In-beam Analogue Pixel Test Structure characterization

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on behalf of the ALICE collaboration

11th Beam Telescopes and Test Beams Workshop

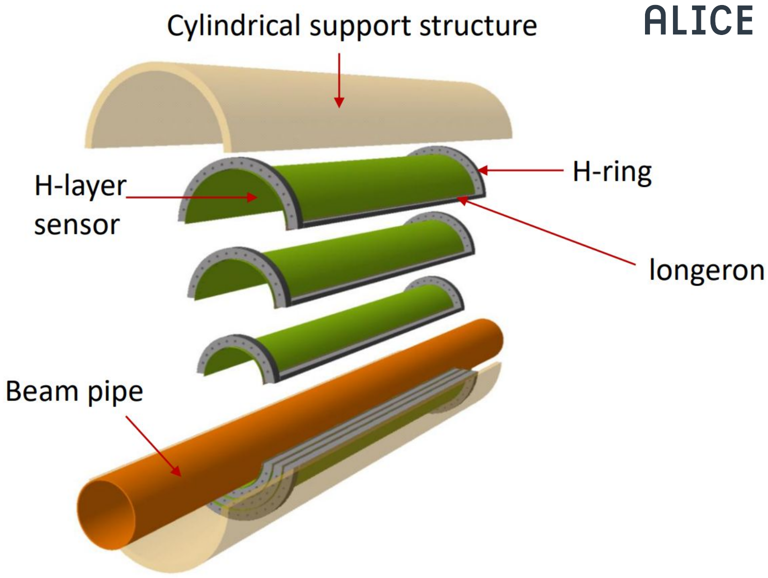
20/04/2023

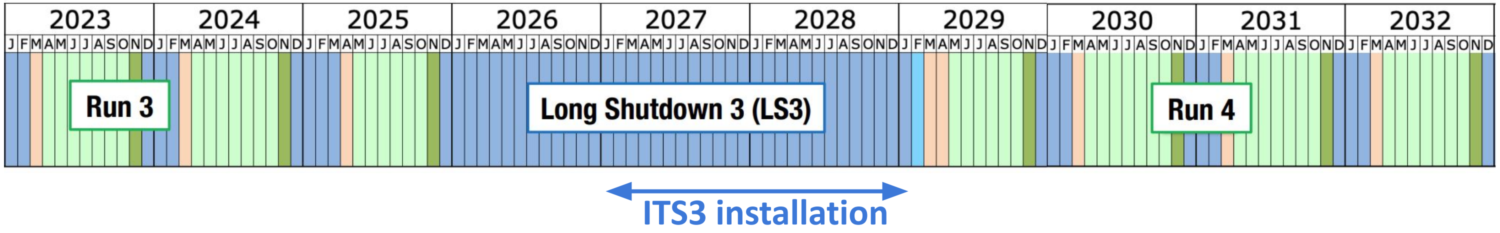
ALICE

Istituto Nazionale di Fisica Nucleare

ALICE ITS upgrade

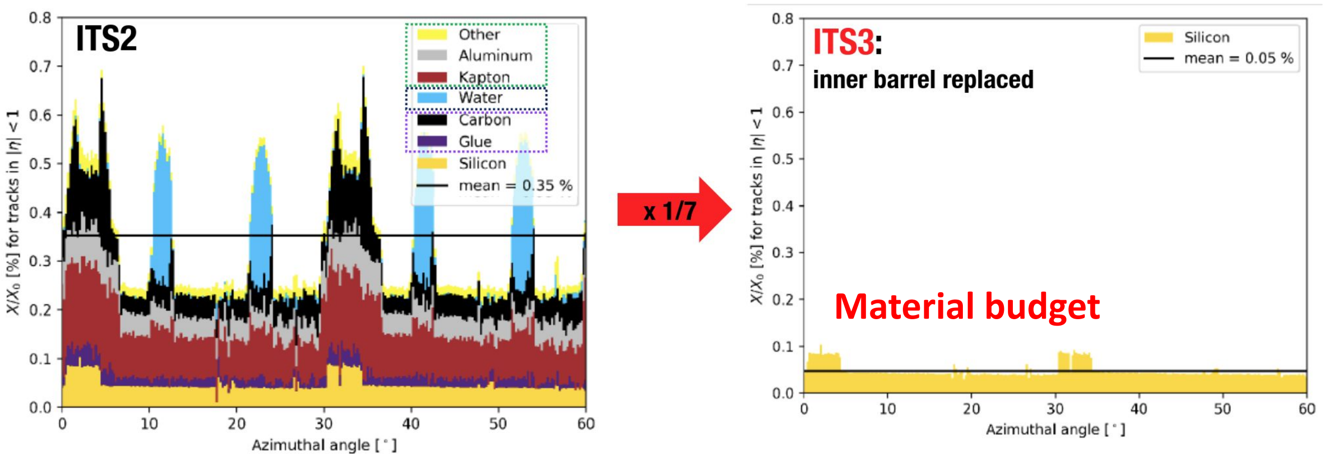
- The 3 innermost layers of the current ALICE inner tracking system (ITS2) will be replaced with the a new detector (ITS3)
- Wafer scale detector (up to 280 x 94 cm^2): stitching will be used
- ITS3 will feature:
  - Bent detectors
  - Innermost layer closer to the interaction point: 18 mm vs 23 mm (ITS2)
  - Less material budget: 0.05% X_0 vs 0.35% X_0 of the current detector (ALPIDE)





ALICE ITS upgrade

- ITS3 will have a lower material budget:
    - Circuit board: **not required** if integrated in circuit
    - Water cooling: **not required** if power consumption < 20 mW/cm^2
    - Mechanical support: **not required** if self supporting arched structure

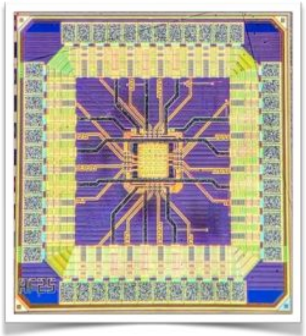


- The new ITS3 detector will improve both the tracking resolution and the tracking efficiency w.r.t the current ITS2 at low p_T

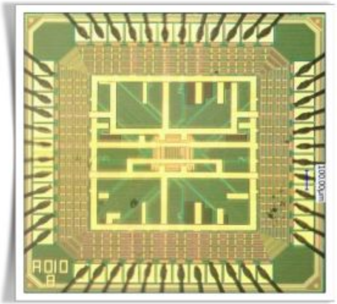
Chip prototypes

- The target technology for these new detectors is the 65 nm CMOS imaging process by Tower Partners Semiconductor Co.
- Chip prototypes developed in collaboration with CERN EP R&D
- 4 prototypes of chips are available:

APTS SF

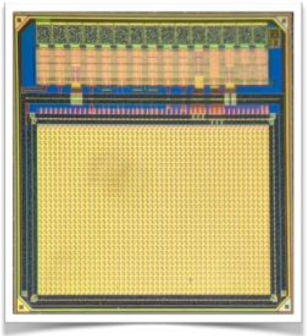


APTS OA



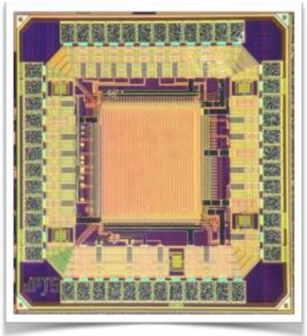
- 4 x 4 pixel matrix
- Analogue readout of all 16 pixels
- 10, 15, 20, 25 µm pitch
- Two versions of output buffer:
  - Operational Amplifier (OA) can directly drive 50Ω to allow faster readout

CE65



- 64 x 32 pixel matrix
- 15 µm pitch
- 3 pixel architectures

DPTS



- 32 x 32 pixel matrix
- 15 µm pitch
- Asynchronous digital readout
- Time encoded pixel position
- ToT measurements

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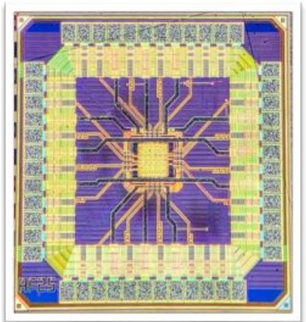
I WILL FOCUS ON THE APTS-SF TEST BEAM

