Pixel detectors for experiments at the NICA collider

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Outline:

Introduction

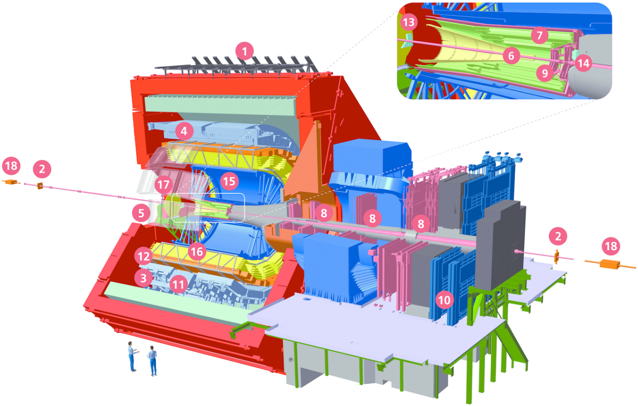
Heavy ion experiments:

- Aims to study properties of strong interacting matter;
- Issues for Quantum Chromo Dynamics, the understanding of confinement-deconfinement and chiral phase transitions;
- Experiments ALICE(LHC, CERN), STAR&PHENIX(RHIC, BNL), NA61(SPS, CERN), FAIR (GSI), MPD (NICA, JINR).

Improving the tracking accuracy and the particle identification efficiency in modern experiments with heavy-ions, requires the development of new detector systems, that are able to read the data related to each individual interaction up to a rate of 100 kHz for Pb–Pb collisions and 400 kHz for pp collisions [1].

Pb-Pb @ sqrt(s) = 2.76 ATeV
Fill : 2290
Run : 167693
Event : 0x3d94315a

The ALICE experiment



1. **ACORDE** | ALICE Cosmic Rays Detector
2. **AD** | ALICE Diffractive Detector
3. **DCal** | Di-jet Calorimeter
4. **EMCal** | Electromagnetic Calorimeter
5. **HMPID** | High Momentum Particle Identification Detector
6. **ITS-IB** | Inner Tracking System - Inner Barrel
7. **ITS-OB** | Inner Tracking System - Outer Barrel
8. **MCH** | Muon Tracking Chambers
9. **MFT** | Muon Forward Tracker
10. **MID** | Muon Identifier
11. **PHOS / CPV** | Photon Spectrometer
12. **TOF** | Time Of Flight
13. **T0+A** | Tzero + A
14. **T0+C** | Tzero + C
15. **TPC** | Time Projection Chamber
16. **TRD** | Transition Radiation Detector
17. **V0+** | Vzero + Detector
18. **ZDC** | Zero Degree Calorimeter

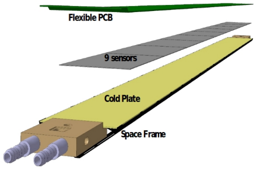
ALICE Inner tracking system upgrade[1]

Inner Barrel

3 Inner Layers: 12+16+20 Staves
1 Module / Stave

9 sensors per Module

108 Modules to produced
(2 Inner Barrels + spares)

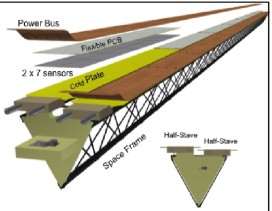


Outer Barrel

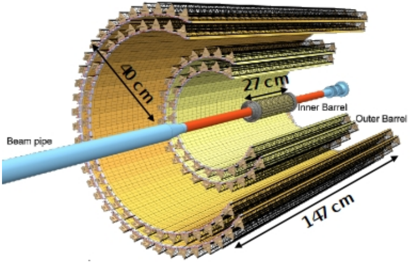
2 Middle Layers: 30+24 Staves
2×4 Modules / Stave
2 Outer Layers: 42+48 Staves
2×7 Modules / Stave

2×7 sensors / Module
(Middle and Outer Layers are equipped with the same Module Type)

2550 Modules to be produced
(including spares)



Layout



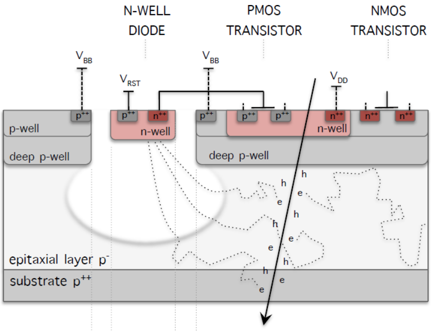
Total:
>24k chips
>11 m^2
>12 GPixel

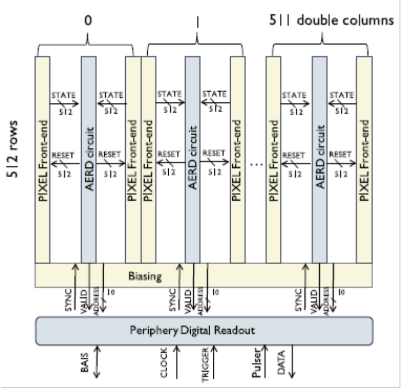
Requirements for the upgraded ITS[1]

