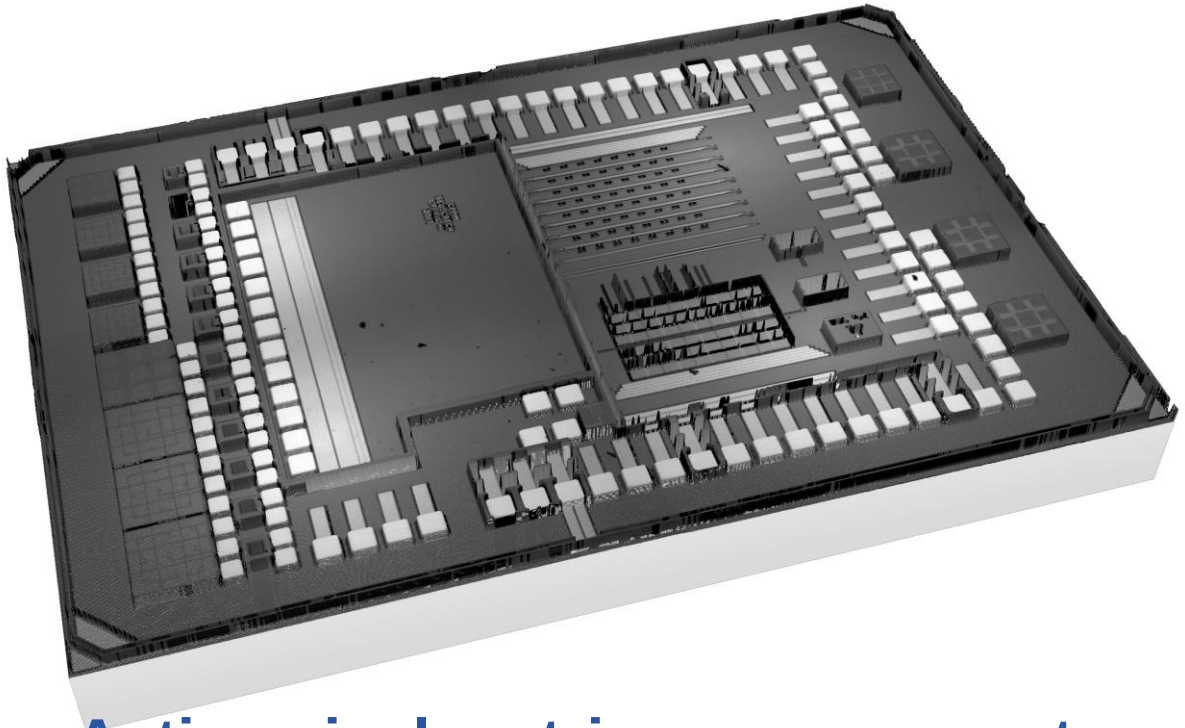
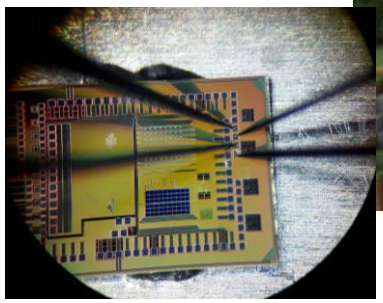
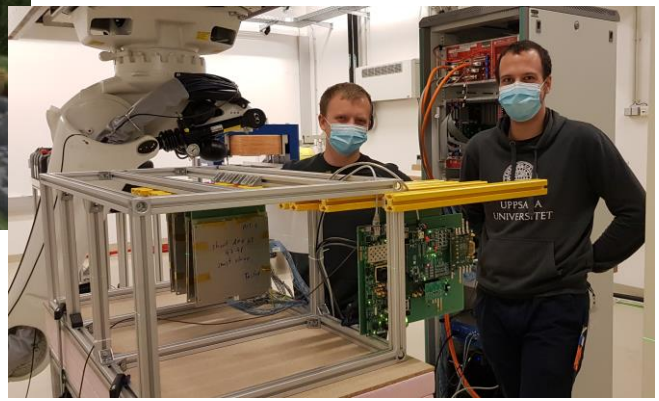


Active pixel matrix measurements of RD50-MPW2 HV-CMOS chip

Patrick Sieberer

Work performed in the framework of RD50





Outline

FROM INJECTION PULSES TO LASER TO RADIOACTIVE SOURCE TO TESTBEAM

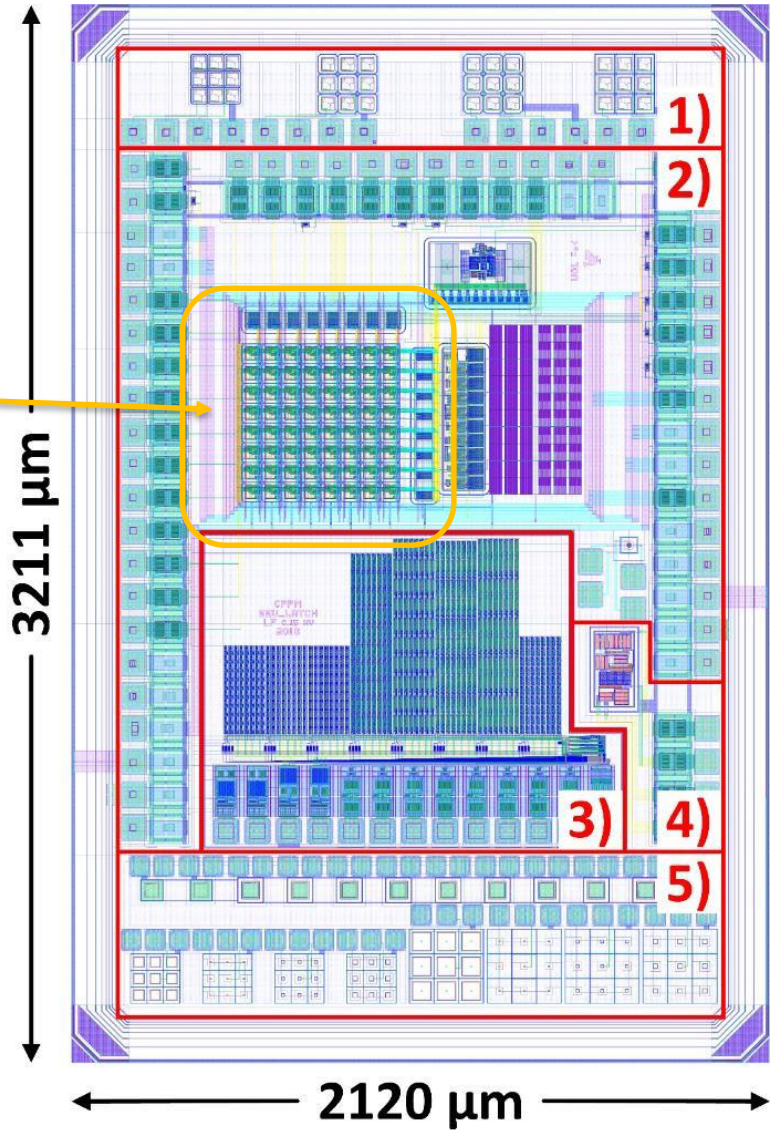
[1] https://www.planetminecraft.com/project/wooden-suspension-bridge/

