GEFÖRDERT VOM
Bundesministerium für Bildung und Forschung

Time Resolution Studies

with the AIDA TLU and the Timepix3 at DESY

Vertex and tracking detector technology meeting

CERN, March 27th, 2020

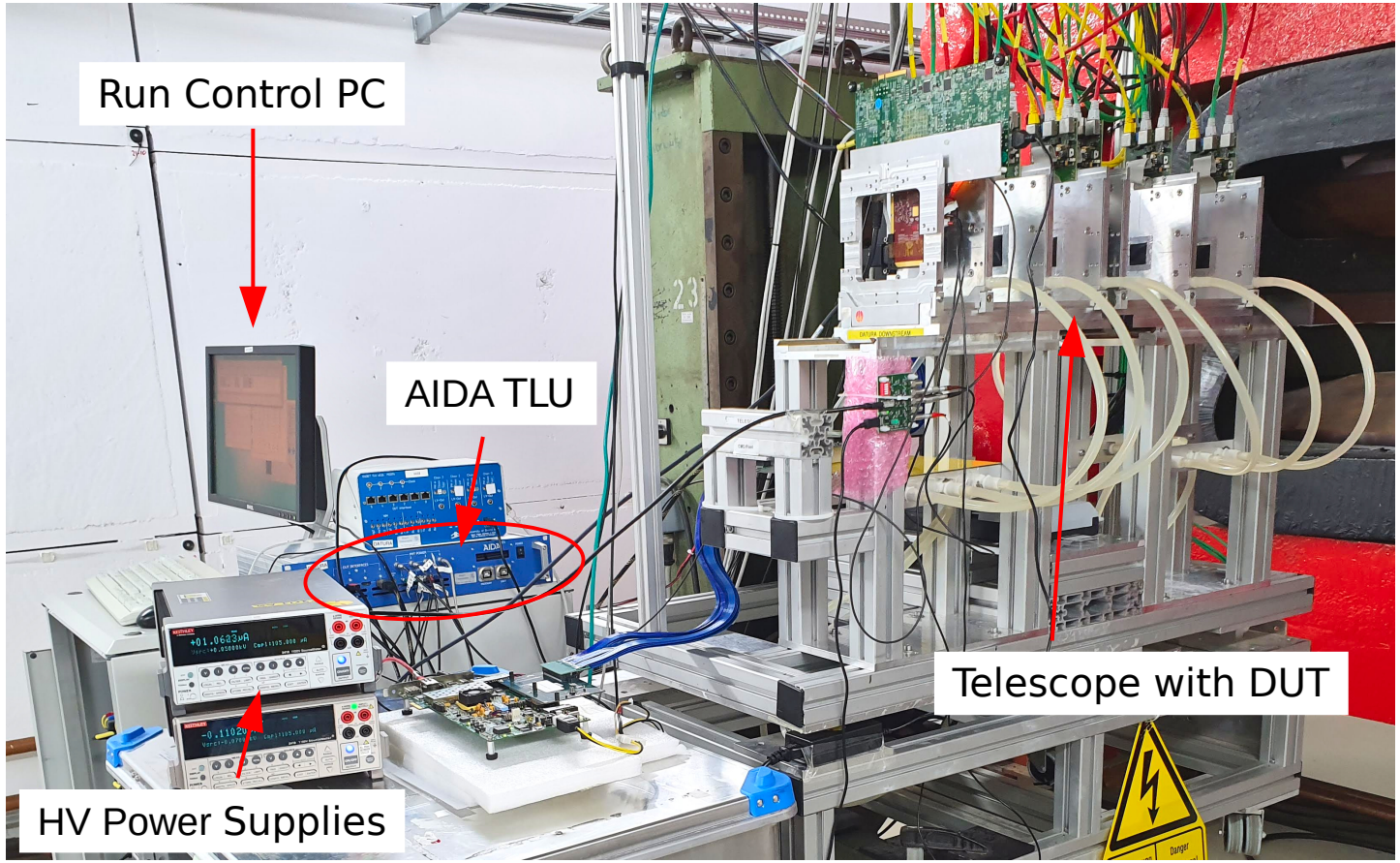
Jens Kröger

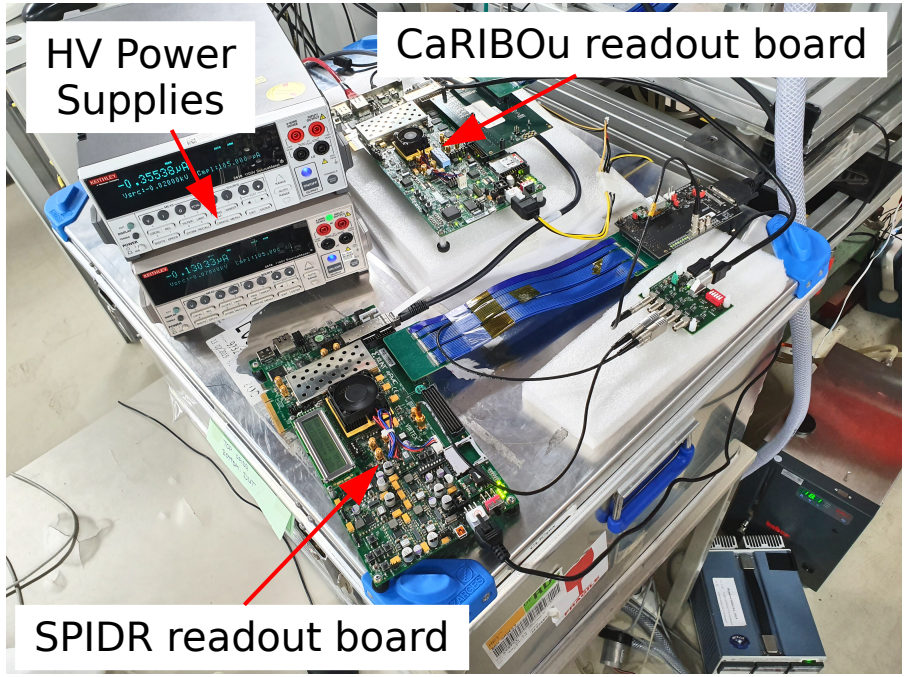
Heidelberg University & CERN

Reminder

Test Beam Setup at DESY

- typical beam conditions:
  5.4 GeV electrons @ few kHz





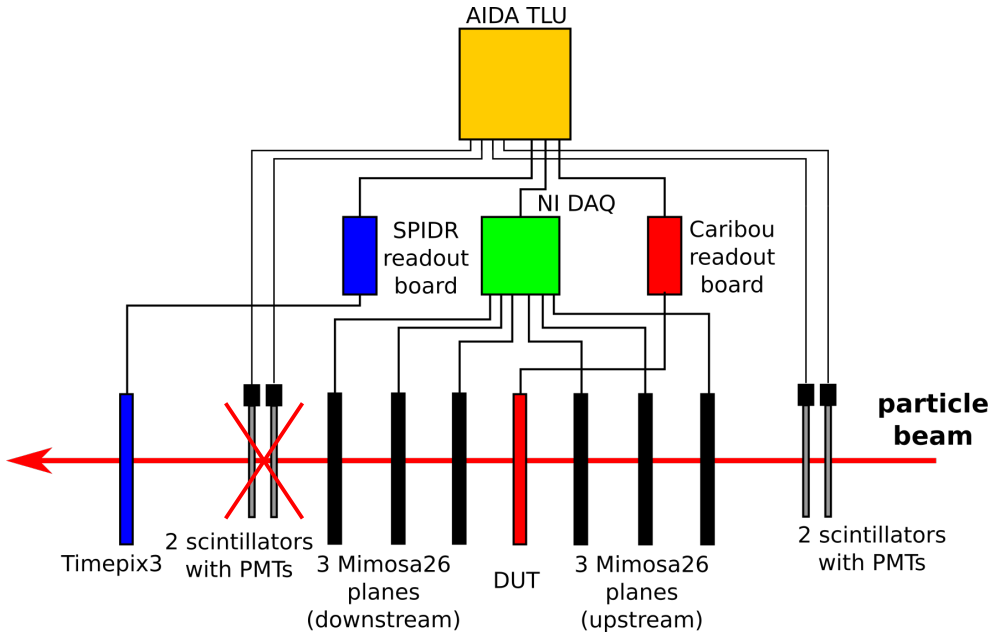
Reminder

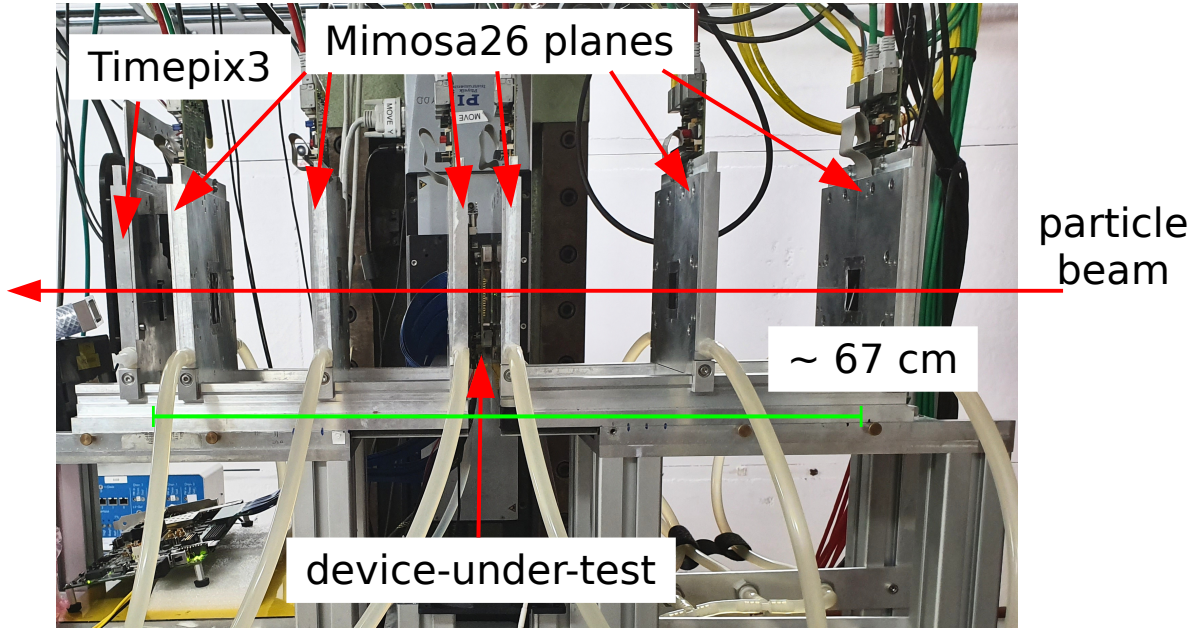
Test Beam Setup at DESY – Readout

- **AIDA TLU** → provides global clock (time sync.) + triggers Mimosa Readout
- 2 scintillators + PMTs → input to TLU
- 6 Mimosa26 planes → good spatial resolution (2x 115µs bins rolling shutter)
- **Timepix3** → used to assign ns timestamp to tracks
- DUT → CLICpix2, ATLASpix, CLICTD

only in early test beams

- 2 upstream (+ 1 downstream) scintillators in coincidence
- coincidence window = 6.25 ns (minimum)





The AIDA TLU:

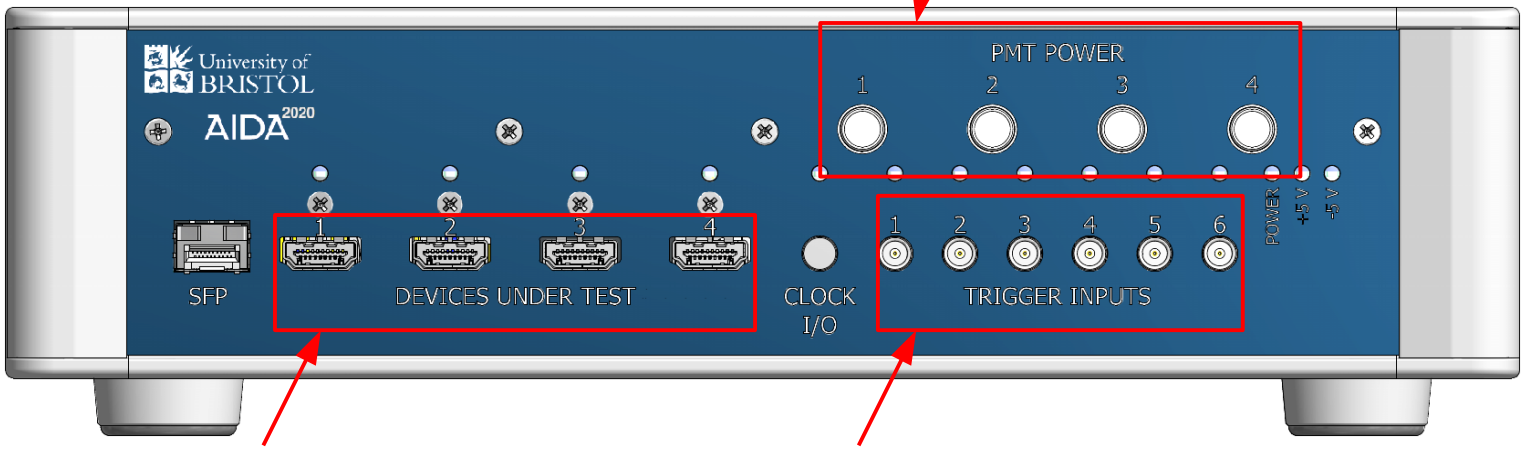
We used:

- February 2019: AZALEA
  March 2019: AZALEA
  → broken channel 3
- June 2019 DATURA
  → time jumps in June
  July 2019: DATURA
  → no time jumps in July
- Septeber 2019: DURANTA
- December 2019: TB24 integrated
- February 2020: DURANTA

→ different devices
+ different firmware versions

table top version:

