Characterization of Silicon n-in-p Pixel Sensors for future ATLAS Upgrades

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ATLAS Pixel Detector upgrade

2013

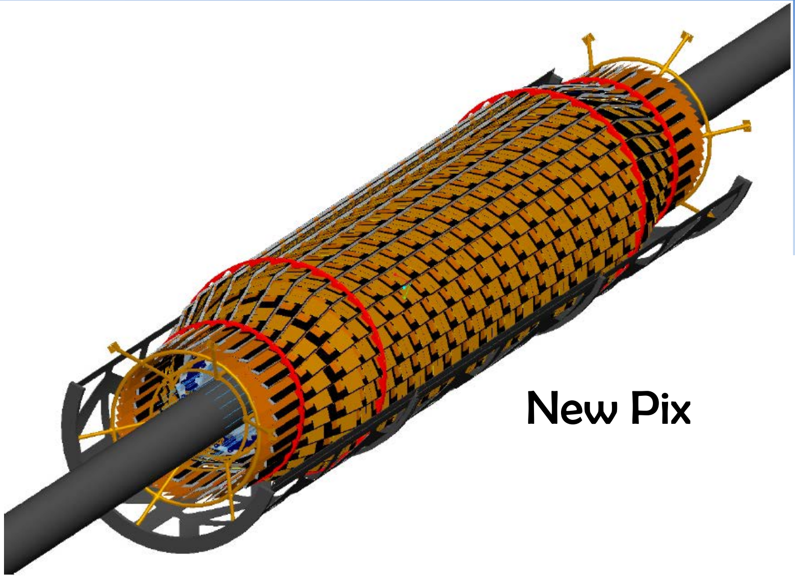
- ATLAS Insertable B-Layer (IBL)
  - Planar n-in-n, 3D n-in-p sensors

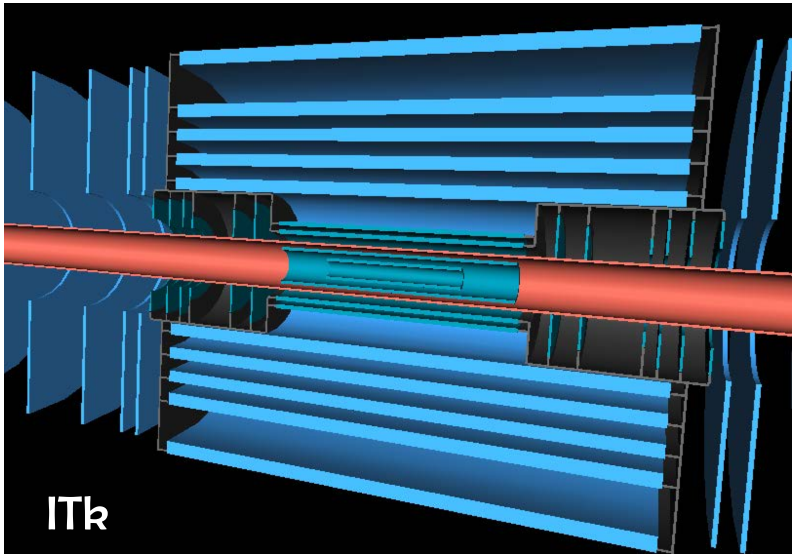
2018

- Phase 1 upgrade: New Pix
  - Full replacement depending on performance (Under discussion)
  - Luminosity: $(2\text{-}3)\cdot 10^{34}\ cm^{-2}s^{-1}$
  - Radiation dose: $5\cdot 10^{15}\ n_{eq}cm^{-2}$ or higher

2022

- Phase 2 upgrade: Inner detector Tracker (ITk)
  - Complete new ATLAS tracker for pixels and strip detectors
  - Luminosity: $5\cdot 10^{34}\ cm^{-2}s^{-1}$
  - Radiation dose: $2\cdot 10^{16}\ n_{eq}cm^{-2}$

