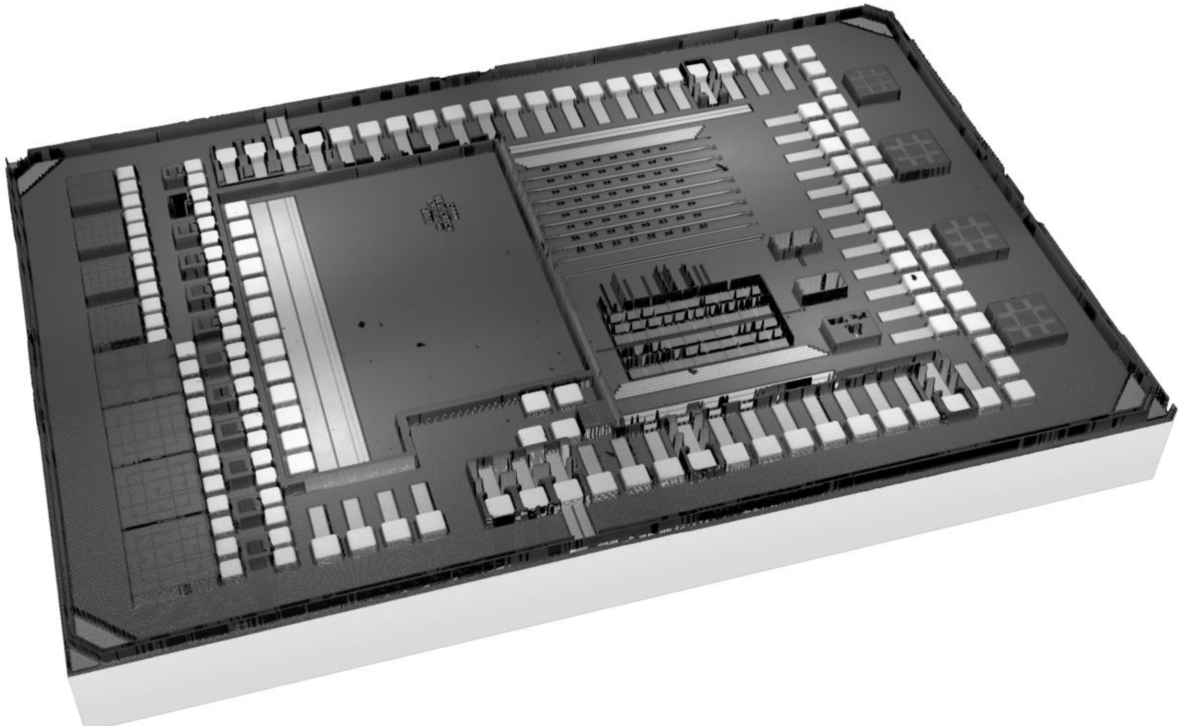


Active Matrix Measurements of Irradiated RD50 HV-CMOS Prototypes

Patrick Sieberer (on behalf of RD50 HVCMOS group)

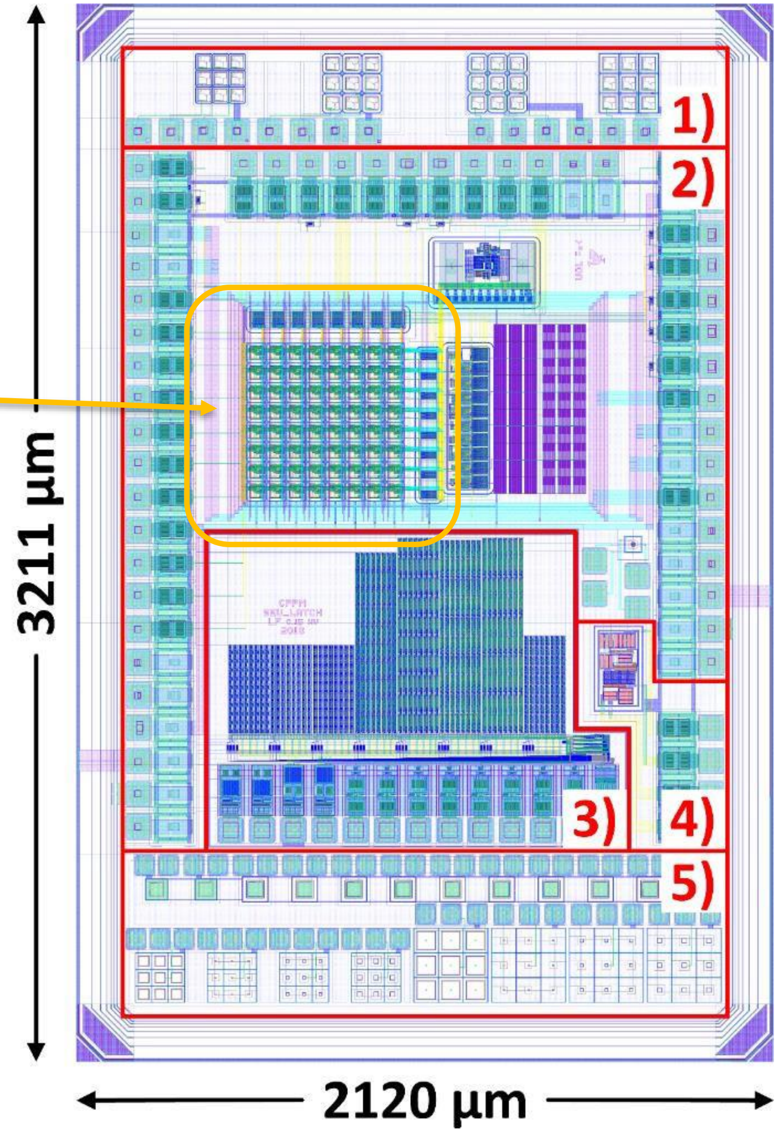
Special thanks to Klemens Flöckner, who made almost all plots

Outline

- Active Matrix
  - Introduction
  - Setup
  - Pixel Sensitivity
  - Corrections and Measurement
- Outlook
  - Test Beam

Introduction RD50-MPW2

- LF 150nm process
- Different Wafer resistivities, >2.2kΩ*cm used for all plots here
- Passive test-structures 1)
- **Active matrix of DMAPS pixel, including analogue readout 2)**
- SEU tolerant memory array 3)
- Bandgap reference voltage 4)
- Test structures with SPADs 5)
- Details on 3) and 4): See Ricardo's talk at last workshop
- Details on 1): See Matthew's talk at last workshop

