Characterization of irradiated passive CMOS sensors for tracking in HEP experiments

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Design

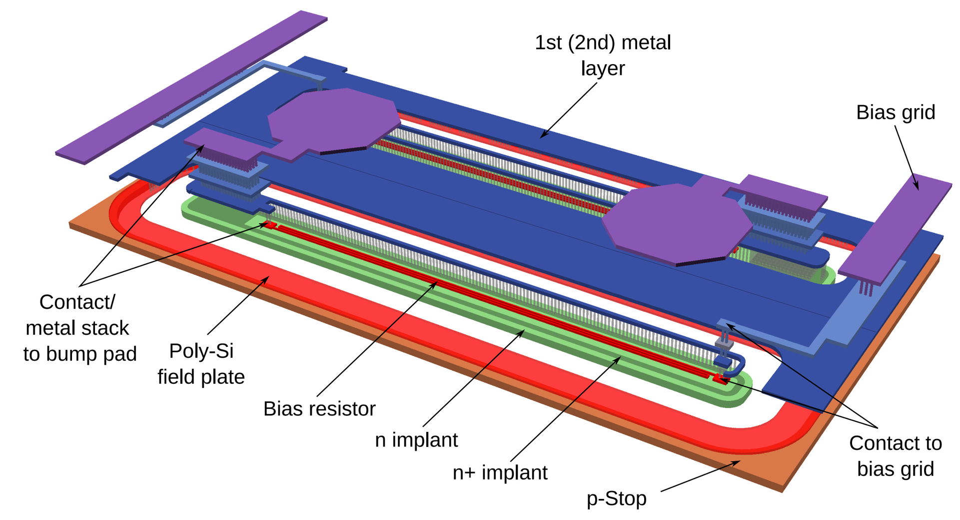
- Planar hybrid n$^+$-in-p sensors with a pixel size of 25x100 μm^2
- The sensors are built in a 150 nm CMOS process for the Phase II upgrade of the CMS Inner Tracker.
- No active components are used (thus passive CMOS sensors).
- Biased using a high resistivity polysilicon layer which allows to measure IV curves of the sensors before flip-chipping.
- CMOS processes give access to new sensor features:
  - Multiple metal layers laid on top of the sensor which can be used for signal redistribution to the ROC.
  - AC-coupled sensors need no leakage current compensation circuit and generate less noise than their DC counterparts.
  - Shielding between the implant and the bump pad to avoid cross-talk.

Current Situation

- → Passive sensors production using contact lithography.
- → Future projects featuring large-area silicon-based tracking detectors.
- → Few large-scale suppliers are available.

Improvements

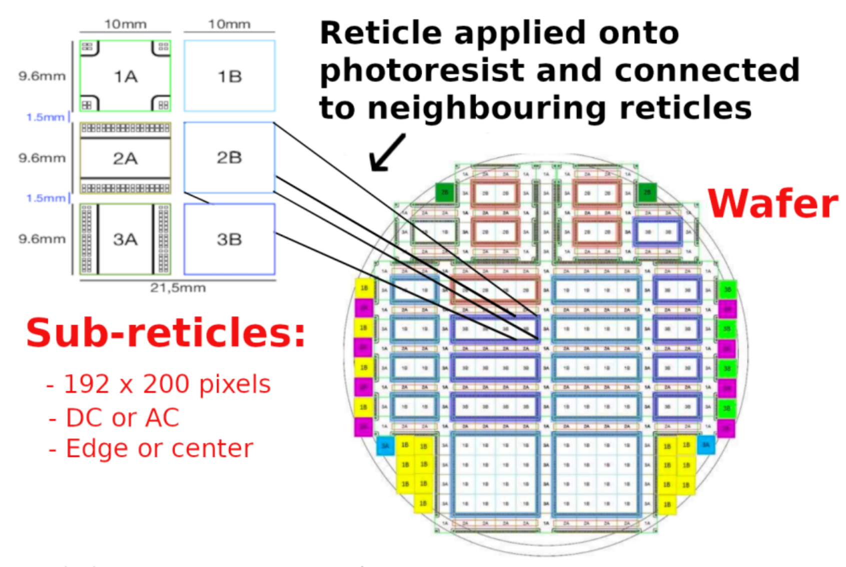
- → Production through CMOS process using stitching (large wafers possible).
- → Potential improvement in throughput and production costs.
- → Access to more industrial vendors.



