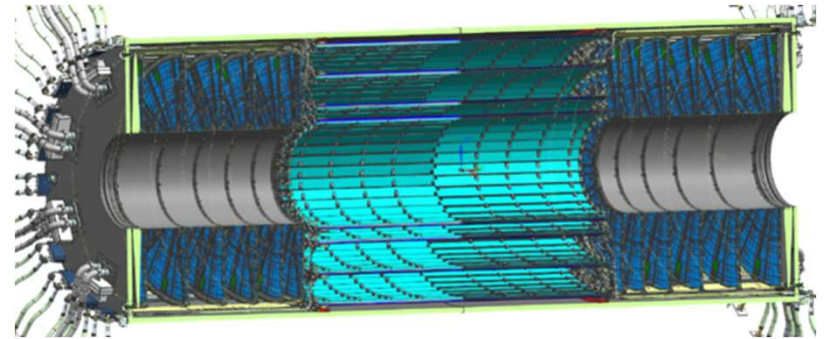


Experiences gained during pre-production of a large-scale detector: expect the unexpected

Sergio Díez Cornell, on behalf of the ITk strips community
Detector R&D retreat@DESY, 19.01.2024



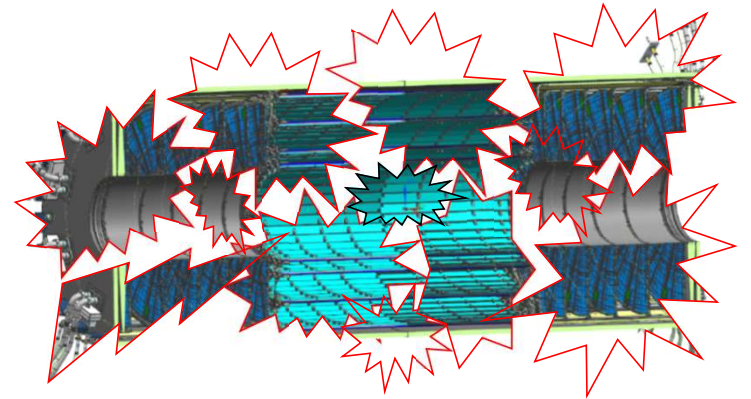
HELMHOLTZ



Experiences gained during pre-production of a large-scale detector: expect the unexpected

Short version title: PANIC AT THE ITK!!!

Sergio Díez Cornell, on behalf of the ITk strips community
Detector R&D retreat@DESY, 19.01.2024

