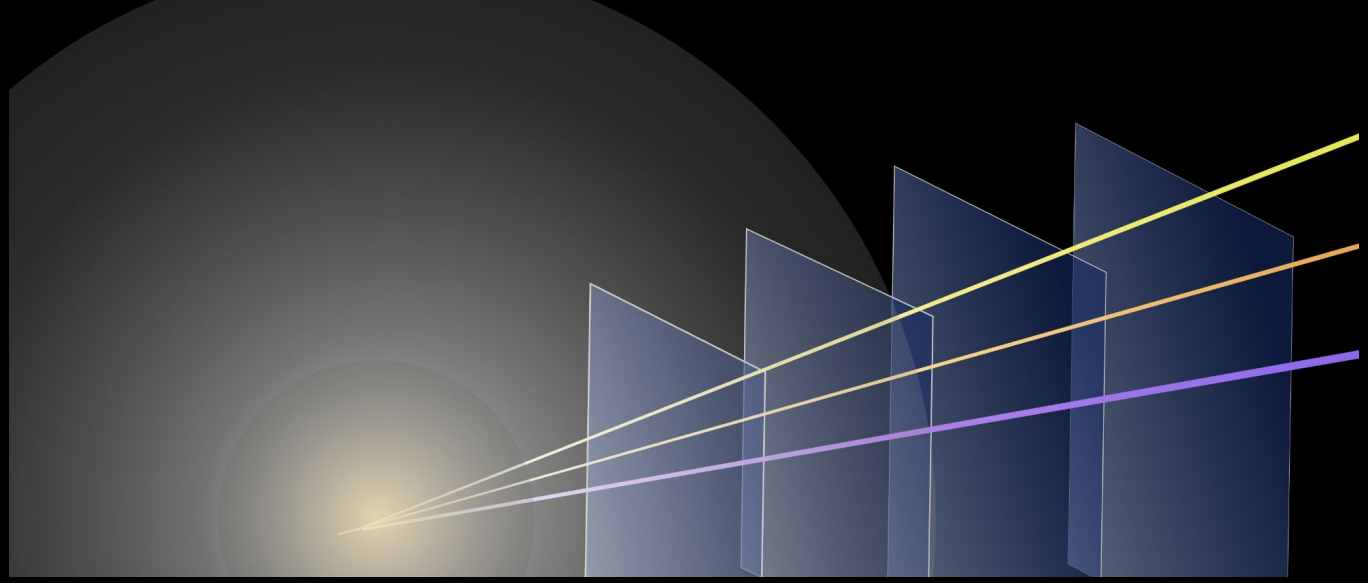


Construction of the ATLAS ITk Strip Detector for the HL-LHC Era

EPS-HEP Conference | Marseille, France

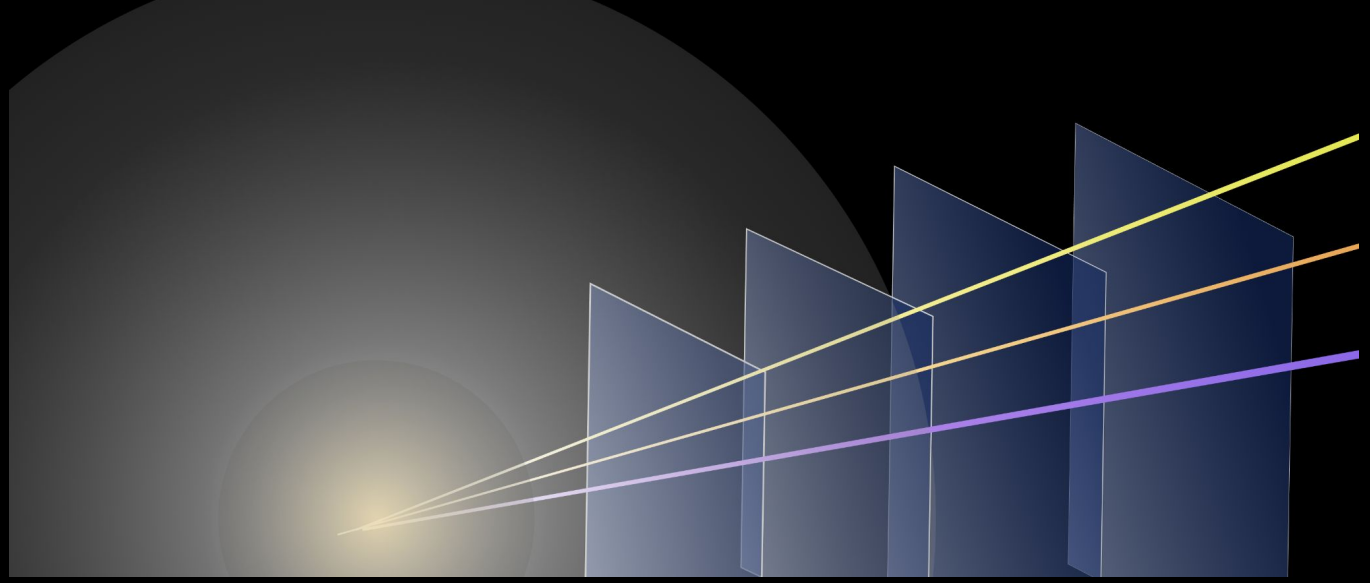
7 July 2025

Jesse Liu

New York University

On behalf of the ITk Strip Collaboration

ATLAS EXPERIMENT NYU



OUTLINE

► *Overview: project highlights*

Motivation | Construction | Sensors & chips
Assembly | Global mechanics | Integration

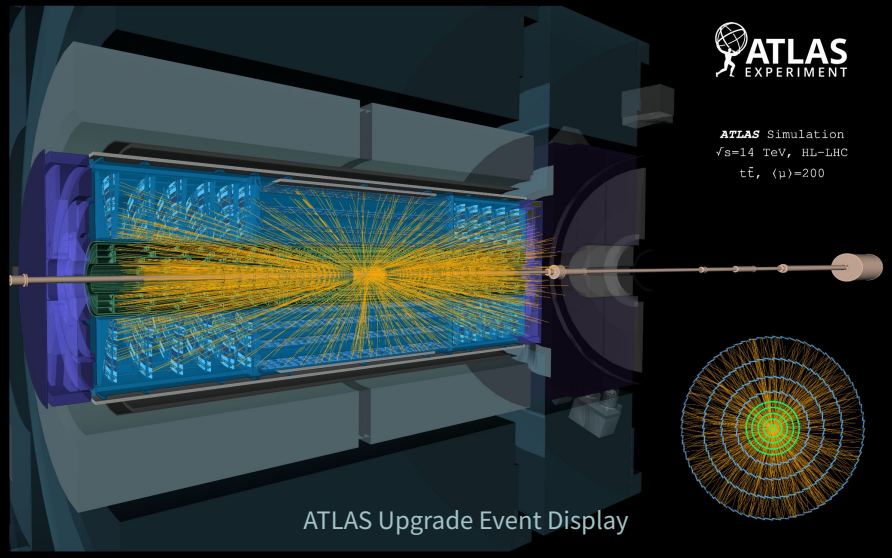
Challenge: sensor fracturing

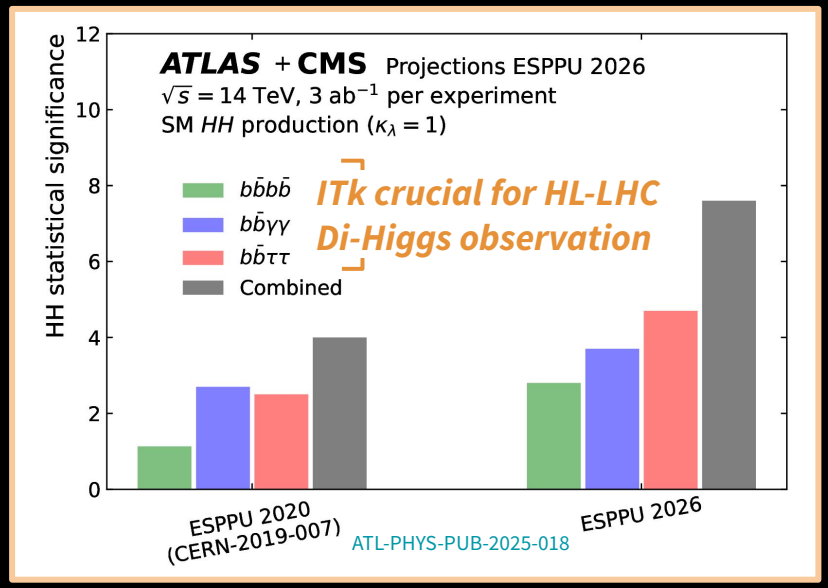
Problem | Mitigation | Validation | Production
Major research focus since Summer 2023

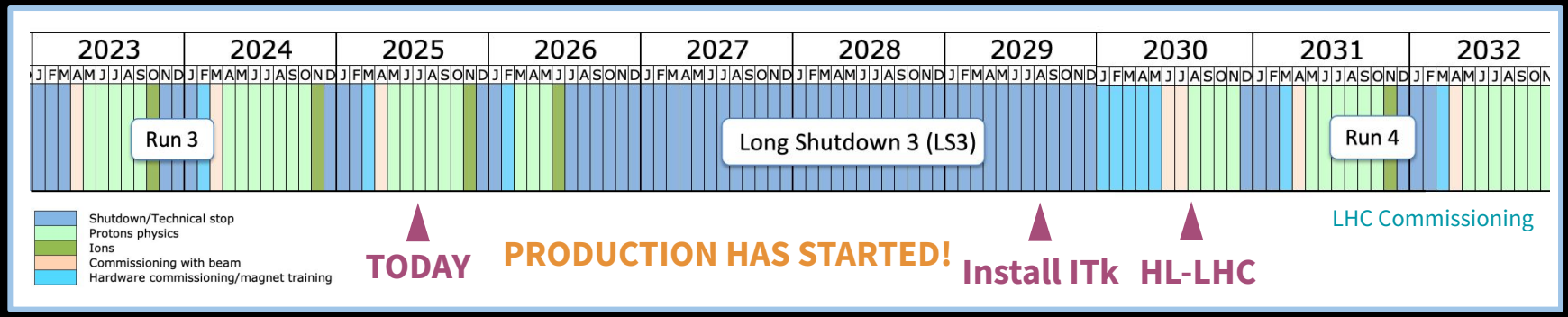
New Inner Tracker (ITk) opens next decade of discoveries

