GEFÖRDERT VOM
Bundesministerium für Bildung und Forschung

Timepix3 Clustering Studies

How to properly cluster Timepix3 data from DESY?

Vertex and tracking detector technology meeting

CERN, May 29th, 2020

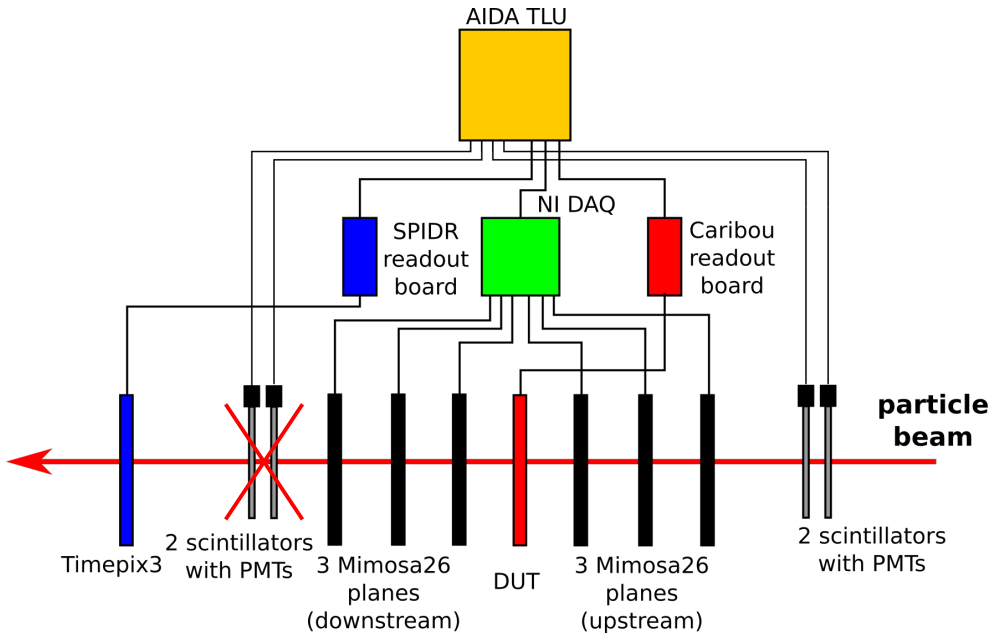
Jens Kröger

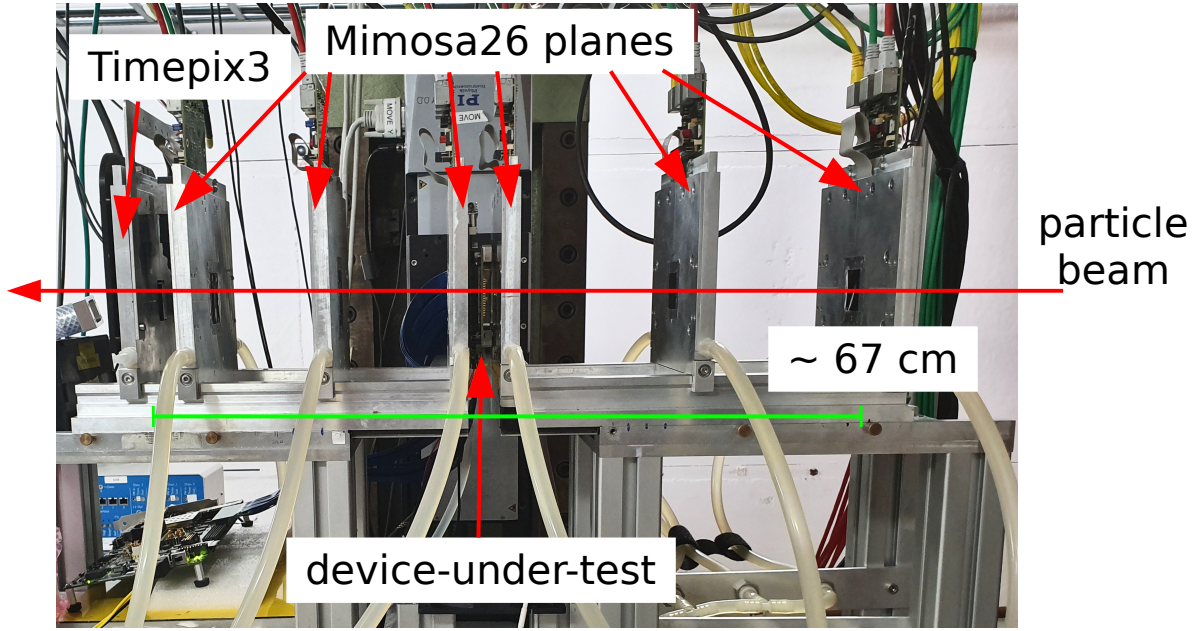
Heidelberg University & CERN

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





The Timepix3 we're using at DESY

Assembly W5_E2

- Timepix3 ASIC + planar sensor (100 µm)
- nominal:
  - bias = -20 V → same at DESY
  - thres = 1160 DAC → thres = 1200 DAC at DESY ("noise free")

Also studied by

Niloufar Alipour Tehrani

https://www.research-collection.ethz.ch/handle/20.500.11850/164813

Florian Pitters

https://cds.cern.ch/record/2649493

https://cds.cern.ch/record/2654139/

https://cds.cern.ch/record/2714709?ln=en

Timepix3 Clustering:

Clustering4D:

- only “touching” neighbours
  (don’t allow split clusters)
- time cut:
  - **relative:** multiple of time resolution
    (1.56 ns w/o calibration)
  - **absolute:** 200 ns

Which time cut is reasonable?

Florian:

- analysis with ***Corryvreckan***
- only “touching” neighbours
- 200 ns

Nilou:

- analysis with ***EUTelescope***
- SciPy `fclusterdata` [see here]
- no info on cuts

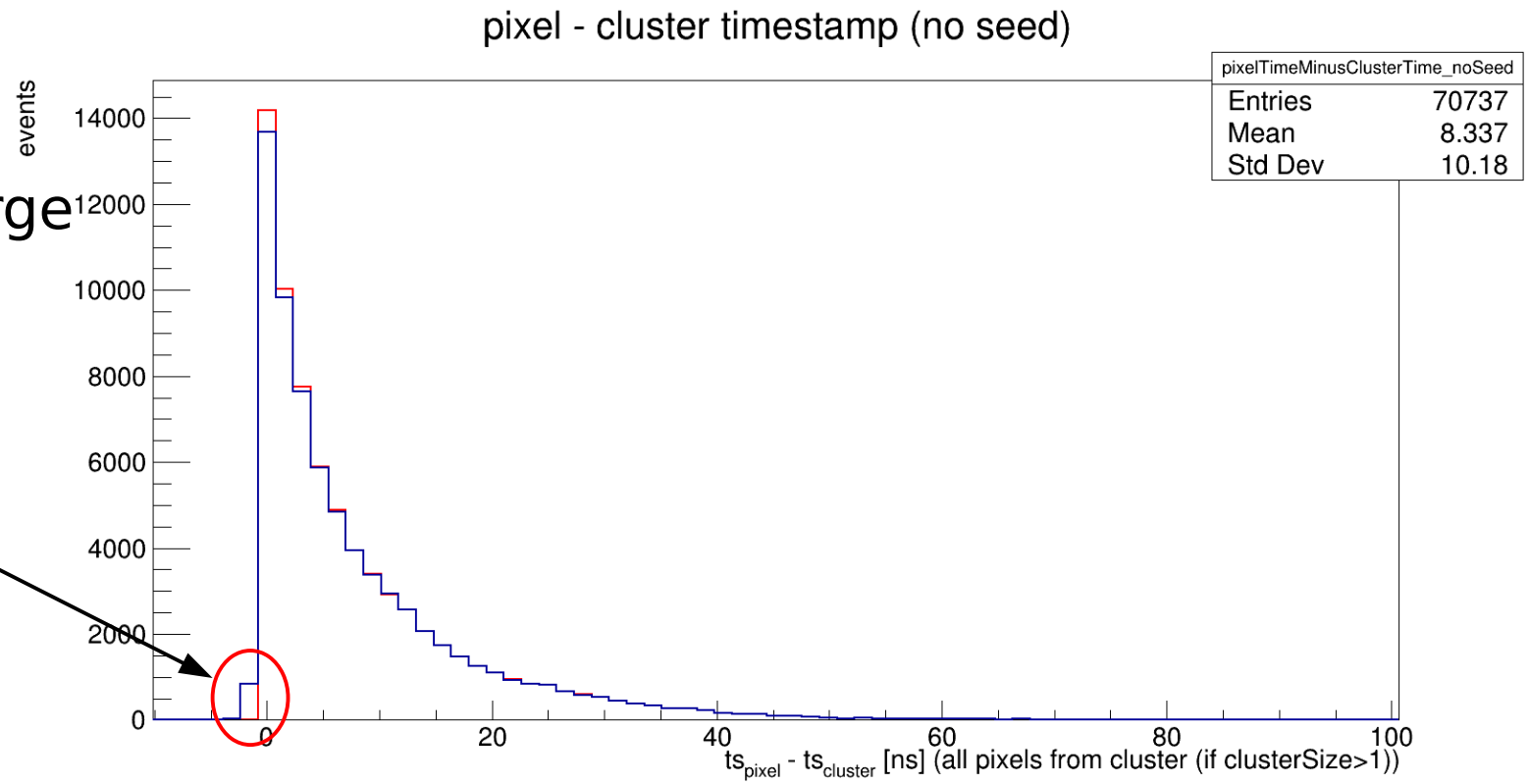
Clustering4D:

- **cluster timestamp**
  = pixel with **largest** charge
  = pixel with **earliest** timestamp

Florian showed:
gives slightly better
time resolution

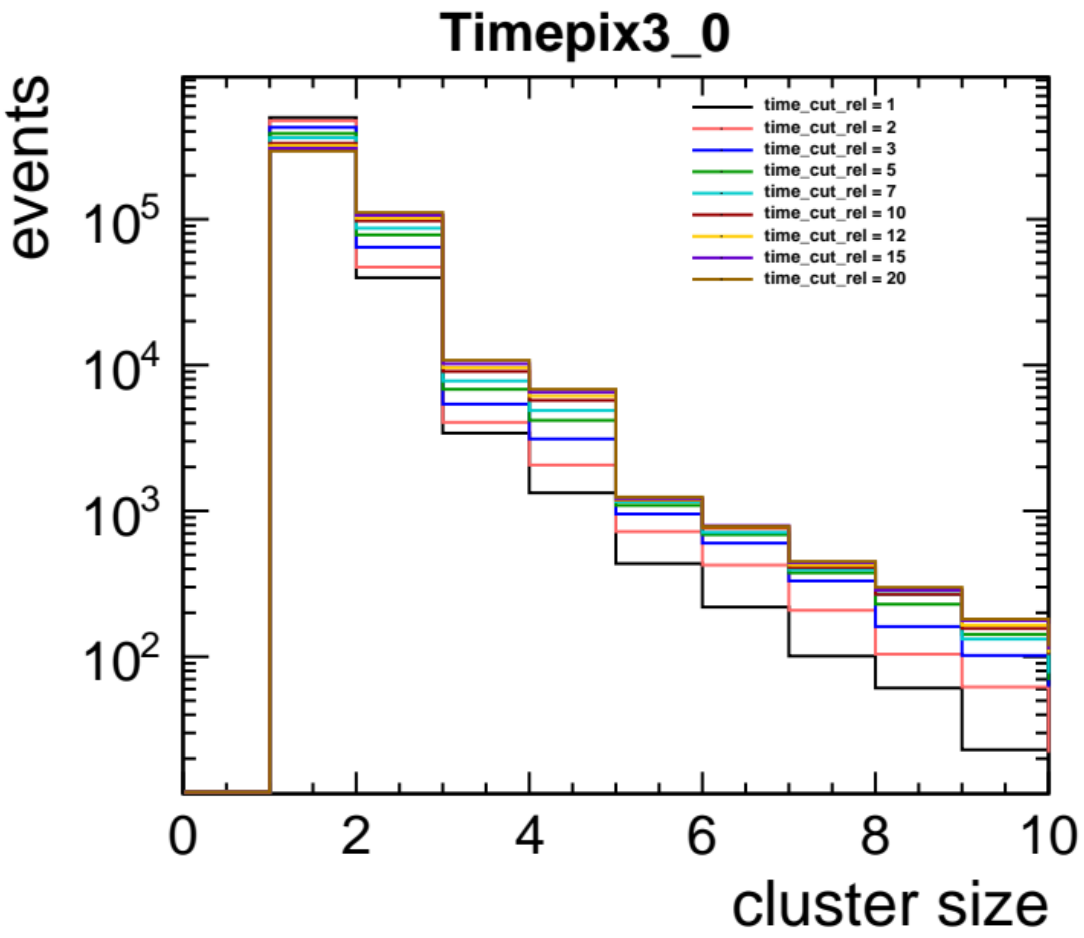
- **seed pixel**
  = pixel with **largest** charge

Occationally:
pixel with largest charge ≠ earliest



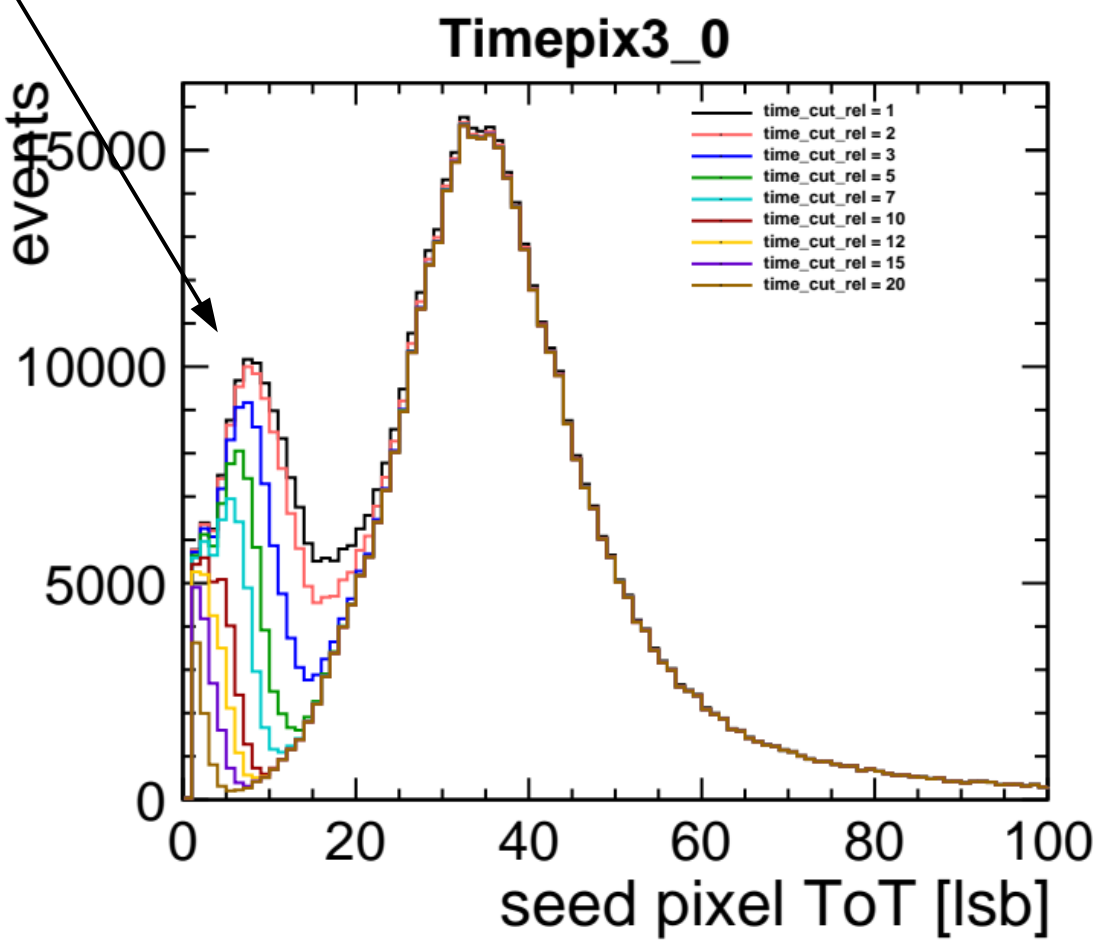
Clustering4D:

cluster sizes:



expected from charge sharing

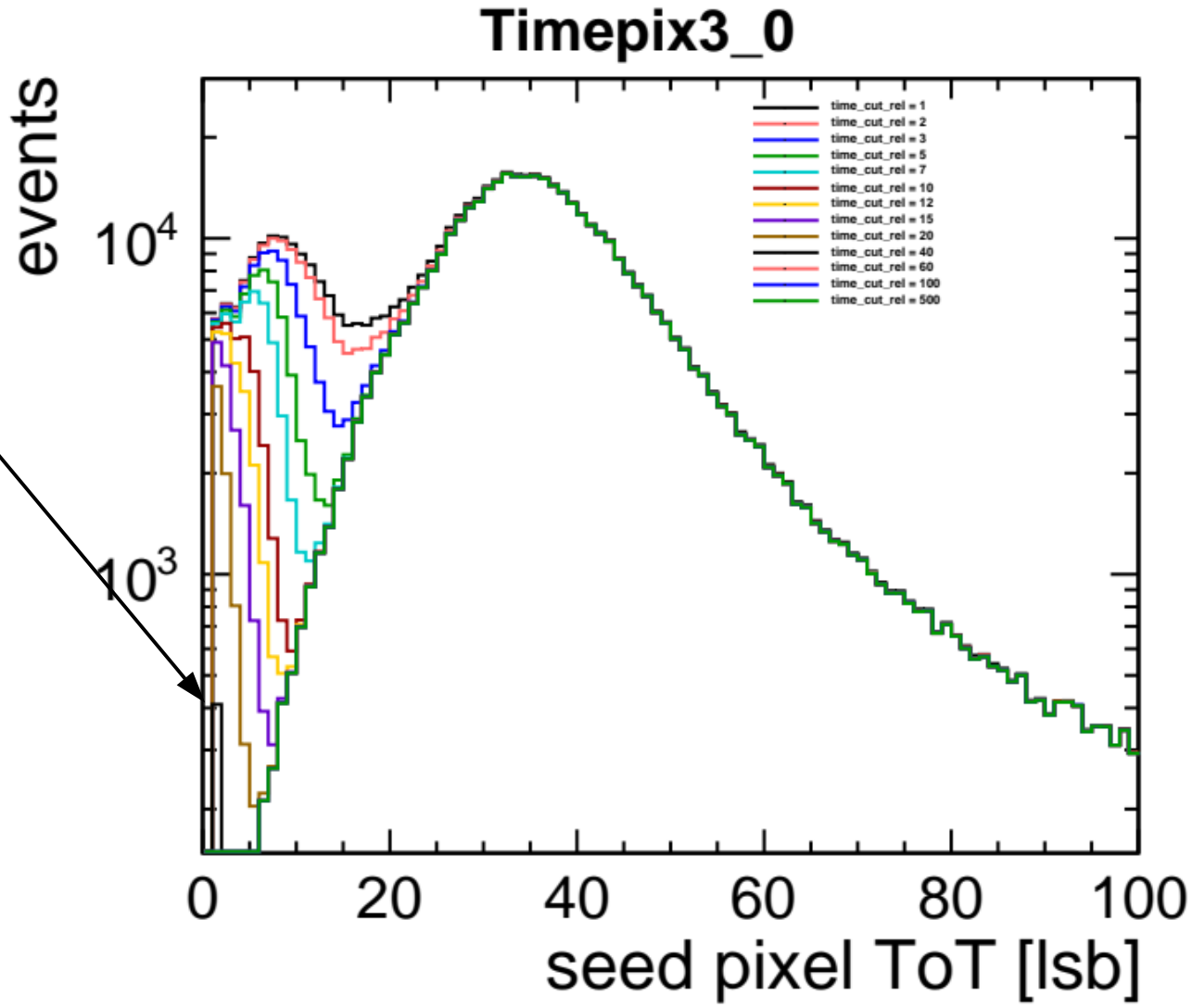
seed pixel ToT:



Clustering4D:

seed pixel ToT **log(y):**

- time_cut_rel = 40 - 60
  → low ToT peak disappears

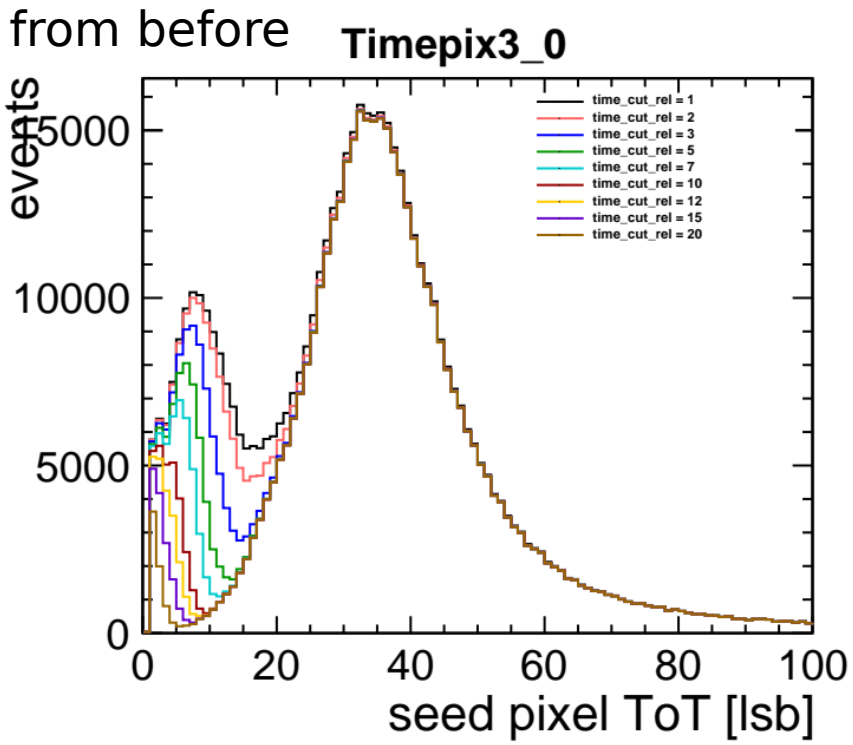


Low ToT bump:

Comparison to Nilou:

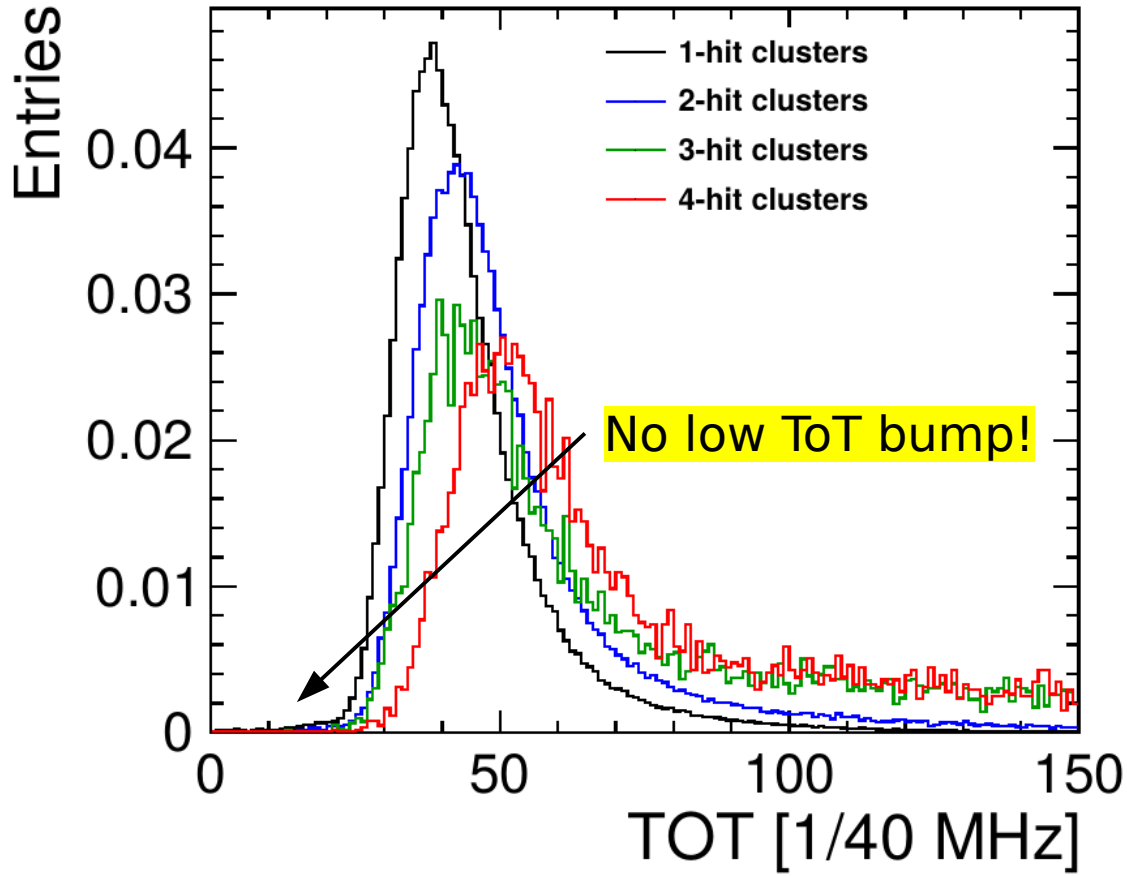
- no low ToT bump visible for her

from before



Reminder:
She used a lower threshold
→ more charge sharing visible

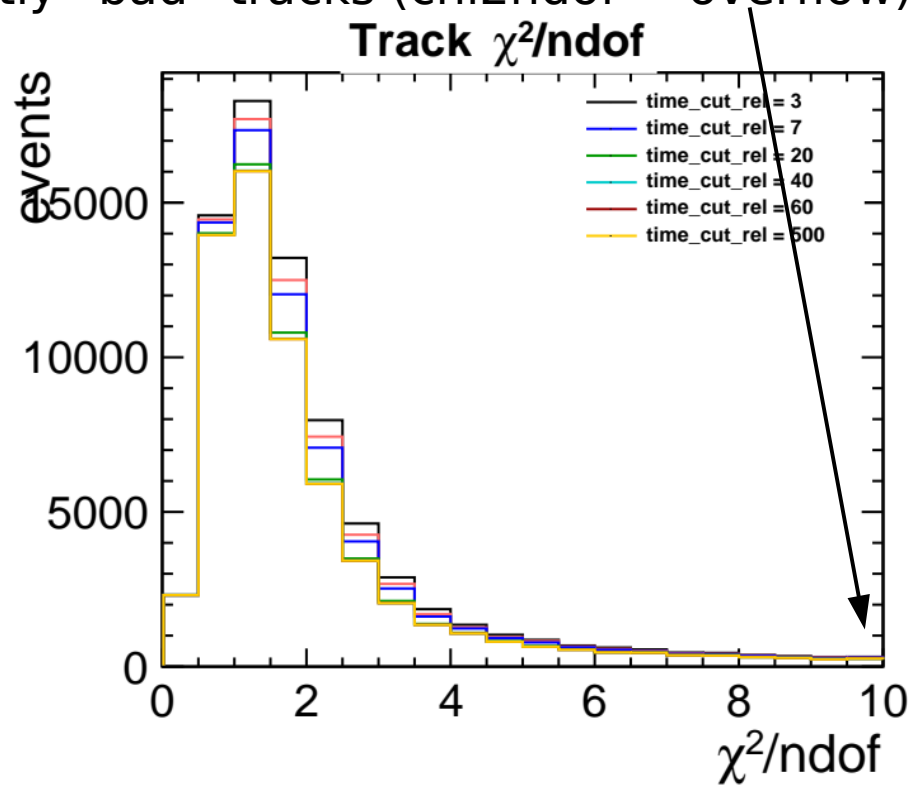
Nilou: Fig. 7.1 (b)

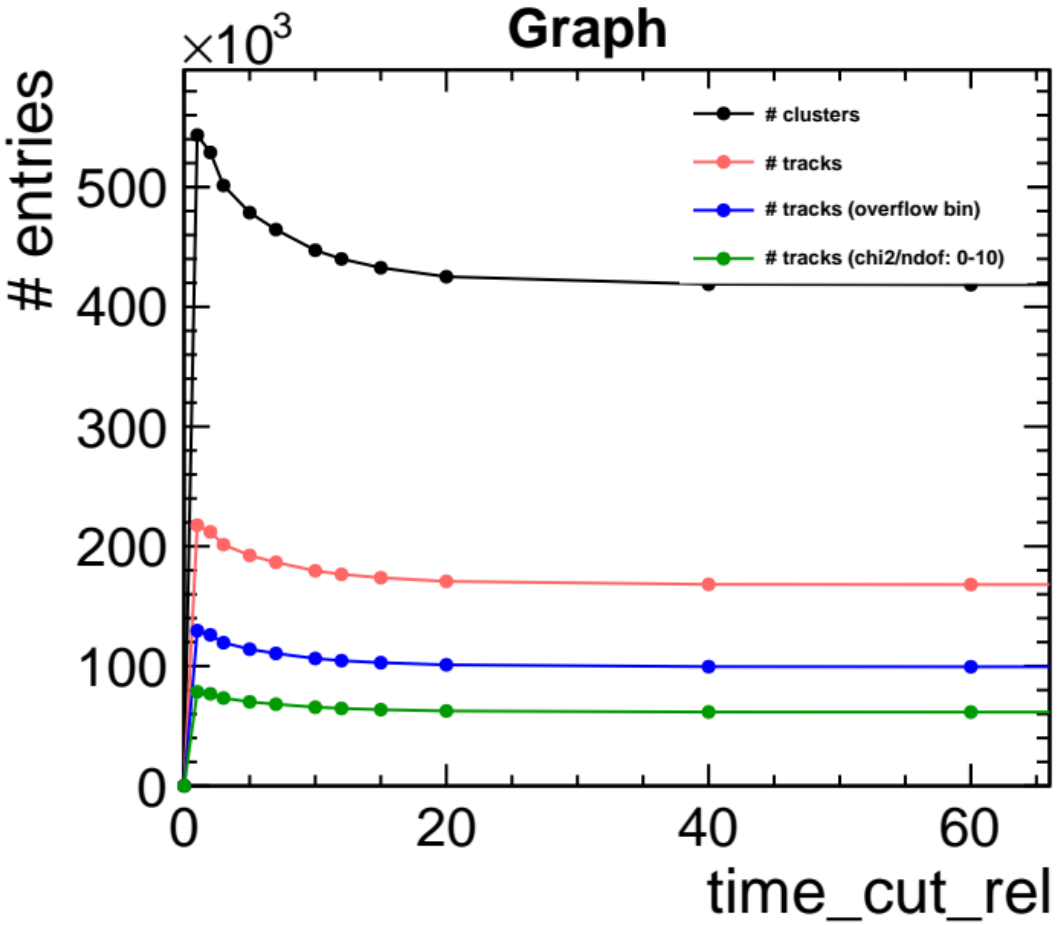


Influence on Tracking

How much does it affect the track quality?

- if cut ≤ 10 – 20:
  - more clusters + tracks
  - but mostly “bad” tracks (chi2ndof → overflow)





