X from 1.14 to 0.3 %X0**
   c) **Reducing pixel size: from 425x50 to 28x28 μm^2**



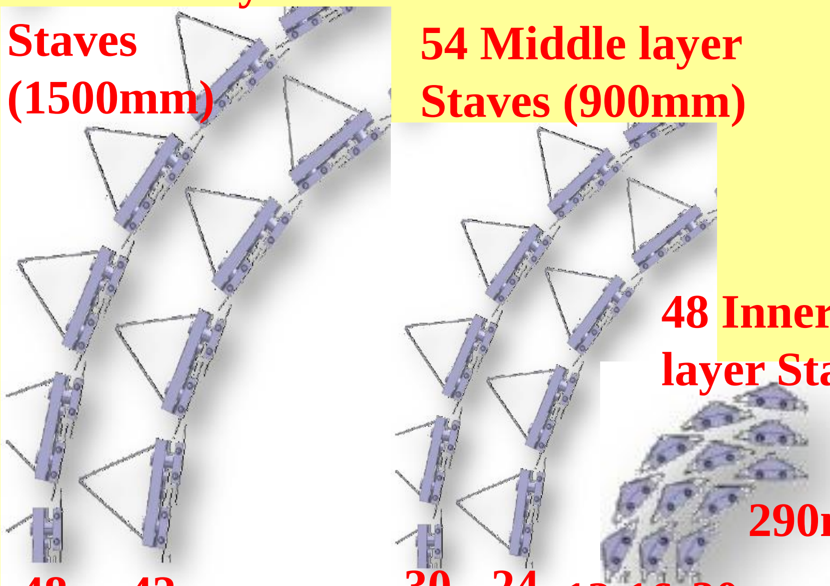
2. **Improve tracking efficiency and p_T resolution at low p_T**
   a) **Increase in granularity (smaller pixels)**
   b) **number of layers (from 6 to 7)**
   c) **instead silicon drift and strips the pixels will be used**



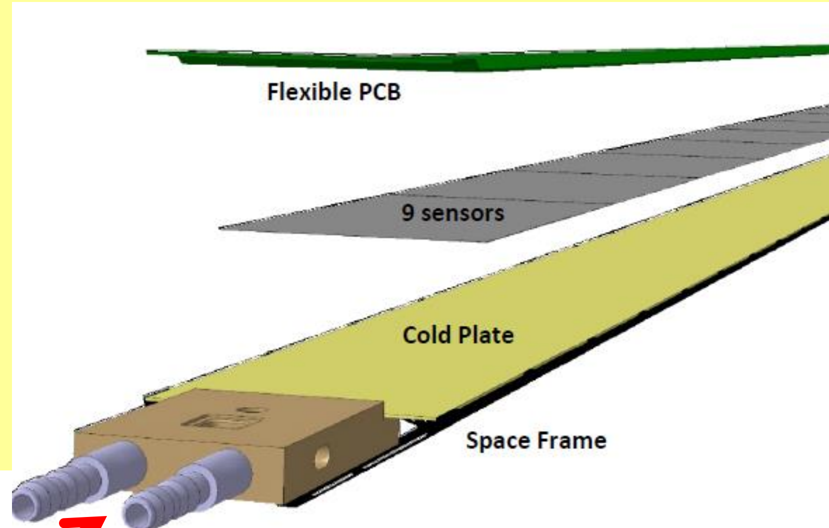
Also:

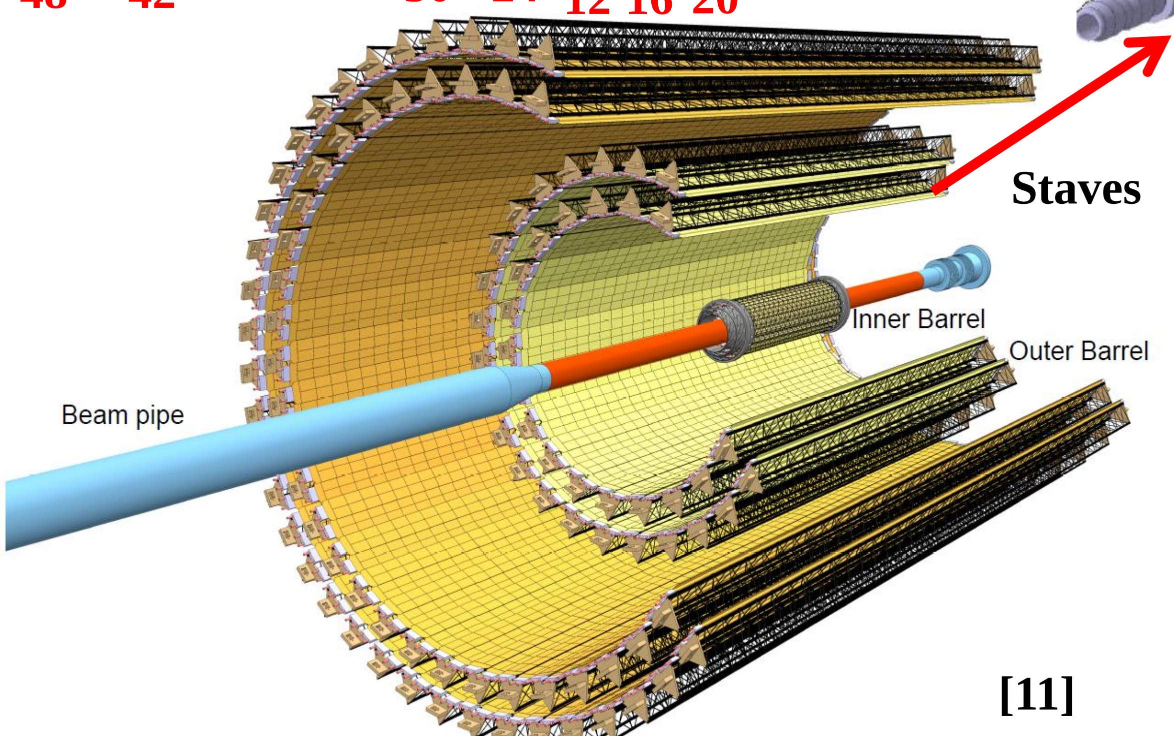
a) **lower power consumption and a highly optimized scheme for the distribution of the electrical power and signals**
b) **mechanics, cooling and other detector elements will be also improved**

ALICE Inner Tracking System: current status and upgrade strategy



Inner Barrel Stave





Stave :

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

Barrel: 7 layers of MAPS
12.5 G pixels
~10m^2 total active area

For the ALICE ITS upgrade TowerJazz technology is being explored by four different chip architectures

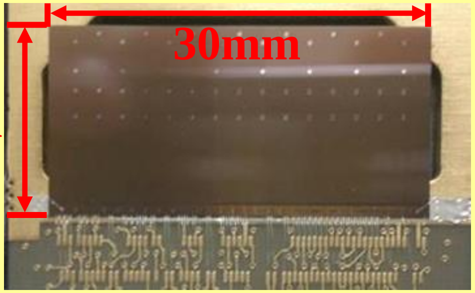
Architecture (discriminator, read-out)	Pitch ($r\phi \times z$) (μm^2)	Integration time (μs)	Power consumption (mW cm^{-2})
MISTRAL **(IPHC)** (end-of-column, rolling-shutter)	22×33.3	30	200
ASTRAL **(IPHC)** (in-pixel, rolling-shutter)	24×31 **IB** 36×31 **OB**	20	85 60
CHERWELL **STFC-RAL in UK** (in-strixel[a], rolling-shutter)	20×20	30	90
ALPIDE (in-pixel, in-matrix sparsification)	28×28	4	< 50

ALice PIxel DEtector

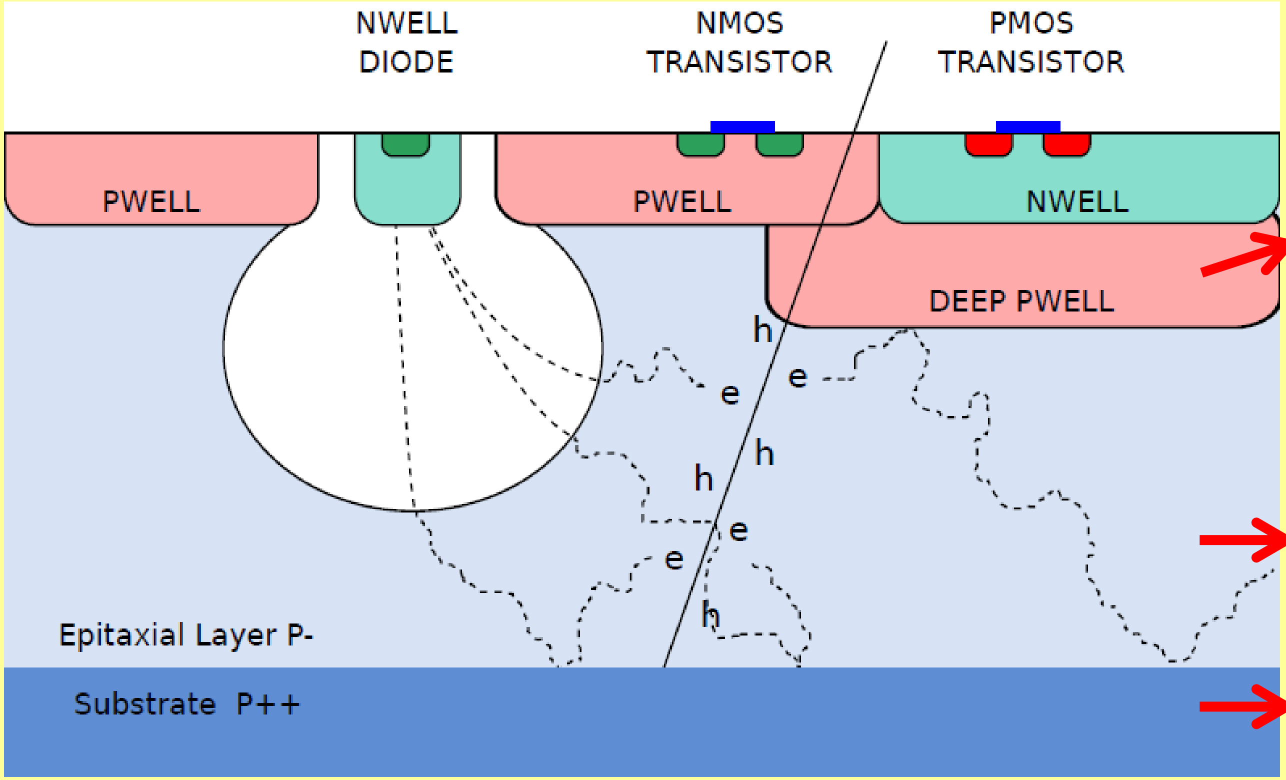
[11]

Main parameters of all chip architectures conform to the requirements of ALICE ITS upgrade.

ALICE Pixel Detectors (ALPIDE family)



MAPS using TowerJazz 180nm CMOS Imaging Process



Shields the other nwells different from the collection electrode, preventing them 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

ALICE Pixel Detectors (ALPIDE family)

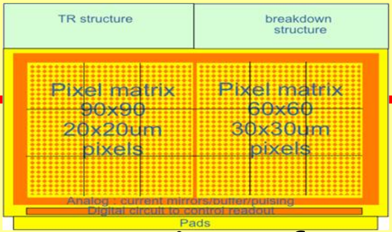
Pixel detector general requirements
(from Technical Design Report for the Upgrade of the ALICE ITS)

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)

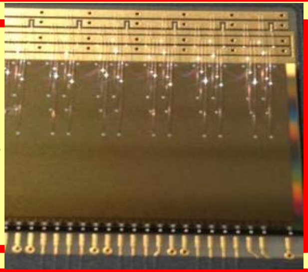
ALICE Pixel Detectors (ALPIDE family)



2012 — Explorer (Explorer-1,2) →
Two submatrices: 90x90 array of 20 x 20µm pixels and 60x60 array of 30x30µm pixels. Each sub matrices is divided in 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. Four sectors with different pixels.



May-2015 — pALPIDE-2 →
Four sectors with different pixels. Optimization of several circuit blocks. Allows integration into ITS modules

Oct-2015 — pALPIDE-3 →
Eight sectors with different pixels. Final interfaces, more features including 1.2 Gbit/s output serial link.

Jul - 2016 →
ALPIDE – Final Version

ALICE Pixel Detectors (ALPIDE family)

The chip measures 15 mm (Y) by 30 mm (X)
Power consumption 40 mW/cm^2
Contains a matrix of 512 × 1024 sensitive pixels

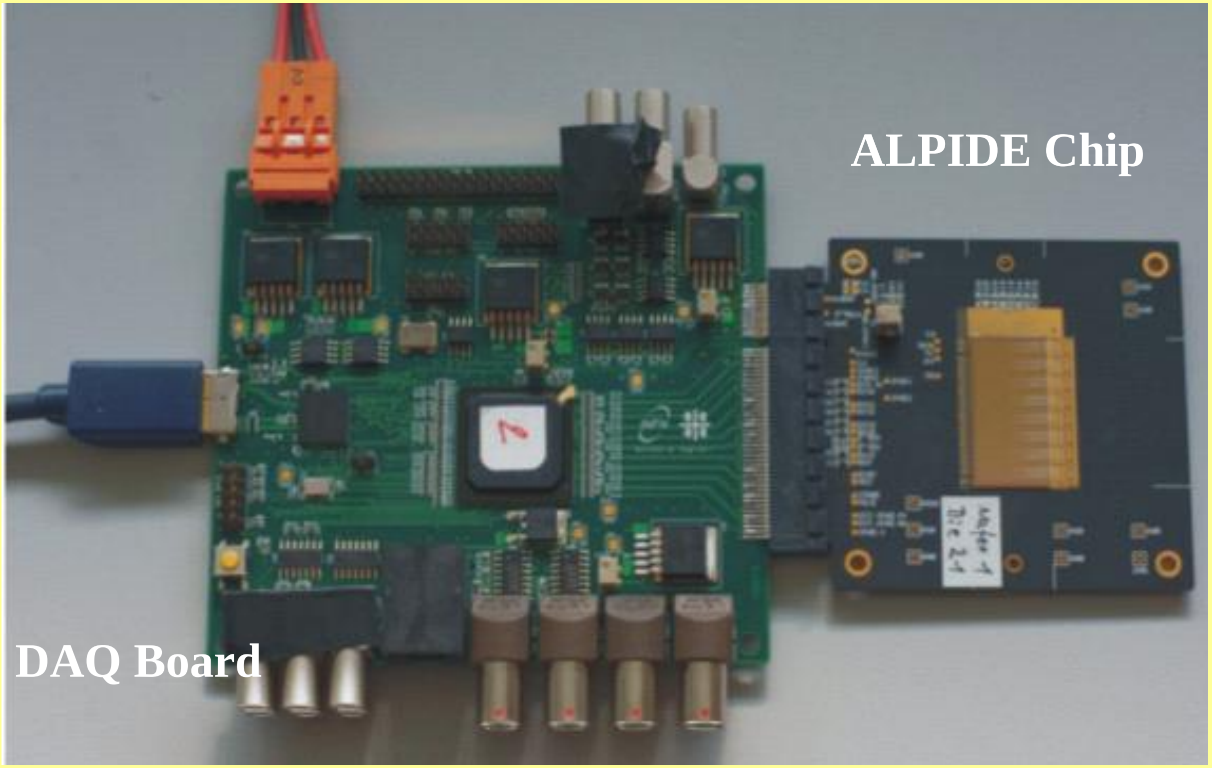
Full-scale Pixel Detector prototypes pALPIDE-1,2: pixel width is 28 μm and the pixel height is 28 μm. Four sub-matrices (sectors) of 512×256 pixels

Full-scale Pixel Detector prototype pALPIDE-3: pixel width is 29,24 μm and the pixel height is 26,88 μm. Eight sub-matrices (sectors) of 512×128 pixels

Sub-matrices (sectors) differing in charge collection diode geometry and in-pixel circuitry

pALPIDE-4 – ALPIDE (final version) one sector

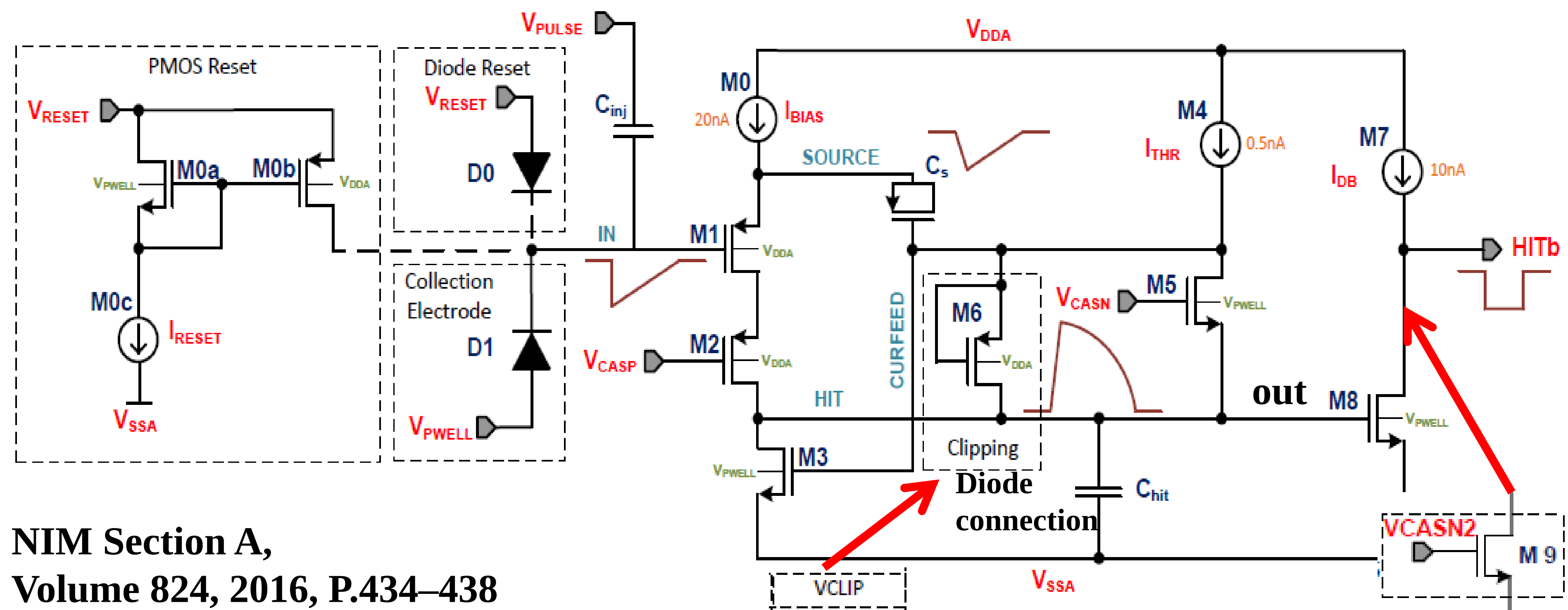
All the analogue signals required by the front-ends are generated by a set of 11 (for pALPIDE-1,2) and 14 (pALPIDE-3) on-chip digital-to-analog converters (DACs).



