First experience from the system tests setup for the ATLAS ITk Strip Endcap detector.

Overview and results from system test at DESY

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from the ITk Strip Endcap System Tests Community

12th Forum on Tracking Detector Mechanics

Purdue University, West Lafayette, USA
29-31 May 2024

The Introduction

The ATLAS Inner Tracker

A new silicon strip detector for the HL-LHC phase

- Current ATLAS Inner Detector (ID) will be replaced by a new Inner Tracker (ITk)
  - All-silicon detector solution
  - Similar performance in harsher conditions
  - More readout channels
  - Better spatial resolution
  - Higher radiation tolerance
  - Lower material budget

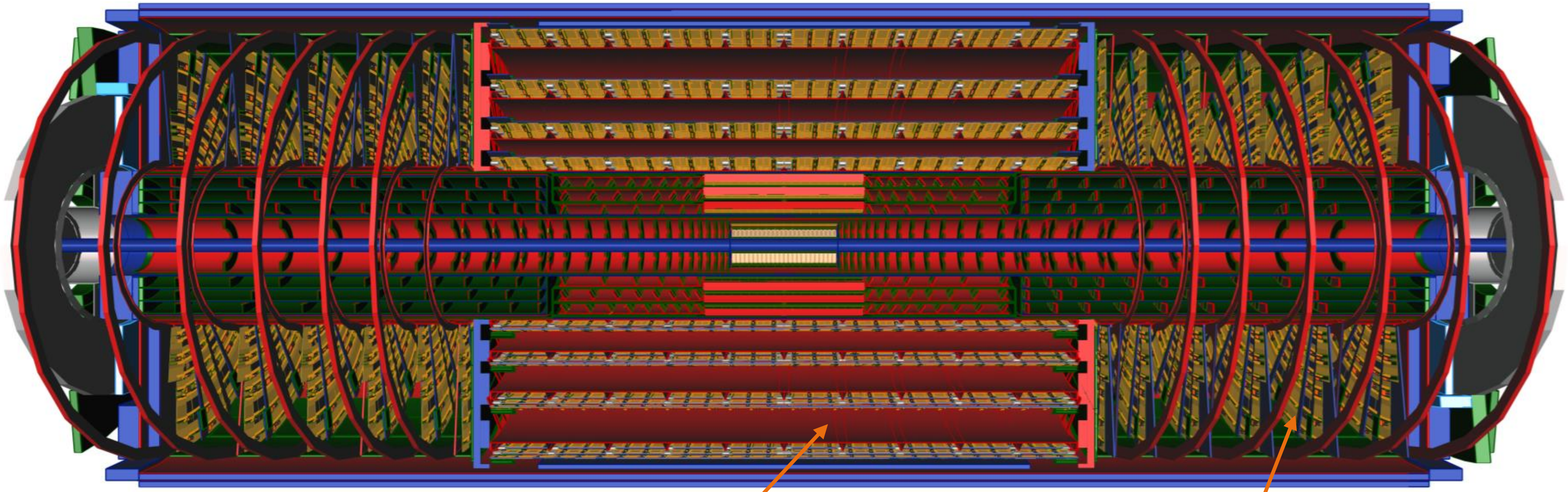
17,888 sensors

165m^2 of silicon

60 million strips

Dose up to 50 MRad

ATL-PHYS-PUB-2021-024



ITk strip *barrel*

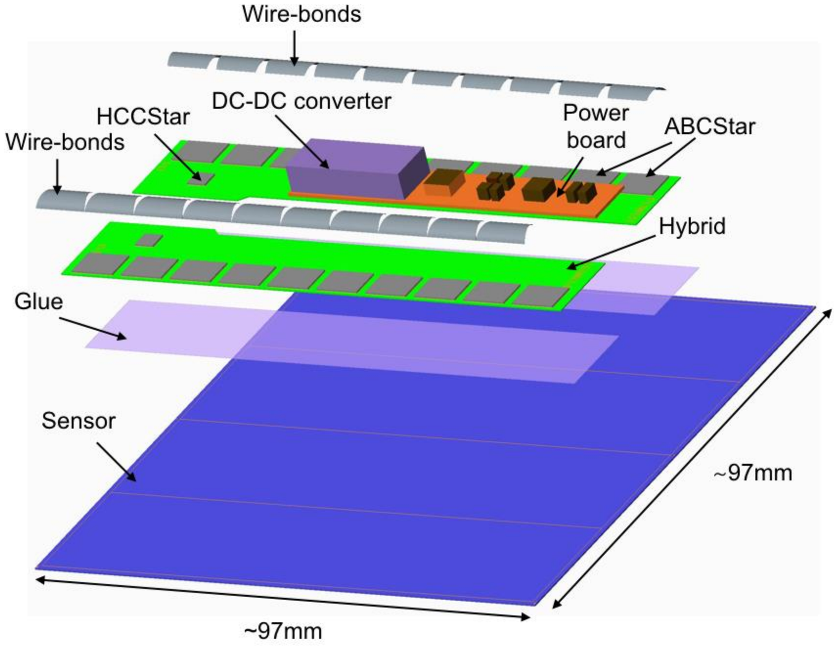
ITk strip *end-cap*

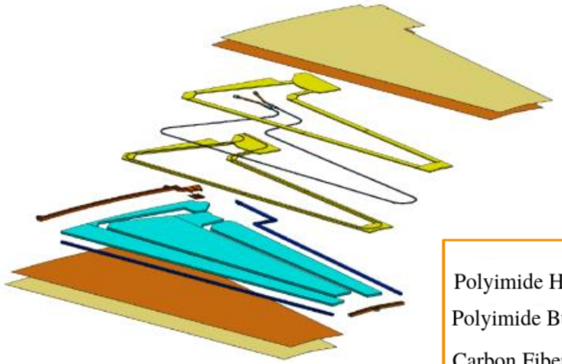
ATL-TDR-025

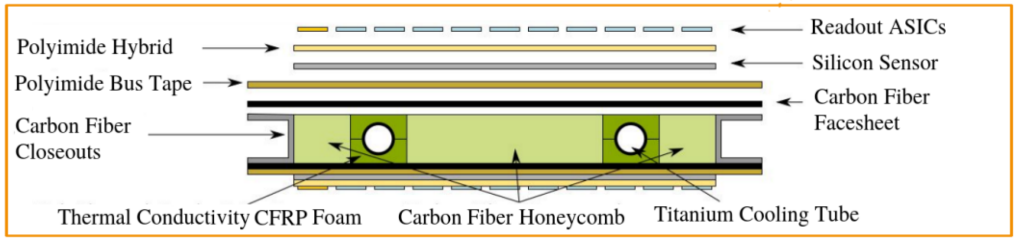
Overview of the detector concept

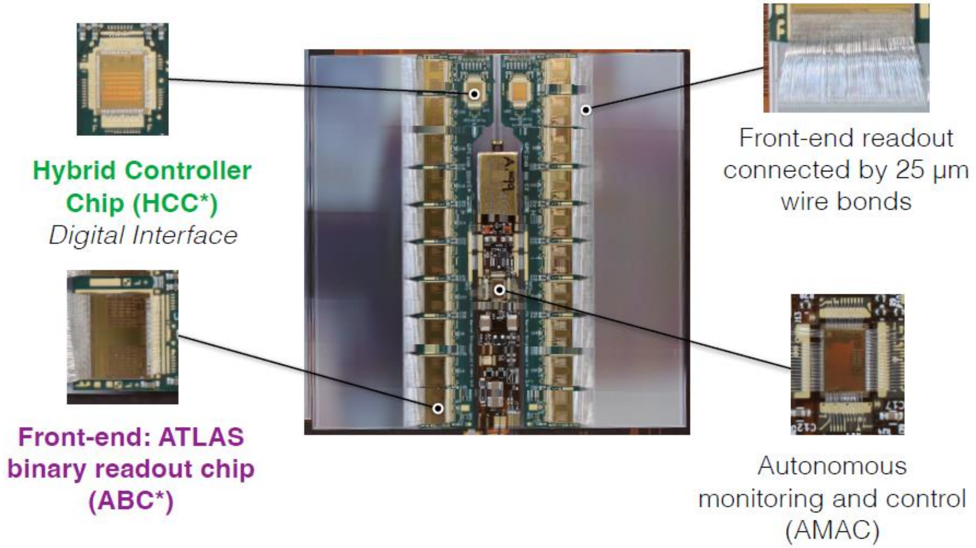
Silicon strip detector modules

- Silicon strip detector module consists of
  - n^+-in-p silicon **strip sensor**
  - Glued on PCB with readout chips (**“hybrid”**)
  - Glued on PCB with power control (**“powerboard”**)
  - Connections via **wire bonds**
  - Different types/shapes depending on location in the detector
  - Modules are directly glued on local support structures **(“cores”)**



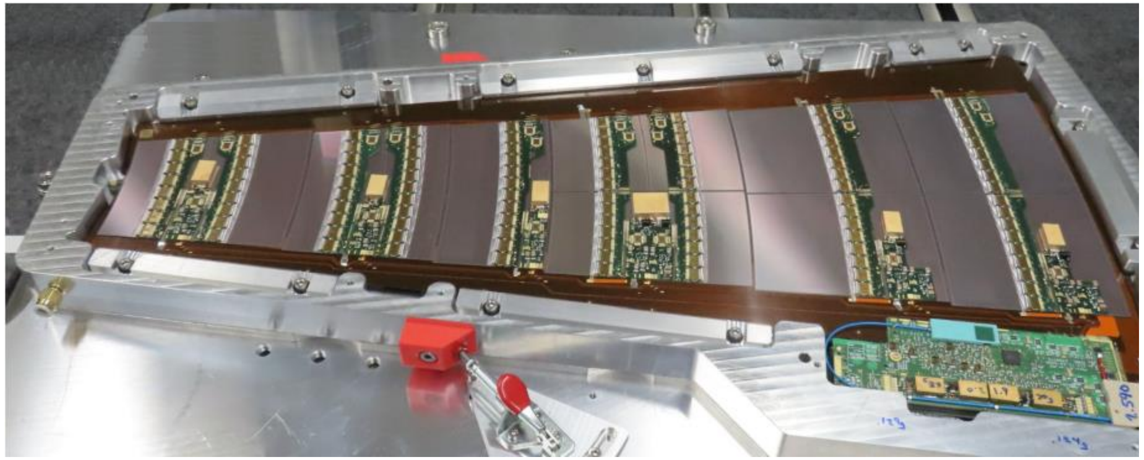


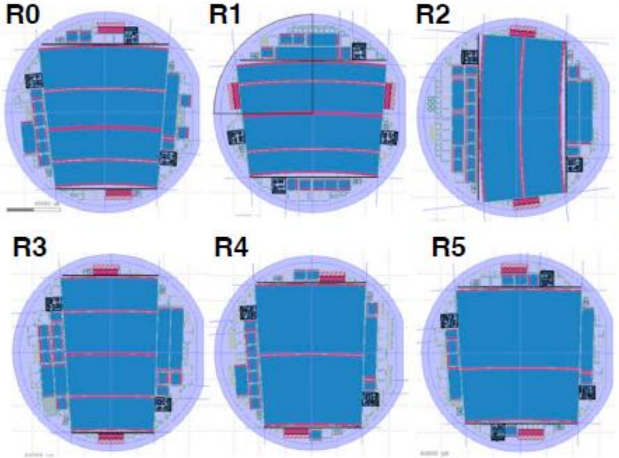


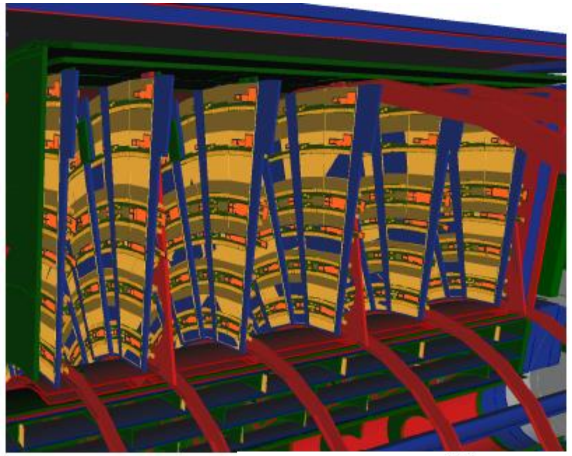


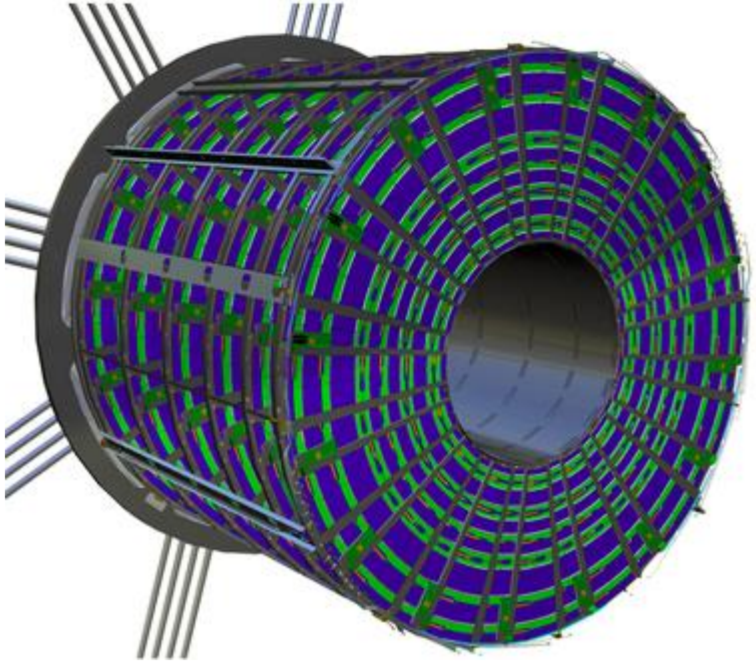
Overview of the detector concept

Petals as building blocks of the end-caps

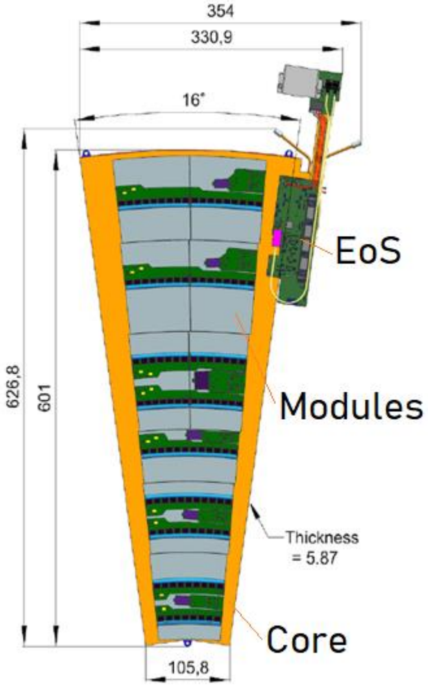








- Main building blocks of the strips end-cap detector are the **petals**
  - Core loaded on both sides with 6 modules (9 silicon crystals) – R0 to R5
  - **End-of-substructure (EoS)** board as off-detector
- **Global support** structure providing mechanical support and connections to the services
  - Arranged in six disks, each disk populated with 32 petals



