

# ATLAS Inner Tracker project - strip detector

Jiri Kroll<sup>1</sup> for Czech ATLAS ITk strip collaboration

<sup>1</sup>Institute of Physics of the Czech Academy of Sciences, Prague, Czech Republic

*jiri.kroll@cern.ch*

October 17, 2022

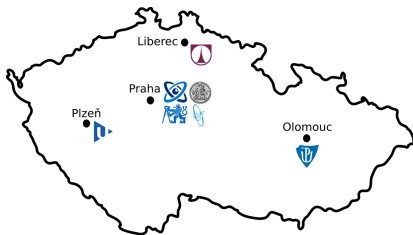


# Large Research Infrastructure CERN-CZ

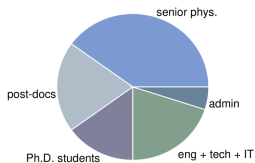
- Large Research Infrastructure CERN-CZ covers most of our activities related to development, building and maintenance of experimental devices at CERN
  - these activities currently require  $\sim 50$  FTEs, from which 10 – 12 FTEs are covered by CERN-CZ budget

## Institutes participating in CERN-CZ

- Charles University
- Czech Technical University in Prague
- Institute of Physics of the CAS
- Nuclear Physics Institute of the CAS
- Palacký University Olomouc
- Technical University of Liberec
- University of West Bohemia



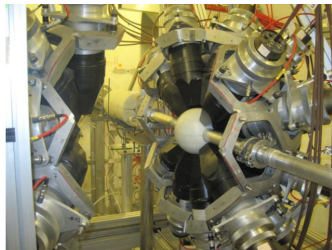
CERN-CZ staff composition





# CERN-CZ - involved CERN experiments and R&D projects

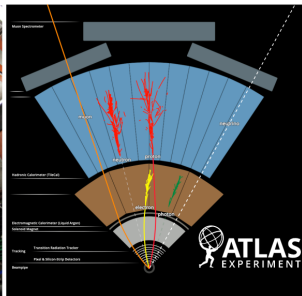
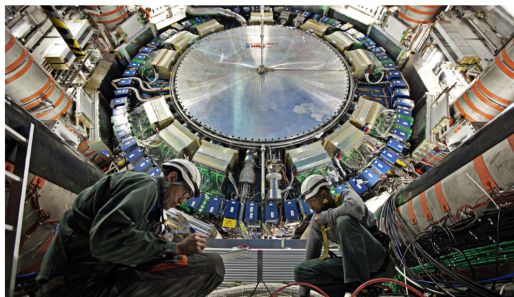
- ATLAS, ALICE, TOTEM, MoEDAL, COMPASS, NA62, n\_TOF, AEGIS, OSQAR, ...
  - Experiments working with absolutely unique technology
  - Number of authors<sup>†</sup>: ATLAS (63/2945), ALICE (19/1006), COMPASS (17/201), TOTEM (8/75), ...
- R&D projects: RD50, RD51, RD53, Medipix, Crystal Clear, CALICE, ...
  - development of new technologies for future HEP experiments
  - medical and industrial applications



<sup>†</sup>Info updated for ATLAS, for other experiments info from May 2021

# ATLAS experiment

- One of the most complex scientific instruments ever built - composed of detection layers constructed to measure different particle species
  - Czech institutes participating in Inner detector, LAr cal. and Tilecal, Forward detectors, radiation monitoring, etc.
- ATLAS collaboration currently includes around 3000 physicists from 181 institutions of 42 countries (authors from Czech Rep.  $\sim 2.1\%$ )
- ATLAS is preparing for HL-LHC operation within 3 upgrade phases, which naturally overlaps with LHC long shutdowns



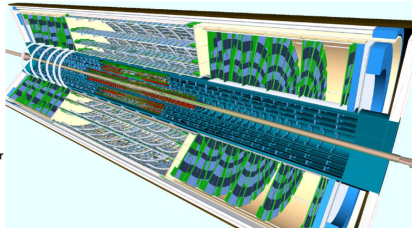
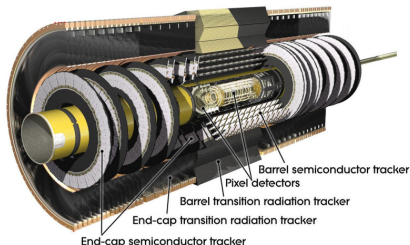
# Preparation of the ATLAS experiment for HL-LHC

