ÖAW AUSTRIAN ACADEMY OF SCIENCES

HEPHY INSTITUTE OF HIGH ENERGY PHYSICS

43rd RD50 Workshop

Beam test characterization of RD50-MPW3

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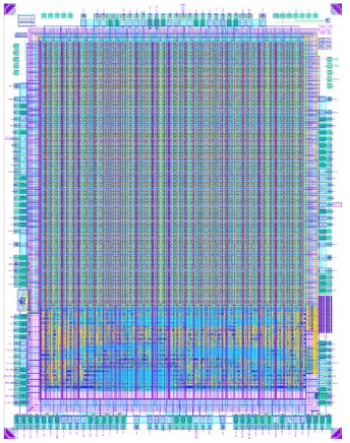
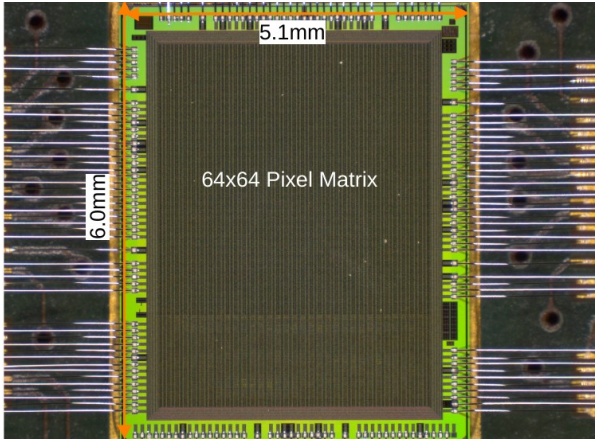
The RD50-MPW3

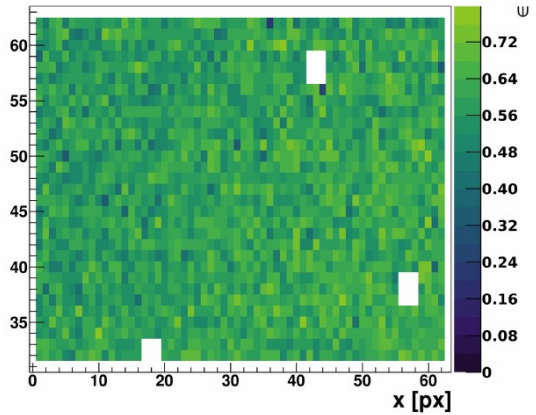
- *HV-CMOS chip fabricated in LFoundry* 150nm process
- Large collection electrode design
- 64 x 64 Pixel with pitch of 62µm
  - Arranged in 32 double columns
- Full analog and digital electronics inside pixel
- Fast clock at 320MHz
- 8 bit 50ns timestamps for ToT
- Digital periphery
  - I2C server for configuration
    - 8 bit per pixel
  - Data FIFO depth of 32 words for each double column

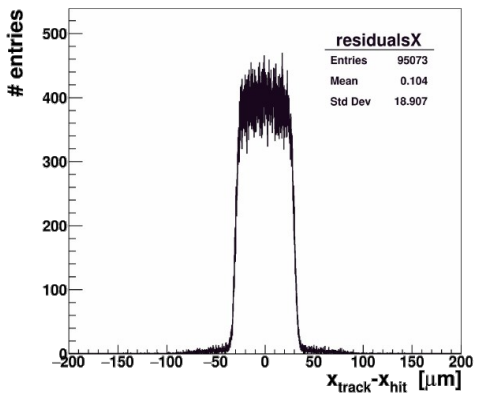


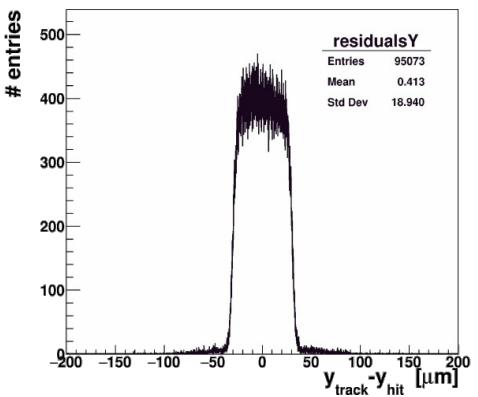


Reminder:
Testbeam at *CERN SPS*

- Beam test at CERN SPS facility in Oct. 2022
- Severe issues with synchronization
- Only low statistic runs taken due to bugs in measurement setup
- Total efficiency of ~60% evaluated
- ~Binary spatial resolution measured ~18.9µm

