Development of the FoCal-E pad detector for the ALICE experiment at the LHC

- Beam tests of the detector prototype and irradiation tests of silicon pad sensors -

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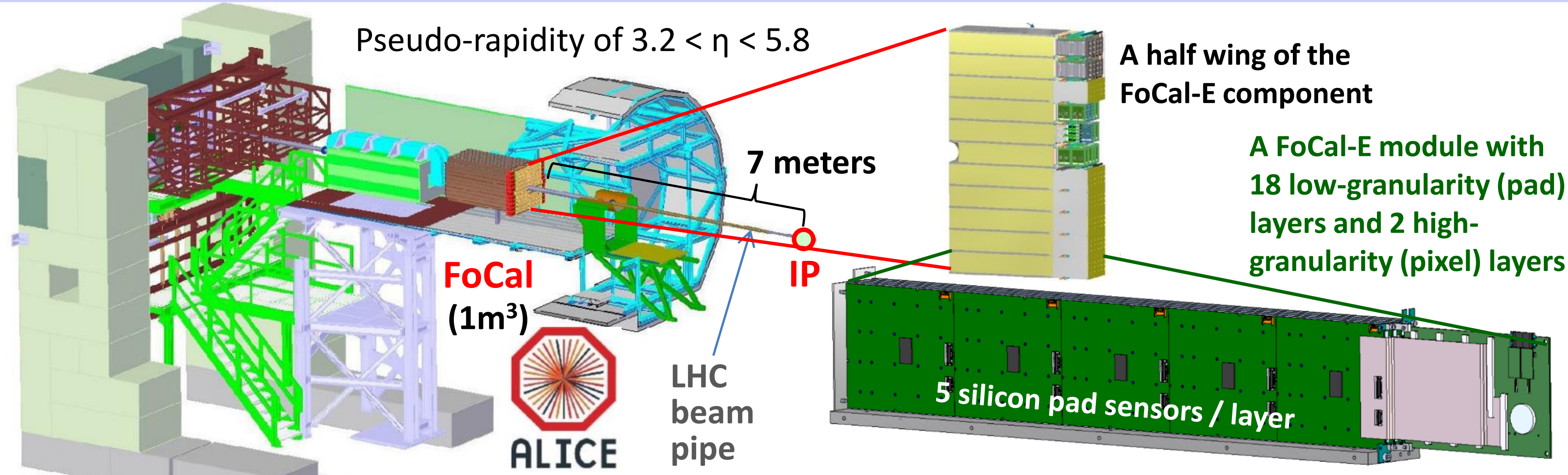
Topics

- **FoCal-E modules for a new ALICE FoCal detector**
- **Beam tests of the FoCal-E single-tower-module prototype**
- **Irradiation tests**
- **Summary**

The FoCal detector for the ALICE experiment



Technical Design Report of the ALICE Forward Calorimeter (FoCal), CERN-LHCC-2024-004.

A new forward calorimeter (FoCal) with a unique capability to measure direct photon production at the forward rapidity is going to be installed to the ALICE Experiment during the next LHC Long-Shutdown.

FoCal-E	FoCal-H
The Si+W electromagnetic calorimeter	The Cu+ Scintilation-fiber hadronic calorimeter

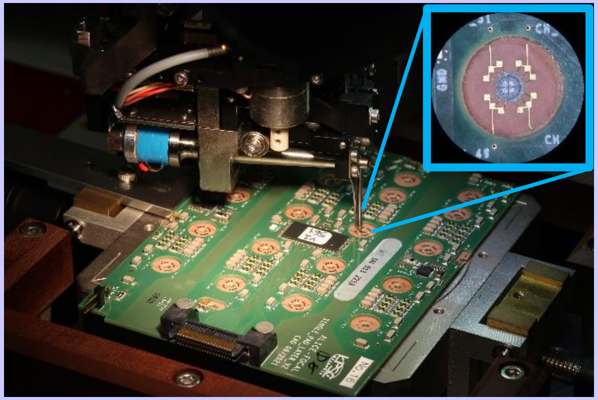
→ 22 FoCal-E modules with longitudinal segmentation.

