Testbeam measurements with ALICE MAPS prototype

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LCWS2023
INTERNATIONAL WORKSHOP ON LINEAR COLLIDERS

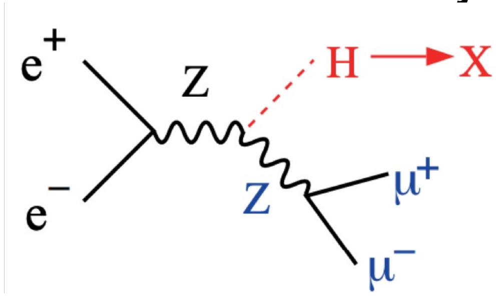
U.S. DEPARTMENT OF ENERGY
Office of Science

SLAC NATIONAL ACCELERATOR LABORATORY

Future Colliders: Physics Requirements

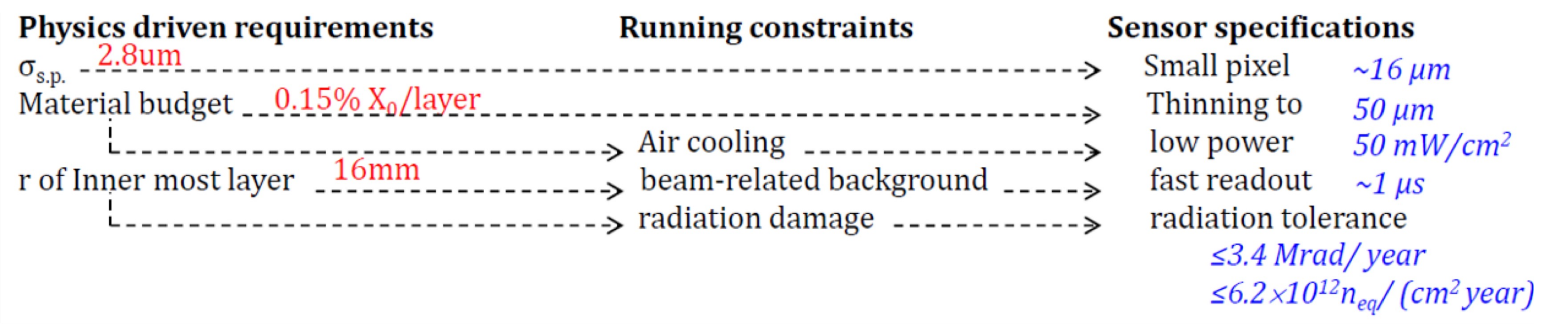
ZH Process: Primary process at e^+e^- collider at 250 GeV

- Drives requirement on charged track momentum and jet resolution



Flavor Tagging: Higgs → bb/cc

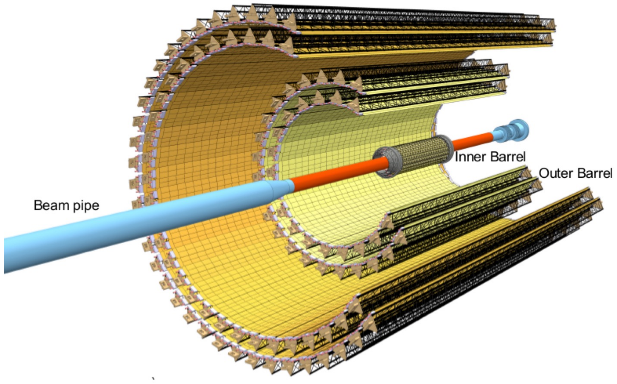
- Drives requirements on track impact parameter resolution
- Low mass tracker close to beam pipe with <.3% X_0 per layer (.15% for vertex)
- Thinned to < 75 μm, < 5 μm spatial resolution



ALICE Inner Tracking System Upgrade Requirements

- Replace inner barrel of ITS2 with 3 fully cylindrical bent MAPS layers

- Improved Tracking :
  - Inner tracking layer closer to interaction point
  - Reduced material budget (0.05 % X_o per layer)
  - Spatial resolution (vertex detector: 5 µm)
  - Timing resolution ~100 ns



- Readout rates: Pb-Pb event rates of 50 kHz, p-p 200 kHz

- Maximum Radiation load ~10^{13} 1 MeV n_{eq}/cm^2 (NIEL) and 10 kGy (TID)

