ATLAS ITk (strips and radmon)

Igor Mandić

F9 Strategic Meeting

Hotel Krvavec 28. – 30. 9. 2026

ITk strips

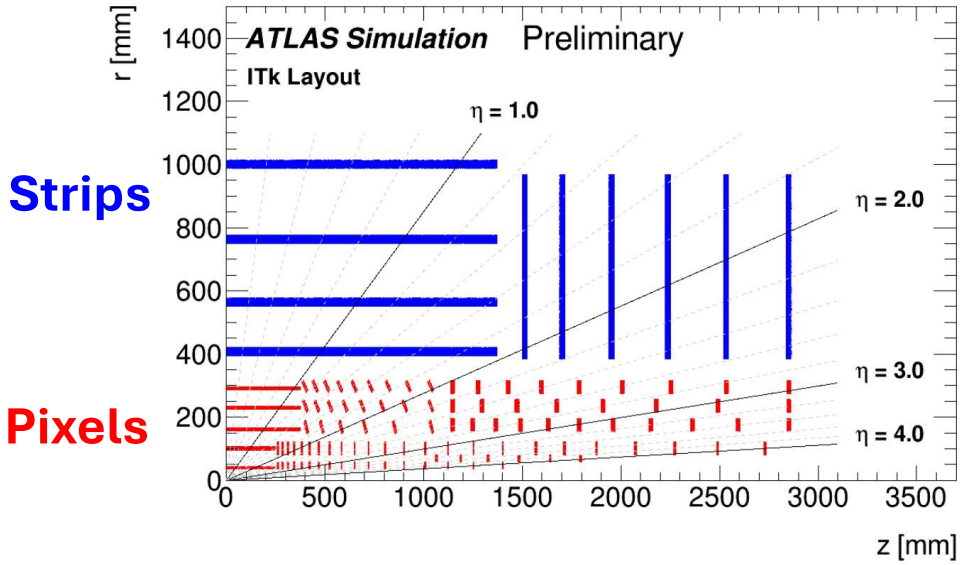
- Ljubljana (Vladimir Cindro, Marko Mikuž, Gregor Kramberger, Andrej Gorišek, Brigita Novak, Igor Mandić…) contributing to:

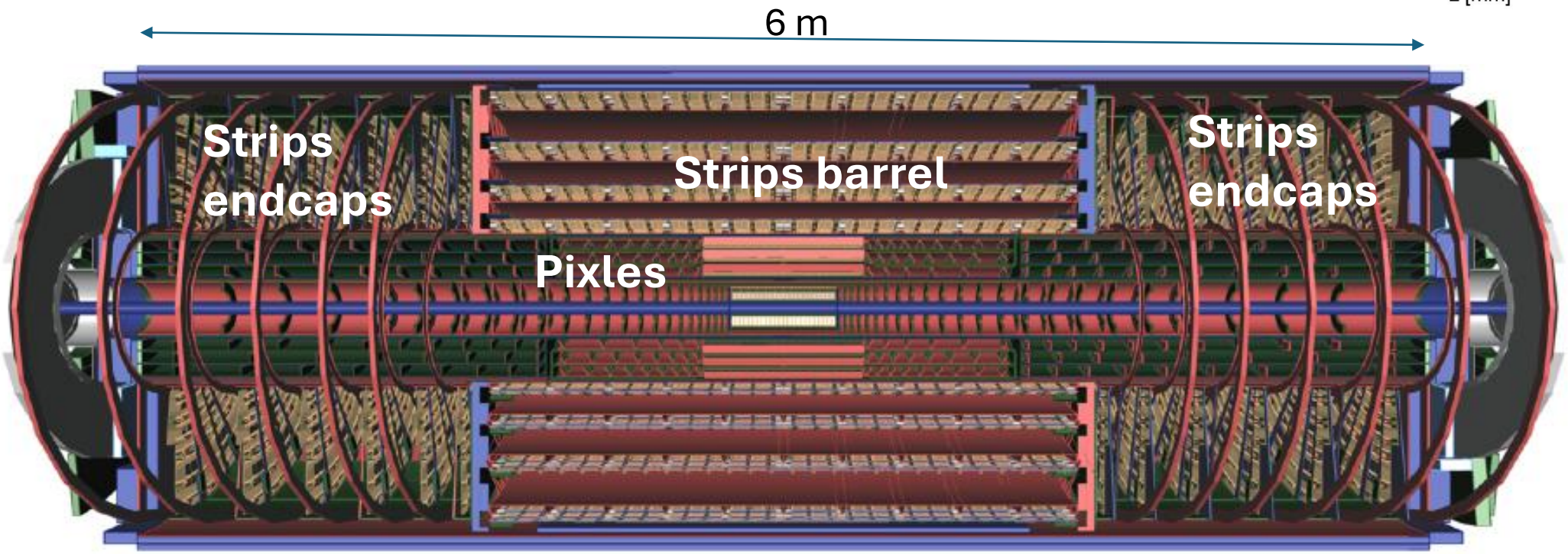
  - development and production of **strip sensor**
  - development and production of **bus tapes** for end caps

ATLAS ITk:

ITk strip detector:

- 4 barrel layers
- 6 strip disks in each end-cap
- coverage up to $\eta = 2.7$
  - ➔ ~ 18000 strip sensors
  - ➔ ~165 m^2 of silicon
  - ➔ ~ 60 million channels





ATL-PHYS-PUB-2021-024

Modules

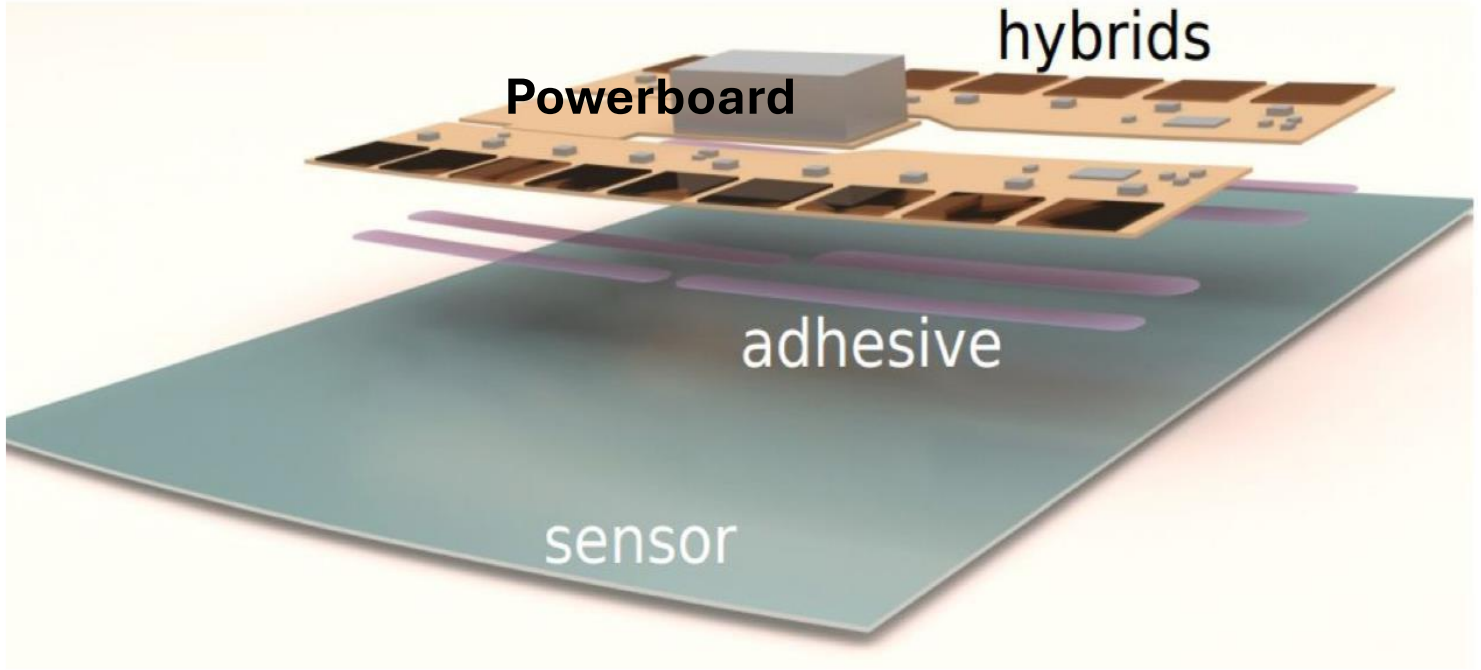
Module:

- Silicon sensors + ASICs + Power control

Hybrids, Powerboard:

- flexible printed circuits
  ➔ glued on the sensor

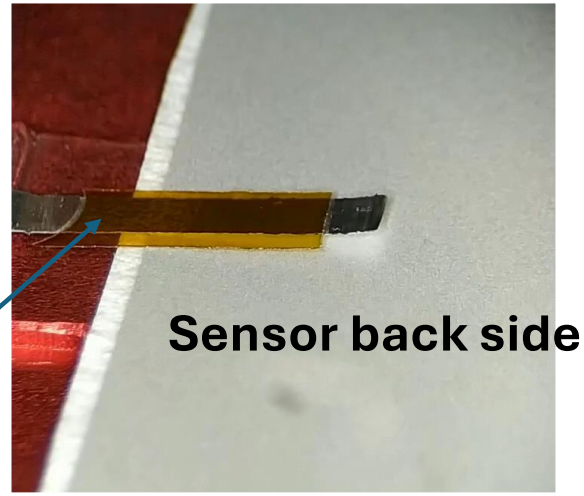
- strips wire-bonded to front end ASIC on hybrids

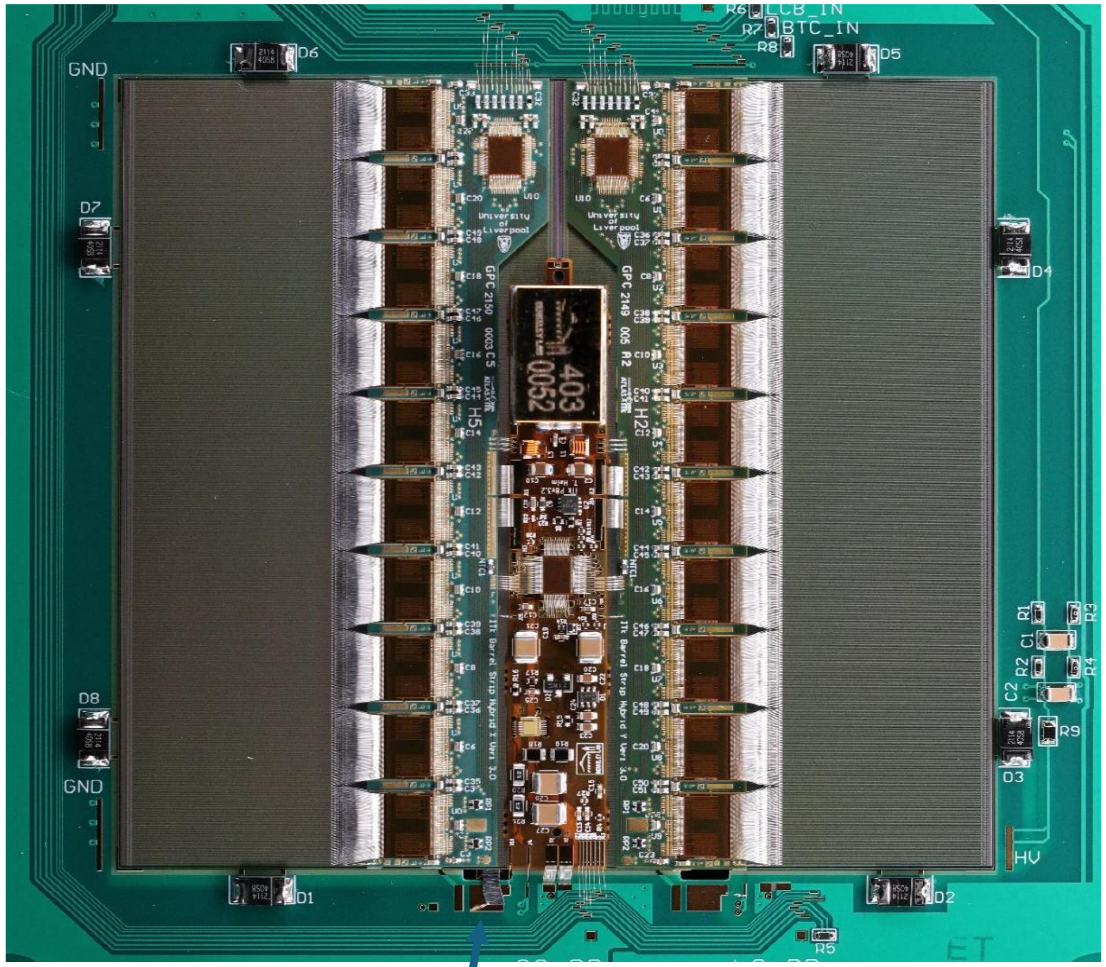


Modules

- High Voltage for sensor bias is connected to sensor back plane by **T**ape **A**utomated **B**onding (**TAB)** bonding

