Timepix4 time resolution iLGAD

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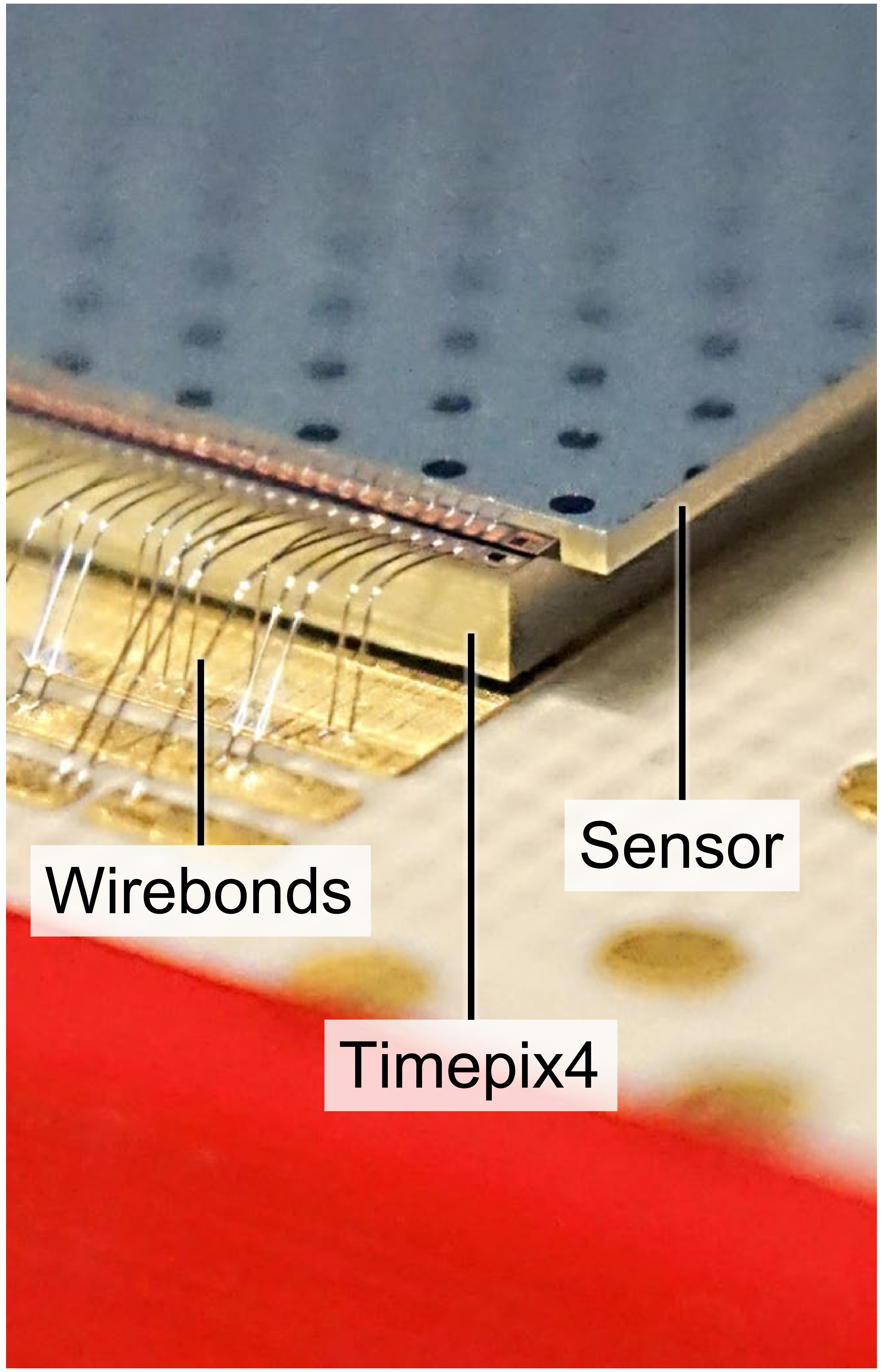
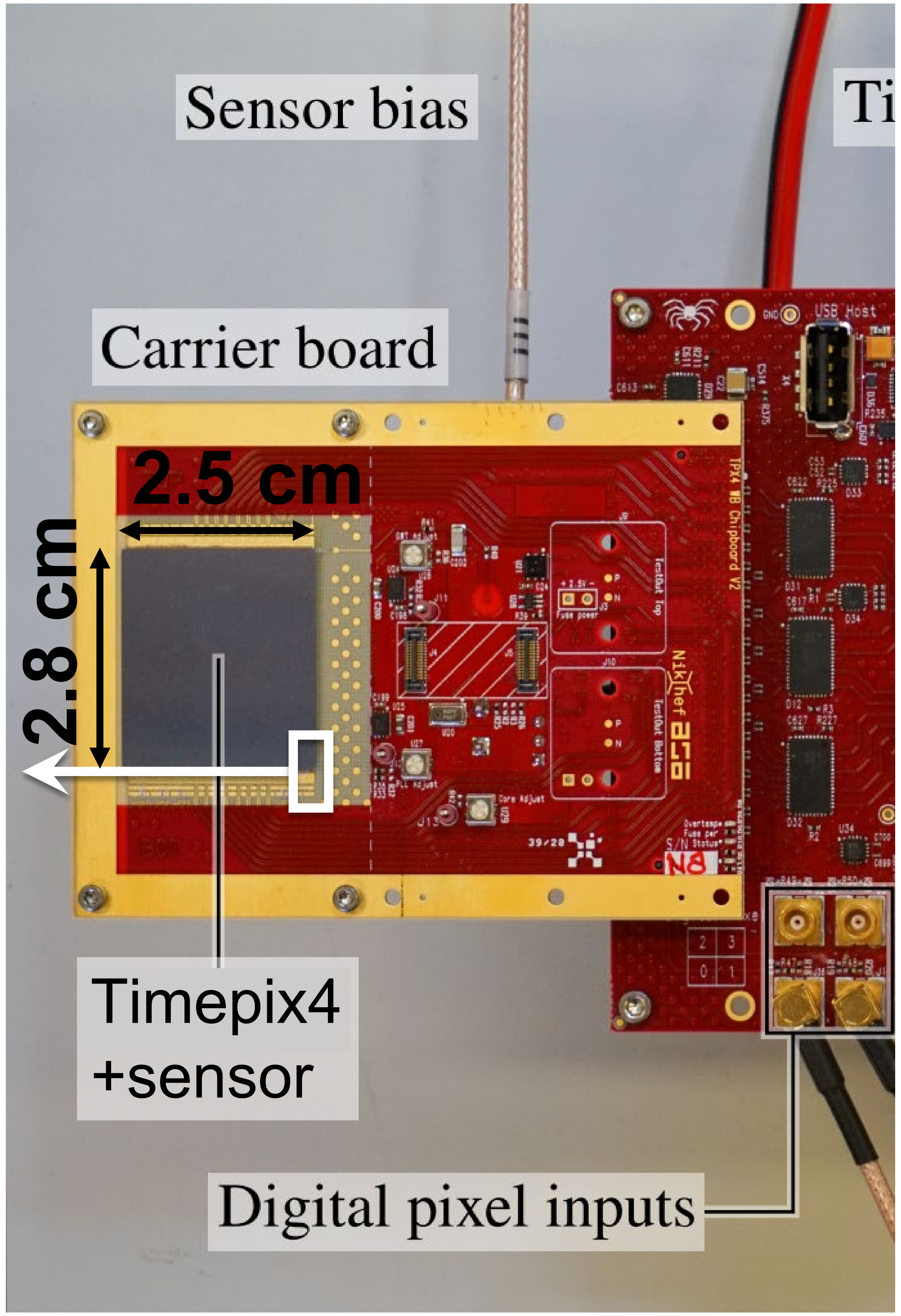
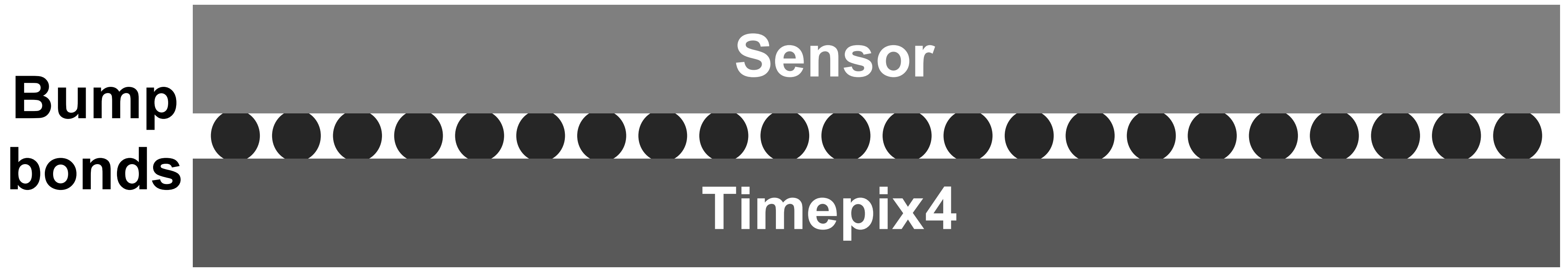
Timepix4: Hybrid pixel detector readout ASIC





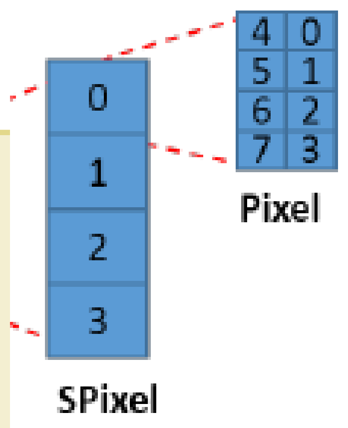
Timepix4:

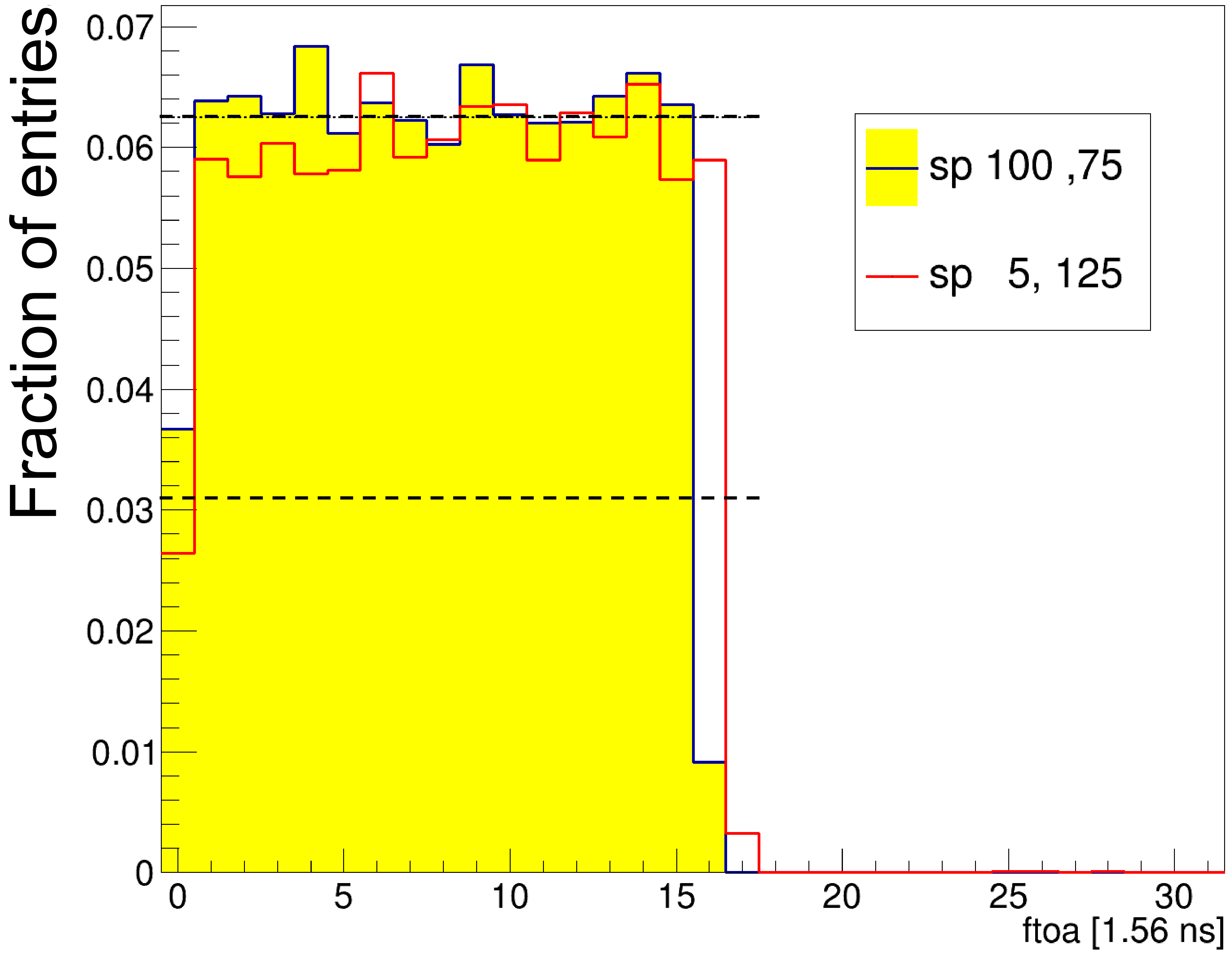
- Developed by CERN, Nikhef, and IFAE
- 448×512 pixels, 55×55 μm^2 pitch
- Time-bin size of 25 ns/128 = **195 ps**



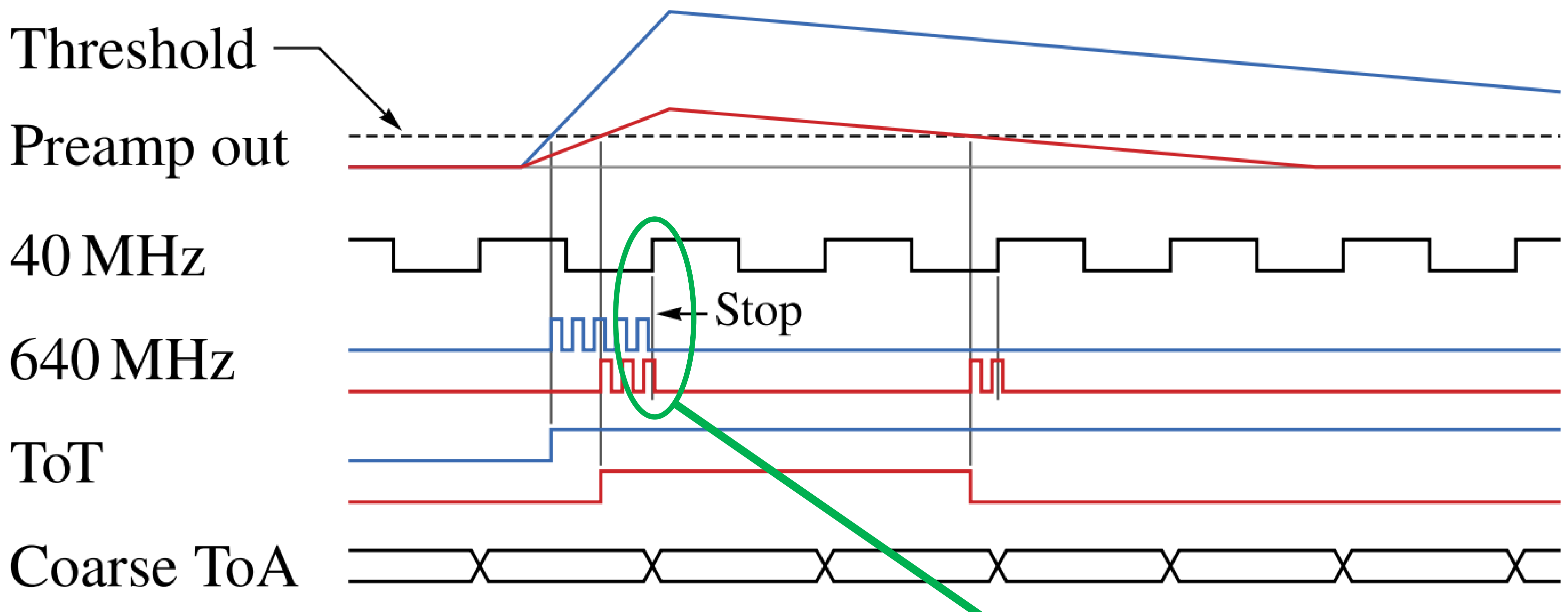
Time measurement in Timepix4

- Each superpixel has a Voltage-Controlled Oscillator
- VCO runs at 640 MHz →1.56 ns
- Four phase shifted copy's
- Optimal TDC resolution: 195 ps/$\sqrt{12}$ = 56 ps
- VCO is stable, but frequency fluctuations over pixel matrix

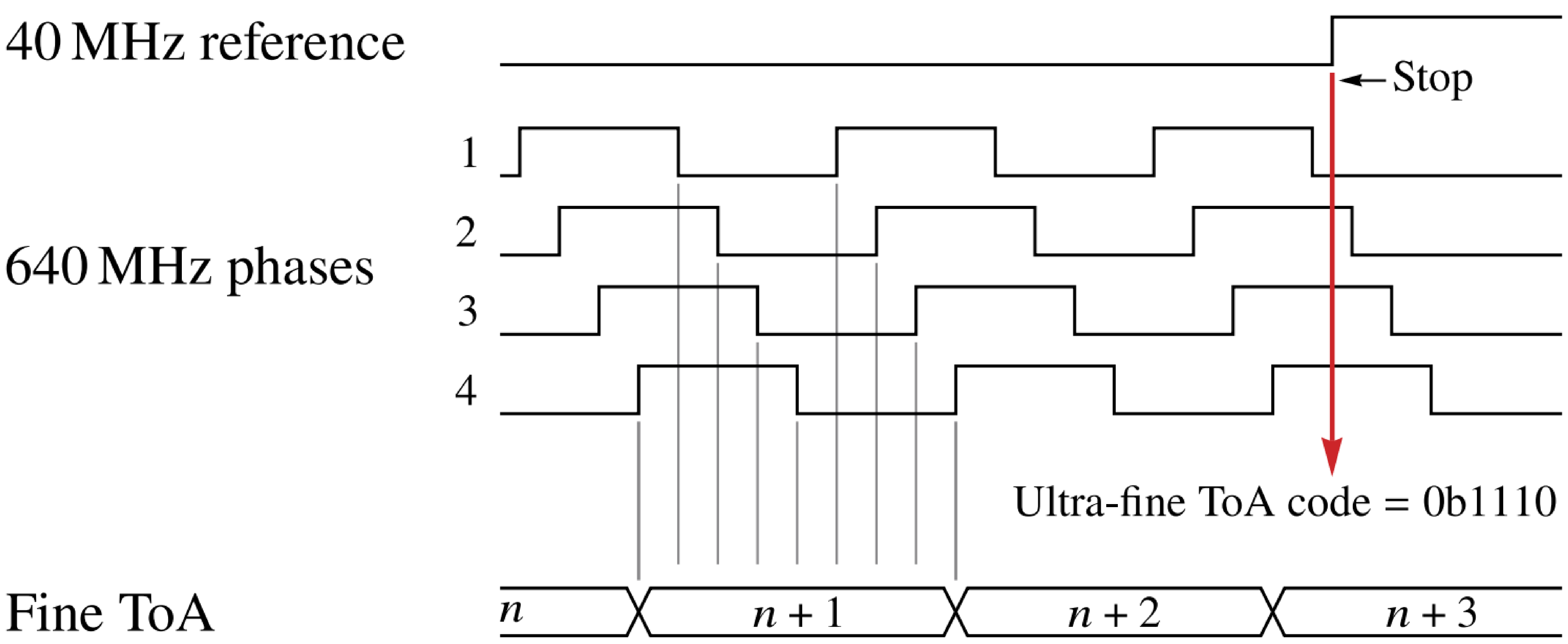




Coarse and fine time measurement – 40 MHz and 640 MHz

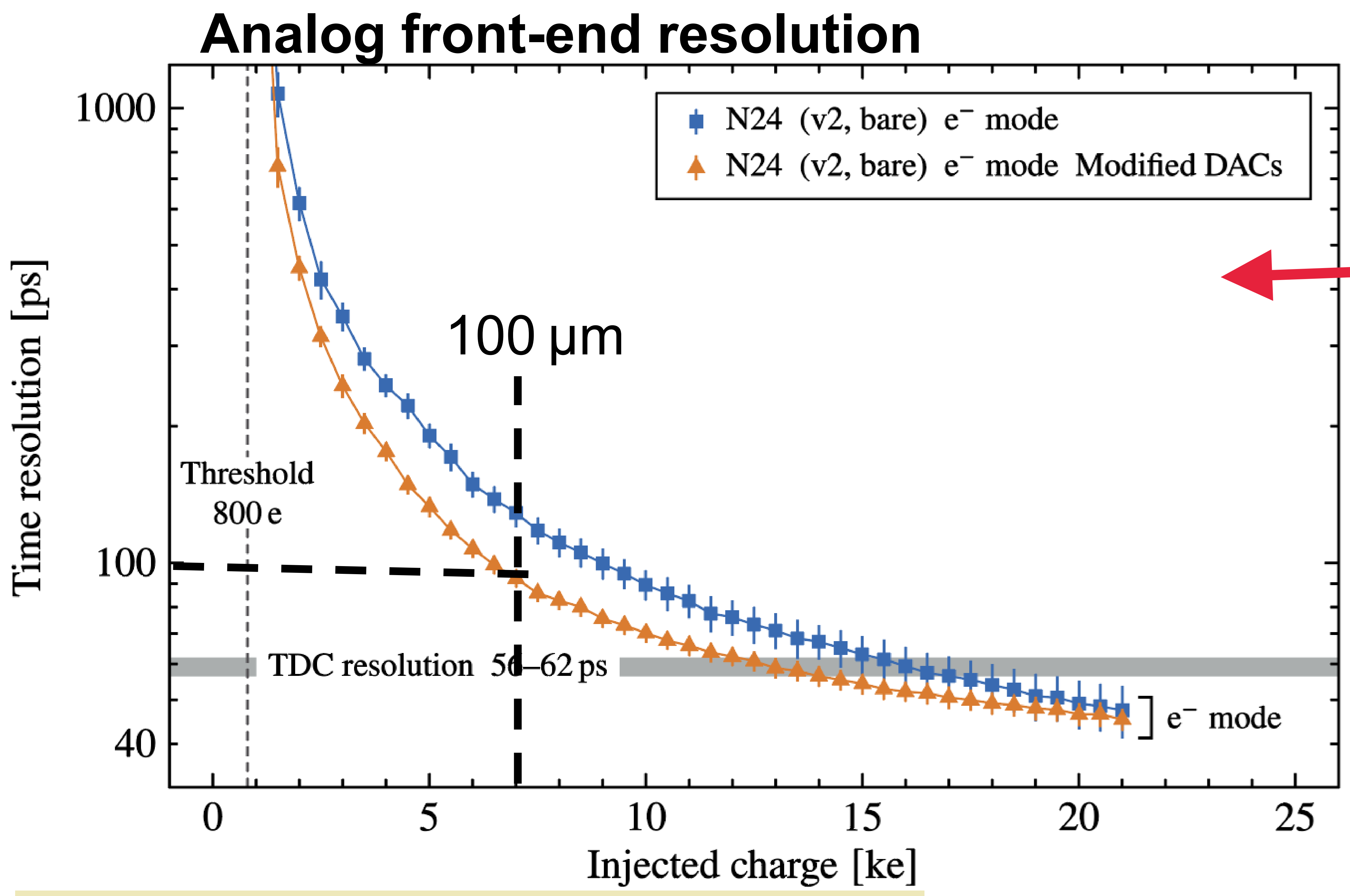


Ultrafine time measurement – 195 ps

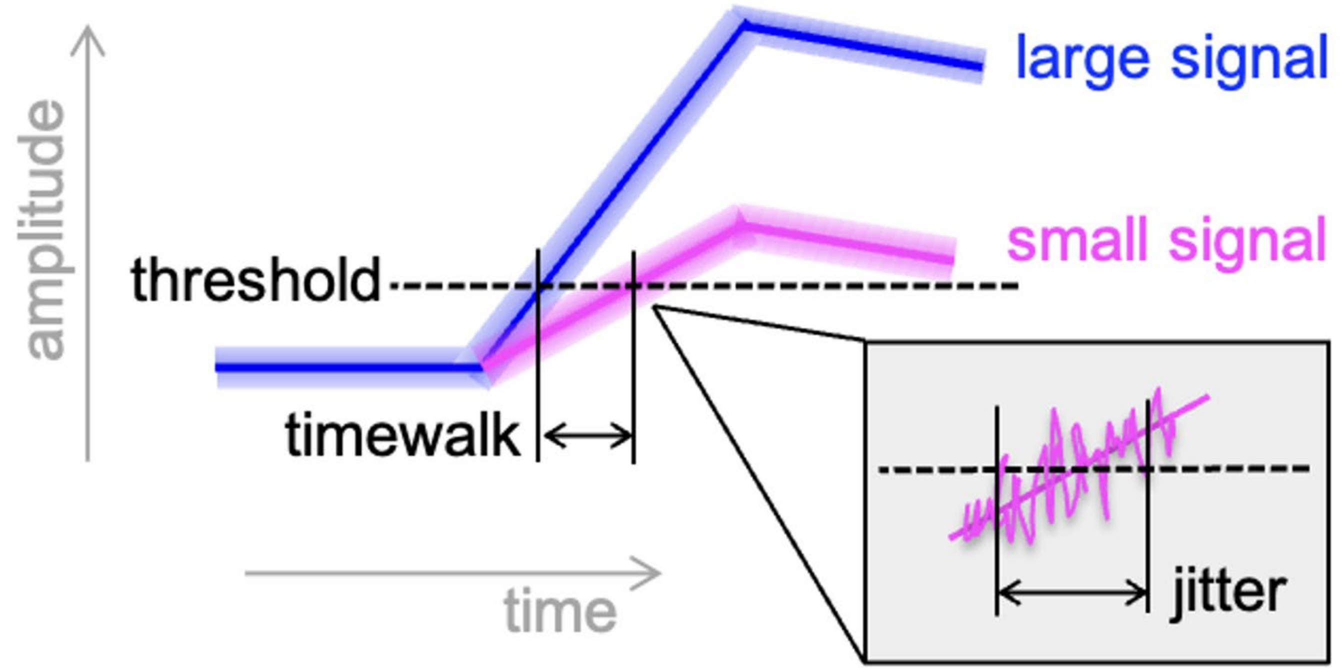


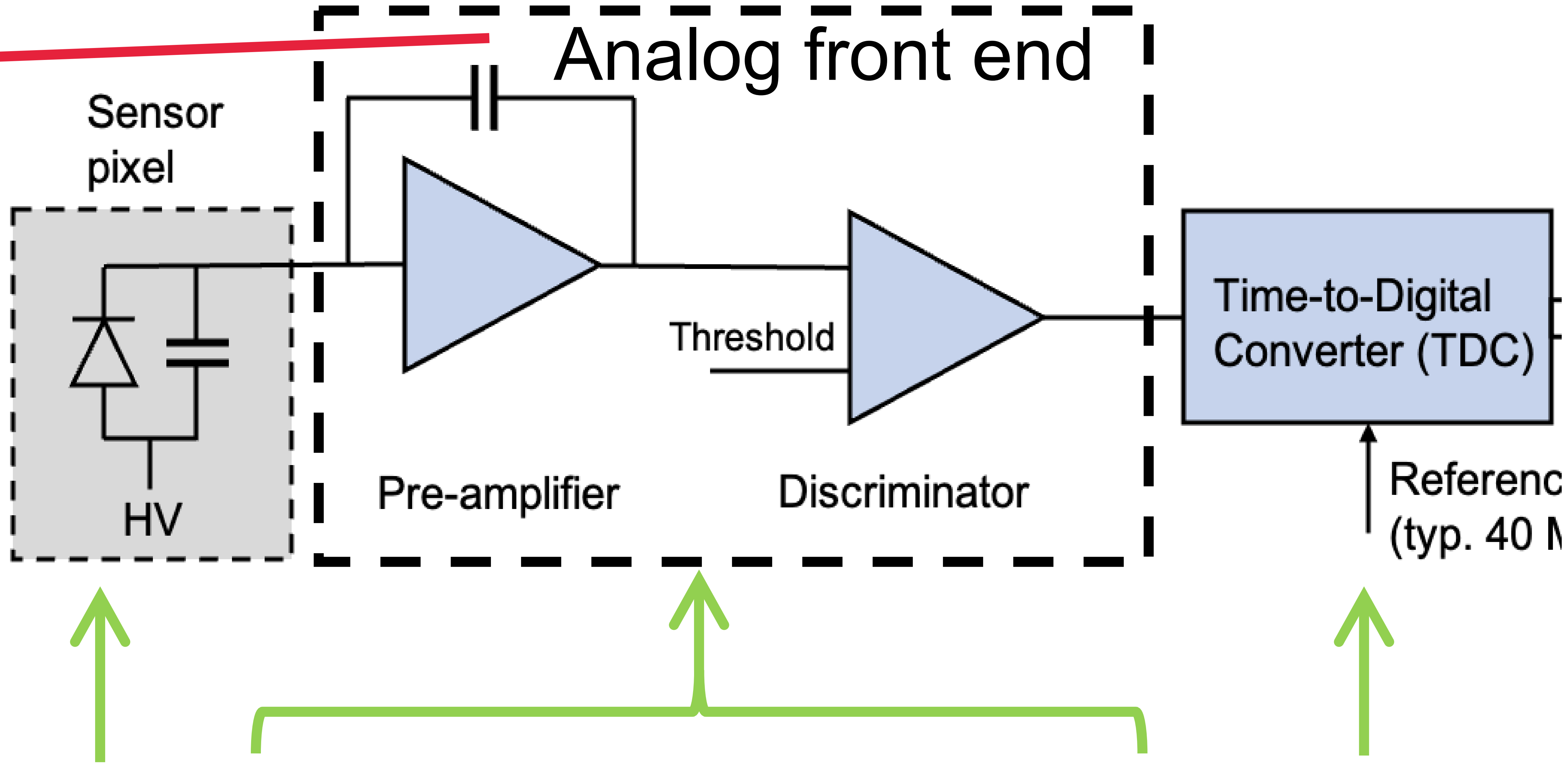
Time measurements in pixel detectors

- Analog front end for a 100 um sensor + TDC σ_t=117 ps



K. Heijhoff *et al* 2022 *JINST* **17** P07006
[DOI: 10.1088/1748-0221/17/07/P07006]





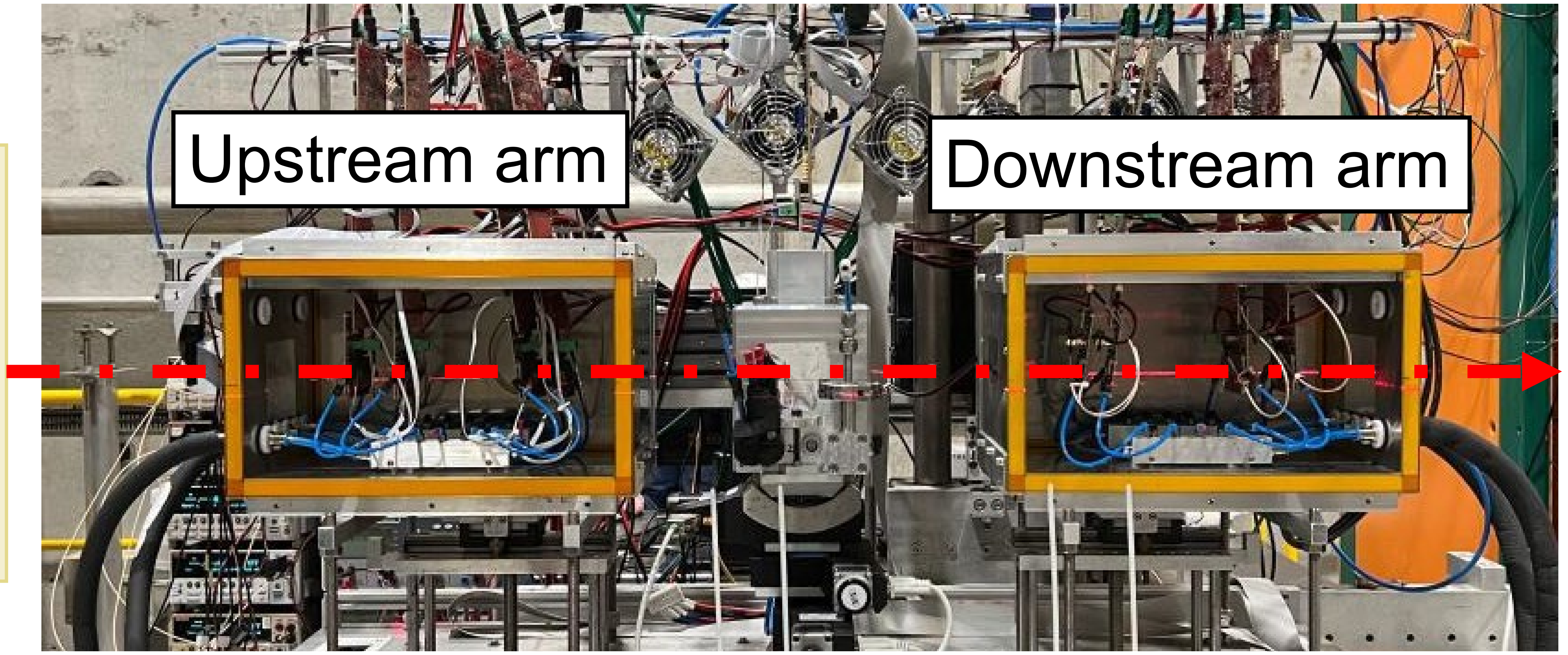
Time resolution = σ_t^2(sensor) + σ_t^2(jitter) + σ_t^2(timewalk) + σ_t^2(TDC)

??? ps = ?? ps + ~100 ps + 60 ps

measured = calculated + assumed + assumed

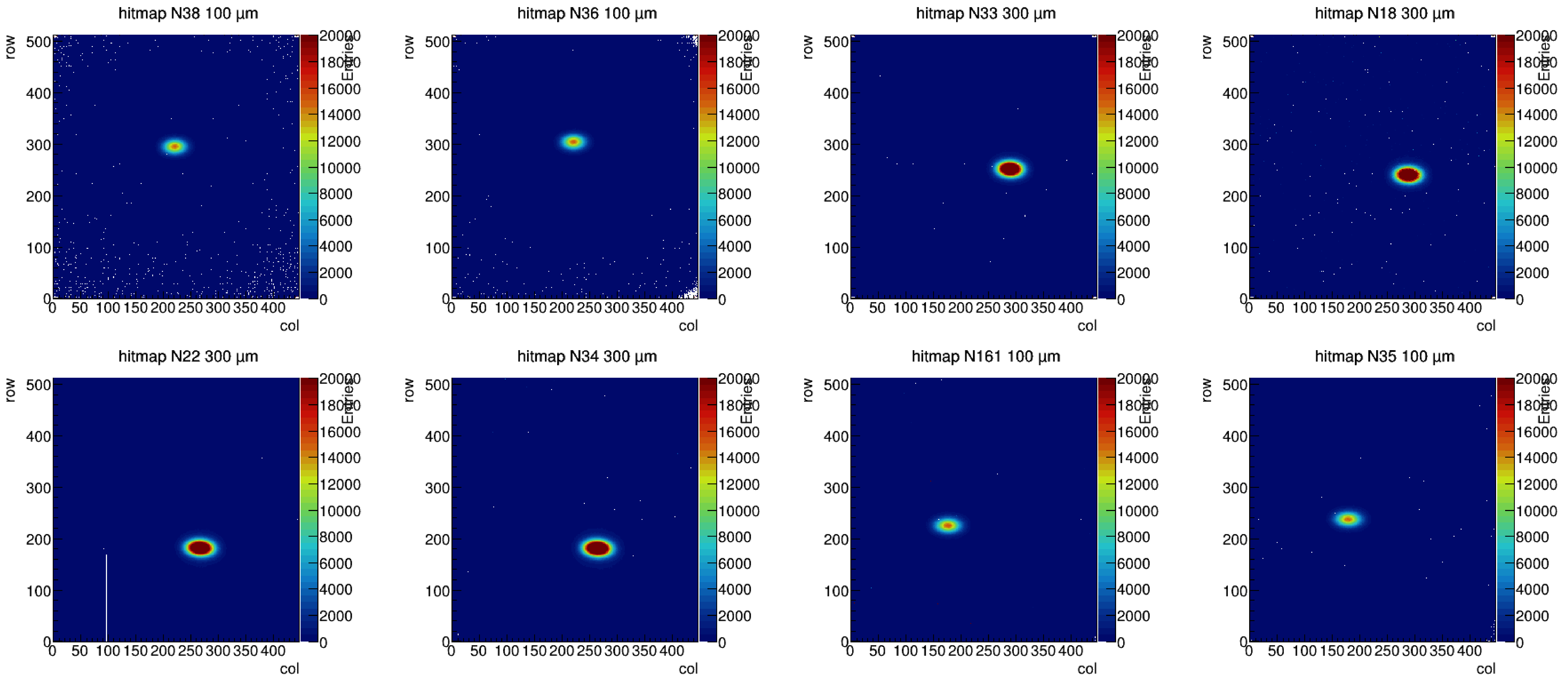
Testbeam august this year

- 180 GeV/c mixed beam at CERN SPS
- Eight telescope planes with n-on-p planar silicon sensors:
  - 4 x 300 μm sensors for spatial resolution (angled)
  - 4 x 100 μm sensors for time resolution

