Upgrade of the ALICE Inner Tracking System (ITS)

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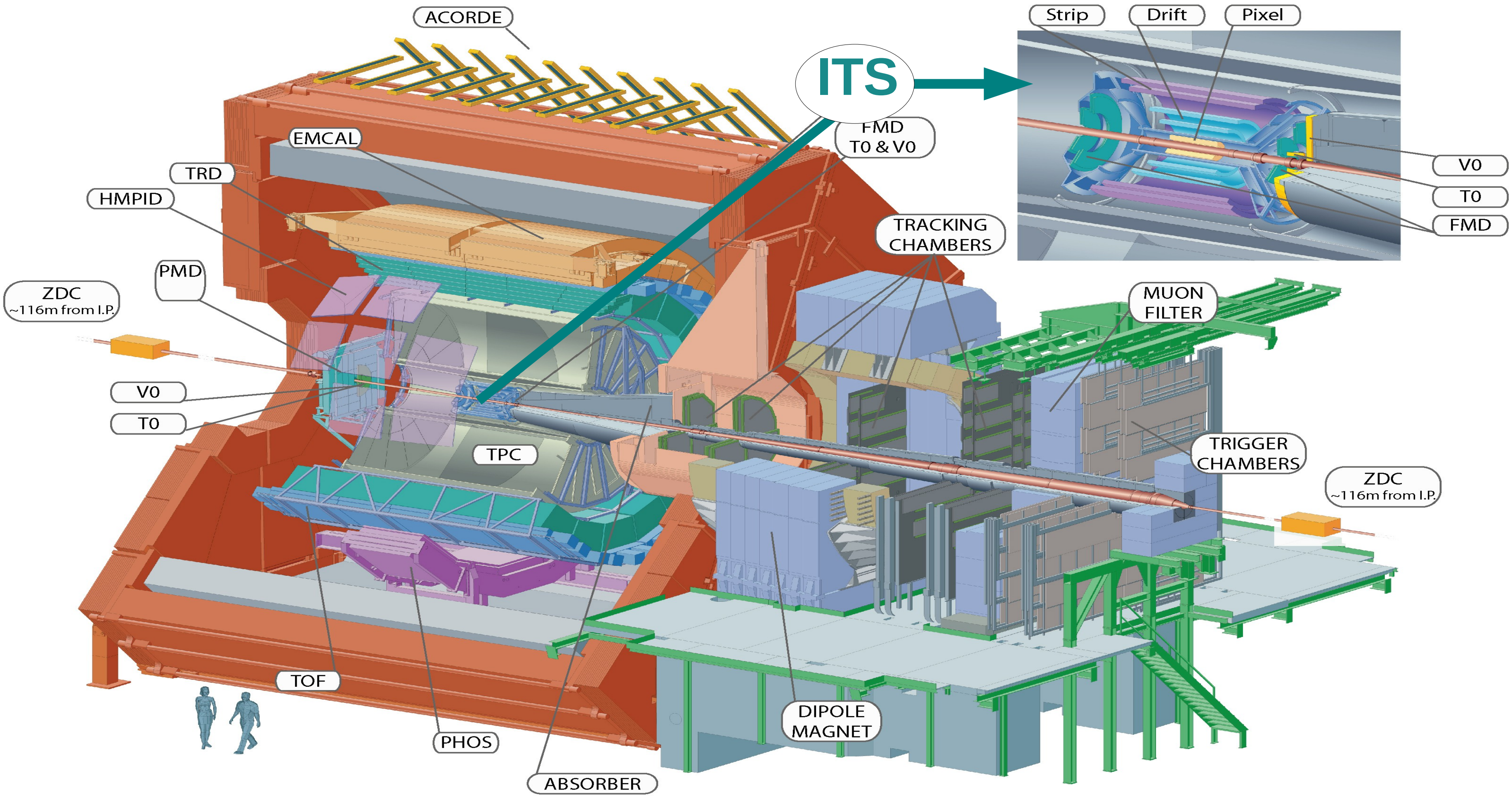
ALICE & present ITS

ALICE is a heavy-ion experiment at the CERN LHC with a main goal to study strongly interacting matter, in particular the properties of the Quark-Gluon Plasma, using Pb-Pb, p-Pb and pp collisions .



ALICE consists of
- a central barrel,
- a forward muon spectrometer,
- several dedicated detectors for triggering and event characterization.

ALICE upgrade

Motivation

High precision measurements of rare probes at low p_T, which cannot be selected by a hardware trigger

Target

Recorded luminosity of 10 nb^{-1} in Pb-Pb (plus pp and p-Pb data)

Increased statistics by a factor of 100 compared to LHC Run 1 and 2 (2009 - 18)

Improved vertexing, tracking and read-out rate capabilities

Upgrades (LHC Long Shutdown 2 – 2019-20)

ALICE readout (of several detectors) and online systems

Read out all Pb-Pb interactions at a maximum rate of 50 kHz with a minimum bias trigger

Perform online data reduction

New silicon trackers: Inner Tracking System (mid-rapidity), Muon Forward Tracker (forward rapidity)

Requirements for ALICE ITS upgrade

Improve impact parameter resolution (≈ factor of **3** **(6)** in r-φ (z) at 500 MeV/c)

First layer closer to interaction point: r_0 = **39 mm** → **22 mm**

Smaller beam pipe radius: **29 mm** → **18.2 mm**

Reduce X / X_0/ layer: **1.14 %** → **0.3 %** (inner layers)

