ALICE

INFN TORINO
Istituto Nazionale di Fisica Nucleare
Sezione di Torino

UNIVERSITÀ DI TORINO

Politecnico di Torino

Validation of the 65 nm TPSCo CMOS imaging technology for the ALICE ITS3

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on behalf of the ALICE collaboration

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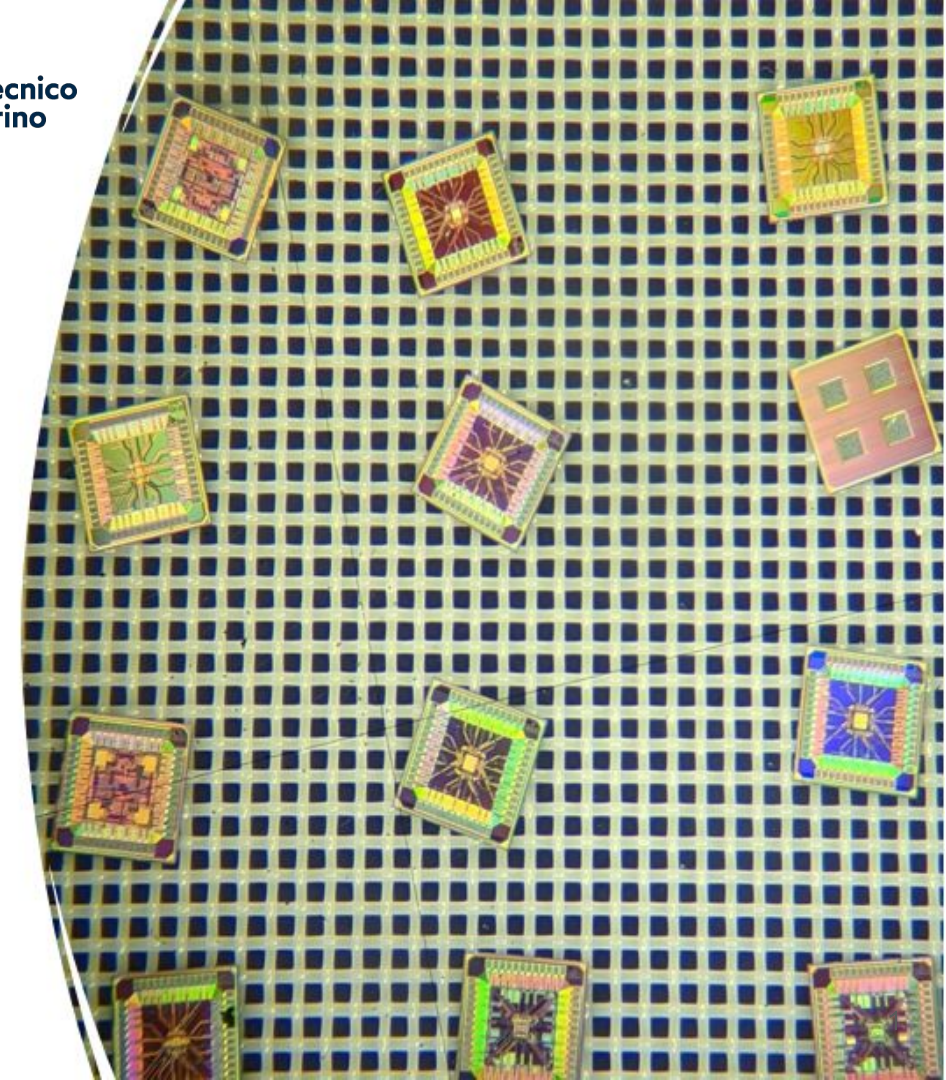
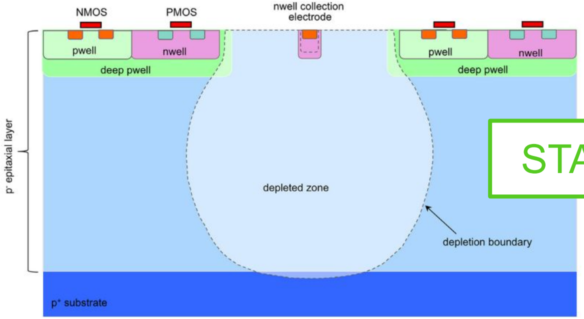
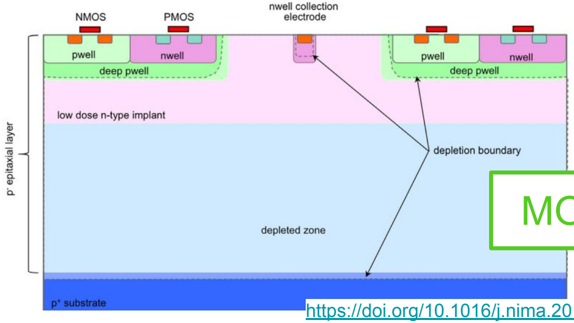


65 nm CMOS IS technology

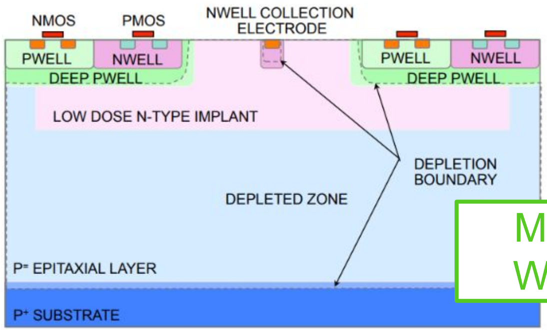


STANDARD



MODIFIED

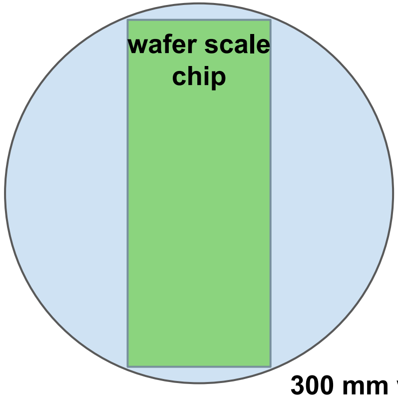
https://doi.org/10.1016/j.nima.2017.07.046



MODIFIED WITH GAP

http://dx.doi.org/10.1088/1748-0221/14/05/C05013

- Available on 300 mm wafers
- Provides 2D stitching
- Chips thinned down to ≤ 50 µm
- 7 metal layers



3 different implant geometries:

- standard
- modified (B)
- modified with gap (P)

4 different pixel pitches (10, 15, 20, 25 µm)

selection of pixel architecture
evaluation of detection efficiency
evaluation of radiation hardness

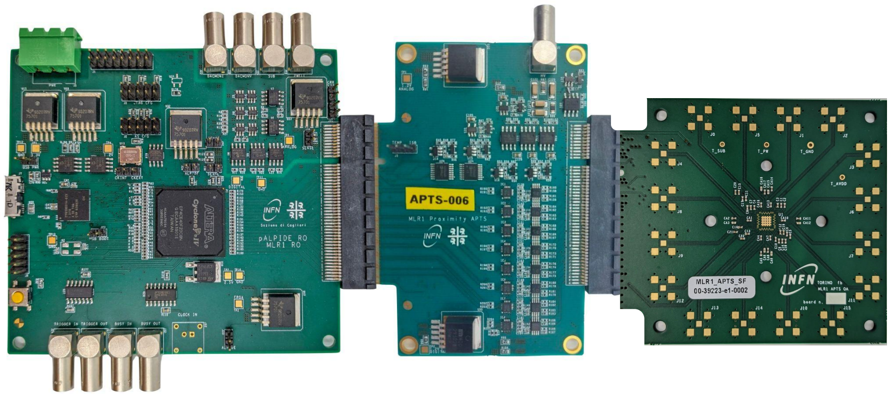
CHARACTERIZATION GOALS FOR TECHNOLOGY VALIDATION

ALICE ITS3: D-MAPS with small collection diode in 65 nm

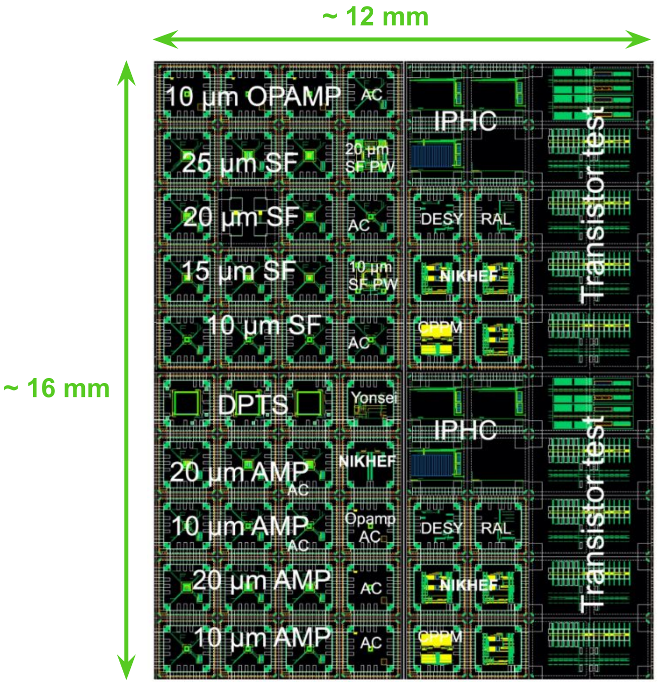
ALICE ITS3 involved in the evaluation of the TPSCo 65 nm technology performance for particle detection

