ROPPERI

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LCTPC Collaboration Meeting
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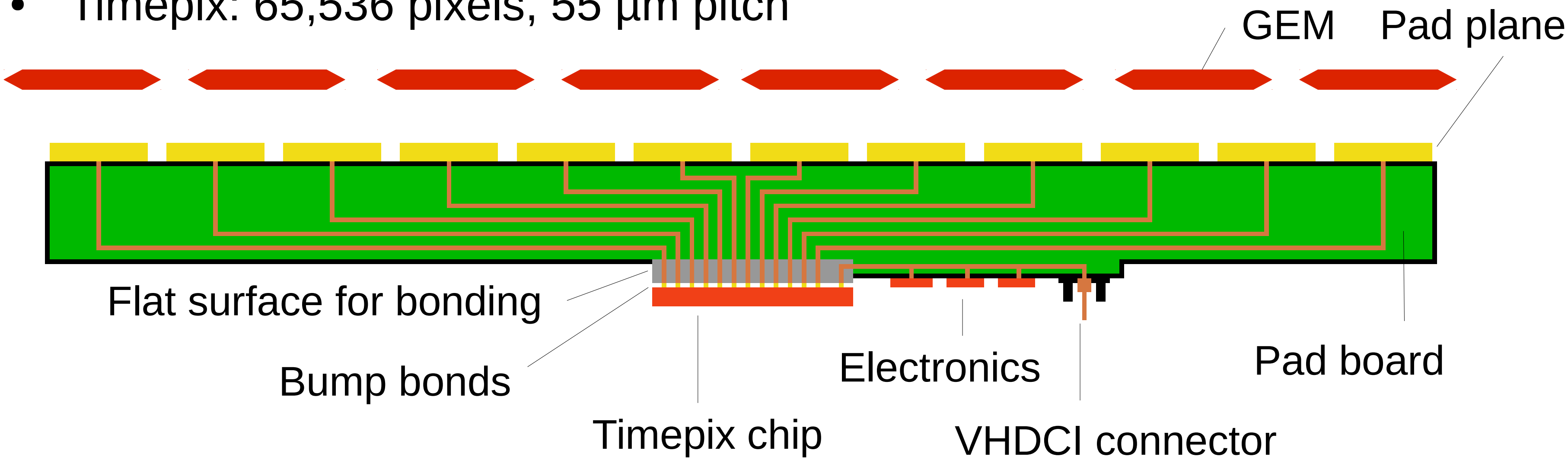
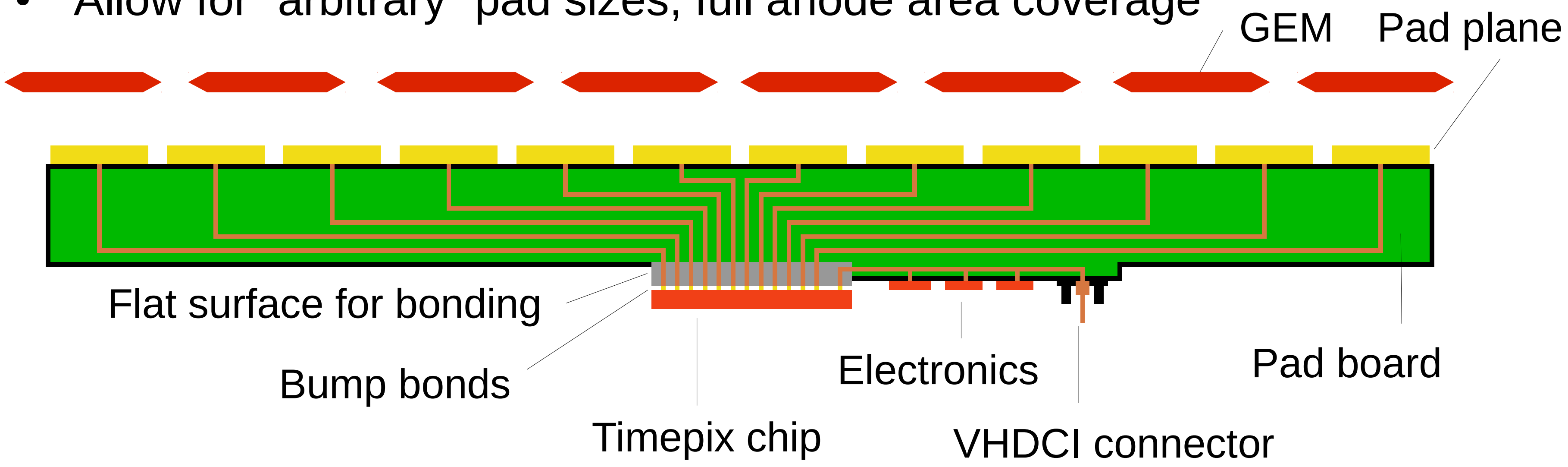
ROPPERI Ansatz

- GEMs, small pads, Timepix chip as readout electronics
- Connections from pads to chip are routed through the board, then bump bonded to the chip
- Timepix wirebond pads for the communication channels are on the same side as the pixels → also bump bonded, back to the board
- Timepix: 65,536 pixels, 55 µm pitch



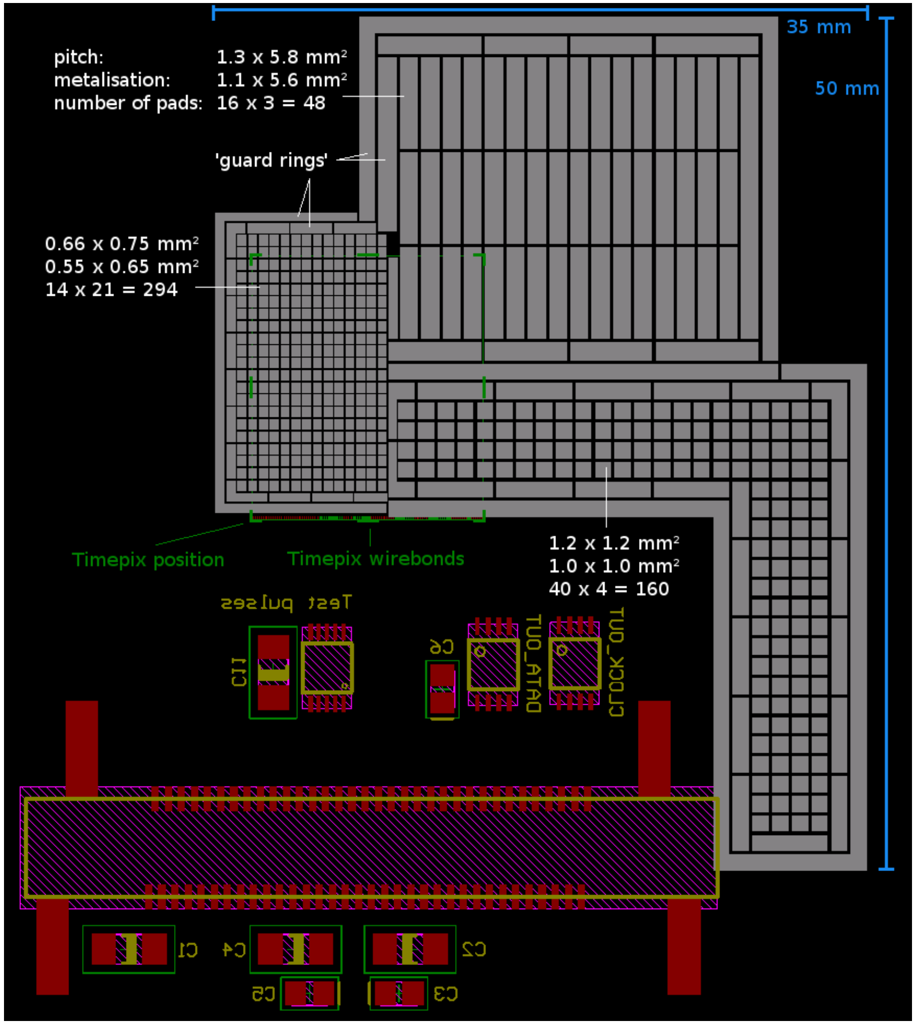
Benefits

- Compared to the existing GEMs+pads system:
  - Higher granularity → better occupancy, double track resolution, possible cluster counting
  - Square pads, several pads per charge cloud → no $\tan^2\theta$ -effect
  - High integration: O(30) smaller footstep
- Allow for “arbitrary” pad sizes, full anode area coverage