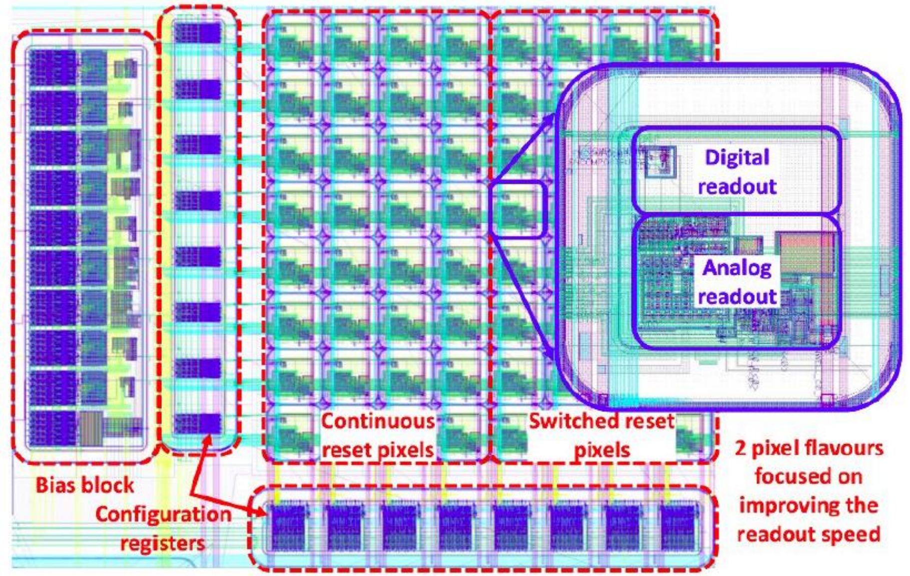


Introduction and Setup

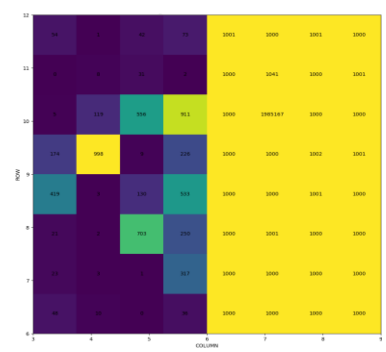
ACTIVE MATRIX

Active Pixel Matrix - Overview

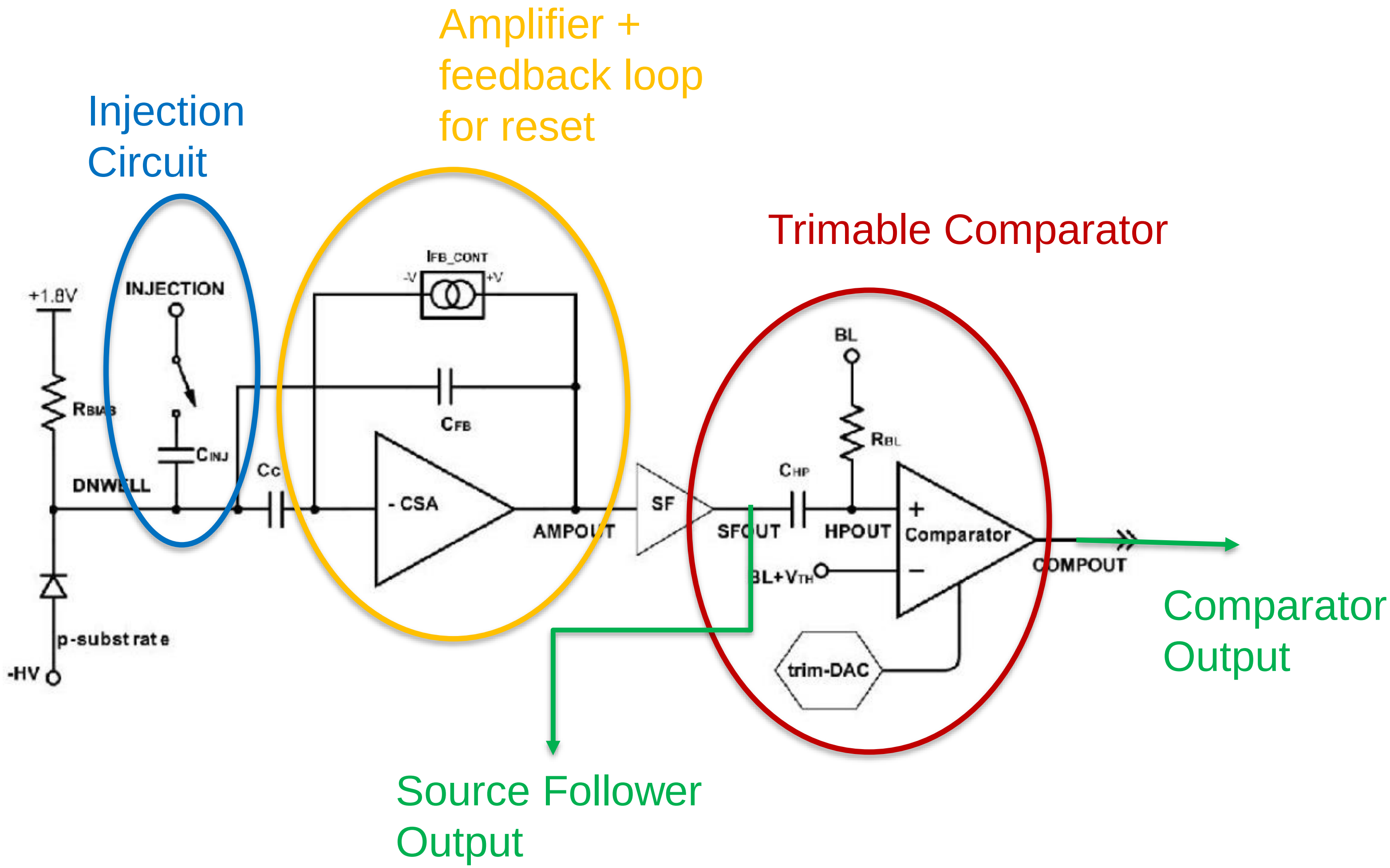
- 64 pixels, 60µm x 60µm
- Two flavors of readout:
  - Continuous reset (Col 0-3)
  - Switched reset (Col 4-7)
- Bias-Block: Generates bias voltages to set the transistor operating points
- Configuration Registers: for Bias-Block and pixel TRIMDAC voltages
- Analogue buffer and multiplexer to monitor voltages and analogue pixel readout



Active pixel matrix floorplan.



Example: Continuous Reset Pixels



Firmware

- COMPOUT used
- Counter + FIFO in FPGA
- **Hits counted** and stored in FIFO
  - After charge injections
  - During shutter window (Test with radioactive source)
- ToT measurement (using SFOUT) available as well

Lab Setup

NIM + VME Crate (for Trigger, not visible)

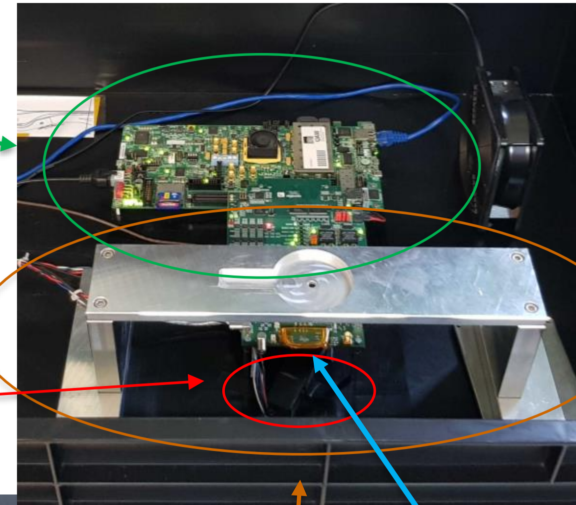
HV supply and control

Caribou

Run Control (EUDAQ)

AIDA TLU

Scintillators (not visible)



RD50 MPW2

Holder for radioactive source

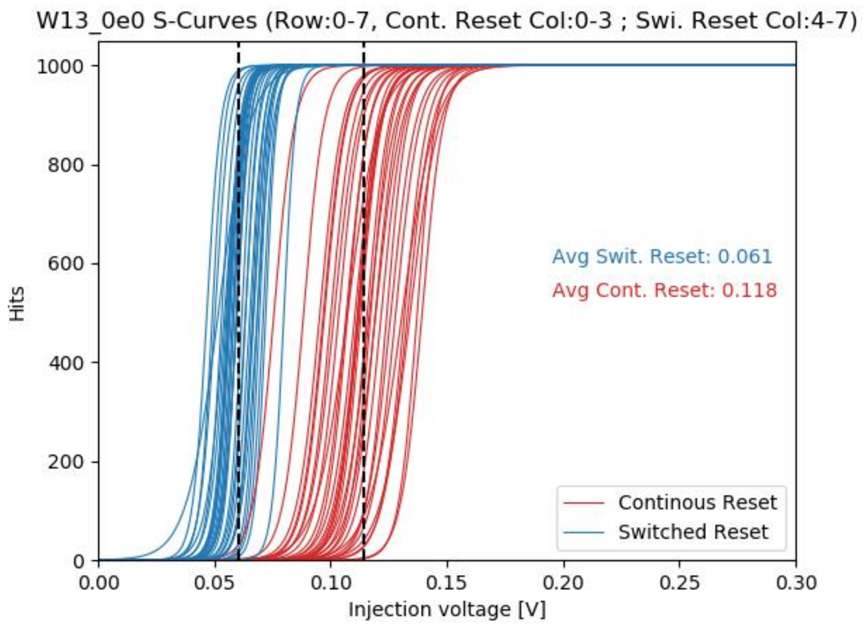
More details on Hardware and Caribou:
See Christian's talk at last workshop

Pixel Sensitivity

ACTIVE MATRIX

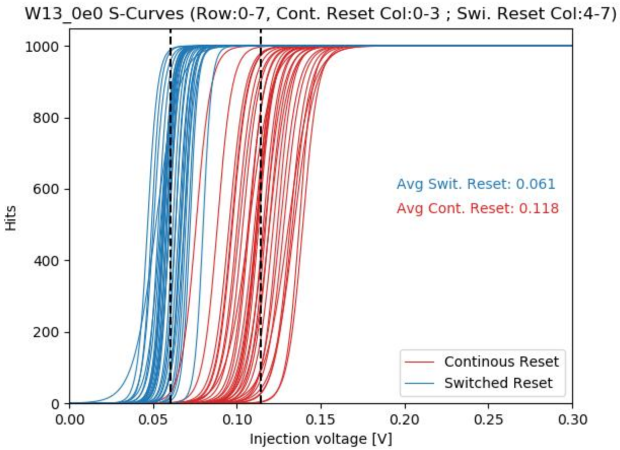
S-CURVES

- Wafer 13 (>2.2kΩ*cm), unirradiated
- No HV applied
- Comparator baseline (BL) at 900mV (subtracted in plot)
- 1000 Pulses per voltage step (Step size 10mV)
  - Sigmoid function fitted

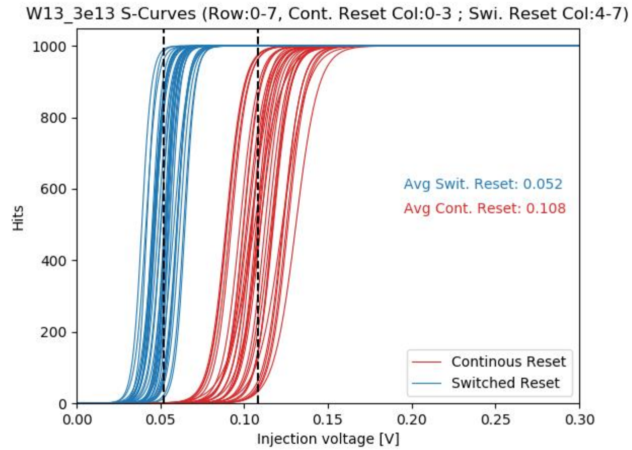


-> Threshold of Continuous Reset Pixels higher than for Switched Reset pixel
-> Quite some variation between pixels