System Tests for the ITk Strip Detector

Motivation

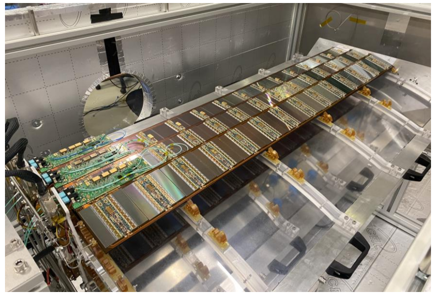
- Goals of system tests
  - Demonstrate full ITk Strip detector system concerning **powering, cooling, readout etc.**
  - Test and train tools (e.g. insertion tooling) and procedures (e.g. welding) for final **detector integration**
  - Develop and test **DAQ** (e.g. high frequency readout) and **DCS** (e.g. interlock)
  - Serve as test stand during lifetime of experiment, e.g. for **operation training**

Barrel

System test @ CERN
Integration @ CERN

Endcap

System test @ DESY
Integration @ Nikhef & DESY



ITk Strip

Combined system test @ CERN
Full detector integration @ CERN

The Setup

Endcap System Test @ DESY

An overview

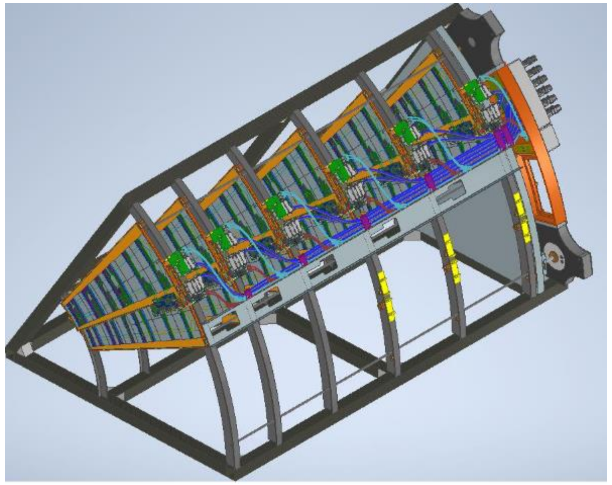
- Realistic **endcap structure** (51deg of full EC) as global support
  - Allows to mount up to 12 petals in system test
  - Surrounded by thermal enclosure and Faraday cage

- Currently populated with **one fully-loaded pre-production petal**
- Cooling with **dual-phase CO_2** cooling (warm: +17°C, cold: -35°C)
- Power delivered using **full powering chain**
- Custom **DCS system** for coldbox control
- Readout with two **DAQ variants** available

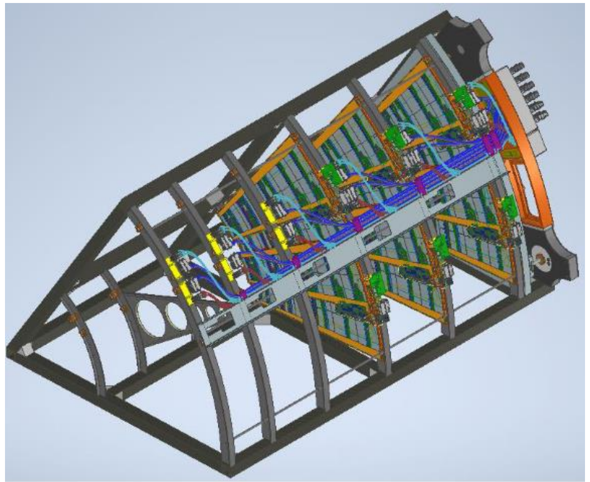
Endcap System Test - Configurations

Planned test configurations

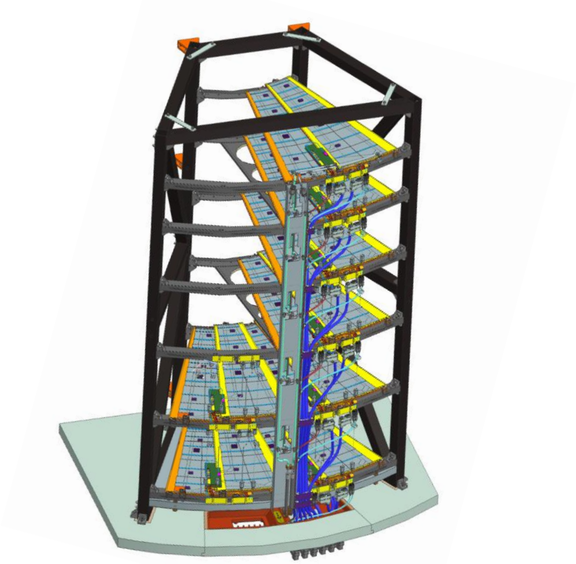
- **2-petal configuration**
  - two petals per disk on one side of the service tray
  - normal configuration for the half service module installed
  - final configuration of the system test ("welded")



- **4-petal configuration**
  - four petals per disk at disks 3, 4 and 5
  - services are re-routed using free connections from the other side of tray
  - allow to test different permutations for noise study

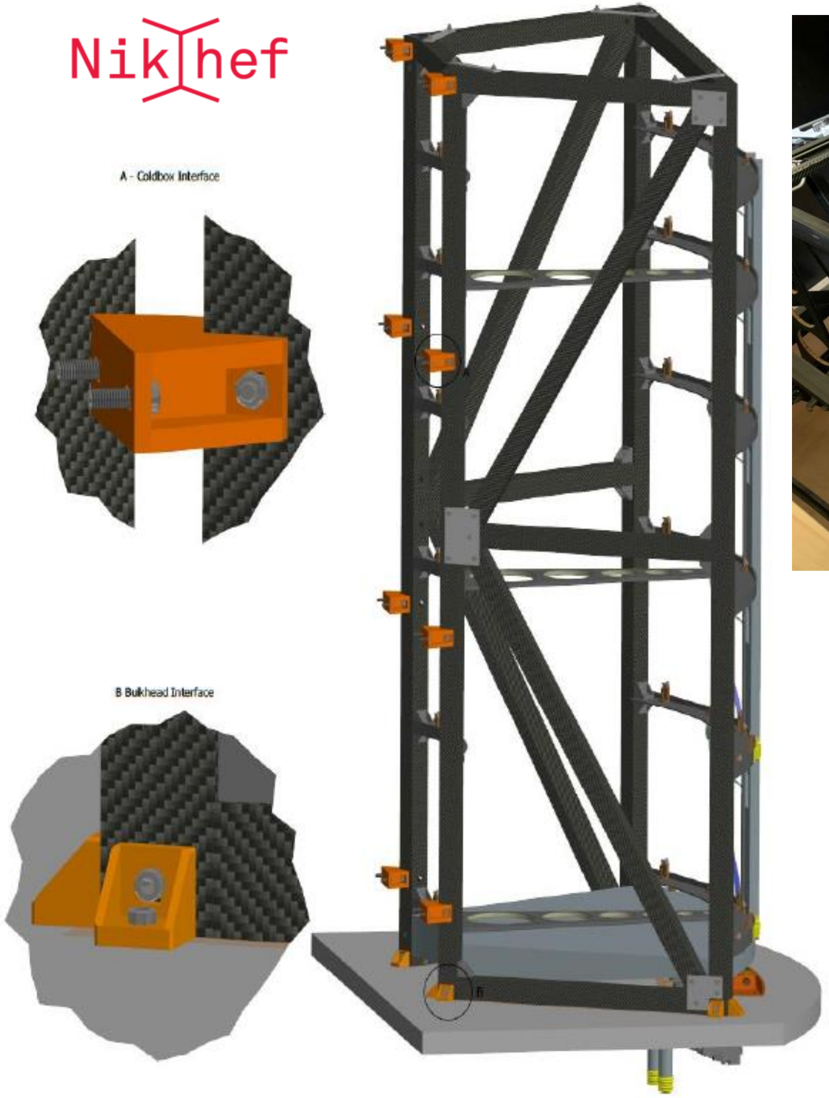


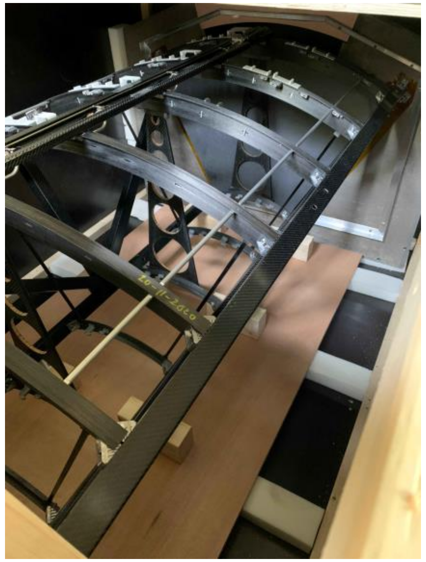
- **horizontal/vertical orientation**
  - allowing to test in horizontal and vertical orientation
  - horizontal orientation as standard configuration
  - vertical orientation interesting to perform cosmics runs



Endcap System Test – Global structure

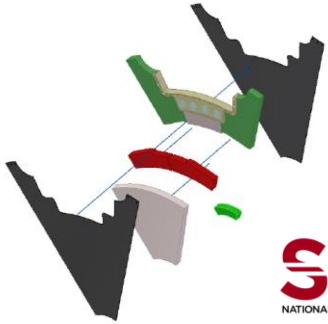
A realistic piece of cake of the endcap structure

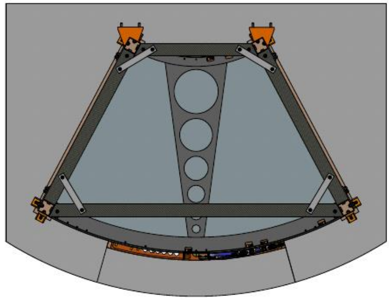




- EC sector for system test providing **mechanical support structure** built from final material choices and production parts
  - 16 carbon fiber squared profiles as core structure joint with Al brackets
  - Real blades and cutouts of wheels with locking points for petal integration
  - Custom plastic brackets for connection between bulkhead and cold box

- System test **bulkhead** as an rectangle covering one octant of the real bulkhead following production design
  - Adapted shape for interface to cold box
  - Inserts added to foam for interfaces to structure and cold box

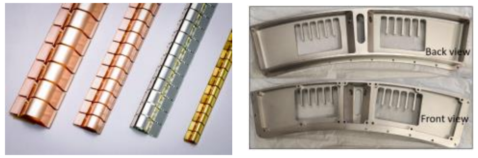




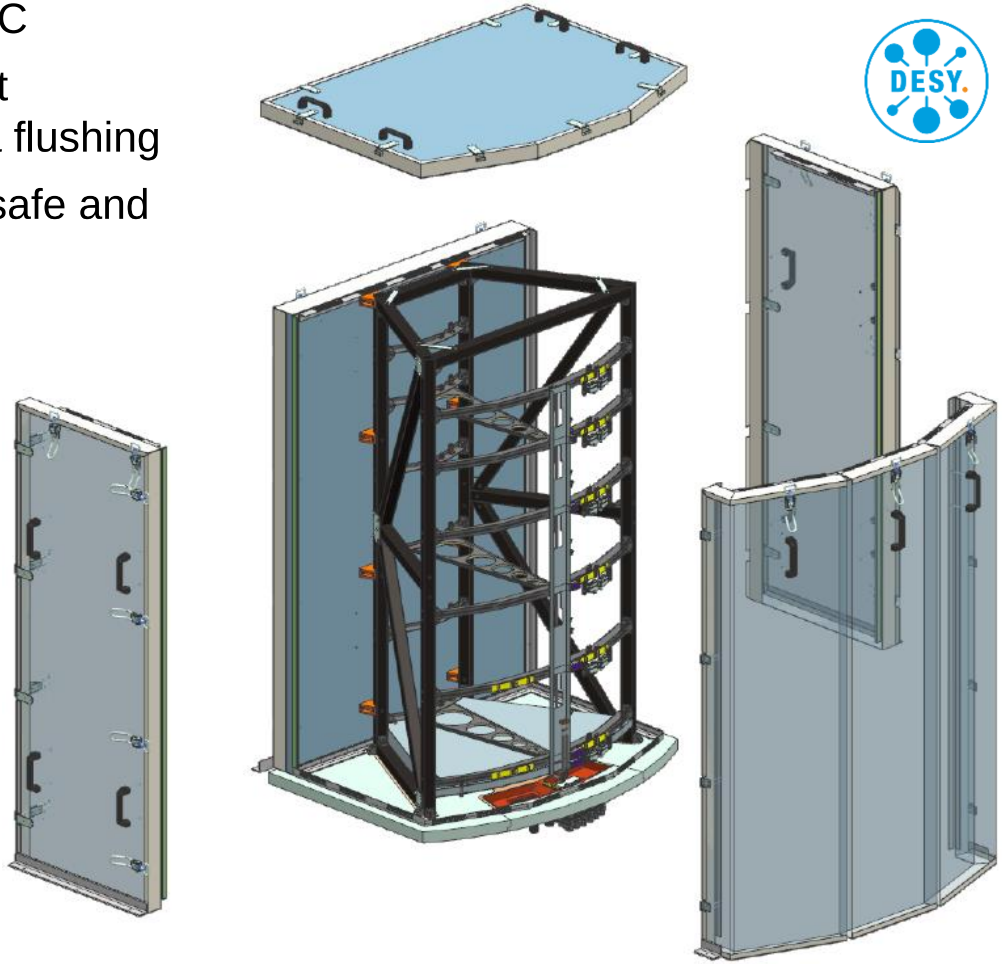
Endcap System Test – Coldbox

Coldbox as thermal enclosure and Faraday cage

- System test will be operated under **realistic detector conditions**
  - Structure need to enclosed in an insulation box providing thermal insulation → cold operation down to -35°C
  - Cold box needs to be leak tight → provide dry environment via flushing
  - Cold box design should allow safe and easy assembly/disassembly