Smaller pixel size: **50 μm x 425 μm** → **28 μm x 28 μm**

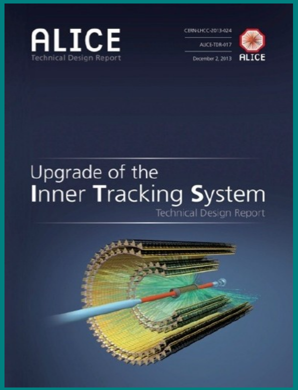
Improve tracking efficiency and p_T resolution at low p_T

Increase the number of layers **6** → **7**

All layers pixel chips

Fast readout : **50 kHz** in Pb-Pb, **200 kHz** in pp (currently **1 kHz**)

Easier maintenance: replacement of faulty detector components during the yearly LHC technical stop



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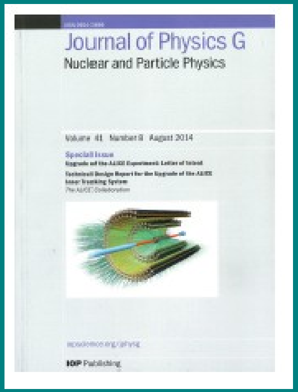

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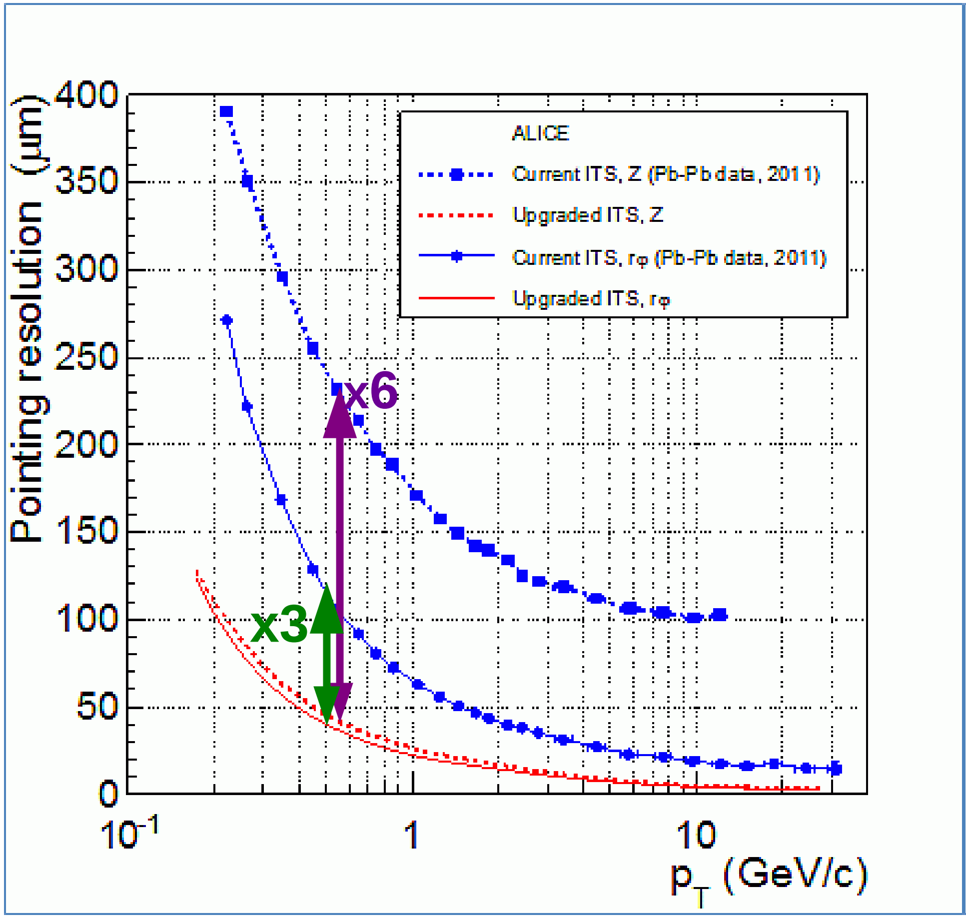
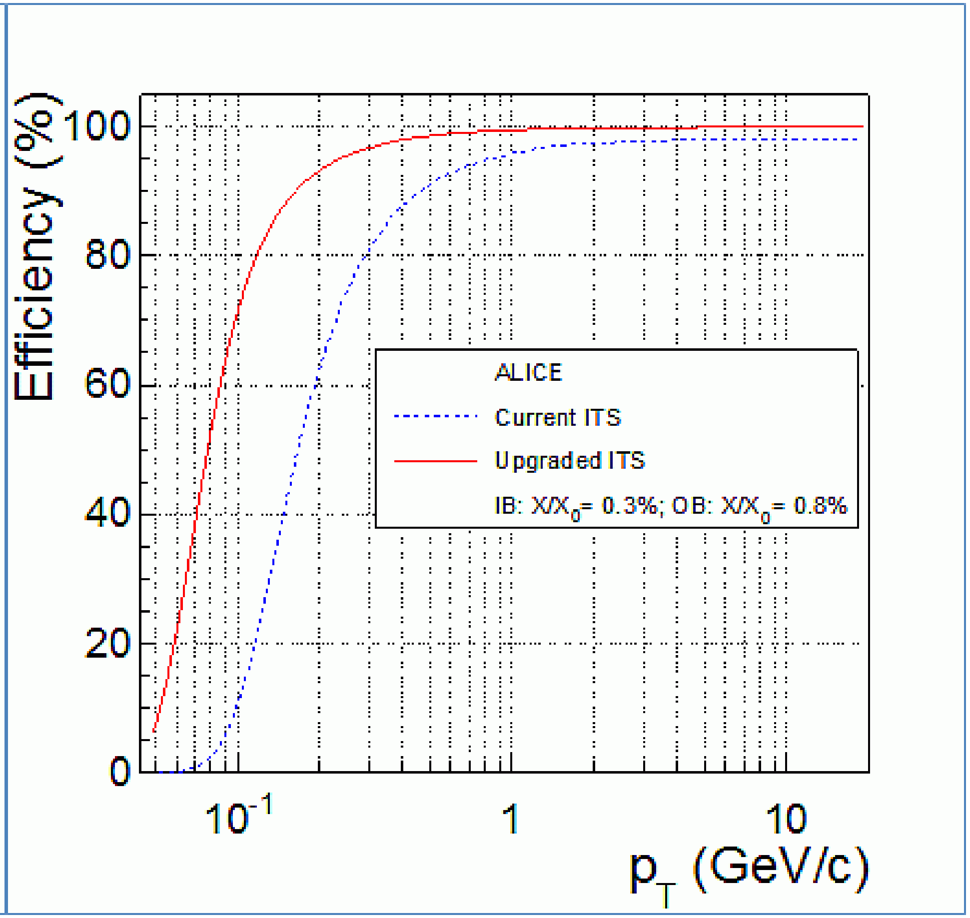
Expected performance of new ITS

