



Characterization of RD53A planar  
pixel modules with HLL sensors

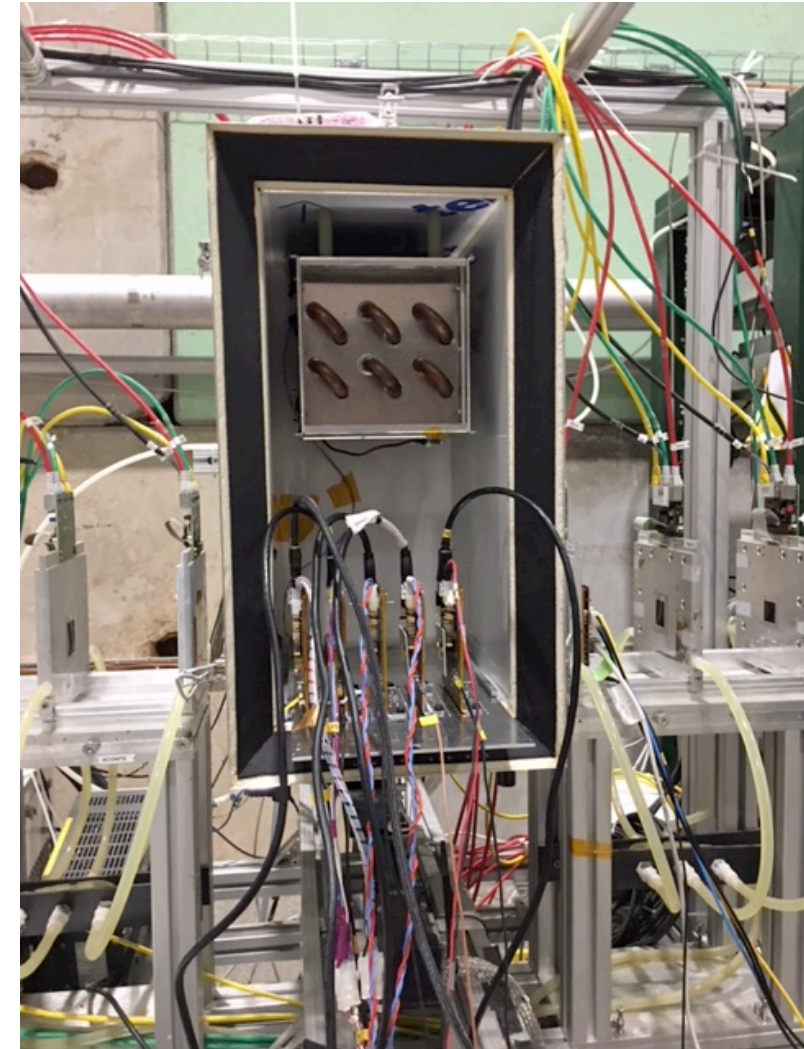
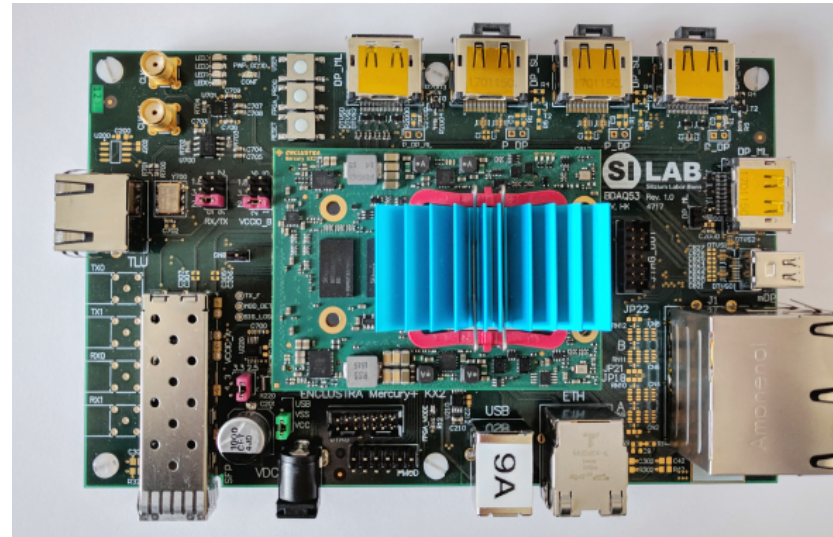
A. Macchiolo  
N. Baron Perez, J. Beyer, M. Chatterjee, A. Chikkaballi, R. Nisius  
Max-Planck-Institut für Physik, Munich





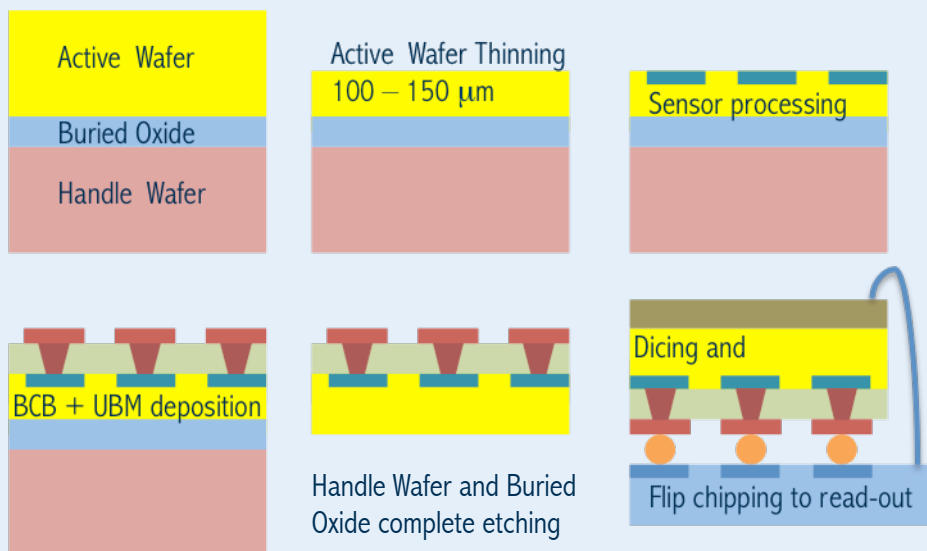
# Test-beam analysis of RD53A planar pixel modules

- RD53A modules mainly from the SOI4 HLL production
- Irradiated at PS at 5e15 and KIT at 3e15 and 5e15 n<sub>eq</sub>/cm<sup>2</sup>
- Measured during May –October 2018 at CERN SPS with the BDAQ53 read-out
  - Thanks to Bonn colleagues for lending us the read-out boards and support in the learning phase!

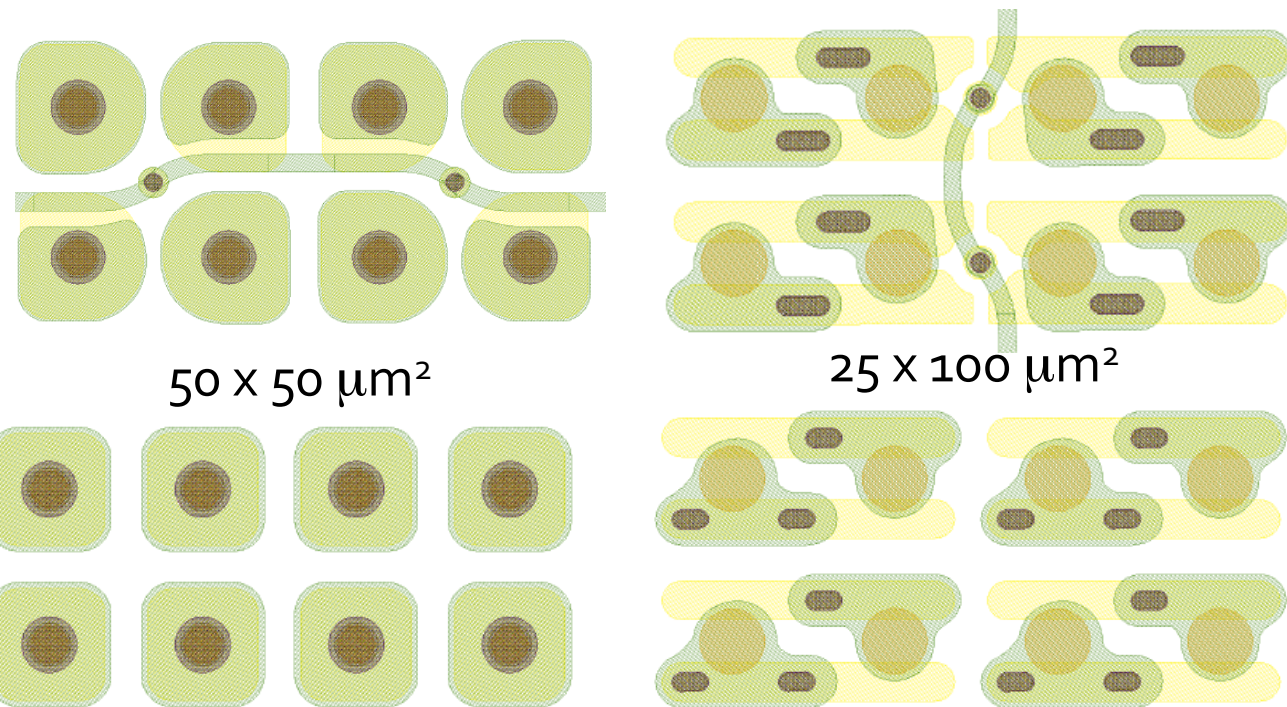


# Production technology and sensor design

- HLL SOI4 production: 8 wafers produced with 100 and 150  $\mu\text{m}$  active thickness
- Cu UBM and BCB passivation deposited at HLL
- Many single chip RD53A sensors:  $50 \times 50$  and  $25 \times 100$   $\mu\text{m}^2$
- Thinning and Aluminum on the backside deposition performed at IZM



With biasing structures



Without biasing structures

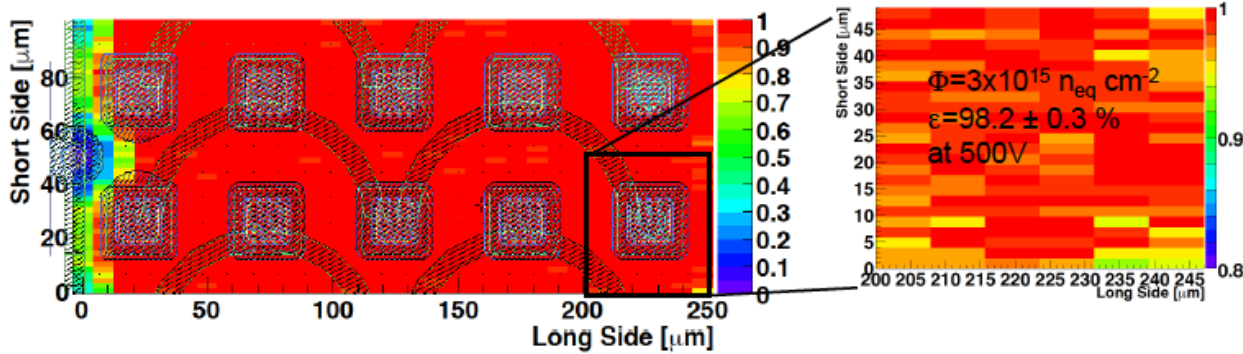
- Both geometries compatible with  $50 \times 50$   $\mu\text{m}^2$  grid of the RD53A chip



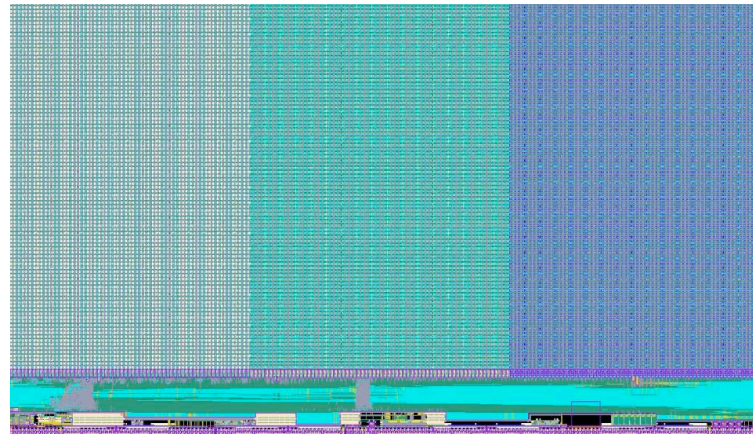
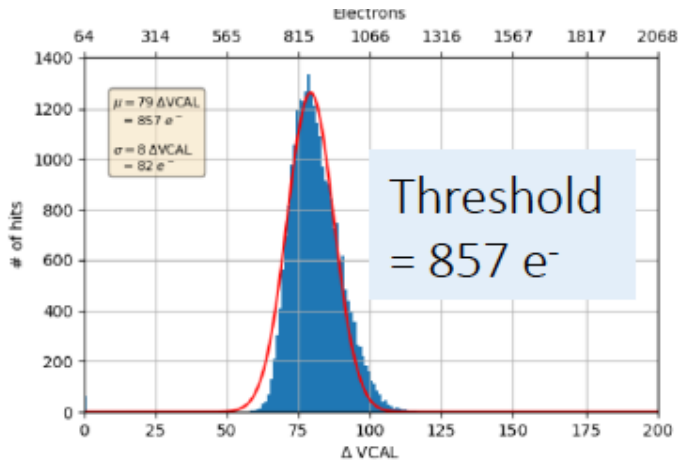


# From the FE-I4 to the RD53A chip

N Savic, Ph.D.Thesis

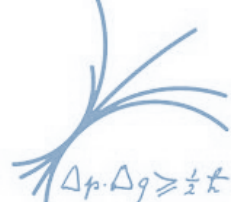


- Estimation of 50x50  $\mu\text{m}^2$  performance obtained with FE-I4 modules mimicking small pixel cells:
  - FE-I4 chip is affected from a shift  $\sim 1.0\text{-}1.5$  ke between nominal and real threshold



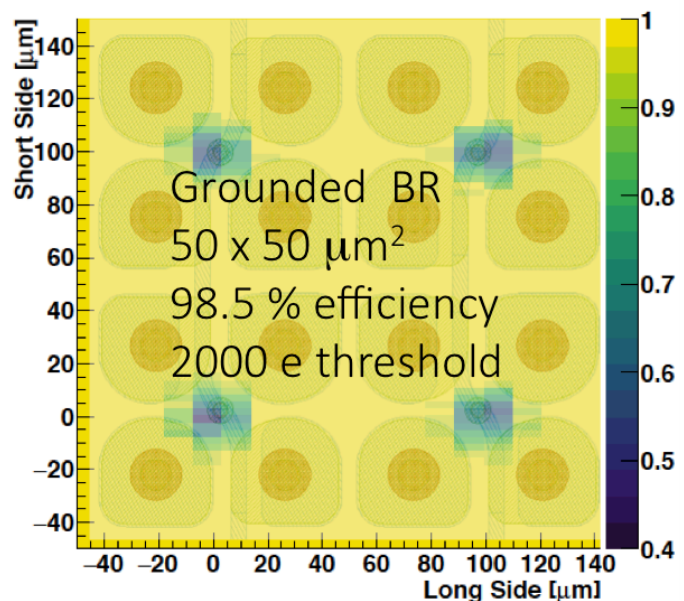
- Results obtained with RD53A modules:
  - Low thresholds achievable
  - DISCLAIMER: the chip tuning has not been optimized
    - The following studies are only focused on sensor performance!



