





The studies of the monolithic active pixel sensors characteristics and investigations of new ultralightweight support and cooling carbon-fiber structures with high radiation transparency for MPD vertex detector

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Outline



- The concept of the Inner Tracking System of the NICA MPD experiment
- Monolithic active pixel sensors for ITS MPD
- The studies of the monolithic active pixel sensors characteristics
- Mechanic and cooling systems
- Summary

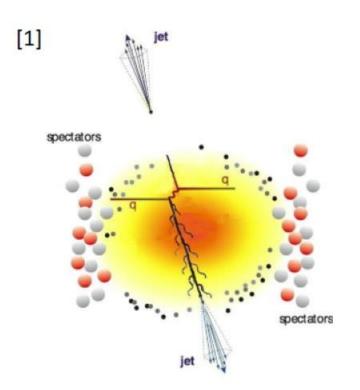
Inner Tracking System of the NICA MPD experiment LUHEP

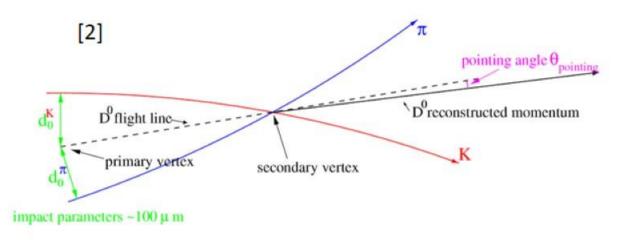




Physics motivations

Hadrons containing heavy quarks are excellent observables since they carry undistorted information about the states of nuclear matter arising during the collision of relativistic nuclei.





Vertex detector makes it possible to study the processes of heavy flavour production by reconstructing secondary vertices with high precision.

Main requirements for the vertex detectors:

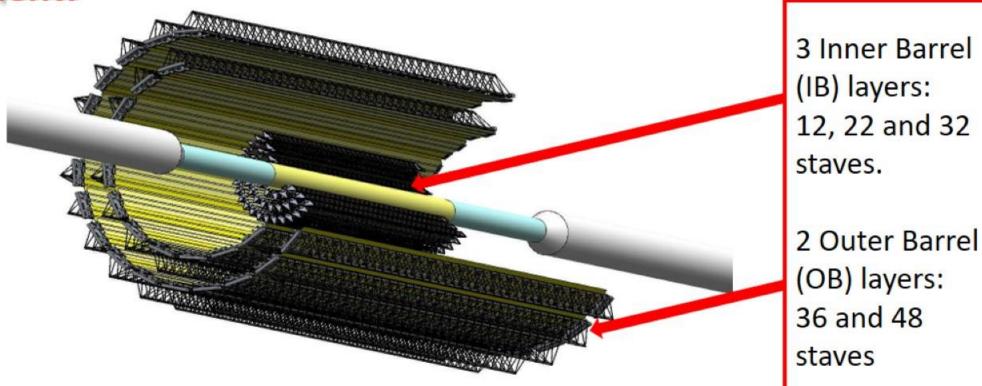
- Low material budget
- · High stability of the detectors position
- High stability of the detectors temperature and characteristics
- High granularity
- · High counting rate capabilities
- High radiation tolerance of the detectors, electronics and materials

The concept of the Inner Tracking System of the NICA MPD experiment (second stage of the MPD





experiment)



Total: 5 layers of Monolithic Active Pixel Sensors (MAPS)

[3]

ALICE technologies:

for IB – ALICE Middle layer staves (900mm)

for OB – ALICE Outer layer staves (1500mm)

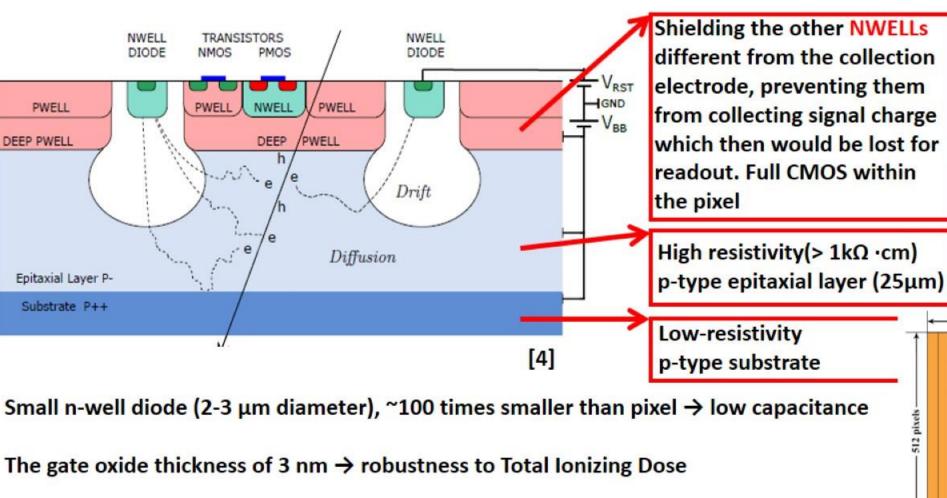
Monolithic active pixel sensors for ITS MPD



