
# Overview of the ATLAS ITk Pixel Detector Project

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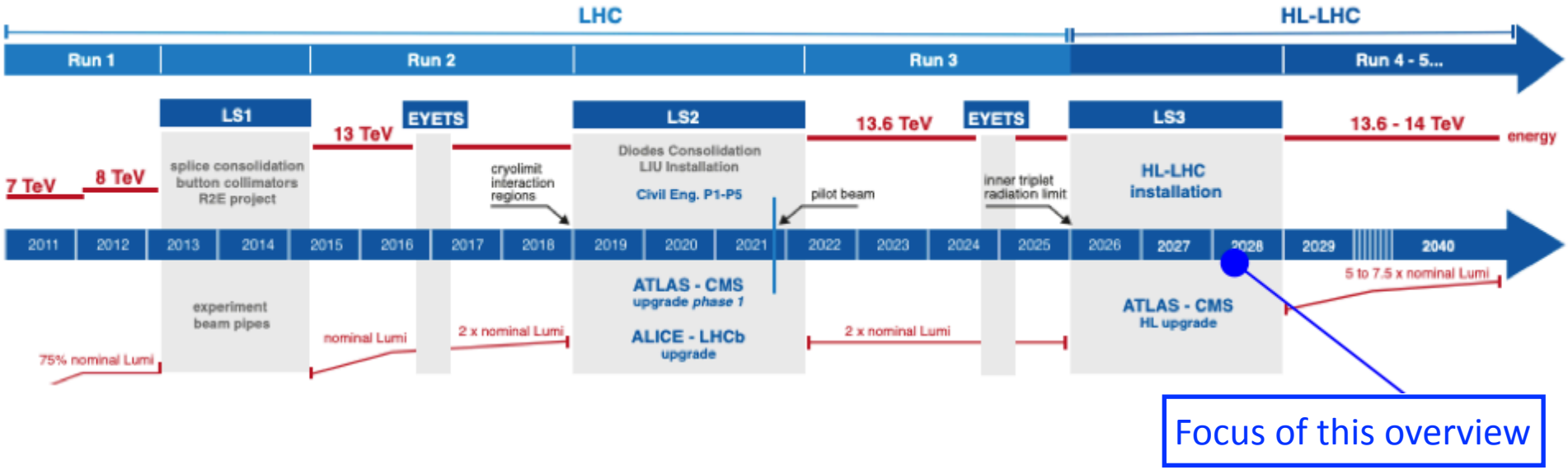
CEPC Workshop October 23, 2023

# The ATLAS Upgrade Programme for HL-LHC

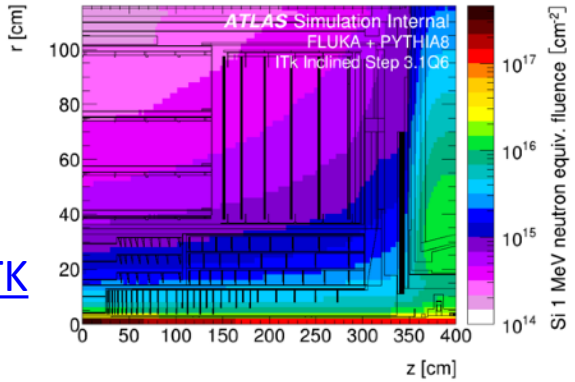


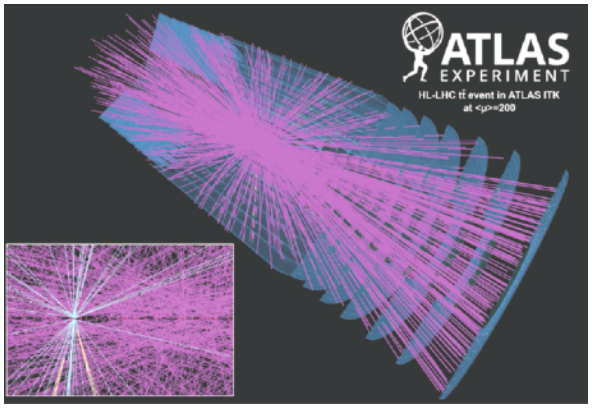

- HL-LHC enables a broad physics programme through a 10-fold increase in luminosity starting after Long-shutdown 3 (LS3)
  - recently CERN approved LS3 start with December 2025 and will last 36 months
  - ATLAS just completed its Phase-I upgrade (e.g. New Small Wheel muon detector) and pursues all HL-LHC Phase-II Upgrade projects now in parallel to Run-3 data taking

# Challenges for pp-experiments at HL-LHC

- → Instantaneous nominal luminosity x 5-7 and integrated luminosity x10
  - New radiation hard sensors - complete new tracker
  - Finer sensor granularity
- → Increase of overlapping proton-proton events (pile-up) from <μ> ~ 50 now to <μ> ~ 200
  - Additional energy in calorimeters, accumulation of “pile-up” jets especially in the forward region
  - High hit rates of up to 3GHz/cm$^2$ in tracker center
- → Increase readout rate 10-fold (L0 trigger rate 1 MHz)
  - requires new front-end and/or back-end electronics for many sub-detectors
  - new DAQ and trigger system to cope with complex high-rate trigger and band-width requirements

