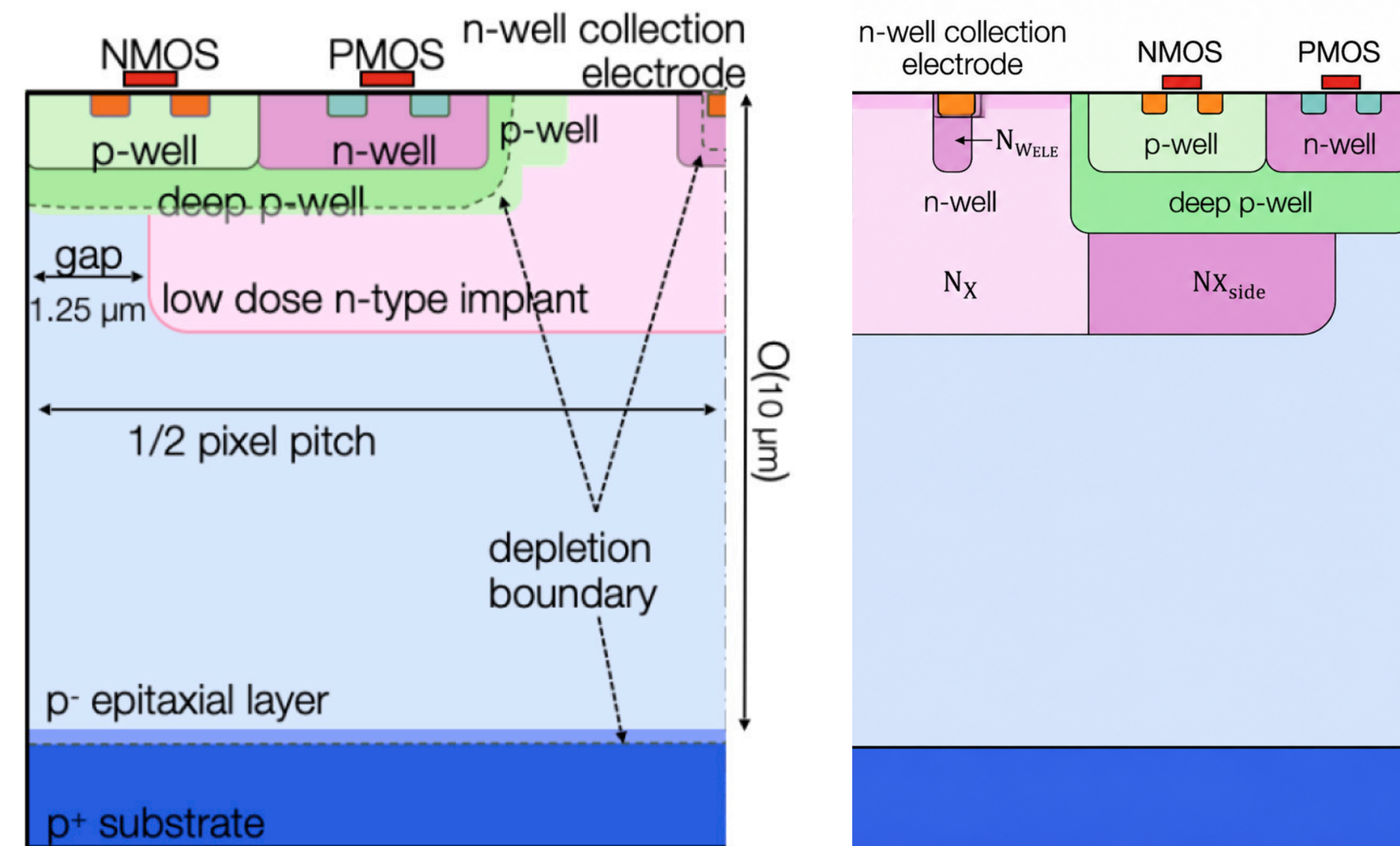
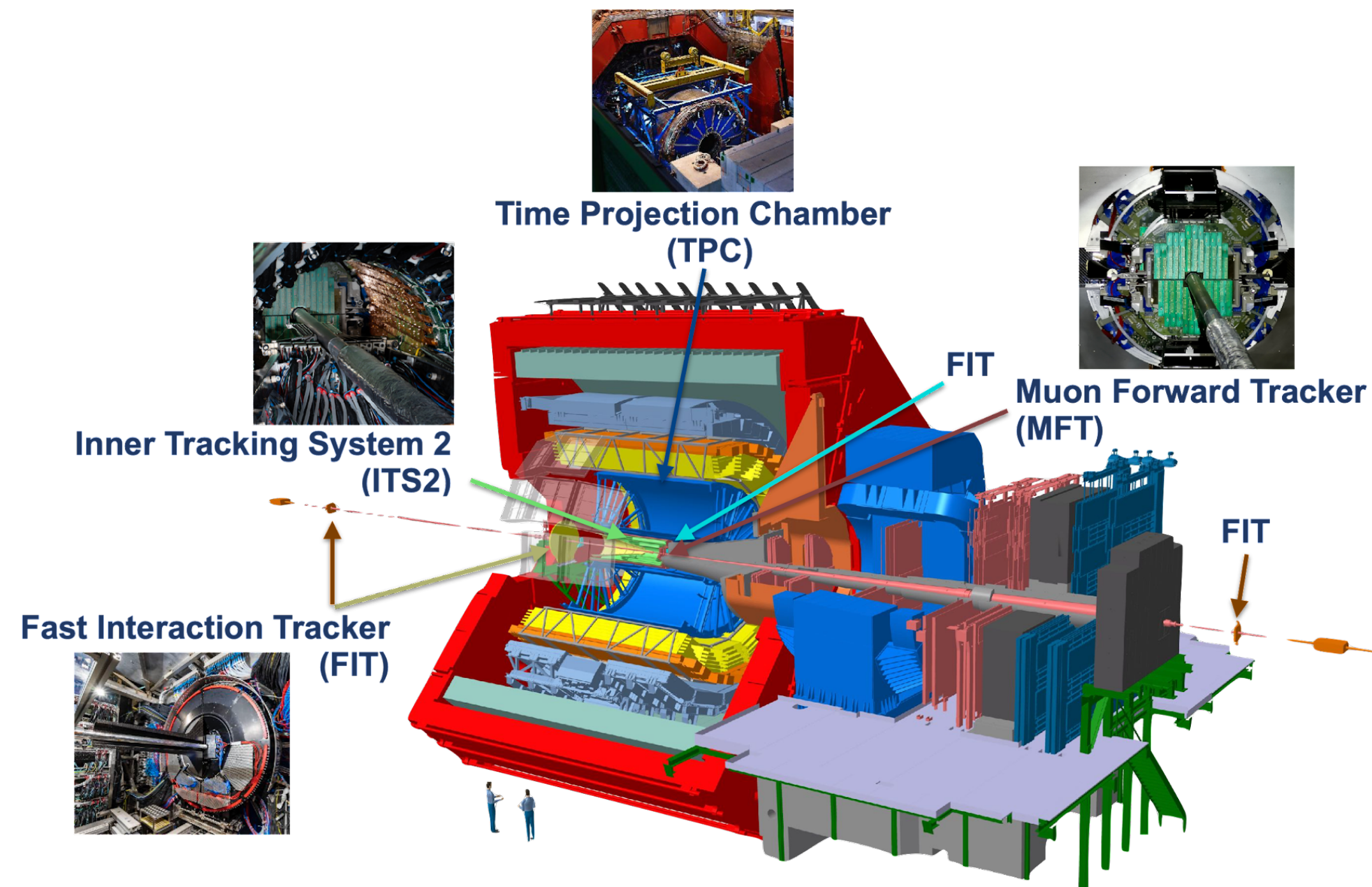


Design and Performance of Fast Analog Pixel Test Structures for the ALICE ITS3 Upgrade

Umberto Savino
on behalf of the ALICE Collaboration



ALICE2 experiment

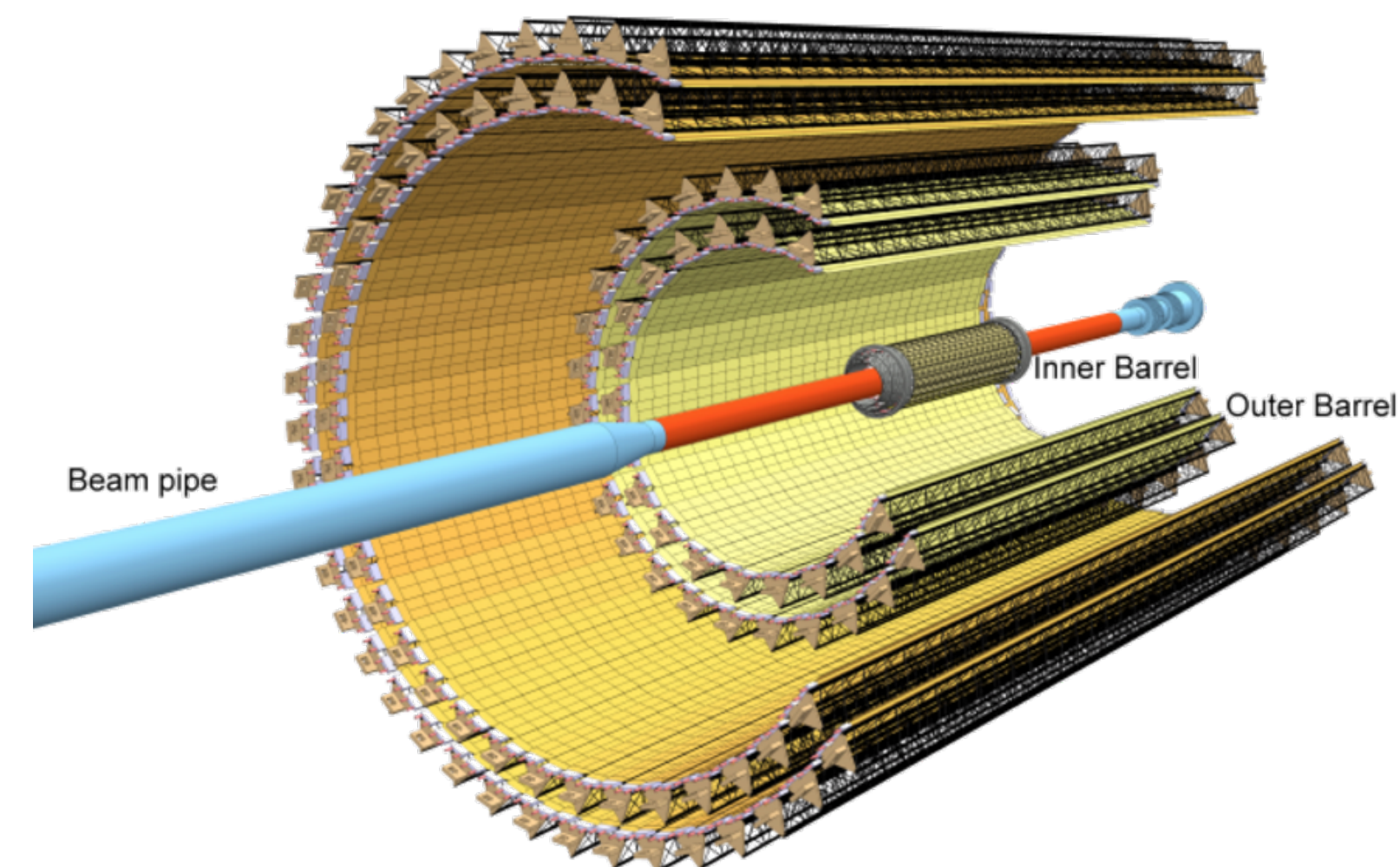


ITS2 first large-area ($\sim 10 \text{ m}^2$) **silicon tracker** $\rightarrow$ MAPS

ALPIDE chip: TowerJazz **180 nm CMOS** imaging process

Main characteristics:

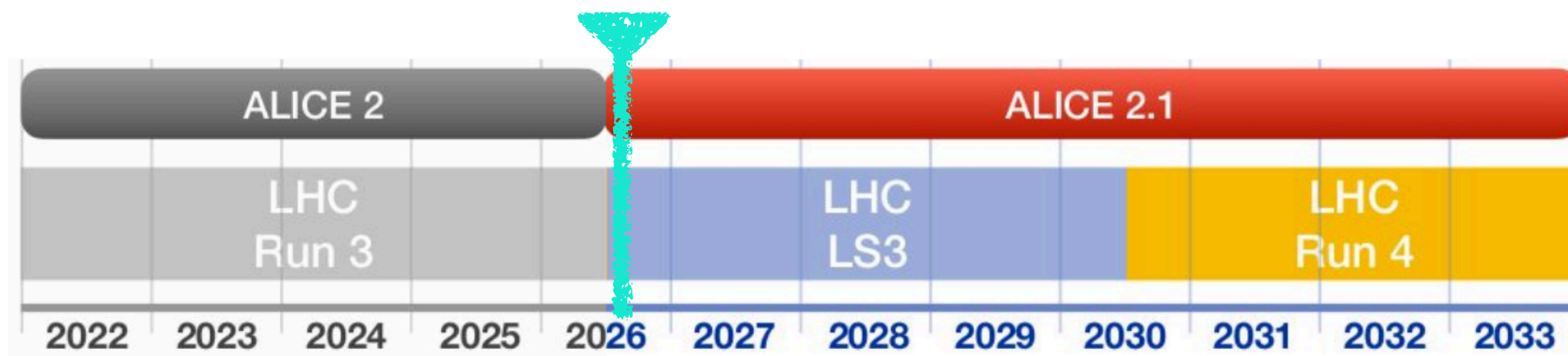
- 7 layers of MAPS (3 inner - 4 outer barrel)
- close to interaction point: **24 mm** radius
- improved single point **resolution** ($5 \mu\text{m}$)
- low material budget: **0.36% X_0/X per layer**



- properties of the **quark-gluon plasma** produced in **heavy-ion collisions**
- low momentum ($\approx 1 \text{ GeV}/c$) particle reconstruction