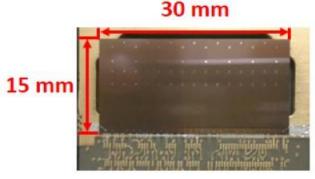




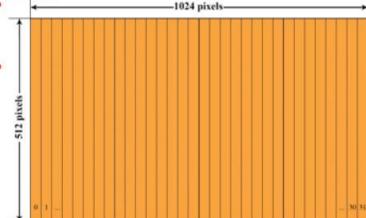
ALPIDE using TowerJazz 180nm CMOS Imaging Process



ALPIDE pixel matrix



[5]



Power, Analog Pads, Digital Pads

Descibility to apply back bigs to the substrate can be used to increase depletion you

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

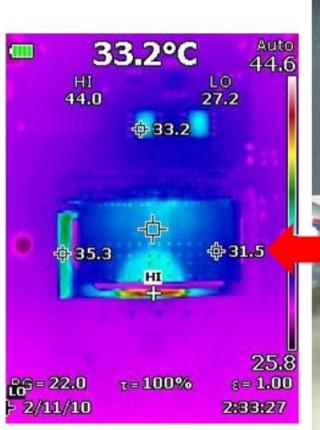
The studies of the monolithic active pixel sensors characteristics: experimental setup 1

DAQ Board

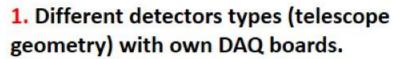
ALPIDE Chip

DAQ Board





Temperature control: infrared Camera



- 2. Dark box with electrical earthing inside.
- detector protection against light and electromagnetic interference
- Temperature control inside the box is available
- 3. The water cooling (heating) system.
- 4. Radioactive source (γβ) positioning system to locate source. Has system for visualization of central area of the source on detector surface.
- 5. Infrared Camera for detector heating investigations.
- 6. Detector Power supply (current control).
 Irradiated detectors:

Detector 1 – 60 krad (low dose)

Detector 2 – 300 krad (high dose)

Detector 3 - non-irradiated

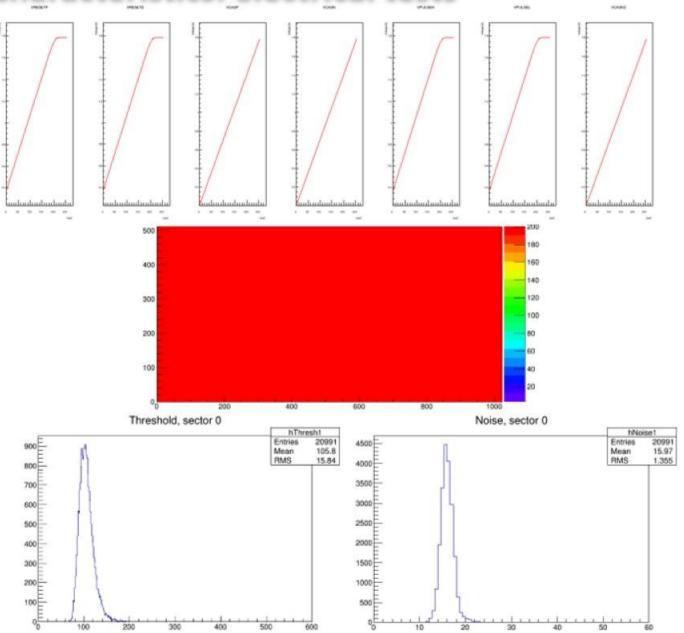
The studies of the monolithic active pixel sensors







characteristics: electrical tests



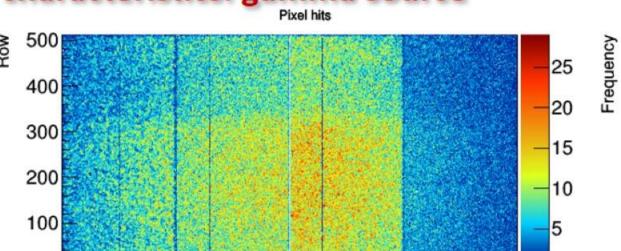
Electrical tests:

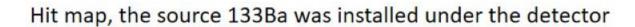
- a) On-chip Digital-Analogue Converter Test. The output of the on-chip DACs is connected to monitoring pins of the detector and measured by ADCs on the DAQ board.
- b) Digital Scan. Scan generates a digital pulse in a number of pixels and reads the hits out. The number of injections per pixel and the 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 VCASN and ITHR can be set.
- e) 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} can be set.

7/17

The studies of the monolithic active pixel sensors

characteristics: gamma source





600

800

1000

Column



400

Gamma source: 133Ba (5.64 keV)

200

Measurements with other gamma, beta and alpha sources are now being carried out.

gamma: 22Na, 60Co, 55Fe(5.9 keV), 137Cs, 152Eu,

241Am (13.9 keV),

beta: 90SrY, 204Tl,

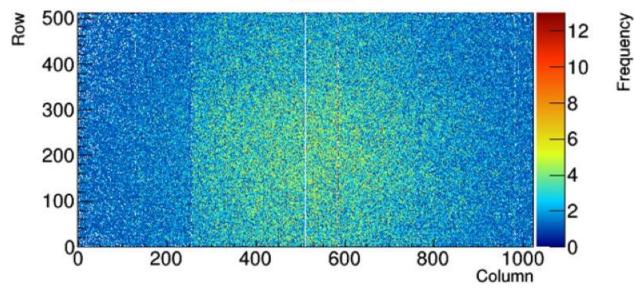
alpha: 226Ra, 233U+238Pu+239Pu.