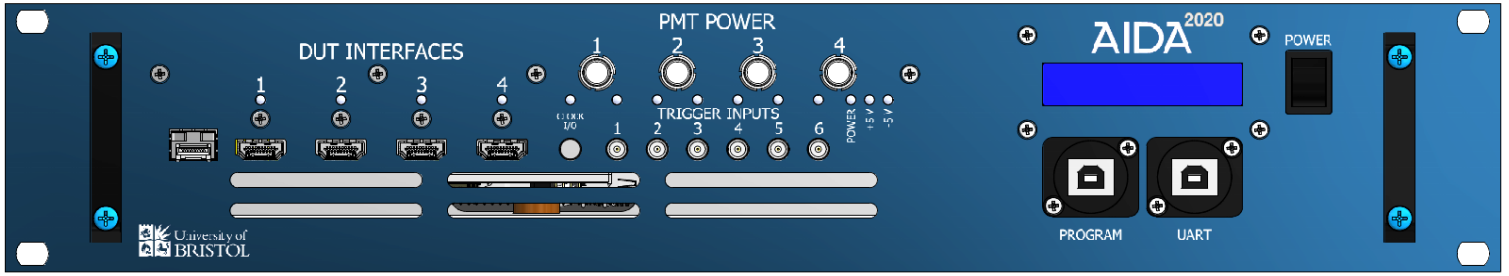
4x LEMO power for PMTs
- up to 12V



4x HDMI outputs
- Mimosa26 telescope
- SPIDR (Timepix3)
- Caribou (DUT)

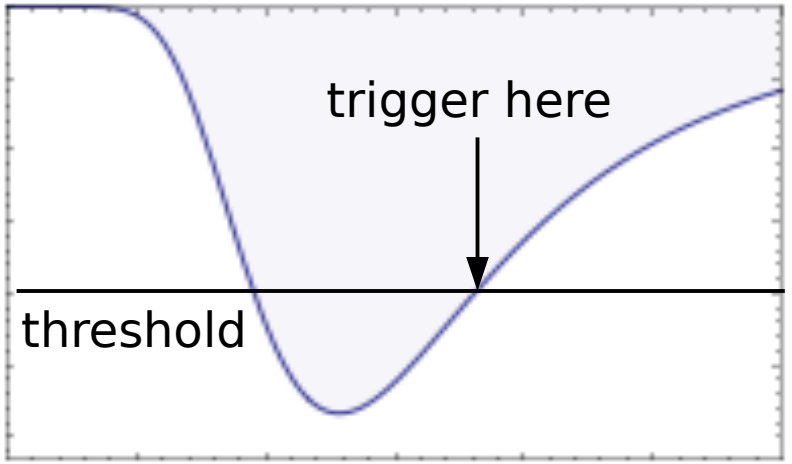
6 LEMO trigger inputs
- configurable coincidence logic
- we used only 2

rack mount version: same functionality



Findings & Solutions

TLU triggered on rising edge



Our friends from DESY:

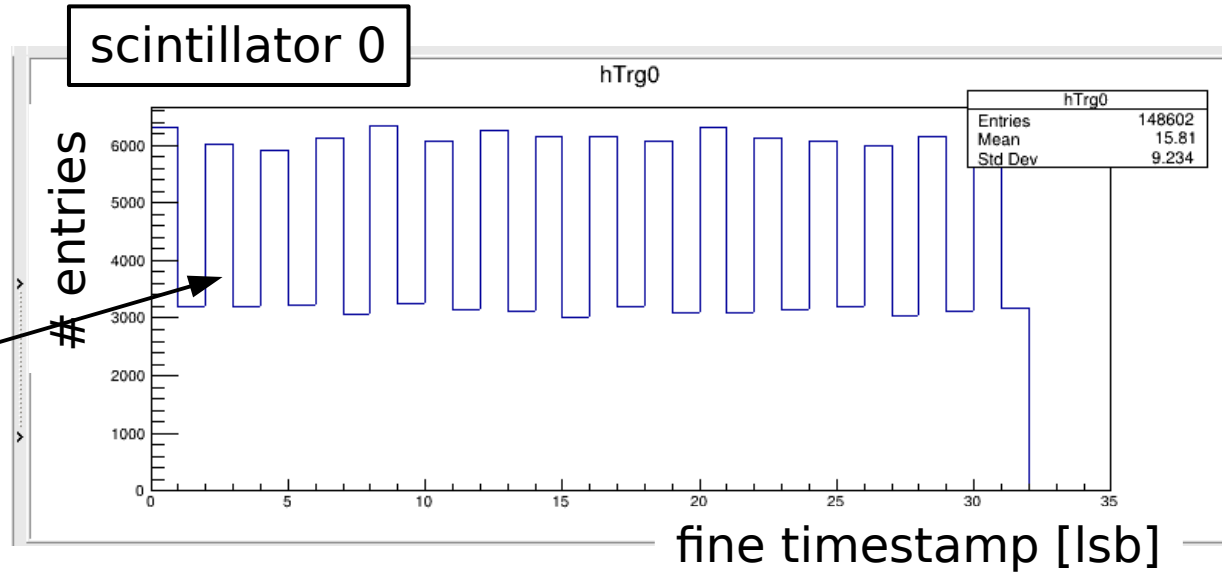
- **Finding:**
  - TLU triggers on **rising edge**
    even though input has **negative polarity!**
  - was planned to be configurable but **not implemented**

    → decreases achievable time resolution (more delay+jitter)
    (cannot quantify, they didn't use the fine timestamps, only looked at it with the scope…)

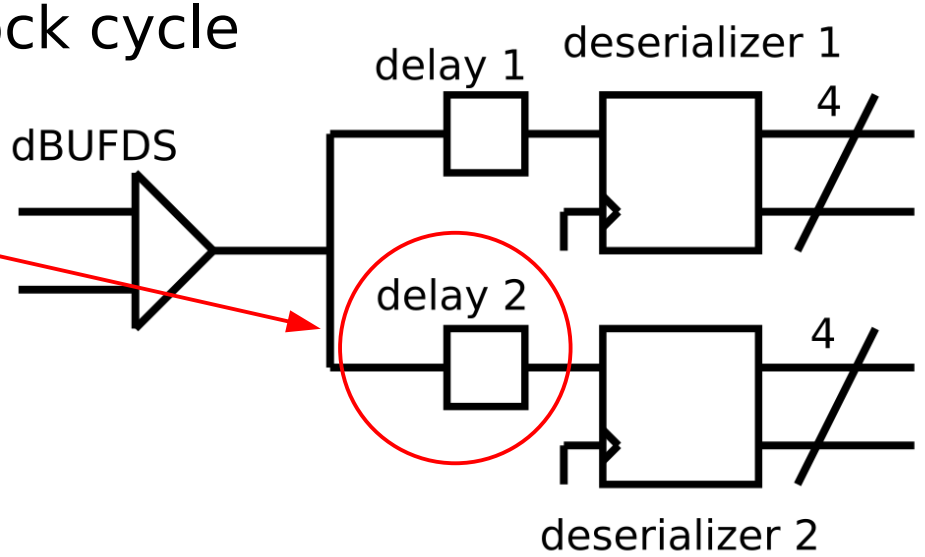
- **Solution:**
  - David Cussans implemented this missing feature
  - **to be tested!**

TLU fine timestamps – Fine Bin Asymmetry

- **Finding:**
  - histograms of the **fine timestamps** should be “flat”
    (free running timestamp)
  - but shows “bin asymmetry”



- **Explanation/Solution:**
  - **trick:** 2 deserializers with delay of ½ clock cycle effectively “double” sampling frequency
  - but needs fine tuning of delays
  - David adjusted this in the new firmware
  - **to be tested!**

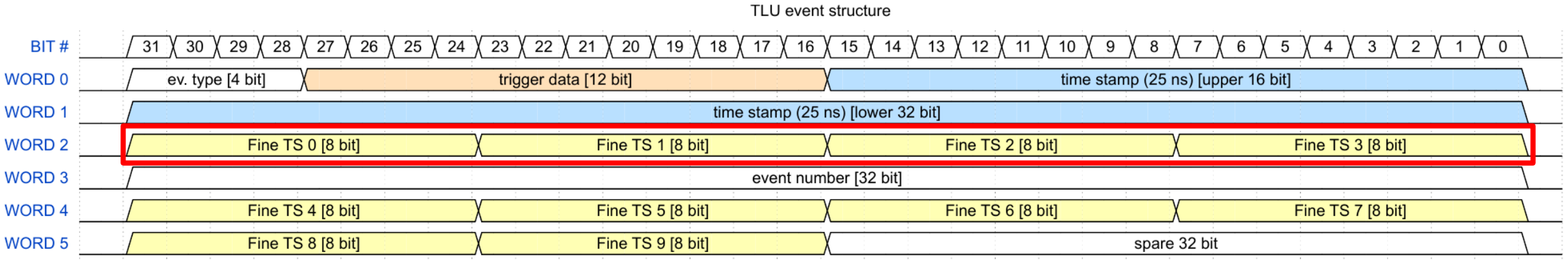


TLU timestamps – which frequencies?

David Cussans:
timing violations in
firmware synthesis

- from the TLU we get:
  - **coarse timestamp** from coincidence: 40 MHz ≙ **25 ns**
  - individual **fine timestamps** from each trigger input: **depending on version**: 1.28 GHz ≙ **781 ps**
    640 MHz ≙ **1.5625 ns**

  → precise timestamp = coarse + fine

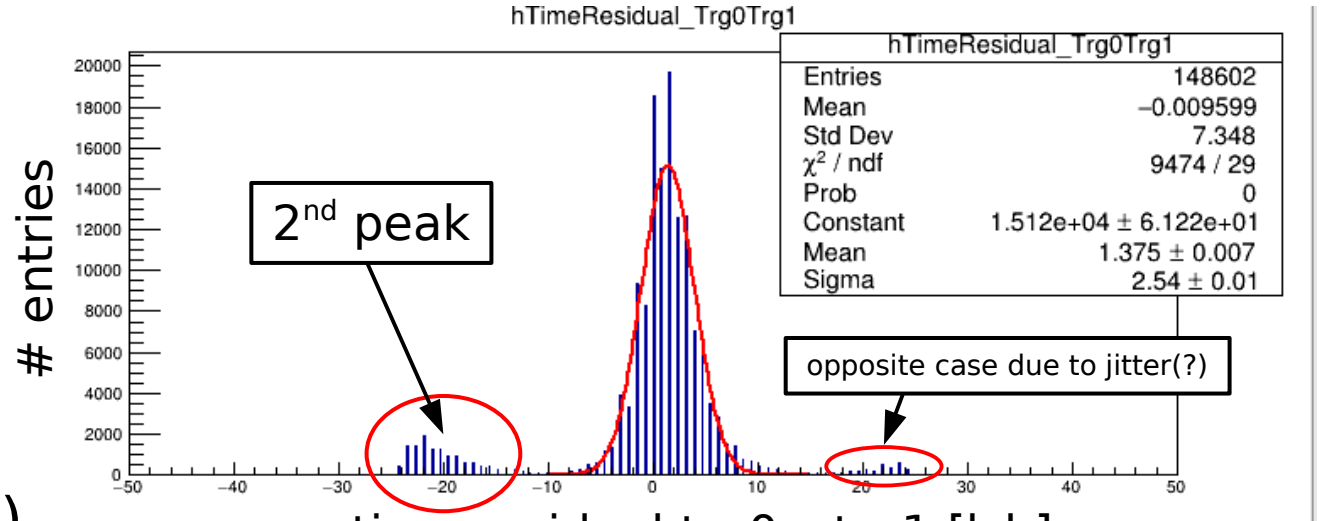


  - TLU manual: event structure → fine timestamps **8 bit** [0-255]
  - implemented so far: only **5 bit** [0-31]

  → leads to the following problem (see next slides)

TLU fine timestamps – fine TS0 vs. fine TS1

- 2nd (and 3rd) peak in time residual
- all we know:
  - precise timestamp = coarse + fine



(fine timestamp, coarse is same → cancels out)

Explanation:

- 2nd peak arises when: (coarse, fine)
  - trg1: (10,30)
  - trg0: (11,2)

  → common coarse = 11
  → precise TS 1 = "**11** + 30" / TS 0 = "11 + 2"

25ns too large!