All sensors were irradiated at the Karlsruher Institut für Technologie using a proton beam

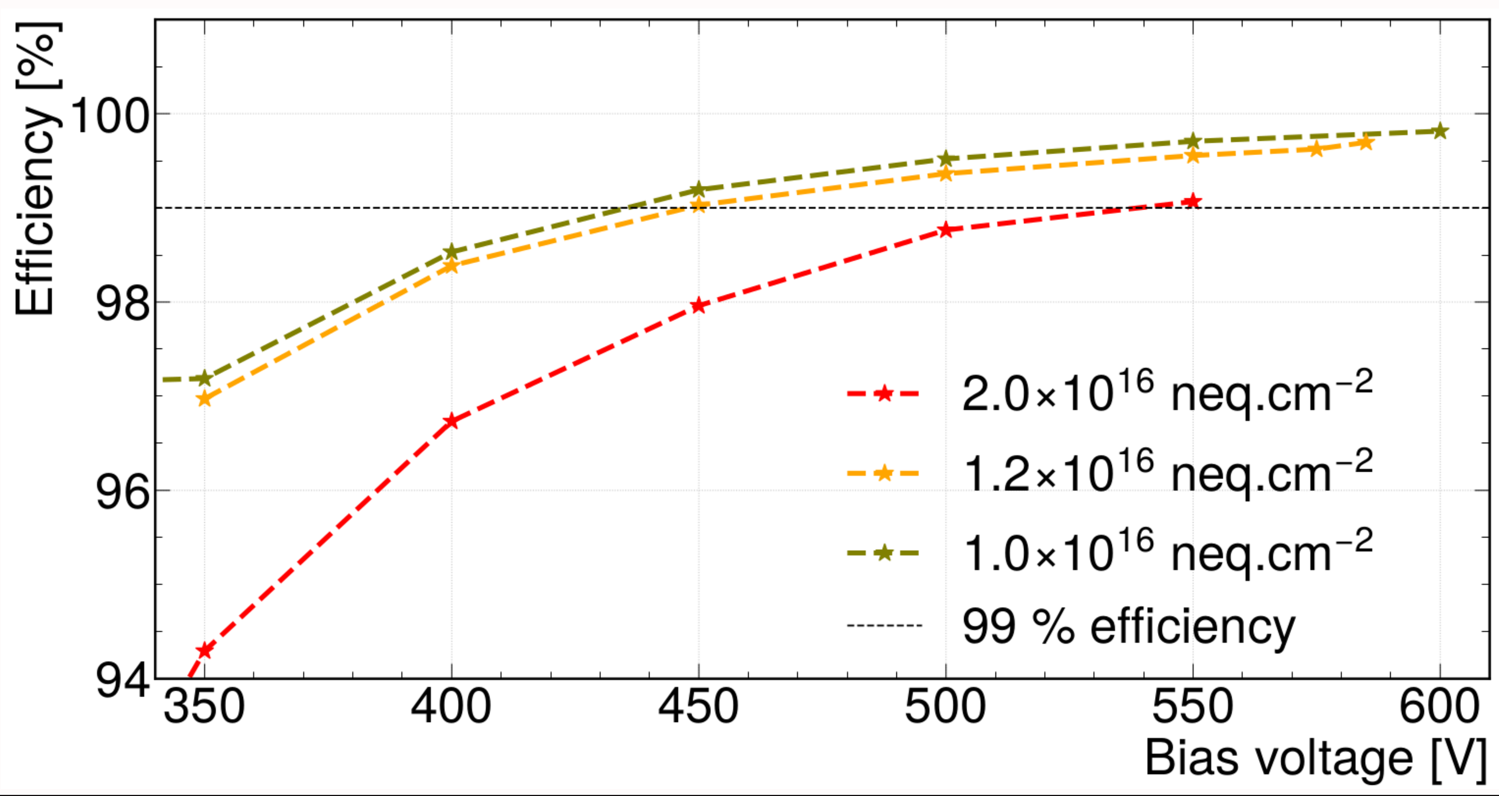
Stitching

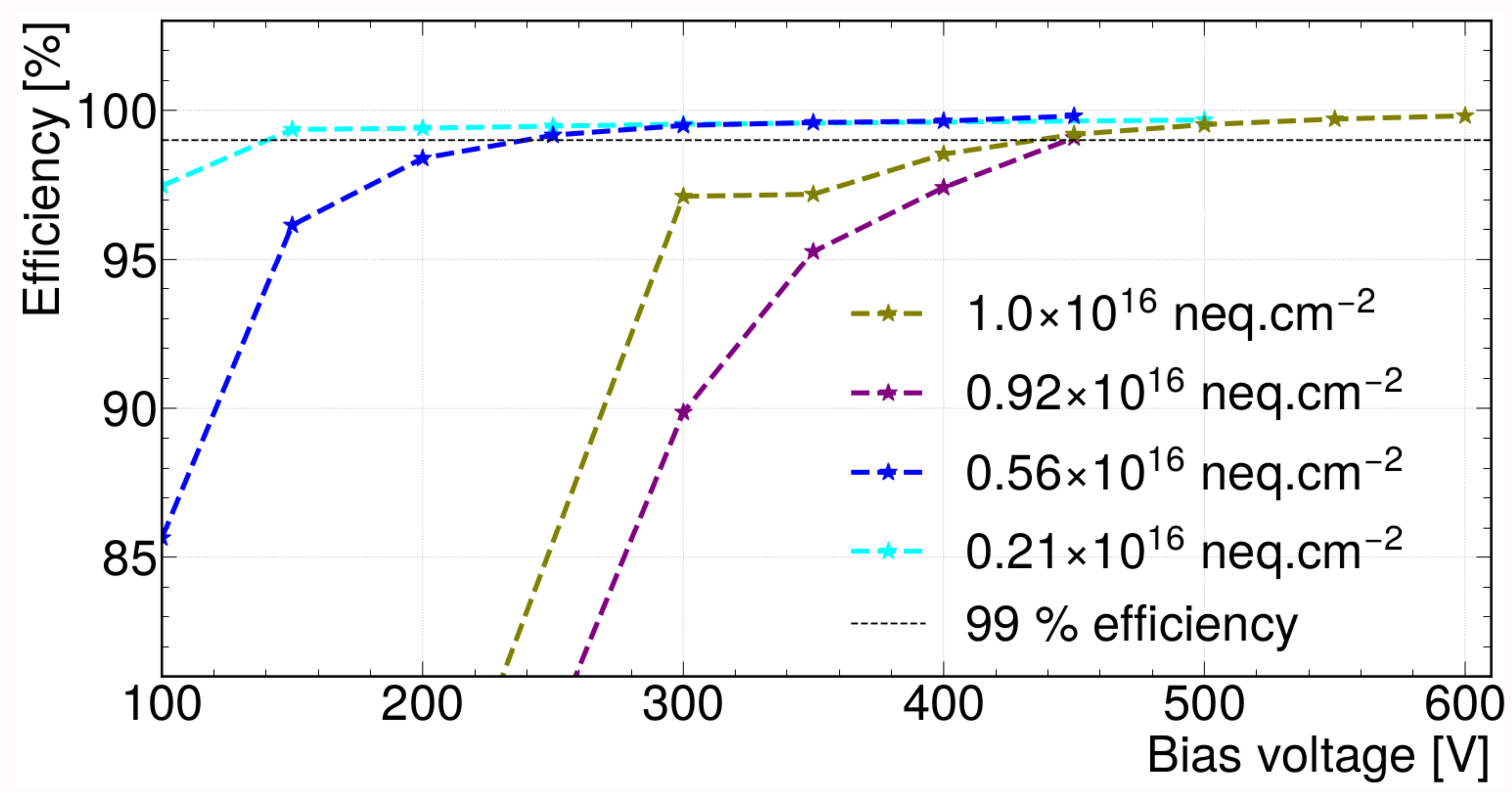
- A small reticle mask is used instead of processing the whole wafer at once.
- Neighbouring areas of a wafer are electrically connected (stitched).
- Sub-reticles (building blocks) define specific areas of the sensor (edge, center, ...).



