Planar Pixel Sensors for the ATLAS Upgrade

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for the
PPS Collaboration
&
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6th "Trento" Workshop
Trento, March 2011

$\Delta p \cdot \Delta q \geqslant \frac{1}{2}\hbar$

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

PPS Collaboration for the ATLAS Pixel Upgrades

Planar pixel technology is likely to play an important role in the upgrades:

- Proven technology with the current n-in-n pixel detector.
- Radiation limit for the current ATLAS detector proven for n-in-n up to $\phi = 2 \cdot 10^{15}\ \mathrm{n_{eq}/cm^2}$.
- For large areas potential for a cost reduction in fabrication with n-in-p.

PPS Main Research Directions:

- Radiation damage studies
- Active area optimization and geometry redesign
- Low-cost module production
- Advanced simulation studies

PPS Collaboration Members

PPS has members from the following institutes:

- CERN
- AS CR, Prague (Czech Rep.)
- LAL Orsay (France)
- LPNHE / Paris VI (France)
- University of Bonn (Germany)
- HU Berlin (Germany)
- DESY (Germany)
- TU Dortmund (Germany)
- University of Göttingen (Germany)
- MPP & HLL Munich (Germany)
- Università degli Studi di Udine – INFN (Italy)
- KEK (Japan)
- IFAE-CNM, Barcelona (Spain)
- University of Liverpool (UK)
- UC Berkeley/LBNL (USA)
- UNM, Albuquerque (USA)
- UCSC, Santa Cruz (USA)

Higlighted institutes have a PPS related talk here in Trento.

PPS - Sensor Productions

Several common sensor productions are conducted within PPS.

- Mainly FE-I3[1] compatible structures
  - CIS, common submission, within RD50 and CMS. Both n-in-n and n-in-p. Completed.
- Mainly FE-I4[1] compatible structures
  - CIS, thin n-in-n (150 μm to 250 μm). Completed.
  - CIS, IBL n-in-n sensor pre-production (200 μm or 250 μm). Just started.
  - HPK, thin n-in-p (150 μm). Completed.
  - Micron, n-in-n and thin n-in-p (150 μm). On-going.
  - HLL, thin n-in-p (150 μm). Completed.

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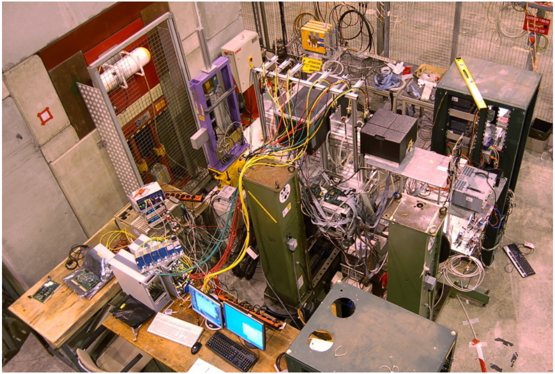
PPS - Testbeam Activities

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

- 5 weeks of beamtime in 2010
- SPS beamline (H6)
- O(40) samples from Barcelona, Dortmund, Munich, KEK, Liverpool
- Results will be shown in this workshop by Y. Unno, A. Rummler, A. La Rosa



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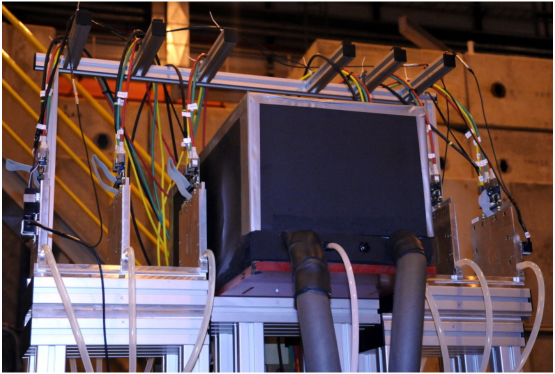

