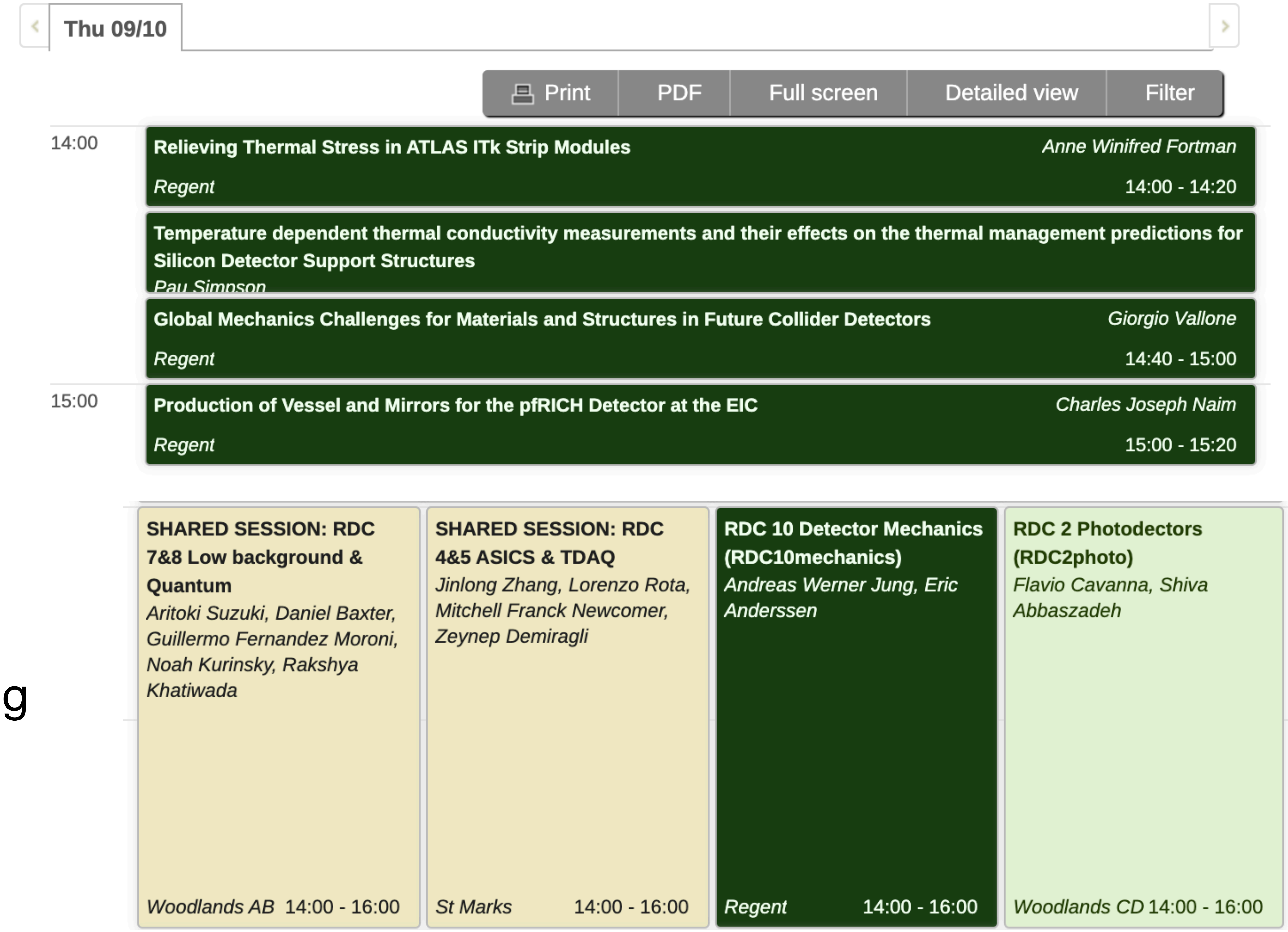
Introduction: CPAD talk

- 20m talk slot (17+3?)
- In the detector mechanics session, not silicon detectors
- Already an ITk strips talk about interposers previous day in silicon detector session (Jesse Liu)
- Special requests for feedback:
  - Should I cut references to cold noise? Worried it's too distracting
  - Tried to word things to avoid placing blame. I might need some help with that…



Relieving Thermal Stress in ATLAS ITk Strip Modules — *Anne Winifred Fortman*
Regent 14:00 - 14:20

Temperature dependent thermal conductivity measurements and their effects on the thermal management predictions for Silicon Detector Support Structures
Pau Simpson

Global Mechanics Challenges for Materials and Structures in Future Collider Detectors — *Giorgio Vallone*
Regent 14:40 - 15:00

Production of Vessel and Mirrors for the pfRICH Detector at the EIC — *Charles Joseph Naim*
Regent 15:00 - 15:20

SHARED SESSION: RDC 7&8 Low background & Quantum
Aritoki Suzuki, Daniel Baxter, Guillermo Fernandez Moroni, Noah Kurinsky, Rakshya Khatiwada
Woodlands AB 14:00 - 16:00

SHARED SESSION: RDC 4&5 ASICS & TDAQ
Jinlong Zhang, Lorenzo Rota, Mitchell Franck Newcomer, Zeynep Demiragli
St Marks 14:00 - 16:00

RDC 10 Detector Mechanics (RDC10mechanics)
Andreas Werner Jung, Eric Anderssen
Regent 14:00 - 16:00

RDC 2 Photodetectors (RDC2photo)
Flavio Cavanna, Shiva Abbaszadeh
Woodlands CD 14:00 - 16:00

Fracturing due to Thermal Stress in ATLAS ITk Strip Modules:

WHY IT HAPPENED
AND HOW TO PREVENT IT FROM HAPPENING TO YOU.

Anne Fortman on behalf of the
ATLAS ITk Collaboration

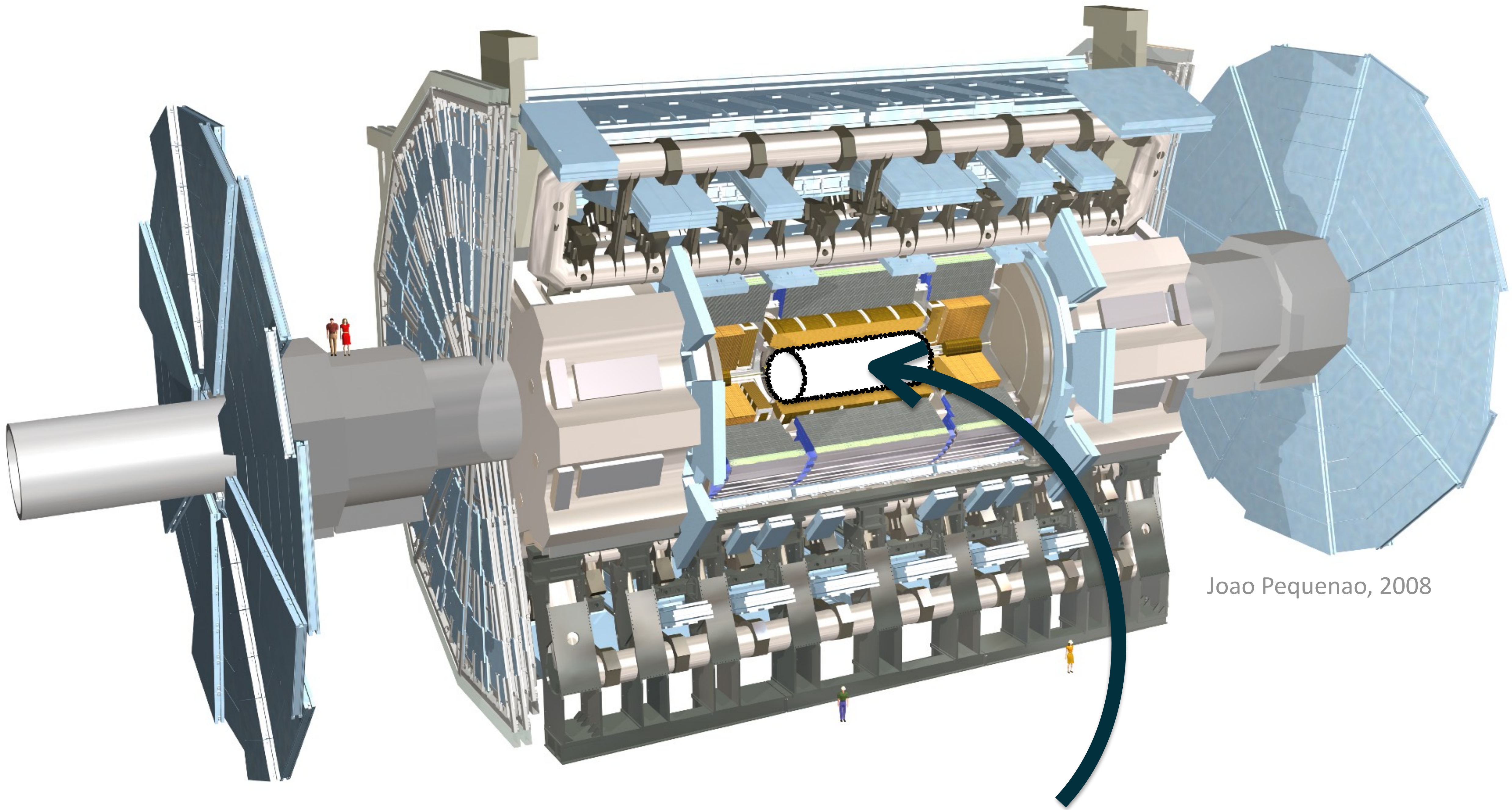
ATLAS ITk

BERKELEY LAB

U.S. DEPARTMENT OF
ENERGY
Office of Science

ATLAS and the ITk Upgrade

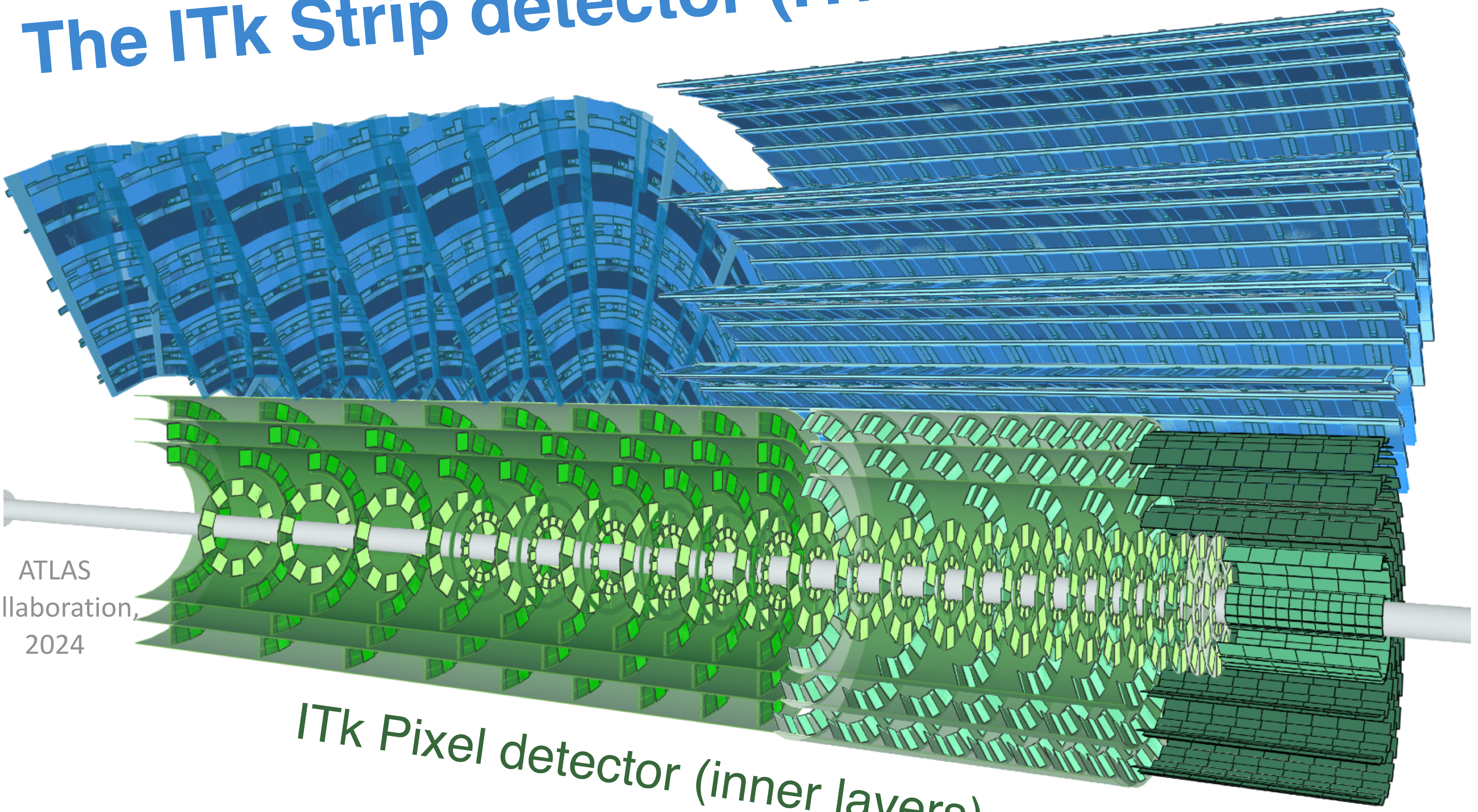
The ATLAS Detector



Joao Pequenao, 2008

ITk will go here

Inner Tracker (ITk)