Pointing resolution

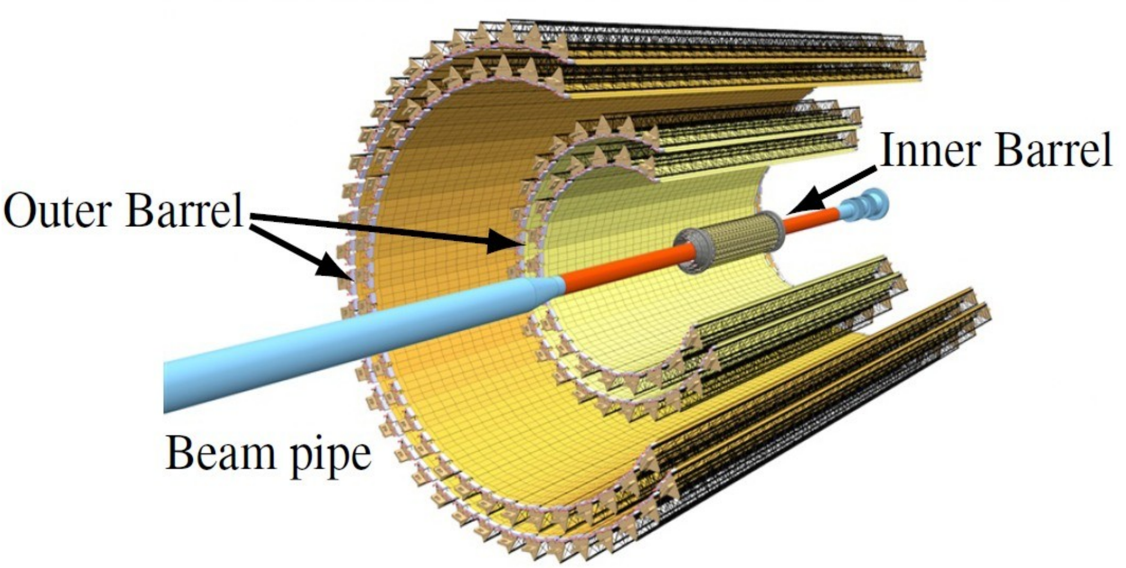


Tracking efficiency



~ 40 μm at p_T = 500 MeV/c

Requirements for the ITS upgrade



7 layers of pixel sensors
(r = 22 − 400 mm)

10 m^2 of silicon with
12.5 Gpixels

|η | < 1.22 for tracks from 90% of the most luminous region

Parameter	Inner barrel	Outer barrel
Silicon thickness	50µm	
Spatial resolution	5µm	10µm
Power density	< 300 mW/cm^2	< 100 mW/cm^2
Event resolution	< 30µs	
Detection efficiency	$> 99\%$	
Fake hit rate	$< 10^{-5}$ per event per pixel	
Average track density	15 - 35 cm^{-2}	0.1 - 1 cm^{-2}
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

=> well suited for Monolithic Active Pixel Sensors

** including a safety factor of 10*

Choice of sensor technology

Monolithic Active Pixel Sensors (MAPS) using Tower Jazz 0.18 μm CMOS imaging process :

Very **thin sensors**
Very **high granularity**
Large area to cover
Modest radiation levels

Parameter comparison for mainstream MAPS architectures

	ALPIDE	MISTRAL
Pixel pitch	**28** μm x **28** μm	**36** μm x **64** μm
Event time resolution	< **2** μs	~ **20** μs
Power consumption	**39** mW/cm^2	**97** mW/cm^2

Baseline solution → ALPIDE

Both architectures have the same dimensions, identical physical and electrical interfaces

