ATLAS ITk strip detector – R&D and integration

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*On behalf of the **ATLAS ITk strip Vancouver team***

TRIUMF Science week

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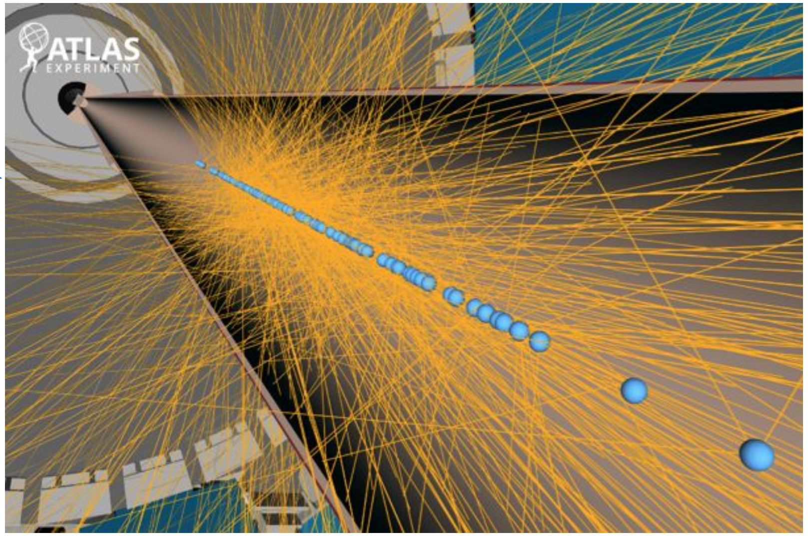
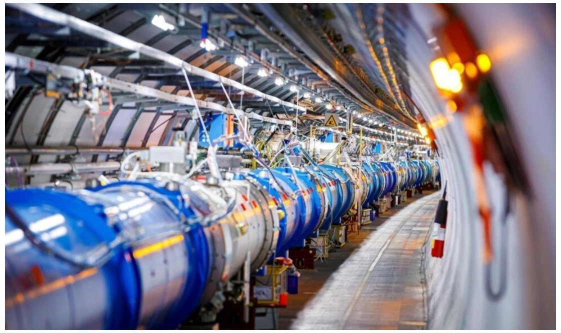
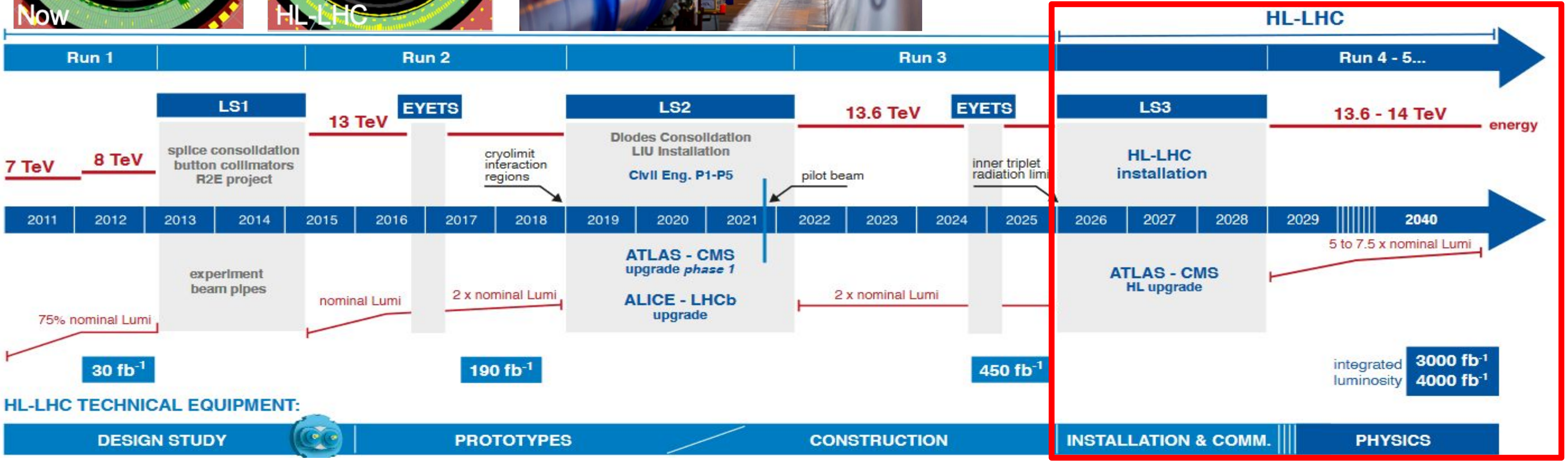
Introduction

The **HL-LHC** will increase the complexity of LHC collisions!

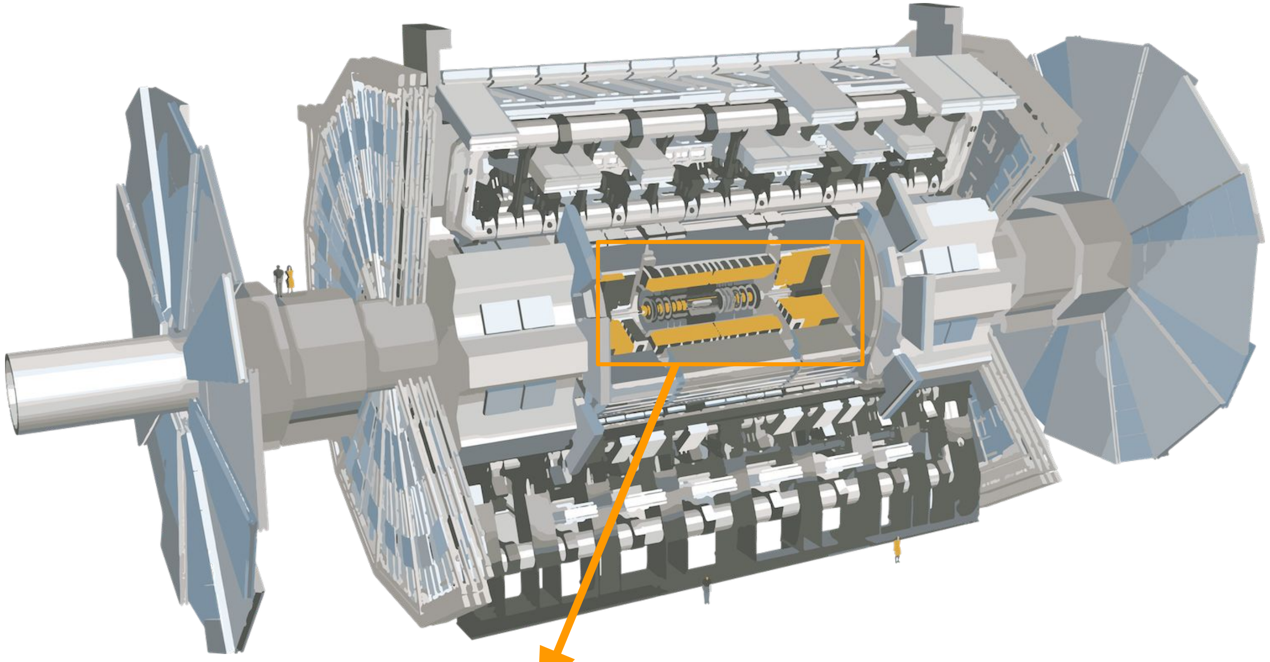
- Luminosity increase by 10x wrt design, much higher radiation
- Number of inelastic (pileup) collisions from ~45 to 200 per bunch crossing
- Large track multiplicity up to 10,000
- Harsh environment: **ATLAS experiment needs to be upgraded!**





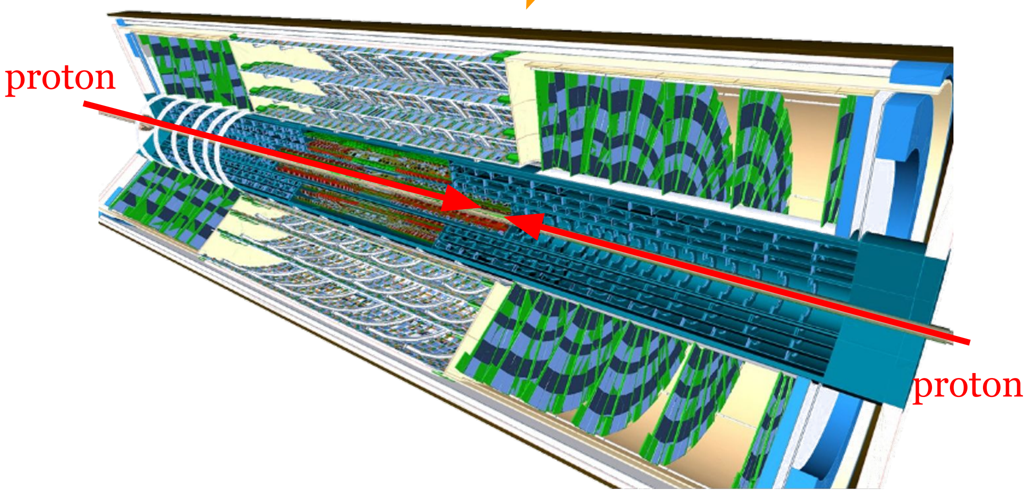


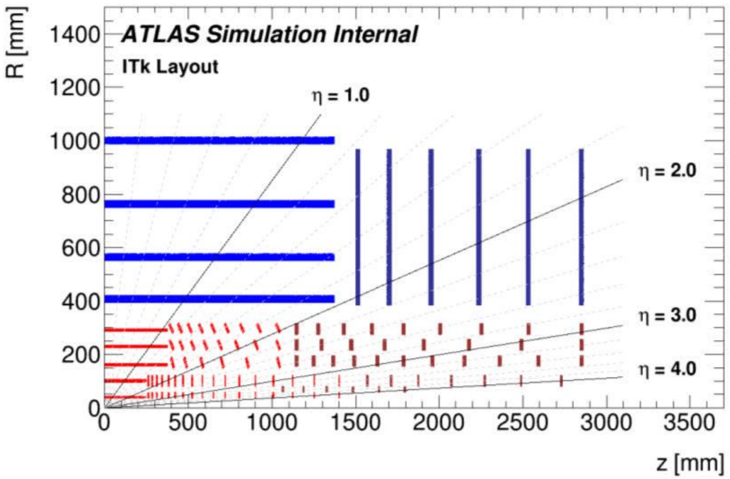
New inner tracker - ITk

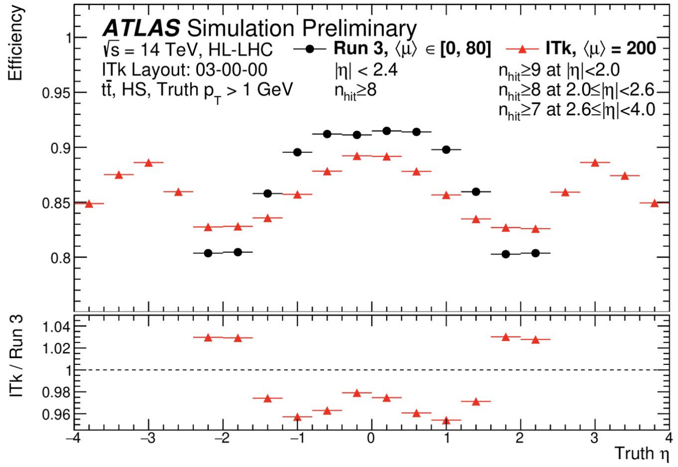


New ATLAS **Inner Tracker (ITk)** replaces current inner-most tracking detector - inner detector (ID)

- **All silicon** - pixels and strips
  - 168 m² of silicon strip + 13 m² silicon pixel detectors
- Higher **radiation tolerance**
- Finer **granularity**: 100M → 5000M channels
- Larger **coverage**: $|\eta| < 2.5 \rightarrow |\eta| < 4.0$
- Faster **response** and reduced **material**
- similar/better **tracking performance** in a harsher environment