APTS SF



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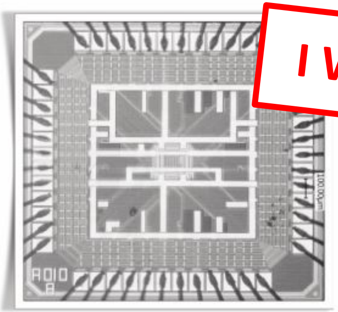

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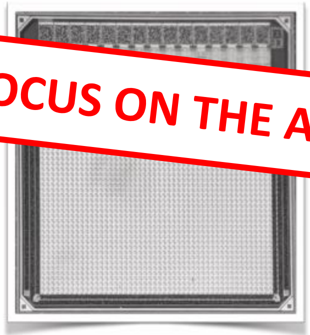

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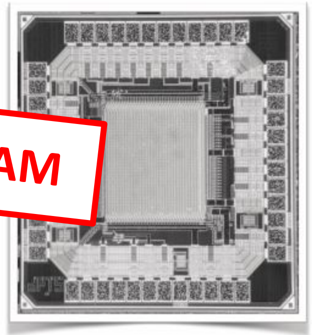
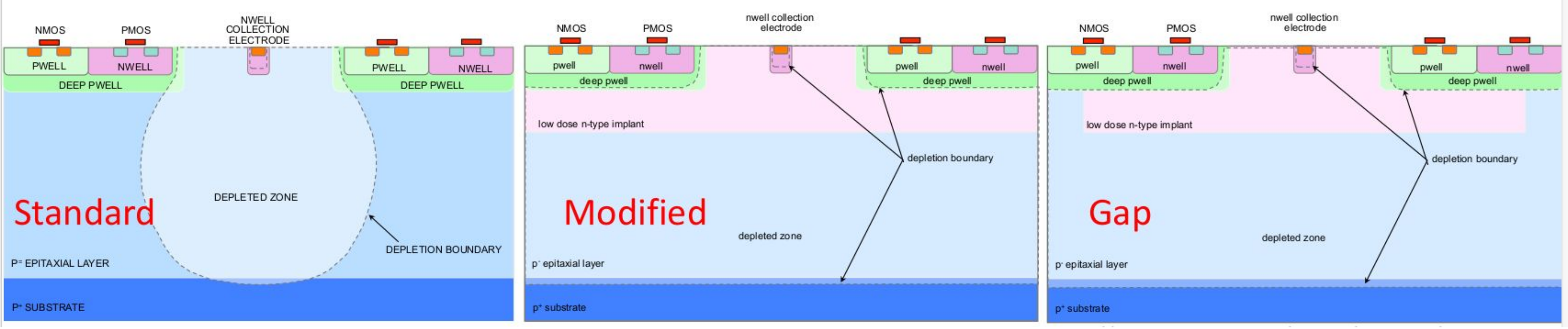


- 32 x 32 pixel matrix
- 15 µm pitch
- Asynchronous digital readout
- Time encoded pixel position
- ToT measurements

Process modification

- The APTS-SF are available with three different types
- The types differs in how the charges left by ionizing particles going through the detectors move

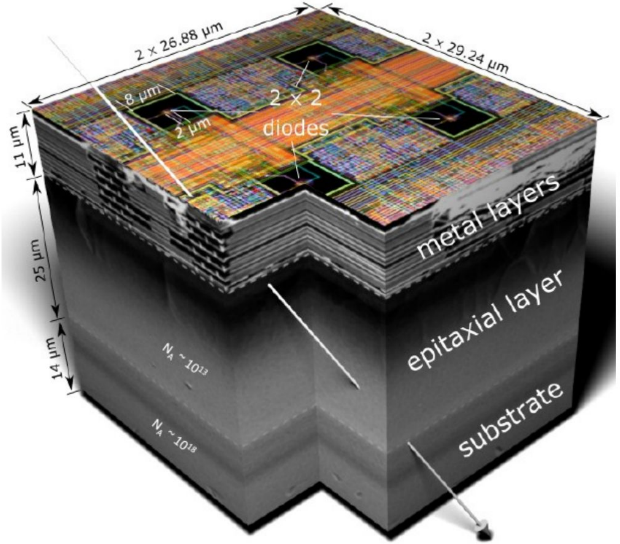


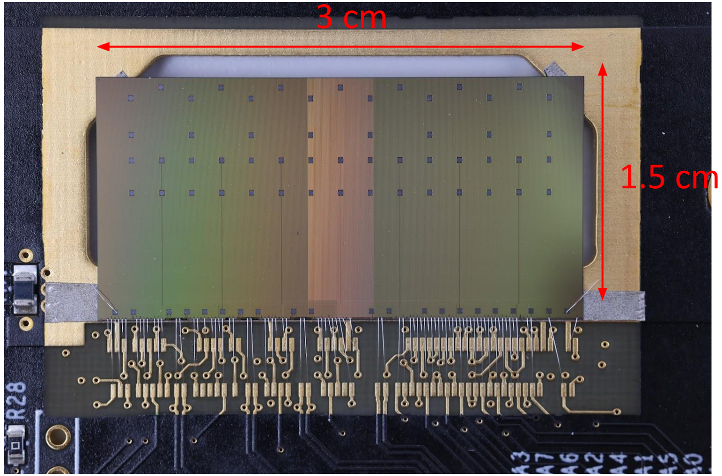
Charge collection efficiency and speed

Charge sharing

The ALPIDE telescope

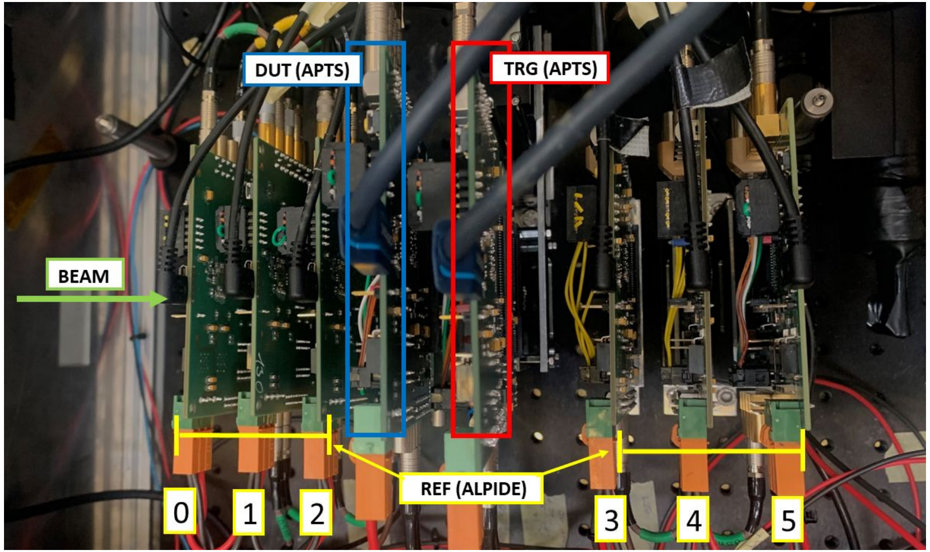
- Beam test telescope based on the ALPIDE chip
  - MAPS detector on 180 nm CMOS technology
  - 1024 × 512 pixels, 29 µm × 27 µm pixel pitch
  - Low material budget: 50 µm of silicon per plane (0.05% X_0)
  - 5 µm spatial resolution
  - Detection efficiency above 99%