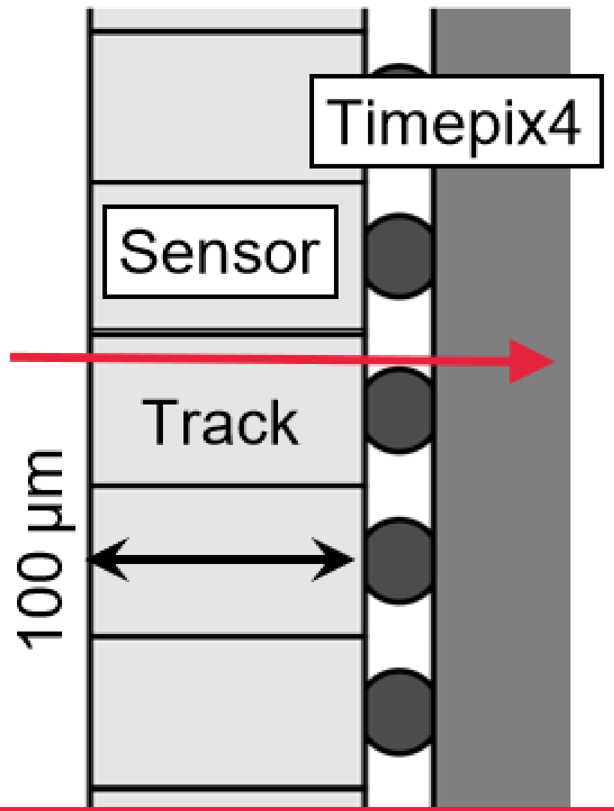


Upstream arm

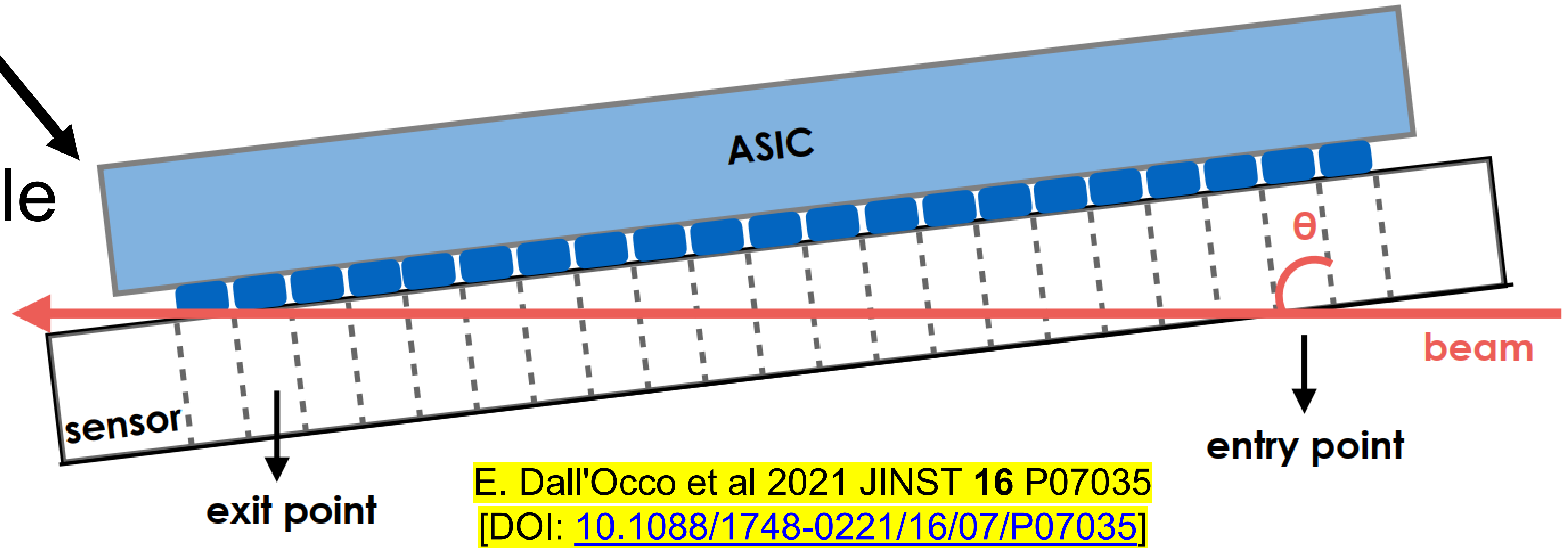
Downstream arm



Telescope configuration



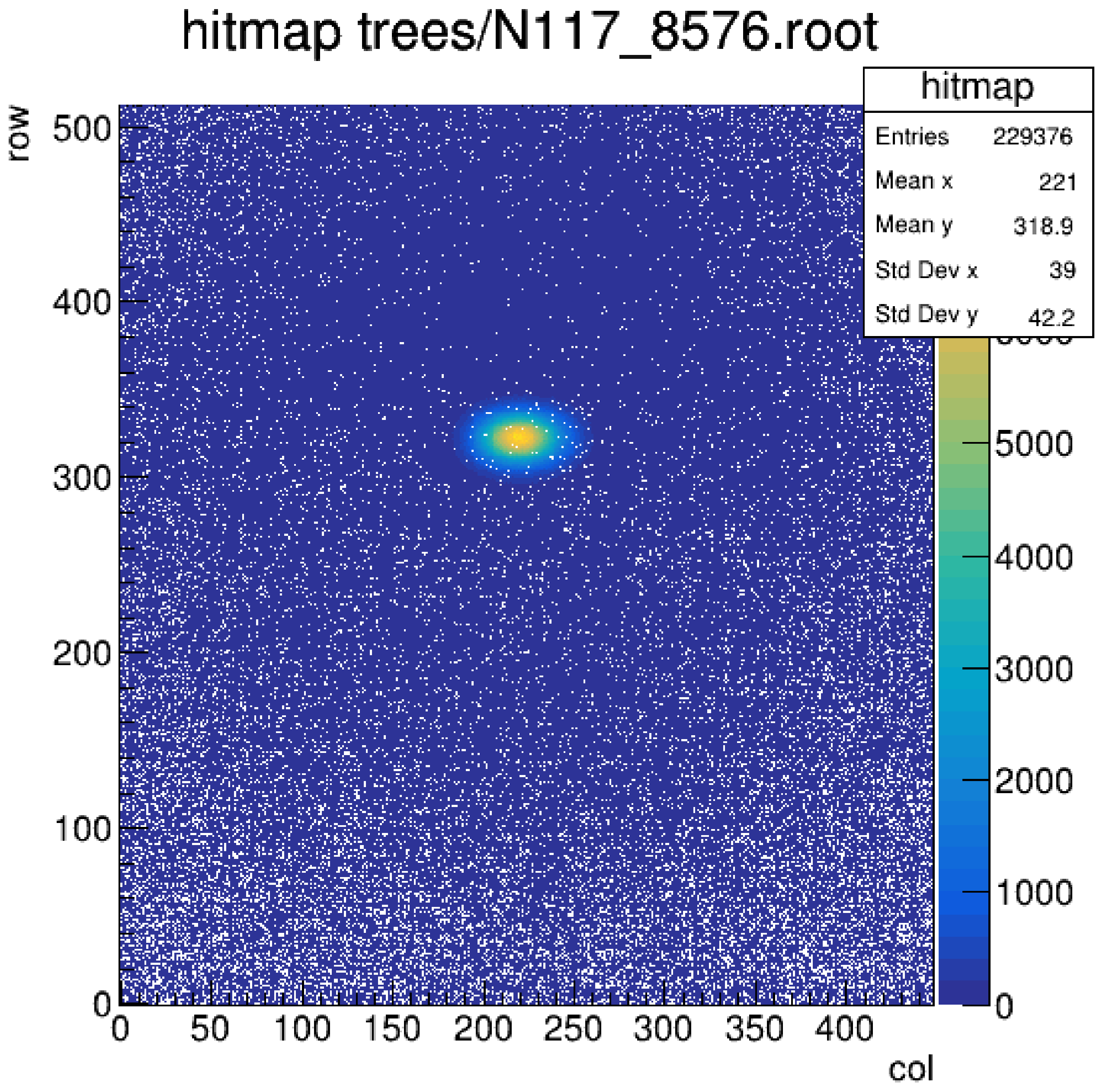
Perpendicular and grazing angle

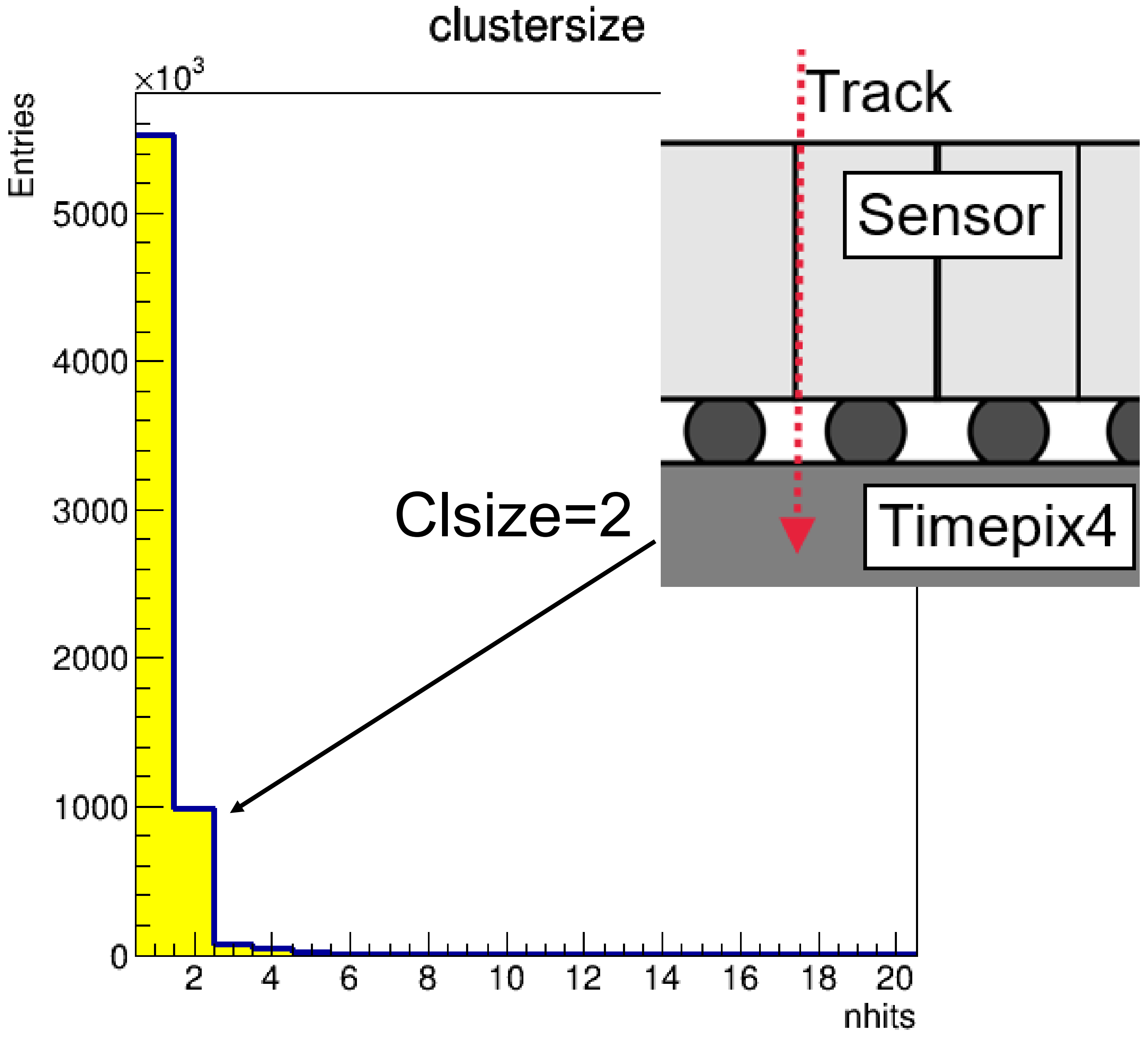


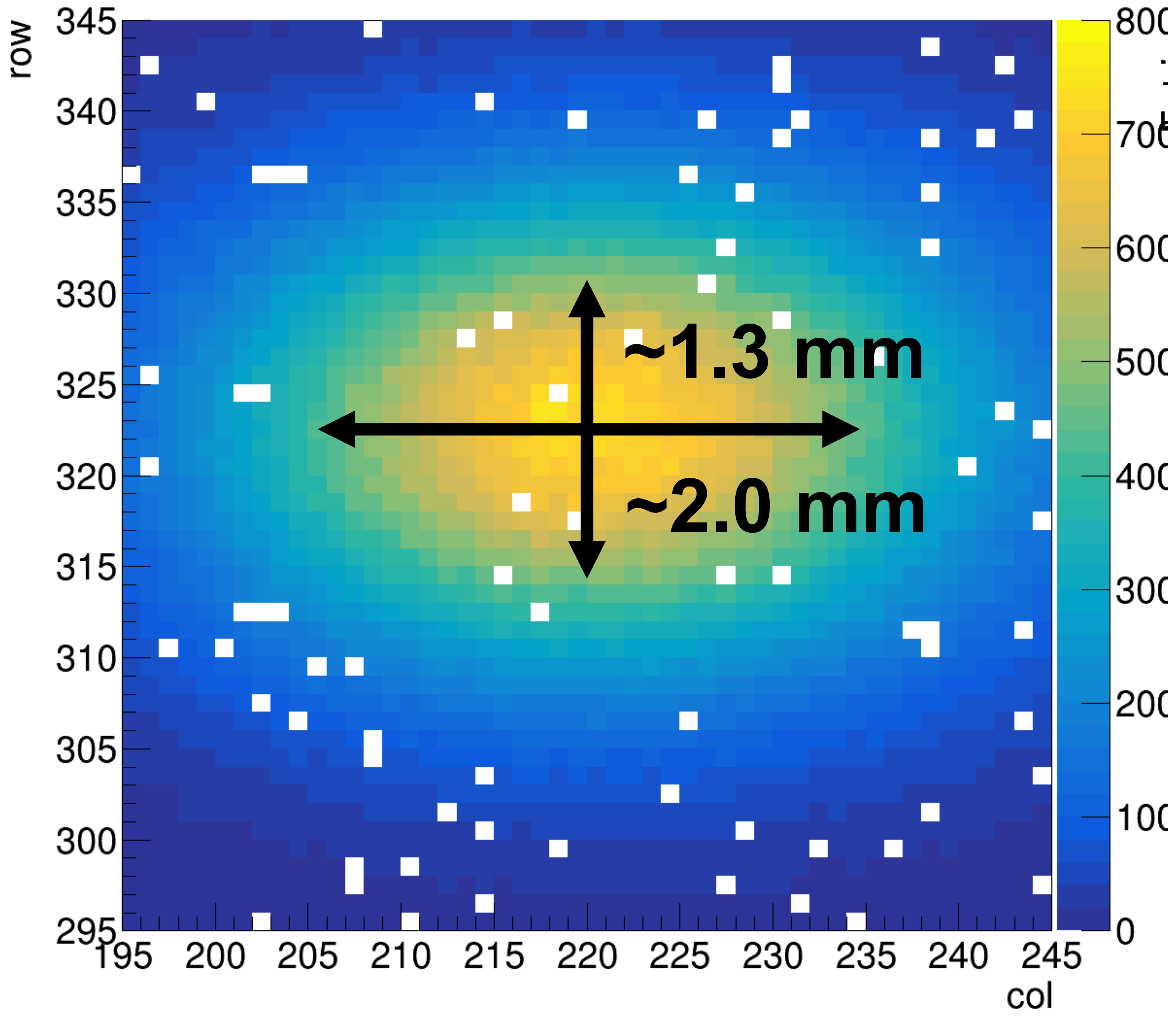
E. Dall'Occo et al 2021 JINST **16** P07035
[DOI: 10.1088/1748-0221/16/07/P07035]

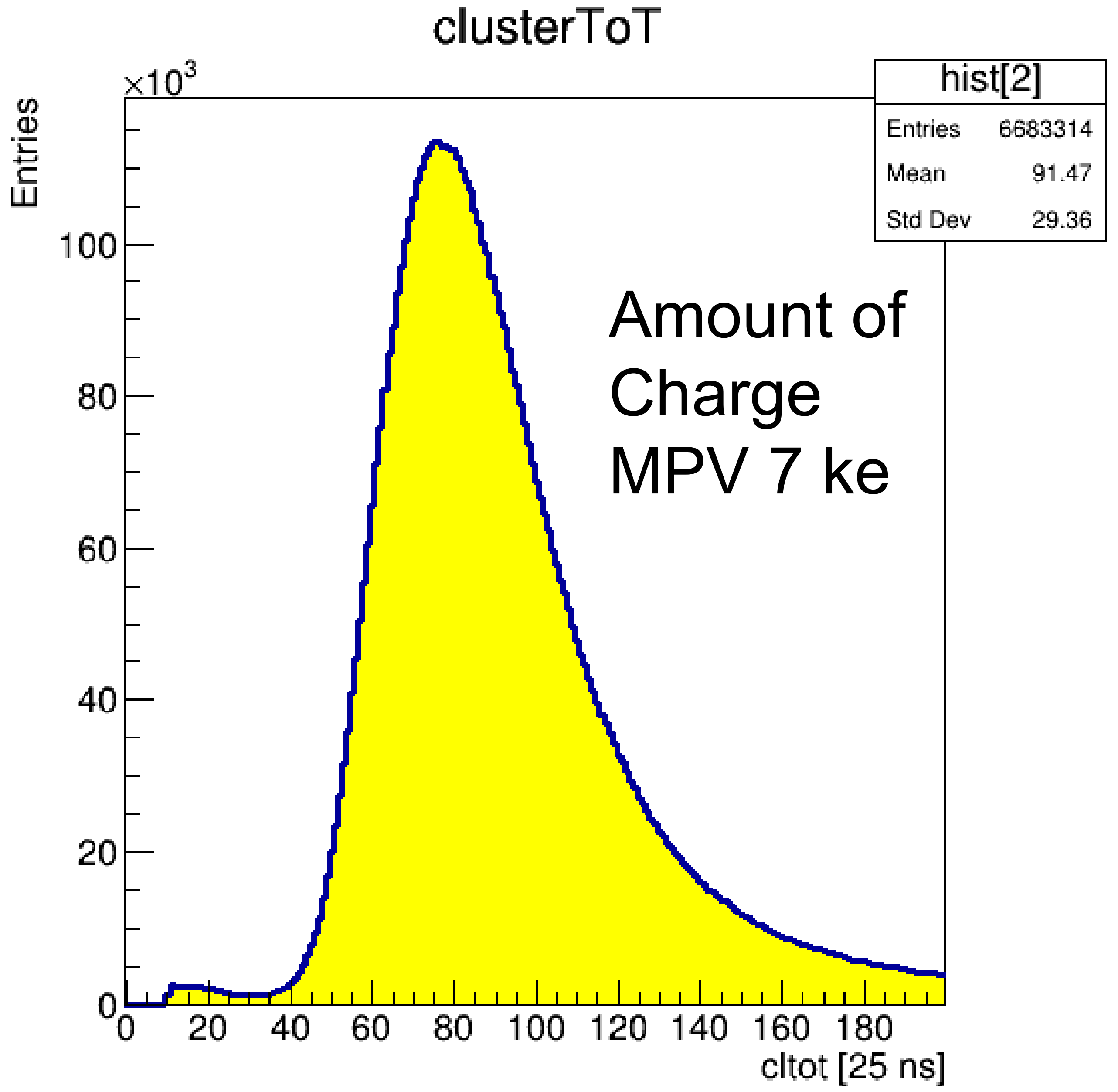
Overview 100 um planar

- 100 μm n-on-p sensors for time resolution
- Small cluster size
- Working on problem with equalization:
- Many pixels masked
- Bias voltage 200V Threshold 1000e



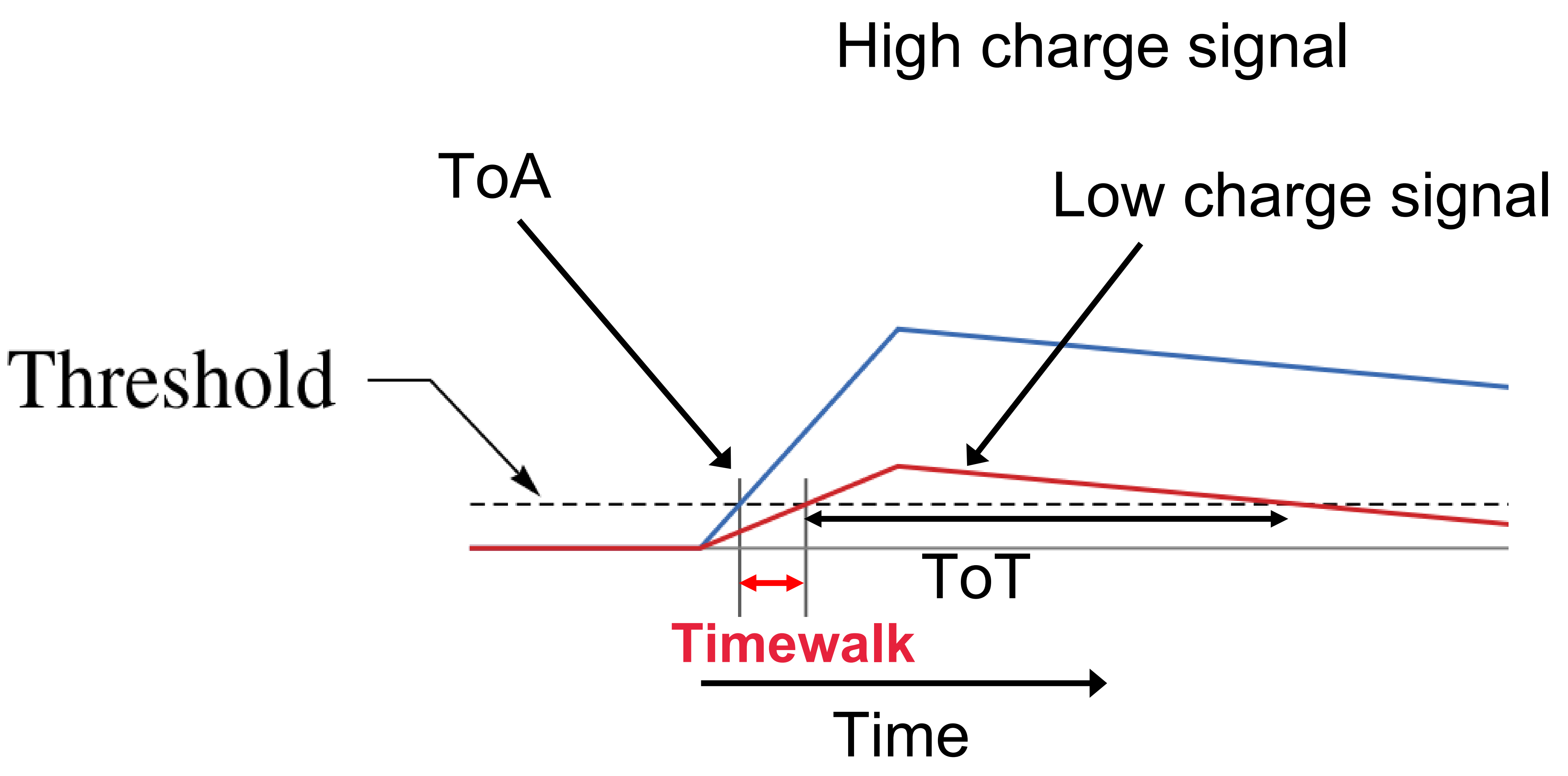


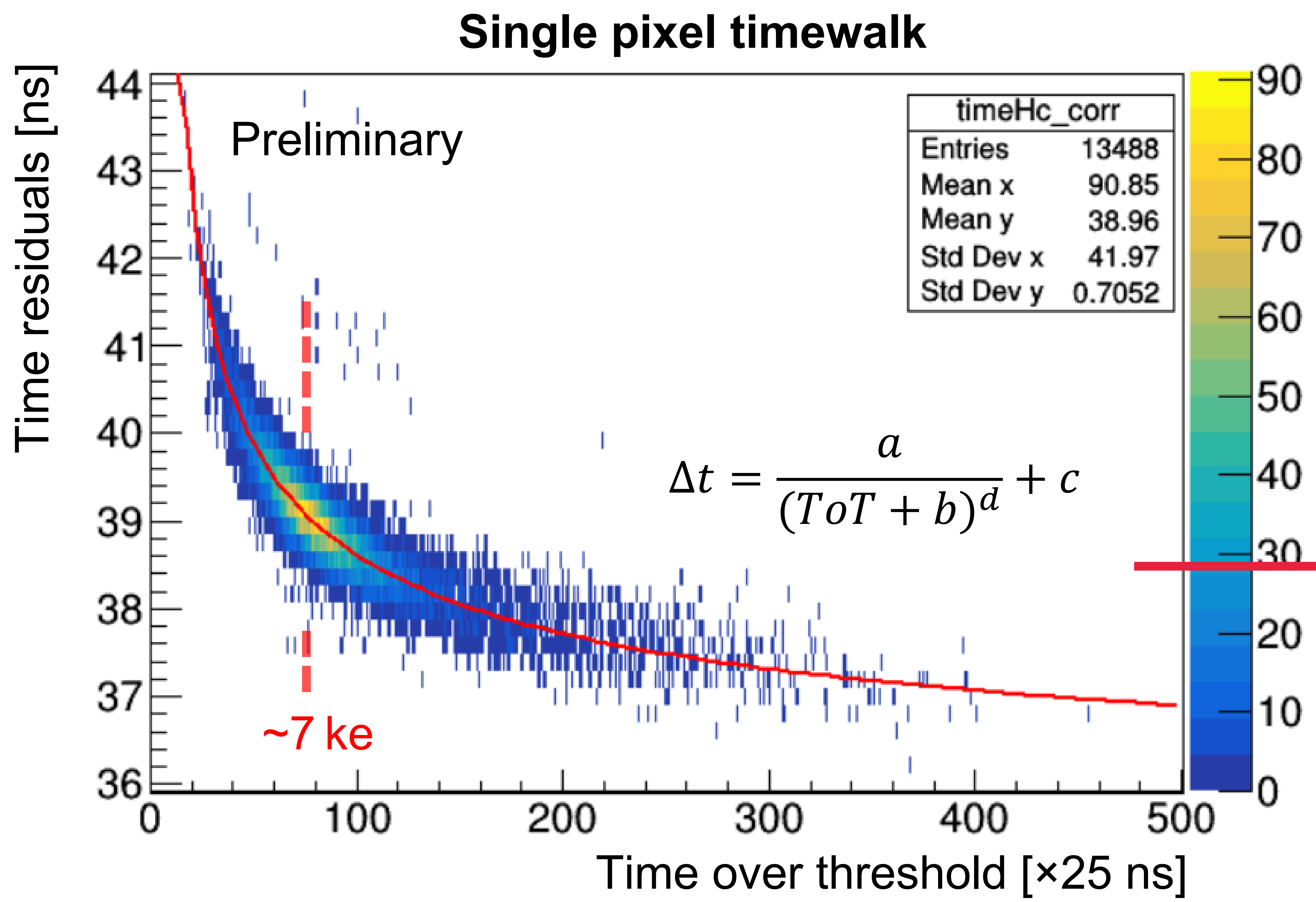


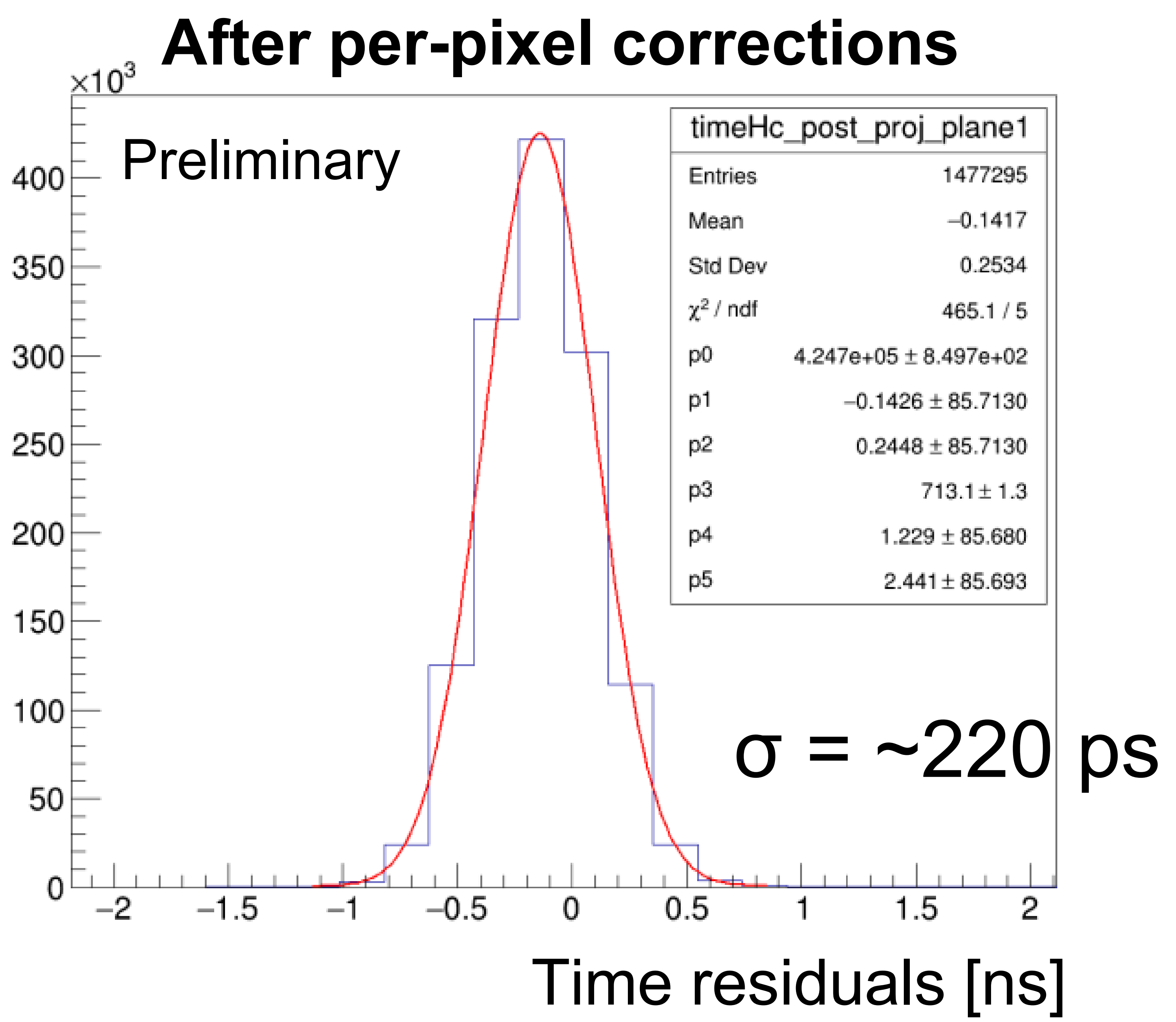


Single plane time resolution 100 um

- Simultaneous measurement of Time of Arrival (ToA) and charge deposition (by measuring Time over Threshold (ToT))
- Per-pixel timewalk corrections are applied
- Improves time resolution: ~500 ps → ~220 ps

