Development of the System Tests for the ATLAS Inner Tracker Strip Detector

Overview of barrel and end-cap system tests

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on behalf of the ITk Strip System Tests Community

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HELMHOLTZ

ATLAS ITk

ATLAS EXPERIMENT

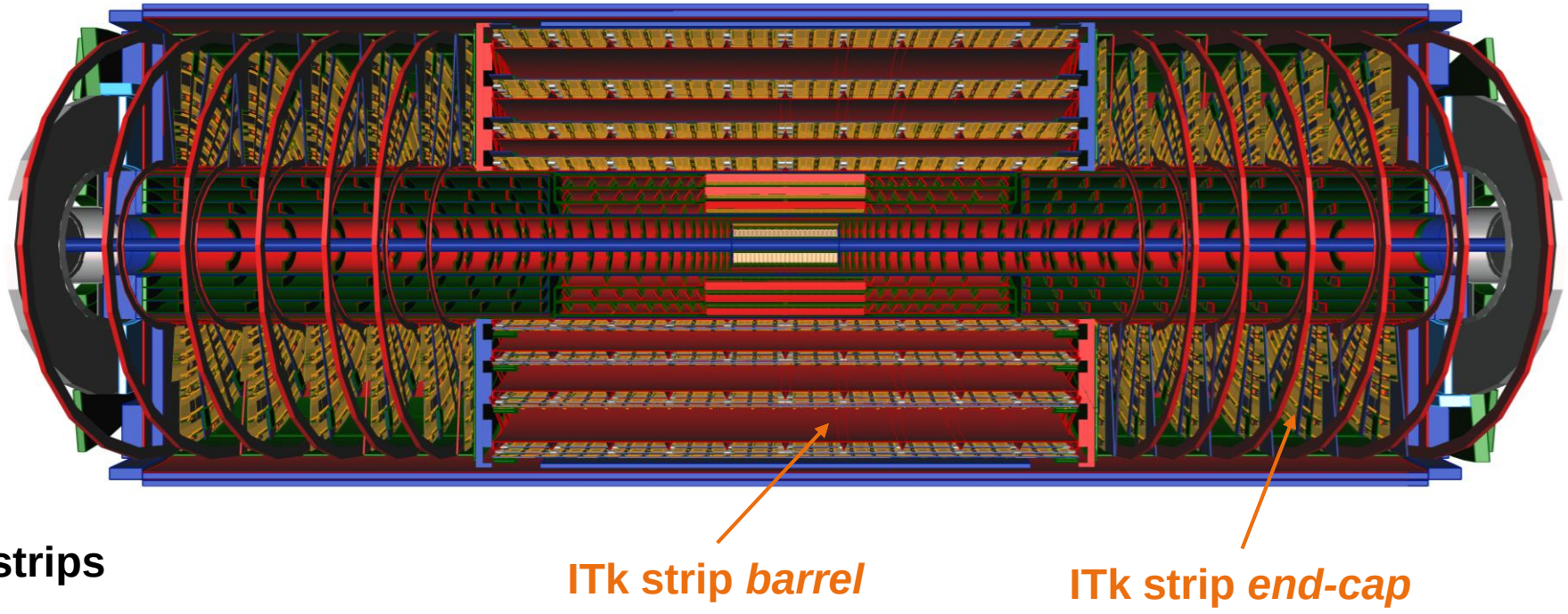
DESY.

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

ATL-PHYS-PUB-2021-024



17,888 sensors

165m^2 of silicon

60 million strips

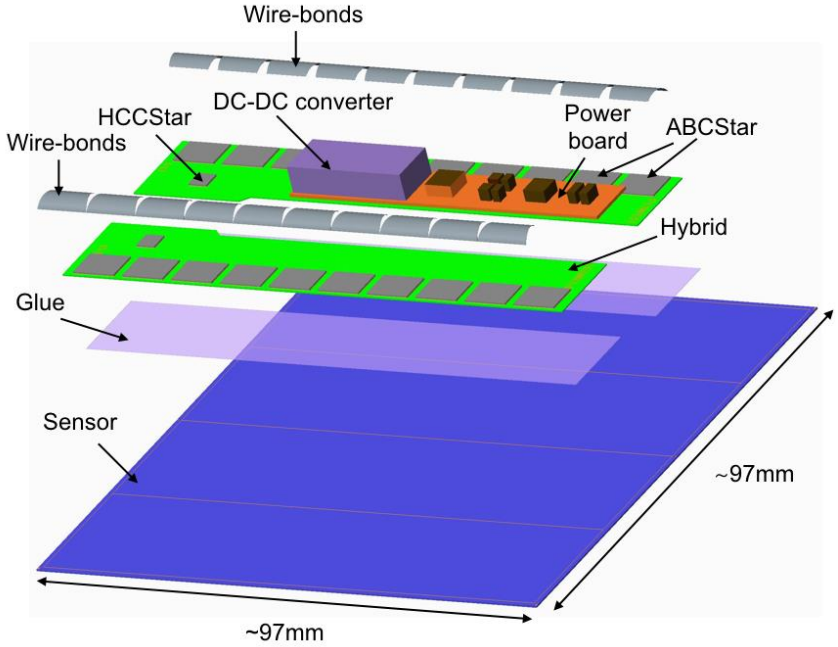
Dose up to 50 MRad

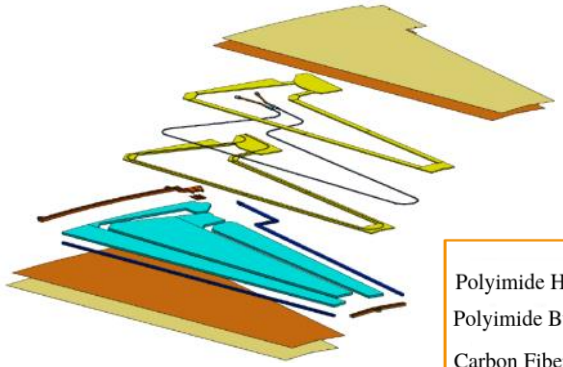
ATL-TDR-025

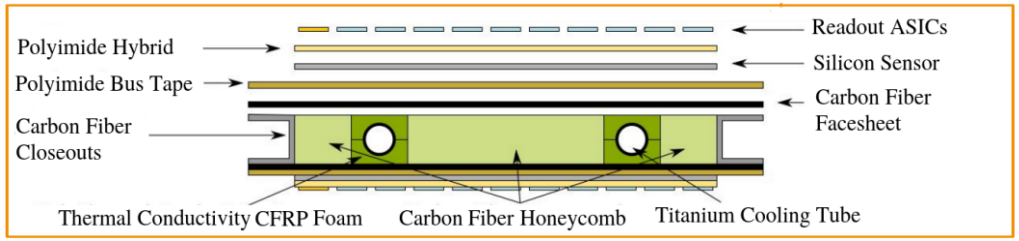
Overview of the detector concept

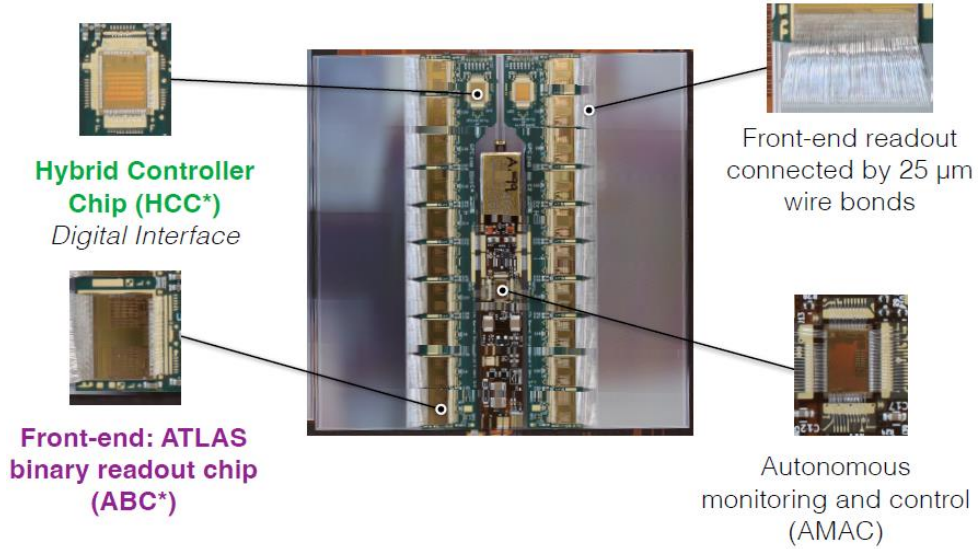
Silicon strip detector modules

- 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 depending on location in the detector
  - Modules are directly glued on **local support structures**