Inner Tracking System 3

Truly Cylindrical Wafer-scale MAPS

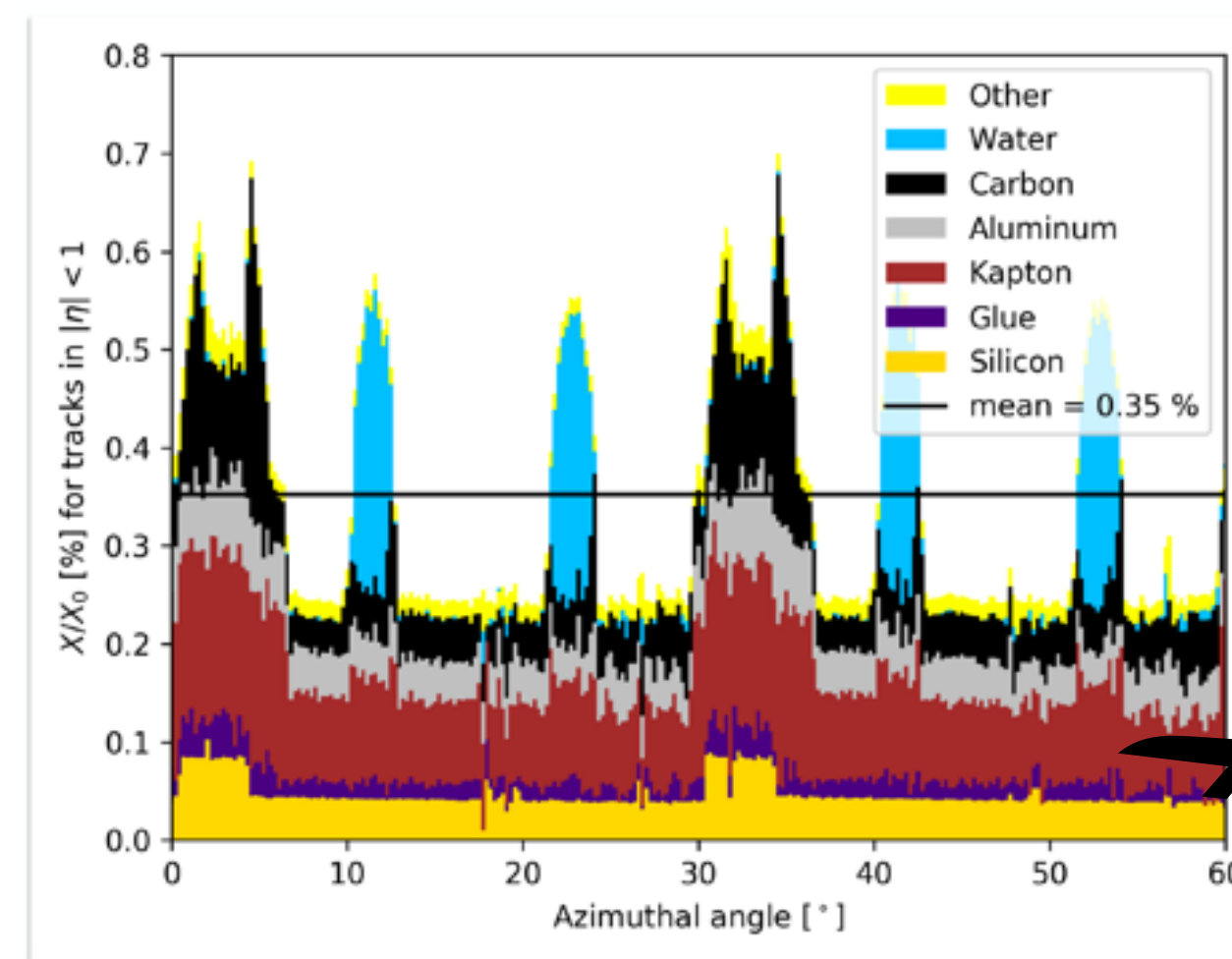
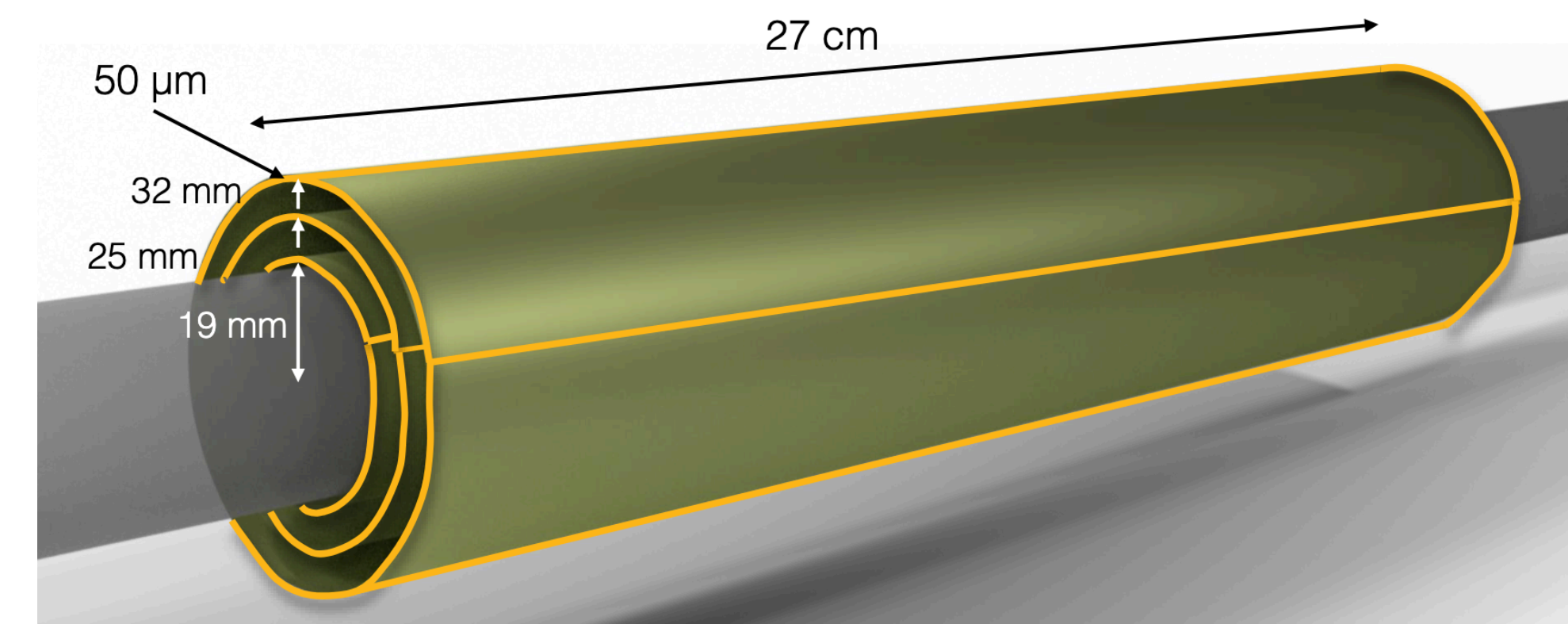


Layout:

- Replace ITS2 Inner Barrel (3 layers)
- Reduce beam pipe inner radius and thickness

Technology:

- **65 nm CMOS** from TPSCo:
 - **wafer-scale chips** (26 cm long)
 - fabricated using **stitching** technology
- thinned down to **50 μm**
 - flexible (bent to target radii)
- mechanically held by carbon foam ribs



to 0.09% X_0/X per layer

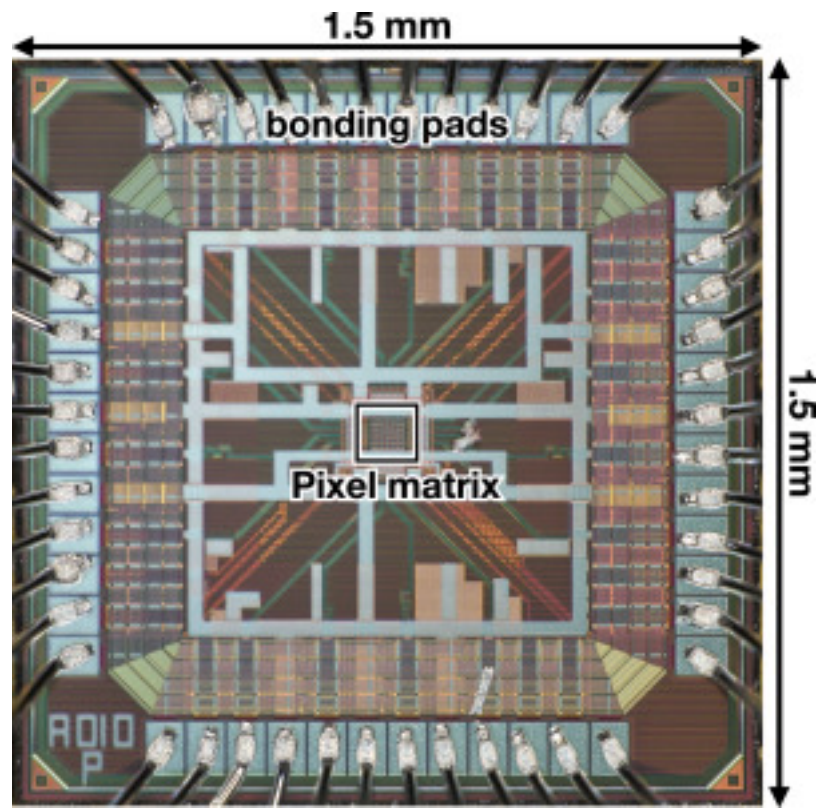


ALICE

Analogue pixel test structures

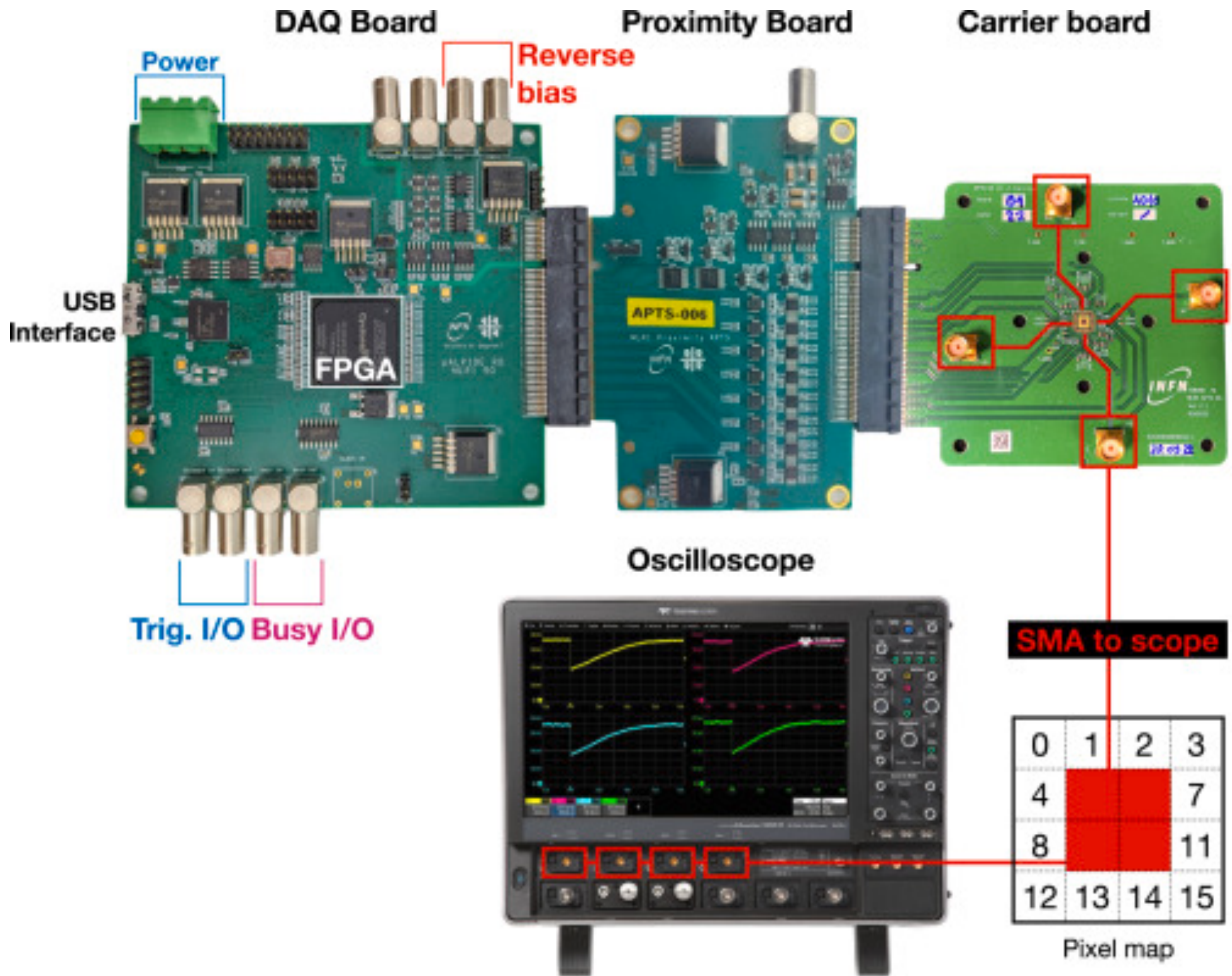


Multi Layer Reticle 1 (MLR1) submission

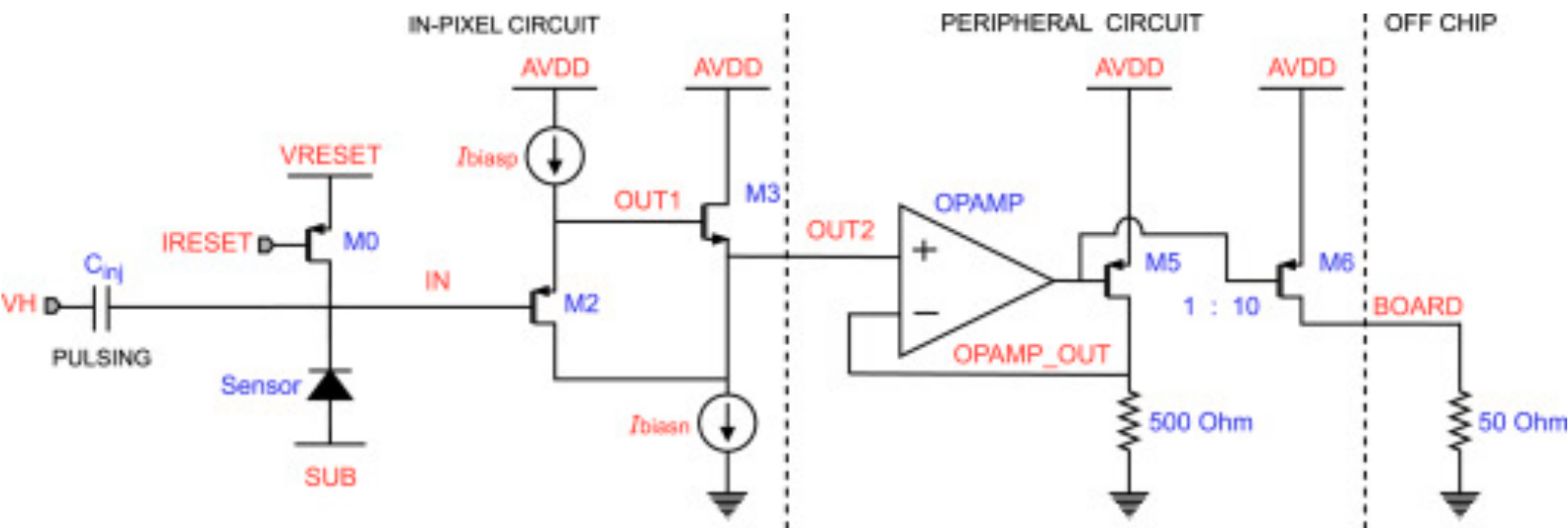


APTS-OpAmp (OA)

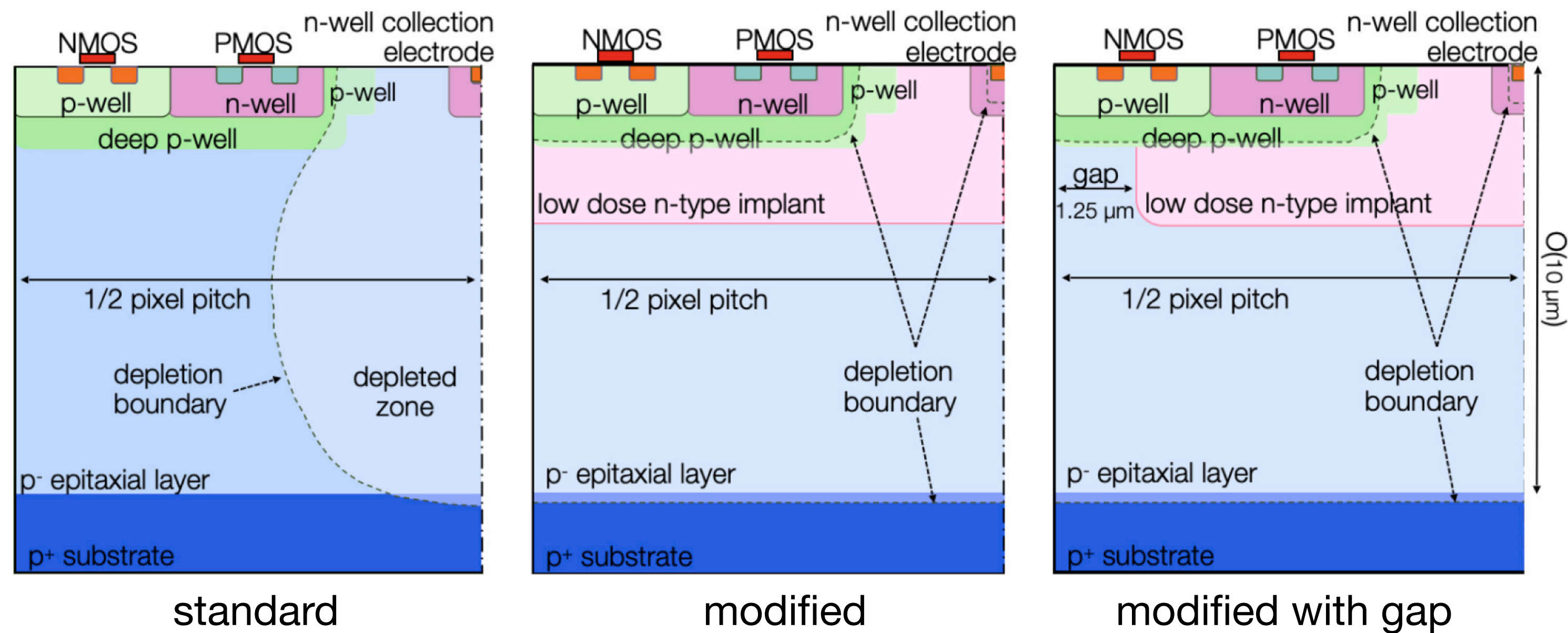
Die size	1.5 mm x 1.5 mm
Matrix	4 x 4 pixels
Readout	Direct analogue
Pitch	10 μ m
Output buffer	Fast operational amplifier