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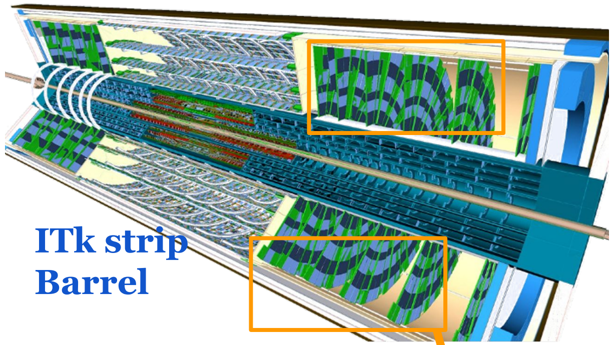
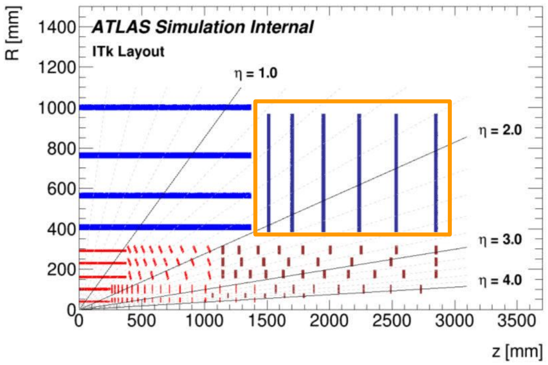
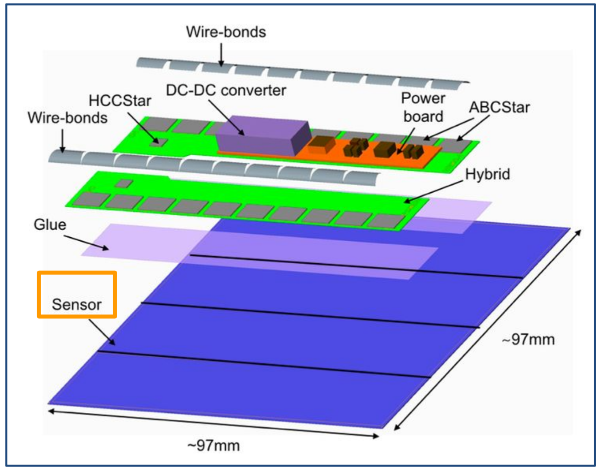
ITk strip endcap, petal, module, sensor

ITk detector



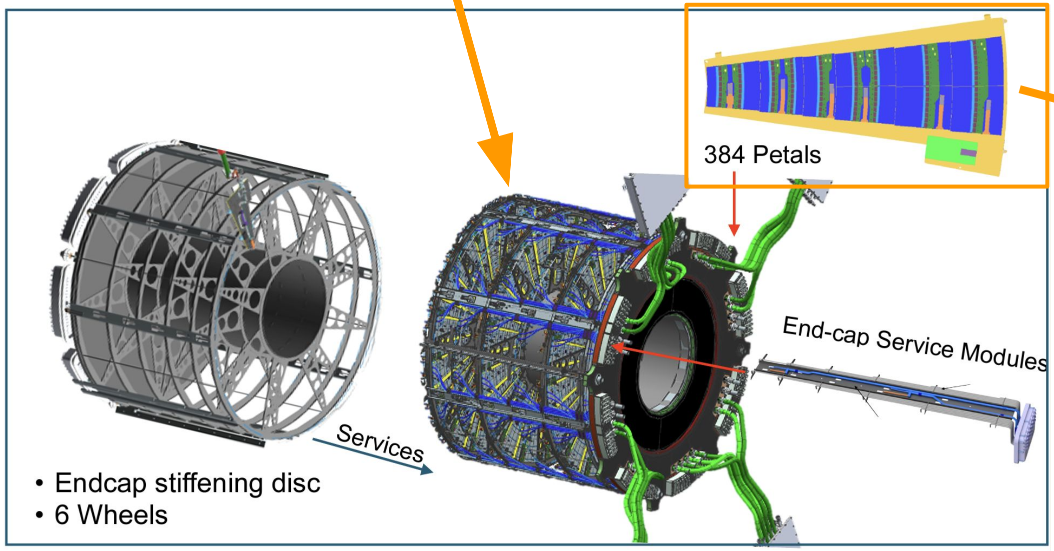


ITk strip module and silicon sensor

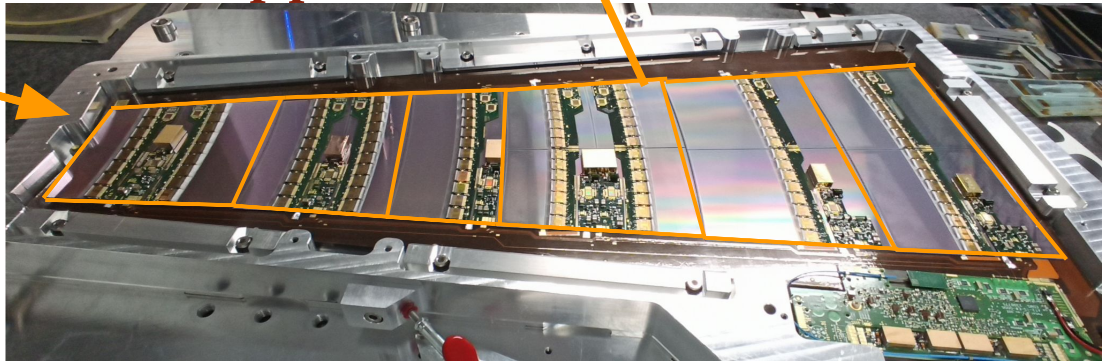


- Smallest electrically functional unit
- Comes in 6 flavors for strip endcap: R0/1/2/3/4/5 (from closest to beamline to furthest)
- Comes in 2 flavors for strip barrel: long/short-strip

ITk strip Endcap



ITk strip petal

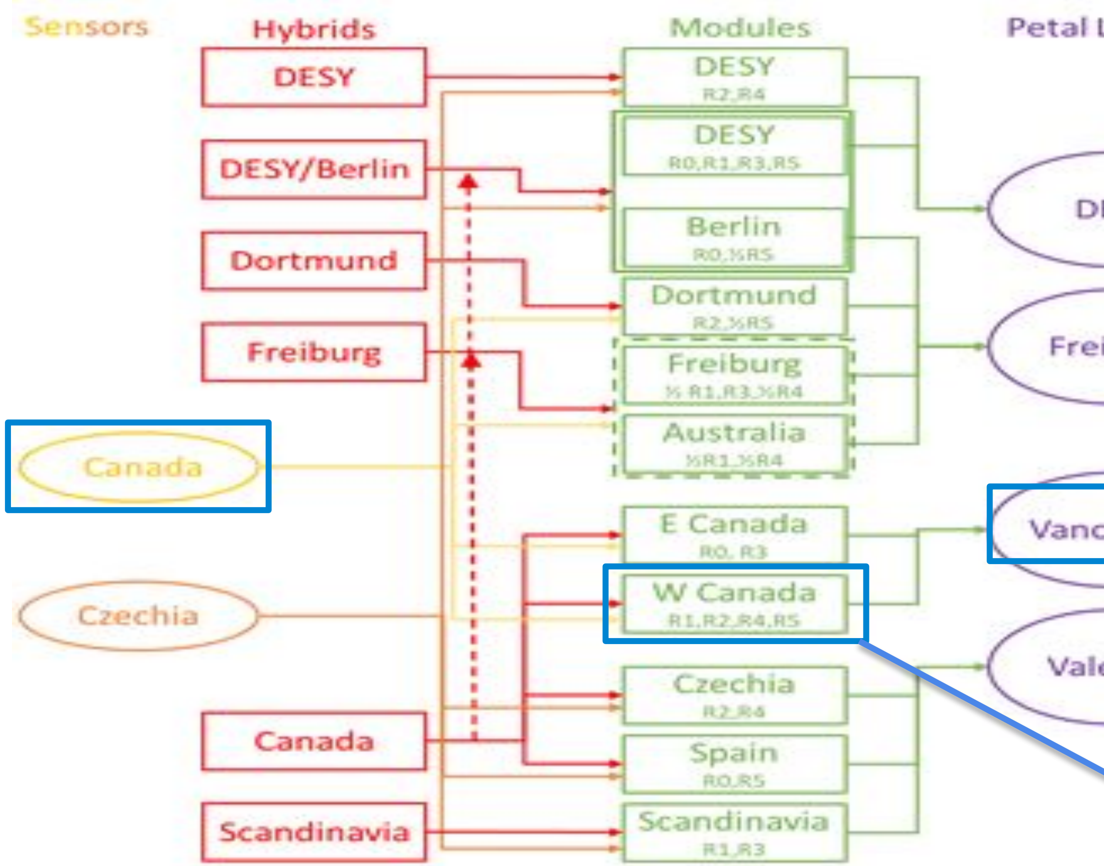


- Support and cooling structure for the modules
- power supply and data transfer

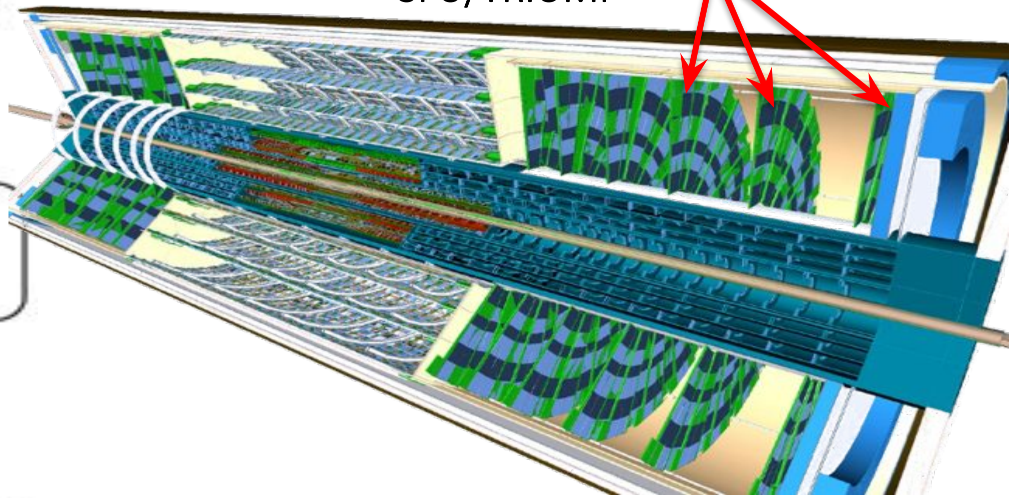
The collaboration

- ITk stip detector production takes place at around 60 institutes in 14 countries around the world