ITk Strip: 10x *finer* & 100x *faster* for 10x *fainter* physics*

6 → 60 million channels **10 kHz → 1 MHz readout** **400 → 4000/fb luminosity**





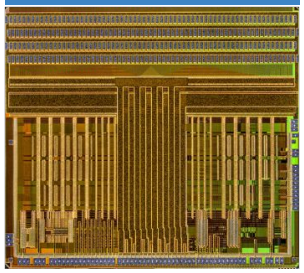


*Compared with current ATLAS SemiConductor Tracker (SCT)

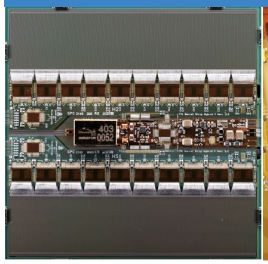
Overview: ITk Strip construction

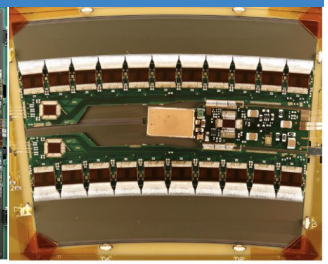
ITk Strip TDR ,
PHYS-PUB-2021-024
Major project:
~500 people ~240 FTE
14 countries, 4 continents

Chips (ASICs)



Modules: 10796 + 2 × 3456





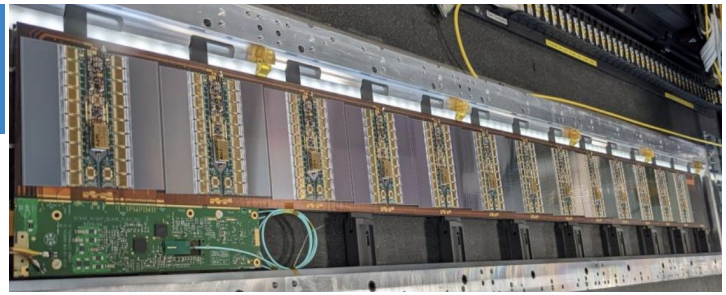
2 types

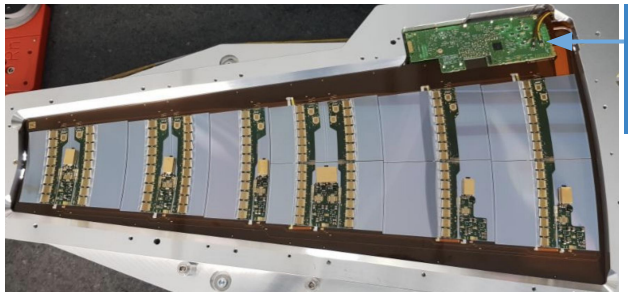
6 types

Sensors

Local Supports

Staves
×392

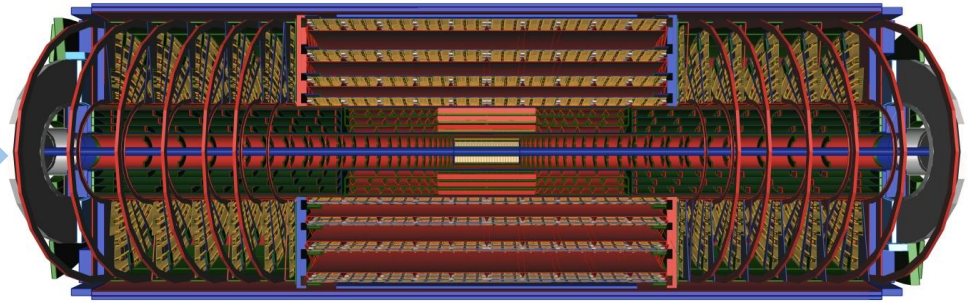




EoS: End of Substructure

Petals
2 × 192

Global Mechanics



Endcap A | **Barrel** | **Endcap C**

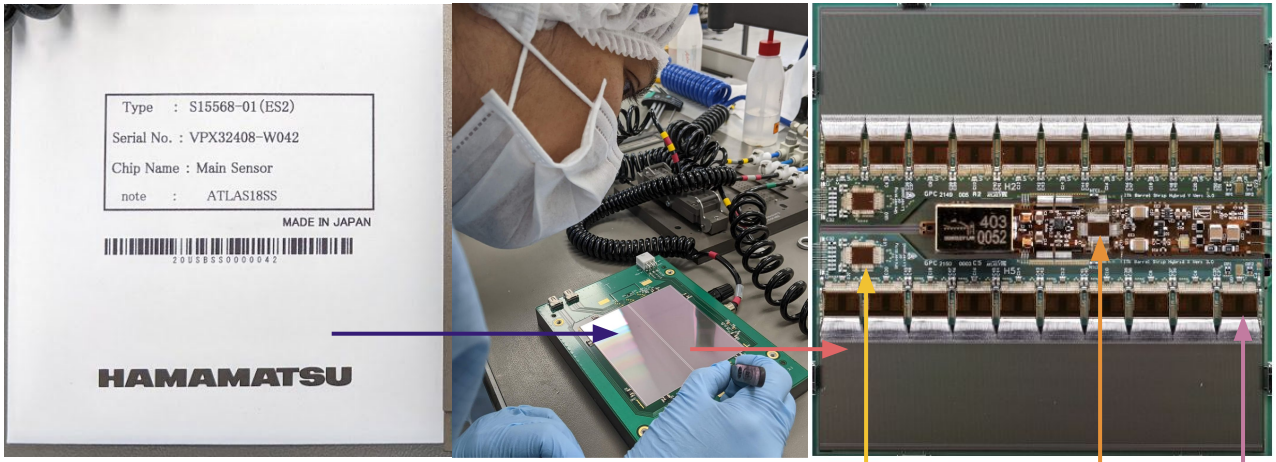
Strips
← Pixels
Strips

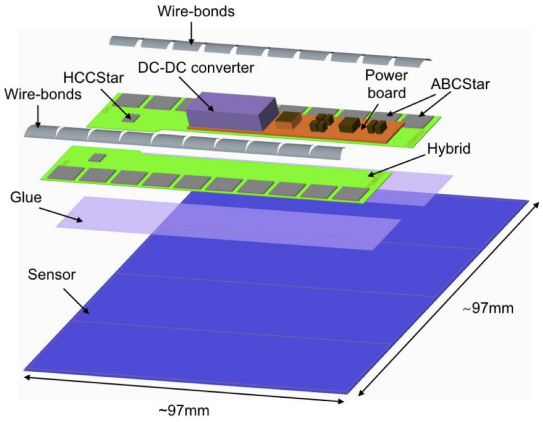
Services

Heart of detector: sensors + chips → module

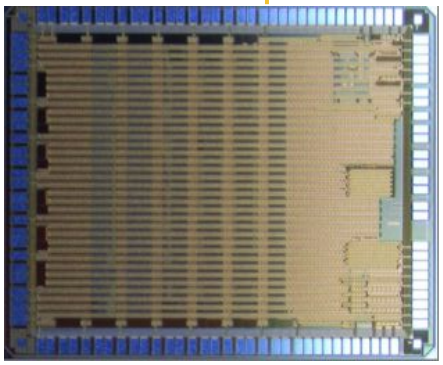
Sensors ↓ 92.5% received (22180/24010) | 84% accepted ready for production

Hamamatsu to replace rejected sensors | Ordered +15% for assembly yield, cold noise & fracturing studies





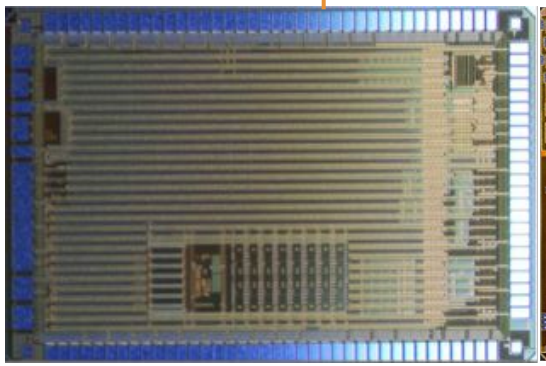
Module schematic



HCCStar

Hybrid Controller Chip

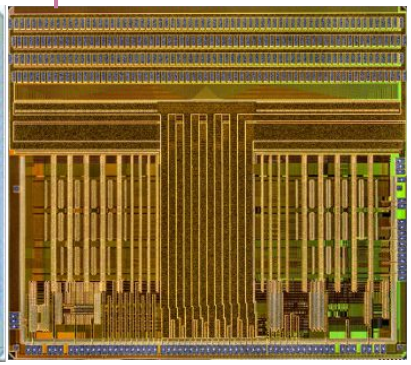
Ready for distribution: 35 587 [104.5%]



AMACStar

Autonomous Monitoring & Control

29 632 [143.8%]



ABCStar

ATLAS Binary Chip Readout

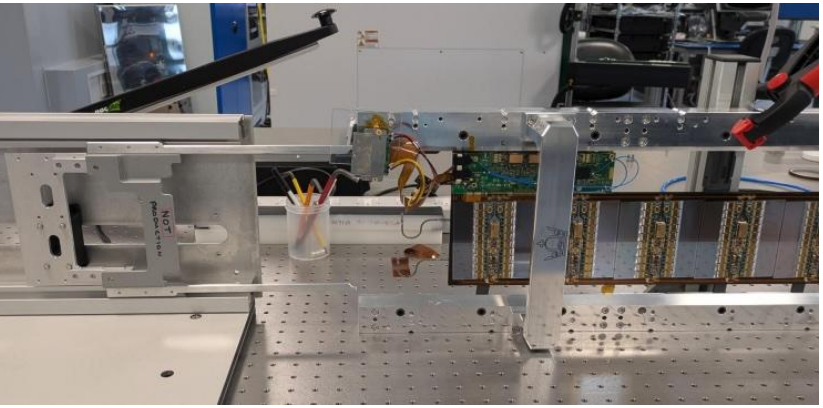
271600 [87.3%]