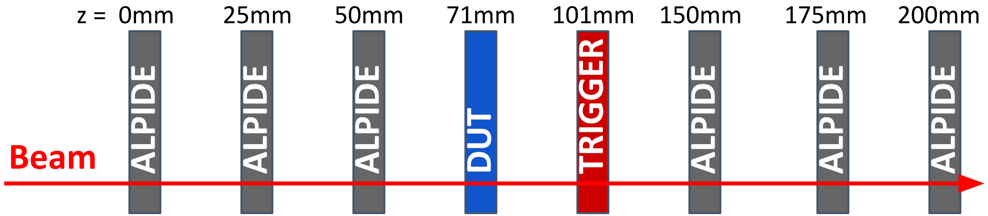




Testbeam setup - PS August 22

- Data taken in August 2022 using hadrons extracted from the CERN Proton Synchrotron (PS) with a momentum of 12 GeV/*c*
- A telescope was built using:
  - 6 ALPIDEs
  - Trigger given by an APTS-SF with a pixel pitch of 25 µm
  - 1 APTS-SF: device under test (DUT) mounted on a moving stage
- ALPIDE planes and DUT are controlled and data acquired by using EUDAQ2:
  - https://github.com/eudaq/eudaq
- Tracking resolution σ_{Trk} = 4 µm at $z = z_{DUT}$



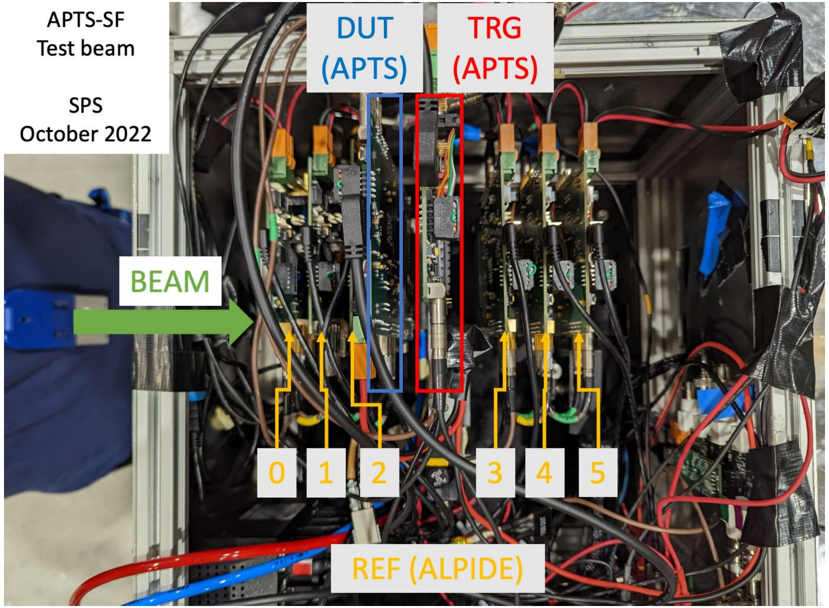


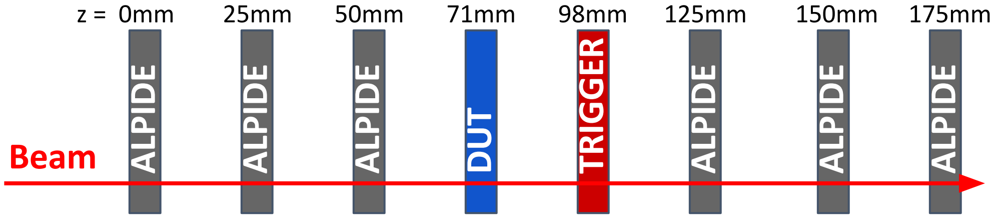
Testbeam setup - SPS October 22

- Data taken in October 2022 using hadrons extracted from the CERN Super Proton Synchrotron (SPS) with a momentum of 120 GeV/c

- A telescope was built using:
  - 6 ALPIDEs
  - Trigger given by an APTS-SF with a pixel pitch of 25 µm
  - 1 APTS-SF: device under test (DUT) mounted on a moving stage

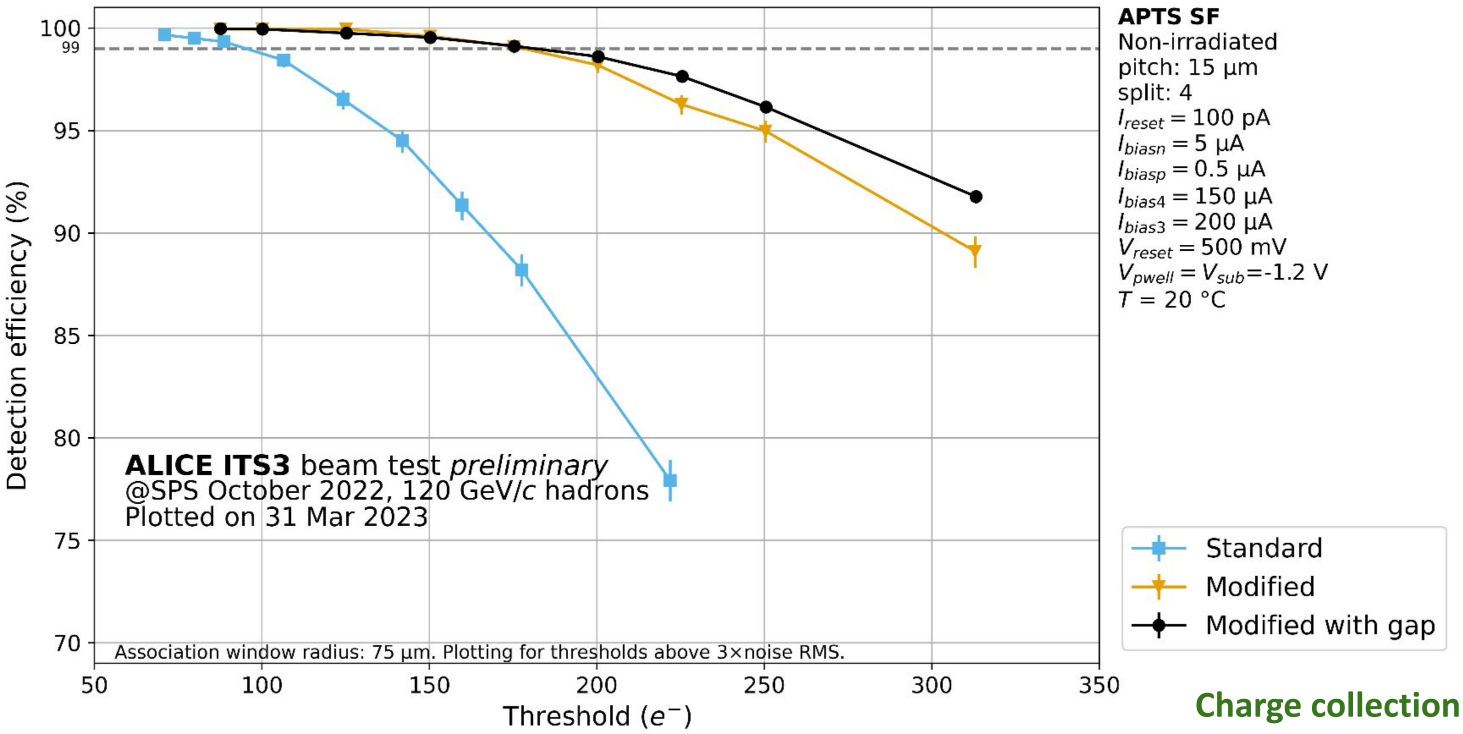
- Tracking resolution σ_{Trk} = 2.1 µm at z = z_{DUT}

