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DRD3 Week Dec. 24 / WG1

The RD50-MPW4 CMOS Pixel Sensor: Performance Post-Irradiation

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on behalf of the (former) CERN RD50 CMOS working group

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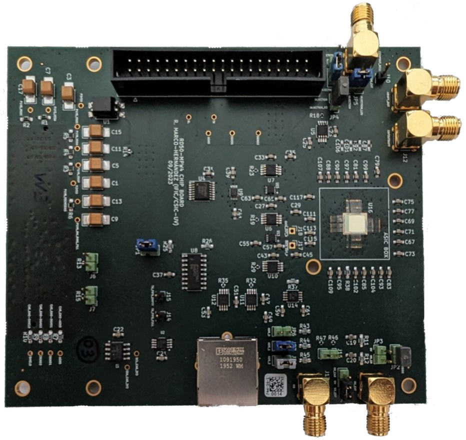
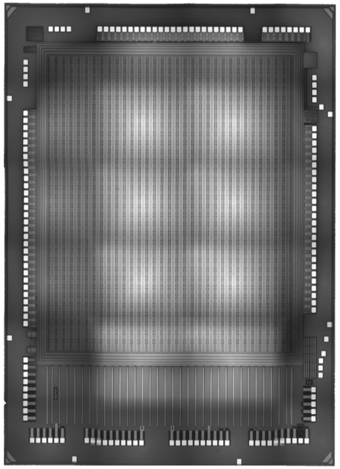
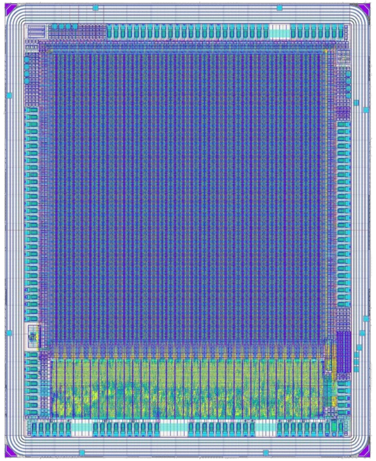
RD50-MPW4

- 64x64 pixel matrix arranged in 32 FEI-3 style double columns
- Active area of 4x4mm²
- Pixel-size of 62x62µm²
- 8 bit timestamp information (based on 25ns) for each hit
- 4 bit in-pixel trimming
- 640MHz readout
- Backside processing of subset of samples
  - Thinned to 280µm
  - Metallized backside
- Several samples were irradiated from the range of $1x10^{14} \rightarrow 3x10^{16}$ n_{eq} cm^{-2}







Irradiation campaign

- Several samples irradiated to various fluences at JSI Ljubljana
- All samples, *besides 3E16*, can still be operated (responding to I^2C messages)
- W3 got backside processed
  - Biased from top or back (jumper on PCB)
- W8 without backside processing
  - Biased only from top

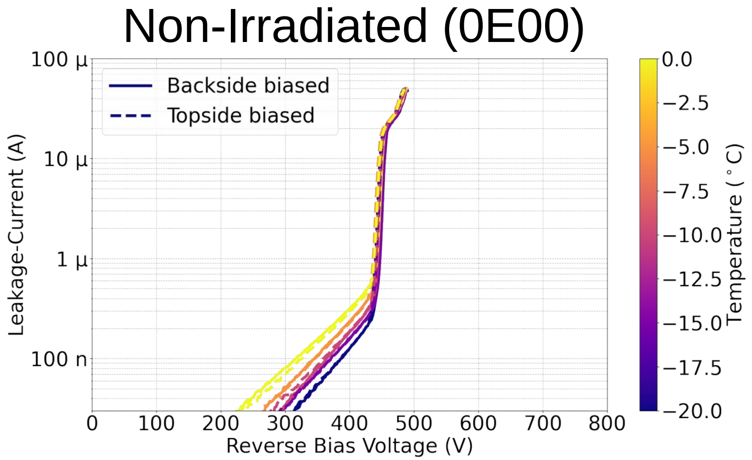
Fluence (1MeV n_{eq} cm^{-2})	Wafer
1E14	W3, W8
3E14	W3
1E15	W3, W8
1E16	W3
~~3E16~~	~~W3~~

