Fighting cold noise and early breakdown on the ATLAS ITk strips tracker

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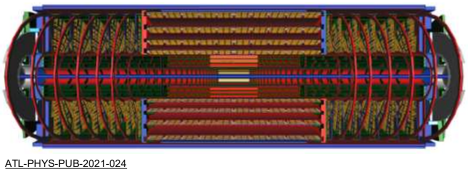
The Detector

- The ATLAS **Inner Tracker (ITk)** will replace the current inner tracking detector in the **HL-LHC** phase to cope with the challenging conditions (occupancy, radiation, etc)
- Tracker is an **all-silicon** detector with **pixel** and **strip** detectors arranged in a central **barrel** region and two **end-caps** in the forward regions



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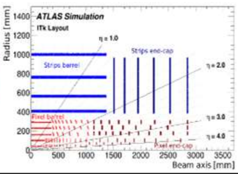
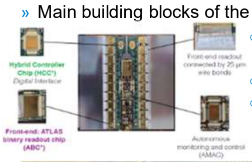
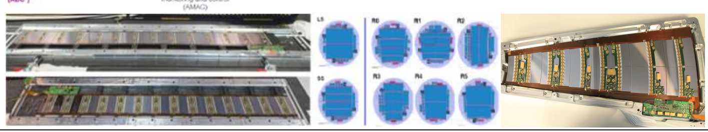


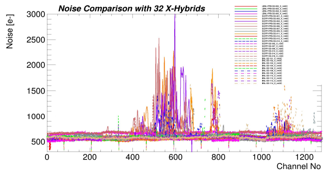
- Main building blocks of the strips tracker are the **staves and petals** consisting of
  - Silicon microstrip detector **modules**: sensor with glued on readout and power electronics
  - Local support structures made out of carbon-based materials
  - Modules directly glued and wire bonded onto supports with low modulus, thermal adhesive

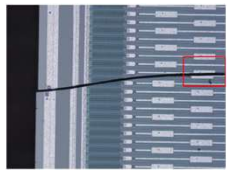




Outstanding issues

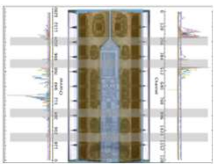
- Two standing issues surfaced on the verge of module production, with the very last pre-production version of components which we believe were mostly not present in earlier prototyping stages:
  - **Cold noise**, discovered ~June 2022
  - **Sensor cracking on loaded modules**, discovered ~ May 2023
- Two taskforces were quickly formed within the ITk strips community and a huge effort has been devoted to understand and solve/mitigate both issues



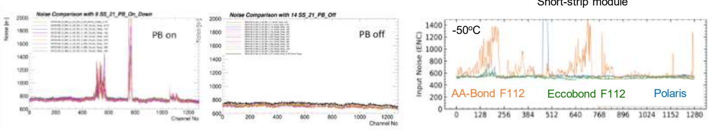


Cold Noise (CN) observations

- **Clusters of noisy channels** observed at operating temperatures at/below -35C
- Sometimes persisting even after returning to warm temperatures
- Correlated with DC-DC power load
- Correlated with glue locations under hybrids
- Strong dependence on glue type:
  - Big variations among electrical grade epoxies
  - Thicker glue layers reduce magnitude
  - Softer (not suitable) adhesives reduce or remove CN
- CN **not present on Endcap modules**

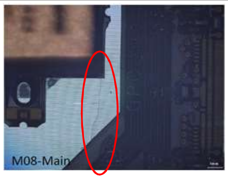


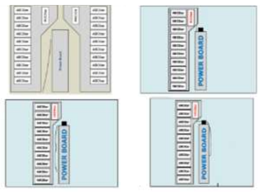
Short-strip module



Sensor cracking

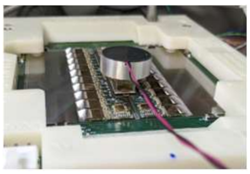
- A fraction of sensors on pre-production staves had "early breakdown" below the 500V specification which was not present in module QC
  - Many modules were correctly attributed to humidity and static charge from handling tools
  - Further investigation found that some of these module had hard (<100V) breakdowns arising from **sensors fracturing when cycled to cold temperatures**
- Most have high or low noise channels associated with the location of the crack
- Cracks located near the power board, typically between hybrid and power board
  - Most didn't propagate to the sensor edges
  - **Affecting approx. 8-10% of modules loaded on supports**