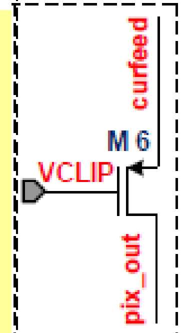
Full-scale Pixel Detector prototypes (pALPIDE -1,2,3)

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)

Full-scale Pixel Detector prototypes (pALPIDE -1,2,3)

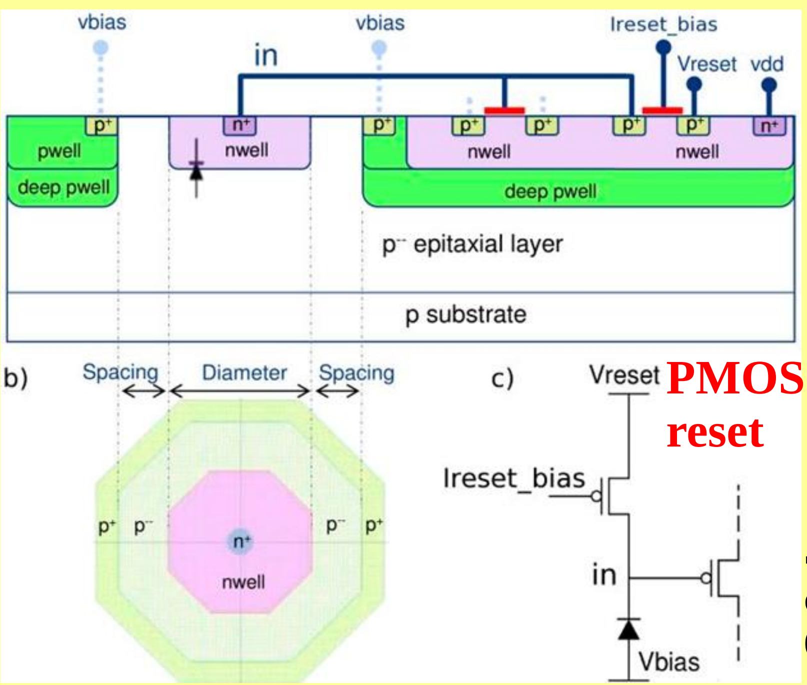
Each sector implements a different front-end electronics

pALPIDE-1

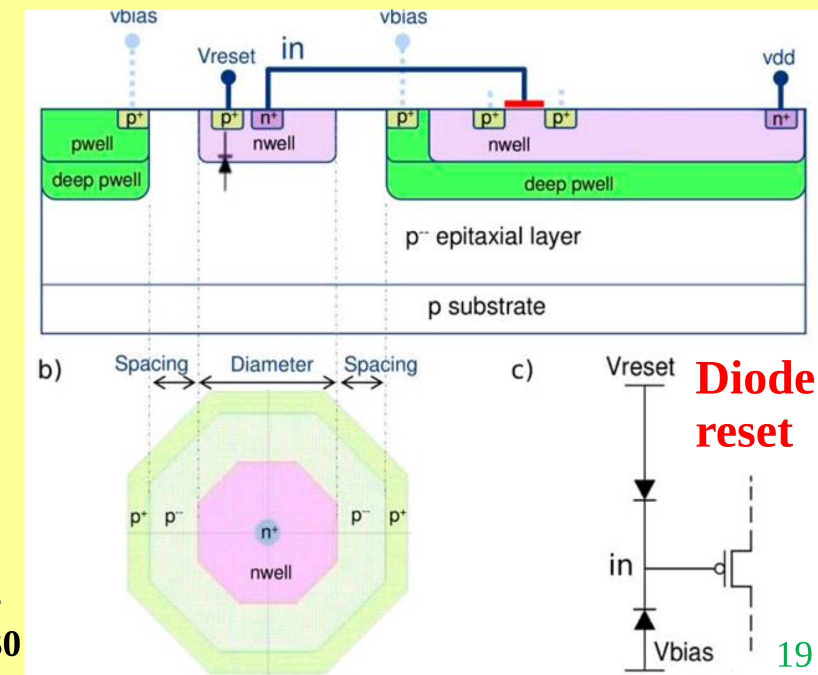
Sector	N-well diameter	Spacing	Reset type
0	2 µm	1 µm	PMOS
1	2 µm	2 µm	PMOS
2	2 µm	2 µm	Diode
3	2 µm	4 µm	PMOS

pALPIDE-2

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



Collection electrode



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

Full-scale Pixel Detector prototypes (pALPIDE-1,2,3)

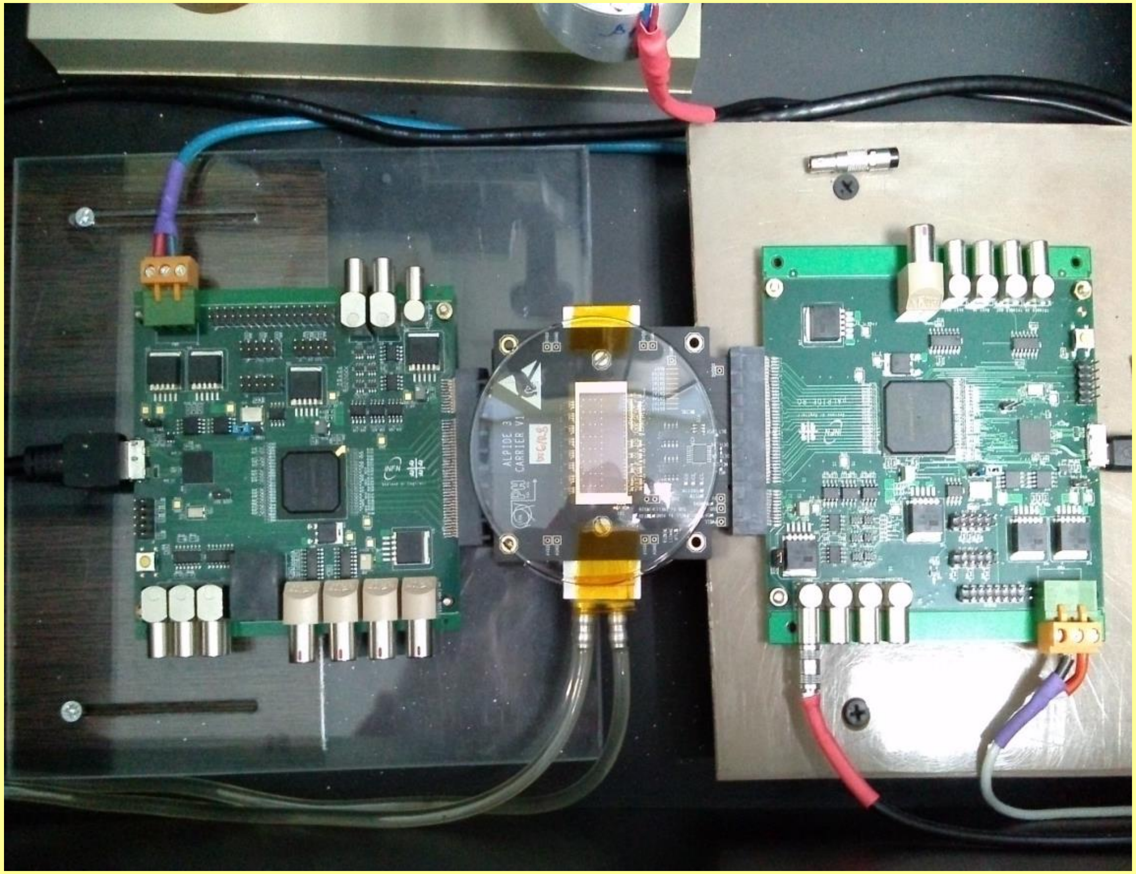
The front-end circuits in pALPIDE-3 are based on the pALPIDE-1, 2 circuit with step by step modifications in order to trace the effects on performance

Sector	M3, M5, M6, M8 (transistors)	Spacing	Reset type	Additional VCASN2 (M9)
0	optimized size	2 μm	Diode	Yes
1	optimized size	2 μm	Diode	No
2	as in pALPIDE-1/2	2 μm	Diode	No
3	optimized size	2 μm	Diode	Yes
4	optimized size	2 μm	Diode	Yes
5	optimized size	3 μm	Diode	Yes
6	as in pALPIDE-1/2	2 μm	PMOS	No
7	optimized size	2 μm	PMOS	Yes

The ALPIDE characteristics studies

For the characterization and tests of the ALPIDE prototypes, three experimental set-ups based on the test boards and software, which were jointly developed within the ITS upgrade project, have been constructed at SPbSU.

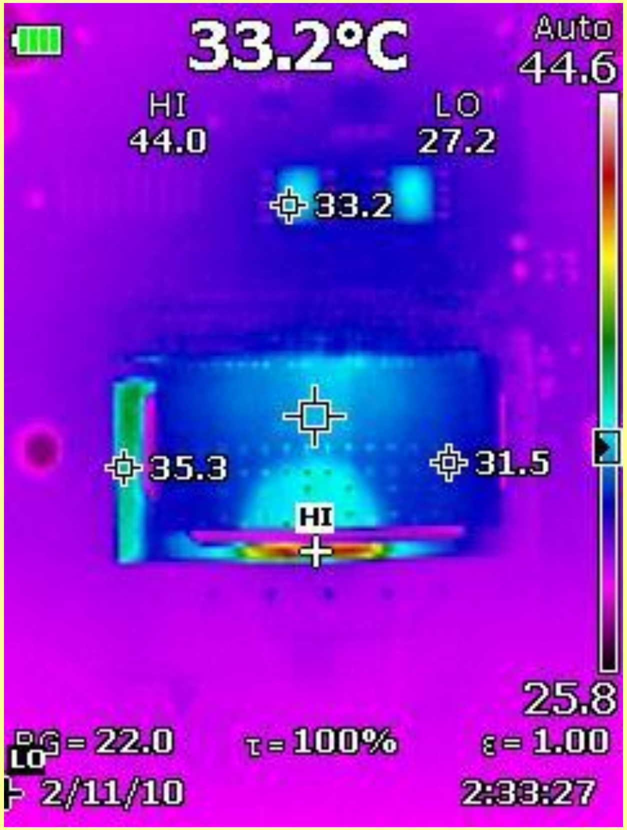
First Experimental Set-up



1. Two different chip types (telescope geometry) with own DAQ boards have been installed.
2. Dark box with electrical earthing inside needed for detector protection against light and electromagnetic interference. Temperature control inside the box is available.
3. The water cooling (heating) system has been implemented.
4. Radioactive source (γβ) positioning system. One can move source in XYZ-directions. It includes also system for visualization of central area on detector surface.
5. Detector Power supply(current control).

Second Experimental Set-up

The same as previous one but with additional system including thermo-camera for detector heating investigations .



Study of the characteristics of full-scale Pixel Detector prototypes

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

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

Also some improvements for Vbb power supply have been done.

Study of the characteristics of full-scale Pixel Detector prototypes

Second Experimental Set-up with cryogenic module

Two different mode of the cooling process:

1. **Cooling by the chiller (alcohol-containing mixture) – only up to -20 ºC.**
   To prevent a chip from the frost the nitrogen was supplied into a cryo-box.

2. **Cooling by cold nitrogen which evaporates from its liquid phase.**
   The liquid nitrogen was heated by nichrome heater putted into the Dewar vessel.
   Then cold gas flowed through platform (inside platform).
   We can regulate the nitrogen flow, powered nichrome heater (different currents up to 6 A).
   Also we can control the volume of the liquid nitrogen weighing Dewar vessel.
   Temperature control:
   a) 3 thermocouples
   b) on-chip temperature sensor. This sensor works only up to -80 ºC.

The temperature -115 ºC has been reached

The ALPIDE characteristics studies

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 V_{CASN} and I_{THR} 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 V_{CASN} and I_{TH} 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 be used then in measurements.

All results see in Back up slides

The ALPIDE characteristics studies

Investigations of the detector’s characteristics for different temperatures

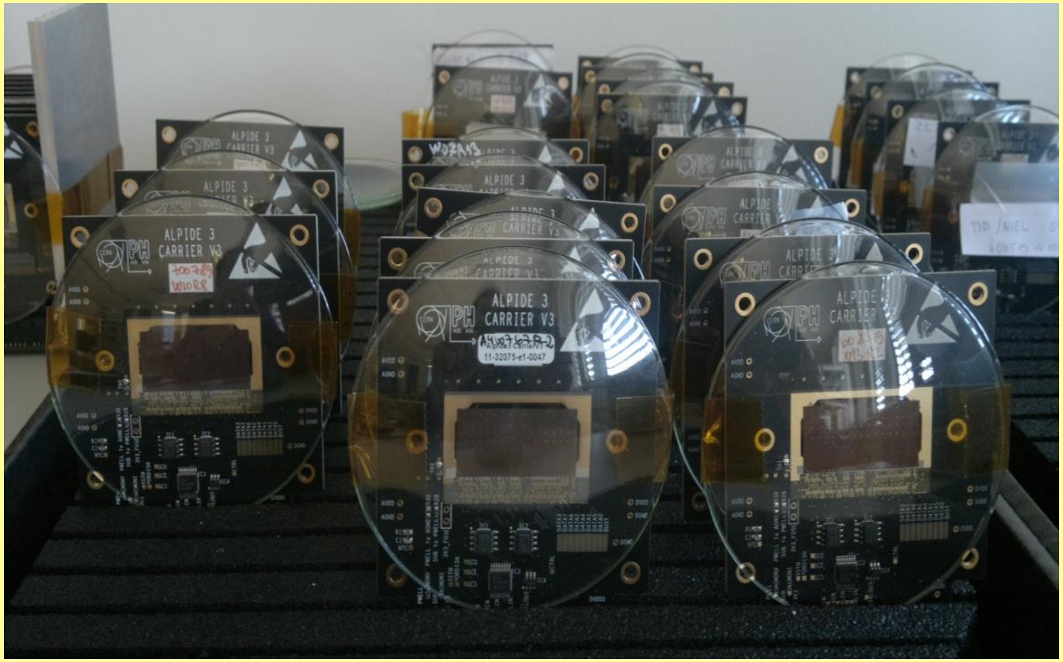
Detectors pALPIDE-4 – ALPIDE (final version)

Detectors were irradiated by:
X-rays

↓

Chip W8R22 – 60 krad (low dose)

Chip W7R12 – 300 krad (high dose)

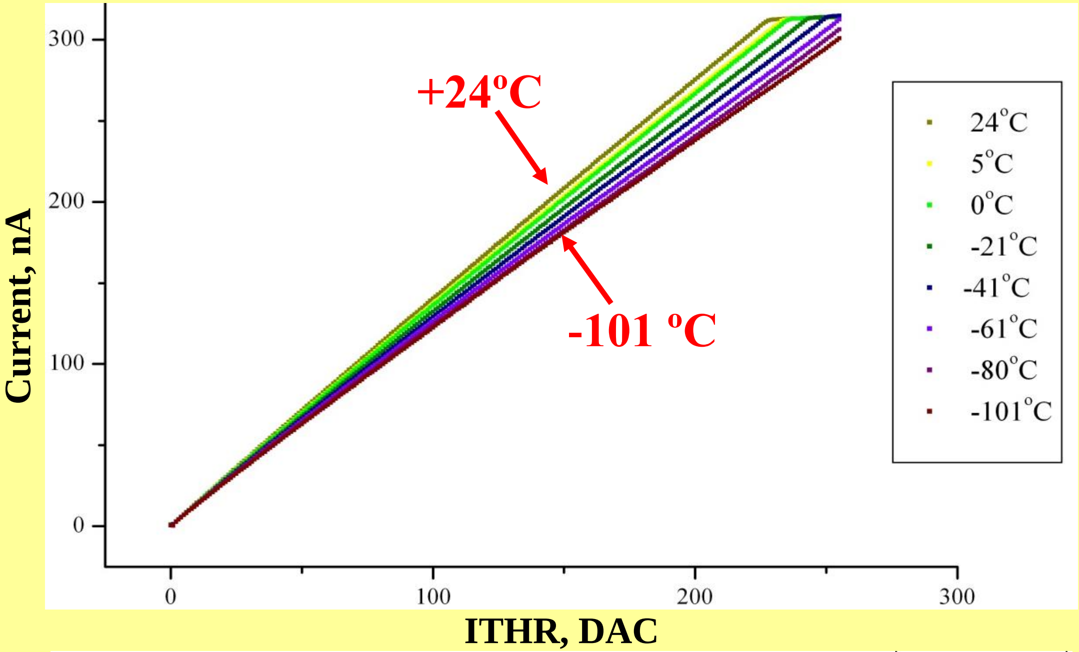


Before irradiation Chip W7R12 was measured at lab.