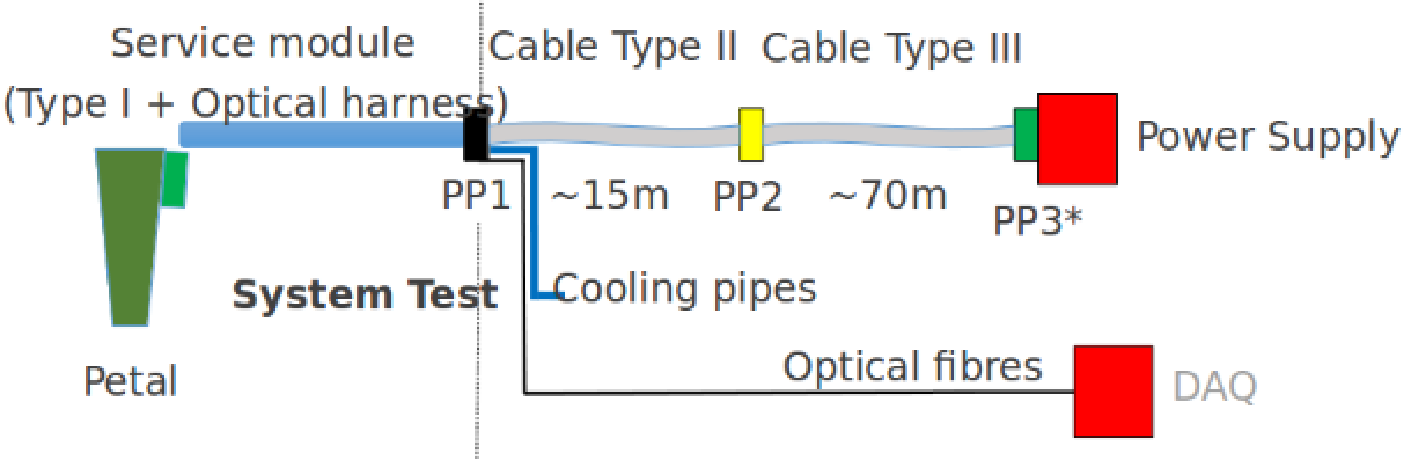
- Custum-made design for **coldbox**
  - Box consists of side wall elements, a front element and a lid
  - Bulkhead forms the lower end of the cold box
- Coldbox as **Faraday cage** for grounding & shielding concept
  - Connection of all housing elements to shield from the outside (by Al plate coating, Al profiles and contact spring fingers)
  - EC frame is insulated from bulkhead by Kapton sheets and cooling pipes come with electrical breaks

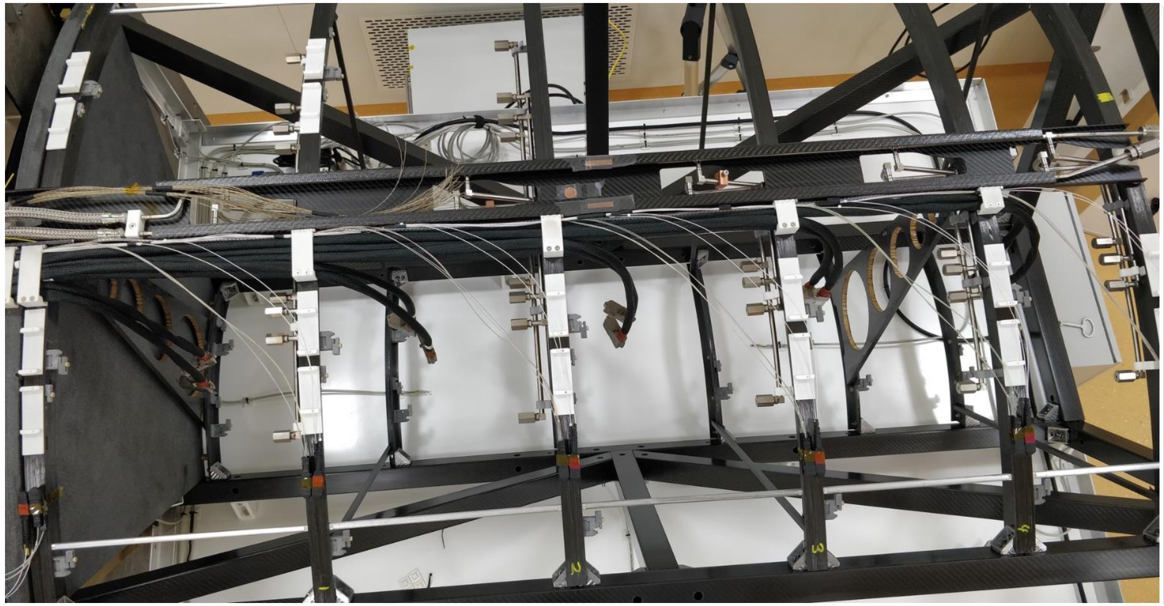


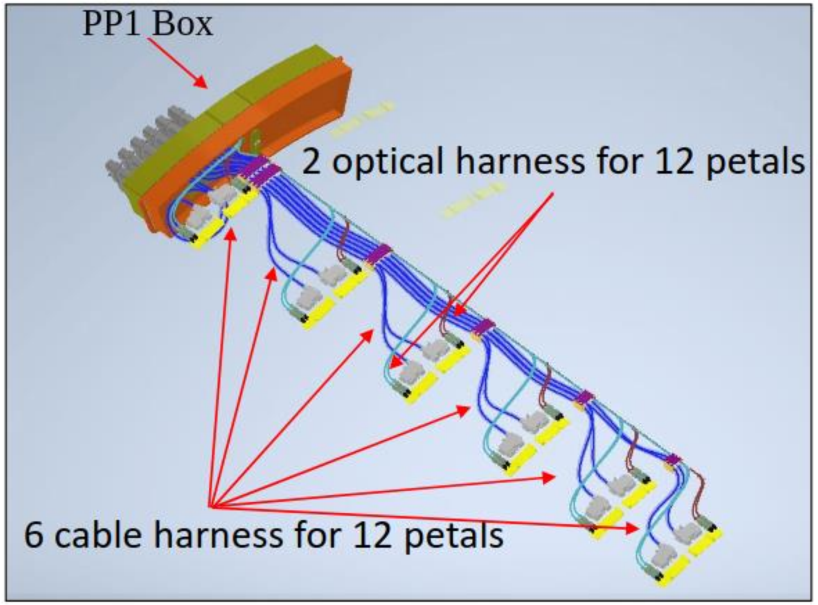
Endcap System Test – Services

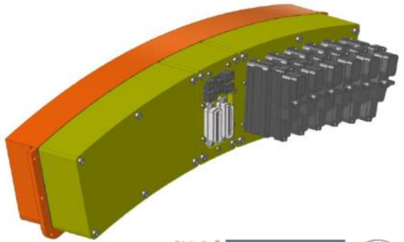
Electrical and optical services

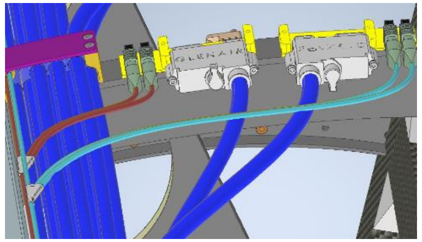
- System test provides **electrical and optical services** to read up to twelve petals in different configurations
  - 2-petal configuration follows final detector design in terms of grouping and routing of electrical and optical harnesses











Endcap System Test - Power chain

Powering of petals in system test

- Electrical services for **powering and interlock** using prototype and pre-production objects
  - LV and HV **power supplies**, type-I/II/III **cables** and **patch panels** PP1/PP2/PP3*

Power Supply (PS) Crate

Patch Panel 3* (PP3*)

type-III cable

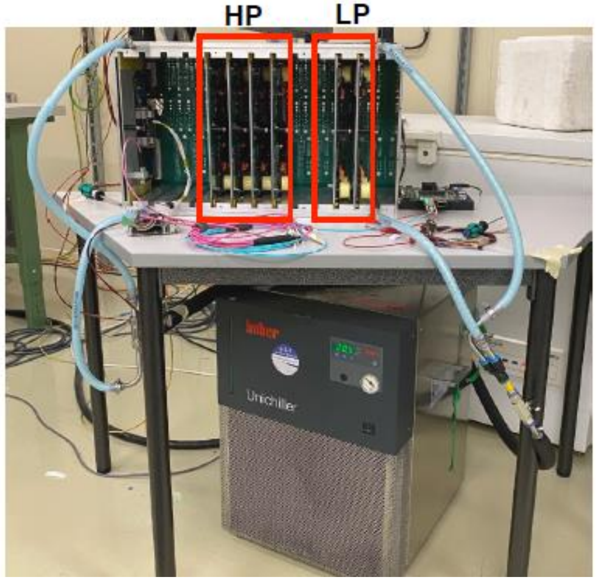
Patch Panel 2 (PP2)

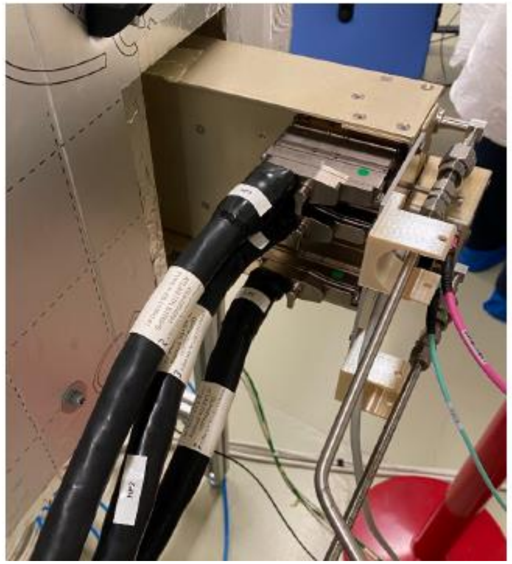
type-II cable

Patch Panel 1 (PP1)

type-I cable

Stave (PP0)



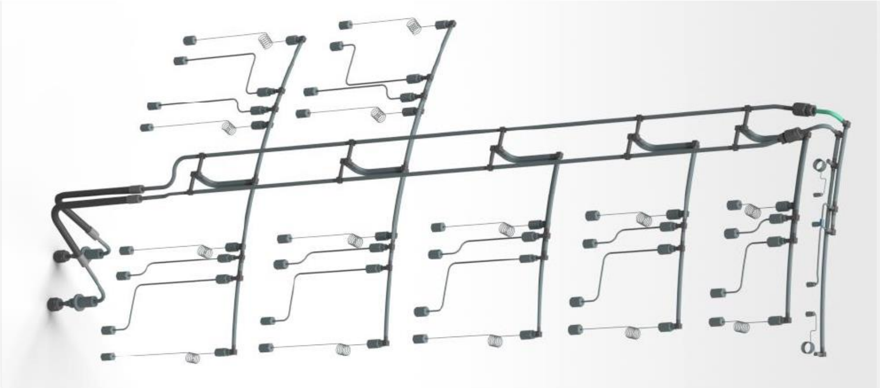


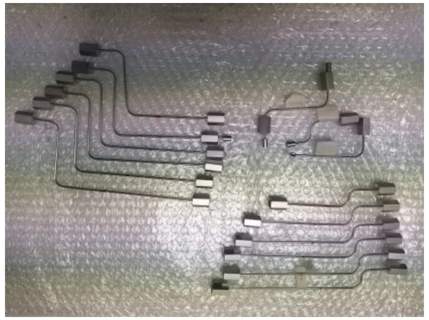
**picture shows setup at barrel system test @ CERN, but identical for end-caps*

Endcap System Test – Cooling

Cooling manifolds, capillaries and LUCASZ CO_2 plant

- Special **cooling services** designed for system test to allow flexibility of petal connection
  - **Manifold** design to fit system test geometry (no half disk, but vertical distribution) for 16 petals
  - Temporary **connectors** to avoid welding in the first place
  - Pre-production CO_2 **capillaries** for testing



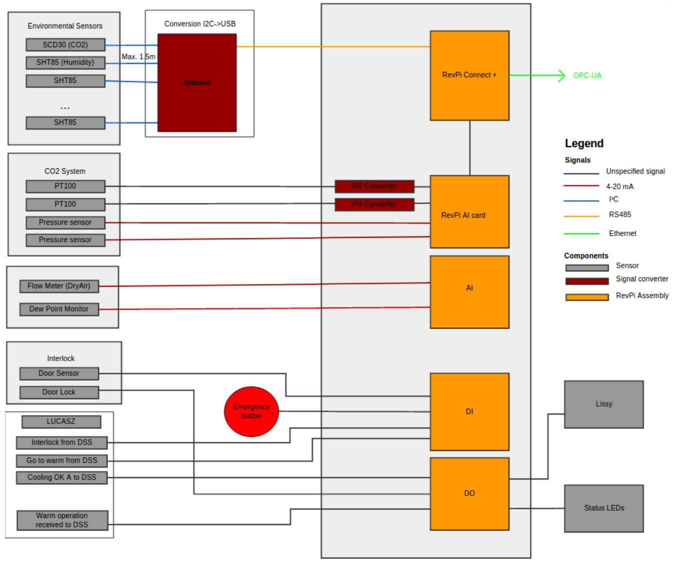


- Two **LUCASZ CO_2 plants** constructed for integration & system tests at DESY & Nikhef
  - Test operation with system test ongoing

