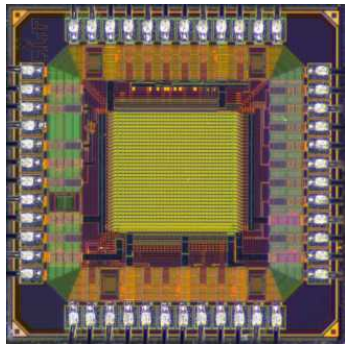
Testbeam and ^{55} Fe-characterisation of DPTS

A MAPS prototype produced in $65\,\mathrm{nm}$ TPSCo CMOS technology towards ALICE ITS3



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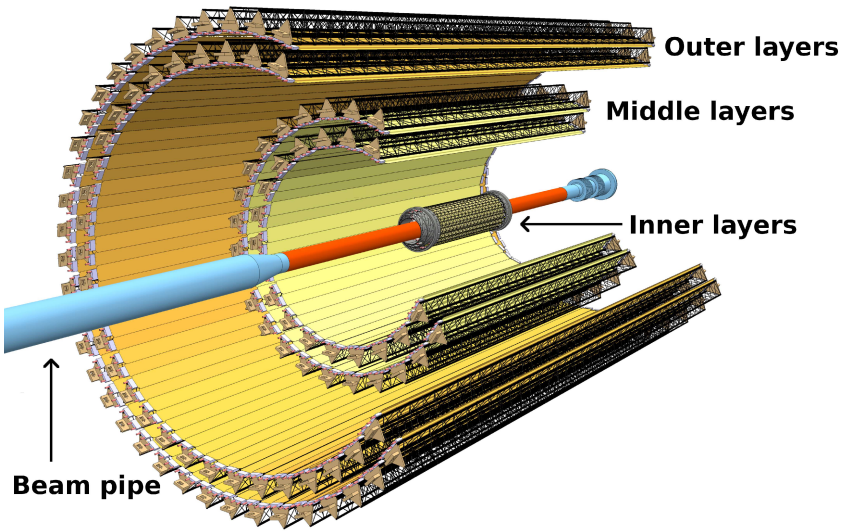
2nd High-D Consortium Meeting

02/09/2022

ALICE ITS

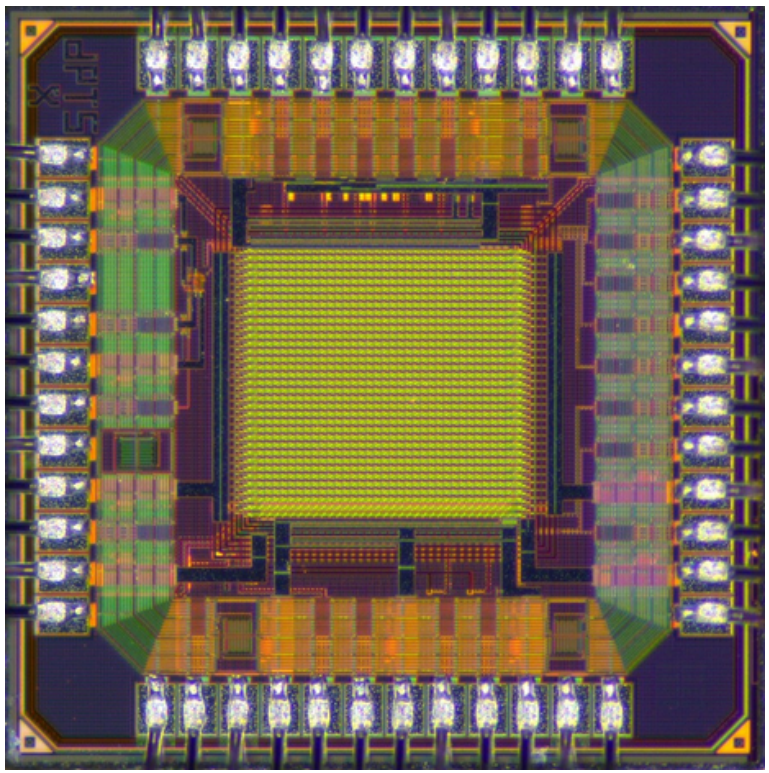
- ALICE **I**nner **T**racking **S**ystem (ITS2) recently installed
- Consists of 7 layers of ALPIDE **M**onolithic **A**ctive **P**ixel **S**ensors (MAPS)
- Towards HL-LHC: Planned upgrade to ITS3
- Three innermost layers will be replaced
- New design features:
  - $65\,\mathrm{nm}$ CMOS technology
  - Stiched, wafer-size sensors
  - Truly cylindrical MAPS due to wafer bending
- Extensive R&D program featuring several sensor prototypes