APTS-OA front end

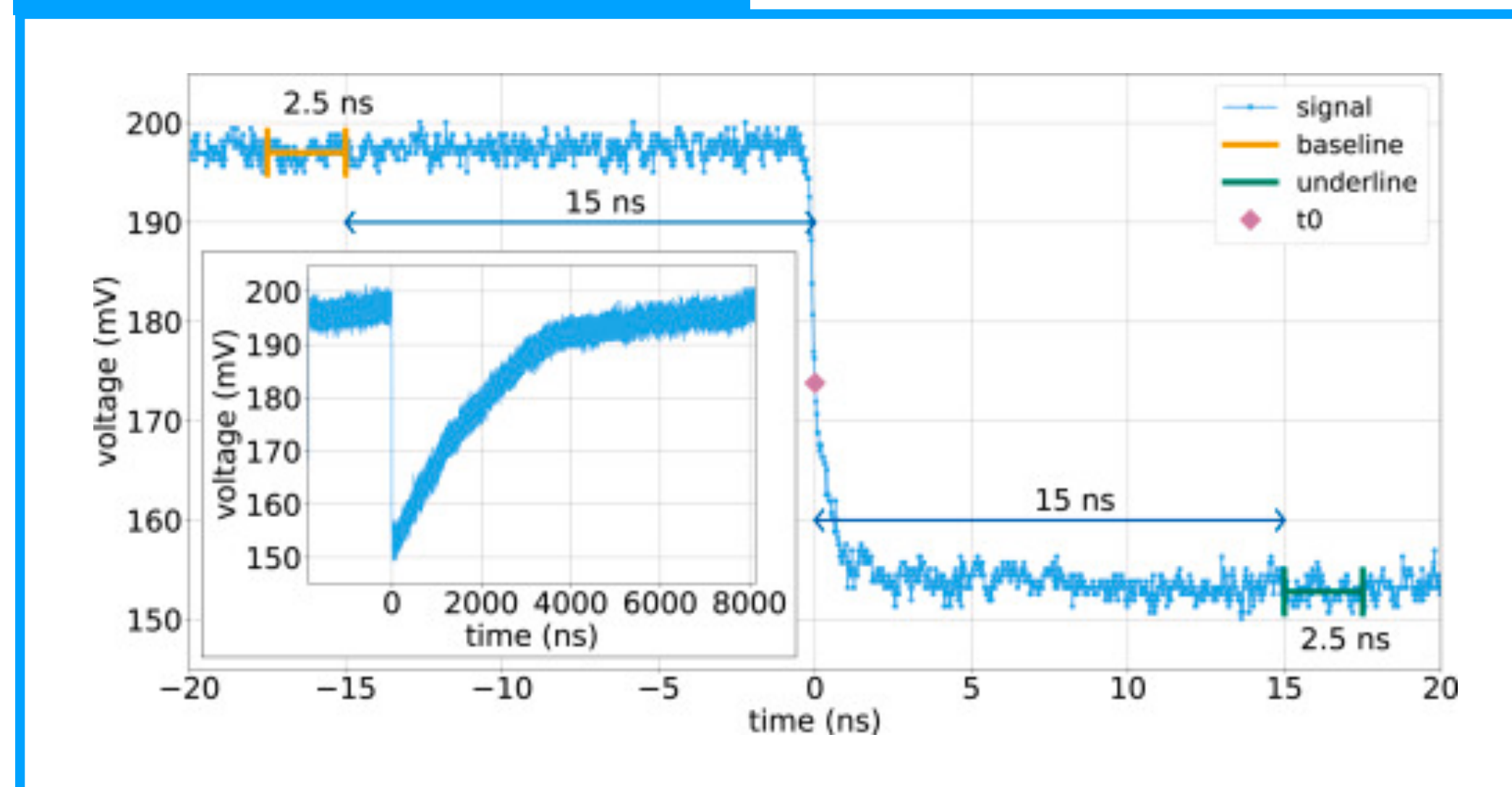


Sensor process from MLR1



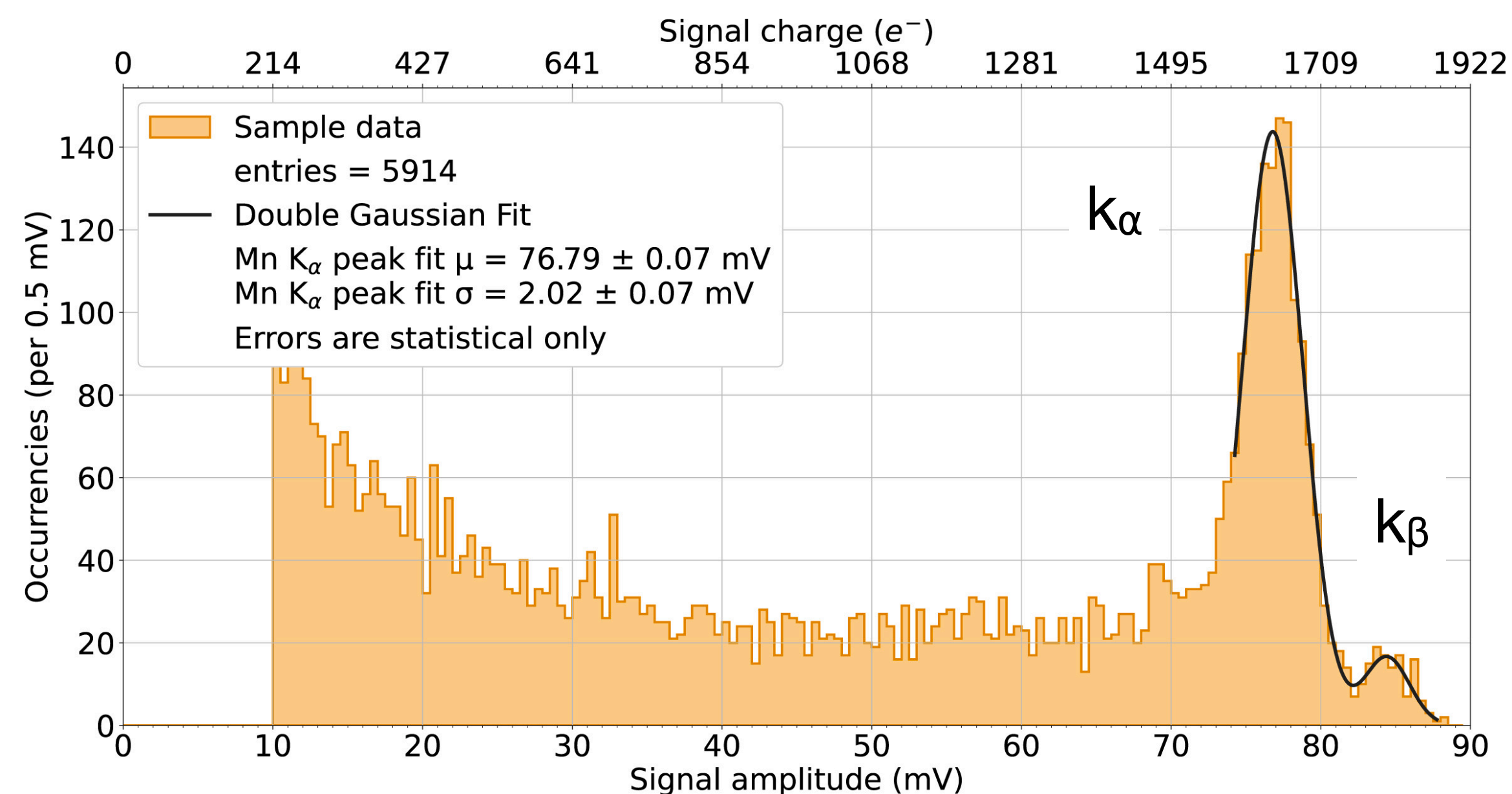
X-ray monochromatic source

APTS-OA typical signal



Full signal information

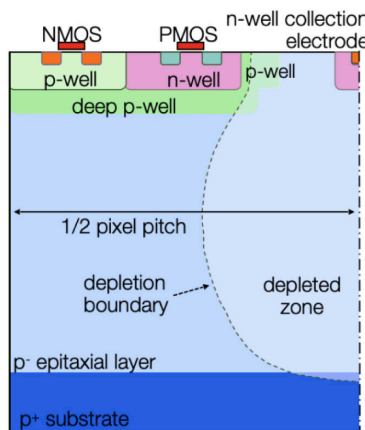
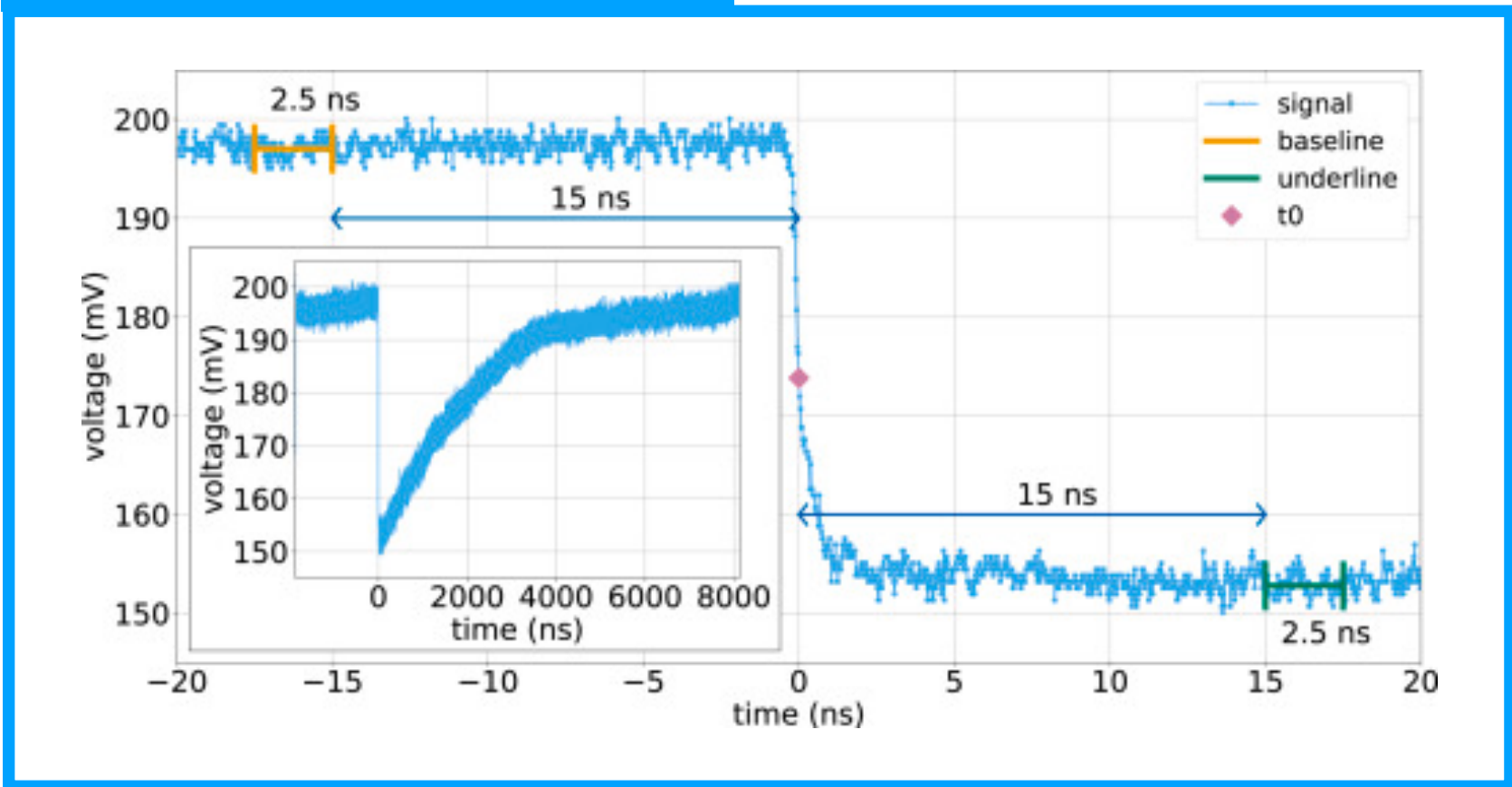
Fast signal: down to 300 ps falling edge
Direct pixel to pixel **charge calibration**