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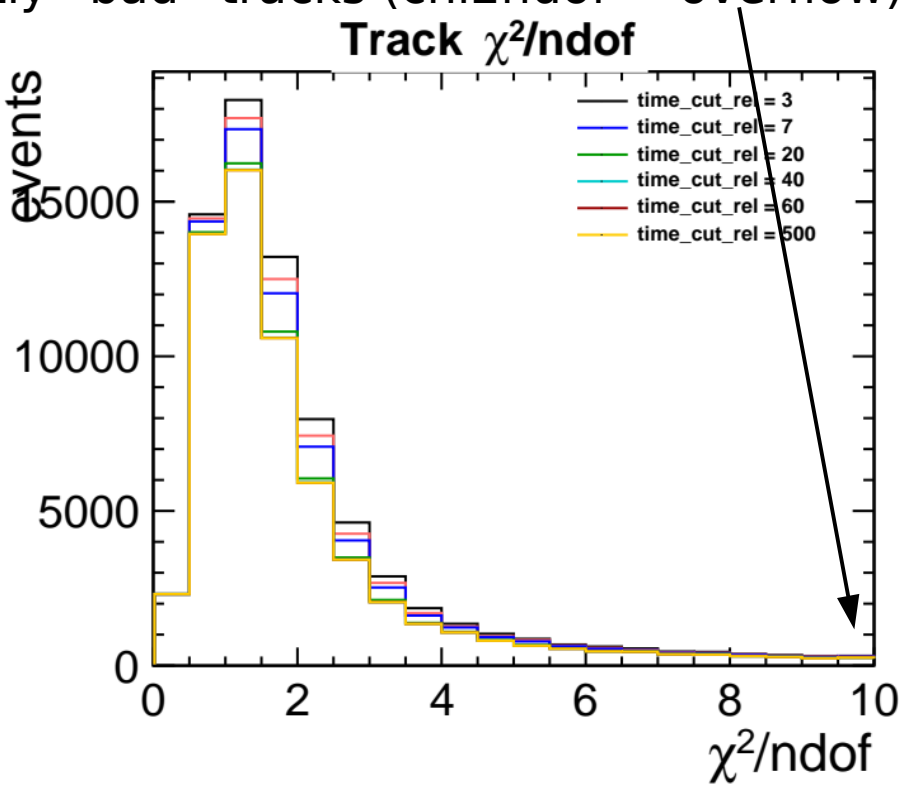
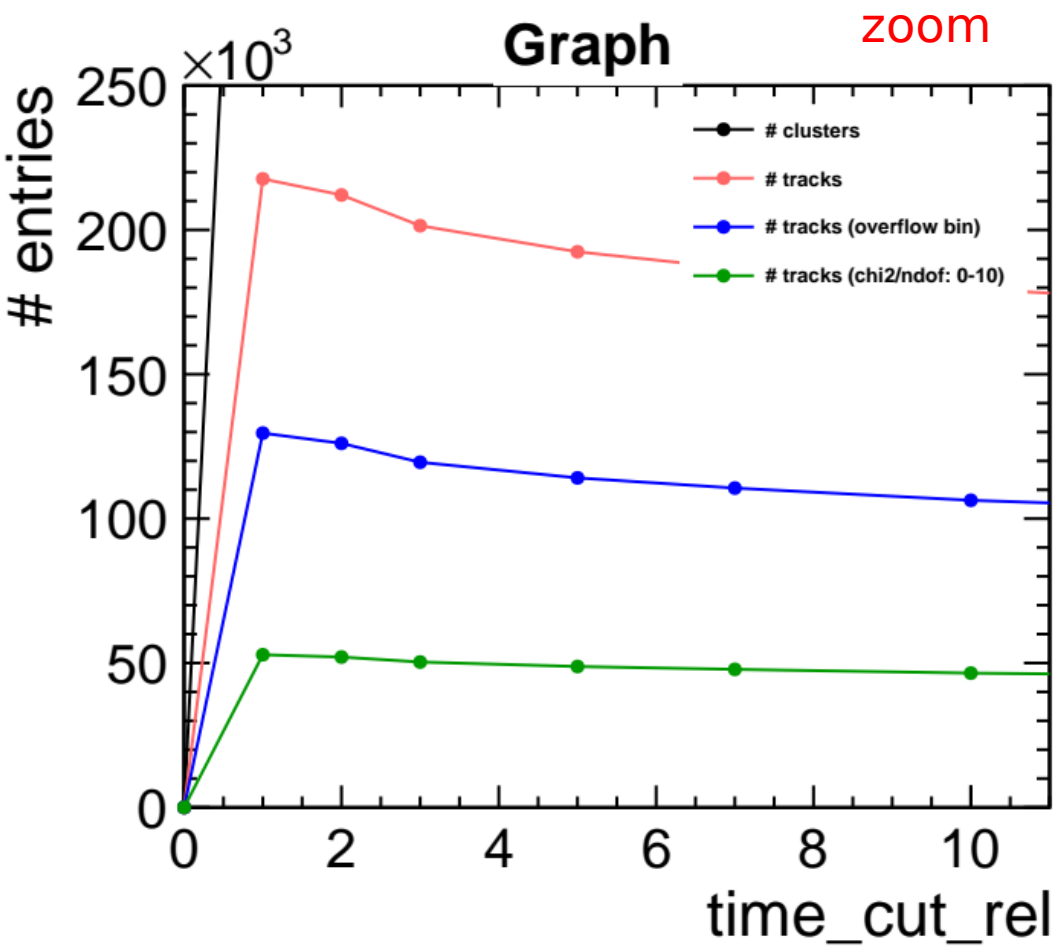
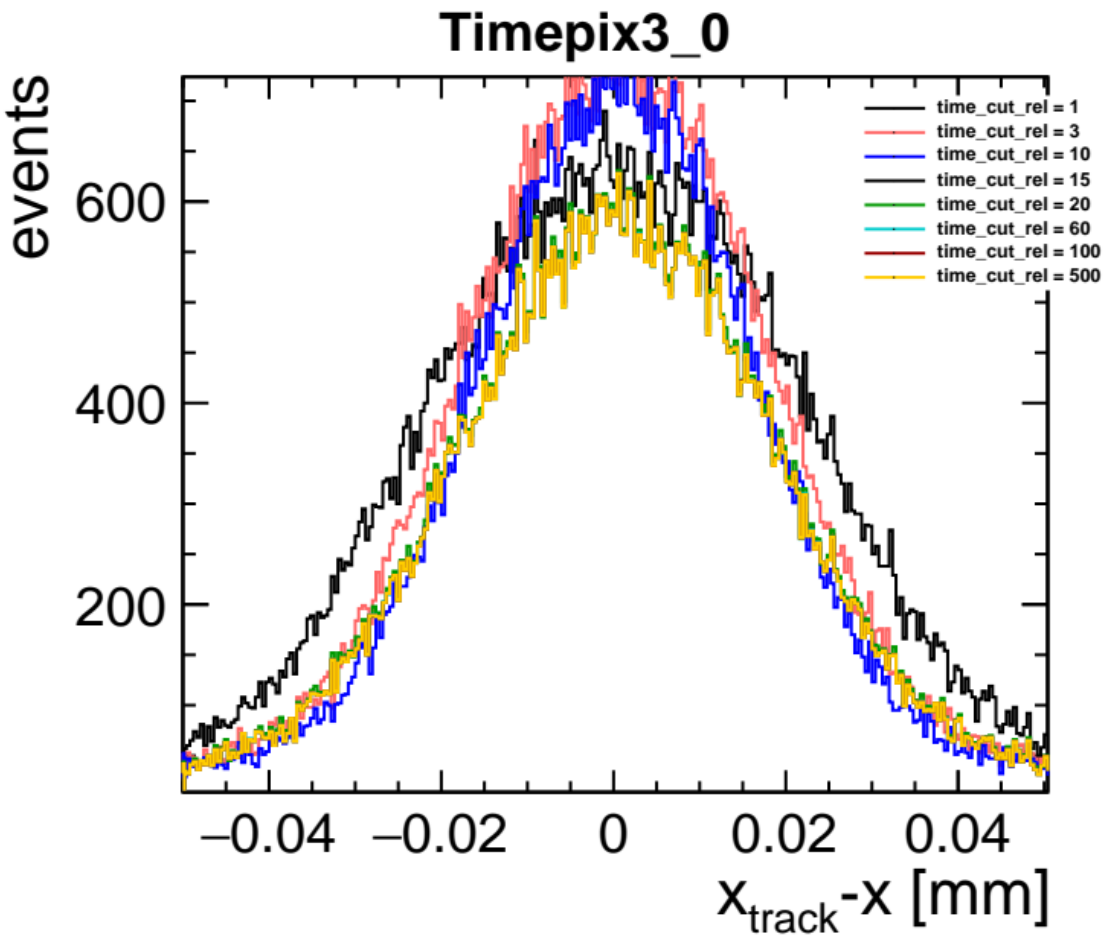
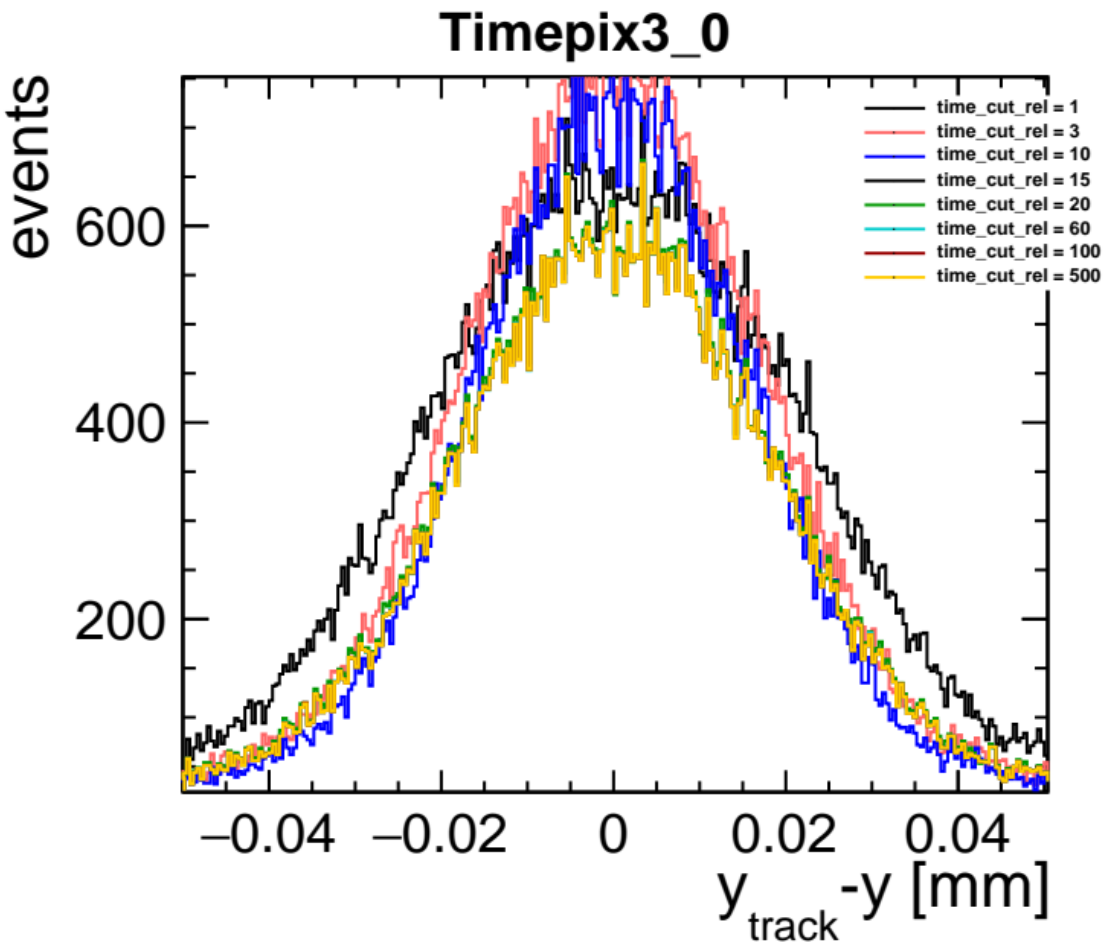


zoom



Tracking4D: biased residuals (x/y)

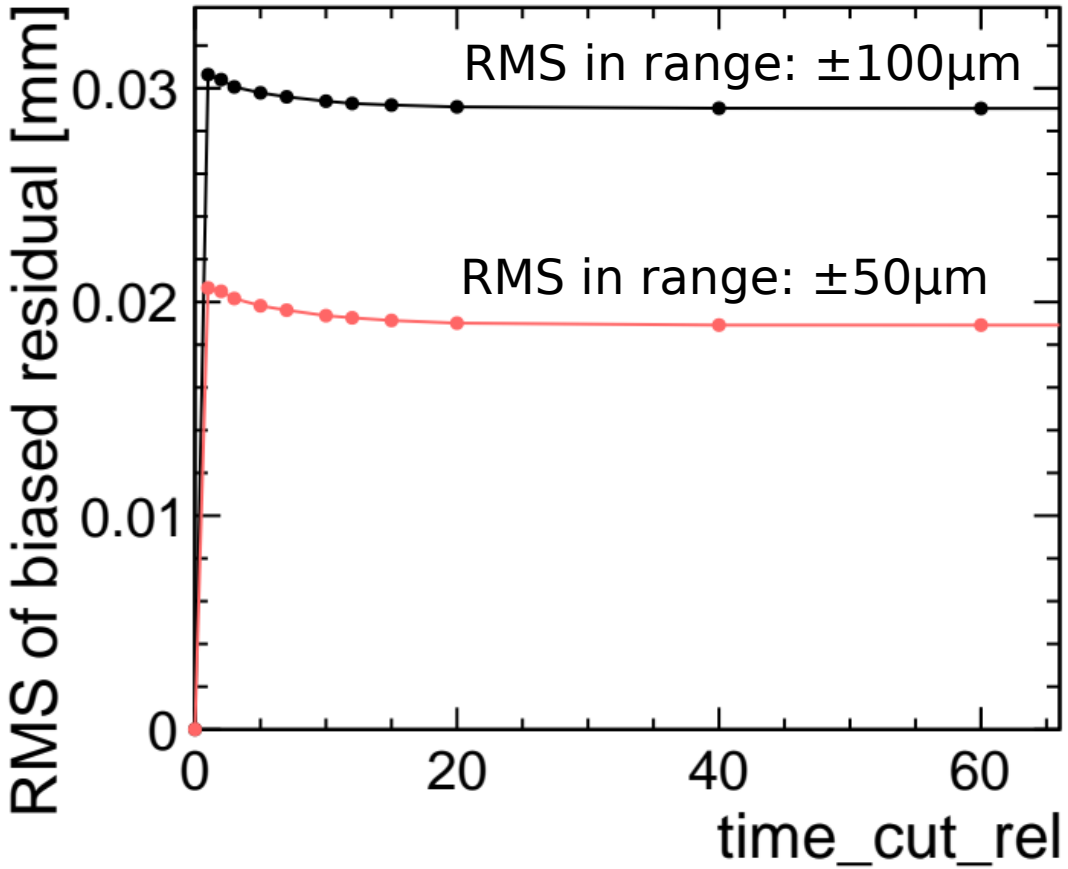




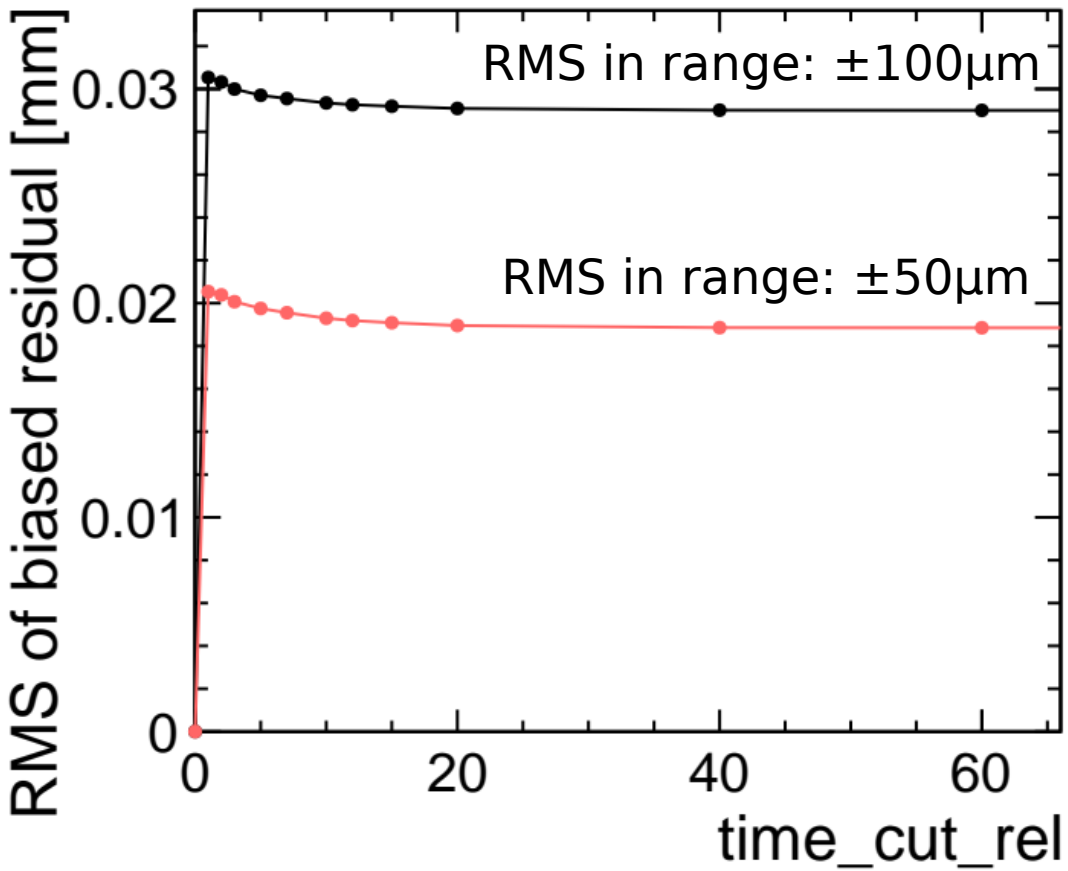
Tracking4D: biased residuals

RMS of biased residuals: wider residuals for small cuts (error bars not visible)

in X:



in Y:



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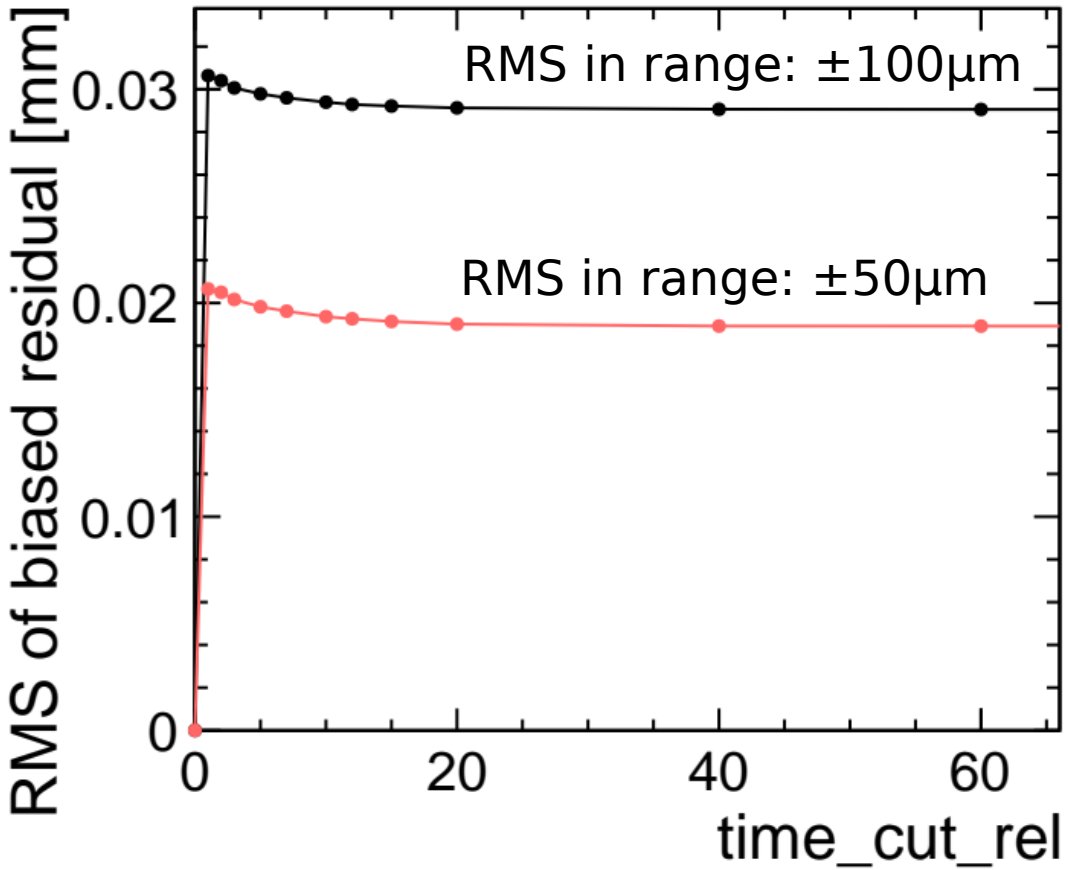
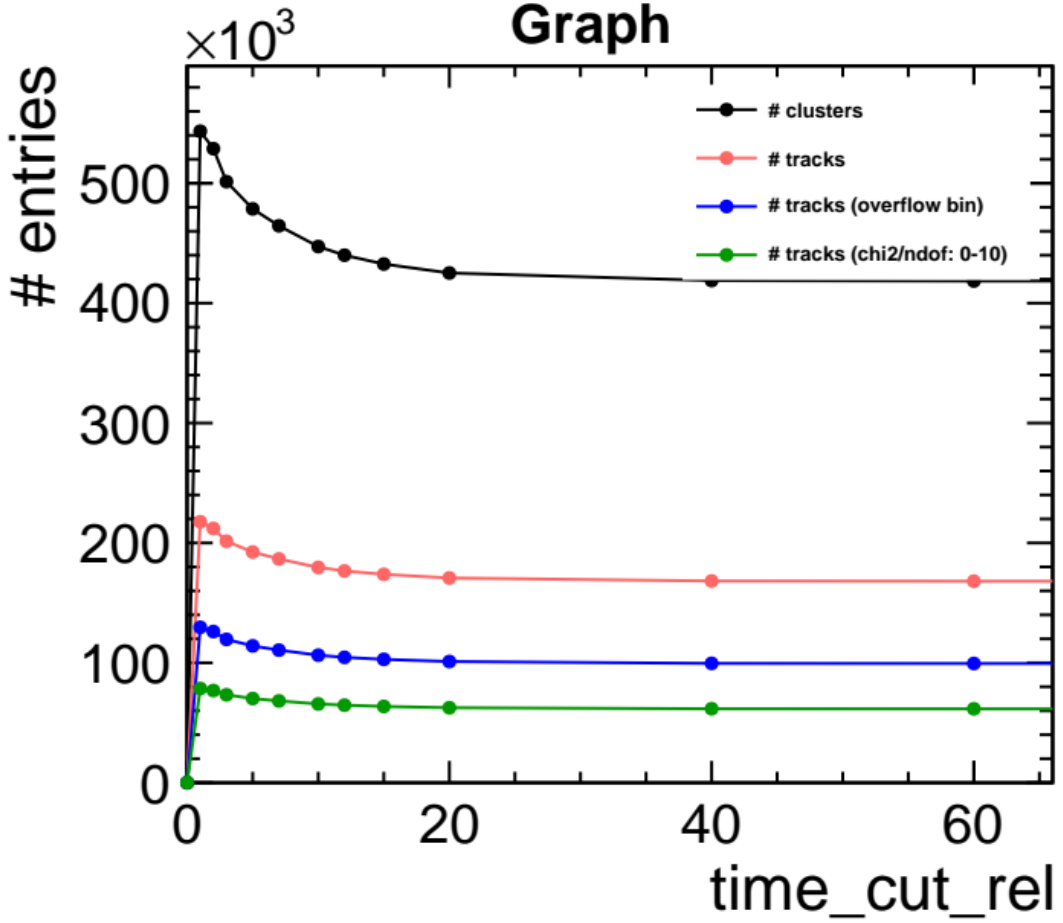
RMS of biased residuals: wider residuals for small cuts