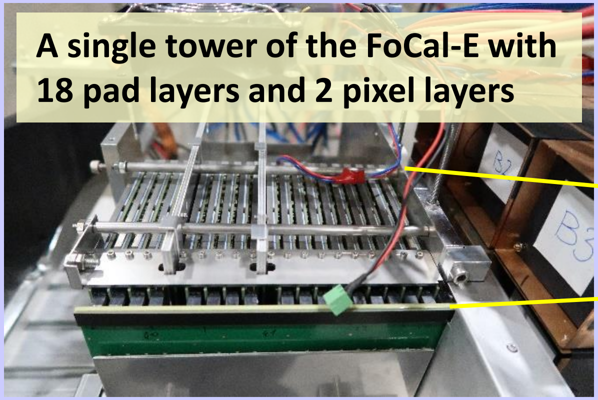
[Our R & D history and an installation plan]

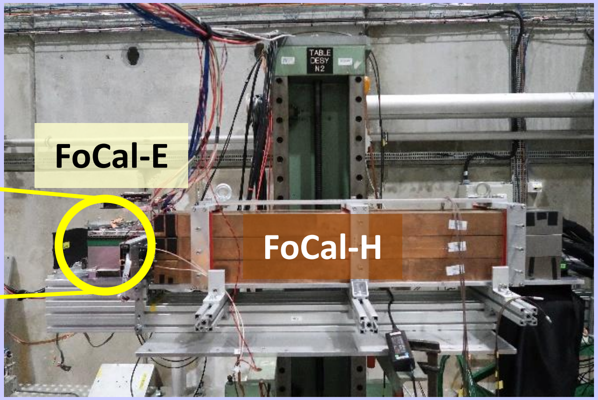
- 2013: The first test of a single-pad-module.
- 2017 - 2018: Beam tests of the FoCal-E pad detector prototype (mini-FoCal-E) with 60 n-substrate 8x8 silicon pad sensors.
- 2019 - 2022: Beam tests of the FoCal-E detector prototype using 18 p-substrate 9x8 silicon pad and some pixel sensors.
- 2020: LoI (CERN-LHCC-2020-009, I-036).
- 2024: TDR was approved !
- 2026 - 2028: Installation in the LHC LS3.
- 2029 - 2032: Data taking will start.

The FoCal-E detector prototype

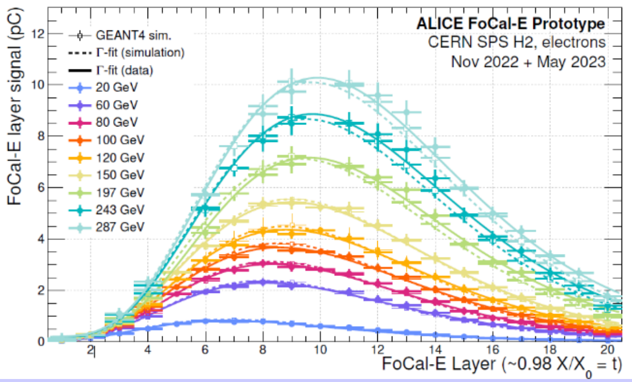
The main sensor was electrically connected to a 10-layer PCB with the HGCROC V2 using bonding wires after gluing. A single tower of the FoCal-E module prototype was tested at the CERN PS / SPS complexes and Tohoku Univ. ELPH test beam line.

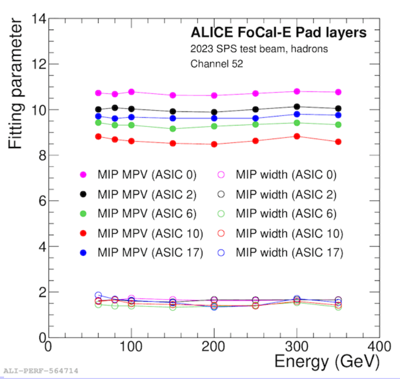






We studied longitudinal shower profiles for 20-287 GeV electrons and the MIP position and width for hadrons between 20 and 350 GeV. The MIP data will be used for the pad-by-pad calibration.