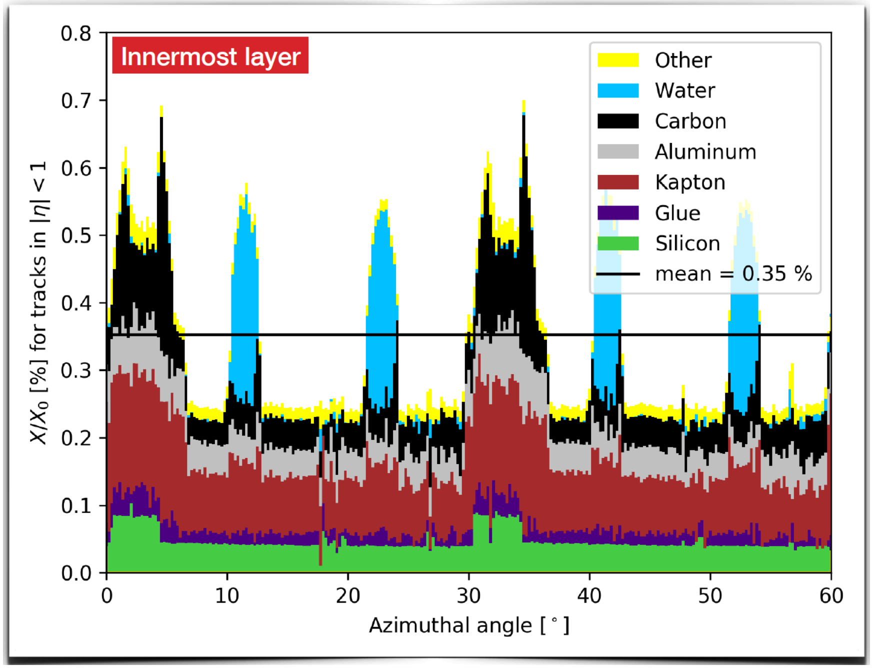
Detector Layout

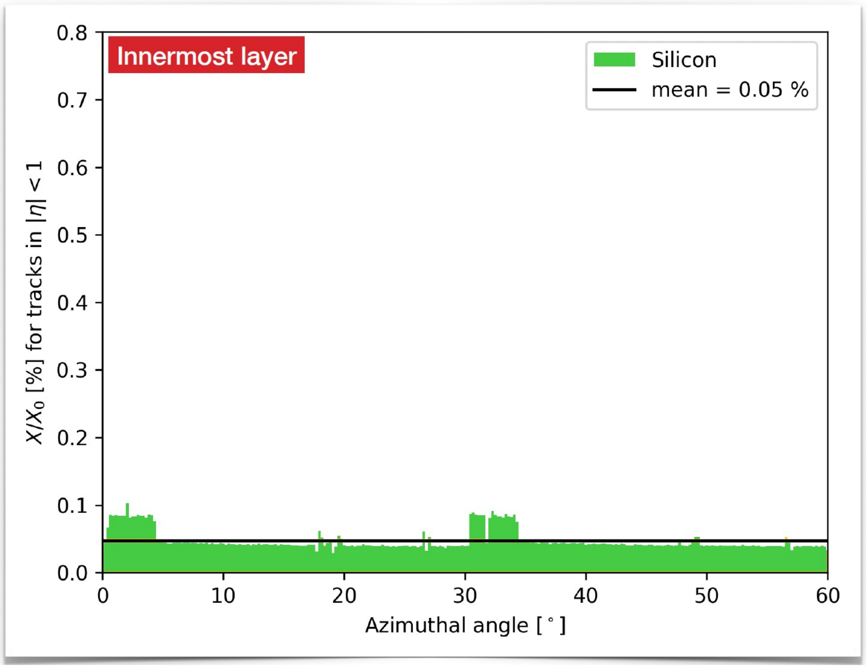
- Inner layer 22 mm(ITS2)-> 18.0 mm(ITS3)
- 3 MAPS layers: two bent half cylinder wafer scale chips
- Carbon foam to hold layers in place

Beampipe inner/outer radius (mm)		16.0/16.5	
IB Layer parameters	Layer 0	Layer 1	Layer 2
Radial position (mm)	18.0	24.0	30.0
Length (sensitive area) (mm)	270	270	270
Pseudo-rapidity coverage[a]	±2.5	±2.3	±2.0
Active area (cm^2)	305	408	508
Pixel sensors dimensions (mm^2)	280×56.5	280×75.5	280×94
Number of pixel sensors / layer		2	
Pixel size (μm^2)		$O(15 \times 15)^b$	

Reduction in Material Budget

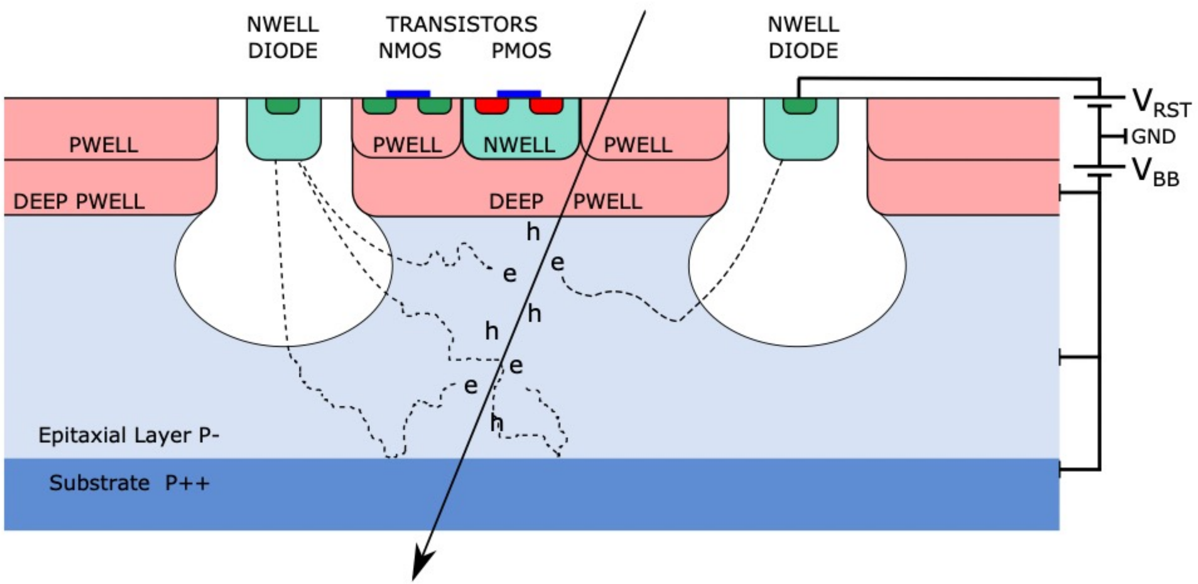
- Self supporting cylindrical structure
- Air cooling: low power consumption (below 20 mW/cm^2)
- Integrated circuit board





MAPS- Monolithic Active Pixel Sensors

- Combine readout electronics and sensitive volume
- e^-/h^+ pairs created by traversing particles, diffuse/drift to electrodes
- Small pixel size, large S/N, low power consumption, low material budget, low cost
- Compared to hybrid: lower radiation resistance, smaller signal, not constrained by size of bump bonds



DPTS: Digital Pixel Test Structure Sensor Design

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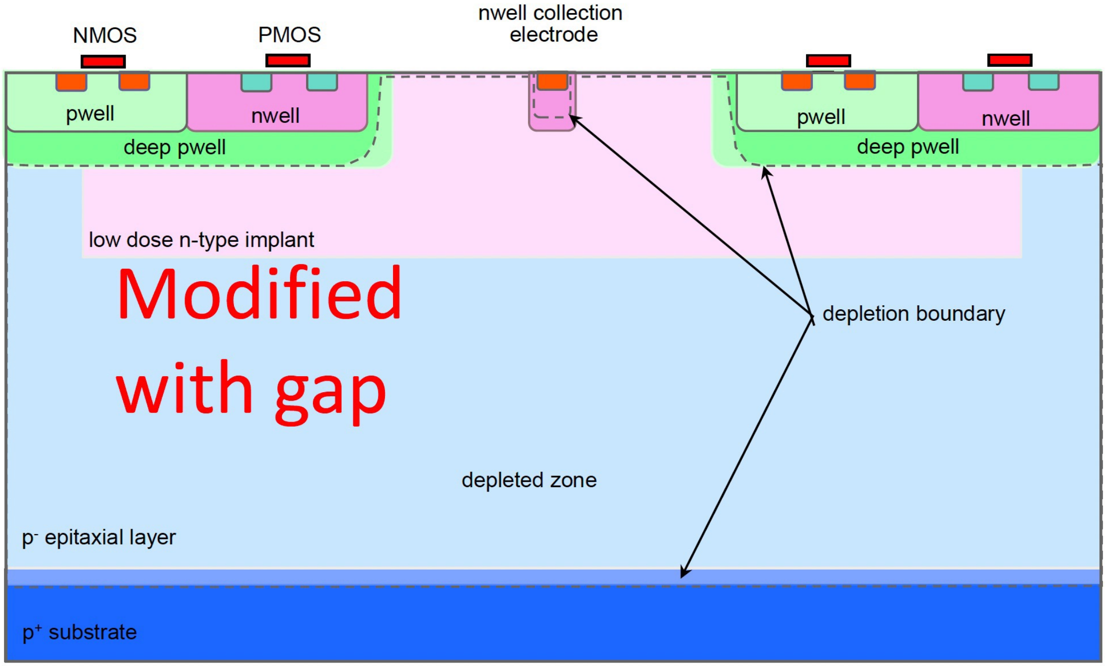
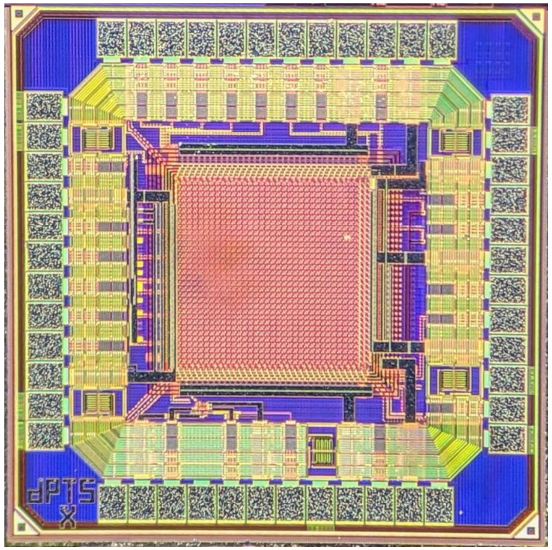
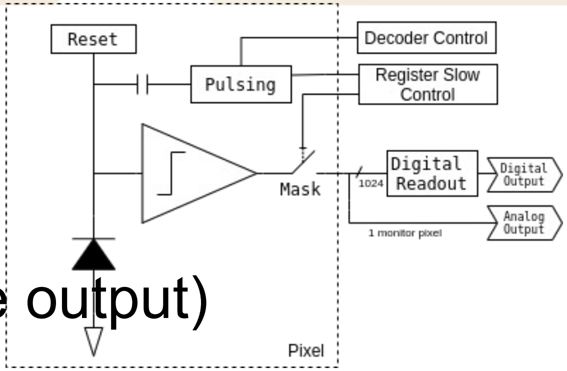
- Back bias + low dose n-type implant: enlarge depletion region at collection diode
- Fully depleted sensors: faster charge collection, improved timing



