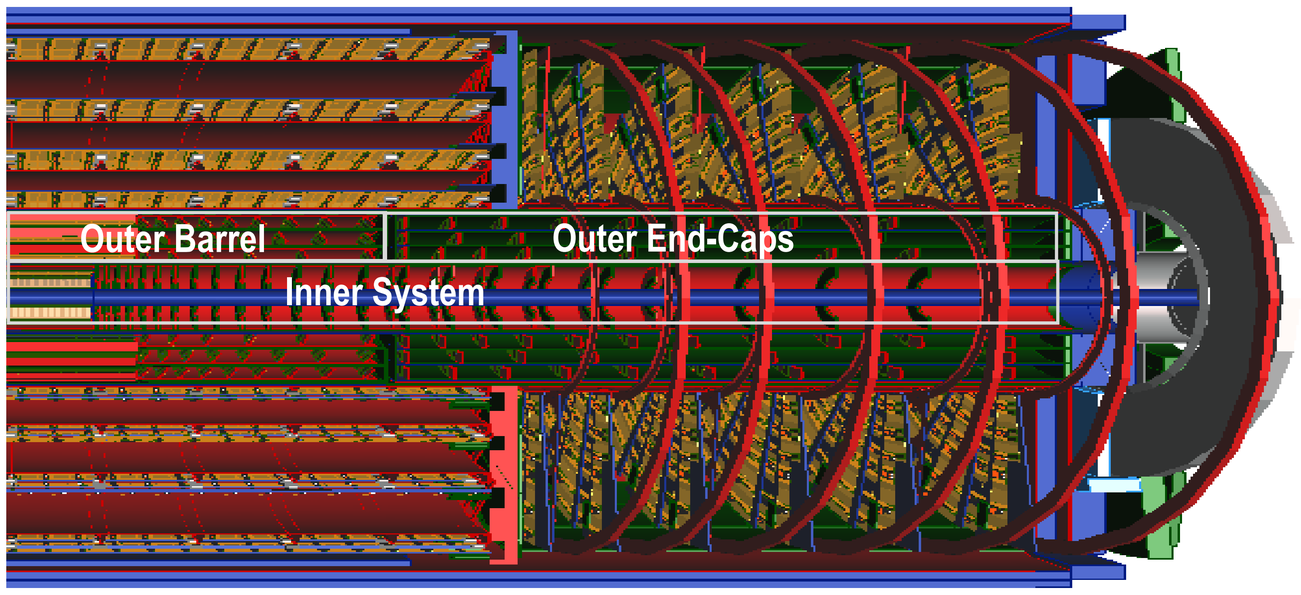
ITk Pixel System Test for the ATLAS Experiment



ITk in a Nutshell

Motivation to HL-LHC

New phase for the LHC machine will be upgraded to explore the Higgs boson properties with higher precision, search for new particles beyond the Standard Model, handle proton-proton collisions up to 14 TeV.

Phase	Peak Luminosity	Pile-up Interactions	Integrated Luminosity
LHC	34×10^{34} cm^{-2} s^{-1}	50	300 fb^{-1}
HL-LHC	10^{36} cm^{-2} s^{-1} ↗ x3	200 ↗ x4	4000 fb^{-1} ↗ x13

ITK Detector Requirements

Challenge: Unprecedented number of collisions per bunch crossing, dense tracking environment, higher radiation dose/fluence.

Solution: Construct an extreme radiation hardness, very high granularity detectors for particle identification in this challenging environment.

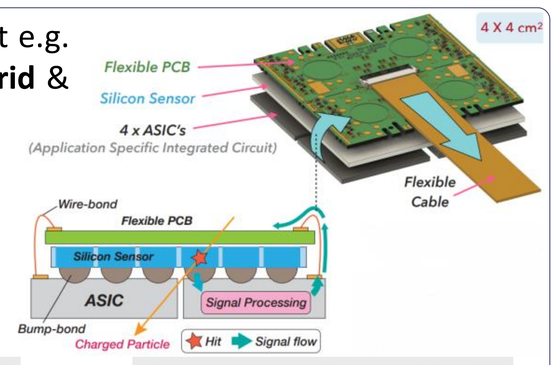
Detector (Pixel)	Area (m²)	Fluences (MeV $n_{eq}.cm^{-2}$)	Total Power (kW)	TID (Grad)
ID	1.9	5×10^{15}	60	0.25
ITk	13.6 ↗ x7	2.5×10^{17} ↗ x10	250 ↗ x4	0.5 ↗ x2

# Modules	# Channels (M)	Pseudorapidity |η|	Readout BW (Mb.s^{-1})
2K	92	<2.5	320
10K ↗ x5	5100 ↗ x55	<4 ↗ x1.6	5120 ↗ x16