Pixel sensor characterizations

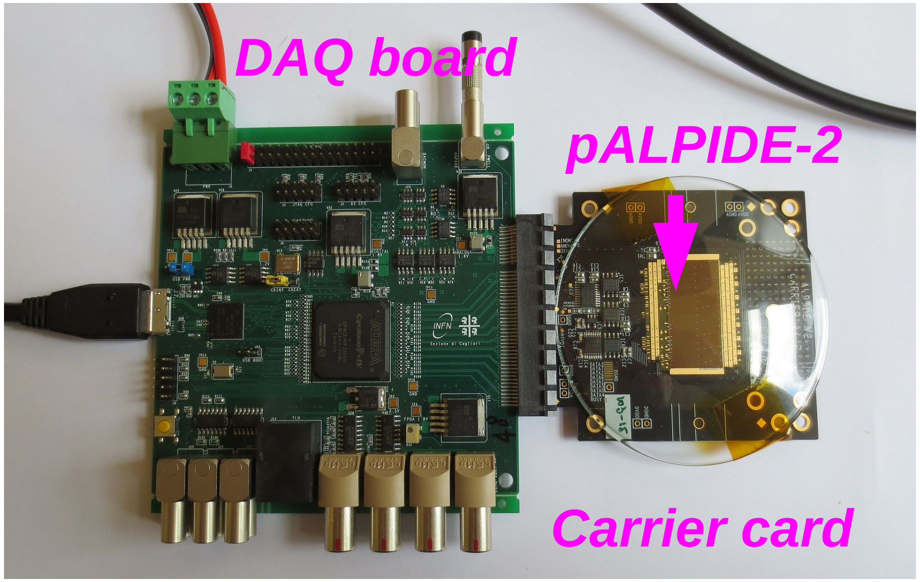
Laboratory

Noise and **threshold** scans

Radioactive source measurements

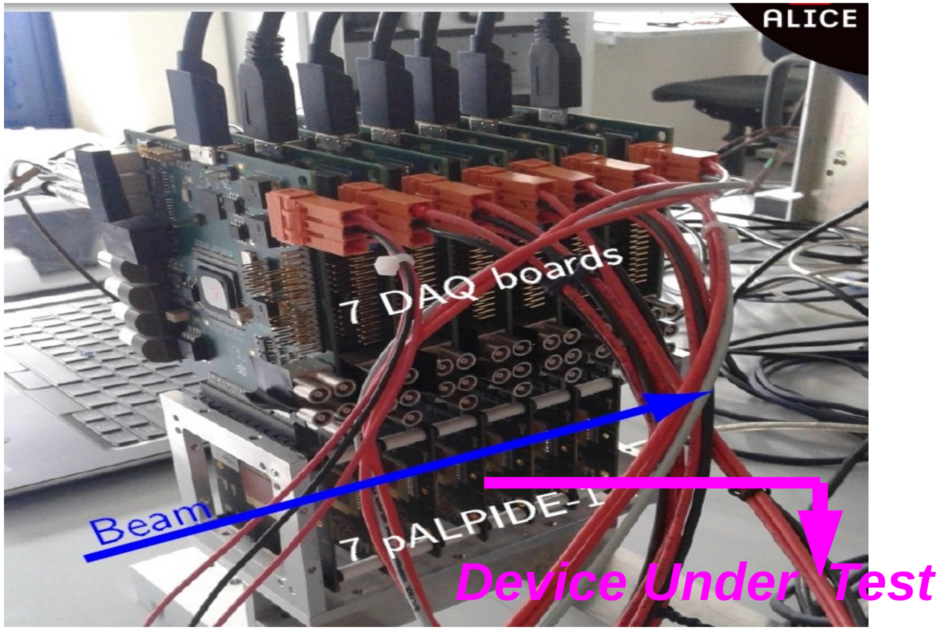
Noise occupancy measurements

Intensive efforts in **a number of institutes** to characterize pixel sensors



Example of pALPIDE test setup

Test beam



Tracking by a stack of **3 + 3** pALPIDE-1 chip around **D**evice **U**nder **T**est

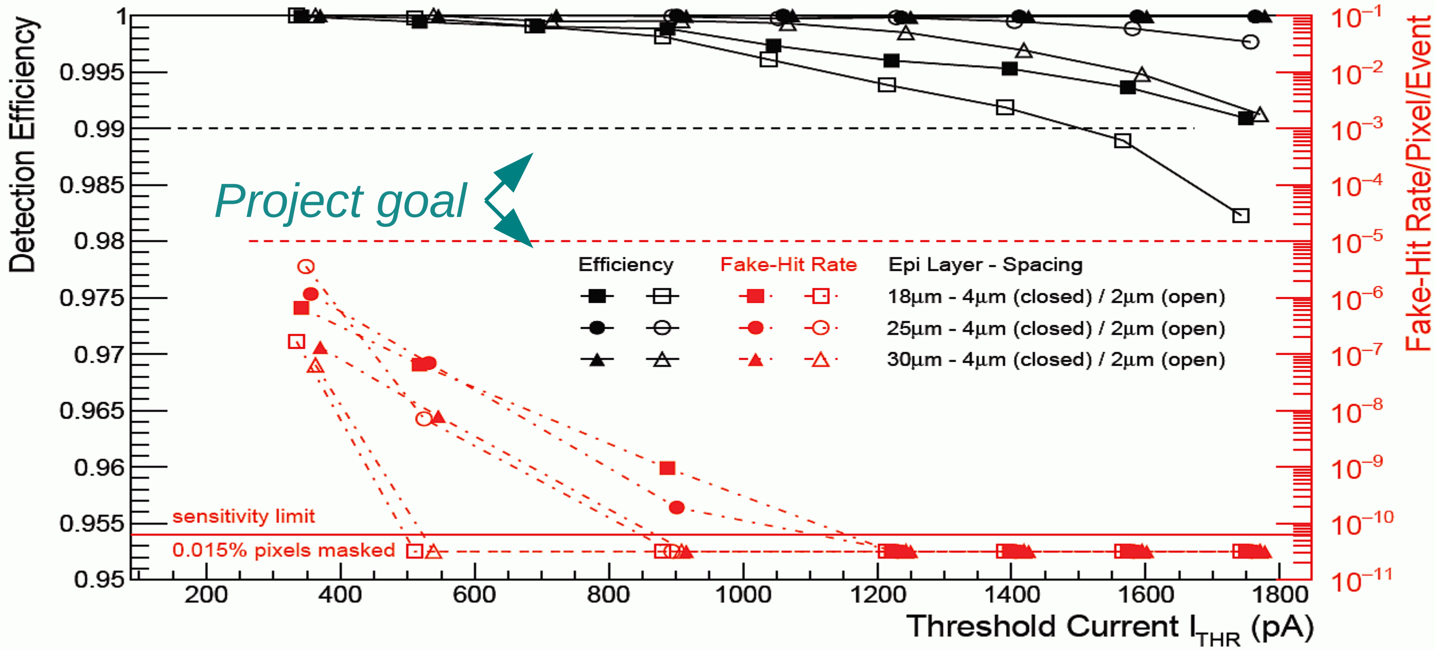
Readout and analysis is done using the **EUDAQ/EUTelescope** framework (created by DESY)

