Radiation hardness test of P-type silicon sensors

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Overview

- FoCal detector @ ALICE
- Radiation Hardness
- Irradiation test results
- Summary

FoCal-E at ALICE

- The **Forward Calorimeter (FoCal)** : aimed at probing small-x physics and parton saturation effects
- The FoCal-E : electromagnetic section of the FoCal
- A high-granularity sampling calorimeter with tungsten absorbers and silicon sensors as active layers.

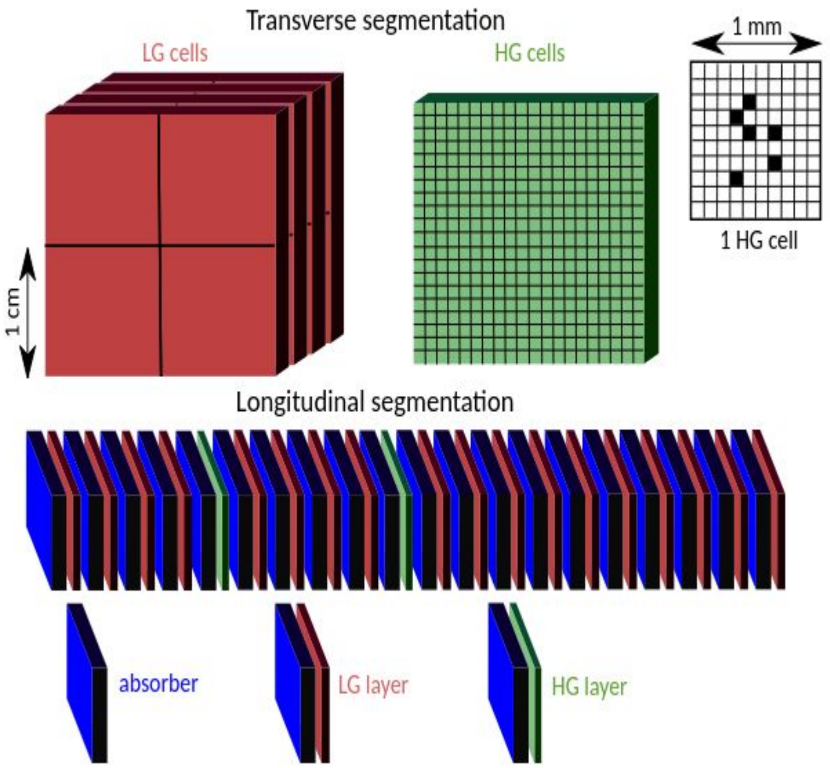
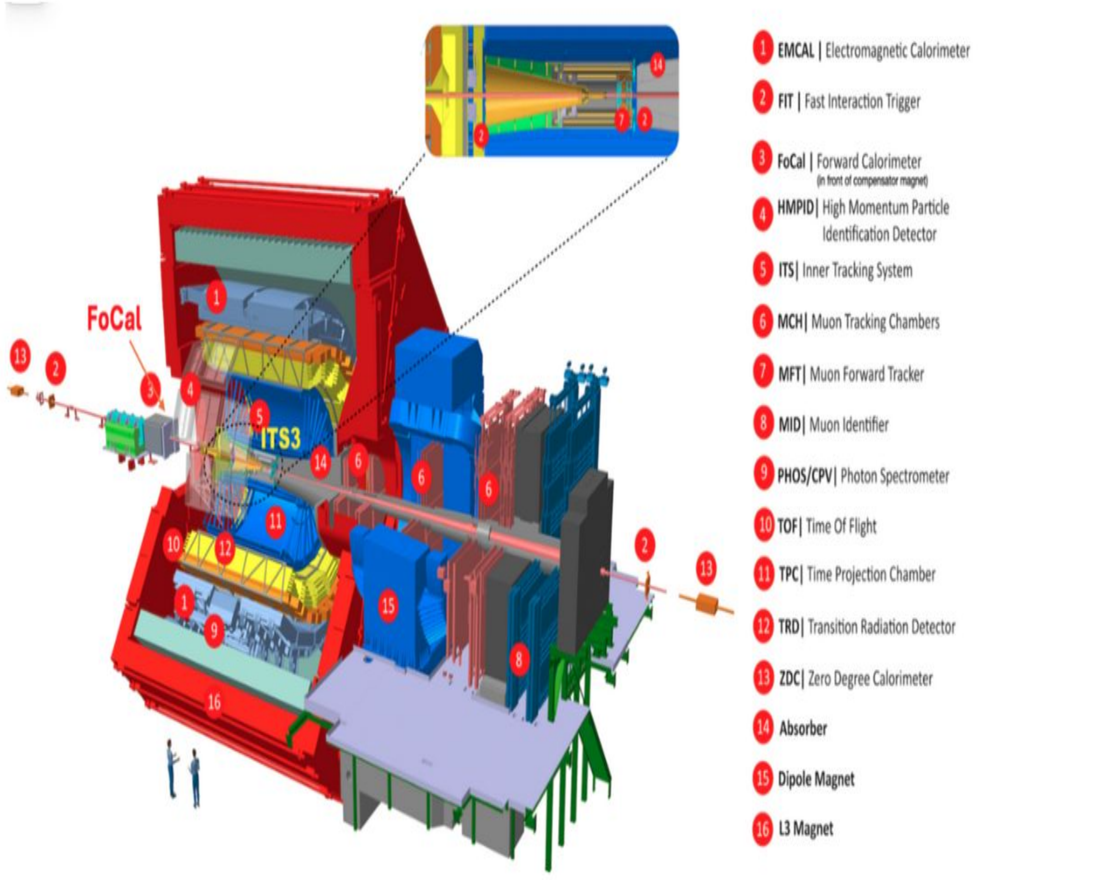


Fig. 2: Sketch of FoCal-E, showing 20 layers of W (each 3.5 mm thick) and Si sensors. There are 18 layers consisting of pad sensors with 1 cm^2 area (low granularity cells, denoted as LG) and two layers, at positions 5 and 10, consisting of pixel sensors with much finer granularity (high granularity cells, denoted as HG). Each layer can be read out individually.