- ATLAS experiment upgrades most of its components in order to successfully operate on HL-LHC, which start is expected at the beginning of 2029
  - Phase 0 (2013-2014), Phase 1 (2019-2021), Phase 2 (2026-2028)
- The most complex upgrade of Phase 2 will be replacement of the current Inner Detector by completely new all-silicon **Inner Tracker**



# Inner Detector vs Inner Tracker

- LHC peak instantaneous luminosity of  $2.0 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$  will be increased to  $7.5 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$ , which will be followed by the increase of pileup from the current  $\langle \mu \rangle = 50$  to  $\langle \mu \rangle = 200 - 250$
- Radiation hardness
  - ID PIX designed for  $\sim 400 \text{ fb}^{-1}$ , ID SCT  $\sim 700 \text{ fb}^{-1}$  a IBL  $\sim 850 \text{ fb}^{-1}$
  - HL-LHC will produce  $\sim 4000 \text{ fb}^{-1}$
- Detector occupancy - granularity of the tracker will be increased by factor of 10
- Track trigger
  - current L1 HW trigger is not using information from tracker
  - information from tracker added to the data from calorimeters and muon chambers should significantly support physical analyses



# ATLAS Inner Tracker - participation of Czech institutes

- ATLAS ITk pixel detector
  - FNSPE CTU intensively participated in development of RD53 chip for ITk pixel detectors
- ATLAS ITk strip detector
  - Purchase of components - sensors, ASICs, services, cables, power supplies
  - QC testing of ITk strip pre-production and production sensors at IoP CAS (50% of all EC sensors meaning 4500 – 5000 pieces)
  - Gamma irradiation (in collaboration with UJP Praha, a.s.) and testing of ITk strip testchips at IoP CAS
  - Assembly and QC/QA testing of EC modules (9% of EC modules - 700 pcs, R2/R4 design) covered by Charles University in collaboration with Argotech, a.s., IoP CAS, FME CTU, and Palacky Uni.
  - ATLAS ITK strip irradiation and testbeam activities dominantly covered by IoP CAS, together with CUNI and Palacky Uni.
- ATLAS ITk Common
  - ITk integration work done locally at CERN by people from IoP CAS and FME CTU
  - ITk Production Database developed and maintained by Unicorn University

# Clean laboratory installed at IoP CAS

- QC and QA testing of ATLAS ITk strip sensors and modules is performed in the Clean laboratory for testing of semiconductor detectors built at IoP CAS
  - Laboratory equipped mainly by IoP CAS and CUNI



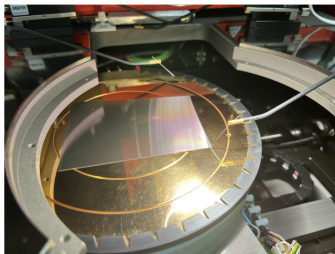
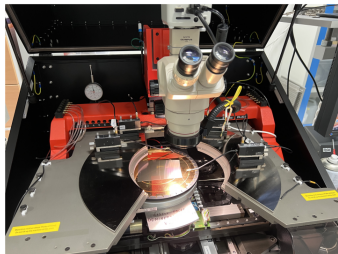
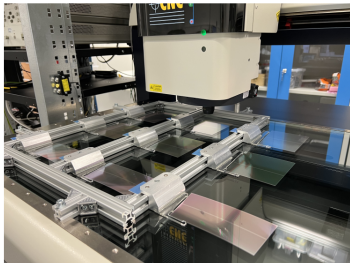
# Clean laboratory - media and laboratory ground

- The clean laboratory is supported by the technical room with the air compressor, nitrogen generator and vacuum pump (all machines are oilless) to provide pressurized air, gaseous nitrogen and vacuum (negative pressure)
- Laboratory ground is completely independent and optimised for laboratory usage



