Characterization and Testbeam Analysis of irradiated Silicon n-in-p Pixel Detectors for the ATLAS Upgrades

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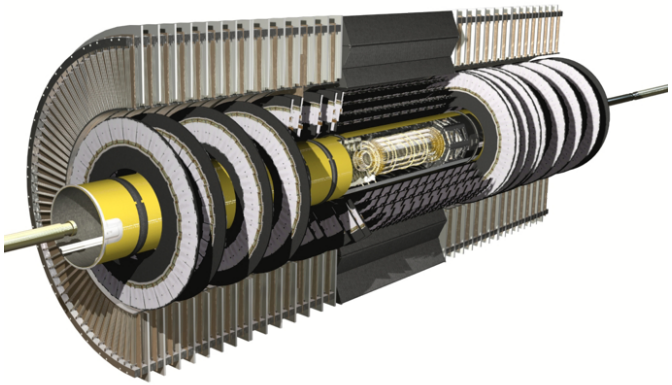
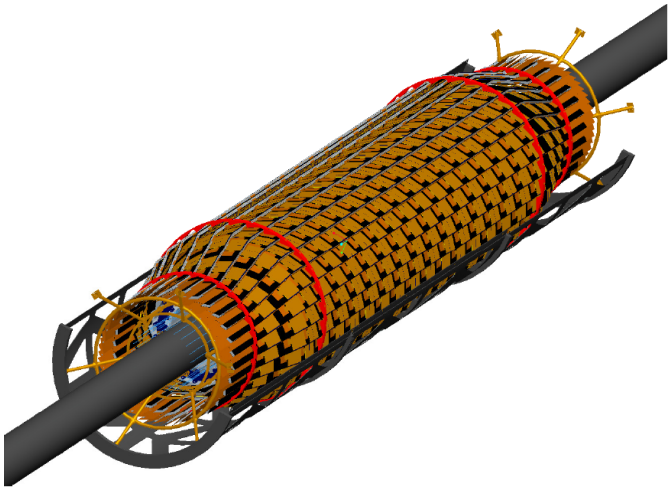
Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)

Future of ATLAS and LHC



NewPix



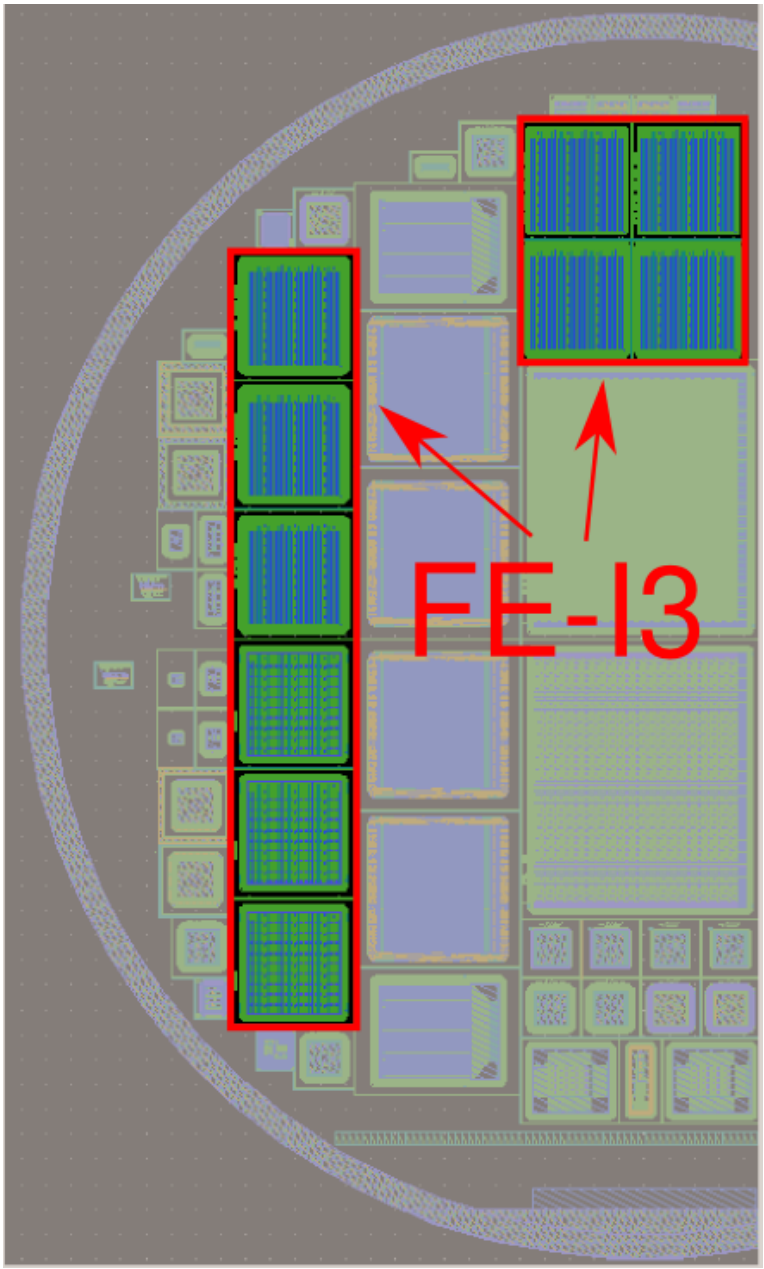
Keystones for upgrade

- Twofold Upgrade:
  - IBL $\sim$2013/4
  - HL-HC/NewPix $\sim$2018 (Under discussion)
- Luminosity: $(2-3)\cdot 10^{34} - 10^{35}/(\mathrm{cm}^2\mathrm{s})$
- $\Rightarrow$ radiation dose: $\phi_{\mathrm{eq}} \approx 10^{15} - 10^{16}\,\mathrm{n_{eq}}/\mathrm{cm}^2$

NewPix Specs

- New front-end chip (FE-I4/5?) and new sensor design (250 µm $\times$ 50 µm) $\rightarrow$ Improved vertex resolution (b-tagging!)
- Present workhorse for R&D: ATLAS front-end chip (FE-I3: 400 µm $\times$ 50 µm)
- Sensor-technology not yet fixed: n-in-p is an excellent candidate for this large volumes.
  - Only one side needs processing $\rightarrow$ reduced cost.
  - Radiation hardness compatible with n-in-n

CiS-Production (n-in-p Batch)