Efficiency measurements

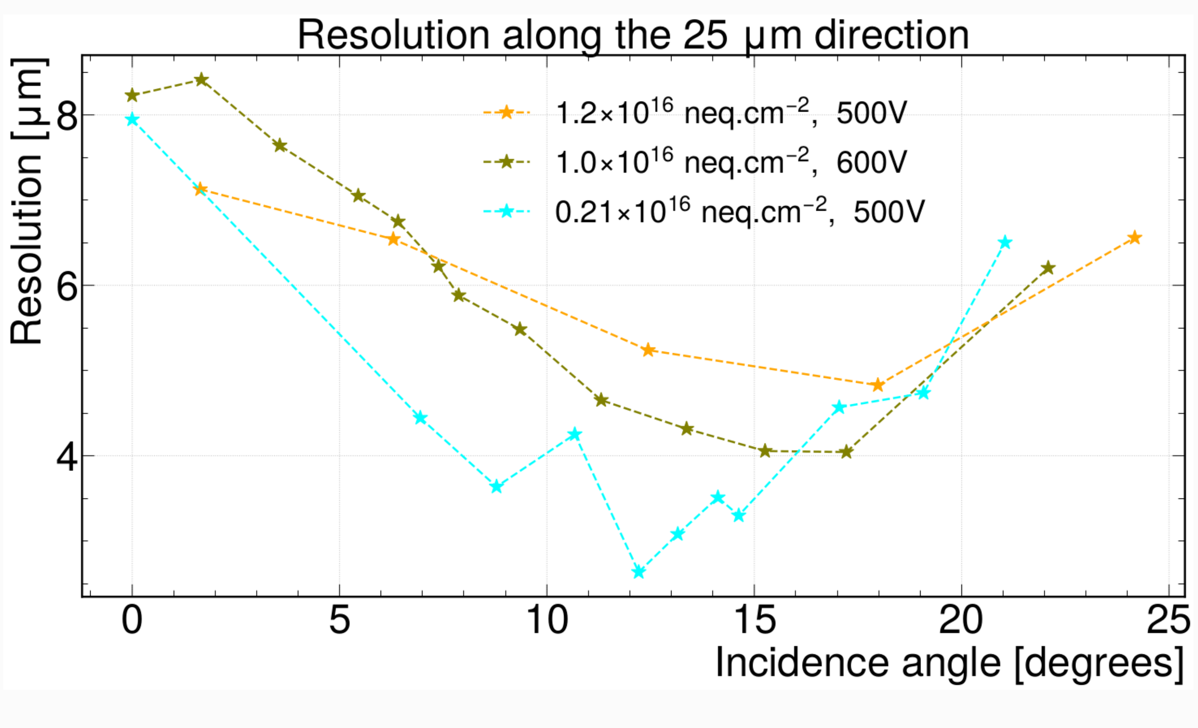
- 99 % efficiency is reached consistently for sensors irradiated up to a fluence of 2×10^{16} neq.cm^{-2} within the required bias voltage interval.
- A total of 4 irradiated sensors were tested in beam, two were further irradiated and tested again.
- Fiducial region cut, timestamp cut, spatial cut and masking of noisy pixels to compare different sensors in different environments (SPS and DESY) consistently.
- 4 additional sensors currently being tested at CERN at irradiation levels of 0.5×10^{16} and 1×10^{16} neq.cm^{-2}