Endcap System Test - Monitoring & Interlock

DCS for petals in system test

- Various tools and systems developed and tested for **monitoring, control and interlock** of the system tests
  - **LISSY** interlock system for PSU interlock depending on petal NTC on EoS board
  - **Coldbox monitoring** (T, RH) including box interlock and programmed alarms via Grafana



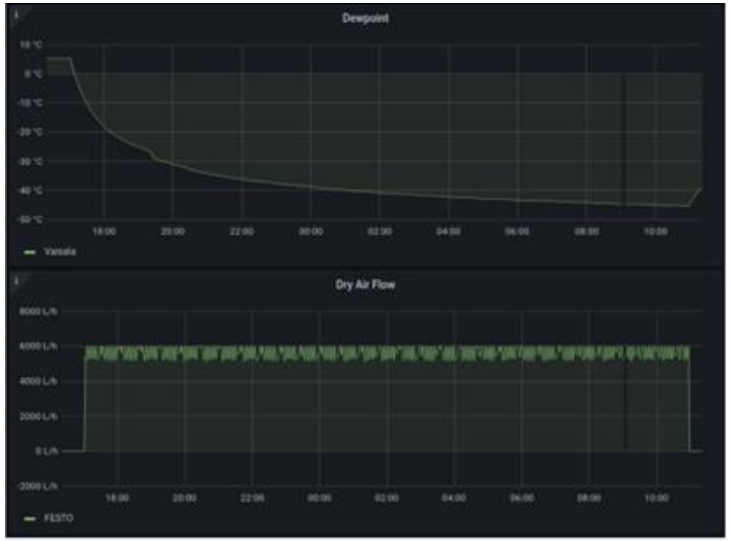
Final state machine for interaction of the different subcontrols under development at CERN → interfaced via WinCC panel

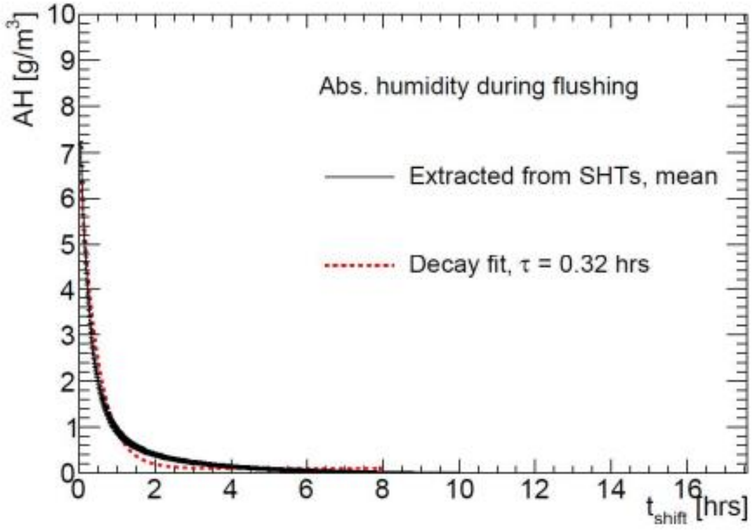
The Results

Characterization of the system test coldbox

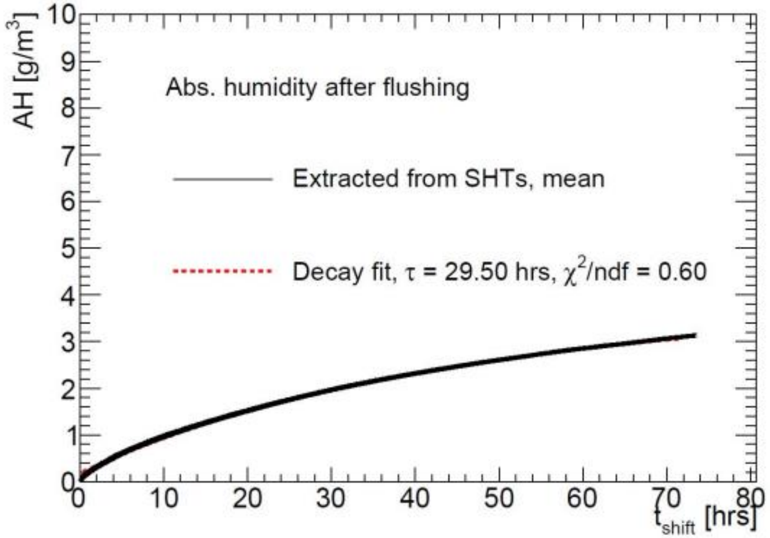
Flushing tests for the thermal enclosure

- **Flushing phase**
  - Performed flushing of ST volume with dry air at a rate of 6 m^3/h
  - Target of -40C dewpoint (DP) reached after ~8 hours of flushing
  - Exponential fit of absolute humidity (AH) shows decay time of 0.32 hours





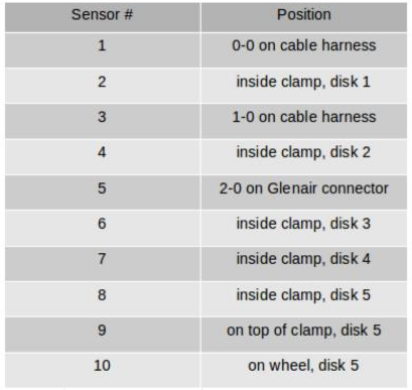
- **Diffusion phase**
  - Keeping the monitoring active after stopping the dry air flushing
  - Exponential fit of AH shows decay time of 29.5 hours



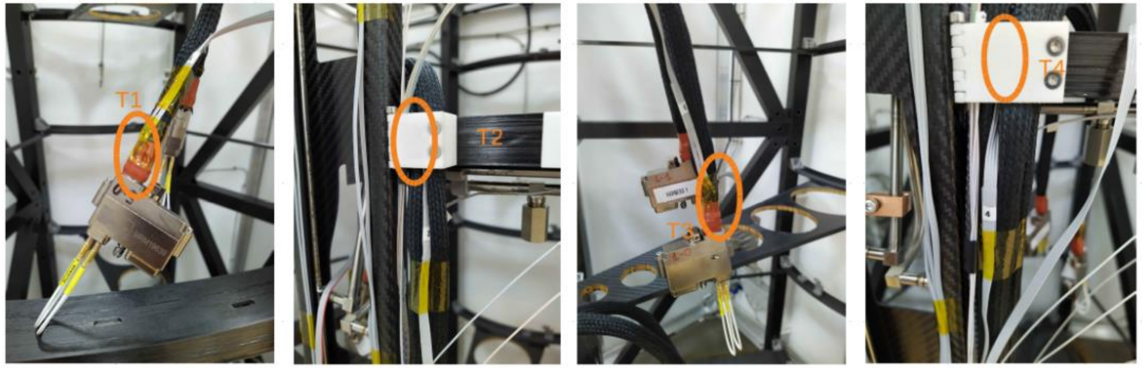
Temperature of the electrical services

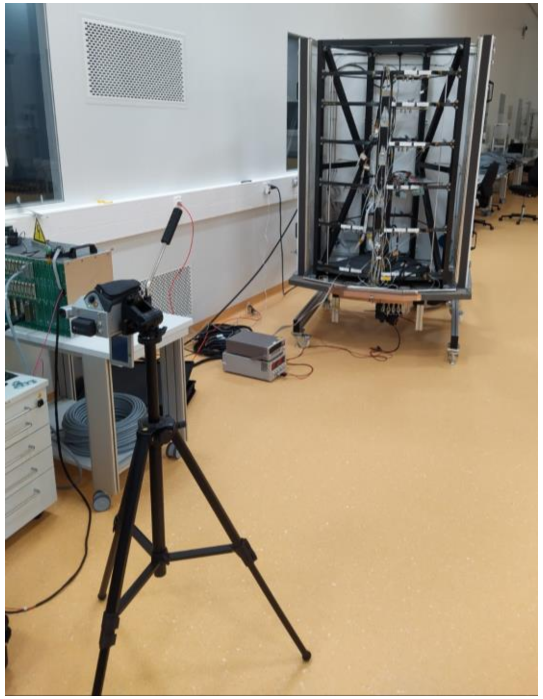
Measurement of the self-heating of type-I cables

- Measurement of **cable temperatures** under load:
  - Daisy-chain all type-I cables in one cable bundle (one patch panel)
  - Power up to the design current of 5A
  - Measure temperature behavior (via PT100 sensors and via an IR camera)



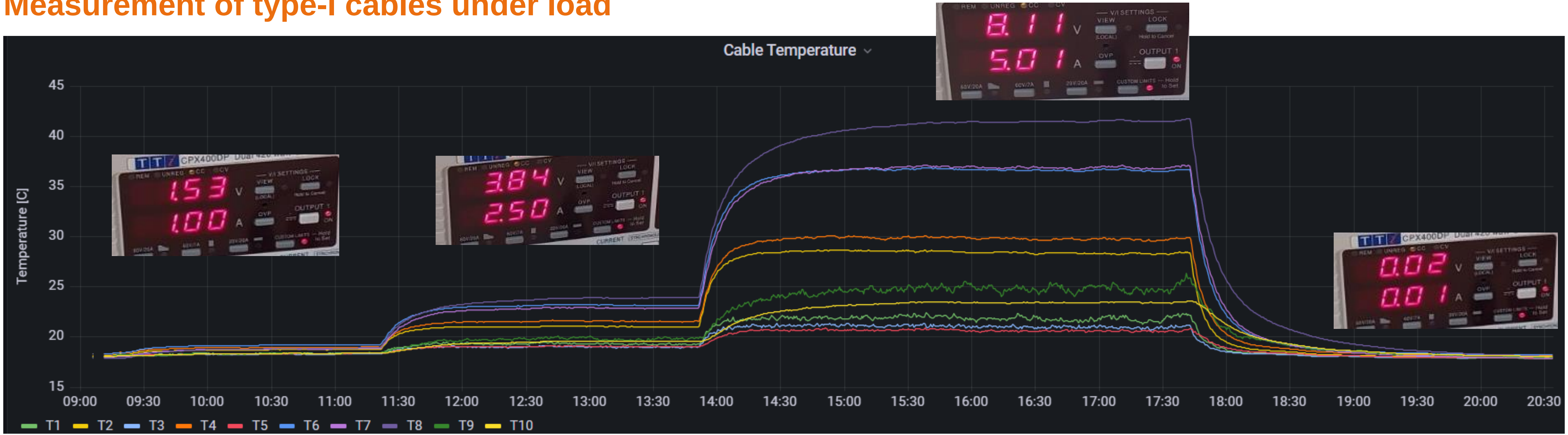
Sensor #	Position
1	0-0 on cable harness
2	inside clamp, disk 1
3	1-0 on cable harness
4	inside clamp, disk 2
5	2-0 on Glenair connector
6	inside clamp, disk 3
7	inside clamp, disk 4
8	inside clamp, disk 5
9	on top of clamp, disk 5
10	on wheel, disk 5

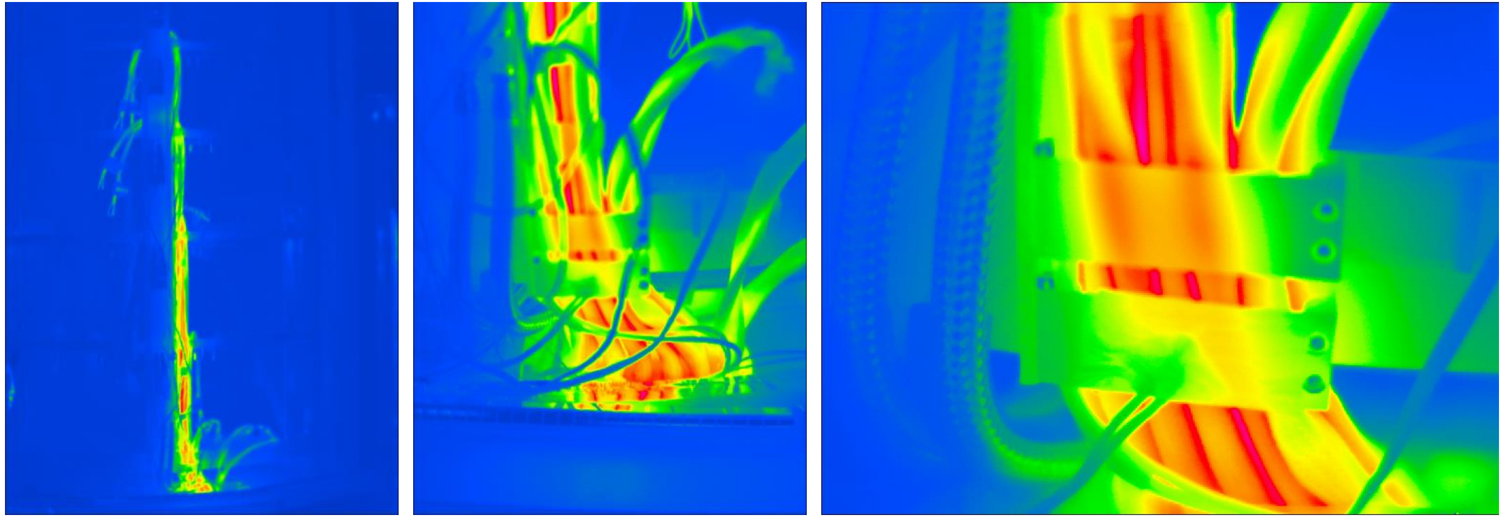




Temperature of the electrical services

Measurement of type-I cables under load





Observations:

- Highest temperature reached in lowest **cable bunch** (maximal ΔT=24K)
- Saturation in **thermal equilibrium**, exponential increase/decrease for switch on/off

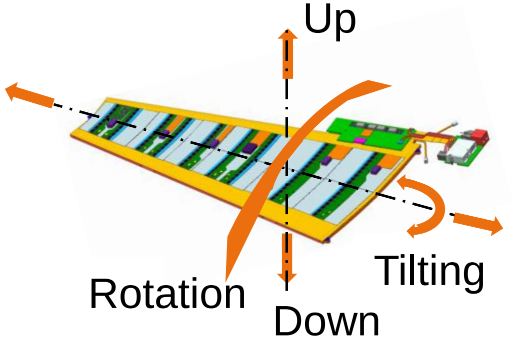
Take away:

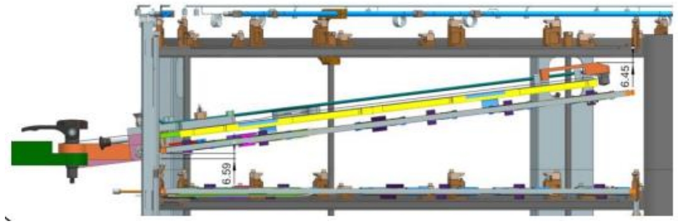
- Cable temperatures **under control**, no dedicated cooling of electrical services required

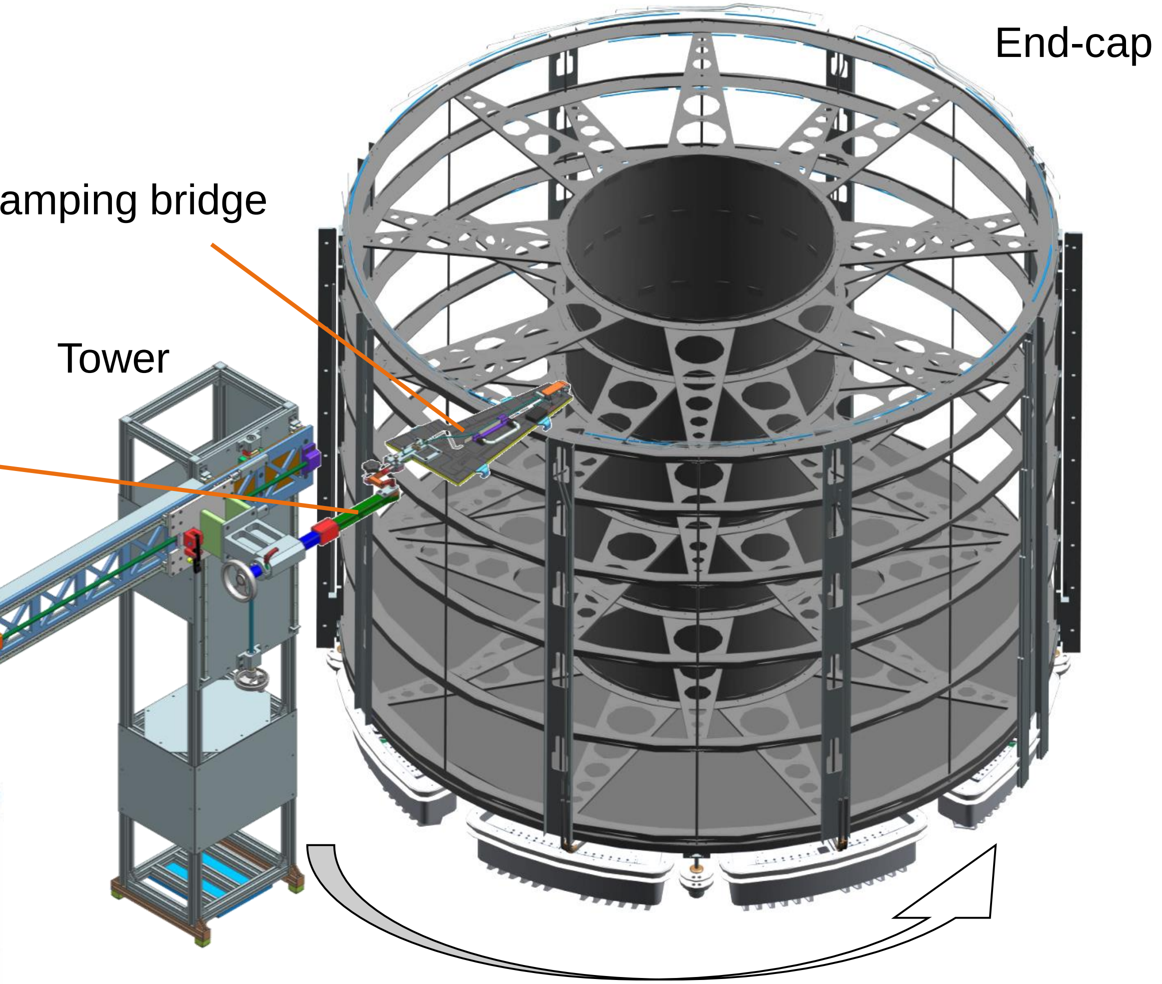
Petal insertion into system test

Field test of the petal insertion tool

- Mechanical tool for **petal insertion** during integration
  - *insertion tower* with attached *insertion hands*
- Characteristics of the tool
  - Safely **pick up** petals from petal support frames
  - Insertion to all possible petal **locations** in the vertical position of the end-cap
  - **Monitor** insertion procedure at all times
  - Simple and safe **release/locking** of the petals into position
  - **Rotation** around long axis of petal to enter windows
  - **Positioning** of the tool around the end-cap





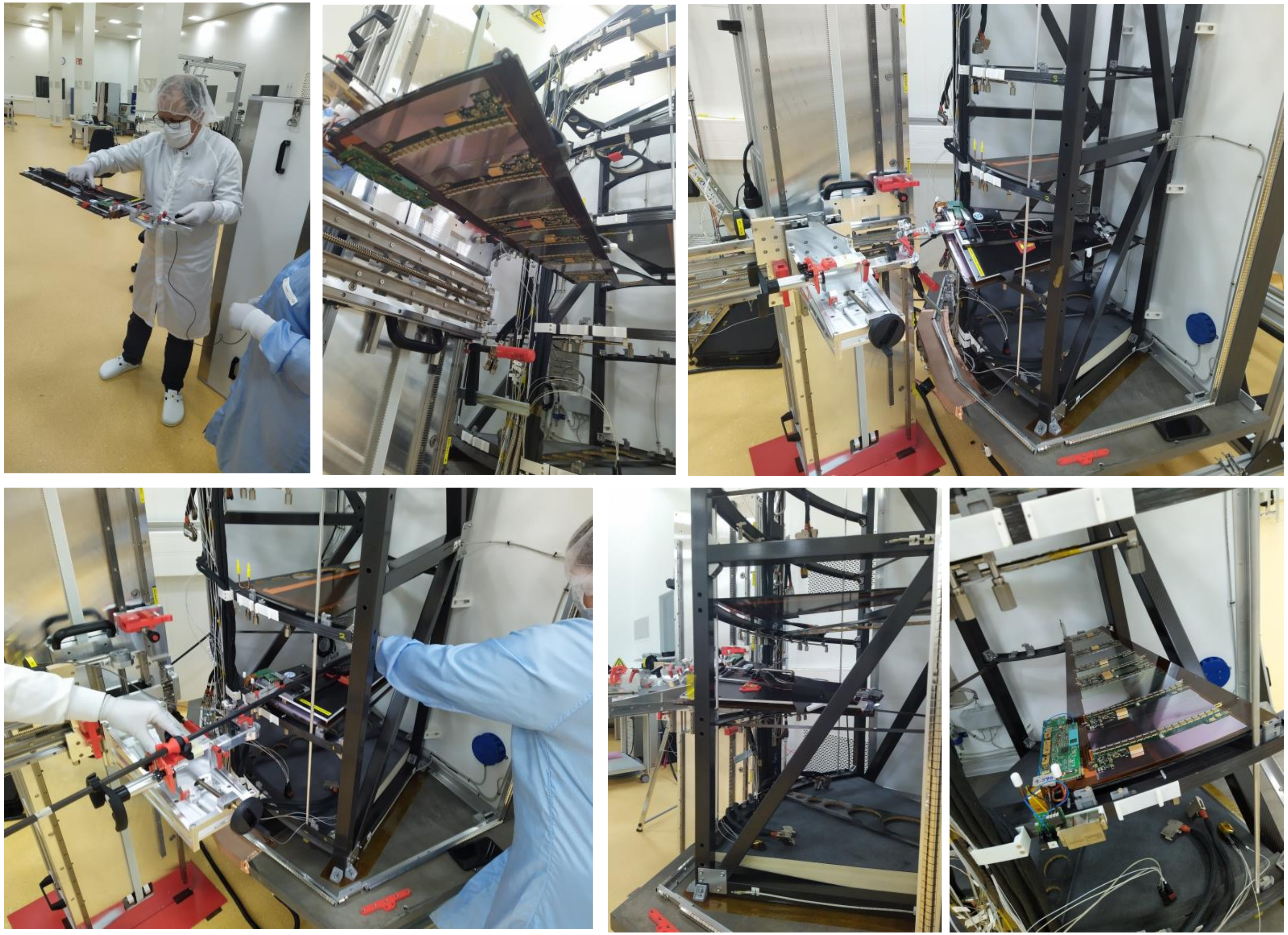


Loading and integration of the strips end-cap tracker for the phase-II upgrade of the ATLAS detector - V. Prahl @ FoTDM19

Petal insertion into the system test

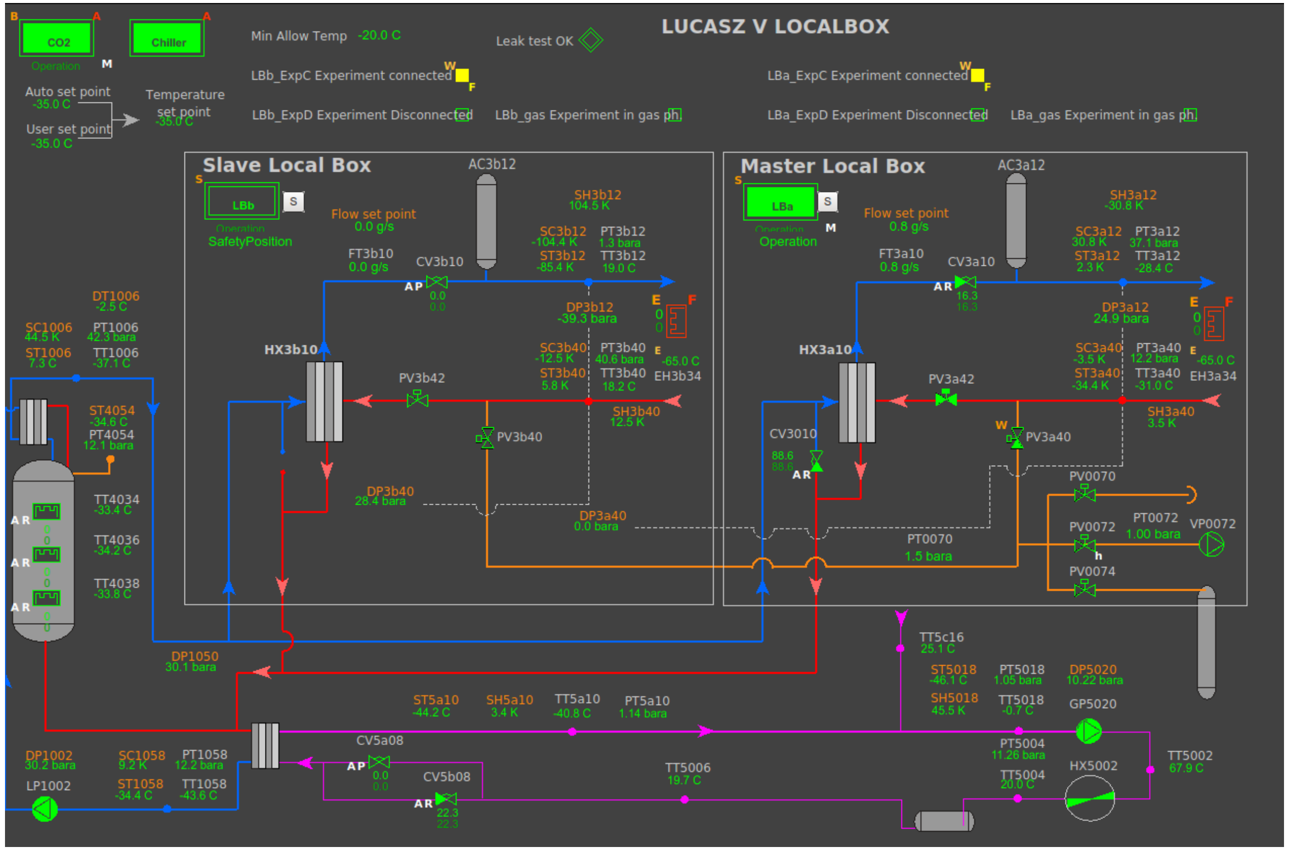
First petal inserted in system test

- Test and train developed tool with fully loaded petal and realistic EC structure at the system test
- Sequence of insertion process:
  1. (1) Attaching petal to insertion hand
  2. (2) Attaching tool to insertion tower
  3. (3) Step-by-step insertion process (including rotation into limited insertion window)
  4. (4) Fixation of locking point screws
  5. (5) Connection of services
  6. (6) Electrical test of petal → Success!