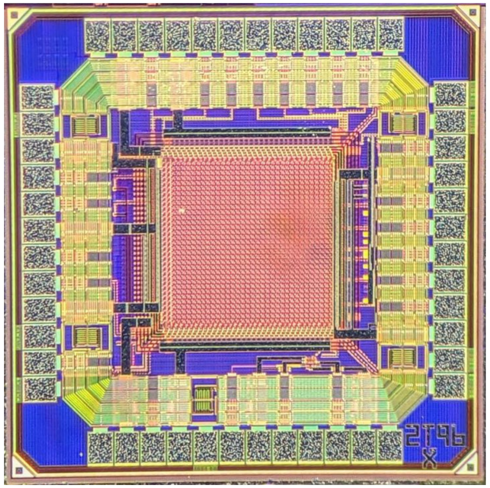


DPTS: Digital Pixel Test Structure

- 32 x 32 pixels, 15 µm pitch
- 1.5 mm x 1.5 mm
- In pixel amplification and discrimination
- Asynchronous digital readout with ToT (single output)
- Pixel pulsing, monitor pixel (analog)



- Goals: Proof of concept and characterization of charge collection



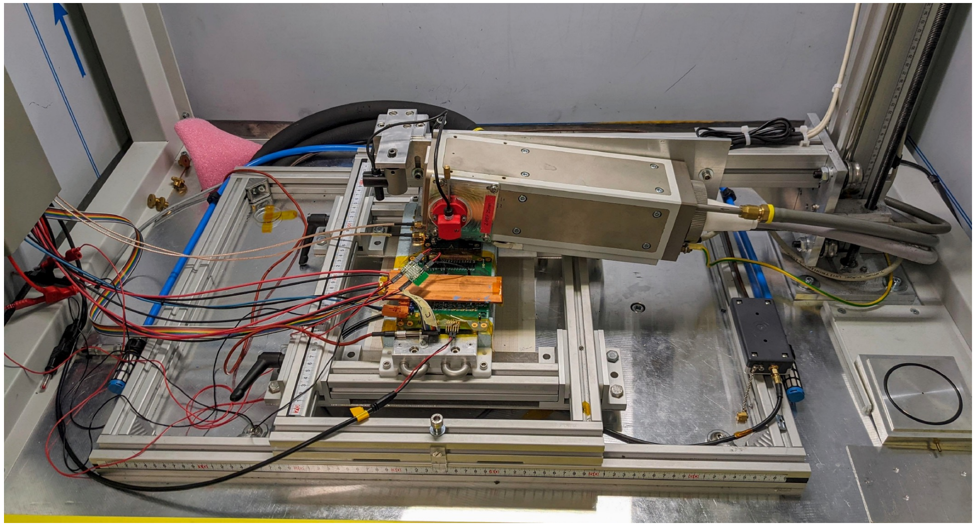
Radiation hardness targets:

- TID (total ionizing dose) 1 Mrad
- NIEL (nonionizing energy loss) 10^{13} n/cm^2

DPTS Irradiation

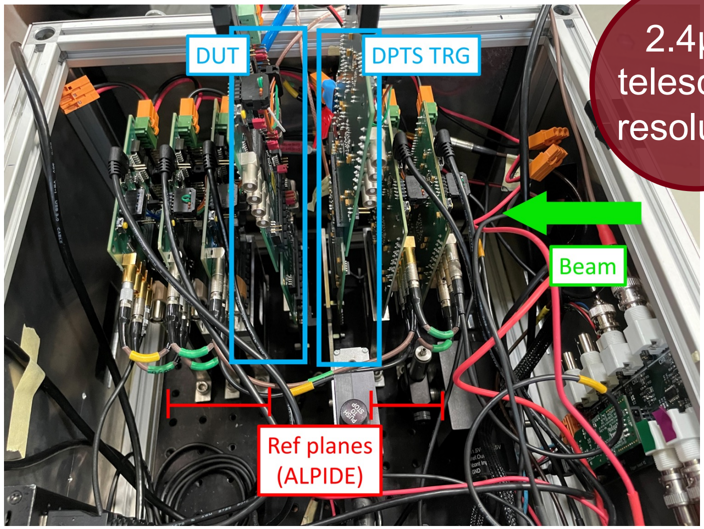
- TID – up to 10 Mrad
- NIEL- up to 10^{15} 1 MeV n_{eq}/cm^2
- NIEL Irradiation @ JSI Ljubljana with neutrons
- TID irradiation @ CERN X-ray Machine
  - Different irradiation rates 12-100 krad/min
  - Continuously and in intervals

Chip serial	NIEL irradiation level
DPTSOW22B7	non irradiated
DPTSOW22B3	Irradiated TID 1 MRad
DPTSXW22B10	Irradiated NIEL 1E13
DPTSXW22B12	Irradiated NIEL 1E14
DPTSOW22B17	Irradiated NIEL 1E15
DPTSXW22B26	Irradiated TID 1 Mrad
DPTSXW22B8	Irradiated TID 10 Mrad



