Test Beam Studies of Passive CMOS Strips

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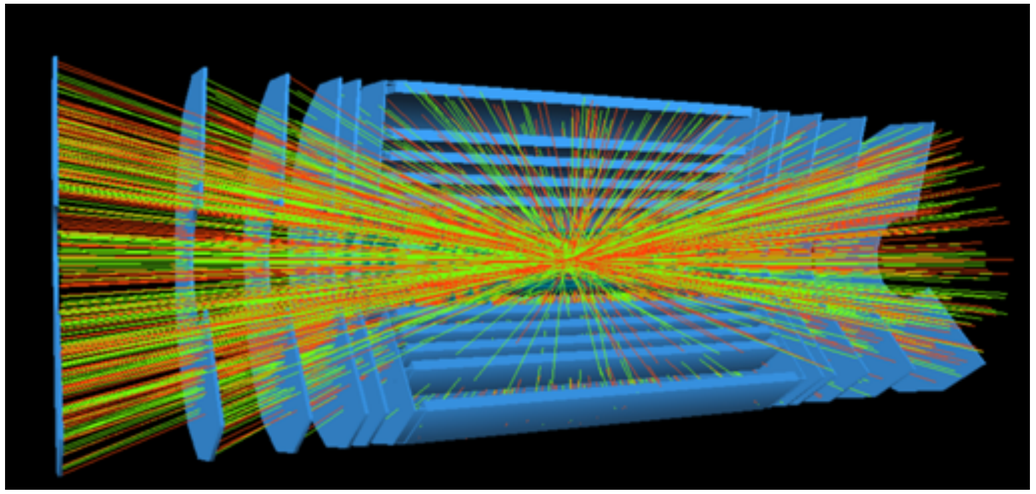
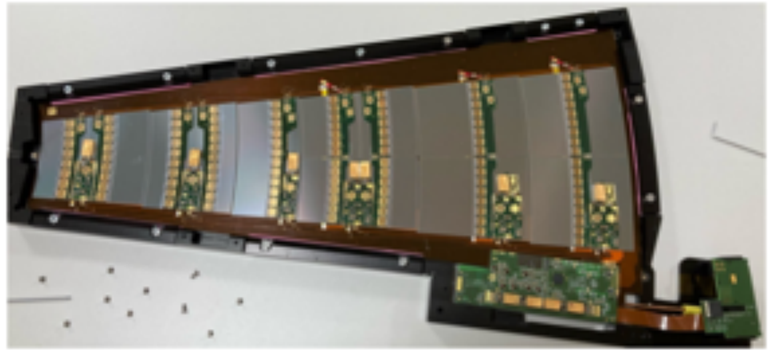
Motivation for passive CMOS

- **Requirements for future HEP detectors**
  - All silicon-based tracker
  - Large surface
  - 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

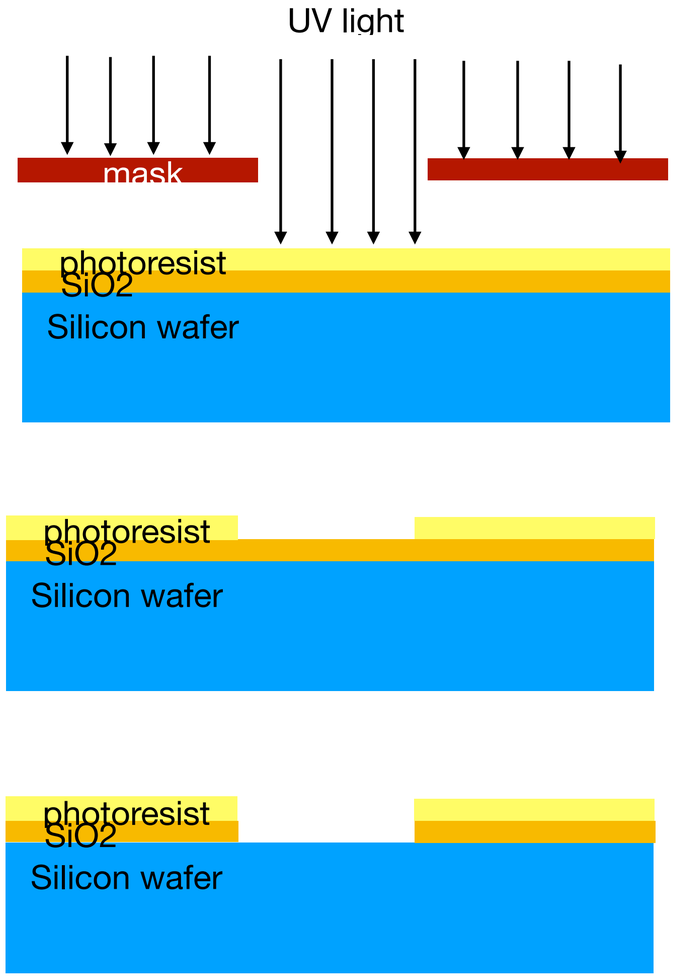


Picture of ATLAS endcap structure showing silicon strip sensor with up to 10 X 10 cm^2

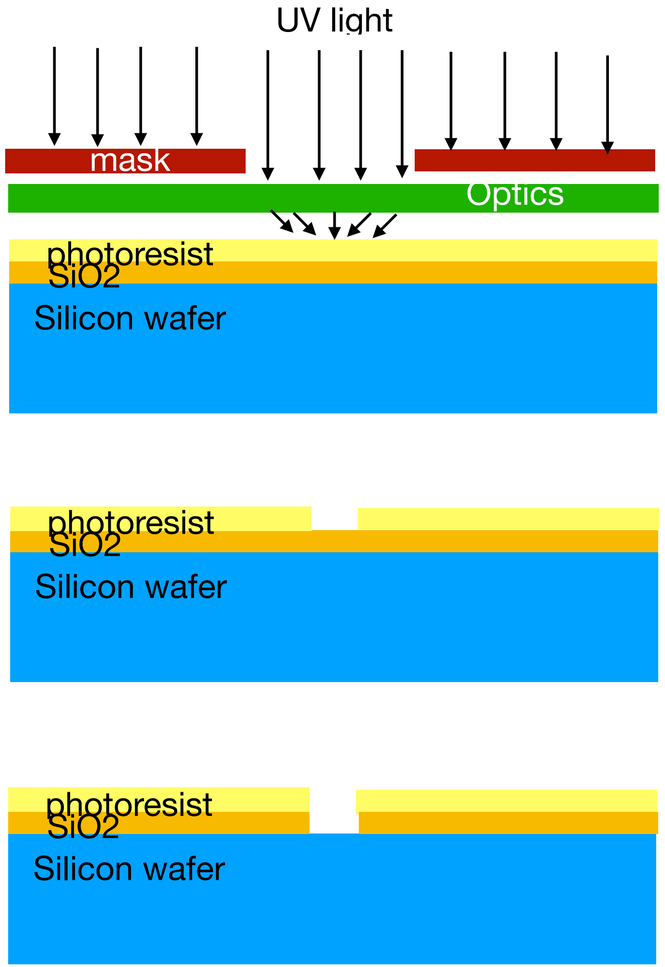
CMOS processing

- CMOS processing compared to microelectronics processing

Microelectronics photolithography

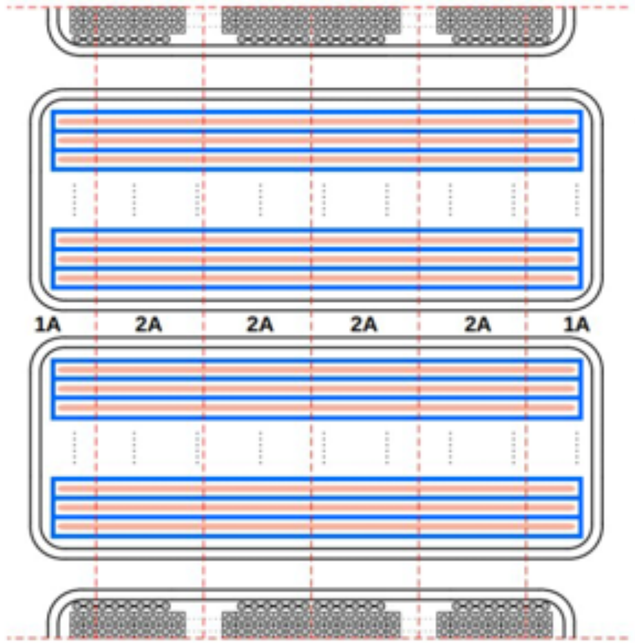


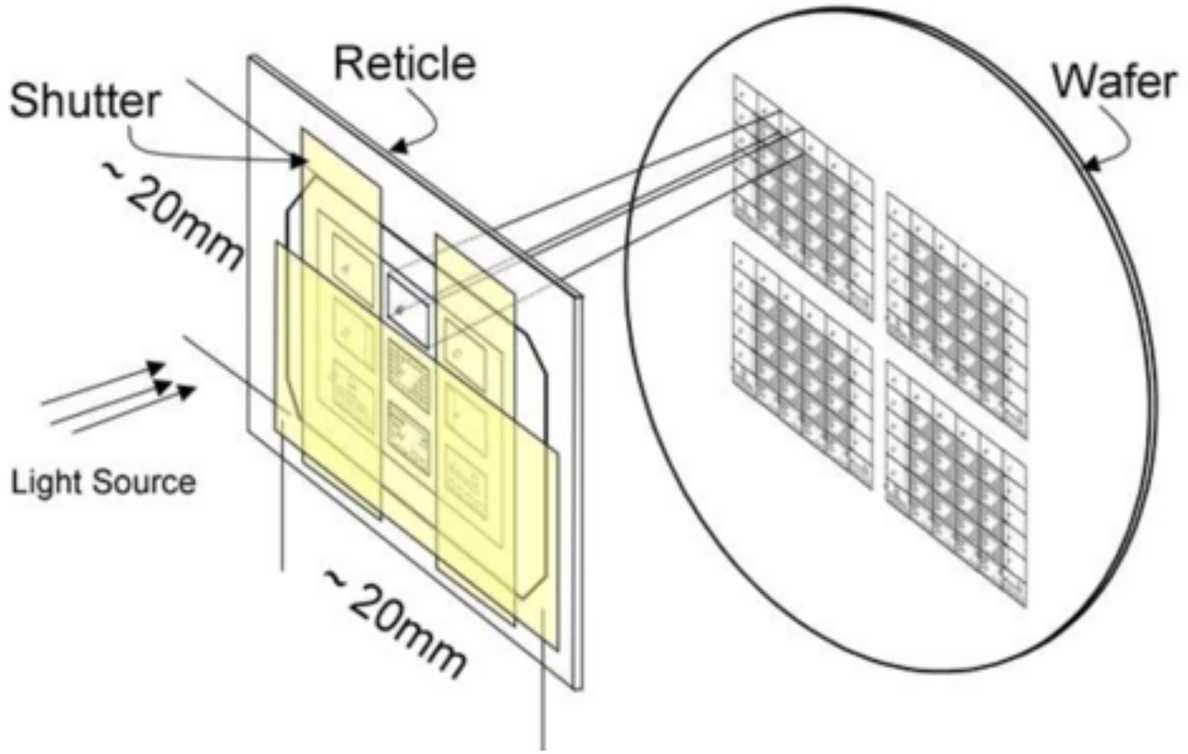
CMOS photolithography



- Using CMOS processing enables more detailed sensor structure

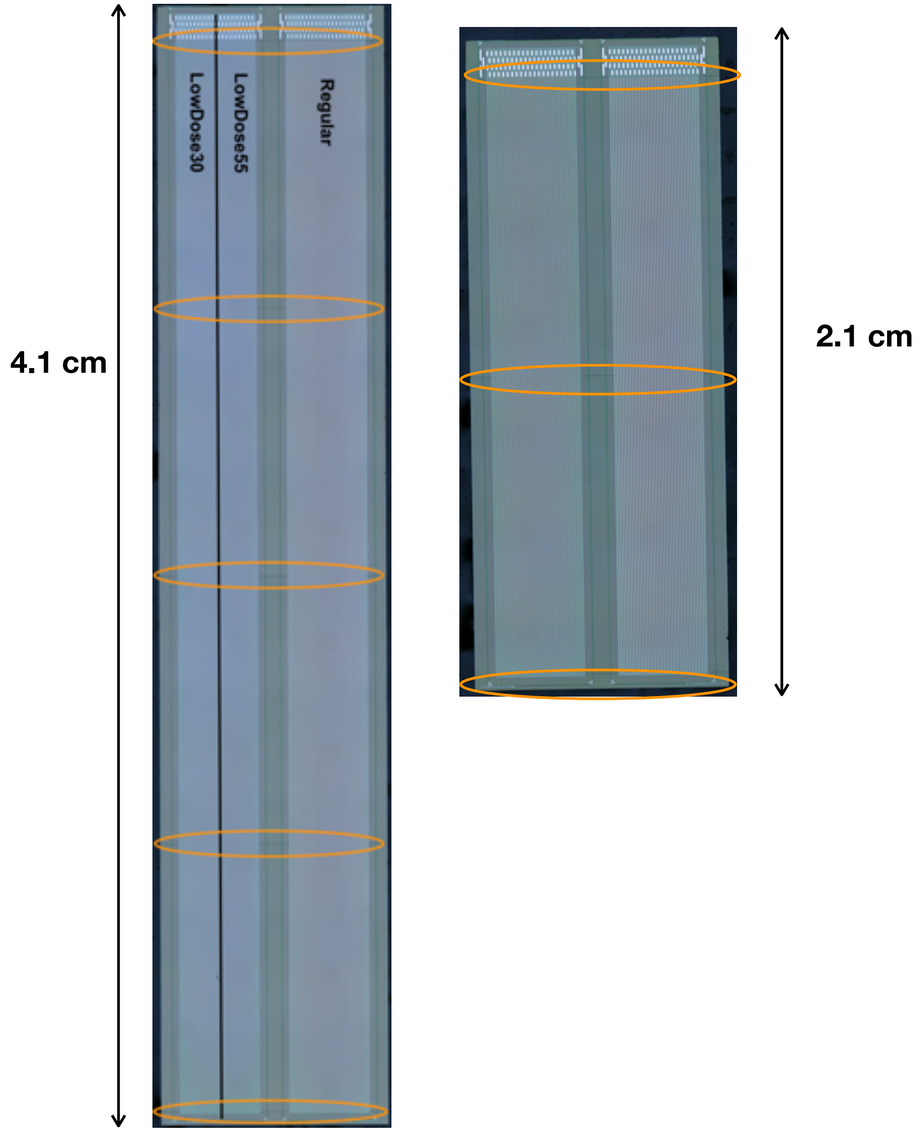
Stitching design





- Stitching merges multiple design structures on a wafer during the photolithographic process -> creates large sensor
- Stitched every ~1 cm along strip length

Sensor Details



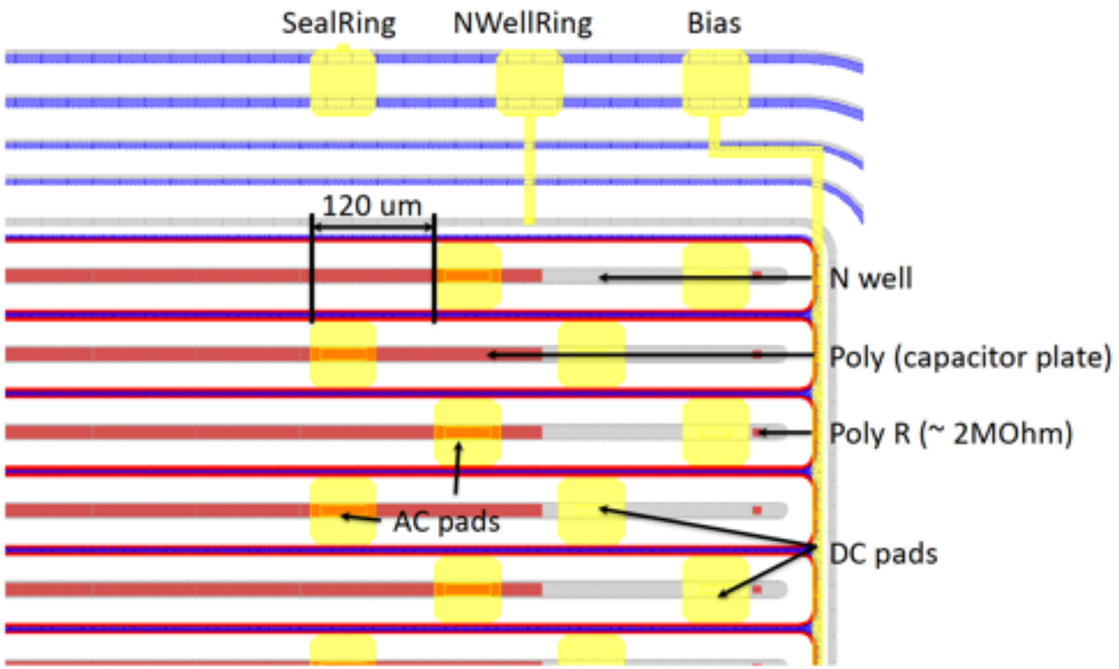
- First stitched strip sensor produced on 8” wafer by a commercial foundry