Setting the stage…

INTRODUCTION

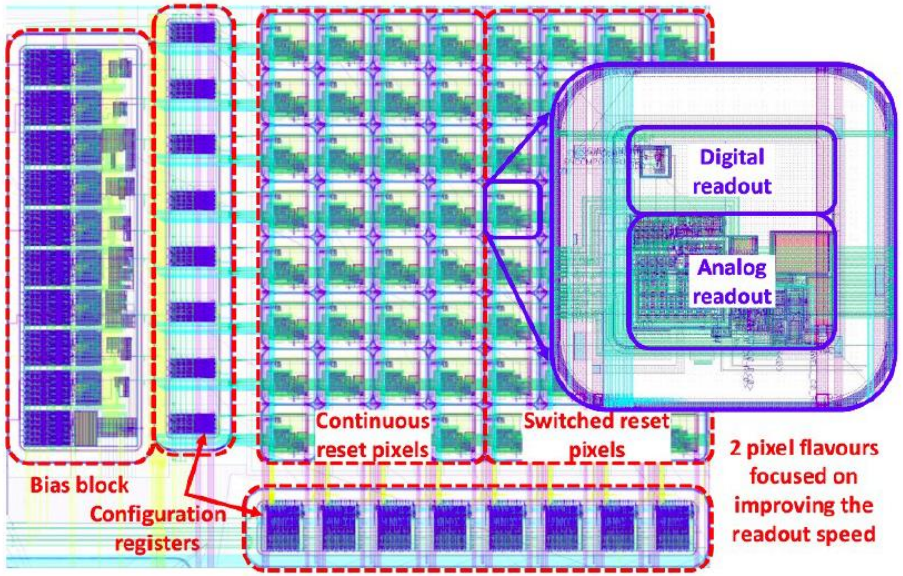
Introduction RD50-MPW2

- LF 150nm process
- Different Wafer resistivities and fluences available
- 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 talk from R. Marco Hernandez at RD50 workshop
- Details on 1): See talk from M. Franks at RD50 workshop or from R. Marco Hernandez at VERTEX 2020

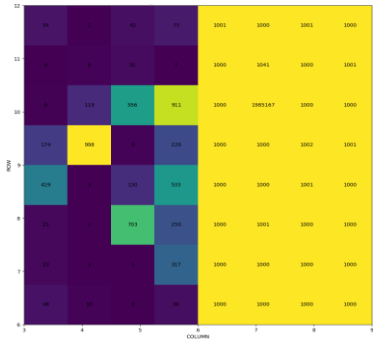


Active Pixel Matrix - Overview

- 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

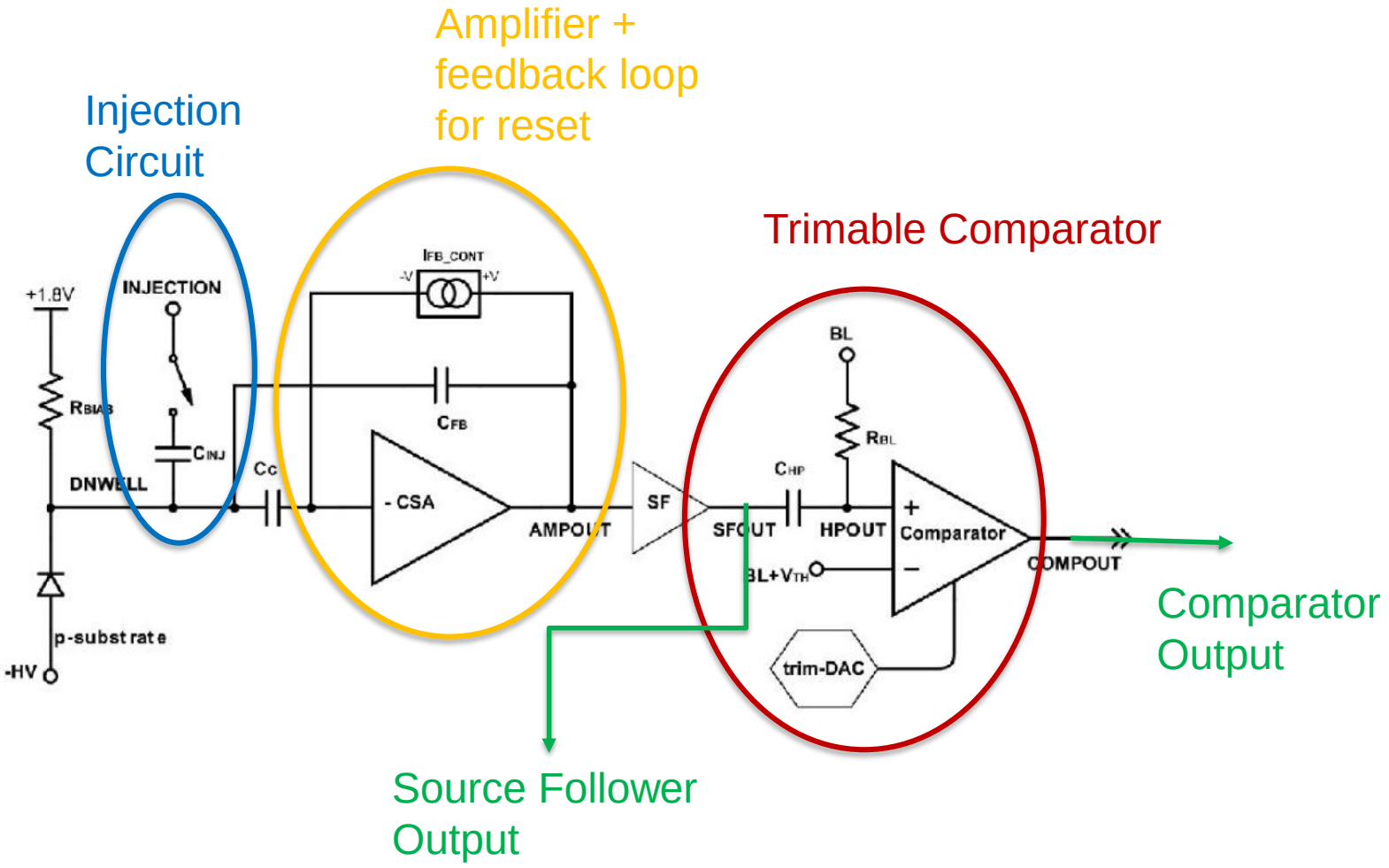


Active pixel matrix floorplan.



