Performance Evaluation of Stitched Passive CMOS Strip Sensors

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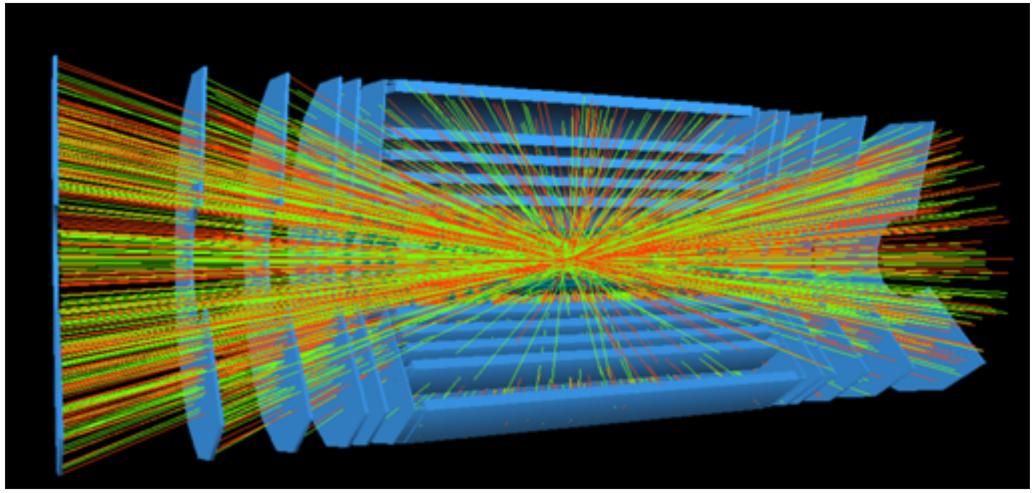
Motivation for passive CMOS

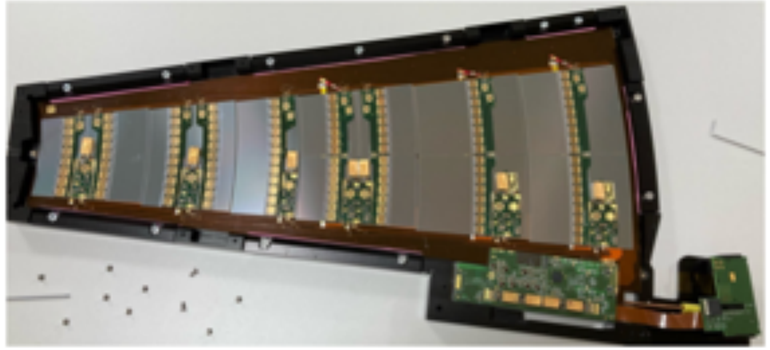
- **Requirements for future HEP detectors**
  - All silicon-based tracker
  - Possibly more radiation tolerant

- **Why CMOS sensors**
  - Cost effective-> Use of commercial CMOS production processes
  - Stitched sensors for large surface
  - Thin detectors

→ R&D program to study feasibility of passive CMOS strip sensors



ATLAS detector in HL-LHC

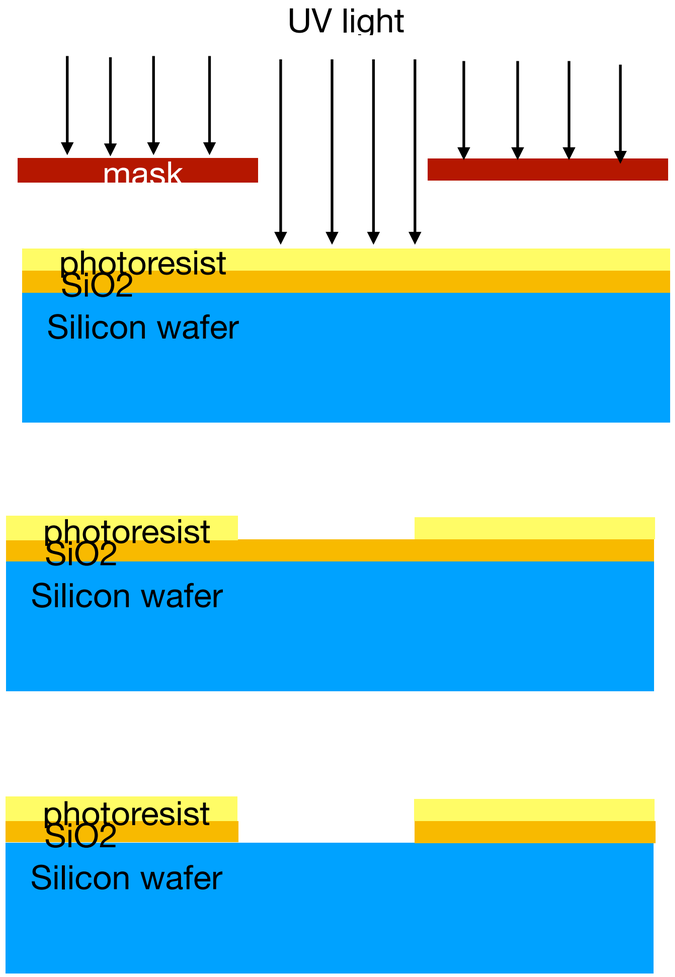


Picture of ATLAS endcap structure showing silicon strip sensor with up to 10 X 10 cm^2

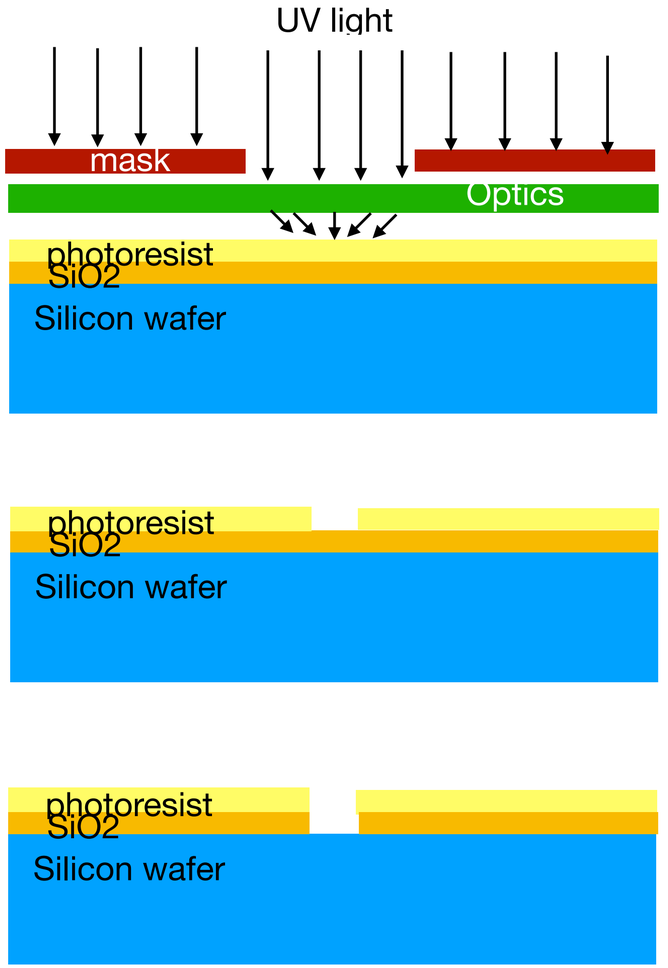
CMOS processing

- CMOS processing compared to microelectronics processing

Microelectronics photolithography

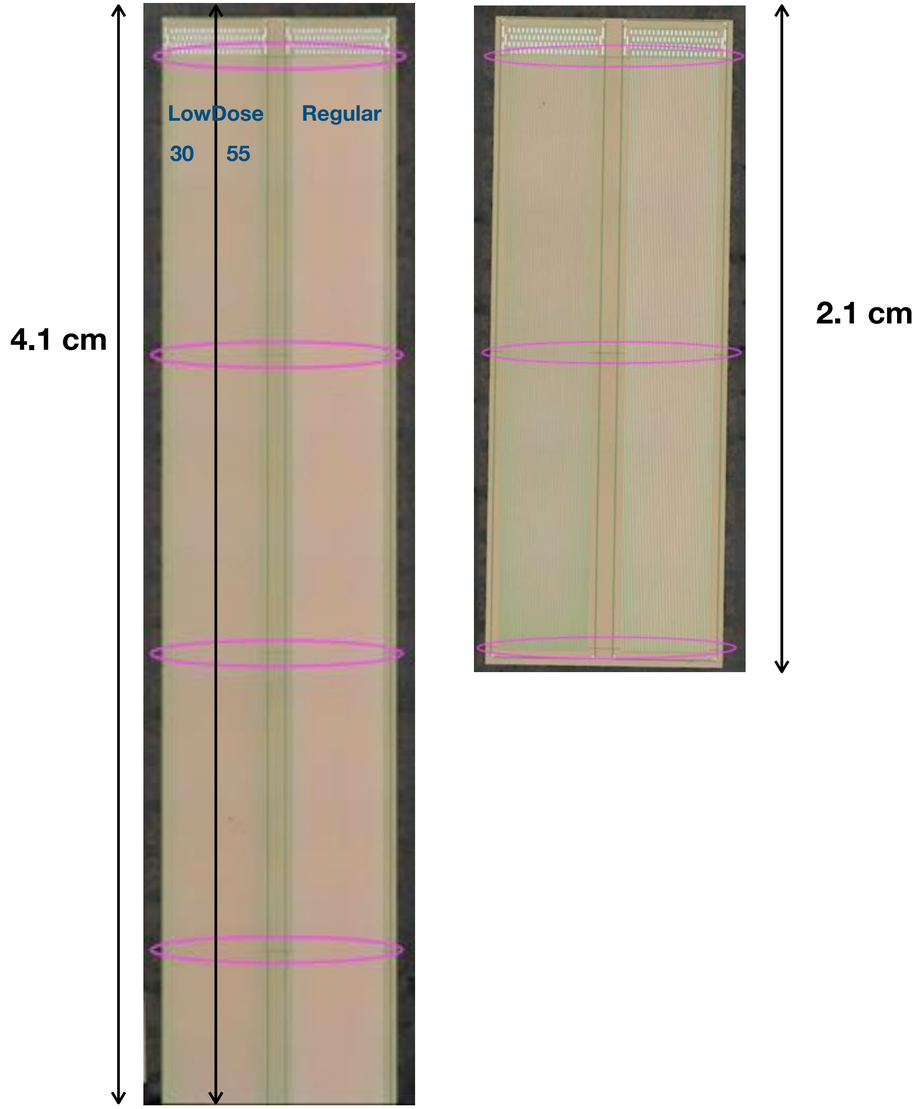


CMOS photolithography



- Using CMOS processing enables more detailed sensor structure

Sensor Details



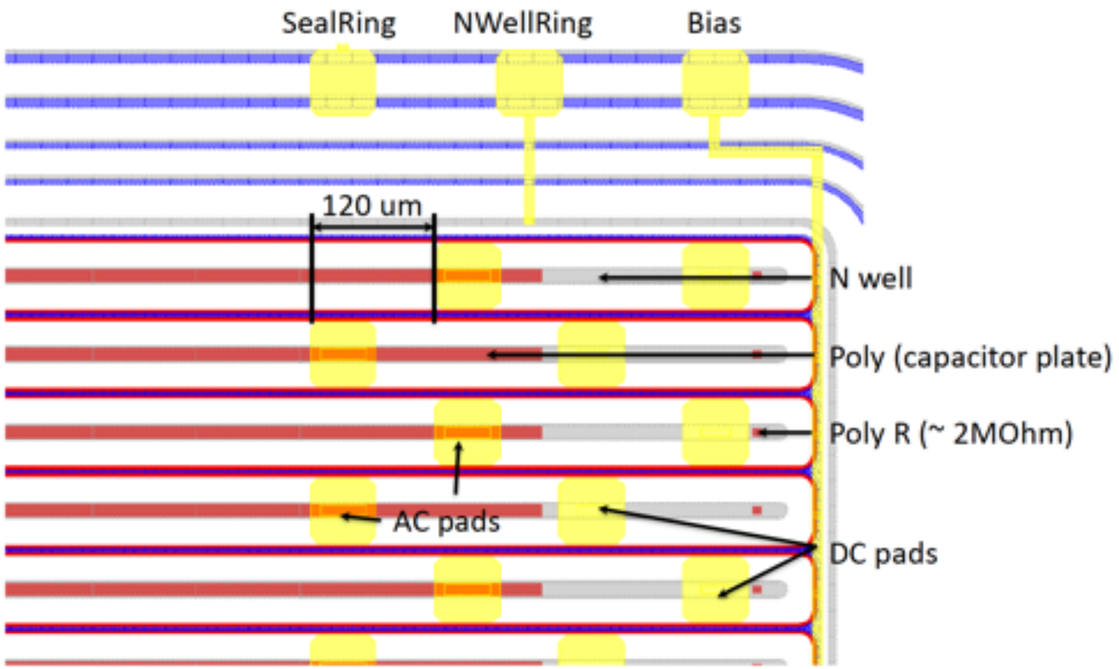
- First stitched strip sensor produced on 8” wafer by a commercial foundry

- L-Foundry 150 nm process (deep N-well/P-well)
- Up to 7 metal layers
- Resistivity of wafer: 3000 - 5000 Ω·cm
- Float-zone wafer

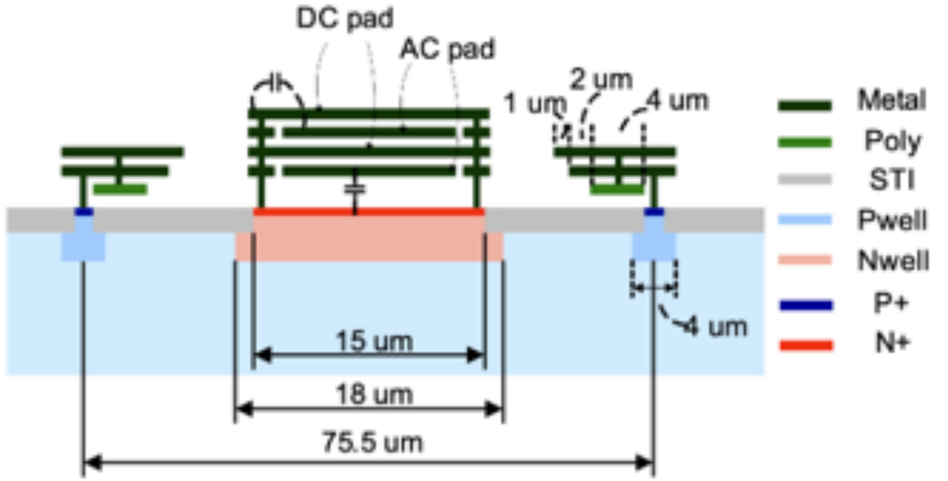
- The strip sensors have 2 different lengths : 2.1 cm and 4.1 cm

