Cold Noise Study in ATLAS ITk Strip Detectors

ZHAN LI 李瞻

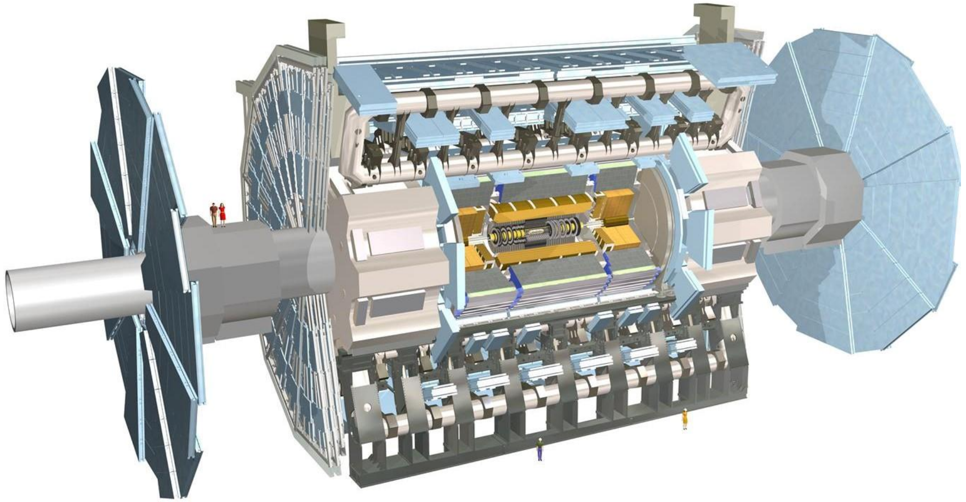
ON BEHALF OF ATLAS ITK GROUP IN CHINA

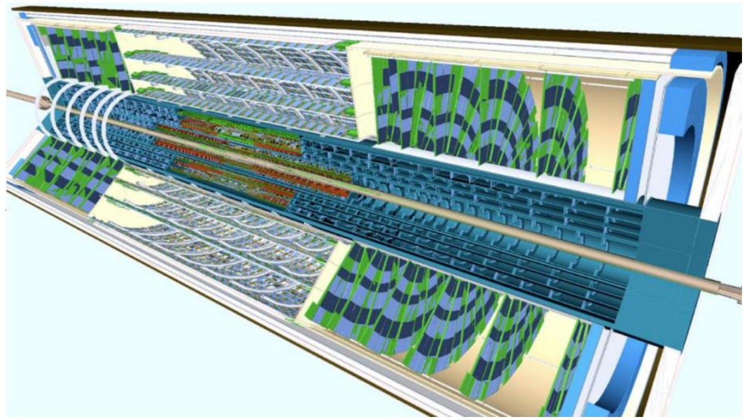
CLHCP 2023, SHANGHAI

2023/11/17

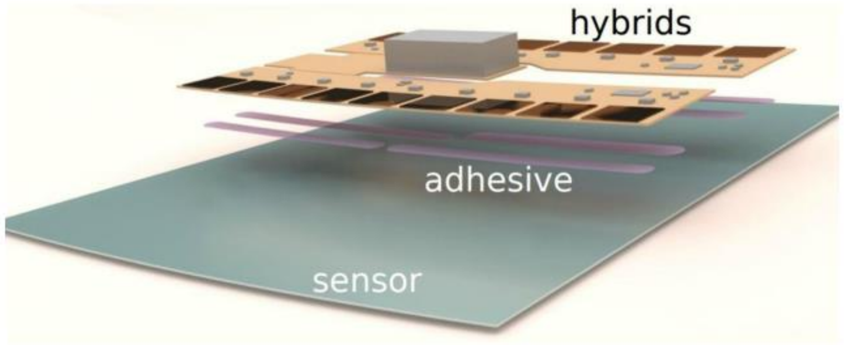
ATLAS Inner Tracker (Itk) Strips

- Itk: All-silicon track detector for HL-LHC
- Itk-Strips – subsystem of the ITk
- Surrounding the Itk pixel sub-system
- Consist of barrel and endcap



