

# ***ATLAS ITK UPGRADE***

## ***SILICON CLEANROOM HIGHLIGHTS***

**Cavendish HEP Research Extravaganza**

**6 December 2023**

**Jesse Liu**

Trinity College & Cavendish Laboratory

*On behalf of Team Cambridge ITk*



## HEADLINES

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*“The successful completion of the high-luminosity upgrade of the machine and detectors should remain **the focal point of European particle physics**”*

— European Strategy Update 2020

*“Remaining technical issues are being intensively studied, most critical is the **observed cracking of mounted ITk Strip barrel modules**”*

— ATLAS Report at LHCC 29 Nov 2023

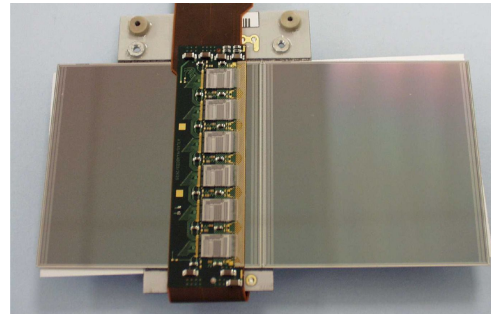
# Inner Tracker (ITk) Strips upgrade

**Barrel module**

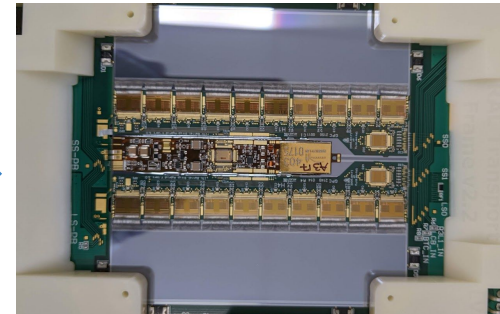
× 10,976

*'Cell of the detector'*

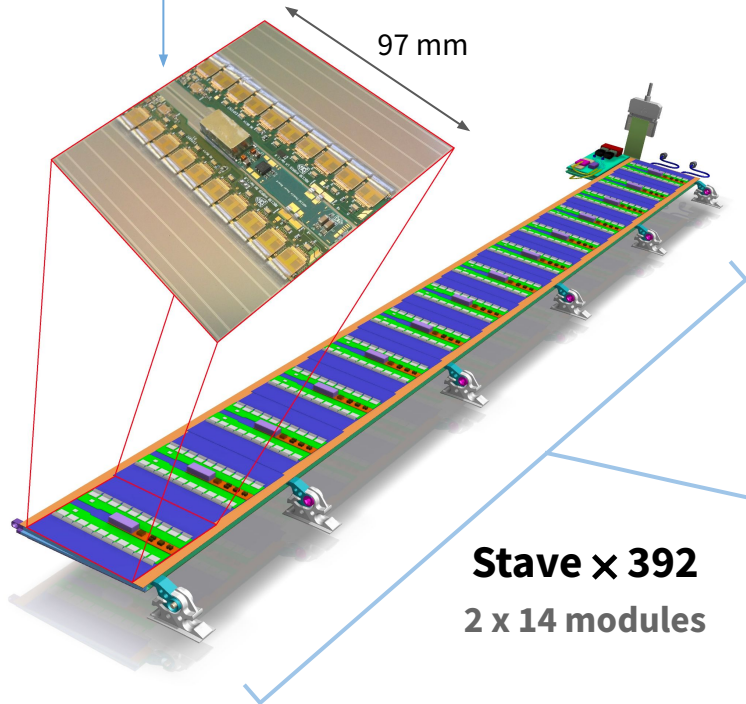
*Key Cambridge deliverable*



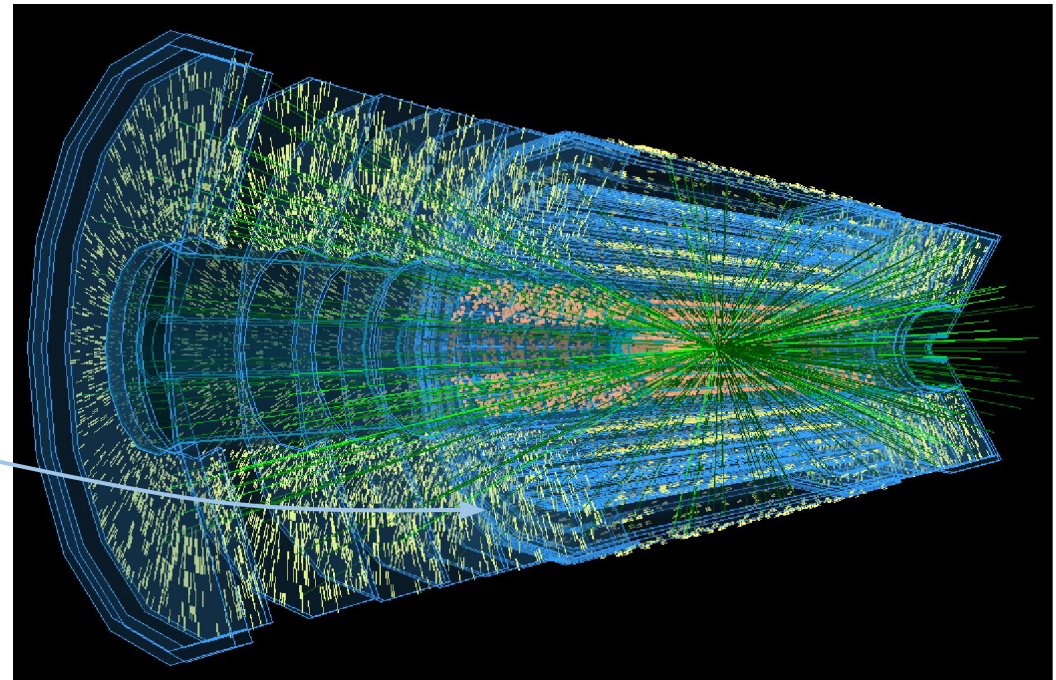
**Current: SCT (60 m<sup>2</sup>)**  
6 million channels @ 10 kHz



