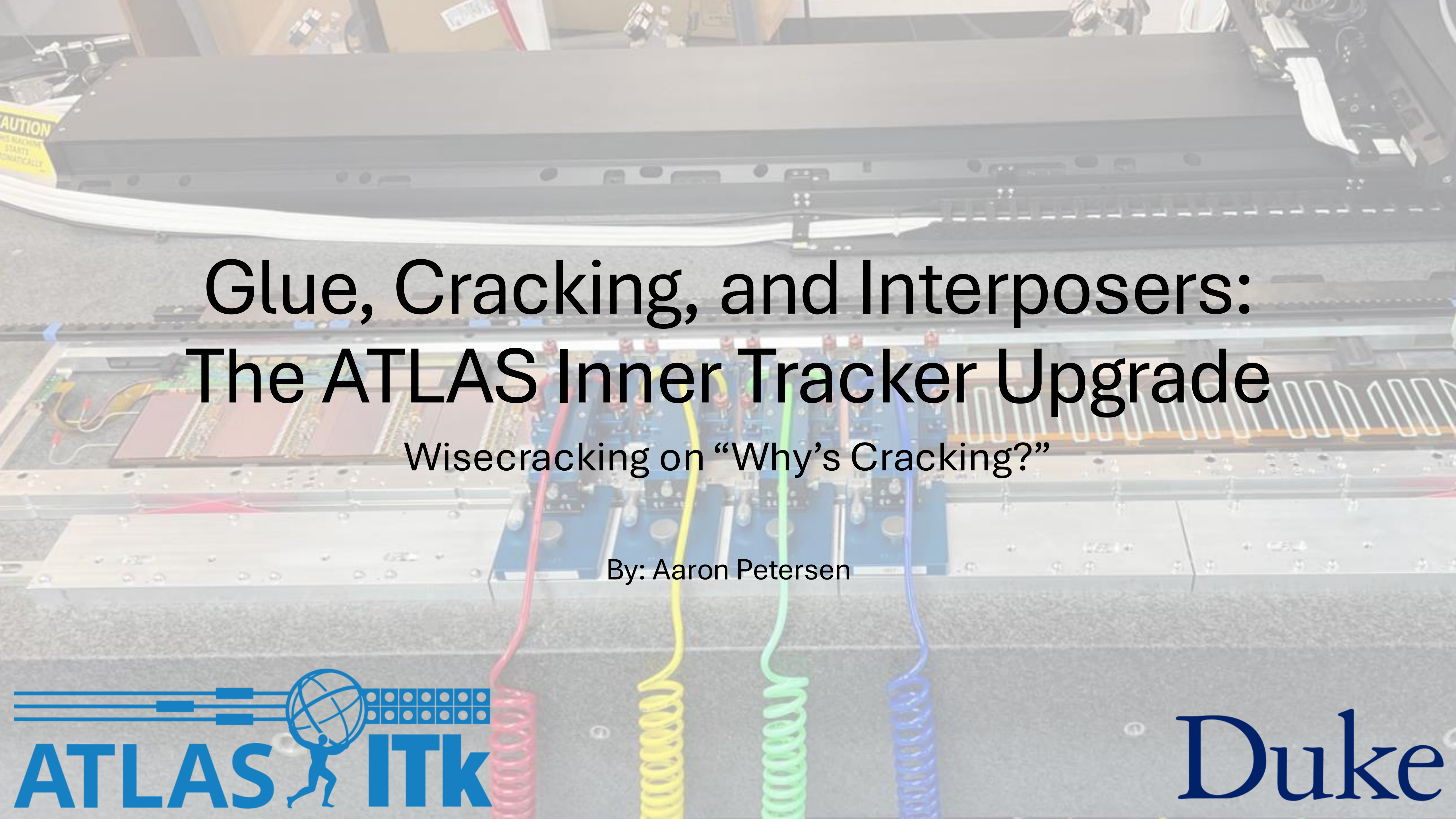


Glue, Cracking, and Interposers: The ATLAS Inner Tracker Upgrade

Wisecracking on “Why’s Cracking?”