18 Fz n-in-p wafers, 285 μm thick delivered by CiS

10$\times$FE-I3: Single Chip Modules (SCM) with different GR and isolation schemes:

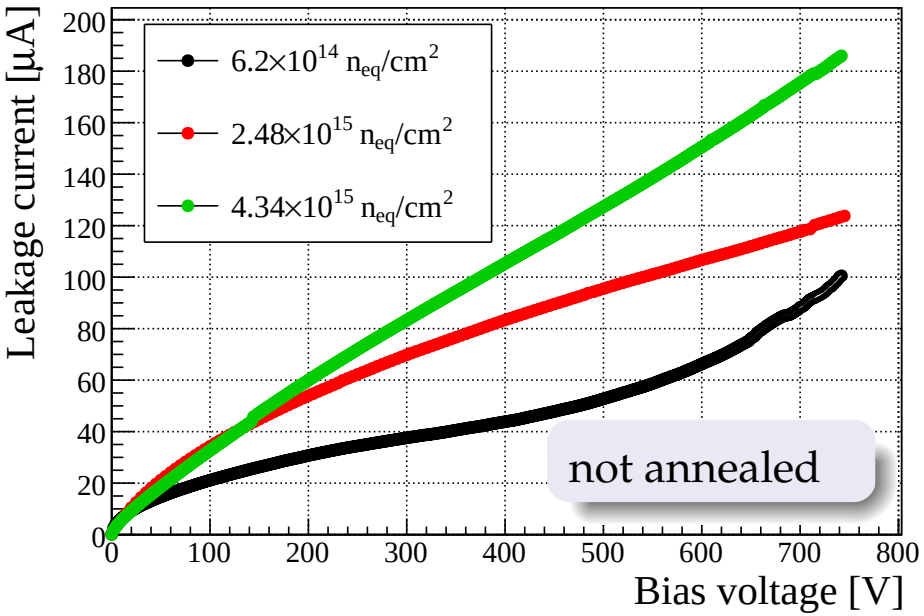
- 2$\times$ 8 GRs, homogeneous p-spray
- 2$\times$ 15 GRs, homogeneous p-spray
- 3$\times$ Standard (19) GR, homogeneous p-spray
- 3$\times$ Standard (19) GR, moderated p-spray

By now 19 SCMs were built by IZM. Assembly on Bonn-boards and wire-bonding done in Bonn.

—Thanks!

Irradiations

- **CERN** protons at 24 GeV
  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 at 25 MeV
  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 $10^{16}\,n_{eq}/cm^2$ (ongoing)
- **Ljubljana** neutrons +
  Karlsruhe protons at 25 MeV
  1 SCM at $10^{15}\,n_{eq}/cm^2$ + $10^{15}\,n_{eq}/cm^2$

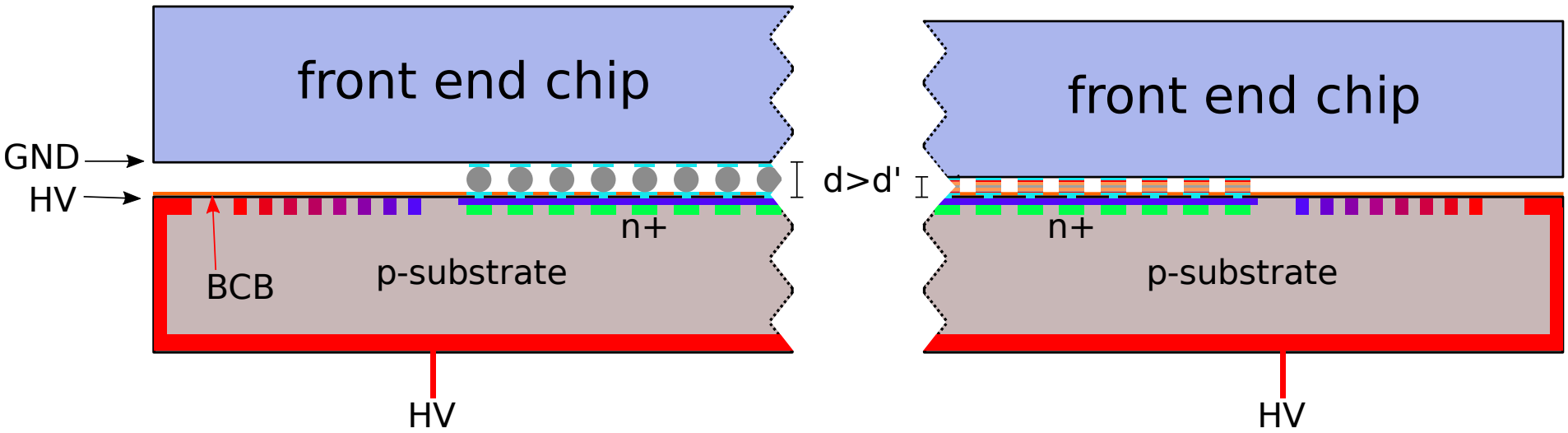


For the irradiations we thank:

M. Glaser at CERN-PS
A. Dierlamm and the Helmholtz Alliance at KIT
V. Cindro in Ljubljana

HV Stability - BCB

n-in-p: HV is on sensor side facing the chip → danger of sparks!



Alternative interconnection technologies like SLID (Solid Liquid Interdiffusion; Cu+Sn pad) further reduce the distance!

Solution: Cover sensor with a thin layer of BCB (Benzo Clyclo Butene)

HV-stability observed @ 1000 V over several hours.