- Frontside process: Reticle stitching for large sensors
- Backside process: Additional p+ implant
  - First Batch: Low p+ dose and no metallisation
  - Second Batch: Increased p+ dose and metal layer

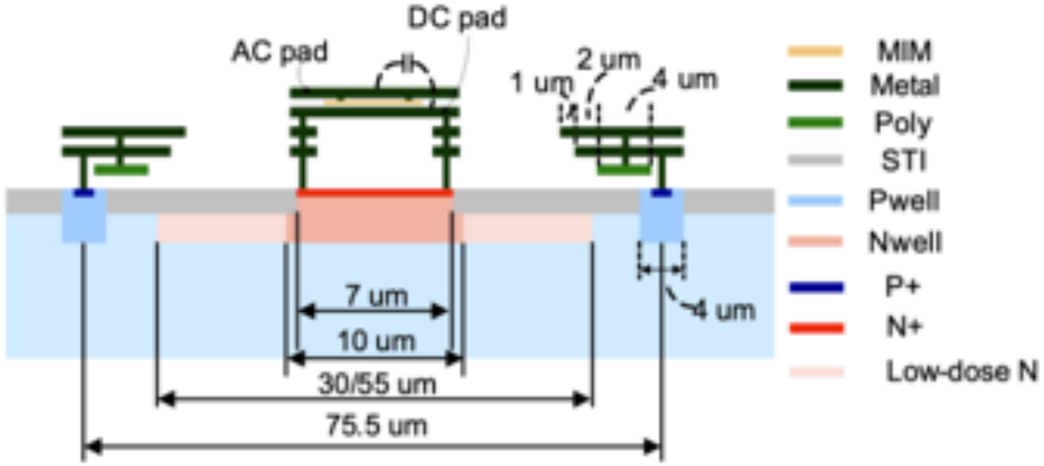
Sensor Structure



Regular design



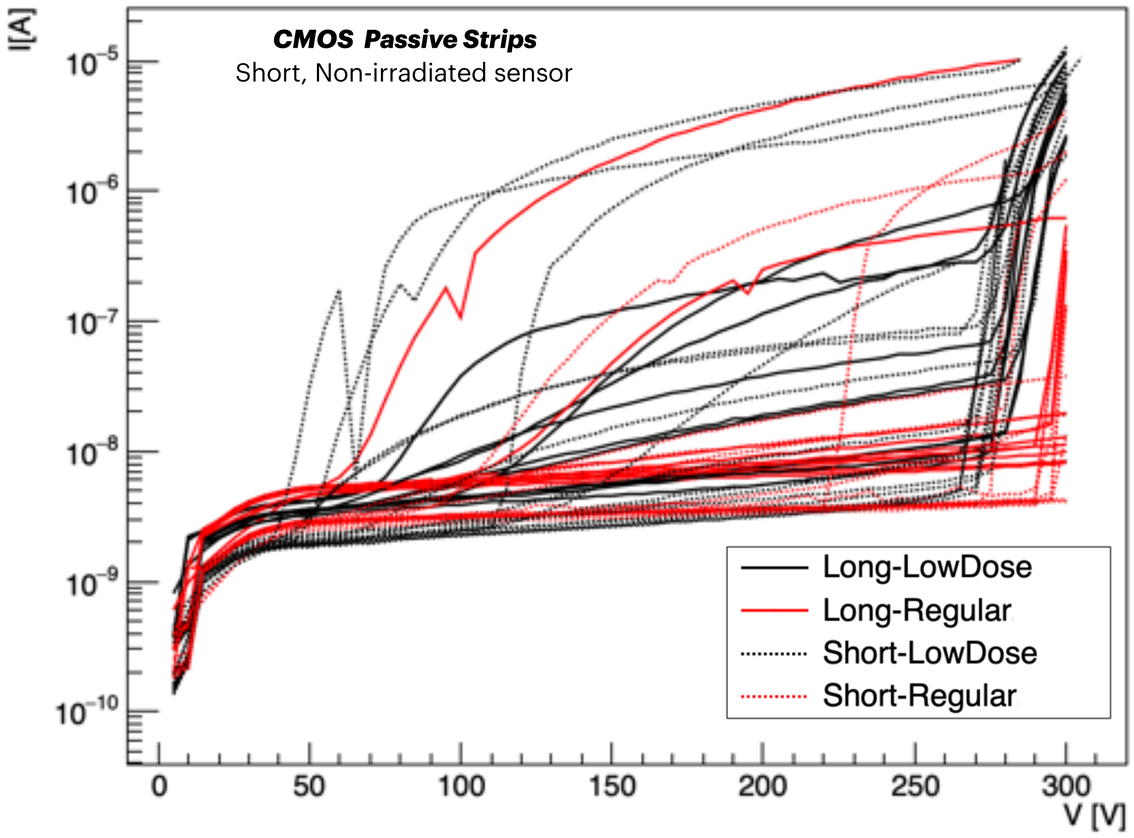
Low Dose design

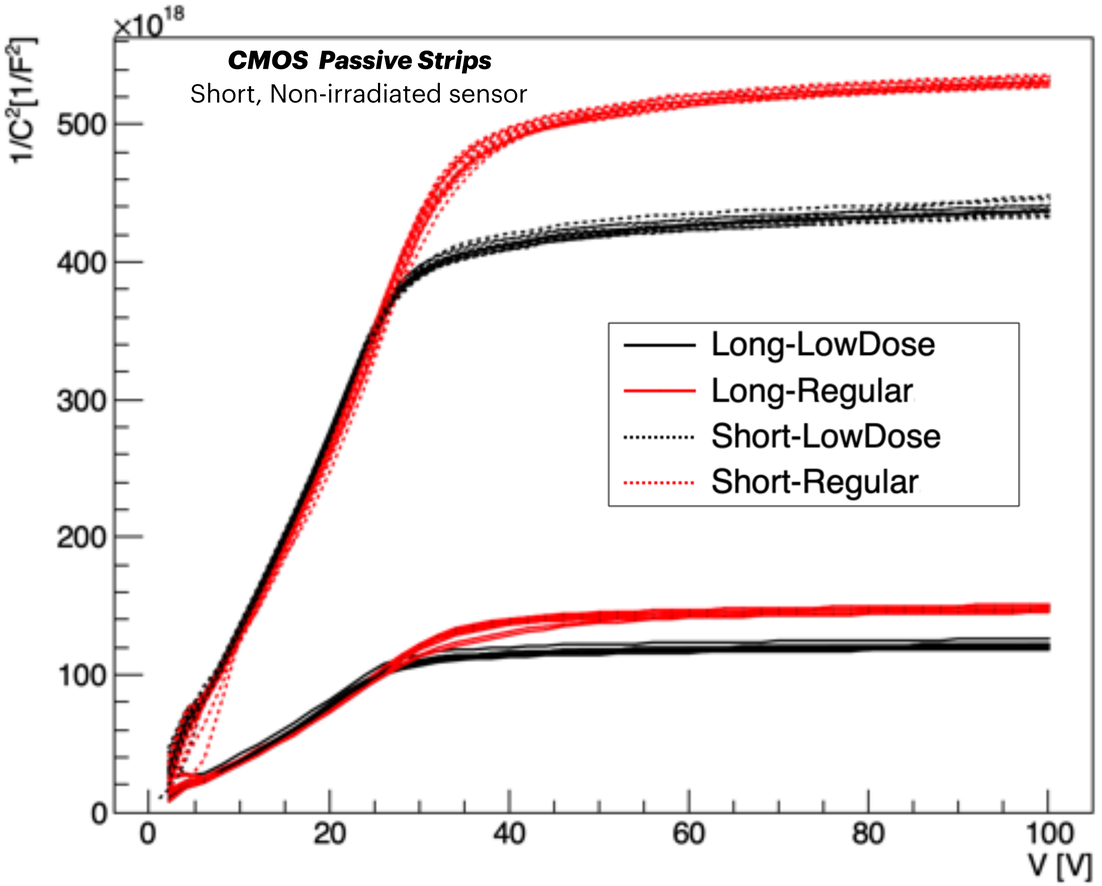


- Sensor thickness ~150 ± 10 µm
- Sensor has 40 strips each, with strip pitch = 75.5µm
- Three different designs: LowDose 30/55 and Regular
- LowDose design comes in two different low dose nwell widths, 30 & 55 um with 20 strips per design

IV and CV Measurements

All measurements are performed at room temperature

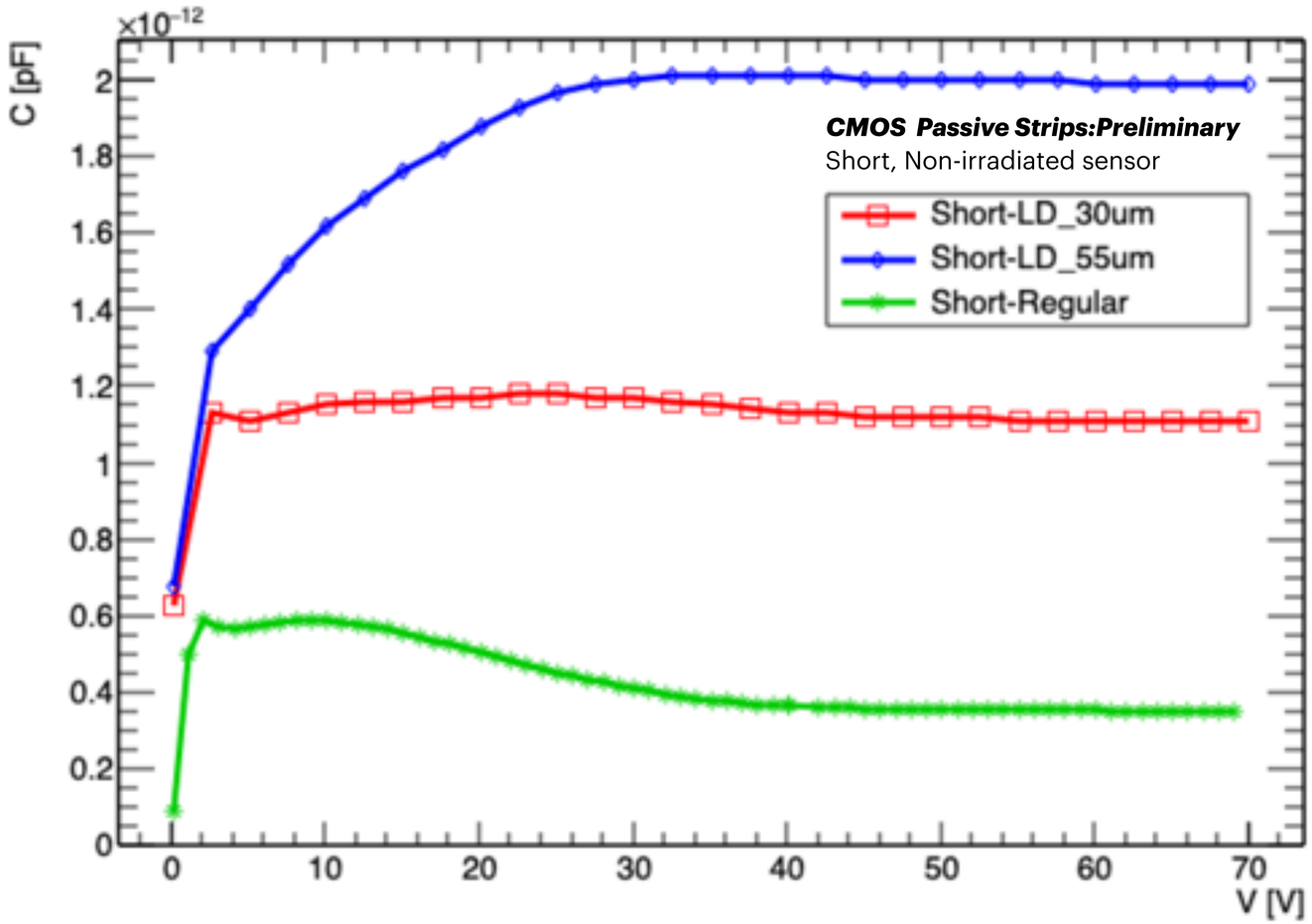




- Breakdown voltage above 250V, improved for batch II (higher backside implant doping concentration, metallization)
- Depletion voltage for LowDose implant (30V) < Depletion voltage for Regular implant (36V)
- Stable capacitance behavior: Bulk capacitance ~50pF (short sensors), ~100pF (long sensors)

Interstrip Capacitance

Measurement at room temperature for frequency of 500kHz

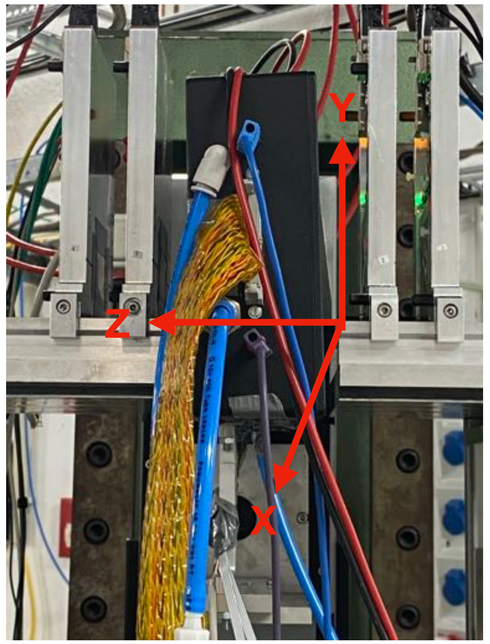


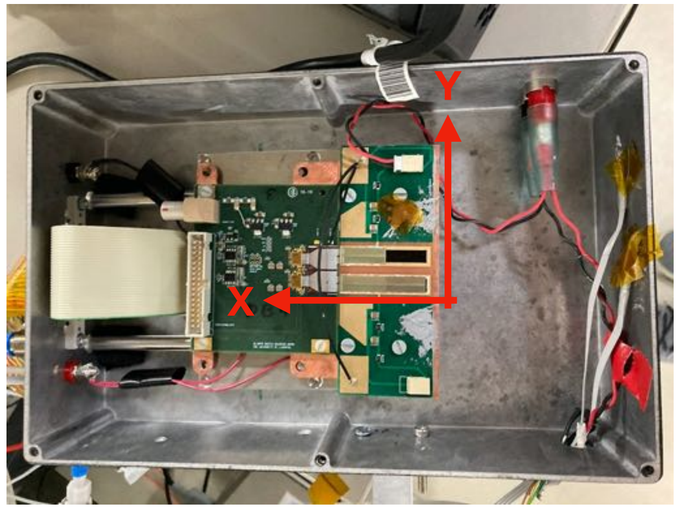
- With increasing width of implant capacitance increases -> highest for LD55 sensor
- Capacitance becomes stable after depletion voltage