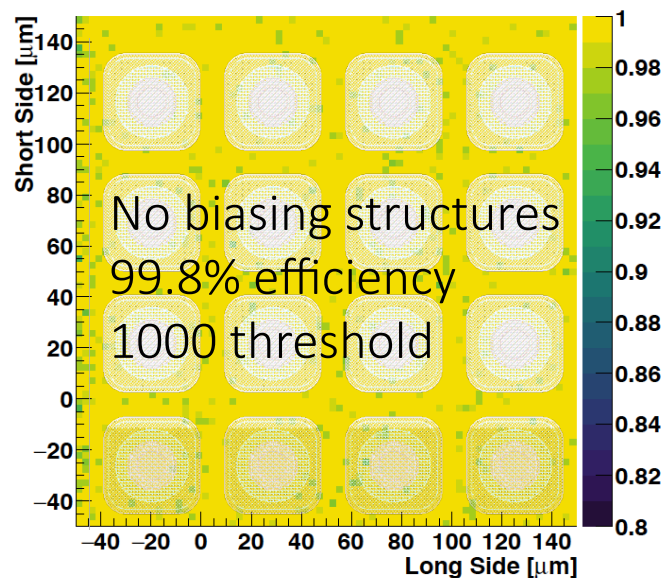
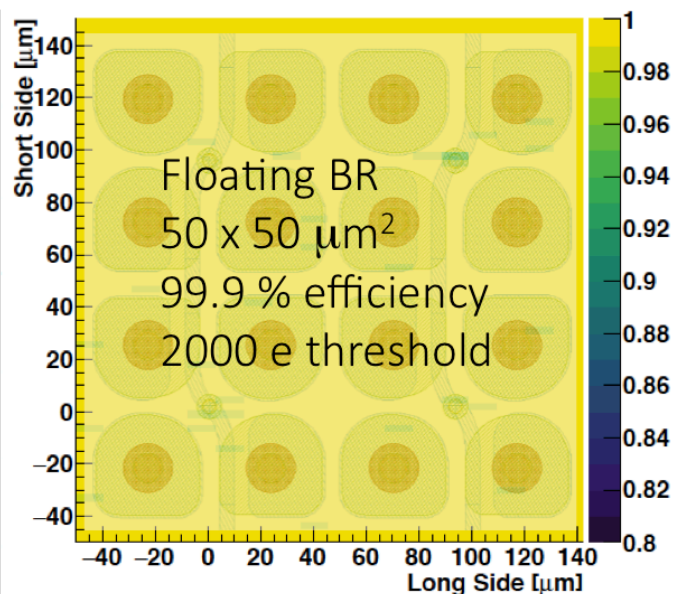


# RD53A assemblies: biasing structure effects in 50x50 cells

J. Beyer, RD53 Testing Meeting



- The RD53A boards allow to ground or leave the BR floating
- 150  $\mu\text{m}$  thick sensors, 50 V bias
  - With PT and floating BR
- 100  $\mu\text{m}$  thick sensors, 50 V bias
  - Without biasing structures

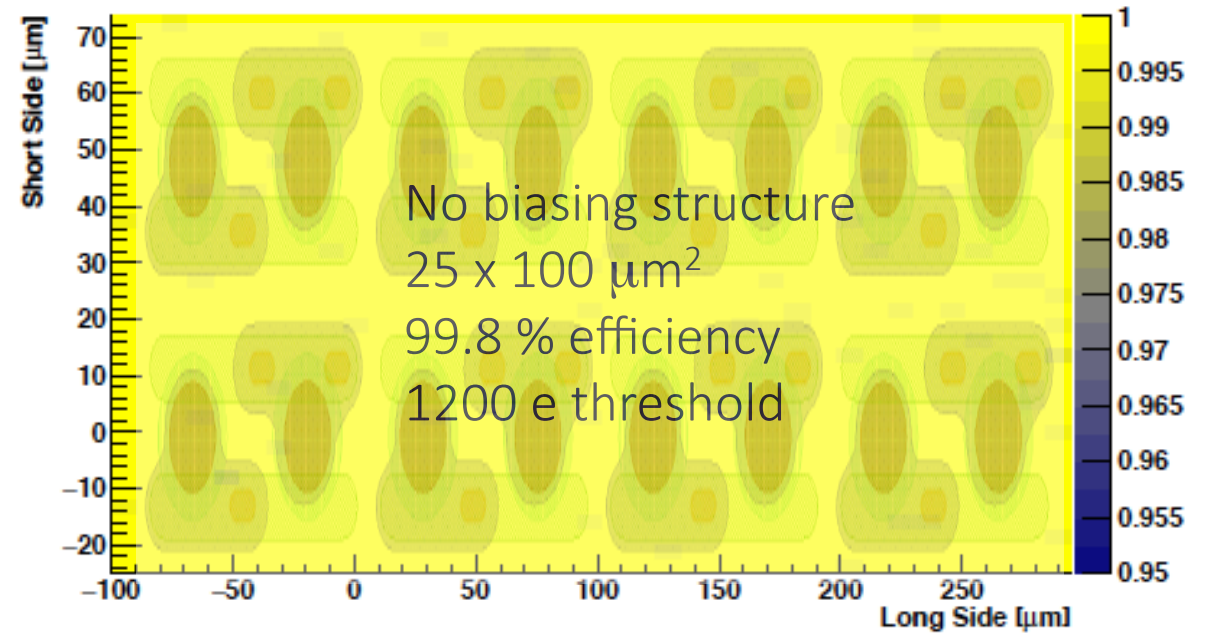
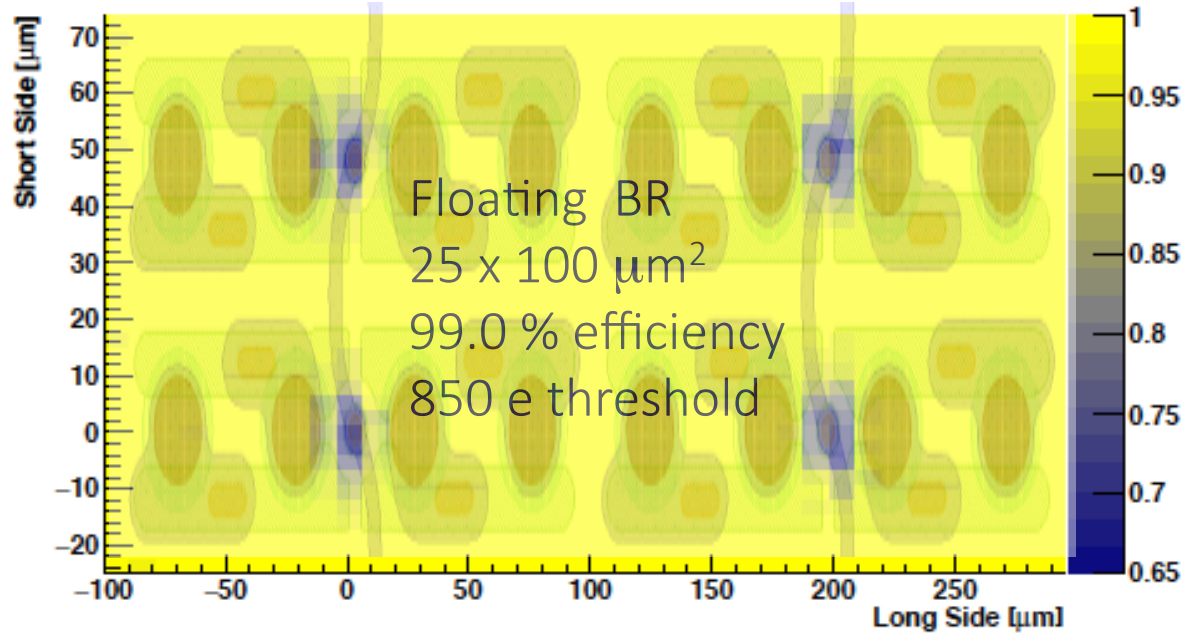




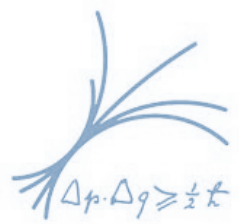


# RD53A assemblies: biasing structure effect in 25x100 cells

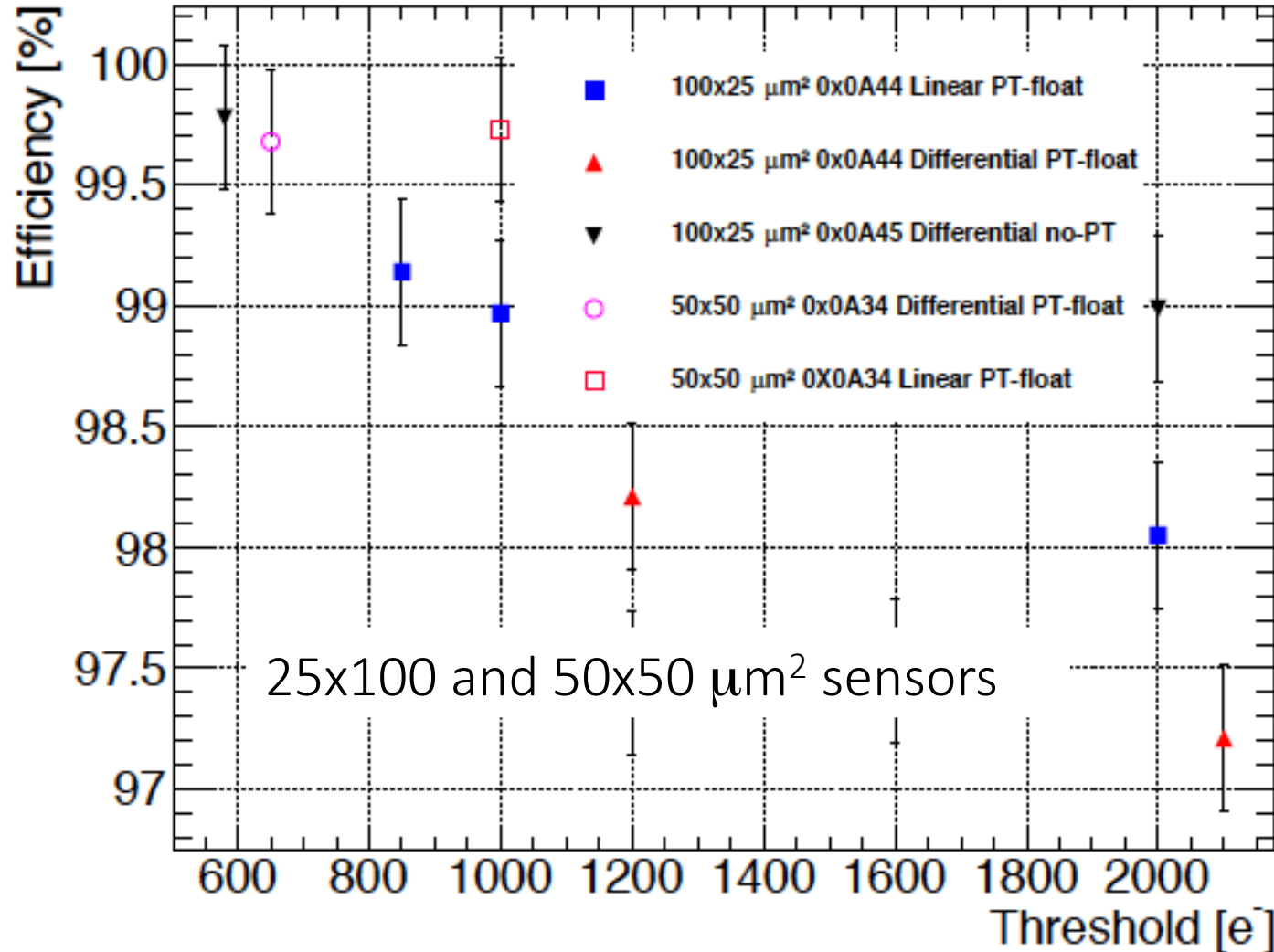
J. Beyer, RD53 Testing Meeting







# RD53A assemblies: threshold dependence



- Hit efficiency increasing with decreasing threshold
- Consistent results between Linear and Differential analog sections
- Sensors without biasing structures deliver higher efficiency