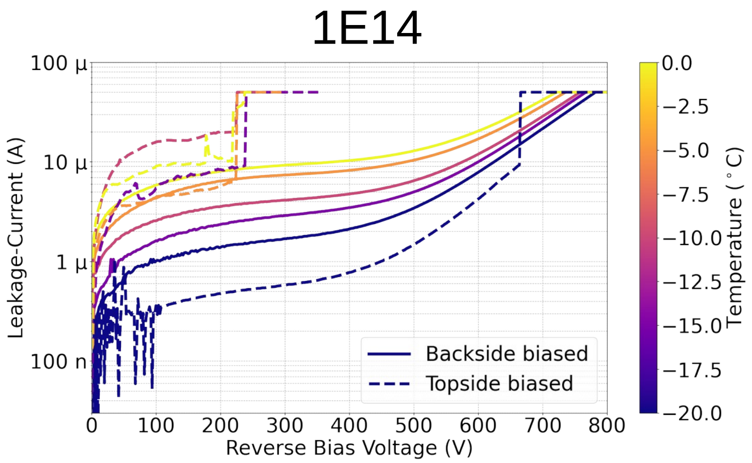
IV Measurements setup

- Increased leakage current → Need for cooling
  - Climate chamber used, temperatures correspond to ambient temperature
  - Going down to -20°C
- Samples annealed at 60°C for 80min
- IV-curves
  - Biased by Keithley 2410
  - Step size = 2V
  - Compliance set to 50µA
  - Chip on PCB measured (no needles, full matrix, no test structures)
- Samples were measured both biased from top and biased from back
- Only one sample per fluence

IV Measurements Results (1)

- Non-irradiated sample shows little temperature dependence of leakage current
- Leakage current increases already at low bias voltages (V < 300V) from O(10nA) to O(1µA) after irradiation to 1E14
- "Breakdown" / reaching compliance with topside biasing scheme already at lower bias voltages
- Cooling from 0°C → -20°C reduces leakage current of 1E14 sample by factor of ~10

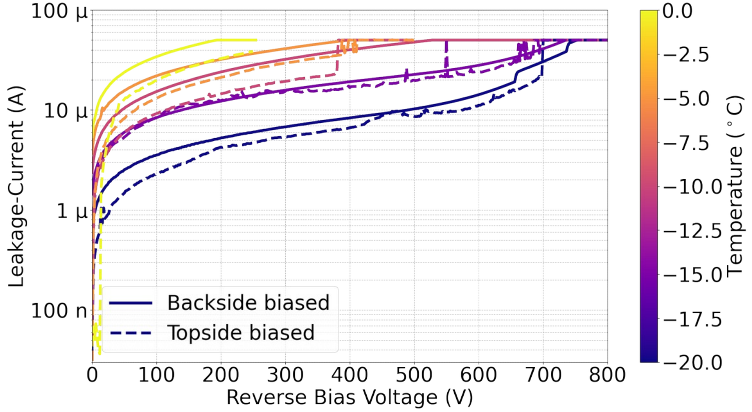




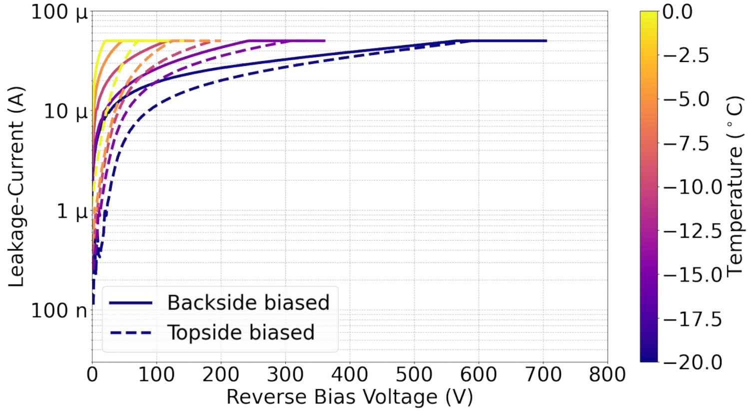
IV Measurements Results (2)

- Difference between top- and backside biasing less pronounced compared to 1E14
- Sample irradiated to 1E16 can still be biased up to O(600V)
  - Cooling mandatory
  - Current increased by factor of ~1000 compared to non-irradiated sample at V_{Bias} < 200V