Several campaigns from 60 MeV to 120 GeV (PS, SPS, DESY, BTF, PAL)

Measurement of **detection efficiency** and **spatial resolution**

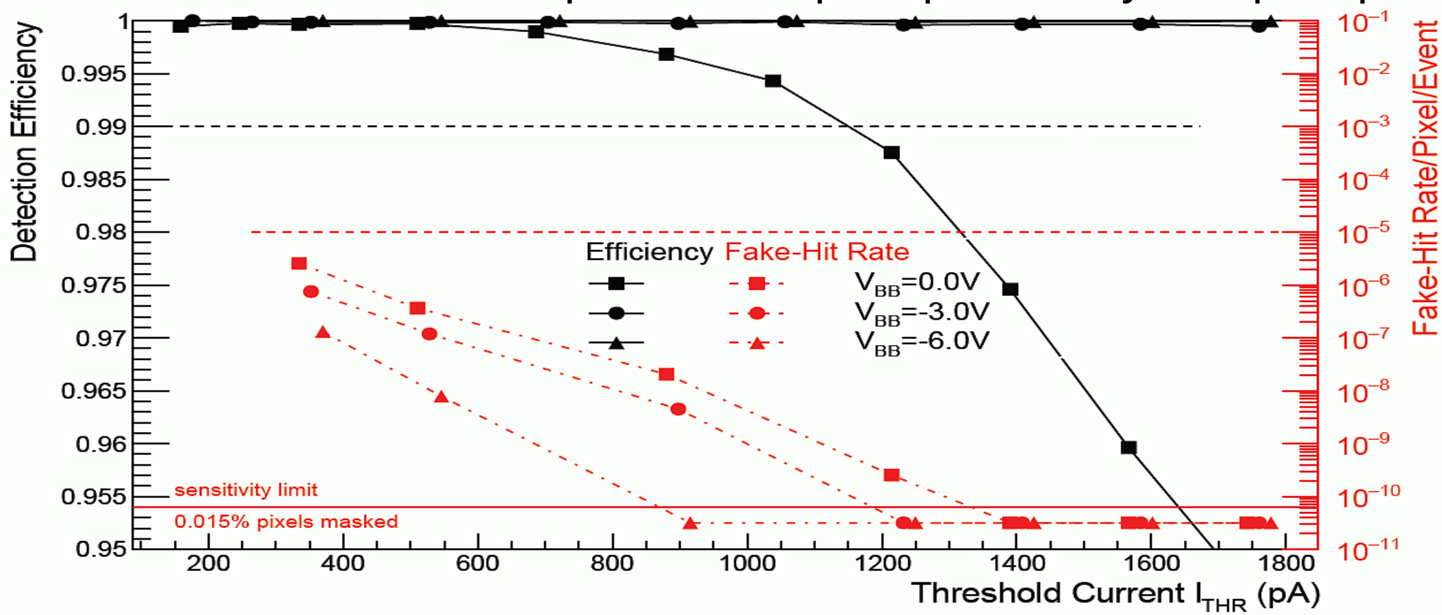
Selected performance : Efficiency & Fake-Hit rate

Reverse substrate bias VBB = −6 V, epitaxial layer and spacing comparison



- *Detection efficiency for MIP increases with increasing epitaxial layer thickness*
- *Goal of the project :*
  *Efficiency > **99%***
  *Fate-Hit rate < **10** $^{-5}$ per pixel and event*