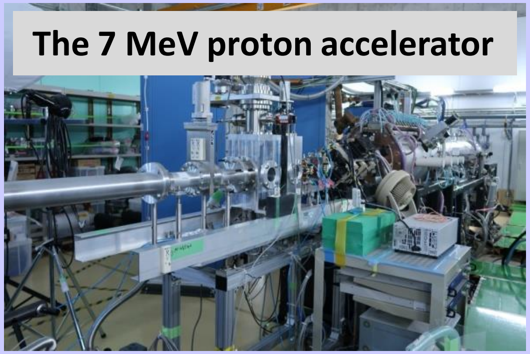




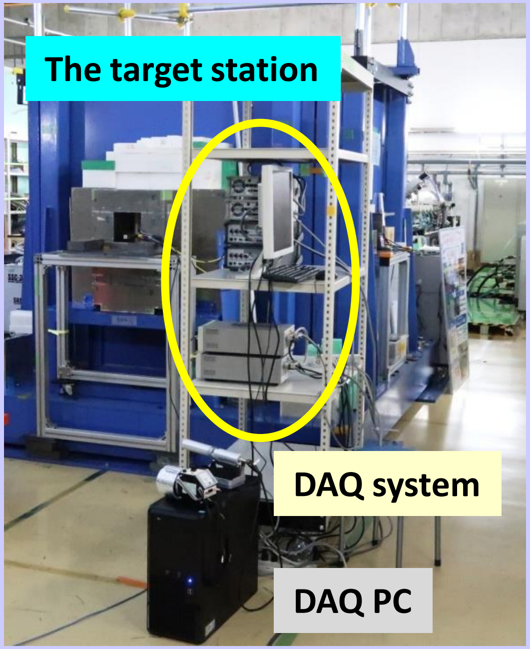
We also checked the temperature dependence of the MIP position using a single-pad-layer at the ELPH test beam line. It worked well though a temperature went up to 55 degrees C.