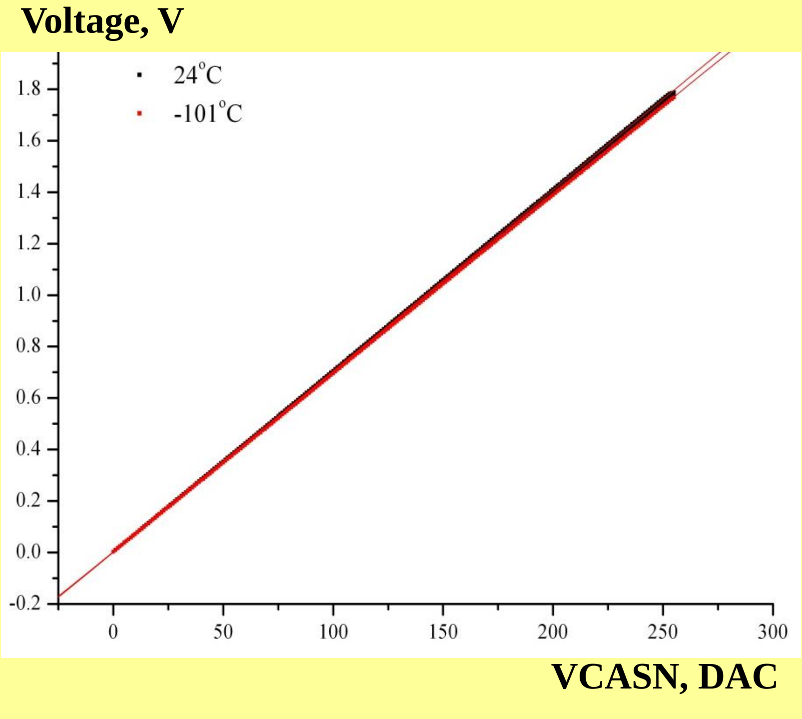
~ 5 month after irradiation

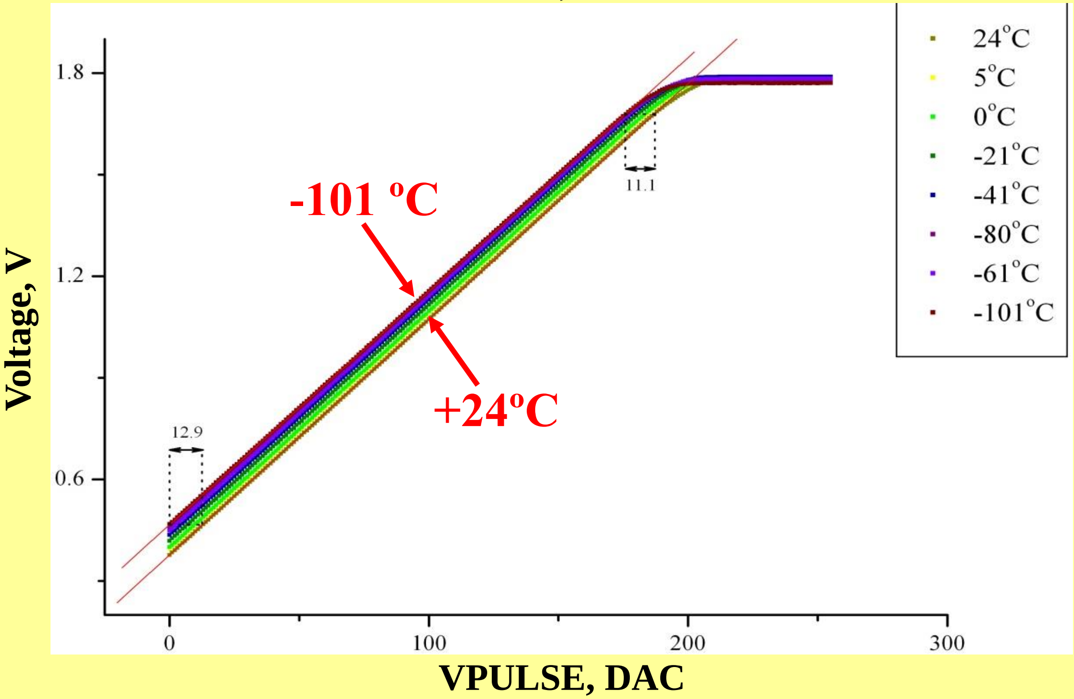
All measurements were done at Vbb = -3V

The ALPIDE characteristics studies

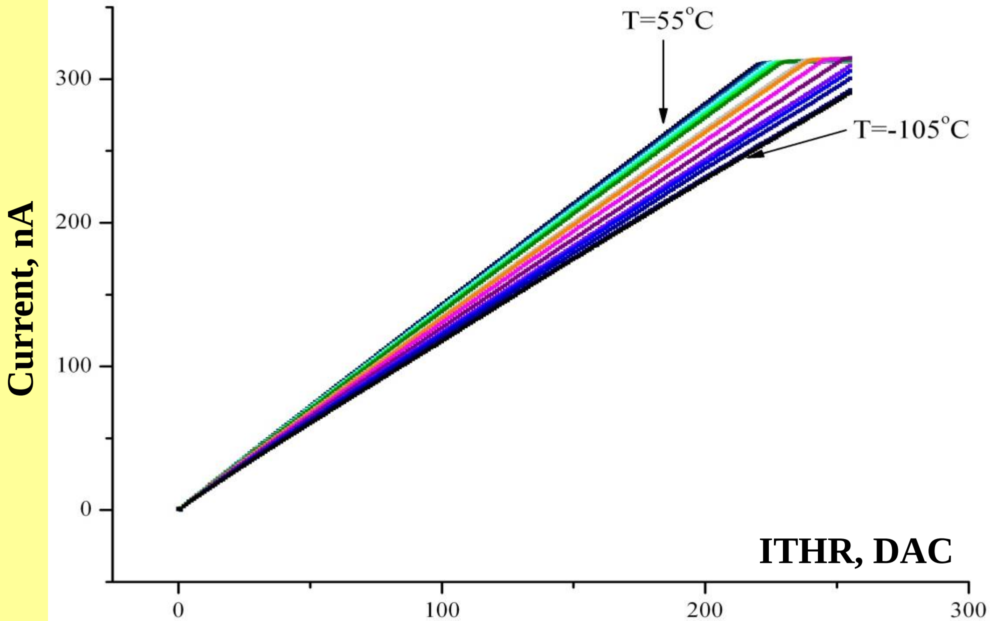


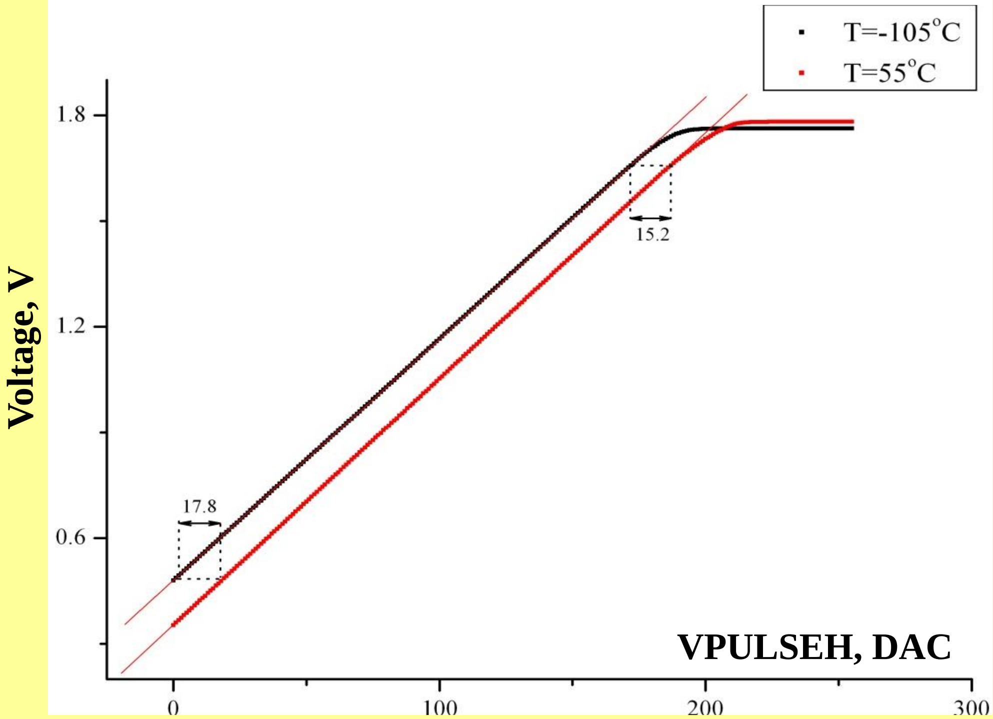
DAC Scan Chip W8R22





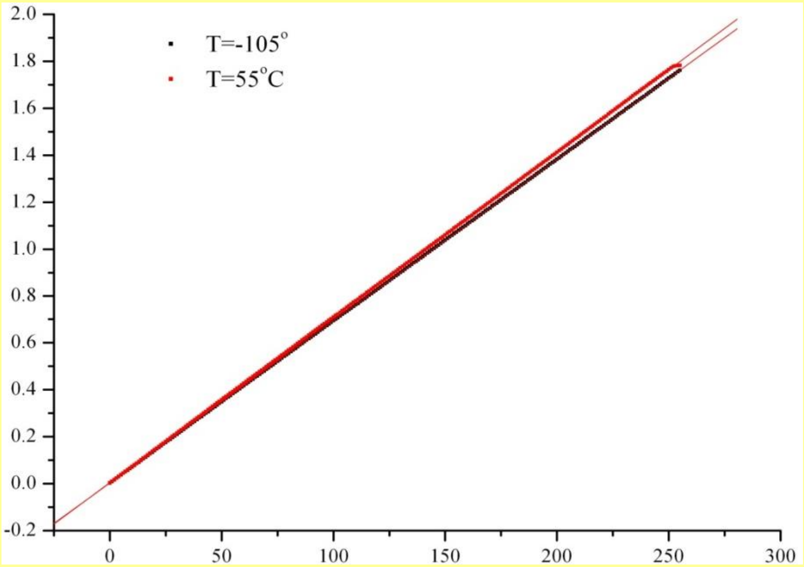
The ALPIDE characteristics studies





DAC Scan Chip W7R12

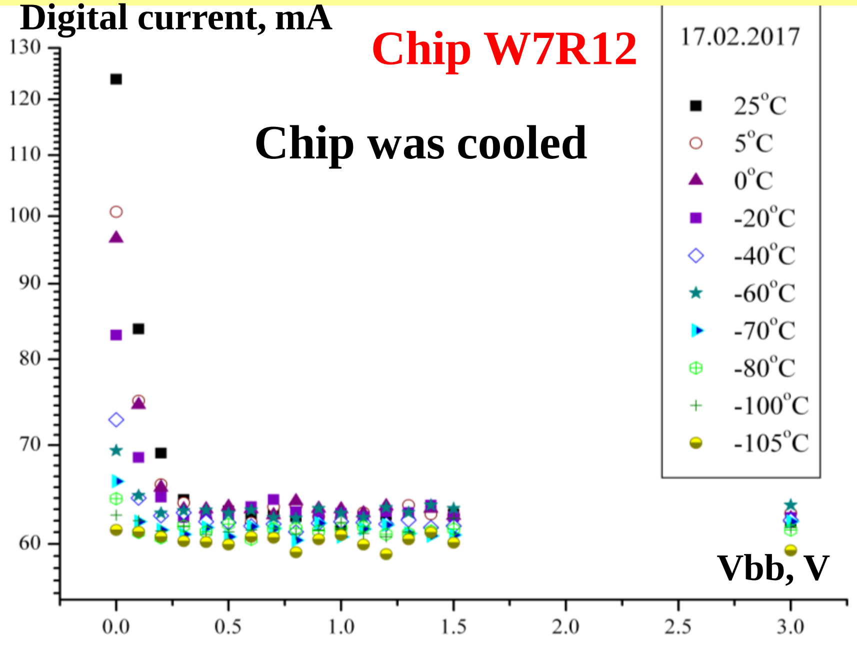
Voltage, V

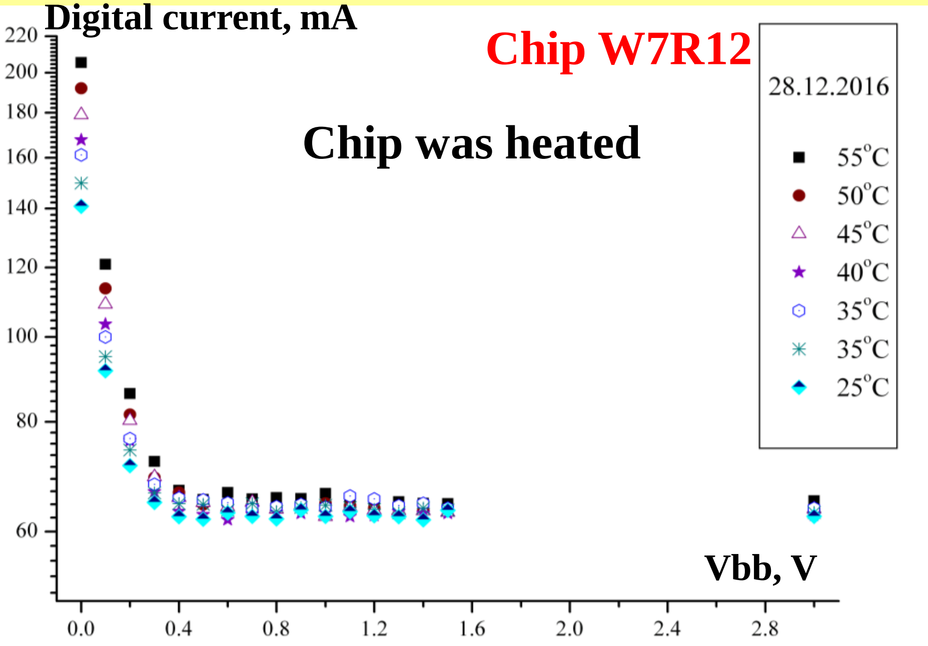


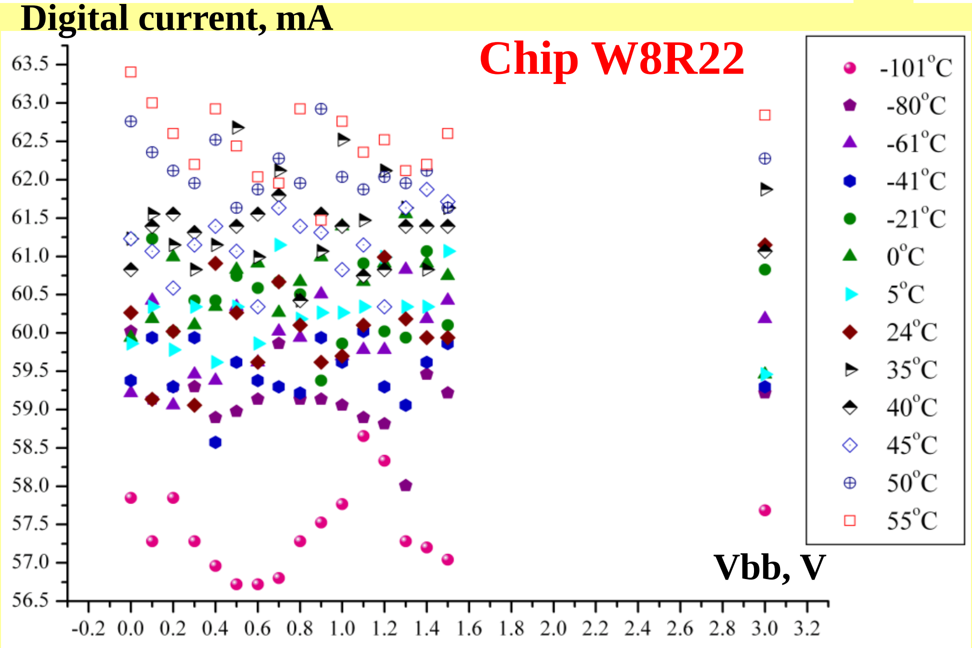
VCASN, DAC

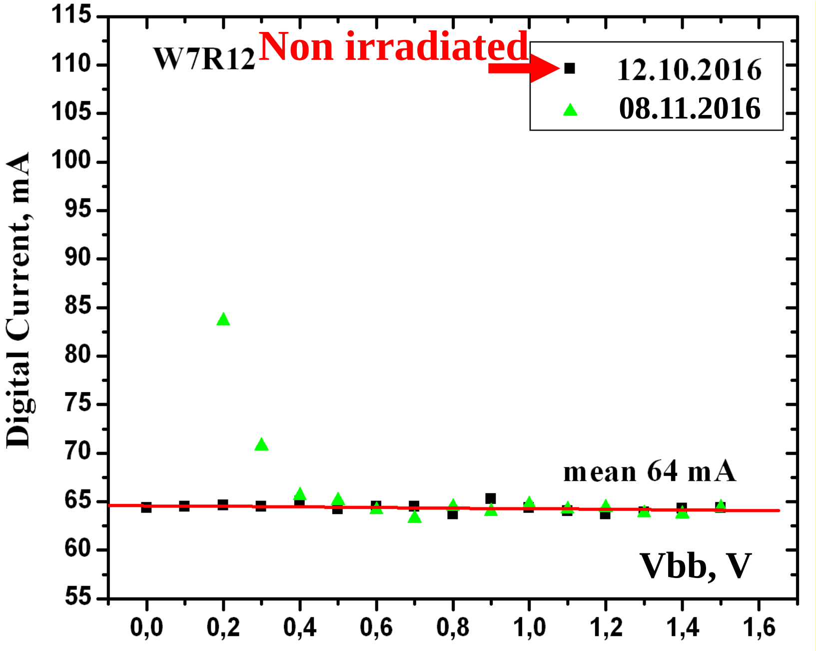
This chip was also heated to 55 ^{0}C (for annealing investigations)

Digital Currents





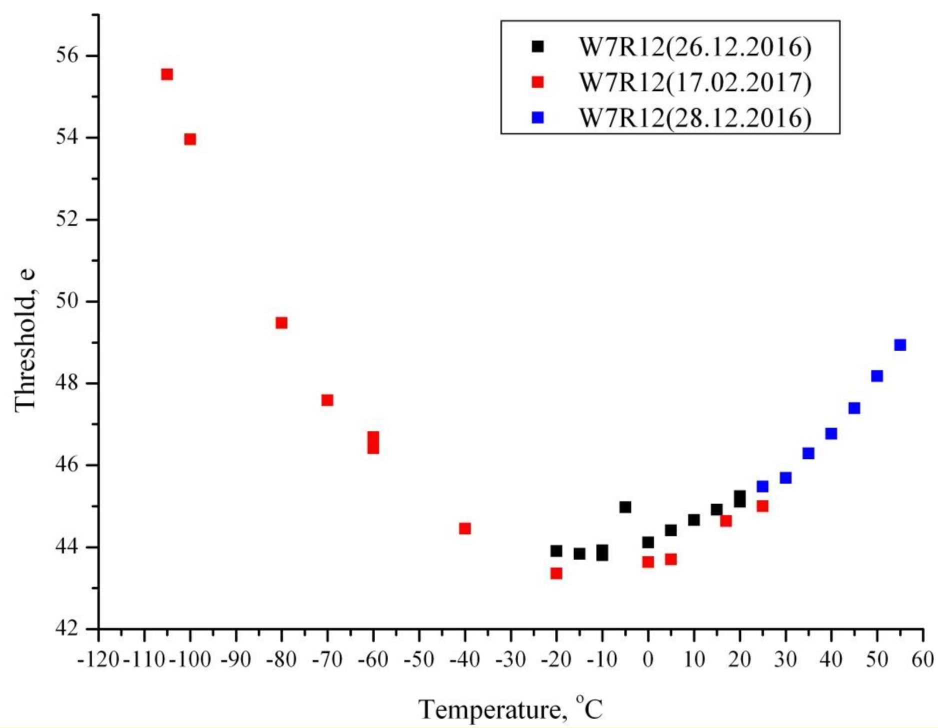


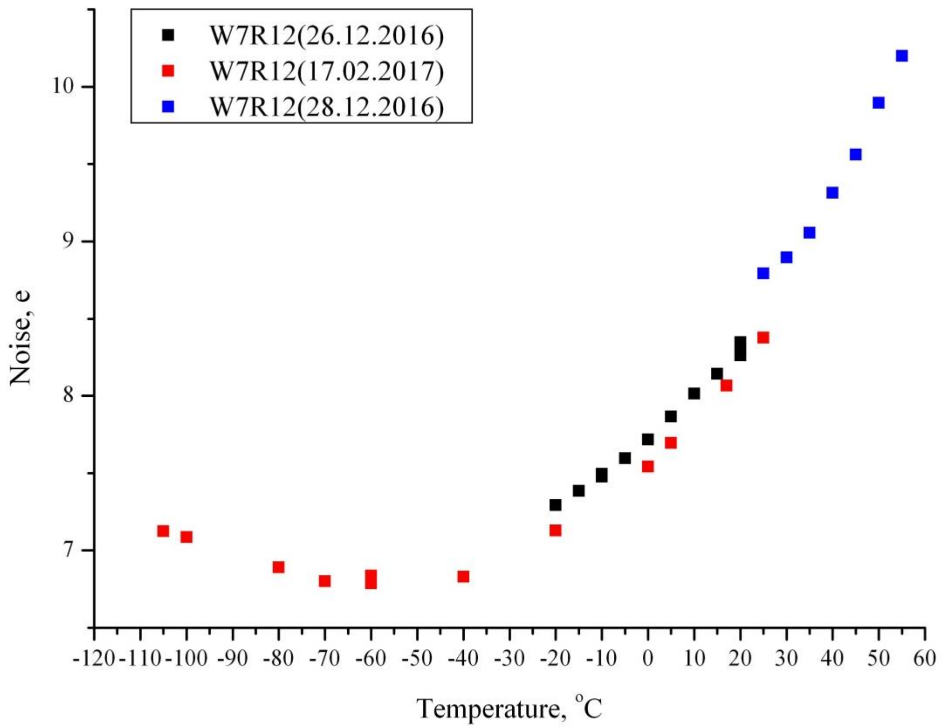


Study of the characteristics of full-scale Pixel Detector prototypes

Results for high dose irradiated chip **Threshold Scan**

Chip W7R12





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

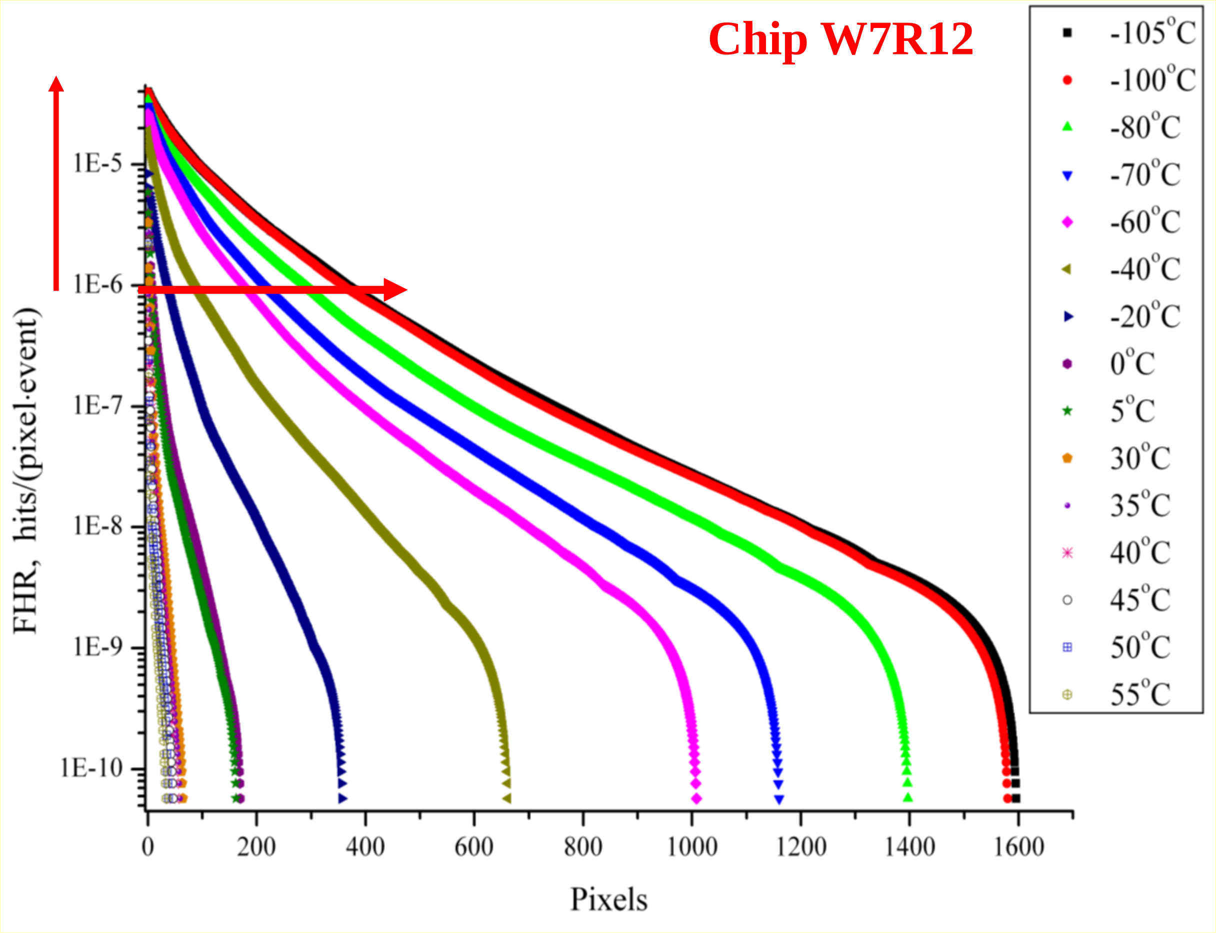
Before irradiation the noise was ~ 6 e,
after irradiation (300 krad)
the noise was ~ 14 e

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

The ALPIDE characteristics studies

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. The same results for low dose irradiated chip