- maximum bias voltage -**500 V**



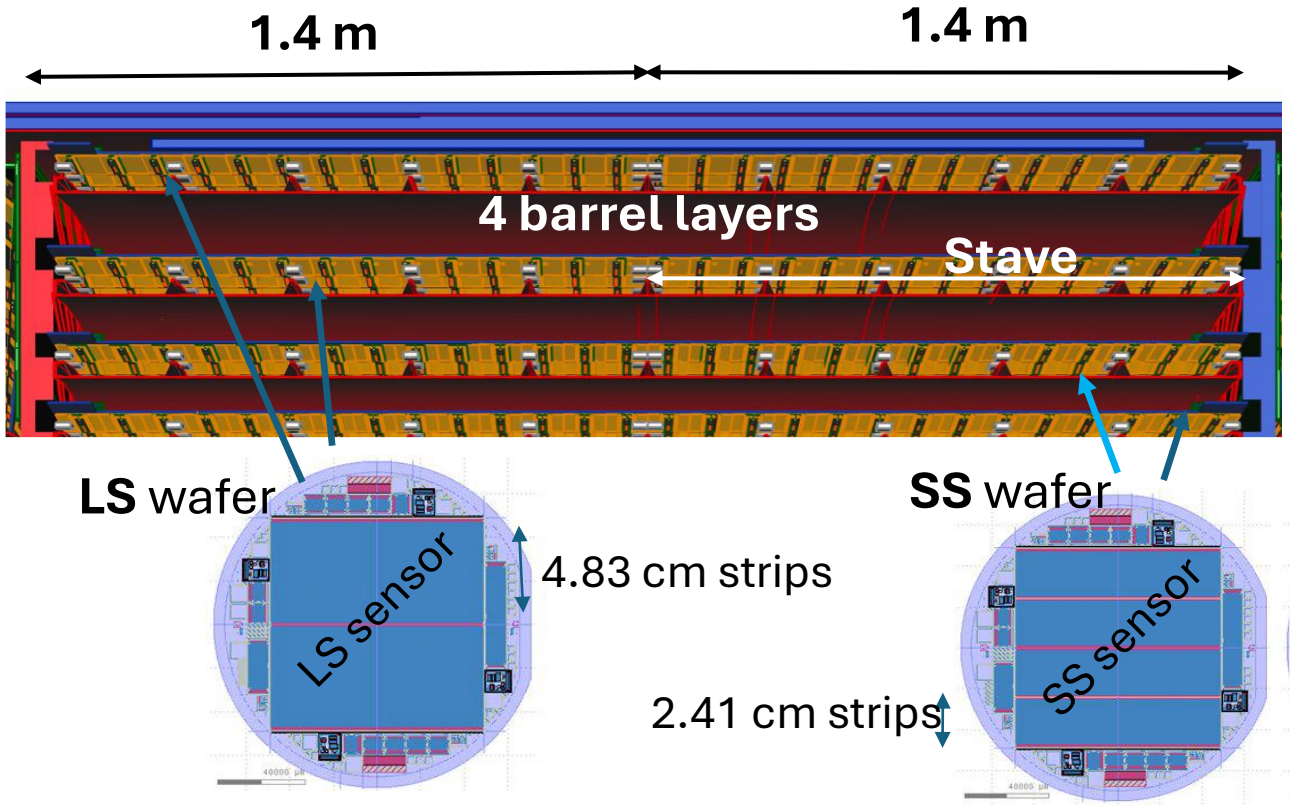


ITk strips - barrel

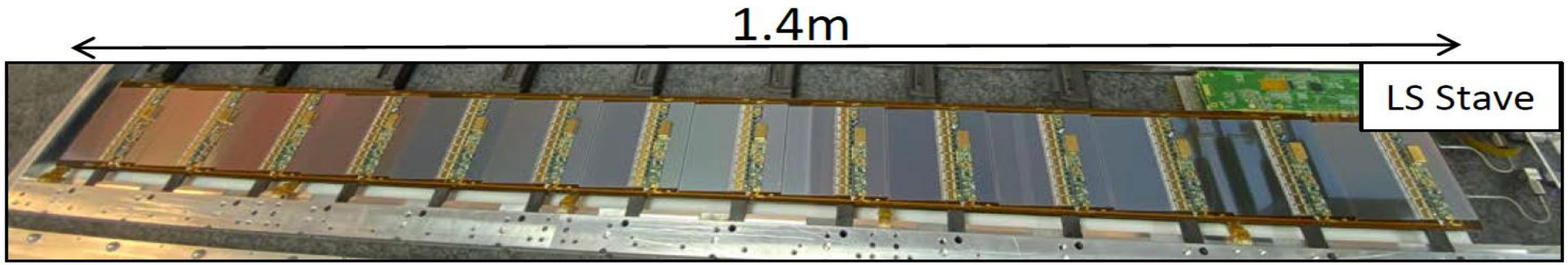
Barrel:

- 4 barrel layers
- barrels are divided in 392 double sided **staves**
- 14 modules/stave/side
  → **10976** modules (sensor+electronics)

- Two types of ~ 9.7 cm x 9.7 cm sensors:
  - outer 2 layers: Long Strips (**LS**)
  - inner 2 layers: Short Strips (**SS**)



- 14 modules mounted on each side of **stave**



ITk strips - endcaps

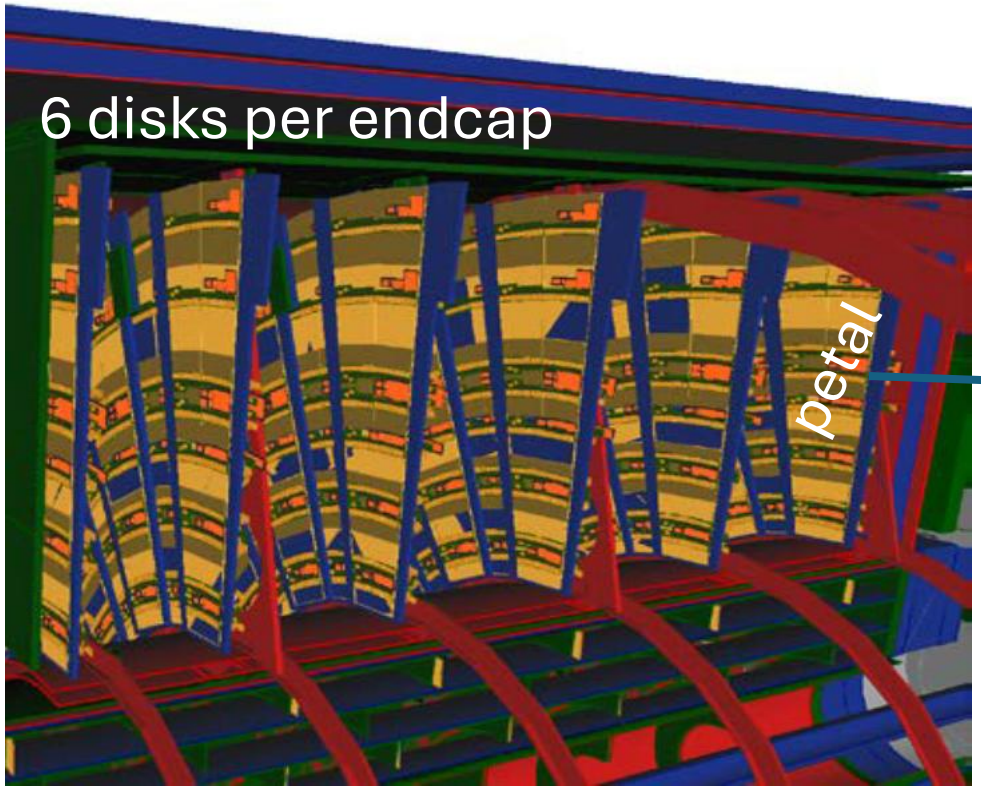
Endcaps:

- 2 endcaps
- 6 disks per endcap
- 32 petals per disk
- 6 modules per petal-side

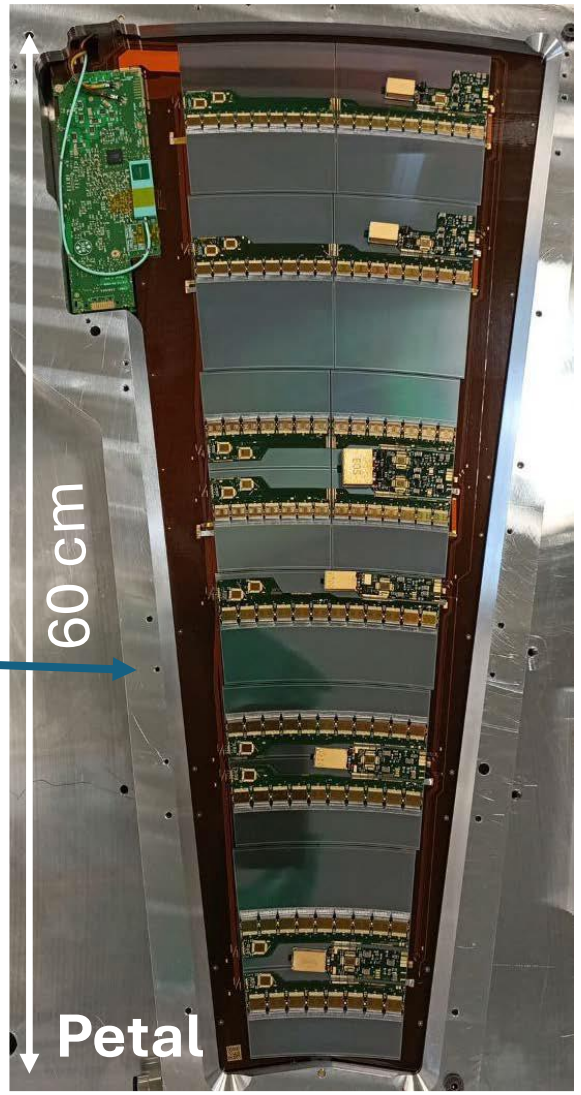
→ **4608** modules

Petal:

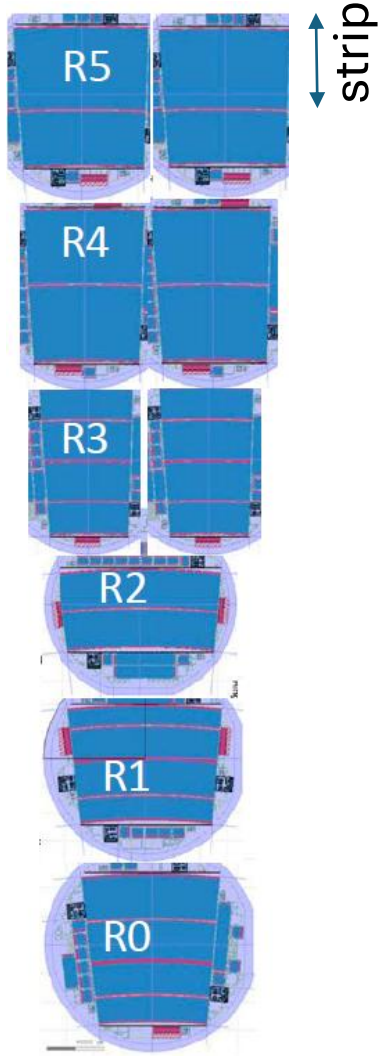
- 6 sensor geometries
- R0,R1,R2 one sensor/module
- R3, R4, R5 two sensors
- strip length: 1.4 –6



6 modules on each side



Sensor geometries



Low mass support structures

Cores:

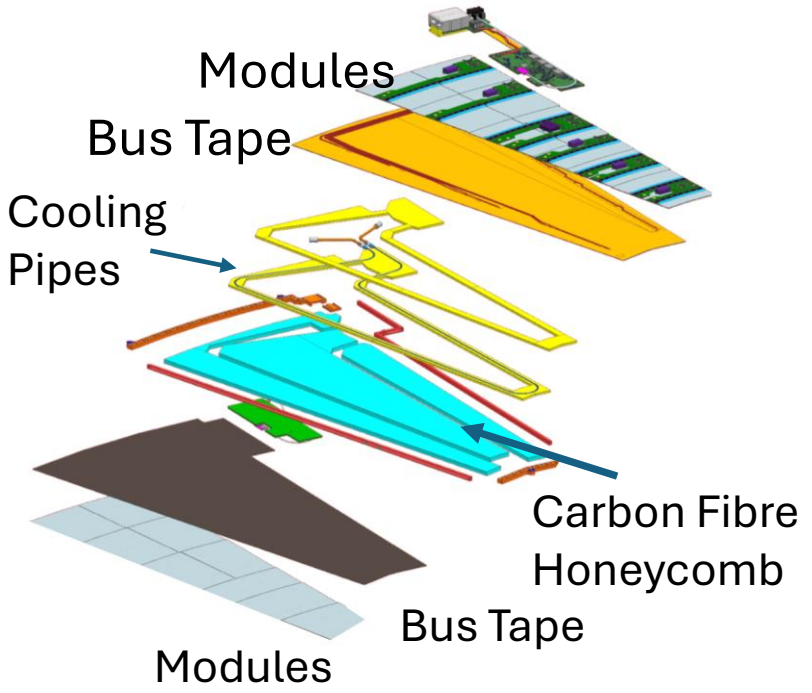
- copper on Polyimide (kapton) bus tapes is routing electrical connections for power and signals
- pipes for evaporative CO_2 cooling in highly thermal-conductive carbon-fibre structure

co-cured

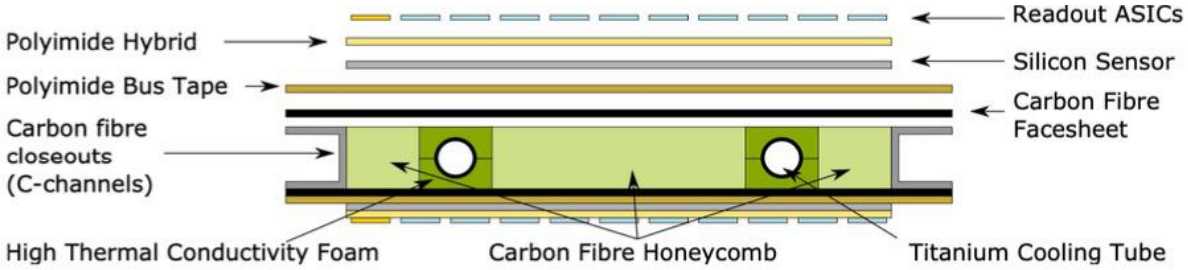
➔ **modules are glued to both sides of cores**

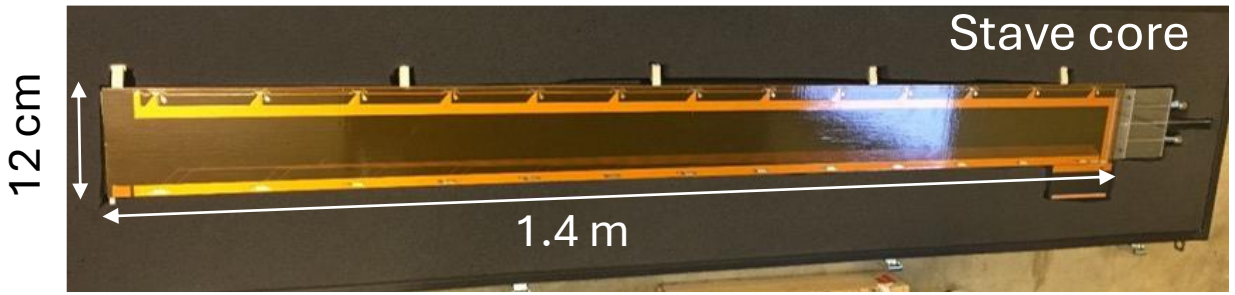
➔ **wire-bonds from modules to bus-tapes (tab bonds for HV)**

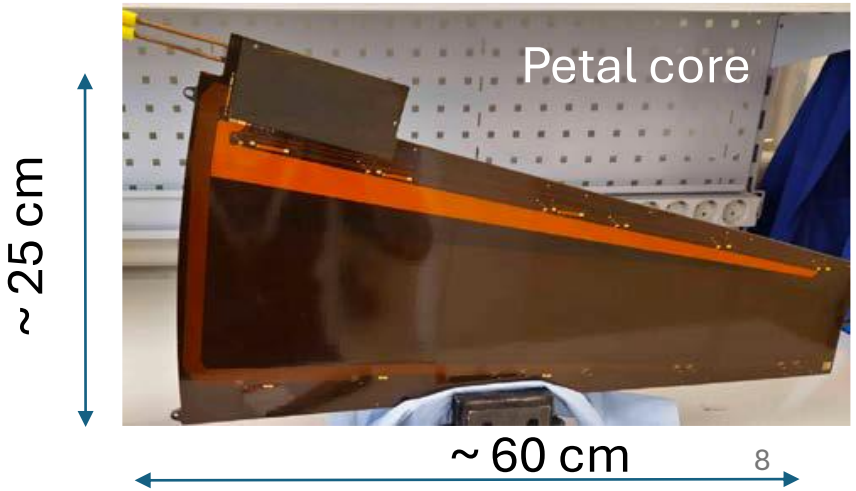
Petal core exploded view



Stave Cross section







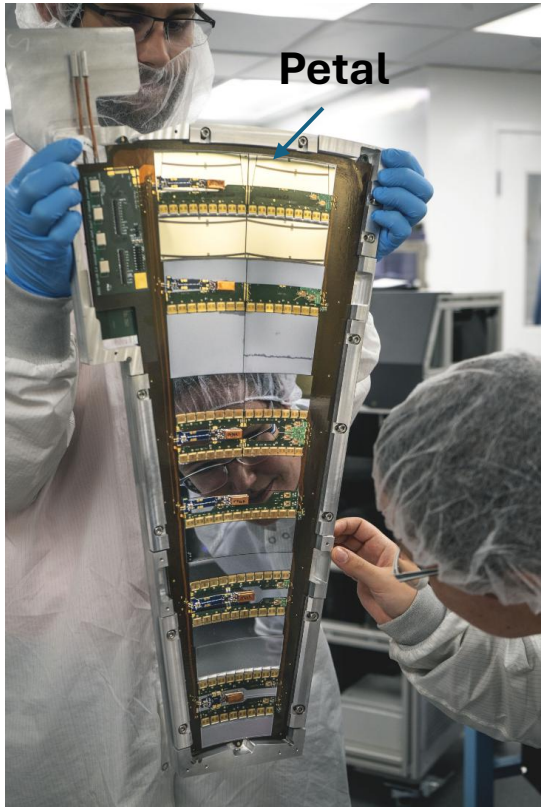
Bus tape development and production

- **Endcap:**
  - bus tapes produced by ELGO-LINE
  - robot test at JSI and send to core production sites
  - core - a carbon fiber structure with cooling pipes
  - half of cores sent to Ljubljana for another robot test

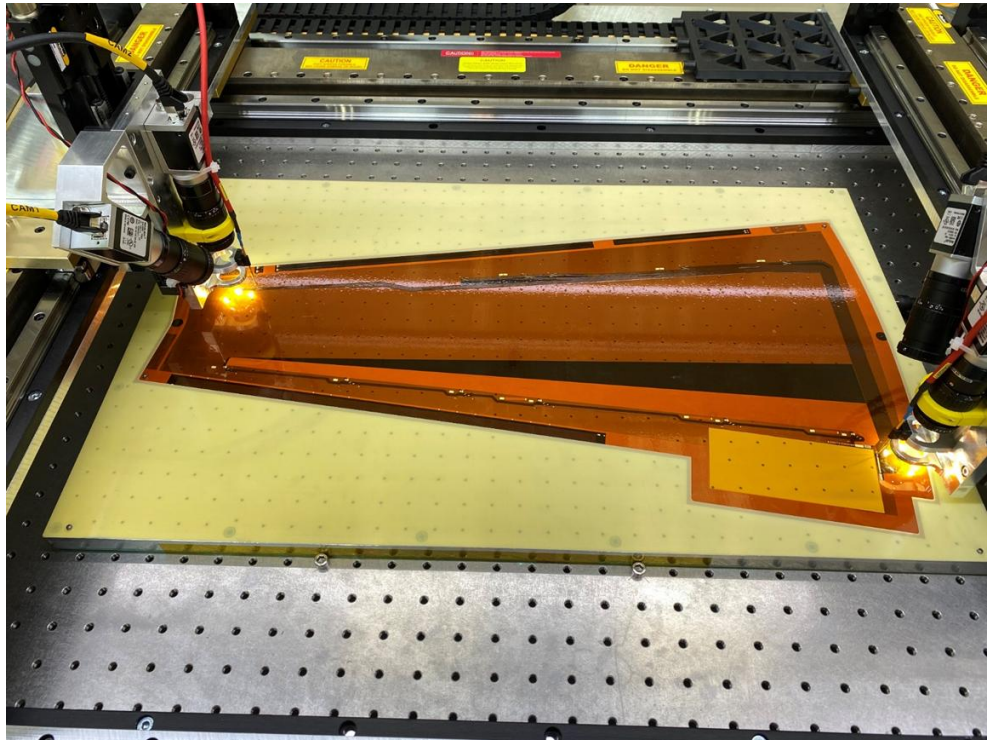
➔ production and robot QC of bus tapes finished