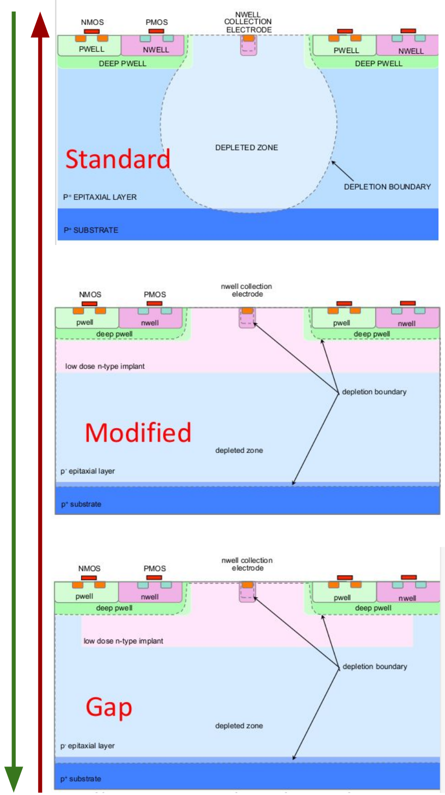




Efficiency vs threshold: type comparison for pitch = 15 µm

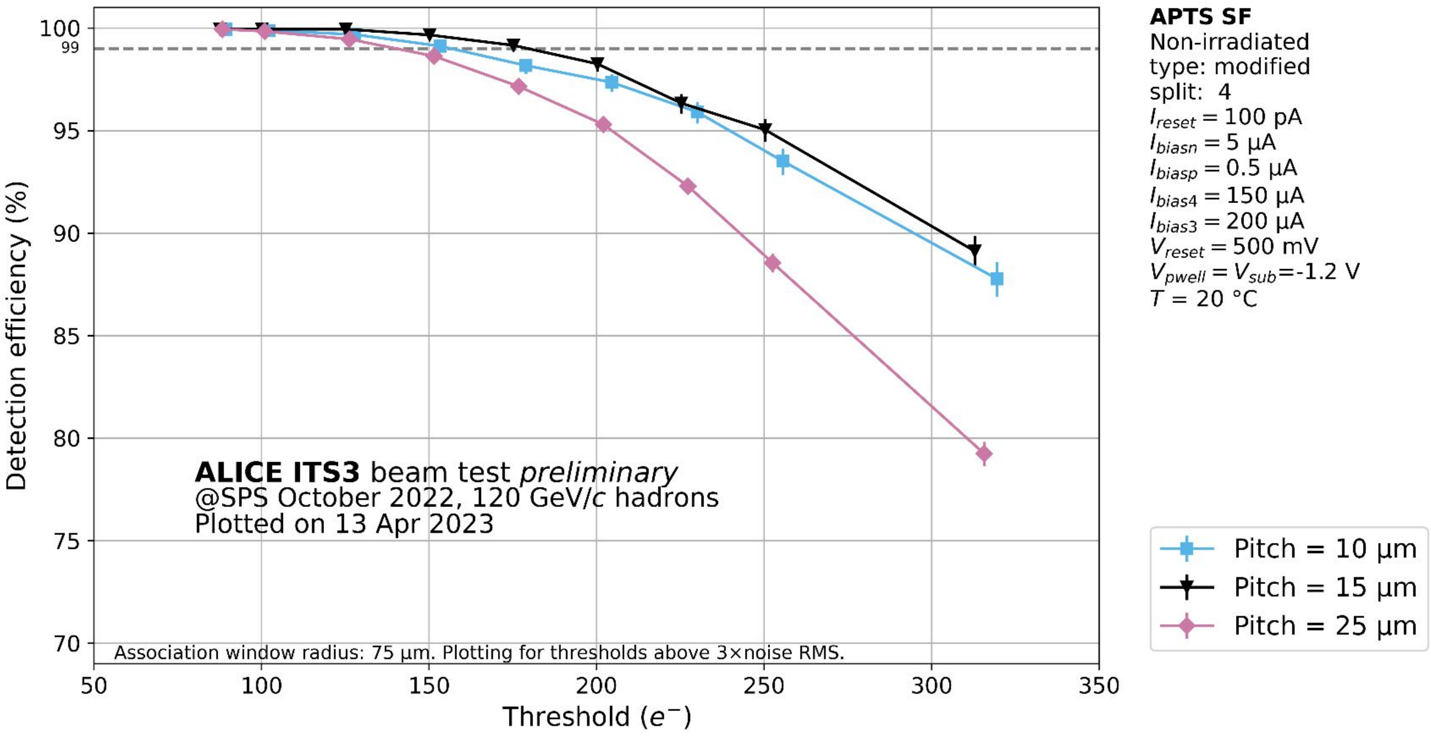
- Analysis is conducted with Corryvreckan:
  - https://gitlab.cern.ch/corryvreckan/corryvreckan
- Data plotted for threshold > $3RMS_{noise}$
- Larger operational margin for the modified with gap and modified type

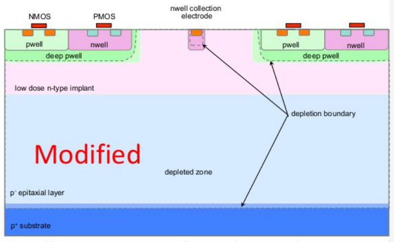




Efficiency vs threshold: modified type pitch comparison

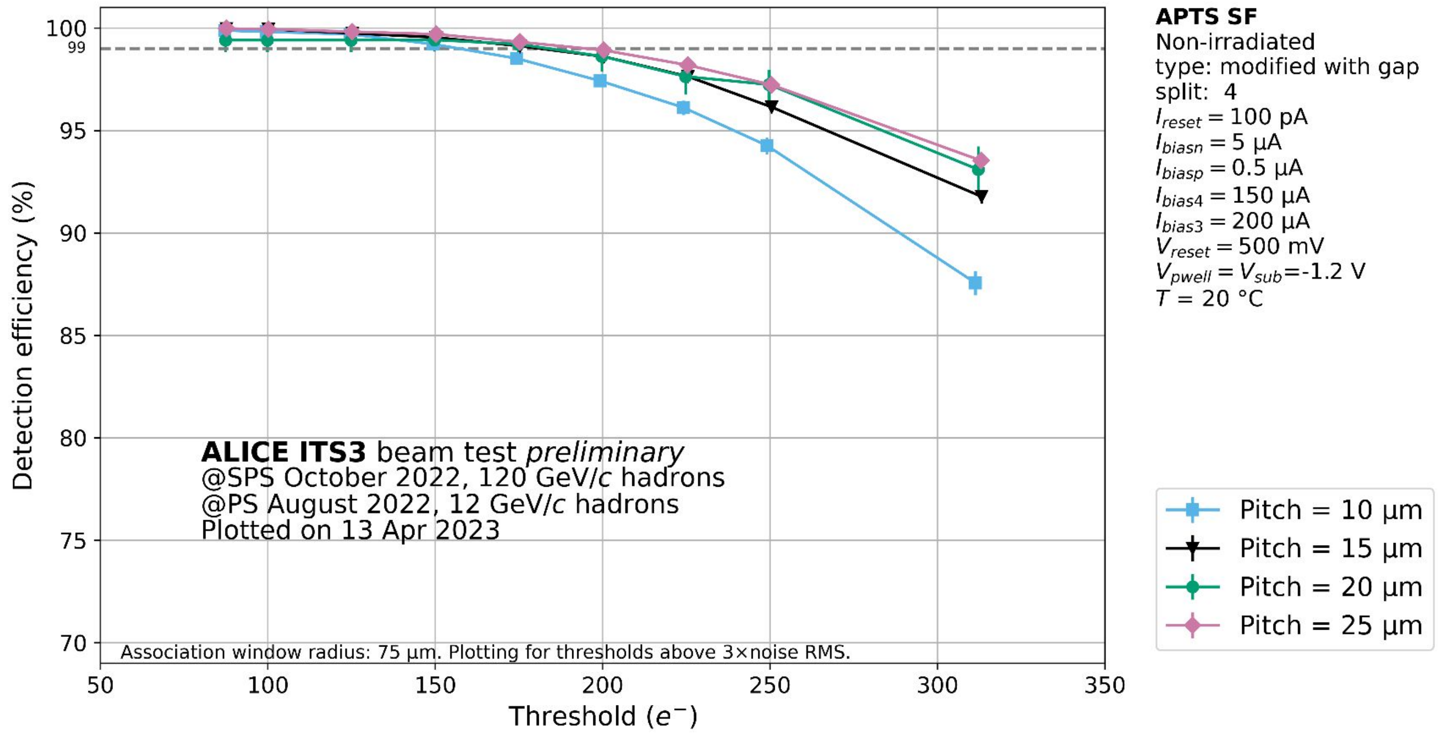
- Data plotted for threshold > $3RMS_{noise}$
- The modified type is available with pitch of 10, 15 and 25 µm
- Larger operational margin for the smaller pitches