- 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

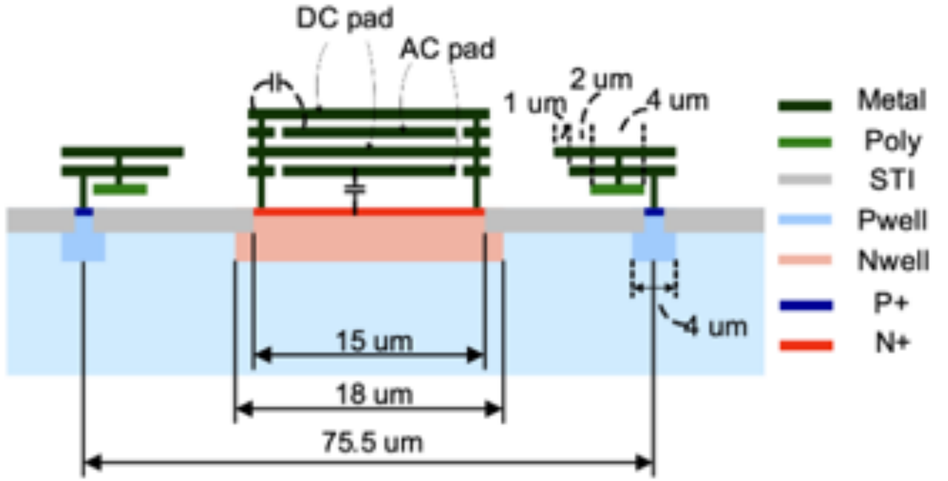
- The strip sensors have 2 different lengths : 2.1 cm and 4.1 cm

- 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

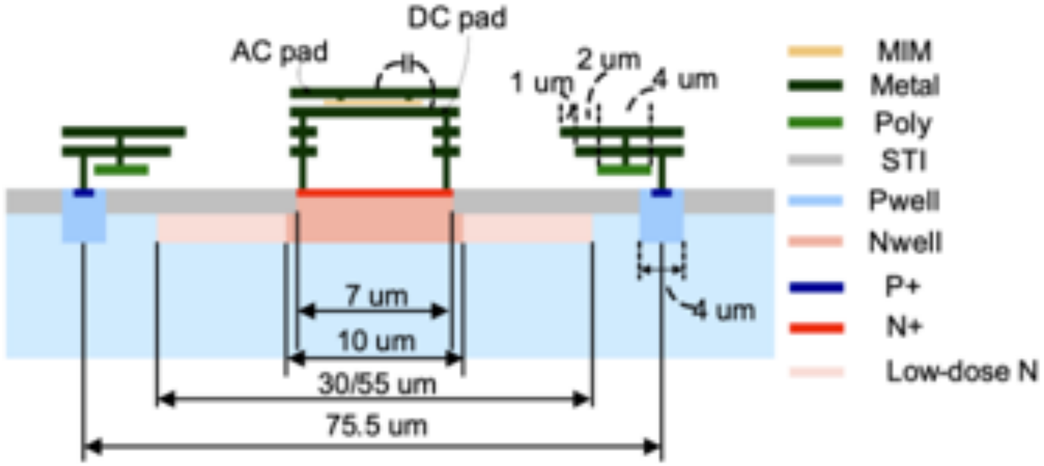
Sensor Structure



Regular design



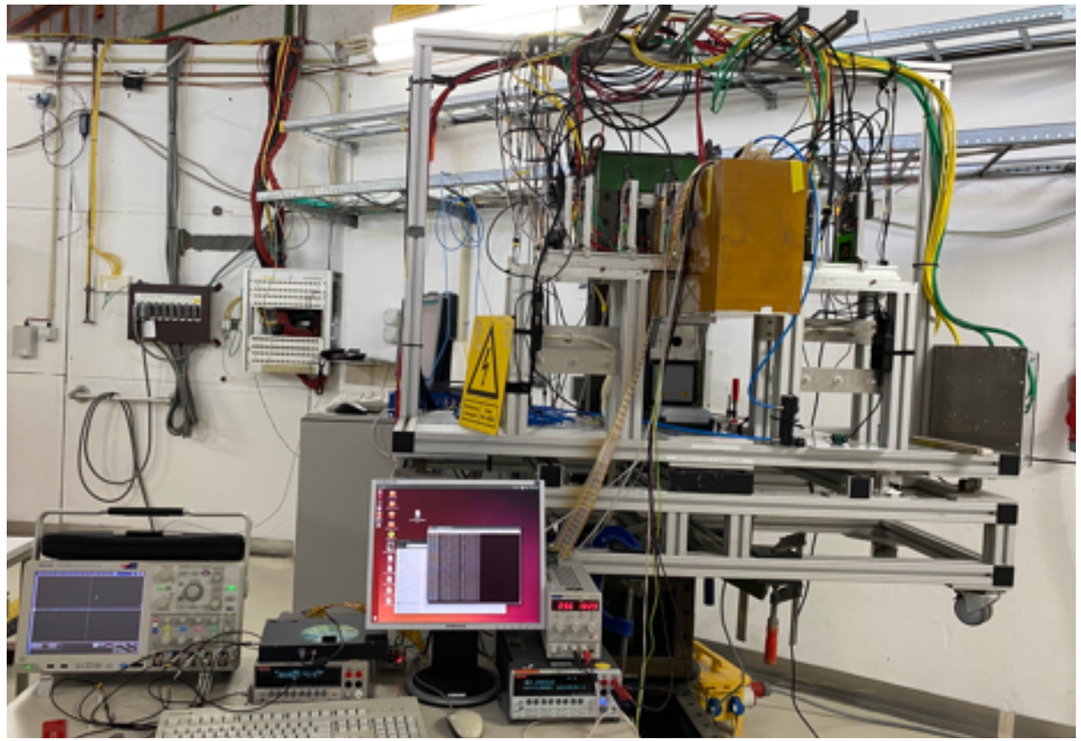
Low Dose design

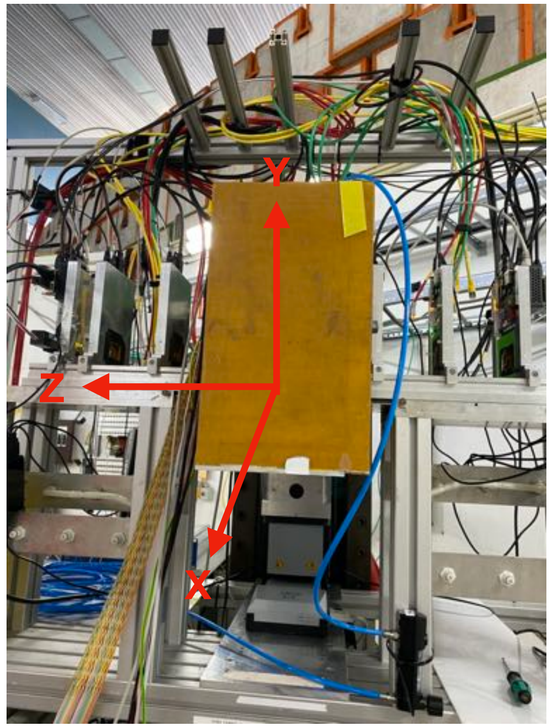


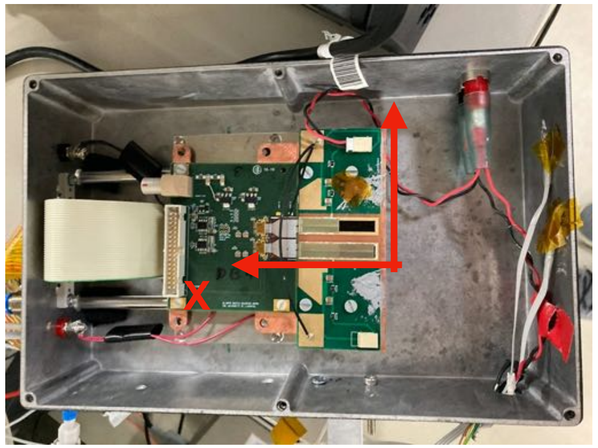
- Sensor thickness ~150 ± 10 µm
- Sensor has 40 strips each, with strip pitch = 75.5µm
- Three different designs: LowDose 30/55 and Regular
- LowDose design comes in two different low dose N widths, 30 & 55 um with 20 strips per design

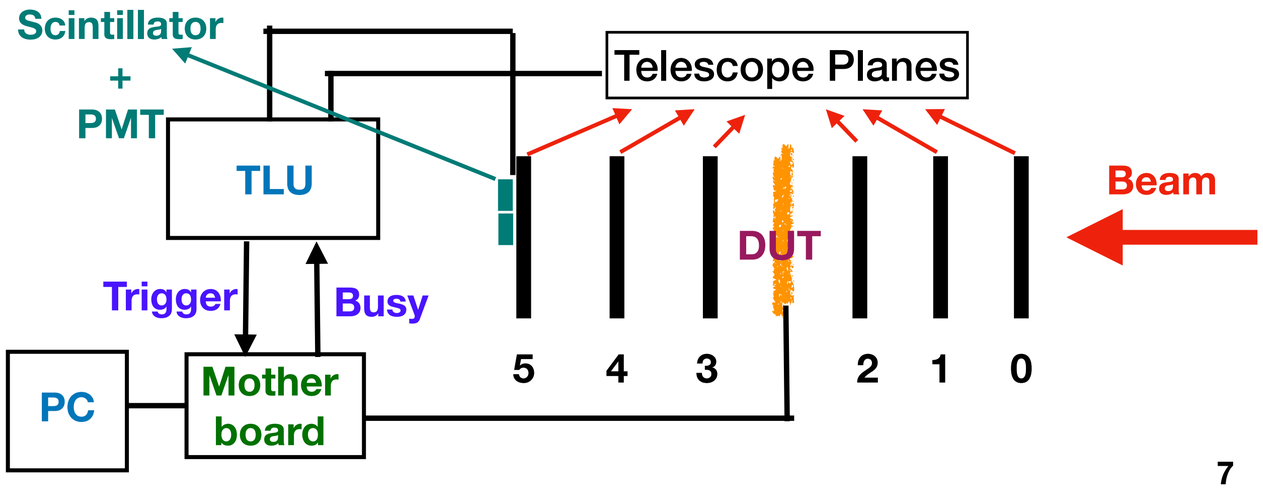
TestBeam Setup

- Data taken at DESY II
  - Electron beam with beam energy 3 GeV and 3.4 GeV is used
  - Using beam line 22 and ALiBaVa system is used for the readout
- Non-irradiated and irradiated sensors tested



