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Case Study: ATLAS Tracker Upgrade

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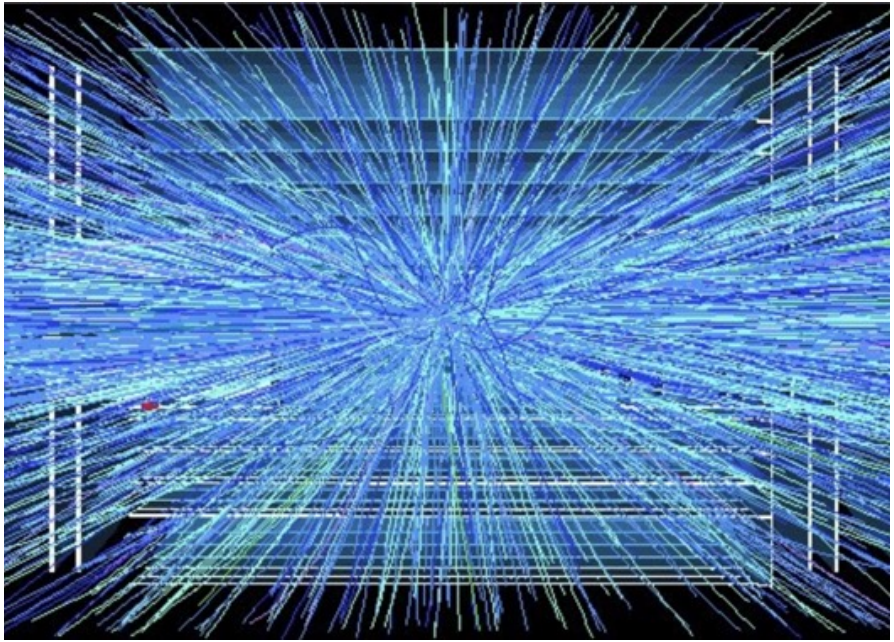
Overview and Objectives

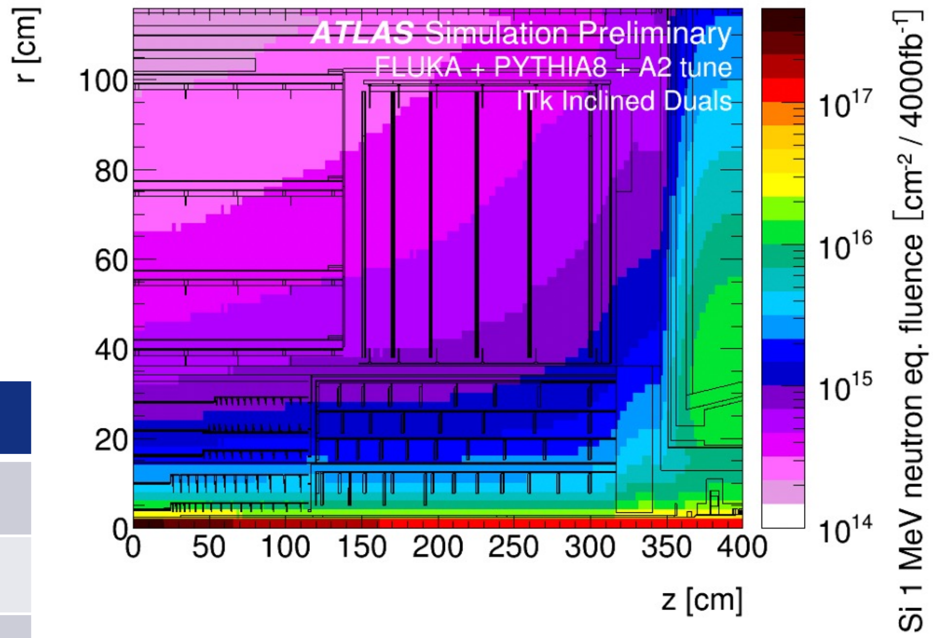
- ATLAS Tracker Upgrade is the core of the ATLAS detector for the High Luminosity Large Hadron Collider (HL-LHC)
- Physics Goals: world-leading measurements of the Higgs and discovery of new particles
  - Requires reconstructing a range of intermediate high-energy states from HL-LHC collisions
  - All of these states depend on high-precision charged particle tracking