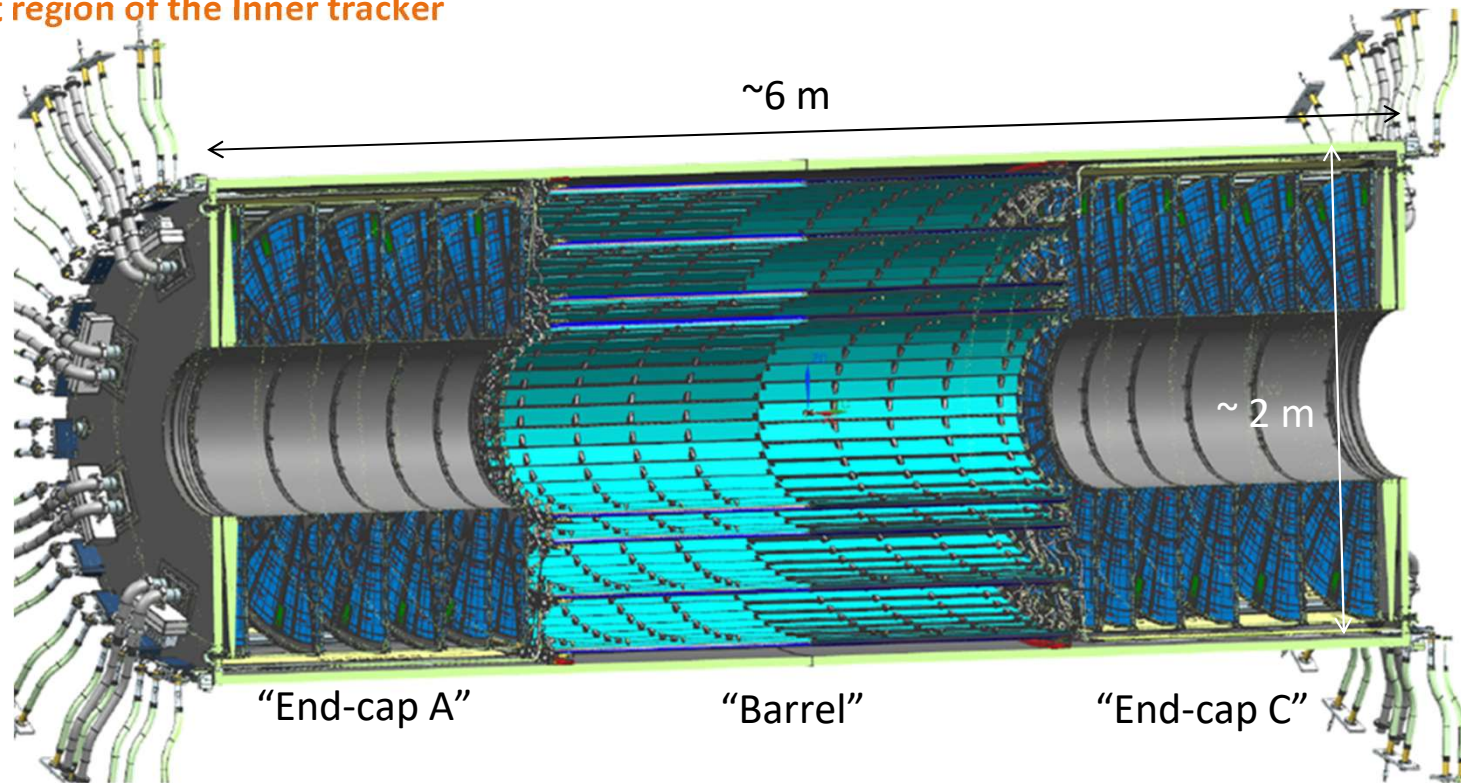


HELMHOLTZ



The strips tracker

The outermost region of the Inner tracker

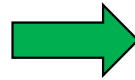
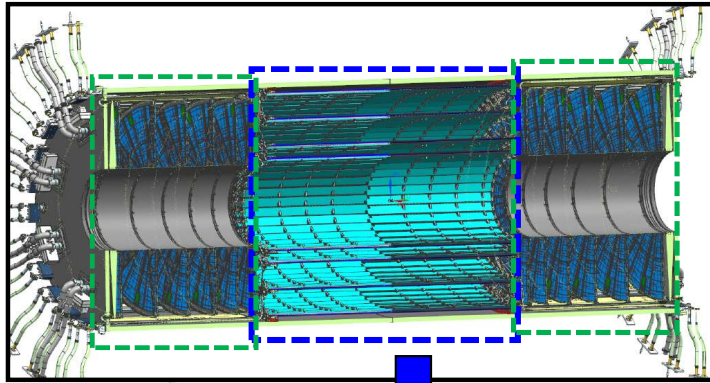