The ALPIDE characteristics studies

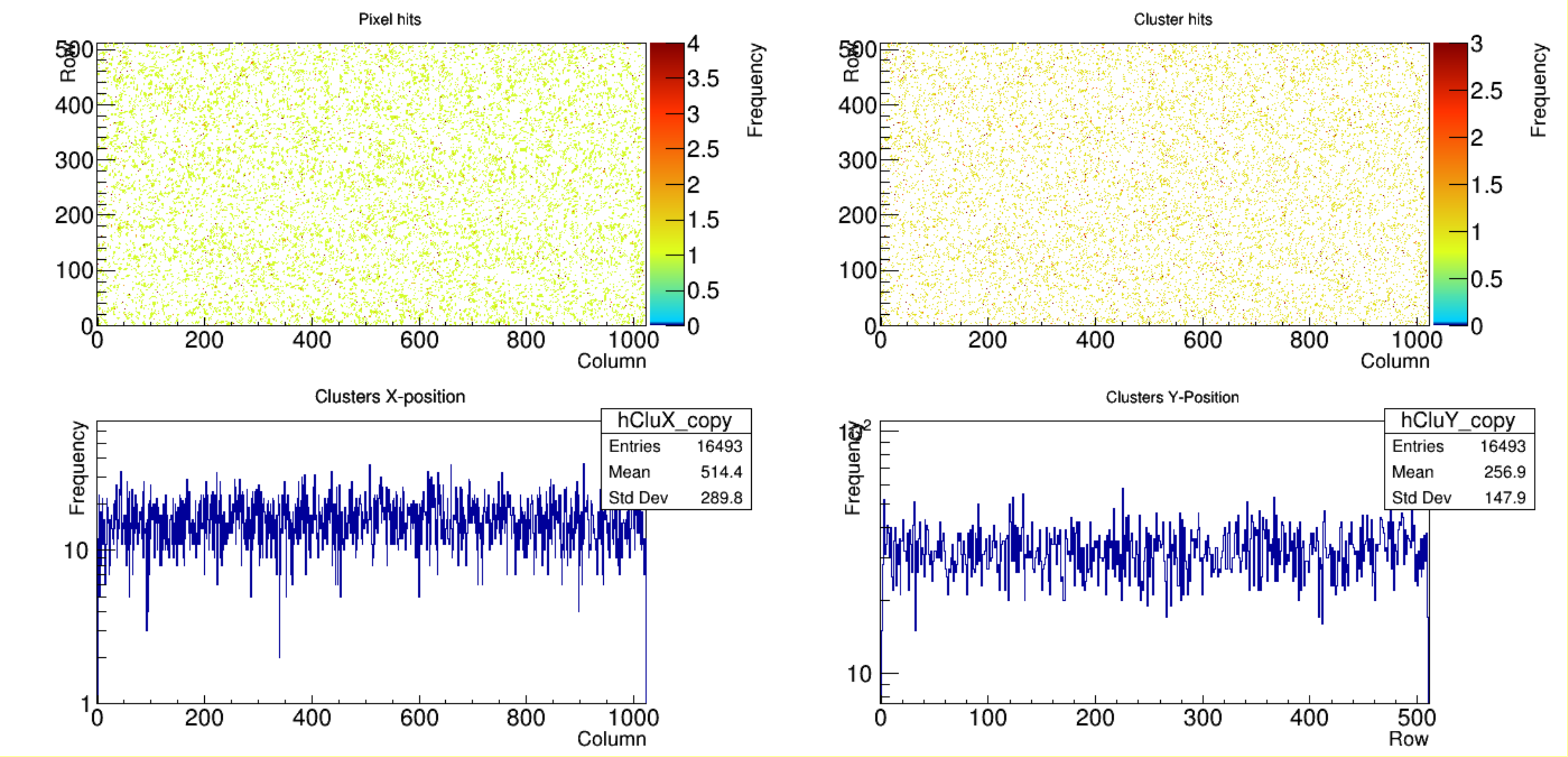
Results for high dose irradiated chip

Source test + Cluster analysis

Triggers: 2000000
Vbb = -3V

Chip W7R12

Masked



Source: 133Ba, chip temperature -115 ºC

The ALPIDE characteristics studies

Results for high dose irradiated chip

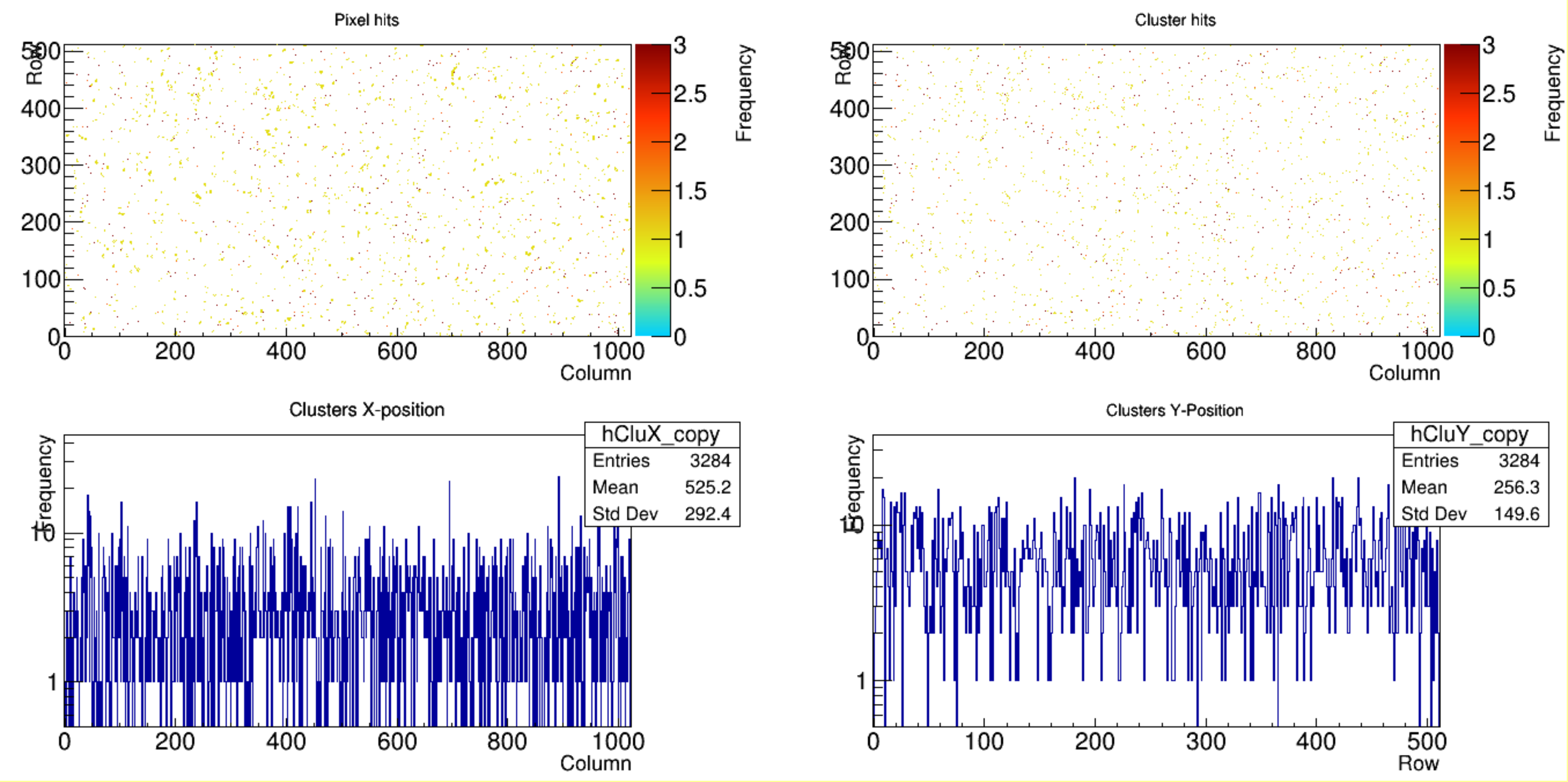
Source test + Cluster analysis

Triggers: 2000000

Vbb = -3V

Chip W7R12

Masked



Source: Sr-Y, chip temperature -100 ºC

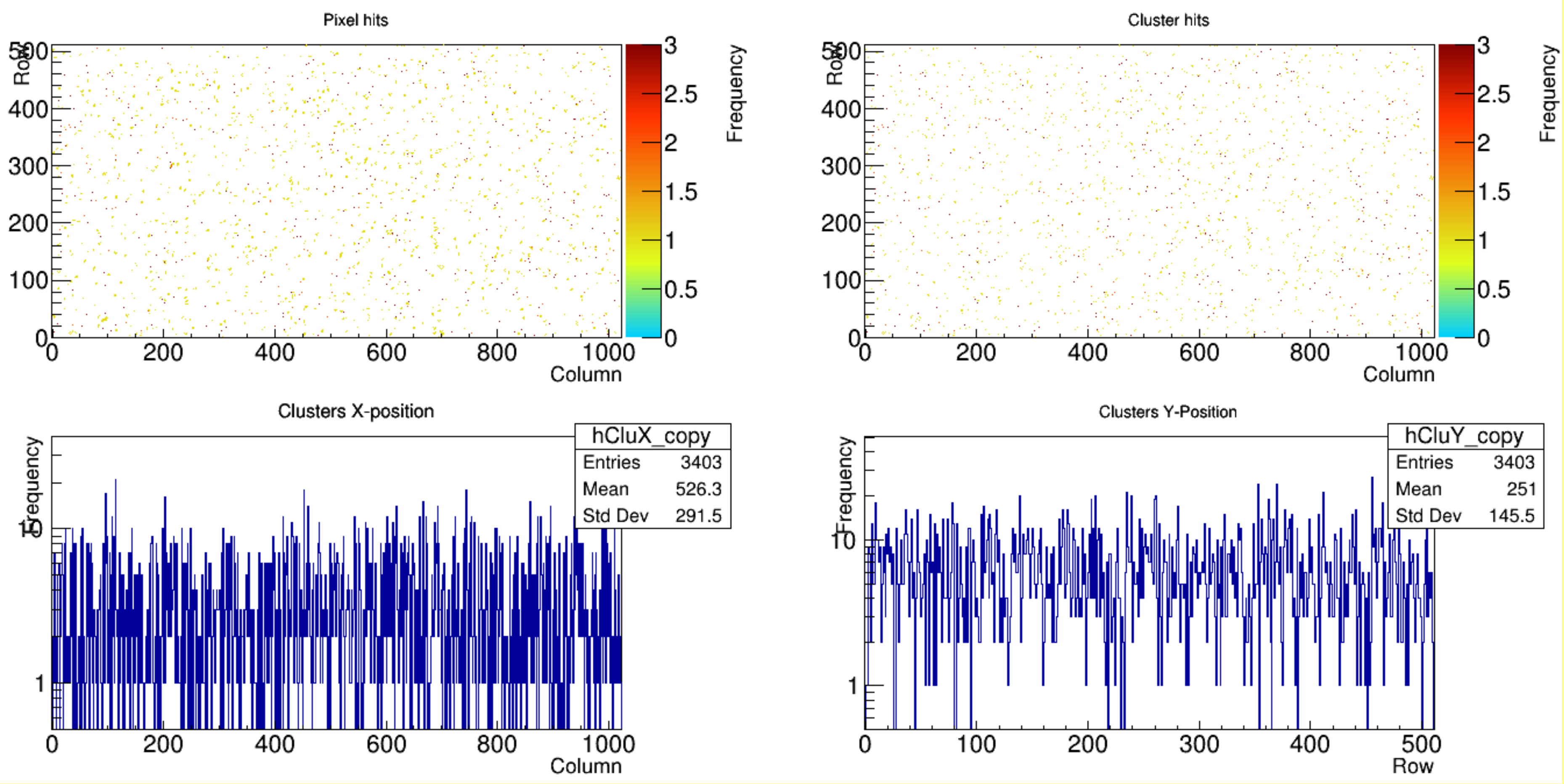
The ALPIDE characteristics studies

Results for high dose irradiated chip

Source test + Cluster analysis

Triggers: 2000000
Vbb = -3V

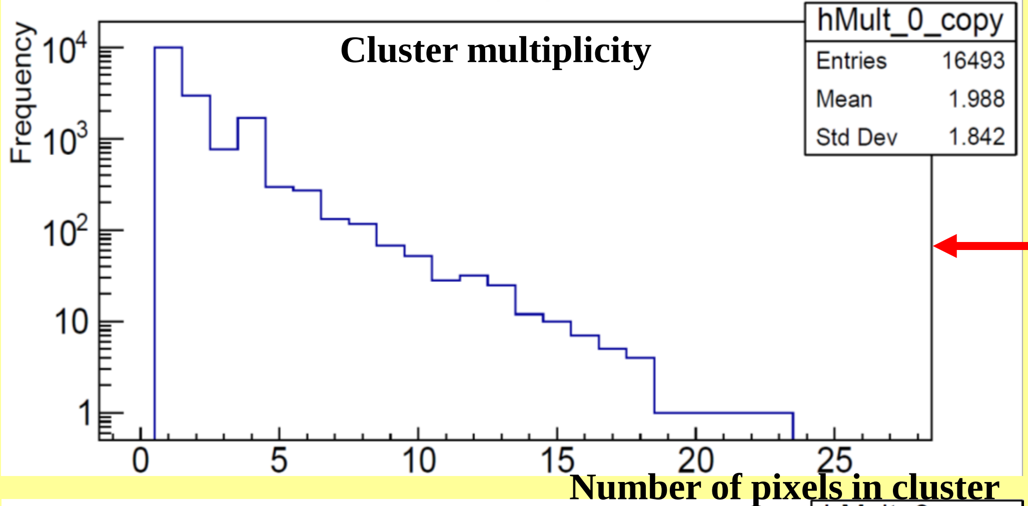
Chip W7R12 **Masked**



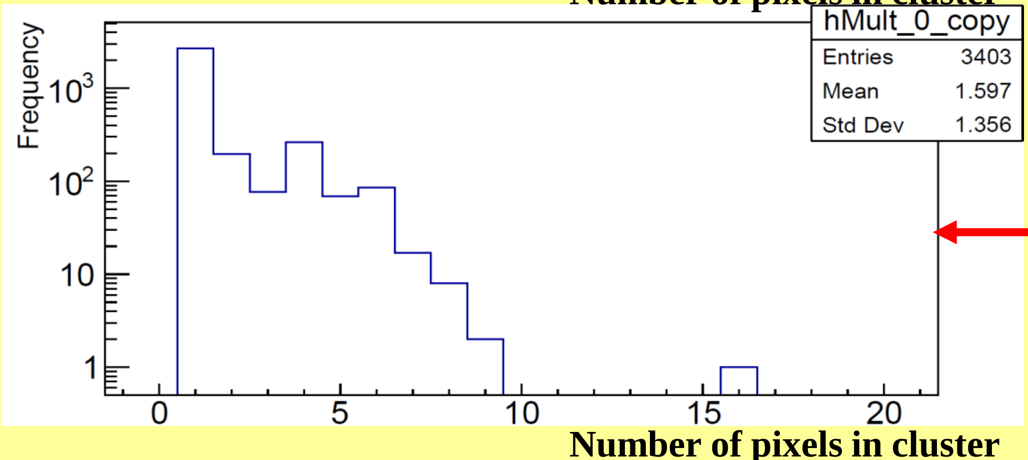
Source: 14C, chip temperature -100 ºC

Source test + Cluster analysis

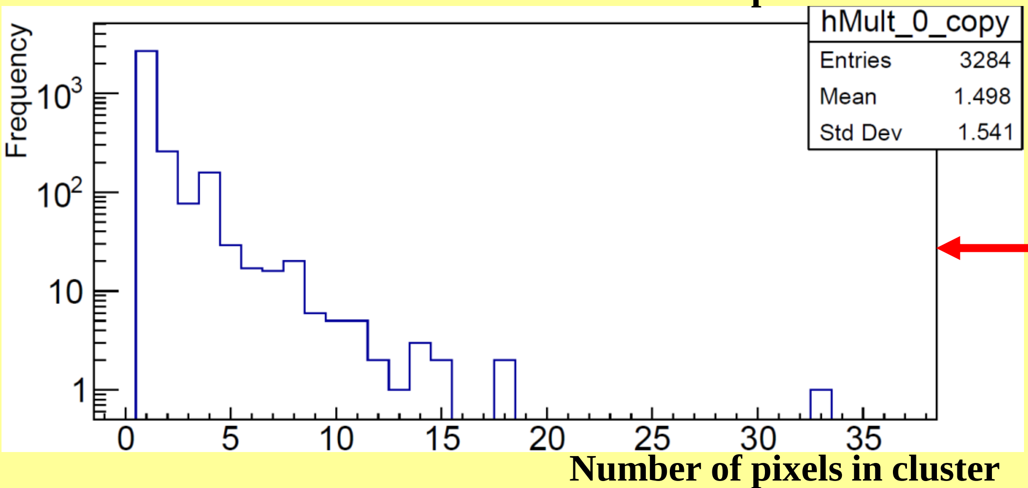
Chip W7R12



133Ba, chip temperature **-115 ºC**



14C, chip temperature **-100 ºC**

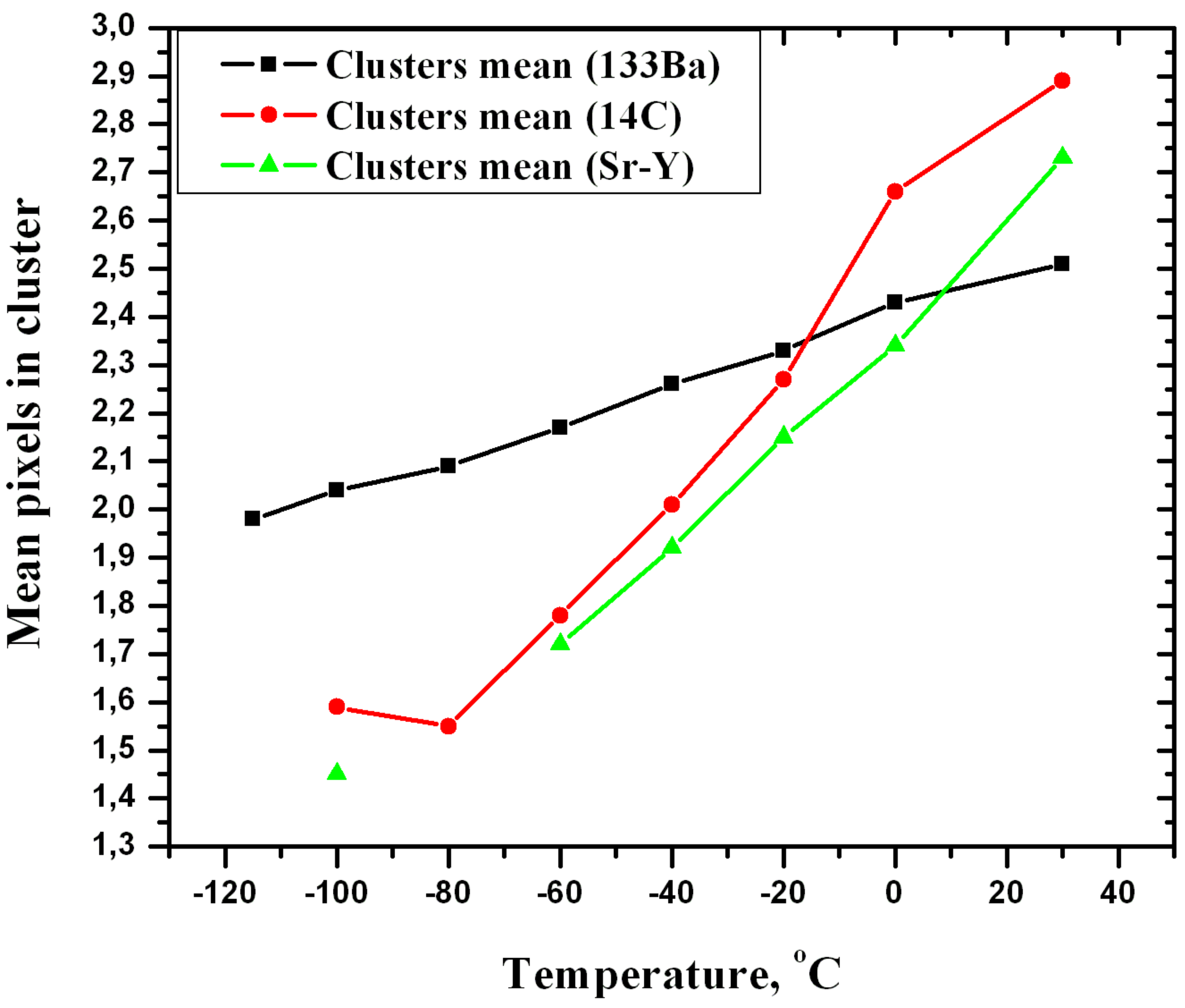


Sr-Y, chip temperature **-100 ºC**

The ALPIDE characteristics studies

Source test + Cluster analysis

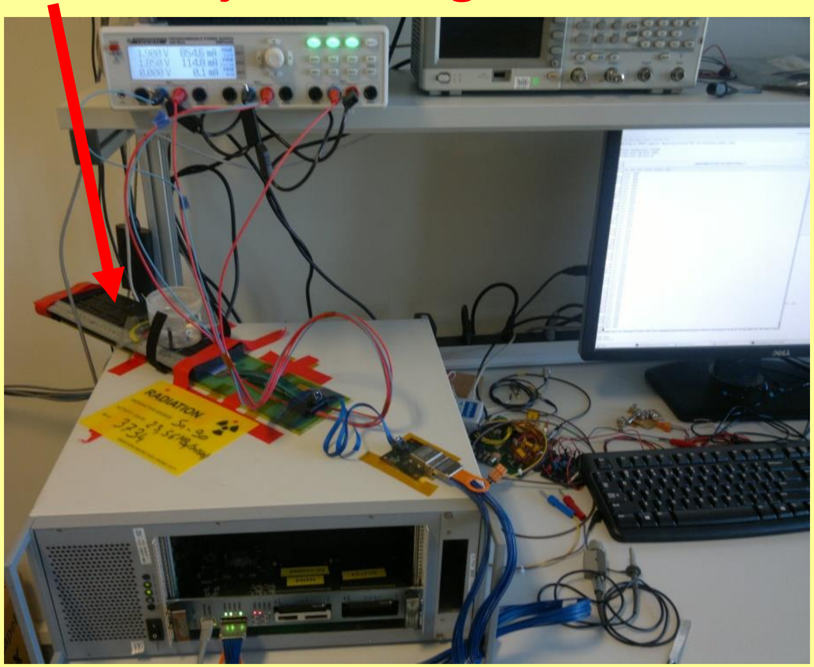
Chip W7R12

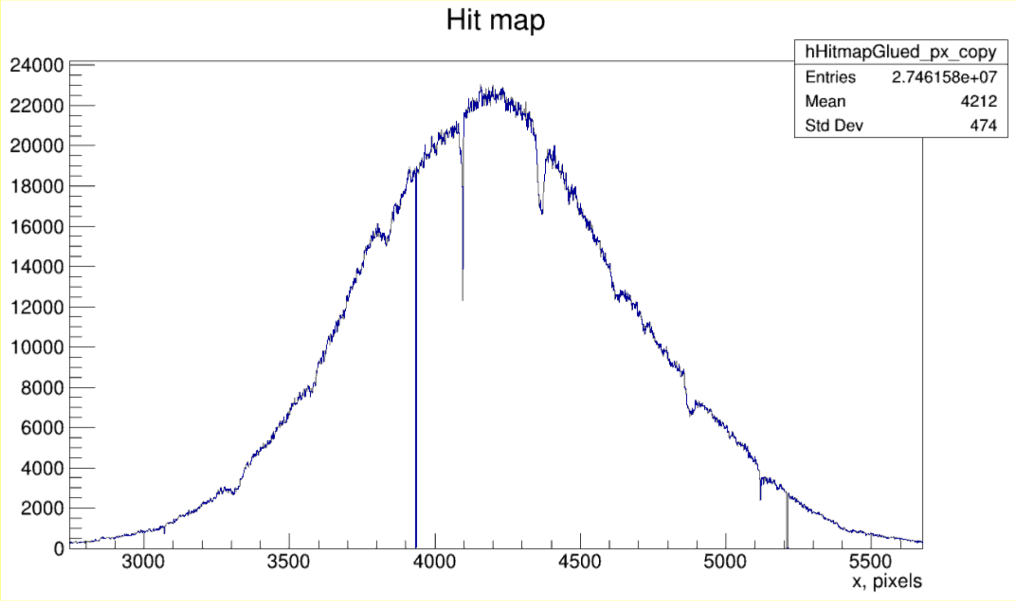


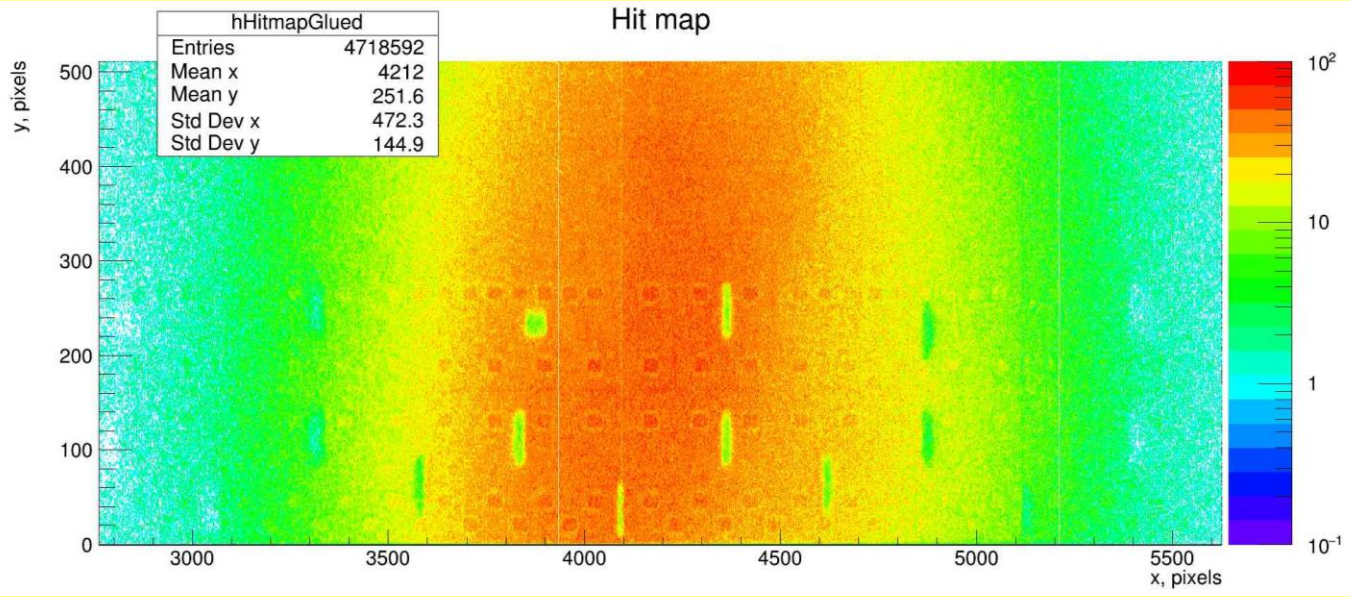
The ALPIDE characteristics studies

HIC – Hybrid Integer Circuit consist of 9 ALPIDE chips

+ adapter IB FireFly-Eyespeed + VME

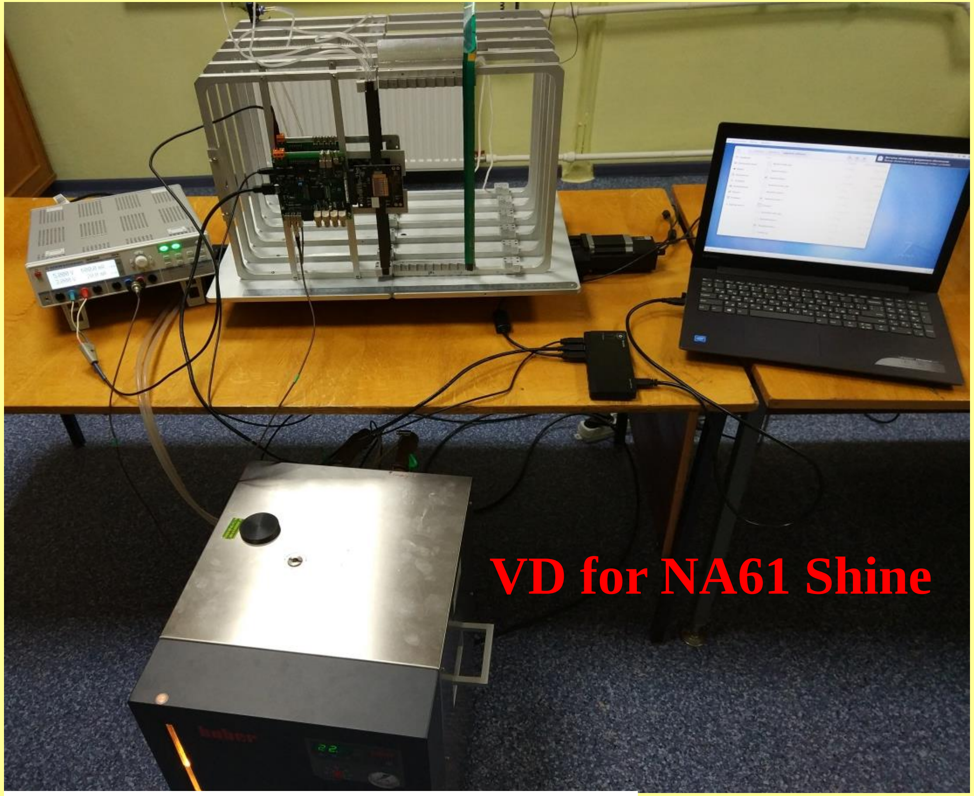


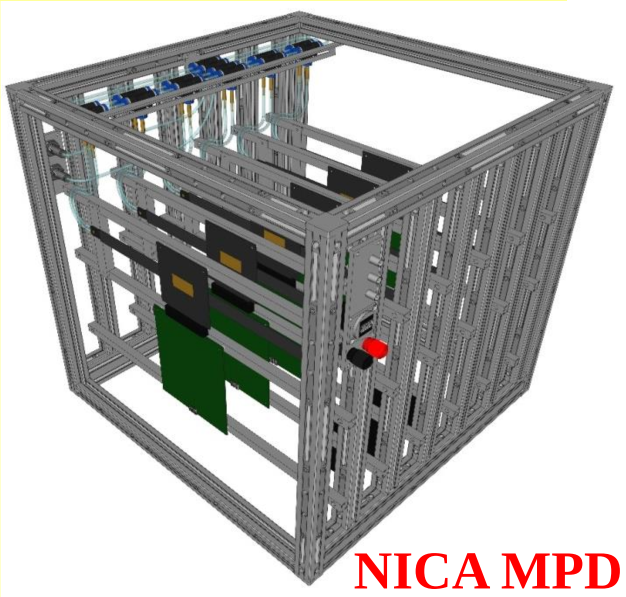


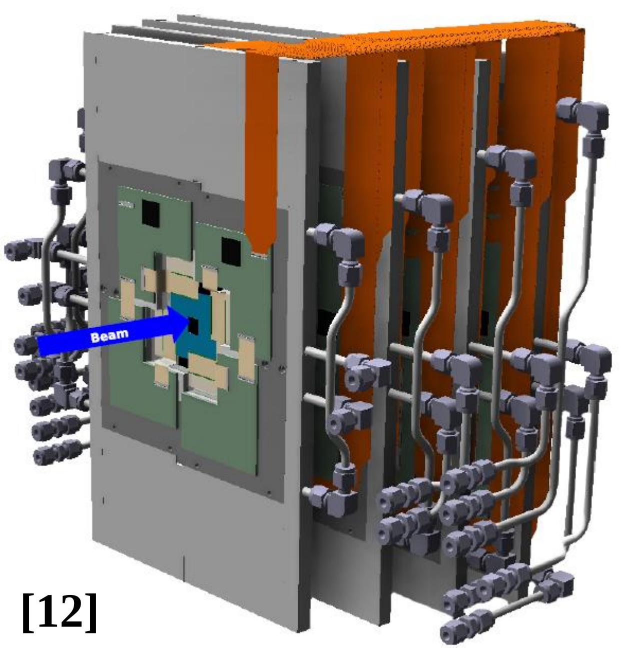


Sr-Y

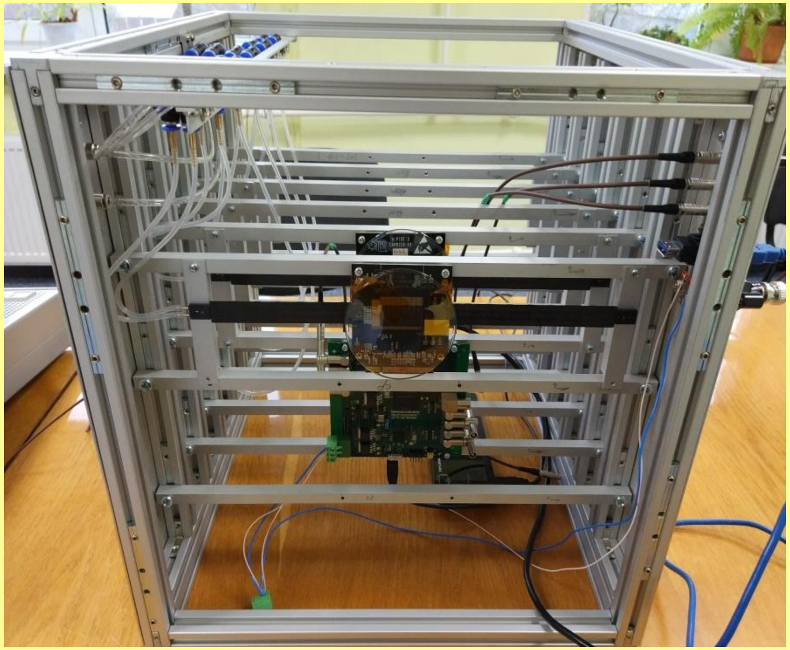
Detectors in Future Experiments





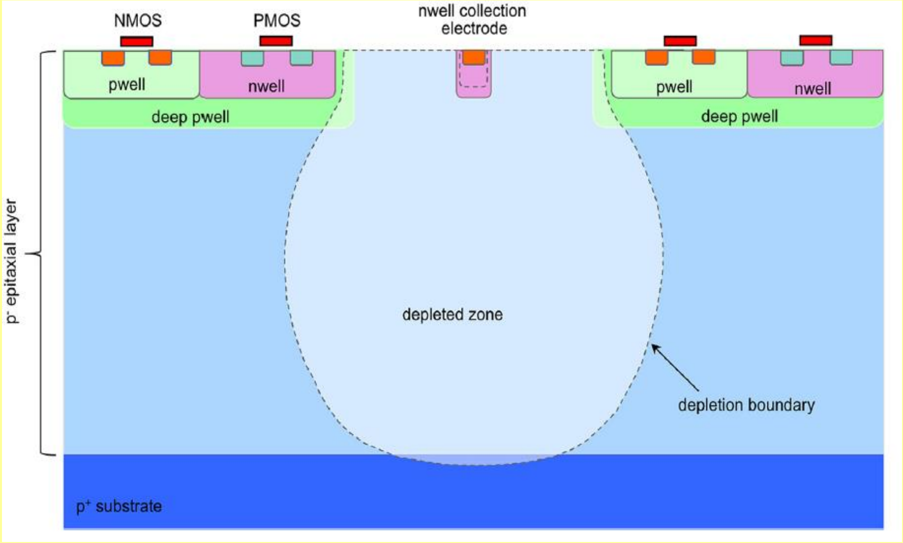


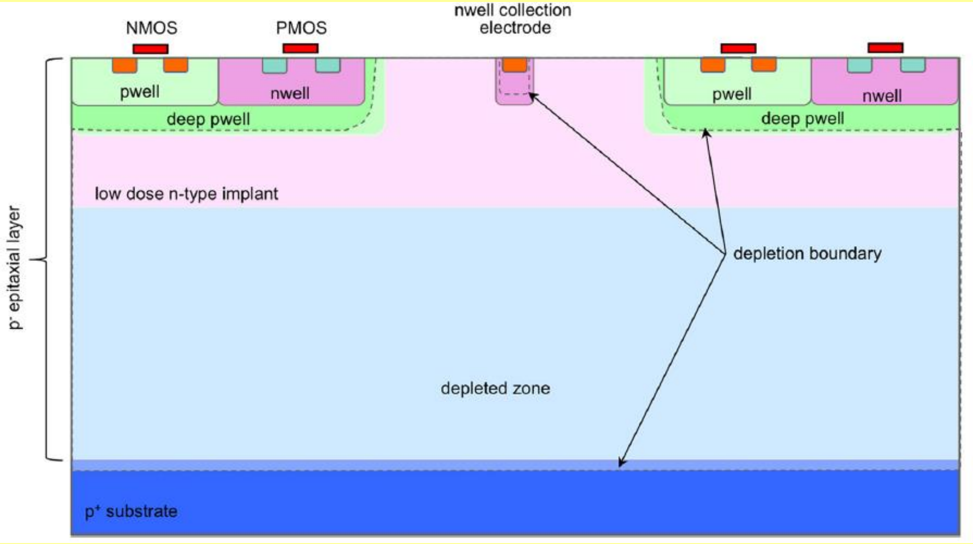
CBM Micro Vertex Detector
Chip MIMOSIS



Detectors in Future Experiments

Modification for CMOS monolithic active pixel sensors





MAPS now. A deep pwell shields the nwells with circuitry from the sensor and allows full CMOS in the pixel. In the standard process it is difficult to deplete the epitaxial layer over its full width

[13]

MAPS future. Modification to fully deplete the epitaxial layer even with a small charge collection electrode. It uses a low dose blanket deep high energy n-type implant in the pixel array.

To improve NIEL tolerance up to 10^{15} 1 MeV n_{eq}/cm^2, a drift field and hence depletion is required over the full sensitive layer. It reduce their collection time and hence the probability for them to be captured by radiation-induced defects or traps and be lost for readout.

Industrial applications

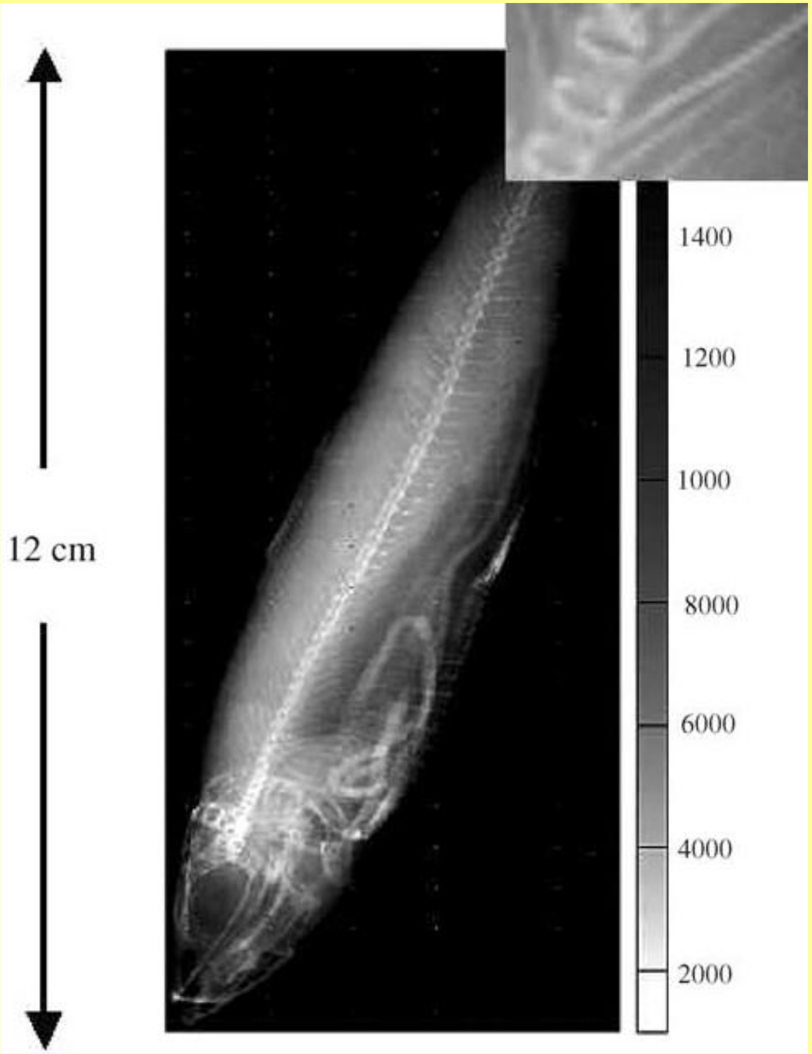
Medical: Scanners, Tomography, X-ray

Material science: Synchrotron, Xray detectors