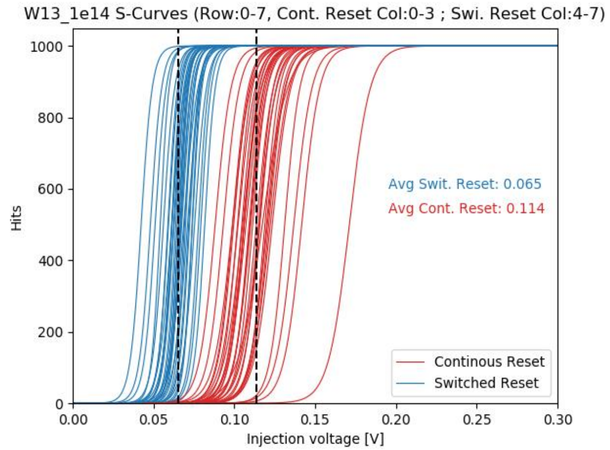
Irradiated samples



Wafer 13, unirradiated



Wafer 13, 3e13N_{eq}

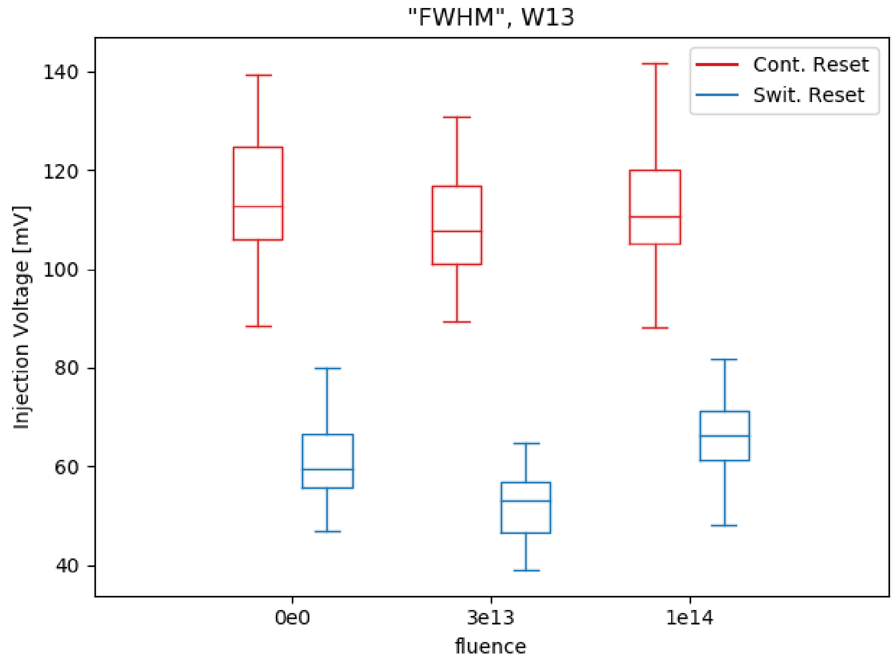


Wafer 13, 1e14N_{eq}

- Wafer 13 (>2.2kOhm*cm)
- Highest TRIMDAC value for all pixel chosen – See next slides
- Threshold of Continuous Reset Pixels higher than for switched reset pixel (for all fluences)
- Chips with higher fluence (up to 2e15N_{eq}) available, but not yet tested

Irradiated samples

- FWHM (Full Width at Half Maximum) = Voltage where 500 hits out of 1000 Injections recorded

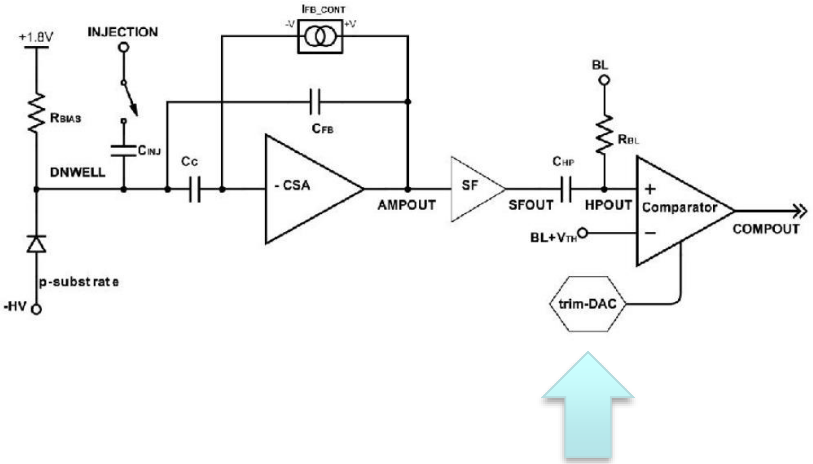


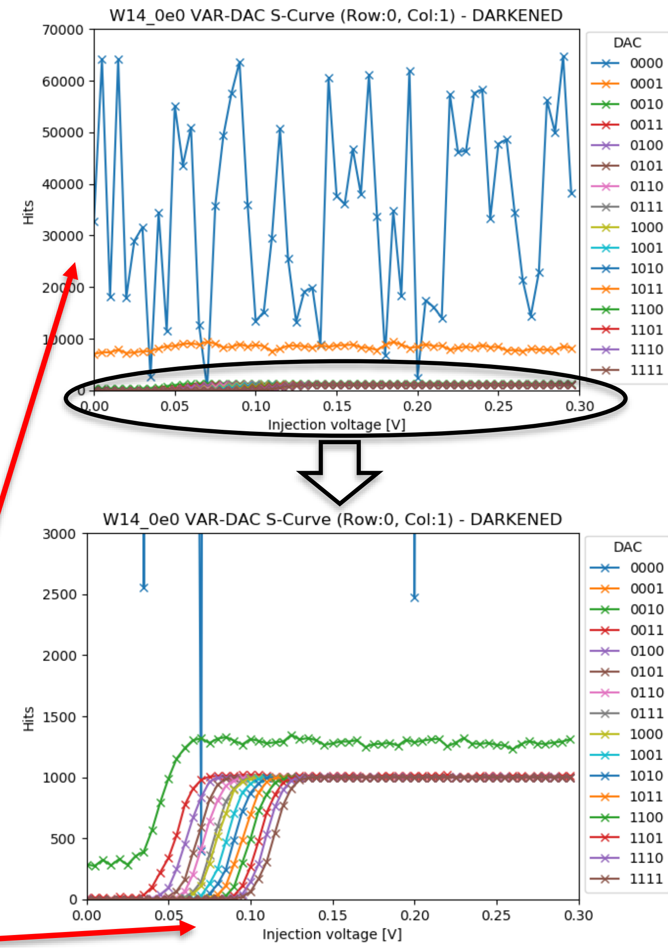
- Threshold seems to be more dependent on *sample variation* than fluence (different sensor (but same wafer) for each fluence measured!)
  - High spread, more statistics needed
  - *Measured at 0V, with max TRIMDAC – (not actual operation mode)*

Corrections and Measurement

ACTIVE MATRIX

TRIMDAC-Range

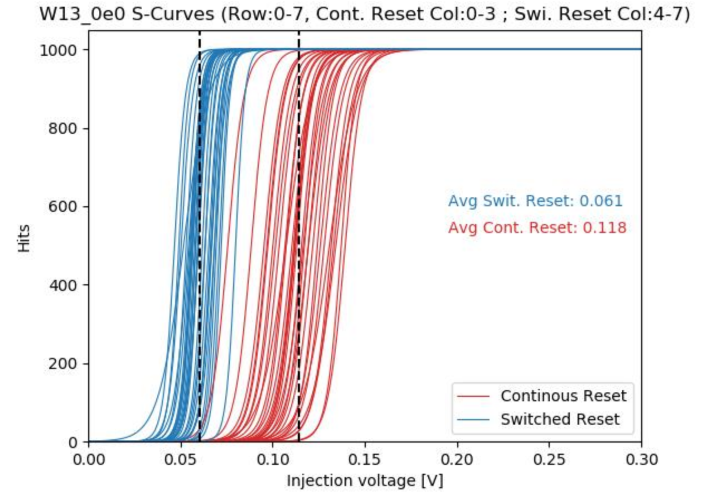


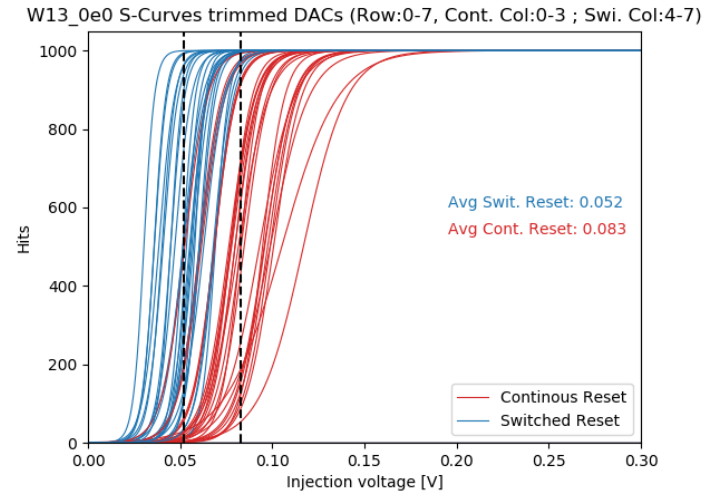


- Wafer14 (same resistivity, >2.2kΩ*cm)
- TRIMDACs are a fine adjustment for comparator threshold
  - Can be set for every pixel individually
- Threshold still below noise level for the lowest 3 TRIMDAC values
- Range of TRIMDACs is ~**50mV**