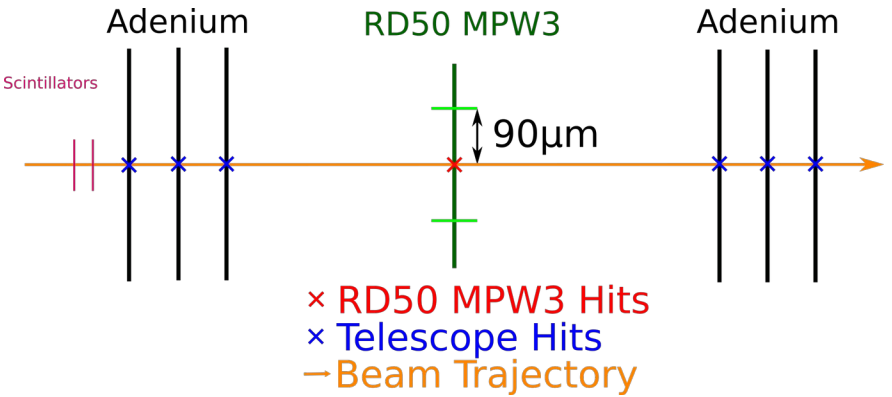


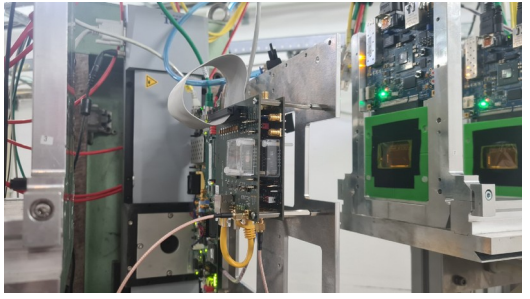


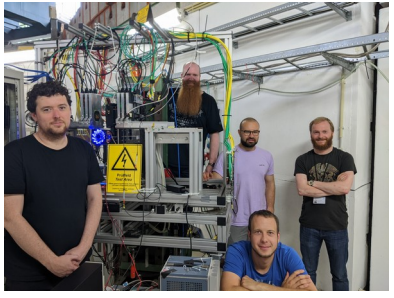


Testbeam Setup *DESY*

- Testbeam done in Jul. 2023 at *DESY* Hamburg
- Utilizing *Adenium* telescope
  - Based on *Alpide* chip
  - Pitch: 29µm x 26µm
  - 1024 x 512 pixel matrix
  - 6 planes
- Setup triggered by 2 scintillators operated in coincidence
- Telescope synchronized via trigger-numbers
- DUT (MPW3) synchronized via time-stamps
- Matching done by AIDA2020-TLU
- Electron beam with (mostly) 4.2 GeV, 6kHz used

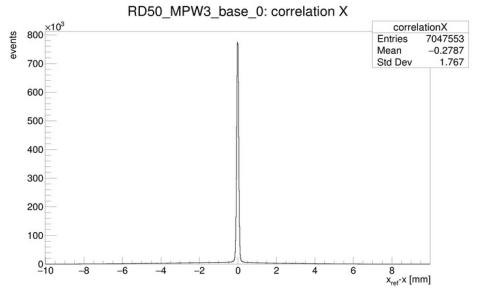


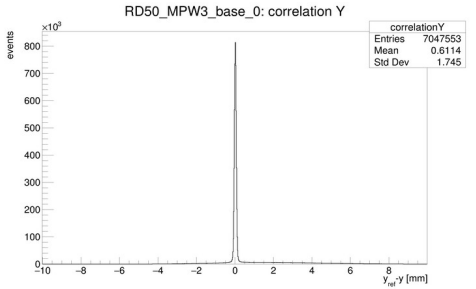


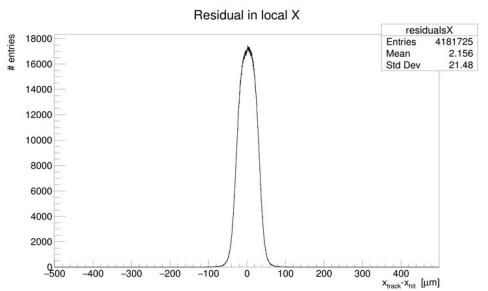


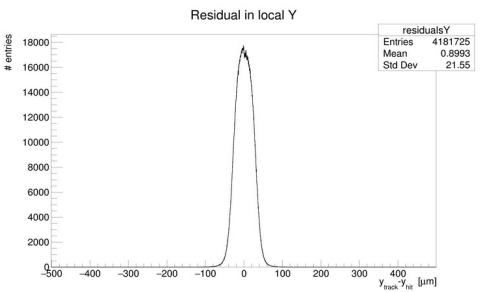
General Results *DESY*

- Correlations with very little background observed
  - Well synchronized
- Std. dev. of residuals show spatial resolution of ~21.5µm
  - Slightly worse than binary resolution of ~18µm
  - Reason: pointing resolution of telescope and alignment?