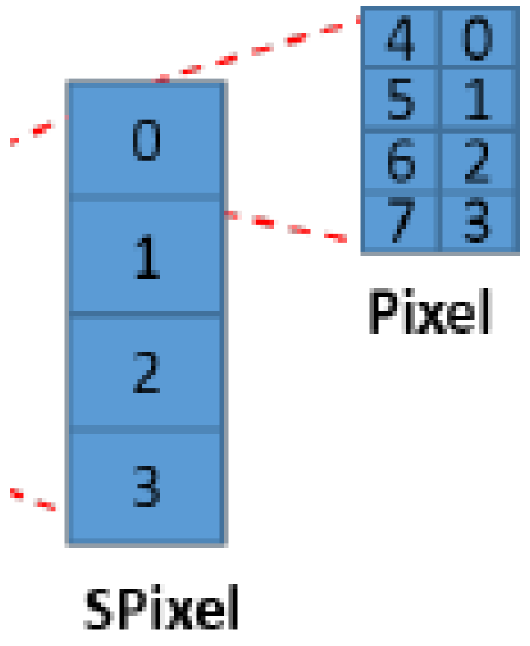


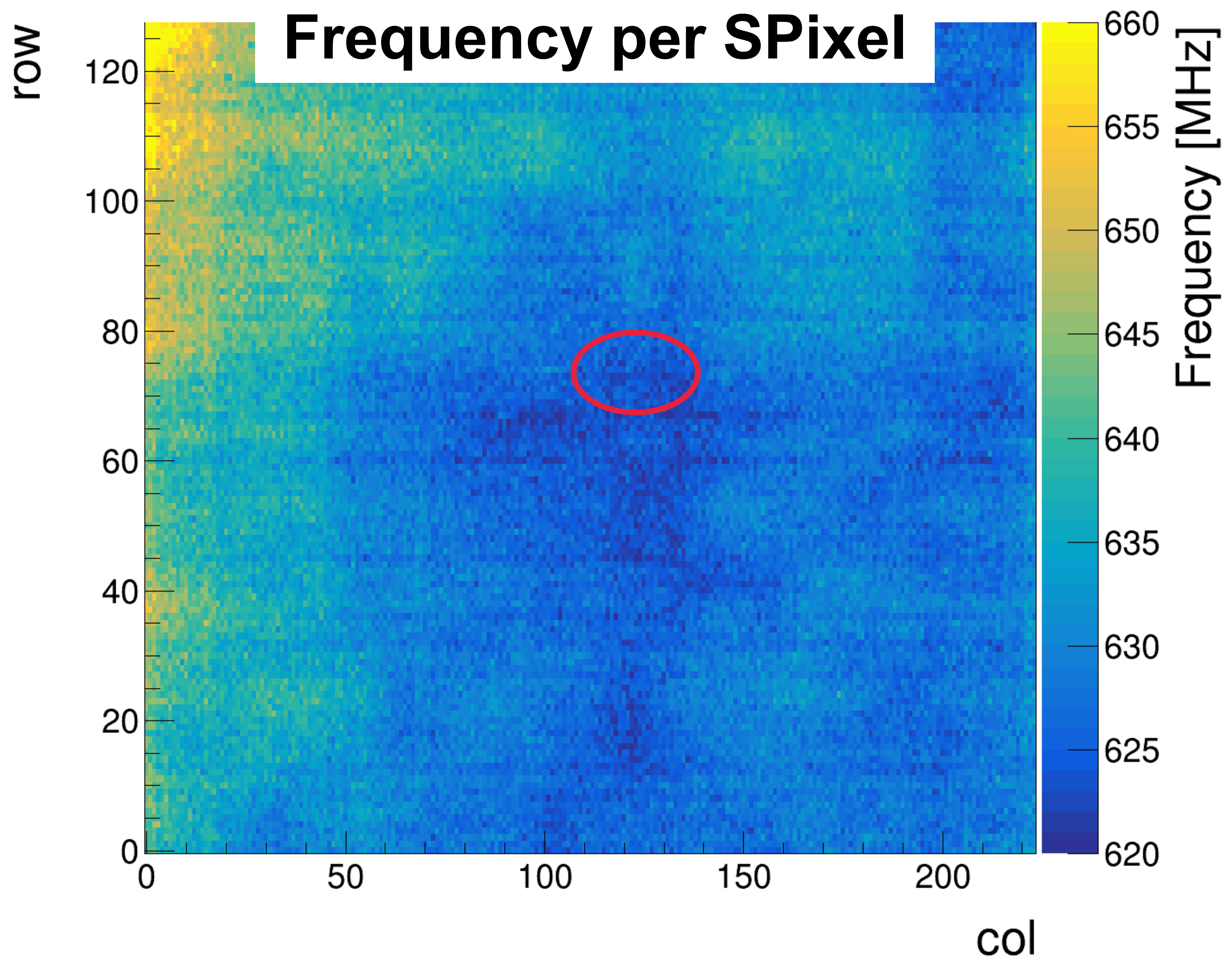


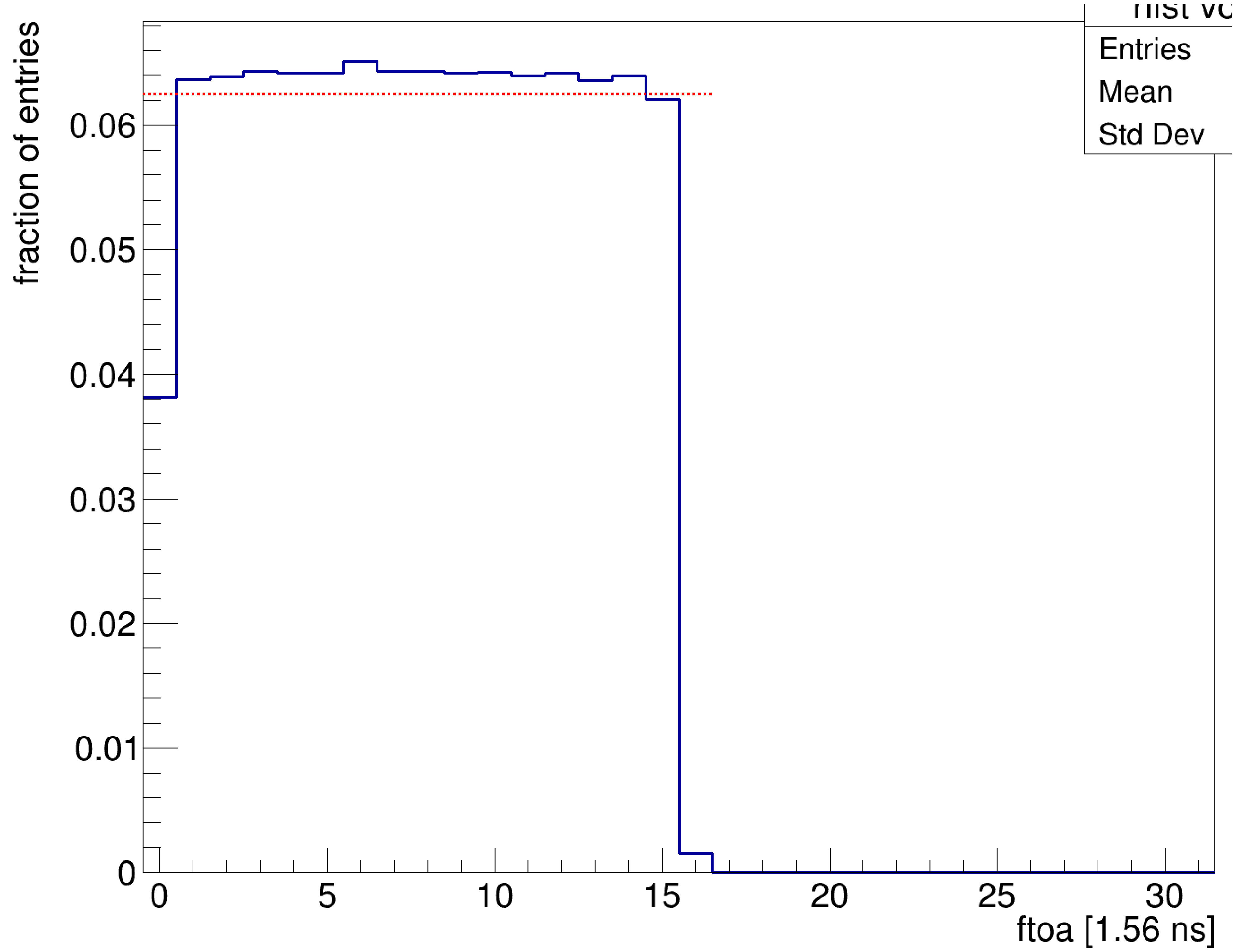


Time resolution

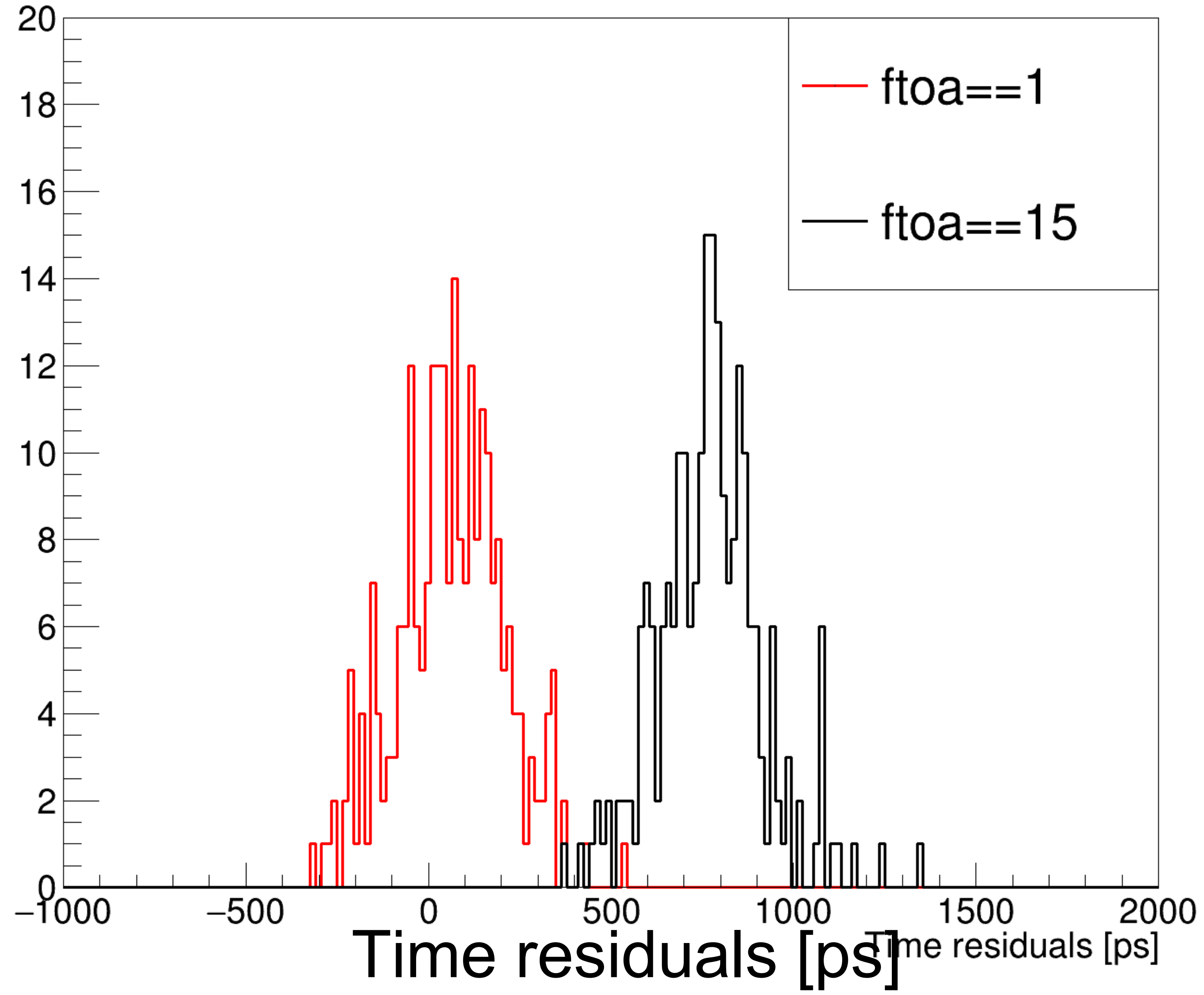
- ToA measurement with 640 MHz Voltage-Controlled Oscillator
- Every superpixel, a group of 8 pixels, has 1 VCO
- VCO is stable, but frequency fluctuations over pixel matrix
- Per superpixel VCO corrections





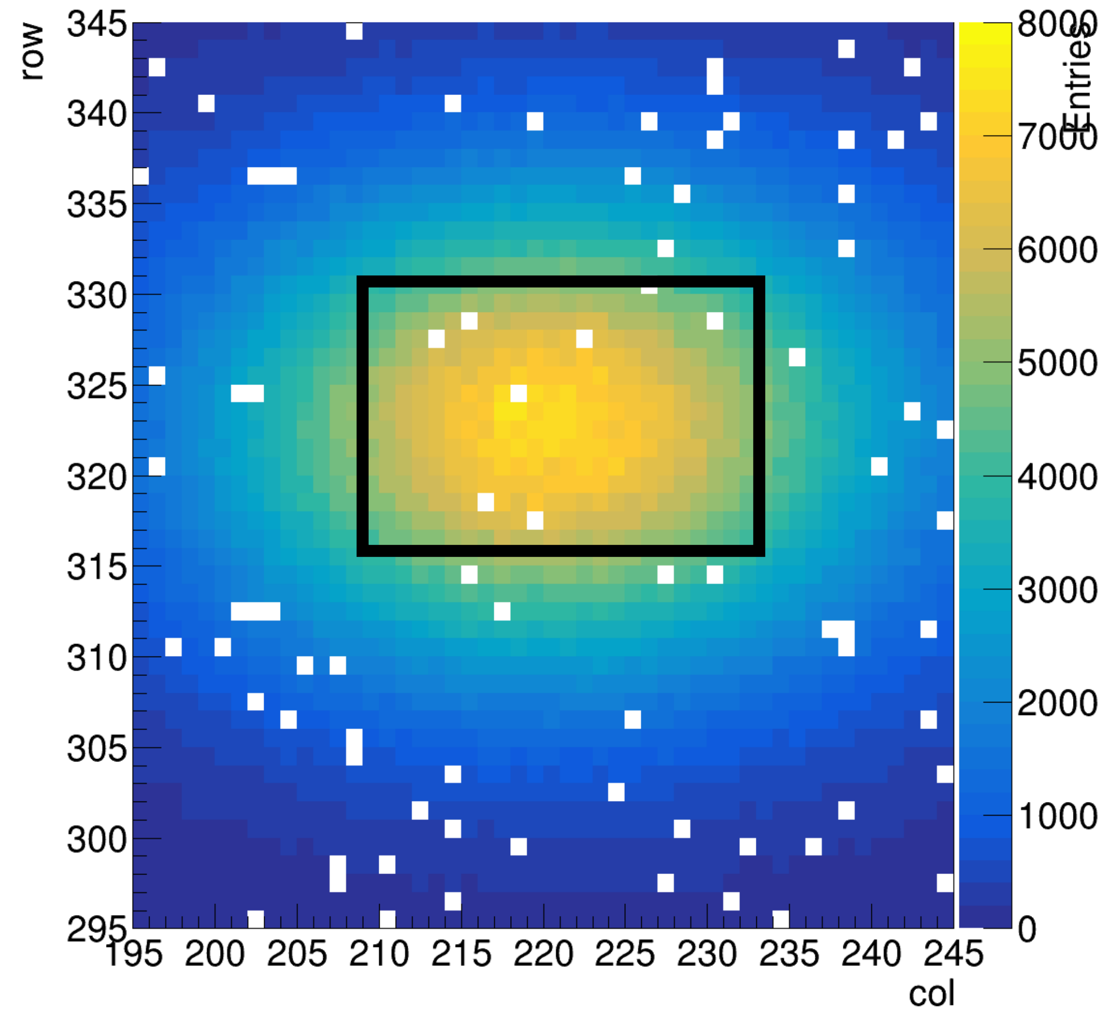


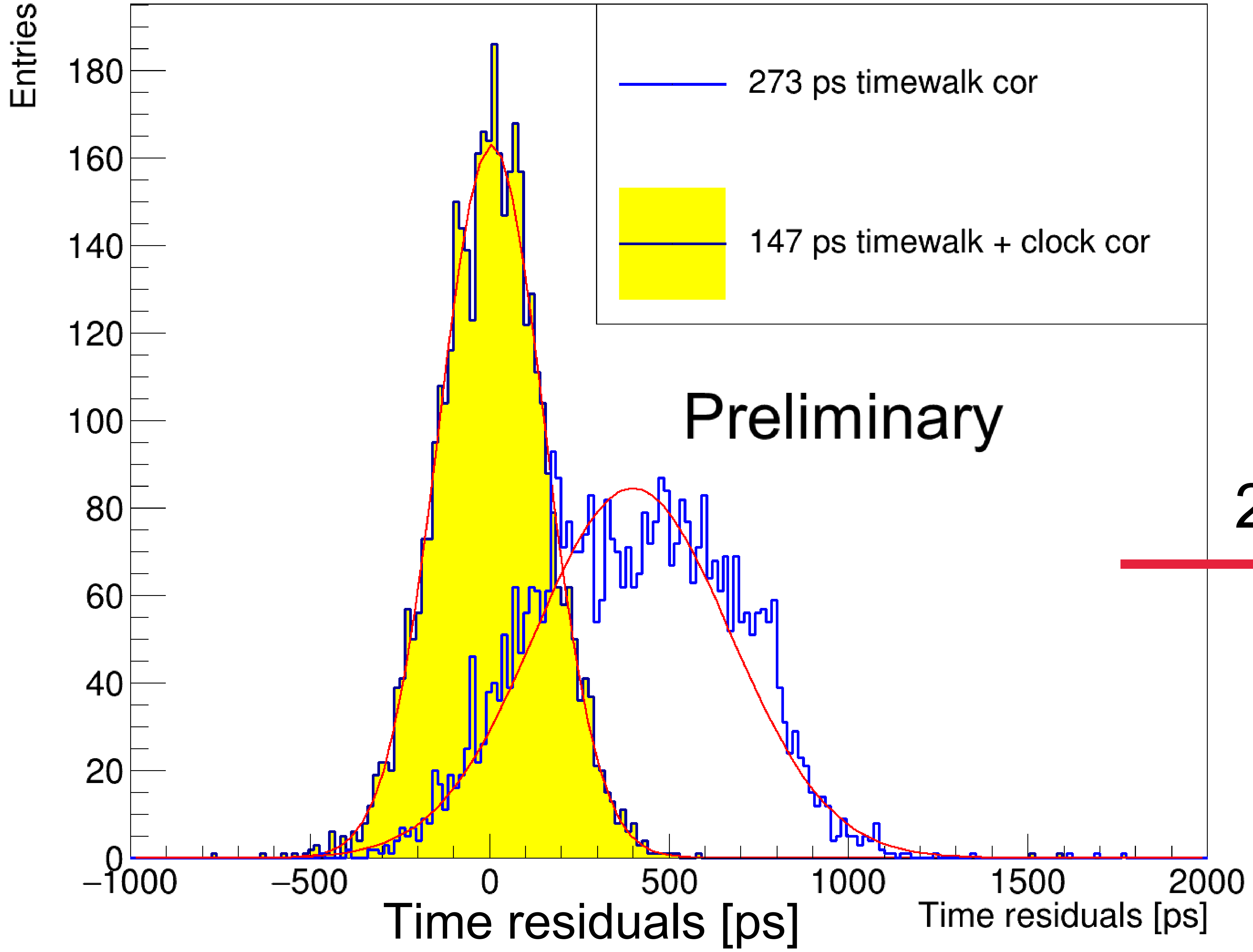
Clock runs too slow



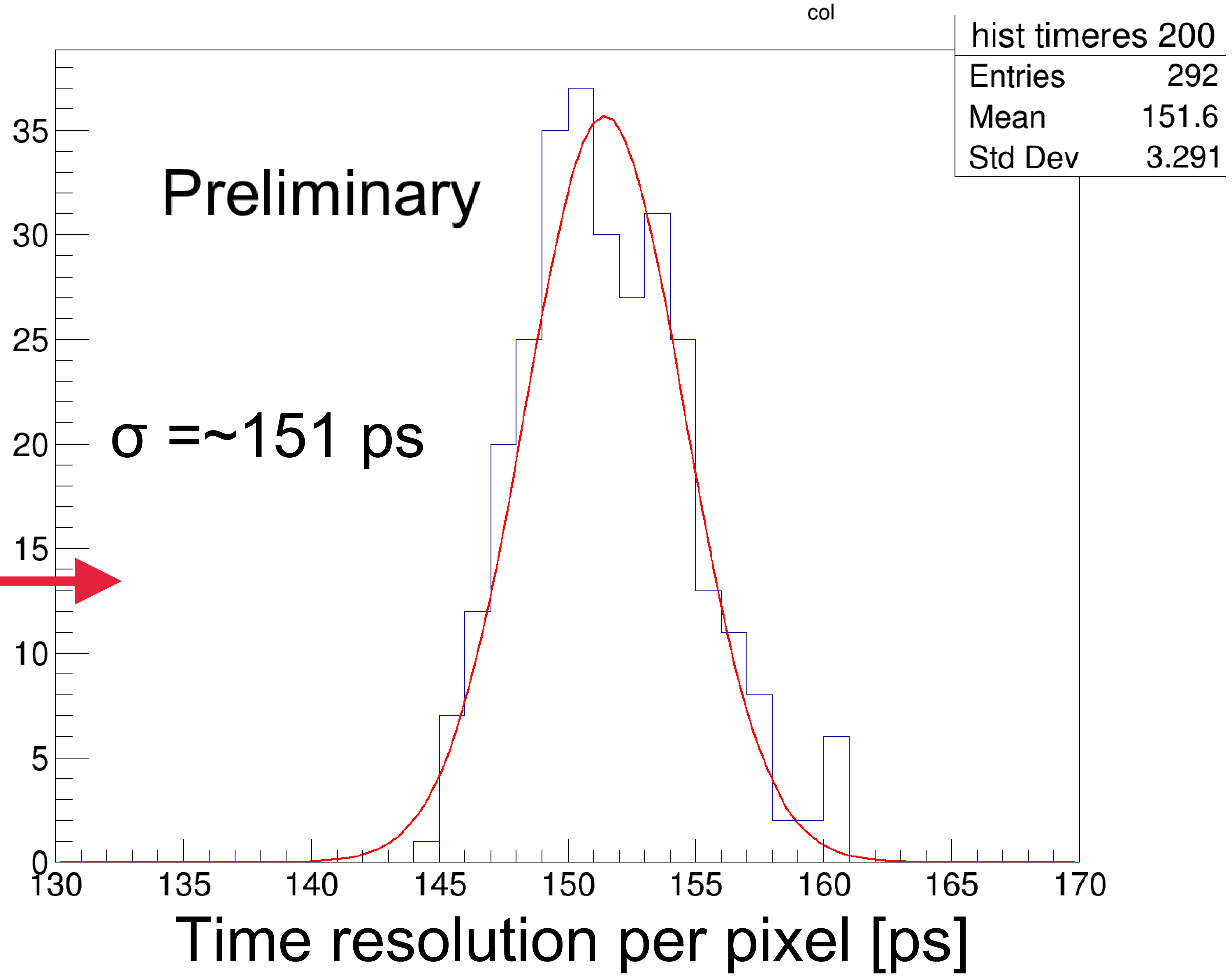
Time resolution

- VCO corrections improve time-resolution by >200 ps for this area of the matrix
- σ_t After Timewalk+VCO corrections: **~151 ps**



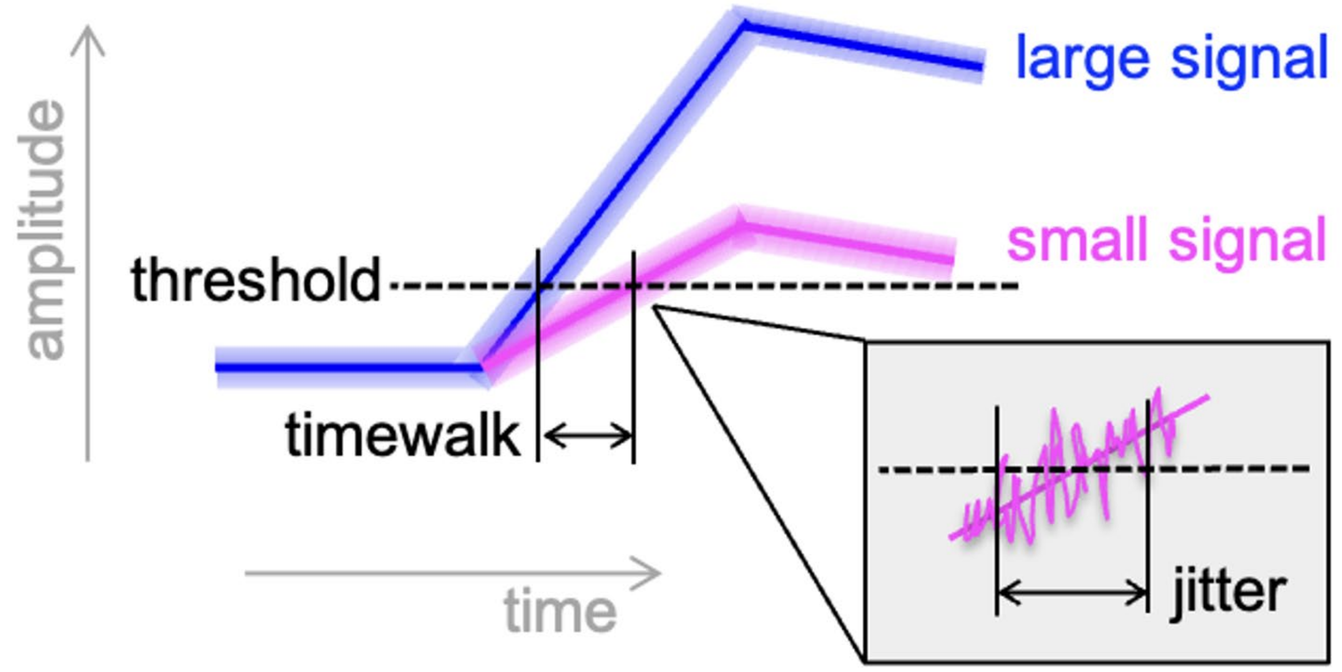


292 pixels

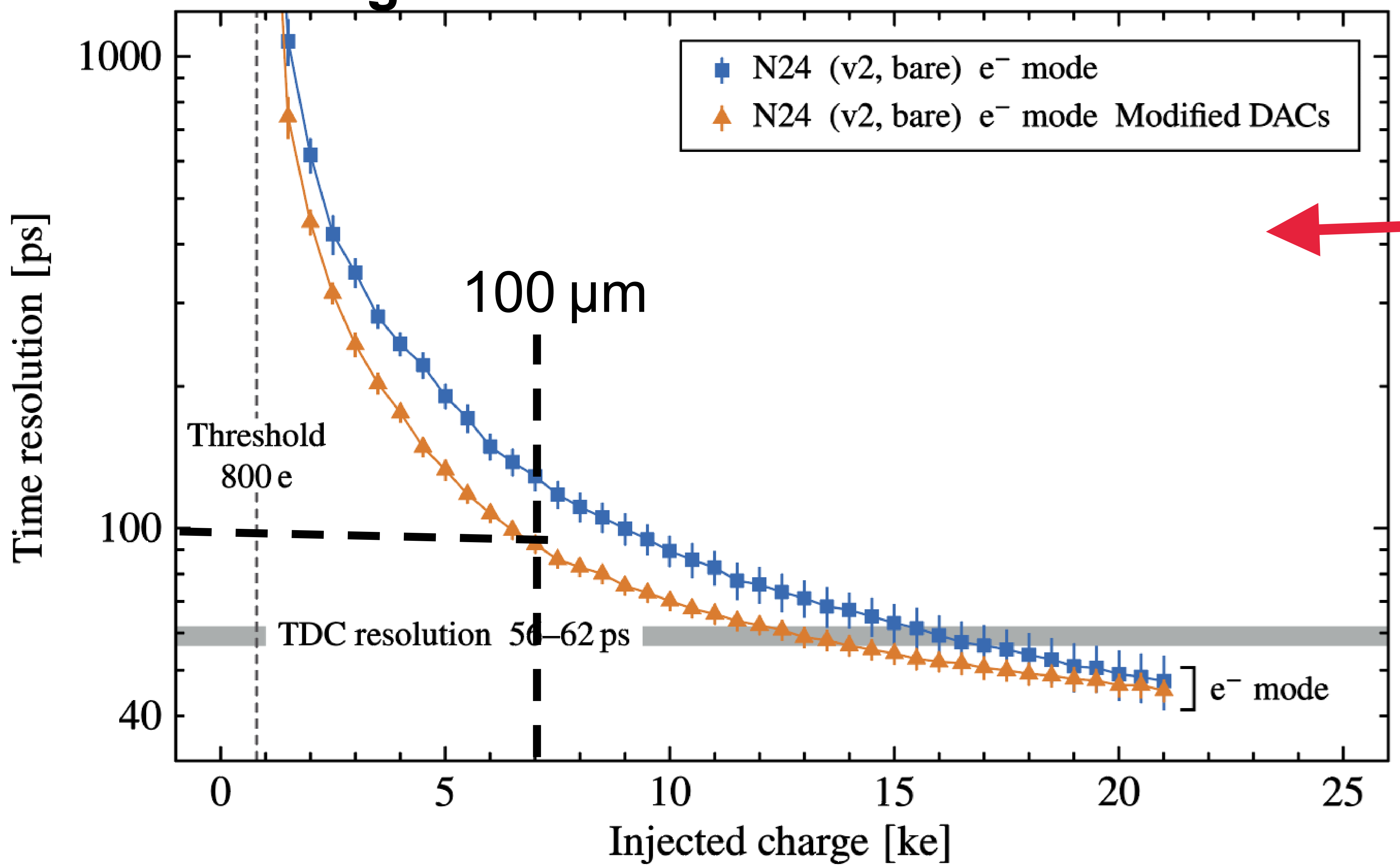


Time measurements in pixel detectors

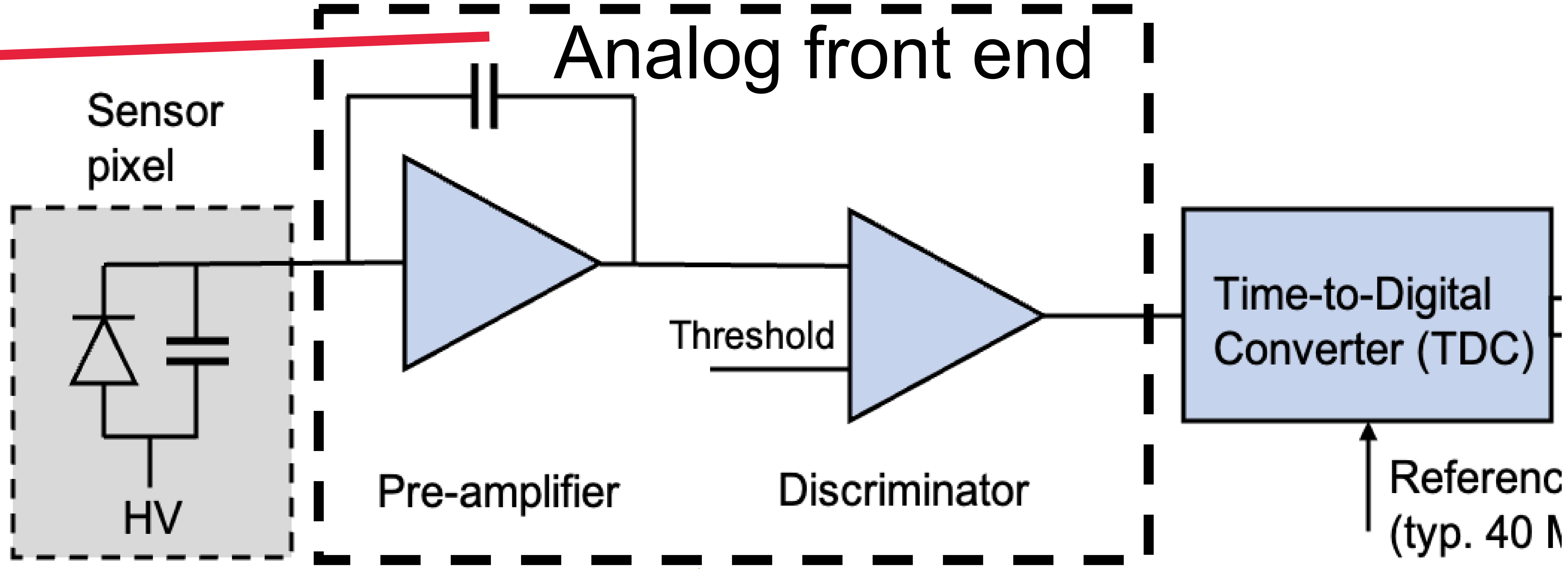
- To improve the time-resolution, we should look into new sensor technologies



Analog front-end resolution



K. Heijhoff *et al* 2022 *JINST* **17** P07006 [DOI: 10.1088/1748-0221/17/07/P07006]

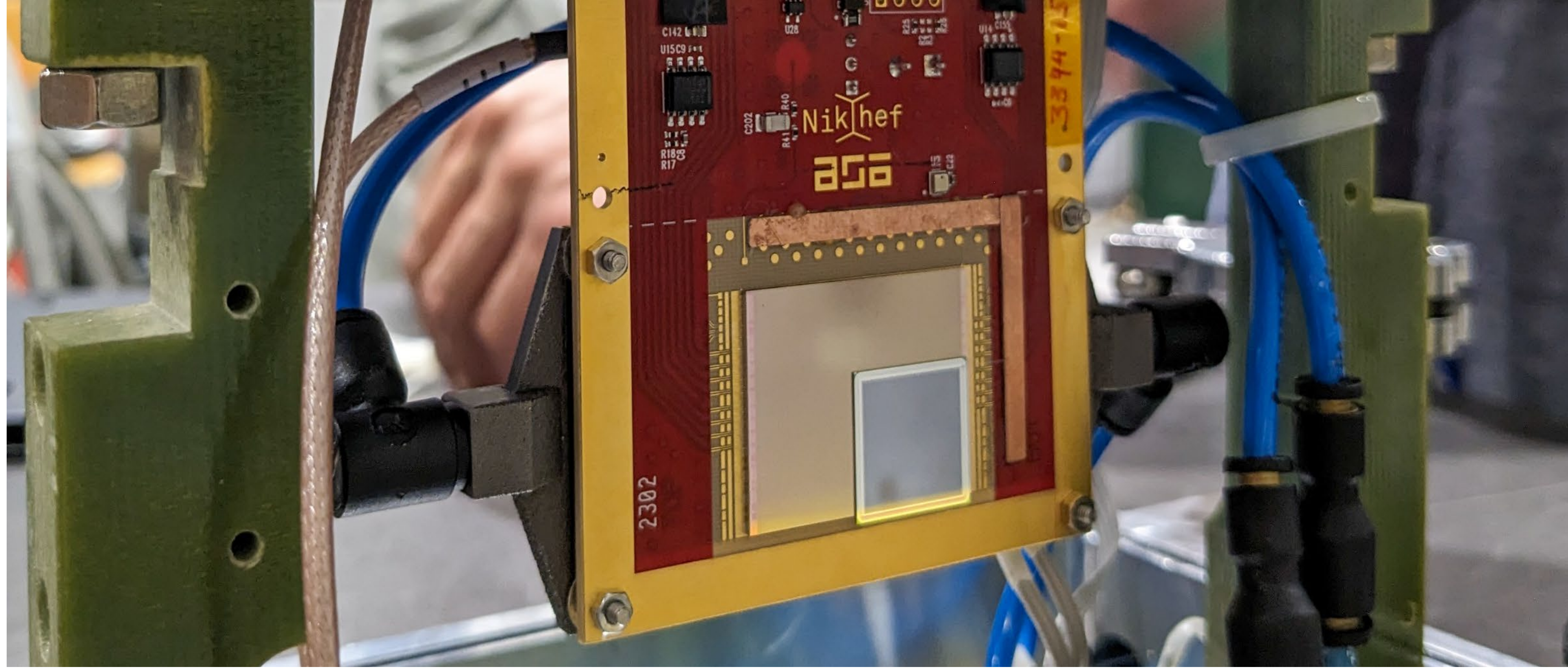


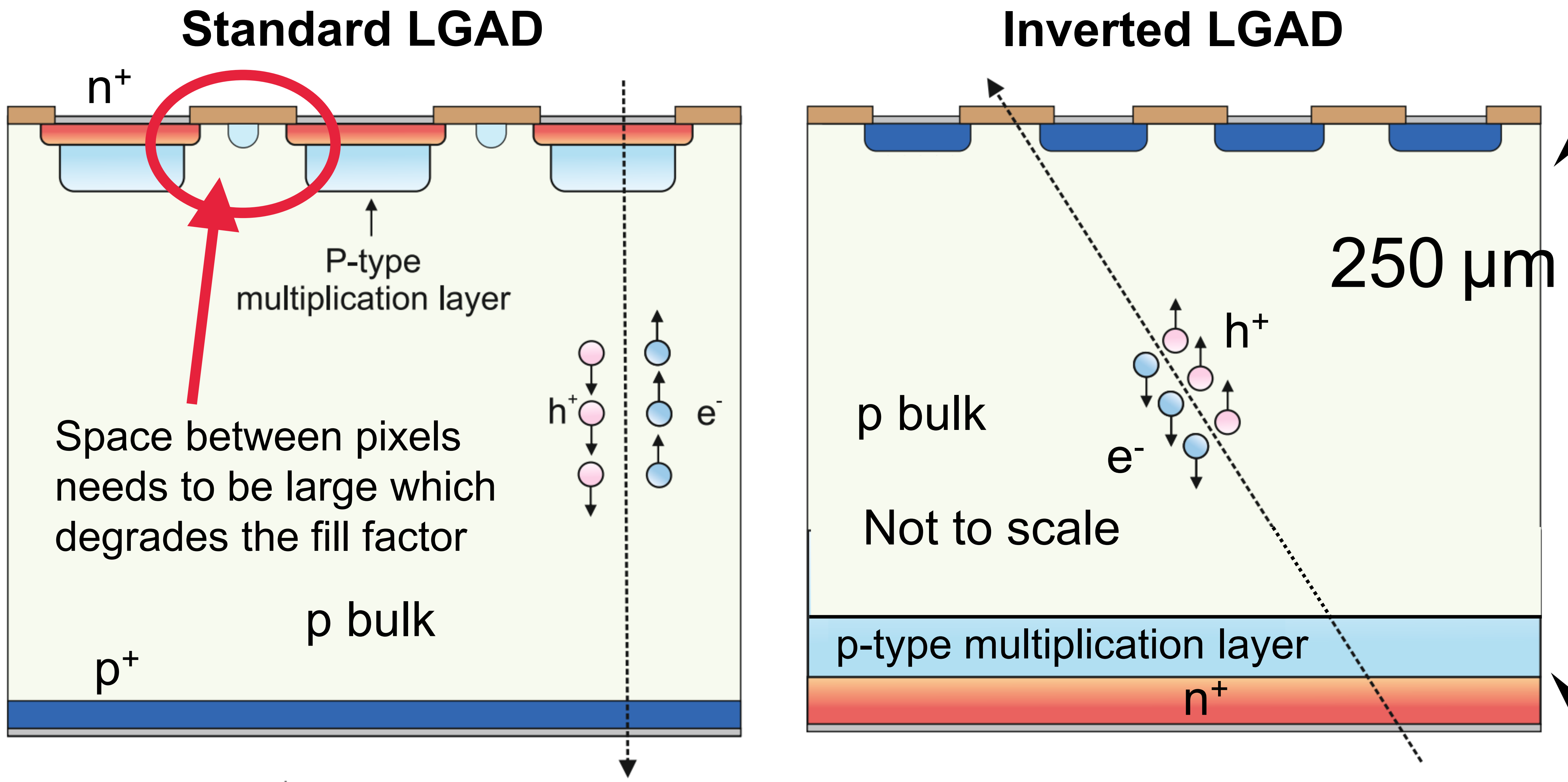
$$\text{Time resolution} = \sigma_t^2(\text{sensor}) + \sigma_t^2(\text{jitter}) + \sigma_t^2(\text{timewalk}) + \sigma_t^2(\text{TDC})$$