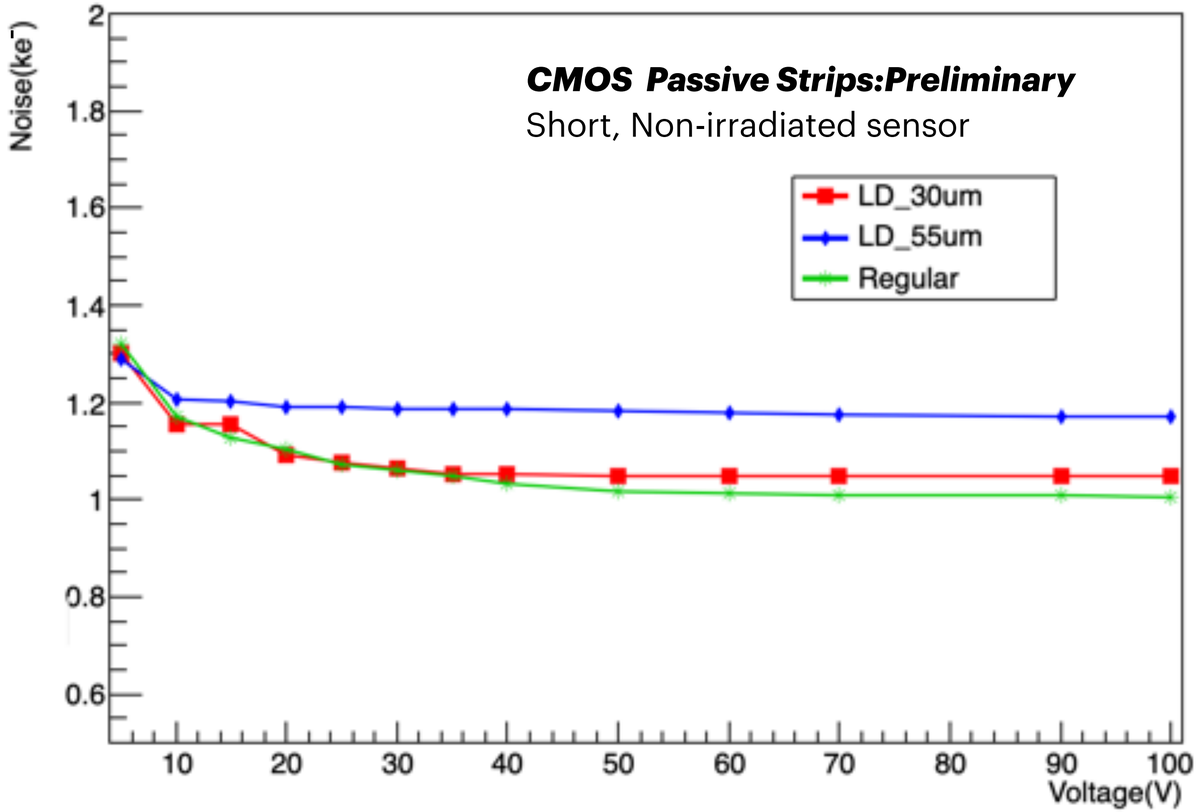


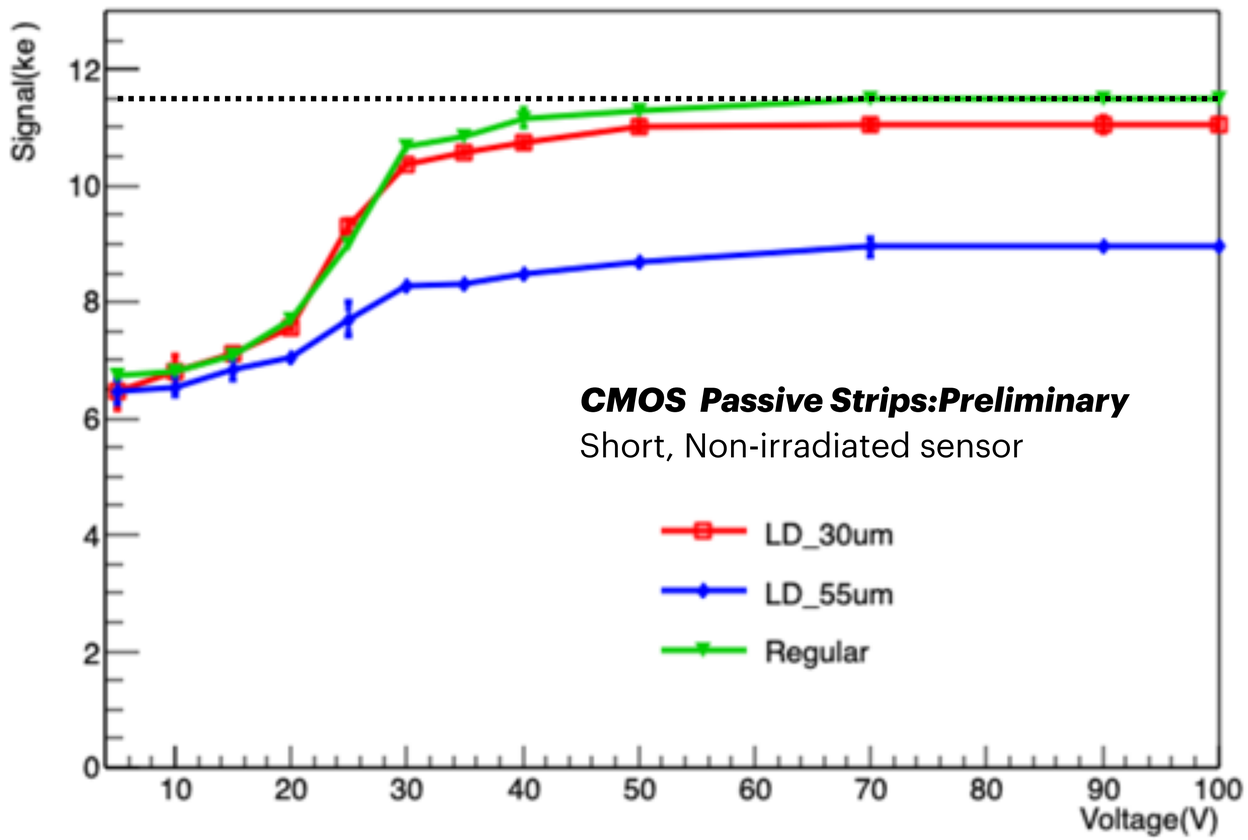




Noise and Signal measurement

All measurements are performed at 18° C

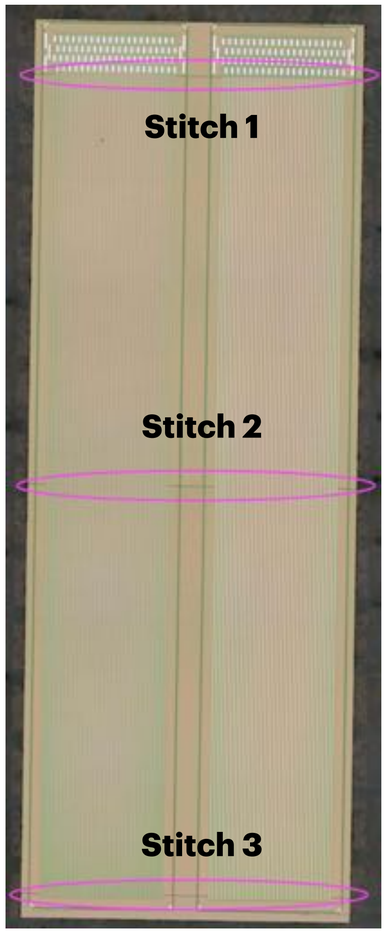




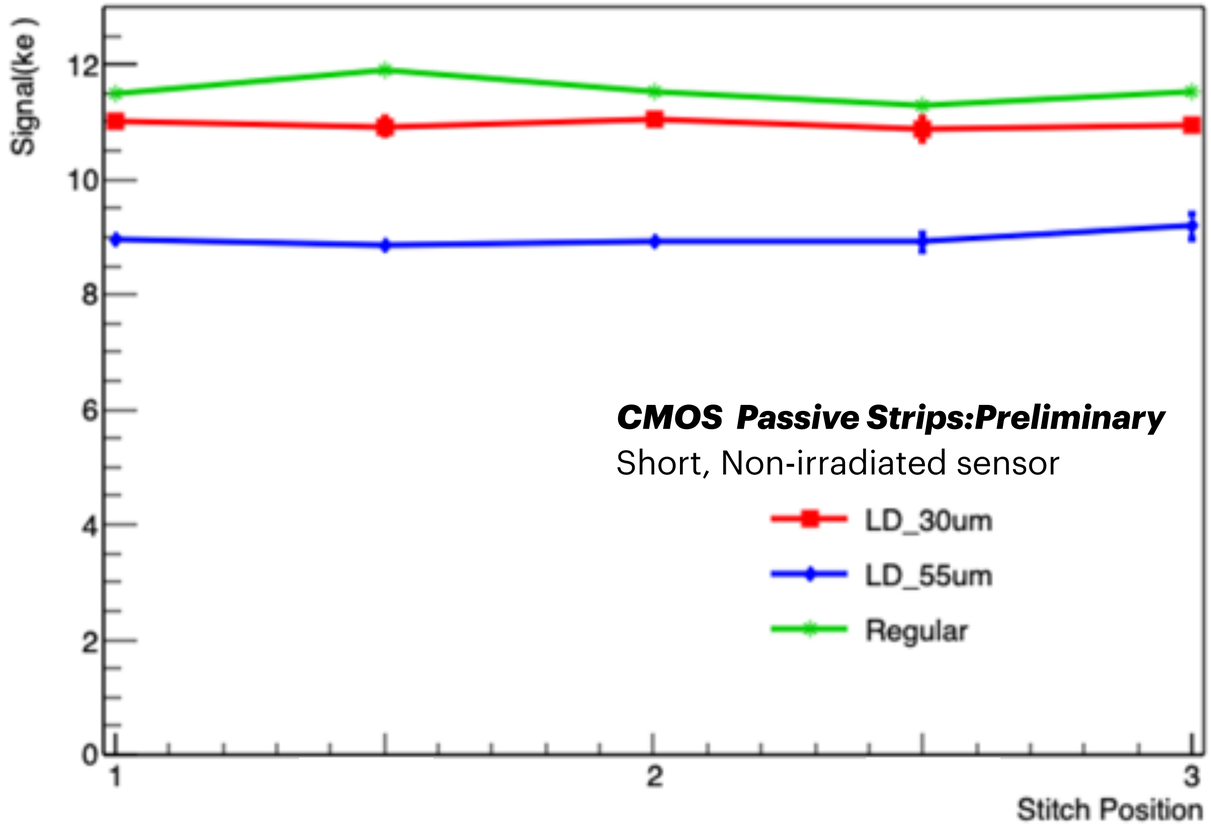
- The noise values decrease with voltage
- Highest signal in Regular sensor, low noise value for regular sensor
- Low dose 55 design has a systematic offset – related to Beetle chip configuration (high capacitance of LD55)

Signal Measurement- Stitching

All measurements are performed at 18° C



2.1 cm

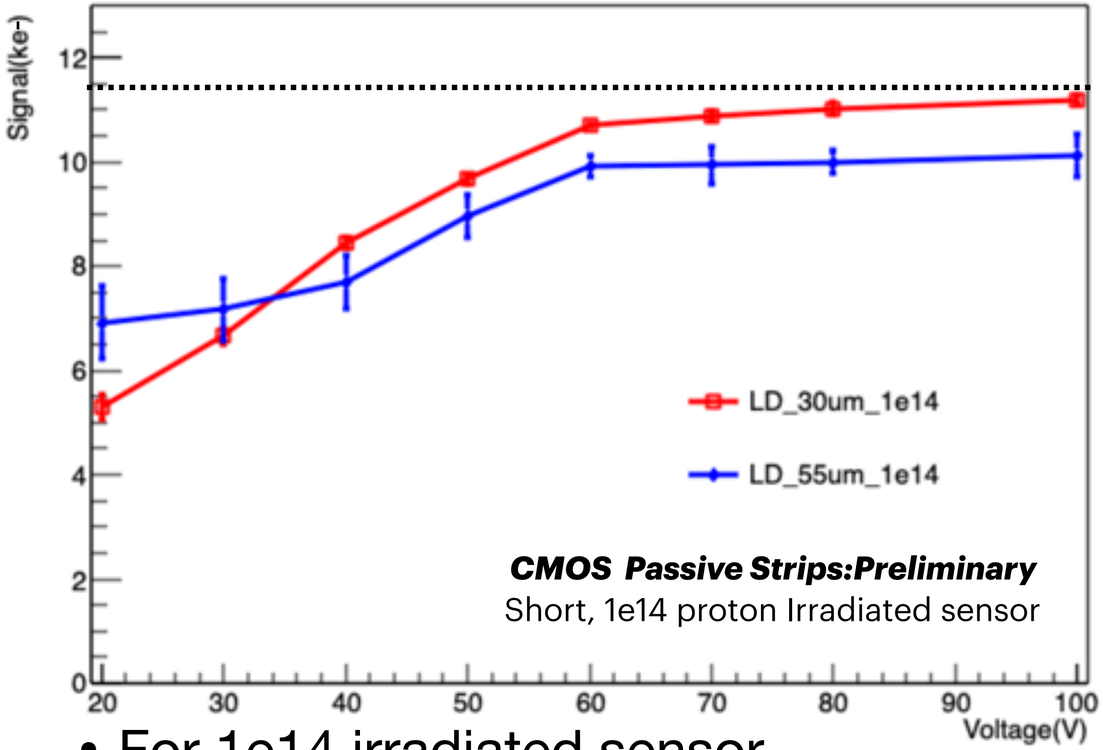


- No effect of stitching is visible for all the designs in charge collection measurement

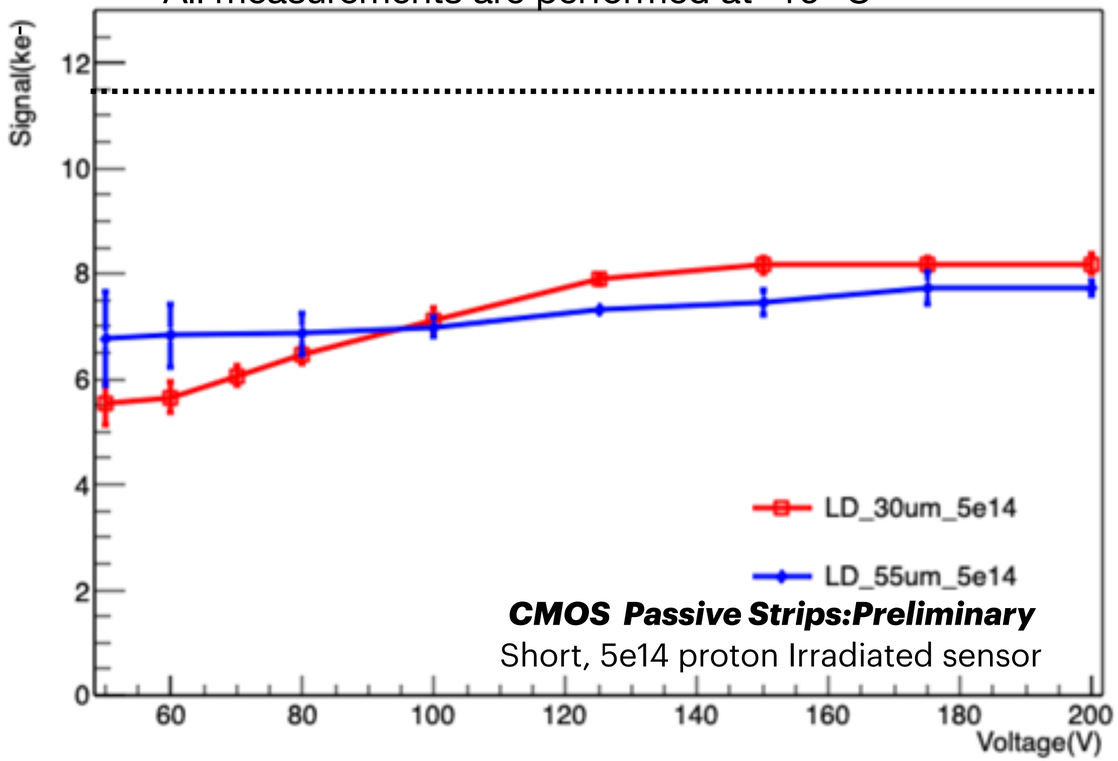
Signal measurement -Irradiated

Sensors are irradiated at KIT with protons of 23 MeV energy

All measurements are performed at -40° C

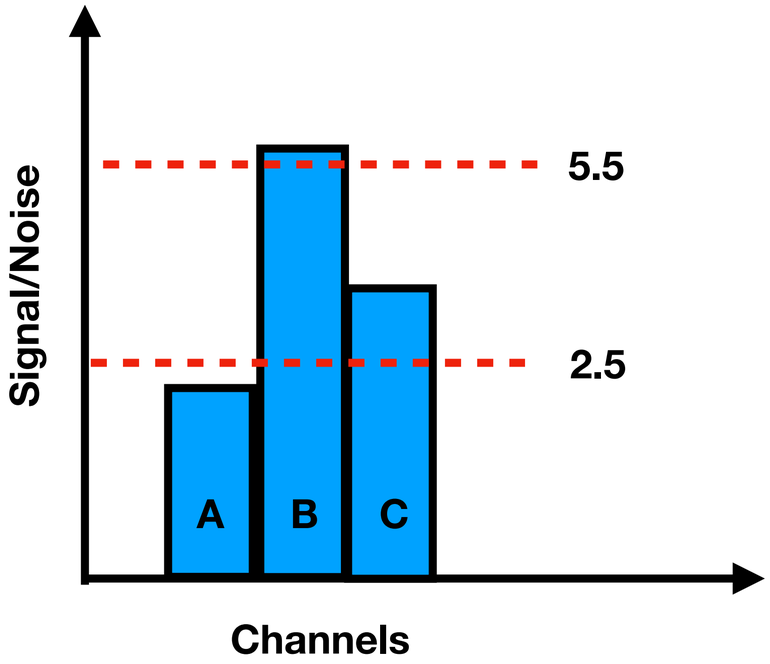


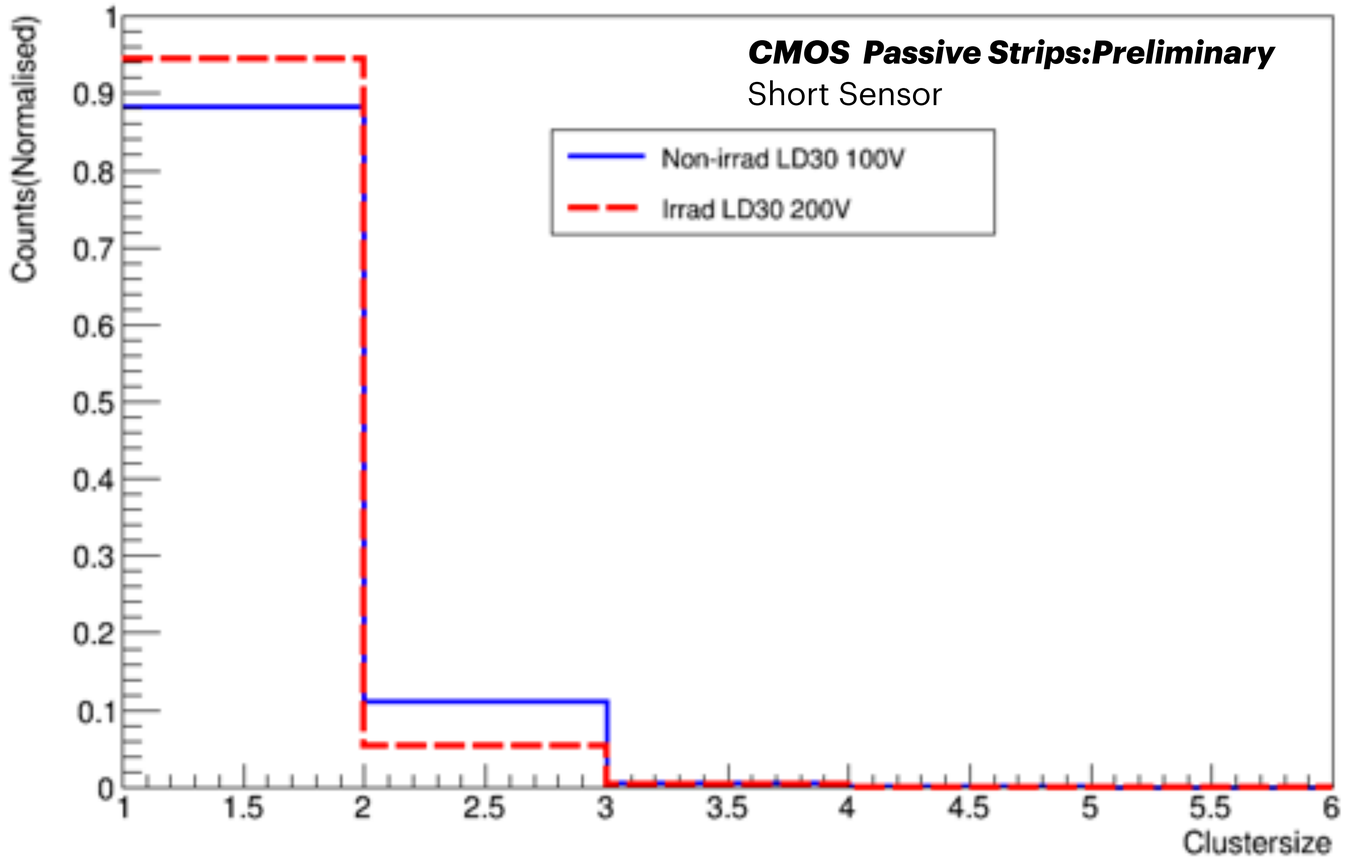
All measurements are performed at -16° C