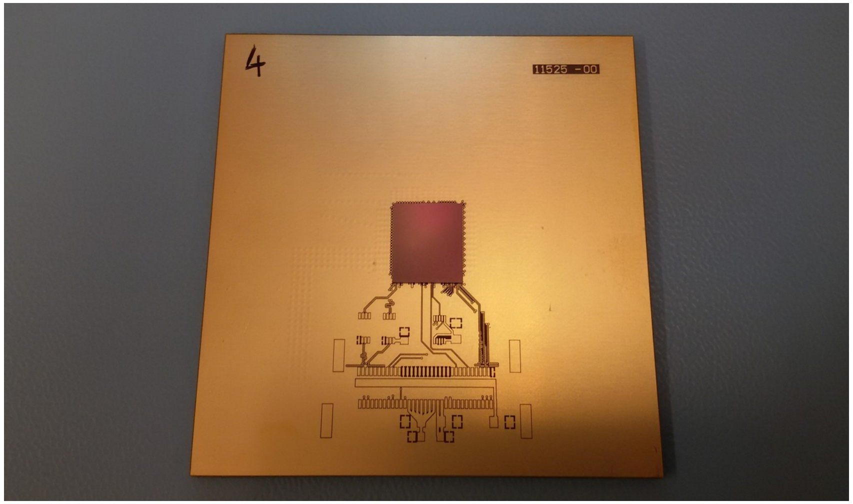
Concept

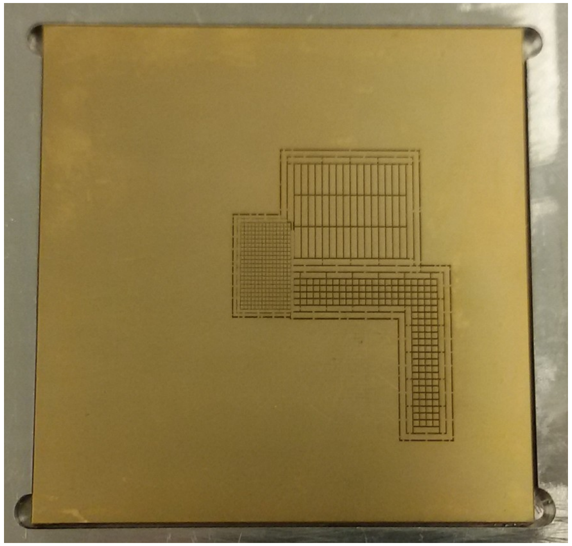
- Prototype board:
- PCB of 9 x 9 cm²
- 3 pad sizes and different connection lengths to be tested, smallest pads with shortest connections directly on the chip → influence of capacitance
- 500 channels connected in total
- To be used with 10 x 10 cm² GEMs in a small TPC
- ENEPIG coating for bonding



1st generation

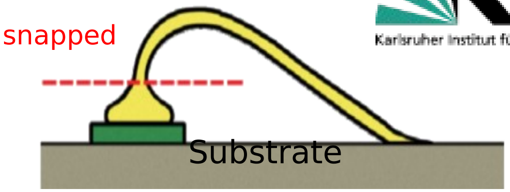
- First 3 prototype boards were ordered for Nov 2016,
- 1st production: Jan 2017, no trough vias
- 2nd production: Mar 2017, bad metalisation
- 3rd production: May 2017, successful, only 2 boards
- First one bonded twice, second time successfully
- Second bonded with pillars was mechanically unstable
- Got 1 readout, then system broke



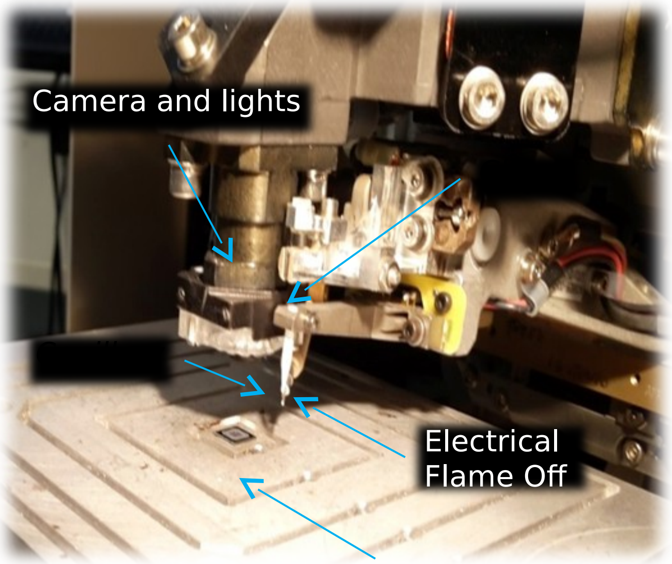


Stud Ball Bumping (SBB) process

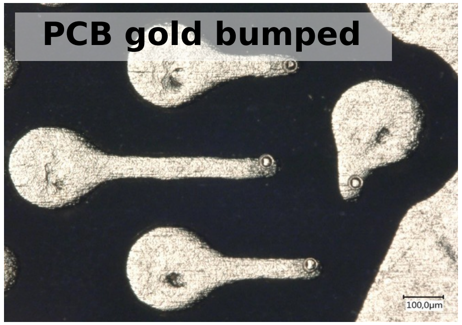
Gold stud bumping is an evolution of the ~ 60 years-old wire bonding process. **Gold stud ball**: the wire is snapped off after the ball is initially connected to the substrate

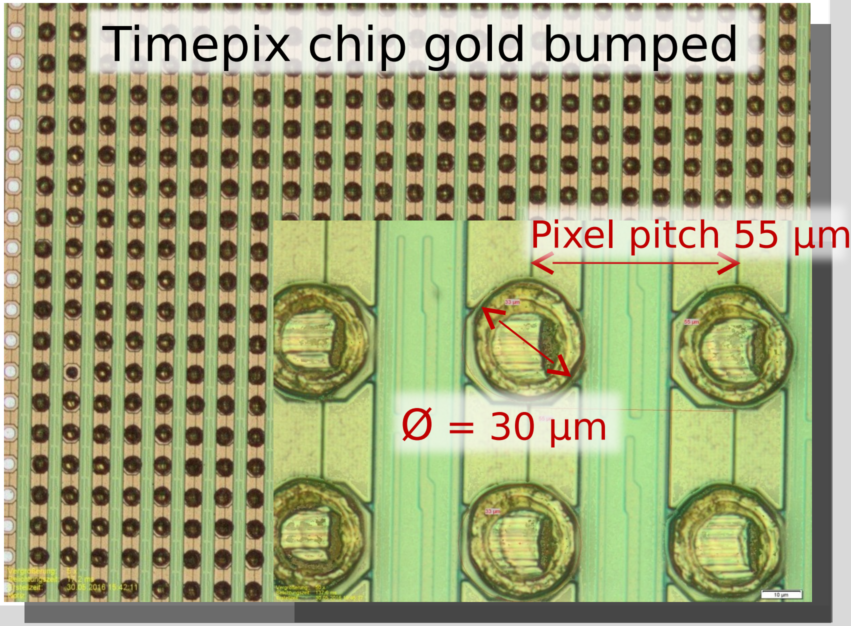


Gold Ball-wedge wire-bonding



- ✓ **Low-cost process**: direct deposition on Al pad (No UBM, lithography process)
- ✓ **Fast deposition**: 20 bumps/s
- ✓ **Short setup time**: ideal for single die bump-bonding (i.e. prototype and R&D)

