

It is all coming together: The Production of ATLAS Inner Tracker

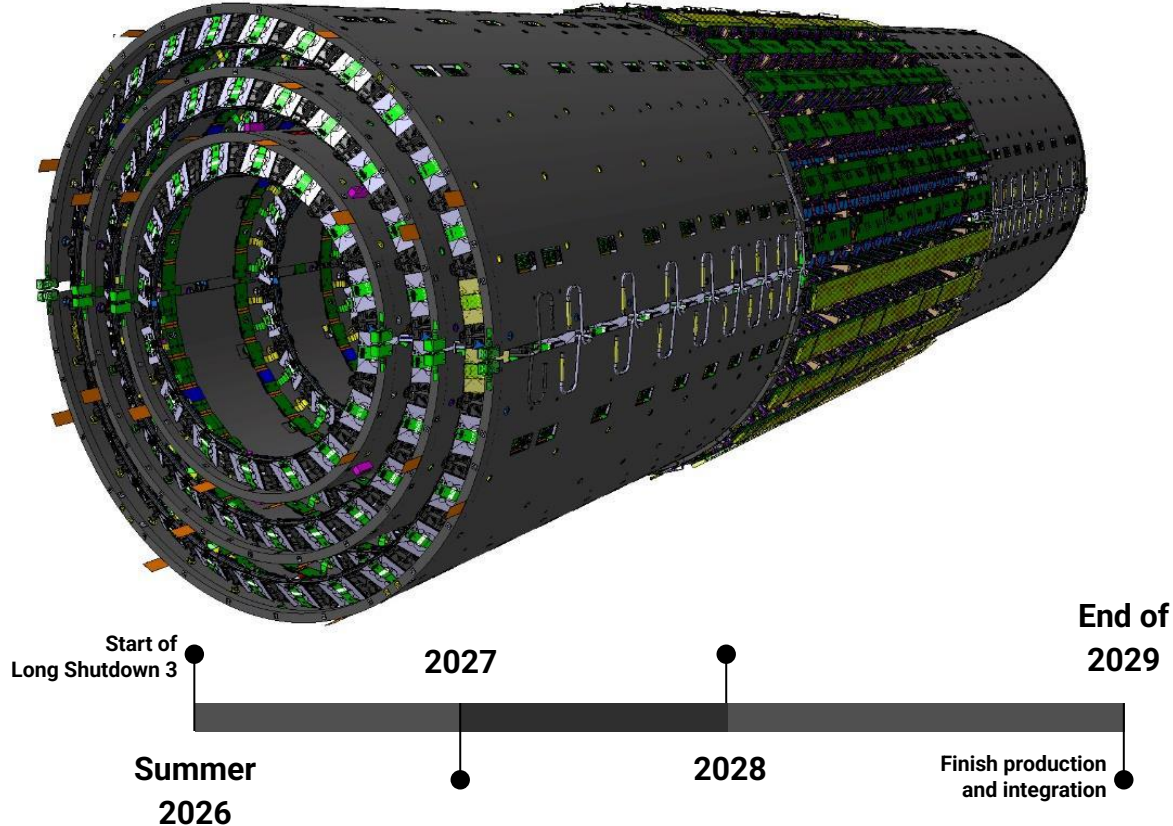
Matej Repik on behalf of ATLAS Inner Tracker

The 2026 International Conference on Instrumentation for Colliding Beam Physics, Hefei, China



ATLAS Phase 2 Upgrade

- Upgrade the ATLAS experiment:
 - due to pileup increase from ~60 up to 200 during High Luminosity-LHC
 - due to up to 7-times higher instantaneous luminosity: $7(10)^{34} \text{ cm}^2 \text{ s}^{-1}$
- Upgrade electronics for new read-out
- Install High-Granularity Timing Detector in the endcaps
- Exchange the Inner Detector for Inner Tracker



Inner Tracker ATLAS Phase 2 Upgrade

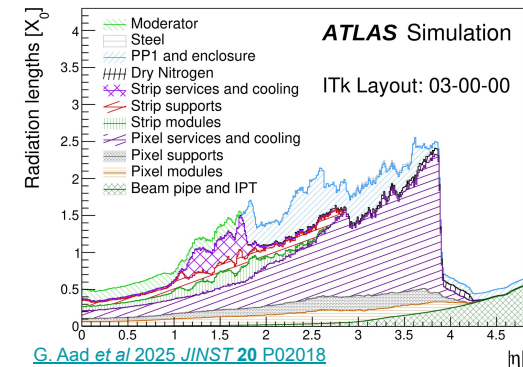
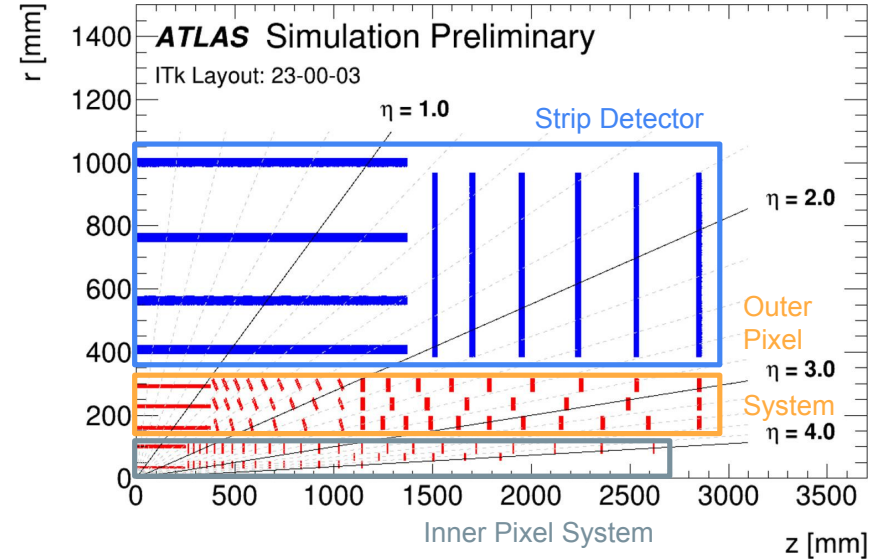
- **5 innermost layers** are pixel sensors
-> **Pixel Detector**
 - **4 outermost layers** are strip sensors
-> **Strip Detector**
-
- Strip Detector has **staves** in the barrel and **petals** in the endcaps
 - Pixel Detector has **staves**, **longerons**, and **inclined half-rings** in the barrel; **rings** and **half-rings** in the endcaps



ATLAS Inner Tracker (ITk)

	Inner Detector		Inner Tracker	
Pseudorapidity coverage	$ \eta \leq 2.5$		$ \eta \leq 4$	
	Pixels	Strips	Pixels	Strips
Area Coverage [m ²]	1.6	61	13	165
Channels x10 ⁶	92	6.3	5000	60

