Sensor prototype characterization for the ALICE ITS upgrade

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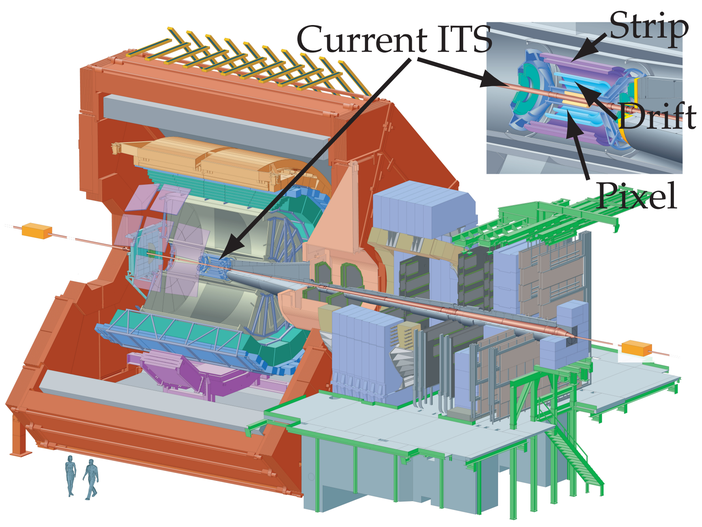
Upgrade of ALICE

The upgrade of ALICE is planned for the 2nd Long Shutdown of the LHC in 2019–2020.



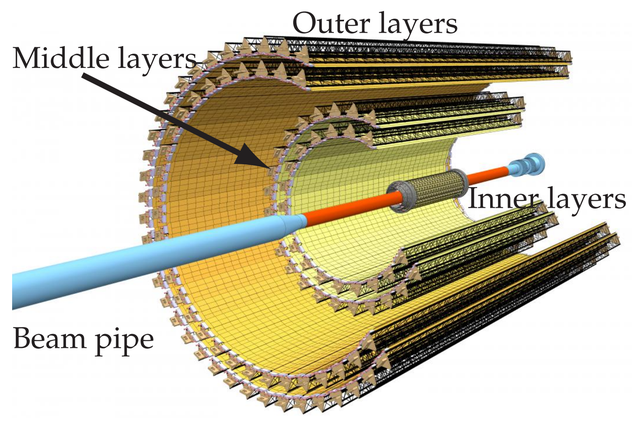
Motivations for the upgrade:

- High precision measurements of heavy flavor and charmonia at low p_T and low-mass dileptons
- Record large minimum bias samples → read out all Pb–Pb collisions at an interaction rate of 50 kHz
- Record integrated luminosity of 10 nb^{-1} in Pb–Pb (plus pp and p–A data)

Upgrade of the Inner Tracking System

Design objectives:

- Improve impact parameter resolution by a factor of 3(5) in r–φ(z) at $p_T = 500$ MeV/c
- Improve tracking efficiency and p_T resolution at low p_T
- Fast readout (the present ITS is limited to 1 kHz)
- Fast insertion/removal for yearly maintenance



Upgrade strategy:

- First layer will be moved closer to interaction point: 39 mm → 23 mm
- Material budget will be reduced from ~ 1.14% X_0 to 0.3% X_0 for the three innermost layers
- Pixel size will be reduced from 50 μm × 425 μm to 29 μm × 27 μm
- 7 layers instead of current 6 layers
- All layers pixel chips

Requirements	Inner barrel	Outer barrel
Spatial resolution	5 μm	10 μm
Detection efficiency	> 99%	
Fake hit rate	$< 10^{-5}$ per event per pixel	
TID radiation *	2700 krad	100 krad
NIEL radiation *	1.7×10^{13} 1 MeV n_{eq}/cm^2	10^{12} 1 MeV n_{eq}/cm^2