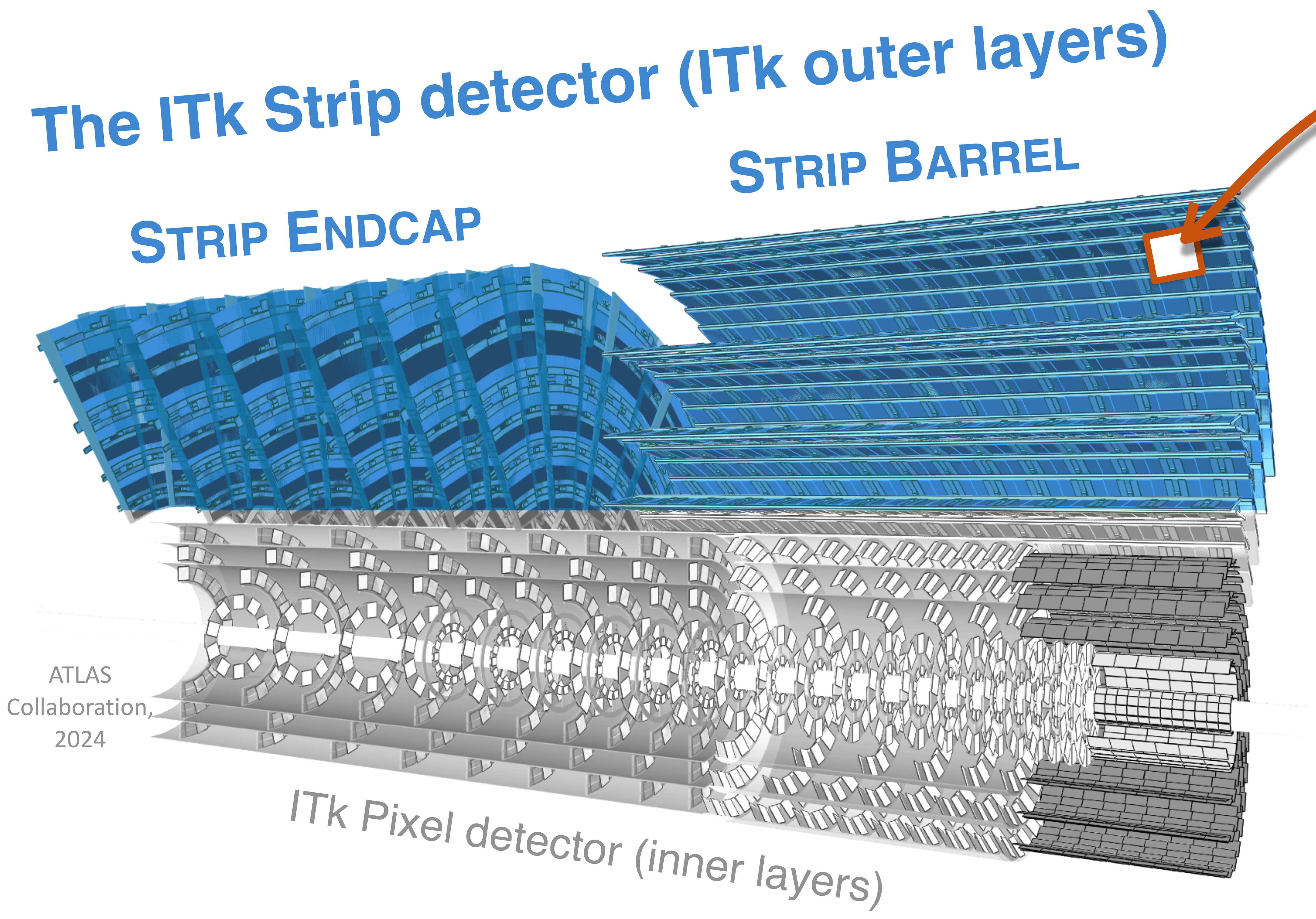


The ITk Strip detector (ITk outer layers)

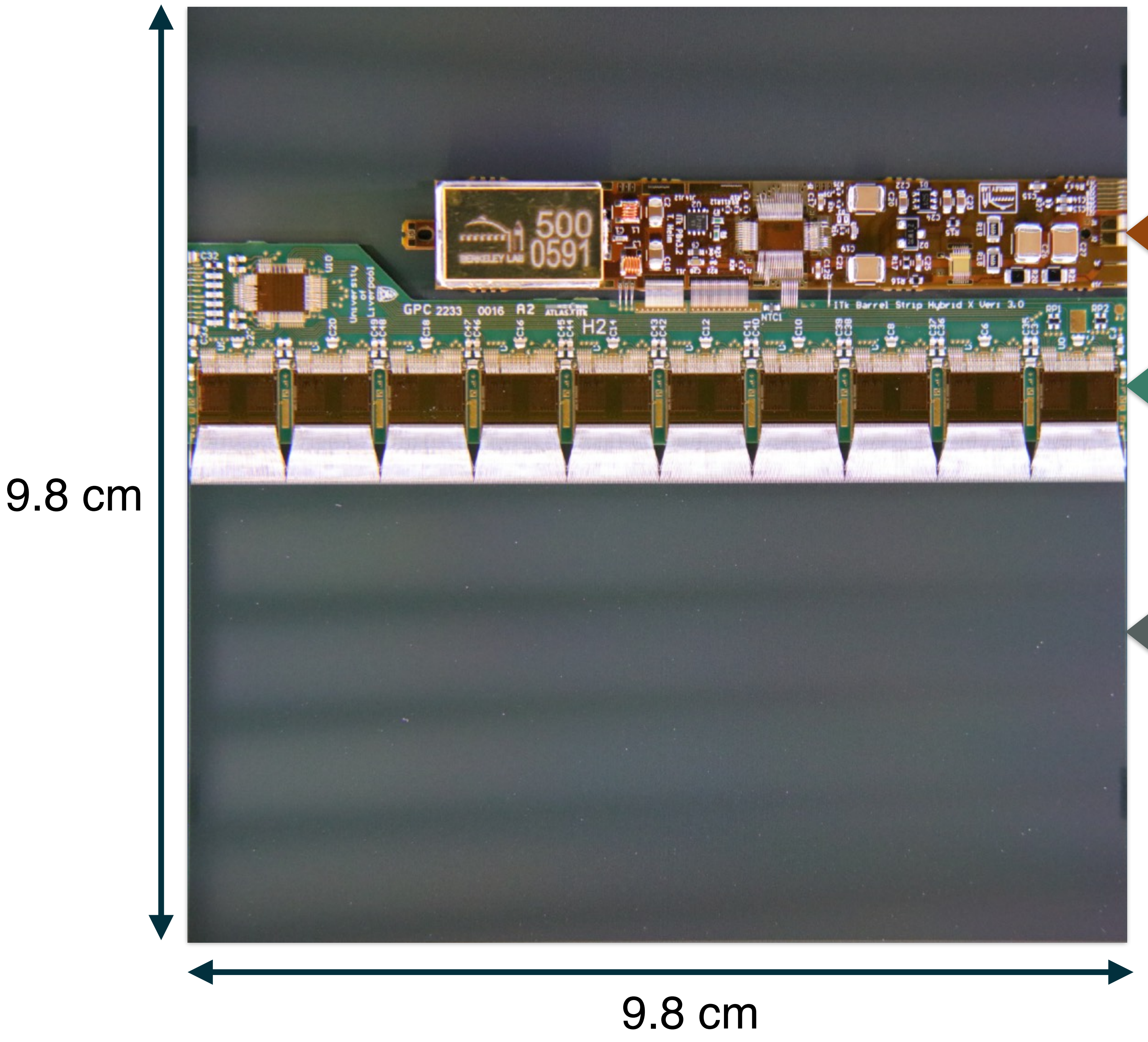
ITk Pixel detector (inner layers)

ATLAS Collaboration, 2024

ITk Strip Modules



A “Module”



A Power PCB

And a Readout PCB

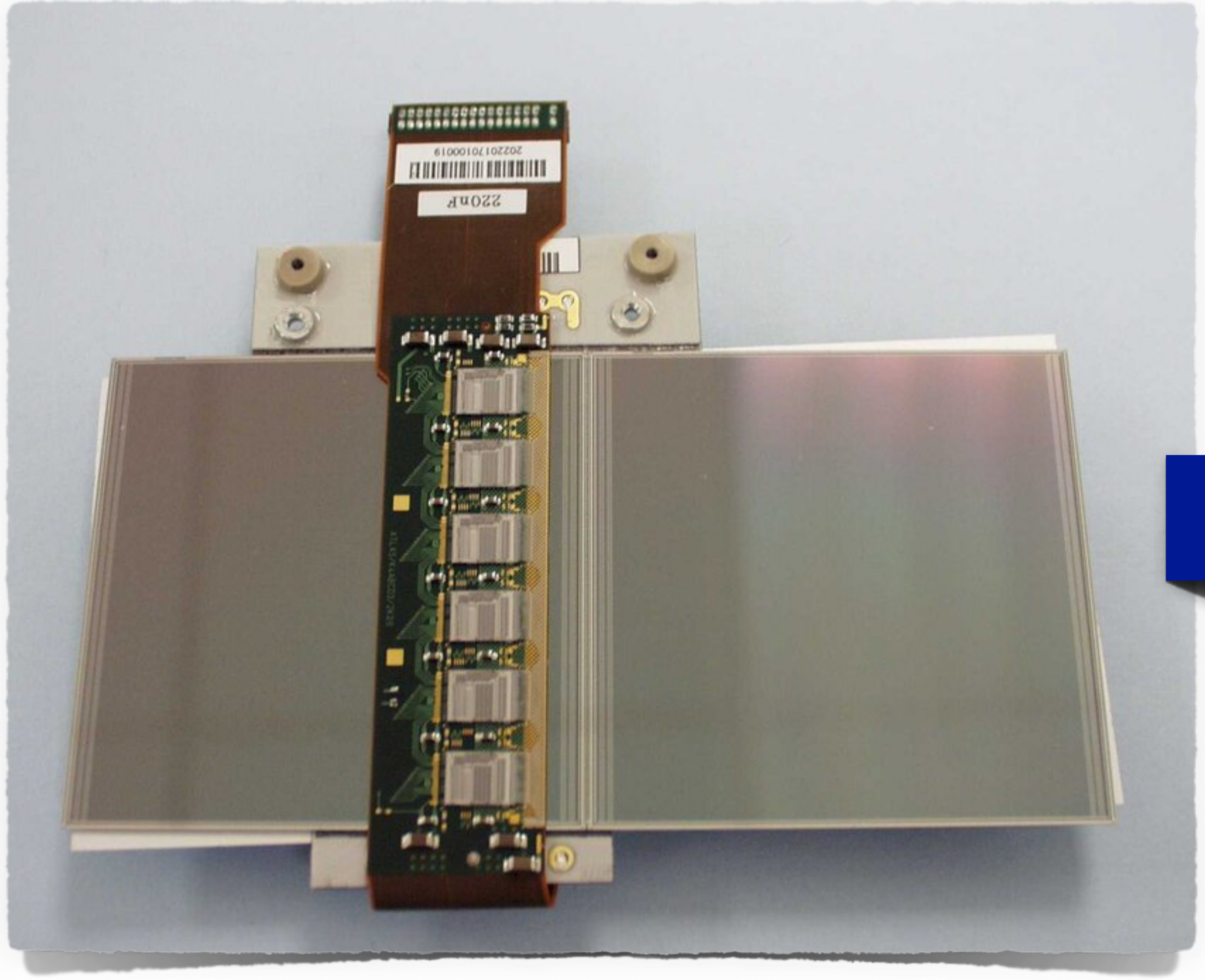
Glued to a silicon microstrip sensor

2,560 strips of 75.5 µm pitch on this sensor alone

17,888 strip modules total!