Sketch of ALICE ITS2

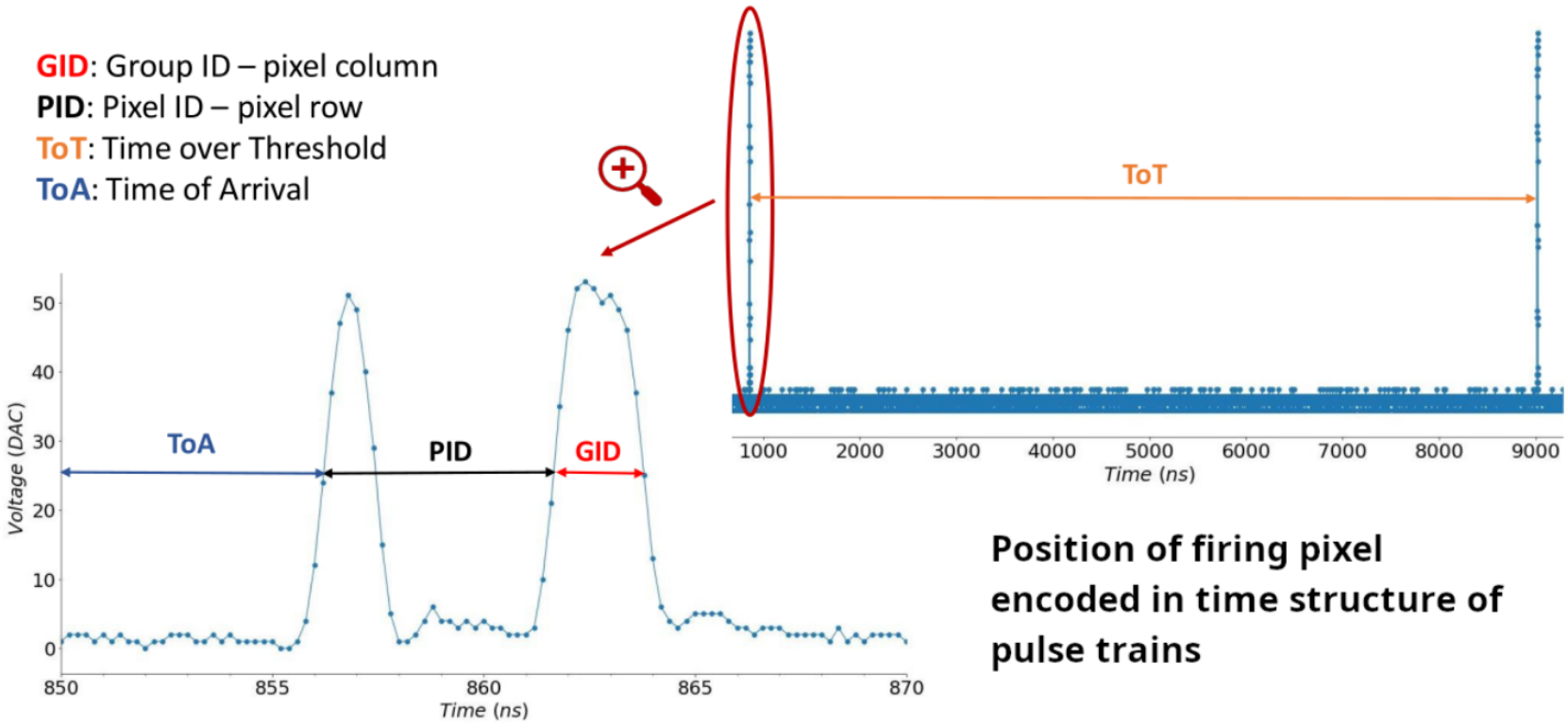
DPTS: general information

- DPTS stands for "**D**igital **P**ixel **T**est **S**tructure"
- 32×32 pixels, 15×15μm^2 pitch each (+1 monitor pixel)
- 480×480μm^2 active area
- Fabricated in 65nm TPSCo technology
- Special Features:
  - Time-based encoding of hit position and ToT
  - Asynchronous digital readout
  - Provides possibility of capacitive test pulse injection
- Aiming at testing reliability of this special architecture



DPTS: digital readout

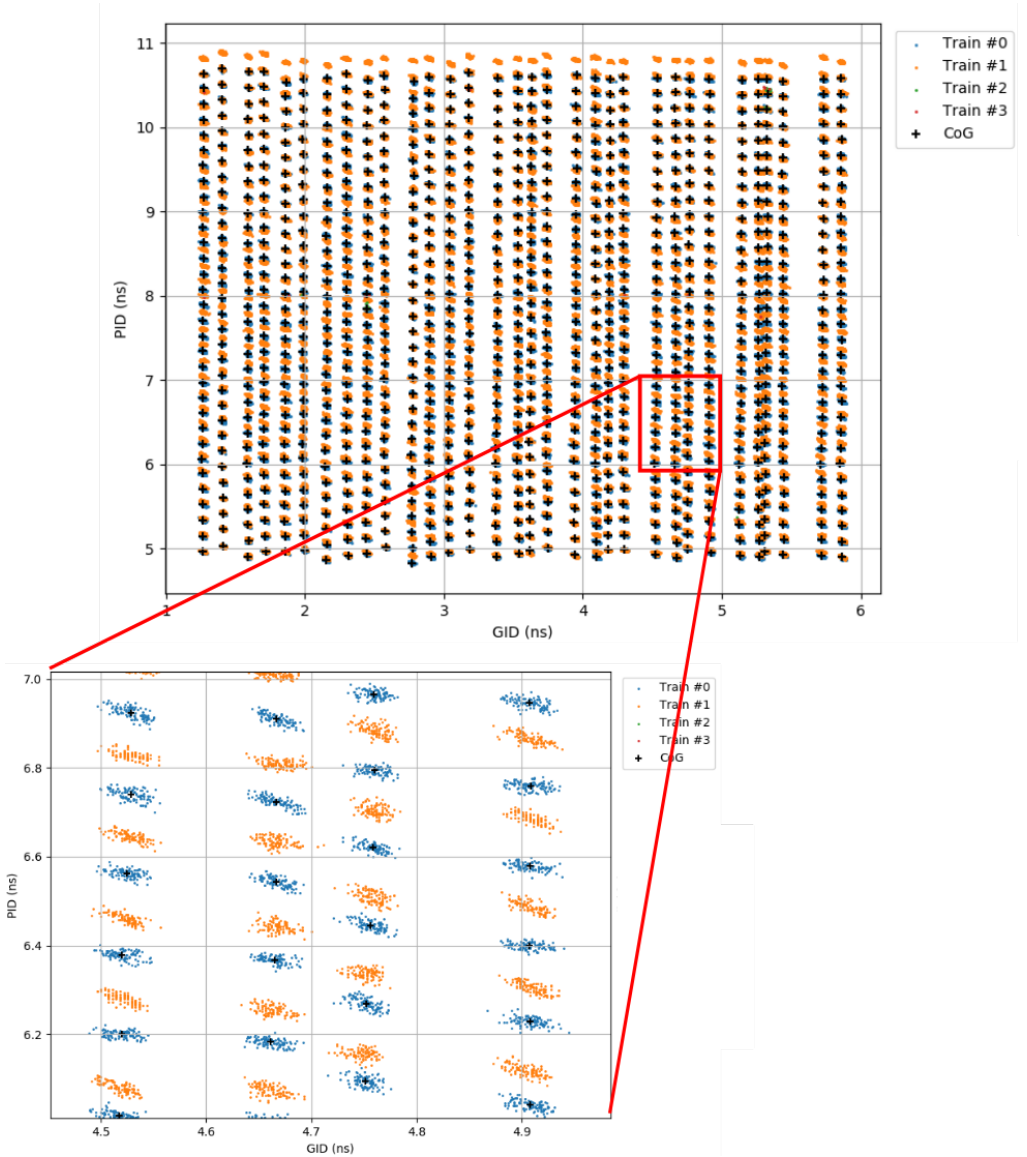
GID: Group ID – pixel column
PID: Pixel ID – pixel row
ToT: Time over Threshold
ToA: Time of Arrival



Position of firing pixel encoded in time structure of pulse trains

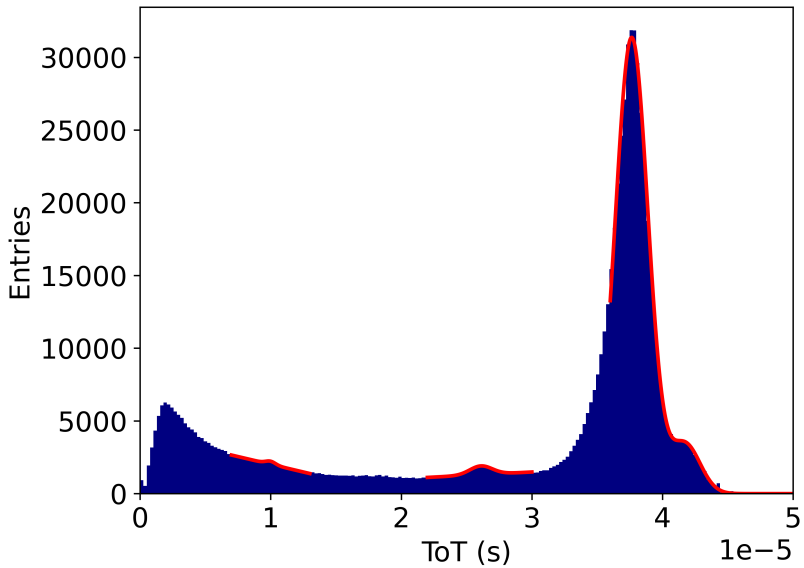
DPTS: position decoding

- Pulse every pixel several times
- Record corresponding PID and GID values
- Calculate calibration point as Center-of-Gravity (CoG) of this distribution
- Use nearest-neighbour search for measured GID/PID pair in order to decode hit-position