- For 1e14 irradiated sensor
  - Signal remains same as non irradiated sensor for LD30
  - Signal increases little as compared to non-irradiated for LD55 -> detail investigation ongoing
- For 5e14 irradiated sensor, collected signal drops significantly till 200V

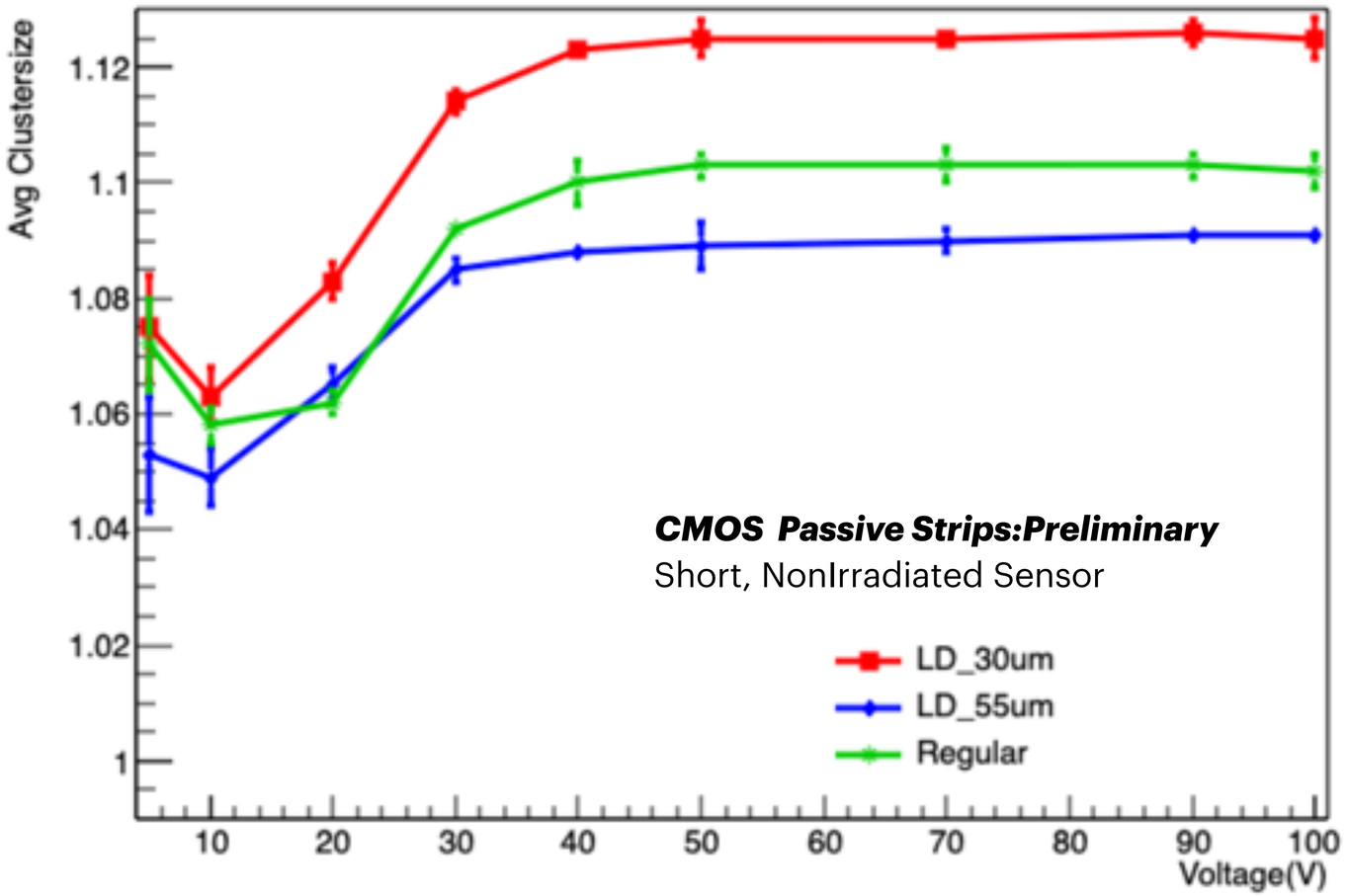
Cluster size





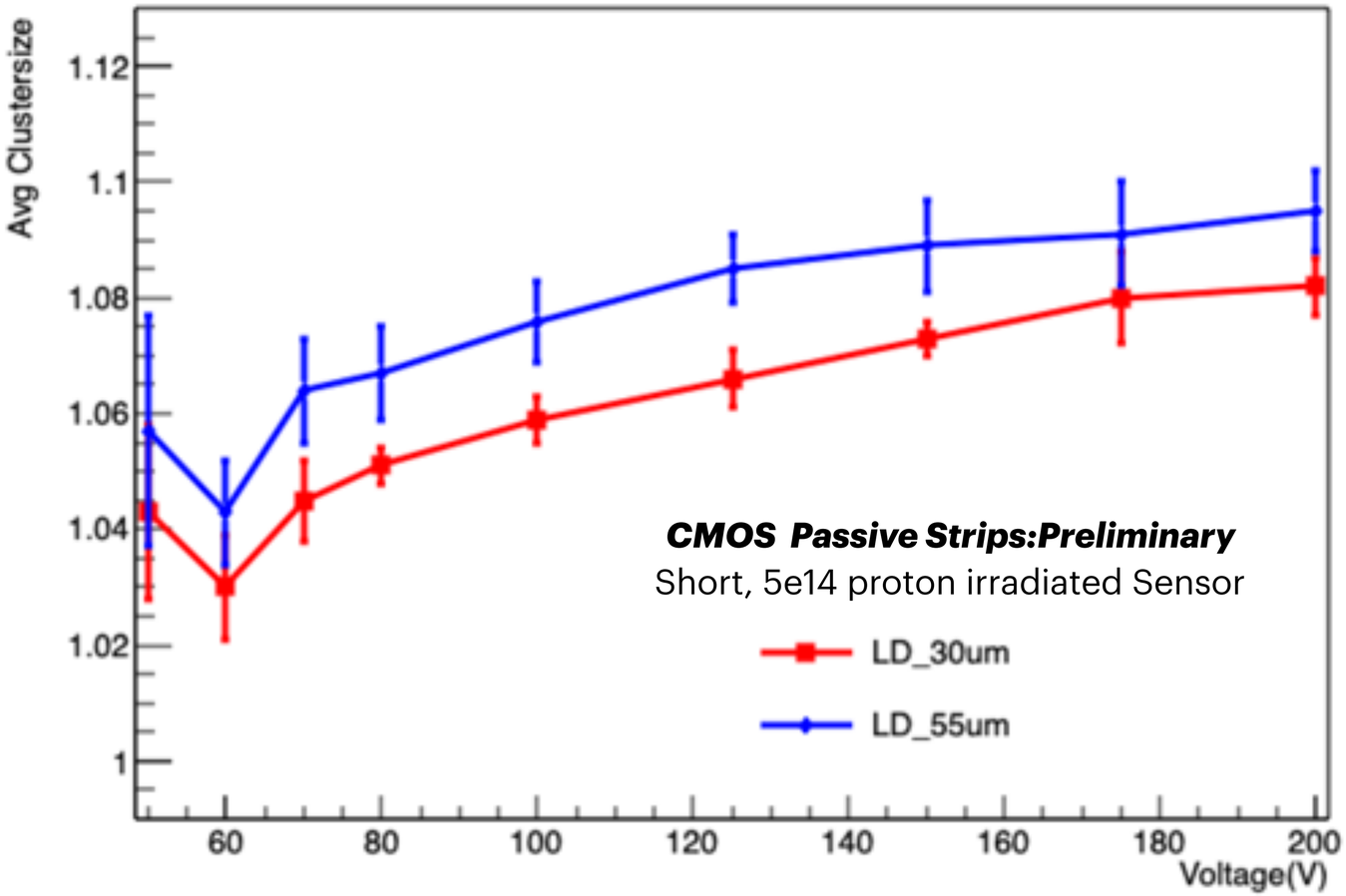
- Cluster size calculated with maximum of 5 strips
- With irradiation -> Cluster size decreases

Cluster size -nonirradiated sensor



- Cluster size become stable after depletion voltage for non irradiated sensors
- Higher cluster size for LD30 -> high interstrip capacitance -> high charge sharing
- For LD55 -> high noise value, increases the threshold cut for signal -> reducing the cluster size

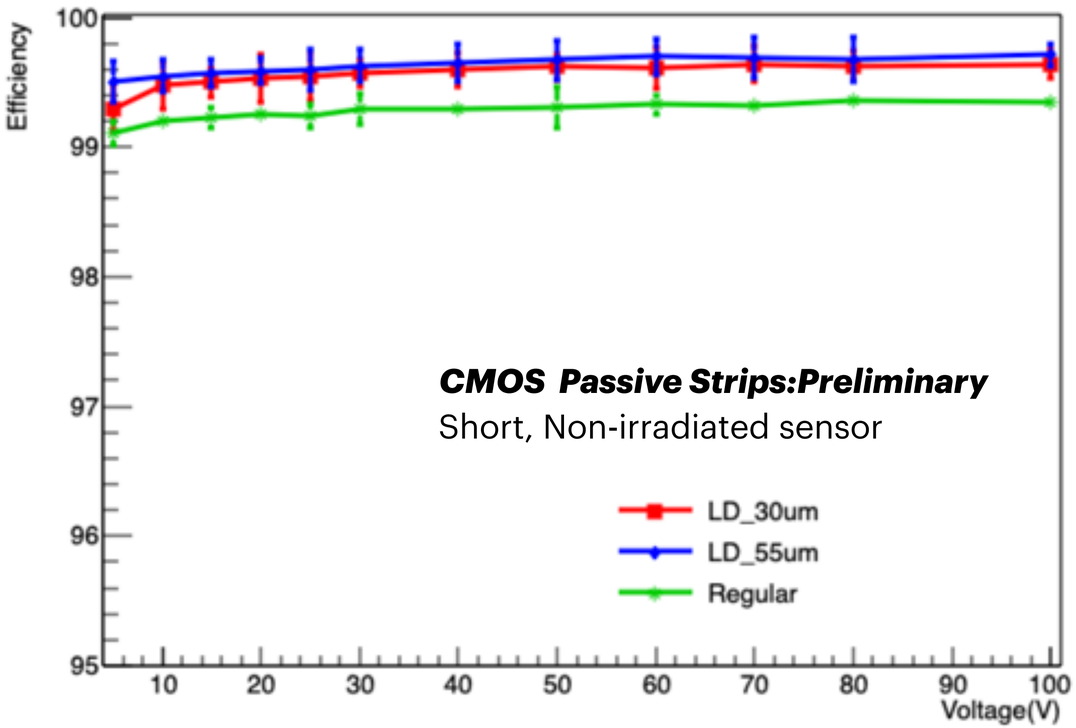
Cluster size- Irradiated sensor



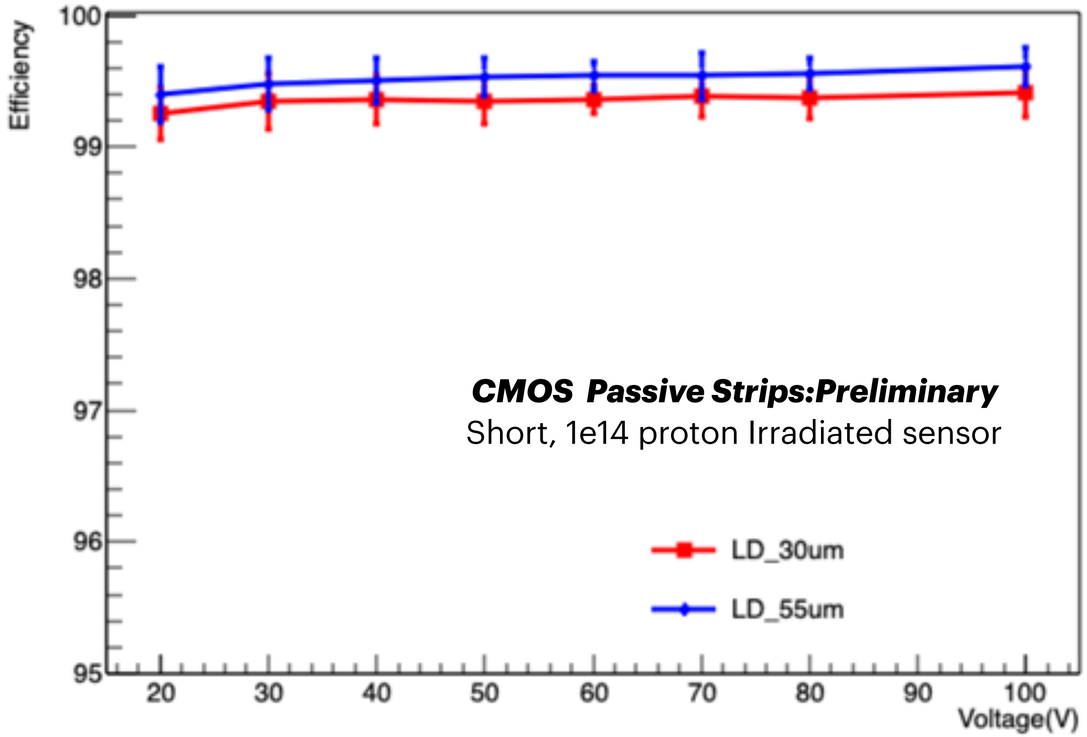
- For irradiated sensor, the cluster size doesn't show high increase
- For LD55, small number of strips are available after irradiation (high noise)

Hit detection efficiency

All measurements are performed at 18° C



All measurements are performed at -40° C



- Before irradiation -> Efficiency is greater than 99 % for all designs
- Fully efficient also at low bias voltage

- After irradiation with 1e14 fluence -> Efficiency is still greater than 99 % for all designs
- Fully efficient also at lower voltages

- Fulfils ATLAS ITk requirement > 97%

Summary

- Successful testbeam campaign for the Passive CMOS strips sensor
- No negative effects of stitching is observed before irradiation
- Hit efficiency above 99% for both non-irradiated and irradiated sensor