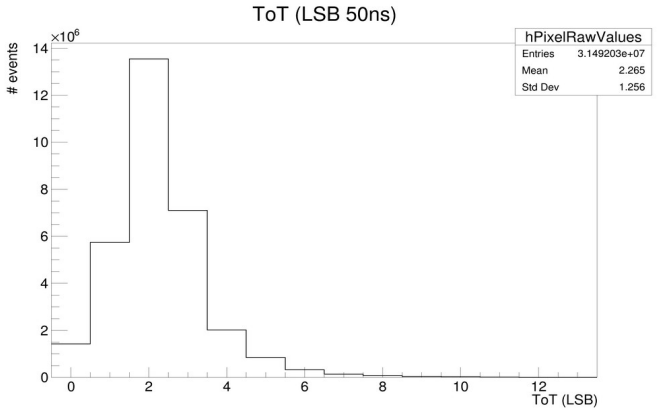


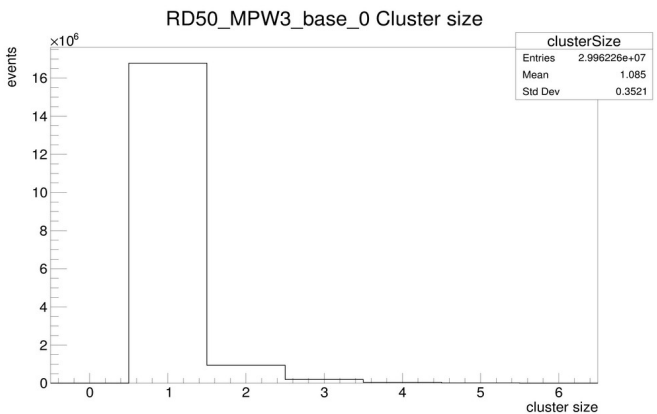






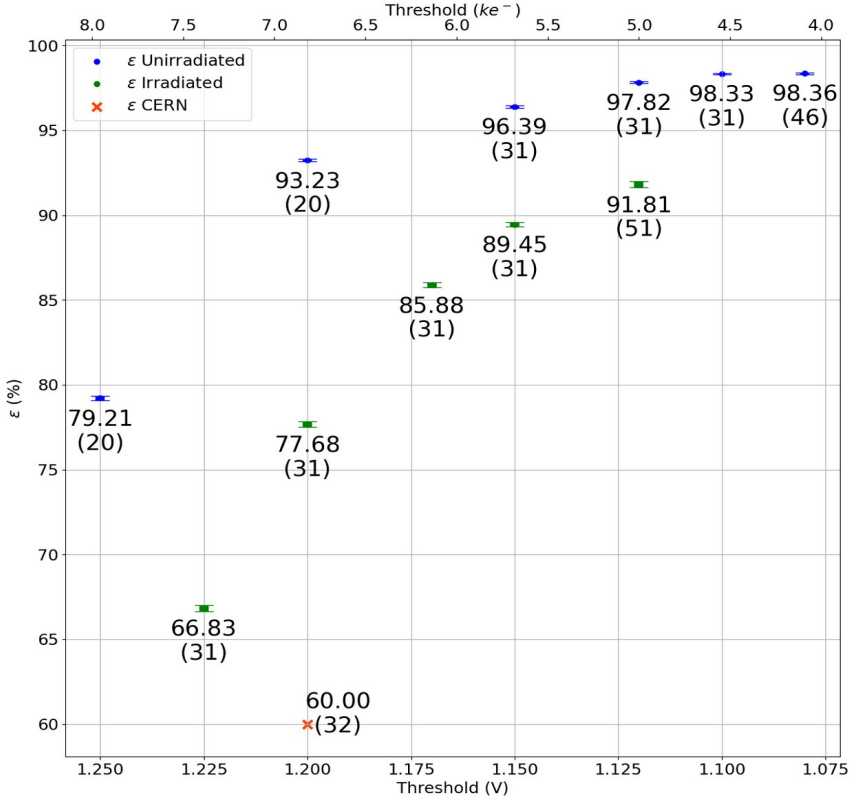
General Results *DESY* (2nd)



