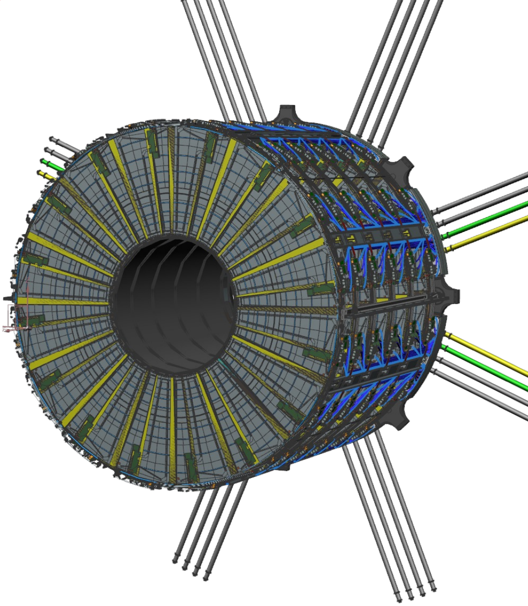


The ATLAS ITk Strip Detector for the Phase-II LHC Upgrade

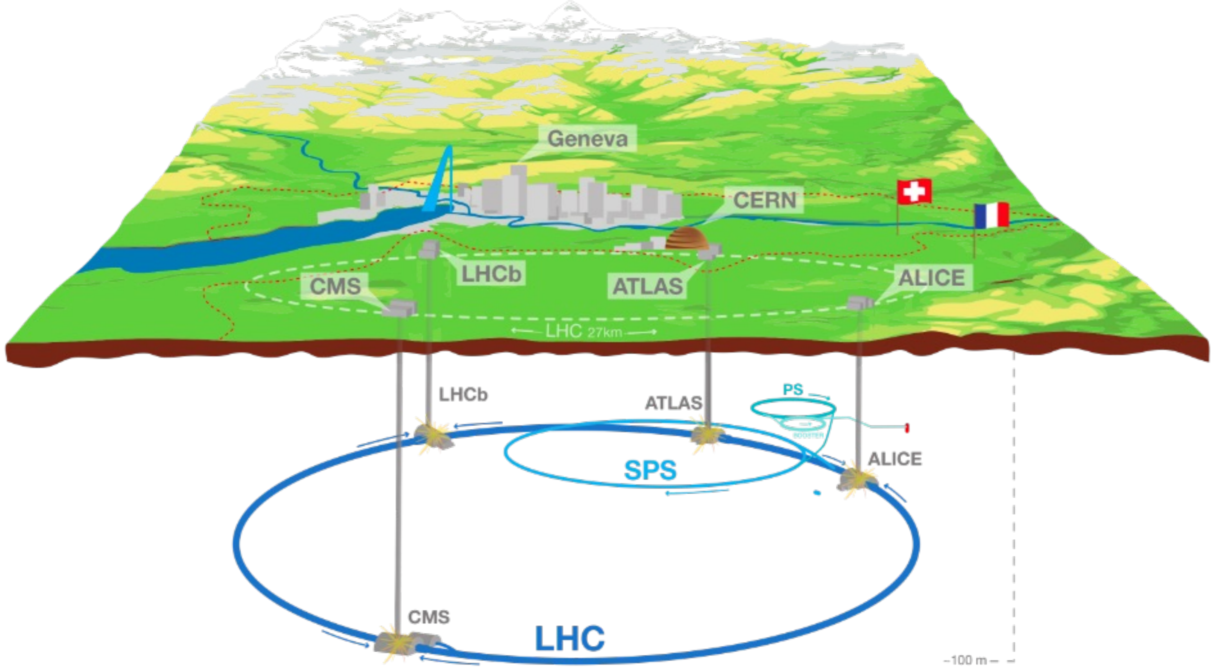
Andrea García Alonso
On behalf of the
ATLAS ITk strip community

Corfu2023 workshop
April 23-29 2023
Corfu, Greece

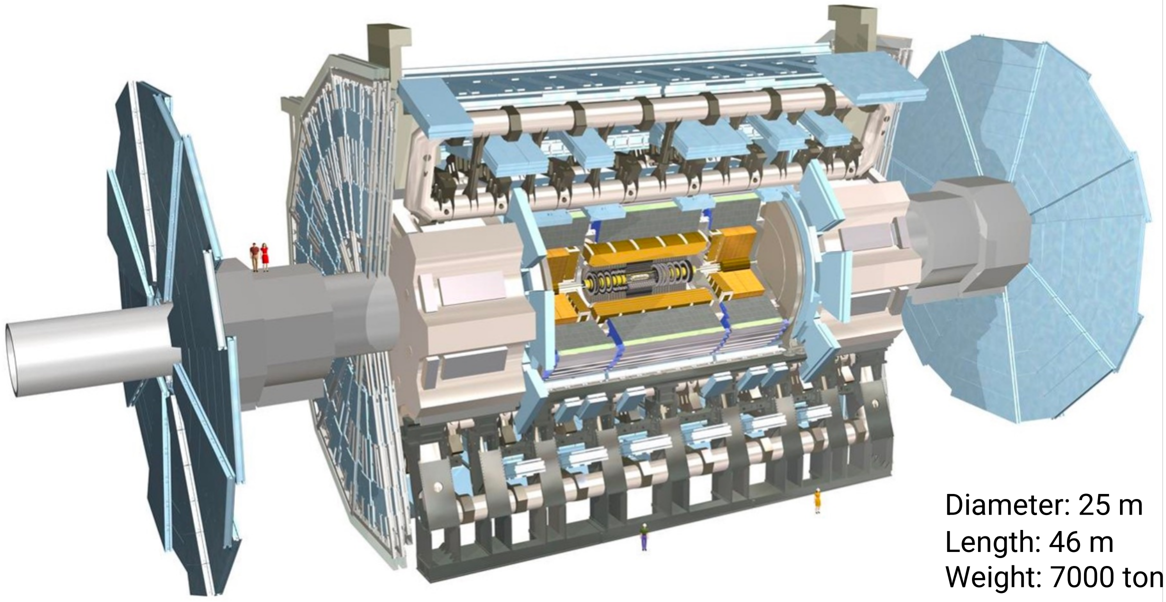
Overview

- LHC and the ATLAS detector
- Tracker, high luminosity upgrade and needs
- The next ATLAS Inner Tracker (ITk)
- The strip detector
- ITk production status and schedule

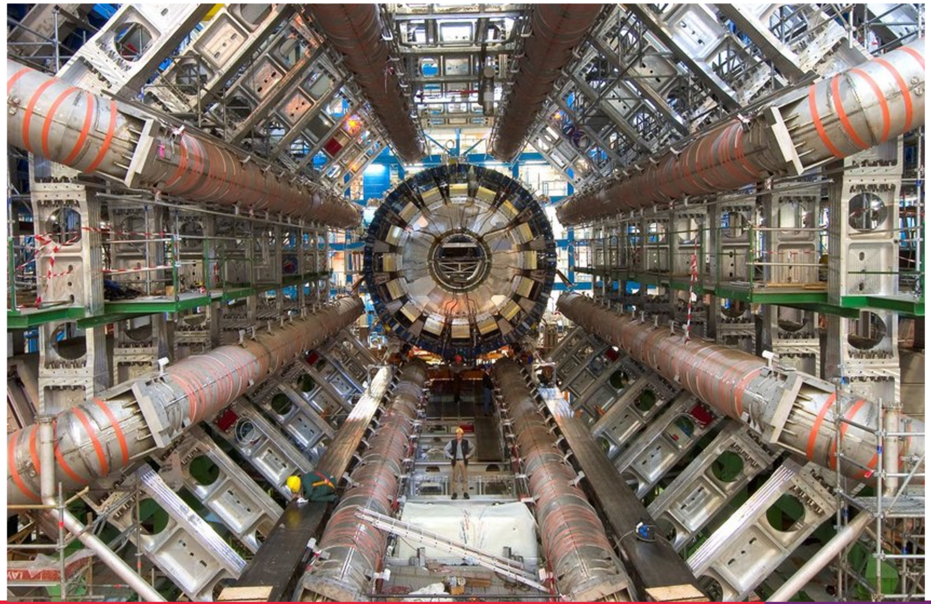
LHC and the ATLAS detector



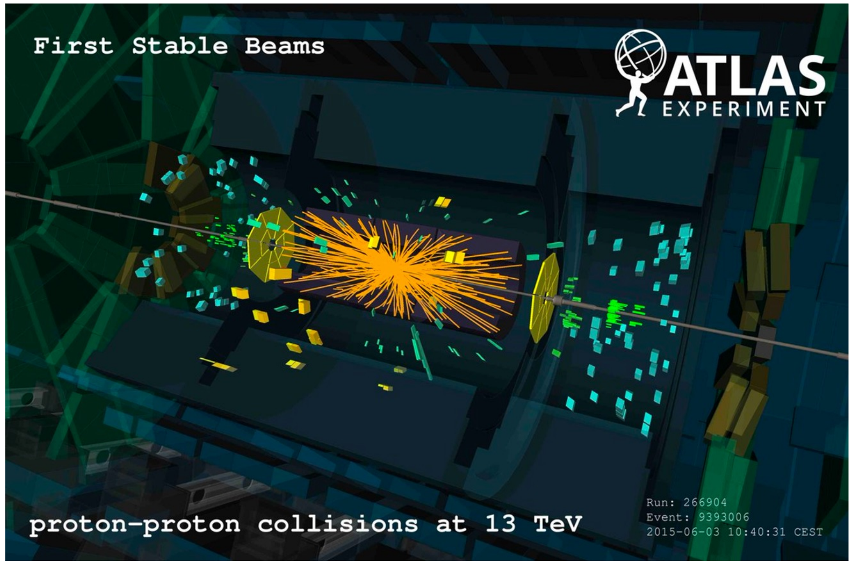
A ToroidaL ApparatuS



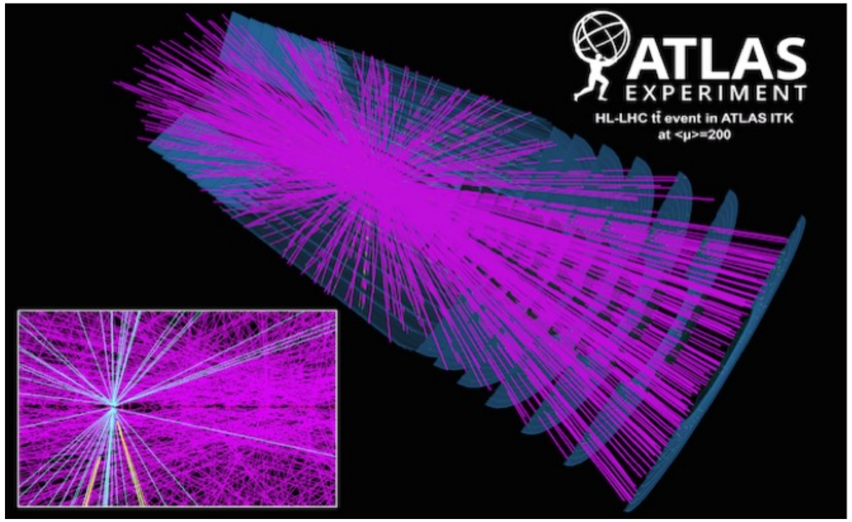
Diameter: 25 m
Length: 46 m
Weight: 7000 tons



Tracker performance



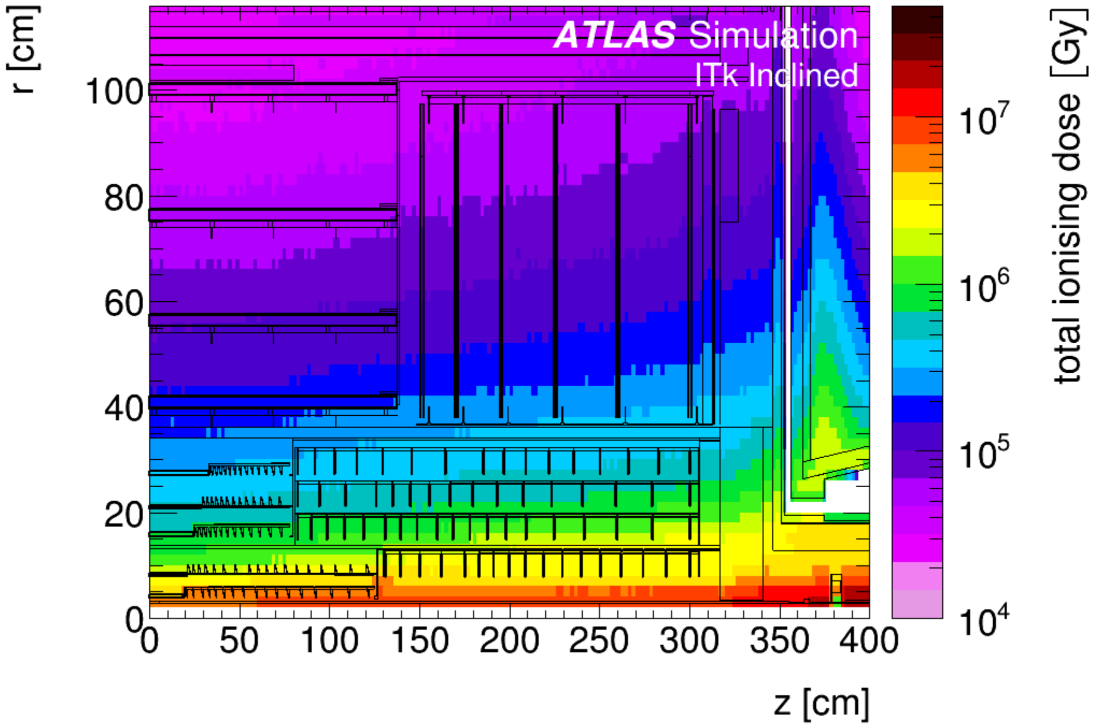
Proton-proton collision
in the current tracker



Proton-proton collision in
the future ATLAS inner
tracker, during HL-LHC

Upgrade to HL-LHC

Plot from:
Technical Design Report for the ATLAS Inner Tracker Strip Detector. ATLAS-TDR-025

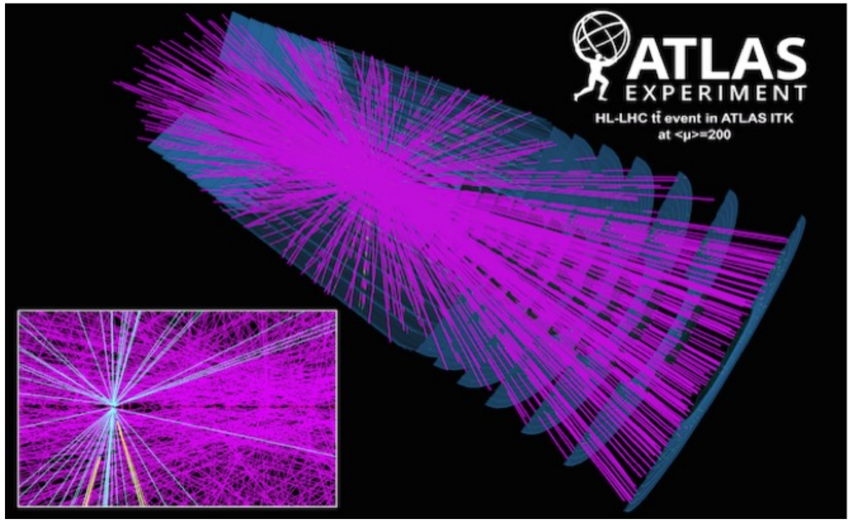


Particle densities and radiation levels will exceed current levels by factor 10

Instantaneous luminosity will reach 7 × 10^{34} s^{-1} cm^{-2}

Up to 200 p-p interactions per bunch crossing

Large particle fluences, unprecedentedly high levels of radiation, pile-up



Proton-proton collision in the future ATLAS inner tracker, during HL-LHC

Upgrade needs for the phase-II upgrade

Higher radiation tolerance → high fluence

Higher granularity → keep low occupancy

Faster response → high track density

Novel powering solutions → power x10 more channels

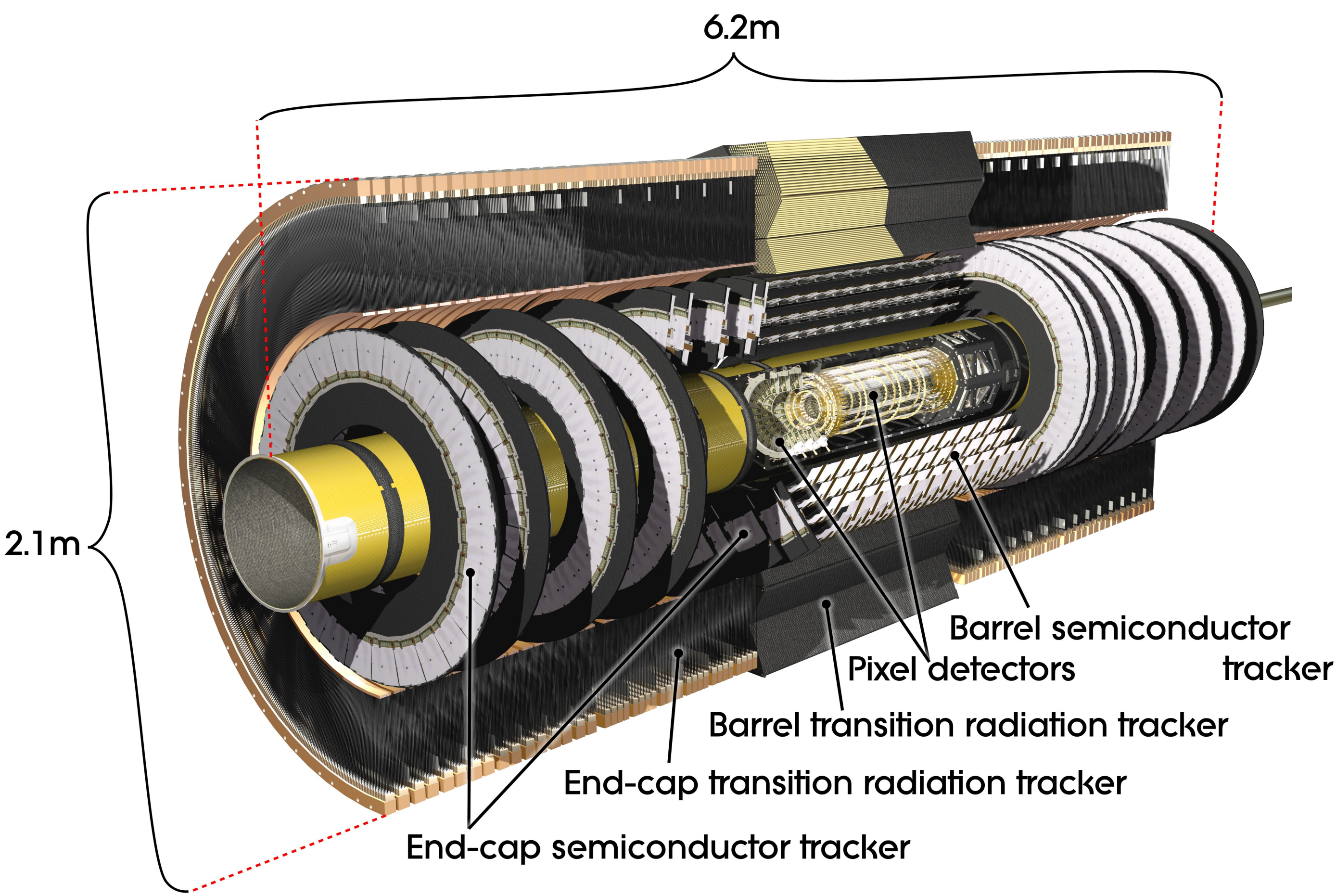
Reduced material in tracking volume → keep performance

Reduced pitch → improve high p_T performance

Reduced sensor cost → cover larger area (~175 m^2)

Trigger rate increased from 100 kHz to 1 MHz → bigger event size

Current Inner Detector (ID)