4 barrel cylinders, 6 EC disks per side

180 m² of silicon, 15584 silicon "modules", 60 M channels

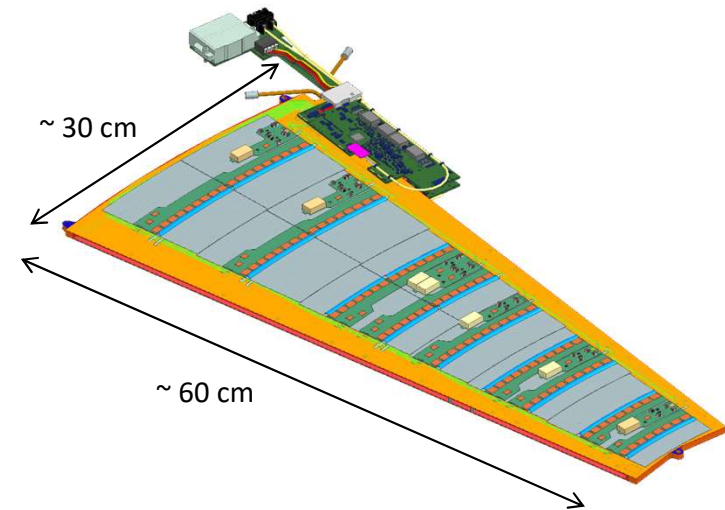
The strips tracker

“Stave” and “petal” concept



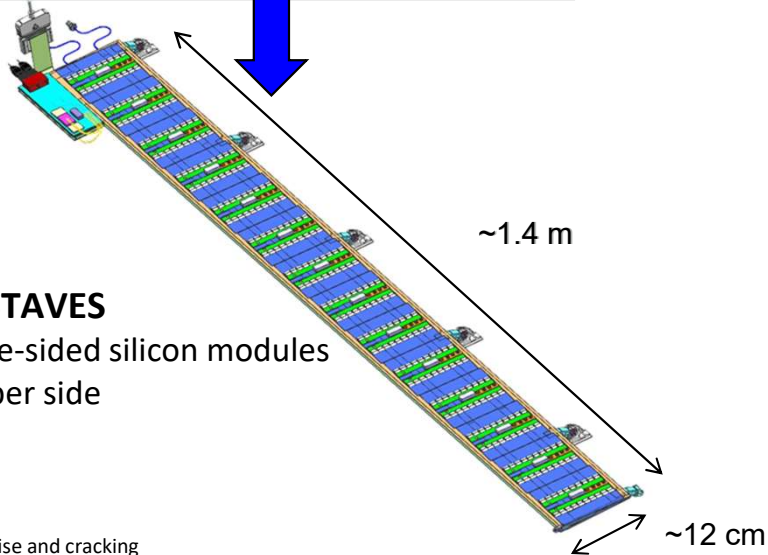
PETALS