^{55} Fe ToT distribution for DPTS

- ToT can be extracted from time difference between rising-edge and falling-edge pulse train
- Spectrum corrected for inter-pixel variation of the ToT response
- K_α, K_β, Si-escape and Si-fluorescence peak resolvable
- Fitted spectrum in order to extract peak positions (Gauss + Background)



Peak	Position μ $(10^{-5}\mathrm{s})$
K_α	3.76
K_β	4.17
$\mathrm{Si}_{\mathrm{ec}}$	2.61
$\mathrm{Si}_{\mathrm{fl}}$	0.99

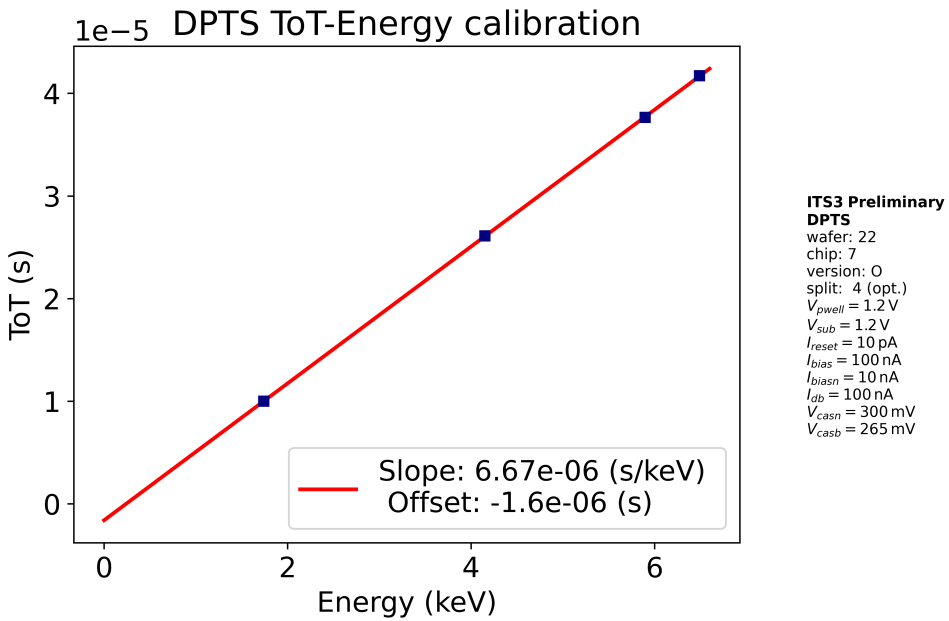
^{55} Fe Energy calibration DPTS

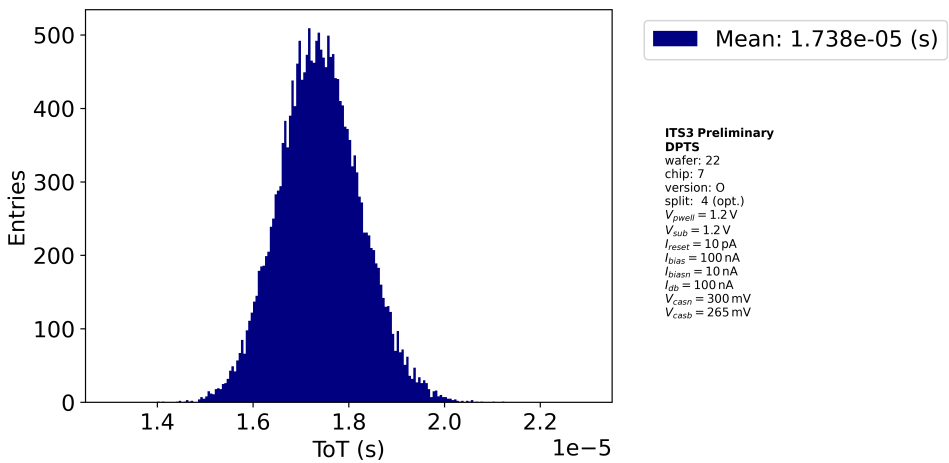
- Peak positions can be used in order to obtain ToT(E) calibration
- Linear fit justified for considered ToT range
- Measured mean ToT response of the sensor at 600mV injection voltage to be: $\mathrm{ToT_{mean}} = 1.74\mathrm{e}^{-05} s$
- Rough estimation of injection capacitance:

$$\mathrm{E(ToT_{mean})} \approx 2.85\mathrm{keV}$$

$$\mathrm{N_{e-}(600mV)} = \frac{\mathrm{E}}{\mathrm{W_{Si}}} \approx 791\mathrm{e}^{-}$$

$$\mathrm{C} = \frac{\mathrm{Q}}{\mathrm{U}} = \frac{\mathrm{N_{e-}} \cdot \mathrm{e}}{600\mathrm{mV}} \approx 210\mathrm{aF}$$

