Evaluation of Passive CMOS Strip Sensors

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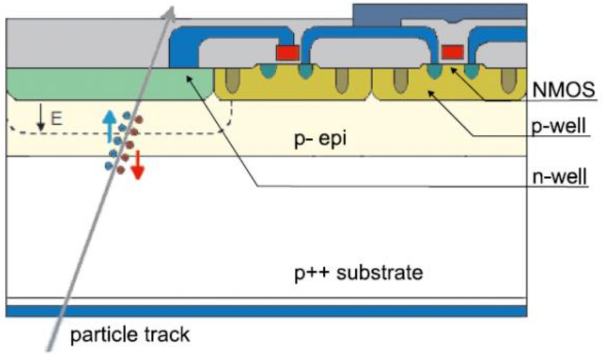
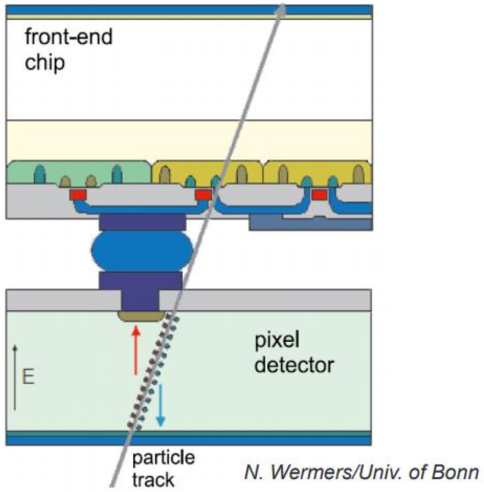
Introduction – Why CMOS?

- All current and envisaged colliders rely on silicon-based detector systems
- CMOS sensors could be optimal to cover large areas at lower cost
  - Commercial processing
  - Large wafer sizes
  - Stitched sensors for larger areas
  - Thin detectors
  - Lower power consumption
- CMOS pixel detectors already installed in ATLAS, CMS and ALICE
  - First study on CMOS strip sensors to possibly cover larger areas



Monolithic Active Pixel Detector



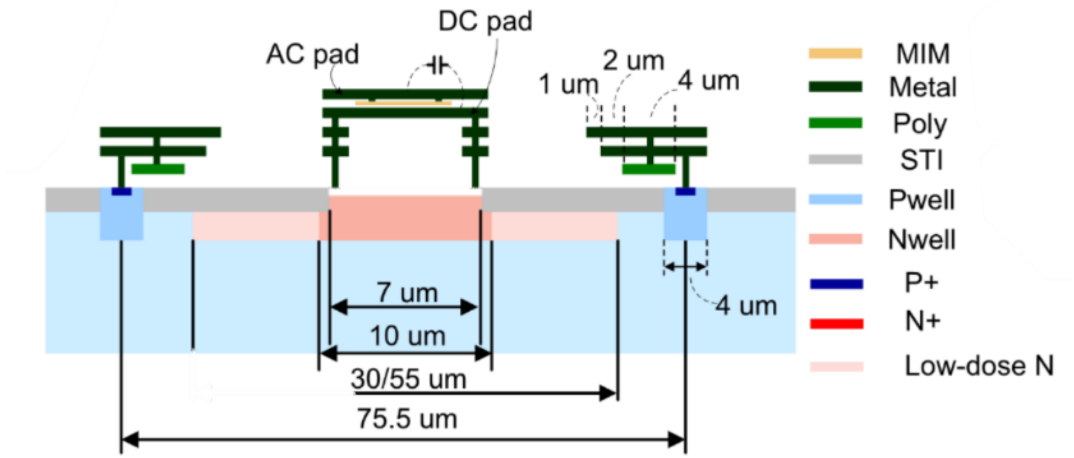
Hybrid Pixel Detector

Passive CMOS Strip Detectors

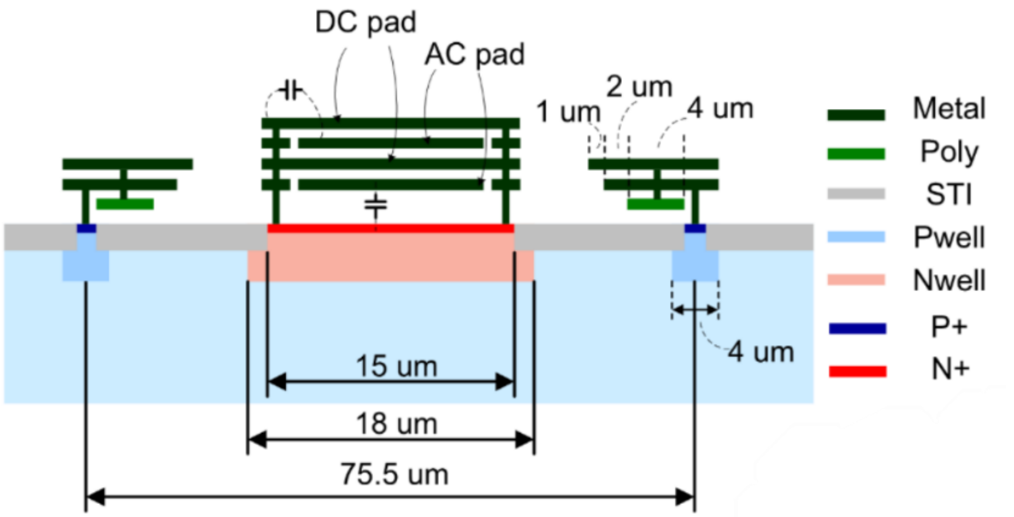
First stitched passive strip sensors produced on 8’’ wafer by a commercial high volume foundry

- L-Foundry 150 nm process (deep N-well/P-well)
- Float-Zone silicon, 3-5 kΩ·cm resistivity
- $150 \pm 10\ \mu$m thickness
- Strip pitch 75.5 μm
- 3 different designs: Low dose 30/55 and regular

Low Dose 30/55



Regular



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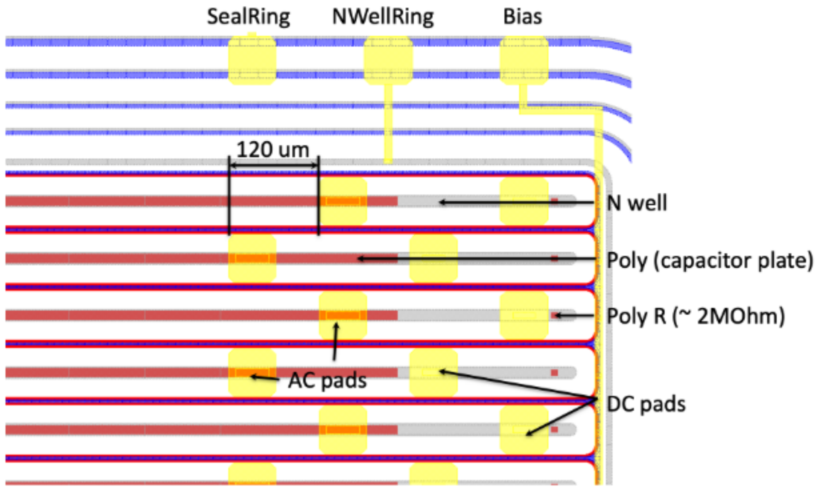
Passive CMOS Strip Detectors

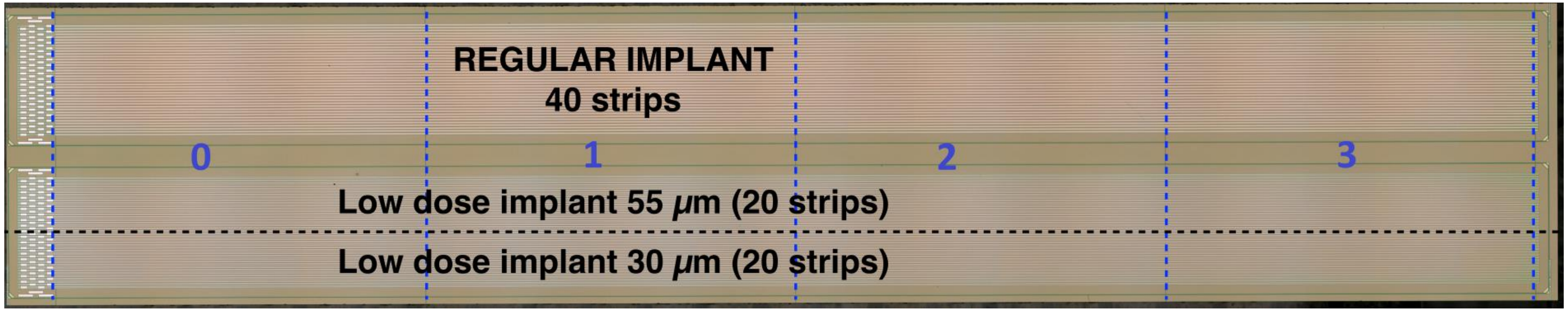
Frontside process: Reticle stitching with masks up to $1cm^2$

- Allows for larger sensors: Strip length 2.1cm and 4.1cm
- Up to five stitch lines

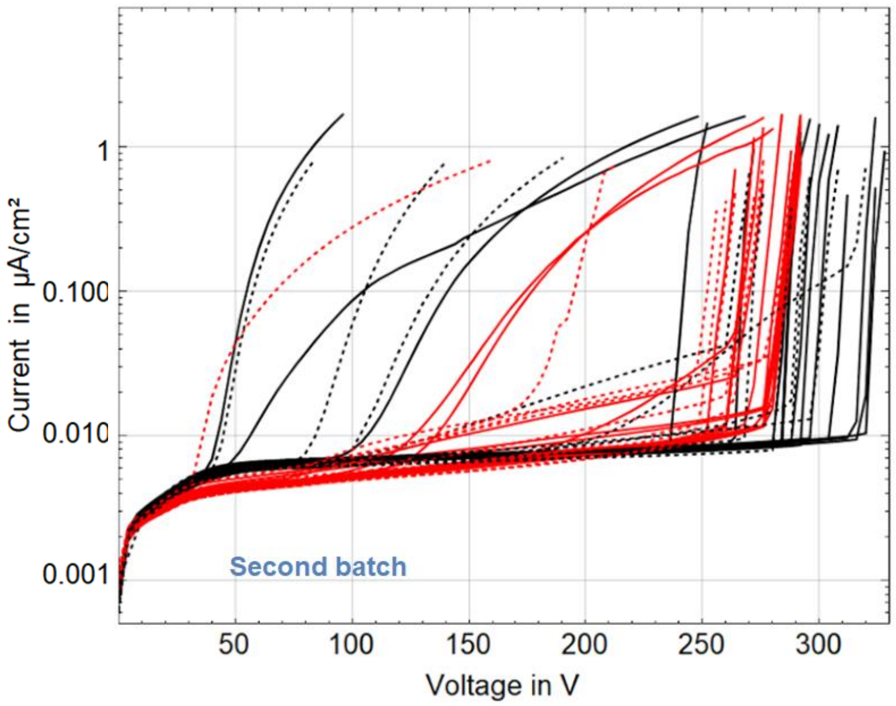
Backside process: Thinned, additional p^+-implant, laser annealing

