University of Glasgow

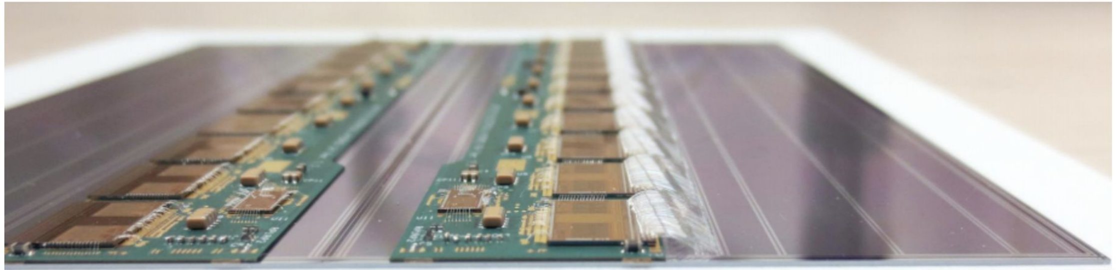
ATLAS ITk Strip Detector for the Phase-II LHC Upgrade

Andy Blue (University of Glasgow)

ATLAS ITk

Outline

- Overview
  - ATLAS Upgrade For HL-LHC
  - The Inner Tracker (ITk)
  - ITK Layout
- ITk Strips
  - Sensors
  - Electronics
  - Modules
  - Local Supports
  - Global Mechanics
- Looking ahead

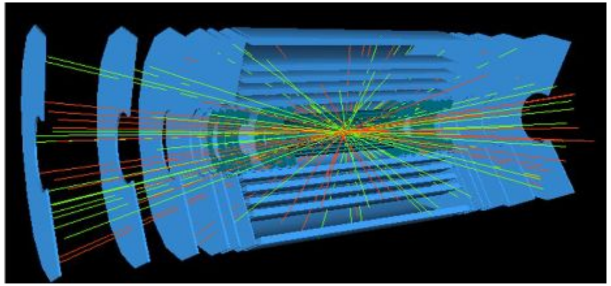


Fully Bonded Electrical Short Strip Barrel Module

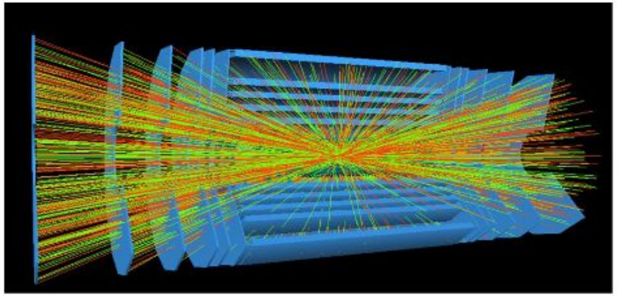
ATLAS Upgrade for HL-LHC

ATL-UPGRADE-PROC-2012-003

- An Upgrade of the Large Hadron Collider (LHC) to the High Luminosity-LHC foreseen in 2029
- Instantaneous luminosity of up to **$7.5 \times 10^{34} cm^{-2} s^{-1}$**
  - Triggering with high rate & increased event sizes
- Delivering an integrated luminosity of **$4000\ fb^{-1}$**
- Up to **200** simultaneous interactions per bunch crossing
  - Limit occupancy to 1%
- High particle fluences
  - Radiation hardness of up to **$1.3 \times 10^{16} neq/cm^2$** (Inner pixel layer) required
  - x1.5 Safety factor
- Low material budget
  - Reduction in scattering & fluences from secondary interactions



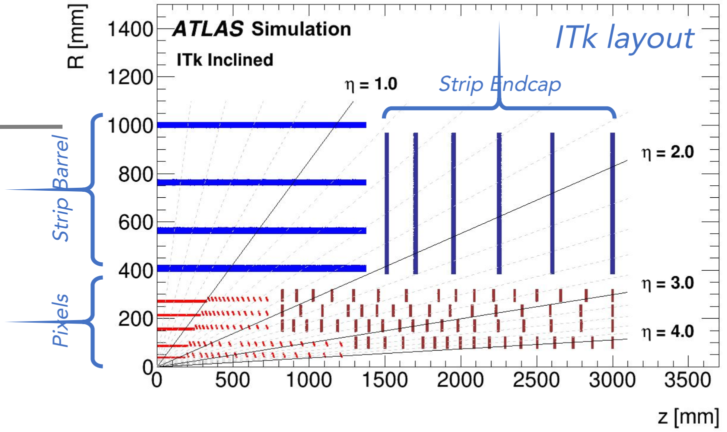
23 collisions per BC (LHC)



230 collisions per BC (HL-LHC)

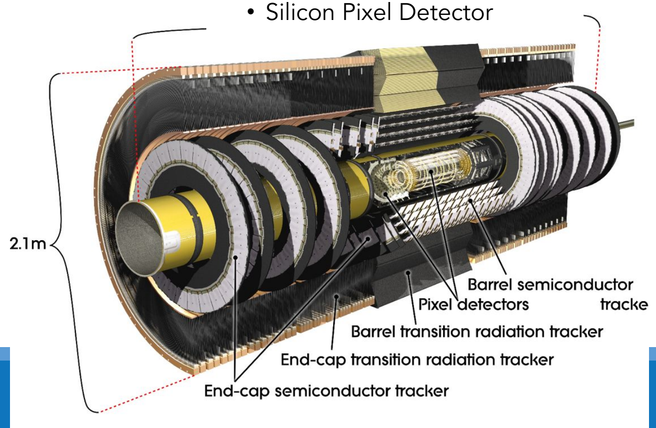
Inner Tracker System

- The new inner tracker (ITk) will be an all Si Tracker system
  - Will replace the current ID (Pixels, SCT + TRT)
  - 'All Silicon' -> no TRT
- 2T magnetic field, ~6m long, ~1m radius & up to $|\eta|=4$
- 5 Central and multiple Forward Pixel layers
- 4 Central and 6 Forward Strip layers



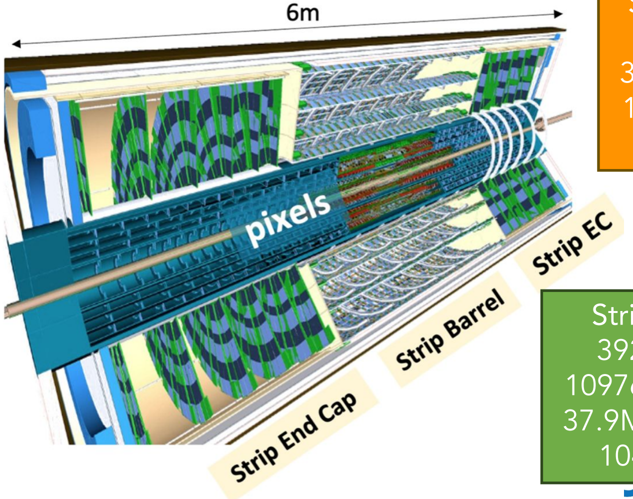
Current Inner Detector (ID)

3 technologies:
- Transition Radiation Detector
- Silicon Strip Detector
- Silicon Pixel Detector



Inner Tracker – data taking in 2029

Full silicon tracker

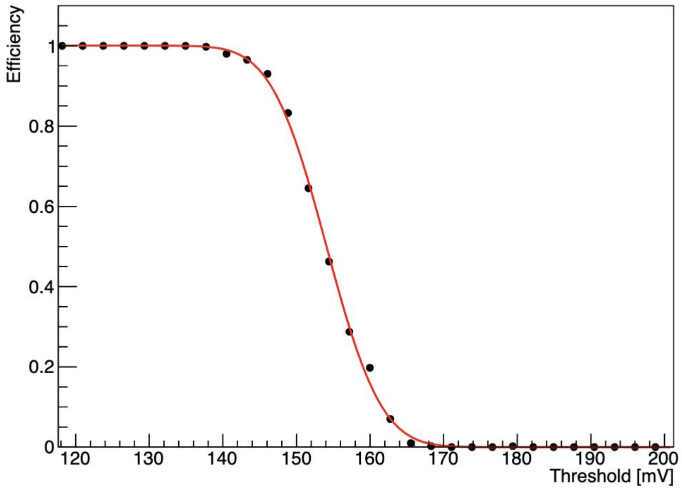


Strip Endcap
192 petals
3456 modules
11M channels
30.2 m^2

Strip Barrel
392 staves
10976 modules
37.9M channels
104.86 m^2

ITK Strips - A Binary Detector

- As Strips has binary readout, the basis for the characterisation is the **threshold scan.**
- Allows the measurement of important figures of merit to evaluate the chip performance, such as **input** and **output noise**, and **gain**.
- Performed by injecting a constant charge and varying the threshold value of the discriminator from zero to its maximum.
- At each threshold level several charge injections are performed. Plotting the measured average hit rate versus threshold gives a plot known as an **S-curve**.
- The value with a 50% hit rate corresponds to the median of the injected charge and it is called **"Vt50".**
- The S-curve is the integral of a Landau convoluted Gauss function. This curve is fitted with a skewed error function which determines the **output noise** in **mV**.



$$\mathrm{ENC} = \frac{\sigma[\mathrm{mV}]}{\mathrm{gain}[\mathrm{mV/fC}]}$$

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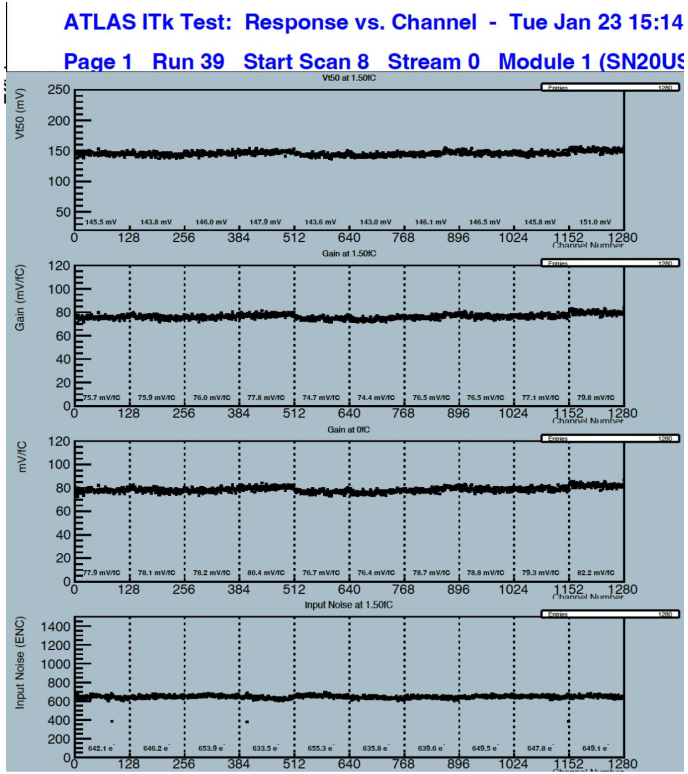
- By measuring the **Vt50** and **sigma** of the distribution for different input charges, the **gain** and **input noise** can be calculated



ITk Strips - Work Breakdown (WBS) Structure

The ITk was formed as **new detector,** and not as an upgrade to the current ID

ITk is made up of

- Pixels
- Strips
- Common Mechanics
- Common Electronics
- General (DB, S/W, Offline)

Strips, like the full project, was split into a **WBS** (Work Breakdown Structure)

2.1 - Sensors

2.2 - ASICs

2.3 - Modules

2.4 - Local support electronics

2.5 - Endcap local supports

2.6 - Module loading

2.7 - Global mechanics

2.8 - Services

2.9 - Integration

2.10 - Power supplies

2.11 - Irradiation and test beam

University of Glasgow

ITk Strips Organigram

Strip Management

- Project Leader: Craig Sawyer
- Deputy Project Leader: Sergio Diez Cornell
- Production Manager: Andrew Blue
- Project Engineer: George Iakovidis
- Resource Coordinator: Trevor Vickey

Strip Contacts

- **TDAQ Firmware**: **Matt Warren**
- DCS (hardware): George Iakovidis
- Database: Sven Wonsak
- ECR Contacts: Hannah Herde, TBC
- Offline Software: ?
- Risk: Dave Robinson

Strip Activity Coordinators

- Production Management: Theo Zorbas, **Chris Meyer**, ?
- Sensors: Vitaliy Fadeyev, Miguel Ullan, Nobu Unno
- Read-out Chips: Jaya John John, Paul Keener
- Irradiations & Test beam: John Keller, Lennart Huth
- Modules: Luise Poley, Cole Helling
- Local Support Electronics: Peter Goettlicher, Mogens Dam
- LS Cores and Tapes: Tony Weidberg, Carlos Lacasta
- LS Module Mounting: Debra Dewhurst, Carles Solaz Contell, **Gabriele D'Amen**
- Global Mechanics: Charles Evans, Marcel Vreeswijk
- Services: Pepe Bernabeu, ?
- Integration: Ingrid Gregor, David Robinson, George Iakovidis, Karolos Potamianos, Laura Franconi
- Power Supplies: Richard Brenner, Ewa Stanecka
- **Quality Control DAQ**: Peter Phillips, Dennis Sperlich, **Stefania Stucci**
- System Test: Dominique Trischuk, Jan-Hendrik Arling
- **Online DAQ**: **Dominique Trischuk**, **Paul Keener**
- **DCS**: **Alex Toldaiev**, **Karol Krizka**

Cluster Managers

UK/China	US	Valencia	DESY	Freiburg	Vancouver
B Hommels/X Shi	T Affolder/C Meyer	C Solaz Contell	C Scharf/C Sander	M Baselga	A Rajagopalan/L Veloce

ATLAS ITk

ITK Strips in production

- The ITk-strips production takes place in ~60 institutes in 14 countries in Europe, Asia, America and Oceania.
- Organised in 6 production clusters
  - 2 Barrel: UK-China and US.
  - 4 End-cap: Canada, Germany1+Australia, Germany2, Spain+Czekia+Scandinavia.
  - Organised around petal/stave assembly sites.
  - Central activities outside the clusters structure.