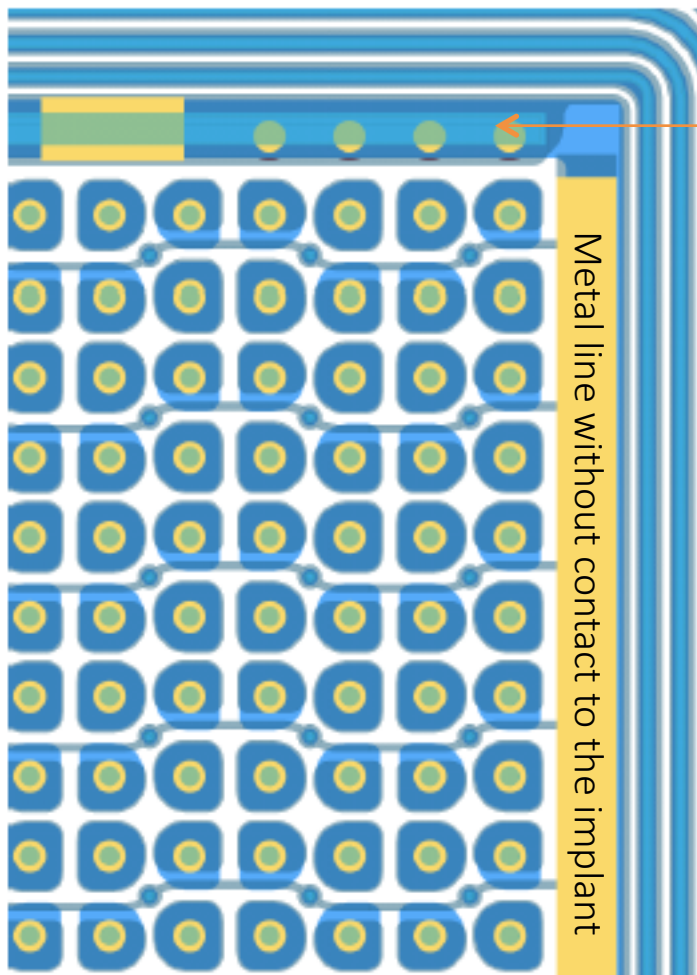
[J. Beyer, RD53 Testing Meeting](#)





# The "Split" Design

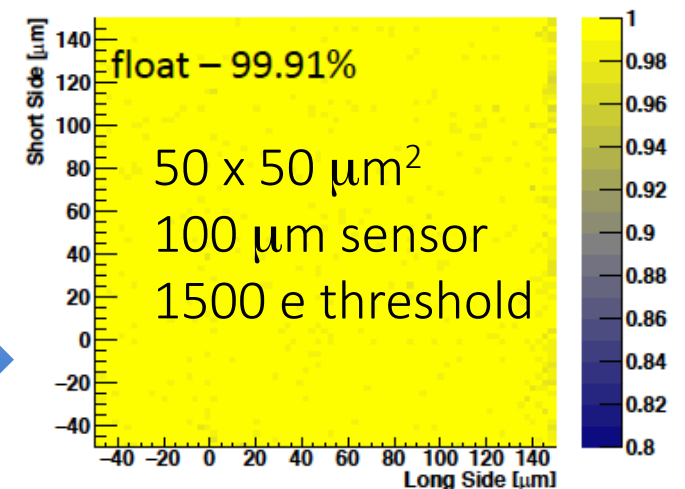
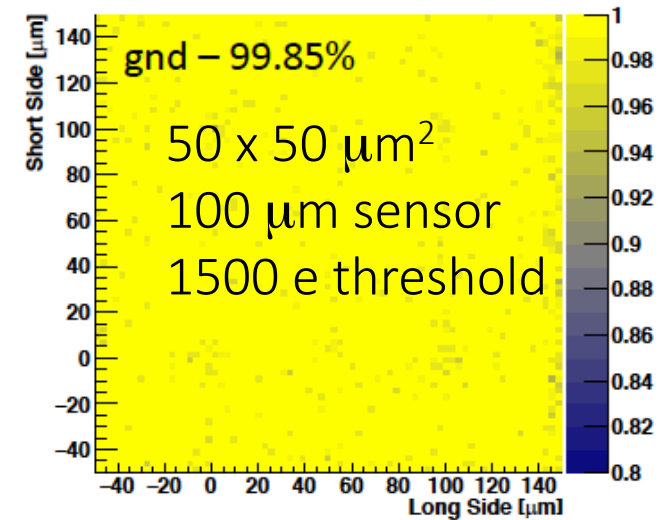
- Developed new design where the implant of the innermost ring can be grounded while the grid for testing is left floating after chip interconnection



UBM pads on a metal line connected to the implant ring

- The ring implant intercept the sensor currents from the sensor edge avoiding the last columns and rows to become noisy
- Implant can be grounded or floating but PT is always floating

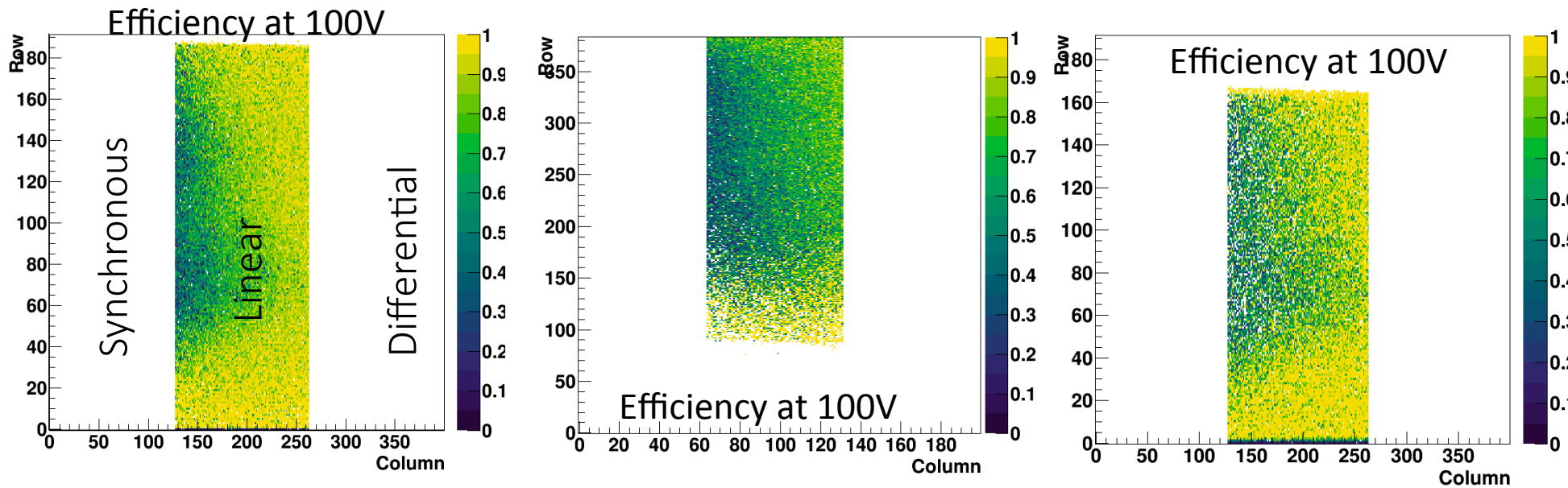
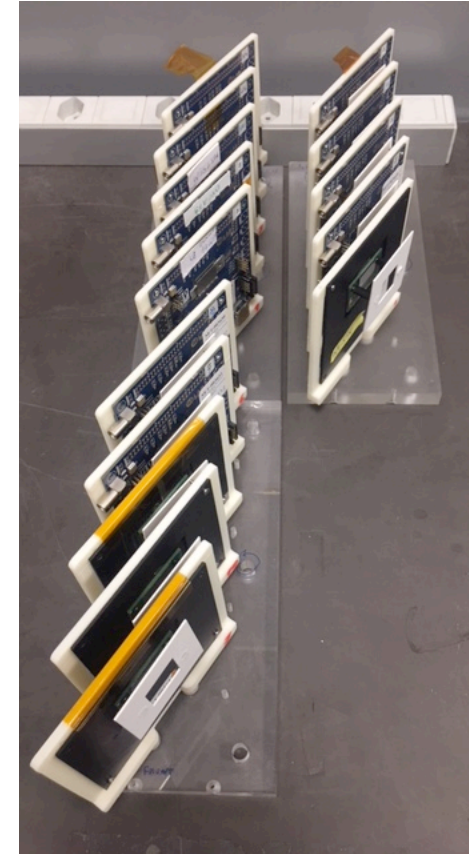
Same efficiency with grounded and floating BR



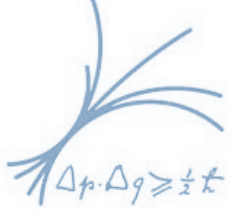


# Irradiation at CERN PS

- Inclined irradiation at 55° in x to have more homogeneous irradiation
  - The beam seems to be not centered on the module
  - Fluence decreases from synchronous -> linear -> differential
  - The expected increase of the irradiated area along x thanks to the 55° inclination not visible in the efficiency plot
- Aluminum foils on top of modules will be measured to reveal actual fluence profile

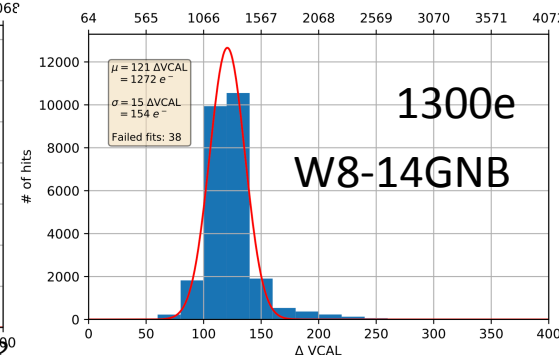
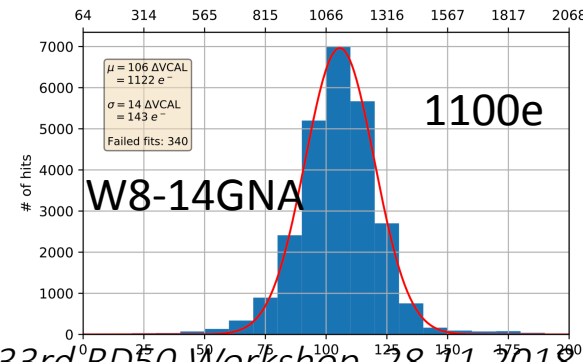
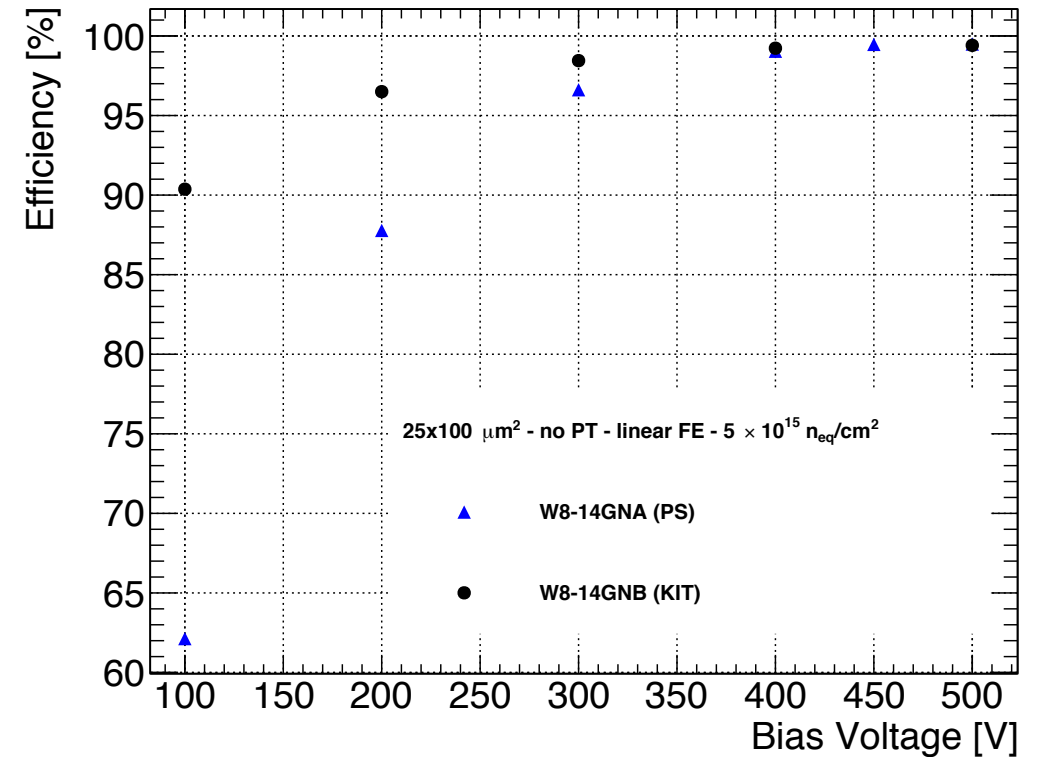
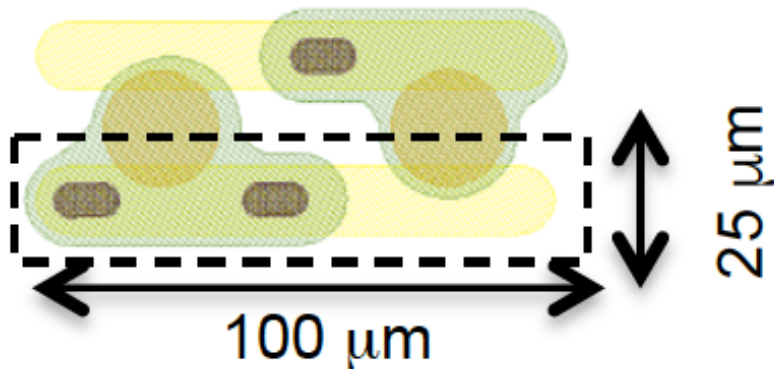






# CERN PS- KIT Irradiation Comparison

- Two modules irradiated at CERN PS and KIT to a nominal fluence of  $5 \times 10^{15} n_{eq}/cm^2$ 
  - PS dose is average (will be higher in central region of linear FE), KIT is homogeneous
- Same sensor design: **25x100 pixel cell, 150 μm thick sensors without PT**
- Analysis performed with the Linear section of the RD53A chip
- Plateau efficiency: 99.0% (PS) - 99.4% (KIT)
- Looking to the evolution of the efficiency with the Bias Voltage it looks like the fluence received by the Linear part is higher than  $5 \times 10^{15} n_{eq}/cm^2$