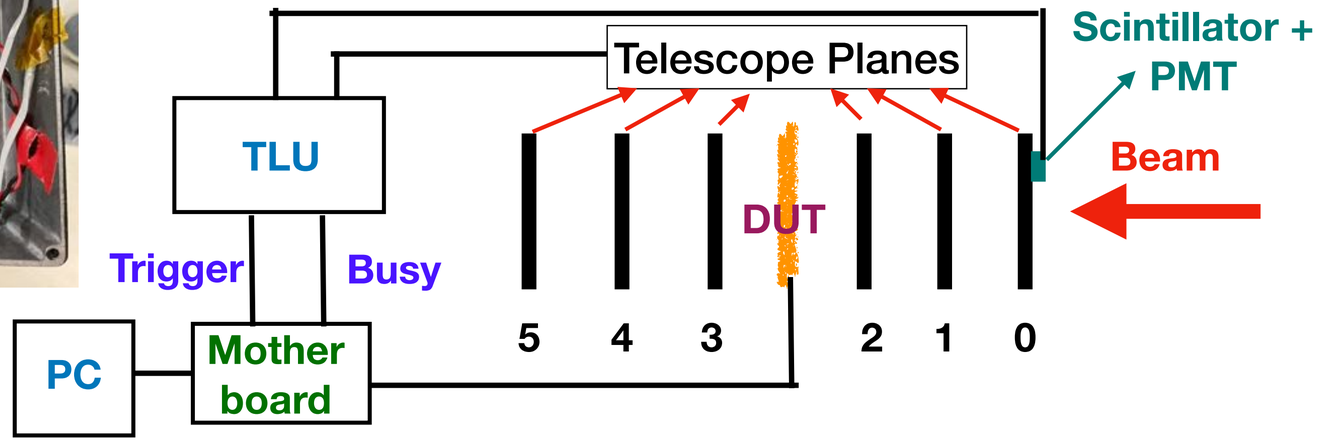
TestBeam Setup

- Data taken at DESY II
  - Electron beam with beam energy 3 GeV
  - ALiBaVa system is used for the readout

- Non-irradiated and irradiated sensors tested



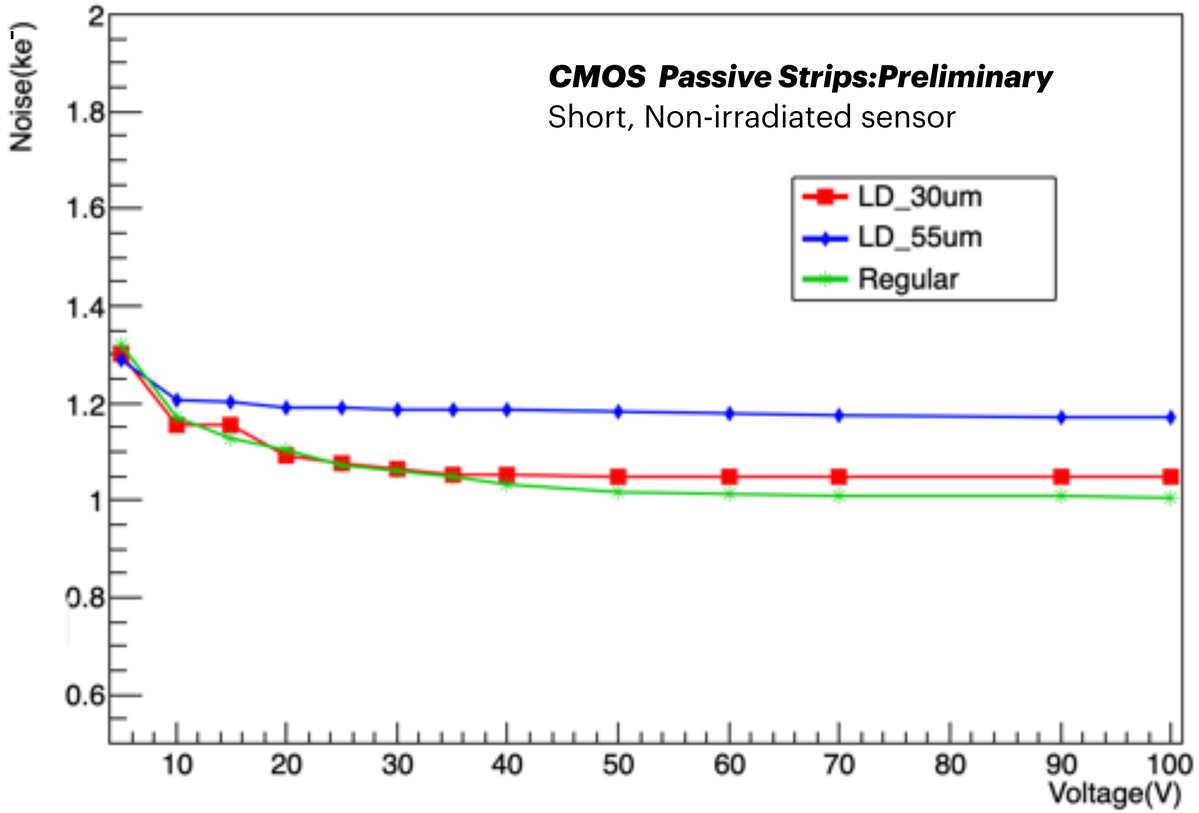


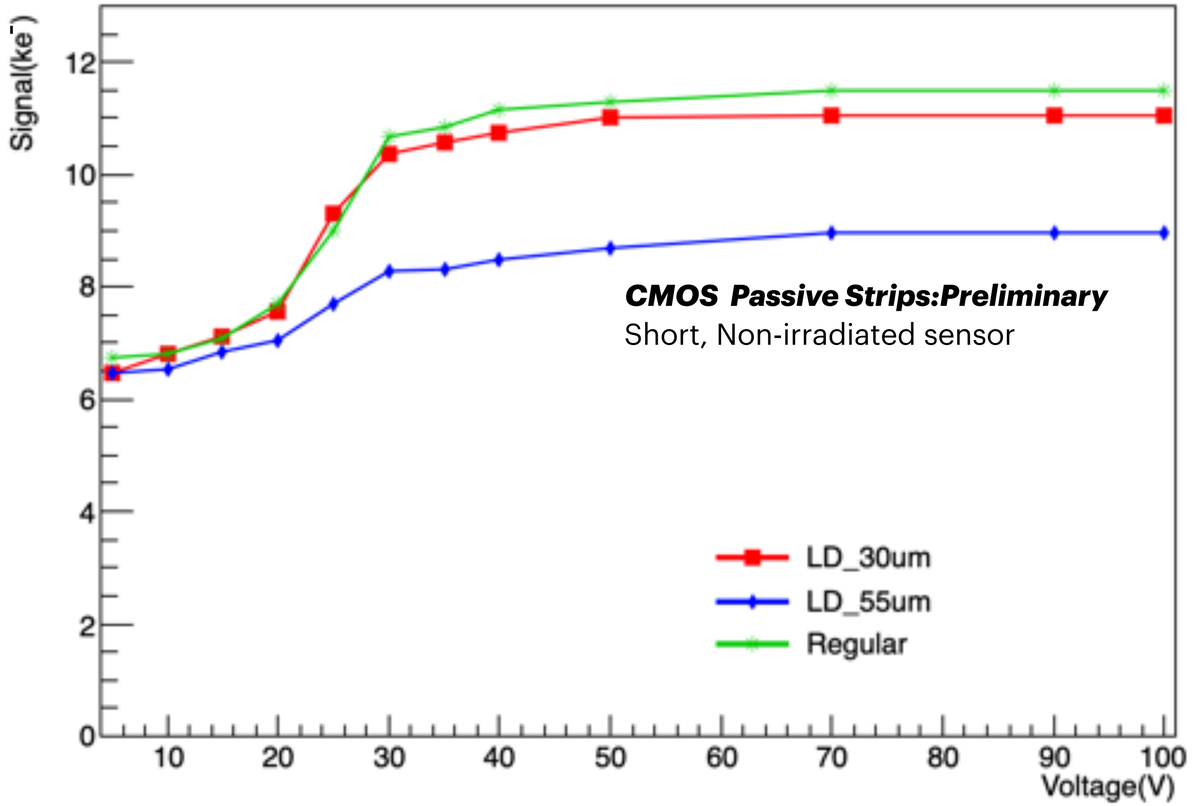


DESY.

Noise and Signal measurement

All measurements are performed at 18° C

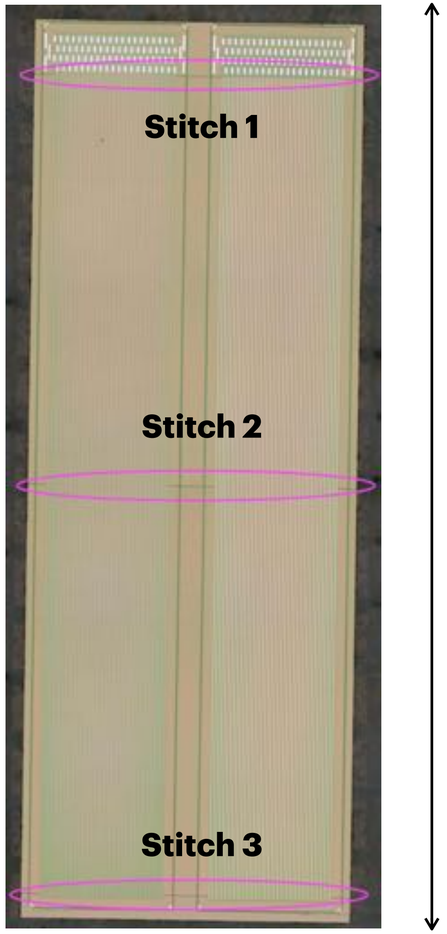




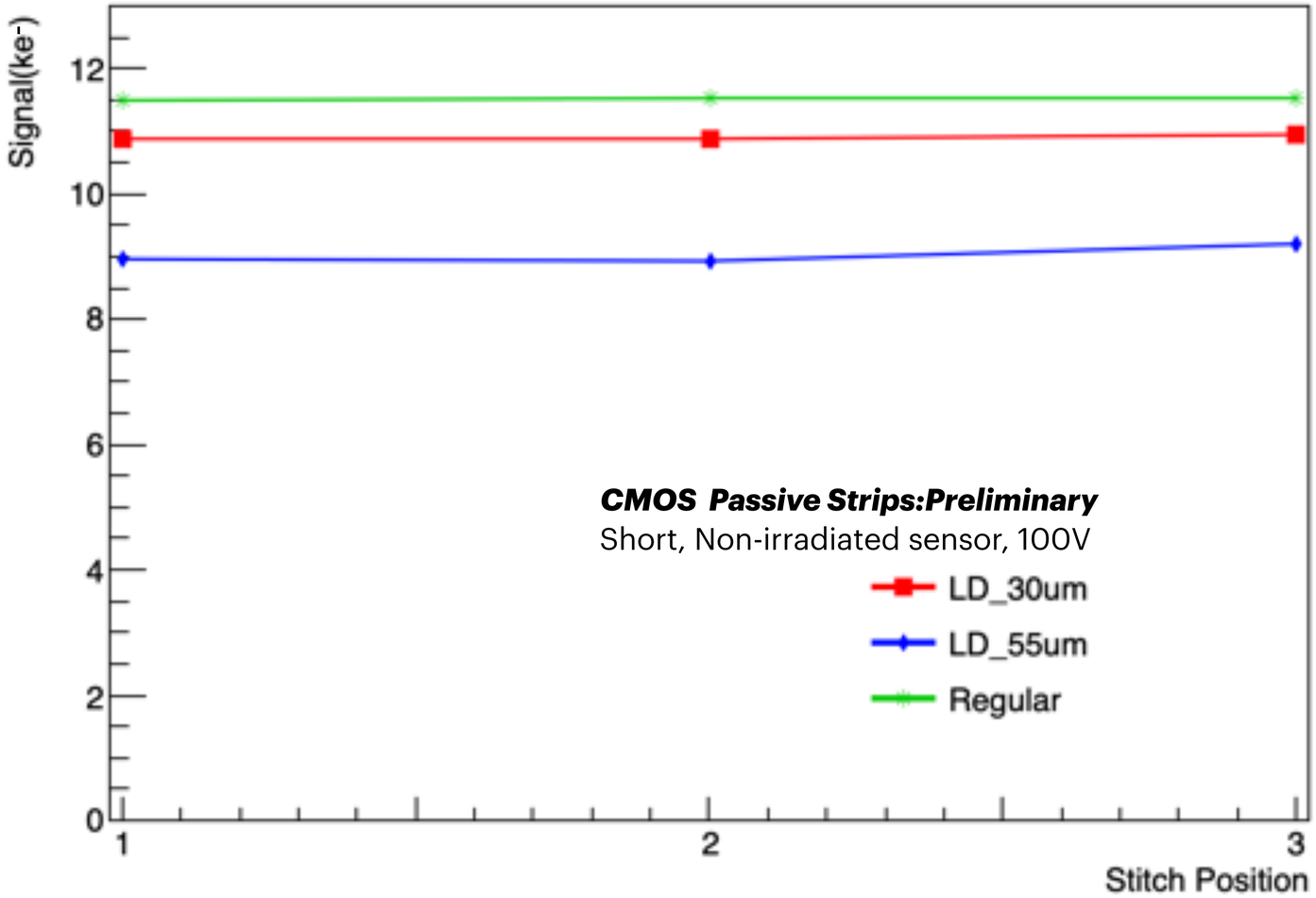
- The noise values decrease with voltage
- Highest signal in Regular sensor, low noise value for regular sensor
- Low dose 55 design has a systematic offset – possibly related to Beetle chip configuration (high capacitance)