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UK- Strips

The UK will be responsible for **40% of the Barrel**

- 10% China
- 50% US

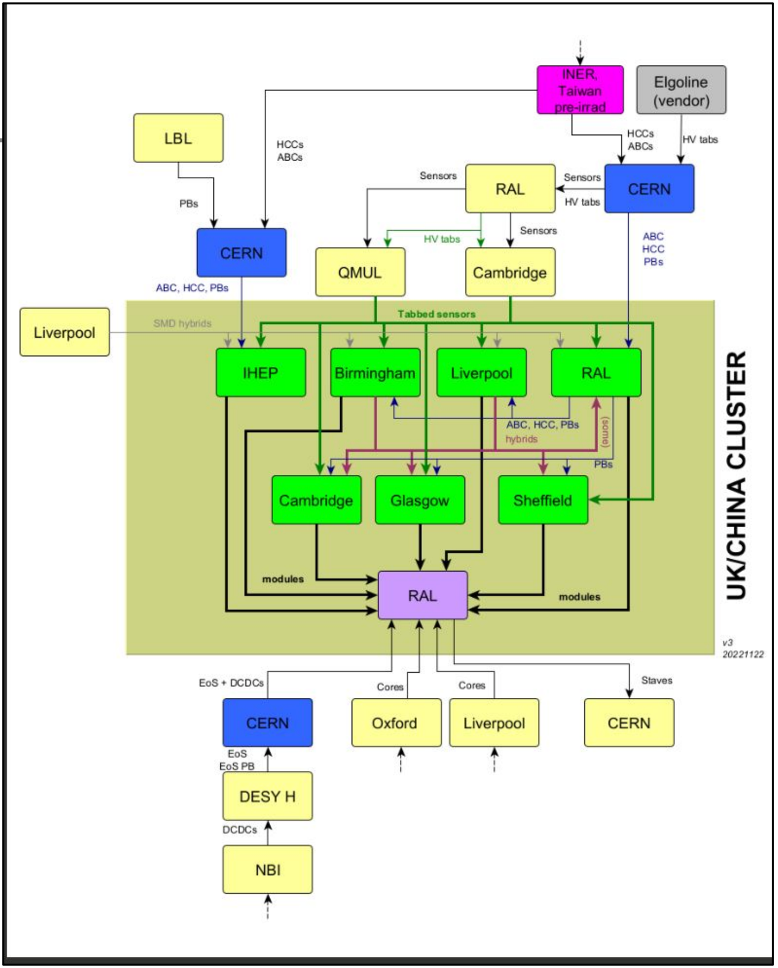
~6000 Modules

- ASIC probing
- Sensor probing
- Hybrid Assembly
- Module Assembly

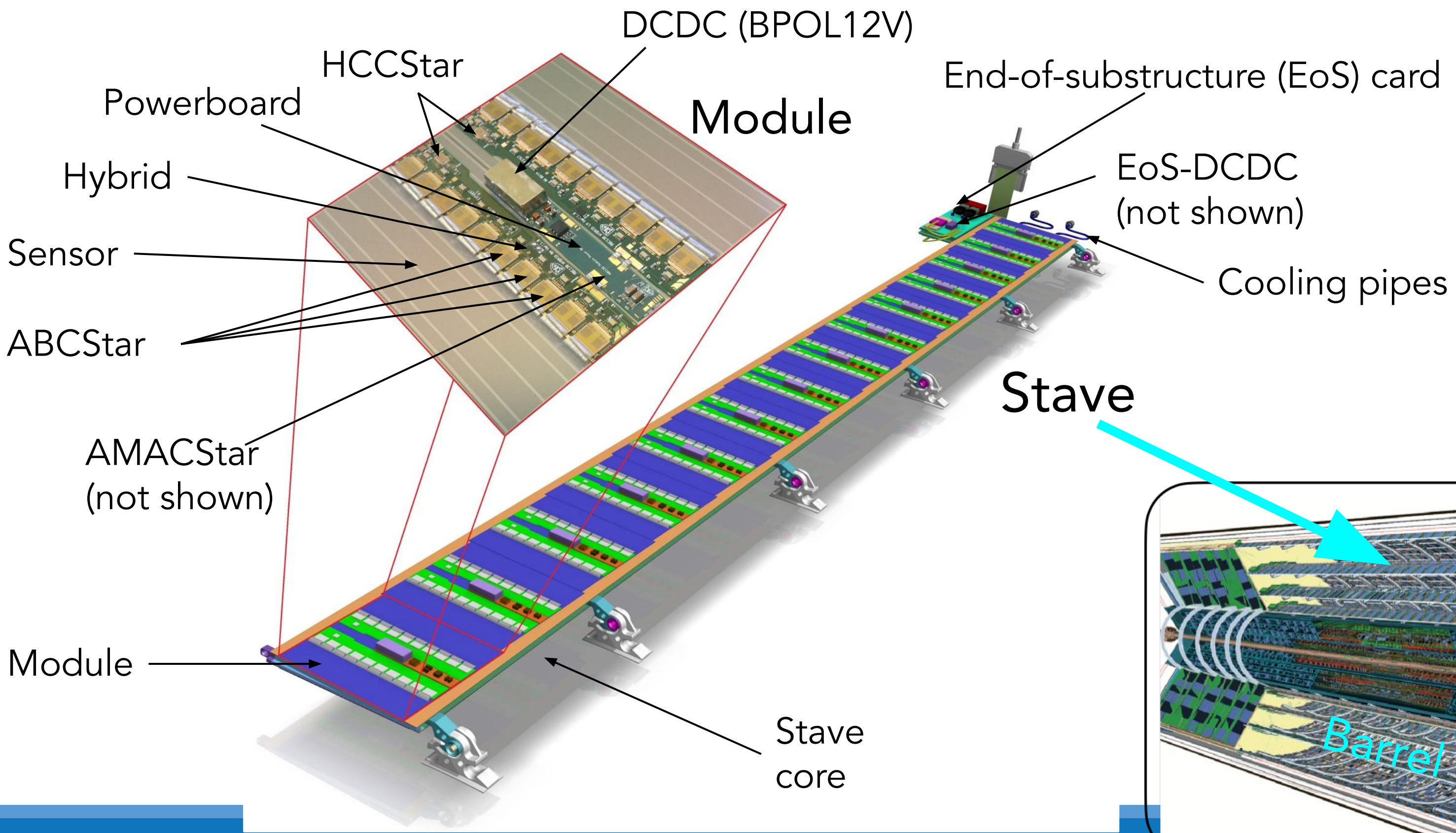
On ~240 Staves, with services

- Piping, cooling, electrical connections etc.

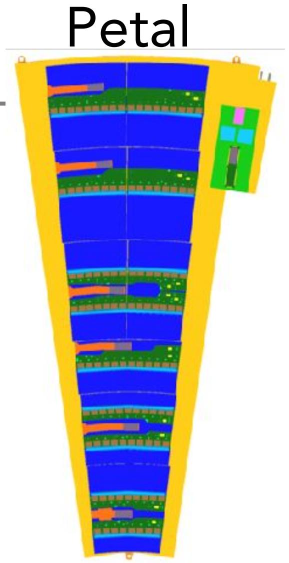
Also performing **Quality Assurance** (QA) procedures like irradiations, sensor diode testing, testbeam effort…

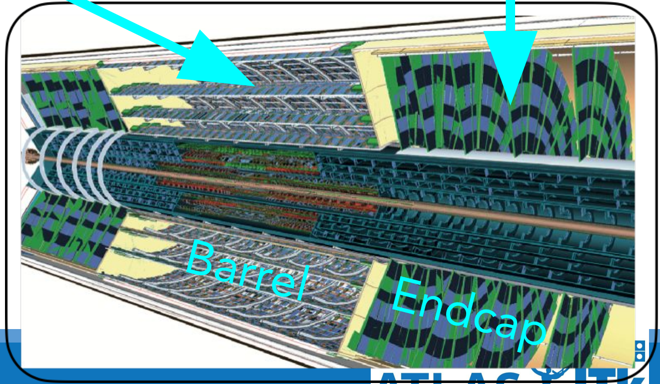


ITk Strip assembly overview



Stave

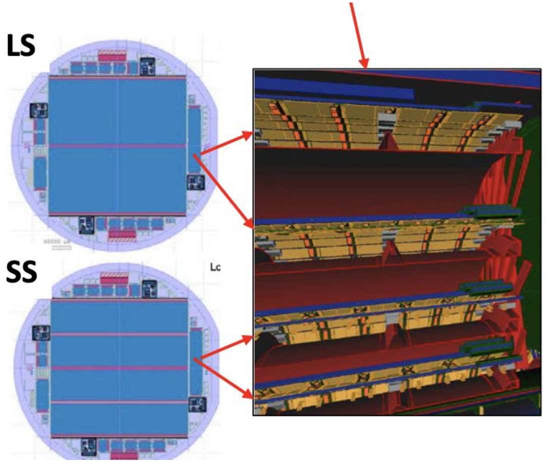


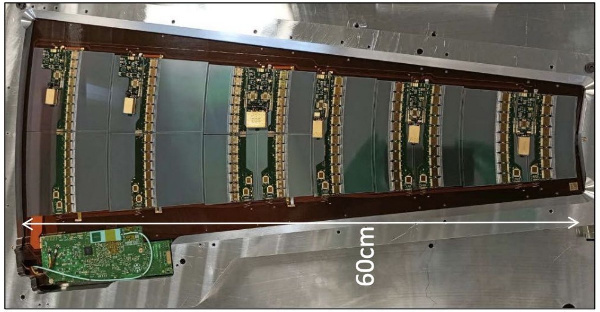


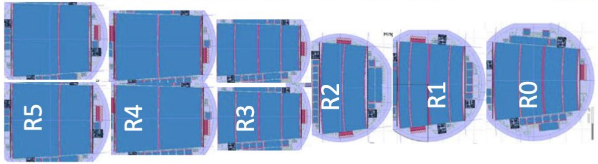
ITK Strip Sensors

- Silicon used by ITK strips are 320μm thick n-in-p float zone Si sensors
- n-in-p sensors allow for
  - Improved tolerance against radiation damage (no p-bulk type conversion)
  - Collection of electrons (fast charge carriers)
  - Single sided processing (easier processing, handling and cost)

- The Central region (**Barrel**) has 1 sensor shape with 74.5um strip pitch, and with strip lengths of
  - 23.9mm (Short Strip)
  - 47.75mm (Long Strip)
- The Forward regions (**Endcap**) has 6 sensor shapes with strip lengths from 8.1 mm to 49.9 mm

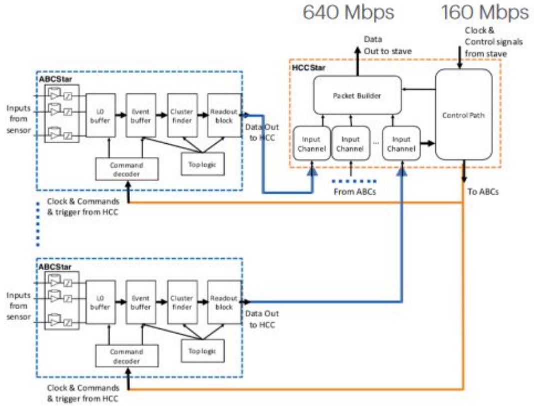






ITK Strip ASICs

- ASICs for readout and control
  - Based on 130 nm CMOS technology
- One chipset for all types of modules
  - The Star architecture: point-to-point connections between each ABC and HCC
- Hosted on low-mass flexible PCBs called a **hybrid**
  - 2 types for barrels
  - 13 types for end-caps

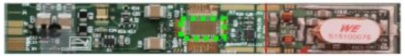


- **ABCStar**: ATLAS Binary Chip
  - Read analog signals from sensors and provide a binary readout per strip
  - Encode hit patterns in clusters

Y barrel hybrid

- **HCCStar**: Hybrid Control Chip
  - Aggregate and send out data packets from ABCStars
  - Send clock and control signals to ABCStars

- **AMACStar**: Autonomous Monitor and Control Chip
  - Module control and monitoring
  - Hosted on the power board