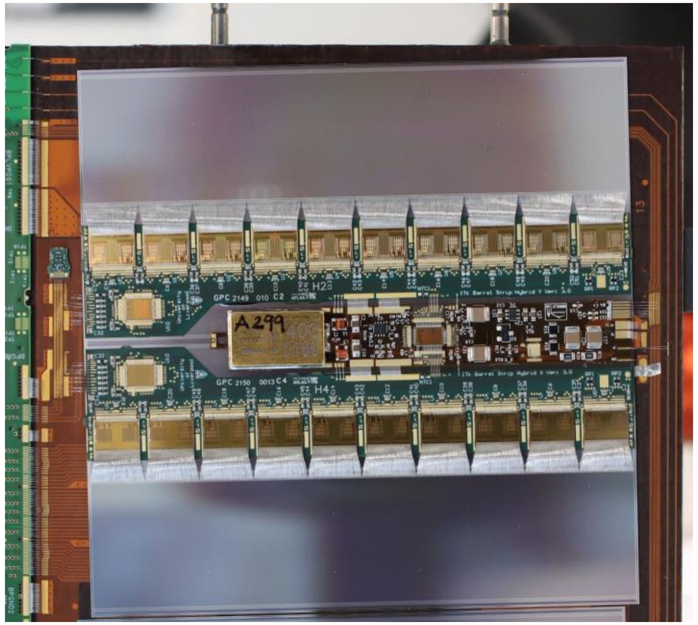


Itk Strips Modules



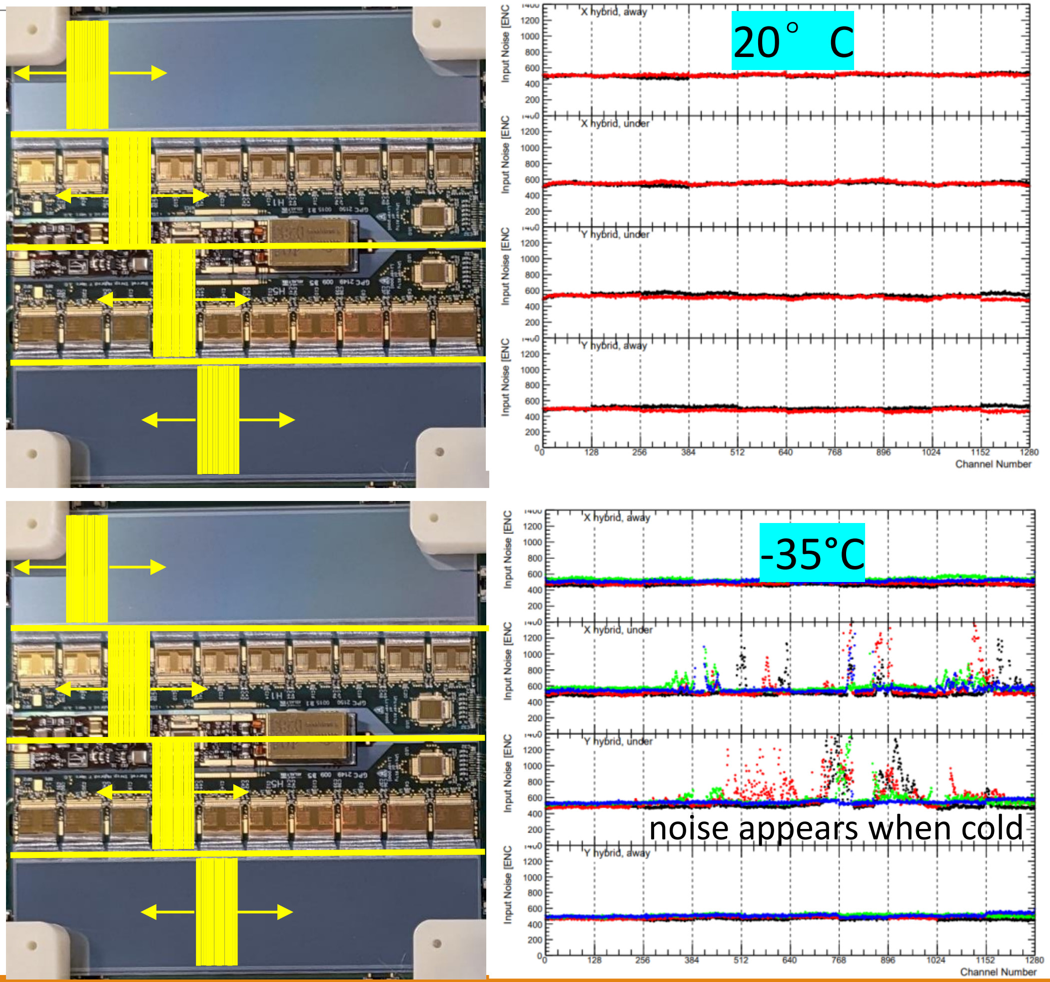
- Modules are assembled from hybrids, power boards and sensors
  - Sensors: Containing 1280 strips in each row
  - Hybrids: 10 ABCs (ATLAS Binary Chip, front-end read-out chips) and 1 HCC (Hybrid Controller Chip).

    Readout the data from each strip on the sensor
  - Power board: DC-DC power board, providing power for module.
- Staves: Modules will be glued on staves and the stave will be installed in Itk.