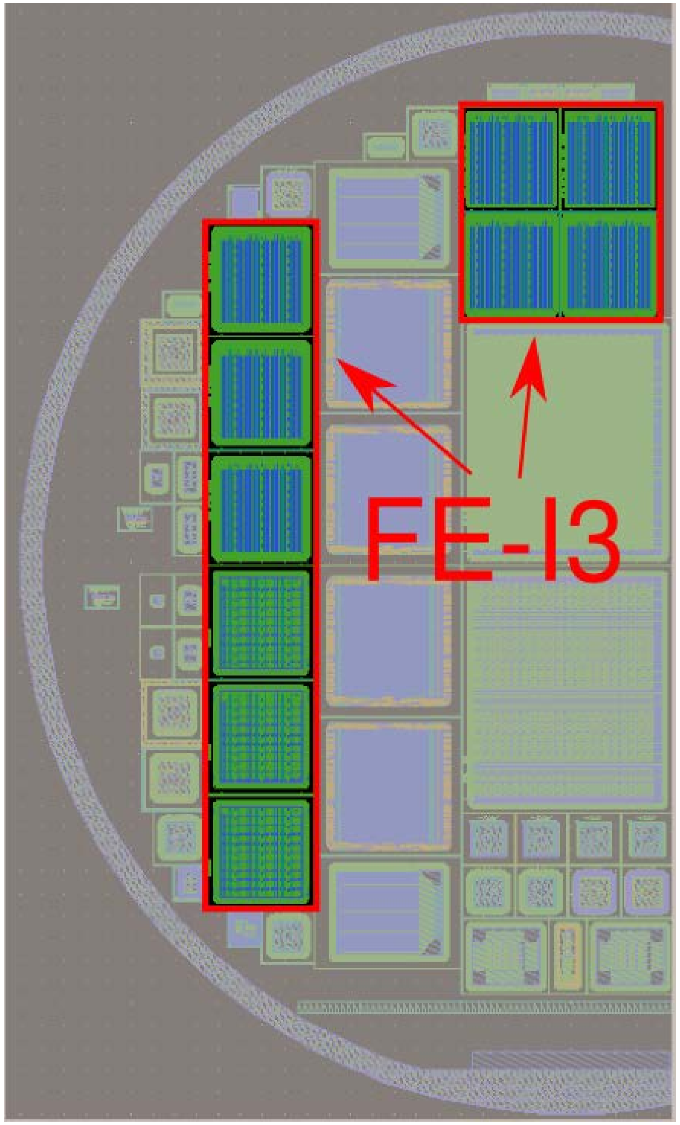




Planar n-in-p as future sensor technologie

- Excellent candidate for large volumes
- Single-sided processing -> reduced cost.
- Radiation hardness comparable to n-in-n
- R&D based on present ATLAS front-end chip

CiS-Production



18 Fz n-in-p wafer, 285µm thick delivered by CiS (Erfurt, Germany)

10 FE-I3: Single Chip Modules (SCM) with different guard ring (GR) and isolation schemes:

- 2·8 GRs, homogeneous p-spray
- 2·15 GRs, homogeneous p-spray
- 3·Standard (19) GR, homogeneous p-spray
- 3·Standard (19) GR, moderated p-spray

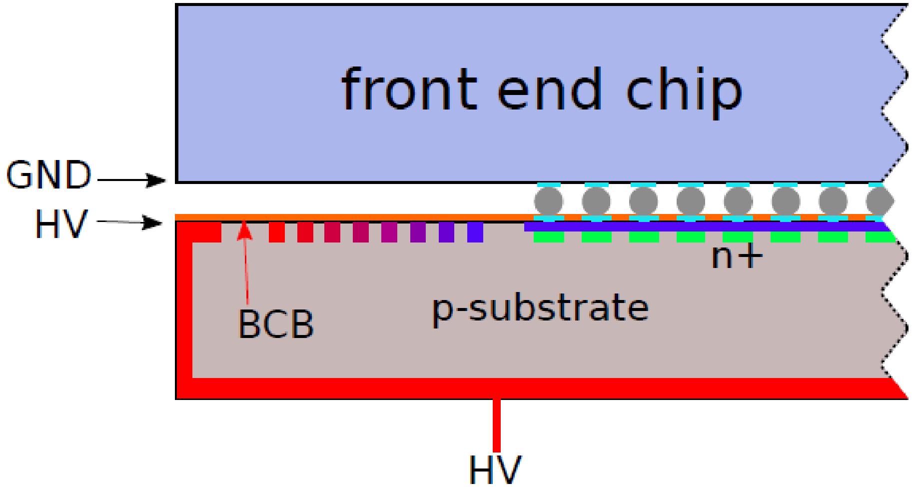
19 SCMs were built by IZM.

Assembling and wire-bonding done in Bonn.

Benzo Cyclo Butene

Planar n-in-p sensors

- High voltage on the sensor reaches the side facing the front-end chip
- This might cause sparks which would destroy the chip



Possible Solution

- Thin layer of Benzo Clyclo Butene (BCB) to cover the sensor
- BCB provides higher electrical insulation capability than SiO_2

Results

- HV-stability observed several hours at voltages up to 1000V

CIS FE-I3 Results

Irradiation

CERN (protons 24GeV)

- 1 sensor at $6.2 \cdot 10^{14}$ $n_{eq}cm^{-2}$
- 1 sensor at $2.5 \cdot 10^{15}$ $n_{eq}cm^{-2}$
- 1 sensor at $4.4 \cdot 10^{15}$ $n_{eq}cm^{-2}$
- 1 SCM at $2.8 \cdot 10^{15}$ $n_{eq}cm^{-2}$
- 1 SCM at $5 \cdot 10^{15}$ $n_{eq}cm^{-2}$

Karlsruhe (protons 25MeV)

- 1 SCM at 10^{15} $n_{eq}cm^{-2}$

Ljubljana (neutrons)