Outlook

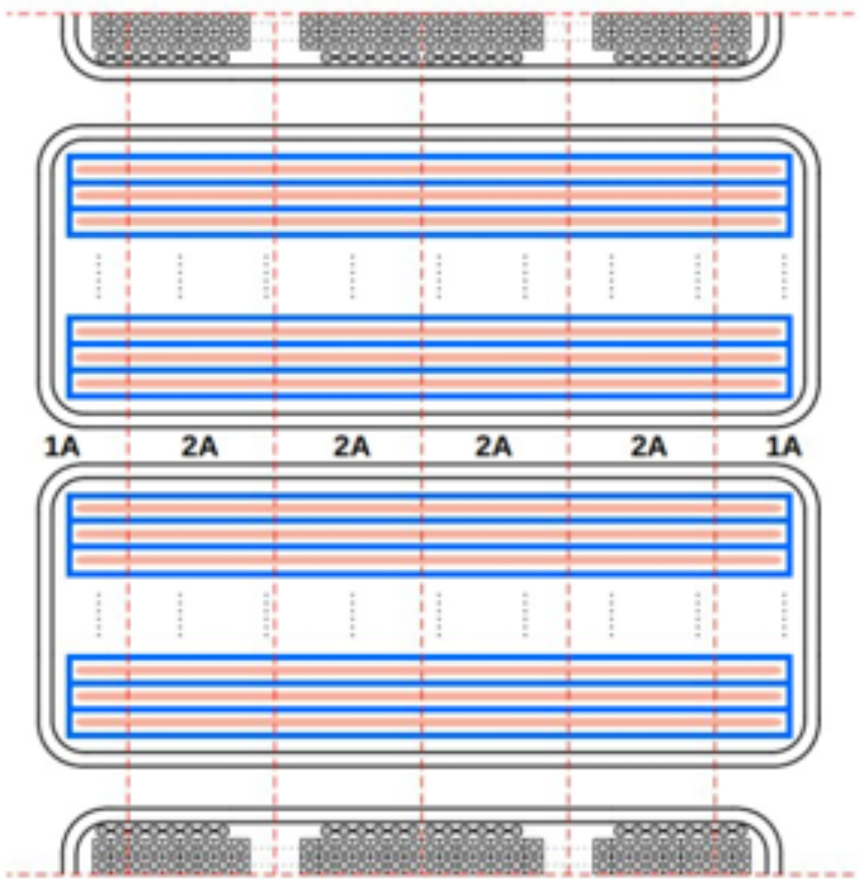
➢ Further analysis from the test beam data is ongoing
➢ TCT and charge collection measurements of irradiated neutron sample are ongoing

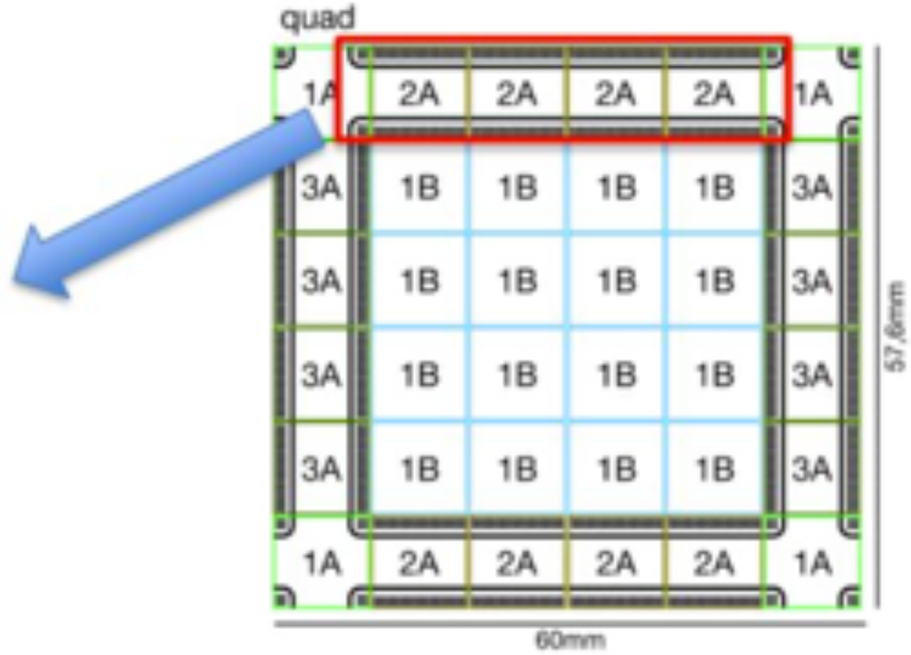
Thank You for Attention

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

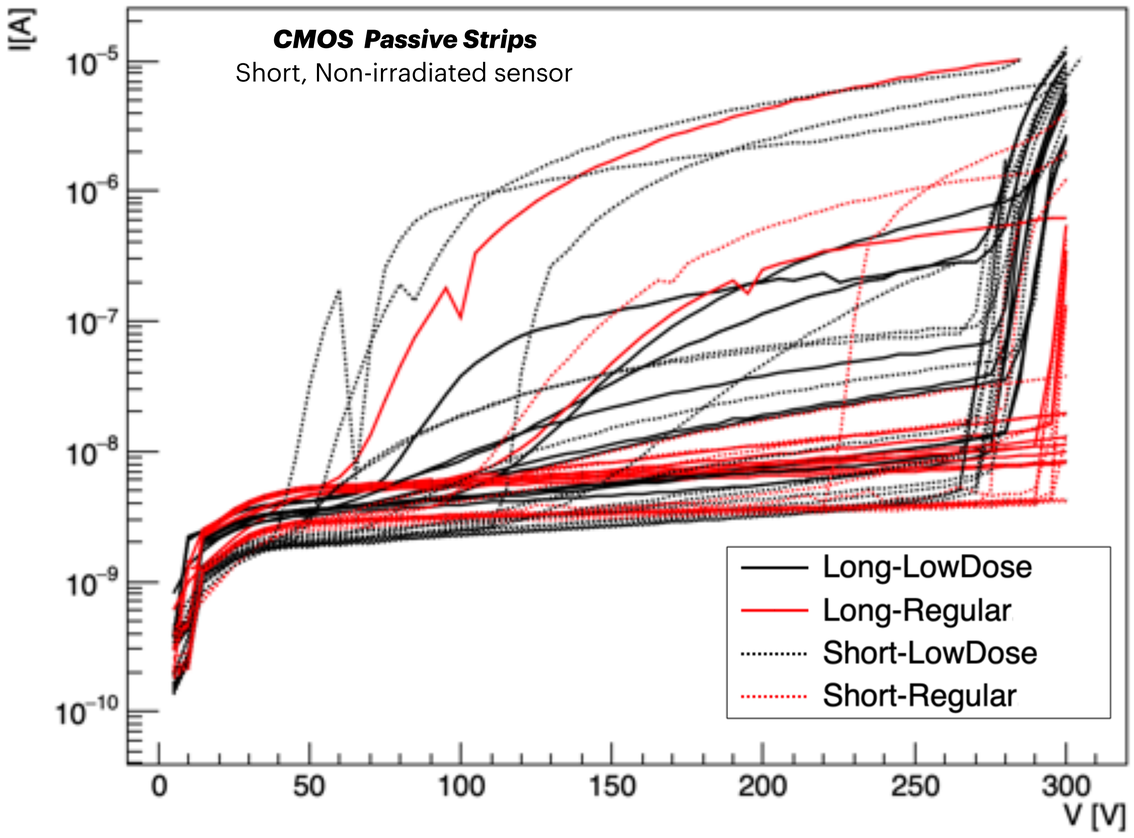


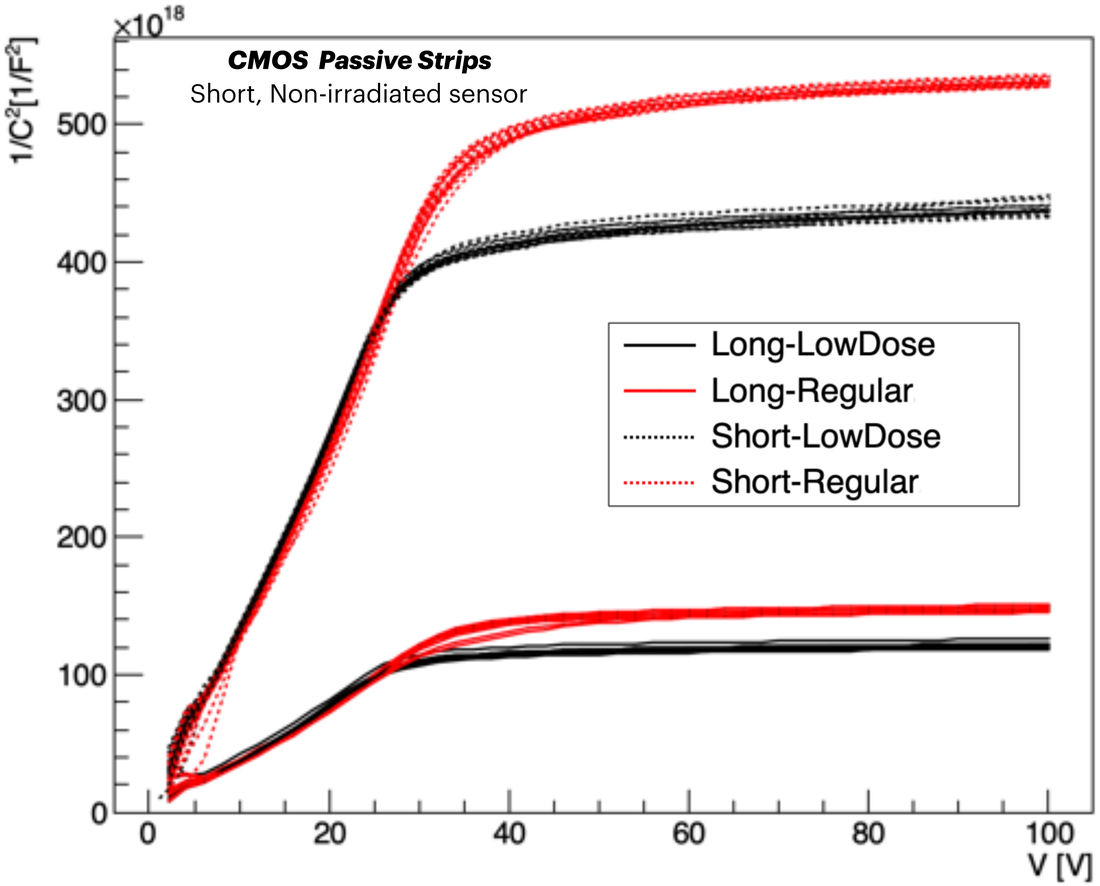


- Strip sensor implemented in 1/2A
- Stitched every ~1 cm along strip length

IV and CV Measurements

All measurements are performed at room temperature

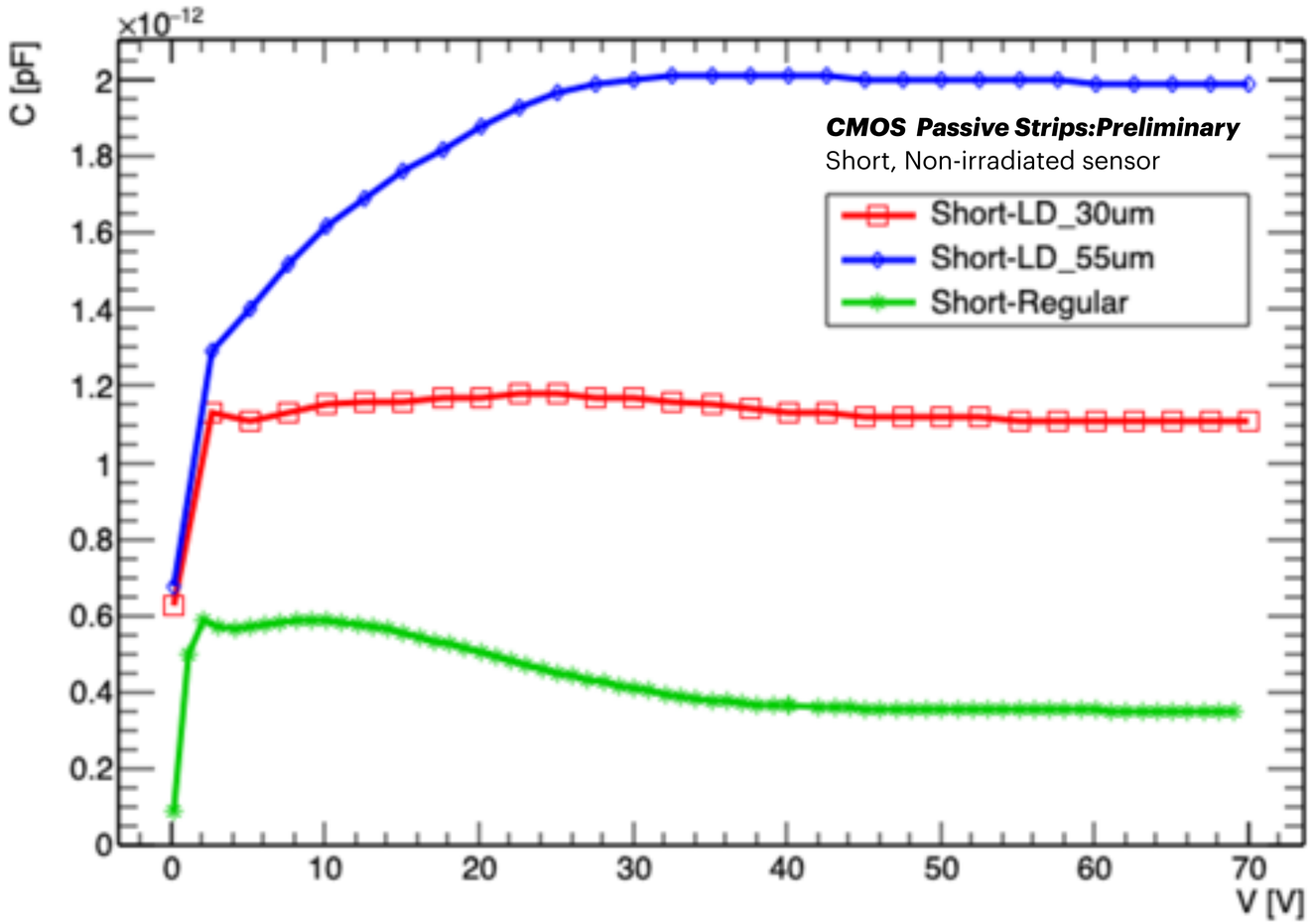




- Breakdown voltage above 250V, improved for batch II (higher backside implant doping concentration, metallization)
- Depletion voltage for LowDose implant (30V) < Depletion voltage for Regular implant (36V)
- Stable capacitance behavior: Bulk capacitance ~50pF (short sensors), ~100pF (long sensors)