Cold Noise

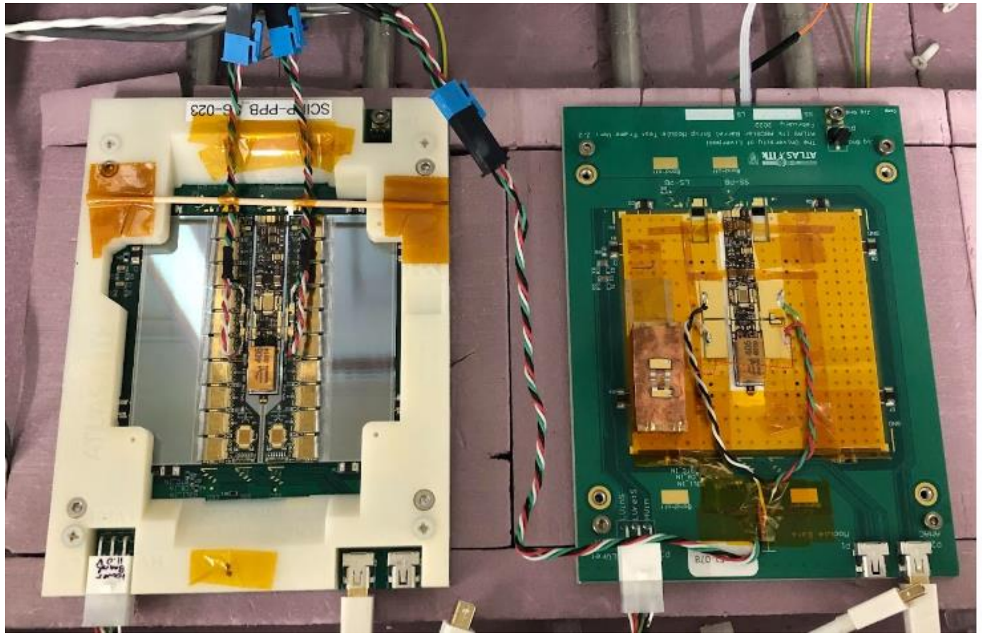
- Noise of un-irradiated strips is around 600 electrons.
- During LHC operation, the modules will be chilled to -35 ° C.
- When module down to -35 ° C, noise appeared.
- The noise was primarily seen on Short Strip module type.
  - Long strip modules with True Blue glue and end cap modules show no cold noise.
- The cold noise has been investigated for year.



Investigation – Which component?

- Check if the noise is associated with a single component
- Power board was the first candidate
- The test was completed with a second power board separated from the module
- When the power board on the module was bypassed