Multi **L**ayer **R**eticle **“MLR1”** submission:

- transistor test structures for radiation hardness studies
- various diode matrices for charge-collection studies
- analog building blocks



D-MAPS: depleted monolithic active pixel sensors

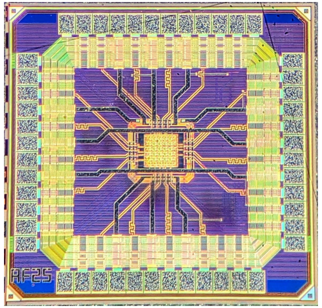


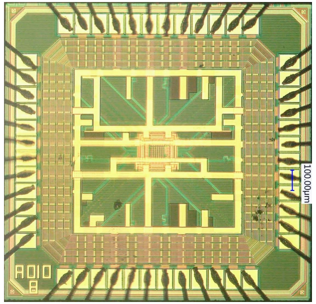
First sensor prototypes in 65 nm process
in collaboration with CERN EP R&D on monolithic sensors

Test structures

APTS
Analogue Pixel Test Structure

Source-follower **OpAmp**

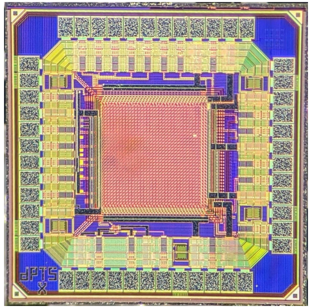




1.5 mm 1.5 mm 1.5 mm

- Matrix: 6×6 pixels
- Pitch: 10, 15, 20, 25 µm
- Direct analogue readout of central 4×4 submatrix
- AC/DC coupling
- 3 process modifications
- Purpose: testing pixel cell

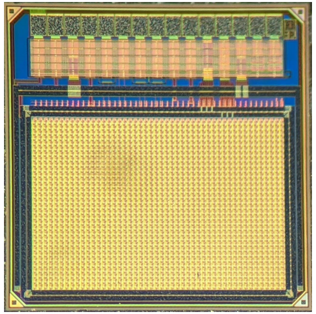
DPTS
Digital Pixel Test Structure



1.5 mm 1.5 mm

- Matrix: 32×32 pixels
- Pitch: 15 µm
- Asynchronous digital readout
- Time-over-Threshold information
- Only modified with gap process modification
- Purpose: testing pixel front-end

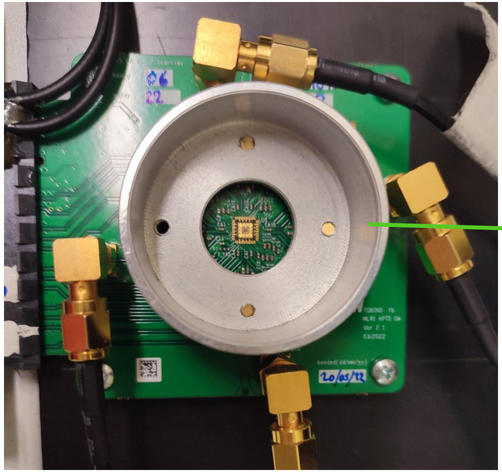
CE-65
Circuit Exploratoire 65



1.5 mm 1.5 mm

- Matrix: 64x32, 48x32 pixels
- Pitch: 15, 25 µm
- Readout: rolling shutter analog
- Purpose: testing pixel with rolling shutter

Characterization tests

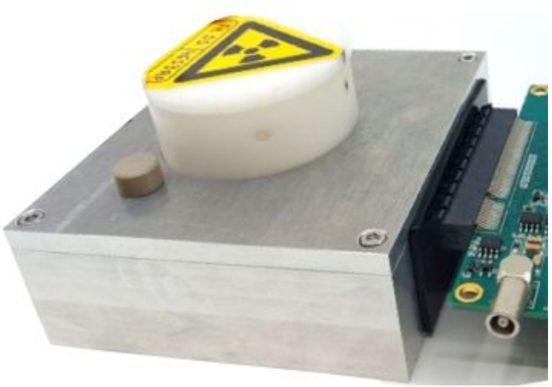


Aluminium holder

Laboratory

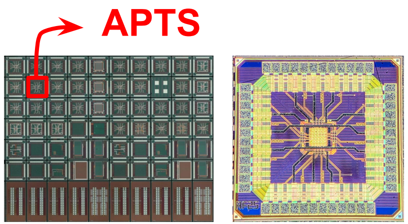
1. Pulse and noise measurements

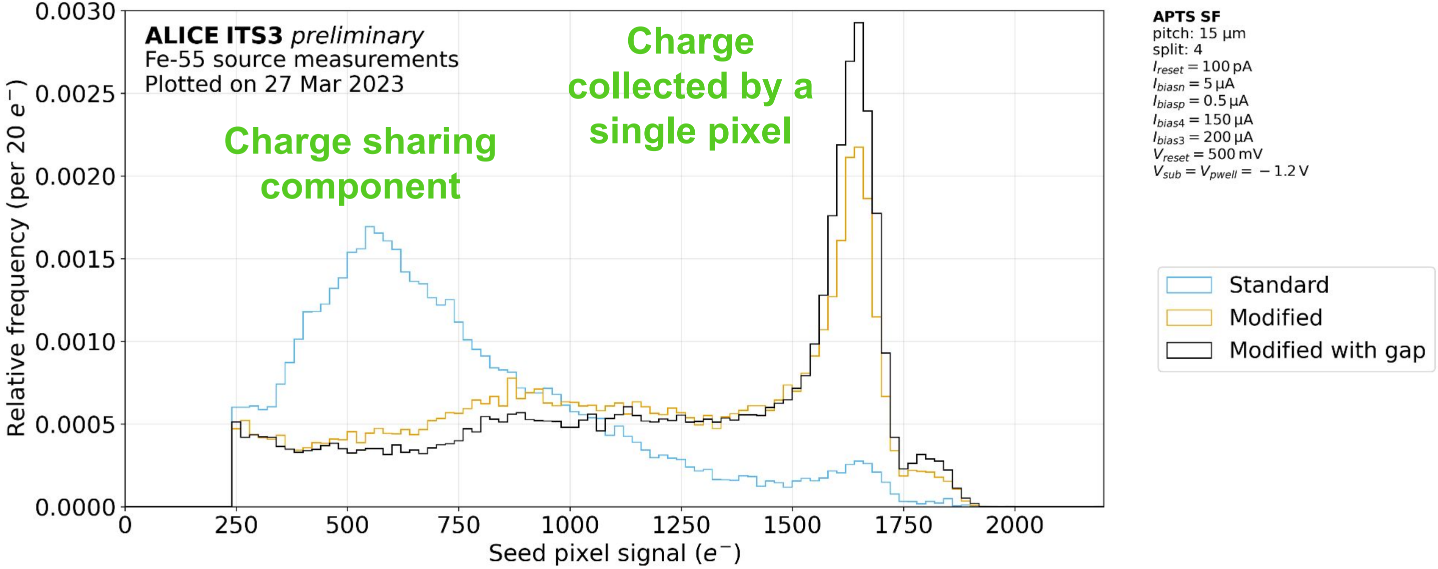
2. Tests with ^{55}Fe source (5.9 keV X-rays)
   - Tuning of chip parameters
   - Signal calibration
   - Study of the charge collection
   - Performance comparison of different process modification and split



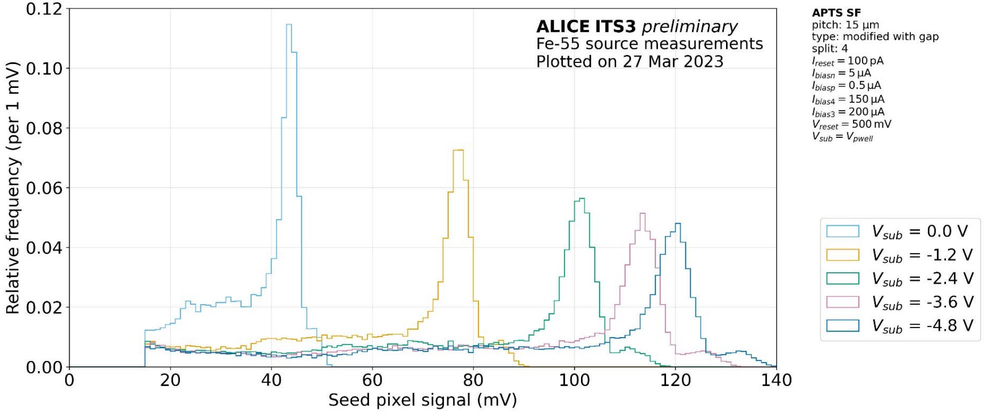
Impact of implant geometry

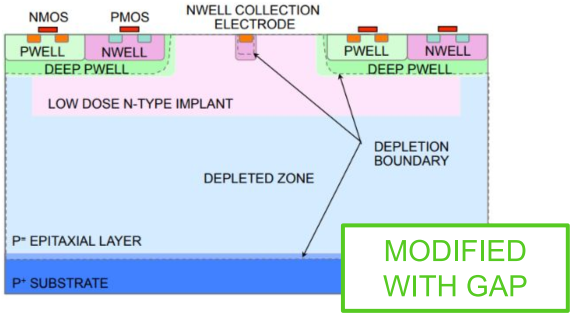
- Performance comparison of different prototype variants
- The standard process shows a charge sharing contribution that is not visible for the modified and modified with gap process





