PSD13

St. Catherine's College
September 3-8, 2023

UNIVERSITY OF OXFORD

ATLAS ITk Pixel Detector Overview

High Energy Accelerator Research Organization (KEK)

Manabu Togawa

On behalf of the ITk pixel collaboration

High Luminosity LHC upgrade

LHC | HL-LHC

Run 1 | Run 2 | Run 3 | Run 4 - 5...

7 TeV | 8 TeV | LS1 | 13 TeV | EYETS | LS2 | 13.6 TeV | EYETS | LS3 | 13.6 - 14 TeV | energy

splice consolidation
button collimators
R2E project

cryolimit
interaction
regions

Diodes Consolidation
LIU Installation
Civil Eng. P1-P5

pilot beam

inner triplet
radiation limit

HL-LHC
installation

2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2040

experiment
beam pipes

ATLAS - CMS
upgrade *phase 1*

ALICE - LHCb
upgrade

Today

ATLAS - CMS
HL upgrade

75% nominal Lumi | nominal Lumi | 2 x nominal Lumi | 2 x nominal Lumi | 5 to 7.5 x nominal Lumi

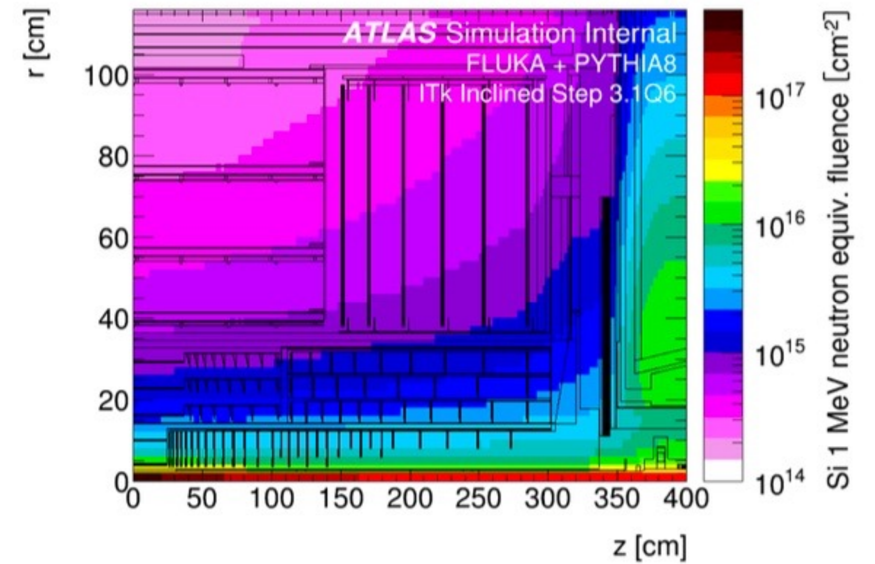
30 fb^{-1} | 190 fb^{-1} | 450 fb^{-1} | integrated luminosity 3000 fb^{-1} 4000 fb^{-1}

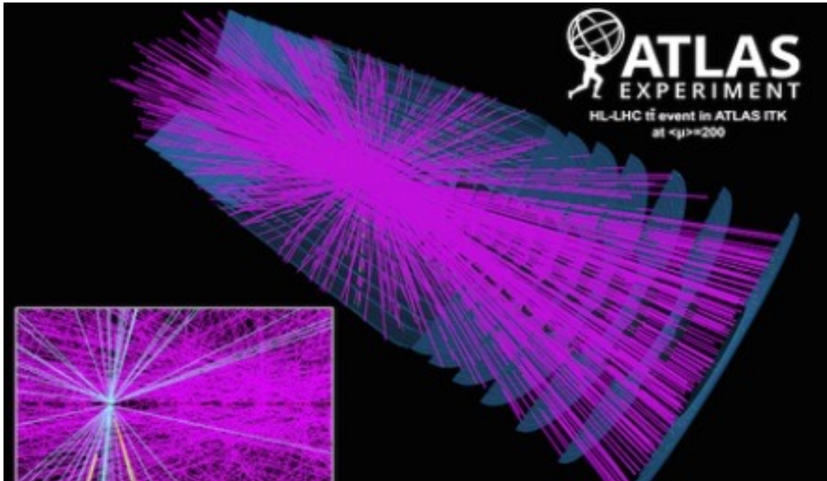
HL-LHC TECHNICAL EQUIPMENT:

- HL-LHC will start at 2029 and accumulate 4000 fb^{-1} (x10 of RUN3)
- ATLAS detector needs to be upgraded to adopt high instantaneous luminosity.

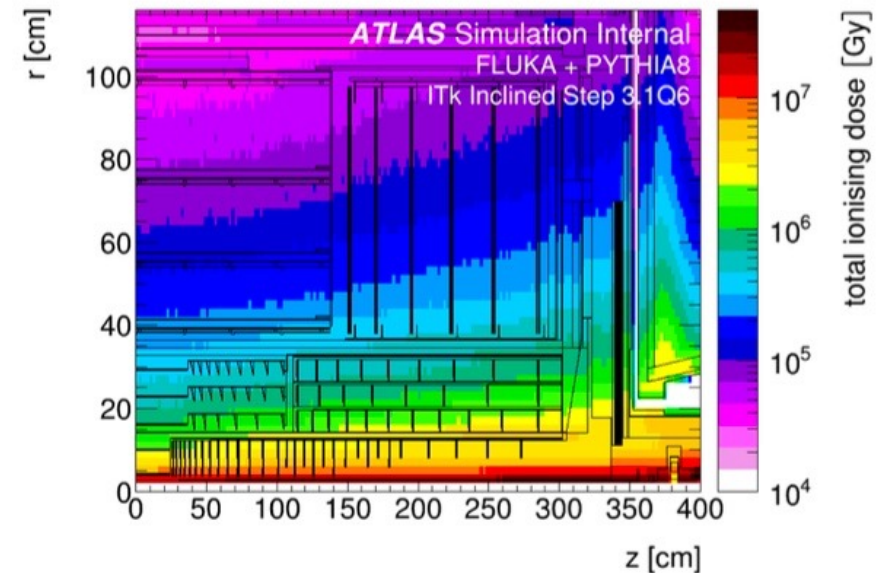
Challenges for Inner Tracker

- HL-LHC luminosity ~ $7x10^{34}$ $cm^{-2}s^{-1}$
  - About 3 times RUN3 peak luminosity.
    - Up to 200 pile-up events !
  - -> Full silicon based system and fast readout
- High radiation dose
  - x10 statistics -> x10 radiation damage
  - -> Radiation hard