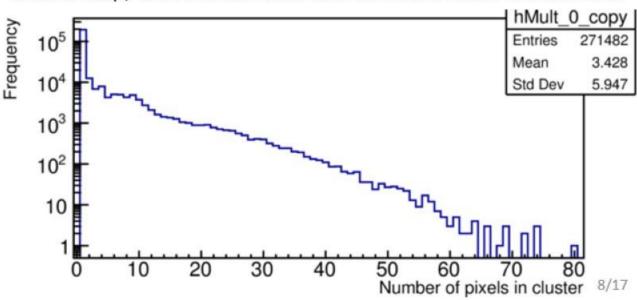








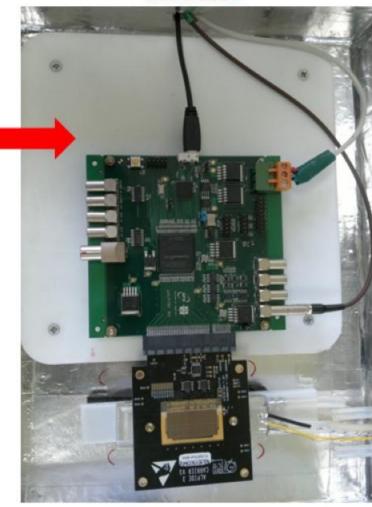
Cluster map, the source 133Ba was installed under the detector



The studies of the monolithic active pixel sensors characteristics: experimental setup 1









Allows us to cool detectors down to -120°C. By using an additional module it is also possible to heat detectors up to +60°C.

The studies of the monolithic active pixel sensors: noise characteristics

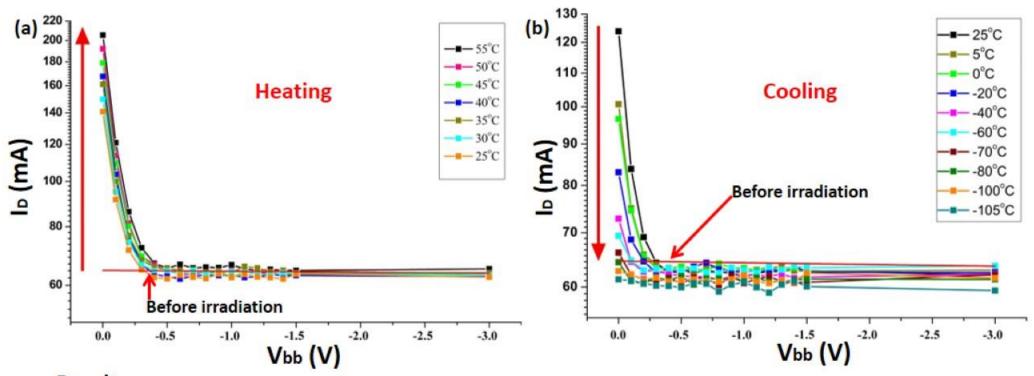






Detector 2 – 300 krad (high dose).

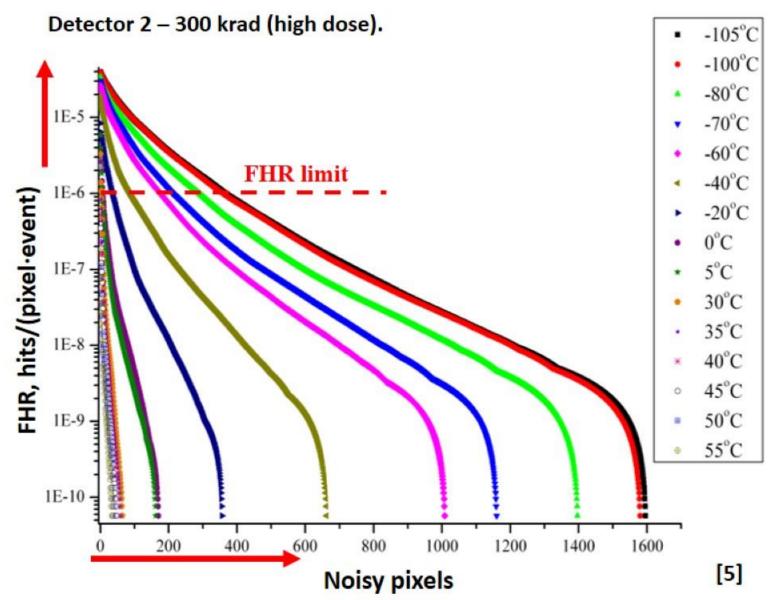
the current of the detector digital part vs. back bias voltage (Vbb).



Results:

- 1) Starting at a temperature of -60 °C, for irradiated (high dose) detector the digital current at Vbb=0V has the same values as before irradiation;
- Annealing effect doesn't affect the current (I_D) corresponding to the digital part of the detector;
- 3) Applied back bias voltage decrease the digital current to value, one had before irradiation.