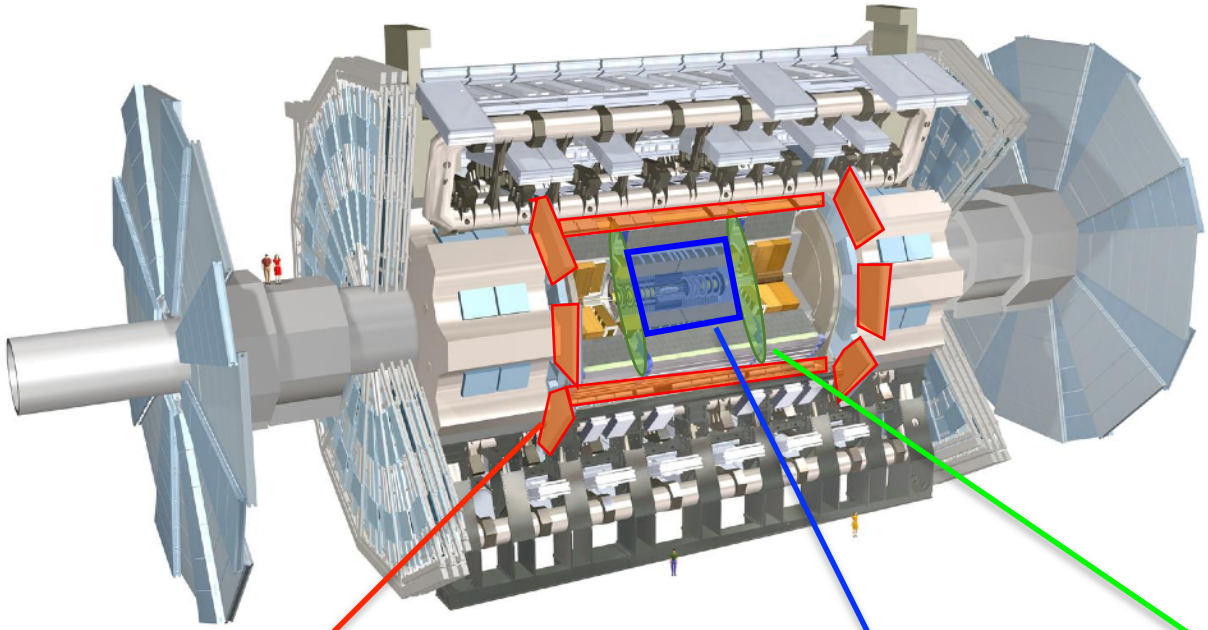
[NIEL fluence ITK]




Simulated event with ttbar events and average pile-up of 200 collisions per bunch crossing

# ATLAS Phase-II Upgrade Projects



## Upgraded Trigger and Data Acquisition System

- Single Level Trigger with 1 MHz output
- Improved 10 kHZ Event Farm

## Electronics Upgrades

- On-detector/off-detector electronics upgrades of LAr Calorimeter, Tile Calorimeter & Muon Detectors

## Forward detector upgrades

- Luminosity detectors (1% precision)
- HL-ZDC (Heavy Ion physics)

## New Muon Chambers

- Inner barrel region with new RPCs, sMDTs, and TGCs
- Improved trigger efficiency/ momentum resolution, reduced fake rate

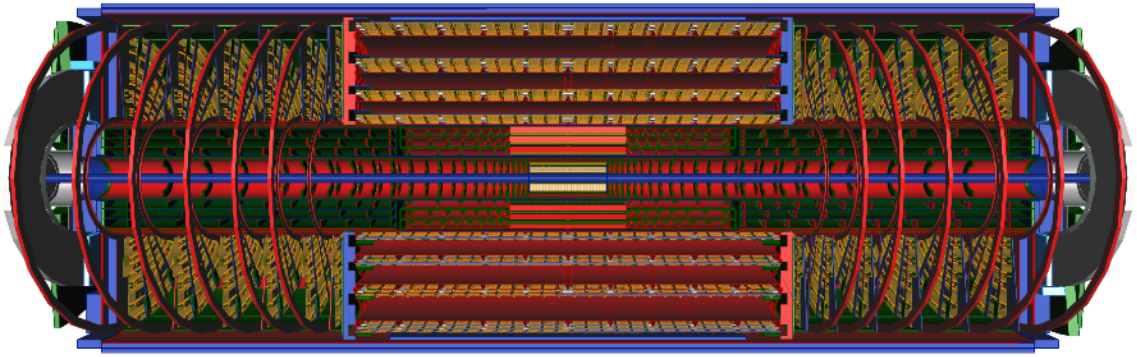
## New Inner Tracking Detector (ITk)

- All silicon with at least 9 layers up to $|\eta| = 4$
- Less material, finer segmentation

## High Granularity Timing Detector (HGTD)

- Precision time reconstruction with Low-Gain Avalanche Detectors (LGAD)
- Improved pile-up separation and bunch-by-bunch luminosity

# ITk Tracker Upgrade



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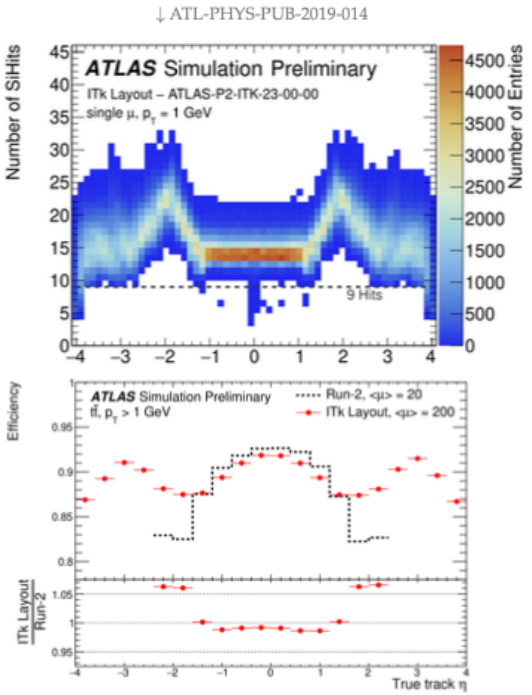
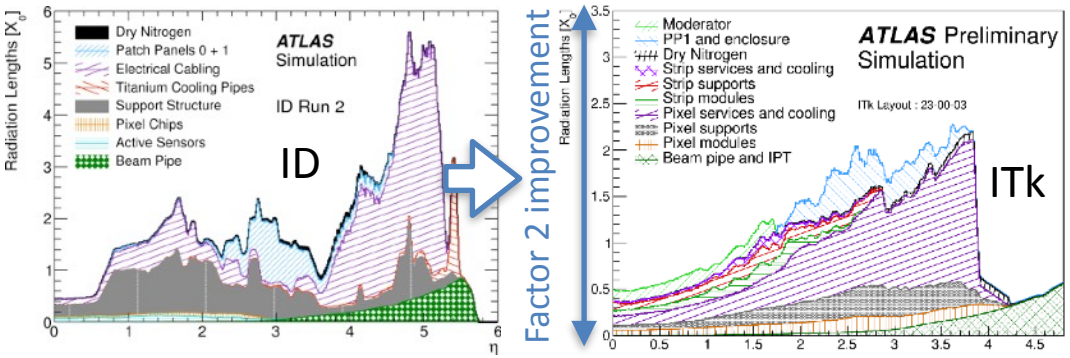
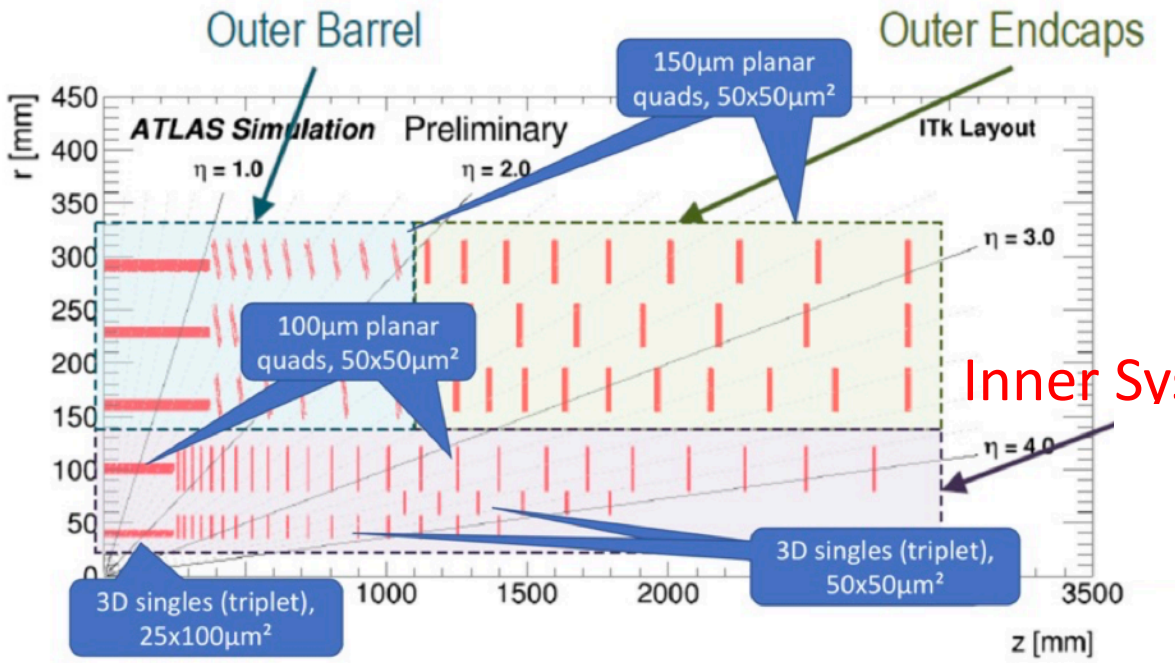