**Upgrade: ITk Strips (165 m<sup>2</sup>)**  
60 million channels @ 1 MHz

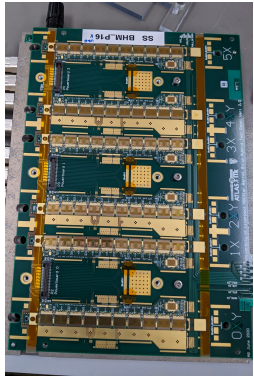


**Stave × 392**  
2 x 14 modules

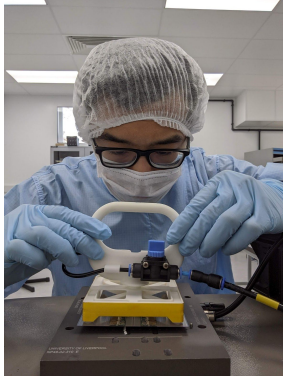


# Production roadmap

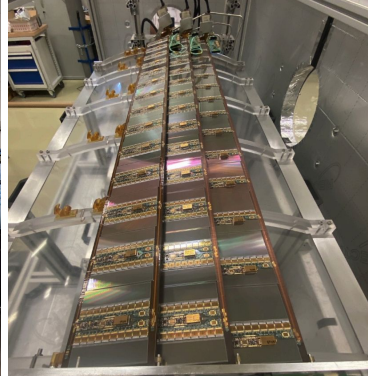
Hybrid panel



Module handling



Stave system tests



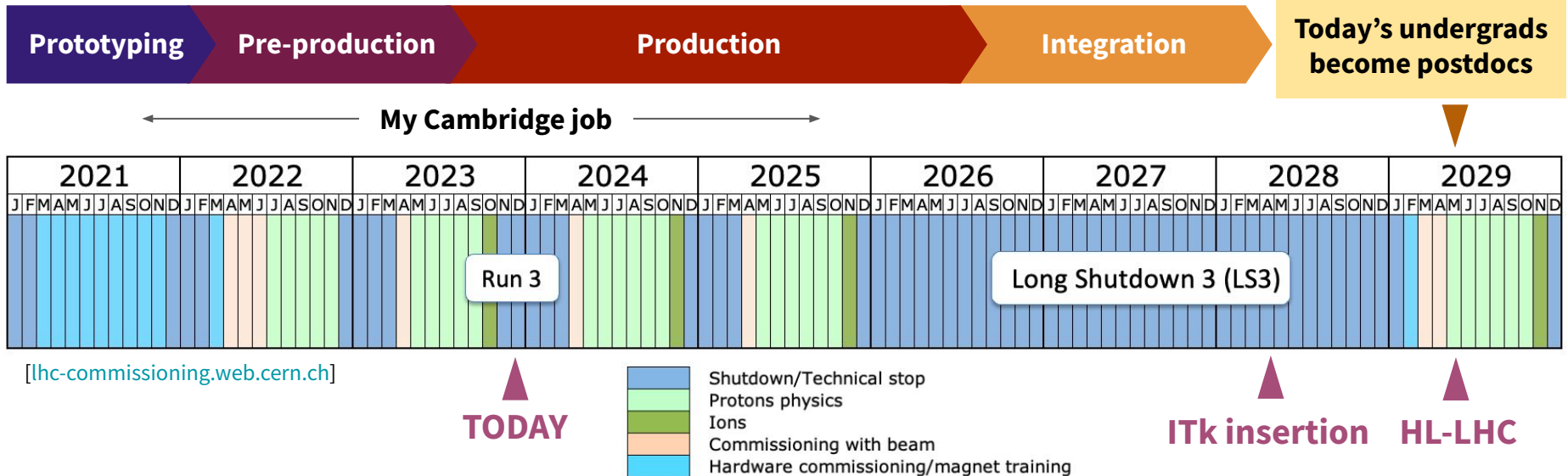
Layer 3 cylinder at Oxford



CERN integration cleanroom



Pics from [Dominique Trischuk](#) & [Silvia Franchino](#) slides; featuring Tony Weidberg & Georg Viehhauser (Oxford)



# International collaboration

ITk = 122 MCHF CORE costs, ~1000 people (Pixels ~260 FTE, Strips ~240 FTE)