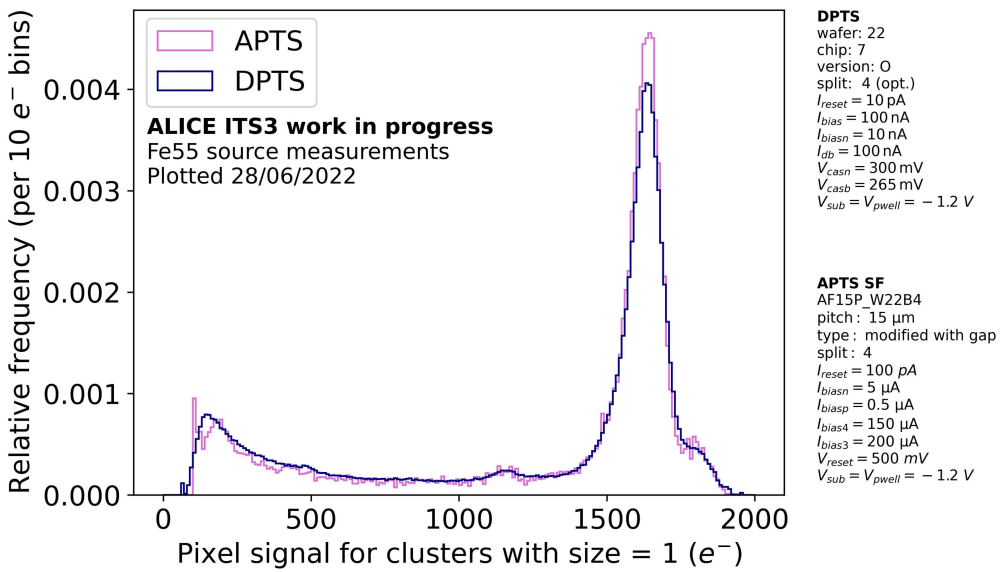




^{55} Fe spectrum APTS vs. DPTS

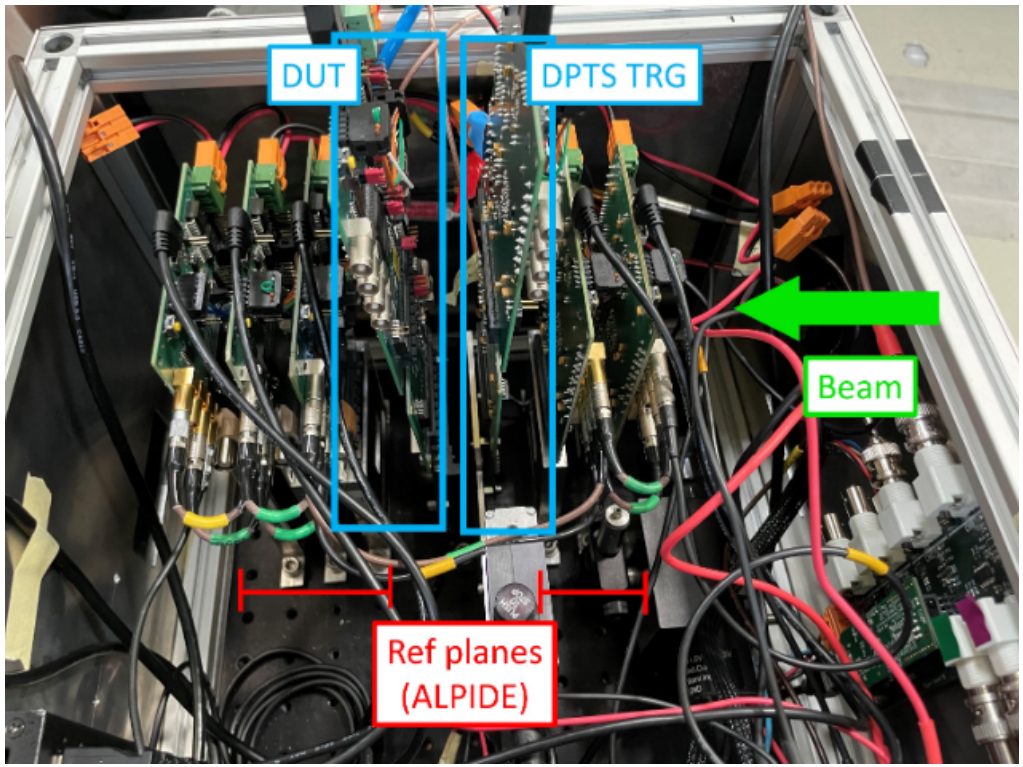
- Comparing DPTS energy resolution to dedicated analogue sensor APTS
- Considering only single-pixel clusters
- Converted to charge using energy-calibration

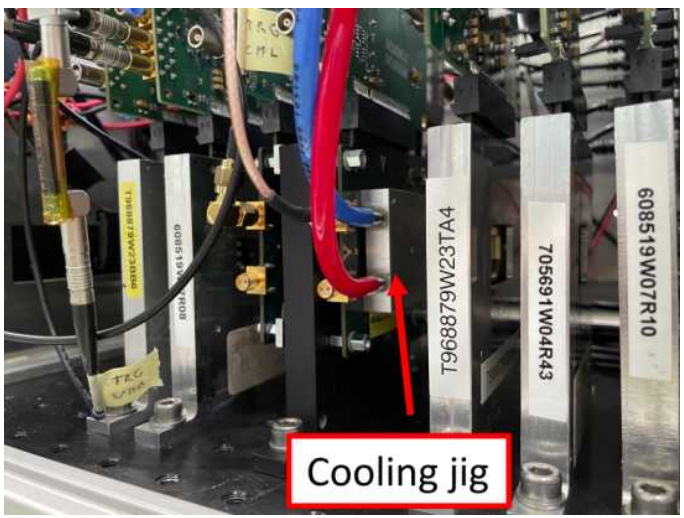
  (ToT $\rightarrow$ energy $\rightarrow$ # electrons)
- DPTS ToT response similar to APTS

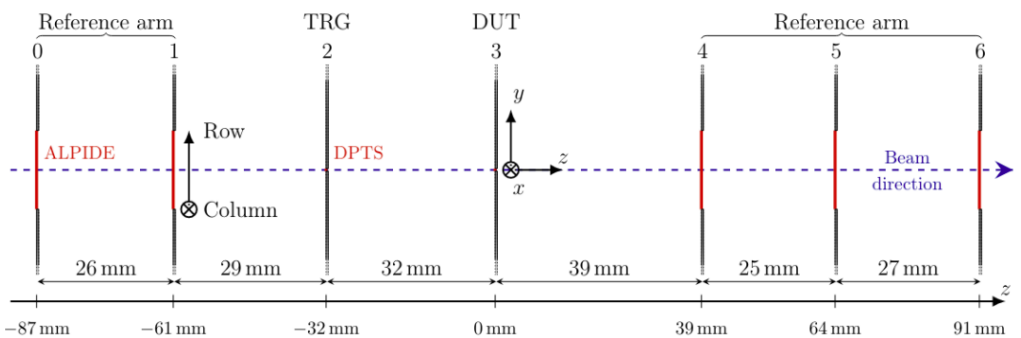


Testbeam setup (PS July 2022)