- 1 SCM at $2 \cdot 10^{15}$ $n_{eq}cm^{-2}$
- 1 SCM at $3 \cdot 10^{15}$ $n_{eq}cm^{-2}$
- 1 SCM at $5 \cdot 10^{15}$ $n_{eq}cm^{-2}$
- 1 SCM at 10^{16} $n_{eq}cm^{-2}$

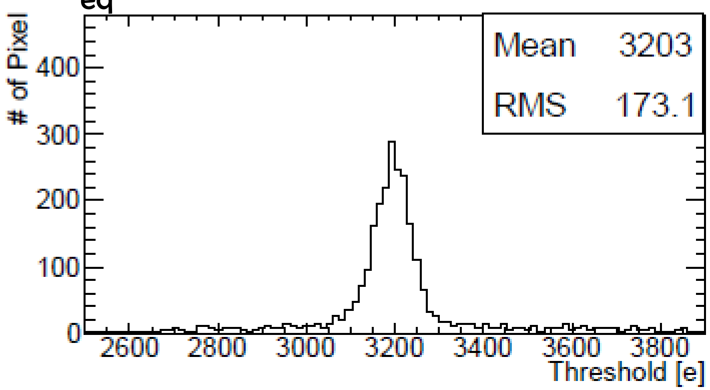
Mixed irradiation (Ljubljana+Karlsruhe)

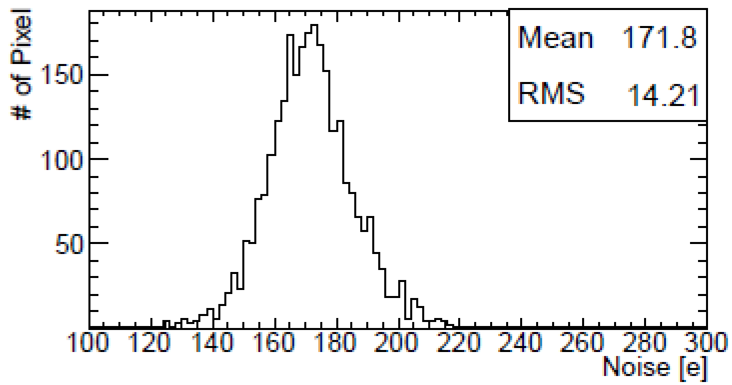
- 1 SCM at 10^{15} $n_{eq}cm^{-2}$ + 10^{15} $n_{eq}cm^{-2}$

Tuning of irradiated sample

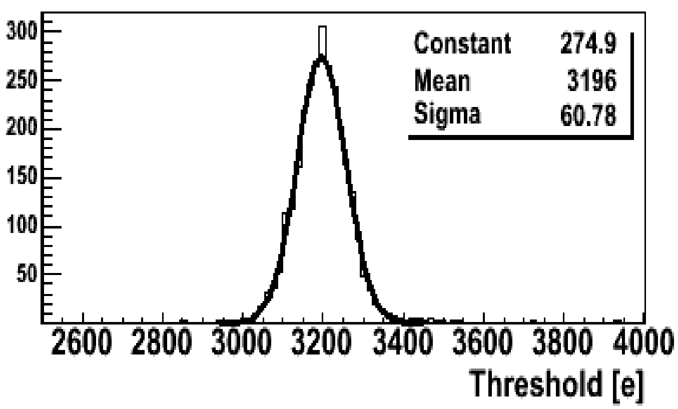
Irradiation effects sensor and front-end properties which influence the tuning behavior

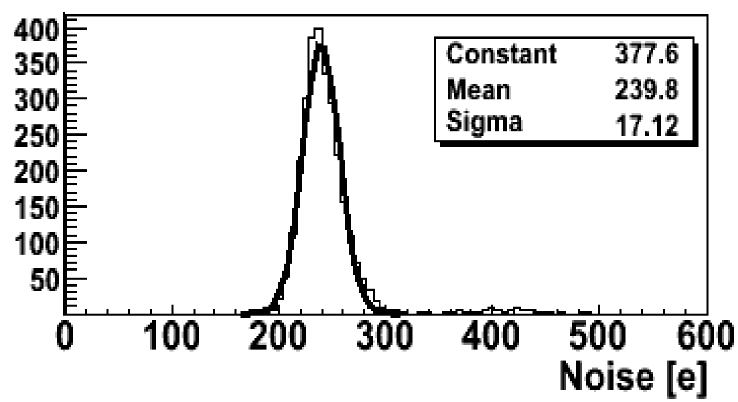
- $5 \cdot 10^{15}\ n_{eq}cm^{-2}$ neutron irradiated: tuning at 1000V and -60°C