Current Strip Module vs ITk

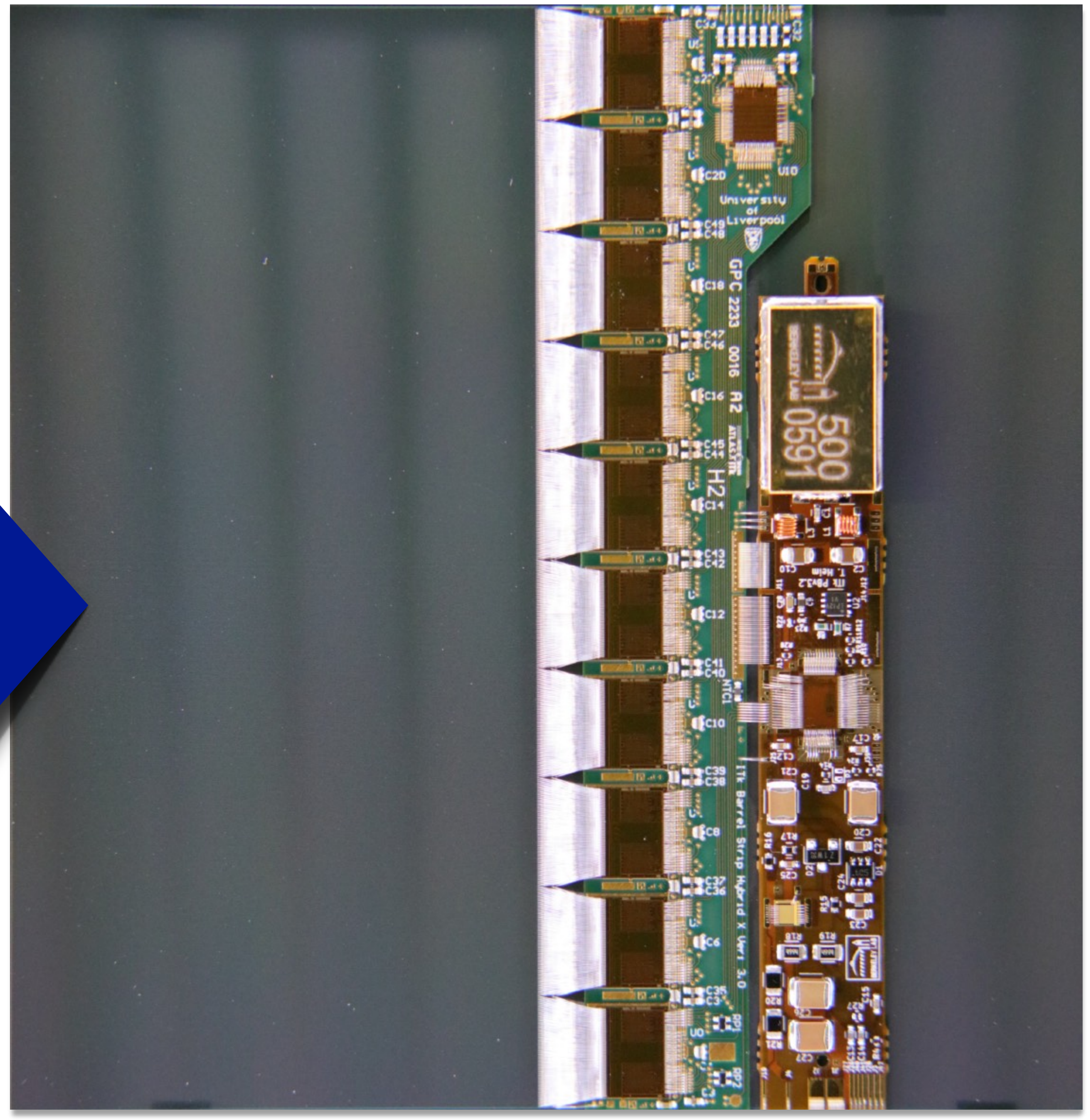
Strip Modules in ATLAS now



Front-end electronics rest on
bridge layer above sensor

UPGRADE!

ITk Strip Module



Reduce material by gluing
electronics directly to sensor!

Building the Detector

Require ~3 years of production to assemble all needed parts

Assemble, test PCBs

Assemble to sensors to form modules

Test modules (e.g. thermal cycling)

Load onto support structures

Test assembled support structures (e.g. thermal cycling)

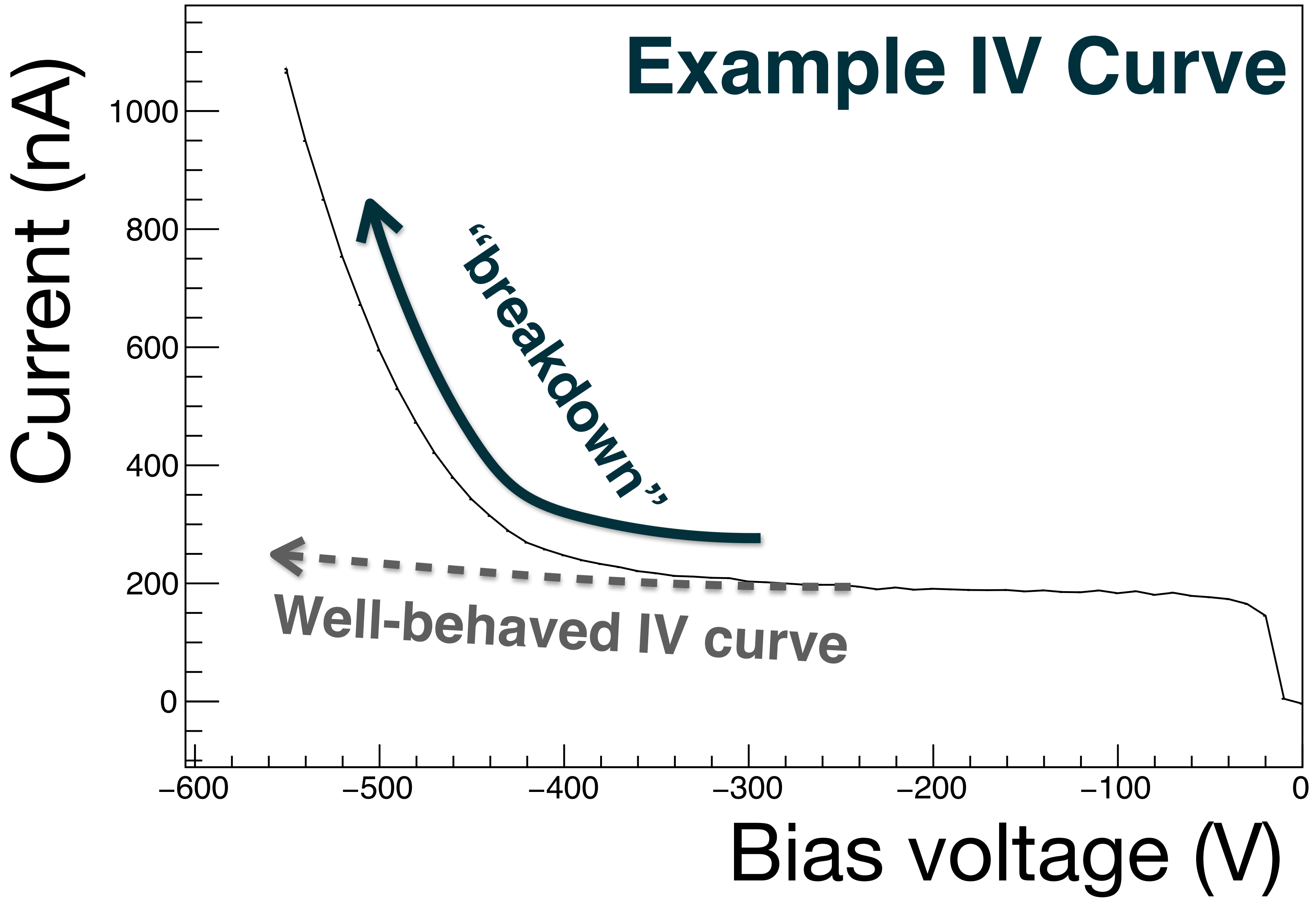
Send to CERN for integration, installation

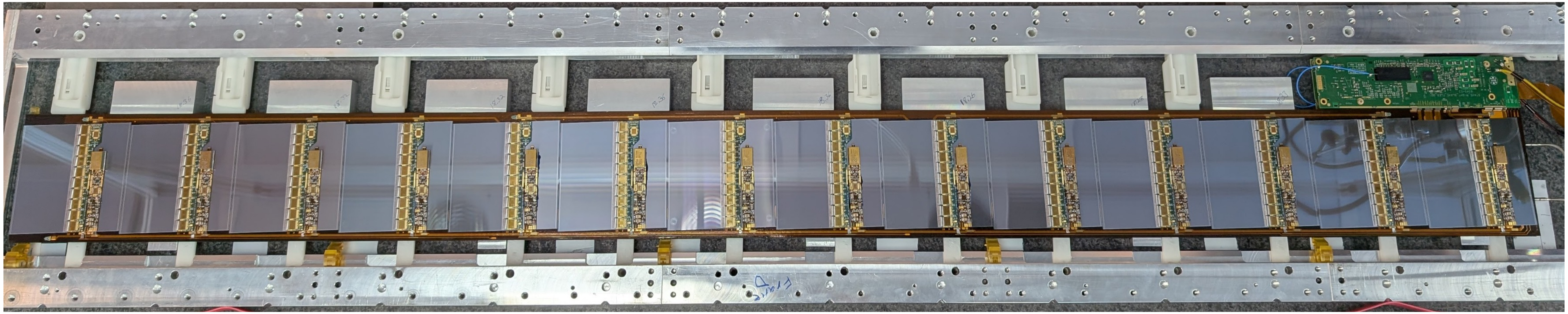
Barrel support structure = “stave”

Problem detected!

- Thermal-cycled prototype support structures [-35°C, 20°C] as part of quality control

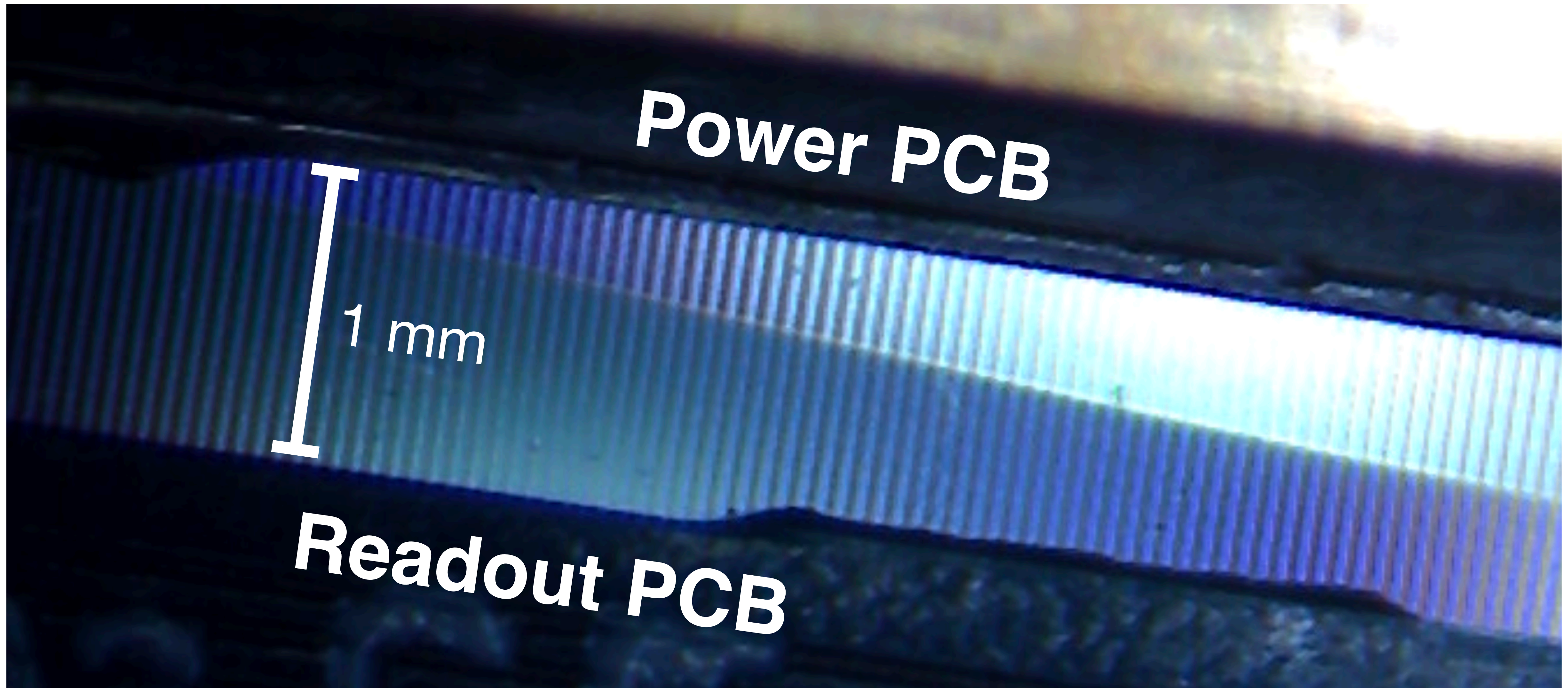
- Post-thermal-cycling, could no longer apply HV to bias some sensors…