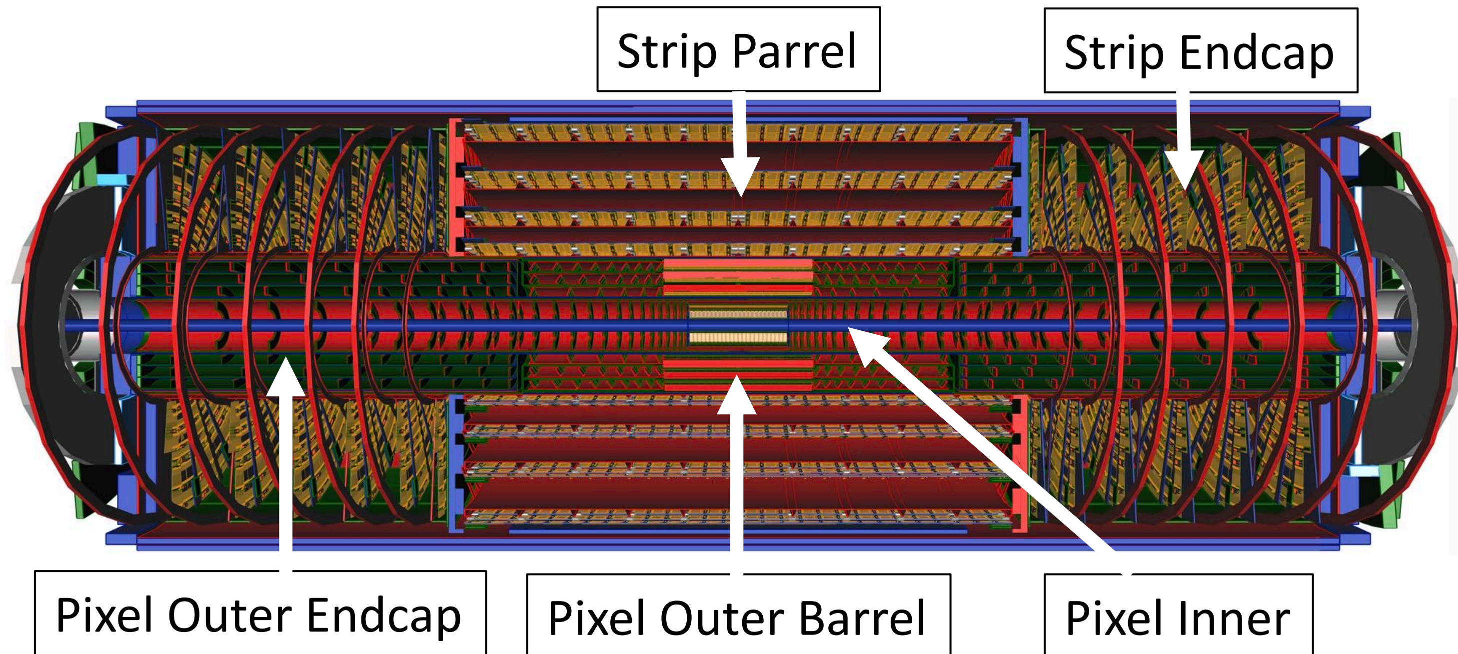




Requirement of Radiation hard for most inner layer $1.7x10^{16}$ neq/cm^2



Inner Tracker Upgrade



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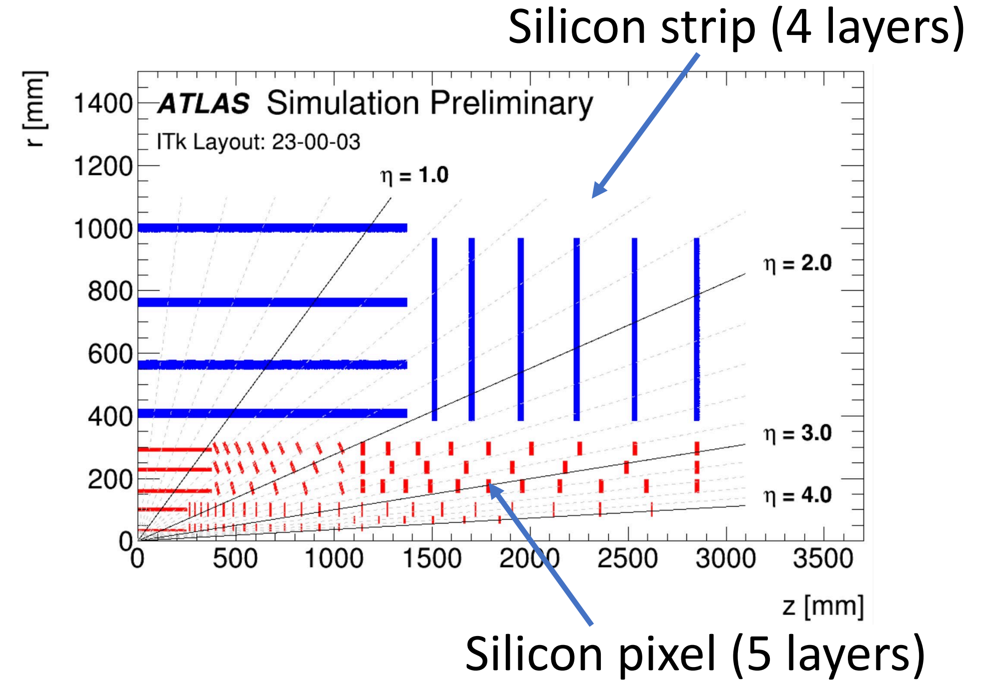


- All-silicon system, 9 layers
- Increasing granularity to keep < 1% occupancy
  - Pixel : 50x400 (μm^2) -> 50x50 (μm^2) : 1/8
  - Strip (length) : 128 mm -> 24 mm : 1/5
- Wide coverage in η : 2.5 -> 4.0

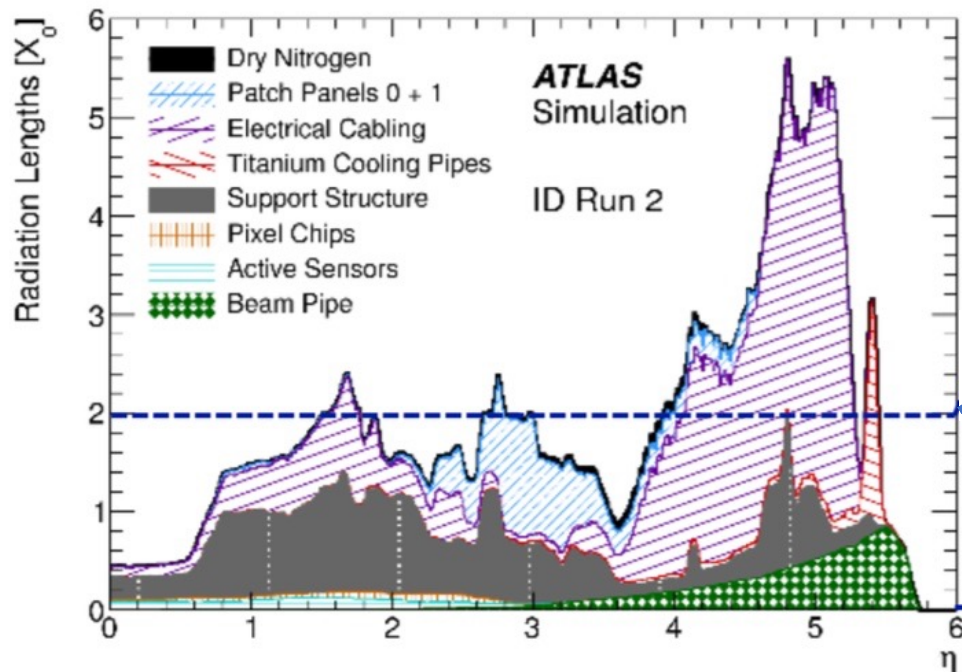
Strip system will be presented by Seth Zenz at 8/9 Friday
The ATLAS ITk Strip Detector System for the Phase-II LHC Upgrade
3 ITk related posters
Serial powering inner system : Md Arif Abdulla Samy
Pixel interlock and DCS : Simon Koch
ITk strip irradiation : Hui Li

