

# First Annealing Studies of Irradiated Silicon Sensors with Modified ATLAS Pixel Implantations

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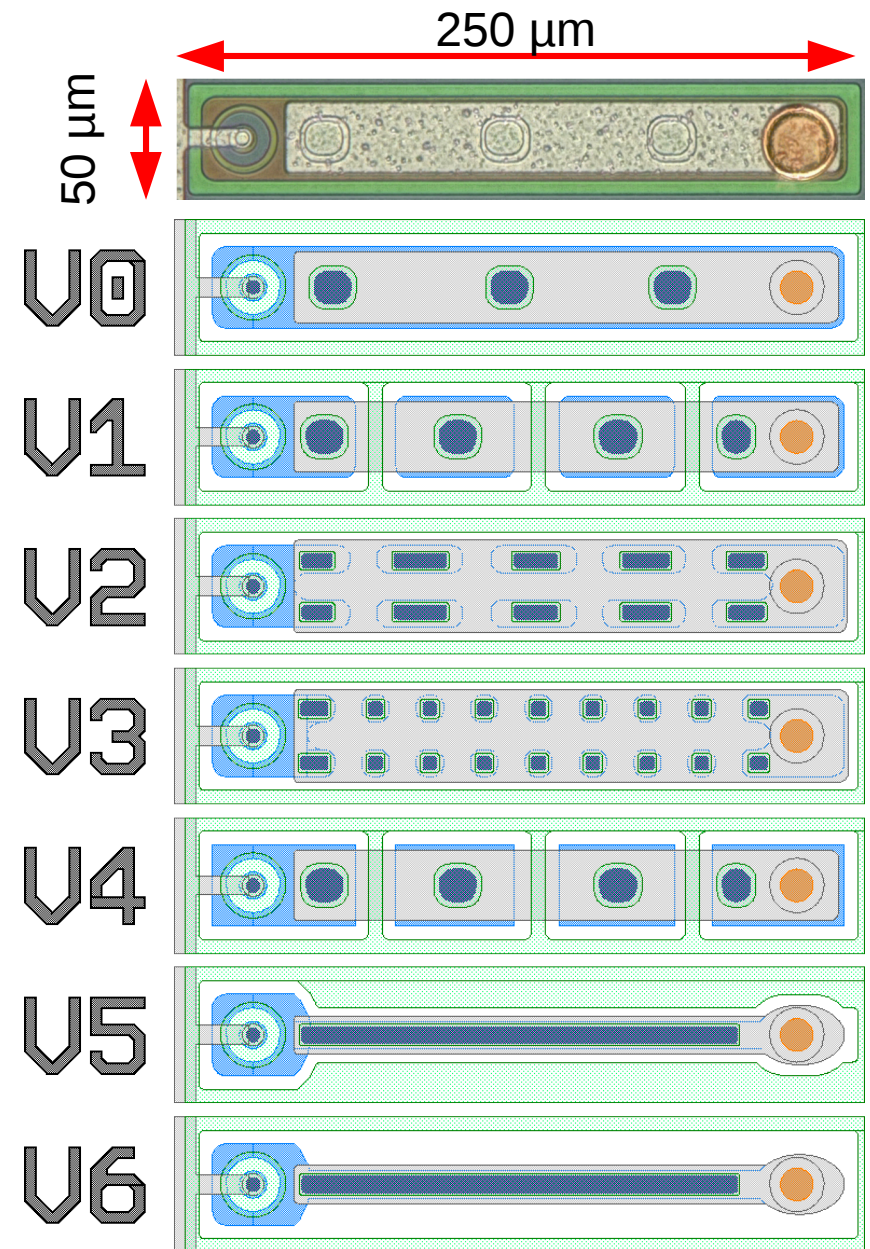
# REINER Pixel Design