- ITk tracker consists of outer strip tracker and inner pixel tracker to replace current ATLAS "Inner Detector"
  - 168 m² of silicon strip and 13 m² of silicon pixel
  - designed to withstand up to $10^{16}$ $n_{eq}/cm^2$ on inner most pixel
- Improve impact parameter resolution and robust tracking
  - Coverage increases from $|\eta|<2.5$ (ID) to $|\eta|<4$ (ITk)
  - Provides >9 silicon hits per track
  - Reduced material and finer segmentation
- Current status & activities
  - Global ITk support mechanics in production
  - $CO_2$ Cooling studies and optimisation
  - Preparation for ITk integration in ATLAS Point 1



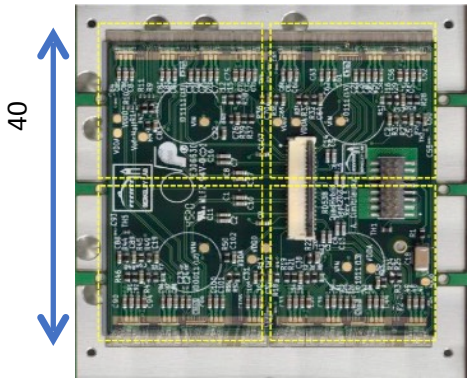
# The ATLAS ITk Pixel Detector

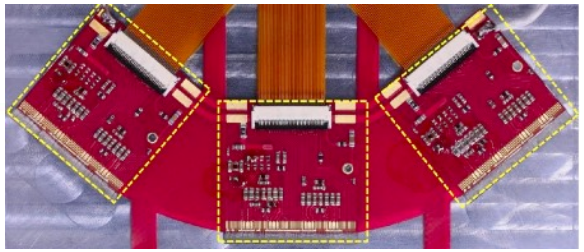
- Outer Pixel system: 3 layer of planar quad modules
- Inner system: 1 layer 3D sensors + 1 layer planar Quad modules.
- Inner system is replaceable




Inner System

Layer 1 – Layer 4



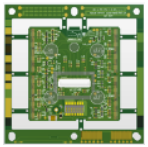



Constructing with about 10,000 modules ~ 13 m² ! (Current : 2 m²)

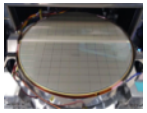
# Production flow

- Number of installed modules 8372 in 5 different types

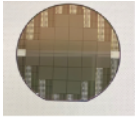
| Modules | Subsystem | Number |
|---|---|---|
| Linear triplets | IS | 96 |
| Coupled ring triplets | IS | 180 |
| Intermediate ring triplets | IS | 120 |
| Thin quad modules | IS | 1160 |
| Thick quads | OB+OEC | 6816 |
| Modules | | 8372 |