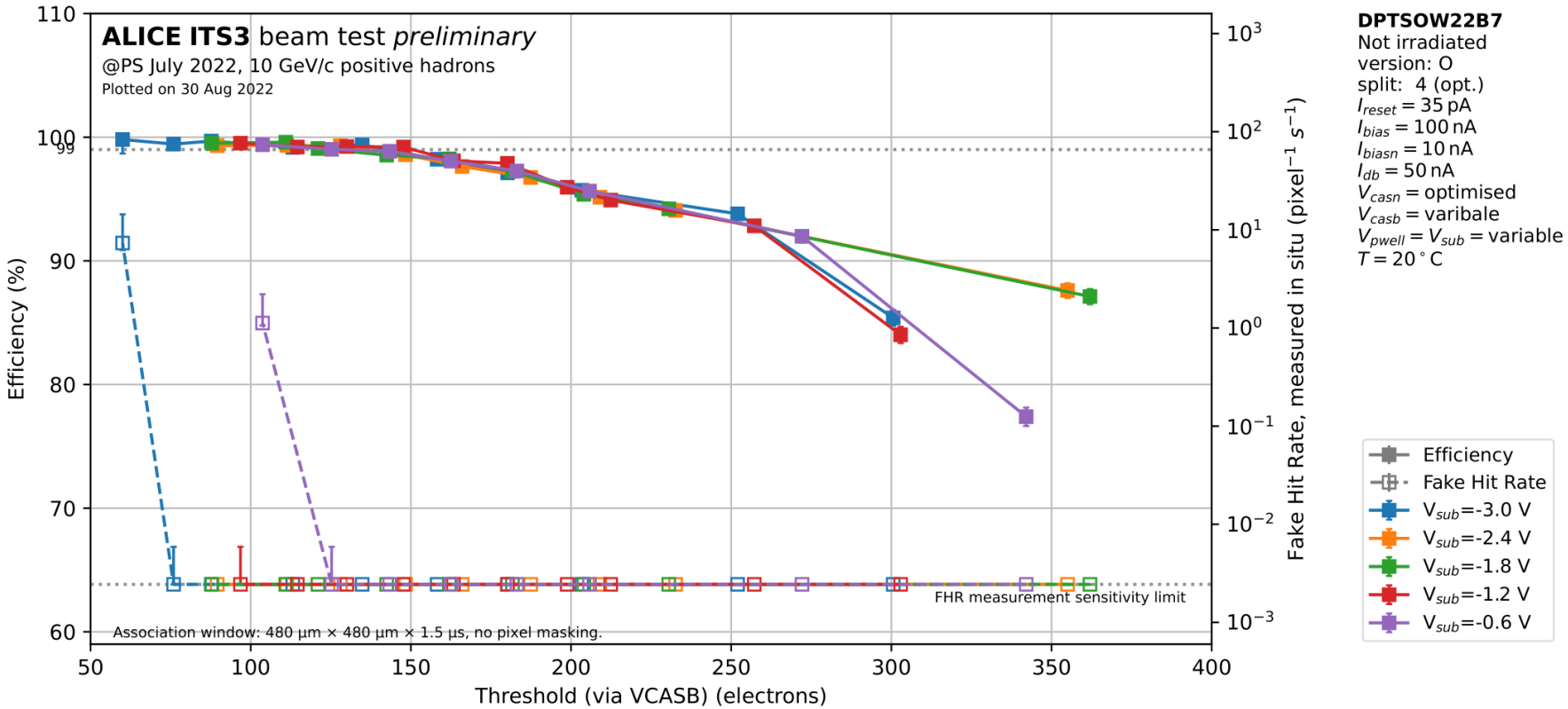
- Aimed to test irradiated/ non-irradiated DPTS under controlled environment
- 5 ALPIDE reference planes (2 upstream, 3 downstream)
- DPTS trigger mounted on a moving stage
- DPTS DUT chilled to 20°C
- 1 upstream scintillator for alignment







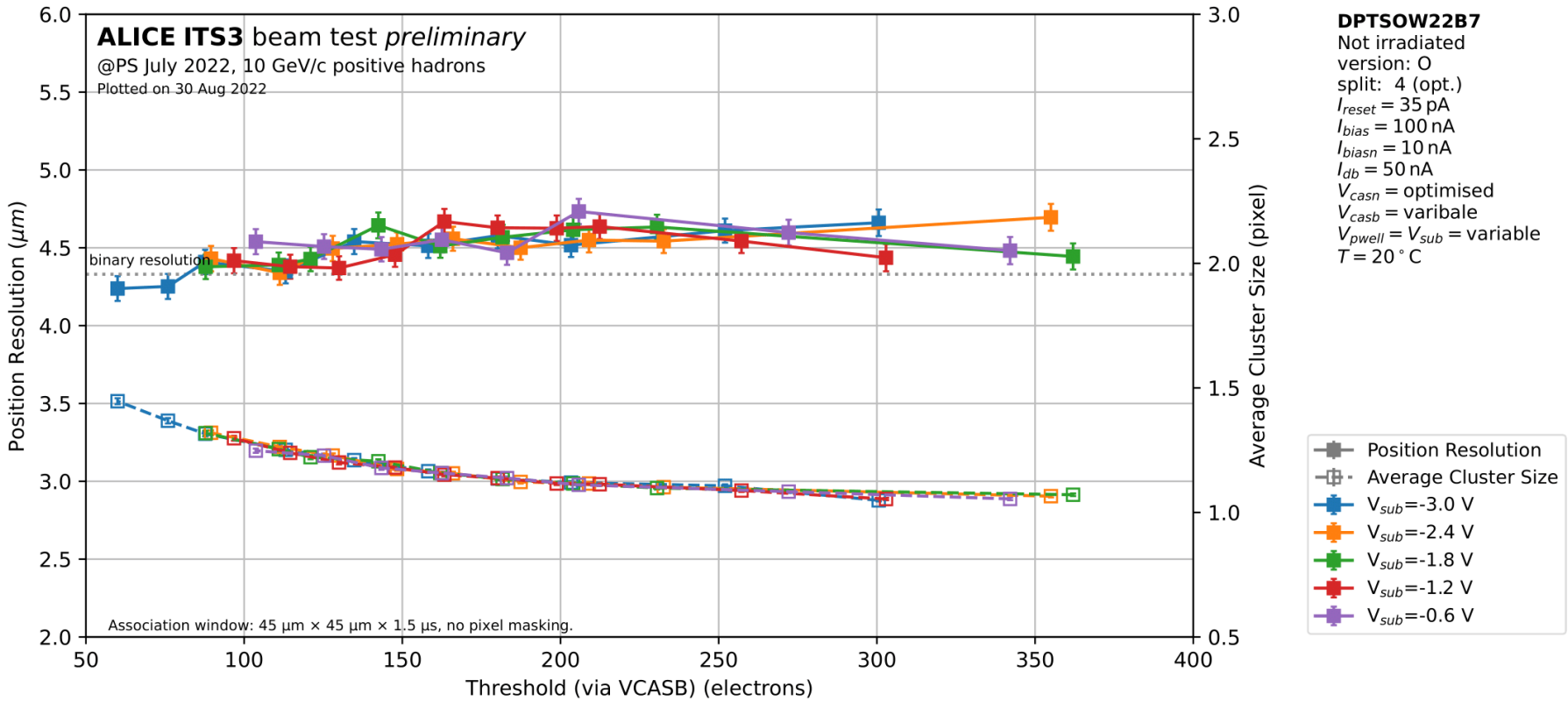
Testbeam results - non irradiated sensor



- $\text{Efficiency} = \frac{\text{efficient tracks}}{\text{total tracks}}$
- FHR obtained by random triggering with no signal source