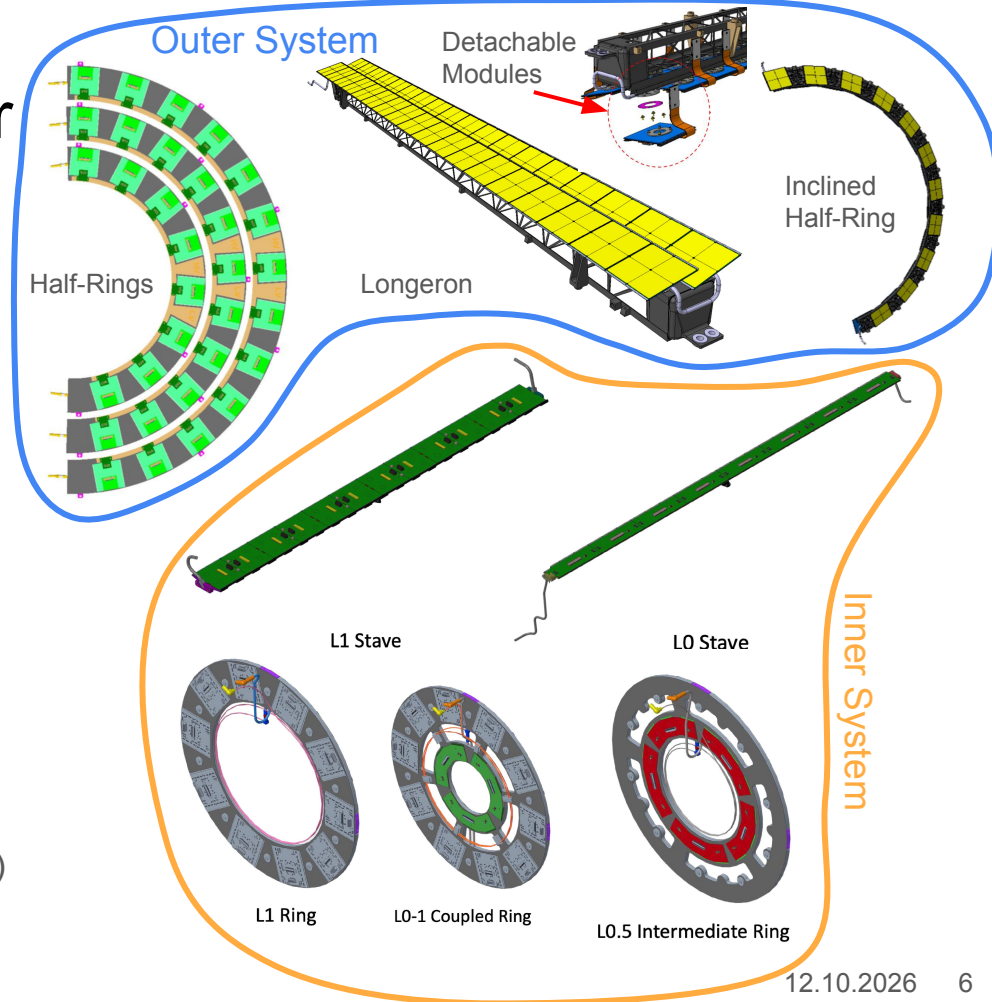
- The extended η coverage covers a 0.6 gap between the Inner Detector and Electromagnetic calorimeter
- Expected vertex resolution of 10 μm
- Inner Pixel System and Strip Detector have flat and perpendicular geometry
- Outer Pixel System includes inclined geometry in the barrel



ITk Pixel Detector

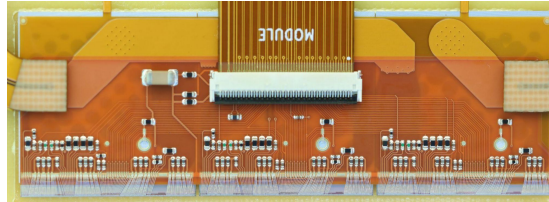
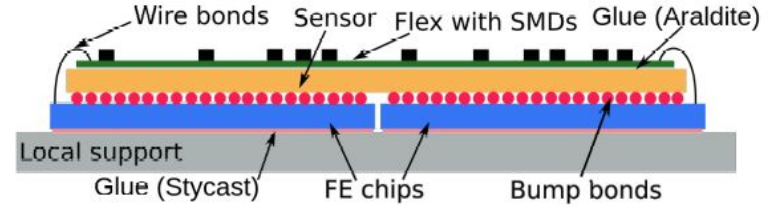
Inner Tracker Pixel Detector

- Active area of almost 14 m²
- Evaporative CO₂ Cooling at -45°C
- Split into **Inner** and **Outer System**, Barrels and Endcaps
- Loaded Local Supports hold the modules (bare are without modules)
- **Outer System** uses:
 - Longerons (36 modules)
 - Inclined Half-Rings (16-28 modules)
 - Half-Rings (16-28 modules)
- **Inner System** uses:
 - Staves (8 triplet and 12 quad modules)
 - Rings (6, 10 triplet and 20 quad modules)

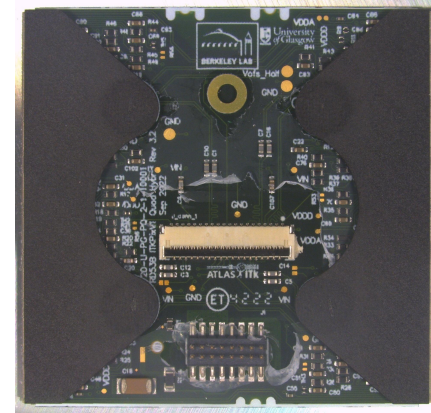


ITk Pixel modules

- Powered in series with a current source
- Layered with front-end chip and flexible PCB
- 4 types of hybridized pixel modules with 3 or 4 front-end chips in triplets and quads



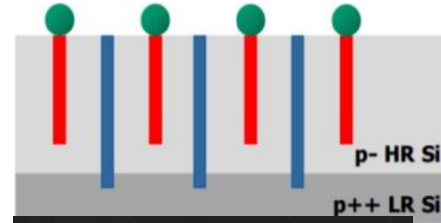
Triplet modules



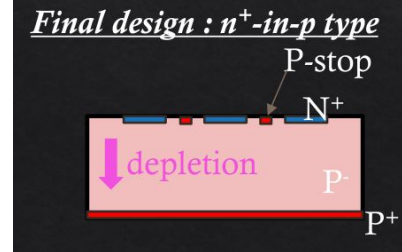
Quad module

ITk Pixel sensors

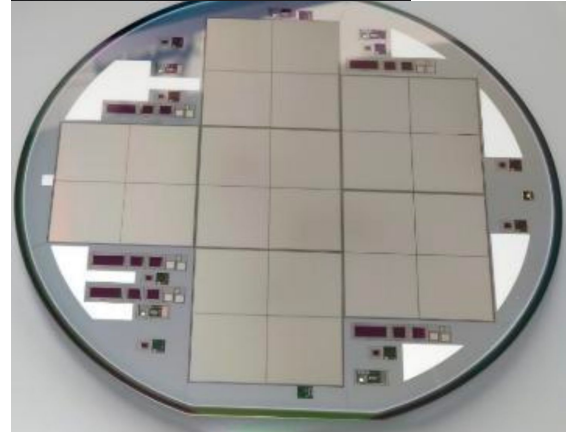
- Layer 0 uses 3D pixels sensors with greater radiation hardness
- Other Layers use Planar pixels sensors with thicknesses 100 μm and 150 μm
- Pixel size: 25x100 μm^2 for stave 3D sensors
- Pixel size: 50x50 μm^2 for ring 3D sensors and all planar sensors