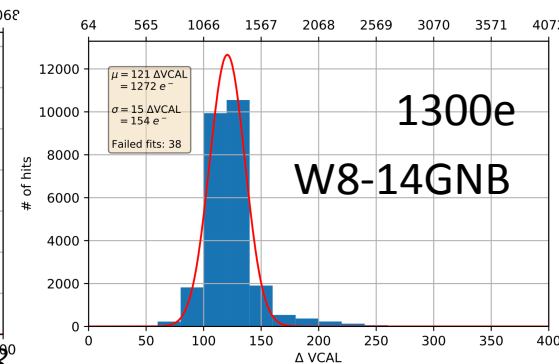
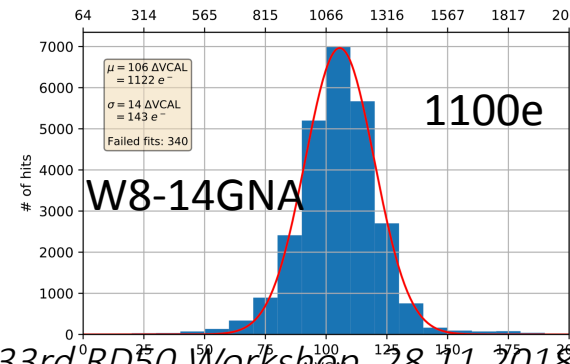
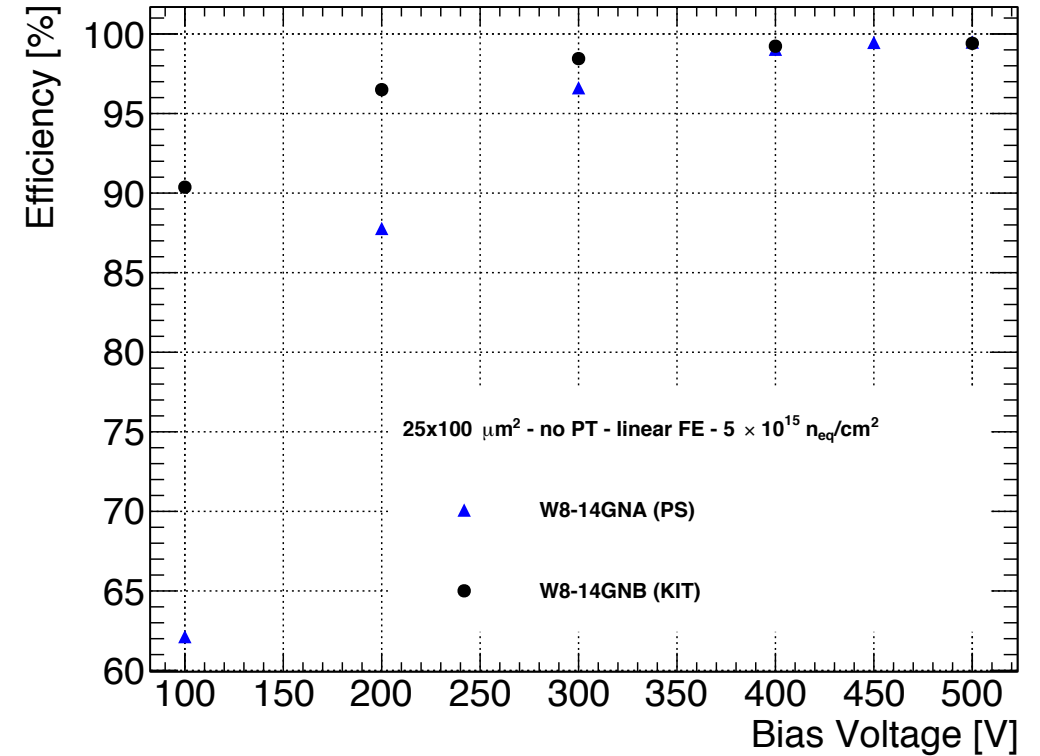
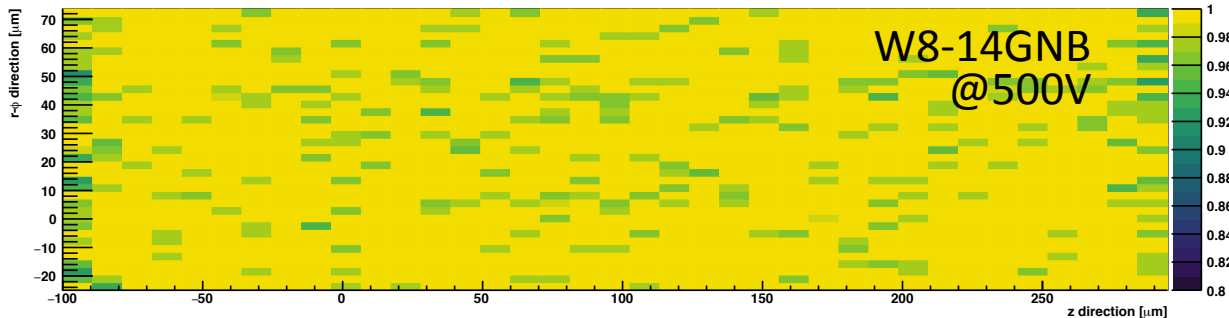
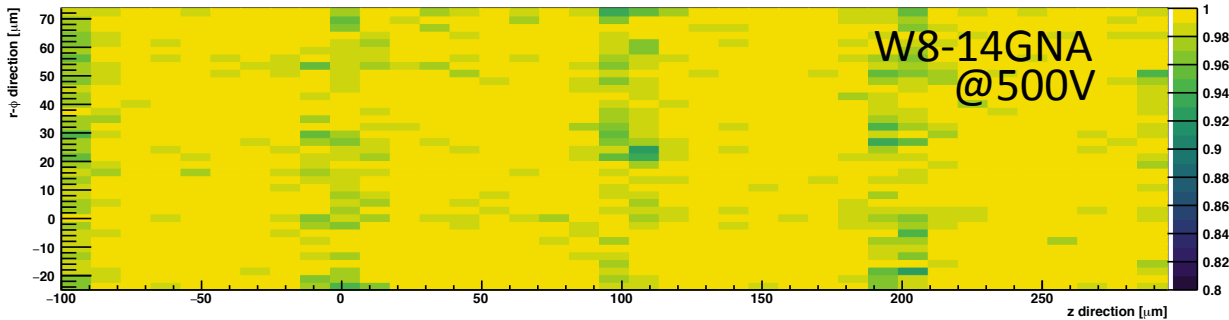




# CERN PS- KIT Irradiation Comparison

- Two modules irradiated at CERN PS and KIT to a nominal fluence of  $5 \times 10^{15} n_{eq}/cm^2$ 
  - PS dose is average (will be higher in central region of linear FE), KIT is homogeneous
- Same sensor design: **25x100 pixel cell, 150 μm thick sensors without PT**
- Analysis performed with the Linear section of the RD53A chip

Efficiency Pixel Map DUT 30 Geometry 0

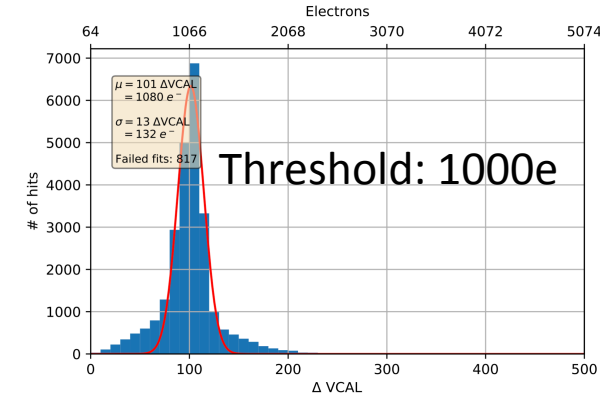
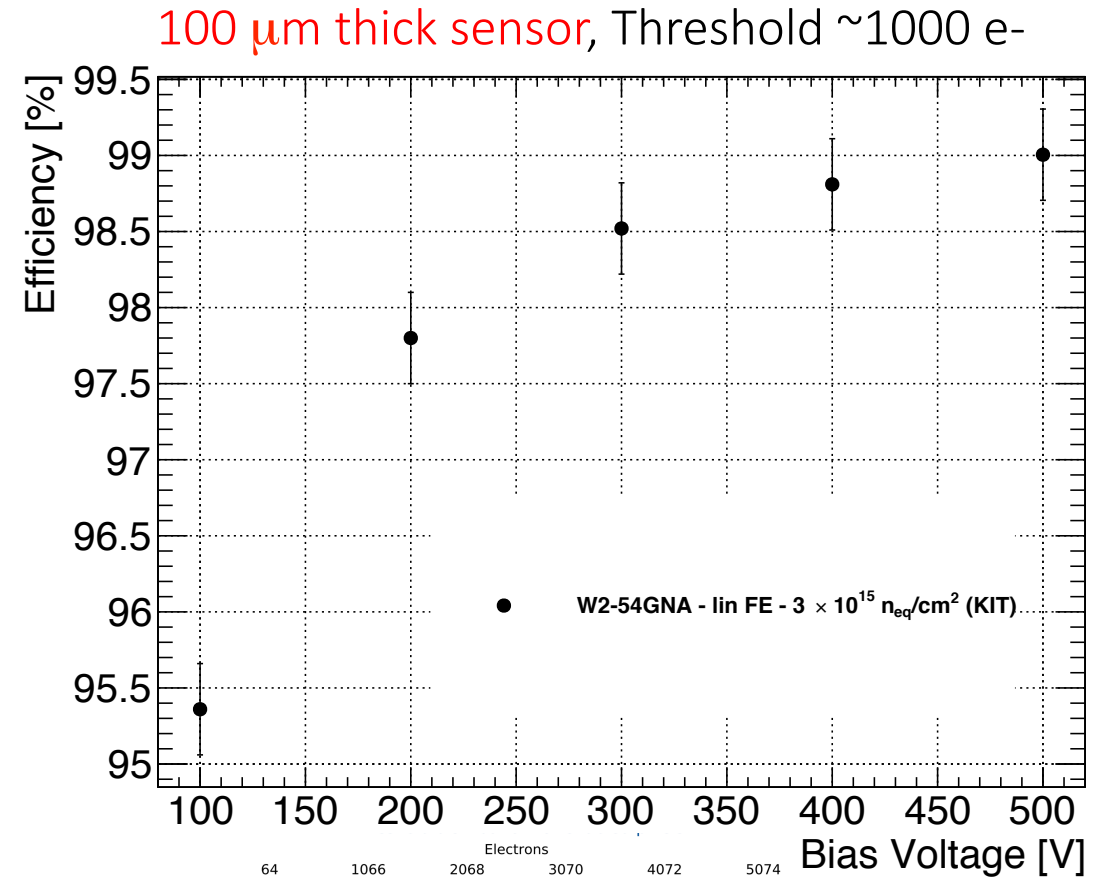
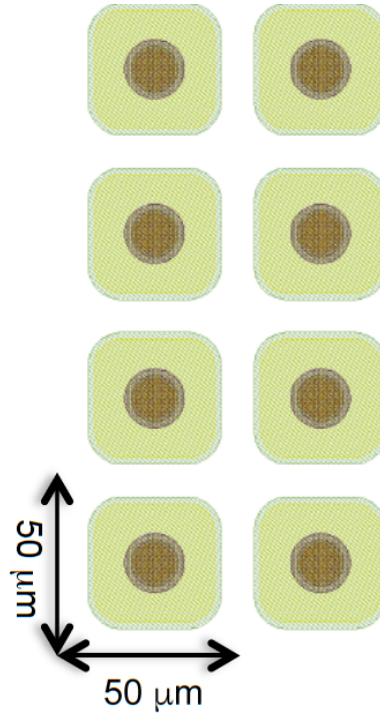
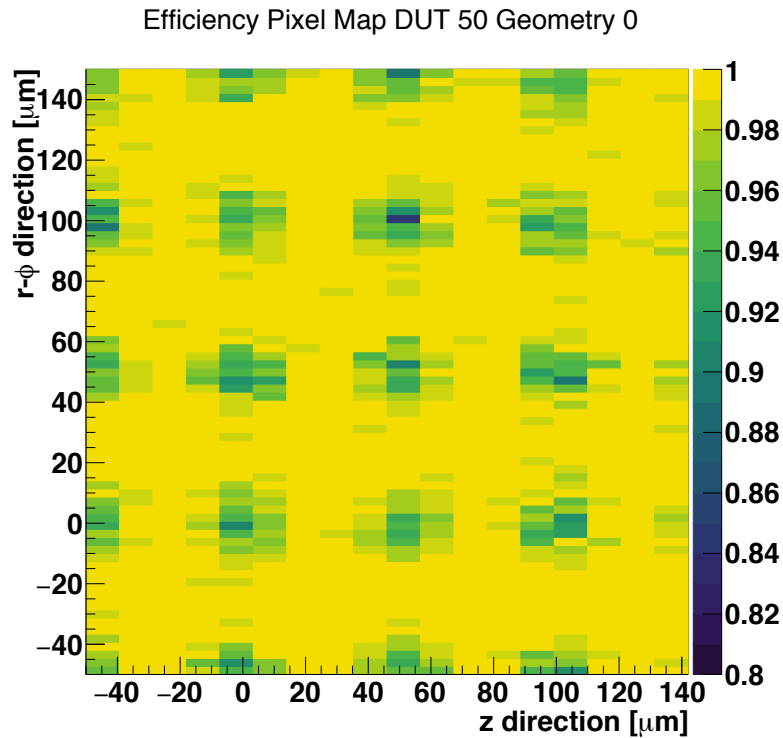




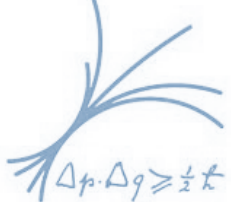


# Again no biasing structures, but 50x50

- Irradiated at KIT to  $3 \times 10^{15} n_{eq}/cm^2$
- Saturation of efficiency around 400V-500V
- Plateau efficiency: 99.0%
  - but even at 200V already >97% efficiency