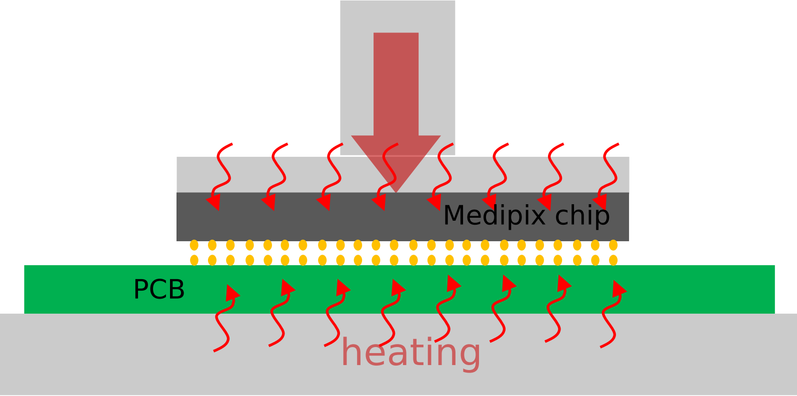




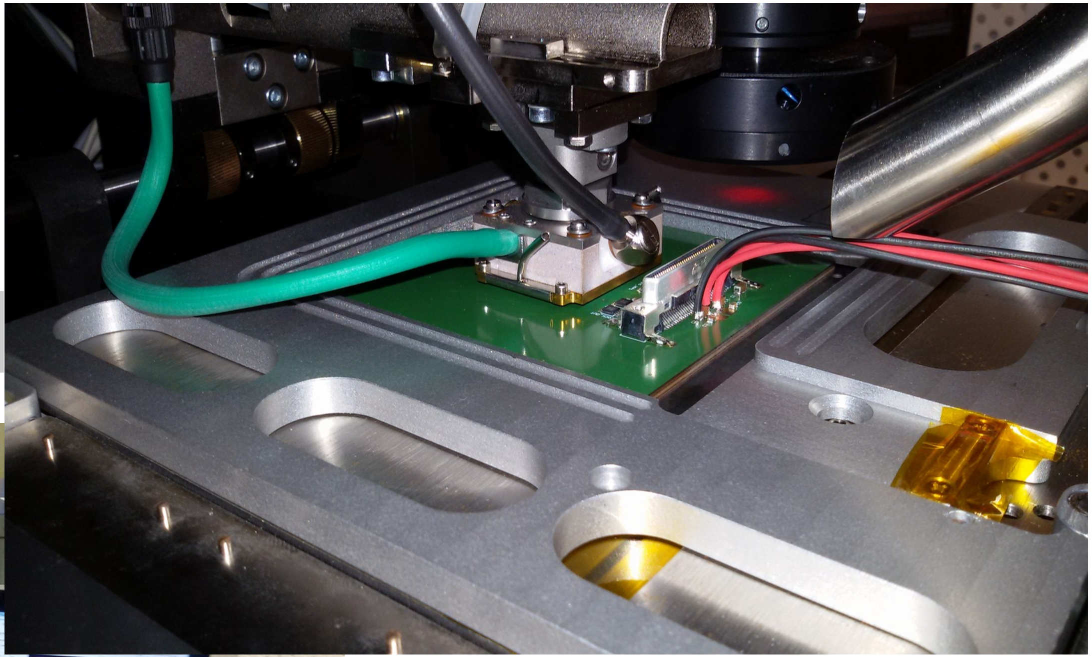
Achieved Bump & pitch size

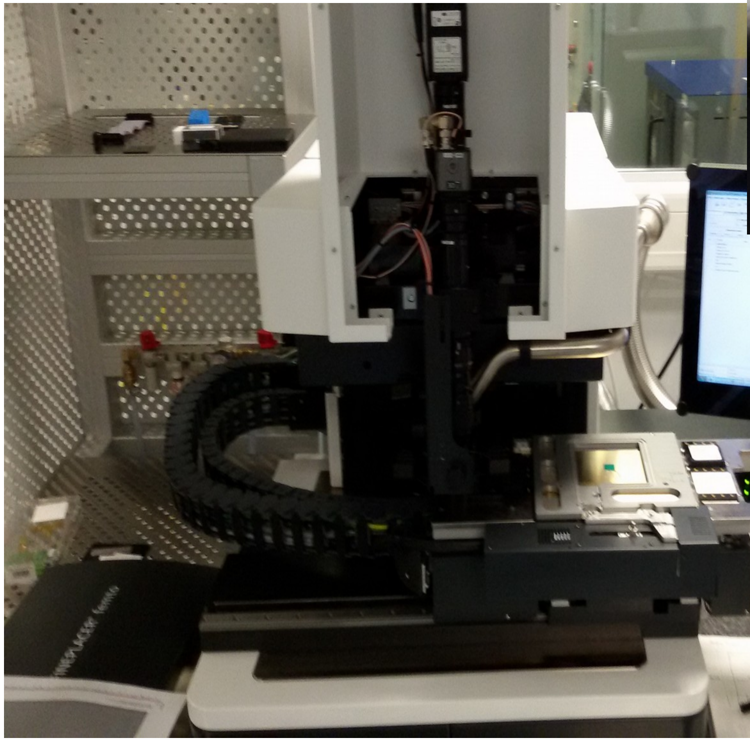
Au wire diameter (µm)	Bump diameter (µm)	Minimum pitch (µm)
25	60	100
15	30	50
12.5	23	35

Flip-Chip Process - Bonding Maschine



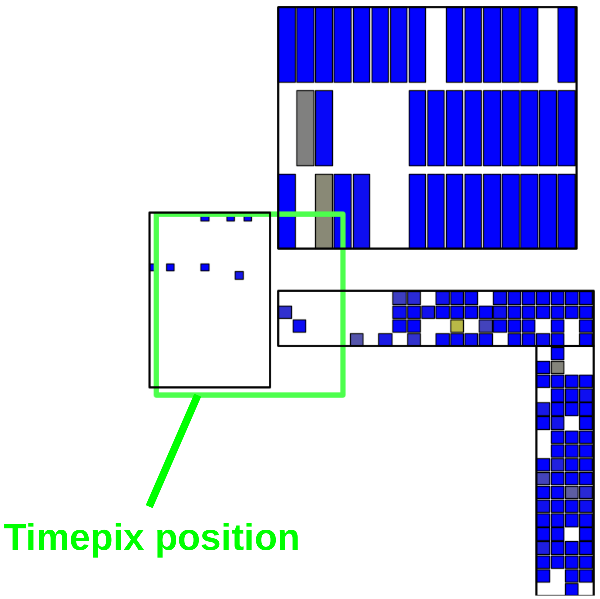
Thermo-compression Bonding process

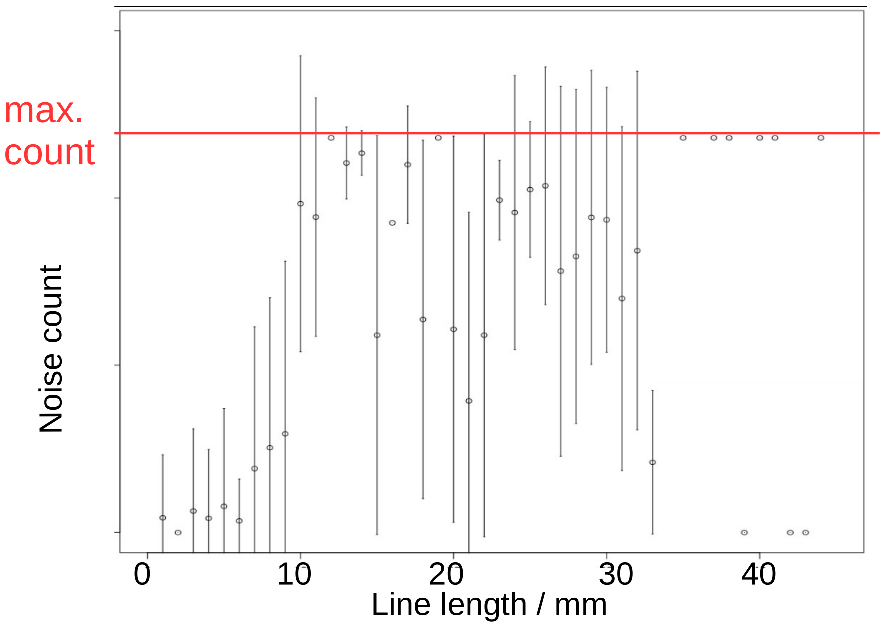




1st generation: Result

- Got 1 reasonably good data set (of noise) before system broke again
- Correlation between pad distance from Timepix and noise consistent with expectation
- Used threshold: 380 counts, typical: 300-400 counts, 1 count = 25 e-