# Sensor QC testing - tests performed on all sensors

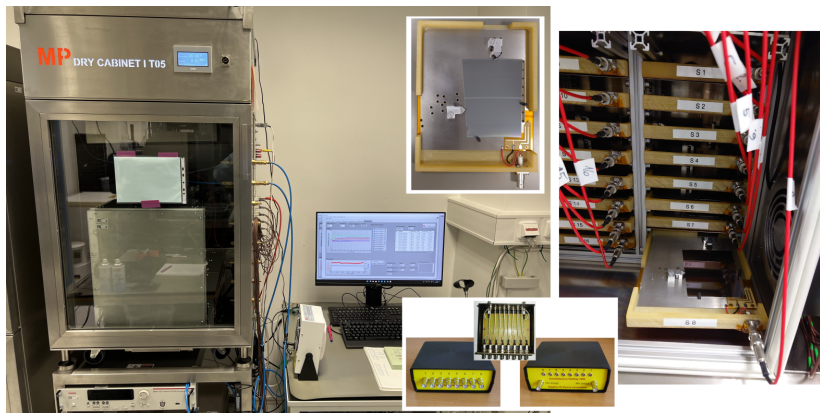
- Sensor QC testing - visual inspection, metrology and visual capture (OGP SmartScope CNC 500) and IV/CV measurements (Karl Suss PA200) are required to be performed on all sensors





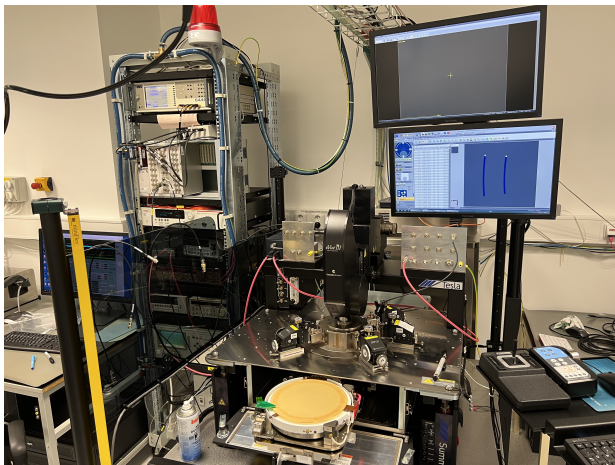
# Sensor QC testing - reverse current stability tests

- QC tests on selected sensors - measurement of long-term leakage current stability of up to 16 sensors by using the setup developed in Prague
  - sensors are wire bonded on the Prague TK jigs by 25  $\mu\text{m}$  aluminium wire and biased via the backplane
  - TK jigs with sensors positioned in MP Dry Storage cabinet (RH < 1%)



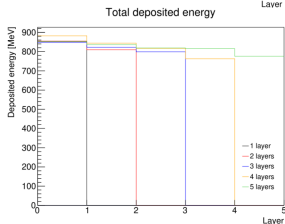
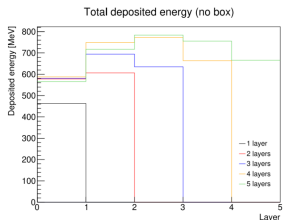
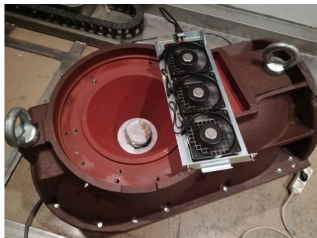
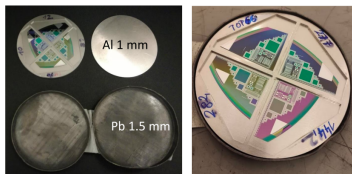
# Sensor QC testing - strip tests

- QC tests on selected sensors - measurement of pinhole current, coupling capacitance and bias resistance on each individual strip of the sensor ( $\sim 5000$  strips per sensor)
  - automatic Tesla 200mm probe station with temperature control of the sample vacuumed to the chuck and RH of the environment