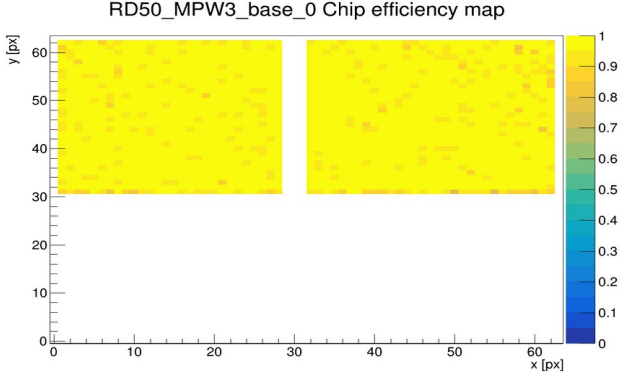


- ToT values of ~2.26 LSBs (on 50ns base) measured at 1.25V ~8ke$^-$ threshold
- Mean cluster size ~1 pixel / cluster
  - Center of gravity approach to increase spatial resolution not possible

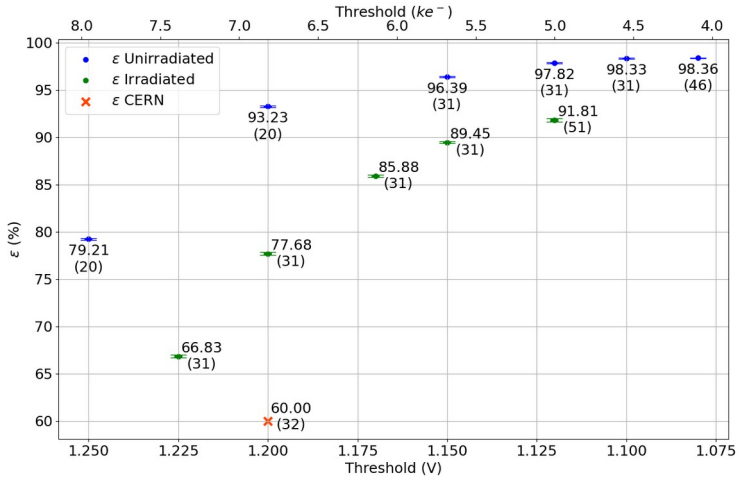
Chip - Efficiency *DESY*

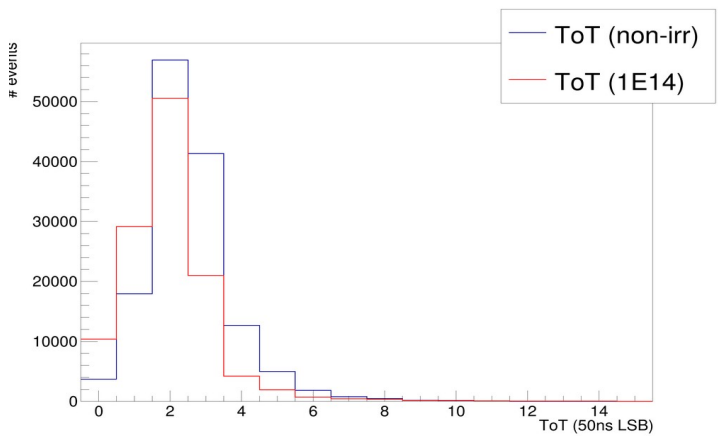


- ~98% total efficiency encountered at threshold of ~4.09ke$^-$ for non-irradiated sample
- After *CERN* test beam ~60% was the accepted value
- Due to noise issue ~bottom half of the matrix needed to be masked (number of masked rows indicated by numbers in brackets)