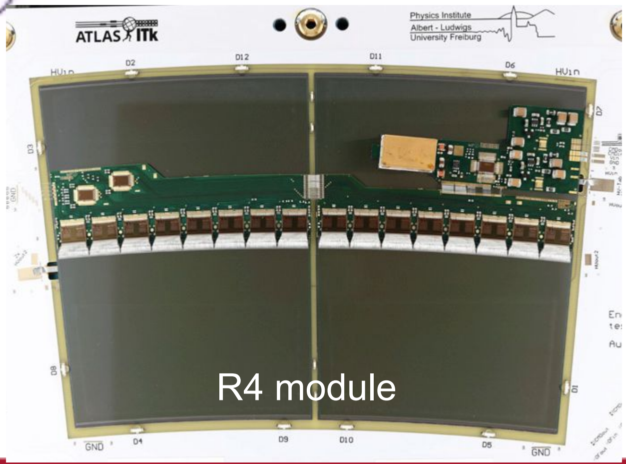
ATLAS ITk strips Production

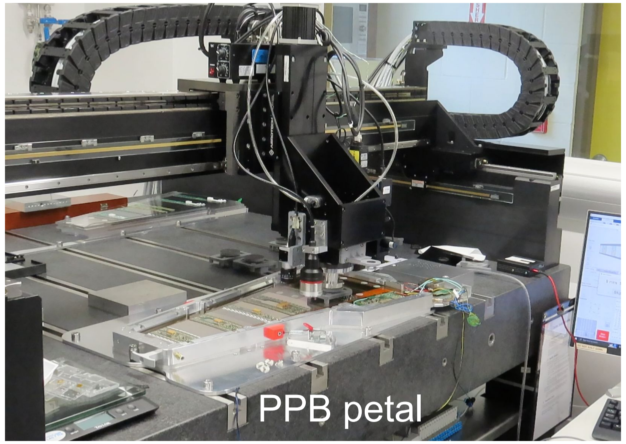


1000 modules and 84 petals at SFU/TRIUMF

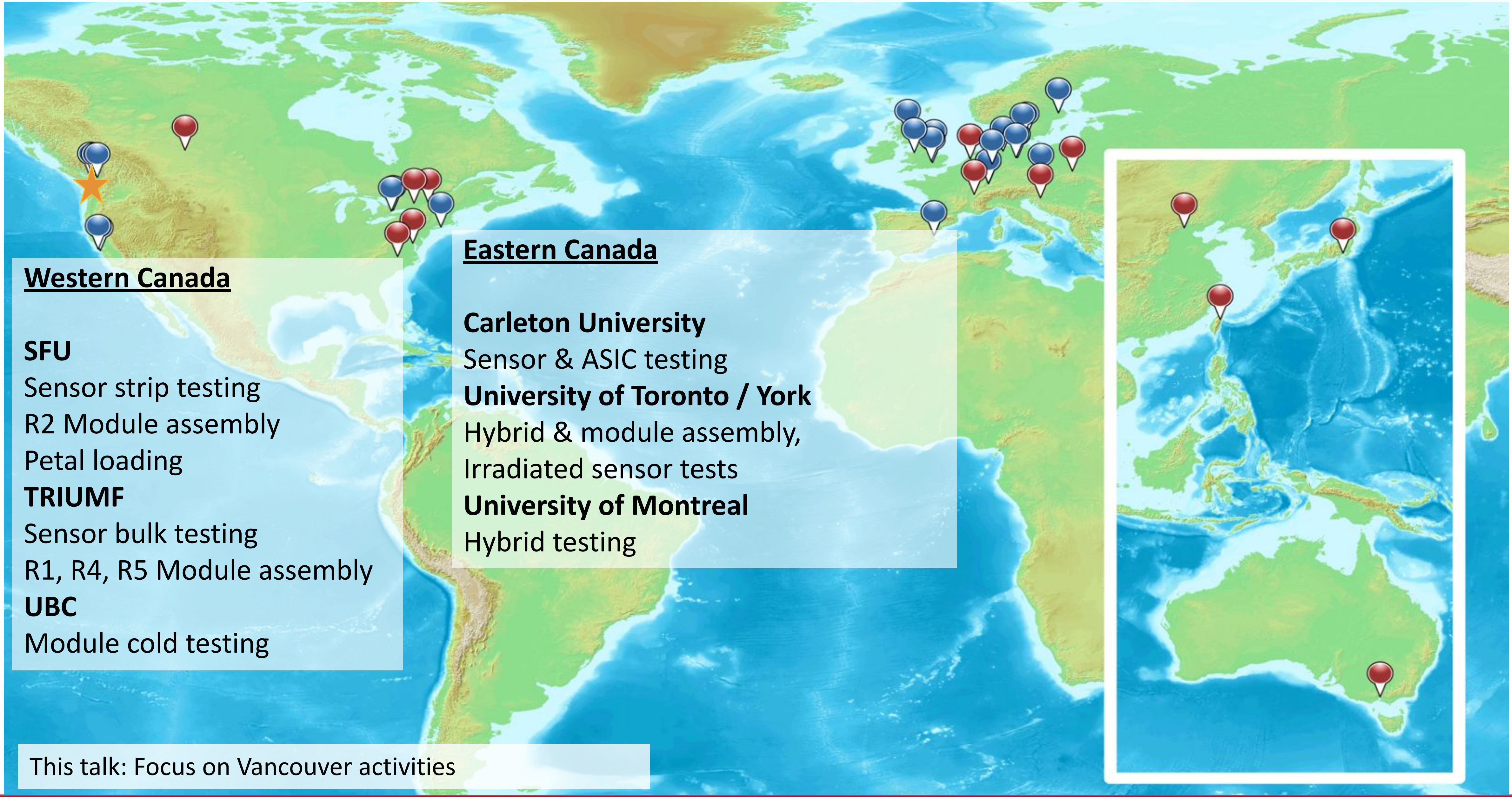


First ITk pre-production modules and petals assembled in Vancouver!





ATLAS ITk strips - A Global Project



Western Canada

SFU
Sensor strip testing
R2 Module assembly
Petal loading
TRIUMF
Sensor bulk testing
R1, R4, R5 Module assembly
UBC
Module cold testing

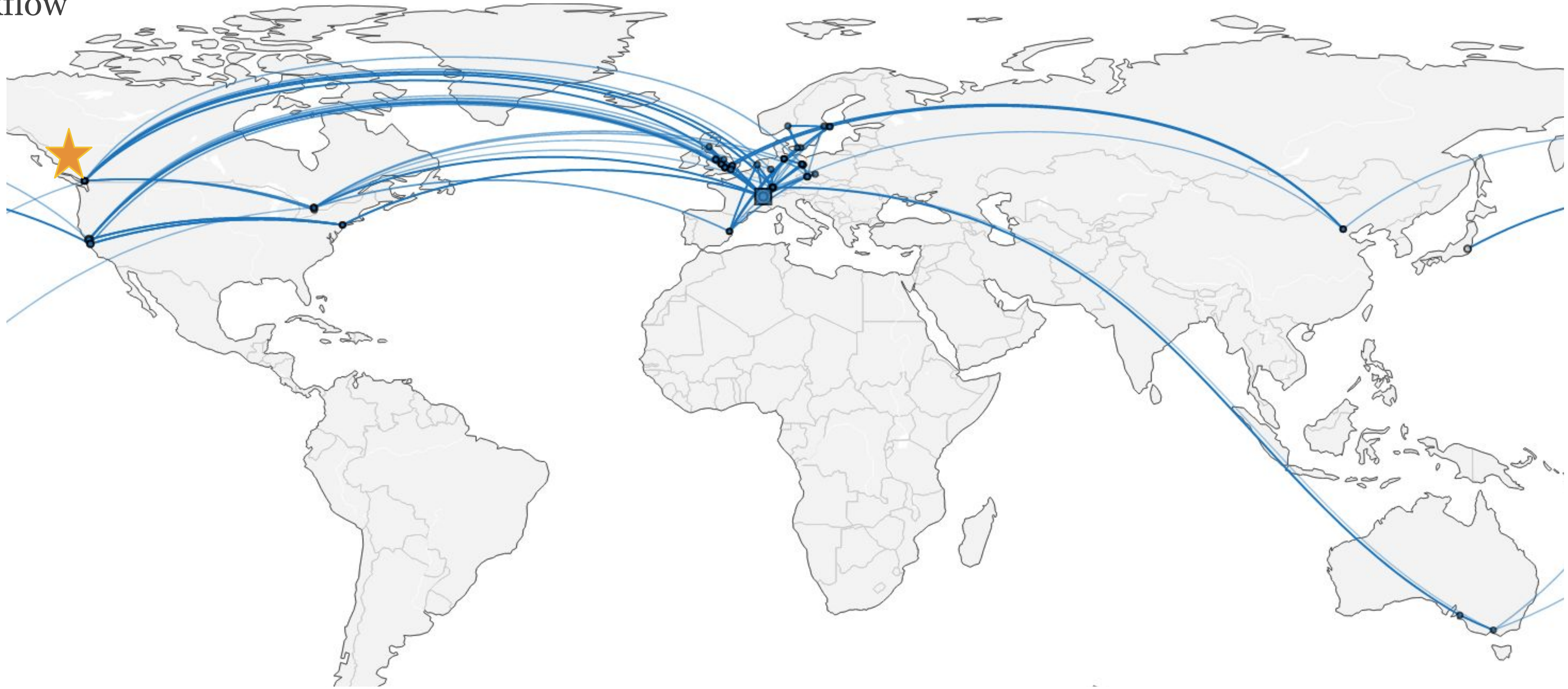
Eastern Canada

Carleton University
Sensor & ASIC testing
University of Toronto / York
Hybrid & module assembly,
Irradiated sensor tests
University of Montreal
Hybrid testing

This talk: Focus on Vancouver activities

The collaboration

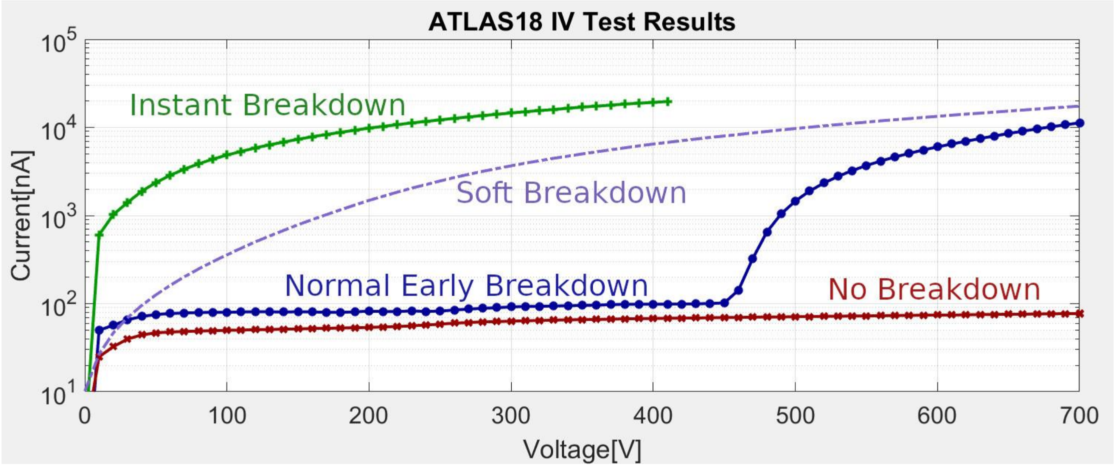
- ITk stip detector production takes place at around 60 institutes in 14 countries around the world
- **Vancouver team** is very active in many areas of the ITk strip project, in particular, **production of endcap modules** and **petals** as well as **cutting-edge silicon detector science programs** aimed at better understanding the detector mechanism and improving the qualification procedures of the production
- Let's take a look at some **production procedures** developed at Vancouver and some interesting **R&D opportunities (study cases)** for improving our understanding to the detector and the reliability of the production workflow

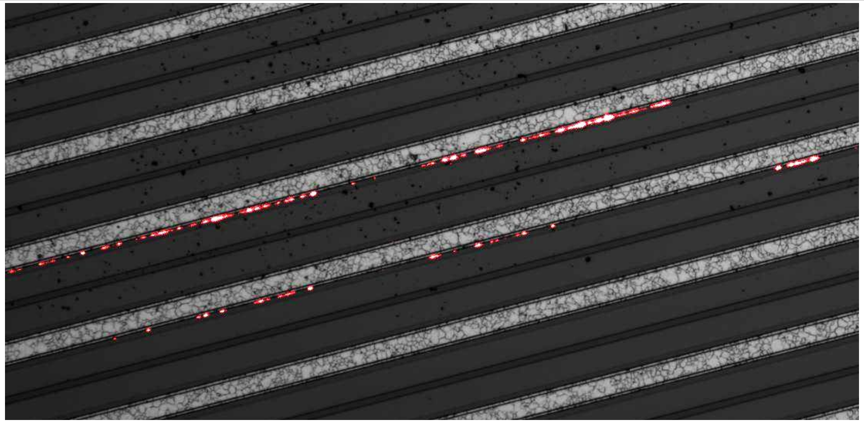


R&D case - Hot Spot camera

Slide credit: Andrew Fournier

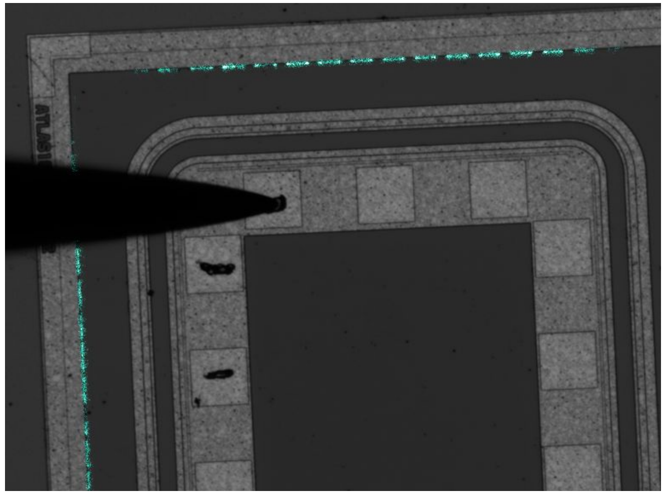
- **Early** leakage current **breakdown** (An unexpected significant increase in leakage current shown below) is a common failure mode for silicon based particle detectors, but its source was normally assumed and not verified.
- The **Hot Spot setup** using the Retiga E7 (left) can capture emissions of hot electrons from silicon breakdown, allowing us to **identify** the damage **source** and better understand failure modes.