The studies of the monolithic active pixel sensors: noise characteristics





- 1. The number of noisy pixels to be masked to achieve certain fake-hit rate increases with the lowering of temperature
- 2. Fake-Hit Rate (FHR) also increases with decreasing temperature

* For low dose irradiated detector and non-irradiated detector fake-hit rate DID NOT change over the full temperature range: from -105 °C to +30°C

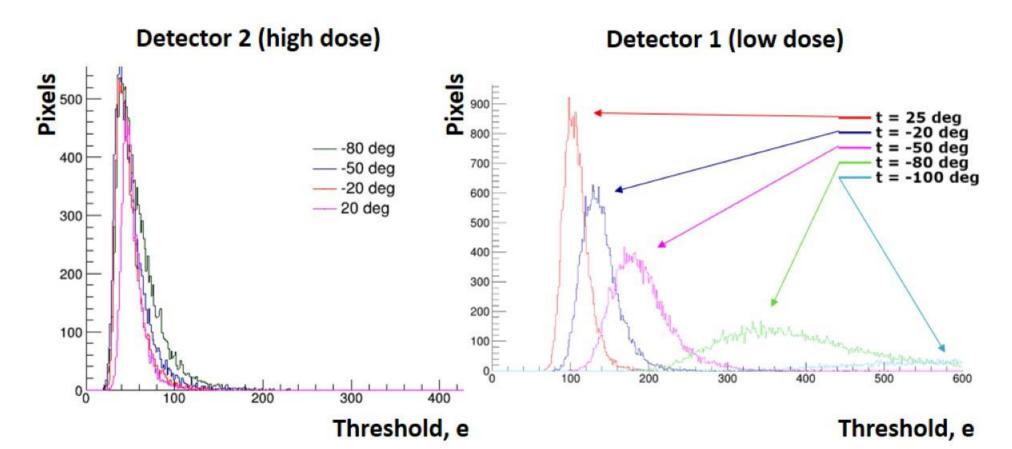
 $FHR = \frac{\text{number of hits}}{\text{number of pixels} \cdot \text{number of events}}$.

The studies of the monolithic active pixel sensors: noise characteristics









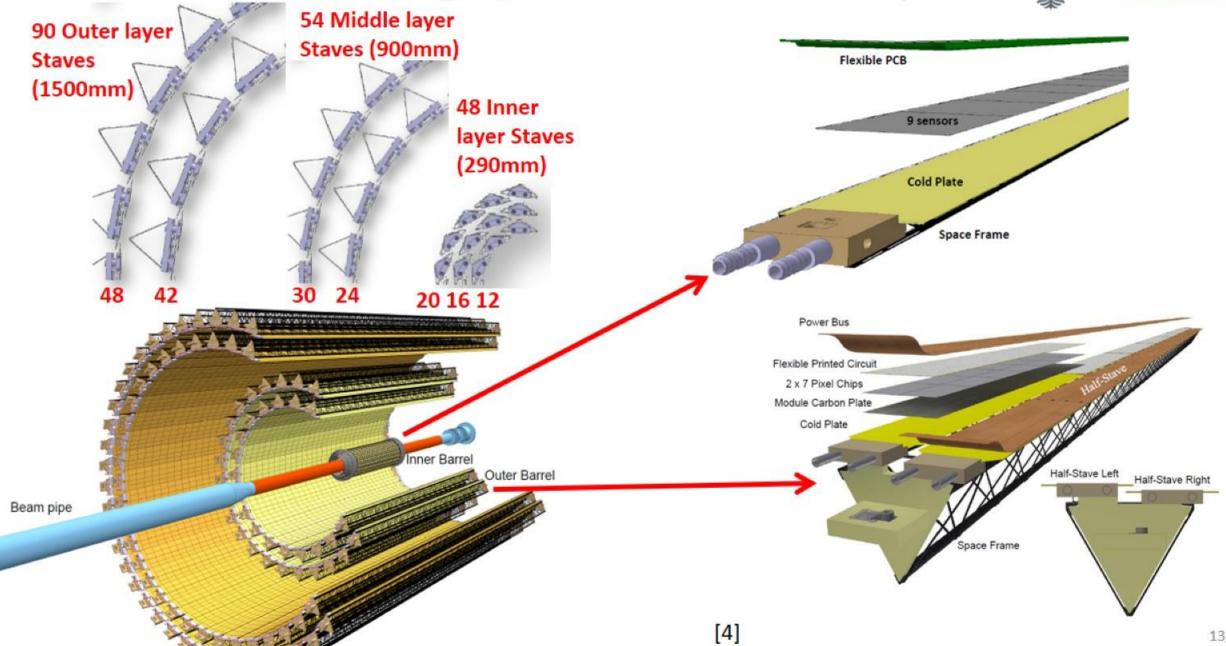
The results are:

- The threshold for high dose irradiated detector stay almost the same;
- 2) For non-irradiated detector the threshold goes up faster (as in Vbb=0 case).