ITKPIX FE

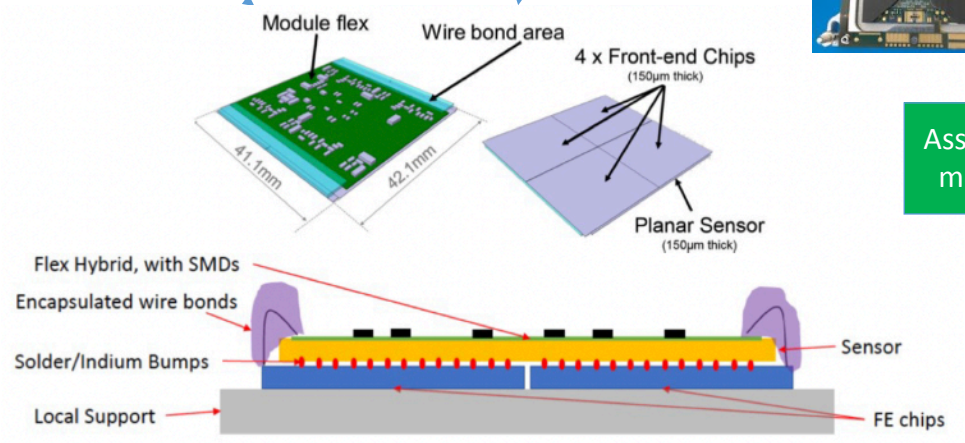


Sensor



Flexible hybrids

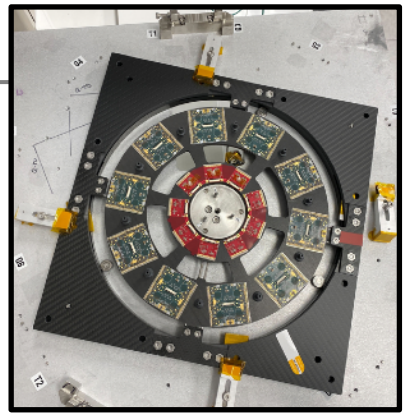
Hybridisation Bare modules



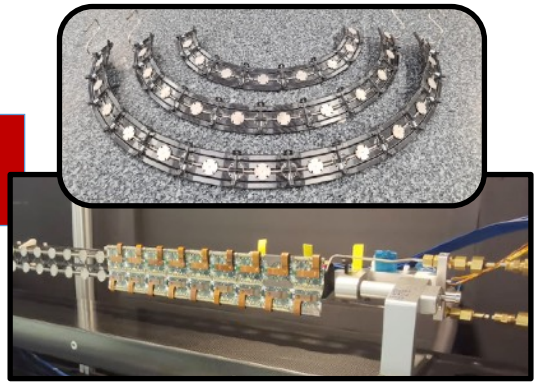

Quad module

Assembled modules

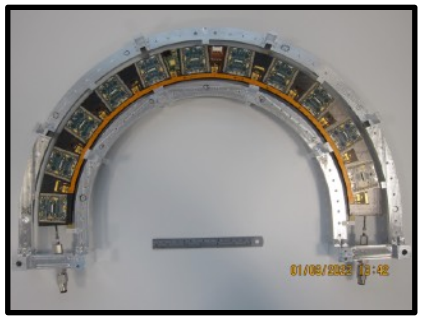
Inner System



Outer Barrel

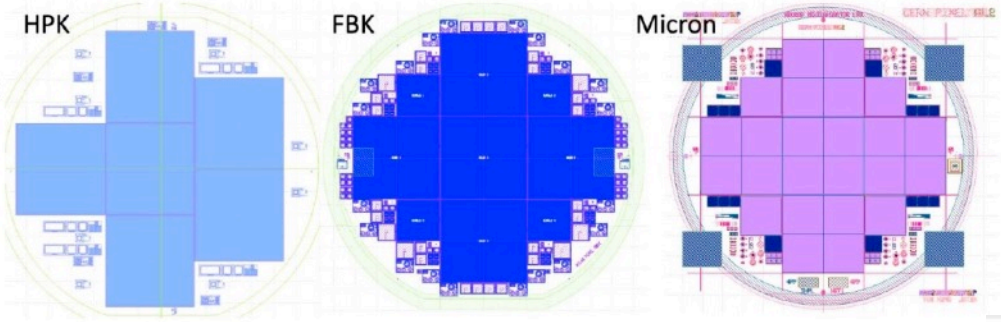


Outer Endcap

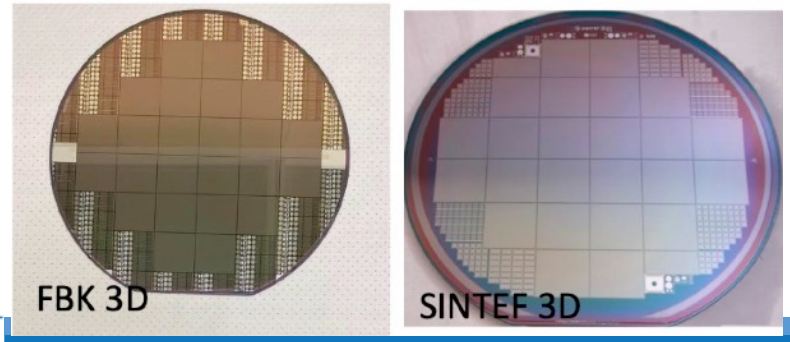


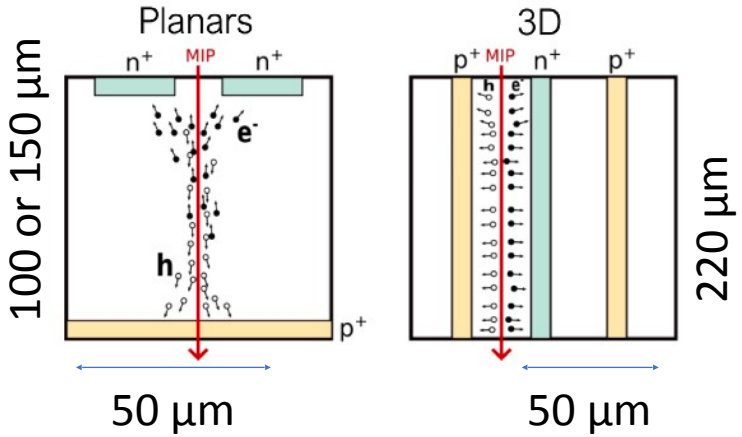
# ITk sensors

- Sensor production in progress
  - preproduction successfully completed and qualified
  - tests in beam tests and irradiations