- $10^{16}\ n_{eq}cm^{-2}$ neutron irradiated: tuning at 950V and -50°C

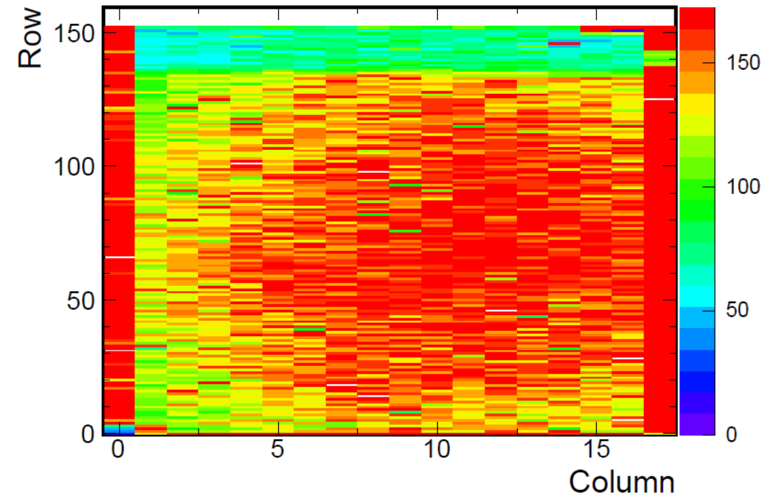




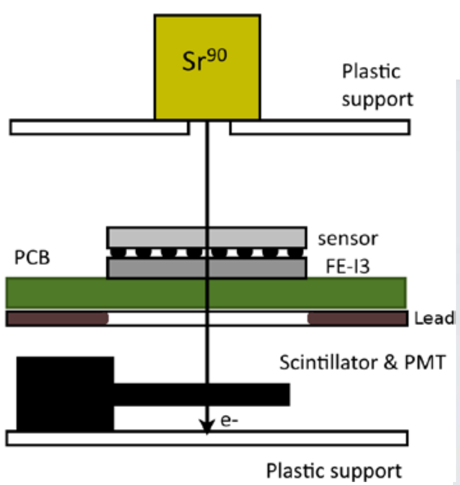
Tuning is still possible with satisfying results

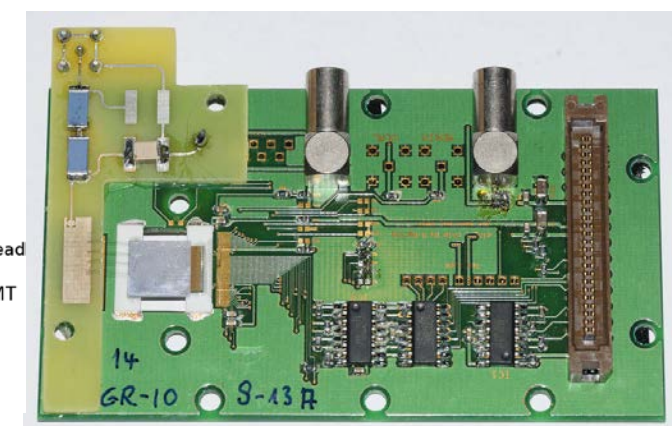
Sr-90 source tests

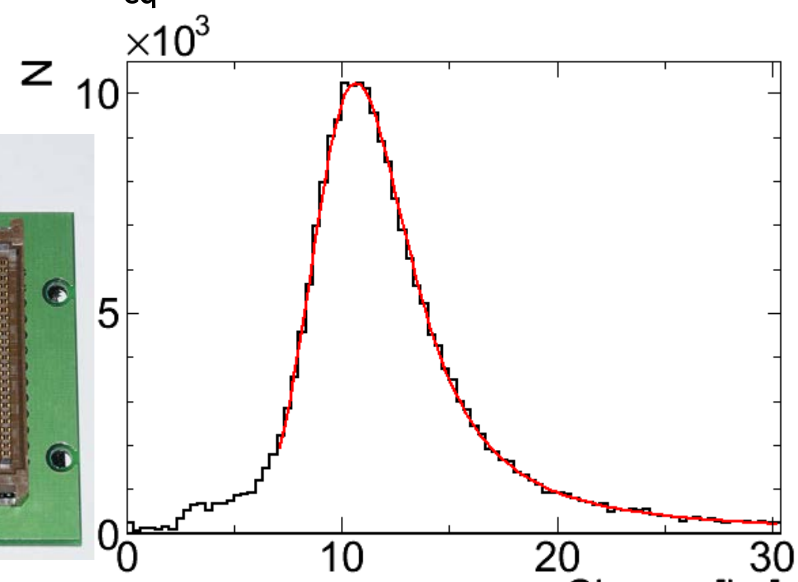
- Sr-90 source is used for charge collection measurement
- External trigger via scintillator
- Measurement done for fluences up to $5 \cdot 10^{15}\ n_{eq}cm^{-2}$ and 1000V
- Events with two independent clusters are discarded in order to minimize noise