Solution:

- use all 8 bits → can correct for roll-over

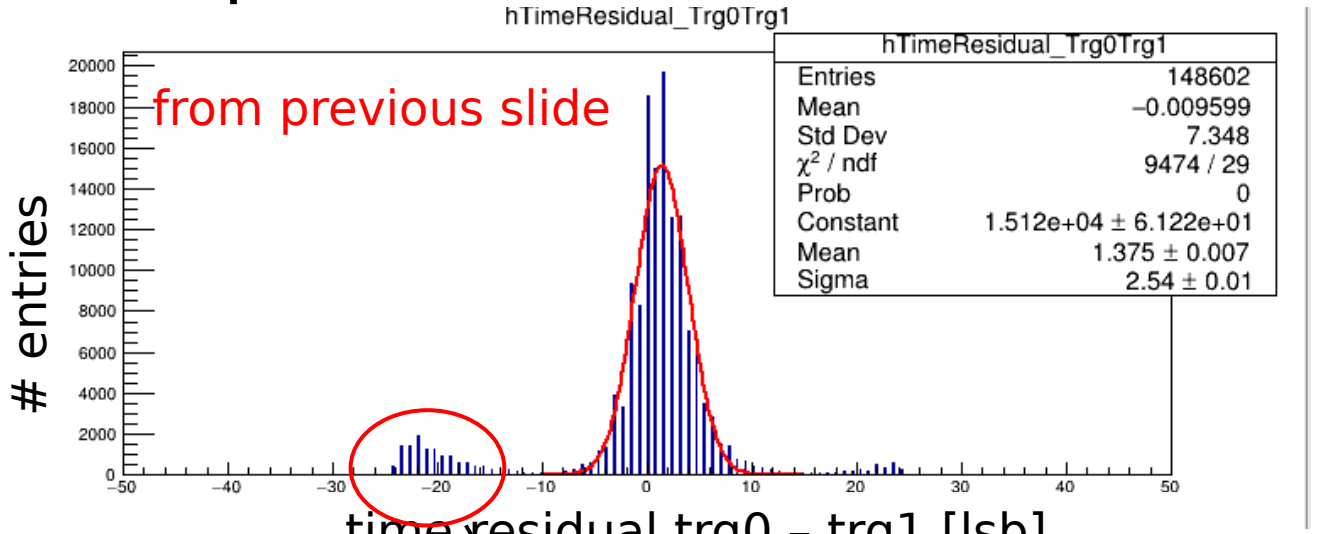
- David implemented this in the new firmware
- **to be tested!**

TLU vs. Timepix3 – also 2nd peak

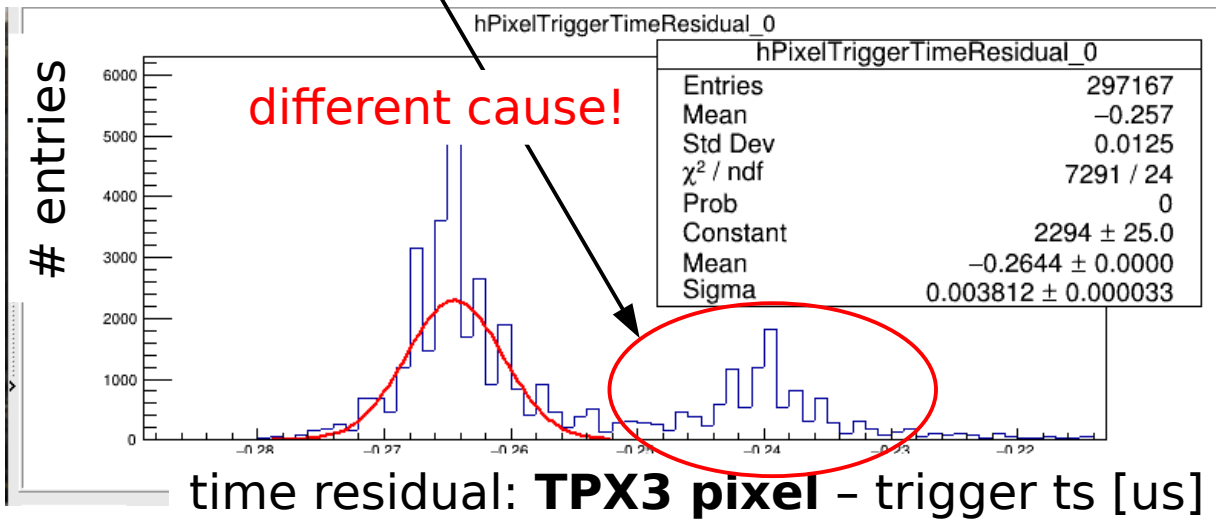
- We also see a 2nd peak here!
- Is it caused by the “wrong coarse TS” from the previous slide?

2 arguments against this idea:

- much more entries compared to previously
- “wrong” side:
  2nd peak on the right can mean:
  1) pixel timestamp is too late
     → why should it be?
  2) trigger timestamp is 25ns too early
     → **opposite** of previous explanation



time residual trg0 – trg1 [lsb]
(fine timestamp, coarse is same → cancels out)

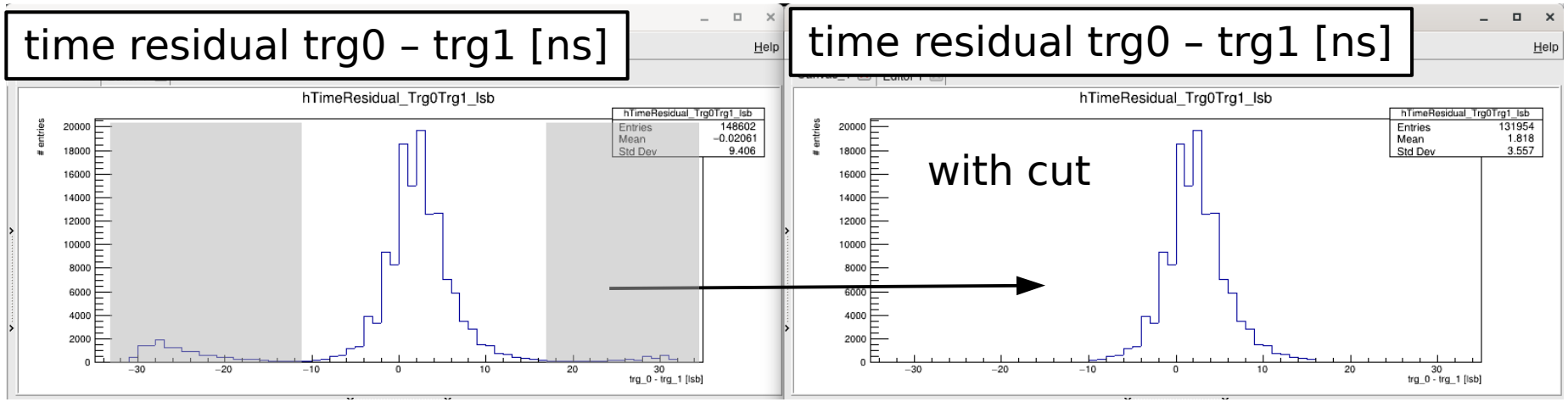


time residual: **TPX3 pixel** – trigger ts [us]

TLU vs. Timepix3 – also 2nd peak

- Try to remove second peak by discarding all triggers in the side peaks

trigger0 vs. trigger1

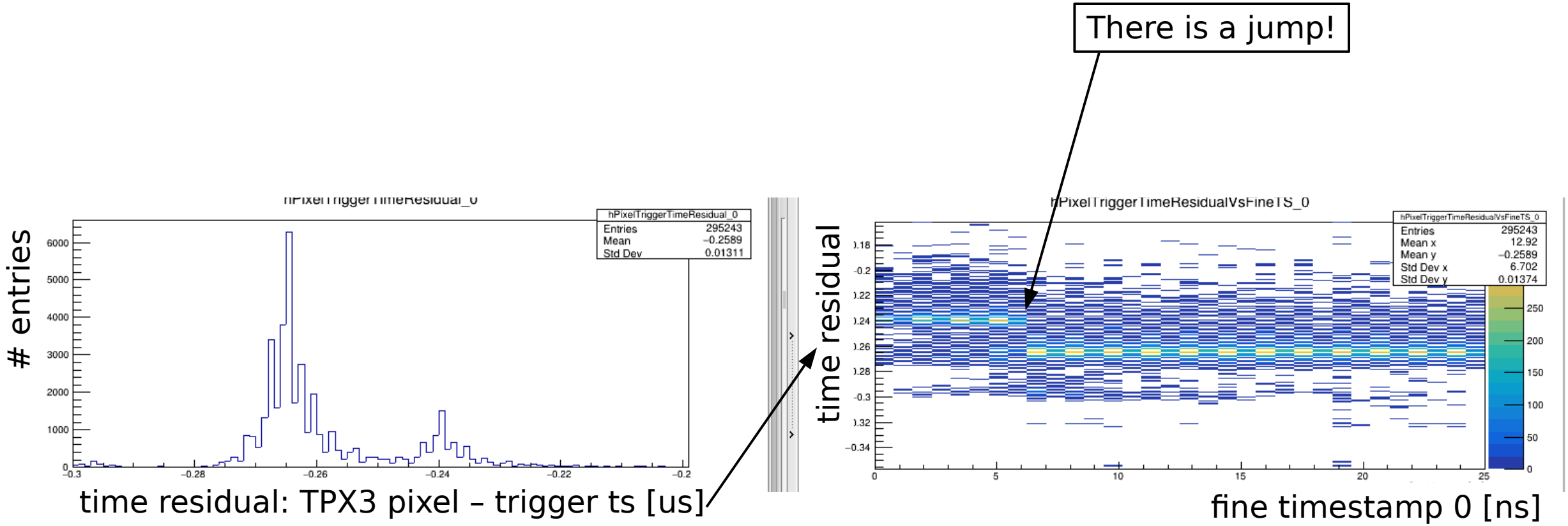


trigger vs. Timepix3

Nothing changes → there must be a different reason!

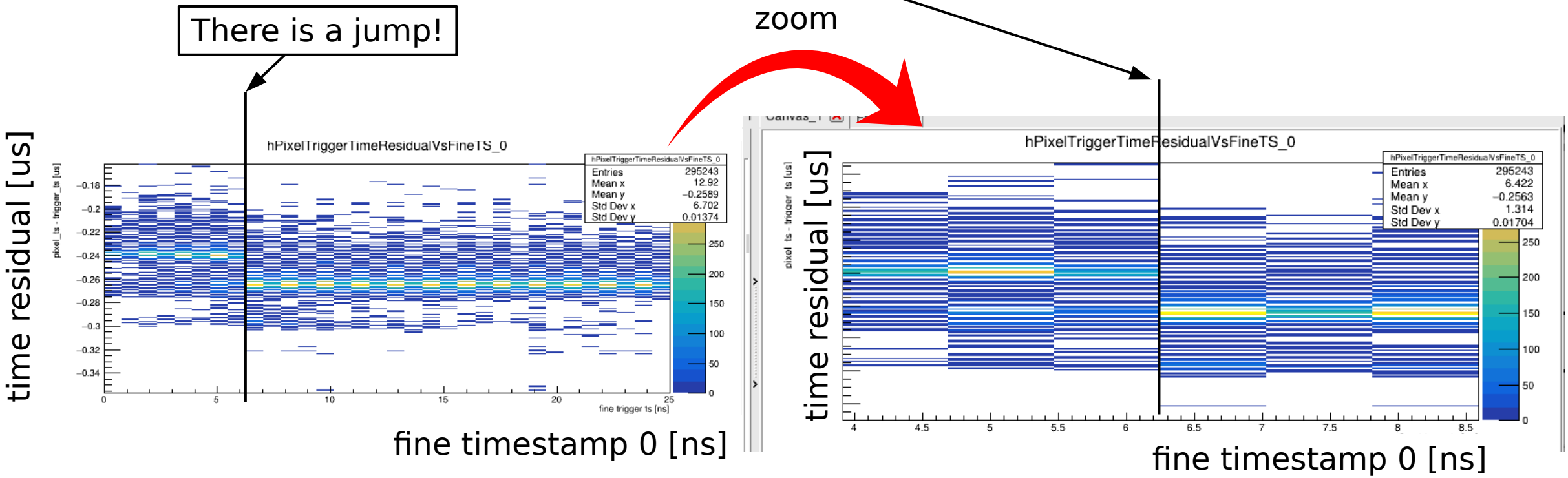
TLU vs. Timepix3 – also 2nd peak

- Plot time residual **vs. fine trigger timestamp**:



TLU vs. Timepix3 – also 2nd peak

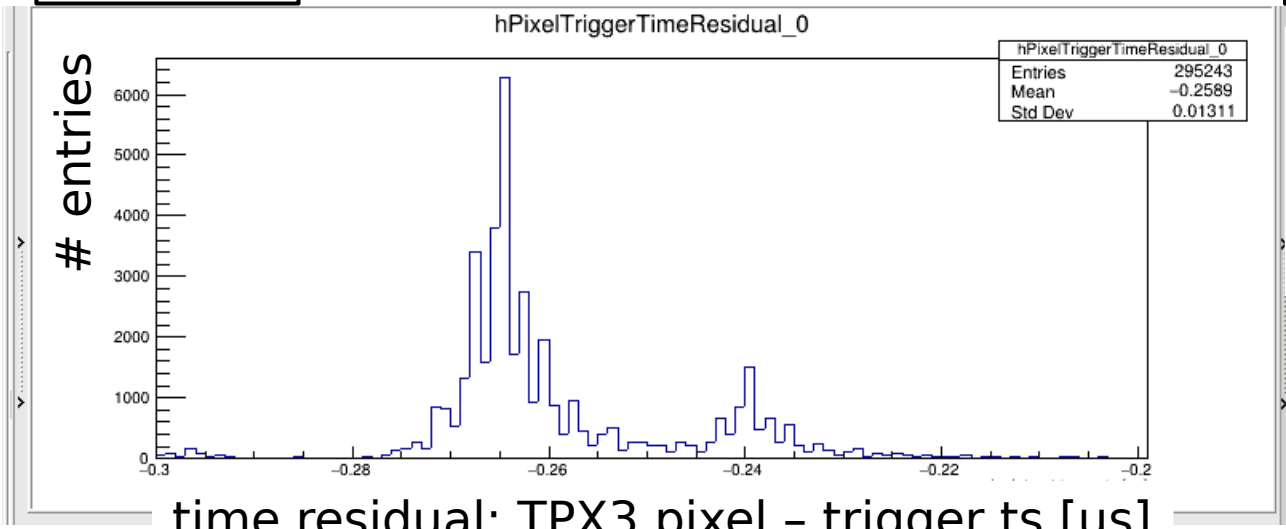
- Jump happens exactly at **6.25ns ← coincidence window**
  (= 8 bins of fine timestamp)