1E15

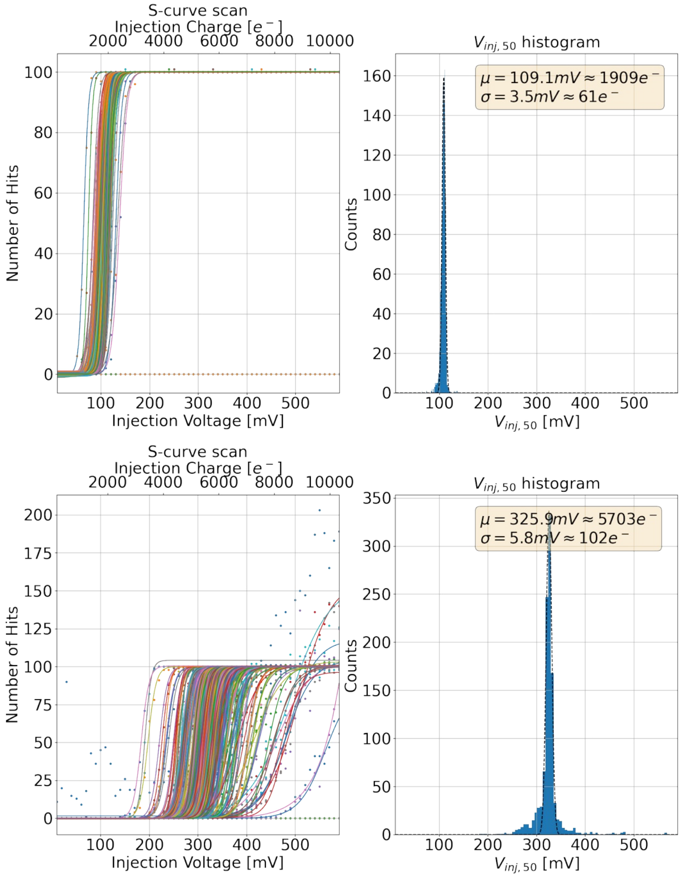


1E16



Sensor response through injections

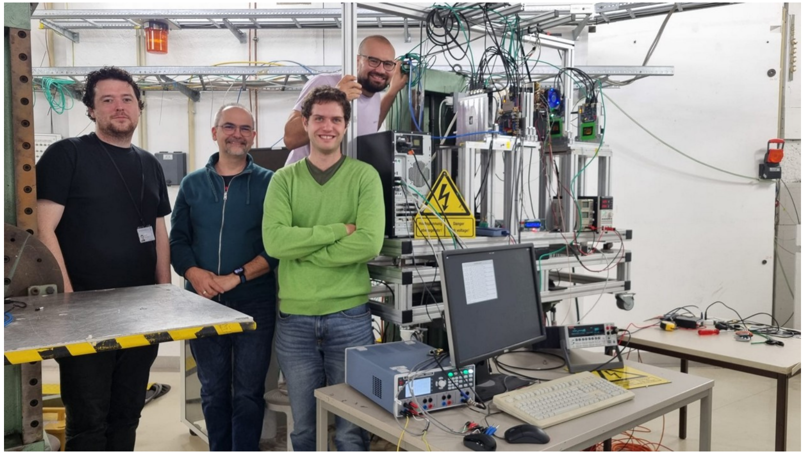
- Utilizing in-pixel injection capacitance (~2.8fF) to study pixel response for 32x32 pixel block
- Minimal possible threshold (without noise) used
- 1E15 still allows for thresholds of ~2000e$^-$
- Same V_{Thr} for 1E16 sample leads to effective threshold of ~5700e$^-$
  - Pixel response less uniform
  - Trimming range no longer sufficient