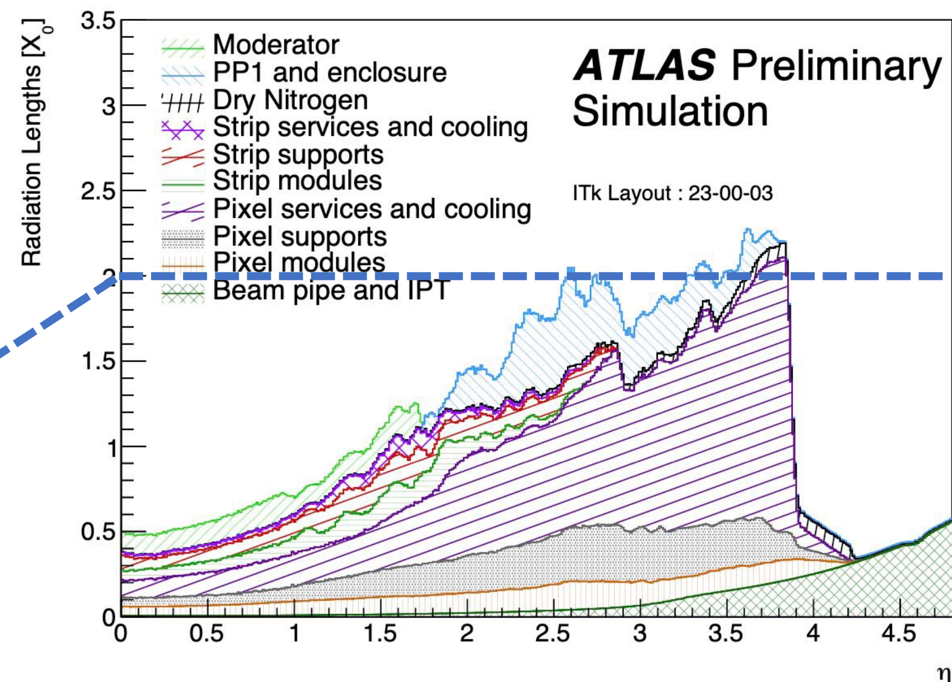
ATLAS ITk

Material Budget

ATL-PHYS-PUB-2021-024

- Significant reduction of material using,
  - CO_2 cooling with thin titanium pipes.
  - Low mass carbon structures.
  - Minimizing material in modules using thin Si and FE- chips.
  - Reducing cabling by serial powering and data sharing for pixels.