➔ tests of cores (petals before sensor mounting) ongoing

➔ wire bonding tests of petal bonding pads done in Ljubljana



Robot testing of petal bus tape



Sensors QA

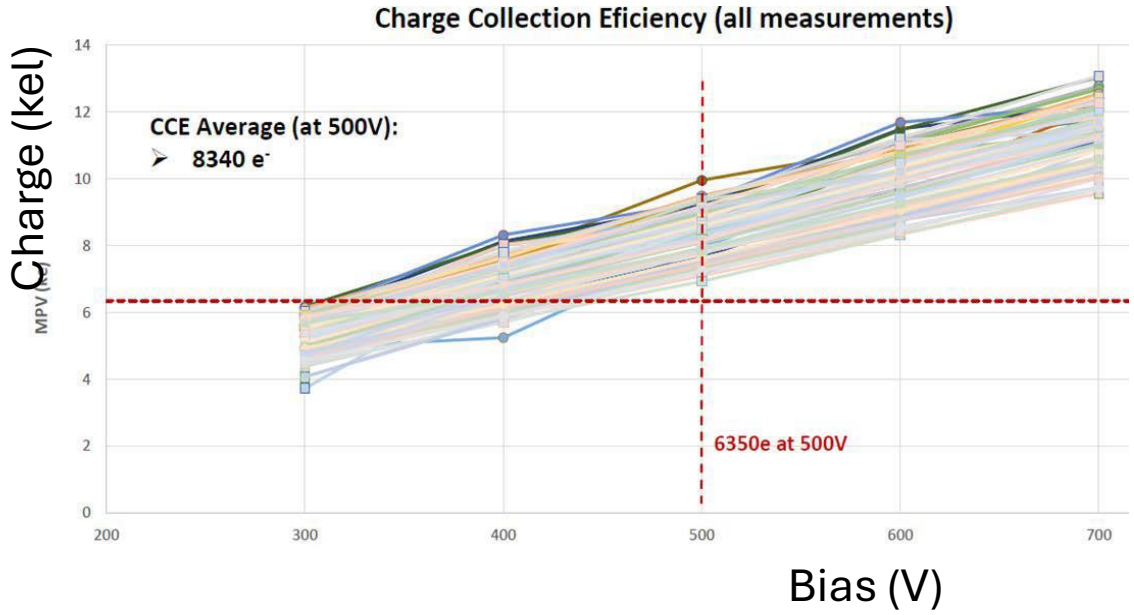
- structures sampled from batches of wafers
- **irradiated up to 1.6e15 n_{eq}/cm^2** with:
  - neutrons at TRIGA reactor in **Ljubljana**
  - protons at CYRIC(KEK) (70 MeV) or Birmingham (27 MeV)
- **TID** to **660 kGy** with γ from ^{60}Co source in Prague
- various parameters followed (Charge Collection, V_{bd}, R_{int}, *PTP*...)
  ➔ **CCE** after irradiation with neutrons measured in **Ljubljana**

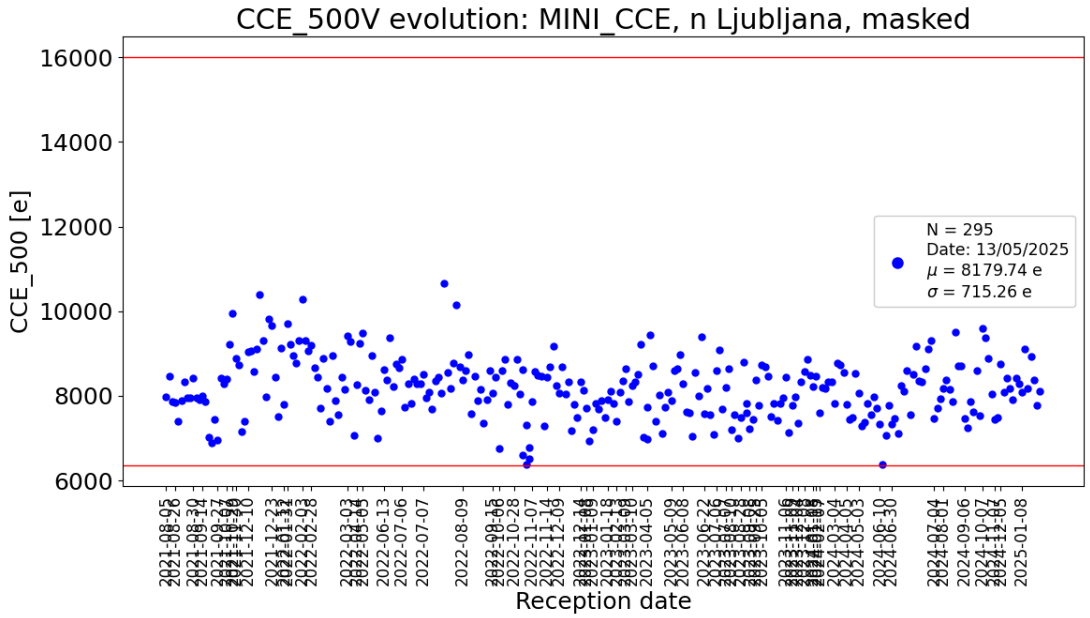
Collected **C**harge measured with ^{90}Sr on **AliBaVa** system

- **acceptance: Charge > 6350 electrons at** bias = 500 V
  ➔ **Production of ~ 25000 sensors finished in 2026!**

Tests structures cut from wafer

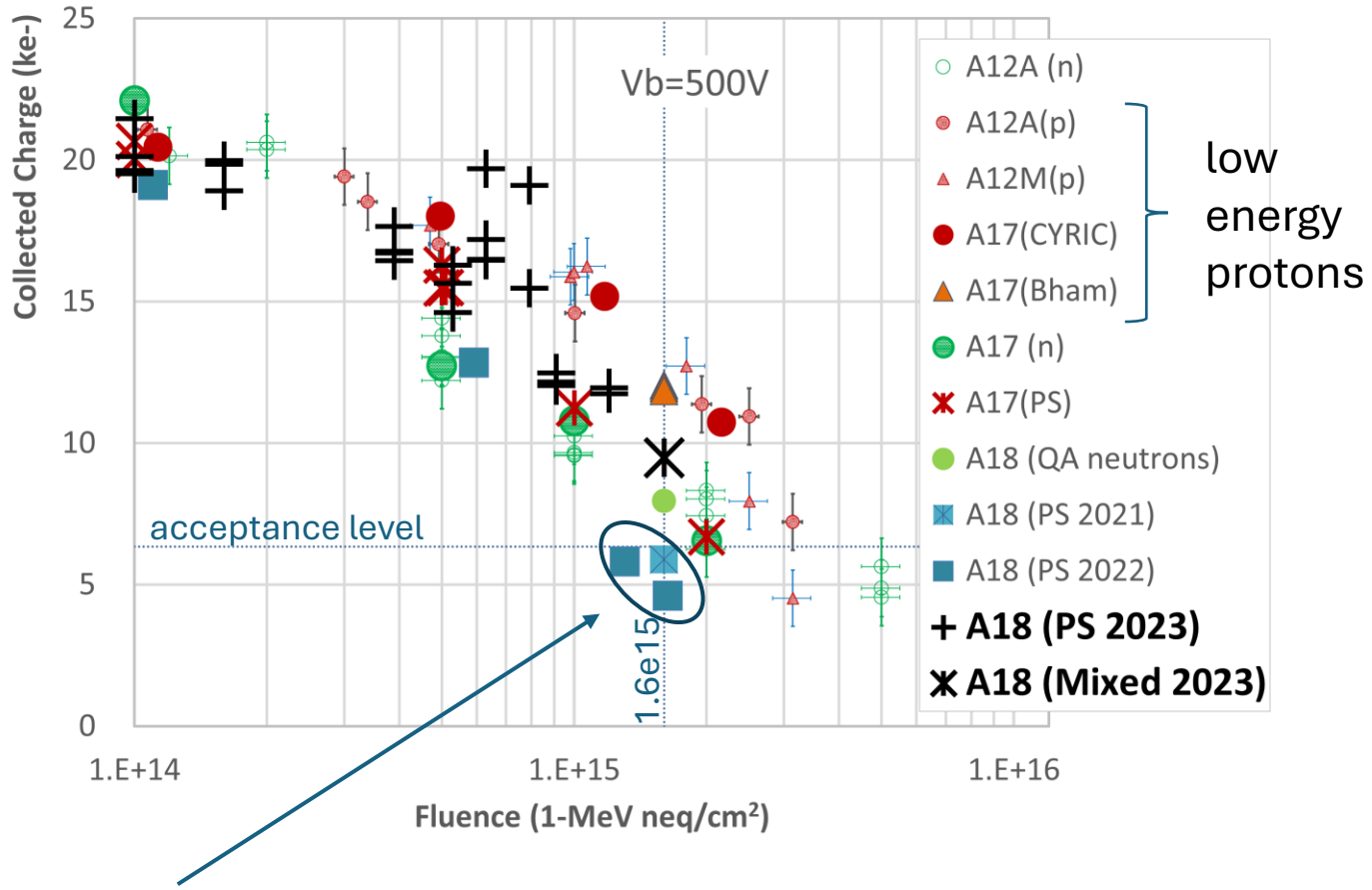






S. Hirose et al., ATL-ITK-PROC-2023-001

Special studies: understand low charge collection efficiency measured after irradiation with 23 GeV protons



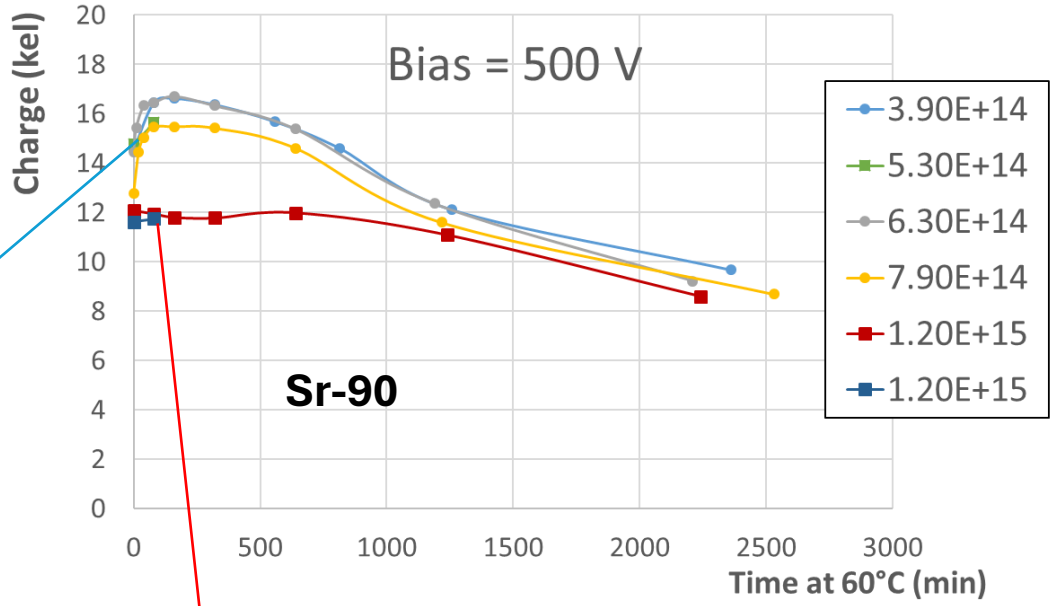
- low charge at high fluence measured after IRRAD 2021 and IRRAD 2022 because of:
  - **uncertain fluences** due to support material and shallow angle
  - effects of 24 GeV/c protons (PS) at high fluences