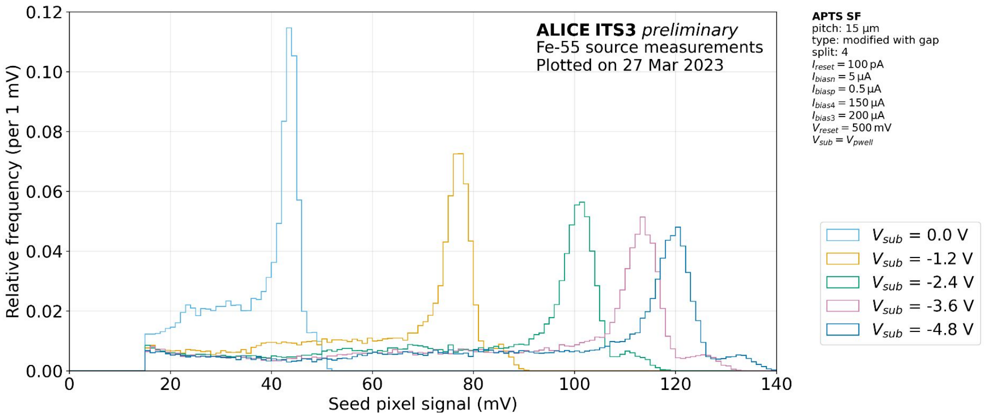
Reverse bias and pixel pitch influence

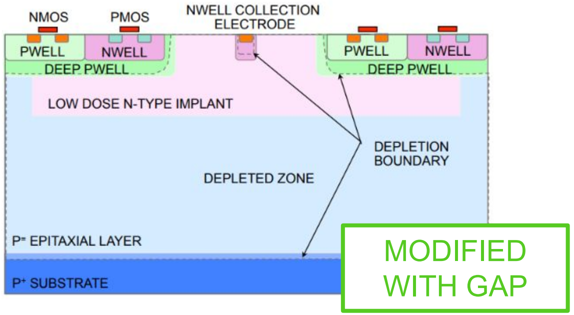


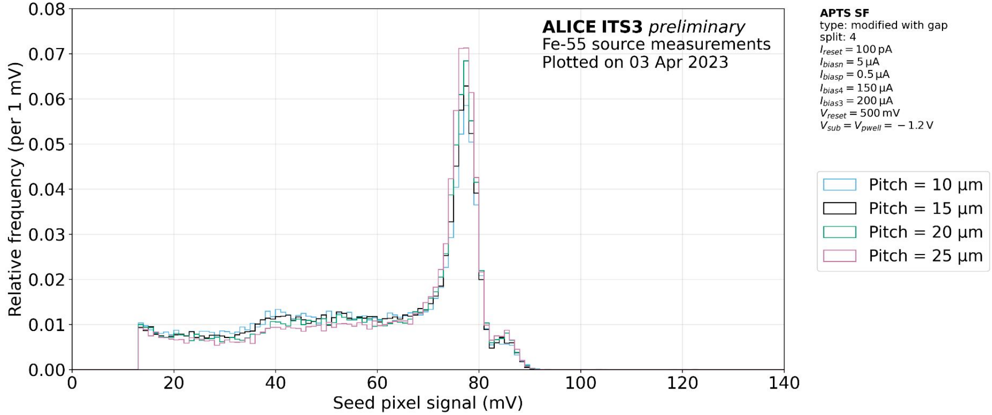


- Signal amplitude increases with reverse bias →reduction of input node capacitance

Reverse bias and pixel pitch influence







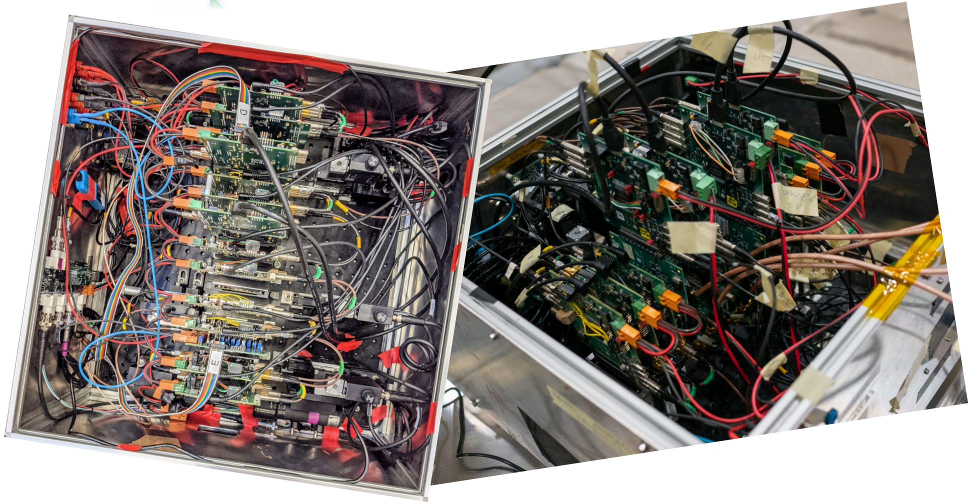
- Signal amplitude increases with reverse bias →reduction of input node capacitance
- Modified with gap shows the best performance in terms of charge collected by one pixel
  → independent from pixel pitch

Characterization tests

In-beam measurements:

- Use of charged particles (π, e^-)
- Reconstruction of particles tracks using the Corryvreckan framework
- Association of tracks with cluster on the plane

→ **Efficiency and FHR**
Spatial and temporal resolution



Beam test campaigns completed:

2021

- DESY September 2021 - DPTS
- PS October 2021 - APTS-DPTS
- SPS November 2021 - APTS-DPTS
- DESY December 2021 - DPTS

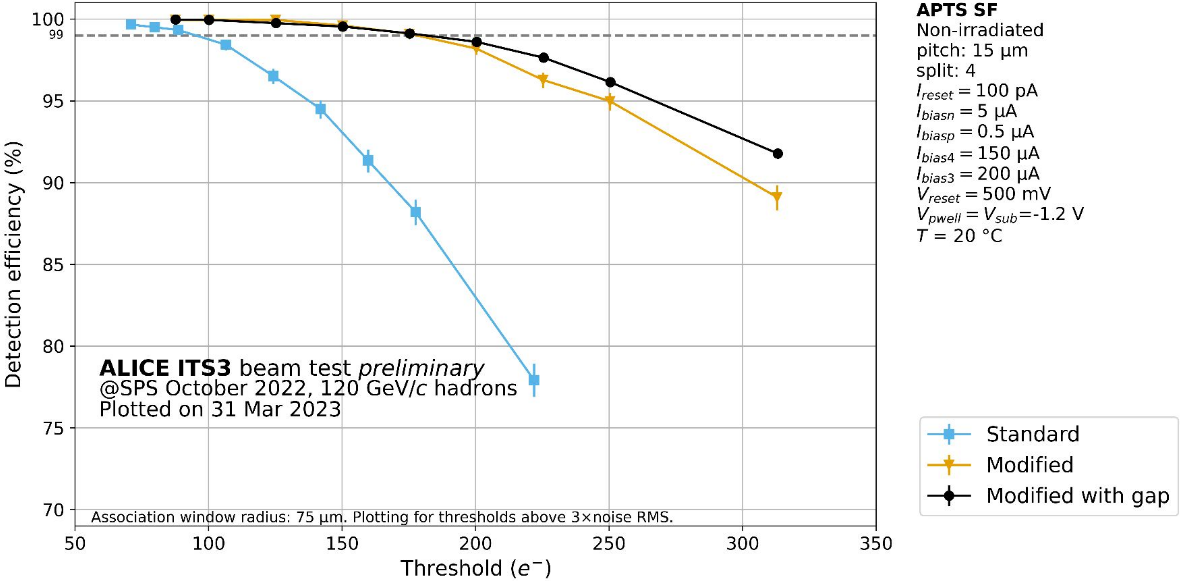
2022

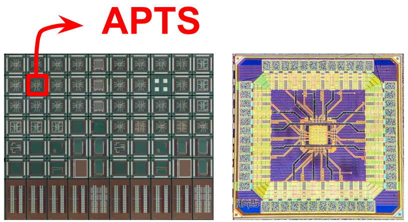
- DESY March 2022 - DPTS
- MAMI April 2022 - APTS SF
- PS May 2022 - DPTS
- PS June 2022 - APTS SF
- SPS June 2022 - APTS OA
- PS July 2022 - DPTS
- PS August 2022 - APTS
- SPS October 2022 - APTS
- SPS November 2022 - DPTS
- SPS November 2022 - APTS OA
- DESY December 2022 - DPTS