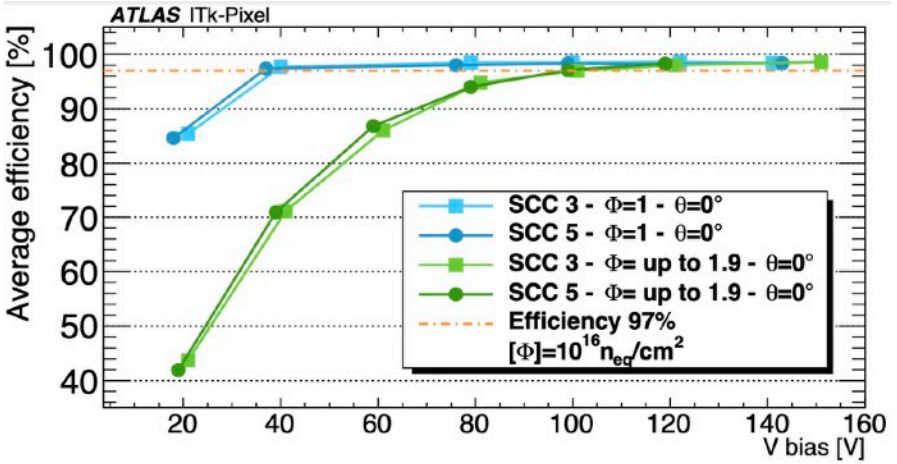



Planer type sensor



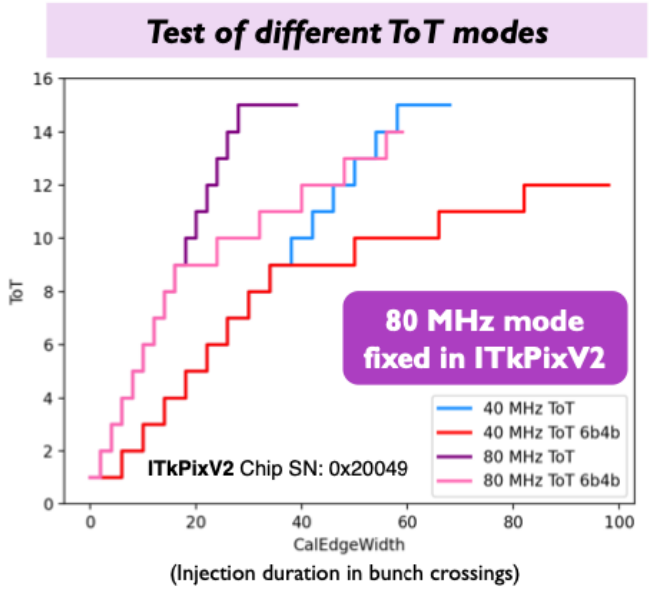



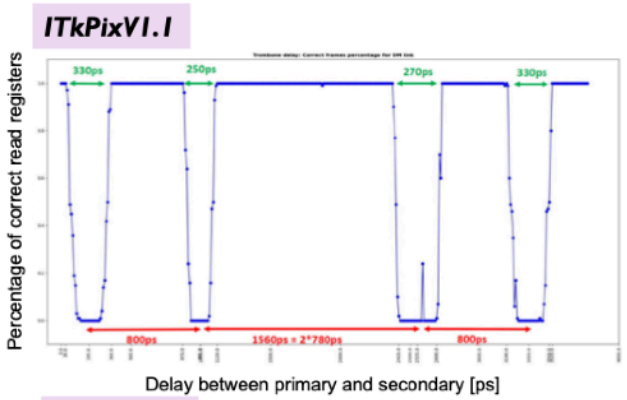

**FBK sensor performance after irrad. (Link)**

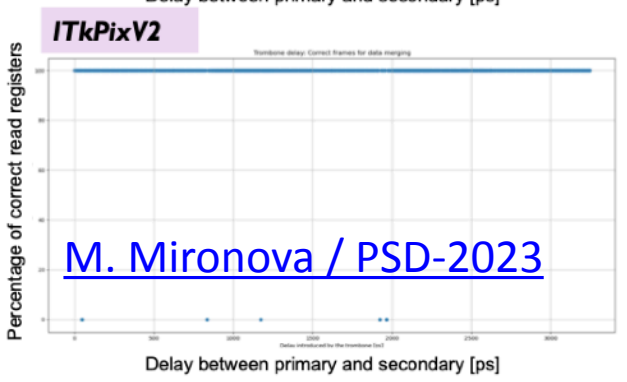


# ITKPIX - The Front-end ASIC

- Developed by RD53 collaboration jointly with ATLAS and CMS support
  - common chip design (slight difference in FE and matrix size)
  - 50×50 μm² pixel size, 153k pixel per FE
- Production Design completed and submitted in March 2023
- First 100 V2 production wafers in hand now
  - Tests on SCC with first diced wafer
  - Wafer probing in multiple sides
- Main focus of tests are verification of fixes implemented from version ITKPIX V1.1 to production version ITKPIXV2
  - Start-up tests SLDO (ok)
  - tests of data merging show that previous bug on V1.1 is fixed
  - TOT working now
  - Threshold tuning at 1000e- ok, thresh. r.m.s. 41e- , mean noise 53e-
  - X-ray irradiation results consistent with previous version (V1.1)



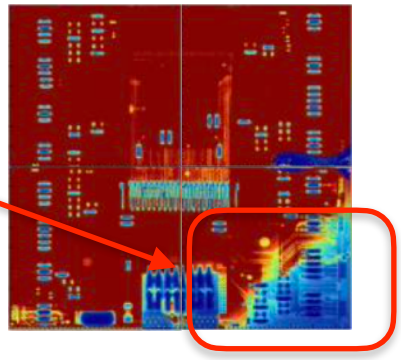




M. Mironova / PSD-2023

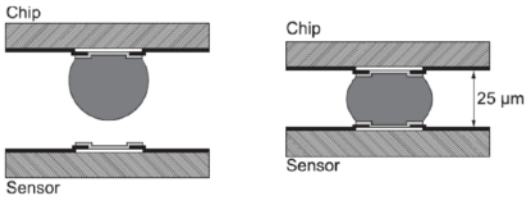
# Hybridization: bump-bonding sensor to ASIC

- Bump-bonding by 4 industrial vendors to complete bare modules
  - Bumping of FE-asic 300mm wafer with Indium or Solder bumps
  - Compatible UBM on sensor
  - Flip chip of 4 ITKPIX to sensor
- Current in preproduction of ~ 600 modules
- Thermal cycling and Connectivity test after module assembly with flex

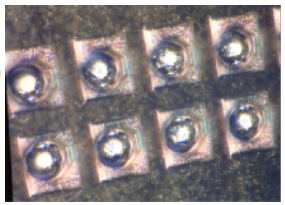
Example of disconnected bumps (reject module)



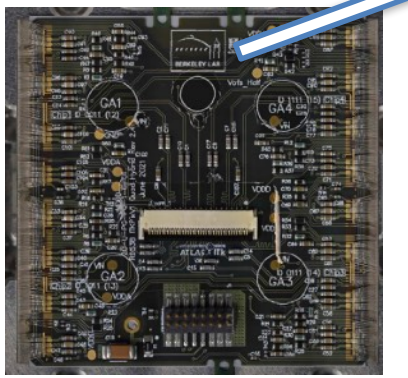
Bump bonding
Technique : Solder and Indium