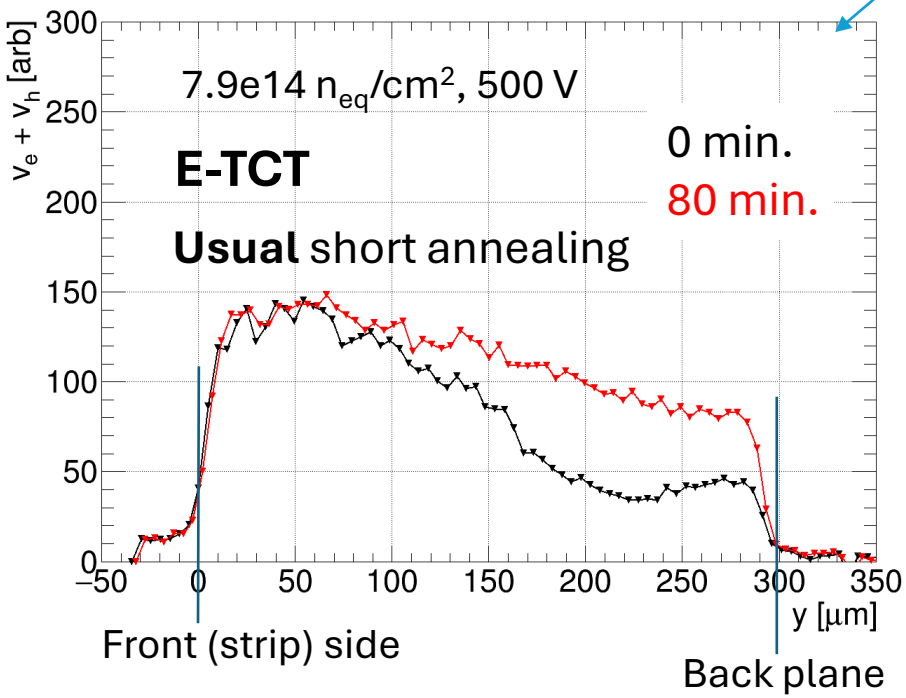
  ➔ not problematic for ATLAS ITk because fast charged hadrons only 50% of radiation field in ITk

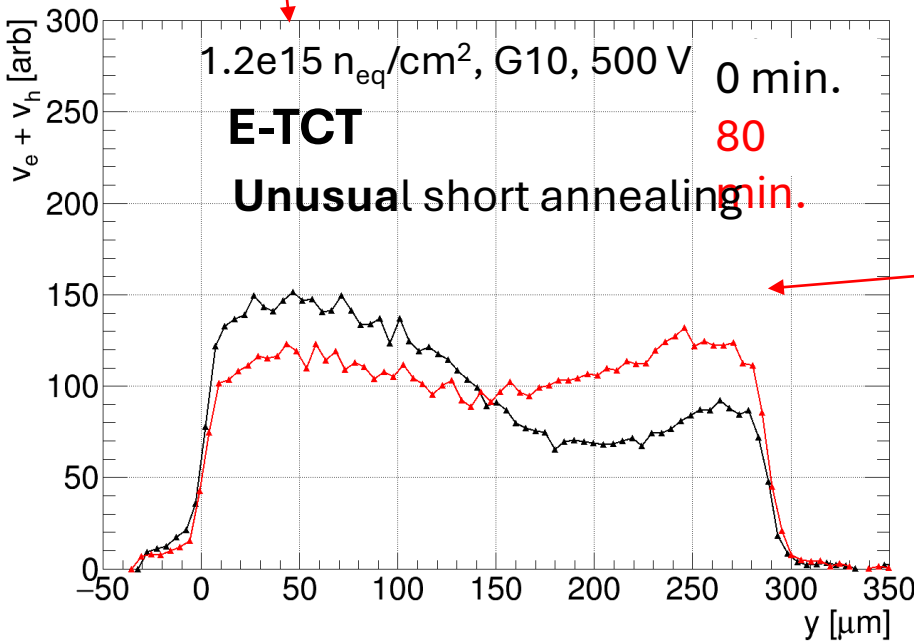
E-TCT, CCE Annealing

- fluences < 1.2e15 n_{eq}/cm^2 : beneficial annealing until up to ~ 200 minutes at 60°C ➔ **“usual”**
- fluence ~ 1.2e15 n_{eq}/cm^2 : no beneficial annealing ➔ **“unusual”**
  ➔ related to “**double peak**” velocity profile measured with **E-TCT**

➔ **after irradiation with 24 GeV protons to fluences > ~ 1.2e15 n_{eq}/cm^2 different behavior than after irradiation with neutrons or low energy protons**







ITk radiation monitor (Marko Puklavec, Erik Margan, Igor Mandić)

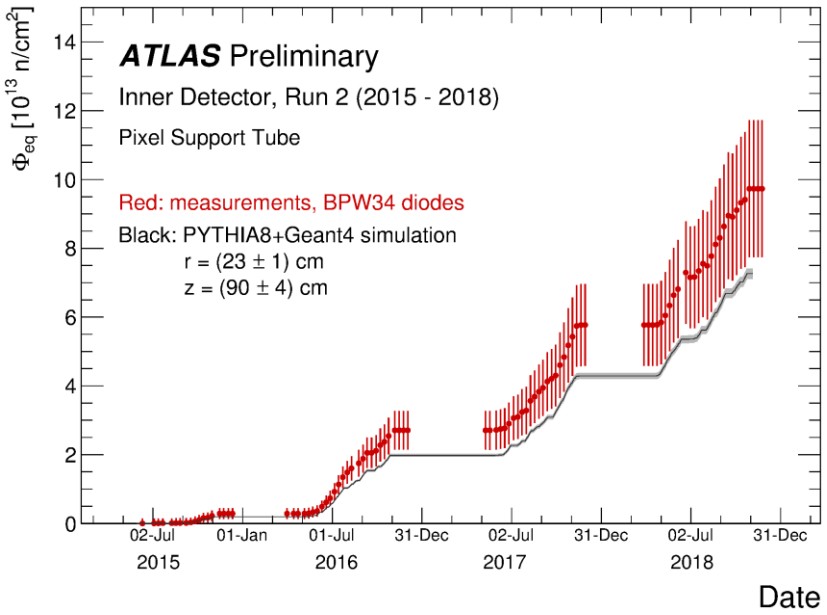
Measure Total Ionising Dose (**TID**) and 1 MeV equivalent neutron fluences (Φ_{eq}) (displacement damage in Si)

- TID from ~ 1 kGy to ~100 kGy
- Φ_{eq} from ~ 10^{13} to ~ 10^{15} n/cm^2

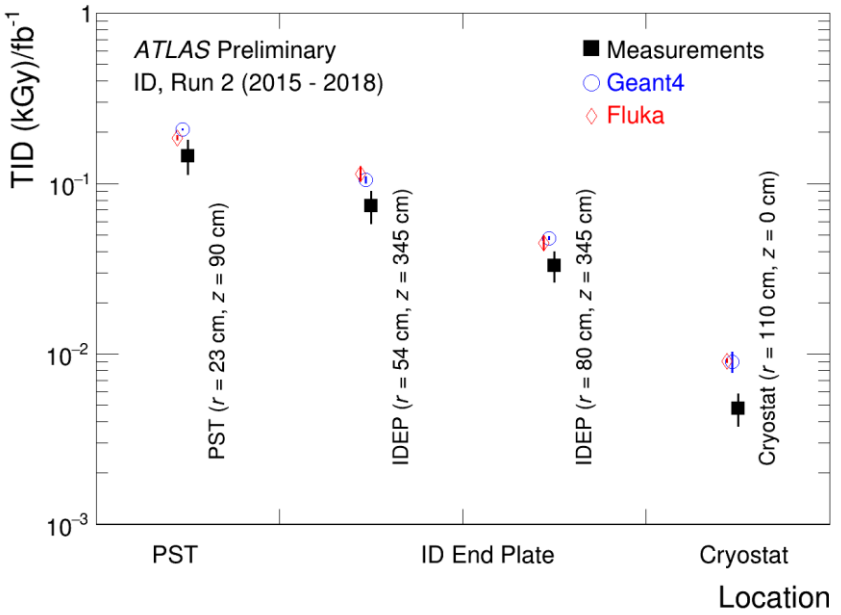
➔ up to date information about accumulated doses and fluences for ATLAS Detector Control System (DCS)
➔ compare with simulations of radiation background

➔ Ljuljana built a similar system for ATLAS ID

Accumulated TID/Φ_{eq} vs. time at different locations:



Ratios: TID/L_{int} (Φ_{eq}/ L_{int})



Sensors

NIEL:

OSRAM BPW34 diodes

- measure forward bias at 1 mA forward current
- can be used to Φ_{eq} > 1e15 n_{eq}/cm^2

  ➔ needs sufficiently high bias voltages

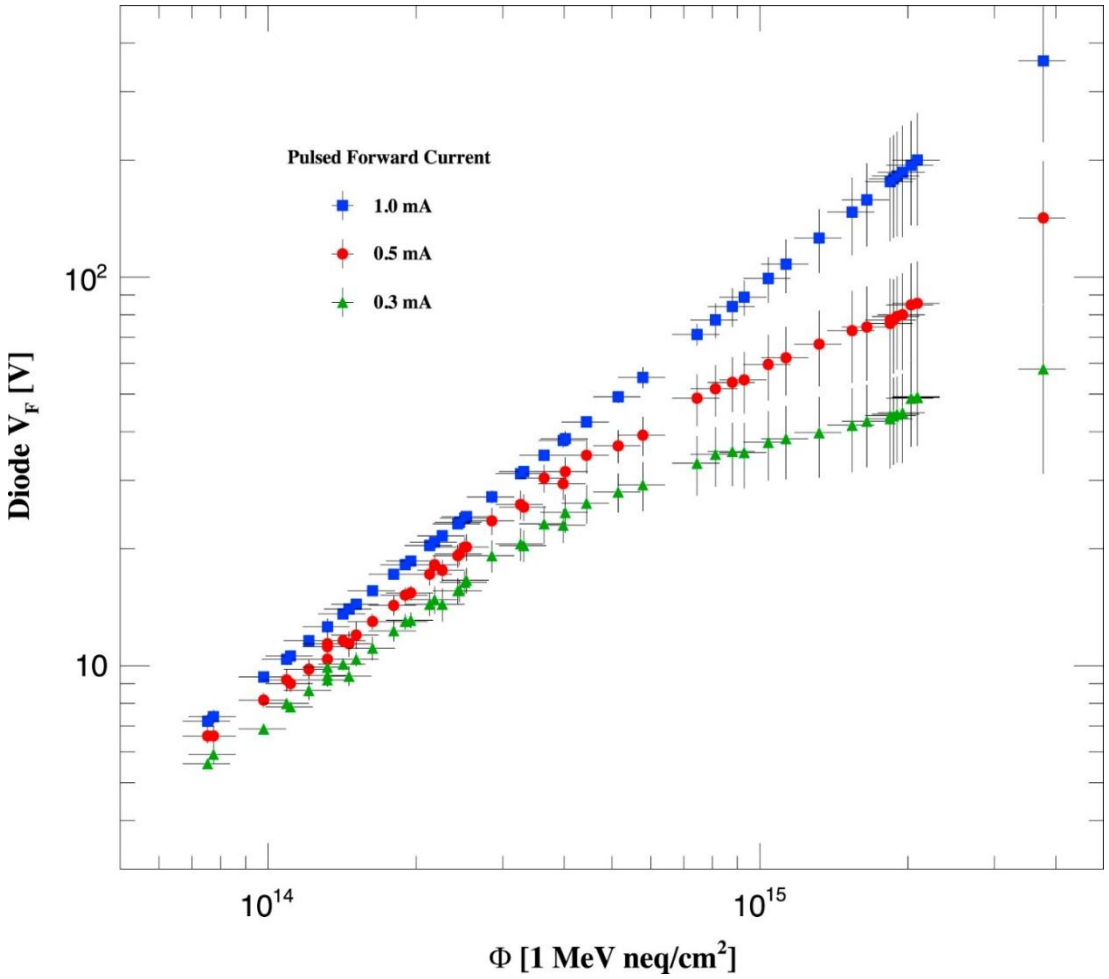
BPW34 well known device used for radiation monitoring in several application including ATLAS ID