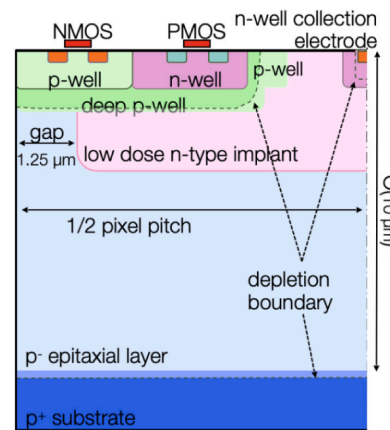
APTS-OA charge collection

Amplitude vs fall time correlation

APTS-OA typical signal



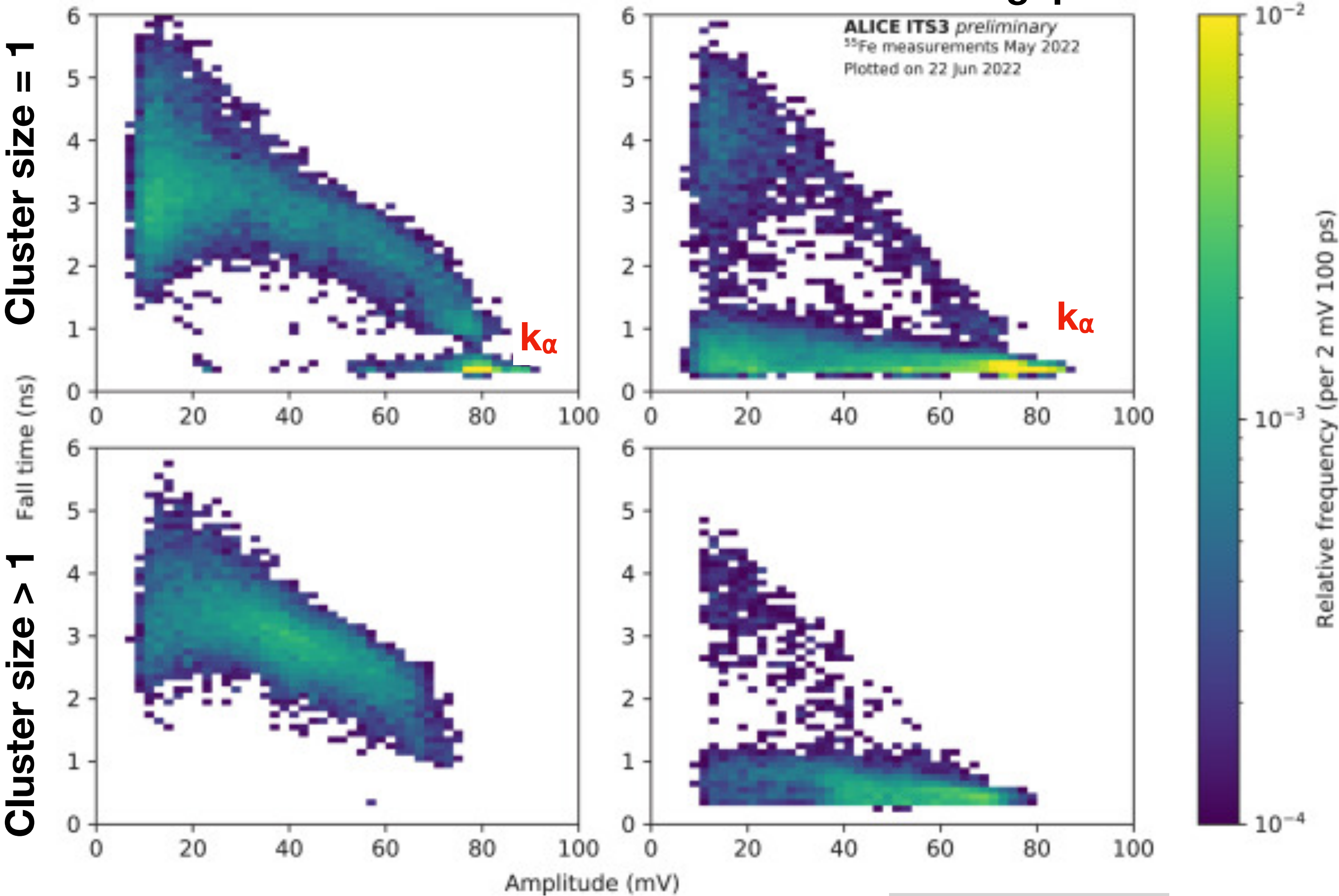
Standard



Modified with gap

Cluster size = 1

Cluster size > 1



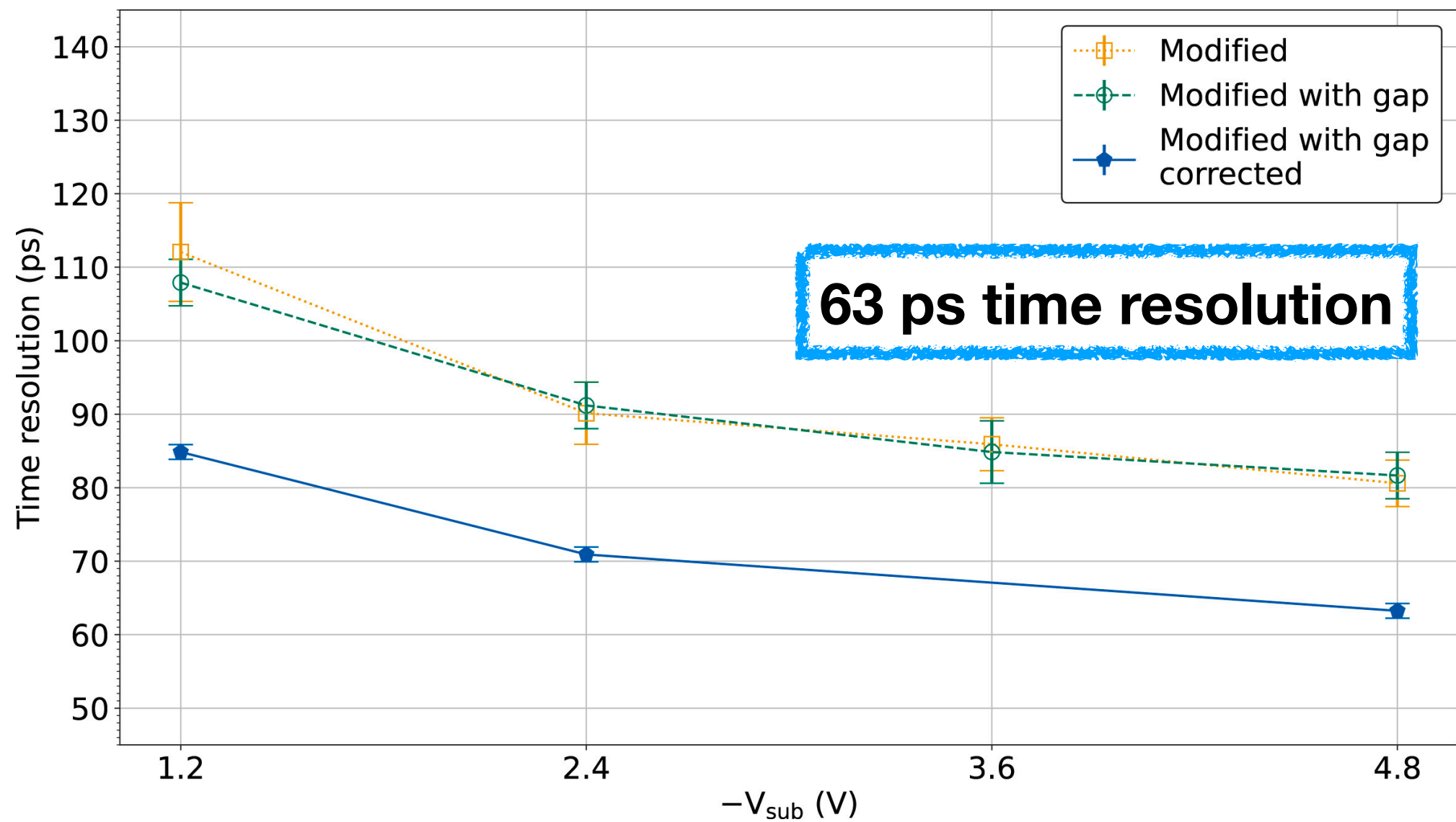
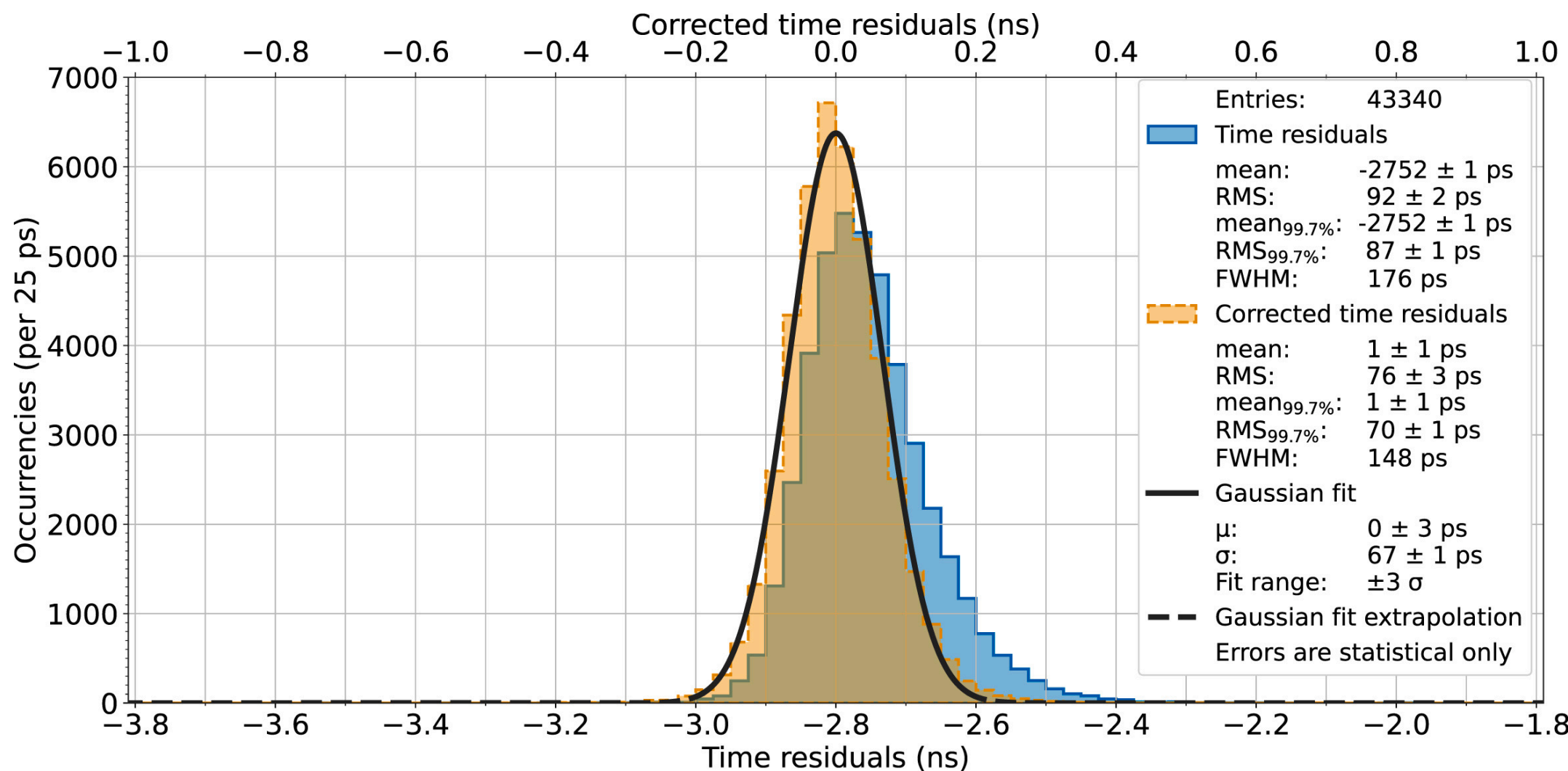
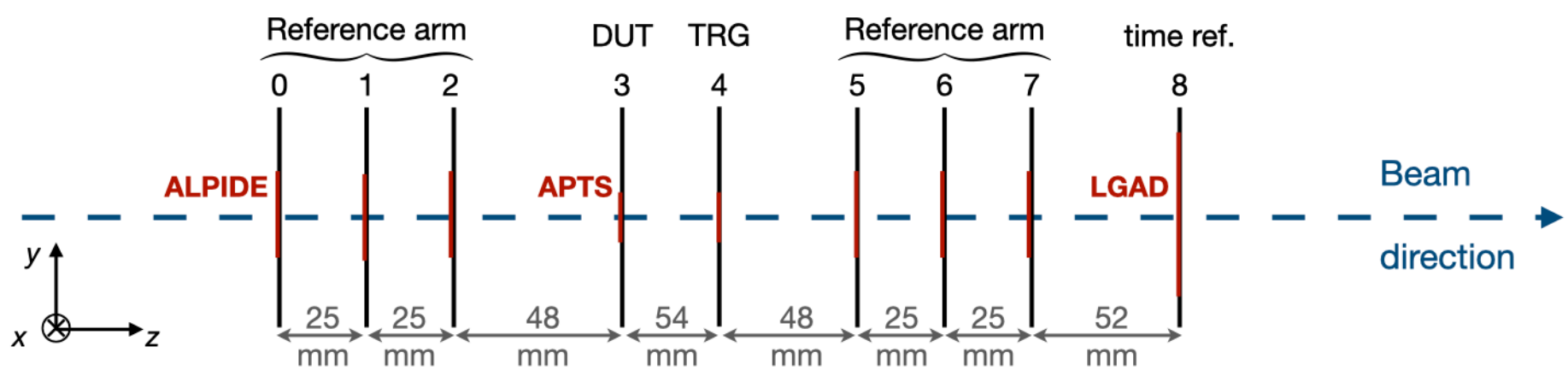
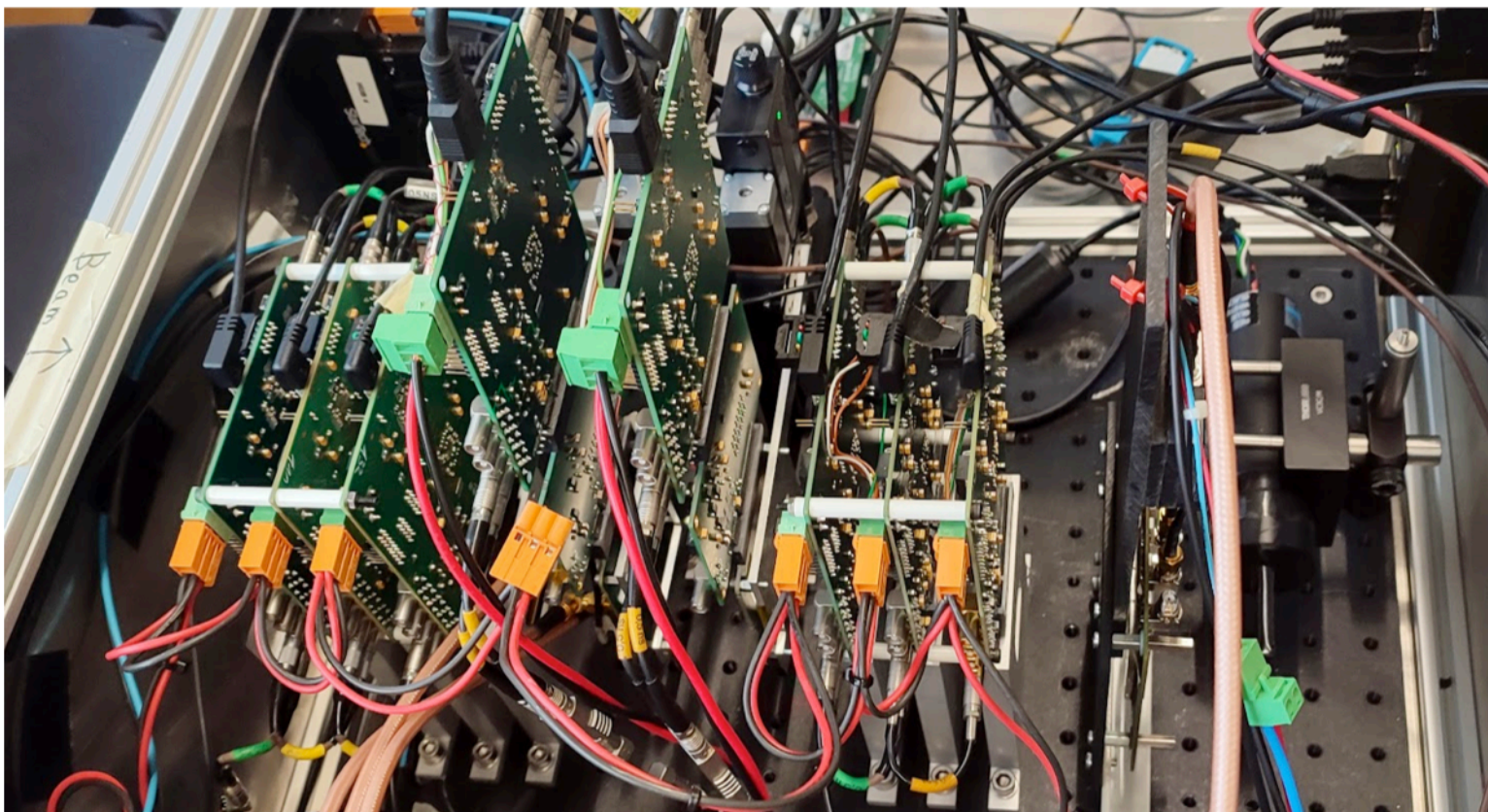
10.1016/j.nima.2023.168478

APTS-OA time resolution

CERN SPS facility - positive hadron beam (120 GeV/c)

Tracking resolution: $1.8 \mu\text{m}^*$
DUT: SPLIT 4 modified with gap
PSUB: from -1.2 to -4.8 V