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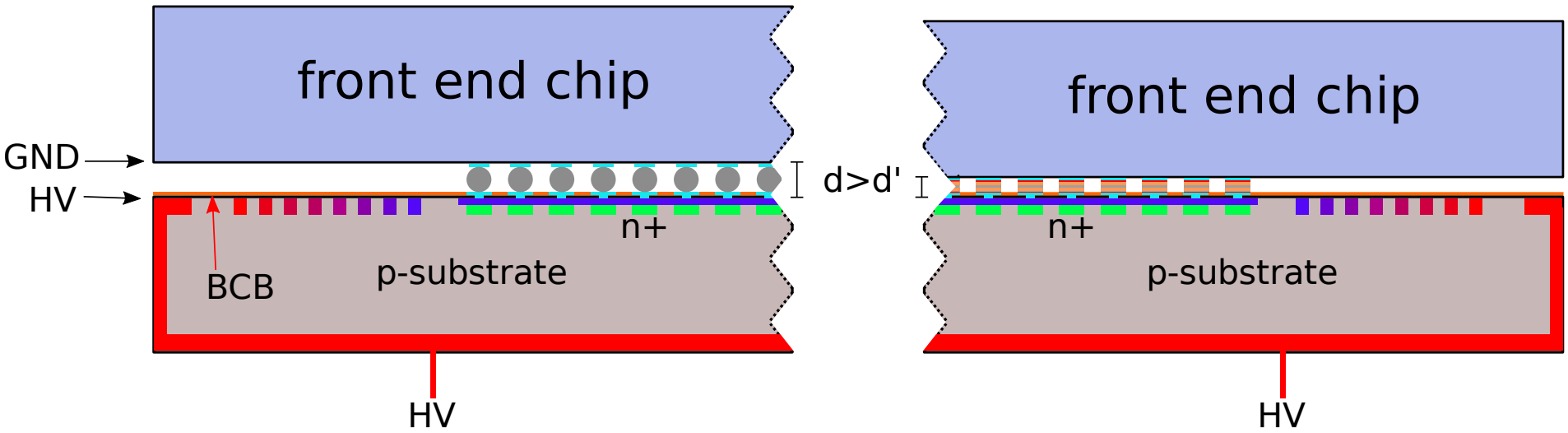

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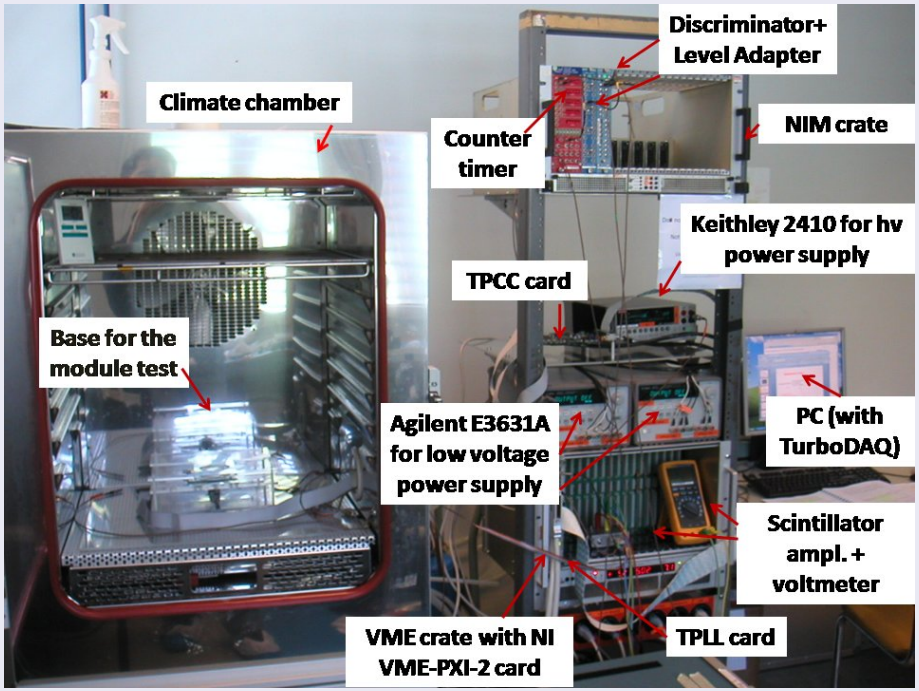
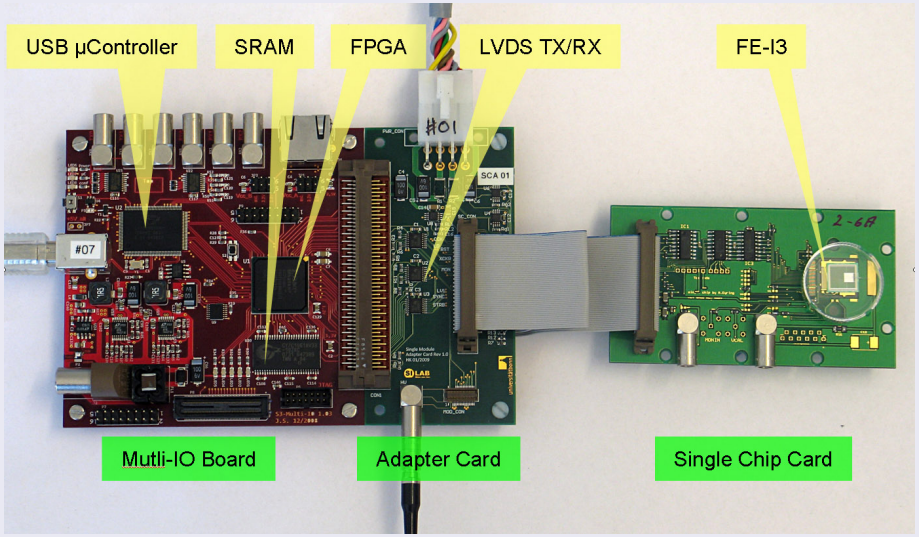
DAQ-Systems

TurboDAQ



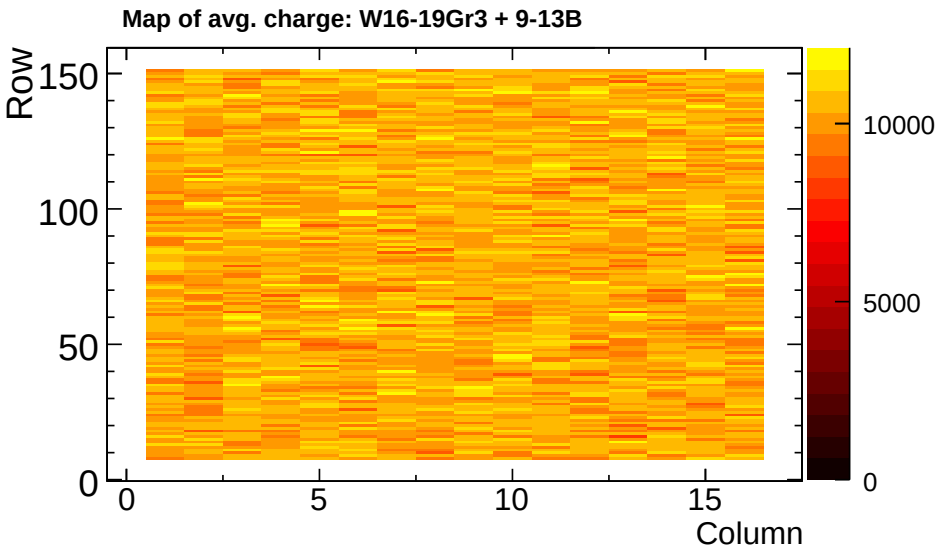
- PC-to-VME interface
- CERN ATLAS Pixel Group setup