## ATLAS UK ITk Strips: cornerstone of STFC science portfolio

Bart Hommels = UK-China Work Package 12 (Strips Modules) Manager



Science & Technology  
Facilities Council



UNIVERSITY OF  
BIRMINGHAM



University  
of Glasgow



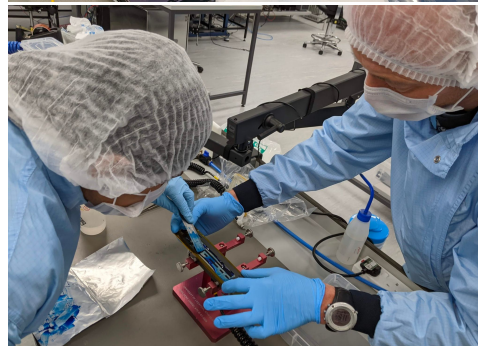
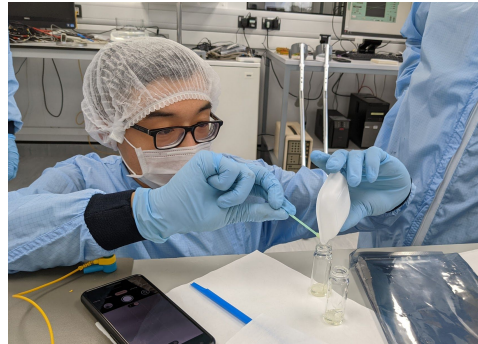
UNIVERSITY OF  
CAMBRIDGE

# Cavendish silicon cleanroom

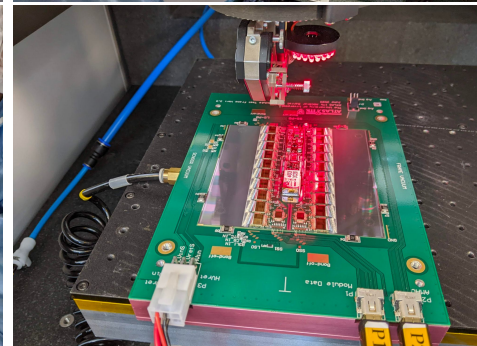
## SETUP



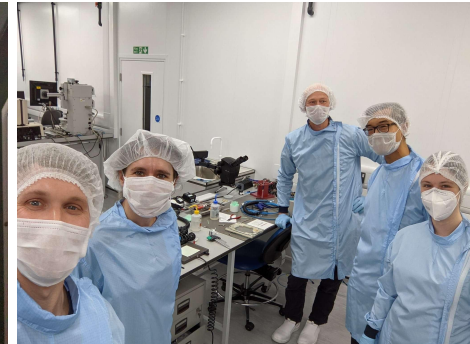
## GLUE



## BOND

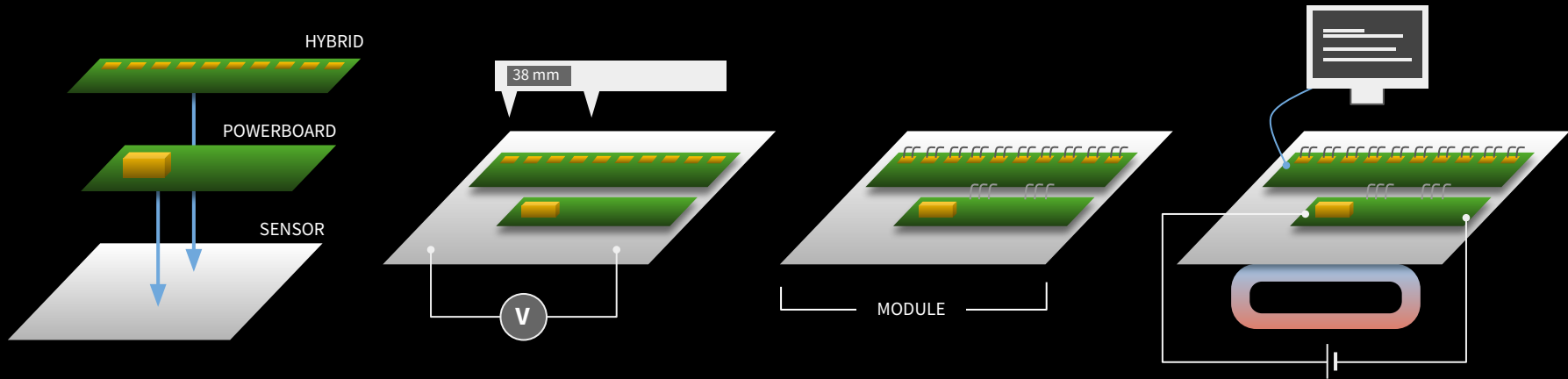


## TEAM



Featuring Bart Hommels, Will Fawcett, Thomas Ivison, Kosala Kariyapperuma, JL, Anna Mullin, Sarah Williams

