TI-LGAD Testbeam analysis results

JSI status

Iskra Velkovska

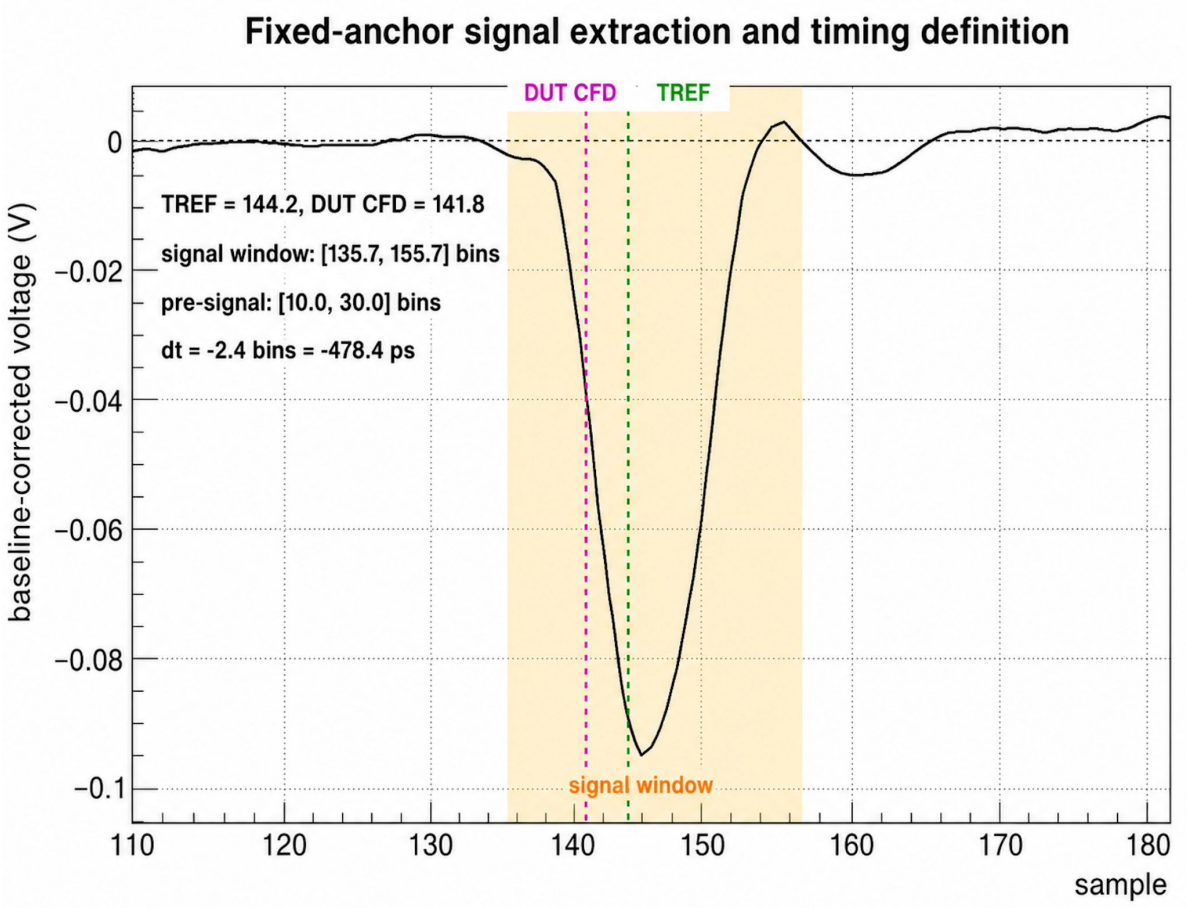
Testbeam Analysis Meeting 31/07/26

Jožef Stefan Institute
Ljubljana, Slovenia

OUTLINE

- Explanation of waveform processing and hit definition
- Track reconstruction and integration of CMS ReadOut Chip
  - Triggering configuration and ROI definition
- Timing and tracking results
  - Results for non-irradiated and irradiated TI-LGAD structures with different trench characteristics
  - Interpixel distance estimation
  - Time resolution with track-based TREF-anchor selection
  - Trench region signal spectrum compared to nearby non-trench region
- Conclusions

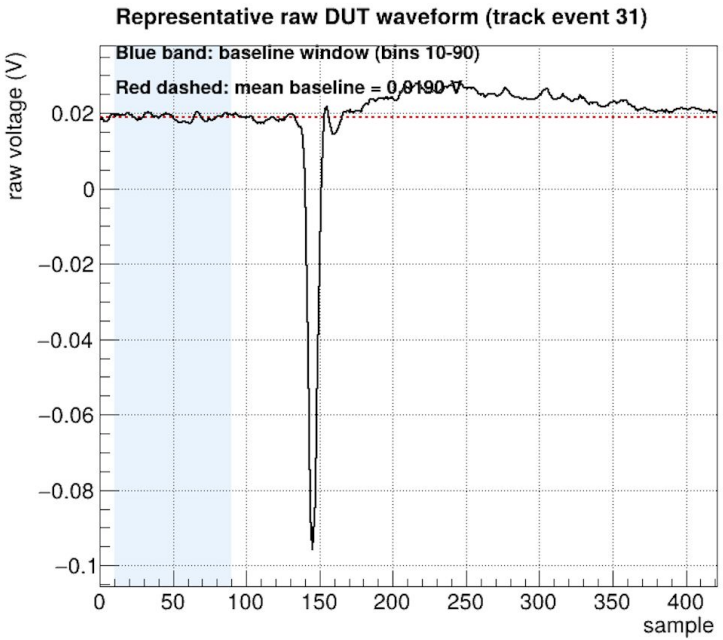
Time reference-anchored signal definition of the DUT

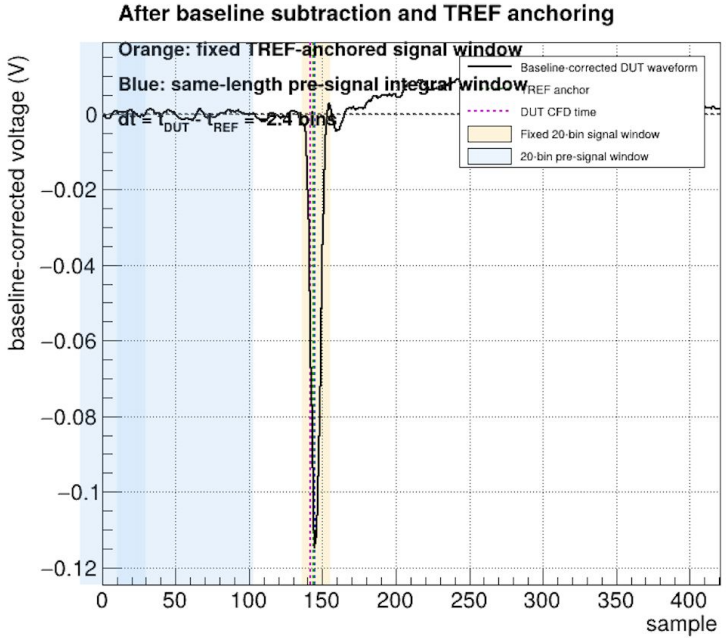


- TREF CFD defines the event time anchor
- Same-length pre-signal window used for baseline reference
- $dt = t_{DUT} - t_{REF}$
- The DUT charge is integrated in a fixed 20-bin window placed relative to the TREF CFD anchor, to avoid the pedestal bias of peak-centering while retaining the main part of the DUT pulse for the selected events in this run

Example event showing the fixed TREF-anchored signal definition

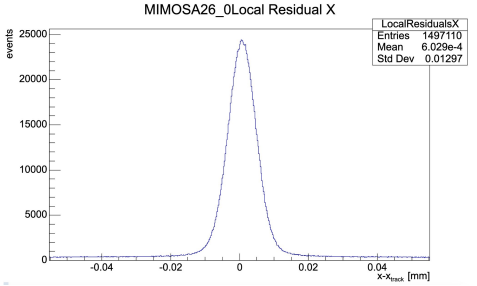
- REF waveform defines the time anchor.
- DUT signal is integrated in a fixed 20-bin window relative to that anchor.
- A same-length pre-signal window is used for the baseline reference.
- dt is the time difference between DUT and reference.

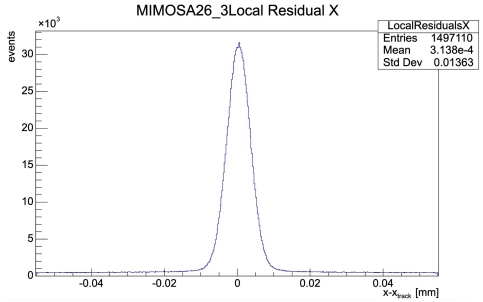


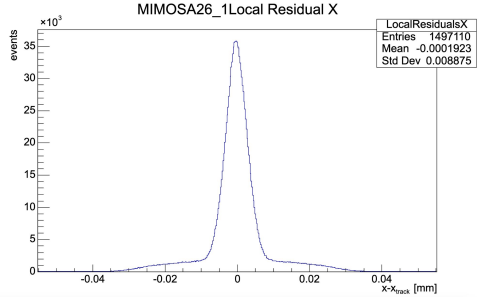


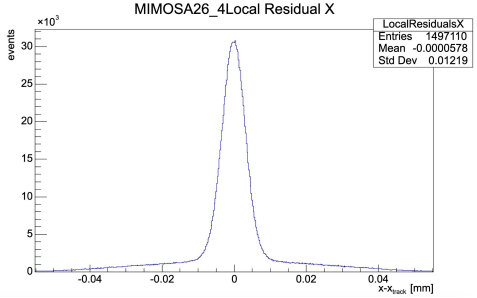
March TB 2026: 100 um x 25 um CROC, efficiency plots with the CROC included

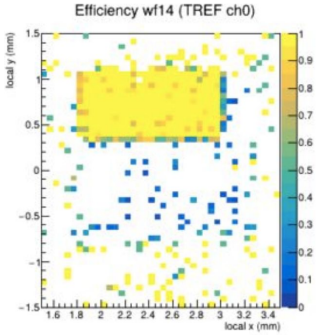
select only tracks that passed through the CROC active region