Analogue Pixel Readout

Example: Continuous Reset Pixels



INJECTION PULSES

Sr90 Source Test Setup

NIM + VME Crate (for Trigger, not visible)

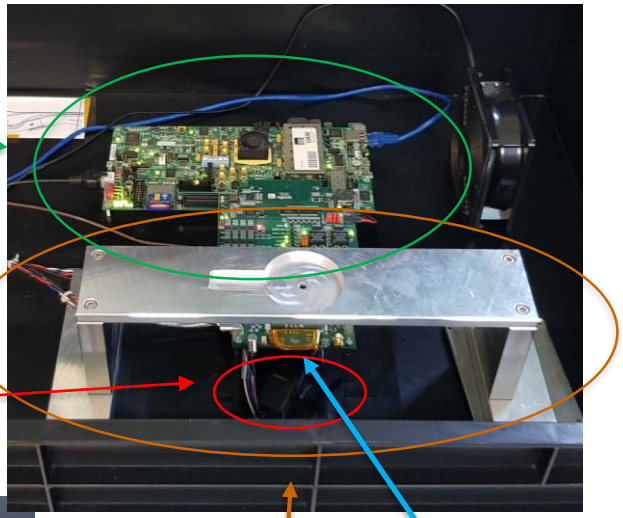
HV supply and control

Caribou

Run Control (EUDAQ)

AIDA TLU

Scintillators (not visible)



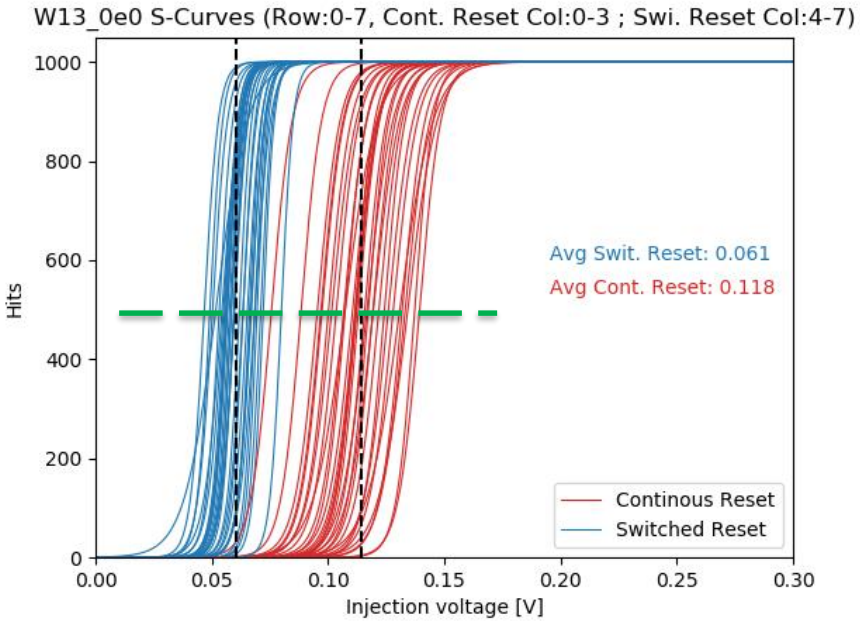
RD50 MPW2

Holder for radioactive source

More details on Hardware and Caribou: See C. Irmler's talk at RD50 workshop

S-CURVES

- **Finding the comparator threshold**
- Comparator baseline (BL) at 900mV (subtracted in plot)
- Threshold at 950mV
- 1000 Pulses per voltage step (Step size 10mV)
  - Sigmoid function fitted
  - Counted after COMPOUT



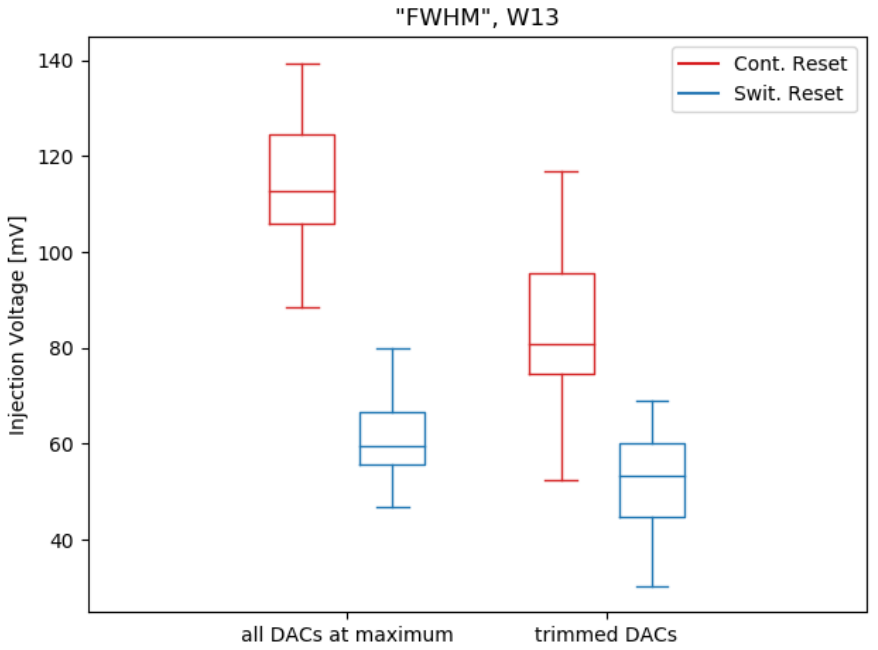
-> Threshold of Continuous Reset Pixels higher than for Switched Reset pixel

-> Quite some variation between pixels

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
  - Open a shutter for 2s, count (noise) hits
  - 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

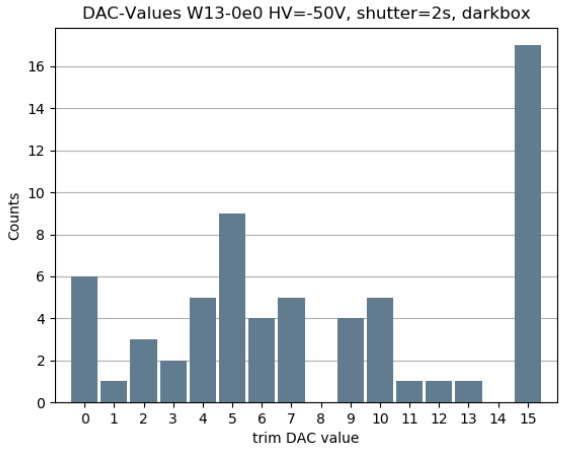
11 pixels masked (noisy)