2023

- PS May 2023 - APTS SF and DPTS
- SPS May 2023 - APTS SF
- SPS June 2023 - APTS OPAMP
- SPS July 2023 - APTS-SF

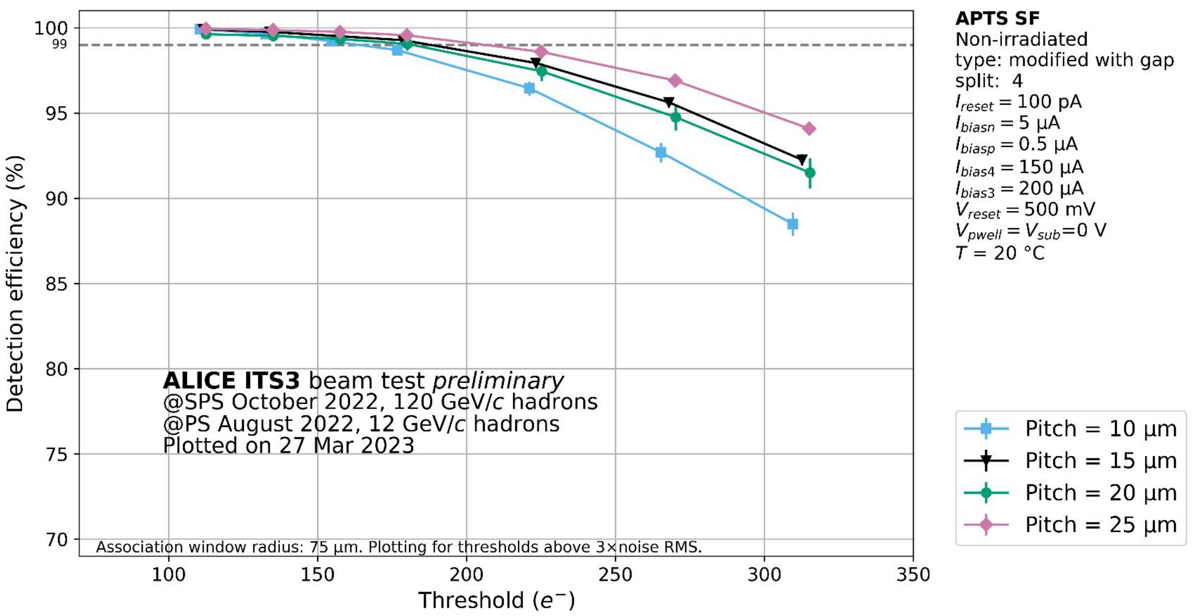
Process impact on APTS detection efficiency

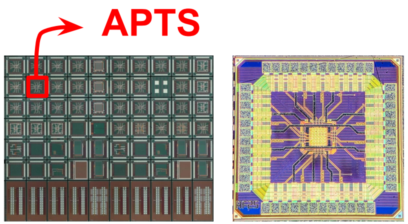




More than 99% detection efficiency over large threshold range for modified processes

Pixel pitch influence on APTS detection efficiency





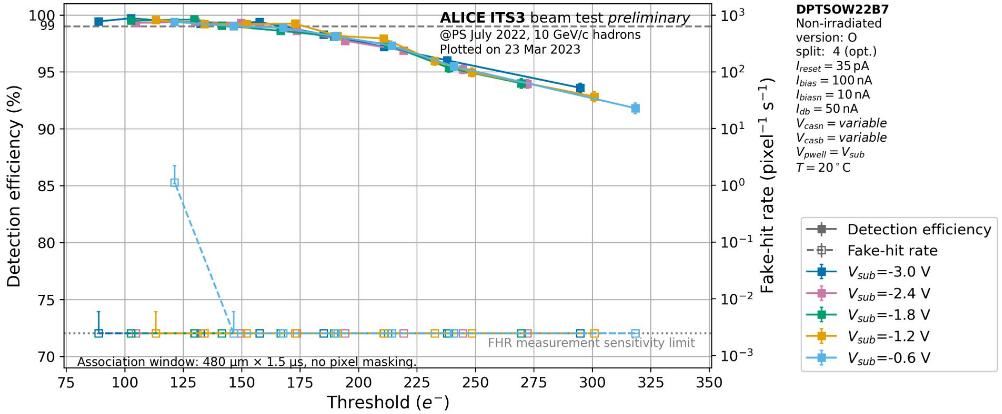
Different pitches:
different ratios of border and central pixel regions

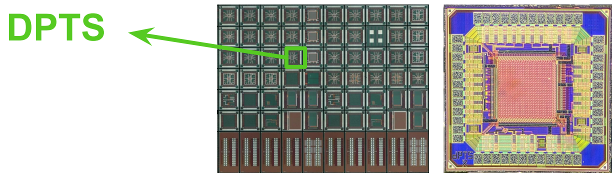
➡ larger pixels have less border contribution

➡ less events with charge sharing

Detection efficiency increases with pixel pitch in the modified with gap process

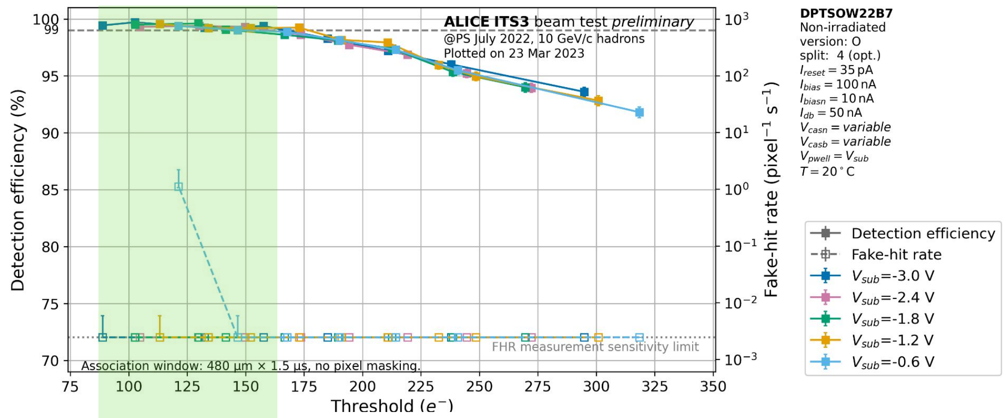
Reverse bias influence on detection efficiency and FHR

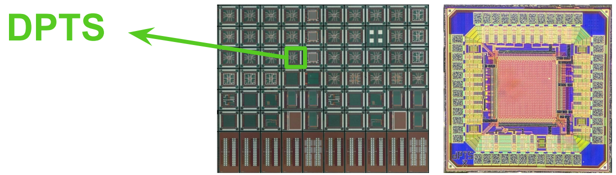




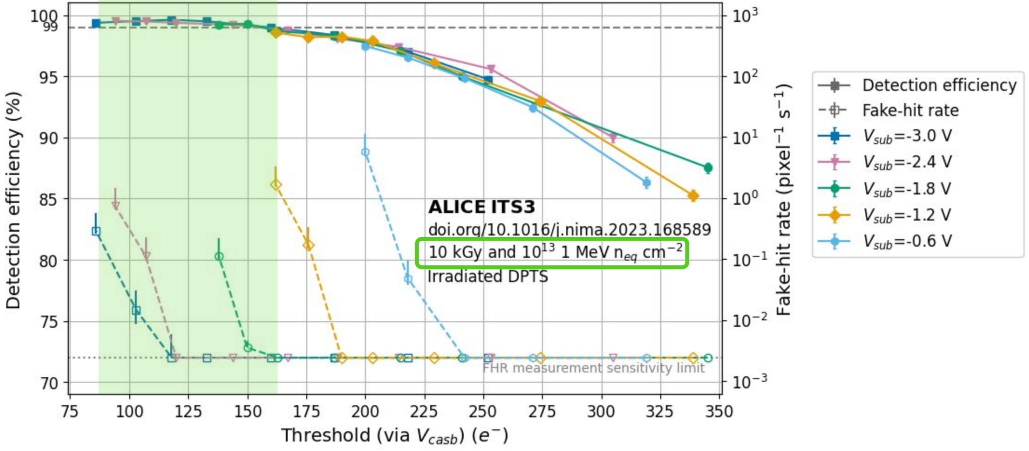
wide operational range of the sensor featuring a detection efficiency above 99%