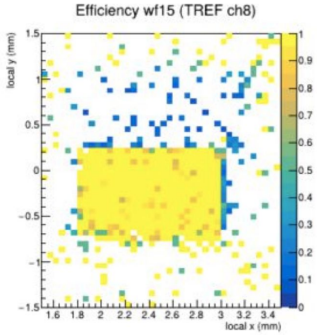


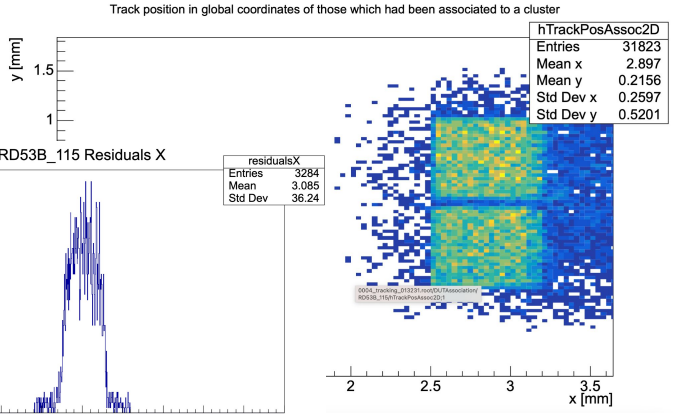


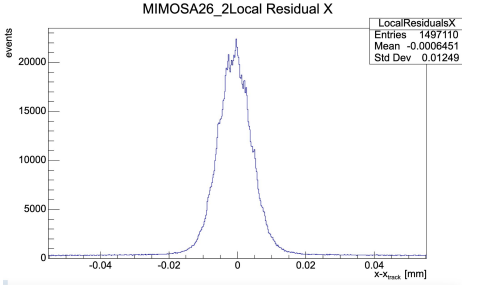


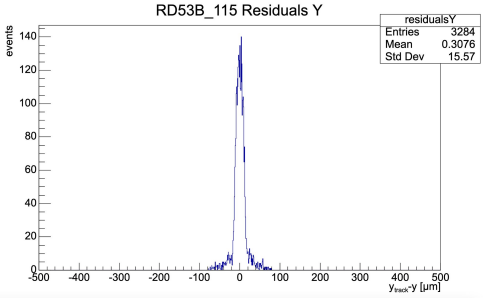




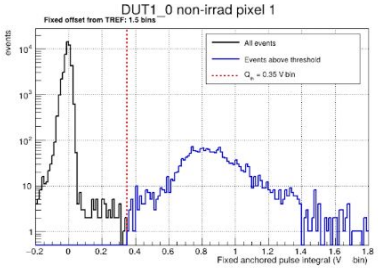


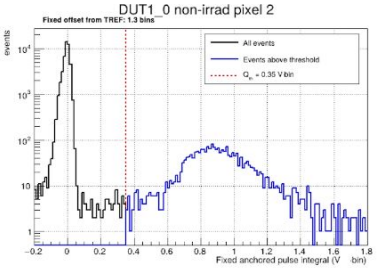


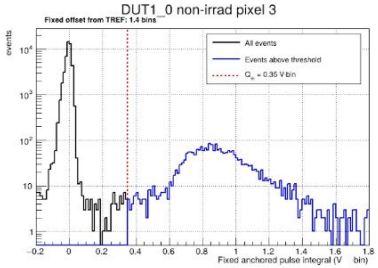


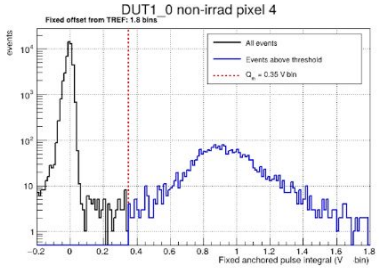


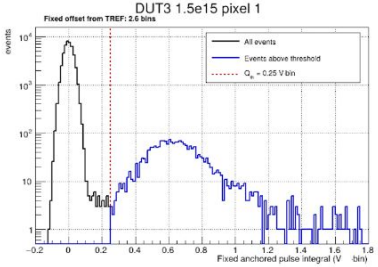
Pulse-integral distributions for TI-LGAD pixels before and after irradiation

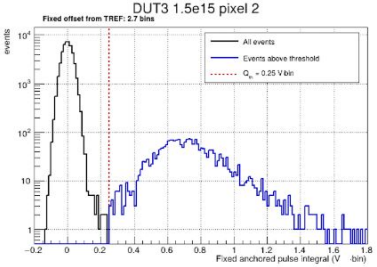


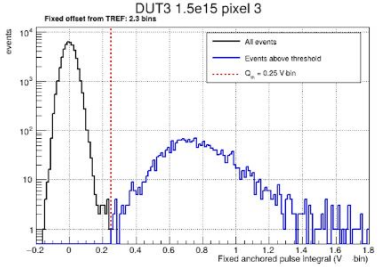


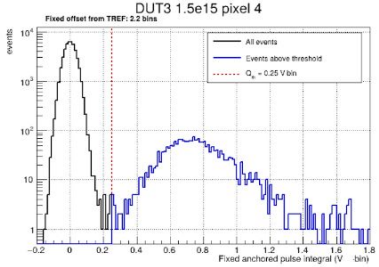








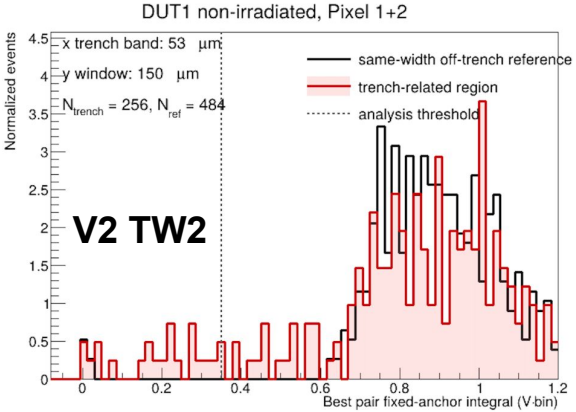


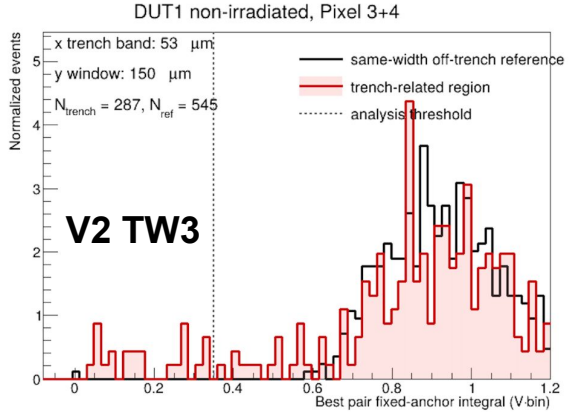


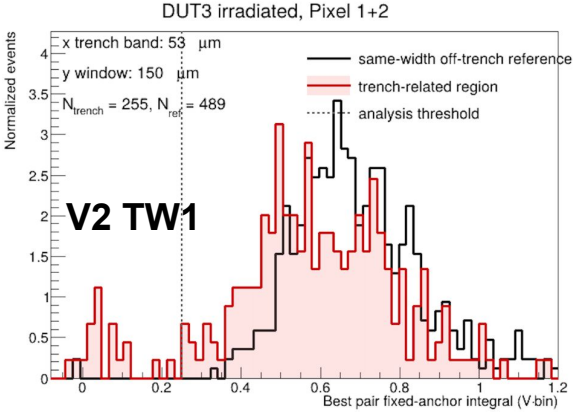
Top: non-irradiated DUT
Bottom: DUT irradiated to 1.5×10^{15} n_{eq}/cm^2

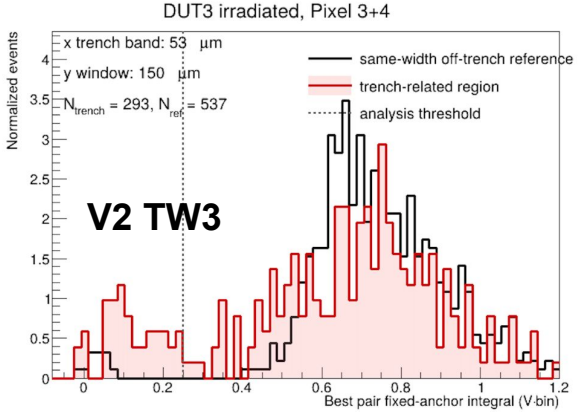
Black distributions contain all events, blue distributions show events passing the pulse-integral threshold

How does the trench-region signal spectrum compare to a nearby non-trench region?