Upgrade needs for the phase-II upgrade

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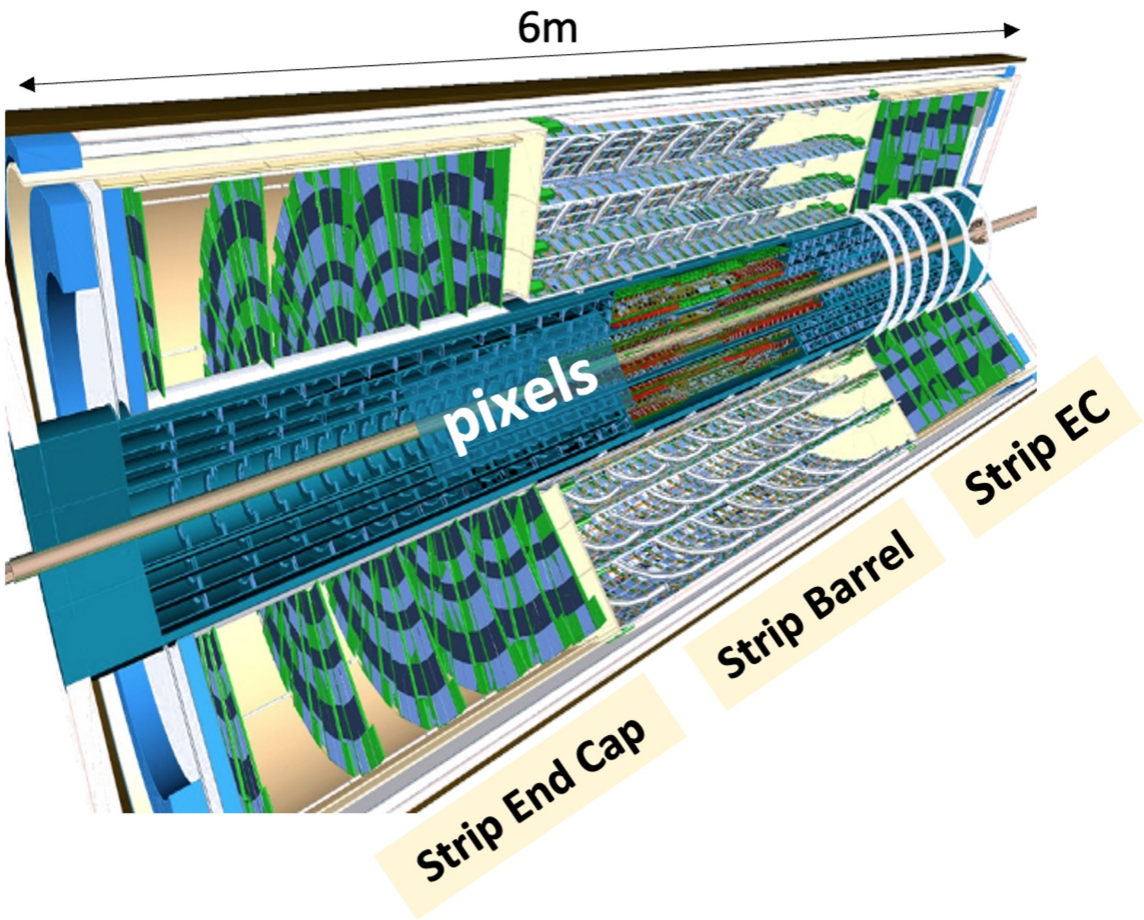
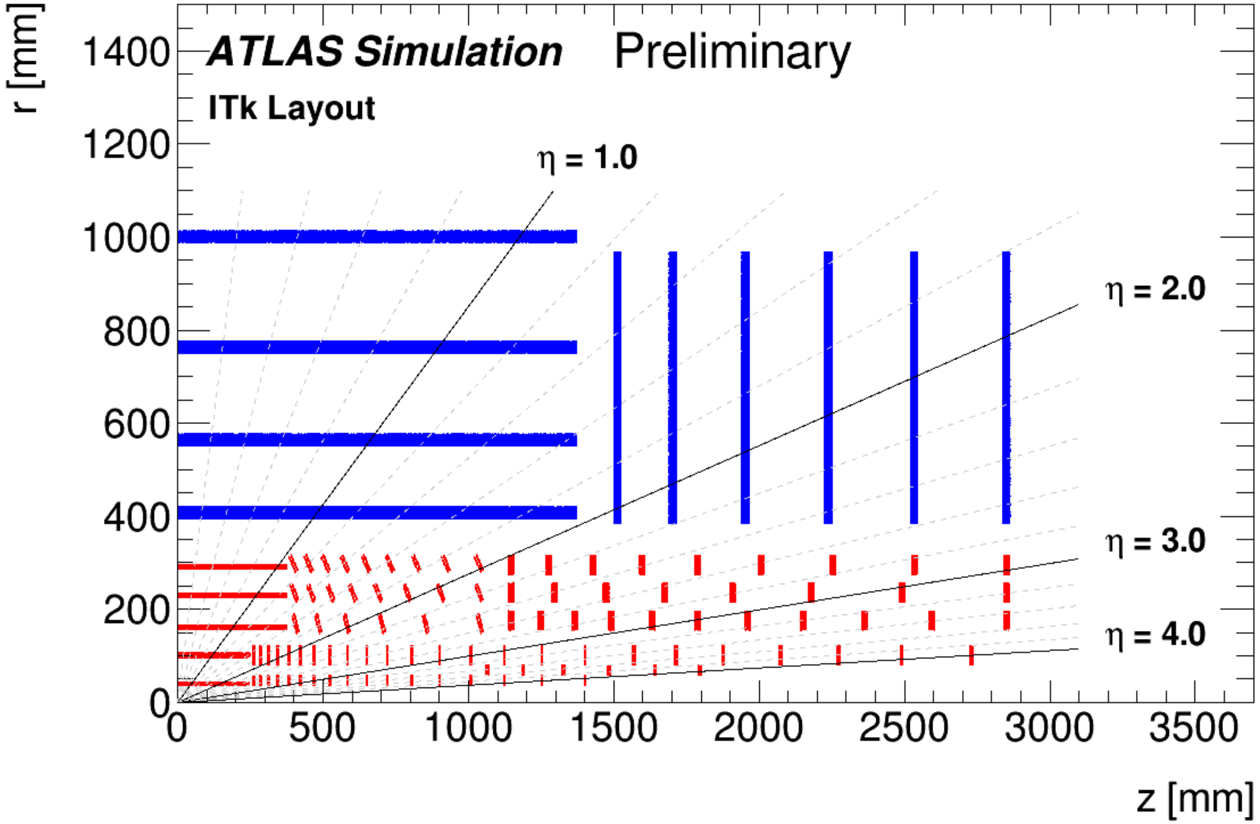
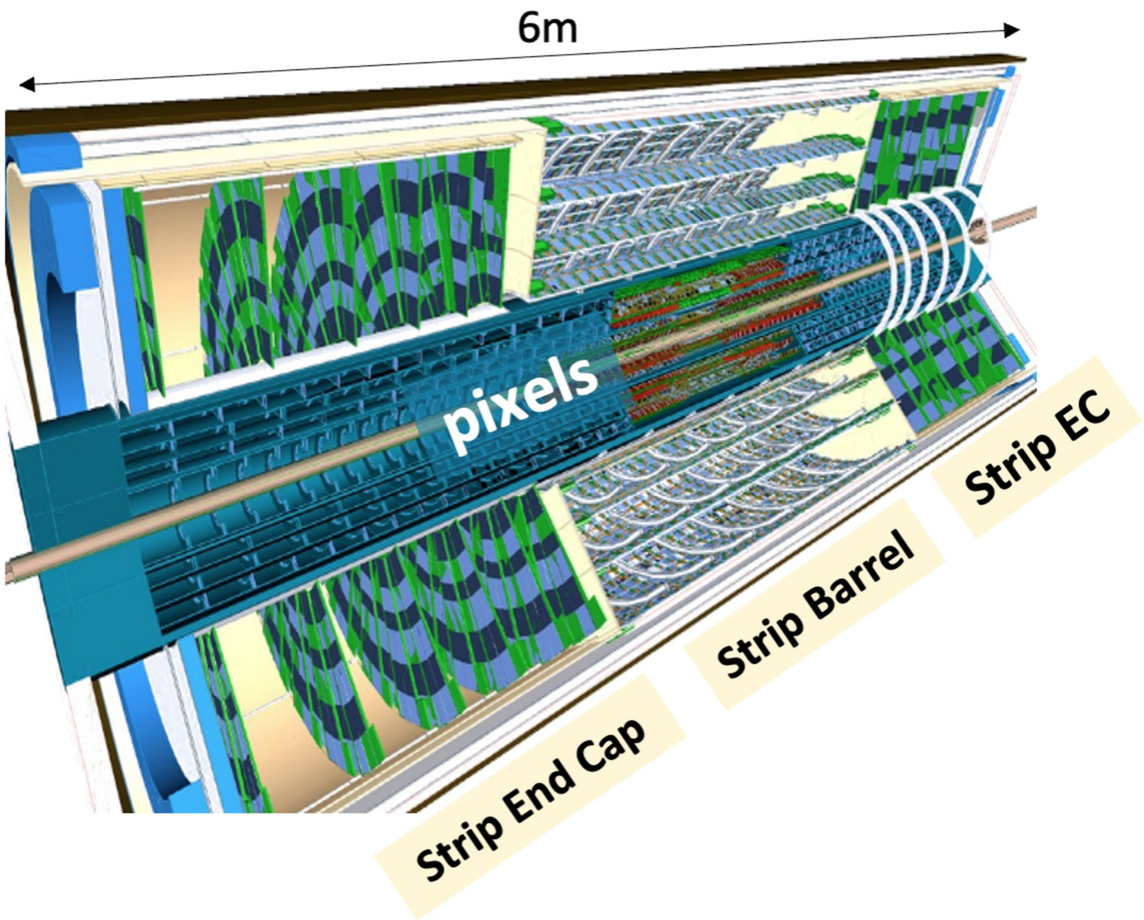
Upgrade: ATLAS Inner Tracker



ATLAS ITk

The *Inner Tracker* (ITk) will be a full-silicon detector with pixel (inner radii) and strip (outer radii) sensors
The ITk is divided in a central region called *Barrel* and two lateral wheels called *End-caps*

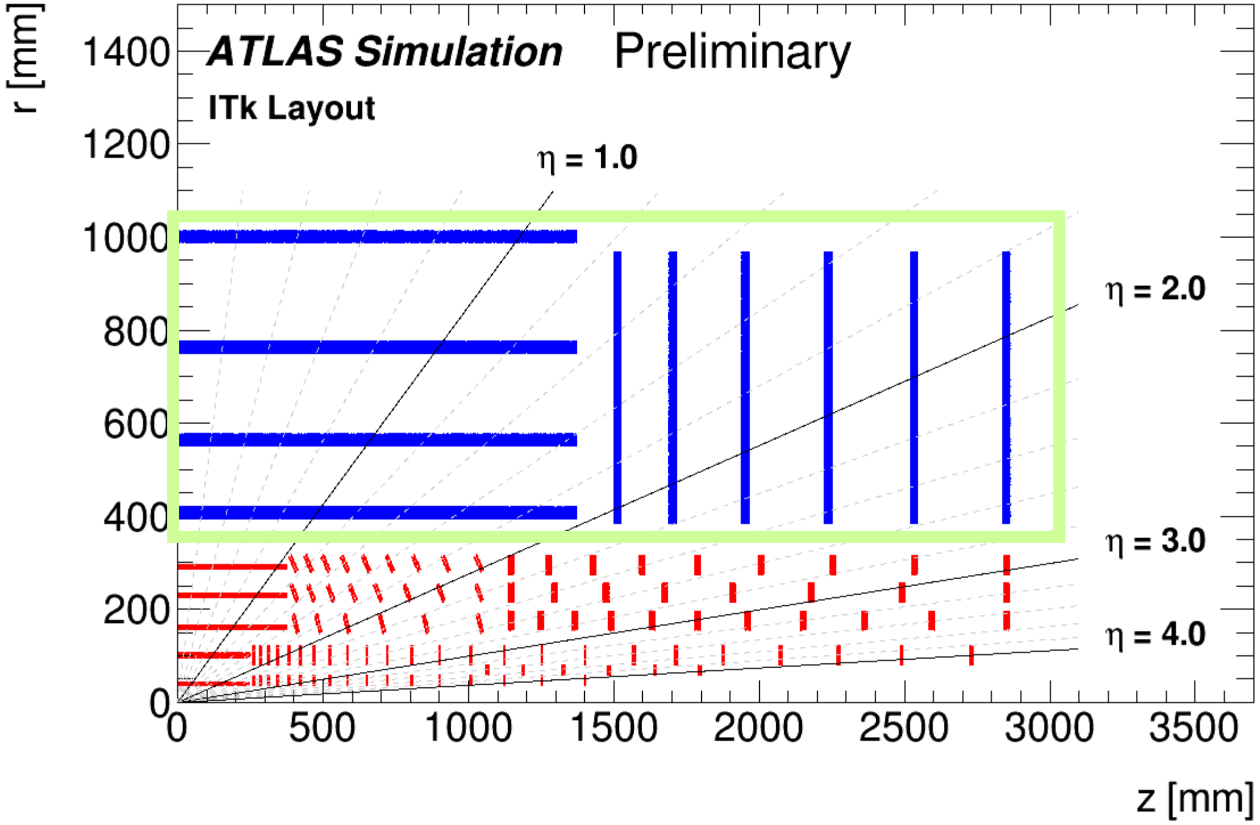


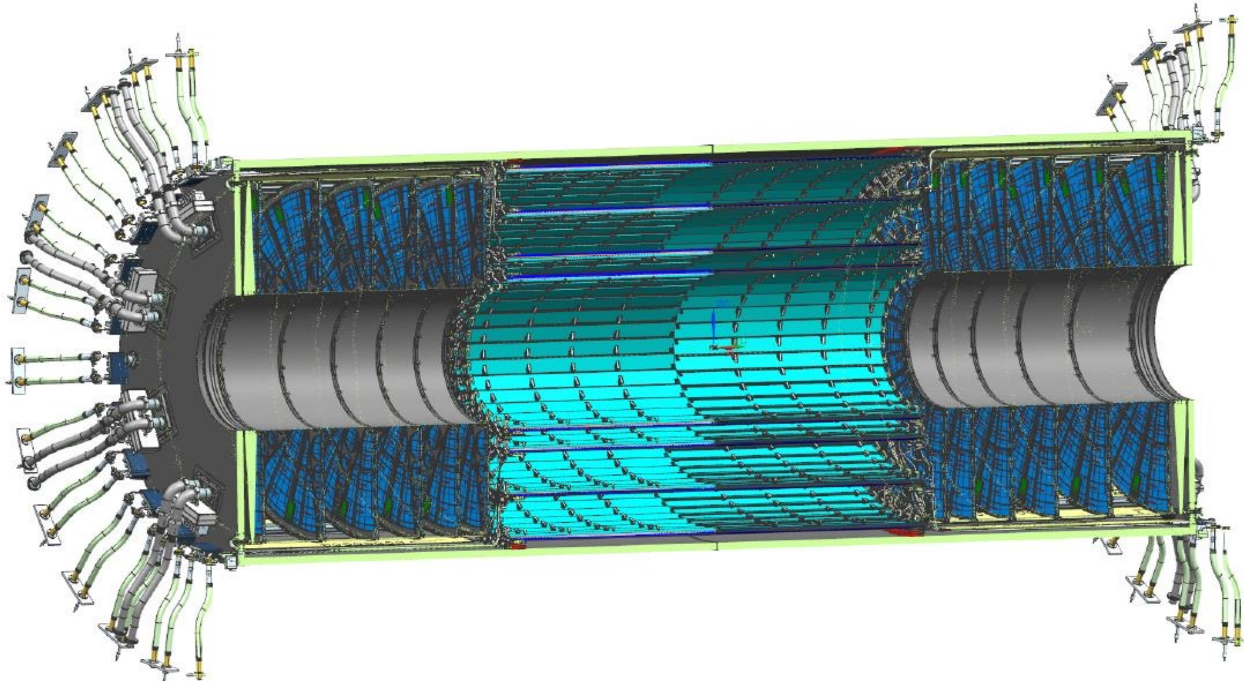


ATLAS ITk: the strip detector

The ITk-Strip detector covers pseudorapidity (η) range of $|\eta| < 2.7$

About 18,000 modules and 60 M strip channels



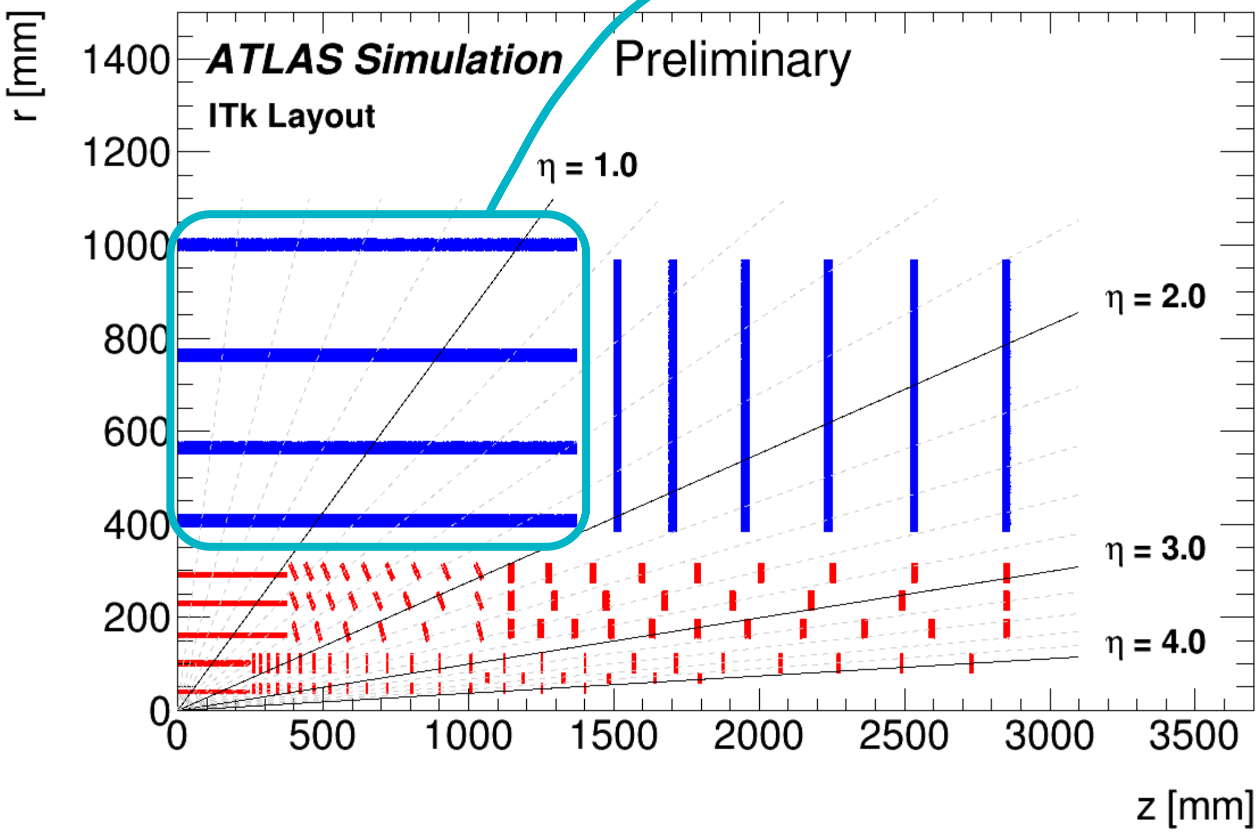


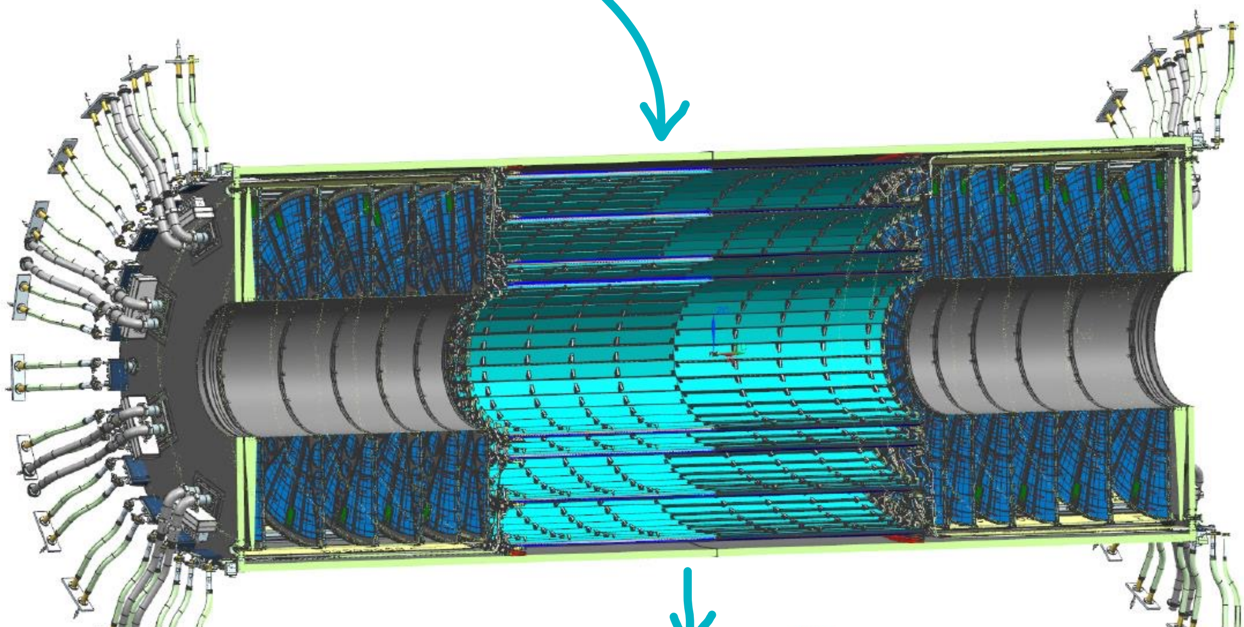
More info about the pixel detector in the ATLAS ITk Pixel Detector talk by Leonardo Vannoli