Assembly: modules → staves/petals

Glue & test modules

Prepare cores & tapes

Load modules to stave/petal via silicone



Insert stave into transport frame @ RAL/BNL

Arrival at CERN

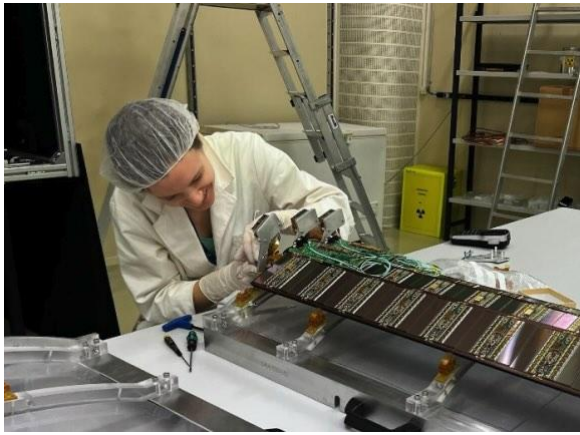
(Un)box package

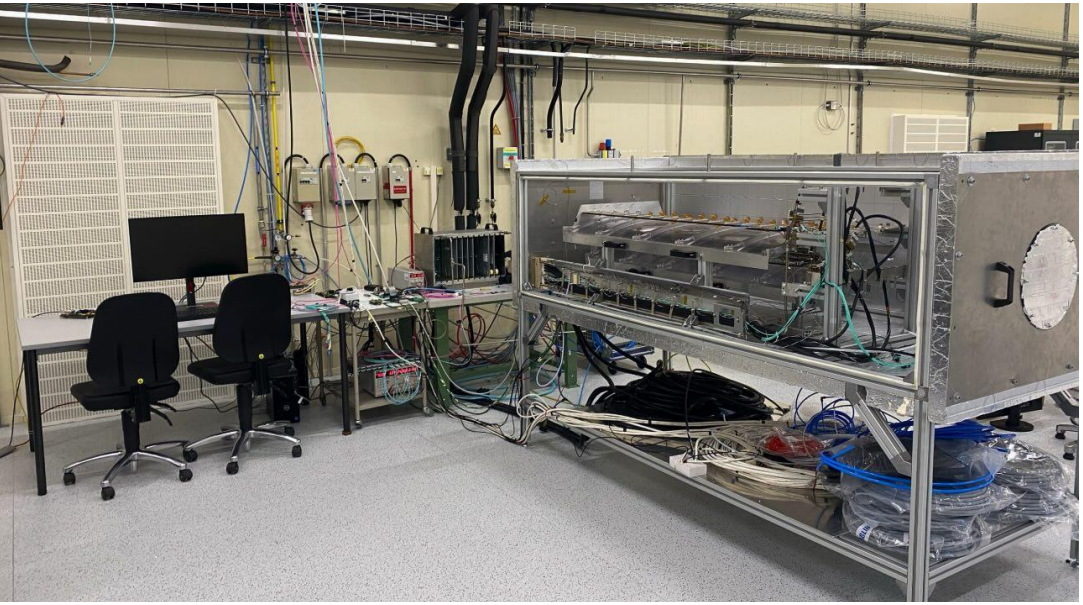
System tests: multiple staves & petals

Stave in transport box

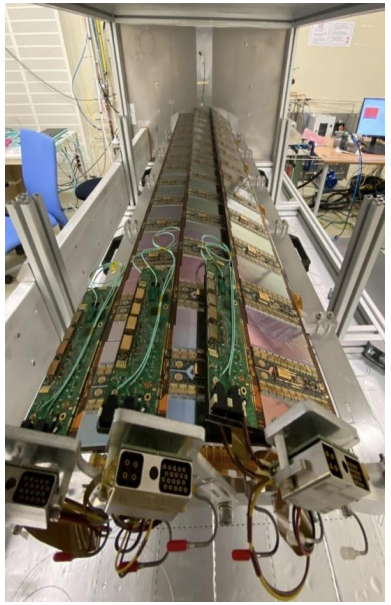
Stave visual inspection

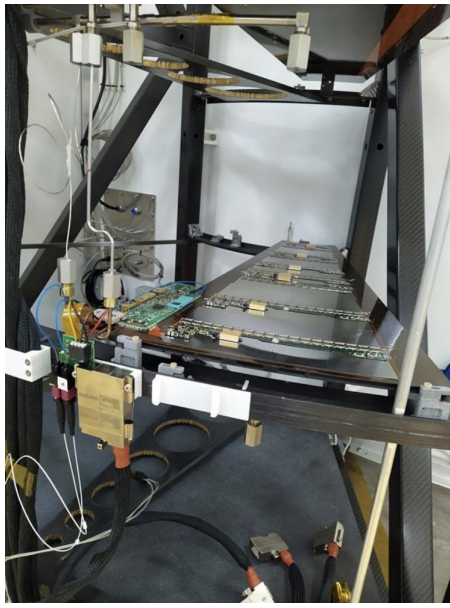
Prepare tests





SR1 stave testing

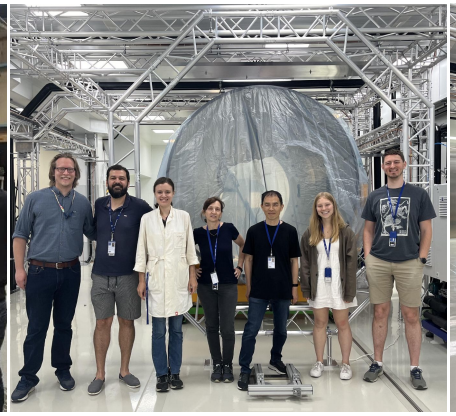




System testing @ CERN & DESY

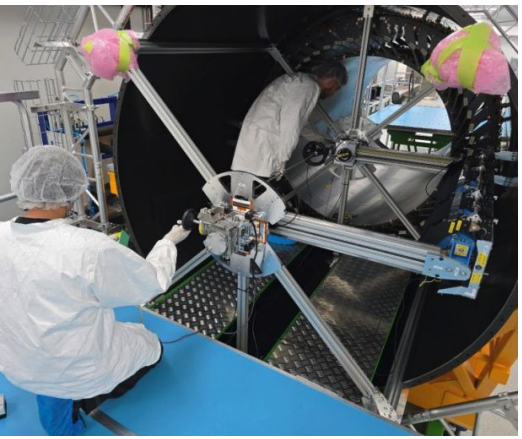
Global mechanics & services

Outer cylinder journey: Berkeley → Oxford → CERN

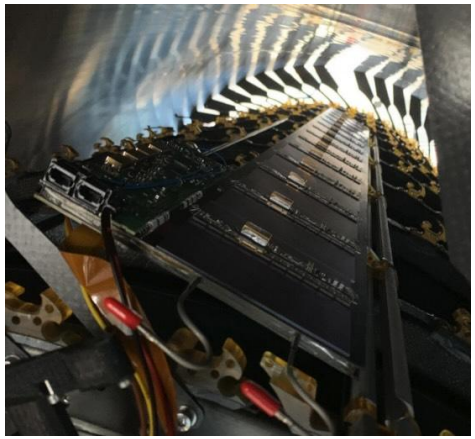




Layer 3 @ Oxford

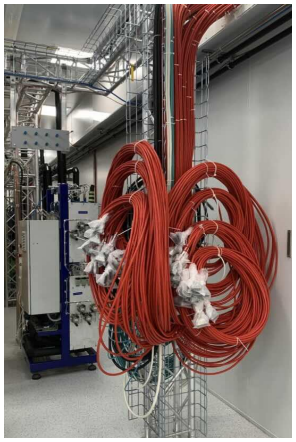
L3 insertion @ CERN



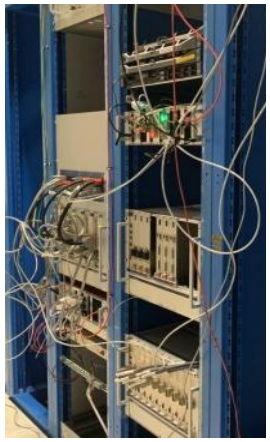
Stave carrier insertion



A-stave at 1 o'clock



Type3/PS cables



Power supplies

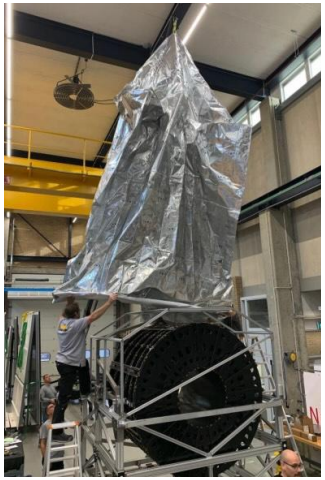
Patch Panel 3* test

Endcap supports arrive at integration sites

Endcap supports @ NIKHEF

Load dummy petals

Humidity bag



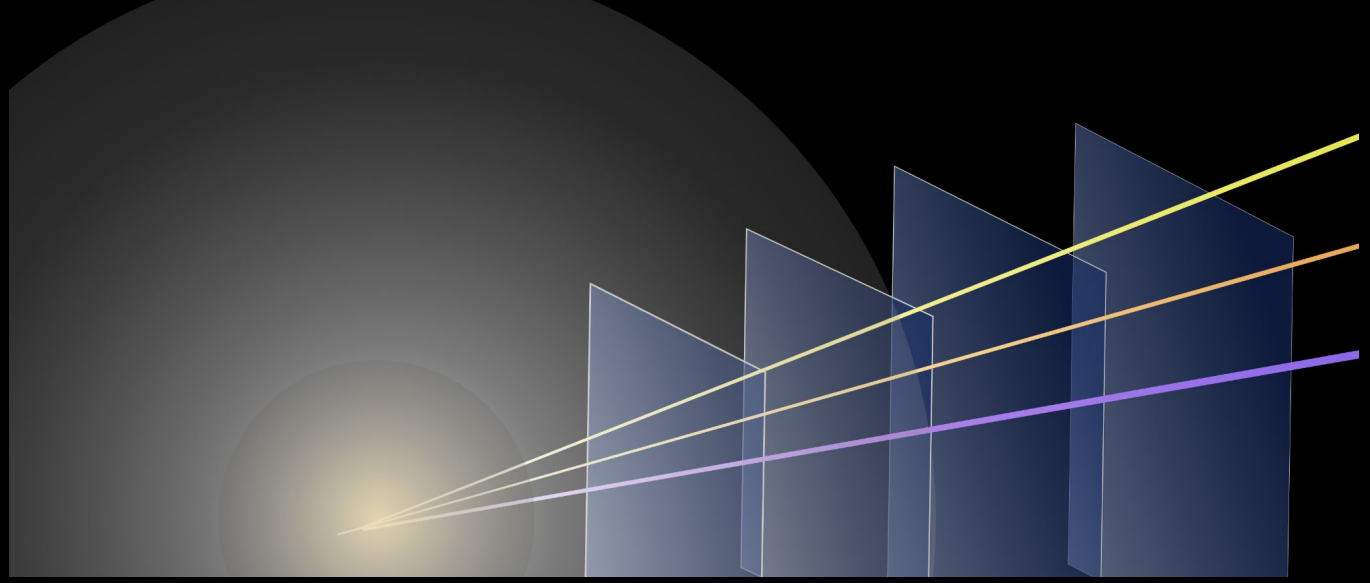
Transport NIKHEF → DESY

DESY arrival

Endcap support enters DESY

Align in superstructure

DESY ITk endcap team



OUTLINE

Overview: project highlights

Motivation | Construction | Sensors & chips

Assembly | Global mechanics | Integration

► ***Challenge: sensor fracturing***

Problem | Mitigation | Validation | Production

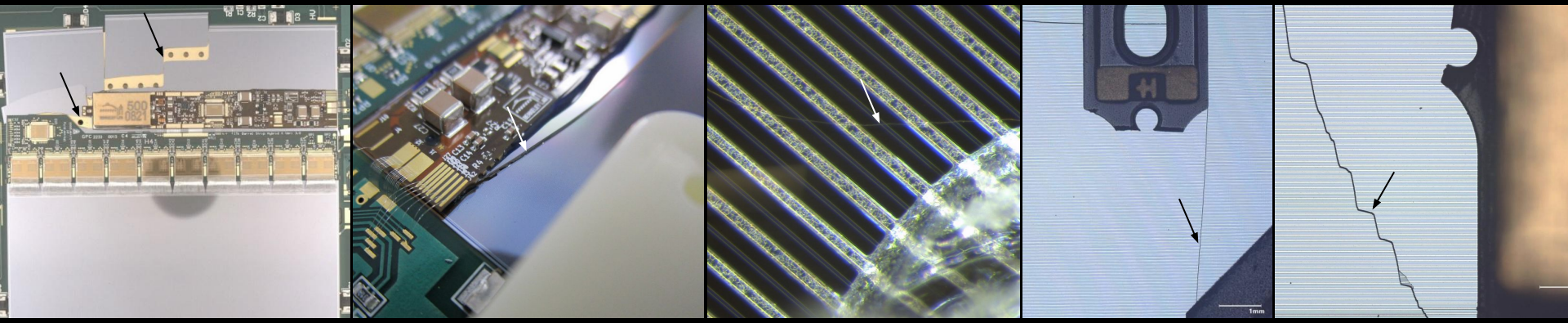
Major research focus since Summer 2023