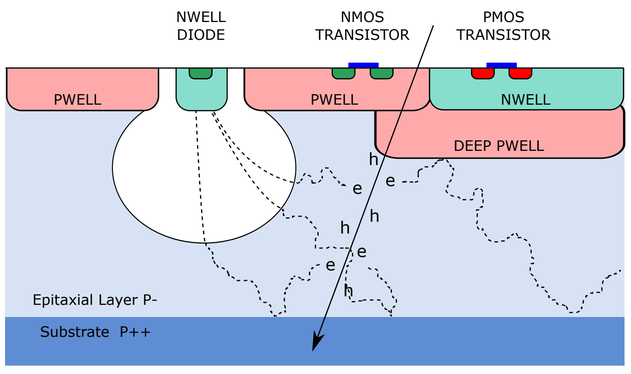
* Including a safety factor of 10

Technology choice

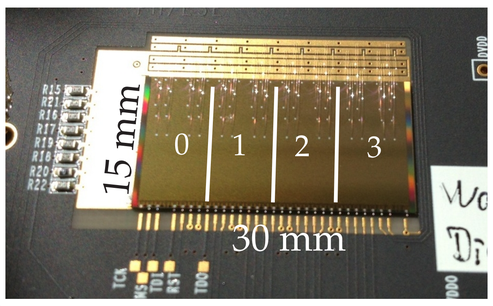
Monolithic Active Pixel Sensors (MAPS) using the TowerJazz 0.18 μm CMOS imaging process

Advantages:

- High-resistivity (> 1kΩ cm) epitaxial layer on p-type substrate
- Deep p-well shields n-well of PMOS transistors ⟶ full CMOS circuitry within active area
- Moderate reverse substrate biasing is possible

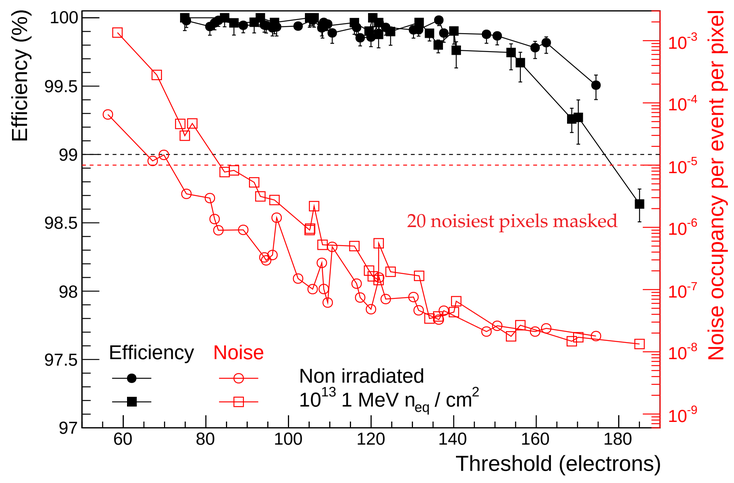


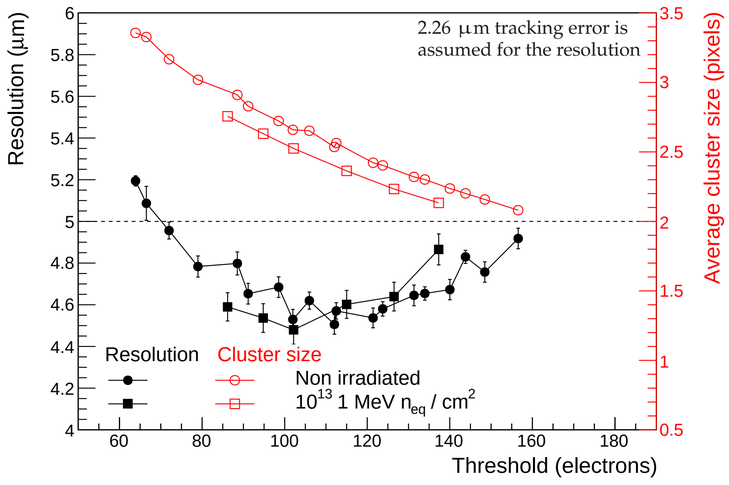
First final-size ALPIDE prototype



- pALPIDE-1 is first prototype with final size of 15 mm x 30 mm
- Produced in May 2014
- 512 × 1024 pixels of 28 μm × 28 μm
- Digital readout with a priority encoder
- Divided into four sectors with different pixel layouts