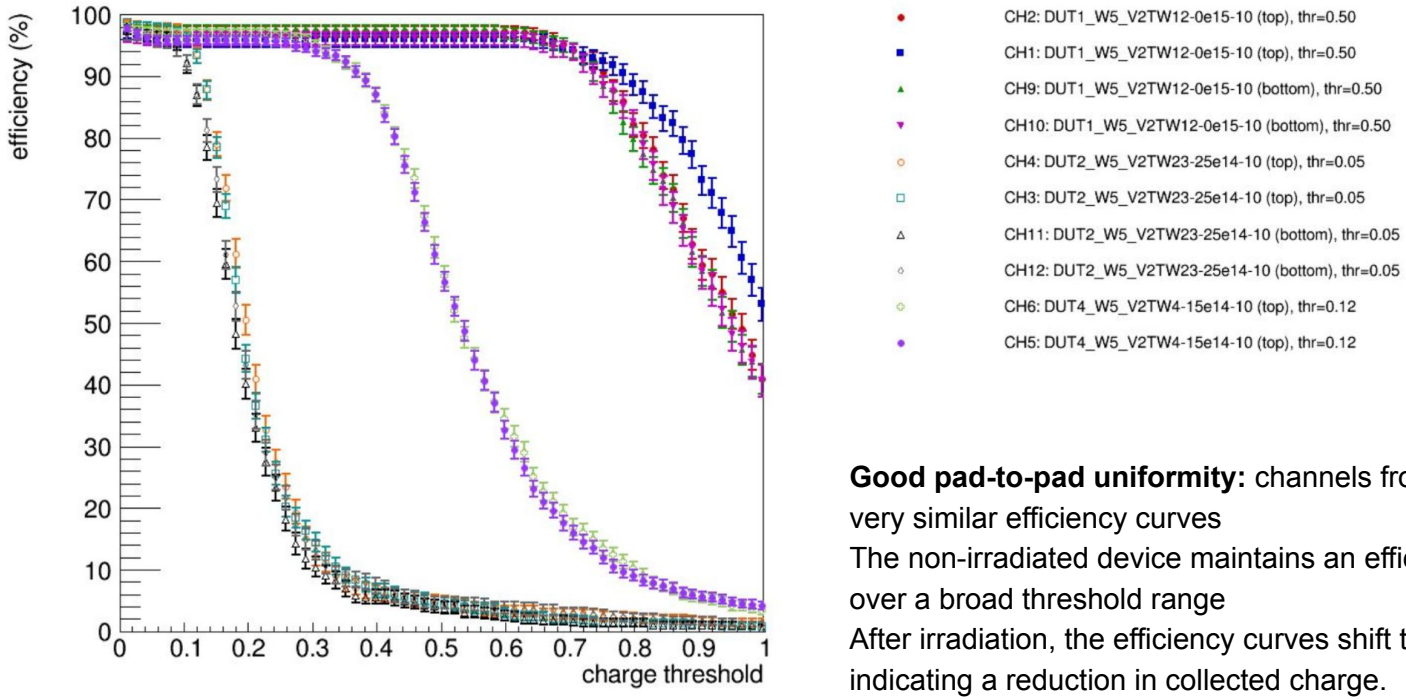






The trench-related region shows a lower-charge population than the off-trench reference region, which is consistent with the local efficiency loss.

Per-pad detection efficiency versus charge threshold

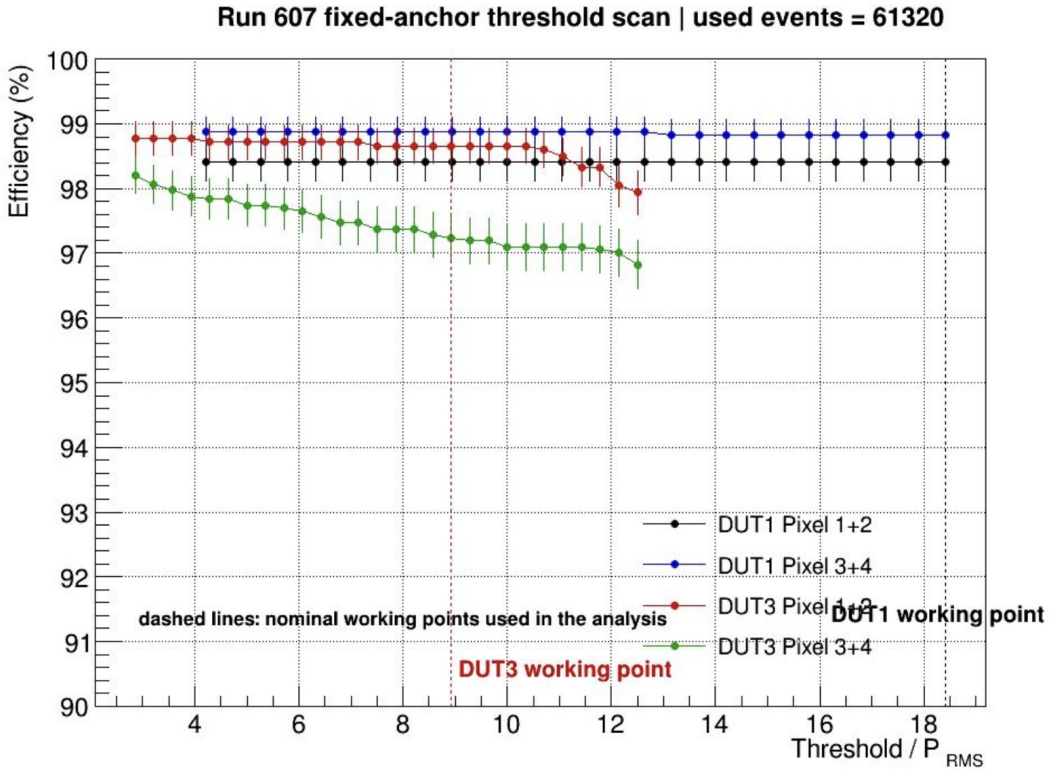


Good pad-to-pad uniformity: channels from the same DUT show very similar efficiency curves

The non-irradiated device maintains an efficiency of about **97–99%** over a broad threshold range

After irradiation, the efficiency curves shift toward lower thresholds, indicating a reduction in collected charge.

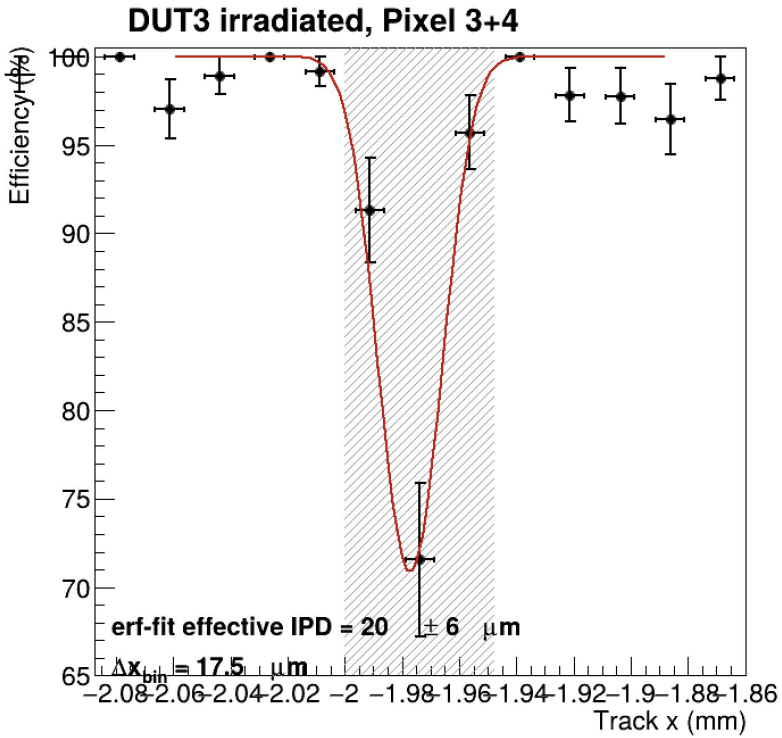
Efficiency vs threshold



DUT1 W2 V2 TW 2/3 0e15 n_{eq}/cm^2

DUT3 W2 V2 TW 1/3 1.5e15 n_{eq}/cm^2

Effective IPD estimate from the efficiency dip



- Summed x projection for DUT3 irradiated, with an error-function fit to the trench-related efficiency dip

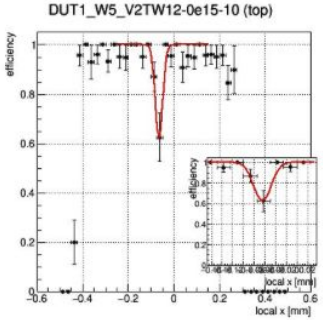
$$\varepsilon(x) = p - (A/2) * [\ \mathrm{erf}((x - xL)/\sigma) - \mathrm{erf}((x - xR)/\sigma)\ ]$$

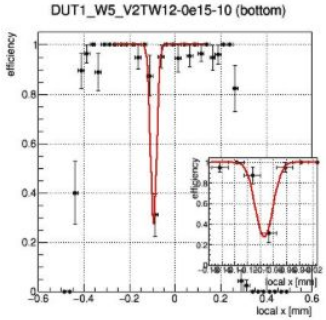
with parameters:

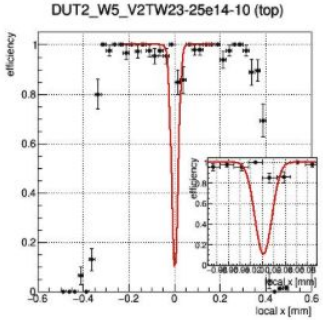
- `p`: plateau efficiency
- `A`: dip amplitude
- `xL`, `xR`: effective dip edges
- `σ`: edge-smearing scale

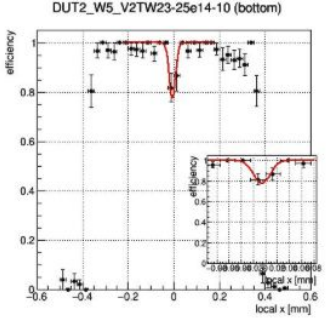
- Larger dip-region errors reflect lower local track statistics
- Grey band: data-driven apparent trench-related region from the efficiency x-profile
- Effective IPD: model-dependent response width of the dip, not physical trench width