TRIMDAC Adjust

- Highest possible pixel sensitivity if comparator **threshold** just **slightly above noise-level**
- Adjust TRIMDACs: Lowest possible value, where number of hits is below a certain threshold
  - Shutter 2s
  - Highest possible DAC with nr. of hits >0 (Better sensitivity than lowest TDAC with 0 hits)
- The goal is NOT to decrease the spread of the S-Curves

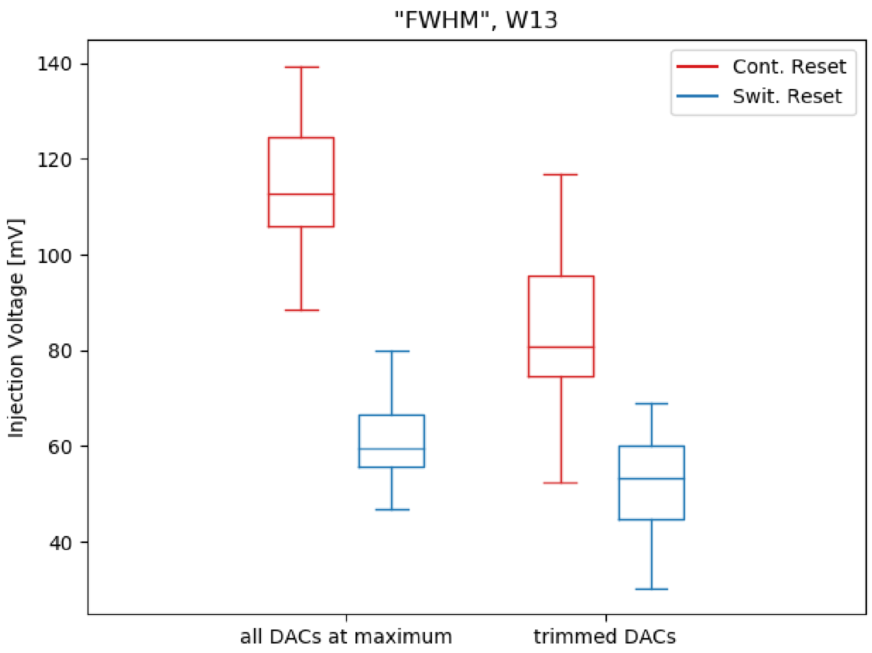




11 pixels masked (noisy)

TRIMDAC Adjust

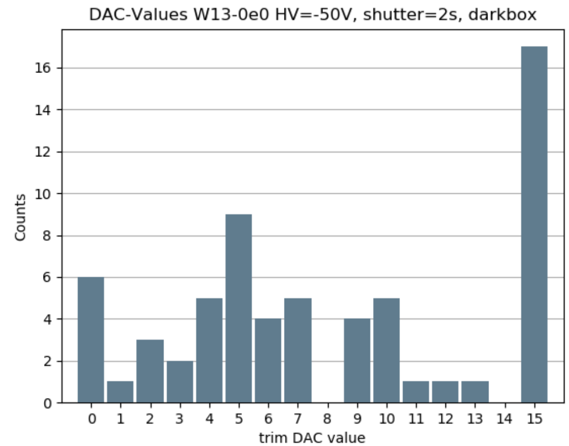
- Highest possible pixel sensitivity if comparator **threshold** just **slightly above noise-level**
- Adjust TRIMDACs: Lowest possible value, where number of hits is below a certain threshold
  - Shutter 2s
  - Highest possible DAC with nr. of hits >0 (Better sensitivity than lowest TDAC with 0 hits)
- The goal is NOT to decrease the spread of the S-Curves

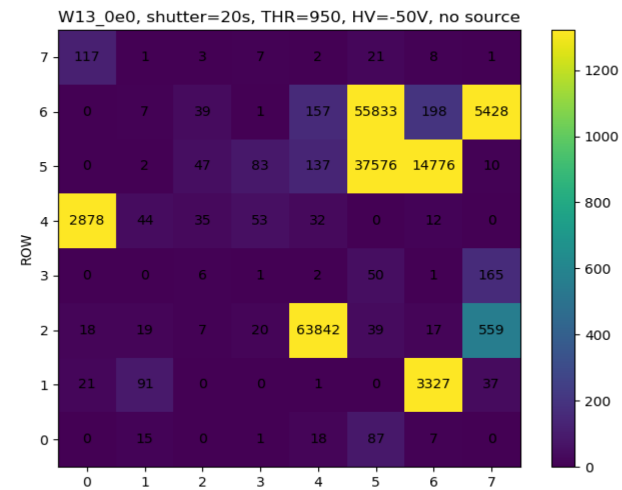


11 pixels masked (noisy)

Open Shutter - Measurement

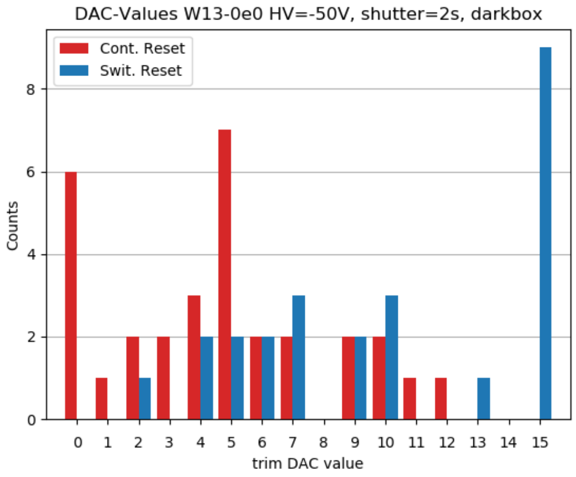
1. Set Bias Voltages
2. Adjust TRIMDACs per pixel as mentioned before
   - Needs to be re-done if environment changes (light, temperature, …)
3. Put radioactive source (Sr90, 10mCi / 370MBq) on top
4. Open a Shutter window (20s) for each pixel and count amount of hits



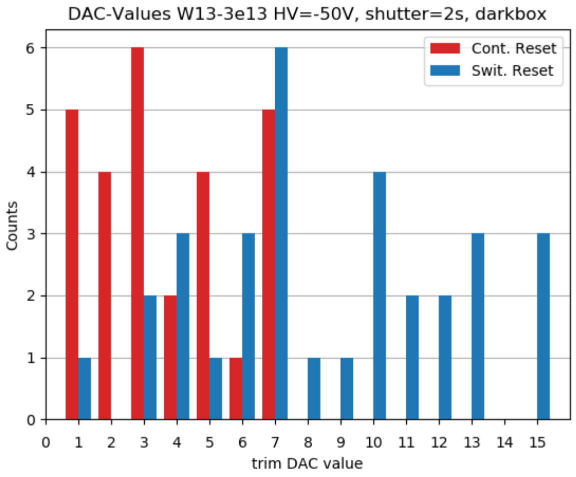


Top: Distribution of adjusted TRIMDAC values for pixels
Bottom: Example Hit-map without source

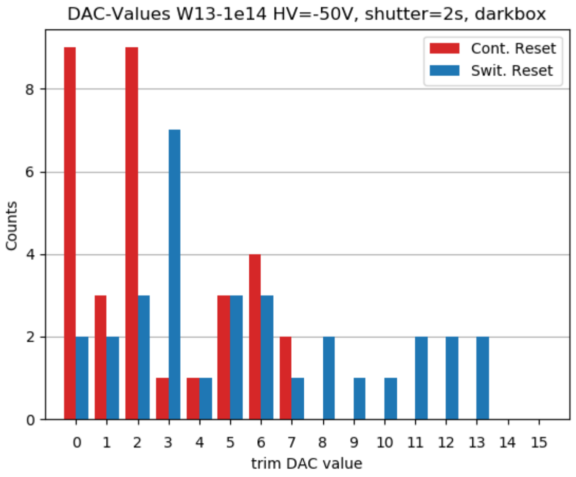
Irradiated samples



Wafer 13, unirradiated



Wafer 13, $3e13N_{eq}$



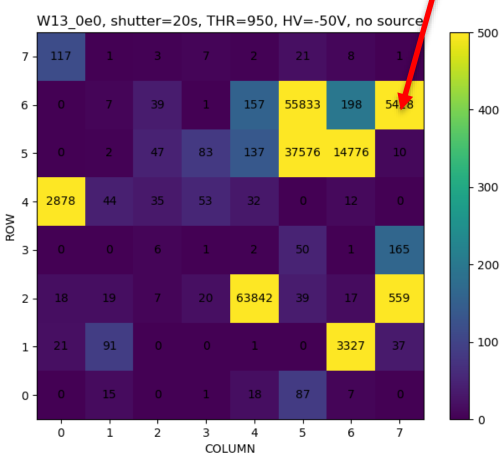
Wafer 13, $1e14N_{eq}$

- Distribution of TRIMDAC values
  - Noisy pixels masked
  - Continuous and switched reset pixels separated
- TRIMDAC values should be higher for irradiated samples (higher noise)
  - Not seen
  - **Sample variations** may affect measurement
  - Peak at TRIMDAC=15 for unirradiated sensor due to noisy pixels