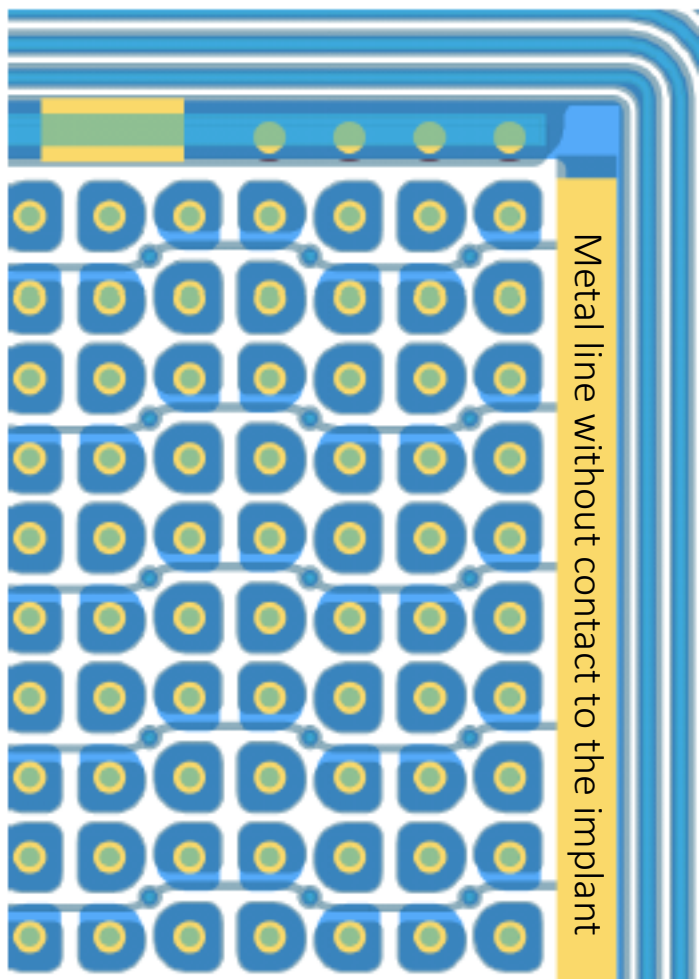


- Inefficiency only due to charge sharing at the four corners of the pixel cell

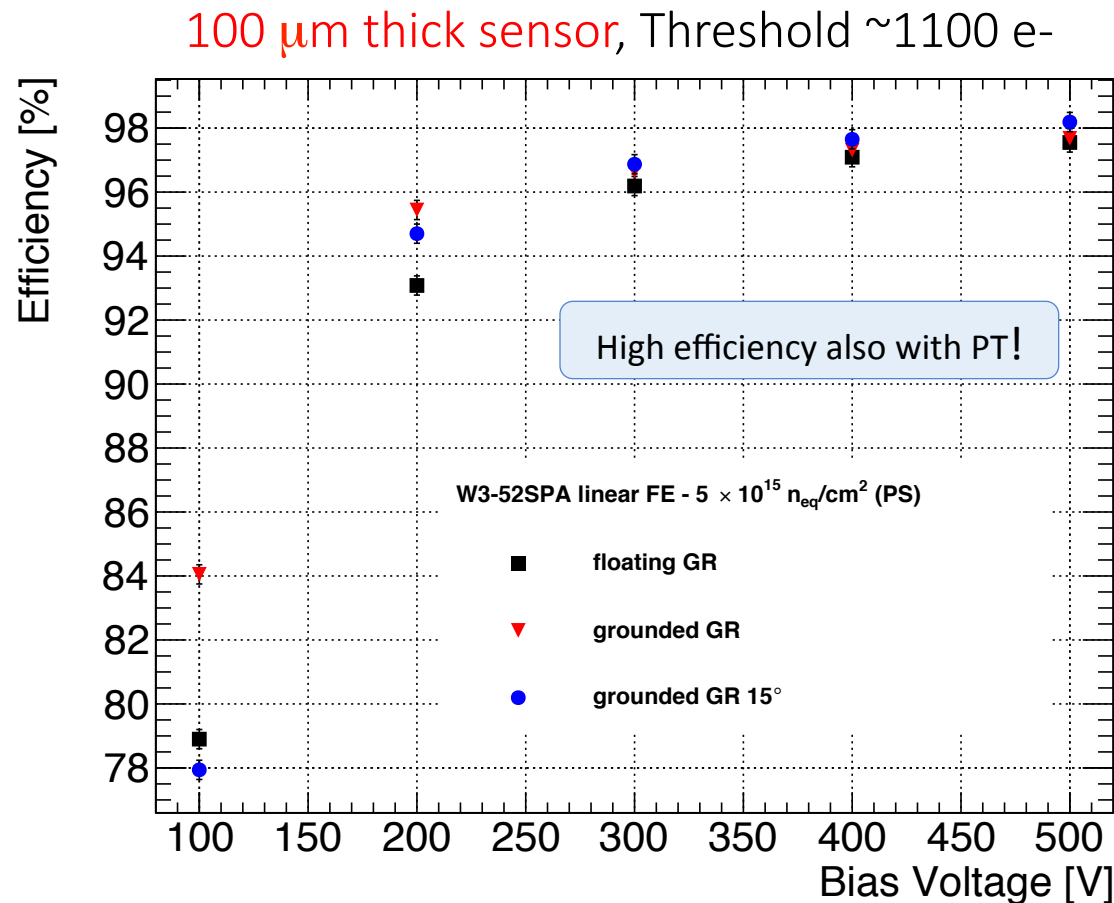


# The "Split" Design

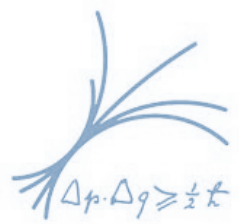
- Split design tested in various configuration after irradiation



- Plateau efficiency: 97.6% (floating) vs 98.2% (grounded) → probably different area illuminated with slightly different fluence
- Also the test with 15 degrees inclination probably focused on higher fluence area





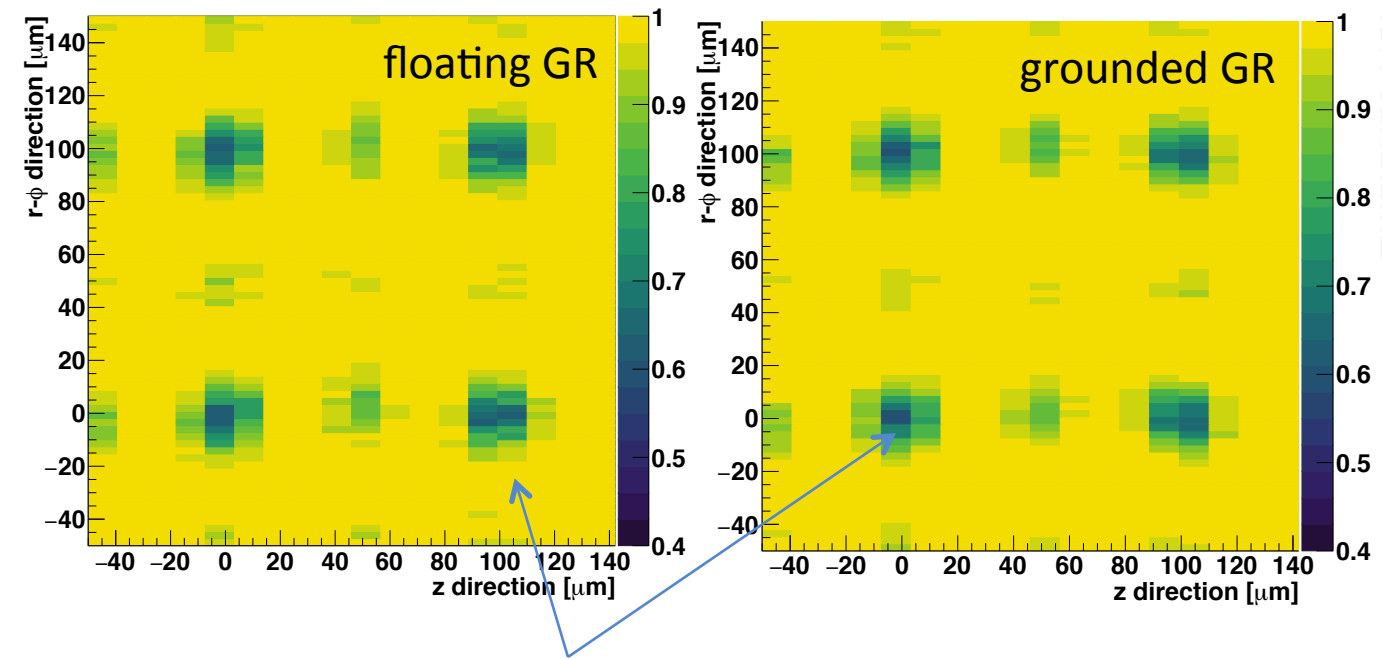


# The "Split" Design

- Developed new design where the implant of the innermost ring can be grounded while the grid for testing is left floating after chip interconnection

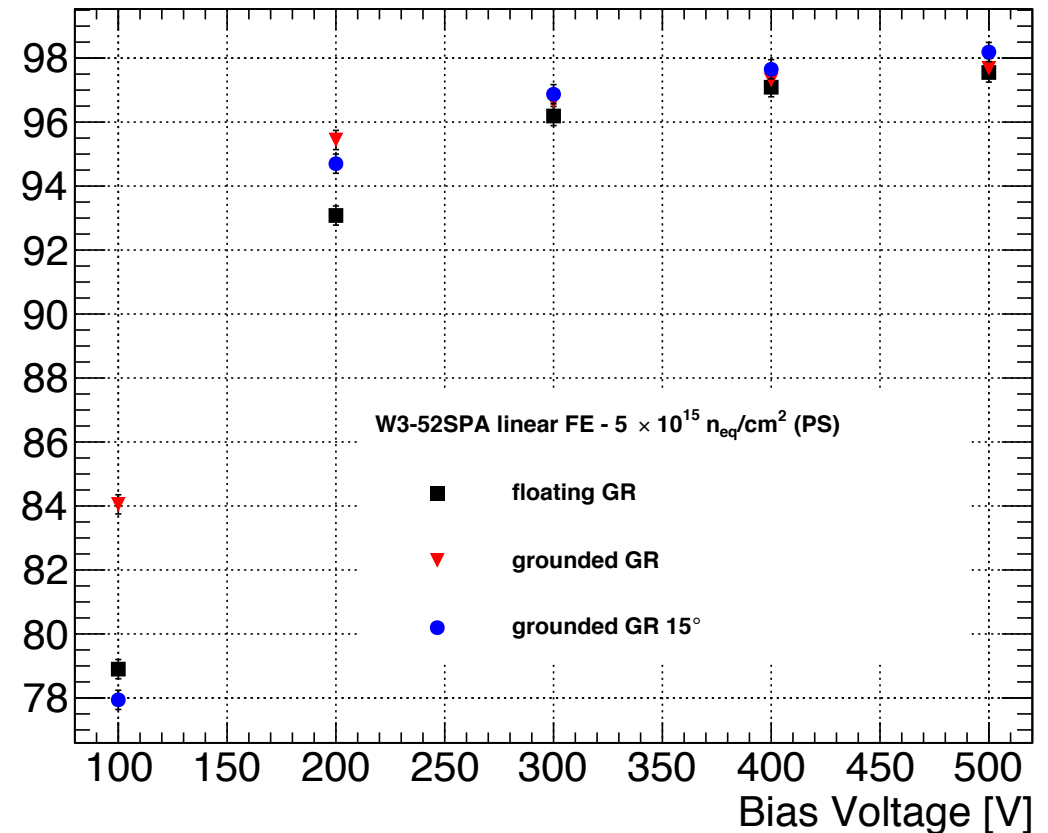
Efficiency Pixel Map DUT 50 Geometry 0

Efficiency Pixel Map DUT 50 Geometry 0



Very similar effect of PT dots with the two different configuration of the ring implant potential

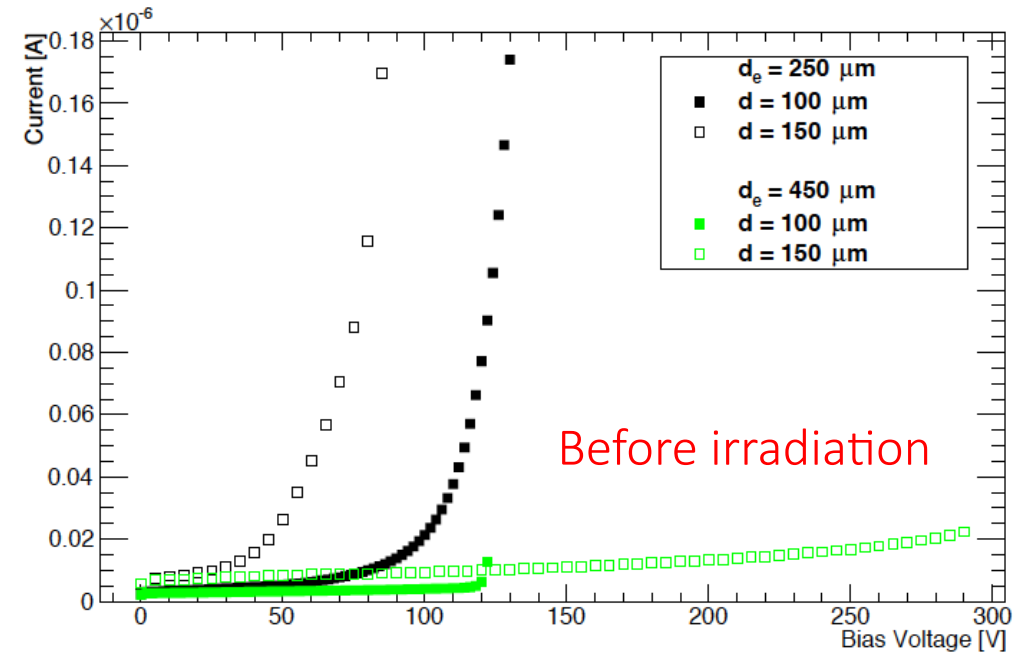
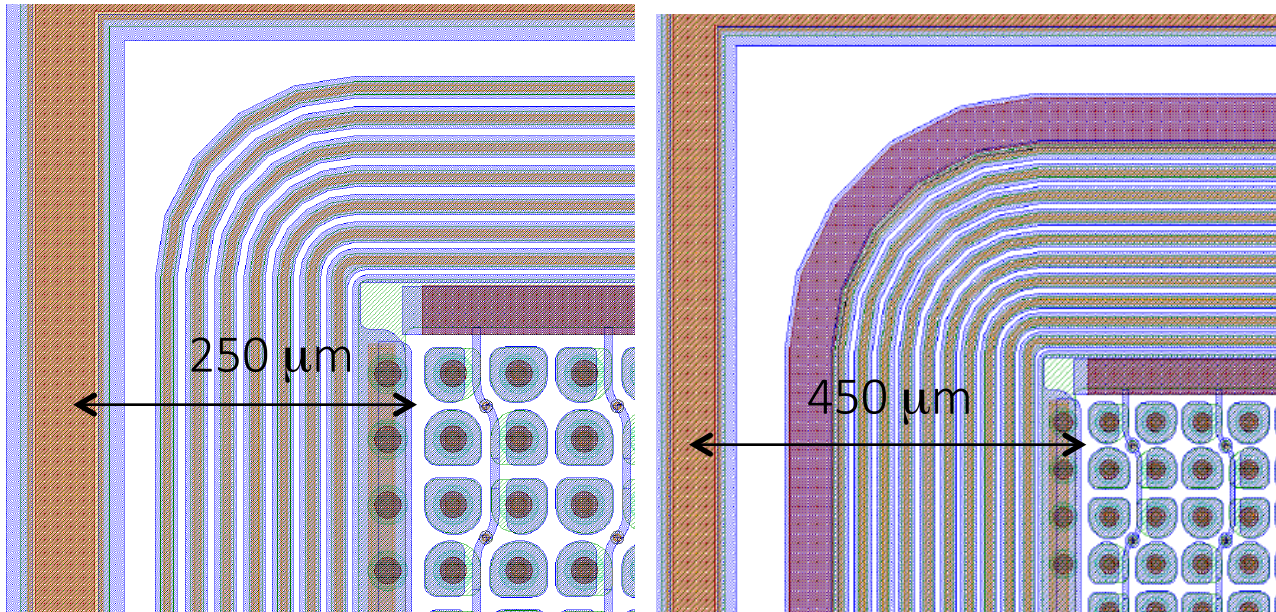
100 μm thick sensor, Threshold ~1100 e<sup>-</sup>