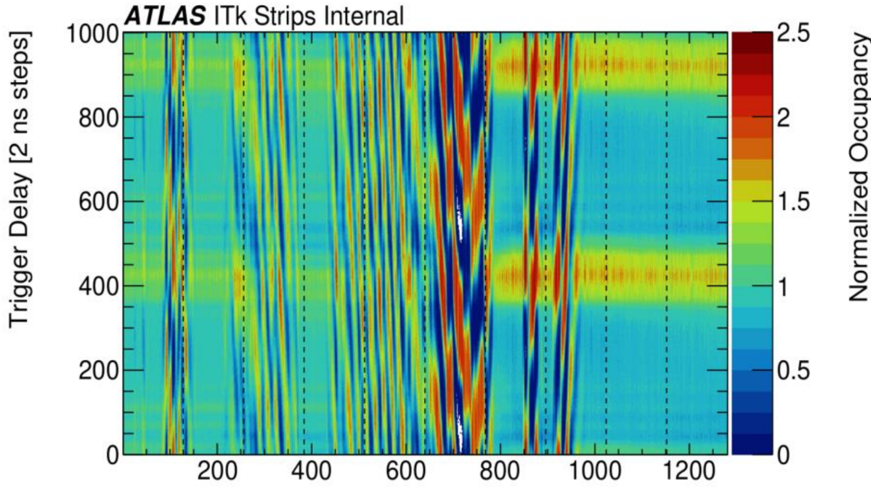
  Cold noise disappeared

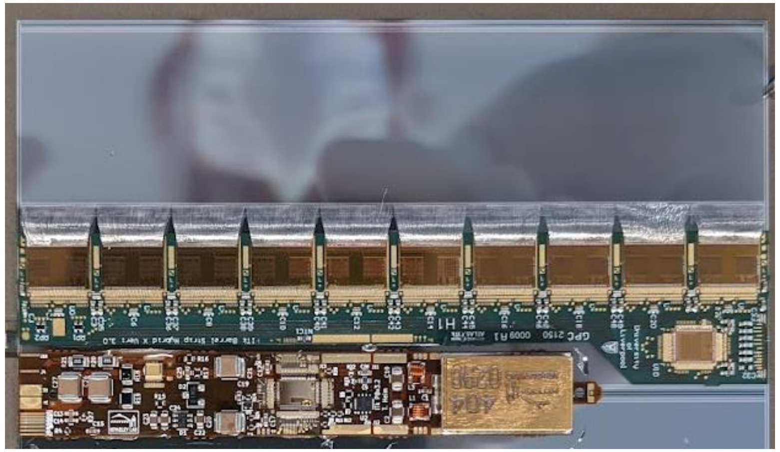


PB off PB on

Investigation – Electrical or Mechanical?

- Triggering off coil of the DCDC converter, the latency could be shown for each channel – cold noise channels had unique pattern
- The strips in the figure was measured the same as the speed of sound in Silicon – indicating that cold noise was caused by mechanical vibration
- Peeling off the power board and place it back at same position and height, but held by few dots of glue on edge – cold noise disappeared.
- If it is electrical people would expect similar cold noise.



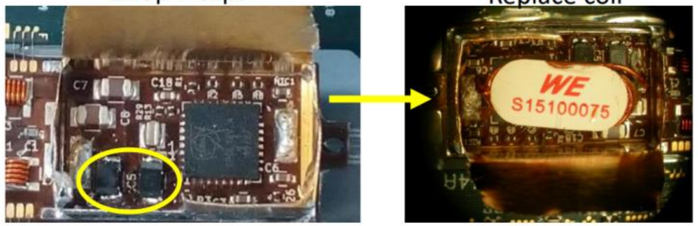


Investigation – What is vibrating?

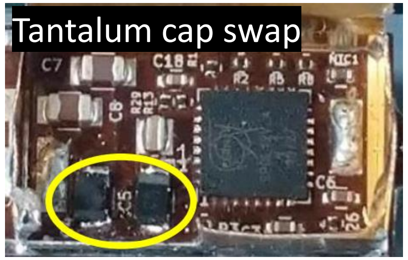
- Power board is likely to be the source of vibration
- People tried to remove or change components to see if the cold noise disappeared
- Fail to indirectly find the vibration source

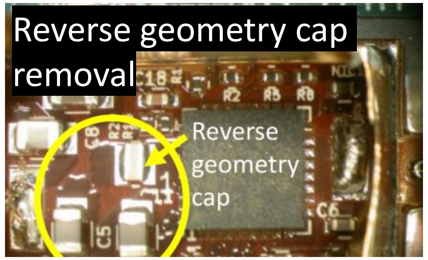
Swap 2 caps

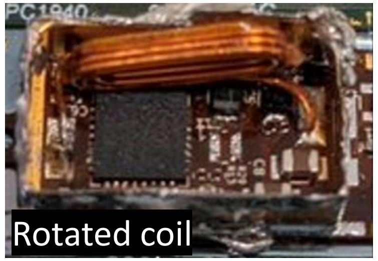
Replace coil

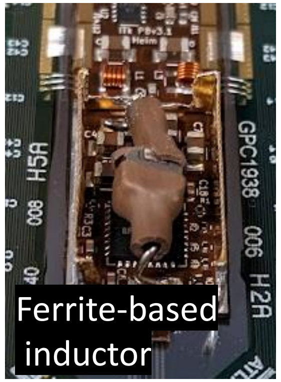


- 3 caps on LV input to minimise dV
- ***Caps' piezoelectric materials*** make prime candidates as ***vibration source***
- reverse geometry cap provides return path for high frequency signals (ie switching edges) close to the bpol, which will help keep the rest of the 11V trace clean
- Reverse geometry cap removed in second step after C4 and C5 removed