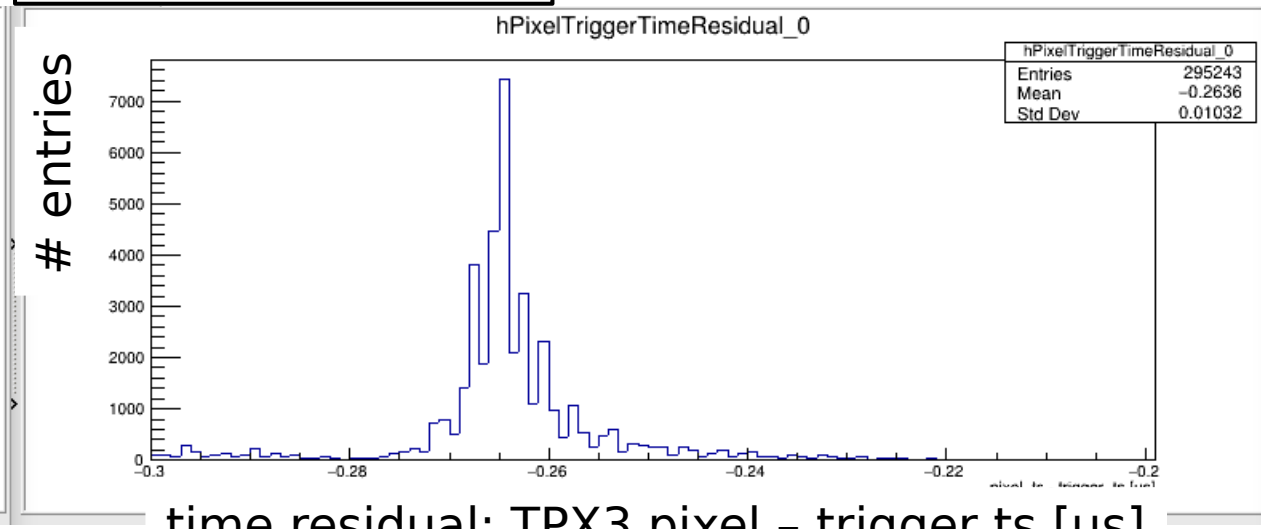
TLU vs. Timepix3 – also 2nd peak

- Jump happens exactly at **6.25ns ← coincidence window**
  (= 8 bins of fine timestamp)
- try correction:

as before



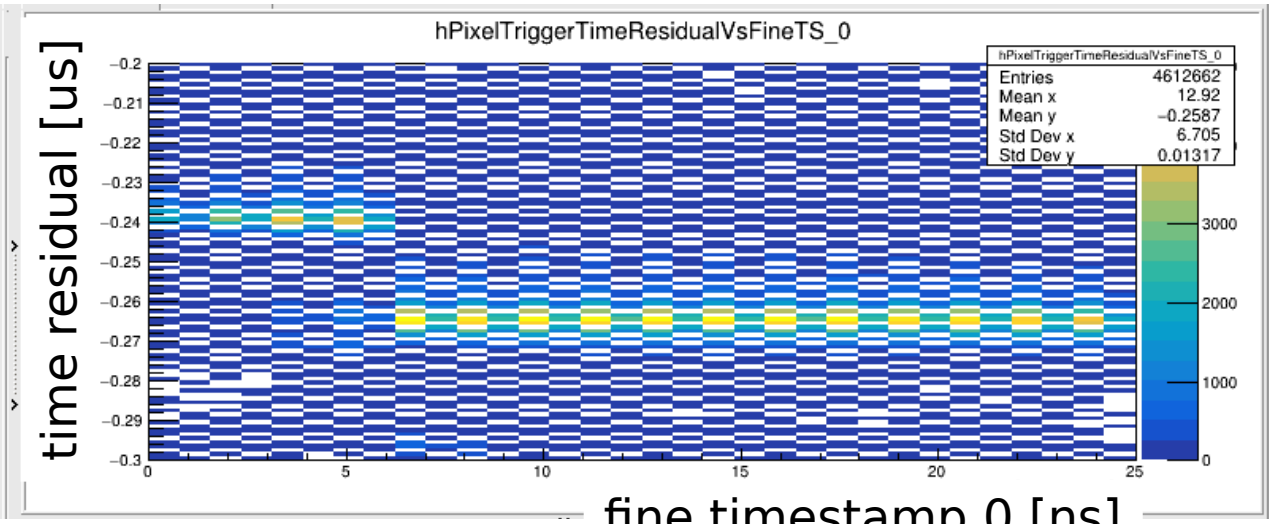
correction:
if(fine_ts < 8) +25ns



TLU vs. Timepix3 – also 2nd peak

- Jump happens exactly at **6.25ns ← coincidence window**
  (= 8 bins of fine timestamp)
- try correction:

as before



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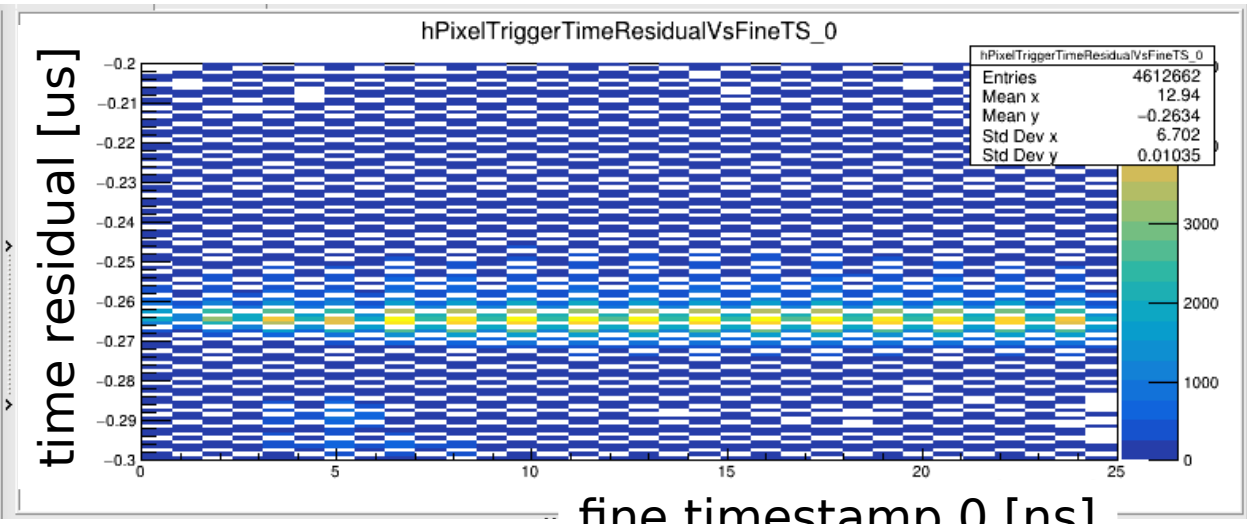


TLU vs. Timepix3 – compare different runs

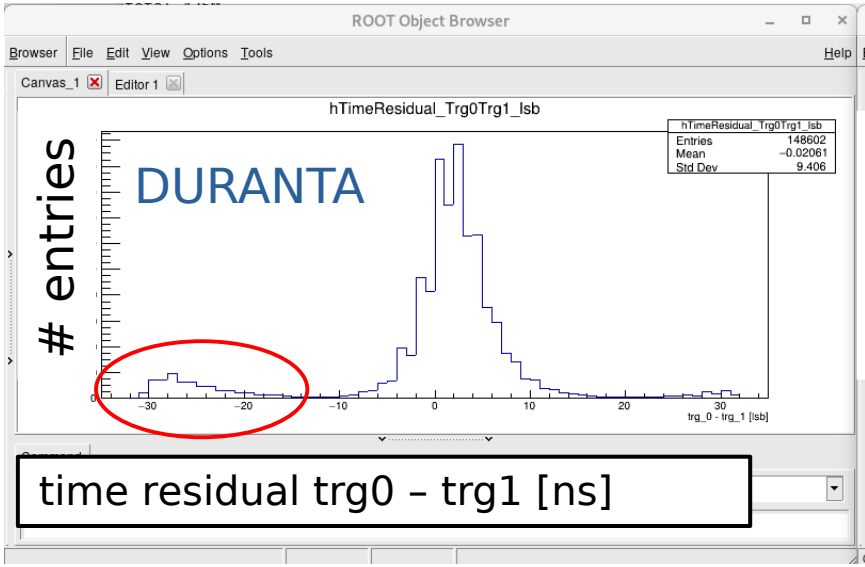
- now compare different runs:
  - run 2740 (September 2019, CLICTD): DURANTA
  - run 877 (July 2019, APX): DATURA
  - run 695 (June 2019, APX): DATURA

2nd peak on other side!

Maybe due to different hardware/different cables/…

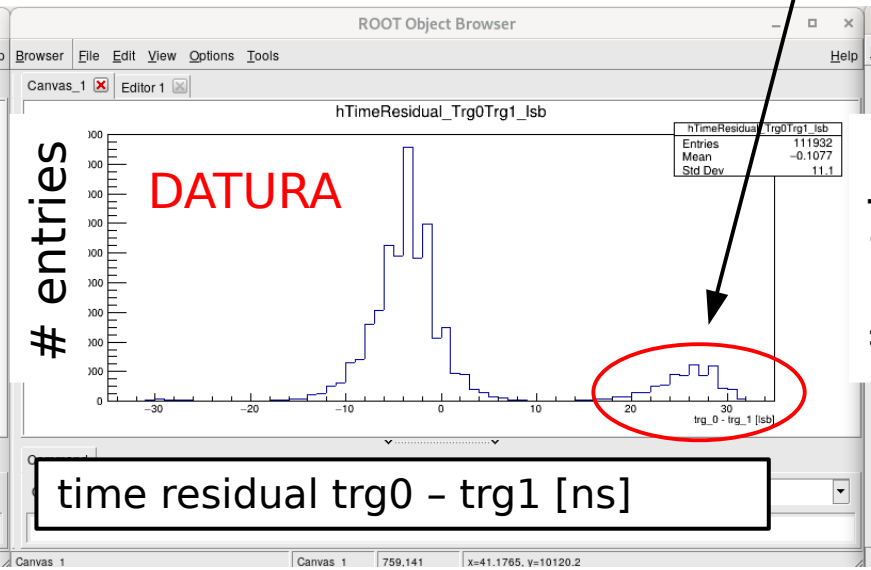
Or maybe due to **timing violations**?

run 2470 (Sept., same as on prev. slides)



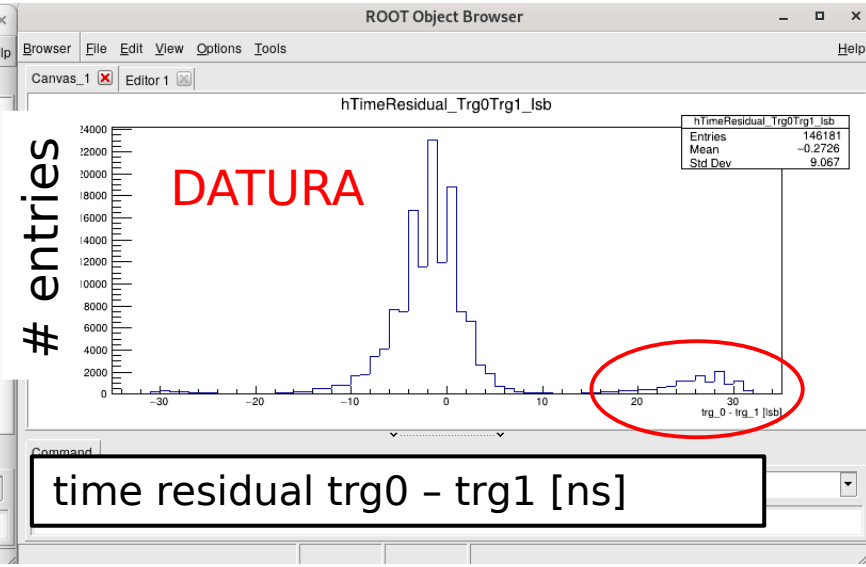
time residual trg0 – trg1 [ns]

run 877 (July)



time residual trg0 – trg1 [ns]

run 695 (June)



time residual trg0 – trg1 [ns]

TLU vs. Timepix3 – compare different runs

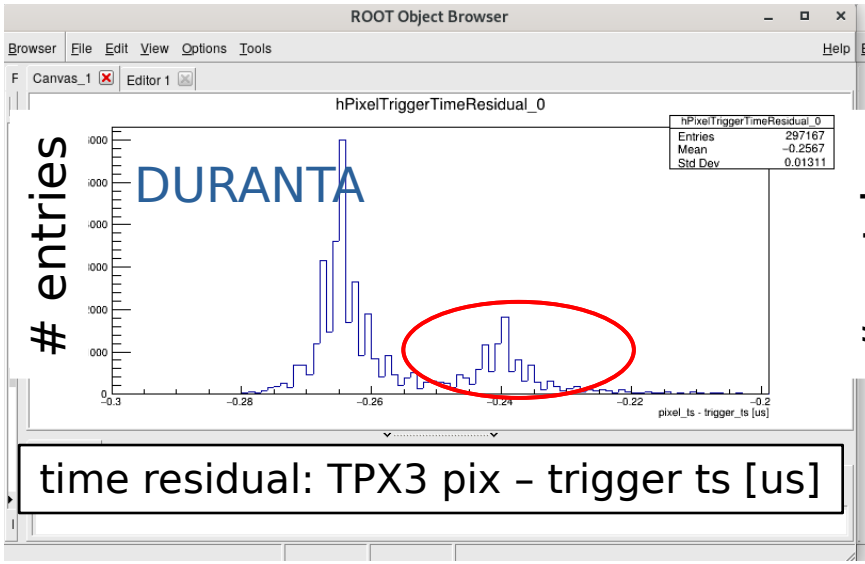
- now compare different runs:
  - run 2740 (September 2019, CLICTD): DURANTA
  - run 877 (July 2019, APX): DATURA
  - run 695 (June 2019, APX): DATURA

Here peaks on both sides!