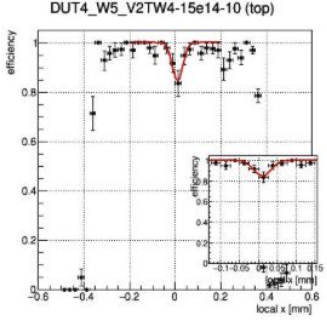
Interpad distance evaluation

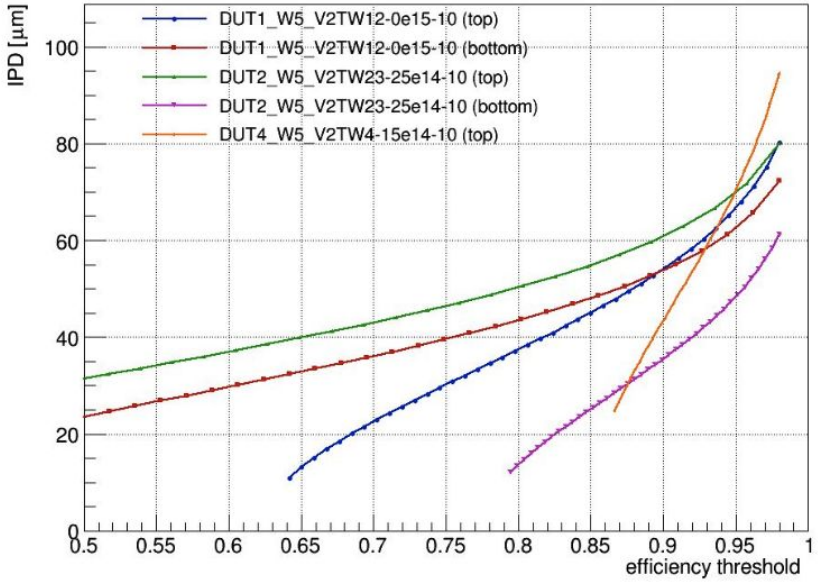






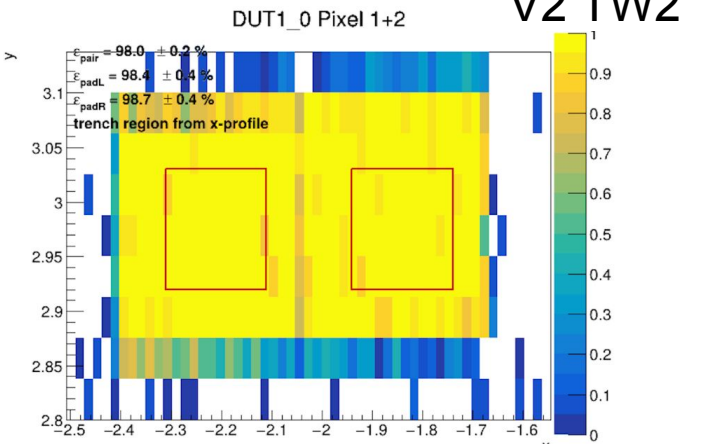




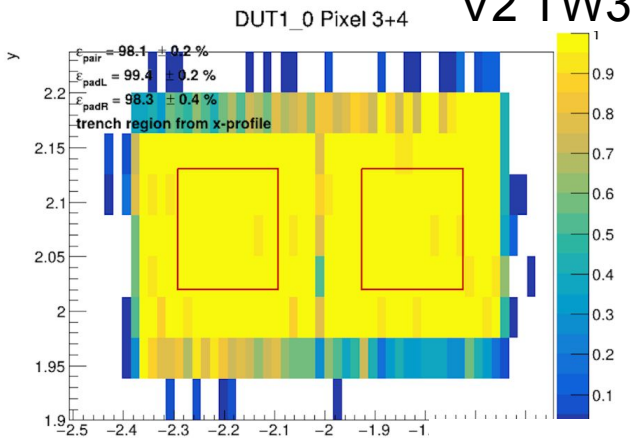


Efficiencies

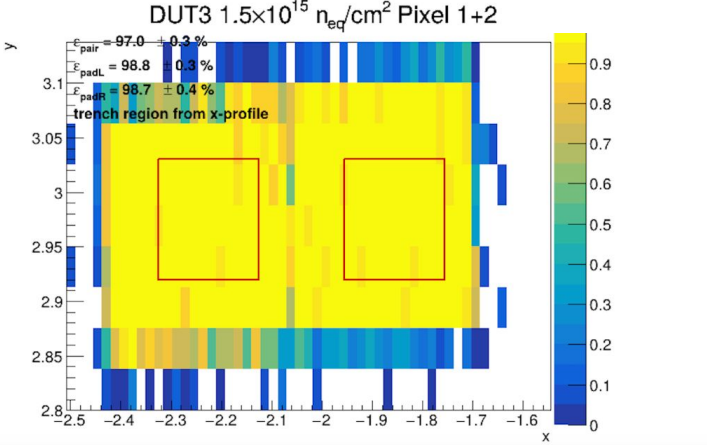
V2 TW2



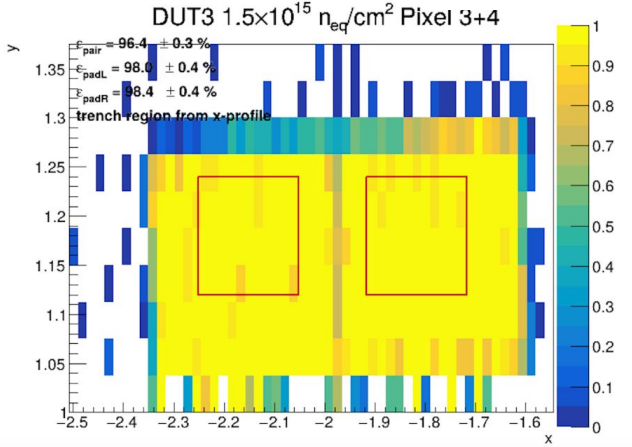
V2 TW3



V2 TW1



V2 TW3



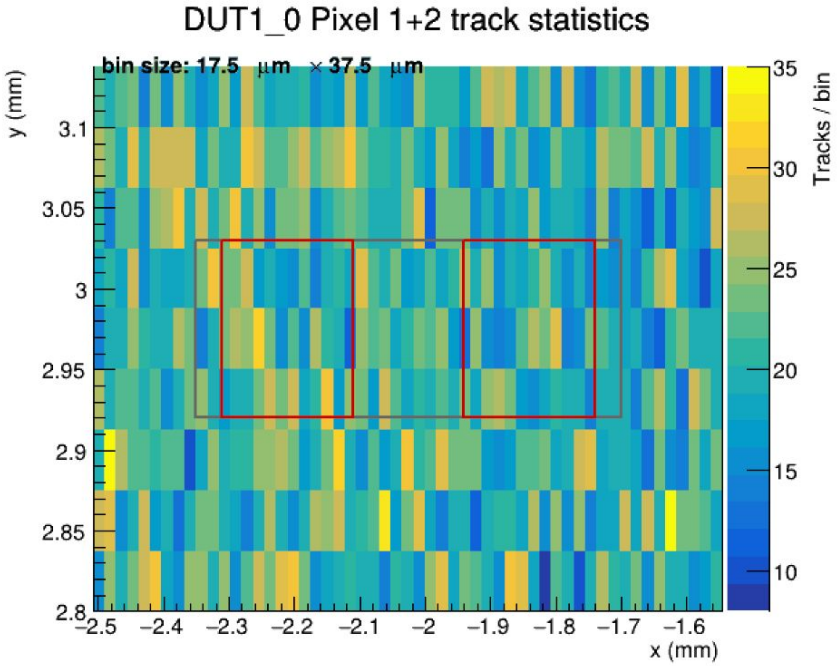
@ 165 V

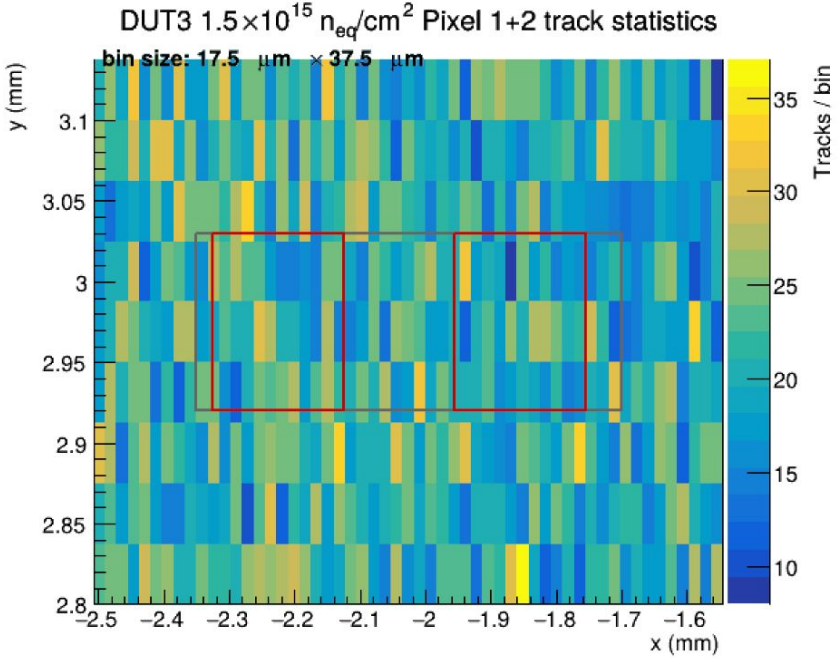
- Pad-only ROIs exclude the trench
  Left and right pad efficiencies quoted separately
- Pair inefficiency is partly driven by the trench region

@ 495 V

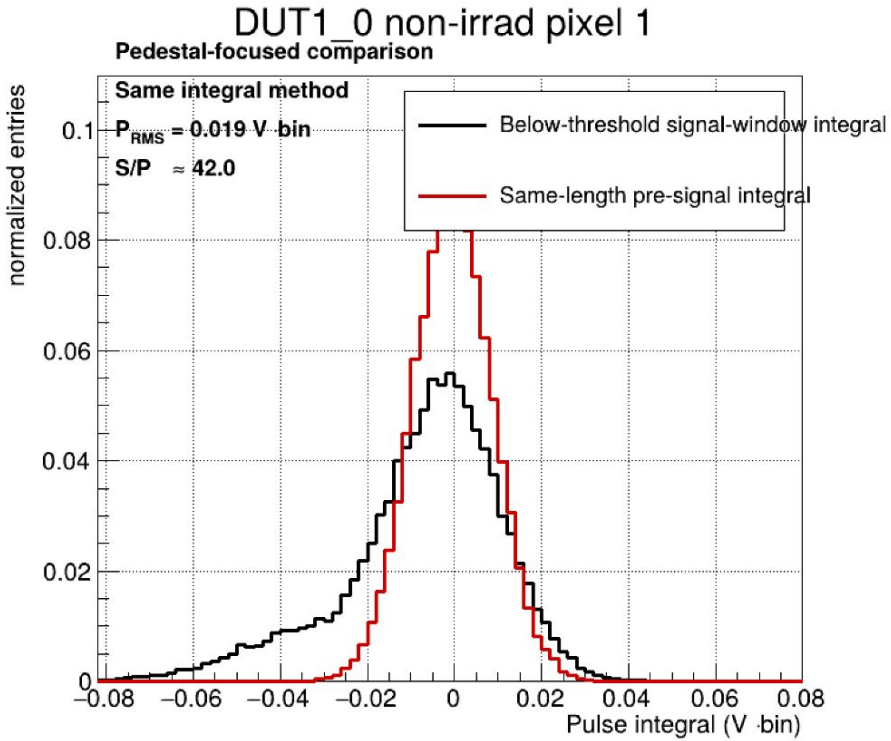
276,813 waveform events
61,311 used (after track matching + TREF anchor)