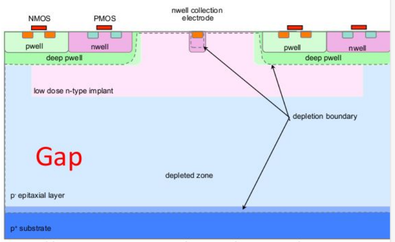




Efficiency vs threshold: gap type pitch comparison

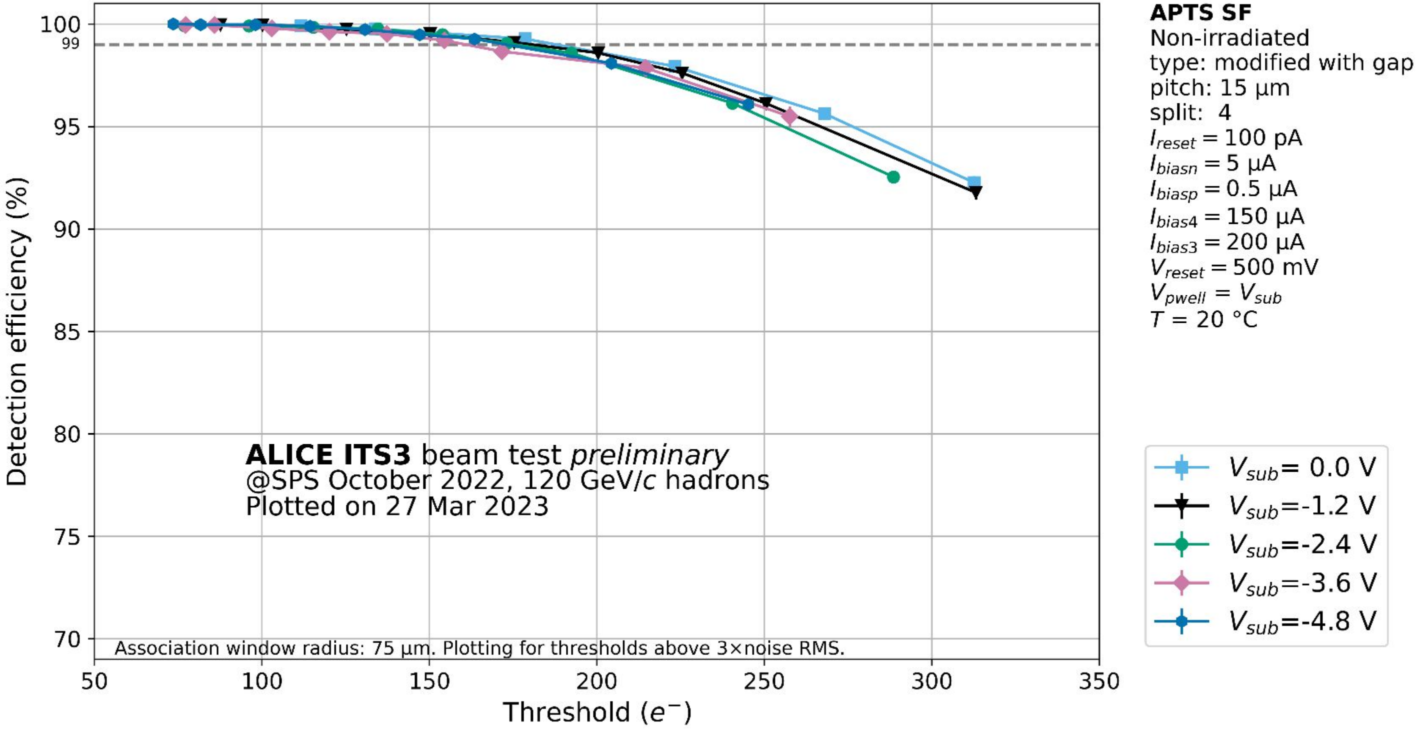
- Data plotted for threshold > $3RMS_{noise}$
- The modified with gap type is available with pitch of 10, 15, 20, and 25 µm
- Different trend w.r.t. the modified:
  - Larger operational margin going to larger pitches

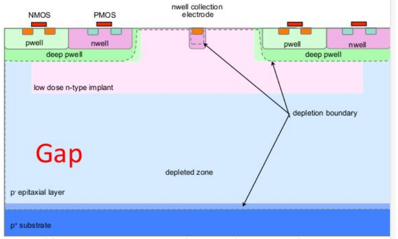




Efficiency vs threshold: gap type bias comparison

- Data plotted for threshold > 3RMS_{noise}
- No effect of the V_{bb} in the efficiency for the pitch = 15µm:
  - True also for the modified type but not for the standard type (check the backup)





Summary

- APTS is a MAPS fabricated in 65 nm CMOS imaging sensor technology
- Chip thoroughly tested during several testbeam campaigns. Data taken for:
  - Standard type:
    - 15µ pitch with V_{bb} scan
  - Modified type:
    - 10, 15, and 25 µm pitch with V_{bb} scan
  - Modified with gap type:
    - 10, 15, 20, and 25 µm pitch with V_{bb} scan
    - 15 µm pitch with V_{bb} scan of irradiated chips: 10^{15}, $2{\cdot}10^{15}$ 1MeV n_{eq} cm^{-2}
- Non-irradiated device under standard operation conditions:
  - Modified with gap and modified have larger operational margin than the standard type
  - Different operational margin for different pitches:
    - Modified: higher for smaller pitches
    - Modified with gap: higher for larger pitches
  - No dependence on the V_{bb} for the modified and modified with gap type

Outlook

- Analysis of the spatial resolution analysis completed:
  - Ongoing discussion on with clusterization method to apply

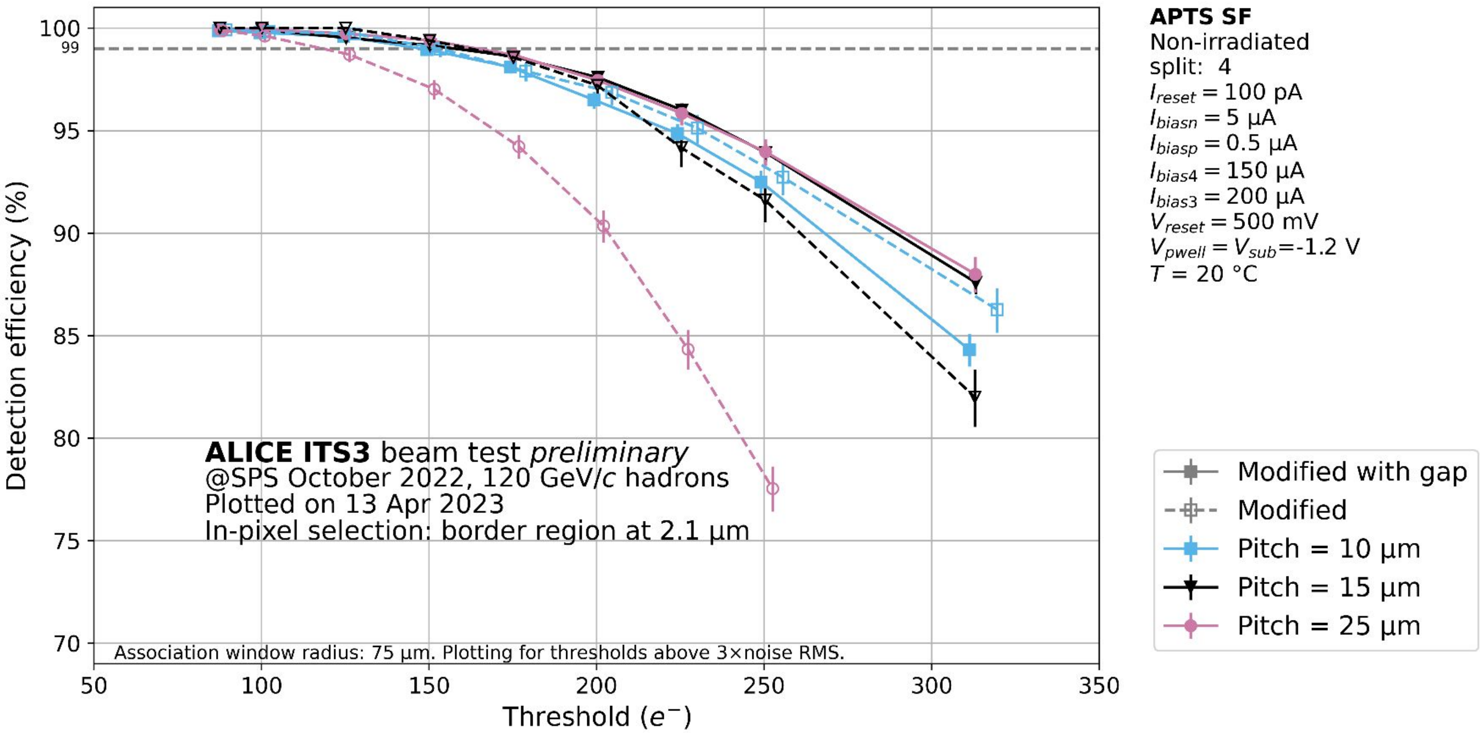
- In-pixel efficiency studies:
  - Precise measurement of effect of the low dose n-type implants (w/o gap)