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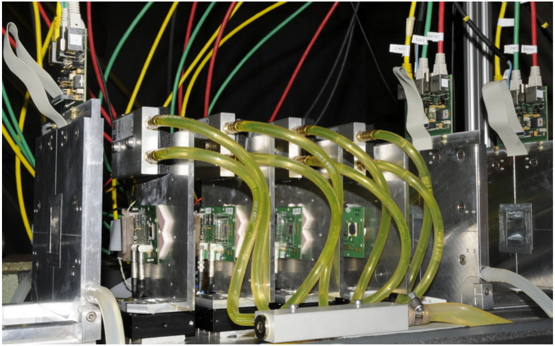
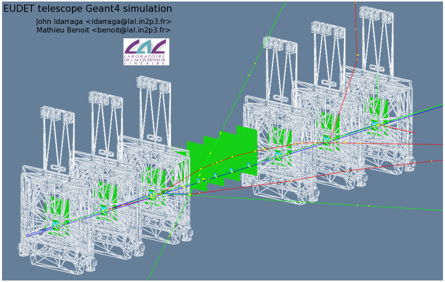
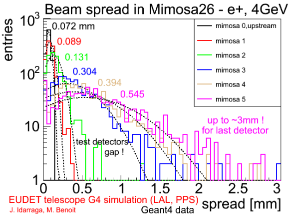


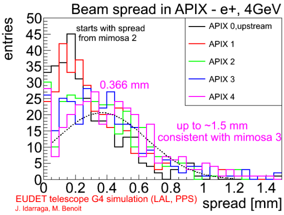
PPS - TB Simulation

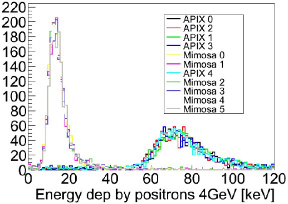


Full Geant 4 simulation of the test beam is being set up.

- Geometry is now in
- First results:
  - Widening of beam due to Devices under test
  - Charge deposition of positrons

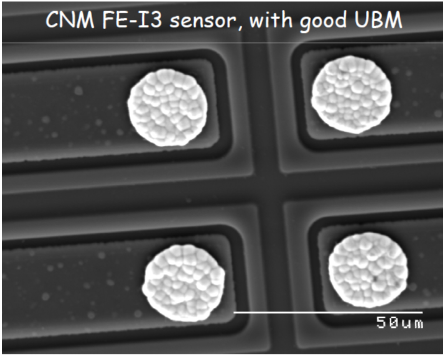




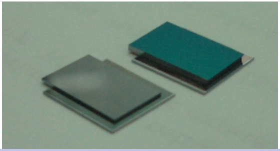


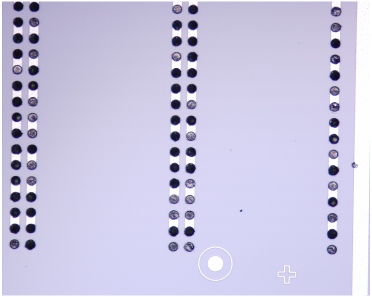
PPS - Low Cost Under Bump Metallization

UBM application on sensors through galvanic deposition (IZM) –reliable, expensive
Possible alternative: electroless processes (CiS, CNM) –less (?) reliable, but cheaper (?)


CNM FE-I3 sensor, with good UBM

S. Grinstein (IFAE) - PPS Meeting Munich





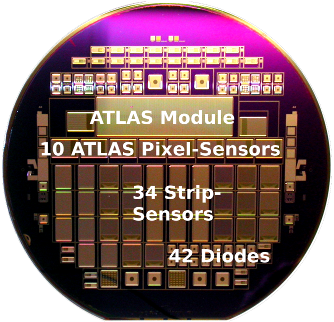
First test with FE-I4 sized daisy chains at IFAE/CNM yield efficiencies above >99 % (disregarding systematic effects in the corners)

Performance of Thin n-in-p Pixel Detectors

1. MPI-HLL Production and Thinning method
2. CCE Measurements with ^{90}Sr Source
3. Characterization with TCT
4. Summary