# Downstairs: ITk Strips module production



Glue circuitry



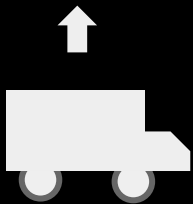
Metrology



Wire bond



Thermal cycle

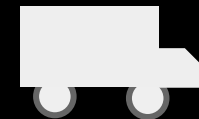


**Receive parts**

*Sensors: Hamamatsu  
Hybrids: Birmingham  
Powerboards: Berkeley*

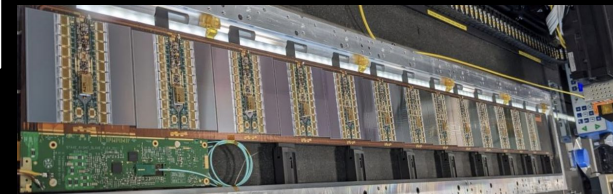
**Cambridge deliverables**

Test 3000 sensors  
Build 1000 modules  
+ 10% yield



**Ship Modules → RAL**

*2 × 14 modules per stave  
10,976 modules on 392 staves*



Pic: Matt Kurth

# Commission thermocycling system

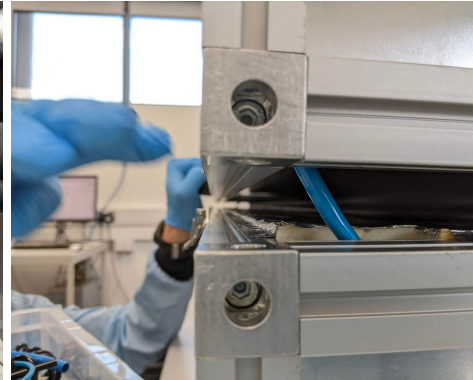
Blown chiller fuse



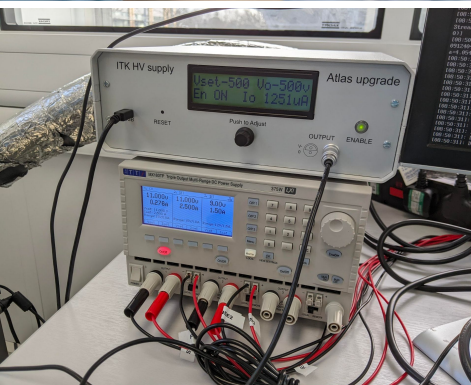
High-voltage short



Lid interlock fault



Expert site visit



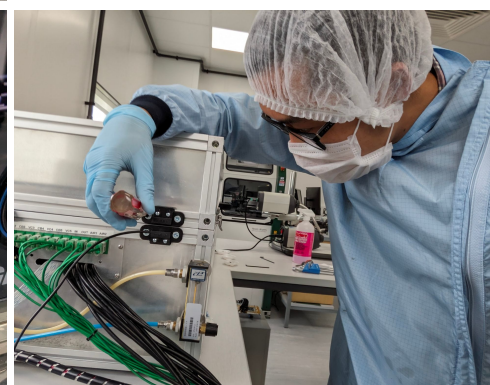
HV firmware bugs



Faulty Pi-plate supply



Chiller leak and frost



Install HV interlock

**Creatively overcame diverse technical challenges both software & hardware**

Essential to verify thermal operation envelope & detector electrical performance





# 2023: celebrate many major milestones



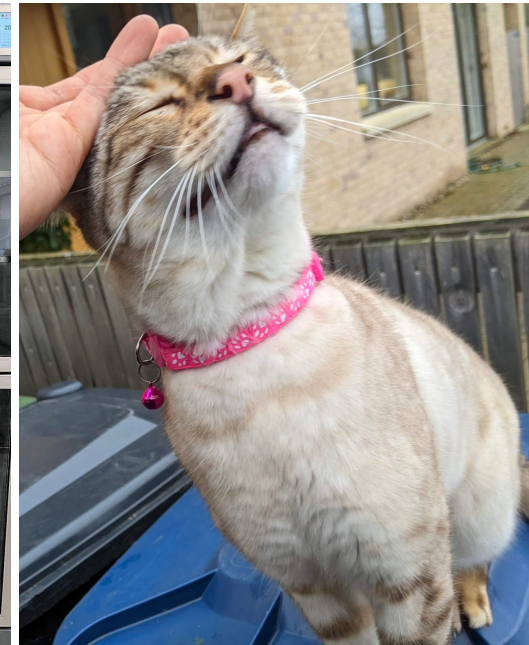
CELEBRATION

Qualification Step	Status	Review Status
Bonding procedures: HV tabs	Qualification Ready	Passed
PB Reception	Qualification Ready	Passed
PB E tests	Qualification Ready	Passed
PB Visual Inspection	Qualification Ready	Passed
PB Storage	Qualification Ready	Passed
Reception: hybrids	Qualification Ready	Passed
Storage of hybrids	Qualification Ready	Passed
Visual inspection: hybrids	Qualification Ready	Passed
hybrid QC: single panel testing	Qualification Ready	Passed
Storage of modules	Qualification Ready	Passed
Cleaning module jigs	Qualification Ready	Passed
Storage + shipping of glue	Qualification Ready	Passed
Removing hybrids from panel	Qualification Ready	Passed
Module Assembly	Qualification Ready	Passed
Metrology: modules	Qualification Ready	Passed
Bonding procedures: modules	Qualification Ready	Passed
Visual inspection: modules	Qualification Ready	Passed
Module Thermal Cycling	Qualification Ready	Passed
Single Module Electrical Test	Qualification Ready	Passed
Shipping modules	Qualification Ready	Passed
Cleanroom standards	Qualification Ready	Passed
ASIC Compliance & Handling	Qualification Ready	Passed
Bond Pulling Procedures	Qualification Ready	Passed
Completed Steps		23
Total Steps		23
Completed (%)		100.00%