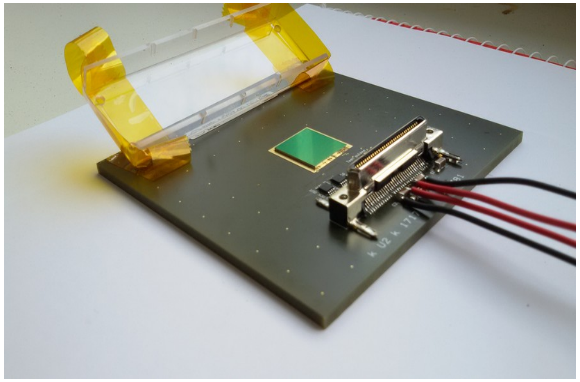




- Large errors, but some confidence reg. noise assumptions

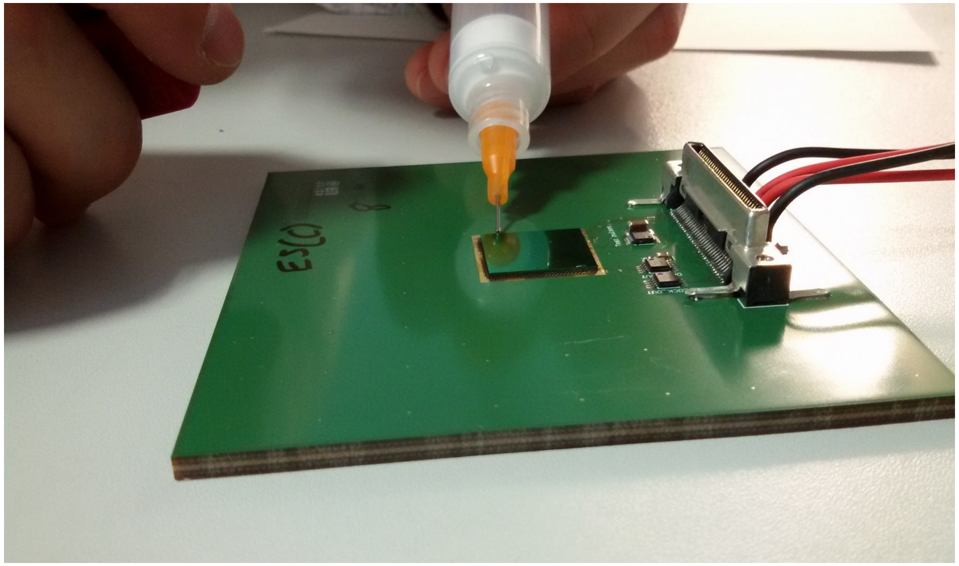
2^{nd} generation

- Biggest issue: coefficient of thermal expansion (CTE)
- This time:
  - PCB with lower CTE and lower bonding temperature
  - More boards
  - Immediate readout
  - Spent several days with group of people on bonding process → Michele Caselle, Markus Gruber, Patrick Pfistner and Sumera Kousar
  - 1. Apply gold studs from 25 µm wire to PCB → rather feasible, but O(10) by-hand corrections to be done
  - 2. Apply gold studs from 15 µm wire to Timepix → difficult to find correct parameters, optimise for bonding strength

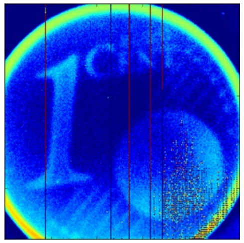


Bonding Result

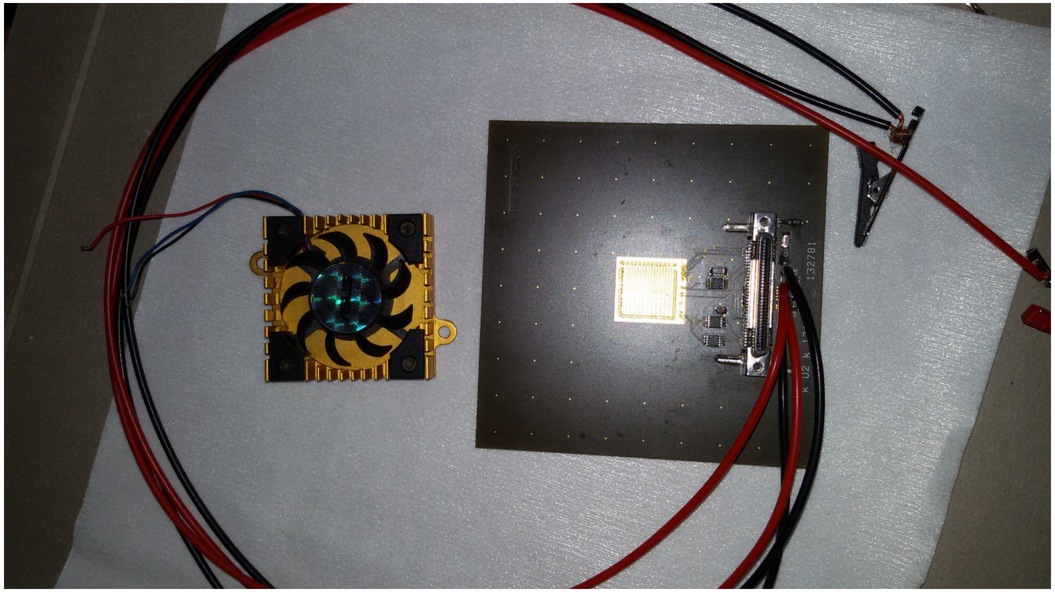
- 7 boards bonded, 6 worked for at least some time, 3 worked in the end
- Data taken: 'threshold campaigns'
  → for different thresholds, runs with 100-200 frames
- Clear signs of temperature issue breaking connections
- Underfill applied to 3 boards for mechanical stability, taken to DESY

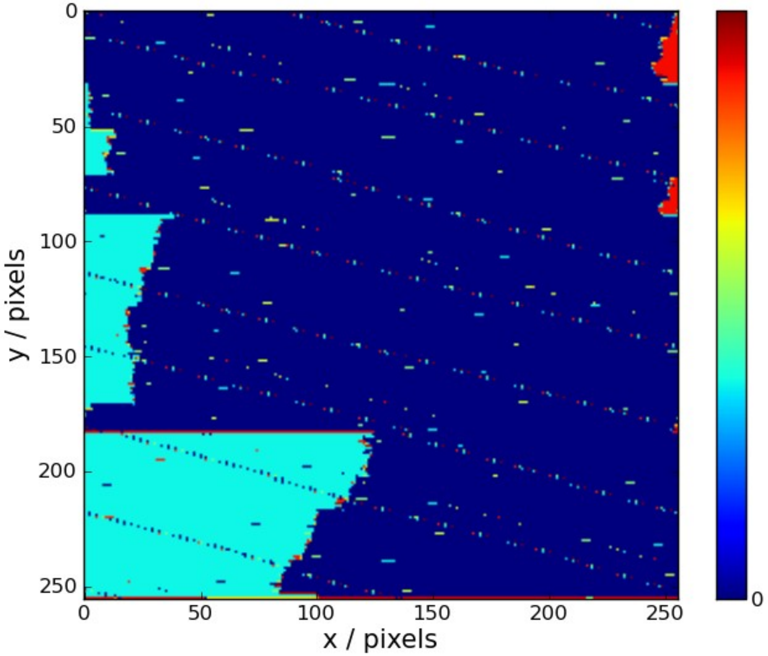


Back at DESY



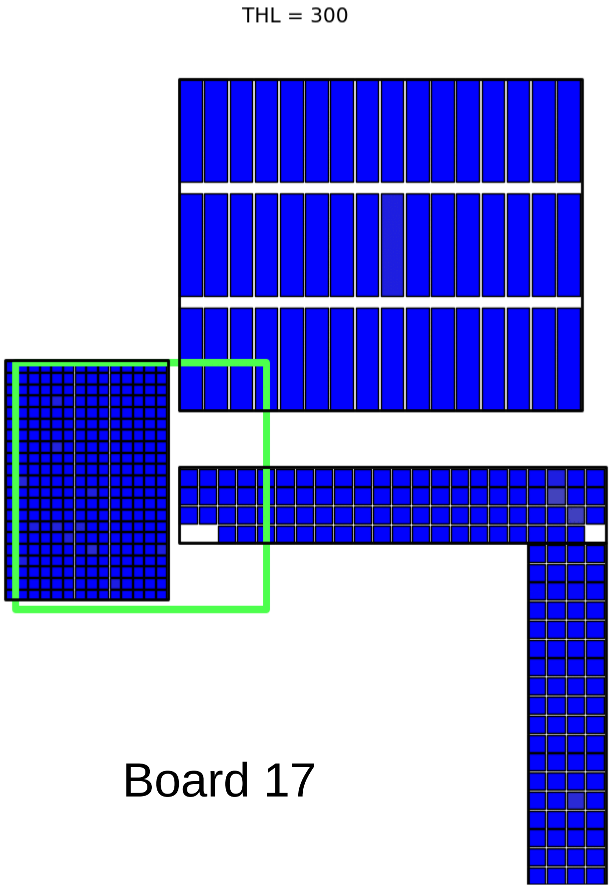
- Applied active cooling blocks + fans to the chips
- One more 'threshold campaign' taken at DESY
- After that, all boards showed similar issues of probable bit shifts



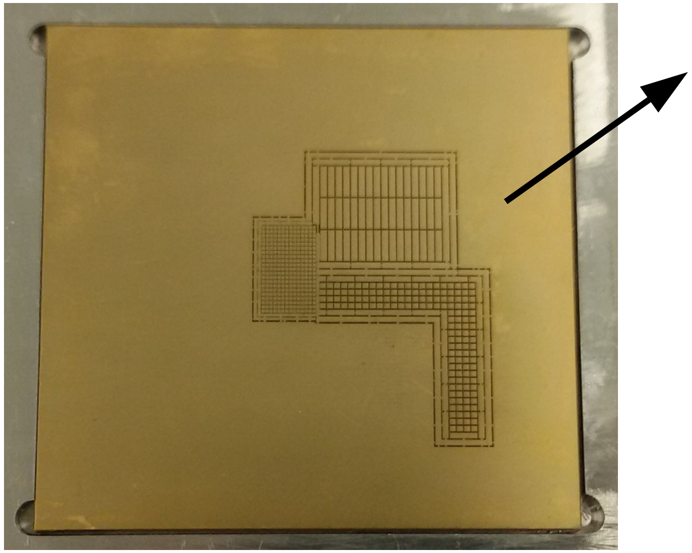


First look into the data

- Active pads in noise at different threshold levels
- Green: Timepix position
- Noise should depend on pad size and line length
- Done for 3 different board, not at the same thresholds