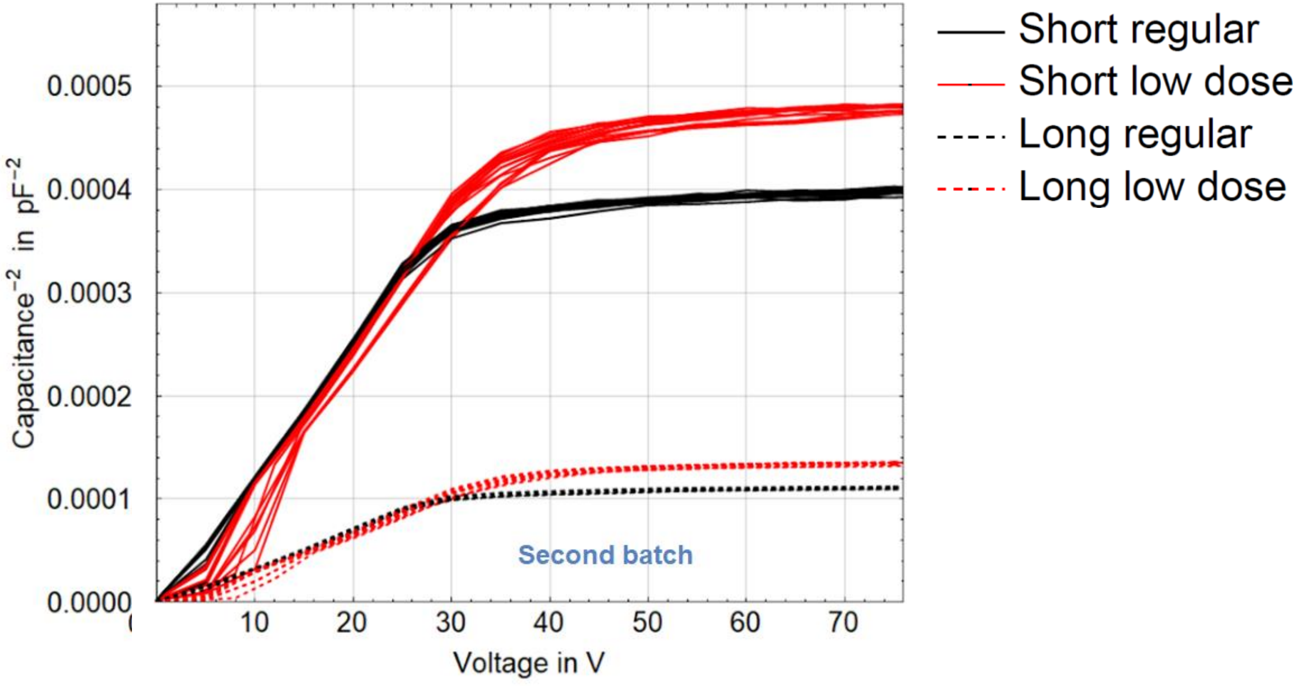
- First Batch: Low p^+-dose and no metallization
- Second batch: High p^+-dose and metal layer





Electrical Characterization

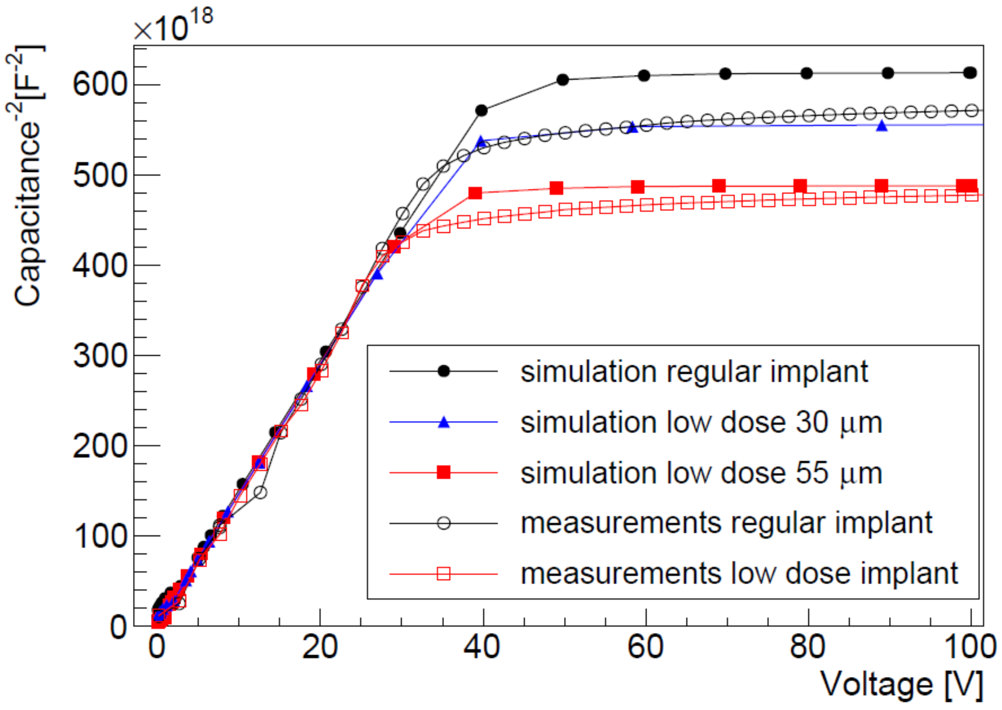


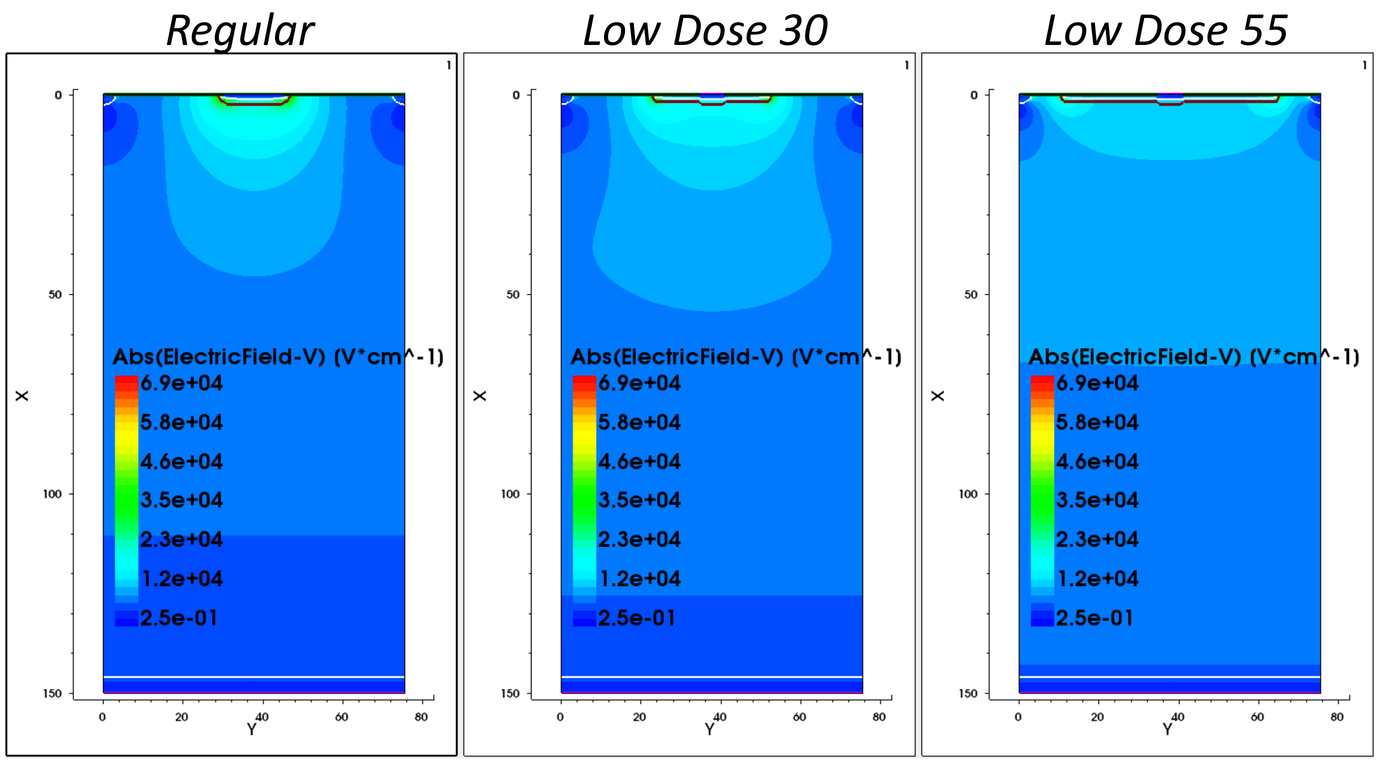


- Second batch: Improved breakdown voltage (higher backside implant concentration, metallization)
- Full depletion between 25-40V for both designs
- Stable capacitance behavior: Bulk capacitance ~50pF (short sensors), ~100pF (long sensors)

TCAD Simulations

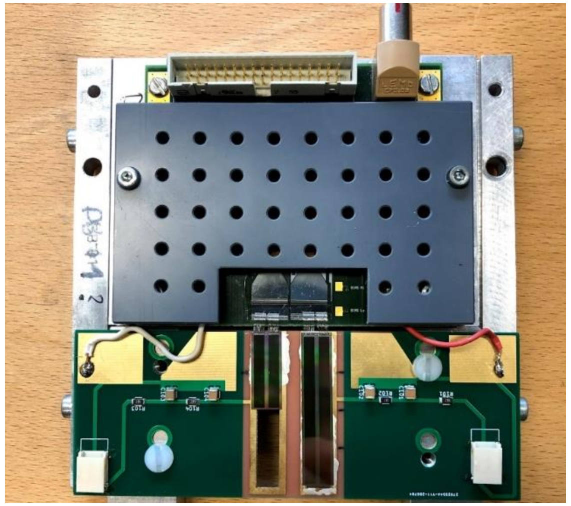
- Simulations for all three strip designs, assuming 150 μm thickness, 75.5 μm strip pitch, standard backplane implant
- Electric field at 100 V shows different shapes around the strip implants
- Simulation of the capacitance agrees well with the measurements