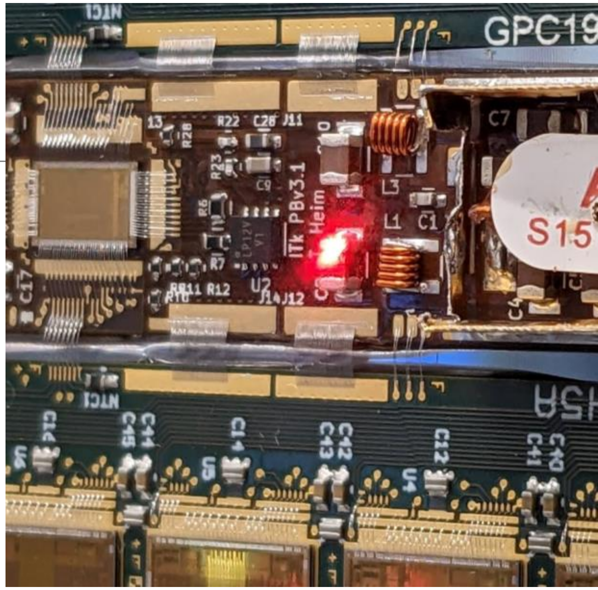




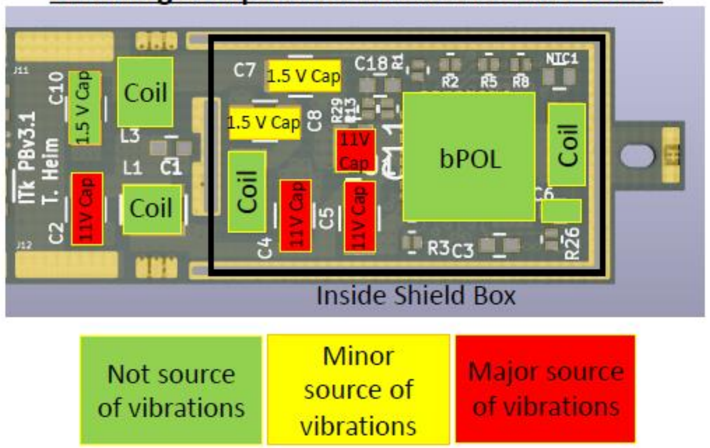


Investigation – What is vibrating?

- We found a vibrometer to measure it directly
- The vibrometer can use laser to measure the amplitude and frequency
- 4 11V capacitors found to have vibrations at about 2MHz
- When these 4 capacitors were replaced or removed then the cold noise disappeared – source of Cold Noise



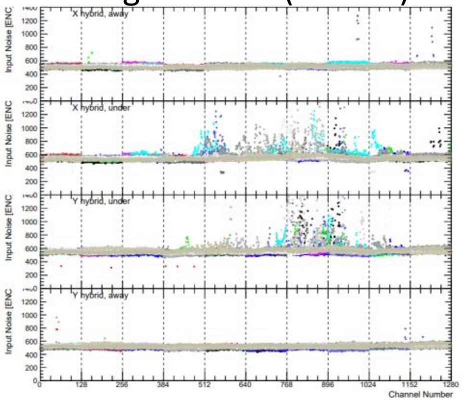
Vibrating Components on Barrel Power Board



Investigation – Glue

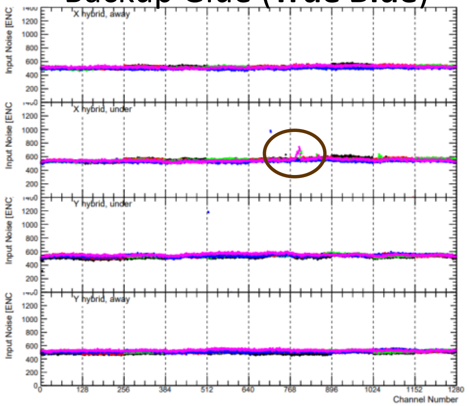
Different glues have significant influence on the cold noise.

Original Glue (**Polaris**)



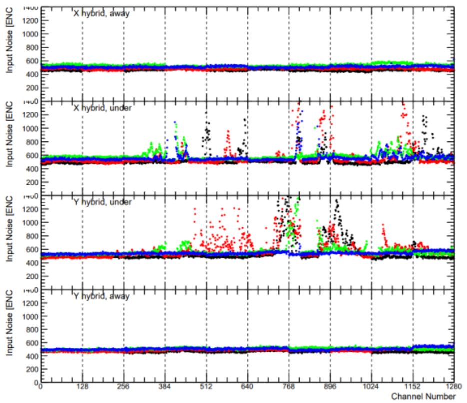
Original CN

Backup Glue (**True Blue**)



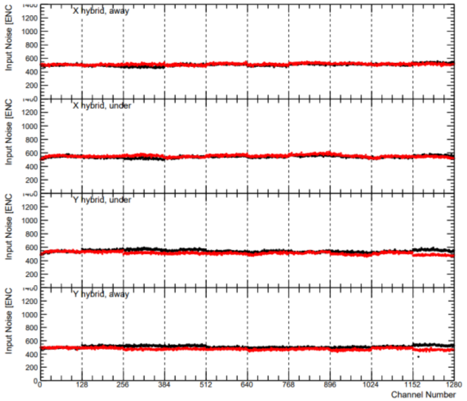
Noise on edge of passing spec

2nd supplier Backup (**False Blue**)



Increased CN

Gel (**SE4445**)



Never shown CN

The CN dependance on glue is might be due to the different CTE (Coefficient of Thermal Expansion) mismatch with Silicon (CTE=3)