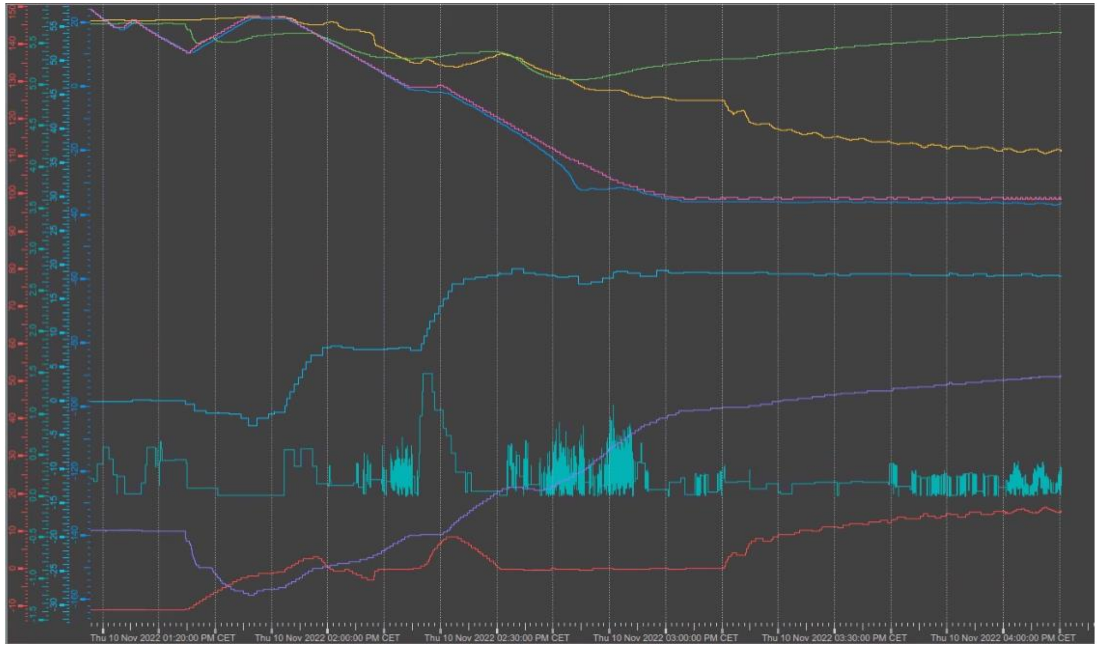
Petal cooling with the system test

First tests with LUCASZ cooling plant



- Studying different configurations for CO_2 **investigations**
  - Analysis and interpretation ongoing

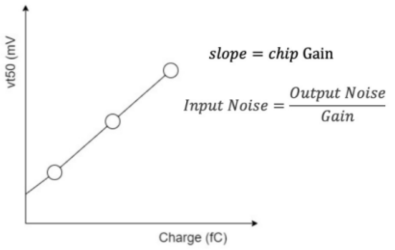
- First **operation of LUCASZ** cooling plant with system test setup
  - Running with real-sized **capillaries**
  - Cooling of one petal with designated **mass flow** (0.8g/s) at **warm** (+17°C) and **cold** (-35°C) set point
  - Limit of LUCASZ operation range



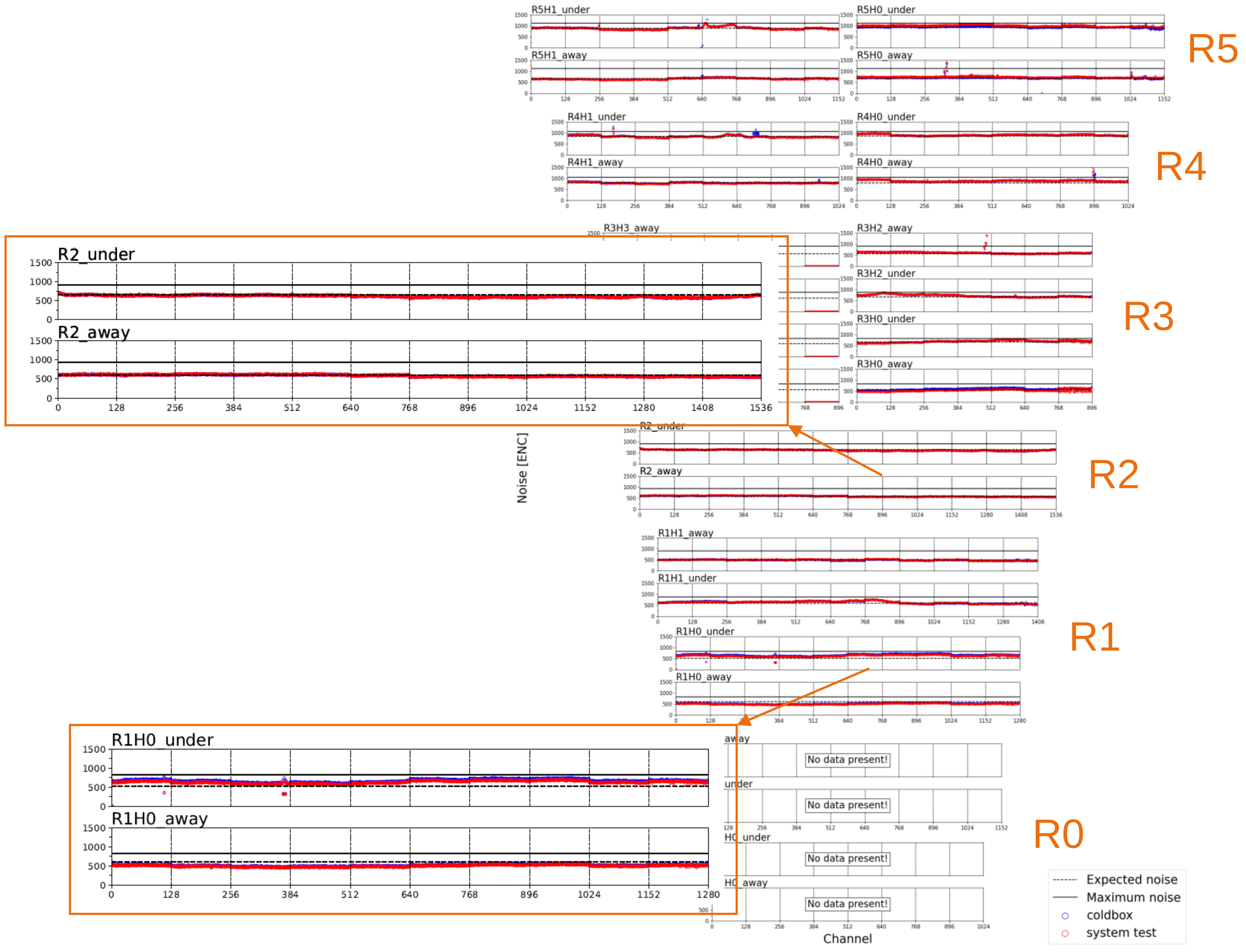
Petal noise performance in system test

Comparison of electrical performance of inserted petal

- Comparison of electrical test results when tested inside the petal coldbox and inside the system test
  - here: input noise distributions of response curve test with injected charge of 1.5fC



- Evaluating at the cold (-35°C) CO_2 set points for
  - MARTA (petal coldbox)
  - LUCASZ (system test)



The Closing

Summary

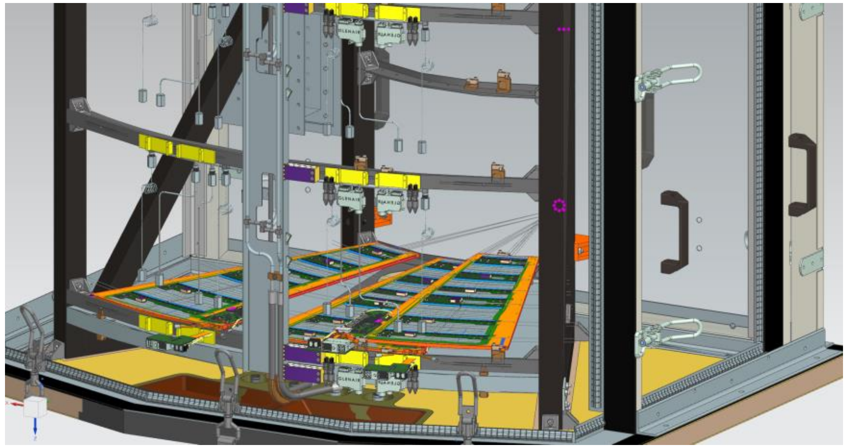
Status of ITk strips endcap system test

- System test for the ITk Strips Endcap detector is fully operational
  - Needed **infrastructure** (services, cooling, DAQ) is available and set up
  - Motivated **team** within system test community is working together and exchange a lot
  - Several **results** for the detector performance are already produced
  - Important **tools**, e.g. for DCS, are being developed and tested at system test
  - System test is an important input for ATLAS internal **reviews** of the production readiness

- Results shown today
  - Validation of mechanical design of system test structure with **coldbox**
  - Measurement of **cable temperature** with full electrical load
  - First hand testing and training with petal **insertion tooling**
  - Operation with complete **power chain, optical services** for readout and **dual-phase CO_2 cooling**
  - Successful **data taking with first inserted petal** in system test

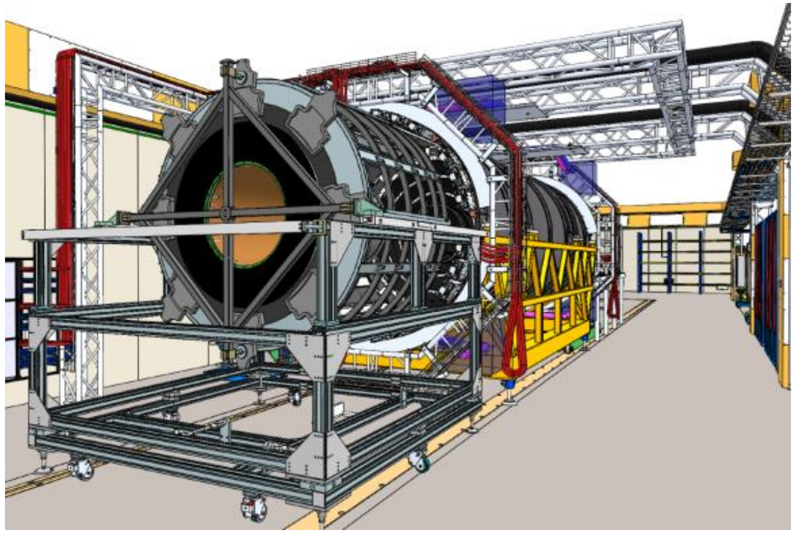
Outlook

What comes next?



- **Endcap system test** @ DESY
  - Populate system test with more petals
  - Run the noise characterization of petals (esp. cross talk)
  - External trigger by cosmics, perform tracking studies with ST

- **Integration** for the ITk Strips detector
  - Several areas of the ITk strips project have reached production readiness
  - All integration sites (CERN, DESY, Nikhef) are in preparation phase
  - System tests are main driver for this phase, e.g. by training people



Thank you

Contact

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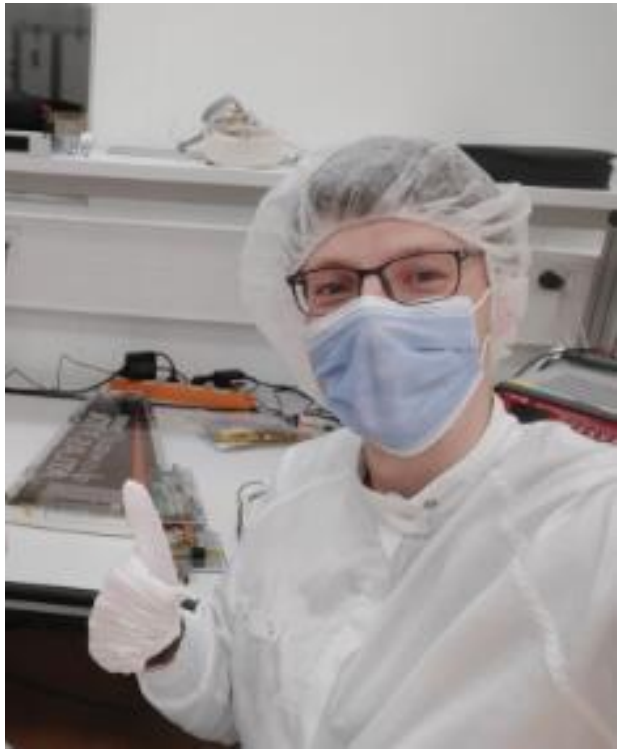
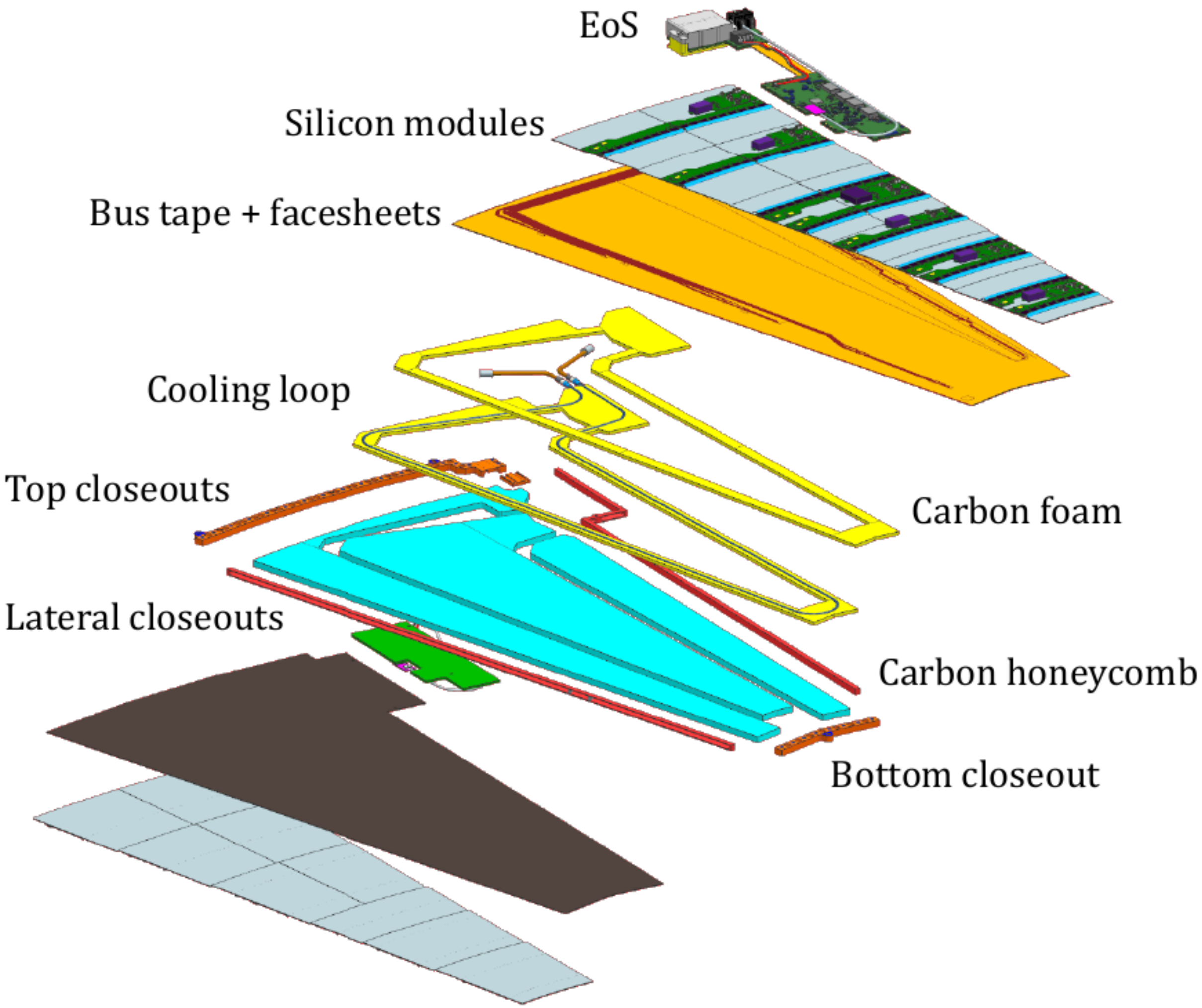
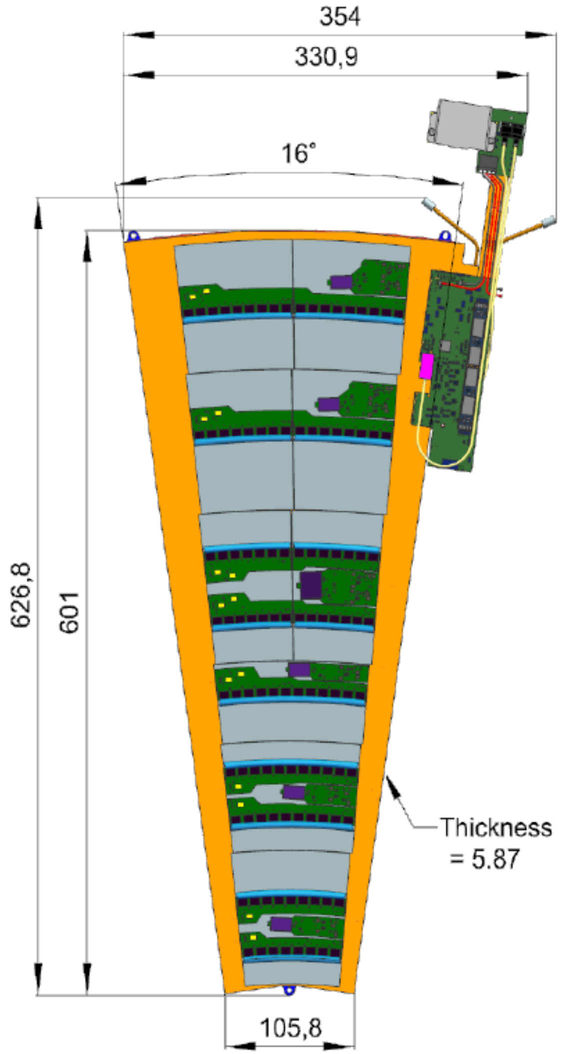