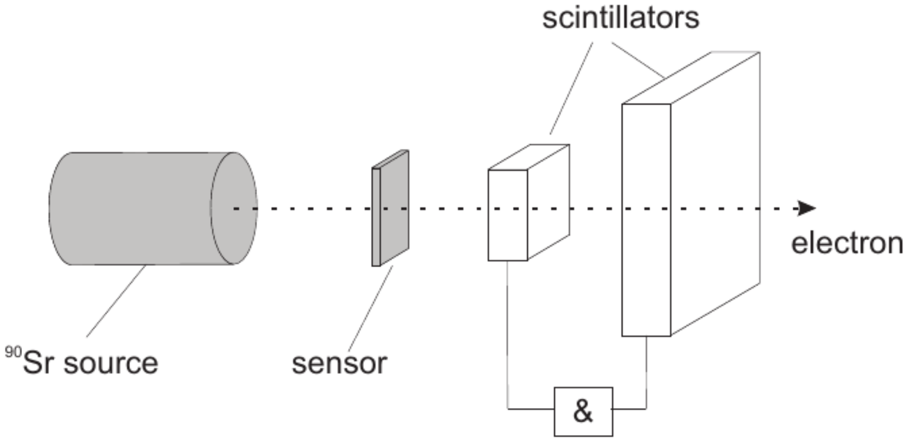


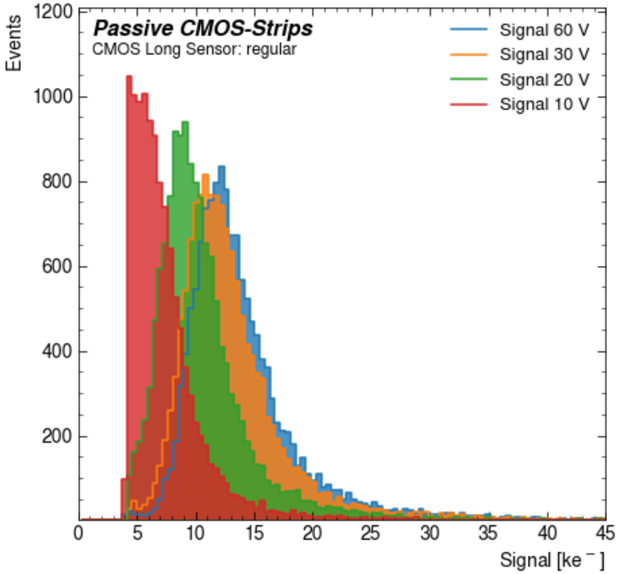


ALIBAVA Set-Up

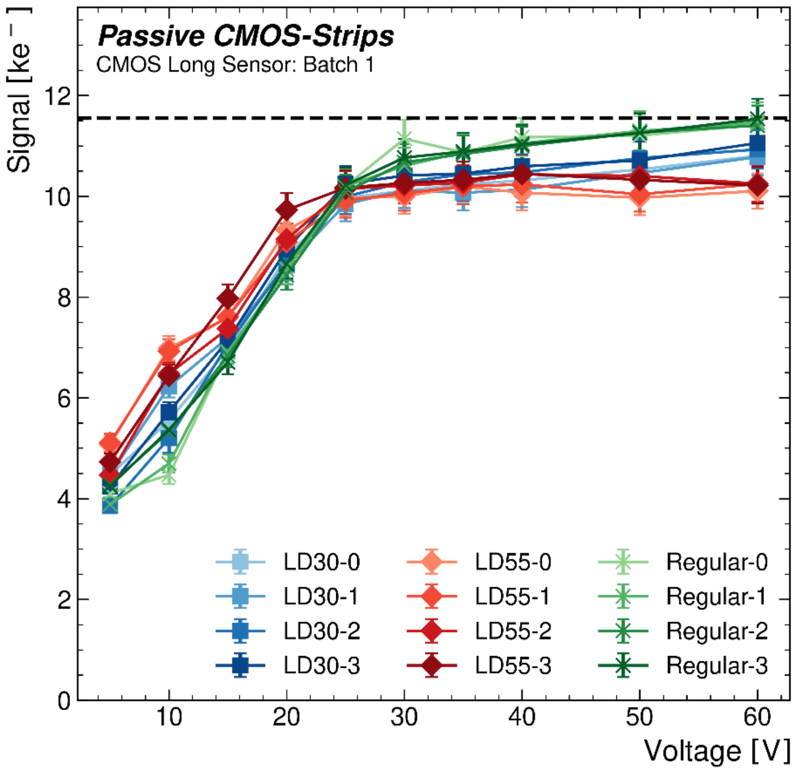
- Radioactive source housed in a Plexiglas cylinder
  - Collimates the electrons towards the silicon sensor
  - Provides shielding
- Two plastic scintillator-photomultiplier combinations
  - trigger for the readout of the sensor
  - Area of 4 x 4 mm^2 and 45 x 45 mm^2
  - 4 mm thickness
- Signal distribution: Landau-Gauss fits determine MPV

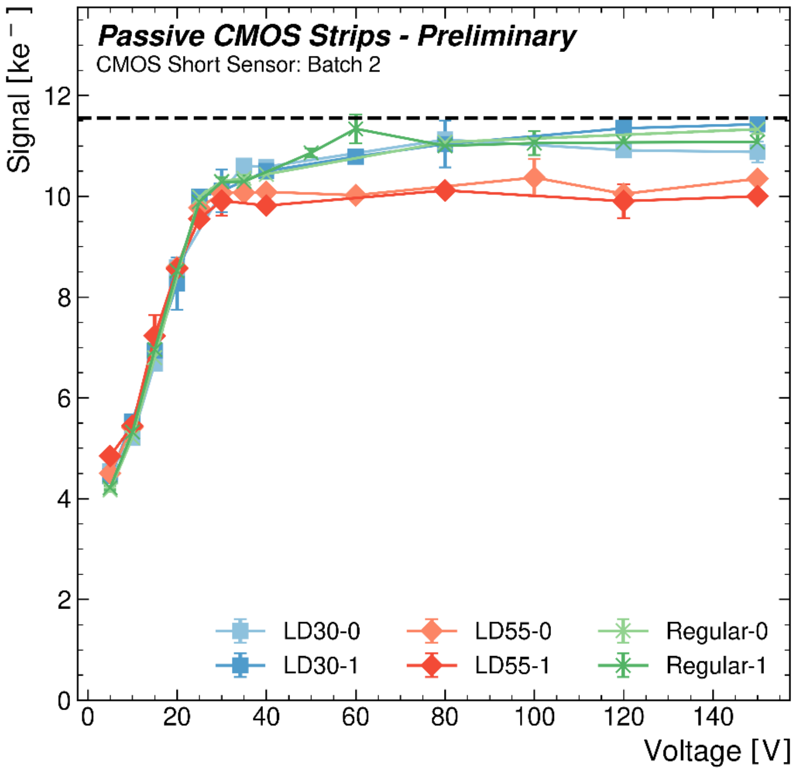






Charge Collection – Not irradiated

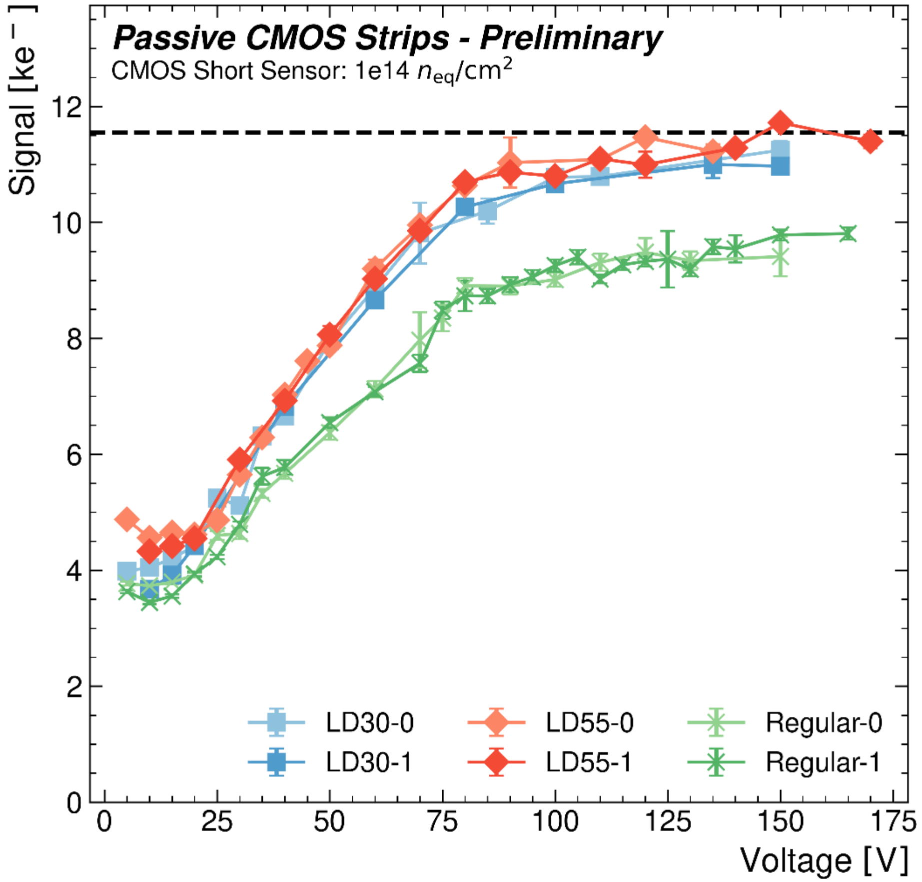




- Regular and Low dose 30 design both reach the expected amount of charge
- Low dose 55 design has a systematic offset – possibly related to beetle configuration (high capacitance)
- No effects of stitching visible in all designs
- Batch 2: Sensors can be biased significantly higher