1E15
V_{Thr} = 30mV

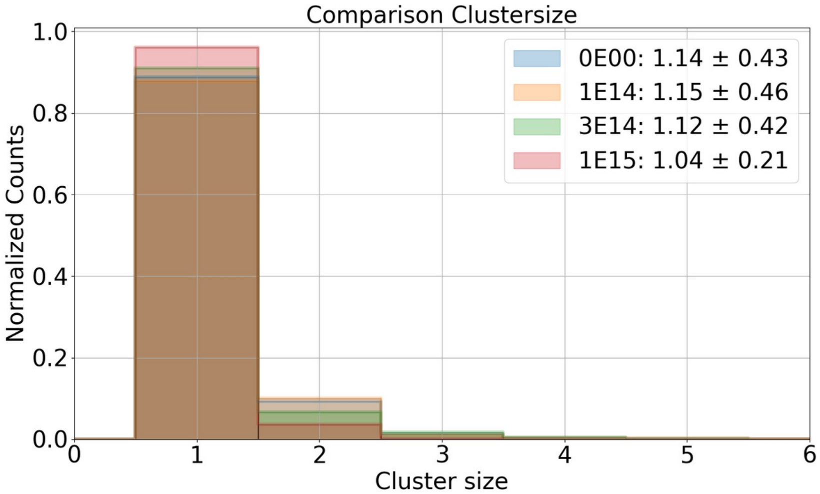
1E16
V_{Thr} = 30mV

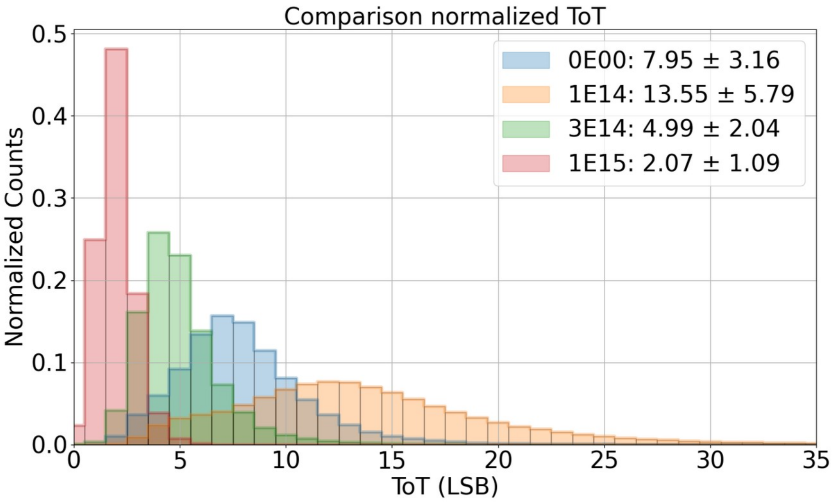
Test-Beam at DESY



- Test-Beam at *DESY* in Oct. 2024
- 4.2 GeV electrons at f ≈ 10kHz
- *Adenium* (*Alpide* based) telescope
- *AIDA 2020 TLU* for synchronization
- *Telepix* as ROI trigger and timing layer
- Peltier based cooling setup installed in telescope
  - Indirect chip cooling via copper plate attached to PCB
  - Going down to ~ -15°C
- *Corryvreckan* used for data analysis

Direct comparison of fluence levels (Charge)





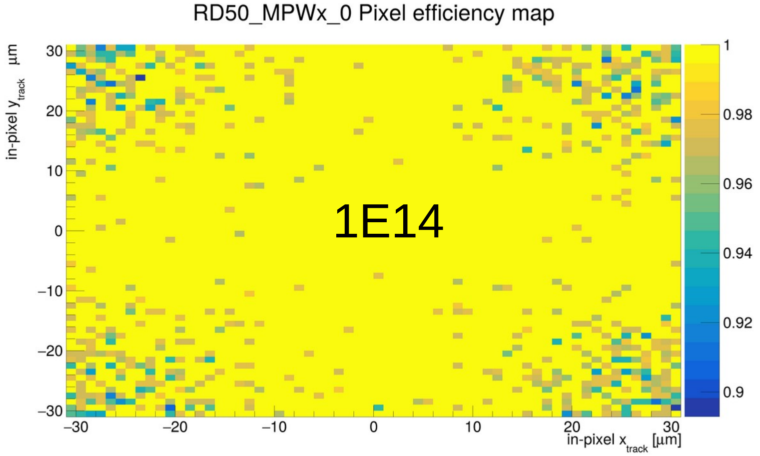
- *Standard* settings:
  - V_{Bias} = 190V
  - V_{Thr} = 200mV~ 5000e^-
- To be on safe side (no noise wanted)