3D Sensor
Area: 20x21 mm^2



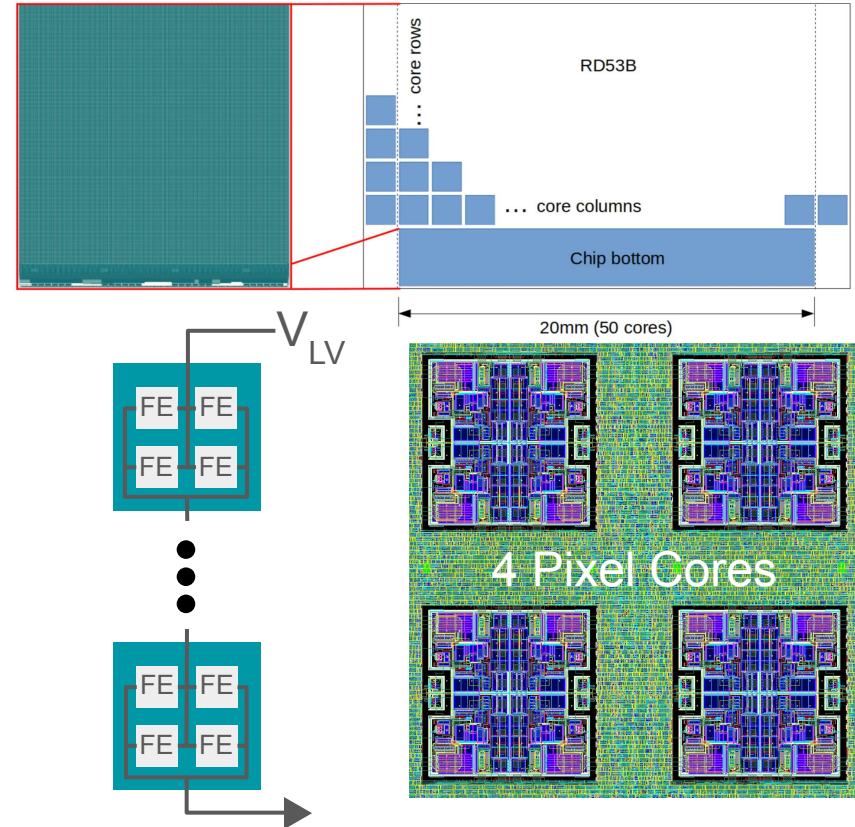
Planar Sensor
Area: 40x42 mm^2



Sensor
Wafer
(150 mm)

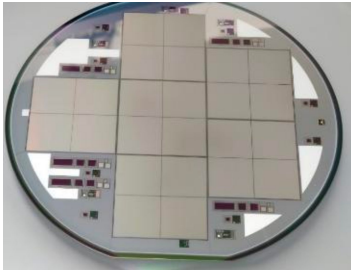
ITk Pixel Front-end chip and serial powering

- Developed by RD53 collaboration
- 384x400 pixels with $50 \times 50 \mu\text{m}^2$ pitch
 - 50 core columns per chip
- 4 data output lines with 1.28 Gb/s each
- Shunt low dropout regulator to allow for serial powering scheme
- Production finished at the end of April 2026 with 91% yield



3D and Planar Pixel sensor production

- 95% of 150 μm planar sensors finished
- 100% of 100 μm planar sensors finished
- 100% of 3D sensors finished
- The best 3D pixel sensors will be installed in Layer 0



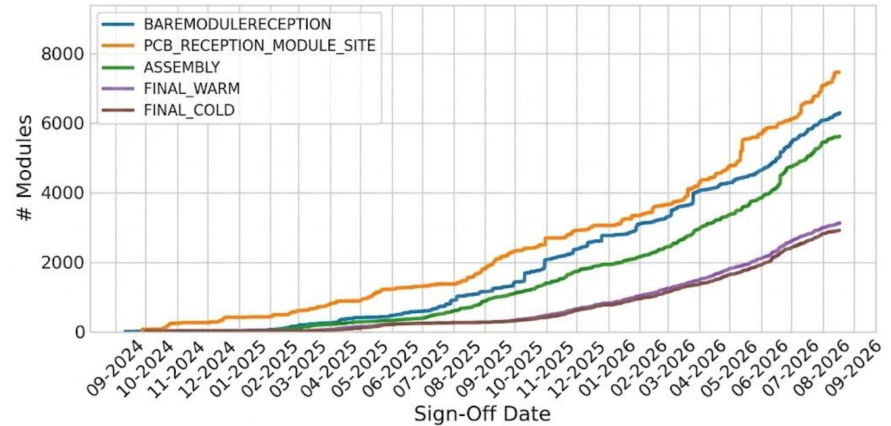
	3D	Planar 100 μm	Planar 150 μm
Installed	~1188	~1100	~6800
Sensor total (with spares)	~2000	~1100	~11000

Pixel Module Production

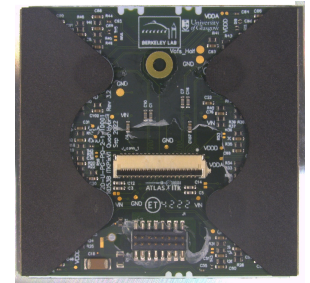
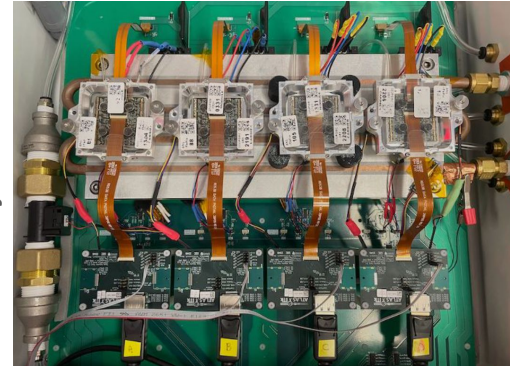
- Majority of hybridization sites at full throughput ~ 750 modules / month
- Module production is accelerating
 - Optimization of quality-control
 - $\sim 25\%$ of ~ 8300 modules produced
- Efforts ongoing to reach the goal of 70% yield

Production stages

[D. Fellers. PIXEL 2026](#)