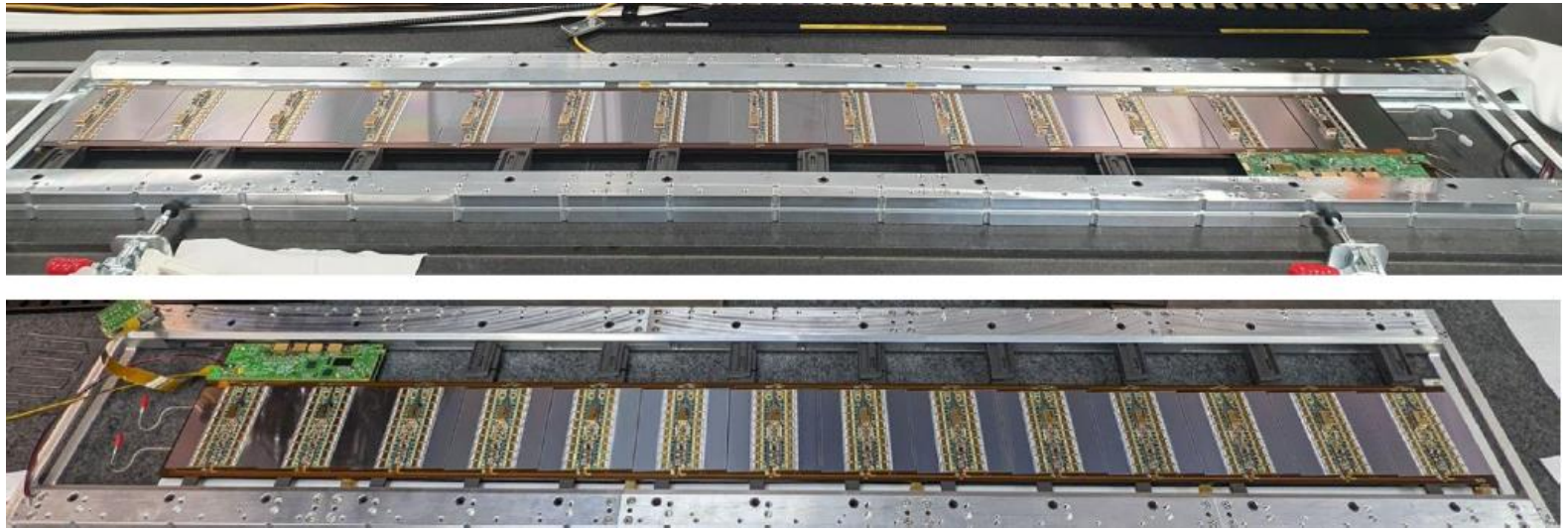


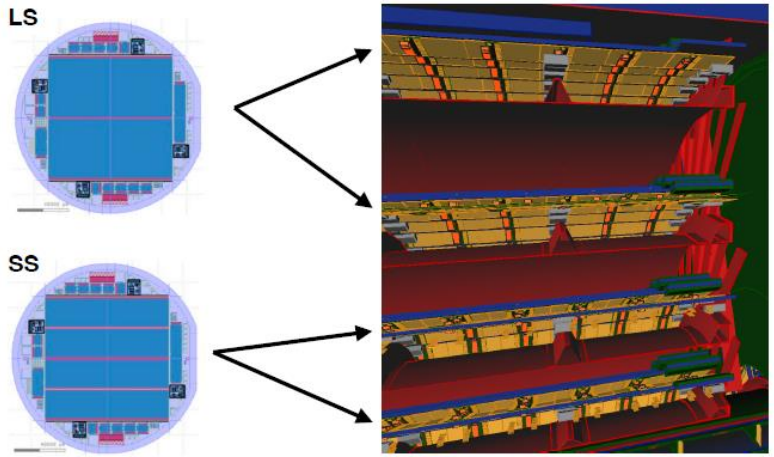




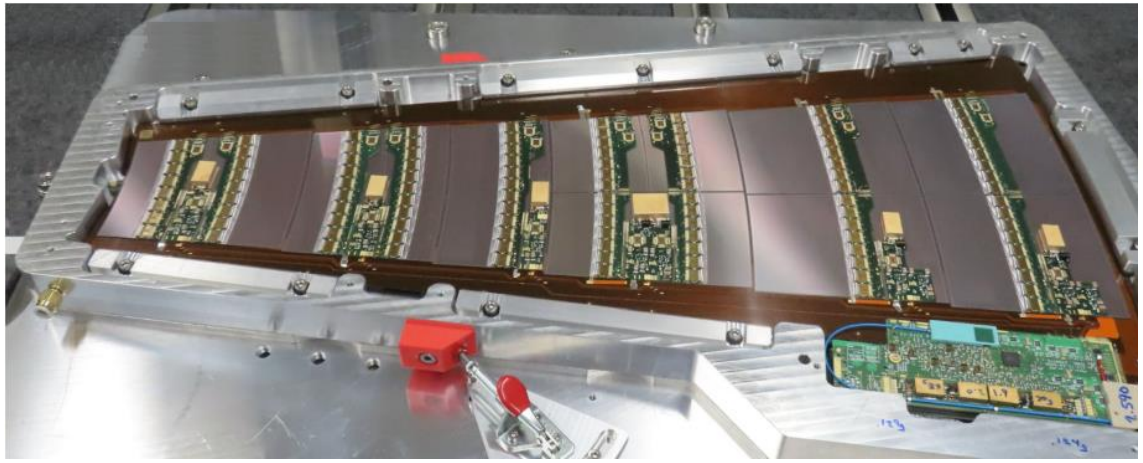
Overview of the detector concept

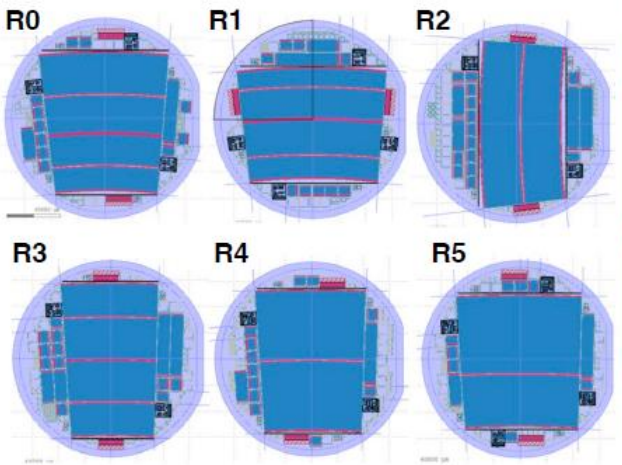
Staves for the barrel

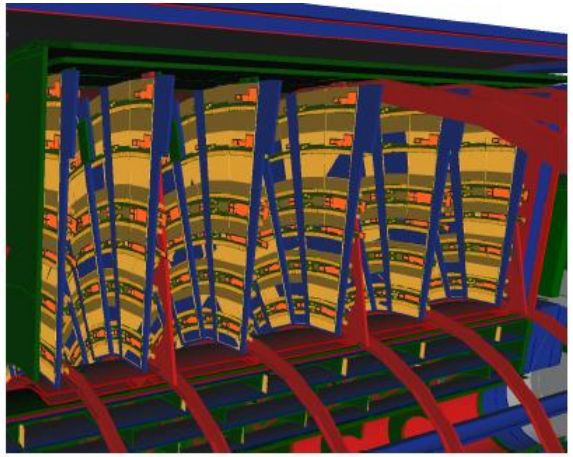




Petals for the endcap



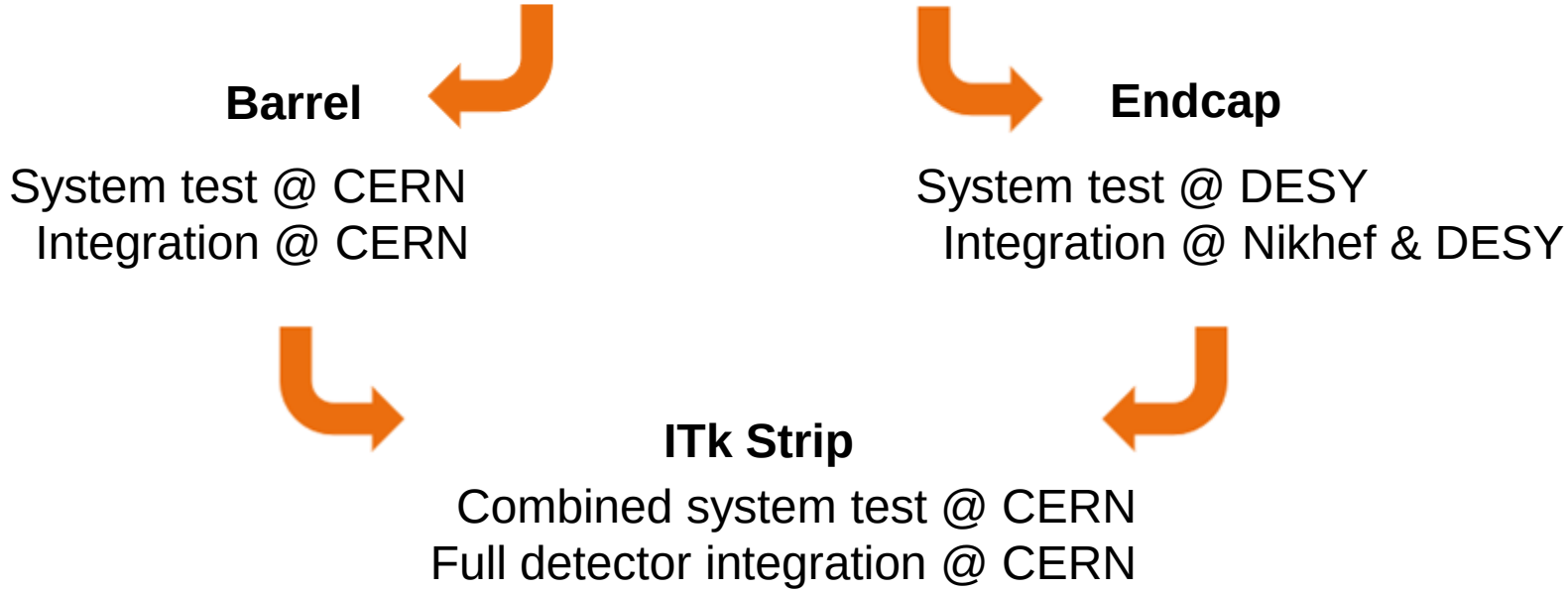




System Tests for the ITk Strip Detector

Motivation

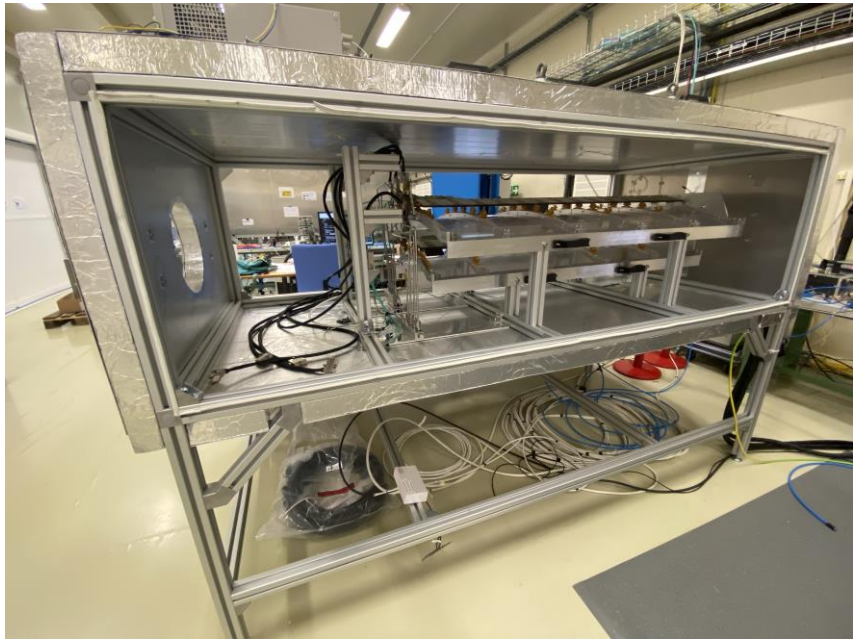
- Goals of system tests
  - Demonstrate full ITk Strip detector system concerning powering, cooling, readout etc.
  - Test and train tools (e.g. insertion tooling) and procedures (e.g. welding) for final detector integration
  - Develop and test DAQ (e.g. high frequency readout) and DCS (e.g. interlock)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

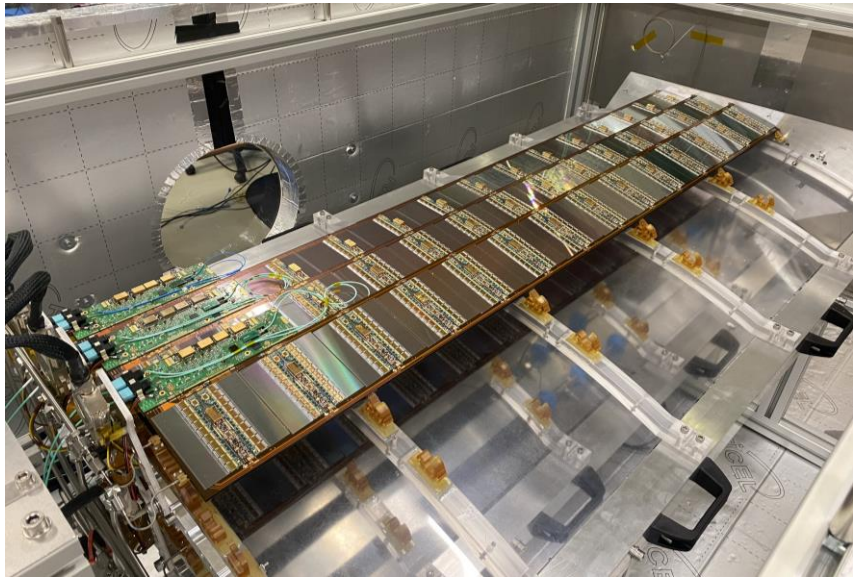


The Barrel System Test @ CERN

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

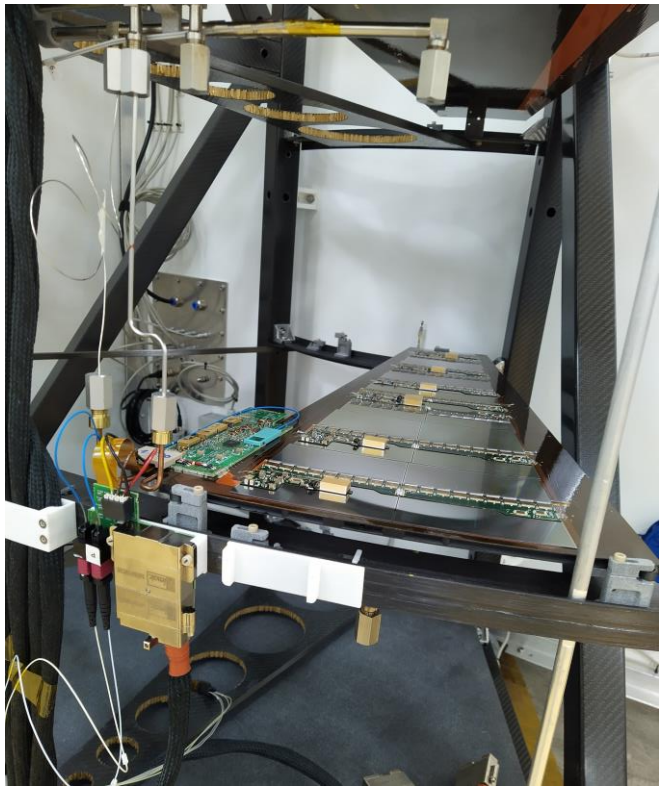




The Endcap System Test @ DESY

A short intro

- Realistic endcap structure (51deg of full EC) as global support
  - Carbon-fiber structure made out of production parts
  - Offering locking points at 16 positions for up to 12 petals
  - Custom made thermal box and variable (cooling) services