Interstrip Capacitance

Measurement at room temperature for frequency of 500kHz

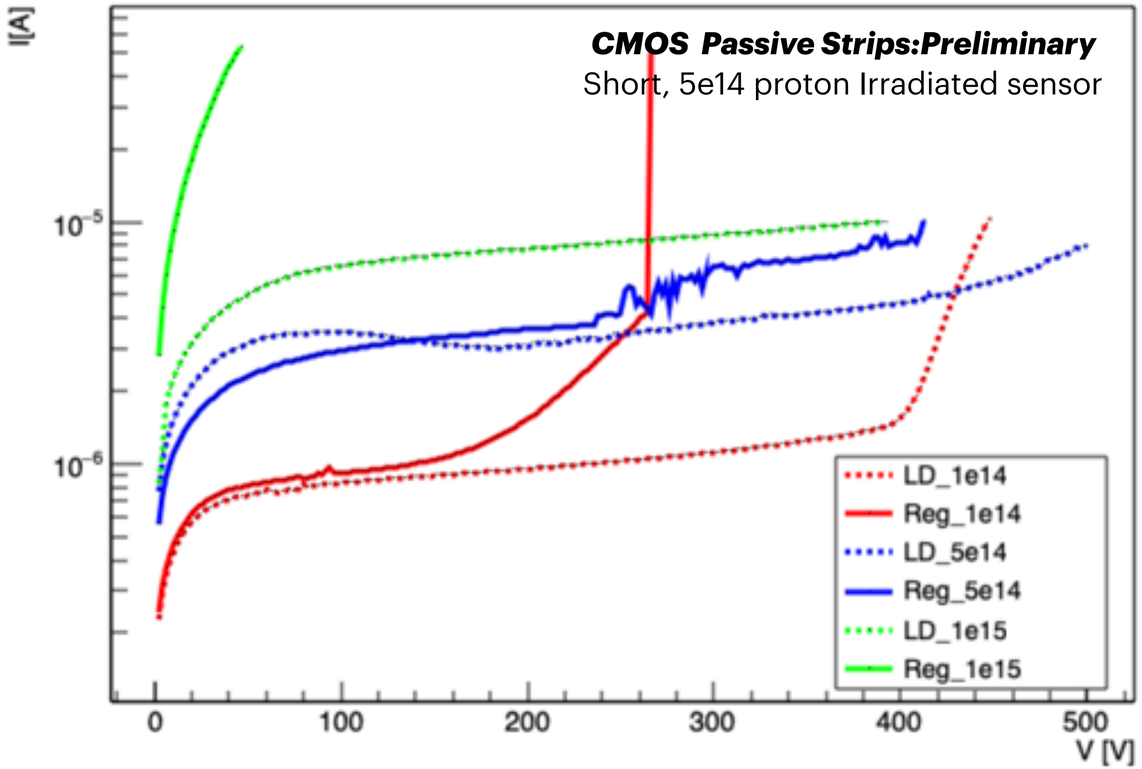


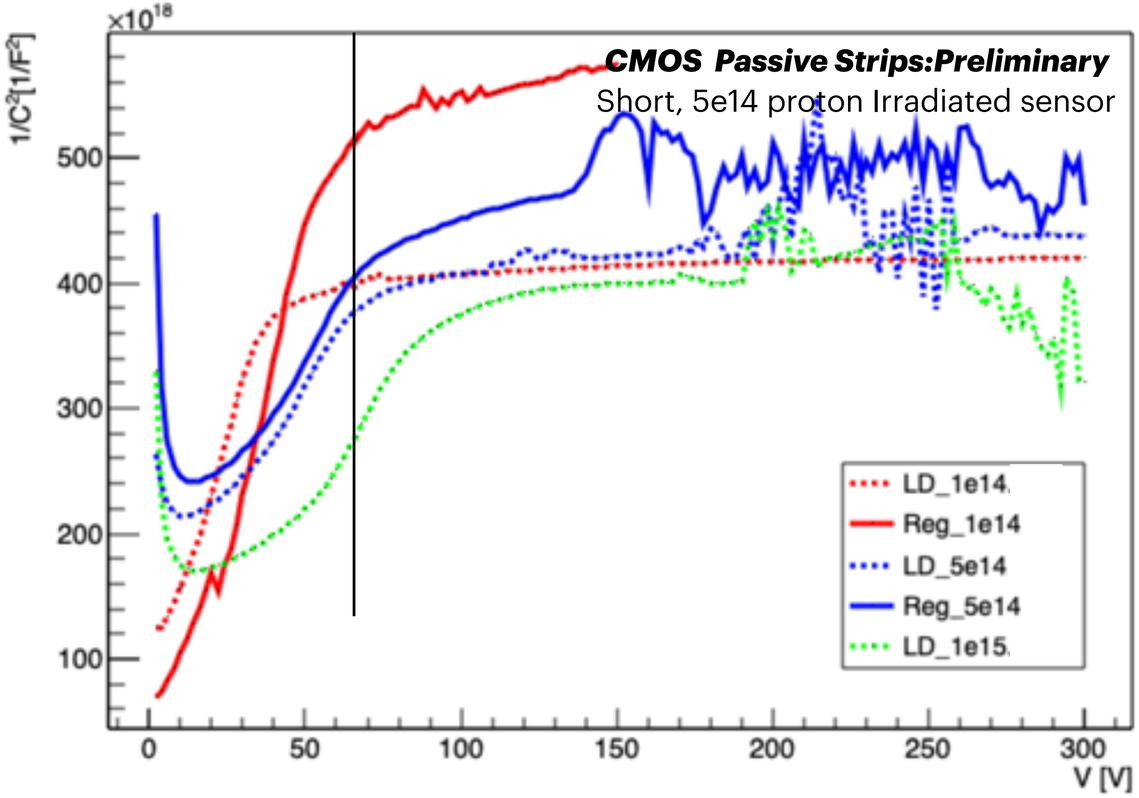
- With increasing width of implant capacitance increases -> highest for LD55 sensor
- Capacitance becomes stable after depletion voltage

IV and CV measurements

Sensors are irradiated at KIT with protons of 23 MeV energy

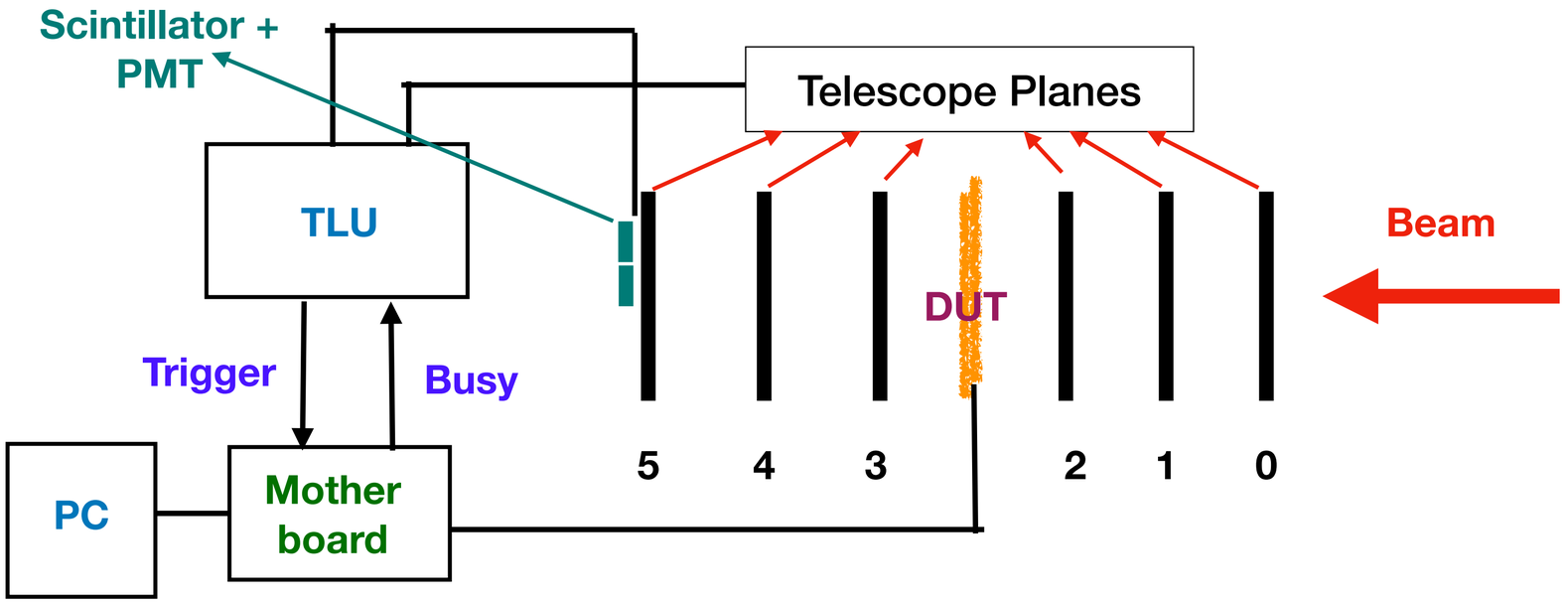
All measurements are performed at -20° C

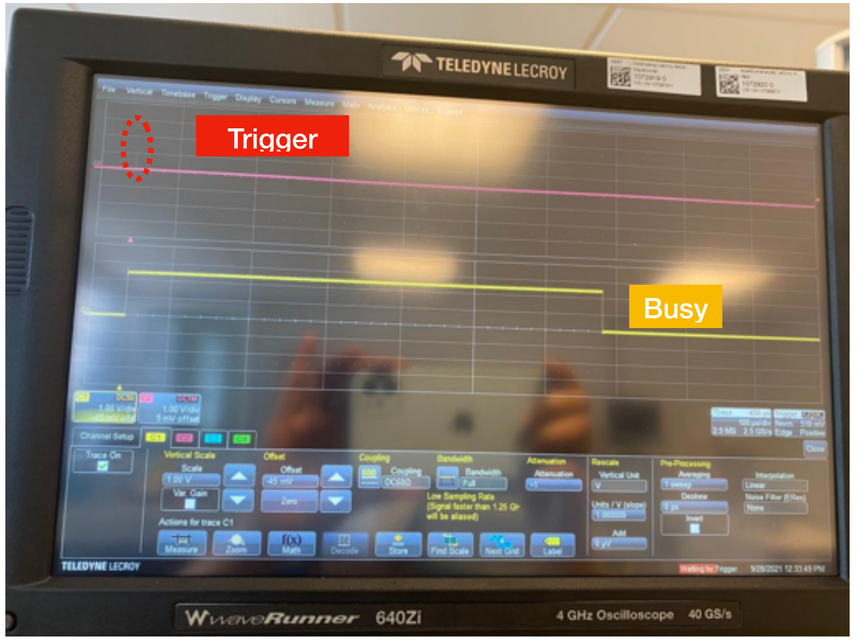




- Sensors are annealed at 60° C for 80 minutes
- IV measurements show both designs survive radiation damage up to the fluence of 1e15 $\frac{n_{eq}}{cm^2}$
- Because of radiation damage, current and depletion voltage increase with fluence

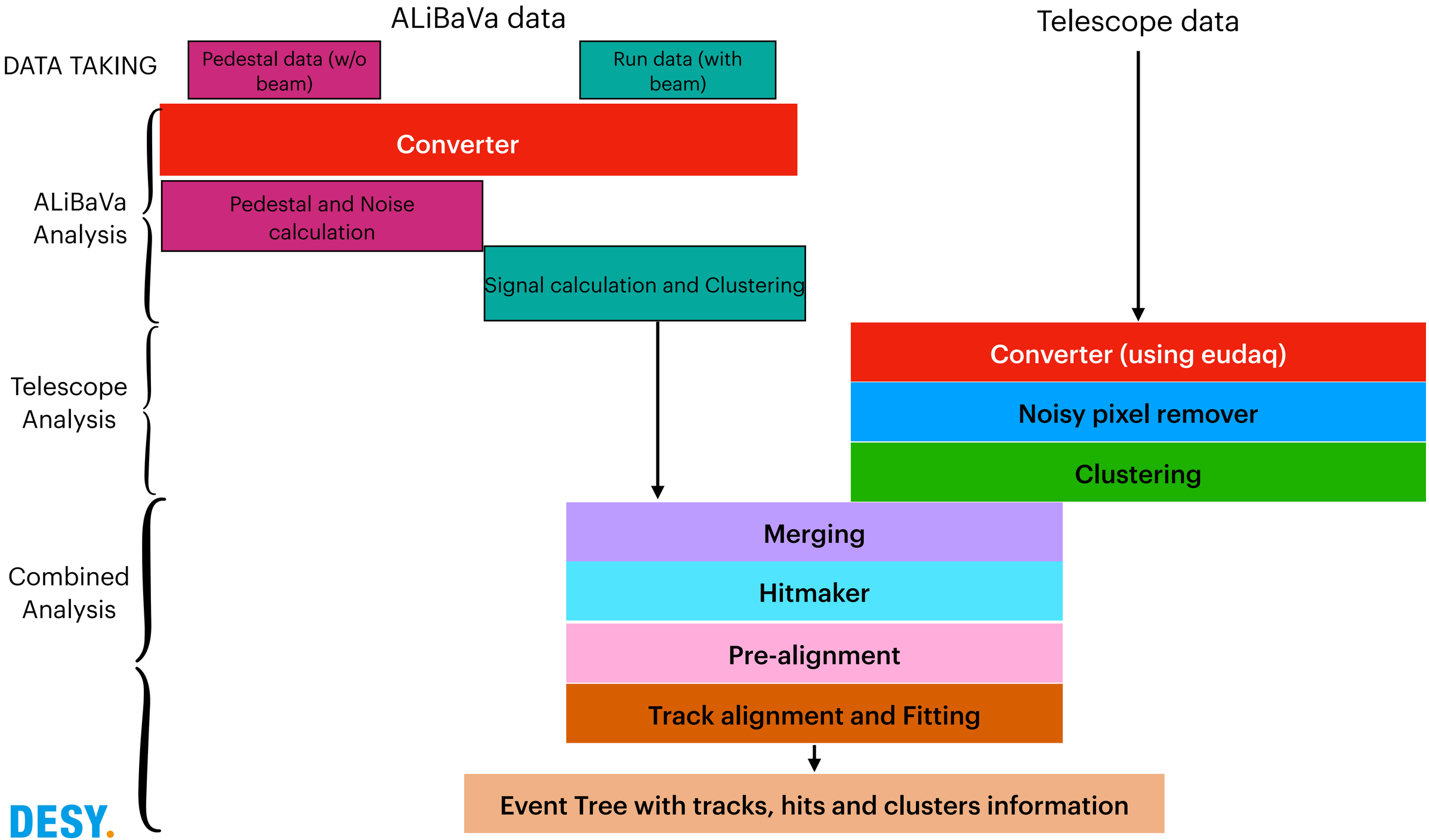
TestBeam Connection



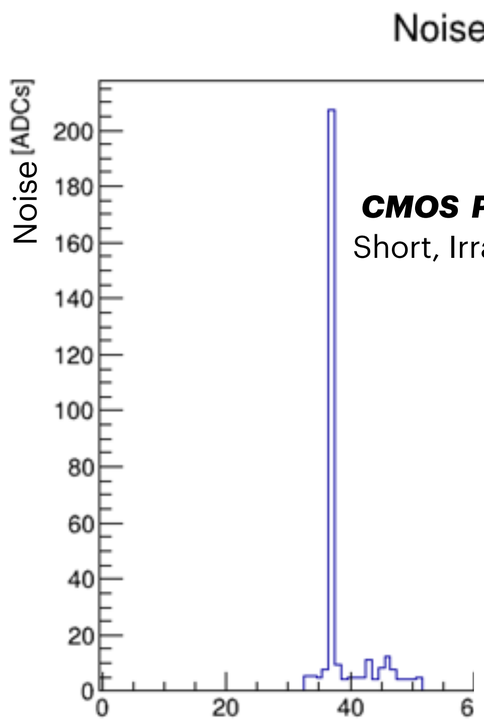


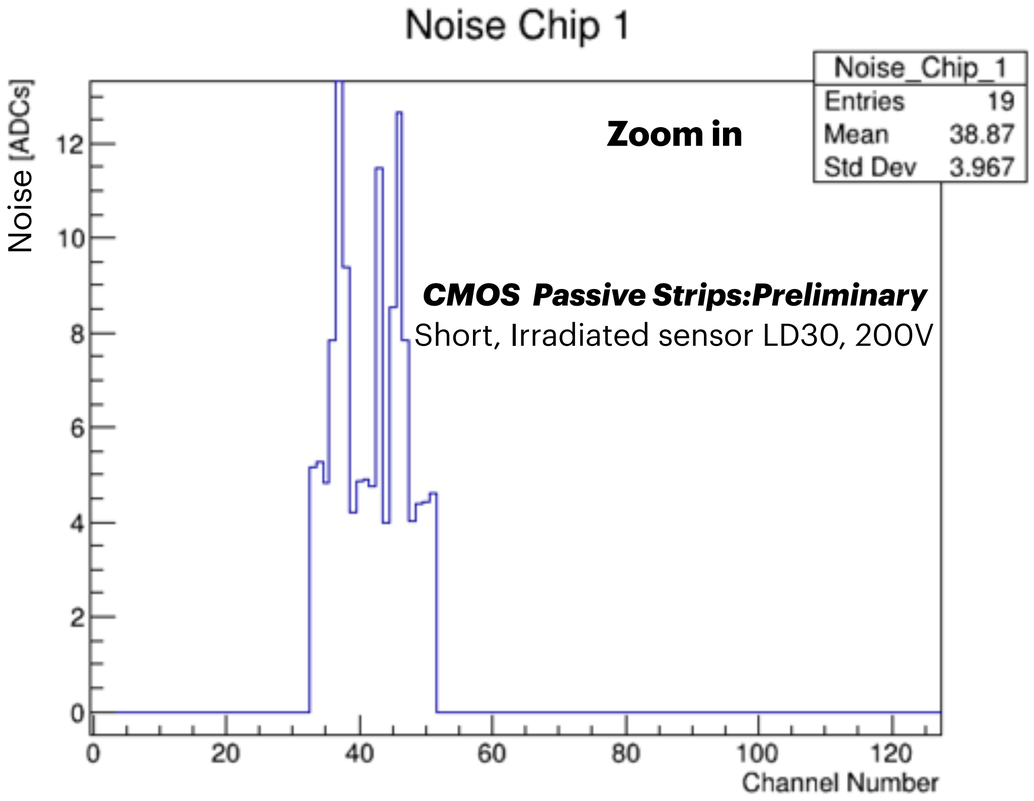
- Two overlap Scintillator at the back and Tracks passing through both qualifies for the trigger to TLU
- TLU setting in EUDET mode
- TLU sends the trigger to the Mother board (Alibava system) and mother boards looks into the received signal with 25 ns timestamp and sends the Busy to TLU -> so no extra trigger come from TLU to motherboard