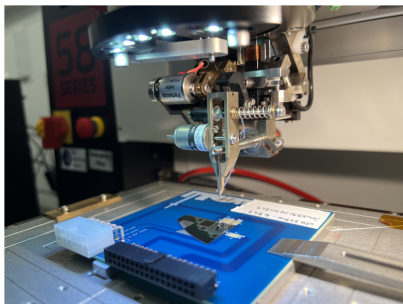
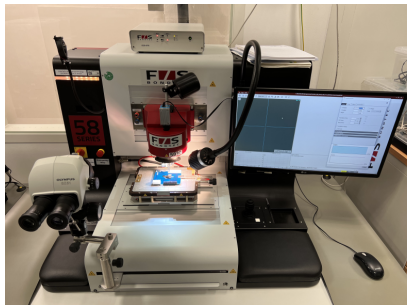
# Gamma irradiation of testchips by $^{60}\text{Co}$ source

- IoP CAS in collaboration with UJP Praha, a.s. covers gamma irradiation of sensors and other ITk strip components - main sensors, testchips, ASICs, etc.
- Samples are irradiated in the CPE box (1.0 mm of aluminium + 1.5 mm of lead) to ensure charge particles equilibrium and uniformity of deposited energy



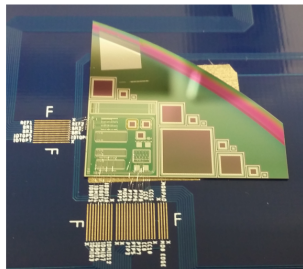
# Sensor QA testing - wire bonding of samples

- When it is not possible to use probe station, samples are wire bonded to specifically designed testing PCBs or jigs
  - F&S Bondtec Series 58 with standard wedge-wedge (5830) and deep access wedge-wedge (5832) wire bonding heads
  - wire bonding with aluminium and gold wires/strips is possible
- Typically we are wire bonding sensor QA testchips on PCBs, main sensors on TK jigs or testframes, modules to their testframes, etc.



# Sensor QA testing - automatic measurement of testchips

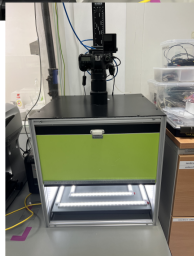
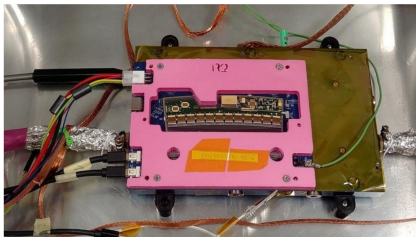
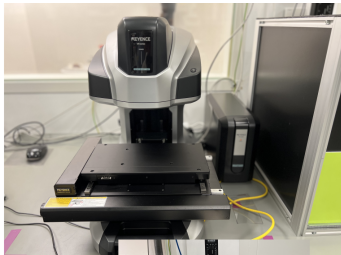
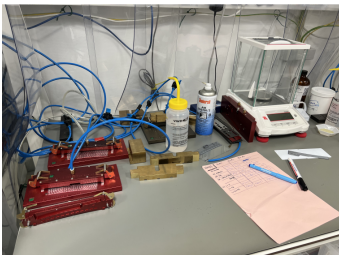
- Gamma irradiated testchips need to be annealed at  $60\text{ }^{\circ}\text{C}$  for 80 minutes, wire bonded to testing PCBs, and tested at  $-20\text{ }^{\circ}\text{C}$ 
  - Annealing and testing is performed in environmental chamber Binder MK56
- Measurement of various quantities on different testing structures of the testchip is enabled by the switching matrix and Python control program



- Production and testing of ITk strip modules ( $\sim 700$  EC module of R2/R4 type) is covered by CUNI in cooperation with Argotech a.s., IoP CAS, FME CUT, and Palacky Uni.
- Production plan (work in Argotech will be done by Argotech people together with people from Prague institutes)
  - Glueing of hybrids and powerboards on sensors (Argotech)
  - Metrology of assembled components (Argotech)
  - Wire bonding of individual readout channels to strips on mass production wire bonding machines (Argotech)
  - Thorough testing of module properties by its thermal cycling with active readout (Clean laboratory at IoP CAS)
- All assembly and testing procedures need to be prepared in our laboratories at CUNI and IoP CAS, and then moved to Argotech