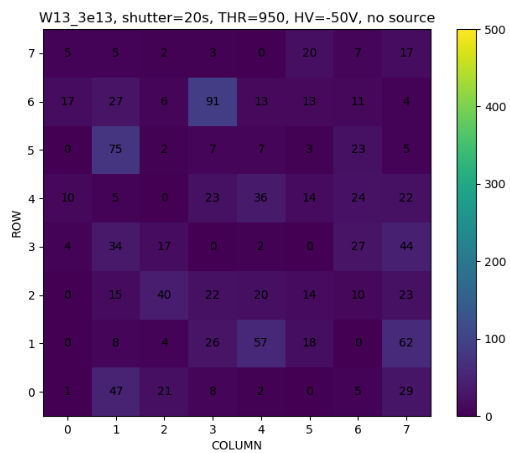
Irradiated samples

- Dark-Count Measurement: Hit-maps at -50V Bias
- 3 different fluences
- No radioactive source

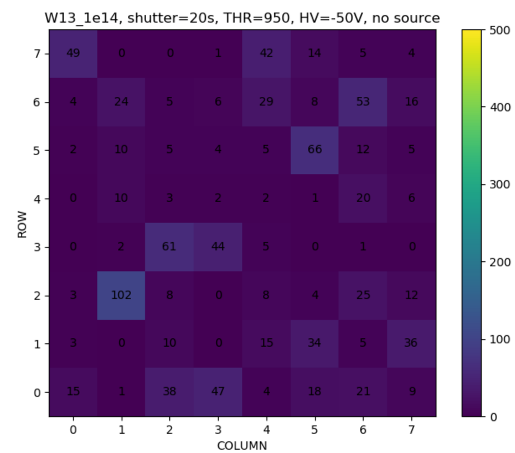
Noisy pixels masked in next plots



Wafer 13, unirradiated



Wafer 13, 3e13N_{eq}

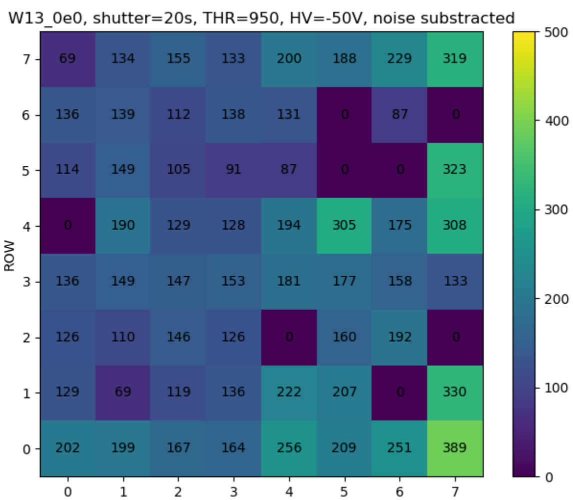


Wafer 13, 1e14N_{eq}

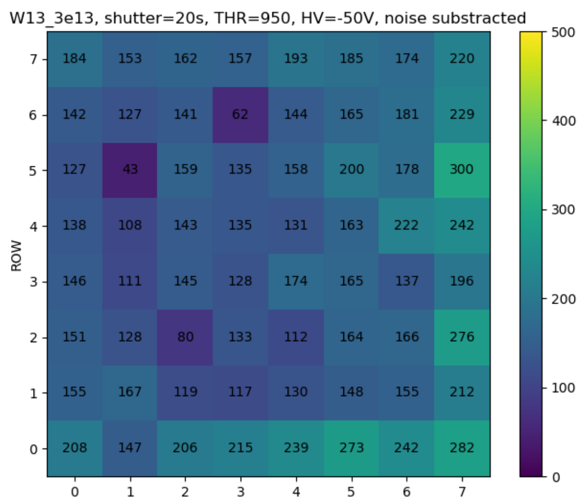
Irradiated samples

- Hit-maps at -50V Bias
- 3 different fluences
- Sr90 source (10mCi)
- Noise subtracted

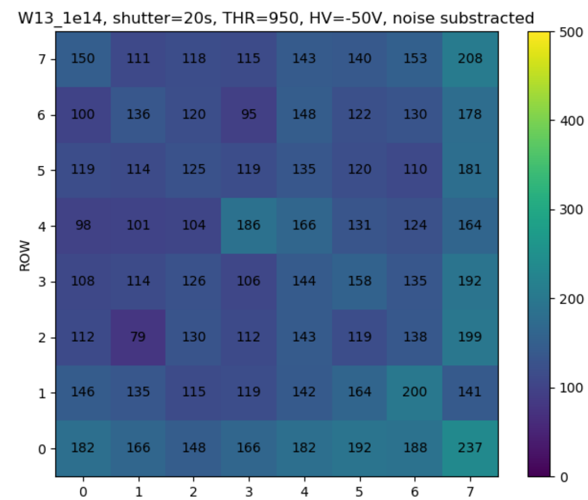
Number of hits decreasing for higher fluences



Wafer 13, unirradiated



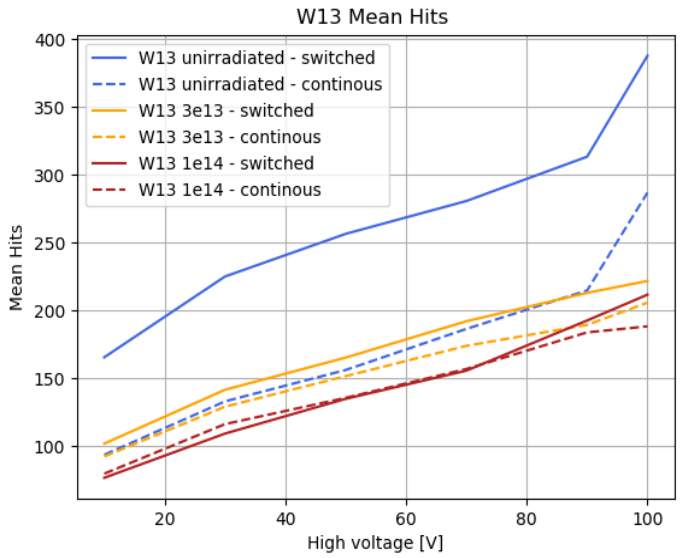
Wafer 13, 3e13N_{eq}



Wafer 13, 1e14N_{eq}

Irradiated samples

- Average number of hits per voltage plotted
  - No noise subtracted
    - Small effect (see backup)
    - Doubles measurement time



-> More hits for switched reset pixels (Lower threshold)
-> Less hits seen for higher fluences (both pixel flavors)
-> Continuous reset pixels less effected by fluence (to be confirmed)

Conclusion

- MPW2 works quite well after irradiation up to $1e14N_{eq}$
- Switched reset pixels have a lower threshold an thus better sensitivity
- Slight decrease in sensitivity seen for higher fluences
  - Sample variations and noisy pixels seem to show more dominant effects than fluence

- Measurement with alpha source (better energy distribution)
- Measurements for higher fluence (up to $2e15N_{eq}$)
- More statistics needed

Outlook

- MPW2 has no digital readout
  - Only one pixel at a time can be readout
    - Very low area
  - No tracking possible
- We still want to get a feeling for the hit efficiency
- Energy measurement with ToT

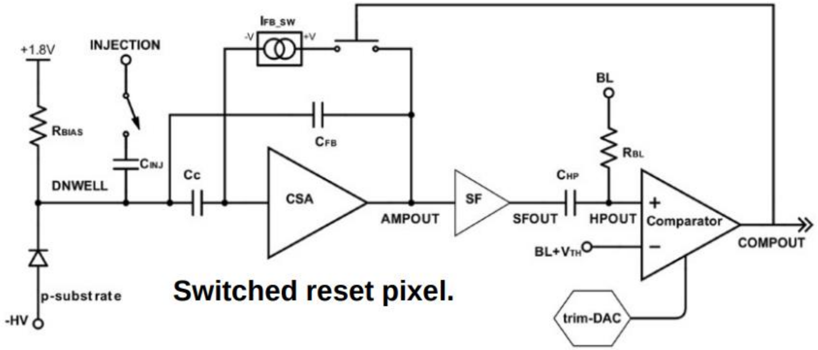
-> First Test Beam planned on 5.12.2020 at MedAustron

- Get familiar with accelerator and AIDA-TLU + EUDAQ
- Measure ToT and hit efficiency
  - Digital part of readout implemented in FPGA
  - Comparing hits of scintillator behind the chip with single pixels hits „relative hit efficiency“