Thin Pixel Production at MPP/HLL

12 × 6″ Wafer

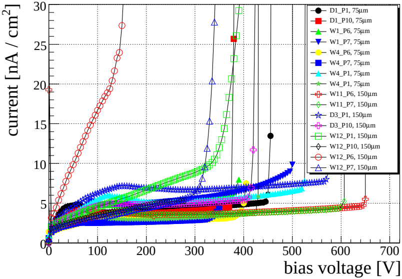


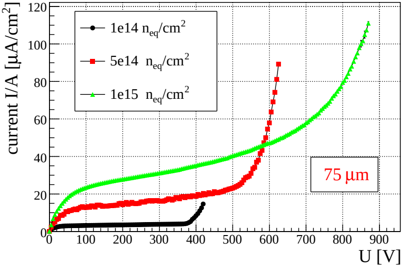
- Four n-in-p wafers of 150 µm and eight (4×n-in-p & 4×n-in-n) wafers of 75 µm active thickness (on handle wafer)
- Proton & neutron irradiations with fluences up to $10^{16}\,n_{eq/cm^2}$ in Karlsruhe (25 MeV), CERN PS (24 GeV) & Lubljana (reactor)

1. Implant backside on sensor
2. Bond sensor wafer to handle wafer
3. Thin sensor side to desired thickness
4. Process on top side
5. Structure resist, etch backside up to oxide

Characterization of the Sensors Irradiated up to 10^{15} n_{eq}

n-in-p Pixel





- Very good yield: 79/80. Before irrad.: low leakage currents $<10\,\mathrm{nA/cm^2}$, very good breakd. behaviour $V_{\mathrm{break}} \gg V_{\mathrm{depl}}$
- As expected all structures showed improved breakdown behaviour after irradiation: $V_{\mathrm{break}} \gg V_{\mathrm{depl}}$
- Annealing decreases V_{depl}

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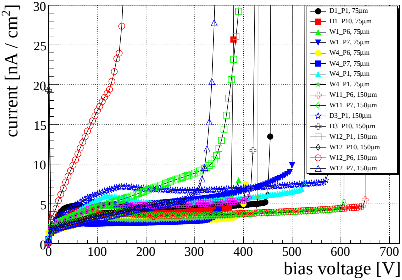

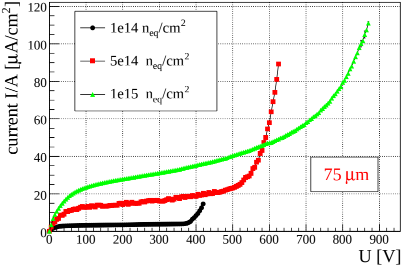

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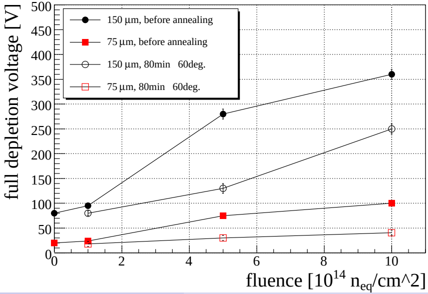
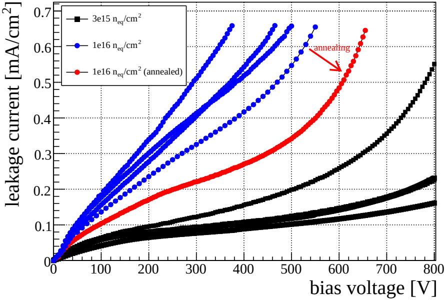
n-in-p Diodes