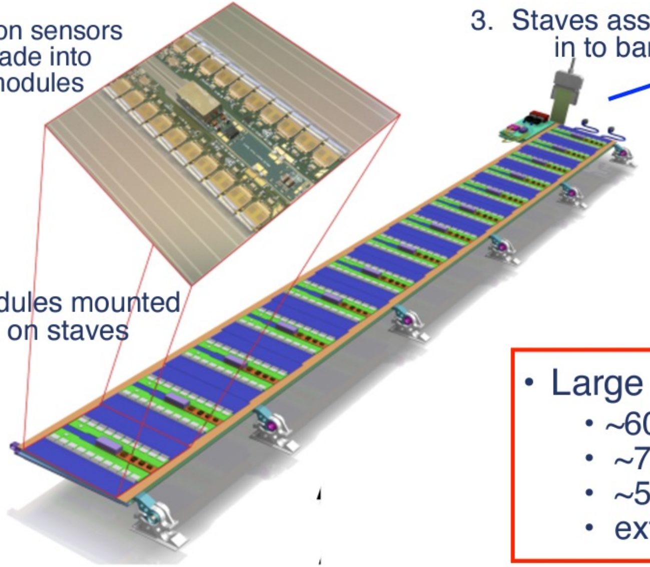
Key Requirements

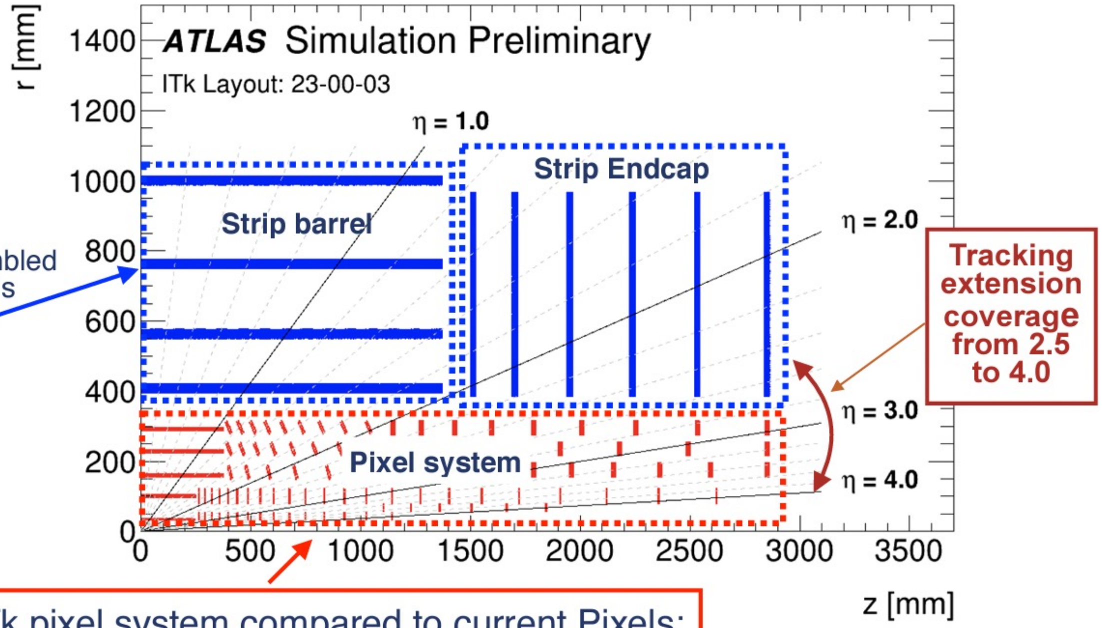
- Readout Rate
- Spatial Precision
- Radiation tolerance

	Pixels	Strips
Collision rate	Up to 200 / 25 ns	
Number of channels	1.4B	60M
Channel size (precision dir.)	25-50 μm	75 μm
Lifetime irradiation (n_{eq}/cm^2)	$\sim 10^{16}$	1.6×10^{15}



- ITk silicon strip system scales up compared to current SCT:
  - ~10x number of channels
  - ~3x sensor area (~10x10cm^2)
  - ~5x number of modules
  - removal of the TRT





- Large ITk pixel system compared to current Pixels:
  - ~60x number of channels
  - ~7x sensor area
  - ~5x number of modules
  - extended eta coverage

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Queen Mary Contributions

1. Silicon strip barrel sensor measurements and QC testing.
2. Stave core R&D and QC testing.
3. Material thermal testing
4. Simulations: Radiation background (FLUKA) and thermal FEA for stave studies (Abaqus).
5. Engineering: pixel system services routing (cabling, cooling etc.) and integration.