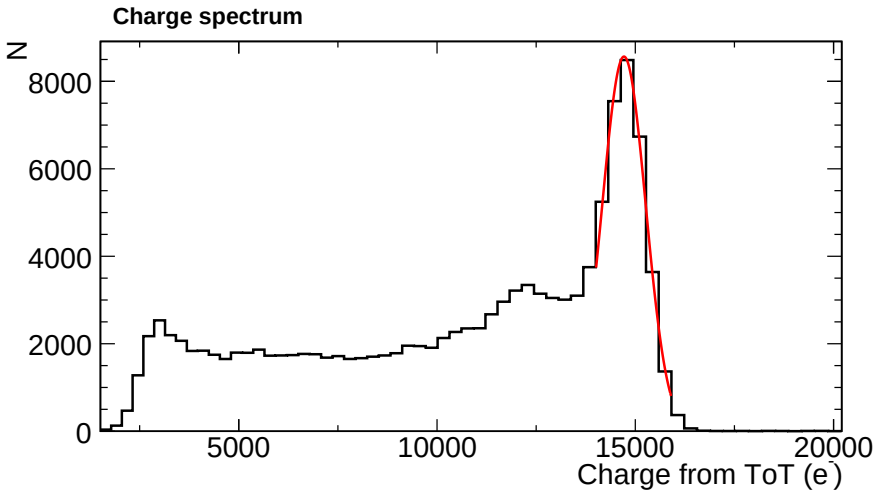
USBPix



- Modular system with USB interface
- Readout based on ATLAS software → reusability

^{241}Am Measurements





Setup:

- ^{241}Am source illuminating full detector
- Internal FE-I3 trigger
- Not irradiated
- TurboDAQ setup

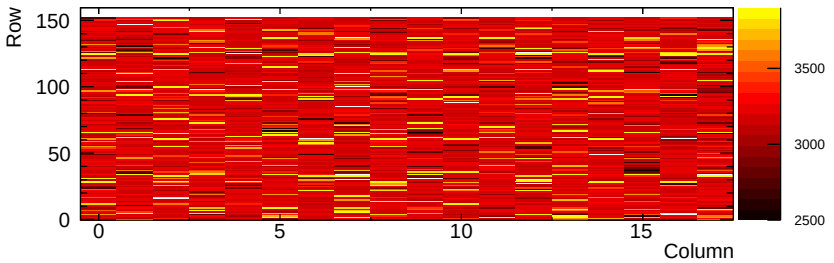
Result:

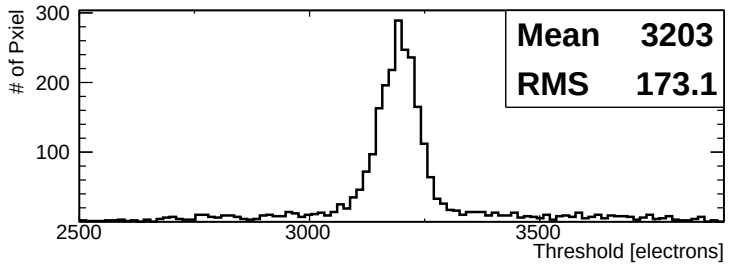
- Nice resolution of spectrum
- 59.5 keV γ-line seen at 14.7 ke$^-$
- 10–15 % uncertainty from TOT-calibration