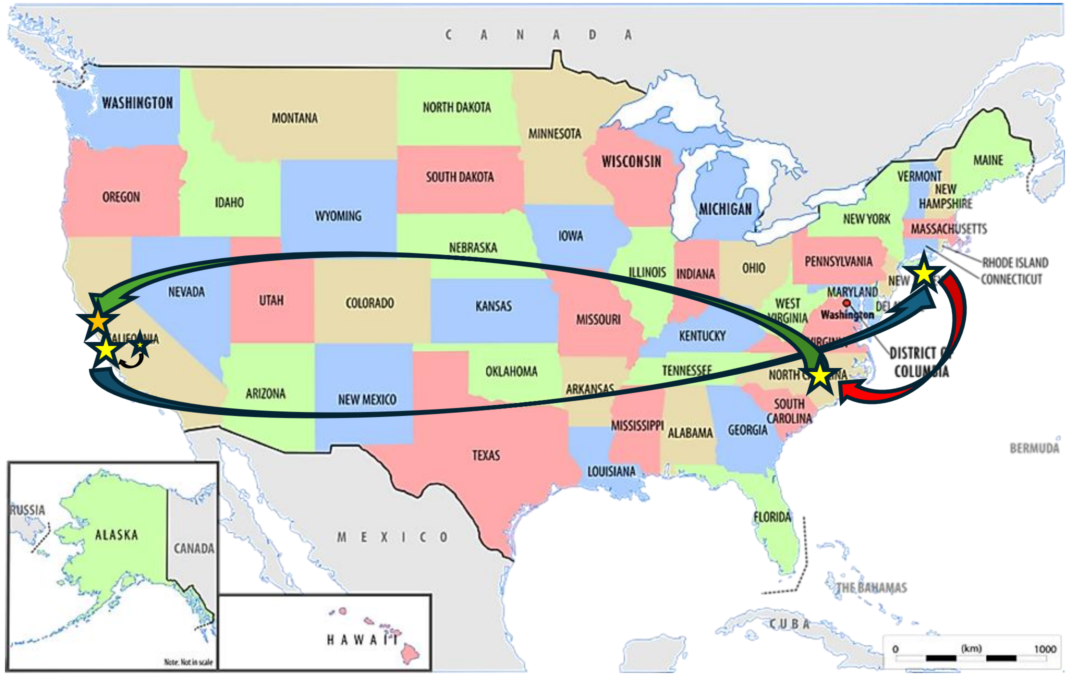
By: Aaron Petersen

ATLAS ITk

Duke

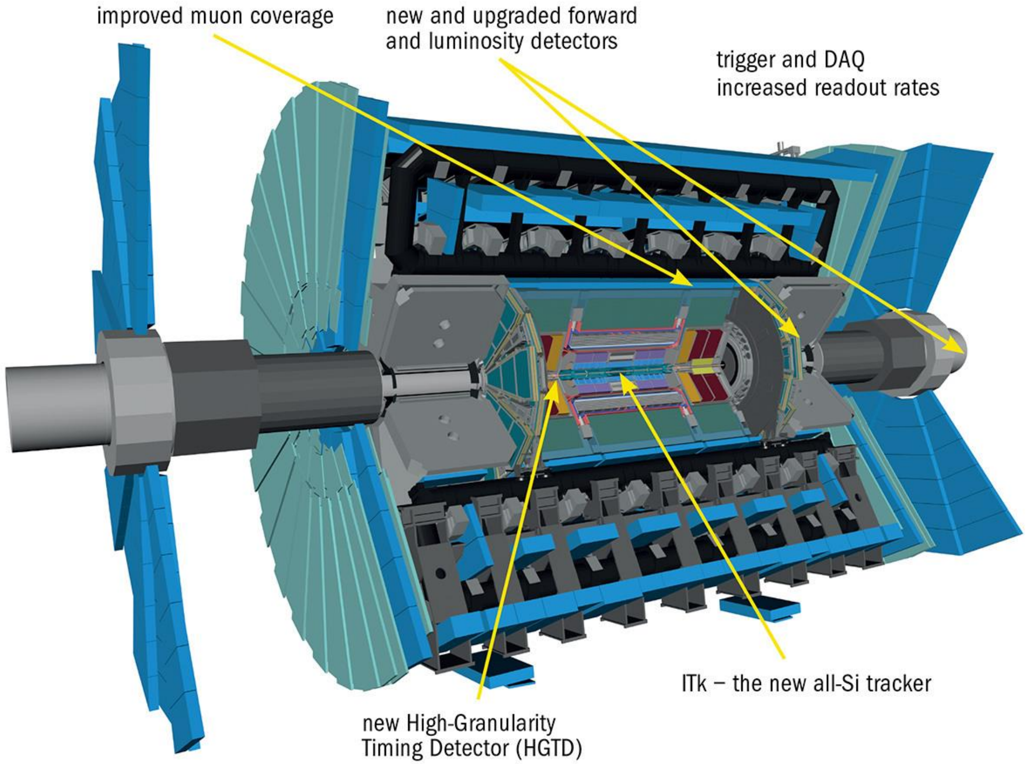
Self-Introduction

- From Clovis, CA
- First Year Graduate Student at Duke University
  - Student of Mark Kruse
- Undergraduate at University of California, Santa Cruz
  - Briefly worked on particle theory research
- Was a Post-Bachelor Researcher at Brookhaven National Lab working on the ATLAS Inner Tracker
  - Worked with Omega Group
  - Part of Sciolla group from Brandeis
  - Focus of today's talk



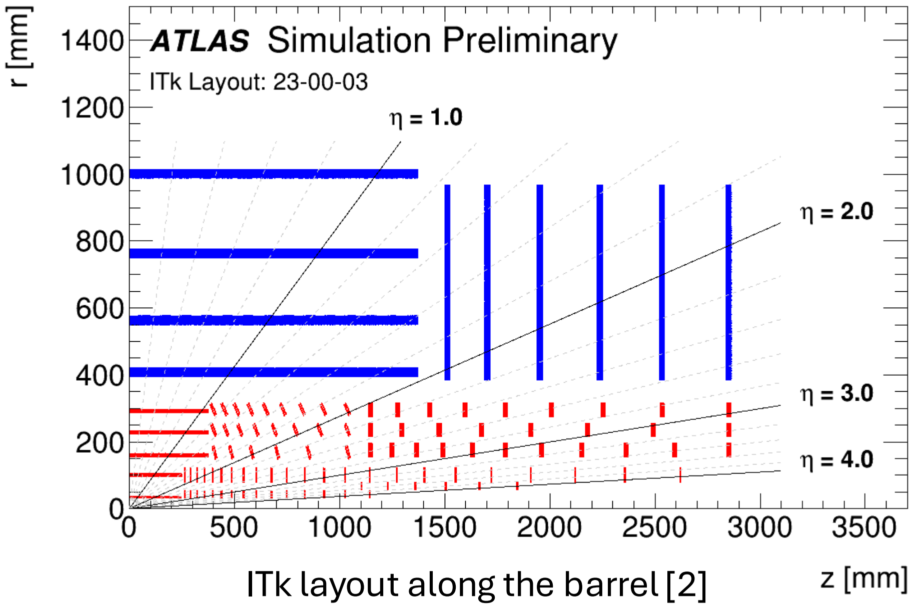
HL-LHC and ATLAS

- HL-LHC expected to see a 3.5x increase in instantaneous luminosity and an integrated luminosity of 3000 fb^{-1} over 10 years
- Present challenges for future operations of ATLAS (at the tracking layers)
  - Expected Total Ionizing Dose over 50 MRad during lifetime
  - Non-ionizing radiation fluence over 1.2×10^{15} $n_{eq}cm^{-2}$ throughout operation[1]
  - Expected pile-up of $\mu \sim 200$
- Requires updated detectors, data acquisition, and computing to meet demands of Phase II upgrade to HL-LHC