$5 \cdot 10^{15}\ n_{eq}cm^{-2}$ neutron irradiated at 1000V

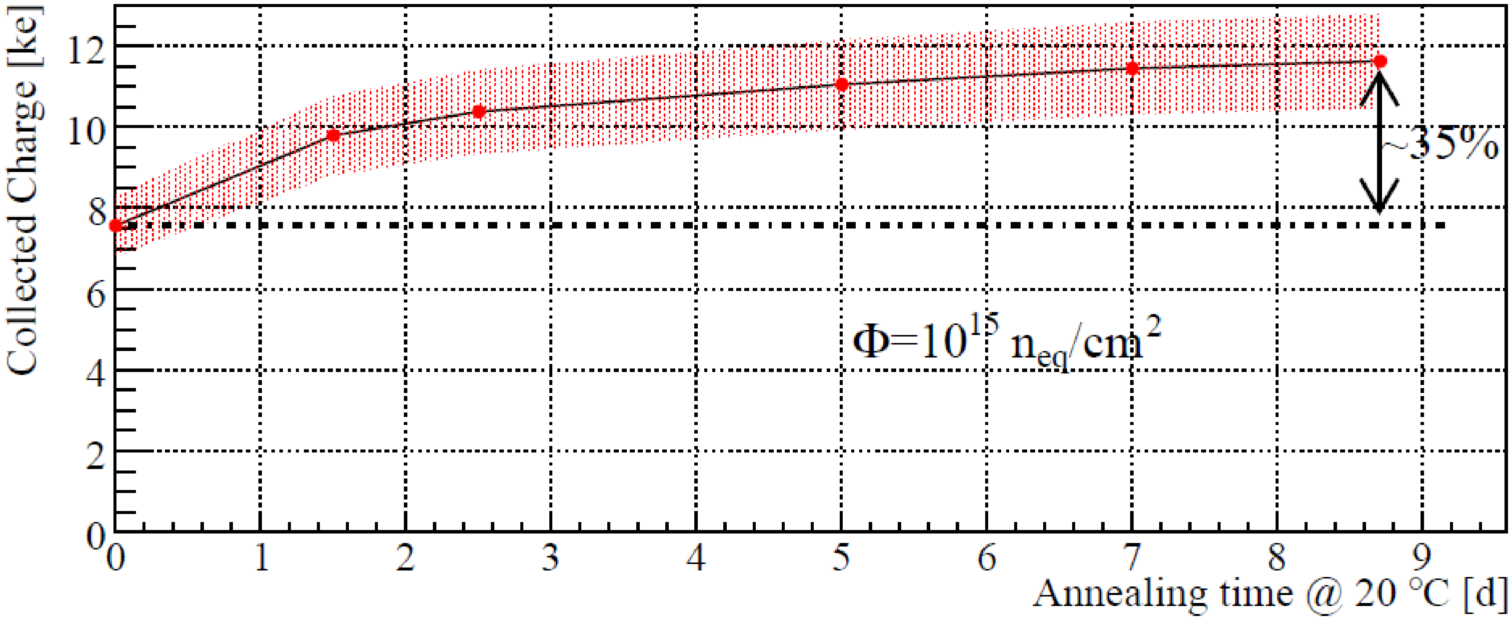






Annealing studie

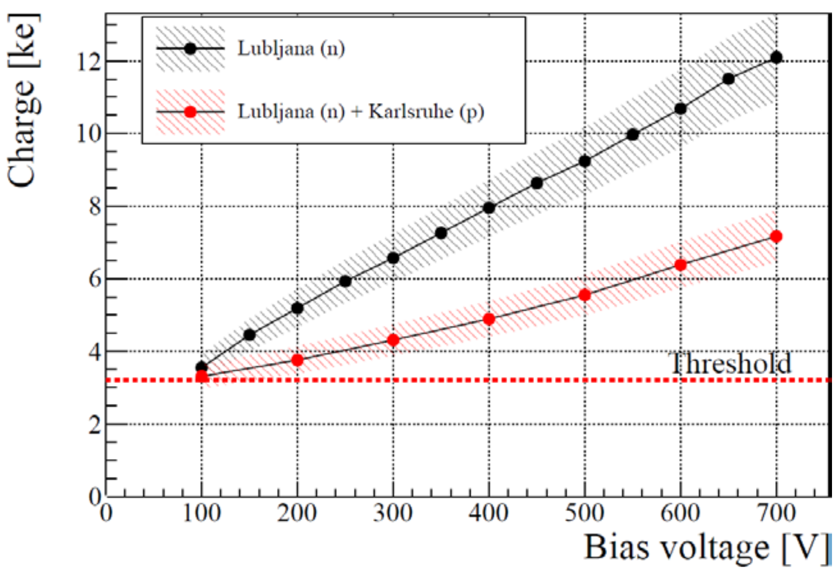
- Proton irradiation at KIT possible with SCM on PCB
- Neutron irradiation needs handling (gluing, bonding) after irradiation (annealing 1-2 days)