6 types of single-sided silicon modules per side



STAVES

14 identical single-sided silicon modules per side

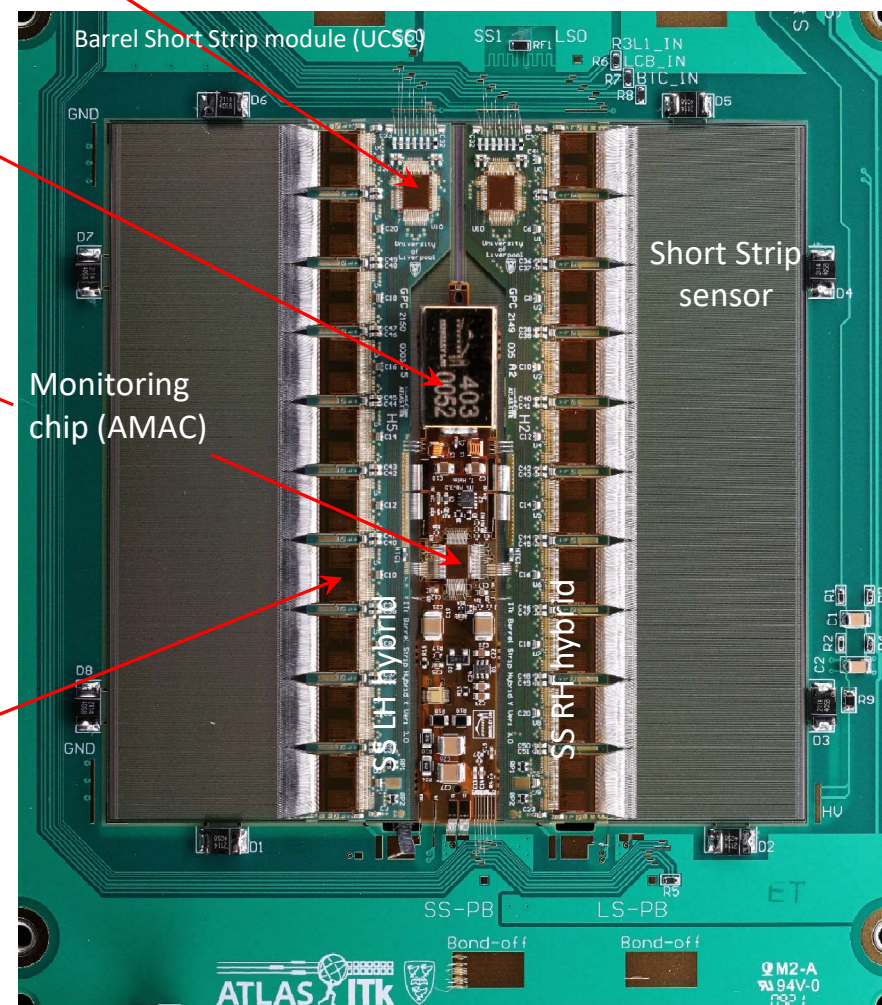
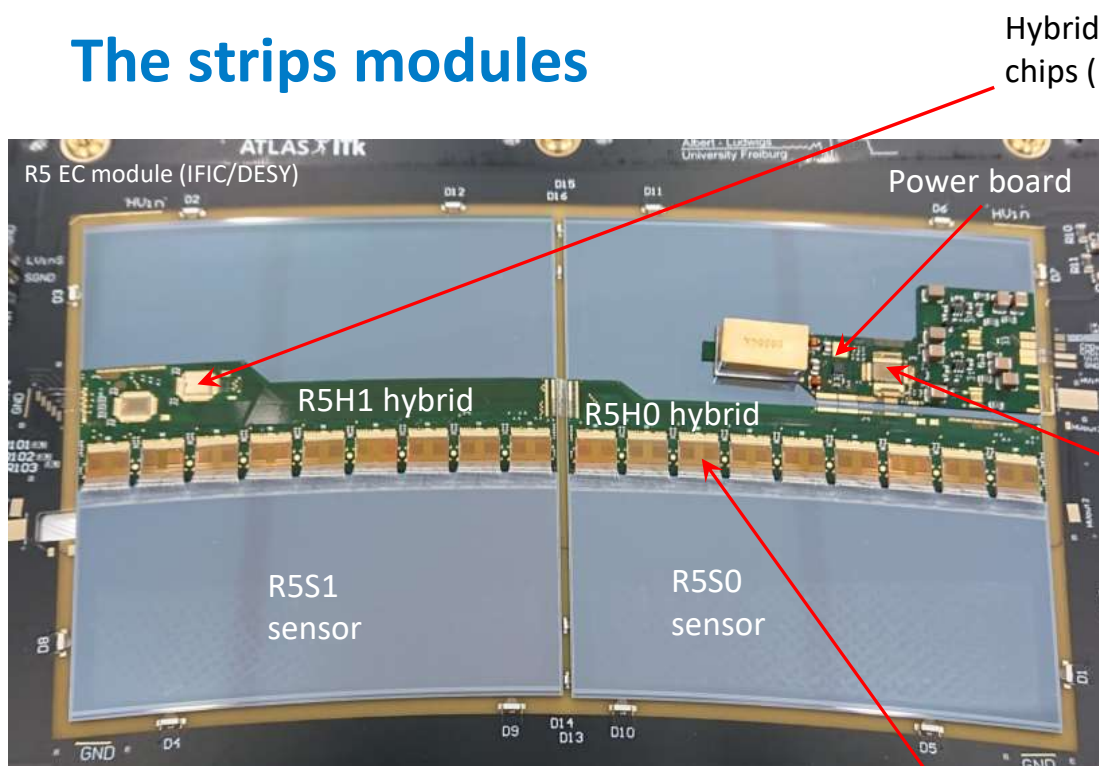


Carbon fiber “sandwich” structures supporting multiple strip silicon modules inside the tracker