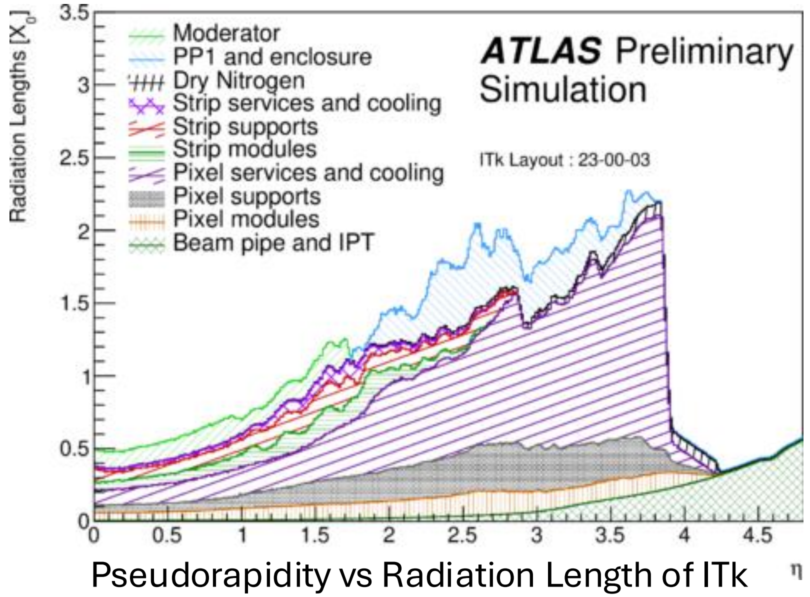


ITk from ID

- The Inner Tracker (ITk) is an all-silicon pixel and strip detector
  - Goal of better performance than Inner Detector (ID) under extreme conditions of HL-LHC
- The ITk features 10x the strip and 60x the pixel channels as the current ID
  - Planned to cover a pseudorapidity of $\eta < 4$ with pixel and $\eta < 2.7$ with strips
- The reduced material from developments in semiconductor technology results in a smaller radiation length in ITk than ID



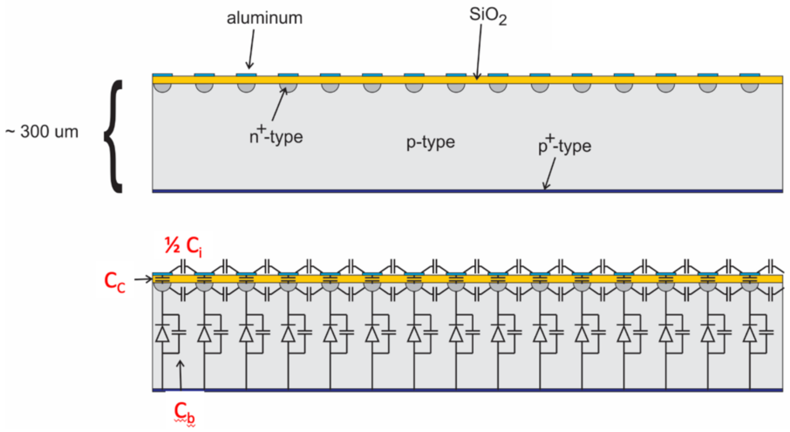
ITk layout along the barrel [2]



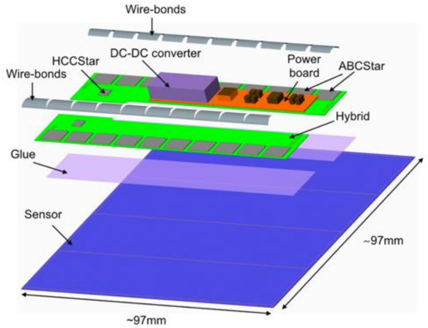
Pseudorapidity vs Radiation Length of ITk [2]

ITk Strips Barrel

- Detector consists of 75.5um pitch silicon strip sensors known as modules
  - Electrically a reversed bias diode between p^+-type backing plate, p-type "dielectric", and n^+-type strips
  - When reversed biased, electron/hole pairs are freed and able to be read out through the strips when an ionizing particle passes through the sensor
- 28 modules (14 modules on each side) are mounted front and back to a carbon fiber mounting board that supplies power, I/O, and cooling known as staves
  - Each module is set to a stereo angle of 26 mRad to allow for hit matching between sensors on opposite sides (52 mRads between the two faces)
  - ~400 of these staves are set to be mounted in 4 layers of the barrel around the beamline
- Operational temperature is intended to be -35C



Make up of and effective circuit overview of ITk strip barrel modules [3]