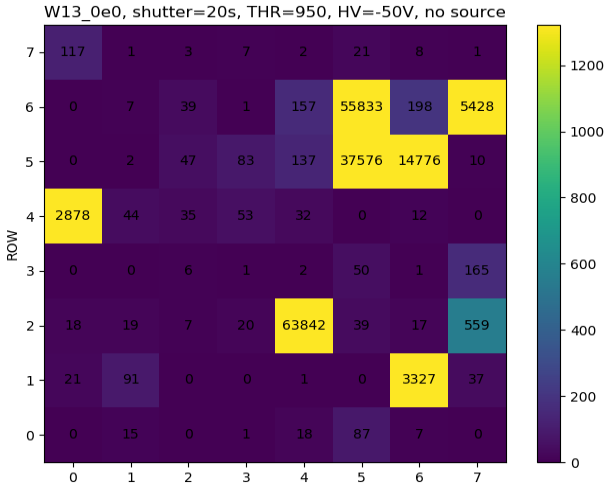
RADIOACTIVE SOURCE

Open Shutter - Darkcount

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



This peak includes noisy pixels

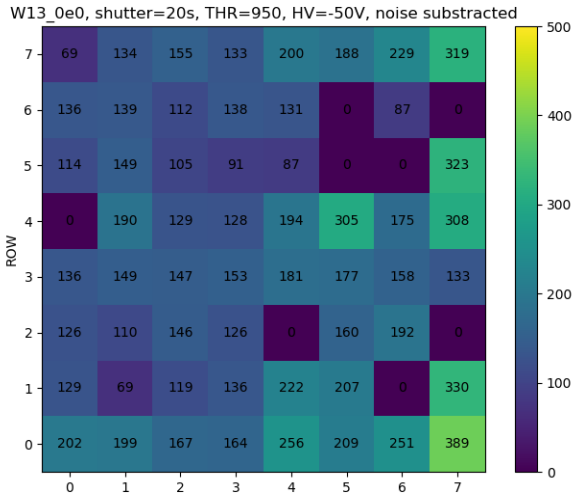


Top: Distribution of adjusted TRIMDAC values for pixels
Bottom: Example Hit-map without source

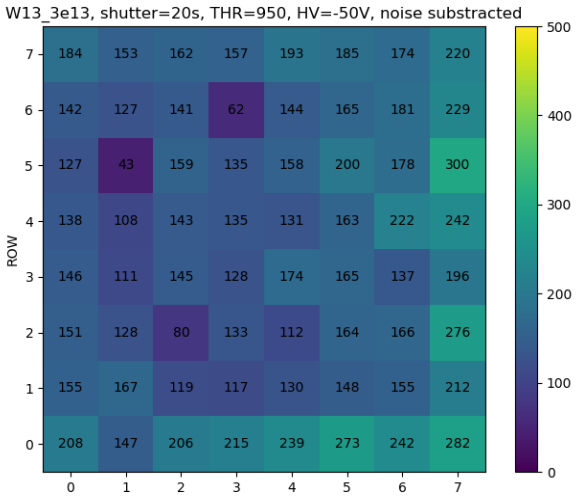
Irradiated samples

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

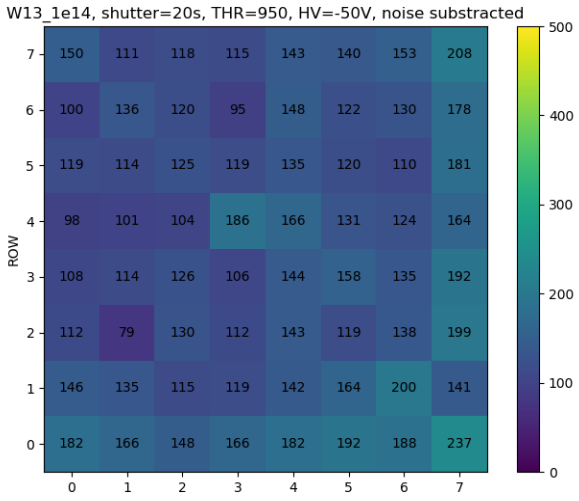
Number of hits decreasing for higher fluences



Wafer 13, unirradiated



Wafer 13, 3e13N$_{eq}$



Wafer 13, 1e14N$_{eq}$

For more results, see this talk from P. Sieberer at RD50 workshop

Institut
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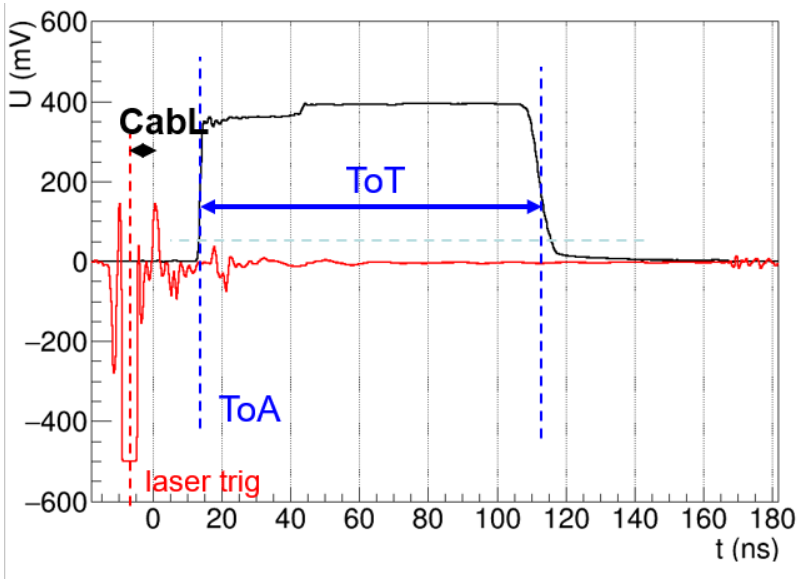
Ljubljana, Slovenija

Work performed by JSI, Ljubljana

LASER - TCT

Setup

- Particulars Setup
- **eTCT using the *Active Matrix***
  - IR light injected through sensor edge
  - **Analog readout of COMPOUT with DRS4 oscilloscope** (Triggered by Laser)
  - Cont. reset pixels used in order to measure charge from ToT



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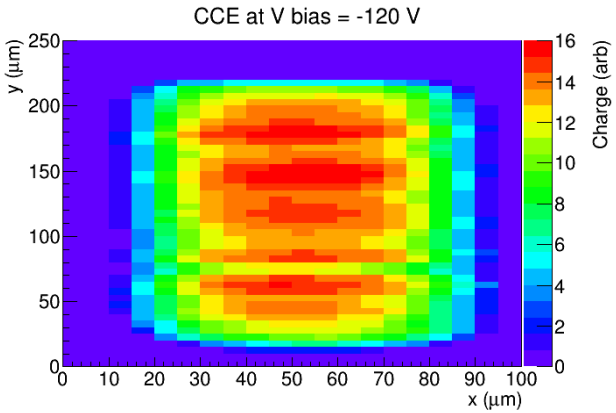
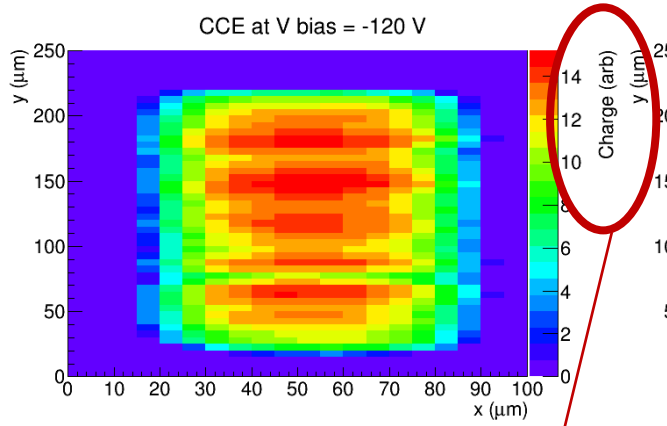
ToT