# Reduced sensor edge

- Smaller inactive edges needed for the innermost layers.
  - Worst performance before irradiation with respect to an inactive edge of 450 μm
  - V<sub>break</sub> high enough after radiation to reach good tracking efficiency



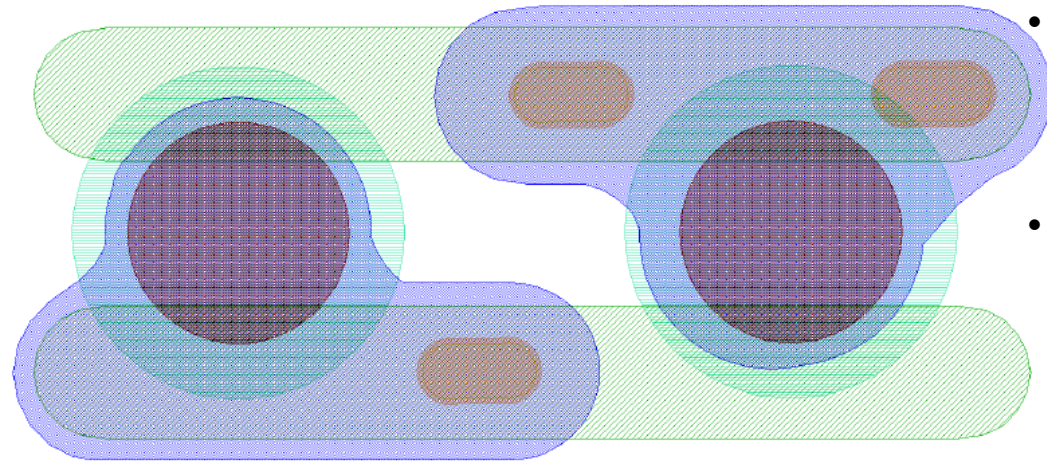




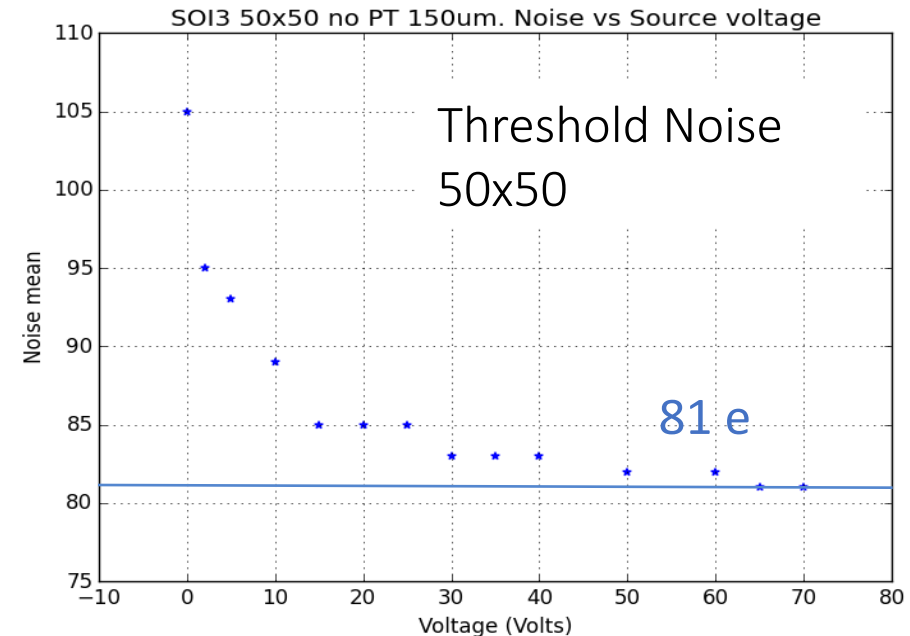
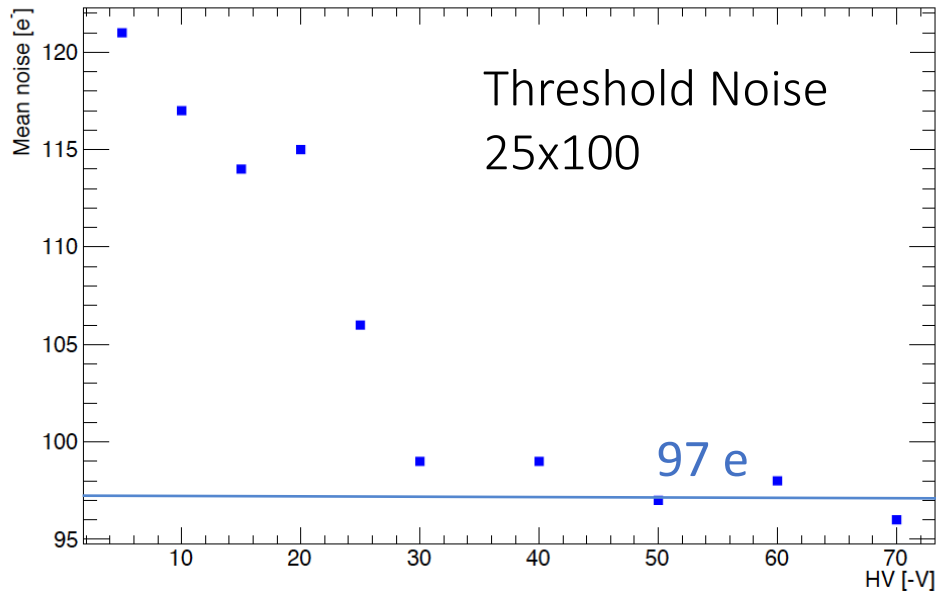
## Investigation of cross talk in 25x100 pixel cells



# Additional capacitance contribution for 25x100 geometry

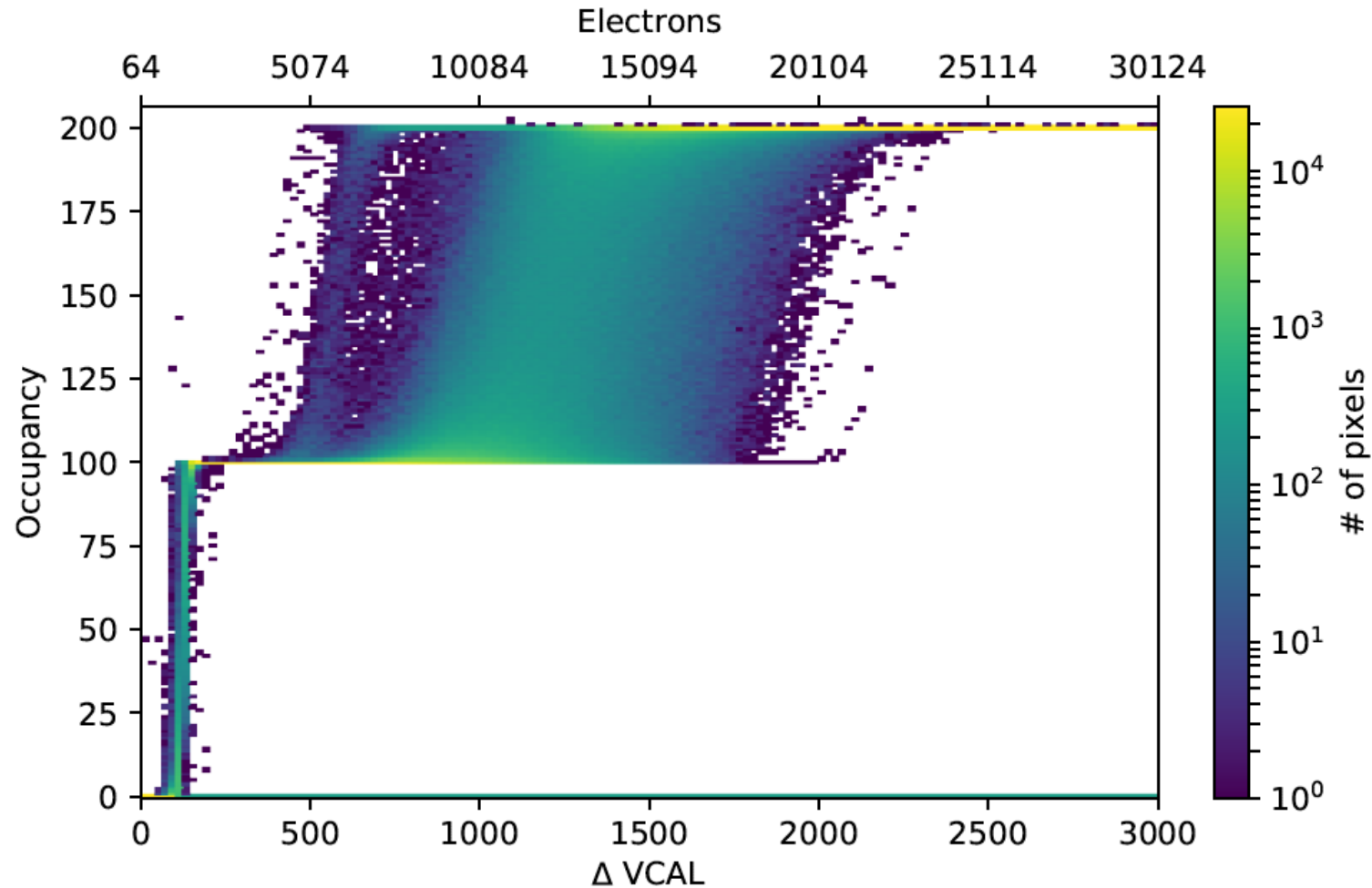


- Capacitance contribution of the overlap of the metal of one pixel with implant of the neighbouring one:
- This capacitance is due mainly to the thin oxide and nitride layers between metal and implant, the capacitance due to the UBM pad is small, thanks to the 3 μm BCB layer in-between metal and UBM pad





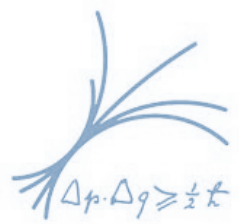
# Cross-talk appearing in self-injection



25x100 module show a sign of cross-talk for high injected charge → doubling of number of hits when injecting charge > 6ke