Modules are directly glued onto the structures

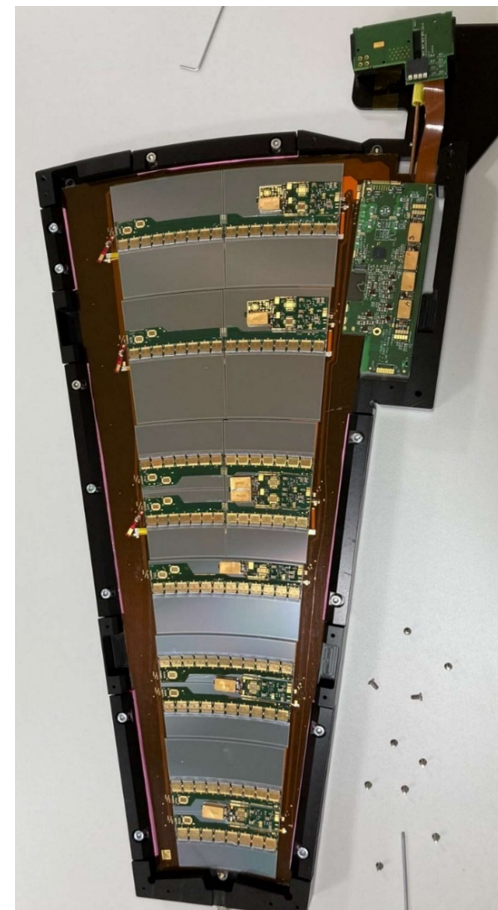
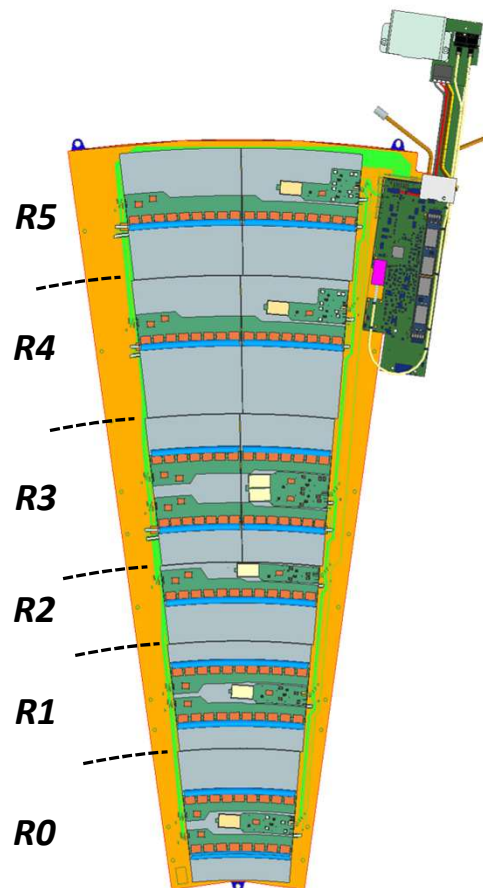
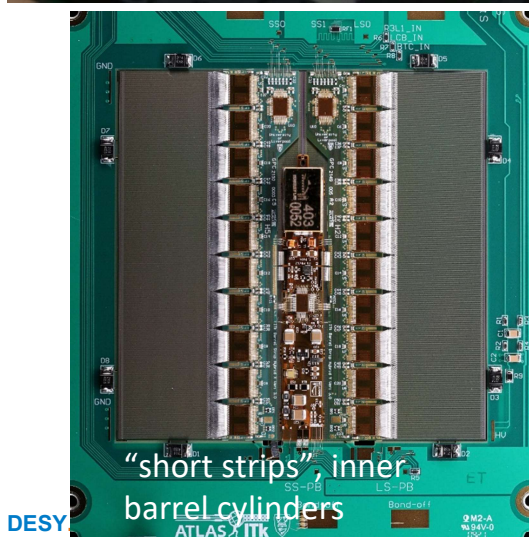
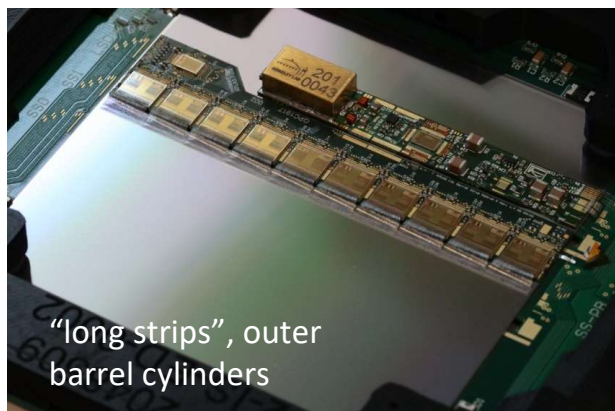
Single power/data cable per stave/petal side

The strips modules



Module flavors

2 module flavors in the barrel, 6 in the ECs



Standing issues at the ITk

Expect the unexpected

An extensive prototyping effort has been one of the trademarks of the strips ITk tracker

Hundreds of modules and dozens of staves and petals have been built and tested over the different phases of the experiment (prototyping, Pre-production A, Pre-production B,...)