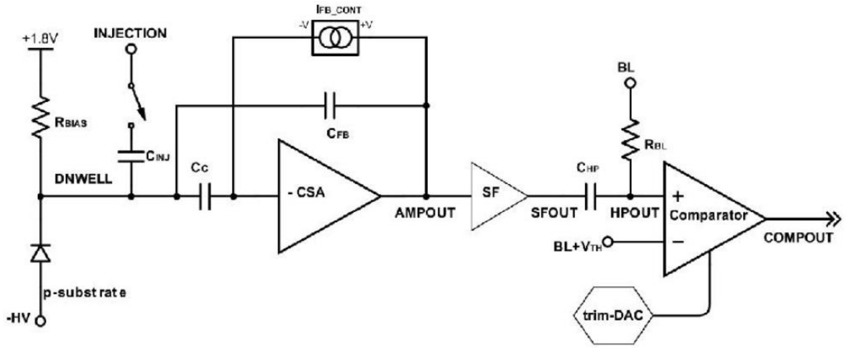
BACKUP

Pixel Flavors

Switched Reset Pixel

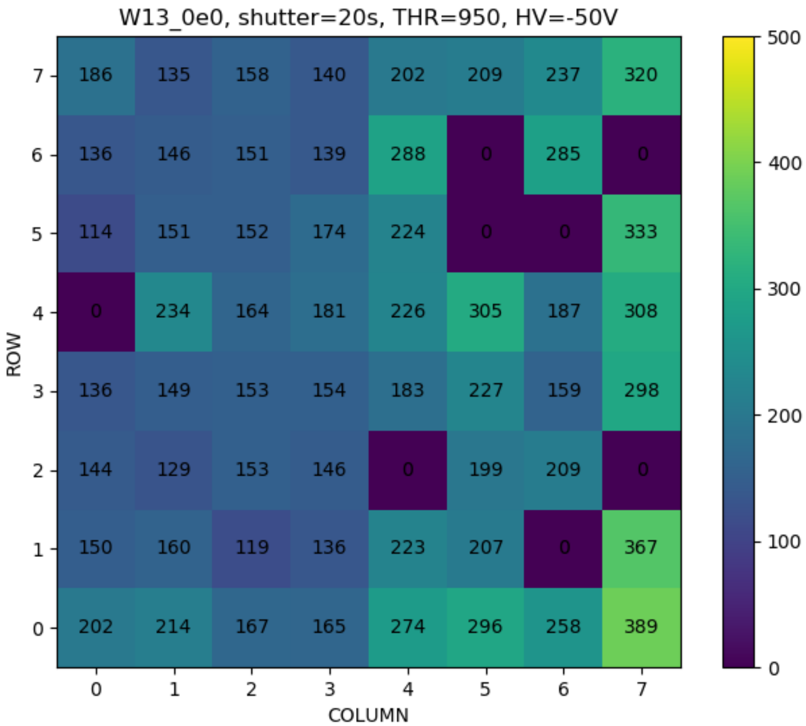


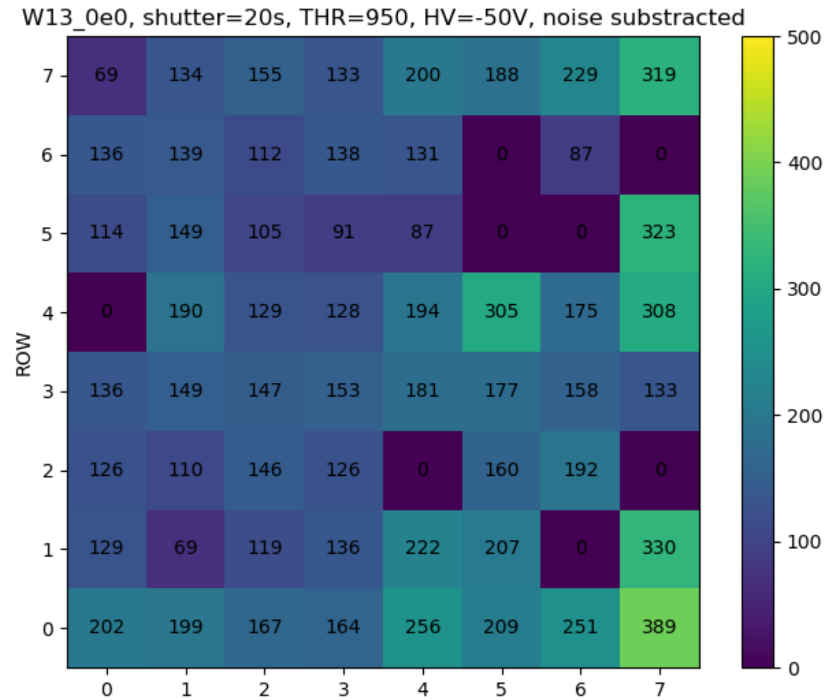
Continuous Reset Pixel



Noise Subtraction

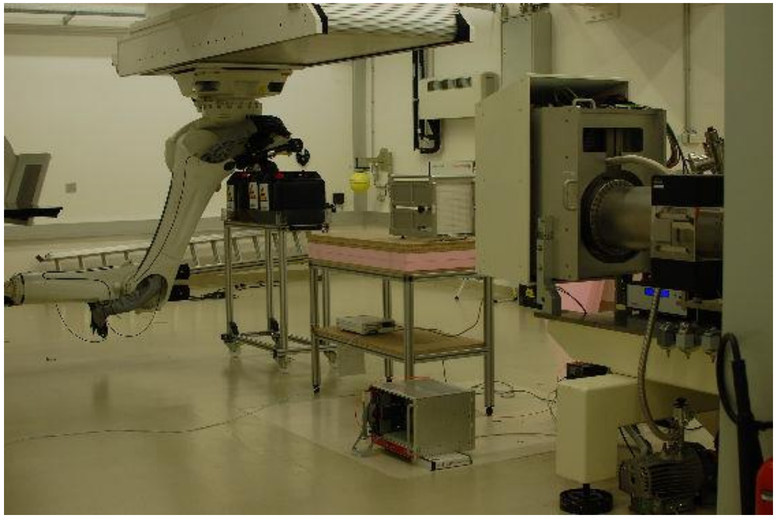
Hitmap at -50V

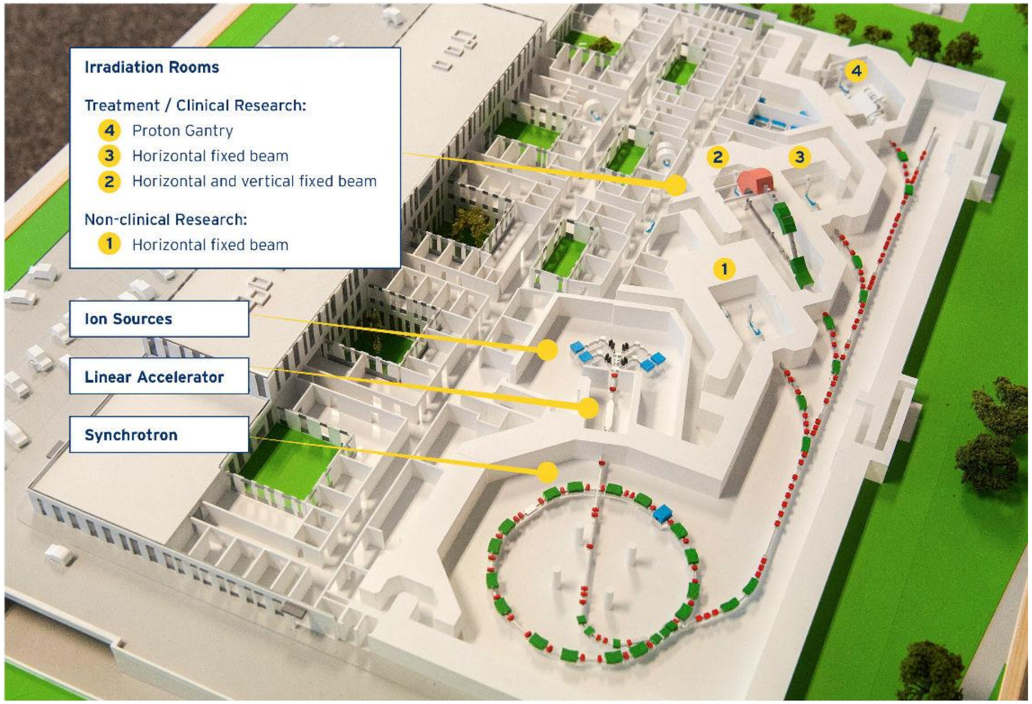




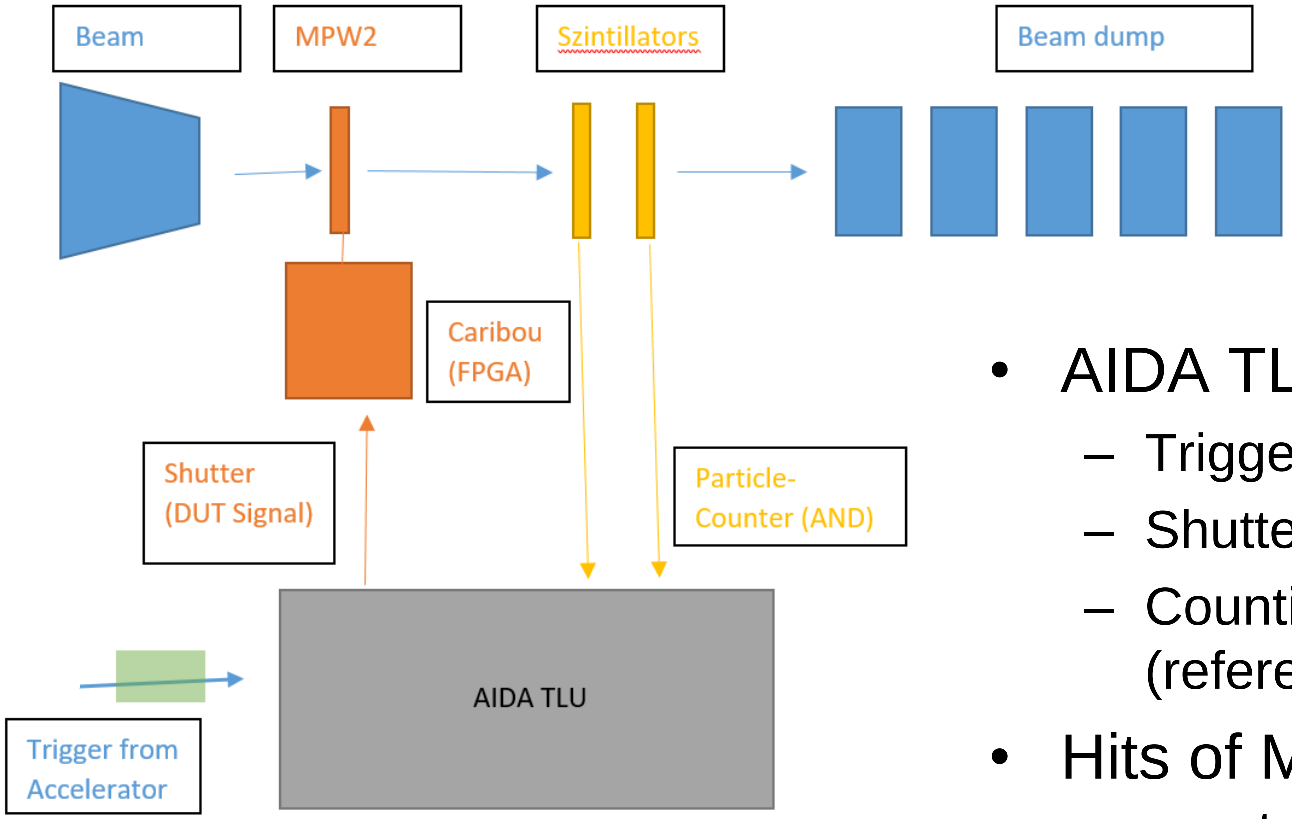
MedAustron – in a nutshell

- Medical Accelerator close to Vienna
- 3 clinical irradiation rooms + 1 additional room for research