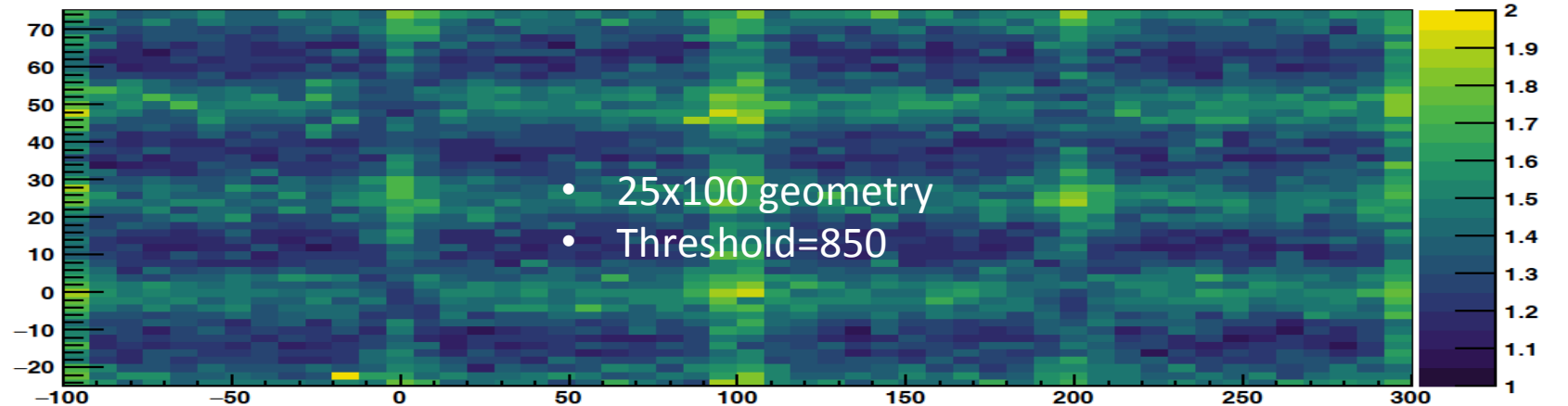
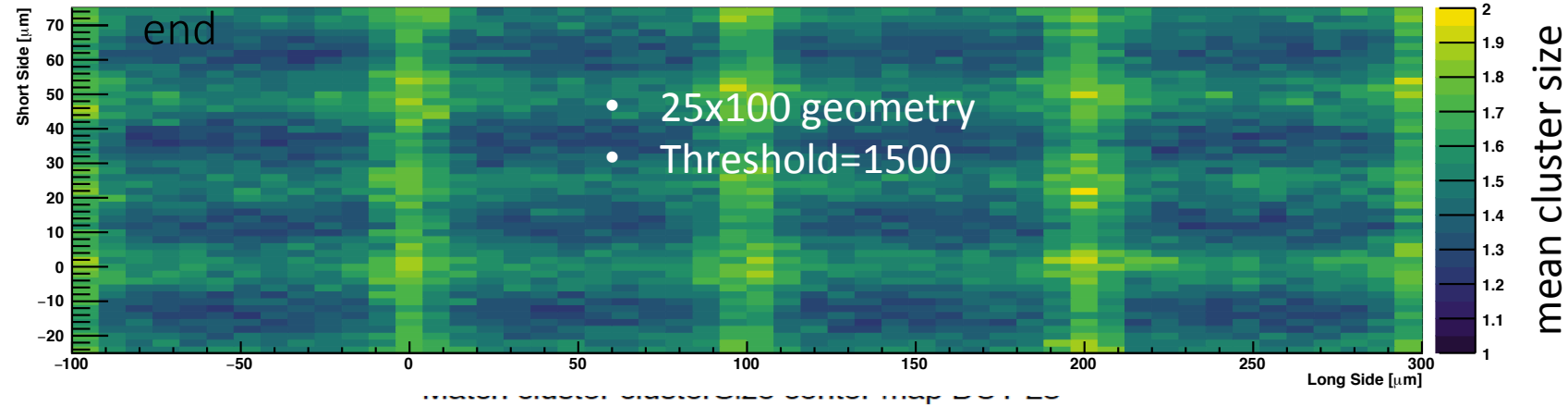
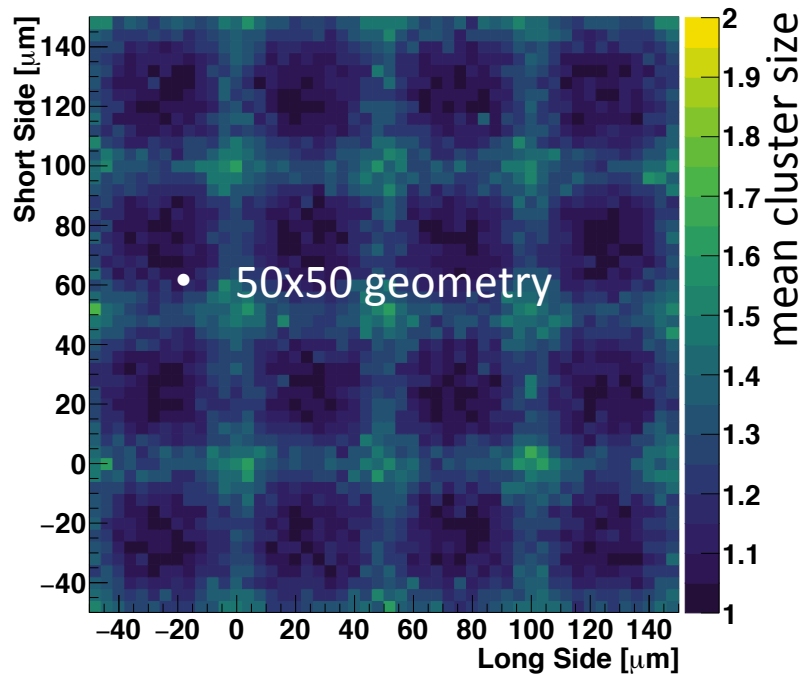
The effect has been seen on multiple modules 25x100 built with SOI3 and SOI4 sensors





# Mean cluster size in test-beam data

- Measurements before irradiation at  $V_{\text{bias}}=50\text{V}$ ,  $150\ \mu\text{m}$  thickness front-



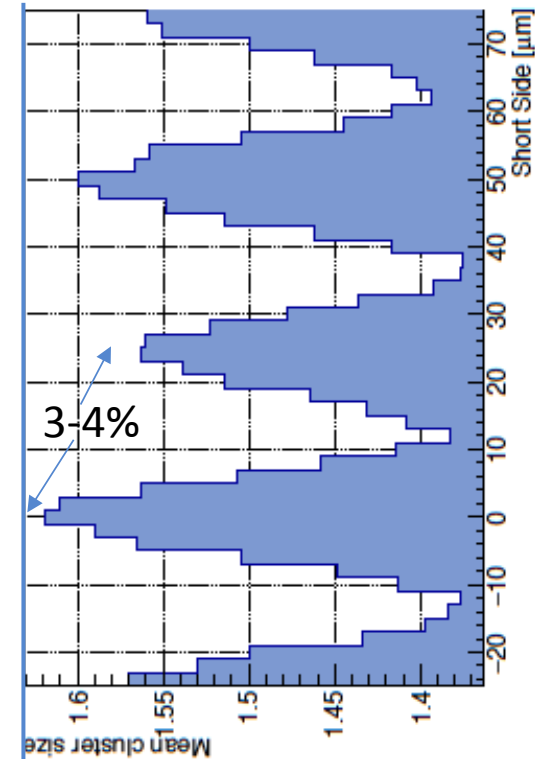
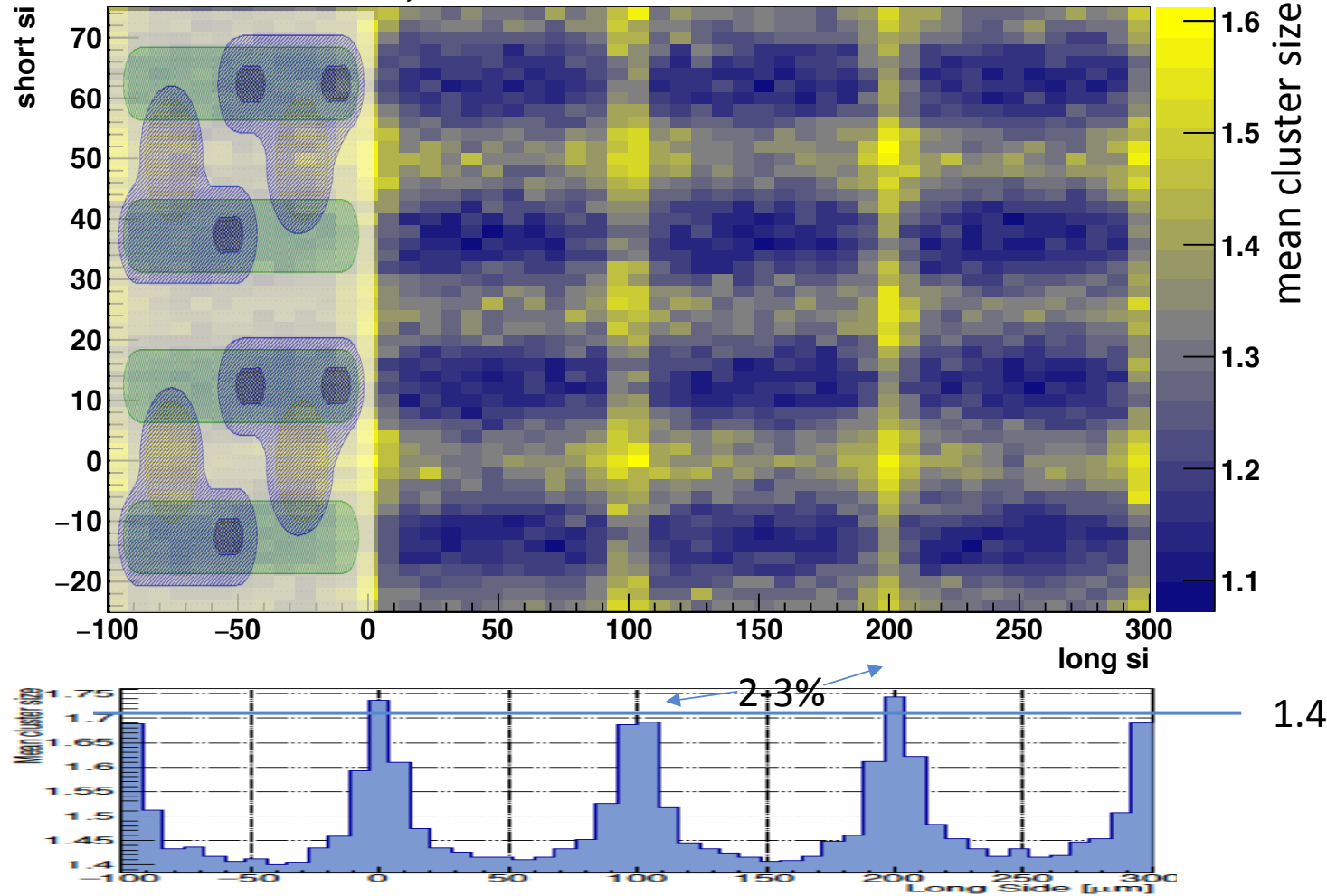
- Strange effects instead seen from threshold  $\sim 600\ e$



# Cross-talk in data?

Cluster size in 25x100 module before irradiation

no PT, 150μm, 1200e threshold, linear FE, 50V bias



- Asymmetry between intersecting and not intersecting pixel pair is only 3-4%
- Most charge is shared along the short side



# Conclusions and Outlook

- Good results obtained with the RD53A compatible sensors of 100 and 150 mm thick sensors up to the maximum fluence foreseen for planar assemblies in ATLAS Itk
- Several sensor design compared, with the “Split” design particularly encouraging thanks to good hit efficiency performance together with the feasibility of characterizing the sensor at each step of the production process
- Investigation of 25x100 possible cross-talk:
  - No evidence in test-beam data at “medium” thresholds
  - More studies needed at lower thresholds
  - Need to understand the difference between injection in the chip and in the sensor



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 654168







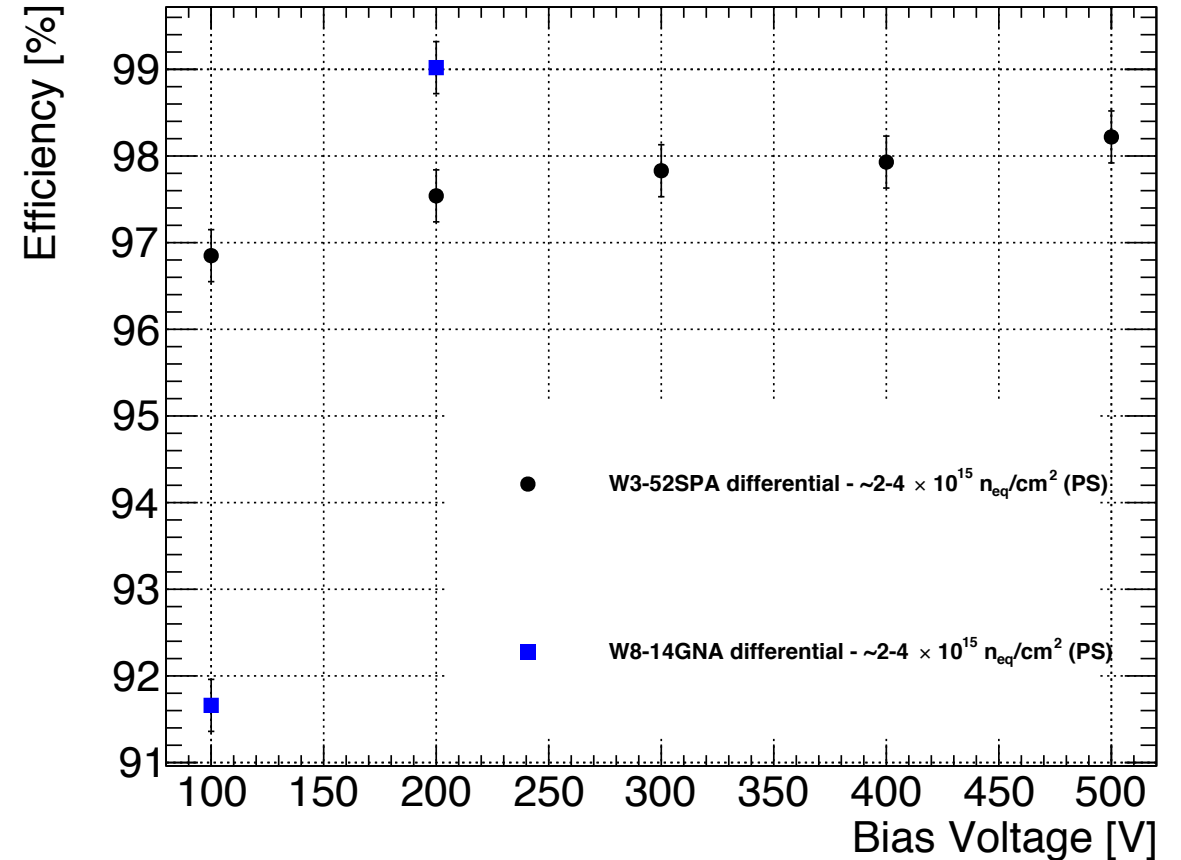
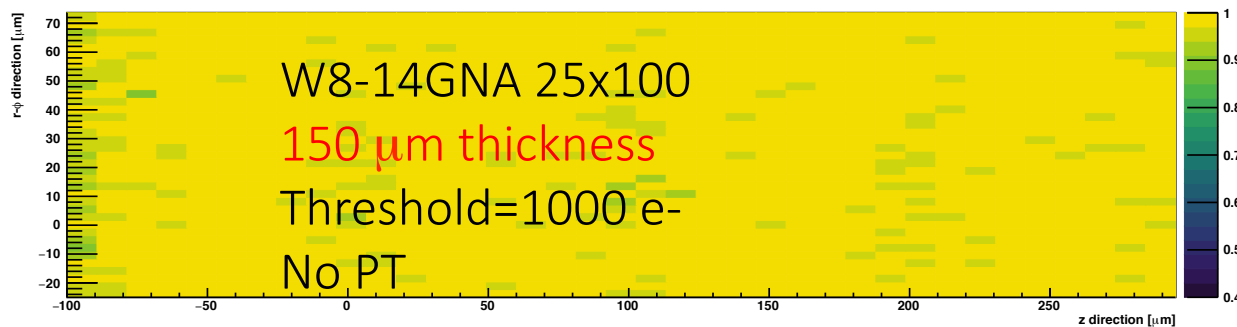
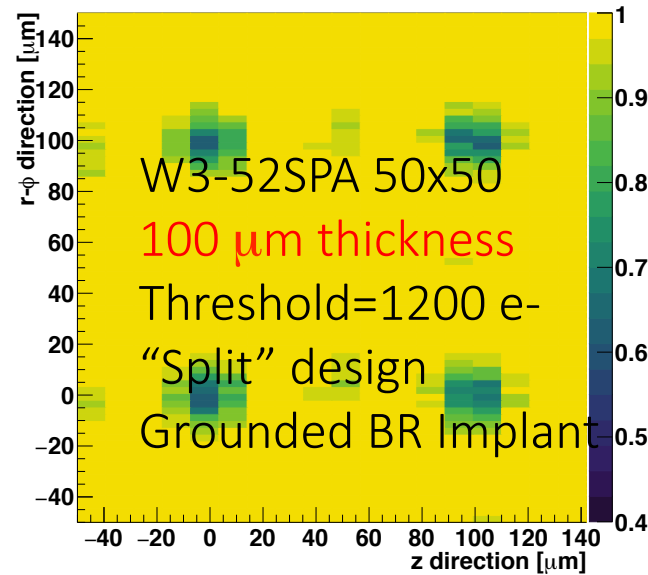
## Additional slides