151 ps	=	97 ps	+	~100 ps	+	60 ps
measured	=	calculated	+	assumed	+	assumed

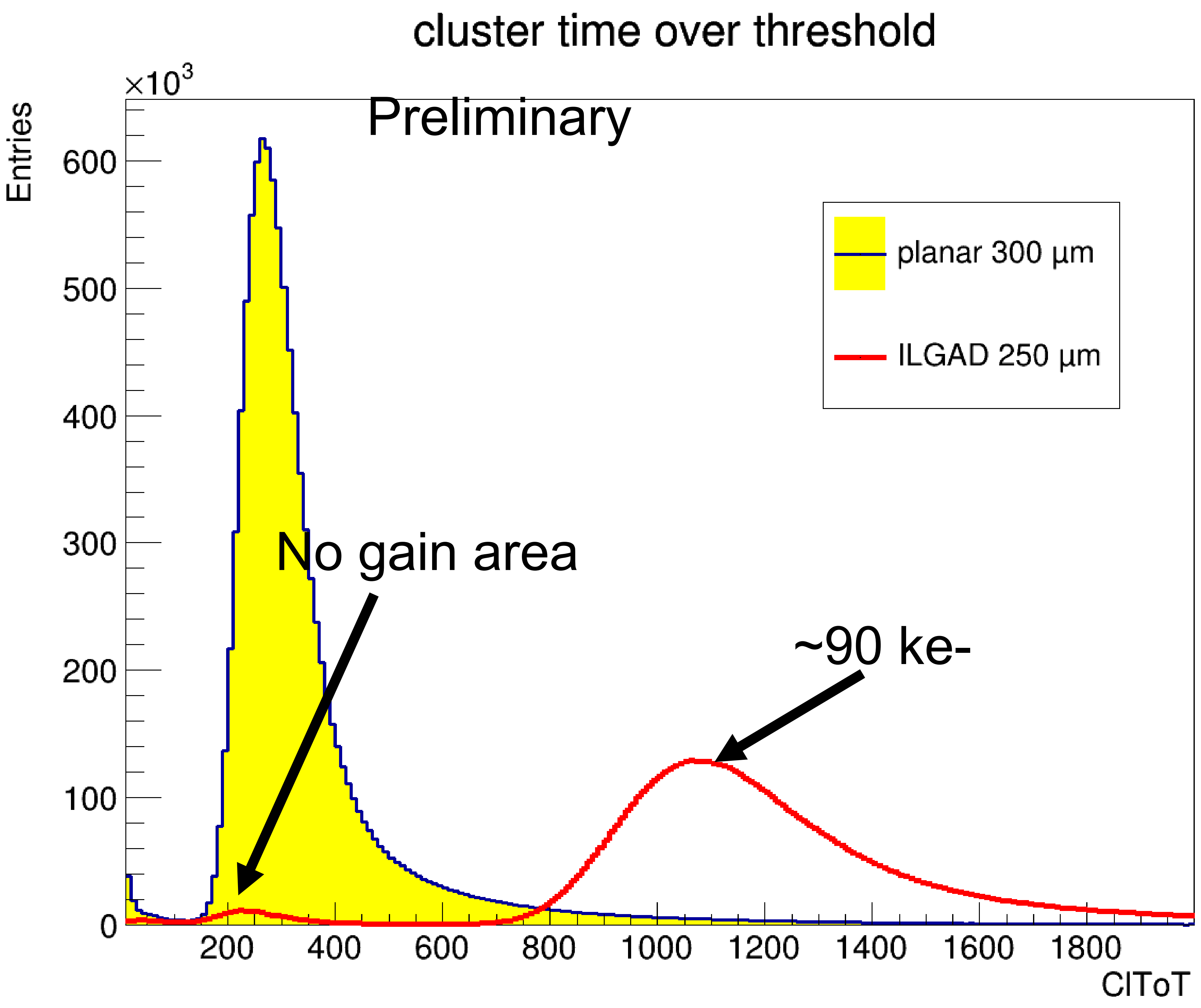
Inverted LGAD on Timepix4 as DUT

- Low-gain avalanche diodes (LGADs) use charge multiplication to deliver larger input signals
- Tested 250 µm thick iLGADs with 55/110 µm pitch (Tpx3 sized)
- Small pixel size cannot be achieved in standard LGAD technology (without losing efficiency)
- Inverted LGADs (iLGADs) solve this by placing the gain layer on the backside
- Sensors produced by Micron and provided by Glasgow University



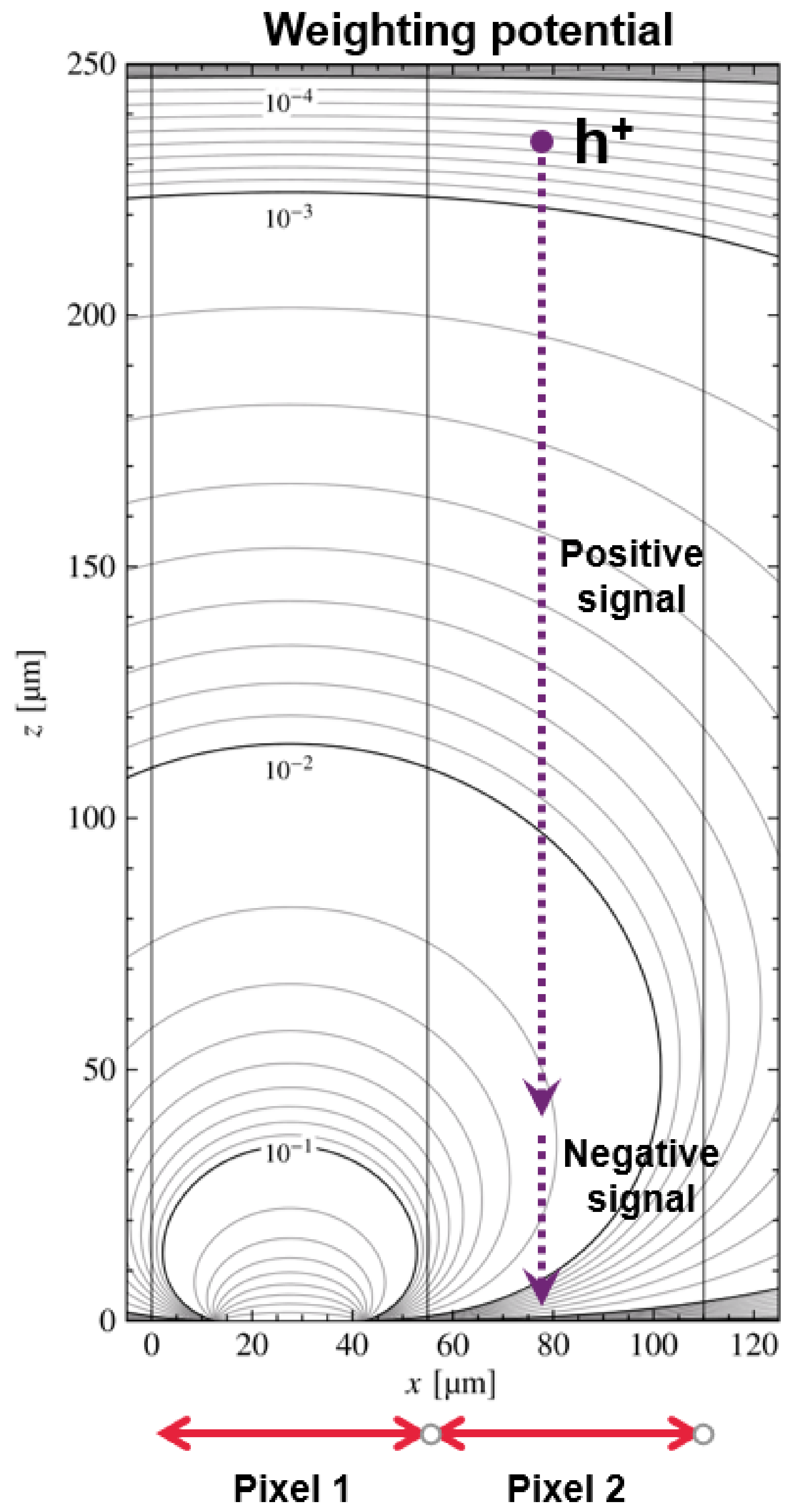


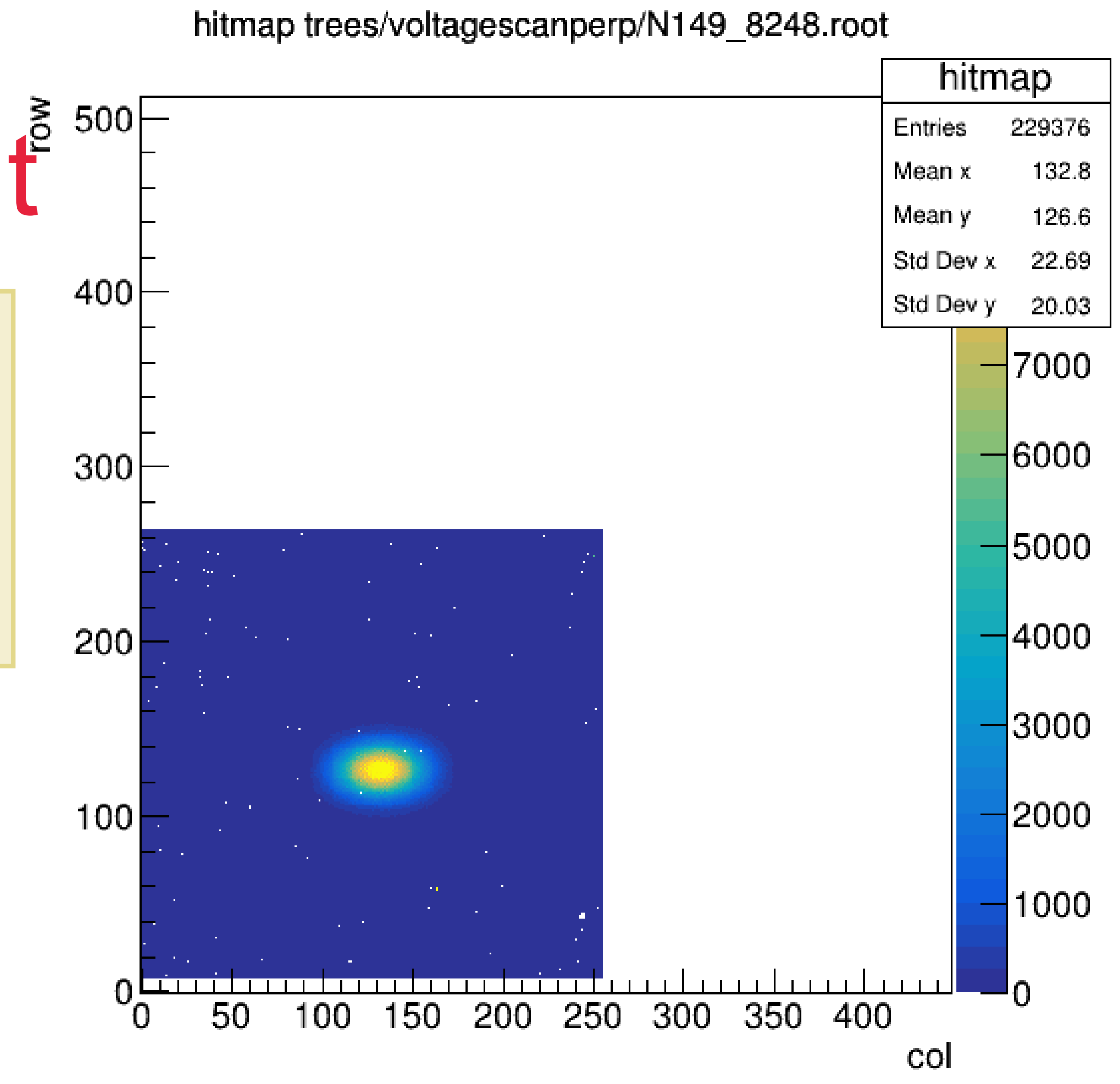
A. Doblas *et al Sensors* **2023**, 23, 3450 [DOI: 10.3390/s23073450]

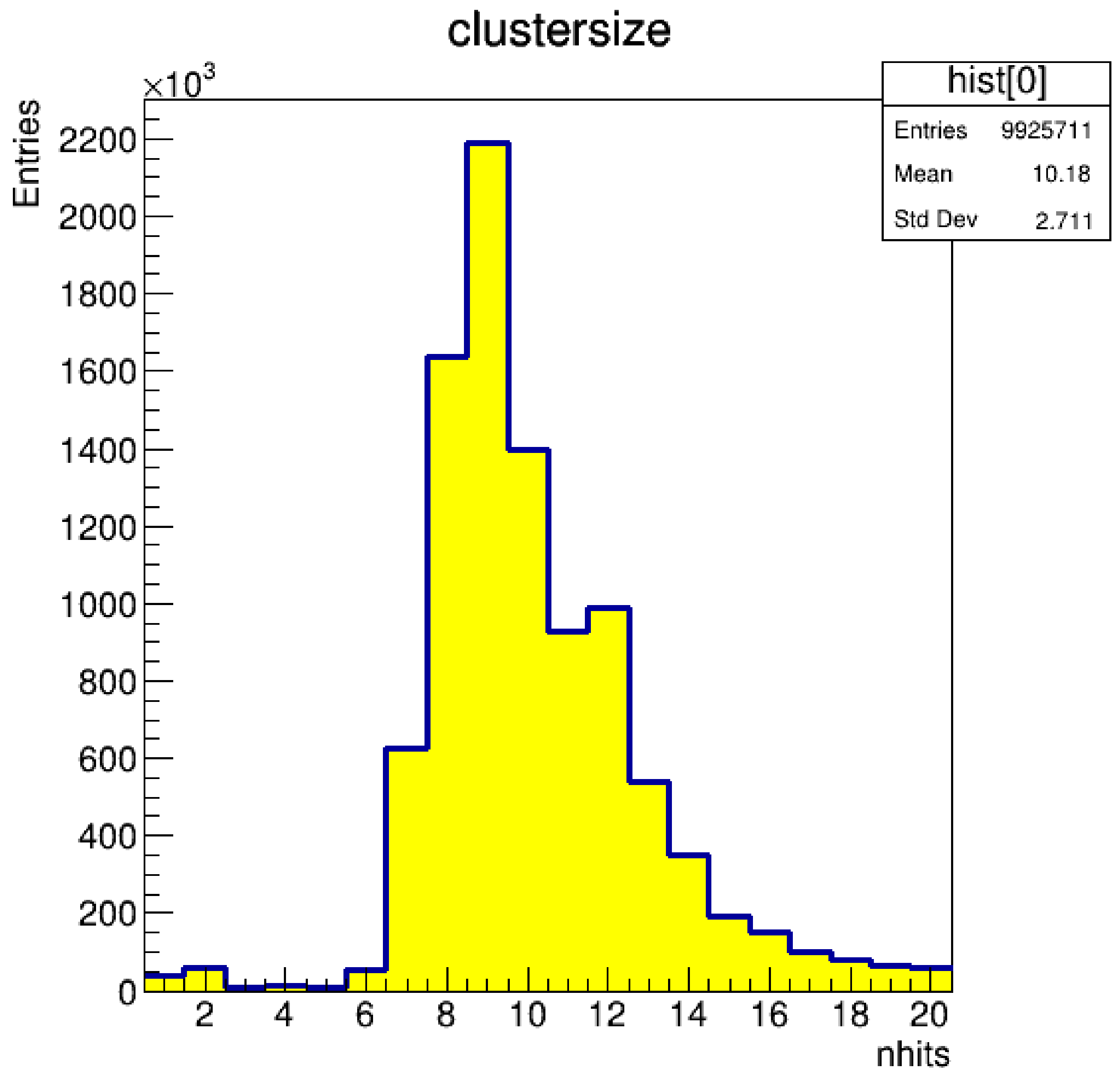


Overview 250 um iLGAD measurement

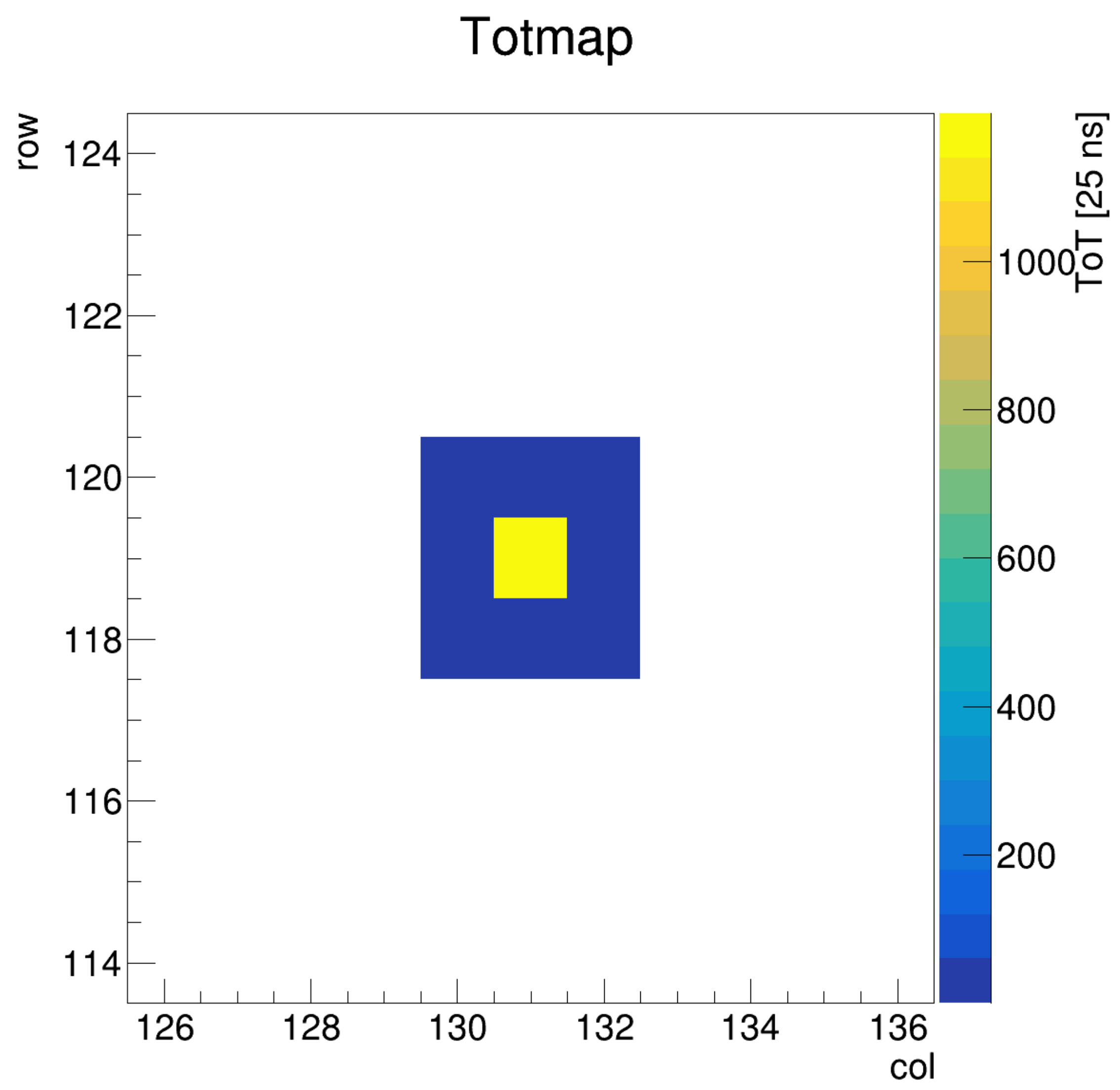
- Large cluster size at perpendicular beam incidence
- We suspect due to bipolar signals in neighboring pixels

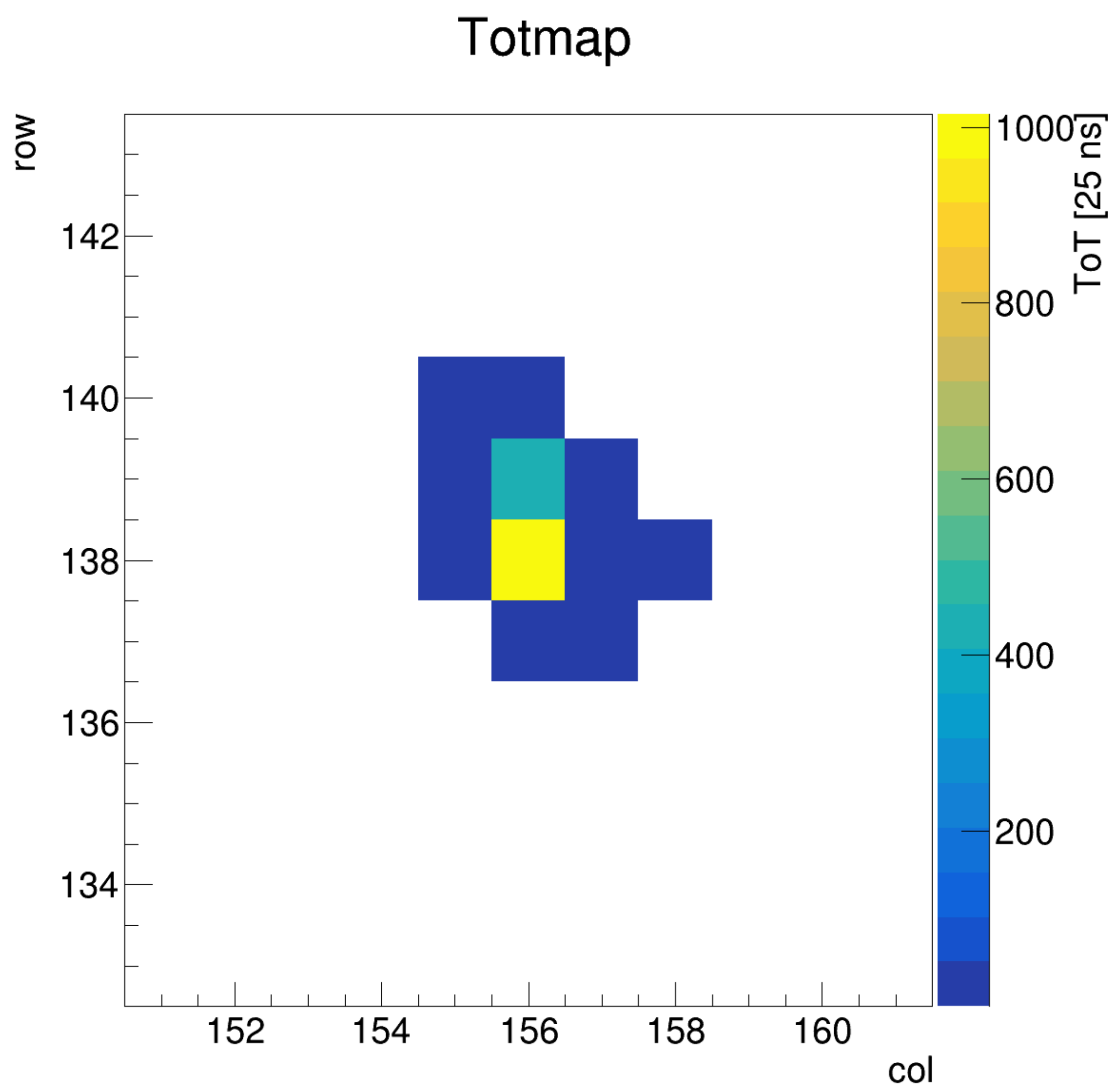


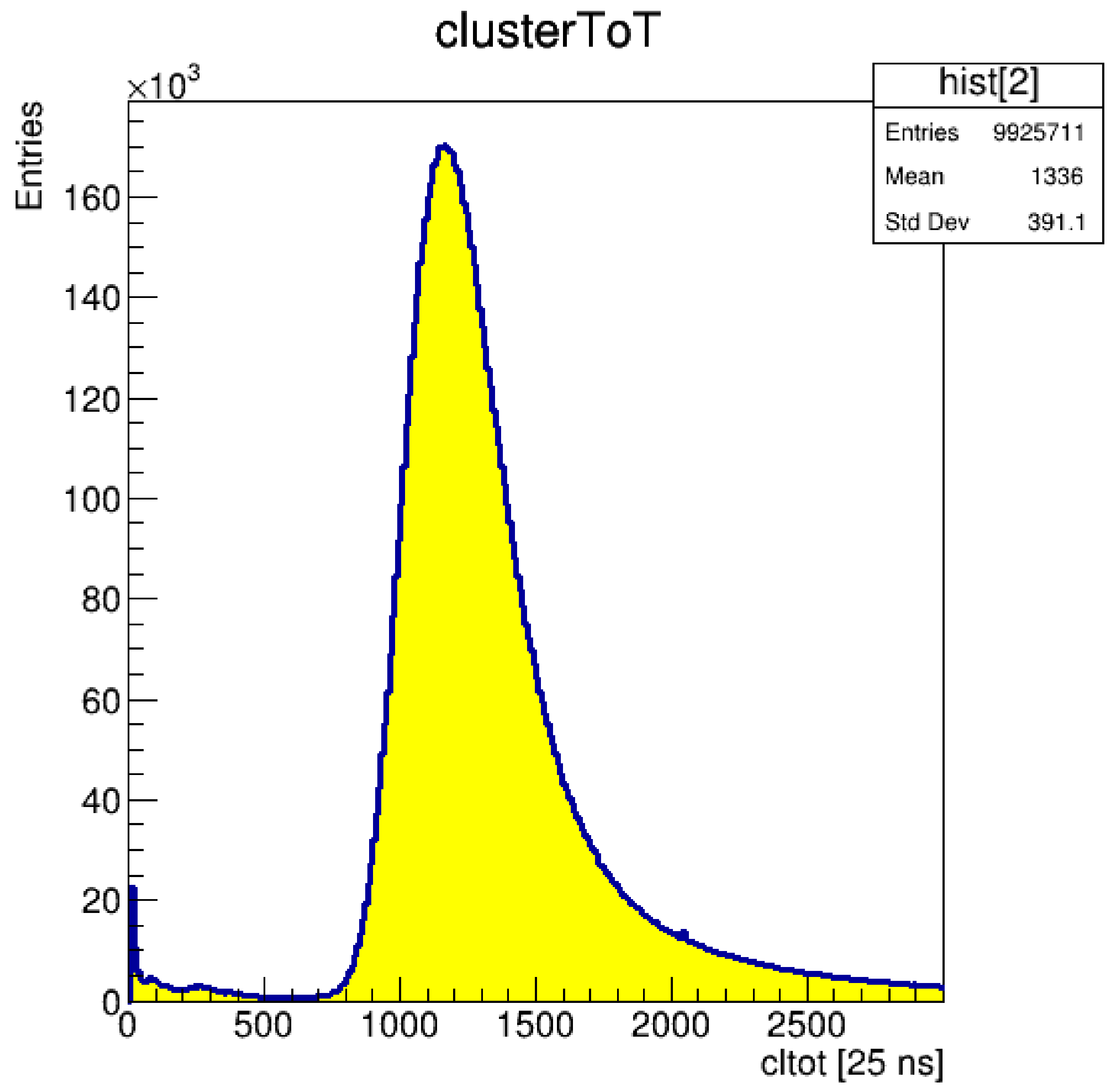




Examples of clusters

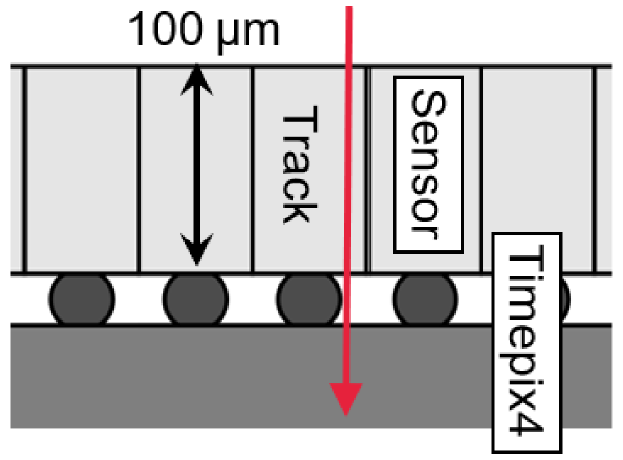


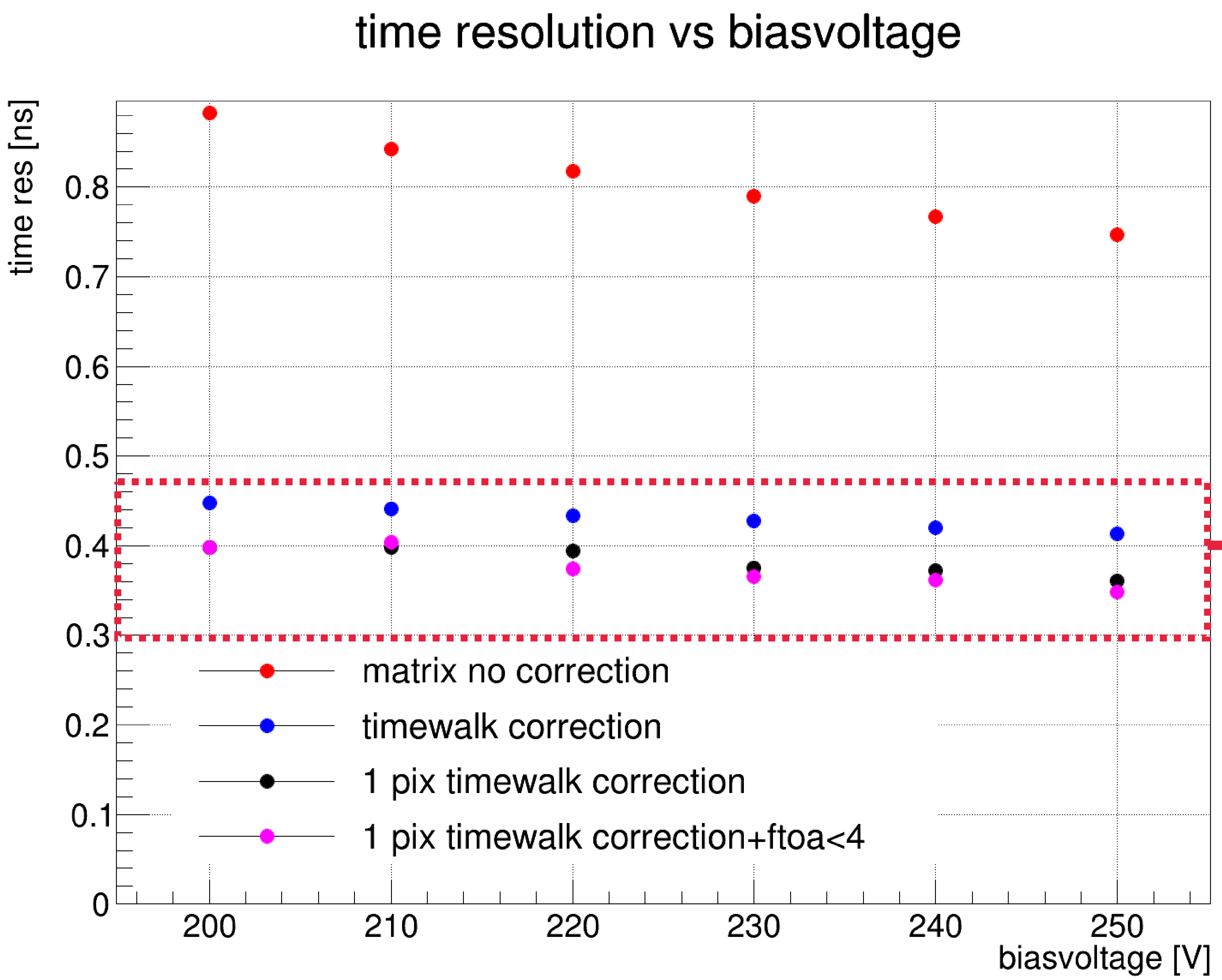


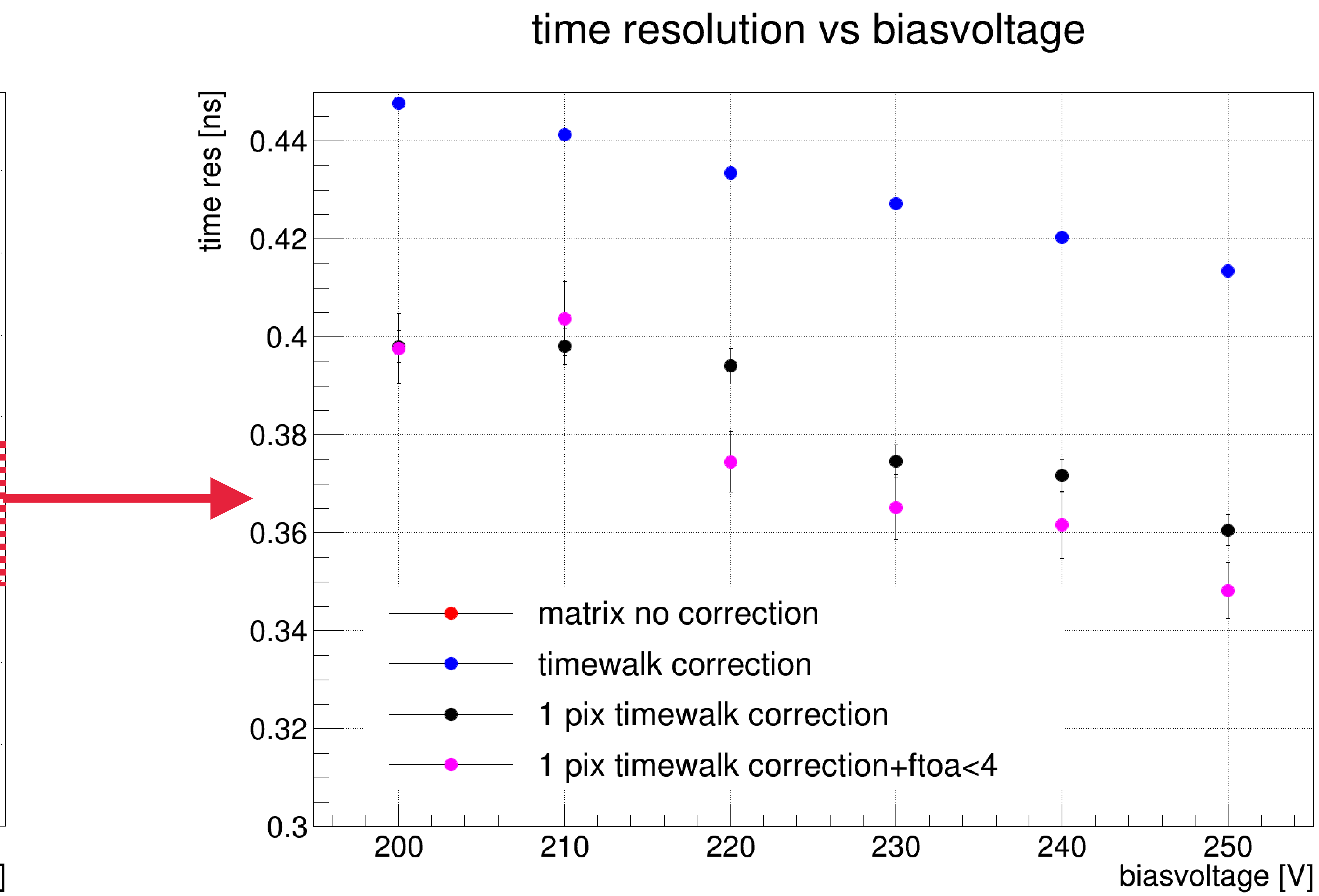


Time resolution for perpendicular tracks

- Time-resolution improves with a higher bias-voltage
- After Timewalk+VCO corrections: **~350 ps**







Grazing angle measurements

- Grazing angle measurement used to study time resolution as function of depth in the sensor
- Selection of clusters without δ-rays
- MCP as time reference
- Operated at different biasvoltages and thresholds