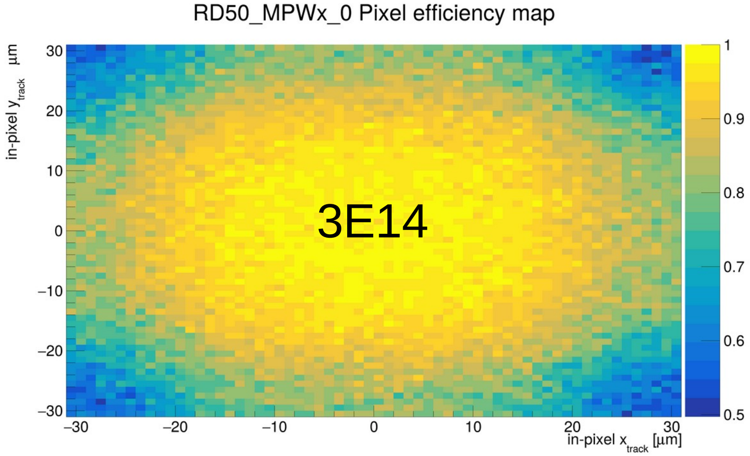
- Behavior as expected:
  - Cluster-size and ToT decreases with increasing fluence levels
- Surprisingly cluster-size and ToT of 1E14 larger than non-irradiated sample
  - Not understood yet
  - First hints (from lab measurement) point towards altered characteristics of in pixel electronics

Direct comparison of fluence levels (Efficiency)

- Significant efficiency decrease observed
- Due to trapping less charge available
  - Charge sharing effects in pixel corners reduce efficiency

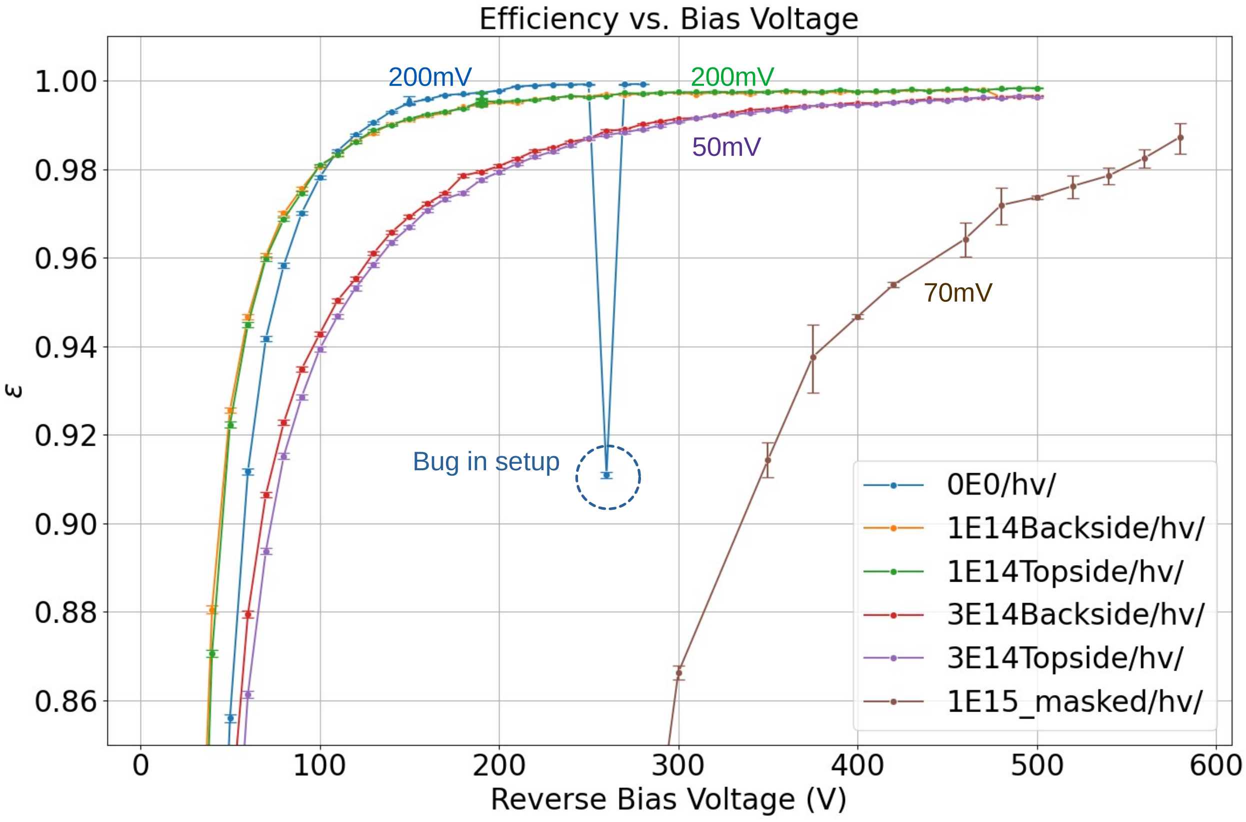
DUT	Total Efficiency
0E00	99.8%
1E14	99.5%
3E14	85.5%
1E15	8.9%