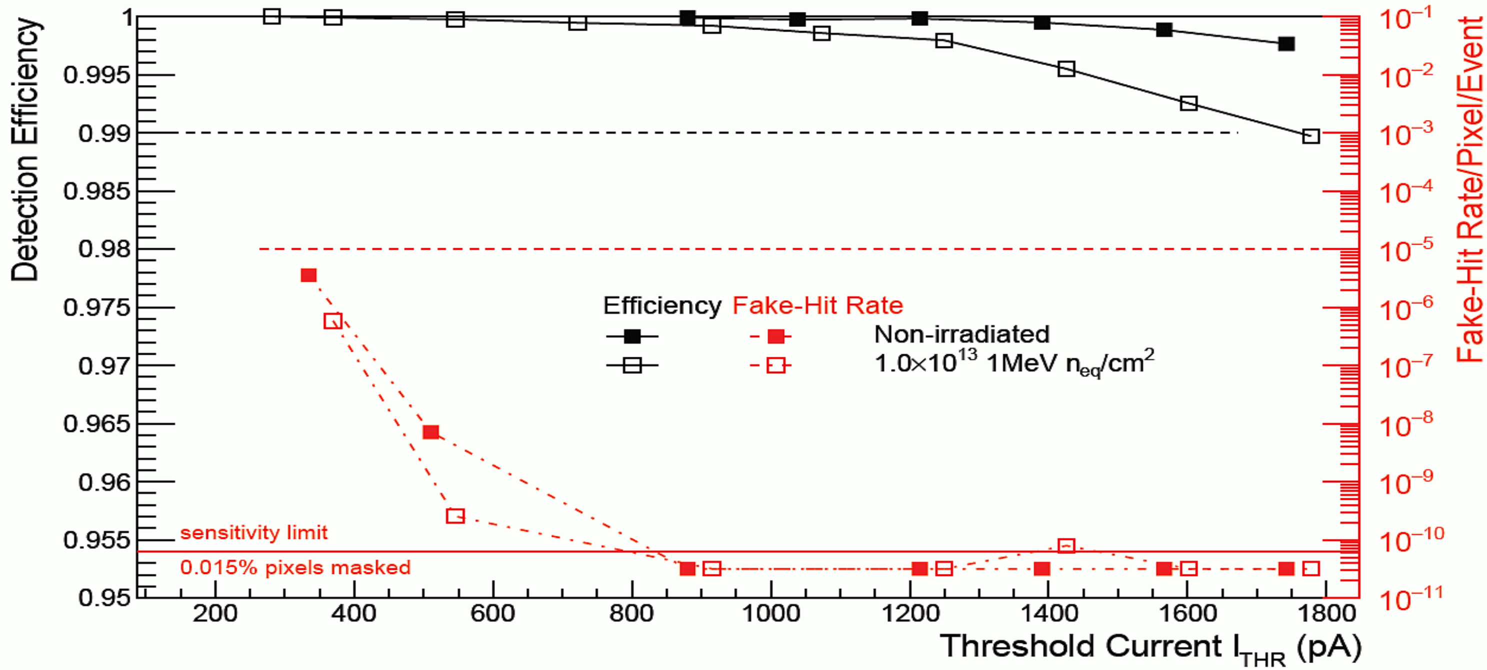
Reverse substrate bias comparison, 30 µm epitaxial layer, 4 µm spacing



- *Measurements meet the requirements*
- *Detection efficiency improves with larger back bias voltage*

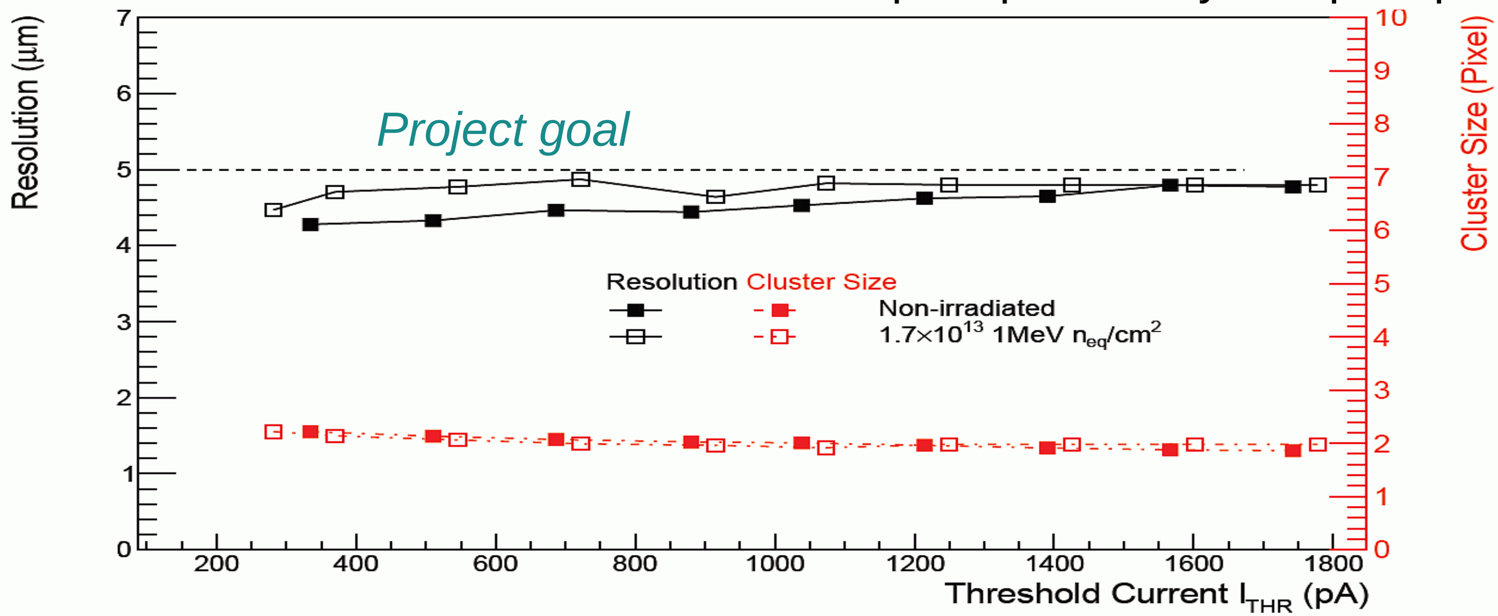
Irradiated prototypes : Efficiency & Position resolution