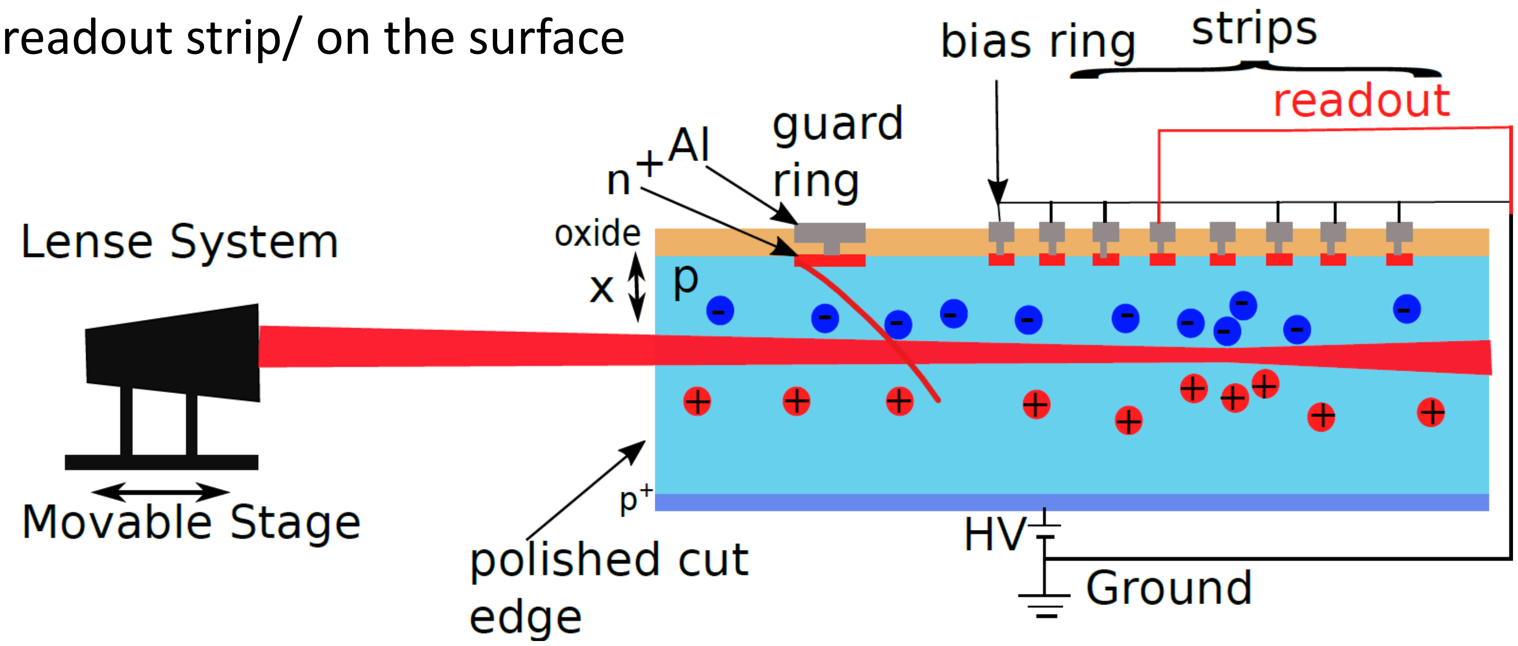
Charge Collection – First irradiated sensor

- Short sensor irradiated to $1 \times 10^{14} n_{eq}/cm^2$ with neutrons
- Depletion voltage around 80-90V
- Amount of collected charge drops significantly for regular design
- Low Dose 30 design collects only slightly less charge
- Low Dose 55 design: More charge measured than in the unirradiated sensor, hinting to a systematic error in the measurement
- Still no stitching effects after irradiation

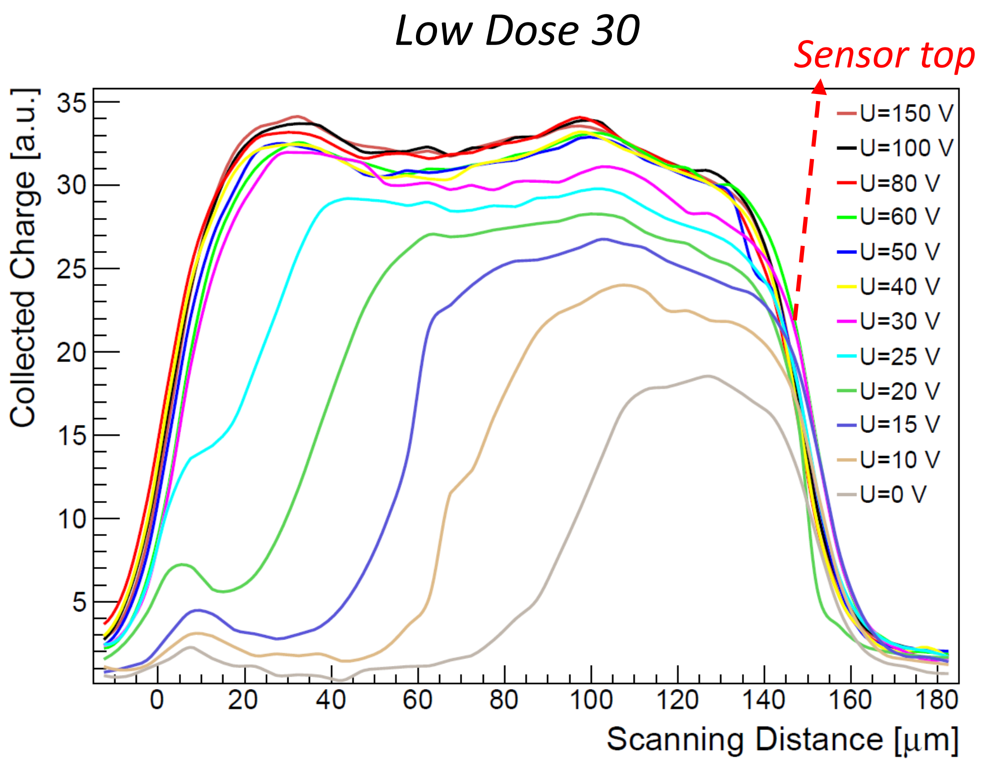


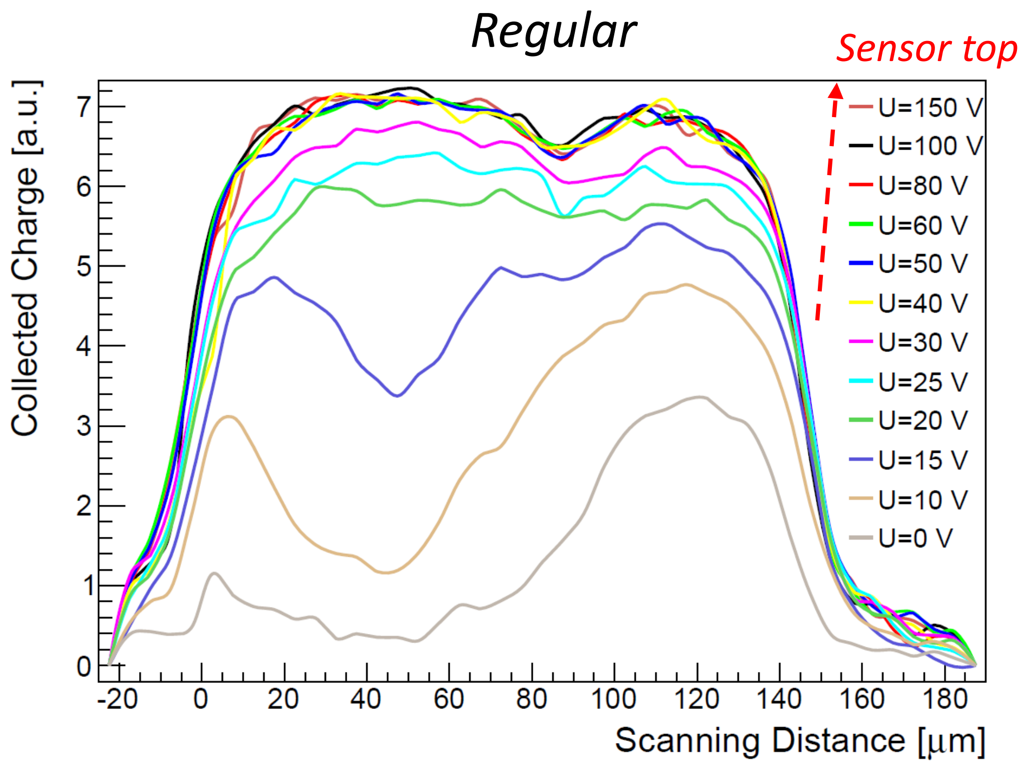
Transient Current Technique (TCT)

- Short laser pulse creates electron/hole-pairs in the sensor, laser wavelength 1060 nm (infrared)
- Edge-TCT: Laser on sensor edge, creating charge at a specific depth
- Top-TCT: Laser directed on sensor top, creating carriers through the entire thickness
- Focus point (~10μm) underneath the readout strip/ on the surface



Edge-TCT: Unirradiated sensor





- Sensors deplete top to back as expected, slight double junction (enhanced by reflections)
- Entire sensor volume sensitive to charge, full depletion around 30-40V for both designs
- Charge remains constant after full depletion