Reverse bias influence on detection efficiency and FHR





wide operational range of the sensor featuring a detection efficiency above 99%

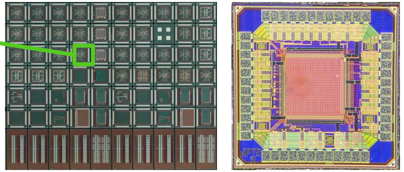


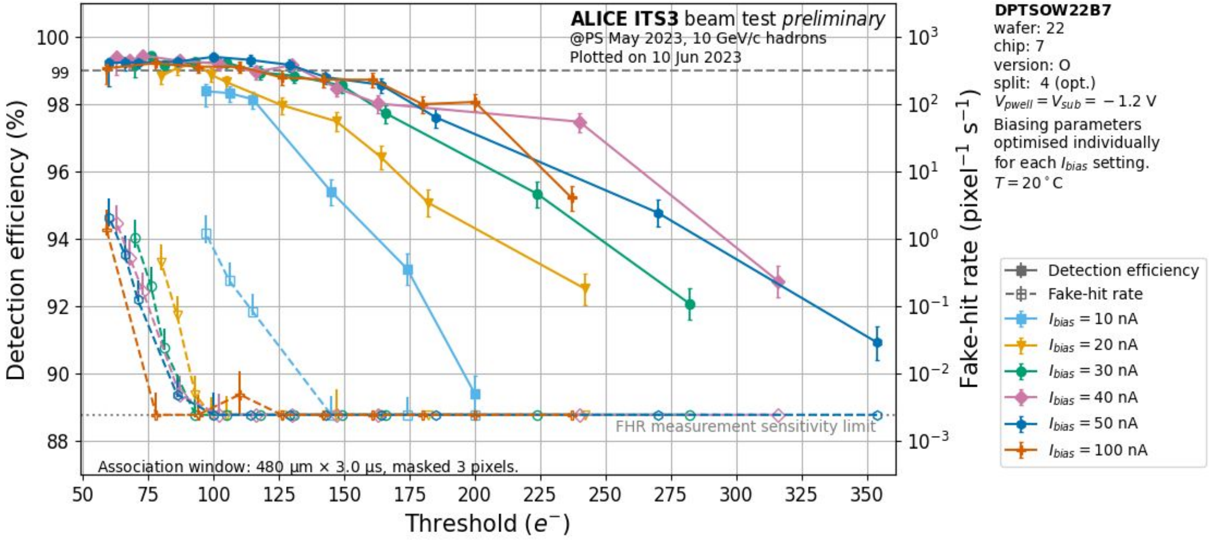
After irradiation
10 kGy + 10^{13} 1MeV neq/cm^2
(**ALICE ITS3 requirement**)

larger reverse bias voltages are favourable to operate the sensor at lower threshold values

I_{bias} influence on detection efficiency and FHR

DPTS





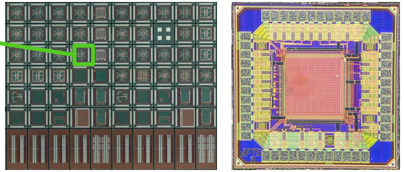
I_{bias} = 10 nA
→ power consumption ~ 5 mW cm^{-2}
I_{bias} = 30 nA
→ power consumption ~ 15 mW cm^{-2}

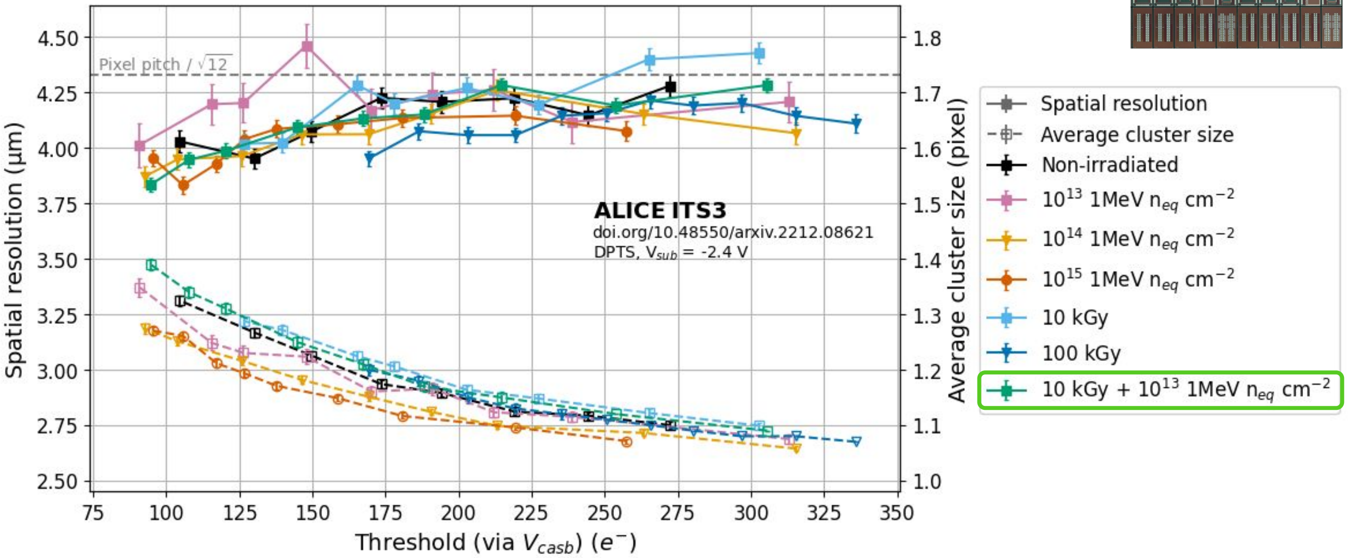
below the target!

Effect of irradiation level on spatial resolution and cluster size

T ~ 20 ℃

DPTS

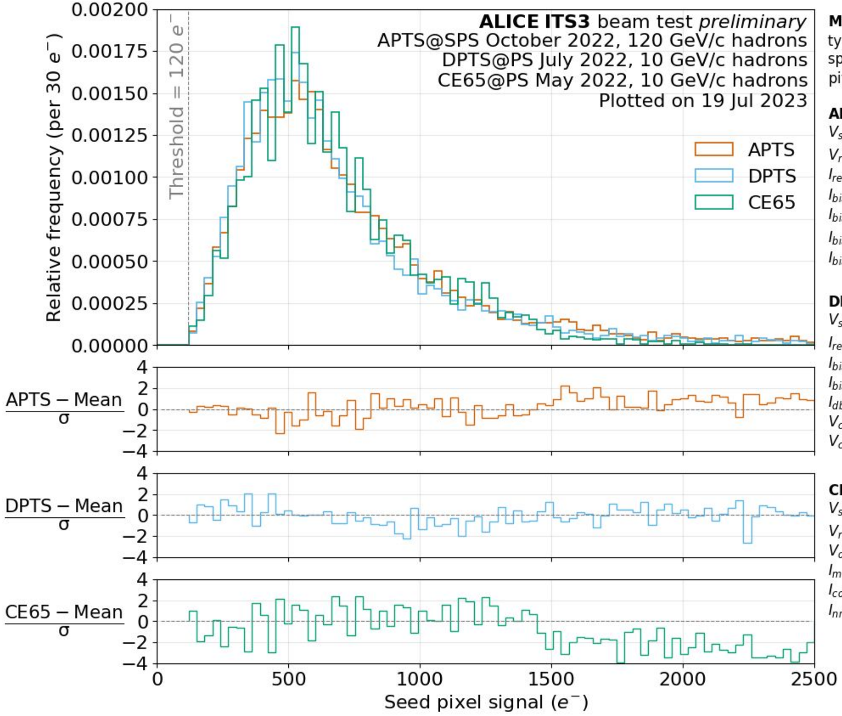




- Different levels of irradiation for various TID and NIEL
- Spatial resolution comparable for different irradiation levels
- Cluster size slightly decreases with NIEL irradiation

APTS vs DPTS vs CE65 testbeam comparison

Seed pixel signal normalized spectra in electrons are all in agreement

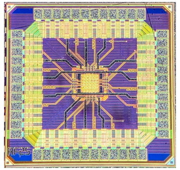


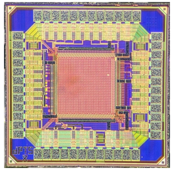
MLR1 comparison
type: modified with gap
split: 4
pitch: 15 μm

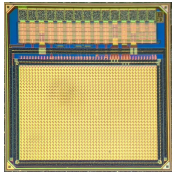
APTS SF
$V_{sub} = V_{pwell} = -2.4\,V$
$V_{reset} = 500\,mV$
$I_{reset} = 100\,pA$
$I_{biasn} = 5\,\mu A$
$I_{biasp} = 0.5\,\mu A$
$I_{bias4} = 150\,\mu A$
$I_{bias3} = 200\,\mu A$

DPTS
$V_{sub} = V_{pwell} = -2.4\,V$
$I_{reset} = 35\,pA$
$I_{bias} = 100\,nA$
$I_{biasn} = 10\,nA$
$I_{db} = 50\,nA$
$V_{casn} = 350\,mV$
$V_{casb} = 500\,mV$

CE65 SF
$V_{sub} = V_{pwell} = 0\,V$
$V_{reset} = 3.3\,V$
$V_{offset} = 0.4\,V$
$I_{mat} = 5\,mA$
$I_{col} = 100\,\mu A$
$I_{nmos} = 1\,\mu A$