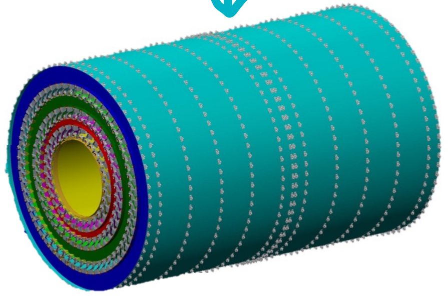
ATLAS ITk: the strip detector

the barrel

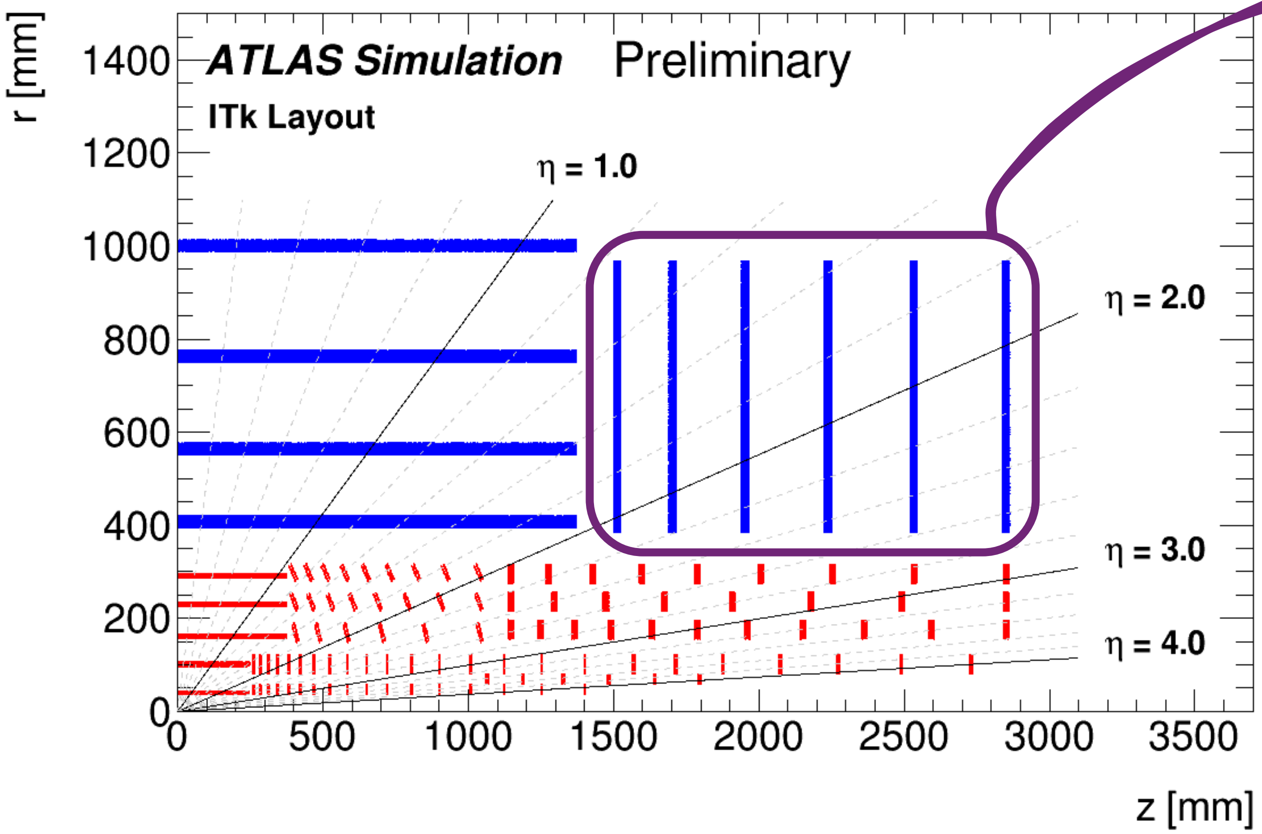
Cylindrical geometry made of four concentric layers





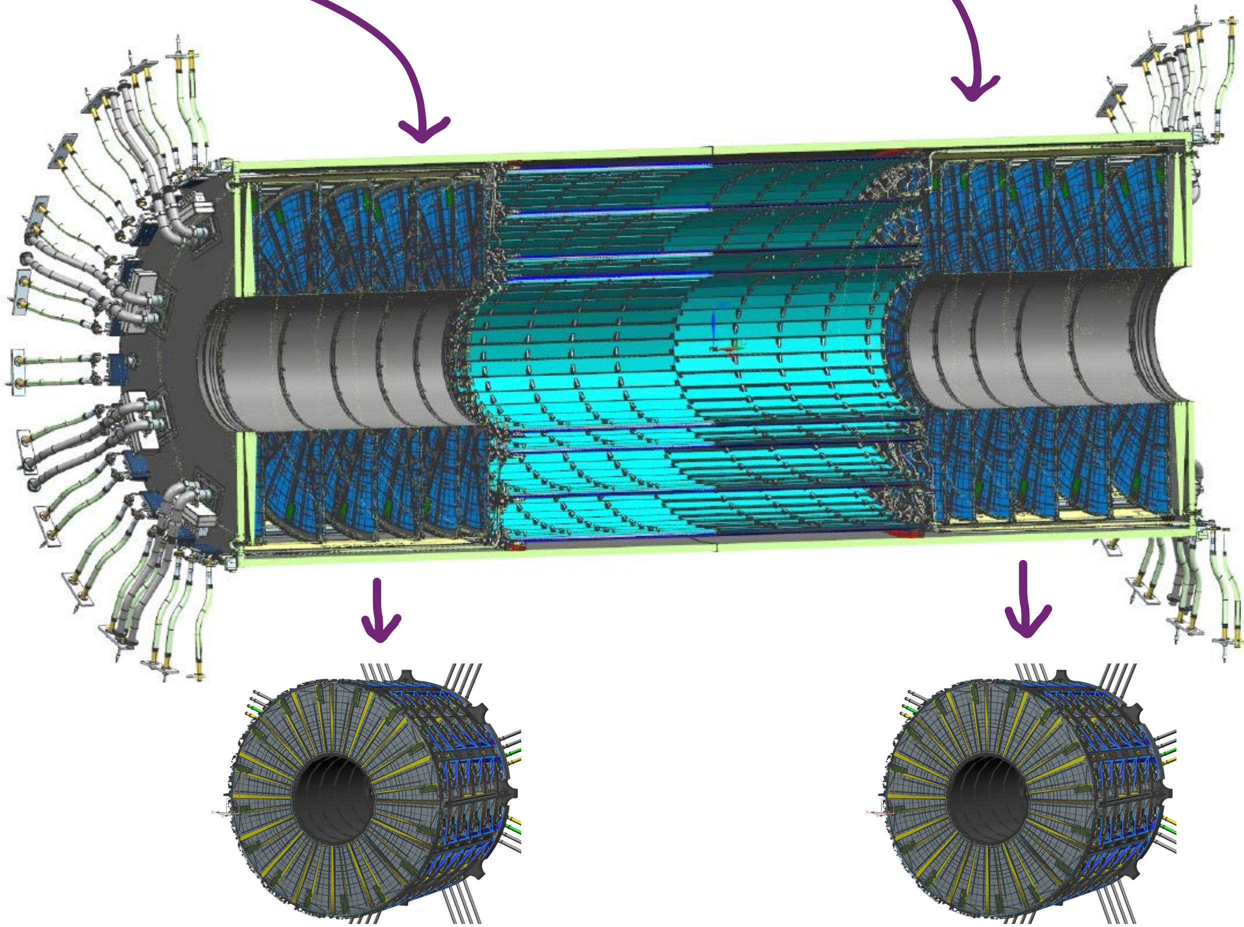


ATLAS ITk: the strip detector

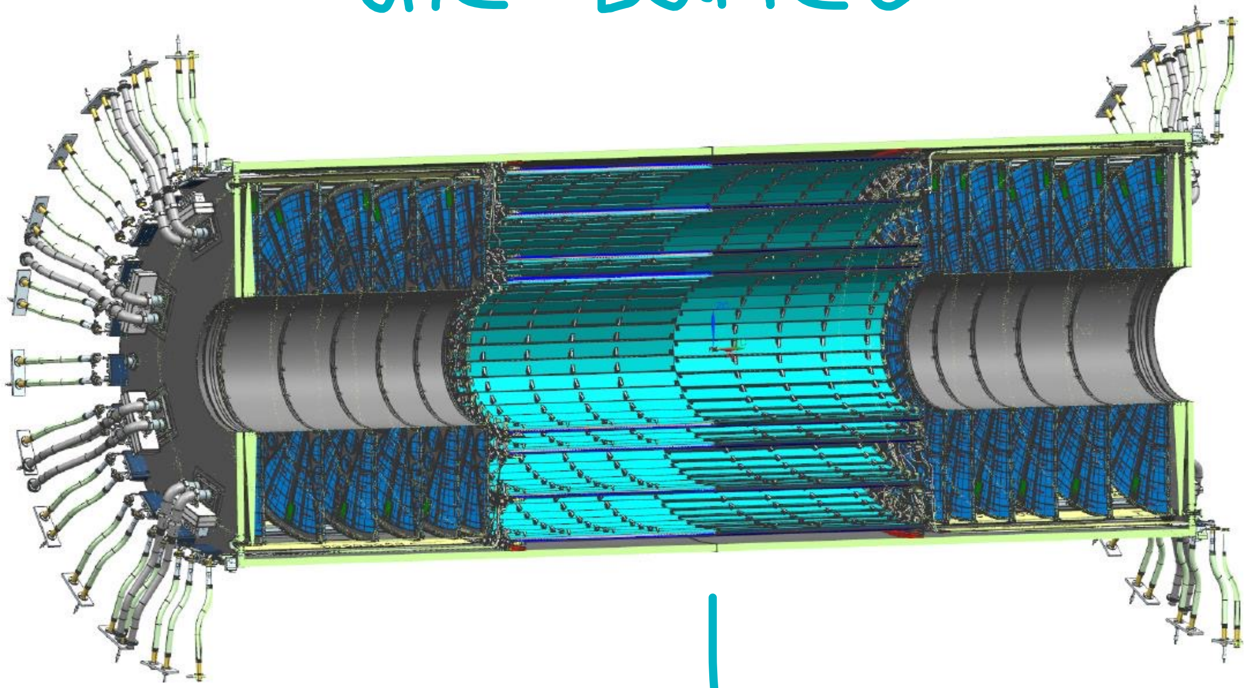


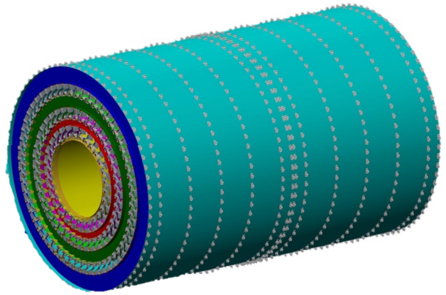
the endcaps

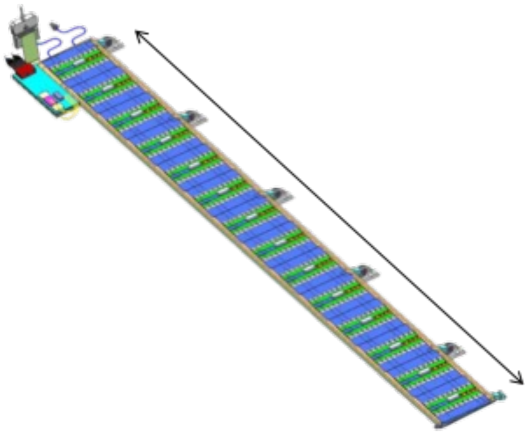
Two cylinders with six disks each



the barrel



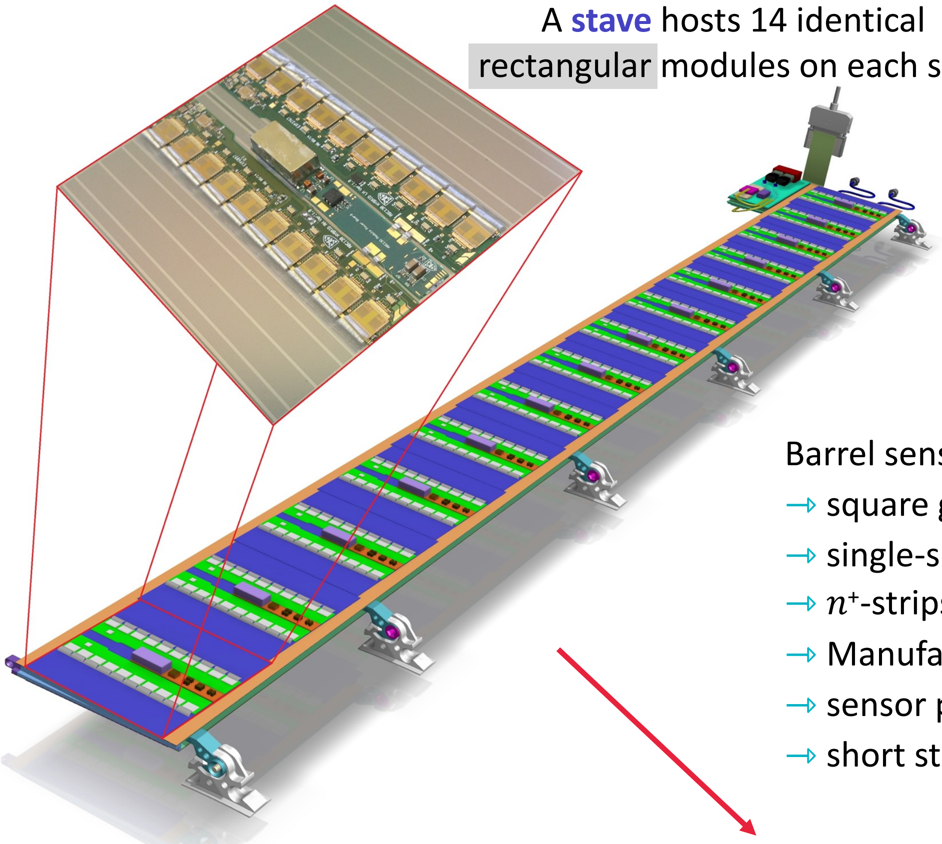




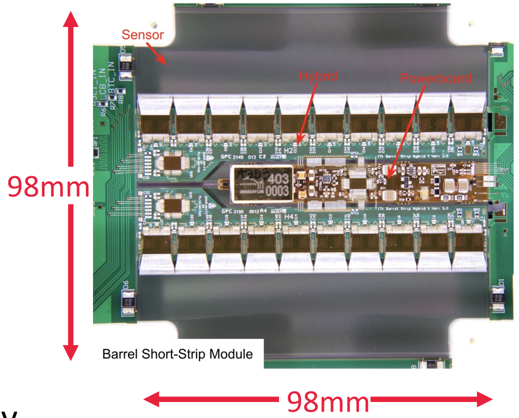
The strip barrel. Staves

Stave → silicon sensors along with application-specific integrated circuits (ASICs) and high and low-voltage power controls for the sensors integrated into a barrel module

A **stave** hosts 14 identical rectangular modules on each side

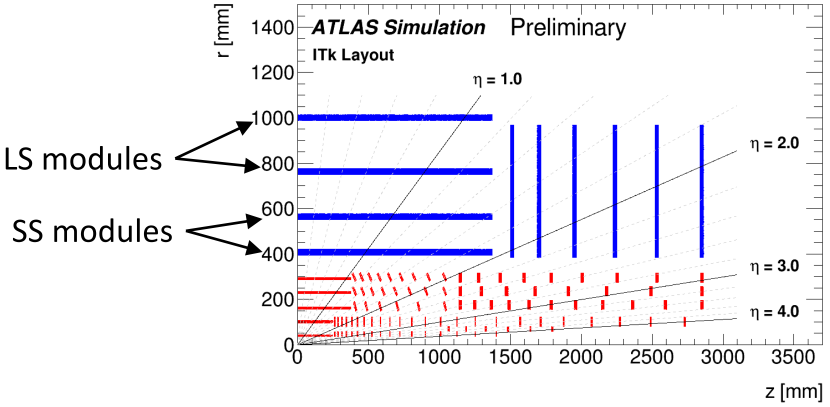


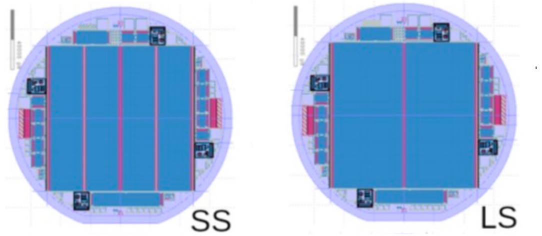
4 rows of 1,280 strips

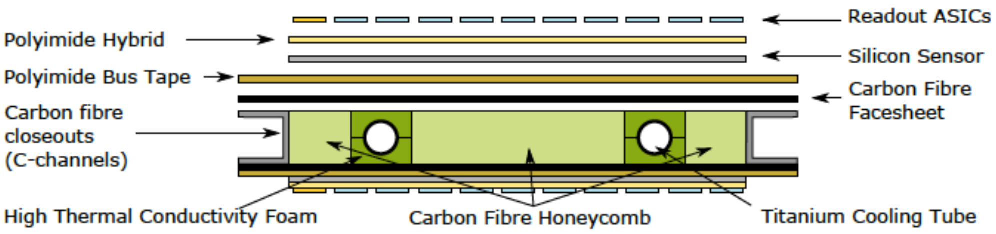


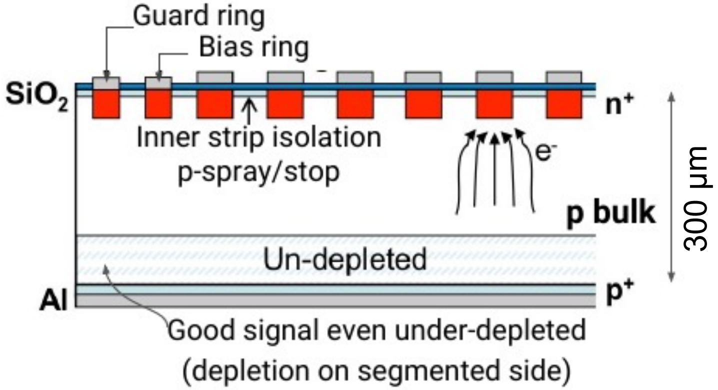
Barrel sensors:

- → square geometry
- → single-sided micro-strips
- → n^+-strips implanted on p-type silicon bulk (n^+-in-p)
- → Manufactured in 6" silicon wafer technology
- → sensor pitch: 75.5 µm
- → short strips: 24.1 mm long & long strips: 48.3 mm long









The strip barrel. Staves

- **Hybrid** (readout PCB). ASICS:
    - → ATLAS Binary Readout Chips (ABC)
    - → Hybrid Controller Chips (HCC)

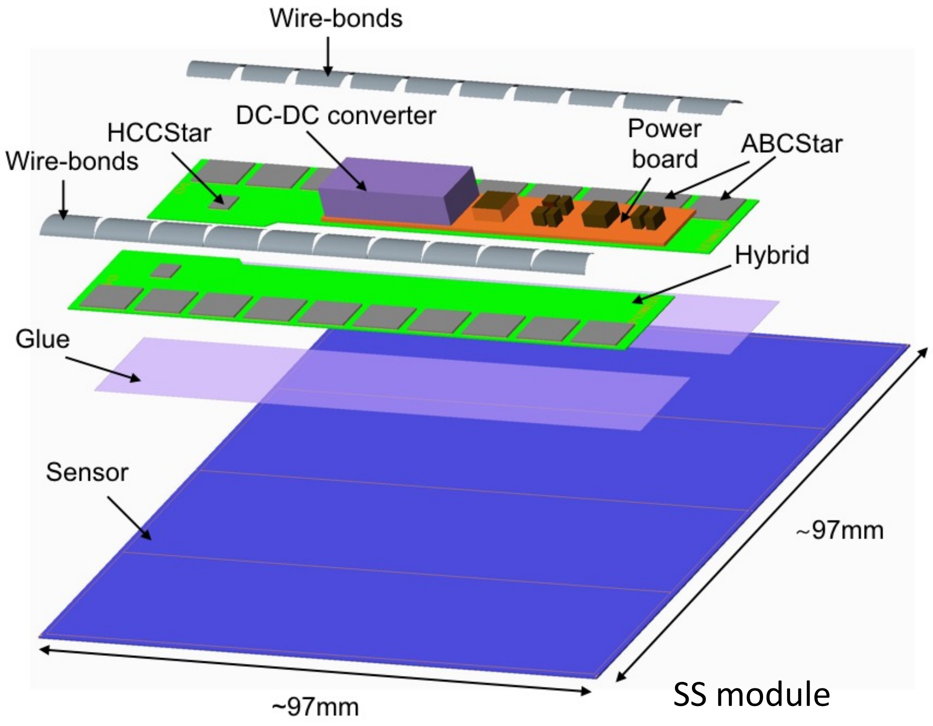
- **Power board** (power PCB) module powering + monitoring
    - → Autonomous Monitor And Control ASIC (AMAC)

DCDC converter for LV powering (ITk Strip Baseline powering scheme uses parallel powering with DC-DC converters). Sensor biasing via HVSwitch