More detail:

F. Ravotti et al. , IEEE TNS, VOL. 55, (2008), p 2133

M.R. Hoeferkamp, et al., NIMA 890 (2018) 108-111, https://doi.org/10.1016/j.nima.2018.02.070

P. Palni, et al., NIMA 735 (2014) 213–217, http://dx.doi.org/10.1016/j.nima.2013.09.037



M.R. Hoeferkamp et al. NIMA 890 (2018) 108-111

Sensors

TID:

RadFET (p-MOS transistors)

- measure gate voltage at given drain current
- need thin oxide RadFETs for high doses (above few kGy)

→ not many manufacturers

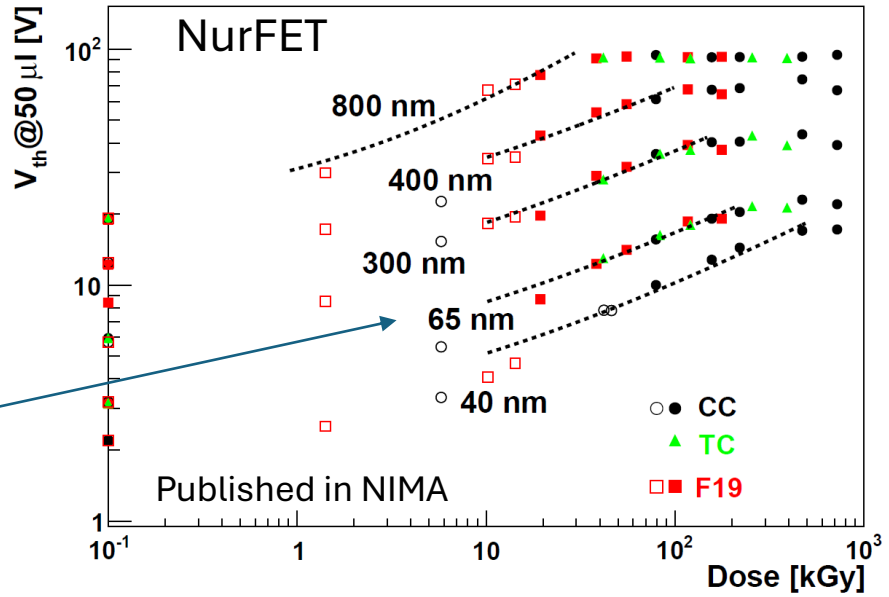
➔ NürFET : Abant Izzet Baysal University, Bolu, Turkey

(Center of Nuclear Radiation Detector Research and Application (NURDAM))

Good results at high doses with 65 nm oxide thickness devices:

G. Kramberger et al., *Development of MOS-FET dosimeters for use in high radiation fields,* NIMA 987, p 164283 (2020)

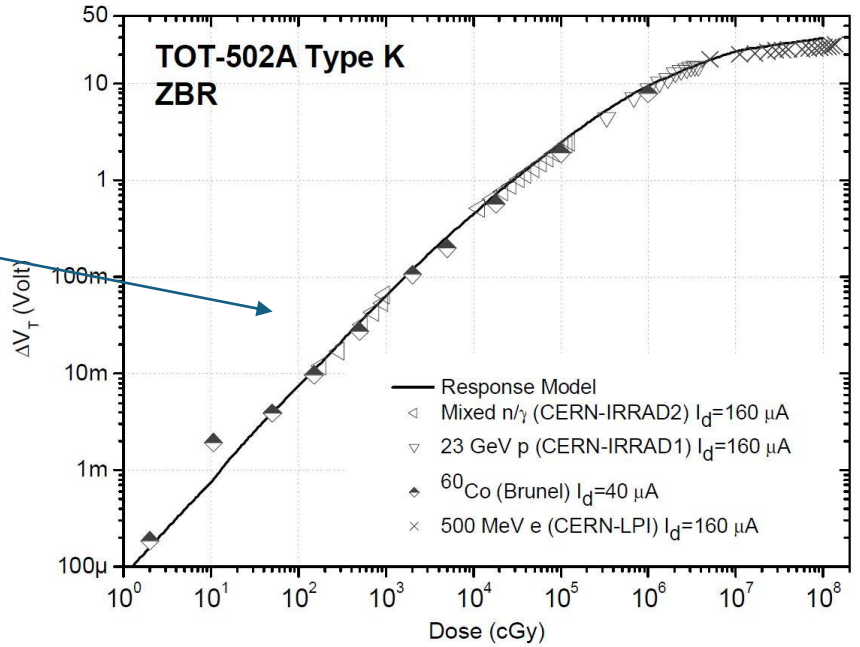
https://doi.org/10.1016/j.nima.2020.164283



➔ a set of devices (REM, oxide thickness 130 nm)

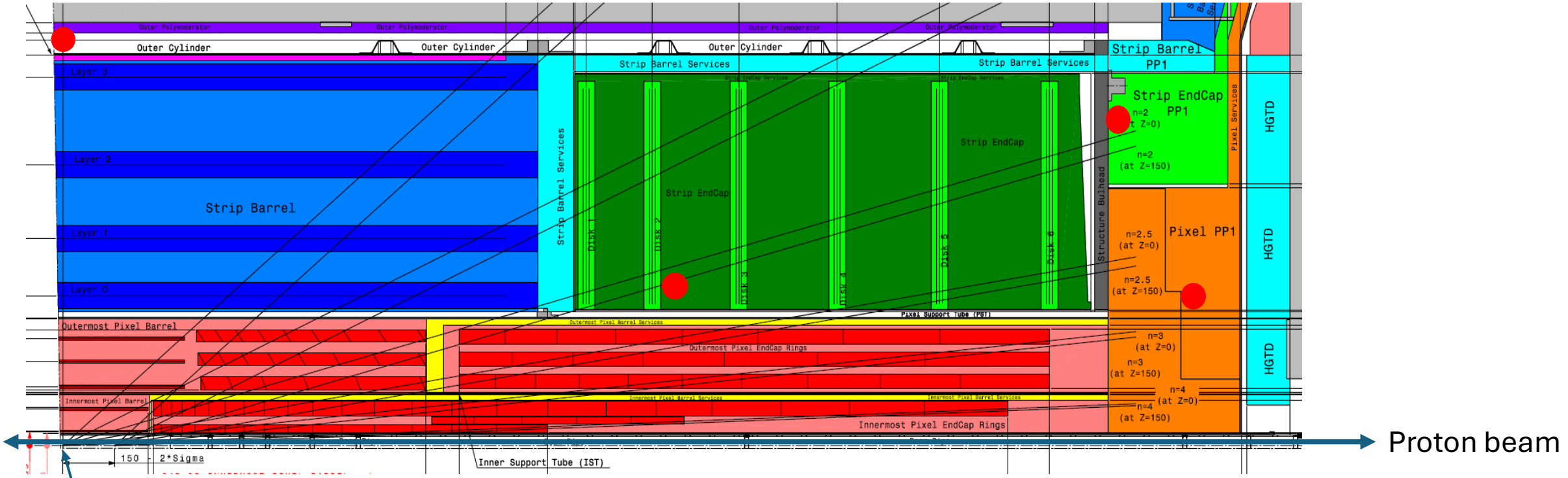
well known, used in ATLAS ID, available from the PS-IRRAD team

A.H. Siedle, F. Ravotti, M.Glaser, *The Dosimetric Performance of RADFETs in Radiation Test Beams,* 2007 IEEE Radiation Effects Data Workshop, https://doi.org/10.1109/REDW.2007.4342539



Locations

- radiation monitoring system is a part of the ITk common environmental monitoring system
- it will measure displacement damage in Si (**1 MeV n_{eq} fluence**) and **TID** on **28** locations in the ITk

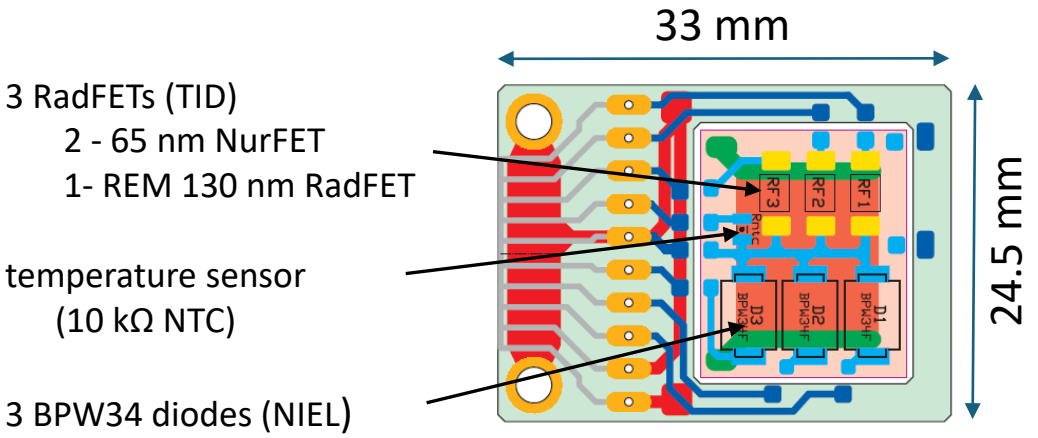


Interaction point

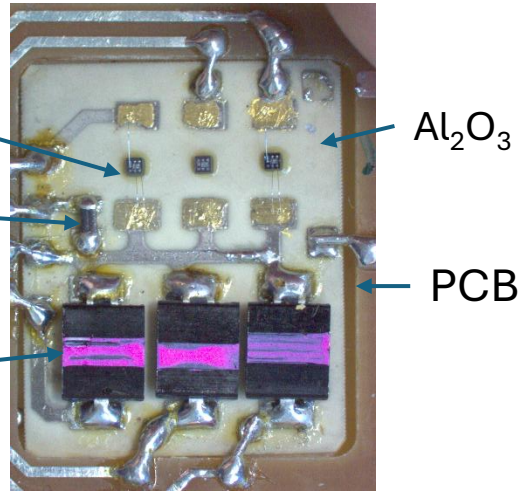
- Monitoring locations in ALTAS Itk
- Repeats in each quadrant and on both sides

Radiation Monitoring Sensor Board

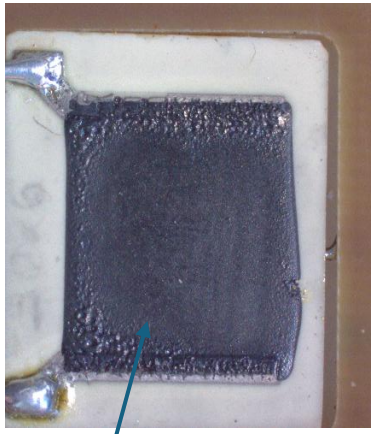
- radiation sensors and temp. sensor on ceramic (Al_2O_3) PCB
- resistive heater on the back side for temperature stabilization
- ceramic soldered to the frame PCB
- cable soldered to the PCB
- enclosed inside PEEK housing