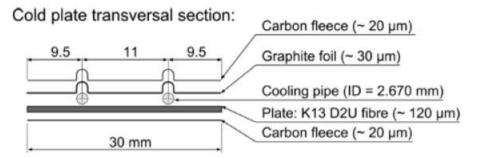




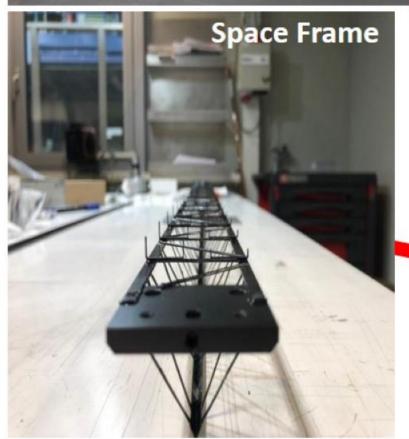


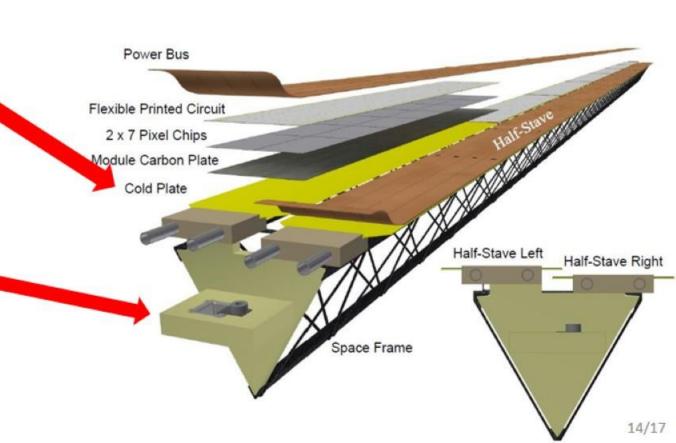






[7]

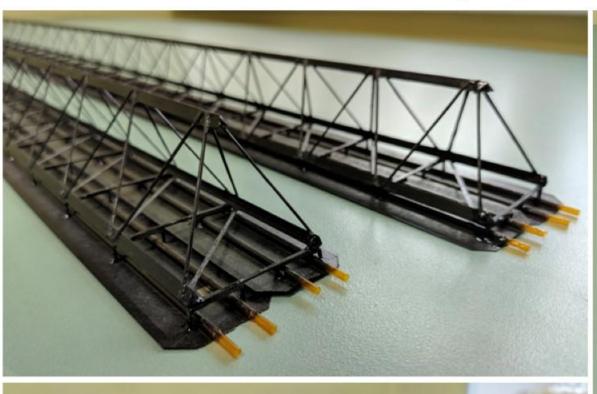


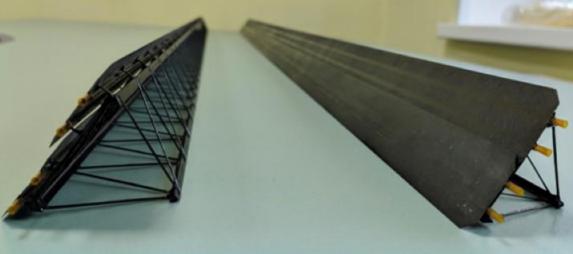














The first samples for the ITS MPD have already been constructed.

Space Frame production technology from SPbU production technology from SPbU Support structure assembling technology from SPbU

Space Frame production, SPbU

production, JINR (Dubna)

Space Frame + Cooling plate = Support structure assembling,
SPbU and JINR

Summary







- The characteristics and properties of new pixel sensors: ALICE Pixel Detectors (ALPIDE family) were investigated in context of the MPD NICA tasks;
- The Extra Lightweight Detector Support Structures were proposed for Inner Tracker of MPD NICA;
- Experimental set-up for the characterization of ALPIDE MAPS for the NICA MPD Inner Tracker has been developed, constructed and tested.



Thank you for your attention!

Literature







- Talk «Two-particle angular correlations», Małgorzata Janik, Faculty of Physics Warsaw University of Technology, Oslo Winter School, 2-7.01.2018;
- 2) Talk «Open Heavy Flavour production», Andrea Rossi, Padua University & INFN, Quark Matter 2018;
- 3) V.I. Zherebchevsky, V.P. Kondratiev, V.V. Vechernin, S.N. Igolkin, The concept of the MPD vertex detector for the detection of rare events in Au+Au collisions at the NICA collider, Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, Volume 985, 2020, 164668, ISSN 0168-9002, https://doi.org/10.1016/j.nima.2020.164668
- 4) The ALICE Collaboration. "Technical Design Report for the Upgrade of the ALICE Inner Tracking System". In: J. Phys. G41 (2014), p. 087002.
- 5) V.I. Zherebchevsky, et. al., «New pixel detectors for alice at Ihc and for nica experiments», XXIV International Baldin Seminar On High Energy Physics Problems Dubna, September 17-22, 2018
- 6) https://indico.jinr.ru/event/756/abstracts/3002/
- 7) The ALICE ITS (Inner Tracking System) Upgrade Monolithic Pixel Detectors for LHC, Petra Riedler, CERN EP-DT, Seminar, February 22, 2018
- 8) https://cerncourier.com/a/star-tracker-snares-heavy-flavours/
- Presentation Experience from ZEUS Microvertex detector is running for more than five years without access! E.N Koffeman NIKHEF & University of Amsterdam.
- 10) https://www.nikhef.nl/~i93/Experiments.html