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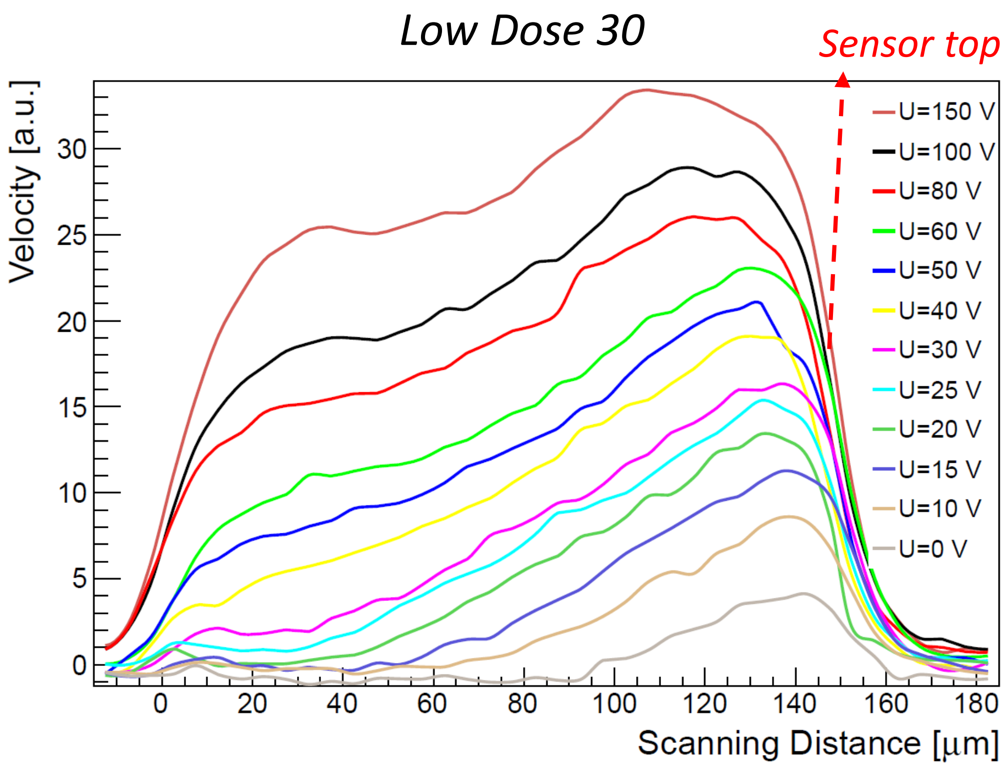
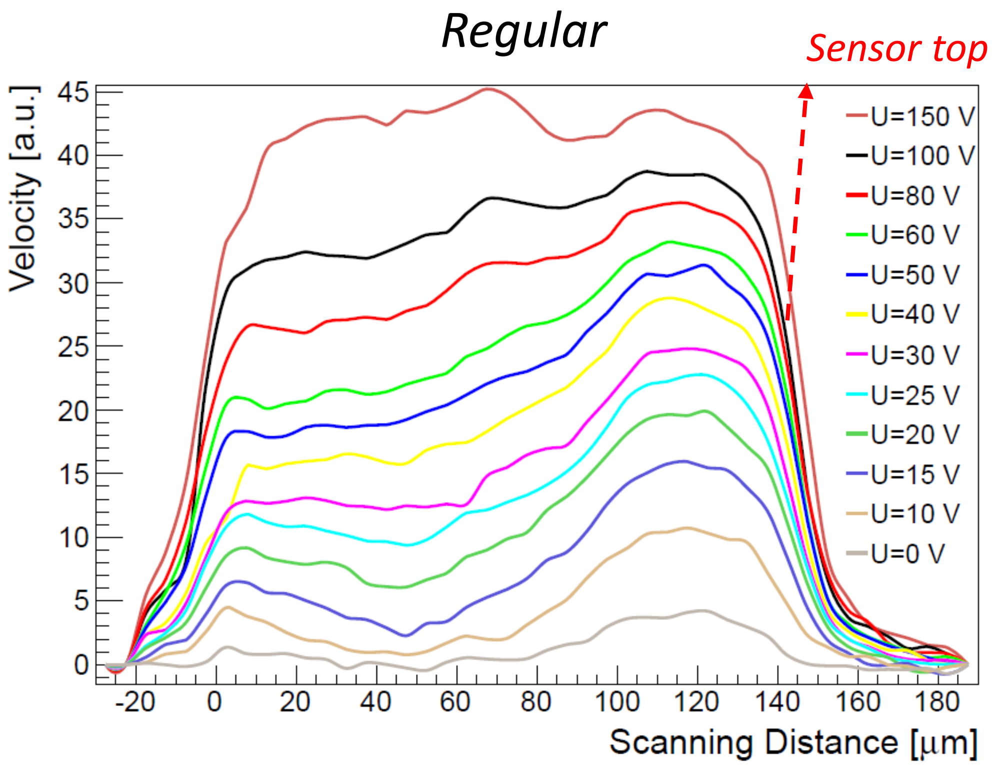
Edge-TCT: Unirradiated sensor

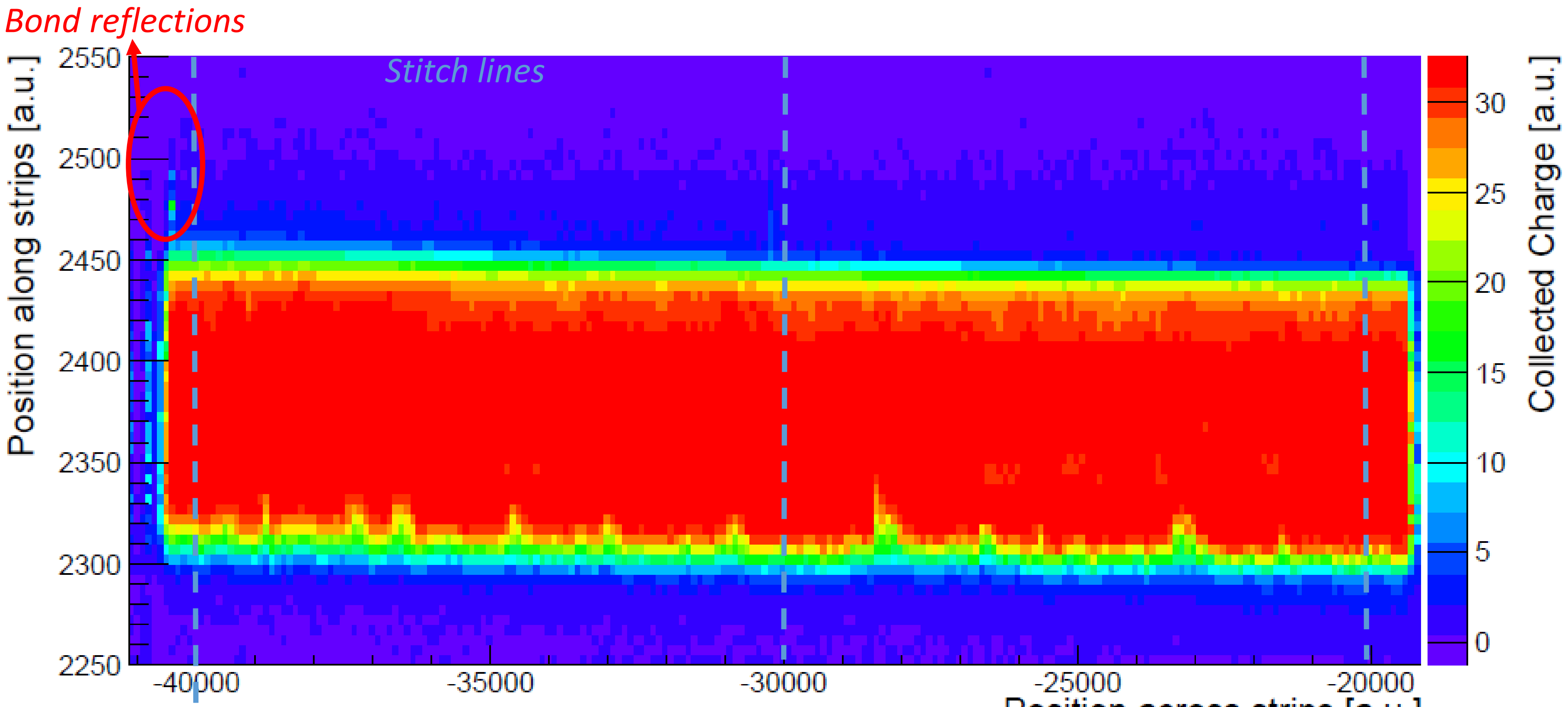




- Expected approximately triangular shape of the velocity (apart from the double junction effect)
- Velocity keeps increasing after full depletion
- Electric field calculation in progress