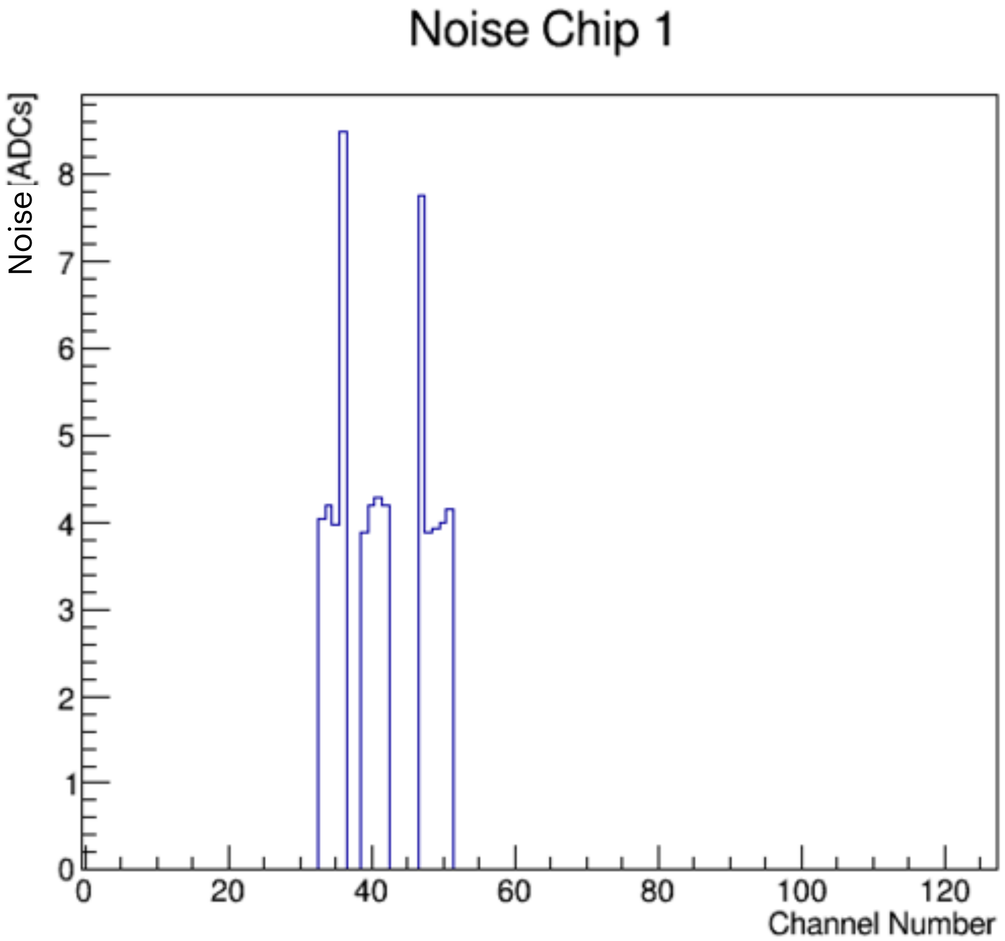
- The trigger is 25ns long (from TLU to Alibava)
- The busy is 630 µs long (from Alibava to TLU)


ALiBaVa data
Telescope data
DATA TAKING
Pedestal data (w/o beam)
Run data (with beam)
Converter
ALiBaVa Analysis
Pedestal and Noise calculation
Signal calculation and Clustering
Telescope Analysis
Converter (using eudaq)
Noisy pixel remover
Clustering
Combined Analysis
Merging
Hitmaker
Pre-alignment
Track alignment and Fitting
Event Tree with tracks, hits and clusters information

Noise measurement



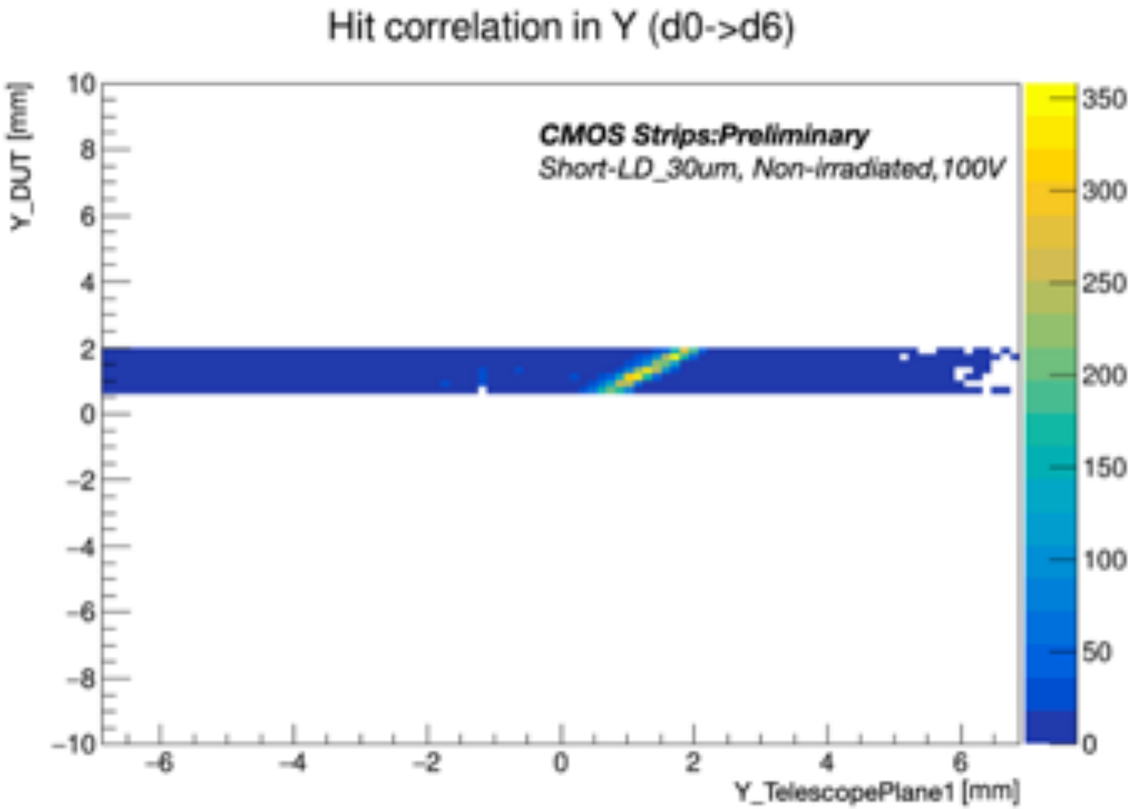


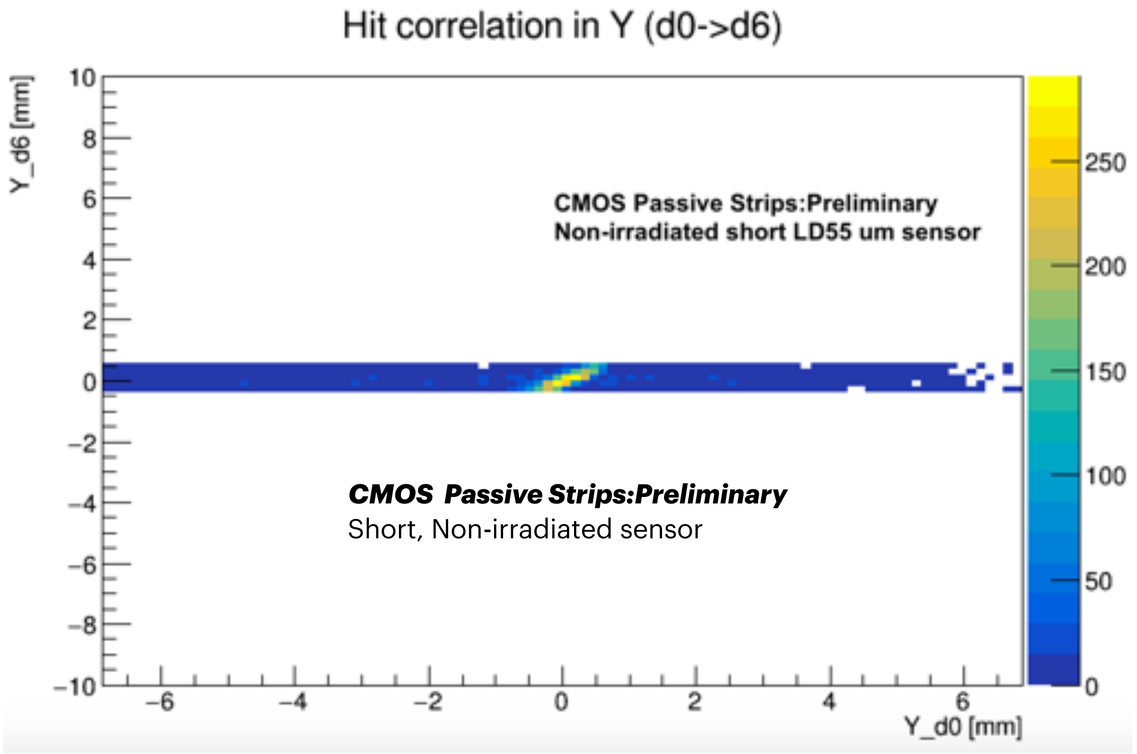


- Noise for all the channels for the LD30

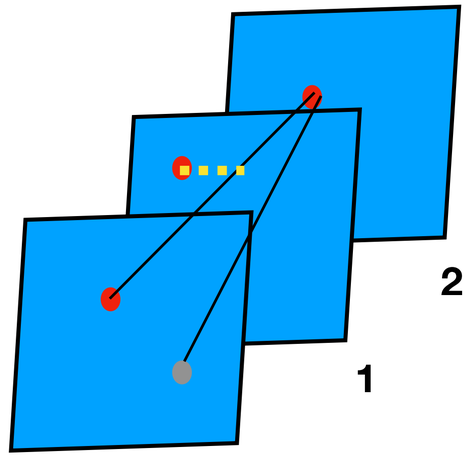
- Noise after high noise channels are masked

Correlation



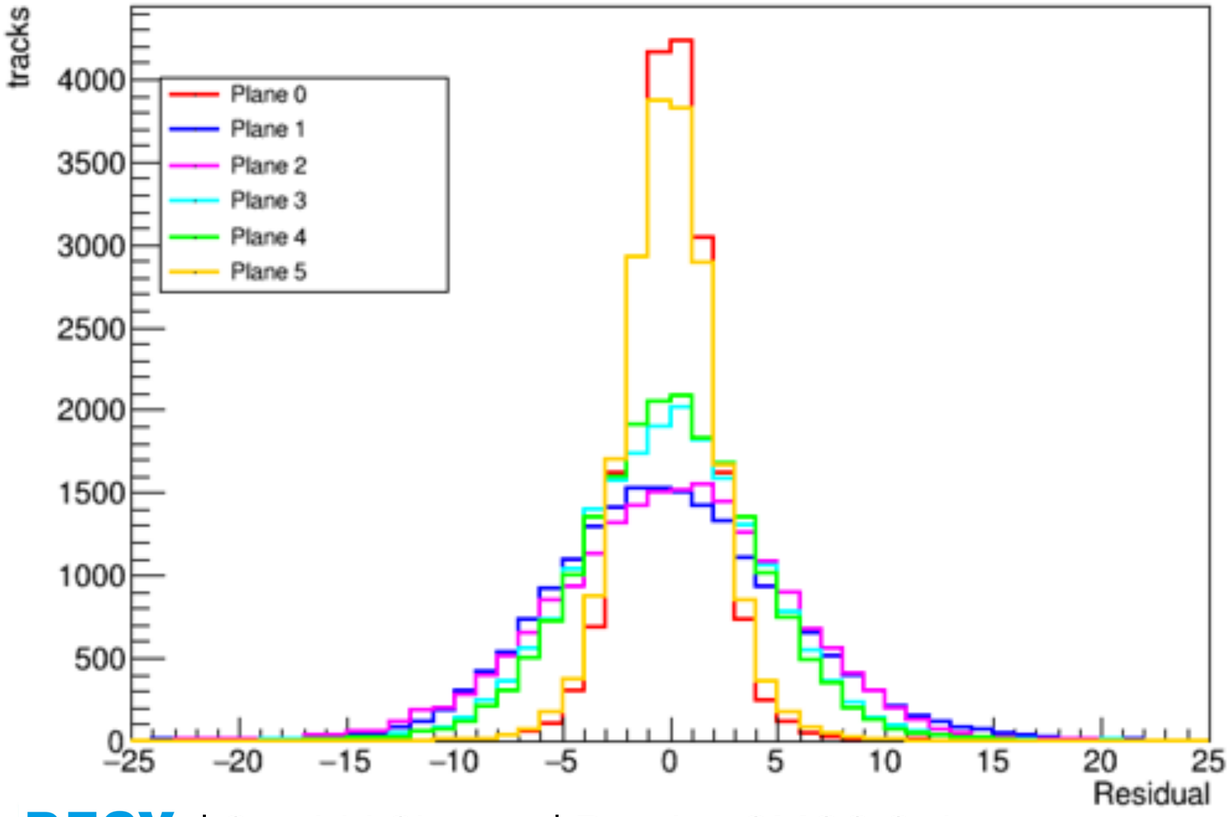


- The correlation plot for LD30 and LD55 sensor
- Similar behaviour is seen in Regular sensor