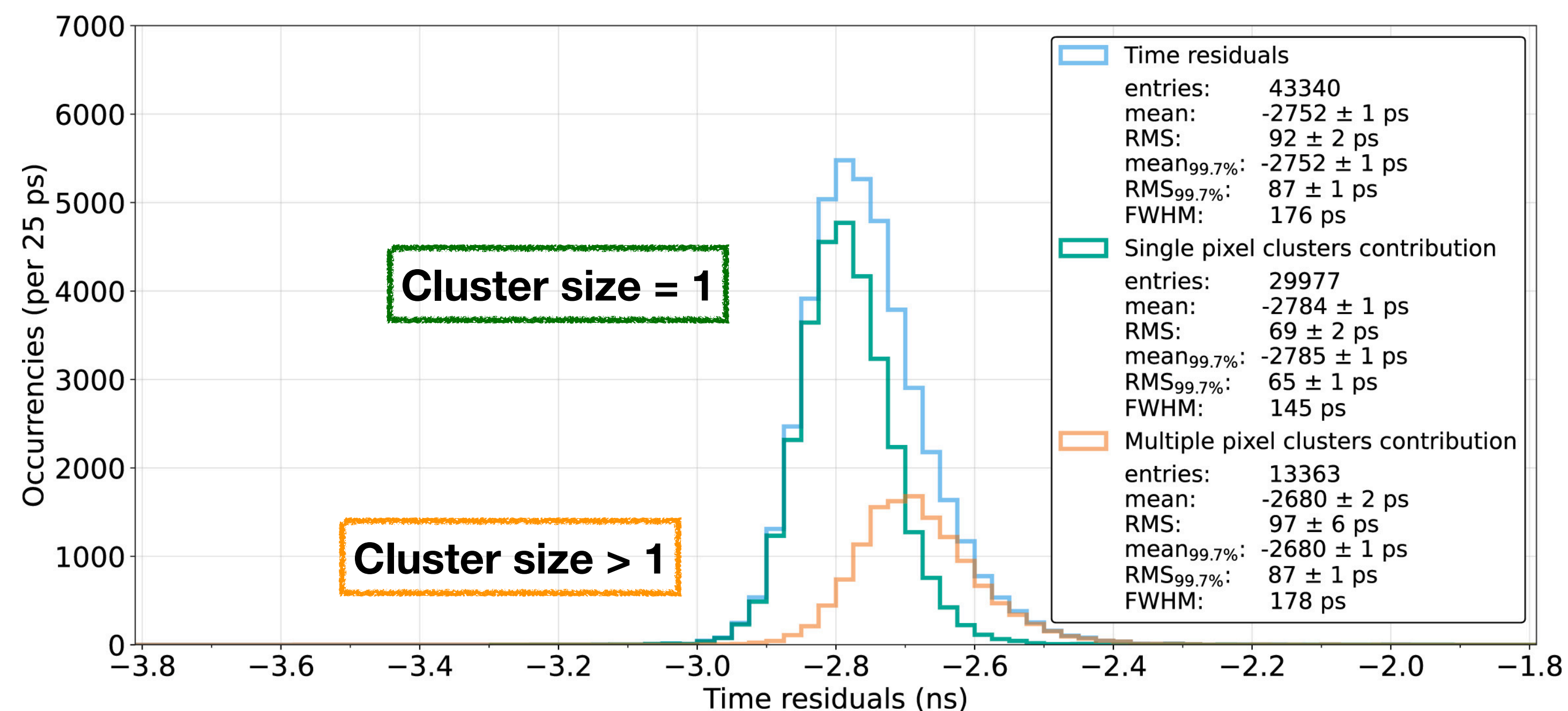
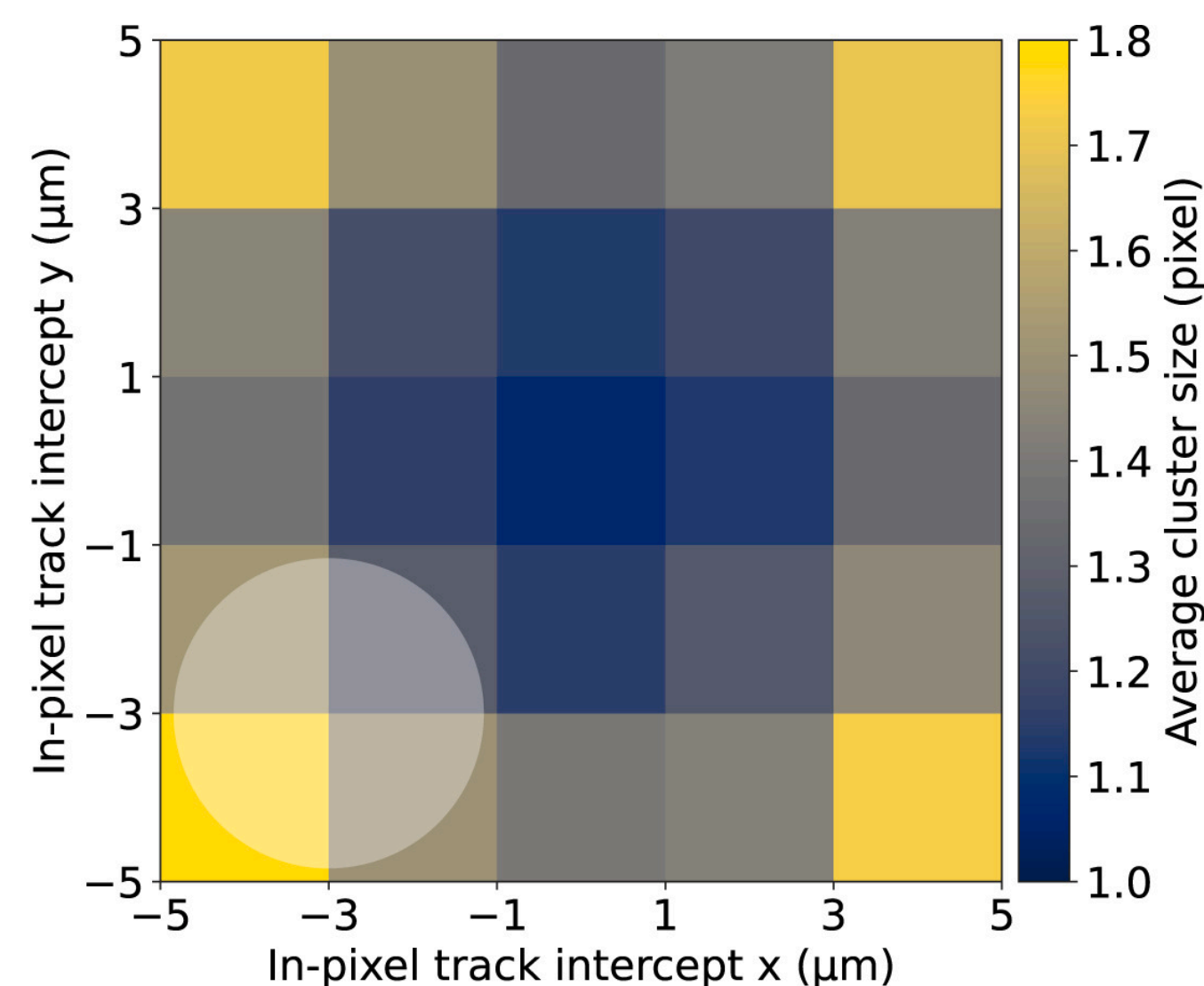
* <https://mmager.web.cern.ch/telescope/>



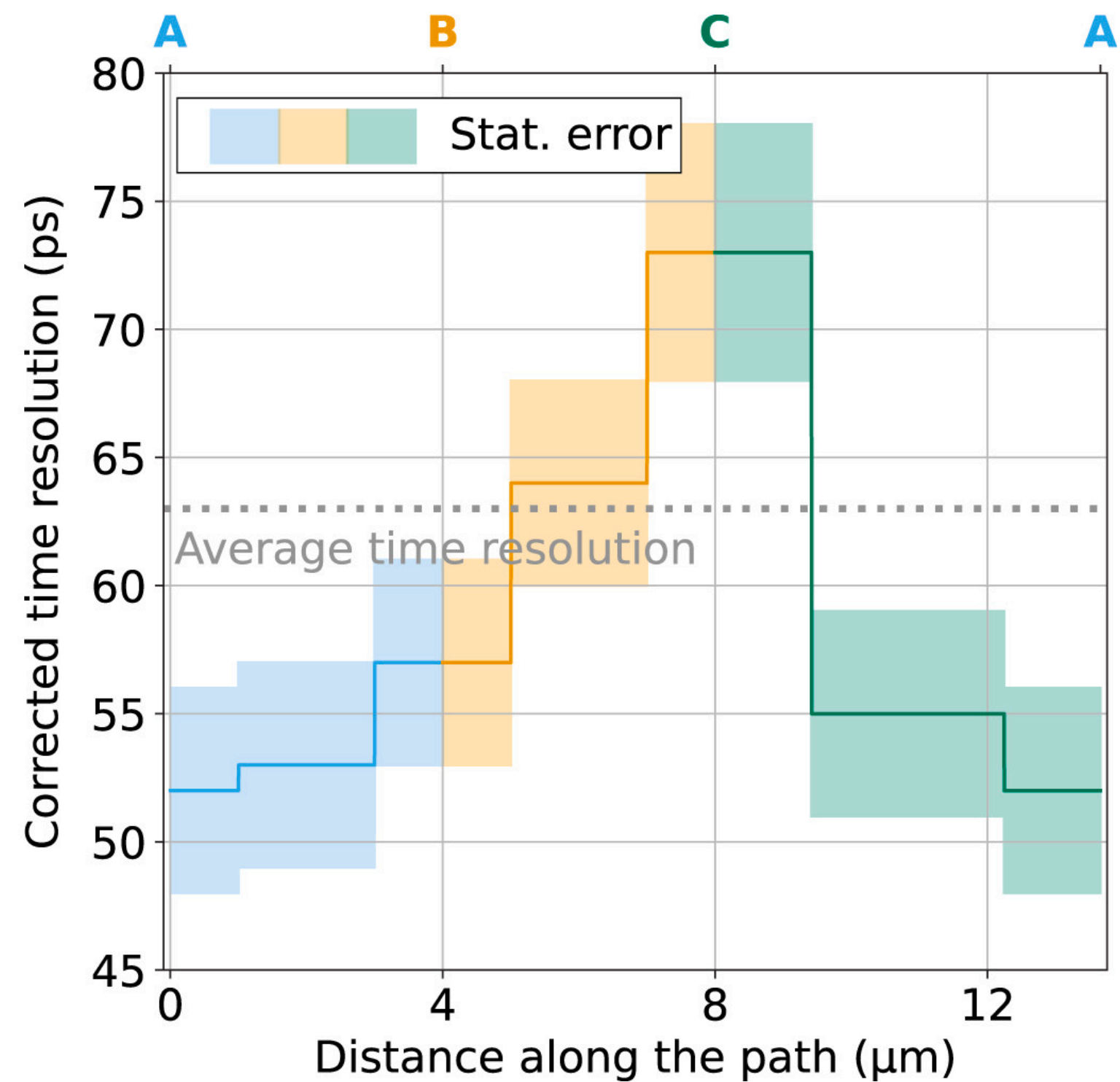
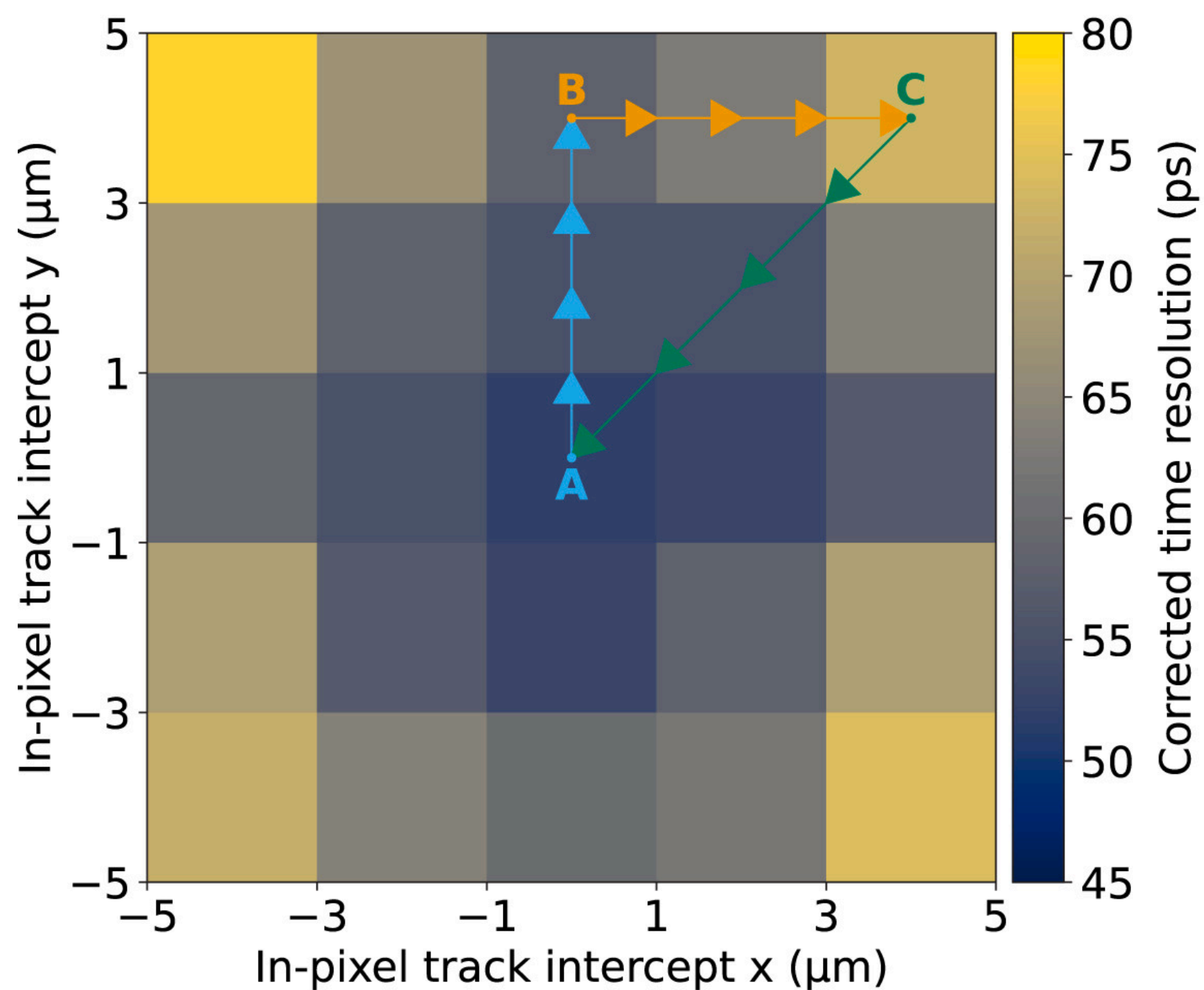
APTS-OA cluster size-based analysis

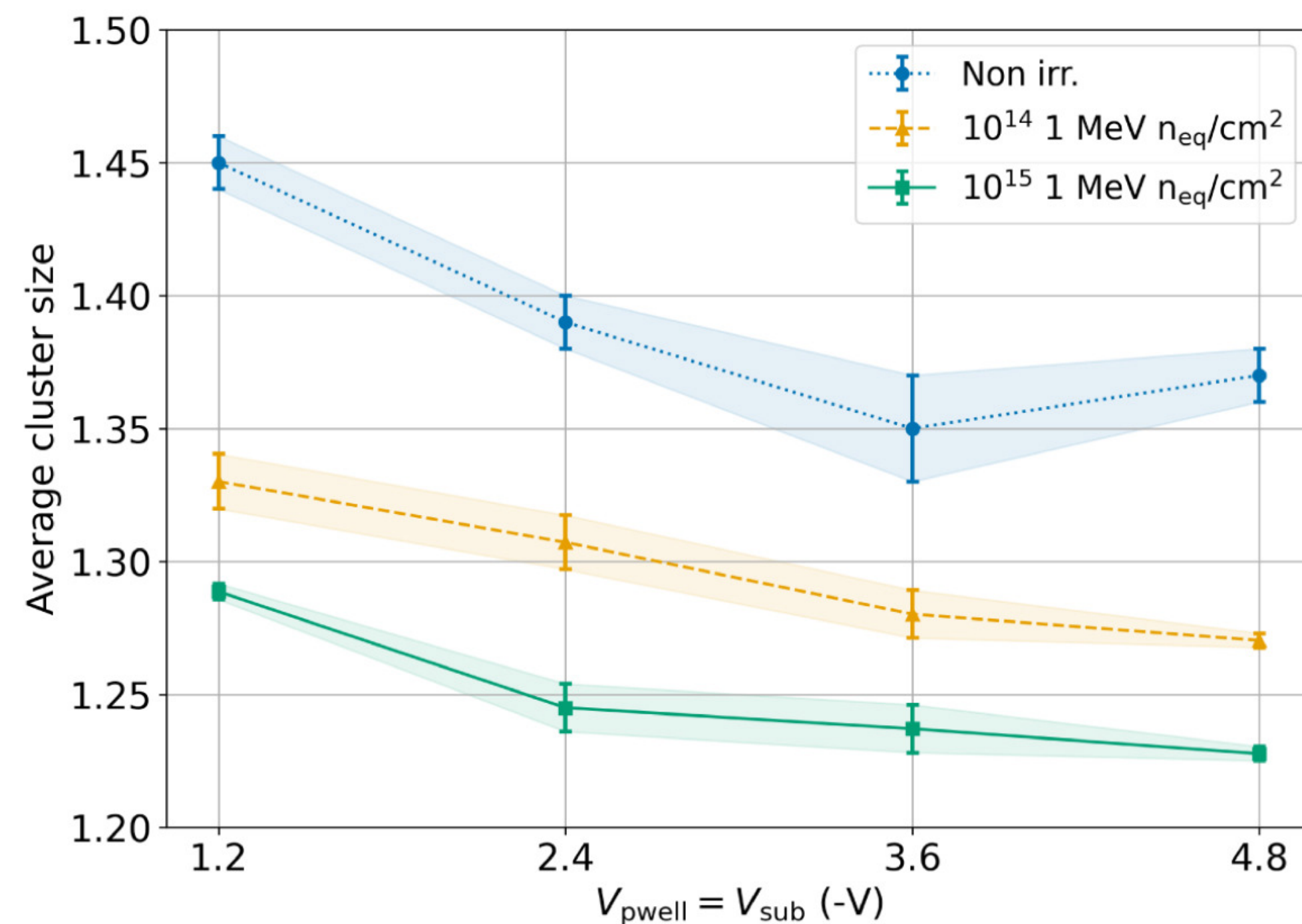
Cluster size provides a proxy for the particle impact position