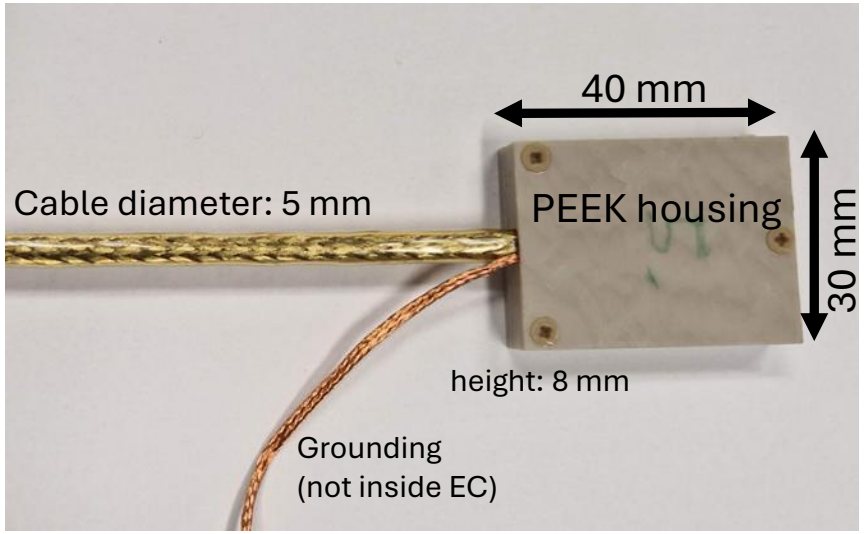


Front side



Back side





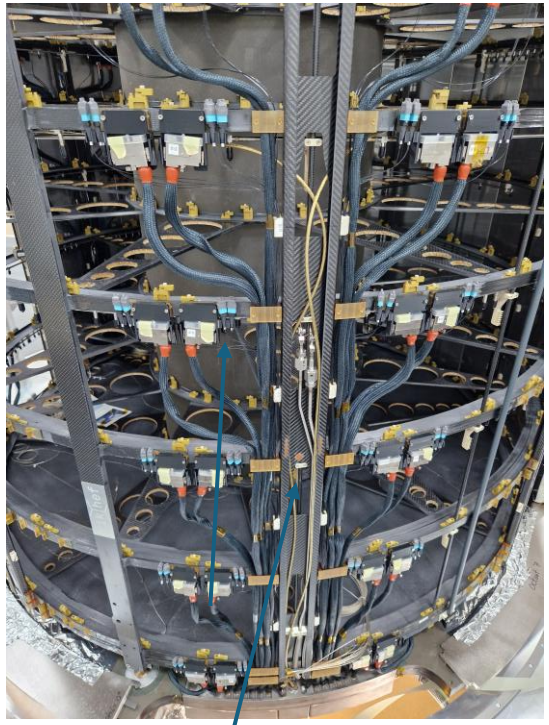
Installation of radiation monitors in End Cap A at DESY

- service module is assembled with radmon cables in Valencia
- At DESY, when service modules are fixed at their position and after the routing the cables we cut the cables to the right length and soldered the radiation monitor to it.
- The other End-Cap is in NIKHEF and we'll solder next 4 monitors there when service modules with cables ready

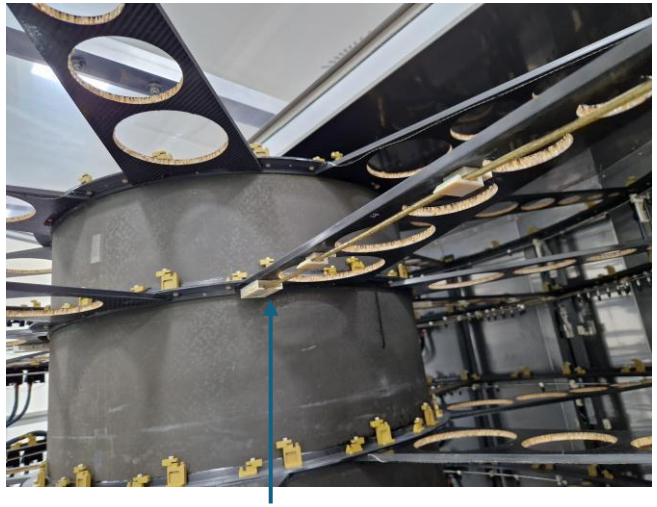
Jure in action, Jul. 2026



ATLAS Itk strips end cap support structure at DESY



Radmon cables



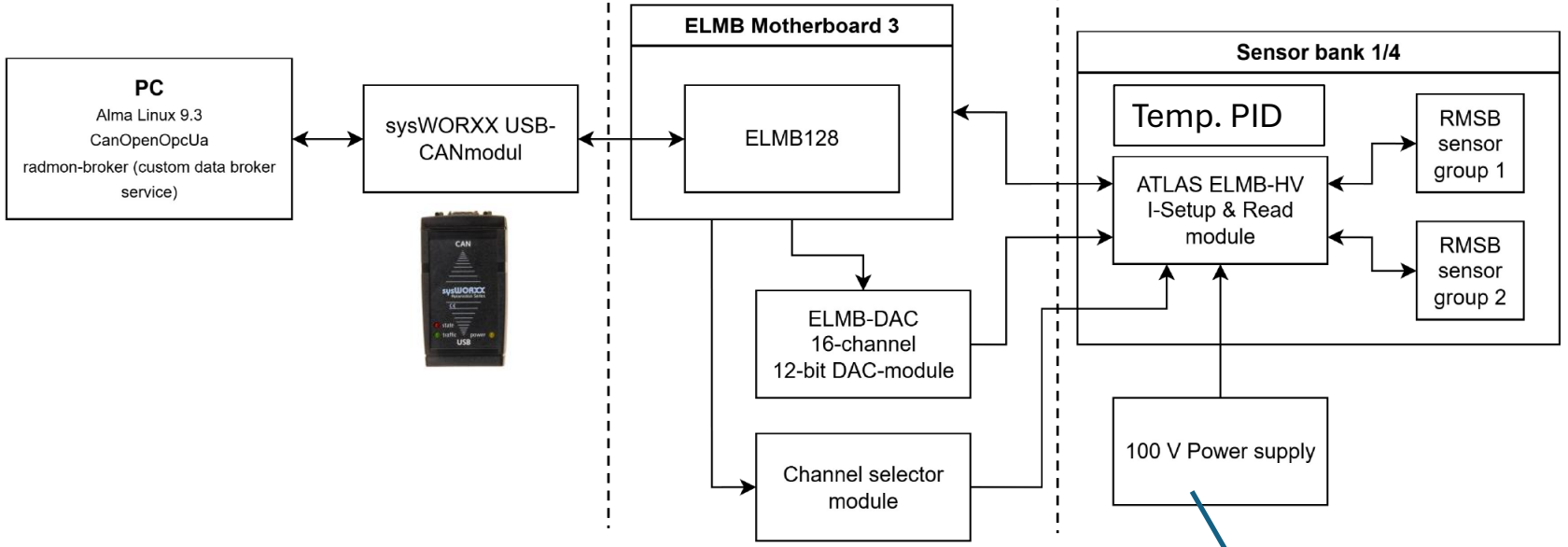
Radiation monitor installed

System overview

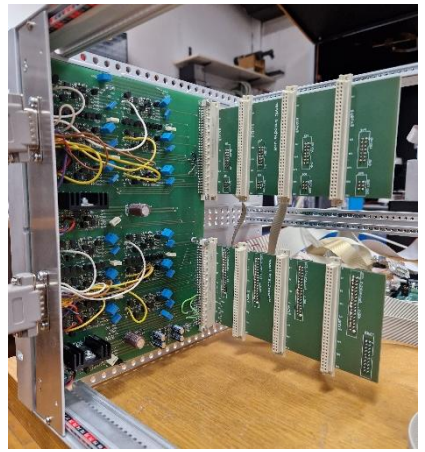
- ➔ readout hardware by **Erik Margan** and **Marko Puklavec**
- ➔ Software, including ELMB firmware, written by **Marko Puklavec**

One ELMB/DAC/selector module controls 4 sensor banks (readout cards)

Each sensor bank (readout card) serves 2 monitors (sensor groups)



Sensor bank:
readout card + 2 monitors

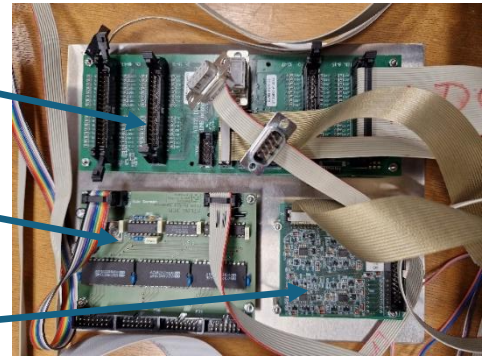


Readout card plugged into backplane card

ELMB motherboard

Channel selector

ELMB-DAC





Floating Power supply

Custom made floating power supply (10 V, -10 V, 60 V and 100 V)

Test of readout system

- Radiation Monitor system monitored using Grafana dashboard (lab testing setup)