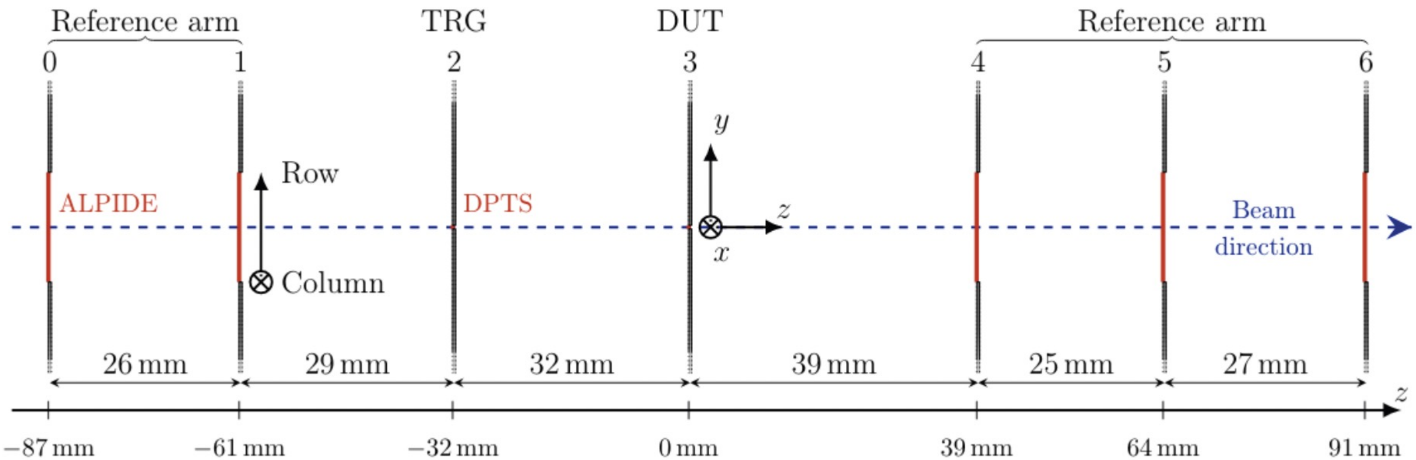
Testbeam Setup

CERN PS 29th June-13th July 2022



2.4μm telescope resolution

- DPTS as trigger
- 5 ALPIDE reference planes
- DUT maintained at 20°C
- 10 GeV positive hadron beam
- EUDAQ and Corryvrecken: DAQ and analysis framework

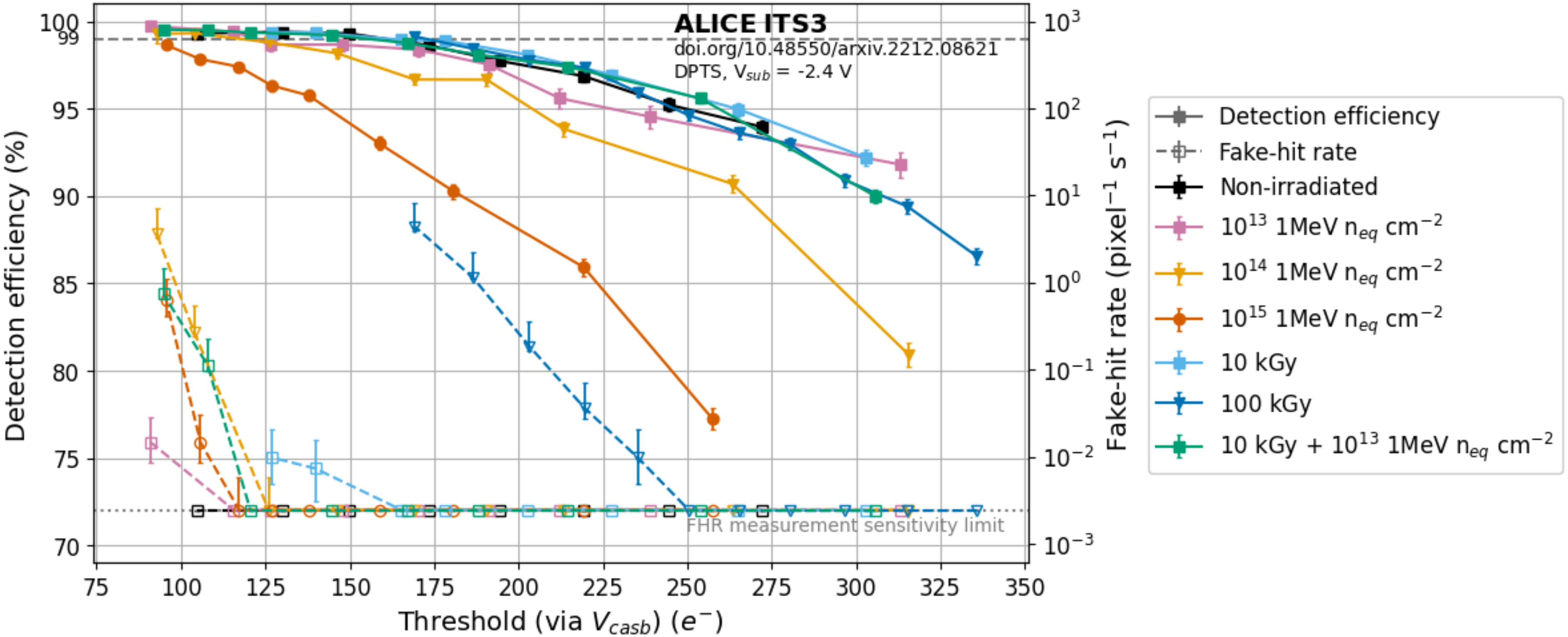


Chip serial	NIEL irradiation level
DPTSOW22B7	non irradiated
DPTSOW22B3	Irradiated TID 1 MRad
DPTSXW22B10	Irradiated NIEL 1E13
DPTSXW22B12	Irradiated NIEL 1E14
DPTSOW22B17	Irradiated NIEL 1E15
DPTSXW22B26	Irradiated TID 1 Mrad
DPTSXW22B8	Irradiated TID 10 Mrad