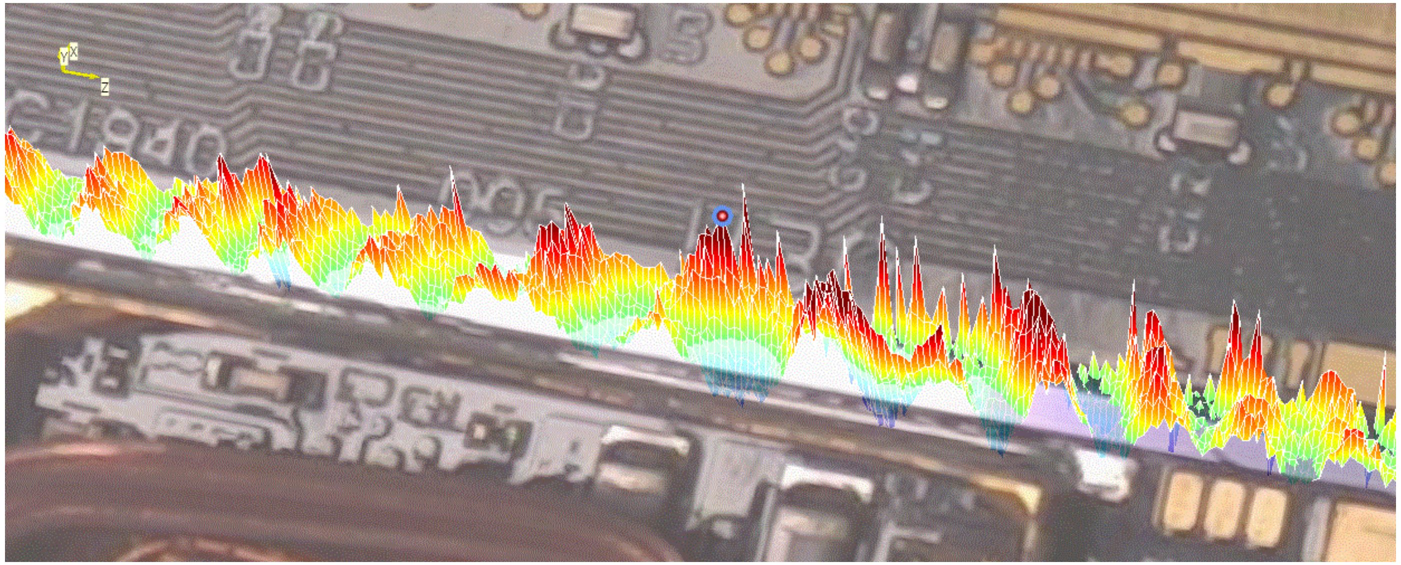
The strain caused by the CTE mismatch seems to increase the piezoelectric signal produced

Investigation – Vibrating across the module

- To better understand how the mechanical wave propagated a 2D scanning vibrometer acquired
- Able to see vibrations on all components of module and not only capacitors
- Able to see modes of vibration for the capacitors as well

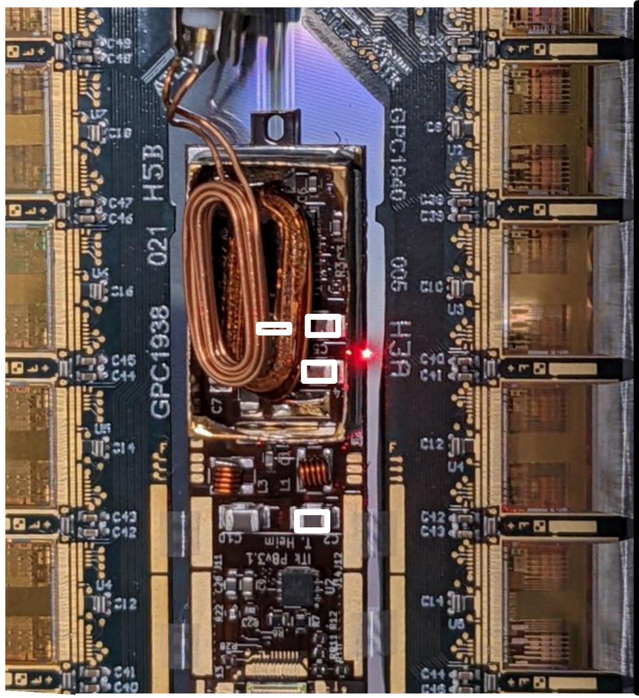
Investigation – Vibrating across the module