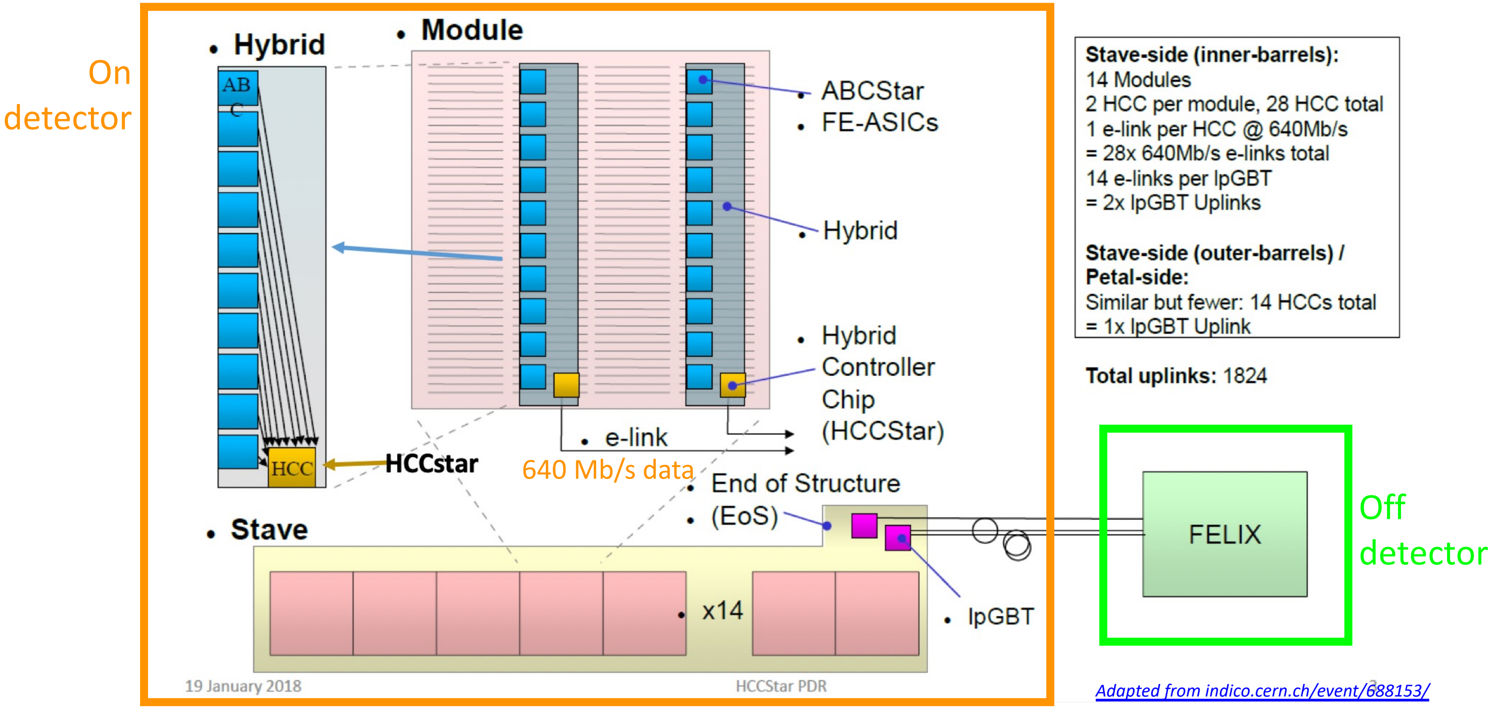
- **STAR architecture**: each ABC directly connected to 1 HCC

→ Cope with 1MHz trigger rates

→ 640Mbit/s downlinks from each HCC



ABCStar	**HCCStar**	**AMAC**
Front-end chip Binary readout	On-hybrid digital interface chip	On-module monitoring and control chip



Stave-side (inner-barrels):
14 Modules
2 HCC per module, 28 HCC total
1 e-link per HCC @ 640Mb/s
= 28x 640Mb/s e-links total
14 e-links per lpGBT
= 2x lpGBT Uplinks

Stave-side (outer-barrels) / Petal-side:
Similar but fewer: 14 HCCs total
= 1x lpGBT Uplink

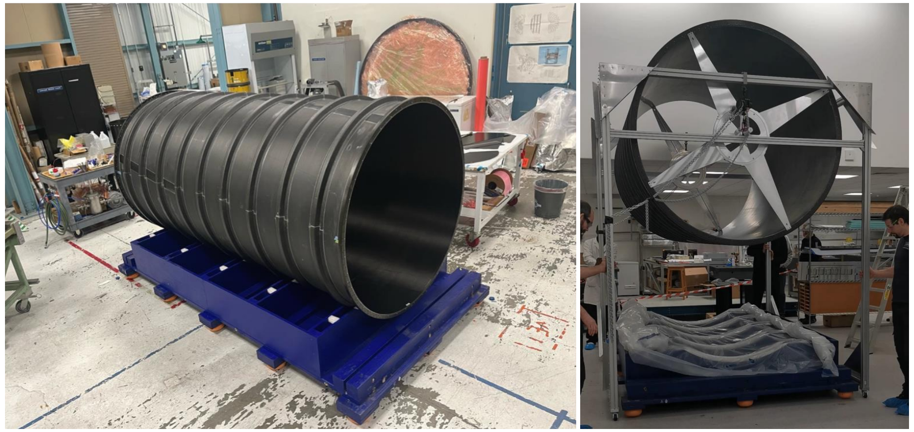
Total uplinks: 1824

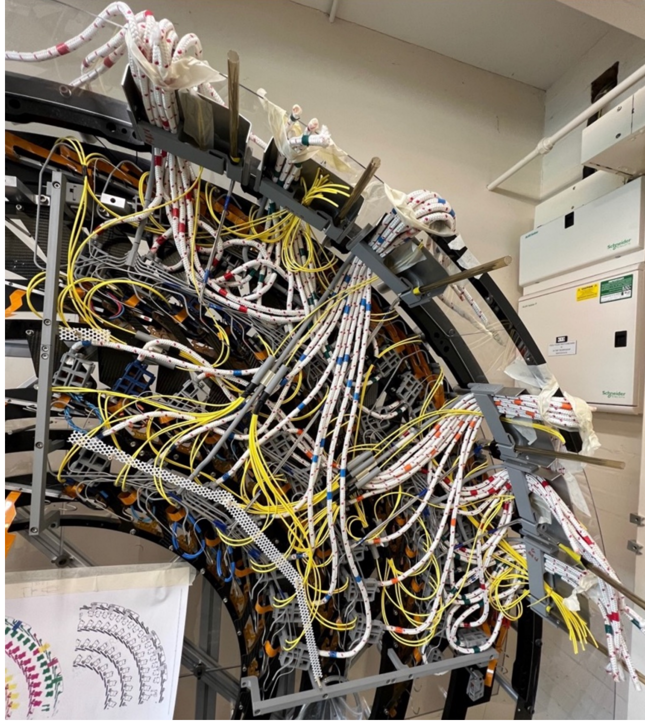
Adapted from indico.cern.ch/event/688153/

Barrel. Integration & installation

Cooling & Environmental: CO2 for staves, C6F14 for PP2, Dry air to -60°C DP, H&T sensors

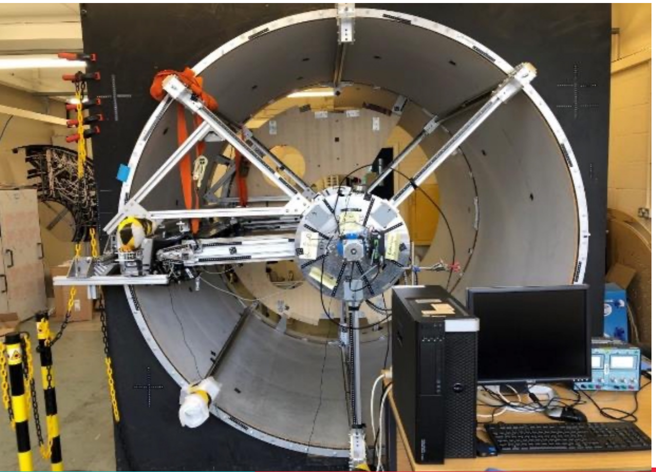
ITk Strip Cylinder 2 and 3

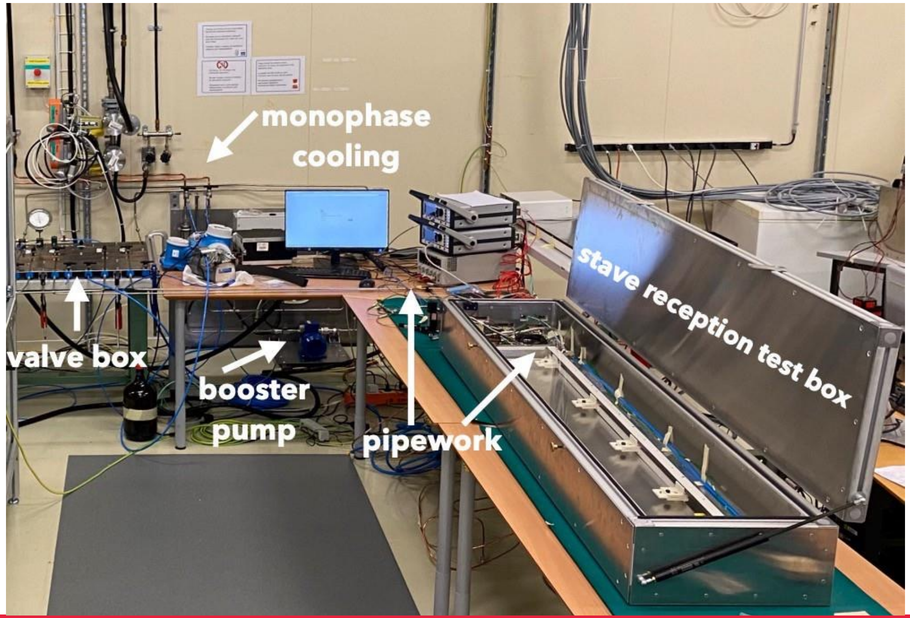




SM installation & connectivity to stave. Power, cooling, opto

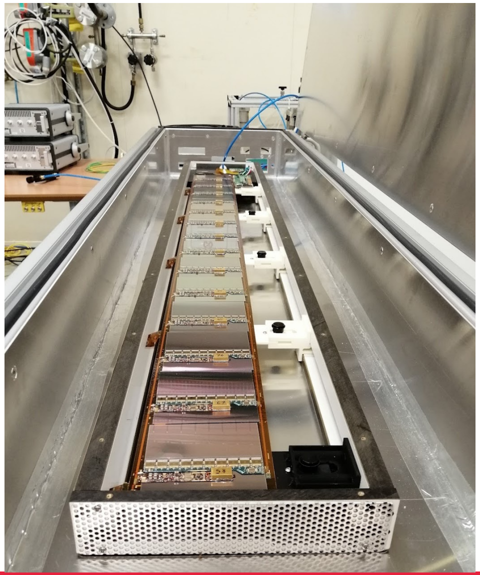
Stave insertion tooling





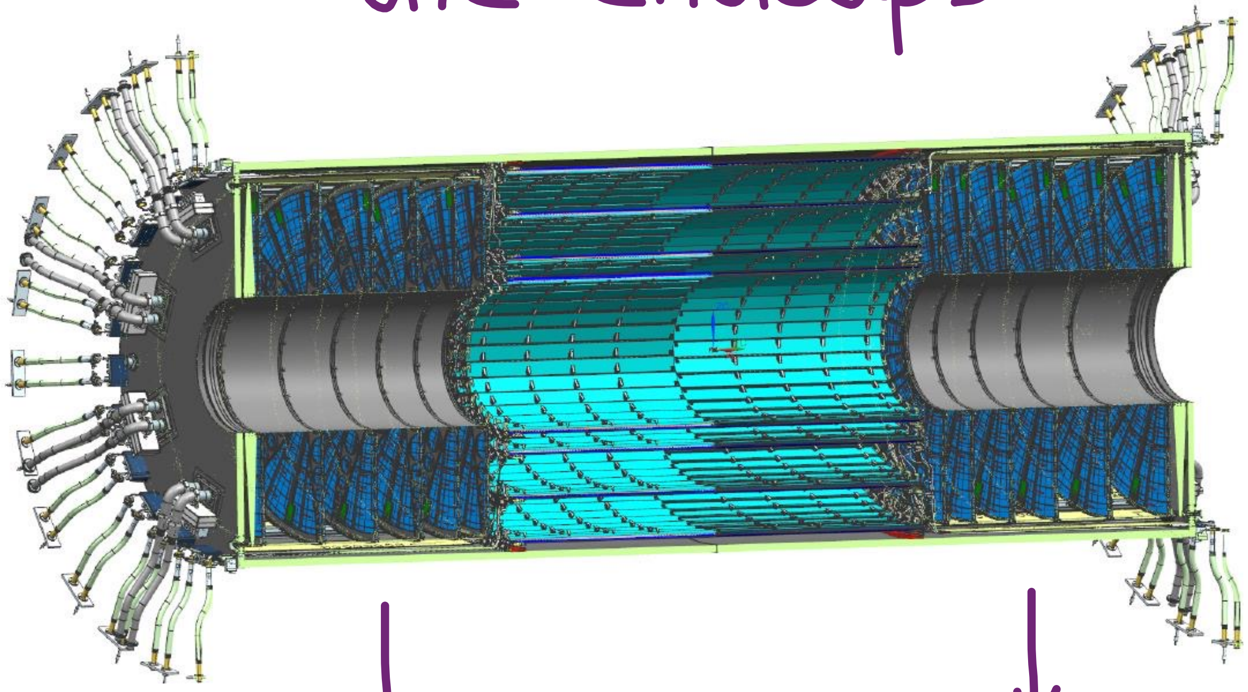
Stave testing

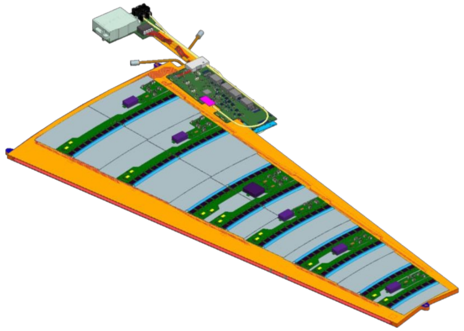
YARR and ITSDAQ

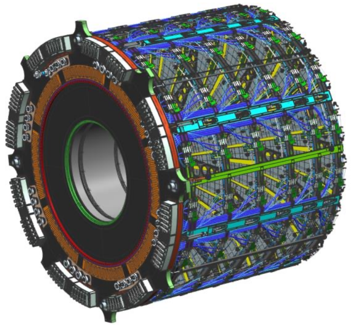


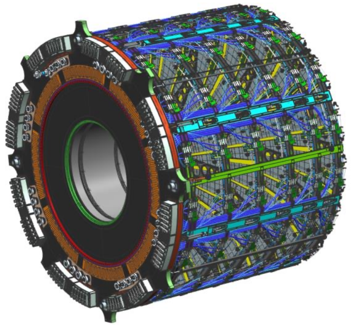
Summary of slides of Dave Robinson.
Global Mechanics meeting ITk week 8/3/2023

the endcaps



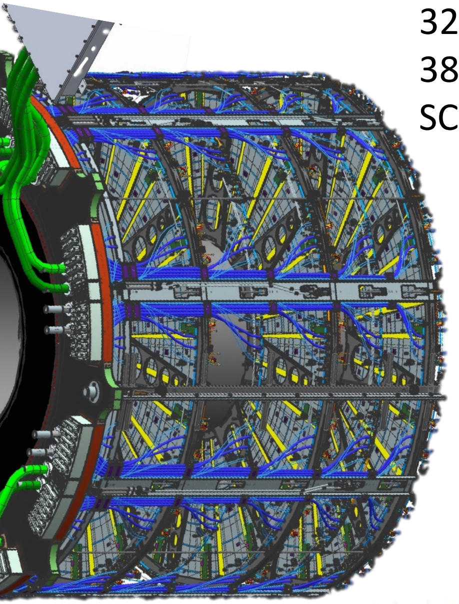






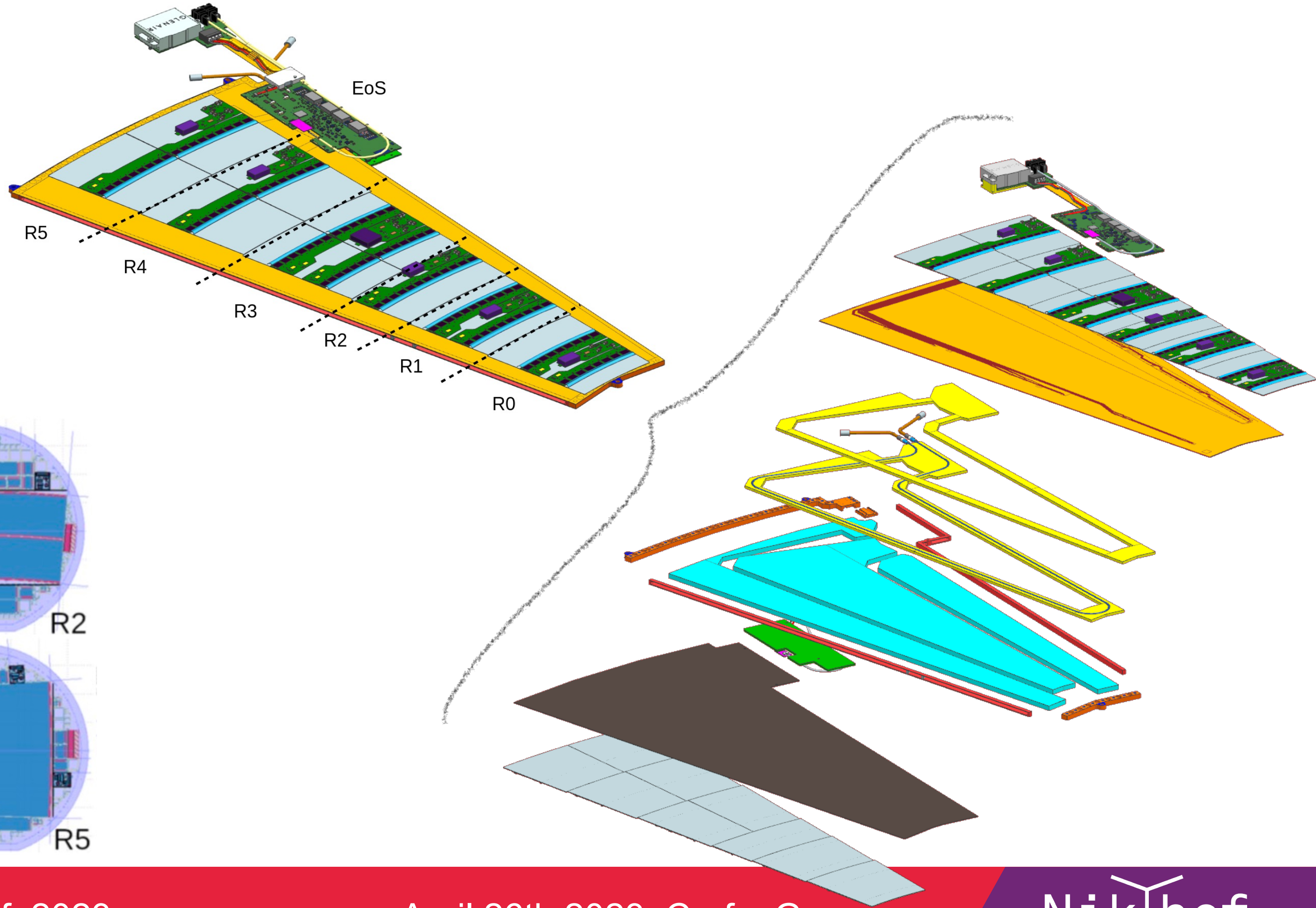
The strip end-caps (EC). Petals

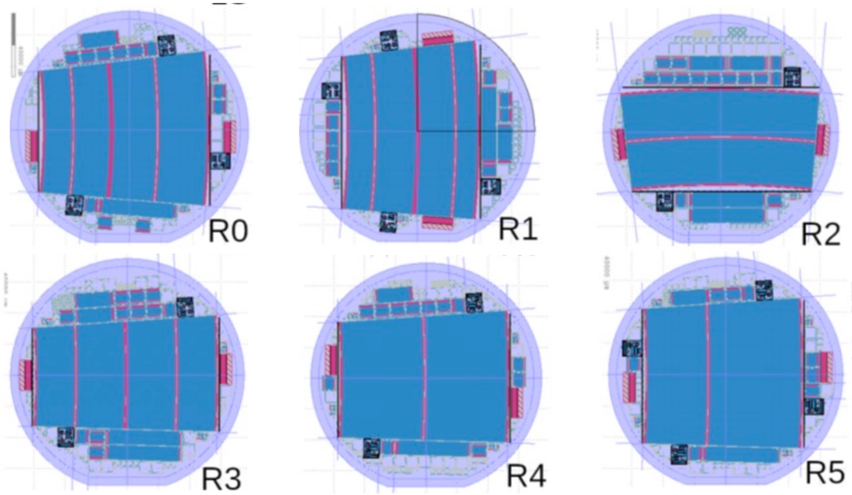
Petal → Low-mass, high precision, double-sided, high thermal conductivity structure. Fully integrated with sensors, readout + control electronics, power components, cooling.
Designed for precision mounting of microstrips, minimize material, power and services for the modules, and for end-insertion in EC disks



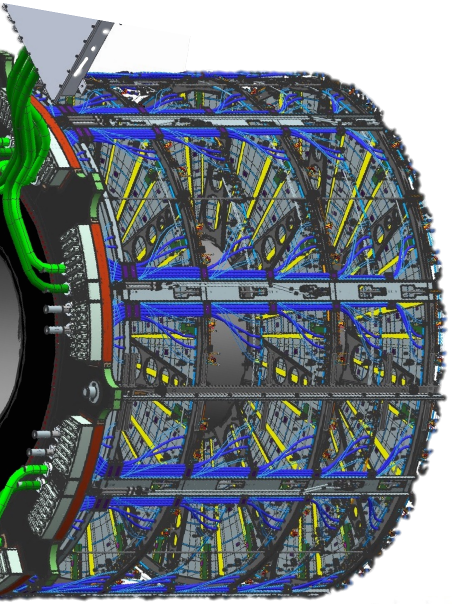
32 **Petals** per disk covering the radial range. 384 petals, 6912 modules, ~8x channels than SCT endcaps