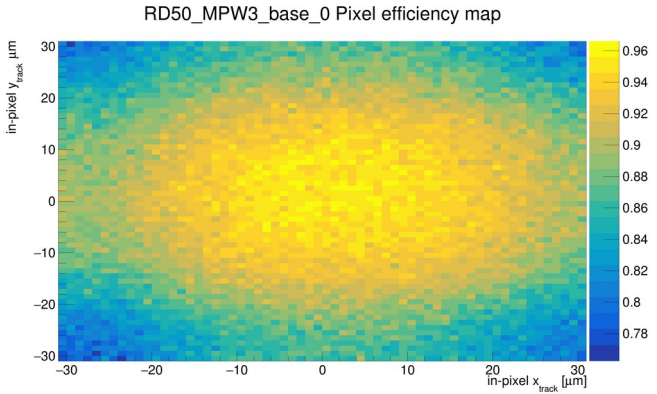
Results irradiated sample *DESY*

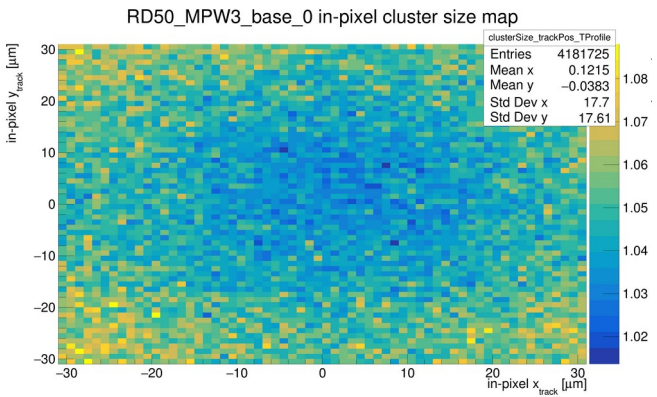




- Samples irradiated with 10^{14} 1MeV n_{eq} at *JSI* in Ljubljana
- Efficiency values in green correspond to irradiated sample
  - Efficiency decreases after irradiation
- Noise also increases (more rows masked)
- ToT decreases with irradiation (shown at 1.15V ~5600e^- thr.)
  - Mean Non-irradiated: 2.53 LSBs
  - Mean Irradiated: 1.98 LSBs
- Cluster-size and spatial resolution basically unchanged

In-Pixel Efficiency *DESY*



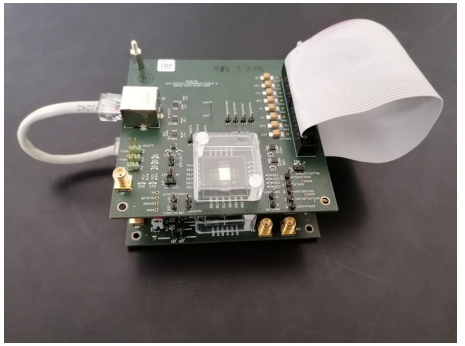


- In-pixel efficiency (shown for 1.15V ~ 5.6ke$^-$ thr.) shows worse efficiency in corners
- Cluster size map shows increased cluster-size in the corners
  - Tracks intersecting pixel corners cause bigger clusters → Charge sharing
- Charge sharing with neighboring pixels attenuated due to high threshold

The measurements leading to these results have been performed at the Test Beam Facility at DESY Hamburg (Germany), a member of the Helmholtz Association (HGF).

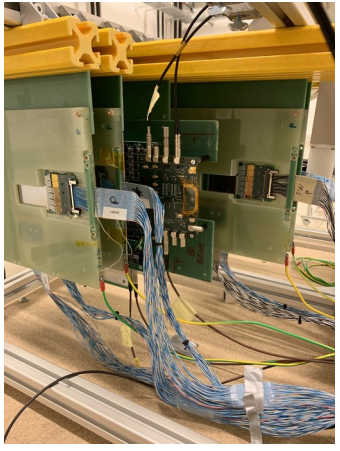
The Piggy Board

- Additional PCB
- Allows to operate two RD50-MPW3s with only one Caribou system
- High speed signals connected via ethernet cable
- Supply voltages connected via standard ribbon cable
- Was also installed at *DESY*, but DAQ was not able to synchronize data
- Intended use:
  - Easier to install / exchange in a telescope than base board (base needs to be plugged into the CaRboard)



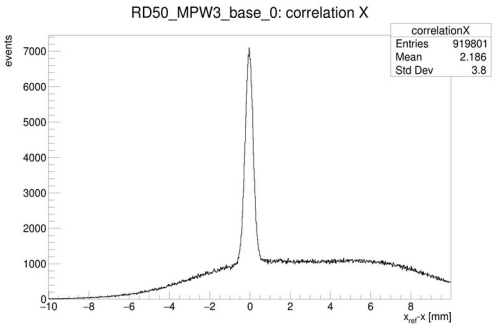
Setup *MedAustron*

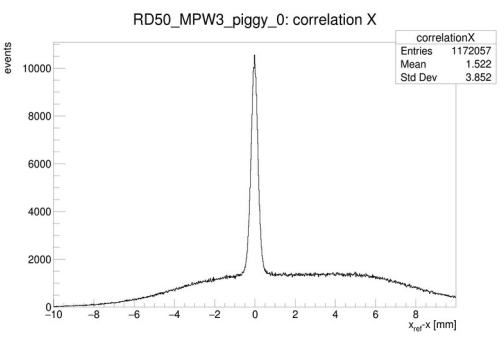
- *MedAustron* is a medical facility located close to Vienna
  - 50 km from *HEPHY*, beam time ~once a month
- Telescope with 4 DSSD planes
  - 512 x 512 “quasi” pixel
  - Pitch: 100µm x 50µm
- Triggered with 2 scintillators operated in coincidence
- 800 MeV proton beam with ~10kHz rate
  - No MIPs
- 2 DUTs
  - Base board 1.9kΩcm non-irradiated
  - Piggy board 3kΩcm non-irradiated
  - 32 bottom rows masked
  - Threshold 1.25V ~ 7900e^-
  - Biased to -90V