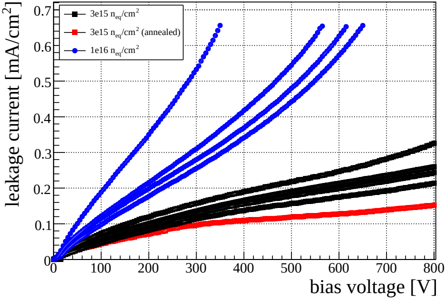


... of the Sensors Irradiated up to $3 \cdot 10^{15}$ n_{eq} & 10^{16} n_{eq}

75 µm



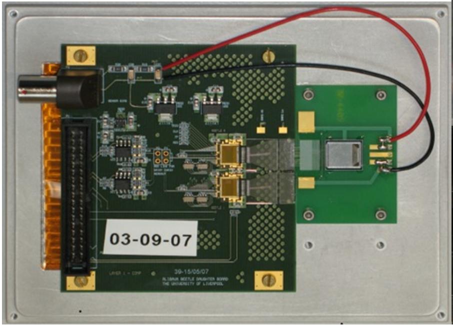
150 µm

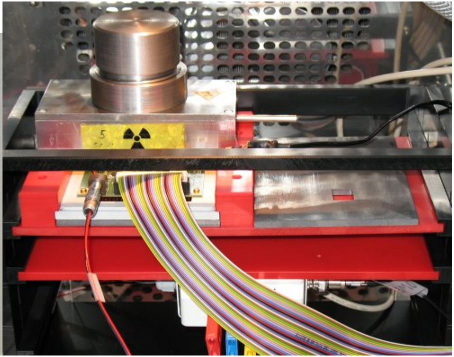


- Four 75 µm & four 150 µm structures were irradiated up to $3 \cdot 10^{15}$ n_{eq} & 10^{16} n_{eq}
- Same trend as for lower fluences (leakage current, breakdown, annealing)

Measurements @ -10°C

CCE Measurements with Alibava - Setup





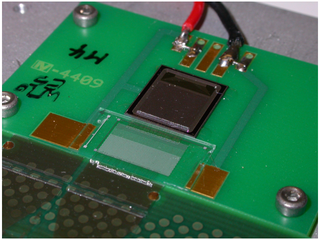
- CCE measurements on pixels only possible after interconnection of sensor and ATLAS read-out chip (in preparation)
- CCE meas. on irradiated strips, from the same production, (75 & 150) μm, are on-going with the ALIBAVA system (40 MHz) and a ^{90}Sr source.
- The strip sensors used in these measurements have exactly the same design as the pixels (punch-through biasing, DC coupling) with the exception of the length (7 mm)

Decoupling Pitch Adapters

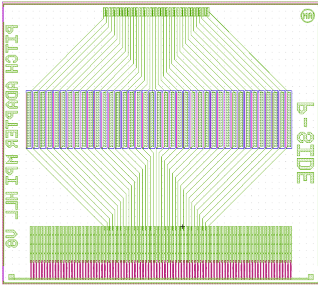
DC-Coupling of strips leads to high currents

- Danger to destroy the beetle chip
- Change of gain

Solutions



Pitch adapter with capacity and resistor to achieve an AC-coupling. Designed and produced by the Helsinki group: Dielectric layer on glass substrate.

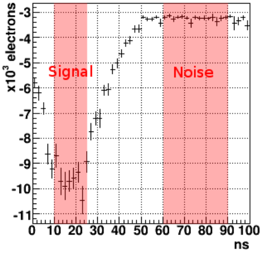


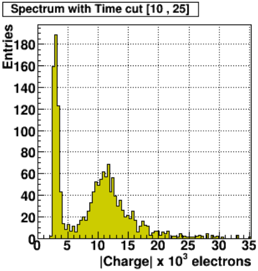
Second design in silicon integrated into an ongoing n-in-n pixel production at CIS (PPS ATLAS group).

CCE Measurements with Alibava - Software

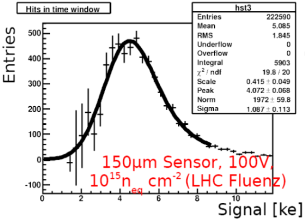
Determination of CCE

Time window to determine signal, another window to determine noise.
Example spectrum for 150 μm thick sensor irradiated up to 3×10^{15} n_{eq} @975 V:

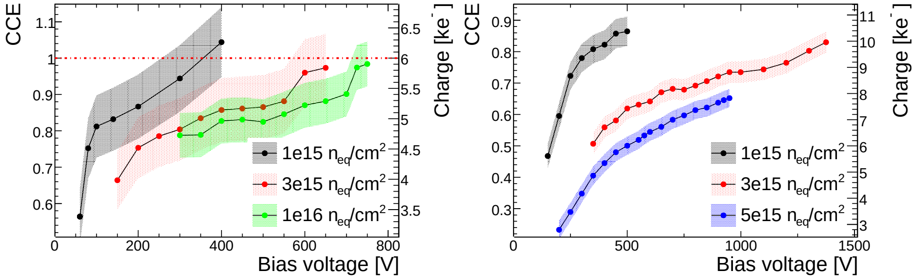




For lower voltages signal shifts to lower values. The procedure works nonetheless:
Example spectrum for 150 μm thick sensor irradiated up to 10^{15} n_{eq} @100 V:



CCE Measurements with Alibava

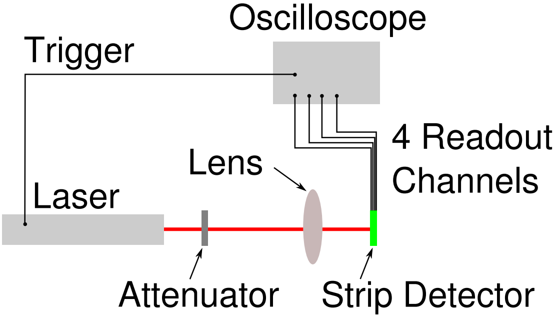


- After irradiation: Signal considerable higher than expected from simulation.