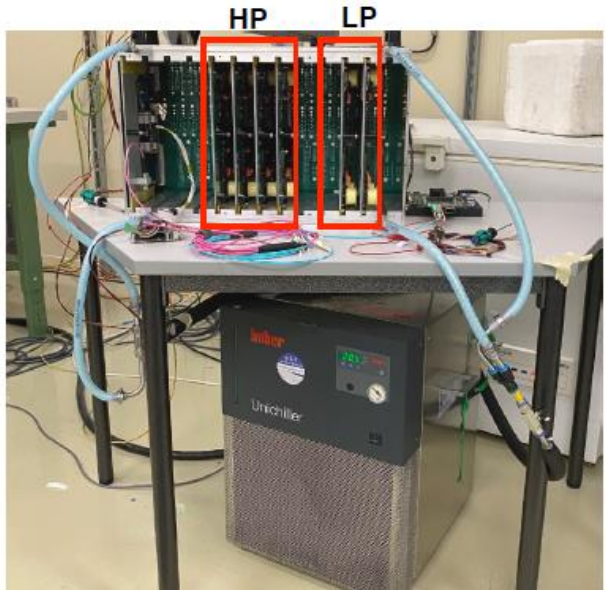


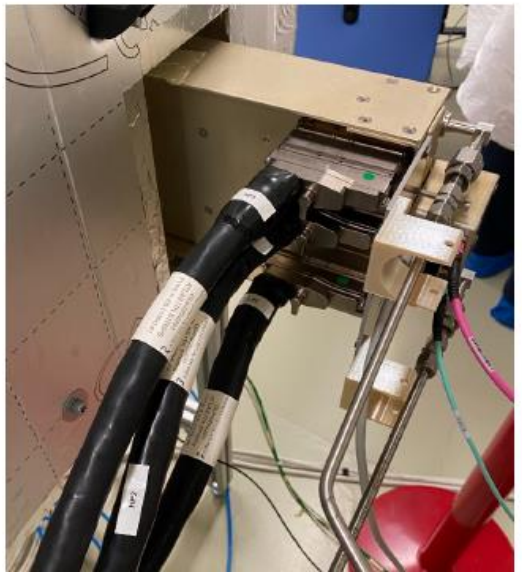
- Currently populated with one fully-loaded PPB petal
  - Petal with pre-production chipsets → more petals in pipeline for system test
- Cooling with CO_2 dual-phase cooling (**warm**: +17°C, **cold**: -35°C)
- Power delivered using full powering chain
- Custom DCS system for coldbox control
- Readout with two DAQ variants available
  - Genesys-II/ITSDAQ and FELIX/YARR

Power chain

Powering of staves and 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*



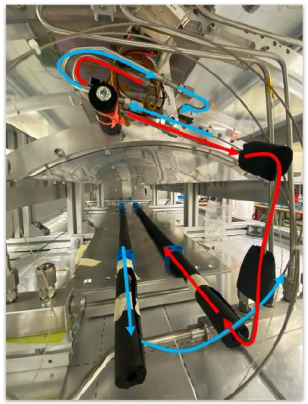


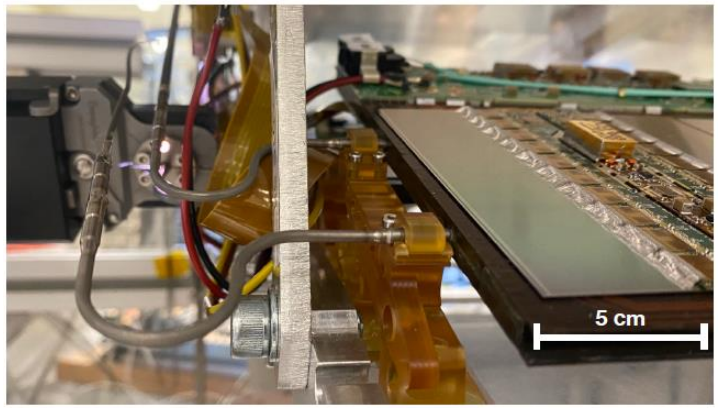
Cooling

Cooling of staves and petals in system test

Staves with C_6F_{14} & CO_2 cooling

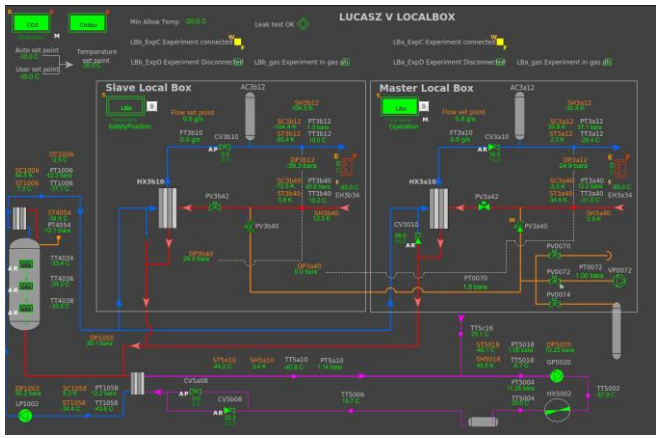
- C_6F_{14} monophase cooling plant
  - Room temperature operation of four staves in parallel with (warm operation at +18°C)
- CO_2 cooling plant in SR1 available
  - Connected temporarily last months to one SS stave
  - Lowest achievable set point: -25°C
- Nov'23: all four staves welded to cooling manifold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

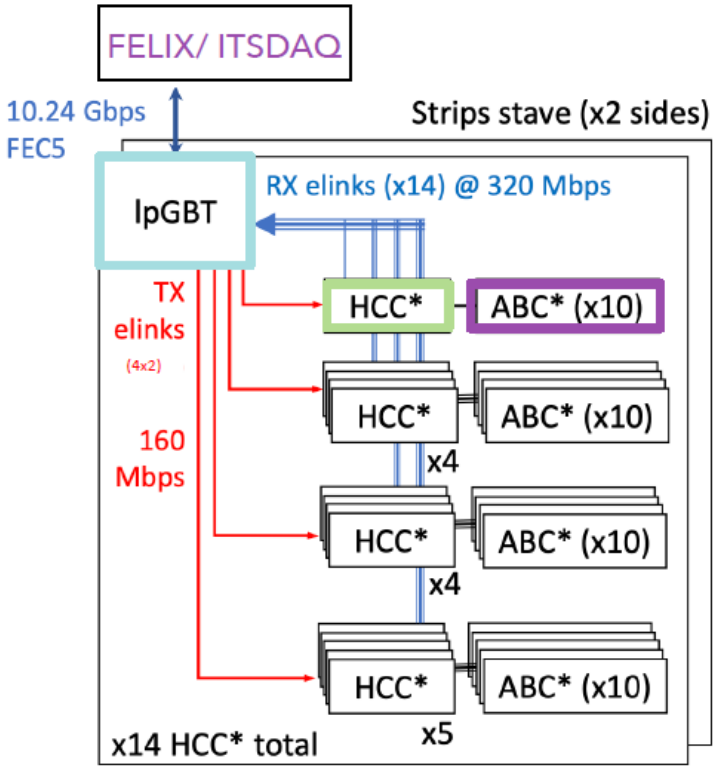


Readout

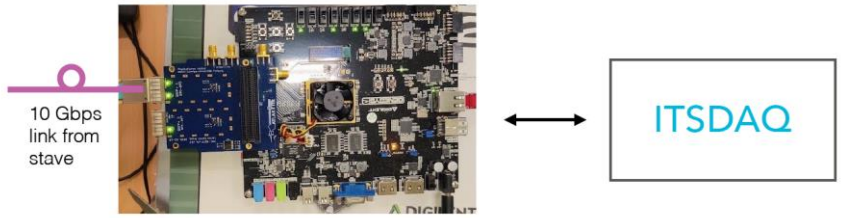
DAQ of staves and petals in system test

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



hardware
(Genesys2)

software

FELIX setup

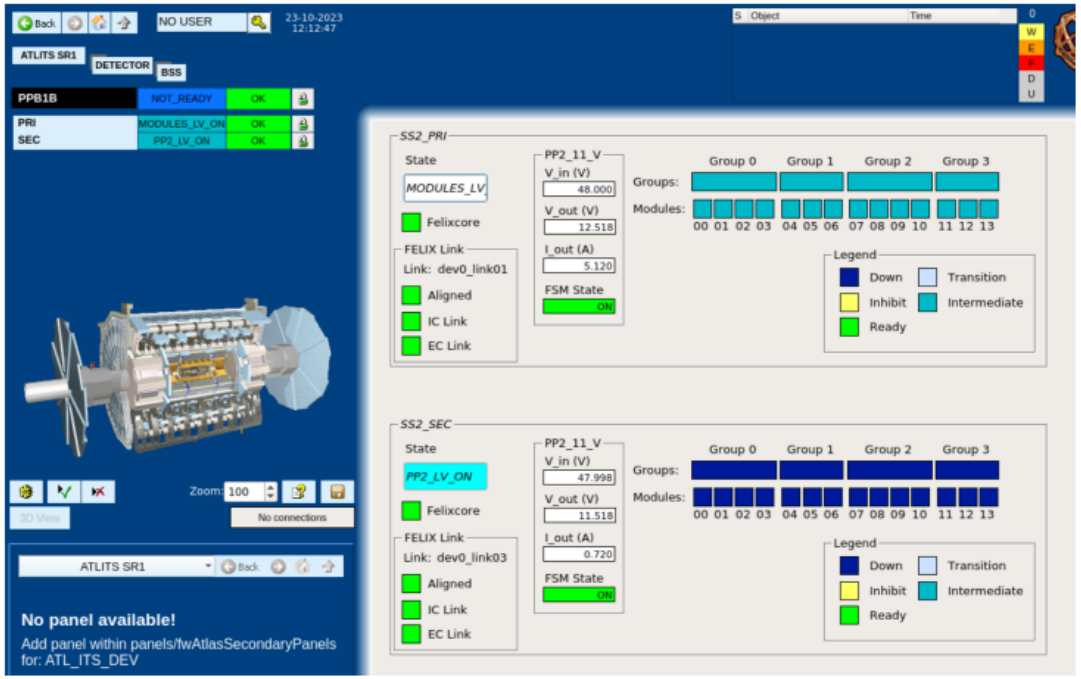
hardware
(FLX 712 - phase-I card)

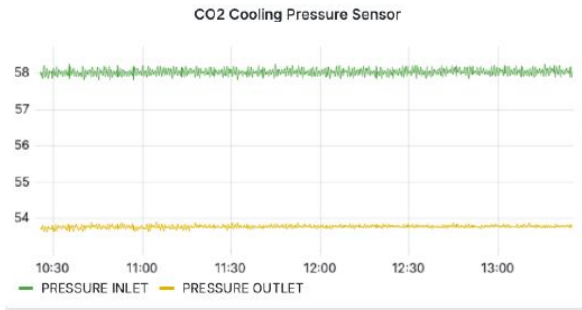
software

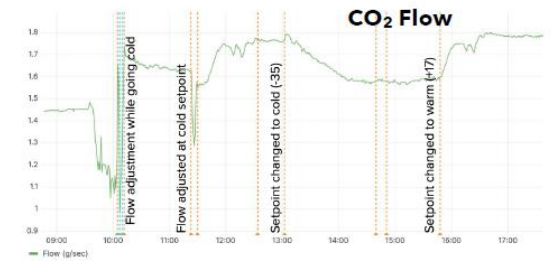
Monitoring & Interlock

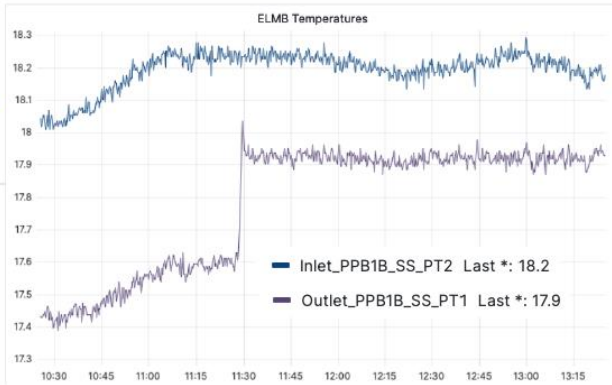
DCS for staves and petals in system test