Signal Collection

All measurements are performed at 18° C



2.1 cm



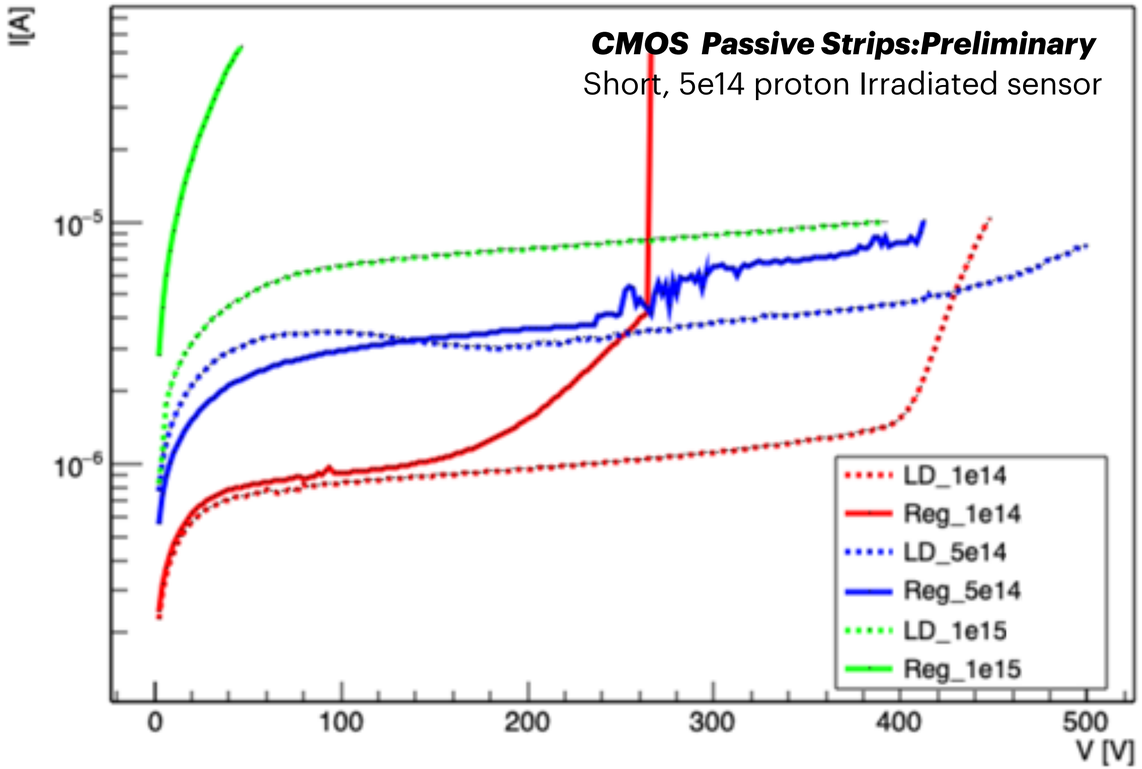
- No effect of stitching is visible for all the designs

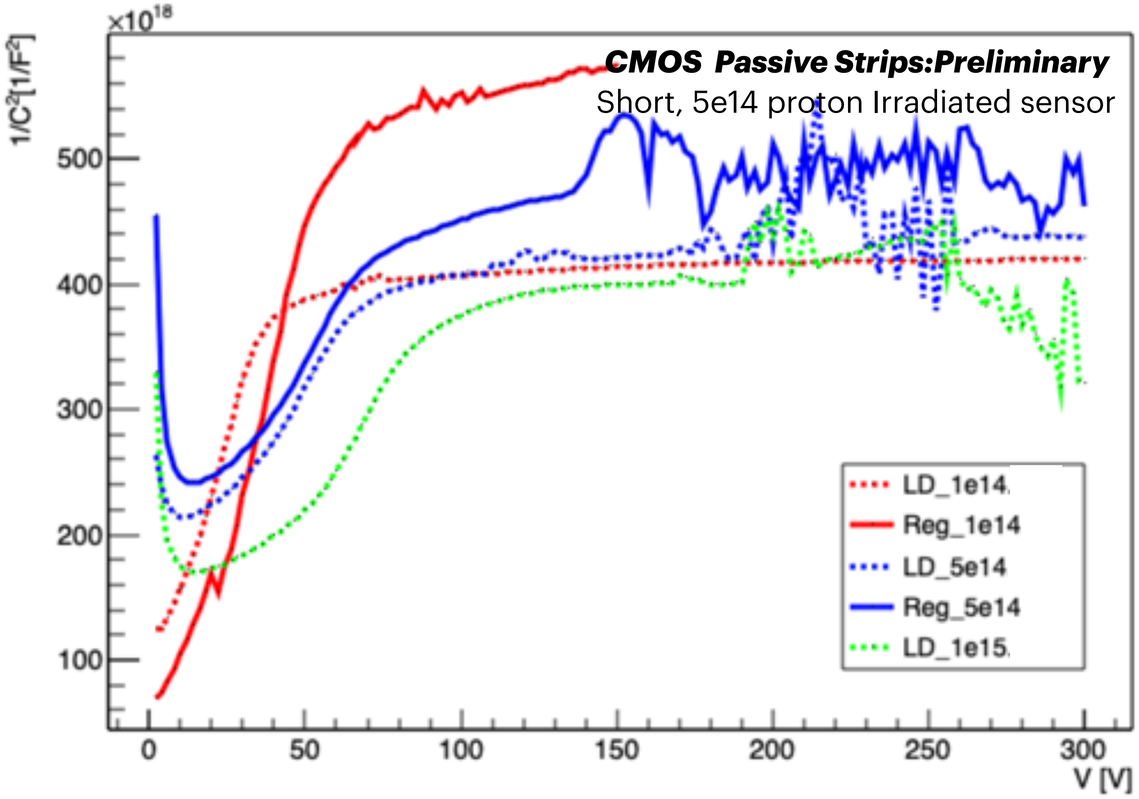
IRRADIATED SENSOR

IV and CV measurements

Sensors are irradiated at KIT with protons of 23 MeV energy

All measurements are performed at -20° C



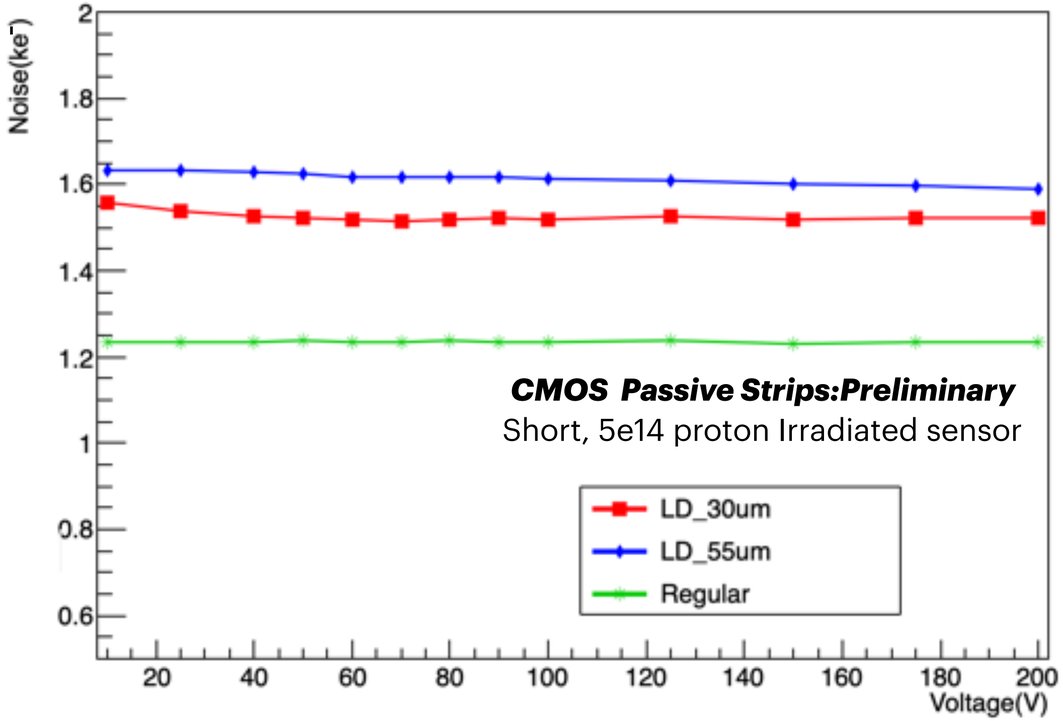


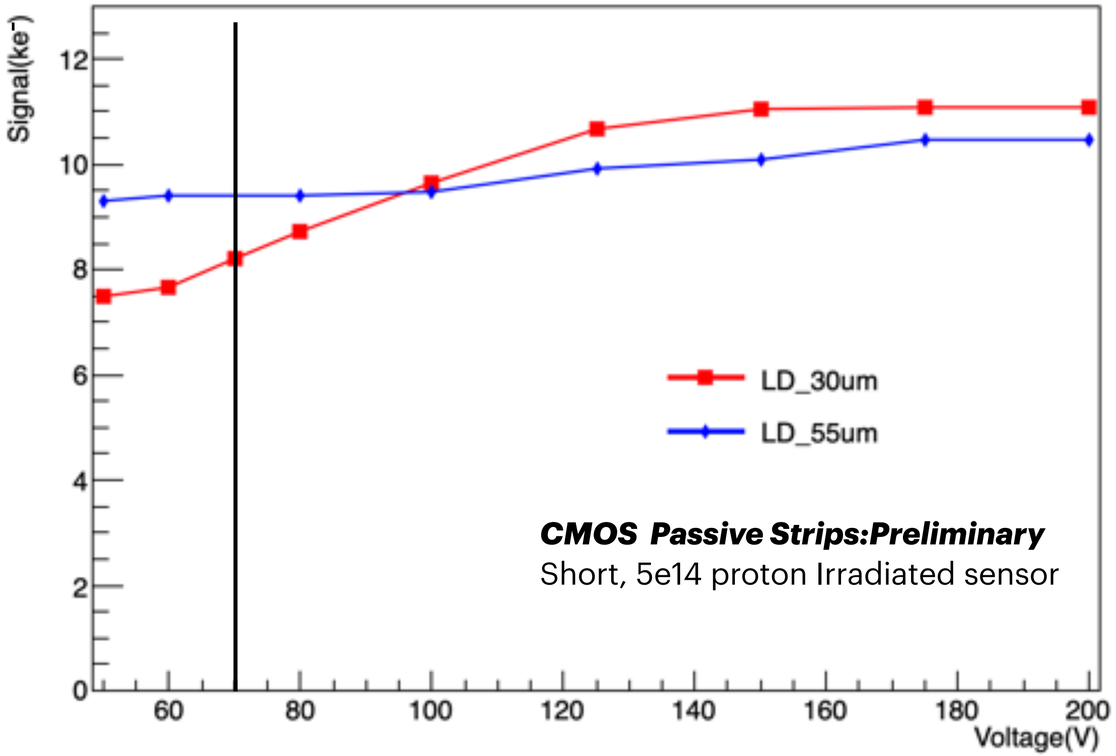
- Sensors are annealed at 60° C for 80 minutes
- IV measurements show both designs survive radiation damage up to the fluence of 1e15 $\frac{n_{eq}}{cm^2}$
- Because of radiation damage, current and depletion voltage increase with fluence

DESY.

Noise and Signal measurement

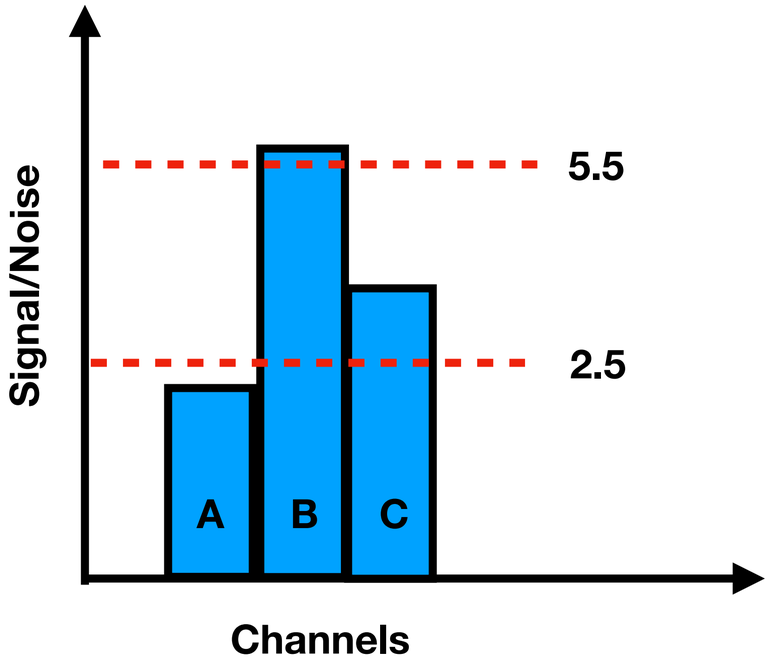
All measurements are performed at -16° C