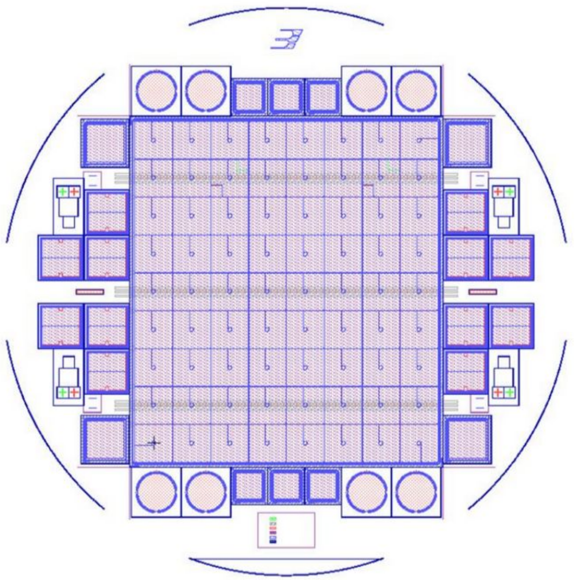
https://alice-collaboration.web.cern.ch/menu_proj_items/FOCAL



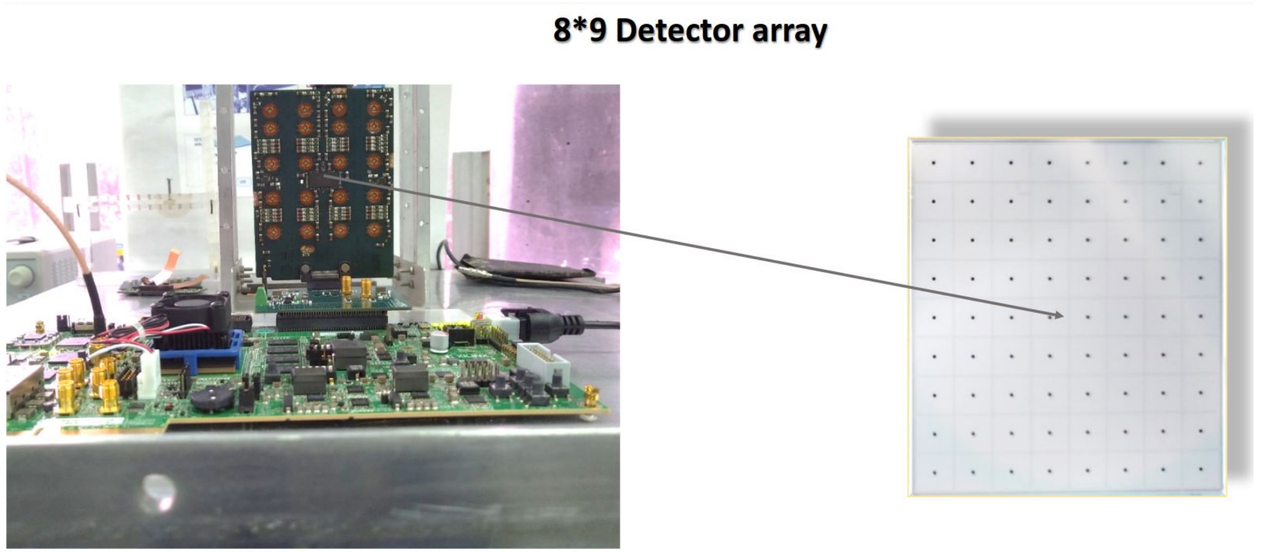
ALICE detector configuration for Run 4. ITS3 is close to the interaction point, whereas FoCal is located in front of the compensator magnet and outside the magnet doors on the A-side, opposite the muon arm.

https://cds.cern.ch/record/2890281/files/ALICE-TDR-022.pdf

p-type silicon R&D at VECC



The schematic of the final mask used for the fabrication of the 8 x 9 sensor array.



The pad prototypes are being tested to study and characterize their response.

Radiation Hardness

- impinging radiation causes dislocation of Si atoms and creates defects
- defects affect the resistivity of the detector
- the leakage current increases
- performance degradation

There are mainly two types of damage:

Surface damage: due to ionisation loss by the impinging radiation

Displacement damage: due to Non-Ionising Energy Loss (NIEL) of impinging radiation