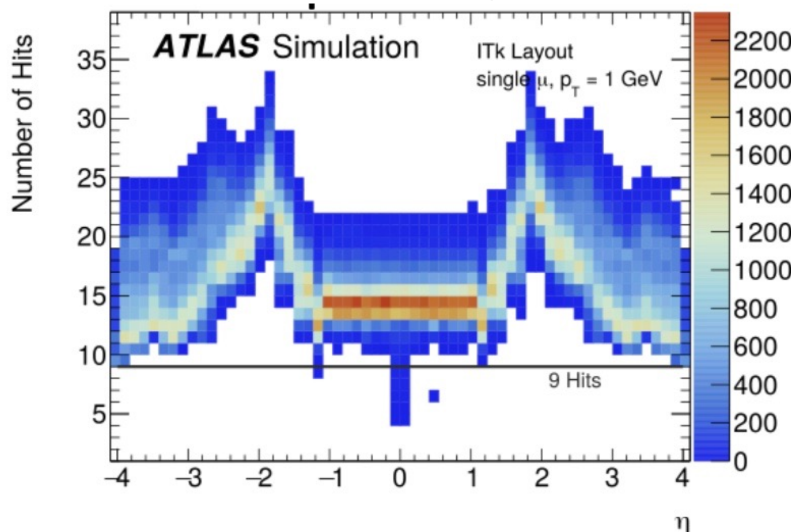




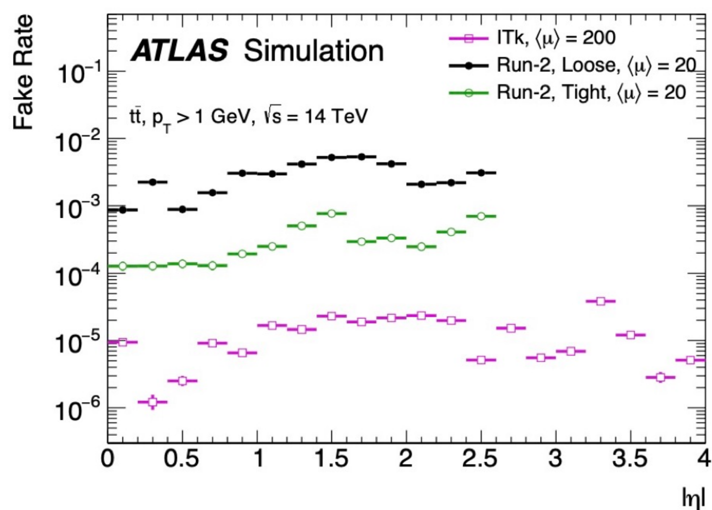
ITk performance

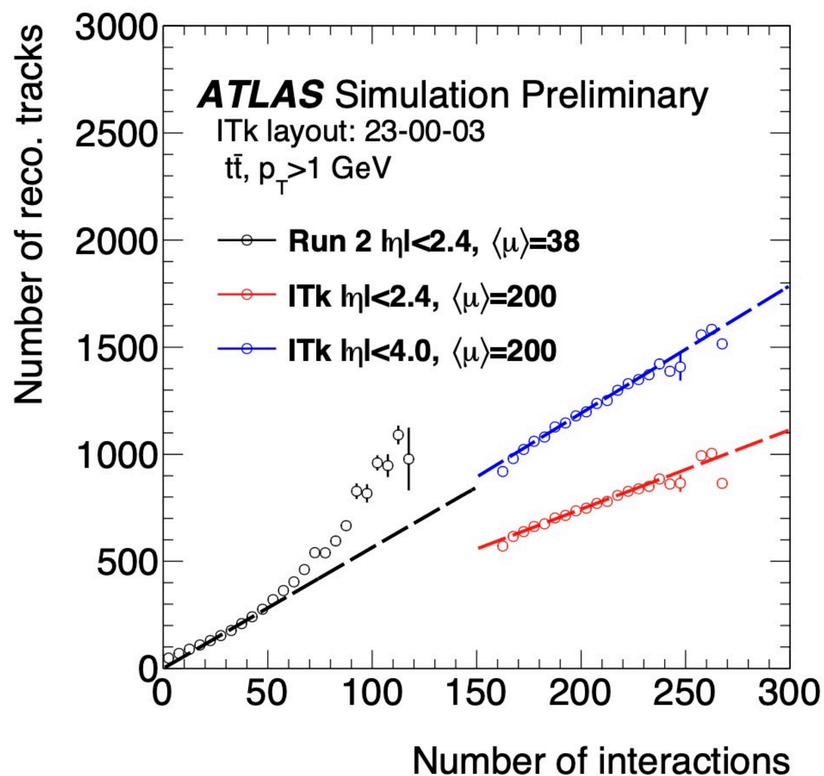
ATL-PHYS-PUB-2021-024

Number of hits / cluster

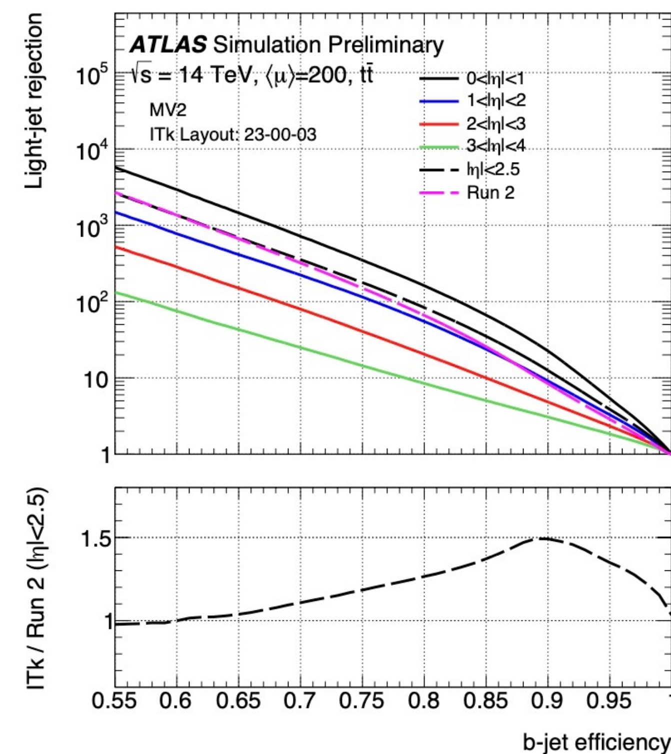


Fake rate vs. η





Pile-up rejection and b-tagging



ITk Pixel Detector

ATLAS ITk

Outer Barrel

Outer Endcaps

150μm planar quads, 50x50μm²

ATLAS Simulation Preliminary

ITk Layout

r [mm]

450 400 350 300 250 200 150 100 50 0

η = 1.0

η = 2.0

η = 3.0

η = 4.0

100μm planar quads, 50x50μm²

3D singles (triplet), 50x50μm²

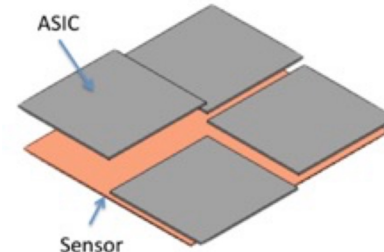
3D singles (triplet), 25x100μm²

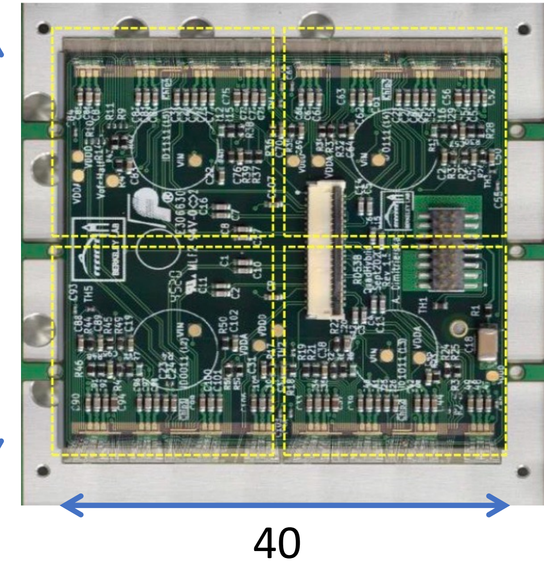
1000 1500 2000 3500

z [mm]

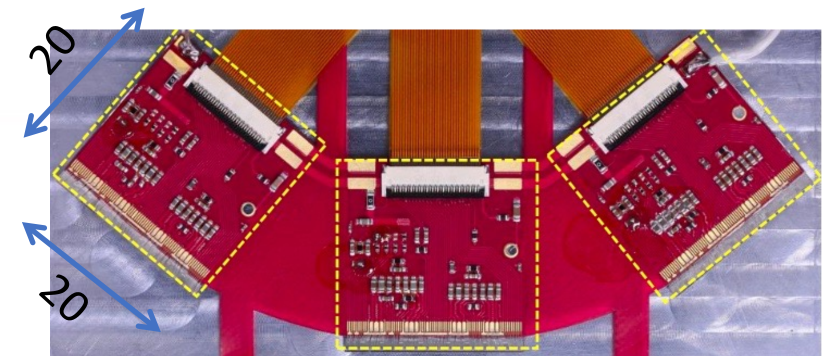
Inner System

L1 – L4 : Planer sensor “Quads”