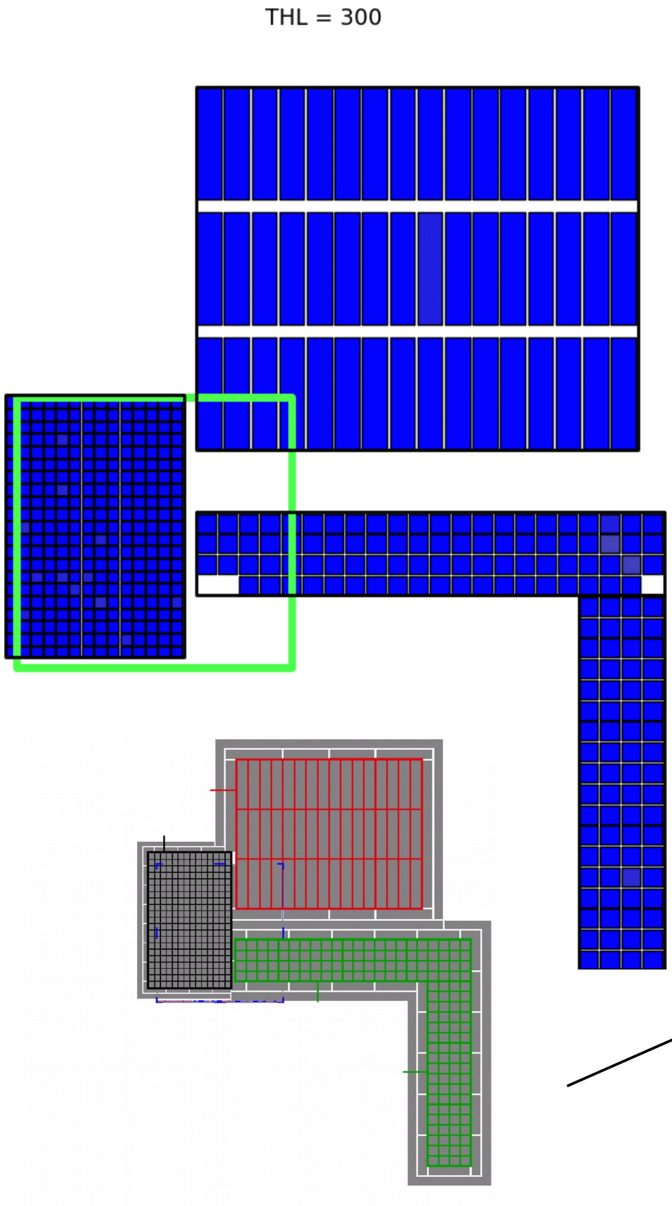


Board 17

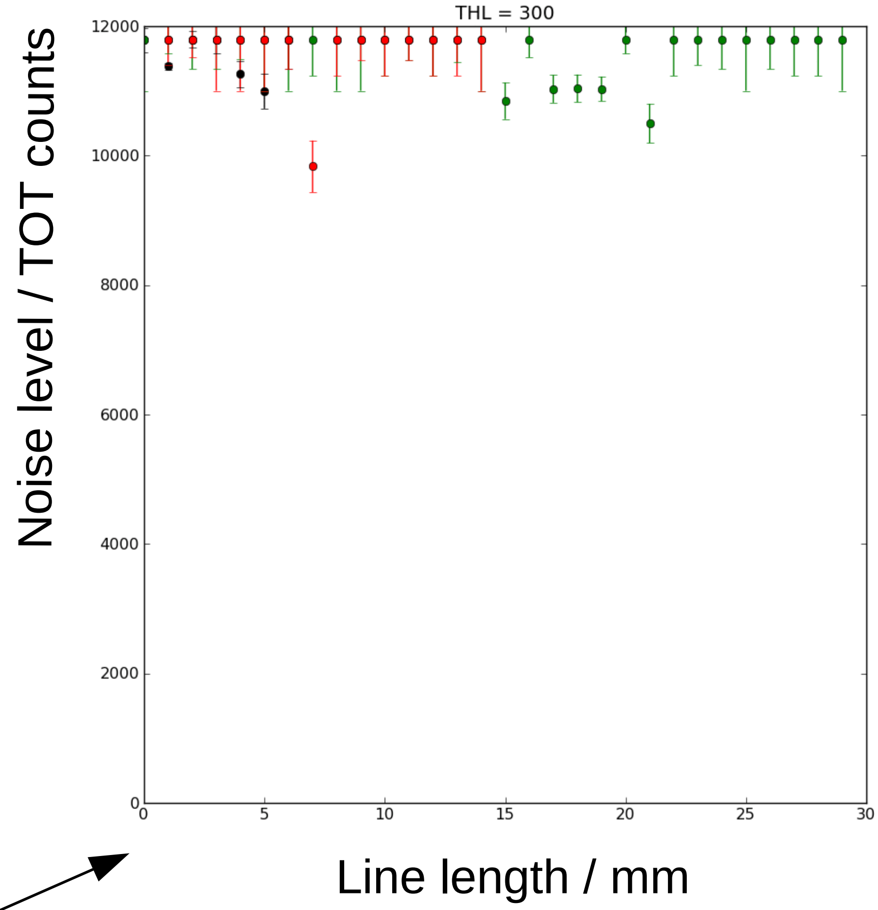


Noise vs. Line Length

Board 17

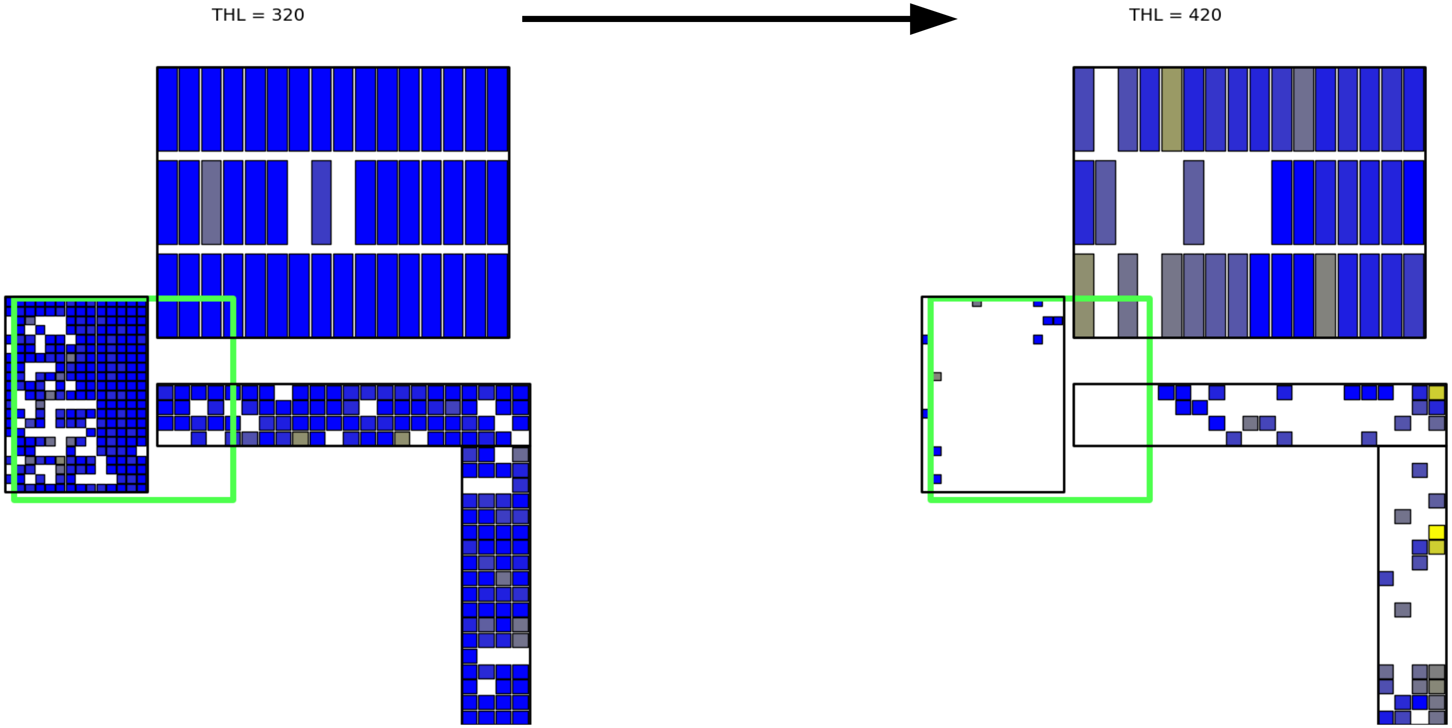


color code



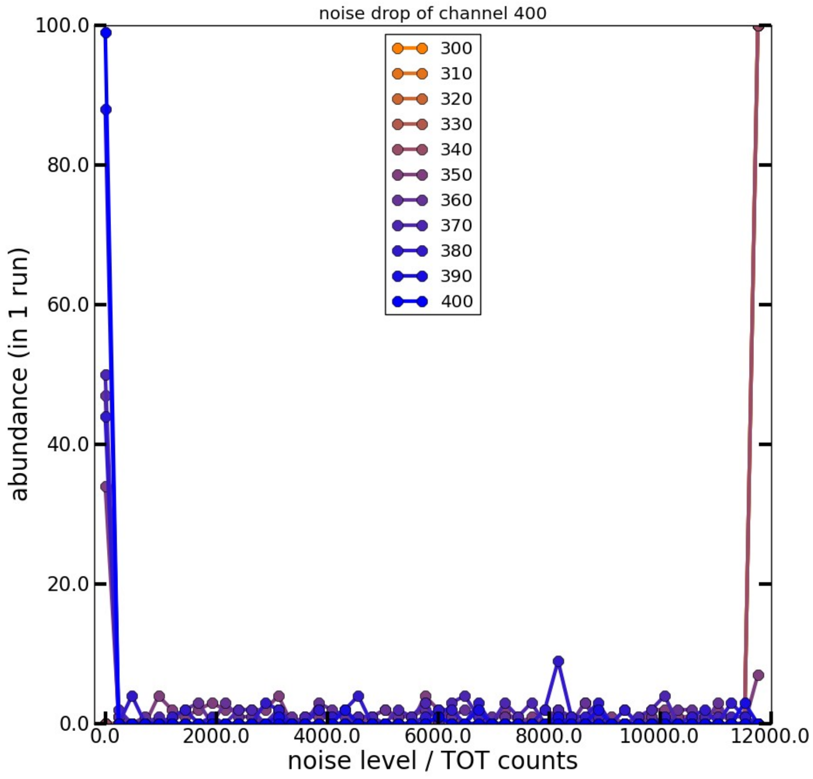
Observed noise drop

THL += 100 DAC = 2500 electrons



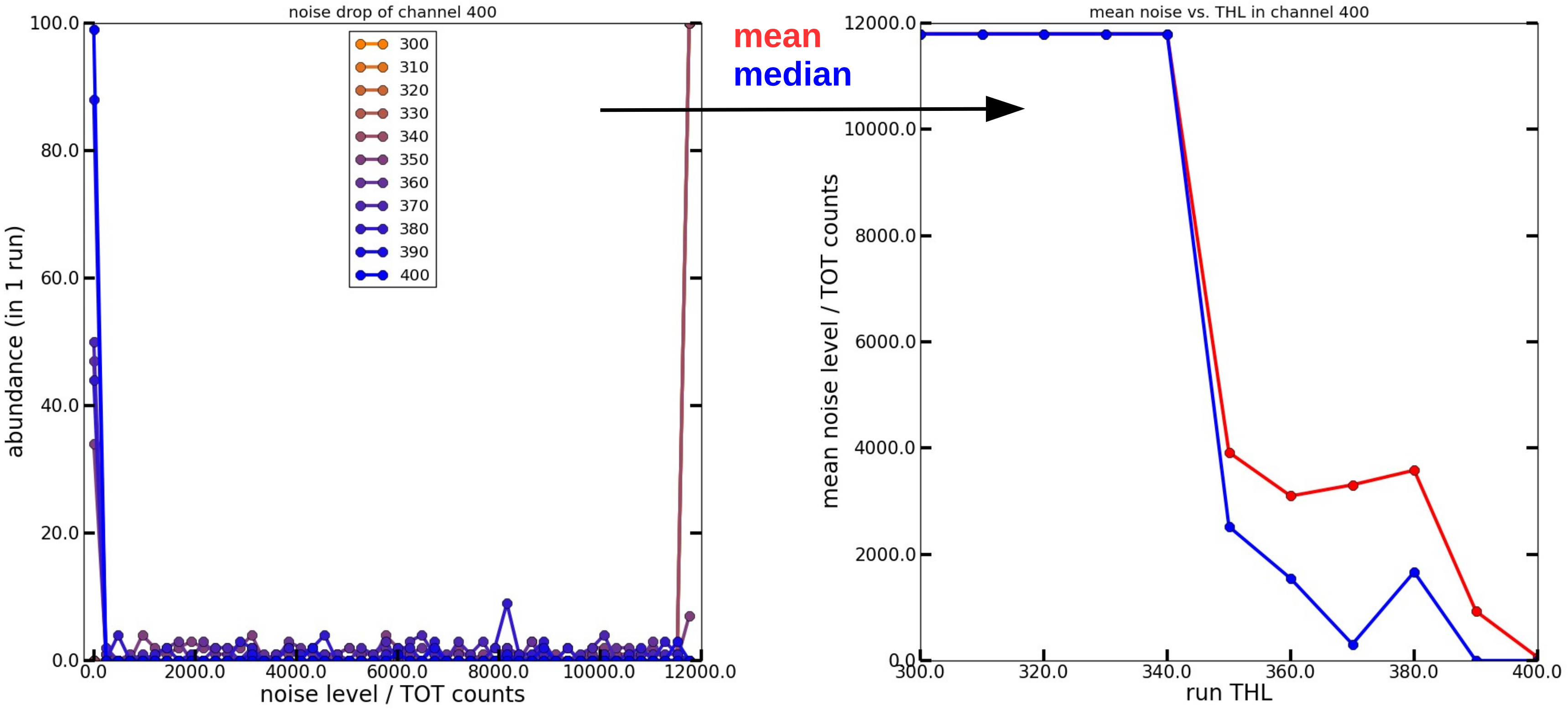
- For one channel: Take 100 frames and plot abundance of noise level, repeat for different thresholds

Take mean or median of the noise



- Most times, the channel is completely silent (0) or completely noisy (11810).
- How does the transition look?
- Check mean and median abundance!