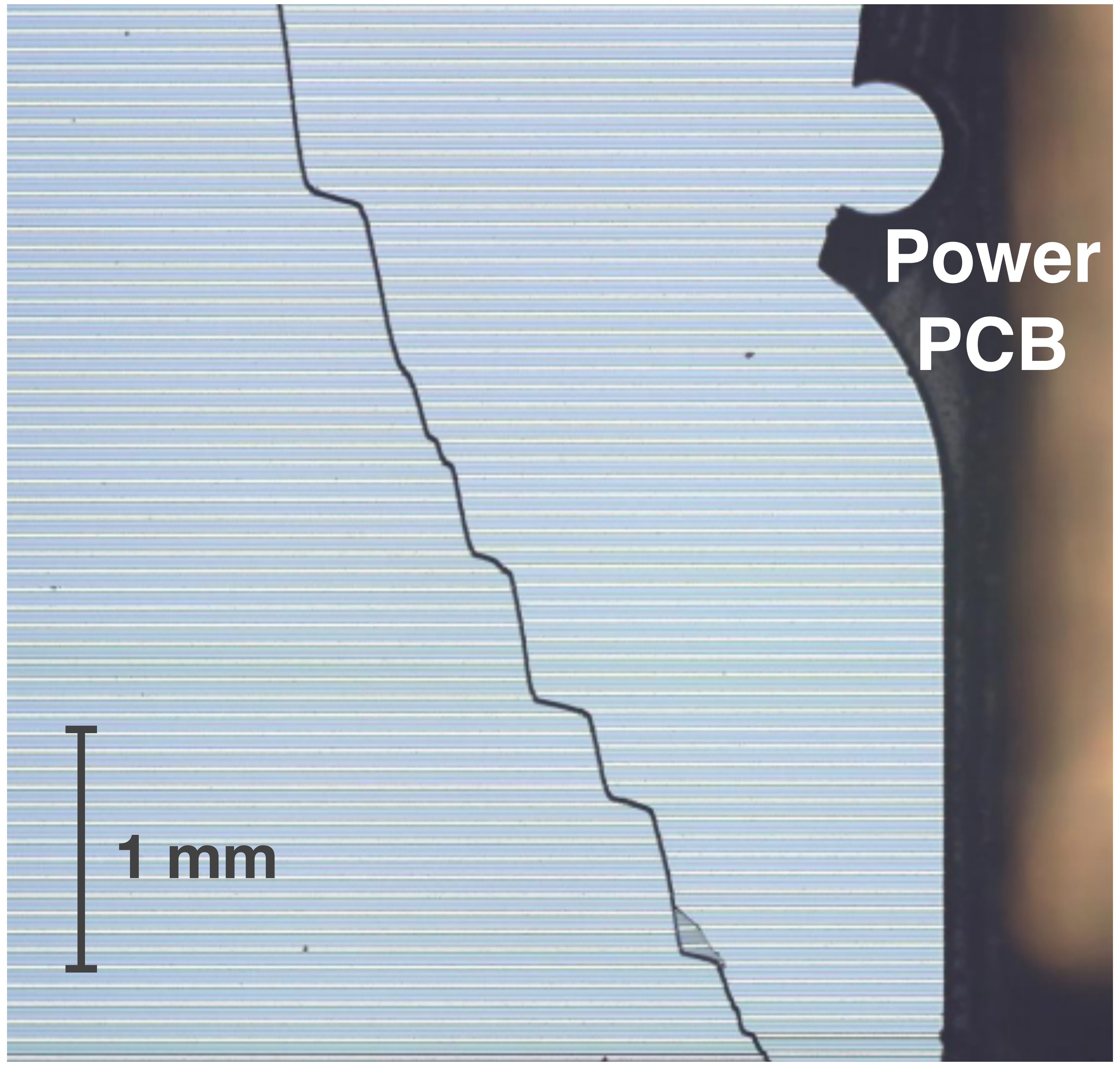




Cracked Sensors!

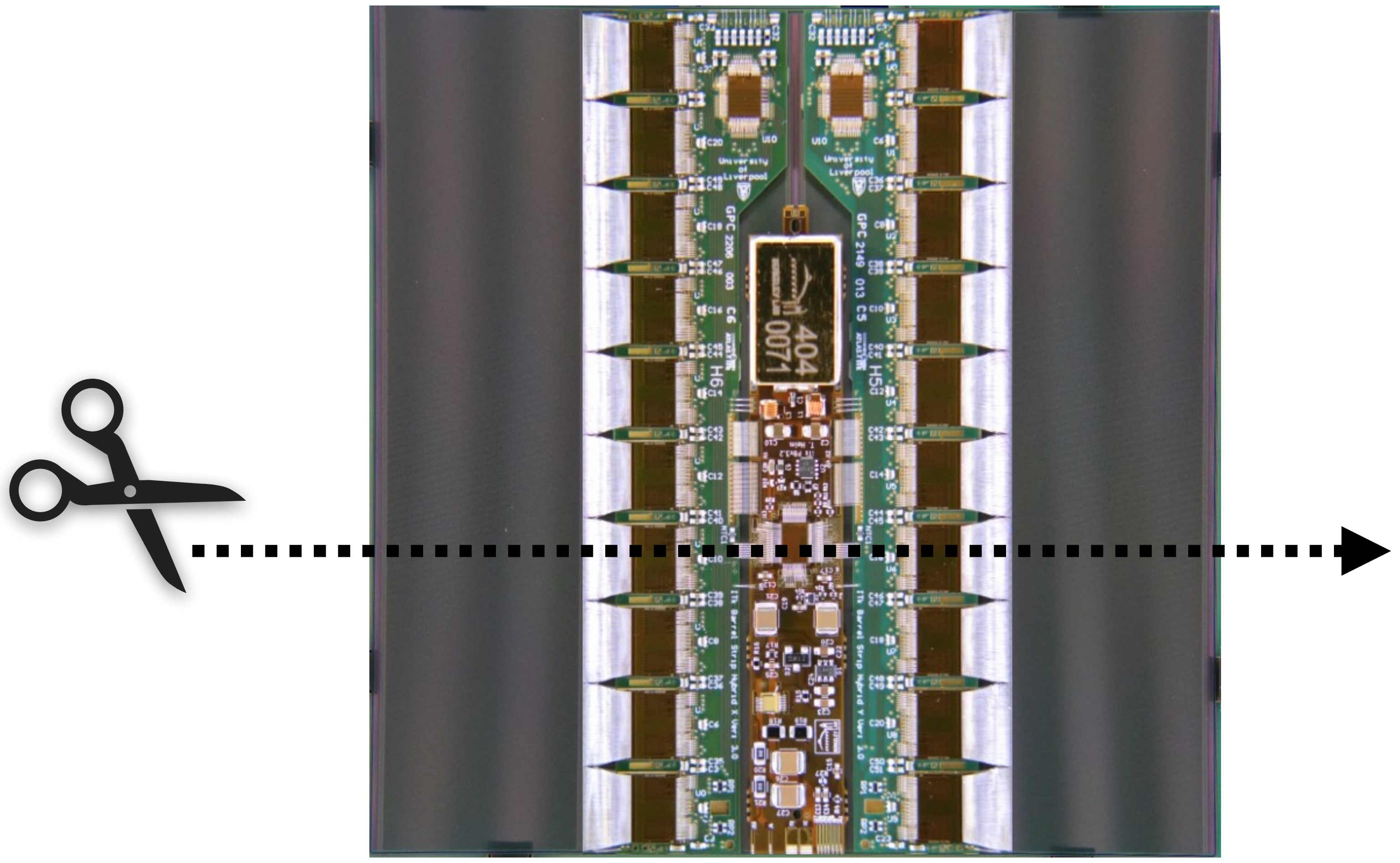
Just before start of module production, in spring 2023, identified the issue: **cracks!**



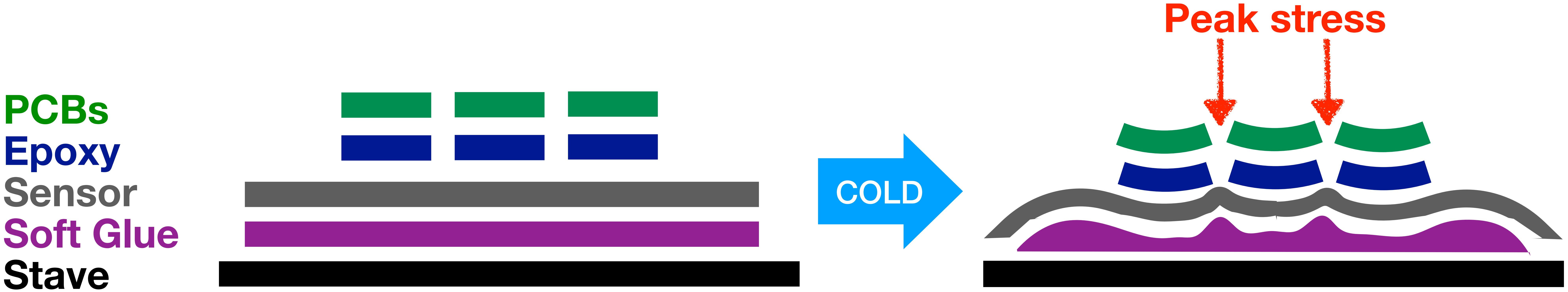


No prior indications of cracks during thermal cycling of individual modules

Cracking: CTE Mismatch



A module on a stave



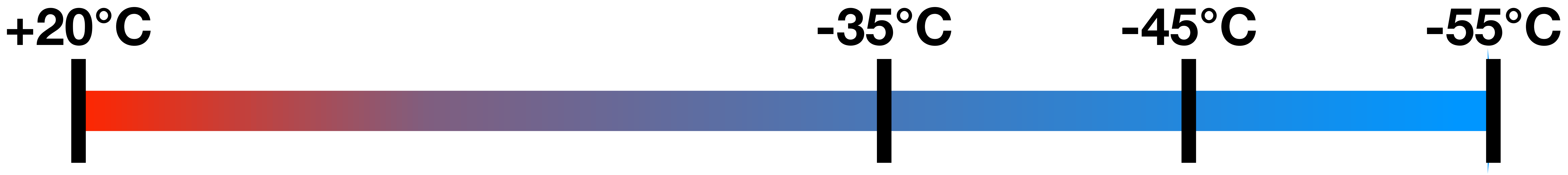
PCBs
Epoxy
Sensor
Soft Glue
Stave

COLD

Peak stress

A Showstopping Problem

- During operation over a 10-year period, expect thermal changes:



Room temp!