REdesigned, INnovative, Exciting and Recognizable

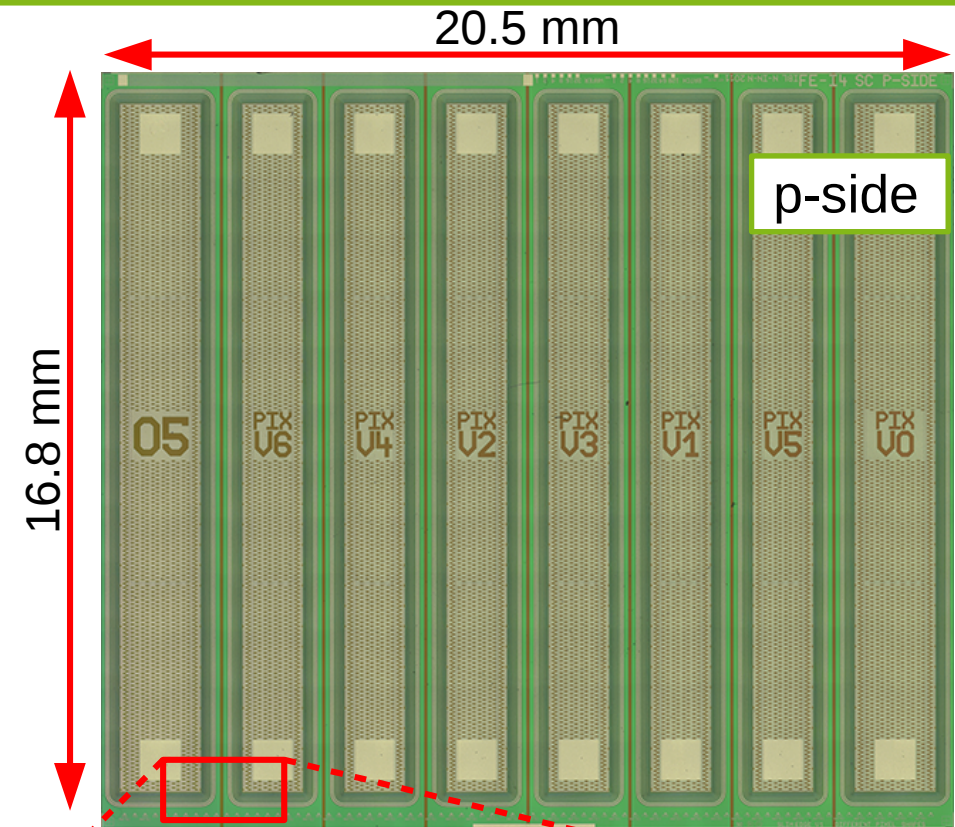
- Pixel size:  $250\ \mu\text{m} \times 50\ \mu\text{m}$  (same as for IBL, Innermost detector of the ATLAS Experiment)
- N-in-n wafer process
- Sensor thickness  $200\ \mu\text{m}$
- Moderated p-spray
- Six modified designs
  - Three divided in 4/10/18 sub implants
  - One with rectangular corners
  - Two with narrowed  $n^+$  implant

V0: IBL-standard  
V1-V6: modified

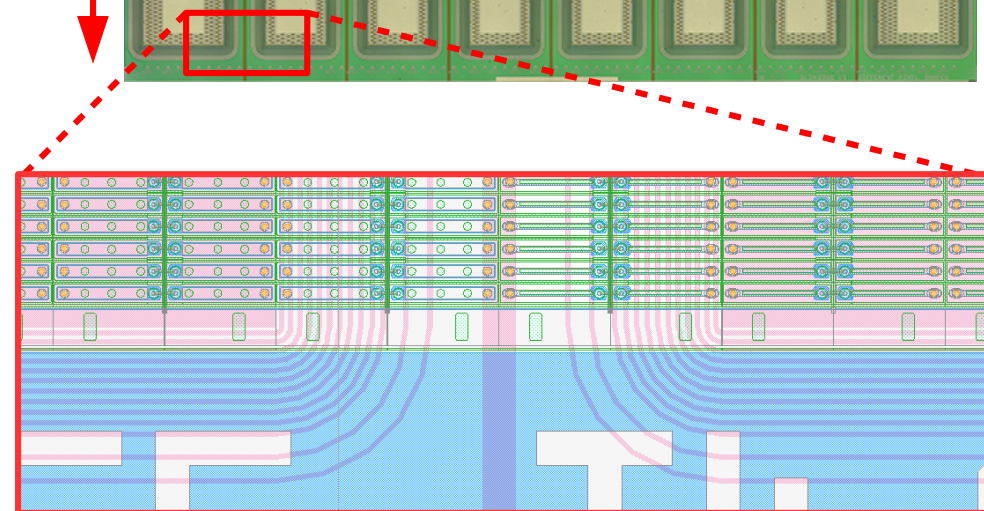
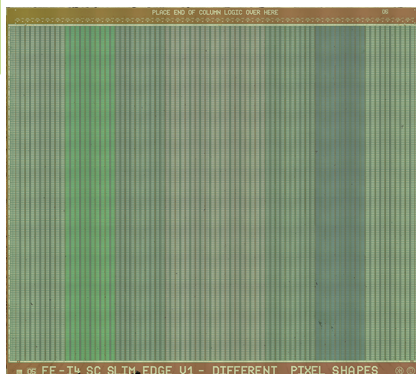
Blue:  $n^+$   
Grey: metal  
Green: Nitride openings



- Eight structures on one sensor
  - Two IBL designs (V0 & 05)
  - Six modified designs
- Each structure consists of 10 columns x 336 rows with the same design
- Separate HV pads
- Individual guard rings
- Readout by one FE-I4