BACK-UP SLIDES

ALICE Pixel Detectors (ALPIDE)

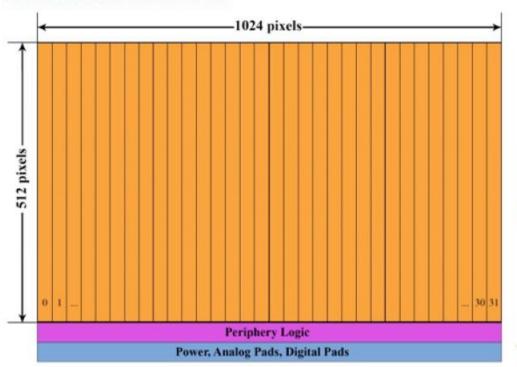


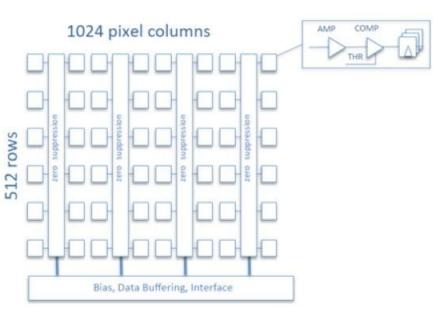


[2]



Pixel matrix of ALPIDE





The pixel matrix is divided into 32 regions.

30 mm

15 mm

In the space between each pair of double columns is a priority encoder circuit that performs the asynchronous reading of a signal from the pixels in these columns.

The edge of the detector also presents
Periphery logic, Analog and Digital pads
and Power circuits.

20/13

ALICE Pixel Detectors (ALPIDE family)

pALPIDEss

pALPIDE-1

pALPIDE-2

pALPIDE-3

2013

May-2014

May-2015

Oct-2015

Jul - 2016





Two submatrices: 90x90 array of 20 x 20μm pixels and 60x60 array of 30x30μm pixels.

Explorer Explorer-1,2

Each sub matrices is divided in 9 sectors with one variant of collection electrode(analogue readout). Investigations: pixel geometry, starting material, sensitivity to radiation.

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

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

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

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

ALPIDE – Final Version



[4]

ALPIDE – Final Ve

ALICE Pixel Detectors (ALPIDE family) Pixel detector general requirements (from Tachnical Design Penart for the Unge







(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)

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

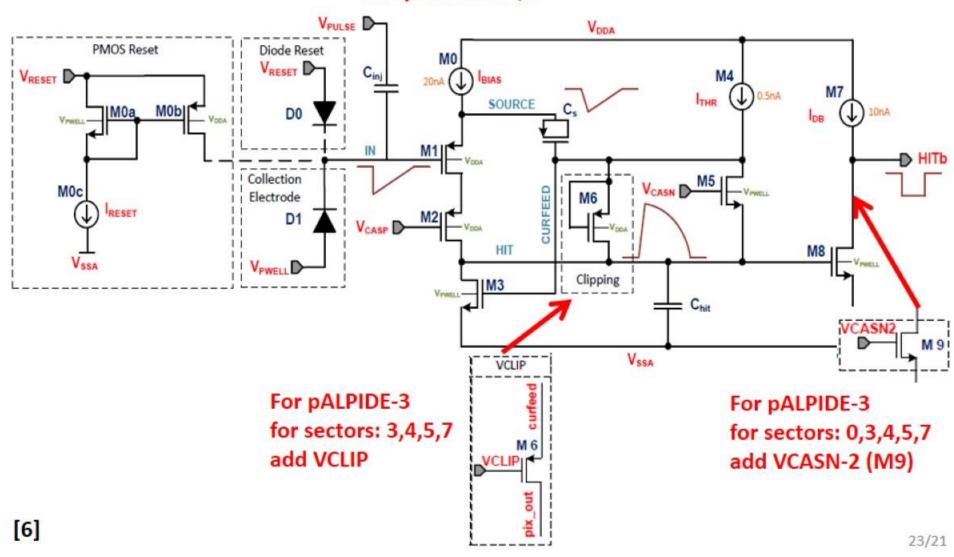






A comprehensive scheme for the pixel front-end circuit Including all possible variations