Reverse substrate bias VBB = −6 V, 25 µm epitaxial layer, 2 µm spacing



- *Deterioration of the detection efficiency & position resolution is tolerable up to the maximal expected dose*

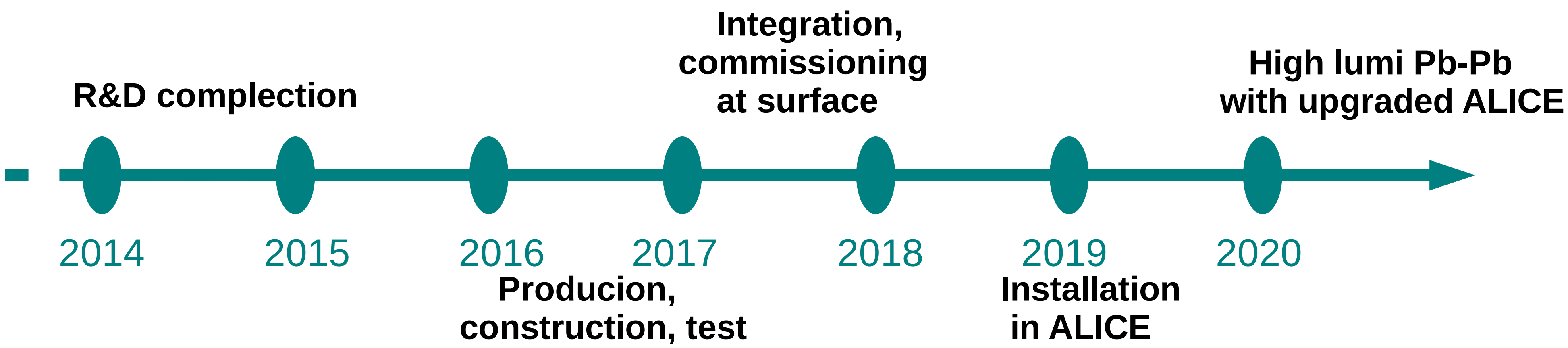
Reverse substrate bias VBB = −6 V, 30 µm epitaxial layer, 4 µm spacing



- *Cluster size is not affected by radiation*

Summary and outlook

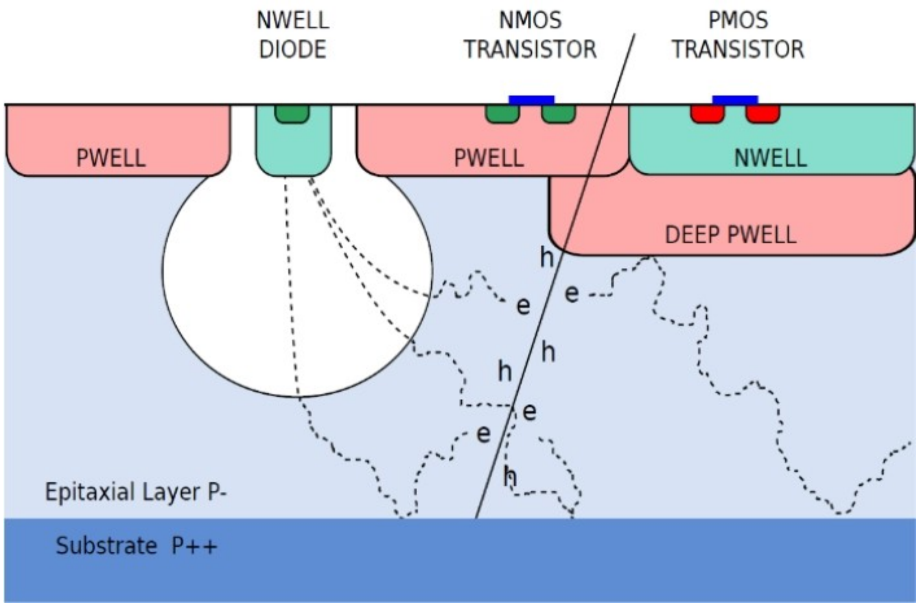
- The Inner Tracking System of ALICE will be replaced during the second long LHC shutdown (2019/20)
- 7 layers of monolithic active pixel sensors will be used
- Expected track impact parameter resolution, tracking resolution and p_T resolution at low p_T will improve significantly
- First full scale prototypes show good performance and large operational margin
- Project is advancing according to schedule