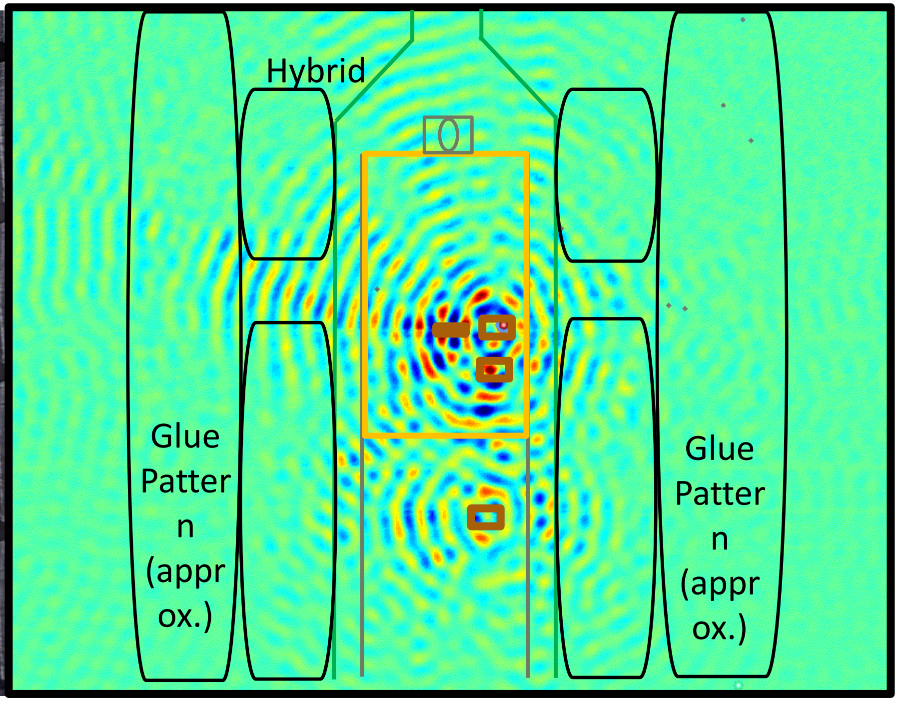
- The vibrations pass through the glues and then can propagate through the whole sensor
- The amplitude on the sensor is on the scale of the width of a Si atom (200pm)



Investigation – Vibrating across the module

- The wave propagation is centered around the C4/C5 capacitors primarily
- The glue gaps allow the waves to pass through
- The glue under the hybrids dampens the vibrations
- The conversion of mechanical to electrical signal is likely occurring on the sensor surface or in the sensor



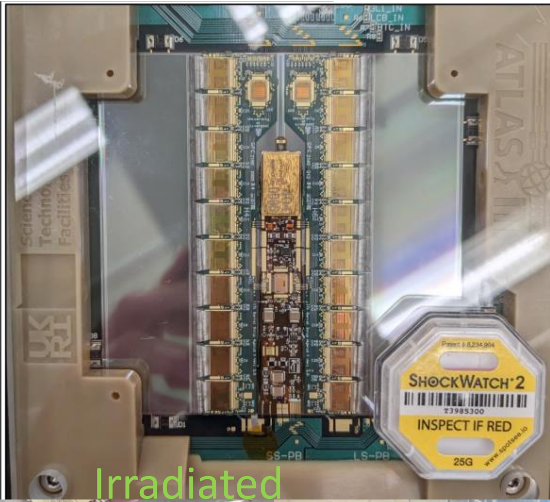


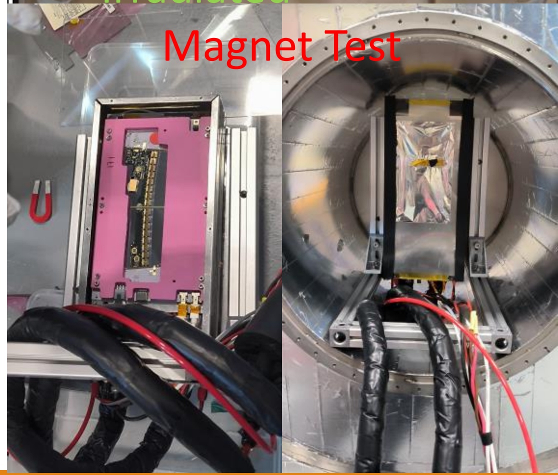
Investigation – Vibration to Electrical Signal

- The mechanism for transferring vibration to electrical noise is still under investigation, and now we have several theories:
- Cold noise caused by the fixed charges in partially depleted strips
  - Mechanical vibrations on the coupling capacitor result in an oscillating capacitance, inducing varying voltage on the metal strip which is read out as extra noise
- Cold noise caused by voltage across the coupling capacitor
  - It is known there is ~ 0.135 – 0.535V voltage offset across the coupling capacitor due to differences between hybrid ground and readout chip, between hybrid ground and sensor bias ring, and (for irradiated sensors) between bias resistors of individual strips. Mechanical vibrations change coupling capacitance
- Mechanical stress was hypothesized as a contributing factor for cold noise