radiation hardness of the detector is an important characteristic

Unit for fluence: 1 MeV neutron equivalents per cm^2

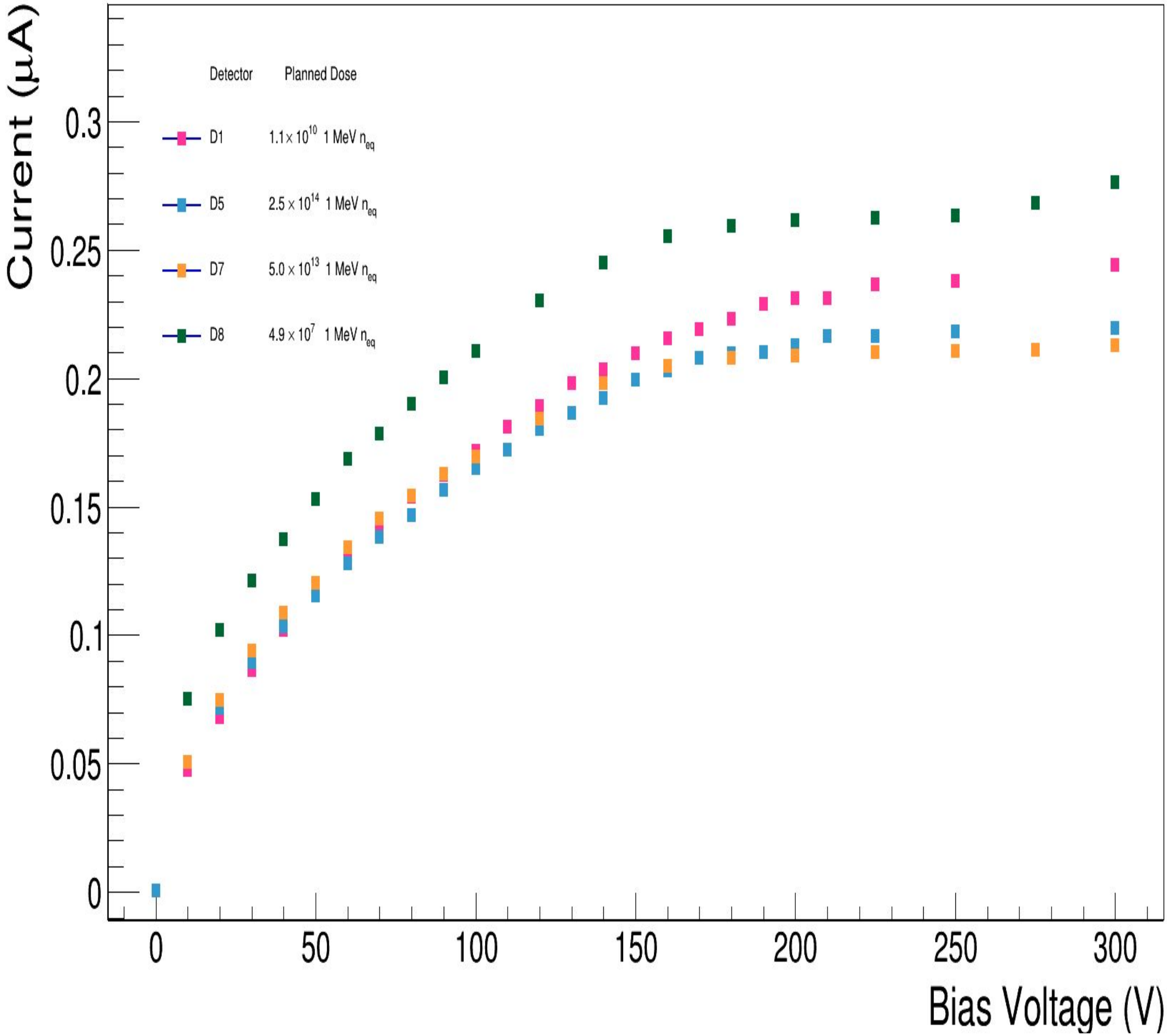
The projected fluence for FoCal is about ~10^{13} 1 MeV neq over its entire run. (considering a safety factor of 10)

We have tested 4 single pad detectors(1 cm x 1 cm) with varying level of irradiation dose:

- 10^7 1 MeV N_{eq}
- 10^{10} 1 MeV N_{eq}
- 10^{13} 1 MeV N_{eq}
- 10^{14} 1 MeV N_{eq}

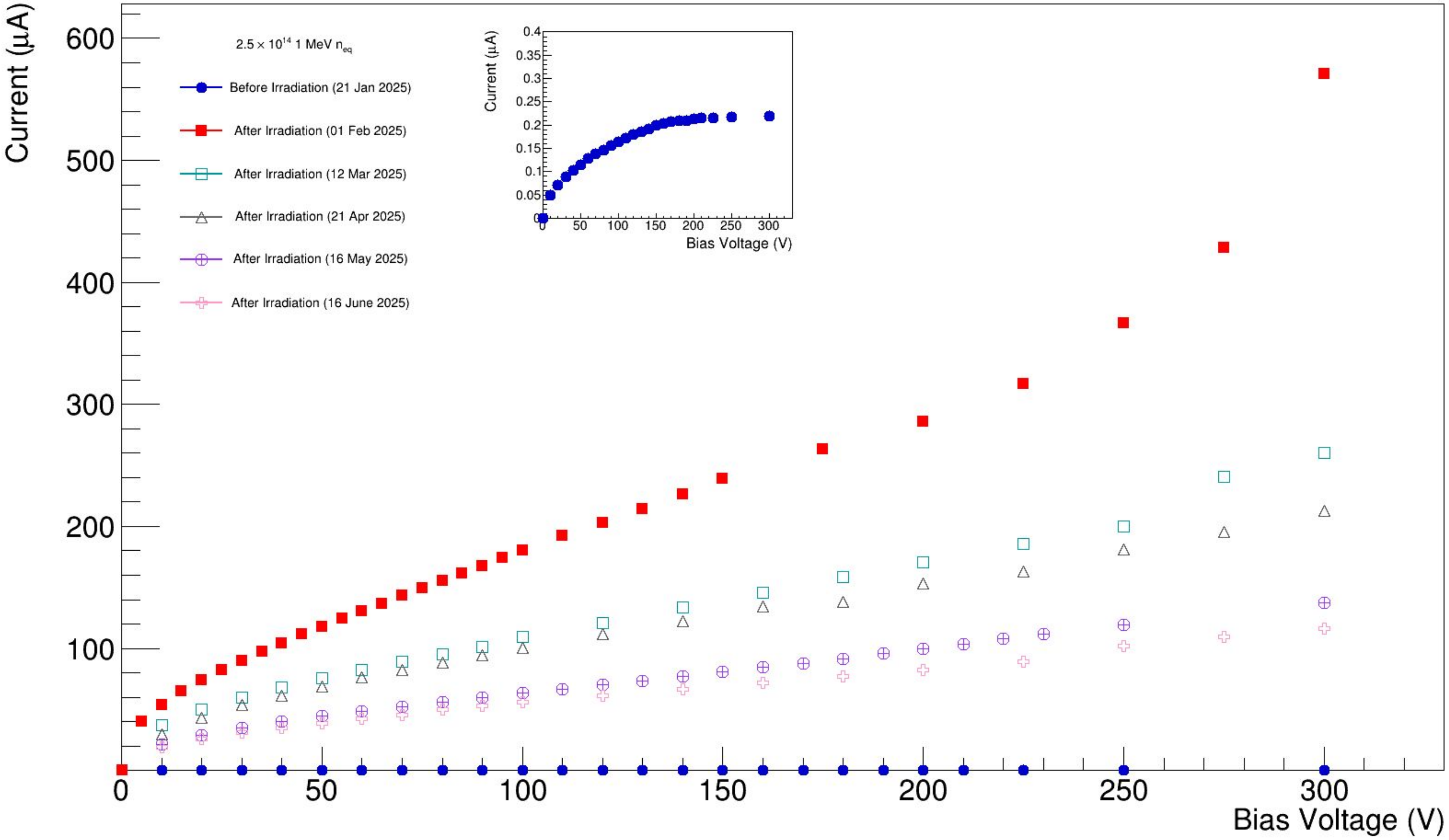
The metrics used to study the performance:

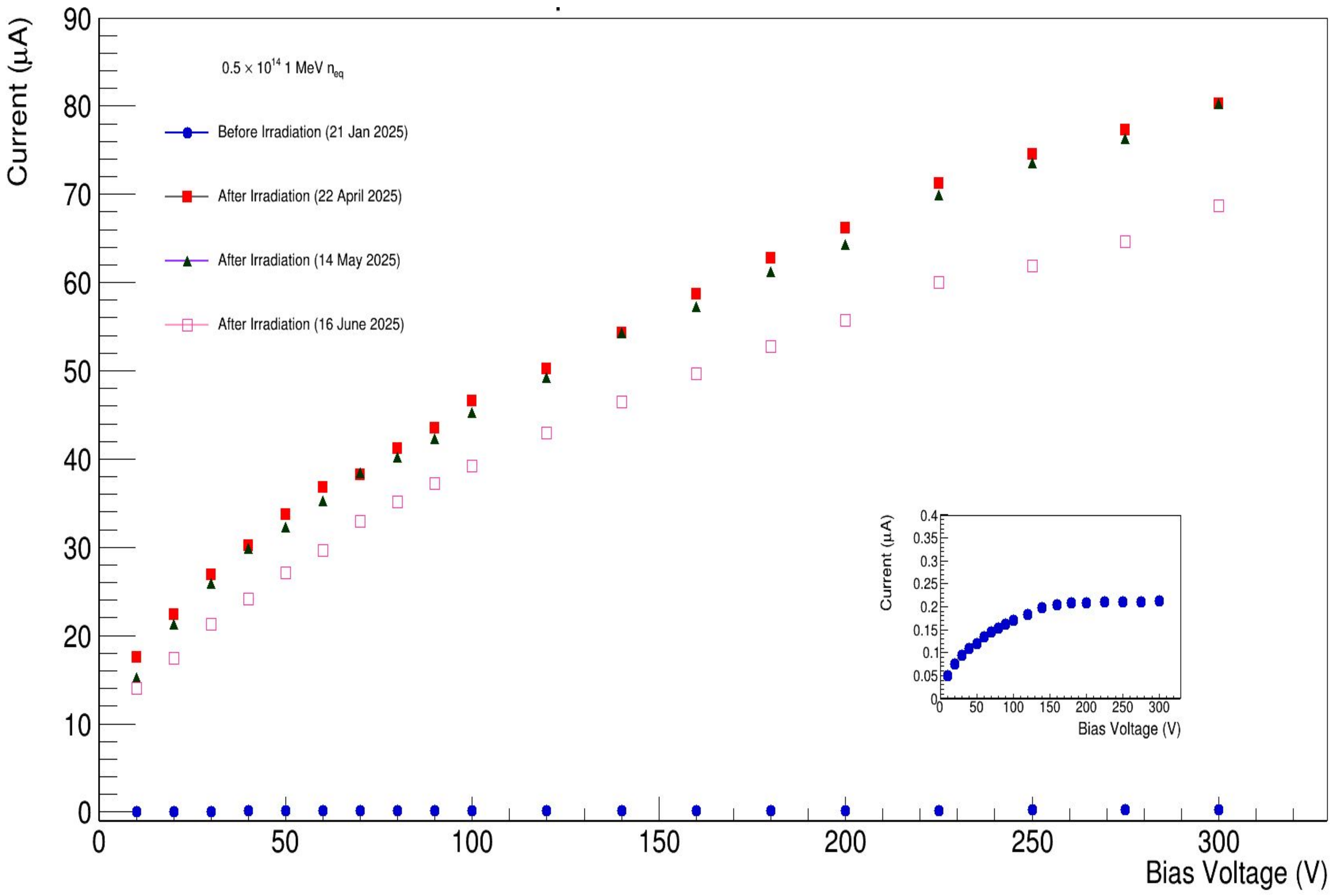
- I-V response and
- response to MIP



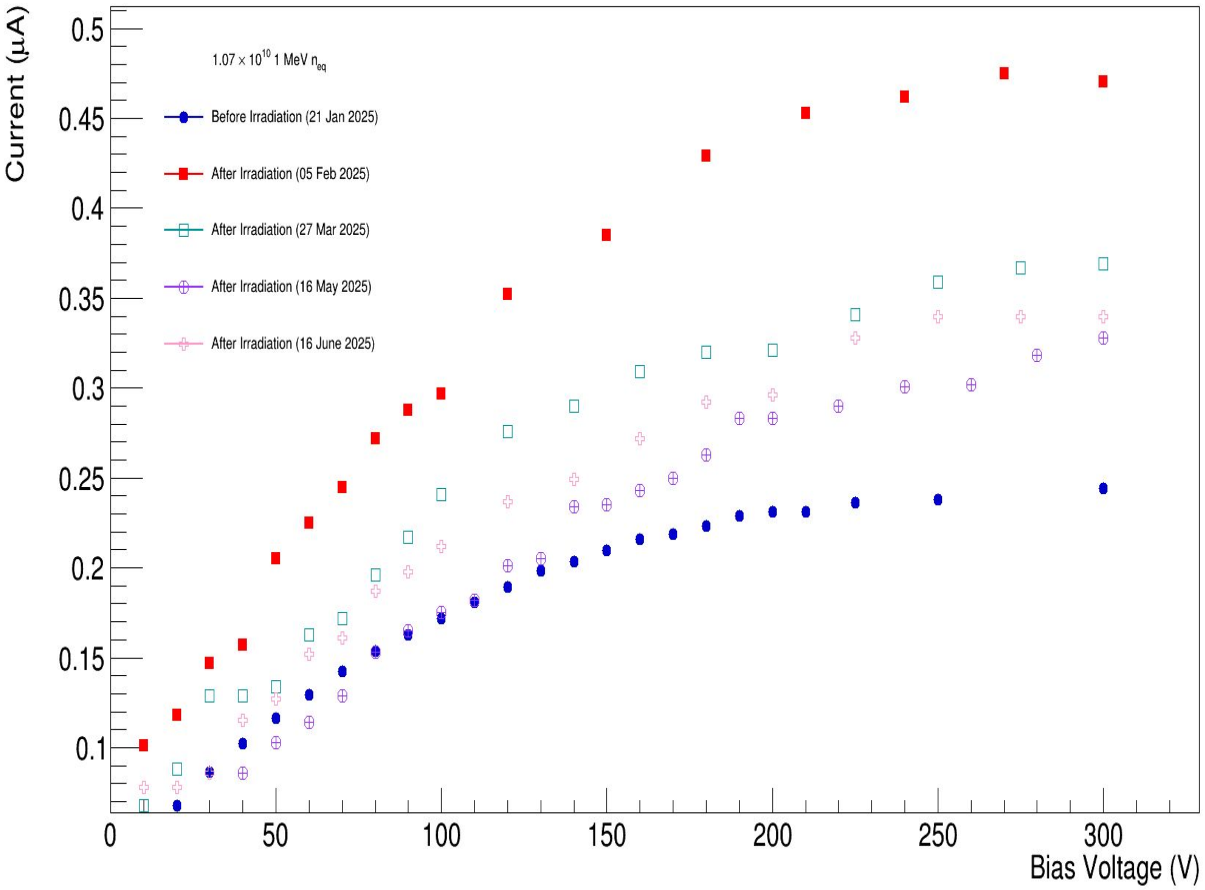
IV response of irradiated sensors, measured at regular intervals

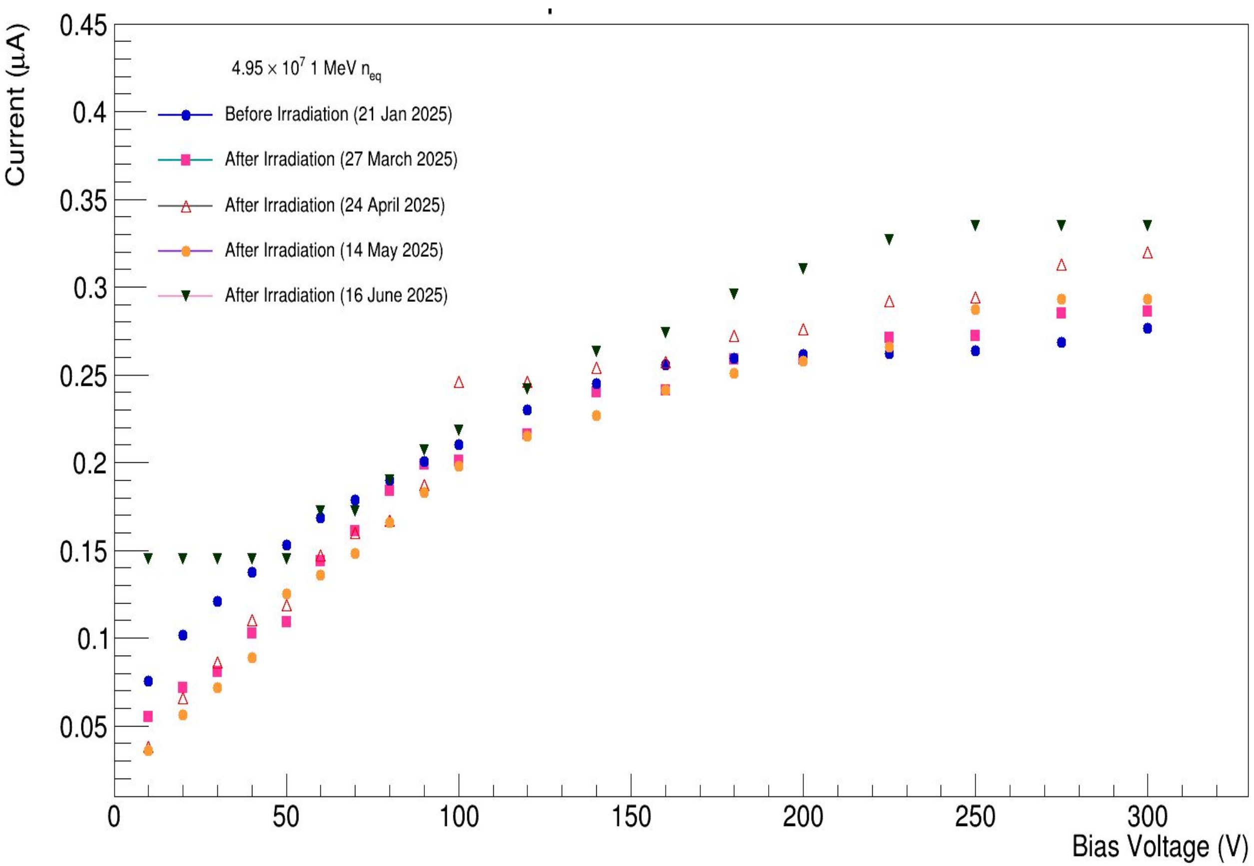
"beneficial annealing"
After irradiation, some defects in silicon are thermally unstable. Over time (or mild heating), vacancies and interstitials recombine or defect complexes dissociate, leading to a partial recovery of doping and leakage current