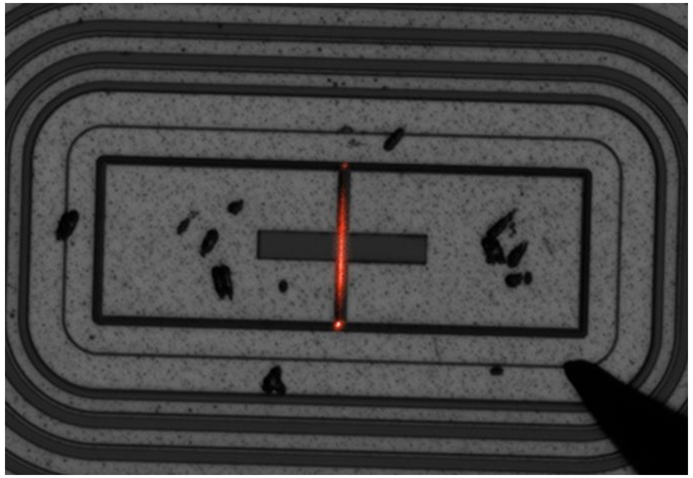




- Emissions can be seen (left) along the edge of strips on an ATLAS endcap sensor. These were caused by damage to the protective passivation layer on the sensors surface.

- Emissions can be seen (below) along the inner edge of the guard ring of a test structure diode. This breakdown was induced by irradiating the sample heavily.

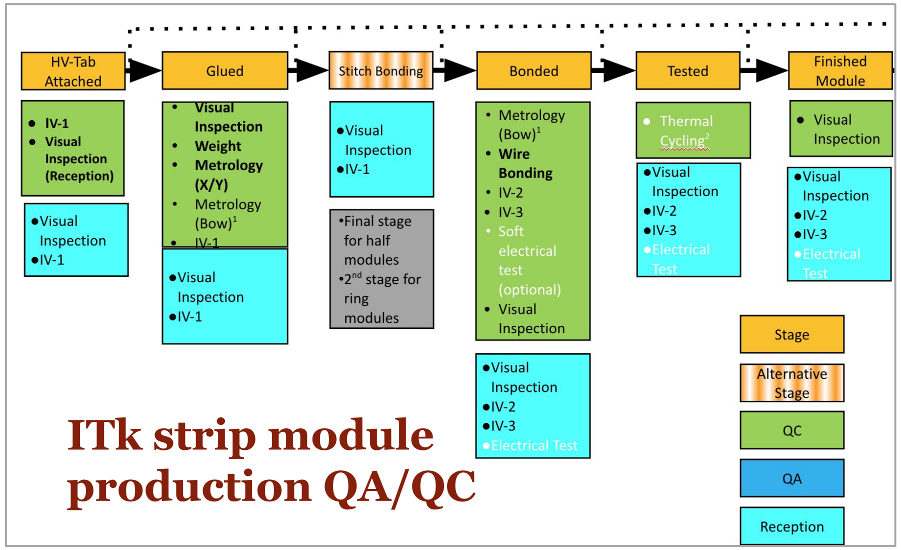




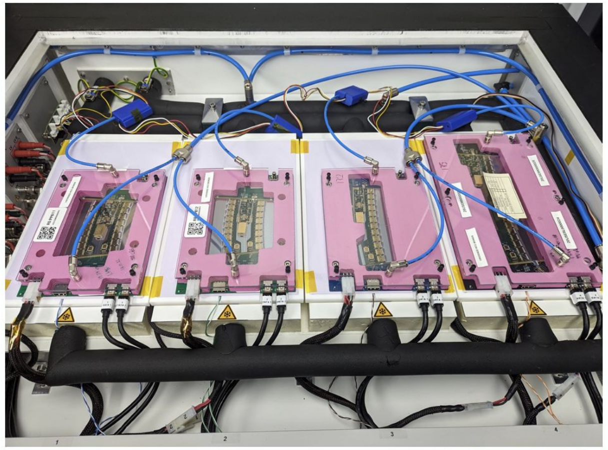
- Emissions can be seen (above) originating from the trench of a damaged Trench Isolated LGAD device.

R&D case - module deformation caused by thermal cycling

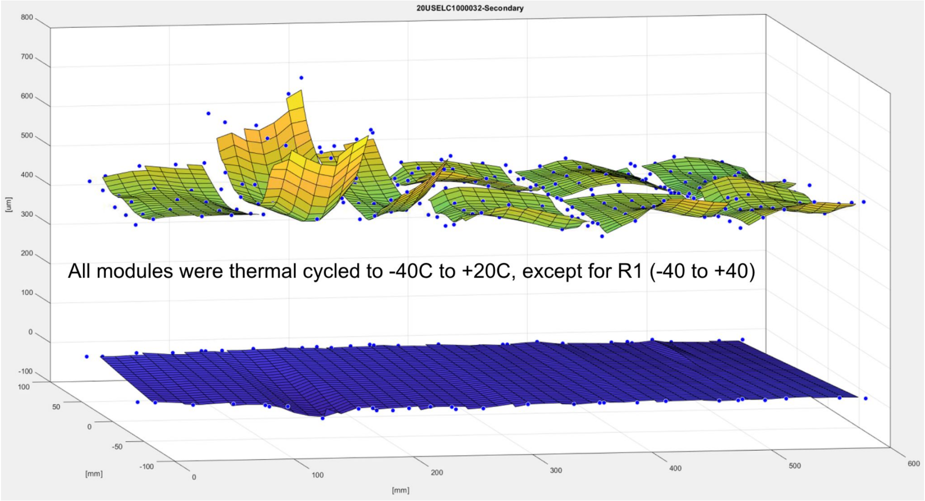
- Module production is streamlined with assembly and QA/QC procedures, e.g.
  - IV scan (look for early breakdown)
  - metrology (measured module bow)



- *Quality concerns caused by quality control - deformation of silicon strip detector modules caused by thermal cycling tests (Richard Salami, et al.)*
  - As part of the QC, modules were requested to be thermal cycled <u>between -35C and +40C</u>
  - Investigation shows this process deforms the module shape
  - thermal cycle now <u>modified to temperature from +40C to +20C</u>, matching the maximum operating temperature.



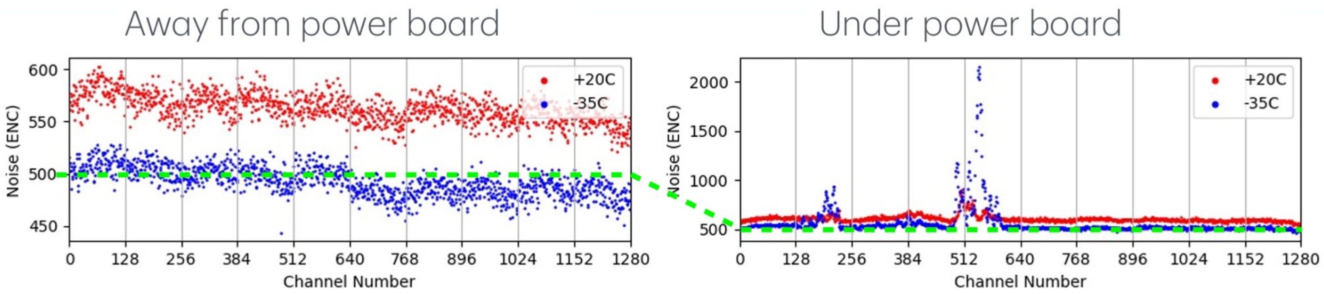
End-cap coldbox

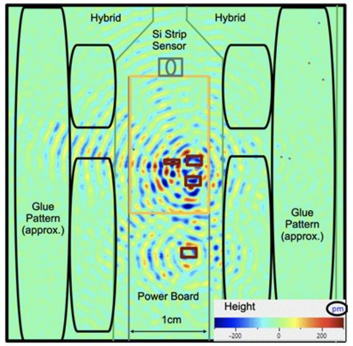


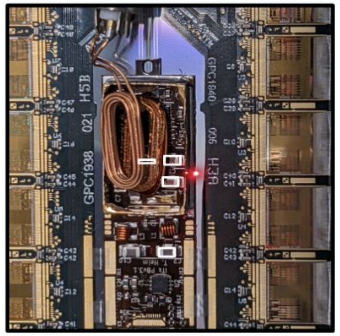
R&D case - module cold noise

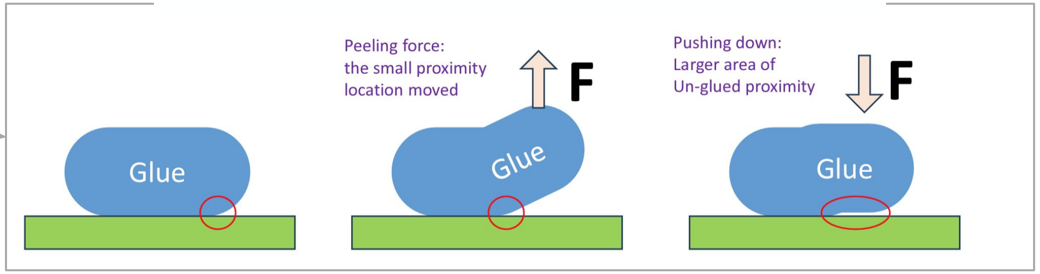
Reference: Sergio PISA poster; Zhengcheng ICHEP talk

- Expect noise level at low temperature to be less, however, observed clusters of **noisy channels around -35C** and some remaining noise even after going back to warm
  - noisy channels only in rows of strips below the power board
- source identified to be **mechanical vibrations** from capacitors on the power board travelling through the sensor and inducing electrical noise
  - Laser vibrometer shows mechanical vibrations propagating through sensors
- Current theory under investigation: cooling cause hybrid to bend and glue to peel off under hybrid edge, releasing charge





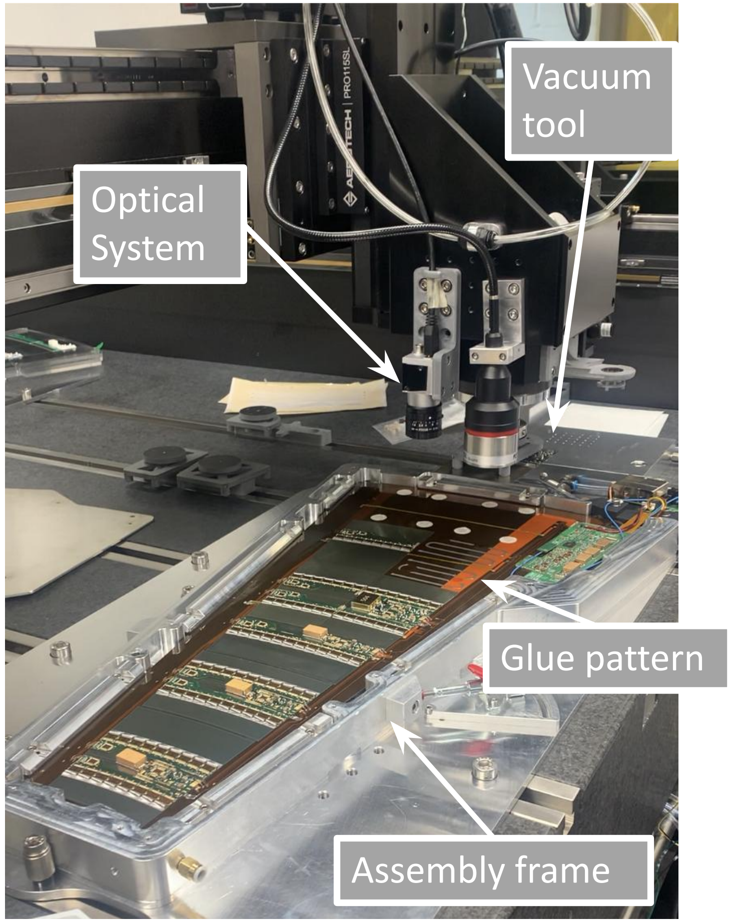


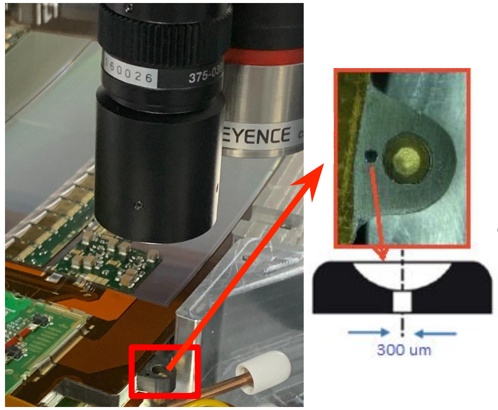


- Mitigation strategies:
  - No cold noise on Endcap modules (magnitude of vibrations on endcap modules is ~10x smaller)
  - No cold noise in long-strip barrel modules using new type of glue
  - Cold noise reduced but still detectable in SS modules with new glue type
- Cold noise no longer blocks the start of module production