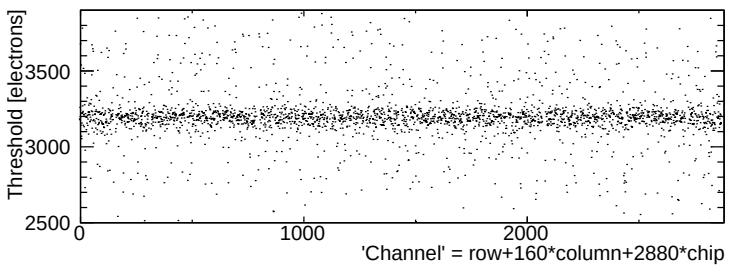
Tuning for Highly Irradiated Sample

Good tuning for the $5 \cdot 10^{15}\ n_{eq}/cm^2$ sample at -60 °C

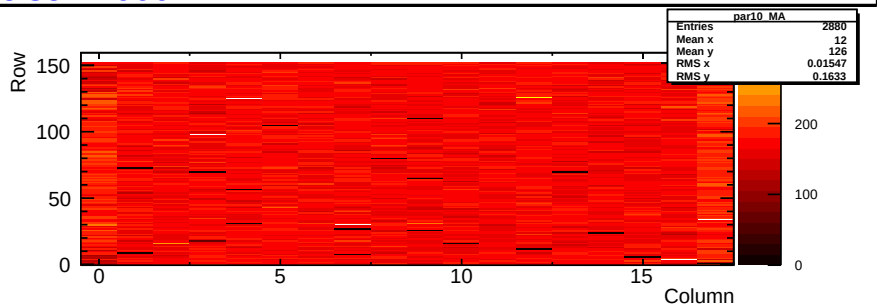
Threshold - 1000V

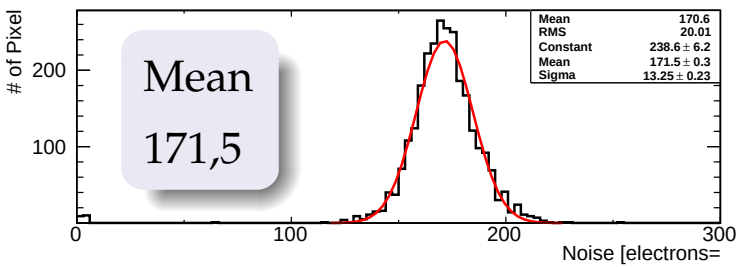


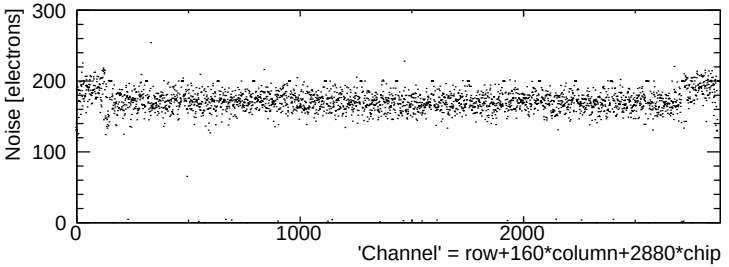




Noise - 1000V

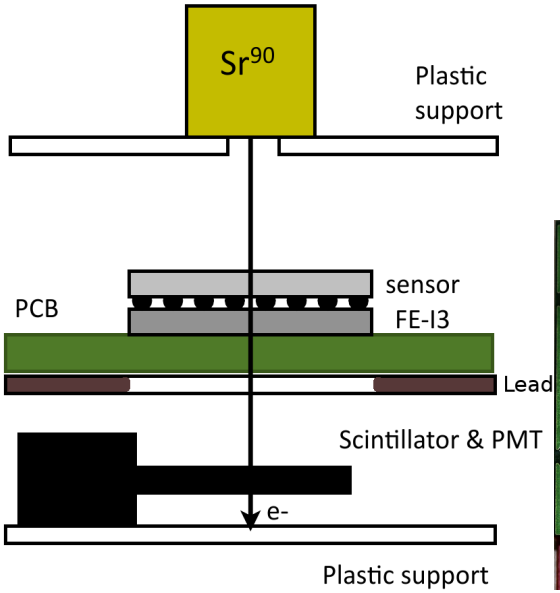


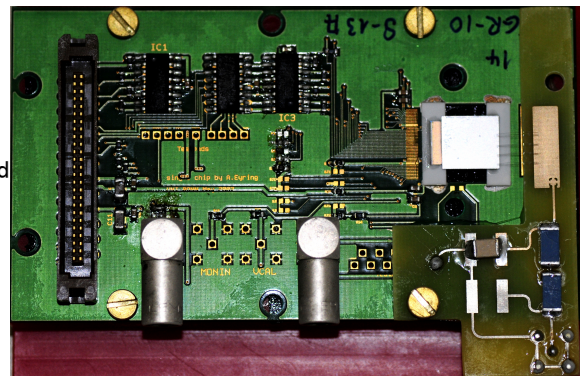




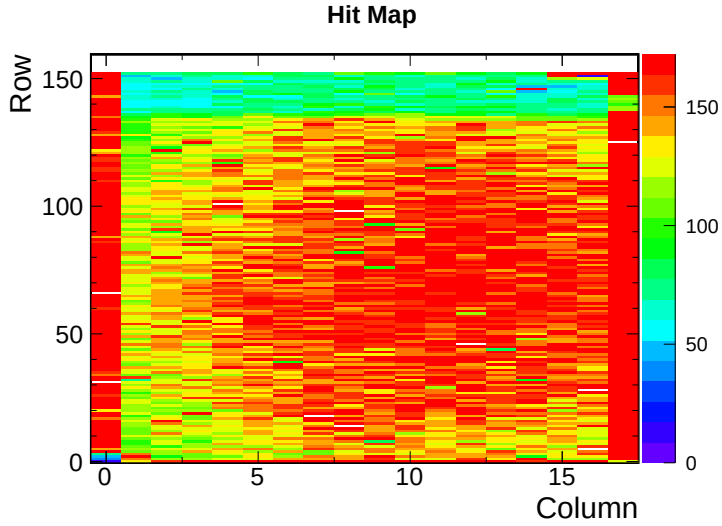
^{90}Sr-Measurement

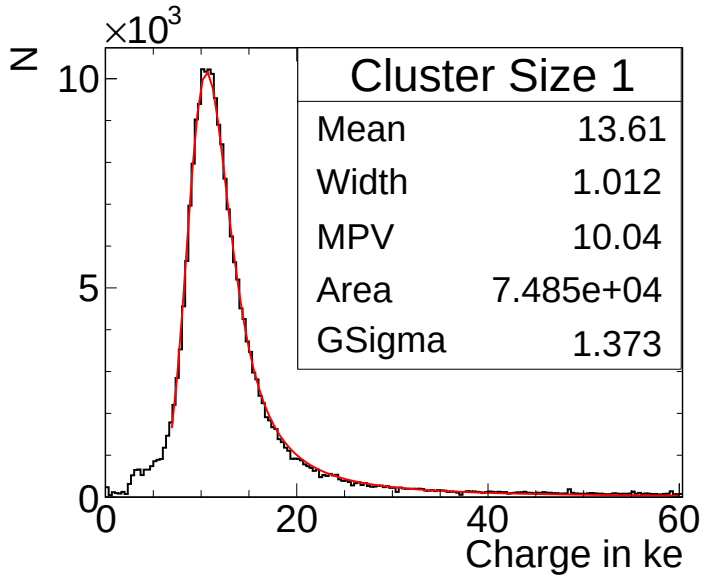
- ^{90}Sr source is used for charge collection measurement.
- External trigger via scintillator.
- Measurement done for fluences up to $5 \cdot 10^{15}\,n_{eq}/cm^2$, 1000 V
- Events with two independent clusters are discarded $\rightarrow$ removes noise