- Wide operating range above 99 % efficiency with low FHR for every V_{sub}

Testbeam results - non irradiated sensor

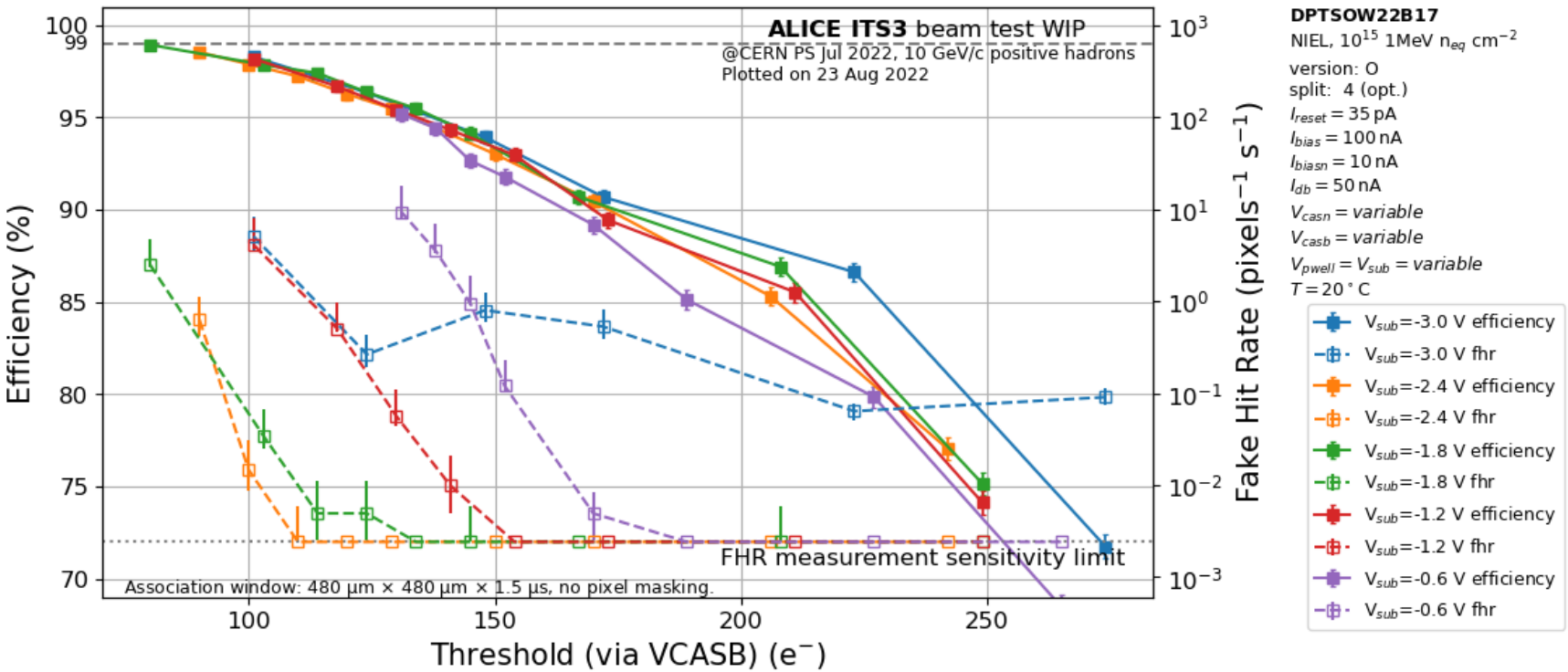


- Position resolution:

$$\sqrt{\mathrm{x_{res}y_{res}} - \sigma^2_{\mathrm{telescope}}}$$

- Due to small epitaxial layer: one pixel clusters dominate → resolution comparable to binary resolution

Testbeam results - irradiated sensor



Summary & Outlook

Achieved:

- ^{55} Fe energy calibration used in order to get a first estimate of the injection capacitance
- ^{55} Fe results hint to a very good energy resolution
- DPTS tested in optimized operation conditions in beam
- Very good results on efficiency

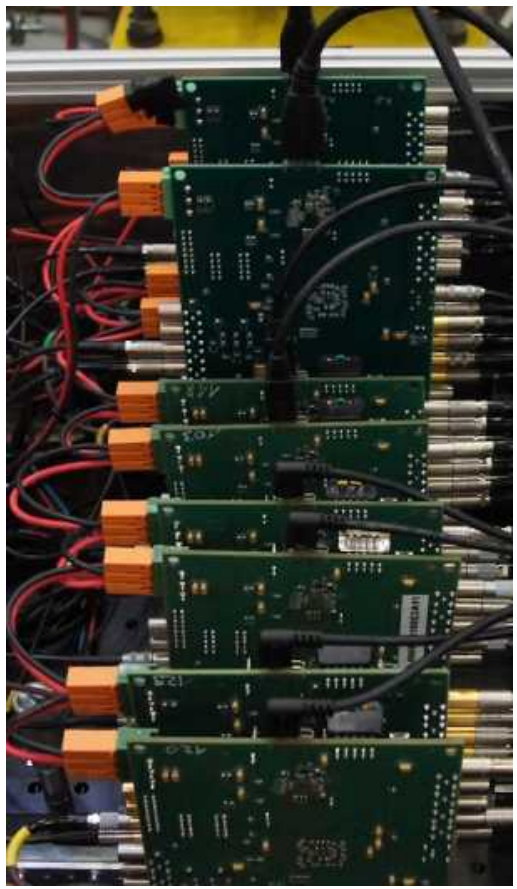
Next steps:

- Measuring ^{55} Fe spectra for all irradiated sensors $\rightarrow$ comparison of energy resolution
- Precise capacitance calibration with different pulsing voltages
- Clustersize analysis of ^{55} Fe measurements
- Paper in preparation with shown and other results

Thank you for your attention! :)

Backup: Testbeam campaigns

- **DESY September 2021**, 5.4 GeV e^-
  - first DPTS Testbeam, fixed working point
- **SPS November 2021**, 10 GeV π/p mixed beam
  - successfully operated first p-irradiated DPTS
- **DESY March 2022**, 3.4 GeV e^-
  - Test of neutron irradiated DPTS ($10^{13} - 10^{15}\ 1\mathrm{MeV n_{eq}}/\mathrm{cm}^2$)
  - no stable environmental conditions
- **PS May 2022**, 10 GeV π/p mixed beam
  - revisited $10^{15}\ 1\mathrm{MeV n_{eq}}/\mathrm{cm}^2$ sensor
  - tried $10^{16}\ 1\mathrm{MeV n_{eq}}/\mathrm{cm}^2$ sensor $\rightarrow$ not operable
  - controlled environment (temperature, in-situ calibrations)
- **PS July 2022**, 10 GeV π/p mixed beam
  - revisited 10^{13} and $10^{14}\ 1\mathrm{MeV n_{eq}}/\mathrm{cm}^2$ sensor
  - tested 1, 10, 50 Mrad TID irradiated sensors
  - Analysis ongoing



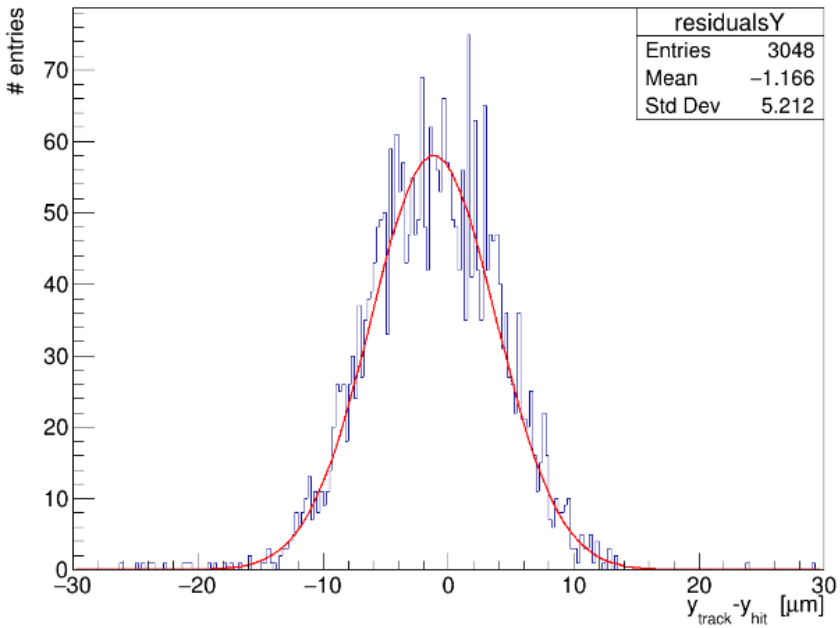
Backup: General Testbeam analysis procedure