Trapezoidal geometry
- → petals are wedge-shaped
- → 6 geometries cover the sensitive area on both sides
- → Manufactured in 6" silicon wafer technology. Those on R3, R4, R5 are split in 2 to cover the full area



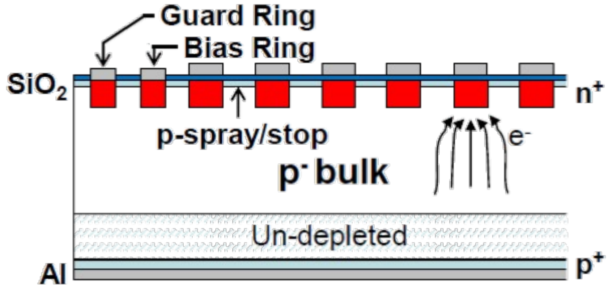


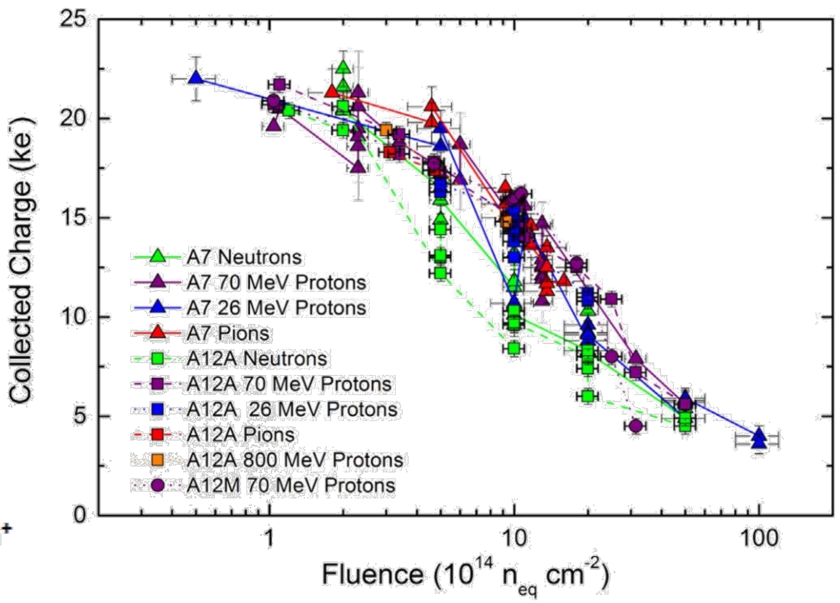
The strip end-caps (EC). Petals



EC sensors:

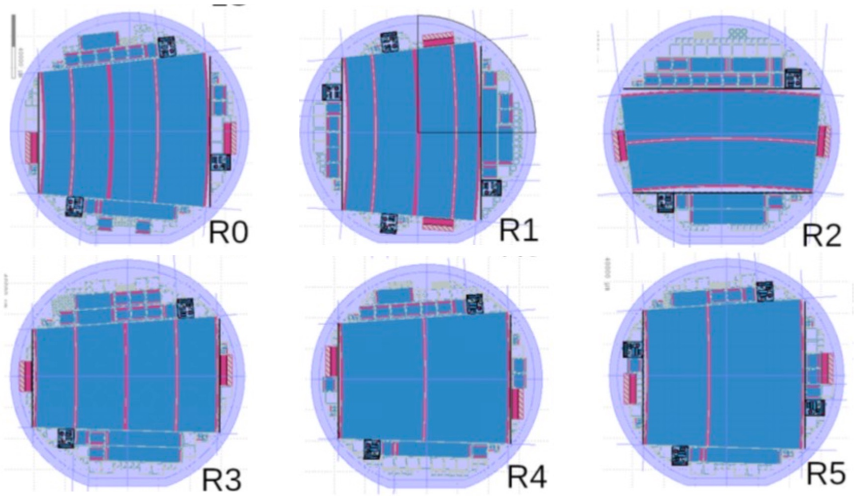
- → single-sided micro-strip
- → n$^+$-type readout implants on p-type, float-zone silicon substrate
- → n$^+$-in-p technology (radiation tolerant)
- → strip: 15-60 mm long depending on radius
- → sensor pitch: 70-80 µm
- → spatial resolution ~20 µm
- → time resolution ~3 ns

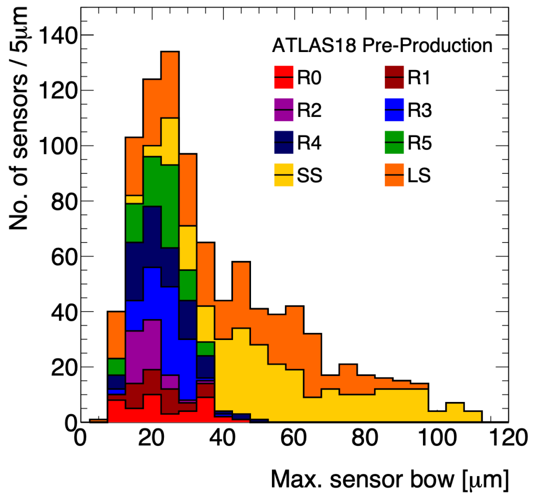


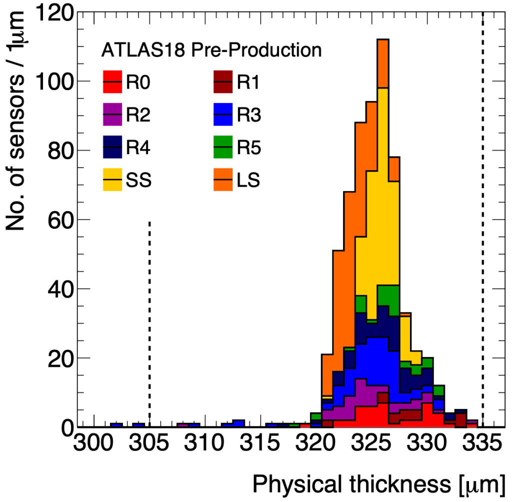


Plots form ATL-ITK-PROC-2023-002

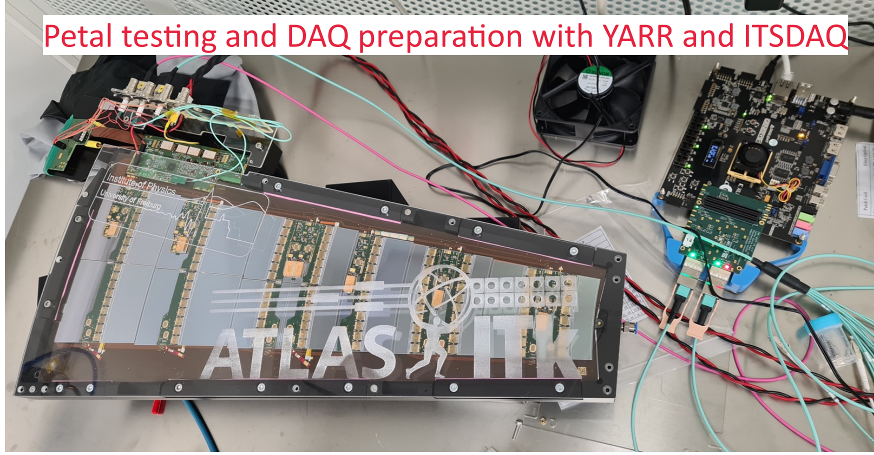
cds.cern.ch/record/2846511





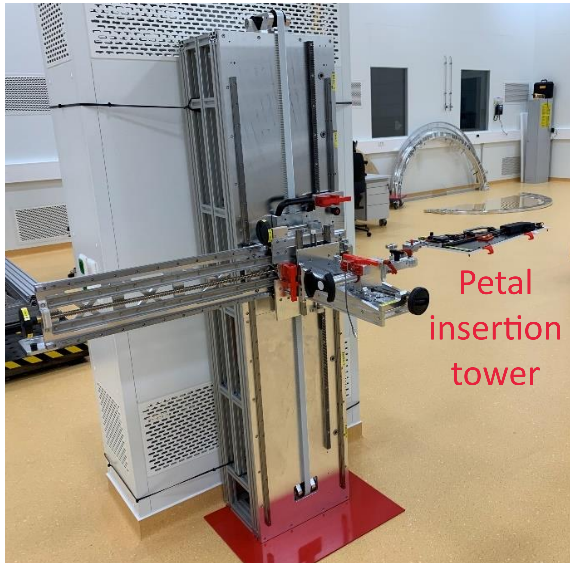


End-caps. Integration & installation

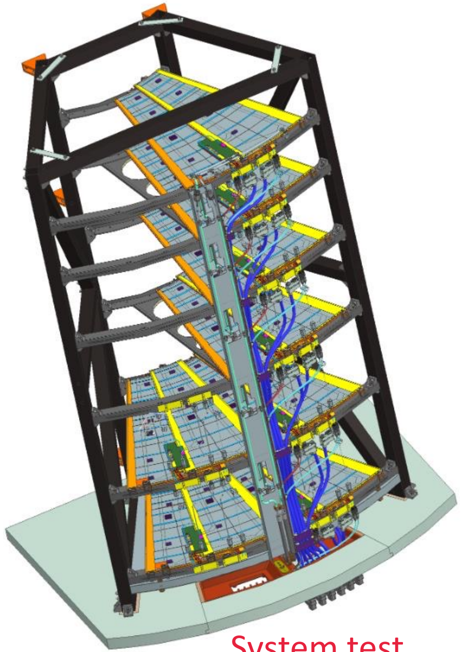


Petal testing and DAQ preparation with YARR and ITSDAQ

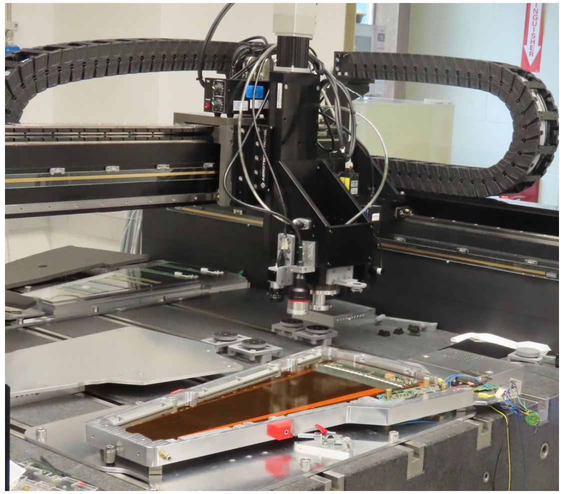
Integration tooling: superframes



Petal insertion tower

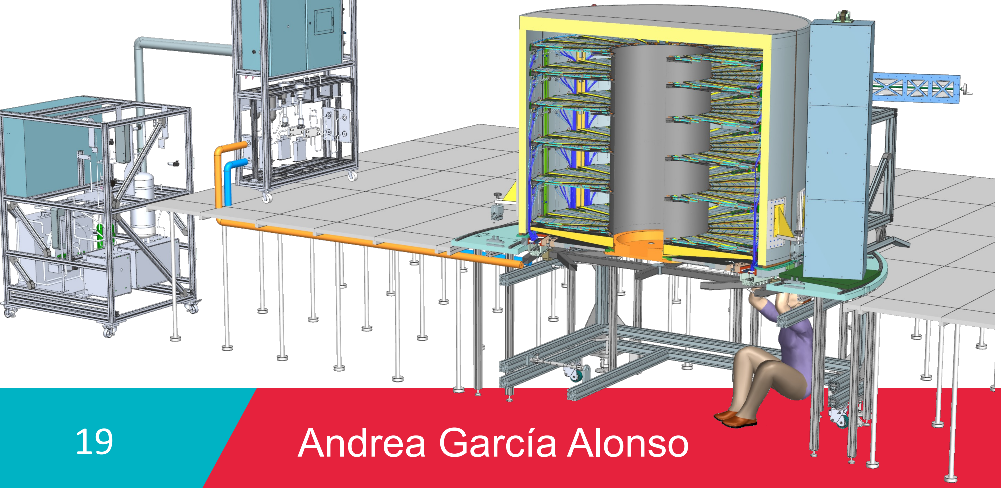


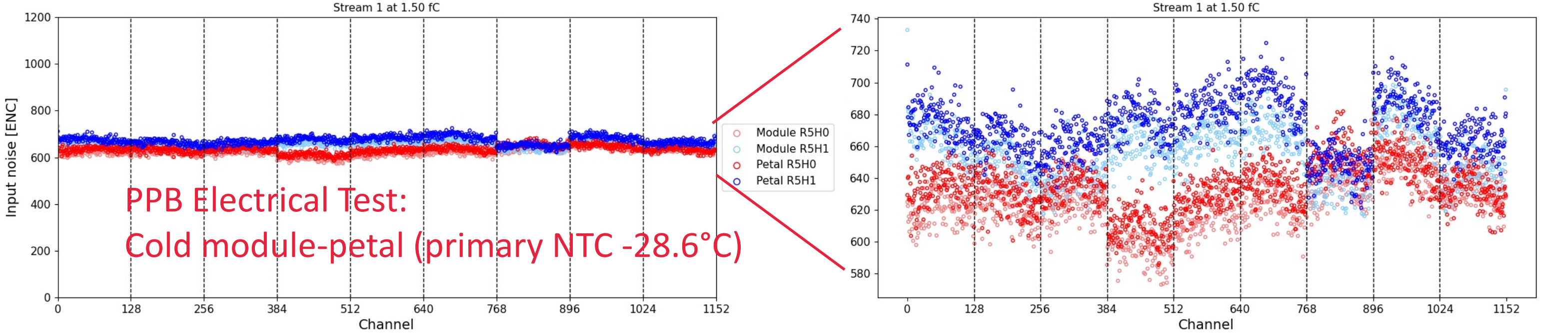
System test



H5 PPB petal

EC integration sites: Nikhef and DESY

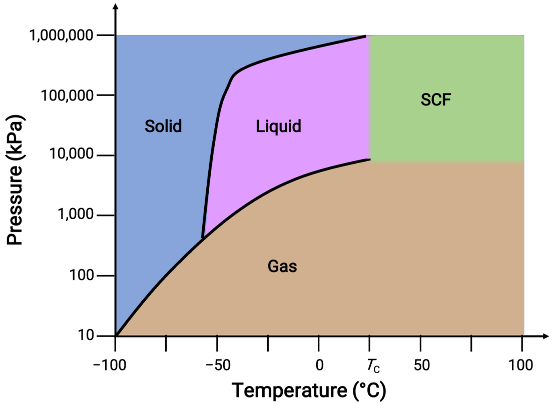




PPB Electrical Test:
Cold module-petal (primary NTC -28.6°C)

indico.cern.ch/event/1223746/contributions/5298041/

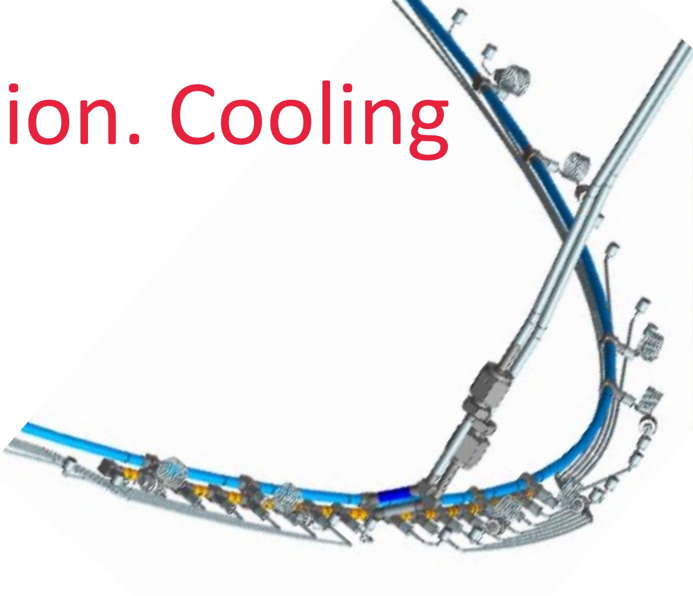
End-caps. Integration & installation. Cooling



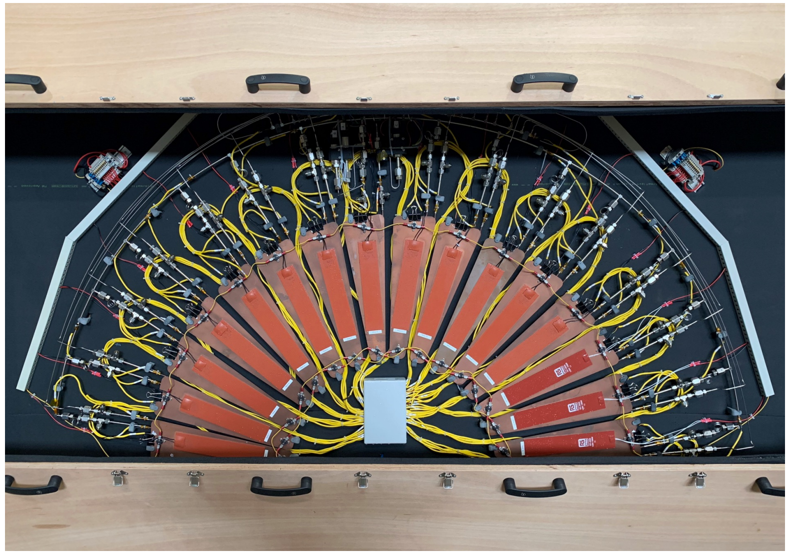
Each petal is expected to generate 68 W at nominal and max 84 W

Cooling:

2-phase CO_2 at -40°C using cooling service modules that serve 16 petals (half a wheel)

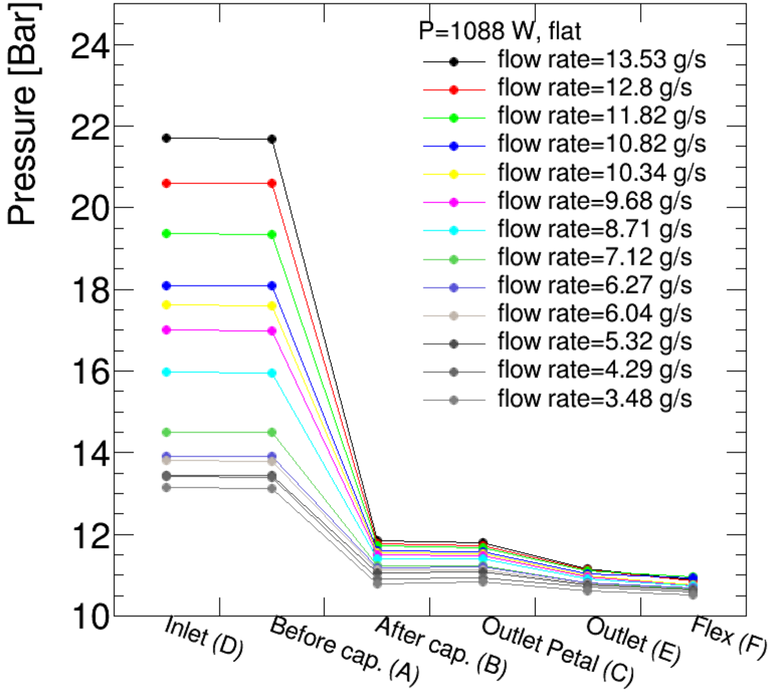


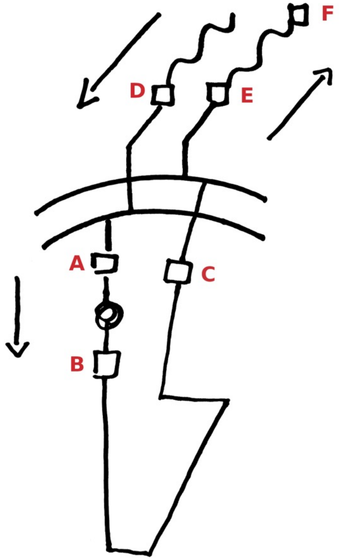
CO₂ cooling LUCASZ plants

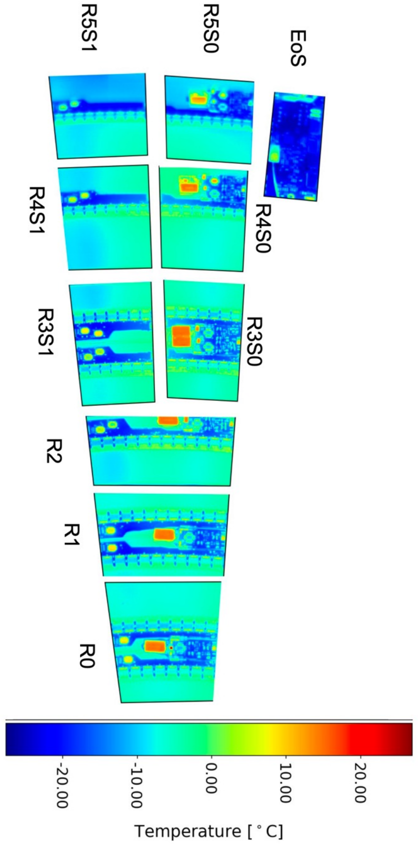


1:1 scale mock-up EC half-disk cooling system

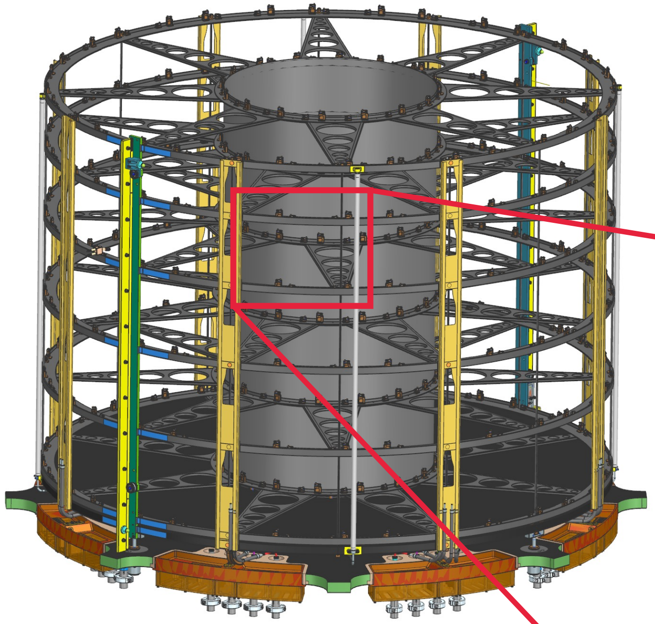
16 copper fake petals with heater pad applied