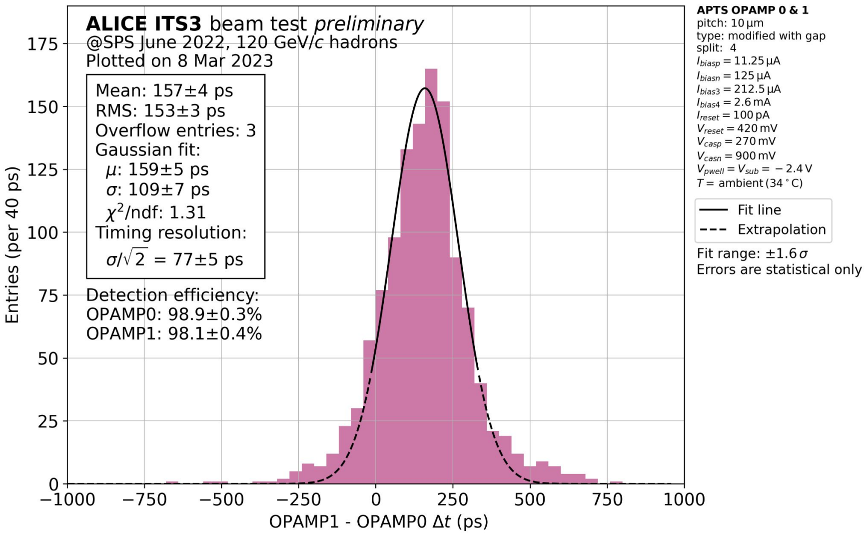






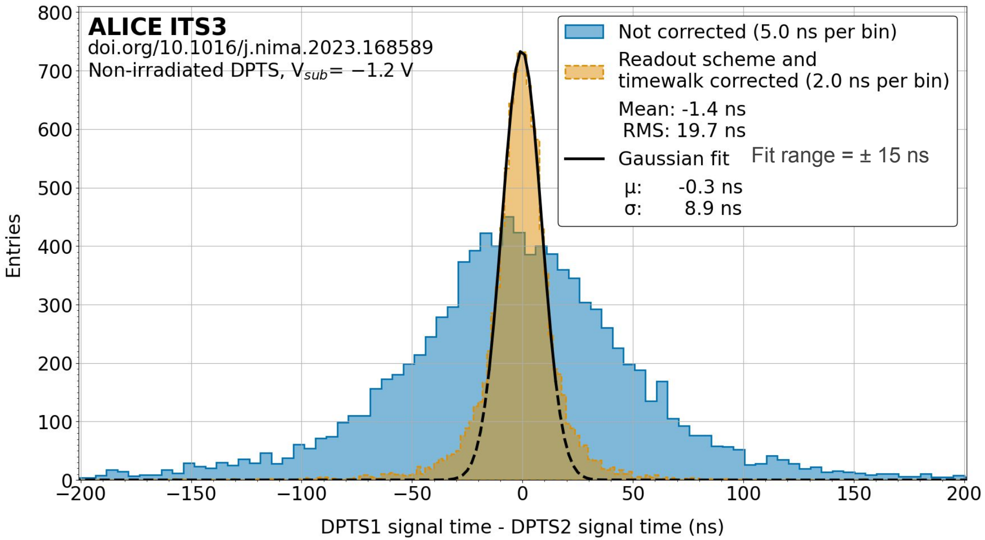
Timing resolution

APTS-OpAmp



Sensor contribution only
~ 77 ps

DPTS



- Readout scheme correction: correction for a fixed offset introduced for odd and even columns
- Time walk correction: fit the ToA vs ToT distribution and subtraction of the value from the measured data points

Sensor + front-end
~ 6 ns

Summary

- Extensive test campaigns have been carried out with ^{55}Fe source on different APTS prototypes:
  - modified with gap process showed the best charge collection performance with suppression of charge sharing

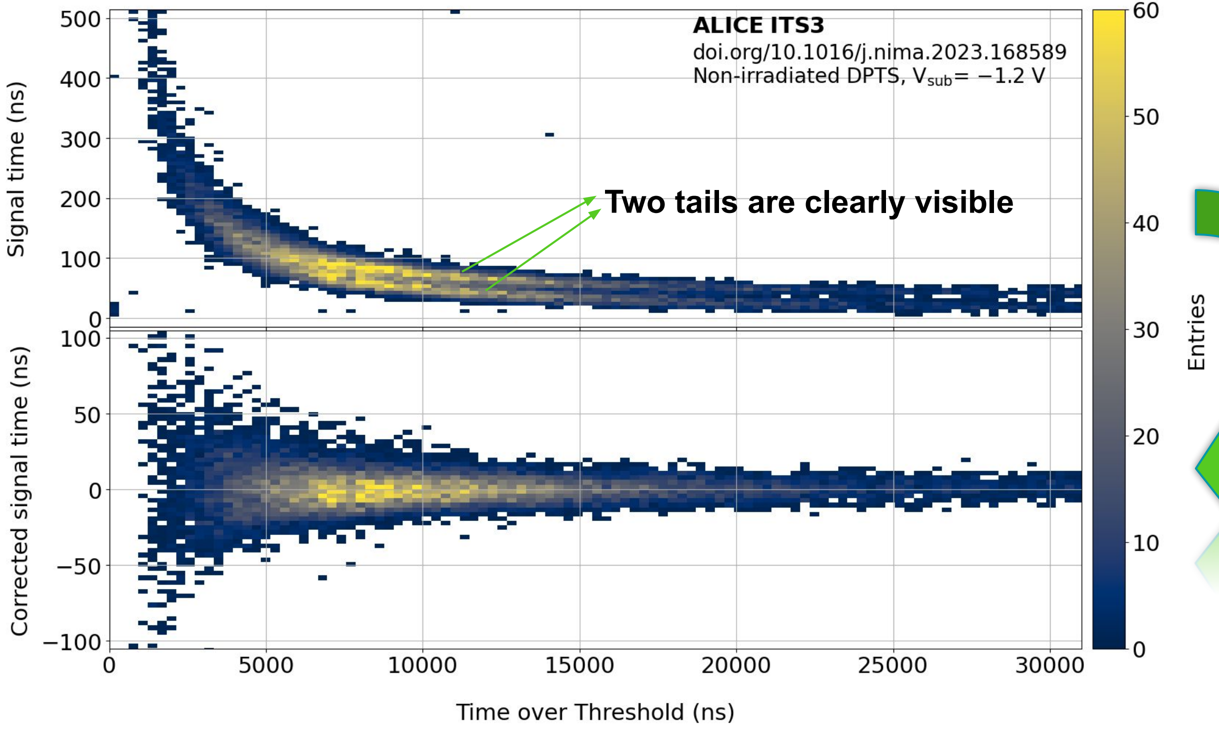
- Multiple beam tests:
  - Above 99% detection efficiency for a wide range of working points
  - Radiation hardness better than the requirement from ALICE ITS3 (10 kGy + 10^{13} 1MeV neq/cm^2)
  - Spatial resolution and cluster size measured for different irradiation levels up to 10^{15} 1MeV neq/cm^2 and 100 kGy
  - Timing resolution measured for both APTS OpAmp (~ 77 ps) and DPTS (~ 6 ns)

The 65 nm technology has been validated for particle detection in terms of charge collection efficiency, detection efficiency and radiation hardness

Thank you for the attention!

Backup slides

DPTS ToA vs ToT distribution



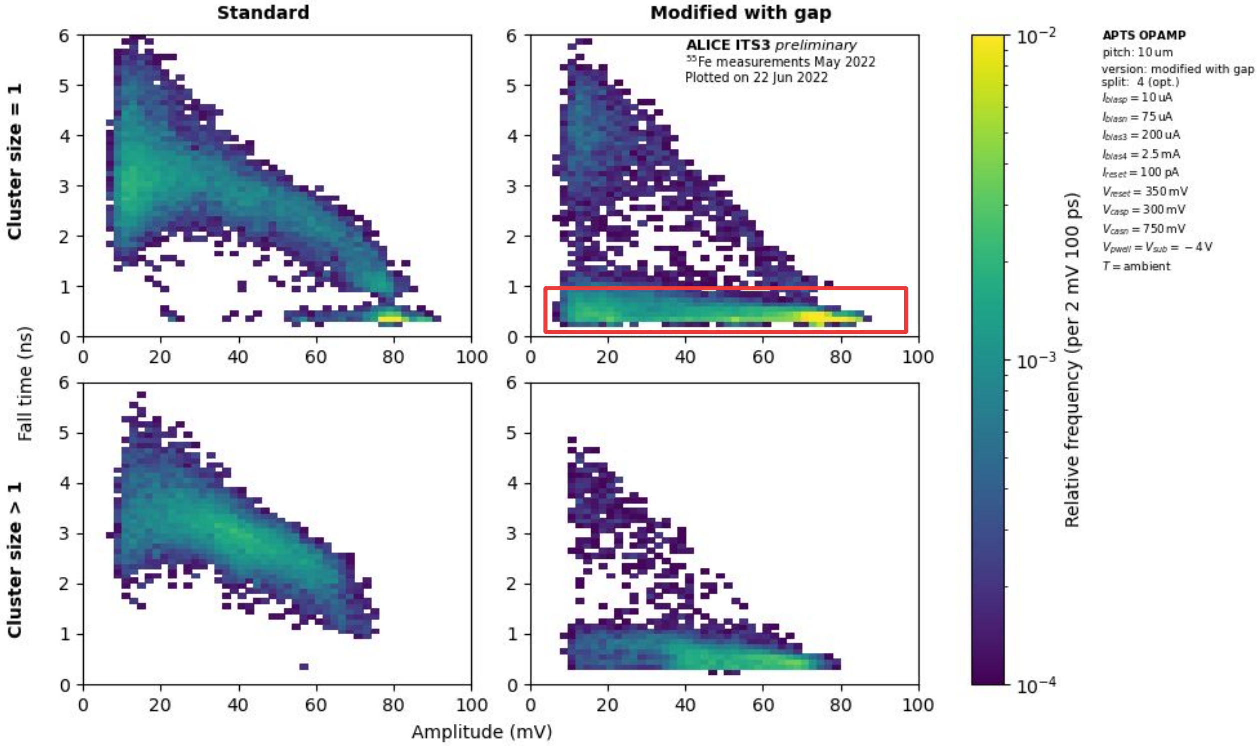
1. **Correction for readout scheme**: subtraction of the asymptotic value of the two tails from even and odd columns