75 µm	Signal height recovered within uncertainties
150 µm	Signal height lower than before irrad. (Higher voltages needed)

- Uncertainties correspond to 500 e^-, estimated for each point.
- Measurements before any intentional annealing: T=-30 °C ($\phi = 10^{15}\ \mathrm{n_{eq}/cm^2}$); T=-40 °C & T=-45 °C ($\phi = (3-10)\cdot 10^{15}\ \mathrm{n_{eq}/cm^2}$); T=-50 °C ($\phi = 5 \cdot 10^{15}\ \mathrm{n_{eq}/cm^2}$).

Transient Current Technique (TCT) Setup in Hamburg



IR-Laser with 1052 nm and $\sigma_{\mathrm{Beam}} = 3\,\mu\mathrm{m}$.
Attenuation length in Si is 900 μm
Cooled via Peltier to -20 °C and flushed with nitrogen.
15 channels are grounded, four are read out.

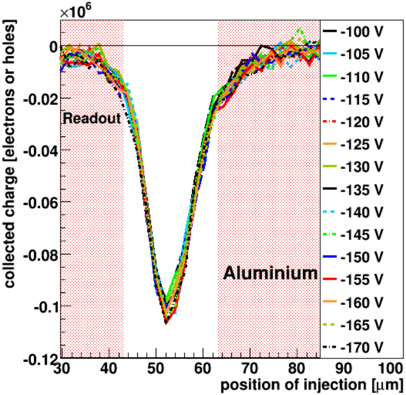
Studied strip sensors

Thickness d=75 μm and 50 μm pitch.
One sample not irradiated (calibration) and one irradiated in Karlsruhe to $10^{15}\,\mathrm{n_{eq}/cm^2}$.

Thanks to Th. Pöhlsen, E. Fretwurst, R. Klanner (University of Hamburg) and the Helmholtz Alliance

Not Irradiated Sensor

Since the number of charge per unit length is not known a priori an not irradiated sensor is used for calibration.



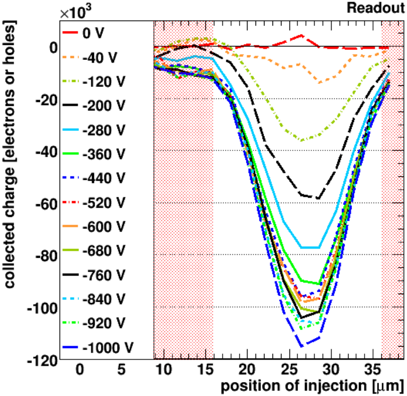
Aluminium on read out strips prevents laser from penetrating ⇒ Only small signal in this region

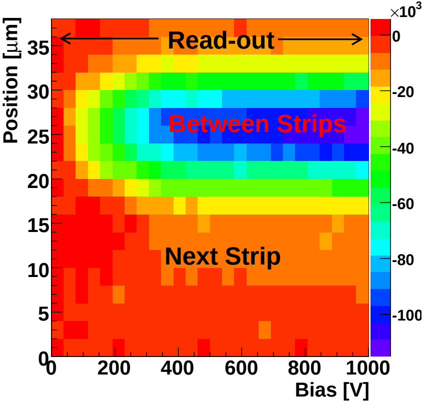
For analysis the channels are treated independently. In the plot, the left channel is read out.

Average of maximum amplitude for fully depleted voltages (>100 V): $-101.7\,\mathrm{ke}^-$ as normalization.

Proton Irradiated sample

Sample irradiated to $10^{15}\,\mathrm{n}_{\mathrm{eq}/\mathrm{cm}^2}$ in Karlsruhe.[1]





Maximum values are used as a measure of charge.