Major critical problem: sensor fracturing

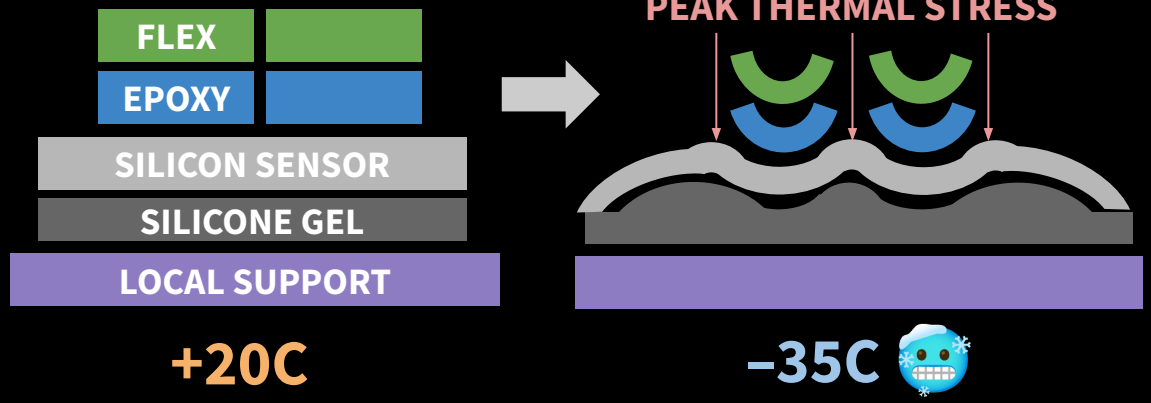
Problem: cooling modules to end-of-life –35C cracks sensors at ~15% rate

Cause: flex-glue-sensor coefficients of thermal expansion (CTE) mismatch

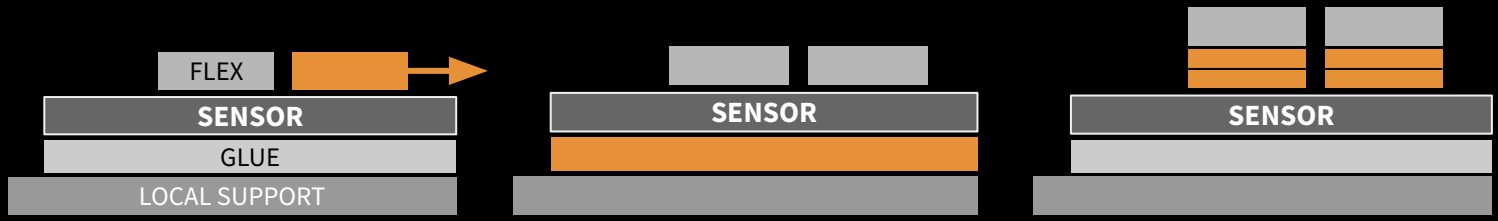
After module thermocycling | **After petal cycling** | **After stave thermocycling**



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



Beginner’s guide to sensor fracturing mitigations



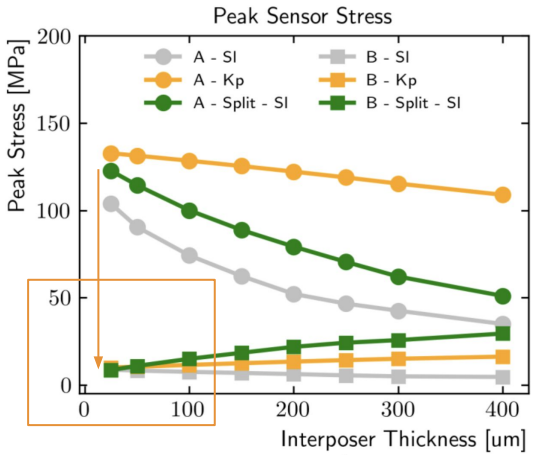
	Wide gap	*Hysol*	*Interposer*
Simulated stress reduction vs nominal	**–20%**	**–50%**	**–95%**
Mitigation strategy	**Relieve flex gap stress region**	**Stiffer glue for sensor to local support**	**Soft silicone alleviates thermal stress**
Benefits	Modest tooling change	Loading change less schedule delay	Large headroom & solves cold noise
Downsides	Only viable for half the modules	Glue pattern tuned, cannot unload	Major redesign & prototyping program
Testing outcome	Hysol stave side sees no cracks	Cracks seen on staves & petal	✅ **Now adopted as production baseline**

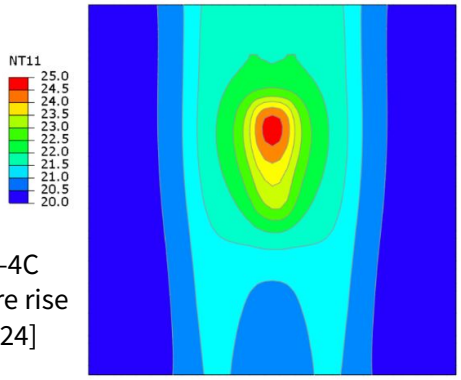
Diez Cornell ATL-ITK-SLIDE-2024-115, Tishelman-Charny PoS 478 (2024)

Interposer: simulation → prototyping → production arrays

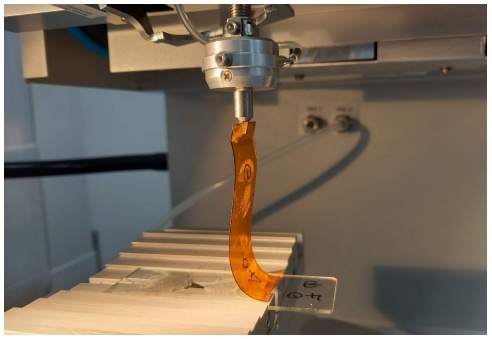
Concept & simulation | **Single prototypes** | **Production arrays**

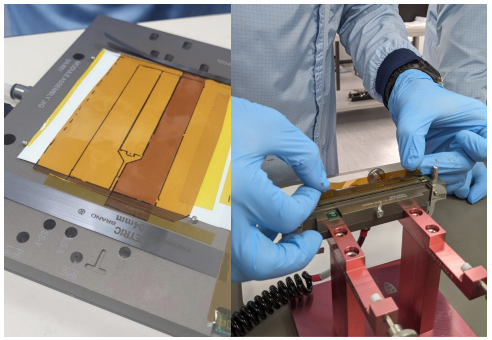
- Flexible printed circuit board
- **100 µm silicone (SE-4445)** — NEW
- **50 µm Kapton interposer** — NEW
- Epoxy glue (Henkel F112)
- Sensor

