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 ~18.9 µm
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 \(~8\)ke\(^{-}\) threshold
- Mean cluster size \(~1\) pixel / cluster
  - Center of gravity approach to increase spatial resolution not possible
- ~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 $74.21(\pm0.18)\%$
  - Efficiency at this threshold ($\sim8ke^-$) at DESY: $\sim79.2\%$
- Total-efficiency Piggy $86.33(\pm0.16)\%$
- 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 Allpix² 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?
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
Efficiency too high?

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