in X:



consistent with: more “bad” tracks



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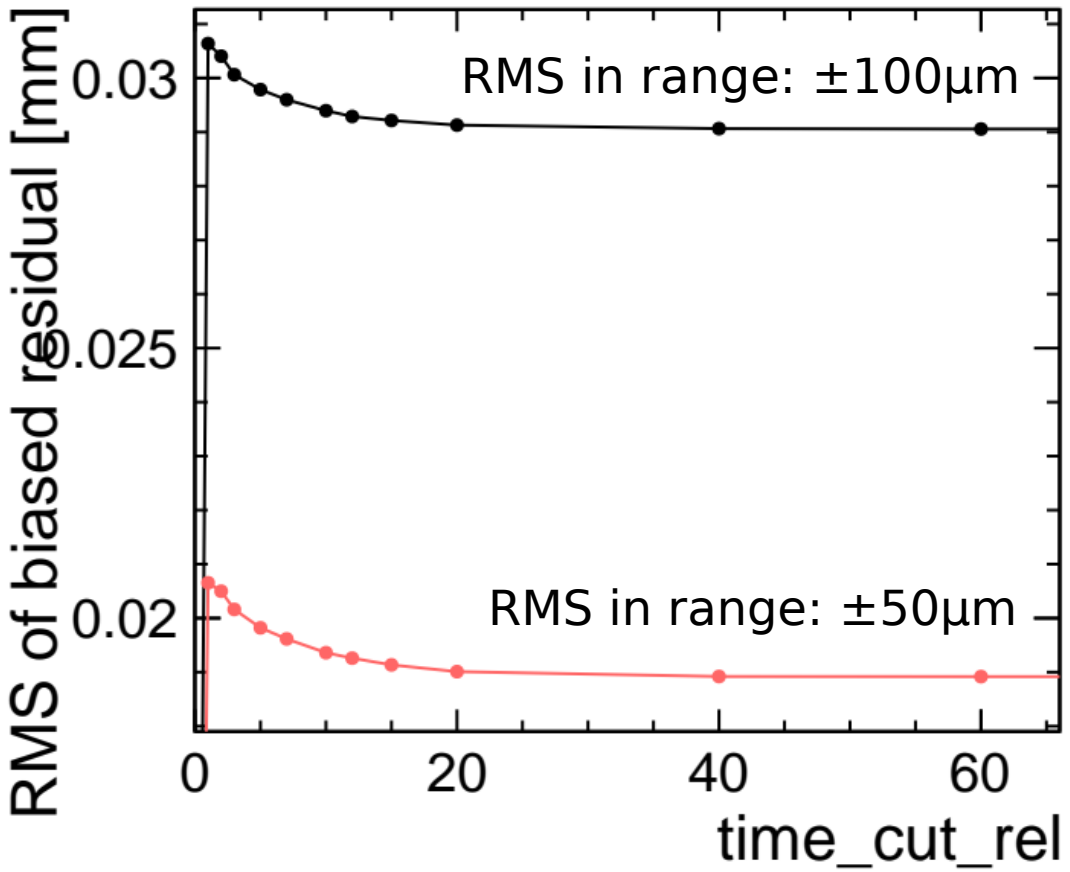

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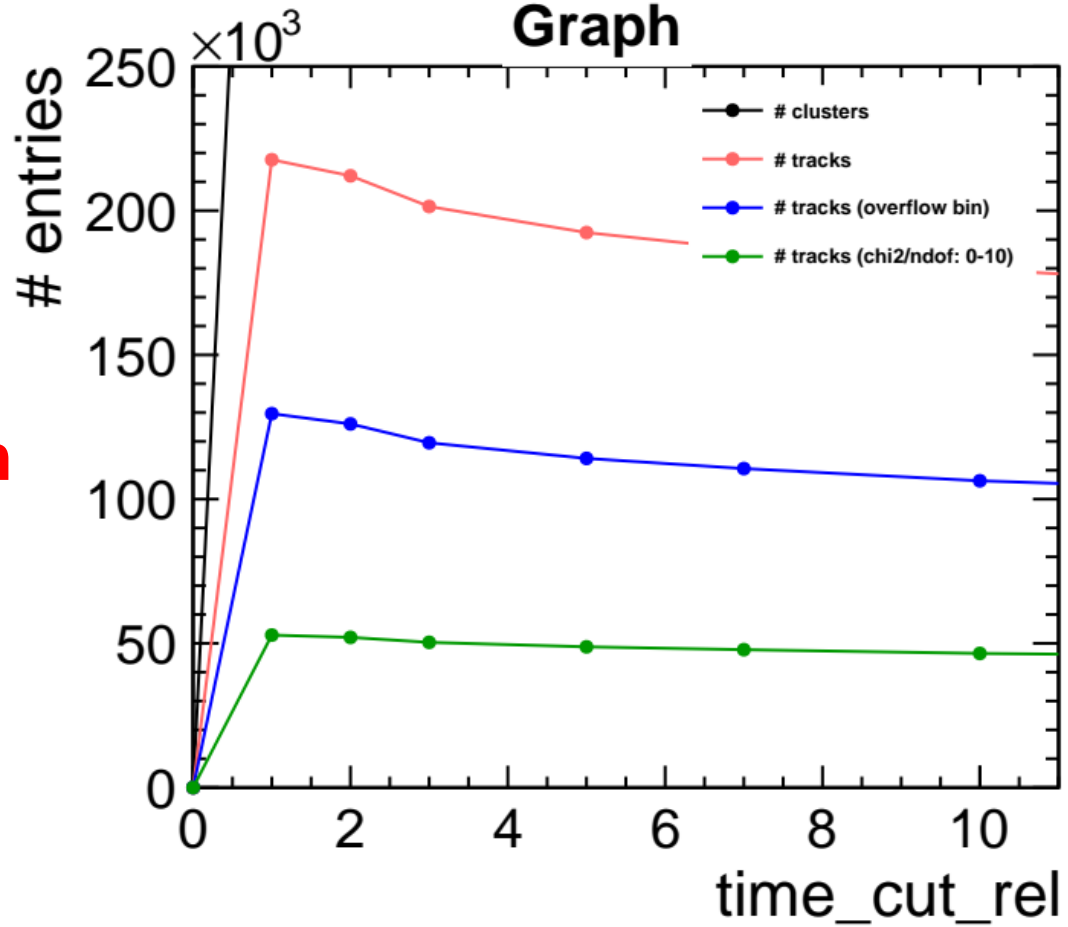
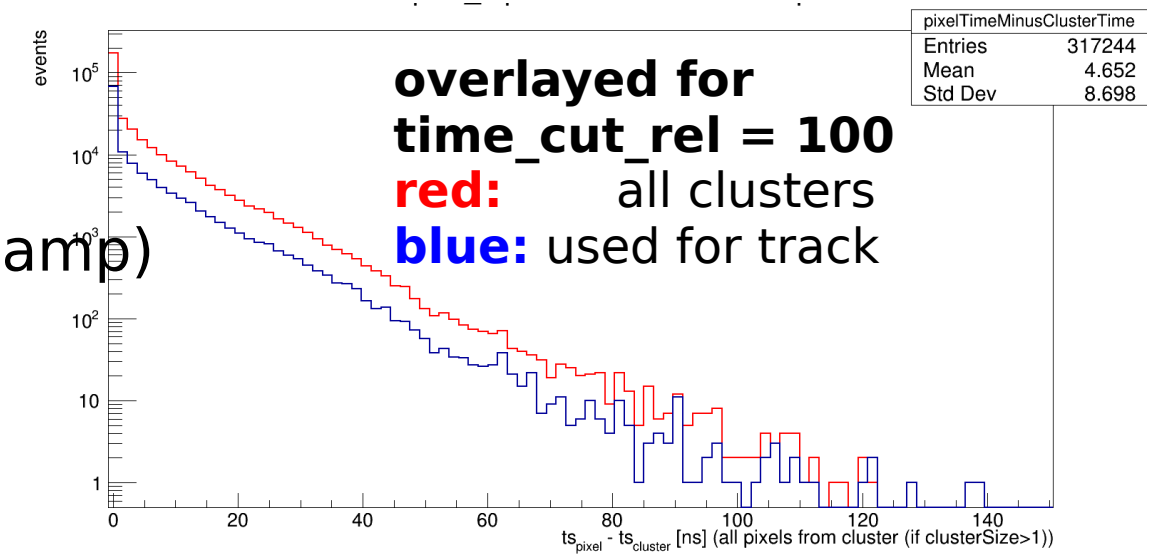
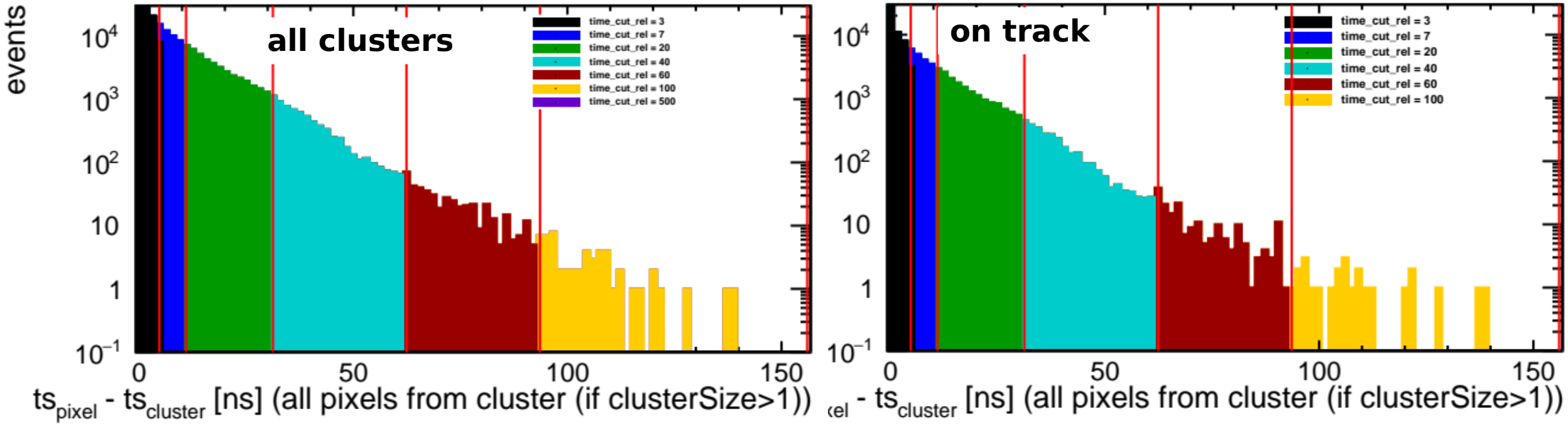


In-cluster timing

plot time difference Δt of:
(all pixels withing cluster) - (cluster timestamp)

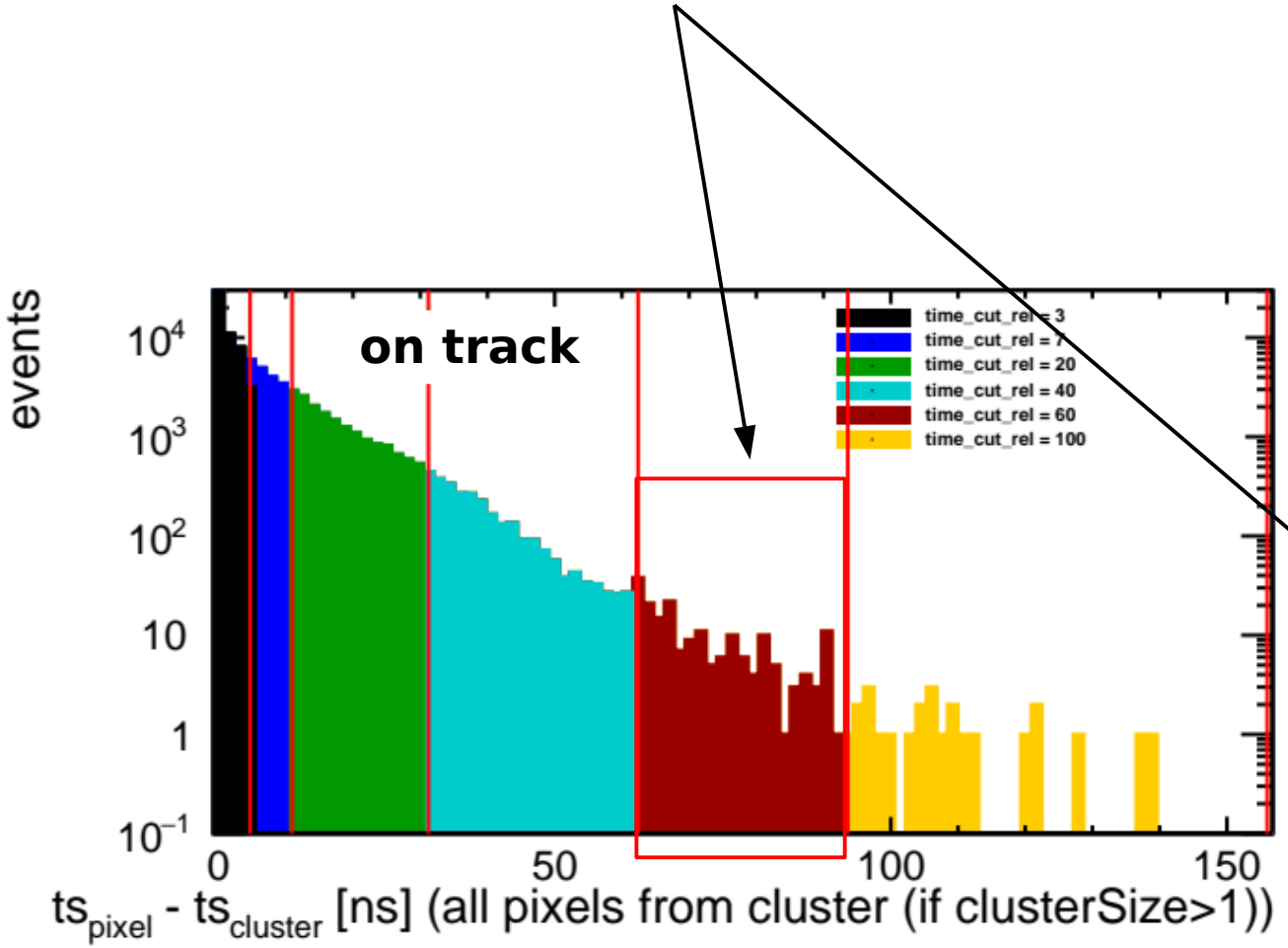
- very large Δt of up to ~100 ns
- silicon processes < 10 ns (?!)