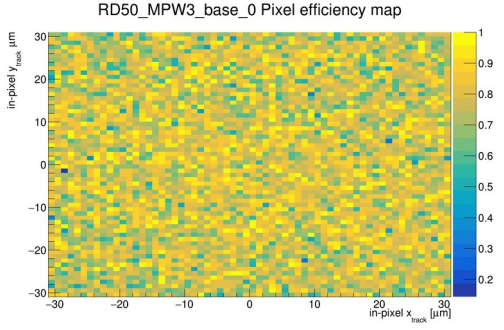


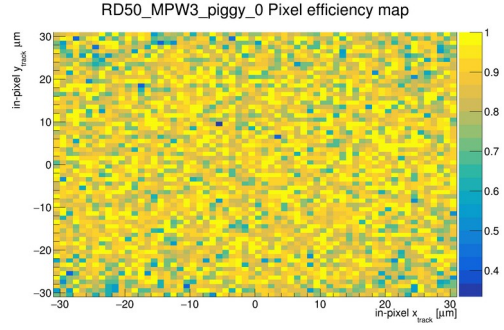
MedAustron Results

- Managed to properly synchronize Piggy board
- Correlations show increased background compared to *DESY* results
  - Synchronization parameters of the DSSD-telescope not known as well
- Total-efficiency Base *74.21(±0.18)%*
  - Efficiency at this threshold (~8ke⁻) at *DESY: ~79.2%*
- Total-efficiency Piggy *86.33(±0.16)%*
- Corner effects for in-pixel plots less pronounced, reason: lack of statistics



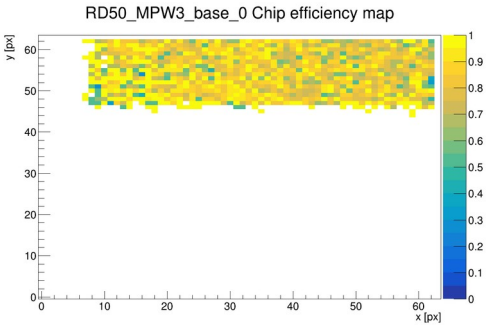


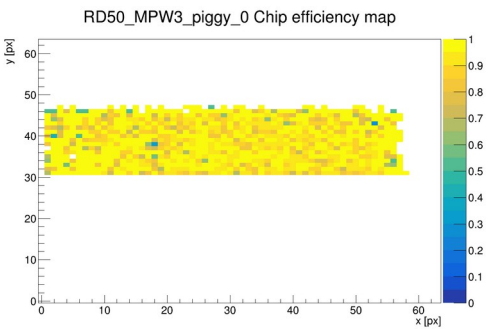




MedAustron: Extending the telescope

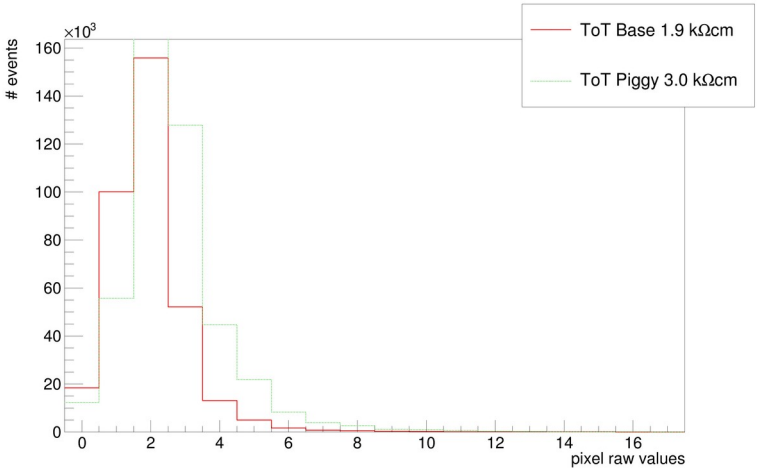
- Sacrificing one DUT in Corryvreckan analysis to act as extra telescope plane
  - Require 5 telescope-hits for each track
  - Yielding ~18 times less tracks
  - Allows to counter systematic (synchronization) errors in the analysis (same DAQ used for both DUTs)
  - Tracks get better resolution
- Efficiency base *81.73(+0.38, -0.39)%*
  - In better agreement with *DESY*
- Efficiency piggy *92.26(+0.28, -0.29)%*
- Misalignment of base and piggy → Only small area of chip taken into account