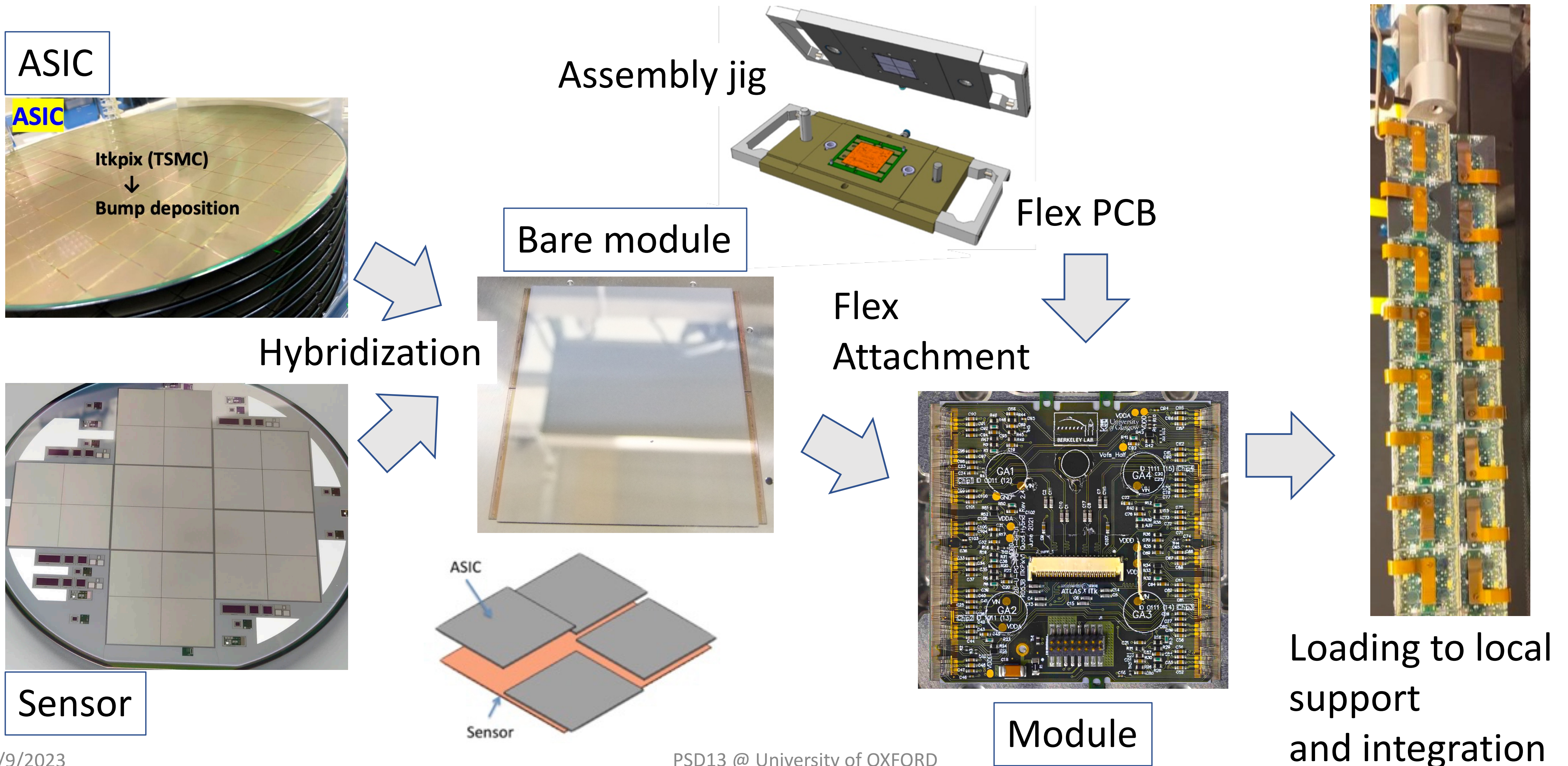


L0: 3D sensor ”Singles (Triplet)”



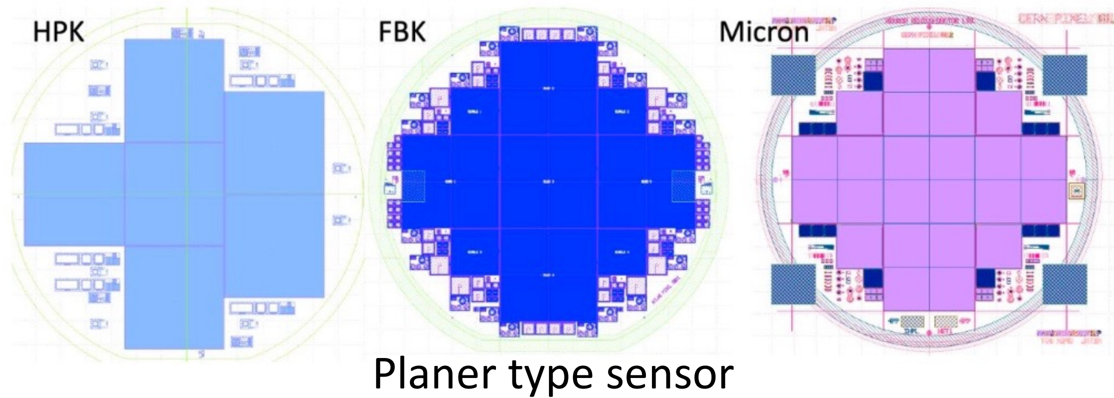
Constructing with about 10,000 modules ~ 14 m² ! (Current : 2 m²)

Production flow

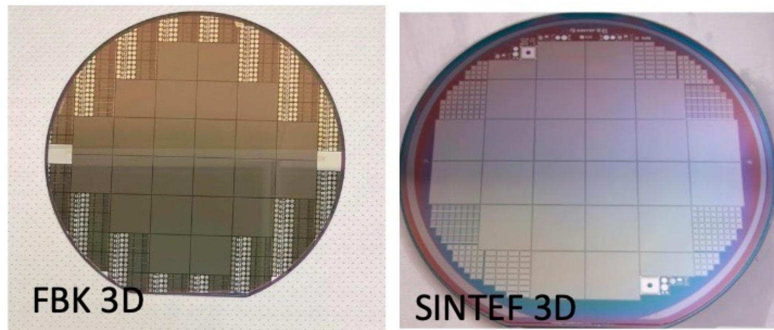


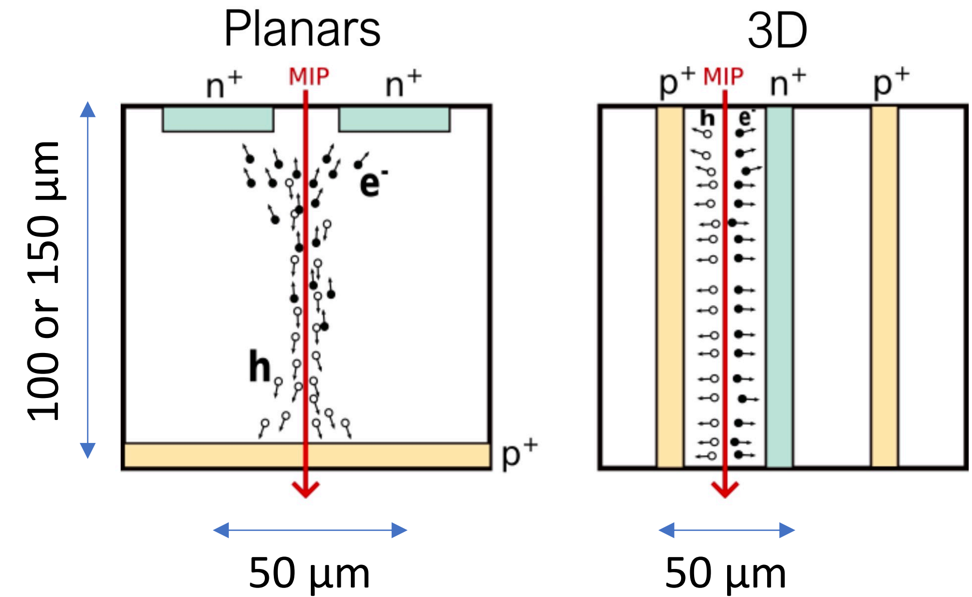
Sensor

- Pre-production (10% of install amount) was finished in 2022.
  - Several Hybridization module tested at the test beam.
  - Qualification for production order was completed.
- Production order has been started.