Strip Barrel Sensor Measurements and QC

R&D ✓
Final Design Review ✓
Production Readiness Review ✓

• QMUL formally certified to provide Inner Tracker silicon sensor pass/fail evaluation.

• Sensor production phase has started
  - Next 3 years
  - 3000+ sensors to be received and evaluated at Queen Mary

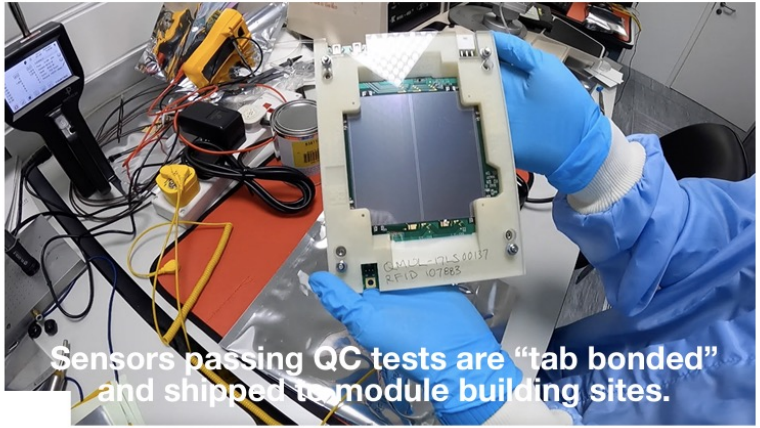
Fully Equipped ISO 7 Certified Clean Room

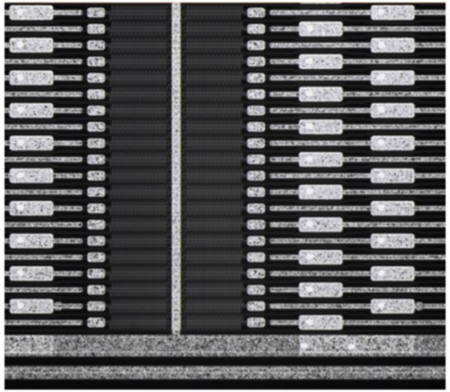
QC tests on every sensor:

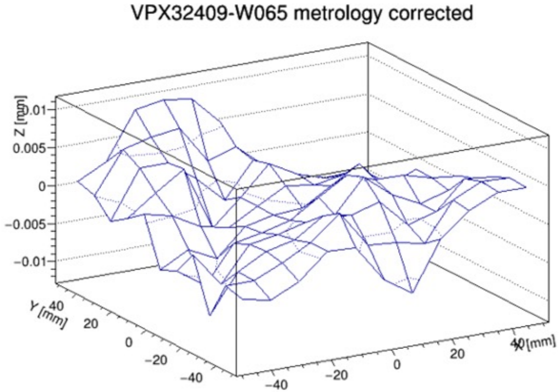
- Visual inspection and high resolution photos
- Metrology measurements
- Leakage current (IV) and bulk capacitance (CV)

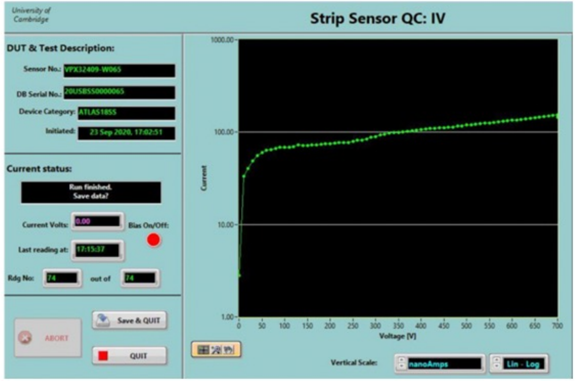
QC tests on ~5-10% of sensors:

- Leakage current stability
- Full strip test: current, capacitance, resistance





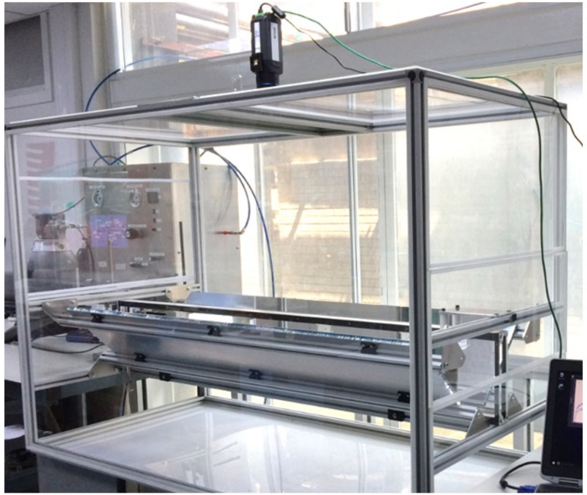




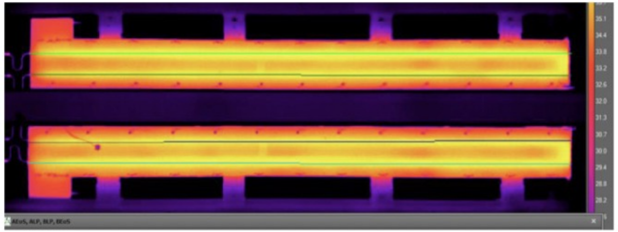
Stave Core QC

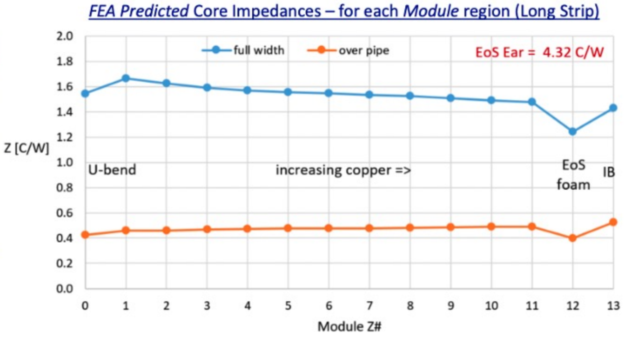
Chiller/pump co-designed with RAL

Stave core in text box in (G5)



Thermal imaging via IR camera

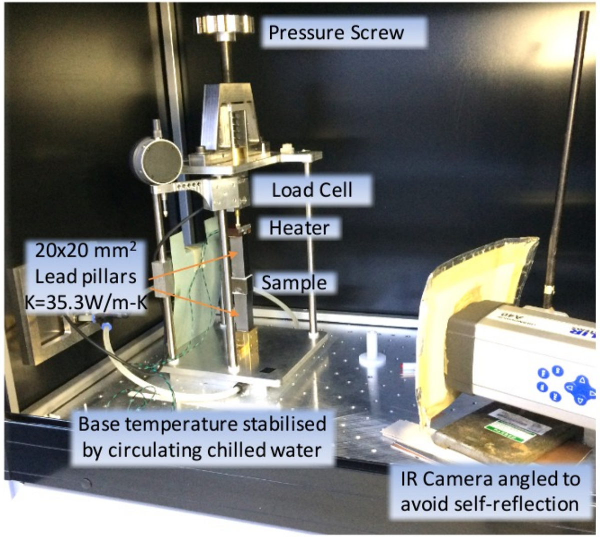


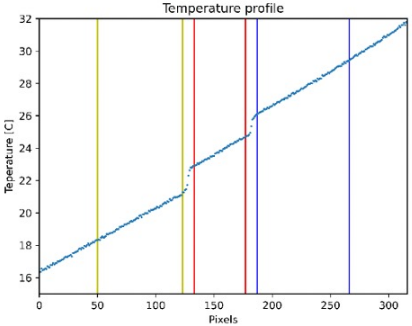


- **Goal is to measure thermal impedances and flag/reject stave cores that fail specifications, before gluing on the very expensive modules.**
- **Achieved by pumping cool (or warm) fluid in the cooling loop and measuring the thermal impedance via infra-red imaging.**

Material Thermal Testing

- Carbon foam provides thermal conductivity within the stave core to remove the heat generated by the modules.
- A set-up in the lab (TIM tower) allows us to measure thermal conductivity of material samples, to check they meet specifications.
- Used to measure conductive foam samples, bus-tapes, components, etc. etc.