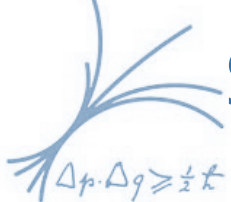


# Differential FE flavour

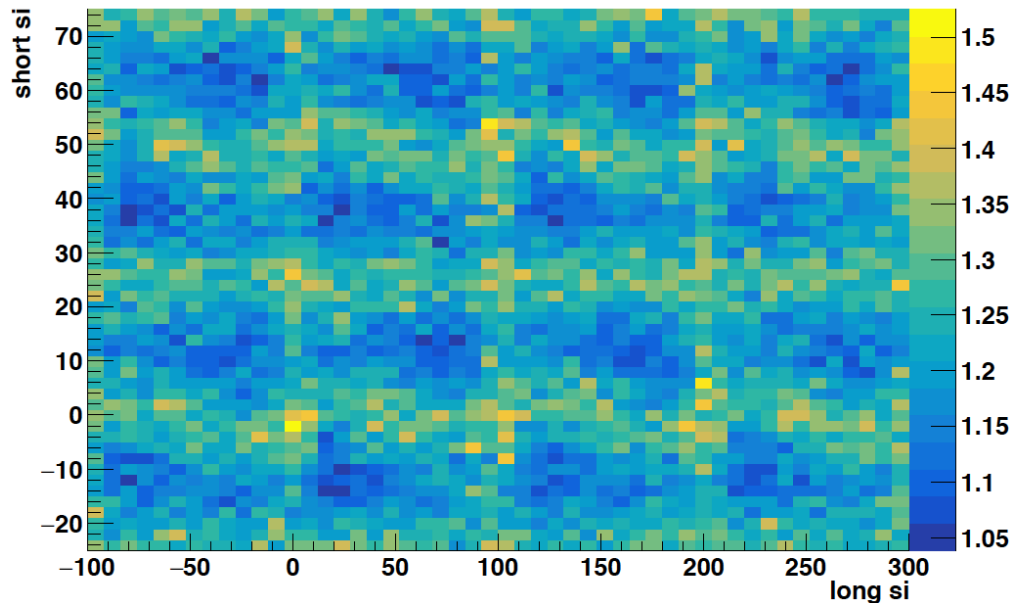
Due to inhomogeneous irradiation, the fluence in the differential section is lower than the average one

- Probable range  $2-4 \times 10^{15} \text{ n}_{\text{eq}}/\text{cm}^2 \rightarrow$  earlier efficiency saturation than for the Linear section

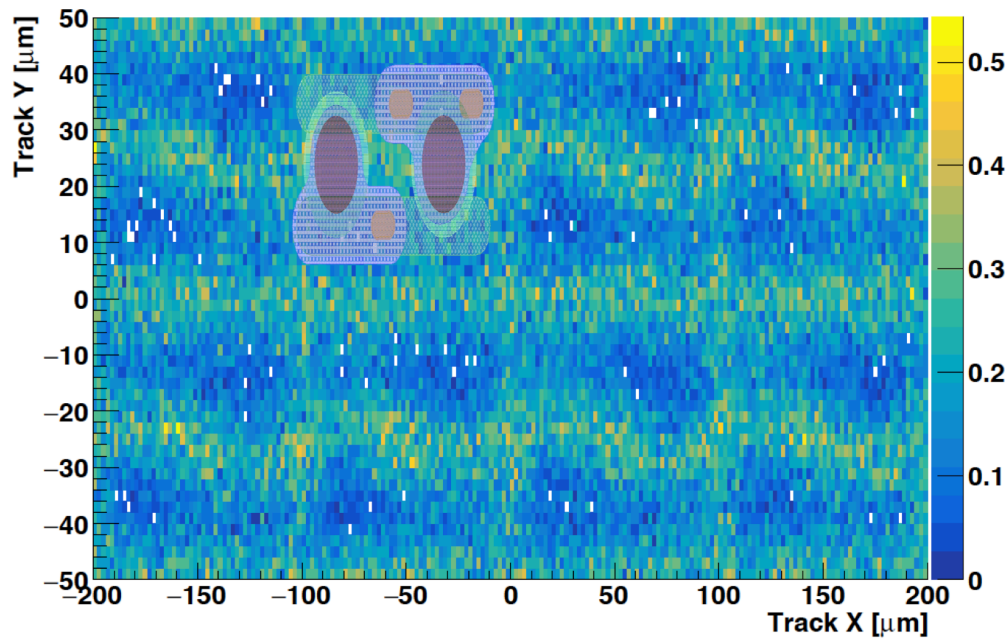
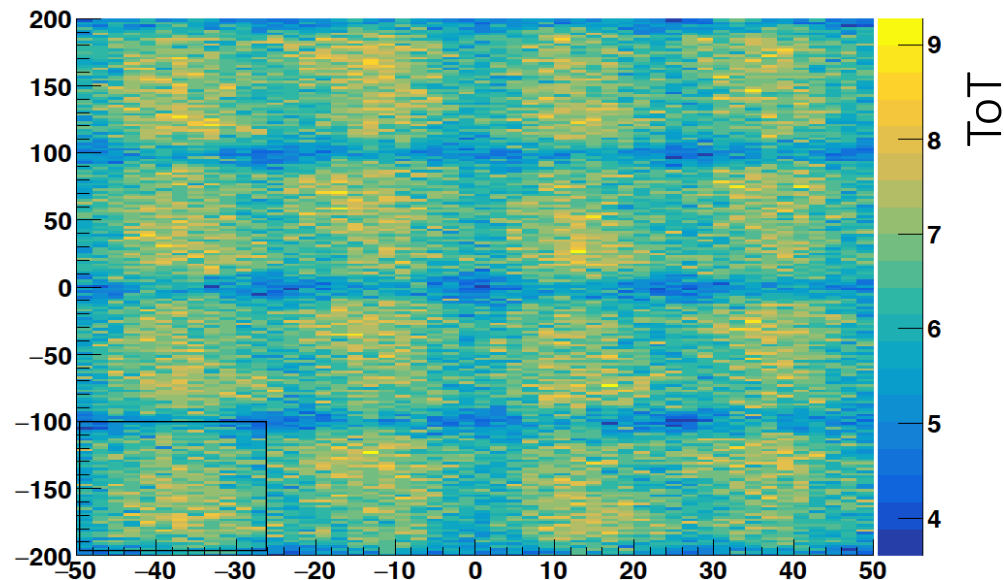




# Shared charge fraction for 25x100 pixel sensors at 5e15 and 400V



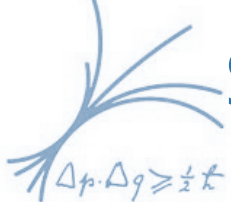
Cluster size



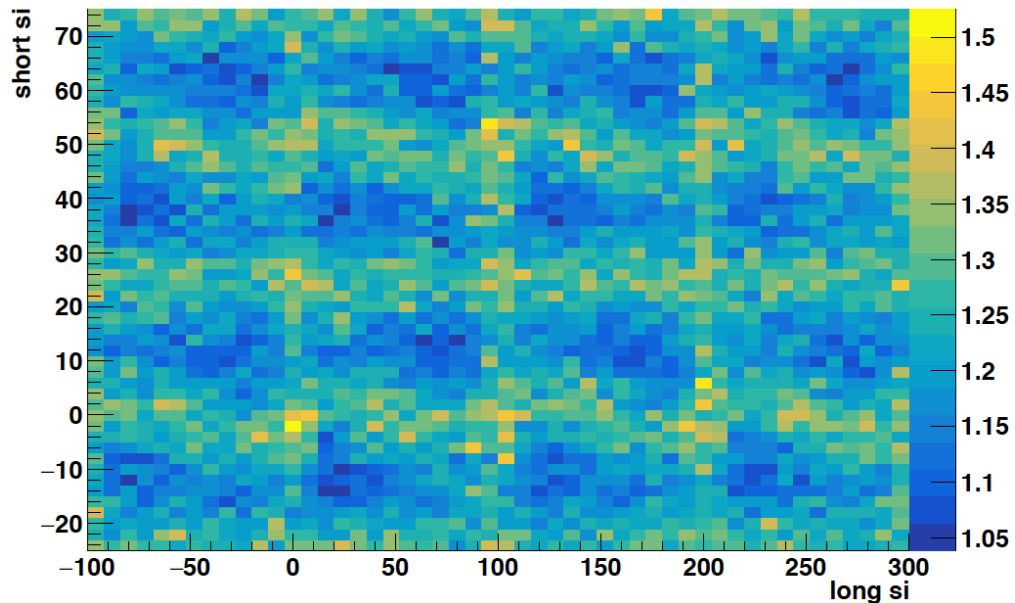
Fraction of shared charge

- The fraction of shared charge does not change significantly in the case of intersecting pairs or not intersecting pairs
- The borders of the shared charge follow the metal shape

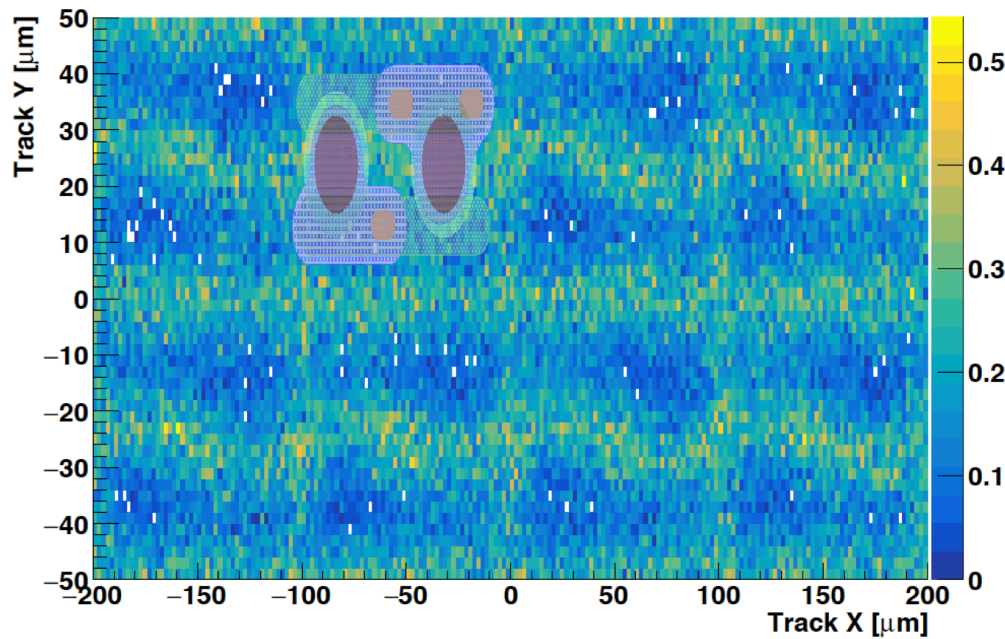
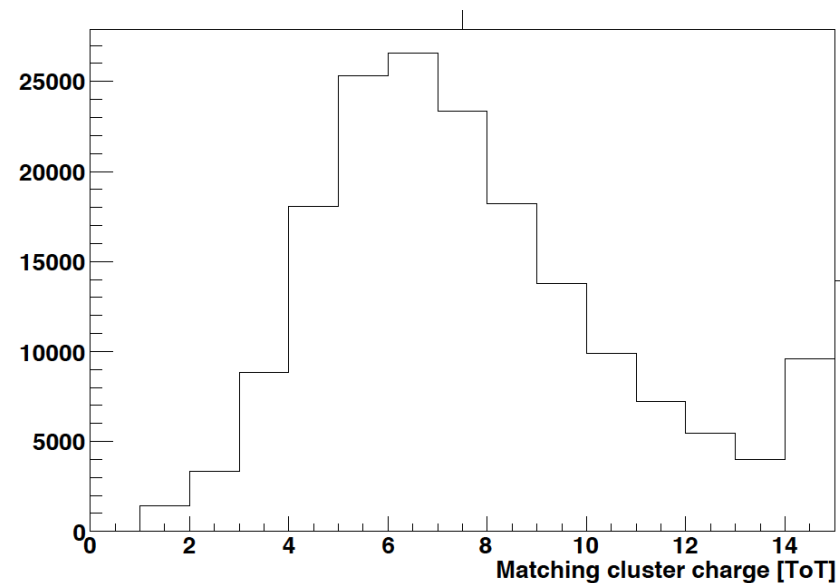




# Shared charge fraction for 25x100 pixel sensors at 5e15 and 400V



Cluster size



Fraction of shared charge

- The fraction of shared charge does not change significantly in the case of intersecting pairs or not intersecting pairs
- The borders of the shared charge follow the metal shape