- General analysis procedure:
  - Reference track fitted with ALPIDE hit information
  - Determine intersection of fitted track with DPTS plane
  - Search for DPTS hit in corresponding time frame

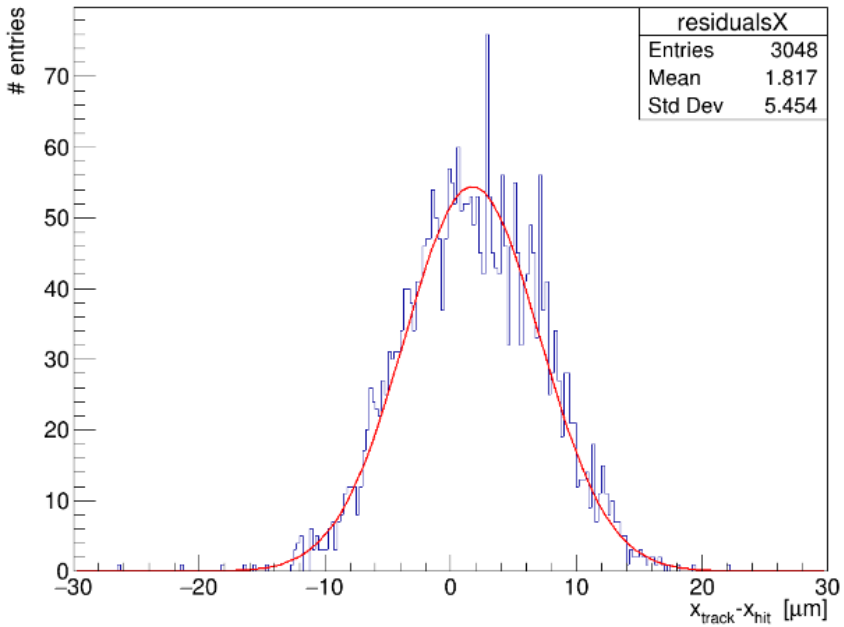
$$\text{Efficiency} = \frac{\text{efficient tracks}}{\text{total tracks}}$$