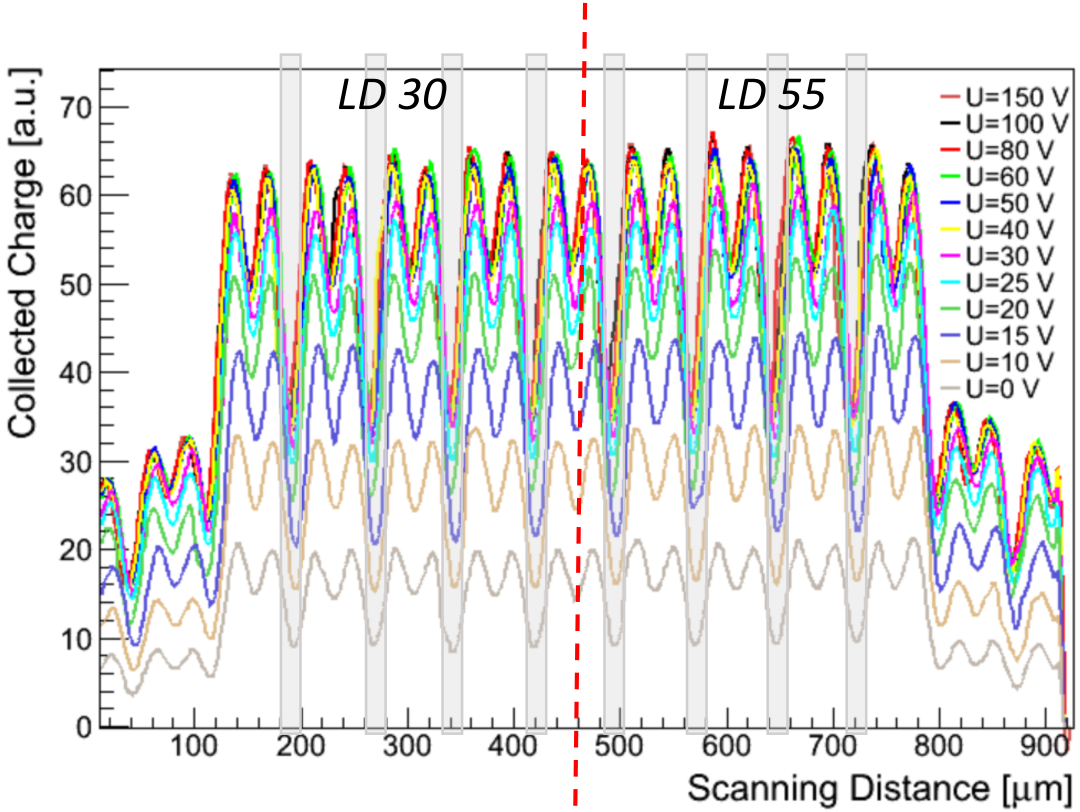
Edge-TCT: Unirradiated sensor

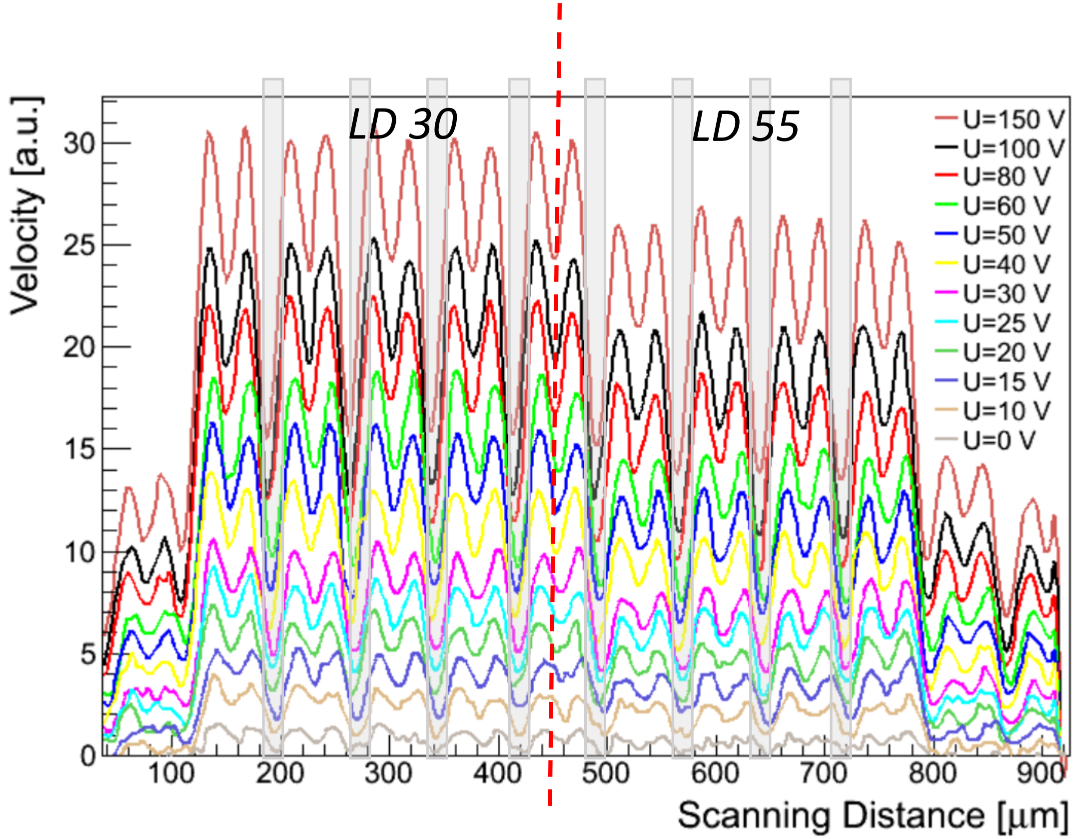
- Scan along entire edge (short sensor, 100V) – no effects from stitching visible
- Homogeneous depletion and charge collection



Top-TCT: Low Dose designs

- 4 strips of LD30 and LD55 design each connected for direct comparison
- Collected charge for both designs similar, constant above depletion voltage
- Velocity differs visibly– lower for LD55 design, in agreement with el. field simulations
- Velocity keeps increasing with voltage (not saturated)

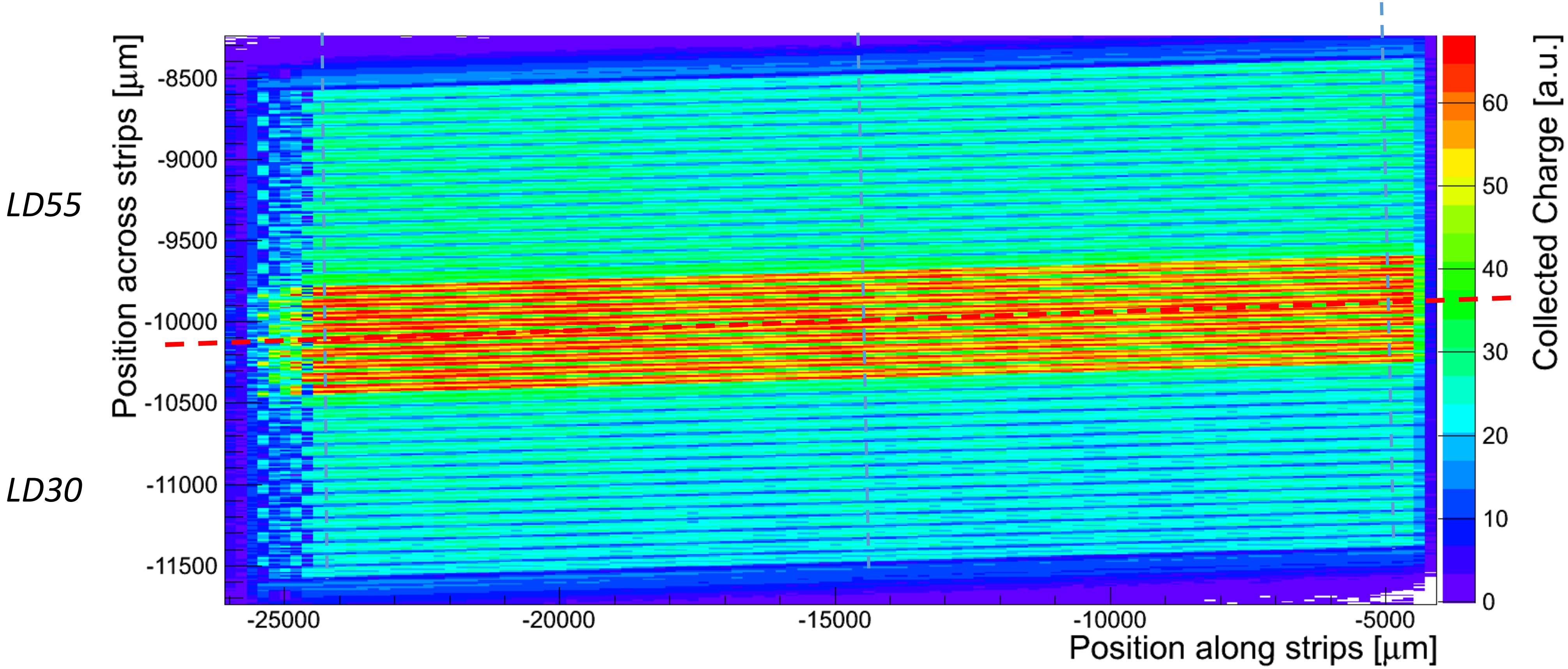




Gray areas: Readout strips. The interstrip metallization causes the dips in the middle between two strips.

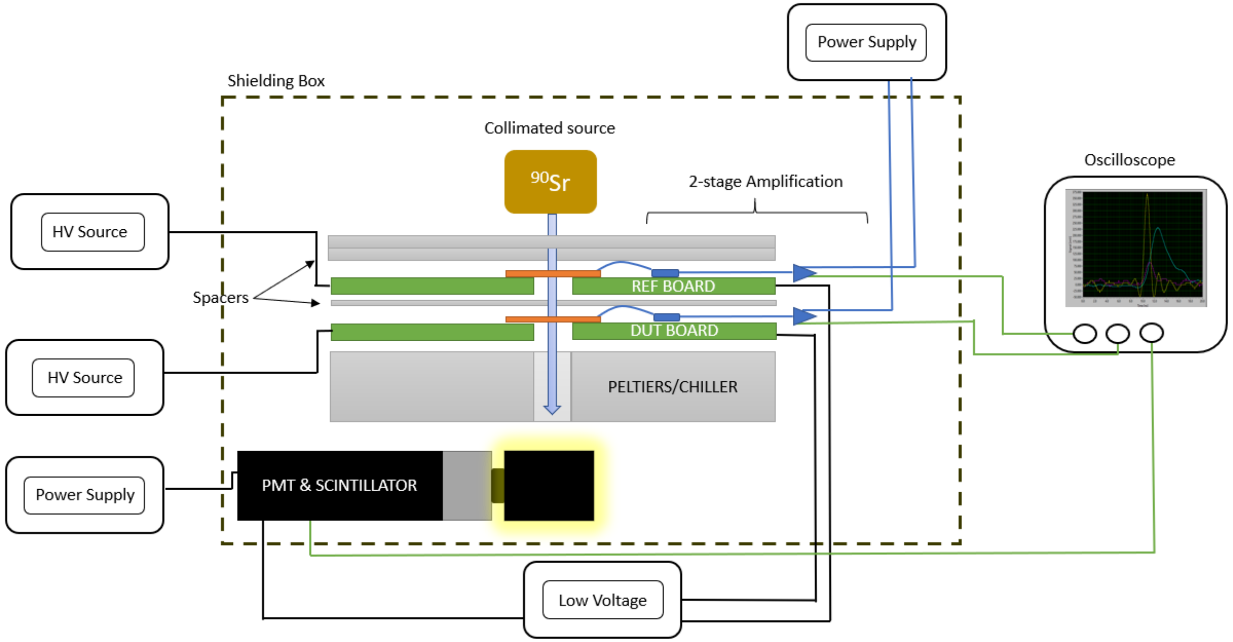
Top-TCT: Low Dose designs

- Homogeneous charge collection along the strips, no difference in designs within the connected strips
- 8 strips connected, but charge measured in all neighboring strips as well
- Slightly higher measured charge in the neighboring channels of *Low Dose 55* design
- No stitching effects visible



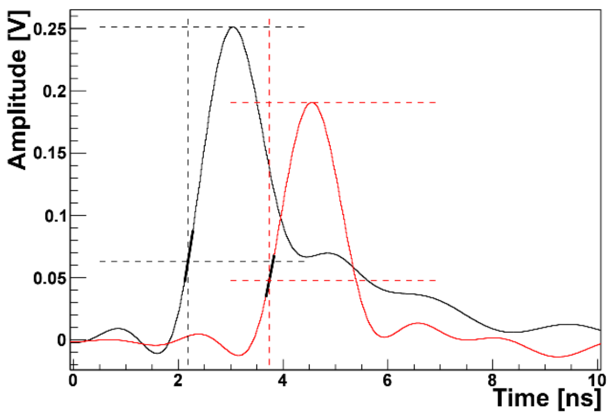
Beta Set-Up for Timing

- ^{90}Sr-source for MIP-like electrons
- LGAD as reference sensor
- Scintillator & PMT as Yes/No trigger
- Reference and DUT signal recorded for each event