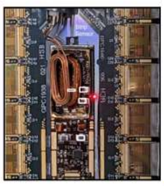


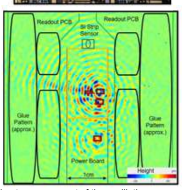


CN understanding

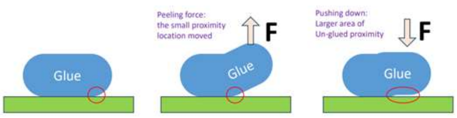
- Further studies revealed that CN is in phase with DC-DC switching frequency (2MHz)
- Able to emulate CN at room T with mechanical transducer
  - → PB vibrates, mechanical waves couple to and travel along the sensor
- Laser vibrometry helped identify the **noise source**:
  - CN caused by **mechanical vibrations from capacitors on the power board** travelling through the sensor and inducing electrical noise
  - Magnitude of vibrations on endcap modules is ~10x smaller
- Coupling mechanism - current theory under investigation: cooling causes hybrids to bend and glue to peel off under the hybrid edge, releasing charge
  - Matches the observed Cold Noise behaviour







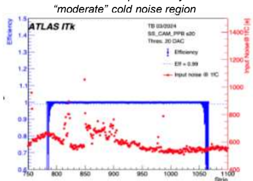
Direct measurement of the oscillation waves with laser interferometer. Scale O(1 Å = 100 pm)



CN status and mitigation

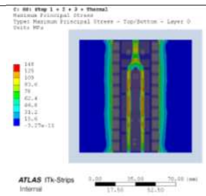
- Identified most favourable adhesive and preparation treatment (Eccobond F112):
  - **NO CN** on barrel Long Strip or endcap modules
  - **Small amounts of CN** on short strip modules
  - Impact on tracking and detector performance of Short Strips (SS) CN under evaluation
- **CN not a barrier to module production any more**

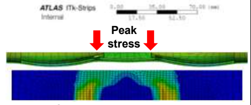
SS module Strip efficiency in "moderate" cold noise region

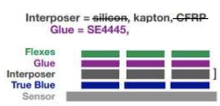


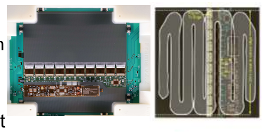
Sensor cracking understanding & mitigations

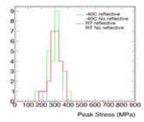
- Intense **thermo-mechanical simulation program**
  - High stress regions coinciding with the observed crack formation regions
  - **Guiding our mitigation efforts**
- **Understanding of the effect**: peak stresses caused by bending of the electronics due to CTE mismatch, causing deformations on constrained sensors
- Mitigations:
  - **"Hysol" adhesive**: counter built-in stress by increasing stiffness at module-to-stave/petal joint
    - Simulations: ~50% peak stress reduction
  - **"Interposers"**: reduce stress region at the module level by decoupling mechanically electronics from sensor with intermediate polyimide layer
    - Simulations: ~ 95% peak stress reduction
  - **"Wide gap"**: spread stress region at the module level by increasing separation between electronic components
    - Simulations: additional 10-20% stress reduction
- Mechanical test program to **establish fracture stress** of sensors also in place
  - Compatible with simulations, no effect from T, but long tail in the crack distribution
- **Ongoing effort**: not a clear solution found yet
  - Hysol staves/petals with nominal geometries still showing cracking signatures
  - Hysol stave with wide gap modules **survived >50 cycles @ -45°C** without any cracks
  - **Interposer modules showing promising results** (mechanical and electrical performance), no cold noise on SS interposed modules
- **Path towards a working solution by Q4 2024**

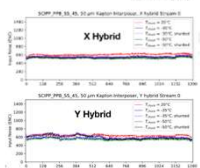












References

- G.I. Dyckes and M.G. Kurth on behalf of the ITk Strip collaboration, JINST 19, C04058 (2024)
- S. Diez on behalf of the ITk strips HV EB task force, ATLAS Open EB meeting (2024)

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