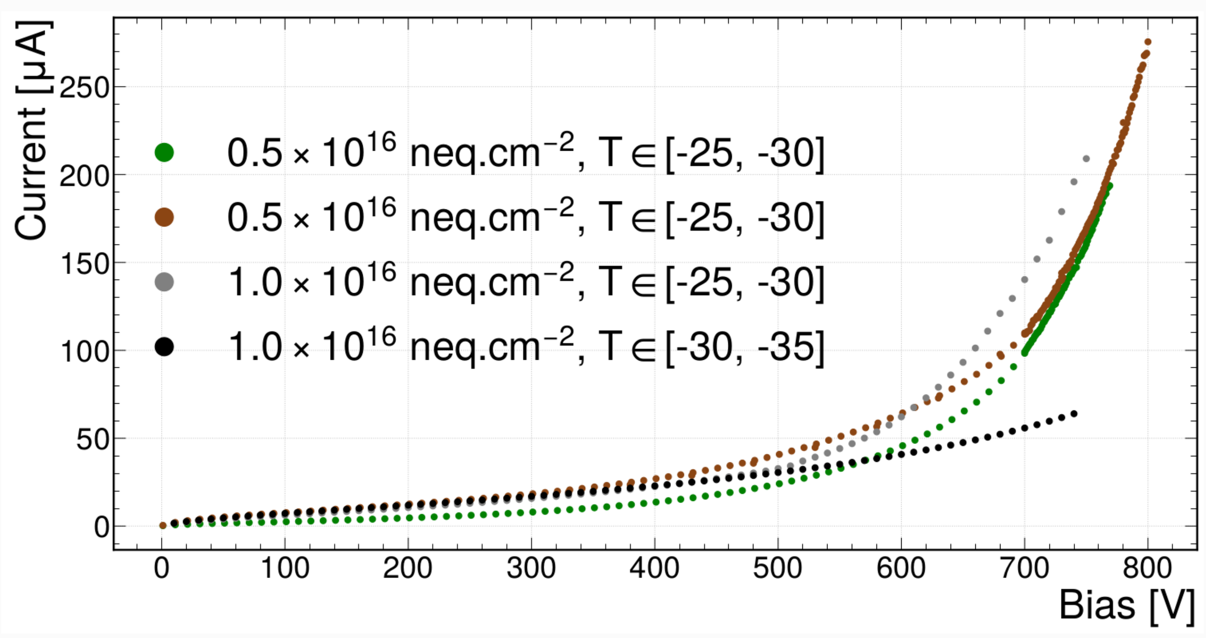
Resolution

- The resolution of the sensor was extracted from a Student's t-fit to the distribution of the residuals.
- The resolution of the telescope was extracted from data and simulation and has been subtracted for the plot.



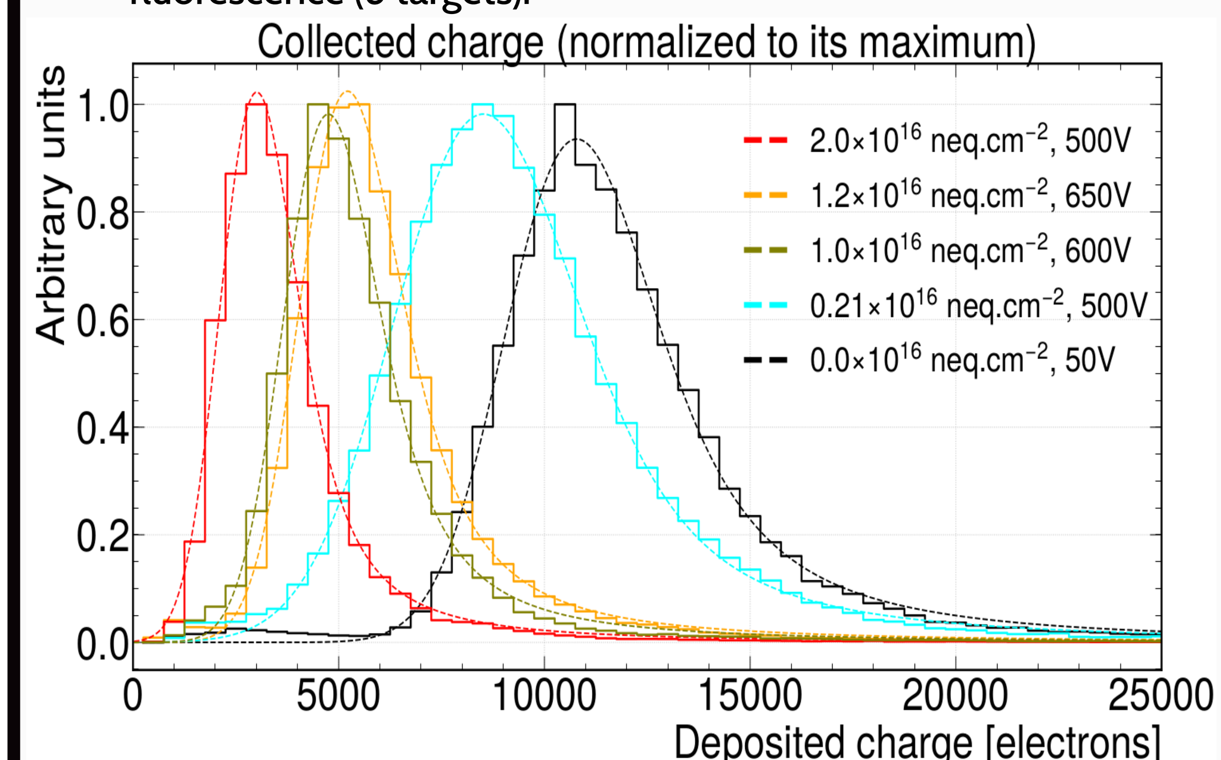
IV measurements

- IV curves were measured for sensors on-chip in a climate chamber at an ambient temperature of -47^{0}C.
- The breakdown voltage is higher than 600 V and was measured on 4 different sensors and for fluences of up to 1×10^{16} neq.cm^{-2}