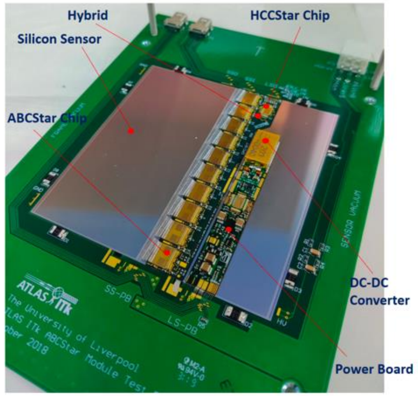
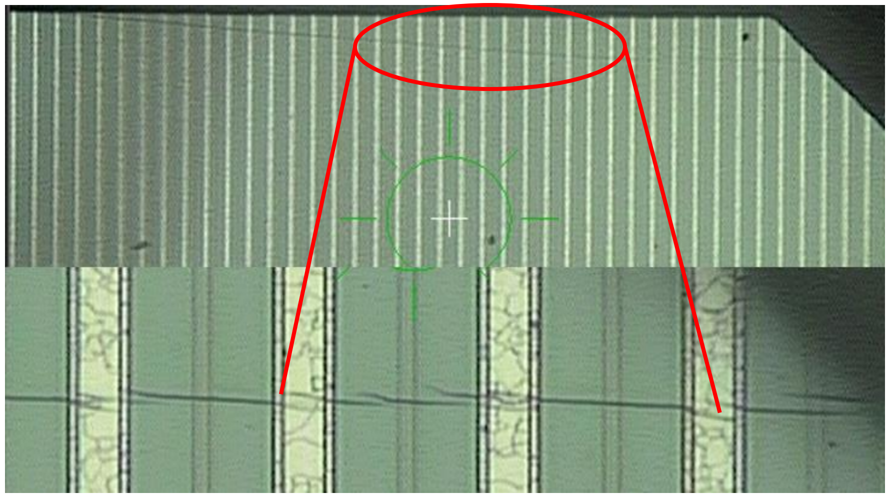
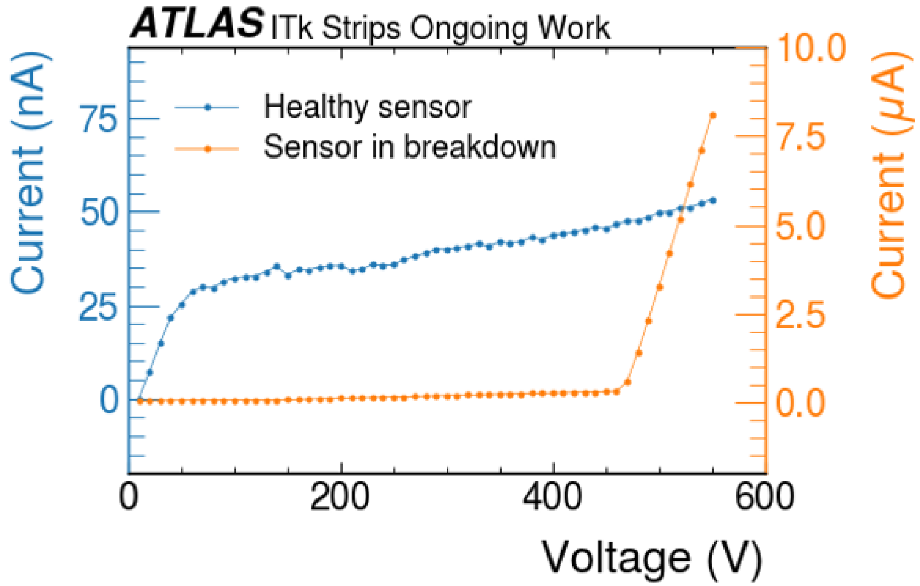


Photo of module (Short strip right, Long Strip Left)

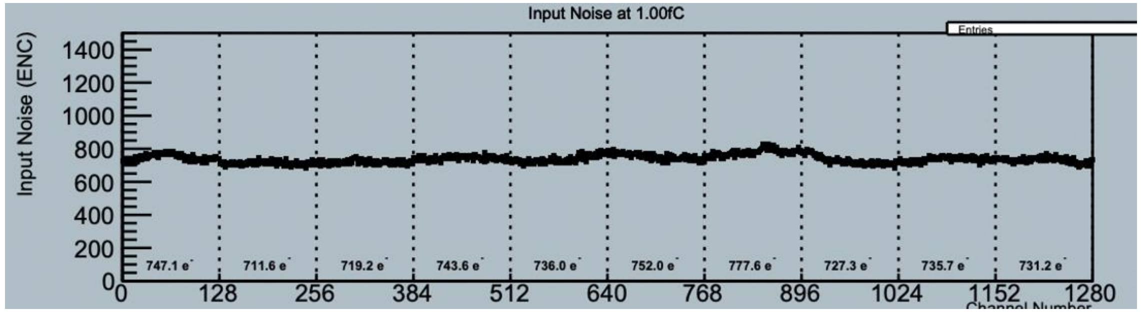
Module Cracking

- Noticed in early 2023, loaded ITk staves were seen to go into early breakdown after being thermal cycled (a sudden large increase in current as voltage increased)
- The entire sensor goes into breakdown during the IV scan, while the noise test reveals the issue is localized to a small group of strips
- This was later determined to be cracking and confirmed visually in June 2023