Coldest operating temperature

Temp if power failure

Lowest possible temp: Burst cooling pipe (Dual-phase CO_2)

- A cracked sensor cannot be operated: lose 100 cm^2 area of detector
- Estimate **~70% of barrel** and **~30% of endcap** will crack between [20°C, -55°C]

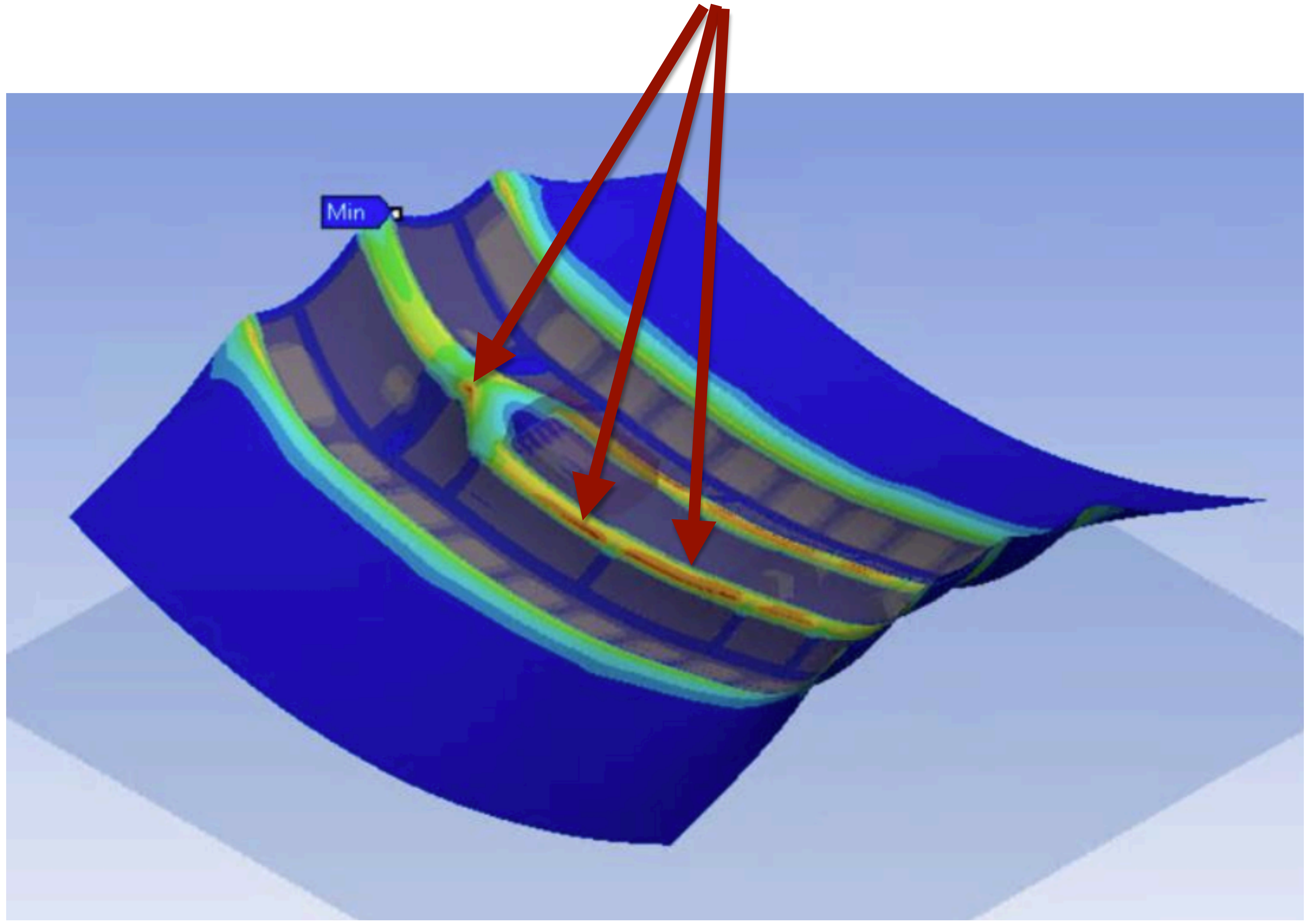
Need to rethink design! Delay production to figure this out.

How did we miss this?

1 Original simulation did not show cause for concern

- Checked for problematic stress with finite-element thermo-mechanical model
- Original model may have been too coarse to capture local stress peaks
  - New simulation shows that details of epoxy glue patterns matter

Localised stress peaks ~150 MPa



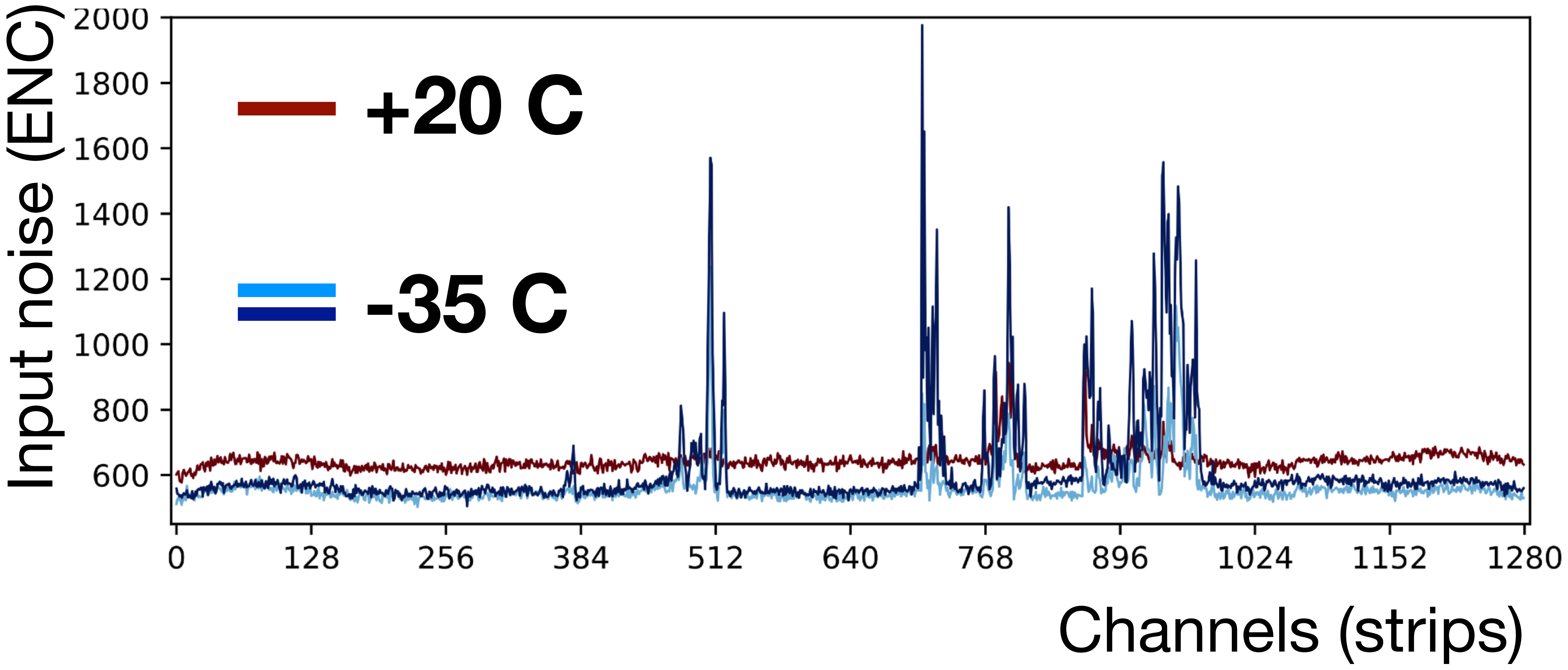
New FEA simulation of module stress

How did we miss this?

2 **Module design evolved over time**

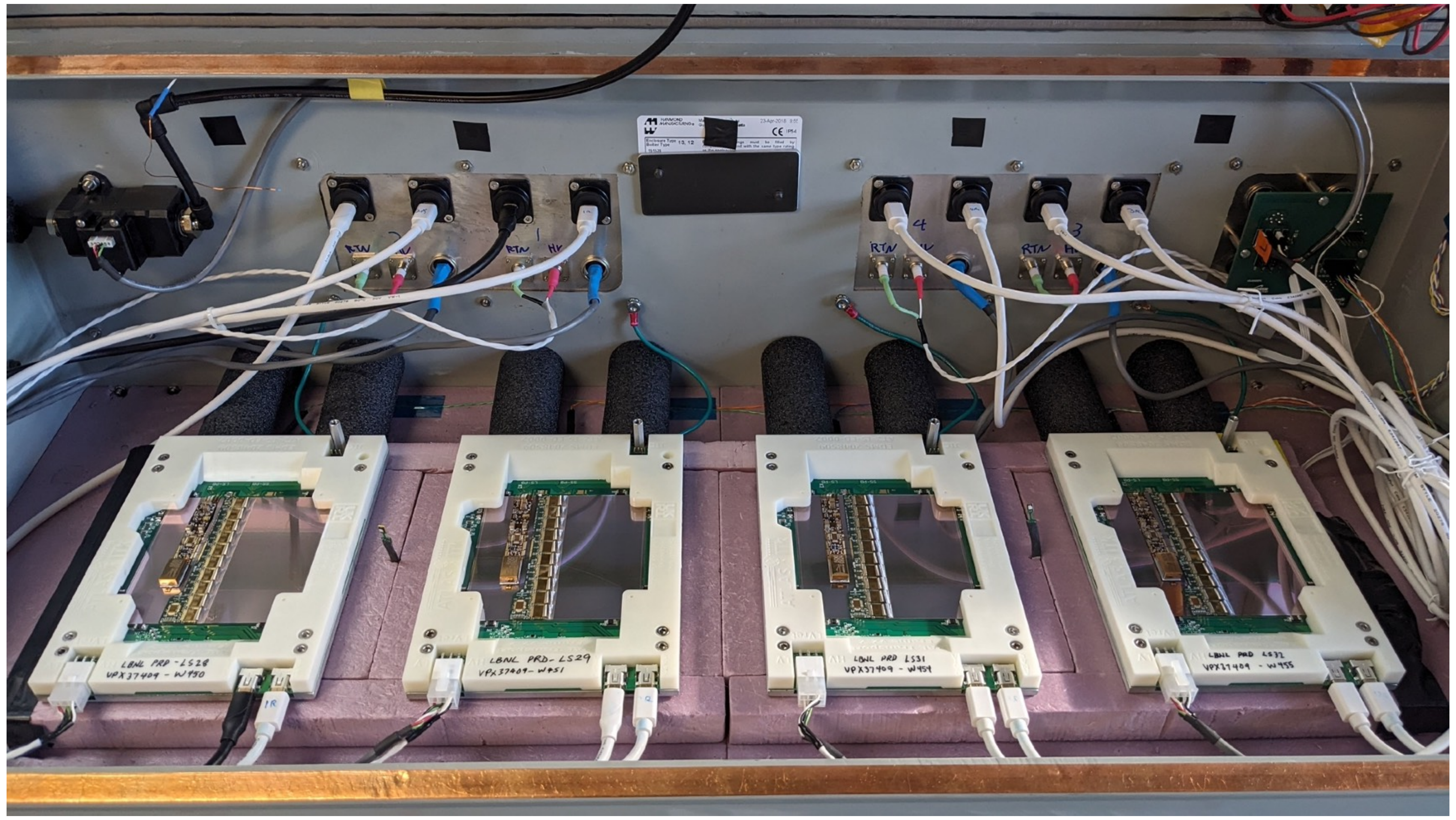
- Many design changes since original modelling
  - E.g. epoxy changed multiple times: discontinued by vendors, attempt to mitigate issues (cold noise)
- Simulation not updated due to lack of personpower

Example of Cold Noise



How did we miss this?

3 Did not observe cracking in module thermal cycling



- Hundreds of individual modules survived routine thermal cycling without problems
- Not obvious that thermal stress of a sensor loaded to a stave greater than a free sensor
- CTE mismatch was not at forefront when diagnosing HV breakdowns on staves

→ **Delayed detection of cracking problem**

How to Reduce Thermal Stress?