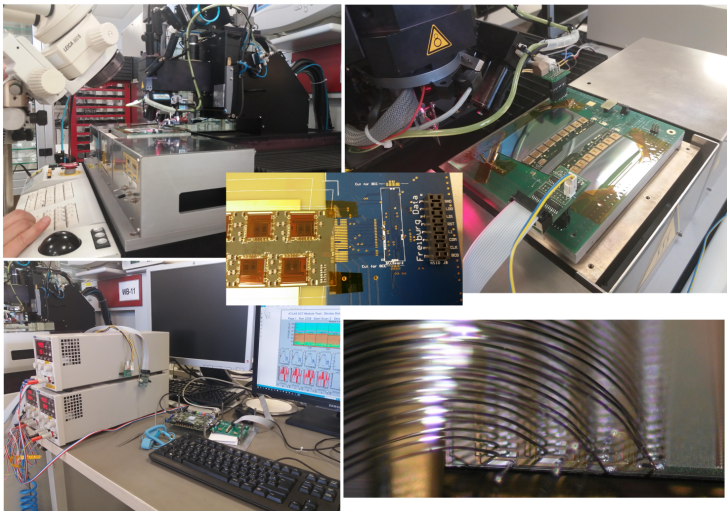
# ITk strip modules - assembly and testing

- Preparation of module assembly, visual capture, metrology (Keyence ONE-SHOT 3D) , and IV testing in the clean laboratory at IoP CAS - coordinated by CUNI people
  - most of this equipment will be moved to Argotech for production



# ITk strip modules - wire bonding of modules

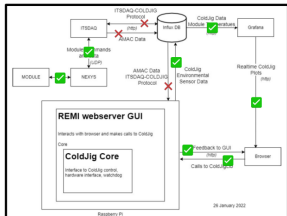
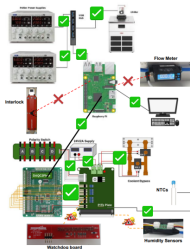
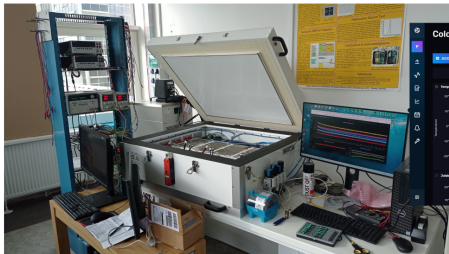
- Wire bonding of individual readout channels of ABC ASICs to sensor strips is done on mass production wire bonding machines in Argotech ( $\sim 5000$  wire bonds per module, wire bonding in 4 rows)



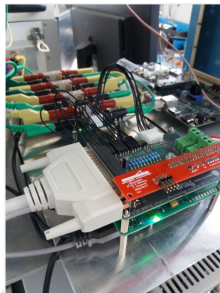


# ITk strip modules - thermal cycling

- 2 thermal cycling boxes built at DESY Hamburg (participation of CUNI) and delivered to CUNI
  - Preparation of a complex testing program and its automation is underway



Communication works - HW connected, SW to be done - HW/SW not connected yet



# All testing procedures need to be officially qualified

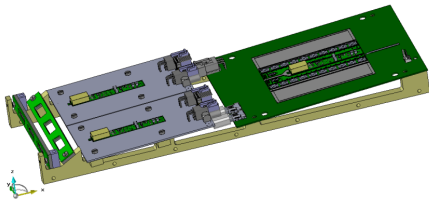
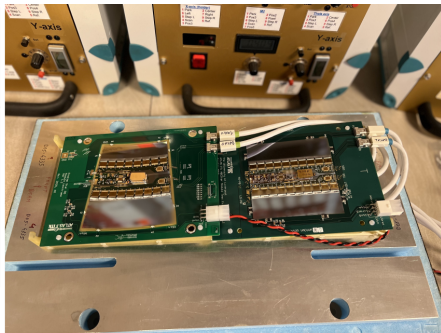
- IoP CAS is the only institute performing both QC and QA sensor testing - qualification was required for all QC and QA procedures (IoP CAS was the 1st institute qualified for production sensor QC testing)
- Qualification for QC/QA testing of modules is very complex - many processes need to be qualified, PPA and PPB components, separate qualification of processes performed in Prague and in Argotech