Home security: Scanners, detectors

Space: rad tolerant electronics

Military

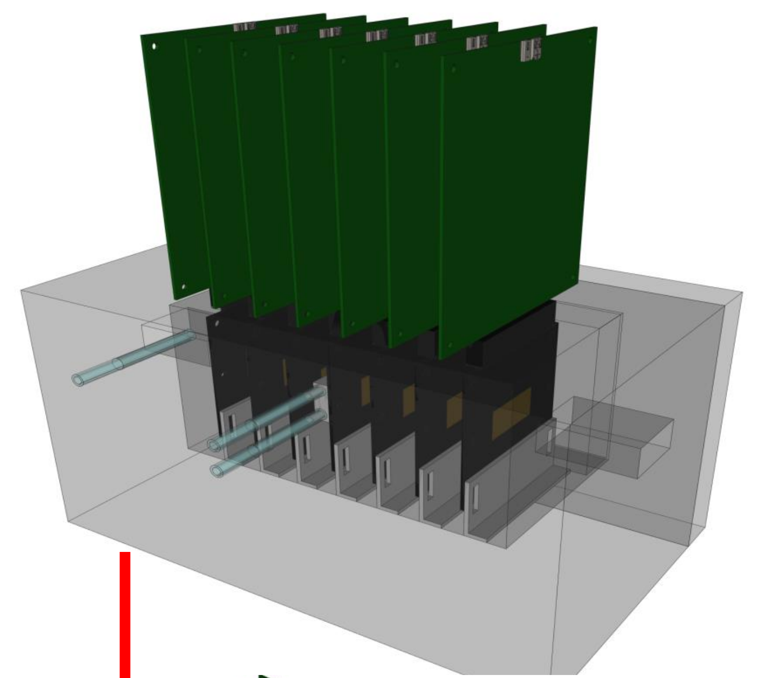


X-ray scan of a sardine with using the hybrid pixel detector MEDIPIX (64x64 pixels,170 um x 170 um) from [14]

Next plans

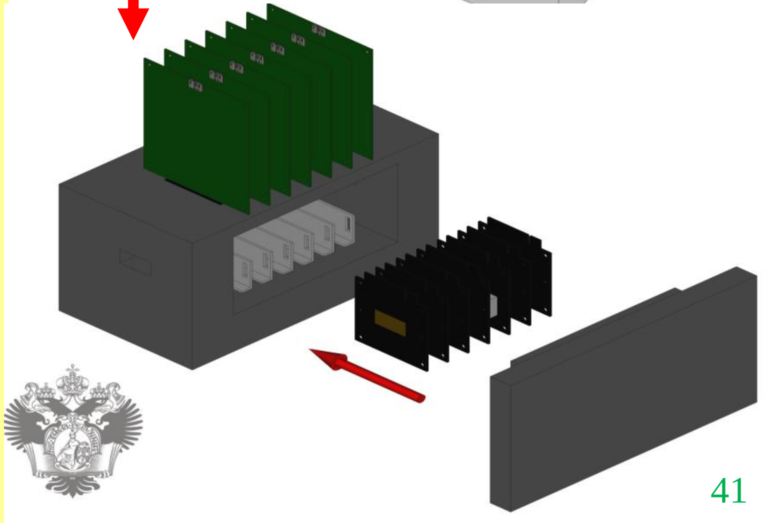
1. Investigations of strongly irradiated ALPIDE – Final Version
   and Hybrid Integrated Circuit with 9 ALPIDE chips.

2. New experimental set-up for detector
   characterization: telescope + cooling.



3. Constructing new VD prototype with
   ALICE inner barrel staves for NA61

4. New experimental set-up for detector tests
   with using Nuclotron beams in JINR
   for NICA MPD project.



New experimental setup for Beam Tests
of Irradiated ALPIDE Chip equipped with
cooling module

Conclusions

The development of MAPS have made significant progress in the last decade.

The big work is being done to make MAPS for using at high rate and high radiation environments in HEP experiments.

Literature

1. ALICE: http://cdsweb.cern.ch/collection/ALICE%20Photos?ln=ru
   The ALICE experiment at the CERN LHC, 2008 JINST 3 S08002, doi:10.1088/1748-0221/3/08/S0800

2. ATLAS Experiment: http://cds.cern.ch/record/1095925

3. ATLAS Experiment: http://cds.cern.ch/record/989408

4. CMS: http://cms.cern/detector/identifying-tracks

5. LHCb:http://cdsweb.cern.ch/search?cc=LHCb+Photos&ln=ru&p=subject%3A%22VELO%22

6. V.Zherebchevsky «WG3 ITS upgrade meeting», CERN, 30.04. 2012: https://indico.cern.ch/event/188015/

7. Felix Reidt CERN-THESIS-2016-033

8. Conceptual Design Report for the Upgrade of the ALICE ITS

9. Flemming Videbaek For the STAR collaboration Brookhaven National Lab
   https://sss.slideserve.com/shaw/the-star-heavy-flavor-tracker

10. Guannan Xie (for the STAR Collaboration). https://arxiv.org/pdf/1704.04353.pdf
    XXVIth International Conference on Ultrarelativistic Nucleus-Nucleus Collisions/ (Quark Matter 2017)

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

12. CBM-MVD. https://indico.gsi.de/event/6234/contribution/2/material/slides/0.pdf

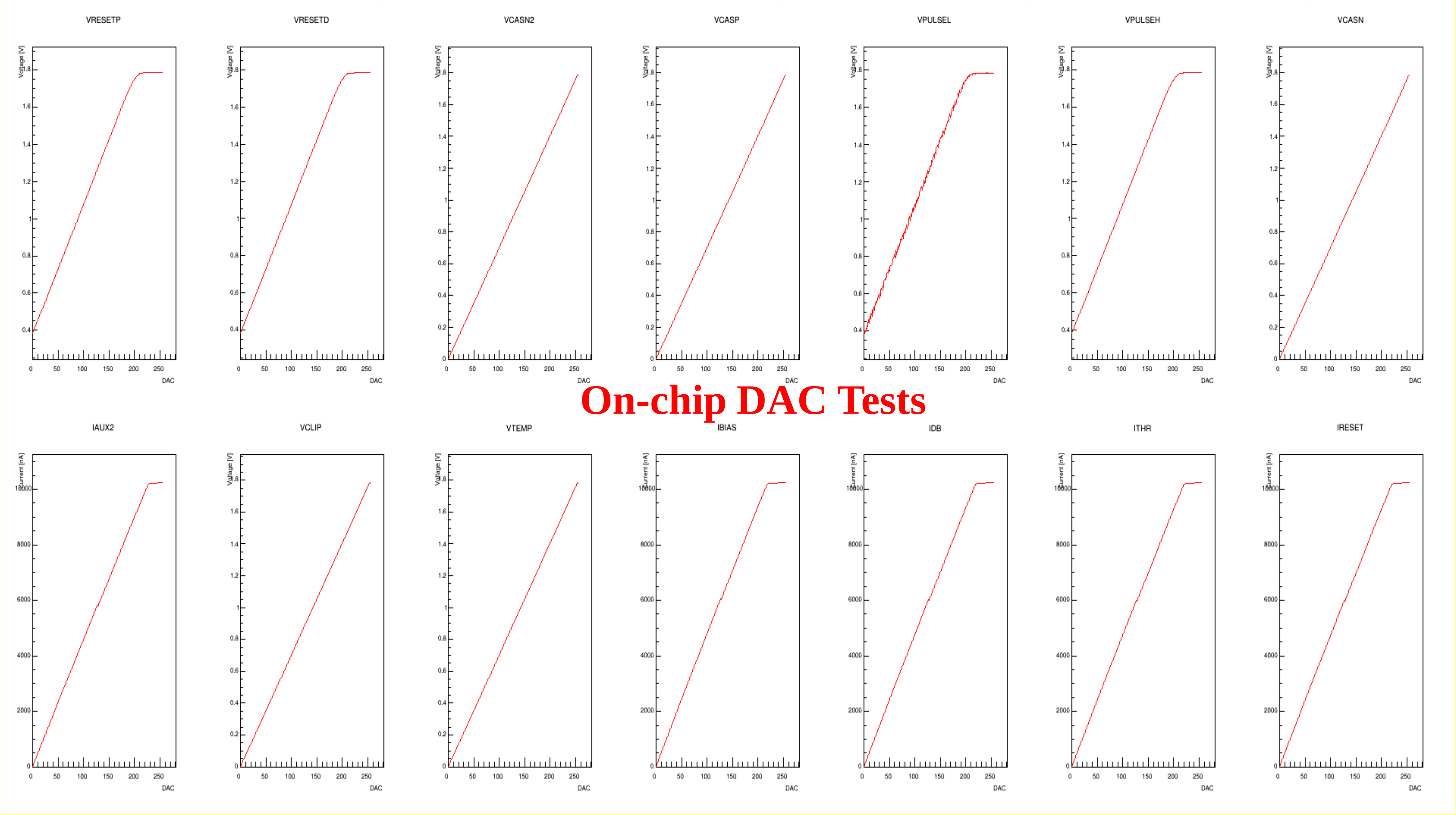
13. W. Snoeys et.al. Nuclear Inst. and Methods in Physics Research, A 871 (2017) 90–96

14. N. Wermes, Nuclear Instruments and Methods in Physics Research, A 512 (2003) 277–288

BACK-UP SLIDES

Study of the characteristics of full-scale Pixel Detector prototypes

All next experimental results are presented for pALPIDE-3 chip



On-chip DAC Tests

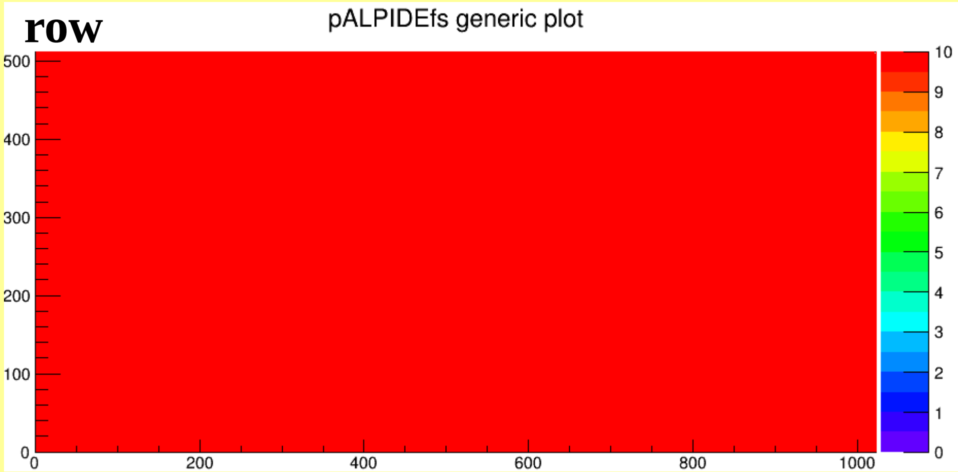
Good linearity of voltage and current settings has been observed. The linear fit demonstrates the same slopes for all parameters for the present chip at different temperatures.