- Particle rate: ≥=10^{10} (protons), ≥ 10^{8} (carbon ions)
- Spill structure: 5s spill, 5s pause
- Beam energy: [60,800] MeV



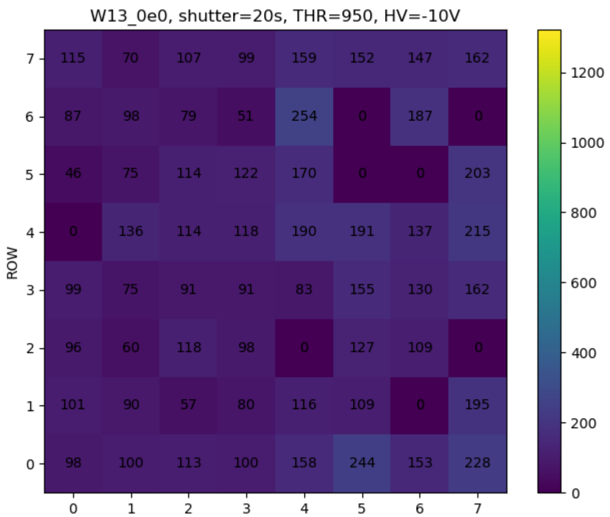


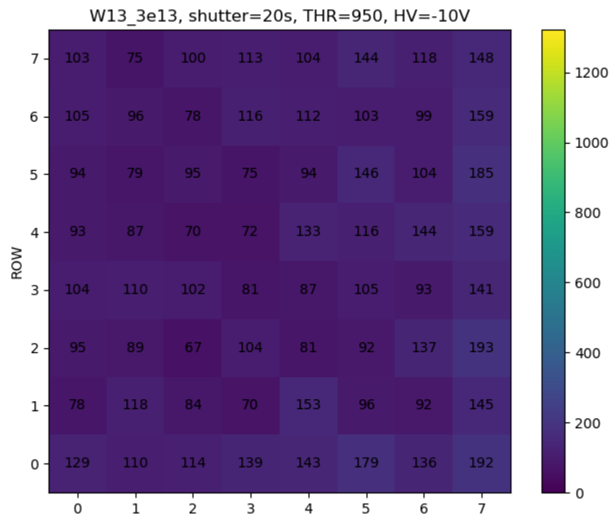
Testbeam Setup

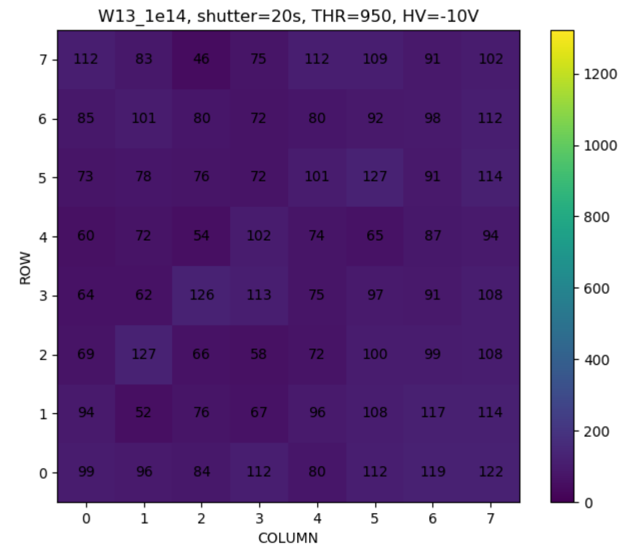


- AIDA TLU used for
  - Triggering
  - Shutter window
  - Counting scintillator hits (reference measurement)
- Hits of MPW2 counted separately with Caribou Setup