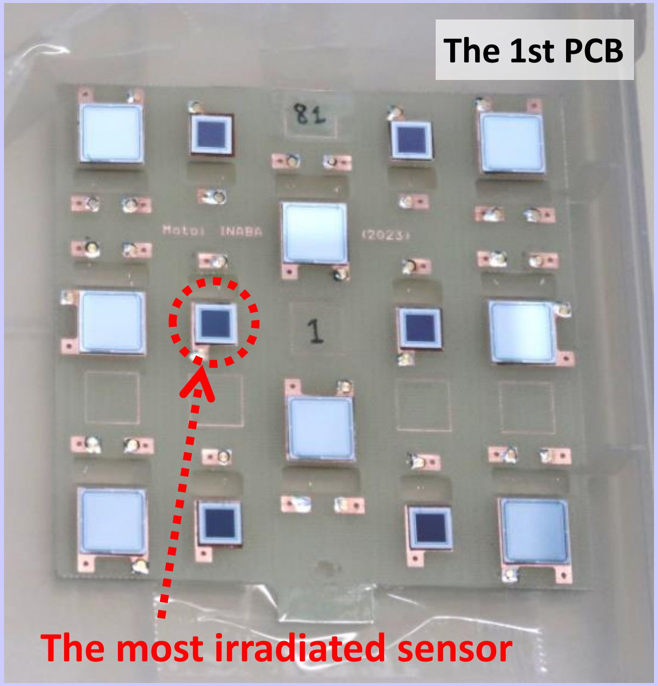
The irradiation test

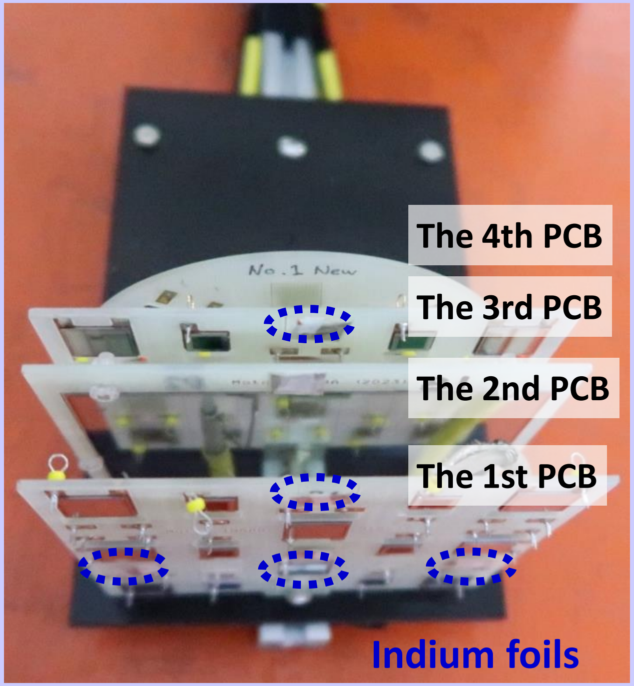
It is estimated that the FoCal detector will get about 7×10^{13} neutron equivalent per cm^2 at the maximum during the operation, and it is important to study how the characteristics of the silicon pad sensors change by the radiation damage.