Threshold at 975mV



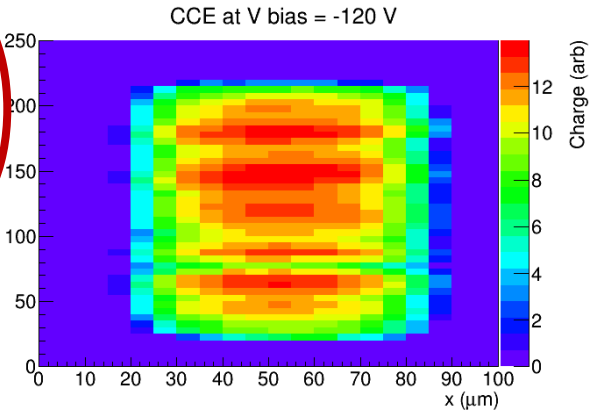
preliminary

Threshold at 1000mV



approx. ke-

Threshold at 1050mV



- Laser intensity selected so that max signals are approx 15 ke
- Conversion Tot -> Charge with simulated results
- Shape of depletion zone is constant at higher threshold
- **Less charge** (color scale!) **at higher threshold** -> Expected due to lower ToT

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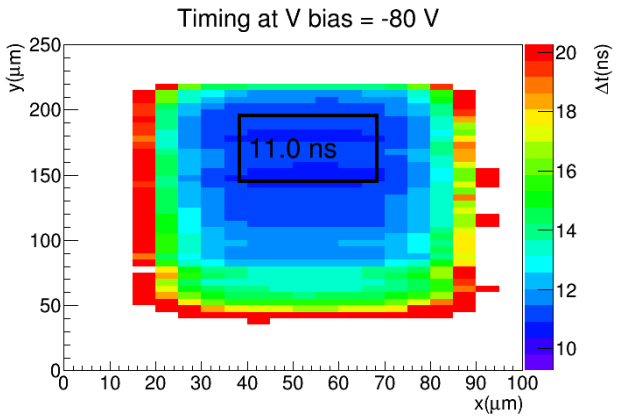
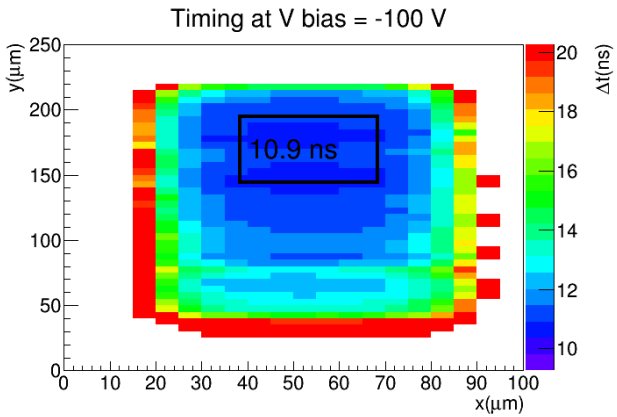
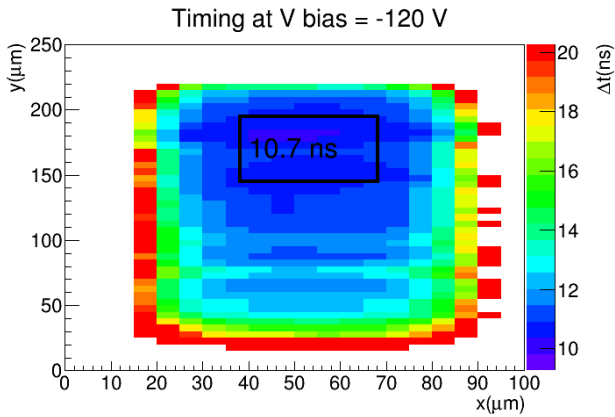
ToA







preliminary

V_{bias} (V)	ToA (ns)
80	11.0
100	10.9
120	10.7

- Timing correct for cable length etc…
- Estimate timing response by averaging ToA in a volume close to the pixel surface at ≈ 15 ke
- ToA decreasing with higher bias as expected

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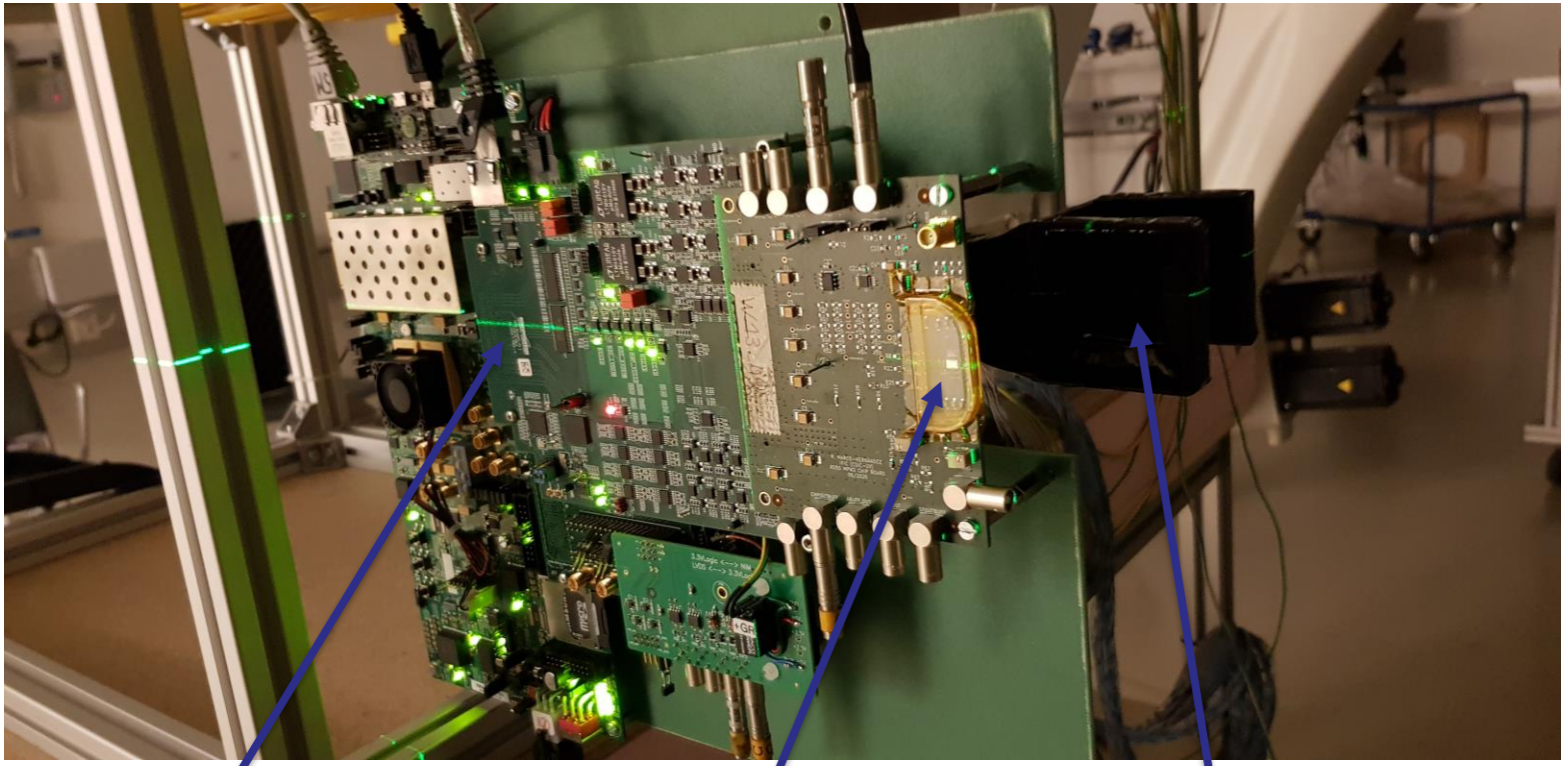
TESTBEAM