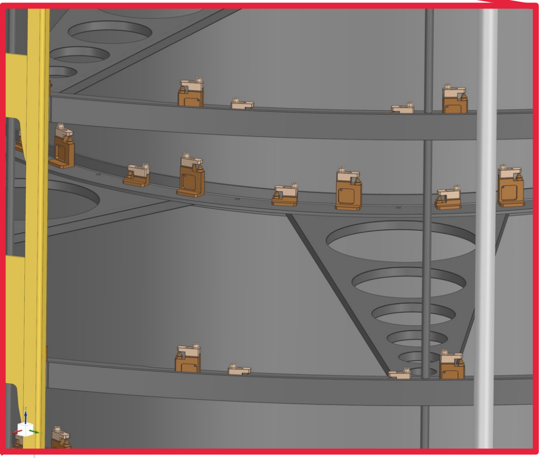




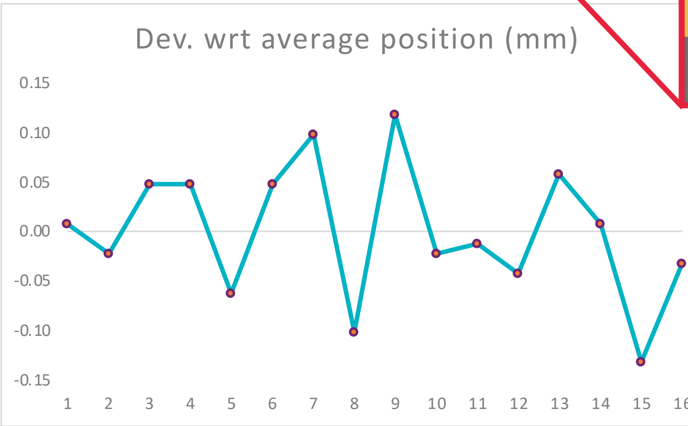
End-caps. Integration & installation

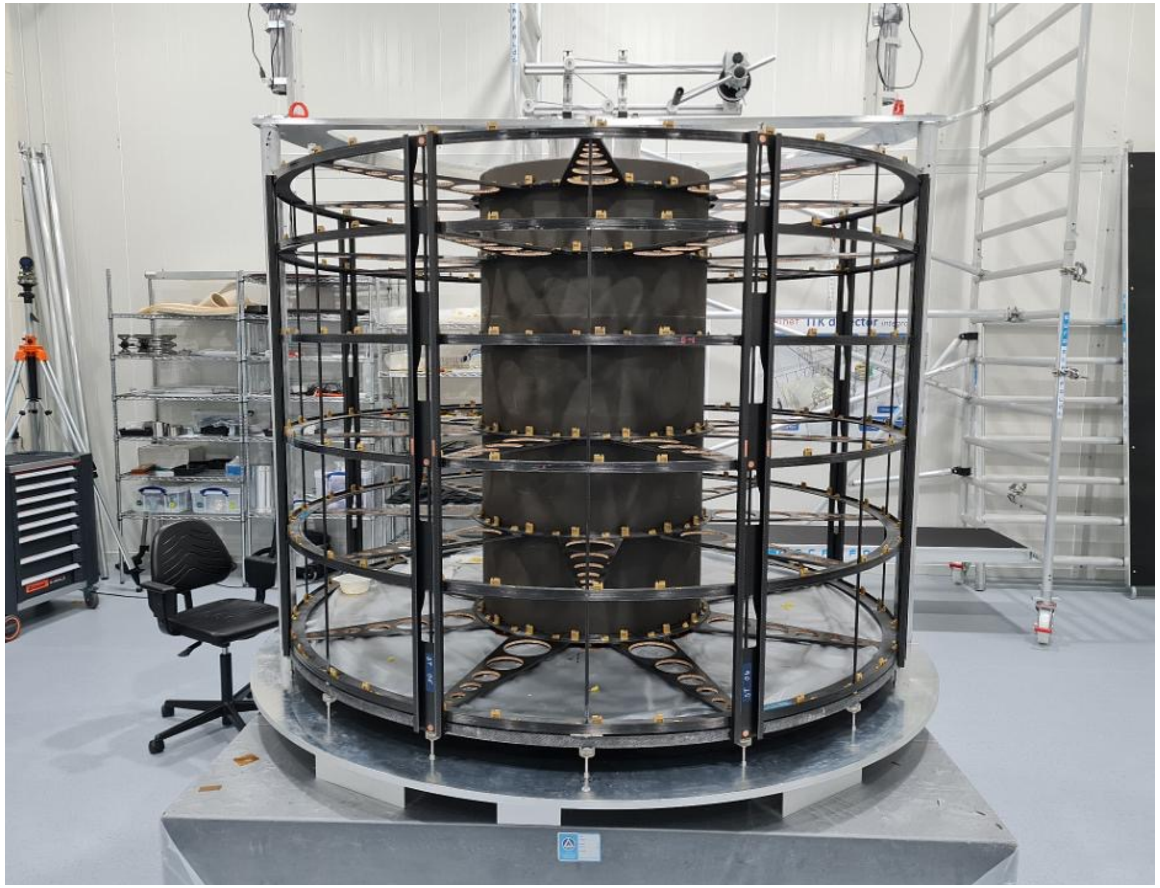


Petals are mounted on the disks with 100 μm required initial accuracy → ATLAS-TDR



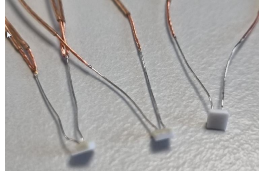
Locking points





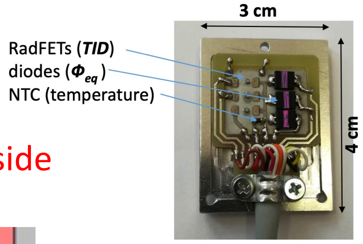
At Nikhef, the construction of the 1st end-cap structure is finished

Strips. Integration & installation
Radiation, T and H monitoring



- More than 500 T sensors in ITk volume for a 9MGy radiation level
- 12 radiation hard optic fibre H sensors in Strip detector (LPG+2FBG)

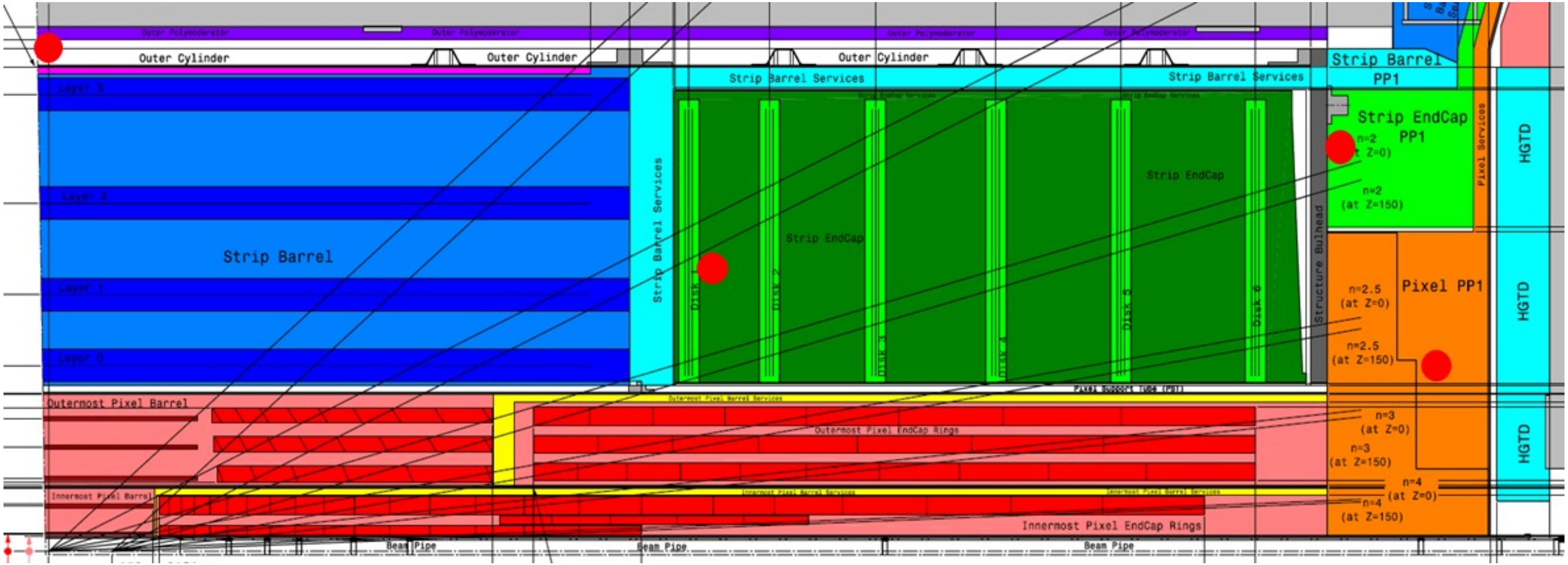
- Radiation monitoring system to measure displacement damage in Si (1 MeV neq fluence) and TID:



4 rad sensors
Strip barrel outer cylinder,
z ~ 0, *r* = 110 cm

8 rad sensors
Strip EC volume, in tracking volume
r ~ 60 cm, *z* ~ 160 cm

8 rad sensors
Strip EC PP1 volume,
structural bulkhead outer side
r ~ 80 cm, *z* ~ 300 cm



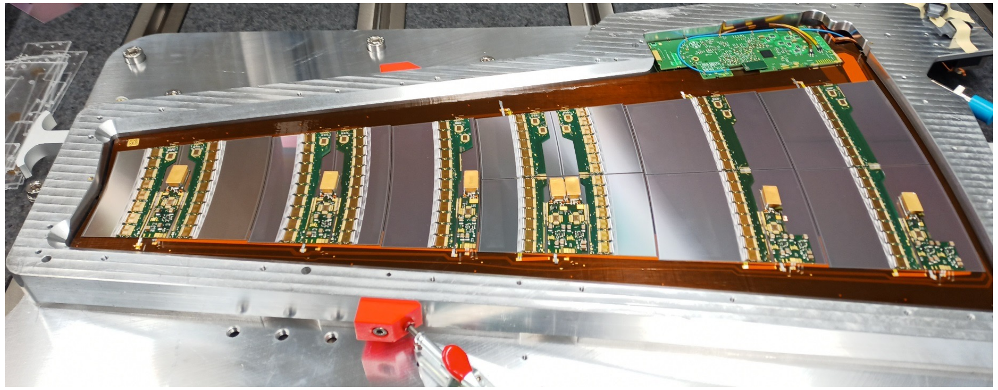
8 rad sensors
Pixel service volume,
enclosure outer side
r ~ 44 cm,
z ~ 320 cm

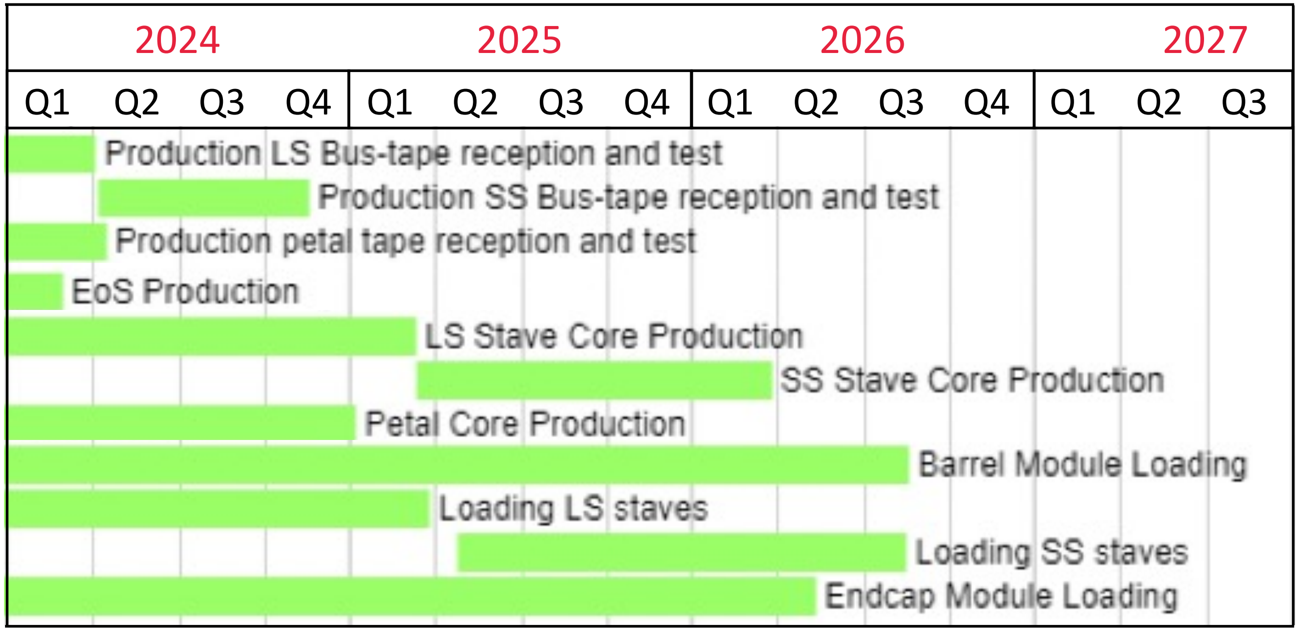
ITk schedule. Production

22,000 ITk **strip sensors production** started in HPK in 2020, finish by 2025

LS stave core production finish in Q1 2025, SS in Q1 2026
Petal core production finish by the end of 2024

Barrel and End-cap **module loading** will finish by mid 2026





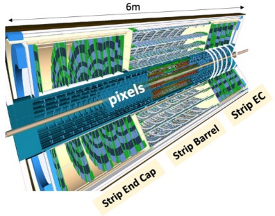
ITk schedule. Integration

Strip DESY EC ready for integration at CERN

Strip Barrel ready for installation

Strip Nikhef EC ready for integration at CERN

Strip Barrel & ECs need



ITk ready for installation

ITk required

ITk inserted

Finish 31/8/2028

Feb 26, Mar 26, Apr 26, May 26, Jun 26, Jul 26, Aug 26, Sep 26, Oct 26, Nov 26, Dec 26, Jan 27, Feb 27, Mar 27, Apr 27, May 27, Jun 27, Jul 27, Aug 27, Sep 27, Oct 27, Nov 27, Dec 27, Jan 28, Feb 28, Mar 28, Apr 28, May 28, Jun 28, Jul 28, Aug 28

ITk ready for Pixel insertion

Pixel Outer System integration in Strips

Pixel Inner System integration in Strips

Petal insertion in DESY EC
15/8/2024 - 3/8/2026

Petal insertion in Nikhef EC
14/10/2024 - 26/10/2026

Barrel loading in SR1
21/11/2023 - 28/9/2026

Waiting for Pixels
30/11/2026 -
14/4/2027

Lowering, insertion, services, connection: ready for full system cold testing
24/3/2028 - 3/8/2028

CONCLUSIONS

Building a detector for operation at the HL-LHC is challenging
→ Radiation hardness, increased granularity, low mass

The new tracking system for the ATLAS experiment for the HL-LHC will cope with increased particle multiplicity and radiation levels

ITk provides large acceptance, large number of points per track, high granularity and radiation hardness with minimised material budget.

The ITk Strip detector is progressing through production and integration
→ sensors, ASICs, modules, structures, services, global mechanics

THANKS FOR YOUR ATTENTION

Andrea García Alonso
agarciaa@cern.ch
PhD thesis: https://cds.cern.ch/record/2790971

BACKUP

Upgrade to HL-LHC

In the High-Luminosity LHC, particle densities and radiation levels will exceed current levels by a factor of 10

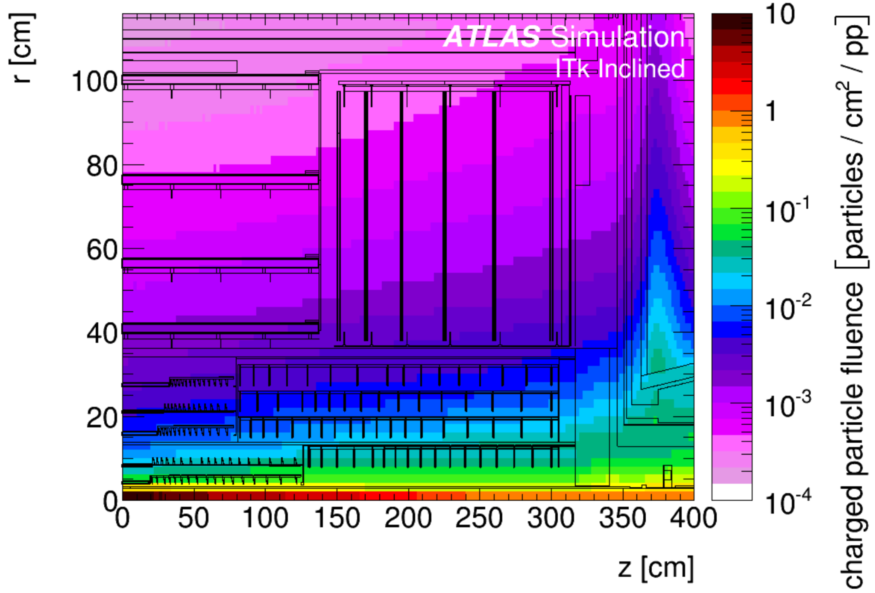
Instantaneous luminosity will reach unprecedented values: 7 × 10^{34} s^{-1} cm^{-2}, up to 200 p-p interactions per bunch crossing

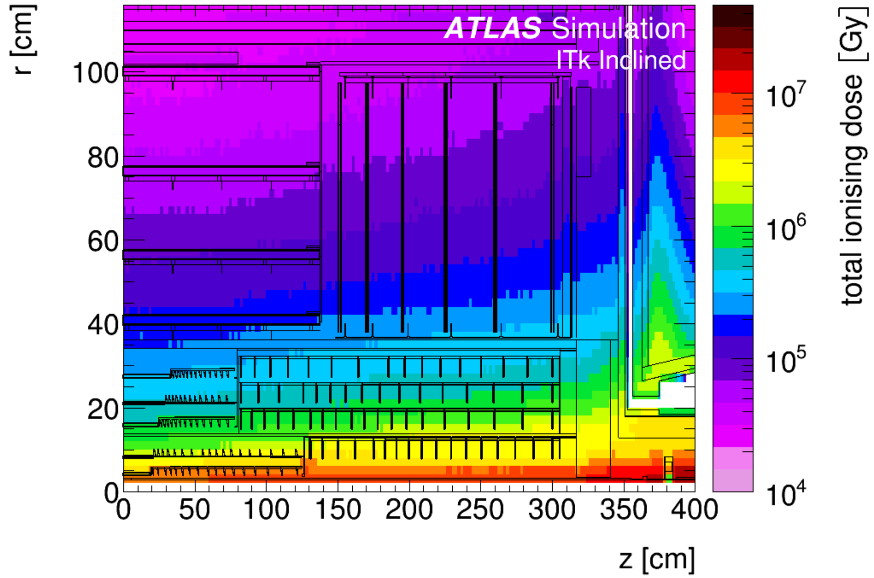
The ATLAS detector will operate after exposure to large particle fluences

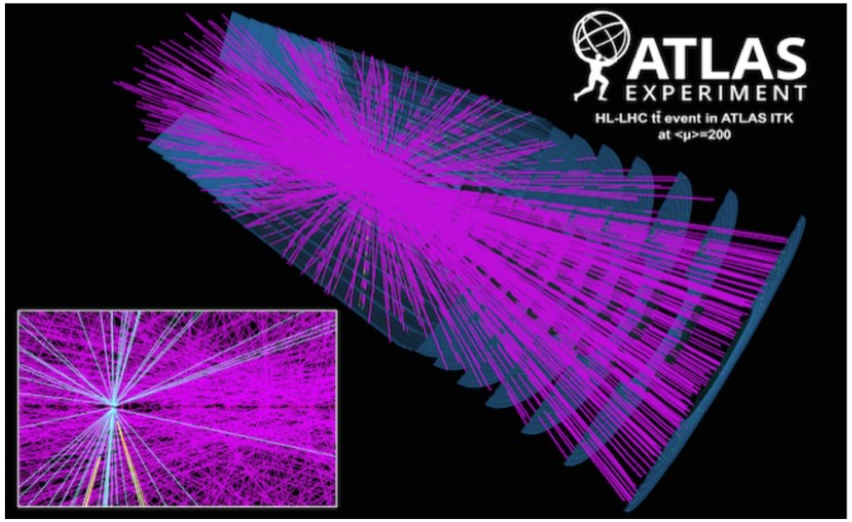
Upgrading is required to guarantee a working detector in these conditions