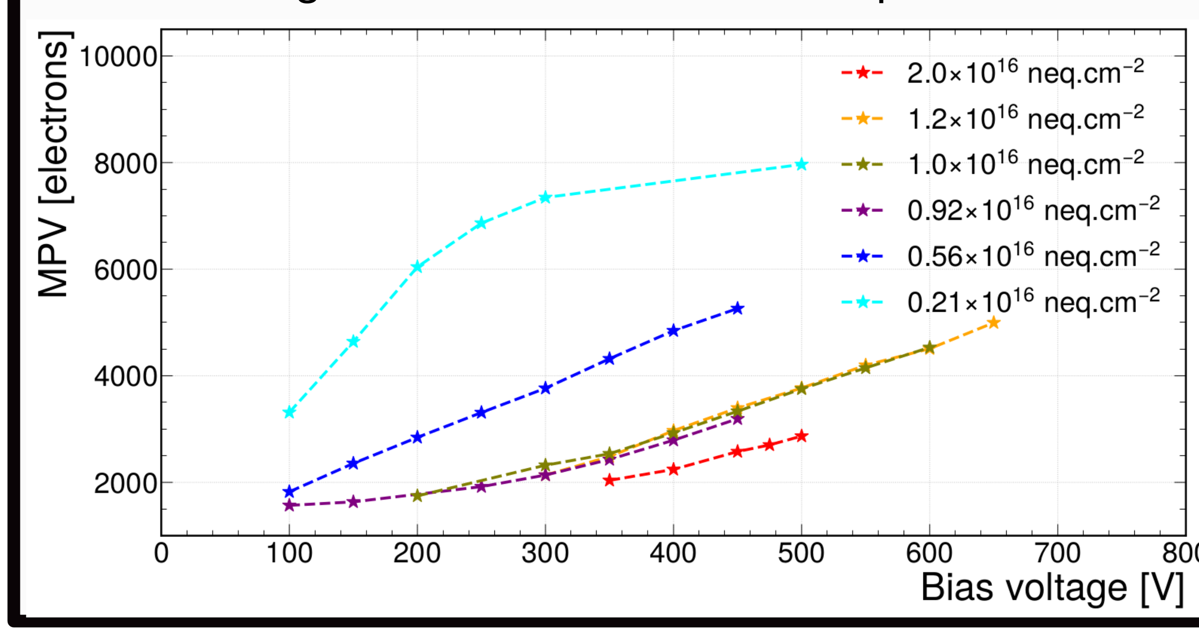


Charge collection

- Pixel charge collection measured in a 4-bit ToT register.
- Charge conversion from ToT to electrons done using x-ray fluorescence (6 targets).