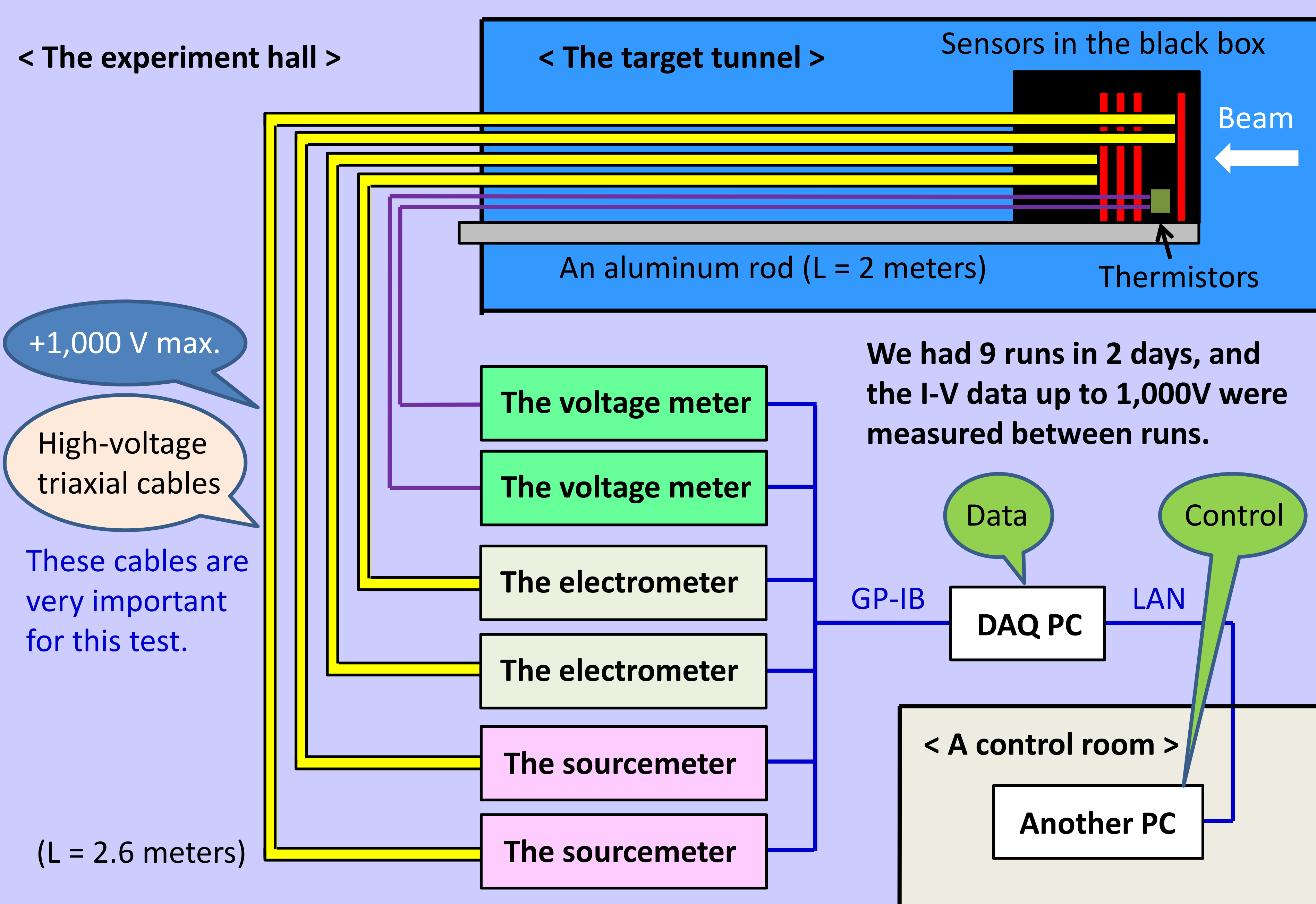
We carried out the irradiation tests of the silicon pad sensors at the Riken RANS (Accelerator-driven compact neutron source). Two main sensors were put on the 2nd PCB and small sensors which came from the same wafer as the main sensor were glued on the 1st and 3rd PCBs.