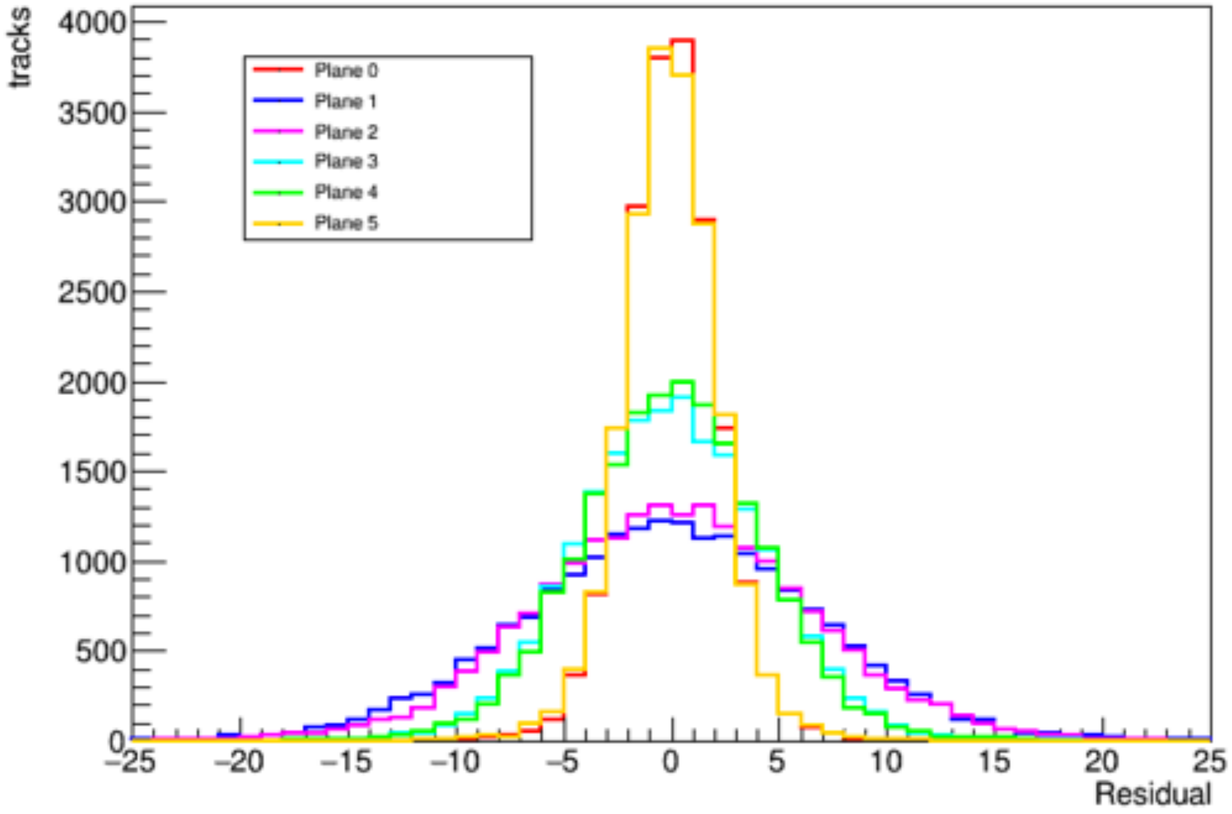


Tracks Parameters

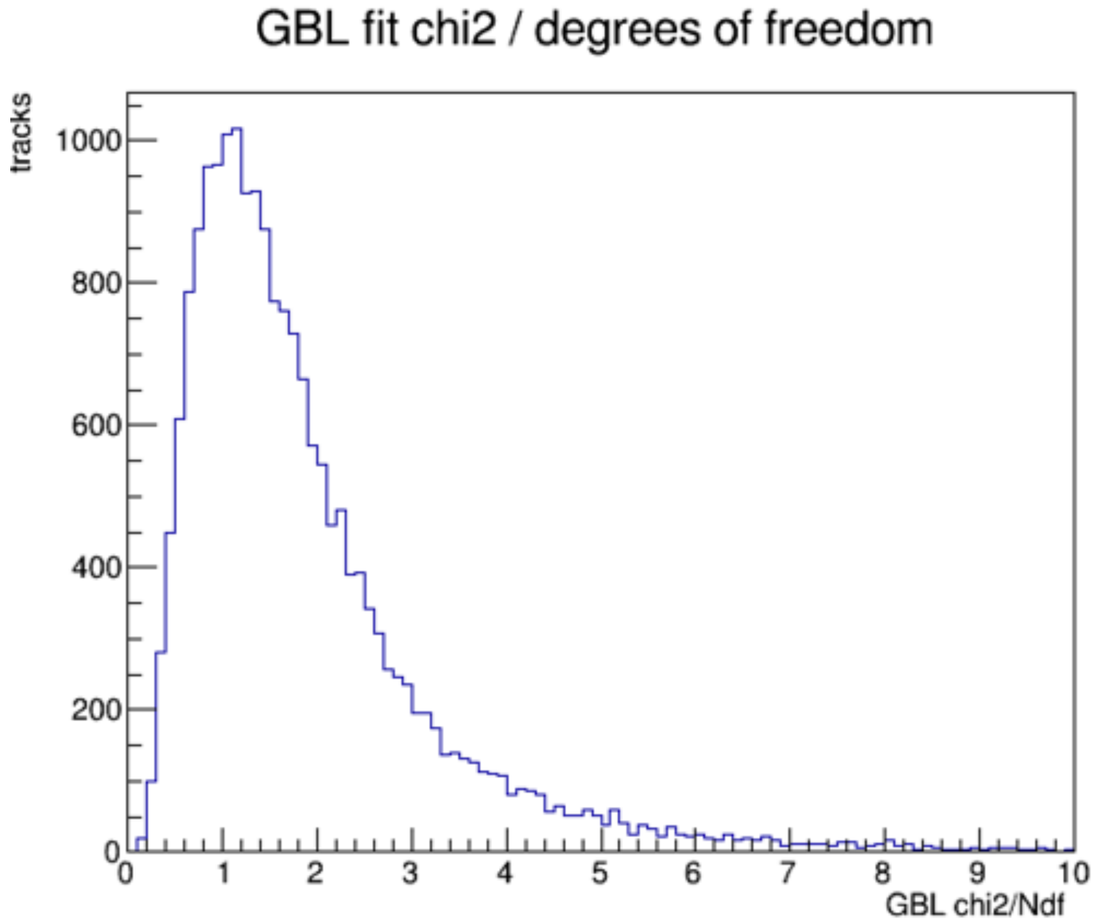
Residual in Y



Residual in X

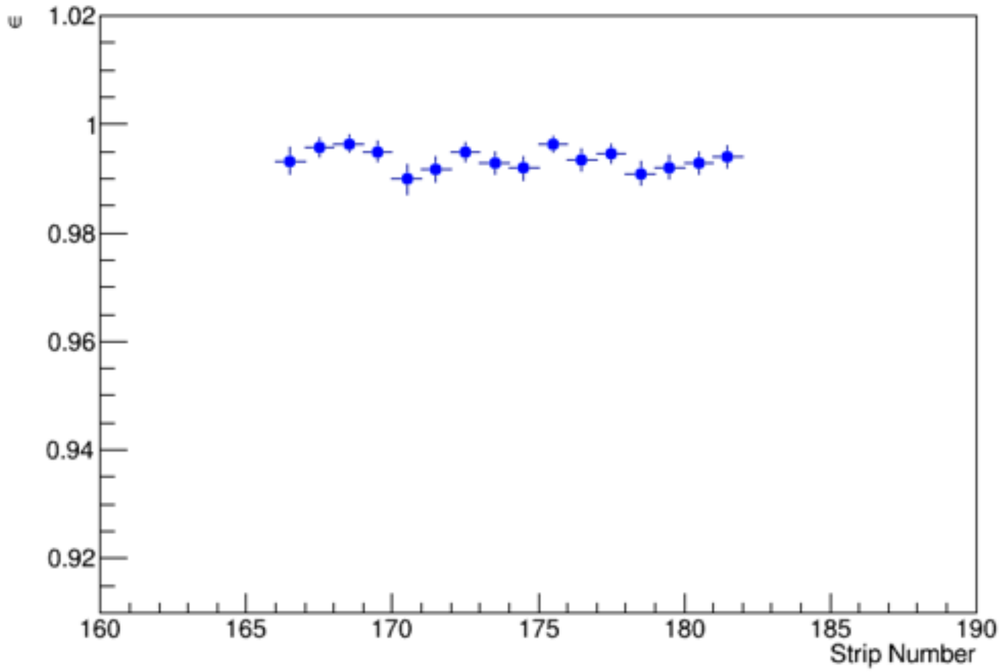


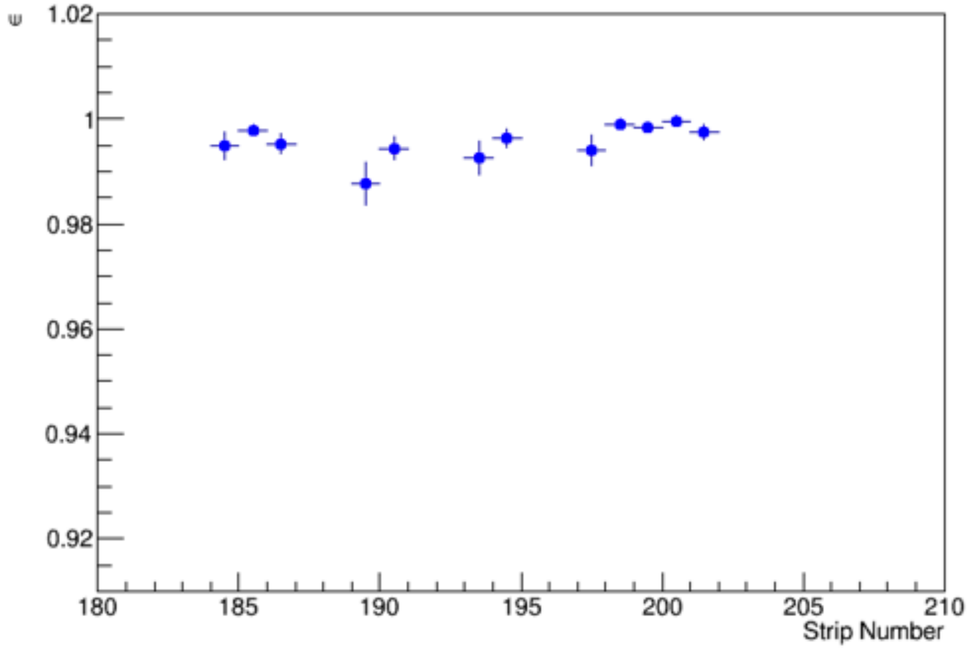
Tracks Parameters



Tracks Parameters

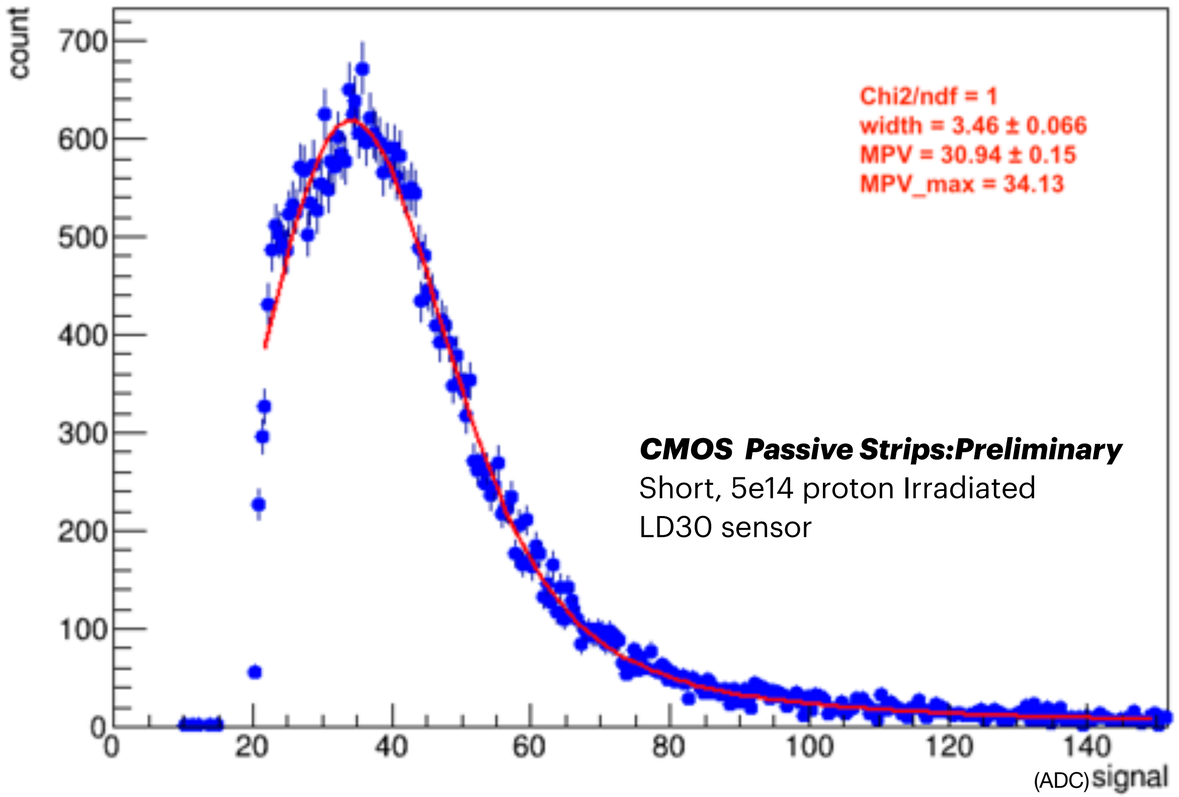
$$Hit\ Efficiency = \frac{Fraction\ of\ tracks\ with\ associated\ hits\ on\ the\ DUT}{Total\ tracks}$$

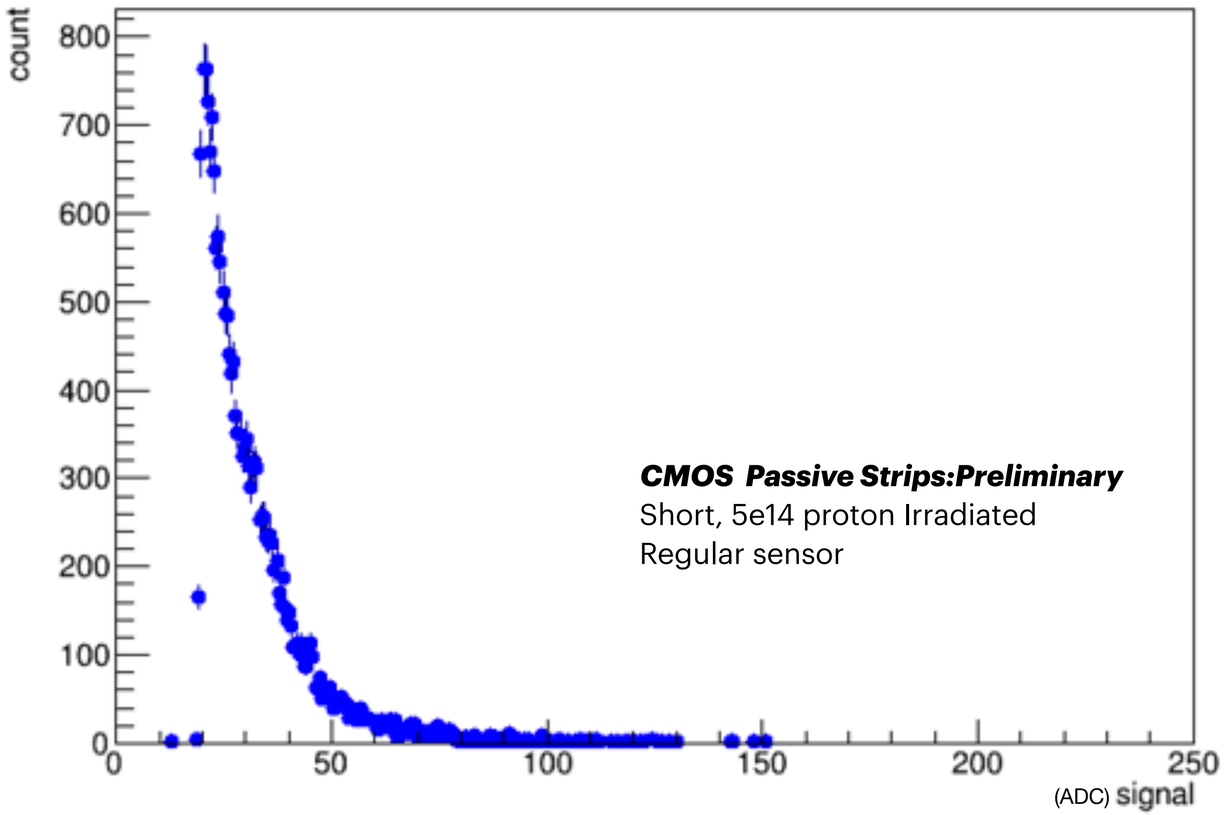




Signal Collection

All measurements are performed at -16° C





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

Tracks Cuts across strips