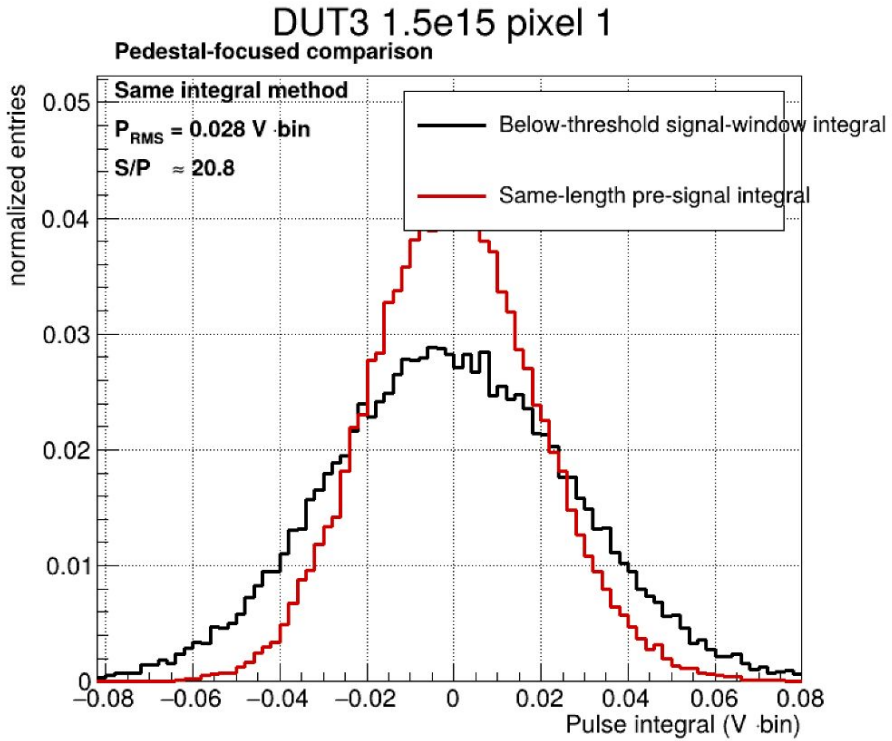
Binning: 17.5 µm × 37.5 µm



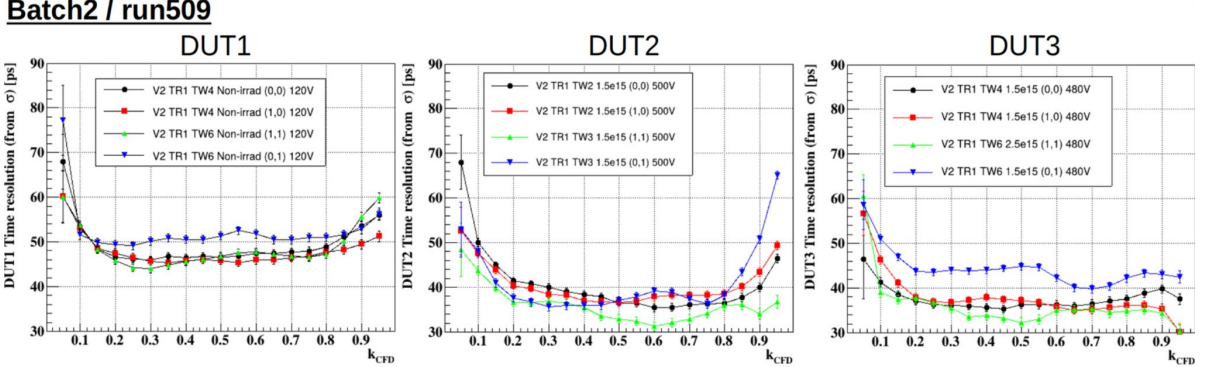


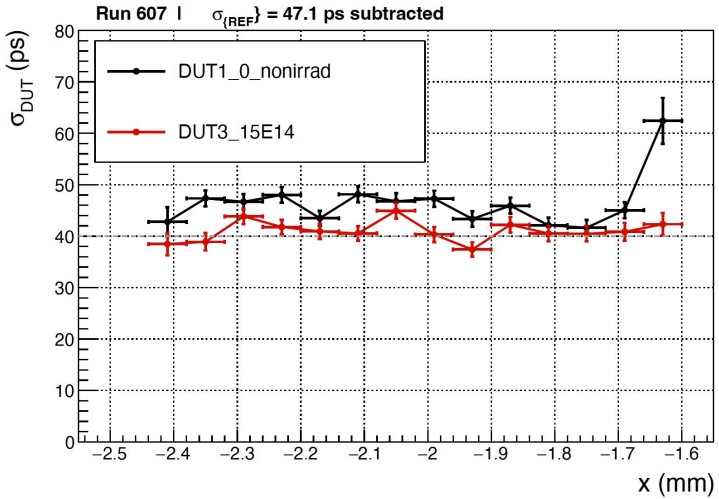
- Track-statistics map shown to indicate local entries per bin-> Typical local statistics: about 17 tracks/bin


DUT1_0 non-irrad pixel 1
Pedestal-focused comparison
Same integral method
P_RMS = 0.019 V·bin
S/P ≈ 42.0
Below-threshold signal-window integral
Same-length pre-signal integral
normalized entries
Pulse integral (V·bin)

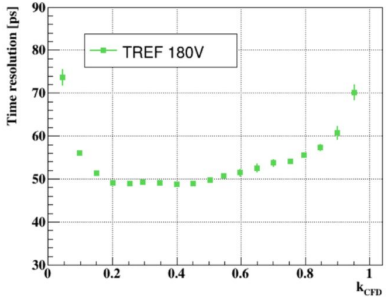

DUT3 1.5e15 pixel 1
Pedestal-focused comparison
Same integral method
P_RMS = 0.028 V·bin
S/P ≈ 20.8
Below-threshold signal-window integral
Same-length pre-signal integral
normalized entries
Pulse integral (V·bin)

Timing tracking-anchored results





Cuts:
NPeaks=1
RiseTime>0.6
(to get rid of digitizer fast noise)