Setup



Laser Alignment

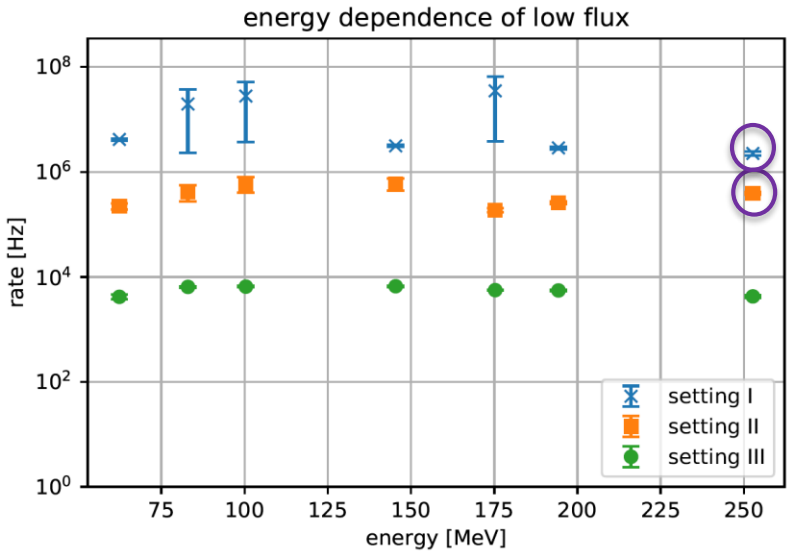
RD50-MPW2

Scintillators (5x5cm)

Beam Settings

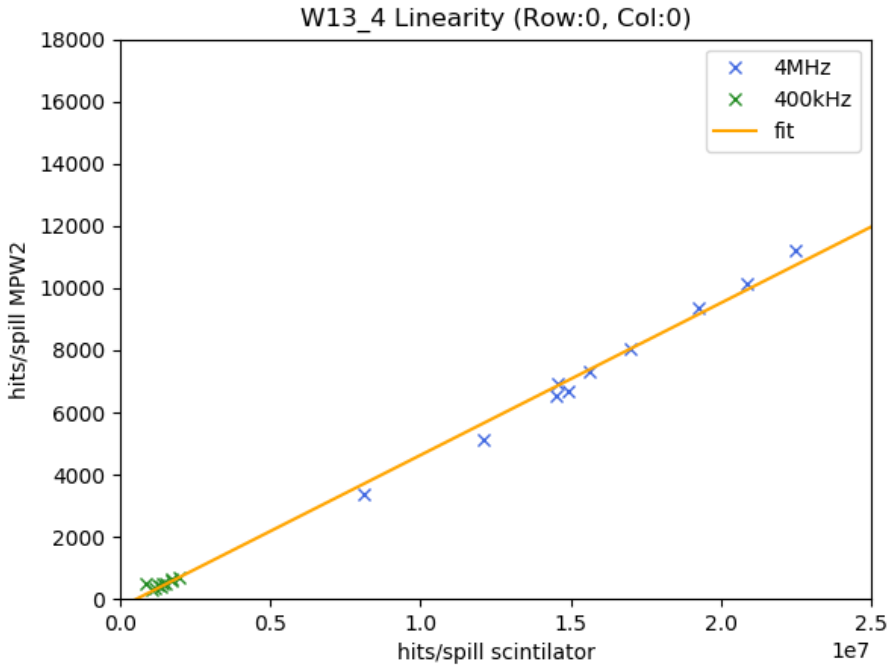
- Testbeam at MedAustron with protons
  - Ion cancer treatment (GHz rate)
- 2 different “Low Flux”- Settings used
  - Complete different beam settings, thus different rate
- Beam Energy: 252.7 MeV (both settings)
- Rate: 2.2MHz and 400kHz
- Beam – Spotsize: ~7mm (both settings)
  - All particles hit scintillators
  - Very few particles hit a pixel (60um x 60um)

Setting	Mean Rate	StdDev Rate
I (at 252.7 MeV)	2.25e6	1.87e5
II (at 252,7 MeV)	3.92e5	1.86e4