Maybe due to different hardware/different cables/…

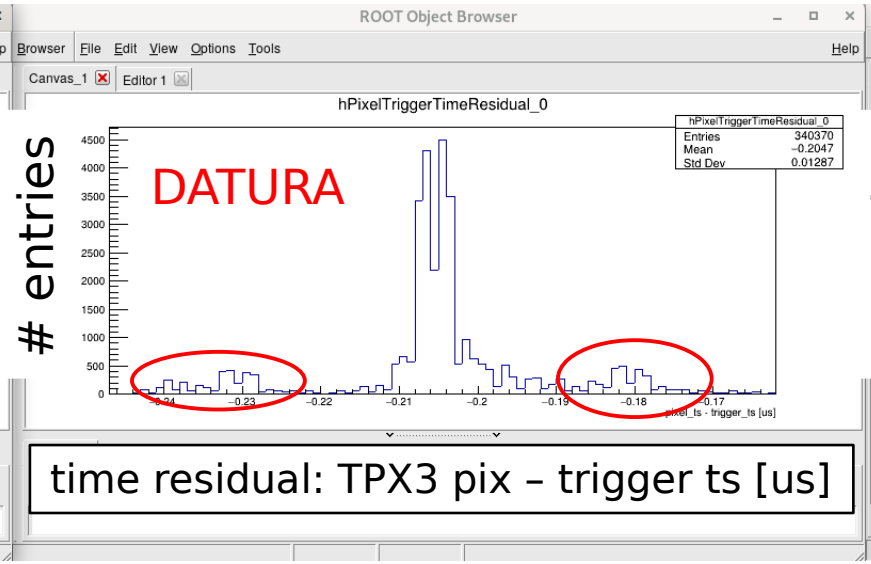
Or maybe due to **timing violations**?

run 2470



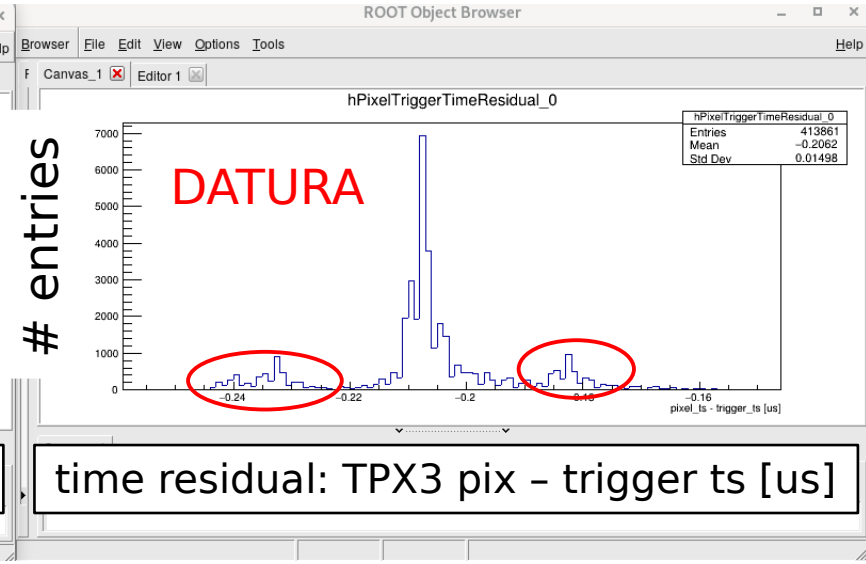
time residual: TPX3 pix – trigger ts [us]

run 877



time residual: TPX3 pix – trigger ts [us]

run 695



time residual: TPX3 pix – trigger ts [us]

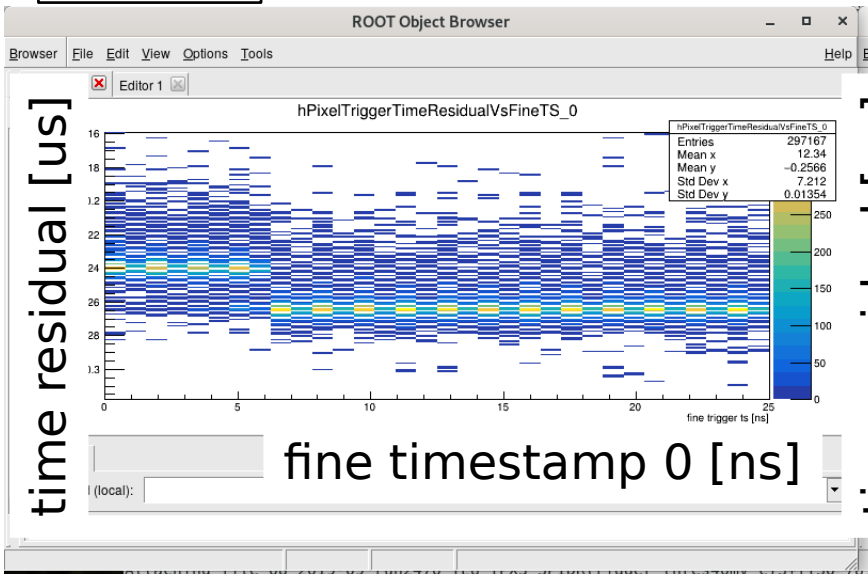
TLU vs. Timepix3 – compare different runs

- now compare different runs:
  - run 2740 (September 2019, CLICTD): DURANTA
  - run 877 (July 2019, APX): DATURA
  - run 695 (June 2019, APX): DATURA

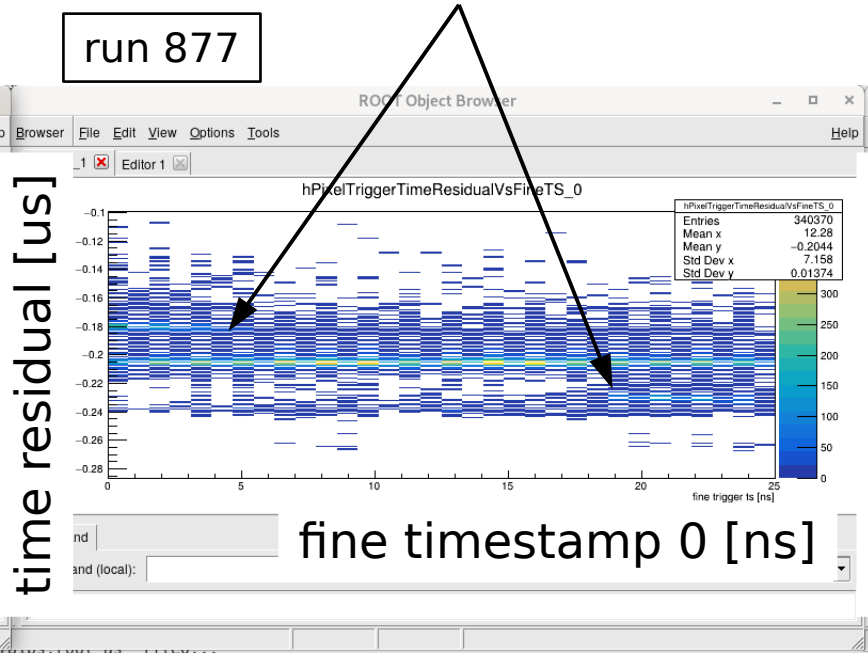
- Here the jumps happen at 6.25ns AND 25-6.25ns
- also: main peak remains + side peaks

→ previous correction cannot be used!

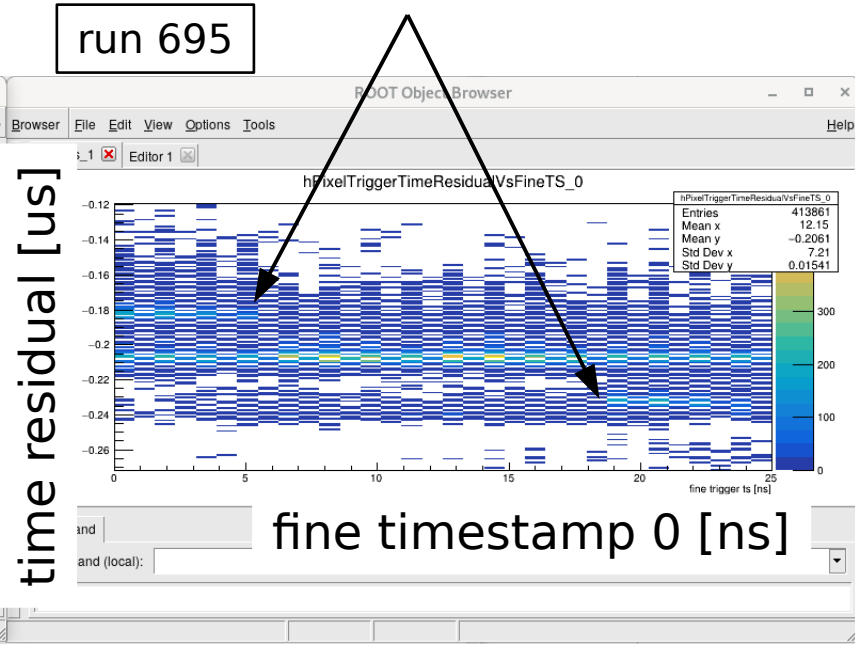
run 2470



run 877



run 695



Summary & Conclusion:

Comment David:

- relates to trigger logic running at 160 MHz ≙ 6.25 ns
- not yet understood!

- **Findings**:
  - trigger edge → implemented → to be tested
  - fine bin asymmetry → delay adjusted → to be tested
  - 2^{nd} peak (trg0 – trg1) → 5 → 8 bits → to be tested
  - 2^{nd} peak (trg – TPX3) → timing violations? → different with slower (1.56ns) firmware?

- TLU **not suitable** to improve our **track timing**
  - Timepix3 still best choice
  - but we can use the TLU to cross-check its performance

- **rest of analysis is not affected**:
  - still building “long” frames around TLU

Next steps:

- look at Feb. 2020 data
- test new firmware (**also 781 ps**)
  - lab
  - next DESY testbeam

Backup

in case there are some questions...

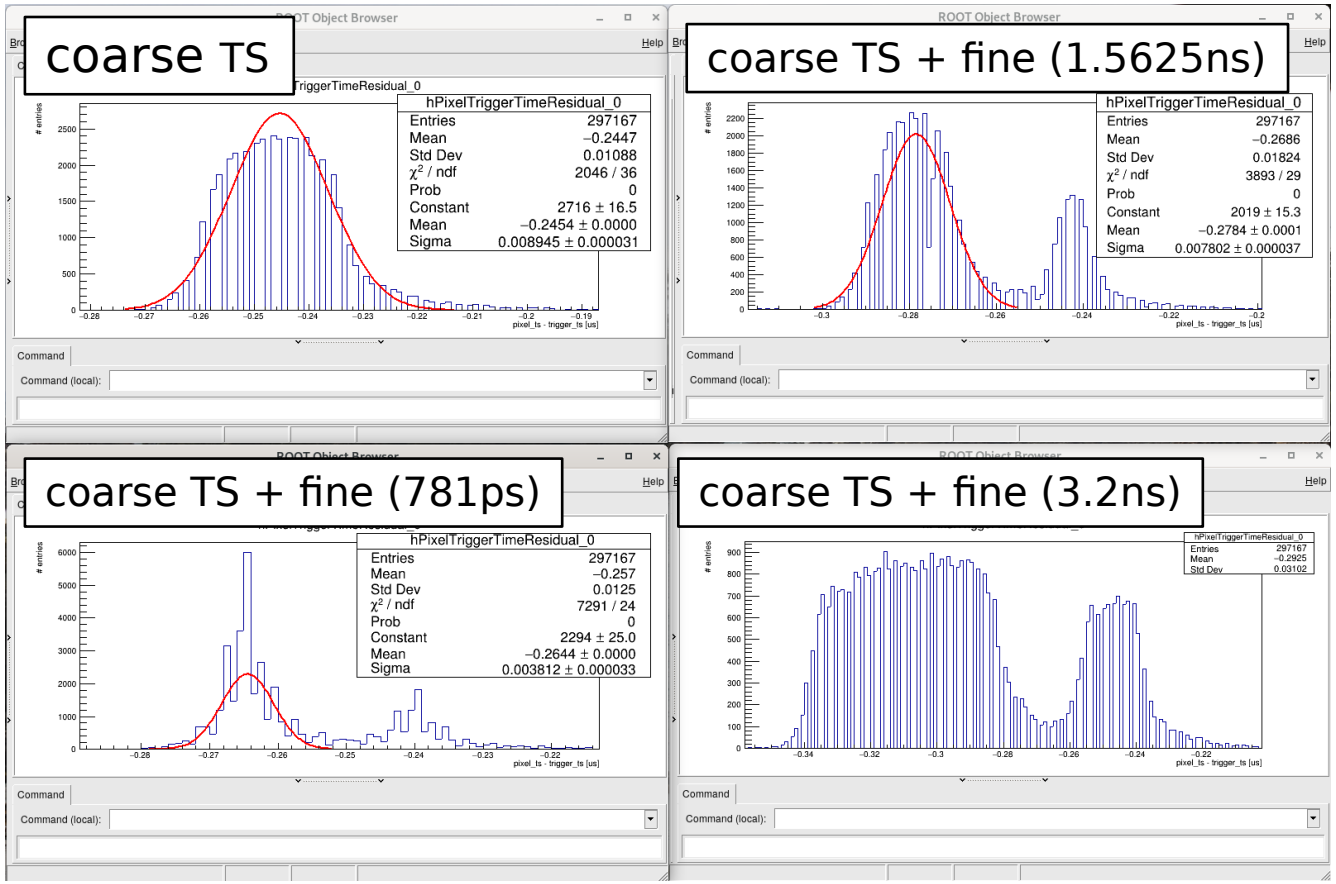
TLU trigger timestamp – Which binning?