Late detection of cracking problem
limited possible mitigation strategies

Need to balance:

Thermal Stress Reduction

as predicted by new simulation

vs

Minimizing disruption

to existing production workflow

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THERMAL STRESS REDUCTION

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VS

MINIMIZING DISRUPTION

to existing production workflow

Least-invasive mitigation strategy:
Replace soft loading glue with rigid glue

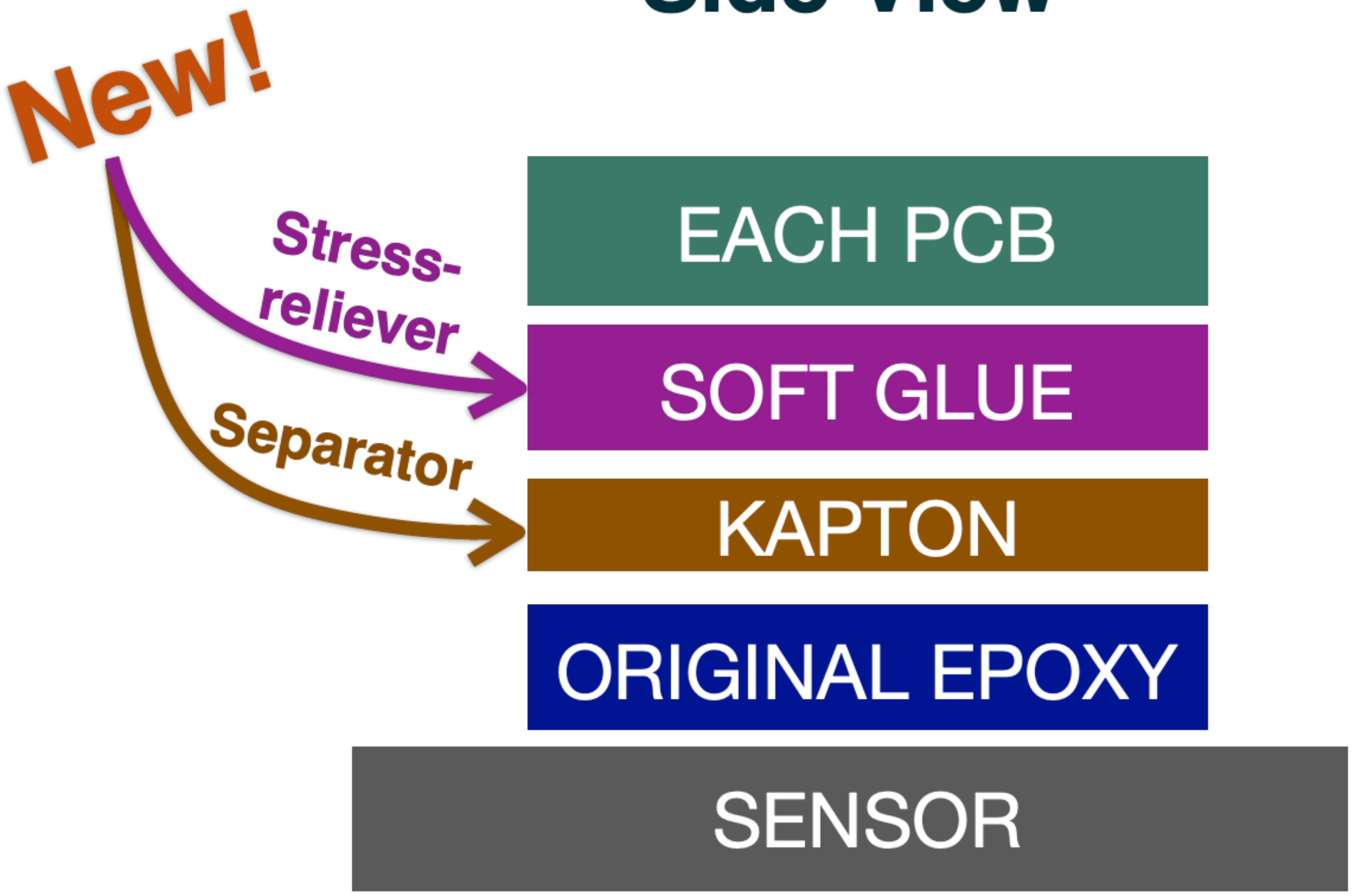
- Expected up to 50% reduction in thermal stress
- Did not sufficiently reduce the cracking rate (~60% in the barrel above -55°C)

Remaining option: change the module design.

The New Design

- Add layer of **soft glue** to underside of each PCB
  - Absorbs stress, PCBs can contract without affecting sensor
- Strategic choice of soft glue:
  - Already in use to load modules to support structures
  - Shown in past cold noise studies to eliminate cold noise (but causes electrical problems if directly contacting the sensor)
- Promising: simulation predicts up to 10x decrease in sensor stress!

New Module Design
Side View



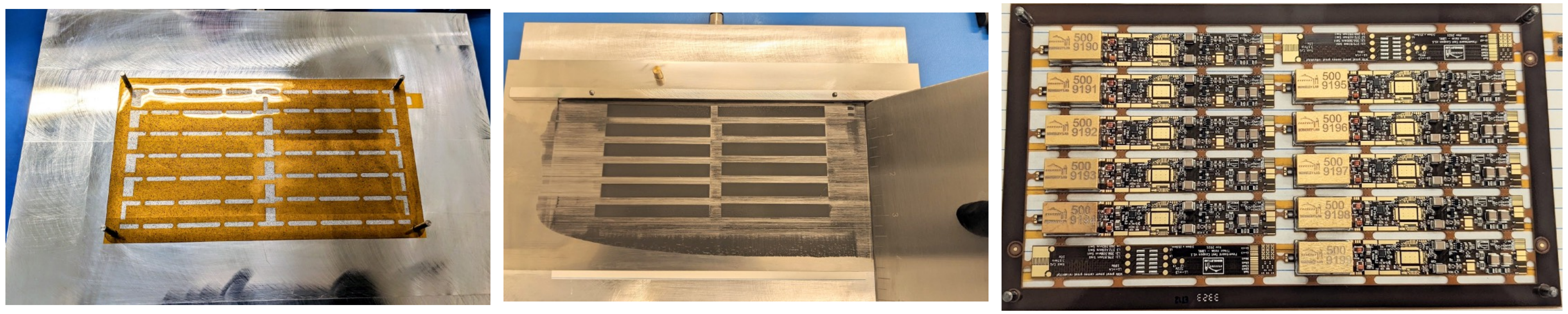
New!
Stress-reliever
Separator
EACH PCB
SOFT GLUE
KAPTON
ORIGINAL EPOXY
SENSOR

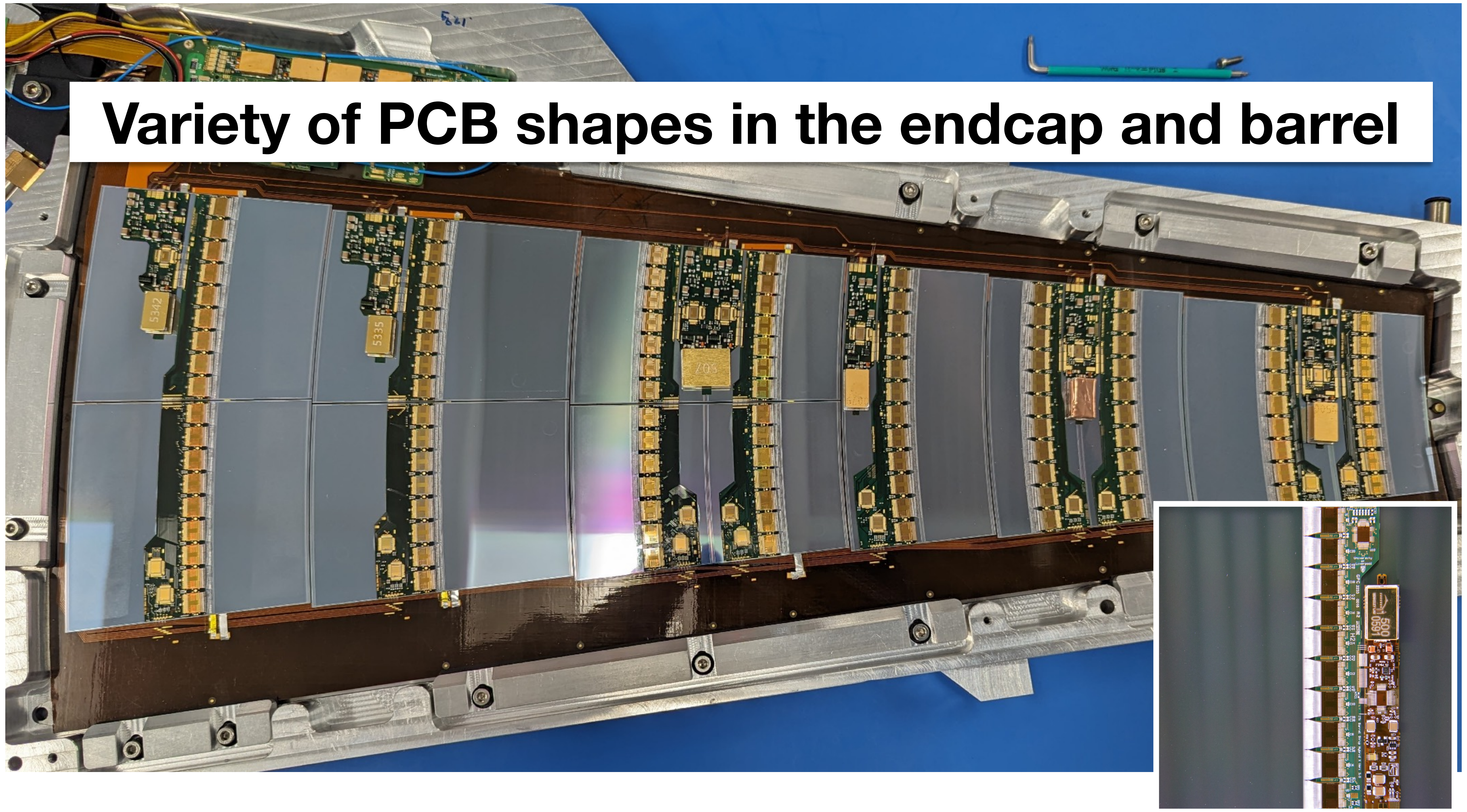
Soft glue = Dow SE 4445 thermally conductive gel
~10,000x softer than original epoxy

Technical Challenges

- Minimize disruption to production by adding new layers to PCBs at selected sites
  - Feed laminated PCBs back into module production chain, assemble modules as before
- Must laminate over 40,000 PCBs at production rates
  - Developed new tooling/procedures to mass-laminate PCBs
  - Needed custom procedures for different PCB types due to multiplicity of designs

Mass lamination of barrel power PCBs



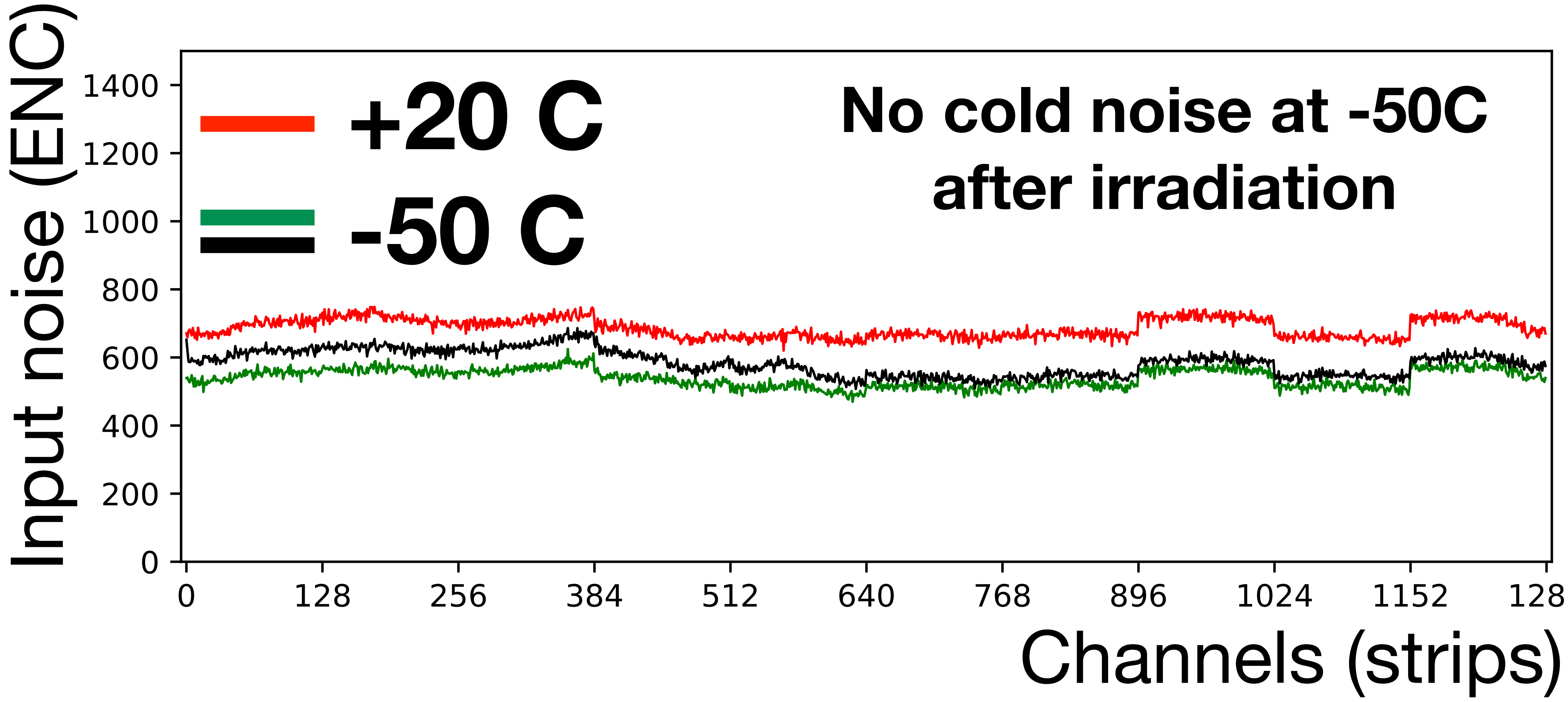


Variety of PCB shapes in the endcap and barrel

Testing Redesigned Modules

- Prototype redesigned modules **passed all destructive tests:**
    - e.g. shear/peel tests of new glue joints, long-term module thermal cycling to extreme temperatures, irradiation to end-of-life doses
- New-design modules **perform similarly to original modules** in quality control tests:
    - Most yield losses due to inexperience in building new module design, expect to reduce over time