Analysis carried out with Corryvreckan

Backup: Testbeam residuals

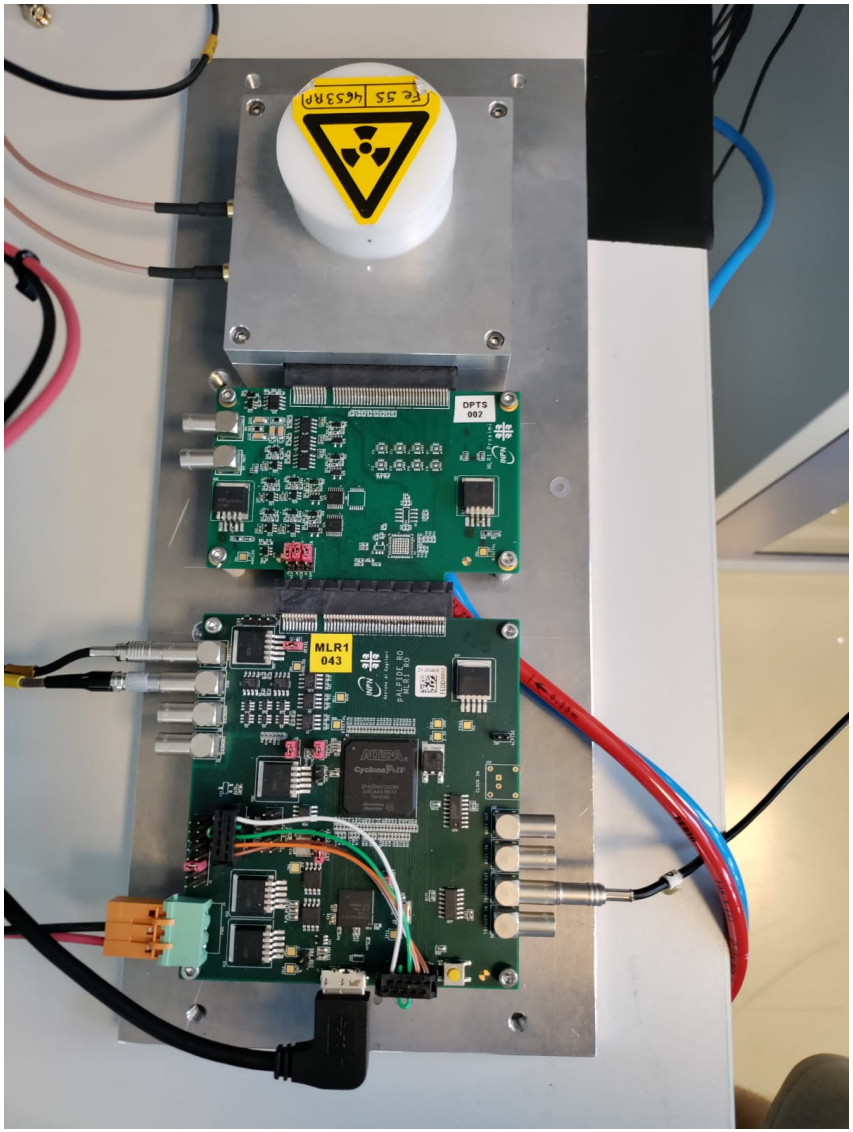


Residuals in X direction

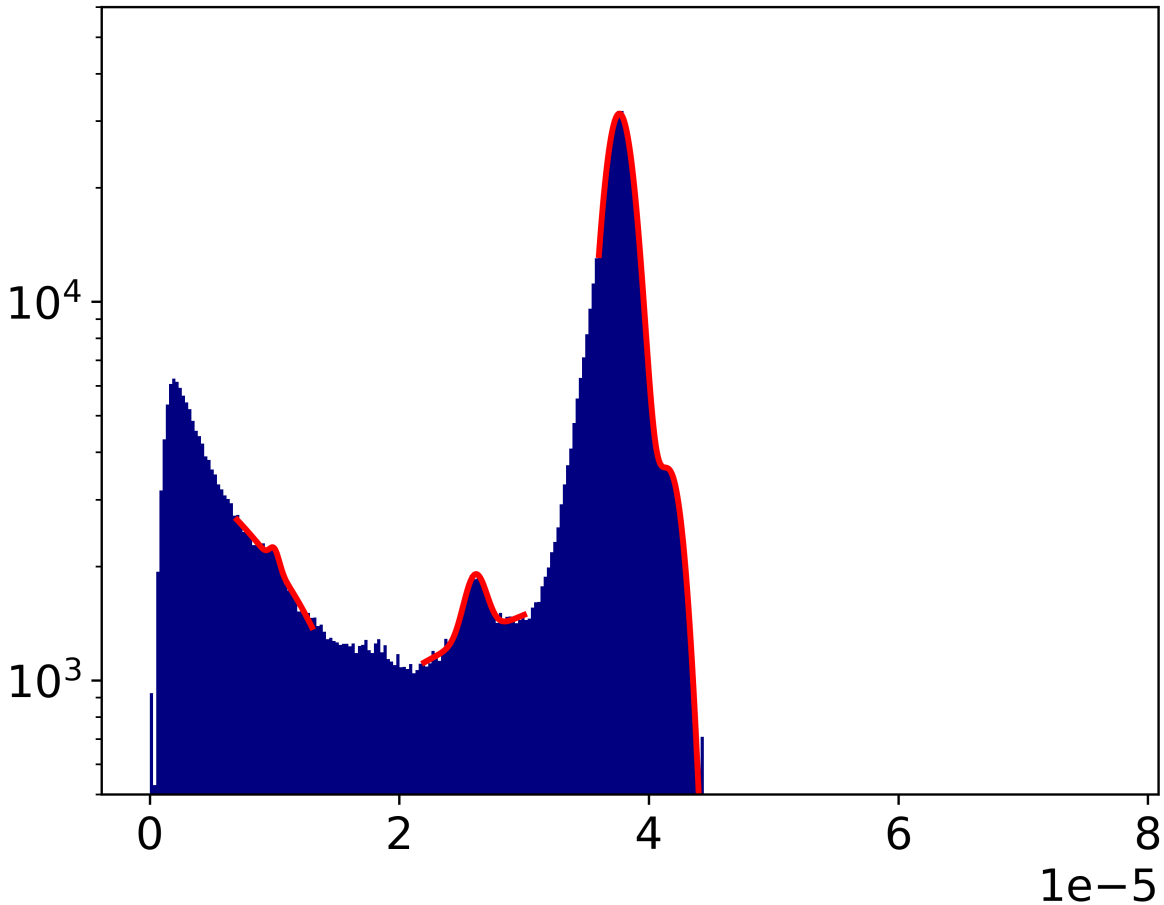


Residuals in Y direction

Backup: ^{55} Fe Setup

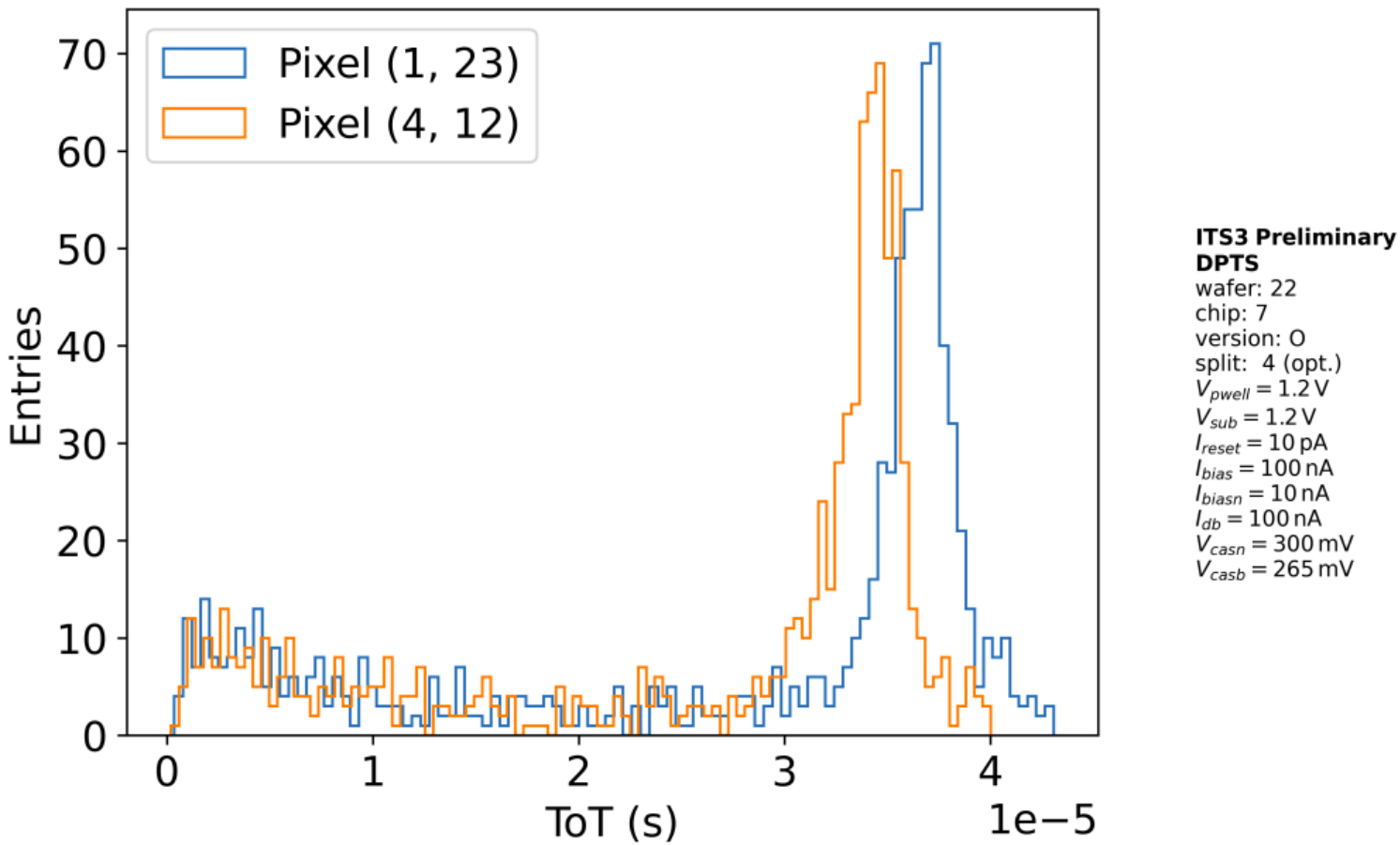


Backup: Logarithmic corrected ToT spectrum



ITS3 Preliminary
DPTS
wafer: 22
chip: 7
version: O
split: 4 (opt.)
$V_{pwell} = 1.2\,\mathrm{V}$
$V_{sub} = 1.2\,\mathrm{V}$
$I_{reset} = 10\,\mathrm{pA}$
$I_{bias} = 100\,\mathrm{nA}$
$I_{biasn} = 10\,\mathrm{nA}$
$I_{db} = 100\,\mathrm{nA}$
$V_{casn} = 300\,\mathrm{mV}$
$V_{casb} = 265\,\mathrm{mV}$

Backup: ^{55} Fe ToT spectrum - interpixel variation



Backup: ^{55} Fe ToT spectrum - uncorrected