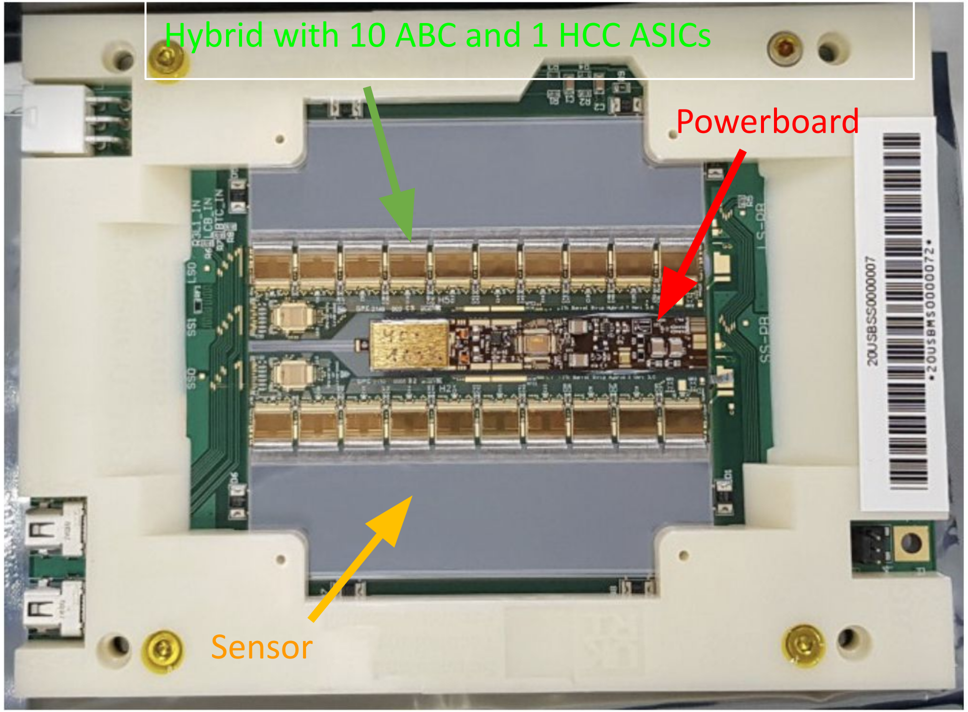


Barrel Power board

ITK Strip Modules

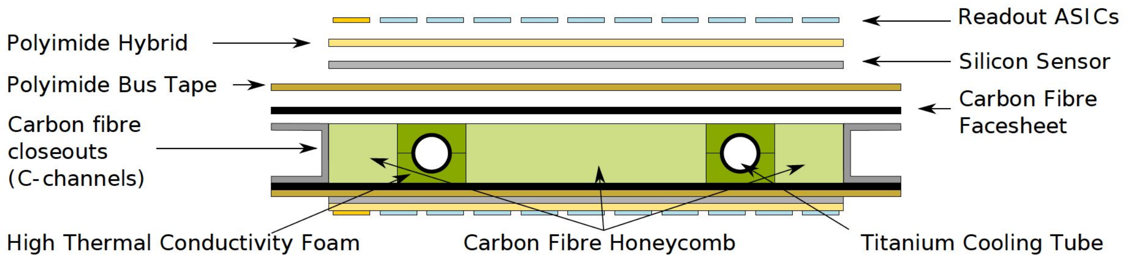
Silicon Modules consist of:

- Binary readout chips (ABCstar) and hybrid controller chips (HCCstar)
  - Glued & wire bonded to a hybrid
  - Data transfer on hybrid at 640 Mbit/s
- Hybrids are glued to the surface of the Si sensor
  - Wire bonds connect FE ASIC channels to Si strips
  - **~5200** wire bonds /module
- **DC-DC powering** via a powerboard allows powering of modules
  - Unlike SCT each module cannot have own Voltage Cable



ITK Strip Local Supports

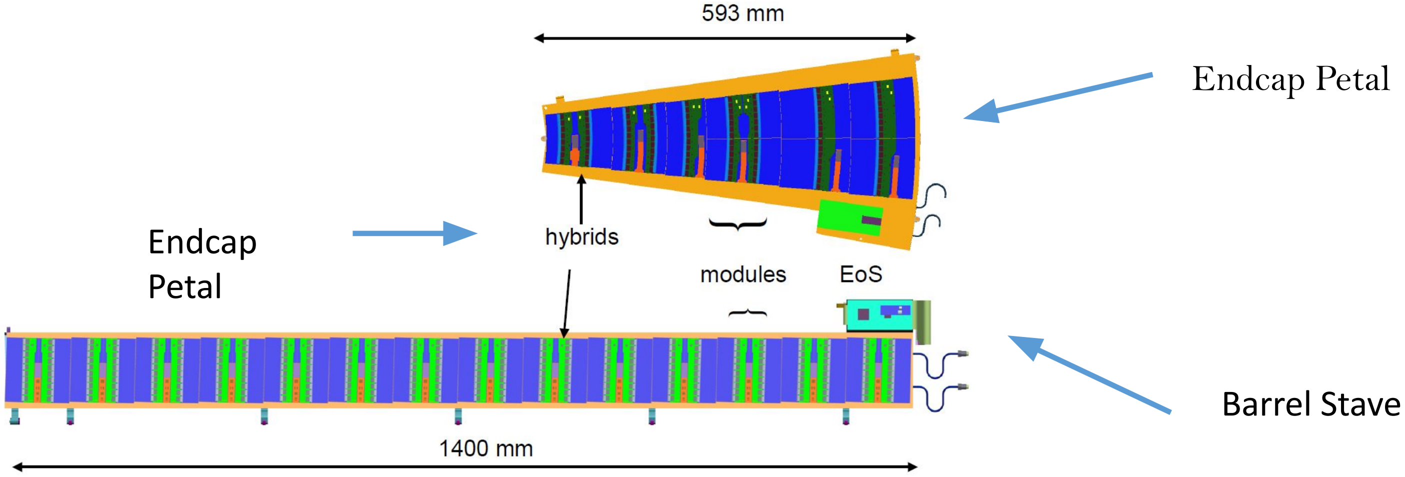
- Staves (Barrel) and Petals (Endcap) provide mechanical, geometric, thermal and electrical support to modules:
  - **Mechanical and Geometric**: local supports interface to global support structures through a series of position locators and locking points
  - **Thermal**: titanium cooling tubes connected to CO_2 cooling system working with temperatures between +20C and - 40C
  - **Electrical**: electrical power (LV and HV), TTC (Timing, Trigger and and Control) data, DCS (Detector Control System) data and measured data transfer services required by the modules are carried by a copper/kapton bus tape mounted on both sides of structure and operated by EoS (End of Substructure) card



ITK Strip Local Supports

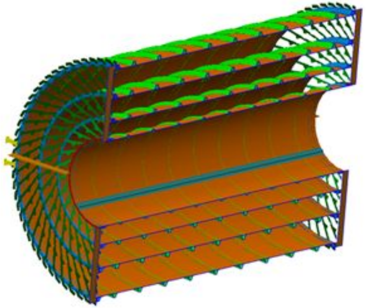
- 28 barrel modules on each stave (14 modules per side)
    - Short strips on inner two cylinders
    - Long Strips in outer two cylinders
- Modules on each side of the stave are rotated with respect to the beam line by a 26 mrad - total rotation of 52 mrad

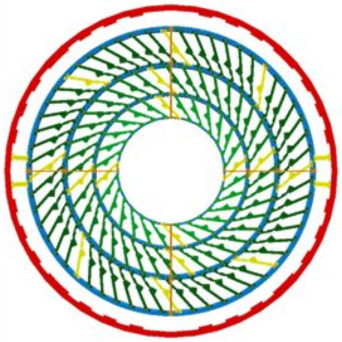
- 18 endcap modules on each petal (9 modules per side, rings R0 - R5), stereo angle of 20 mrad directly implemented in sensor geometry - total stereo angle of 40 mrad

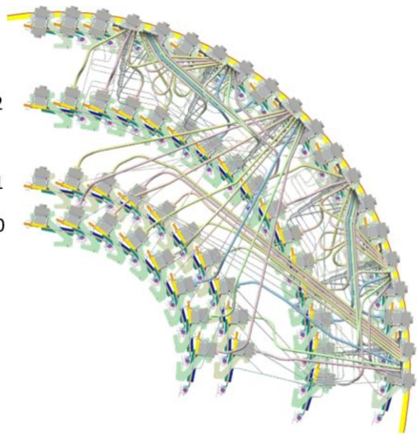


ITK Strip Global Mechanics

- 4 Layers of Staves in Strips System
- Cylinders are installed one by one into OC and populated as they are installed
- L3 (outermost) and next one in are installed, fully populated, serviced and tested
- L1 is installed, populated, serviced and tested
- L0/PST (Poxel Support Tube) is installed, populated, serviced and tested





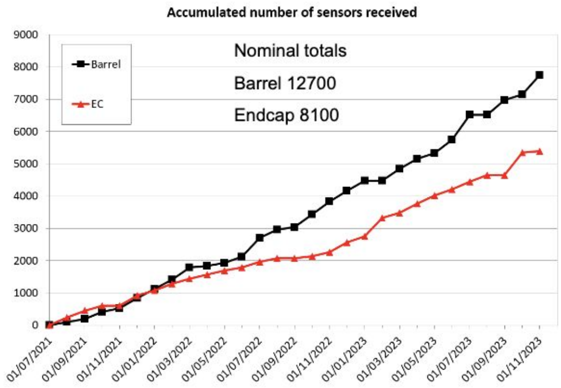


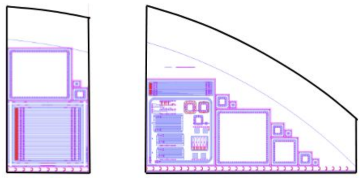
- Shells: 'Dressed' in UK, Installed in Outer Cylinder SR1/CERN
- Shell by Shell

Latest Results

Sensor Production

- Production in HPK (Hamamatsu) started Aug 2021:
- As of May 2024, **76.5%** of the total target received (63.3% accepted)
- However, the parts needed have **increased**
  - Re evaluation of the module yields
  - Use of production parts for R&F (see later slides)
- The last delivery for Barrel is likely in December 2025
  - Testing finished in April 2026.
- Active **QA campaign continues**. Irradiating and testing samples during production

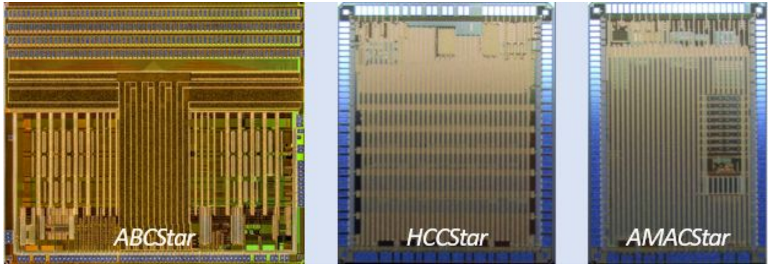




Mini&MD8 Testchip&MD8

ASICs Production

Triplication to mitigate **S**ingle **E**vent **E**ffects
Triplicating clocks, resets, logic blocks
Extensive tests and validations at test beams
Pre-irradiation to mitigate Total Ionizing Dose effect
"TID bump": increased leakage current at the beginning of data taking due to radiation



Manufacture → Probe → Dice → Pre-irradiate → Distribute

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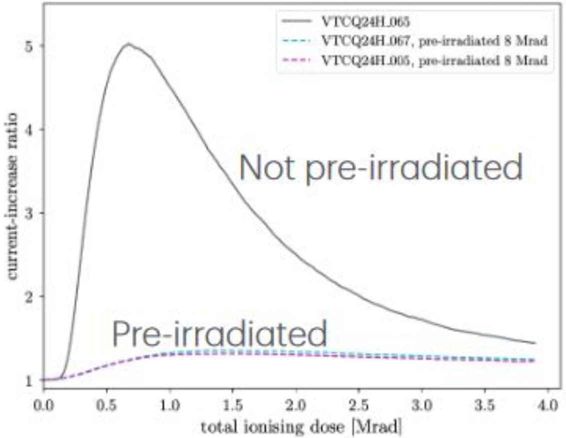
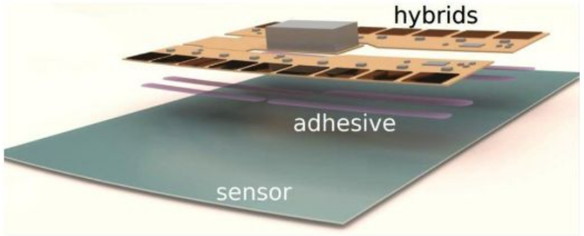
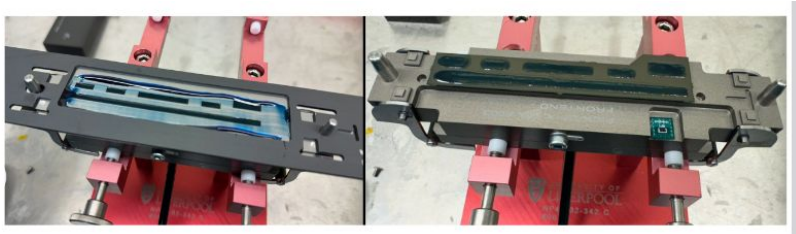


As of June 2024

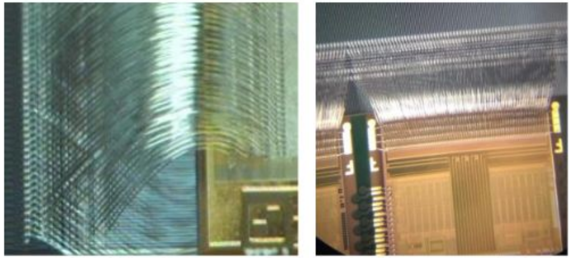
ASIC		Manufactured	Probed	Diced	Pre-Irradiated	Distributed
Overall	%	106.9%	97.6%	68.3%	62.2%	6.2%
ABCStar	%	101.4%	92.0%	59.7%	52.5%	4.7%
HCCStar	%	121.0%	107.0%	104.5%	104.5%	5.9%
AMACStar	%	166.7%	166.7%	143.9%	43.8%	28.6%
PP2 AMACStar (thinner die)	%	127.6%	127.6%	0%	Not applicable	0%