Discrepancies

- Base vs. Piggy:
  - ~10% higher efficiency for MPW3 on Piggy
  - Only significant difference: resistivity of substrate
  - Differences also seen in ToT values
    - 1.9kΩcm: 1.94 LSB
    - 3kΩcm: 2.68 LSB
  - Different threshold behavior?
  - Greater depletion depth for 3kΩcm substrate?
  - Work in progress
- *MedAustron* vs. *DESY*
  - *Efficiency at MedAustron* ~2% higher at same threshold
  - Lower beam energy at *MedAustron* → More energy deposited in detector



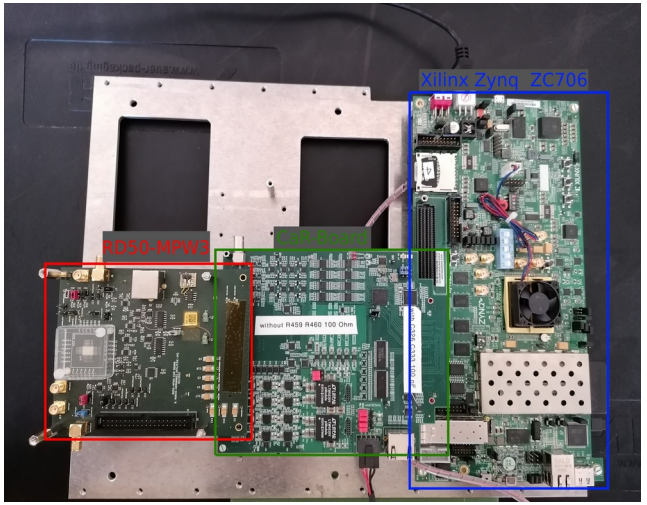
Outlook

- MPW3:
  - Work on Allpix^2 simulations started
    - Aiming to reproduce *DESY*-TB results to improve understanding of chip
  - Annealing studies with irradiated samples
- MPW4:
  - Should be delivered by *LFoundry* in the next few weeks
  - Noise issue should (hopefully) be resolved
  - Lab work: I-V measurements, proper calibration with injections
  - 2 Beam test campaigns already scheduled in 2024
    - End of Mar. at *MedAustron*
    - End of Apr. at *DESY*

- Thanks for your attention!
- Questions?

BACKUP

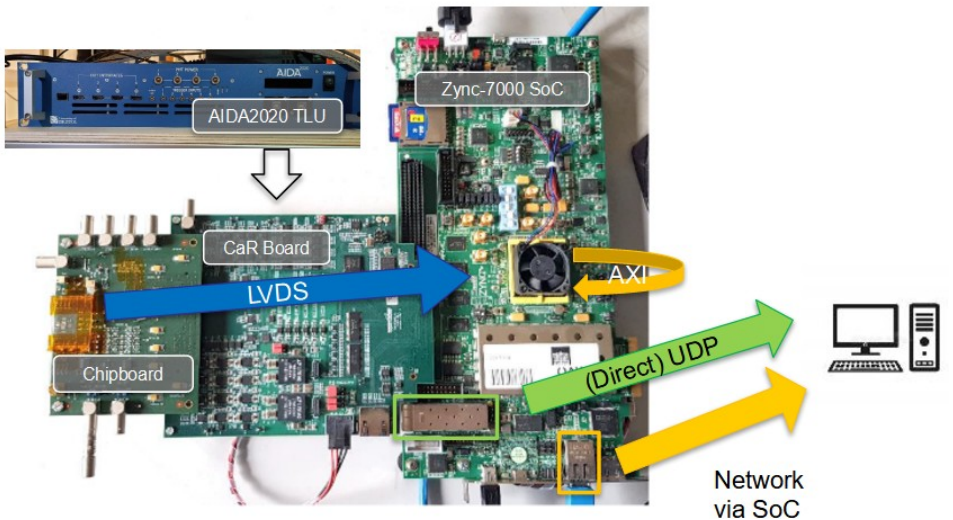
Base DAQ



- Caribou system
- Implemented Peary Device
  - Custom I2C interface (16 bit addresses)
- GUI for configuration
  - Generating Peary config files