- No noise subtracted

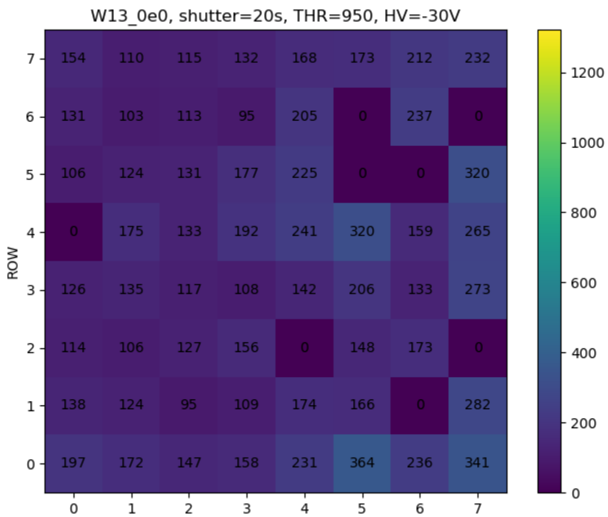


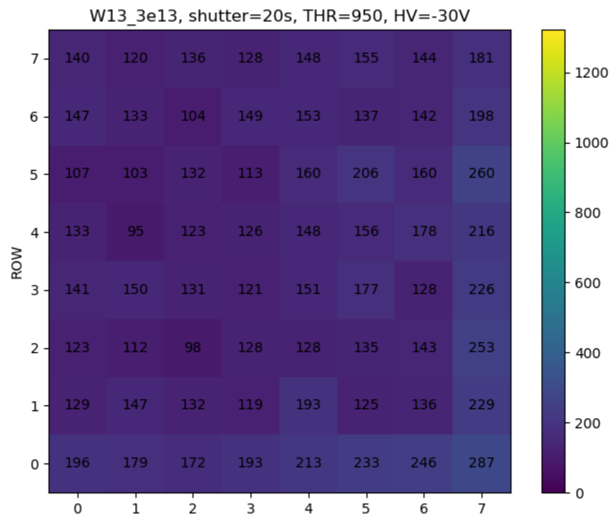


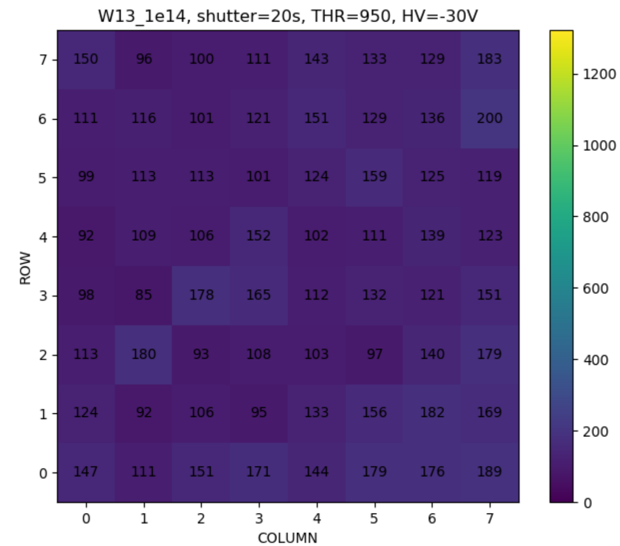


30V Bias

- No noise subtracted

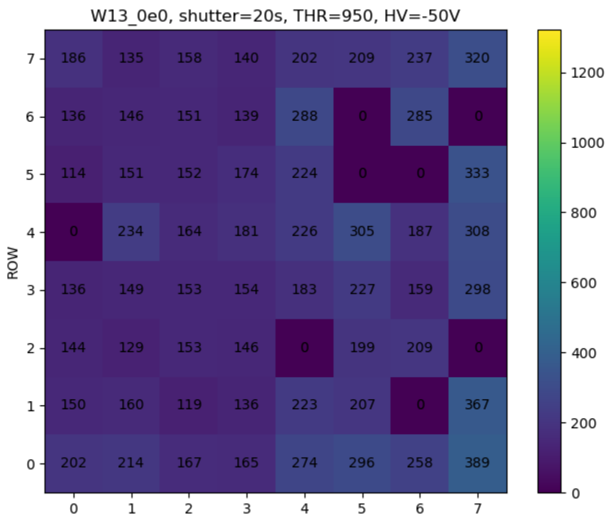


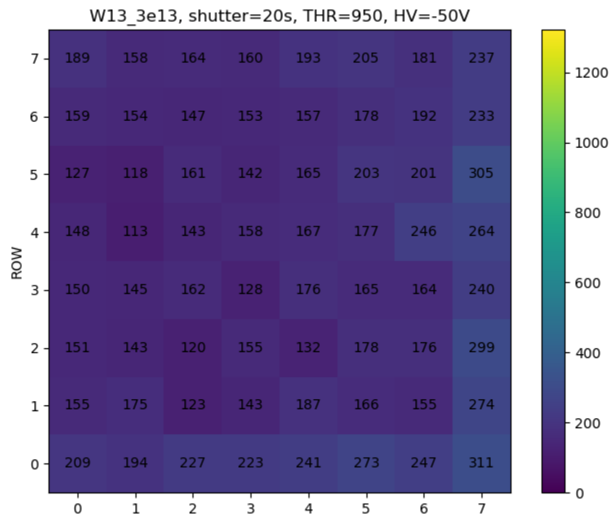


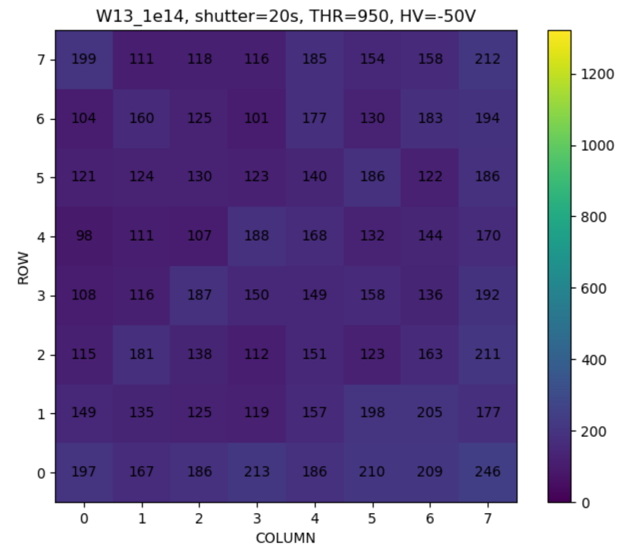


50V Bias

- No noise subtracted

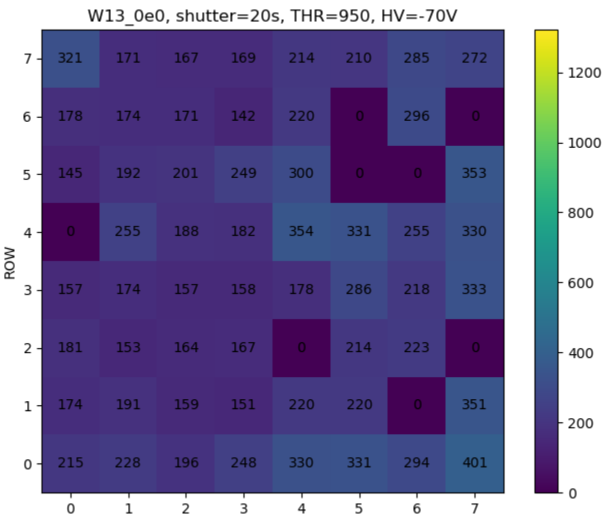


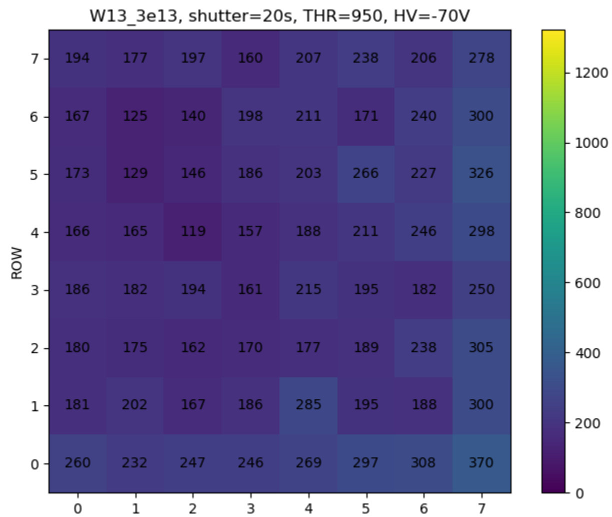


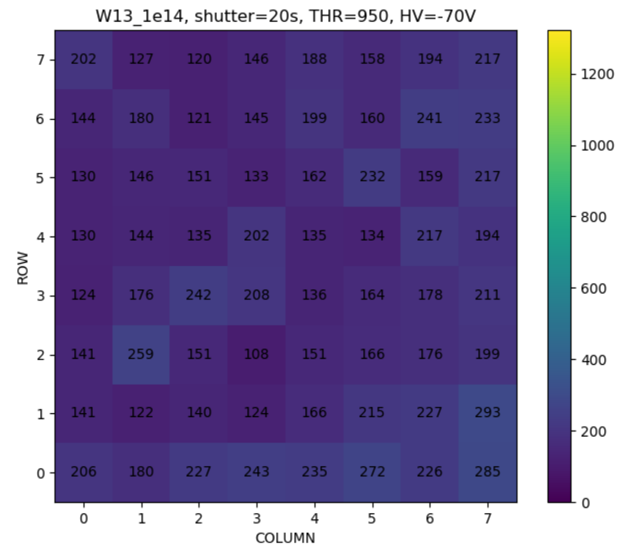


70V Bias

- No noise subtracted







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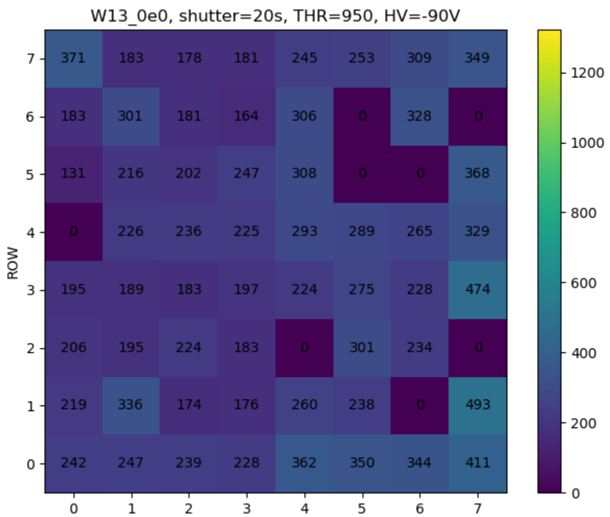
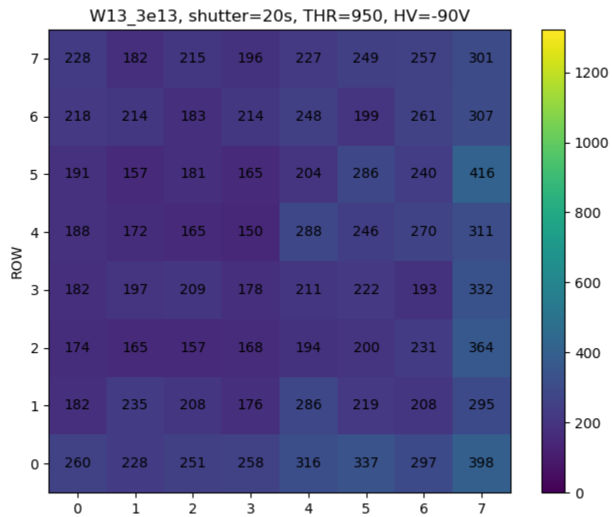
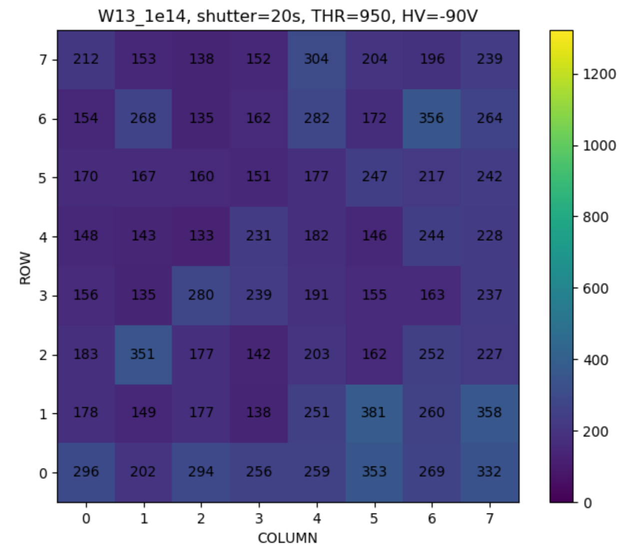
90V Bias

ÖAW

- No noise subtracted







100V Bias

- No noise subtracted