$5 \cdot 10^{15}\,n_{eq}/cm^2$, 1000 V



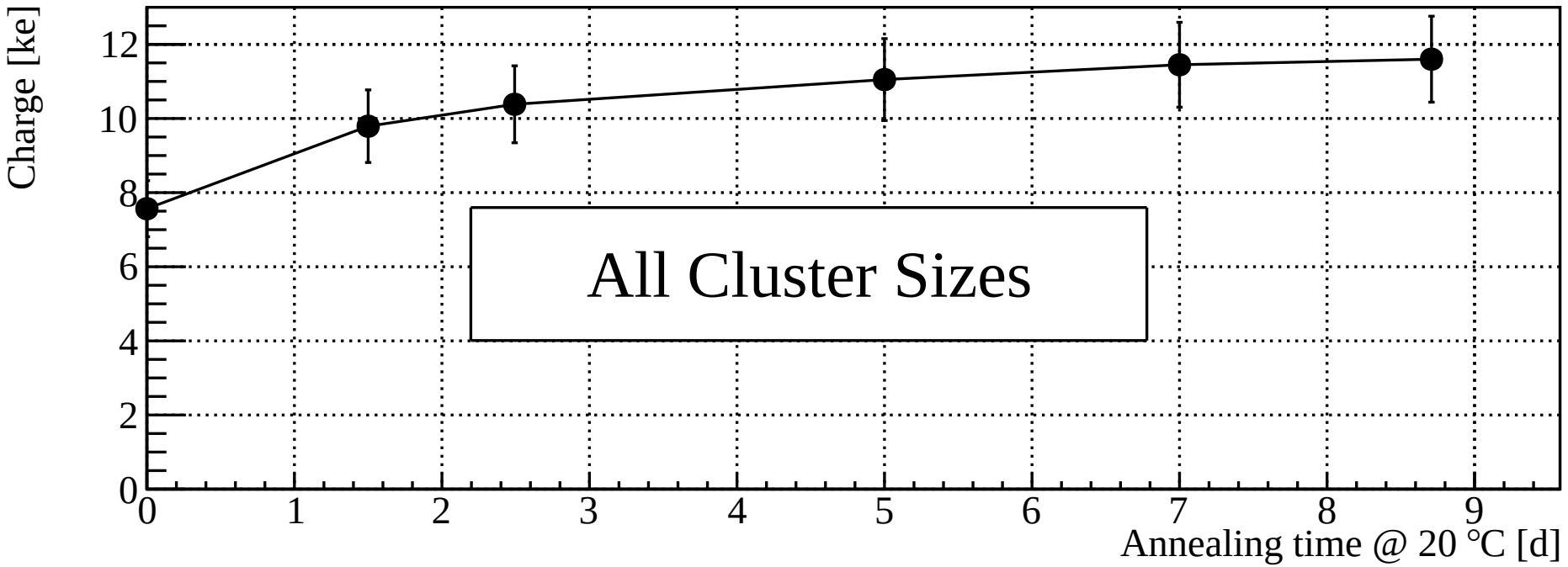


Proton Irradiated Sample - Annealing

Proton irradiation at KIT possible with SCM mounted on card $\rightarrow$ no/minimal annealing due to handling (gluing, bonding) after irradiation.

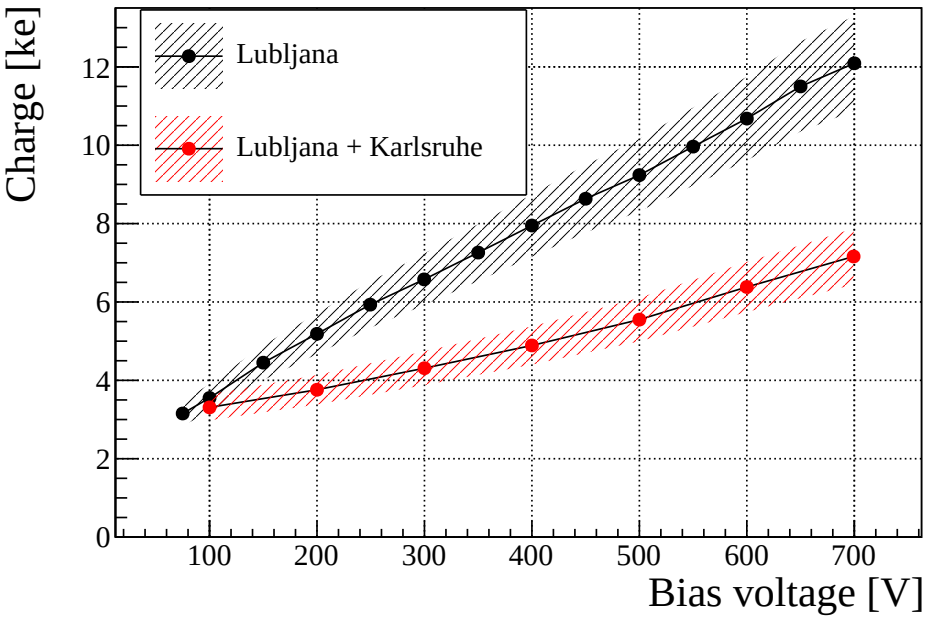
One SCM was irradiated to $10^{15}\,n_{eq}/cm^2$ with $E = 25\,MeV$ p. in Karlsruhe

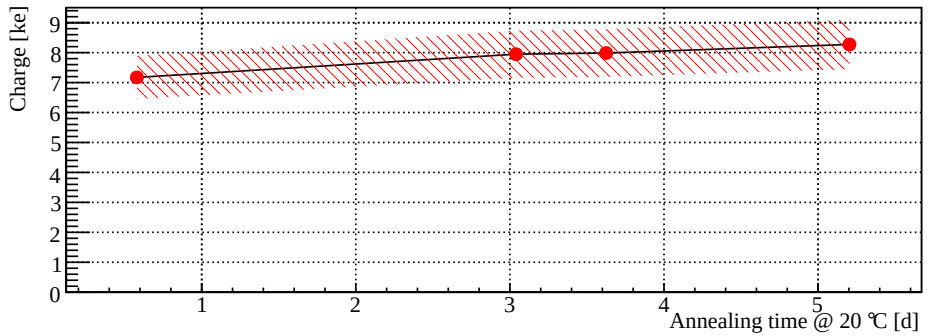
Around 25 % of the collected charge recovers within 9 days at room temperature. As expected biggest effect in the beginning.