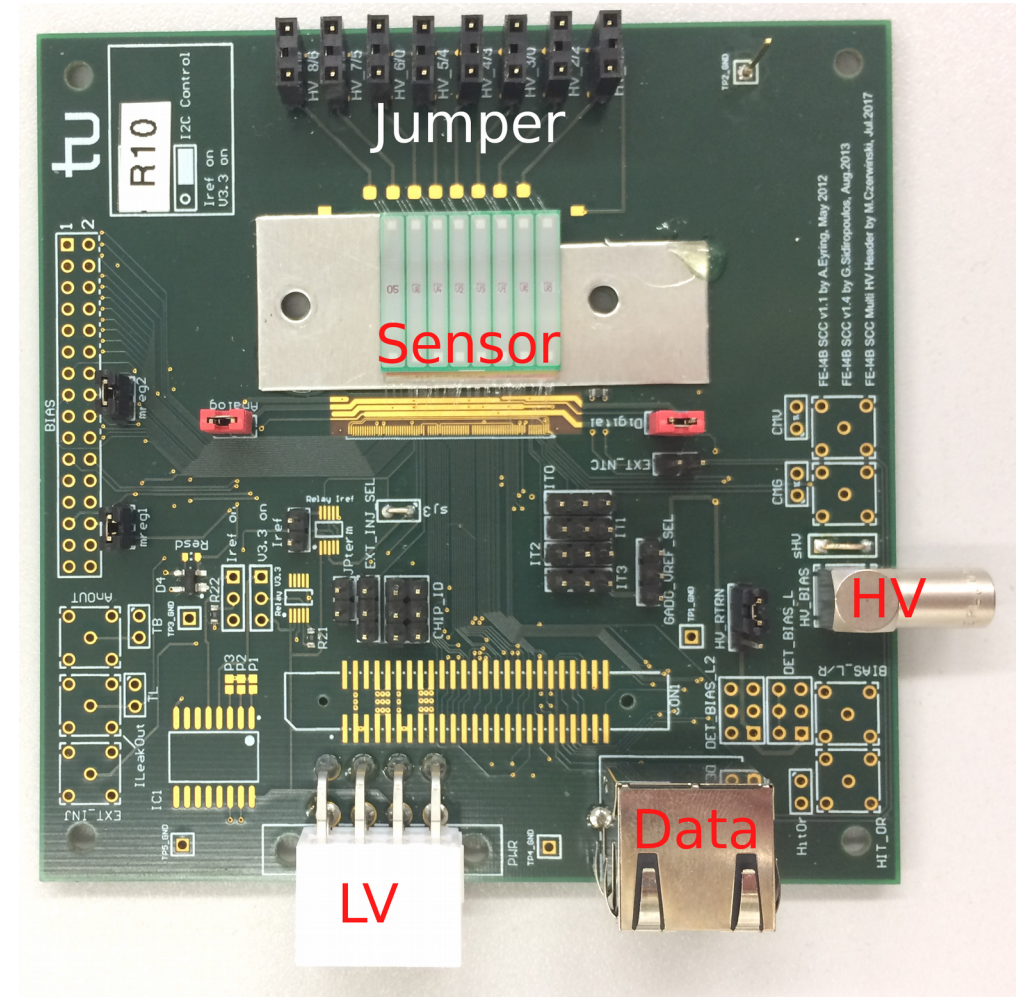


n-side



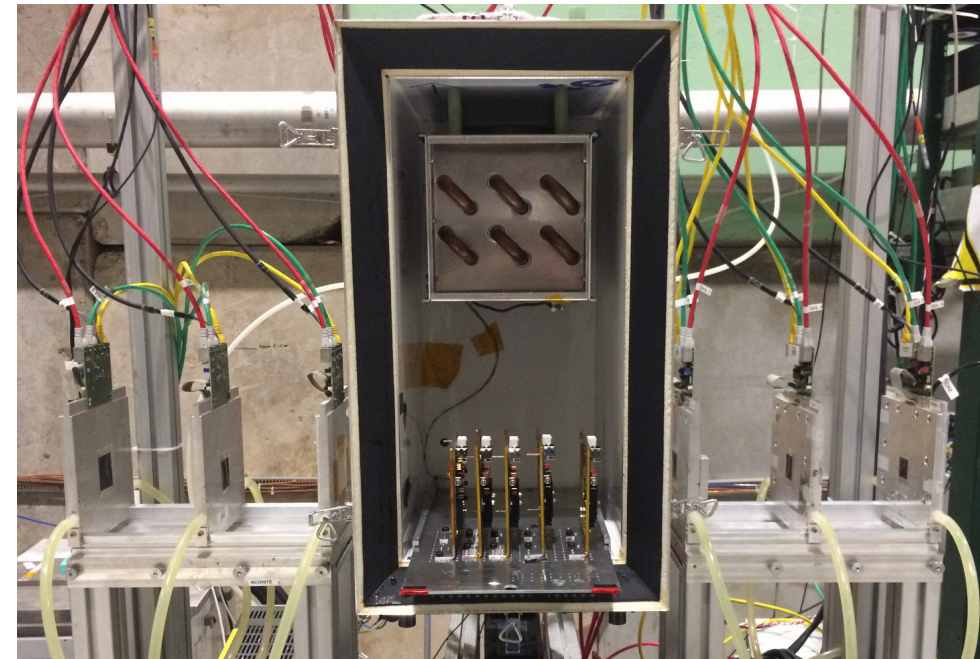
## Neutron irradiated samples:

- R1 (Sandia,  $5e15$   $n_{eq}/cm^2$ )
- R3 (Ljubljana,  $5e15$   $n_{eq}/cm^2$ )
- R5 (Ljubljana,  $5e15$   $n_{eq}/cm^2$ )
- R7 (Ljubljana,  $1e15$   $n_{eq}/cm^2$ )
- R9 (Ljubljana,  $1e15$   $n_{eq}/cm^2$ )