The current tracking detector will be completely replaced to deal with the unprecedentedly high levels of radiation and pile-up of the collider

Plot from: Technical Design Report for the ATLAS Inner Tracker Strip Detector. ATLAS-TDR-025

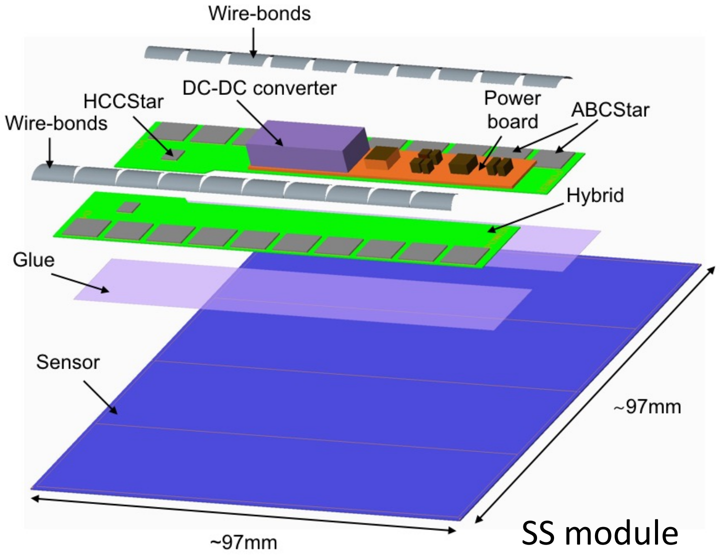


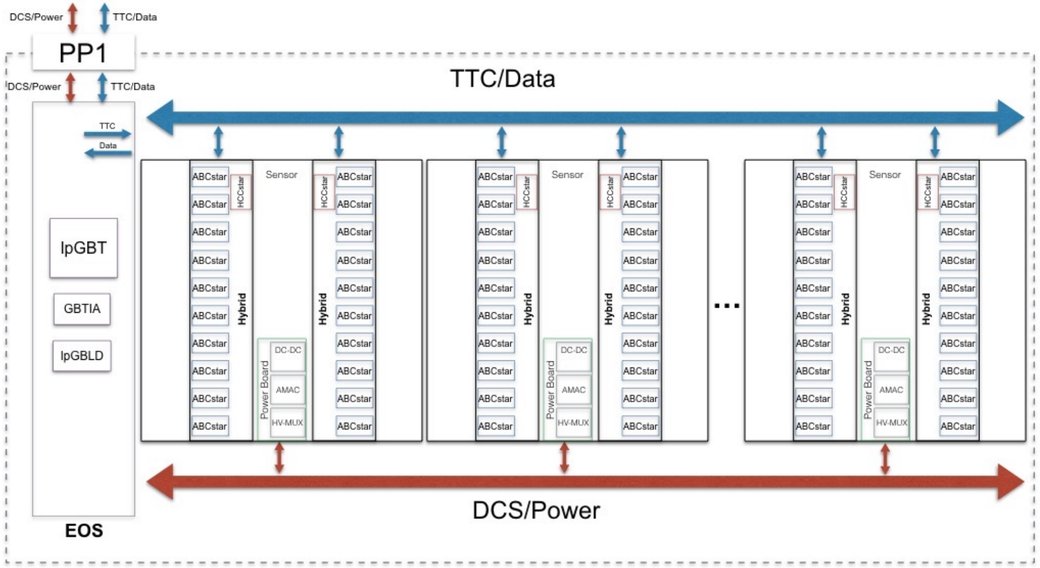




Proton-proton collision in the future ATLAS inner tracker, during HL-LHC

The strip barrel. Staves





Segmented Multidrop controls @160Mbit/s
Point to point data at 640 Mbit/s

LV power bus at ~11V
4 (2) HV lines at <550V
Common LV/HV return
AMAC control & data

→ **Hybrid** (readout PCB) glued to sensors.
Readout ASICS glued to hybrid, wire-bonded to sensor:

ATLAS Binary Readout Chips (AB
Hybrid Controller Chips (HCC)

→ **Power board** (power PCB) for modu
Control and monitoring ASIC:

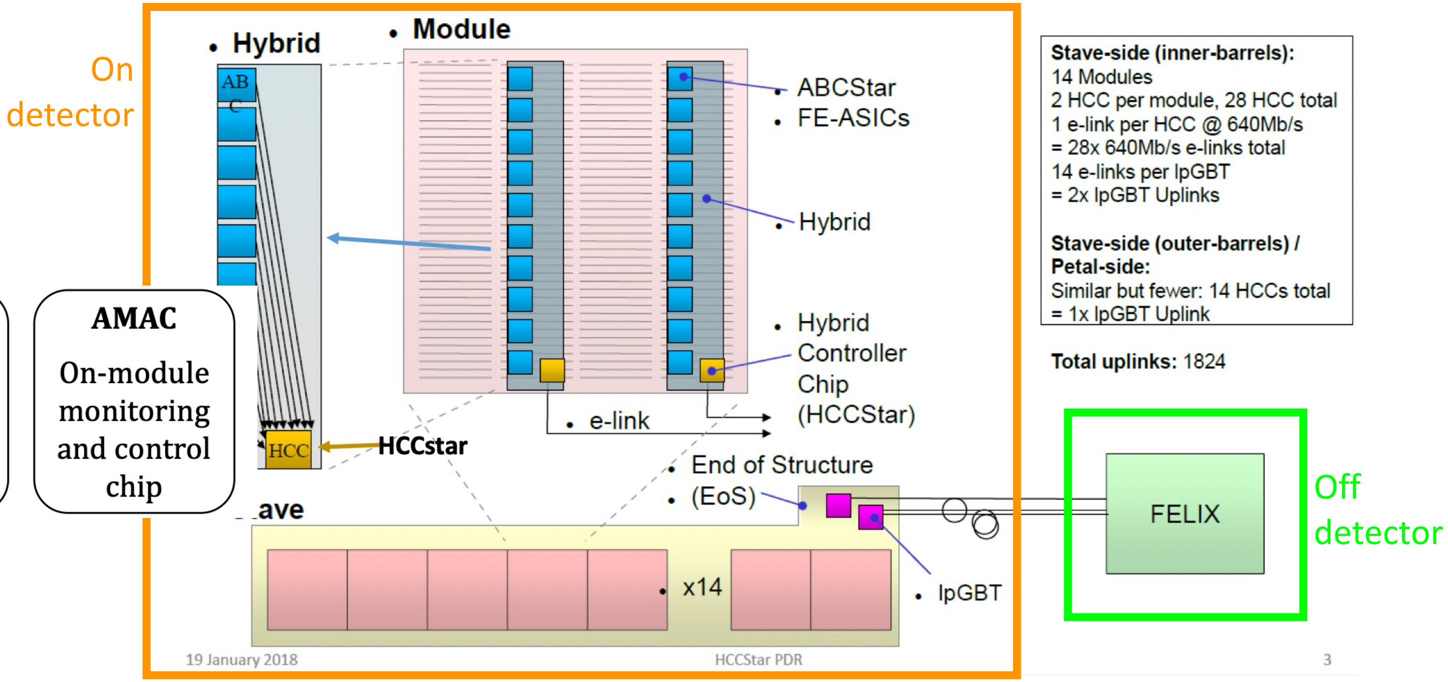
Autonomous Monitor And Control ASIC (AMAC)

DCDC converter for LV powering – ITk Strip Baseline powering scheme uses parallel powering with DC-DC converters
Sensor biasing via HVSwitch

ABCStar
Front-end chip
Binary readout

HCCStar
On-hybrid digital interface chip

AMAC
On-module monitoring and control chip



Stave-side (inner-barrels):
14 Modules
2 HCC per module, 28 HCC total
1 e-link per HCC @ 640Mb/s
= 28x 640Mb/s e-links total
14 e-links per lpGBT
= 2x lpGBT Uplinks

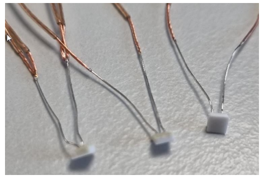
Stave-side (outer-barrels) / Petal-side:
Similar but fewer: 14 HCCs total
= 1x lpGBT Uplink

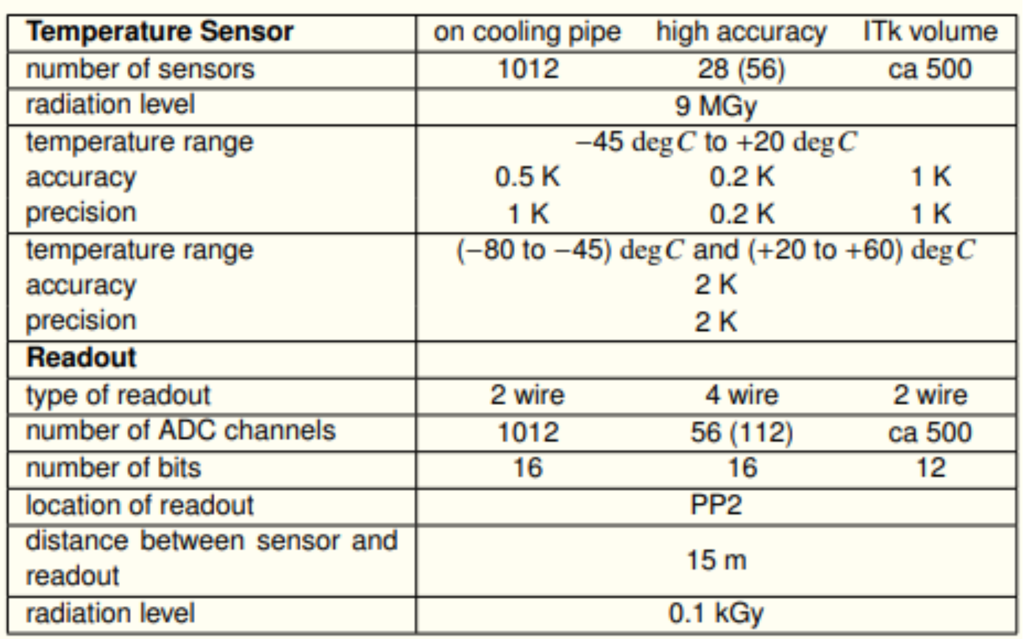
Total uplinks: 1824

Adapted from https://indico.cern.ch/event/688153/contributions/2964638/attachments/1655815/2650557/ATLAS_Star_Chipset_c-2.pdf

Strips. Integration & installation
More about T and H monitoring

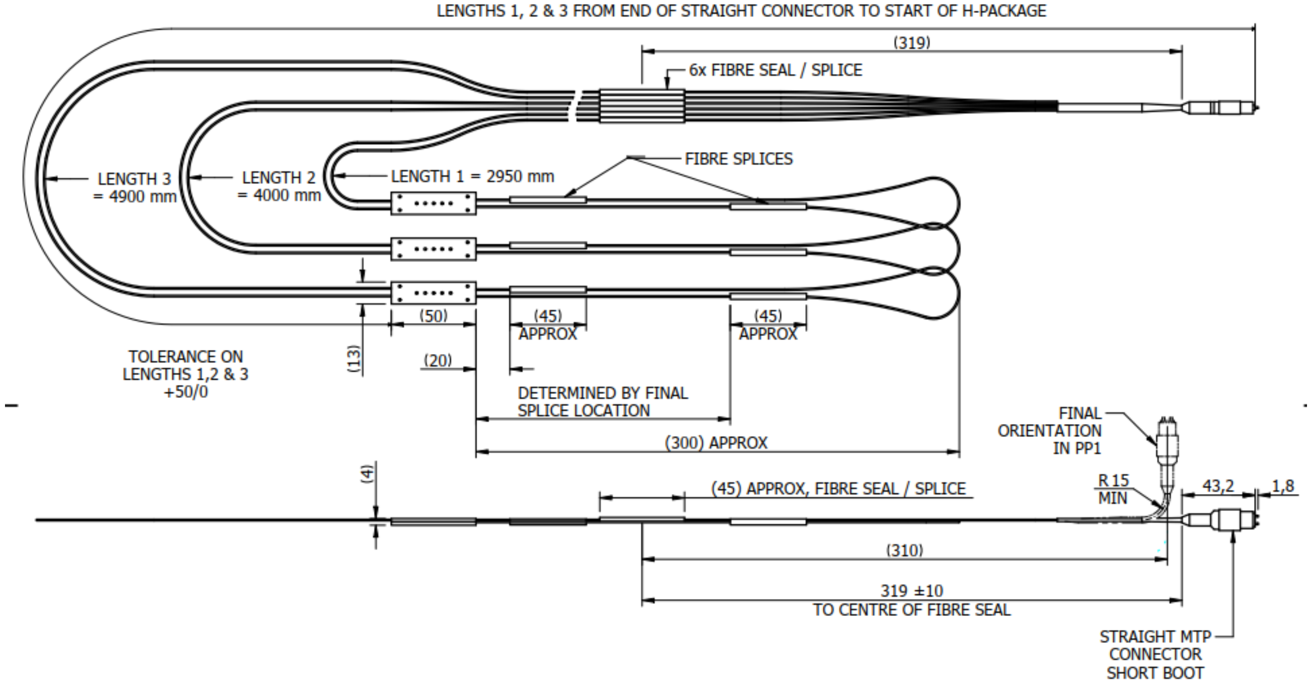
More than 500 T sensors in ITk volume for a 9MGy radiation level



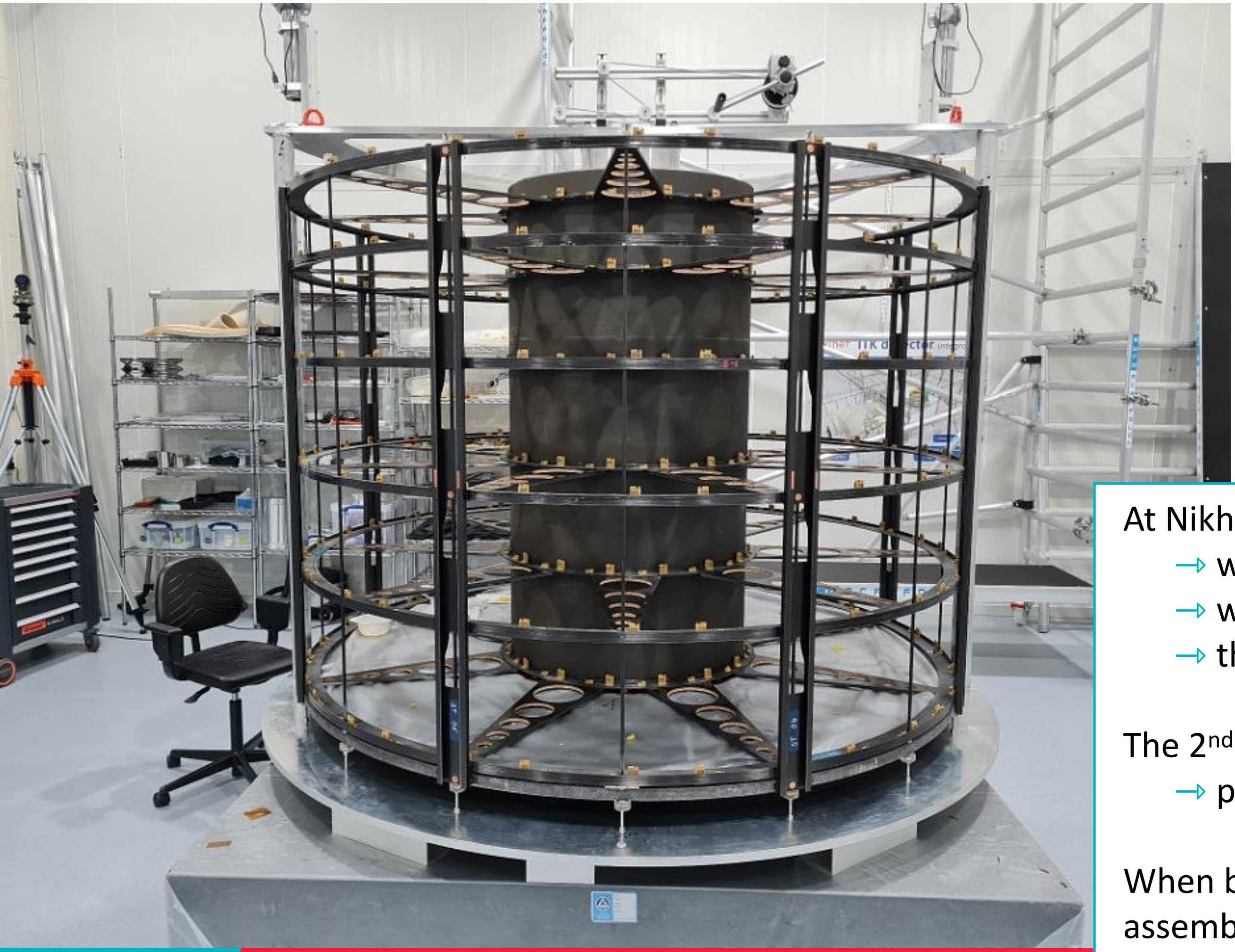


Temperature Sensor	on cooling pipe	high accuracy	ITk volume
number of sensors	1012	28 (56)	ca 500
radiation level	9 MGy		
temperature range	-45 deg C to $+20$ deg C		
accuracy	0.5 K	0.2 K	1 K
precision	1 K	0.2 K	1 K
temperature range	$(-80$ to $-45)$ deg C and $(+20$ to $+60)$ deg C		
accuracy	2 K		
precision	2 K		
Readout			
type of readout	2 wire	4 wire	2 wire
number of ADC channels	1012	56 (112)	ca 500
number of bits	16	16	12
location of readout	PP2		
distance between sensor and readout	15 m		
radiation level	0.1 kGy		

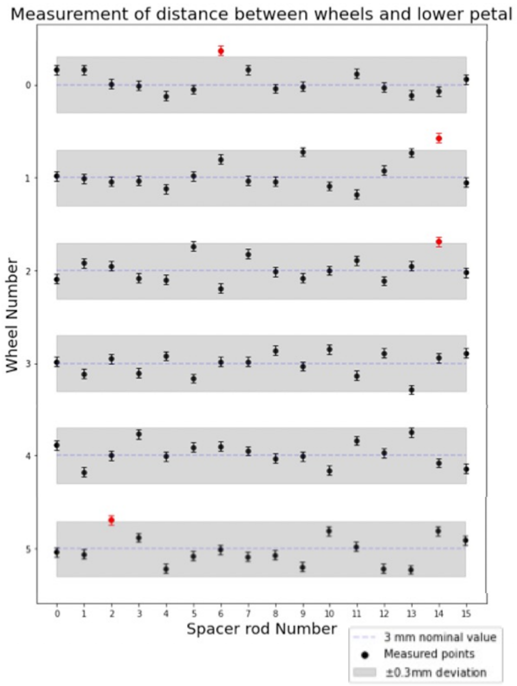
12 radiation hard fibre optic humidity sensors in Strip detector (LPG+2FBG)

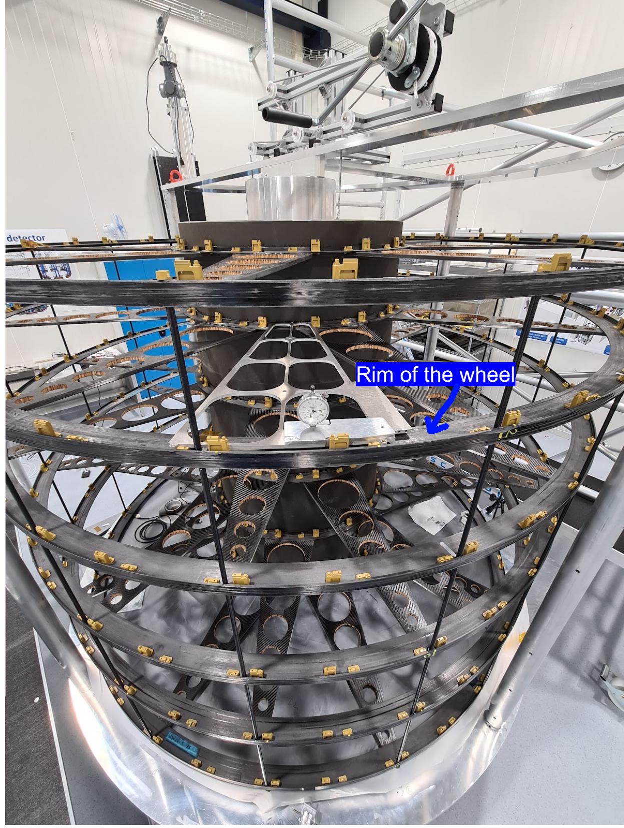


End-caps. Integration & installation



https://indico.cern.ch/event/1176882/





At Nikhef, the construction of the 1st end-cap structure is finished

- → wheel notches, to solve issue with some petals RF-box
- → working on CF support beams installation
- → this EC will be sent to DESY for petal insertion this year