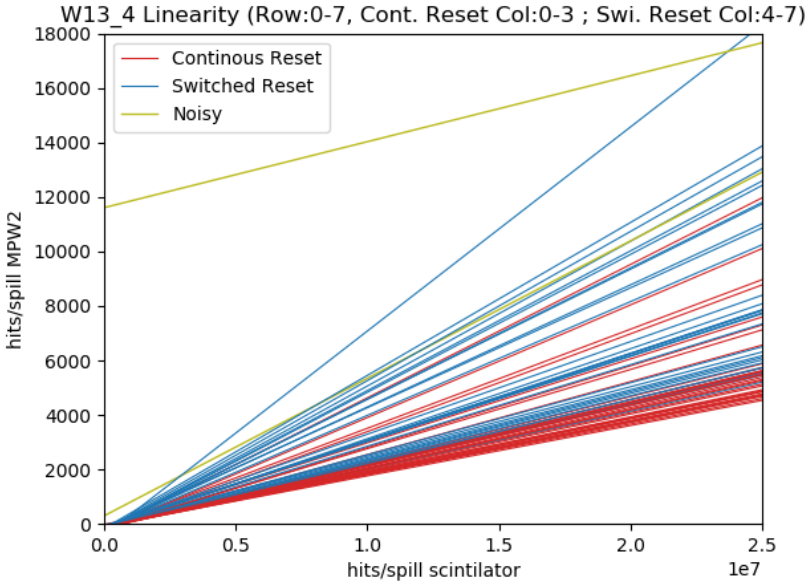


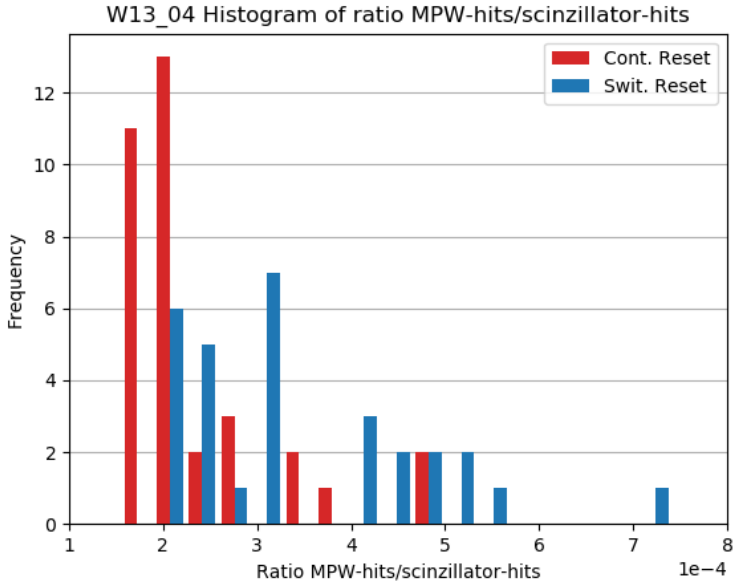
Simple counting

- 20 spills (5s) for each pixel measured
  - 10 spills per rate
  - Hits summed up over whole spill
- 400kHz Beam rather stable particle rate
- 2.2MHz Beam larger variation of particle rate per spill
  - as seen on previous slide
- Much higher rates (10^9) possible
  - Scintillators not fast enough for single particle counting



Linearity





- Straight line fit plotted for all pixels
- Switched reset pixel see more hits (Thus better sensitivity)
  - Already known from source-measurements

RD50 HVCMOS Roadmap

- RD50-MPW2 has no digital readout
  - Only one pixel at a time can be readout
    - Very low area
  - No tracking possible
  - However, compared to RD50-MPW1, RD50-MPW2 works really nice
- RD50-MPW3 is designed currently
  - Same analog frontend as RD50-MPW2
  - Much bigger matrix (~5mm x 5mm)
  - FEI3-style
  - State-of-the-Art digital interface
    - I2C for Slow Control
    - Wishbone Bus for communication inside the chip
    - 1 or 2 640MHz LVDS links for data
      - Fully encoded, framed and with an idle pattern for synchronization with FPGA
  - Tape Out planned ~**April/May 2021**

CONCLUSION AND OUTLOOK

Conclusion

- **RD50-MPW2 works as expected for all different kinds of penetration**
  - TRIMDAC calibration is working (Injection)
  - Hit counting is working (real particles from source)
  - Depletion zone (Laser)
  - Counting is linear with rate (testbeam)
- Switched-reset pixels have a better sensitivity than continuous-reset pixels (different measurements)

Outlook

- (costume) ToT measurement implemented in FPGA
  - Using Source Follower Output (SFOUT)
- Waveform measurement (“oscilloscope”) implemented using a fast ADC of the CaR-Board
  - Using SFOUT
- Telescope setup
  - Synchronization between telescope and RD50-MPW2
  - Attempt to measure “hit efficiency” (difficult, just one pixel!)

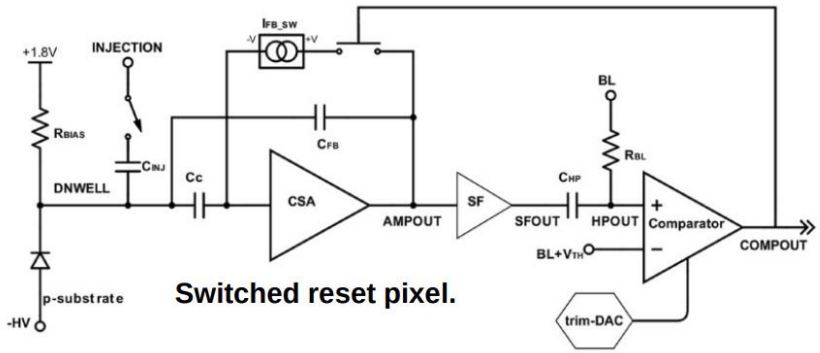
=> will be tested in a testbeam in 2 weeks!

BACKUP

INJECTION PULSES

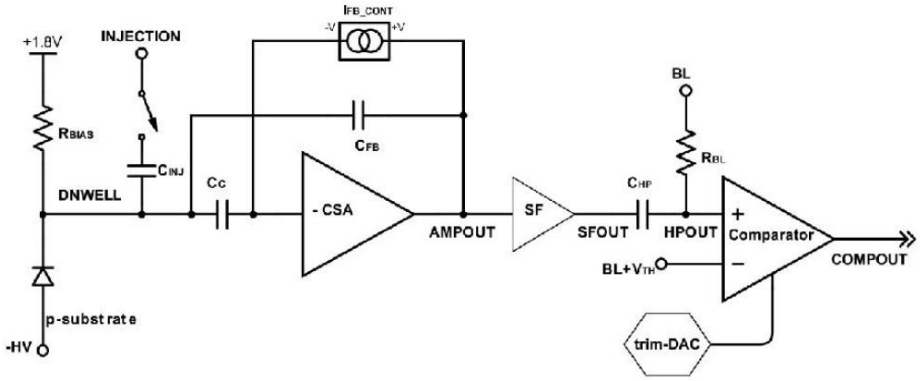
Pixel Flavors

Switched Reset Pixel



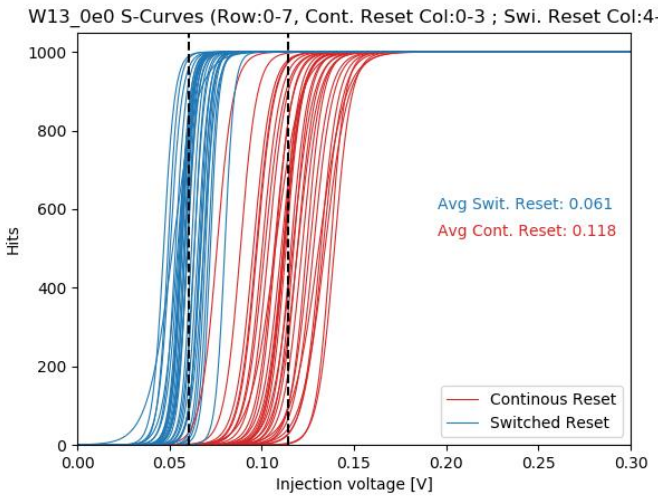
Switched reset pixel.