Study of the characteristics of full-scale Pixel Detector prototypes

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

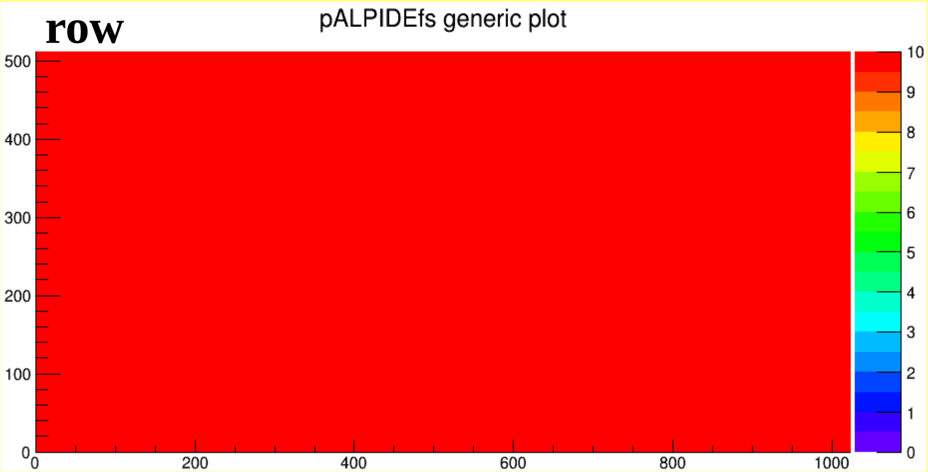
For both tests common parameters: 10 (number of injections per pixel) and test 100 % of the pixels
For analogue test an additional parameter the charge equal 350 e^- was used.

Digital Scan



column

Analogue Scan



column

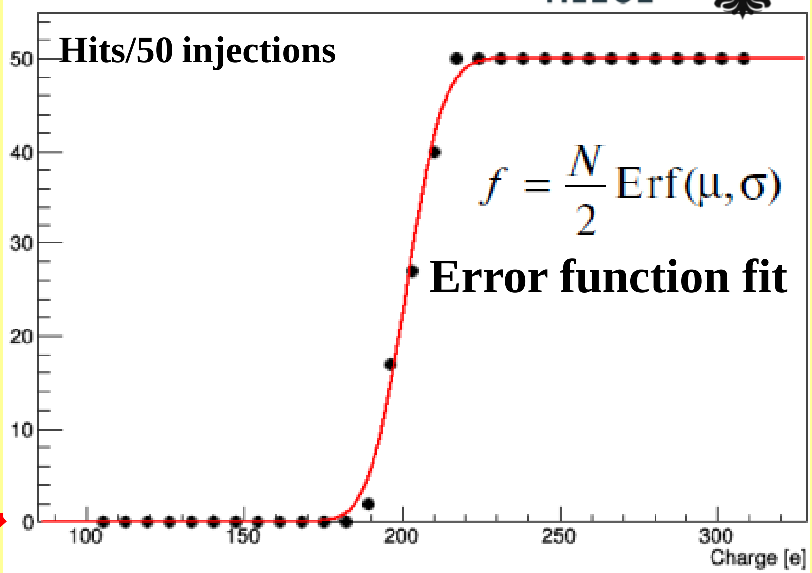
Good homogeneity of the pixel maps for both scans has been observed.

Study of the characteristics of full-scale Pixel Detector prototypes

Threshold Scan

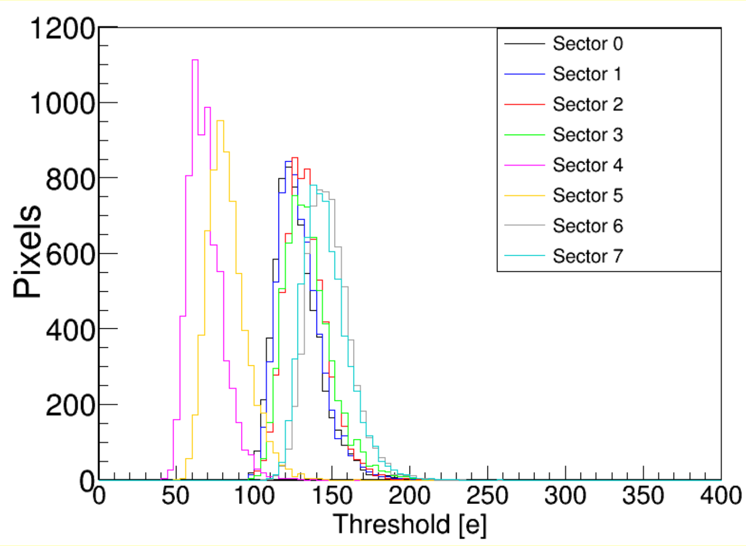
The operational thresholds for a certain set of detector's pixels depending on the charge delivered to the chosen pixels was determined

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.

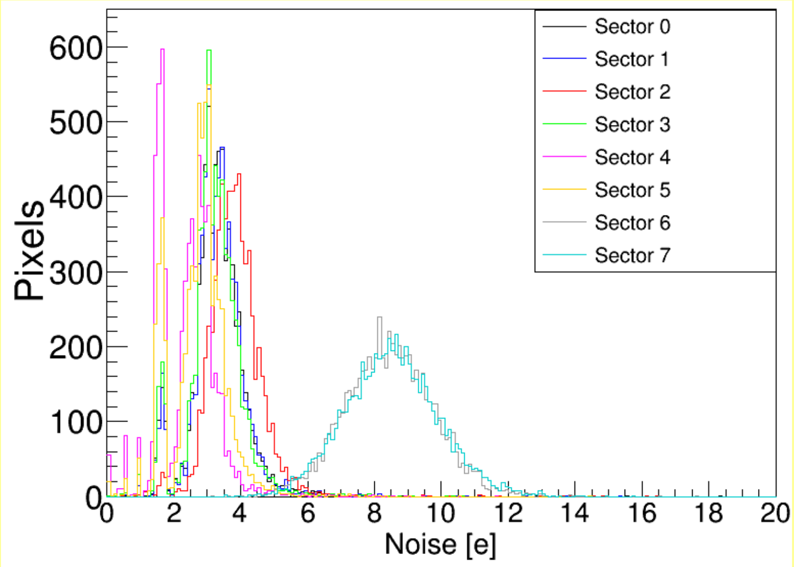


$$f = \frac{N}{2}\,\mathrm{Erf}(\mu,\sigma)$$

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



Pixel threshold distribution for 8 sectors

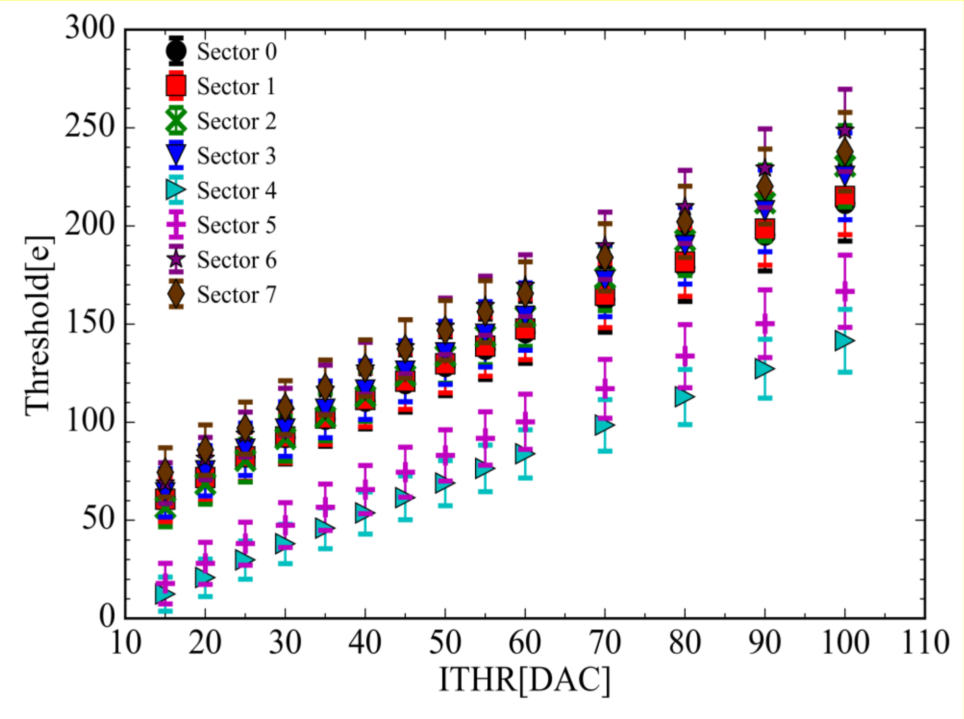


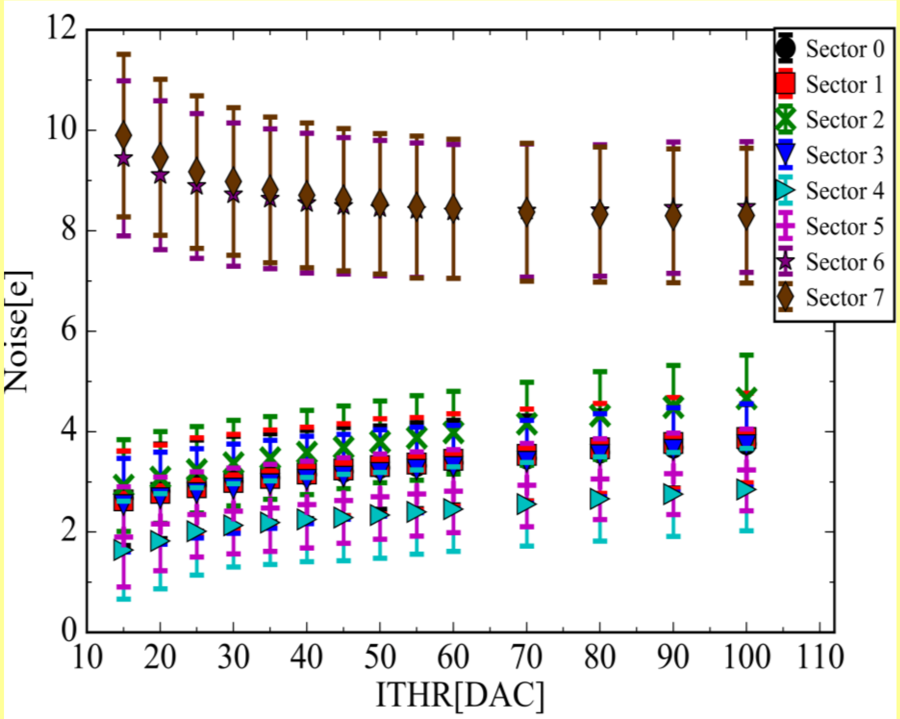
Temporal noise values for the pixels for 8 sectors

Study of the characteristics of full-scale Pixel Detector prototypes

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.

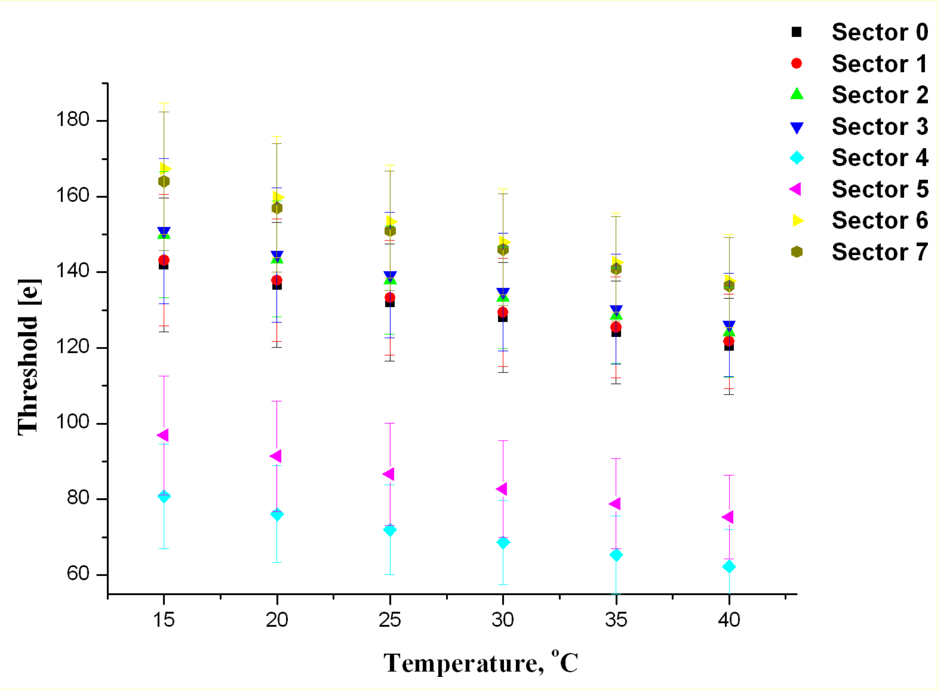
The threshold noise distributions are constant in the Ithr region: 40 - 60 DAC.

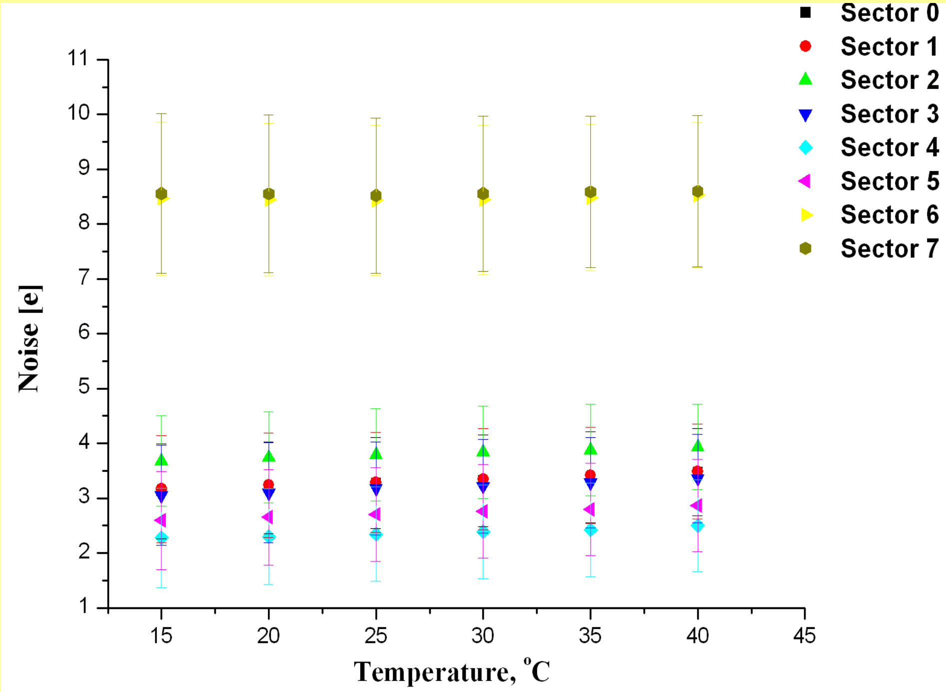
The thresholds in sectors 6-7 are bigger than in other sectors.

Study of the characteristics of full-scale Pixel Detector prototypes

Threshold Scan

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



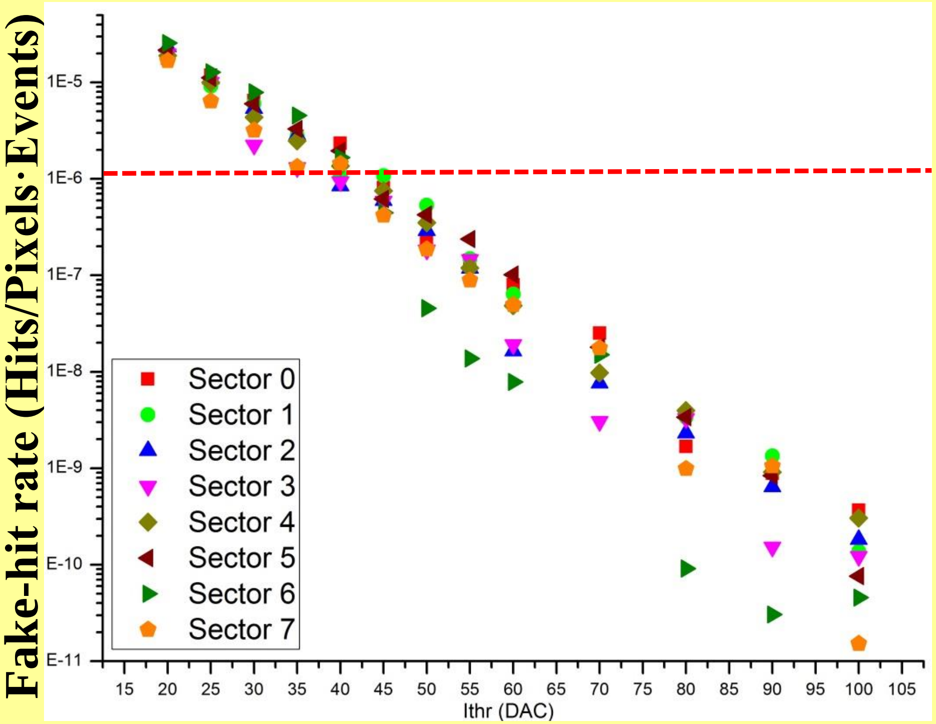


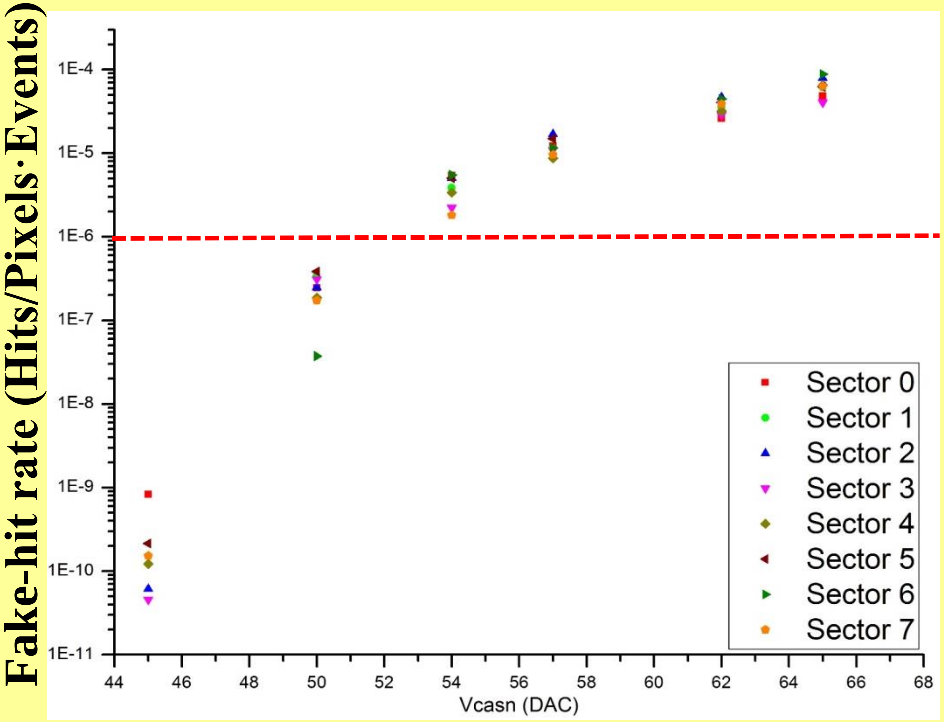
The threshold goes down slowly with the increasing of Temperature for all sectors.