- **T**ime **o**f **A**rrival determined with **C**onstant **F**raction **D**iscrimination
- Time Spread: Sigma of the distribution of the different ToAs

$$\sigma_{DUT} = \sqrt{\sigma_{TS}^2 - \sigma_{Ref}^2}$$



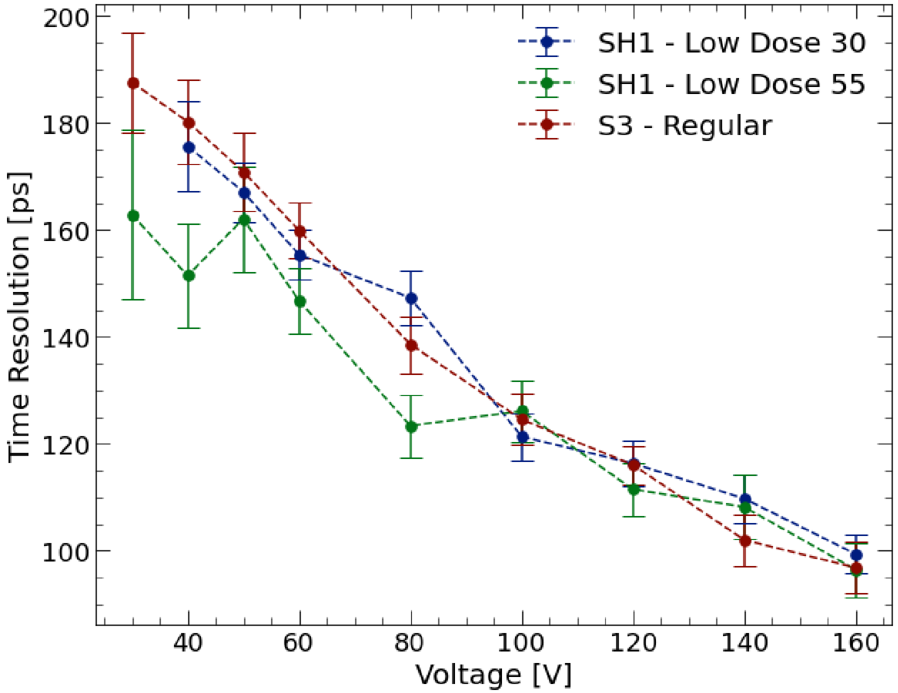
$$\sigma_{Ref} = 25.18 \pm 0.35\ ps$$

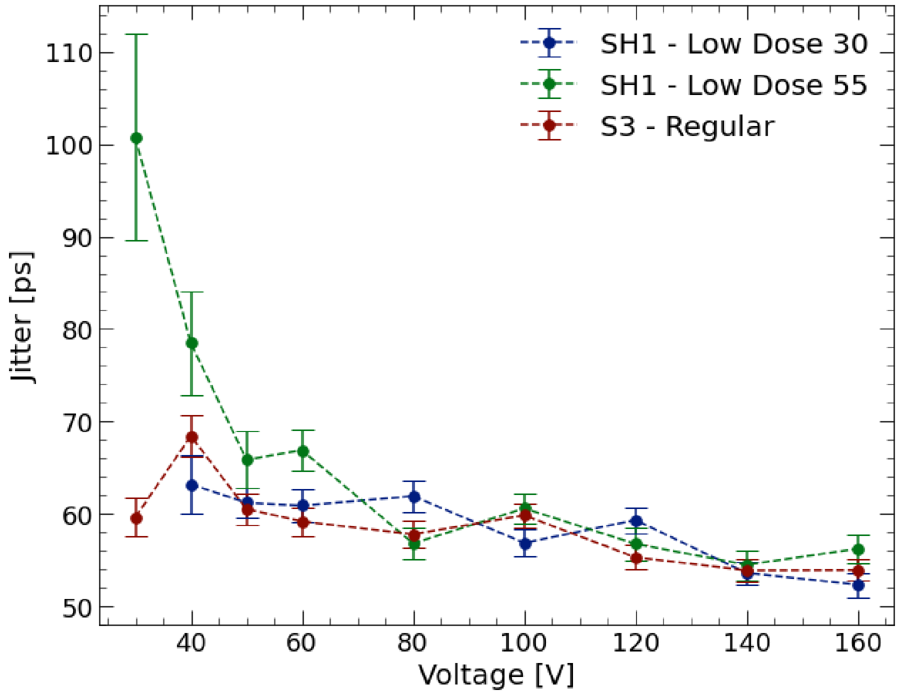
Time Resolution

- Similar time resolution for all designs, expected dependence on voltage
  - ➢ Values within the expected range for a 150μm thick planar sensor
- Jitter in the range of 60ps
- High capacitance: sensors are noisier -> negative effect on jitter &resolution

At 160V

Design	Resolution [ps]
Low Dose 30	99.4 ± 3.6
Low Dose 55	96.5 ± 5.1
Regular	96.9 ± 4.7





Conclusion and Outlook

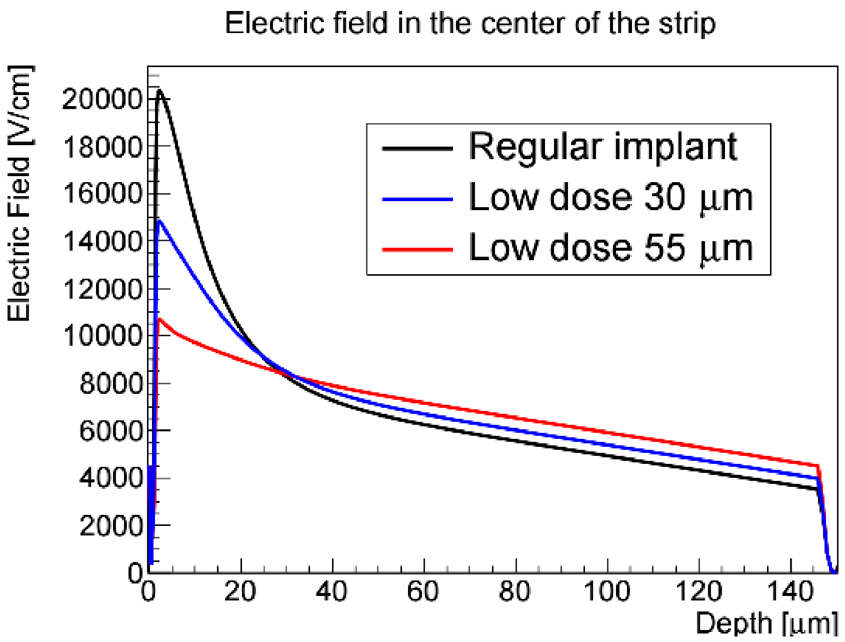
- Successful design, production and measurements of the first passive CMOS strip sensors
- Voltage stability improved (>250V) for the second sensor batch
- No stitching effects observed in charge collection and TCT measurements
- Time resolution below 100ps, entire sensor thickness sensitive to charge, expected amount collected

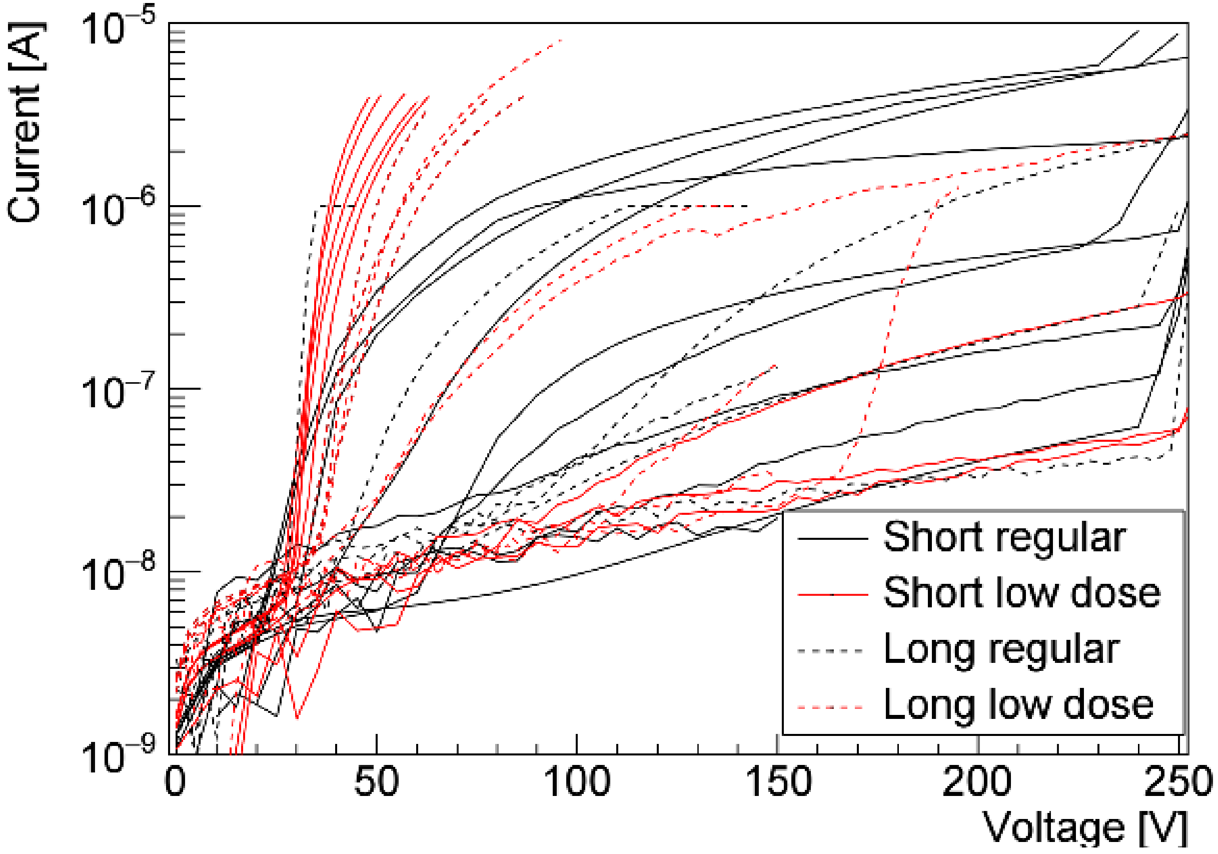
  - ➢ Test beam studies with unirradiated and irradiated samples are ongoing
  - ➢ Characterization of further irradiated sensors ongoing as well

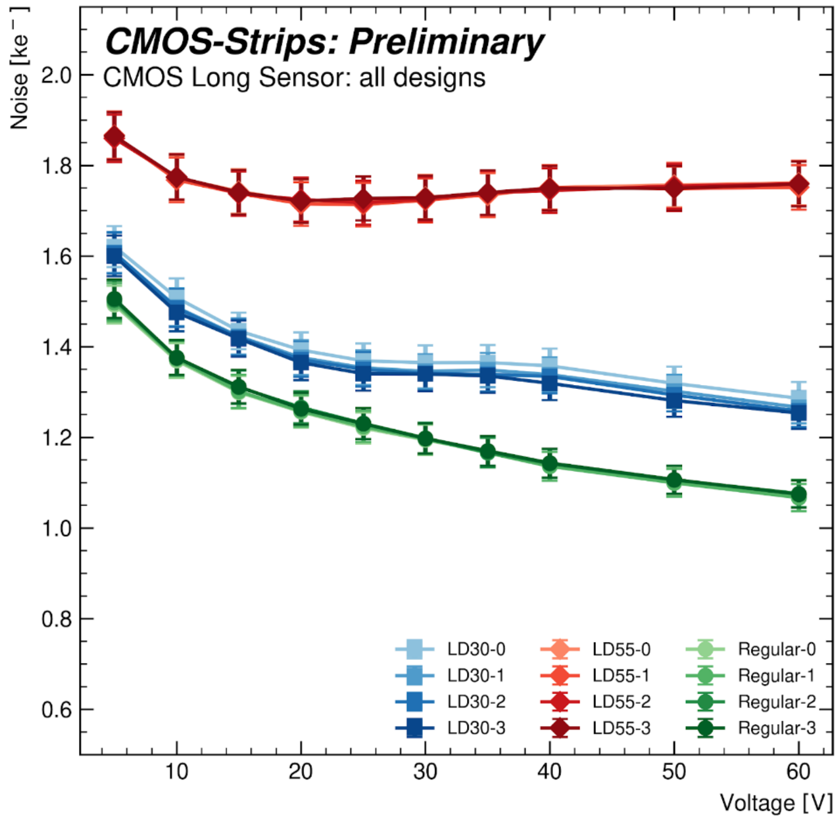
Thank you for your attention!