- What we know for sure:
  - coarse TS: 25ns bins
- Not clear: binning of fine TS?
  - try different combinations:
  - coarse: σ = 8.9ns
  - coarse + fine (1.5ns): σ = 7.8ns
  - coarse + fine (781ps): **σ = 3.8ns**
  - coarse + fine (3.2ns): σ = 31ns

→ 781ns binning gives most narrow residual

- In principle I can NEVER get a more narrow residual with a **wrong** correction!

time residual: TPX3 pixel – trigger ts [us]



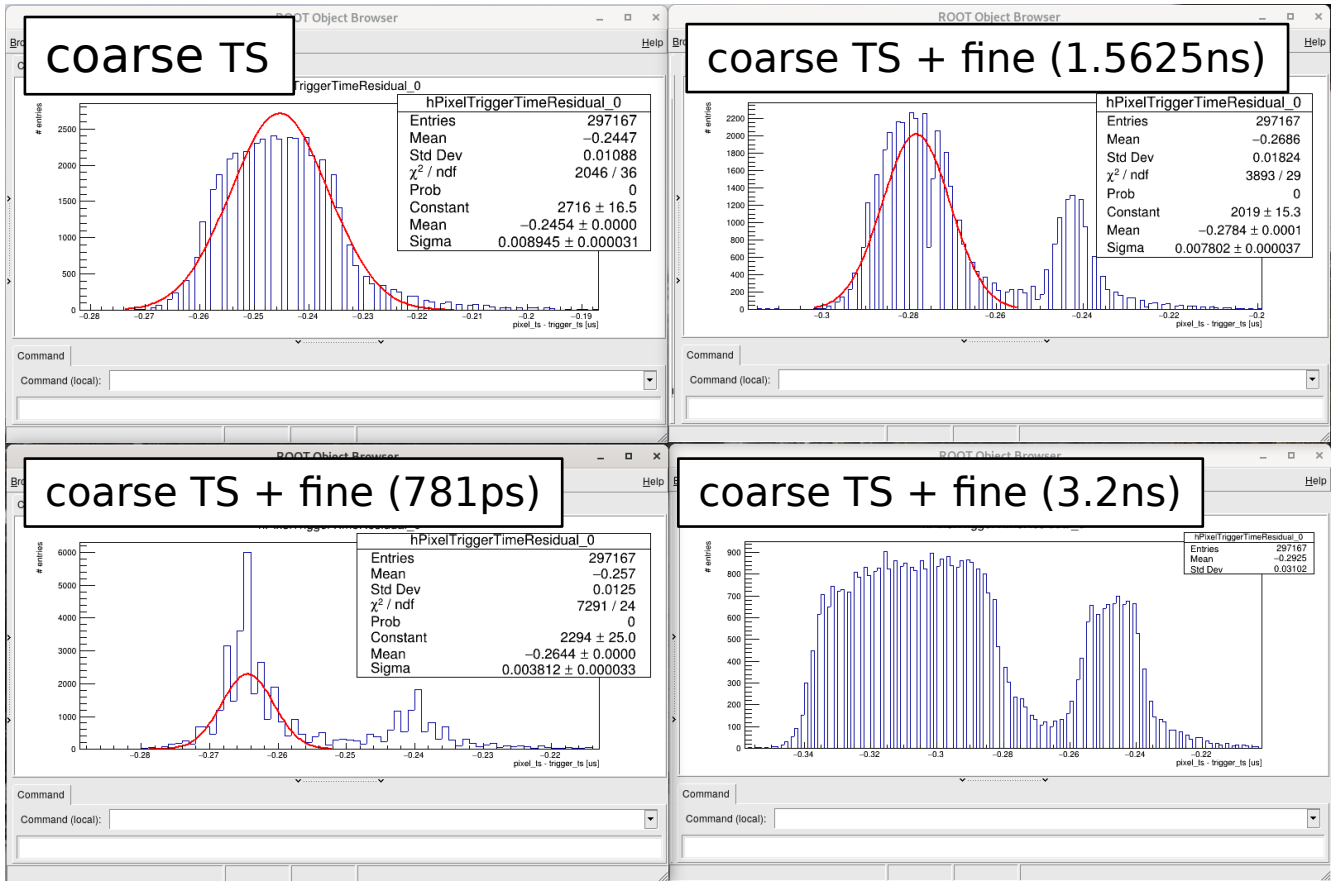
TLU trigger timestamp – Which binning?

- What we know for sure:
  - coarse TS: 25ns bins
- Also: distance between peaks
  - coarse: -
  - coarse + fine (1.5ns): 38ns
  - coarse + fine (781ps): **25ns**
  - coarse + fine (3.2ns): 63ns

→ 781ns binning gives expected distance of 1 coarse bin!

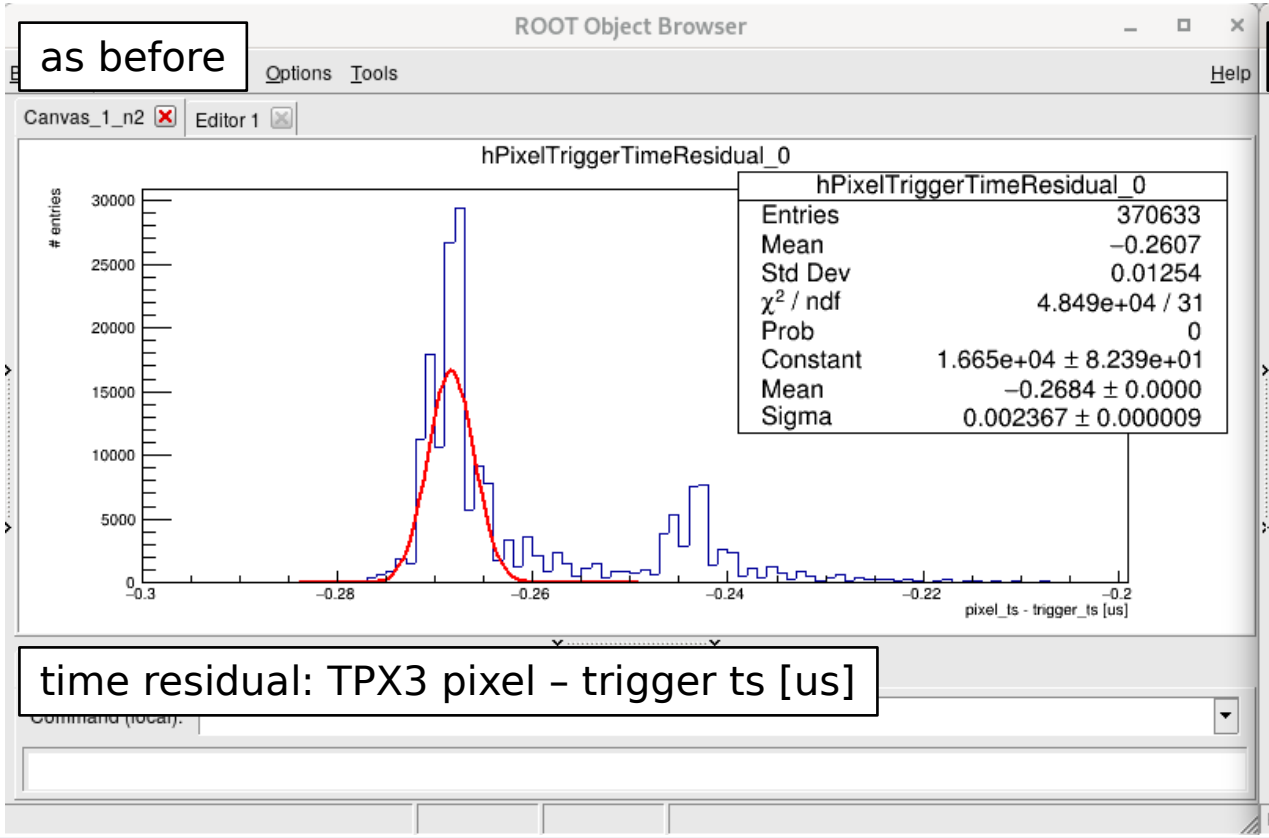
This way we can always check the frequency of the fine timestamps!

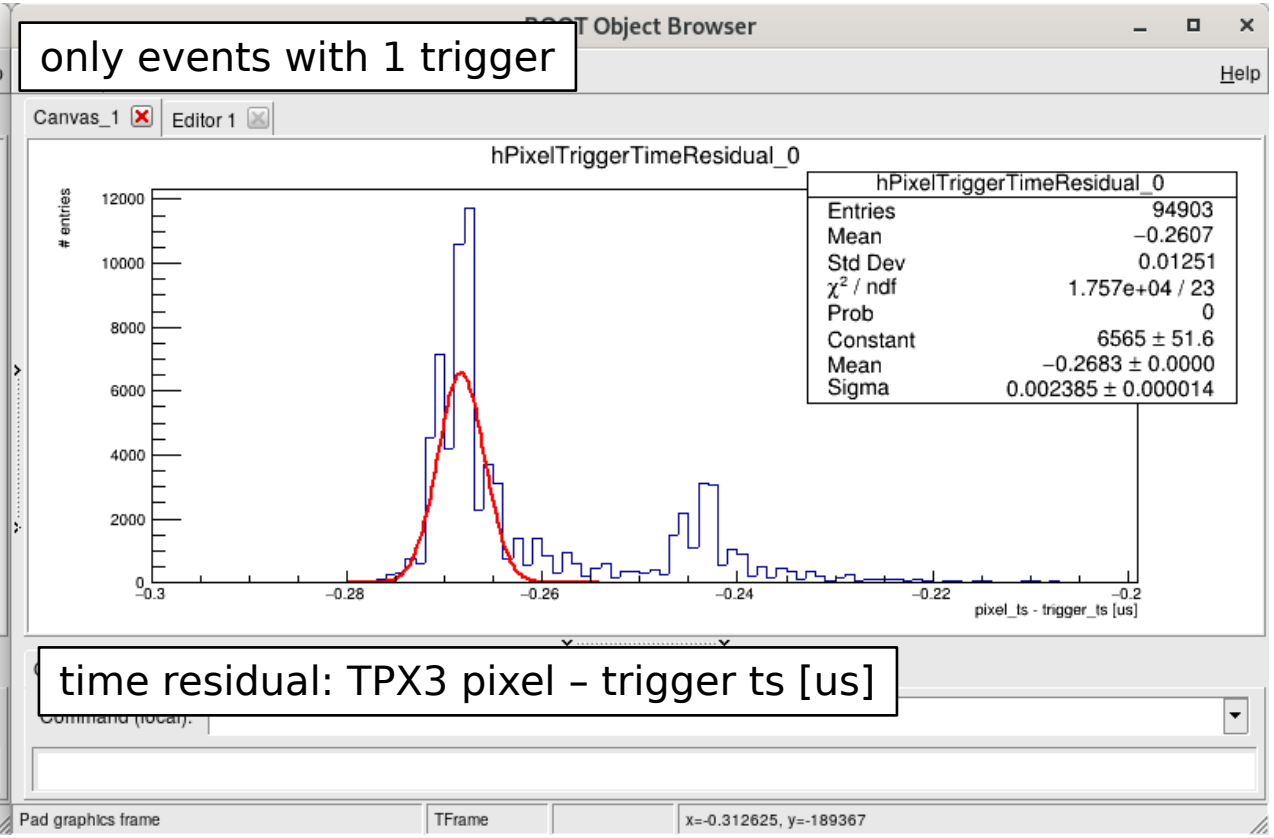
time residual: TPX3 pixel – trigger ts [us]



Any effect of the double triggers?

- Can we see a different related to the double triggers we observed at some point?
- Here compare full run 3273 (537sec, December 2019) → no difference