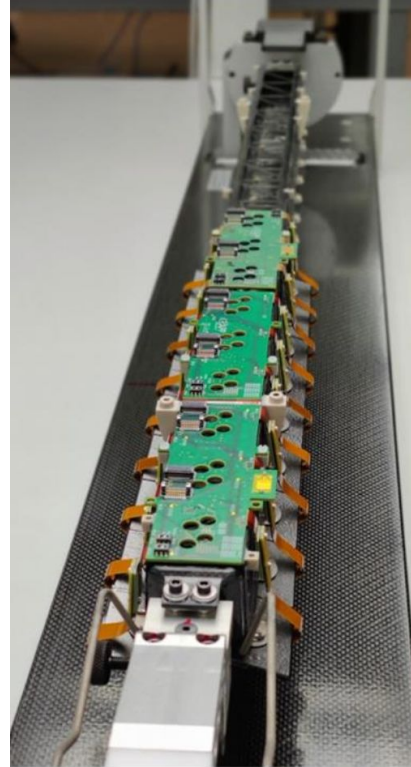
Quality Control



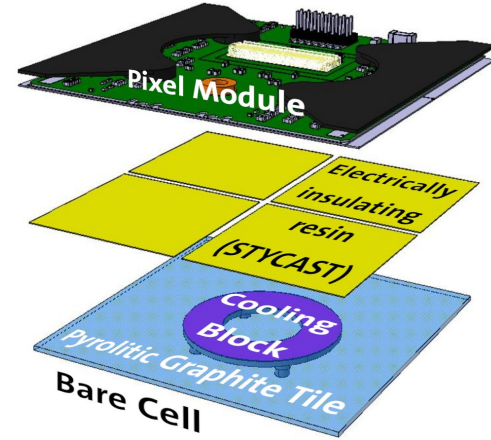
Outer Barrel production status

- Pre-production Layer 2 Inclined Half Ring (IHR) assembly and testing finished
- >92% of 154 Bare Local Supports produced
- Loaded Module Cell production started after solving the insulation issue

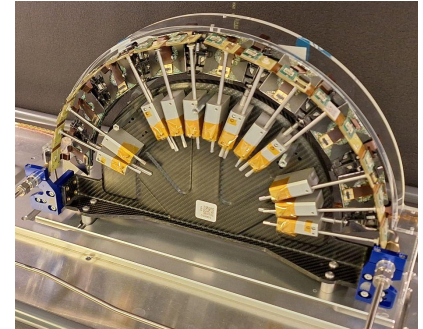
Lonngeron



Loaded Module Cell

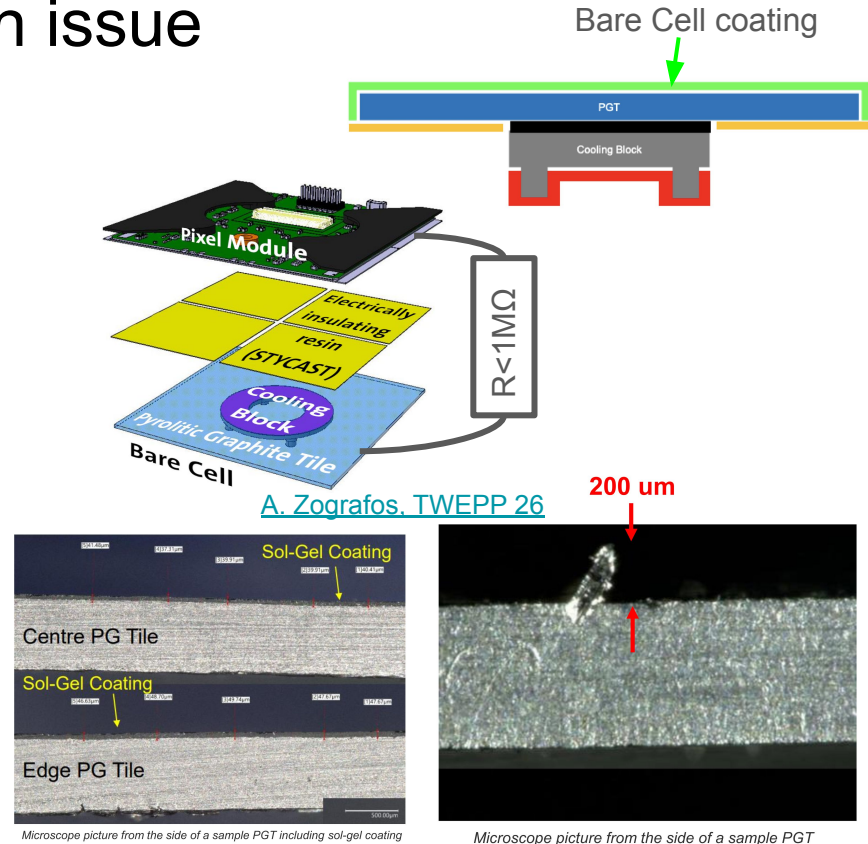


Layer 2 IHR



Loaded Module Cell Insulation issue

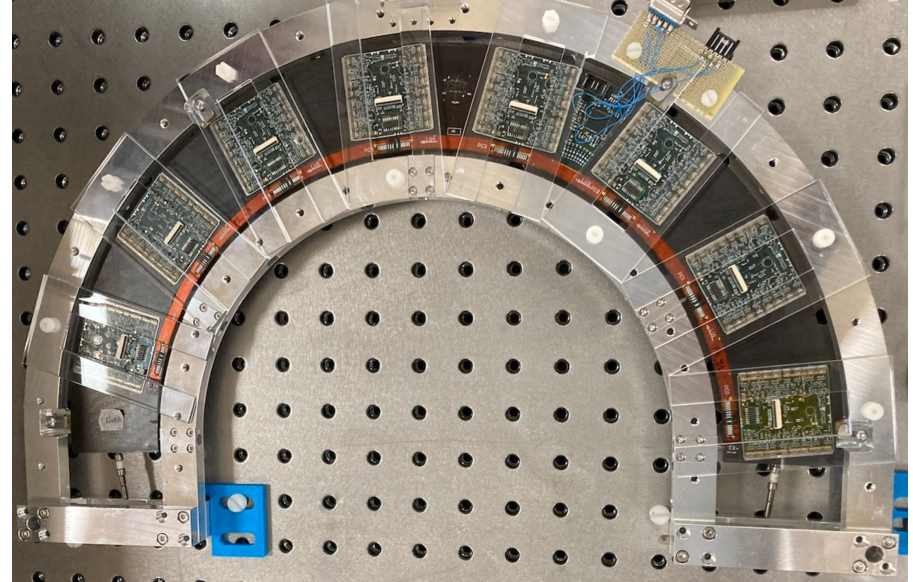
- Resistance between the bare cell and module ground measured below $1\text{M}\Omega$
- Pyrolytic graphite flakes lower resistance between the bare cell and module
- Add a thin insulating coating to the bare cell to cover and freeze flakes



Outer Endcaps started production

- All sites finished pre-series production of L2 half-rings
- 1 half-ring / week / endcap
 - 2 half-rings / week
- 56 loaded half-rings needed in total