- various tools and systems developed and tested for monitoring, control and interlock of the system tests
  - LISSY interlock system for PSU interlock depending on stave/petal NTC
  - Coldbox monitoring (T, RH) including box interlock and programmed alarms via Grafana
  - **Final state machine** for interaction of the different subcontrols → interfaced via WinCC panel





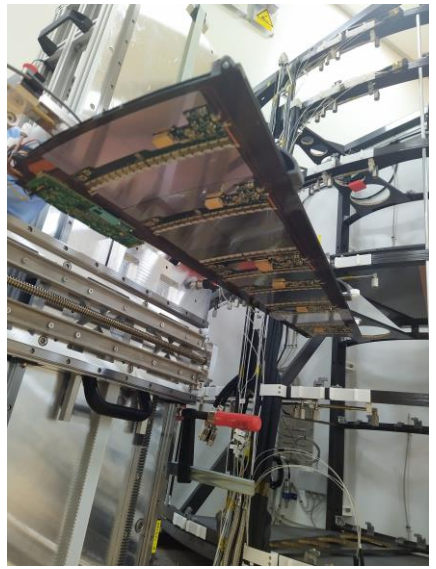
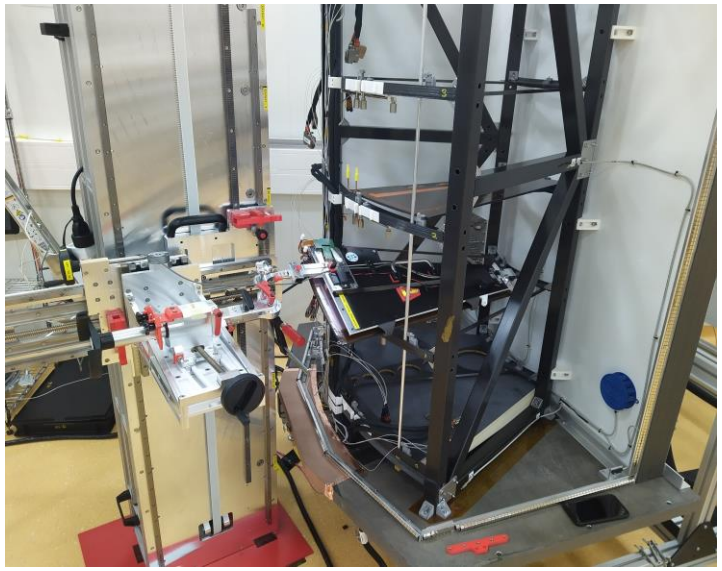
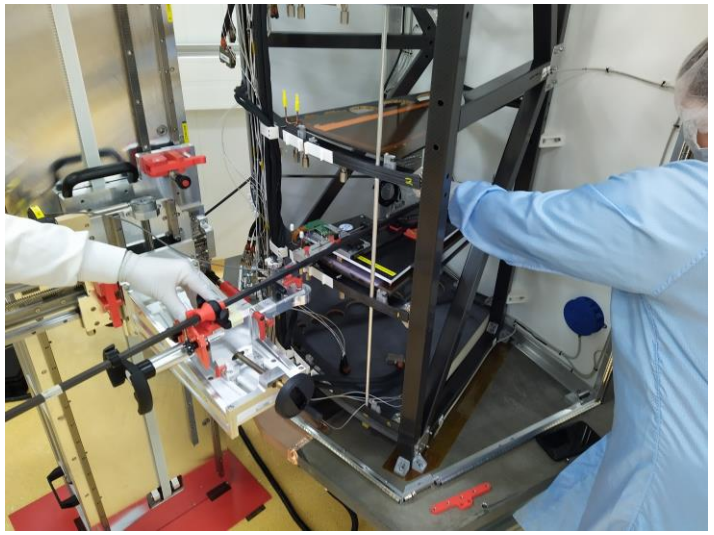
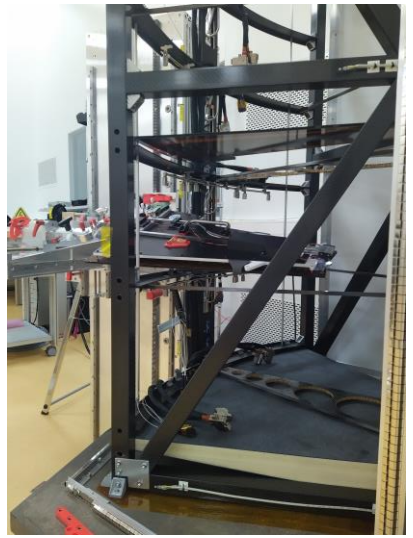




Results: Petal insertion procedure

First petal inserted in system test

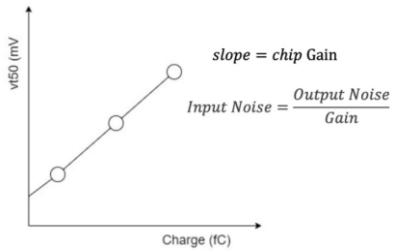
- Mechanical tool for petal insertion during integration
  - *insertion tower* with attached *insertion hands*
- Test and train developed tool with fully loaded petal and realistic EC structure at the system test
- Sequence of insertion process:
  (1) Attaching petal to insertion hand
  (2) Attaching tool to insertion tower
  (3) Step-by-step insertion process (including rotation into limited insertion window)
  (4) Fixation of locking point screws
  (5) Connection of services

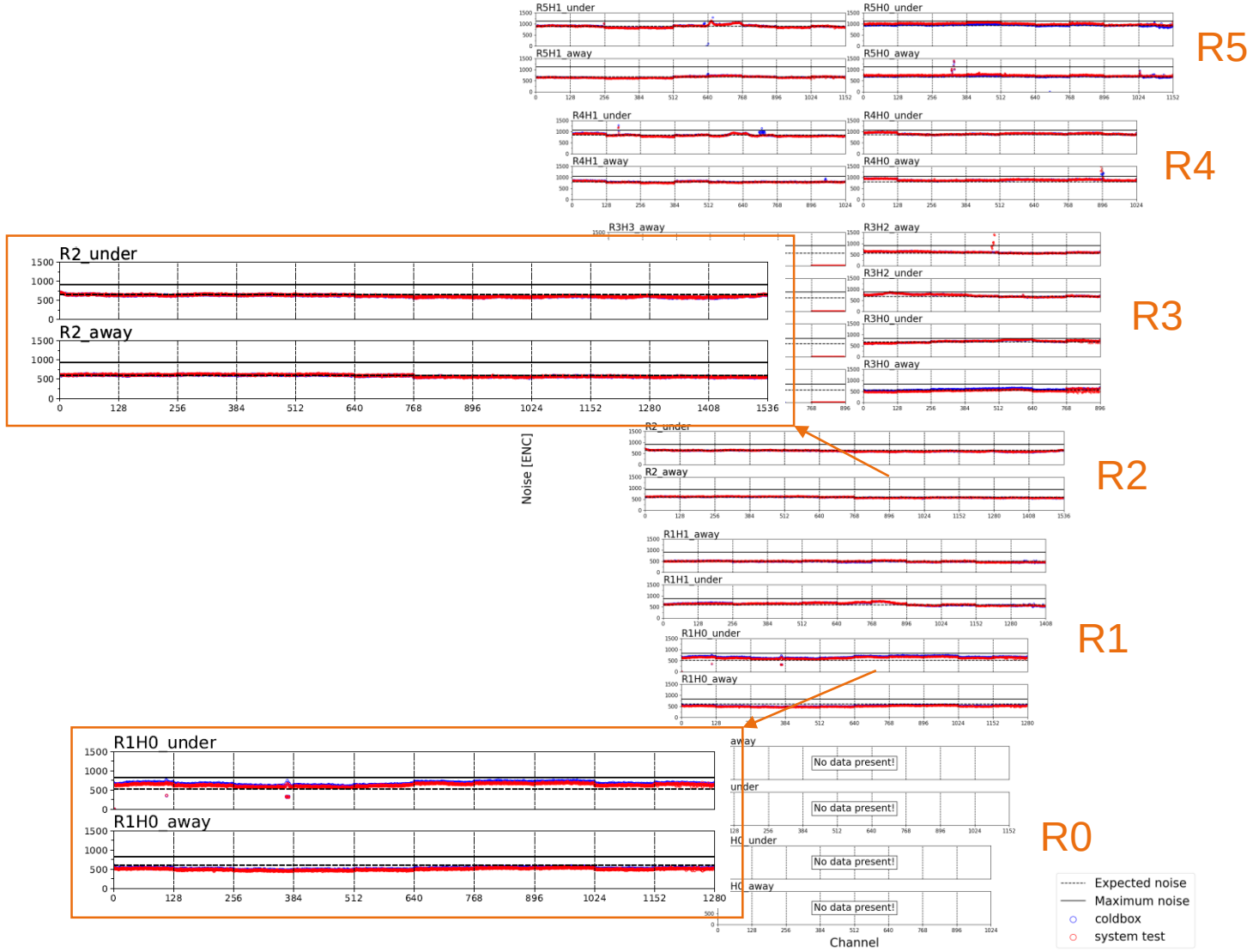

Results: Comparison of petal noise performance

First petal inserted in system test

- Comparison of ITSDAQ 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)

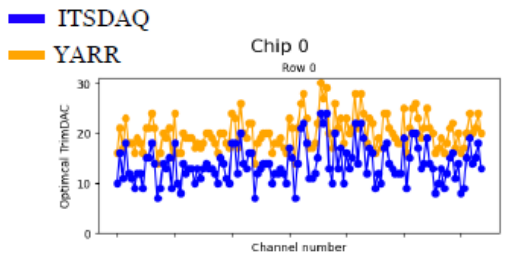


Results: YARR/ITSDAQ validation for staves

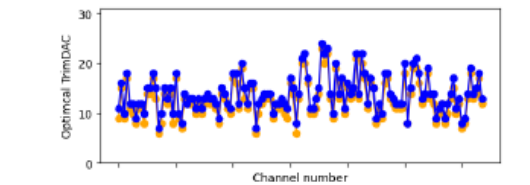
Comparison of DAQ variants

- Development of YARR software to read out stave and petal objects via FELIX
- Validation done by comparing results with the benchmark ITSDAQ software
  - Comparison results shown for trimming, strobe delay and gain
  - Small differences can be observed due to different fit strategy choices (optimization of trim target versus fixed target)