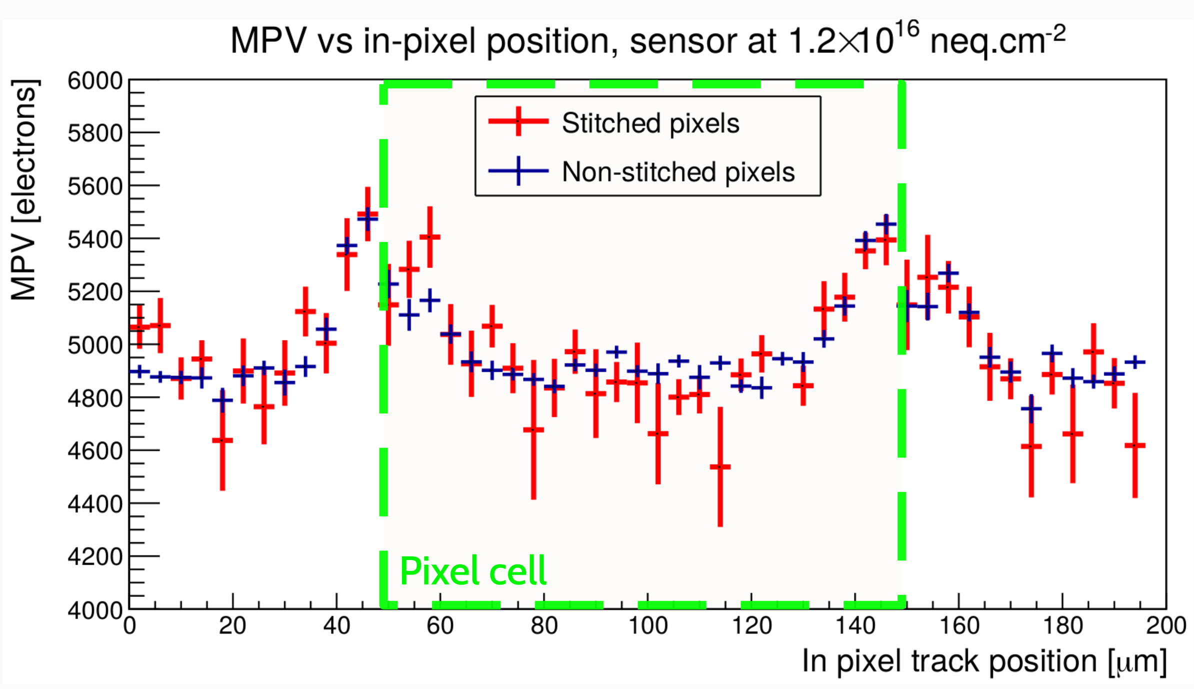


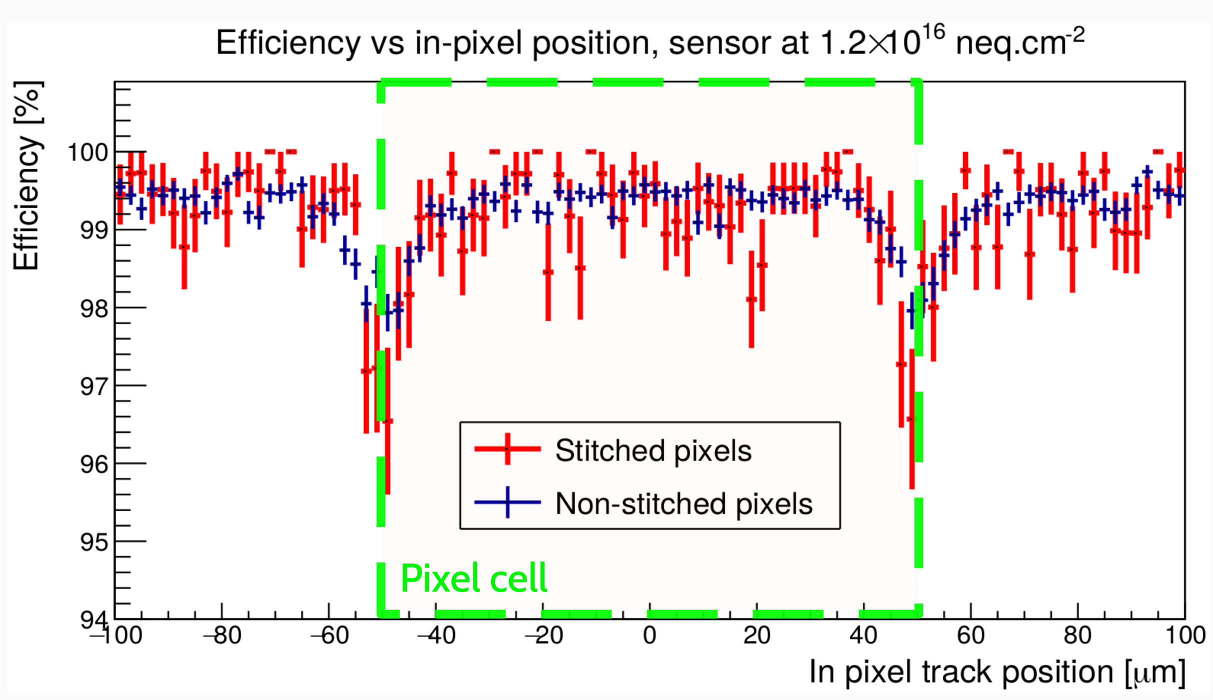
- Fit to charge distribution to obtain the most probable value.



Stitching

- Charge collection in the columns adjacent to the stitching line is indistiguishable from the other columns.
- Per column efficiency in the stitching region shows no difference to the other columns for irradiated sensors.





Outlook

- → Passive CMOS technology is promising in terms of cost and throughput.
- → The performances of the sensors match the requirements for the HL-LHC Inner Tracker Upgrade and are comparable to established technologies.
- → The characterized sensors are considered a candidate for the CMS Phase-2 upgrade.
- → A new submission towards the final pixel module geometry and with increased breakdown voltage is ongoing.