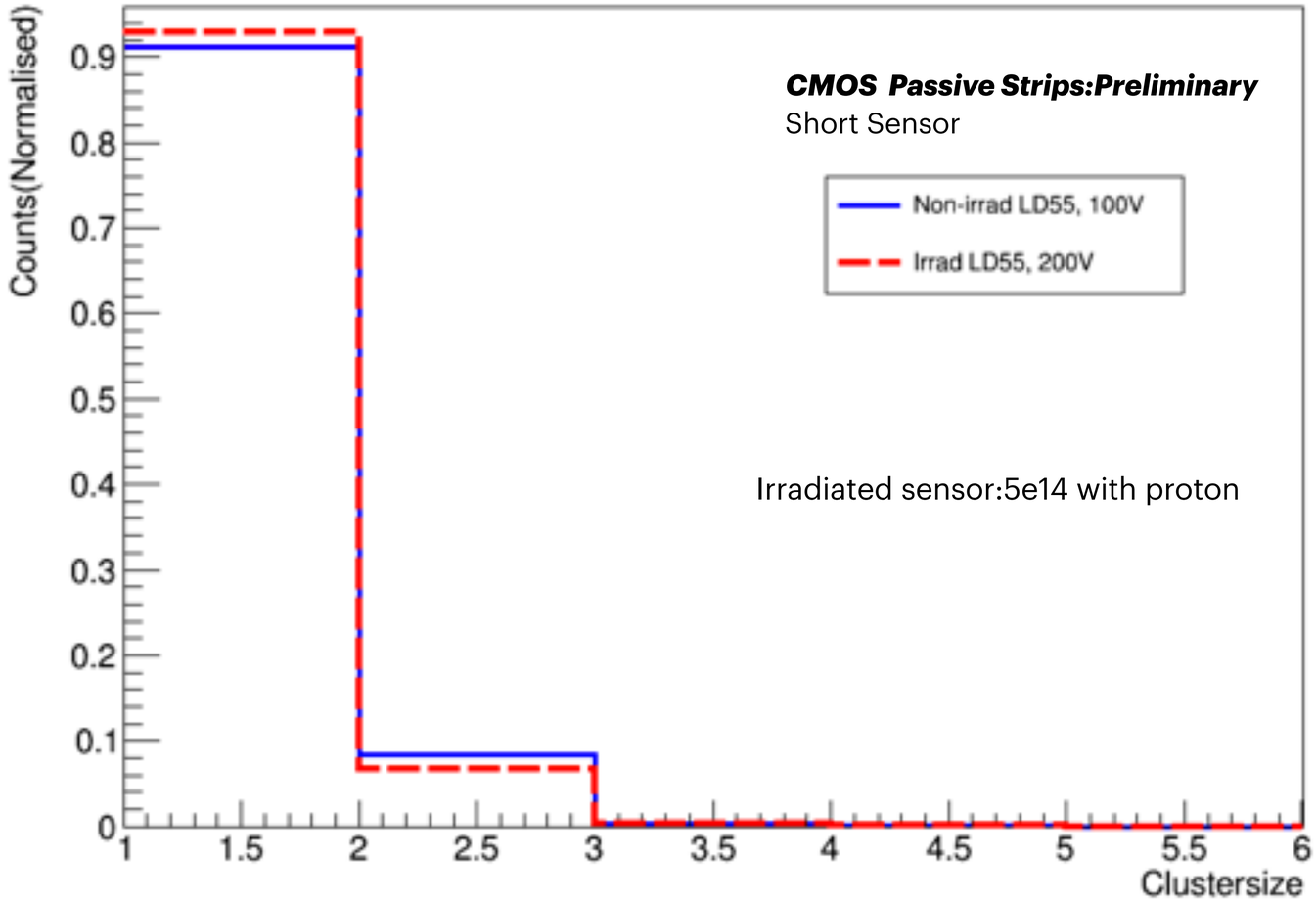




- The noise values show very little change with voltage
- Regular design shows no charge collection
- LD30 shows higher signal collection than LD55 for higher voltages -> high capacitance for LD55
- For lower voltage, higher noise and seed cut for LD55 -> threshold values increase

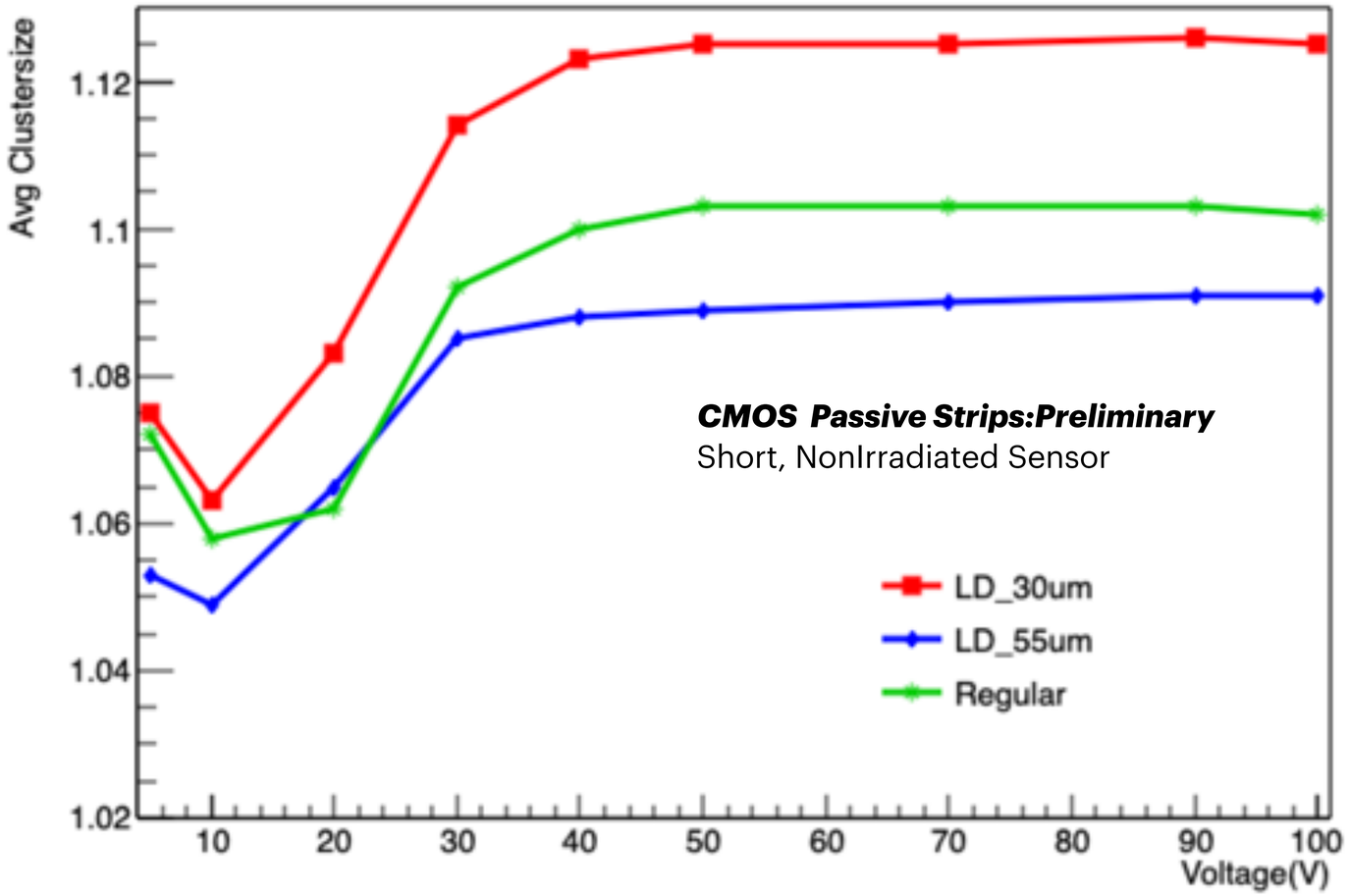
Cluster size





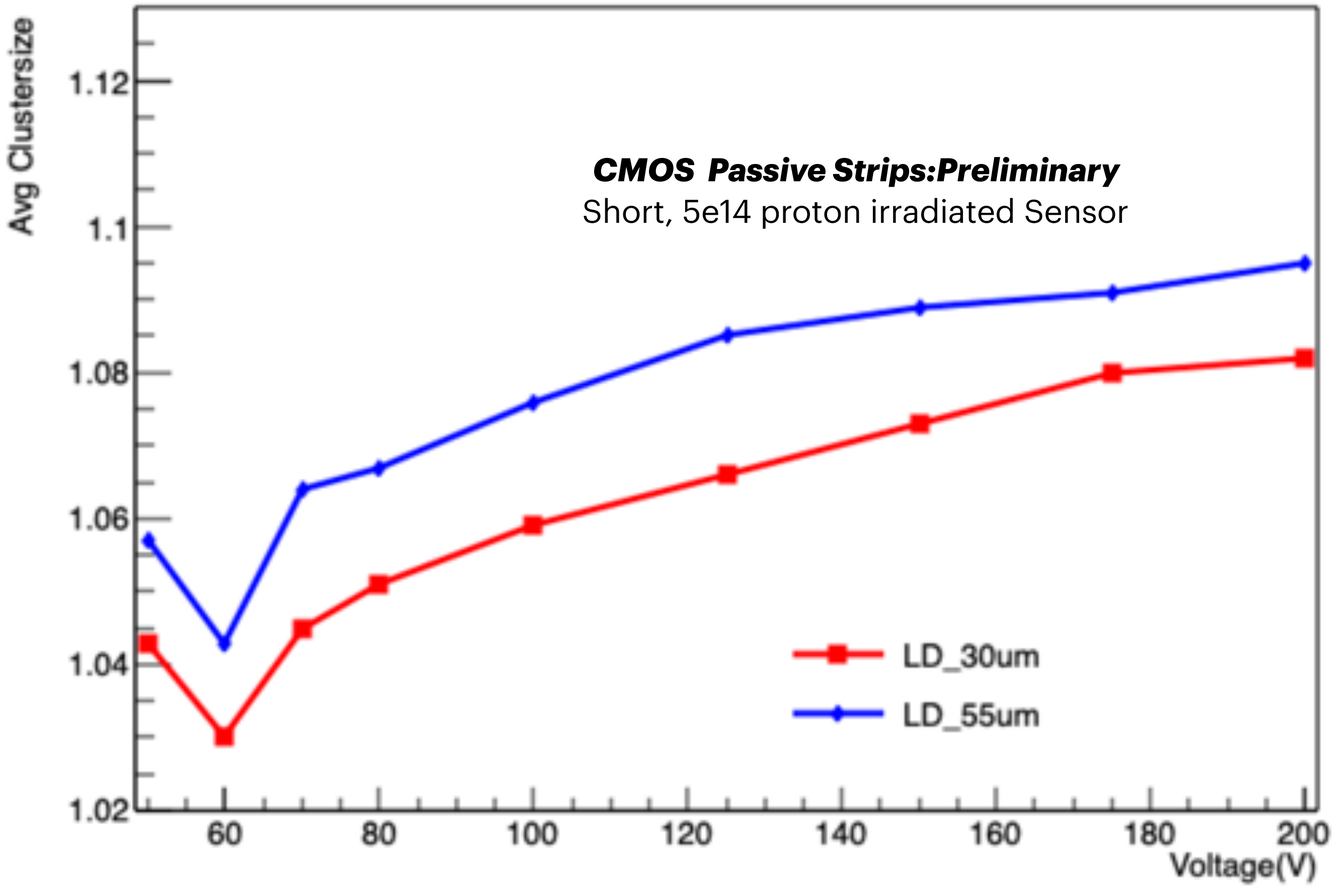
- Cluster size calculated with maximum of 5 strips
- With irradiation -> Cluster size decreases

Cluster size



- Cluster size become stable after depletion voltage for non irradiated sensors
- Higher cluster size for LD30 -> high interstrip capacitance
- For LD55 -> high noise value, increases the threshold cut for signal -> reducing the cluster size
- For lowest voltage approximately no signal collection is observed

Cluster size



- For irradiated sensor, the cluster size doesn't increase much (4%)
- Because of radiation damage effects -> keeps increasing for higher voltage
- For LD30, small number of channels are available after irradiation (high noise)
- For lowest voltage approximately no signal collection is observed

Summary

- Initial characterisation of CMOS strip sensors shows promising results
- No negative effects of stitching are observed for charge collection
- Irradiation with different fluences(up to 5e14 $\frac{n_{eq}}{cm^2}$) shows LowDose design is more radiation tolerant
- Regular design performance degraded after irradiation
- The used S/N cut of 5.5 maybe too high -> low signal confirmed with a neutron irradiated sensor in a beta set-up

Outlook

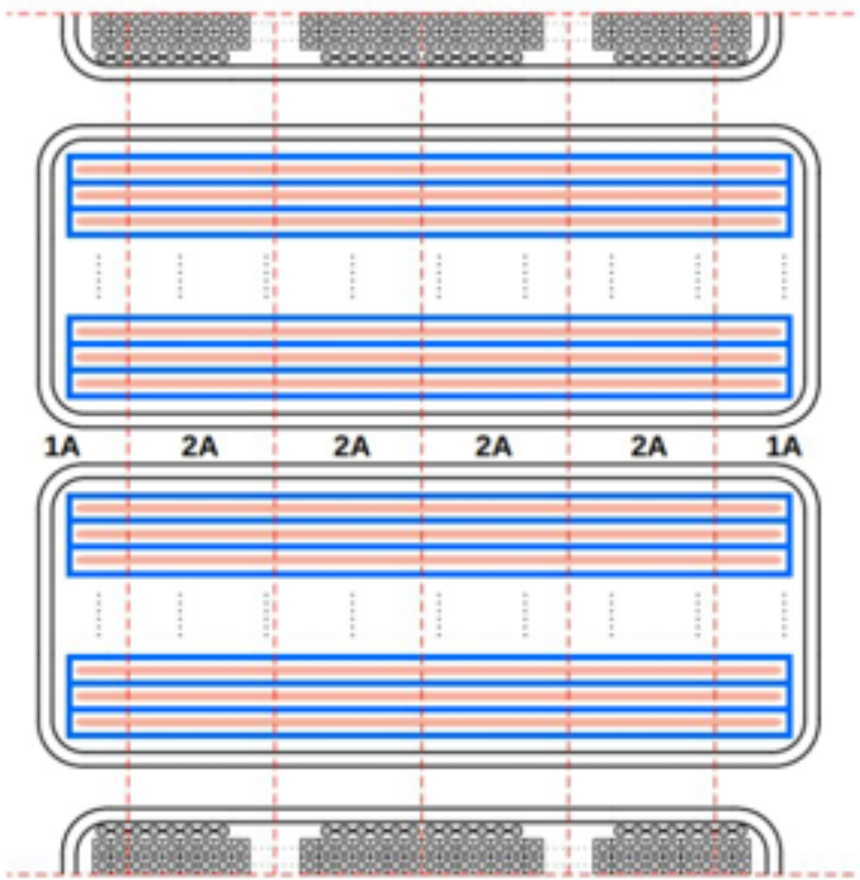
➢ Further analysis for test beam data is ongoing
➢ TCT and charge collection measurements of irradiated sample are ongoing