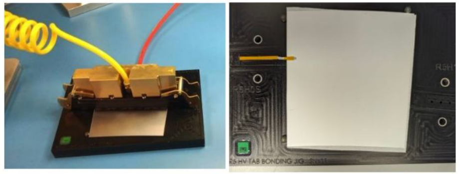
Module Production





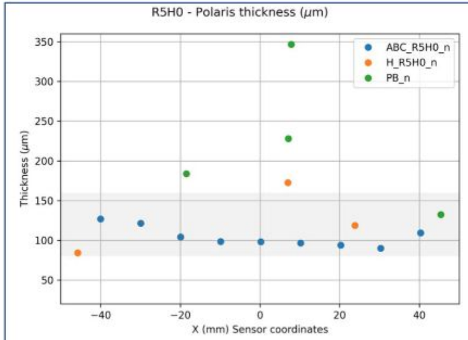
- Precision assembly (tens of μm accuracy) to
  - Guarantee good heat dissipation
  - Reduce stray capacitance between F-E and sensor
  - Avoid glue seepage on bias rings
- High precision custom tooling





- Electrical connections provided by wire-bonding
  - Each module around 1.5 m of wire.
- Sensors are tab-bonded on the back side for bias connection

Modules: QC

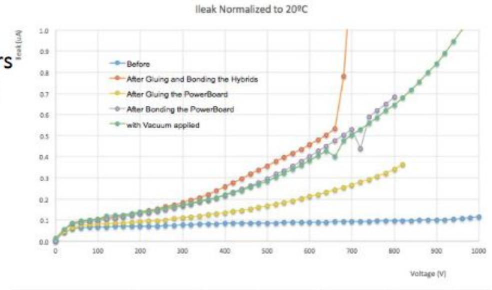


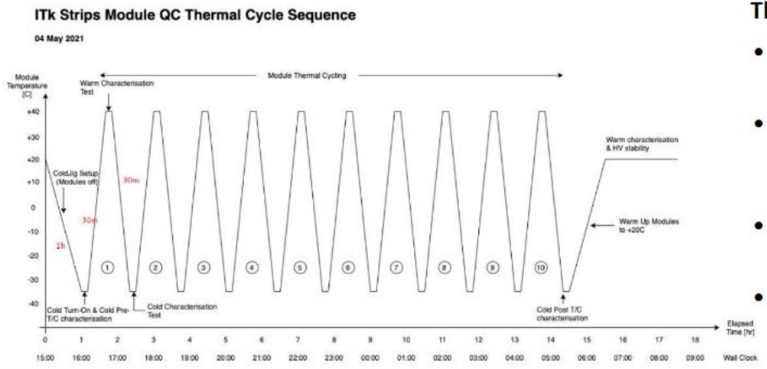
Metrology

- Ensure X,Y,Z precision of the assembly.
- Bow of sensor in specs

IV curves

- Measure IV of the sensors in the different stages of assembly
- Ensure there's no early breakdown



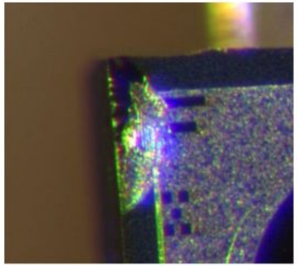


Thermal cycles

- Electrical tests with internal circuitry and biased sensor
- Prove that the electronics survive to changes of temperature
- Also prove they can operate at -35ºC (nominal working temp.)
- 10 cycles from 20ºC to -35ºC with electrical tests at each target temperature

Visual inspection and pictures

- After each step to catch damage and improve handling and procedures



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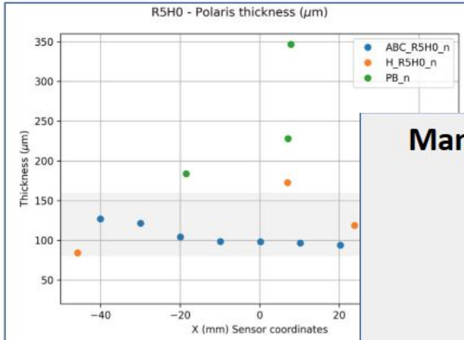
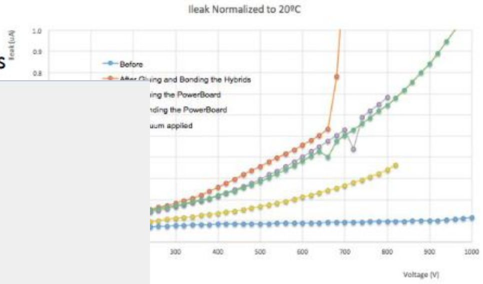


Metrology

- Ensure X,Y,Z precision of

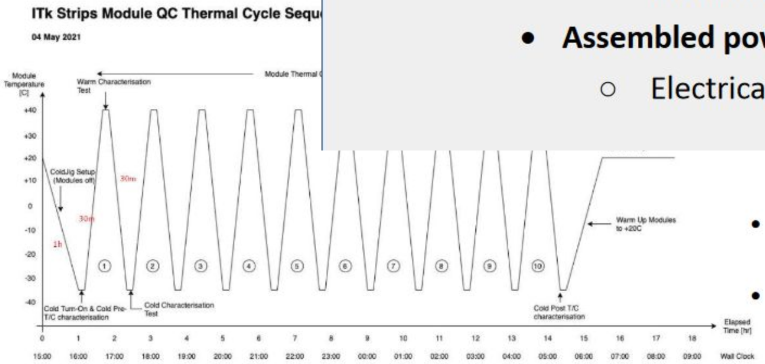
IV curves

- Measure IV of the sensors



Many more QC tests!

- **PCBs**
  - Visual inspection, pull-tests, delamination…
- **Assembled hybrids**
  - Electrical performance, burn-in…
- **Assembled power boards**
  - Electrical performance, thermal cycles…



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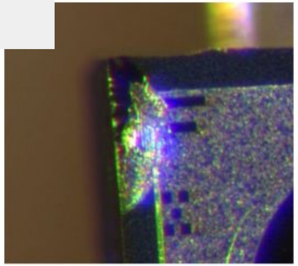

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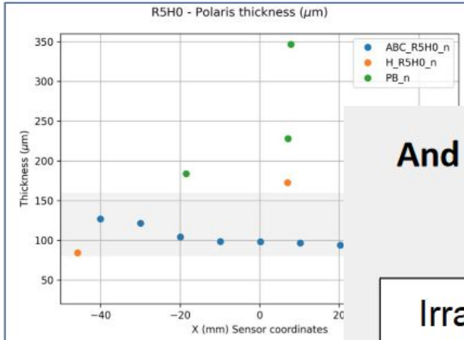

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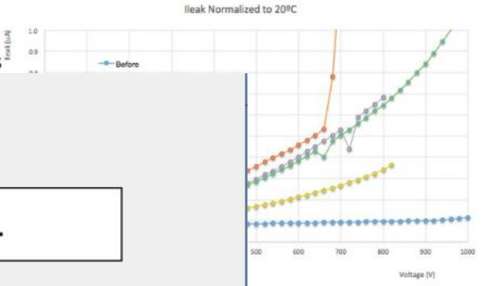
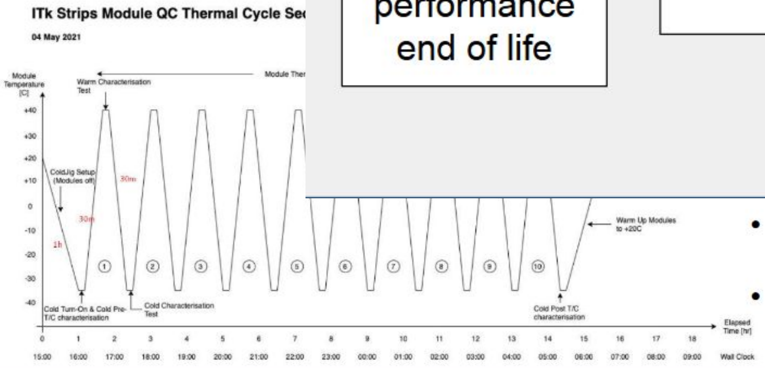
- Measure IV of the sensors

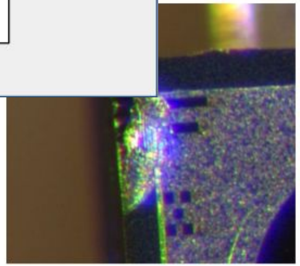




- Also prove they can operate at -35ºC (nominal working temp.)
- 10 cycles from 20ºC to -35ºC with electrical tests at each target temperature

d pictures

o catch damage and
g and procedures



And QA!

Test beams

...

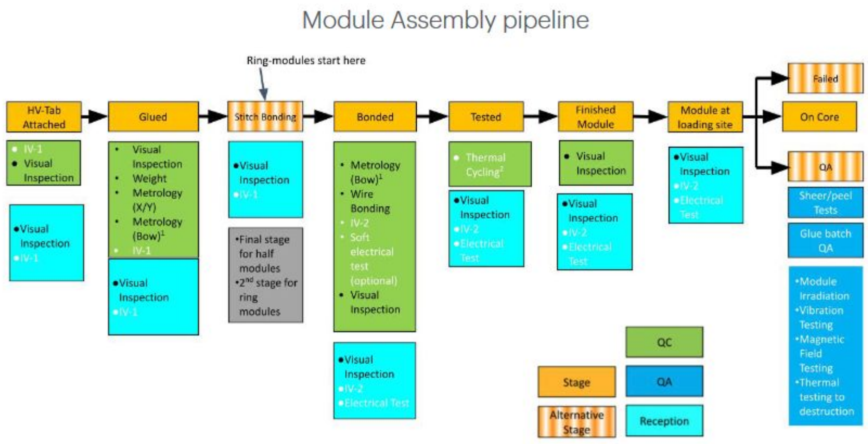
Irradiations: module's performance end of life

Long term thermo cycling

Long term testing

Module Production

- Streamlined production
  - Dedicated high-precision tools for different module types
  - Precision assembly: from sensor positioning to glue thickness
- Rigorous QC/QA procedures at every production stage
  - Visual inspections and metrology
  - IV curves
  - Thermal cycling
  - Hybrid burn-in test
- Towards full production
  - In 2023 nearly all (93%) module sites were now production ready
- Passed all reviews, so started pre-production
  - **And then….**



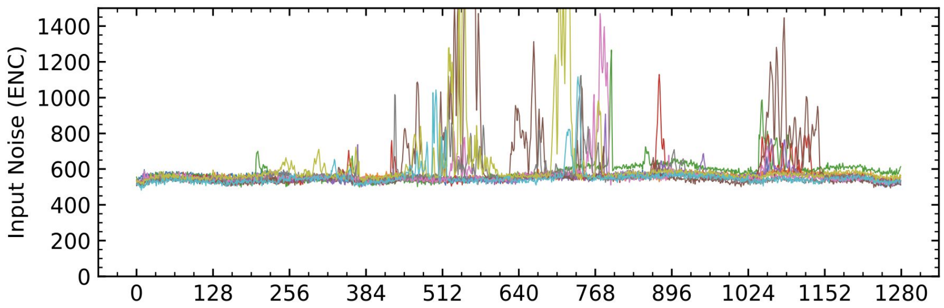
COLD NOISE

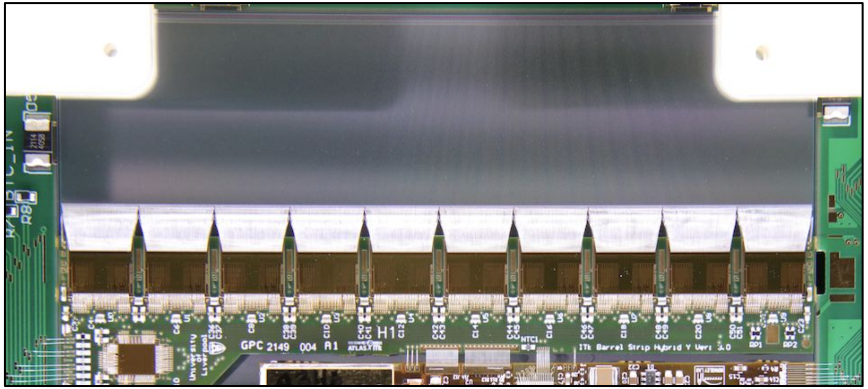
Cold Noise

Early Observations:

- Only appears on the strip rows under the hybrids & PB.