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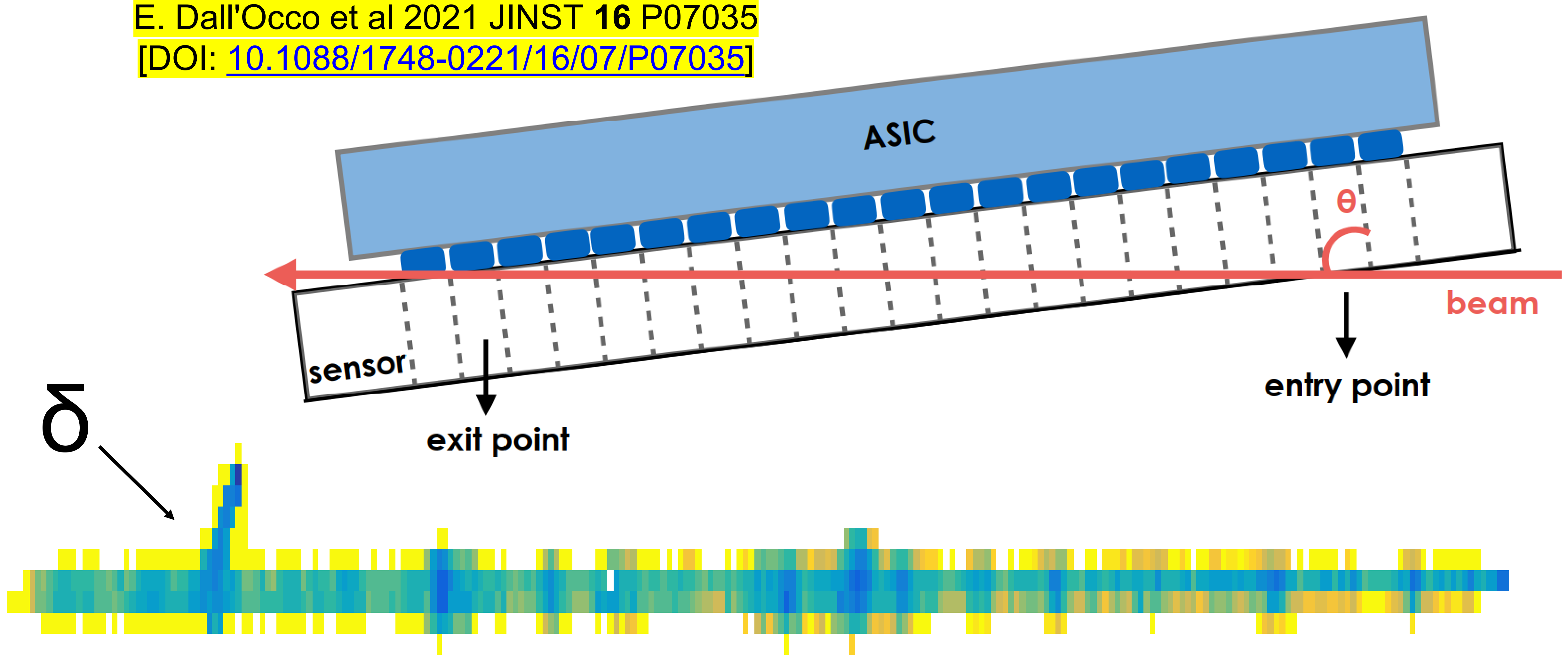
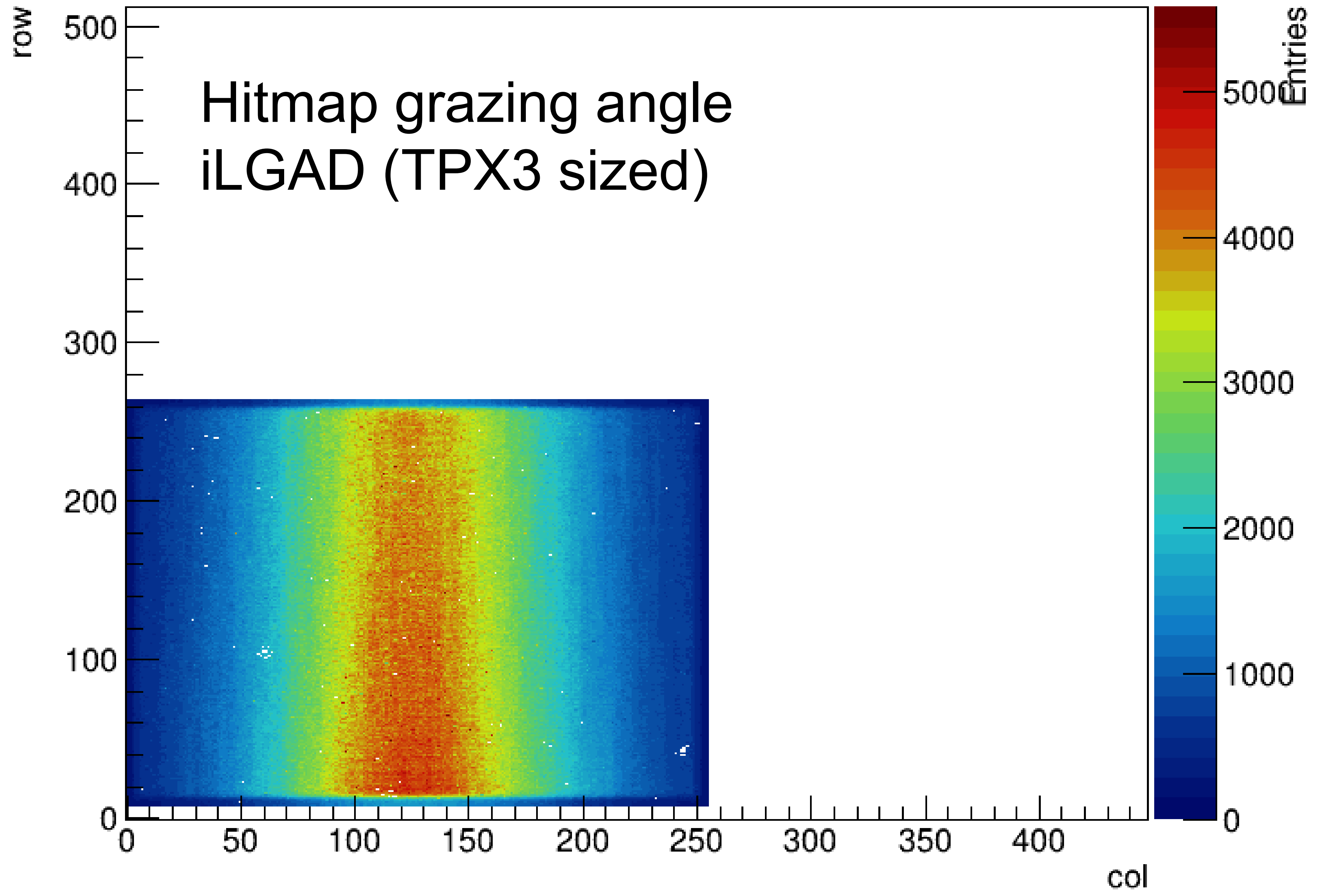
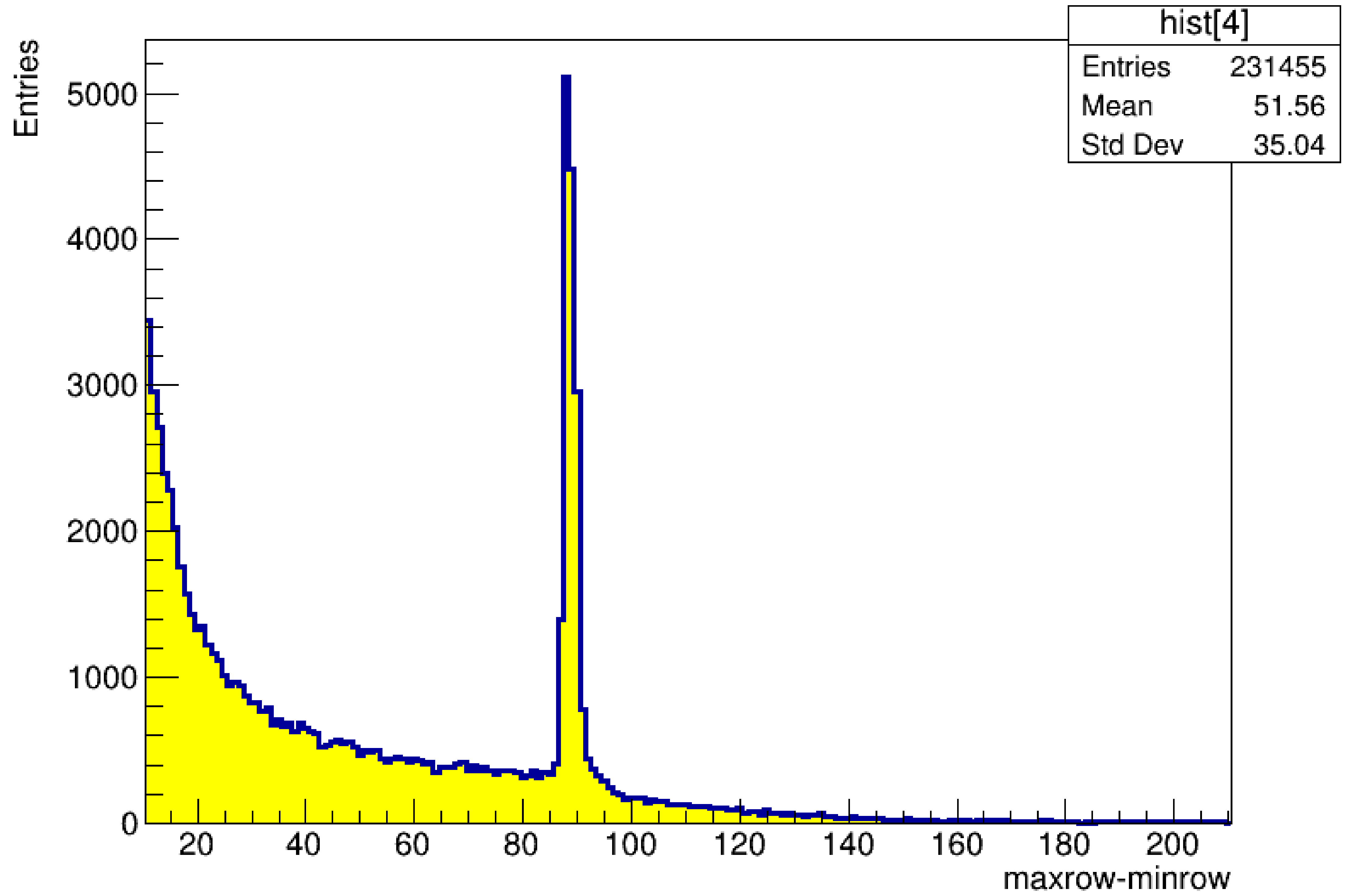
[DOI: 10.1088/1748-0221/16/07/P07035]

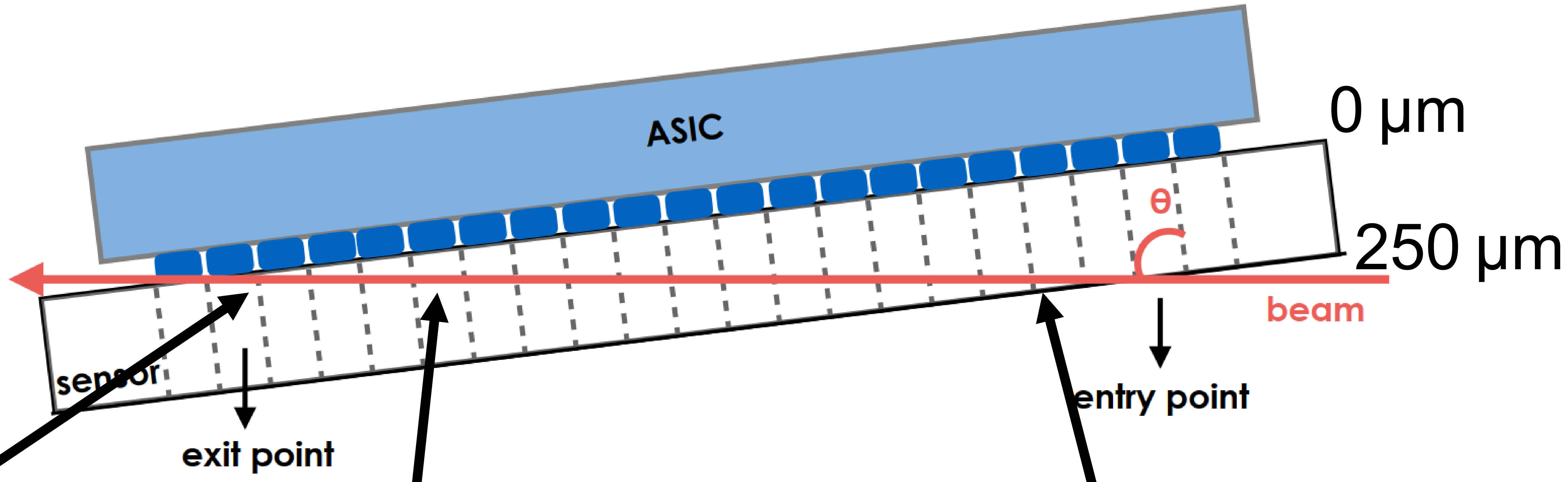


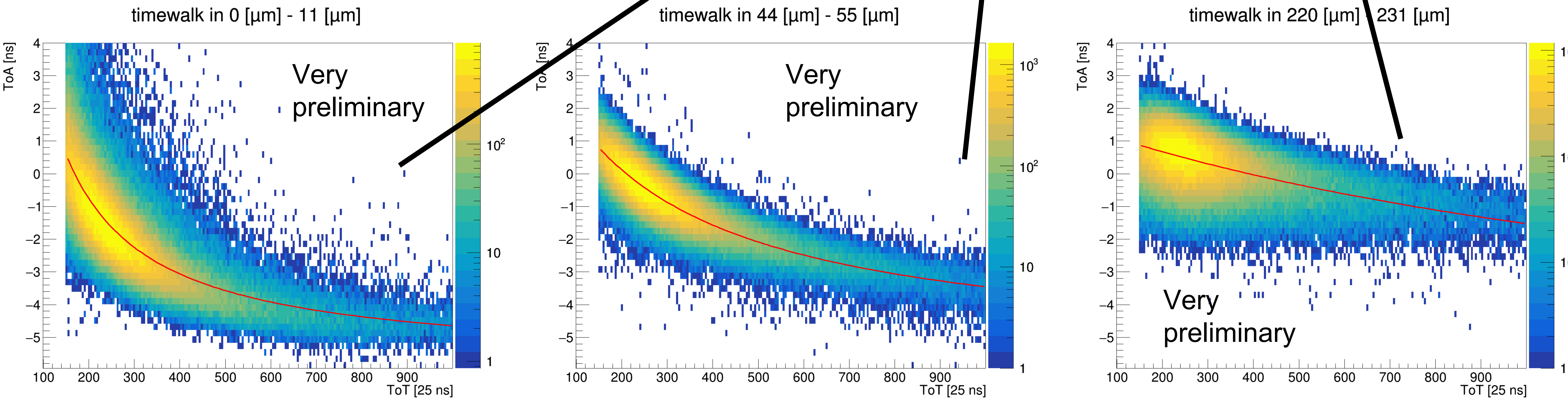




Timewalk+drift correction per depth

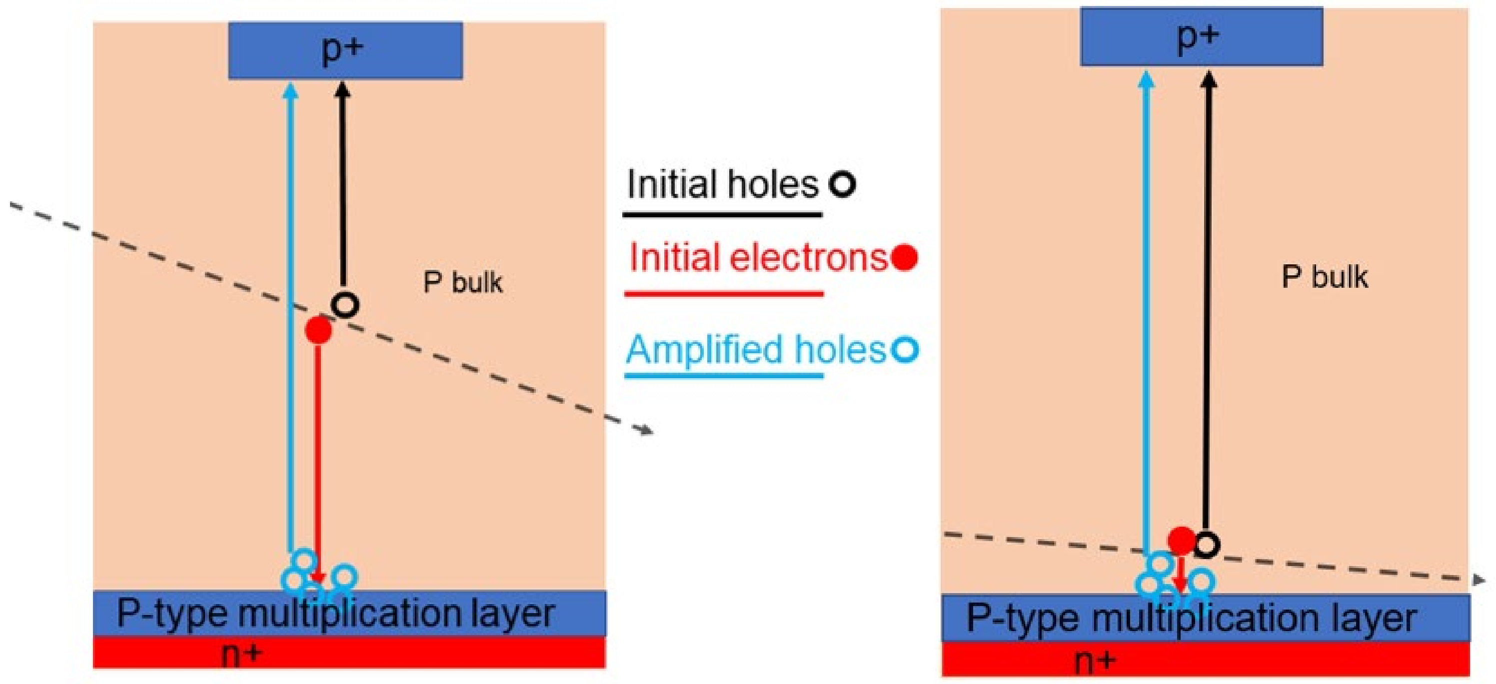
- Timewalk curve is a mix of drift in sensor and timewalk
- Close to the ASIC timewalk dominated by initial signal
- Near the gain layer there is more drift and therefore the slope of the curve is flatter



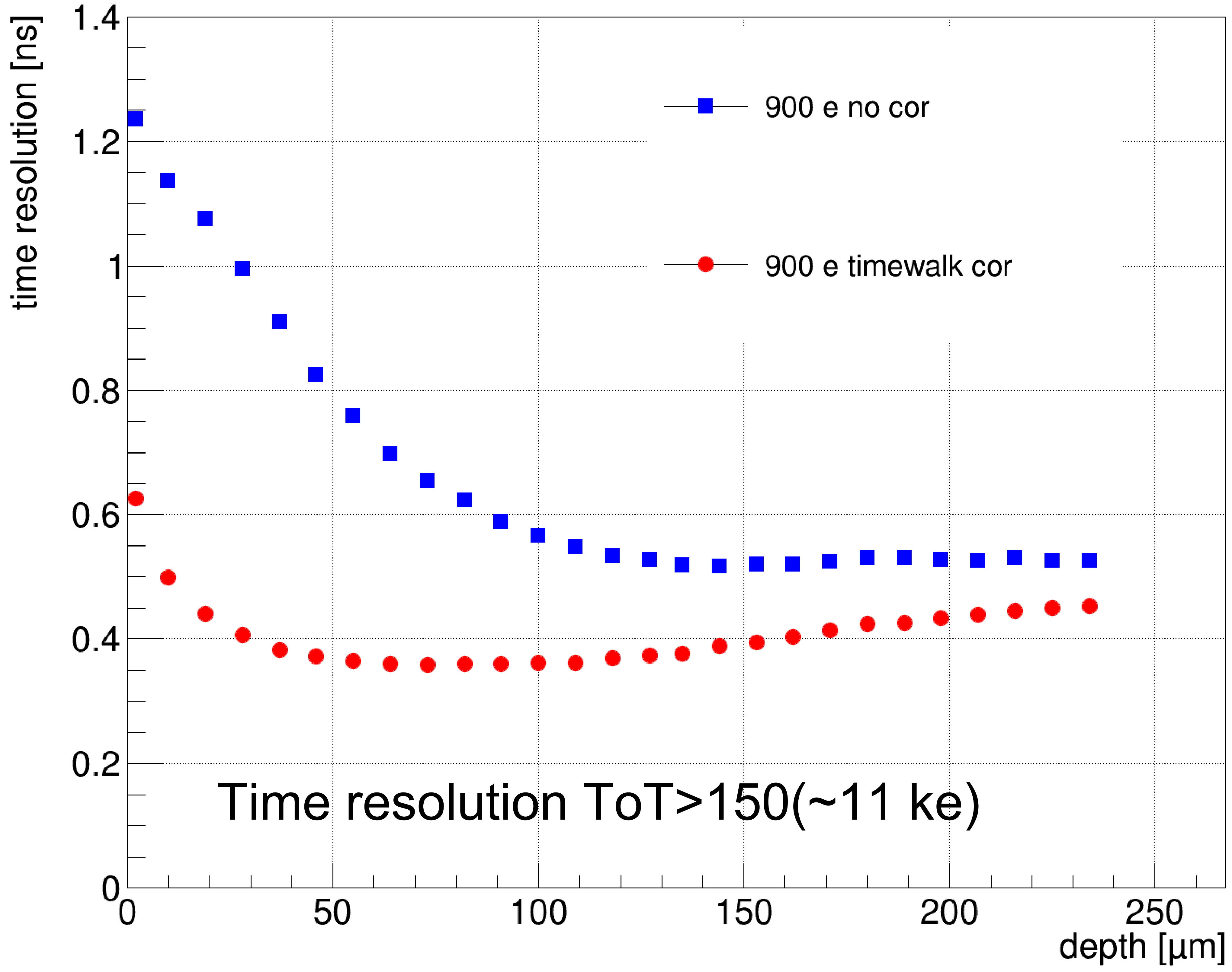


Time resolution as function of depth

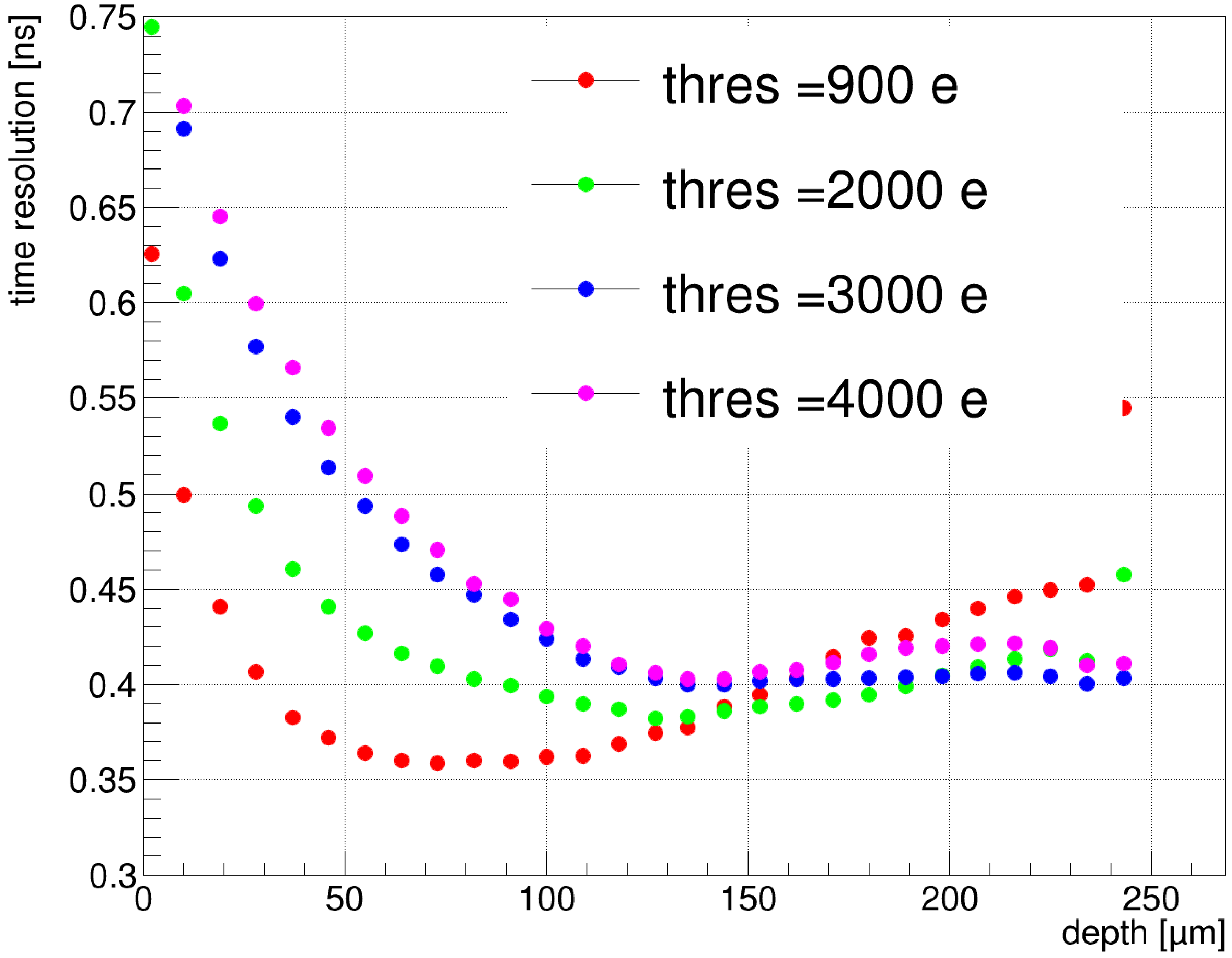
- Timewalk correction has more effect close to read-out electrode
- Time resolution seems best at 70 μm depth
- Shape of the time resolution curve depends on threshold
- Best time resolution at low threshold



Time resolution vs depth

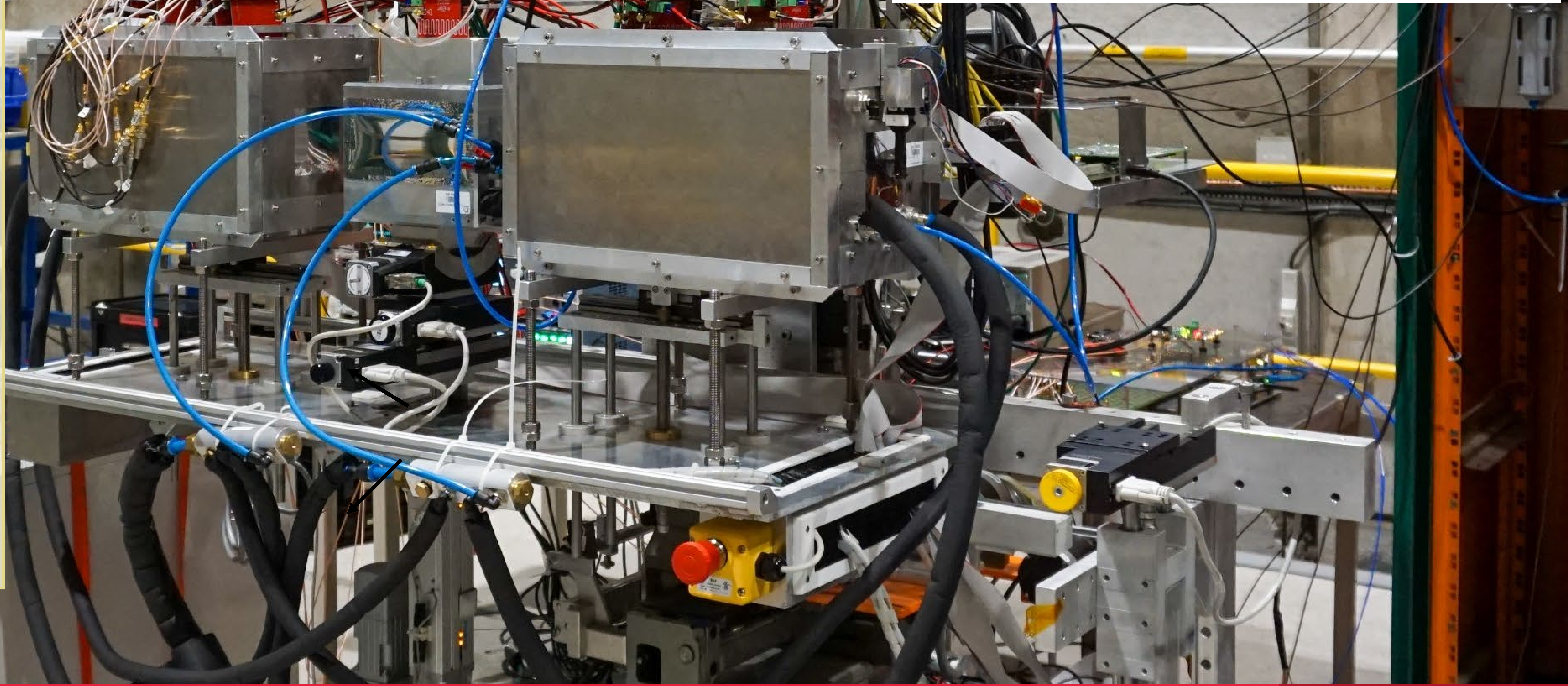


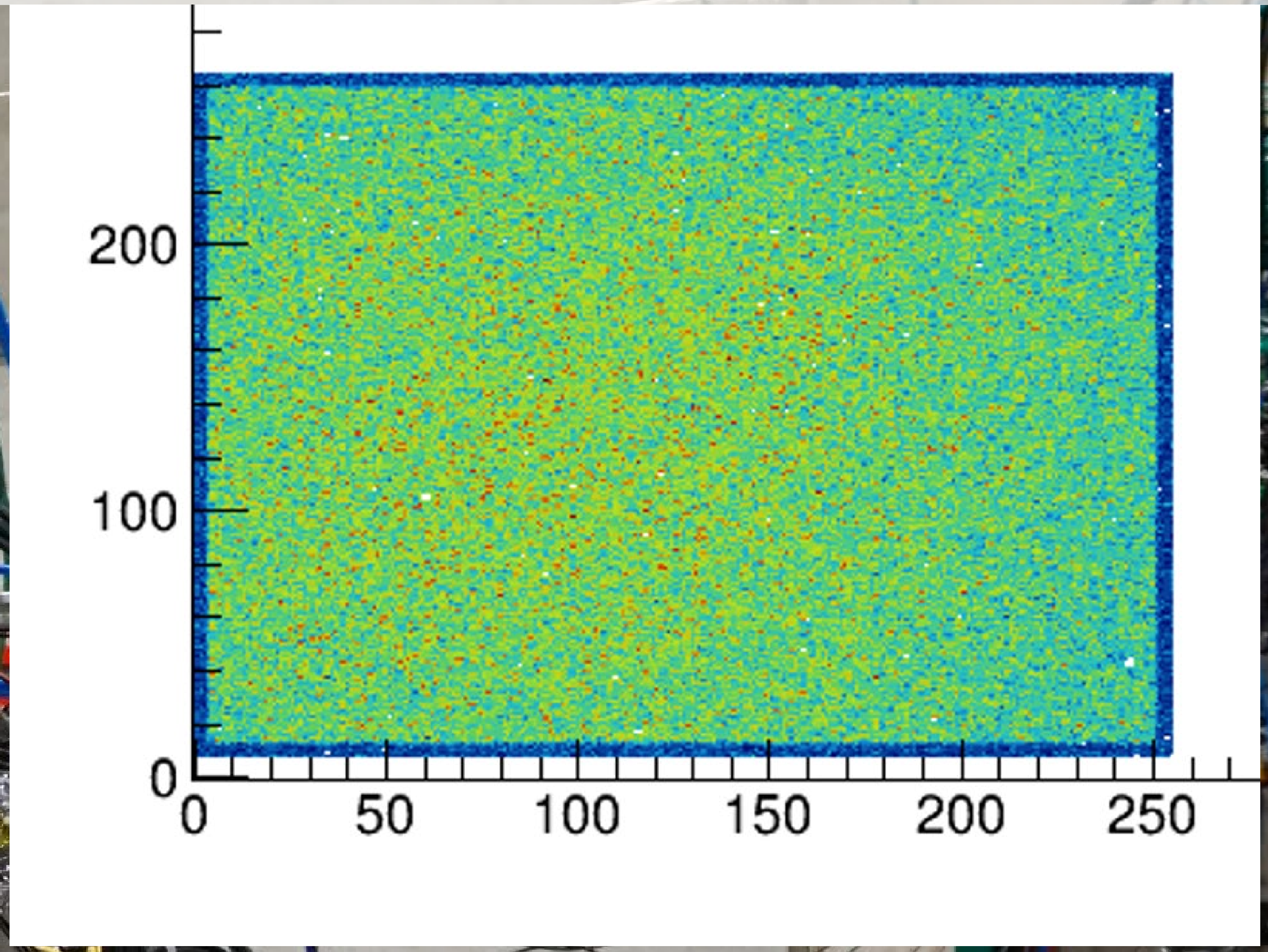
Time resolution vs depth



Future research

- Probe larger parameter space of iLGADs (threshold, voltage)
- Use the non-gain region of the iLGAD for comparison
- Investigation of correlations in timing in Timepix4 ASIC using grazing angle tracks
- Understand why the time-resolution is worse close to the gain layer





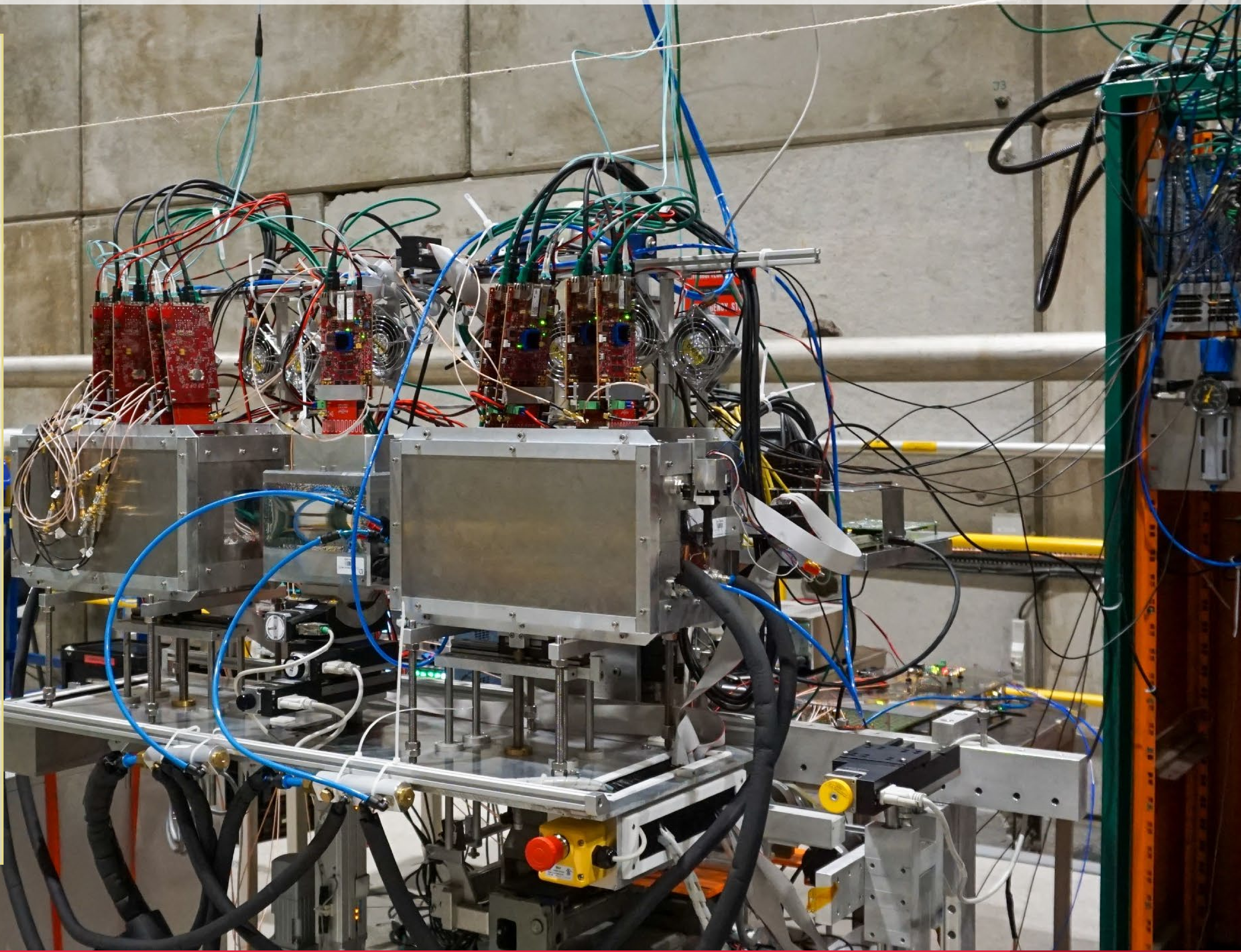
BACK-UP SLIDES

Contact: doppenhu@nikhef.nl

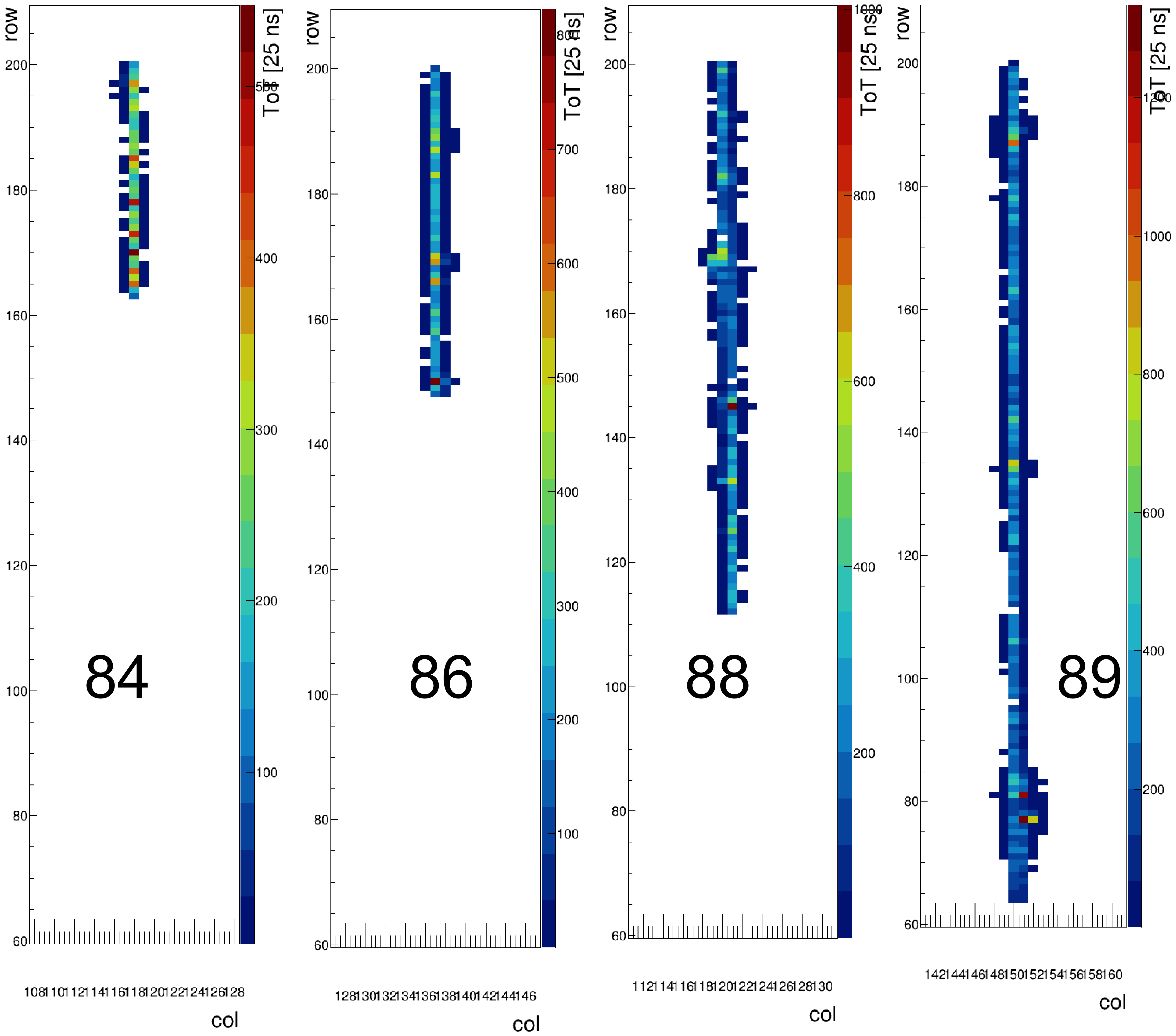
Conclusion

- Planar 100 um:
- Perpendicular time resolution: **151 ps**

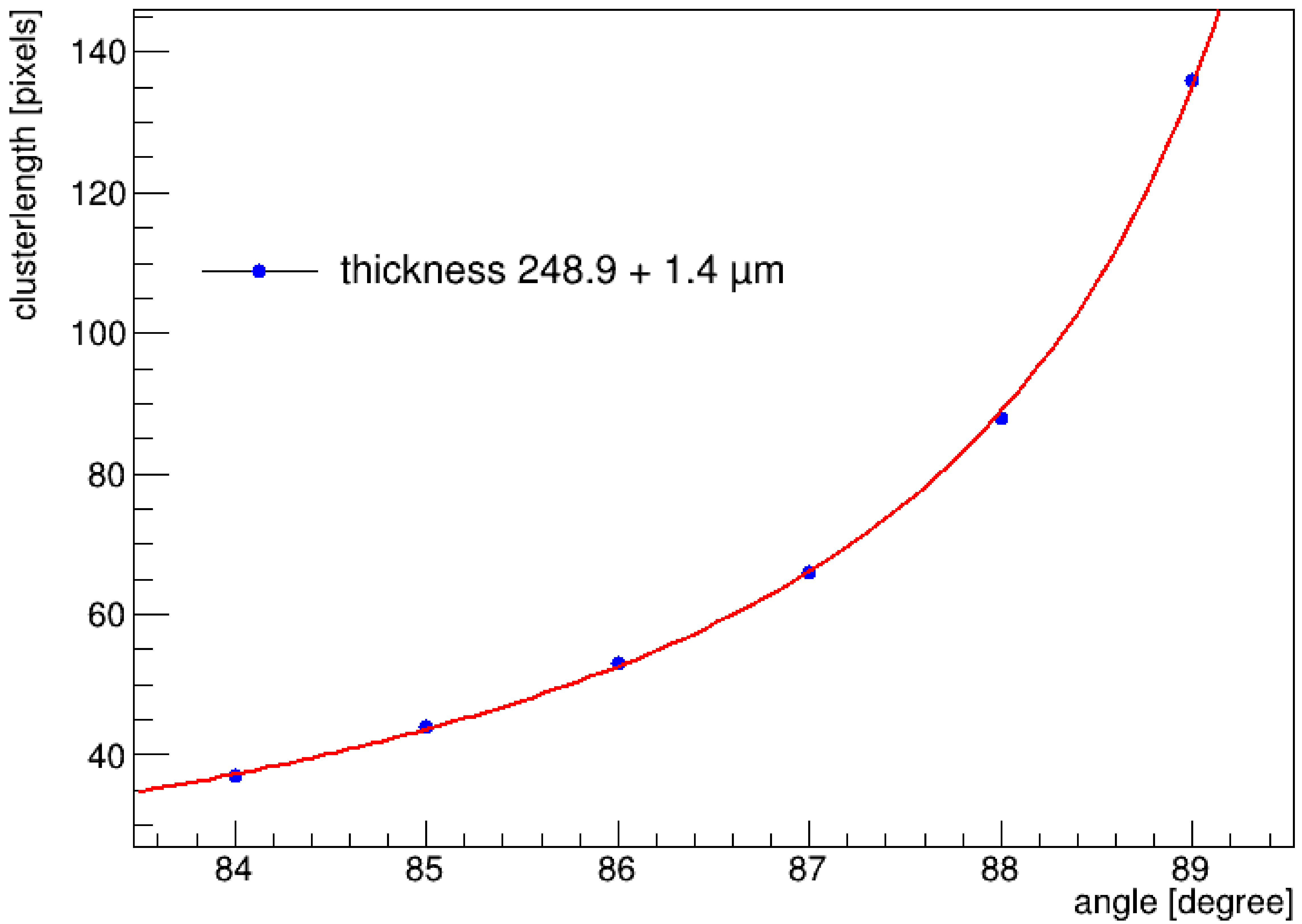
- iLGAD 250 um:
- Perpendicular resolution: ~ **350 ps**
- Grazing resolution:~ **360 ps**