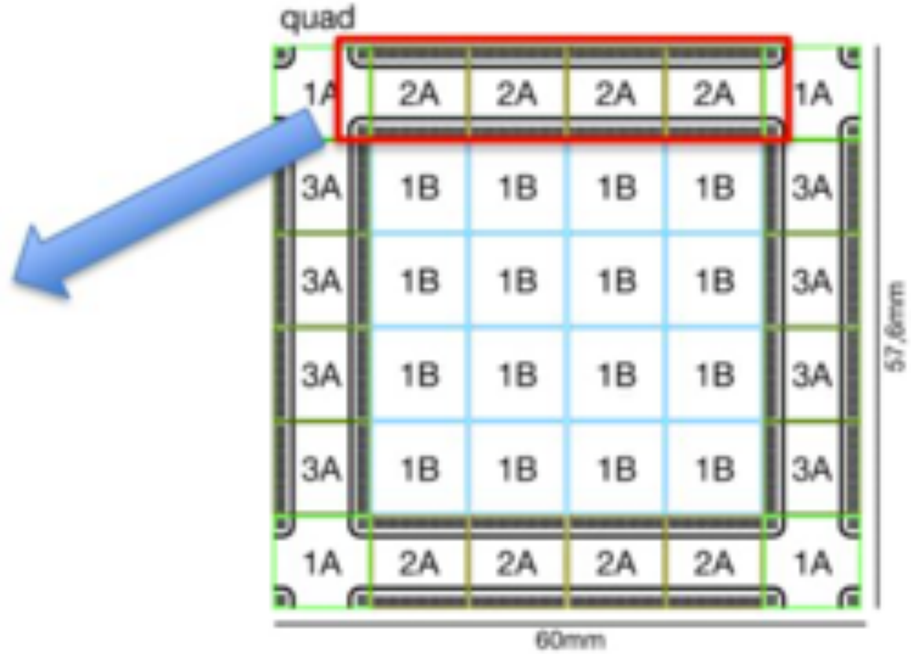
Thank You for Attention

The measurements leading to these results have been performed at the Test Beam Facility at DESY Hamburg (Germany), a member of the Helmholtz Association (HGF)

Back-up

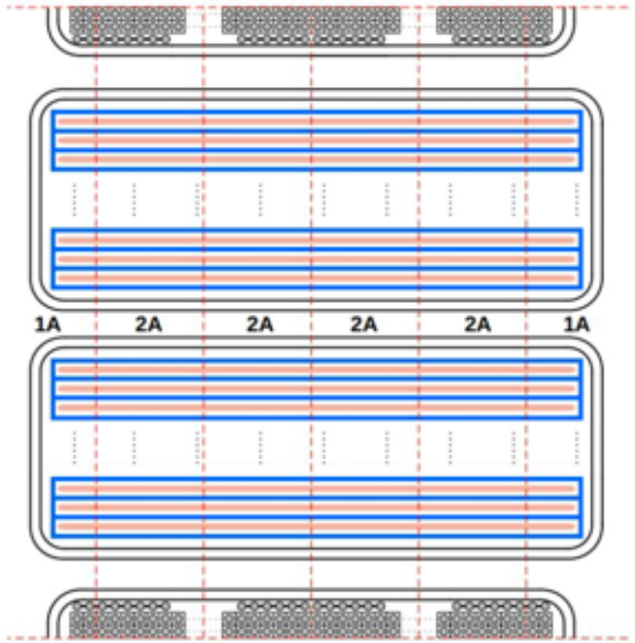
Wafer design

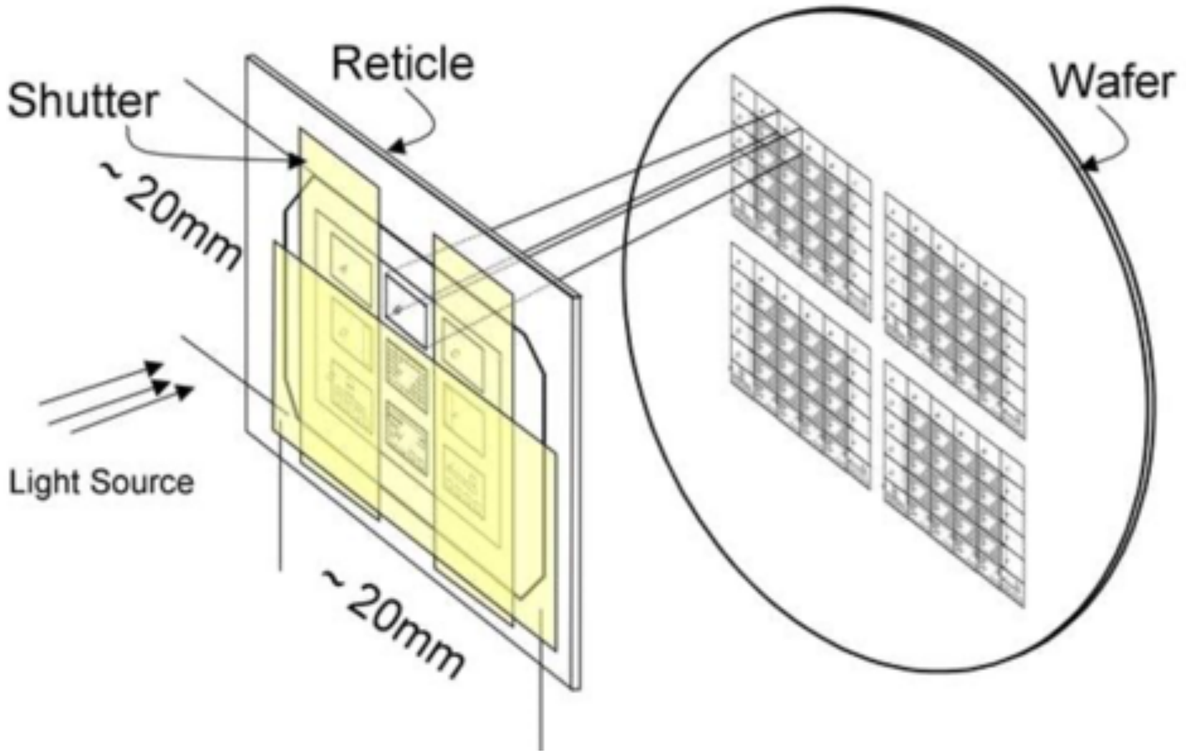




- Strip sensor implemented in 1/2A
- Stitched every ~1 cm along strip length

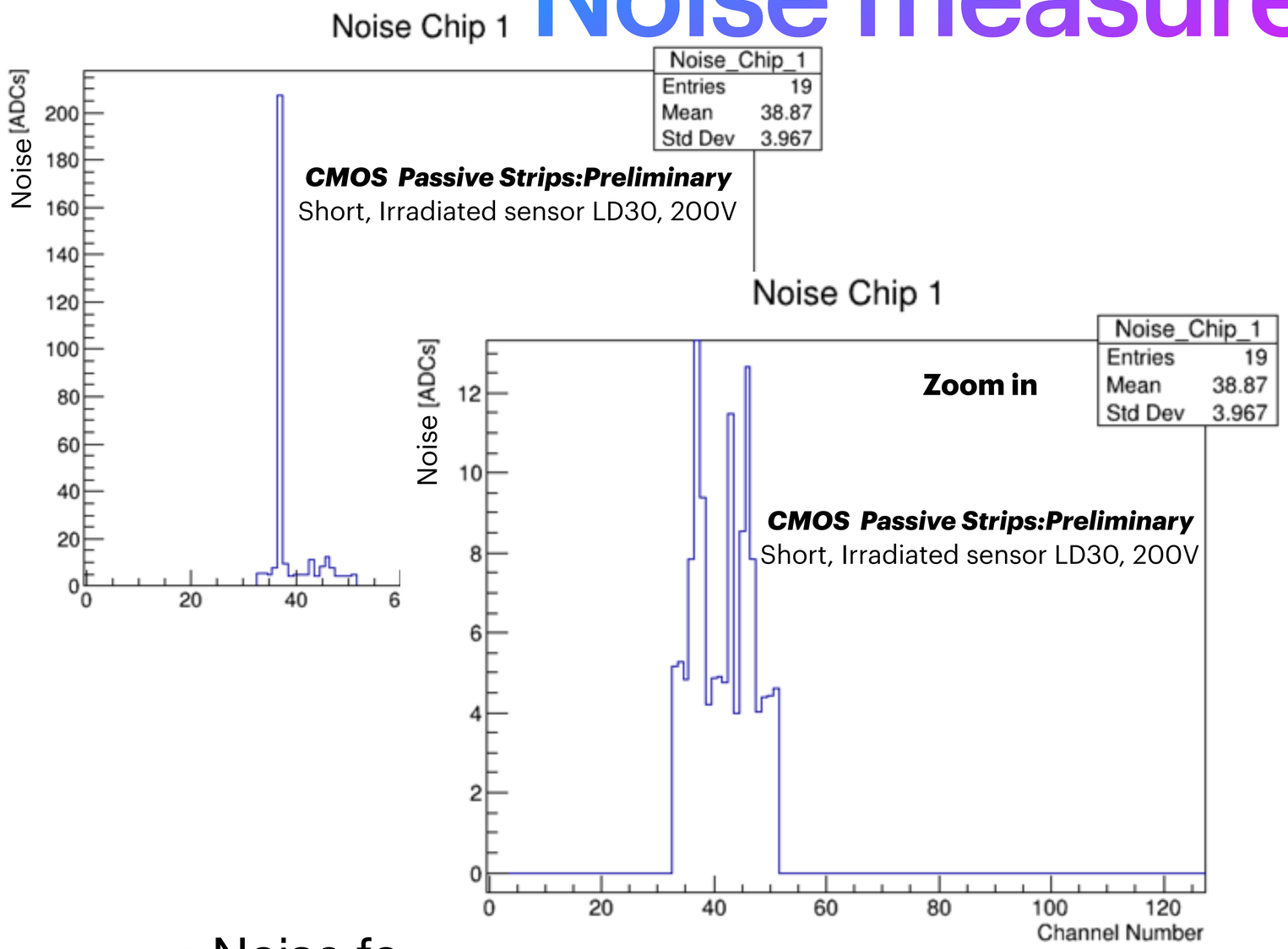
Stitching design



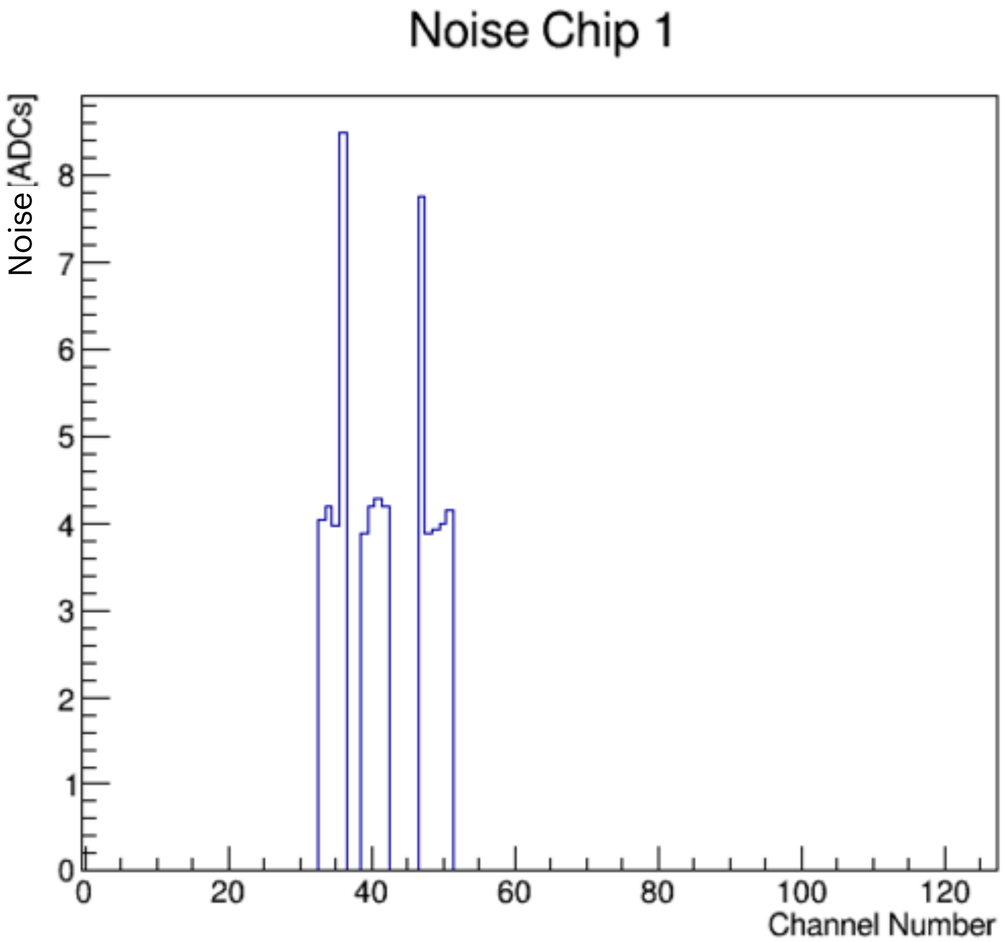


- Stitching merges multiple design structures on a wafer during the photolithographic process -> creates large sensor