Parameter	Inner Barrel	Outer Barrel	ALPIDE performance
Silicon thickness	50 μm	100 μm	✓
Spatial resolution	5 μm	10 μm	$\sim$5 μm (both IB and OB)
Chip dimension	15 mm $\times$ 30mm		✓
Power density	<300 mW/cm^2	<100 mW/cm^2	<40 mW/cm^2(IB) <40 mW/cm^2(OB)
Event-time resolution	<30 μs		$\sim$2 μs
Detection efficiency	>99%		✓
Fake Hit Rate	10^{-6} hits/(pixel · event)		<10^{-10} hits/(pixel · event)
TID radiation hardness*	700 krad	100krad	tested at 500 krad
NIEL radiation hardness**	10^{13} (1 MeV n$_{eq}$/cm^2)	3·10^{12} (1 MeV n$_{eq}$/cm^2)	✓

*TID – Total Ionizing Dose (with safety factor 10)
**NIEL – Non Ionizing Energy Losses (with safety factor 10)

CMOS* Monolithic Active Pixels Sensors[1, 3]





- Based on 180 nm TowerJazz technology;
- Size of pixel 30×30 μm;
- Matrix: 512×1024 pixels;
- Priority Encoder readout scheme.

*CMOS – Complimentary Metal-Oxide-Semiconductor

The ALICE pixel detector (ALPIDE)[1]

Main features:

- In-pixel discriminator and digital memory;
- In-column address encoder;
- End-of-column read-out.

Development stages of new detector for the upgraded ITS:

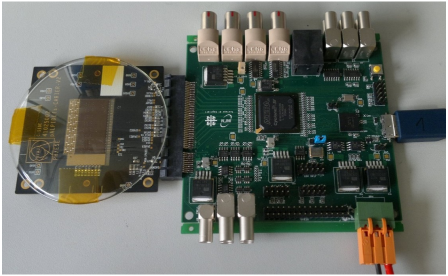
- Explorer-0, Explorer-1: analogue output;
- pALPIDEfs: 4 sectors, Diode/PMOS* reset;
- pALPIDEfs-2: 4 sectors, Diode/PMOS reset + back-bias voltage;
- pALPIDEfs-3: 8 sectors, Diode/PMOS reset + back-bias voltage;
- ALPIDE: Diode reset (5th sector of the pALPIDEfs-3);

New!

Investigator: development is in progress, active volume is fully depleted.

*PMOS – P-type metal-oxide-semiconductor

Single detector setup



Detectors and carriers for the SPbU were provided by the ALICE collaboration.

Saint-Petersburg laboratory is equipped with setups for the detector characterization tests, temperature measurements and for the work in telescopic mode.

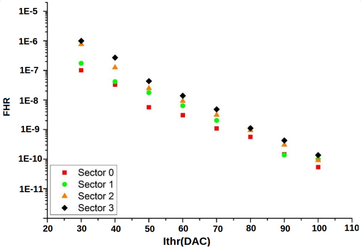
Detector characterisation tests include:

- DAC tests;
- Analogue/digital tests;
- Threshold tests;
- Noise tests;
- Tests with radioactive sources;
- Temperature tests;
- Beam tests

Noise occupancy tests

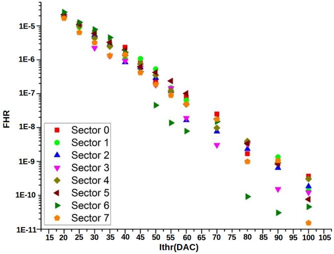
Pixel threshold can be regulated by the threshold current Ithr and voltage Vcasn. Increase of the threshold can supress probability of fake pixel firing.

Normal operating threshold is 50 (in DAC units).