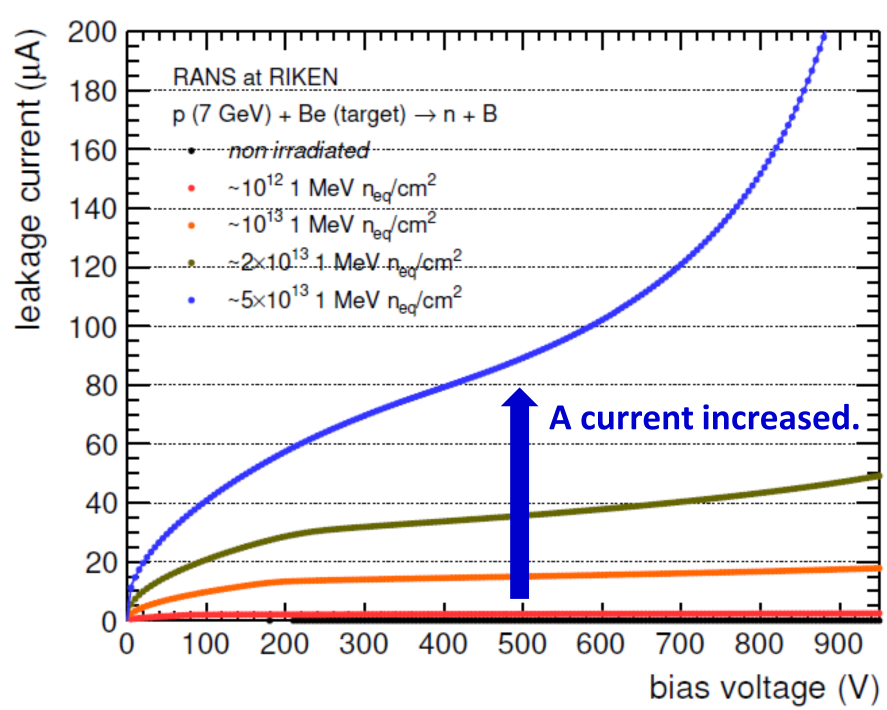
A setup for the online measurement

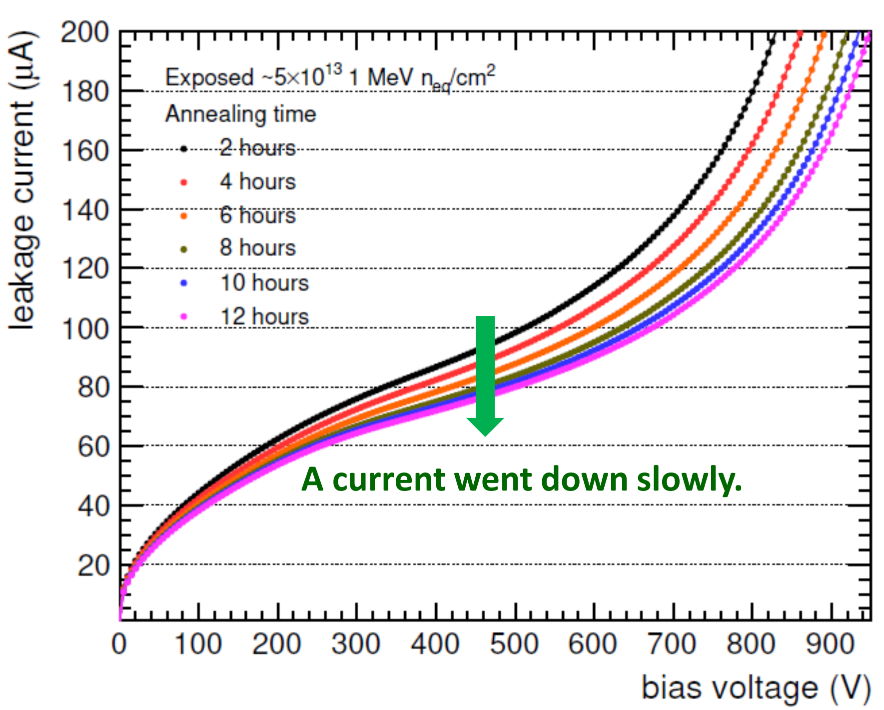


A change of a leakage current

The sensors on PCBs in the target station of RANS were irradiated by the neutron beam in the daytime of the 1st and 2nd days, and a leakage current has increased according to an irradiation time. In the 1st night and after