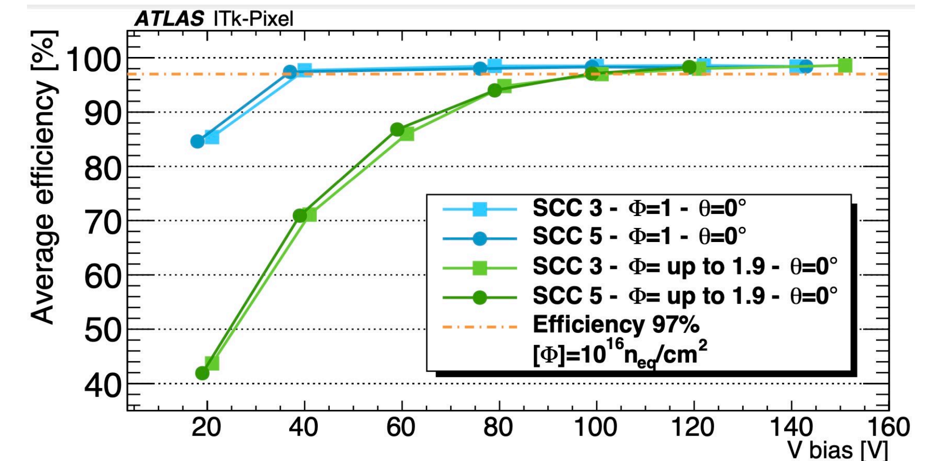


Planer type sensor





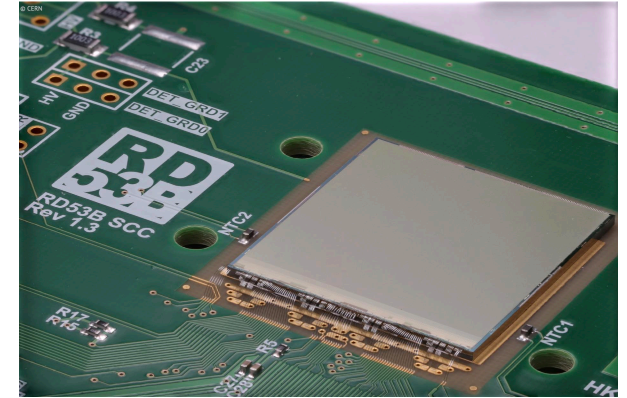
FBK sensor performance after irrad. (Link)



FE ASIC : ITkpix

- Prototype chips RD53A and ITkpix-v1 were validated and used as prototype program
- Final FE-chip (ITkpix-v2) was approved on 17th March
  - First delivery of 20 wafers (engineering run) 26th June.
- First verification of new chip and preparation for chip testing:
  - Basic functions are working as expected. Detailed checks are ongoing.

ITkpix-v1



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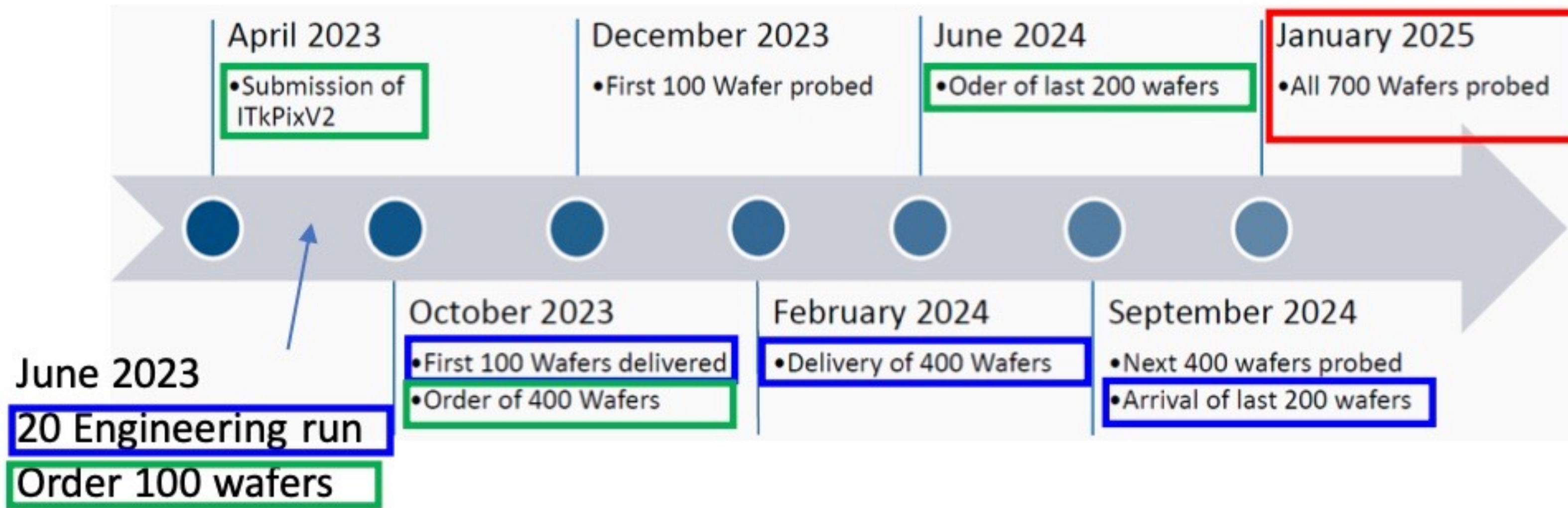
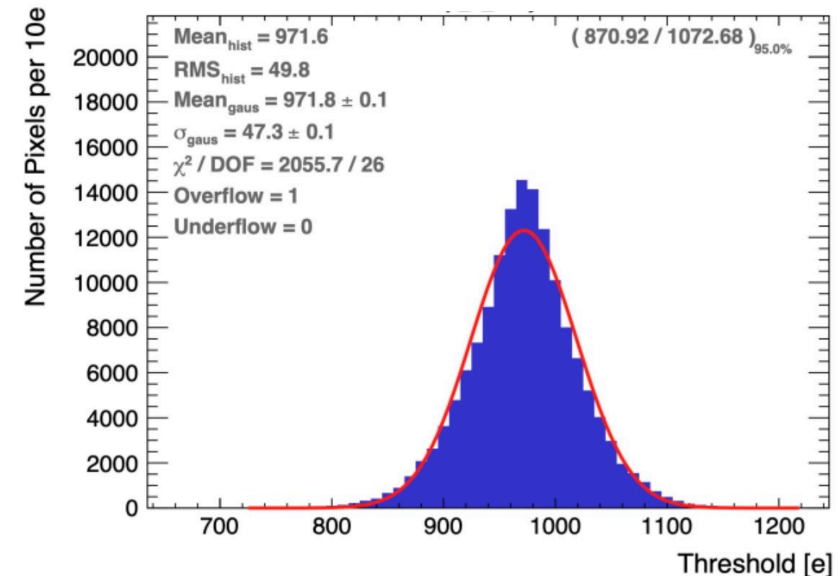
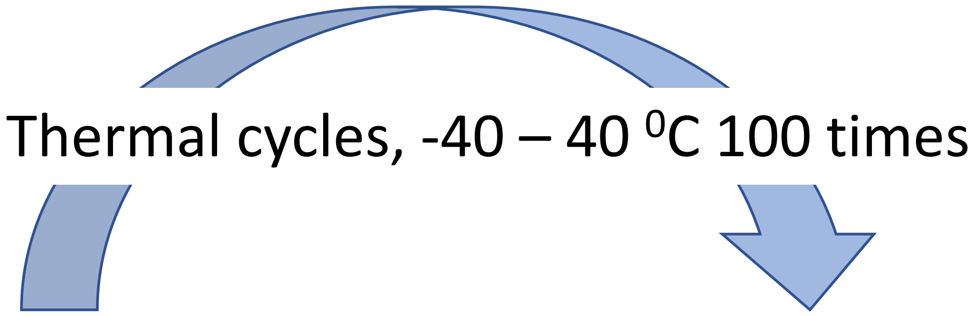