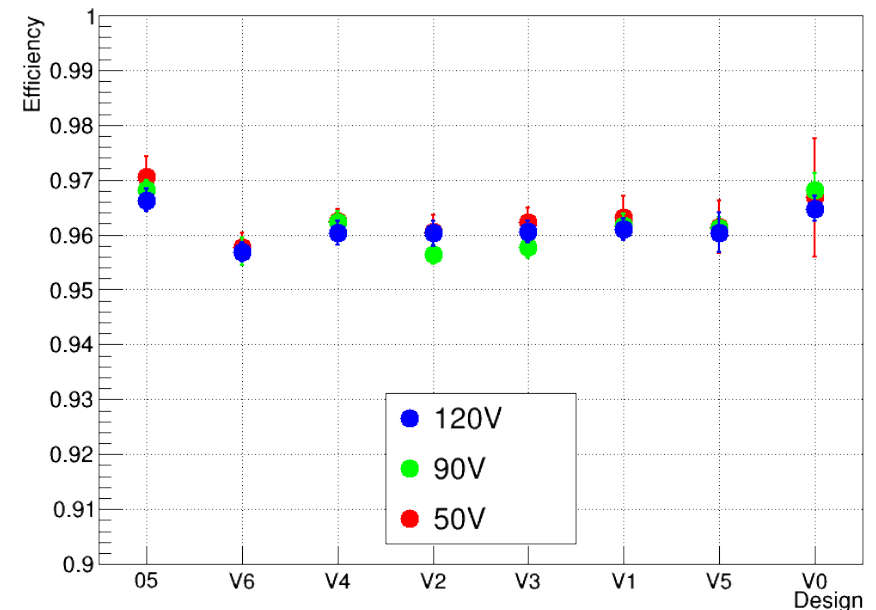
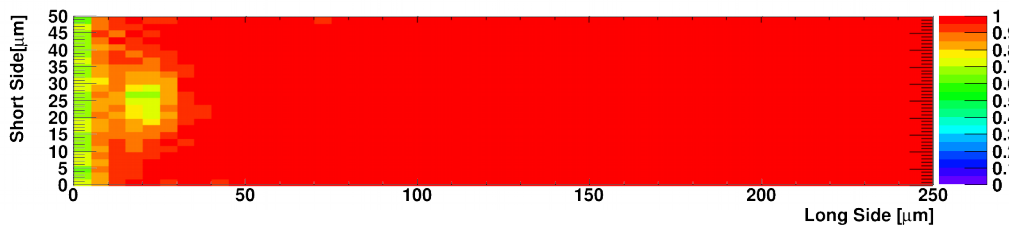
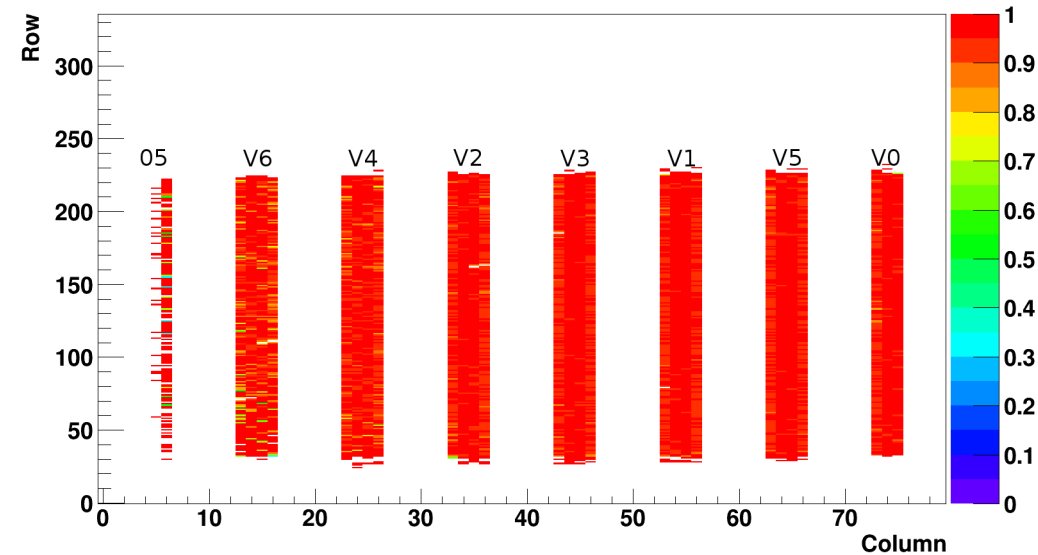
Test Beam:

- DESY or CERN
- 5GeV Electron or 120GeV Pion Beam
- EUDET-type telescope
- Cooled setup
- REINER sensors measured at different tuning, positions and voltages



- To prevent influence of guard rings:  
Only four innermost columns of each pixel design
- When sensor fully depleted:  
No differences in the efficiency between voltage steps
- ➔ To observe differences of the pixel designs use lower voltages
- Projection of the track position into one pixel: In-Pixel Maps