Correlation between cluster size and particle impinging position

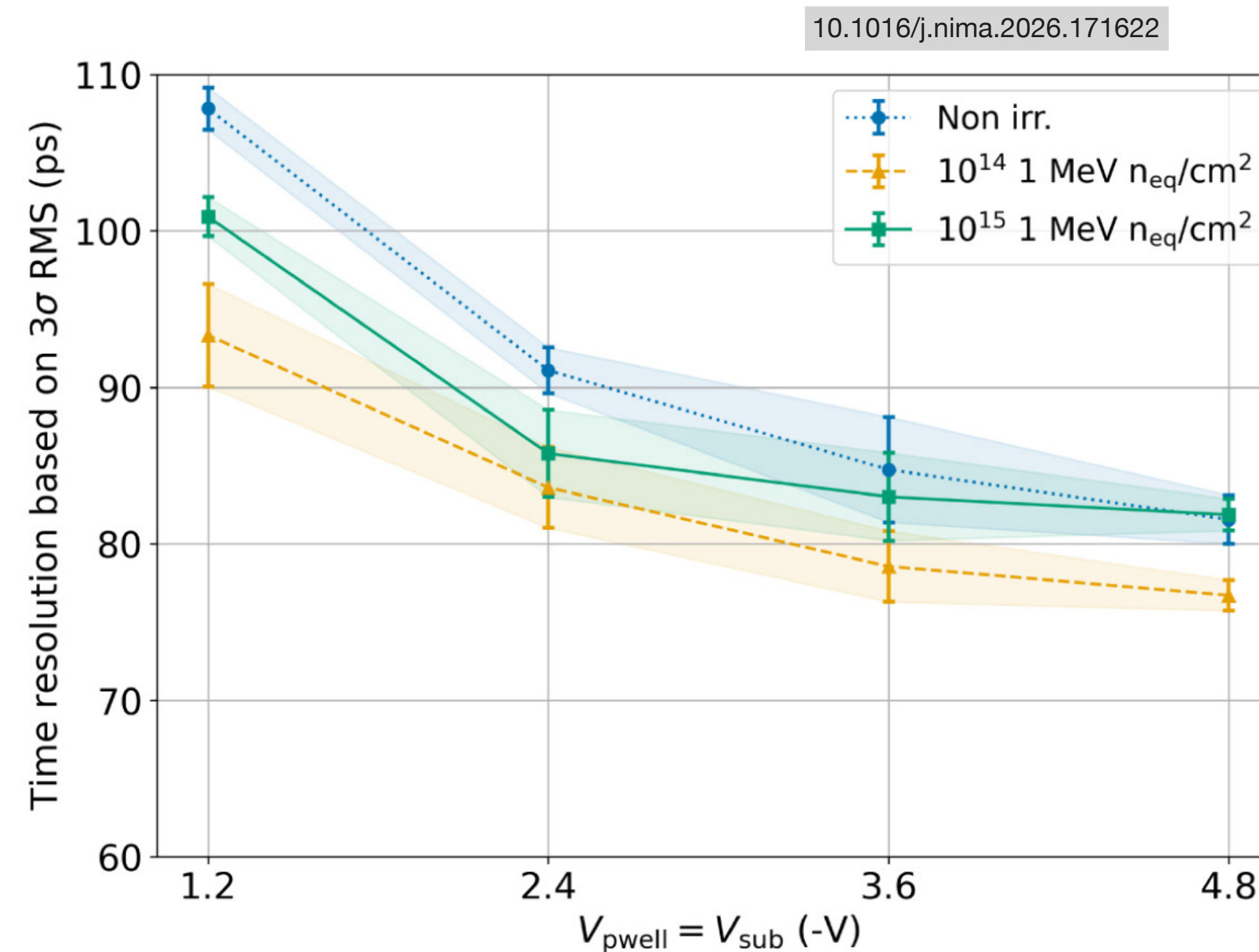


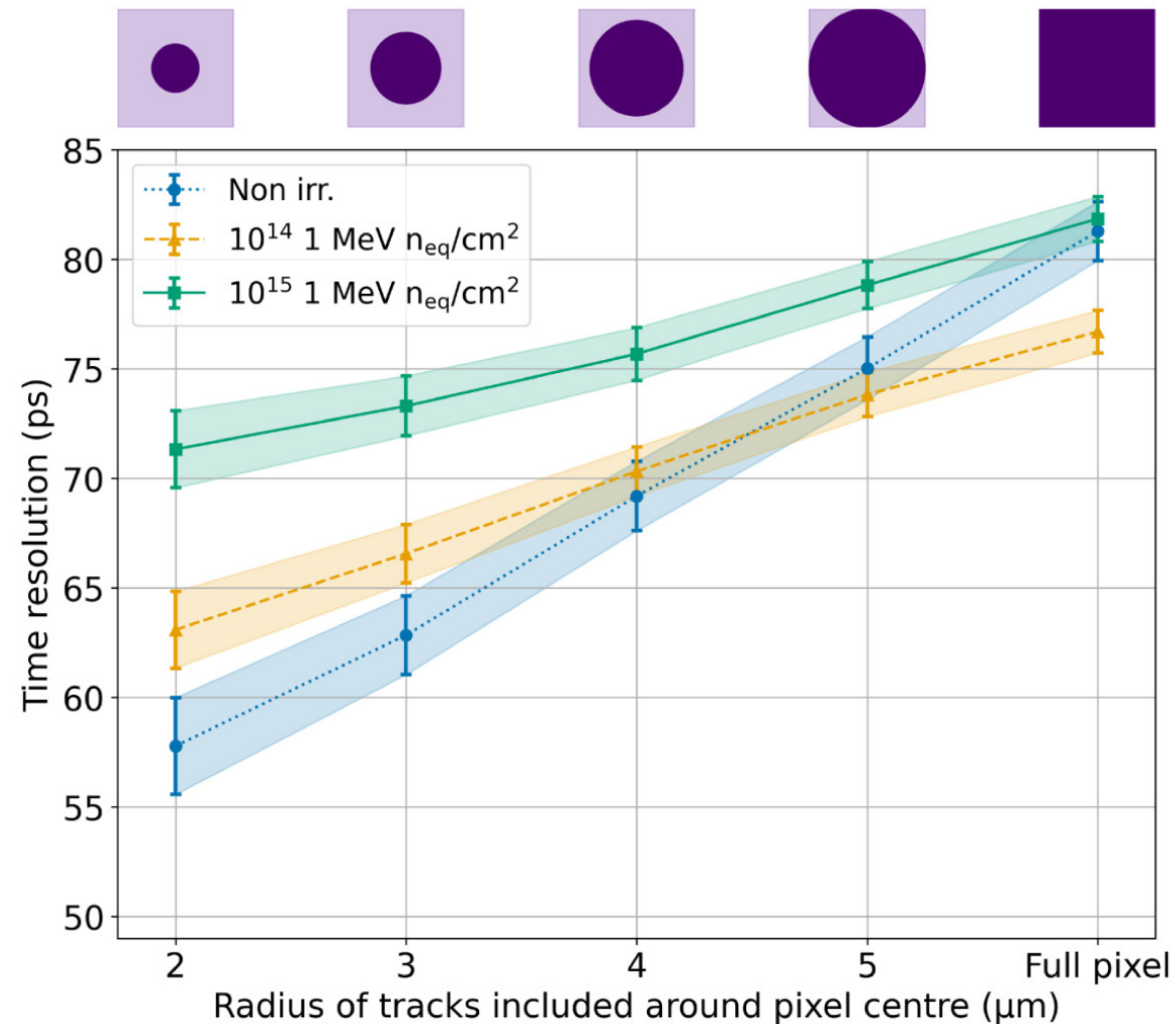
Timing performance degrades at pixel edges and corners





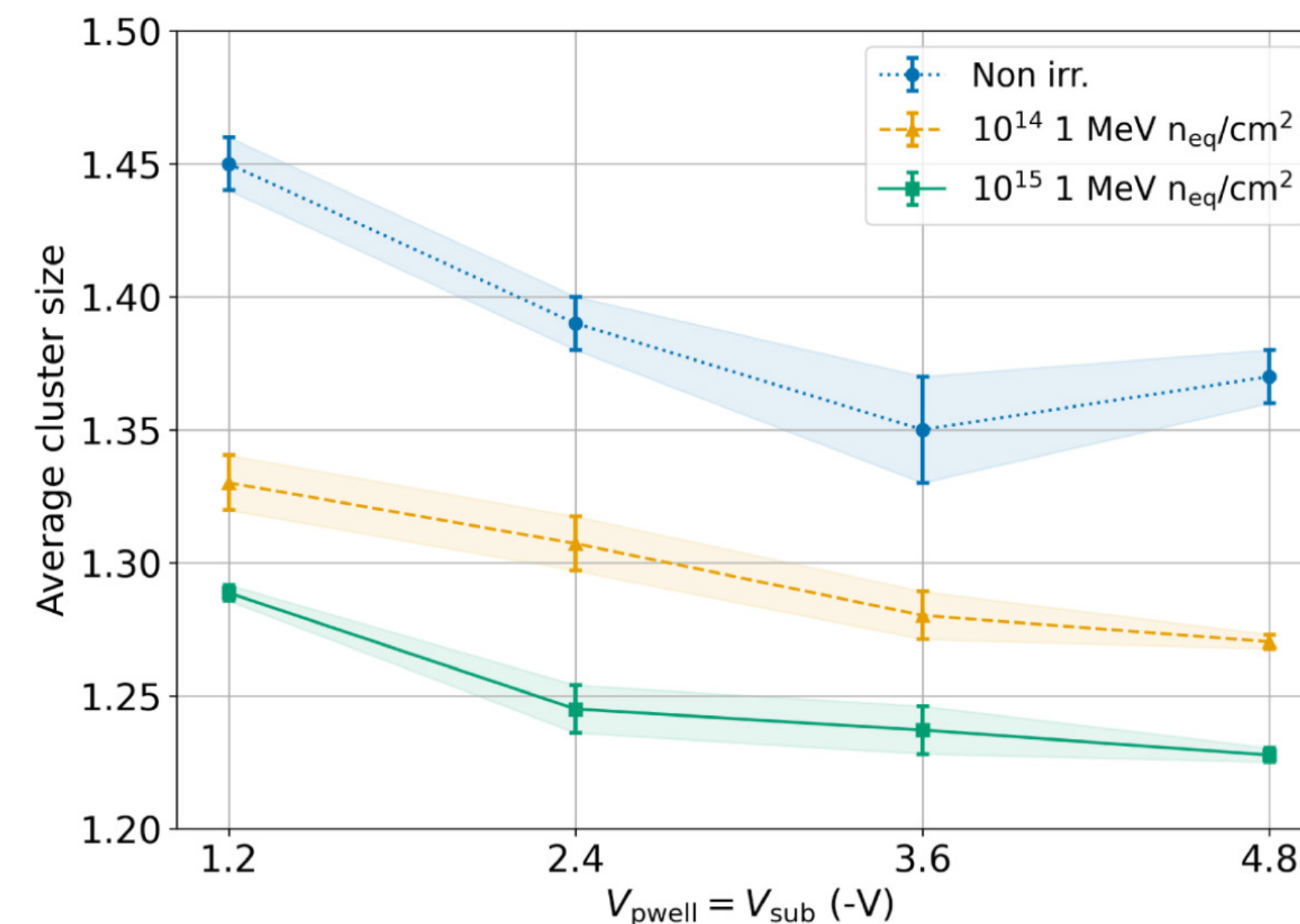
Irradiation reduces cluster size consistently with increased trapping and recombination





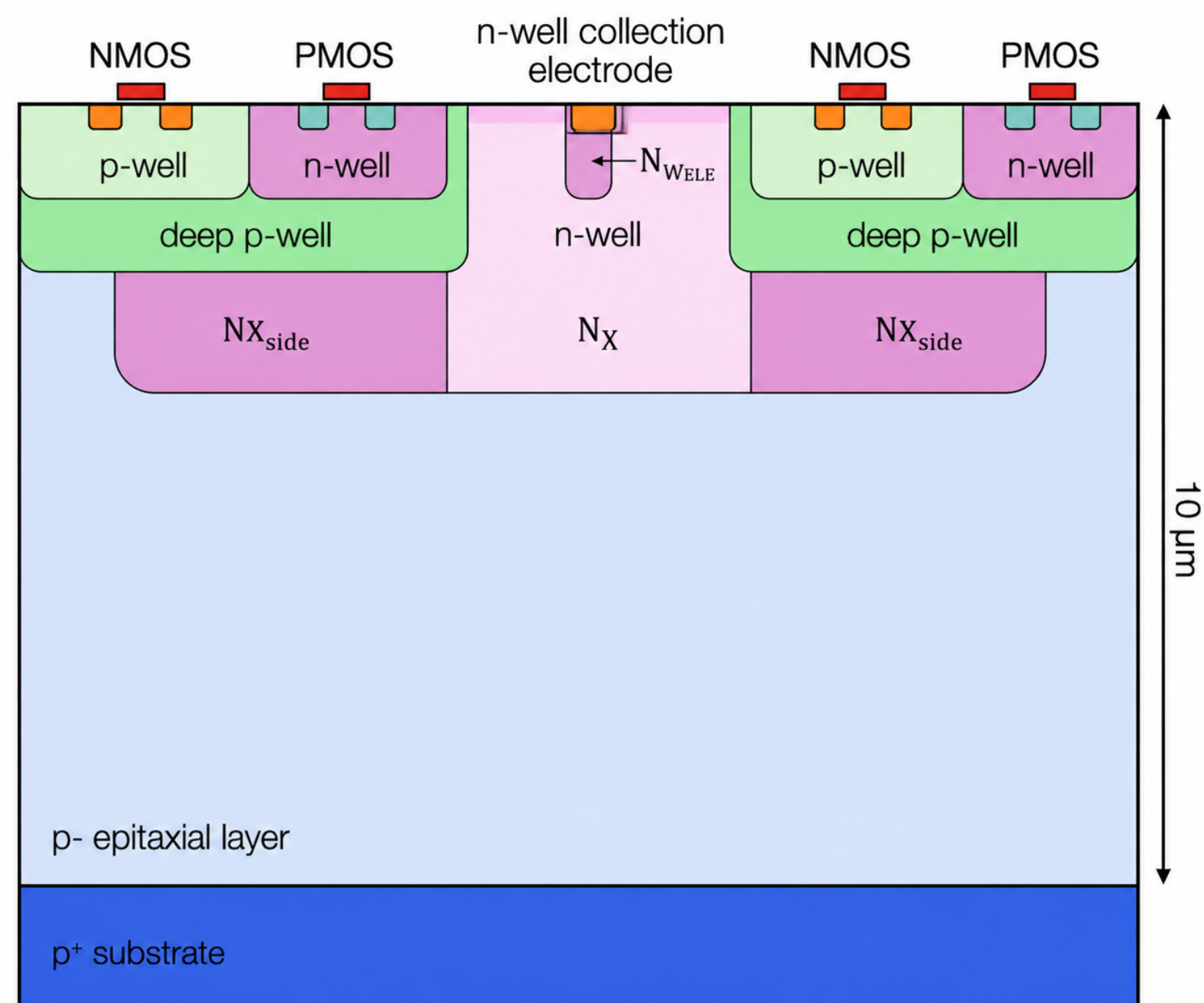
Two competing mechanisms:

1. the time resolution degradation due to reduced electric field and carrier trapping
2. preferential suppression of the slow component of the signal