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

Study of the characteristics of full-scale Pixel Detector prototypes

Noise characteristics of the sensor

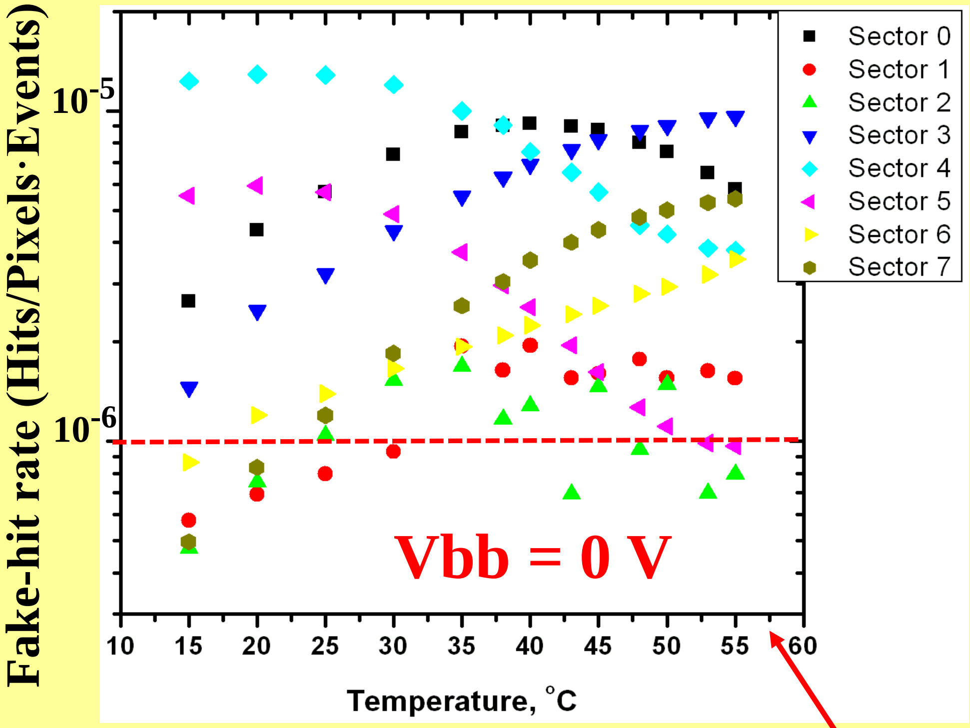


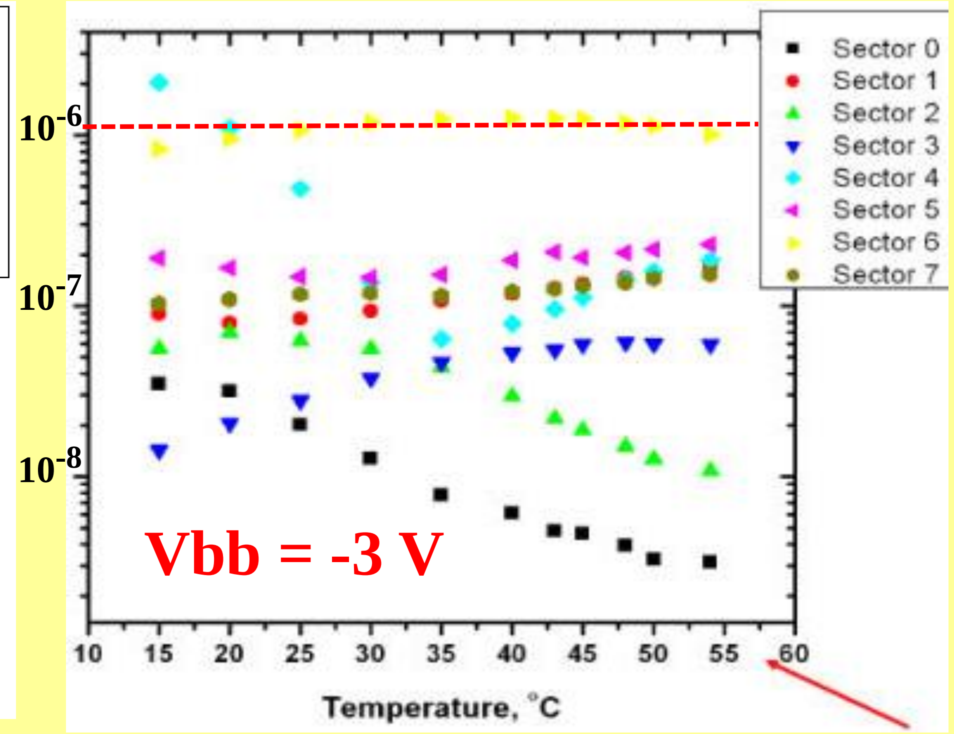


Noise occupancy strongly depends on the main detector settings I_{TH} and V_{CASN}
The values of these parameters which does not exceed the acceptable level of Fake hits per pixel per event (upgrade requirements) have been found.

Study of the characteristics of full-scale Pixel Detector prototypes

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 full-scale Pixel Detector prototypes

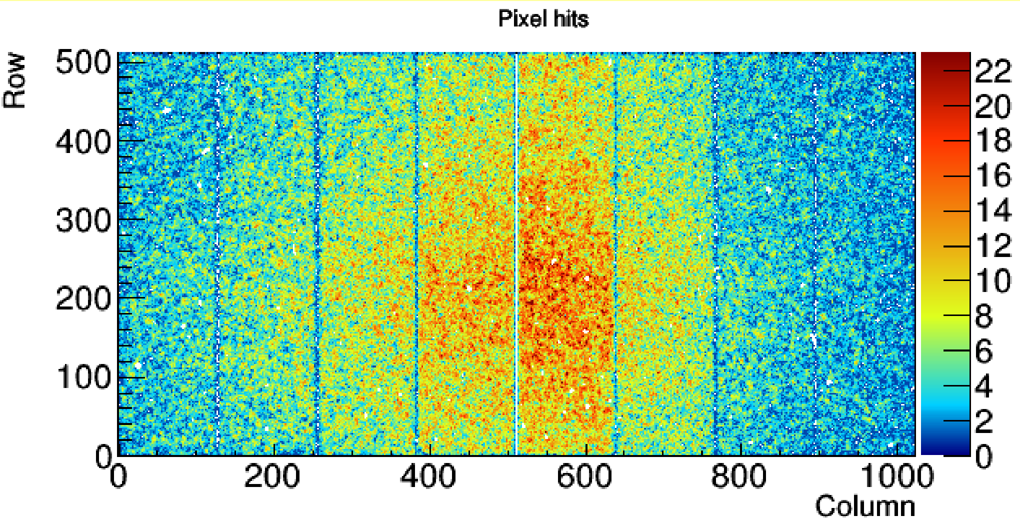
Studies with gamma and beta sources. Cluster analysis

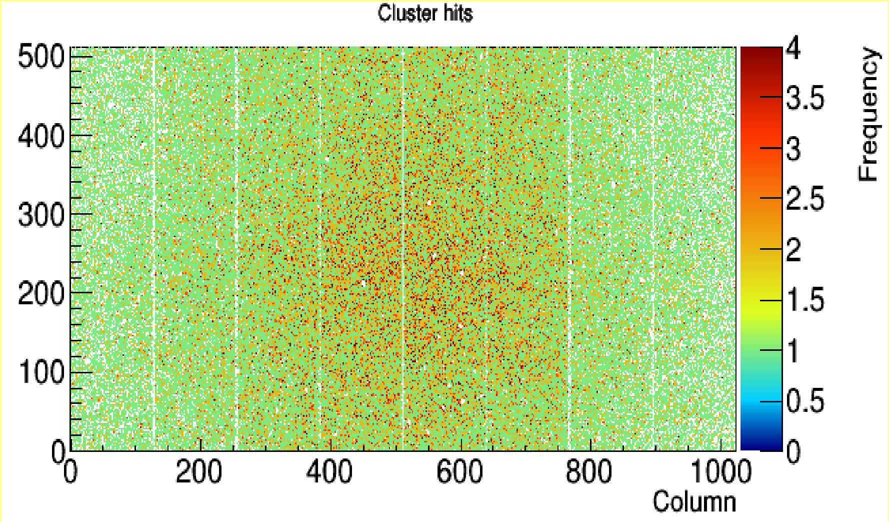
Gamma sources: 241Am (13.9 keV), 133Ba (5.64 keV), 152 Eu (4.29), 55Fe (5.9 keV)
Beta sources: 14C, 90Sr-Y

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.

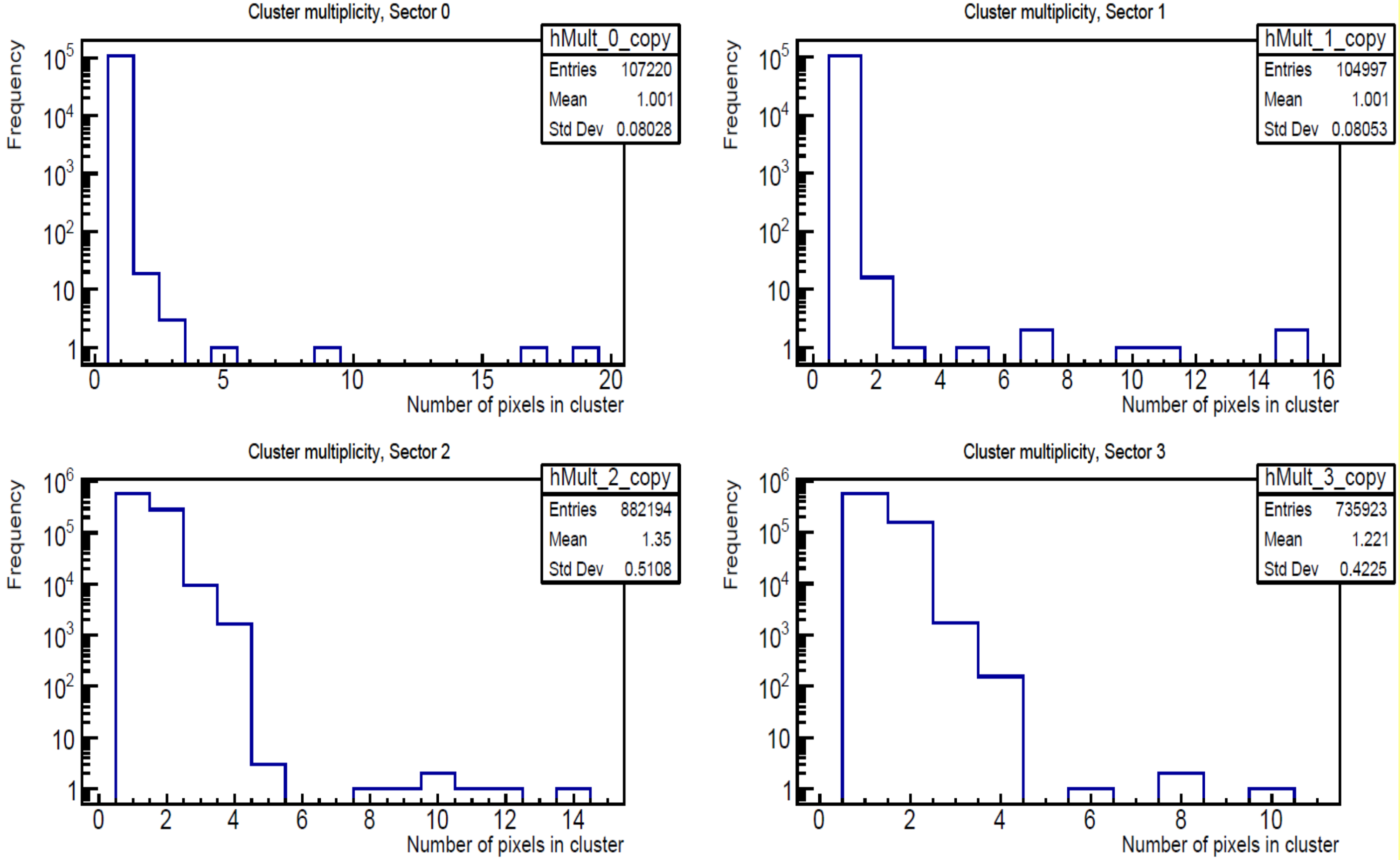
Pixel and cluster hits for 152Eu





Study of the characteristics of full-scale Pixel Detector prototypes

Cluster multiplicity in different sectors for 55Fe



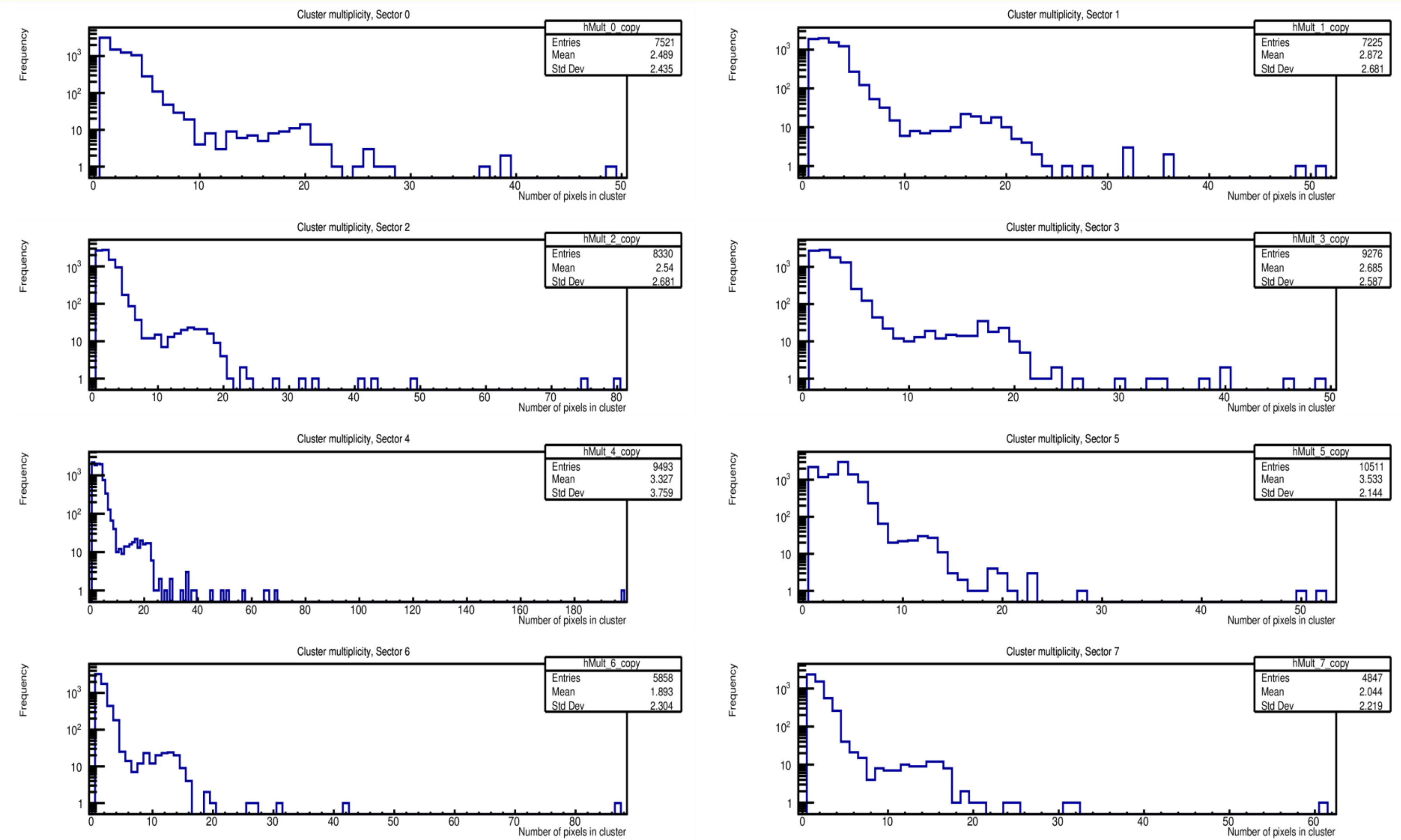
No large clusters. Average cluster multiplicity no more 1.35

Study of the characteristics of full-scale Pixel Detector prototypes

Cluster multiplicity in different sectors for 241Am

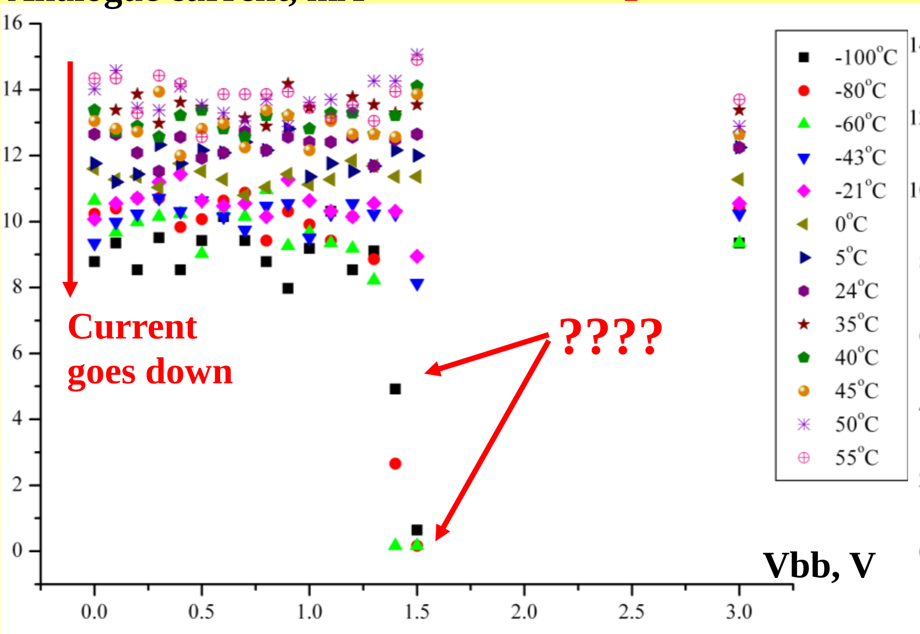
The highest yield of large clusters in Sector 5

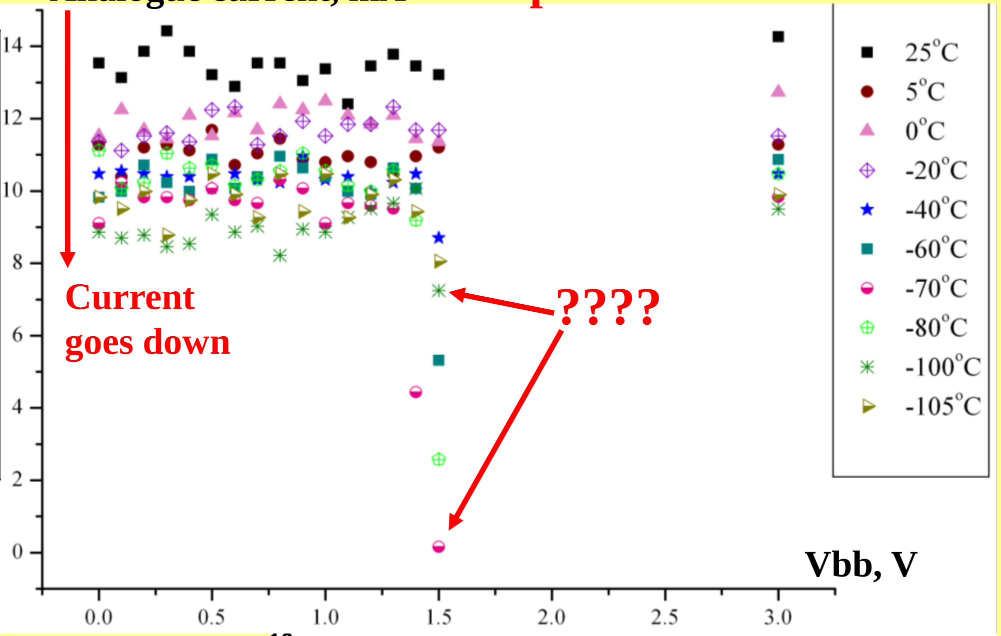
Occurrence of the large clusters could be explain by registration of the electrons emitted from these sources. For 55Fe there is no large clusters (only gamma emits from source)



Study of the characteristics of full-scale Pixel Detector prototypes

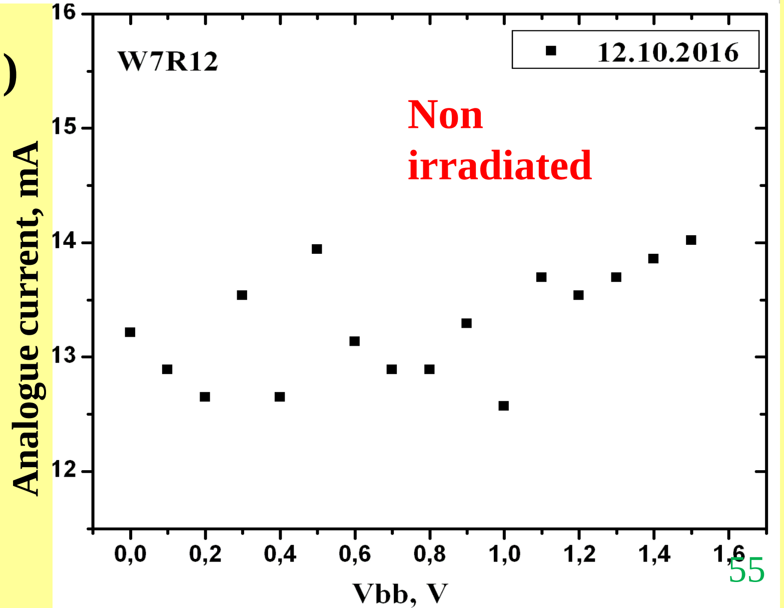
Analogue Currents



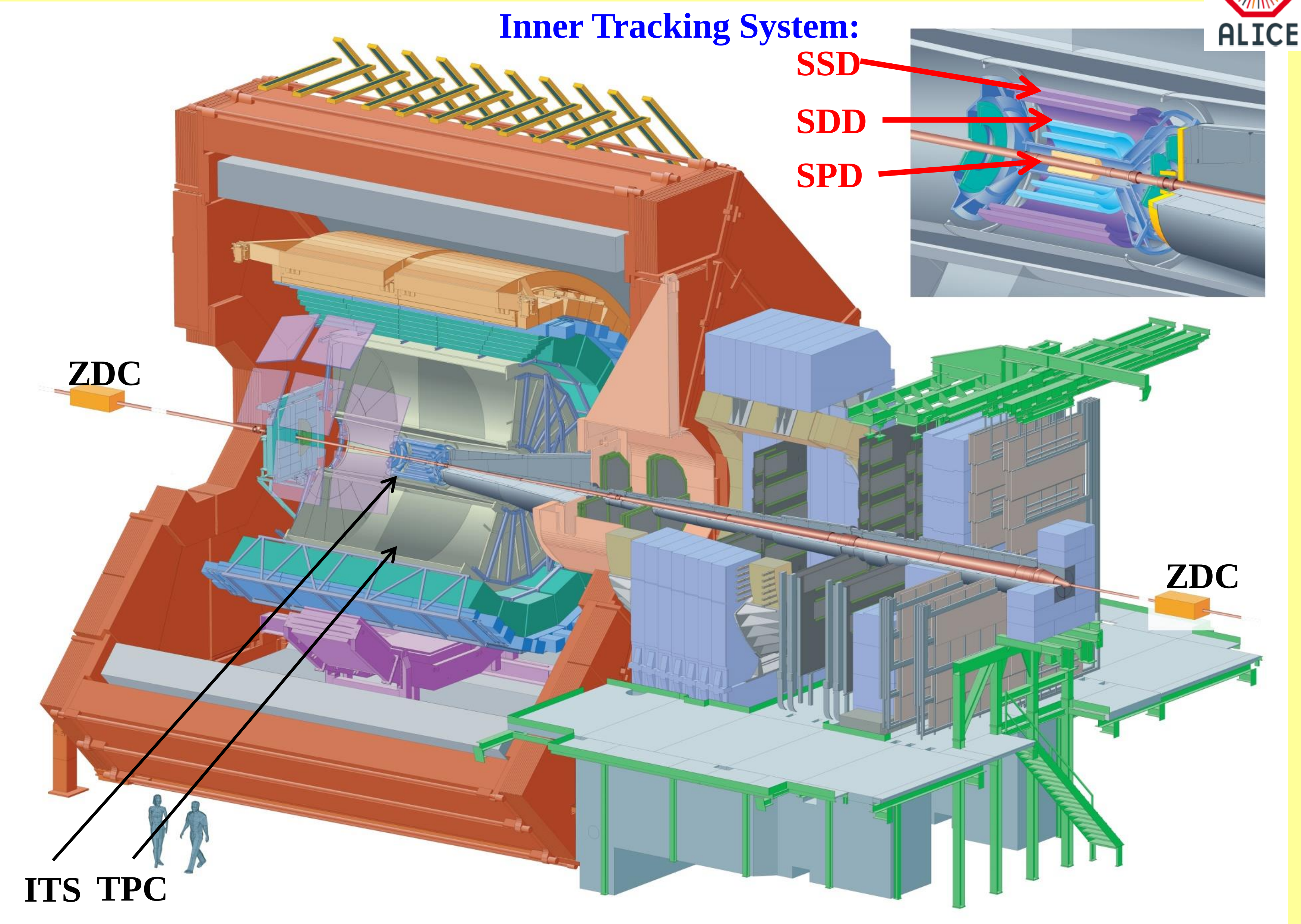


1. With lowering temperature (from +24 ºC to -105 ºC) for both Chips analogue current goes down from 14 to 9 mA;

2. Strange current behavior for Vbb = 1.4-1.5 V has been observed for temperature range: -60 ºC → -100 ºC



ALICE Inner Tracking System (current status)