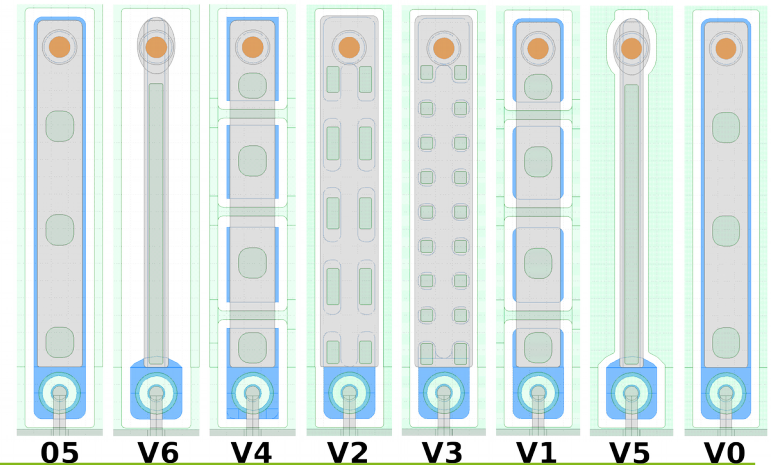
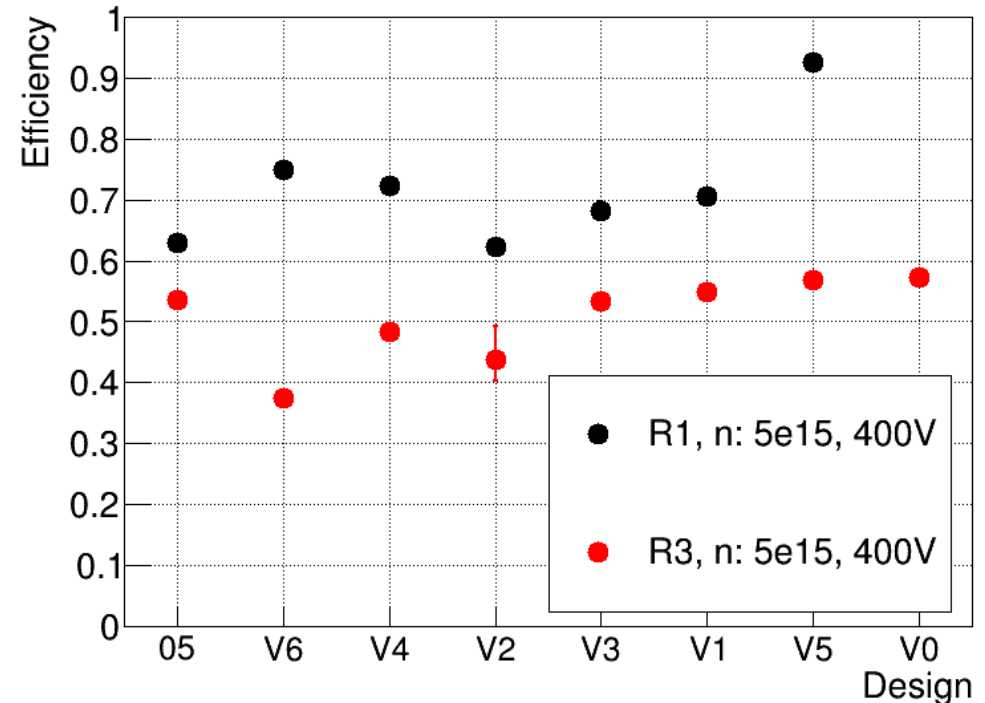
Efficiency Map R2 (non-irrad.) 120V



- Two sensors, both irradiated with neutrons to  $5e15 n_{eq}/cm^2$
- Only difference is irradiation facility:  
R1 = Sandia, R3 = Ljubljana

- Lower efficiencies for pixel designs on sensor R3
- Especially narrowed pixel designs (V5 and V6) show different trends