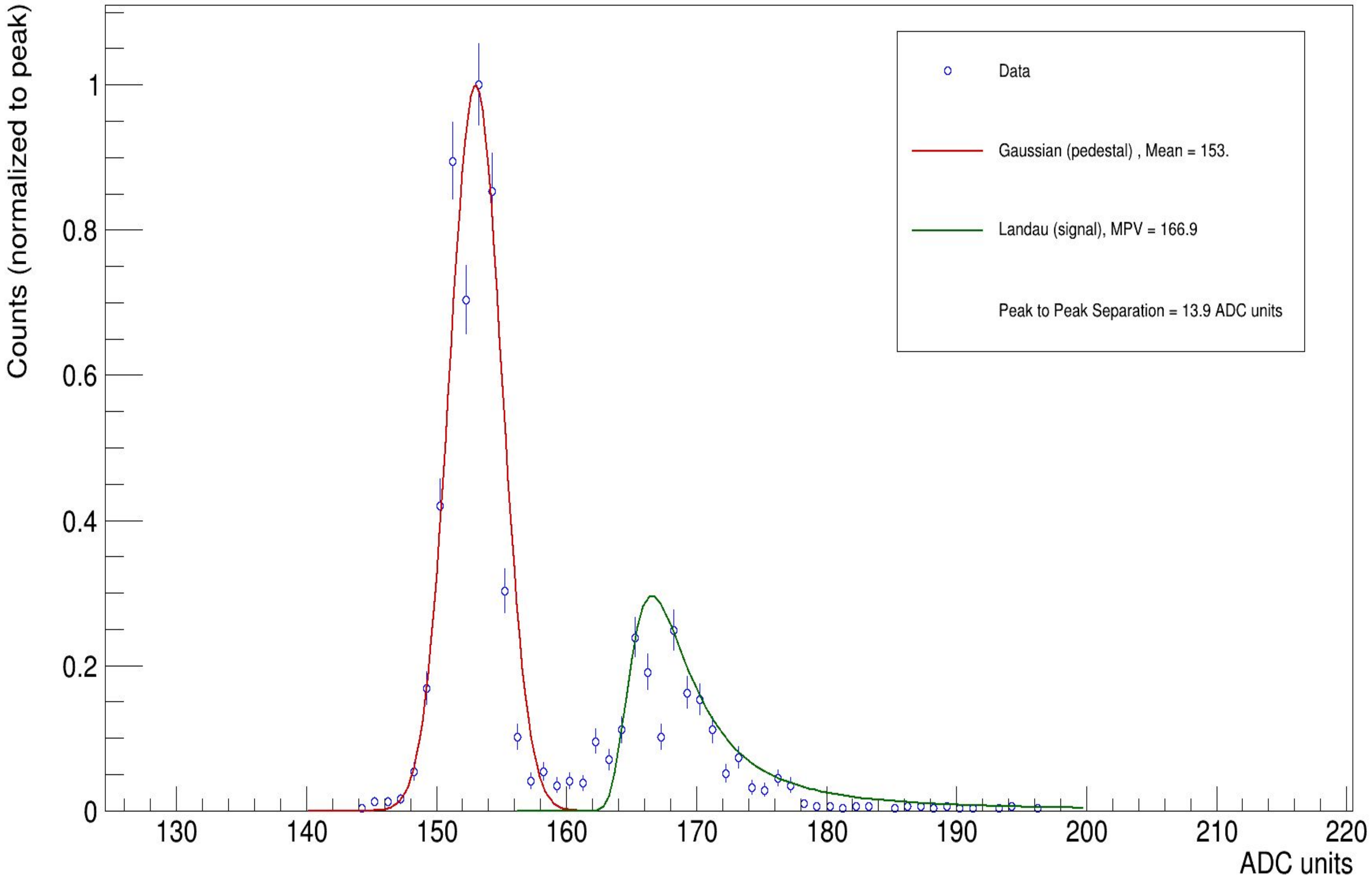


Current (µA)
0.5×10^{14} 1 MeV n_{eq}
Before Irradiation (21 Jan 2025)
After Irradiation (22 April 2025)
After Irradiation (14 May 2025)
After Irradiation (16 June 2025)
Bias Voltage (V)
0
10
20
30
40
50
60
70
80
90
0
50
100
150
200
250
300
Current (µA)
Bias Voltage (V)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4