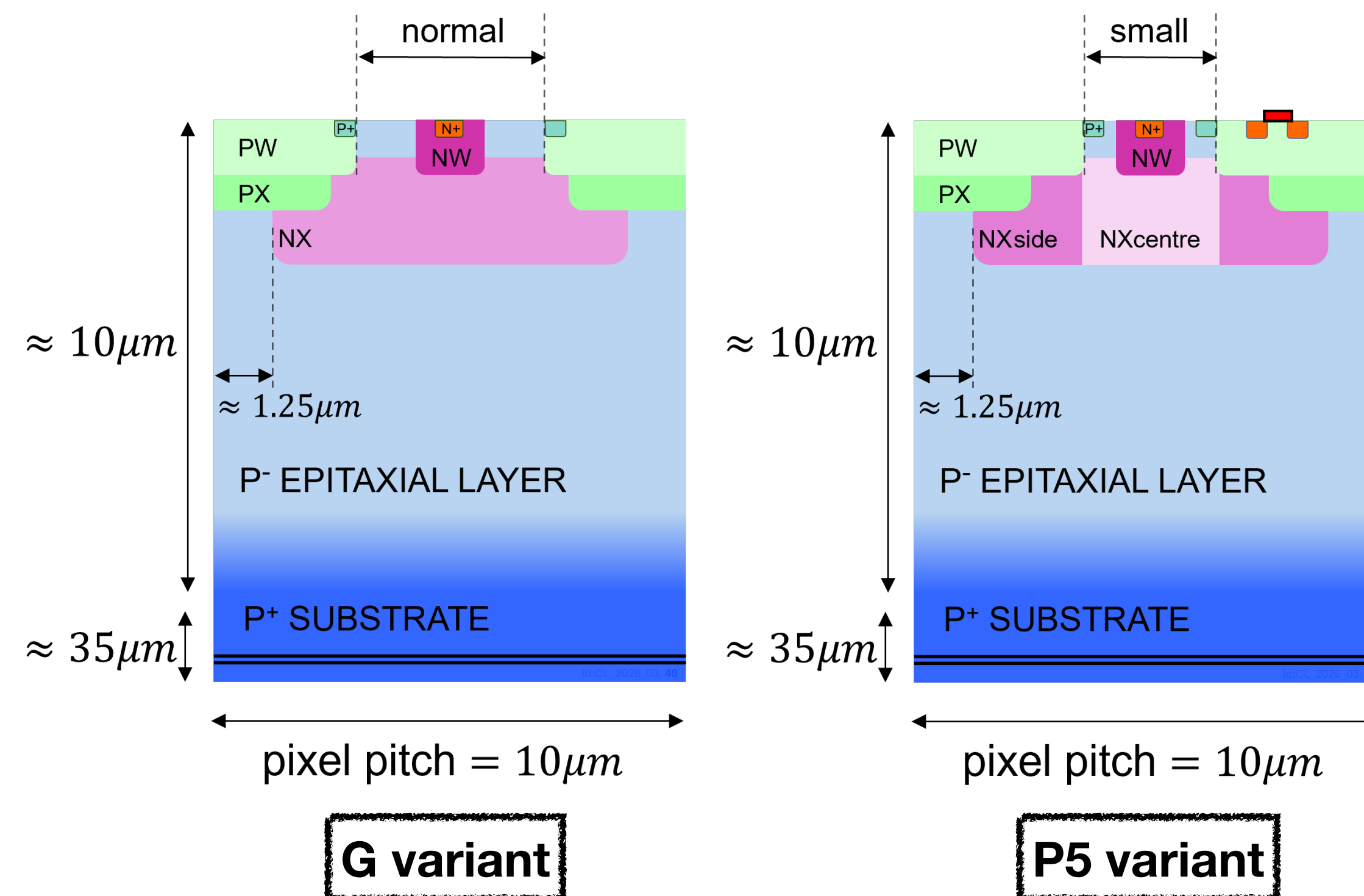


ER2 pixel developments

MLR1 results guide the design the ER2 structures



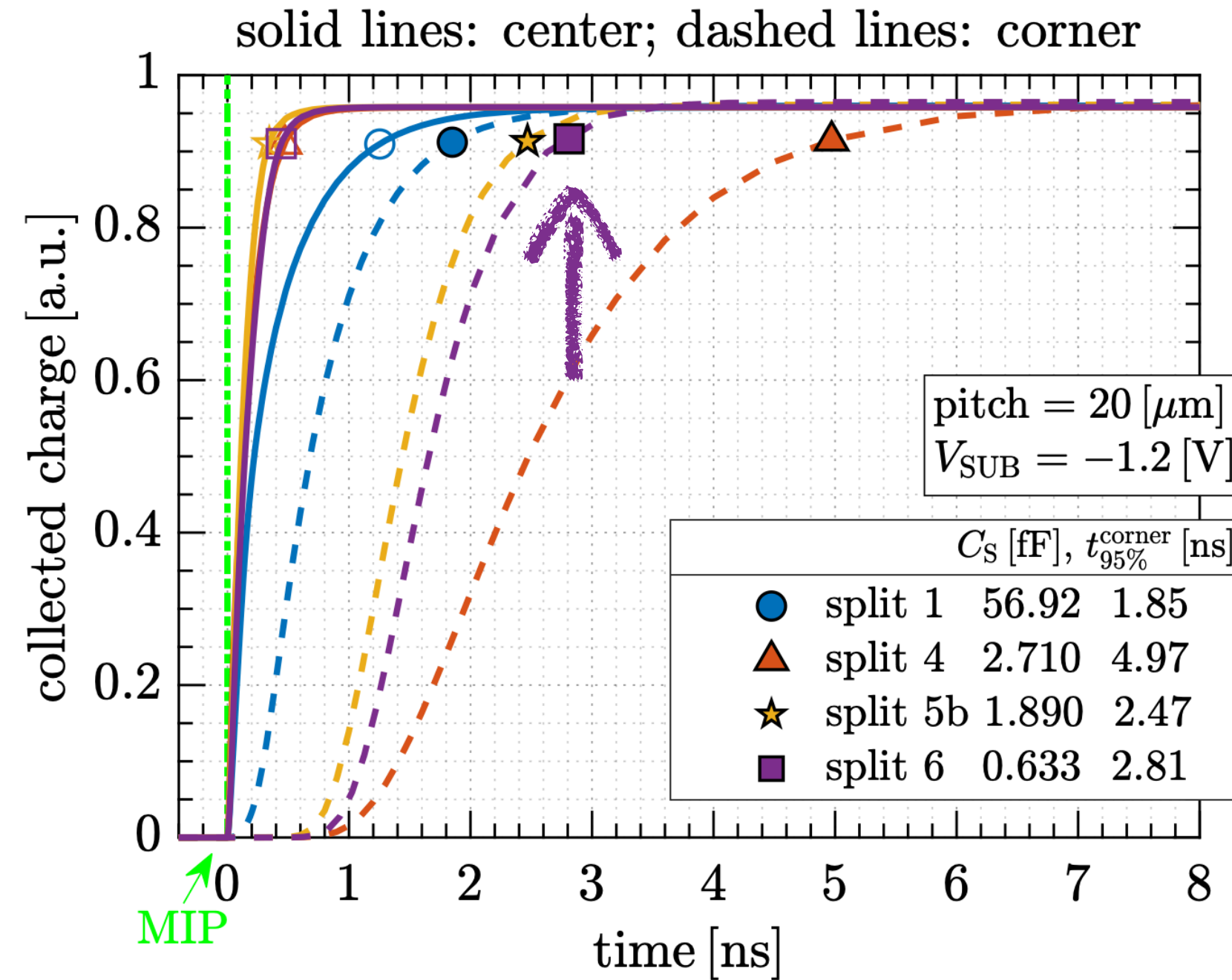
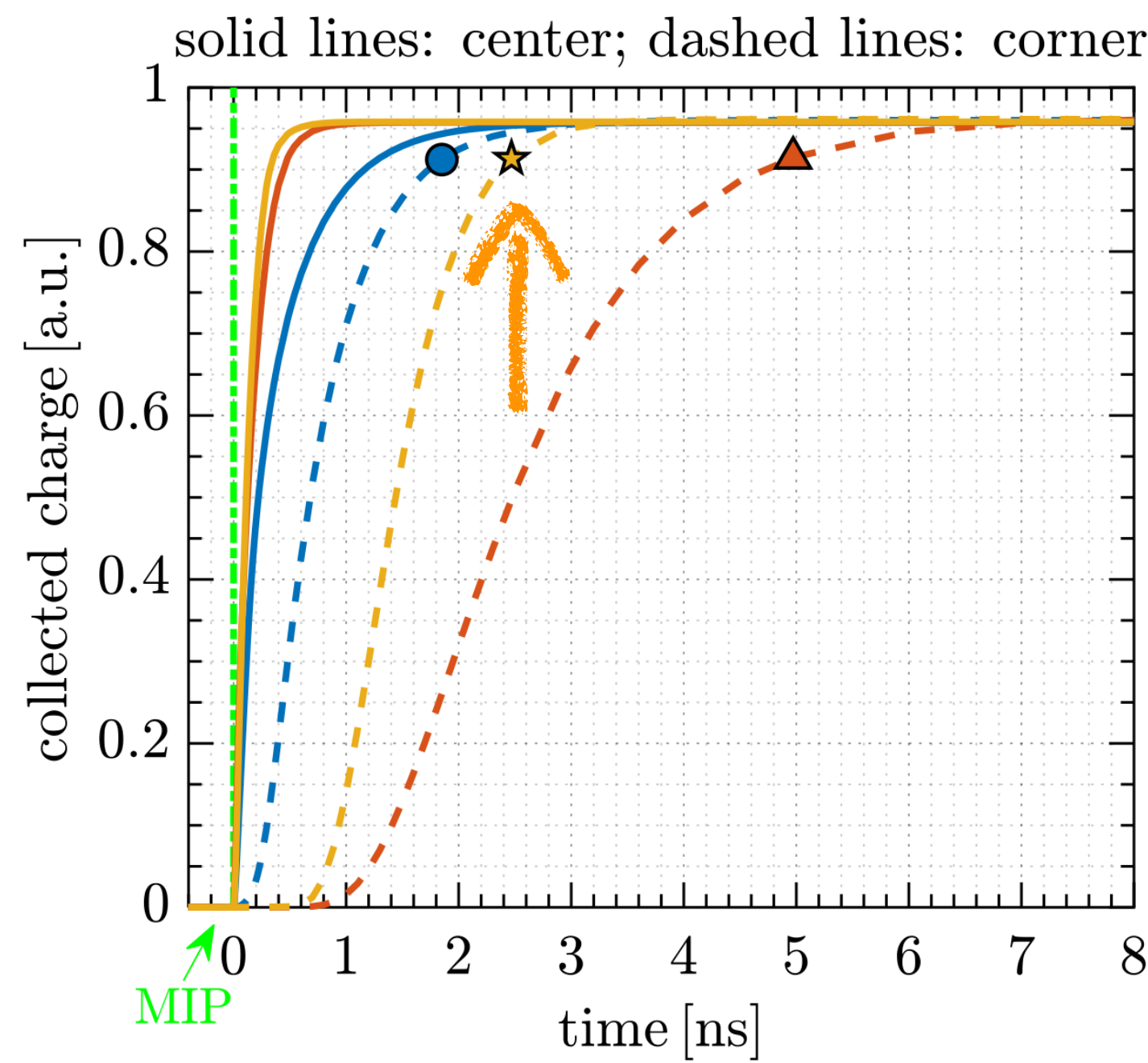
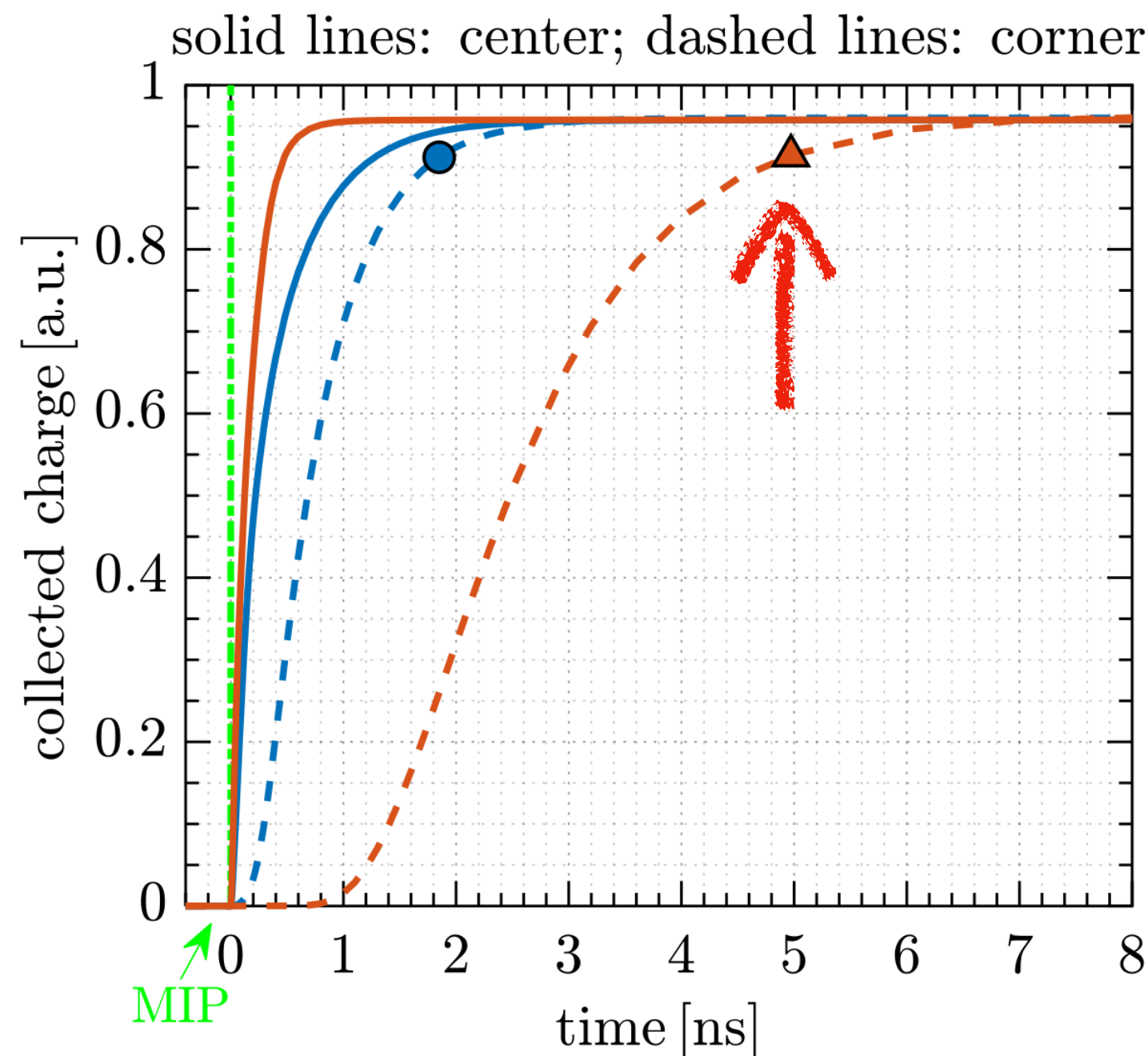
Two different doped regions into the epitaxial layer (N_x and N_{x-side}) to combine low sensor capacitance and good charge collection



Larger PWELL to allow more space for circuit

ER2 sensor split modifications

Simulation results



10.1088/1748-0221/20/07/C07053

SPLIT	1	4
Cs [fF]	56.92	2.71
T _{corner} [ns]	1.85	4.97
Pitch [μm]	20	20
PSUB [V]	-1.2	-1.2