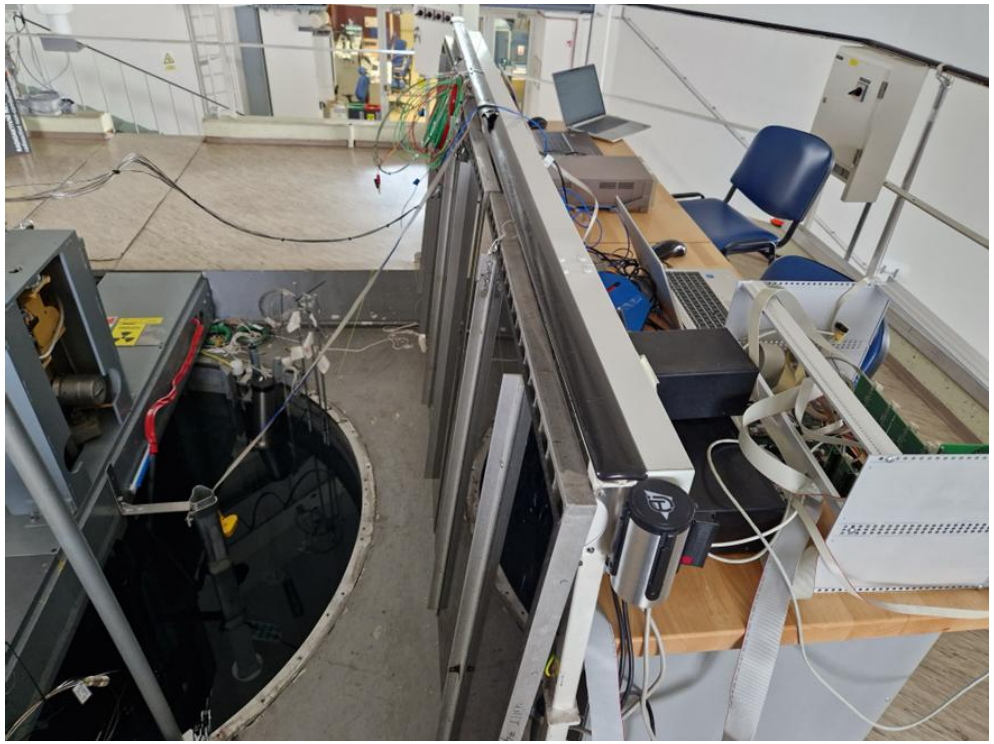


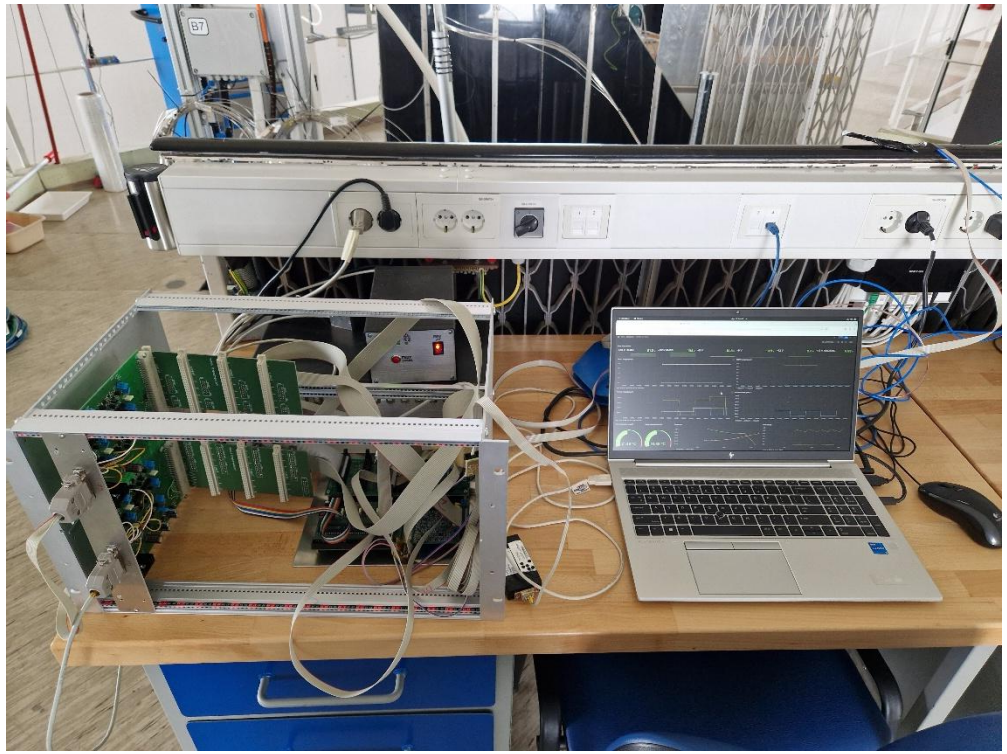
Disable heater turn off during readout → not much effect on sensor voltages

➔ **Readout system works!**

Test at the reactor

- readout system on reactor platform





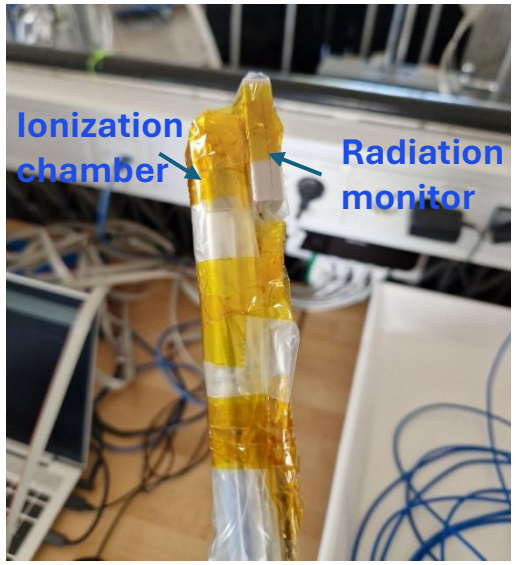
Test of sensors measuring TID:

- monitor inserted into the reactor core through the irradiation tube
- when reactor is off (no fission) neutron flux is zero but there is ionizing radiation in the core due to radioactivity of fission products in fuel elements
- dose rate depends on reactor running history: between several kGy/h and few 100 Gy/h

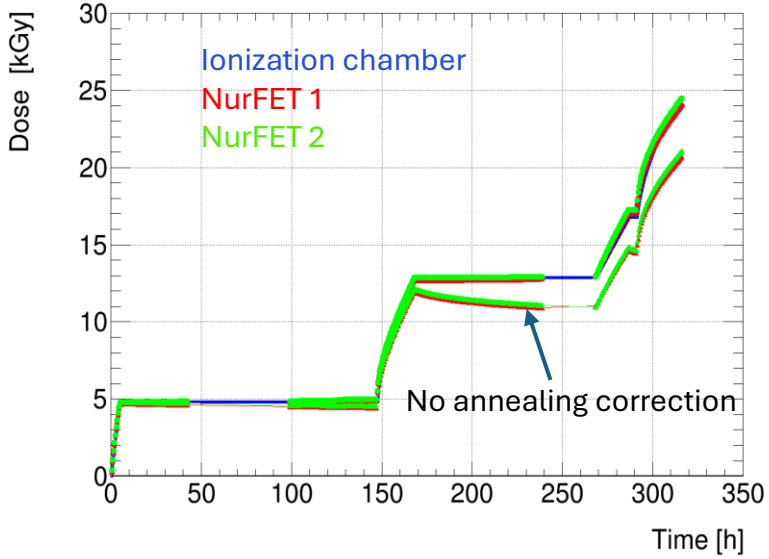
When reactor running test the response of sensors sensitive to neutrons (displacement damage in Si)

Compare RadFETs with ionization chamber

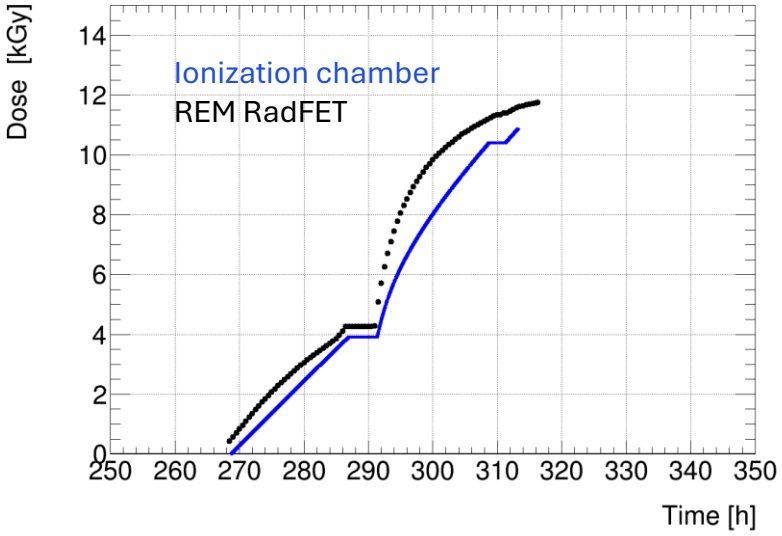
- good agreement



NurFETs
➔ calibrated in the reactor

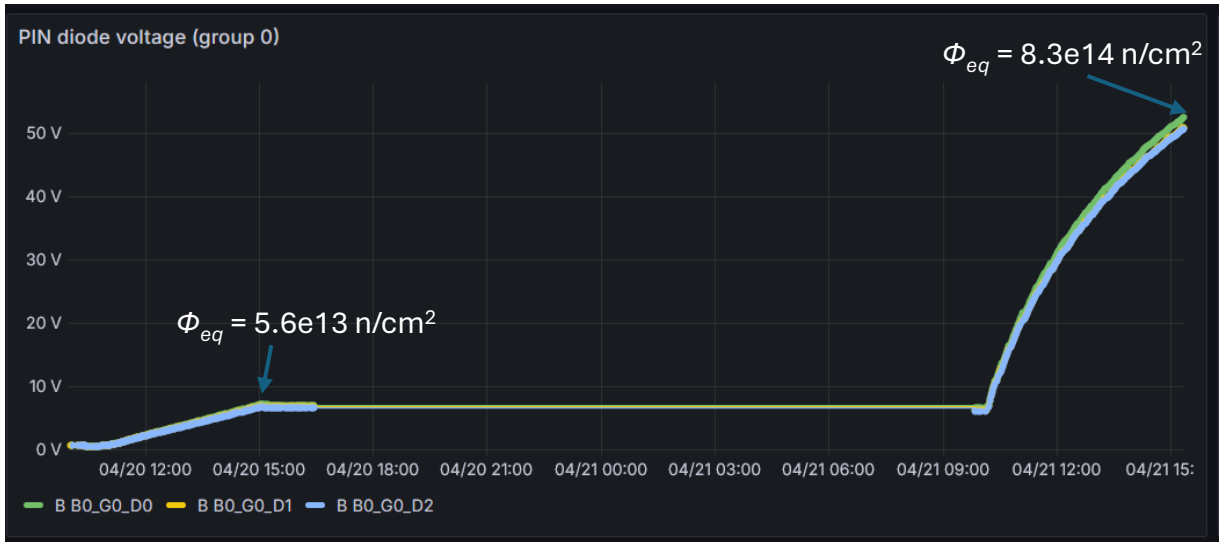


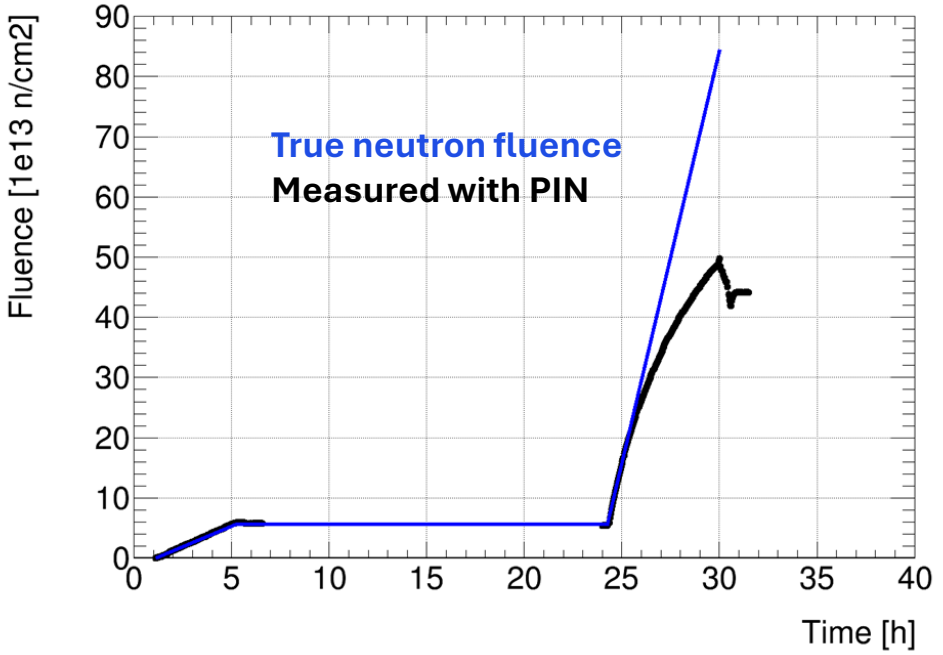
REM RadFET was replaced at Time = ~250 h
➔ calibrated with Co-60
➔ good agreement with ionization chamber



Irradiation with neutrons

- uniform response of 3 diodes
- response non-linear above 20 V (~ 2e14 n/cm^2)
- at Φ_{eq} ~ 8e14 n/cm^2 readout voltage < 60 V
  ➔ power supply max voltage 100 V → sufficient voltage for fluences well above 1e15 n/cm^2





- linear response $\Phi = k \cdot \Delta V$, k = 9.1e12 cm^{-2}V^{-1}
  up to 2.5e14 n/cm^2
- starts to behave non linear at higher fluences (expected)

Summary

- visible contribution of Ljubljana to ATLAS ITk
- sensor production QA ➔ finished
- petal bus tapes and HV tabs ➔ production finished
  ➔ tests of cores ongoing
- radiation monitor ➔ progress OK but still plenty to do:
  - buy cables, connectors
  - produce radiation monitors and connect to cables
  - produce and install readout electronics
  - work out the procedure of underground installation
  - integration into ATLAS DCS
  - still work to be done to understand the response of sensors to irradiation with charged hadrons, annealing ...