- New test beam planned at the CERN PS in May:
  - To study more irradiation levels, V_{bb} values
  - High statistics run data taking for in-pixel studies

Backup

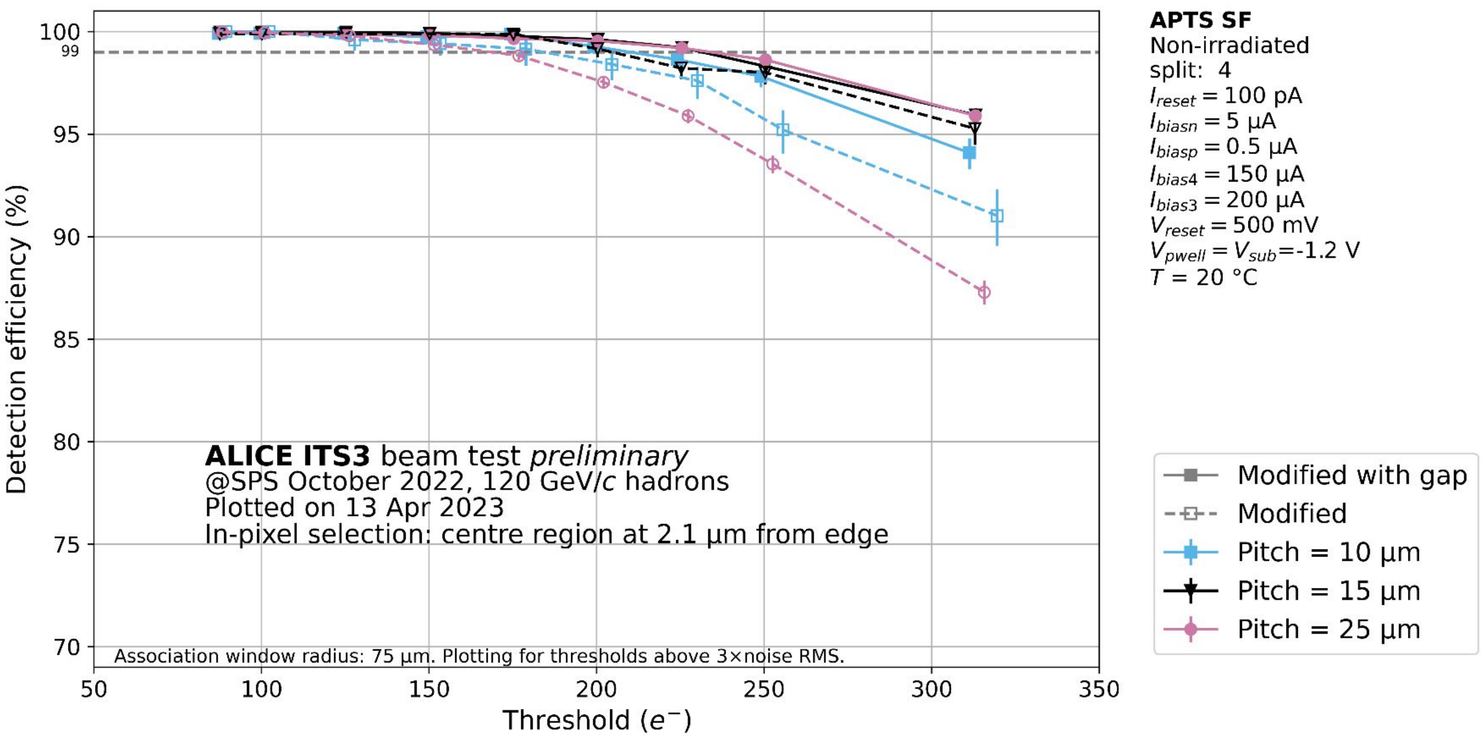
Efficiency vs threshold: pitch comparison

- Measuring the efficiency in the border region of the pixels:
  - The modified with gap show similar trend
  - For the modified it still depend on the pixel pitch



Efficiency vs threshold: pitch comparison

- Measuring the efficiency in central region of the pixels:
  - The modified with gap show similar trend
  - For the modified it still depend on the pixel pitch



Noise estimation

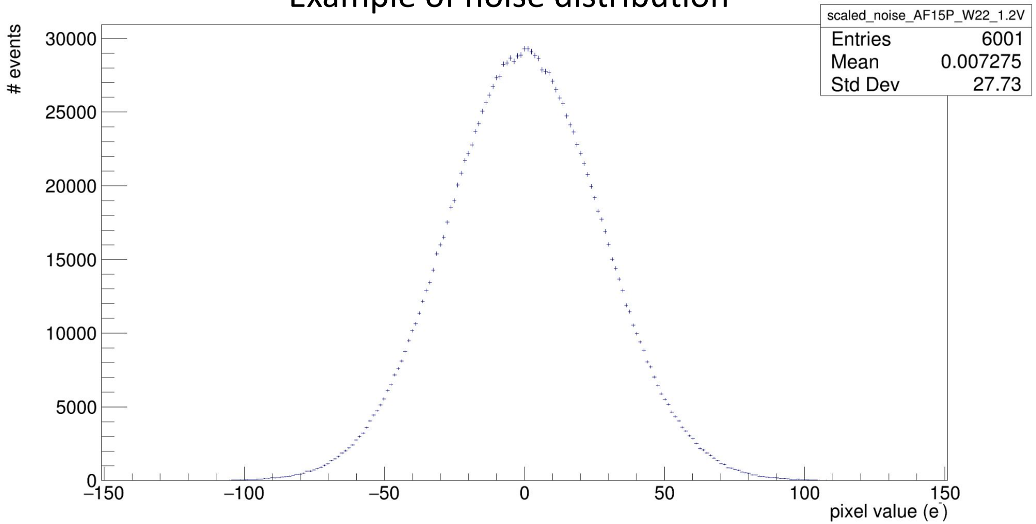
- For each event 200 frame of are recorded for the APTS (∽100 frames before and after the trigger)
- Baseline selection: frame 96 (N_b)
- Sampling frame (N_s): frame with the pixel with the minimum between frame 98 and 101
- For each pixel the noise is computed computed as the value in the frame: $2N_b - N_s$

For each pixel we obtain a gaussian distribution:

- The RMS of the pixel value distributions is the noise
- Noise estimation done for all the analysed runs
- Resolutions and efficiencies plotted only for:

  threshold > $3\sigma_{noise}$

Example of noise distribution



ALICE ITS upgrade

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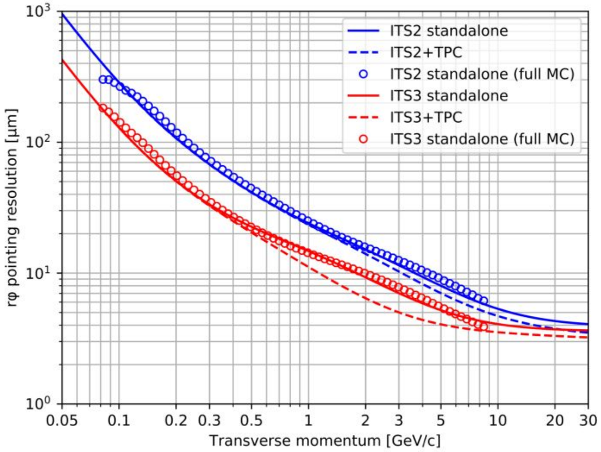
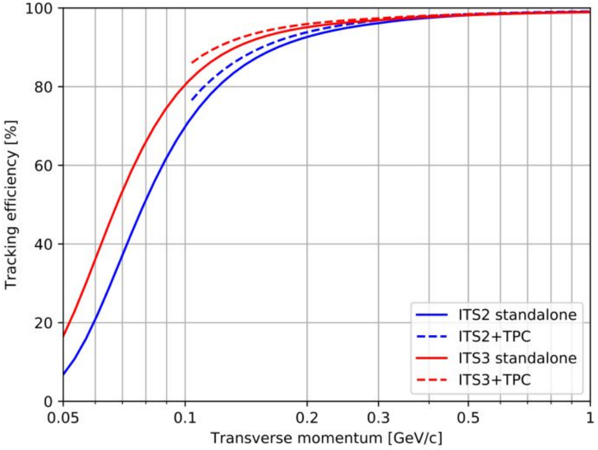
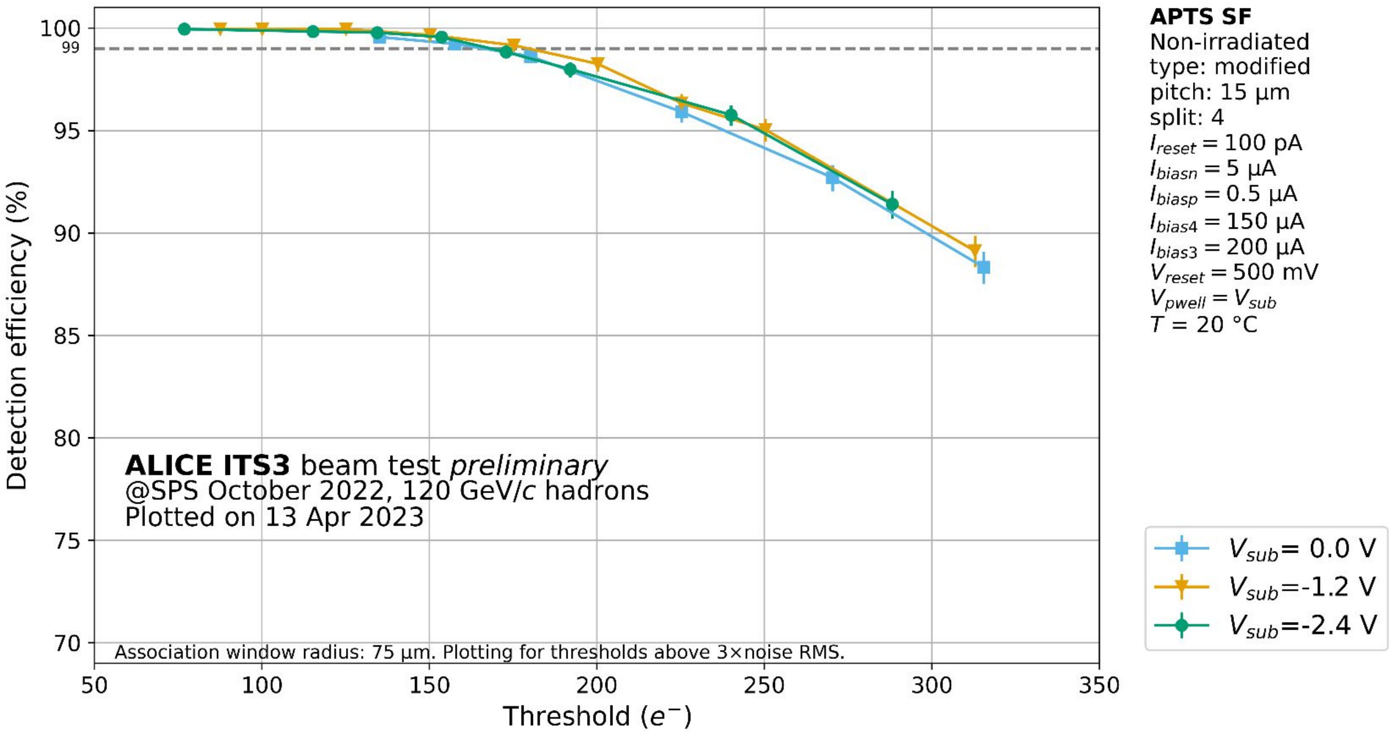
- ITS3 will feature:
    - Bent detectors
    - Innermost layer closer to the interaction point: 18 mm vs 23 mm (ITS2)
    - Less material budget: 0.05% X_0 vs 0.35% X_0 of the current detector (ALPIDE)

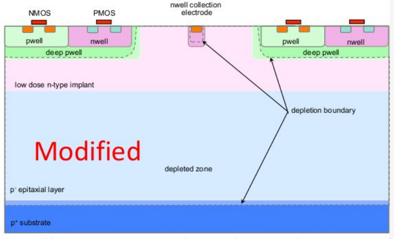




Efficiency vs threshold: mod. type bias comparison

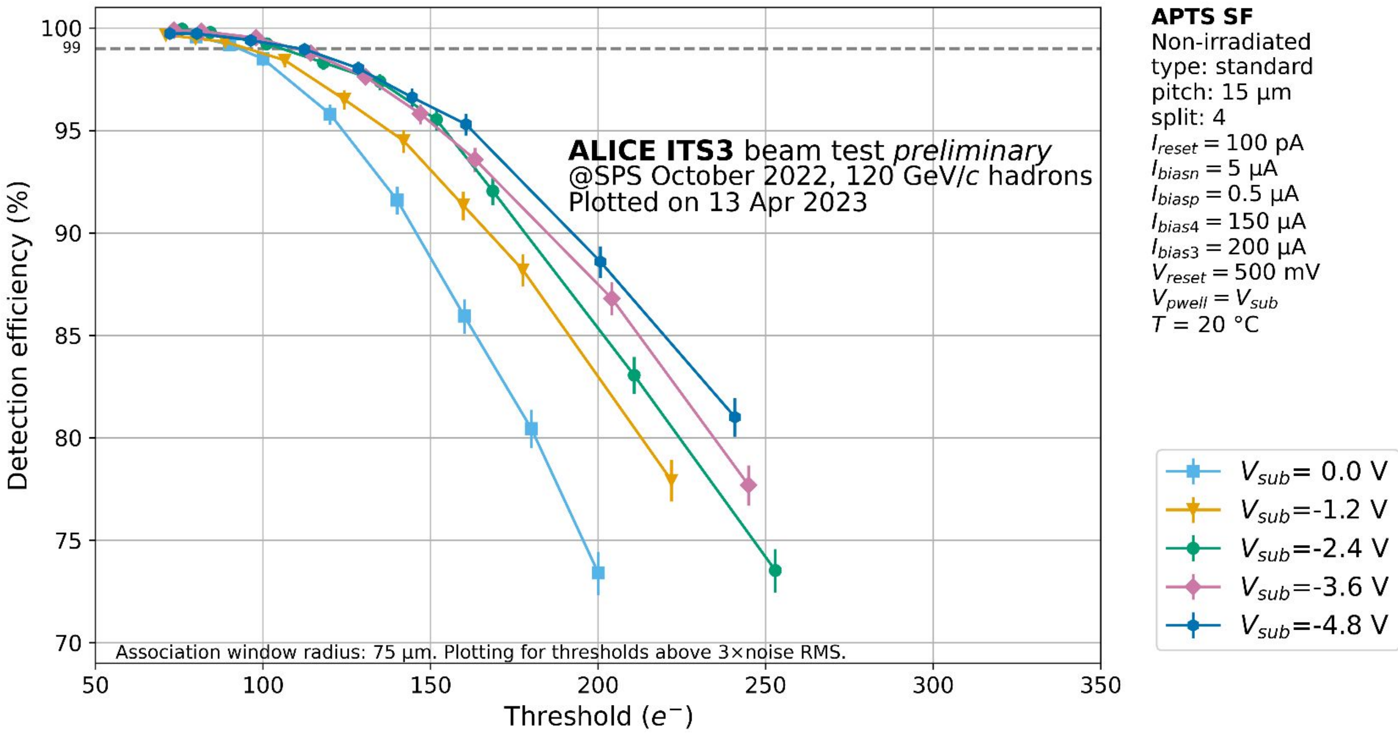
- Data plotted for threshold > $3RMS_{noise}$