SITE QUALIFICATION STATUS



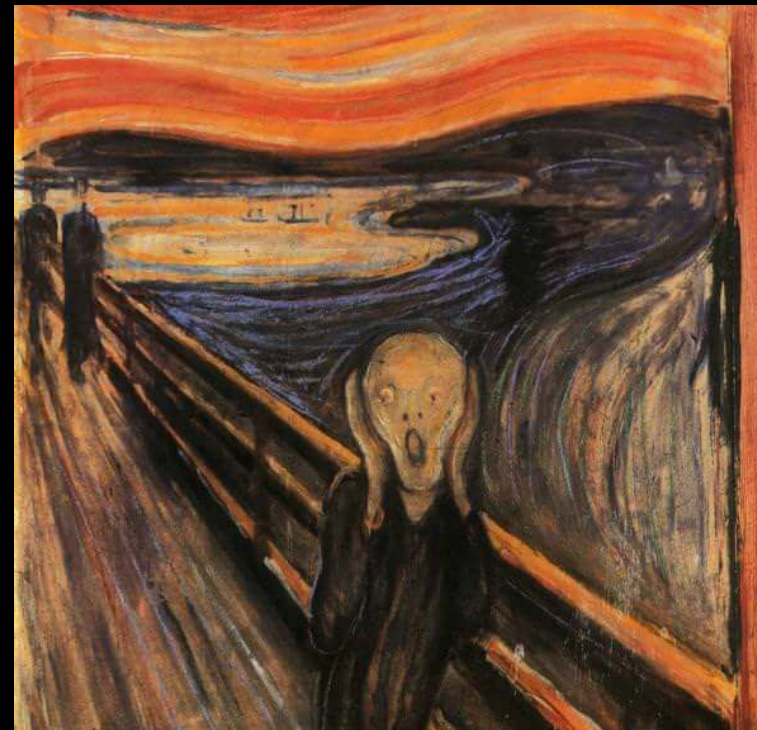
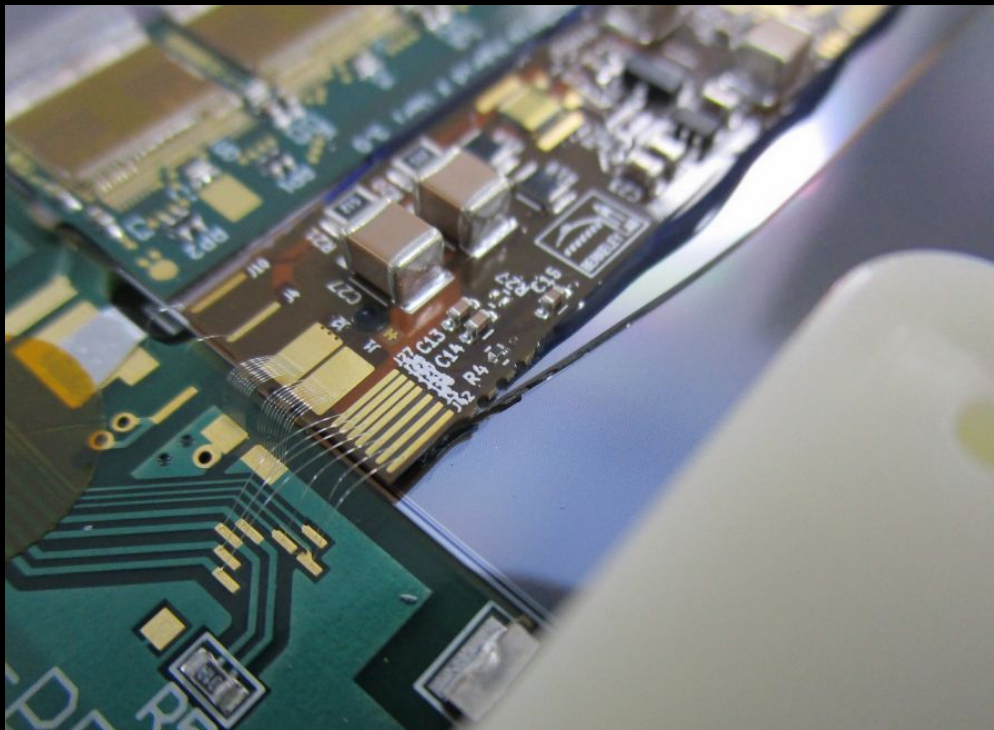
SENSORS IN NEW CABINET



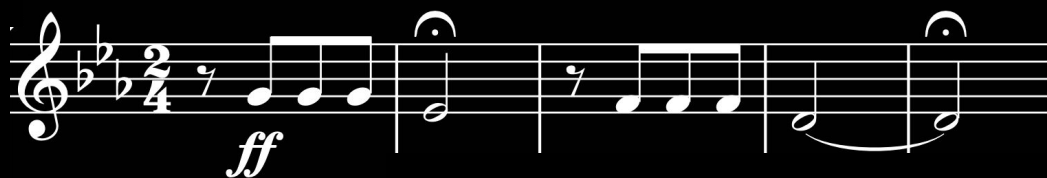
HAPPINESS

**889 (30%) production sensors** received in Cambridge allocation  
 Assembled 47 modules **proving production capability & capacity**  
 Cambridge 1st site worldwide to **qualify thermal cycling 26 May**  
 Barrel modules **passed international readiness review 12 Jul**  
 1st UK-China cluster site **approved for module production 13 Oct**