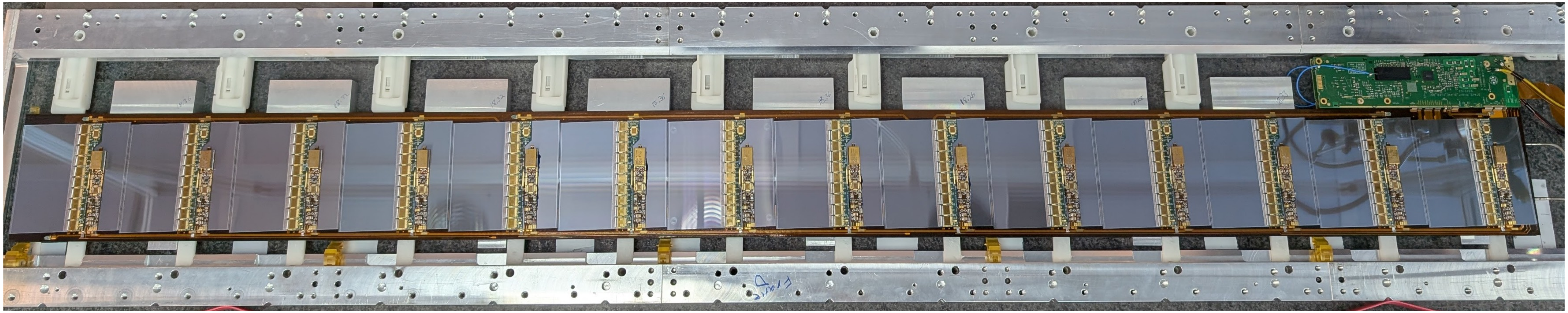
Highlight: new design solved cold noise!



Vestiges of cold noise eliminated in new-design modules, even at extra-cold temps and after irradiation

Outcome

- See slides from Jesse Liu for tests demonstrating evidence of stress reduction in individual redesigned modules
- Preliminary new staves: **no cracks** in relevant temperature range



- After 2 years, in a position to begin building the detector again

Takeaways

Consider carefully before gluing parts directly to sensor surface

Be aware that problematic CTE mismatch can be lurking close by

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Use simulation wisely

- Ensure resolution captures local features
- Revisit for each design update
- Useful to understand how far away potential problems are, which is not obvious from empirical data

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- Not safe to assume a combined structure will have fewer potential problems than individual parts
- Prioritize extreme stress testing in prototyping

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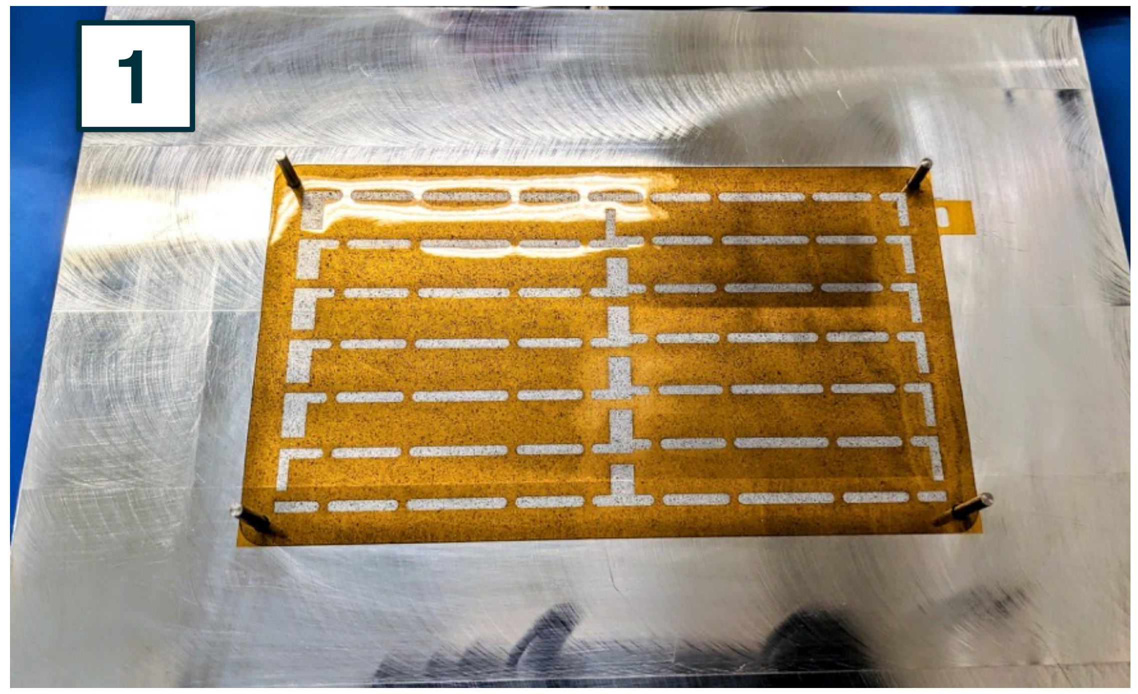
Reduce complexity in design where possible

- Simple designs are easier to adapt to change if needed
- Proliferation of part varieties means fewer people to validate each one

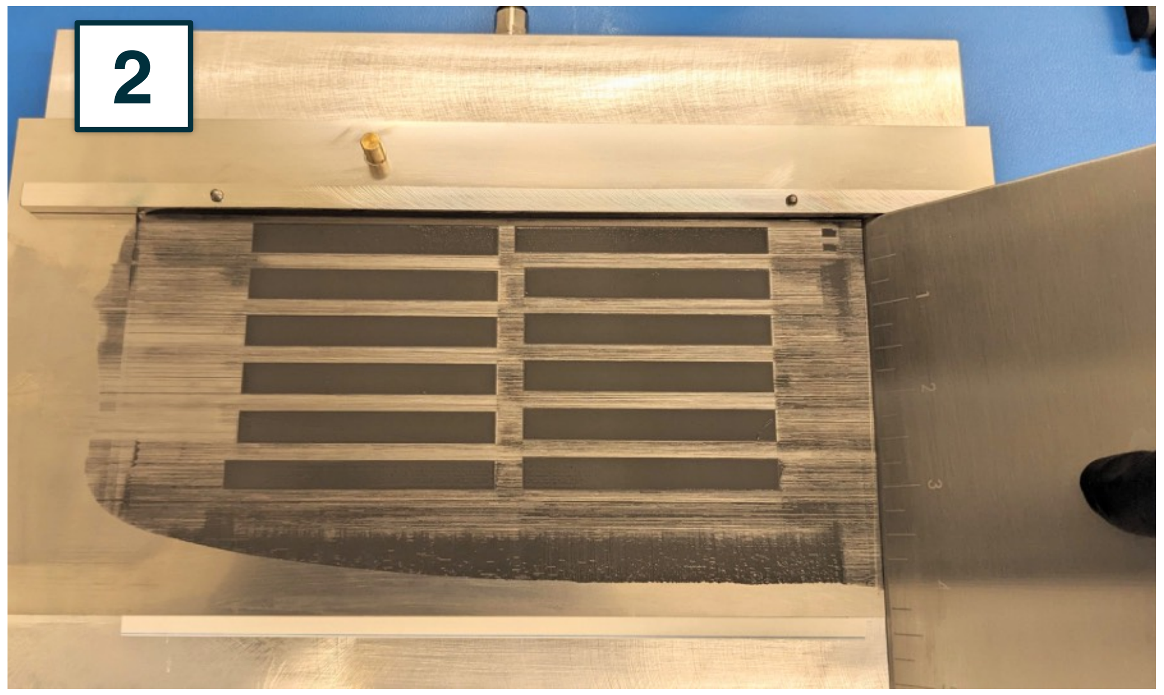
Backup

Barrel Power PCB Lamination

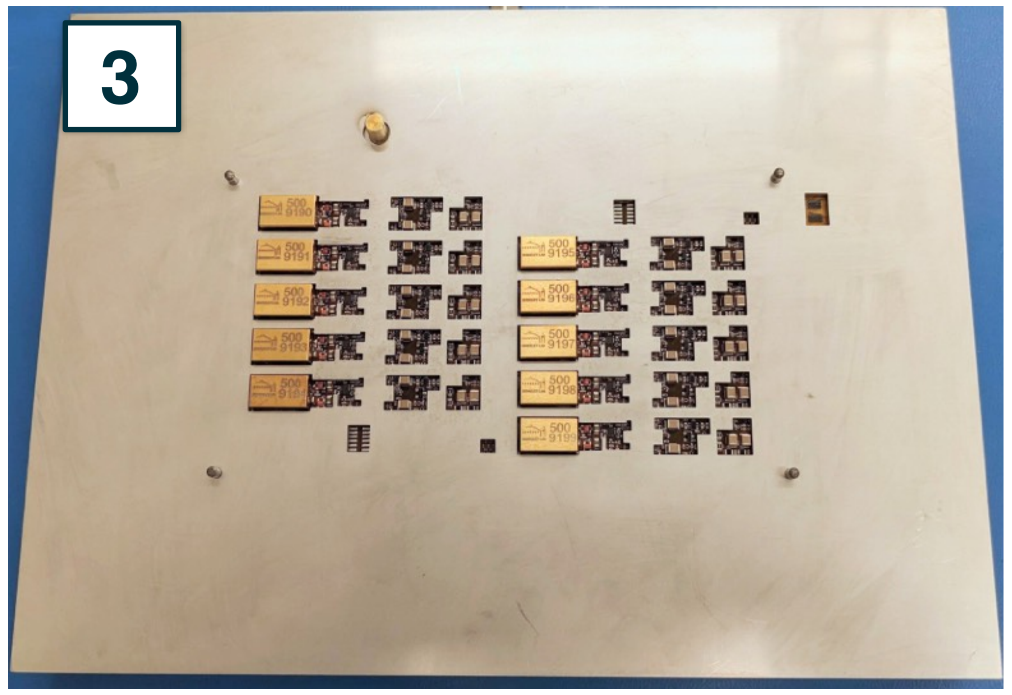
Developed at LBNL, transferred to industry partner for production



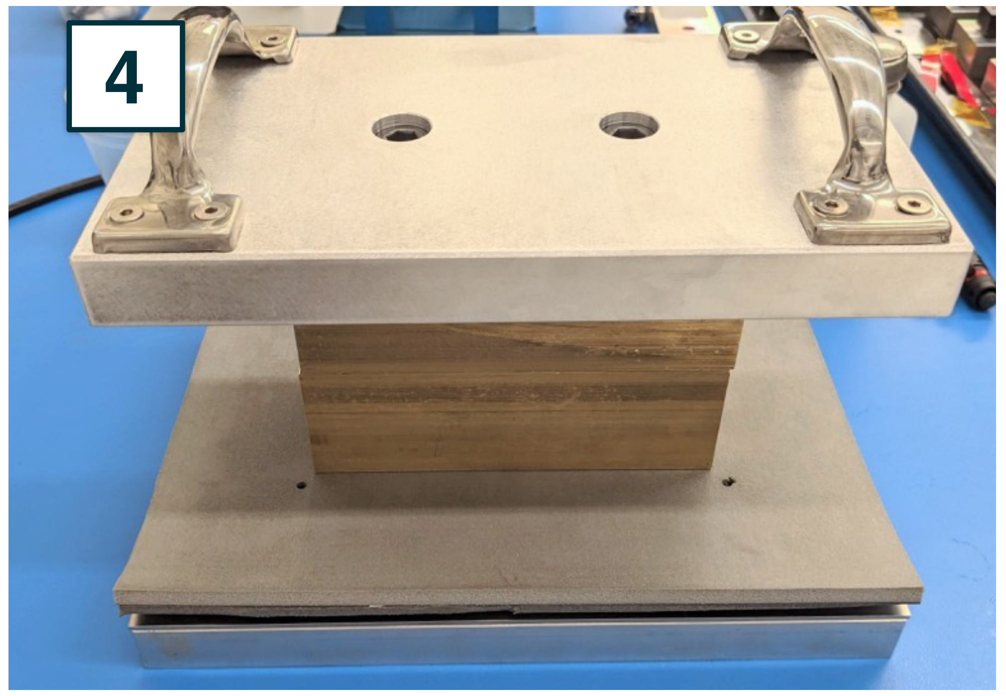
Hold thin (50µm) kapton flat with a metal foam vacuum tool.