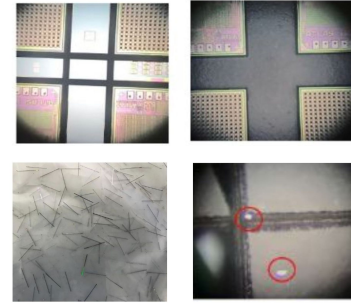
Layer 2 Half-Ring



ITk Pixel Detector Challenges

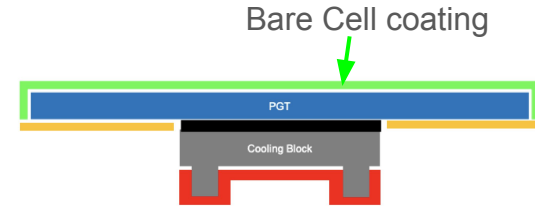
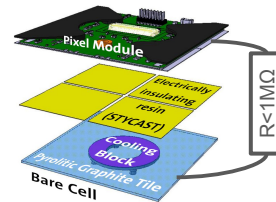
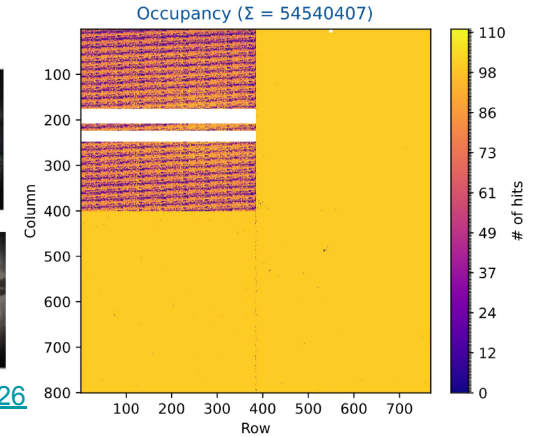
- The core column issue is under investigation and is being mitigated
 - Core column rate decreased by a factor of 2-3.5
- The bare cell insulation was solved by thin coating

Improved cleaning



[D. Fellers, PIXEL 2026](#)

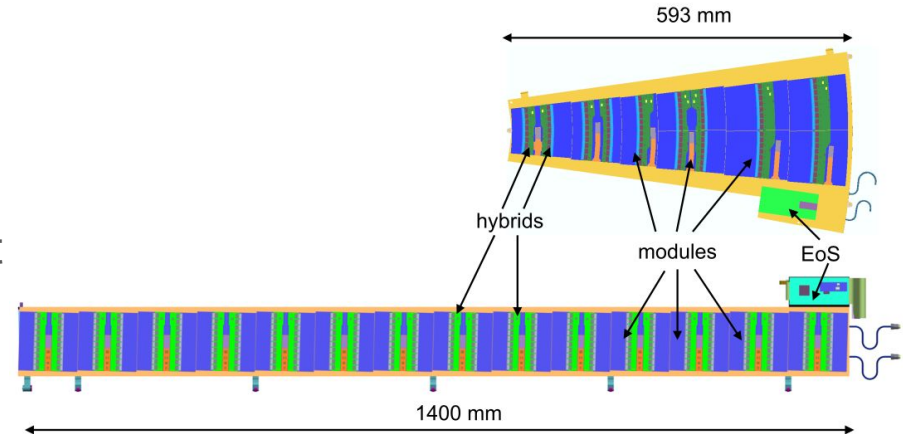
Scan results with bad core columns



ITk Strip Detector

Inner Tracker Strip Detector Architecture

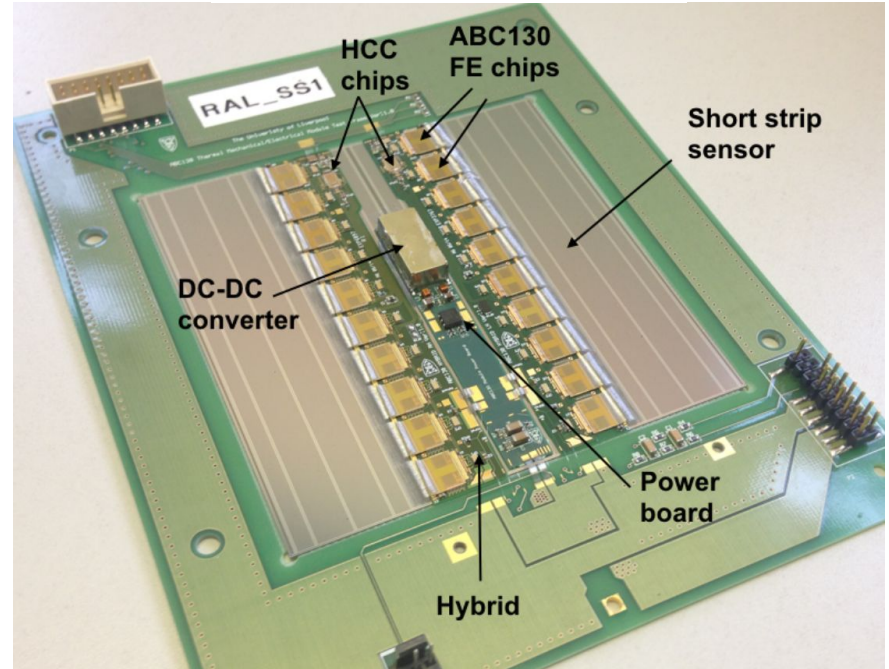
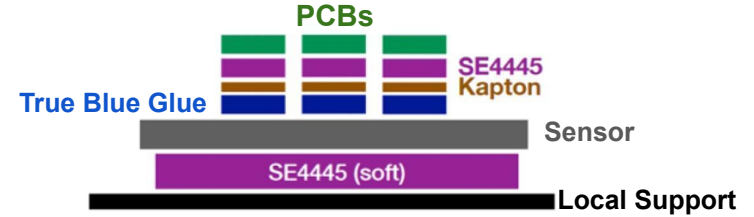
- Staves have long and short strip modules
 - 28 modules per stave
- Petals have sun-ray strip arrangement with 6 module variants
 - 12 modules on 2-sided petals
- 392 staves and 384 petals make the $\sim 165 \text{ m}^2$ active area