the irradiation test, a current of the sensor went down slowly in a room temperature because of the annealing effect. A change of the current was monitored for about 2 months.

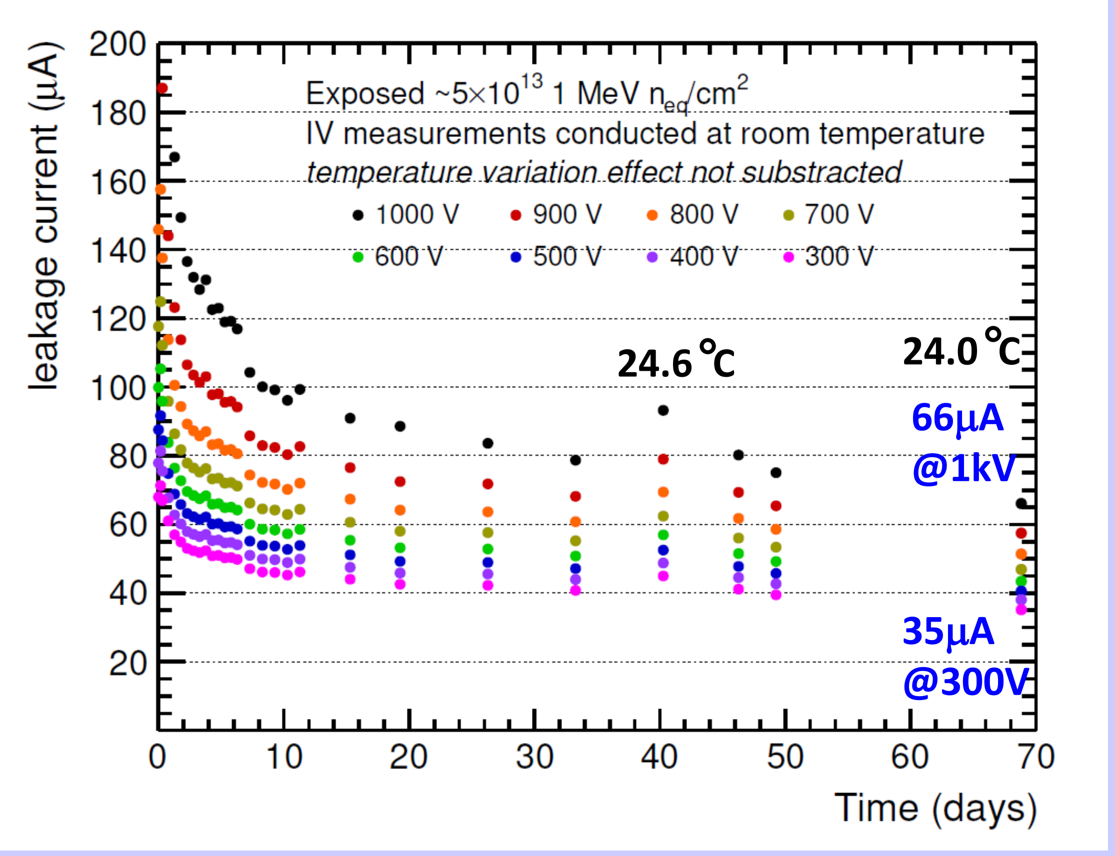
The 1st day		The 1st night		The 2nd day		
Beam ON	→	**Beam OFF**	→	**Beam ON**	→	**A continuous measurement from the 2nd night for about 2 months**