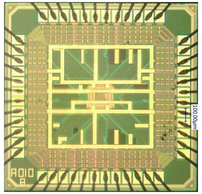
2. **Correction for time walk**: fit the data with

$$\text{Signal time} = A + \frac{B}{ToT - C}$$

and subtraction of its value from the measured data

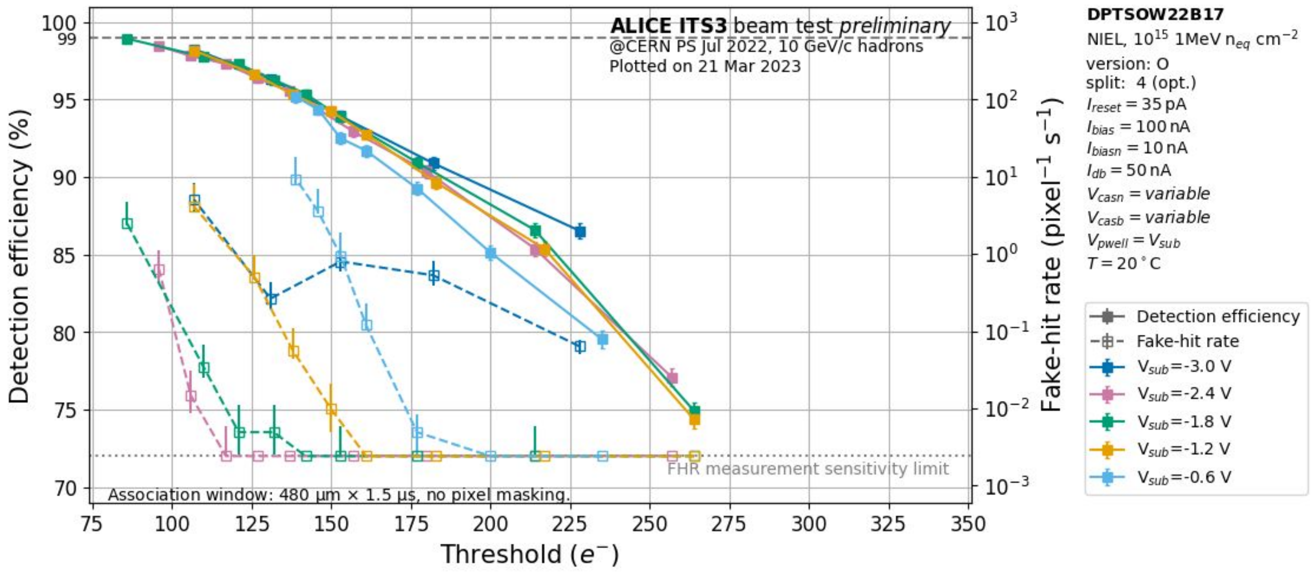
APTS OpAmp - Fall time vs amplitude



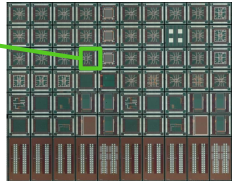


Modified with gap: 80% of cluster size 1 events lies in the region with fall time lower than 1 ns, compared with 20% of the standard process

Reverse bias influence - NIEL 10^{15} 1MeV neq/cm^2

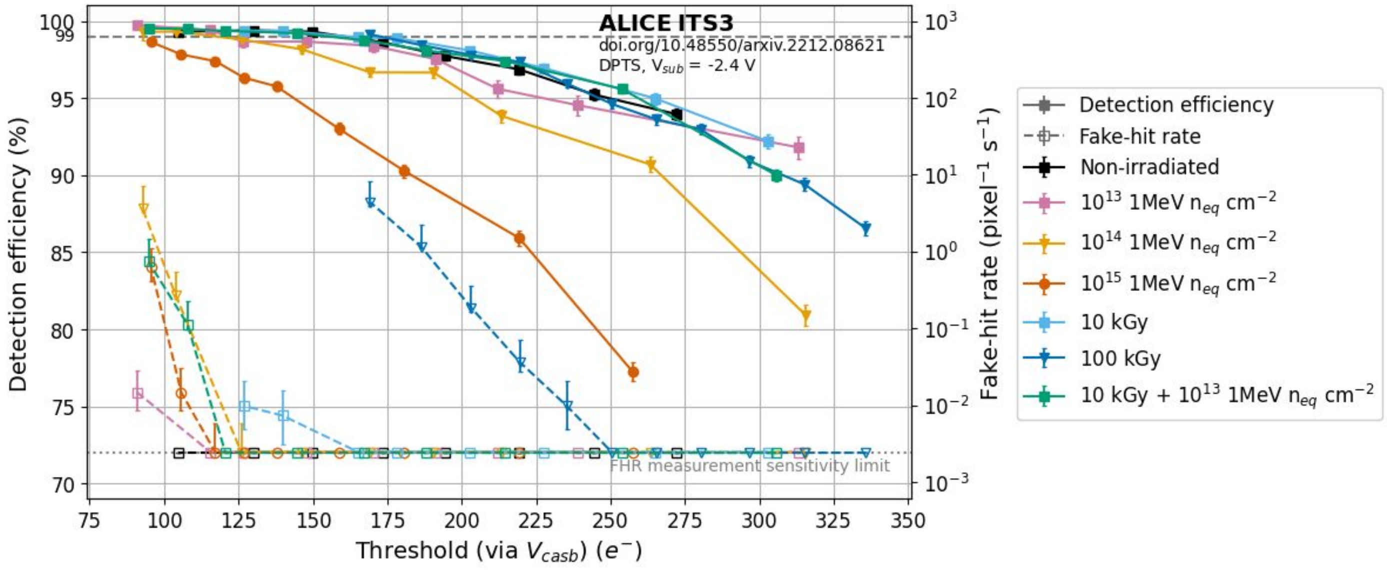


DPTS



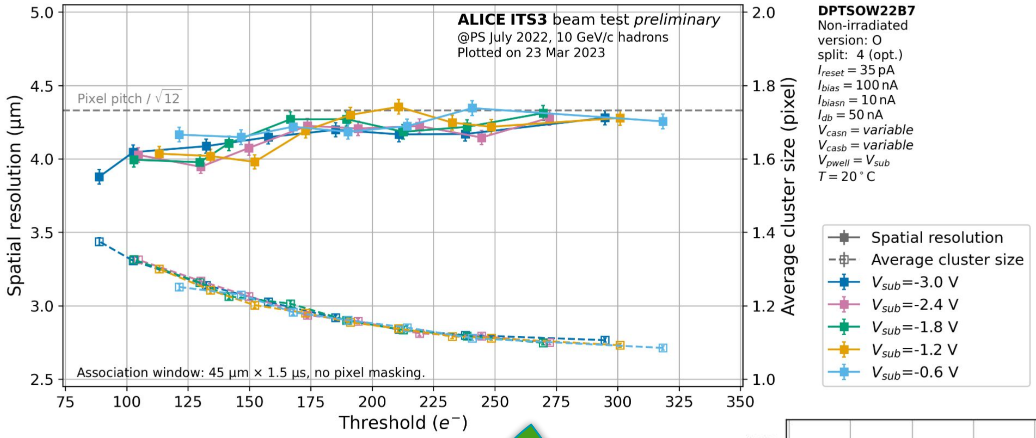
~ 99% efficiency reached at 20°C

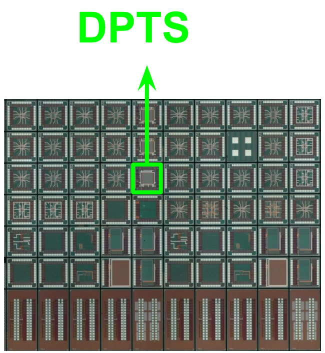
Irradiation level impact on Efficiency and FHR