Mixed irradiation

One SCM was irradiated 2x: $10^{15}\,n_{eq}/cm^2$ (LJ) + $10^{15}\,n_{eq}/cm^2$ (KA)

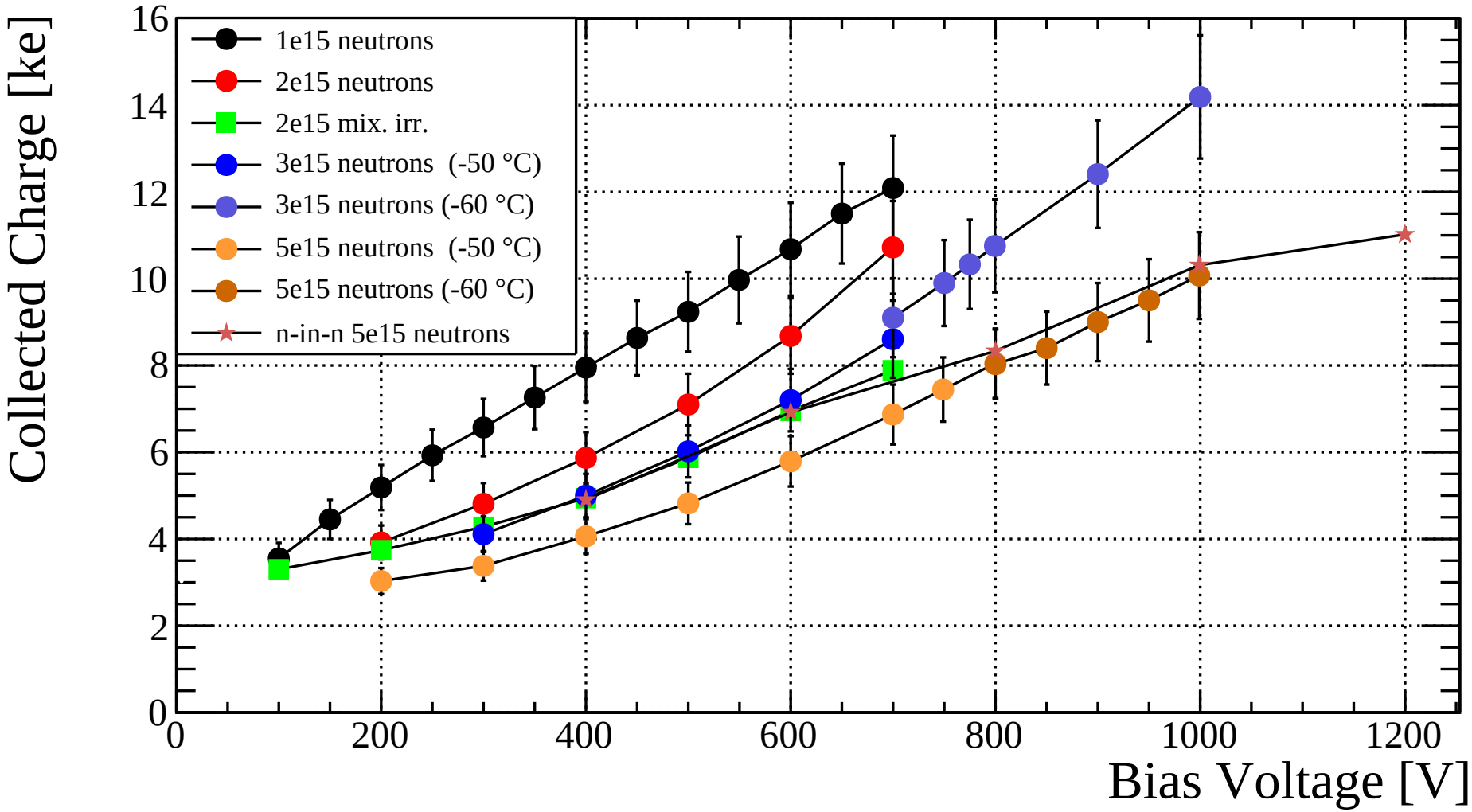




- Sufficient charge collection after irradiation
- Measurements at higher voltages limited by HV capabilities of Bonn-board
- Compared to not irradiated sensors the collected charge at 700 V is
  - ∼65 % after irradiation in Ljubljana
  - ∼39 % after both irradiations
- Low noise between 100 and 120 e^-

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

Collected Charge (Overview)

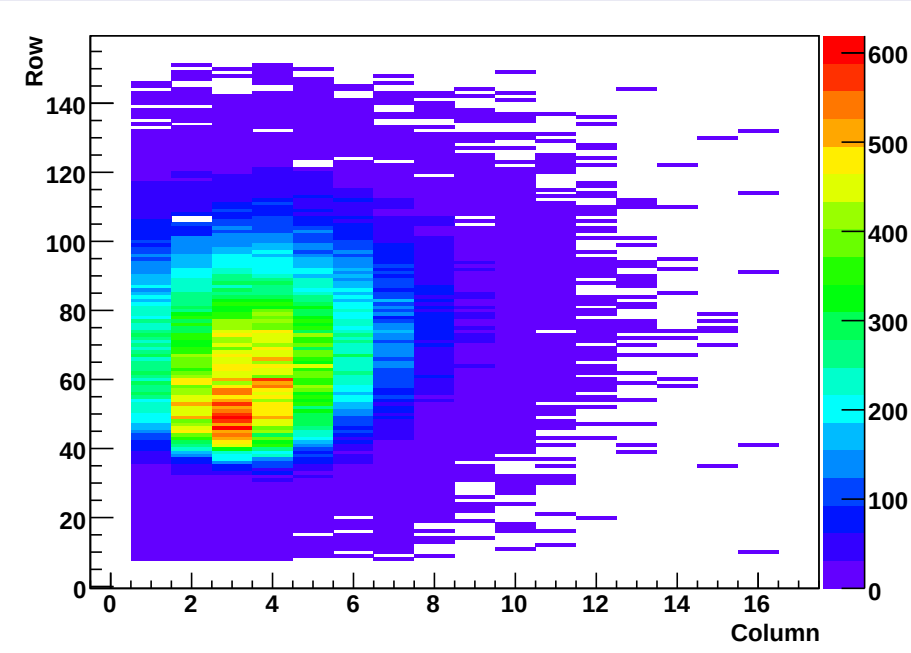


All neutron samples got annealing of around 2 days due to mounting back to cards after irradiation. Highest leakage currents $\sim 5\,\mu$A. n-in-n sample measurements by A. Rummler.