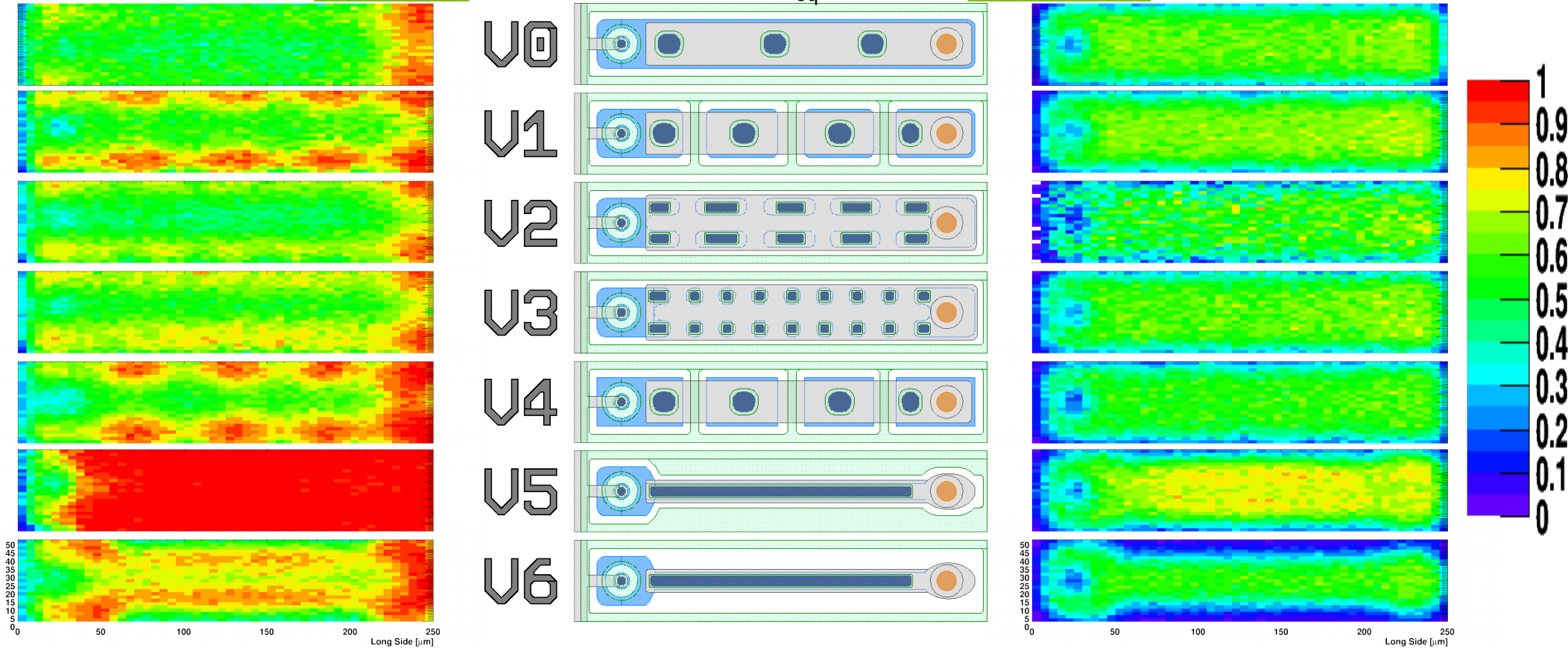
Tuning: 3200e, 6ToT@20ke



R1 400V Sandia

$n: 5e15 n_{eq}/cm^2$

Ljubljana R3 400V Tuning: 3200e, 6ToT@20ke

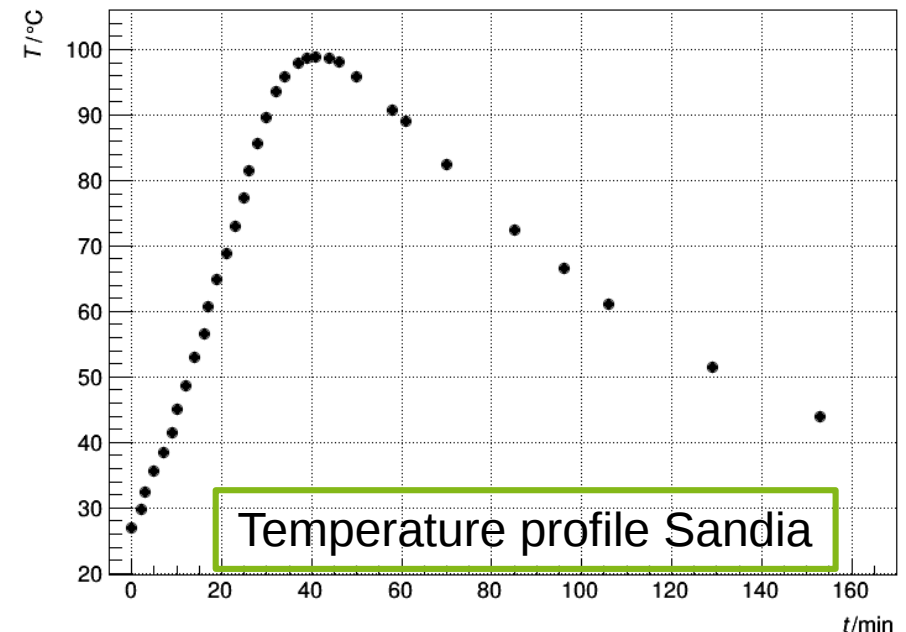
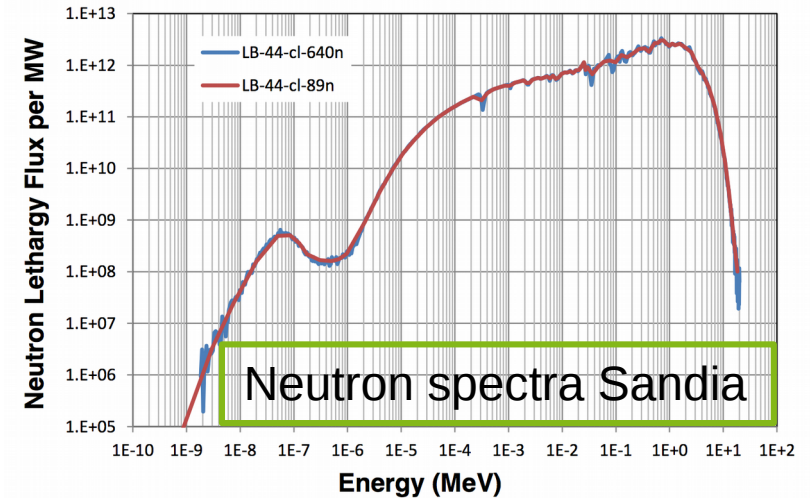