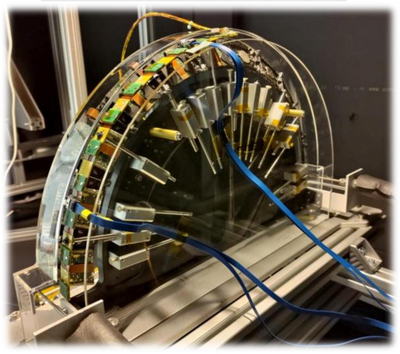
ITk Layout

Complete **All-Silicon tracker**, low material budget e.g. due to **serial powering** & CO_2 **cooling** with **Hybrid** & **3D** Pixel Modules:

- 65nm CMOS Tech.
- SLDO for serial powering.
- Inner layers featuring 3D & Plannar n-in-p.
- Outer layers featuring plannar n-in-p.
- Pixels of 25x100 µm & 50µm².



Outer Barrel (OB)



Three Layers of two Stru.:
Longeron & inclined half rings
In OB flat & Inclined section
66 Lngrs (2376 M.) & 92 IHRs (2096 M.)

Inner Sys. (IS)

Two rings L_0 & L_1:
Innr R. of 3D M. & Outer R. of Plannar M.
Inner Part replaceable after 2000 fb^{-1}
396 3D M. & 1160 Plannar M.

Outer End-Caps (OEC)

Three rings L_2 & L_3 & L_4:
2344 Plannar Pixels distributed on Half Rings.

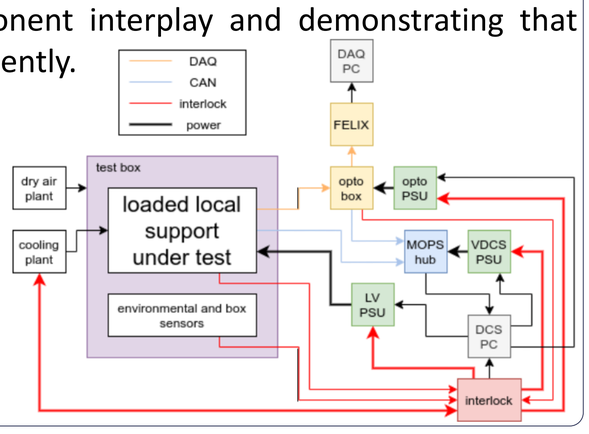
ITk Pixel Sys. Test

Proof of Concept of ITk Detector Services

Motivation and Goals: Construct a prototype to mimic the real detector, enabling **design validation** and testing of component interplay and demonstrating that detector units meet requirements consistently.

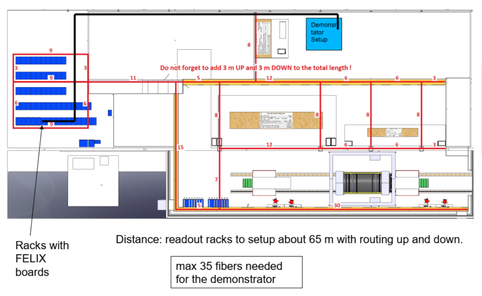
Main study objectives:

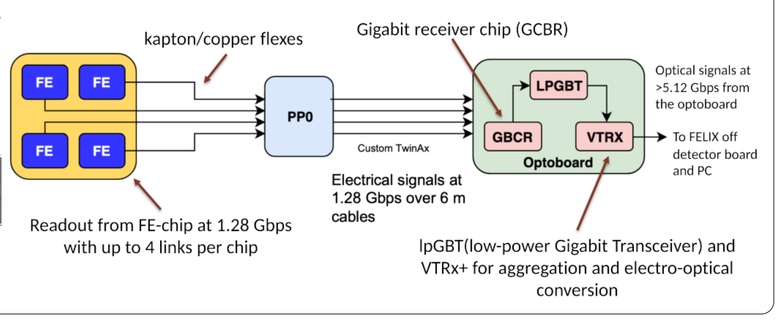
- Serial Powering.
- LLS validation with QC for production.
- Detector Control System (DCS).
- Interlock Matrix.
- CO_2 cooling.
- Data Transmission & DAQ.



Data Transmission

Each front-end (FE) chip supports up to 4 × 1.28 Gbps uplinks (vs. 160 Mbps in the current ID) with up to 16 links per quad module. GBCR interfaces with lpGBT and VTRx+ for data transmission at 10.24 Gbps over 65m optical cables, using FELIX for efficient DAQ handling.