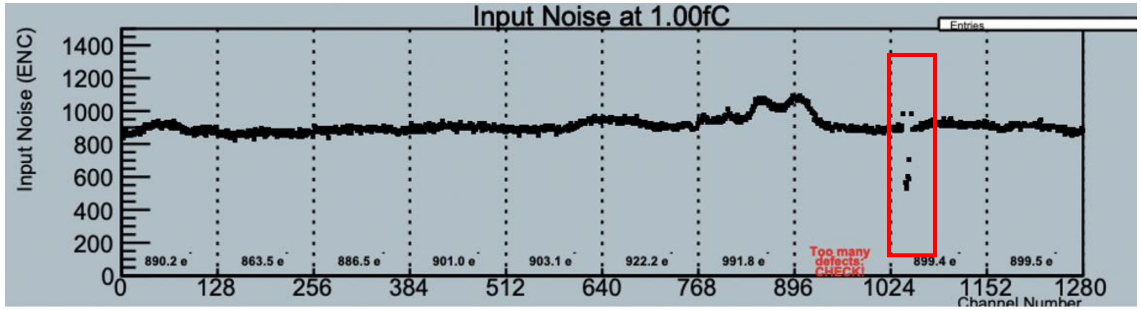




Healthy



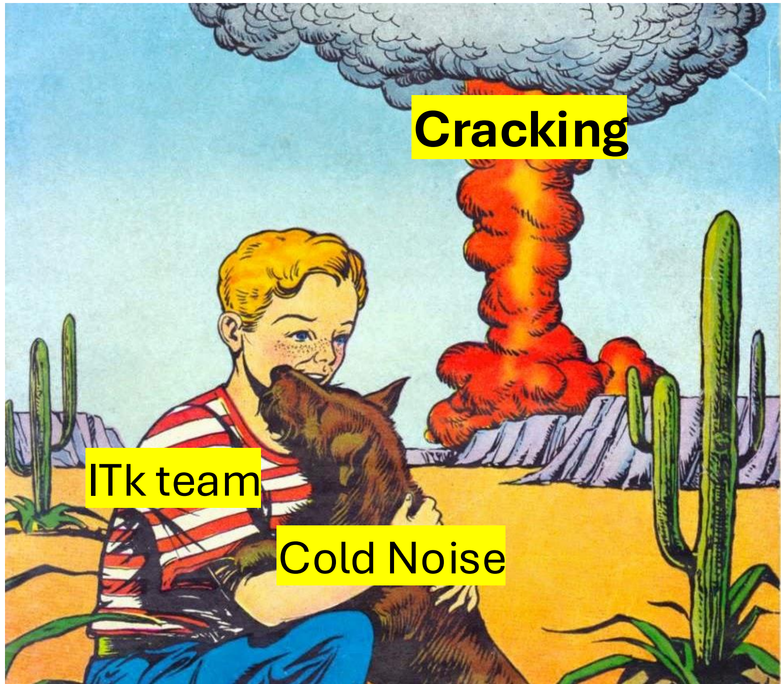
Symptom of Crack



Photos Courtesy of Emily Duden

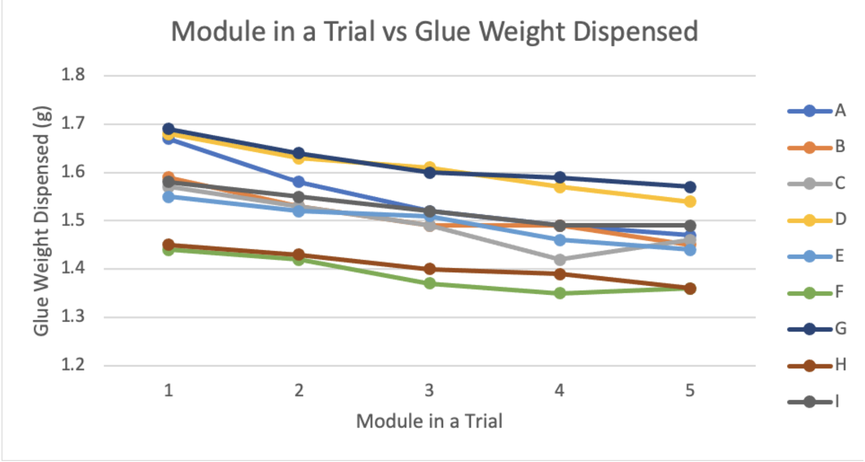
Possible Causes of Cracking

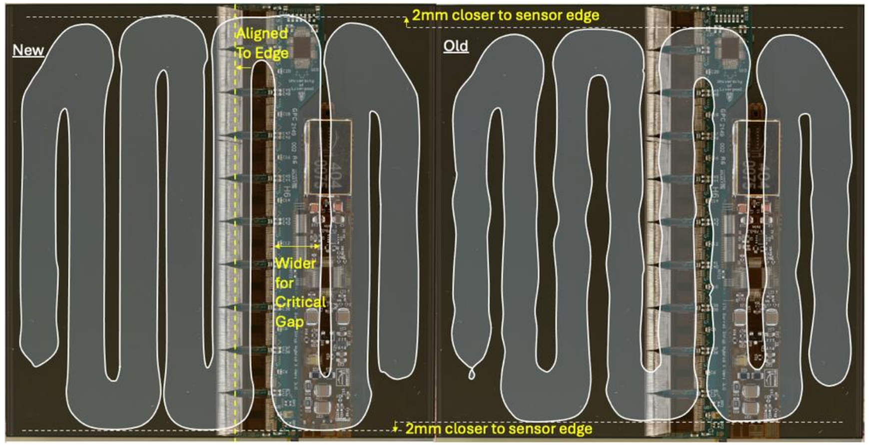
And a hopeful solution

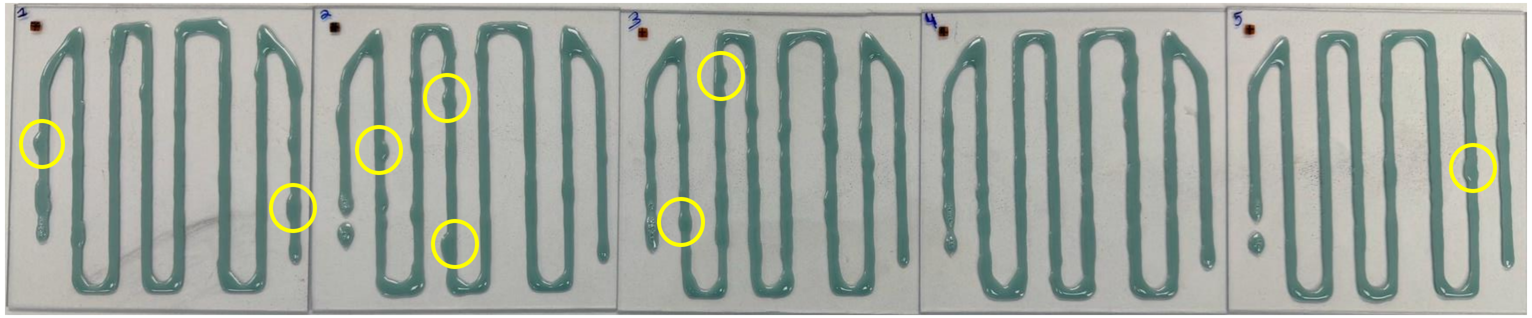


Glue/Adhesives

- Simulation showed the adhesive used to mount the modules onto the staves could result in excess strain on the surface when thermal cycled
- Attempted to resolve this issue by swapping the softer adhesive for a much harder glue Hysol with ceramic doping for bettered thermal properties
- Attempted with difference values of different ceramics (Alumina and Aluminum Nitride of varying grain sizes) to observe dispensing patterns and repeatability
- Unknown at that time that when taken to -45C or below, SE4445 and Hysol act the same
    - SE4445, once almost spongy, turns as hard as Hysol