Petal loading

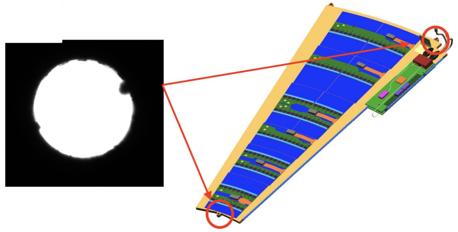
- Automated petal loading: Matlab program that controls robotic gantry to

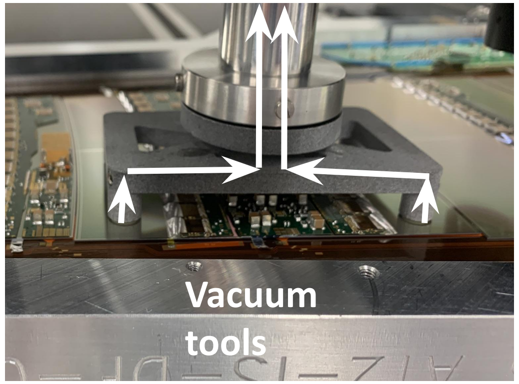




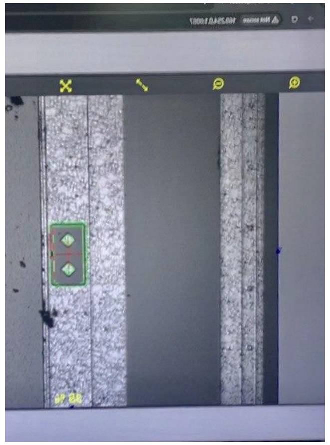
- calibrate between lab frame and petal frame

- Dispense adhesive (thermal conductivity)



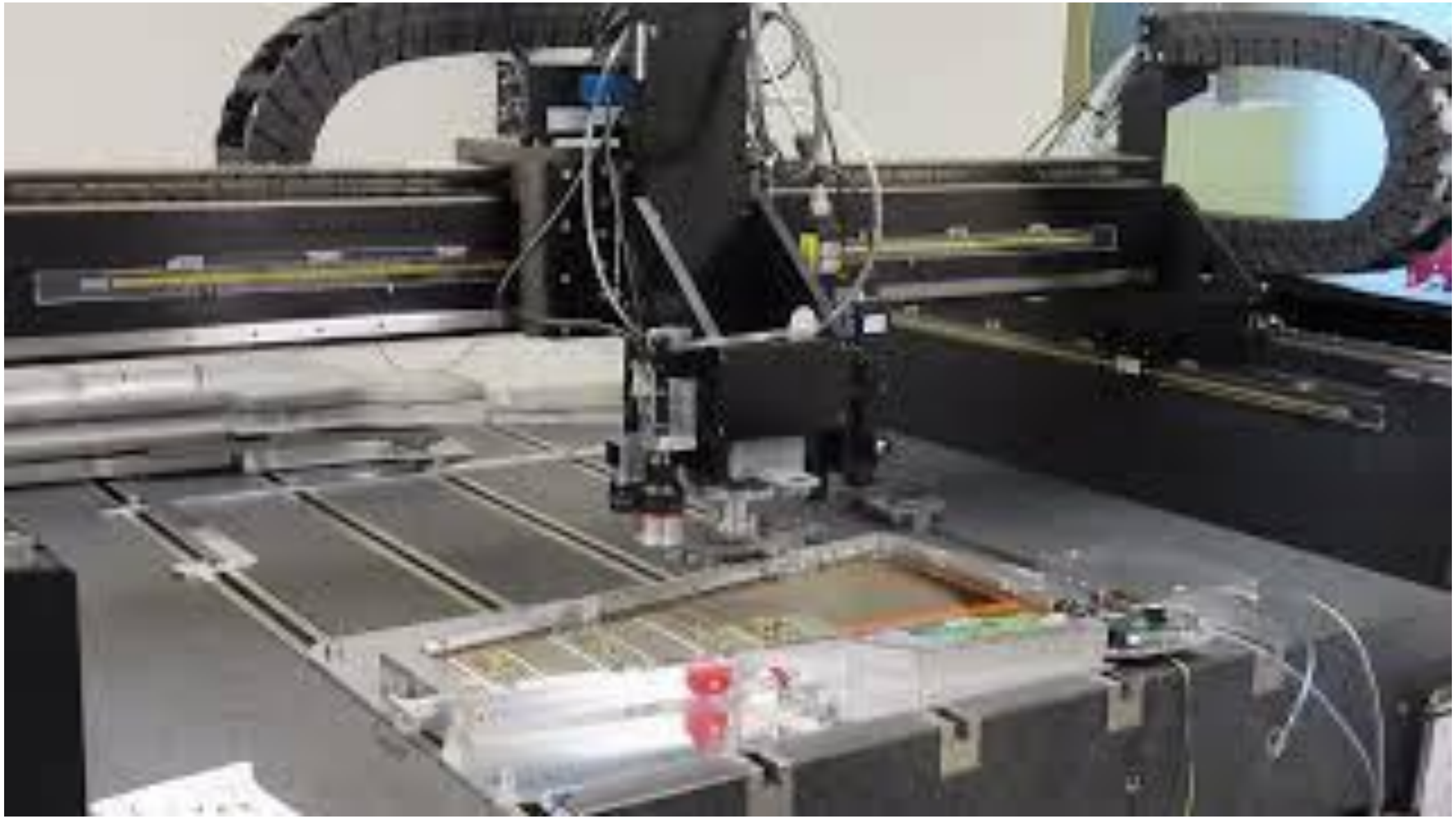


- pick up and place modules precisely (well within 50-micron specification)



- 3D metrology and visual capture
- picture shows field of view from mega-pix cameron on gantry

Petal loading in action

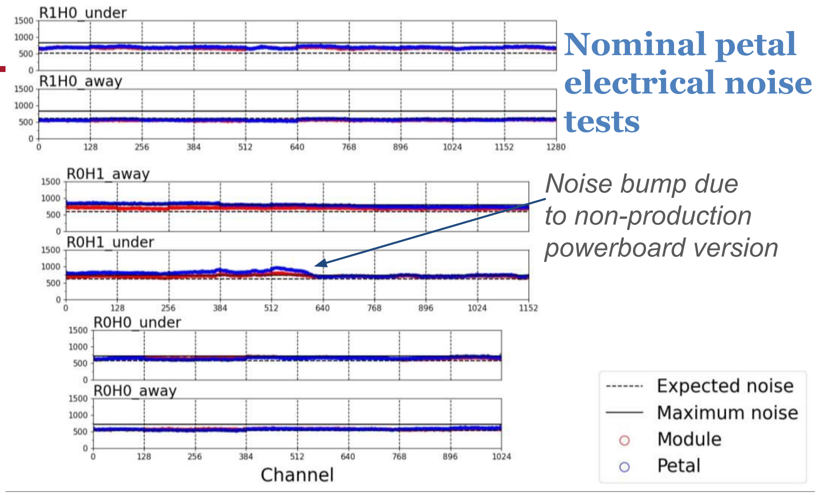


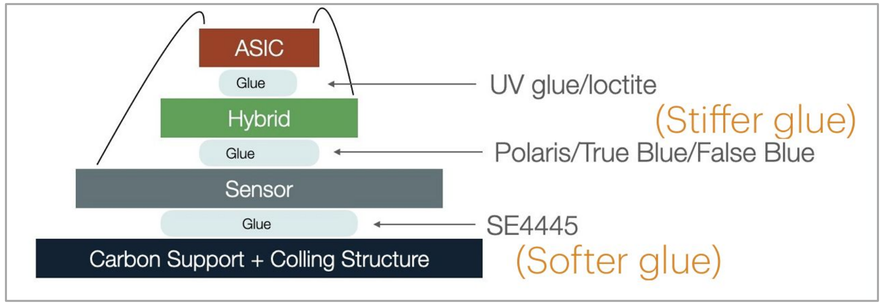
https://www.youtube.com/watch?v=6VzCVn3Wd2U

Local support testing

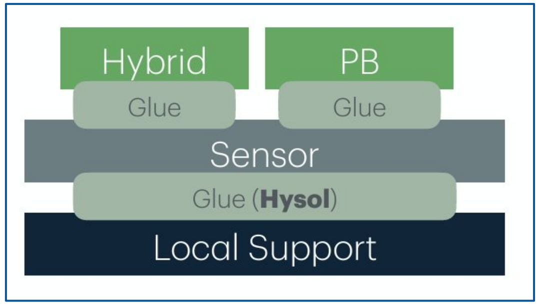
- **Nominal** QC temperature is **-35C** and noise **consistent before** and **after** *loading*
- For temperatures **colder than -35C,** some sensors have early breakdown after loading and visual inspection manifested these sensors have **cracks**
  - source is mismatch of thermal expansion between sensor and electronics
  - -35C is the planned end-of-lifetime temperature, the **goal** is to have **sufficient headroom** to accommodate cooling plant issues / potential failure modes
  - several mitigation strategies are experimented at Vancouver

Nominal petal electrical noise tests

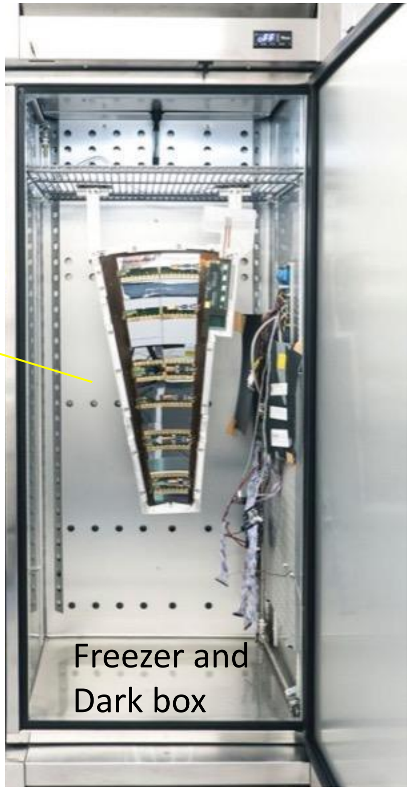




- Original design



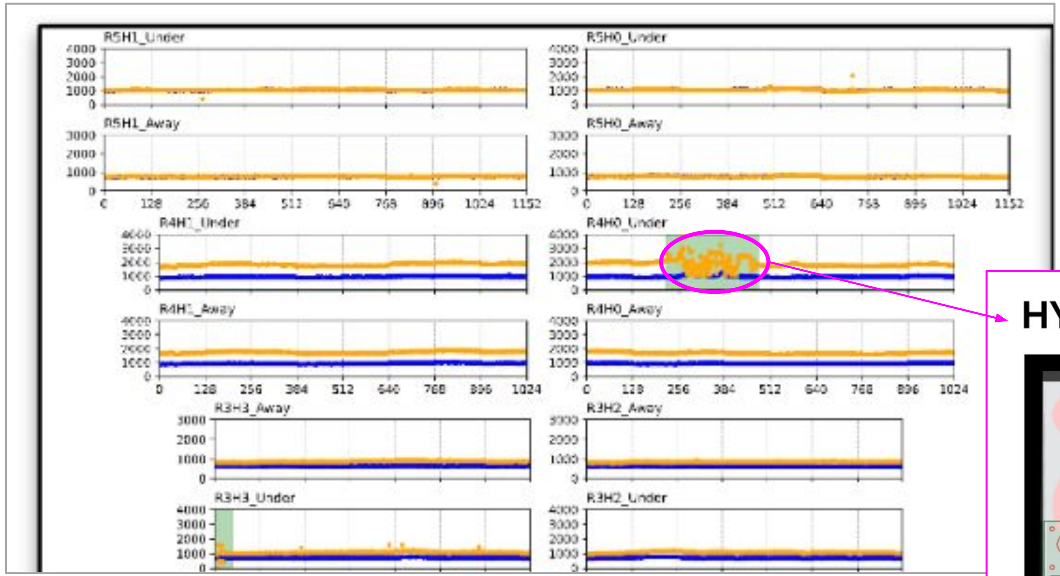
- use **stiffer glue** between sensor and local support
- Need **sufficient glue coverage** to area prone to cracking
- relatively easier solution