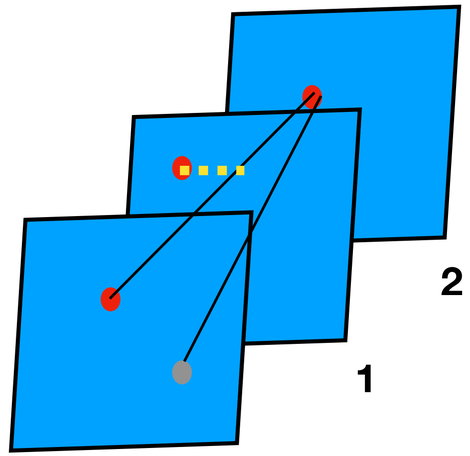
Noise measurement



- Noise for all the channels for the LD30

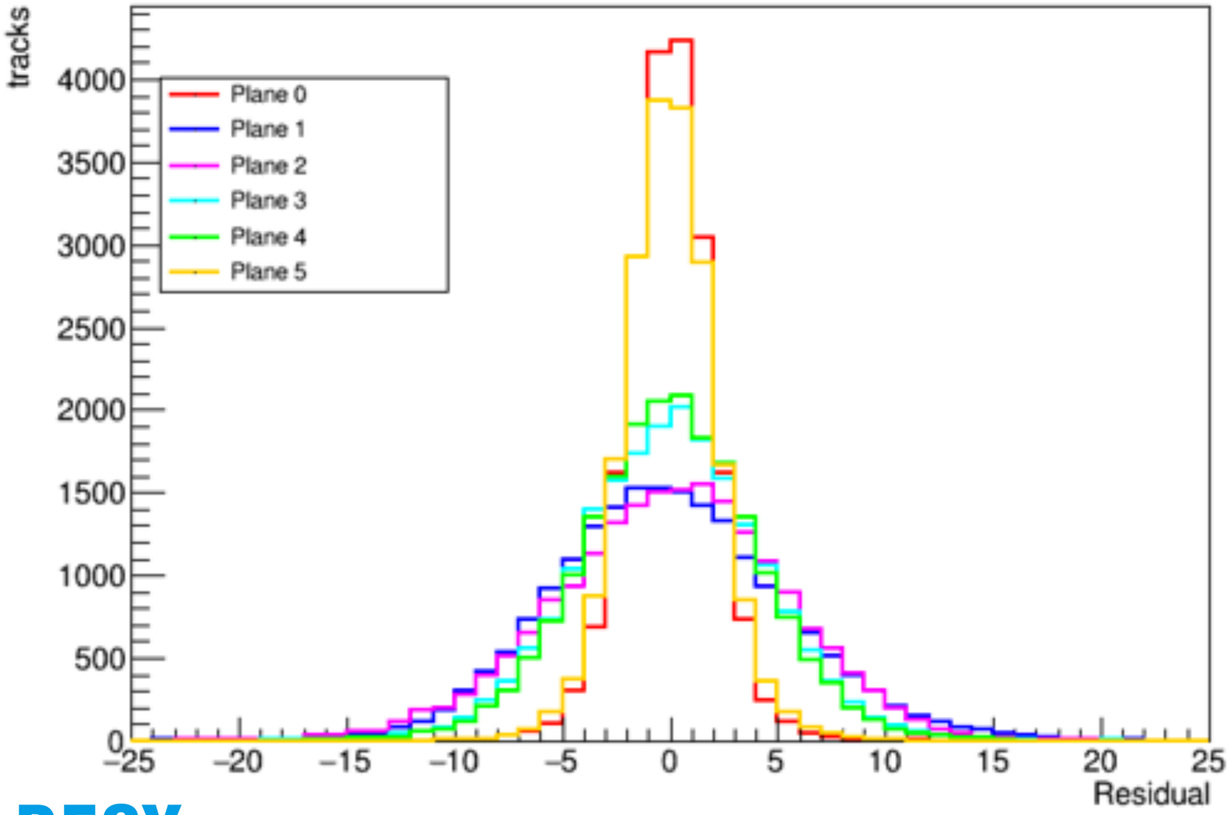


- Noise after high noise channels are masked

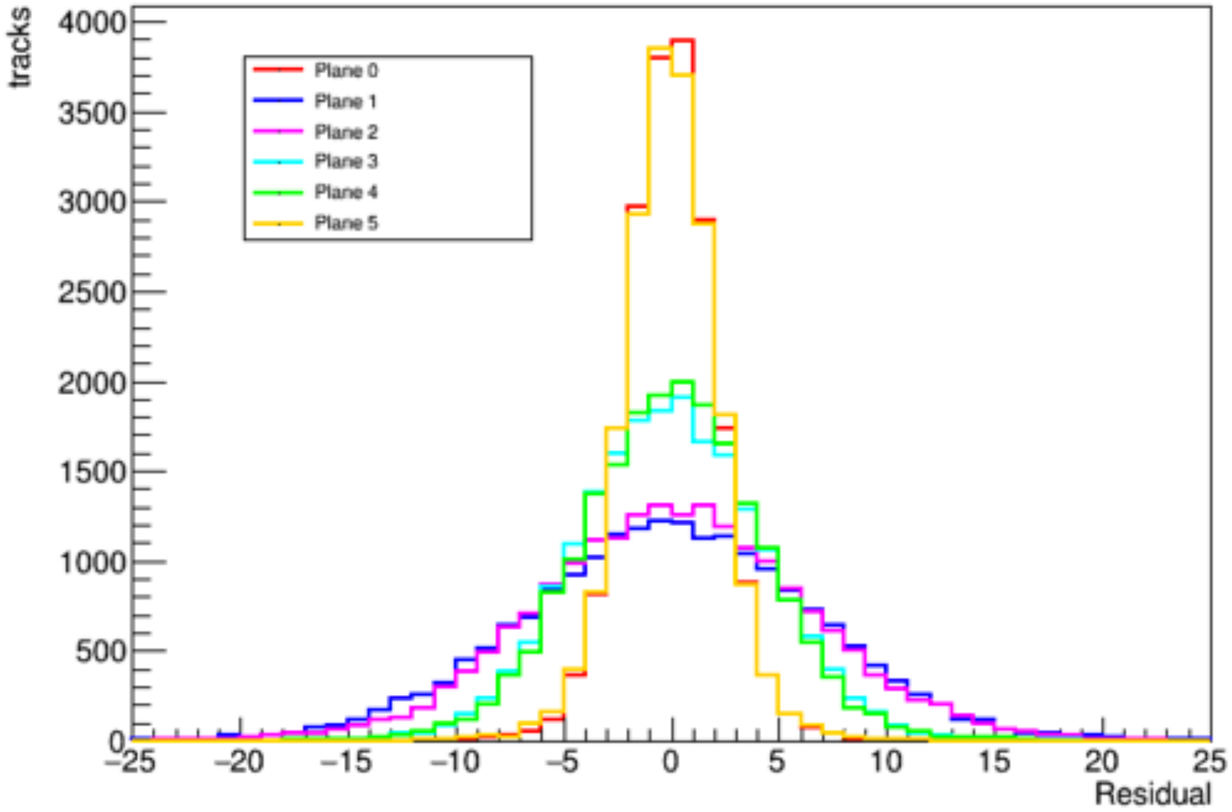


Tracks Parameters

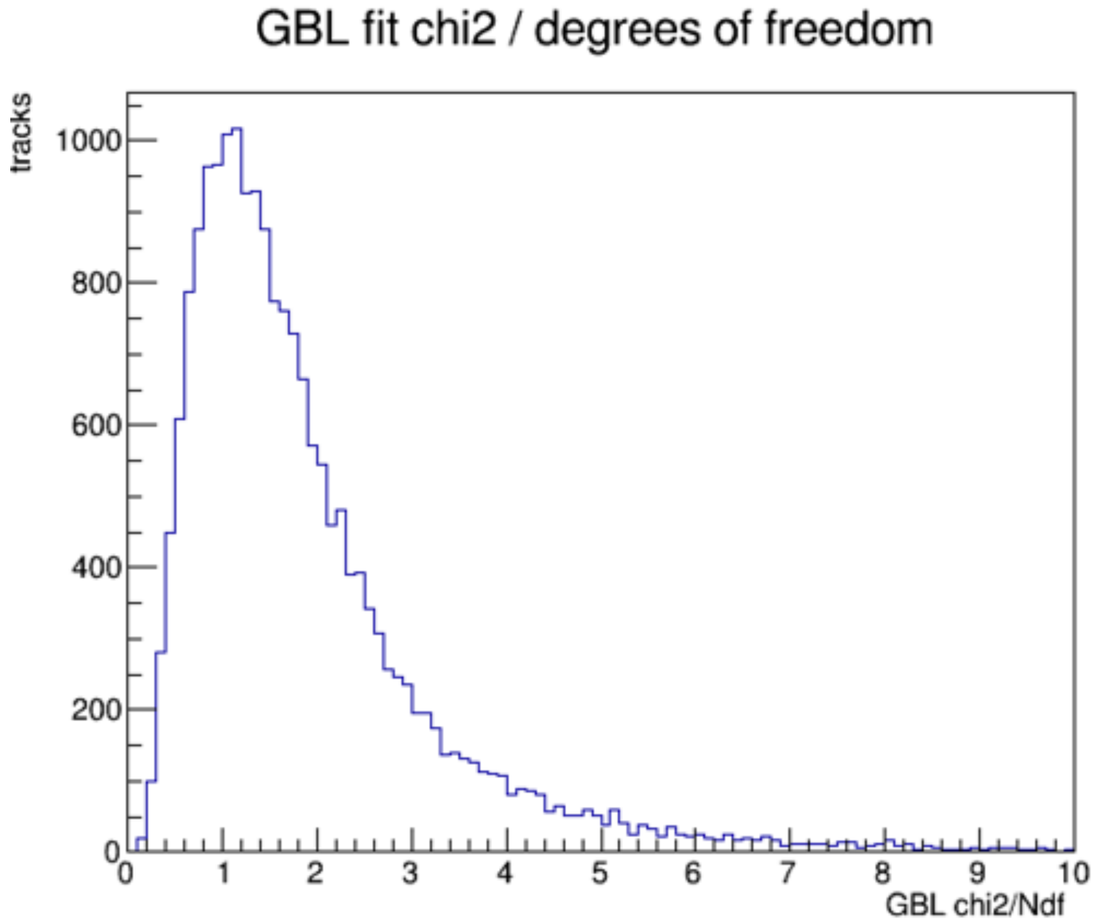
Residual in Y



Residual in X

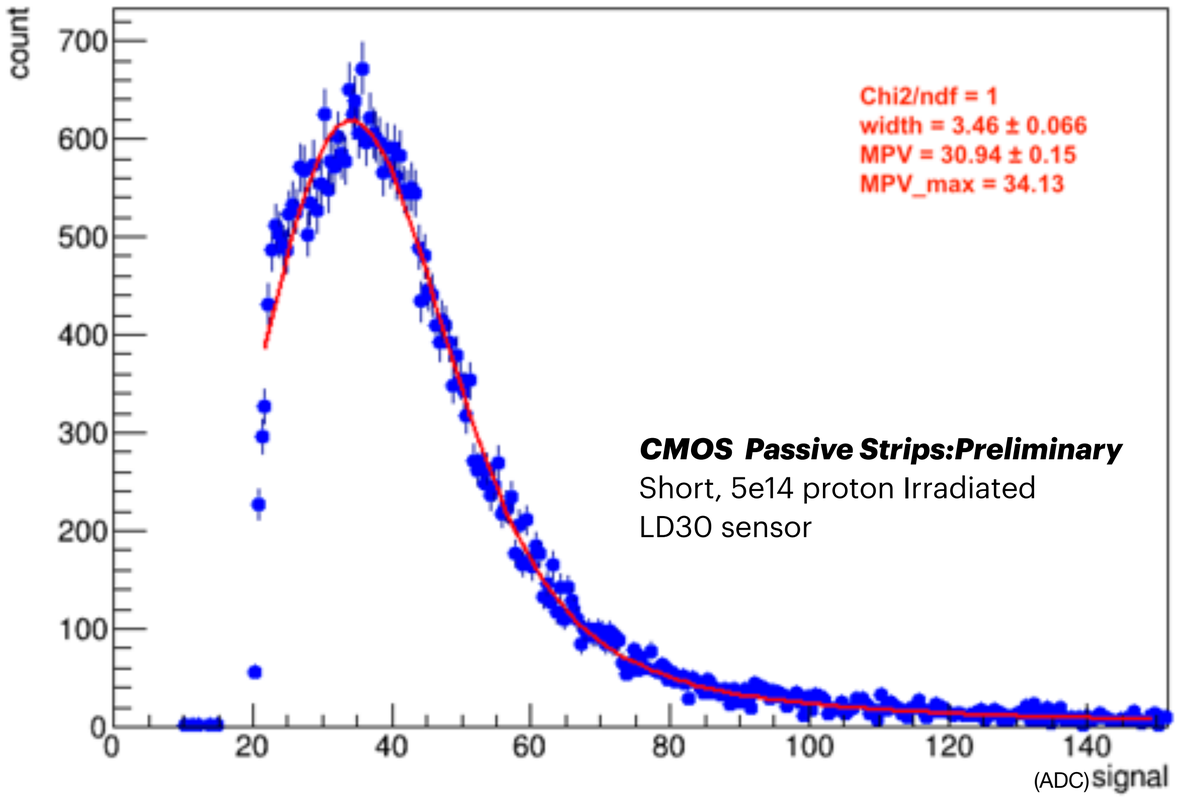


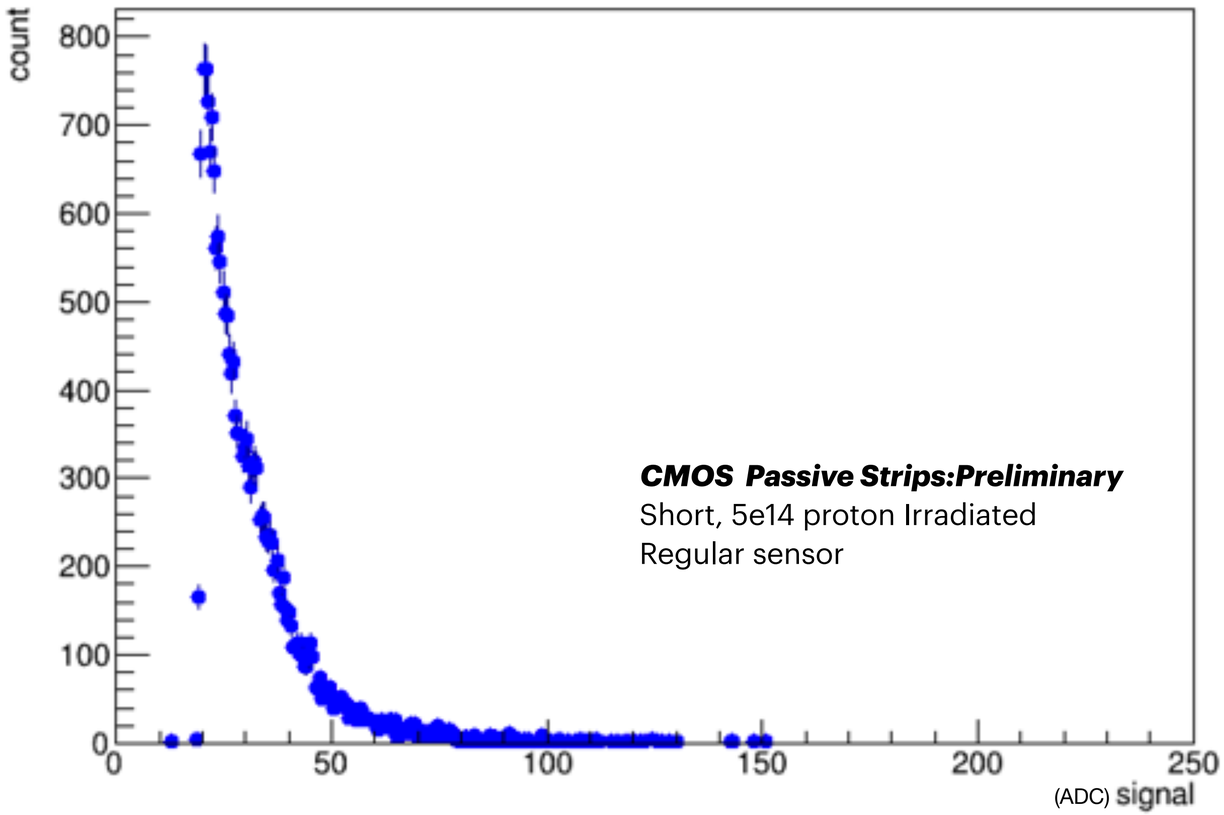
Tracks Parameters



Signal Collection

All measurements are performed at -16° C

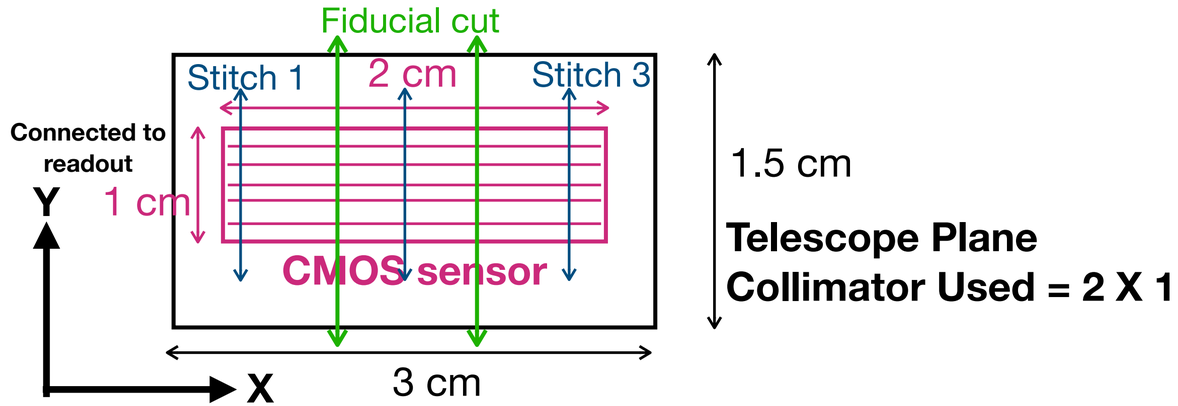


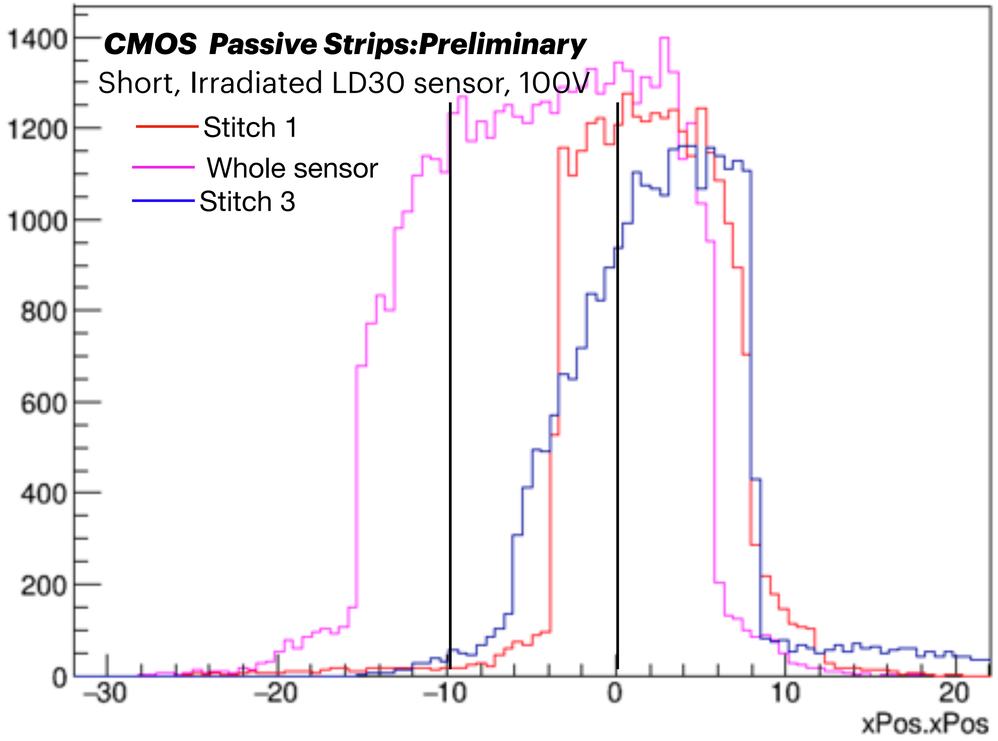


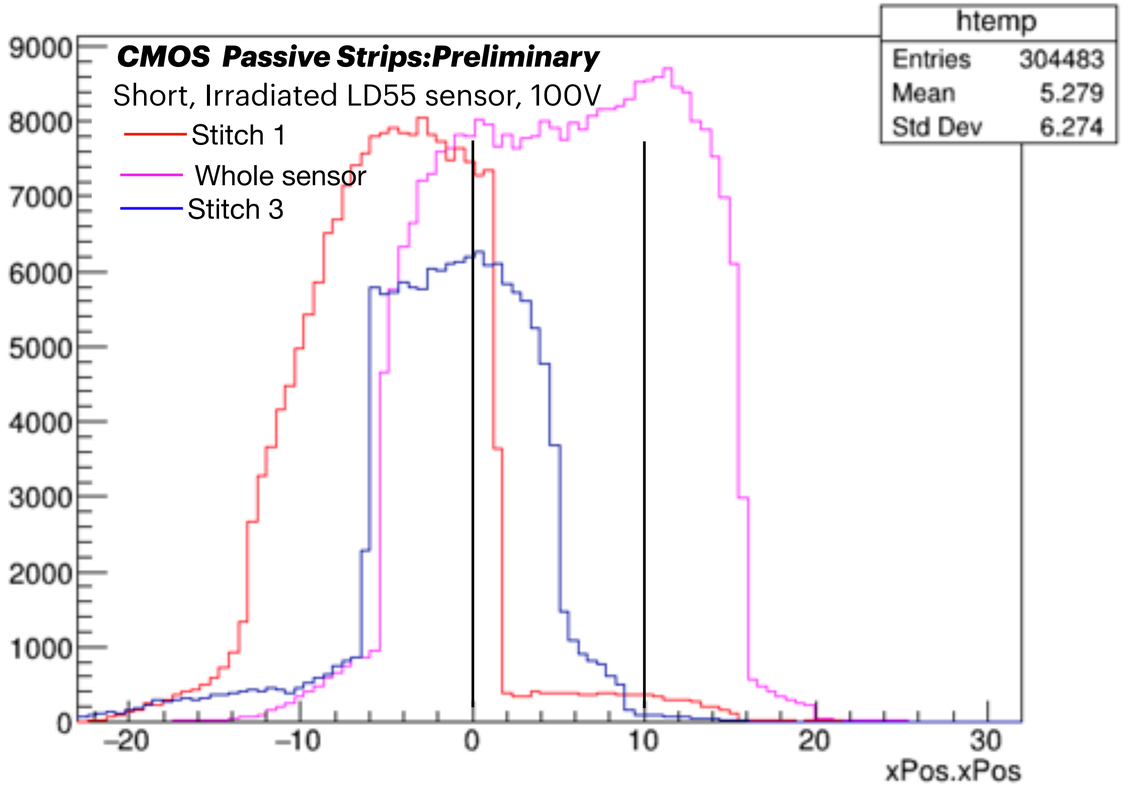
- Signal plot for LD30 and Regular sensor