Ramping up the bias voltage

- This is HV-CMOS
  - Increase bias voltage well above 190V
- Due to different noise behavior slightly different V_{Thr} used
- 1E15 contains one damaged double column → masked here
- 1E14 + 3E14 recover to ε > 99.9%
- 1E15 reaches ε ~ 98.7%
- Biasing method (top- or backside) for 1E14 and 3E14 not making a major difference
  - 1E15 and 0E00 from W8 (only topside biasing)



Summary / Outlook

- Characterized samples after exposure to different radiation levels in lab and at testbeam
- Efficiency almost fully recoverable by increasing bias voltage for fluences up to 1E15
- HV-CMOS approach (large bias voltages) allows for radiation hard sensors
- Cluster-size and ToT indicate increased charge trapping

- Further irradiation campaign with more samples about to start
  - Targeted fluences: 5E14, 1E15, 2E15, 3E15, 5E15
  - Including samples without backside processing
- Next beam time at DESY in spring 2025
- Stay tuned

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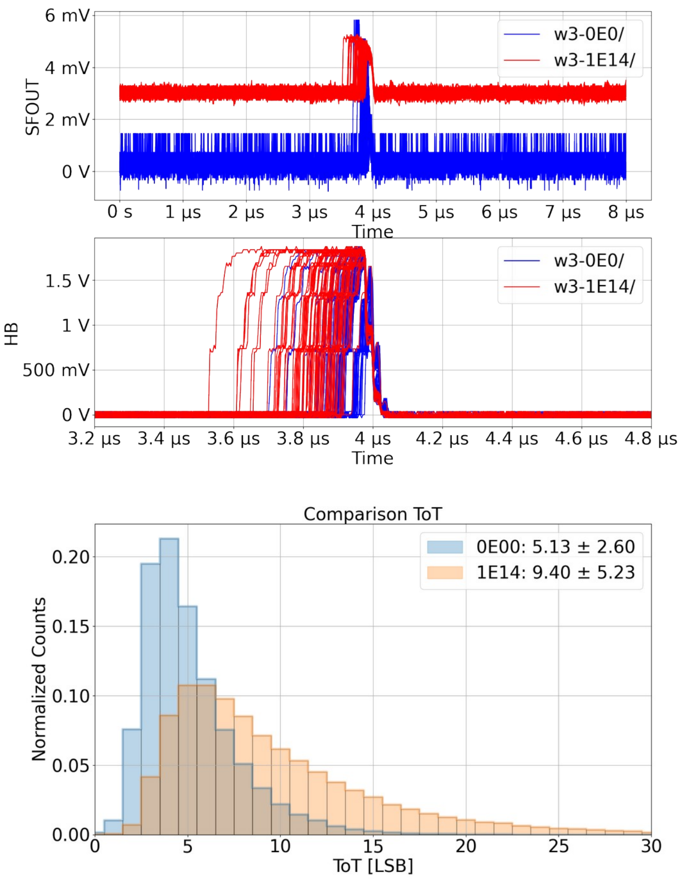
Thank you for your attention!
Questions?

- This work has been partly performed in the framework of the CERN-RD50 collaboration.
- The measurements leading to these results have partly been performed at the Test Beam Facility at DESY Hamburg (Germany), a member of the Helmholtz Association (HGF).
- This project has received funding from the European Union's Horizon Europe Research and Innovation programme under Grant Agreement No 101057511 (EURO-LABS).
- We thank our colleagues from the TRIGA reactor in Ljubljana for irradiating the sensors.