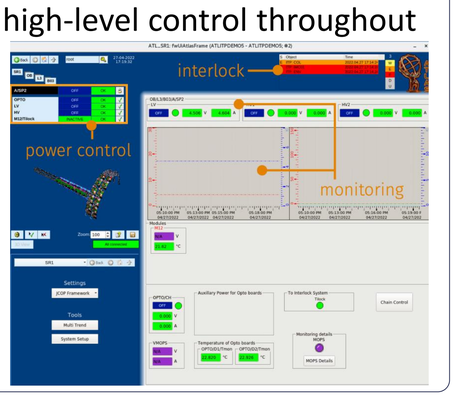




Detector Control System (DCS)

Developed DCS with GUI for managing large multi-module detector assemblies. It uses a Finite State Machine to provide efficient, high-level control throughout all operational states.

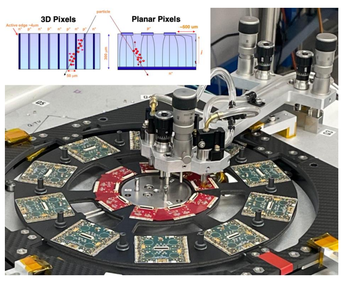
Interplay different sub-systems, e.g. the interlock to ensure safety of modules and operators with collected data from MOPS that reads each module voltage and temperature. Configure module DAQ, power and monitoring.



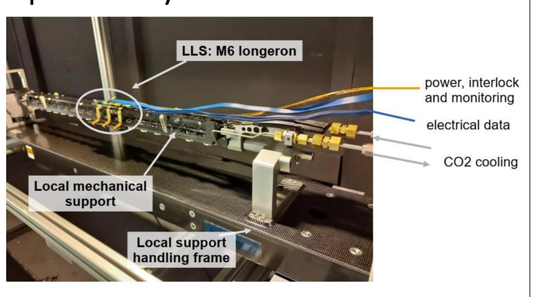
RD53A Modules Program

All Local Loaded Support (LLS) types were tested, providing the first opportunity to assess complete detector system. Using **RD53A** prototypes, Quality control assessments of components with modules performance were tested to demonstrate indiv. testing doesn't differ from collective test. IV, electrical scans and cooling were compared before & after loading on LLS to ensure repeatability of measurements.

OEC half rings with RD53A pixel quad at RAL (UK)



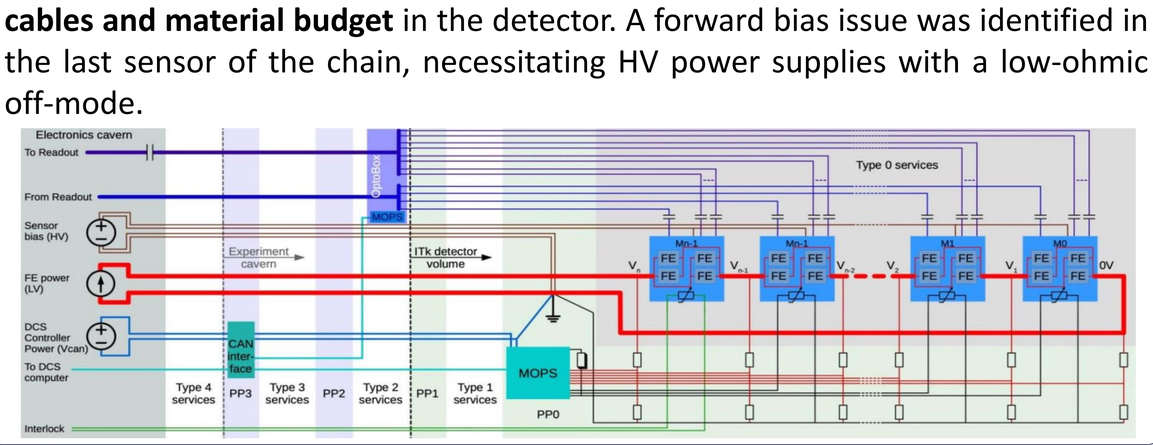
Inner sys. Triplet & 3D sensors onto a coupled ring at SLAC (USA).



OB demonstrator test stand at SR1 (CERN) populated with RD53 quads.

Serial Powering

Front-end ASICs in different quad modules are serial powered. Serial powering chains can connect up to 13–14 modules, **significantly reducing the required cables and material budget** in the detector. A forward bias issue was identified in the last sensor of the chain, necessitating HV power supplies with a low-ohmic off-mode.



Outlook

Plan: In early 2025, preproduction detector units of the Outer System (OB + OEC) will be assembled to build a detector slice. A successful slice test will initiate full-scale production of the pixel detector units.

References

ATLAS Inner Tracker Pixel Detector: Technical Design Report, CERNLHCC-2017-021, CERN, 2017 | Expected Tracking and Related Performance with the Updated ATLAS Inner Tracker Layout at the High-Luminosity LHC, ATL-PHYS-PUB-2021-024, CERN, 2021

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