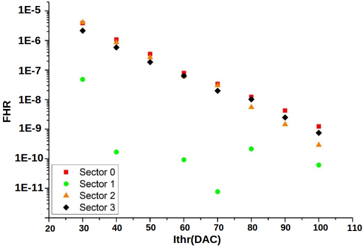


FHR* as a function of Ithr for pALPIDEfs (FHR_{max} $\sim 10^{-6}$)

Masked 20 pixels for all measurements



FHR* as a function of Ithr for pALPIDEfs-3 (FHR_{max} $\sim 10^{-5}$)



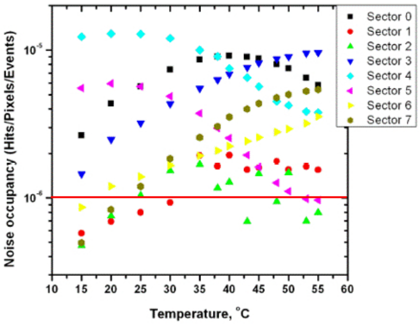
FHR* as a function of Ithr for pALPIDEfs-2 (FHR_{max} $< 10^{-5}$)

*FHR – Fake Hit Rate

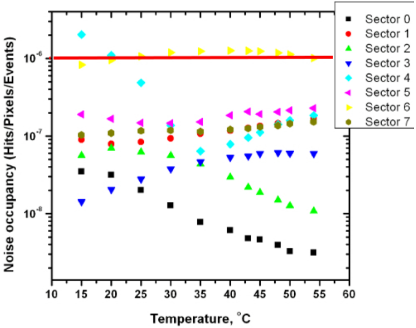
Noise occupancy tests

Apart from the threshold, fake hit rate can be influenced by back bias voltage (Vbb) applied to the detector substrate.
Figures represent temperature dependences of fake hit rate on temperature for the pALPIDEfs-3 sample for Vbb = 0 V and Vbb = -3 V.

NB: sector 5 has stable behaviour!



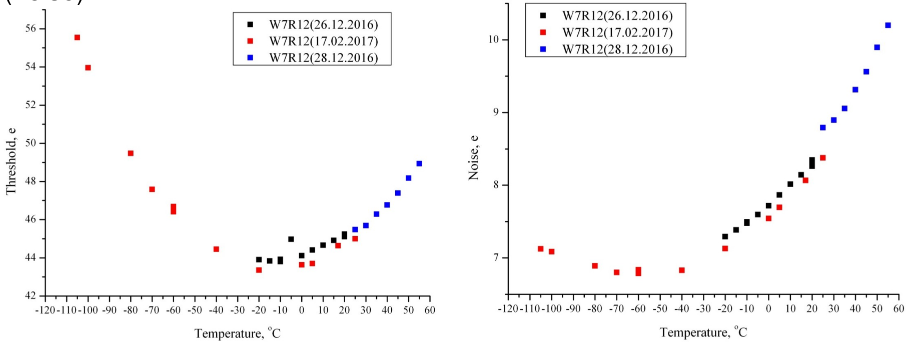
Vbb = 0V



Vbb = -3V

Threshold tests

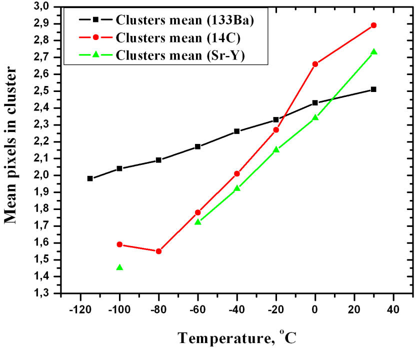
In order to extract operational threshold (in the units of charge) certain number of charge injections ($\sim$ 50 injections per point) with different amplitudes are applied to a set of pixels. A probability distribution of fired pixels in dependence of injected charge can be fitted with S-curve ($f = \frac{N}{2} Erf(\mu, \sigma)$). Parameters of the fitting (μ, σ) are the operational threshold and dispersion (noise).



Threshold and noise as a function of temperature for the ALPIDE irradiated up to 300 krad.

Source tests

Source test & cluster analysis



Due to the charge collection by drift and diffusion, the charge is shared by neighbouring pixels.

Average cluster size do not exceed 3 pixels. A decrease in temperature leads to a decrease in cluster size.

Sources with low activity:

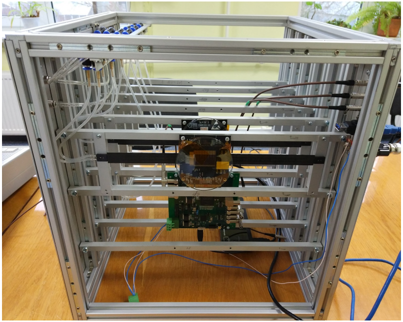
Source	Energy, keV	Radiation type
133Ba	5.64	γ
14C	cont. spect.	β
Sr-Y	cont. spect.	β

Tests were carried out for ALPIDE irradiated up to 300 krad.