Trim

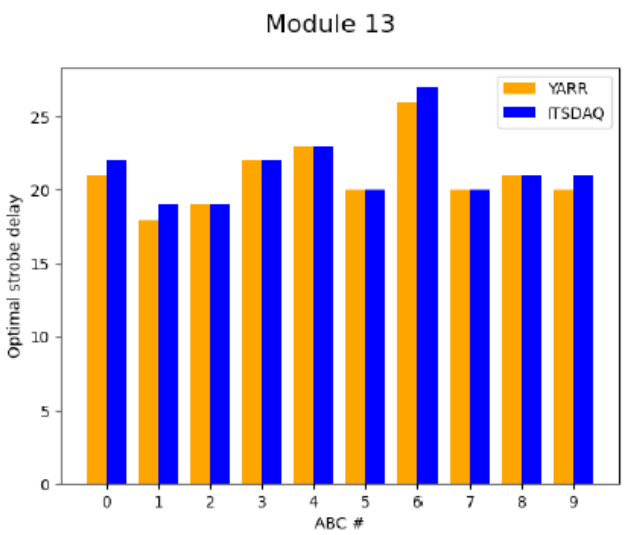


YARR with optimized trim target



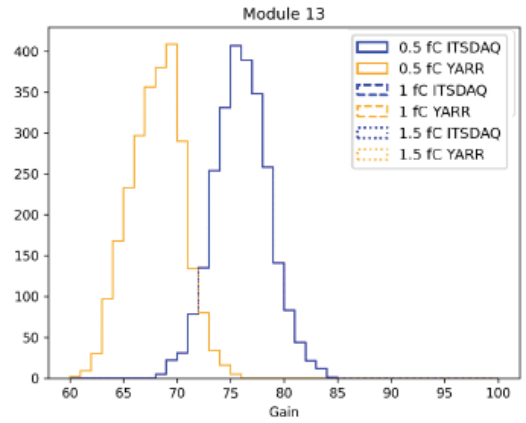
YARR with trim target as close as possible to ITSDAQ

Strobe Delay

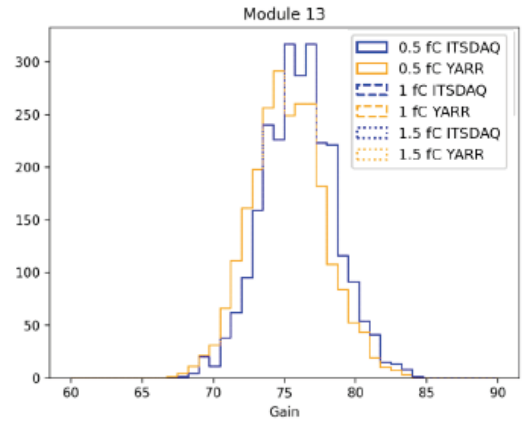


Strobe delays distributions with YARR using trim target as close as possible to ITSDAQ

Gain



Gain distribution with YARR using optimized trim target

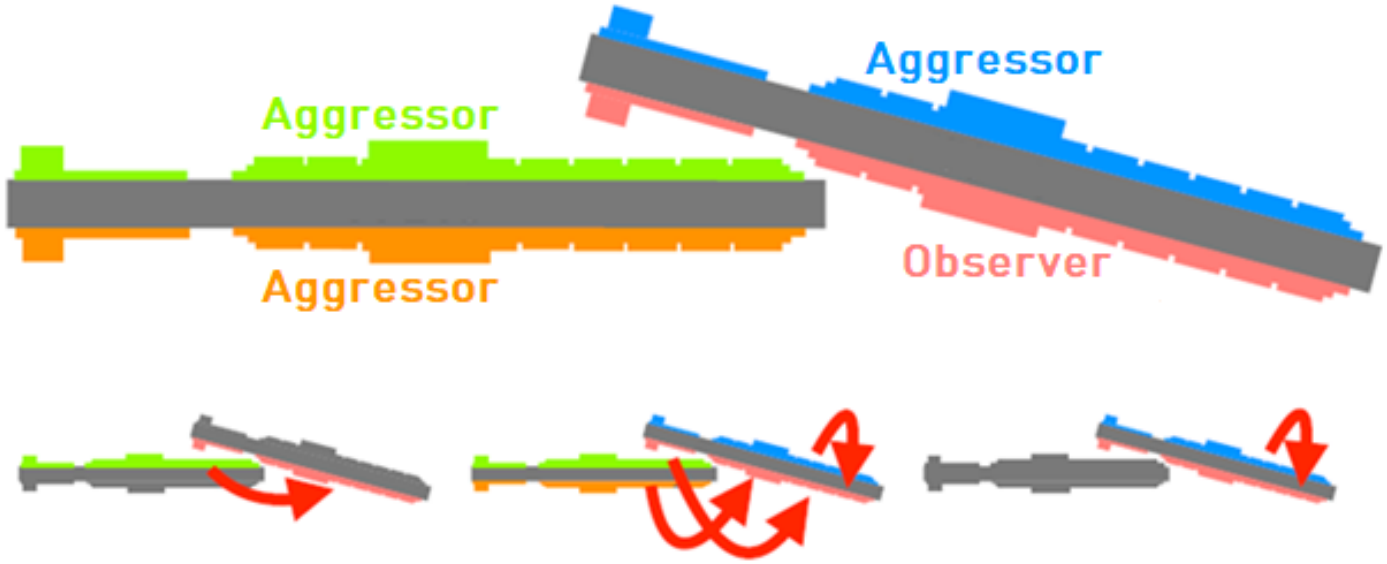


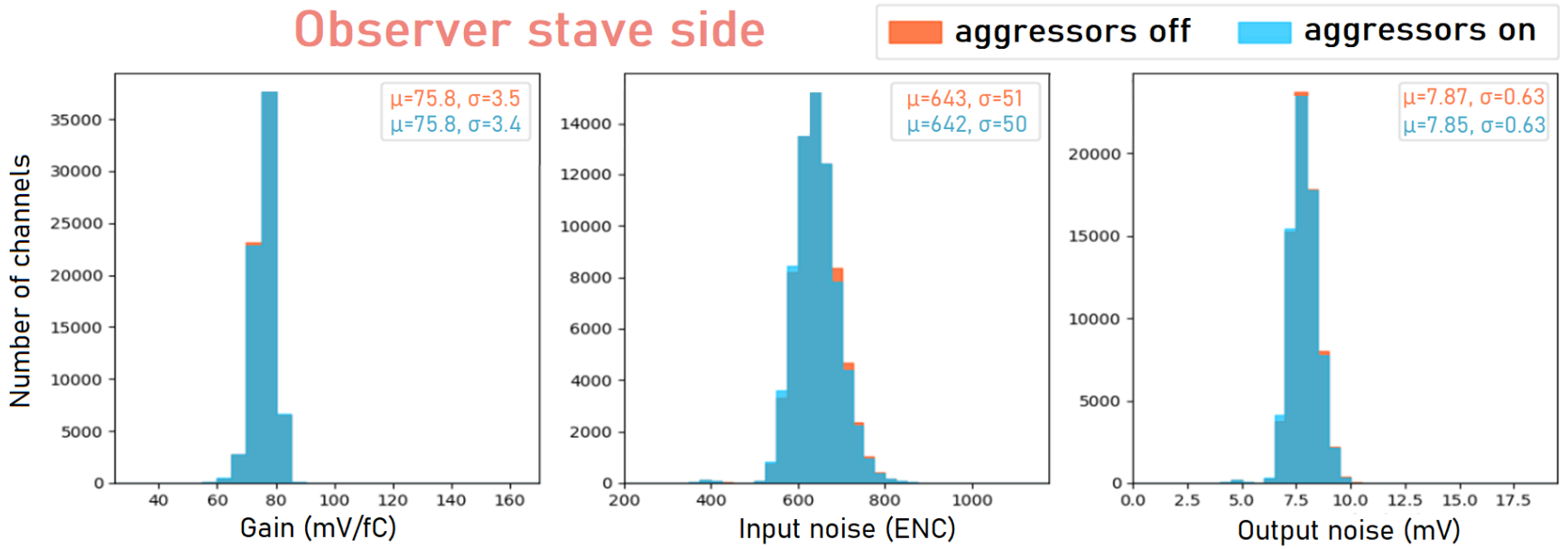
Gain distribution with YARR using trim target as close as possible to ITSDAQ

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)





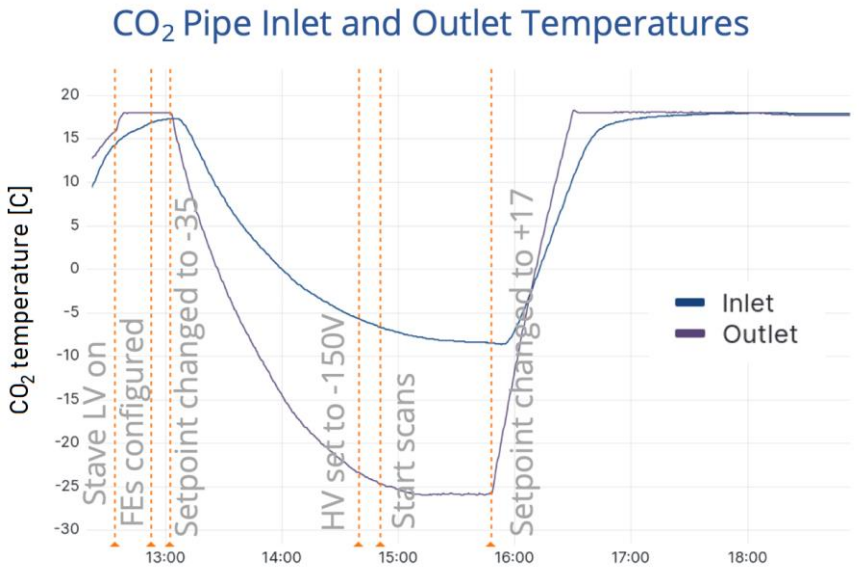
- **Result:** no change in distributions of gain, input and output noise observed

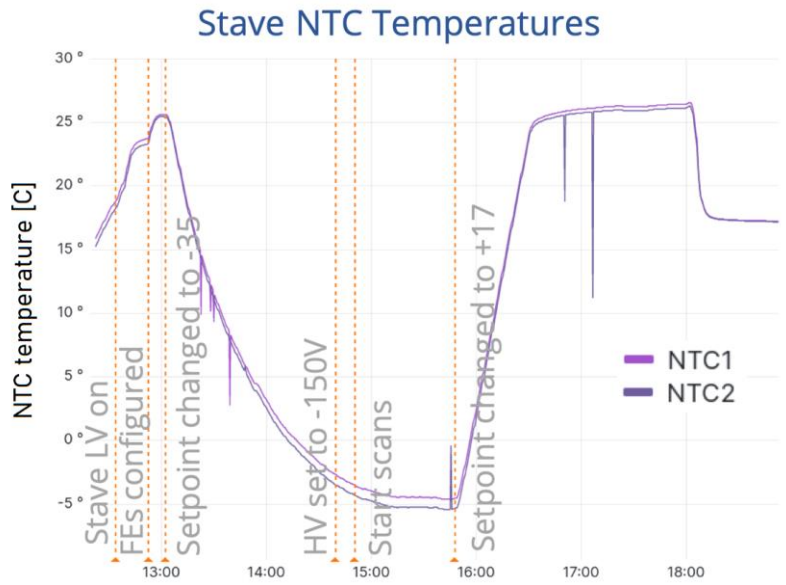
→ no indication for cross talk

Results: Stave cooling performance

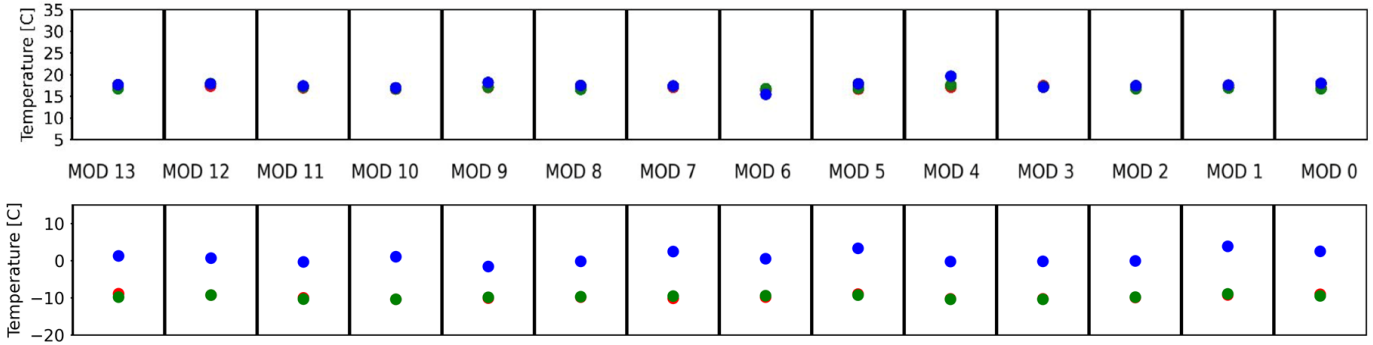
Temperatures measured along stave at warm/cold set point