Backup slides

Pixel Specifications

Pixel choice: Monolithic Active Pixel Sensors (MAPS) using Tower Jazz 0.18 µm



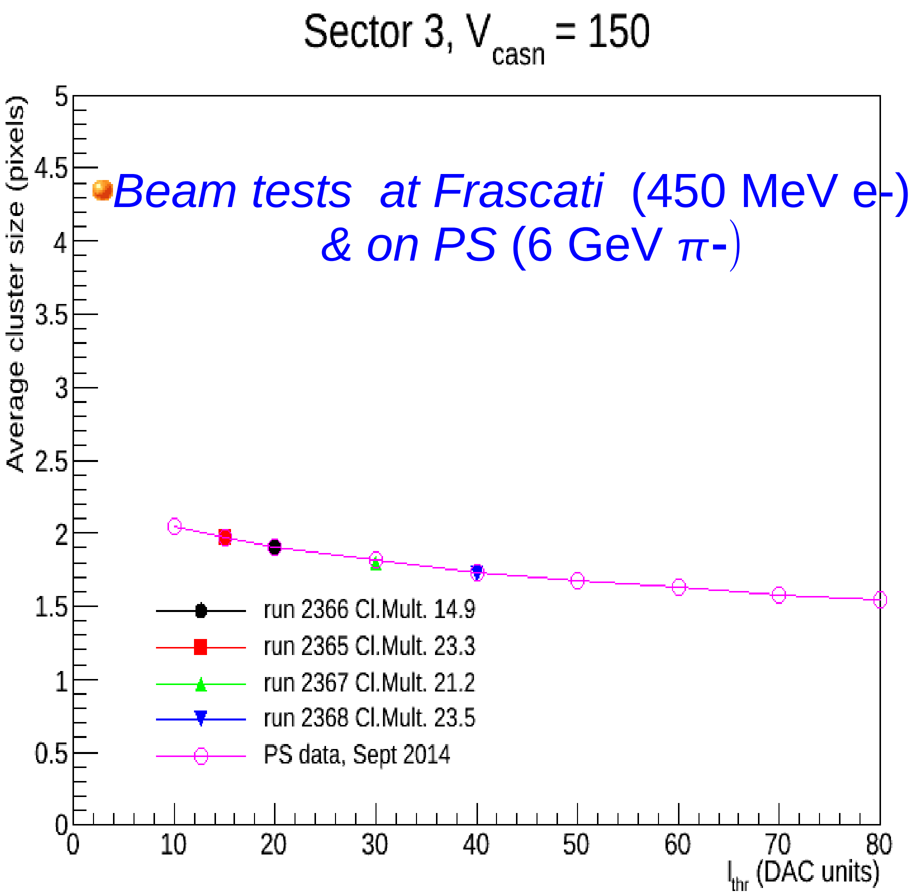
Schematic cross section

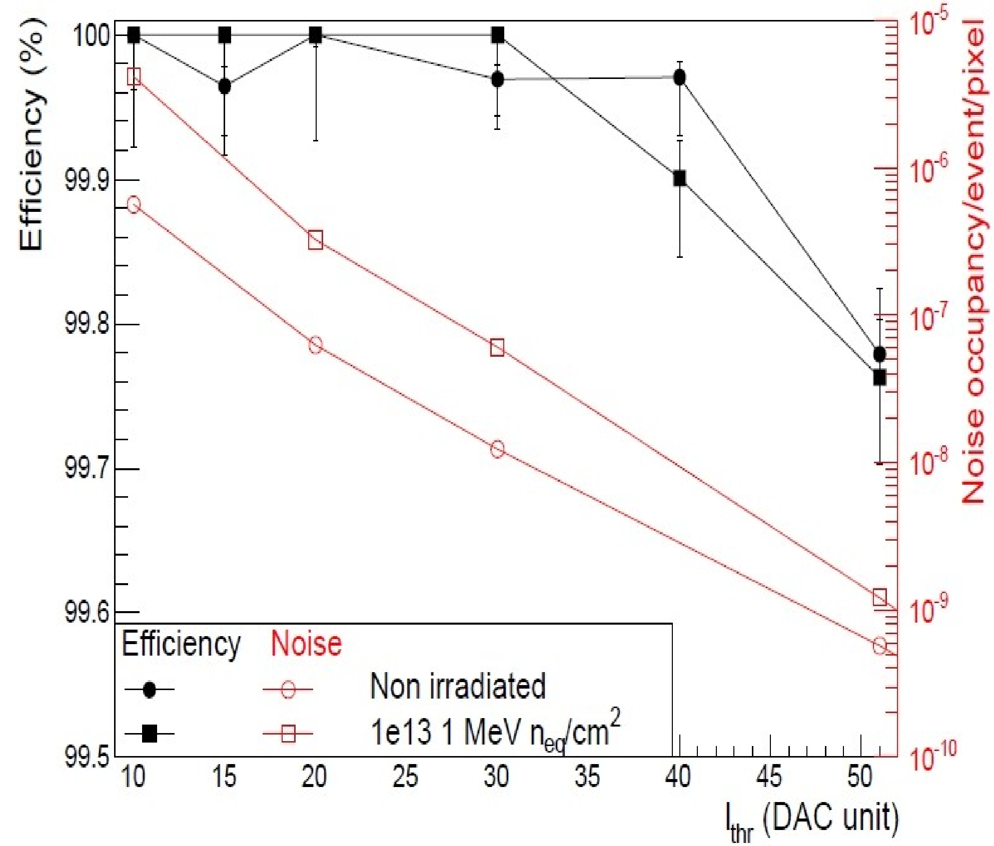
- Chip size: 15 mm x 30 mm
- Pixel pitch ~ 30 µm
- Si thickness: 50 µm
- Spatial resolution ~ 5 µm
- Power density < 100 mW/cm^2
- Integration time < 30 µs
- Fake-hit rate < 10 $^{-5}$ per pixel per event

Performance Example

pALPIDEfs: first full scale prototype of ALPIDE, pixel size: 28 x 28 mm^2

- *Beam tests at Frascati (450 MeV e-) & on PS (6 GeV π-)*





- *Cluster size is consistent for data, measured at Frascati & on PS*
- *Cluster size does not depend on multiplicity*

- *20 most noisy pixels masked*
- *Wide operating range with effciency ~99% and noise occupancy < 10^{-5} /event/pixel*
- *noise occupancy increases after irradiation*