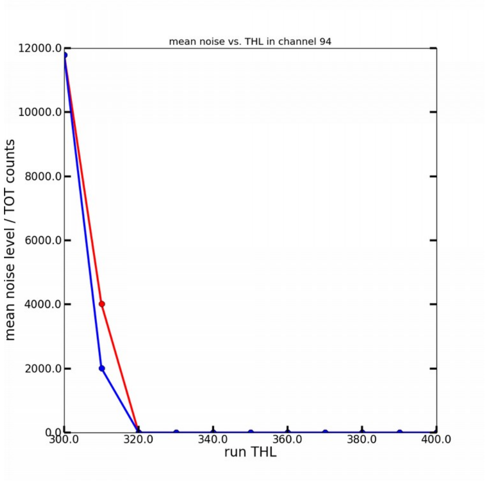
Take mean or median of the noise

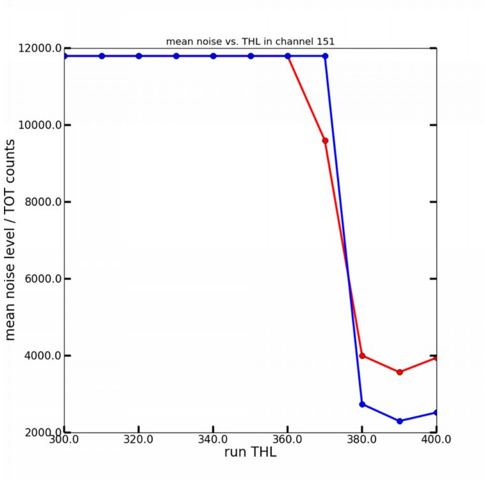


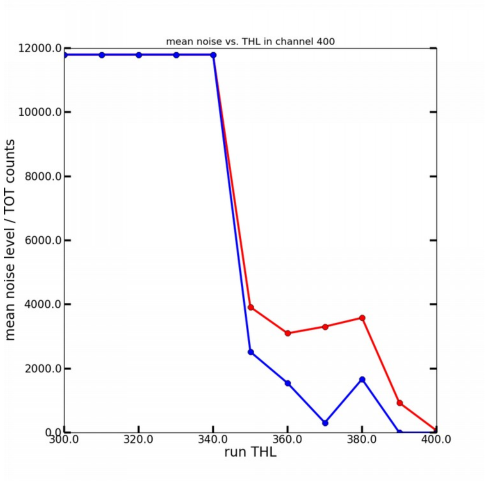
mean

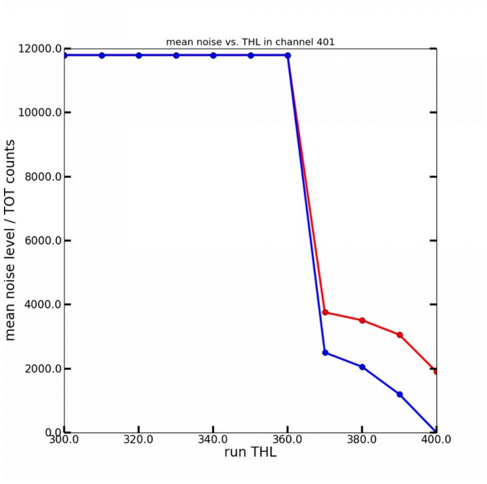
median

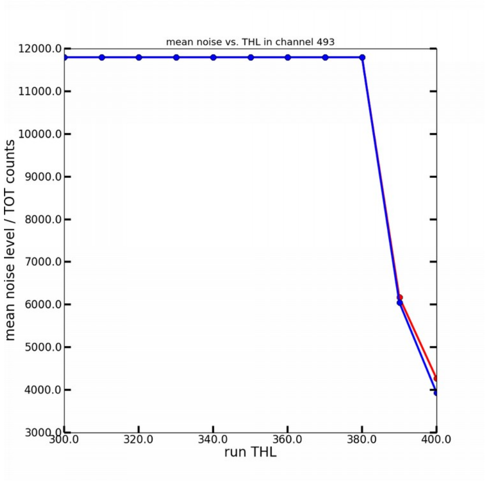
5 example channels





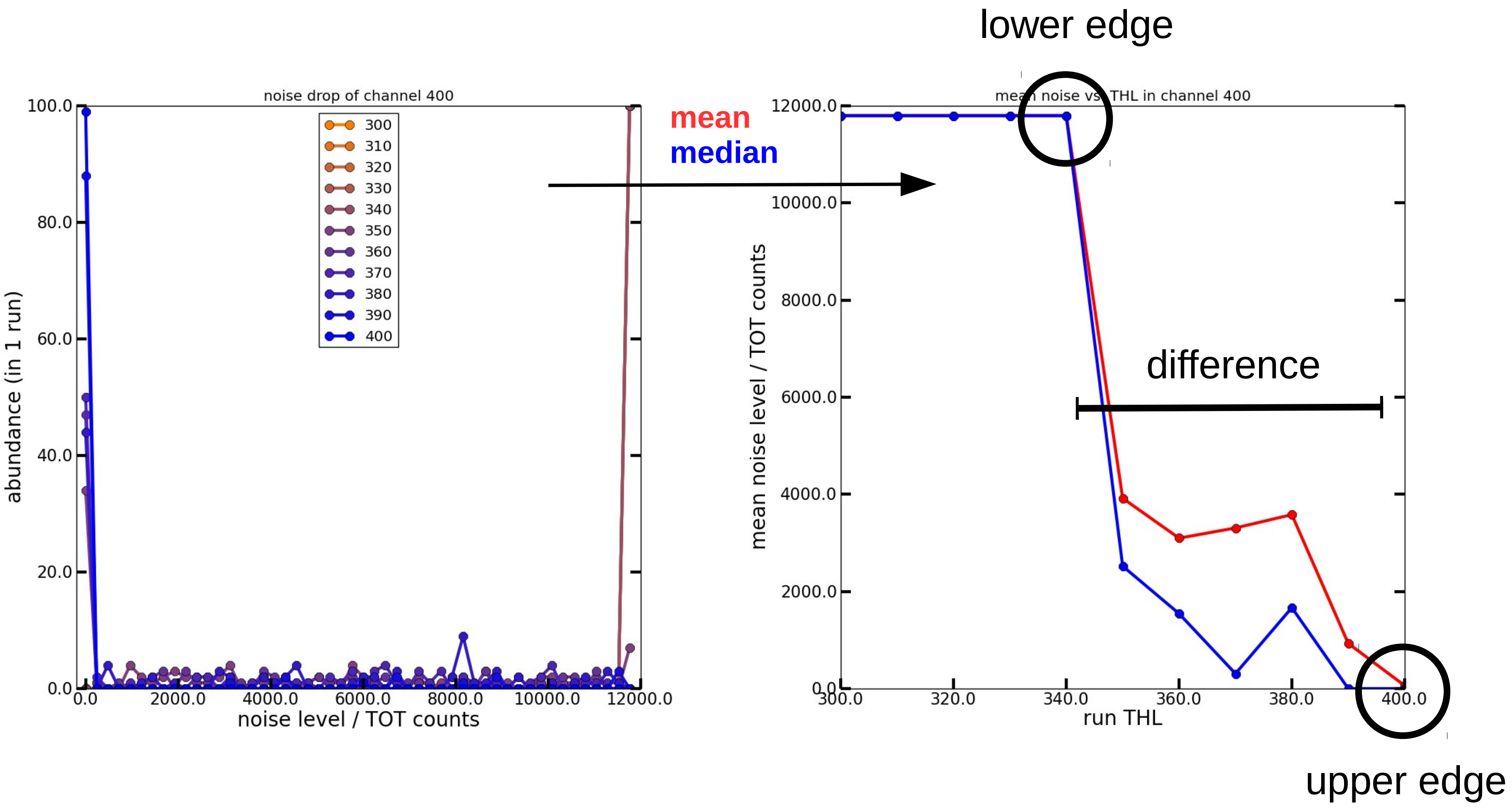






mean
median

Identify edges & difference



lower edge

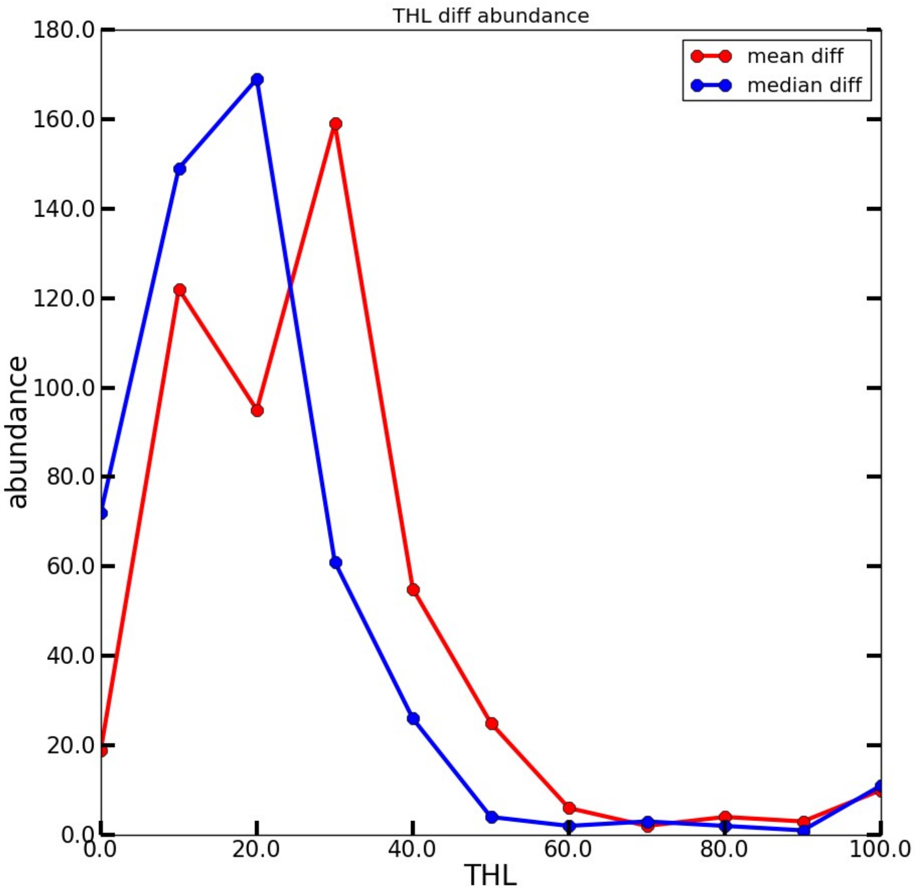
mean

median

difference

upper edge

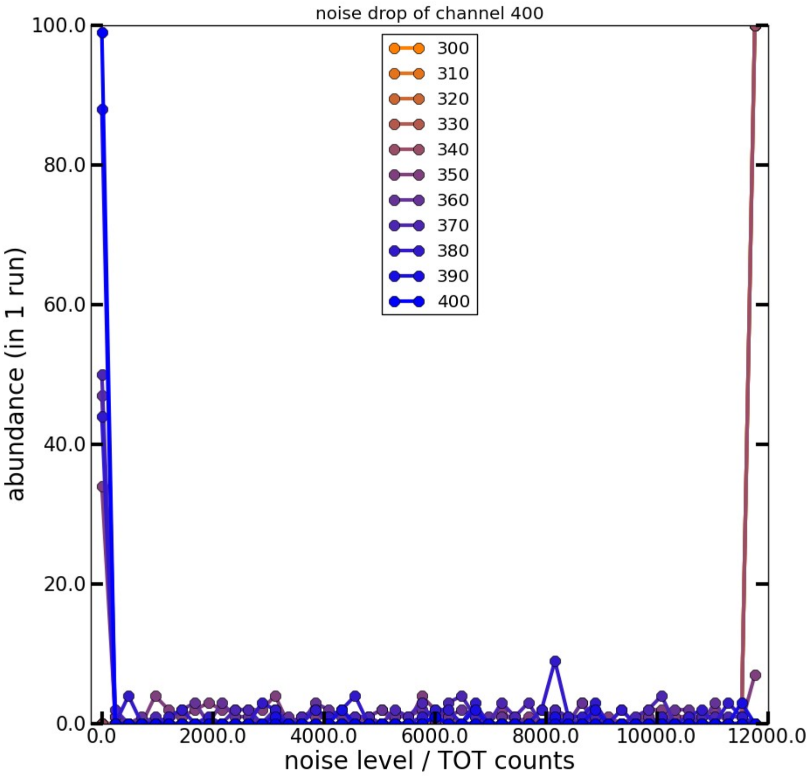
THL difference



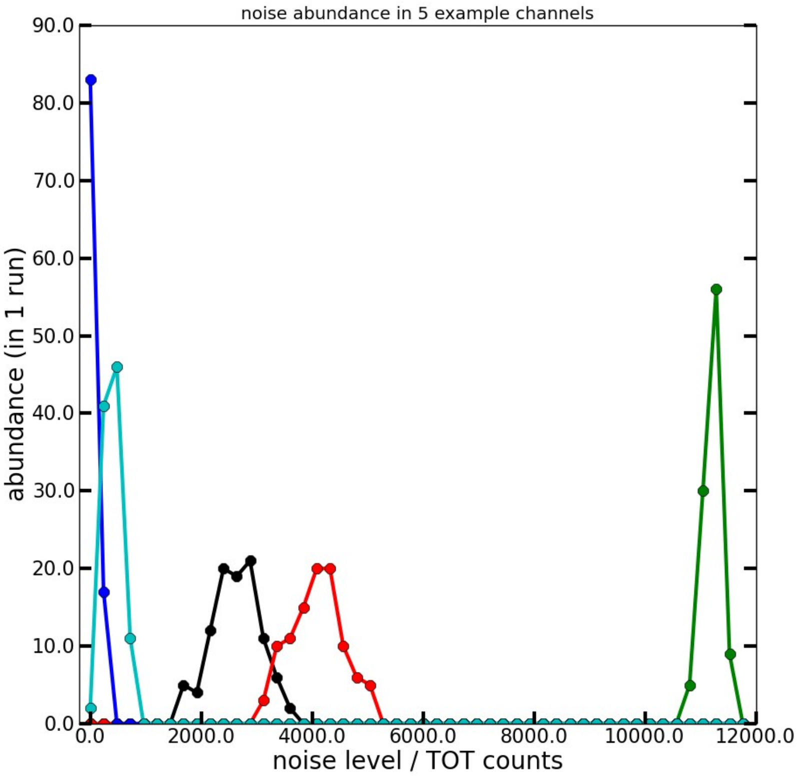
THL edge difference
is mostly below 50 DAC
→ sigma < 25 DAC
= 625 electrons

Comparison with bare Timepix

ROPPERI

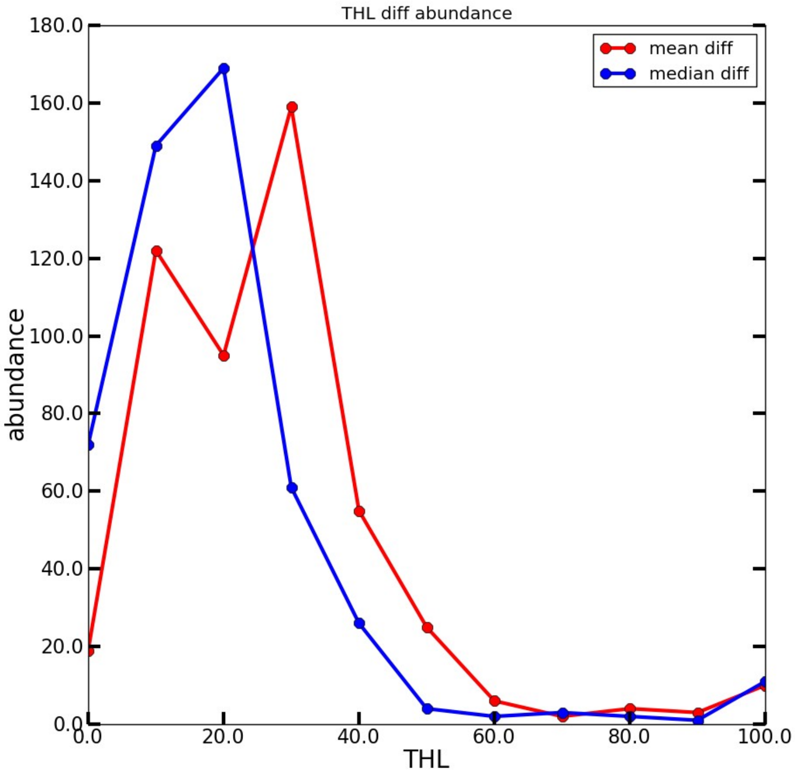


bare TP

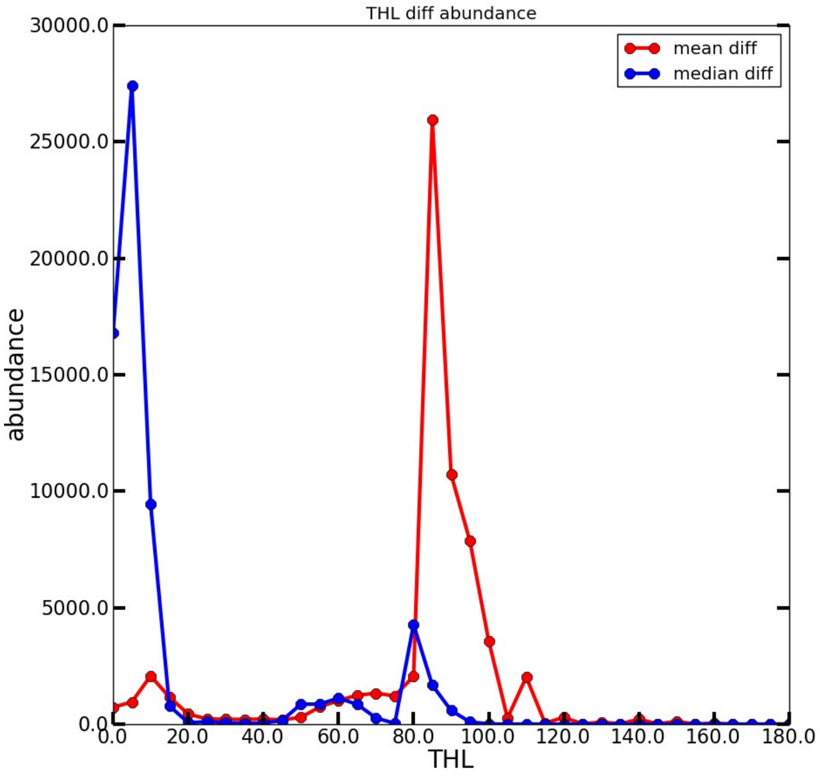


Comparison with bare Timepix

ROPPERI



bare TP



bTP: channels are unlikely to go into total noise or total silence,
so by requiring the mean to be min/max the THL-difference gets very large.
Taking the median compensates for this.

Comparison with bare Timepix

- ROPPERI board has about 3 times the noise as a bare Timepix with a known ENC of 90 electrons → ~ 300 electrons for ROPPERI.
- So far, in simulation an automatic threshold of 560 electrons is applied.
- A by-eye comparison of simulation with no noise and with 500 electrons noise gives very similar results, plots are work in progress.
- A GEM-gain of 10k would allow the identification of a single electron with 3x3 300 µm pads each receiving 3 ENC.
- Depending on the algorithm, combining 9 pads into one measurement, this increases the S/N by sqrt(9)=3 to be 9.

Conclusion

- An estimate for a equivalent-noise-charge for the ROPPERI system of about 300 electrons, as well as for a signal-to-noise level including MPGDs was calculated, the result is reasonable in combination with achievable GEM gains.

- The system built was still not stable, despite being optmised within the given base material category. The difference in CTE still destroyed the connections and made long-term measurements impossible.

- A new base material, e. g. ceramic, could be used. This would typically have a CTE much closer to silicon, as well as the potential of significantly smaller feature sizes.

The End

Thank you!