The Bonus

Local support structures

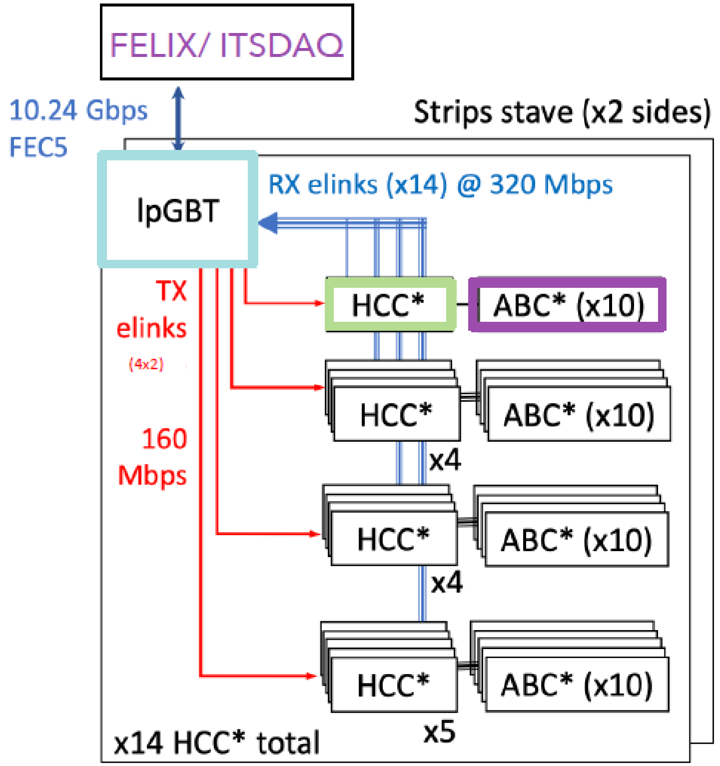
Exploded view of a petal





Endcap System Test - Readout

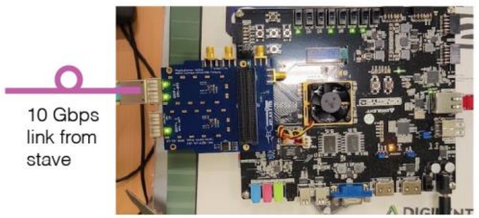
DAQ of petals in system test



1) **Genesys2 + ITSDAQ**
   - Only used within ITk strips (development based on SCT software)
   - Used as baseline at building/QA/QC sites for staves/petals
   - Foreseen for reception testing, but not easily scalable for multiple objects

2) **FELIX + YARR**
   - Under development for ITk online software (common with Pixels)
   - Uses TDAQ hardware (FLX-712 card) and YARR readout software
   - Scalable for multiple staves/petal, baseline for system tests and onwards

ITSDAQ setup



↔

ITSDAQ

hardware
(Genesys2)

software

FELIX setup

↔

YARR

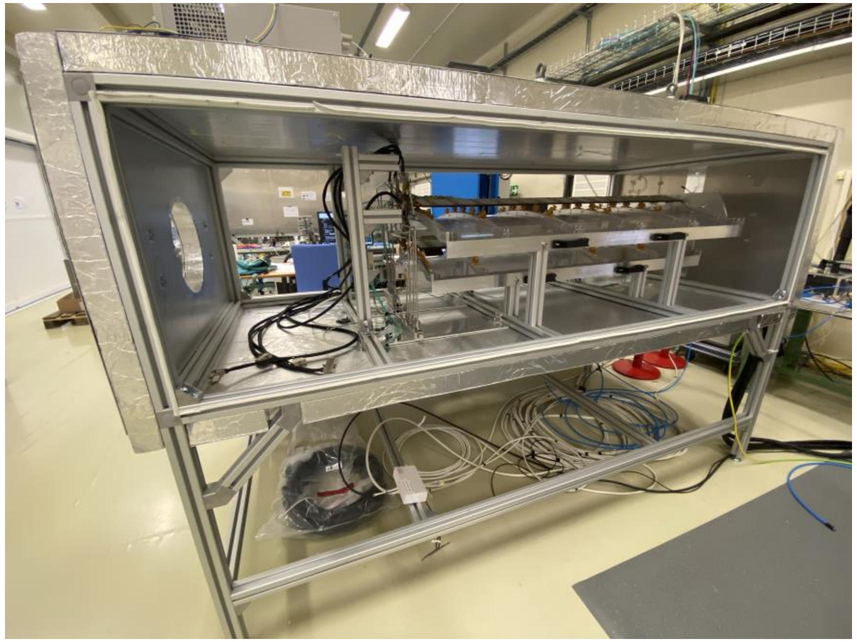
hardware
(FLX 712 - phase-I card)

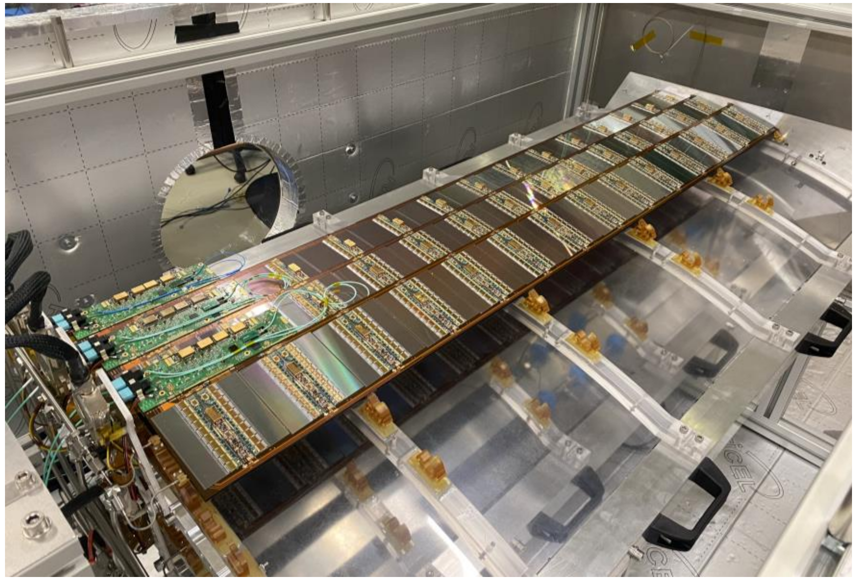
software

The Barrel System Test @ CERN

A short intro

- Custom made barrel support structure
  - Mechanical holder offering locking brackets for up to 8 staves
  - Thermal insulation and feedthroughs for services
- Currently populated with 4 fully loaded PPB staves
  - Three short-strip and one long-strip stave with pre-production chipsets
- Two cooling options for staves
  - C_6F_{14} monophase (**warm**: +18°C)
  - CO_2 dual-phase (**cold:** -25°C)
- Power delivered using complete powering chain
- DCS system operated by WinCC panels
- Readout with two DAQ variants available
  - Genesys-II/ITSDAQ and FELIX/YARR





Cooling

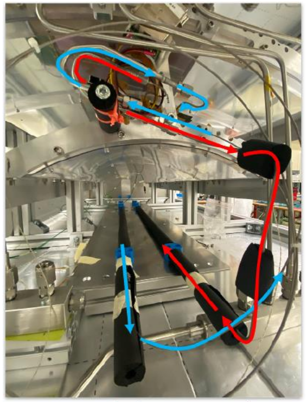
Cooling of staves and petals in system test

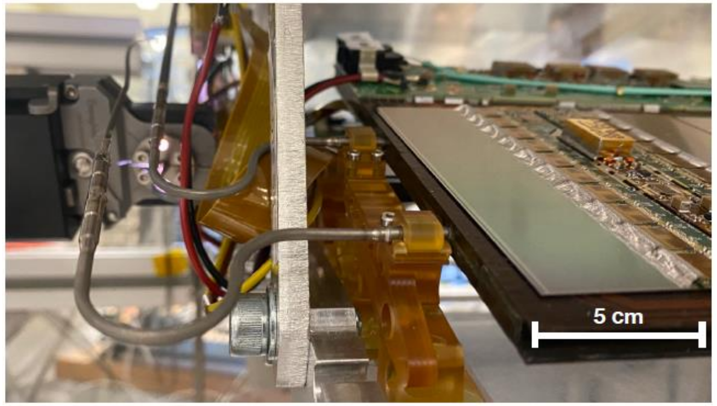
Staves with C_6F_{14} & CO_2 cooling

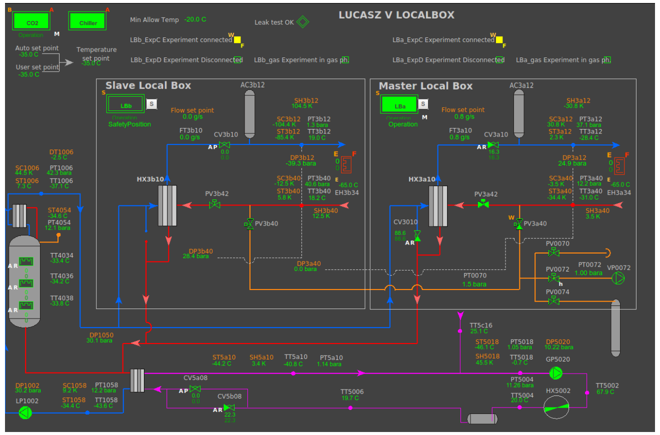
- C_6F_{14} monophase cooling plant
  - Room temperature operation of four staves in parallel with (warm operation at +18°C)
- CO_2 cooling plant in SR1 available
  - Connected temporarily last months to one SS stave
  - Lowest achievable set point: -25°C
- Nov’23: all four staves welded to cooling manifold
  - Operation of all staves with cold CO_2 soon possible

Petals with CO_2 cooling using LUCASZ

- Two LUCASZ CO_2 plants constructed for integration & system tests at DESY & Nikhef
- First operation with system test
  - Running with real-sized capillaries
  - Cooling of one petal with designated flow (0.8g/s) at warm (+17°C) and cold (-35°C) set point
  - Studying different configurations for CO_2 investigations