But then...disaster strikes! 🤯

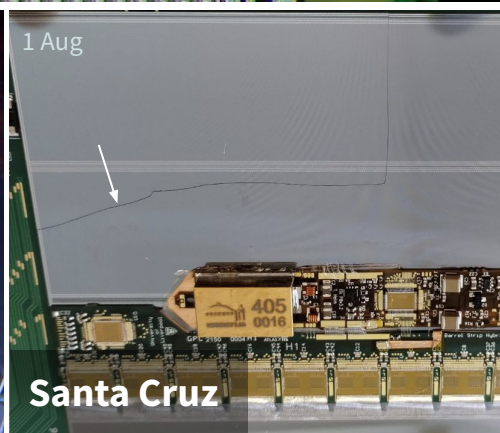
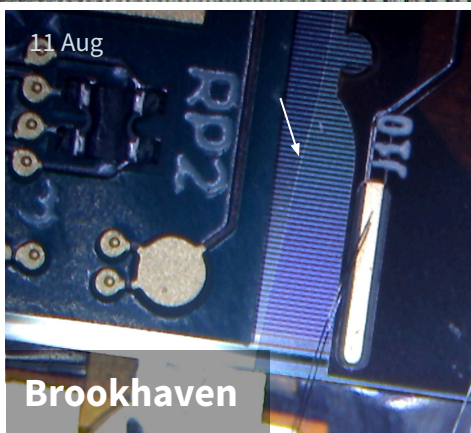
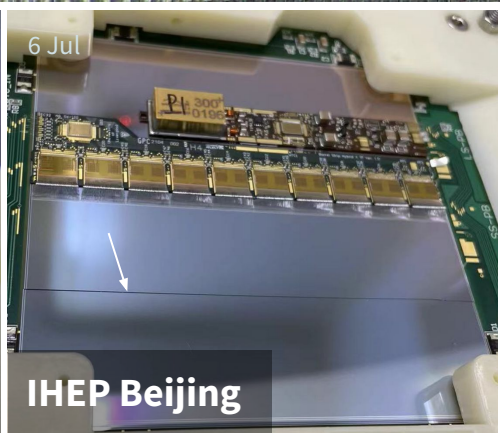
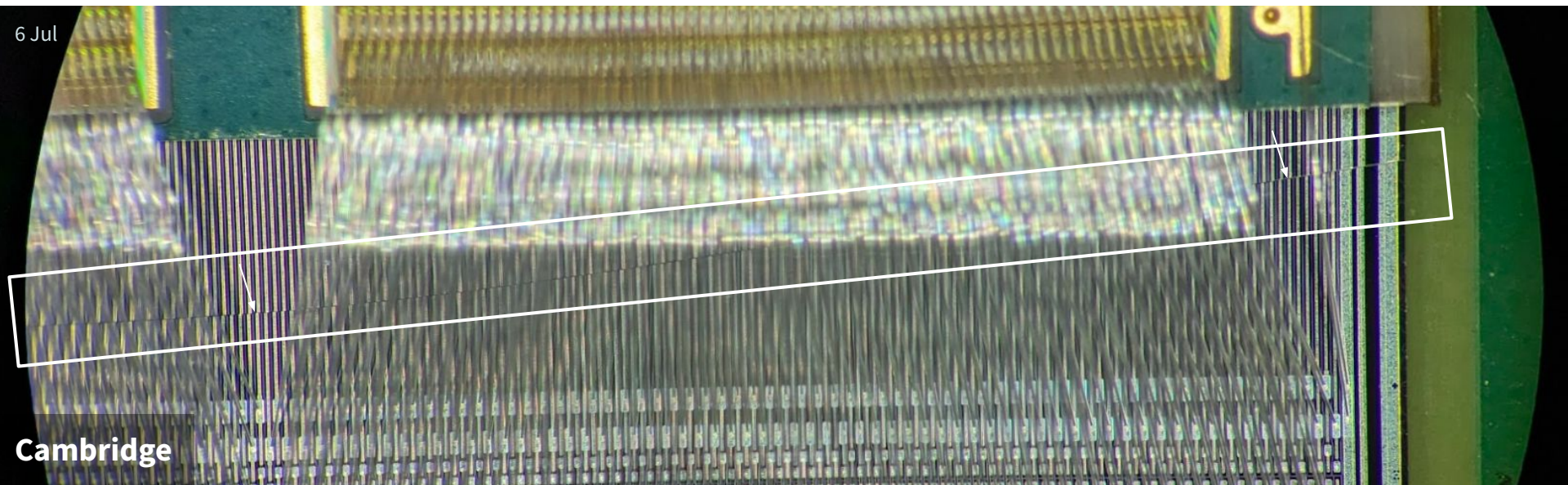