The 2nd end-cap will start to be built at Nikhef soon

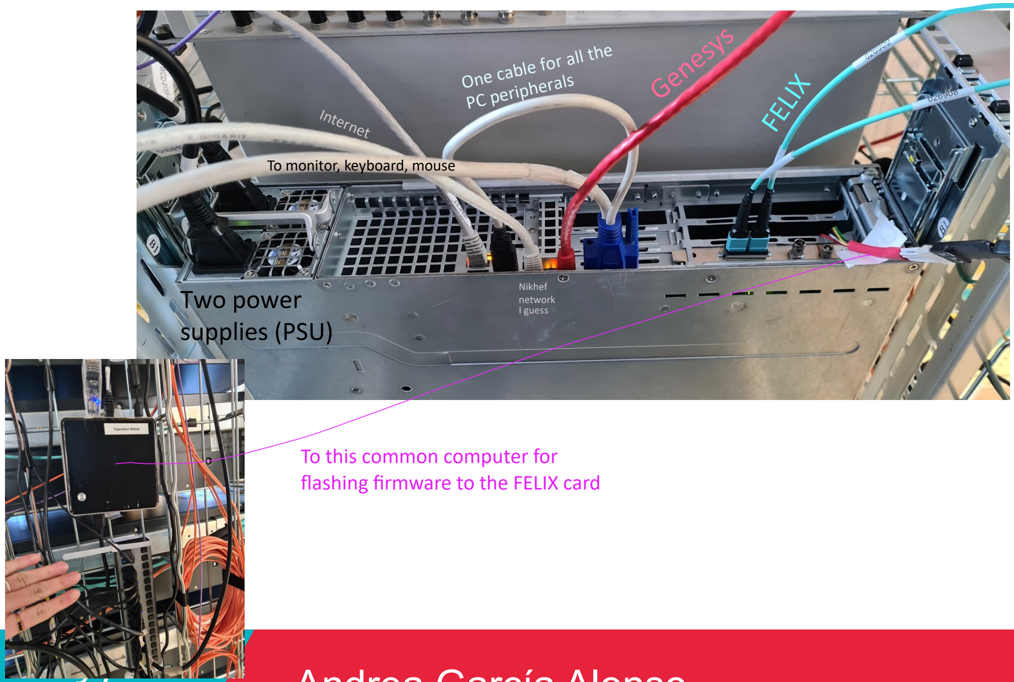
- → petal insertion will take place at Nikhef too

When both end-caps are final, they will be shipped to CERN for assembling with the barrel

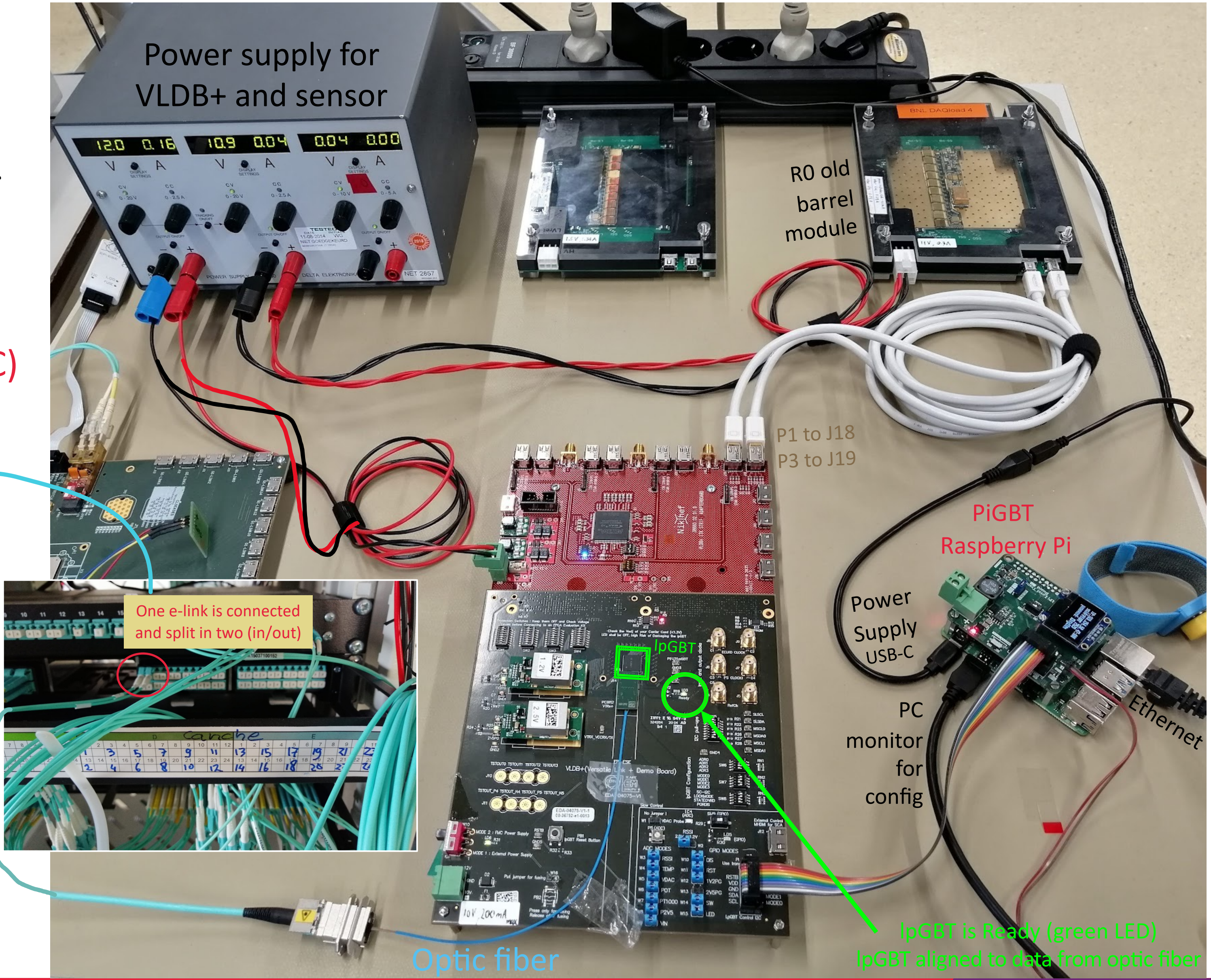
DAQ activities. FELIX

- The module is an old R0 barrel without AMAC chip, with one HCC star and one ABC star
- Communication is reached, links are aligned, all dependencies for scans are working in the ITk-server
- readout hybrids with
    - front-end chips (ABCStar)
    - Hybrid Controller Chip (HCCStar)
- Autonomous Monitor And Control ASIC (AMAC) (for control and monitoring)

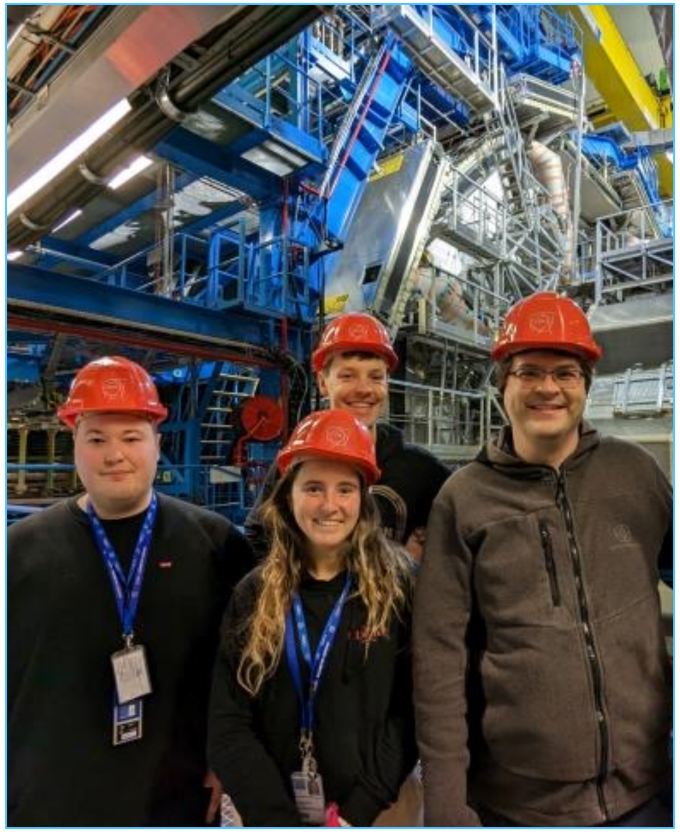
ITk-server



To this common computer for flashing firmware to the FELIX card



DAQ - The EC team



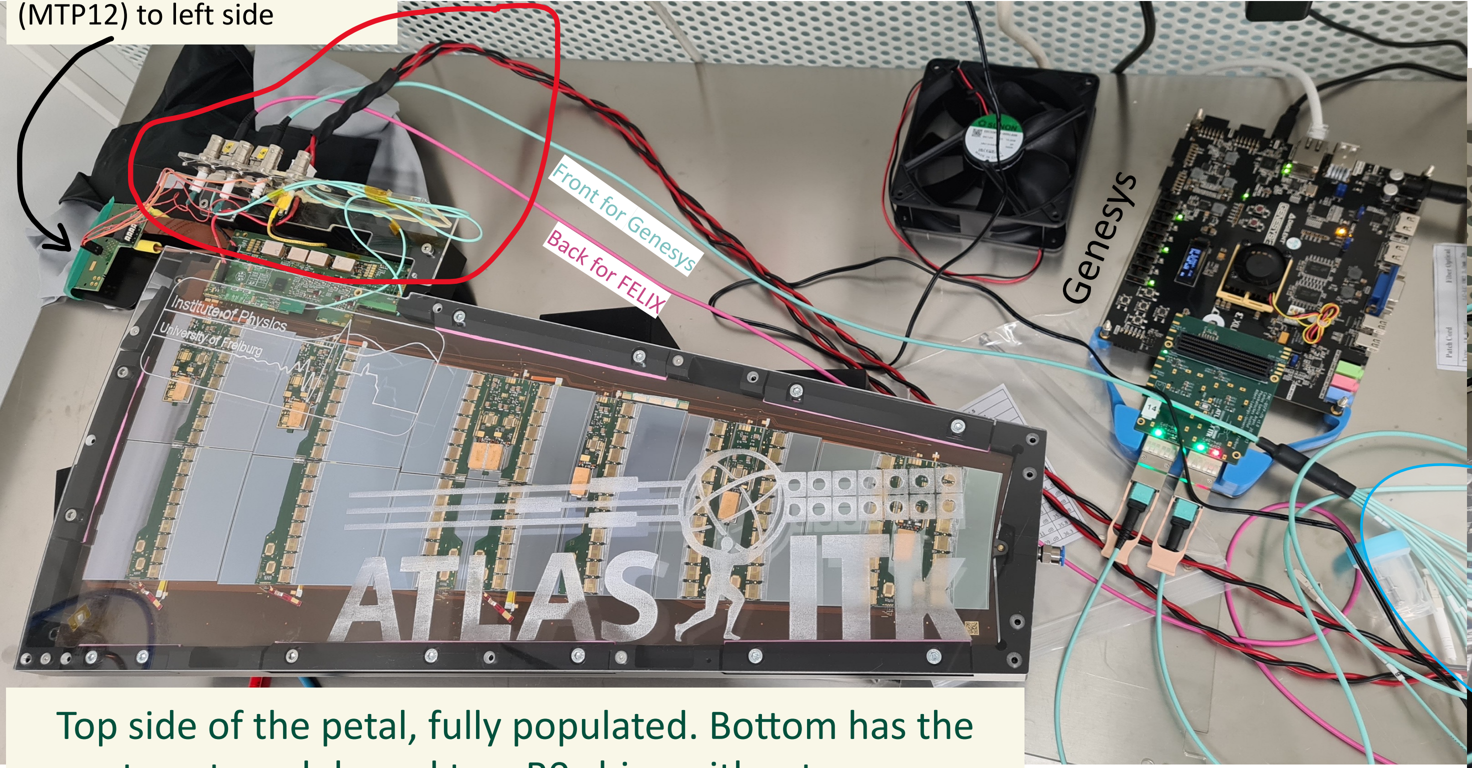
Visit to ATLAS during the EC team (Max, Jan-Hendrik, Dennis, myself) visit to SR1 in January 2023

Team working on the preparation of DAQ setups for petal reception and petal testing:

- Universität Freiburg → Dennis Sperlich
- DESY → Maximilian Caspar, Jan-Hendrik Arling, Lennart Huth
- Nikhef → Andrea García Alonso

Many thanks to the barrel SR1 team for showing and explaining their setup, as well as helping to get ours running!

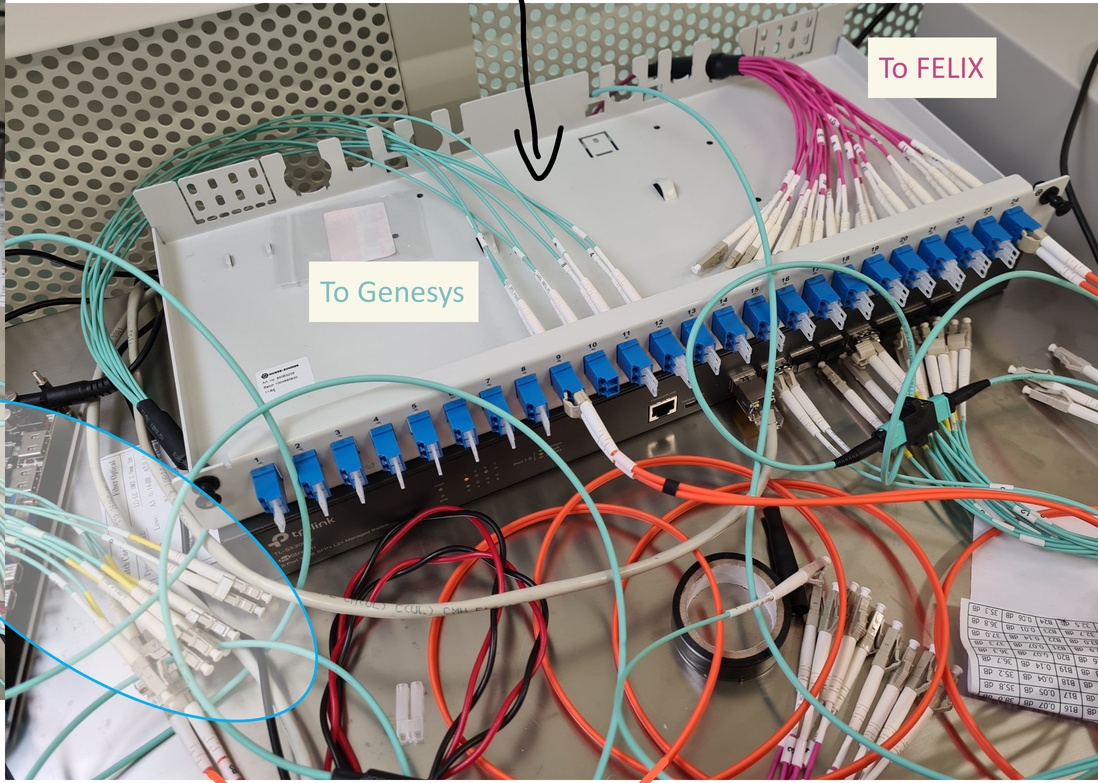
DAQ setup - Freiburg. Genesys and FELIX



Final EoS will substitute this with a simple connector (MTP12) to left side

Top side of the petal, fully populated. Bottom has the outmost module and two R0 chips without sensors

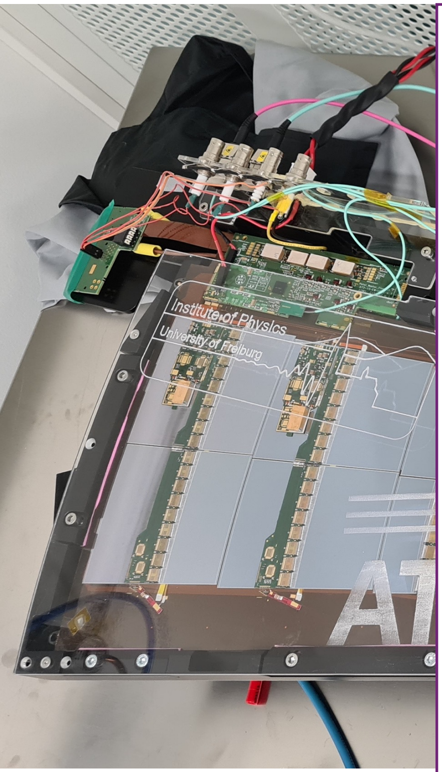
Genesys can read 2 full petals at the same time (8 fibers)



One fiber per lpGBT → two fibers per petal (2 sides = 2 lpGBTs)

Each fiber gets split into 12, from which only 2 are not empty (in + out of the fiber from the petal). These two are connected to the bulkhead to change to the bunch of eight optic fibers that go to Genesys

DAQ setup - Freiburg. Genesys and FELIX



- Successful communication with petal lpGBT through both Genesys and FELIX
- Implementing modifications for FELIX scans on petals, based on the repositories created by the SR1 team for staves
- Preparation for running scans
- Implemented first version of petal readout in FELIX → still to be tested/validated

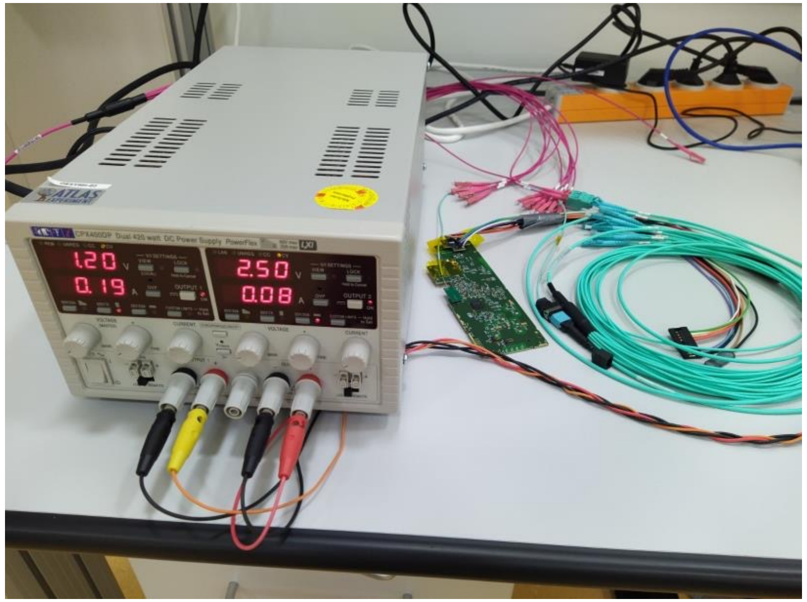
DAQ setup - DESY. Genesys and FELIX

Tested the FELIX readout with a EoS secondary board:

- installation of FELIX packages
- routing of optical fibers
- configuration of lpGBT and register readback
- successful demonstration of complete readout chain

At the moment waiting for PPB petal with R5 module from TRIUMF for real petal tests and scans:

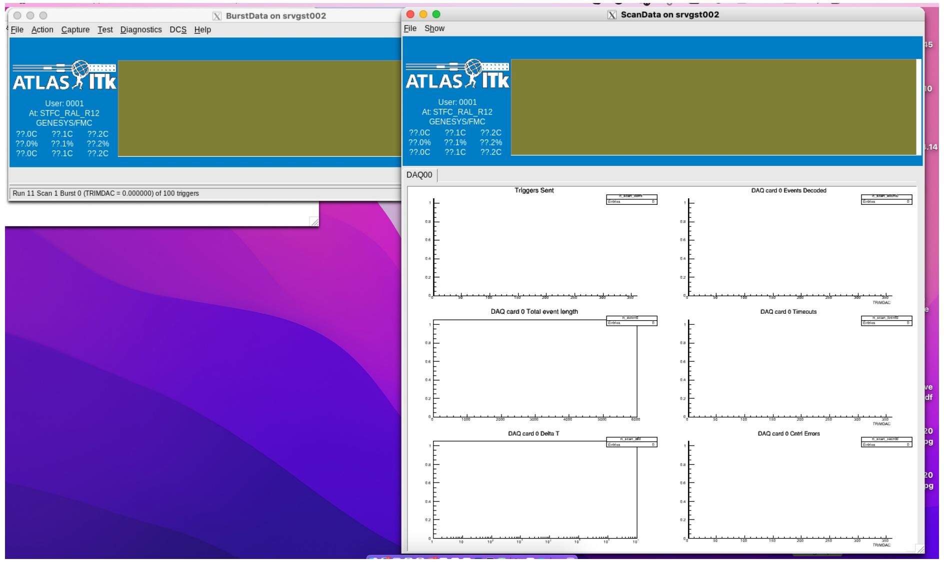
- testing with FELIX and ITSDAQ (parallel Genesys setup available)
- implementing and testing petal-specific changes for HCC/ABC mapping
- testing of lpGBT v1 within FELIX



DAQ setup - Nikhef

Genesys

One fiber comes from the lpGBT to the 12-channel LC connector. 10 channels go empty through the LC connector till the transceiver to the FMC-QSFP.
This is the same setup as the FELIX one, substituting the optic fibers bulkhead and the FELIX server with a connector and the Genesys card.



```
User: 0001
At: STFC_RAL_R12
GENESYS/FMC
??.0C    ??.1C    ??.2C
??.0%    ??.1%    ??.2%
??.0C    ??.1C    ??.2C
```

```
Run 11 Scan 1 Burst 0 (TRIMDAC = 0.000000) of 100 triggers
```