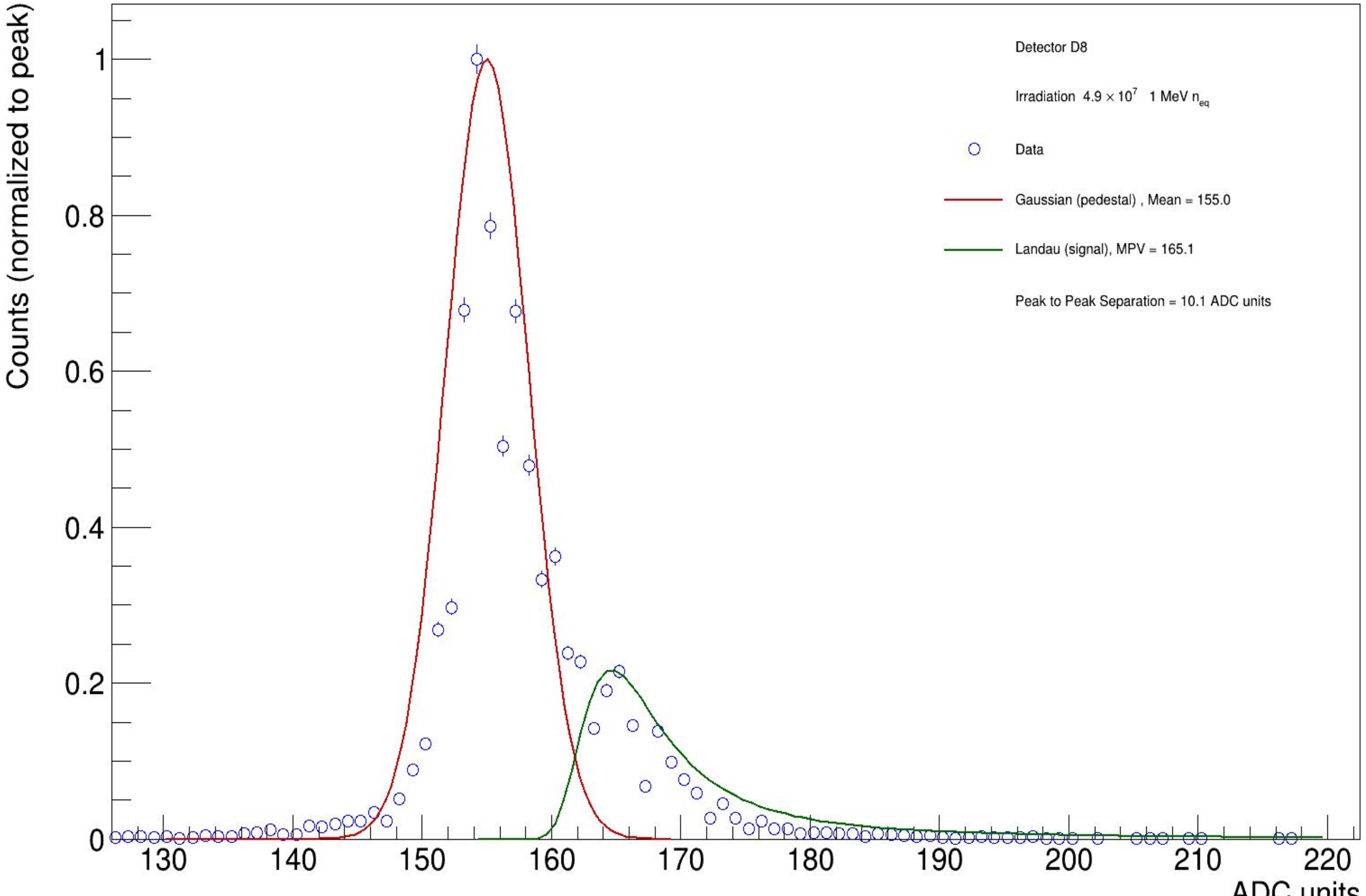

1.07×10^{10} 1 MeV n_{eq}
Before Irradiation (21 Jan 2025)
After Irradiation (05 Feb 2025)
After Irradiation (27 Mar 2025)
After Irradiation (16 May 2025)
After Irradiation (16 June 2025)
Current (μA)
Bias Voltage (V)


4.95×10^{7} 1 MeV n_{eq}
Before Irradiation (21 Jan 2025)
After Irradiation (27 March 2025)
After Irradiation (24 April 2025)
After Irradiation (14 May 2025)
After Irradiation (16 June 2025)
Current (μA)
Bias Voltage (V)

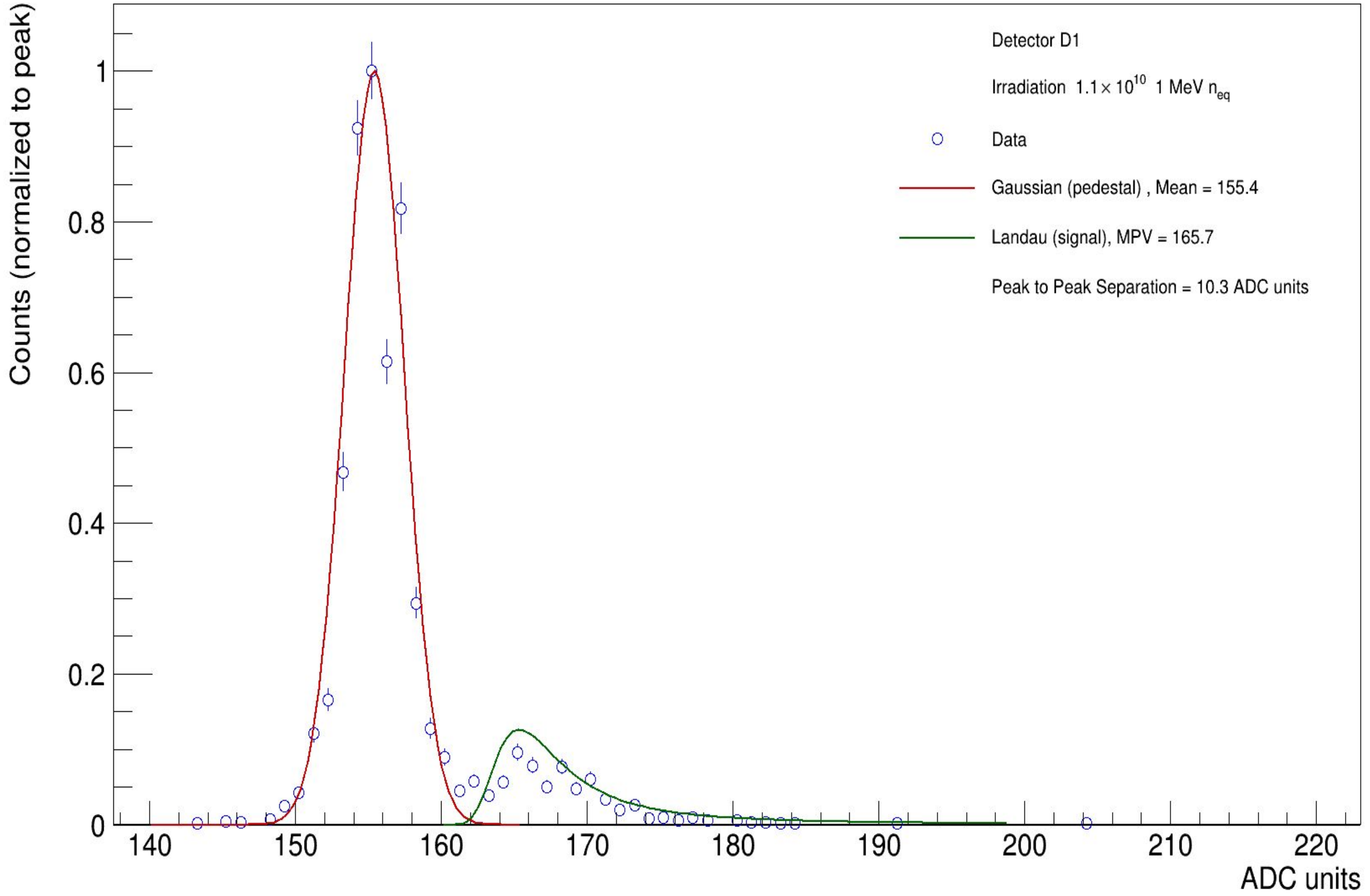
Pedestal noise and MIP signal in non irradiated sensor