|                                    | Cambridge | Carlson                  | Prague                    | SCPP        | GMU         | Vancouver | EXX/Truckola |         |
|------------------------------------|-----------|--------------------------|---------------------------|-------------|-------------|-----------|--------------|---------|
| 1. General requirements - facility | AAA       | AAA                      | AAA                       | AAA         | A,B,B       | AAA       | AAAA         |         |
| 2. Reception procedures            | AAA       |                          |                           | AAA         | A,-         | AAA       | A,A,B,B      |         |
| 3. Initial Visual Inspection       | AAA       | Fully qualified Nov. 9th | Fully qualified Oct. 14th | AAA         | AAA         | AAA       | Not planned  |         |
| 4. Jig mounting procedure          | AAA       |                          |                           | AAA         | A,B,B       | AAA       | AAAA         |         |
| 5. Metrology                       | A,A,B     |                          |                           |             | AAA         | B,B,B     | A,B,B        | B,B,B,B |
| 6. Visual capture                  | A,-,-     |                          |                           |             | Not planned | A,B,B     | AAA          | A,A,B,B |
| 7. IV and CV                       | A,A,B     |                          |                           | Not planned | A,A,B       | A,A,B     | Not planned  |         |
| 8. Stability tests                 | A,A,B     |                          |                           | A,A,B       | A,A,B       | A,A,B     | Not planned  |         |
| 9. Strip test                      | A,B,B     |                          |                           | Not planned | -           | -         | A,A,B,B      |         |
| 10. Packaging and shipping         |           |                          |                           |             |             |           |              |         |