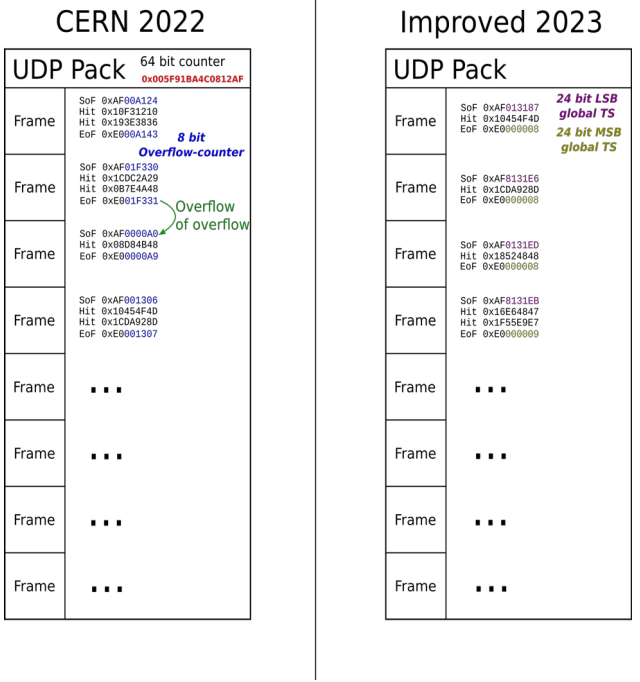
Testbeam DAQ

- Fully integrated into EUDAQ2
- CaribouProducer too slow for full read-out rate
  - Only used for run-control commands
- Custom UDP (1 Gbit/s) Data-Collector implemented
  - Multi–threaded approach
  - More like a EUDAQ-producer, but directly storing to disk
- EUDAQ-monitor integrated in GUI
- EUDAQ-Producer for submission of run info to ELog server
- Analysis done with *Corryvreckan*



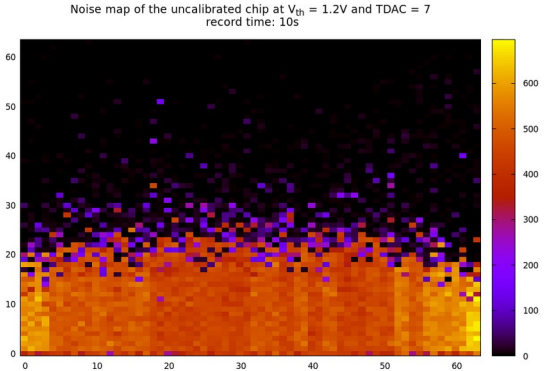
DAQ improvements

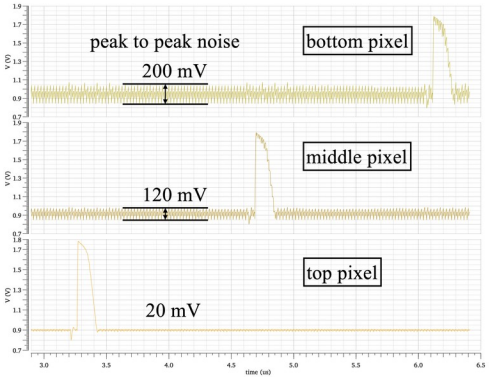
- Problem at *CERN*: synchronization
  - 1 global timestamp for ~1300 hits
  - Data preprocessor looking for overflows in TS-LE to refine hit-timestamps
- FW adjustments allow for global timestamp for ~each hit



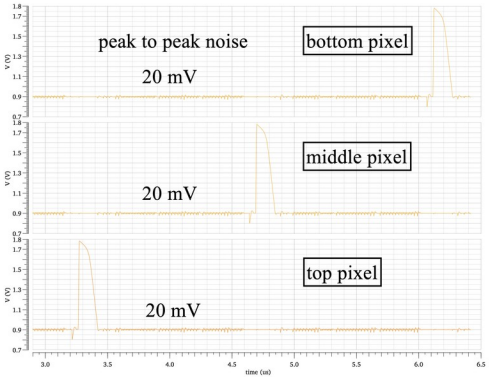
The Noise Issue

- Shared power lines between pixel matrix and digital periphery
  - High noise occurrence in bottom rows correlated to digital activity
- Analog simulations as reported in last RD50 workshop reproduced the measured behavior
- Changes in design of upcoming RD50-MPW4 should (hopefully) fix this behavior





Common Power and GND (MPW3)



Separated Power and GND (MPW4)

Efficiency too high?

- According to (Allpix^2) simulations MPV of deposited charge ~46ke$^-$ in 300µm silicon with *DESY* beam
- Assuming depletion depth of 100µm
- (Back of the envelope) calculation yields ≳ 15ke$^-$ transferred to implants
- With threshold of ~5ke$^-$ efficiency of 98% plausible