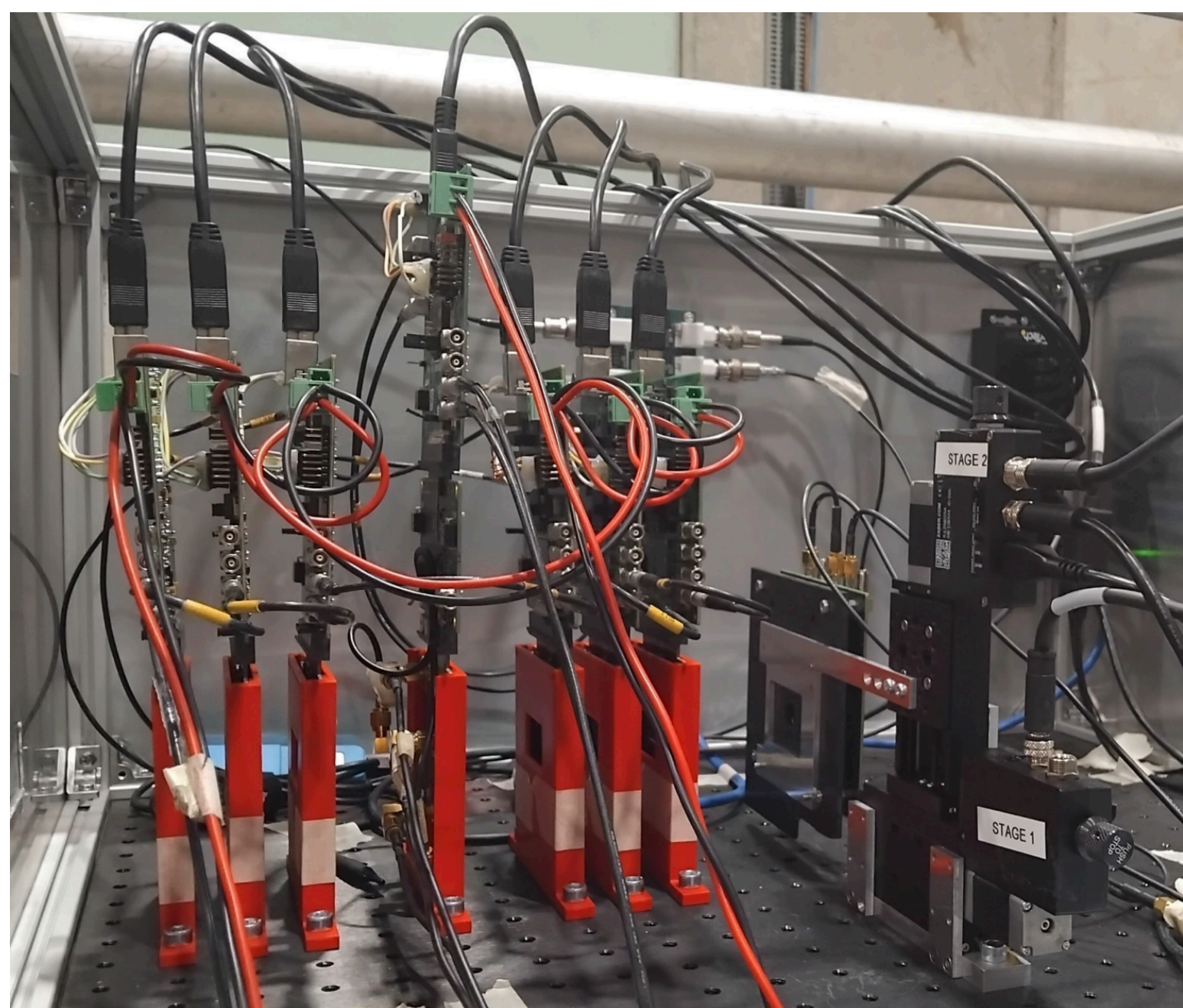
SPLIT	5
Cs [fF]	1.89
T _{corner} [ns]	2.47
Pitch [μm]	20
PSUB [V]	-1.2

SPLIT	6
Cs [fF]	0.63
T _{corner} [ns]	2.81
Pitch [μm]	20
PSUB [V]	-1.2

Test beam campaign

CERN SPS facility - positive hadron beam (120 GeV/c)

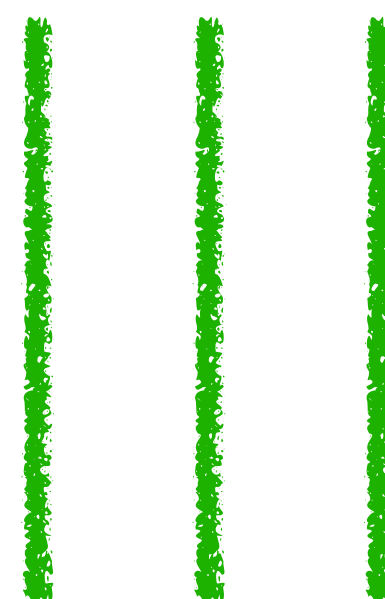
Analysis ongoing



Trigger plane: APTS-OA
Tracking resolution: 2.5 μm *
DUT: split 5, 6 - P5 variant
PSUB: from -1.2 to -4.8 V

* <https://mmager.web.cern.ch/telescope/>

Tracking



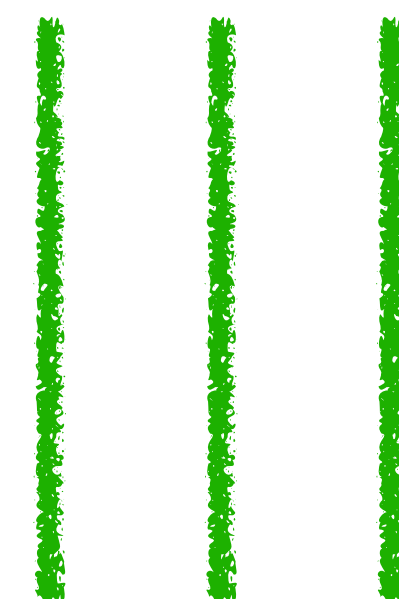
ALPIDE
 1024x512
 30 μm

DUT



APTS OA
 4x4
 10 μm

Tracking



Time ref.



LGAD
 1x1
 1 mm

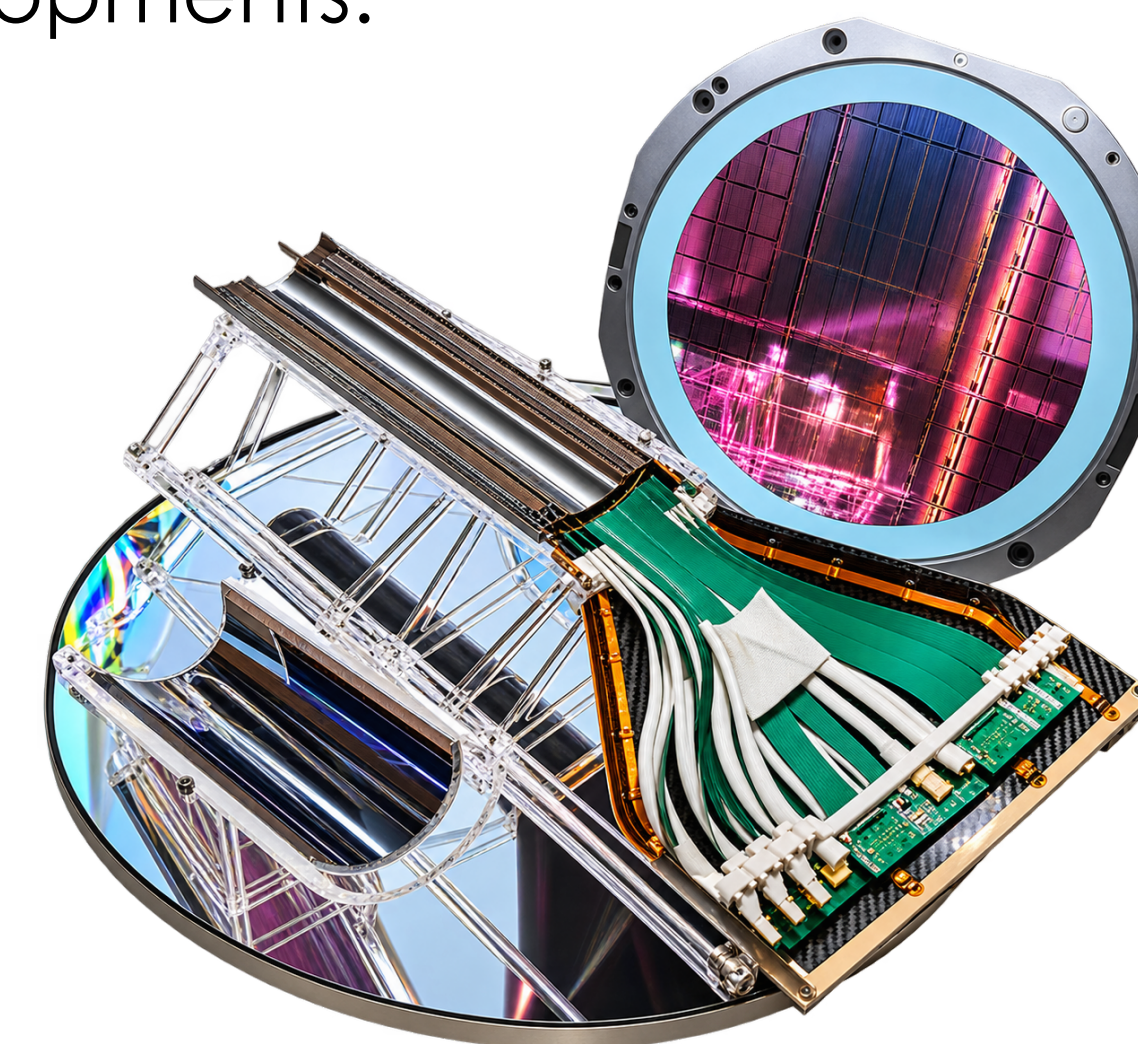
** w/ moving stage

APTS-OA measurements **link sensor geometry to charge-sharing and timing performance.**

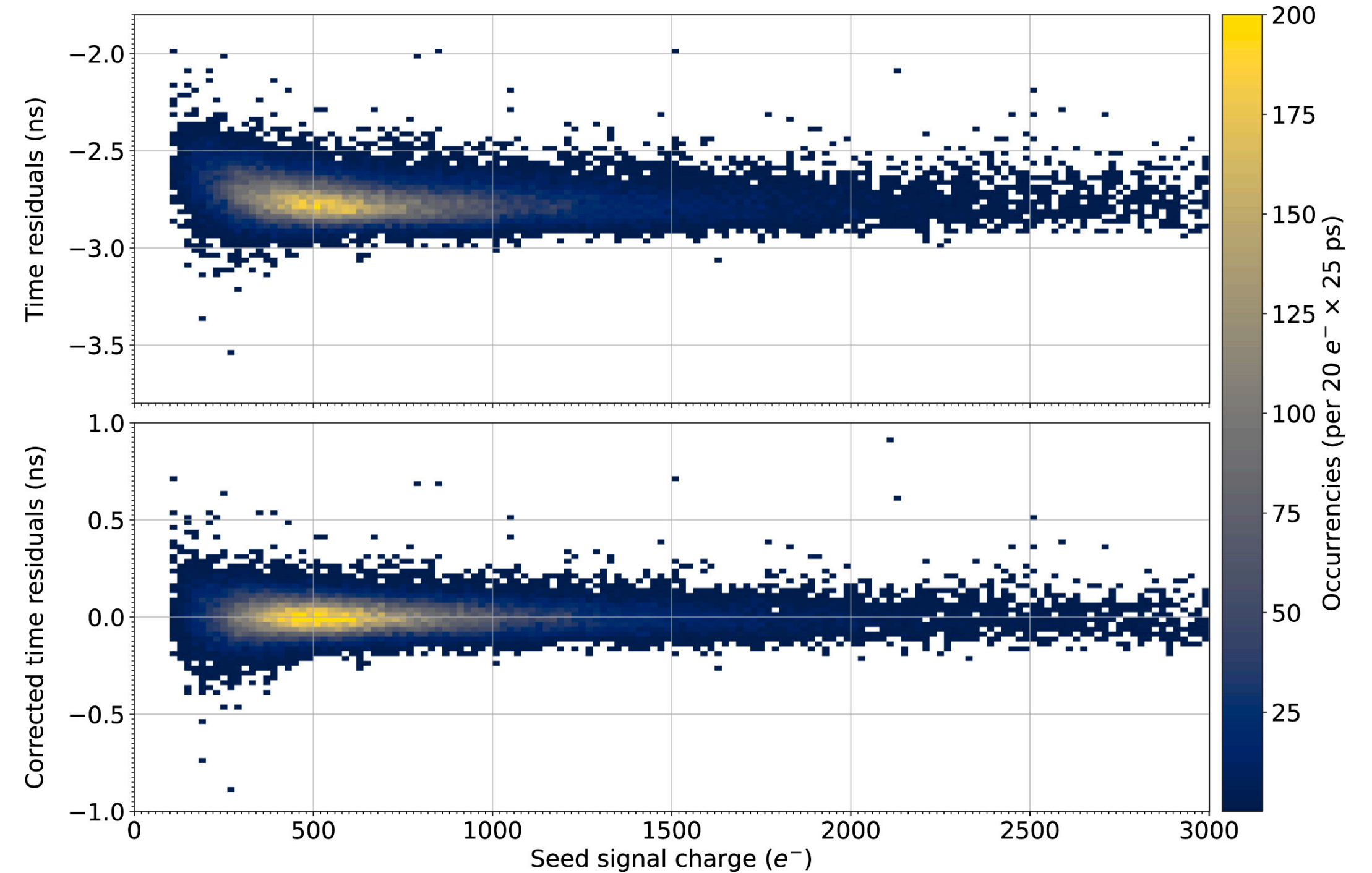
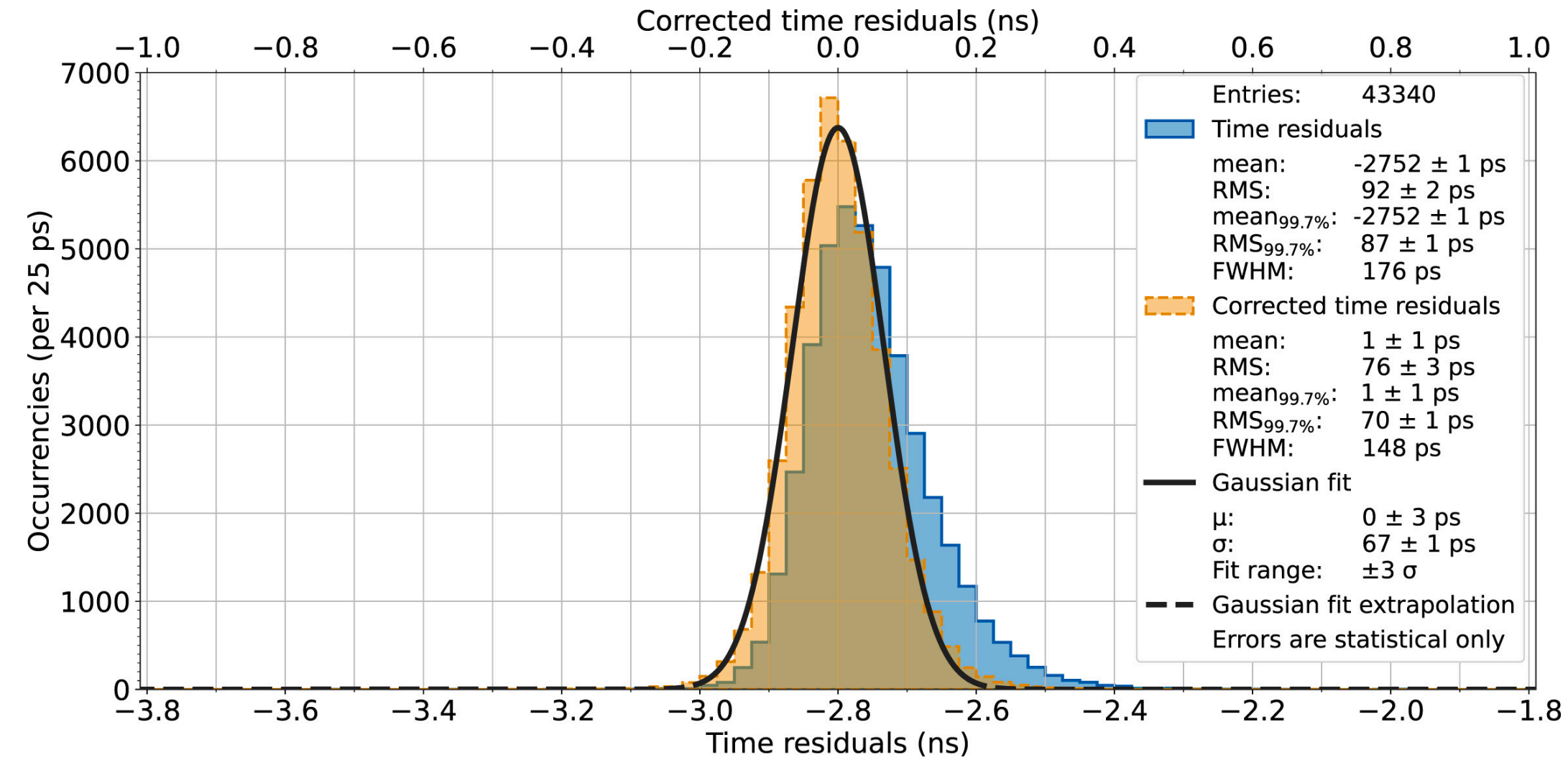
The modified-with-gap process **suppresses the slow charge-sharing** component and achieves a **time resolution of 63 ps.**

After irradiation, charge trapping changes the spatial timing response, while **performance remains beyond the ITS3 radiation target.**

Guided by these results, the ER2 splits 5 and 6 designs **reduce input capacitance** and **charge sharing**, making them promising candidates for future ITS developments.



Backup slides



Time-correction procedure

- Divide the dataset according to cluster size:
 - single-pixel clusters ($CS = 1$)
 - multi-pixel clusters ($CS > 1$)
- Split each cluster-size sample into two independent subsets
- Derive the time correction from the first subset
- Apply it to the second subset to avoid introducing analysis bias