Threshold distribution after tuning



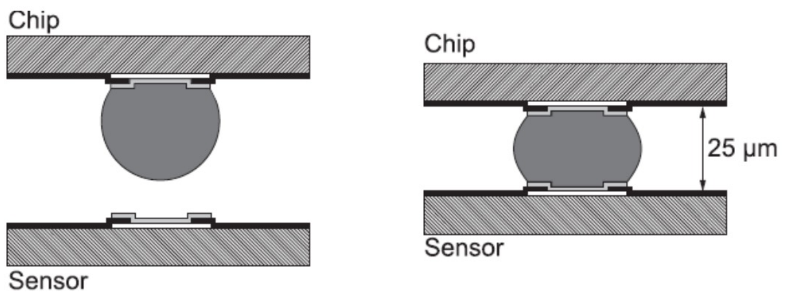
Hybridization (Flip-chip)

- Qualify bump-strength with thermal cycle
- Cross check with FEA and share stress measurement
- Design validated by prototype, follow-up during pre-production



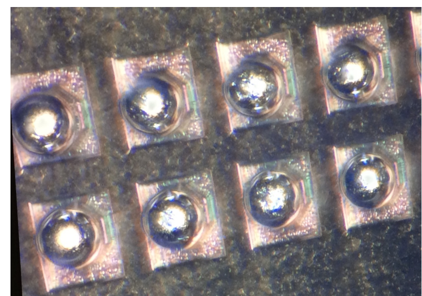
Assembled Modules

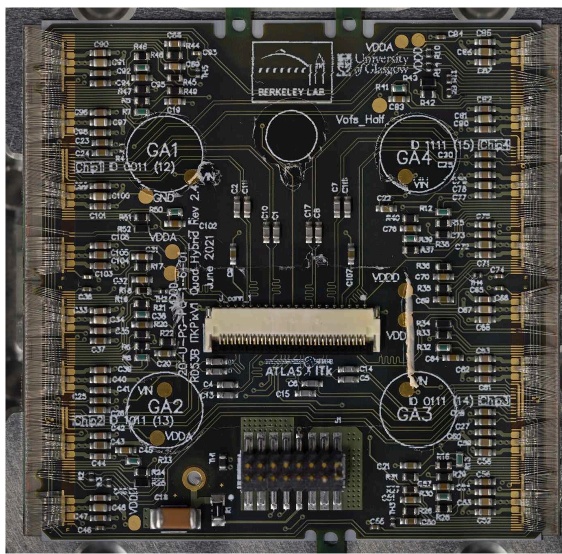
Delamination test with x-ray scan

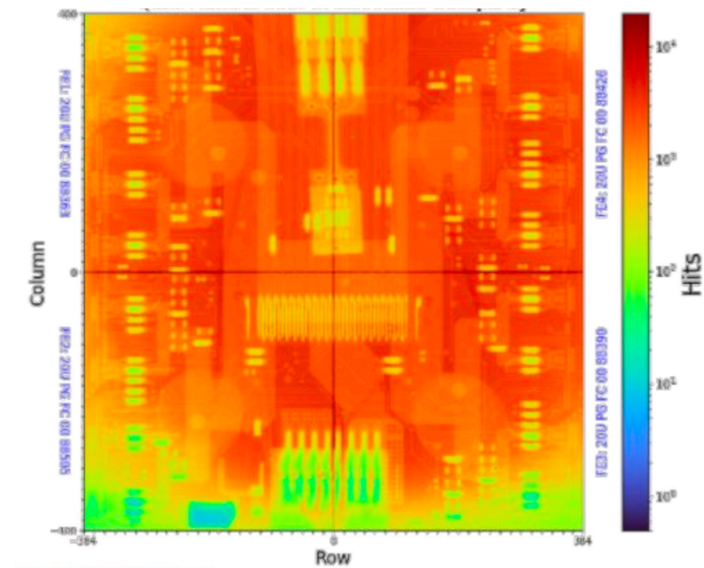


Bump bonding Technique

~640k pixels in quads







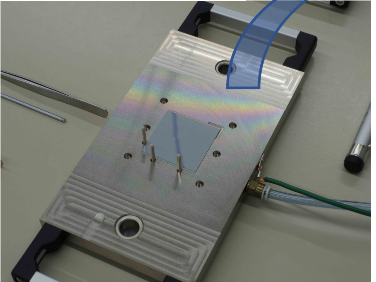
Module Assembly & Testing

- Assembly has been done with dedicated tooling
- Extensive module QC tests
  - High-res. photos for visual inspection, Electrical readout, metrology, bump-stress, operation at low temperature

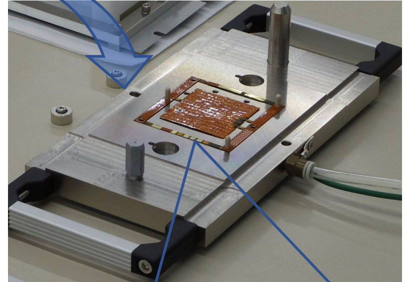
Exercising across module sites, “Qualification” in pre-production