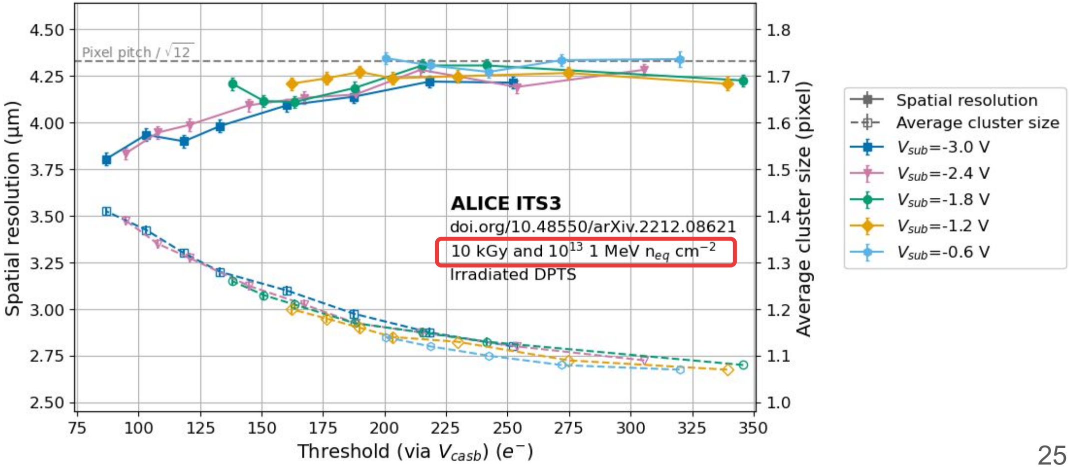
Only the **10^{15} 1MeV neq/cm^2** irradiated sensor shows performance deterioration

Reverse bias influence on DPTS spatial resolution and cluster size

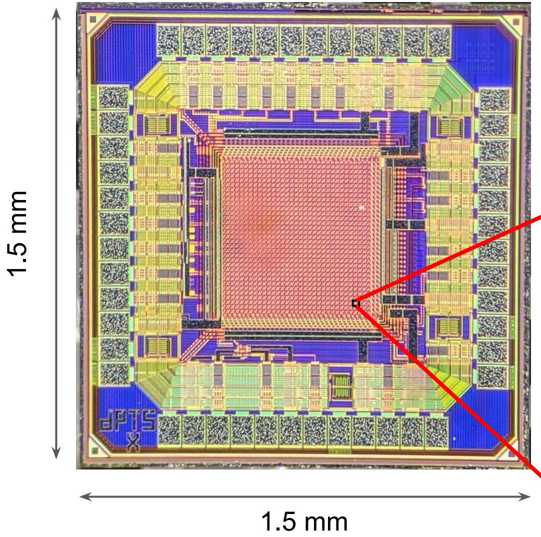


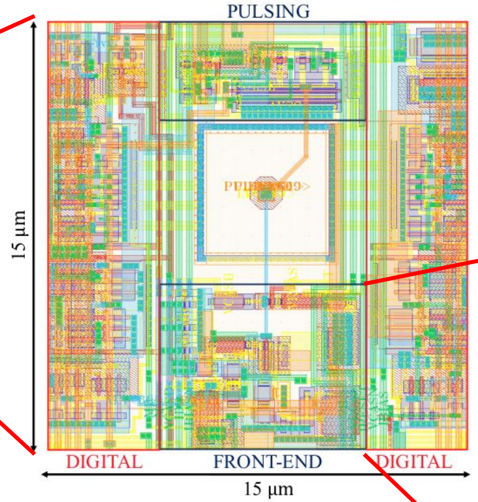


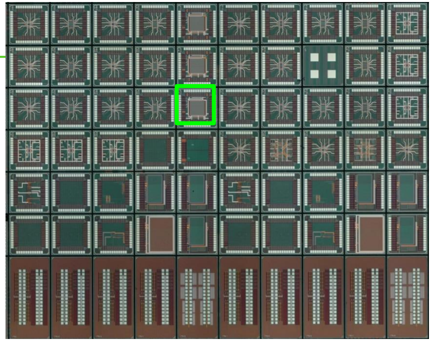
After irradiation
10 kGy + 10^{13} 1MeV neq/cm²
(ALICE ITS3 requirement)

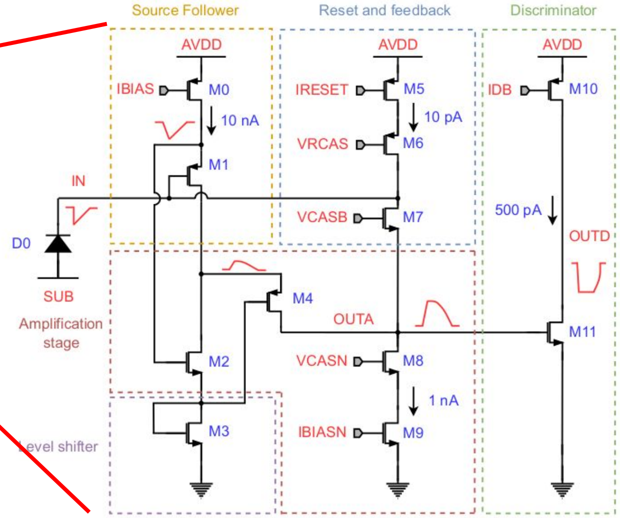


Monolithic design - DPTS

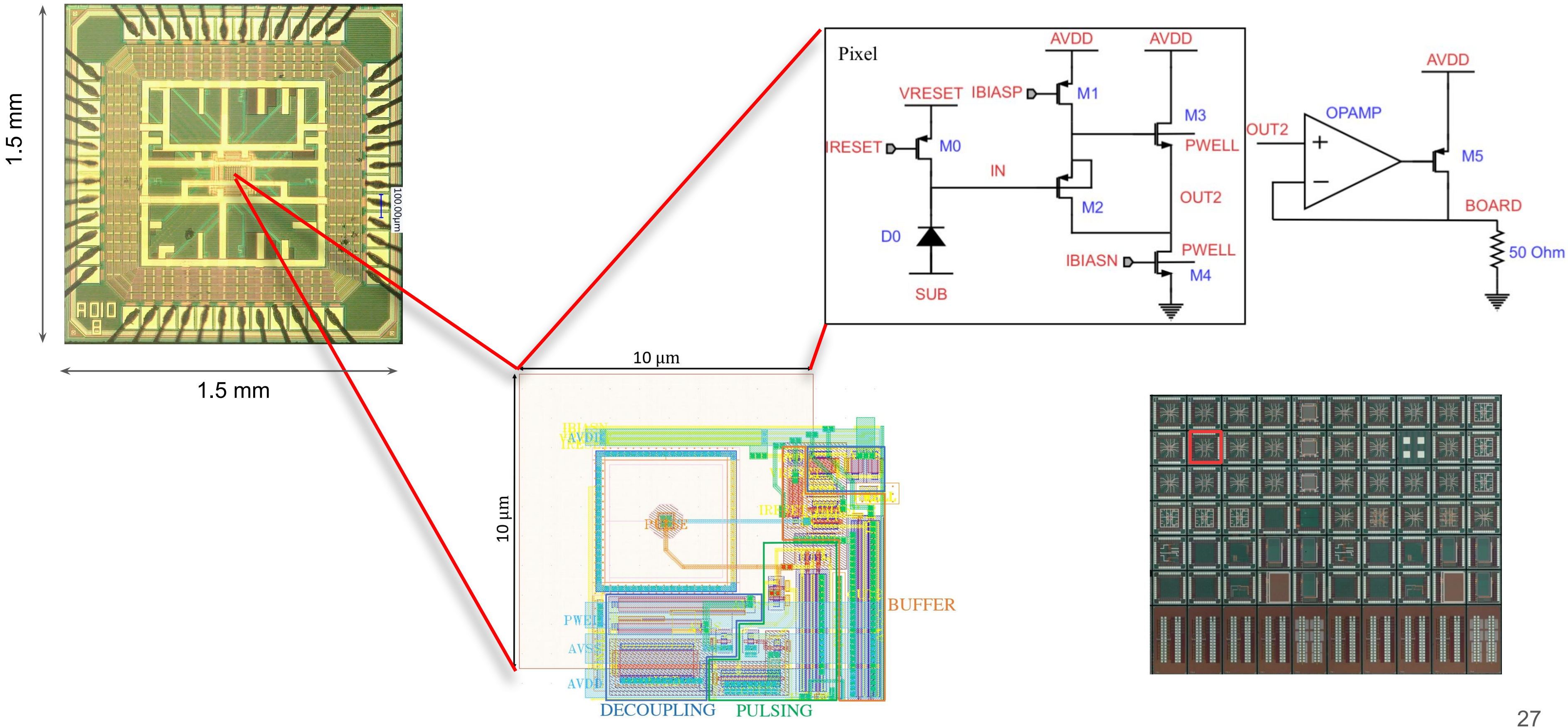




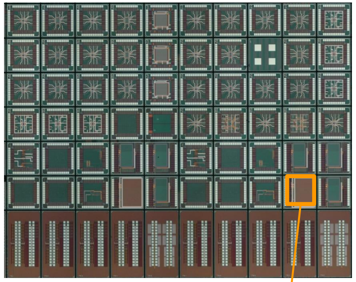




Monolithic design - APTS



CE65: Process modification reduces charge sharing



CE65

- In-pixel architecture and process have an impact on the charge collection properties
- Effect observed in APTS with ^{55}Fe sources confirmed at beam test
- In modified process all charge is mostly collected by single pixel