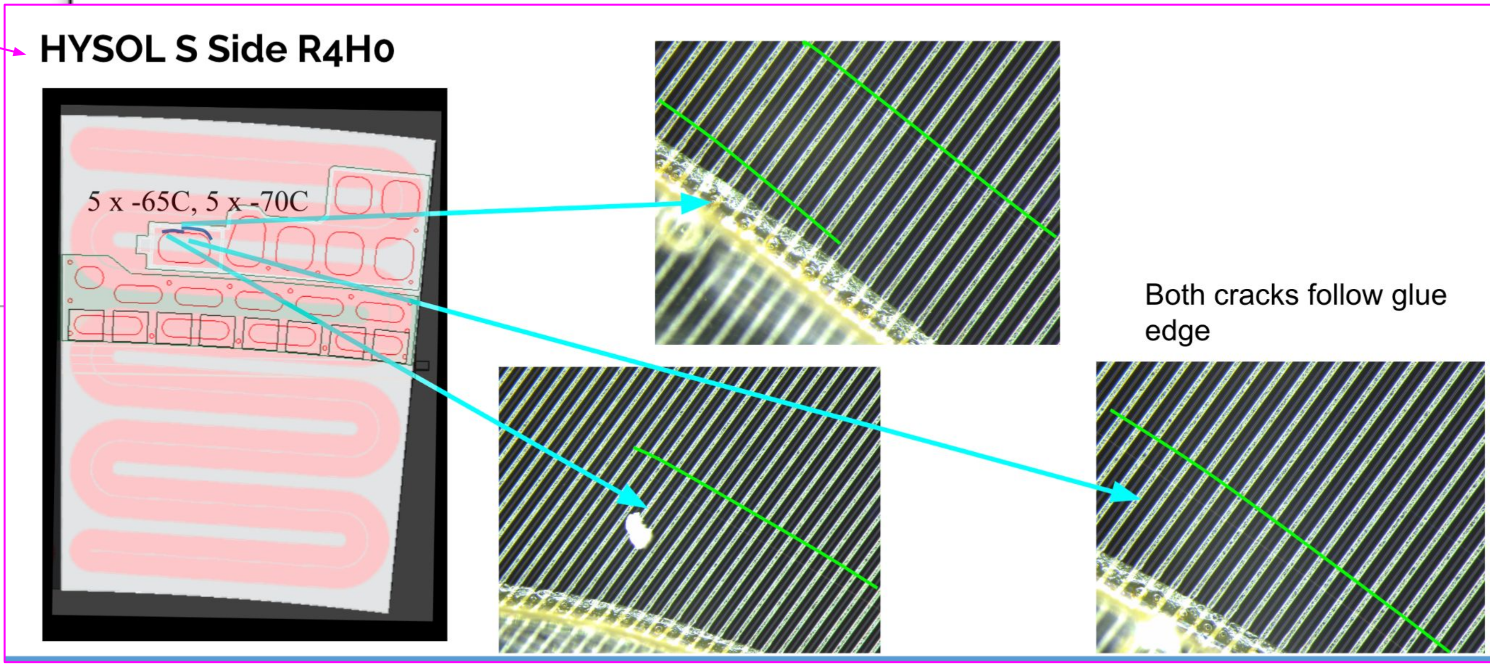


R&D case - identify "crack" suspect

Slide credit: Chaitanya K. Mahajan

- cracking signature: cluster of channels with "bumpy noise"
- Example from the **1st Hysol petal** built at Vancouver
- Cracking is suspected via noise and IV and later visualized under microscope

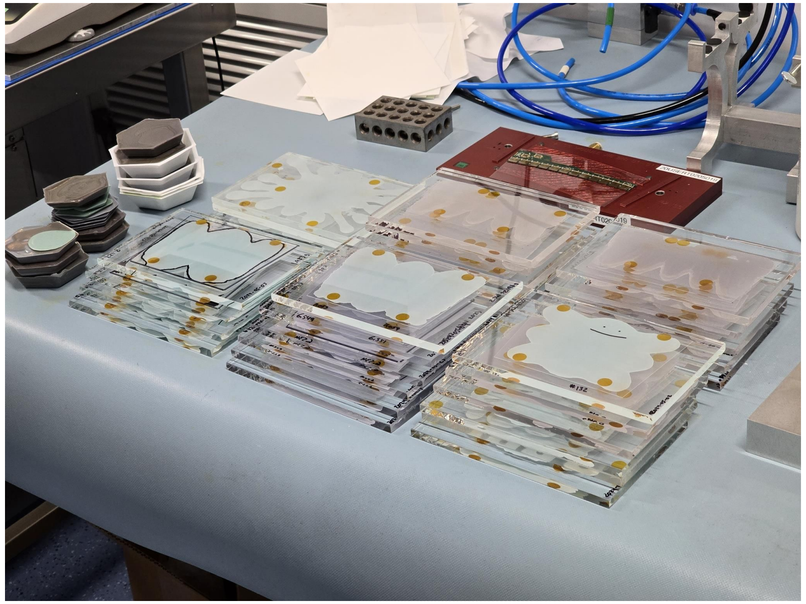


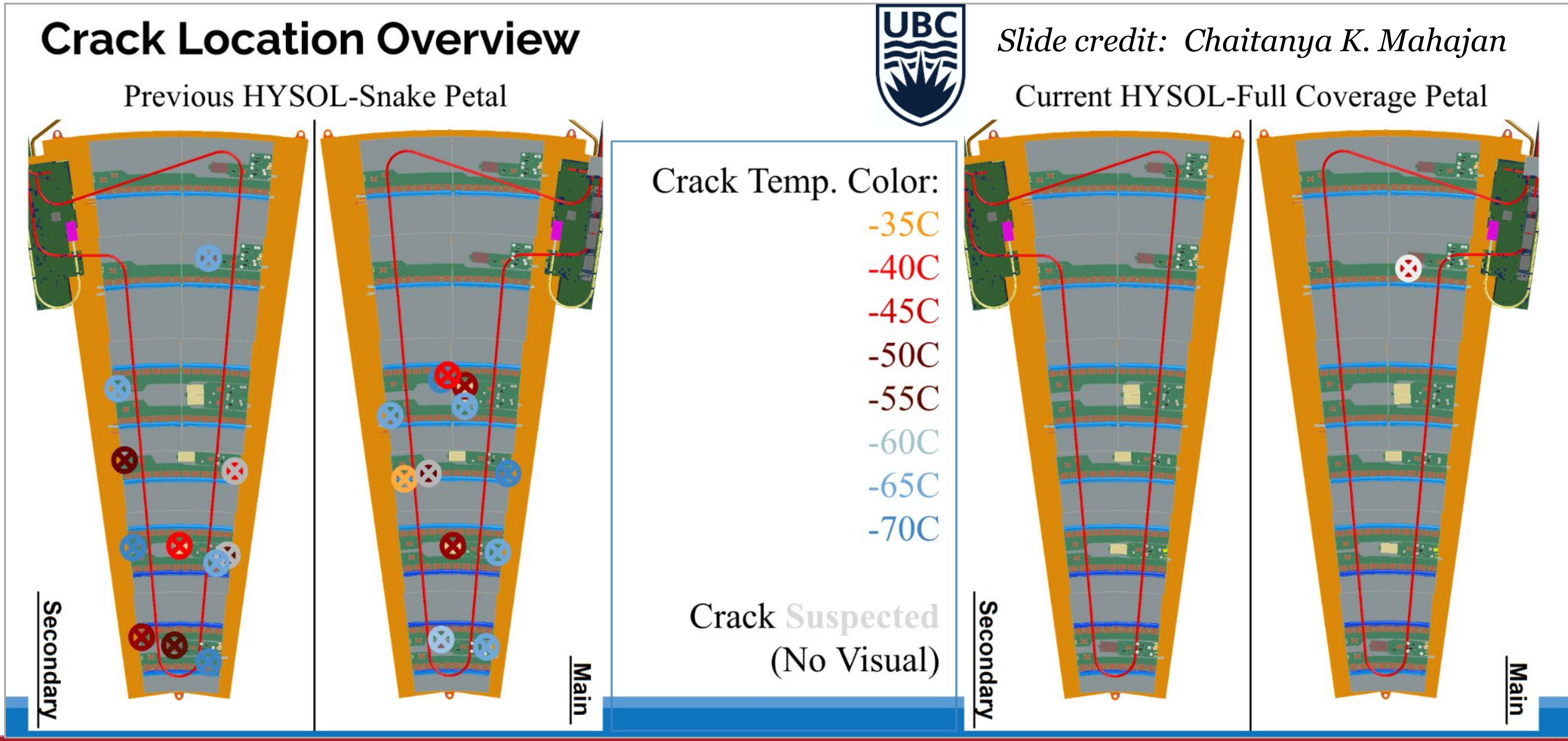


R&D case - study sensor cracking with hysol (stiffer glue)

- After the 1st Hysol petal, an **enormous** amount of work was devoted into glue test, finding the optimal glue coverage
  - see pictures of glue test using plexiglass
- 2nd Hysol petal was freshly built early July and just went through the first week of thermal cycle
  - currently only have one suspected crack (seeing bumpy noise feature), but this petal is undergoing more cycles at the moment to deliver more confirmative results
- The test will continue and other mitigation strategies will also be explored (e.g. adding kapton layer for module)

Picture credit: Andrew Fournier and Scott Beaupre





There's more!

Please take a look at the list of publication of papers of the Vancouver ITk strip team:

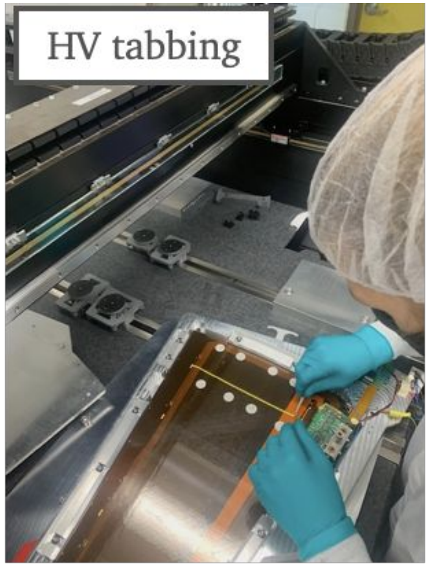
- *All silicon Curing early breakdown in silicon strip sensors with radiation* (Luise Poley, et al.)
  - Controlled irradiation studies on the ITk Strip modules showed that exposure to low levels of radiation can improve the breakdown voltage in susceptible sensors. Gamma irradiation and neutron exposure on silicon sensor test structures both led to discernible improvements in the breakdown voltage. For any future modules showing an early breakdown after assembly, **gamma irradiations** are planned to be conducted to study the reliability of **curing premature breakdown in modules** with radiation.
- *Hot spot visual evaluation of breakdown locations in ATLAS18 ITk strip sensors and test structures* (Andrew Fournier, et al.)
- *Threshold bounce — occupancy-dependent modulation of the discriminating threshold in silicon detectors* (Matthew Basso, et al.)
  - **Threshold bounce is measured** with ITk strip modules using micro-focused photon beam at the B16 Test Beamline at the Diamond Light Source synchrotron. Its impact is significant during beam tests with high local occupancy. However, it is **not expected to impact the operation of the ATLAS ITk strip detector** due to much lower hit occupancy.