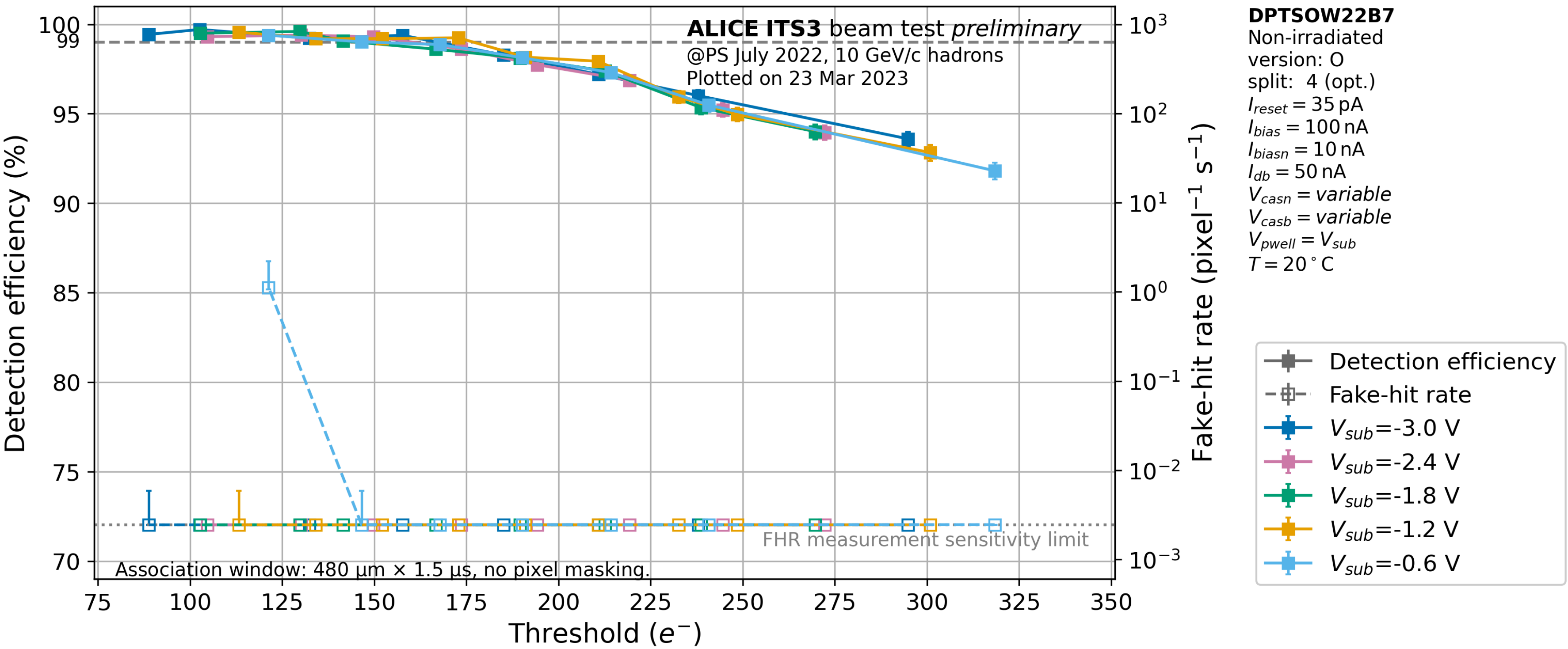
Testbeam Analyses

- Total efficiency
- In-Pixel Analyses: Efficiency, Mean Cluster Size
- Spatial Resolution
- Timing Resolution

Total Efficiency



Total Efficiency: Nonirradiated

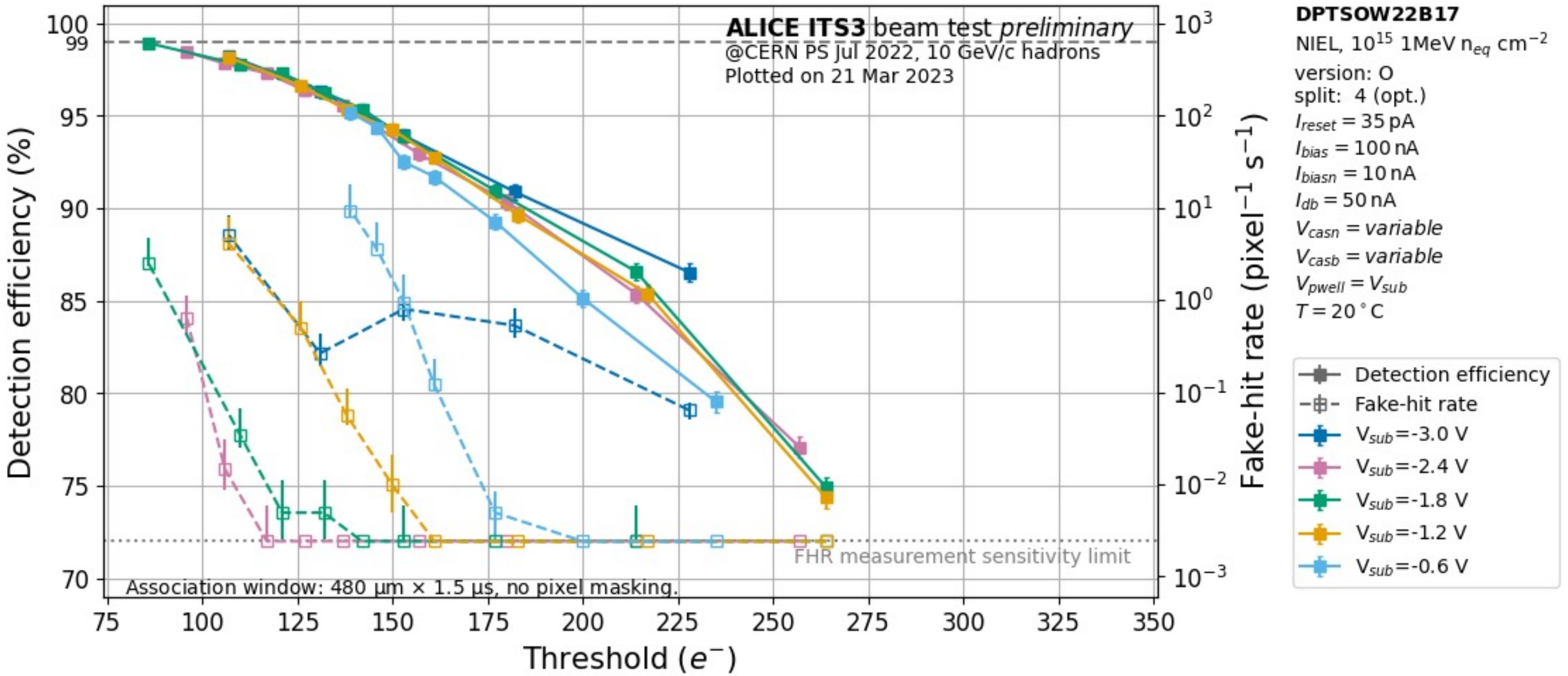


high statistic runs:

Efficiency: .911
Mean Threshold: 315

Efficiency: .951
Mean Threshold: 265

Total Efficiency: NIEL Irradiated 10^{15} 1 MeV n_{eq} cm^{-2}



high statistic runs:

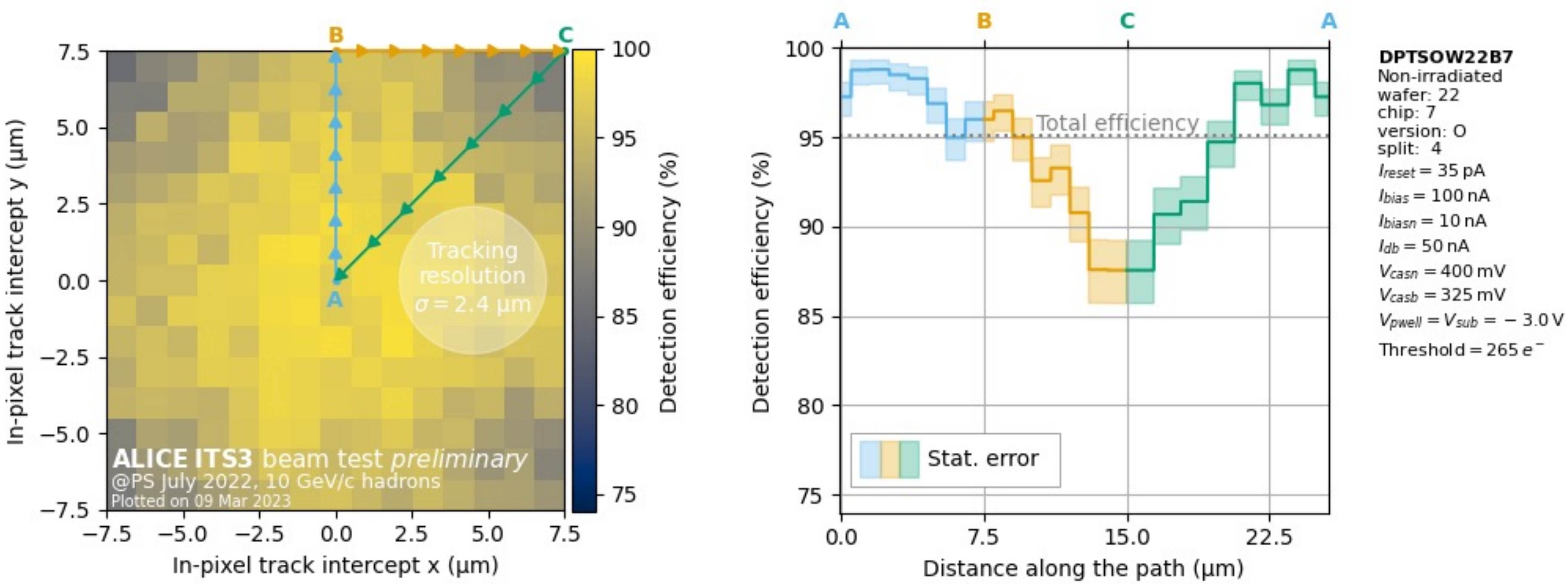
Efficiency: 0.928
Mean Threshold: 160

Efficiency: 0.956
Mean Threshold: 135

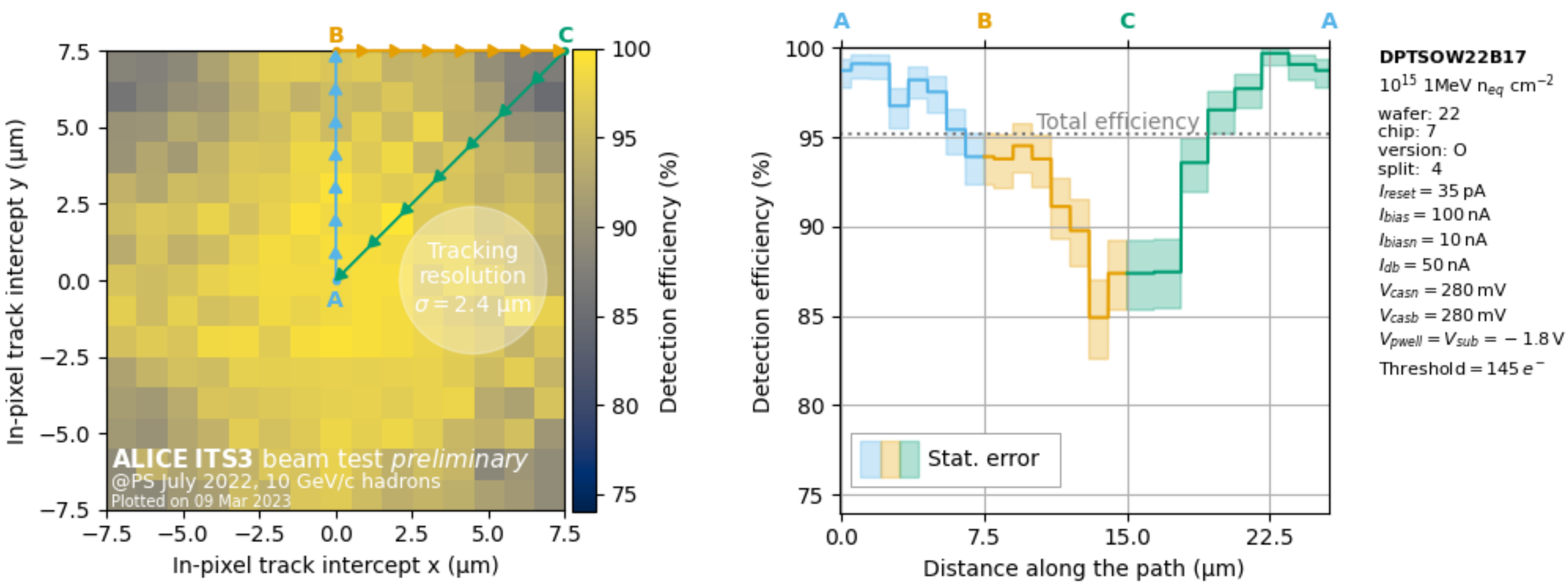
Efficiency: 0.954
Mean Threshold: 145

Efficiency: 0.963
Mean Threshold: 130

In Pixel Efficiency: Nonirradiated

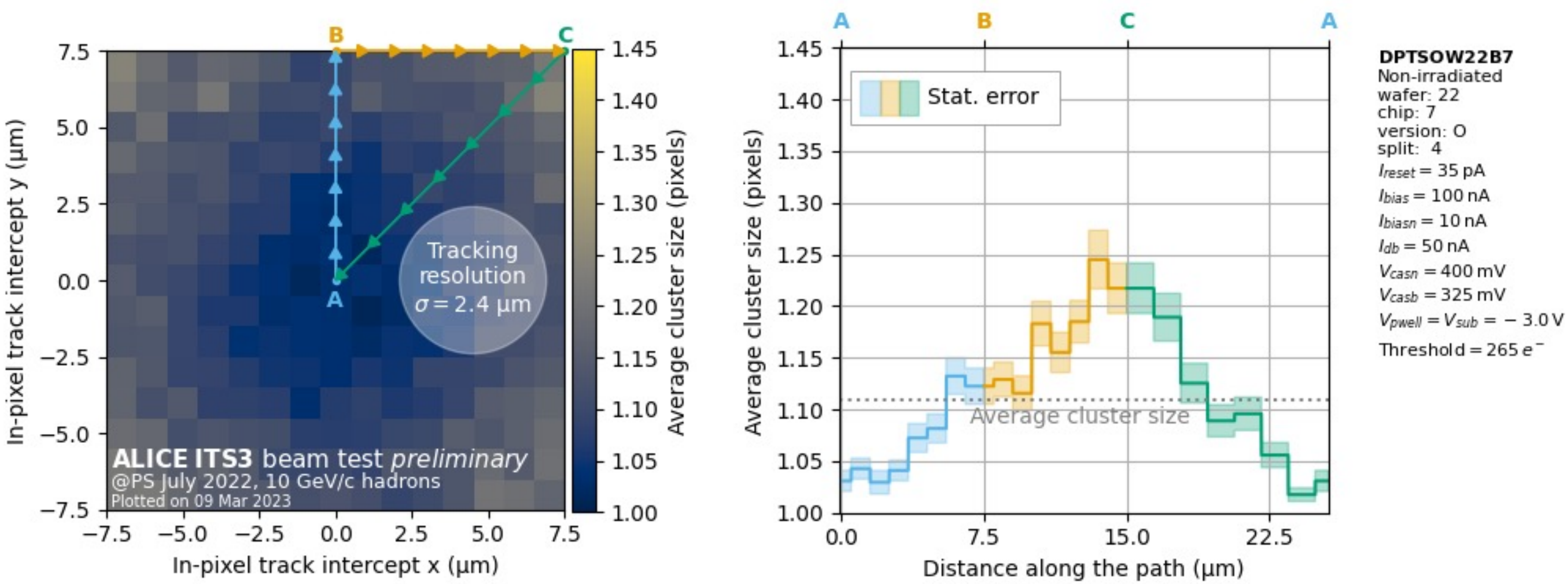