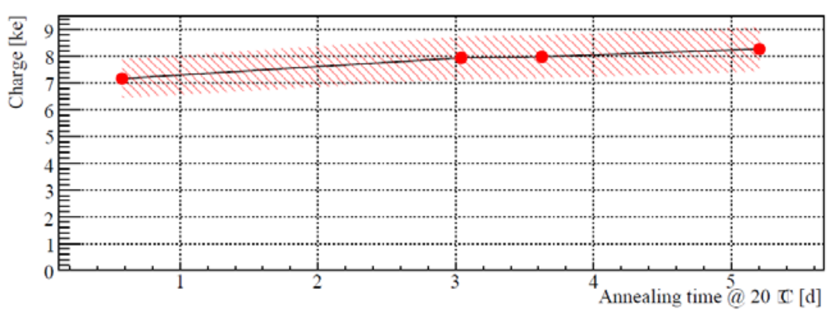


- Uncertainties arise from limited knowledge of capacitors used in ToT to charge transformation

Mixed irradiation

One SCM was twice irradiated : 10^{15} $n_{eq}cm^{-2}$ (LJ) + 10^{15} $n_{eq}cm^{-2}$ (KIT)

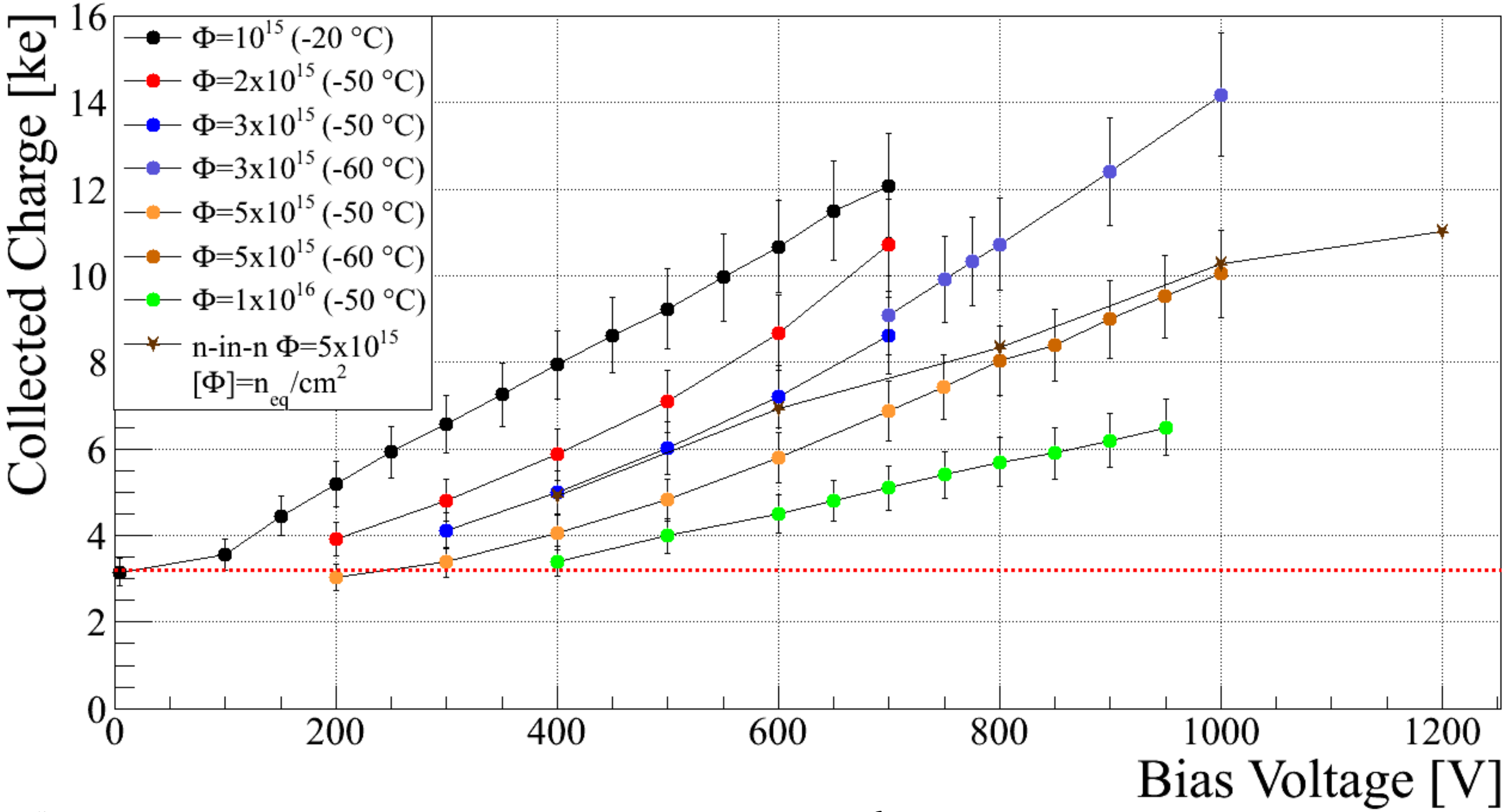




- Sufficient charge collection after irradiation
- Measurements at higher voltages limited by HV capabilities of PCB
- Compared to unirradiated sensors the collected charge at 700V is
  - 65% after irradiation in Ljubljana
  - 39% after both irradiations
- Low noise between 100e⁻ and 120e⁻