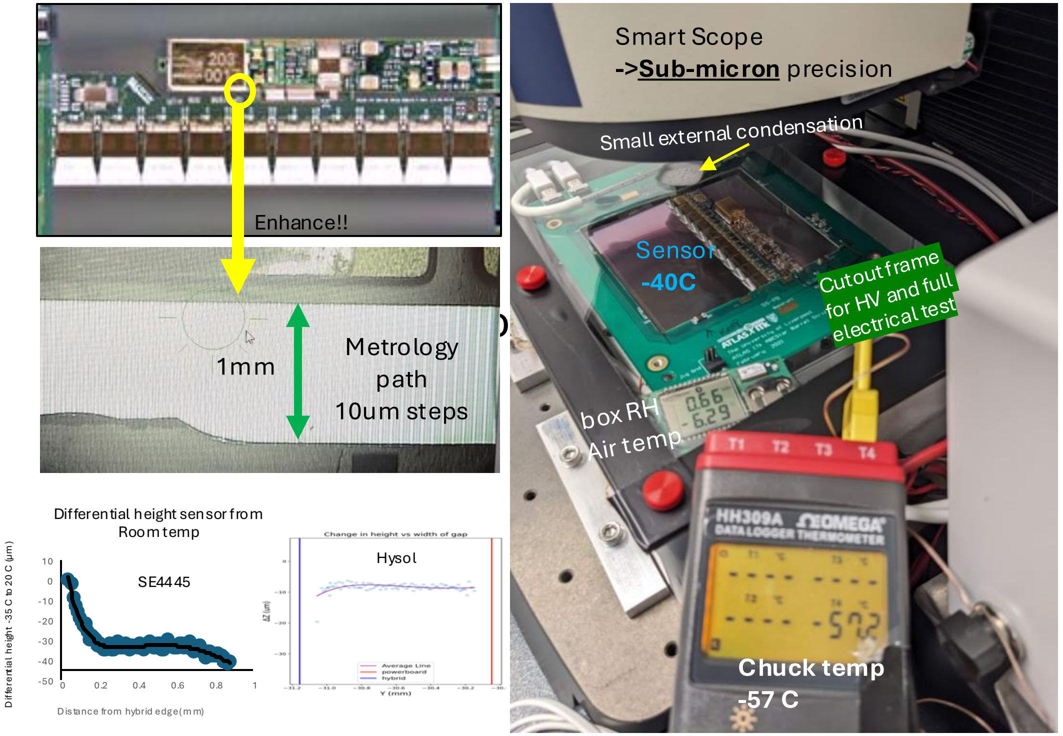




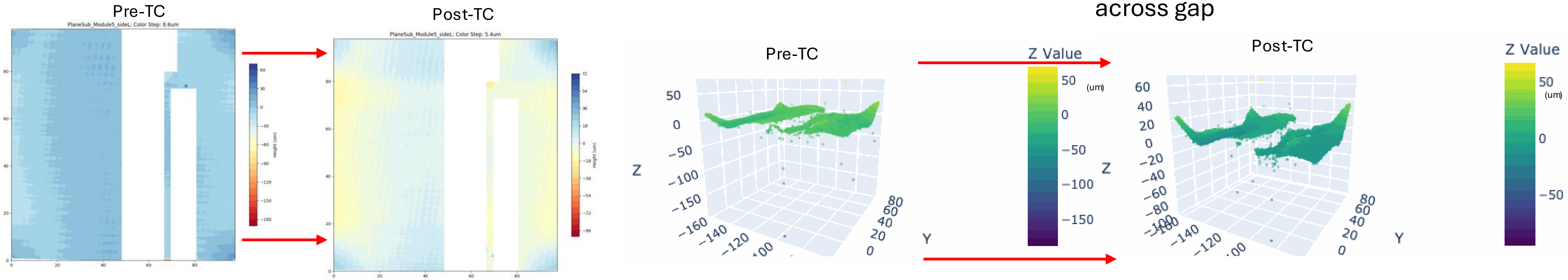
Examples of identifying inconsistencies in dispensing

Geometry of module

- The crack was seen in the gap region between the power board and hybrid
- Cold metrology confocal scans were taken down to -50C between the region
- At room temp, high resolution confocal scans of module mounted to the 1.4m staves were taken to observe lingering bending from thermal cycling



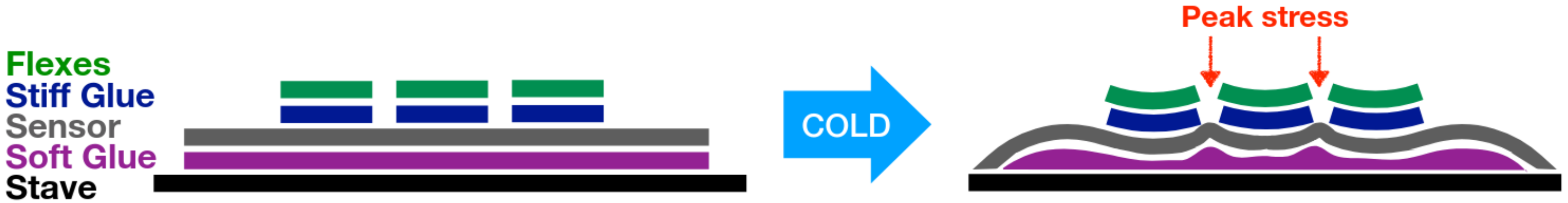
Cold metrology set-up, photo of gap, and example data across gap



High Resolution confocal scans before and after stave thermal cycle (heat map left, 3D GIF right)

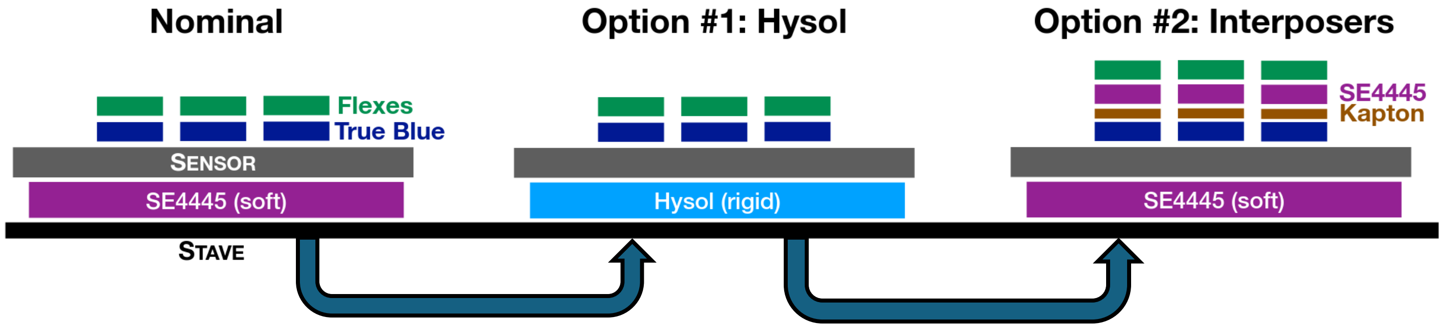
CTE Mismatch and Interposers

- Determined the Coefficients of Thermal Expansion (CTE) between the mounted circuit boards and silicon strip sensor was resulting in excess strain on the module
- The promising solution is an interposer between these two components
  - The hybrids and powerboards are first mounted on 100 um of SE4445 and 50 um of kapton (together are called the interposer) to absorb the CTE mismatch between the boards and the sensor
- Currently being tested to determine the reliability of the CTE transition
  - Of a sample size of 70 Long Strip modules, we're seeing a failure rate of ~1% at -60C compared to a 95% failure without