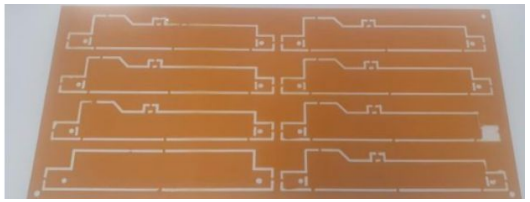


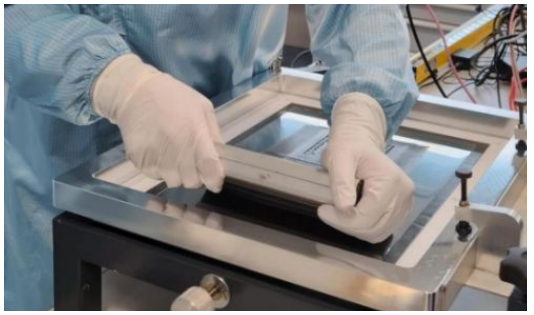


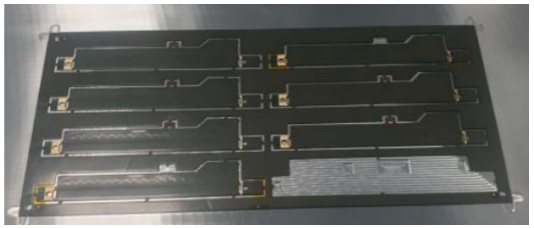
✅ OK 3–4C temperature rise [Beck 2024]

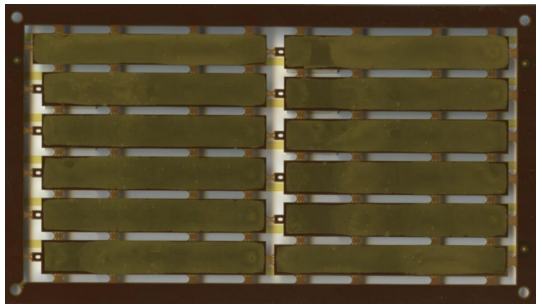








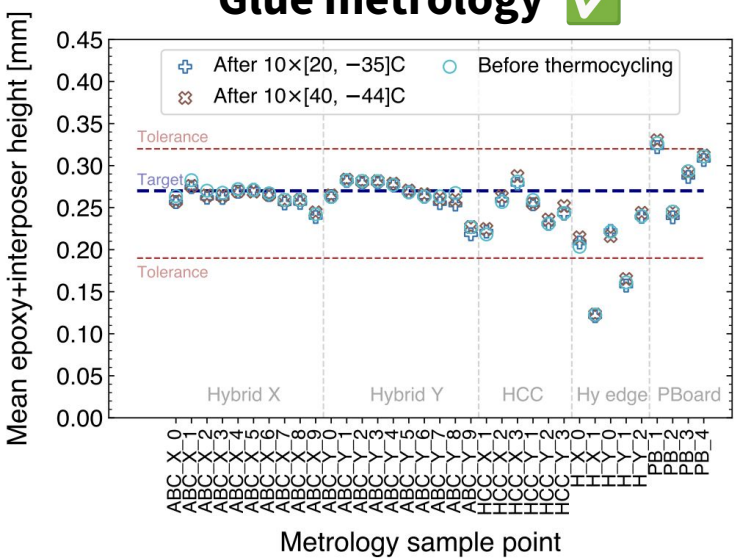




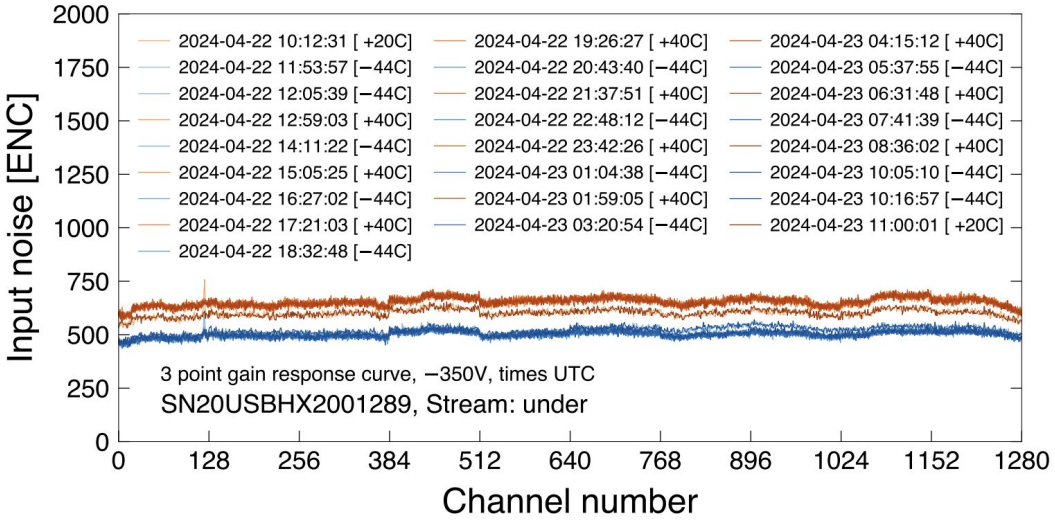
Vallone & Abidi (2024), Fortman ATL-ITK-PROC-2025-009

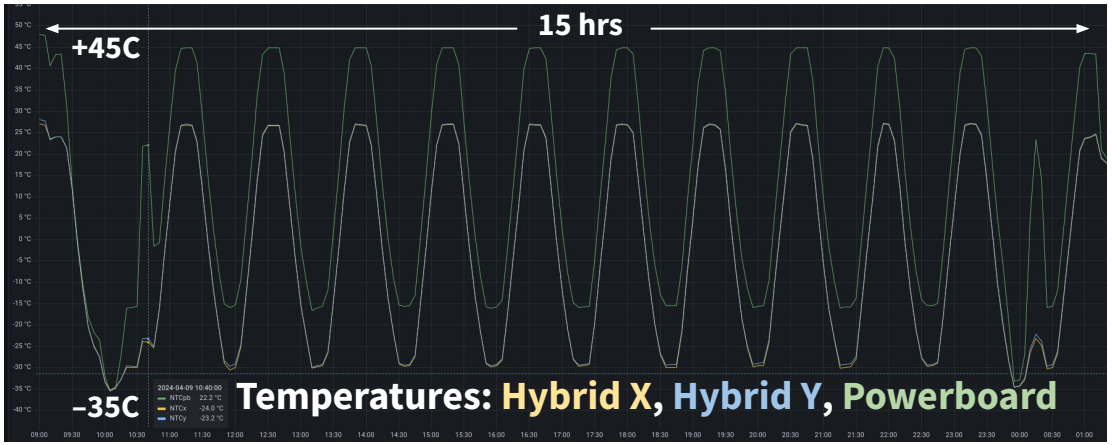
First interposer module: viable quality control

Glue metrology ✅

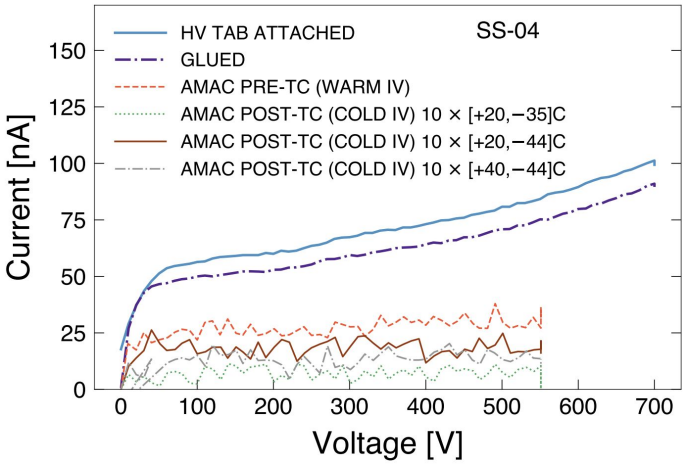


Readout noise ✅





Thermocycling stability ✅



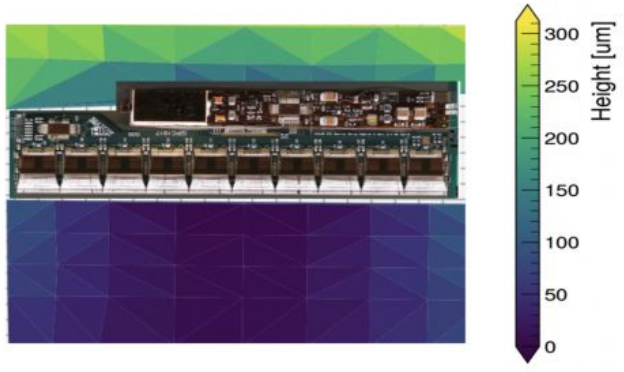
High voltage ✅

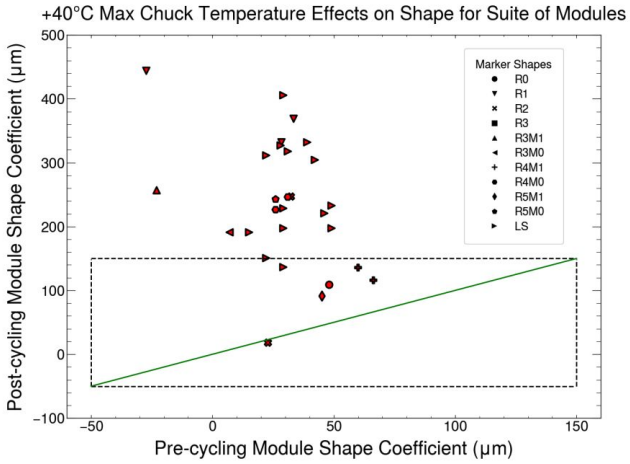
Fomin, Hommels, Ivison, Kariyapperuma, JL *In Preparation*