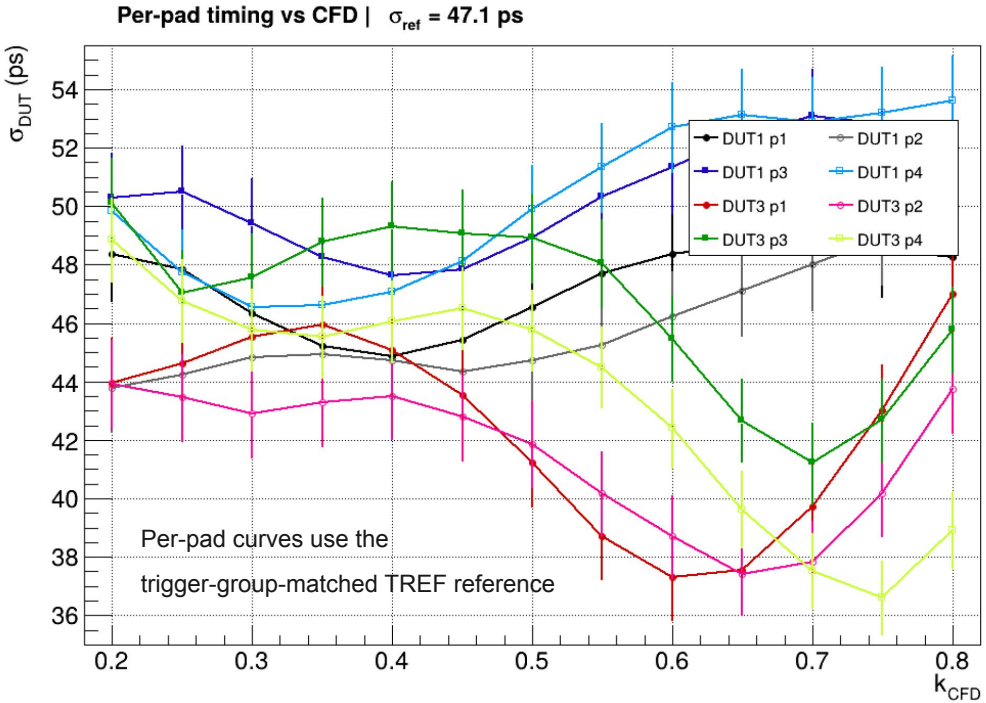


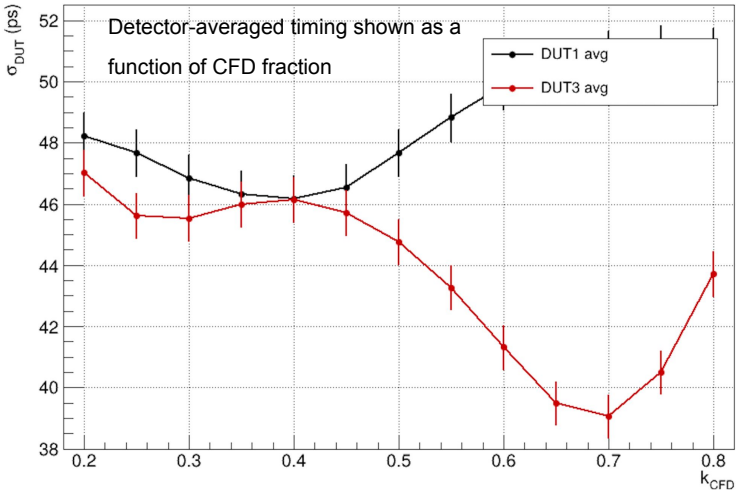
Comparison with Marcos' results

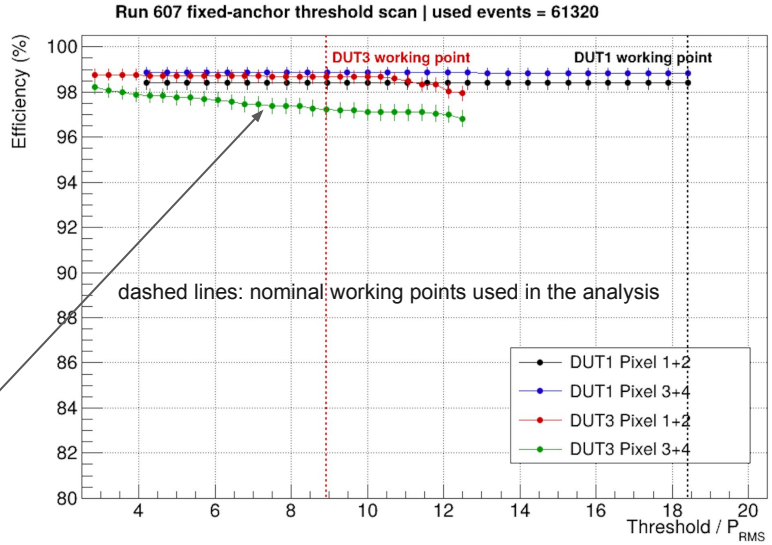
	Batch 2 run509	Batch 3 run607
DUT1 non-irrad	~47 ps @ 120V	**43 ps @ 165V**
DUT3 1.5×10¹⁴	~38 ps @ 500V	**38 ps @ 495V**
TREF 180V	~49 ps	47 ps ✓

Batch 3: σ_{REF}= 47.1 ps (triplet method)

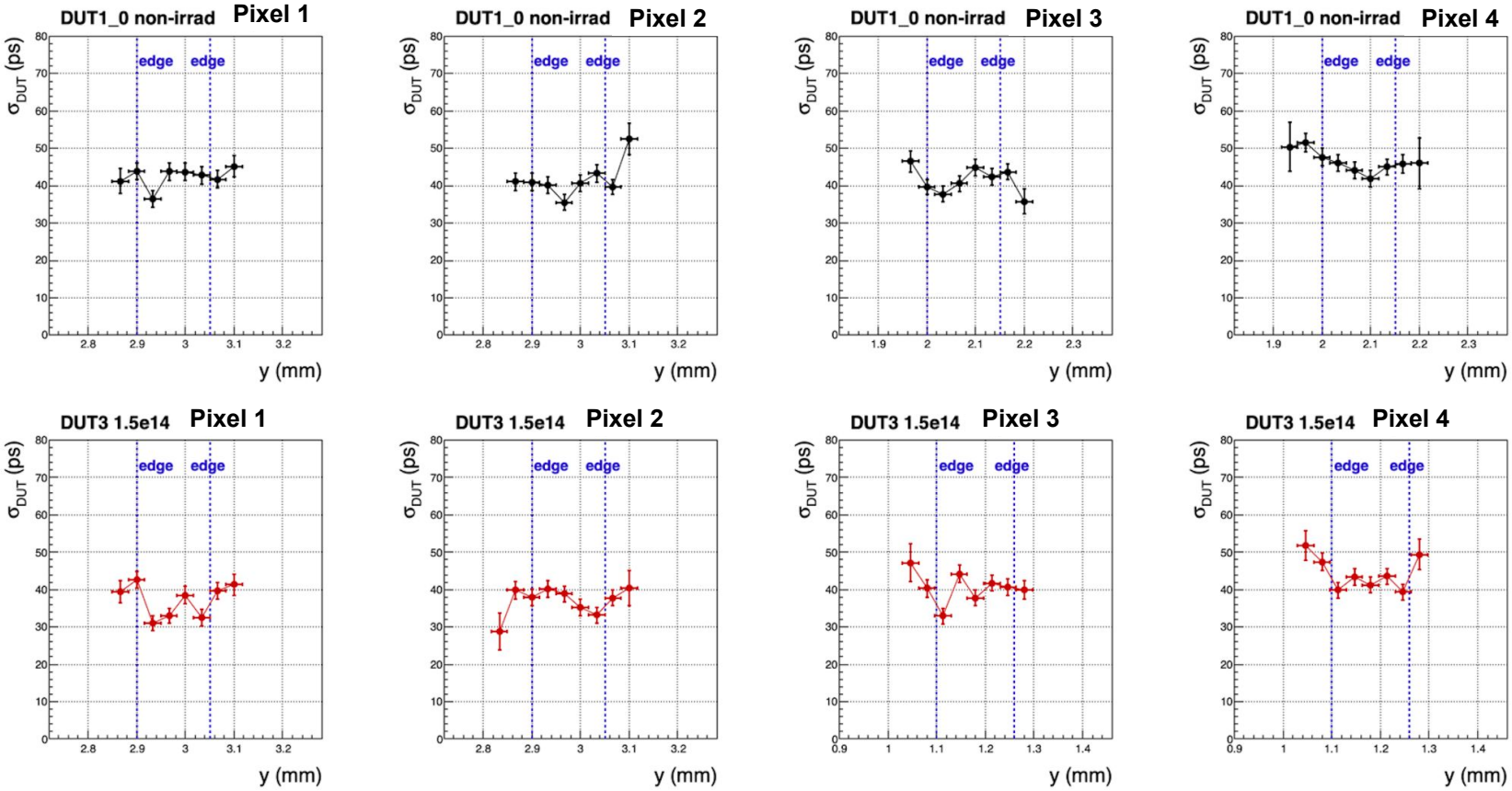
Threshold and CFD scans with track-based fixed-anchor selection







Threshold choice is much more critical for DUT3 than for DUT1

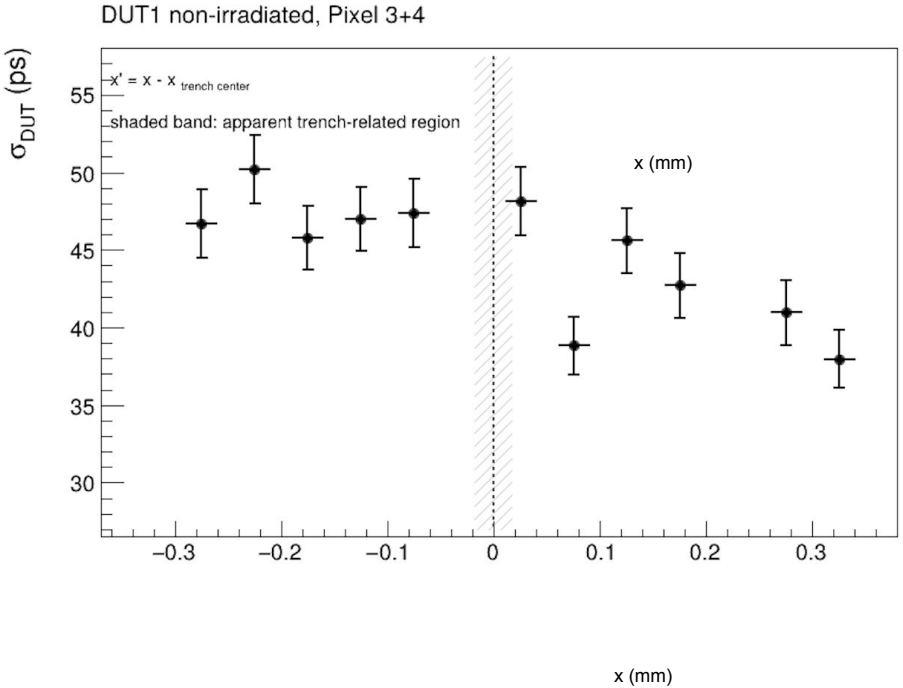


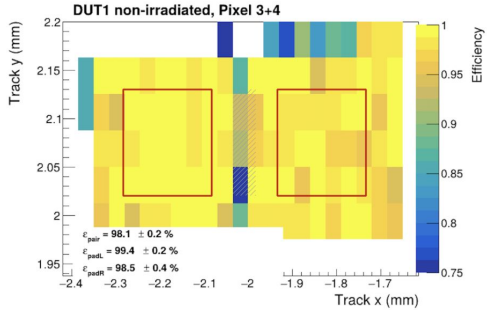
Time resolution as a function of position across the pixel width for DUT1_0 (black) and DUT3 at 1.5×10^{14} n_eq/cm² (red). Blue dashed lines indicate pixel boundaries. Resolution is uniform within the active area with no degradation at the LGAD edges — direct evidence of the TI-LGAD full fill factor

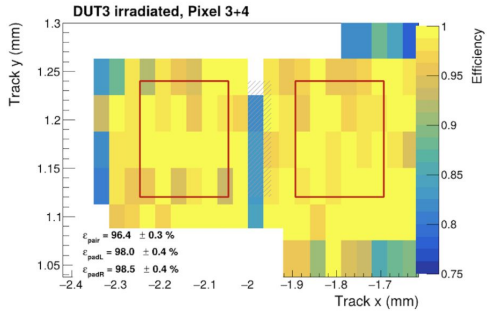
Note: ~30-50 events per y-bin

Trench-centered timing x-projection plots

- Timing projected in x after aligning each pair to its own trench center
- Grey band: apparent trench-related region from the efficiency x-profile
- No strong universal timing degradation is observed