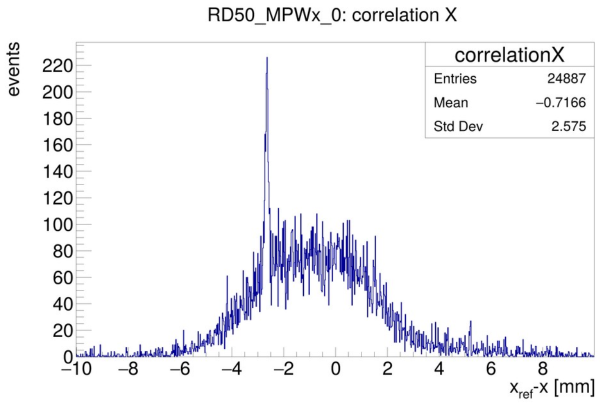
BACKUP

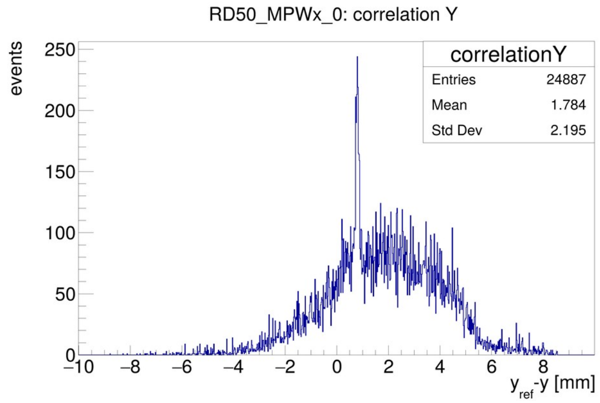
Investigating Charge effects

- Why is ToT of 1E14 > ToT of non-irradiated sample?
- Use ^{90}Sr source in lab to reproduce test-beam results
- 1E14 sample indeed shows larger ToT
  - Using test-beam data taking
- Measuring analog signals (source follower output and hitbus)
  - SFOUT shows 3mV offset and hitbus is high for a longer time



Test-beam results of 1E16 sample

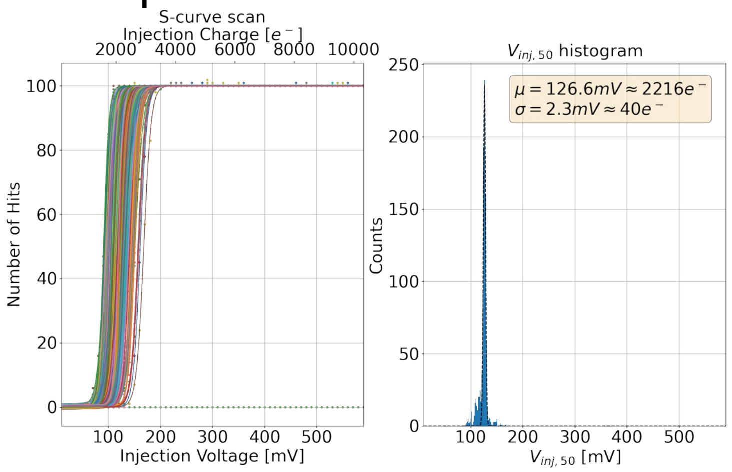


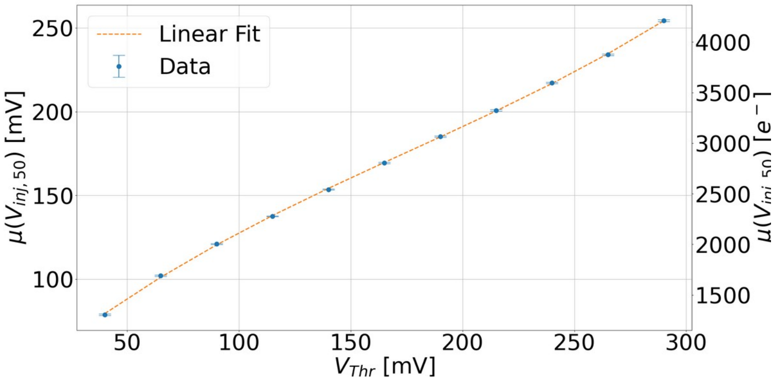


- Correlation with telescope reference plane still observable
- Too low efficiency for proper analysis
- Noise level increased as shown by background

Injection Response of 1E14 sample

- Not fully comparable to 3E14 and 1E15 sample as V_{Thr} of 100mV used
- Noise level appears larger than in other samples





Spatial Resolution

- Different efficiencies at *std. settings* don't allow to directly compare spatial resolution
- Non-irradiated:
  - Best Spatial Resolution in X ~ 15.8µm
  - At cluster-size of ~ 1.3 pixel / cluster
- Reduced cluster-size after irradiation → reduced spatial resolution
- Minor differences between fluence levels
  - Mostly one pixel clusters at all samples
- Spatial resolution decreases by O(1µm)