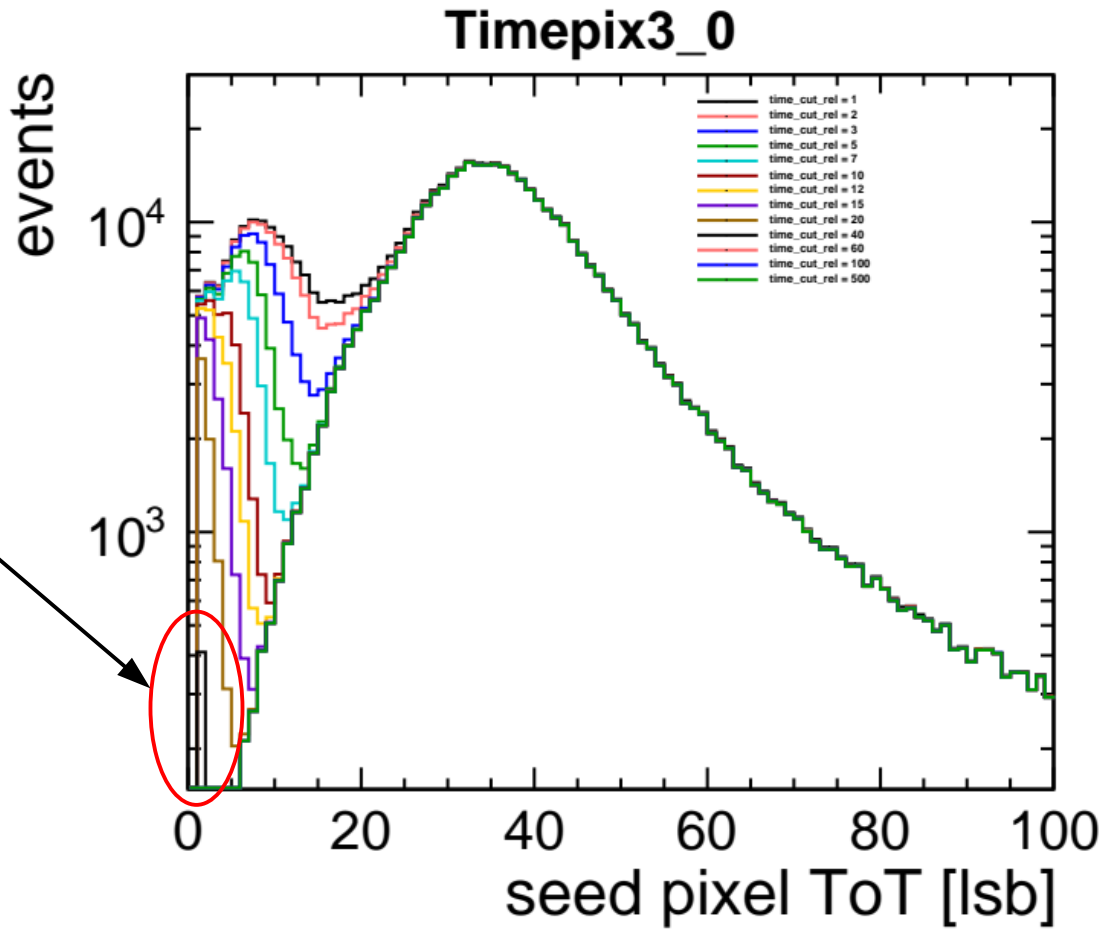




In-cluster timing

Coincides with low ToT bump disappearing for
time_cut_rel = 40 - 60 → 60 – 90 ns





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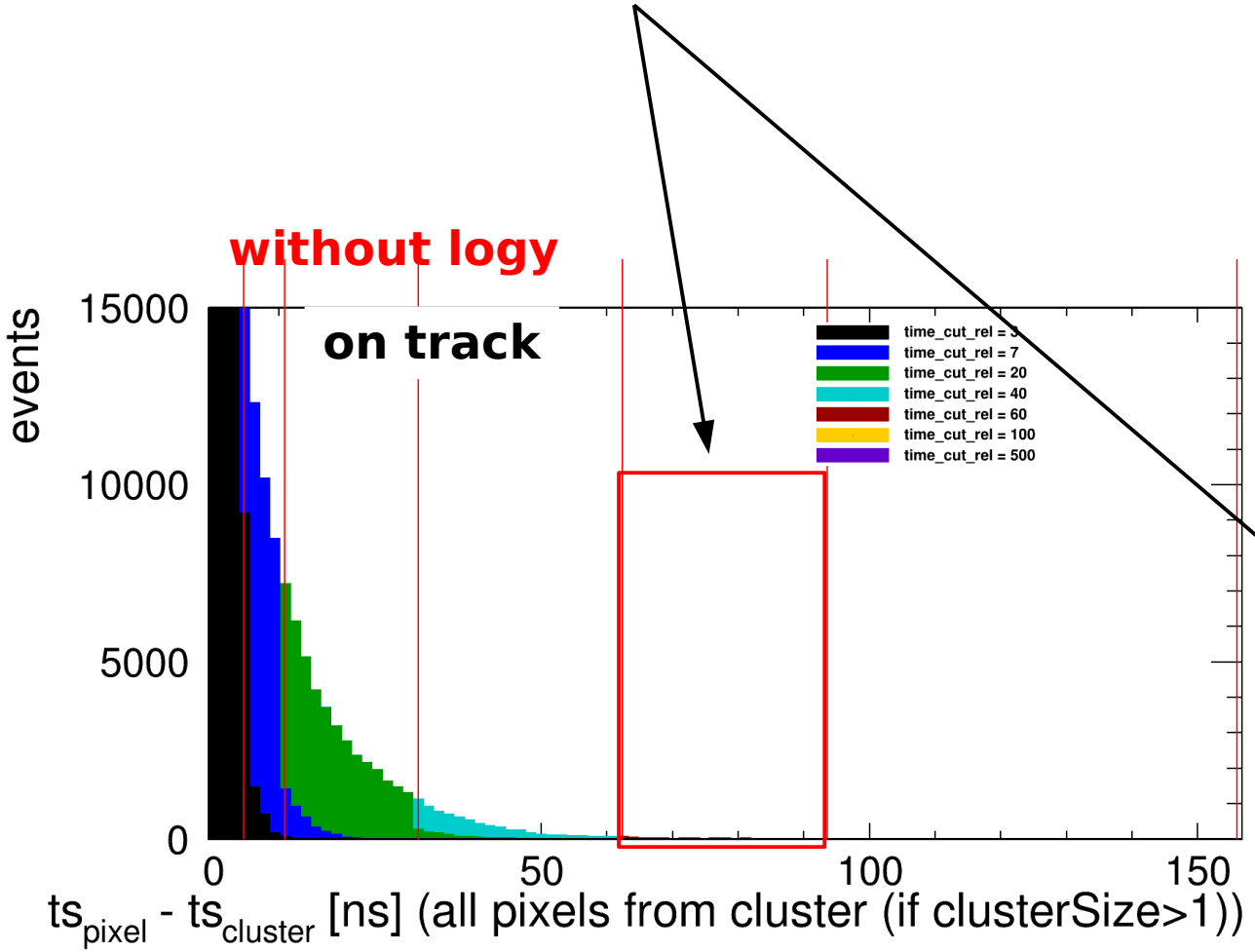
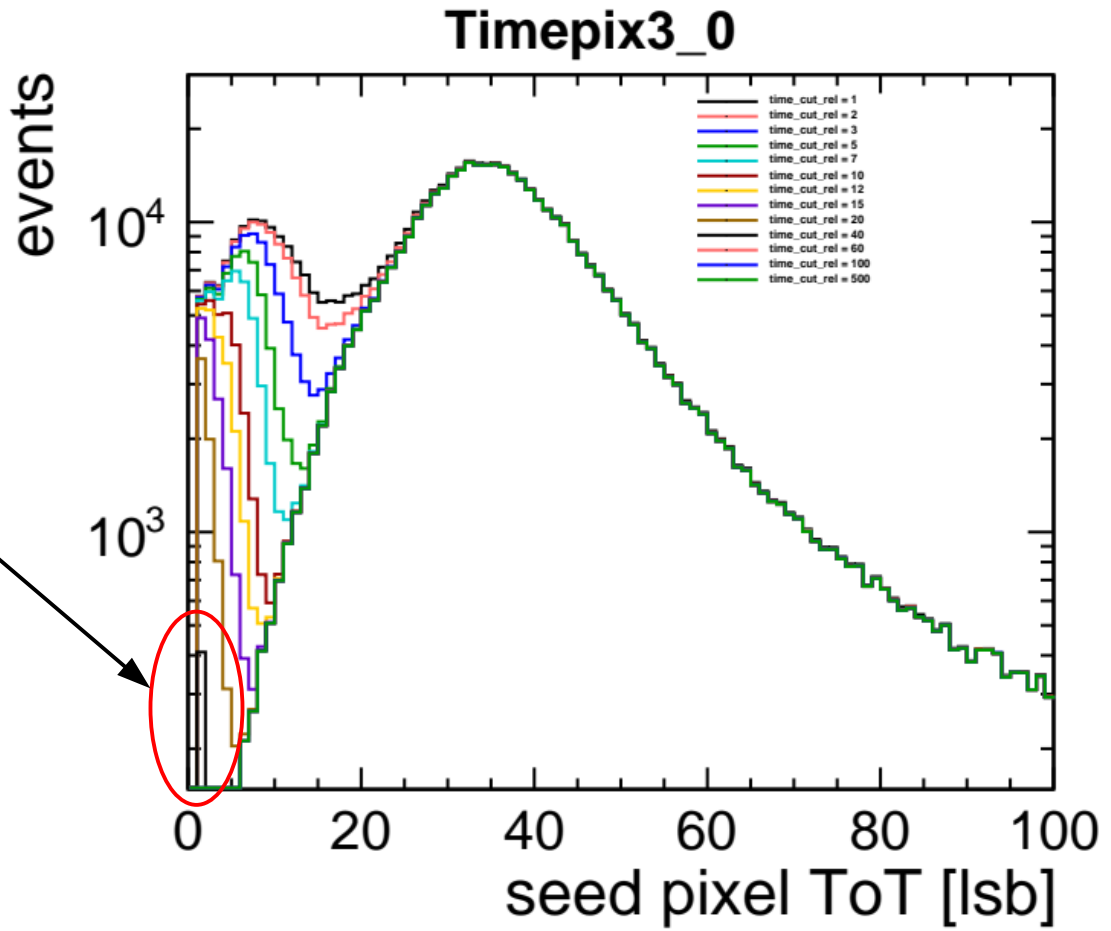


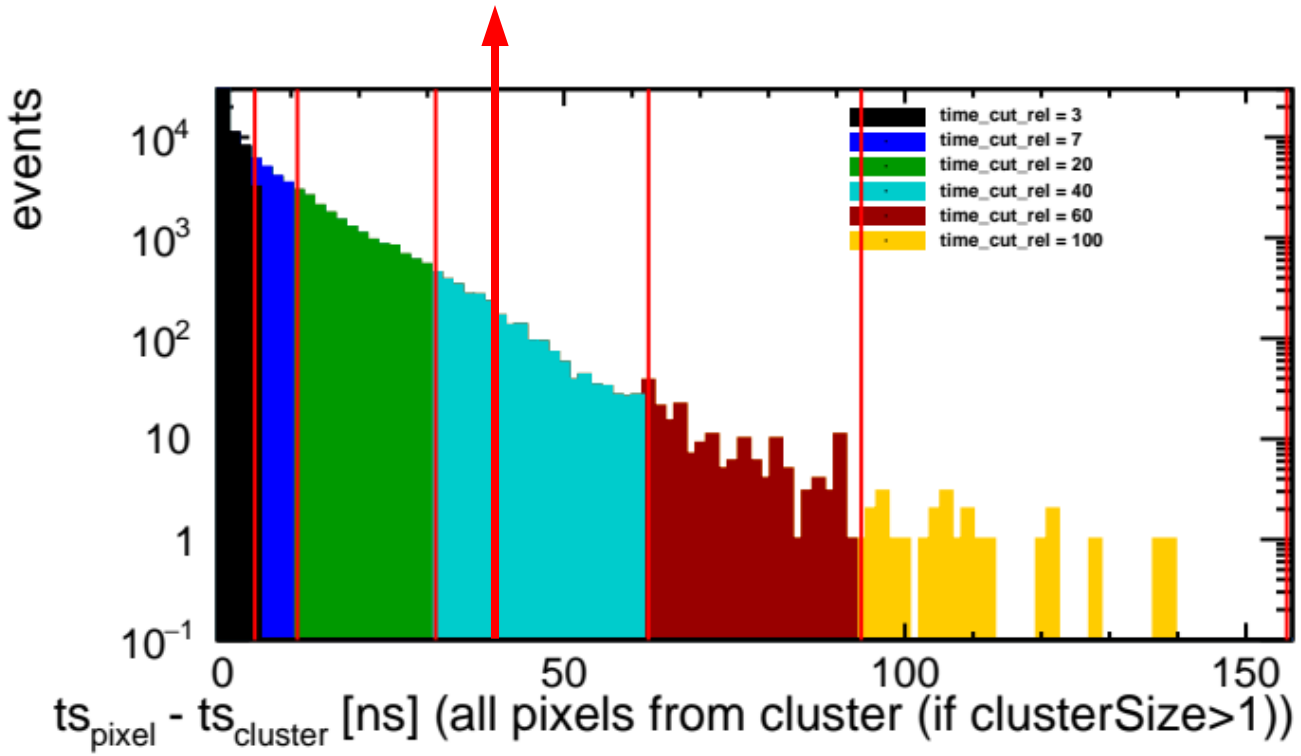


In-cluster timing

Check if correlated large Δt with **”high occupancy” events**:

- larger trackChi2ndof (?)
- larger occupancy (?), i.e.
  - #tracks
  - #clusters
  - #pixels
  - #triggers

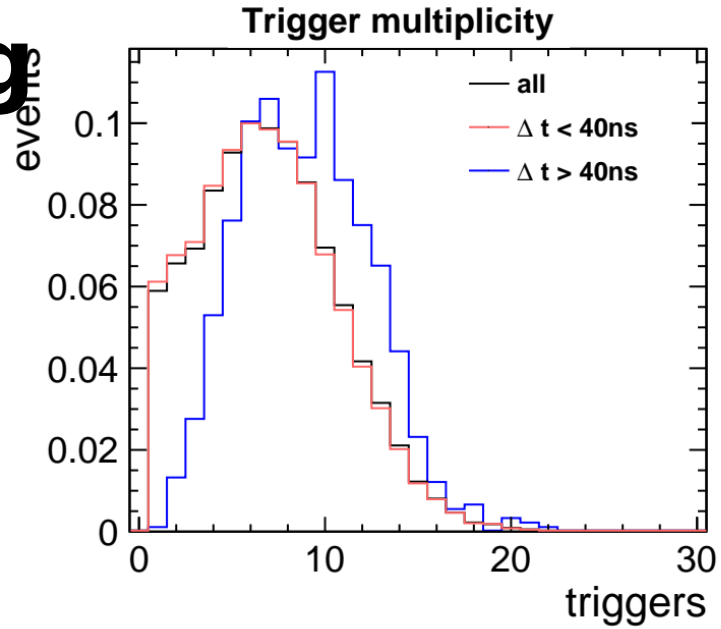
Large Δt: larger than 40ns

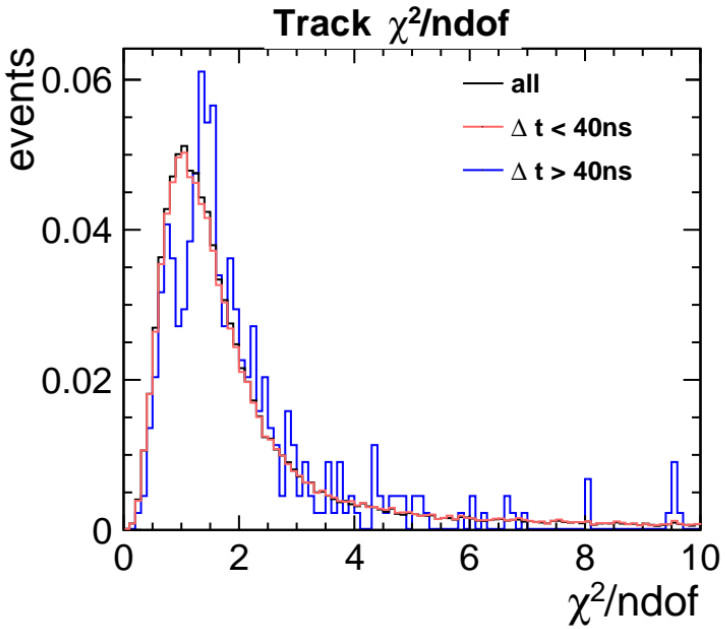


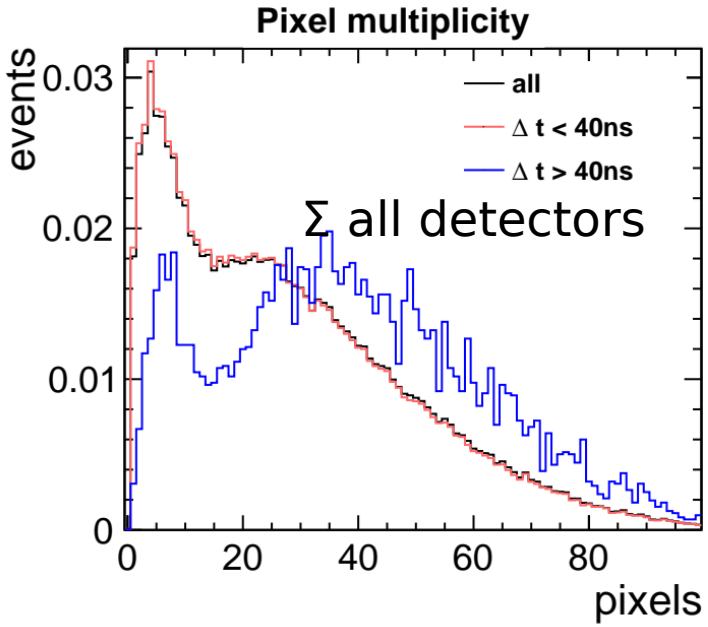
In-cluster timing

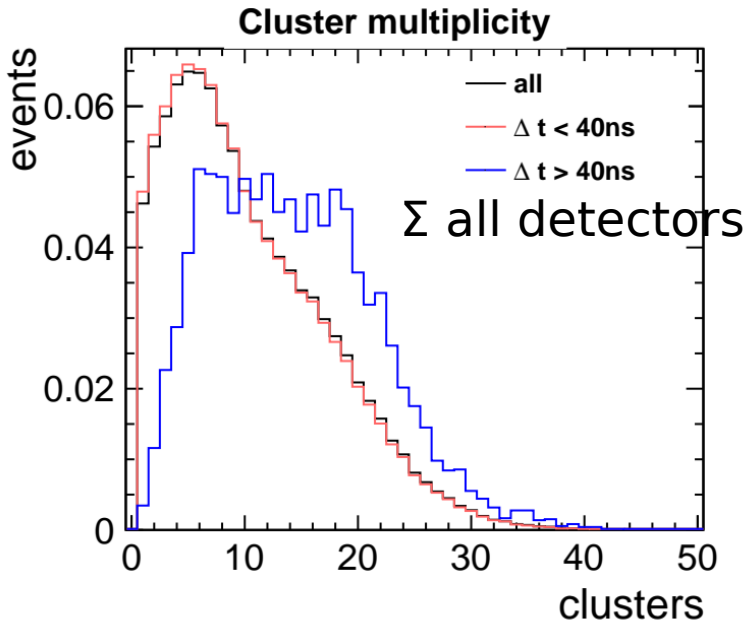
Correlate large Δt with
”high occupancy” events:

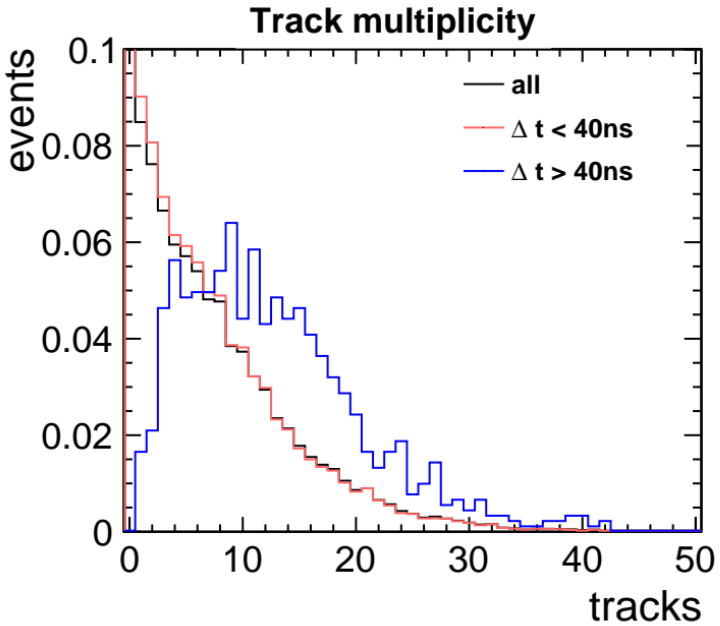
- **red:** event which does not contain cluster with large Δt
- **blue:** event which contains cluster with large Δt