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

ALICE Inner Tracking System upgrade strategy

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

ALICE Inner Tracking System upgrade strategy

Physics

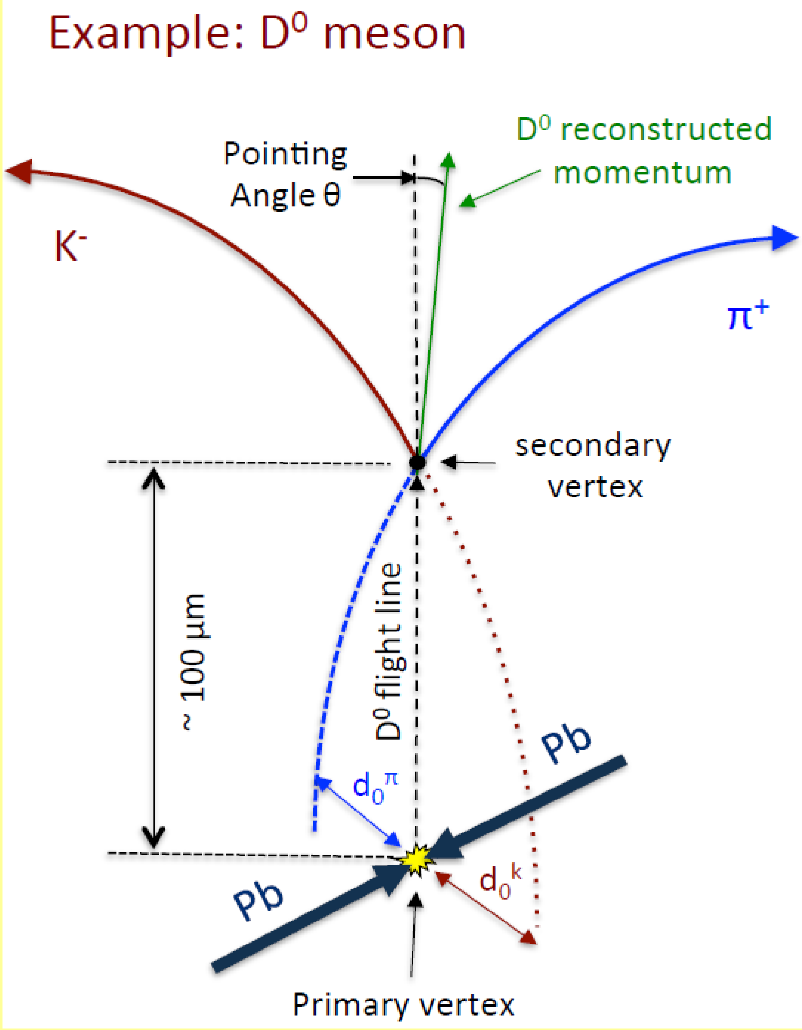
Improve primary vertex reconstruction, momentum and impact parameter Resolution

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

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

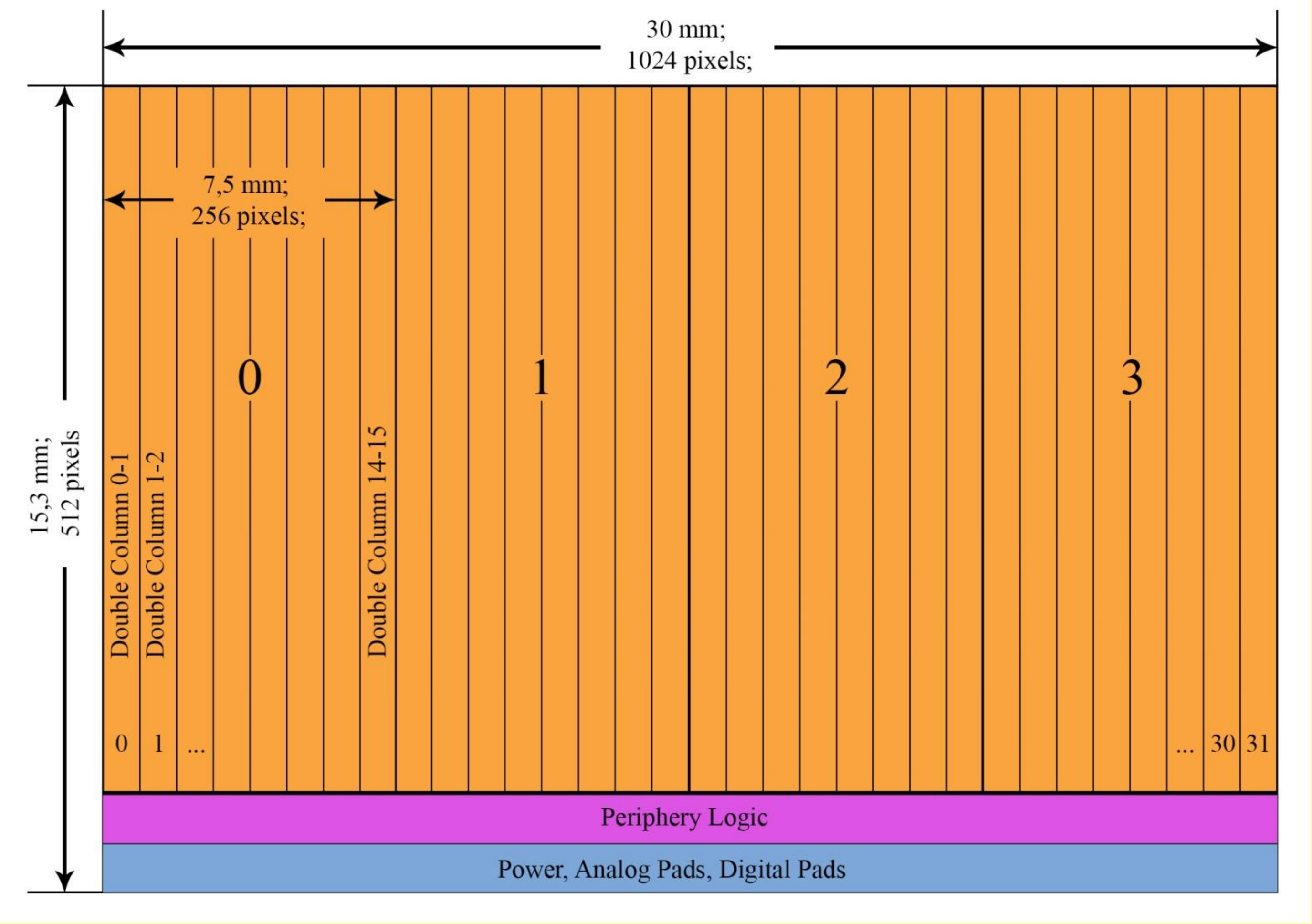
Current ITS Impact Parameter Resolution ~ 70 μm at p_t=1GeV/c

Secondary vertex determination



ALICE Pixel Detectors (ALPIDE family)

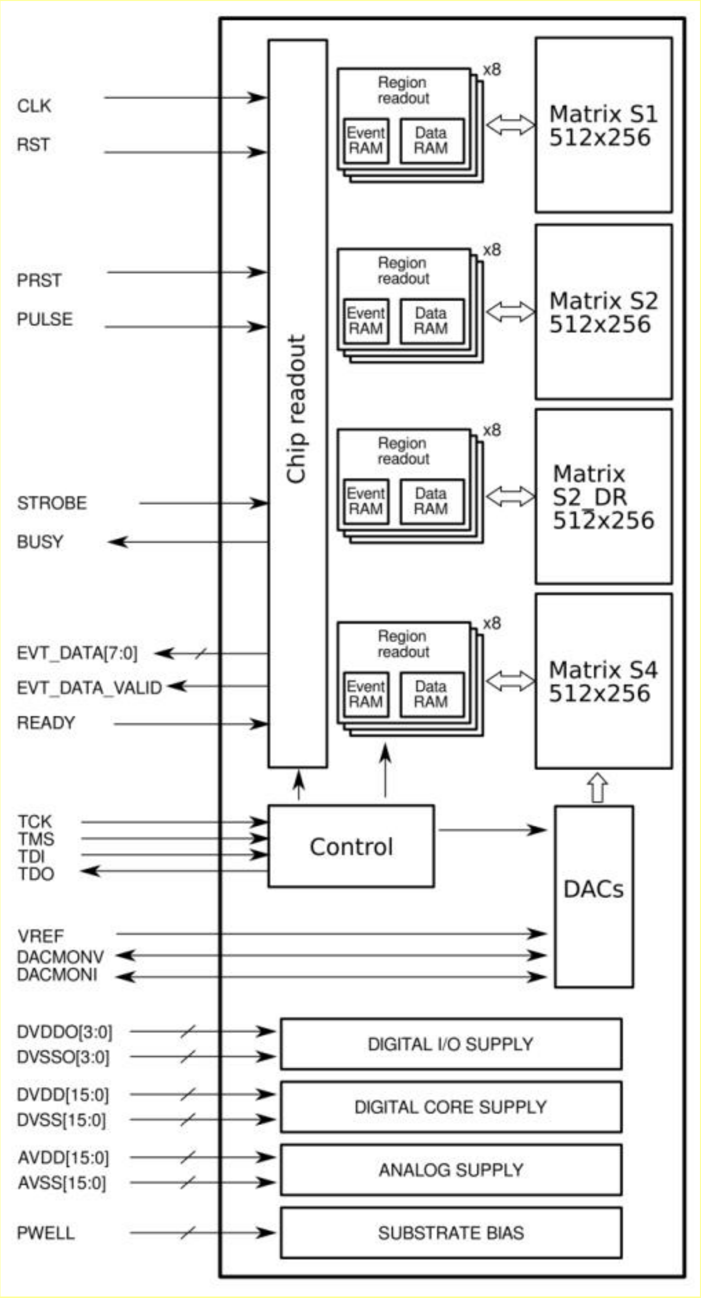
Pixel matrix of pALPIDE-1,2



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.

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).

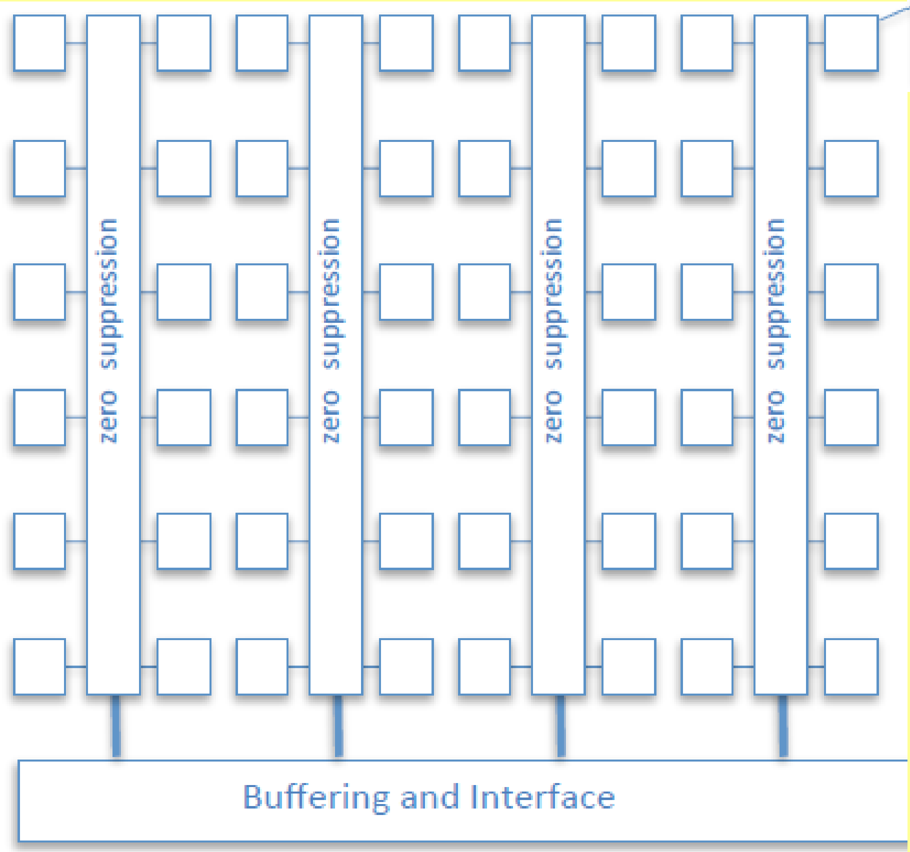
The region readout units contain multi-event storage SRAM memories.

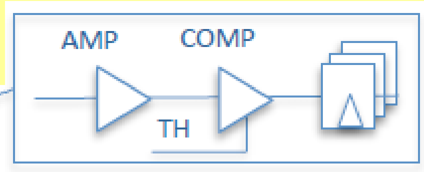
Hit data from the 32 region readout blocks are combined and transmitted on a parallel 8-bit output data port.

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

ALICE Pixel Detectors (ALPIDE family)

ALPIDE chip architecture





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

Advantages

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

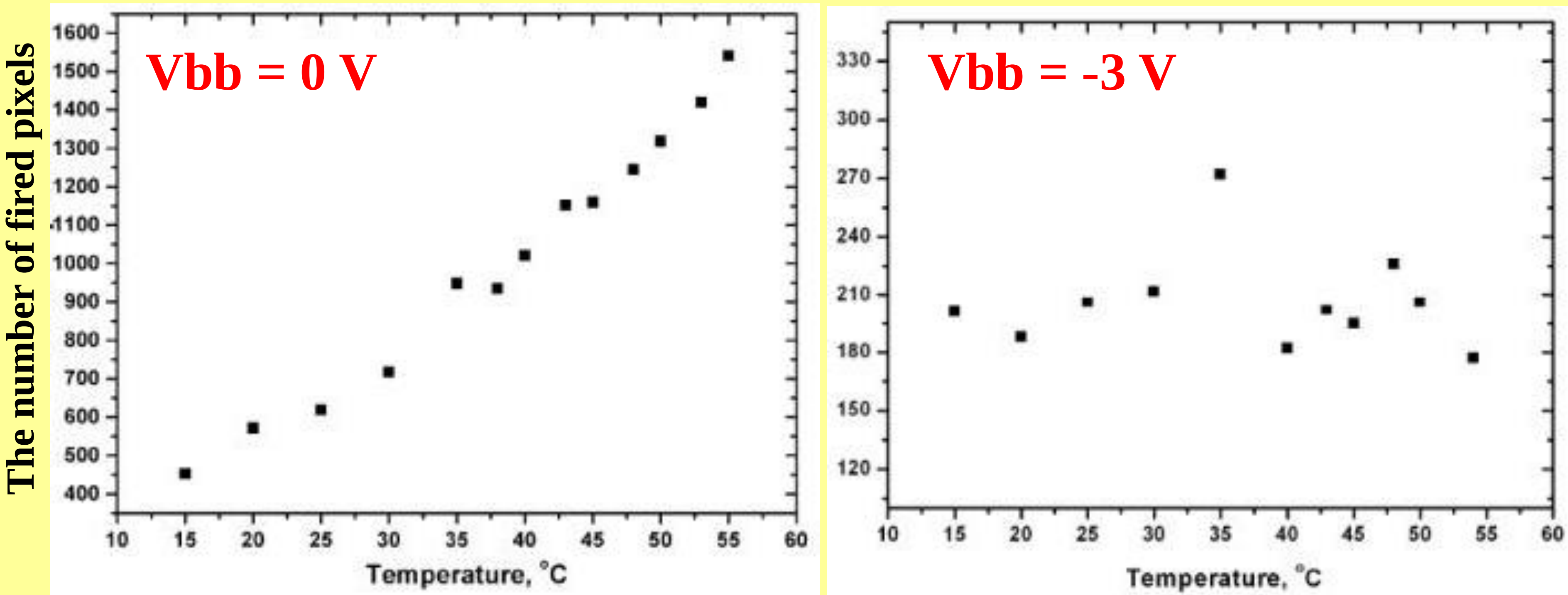
2. The realization of in-pixel discriminators: opportunity of readout, in which the digital outputs of the pixels are scanned by an encoder circuit that directly produces the address of hit pixels as output.

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.

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.

Study of the characteristics of full-scale Pixel Detector prototypes

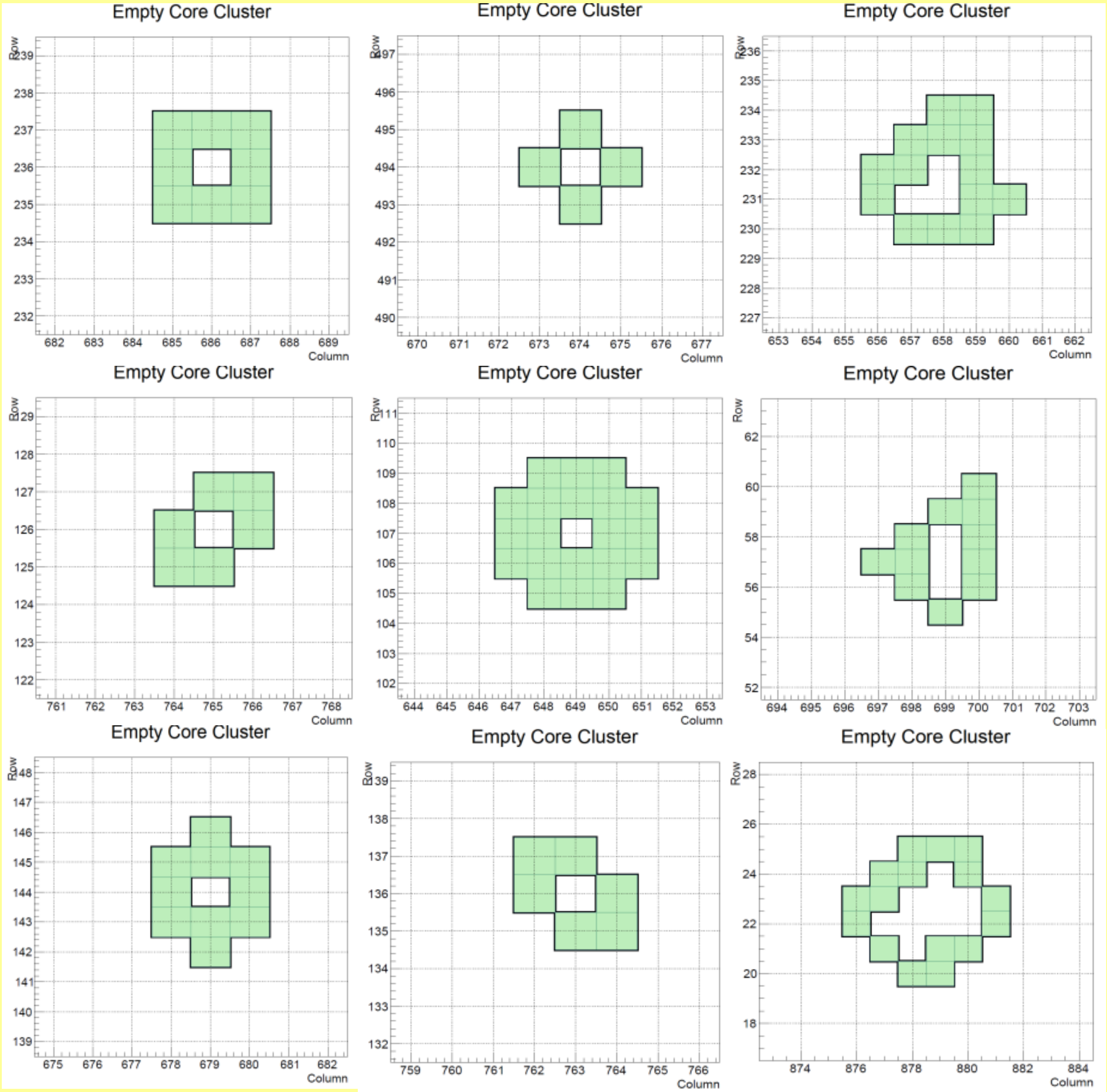
Noise characteristics of the sensor and its temperature dependence



The number of the fired pixels strongly depends on temperature
After applying Vbb the number of the fired pixels does not changed.

Study of the characteristics of full-scale Pixel Detector prototypes

Empty core clusters



The empty core cluster analysis has shown that form of such a clusters don’t depend on a source