Measurements done at -20°C (Ljubljana) and -50°C (Ljubljana + Karlsruhe)

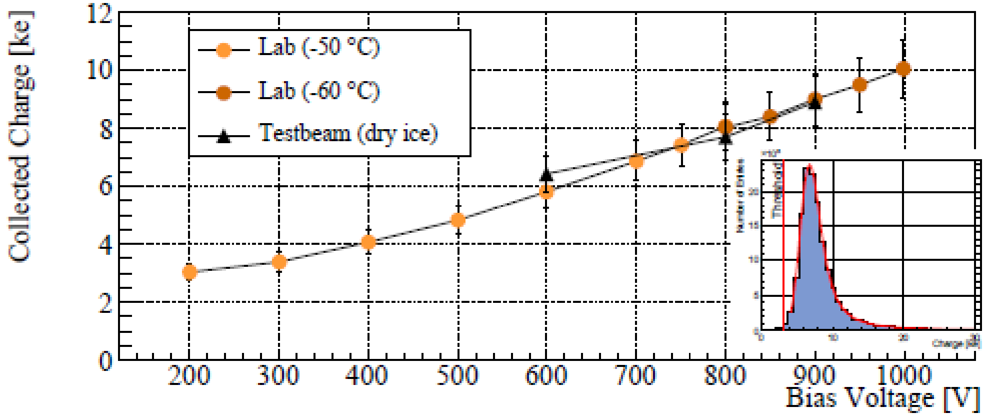
Charge collection

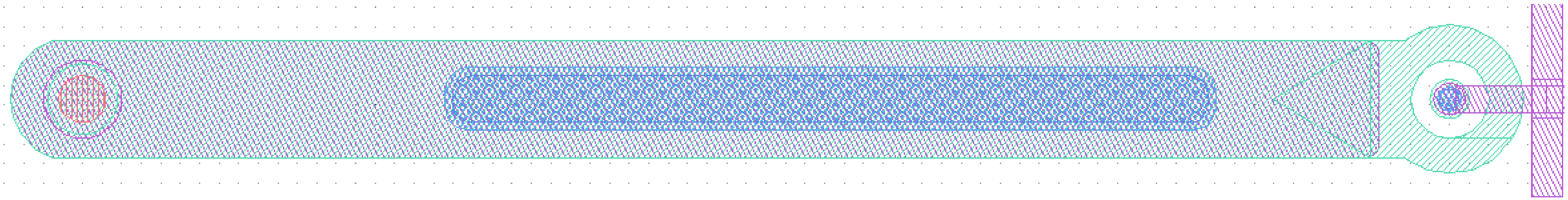


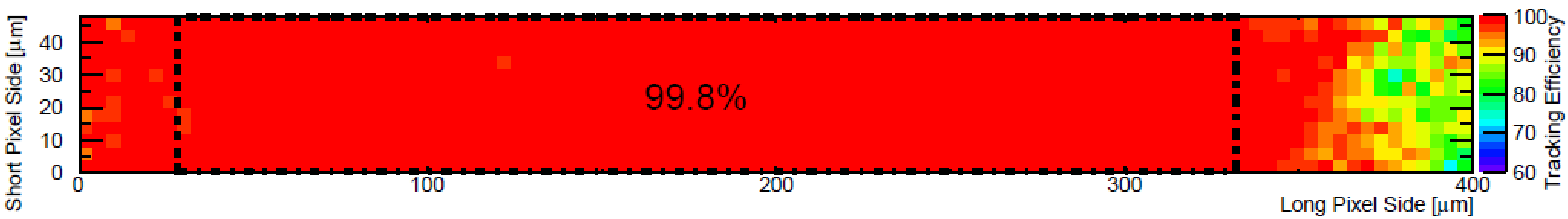
- All neutron samples were annealed for around two days
- Highest leakage currents ~20µA
- n-in-n sample data from S. Altenheiner et al. (doi:10.1016/j.nima.2011.05.074)

Testbeam results at $5 \cdot 10^{15}$ $n_{eq}cm^{-2}$

- TB with 120GeV π-beam at CERN SPS + Eudet telescope
- Neutron Irradiated Sample ($5 \cdot 10^{15}$ $n_{eq}cm^{-2}$)
- Threshold of $3.2ke^-$ (MPV $6.4ke^-$)
- Efficiency at 600V: 98.7% overall
- (99,8% in central region)