Interposers mitigate module-level thermal stress

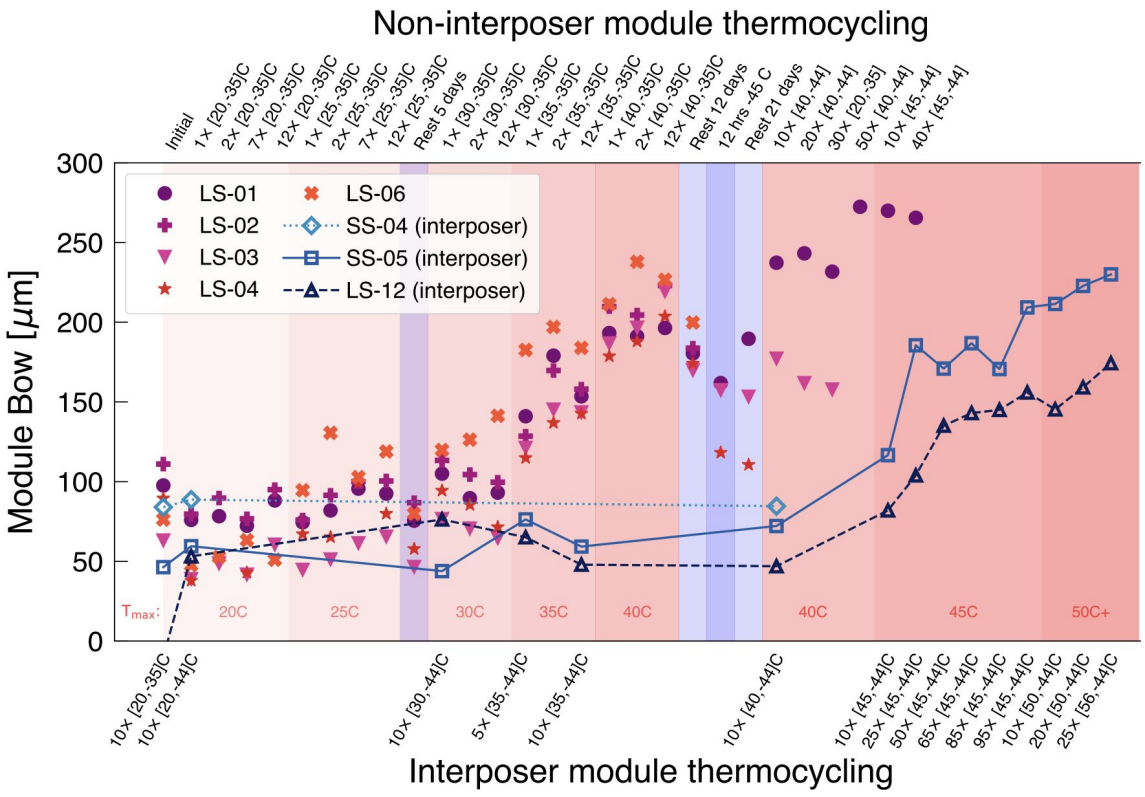
No interposer 😕
Significant sensor deformation

Compare with interposers ✅
Reduced sensor deformation





Salemi, Poley et al 2503.03133



Fomin, Hommels, Ivison, Kariyapperuma, JL *In Preparation*

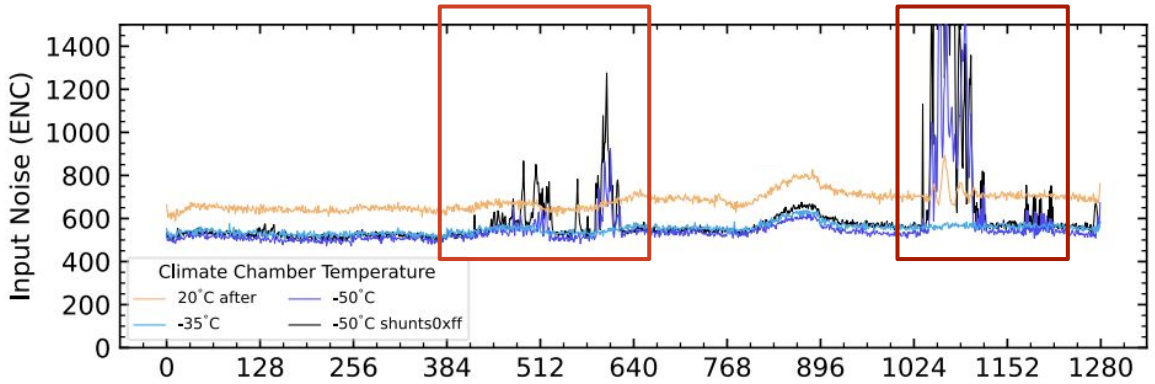
↑ Epoxy glass transition T_g ~ 50C 'bakes in' thermal stress in sensor deformation

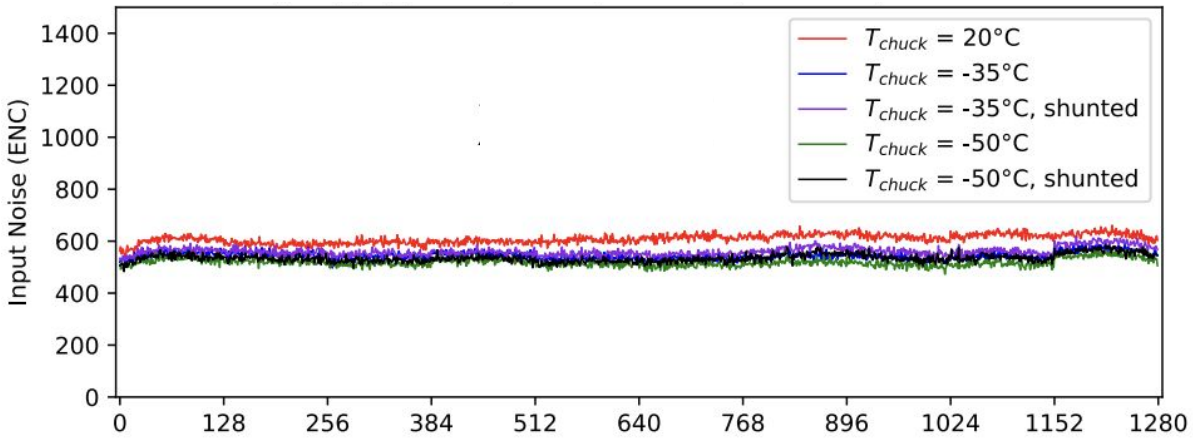
Carbas et al The Journal of Adhesion 90 (2014) 104

Bonus: interposers solve ‘cold noise’ problem

OLD 😕
No interposers: cold noise problem
→ Excess ‘mountain peaks’ localised noise ≤ –35C vs +20C in short strip modules

NEW ✅
With interposers: cold noise solution →
No ‘mountain peaks’ even with cold noise enhancing (‘False Blue’) glue

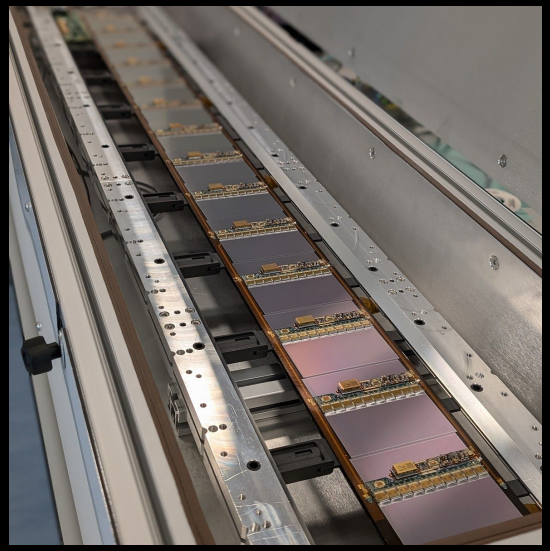




Cold noise originates from 2 MHz powerboard capacitor vibrations
Soft glue (SE-4445) absorbs vibrations, mitigates readout coupling