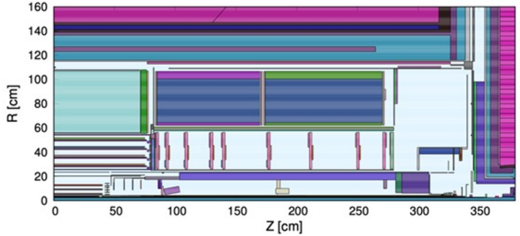


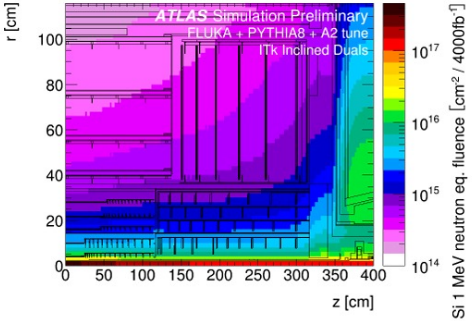


Simulation Studies

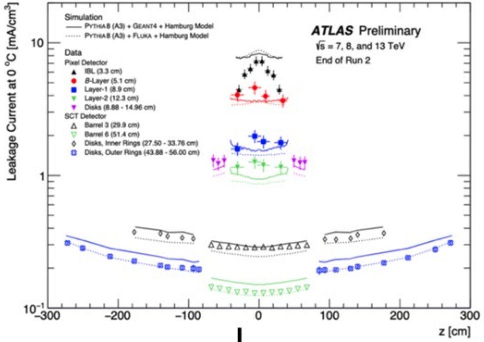
Radiation backgrounds (FLUKA)

Run 2 inner detector FLUKA geometry used to predict fluences/doses in ID



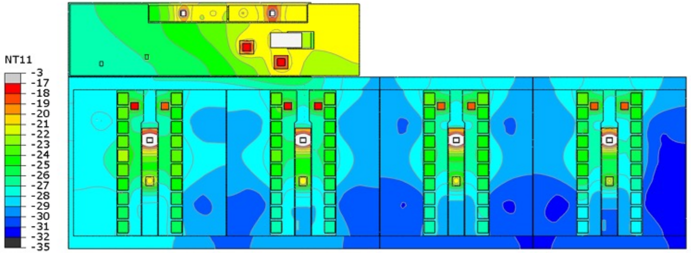


Fluence simulations used to predict leakage currents and radiation damage in Pixel and SCT systems.



Comparisons with measurements used to estimate uncertainties in fluence/ dose predictions for the ATLAS ITk.

Thermal FEA (Abaqus)



Temperature plots of "short staves" derived from Abaqus FEA simulations. If the heat generated by the module sensors and electronics exceeds that removed by the cooling, then thermal runaway will occur along with potential damage.

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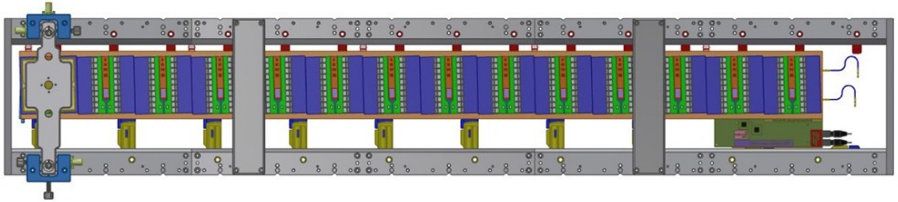
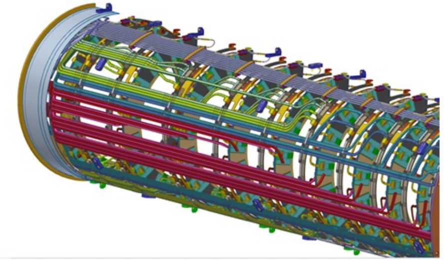
Inner Tracker Engineering at Queen Mary

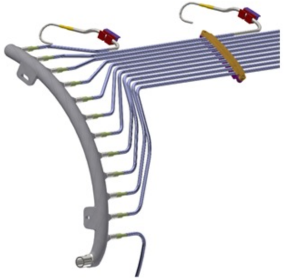
- Responsible for the design, development and manufacture of many key components of the ATLAS upgrade project, for example …



Design and manufacture of stave assembly frames to facilitate loading the modules.
(To deliver to UK and US national labs.)

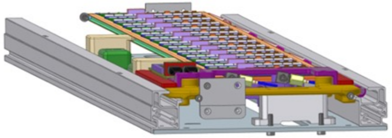


Pixel services (cable and cooling routings) and system integration methods.



Cooling services (e.g. demountable couplings, 3D printed titanium exhaust manifolds)

Design of demountable high pressure cooling couplings, facilitating stave testing and giving significant cost savings compared to baseline.



Design and manufacture of insertion/transport frames for the assembled staves.

Conclusions

- Queen Mary central to this major international project
  - Underpins CERN’s flagship results through 2040
- Significant capacity in:
  - Characterization of silicon sensors
  - Simulation of high-radiation environments
  - Measurement and simulation of sensor thermal properties
  - Large-scale design and integration of detector systems

Thank you

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