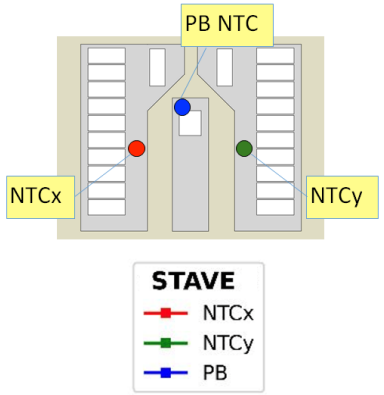
- Cooling of one stave with CO_2
  - Study at two different temperature set points:
    warm = +17°C
    cold = -25°C
  - Study different power settings (DCDC on, FEs configured, HV biased, running scans)
- Corresponding temperatures measured on/at
  - CO_2 pipe inlet and outlet temperature
  - NTC sitting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





Warm (17 °C) + **DCDC off**:





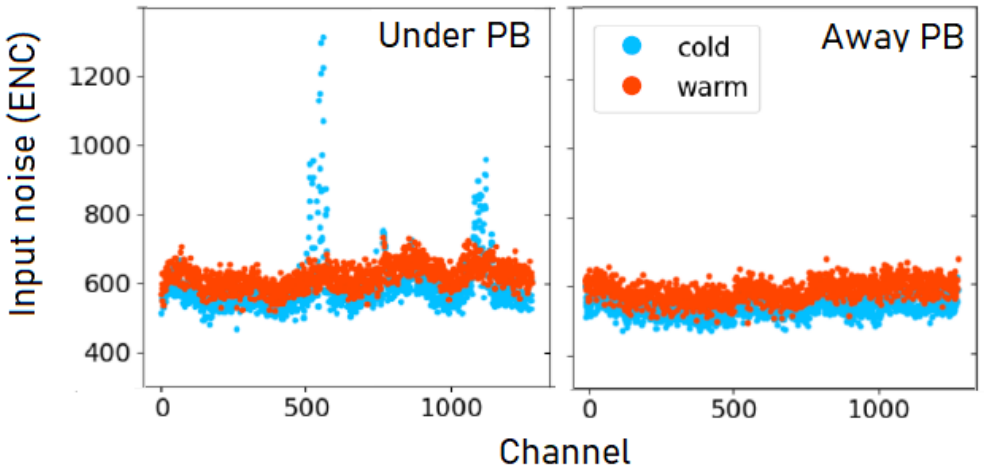
Cold (-25 °C) + **DCDC on**, front-ends configured:

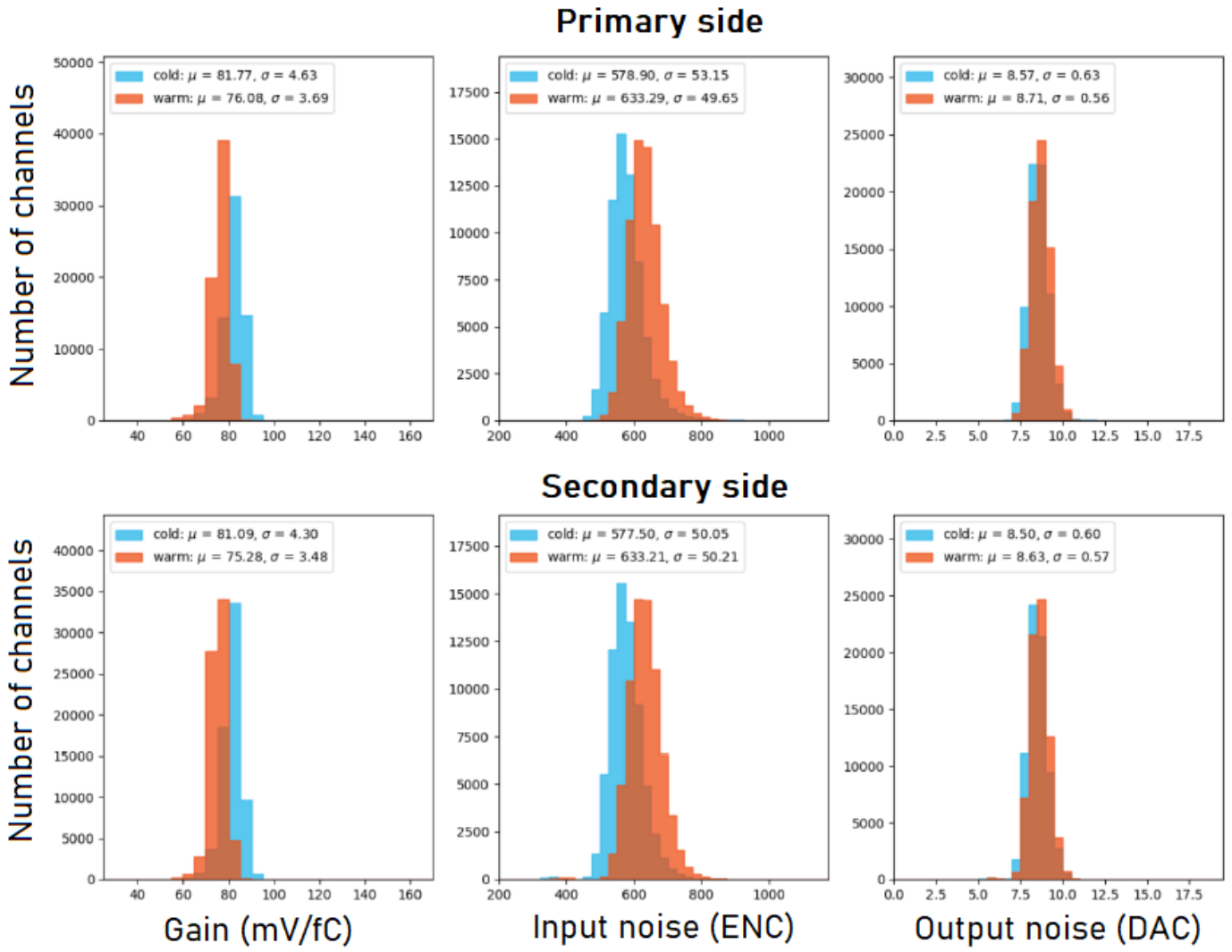
Results: Noise comparison warm/cold for staves

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





Summary

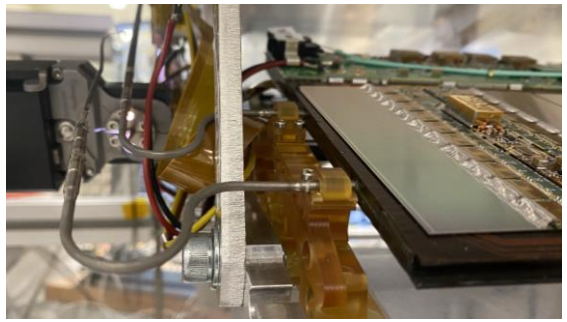
Status of ITk strips system tests

- Both system tests for the ITk Strips detector are fully operational
  - Needed **infrastructure** (services, cooling, DAQ) is available and set up
  - Motivated **teams** at both sites are 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 tests
  - System test is an important input for ATLAS internal **reviews** of the production readiness

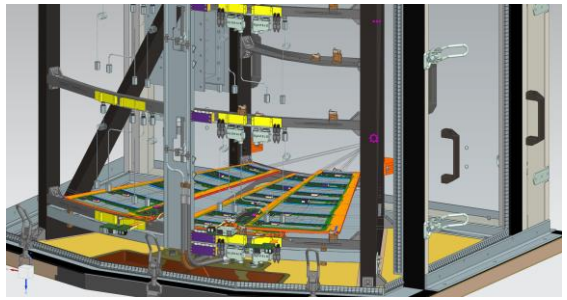
- Summary of system test results
  - **Noise performance** of four staves, read out in parallel at warm set point
  - Running of a single stave and a single petal with **CO_2 at cold set point**
  - Validation of **FELIX-based DAQ** systems against ITSDAQ benchmark readout
  - Operation of services: complete **power chain** and optical fibers for data transfer
  - First hand testing and training with petal **insertion tooling**

Outlook

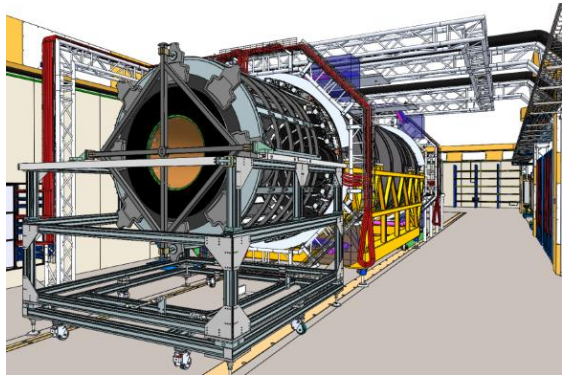
What comes next?



- **Barrel system test** @ SR1
  - Run all four staves with CO_2 cooling at cold set point
  - Repeat the noise characterization of staves (e.g. cross talk)
  - Validate further pre-production objects of (electrical) services
  - Develop DAQ & DCS for detector readiness

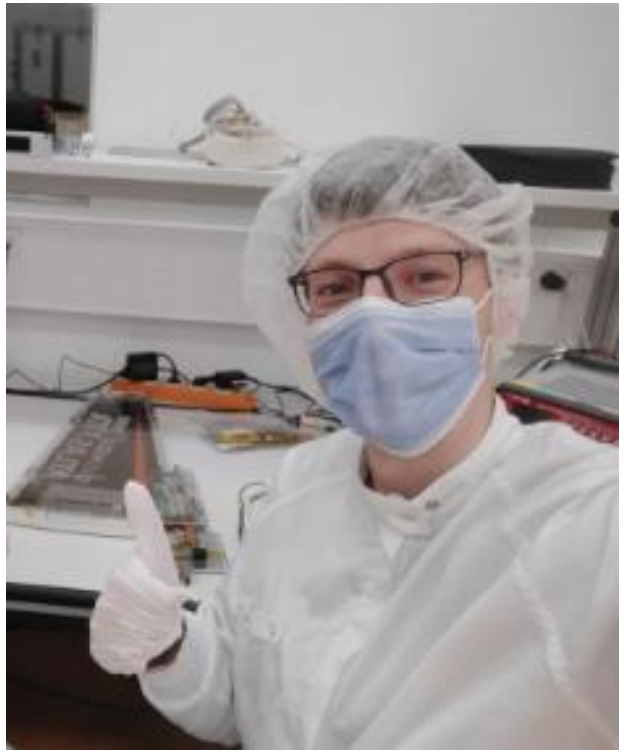


- **Endcap system test** @ DESY
  - Populate system test with more petals
  - Run the noise characterization of petals (esp. cross talk)
  - Special topic: external trigger by cosmics, perform tracking studies with ST