Birmingham 15 Jun



Edvard Munch *The Scream*; Ludwig van Beethoven *Symphony no. 5, 1st mvt*

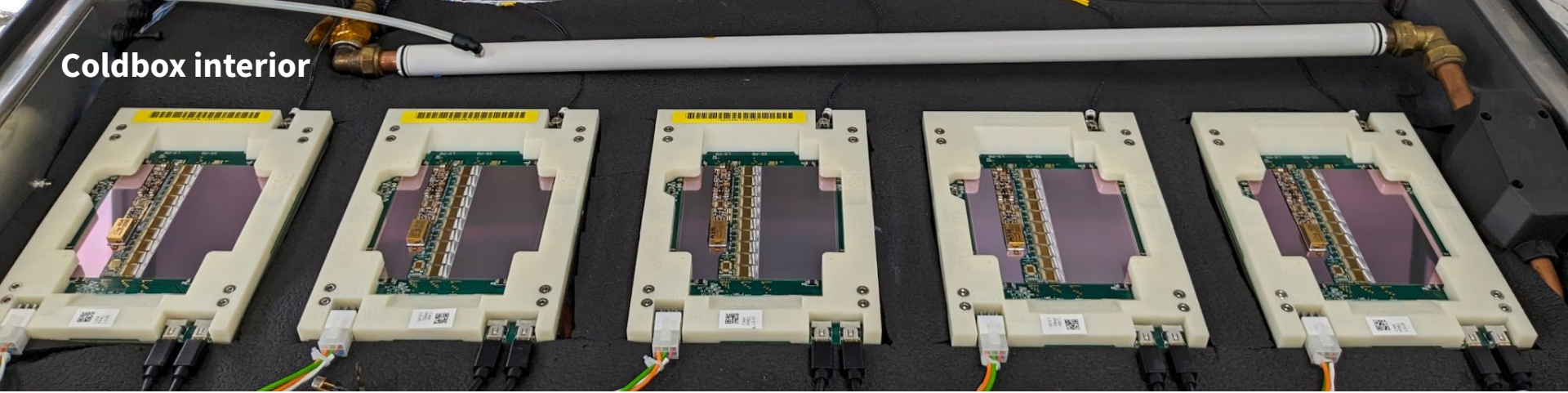
# Showstopper: cracked silicon modules 🙄



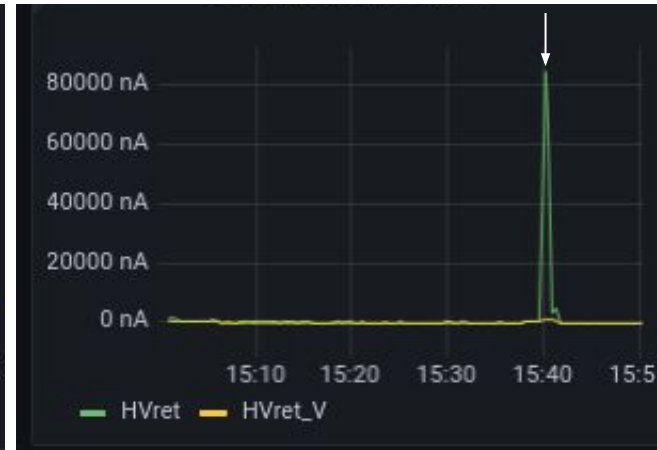
**Crack morphology similar worldwide:** along glue interface seen at 10-20% rate  
**Full production paused:** schedule impact uncertain while seeking mitigations

# Post-mortem: reconstruct moment of death

Coldbox interior



-350V, 183uA, Tue Jul 4 15:05:30 2023
0V, 0uA, Tue Jul 4 15:05:55 2023
-199V, 104uA, Tue Jul 4 15:38:06 2023
-199V, 104uA, Tue Jul 4 15:38:36 2023
-350V, 202uA, Tue Jul 4 15:39:08 2023
-351V, 185uA, Tue Jul 4 15:39:39 2023
-350V, 184uA, Tue Jul 4 15:39:45 2023
TRP, TRP, Tue Jul 4 15:40:00 2023 ←
0V, 0uA, Tue Jul 4 15:42:42 2023
0V, 0uA, Tue Jul 4 15:44:22 2023
0V, 0uA, Tue Jul 4 15:44:42 2023
TRP, TRP, Tue Jul 4 15:45:12 2023



Power supply monitoring

On-module temperatures

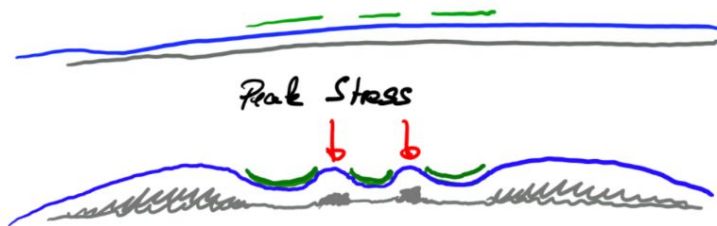
Sensor HV leakage current

JL led **operations**, developed high-voltage **monitoring+control**, **interlocks**, **analysis**  
**Pinpoint time of crack to within 5 seconds** vs staves lacking live electrical monitoring