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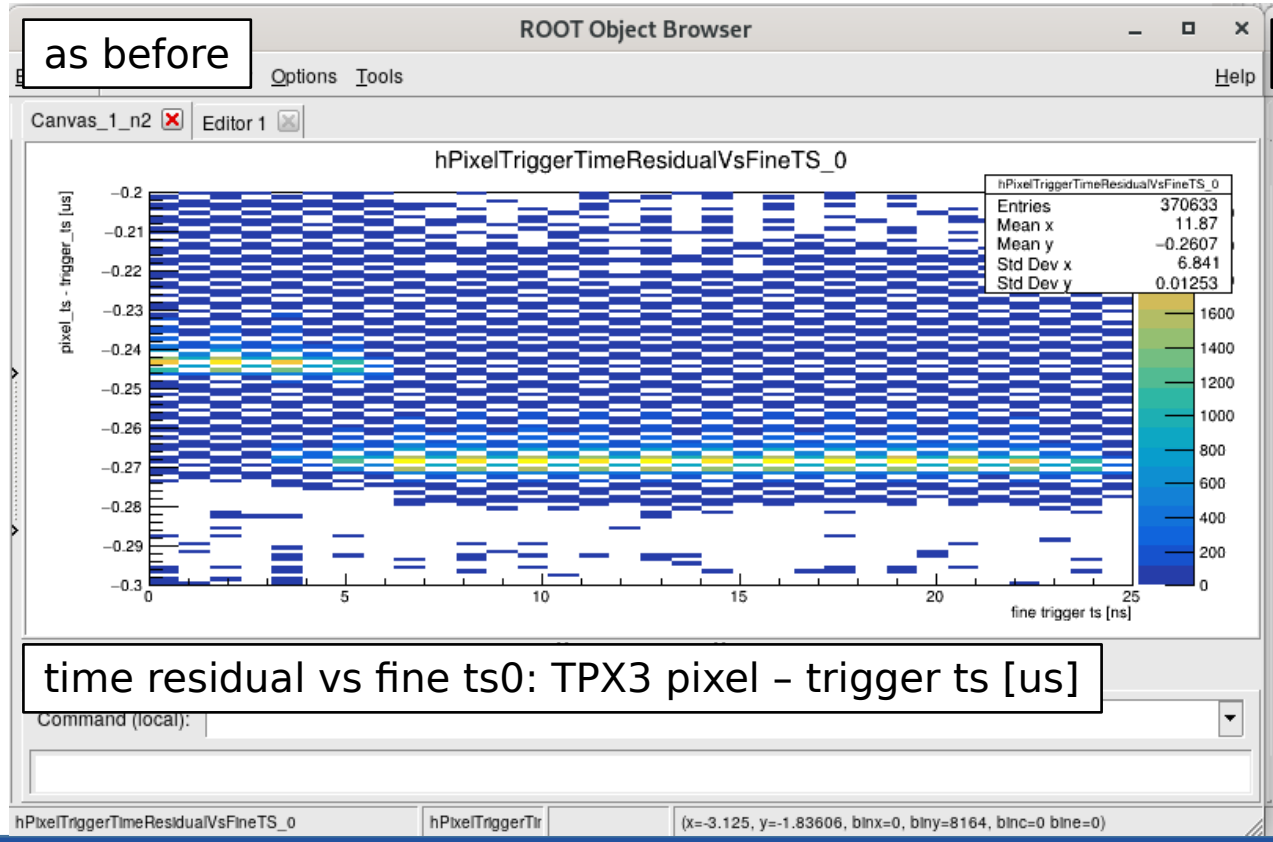
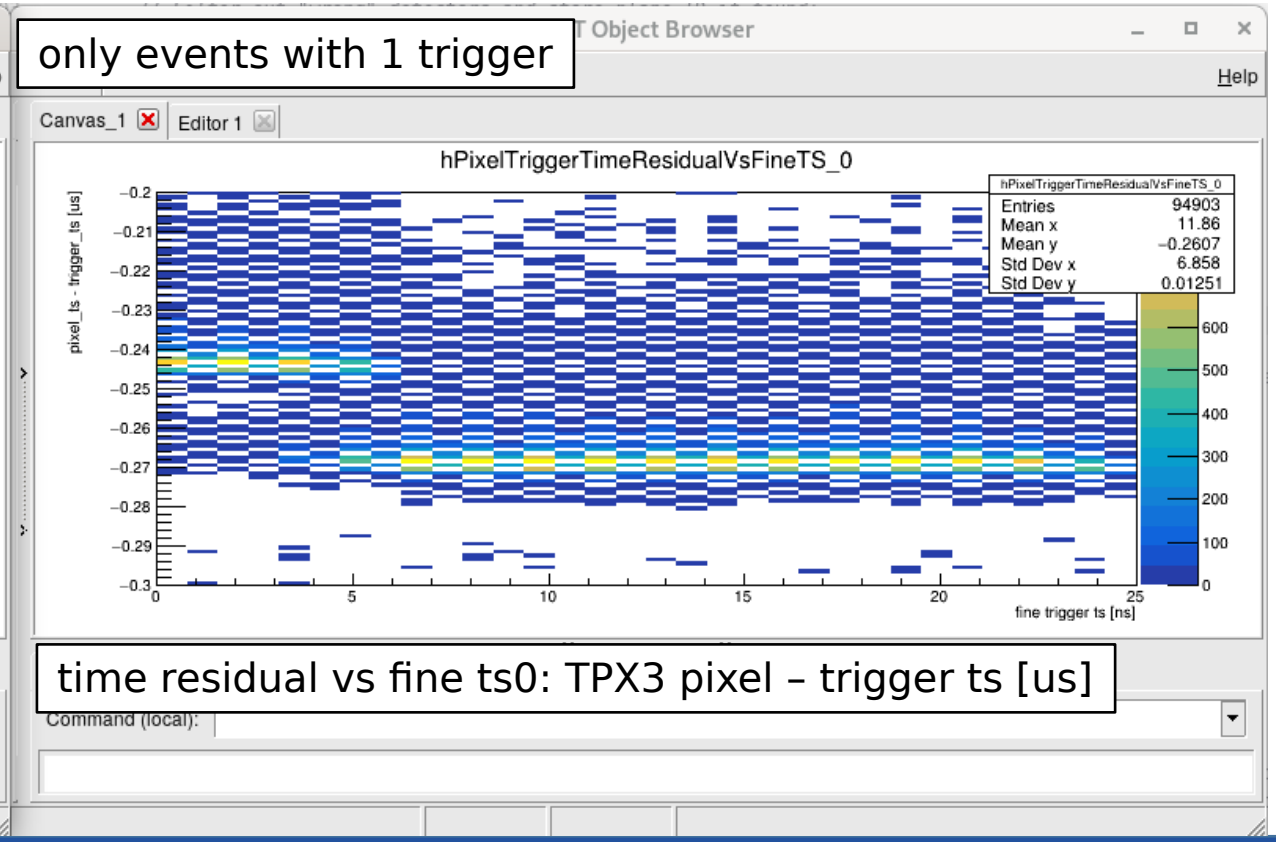
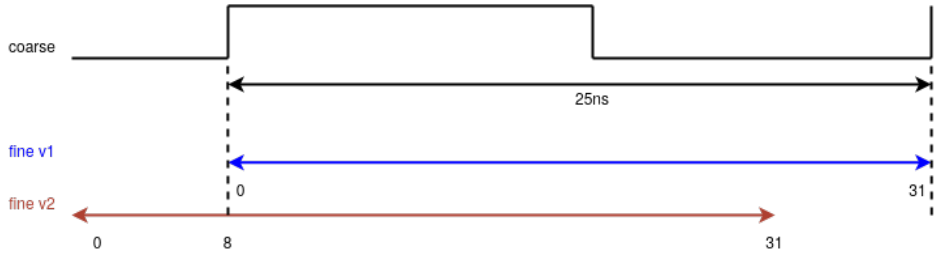




TLU vs. Timepix3 – also 2nd peak

- Jump happens exactly at **6.25ns ← coincidence window**
  (= 8 bins of fine timestamp)
- try correction:

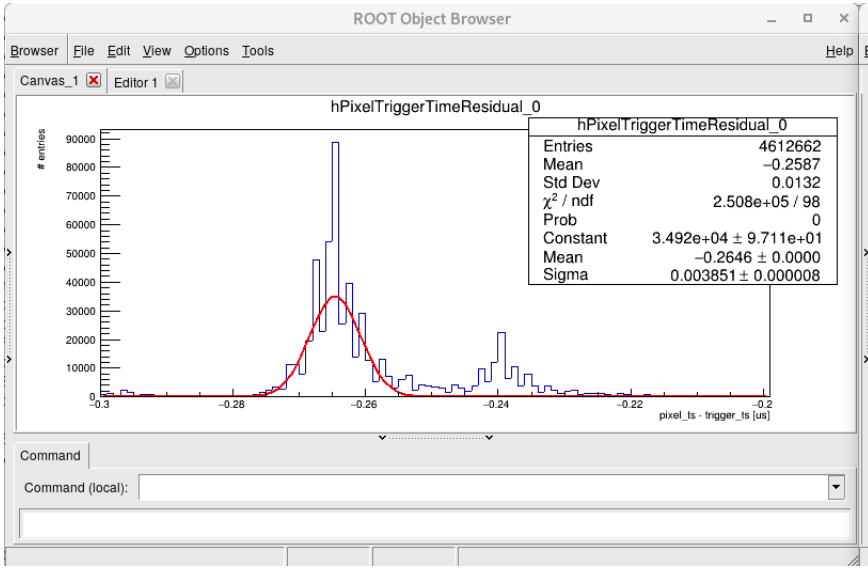


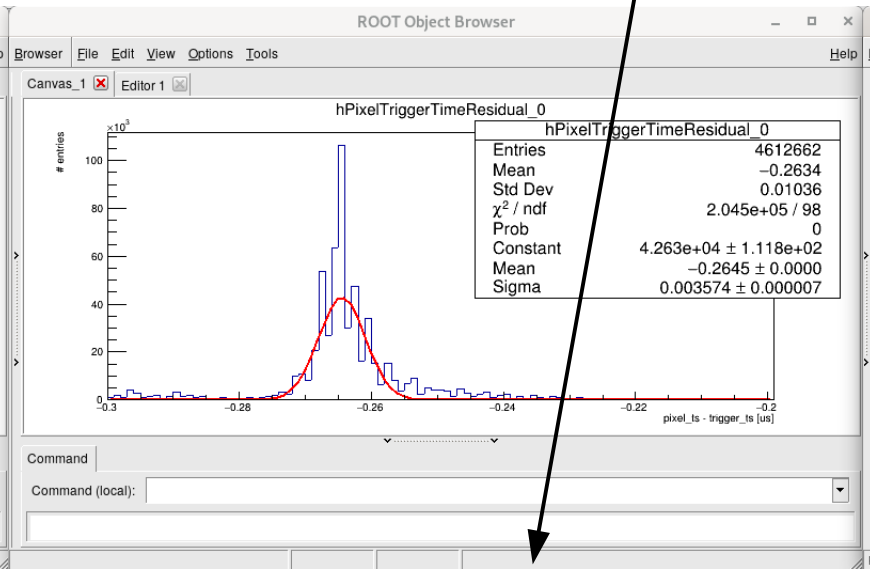
Correction seems to give best result! full run of 800sec

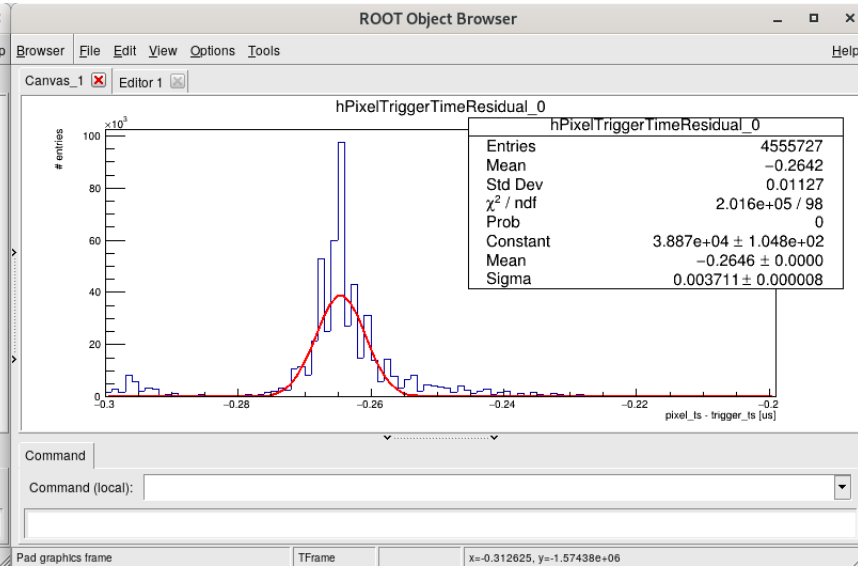
as before

correction: if(fine_ts < 8) +25ns

cut: if(fine_ts < 8) discard







σ = 3.88ns

σ = 3.57ns

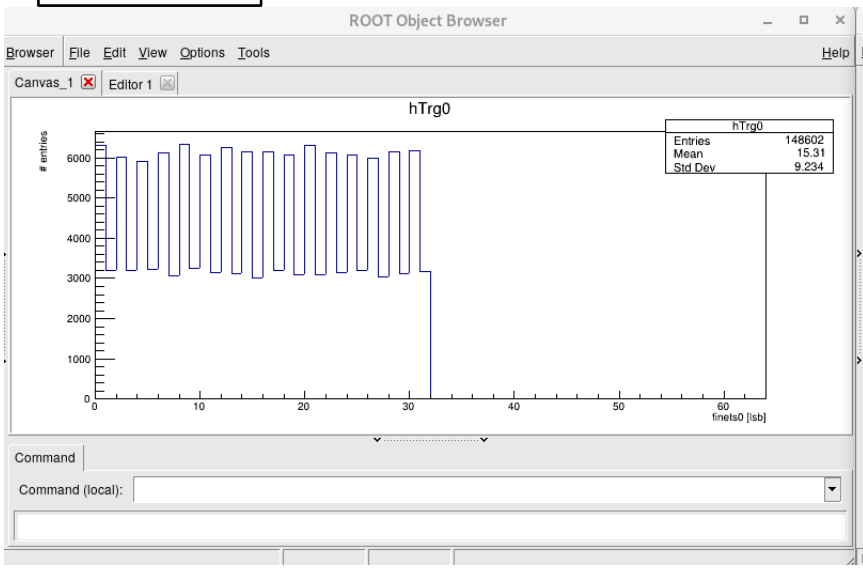
σ = 3.72ns

TLU vs. Timepix3 – compare different runs

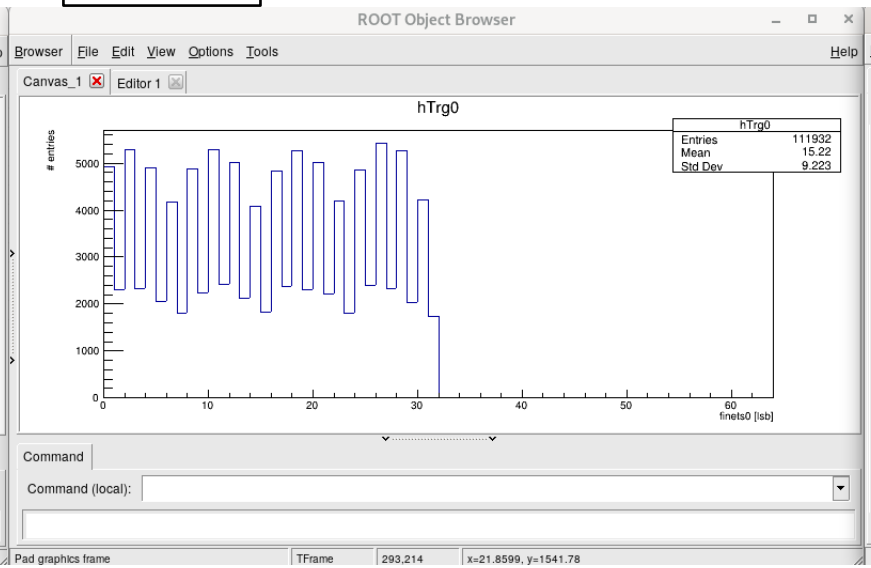
- now compare different runs:
  - run 2740 (September 2019, CLICTD)
  - run 877 (July 2019, APX)
  - run 695 (June 2019, APX)

Looking at the counter distribution of trg0, **maybe something else was wrong** in June/ July with the DATURA?