Angle scan

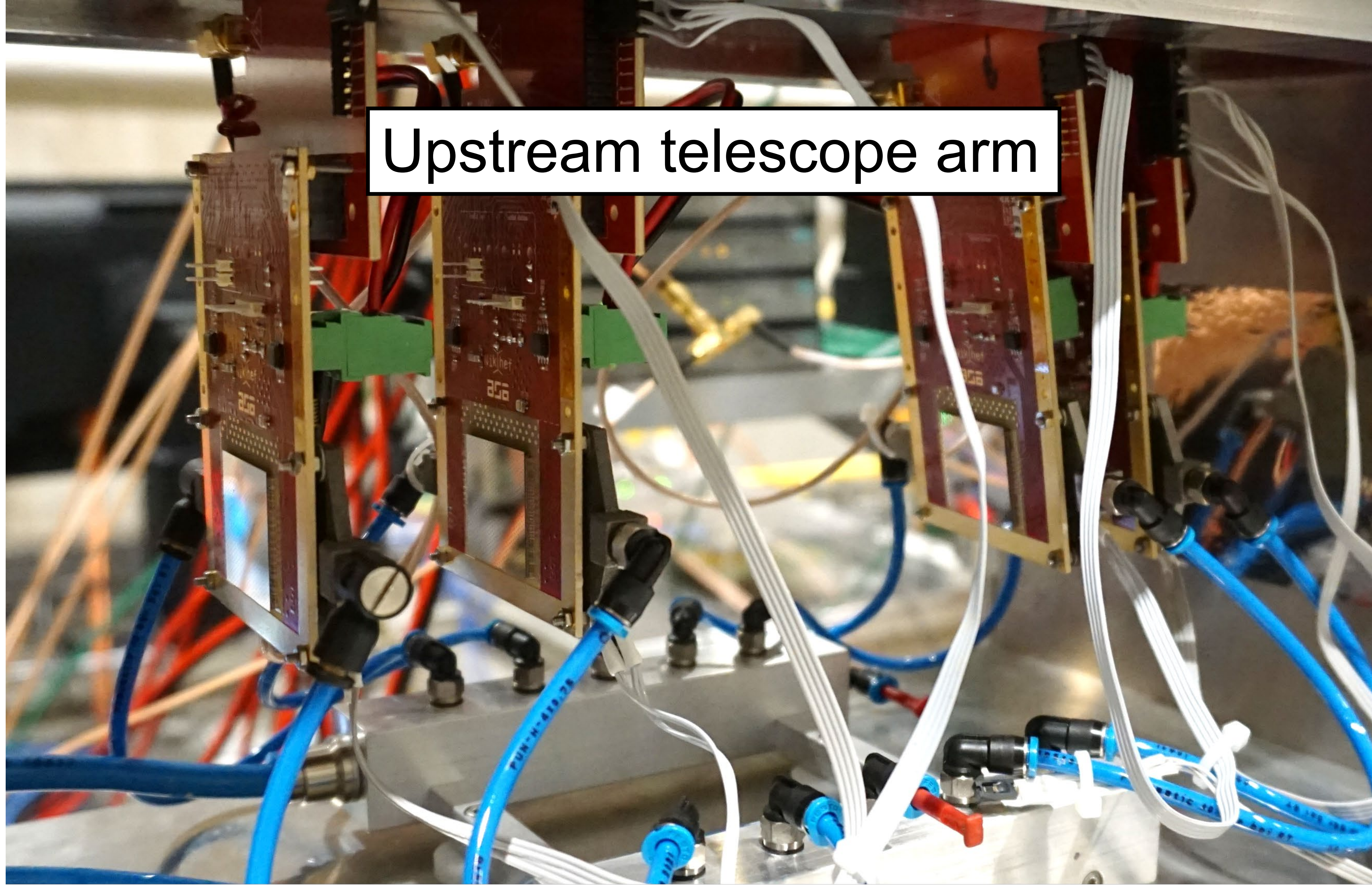


$$N(\theta) = \frac{\tan\,\theta \times \lambda}{55\ \mu\mathrm{m}}$$

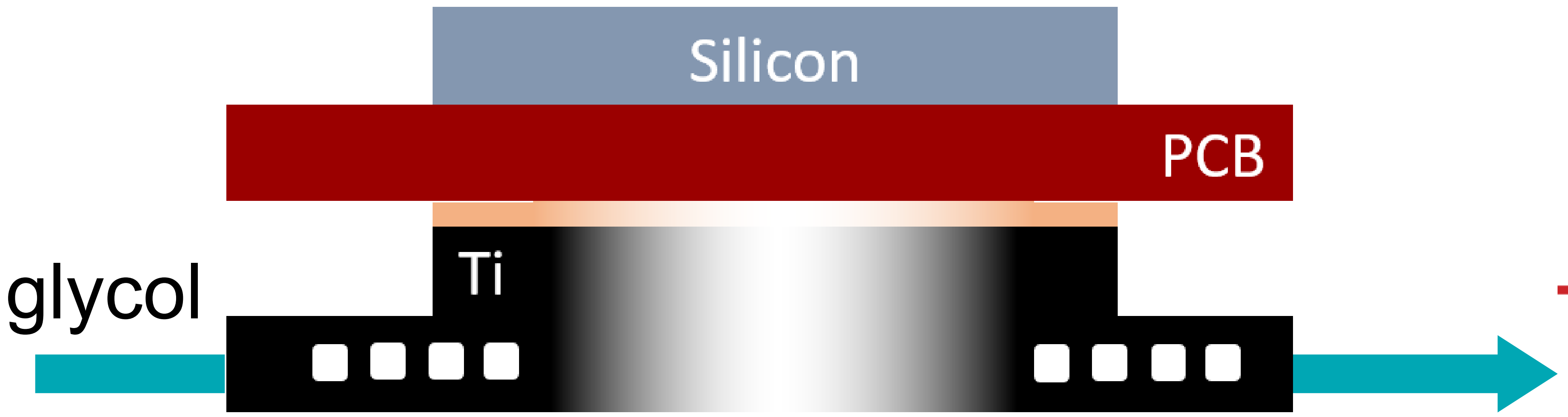


Plane assemblies (all Timepix4v2)

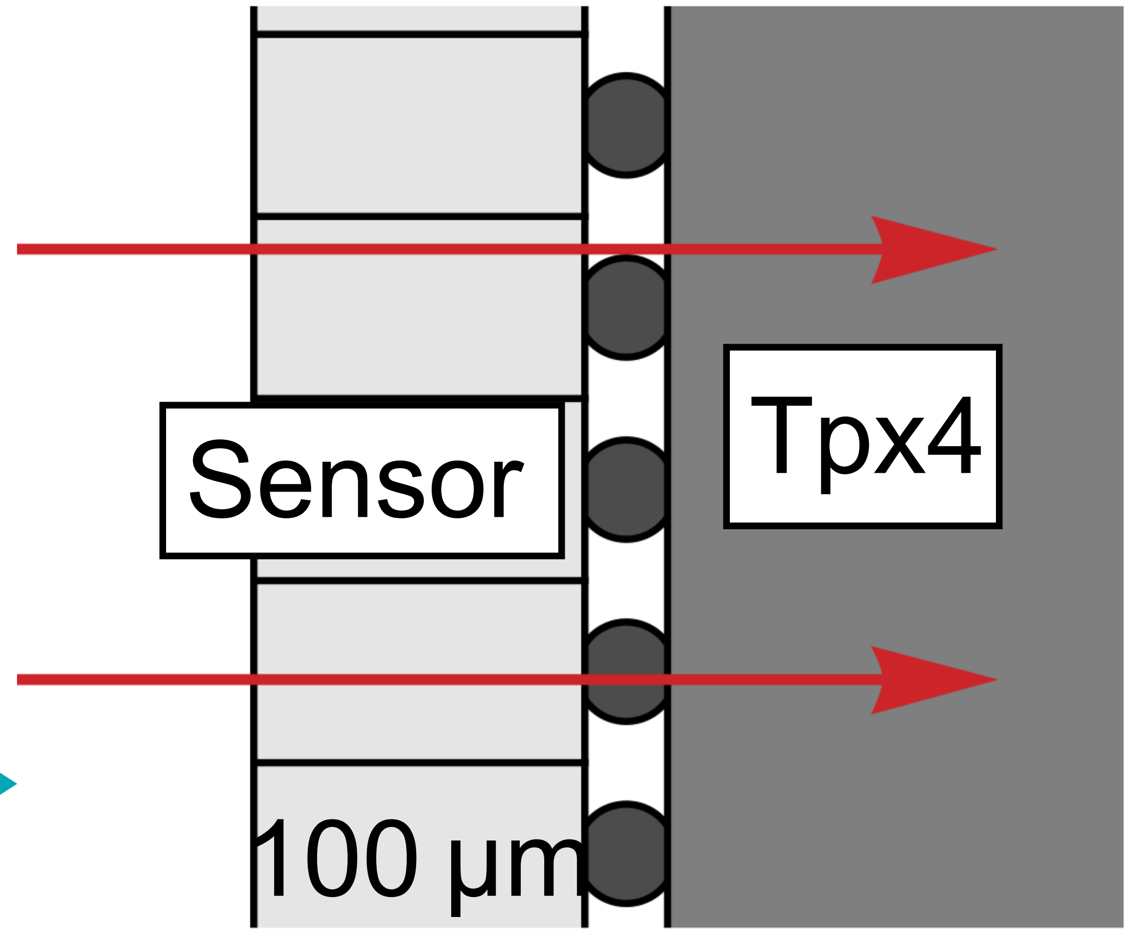
- Eight telescope planes with n-on-p planar silicon sensors:
  - 4 x 300 µm sensors for spatial resolution (angled)
  - 4 x 100 µm sensors for time resolution (perpendicular)
  - Sensor upgrades are anticipated (LGAD, 3D, …)
- Several DUT assemblies:
  - 50 µm, 100 µm, and 200 µm n-on-p planar silicon
  - 300 µm p-on-n
  - 2 x 250 µm iLGAD sensor 55 and 110 µm pitch
  - Cooled using glycol at 20 °C

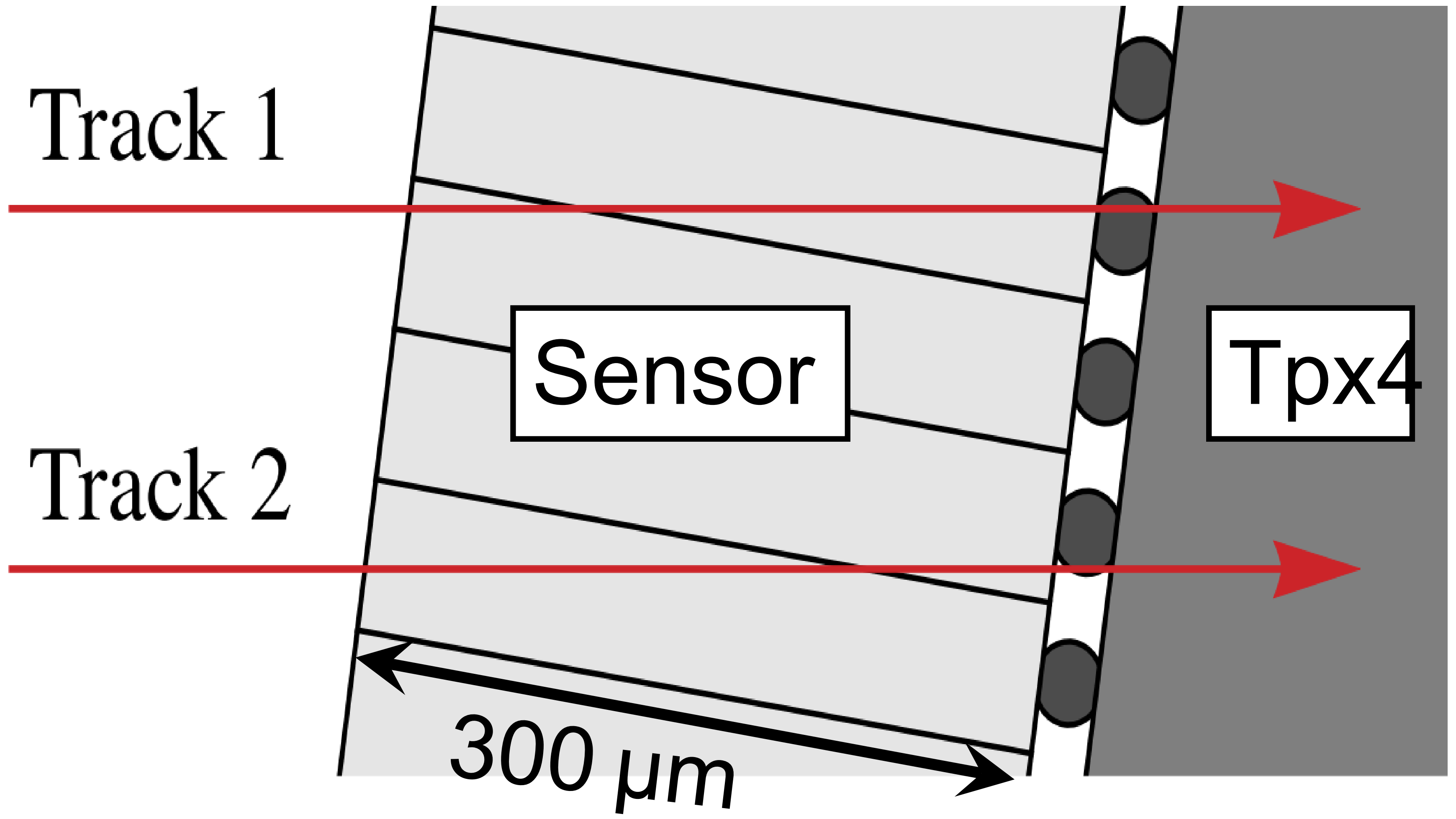


Current cooling



No Titanium in beam

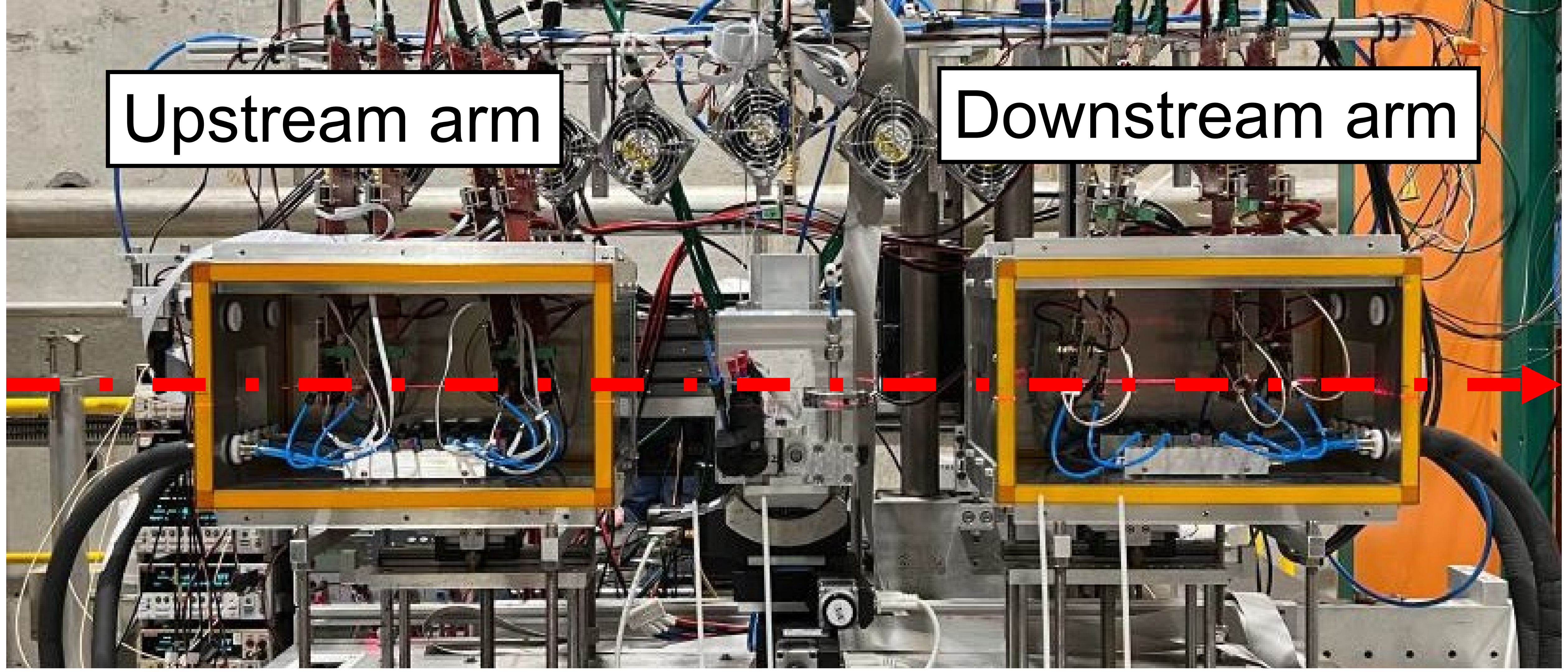




Hitmap 8 planes

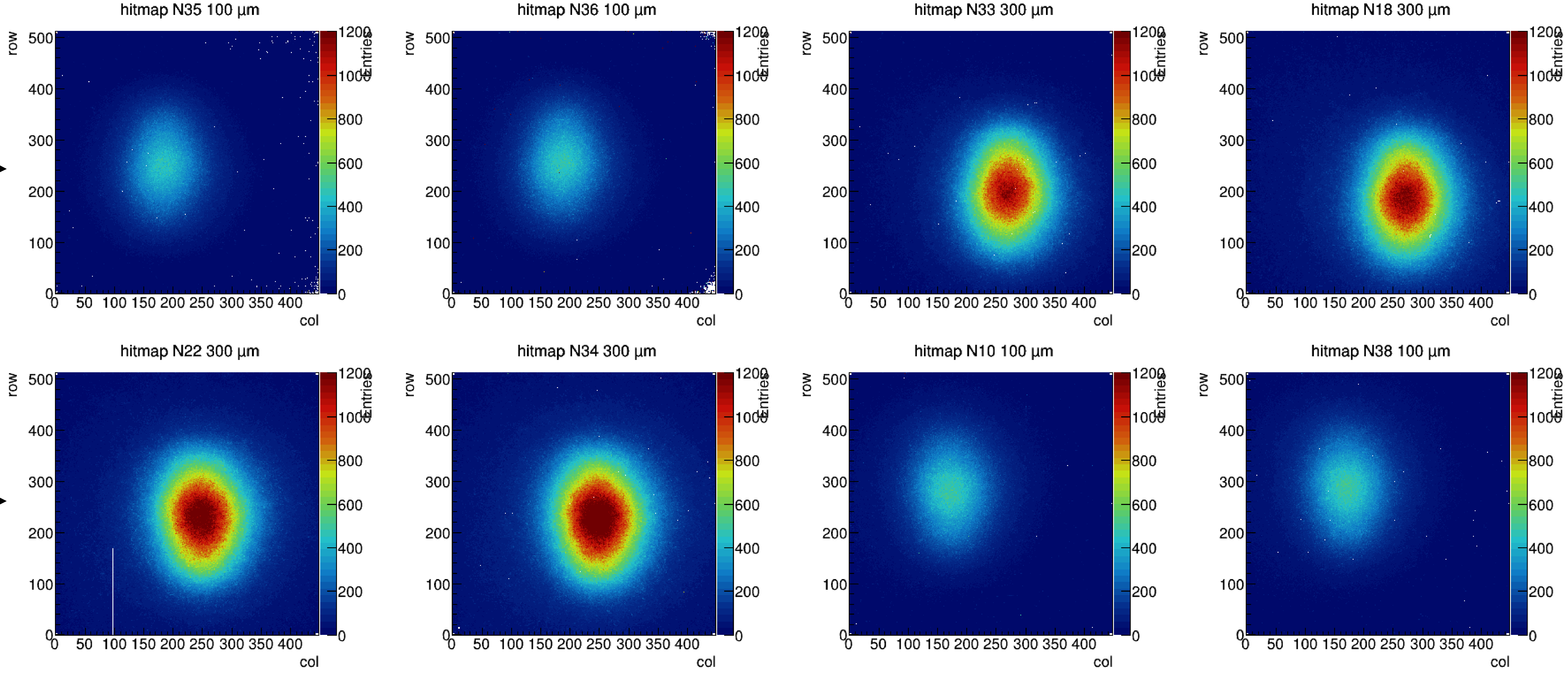
- H8 beamline at SPS / CERN
- 180 GeV/c mixed beam

- To optimize time and spatial resolution:
- charge calibration
- timewalk correction
- clock correction