- R1: Regions with higher efficiencies inside the pixel, V5 homogeneously high efficient
- R3: No hot spots



Differences between irradiation at Sandia and Ljubljana:

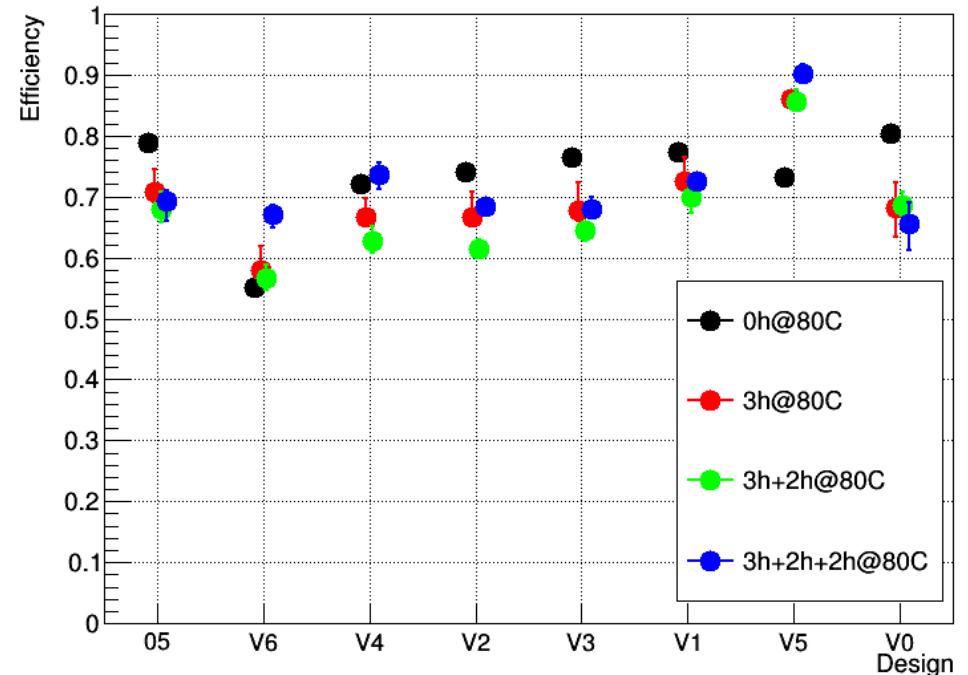
- Neutron energy spectra:
  - Sandia: Absorption of thermal neutrons
  - Ljubljana: Continuous spectra
- Temperature:
  - Sandia: max.  $T \sim 100^{\circ}\text{C}$
  - Ljubljana: max.  $T \sim 40^{\circ}\text{C}$
- Annealing studies of sensors irradiated at Ljubljana



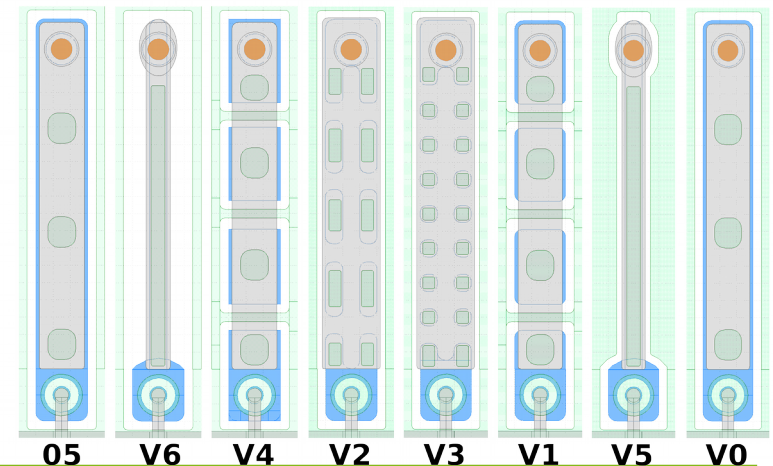
# Annealing Results of R3 at 300V

- Annealing steps: 3h and 2h at 80°C (long term)
- Efficiencies of standard designs dropped
- Efficiencies of pixel designs with smaller implantation (V5 and V6) increased

Tuning: 1600e, 6ToT@20ke



- Agrees with hypothesis: Annealing caused the increase in efficiency of pixel design V5 and V6 on sensor R1