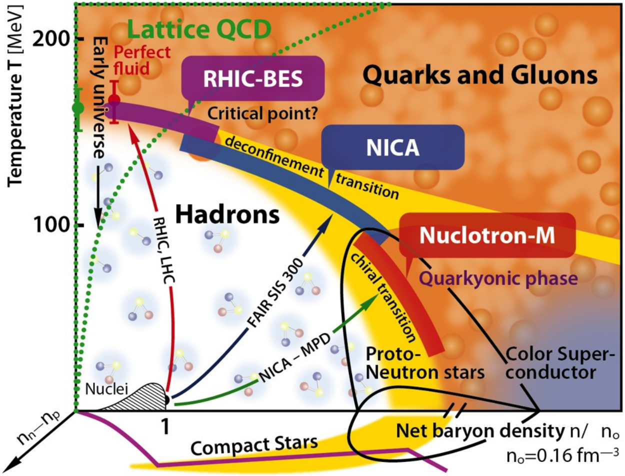
Status of detector characterisation

- All tests carried out for single detector prototypes showed good correspondence with requirements;
- Tests of detectors assembleys for Inner and Outer Barrels carried with satisfying results;
- Mass production of detectors and assembleys is in progress.

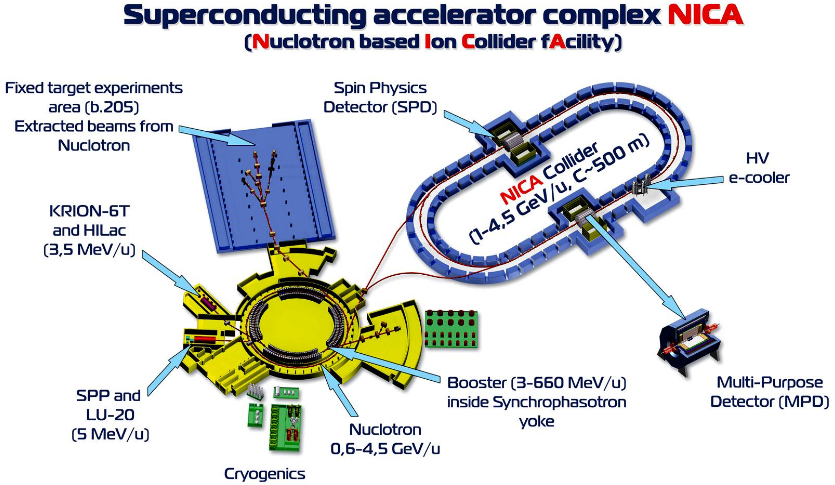
Telescopic setup with pALPIDE sensors for the beam tests is ready for studying tracking efficiency at Nuclotron, Dubna.
The main goal is to consider possibility of using pALPIDE sensors for the MPD (Multi Purpose Detector) tracking system at NICA.



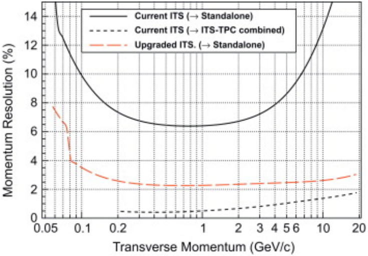
Heavy ion experiments[4, 5]

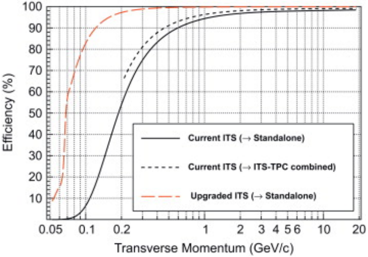


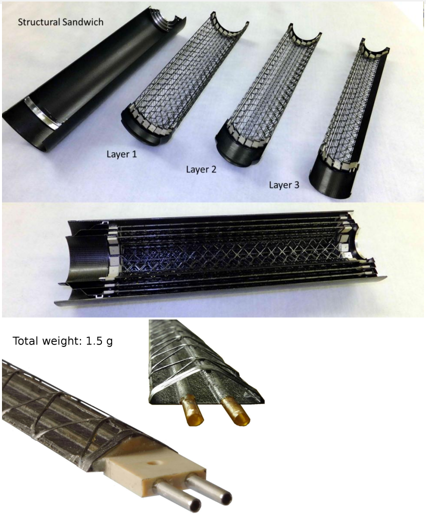
NICA facility[5]