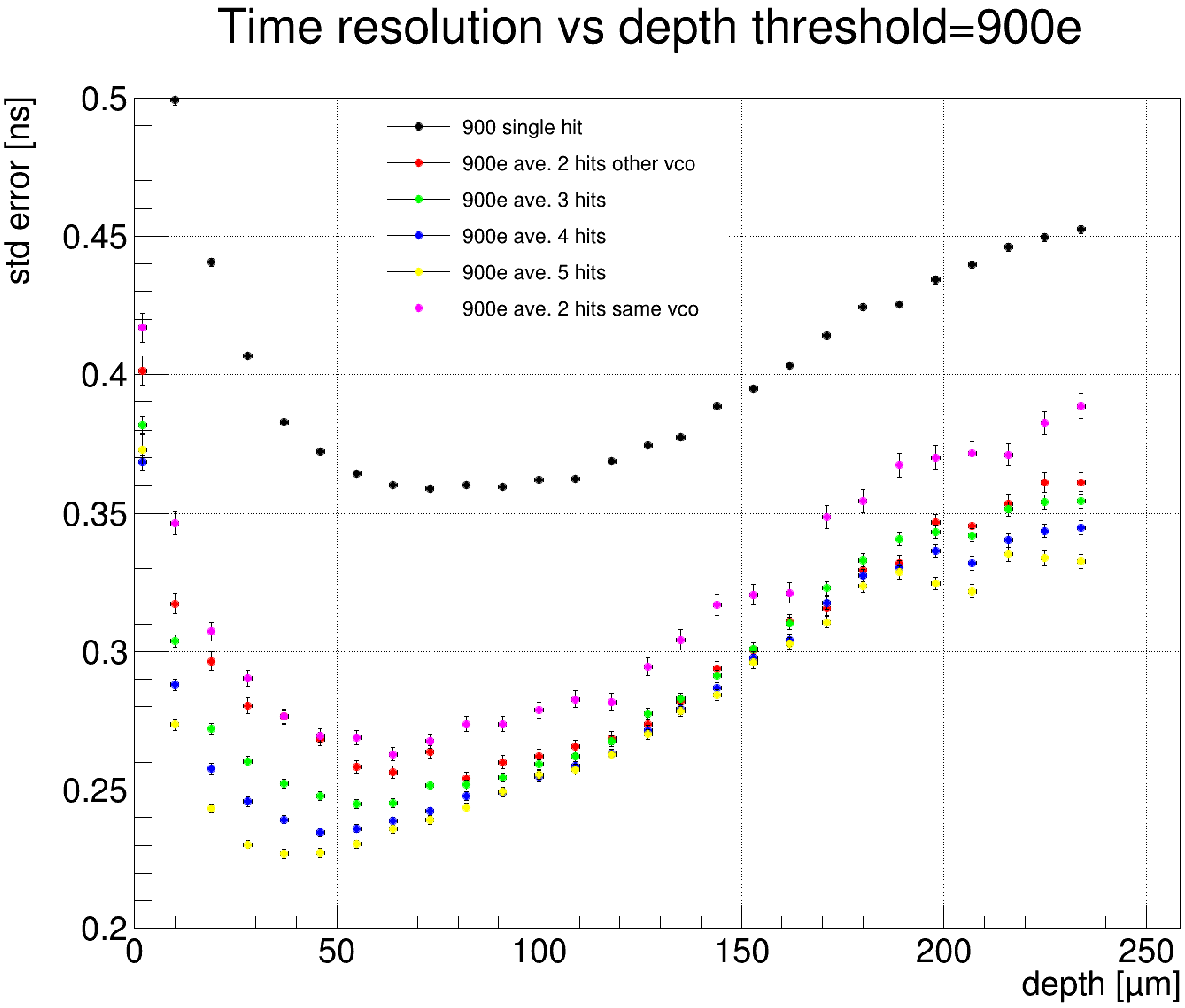


Upstream arm

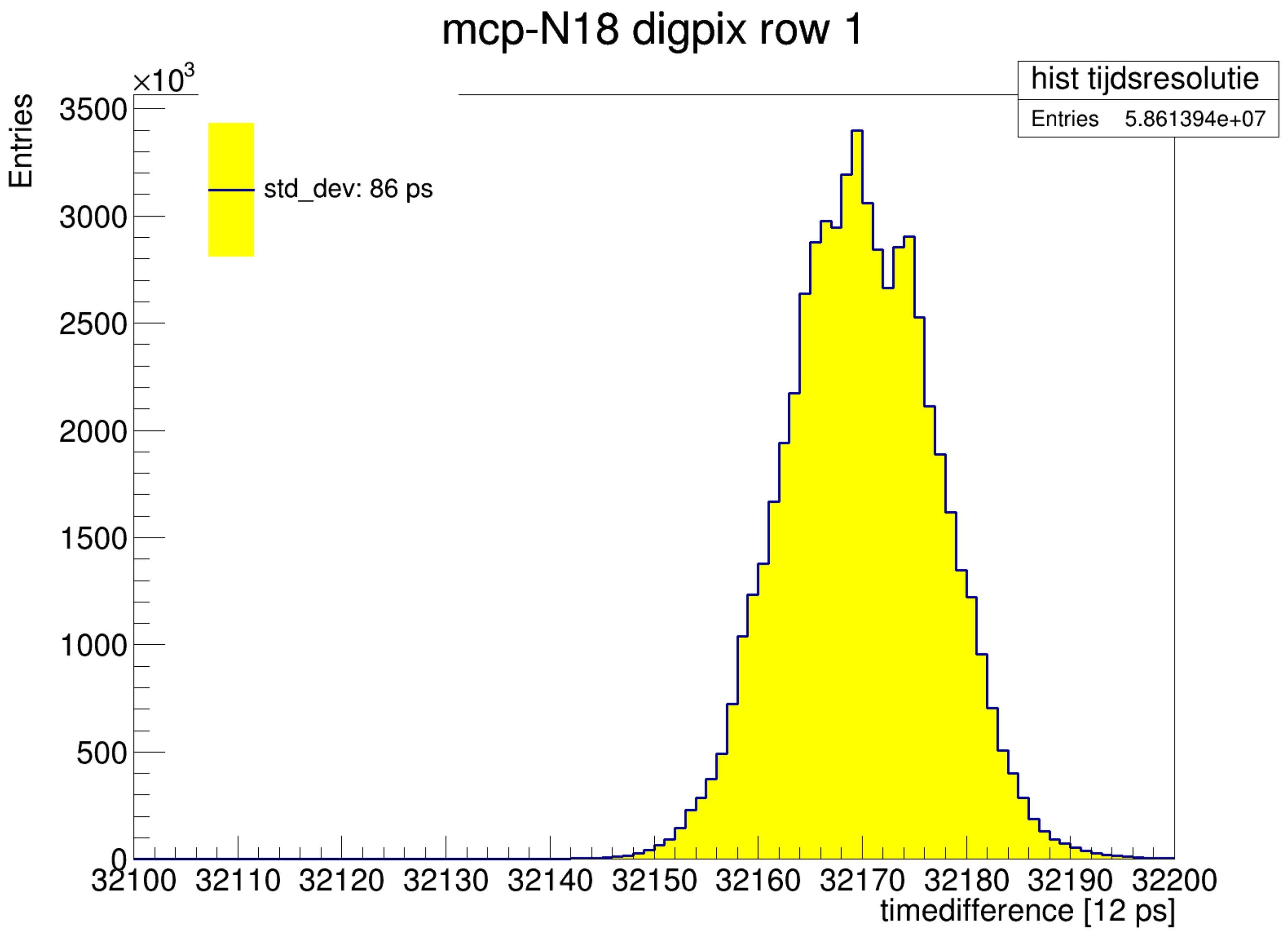
Downstream arm

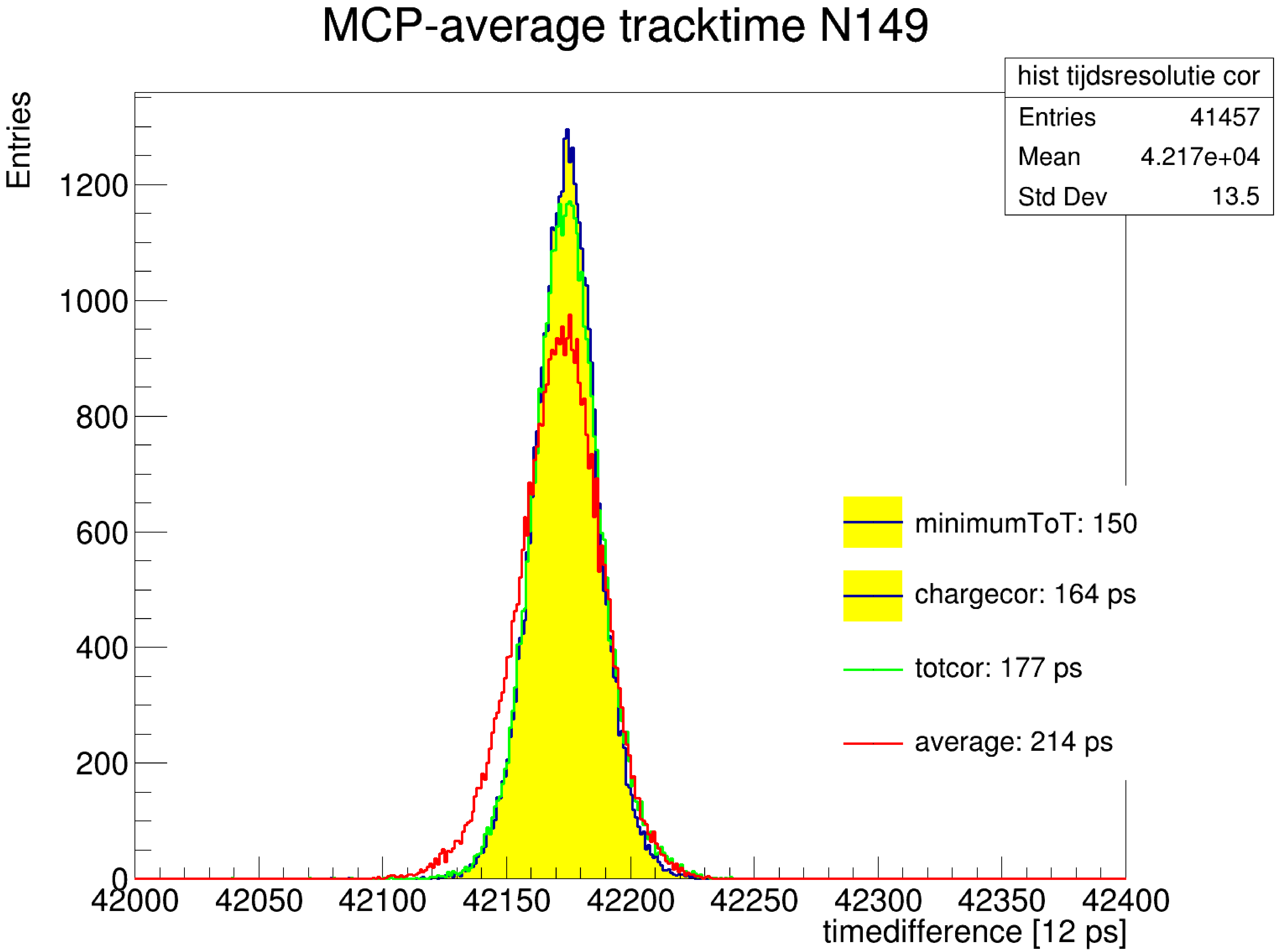


Correlations

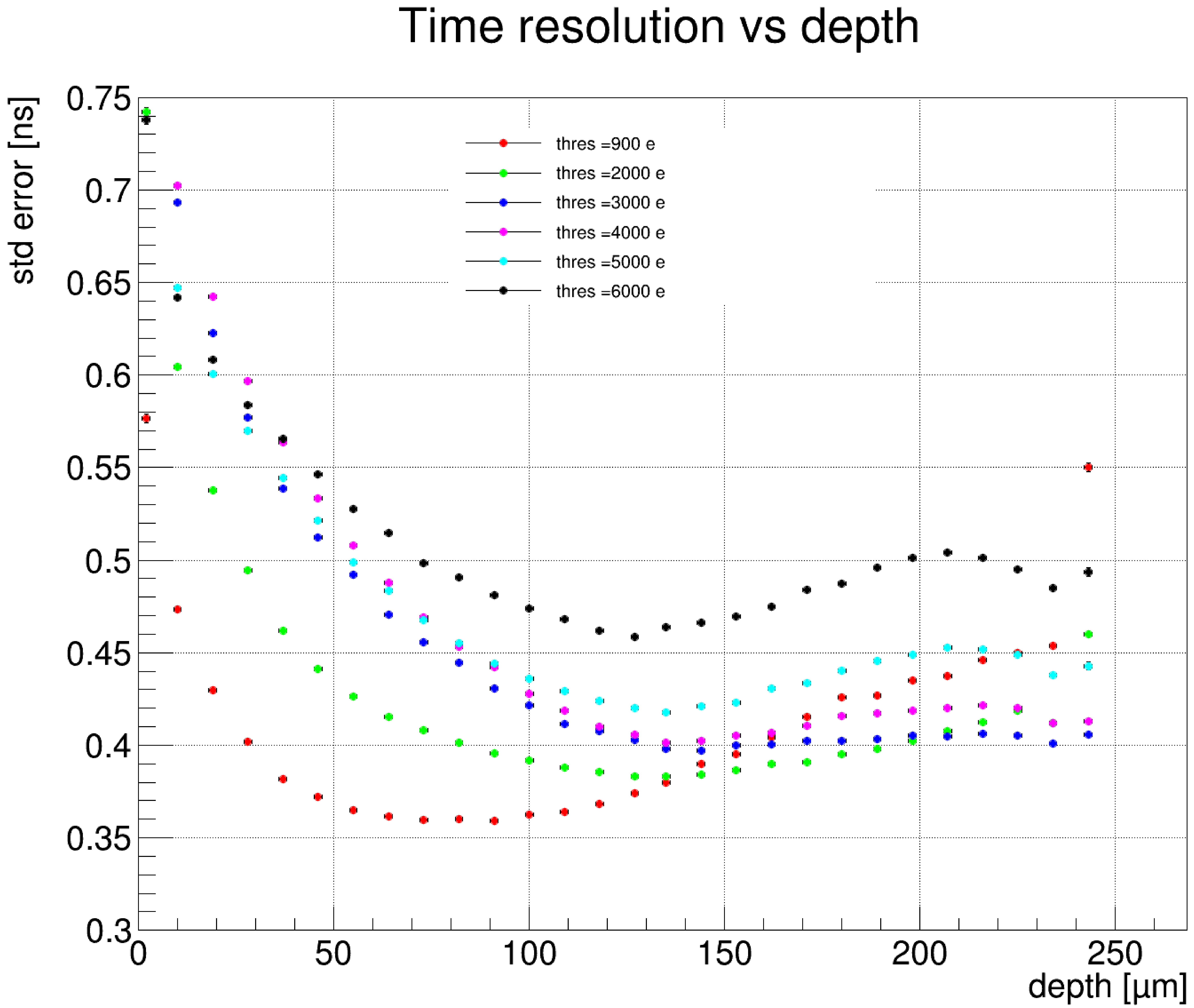


Average Track time

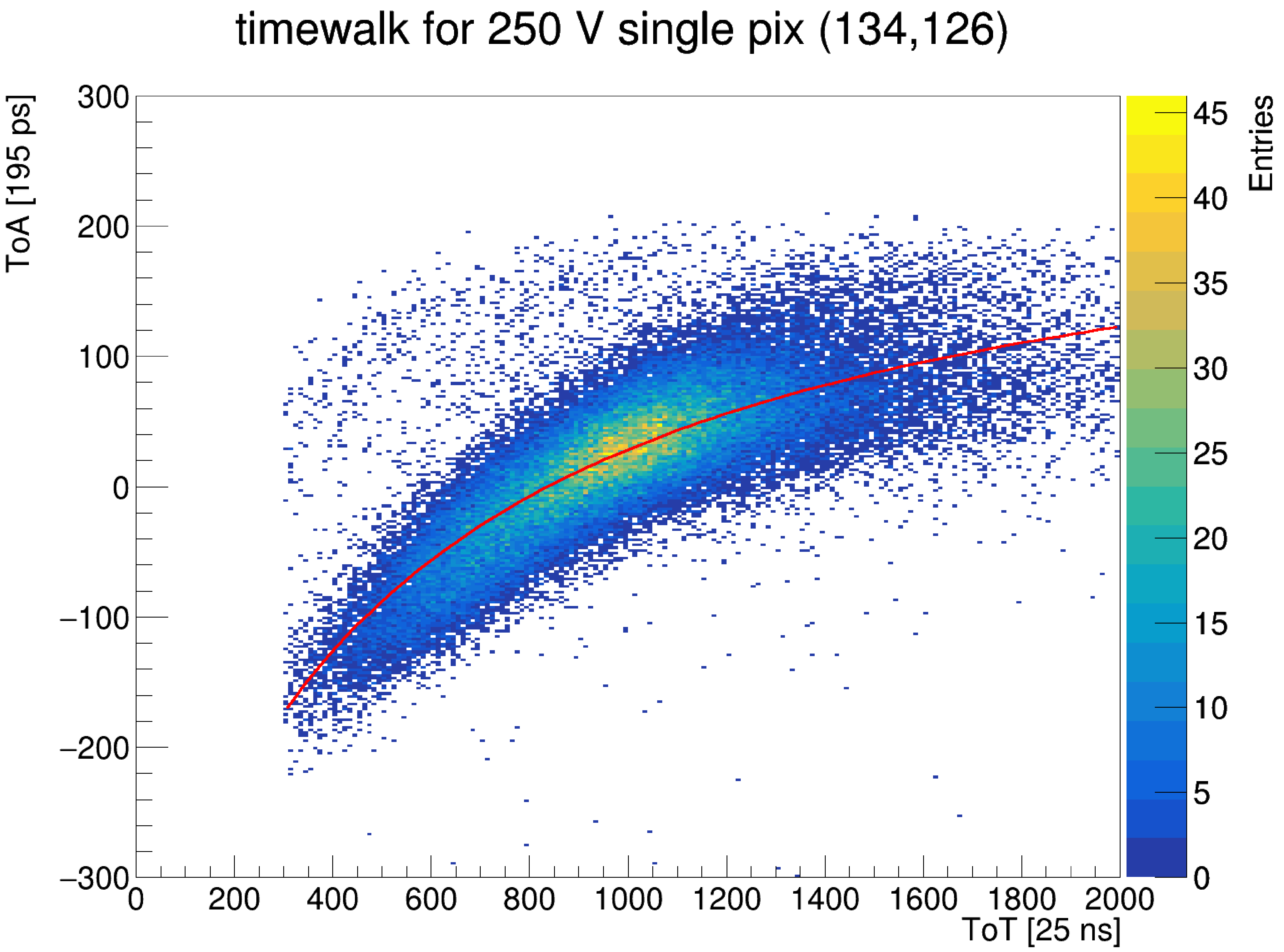


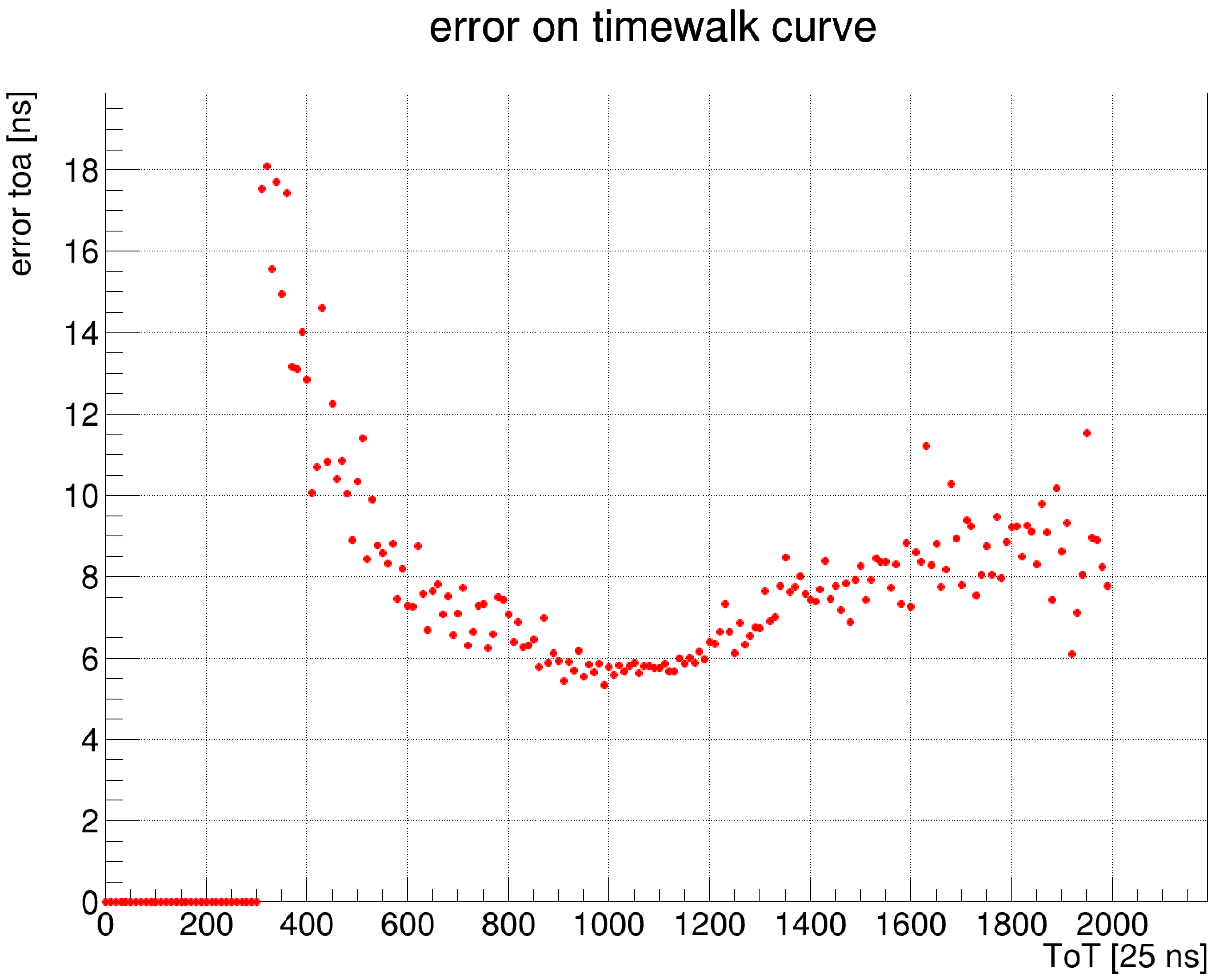


time resolution as function of Depth and Threshold zoomed

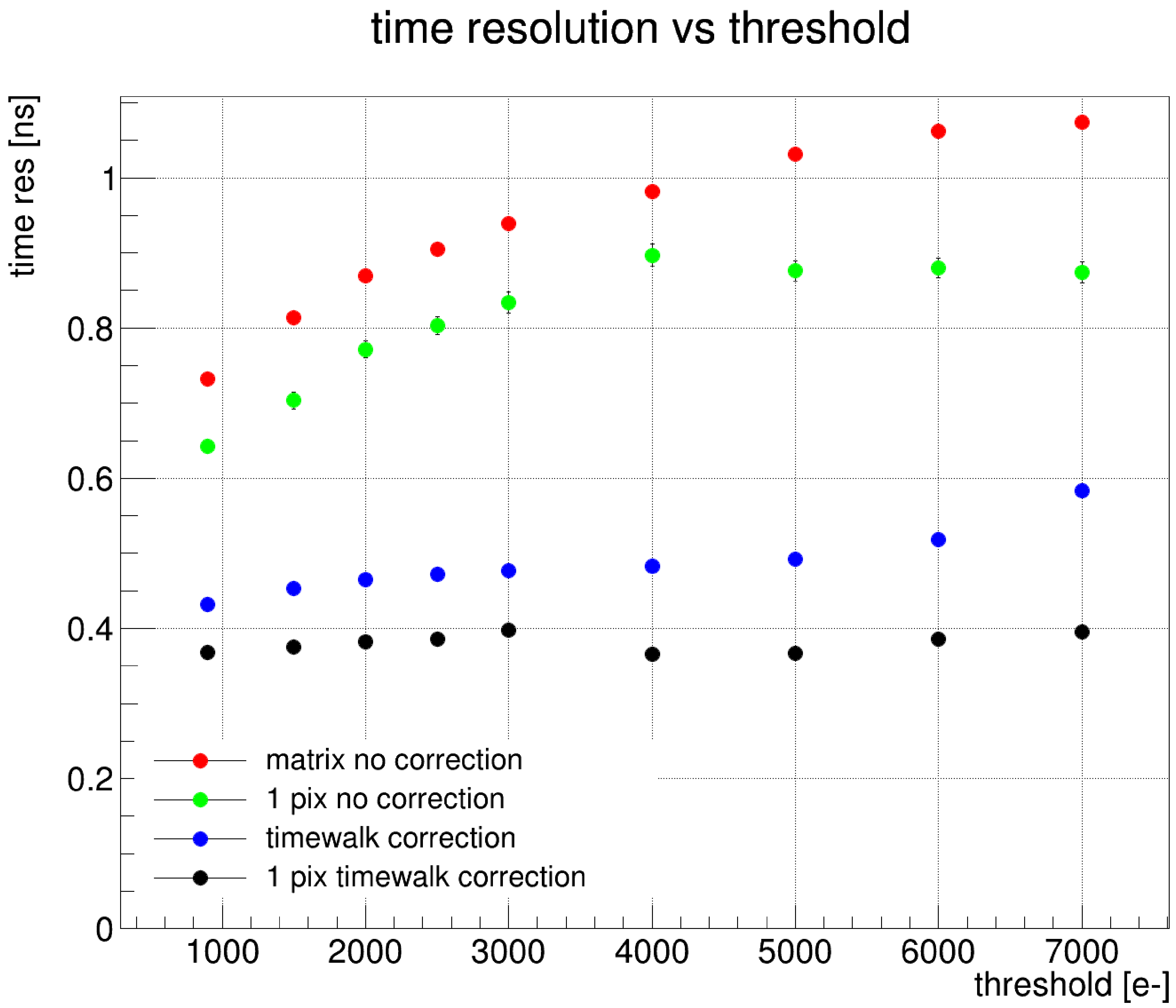


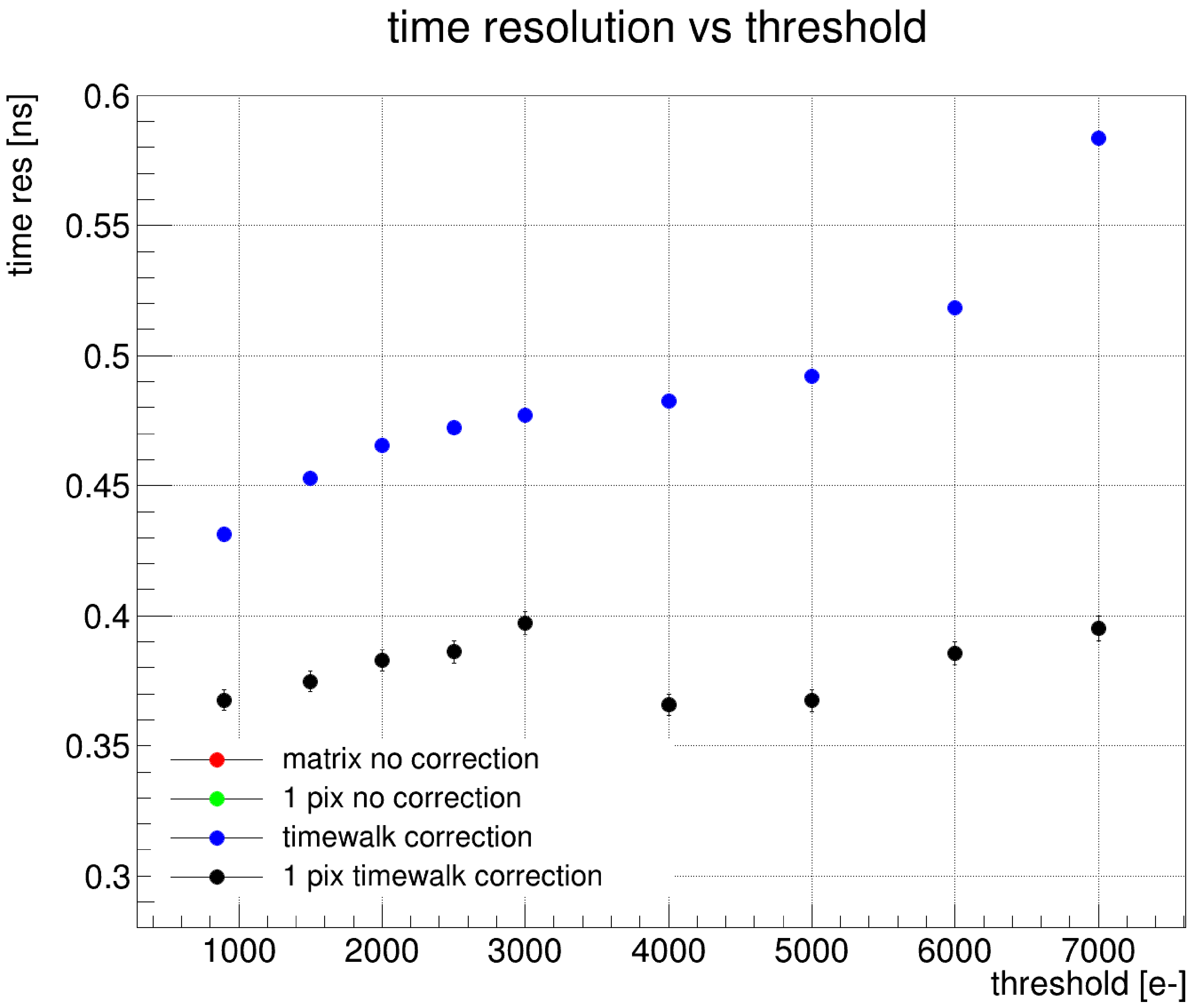
Single pixel timewalk (axis to ns)



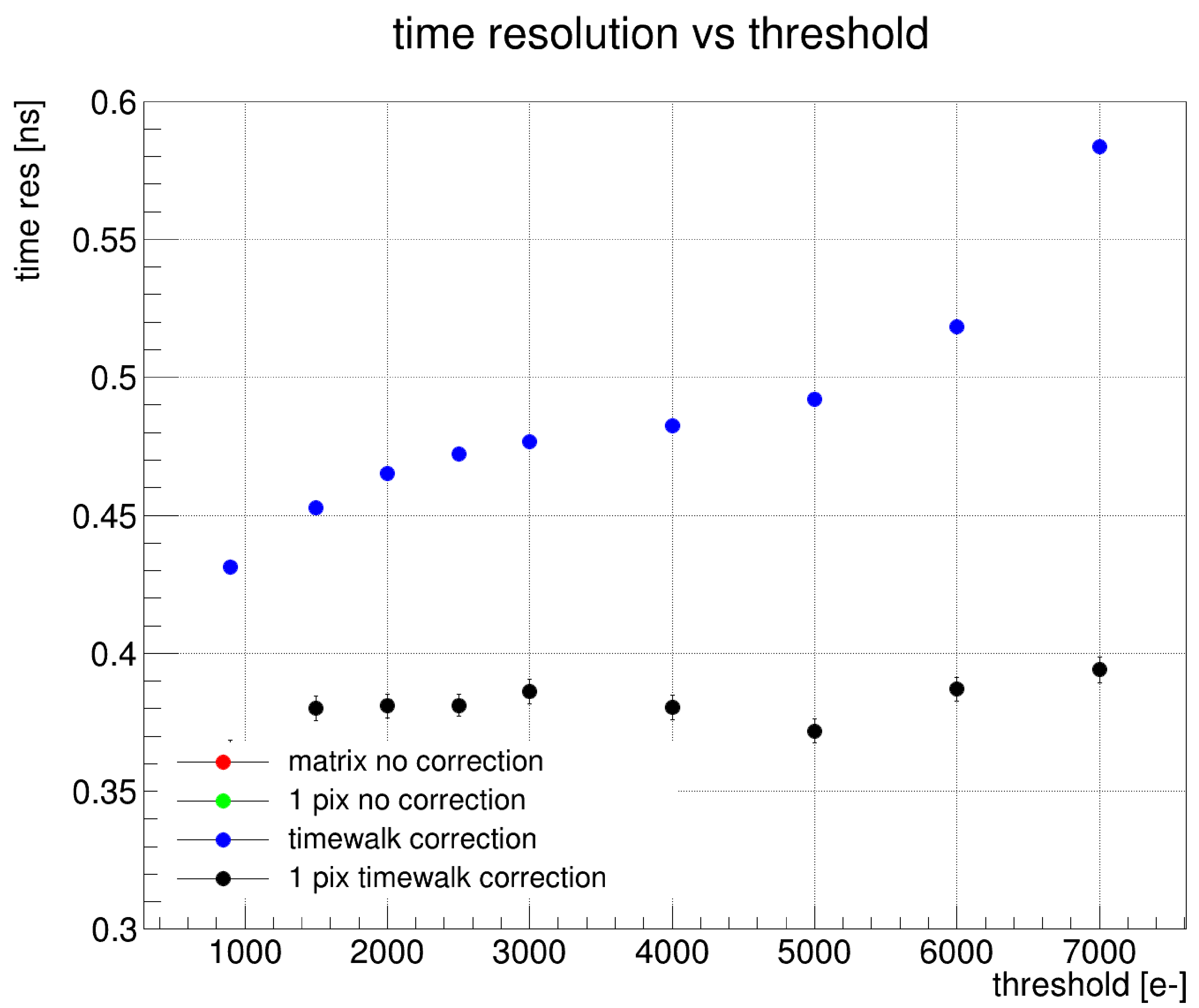


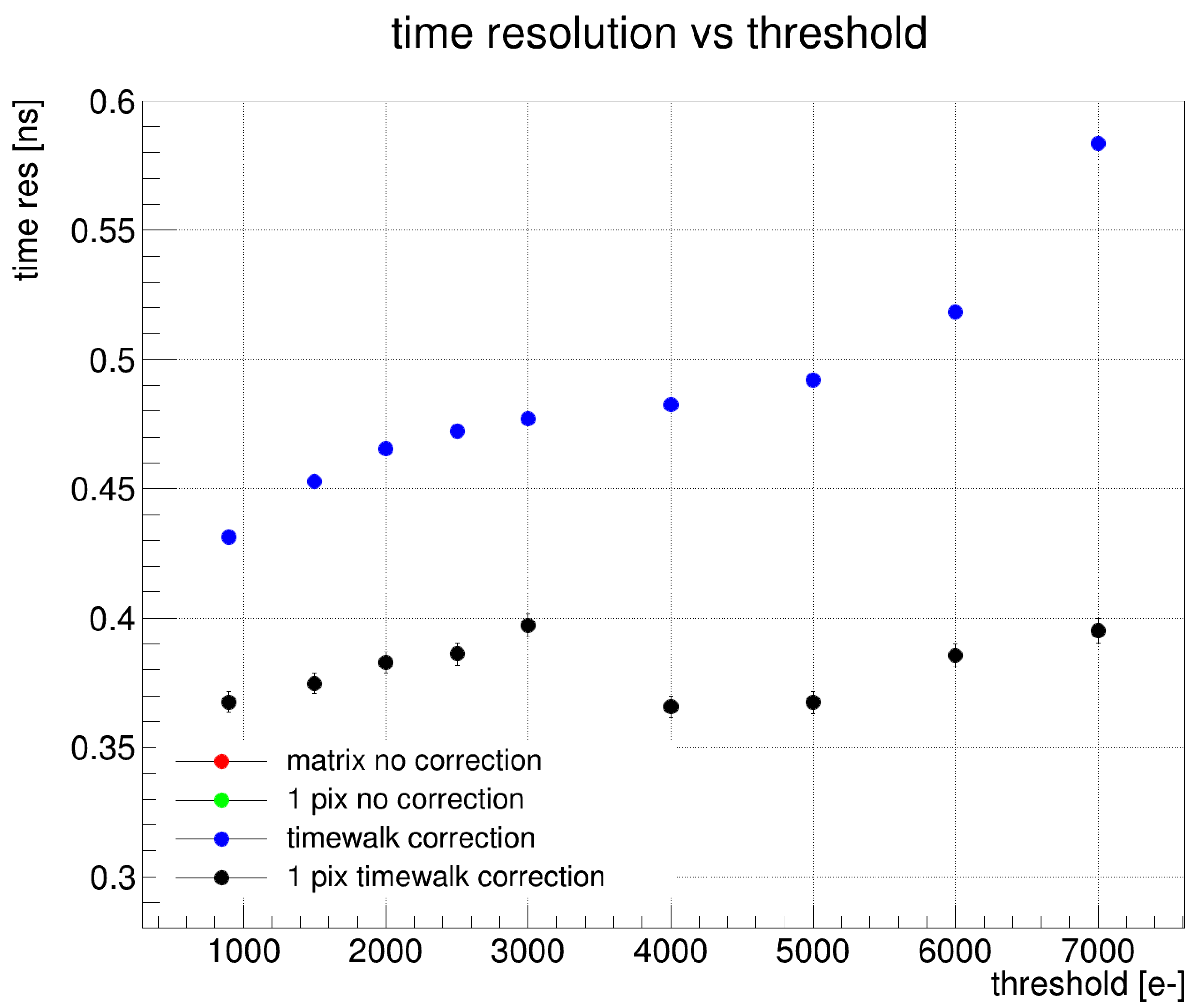
Perpendicular time resolution (N149 250 um ILGAD) Threshold scan

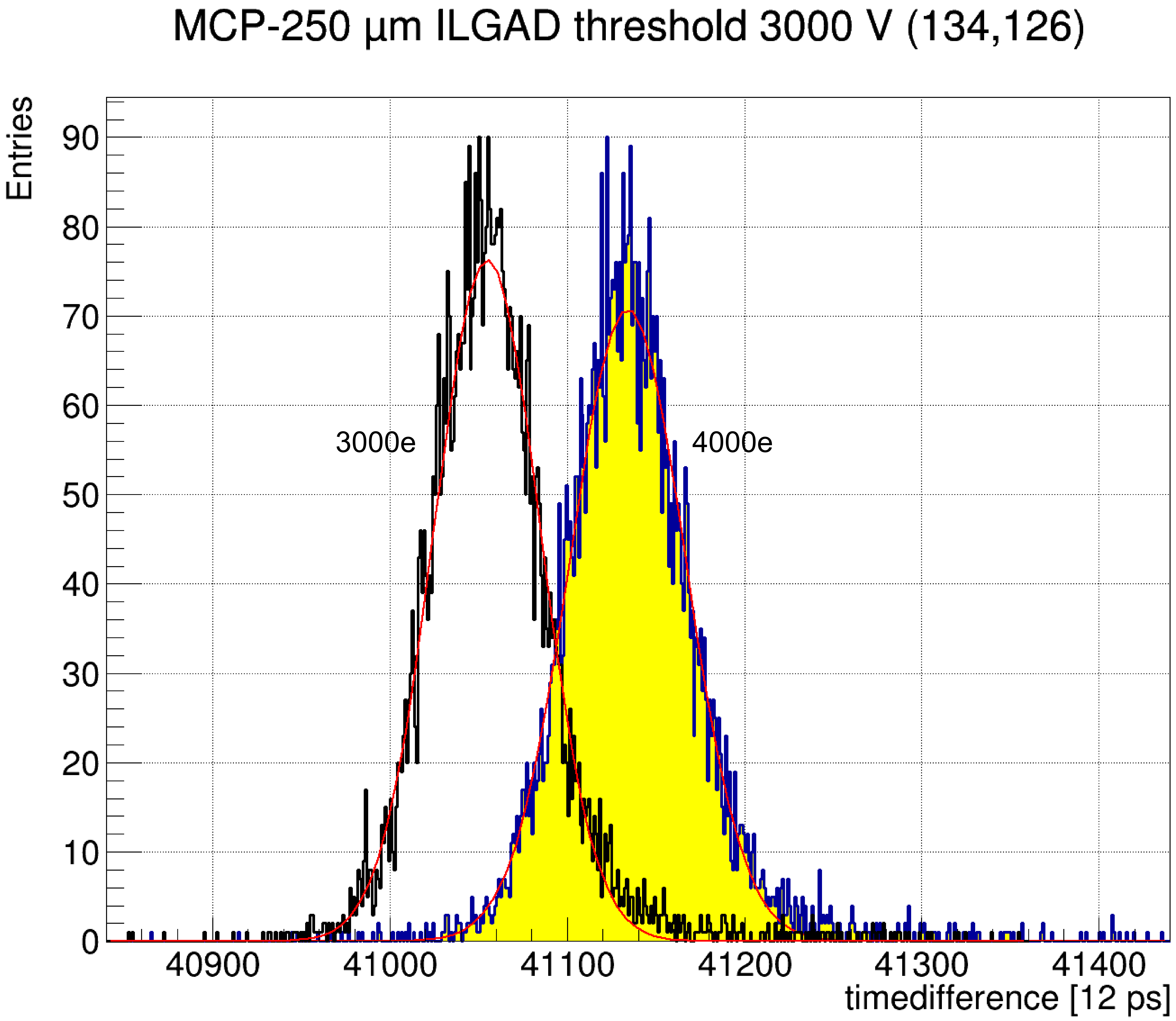




Perpendicular time resolution (N149 250 um ILGAD) Threshold scan






MCP-250 µm ILGAD threshold 3000 V (134,126)
Entries
90
80
70
60
50
40
30
20
10
0
3000e
4000e
40900
41000
41100
41200
41300
41400
timedifference [12 ps]

Timewalk

- Earlier signal close to read-out electrode
- Worse time resolution close to read-out electrode
- Multiple bands in timewalk curve
- Timewalk correction as function of depth

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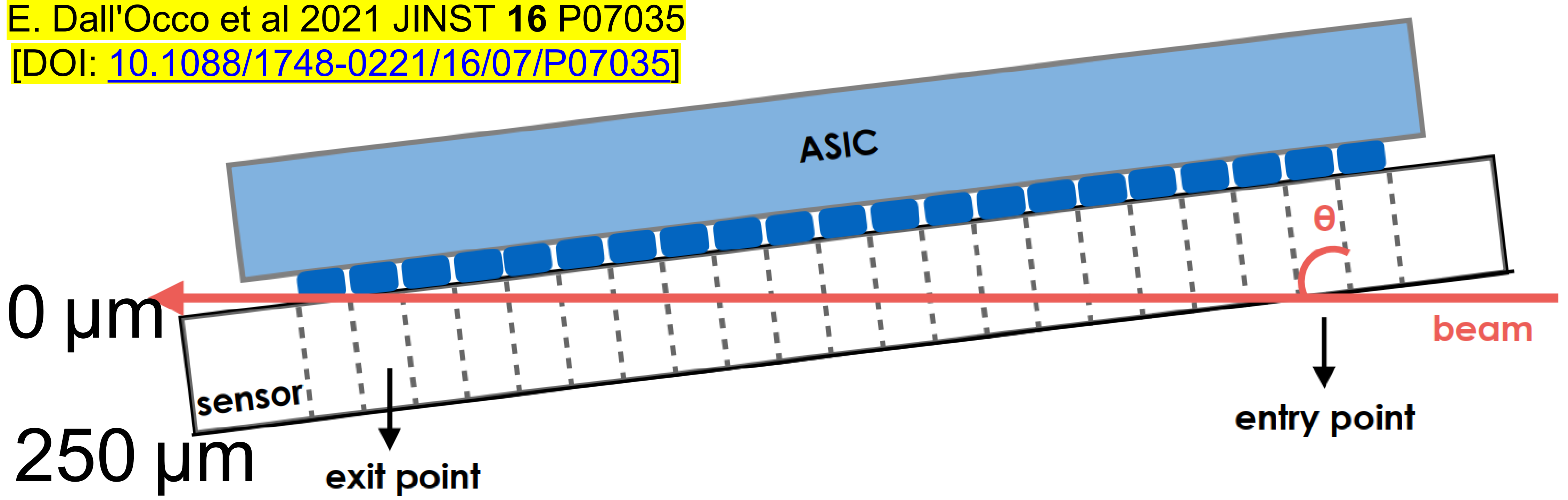
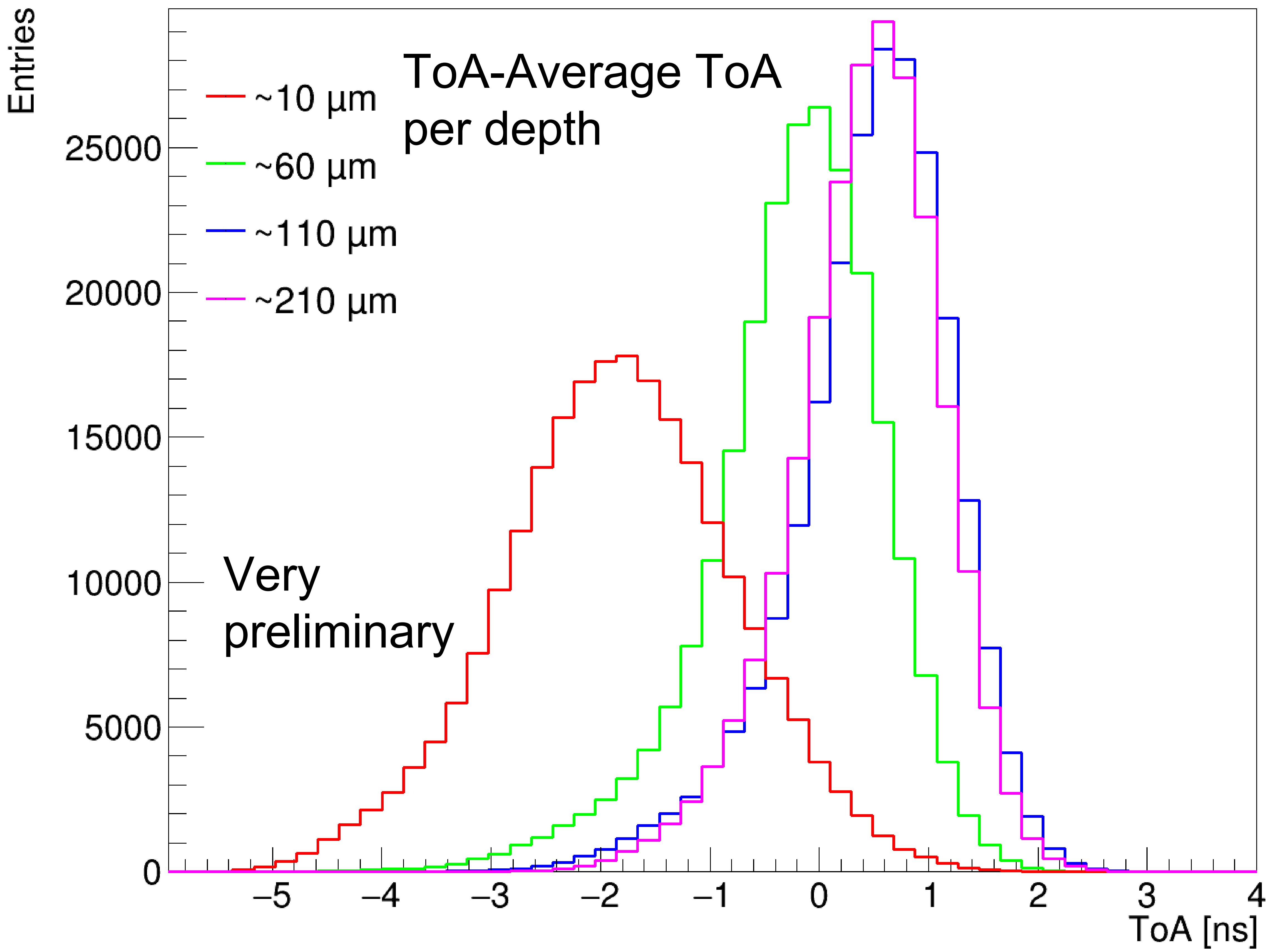
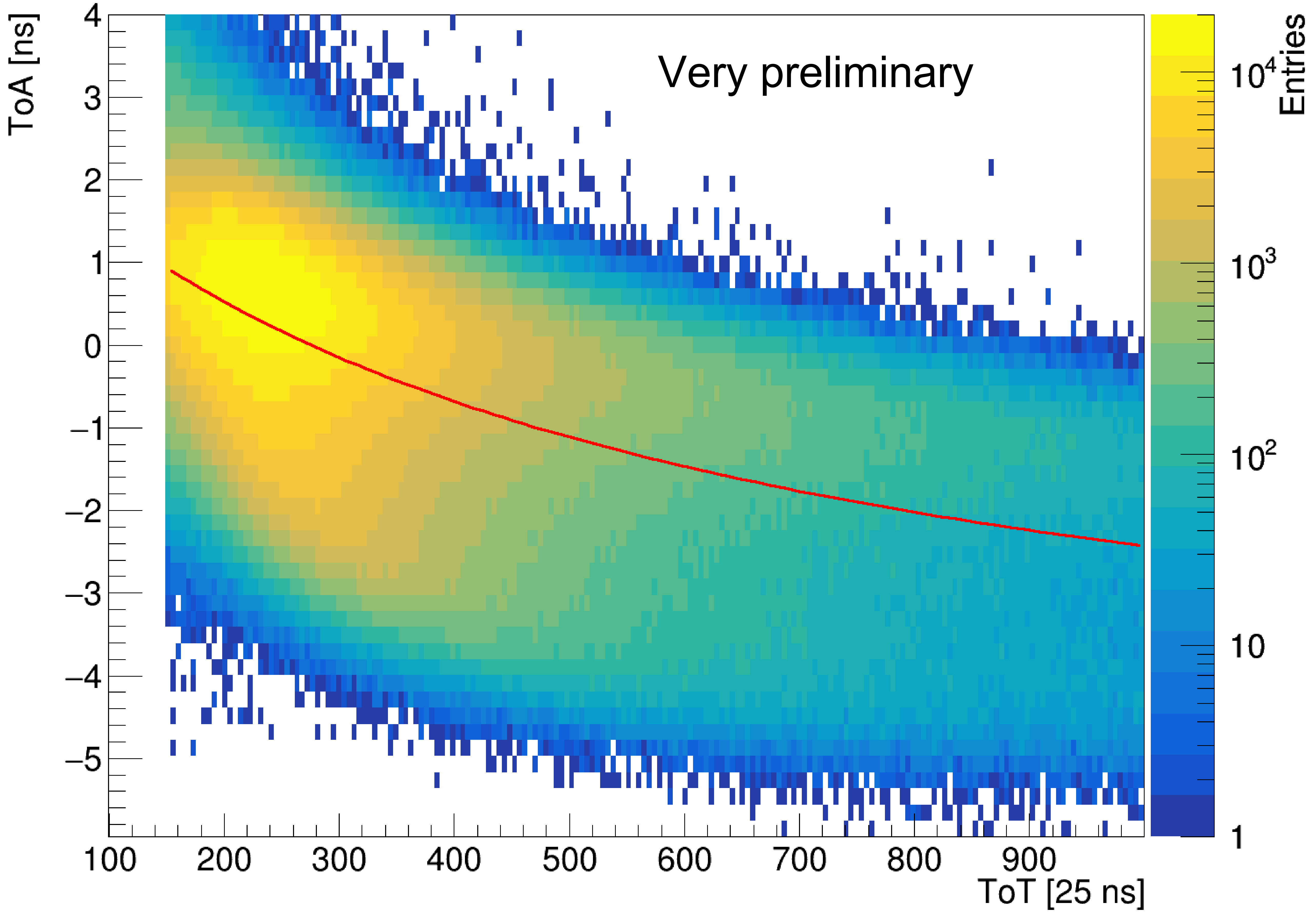
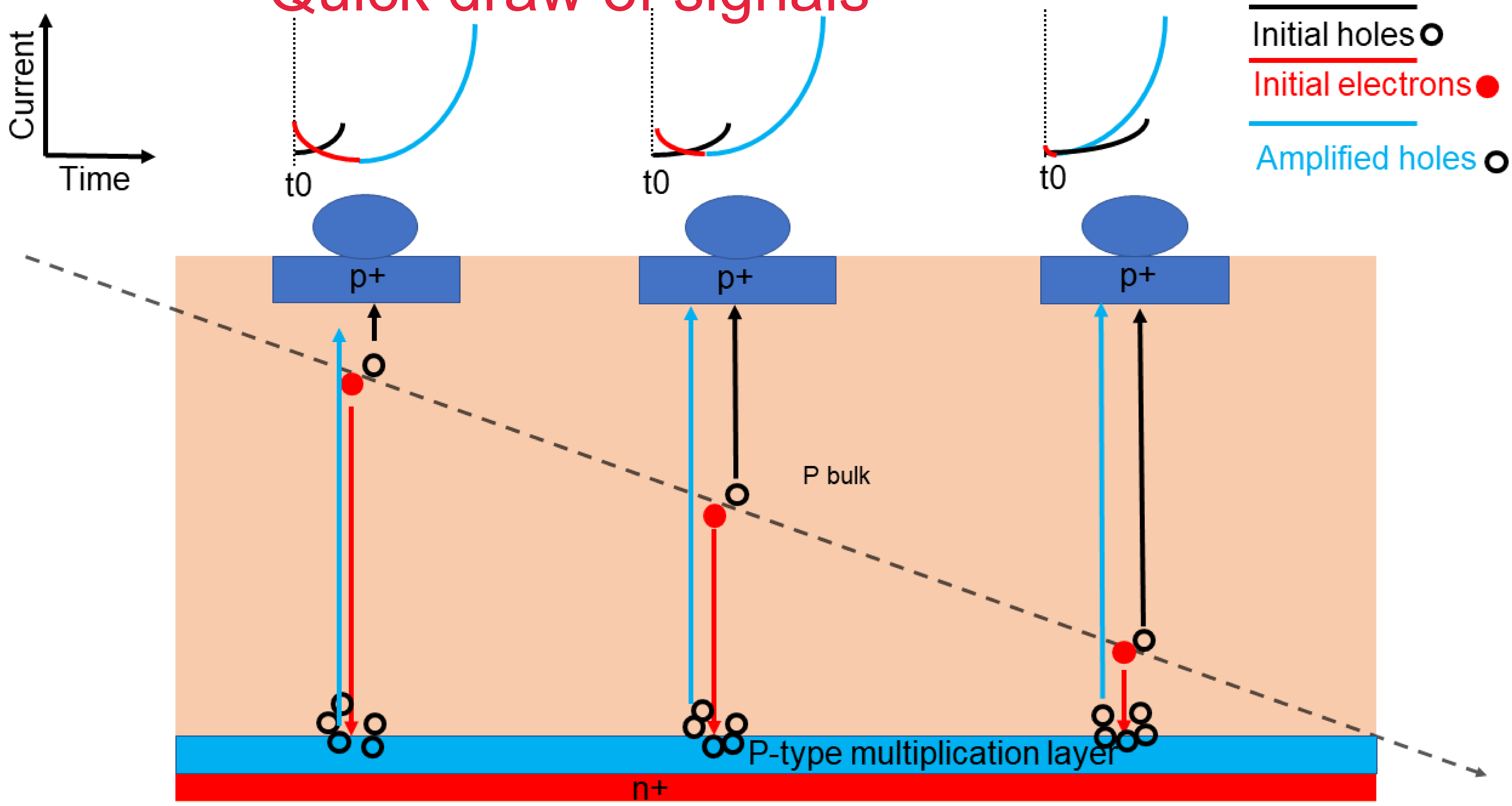