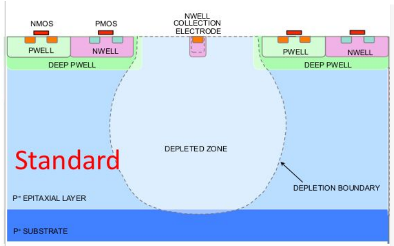




Efficiency vs threshold: standard type bias comparison

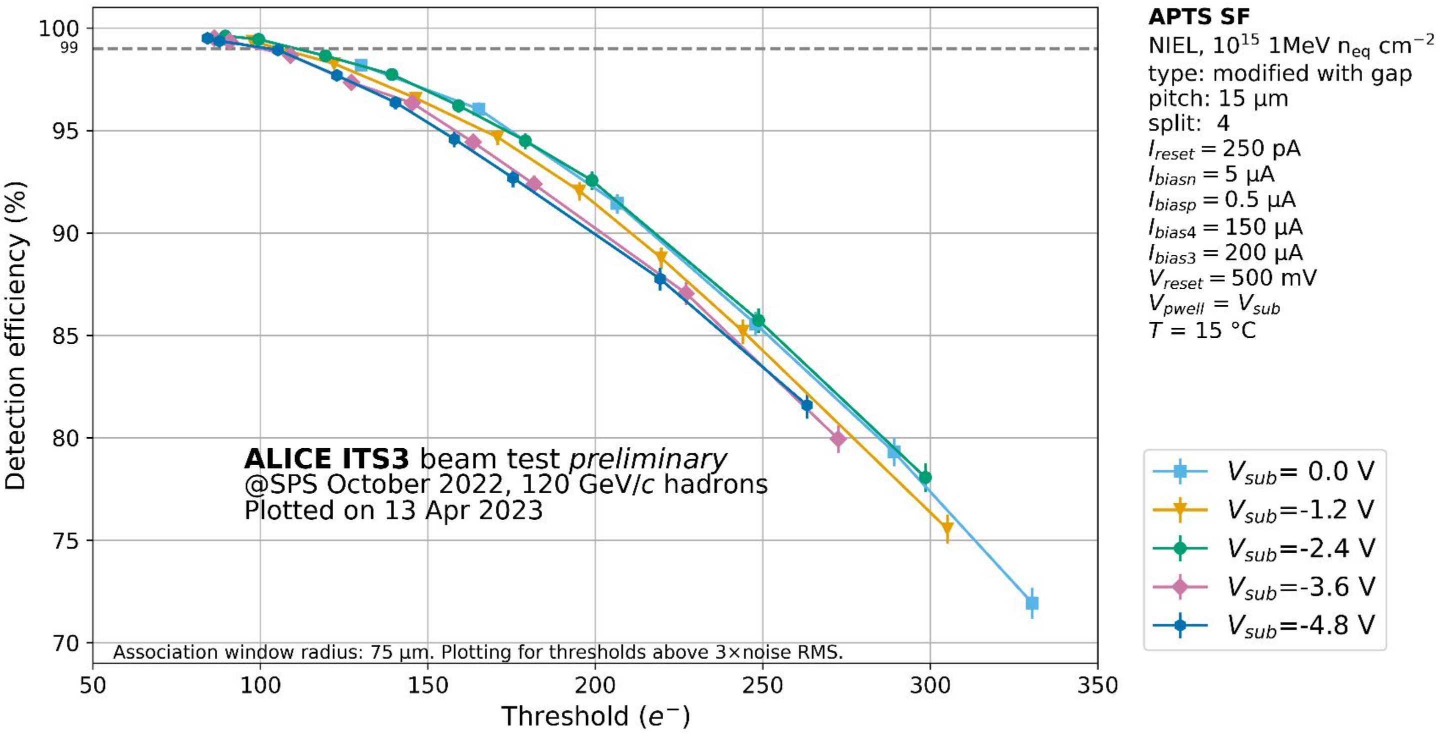
- Data plotted for threshold > $3RMS_{noise}$

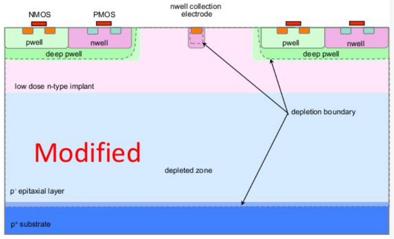




Efficiency vs threshold: Irrad. gap type bias comparison

- Data plotted for threshold > $3RMS_{noise}$





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ALICE

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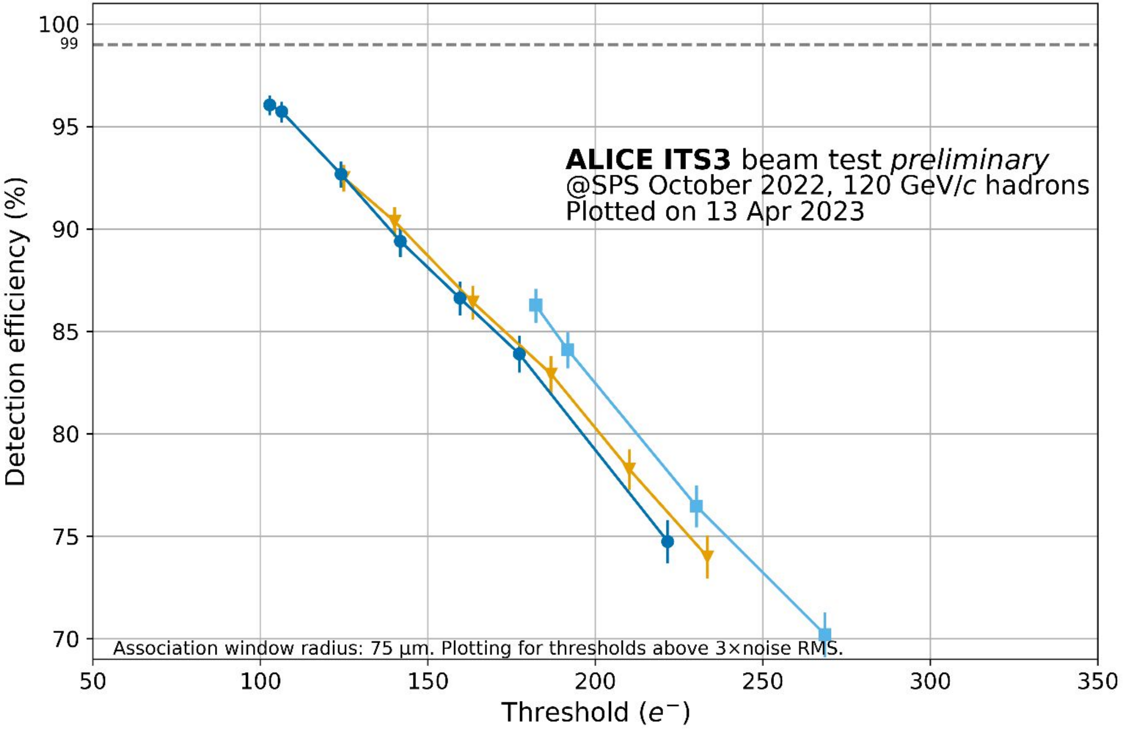

APTS SF
NIEL, 2×10^{15} 1MeV n_{eq} cm^{-2}
type: modified with gap
pitch: 15 µm
split: 4
$I_{reset} = 250$ pA
$I_{biasn} = 5$ µA
$I_{biasp} = 0.5$ µA
$I_{bias4} = 150$ µA
$I_{bias3} = 200$ µA
$V_{reset} = 500$ mV
$V_{pwell} = V_{sub}$
T = 15 °C