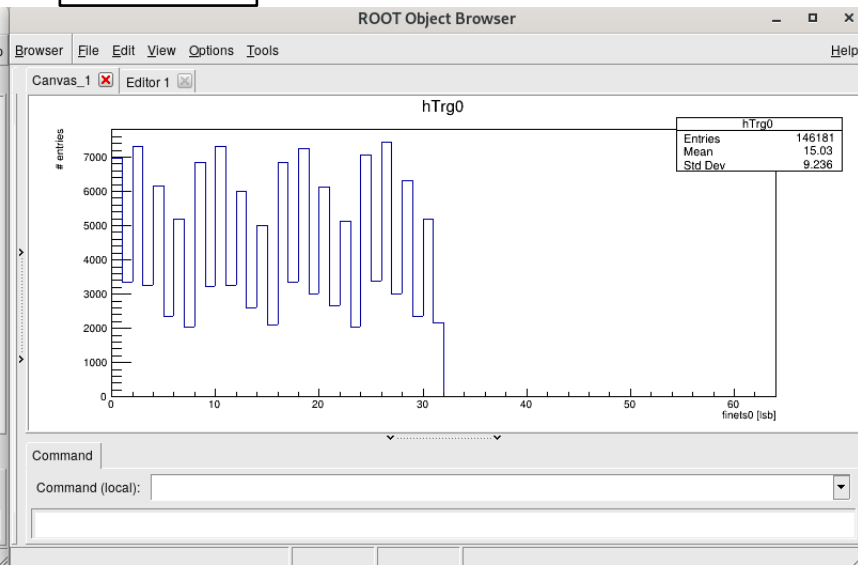
run 2470



run 877



run 695

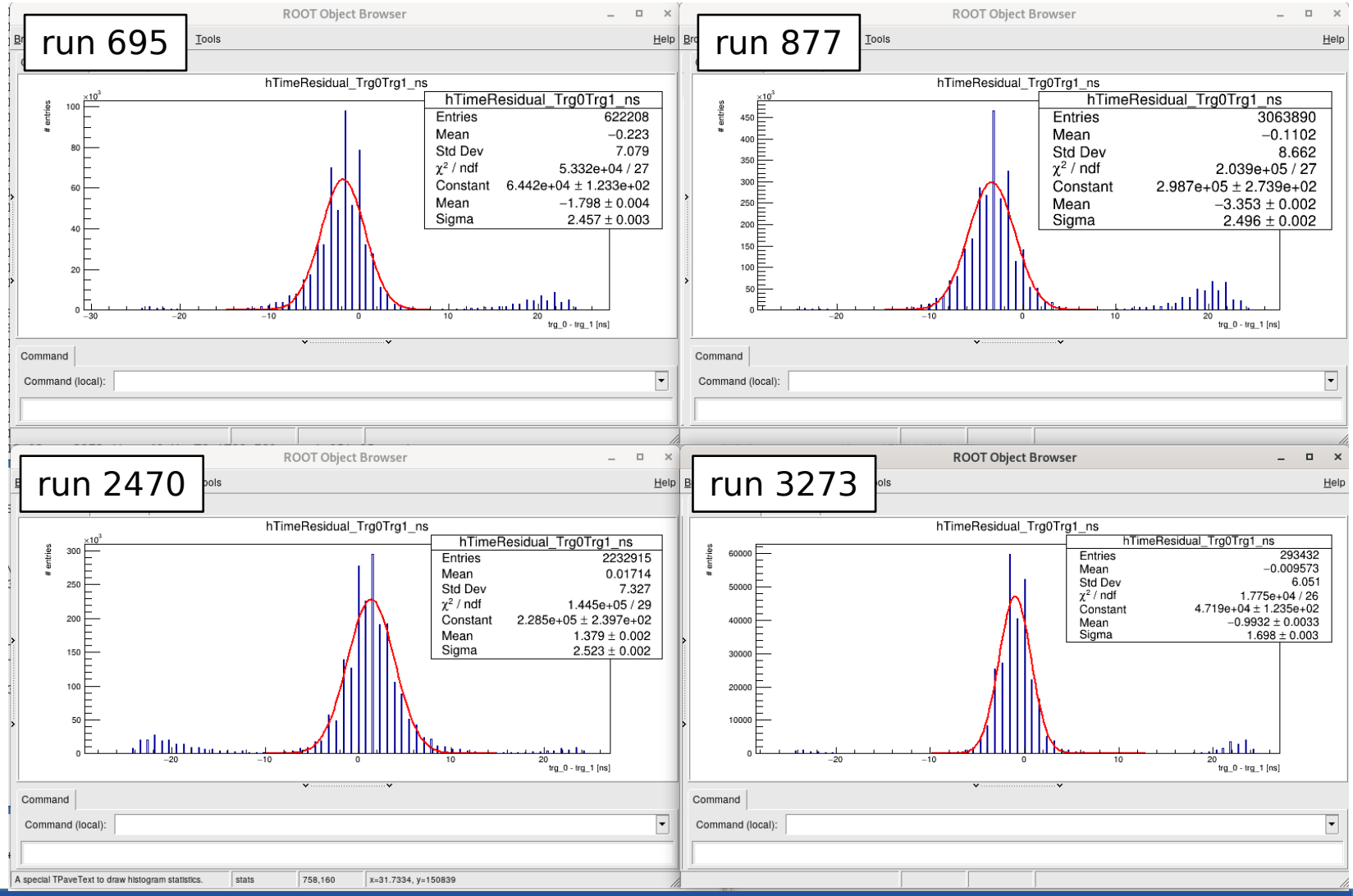


Time resolution: different TLUs

$$\sigma_{meas} = \sqrt{\sigma_{trg0}^2 + \sigma_{trg1}^2}$$

- run 695:
  - June 2019, AZALEA
  - σ = 2.46ns
- run 877:
  - July 2019, AZALEA
  - σ = 2.50ns
- run 2470:
  - September, DURANTE
  - σ = 2.53ns
- run 3273:
  - December, TB24
  - σ = 1.70ns

time residual trg0 – trg1 [ns]



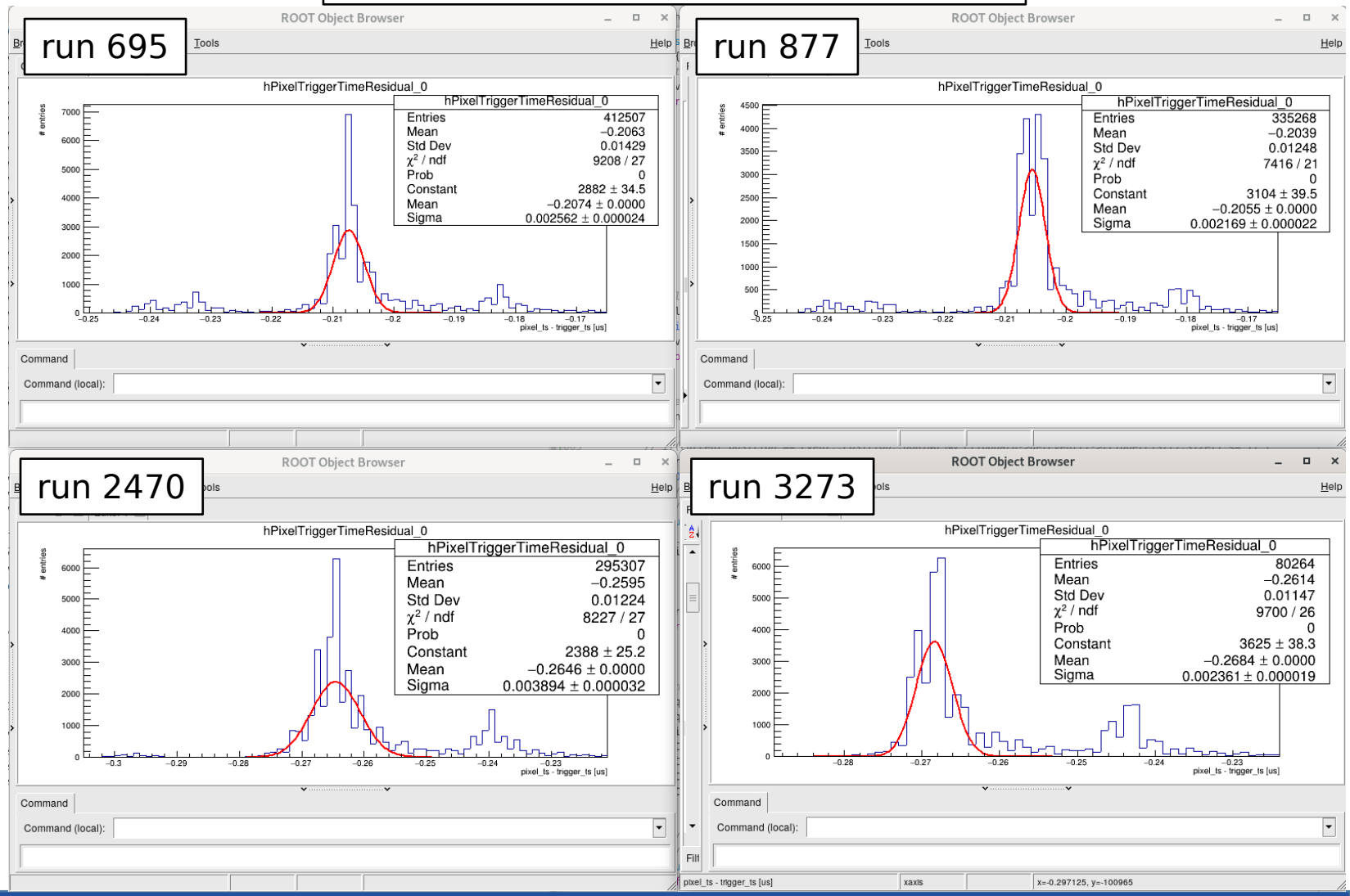
different hardware, different scintillators

Time resolution: different TLUs

$$\sigma_{meas} = \sqrt{\sigma_{trg0}^2 + \sigma_{TPX3}^2}$$

- run 695:
  - June 2019, AZALEA
  - σ = 2.56ns
- run 877:
  - July 2019, AZALEA
  - σ = 2.17ns
- run 2470:
  - September, DURANTE
  - σ = 3.9ns
- run 3273:
  - December, TB24
  - σ = 2.36ns

time residual: TPX3 pixel – trigger ts [us]



TLU and Timepix3 Time Resolutions

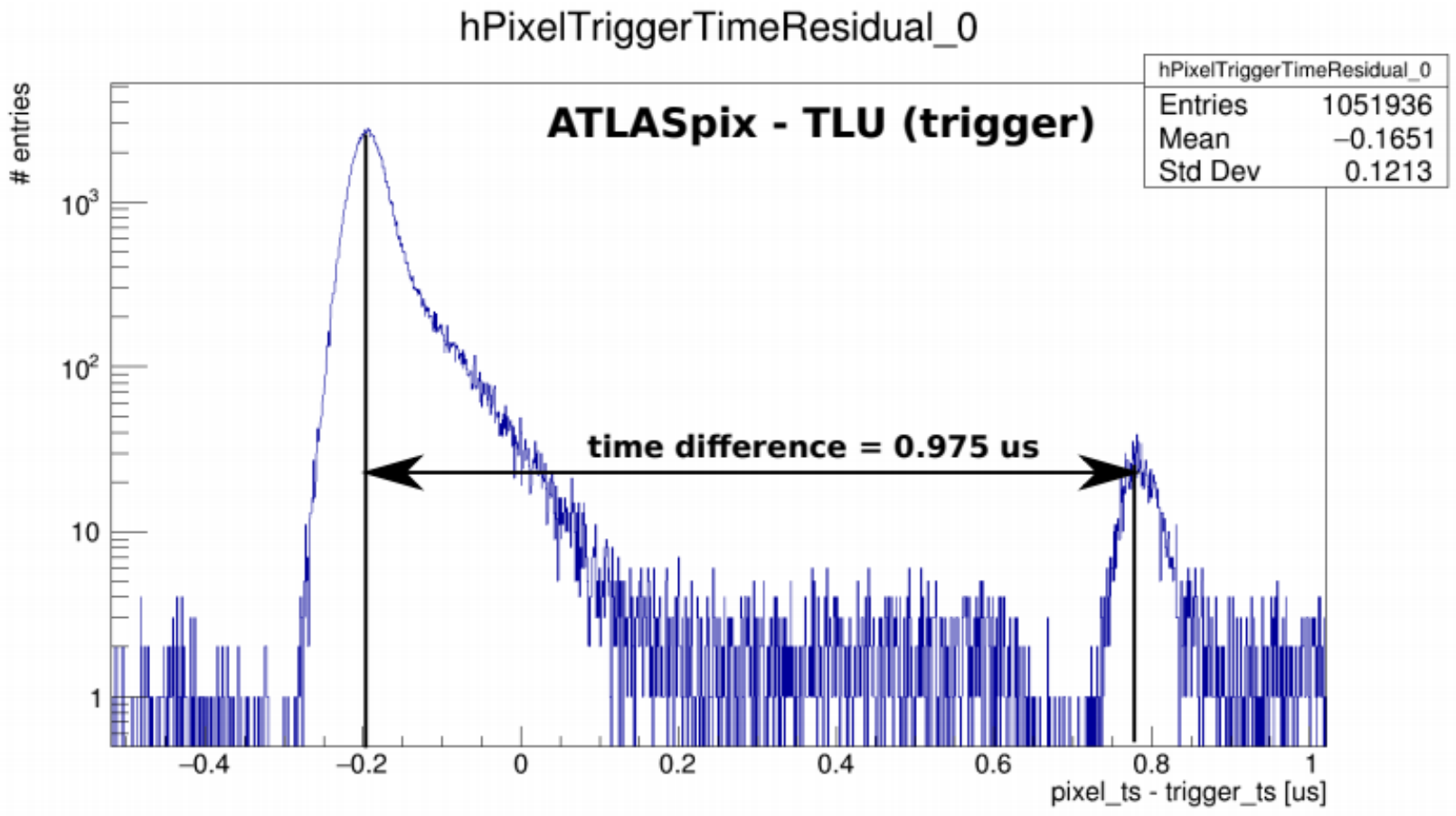
- using best results
  from run 3273:

$$\sigma_{TLU} = \sqrt{\sigma^2_{meas}/2} = 1.2ns$$

$$\sigma_{TPX3} = \sqrt{\sigma^2_{TPX3-TLU} - \sigma^2_{TLU}} = 1.96ns$$

- expect 1-1.5 ns
- **but:**
  non-gaussian tails not considered here!

DESY beam structure visible:



Nuclear Inst. and Methods in Physics Research, A 922 (2019) 265–286:
"The DESY II test beam facility"

7.1.3. DESY II bunch cycle

A DESY II bunch hits the primary target every $L_{\text{DESY II}}/c = 0.976\,\mu\text{s}$.