Characterization results





- Efficiency is well above 99% before and after irradiation with a large operational margin
- Noise occupancy is slightly higher after irradiation, but stays below 10^{-5} hits/event/pixel
- Resolution is below 5 μm with a large operational margin
- Average cluster size gets slightly smaller after irradiation

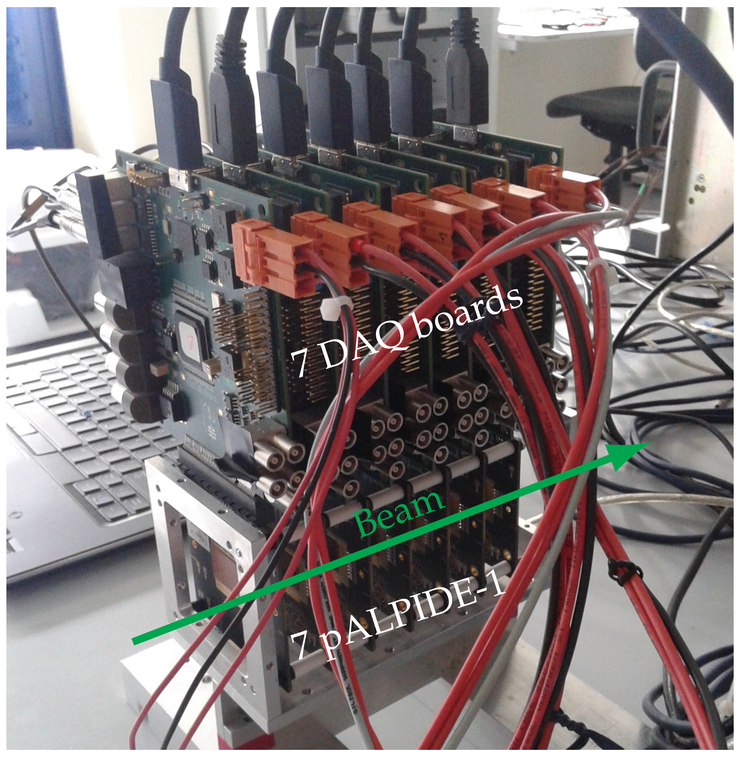
References

[1] EUTelescope. https://eutelescope.web.cern.ch.

[2] ALICE collaboration. Upgrade of the ALICE Experiment: Letter Of Intent. *J. Phys.*, G41:087001, 2014.

[3] ALICE collaboration. Technical Design Report for the Upgrade of the ALICE Inner Tracking System. *J. Phys.*, G41:087002, 2014.

Test beam setup



- Seven layers of pALPIDE-1
- Six outer layers are kept at same settings for tracking
- Chip in the center is used as DUT (Device Under Test)
- Tests at various test beam facilities ranging in momentum from 60 MeV/c to 120 GeV/c (PS, SPS, DESY, BTF, PAL)
- Readout and analysis is done using the EUDAQ/EUTelescope framework [1]

Status and conclusions

- Since the first full-size prototype, two new prototypes have been produced and tested which include the features missing from the pALPIDE-1
- Improved performance with the new prototypes (e.g. orders of magnitude lower noise occupancy) → all prototypes fulfill the upgrade requirements
- Prototypes stay fully functional after irradiation of 1.7×10^{13} 1 MeV n_{eq}/cm^2
- Submission of the final ALPIDE chip is planned within a few weeks