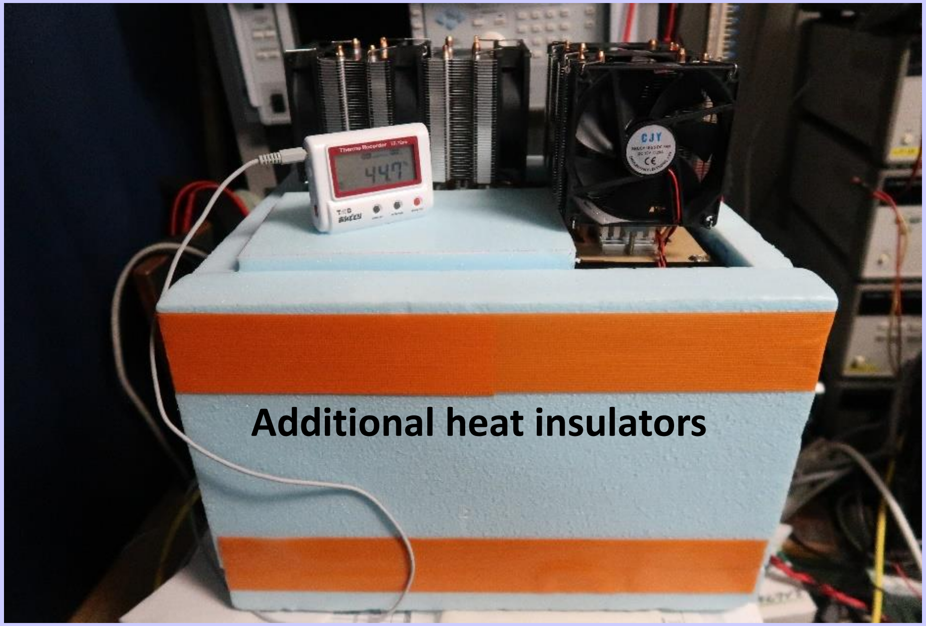
The long-term measurement

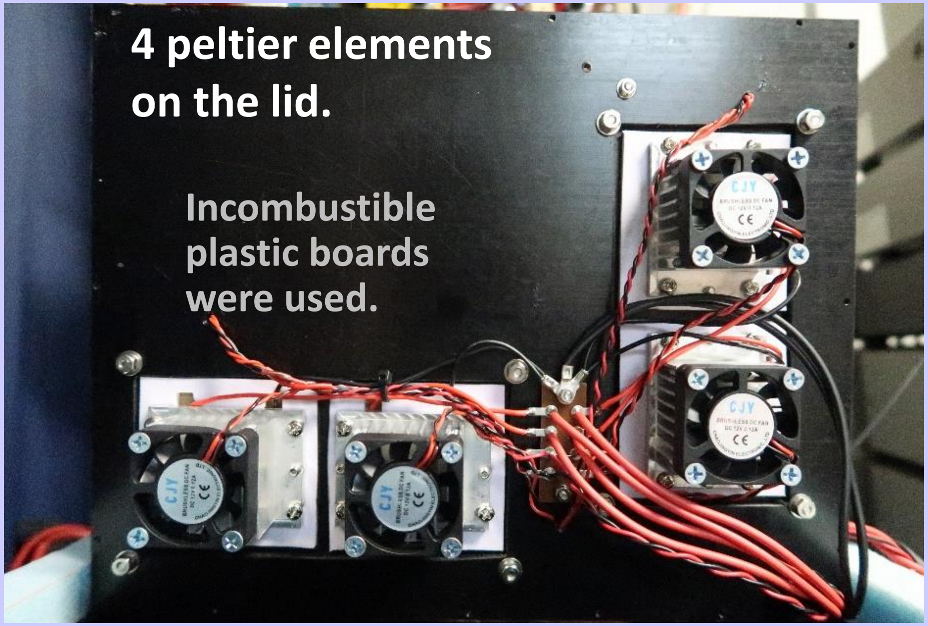
We took out the sensors from the target station and measured a change of the I-V characteristics in a room temperature for about 2 months continuously.
A temperature in the room had fluctuations of +/- 2 degrees C.



The leakage current slowly went down to 66μA and 35μA at bias voltages of 1kV and 300V, respectively, when a temperature was 24.0 degrees C.

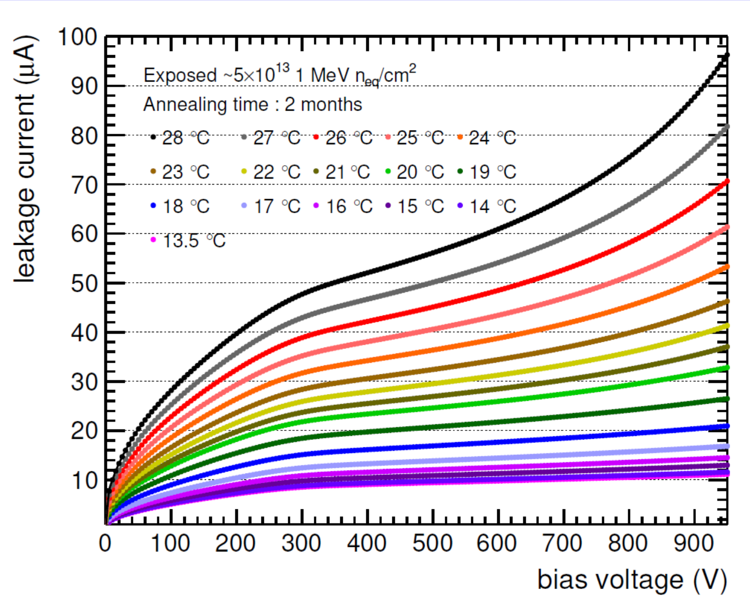
A temperature dependence





A temperature dependence of the leakage current of the irradiated silicon pad sensors was measured using a new cooling / heating test bench with 4 peltier elements on the lid. The leakage current of the irradiated sensors was very sensitive to a temperature.

We also tried to estimate the full-depletion voltage from the I-V characteristics and measure the MIP position and width.



Summary

Development of the new FoCal detector for the ALICE experiment is coming to the final stage. The longitudinal shower profiles and a good S/N for the MIP measurement were successfully confirmed using FoCal-E single-tower-module prototype with 18 low-granularity layers (pad) and 2 high-granularity layers (pixel) at the CERN PS / SPS complexes and Tohoku Univ. ELPH test beam line.

Before mass production of the silicon pad sensors begins, we studied a change of a leakage current of the silicon pad sensor by the radiation damage at the Riken RANS facility.

Test results of the temperature dependence using a new cooling / heating black box shows that leakage currents of the irradiated sensers were very sensitive to a temperature.

Thank you for your attention !