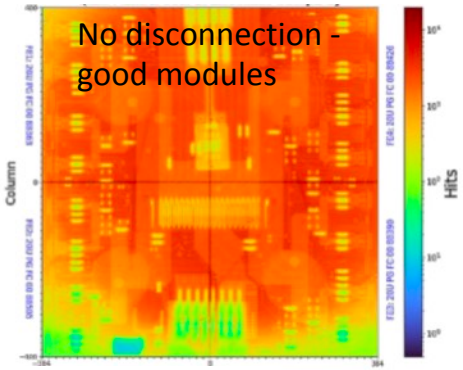

~640k pixels in quads



Assembled Modules



Delamination test with x-ray scan

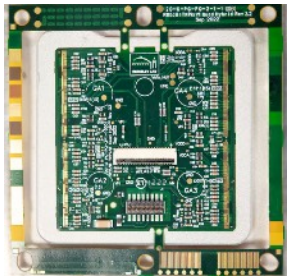



Thermal cycles, -45 – 40 $^{0}$C 100 times

# ITK Module assembly and test

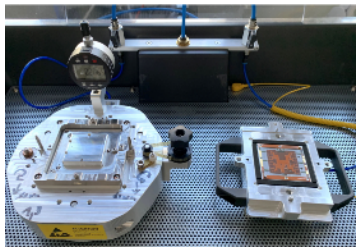
- Currently in pre-production of ~ 500 modules
  - qualify assembly process, QC test procedures and assembly sites
  - provide modules to system test and loading of support structures
  - test of bump-bonding quality and strength

Flex PCB

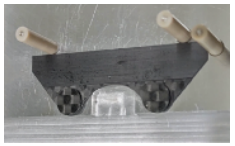


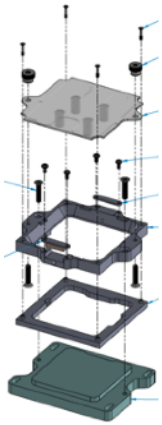
Bare Module

Assembly

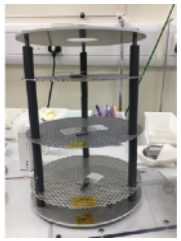


Protection (OB only)

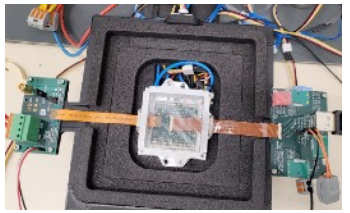




Carrier

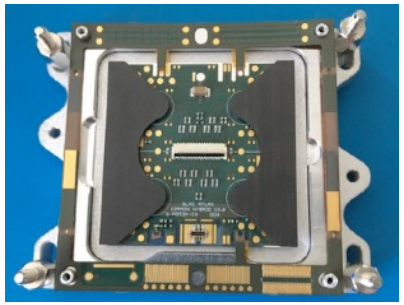


Parylene Coating



Testing electrical and source

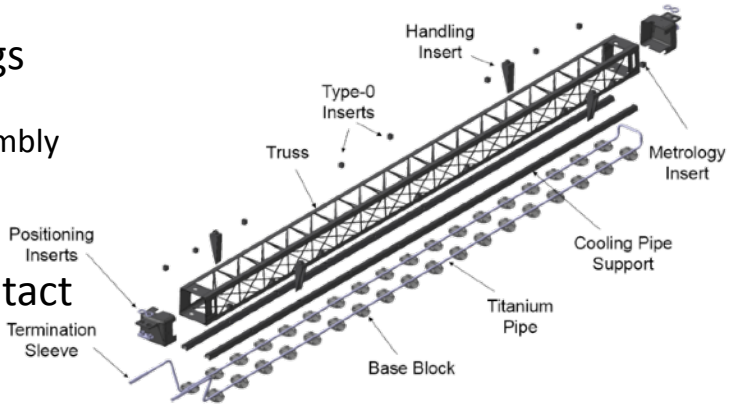
OB Quad Module

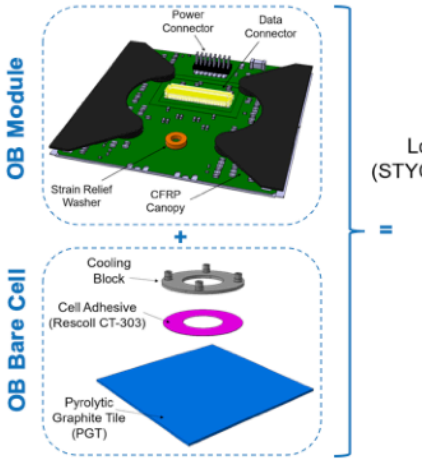


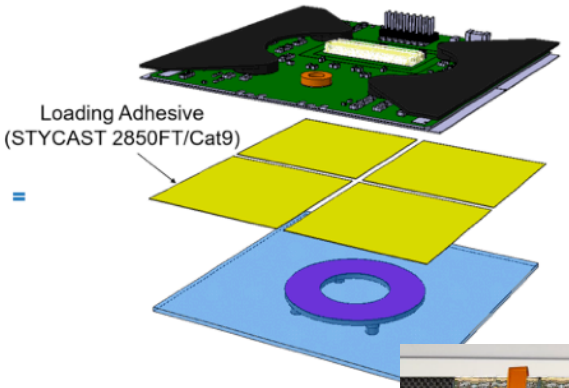
IS Triplet Module

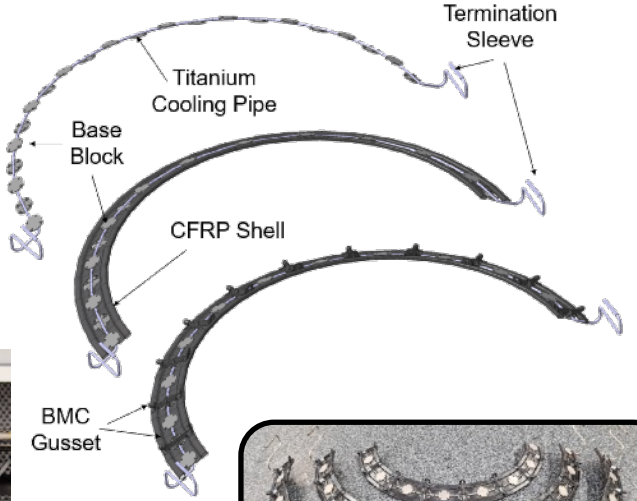
# Outer Barrel Local supports

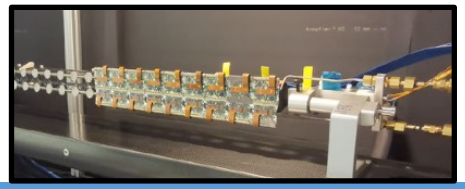
- Functional Local Supports: Longerons and Inclined Half Rings
  - CFRP “skeleton” for mechanical support and stiffness
    - Inserts and gussets position the local support in the global assembly
  - Functional cooling pipe = titanium pipe + base blocks
    - Both are Ni-coated and soldered
- Bare Cells hold modules in precise location and provide contact to cooling pipe via the cooling blocks
  - Fixed to the functional supports with screws --> reworkability