- **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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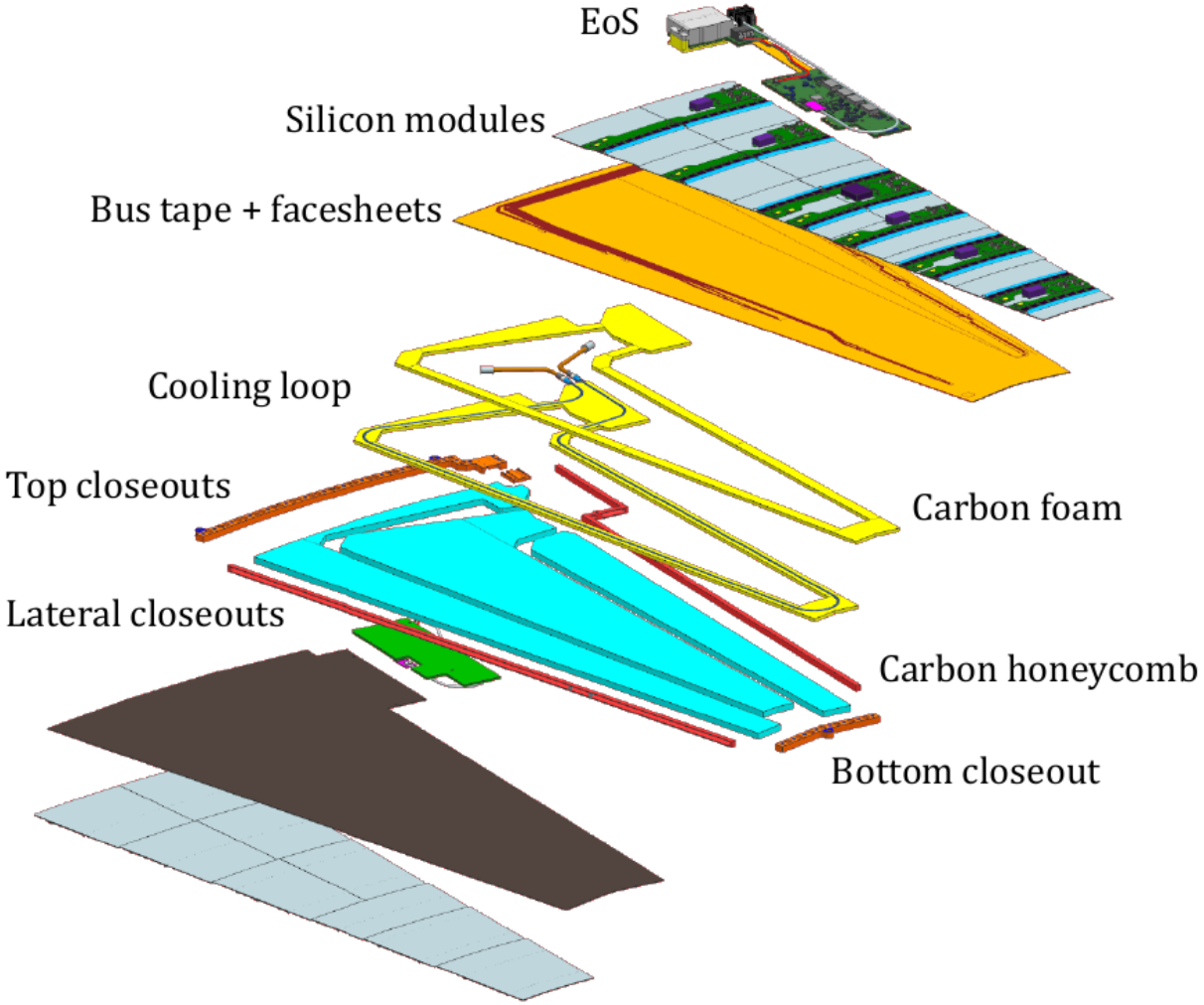
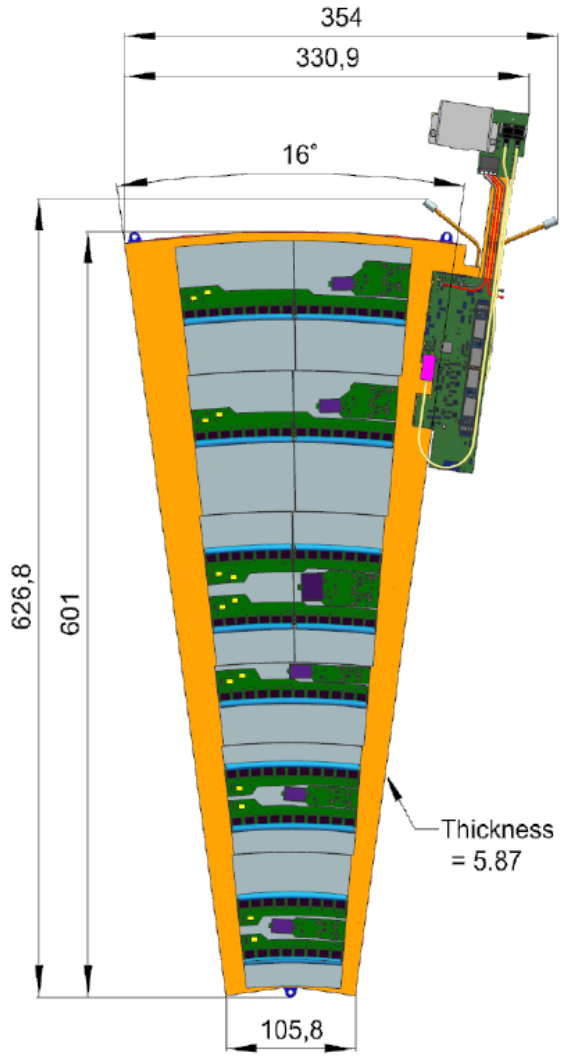
Local support structures

Exploded view of a petal

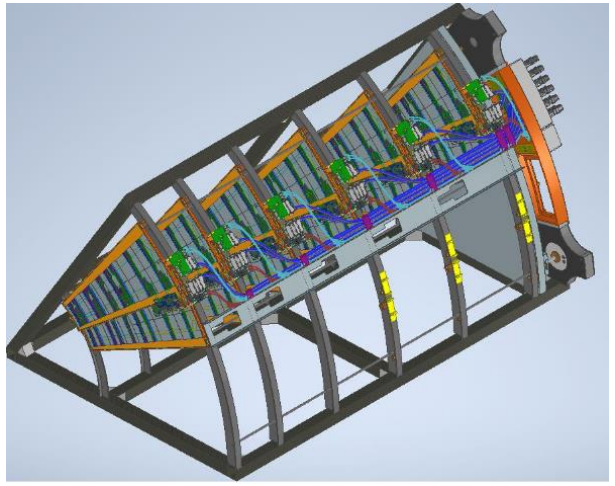




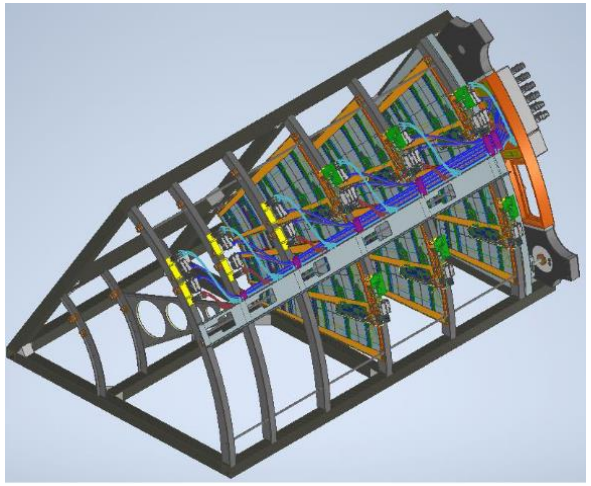
Endcap System Test configurations

Planned test configurations

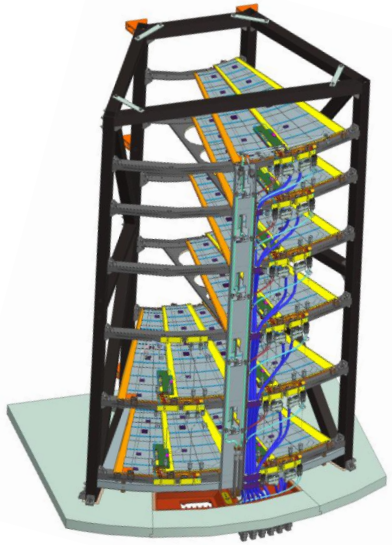
- 2-petal configuration
  - two petals per disk on one side of the service tray
  - normal configuration for the half service module installed
  - final configuration of the system test (“welded”)



- 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

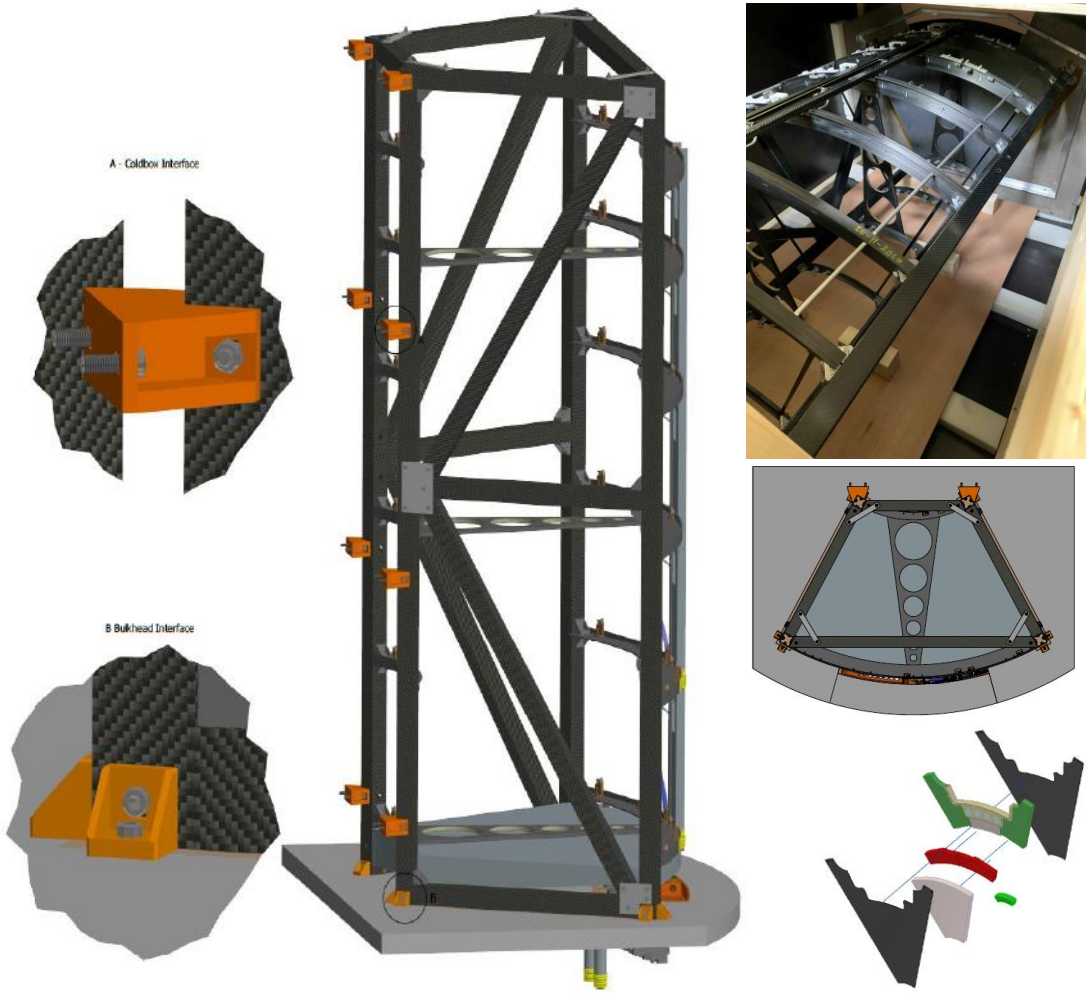


- horizontal/vertical orientation
  - allowing to test in horizontal and vertical orientation
  - horizontal orientation as standard configuration
  - vertical orientation interesting to perform cosmics runs