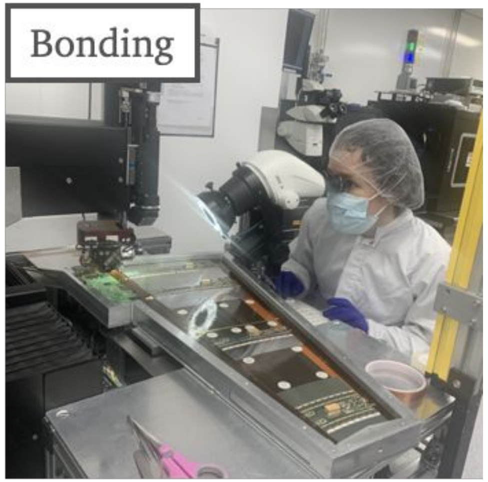
There's more!

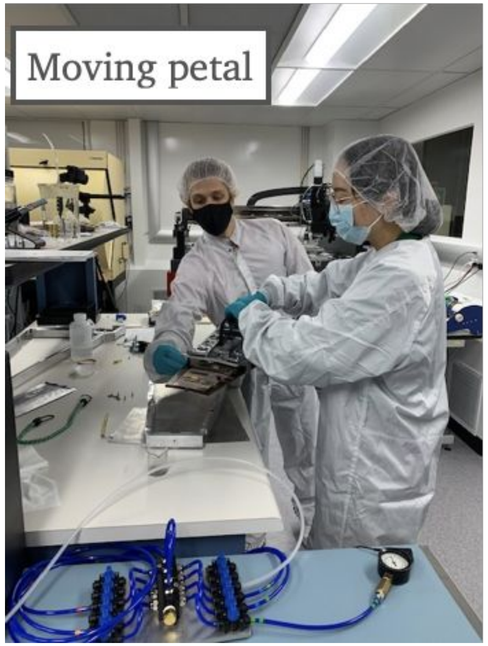
More papers to come:

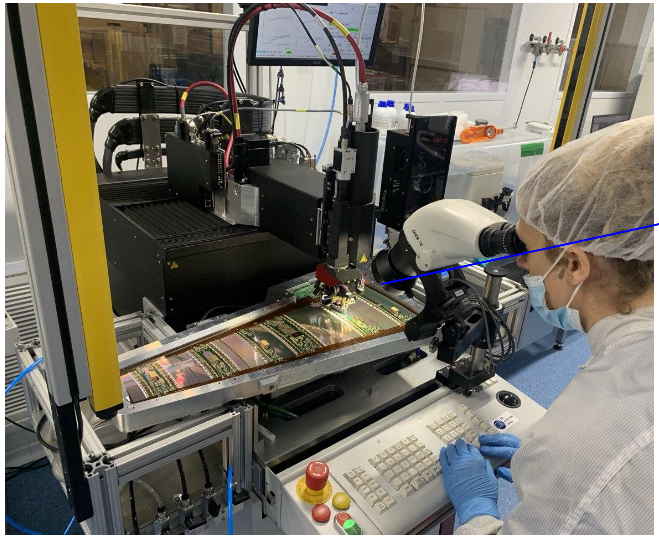
- *Quality concerns caused by quality control - deformation of silicon strip detector modules caused by thermal cycling tests* (Richard Salami, et al.)
    - As part of the qualification control procedure, modules were requested to be thermal cycled between -35C and +40C. An investigation has shown that this process deforms the module shape and therefore calls for modification to the thermal cycle procedure which now reduced temperature from +40C to +20C, matching the maximum operating temperature.
- *Early breakdown caused by sensor defects* (Jack Osieja, et al.)
    - we know that some effects cause early breakdown on sensors (glue on guard ring, scratches), but not why it happens sometimes and sometimes not and what the mechanism is. This study uses ITk sensor diodes to introduce defects in a controlled way and to check the impact on the breakdown voltage afterwards to get **a better idea of what causes early breakdown and why**.
- *Investigating the impact of the diode edge ring geometry on the active area of silicon sensors using AREA-X* (Luise Poley, et al.)
    - This one studies how various design geometry parameters affect the diode behaviour, mostly for **future sensor designs**. The assumption used to be that the active sensor area is defined by the size of the guard ring and bias ring, but we have shown that it actually depends on the sensor edge ring and is almost independent of the other two, which is important to know for future sensors.

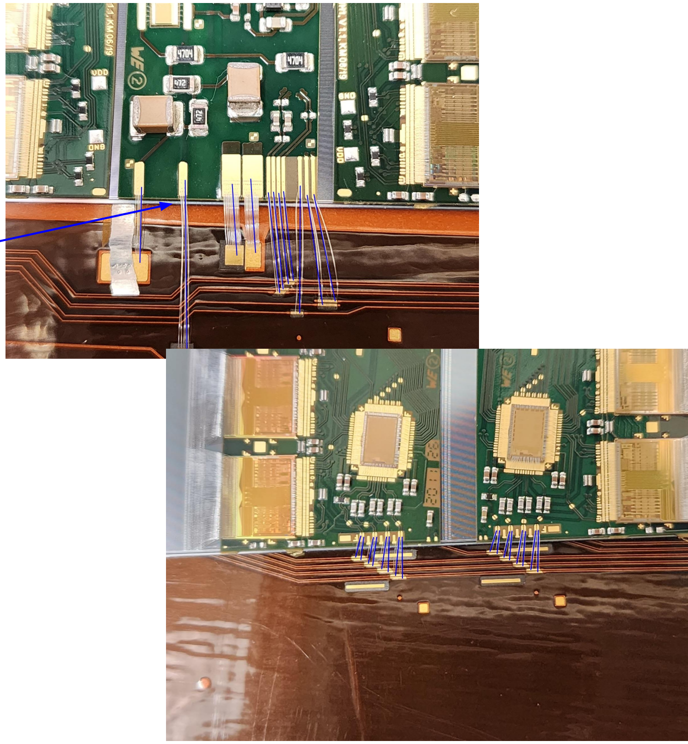
Thank you and questions?











ATLAS ITk

SFU TRIUMF

Backup

Local support testing

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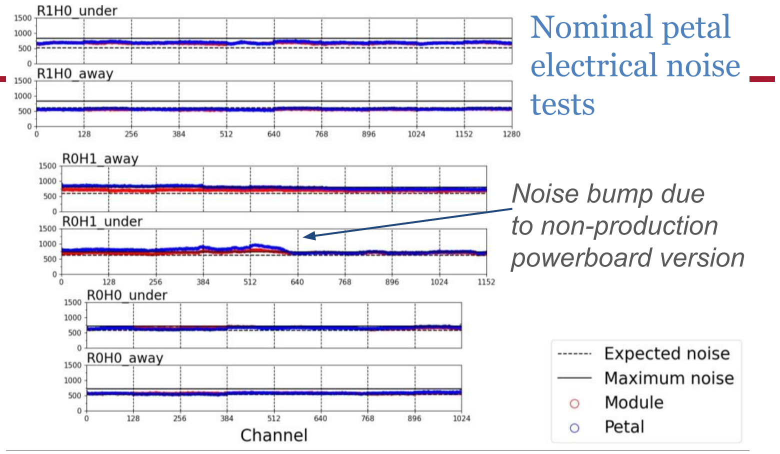
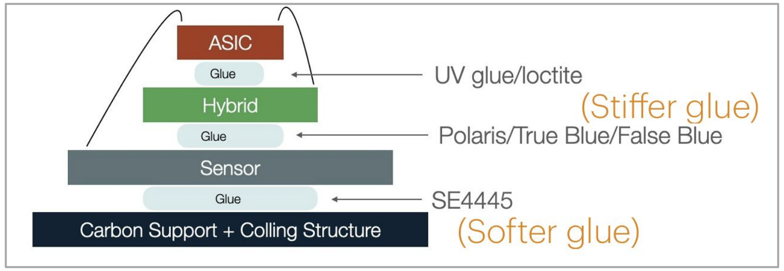
    - source is mismatch of thermal expansion between sensor and electronics
    - -35C is the planned end-of-lifetime temperature, the Goal is to have sufficient headroom to accommodate cooling plan failure modes
    - several mitigation strategies are experimented at Vancouver



Nominal petal electrical noise tests

Noise bump due to non-production powerboard version



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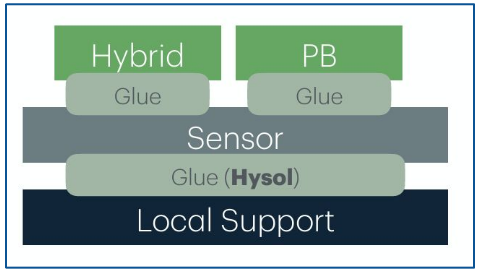

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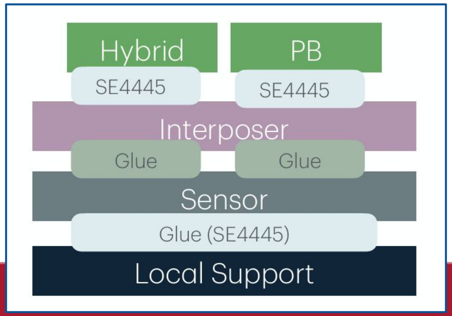
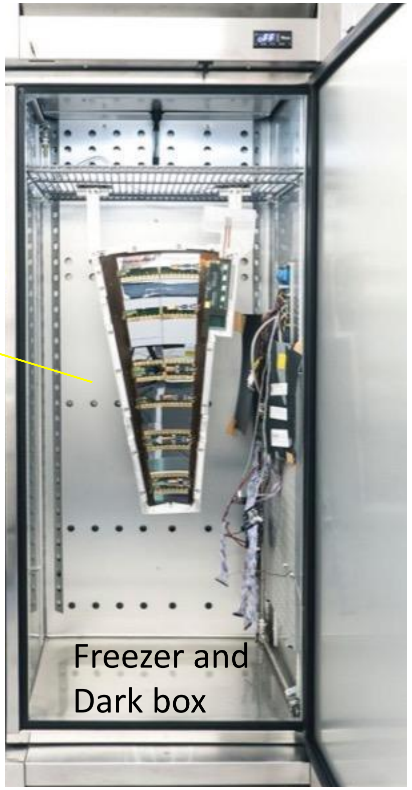
- relatively easier solution



- Additional **kapton layer for module assembly**
- would be major module design change and comes with additional QC



R&D case - sensor cracking with hysol (stiffer glue)