# Annealing Results of R9 at 100V

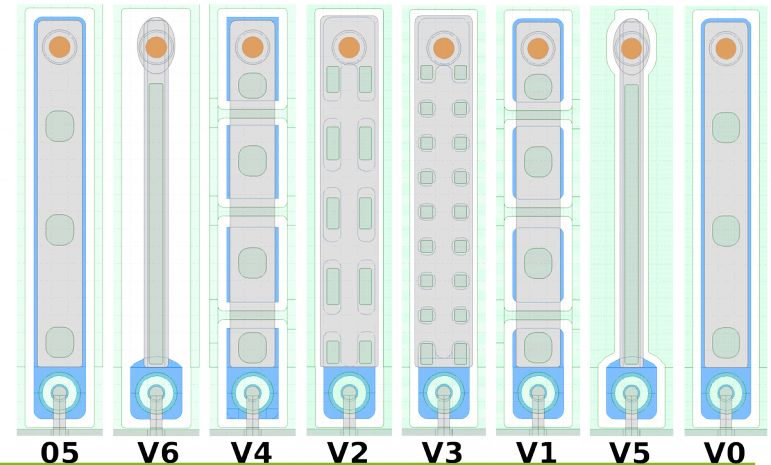
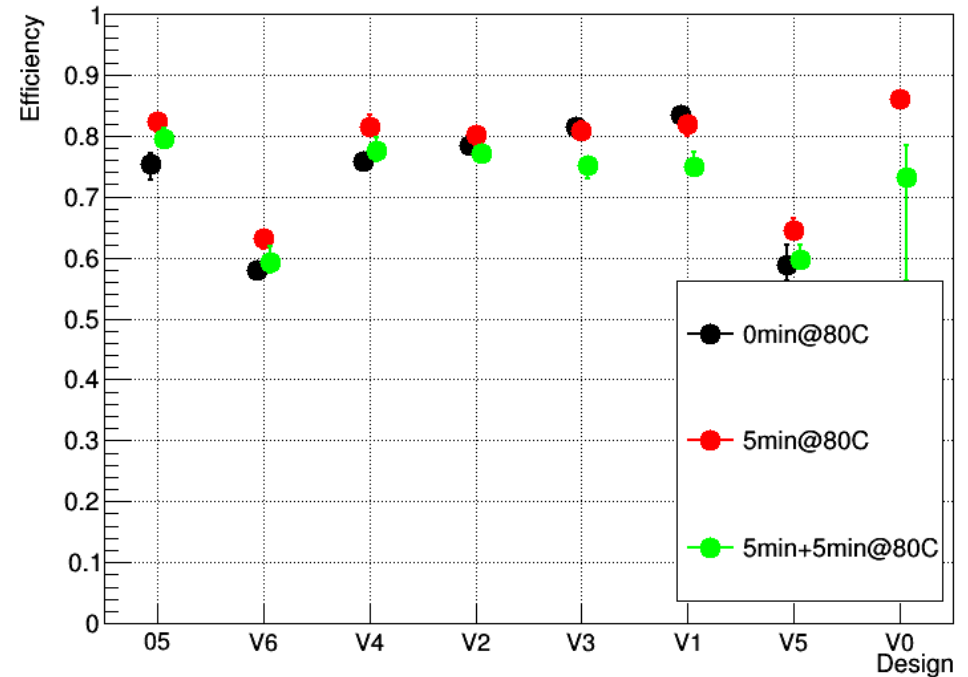
- R9: Irradiated with neutrons to  $1e15n_{eq}/cm^2$

- Annealing steps: 5min at 80°C

→ Transition from beneficial to reverse annealing

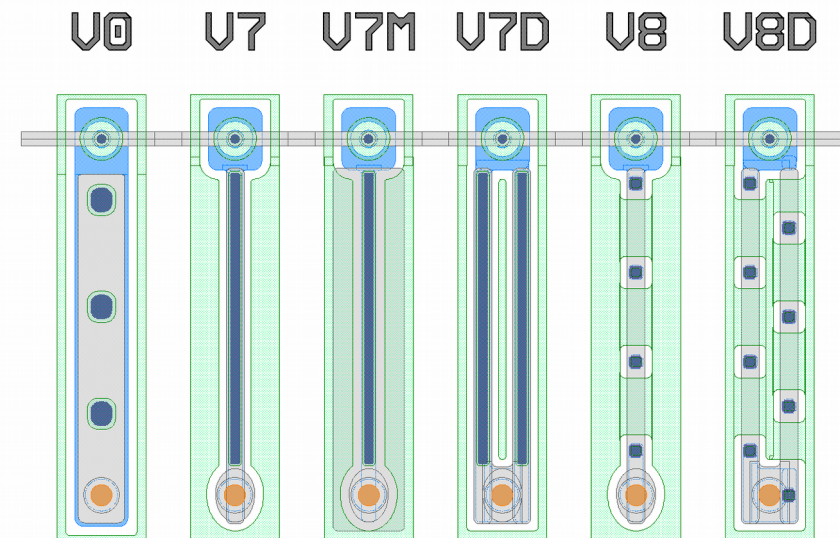
- Efficiencies of all designs increased at first annealing step
- Efficiencies of all designs decreased at second annealing step

Tuning: 1600e, 6ToT@20ke



- Test beam results of two sensors irradiated with neutrons showed disagreeing results
- During irradiation at Sandia the sensor reached very high temperatures
- ➔ Performed annealing studies with sensors irradiated in Ljubljana
- Efficiencies of the pixel designs with smaller implantation increase with annealing

- Further annealing steps of sensors irradiated at Ljubljana
- Annealing studies of proton irradiated sensors
- REINER-Design (V0-V6) adapted for n-in-p production, irradiated with neutrons (at the moment)
- Annealing studies of these n-in-p sensors



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