Back to the ALICE ITS[1, 6]







Mechanical support for the ALICE ITS (IB)

Conclusions

Advantages of using the technologies of the upgraded ALICE ITS for the MPD/SPD* experiments:

- Suitable for collisions with A=1 – 197 at $\sqrt{S_{NN}}$ = 11 GeV/u (ALICE: $\sim$14 TeV GeV/u [1]);
- Suitable for L = 10^{27} cm^{-2}s^{-1} (ALICE: 6·10^{27}cm^{-2}s^{-1} [1]);
- Unique construction and mechanical support $\Rightarrow$ closest to the interacting point;
- Low power-consumption;
- Good efficiency and resolution even at low momentum (p$_T$<1GeV/c);
- Experience of work with pALPIDE sensors and their assemblies.

*SPD – Spin Physics Detector

Thank you for your attention!

References

- ALICE Collaboration, *Technical Design Report for the Upgrade of the ALICE Inner Tracking System*, *J. Phys. G: Nucl. Part. Phys.* **41**(2014) 087002
- http://alice.cern.ch/
- Jacobus Willem van Hoorne. Study and Development of a novel Silicon Pixel Detector for the Upgrade of the ALICE Inner Tracking System. PhD thesis. CERN-THESIS-2015-255, 2015.
- V. Kekelidze, V. Matveev, I. Meshkov, A. Sorin, G. Trubnikov, *Project Nuclotron-based Ion Collid-er Facility at JINR.*, *Physics of Particles and Nuclei*, **48**(2017), No. 5, pp. 727–741
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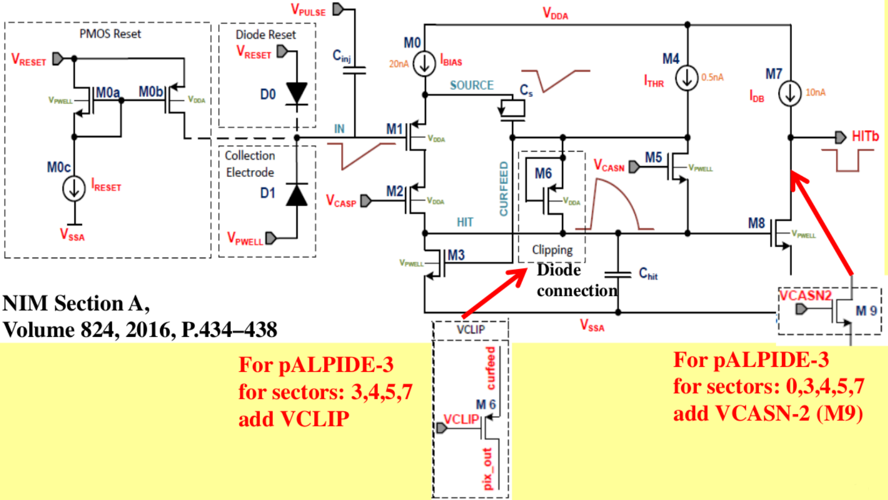
Back-up slides

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

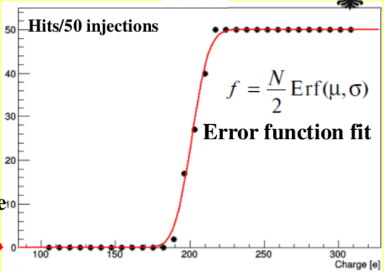
For pALPIDE-3
for sectors: 0,3,4,5,7
add VCASN-2 (M9)

Study of the characteristics of full-scale Pixel Detector prototypes

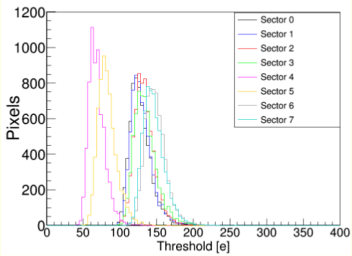
Threshold Scan

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

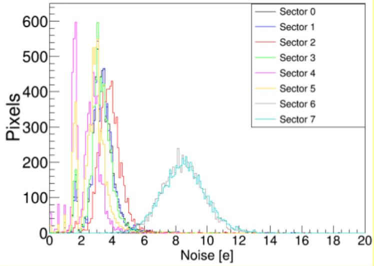
In order to extract threshold a number of charge injections with different amplitude are performed (50 points with 50 injections per point). A probability distribution of fired pixels measuring a pixel response (S-curve) has been obtained.



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



Pixel threshold distribution for 8 sectors



Temporal noise values for the pixels for 8 sectors