| Block                 | Step Number | Qualification Step  | Status          | Ready to Review | Project Completed | Document Link | Video Link | SB Entry       | Review Status | Review End Date | Reviewer 1 Comments | Reviewer 2 Comments | Reviewer 3 Comments |
|-----------------------|-------------|---------------------|-----------------|-----------------|-------------------|---------------|------------|----------------|---------------|-----------------|---------------------|---------------------|---------------------|
| Initial Qualification | 1.1         | Assembly procedures | Completed (Yes) | Yes             | Completed         | Document      |            |                | Completed     | 2023-09-15      | Completed           | Completed           | Completed           |
|                       | 1.2         | Strip procedure     | Completed (Yes) | Yes             | Completed         | Document      |            |                | Completed     | 2023-09-15      | Completed           | Completed           | Completed           |
| PBA Qualification     | 2.1         | Pre-assembly        | Completed (Yes) | Yes             | Completed         | Document      |            |                | Completed     | 2023-09-15      | Completed           | Completed           | Completed           |
|                       | 2.2         | Pre-assembly        | Completed (Yes) | Yes             | Completed         | Document      |            |                | Completed     | 2023-09-15      | Completed           | Completed           | Completed           |
|                       | 2.3         | Pre-assembly        | Completed (Yes) | Yes             | Completed         | Document      |            |                | Completed     | 2023-09-15      | Completed           | Completed           | Completed           |
|                       | 2.4         | Pre-assembly        | Completed (Yes) | Yes             | Completed         | Document      |            |                | Completed     | 2023-09-15      | Completed           | Completed           | Completed           |
| PBB Qualification     | 3.1         | Pre-assembly        | Completed (Yes) | Yes             | Completed         | Document      |            |                | Completed     | 2023-09-15      | Completed           | Completed           | Completed           |
|                       | 3.2         | Pre-assembly        | Completed (Yes) | Yes             | Completed         | Document      |            |                | Completed     | 2023-09-15      | Completed           | Completed           | Completed           |
|                       | 3.3         | Pre-assembly        | Completed (Yes) | Yes             | Completed         | Document      |            |                | Completed     | 2023-09-15      | Completed           | Completed           | Completed           |
|                       | 3.4         | Pre-assembly        | Completed (Yes) | Yes             | Completed         | Document      |            |                | Completed     | 2023-09-15      | Completed           | Completed           | Completed           |
| Module Assembly       | 4.1         | Pre-assembly        | Completed (Yes) | Yes             | Completed         | Document      |            |                | Completed     | 2023-09-15      | Completed           | Completed           | Completed           |
|                       | 4.2         | Pre-assembly        | Completed (Yes) | Yes             | Completed         | Document      |            |                | Completed     | 2023-09-15      | Completed           | Completed           | Completed           |
|                       | 4.3         | Pre-assembly        | Completed (Yes) | Yes             | Completed         | Document      |            |                | Completed     | 2023-09-15      | Completed           | Completed           | Completed           |
|                       | 4.4         | Pre-assembly        | Completed (Yes) | Yes             | Completed         | Document      |            |                | Completed     | 2023-09-15      | Completed           | Completed           | Completed           |
| Module Assembly       | 5.1         | Pre-assembly        | Completed (Yes) | Yes             | Completed         | Document      |            |                | Completed     | 2023-09-15      | Completed           | Completed           | Completed           |
|                       | 5.2         | Pre-assembly        | Completed (Yes) | Yes             | Completed         | Document      |            |                | Completed     | 2023-09-15      | Completed           | Completed           | Completed           |
|                       | 5.3         | Pre-assembly        | Completed (Yes) | Yes             | Completed         | Document      |            |                | Completed     | 2023-09-15      | Completed           | Completed           | Completed           |
|                       | 5.4         | Pre-assembly        | Completed (Yes) | Yes             | Completed         | Document      |            |                | Completed     | 2023-09-15      | Completed           | Completed           | Completed           |
| Module Assembly       | 6.1         | Pre-assembly        | Completed (Yes) | Yes             | Completed         | Document      |            |                | Completed     | 2023-09-15      | Completed           | Completed           | Completed           |
|                       | 6.2         | Pre-assembly        | Completed (Yes) | Yes             | Completed         | Document      |            |                | Completed     | 2023-09-15      | Completed           | Completed           | Completed           |
|                       | 6.3         | Pre-assembly        | Completed (Yes) | Yes             | Completed         | Document      |            |                | Completed     | 2023-09-15      | Completed           | Completed           | Completed           |
|                       | 6.4         | Pre-assembly        | Completed (Yes) | Yes             | Completed         | Document      |            |                | Completed     | 2023-09-15      | Completed           | Completed           | Completed           |
| Steps that Are Ready  |             |                     | 27              | Completed Steps | 58                | Under review  | 8          | Passed Steps   | 58            |                 |                     |                     |                     |
|                       |             |                     |                 | Total Steps     | 58                |               |            | Failed Steps   | 0             |                 |                     |                     |                     |
|                       |             |                     |                 | Completed (%)   | 88.00%            |               |            | Failed (%)     | 0.00%         |                 |                     |                     |                     |
|                       |             |                     |                 |                 |                   |               |            | Passed PPA (%) | 100.00%       |                 |                     |                     |                     |
|                       |             |                     |                 |                 |                   |               |            | Passed PPB (%) | 100.00%       |                 |                     |                     |                     |
|                       |             |                     |                 |                 |                   |               |            | Passed IQC (%) | 80.00%        |                 |                     |                     |                     |

- We are intensively participating in ATLAS ITk strip proton irradiation campaigns at CERN IRRAD facility, and especially in ATLAS ITk strip testbeam campaigns organized at DESY II and CERN SPS testbeam facilities
  - Coordinating WBS 2.2.11 activity - ATLAS ITk strip irradiation and testbeam - since 2016
  - In the last years people from IoP CAS, CUNI and Palacky Uni. cover most of the testbeam shifts, as well as irradiation campaigns at IRRAD
  - IoP CAS and CUNI provide the equipment needed for these campaigns
- IoP CAS has also developed and prepared several tools needed for the irradiation and testbeam campaigns
  - designing and manufacturing all holders for an installation of DUTs into the IRRAD cold box since 2018
  - testbeam polystyrene cold box with dry ice cooling
  - building of new moving stages for testbeam in progress

# ATLAS ITk strip proton irradiations at CERN IRRAD



# ATLAS ITk strip testbeam campaigns