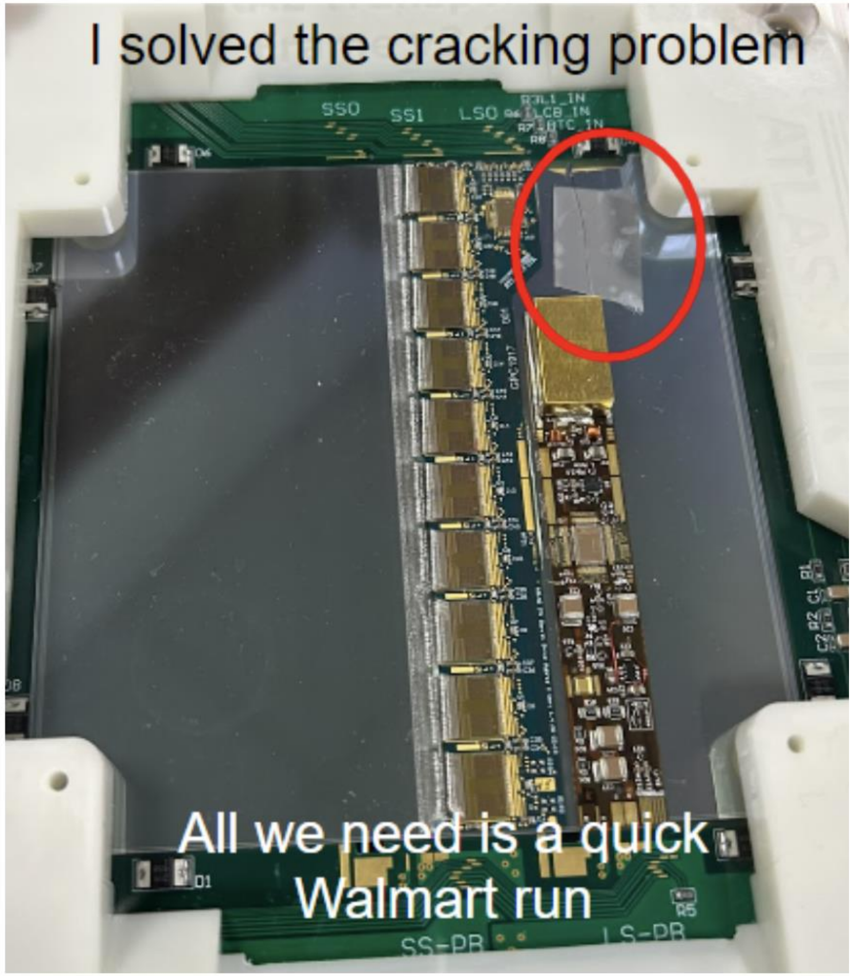
Strain on Plain Module

Iteration of Module Structure



Summary

- The ATLAS ITk is the upgrade intended for the HL-LHC upgrade
  - 10x the strip and 60x the pixel channels compared to the Inner Detector
- Over the past year, cracking has appeared when thermal cycling detectors to operational temperatures
- Measured surface strain on modules both unloaded and loaded onto a stave to see regions of interest
- Attempted to change glue pattern to observe change in module strain
- Currently testing interposer solution between powerboard/hybrid and sensor surface to provide CTE transition between materials
  - Looks promising with a ~1% failure rate thus far compared to a previous 95% at temperatures well beyond operational temp