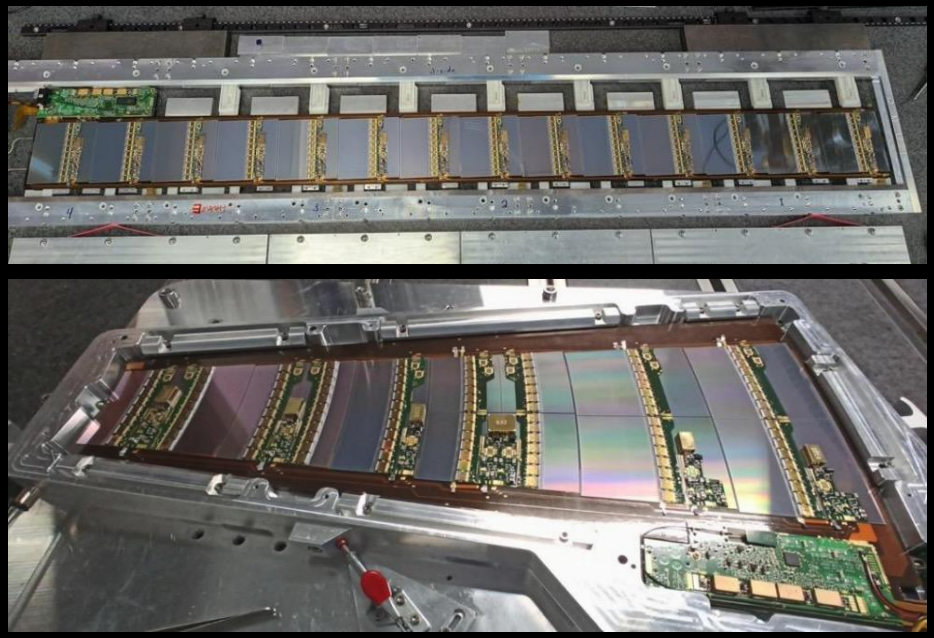
Dickes & Kurth JINST 19 (2024) C04058

Path to production: prototypes to –70C → pre-series to –45C

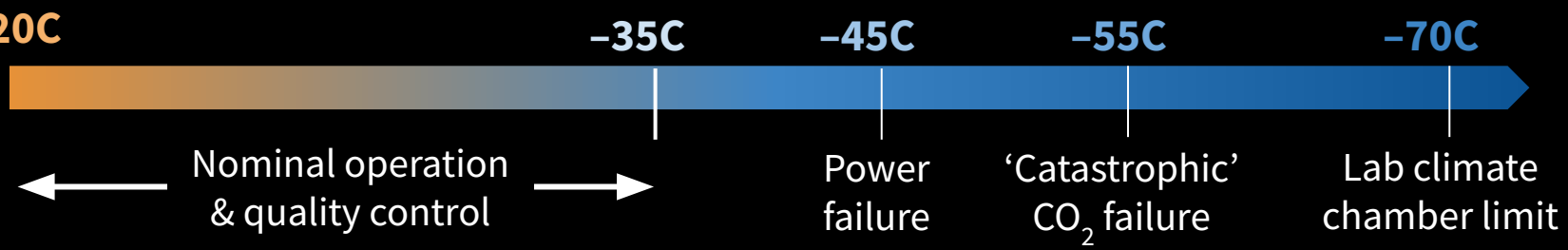


↑ **First prototype interposer half-stave**

No fractures after 5 cycles to ultra cold:
–35C, –45C, –50C, –60C, –65C, –70C ✅



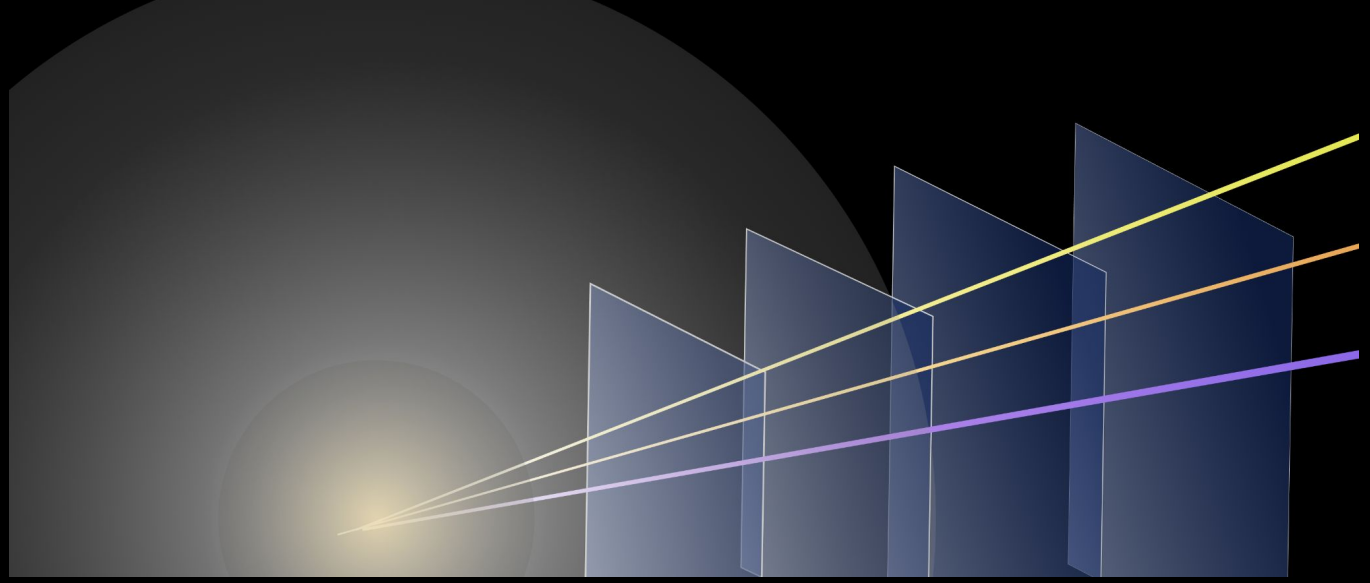
↑ **First complete pre-series petal and staves** ✅



Pre-series: installable with extended QC down to 5× –45C cycling

Ramping up assembly: finished first 3 pre-series staves & 1 petal

Tishelman-Charny, D'Amen, Dewhurst, Solaz Contell et al *In Preparation*



SUMMARY

Overview & progress highlights

Sensors, chips, mechanics, services in production

Global support structures now at integration sites

Challenge: sensor fracturing

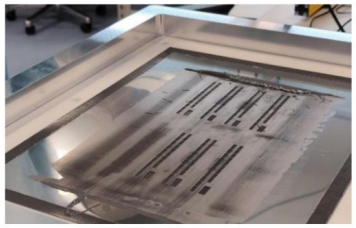
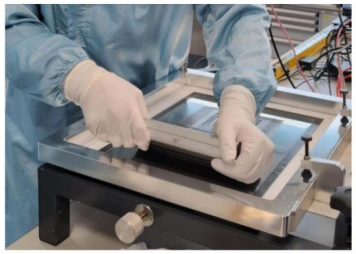
Extraordinary creativity solved major roadblock

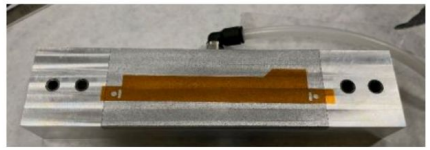
Interposers reopen path to pre-series & production

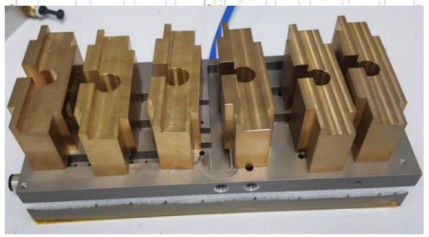
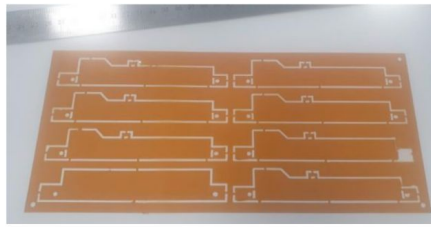
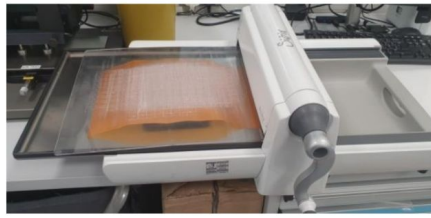
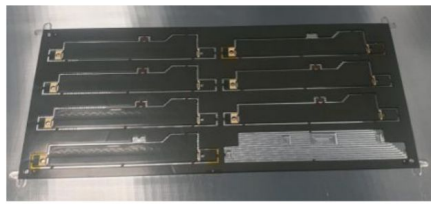
EXTRAS

Scalability challenge: N ≃ 4 → 40000 interposers





Major effort beyond original design: single-flex success → arrays for mass production

Interposing efforts: Barrel hybrids (Liverpool) & powerboards (Berkeley), Endcap hybrids (DESY+CERN) & powerboards (Freiburg)

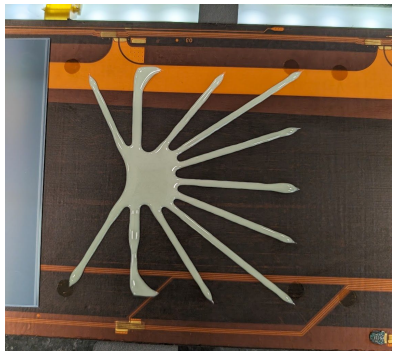
Single prototypes Q2 2024	Prototype staves Q3 2024	Production interposers Q3+Q4 2024	Pre-series Q1+2 2025	Production Late 2025+
Single flexes Prototype modules Array R&D	Prototype interposer staves Finalise arrays	Pre-production demonstrators Multiple staves & petals	Pre-series: slow ramp up to production Pre-production like statistics Test scalability with 10+ staves & petals	

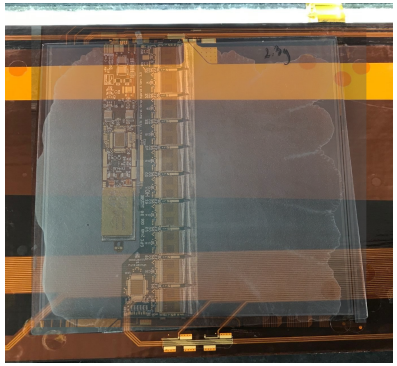
Fortman et al *In Preparation*

Hysol mitigation: tour-de-force testing (not adopted)