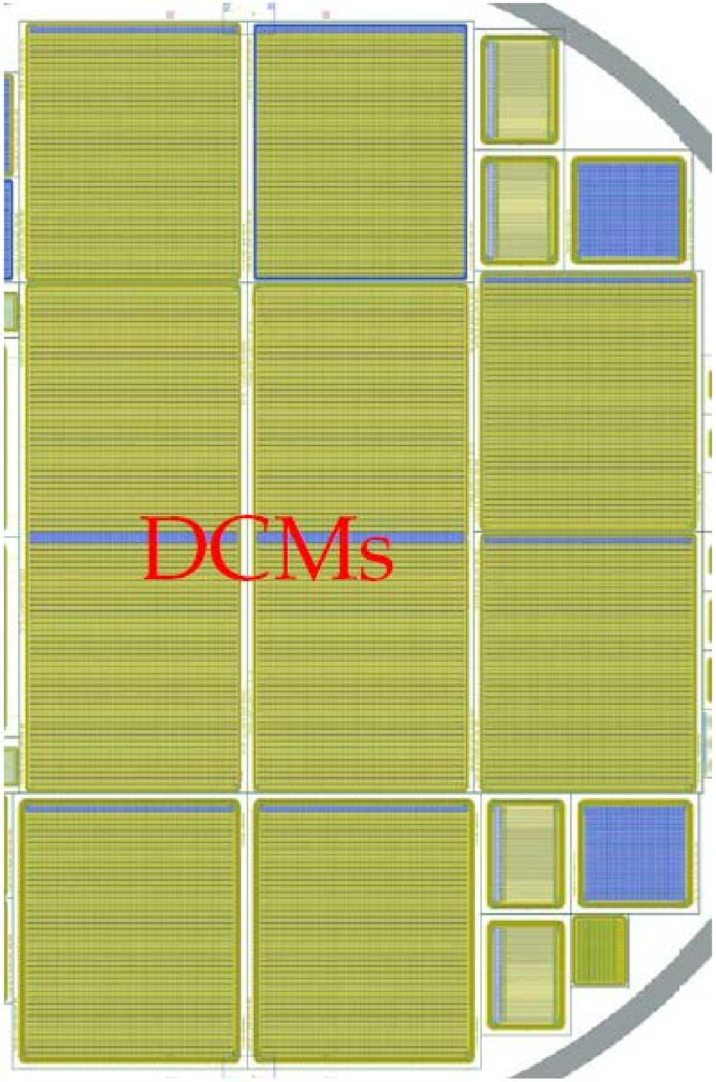




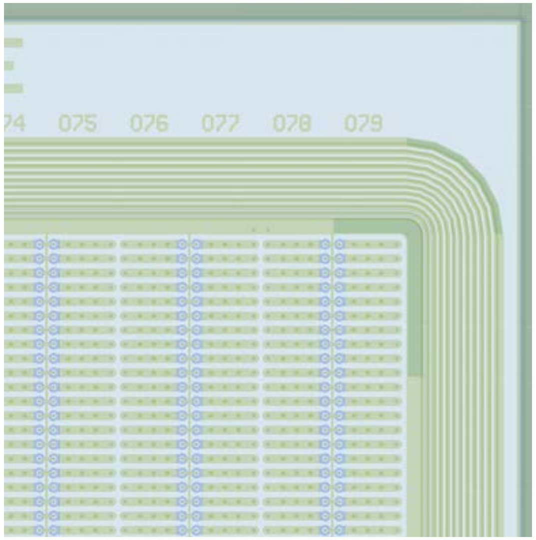
TB-Group 2011: S. Altenheiner, M. Backhaus, M. Bomben, D. Forshaw, Ch. Gallrapp, M. George, J. Idarraga, J. Janssen, J. Jentzsch, T. Lapsien, A. La Rosa, A. Macchiolo, G. Marchiori, R. Nagai, C. Nellist, I. Rubinskiy, A. Rummler, G. Troska, Y. Unno, P. Weigell, J. Weingarten

NEW CIS FE-I4 PRODUCTION

New CiS FE-I4 Production



- Pixel sensors compatible with FE-I4 (new ATLAS read-out chip)
- 6 Single Chip Module
- 2 Double Chip Module
- Thinner bulk: 150μm and 200μm
  - Higher CCE after irradiations.
  - Less material in crucial part of the detector
- Guard-rings are following the IBL design:
  - 450μm inactive edge
- Pitch: $50 \cdot 250 \mu m^2$



SUMMARY AND OUTLOOK

Summary and outlook

Summary

- SCM properly working up to $10^{16}\ n_{eq}cm^{-2}$
- Stable operation at 1000V for several hours.
- Charge collection for voltages higher than 600V well above threshold (3.2ke^{-}) up to $10^{16}\ n_{eq}cm^{-2}$
- High efficiency >98% at $5\cdot10^{15}\ n_{eq}cm^{-2}$ already at 600V

Outlook

- Test beam measurements with $10^{16}\ n_{eq}cm^{-2}$ neutron irradiated samples will follow
- Testbeam analysis including tracking efficiency for $10^{16}\ n_{eq}cm^{-2}$
- Compare results with the new FE-I4 based production which hopefully arrives soon.

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