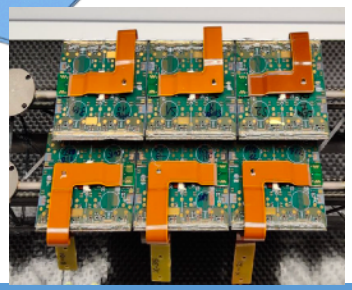


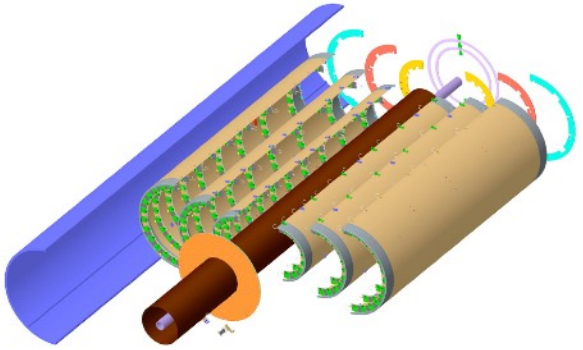



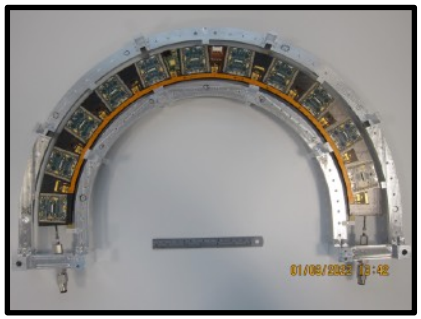



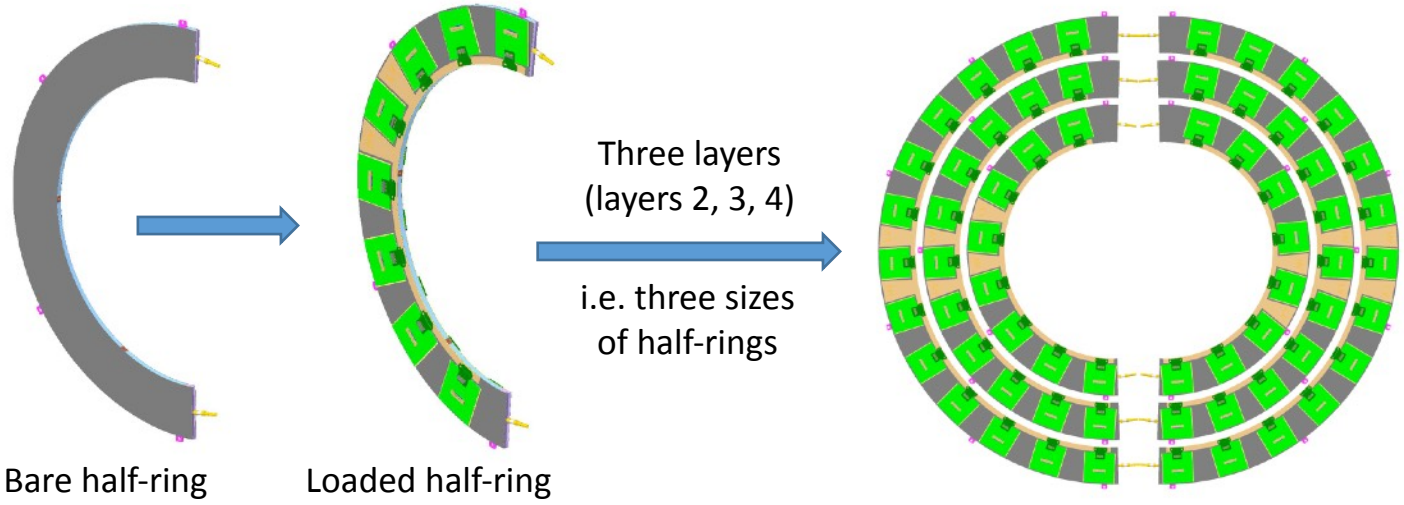


# Outer Endcap Local supports



- Single rows of modules on half-ring-shaped supports
  - Module-loaded half-rings are supported in half-cylinders
  - Half-cylinders are assembled by layers, inside to outside
  - R-z Hermeticity provided by strategic z-placement of half-rings
- Module-loaded half-rings are identical front-back…
  - Modularity
- …but are 'handed'.
  - Uniform z separation of modules at top/bottom overlaps



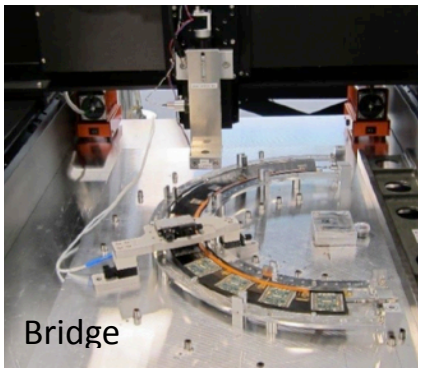



Bare half-ring

Loaded half-ring

Left-handed

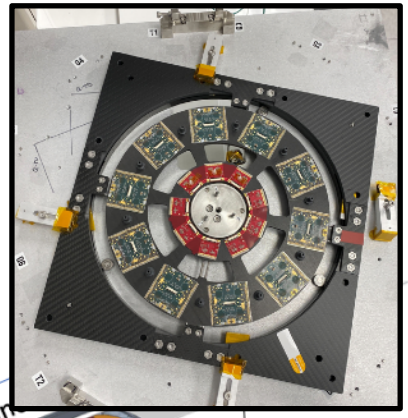
Right-handed



Bridge

# Inner System Local supports

- The Inner System will be contained inside an Inner Support Tube and will be replaced once at ~half-lifetime
  - Short 2-layer flat barrel + long section of rings (3 types)
  - Assembled in quadrants – one quadrant shown below.