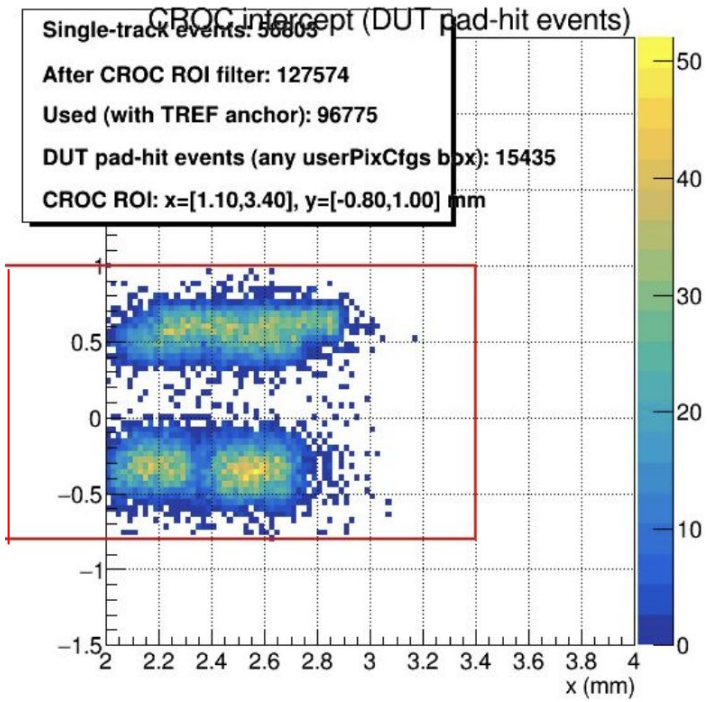


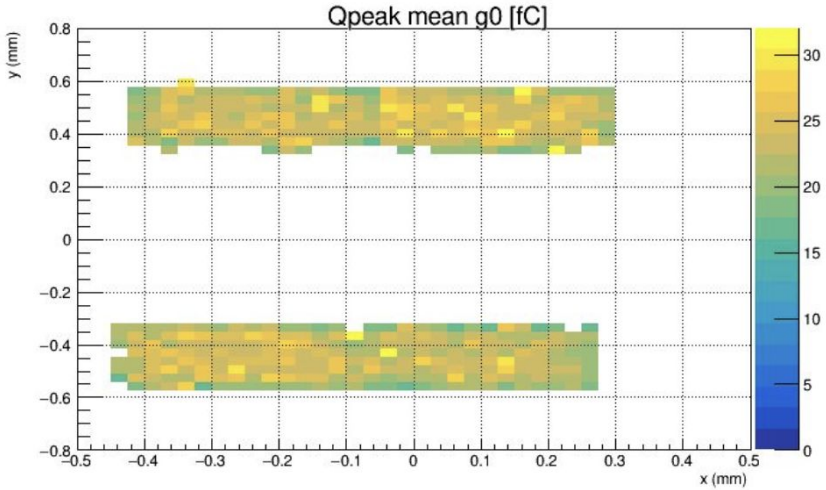




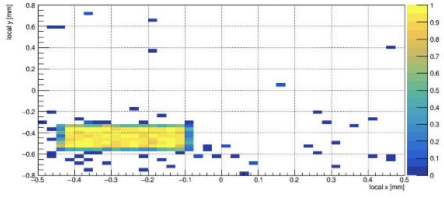
BACKUP SLIDES

Non irradiated W5 V2TW12 angle 10

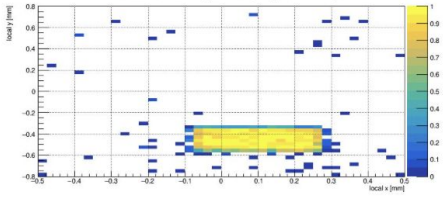




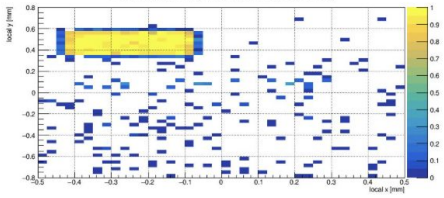
DUT1 CH9 efficiency (chi2<3.0, Clopper-Pearson)



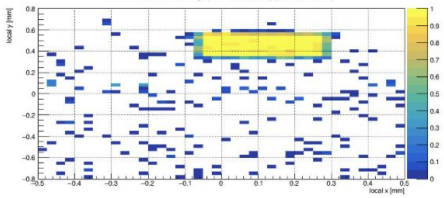
DUT1 CH10 efficiency (chi2<3.0, Clopper-Pearson)



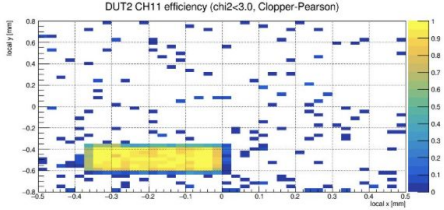
DUT1 CH2 efficiency (chi2<3.0, Clopper-Pearson)



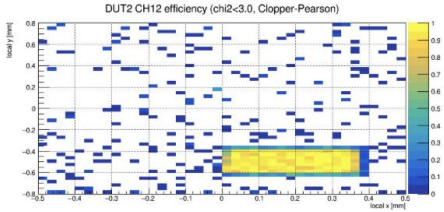
DUT1 CH1 efficiency (chi2<3.0, Clopper-Pearson)



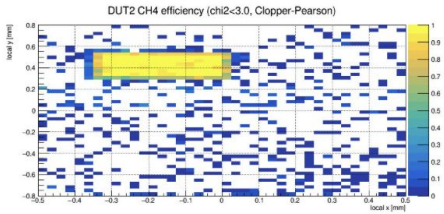
DUT2 CH11 efficiency (chi2<3.0, Clopper-Pearson)



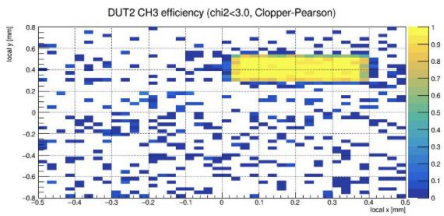
DUT2 CH12 efficiency (chi2<3.0, Clopper-Pearson)



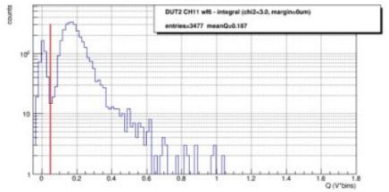
DUT2 CH4 efficiency (chi2<3.0, Clopper-Pearson)



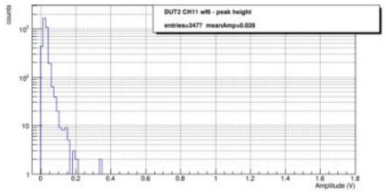
DUT2 CH3 efficiency (chi2<3.0, Clopper-Pearson)



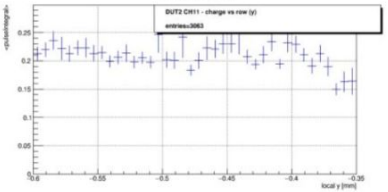
DUT2 CH11 (generic), integral



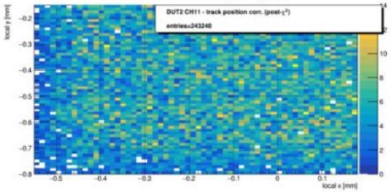
DUT2 CH11 (generic), peak height



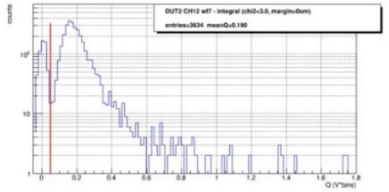
Charge vs local y



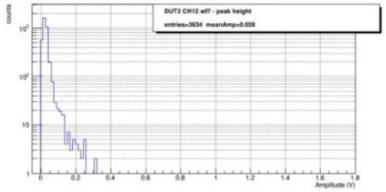
Track position correlation (post- χ^2 cut)



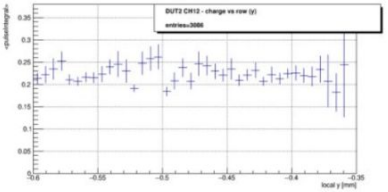
DUT2 CH12 (generic), integral



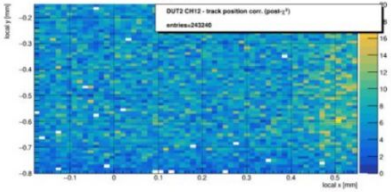
DUT2 CH12 (generic), peak height



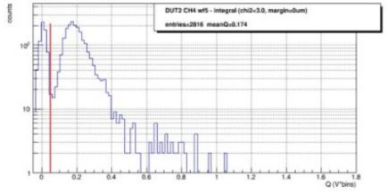
Charge vs local y



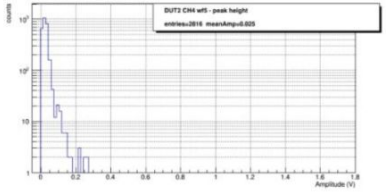
Track position correlation (post- χ^2 cut)



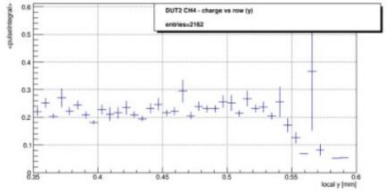
DUT2 CH4 (generic), integral



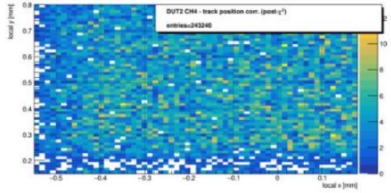
DUT2 CH4 (generic), peak height



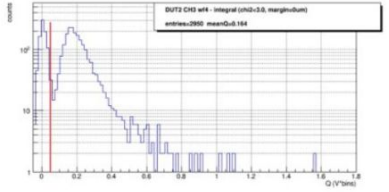
Charge vs local y



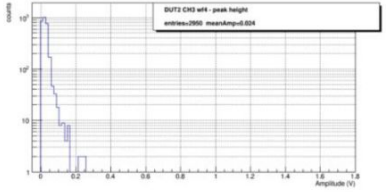
Track position correlation (post- χ^2 cut)