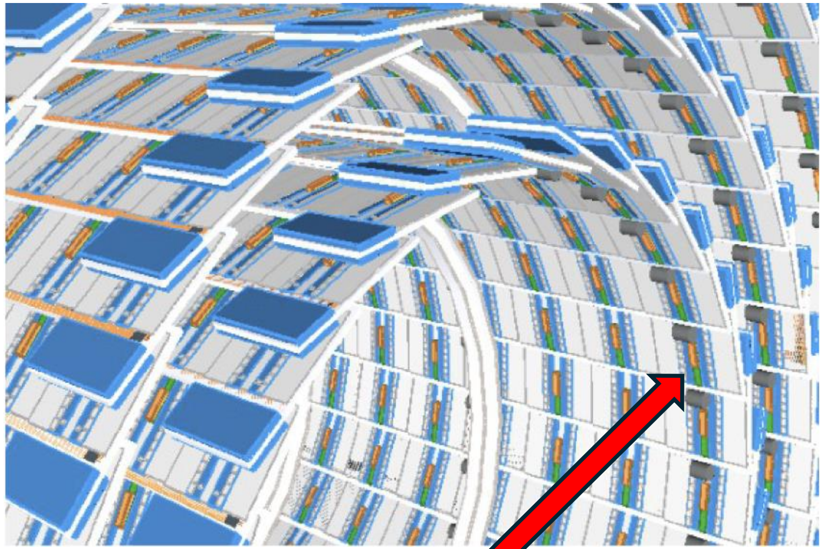


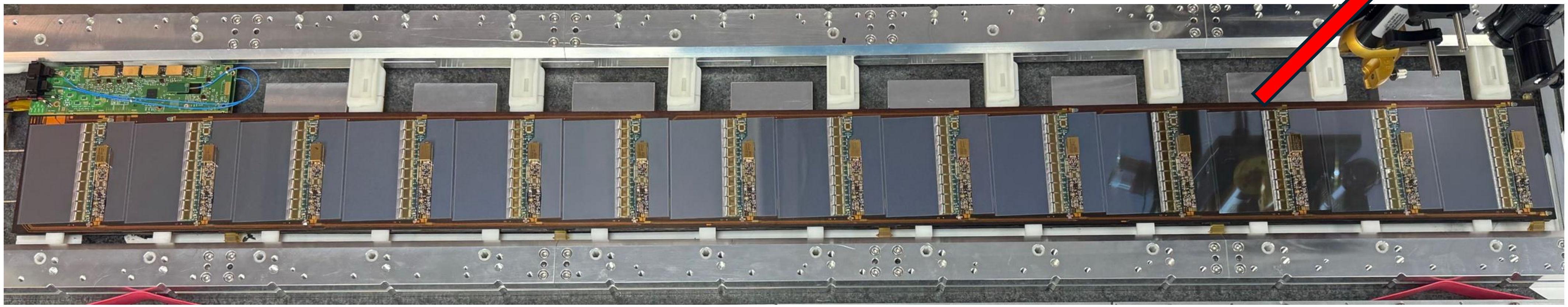
Credit: DanielHouse

Backup Slides

ITk Strips Barrel Structure

- 28 modules (14 modules on each side) are mounted front and back to a carbon fiber mounting board that supplies power, I/O, and cooling
  - Uses thermally conducive adhesive SE4445
  - A fully mounted board is referred to as a stave
- Each module is set to a stereo angle of 26 mRad to allow for hit matching between sensors on opposite sides of the carbon composite support structure when a particle impacts the stave
  - Totaling 52 mRads between the two faces
- ~400 of these staves are set to be mounted in 4 layers of the barrel around the beamline (2 Long Strip, 2 Short Strip)
- Operational temperature is intended to be -35C





ITk Strips Barrel Module

- 97x97mm, 75.5um pitch silicon strip detector
  - 1 mounted powerboard
  - 1 or 2 hybrid readouts (long strip or short strip respectively)
  - Operates from -350V to -500V
- Electrically a reversed bias diode between p^+-type backing plate, p-type "dielectric", and n^+-type strips
- When reverse biased, the "dielectric" p-type becomes a negatively charged depletion region
- After an ionizing particle interacts with this depletion region, electron/hole pairs are freed and able to be read out through the strips

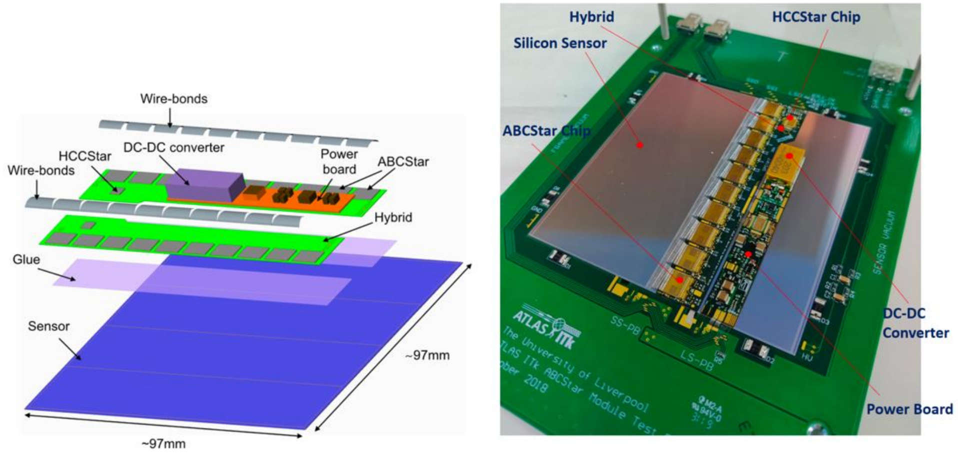
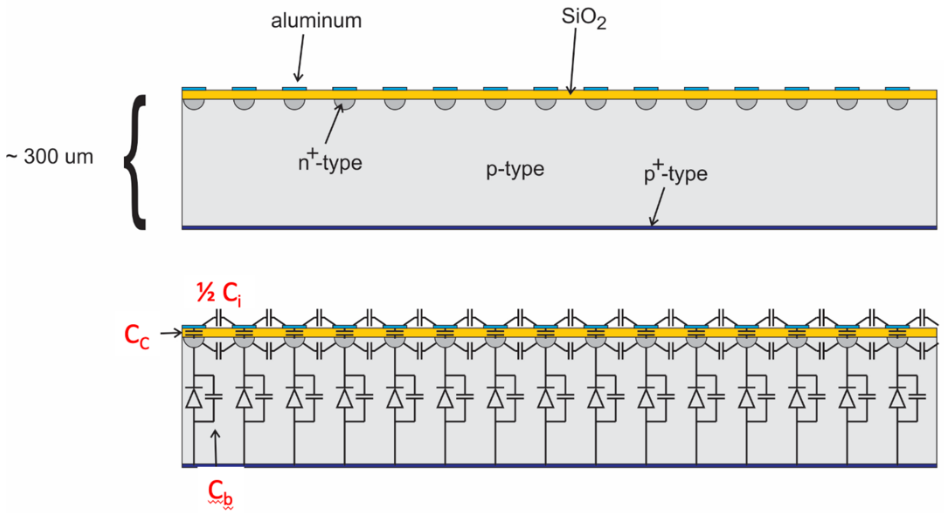


Photo of module (Short strip right, Long Strip Left)



Make up of and effective circuit overview of ITk strip barrel modules [3]

Citations

- [1] ATLAS CMOS Pixel Collaboration, B. Ristic, Measurements on HV-CMOS Active Sensors After Irradiation to HL-LHC fluences, JINST 10 (2015) no. 04, C04007, arXiv:1412.1589 [hep-ex].
- [2] Expected tracking and related performance with the updated ATLAS Inner Tracker layout at the High-Luminosity LHC. Technical report, CERN, Geneva, 2021.
- [3] Building the ATLAS ITk Strip detector: a journey from sensors to multi-module staves. A Dissertation, Francesca Capocasa, 2023.