X Hybrid Stream 0 Input Noise at 1.50 fC





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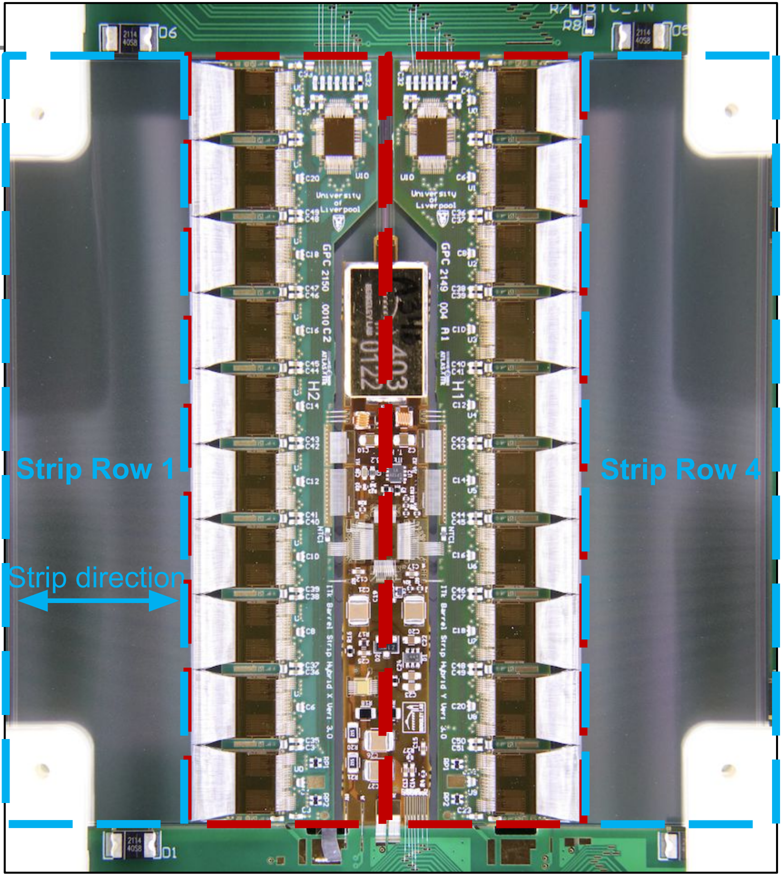

Short-strip module

Cold Noise Observations

Early Observations:

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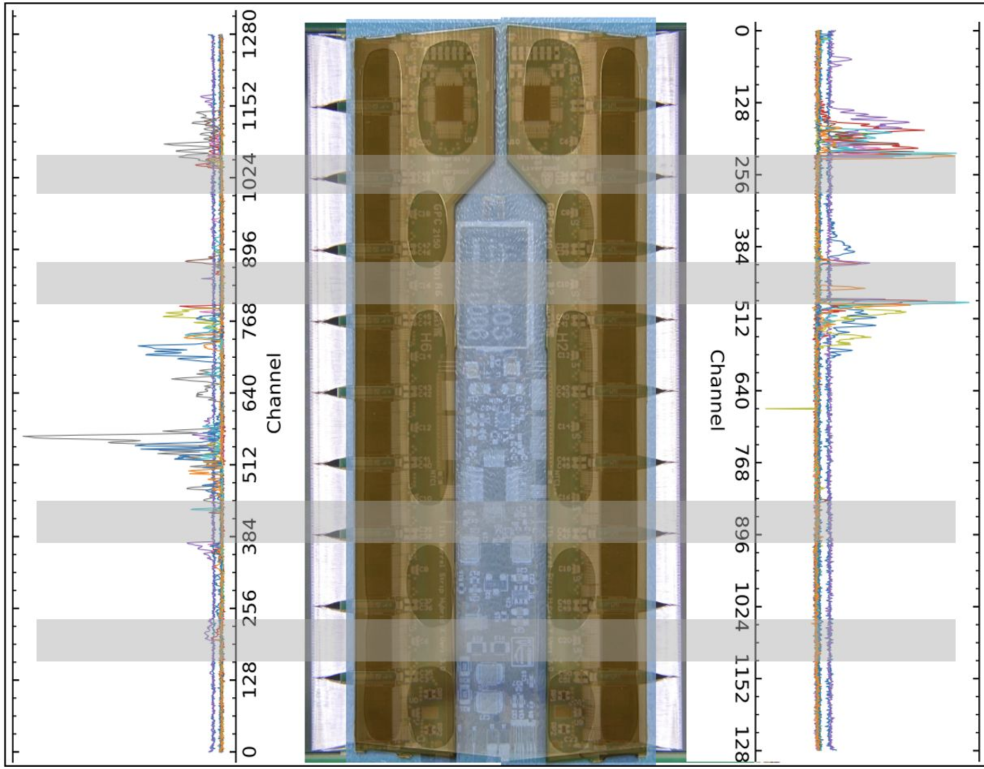
  - Correlated with glue under hybrids.



Short-strip module

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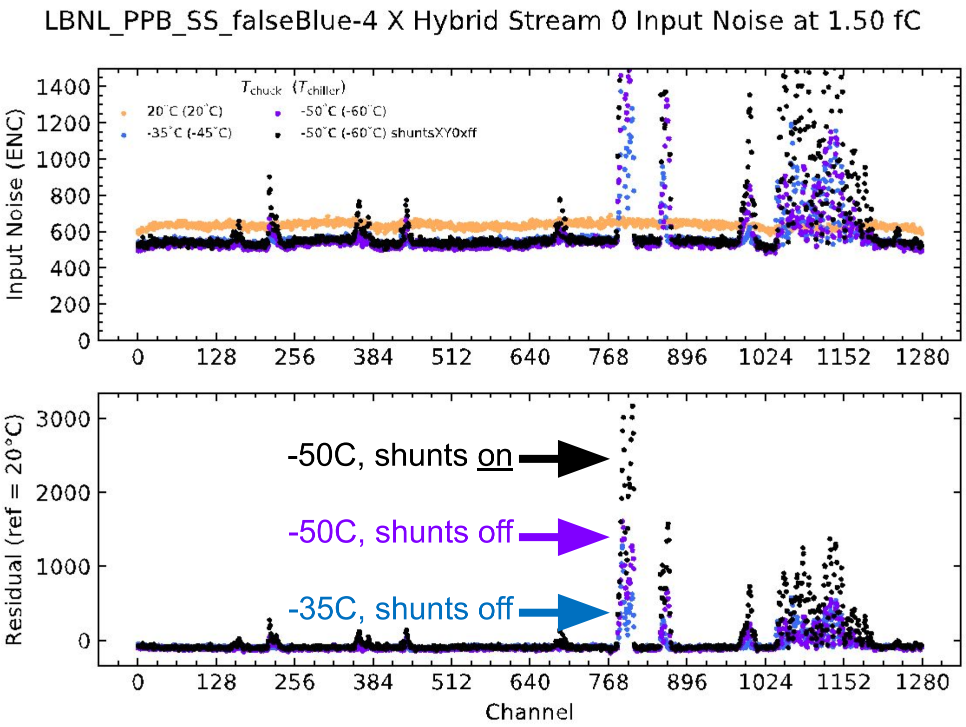
    - Can increase load by shunting current on ABCs.



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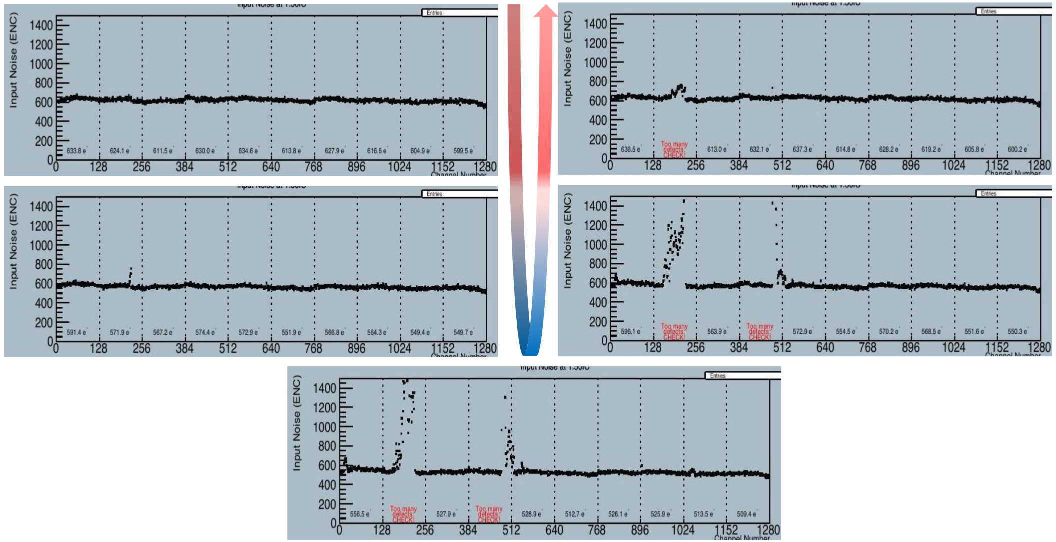
- Noise “freezes-in” during 1st thermal cycle.
    - Persists while warming.
    - Occasionally have residual “cold” noise at room temp!

1st thermal cycle



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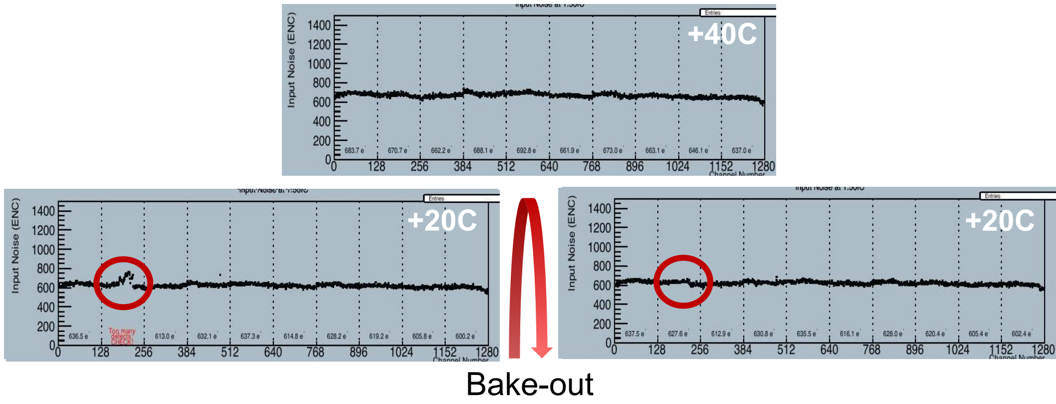

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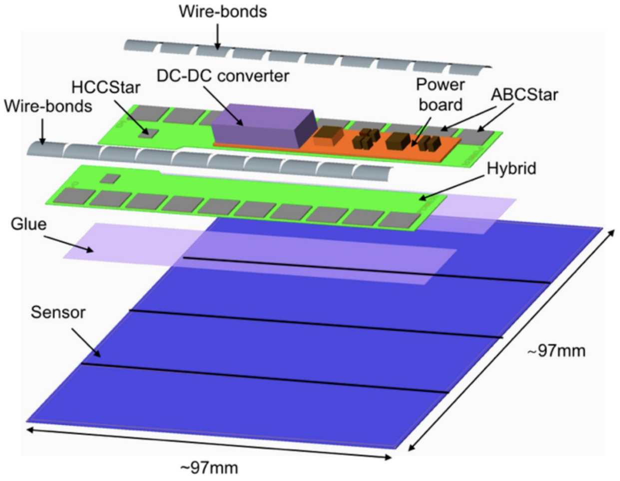

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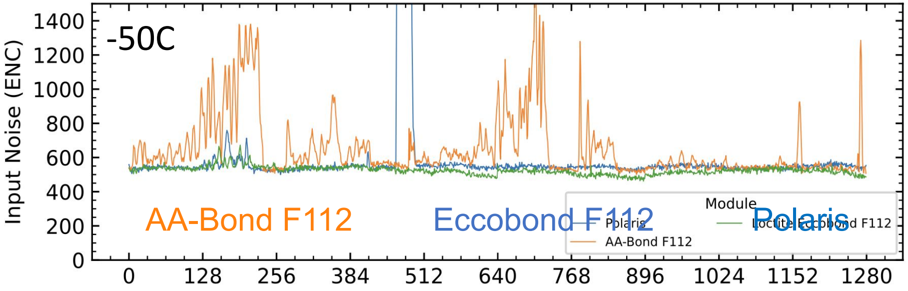
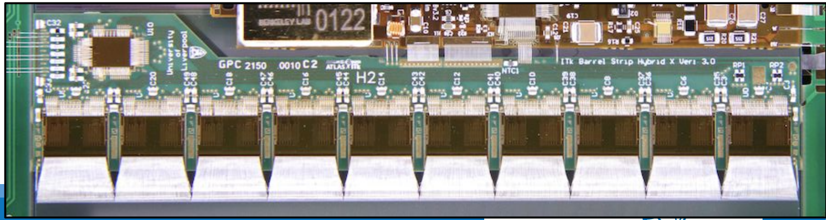
- Severity varies greatly among "nearly identical" epoxies.
  - Unable to correlate with any info in data sheets…





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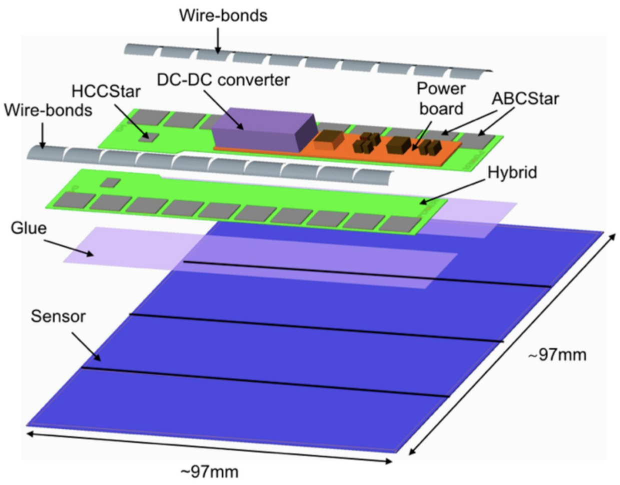