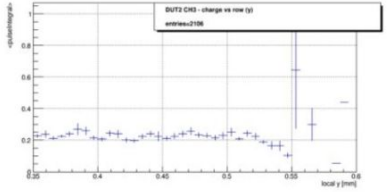
DUT2 CH3 (generic), integral



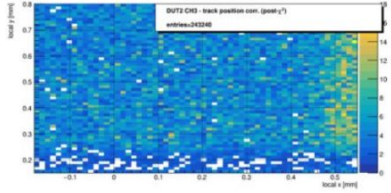
DUT2 CH3 (generic), peak height



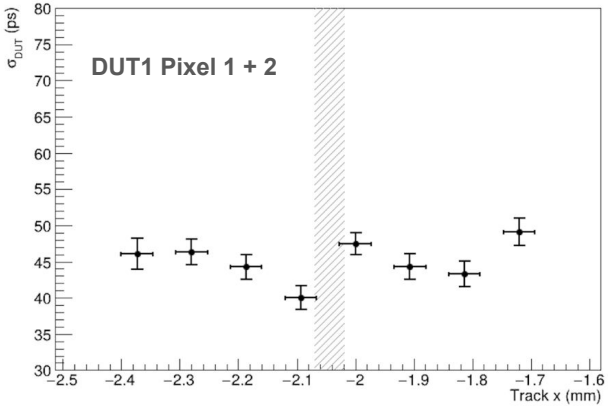
Charge vs local y

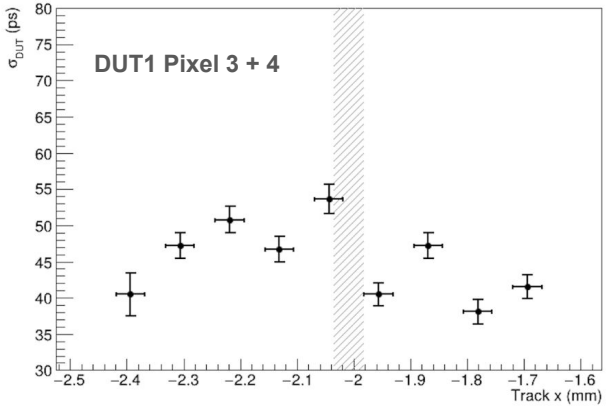


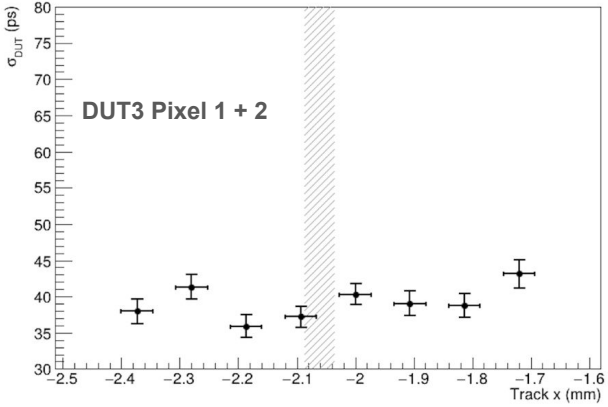
Track position correlation (post- χ^2 cut)

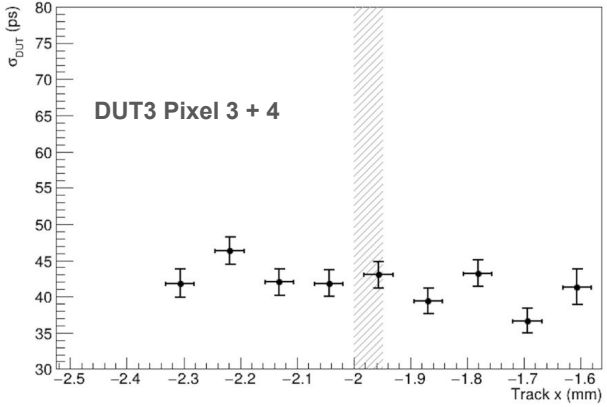


Timing projected in x near the trench







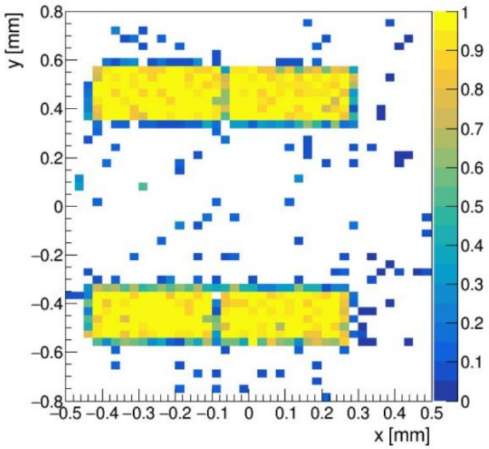


- Timing evaluated as a function of track x
- Shaded band: apparent trench-related region from the efficiency x-profile
- No strong timing degradation is observed

Preliminary **Efficiency: Run 13231**

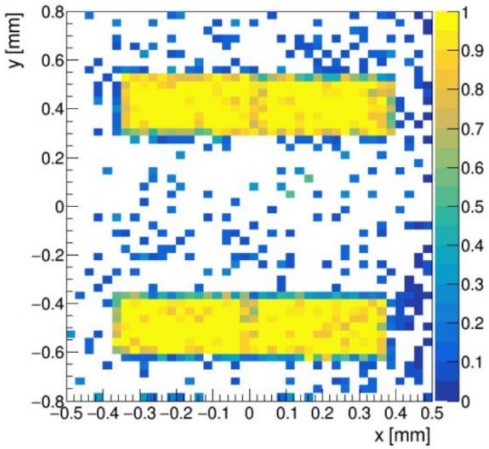
DUT 1

Local Efficiency TGraph for CAEN_IJS_0



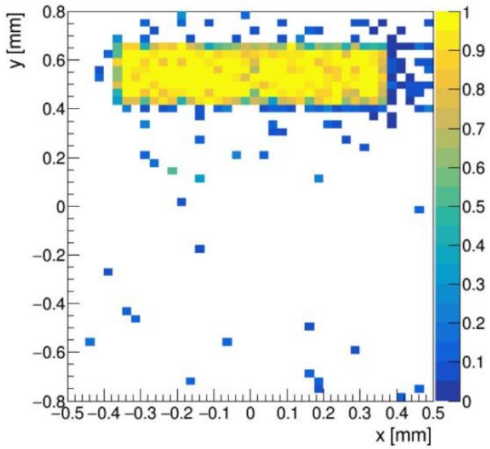
DUT 2

Local Efficiency TGraph for CAEN_IJS_1

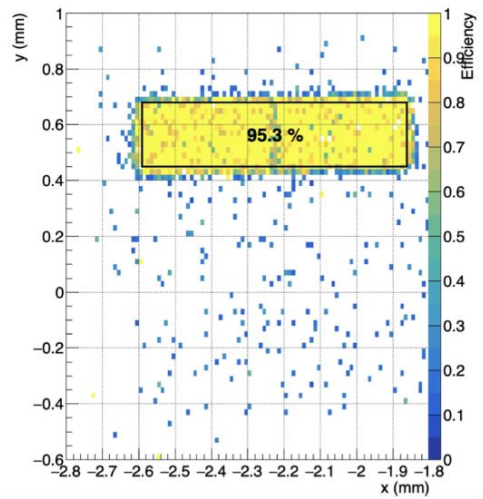


DUT 4

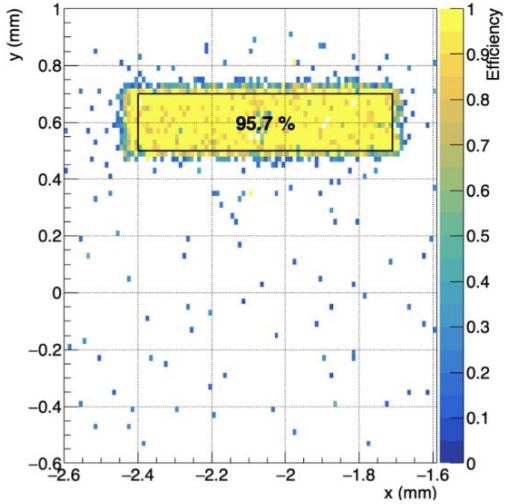
Local Efficiency TGraph for CAEN_IJS_4



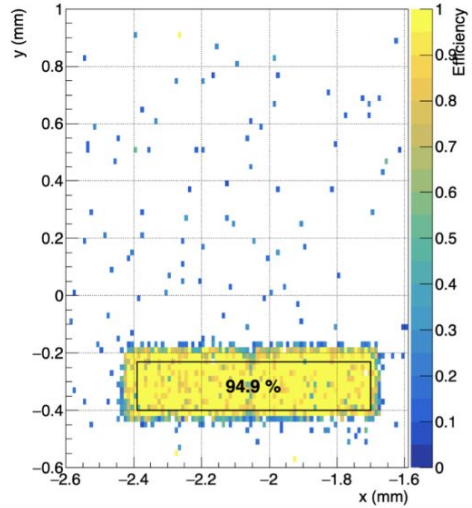
Next step: Testbeam October 2024 -> regenerate plots with the new TB analysis



(a) Unirradiated TW5, 50 V.
$S/N_{\text{peak}} = 48$, $S/N_{\text{cut}} = 13$



(b) Irradiated TW4, 530 V.
$S/N_{\text{peak}} = 68$, $S/N_{\text{cut}} = 25$



(c) Irradiated TW6, 530 V.
$S/N_{\text{peak}} = 68$, $S/N_{\text{cut}} = 25$

Validation for the signal definition: peakPos - tTREF

- Validation of the fixed TREF-anchored signal window
- Observed DUT pulse remains inside the chosen window