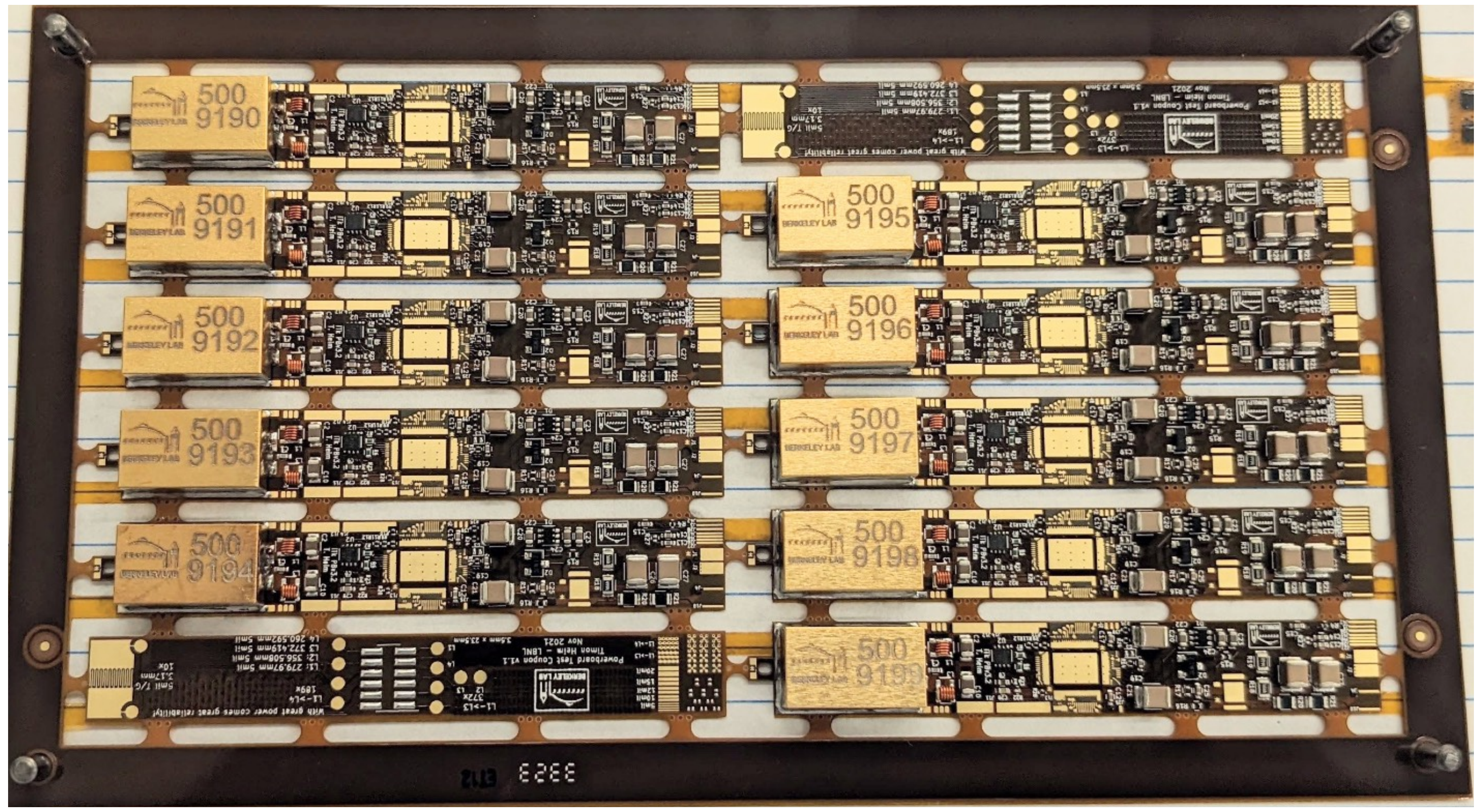
Stencil the soft glue onto the kapton.

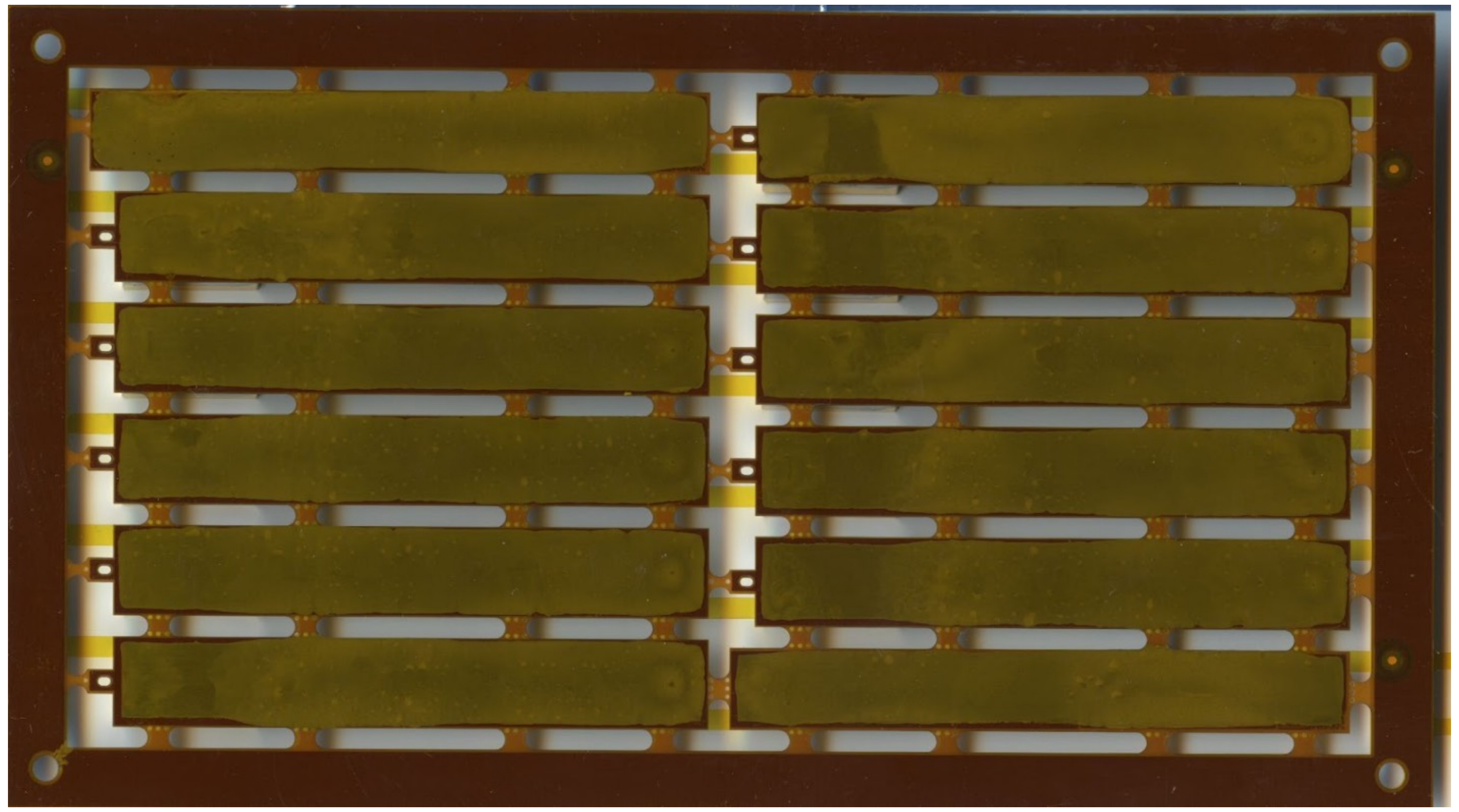


Align the PCB array and press on non-sensitive areas.



Cure under weight. Glass beads in the glue set the glue layer thickness.





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- Not obvious that the thermal stress of a sensor loaded to a stave greater than a free sensor
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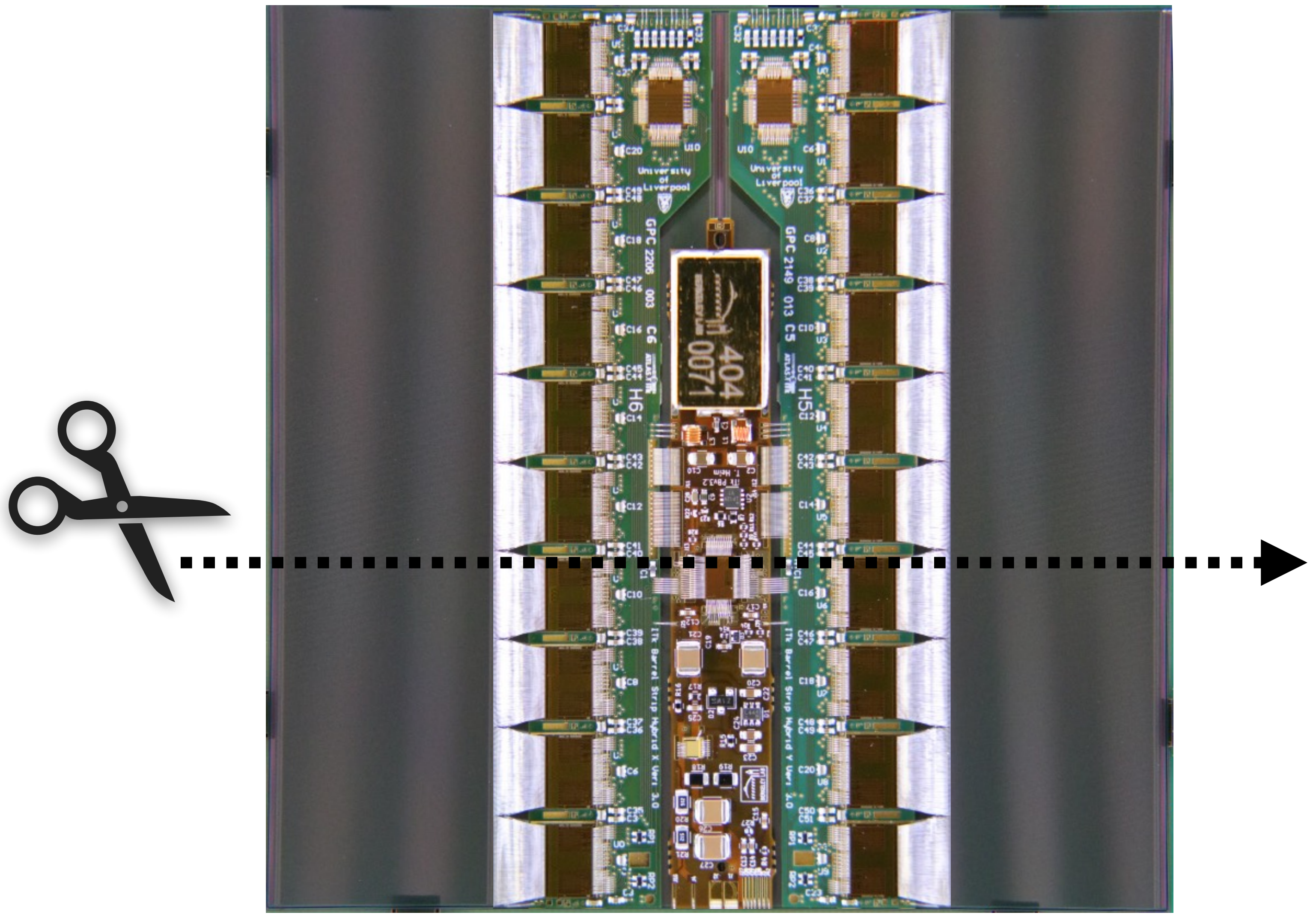
➡ **Delayed detection of cracking problem**

*Later destructive thermal cycling tests to extreme temps succeeded in cracking free modules: see Jesse Liu's slides

Cracking: CTE Mismatch



A module on a stave

Mostly copper	**PCBs**
Loctite Eccobond F112	**Stiff Glue**
Silicon	**Sensor**
Dow SE 4445	**Soft Glue**
Carbon-fiber	**Stave**