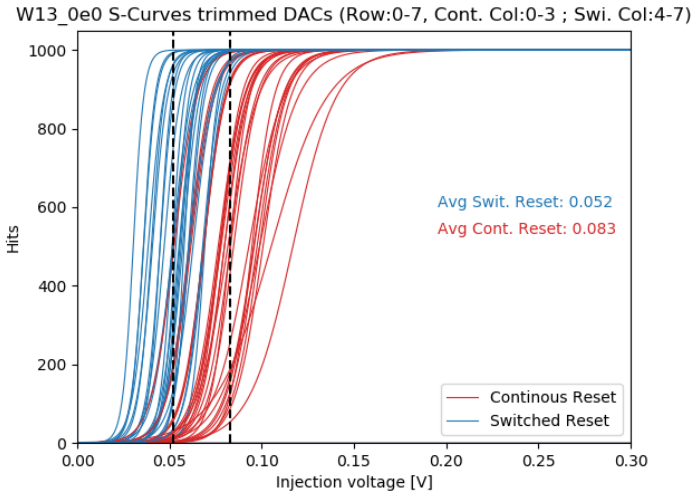
Continuous Reset Pixel



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

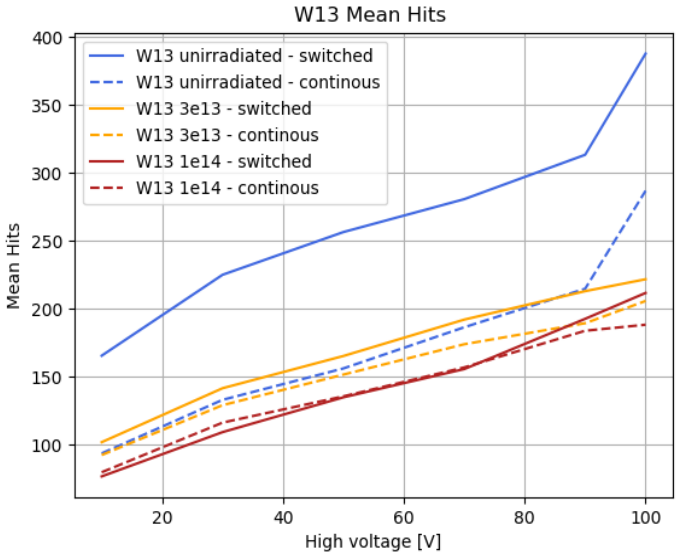




11 pixels masked (noisy)

Irradiated samples

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

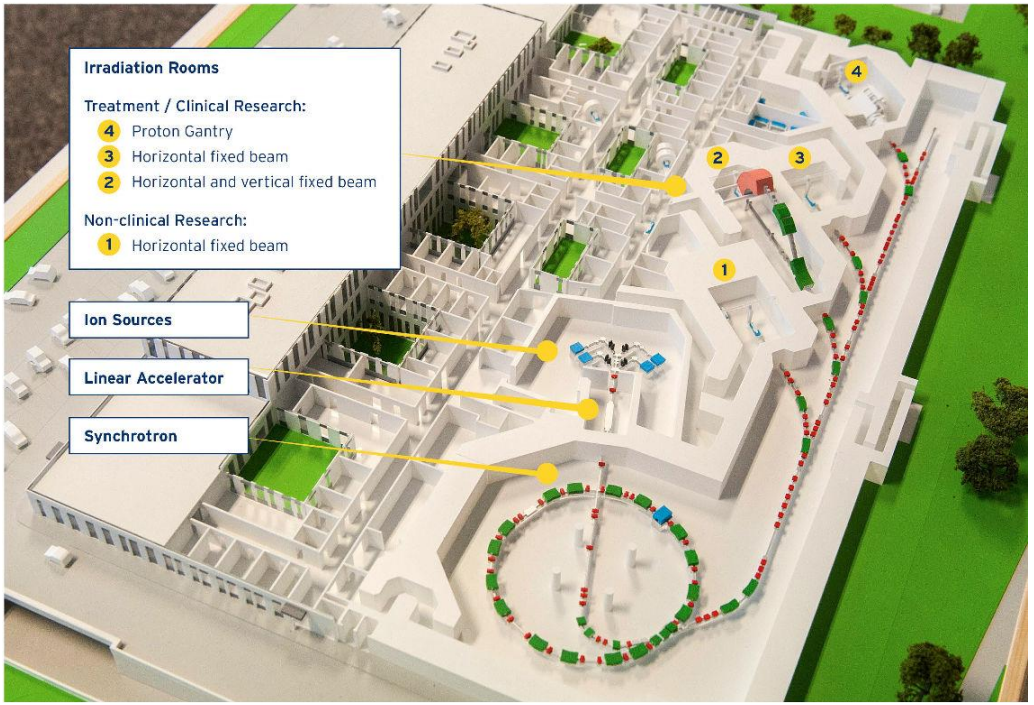


-> More hits for switched reset pixels (Lower threshold)
-> Less hits seen for higher fluences (both pixel flavors)
-> Continuous reset pixels less effected by fluence (to be confirmed)

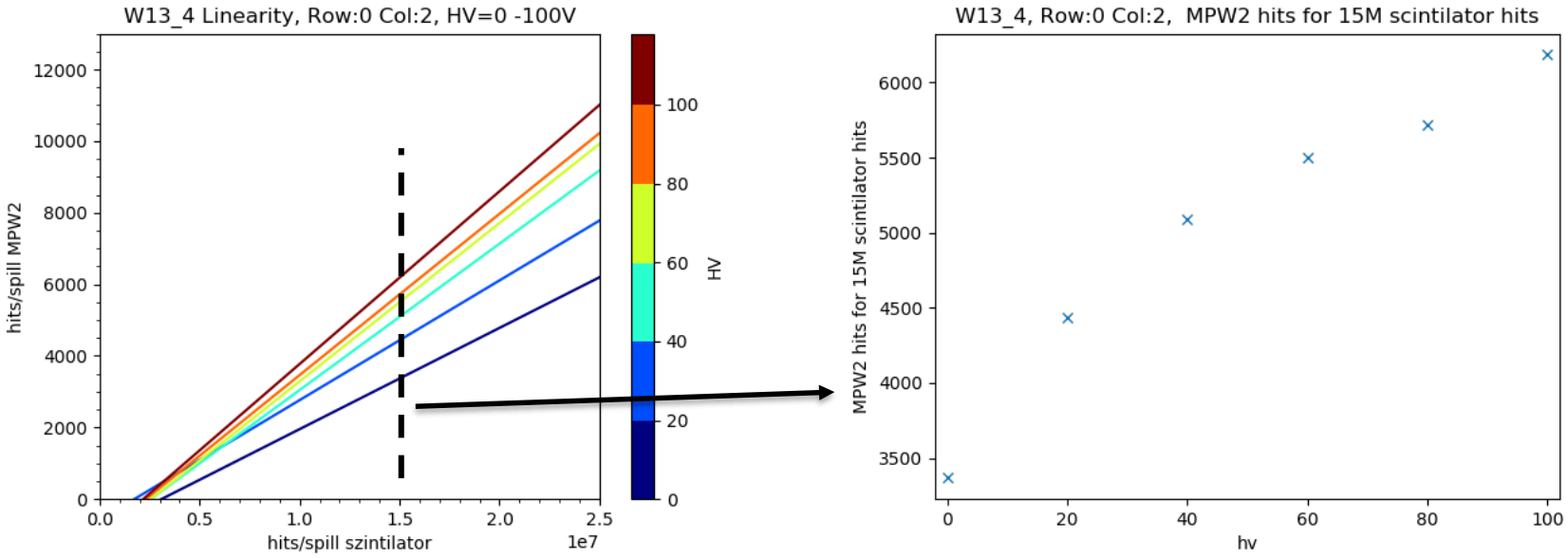
TESTBEAM

MedAustron – in a nutshell

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



HV Scan



- Just one Pixel for one rate ramped over HV (20V stepsize)
- Better performance for higher bias voltage (as expected)
- Follows expected sqrt(U) function, but low statistics