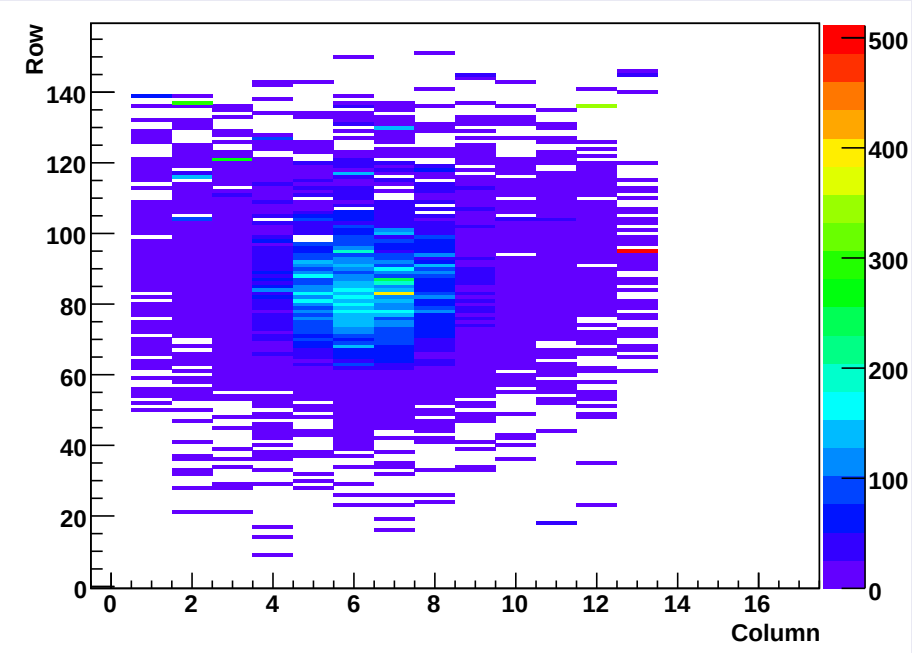
PS irradiation

Temperature -20 °C ⇒ Only tested up to 200 V till now.

$2.8 \cdot 10^{15}$ n_{eq}/cm^2



$5 \cdot 10^{15}$ n_{eq}/cm^2

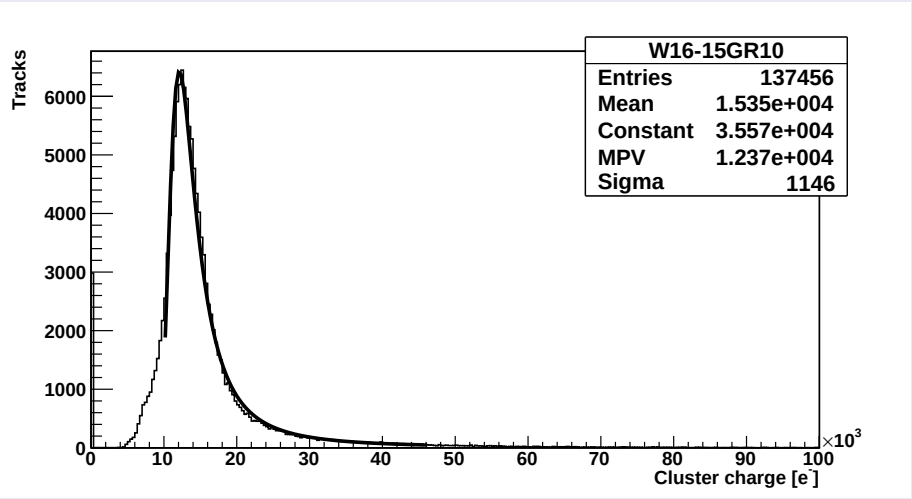


Tuning worked fine, no dead pixels in collimator region. CCE measurements need cooler environment, provided by new climate chamber.

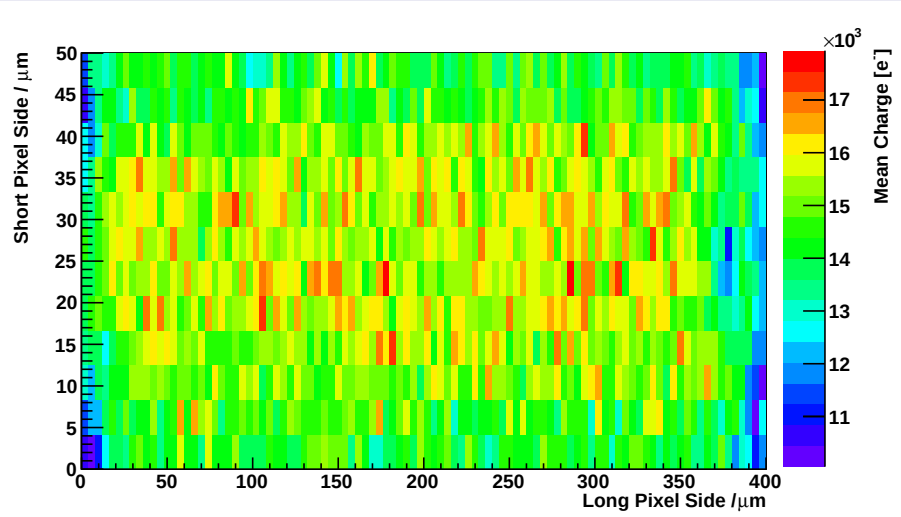
Proton Irradiated Sample - Testbeam results (prelim.)

- Run at 500V with a fluence of $10^{15}\,n_{eq}/cm^2$
- Collected charge in agreement with lab measurements
- Good charge collection in the whole sensor area

Collected charge



Collected charge by track position



Testbeam-Group July/Oct 2010: M. Beimforde, M. Benoit, M. Bomben, G. Calderini, Ch. Gallrapp, M. George, S. Gibson, S. Grinstein, Z. Janoska, J. Jentzsch, O. Jinnouchi, T. Kishida, A. La Rosa, V. Libov, A. Macchiolo, G. Marchiori, D. Muenstermann, R. Nagai, G. Piacquadio, B. Ristic, I. Rubinskiy, A. Rummler, D. Sutherland, Y. Takubo, G. Troska, S. Tsiskaridze, I. Tsurin, Y. Unno, P. Weigell, J. Weingarten, T. Wittig

Summary and Plans

Summary

- SCM irradiated up to $5 \cdot 10^{15}\,n_{eq}/cm^2$ were measured up to 1000 V.
- Stable operation at 1000 V for several hours.
- Charge collection for voltages higher than 600 V well above threshold (3.2 ke) up to $5 \cdot 10^{15}\,n_{eq}/cm^2$.

Plans

- Finish measurements for CERN PS irradiated samples.
- Extend fluence to $10^{16}\,n_{eq}/cm^2$, sample irradiated last week in Ljubljana.
- Put $5 \cdot 10^{15}\,n_{eq}/cm^2$ and $10^{16}\,n_{eq}/cm^2$ sample into testbeam.
- Extend the testbeam analysis.
- Gamma source scans for irradiated samples.