- CO₂ cooling at -35°C

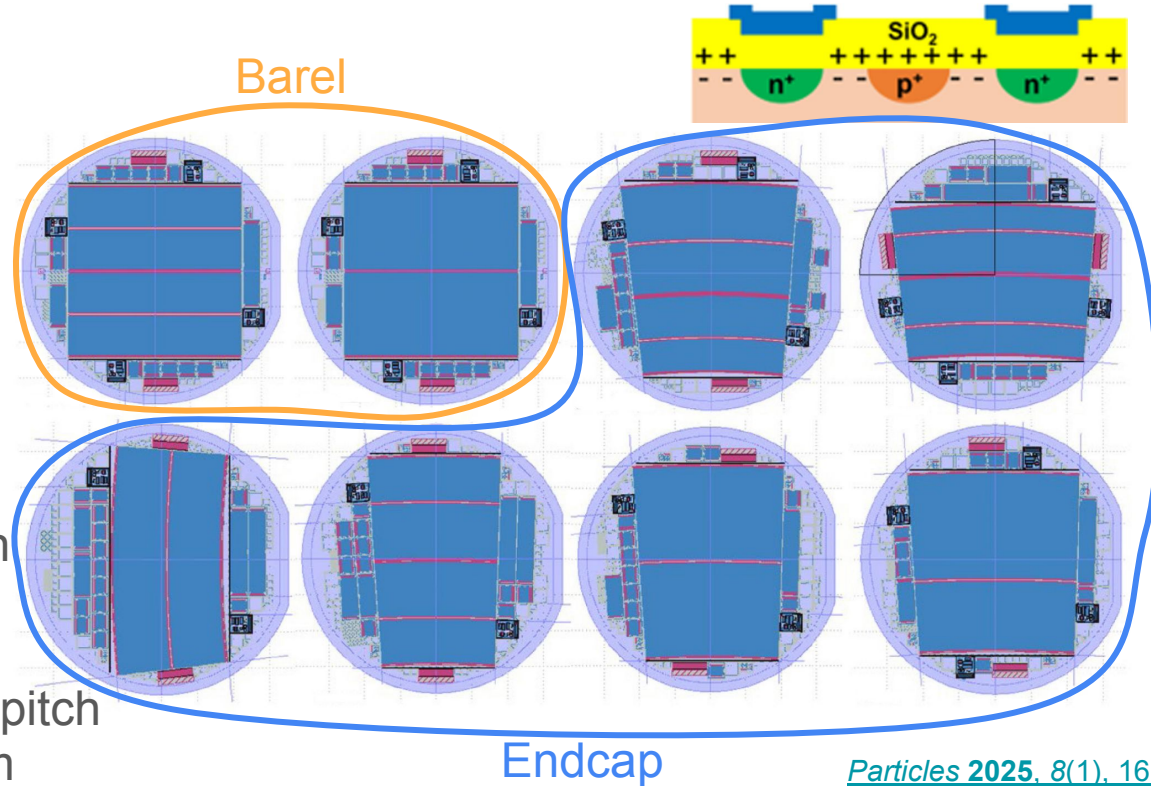
ITk Strip modules

- Large stack of flexible PCB, SE4445 glue, kapton, True Blue glue, sensor, soft glue, and local support
- Short strip module to keep occupancy below 1%
- Petal modules have one sensor in rings 0-2 and two sensors in rings 3-5
- Redout done with ATLAS binary chip(ABCStar) and Hardware Control Chip (HCCStar)



ITk Strip Sensors

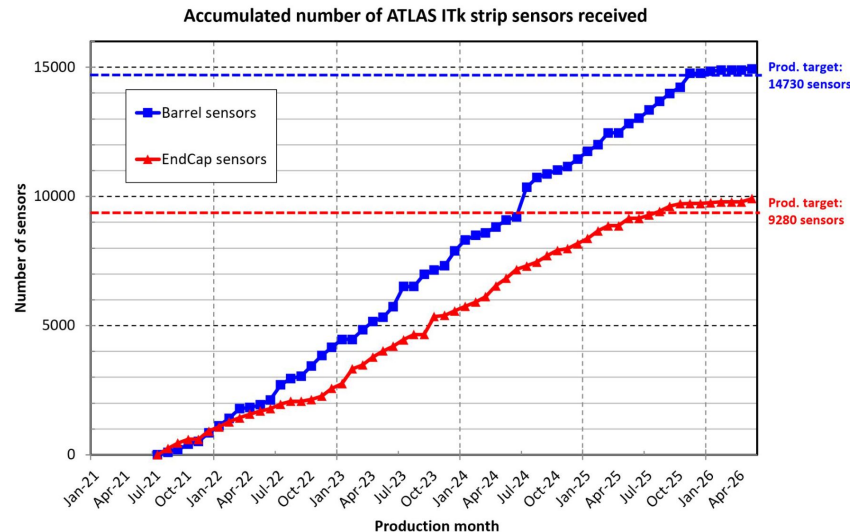
- N+ in p type
- 300-320 μm thickness
- **Barrel**: 75.5 μm strip pitch
 - Short strips 24 mm
 - Long strips 48 mm
- **Endcap**: 69 - 84 μm strip pitch
 - Shortest strips 15 mm
 - Longest strips 60 mm



Particles **2025**, 8(1), 16

Sensor Production

- Received 3.5% above nominal values to account for 2.8% reception rejection rate
- Provided 100% sensors for module production
- Sensor recovery efforts done by UV irradiation, baking, and ion cleaning



[B. Paschen, VERTEX 2026](#)

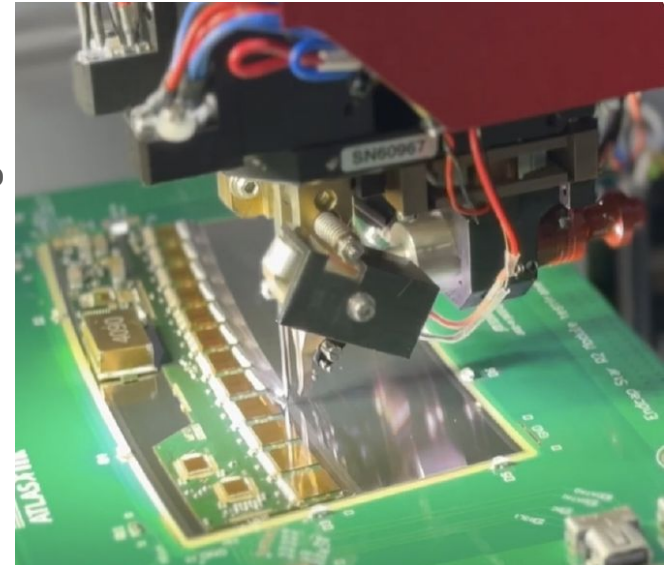
Received Sensors

Barrel	>14750
Endcaps	>9500
Combined	>24000

Strip Module Production

- 90% yield for the barrel modules
- yield between 86.7% – 93.7% for the endcap modules
- Solution for bPol issue is being investigated
- ~20% of 10976 barrel and ~10% of 4608 endcap modules finished

Wirebonding

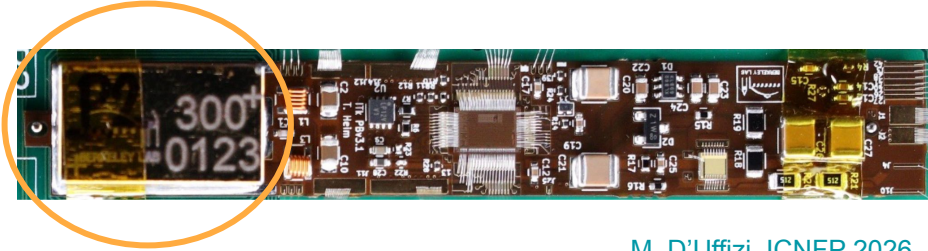


PCB to sensor application

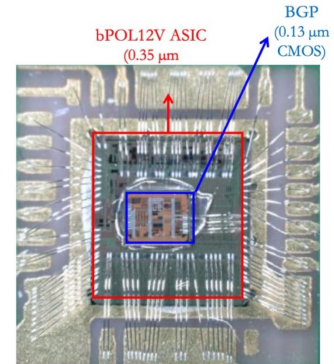
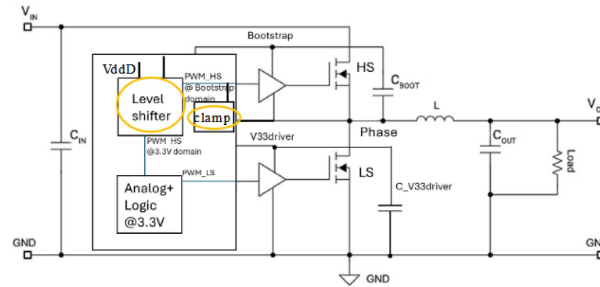