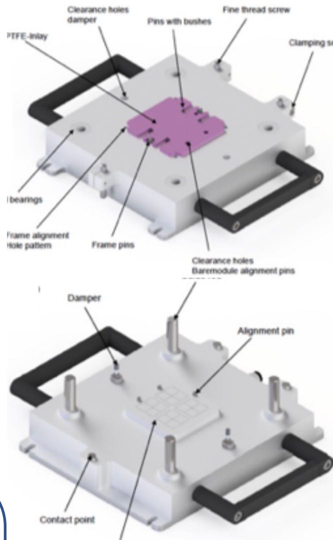
Module assembly by jig

Bare module base

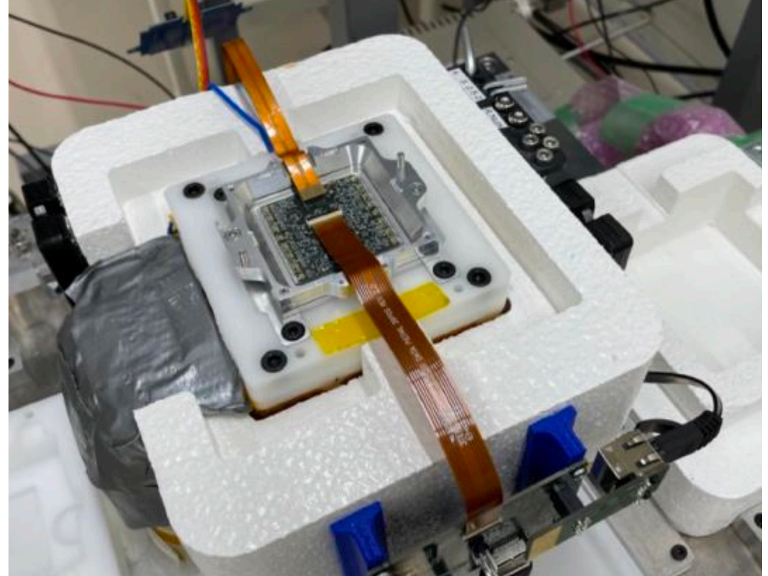


Flex base

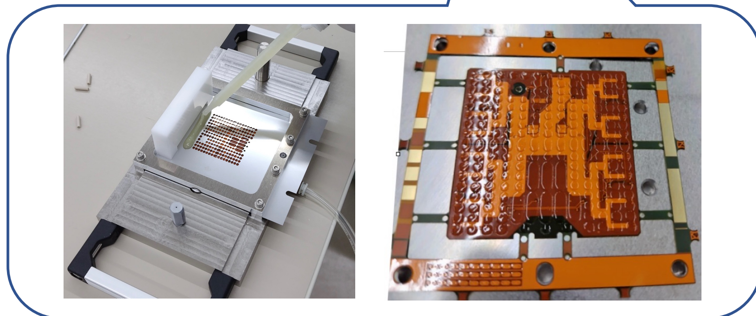




Module on the Cooling box



Adhesive deposition by Stenciling

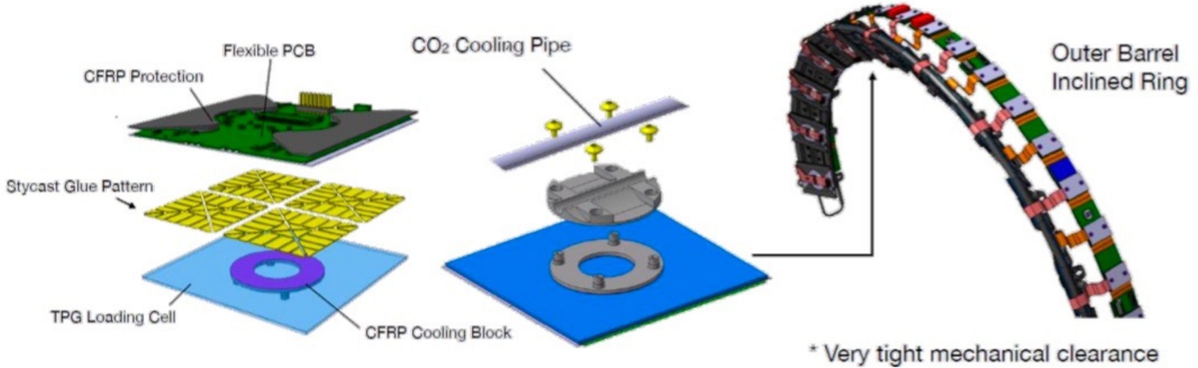


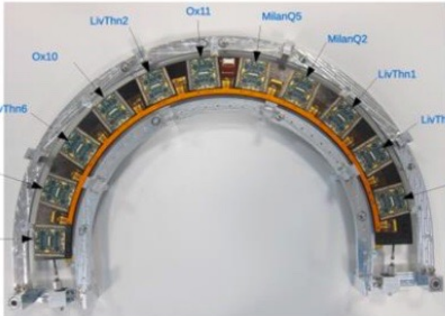
Adhesive : Araldite 2011

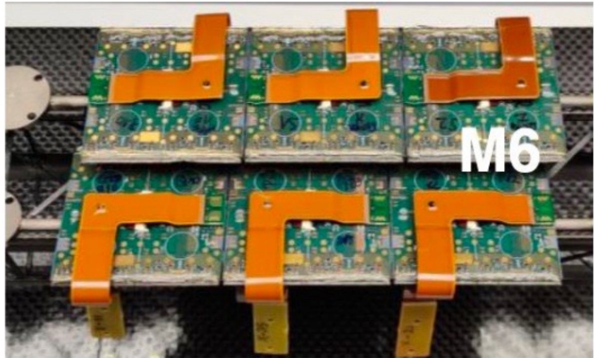
Local Support & Prototypes

- Local support
  - Stable low-mass support
  - Critical element is interface to cooling pipe

- Prototypes
  - Demonstration of module loading
  - System test



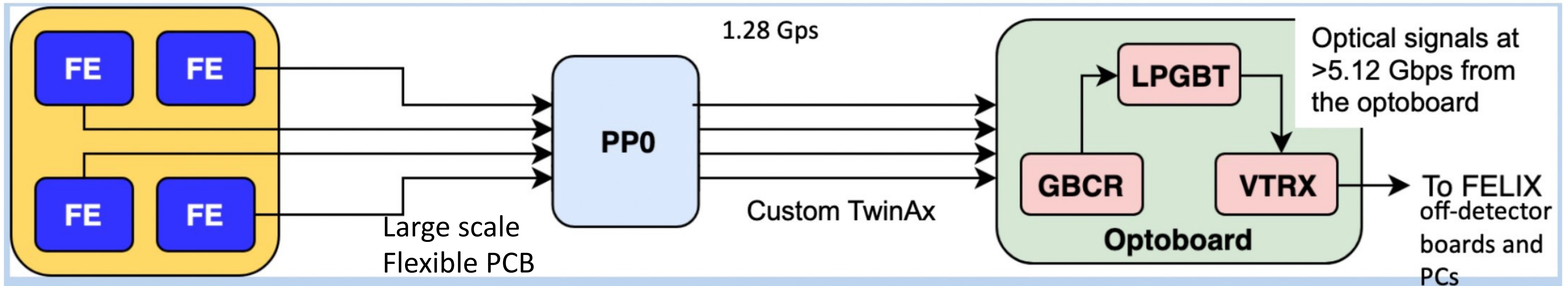




Procurement for Pre-production parts started.

Data transmission & services

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
- Serial powering modules up to 16 quad modules
  - Reduced number of supply lines, less material
  - Less power dissipation on services than with parallel powering
  - Radiation hard on-chip shunt-LDO allows regulation of voltage on chip

System tests have been performed.

Electrical

Serial powering

Thermal-mechanical

Progress in Samy's and Simon's posters !

Conclusion

- For the HL-LHC, ATLAS Inner detector replaced to be all silicon detector.
  - Many challenging to achieve,
    - Increased granularity
    - Radiation hardness
    - Low mass
- The project is now moving to production.
  - Production and pre-production has started in each components
  - System tests have been performed
  - Integration will follow soon