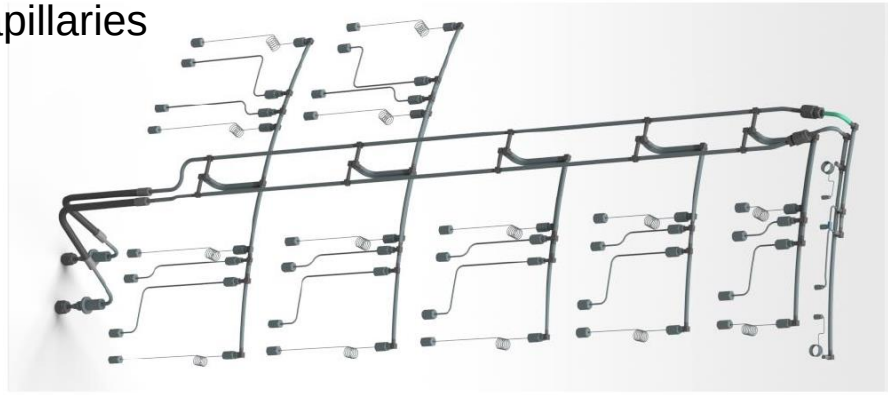
Preparations for system test

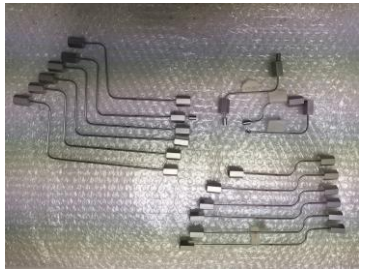
System test structure, services and cold box

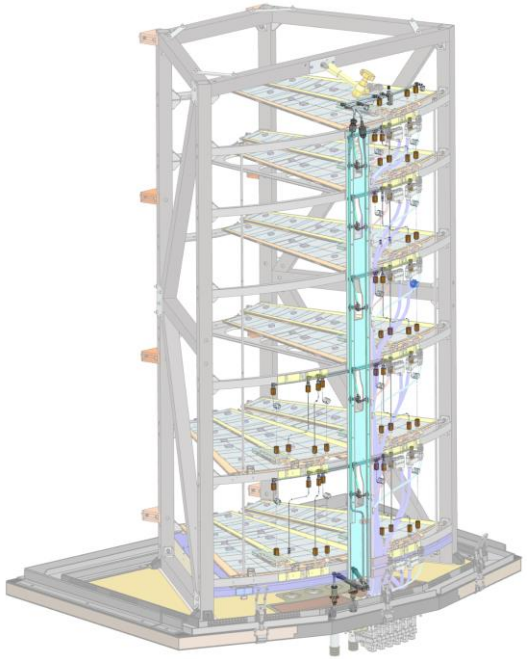


- ST structure design follows closely the real EC structure (e.g. production parts, material choice, grounding & shielding concept)

- special cooling services for ST to allow flexible design (e.g. temporary connectors for no need of welding in first place), but realistic CO2 capillaries

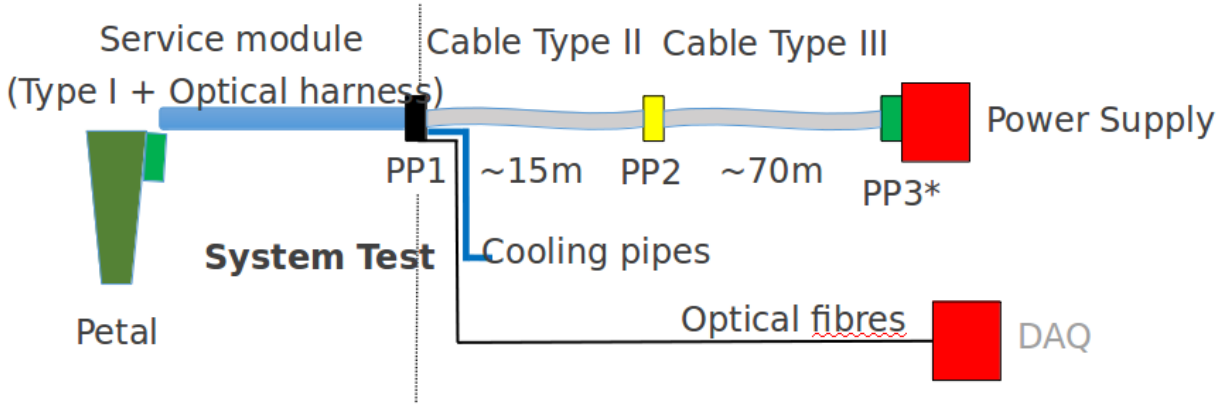


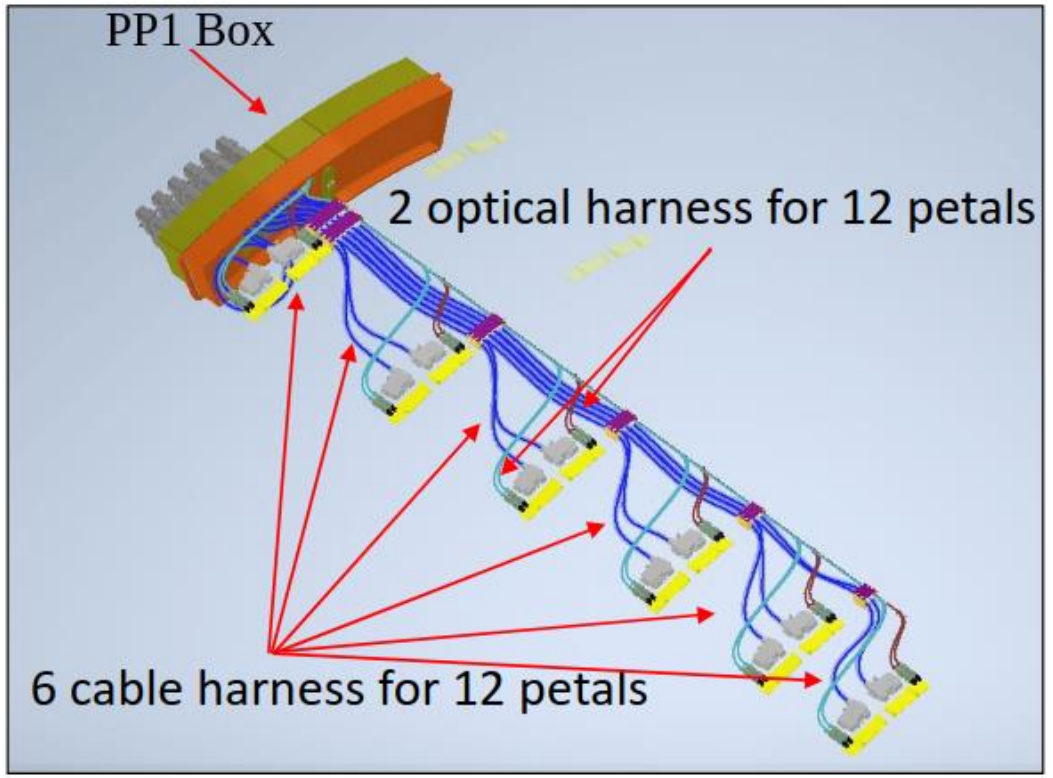


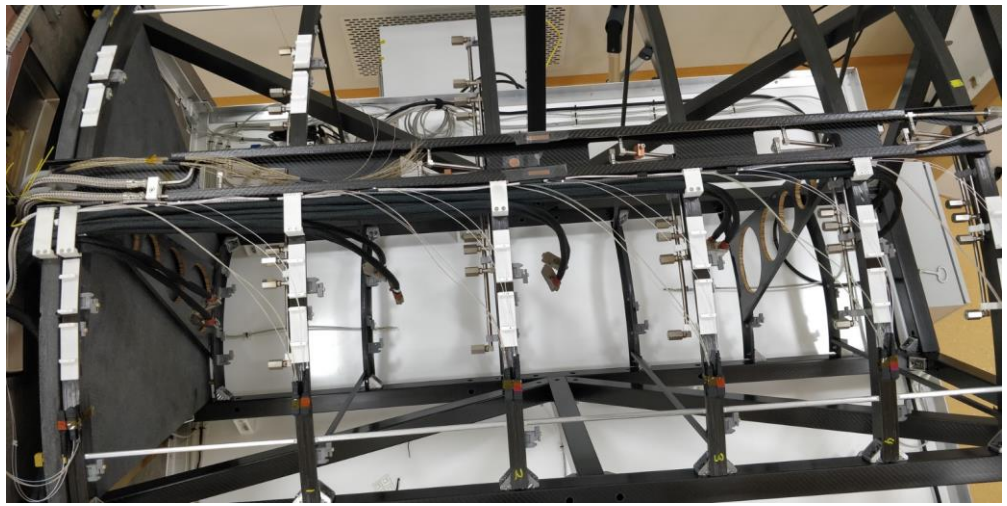


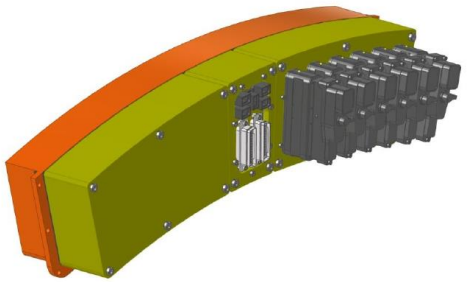
Preparations for system test

System test structure, services and cold box





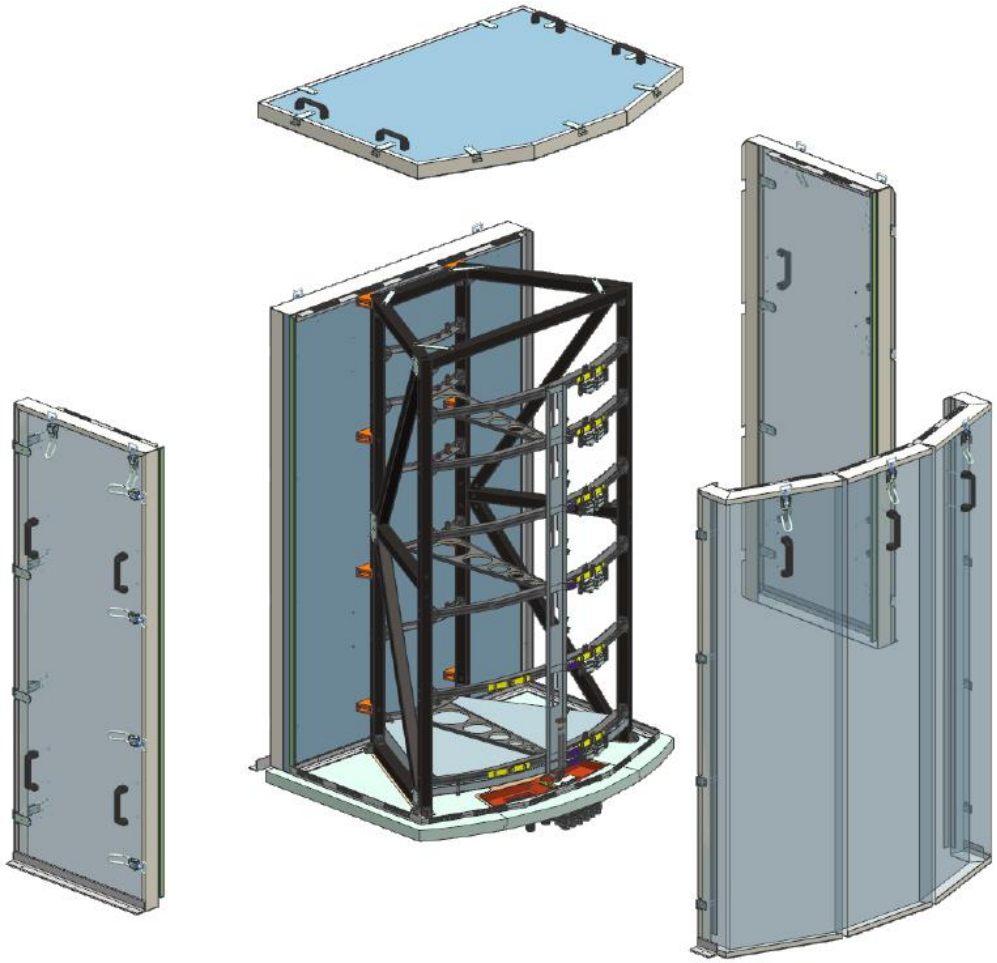




- electrical and optical services following EC design
- testing the (almost complete) powering chain

Preparations for system test

System test structure, services and cold box



- custom-made coldbox made out of individual panels
- serves as thermal enclosure and Faraday cage