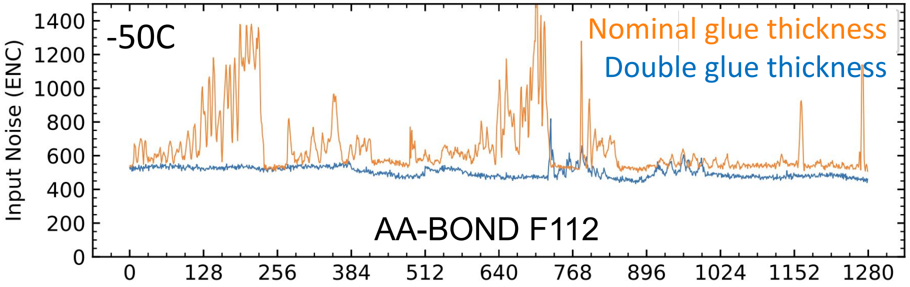

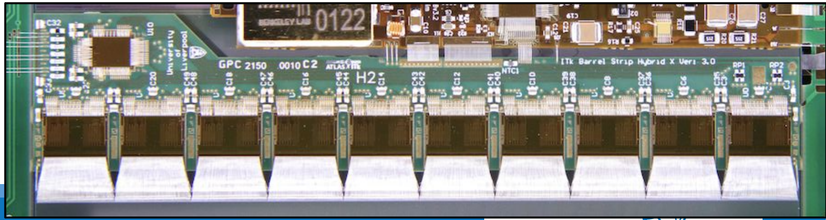

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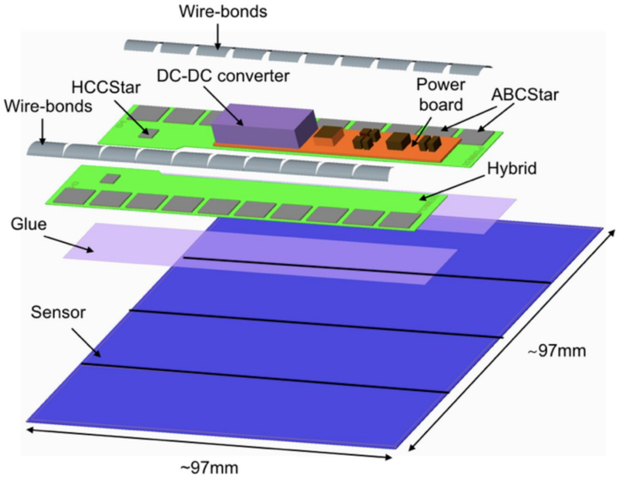
Cold Noise Observations



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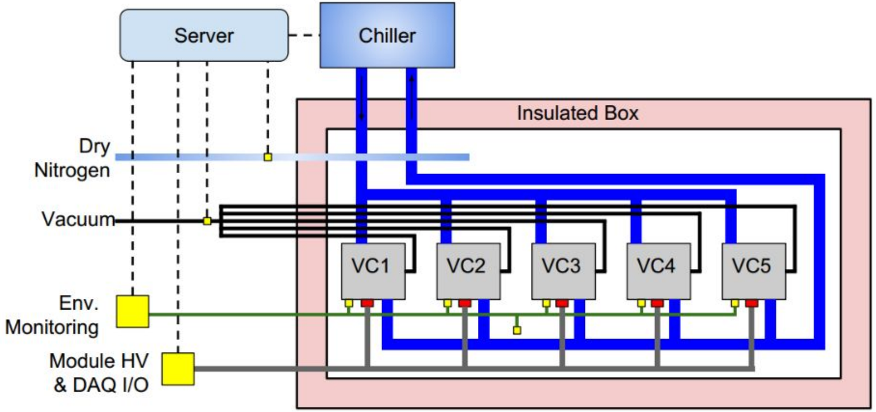
Glue dependence:

- Severity varies greatly among "nearly identical" epoxies.
    - Unable to correlate with any info in data sheets…
- Thicker glue layers under PB and hybrid(s) can reduce CN.
- Softer "glues" (Sylgard encapsulant, SE-4445 gel) remove CN.
    - Only diagnostic, not suitable for detector.

Cold Box

Central to the Cold noise Investigations was the ability to ‘cold cycle’ modules to investigate mitigation strategies

Warwick Box



VC : Vacuum Chuck

Addition of setting chuck to +20°C, rather than “room temperature”, before running initial IV scan & module tests

	Setup	Pre T/C Test			Initial cool down	Cold turn on				Thermal Cycle 1			
Chuck Temperature	Room temp	cool to +20°C	+20°C		cool to -35°C	-35°C				heat to +20°C	+20°C	cool to -35°C	-35°C
ITSDAQ Testing	PING	IDLE	IV	TEST	IDLE		IV	TEST	SHUNT	IDLE	TEST	IDLE	TEST
HV Bias	OFF		-550V	-350V	OFF		-550V	-350V		OFF	-350V	OFF	-350V
HYBRID Power	OFF		ON		OFF		ON						
Module LV / AMAC	OFF		ON			OFF	ON						

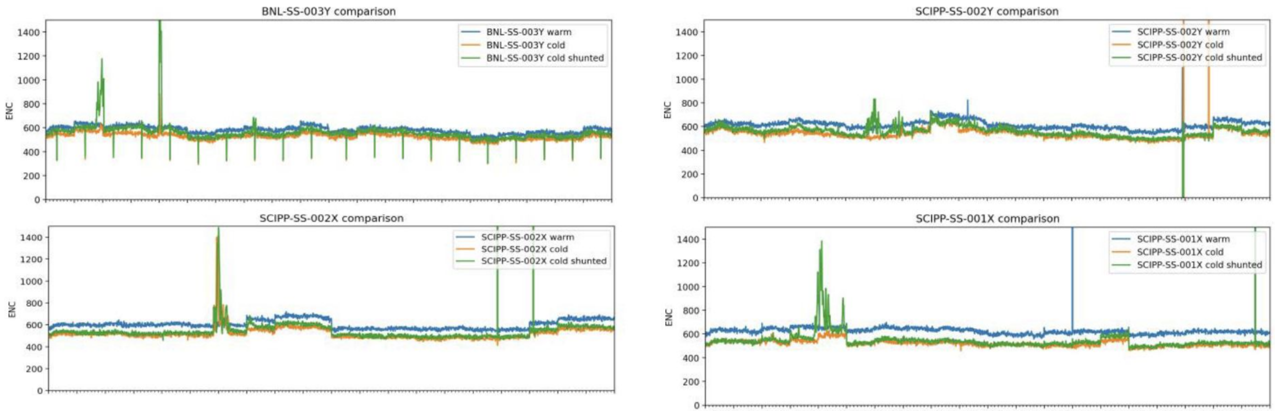
	Thermal Cycle 2				Thermal Cycle 3				Thermal Cycle 4				Thermal Cycle 5			
Chuck Temperature	heat to +20°C	+20°C	cool to -35°C	-35°C	heat to +20°C	+20°C	cool to -35°C	-35°C	heat to +20°C	+20°C	cool to -35°C	-35°C	heat to +20°C	+20°C	cool to -35°C	-35°C
ITSDAQ Testing	IDLE	TEST	IDLE	TEST	IDLE	TEST	IDLE	TEST	IDLE	TEST	IDLE	TEST	IDLE	TEST	IDLE	TEST
HV Bias	OFF	-350V	OFF	-350V	OFF	-350V	OFF	-350V	OFF	-350V	OFF	-350V	OFF	-350V	OFF	-350V
HYBRID Power	ON															
Module LV / AMAC	ON															

	Thermal Cycle 6				Thermal Cycle 7				Thermal Cycle 8			
Chuck Temperature	heat to +20°C	+20°C	cool to -35°C	-35°C	heat to +20°C	+20°C	cool to -35°C	-35°C	heat to +20°C	+20°C	cool to -35°C	-35°C
ITSDAQ Testing	IDLE	TEST	IDLE	TEST	IDLE	TEST	IDLE	TEST	IDLE	TEST	IDLE	TEST
HV Bias	OFF	-350V	OFF	-350V	OFF	-350V	OFF	-350V	OFF	-350V	OFF	-350V
HYBRID Power	ON											
Module LV / AMAC	ON											

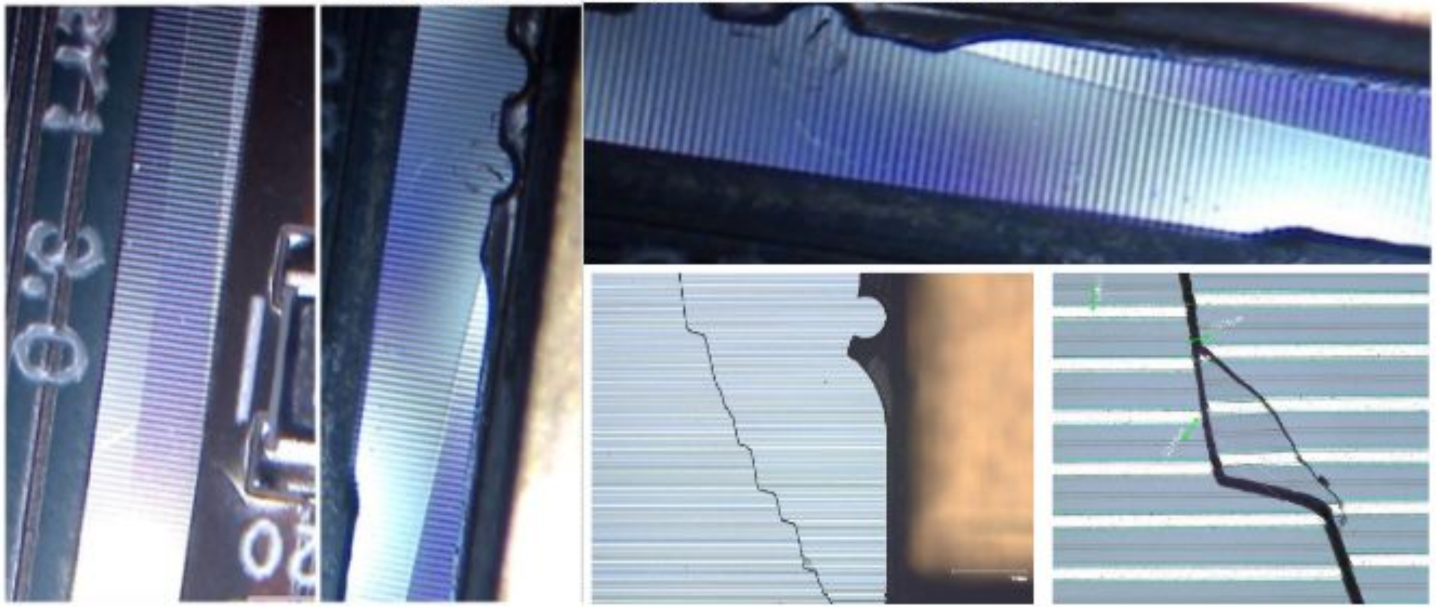
	Thermal Cycle 9				Thermal Cycle 10						Warm-up	Post T/C Module Test & HV stabilisation			Warm-up	End of Module QC
Chuck Temperature	heat to +20°C	+20°C	cool to -35°C	-35°C	heat to +20°C	+20°C	cool to -35°C	-35°C			heat to +20°C	+20°C			heat to +22°C	+22°C
ITSDAQ Testing	IDLE	TEST	IDLE	TEST	IDLE	TEST	IDLE	IV	SHUNT	TEST	IDLE	TEST	HV stabilisation	IV	IDLE	
HV Bias	OFF	-350V	OFF	-350V	OFF	-350V	OFF	-550V	-350V		OFF	-350V		-550V	OFF	
HYBRID Power	ON															OFF
Module LV / AMAC	ON															OFF

Solving Cold Noise

- Mitigations: changing the glue type ("True Blue")
  - **No cold noise** in the barrel LS modules and EC modules
  - Cold noise **reduced but still detectable** in the barrel SS modules with the new glue type
  - Impact on the tracking performance due to cold noise on the SS modules under evaluation
- Cold noise no longer blocks the start of module production!

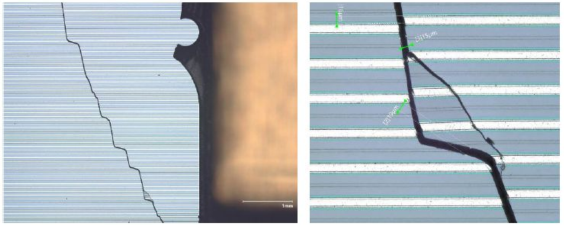


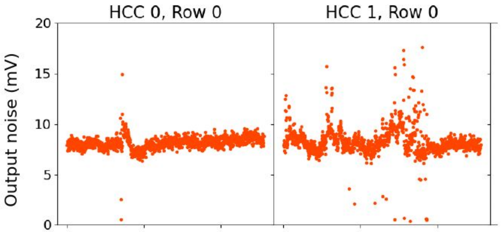
And then…



HV breakdown and task force

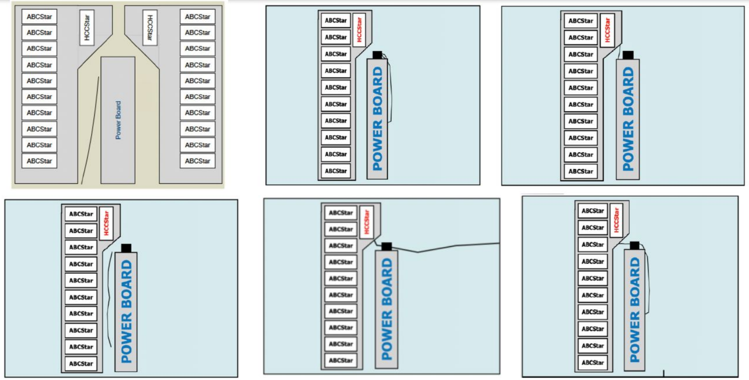
- A fraction of sensors on pre-production staves had “**early breakdown**” below the 500V specification which was not present in module QC
    - Many modules were correctly attributed to humidity and static charge from handling tools
    - Confirming the cause of these failures on stave was the last action to clear to module production at full rate
        - As issue impacted sensors, modules and loaded structures, **a task force** was founded
- Further investigation found that some of these module had hard (<100V) breakdowns arising from sensors **fracturing** when cycled to cold temperatures
    - Most have **high** or **low noise** channels associated with the location of the crack
- Removing this issue is the **largest barrier** to beginning module production and loading