In Pixel Efficiency: NIEL Irradiated 10^{15} 1 MeV n_{eq} cm^{-2}

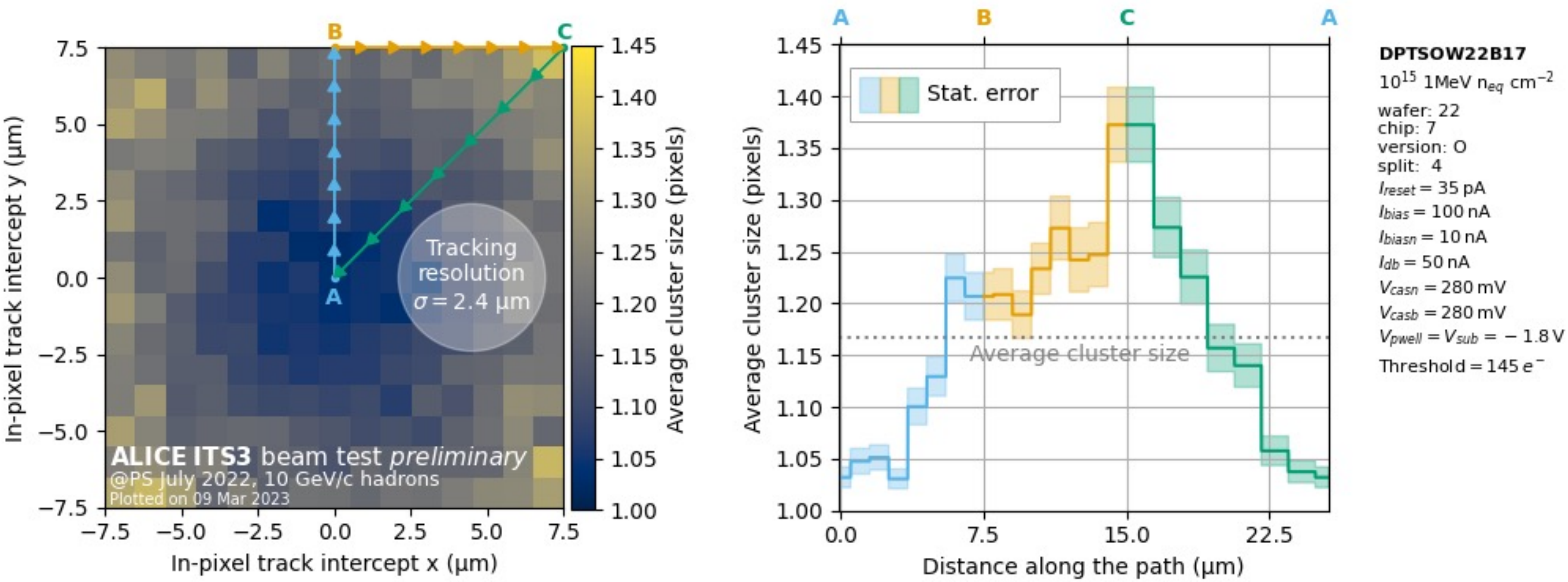


Mean Cluster Size: Nonirradiated

- Cluster is a set of adjacent pixels that go over threshold



Mean Cluster Size : NIEL Irradiated 10^{15} 1 MeV n_{eq} cm^{-2}



Spatial Resolution:

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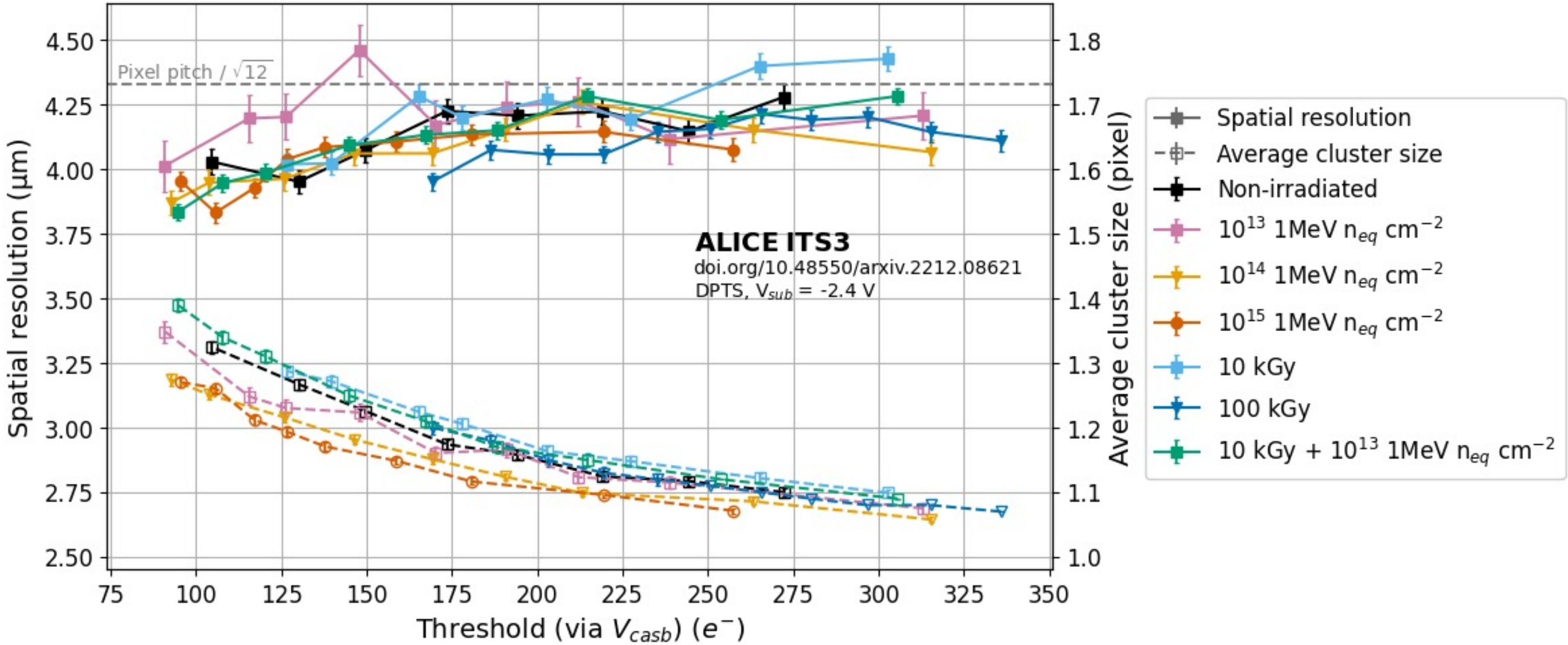
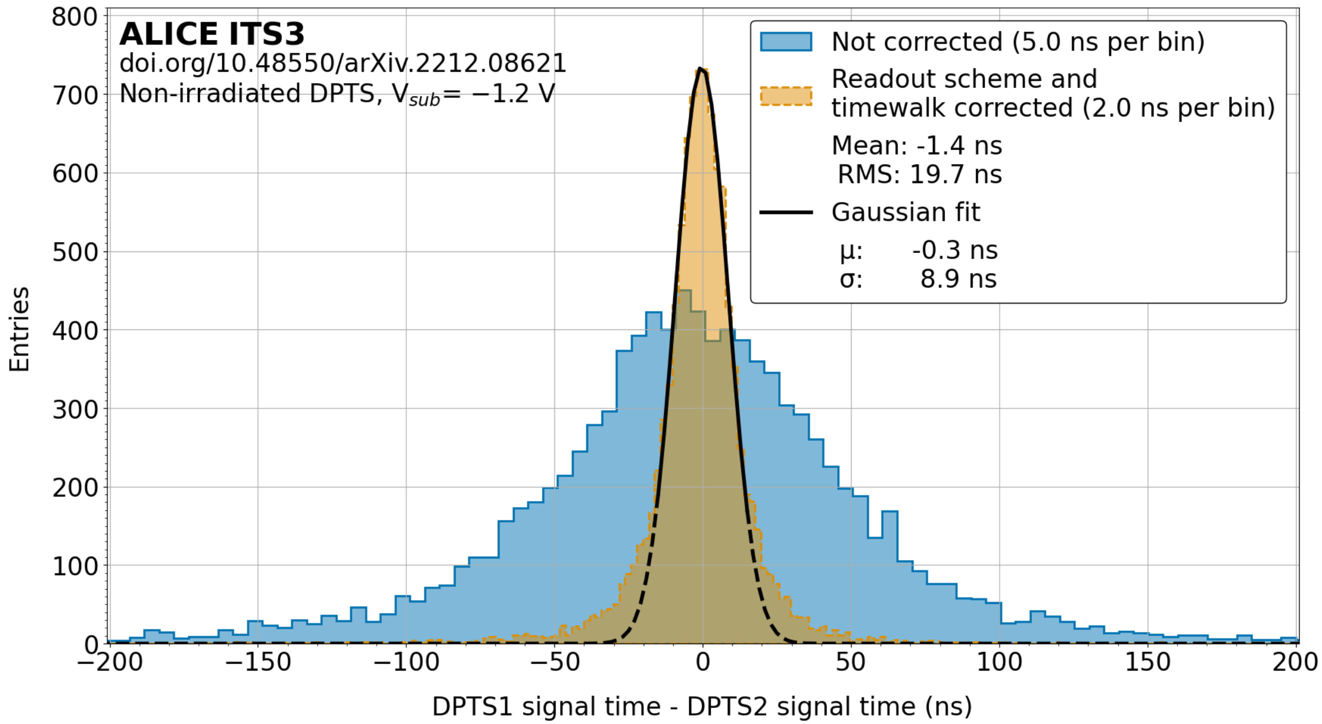
- Requirement: 5 μm
- Telescope resolution: 2.4 μm
- Spatial resolution is average of row/column resolutions
- Fit gaussian to spatial residual distributions:

$$\sigma^2 = \sigma_{row/column}^2 - \sigma_{telescope}^2$$



Timing Resolution:

- Requirement: 100ns
- 5.4 GeV electron beam
- Distribution of time residuals: σ_t = 6.3±0.1 ns
- Readout scheme correction: time delay between even and odd columns



Performance Summary

- ITS3 Radiation hardness targets:
  - TID (total ionizing dose) 1 Mrad
  - NIEL (nonionizing energy loss) 10^{13} 1 MeV n/cm^2
- Spatial resolution (vertex detector: 5 μm) : <4.33 μm
- Timing resolution ~100 ns : 6.3 ns
- Working points with 99% detection efficiency at room temperature even up to 10^{15} 1 MeV n/cm^2
- More R&D needed to realize stitched sensors

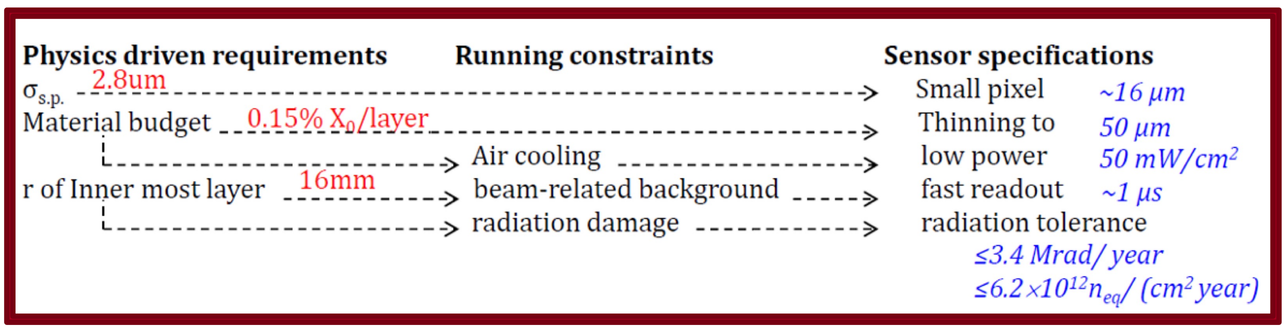
- MAPs are established vertex detectors that have widespread applications, including at future colliders!

e^+e^- Requirements vs. ALICE

- MAPS are viable technology in future e^+e^- colliders
- Similar requirements to ALICE ITS3 Upgrade

<u>ALICE</u>
5 µm
0.05 % X_o/layer

18 mm



<u>ALICE</u>
15 µm
<50 µm
20 mW / cm^2
–

1 Mrad
10^{13} 1 MeV n_{eq}/cm^2

- More R&D on fast readout/stitching/power consumption