Buck DC-DC converter bPolV12 issue

- Front-end chip damage during stave thermal cycling
- bPolV12 DC-DC converter stays powered if disabled after irradiation at -35°C
- Solutions under investigation:
 - New version of the converter bPolV12_Fx1
 - bPol Vout decreased with extra resistance
 - Hard wired enable



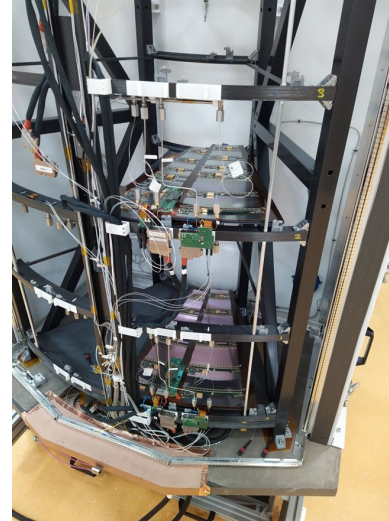
M. D'Uffizi, ICNFP 2026



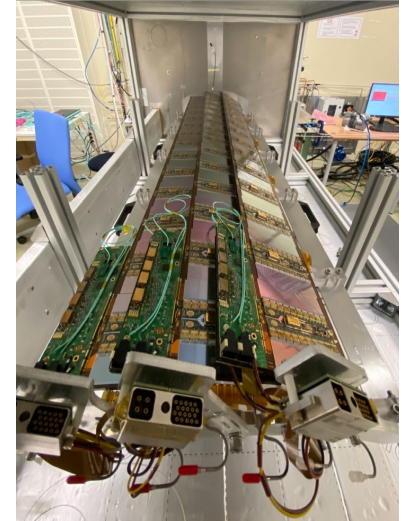
Co-packaging in QFN32

ITk Strip Integration

- > 20 / 384 petals available
 - Enough for the first post-installation readout test
- > 30 / 256 longs strip staves
- First cold tests are to start in Q4 of 2026 for the endcap
- First barrel cold tests are expected in Q1 2027



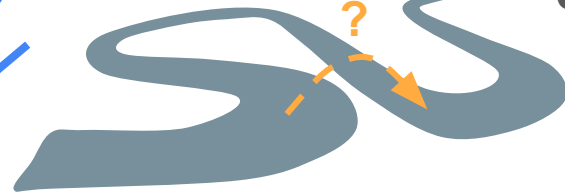
Endcap system tests @DESY



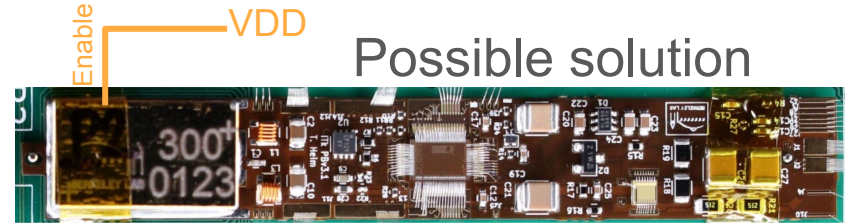
Barrel system tests @CERN (SR1)

ITk Strip Detector production challenges

- Efforts underway to meet the Nov 2028 deadline
- Solutions for bPolV12 issue under investigation
- The earlier issues of cold noise and sensor cracking solved by kapton and glue module interposing



End of Long
Shutdown 3



Possible solution

[M. D'Uffizi, ICNFP 2026](#)



Summary

- Production of the Pixel and Strip Detector of ITk are well underway
- Production challenges in both Strip detector and Pixel Detector are being solved
- All sites are optimizing production procedures to meet the Long Shutdown 3 deadline
- In a few years ATLAS experiment will be ready to deal with HL-LHC

Thanks to the whole collaboration for their help and hard work!



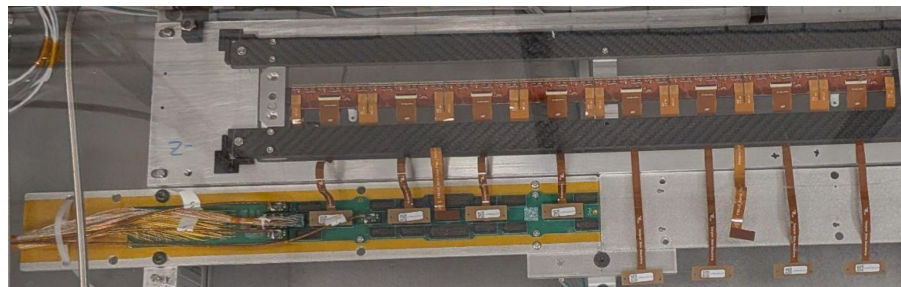


Backup

Inner System production

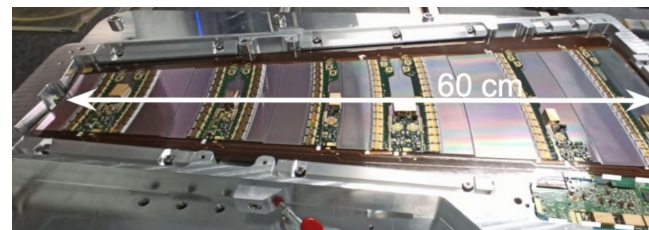
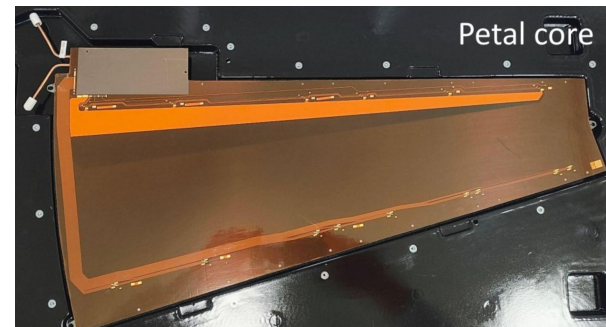
- First production bare rings are being manufactured (29 needed)
- Ring production starts soon with ~100 modules waiting for loading

Module Type	Ready for loading
Quads	72
R0 Triplets	13
R0.5 Triplets	11
L0 Triplets	11