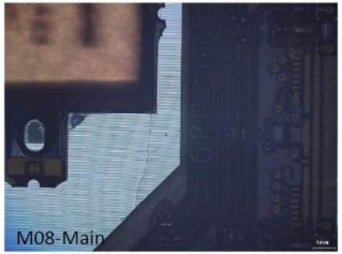


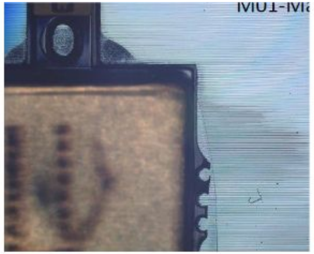


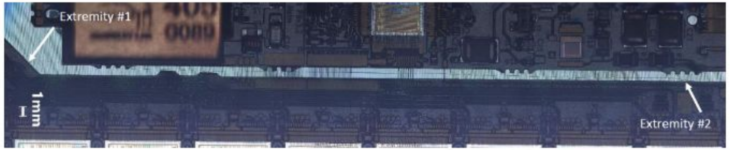
Crack Locations (First Impressions)

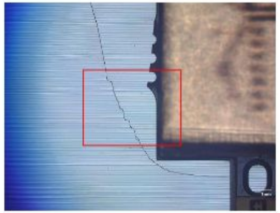
- Cracks seen from stave thermal cycling were observed near the power board, typically between hybrid and power board
    - Most didn’t propagate to the sensor edges
    - Integrated to 23 Modules over 11 Staves (Prototype, PPA, PPB)
        - ~7.5% of modules
- First cracks observed on PPB petals located below powerboards, only after -45 C tests on environmental chambers

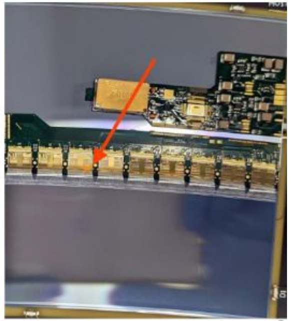






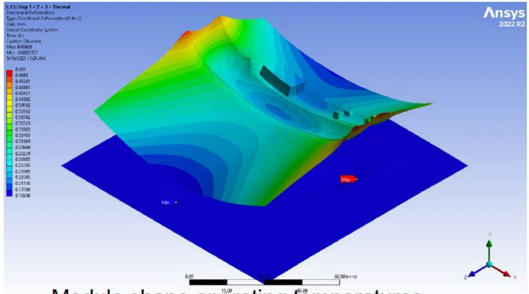






Qualitative Understanding

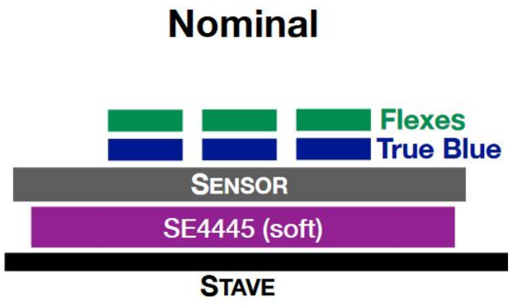
- When cooling down the module, copper in flexes contracts more than sensor (CTE mismatch)
  - The free sensor wants to **bend** up in a ‘bowl’ shape
- The **attachment** to the stave **constrains** this effect, creating local bent regions with high stress
  - Flexes and sensor curl upwards
  - Sensor between flexes is bent in opposite direction
  - Peak stress occurs in gaps between flexes
  - SE4445 silicone gel elongates instead of preventing localized change in bend direction



Module shape operating temperatures

Potential Solutions

Stress simulation pointed to many options to reduce stress on sensor. Developed two main strategies for significant stress reduction:



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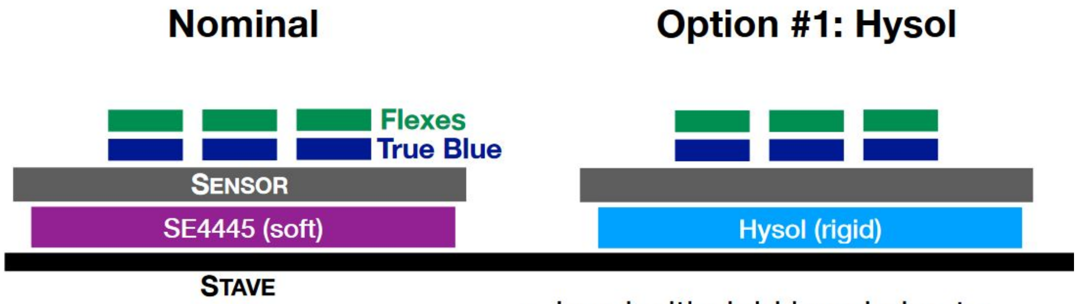

- Load with rigid hysol glue to support sensor from below
- Simulation predicts up to ~50% stress reduction
- Simple to integrate into existing procedures

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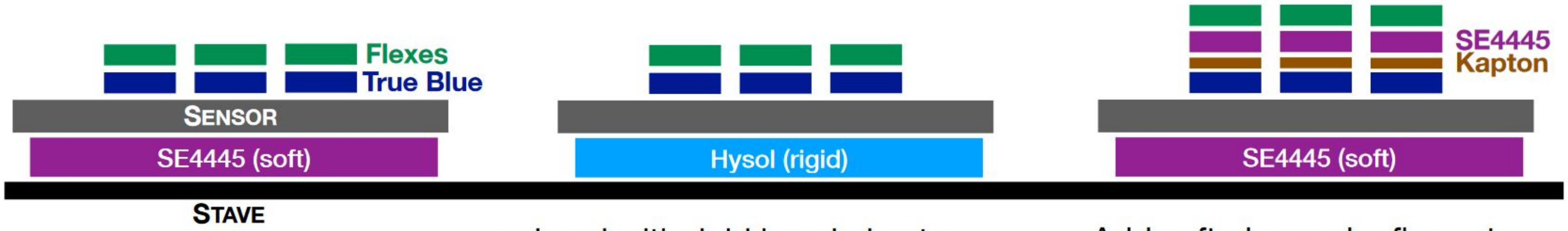
Stress simulation pointed to many options to reduce stress on sensor. Developed two main strategies for significant stress reduction:

Nominal | **Option #1: Hysol** | **Option #2: Interposers**



Option #1: Hysol

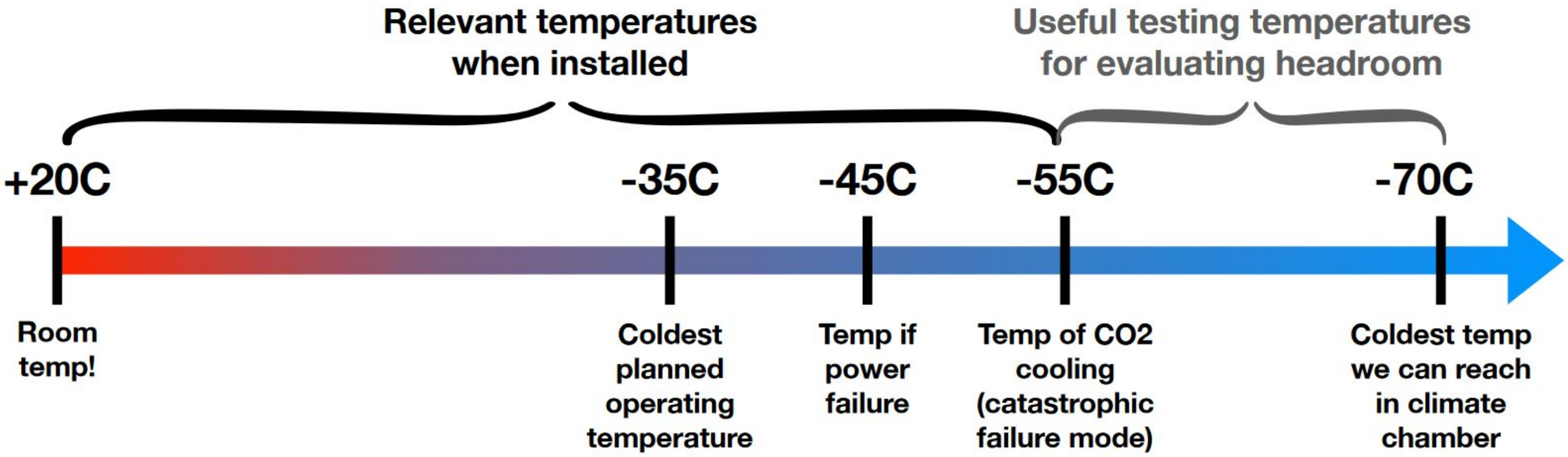
- Load with rigid hysol glue to support sensor from below
- Simulation predicts up to ~50% stress reduction
- Simple to integrate into existing procedures

Option #2: Interposers

- Add soft glue under flexes to decouple thermal stress
- Simulation predicts up to ~95% stress reduction
- More complex to integrate into workflow

Testing Strategy

- Evaluate impact of each potential on cracking problem by building loaded objects (petals, staves) and test at progressively lower temperatures
  - Expect stress to increase as temperature decreases, so testing at low temperatures helps quickly evaluate how much “headroom” in stress is available for each solution



Mitigation 1: Hysol Studies

- A stave (#38) was loaded with Long Strip Modules assembled in the UK
  - One side used **SE445** used for Module->Stave attachment
  - One side used **Hysol** used for Module->Stave attachment

- A stave (#40) was loaded with Long Strip Modules assembled in the UK
  - Both sides used used **Hysol** used for Module->Stave attachment

- Another stave (#8) was loaded with Long Strip Modules assembled in the US
  - **Wide Gap** module on 1 side
  - Standard modules on the 2nd side
  - **Hysol** was used for Module->Stave attachment

- A petal was loaded with Modules in Vancouver
  - **Hysol** was used for Module->Petal attachment
- A 2nd petal was loaded with Modules in Vancouver
    - **Hysol with a modified pattern** was used for Module->Petal attachment

Mitigation 1: Hysol Stave #8 Results

Previous testing in the US testbox:

J side (pre L loading)

cycles	Temperature	Status
5 cycles	-35C	Good
11 cycles	-45C	Crack on cycle 4, module 10

Before going cold for the first time with full stave, refrigeration issue caused temperature increase (Inlet/outlet and NTC temps up to +40C)

Full stave

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

Full stave (Passive cycling in 10s)

Thermal cycle number	Temperature	Status
20-30	-45C	No new suspected cracks
30-40	-45C	No new suspected cracks
40-50	-45C	No new suspected cracks

3 suspected cracks for the nominal modules

No cracks for the wide gap modules

Stave now on its way to RAL for testing in the climate chamber to -70C

7

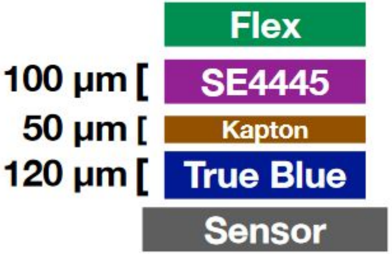
Climate chamber at RAL:

Thermal cycle number	Temperature (°C)	Status
1	-35	No evidence of new cracks
1	-45	No evidence of new cracks
2	-45	No evidence of new cracks
3	-45	No evidence of new cracks
4	-45	No evidence of new cracks
5	-45	No evidence of new cracks
1	-35	No evidence of new cracks
1	-45	No evidence of new cracks
2	-45	Early breakdown Module 12
3	-45	No evidence of new cracks
4	-45	No evidence of new cracks
5	-45	No evidence of new cracks

Thermal cycle number	Temperature (°C)	Status
1	-50	No evidence of cracks
2	-50	Early breakdown M9
3	-50	No evidence of new cracks
4	-50	No evidence of new cracks
5	-50	No evidence of new cracks
1	-60	Early breakdown M8
2	-60	
3	-60	
4	-60	
5	-60	

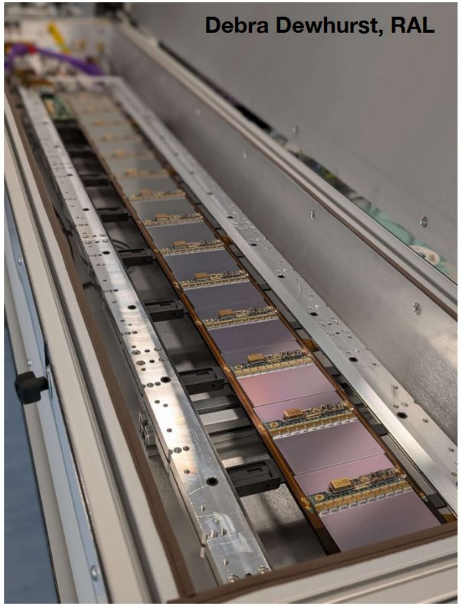
Interposing

= attaching **kapton**, **SE** to **flex**



Agreed on standard build of interposed objects:

100 µm layer of SE4445, 50 µm kapton



So far, interposing hybrids/powerboards (PBs) one by one and panels of flexes at flex sites

UK led effort, with construction of a half interposer stave (14 Modules)

Planning for minimal changes at module assembly sites: add shim to assembly jig to account for extra height of flexes

Developing processes, plan to use mass- interposed flexes in next couple months

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Mitigation 2: Interposers

- 1 side of a stave (#43) was loaded with **interposed** Long Strip Modules assembled in the UK
  - Hybrids and Powerboard were interposed ‘by hand’
  - **SE445** was used for Module->Stave attachment

Mitigation 2: Interposer Stave #43 Results

NOVEC testbox at RAL:

Thermal cycle number	Temperature (°C)	Status
1	-35	No evidence of cracks
2	-35	No evidence of cracks
3	-35	No evidence of cracks
4	-35	No evidence of cracks
5	-35	No evidence of cracks
1	-42	No evidence of cracks
2	-42	No evidence of cracks
3	-42	No evidence of cracks
4	-42	No evidence of cracks
5	-42	No evidence of cracks

Climate chamber at RAL:

Thermal cycle number	Temperature (°C)	Status
1	-35	No evidence of cracks
1	-45	No evidence of cracks
2	-45	No evidence of cracks
3	-45	No evidence of cracks
4	-45	No evidence of cracks
5	-45	No evidence of cracks
1	-50	No evidence of new cracks
2	-50	No evidence of new cracks
3	-50	No evidence of new cracks
4	-50	No evidence of new cracks
5	-50	No evidence of new cracks
1	-60	No evidence of new cracks

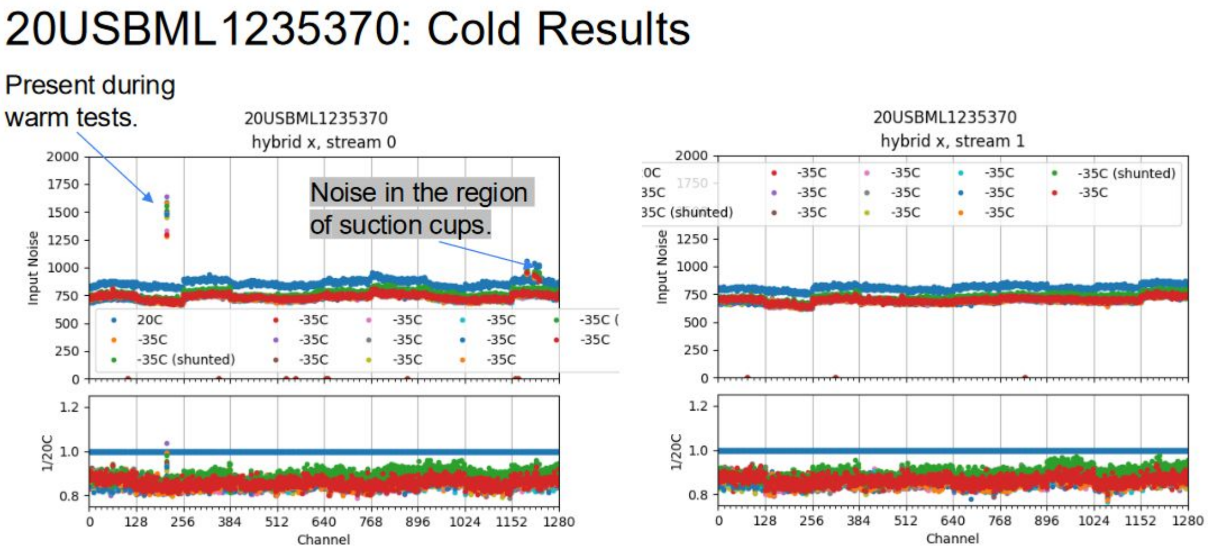
+

- 5 cycles to -70
- Five more cycles +20 to -70, with 4 hour dwell at -70 before cold test
- Five more cycles "+35" to -70, with 1 hour dwell at each temperature

No Cracks

Cold Noise?

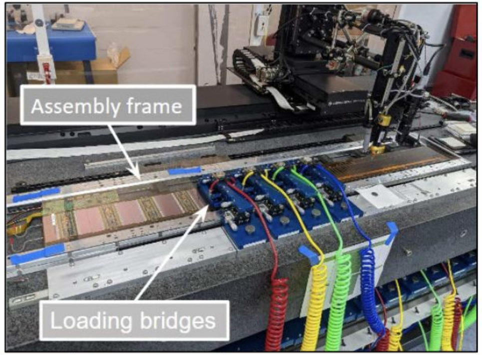
Have found that interposer solution also removes short strip module cold noise



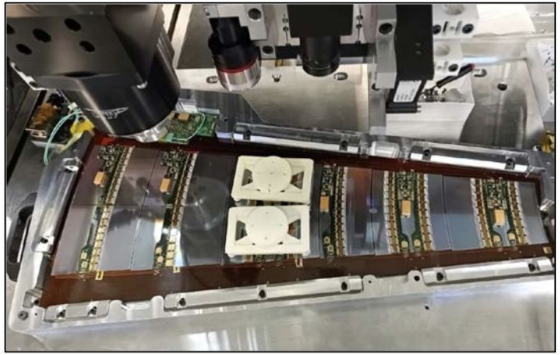
Stave & Petal Pre-Production

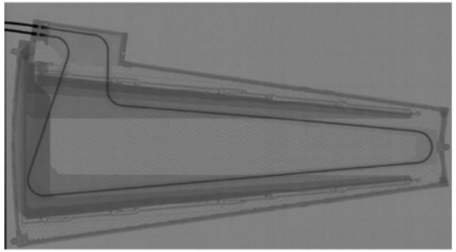
- Loading efforts strongly driven by HV-TF needs/outcomes
  - Exploring mitigation strategies for cracking
    - SE-4445/hysol, different glue patterns
    - Wide-gap, thin/thick hybrids
    - Interposers
  - Performing thermal cycling down to QA-level temperatures
- ➢ 11 PPB/C staves and 8 PPB/C petals built so far

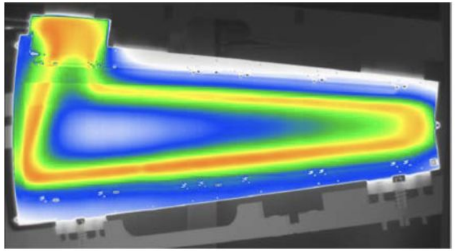
Barrel Loading System



Endcap Loading System

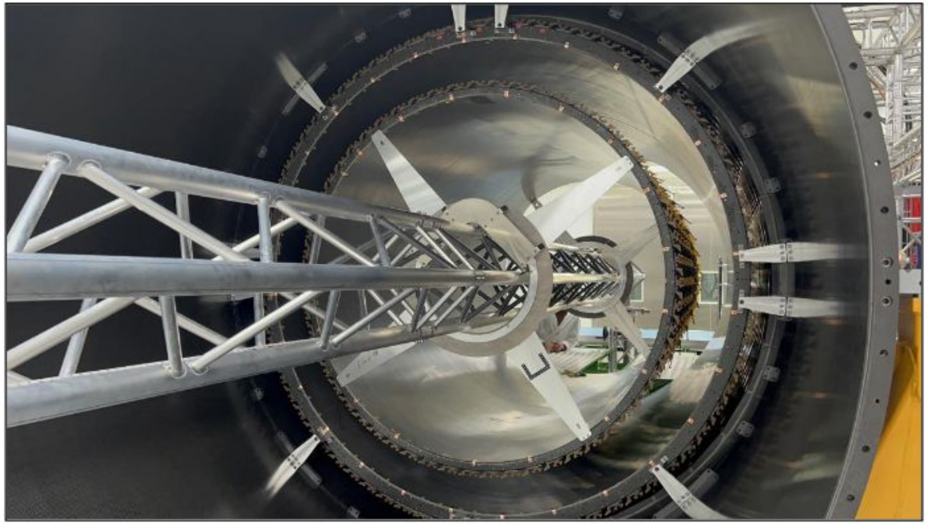






Global Mechanics

- L3 installed inside outer cylinder (July)
- L2 installed inside outer cylinder (September)
- L1 and L0 flange tooling and mandrels received at LBNL
- L1 component carbon fibres due in October

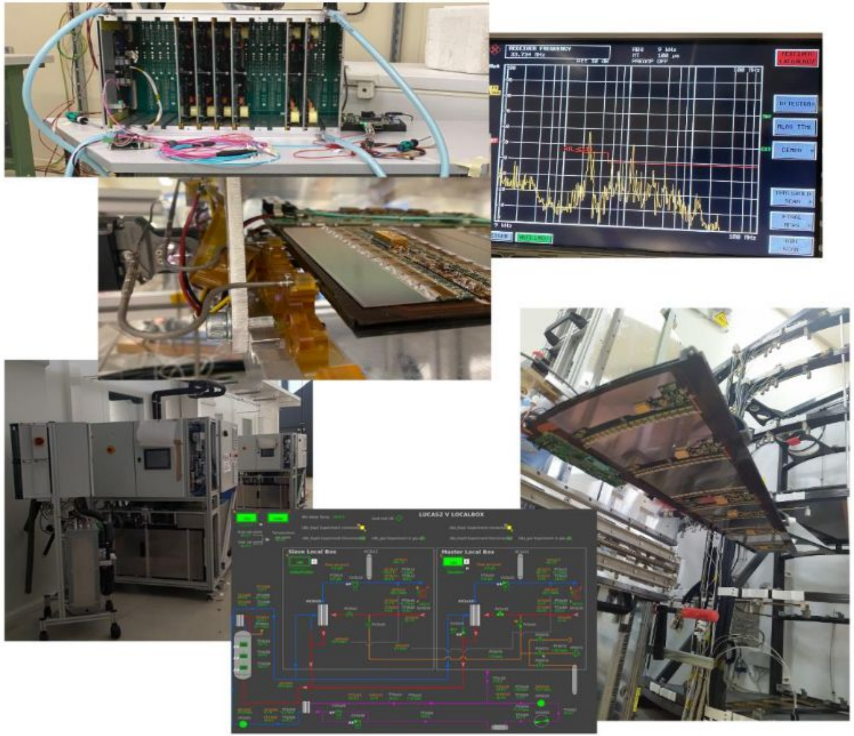


Integration (Stave/Petal installation)

- Preparations for integration are progressing across all areas
- Final services for integration tests partially installed in SR1 and arriving at DESY/NIKHEF
  - Type-IIIs and fibres installed in SR1
  - Type-IIs pending
  - PSUs undergoing reception tests
- Stave reception at SR1 advanced
  - Two reception setups close to fully commissioned
  - Stave storage (up to 56 staves) in place and running
- Stave insertion tooling and dummy bulkheads in preparation at RAL and LBNL
- Ping testing procedure/software/hardware being developed

Systems Test

- Powering with full power chain
  - Power chain tests at DESY & CERN done for at least 1 stave/petal with integration power chain
  - Electromagnetic compliance testing completed
  - In progress: tests with full power chain, including PP3/PP4 & Type-IV cables
- Cooling with CO2
  - Cold tests in barrel down to -25˚C with IBL cooling plant
- Data acquisition (DAQ) / Detector Control System (DCS)
  - Finite state machine in place for ~1 service module
  - In progress: Demonstration of DAQ in fully integrated TDAQ environment with FELIX,
  - data handler etc. and scaling studies of
  - DCS projects

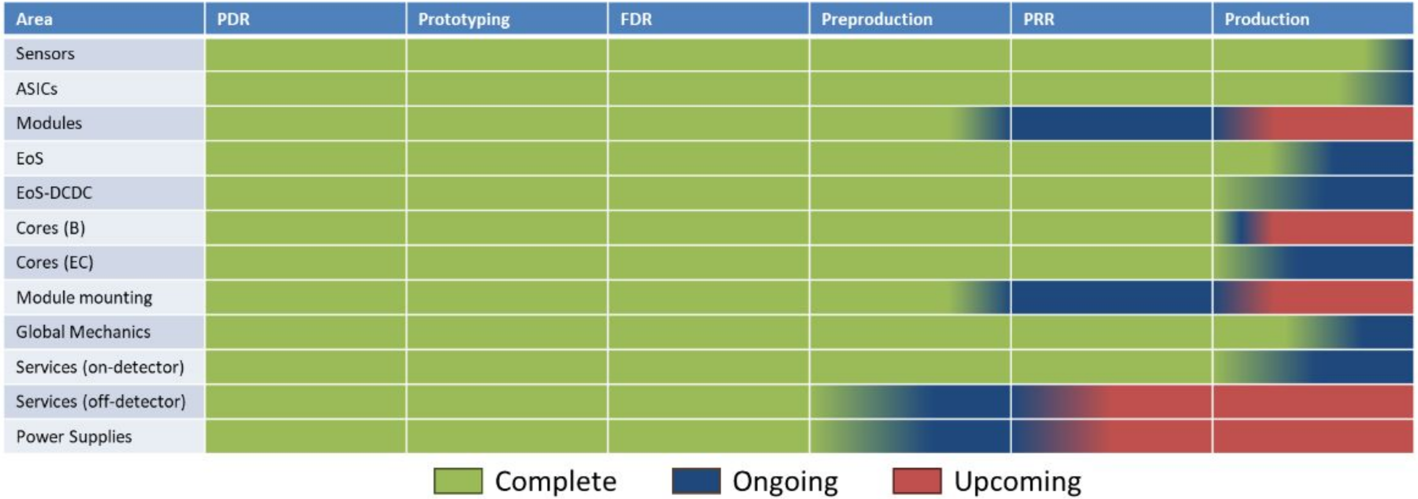


Conclusions

- Building a tracker detector for operation at the high luminosity LHC is challenging
  - Radiation hardness, increased granularity, low mass
- The ITk Strip detector is progressing through production and integration
  - Sensors, ASICs modules **in production**
  - Local Supports, global structures, services and power supplies to follow
- Not an easy path
  - Faced issues, like the Cold Noise & Cracking in Modules
- Important effort needed for project coordination
  - 57 institutes from 14 countries

BACKUP

ITK Strips Reviews



Inner Tracker System

- The new inner tracker (ITk) will be an all Si Tracker system
  - Will replace the current ID (Pixels, SCT + TRT)
  - 'All Silicon' -> no TRT
- 2T magnetic field, ~6m long, ~1m radius & up to $|\eta|=4$
- 5 Central and multiple Forward Pixel layers
- 4 Central and 6 Forward Strip layers

	Present Inner Detector	New ITk for HL-LHC
Sub-detectors	Si (pixels+strips) & gas tracker	Si (pixels+strips)
Coverage $\|\eta\|$	<2.5 (Si) < 2.0 (gas tracker)	<4.0 (pixels) <2.7 (strips)
Trigger rate	100 kHz	1 MHz