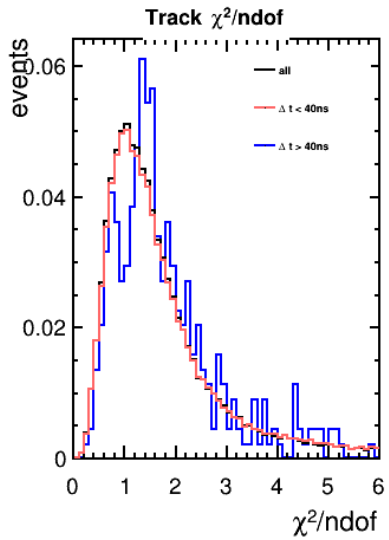


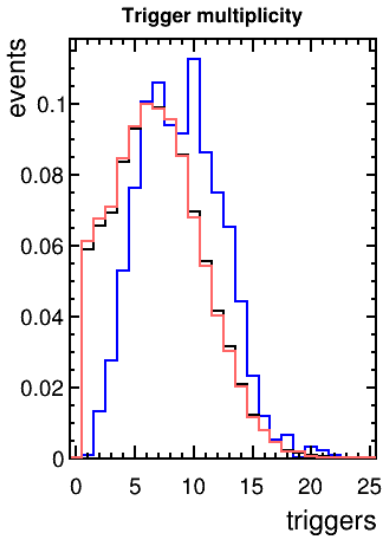


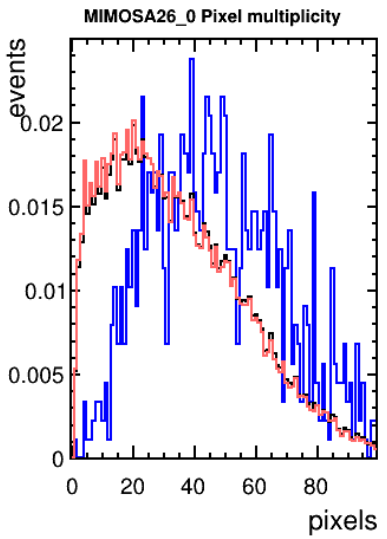


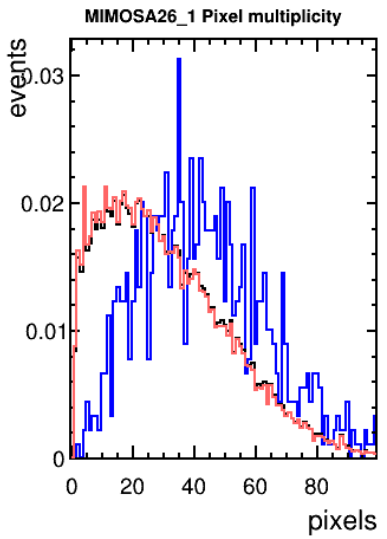
Pixel Multiplicity

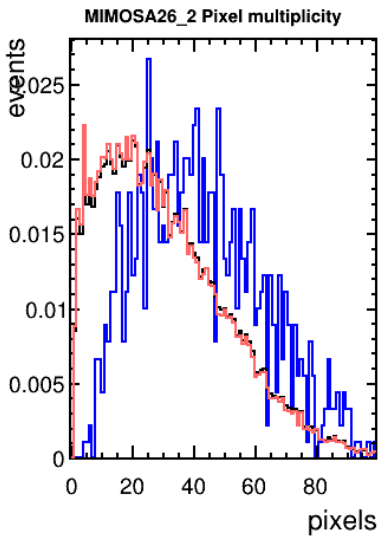
Black: all
Blue: Δt > 40ns
Red: Δt < 40ns

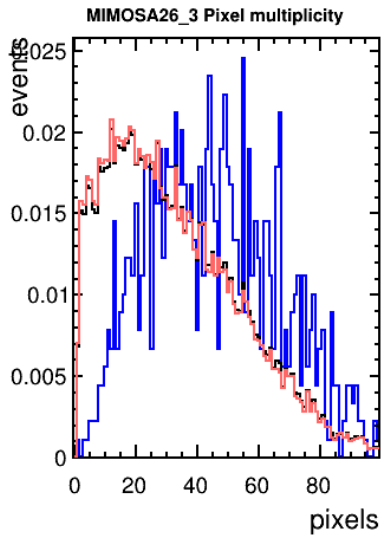


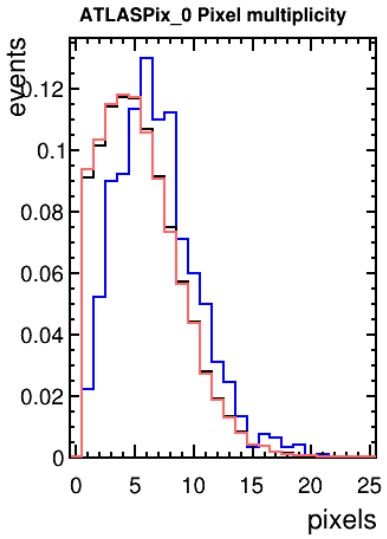


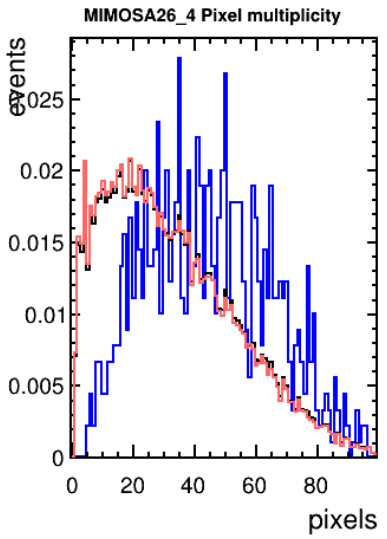


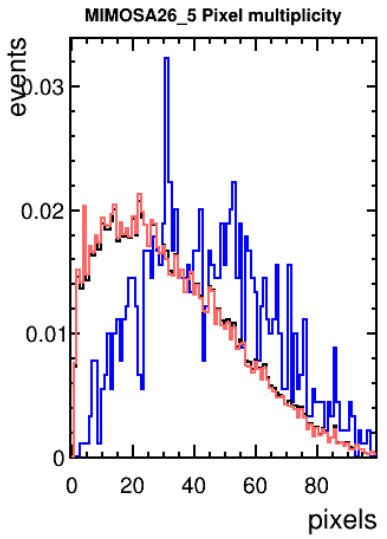


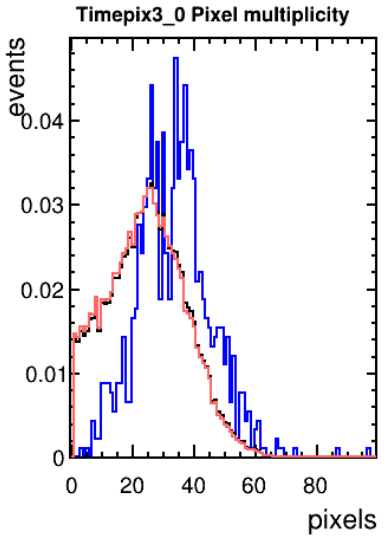












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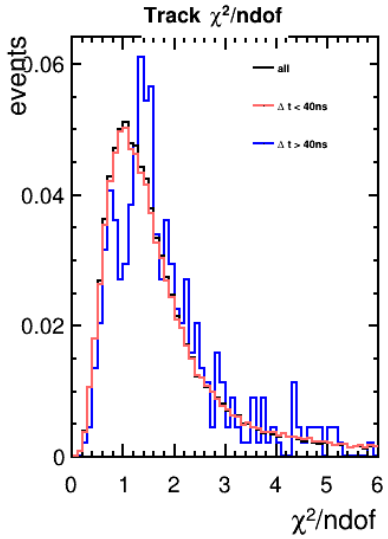
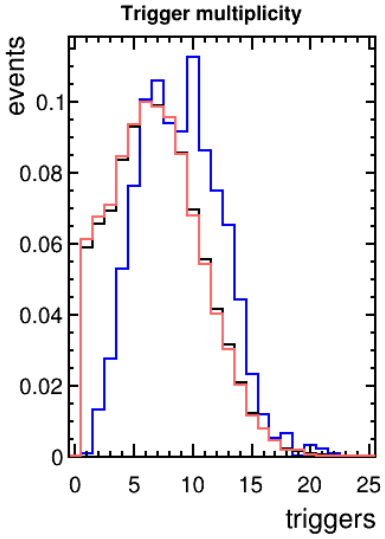
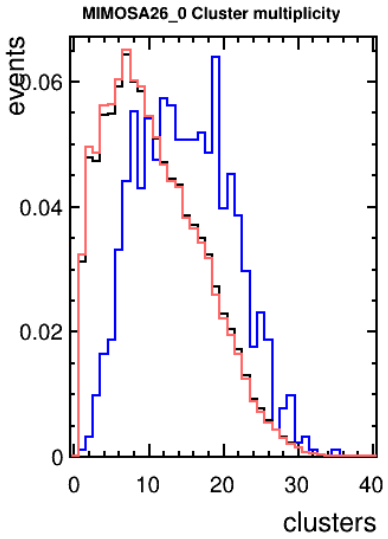
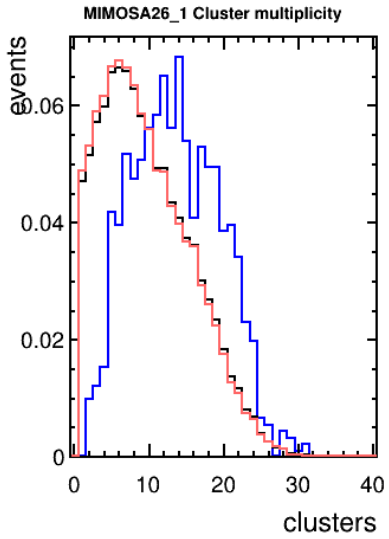
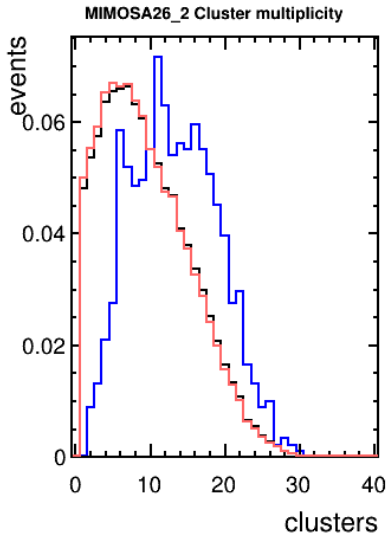
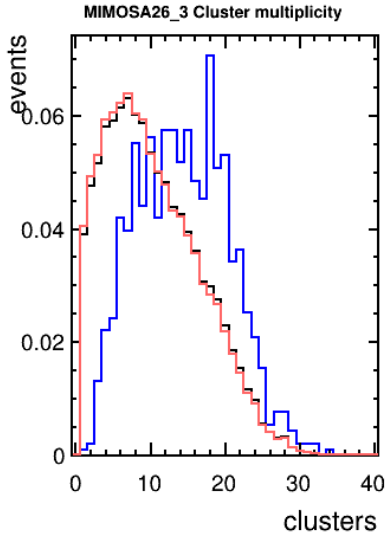


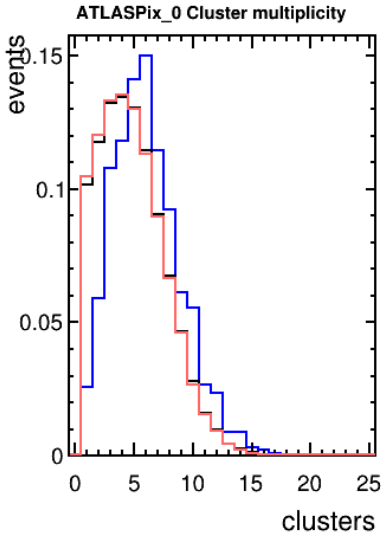


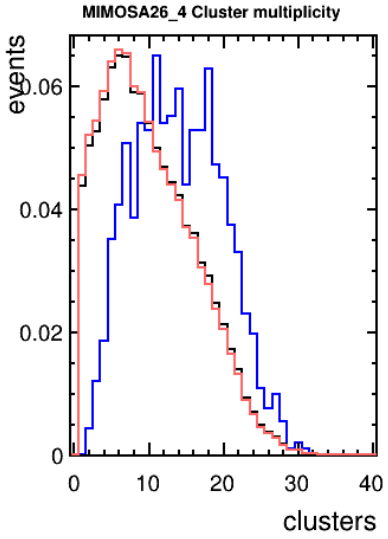


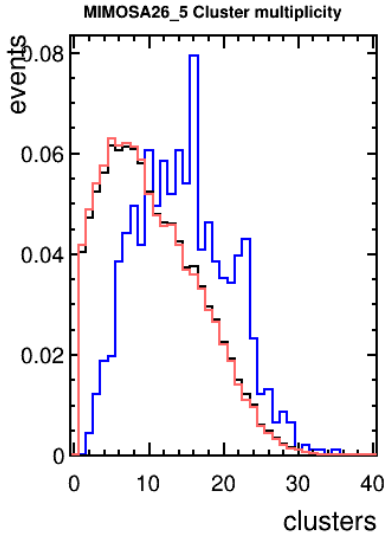


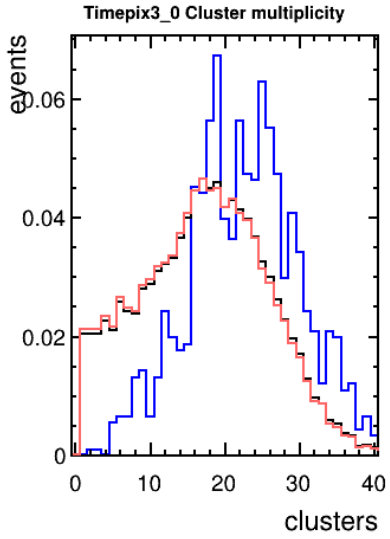






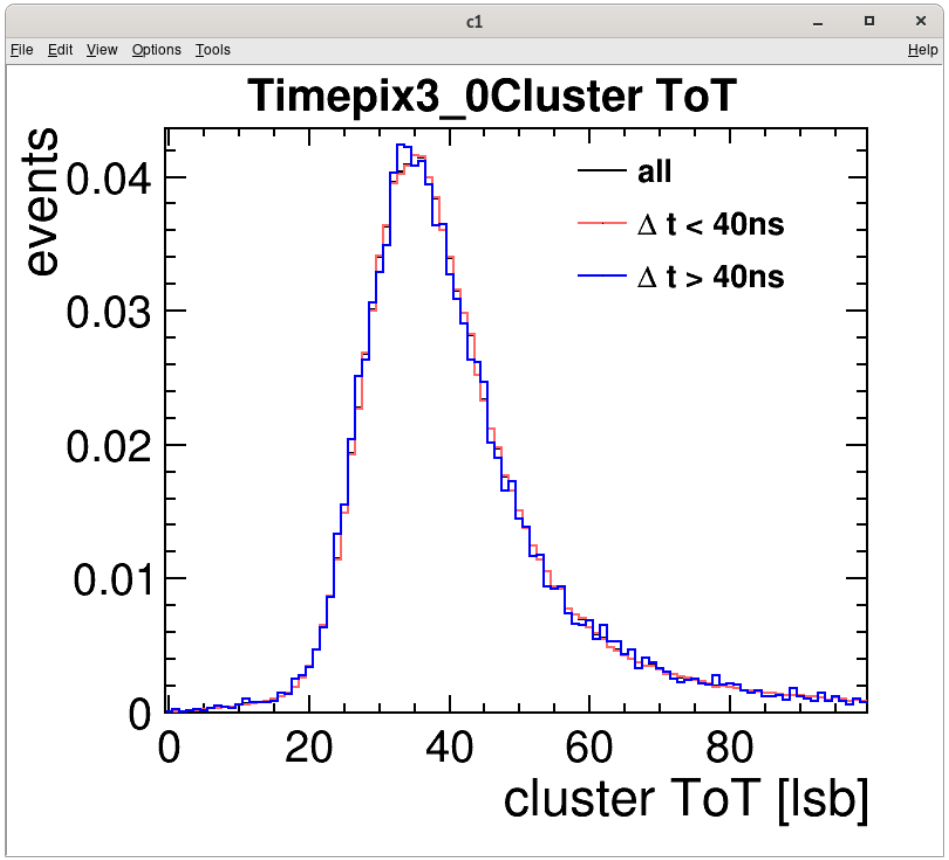


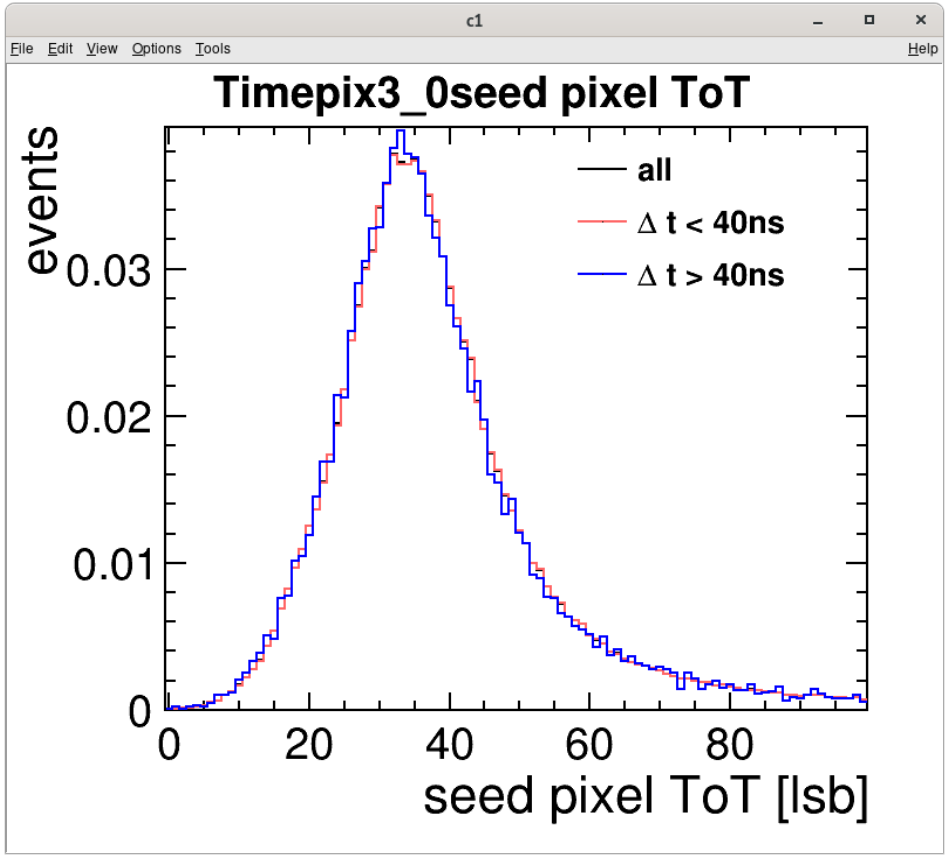




ToT Spectrum:

- cluster ToT spectrum → same
- seed pixel ToT spectrum → same

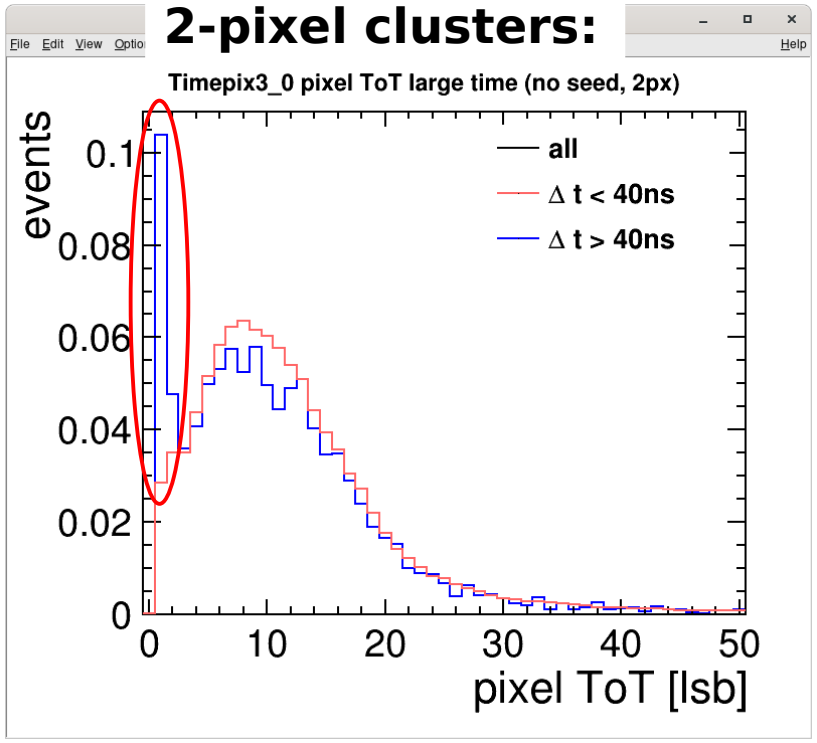




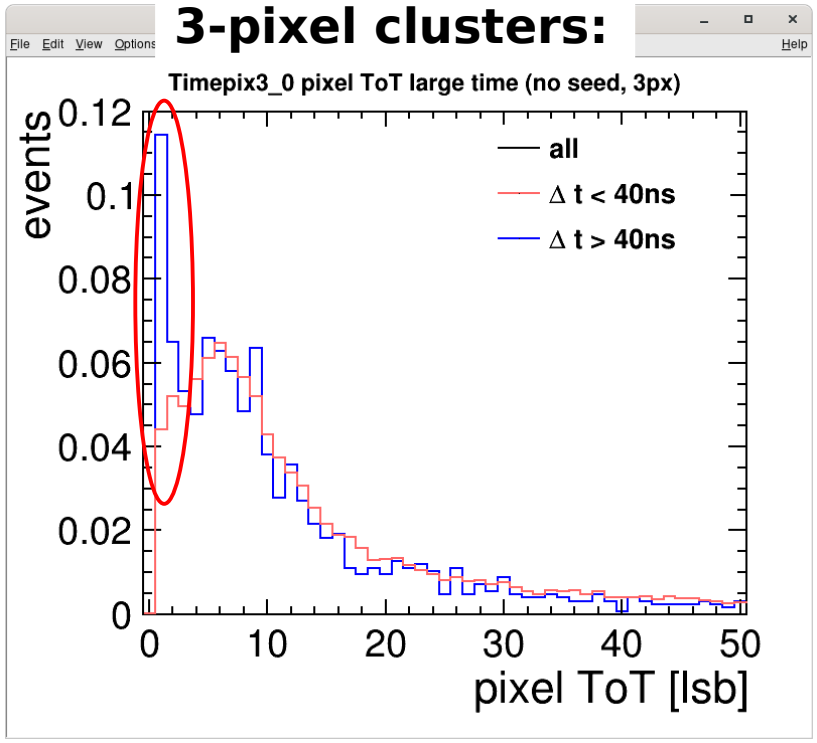
ToT Spectrum without seed pixel:

- secondary pixel(s) sometimes very low ToT
- low ToT→ effect on the analysis is negligible
  - small effect on charge-weighted cluster position
  - no effect on timestamp

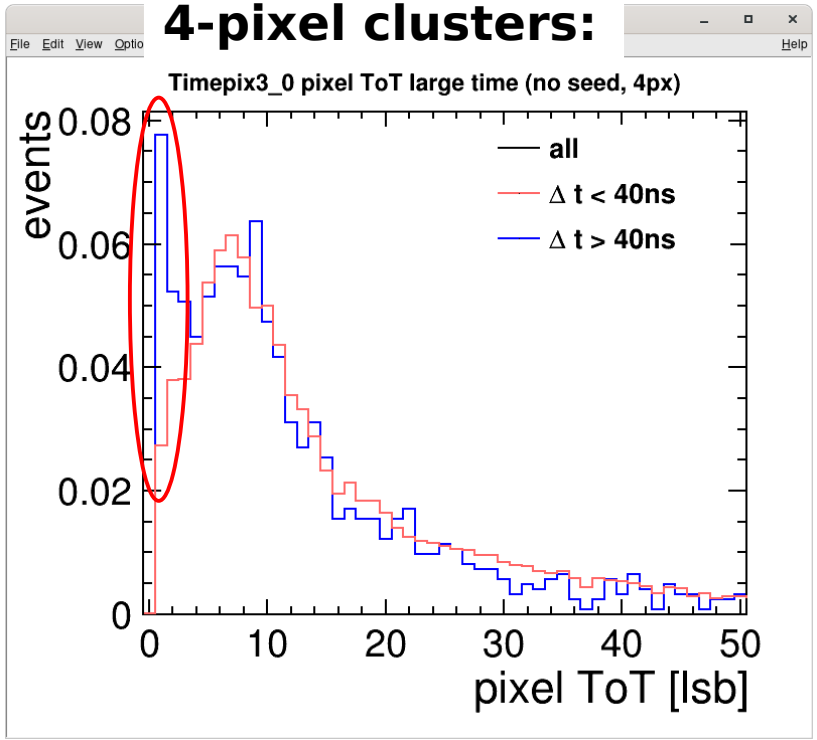
2-pixel clusters:



3-pixel clusters:



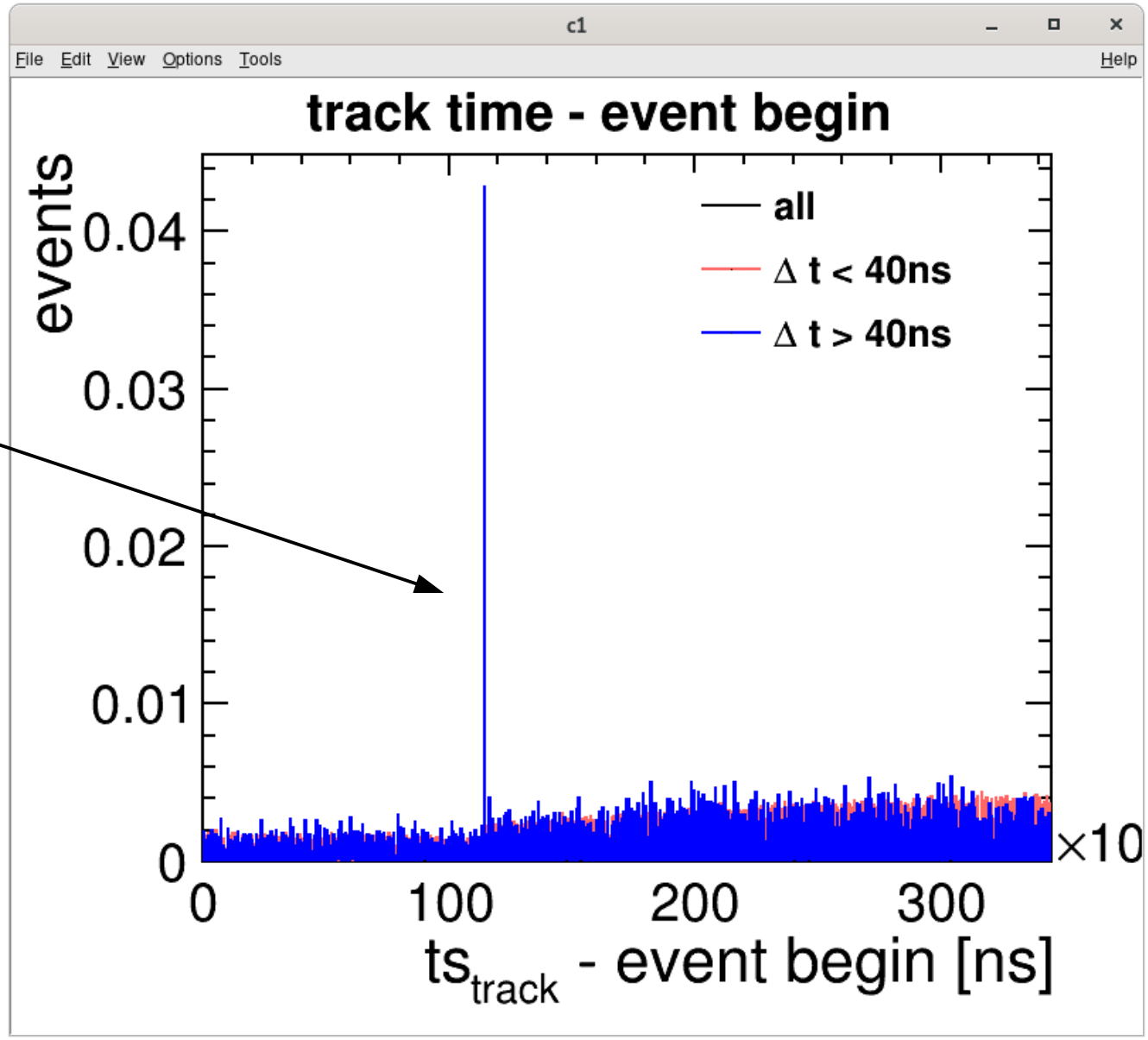
4-pixel clusters:



Time within event:

- event length = 345 µs
  (due to Mimosa26 readout cycle)
- peak at 115 µs as expected
  = trigger time from TLU

→ nothing suspicious



Summary & Conclusion

large timing cut:

- no ToT bump in ToT spectrum
- slightly better biased residuals
- don’t cut into in-cluster timing
- no change in relevant track chi2/ndof regime for further analysis: 0-5
- large in-pixel Δt correlated with higher occupancy (?)

Possible interpretation:

If too small timing cut:
split real clusters

→ more tracks (but bad chi2)

→ worse biased residuals
(because cluster centre is off)

small timing cut:

- low ToT bump in ToT spectrum
- slightly worse biased residuals
- more tracks but mostly chi2/ndof → overflow bin
- hard cut into in-cluster timing spectrum

But:

- physics effect for large Δt within cluster not understood
- Why correlated with higher occupancy if not merging independent clusters?

→ any ideas?

Summary & **Conclusion**

→ if large time cut for cluster:

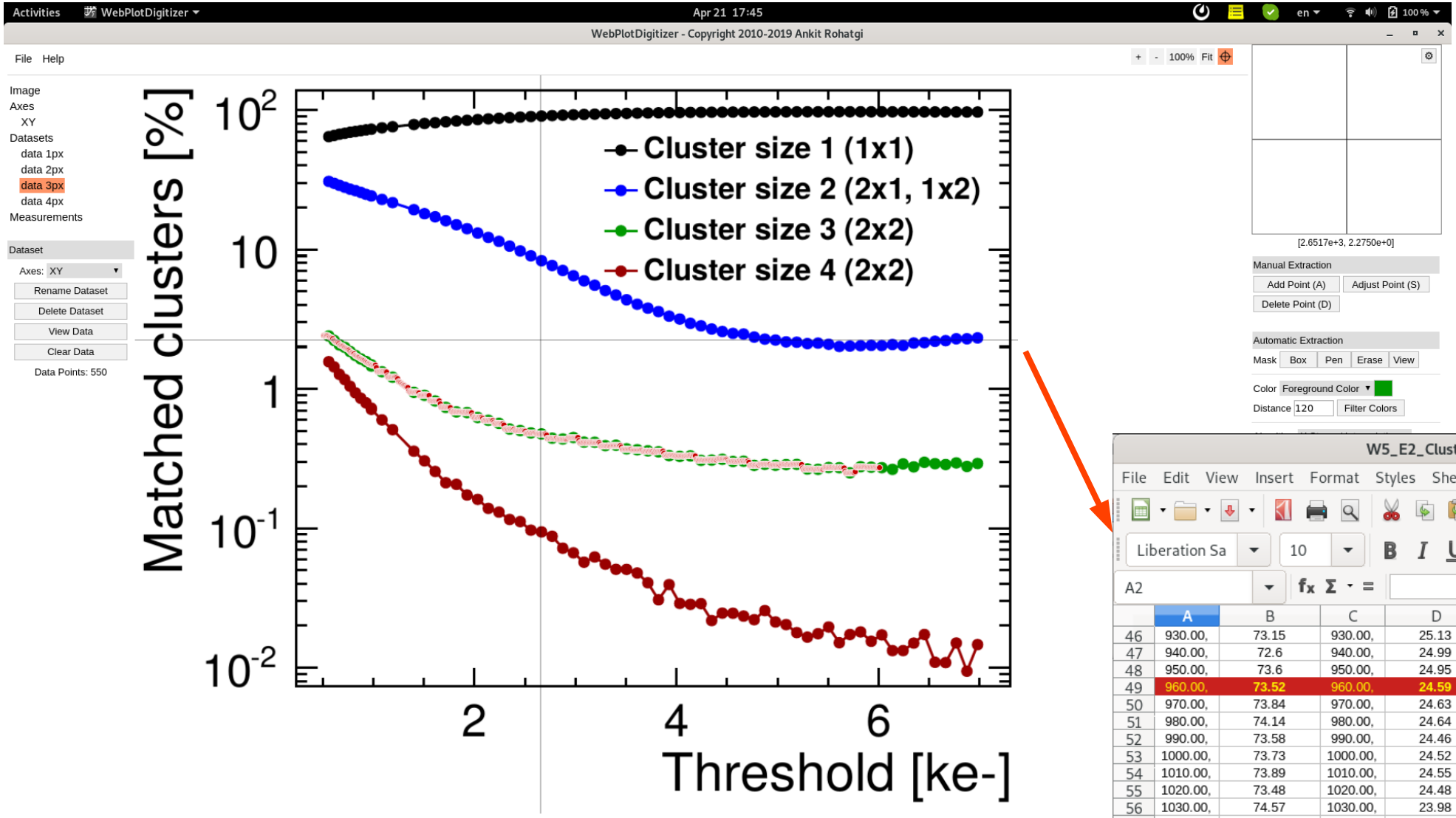
- no (significant) “independent cluster” merging
  - # clusters ~ stable for time_cut_rel > 20
  - spatial residuals don’t get worse → no visible pull on cluster position
  - still low occupancy: ~ 40 pixels per 345 µs

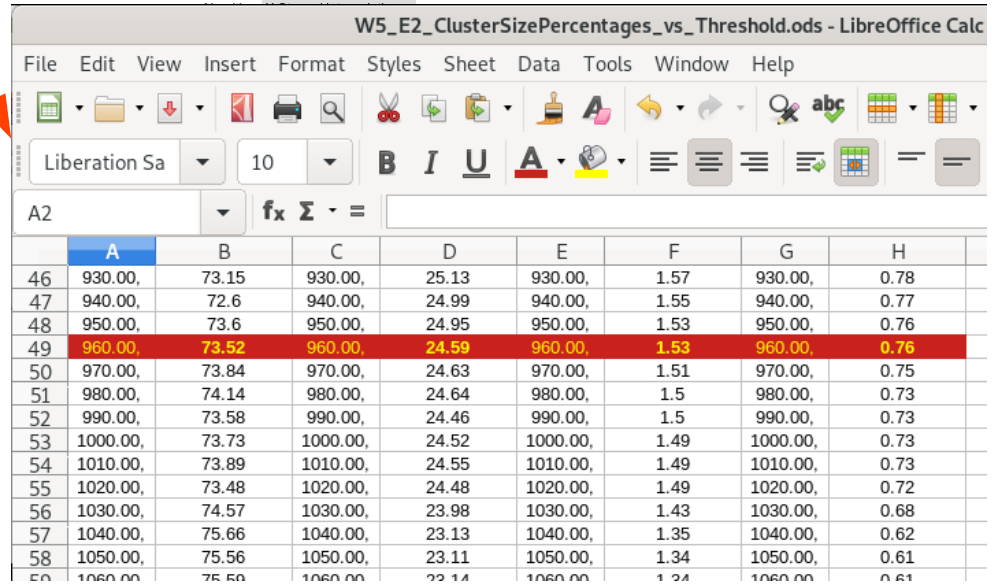
- no influence on cluster time
  - seed pixel ToT spectrum unchanged & seed pixel defines timestamp

Backup

in case there are some questions...