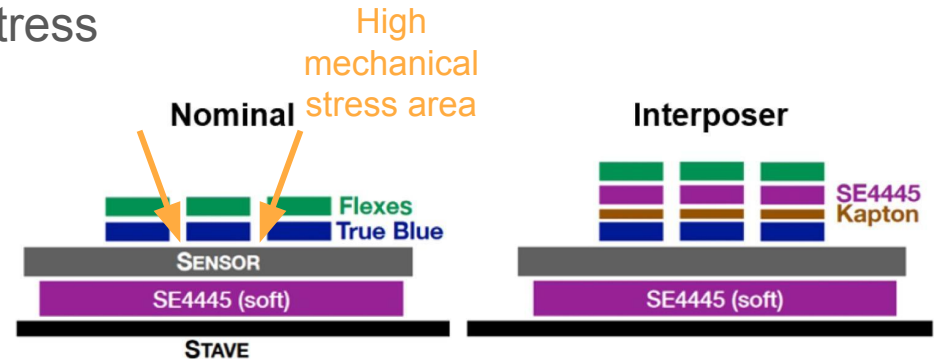
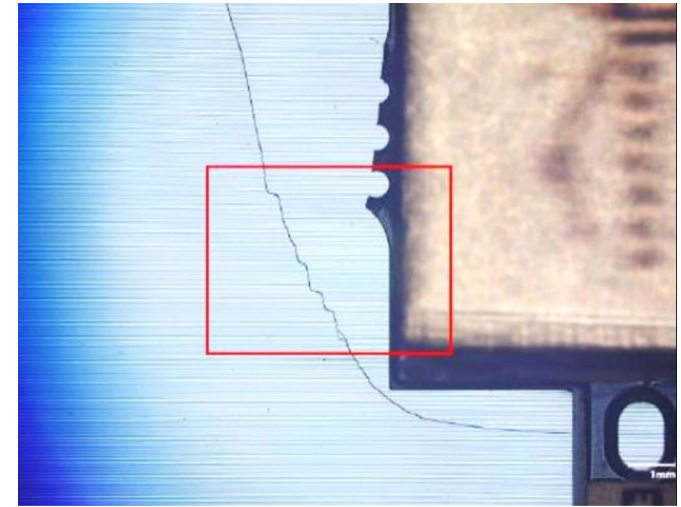
Petal and Stave production

- Good results for 93 stave cores
- 57% of 400 petal cores complete with 95% yield
- ~21% of 256 long strip staves loaded and ~18% tested
- ~9% of 384 petals loaded and ~7% tested



Strip Sensor cracking

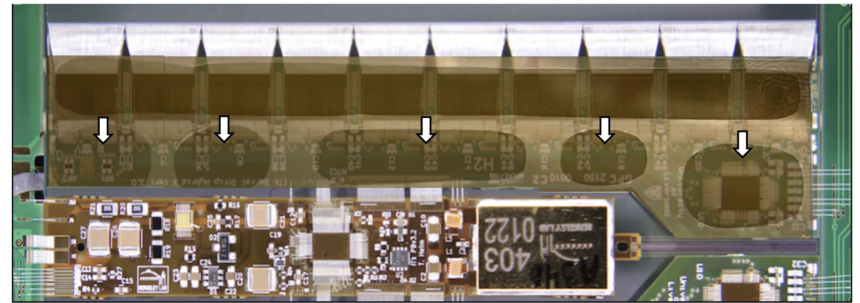
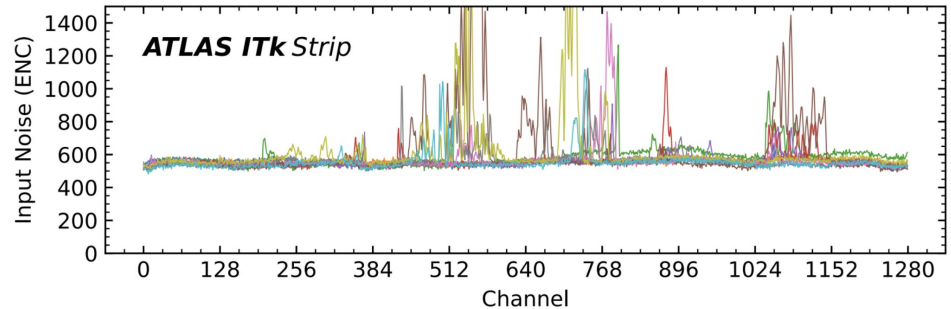
- Strip sensor cracks observed during thermal cycling
- Due to mismatch of coefficients of thermal expansion of the materials and design concentrating mechanical stress
- Solved by adding an interposer Between original glue and flexible PCB



Strip Cold noise issue

- Electrical noise recorded at -35°C
- Found correlation between glue location, capacitors, and recorded noise
- Due to vibrating capacitors on the power board
- Solution was to change the power board glue for better isolation

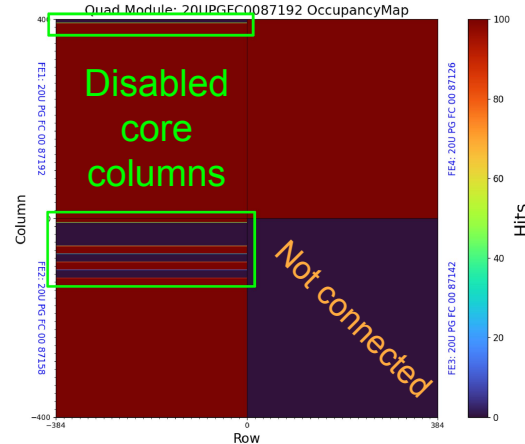
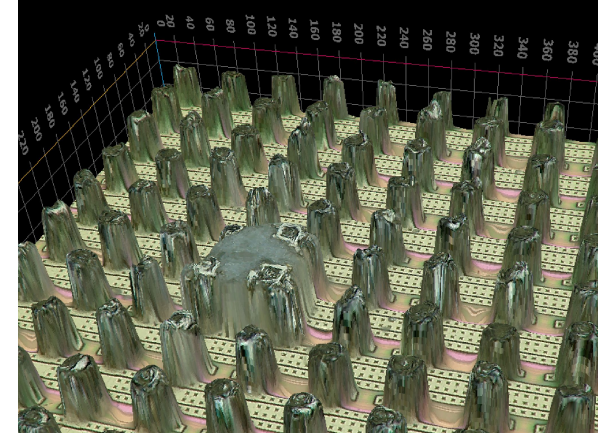
[Particles 2025, 8\(1\), 16](#)



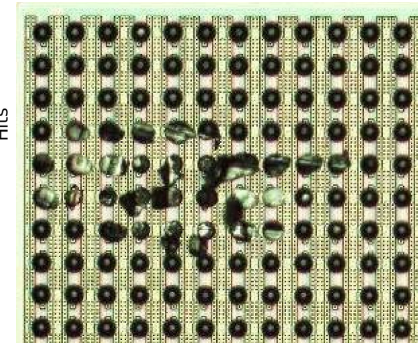
Pixel Module Core Column Issue

- ITkPix scans take too long or get stuck
- Masking the right core columns allows smooth operations
- Caused by a handful of damaged pixels because of scratches or debris between the sensor and chip
- Masking the right pixels fixes operations

L. Meng et al 2025 JINST 20 C06065



Debris



ITk Pixel Quad Module Exploded view