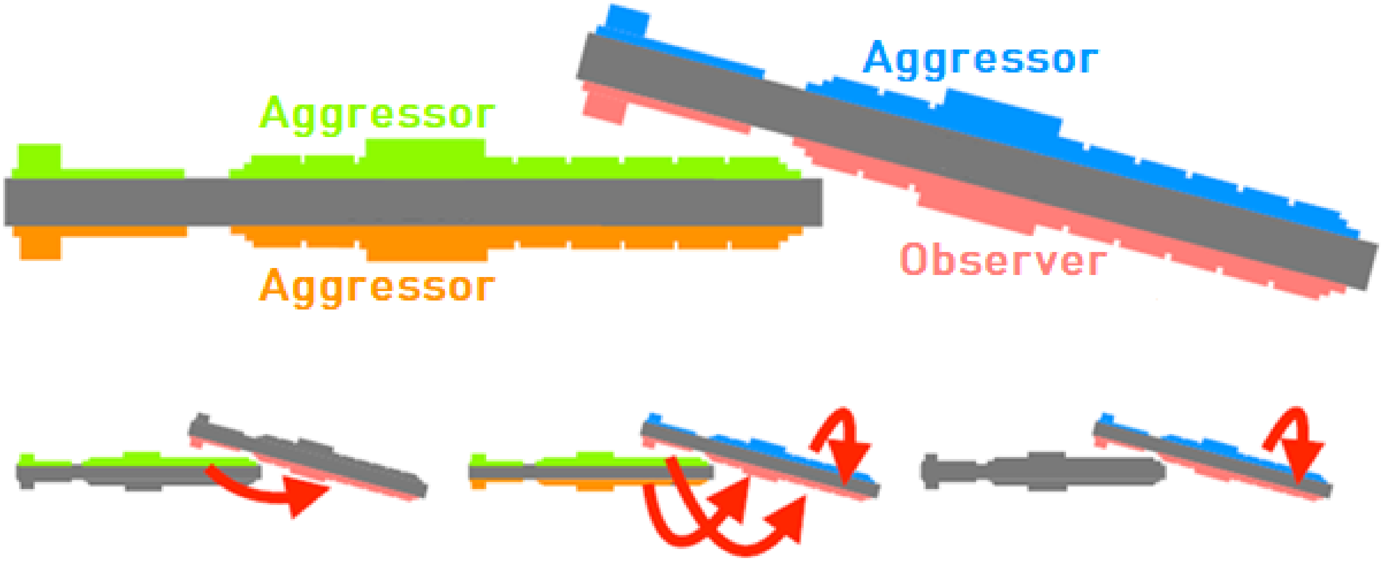


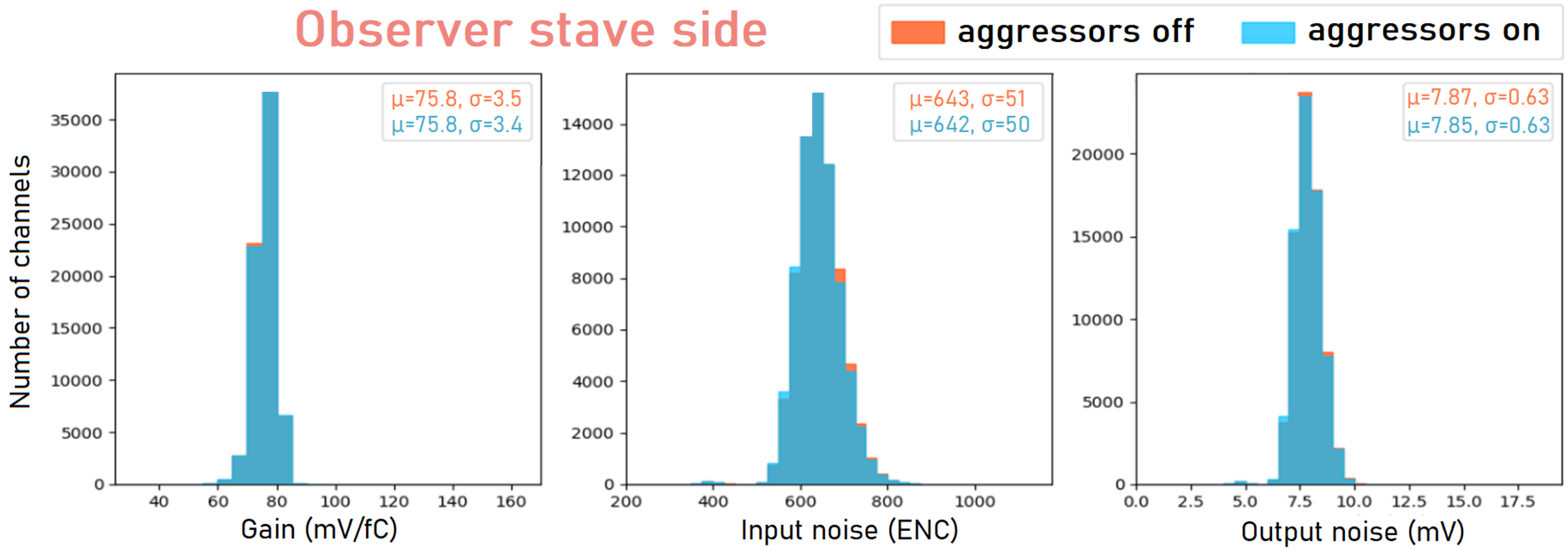


Results: Cross talk tests with staves

Influence of neighboring staves

- **Goal:** test for electrical noise on stave due to cross talk between neighboring staves
- **Setup**: perform calibration scans on one stave side (observer) with different powering configurations on neighboring stave sides (aggressors)





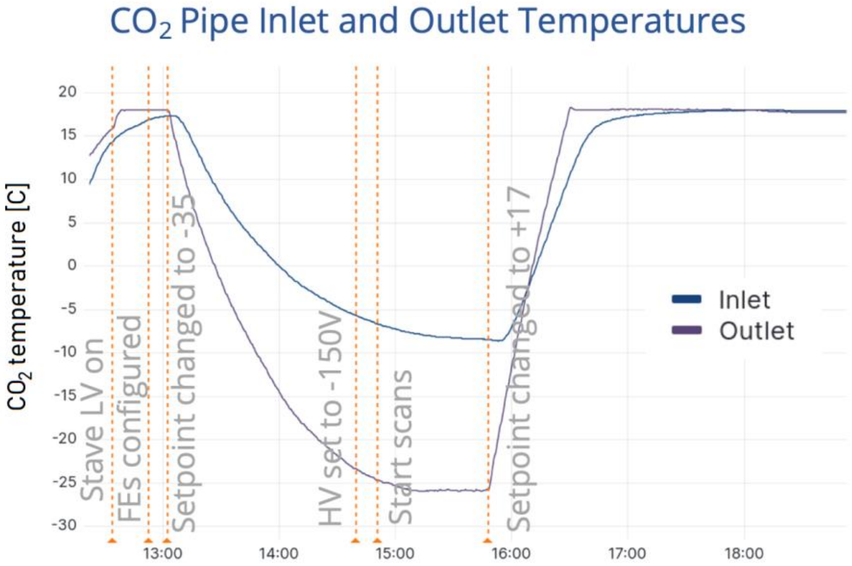
- **Result:** no change in distributions of gain, input and output noise observed

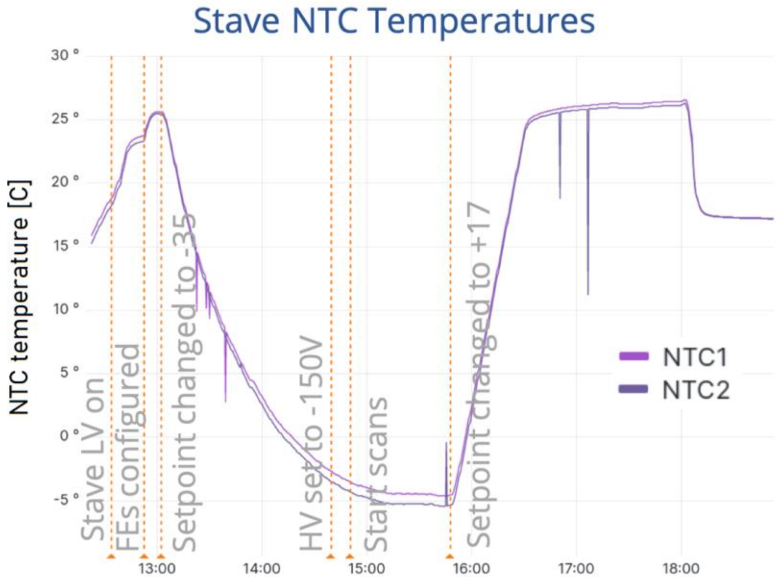
→ no indication for cross talk

Results: Stave cooling performance

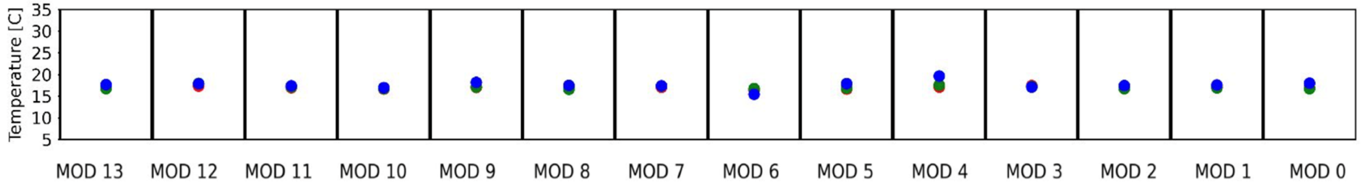
Temperatures measured along stave at warm/cold set point

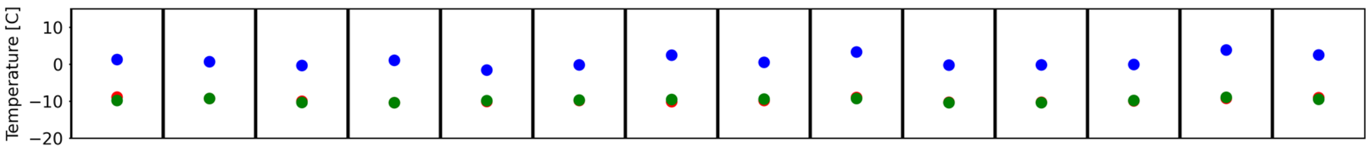
- Cooling of one stave with CO_2
  - Study at two different temperature set points:
    warm = +17°C
    cold = -25°C
  - Study different power settings (DCDC on, FEs configured, HV biased, running scans)
- Corresponding temperatures measured on/at
  - CO_2 pipe inlet and outlet temperature
  - NTC sitting on EoS board
  - Three module NTCs


CO_2 Pipe Inlet and Outlet Temperatures

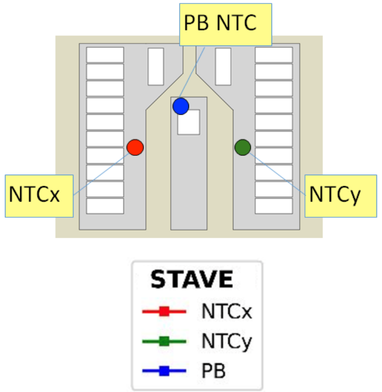

Stave NTC Temperatures

Warm (17 °C) + **DCDC off**:





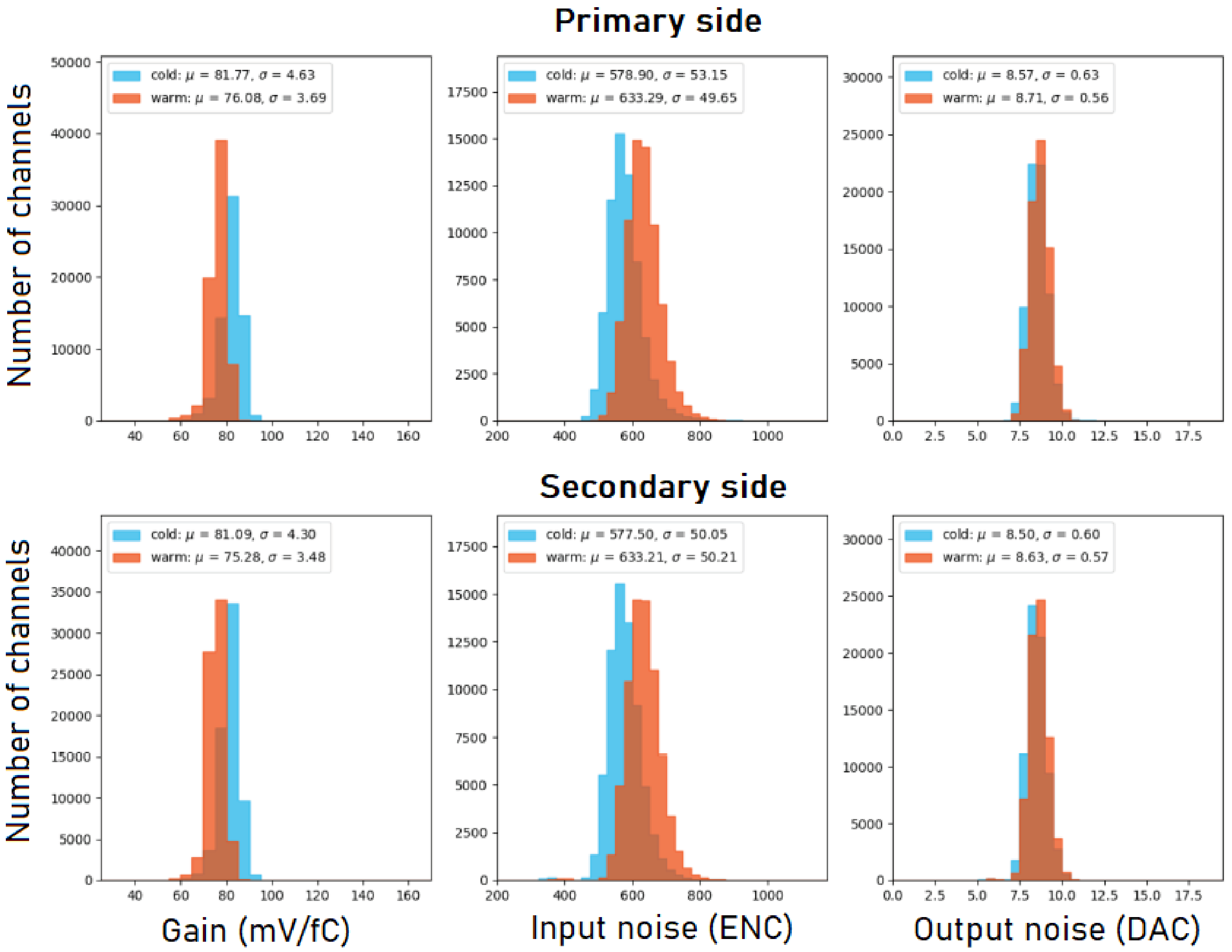
Cold (-25 °C) + **DCDC on**, front-ends configured:



Results: Noise comparison warm/cold for staves

Temperature-dependence of electrical noise

- Comparison of distributions of gain, input and output noise at warm and cold temperature (injected charge: 1fC)
  - Higher gain when running cold
  - Lower noise when running cold
- Additionally: observed indications of “cold noise” phenomenon



Cold noise @ TWEPP23