WebPlotDigitizer: get values from plot





	A	B	C	D	E	F	G	H
46	930.00,	73.15	930.00,	25.13	930.00,	1.57	930.00,	0.78
47	940.00,	72.6	940.00,	24.99	940.00,	1.55	940.00,	0.77
48	950.00,	73.6	950.00,	24.95	950.00,	1.53	950.00,	0.76
49	960.00,	73.52	960.00,	24.59	960.00,	1.53	960.00,	0.76
50	970.00,	73.84	970.00,	24.63	970.00,	1.51	970.00,	0.75
51	980.00,	74.14	980.00,	24.64	980.00,	1.5	980.00,	0.73
52	990.00,	73.58	990.00,	24.46	990.00,	1.5	990.00,	0.73
53	1000.00,	73.73	1000.00,	24.52	1000.00,	1.49	1000.00,	0.73
54	1010.00,	73.89	1010.00,	24.55	1010.00,	1.49	1010.00,	0.73
55	1020.00,	73.48	1020.00,	24.48	1020.00,	1.49	1020.00,	0.72
56	1030.00,	74.57	1030.00,	23.98	1030.00,	1.43	1030.00,	0.68
57	1040.00,	75.66	1040.00,	23.13	1040.00,	1.35	1040.00,	0.62
58	1050.00,	75.56	1050.00,	23.11	1050.00,	1.34	1050.00,	0.61

One other thing: alignment drift at DESY

In July 2019 (not in June 2019, same beamline):

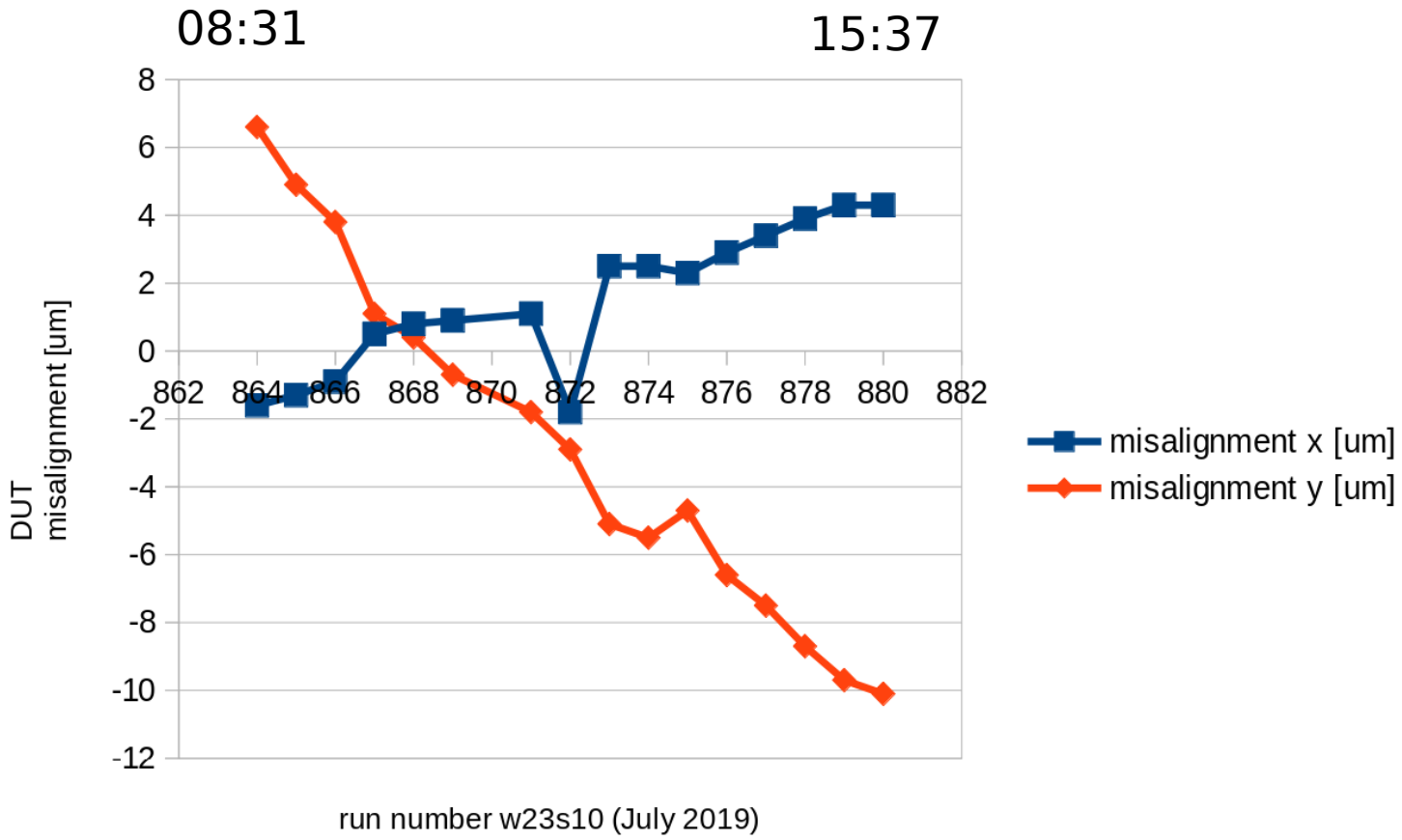
observed that DUT sags over time:

During runs it’s okay

Have to perform re-alignment ru

How can this happen?
Screw not tight enough?

Did other users experience
a sagging XY stage?



Timepix3 DESY/SPS:

Our Timepix3 sensor: W5_E2

- bias = -20 V, thres = 1200 DAC

→ found run 669 from Oct. 2015

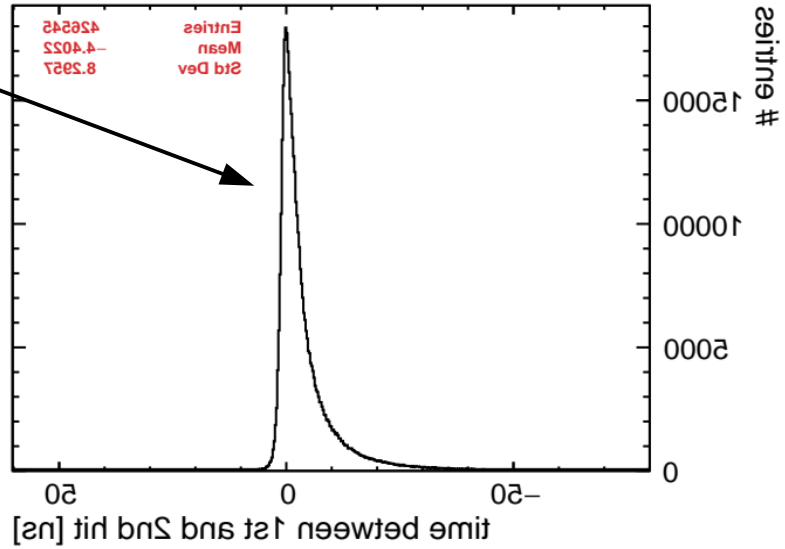
Also compare with run 661
(which Flo sent me):

- bias = -20 V, thres = 1160 DAC

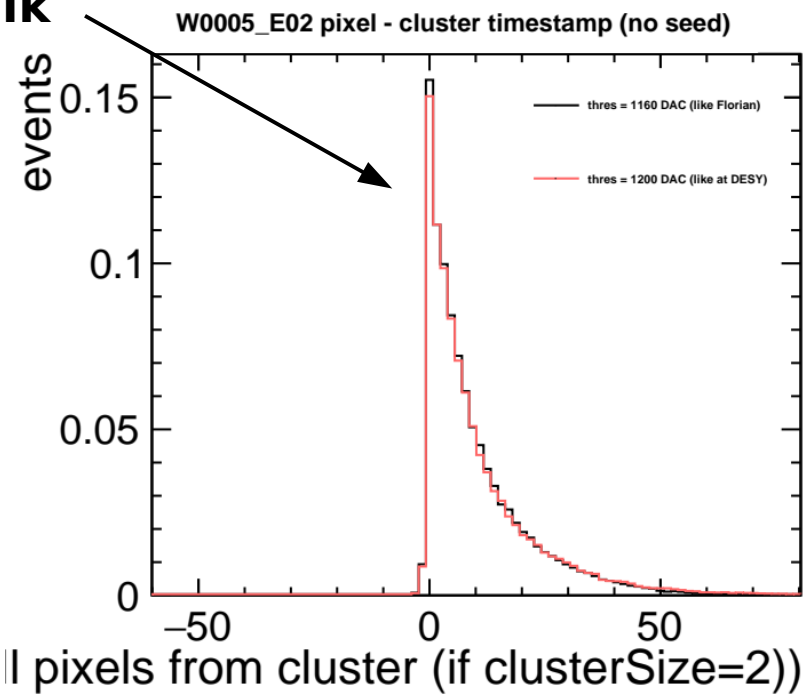
Why is my tail wider than Flo's?

→ No timewalk correction (yet)

**sent by Flo:
run 661
with timewalk
correction**



**no timewalk
correction**

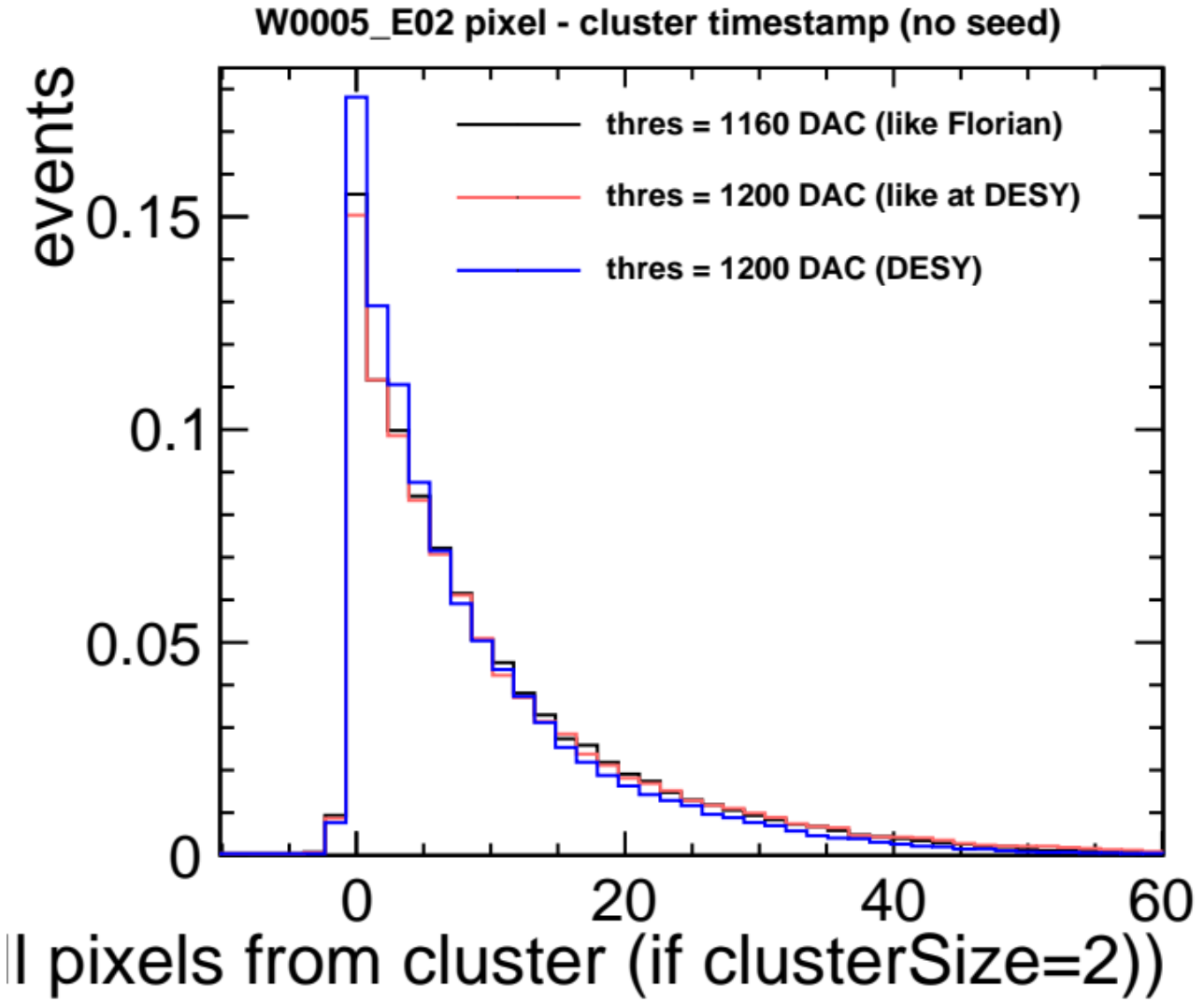


Timepix3 DESY/SPS:

Now compare with DESY:

DESY: even a bit more narrow

→ Looks like it’s all fine and consistent



Timepix3 cluster size:

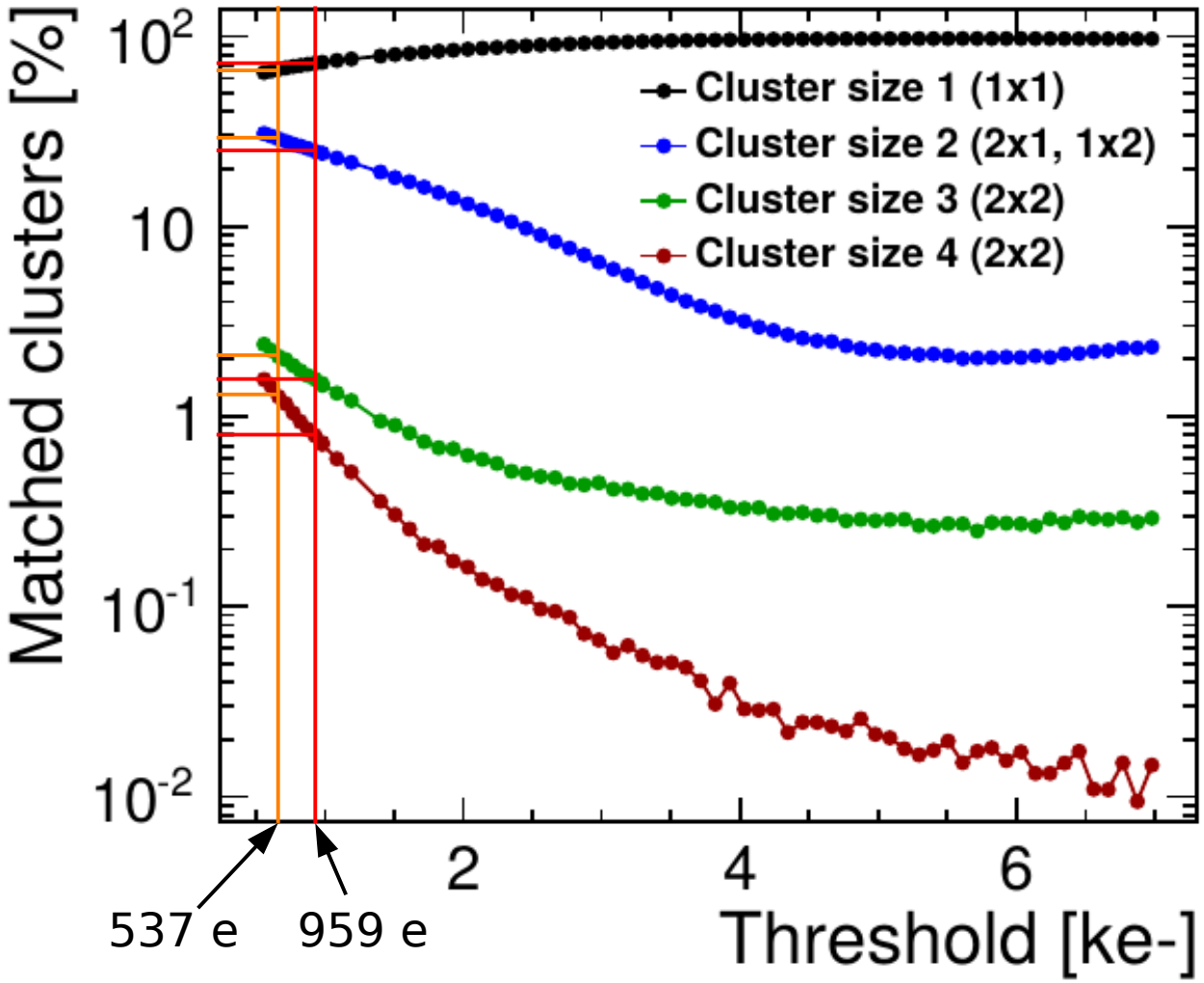
Cluster size fractions:

- bias = -20V → same
- Nilou/Flo:
  thres = 1160 DAC = 537 e
- we:
  thres = 1200 DAC = 959 e

Calibration (thesis Nilou):

THLe = (1200 – 1109.3)/94.5 ke-
= **0.9598 ke-**

Nilou: Fig. C2 (e)

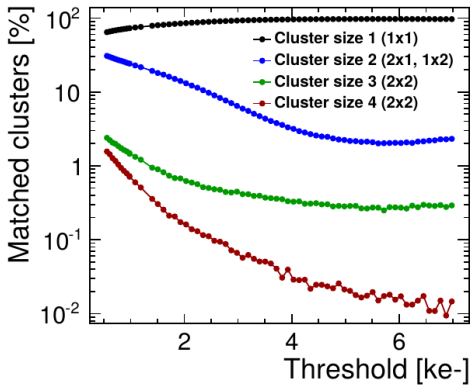


Timepix3 cluster sizes:

Cluster size fractions:

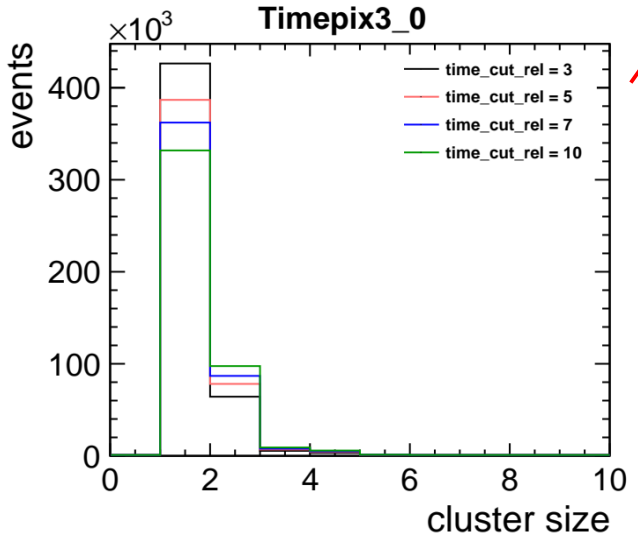
	1160 DAC,	1200 DAC
• 1px:	65.2 %,	73.5 %
• 2px:	31.2 %,	24.6 %
• 3px:	2.4 %,	1.5 %
• 4px:	1.6 %,	0.8 %

extracted from here



best match:
time_cut_rel = 12 ≙ 18.7 ns

DESY July 2019: run 868




```
time_cut_rel = 3
percentage 1px clusters: 0.850326
percentage 2px clusters: 0.128096
percentage 3px clusters: 0.0107599
percentage 4px clusters: 0.00620864
-------------------
time_cut_rel = 5
percentage 1px clusters: 0.808079
percentage 2px clusters: 0.163215
percentage 3px clusters: 0.0142412
percentage 4px clusters: 0.00872815
-------------------
time_cut_rel = 7
percentage 1px clusters: 0.779527
percentage 2px clusters: 0.186899
percentage 3px clusters: 0.0167474
percentage 4px clusters: 0.0104983
-------------------
time_cut_rel = 10
percentage 1px clusters: 0.741973
percentage 2px clusters: 0.218
percentage 3px clusters: 0.0202182
percentage 4px clusters: 0.0128021
-------------------
time_cut_rel = 12
percentage 1px clusters: 0.725534
percentage 2px clusters: 0.231327
percentage 3px clusters: 0.0218729
percentage 4px clusters: 0.0139546
-------------------
time_cut_rel = 15
percentage 1px clusters: 0.707936
percentage 2px clusters: 0.245831
percentage 3px clusters: 0.0235903
percentage 4px clusters: 0.0150358
-------------------
time_cut_rel = 20
percentage 1px clusters: 0.689223
percentage 2px clusters: 0.261462
percentage 3px clusters: 0.0253646
percentage 4px clusters: 0.0160504
```

Cluster ToT: low ToT bump

time_cut_rel = 40 - 60
→ low ToT peak disappears

before: seed pixel ToT, **now: cluster ToT**