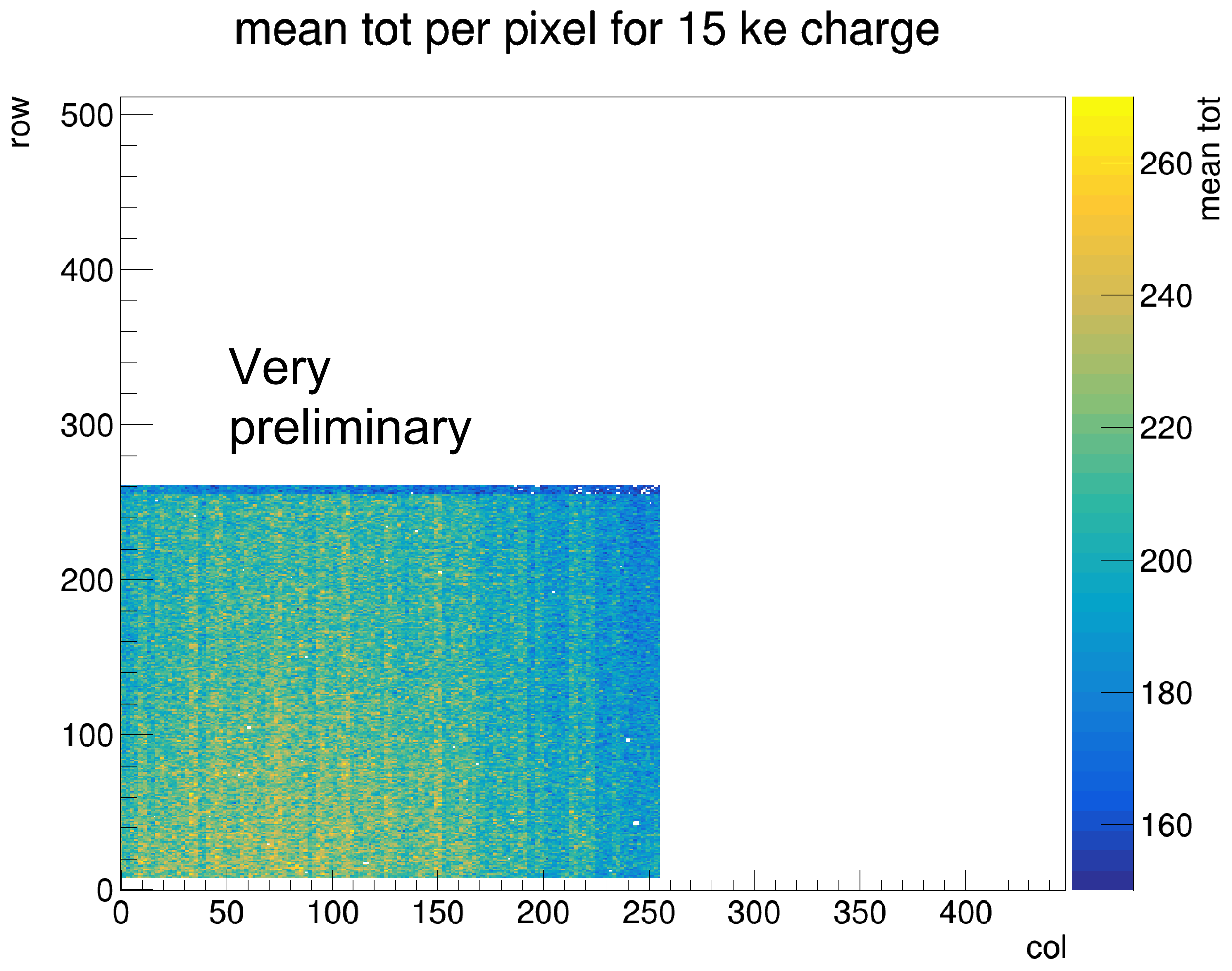


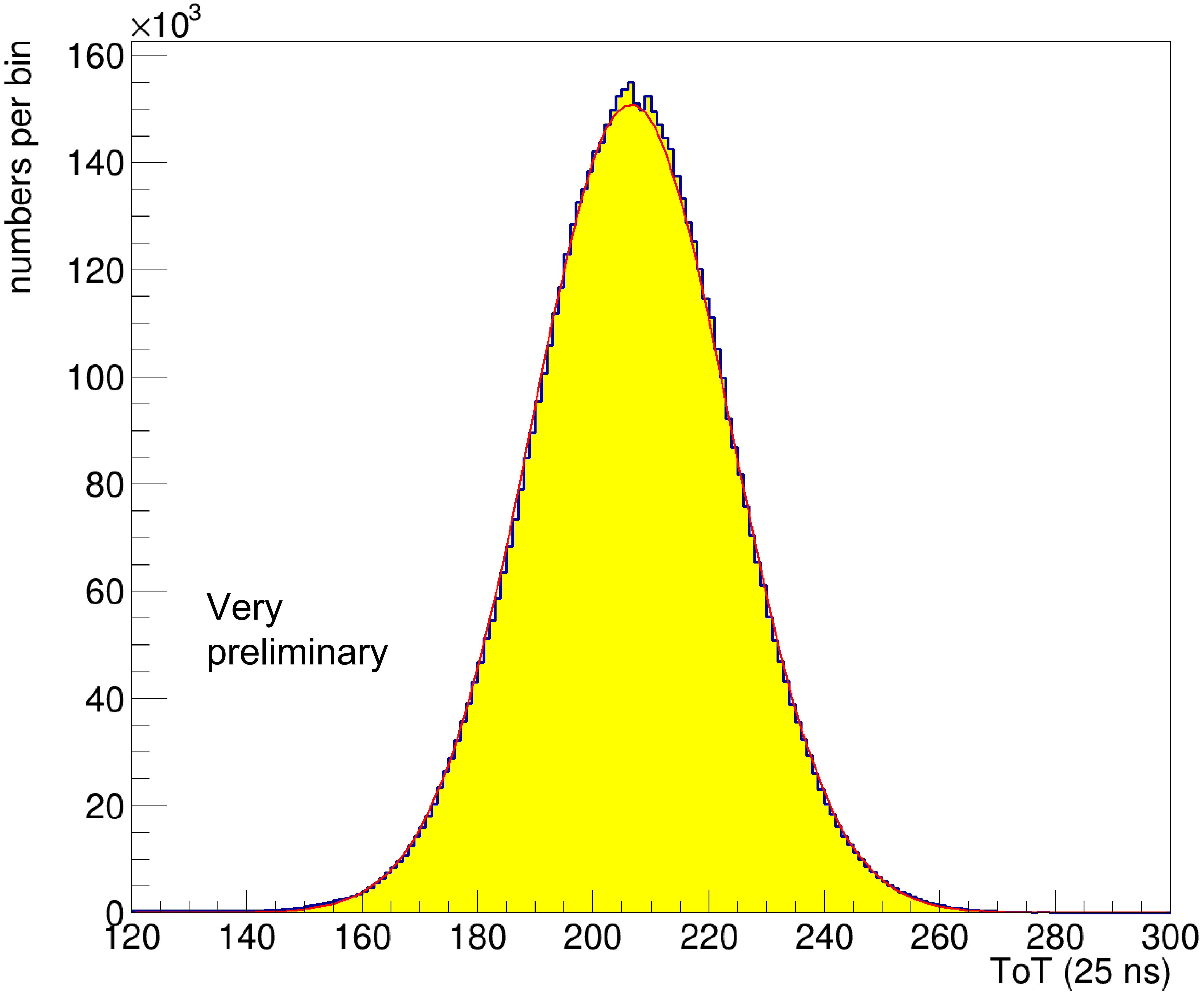
Quick draw of signals



Charge calibration with test pulses

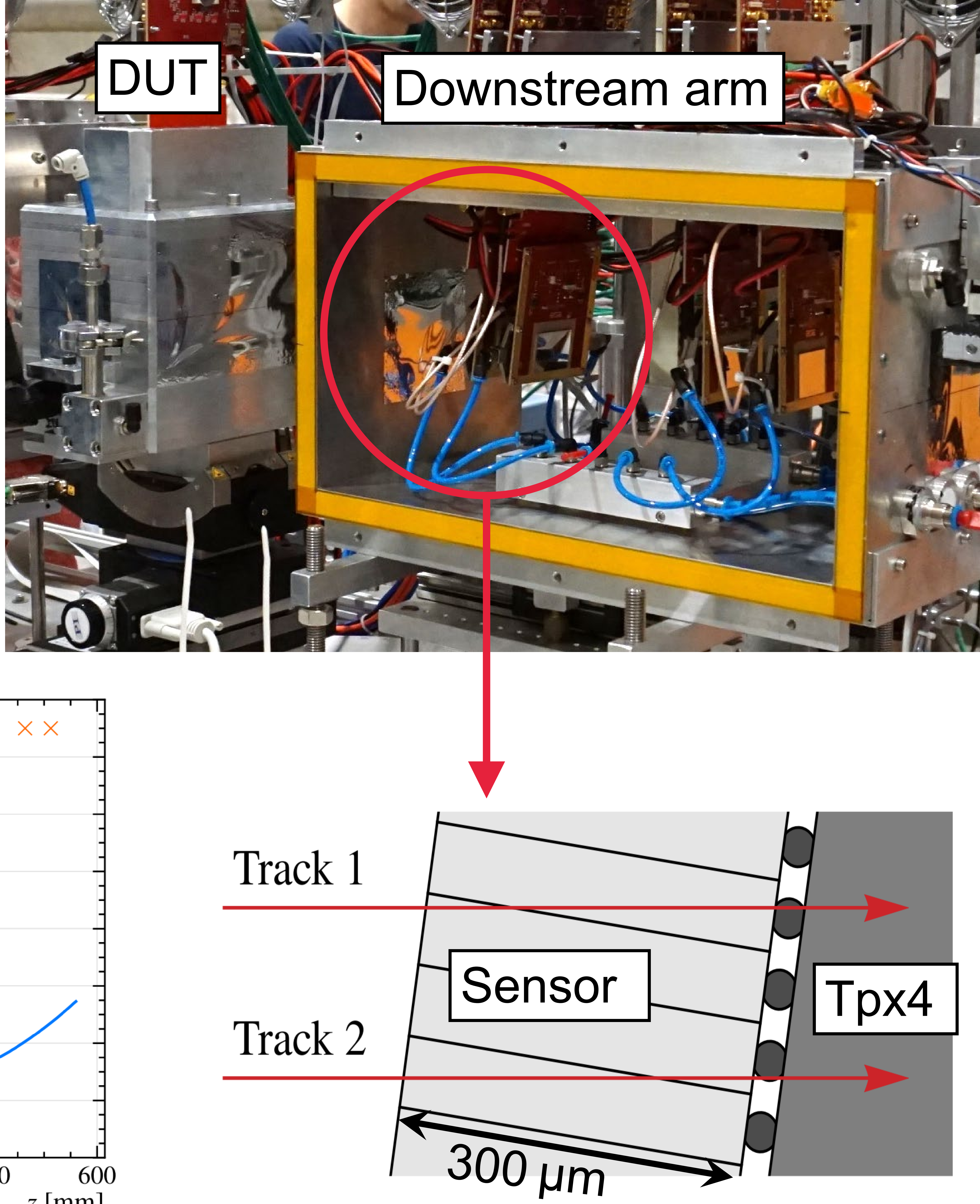
- ToT for a test pulse charge of 15 ke

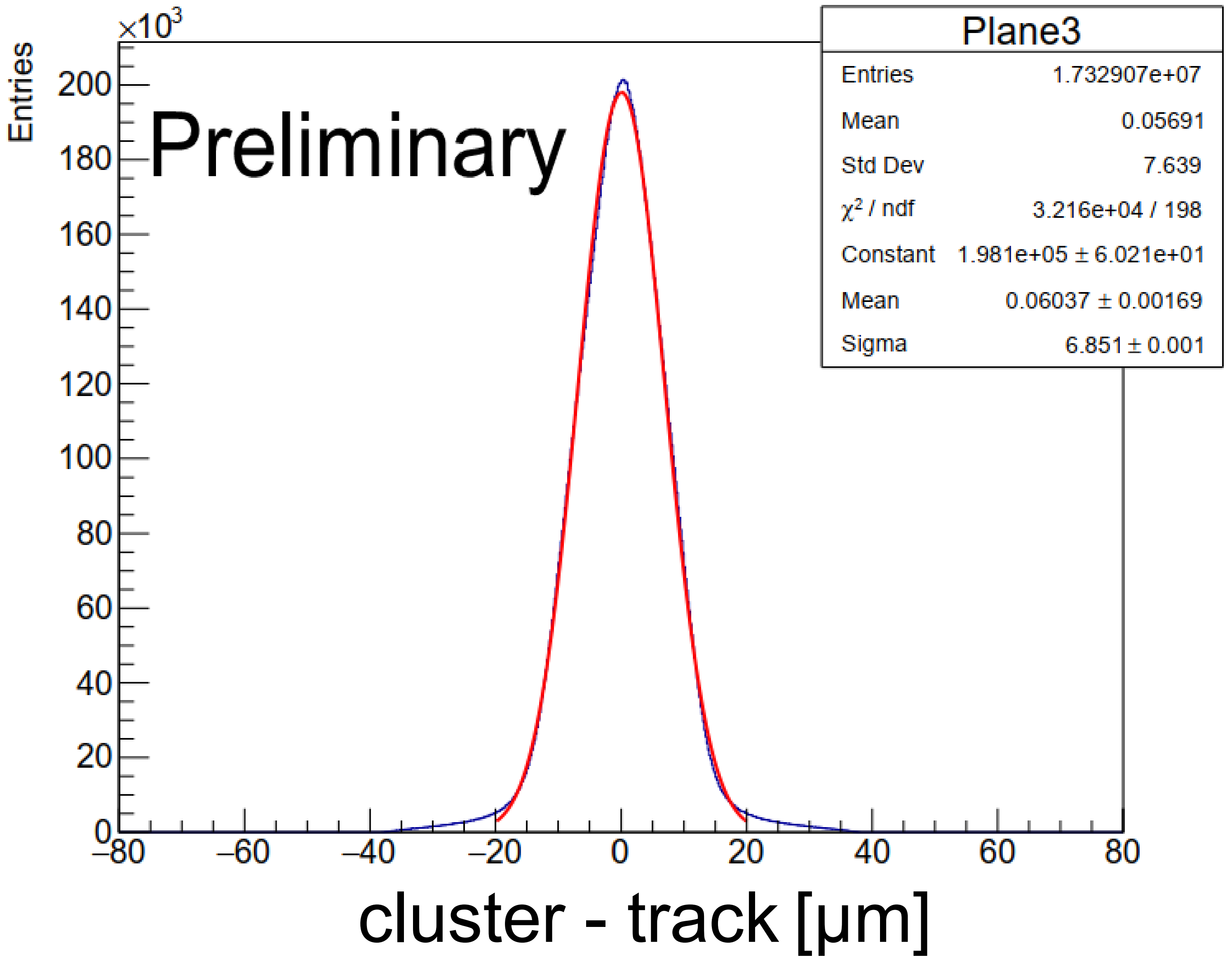


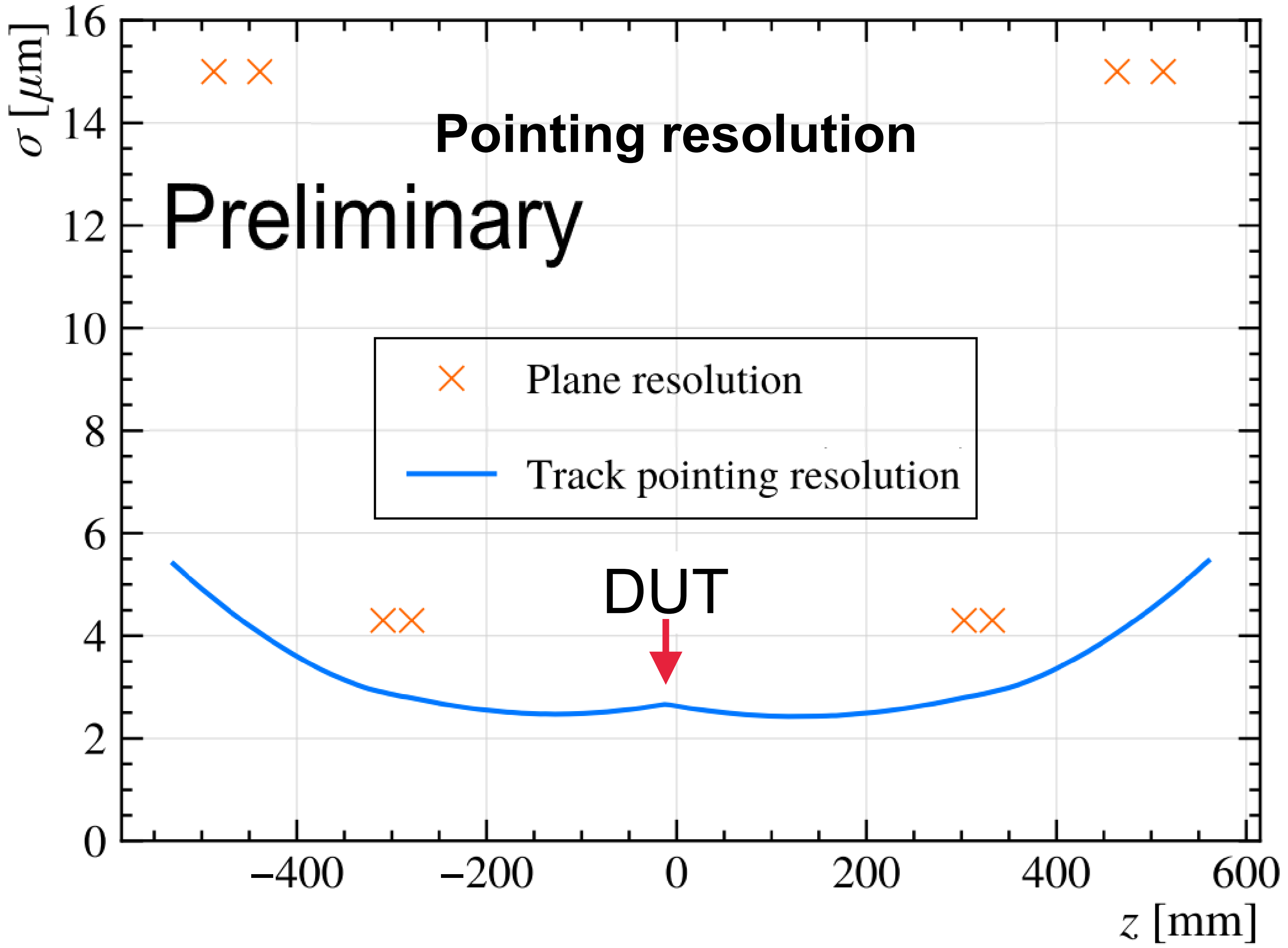


Spatial resolution

- Four innermost planes rotated 9° around x and y to enhance charge sharing between pixels
- Charge-weighted mean gives cluster position
- Single plane resolution: **4.3 µm**
- Pointing resolution at DUT: **2.7 µm** (Mixed hadron beam 180 GeV/c)
- Working on η corrections to improve spatial resolution

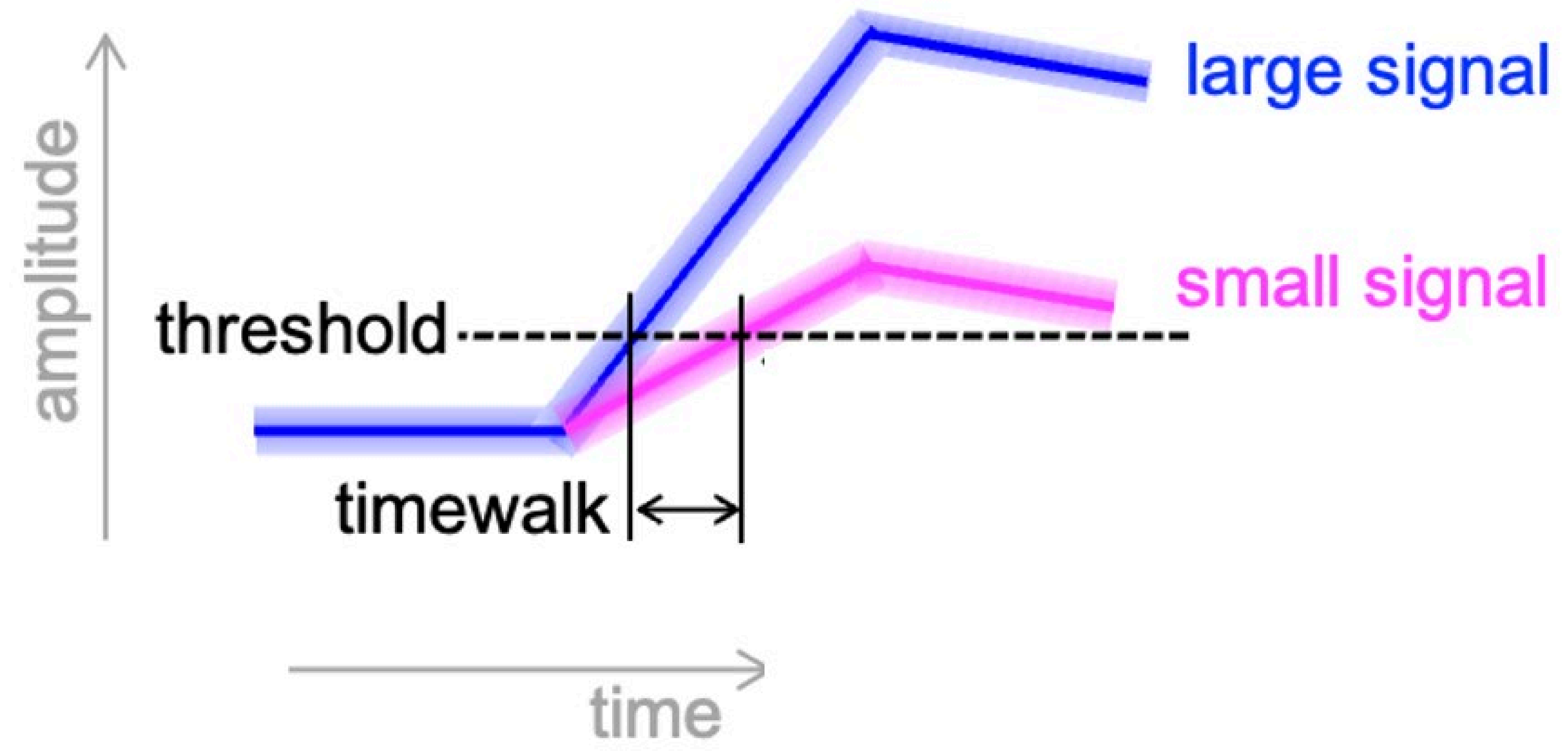


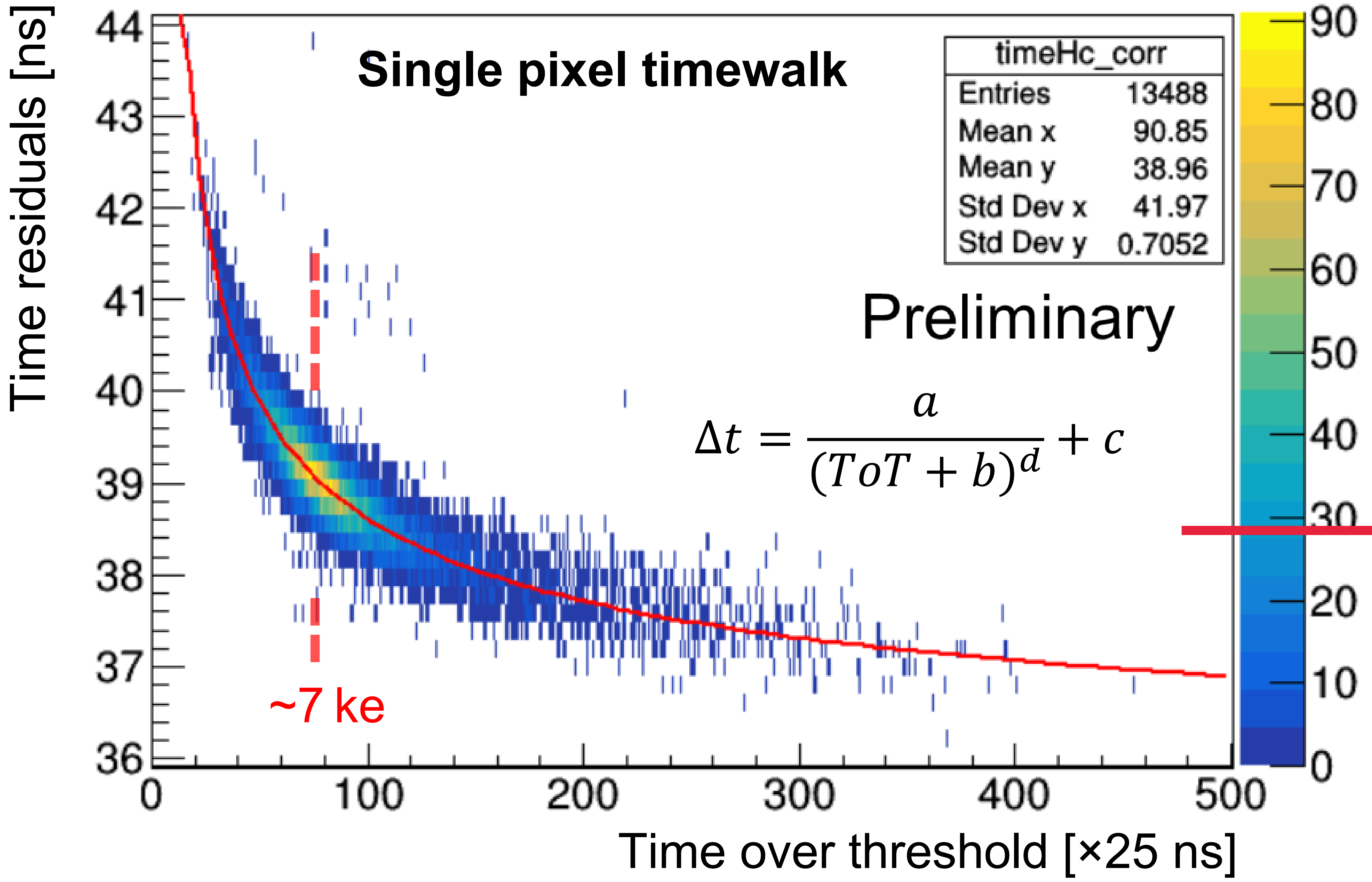


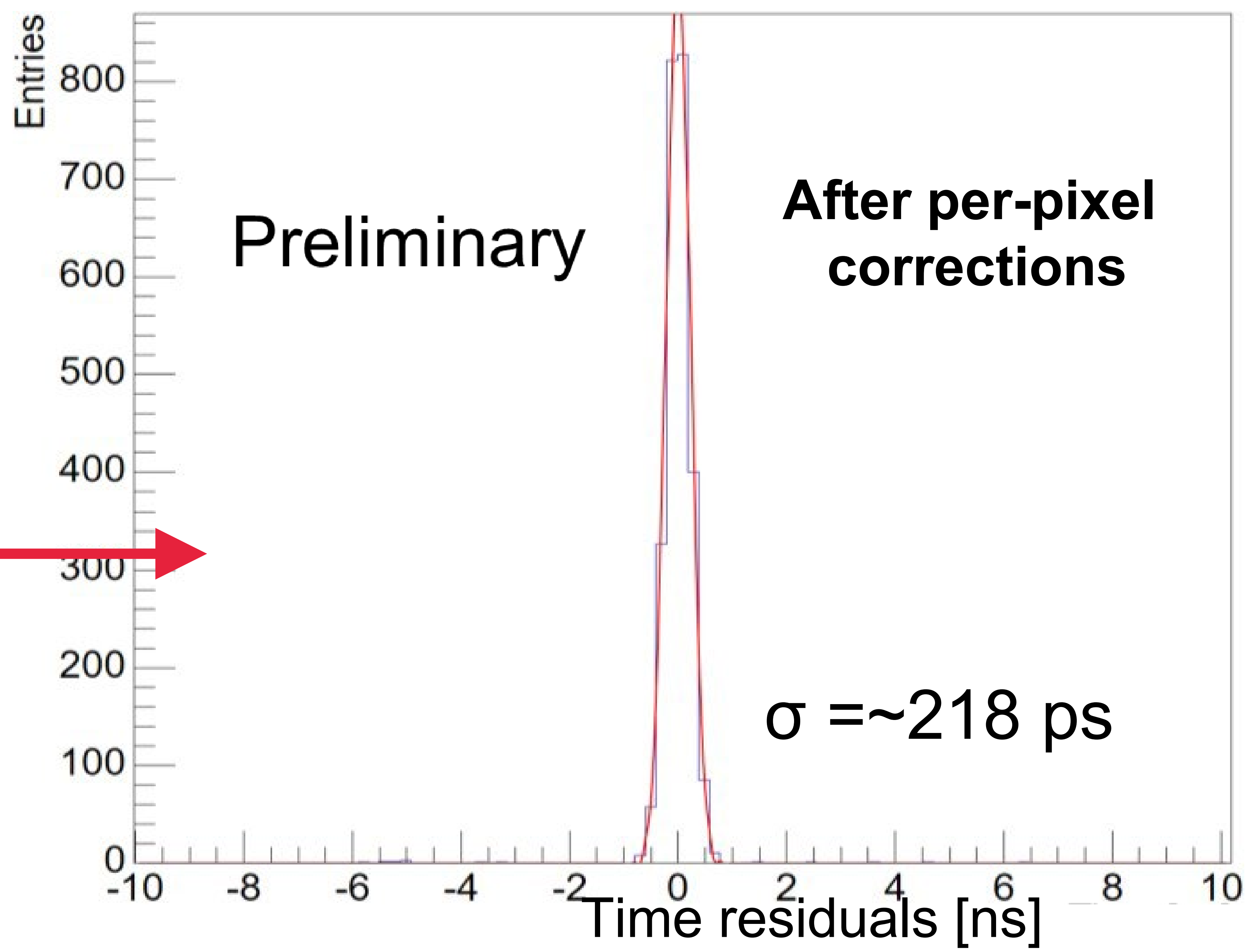


Time resolution

- Large signals cross threshold earlier than smaller ones
- Working on per-pixel timewalk corrections
- Current cluster-time resolution without Clock corrections: **~210-220 ps**







Time resolution

- ToA measurement with 640 MHz voltage-controlled oscillator
- Per superpixel VCO corrections
- After Timewalk+VCO corrections: **~168-185 ps**
- Track time: 4 × 100 µm orthogonal planes : **90 ps**