# Problem: thermomechanical stress

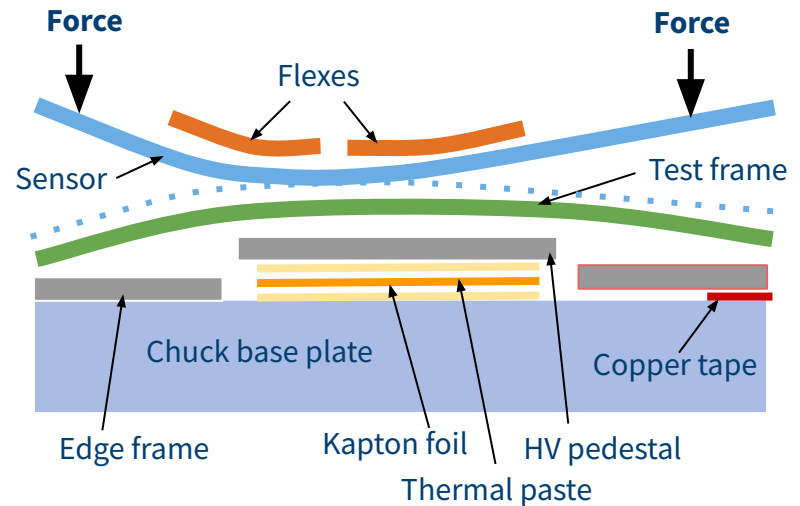
CTE = Coefficient of Thermal Expansion =  $(1/L)(dL/dT)$

Material	Modulus (GPa)	CTE ( $10^{-6}/K$ )
Silicon	160	2.6
Copper	120	16.7
Kapton	2.5	20
Epoxy	3.1	60
SE4445	0.001	—



**Mismatched CTEs between glue at flex-sensor & sensor-stave interfaces**

FEM simulations: Giorgio Vallone (LBNL) & Haider Abidi (BNL)  
Sketches: Jens Dopke (RAL), Bart Hommels (Cambridge)  
Analytic model: Masahiro Morii (Harvard)



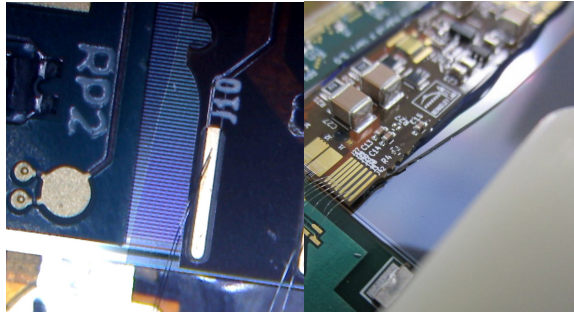
**Aplanar coldbox chucks exacerbate stress on cold bowl-shaped modules**

**Mitigation:** simulation favours thinner flexes, wide/filled glue gaps, stiffer stave glue.

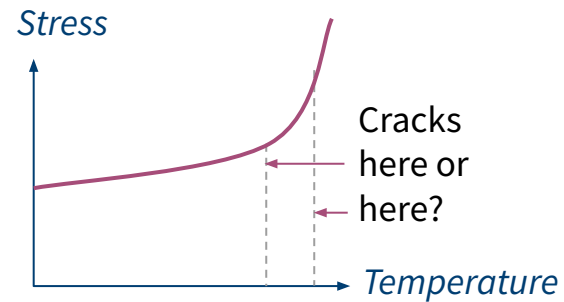
**Impact:** design changes likely  $\Rightarrow$  implications for costs, tooling, resources, schedule.

# No sugarcoating: grave unforeseen challenges

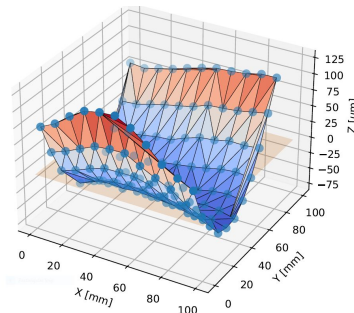
*International efforts to pinpoint problems with mitigations in sight  
Cambridge proposed test-to-destruction study to sharpen solutions*



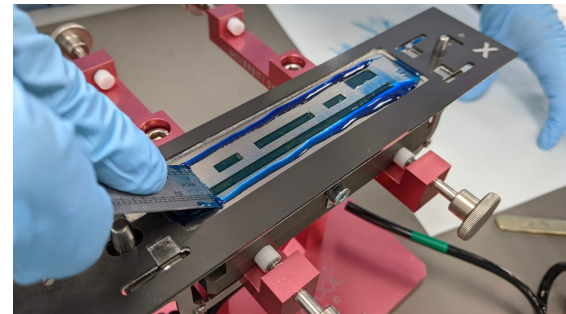
***To what extent can we verify mitigation options in coldbox?***



***What is the thermal headroom before modules crack?***



***What lab measurements can help calibrate simulation?***



***How do glue phase transitions 'bake in' bow in thermocycling?***

# 2024: a new hope — start production in new laboratory 🙌

Next chapter of **landmark instrumentation** enabling **historic discoveries**

## Cavendish 1

Beryllium scattering

Discover neutron

PRSLA 136 (1932) 692/Cavendish Lab

## Cavendish 2

SemiConductor Tracker

Discover Higgs boson

NIMA 568 (2006) 642, CERN/ATLAS

## Cavendish 3

Inner Tracker upgrade

Discover dark matter?

Bouygues UK