Investigation – Irradiation and Magnet Field

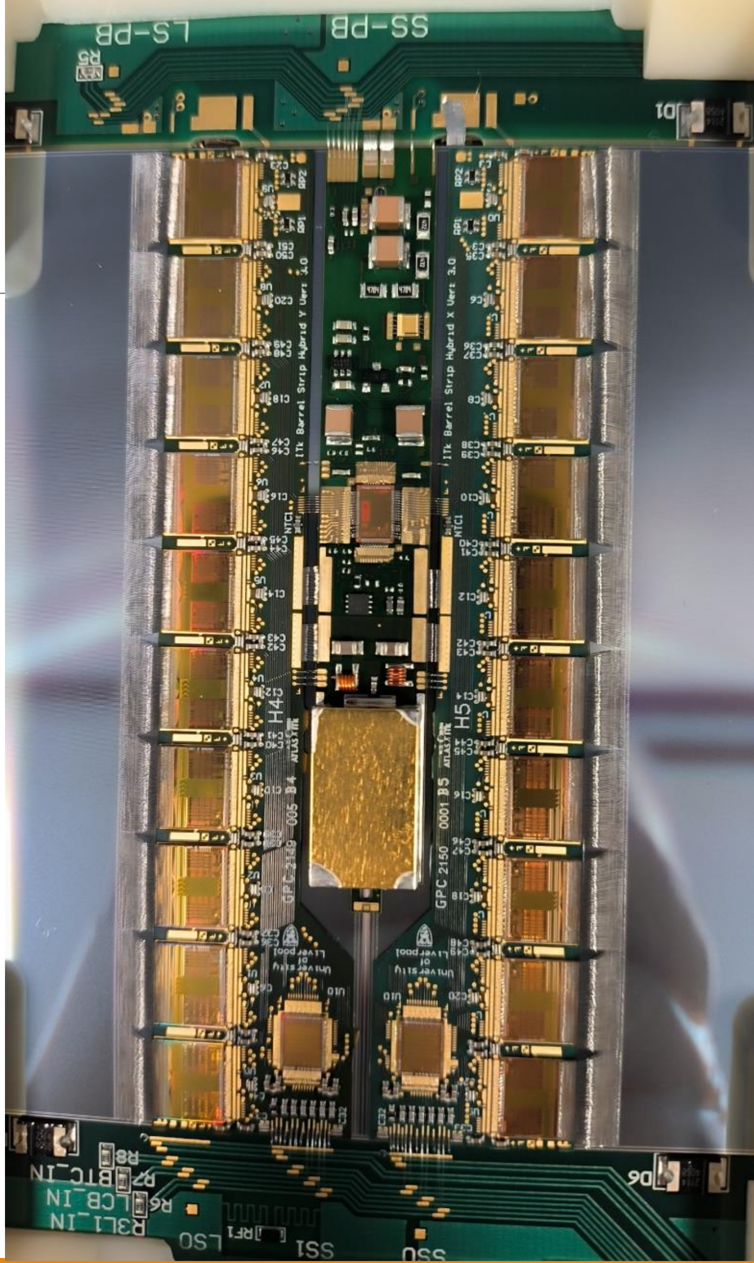
- Irradiation:
  - It is known that the glues will change properties after irradiation
  - Gamma source (Co60) used for 72MRad exposure (lifetime dose HL-LHC)
  - No change in cold noise after irradiation for any glue type
- Magnet Field:
  - Aiming to specify if the module has cold noise under strong field, and if the wirebonds of module can survive through the Lorentz force caused by field.
  - No cold noise change seen during and after the test
  - The wirebonds remains well after the suffering of Lorentz force





Solutions under Investigation

- Endcap module shows no cold noise, so replacing the power board with Endcap power board is considered. (The power board from Wurth company, so called Wurth power board)
- Test of using Wurth power board and False Blue glue on SS modules.
- Results from RAL and LBNL show possible mitigation in the magnitude of the cold noise but still inconclusive with current samples
- We can reach a preliminary conclusion that cold noise is related to the method of precuring the glue.


Module with Wurth PB assembled at RAL

Conclusion

- The source, propagation and electrical readout of the cold noise has been studied.
- No change in cold noise after irradiation and magnet field.
- Possible strategies on-going:
  - The power board of Endcap module shows no cold noise. Investigating using EC power board.
  - Some test showed that False Blue can also has low cold noise, but concerned with method how people precured the glue, still under investigation.
- Continue studies may give more info on mechanism

Thank you!