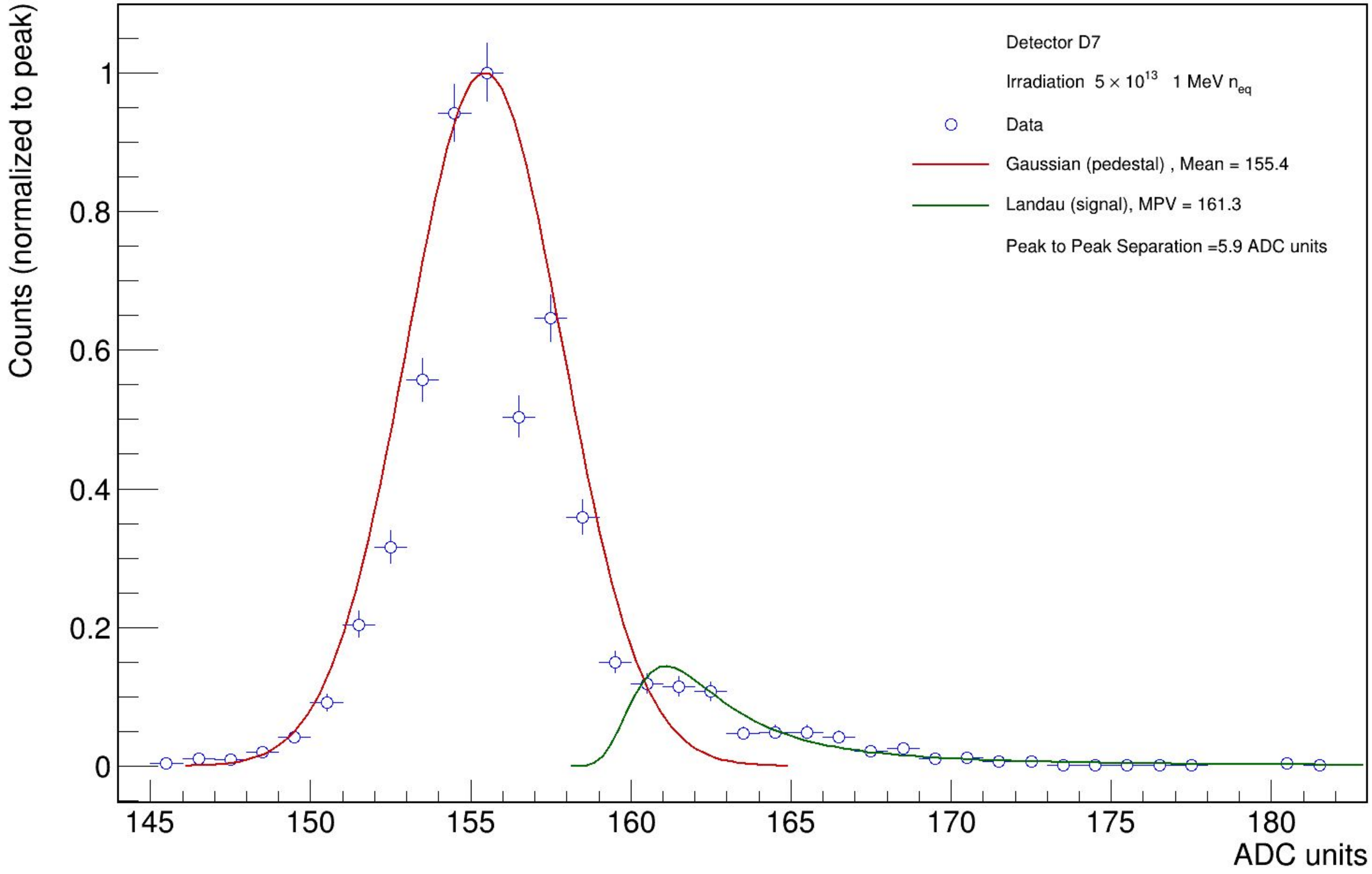
Pedestal noise and MIP signal irradiated sensor D8



Pedestal noise and MIP signal irradiated sensor D1



Pedestal noise and MIP signal irradiated sensor D7



Summary

- single pad test detectors have been irradiated with different irradiation doses
- we continue to monitor the leakage current
- we are able to detect MIP in Irradiated sensors