Hysol glue pattern

Hysol glue uk.rs-online.com





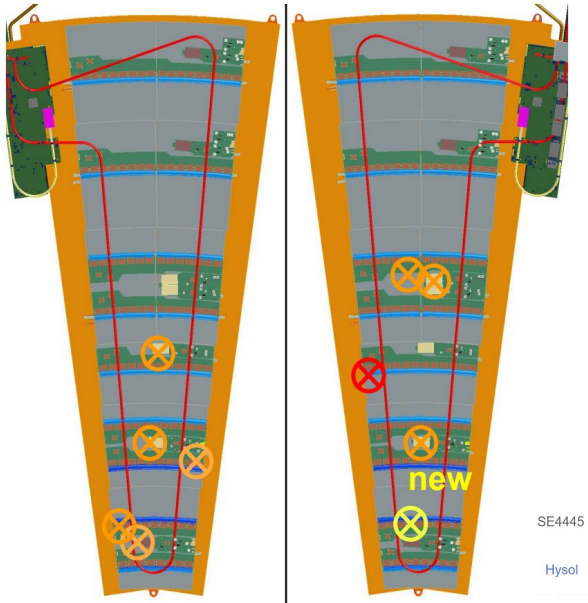
↑ Optimise ‘starburst’ pattern

Hysol petal

Vancouver petal

5x –45C → 5x –55C → 1x –60C

↓ **Crack Suspected / Observed**



Secondary **Main side**

Hysol staves

→ Brookhaven

50:50

Nominal:wide gap. Down to –45C. No wide gap cracks

↓ Rutherford Appleton Lab

50:50

Hysol:SE4445

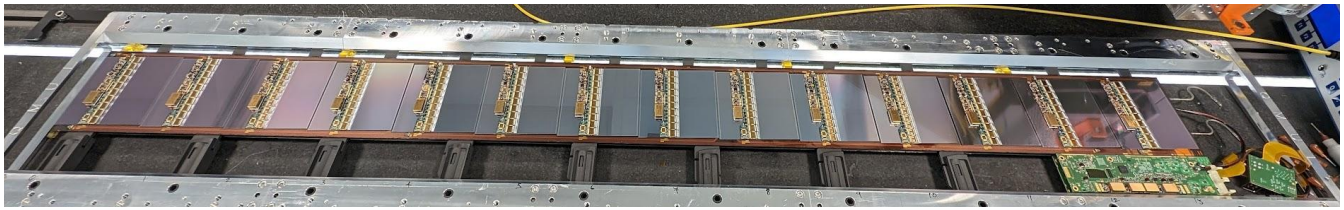
Down to –50C

Thermal cycle number	Temperature	Status
1	Down to -38.5C	Early breakdown and noise in module 1 (J side)
2	-35C	No new suspected cracks
3	-35C	No new suspected cracks
4	-35C	No new suspected cracks
5	-35C	No new suspected cracks
6	-45C	No new suspected cracks
7	-45C	No new suspected cracks
8	-45C	No new suspected cracks
9	-45C	No new suspected cracks
10	-45C	No new suspected cracks
10-20	-45C	Early breakdown and noise in module 4 (J side) cold, not warm

SE4445	0	1	2	3	4	5	6	7	8	9	10	11	12	13
Hysol	0	1	2	3	4	5	6	7	8	9	10	11	12	13

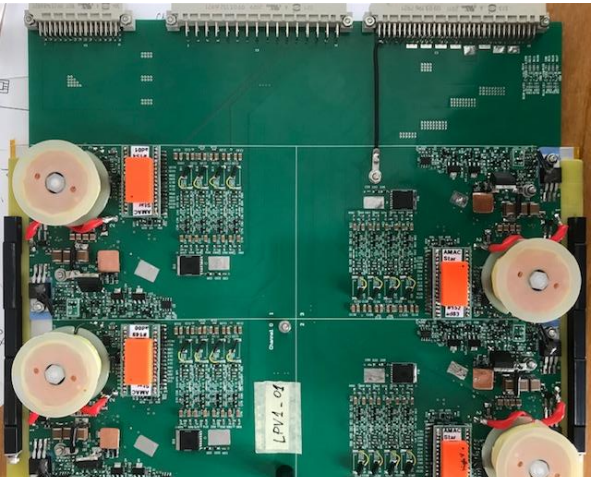
Suspected crack

Early breakdown from start of testing

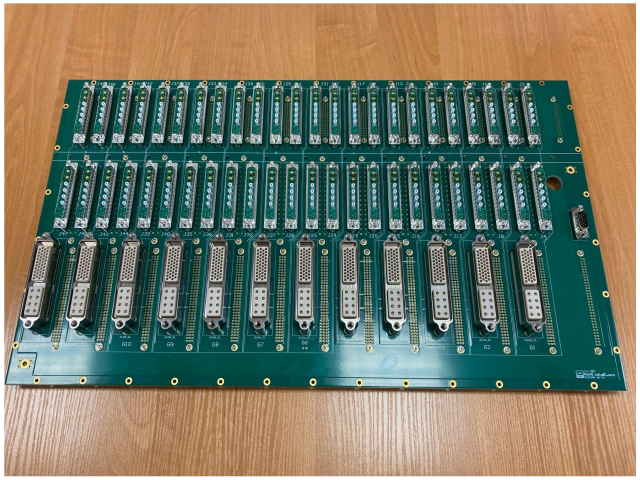


Services & power supplies: pre-production transition

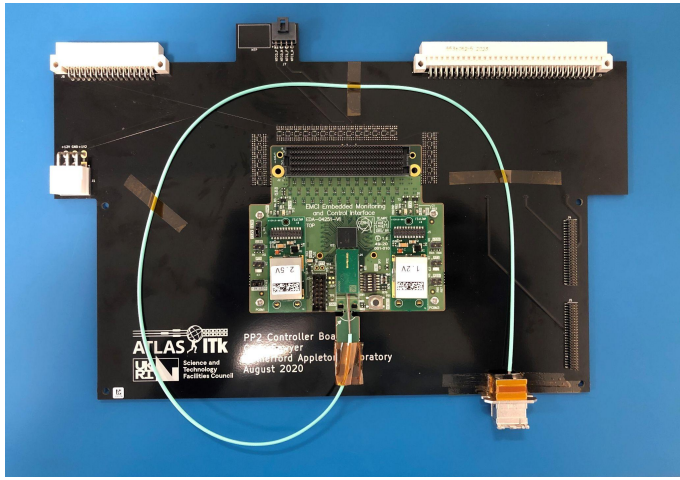
Voltage converters (DCDC)
Pre-production soon



Backplane boards
Testing pre-production



Crate converter boards
Release ready

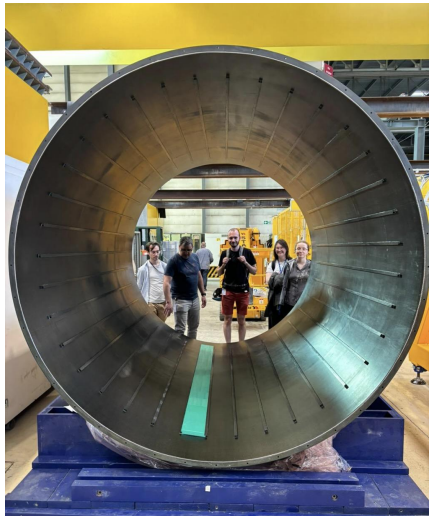


On-detector (Type 1) cables
Received at CERN

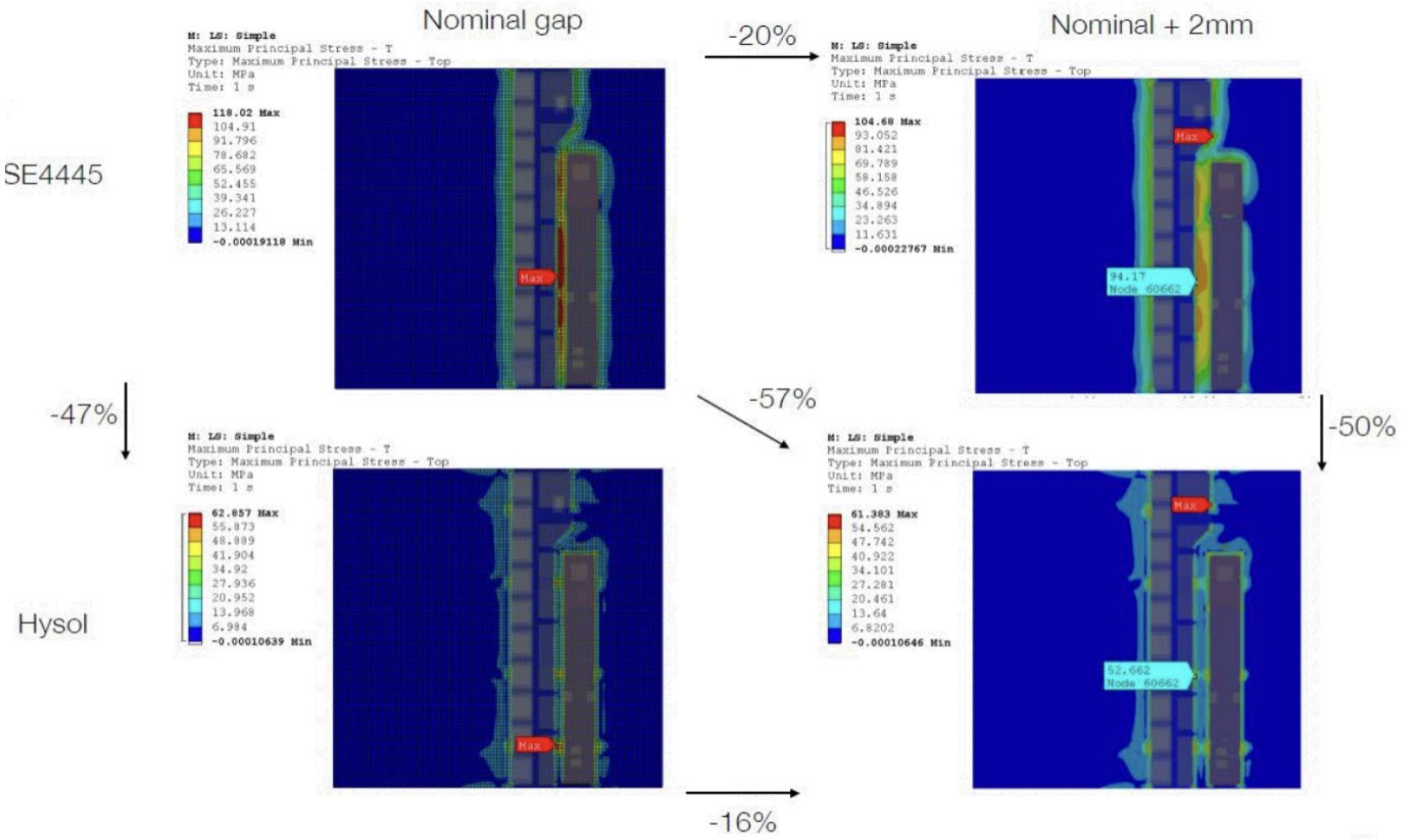
Detector Control System
Connectors ready

Patch Panel 3* prototyping
For integration | Connectors received

Initiatives empowering ITk Early Careers



Hysol + wide gap simulation



Giorgio Vallone, Haider Abidi, Eric Anderssen, Barnaby Matthews