- No charge collection is seen for Regular sensor

DESY.

Tracks Cuts across strips







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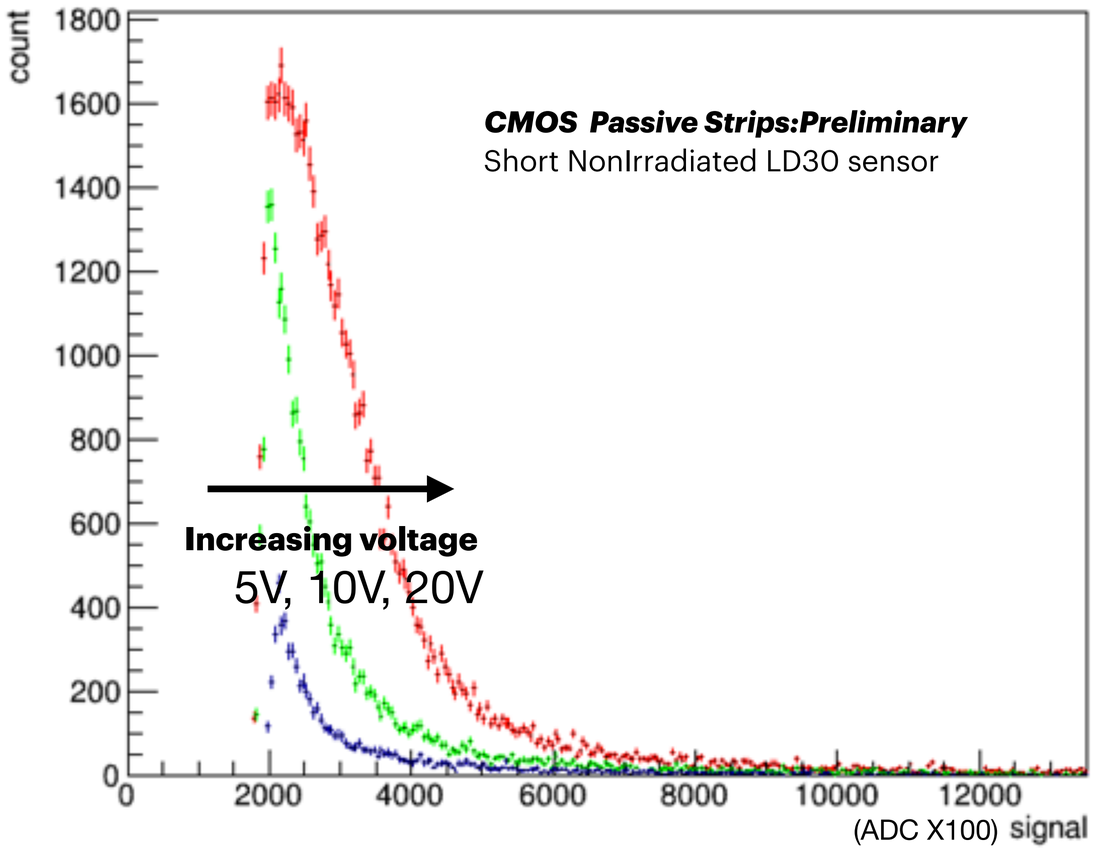
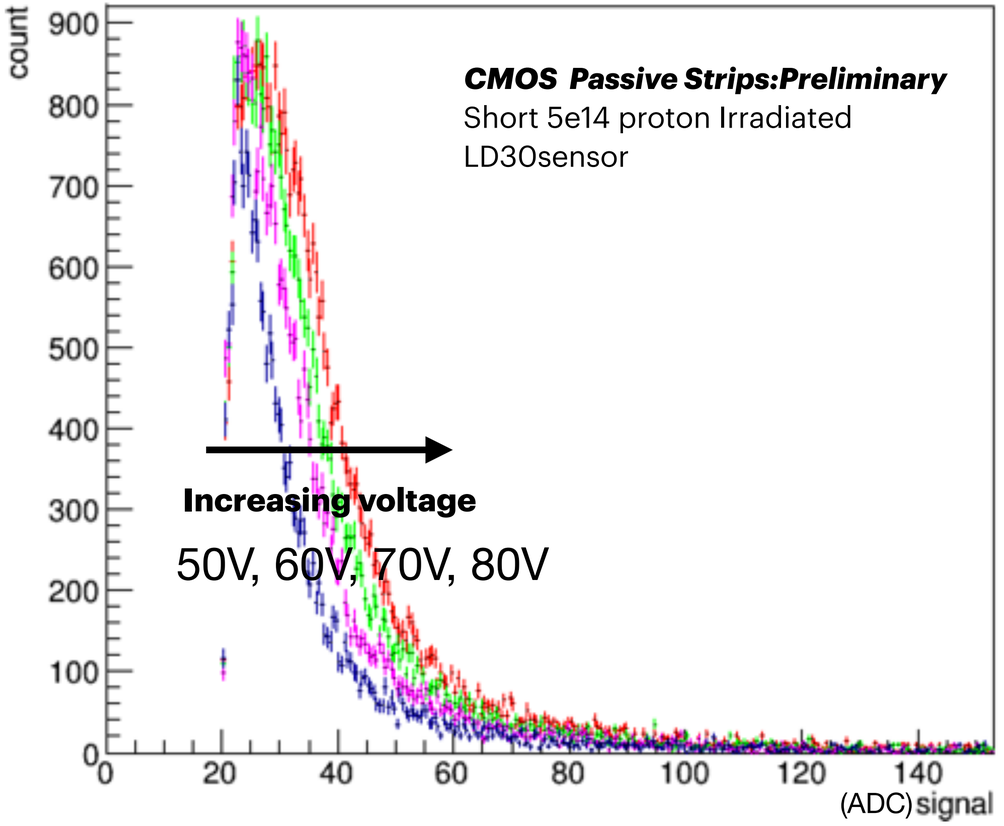
Signal Plot


count
1800
1600
1400
1200
1000
800
600
400
200
0
0
2000
4000
6000
8000
10000
12000
(ADC X100) signal
CMOS Passive Strips:Preliminary
Short NonIrradiated LD30 sensor
Increasing voltage
5V, 10V, 20V


count
900
800
700
600
500
400
300
200
100
0
0
20
40
60
80
100
120
140
(ADC) signal
CMOS Passive Strips:Preliminary
Short 5e14 proton Irradiated
LD30sensor
Increasing voltage
50V, 60V, 70V, 80V