- 2nd Hysol petal noise after TC

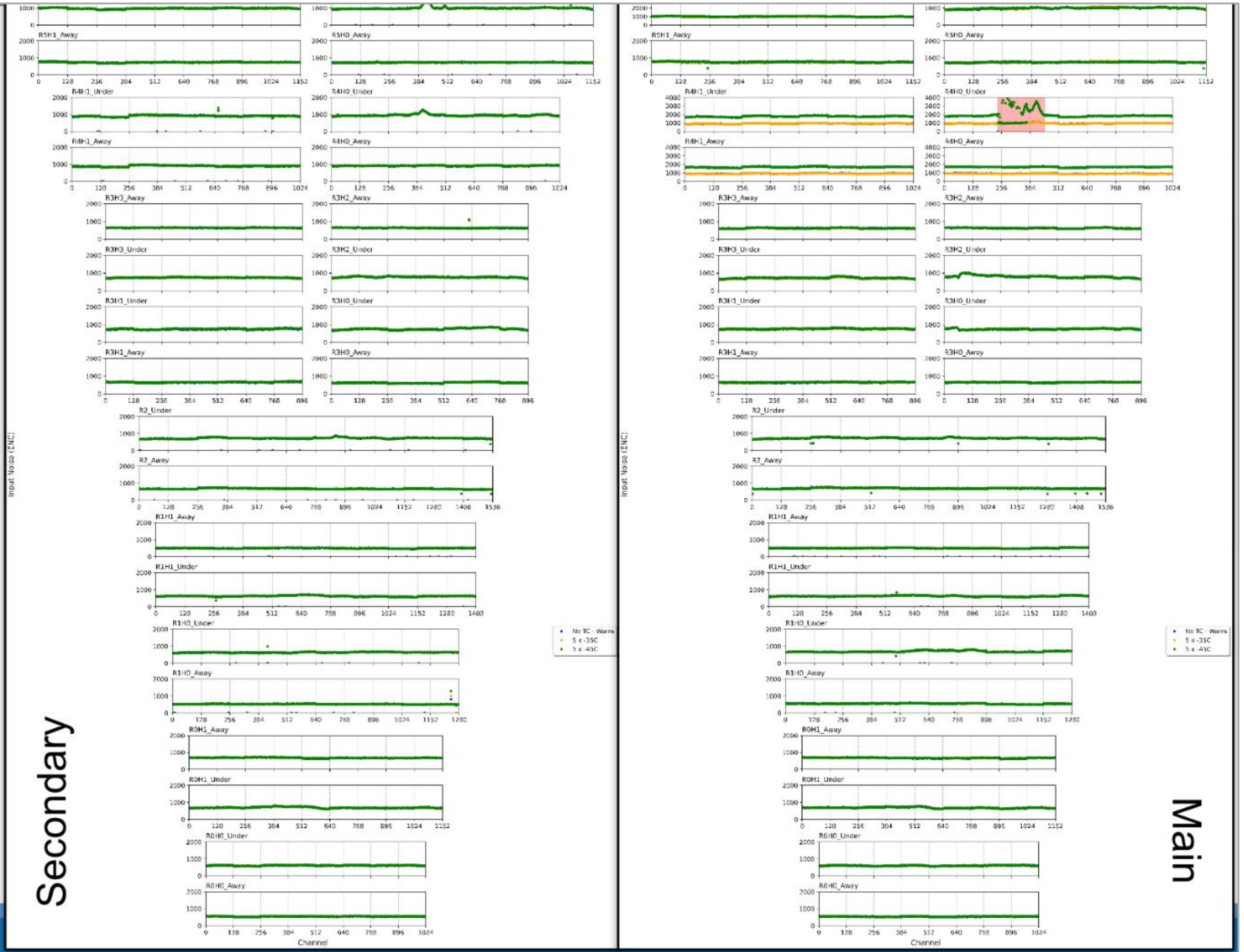
Slide credit: Chaitanya K. Mahajan

Noise Overview

Full coverage petal
(tested down to - 45C)

Blue: No TC - Warm
Orange: 5 x -35C
Green: 5 x - 45C

- Petal cycled to temperature lower than end-of-lifetime temperature (-35C) or QA (-55C)



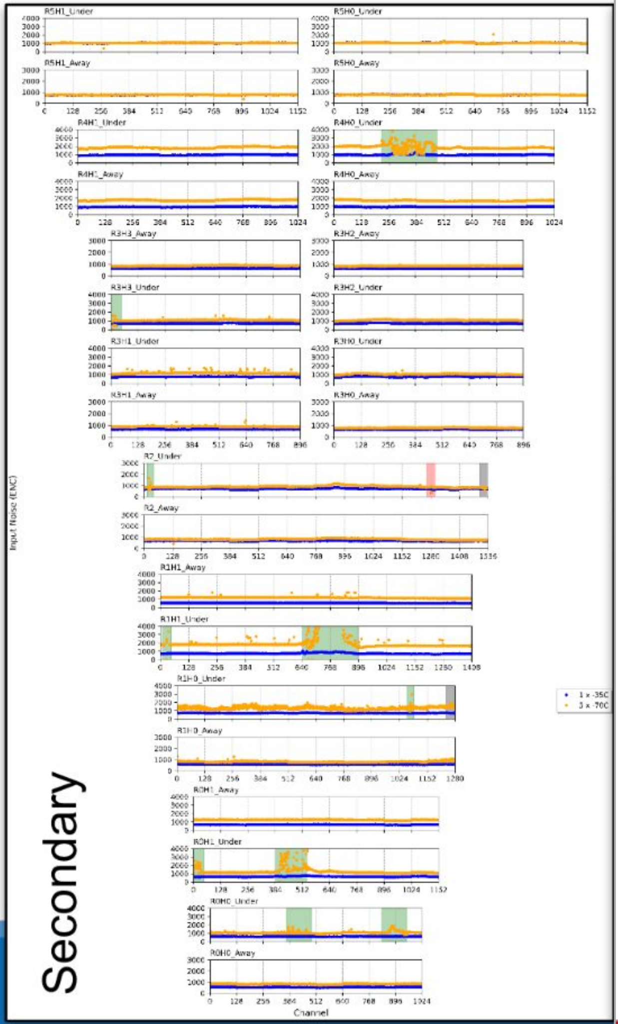
R&D case - sensor cracking with hysol (stiffer glue)

- 1st Hysol Petal

Slide credit: Chaitanya K. Mahajan

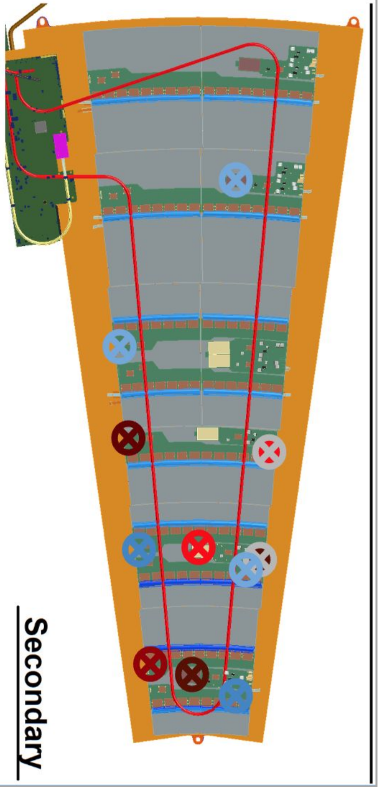
Crack Location Noise Overview

Green highlight: seen visually
Gray highlight: not seen
Red highlight: likely not a crack (feature present since no TC)



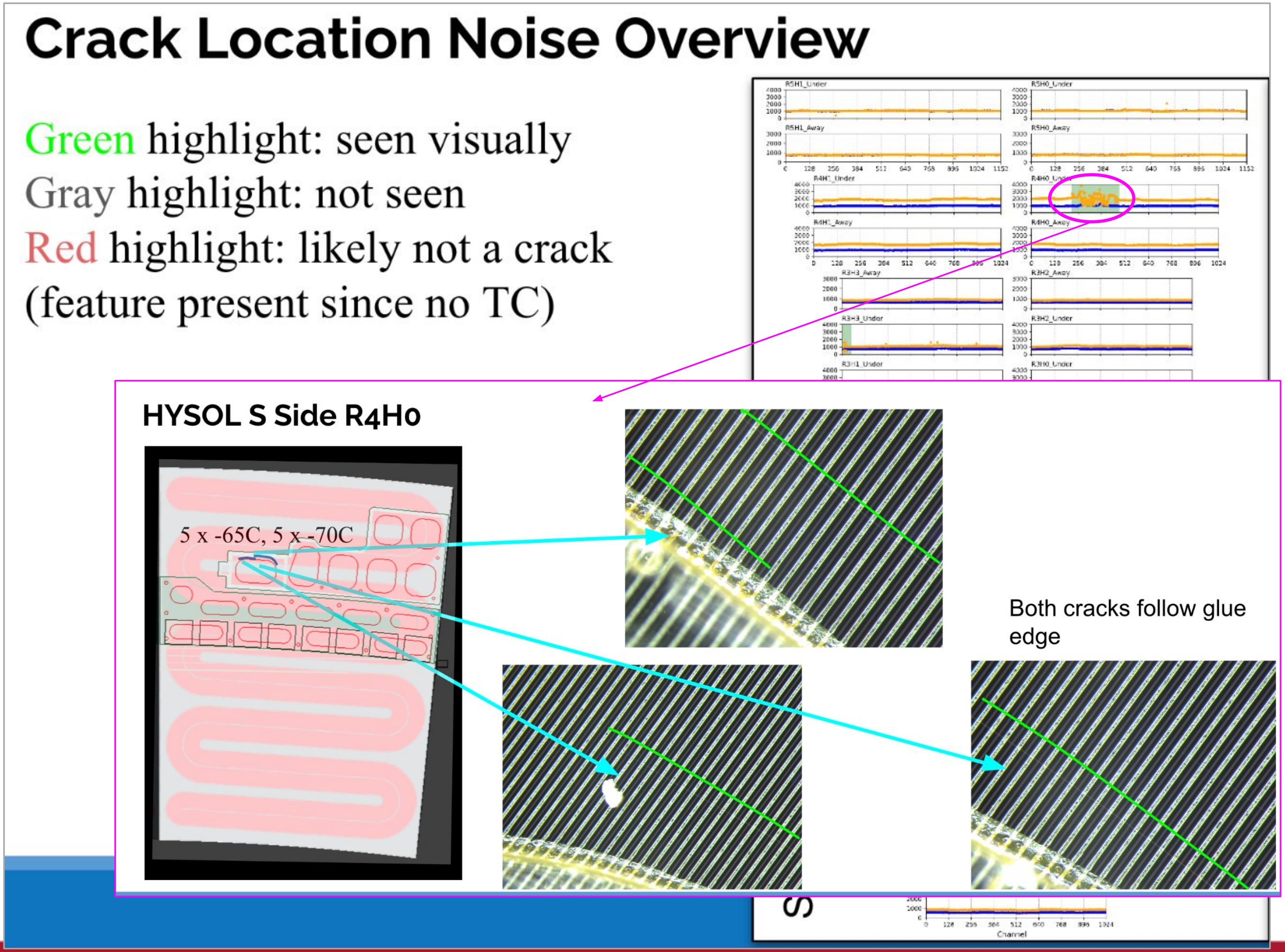
Crack Temp. Color:
-35C
-40C
-45C
-50C
-55C
-60C
-65C
-70C

Crack Suspected (No Visual)

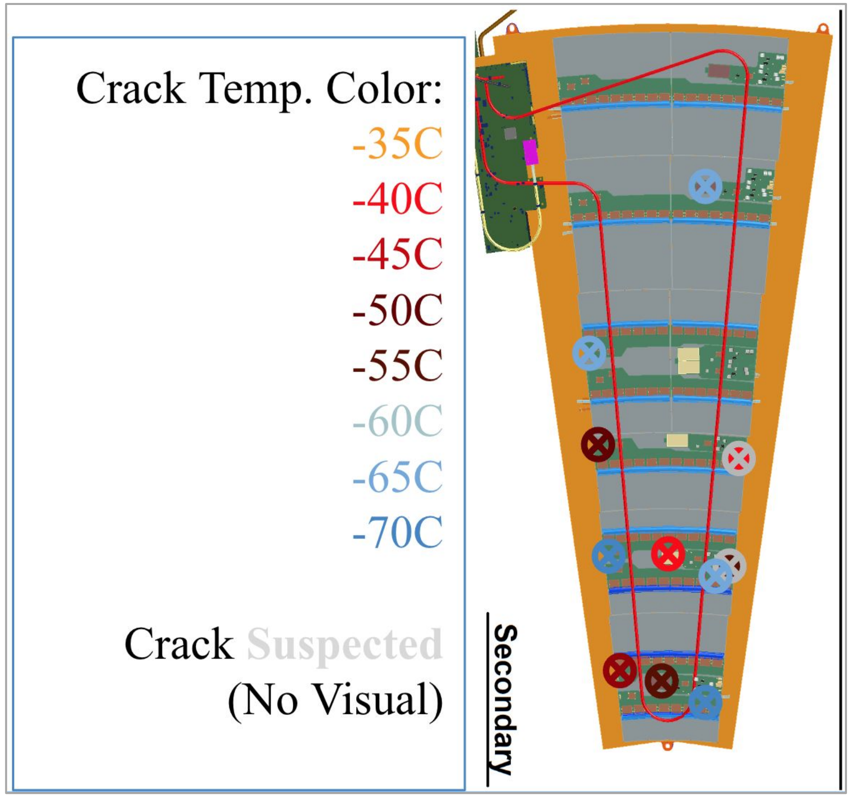


- Petal is cycled in climate chamber to temperature much lower than end-of-lifetime temperature (-35C)

R&D case - sensor cracking with hysol (stiffer glue)



Slide credit: Chaitanya K. Mahajan



- Petal is cycled in climate chamber to temperature much lower than end-of-lifetime temperature (-35C)