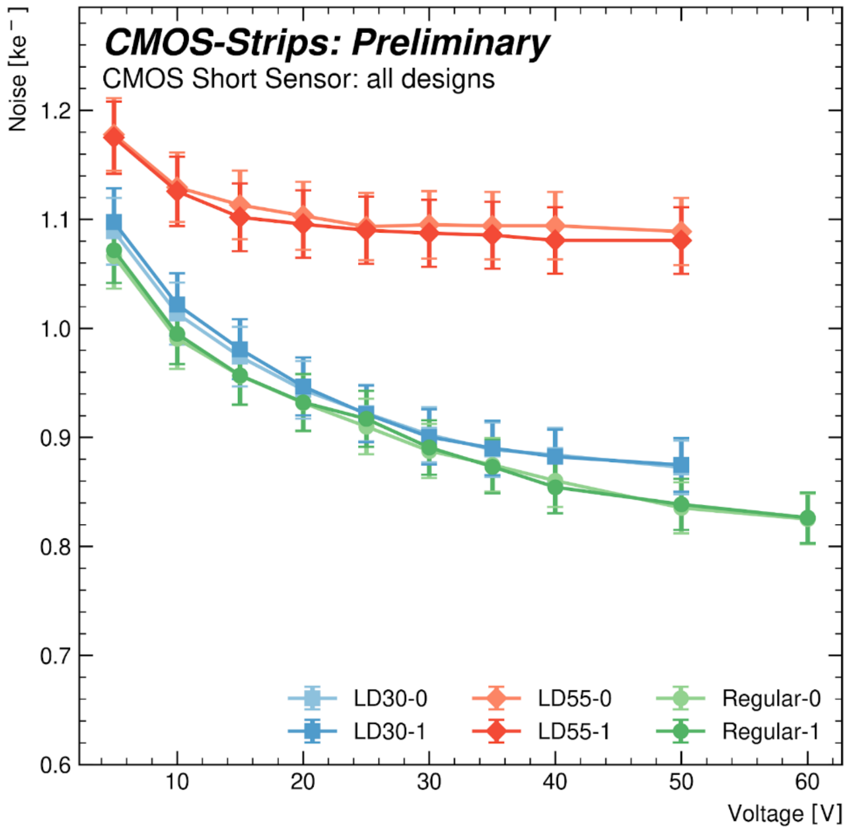
BACKUP

Batch 1


Electric field in the center of the strip
Electric Field [V/cm]
Depth [μm]
Regular implant
Low dose 30 μm
Low dose 55 μm
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
20000
0
20
40
60
80
100
120
140


Current [A]
Voltage [V]
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
0
50
100
150
200
250
Short regular
Short low dose
Long regular
Long low dose

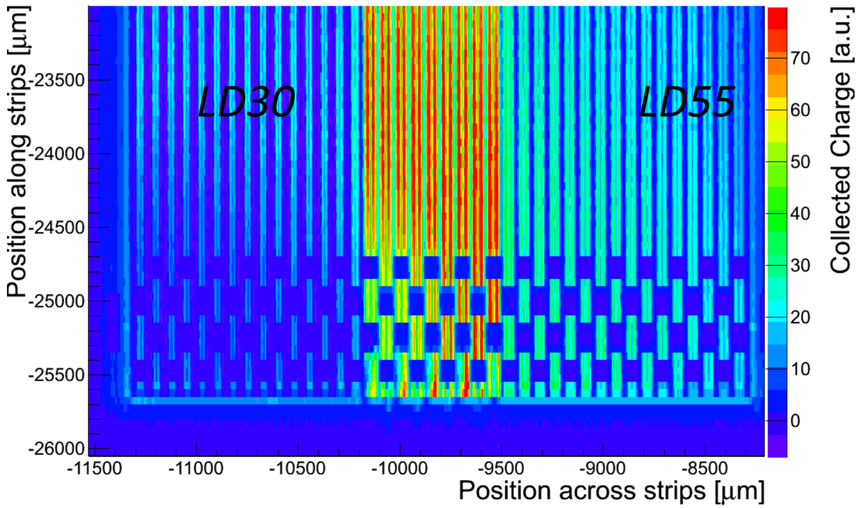


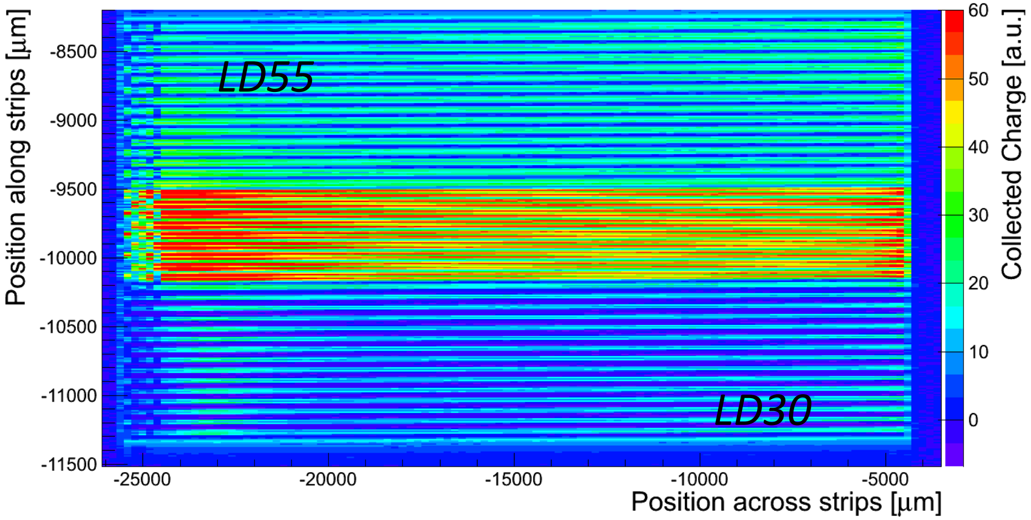


Low signal to noise ration, no effects of stitching in noise, high noise for LD55

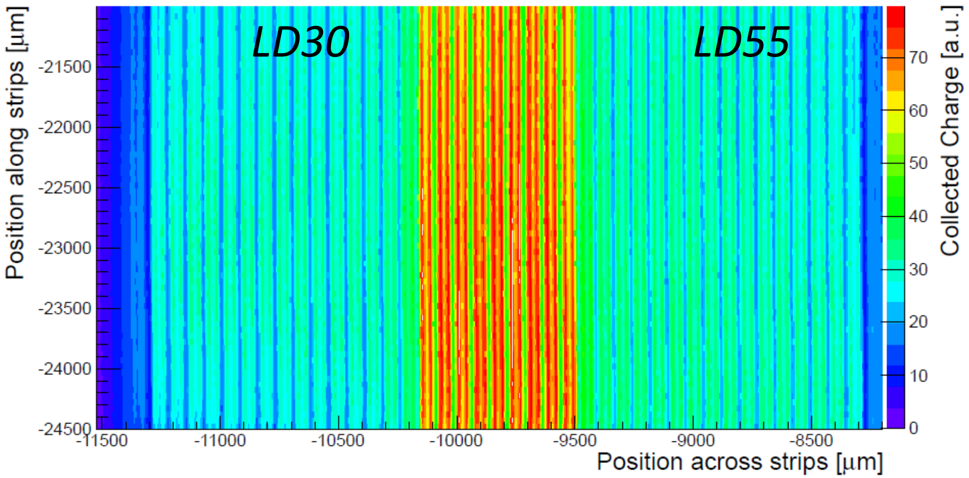
Top TCT - Low dose Sensor SH1

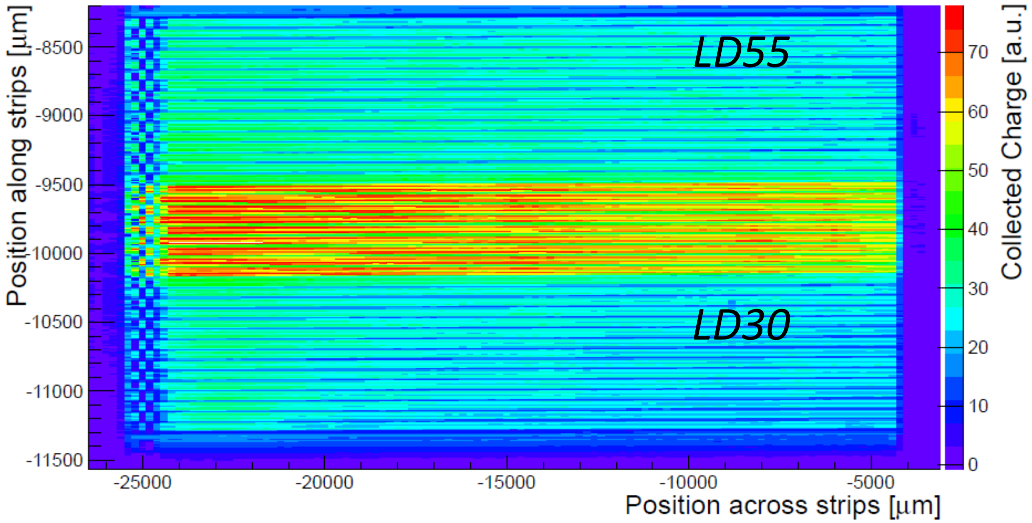
Red laser





Infrared laser





Top TCT - Low dose Sensor SH1

Phenomenon vanishes (LD30) or decreases strongly (LD55) for terminated strips