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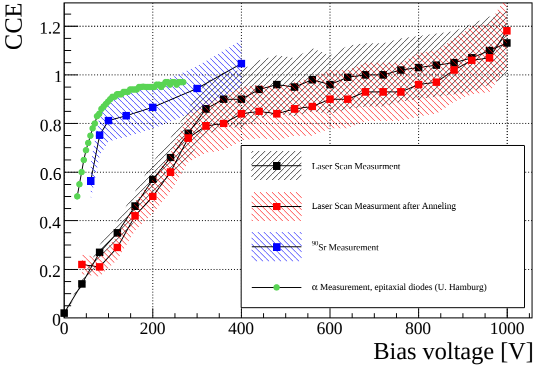
[1] Thanks to Alexander Dierlamm and the Helmholtz Alliance

CCE Measurement

In the laser scan case, the CCE is computed as the ratio of the maximum charge values of the irradiated sensors and the averaged maximum of the not irradiated sensor.



- ^{90}Sr Measurement agrees with depletion voltage determined via C-V
- Both methods yield a CCE slightly above 1
- Annealing for 20 min at 80 °C decreases CCE slightly but does not change general characteristics.

Apparent differences between the two approaches - not yet understood.

α Measurement by Jörn Lange (University of Hamburg), Nucl. Instrum. Meth. A 622 (2010) 49

Summary

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- Measured CCE for sensors irradiated up to $10^{16}\,\mathrm{n_{eq}}$ for 75 µm: Same signal height as before irrad. could be achieved.
- Measured CCE for sensors irradiated up to $3 \cdot 10^{15}\,\mathrm{n_{eq}}$ for 150 µm: Signal higher than expected from simulation but lower than before irradiation.
- Alternative approach via laser scan, results in compatible results, although some characteristics are different.

Plans

- Laser scan for a 150 μm active thickness sensor.
- Measurements with red (660 nm) lasers. (Smaller attenuation length)
- Explore the CCE with the ^{90}Sr to higher fluences and bias voltages.

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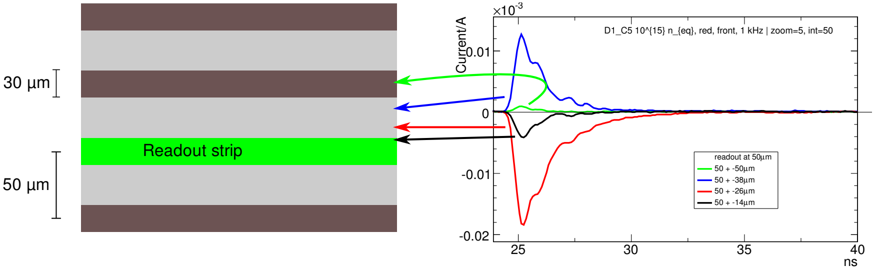
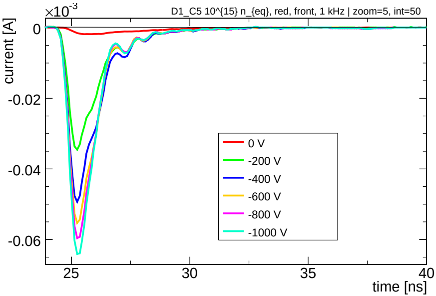
BACKUP

Step-by-step (1)

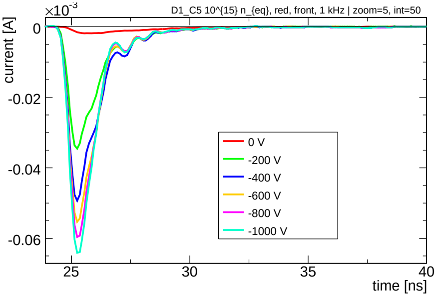


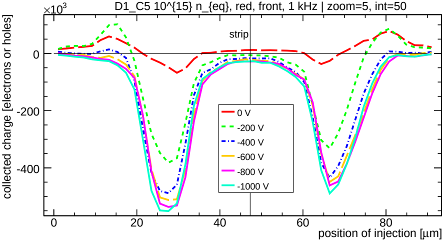


Signal shape depending on position w.r.t readout strip and voltage

- negative signal → electrons are collected
- positive signal → holes are collected, electrons drift to other strip

Step-by-step (2)





Integration over transient gives charge.