For pALPIDE-1,2



Study of the characteristics of full-scale Pixel Detector prototypes

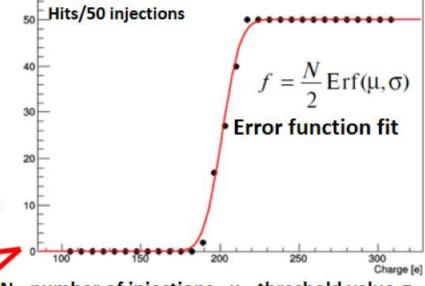




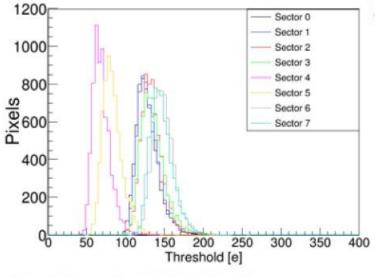
Threshold Scan

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

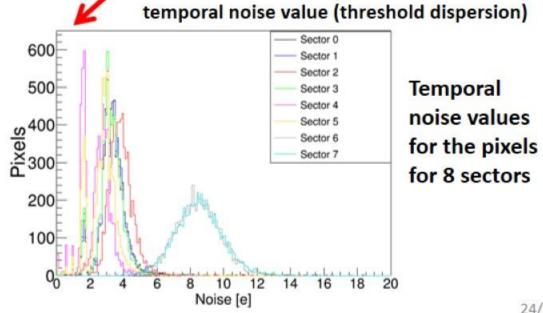
In order to extract threshold a number of charge injections with different amplitude are performed (50 points with 50 injections per point). A probability distribution of fired pixels measuring a pixel response (S-curve) has been obtained.



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



Pixel threshold distribution for 8 sectors



Study of the characteristics of full-scale Pixel Detector prototypes



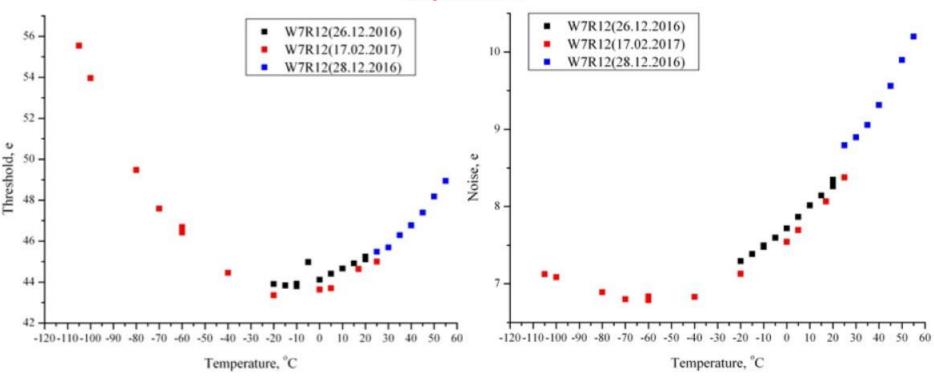




Results for high dose irradiated chip

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.

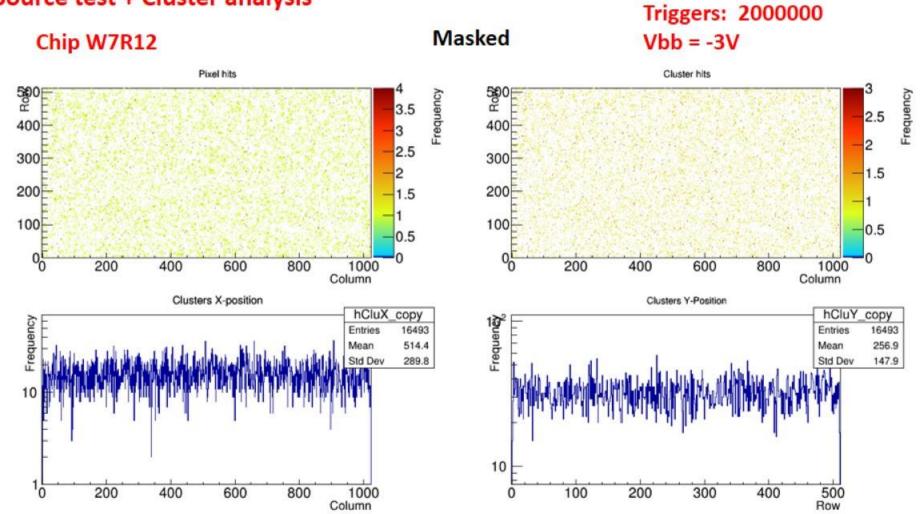
The ALPIDE characteristics studies

LUHEP SPb SU





Results for high dose irradiated chip Source test + Cluster analysis



Source: 133Ba, chip temperature -115 °C

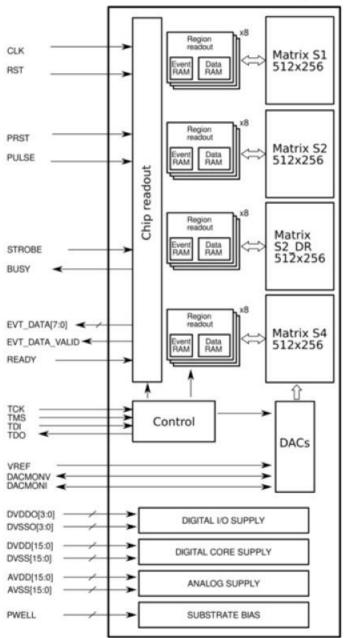
[4]

ALICE Pixel Detectors (ALPIDE family)









A general block diagram of pALPIDE-1,2

All the analogue signals required by the frontends 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.