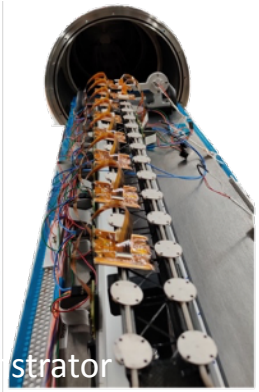


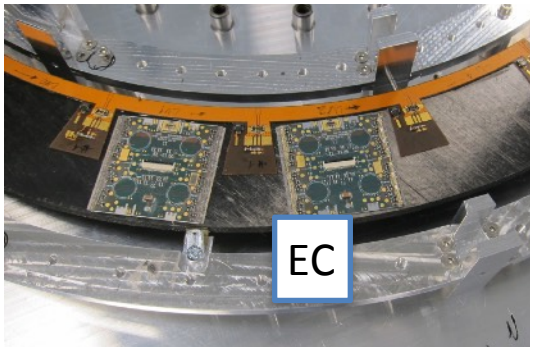


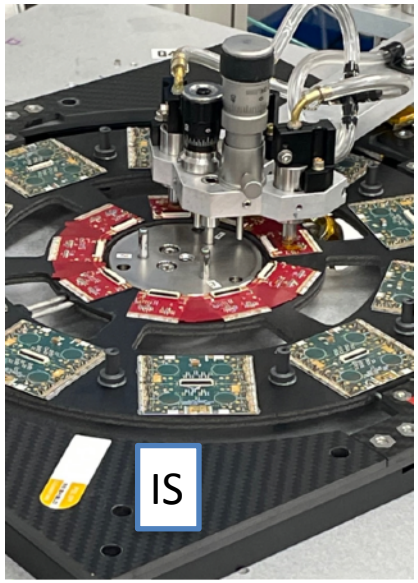

N.Hartman

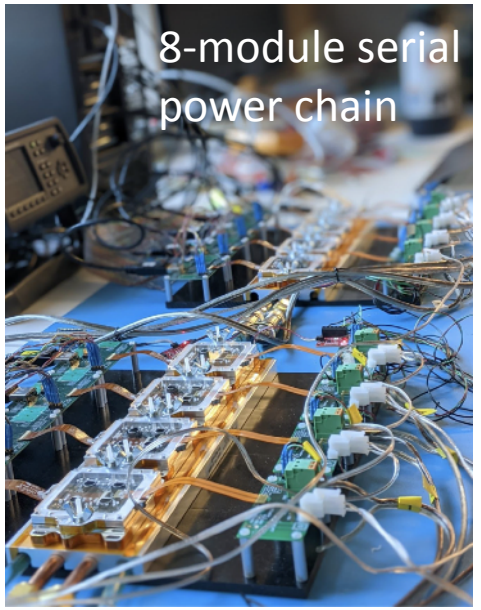
# ITk Pixel Detector Systemtest and Serial Powering

- Carbon fibre support for pixel modules passed thermal and mechanical qualification and are in pre-production / production
- "ITK demonstrator" & System test
  - first prototype staves & rings are loaded with RD53A modules to test system aspects of ITk Pixel
  - qualify module loading and electrical tests on support mechanics
  - essential to sign-off components
- Powering based on serial powering concept
  - chain of up to 13 modules are fed with constant current and chip voltage produced inside FE-chip
  - serial powering implementation is most essential to reduce power cable volume and material budget
  - First two 8-quad module long serial powering chains built and under test

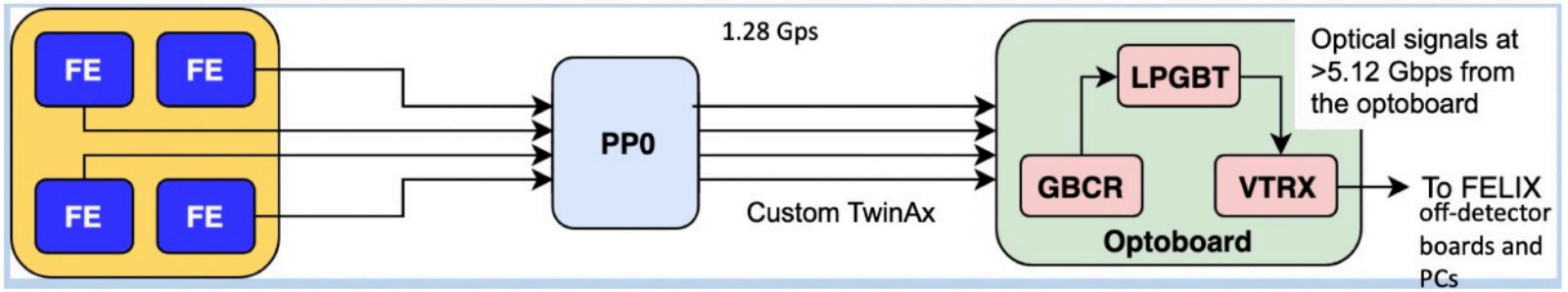


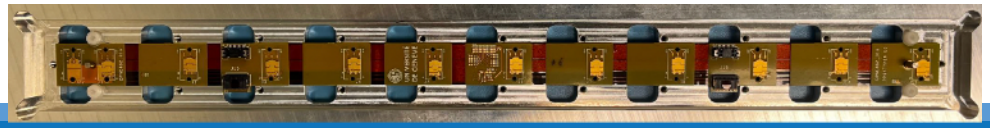
# Data transmission module to opto to FELIX

kapton/copper flexes → PP0 → TwinAx cables → Gigabit receiver chip (GCBR) → lpGBT (low-power Gigabit transceiver and VTRx+) for aggregation and electro-optical conversion




- Readout from FE-chip at 1.28 Gbps with up to 4 links per chip depending on position in pixel system
  - Uplink sharing on module used on all layers to reduce material
- Very tight integration constraints for power and data services to support structures


Outer Barrel Inclined L3 PP0



# Summary

- The ATLAS ITk Pixel Detector will be at the center of the new ATLAS tracker for HL-LHC Run 4
- The detector is currently progressing in pre-production for modules as well as support structures, services and readout
- Individual components have been verified in prototype runs during last two years and passed final design reviews
- The production of modules will start early 2024, production of sensors, FE-ASIC and local supports is already in progress.
- Module production, loading to staves and integration will be carried out the the collaboration largely in parallel tasks to complete the ITK pixel detector in 2027 ready for installation in the ITK strips and the ATLAS cavern