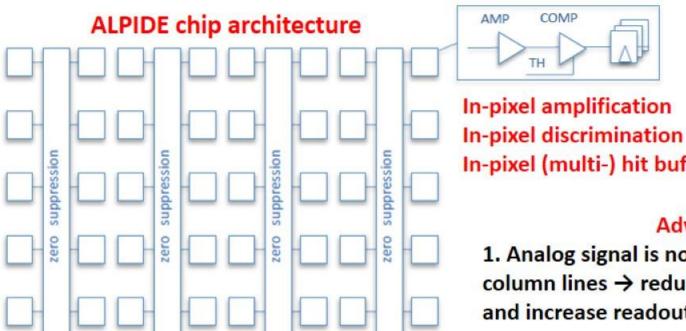
[1] 27/21

ALICE Pixel Detectors (ALPIDE)









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.

Buffering and Interface

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.

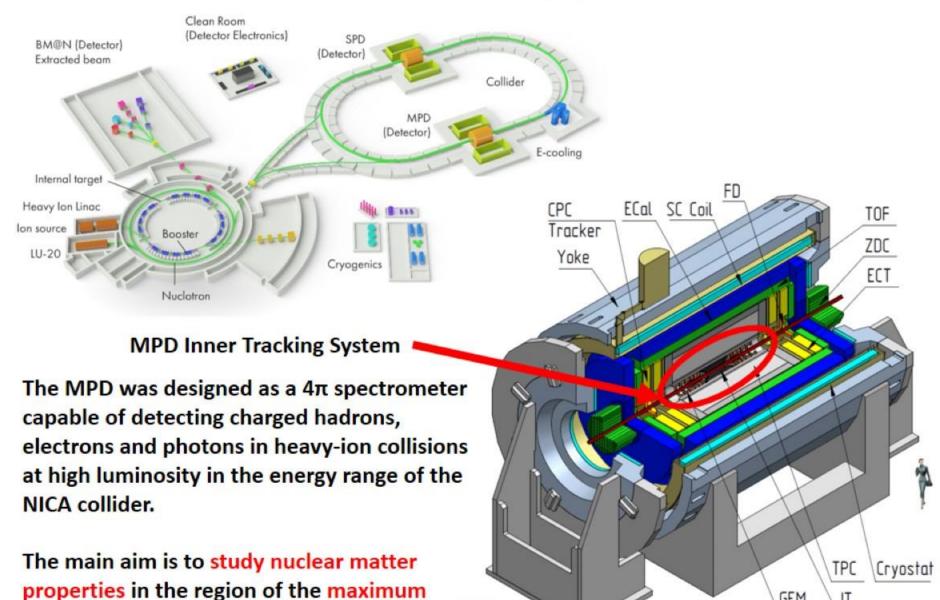
[2]

Multi-Purpose Detector (MPD)

baryonic density.

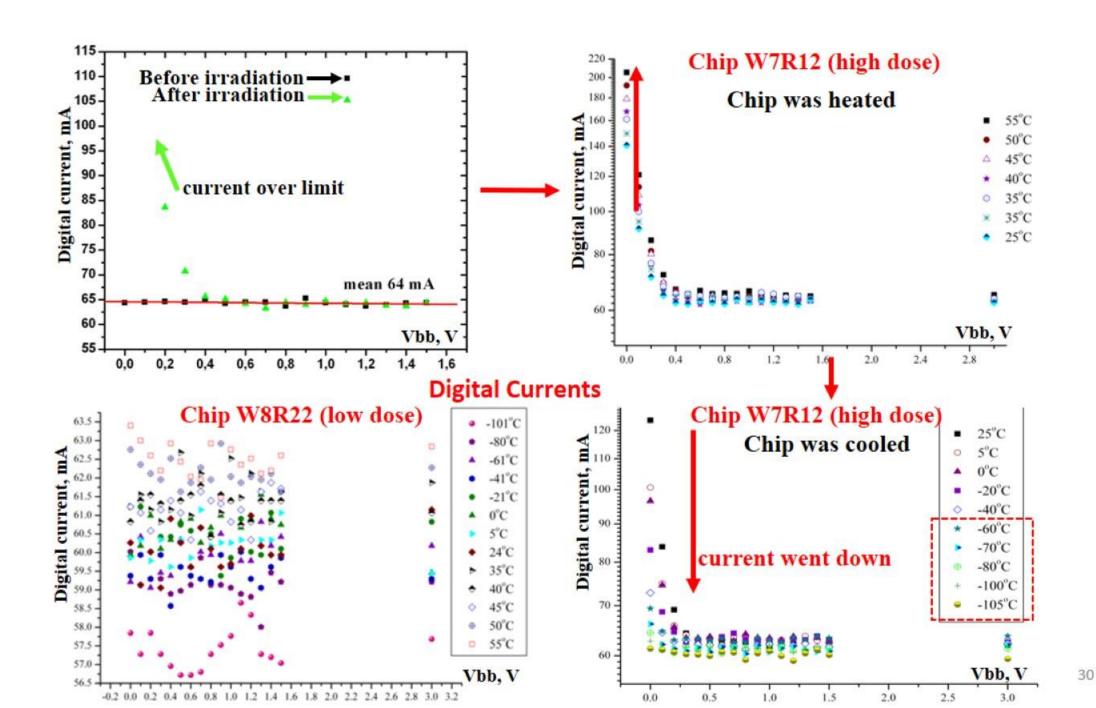
The ALPIDE sensor will be used also for the NICA MPD project.





[8]

GEM





V0

T0

FMD



Extra lightweight detector support structures for the IT