- ❖ Three generation of HPK sensors (ATLAS7, ATLAS12, ATLAS18) and GF ASICs (ABC25, ACB130, ABCStar, with different versions each) have been utilized for this effort

Despite this, **not one, but two massive standing issues** surfaced on the verge of module production, with the very last pre-production version of components which (we are almost sure) were not present in any earlier prototyping stage:

- ❖ **Cold noise**, discovered ~June 2022
- ❖ **Sensor cracking on loaded modules**, discovered ~ May 2023

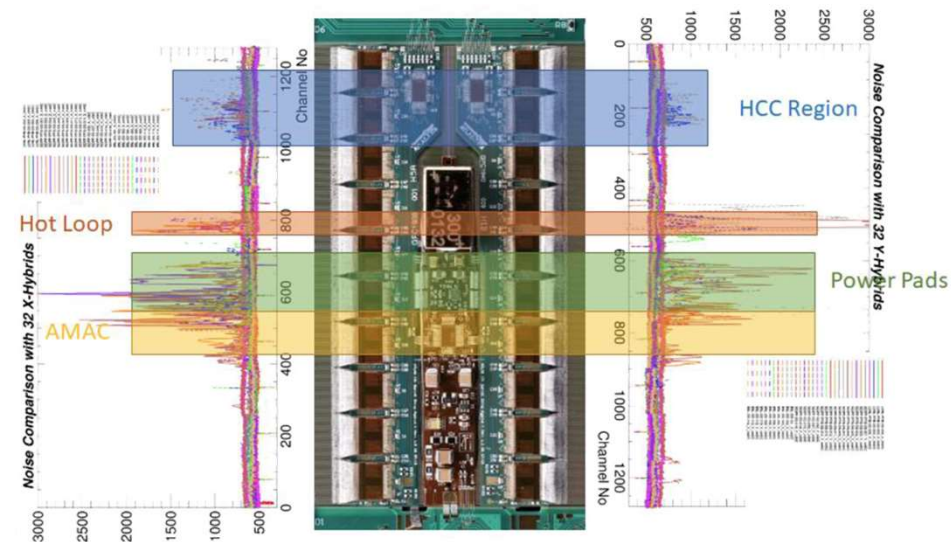
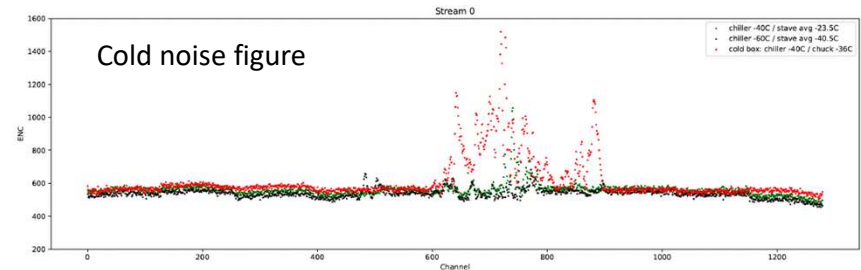
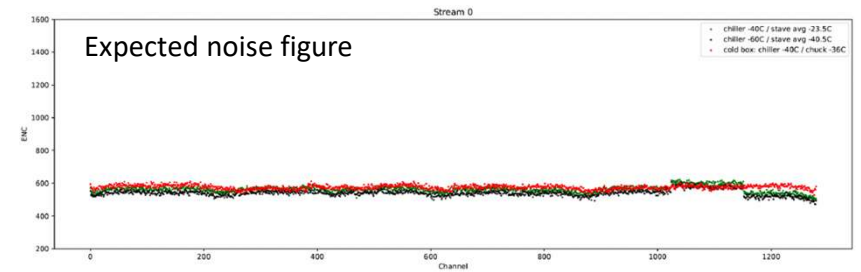
Two taskforces were quickly formed within the ITk strips community and a huge effort has been devoted to understand and solve/mitigate both issues

Cold noise on modules

Main observations

When cooled down, noise peaks occur in different areas of the module

- ❖ Turns on at different temperatures (typically -10 C)
- ❖ Affects specific sections of modules
- ❖ Typically reversible when module warmed again
- ❖ Increasing power leads to increasing effect
 - Short strip modules more prone to cold noise
- ❖ Observed on single modules as well as staves
- ❖ It was not observed on prototype modules
- ❖ It was not observed in endcap modules

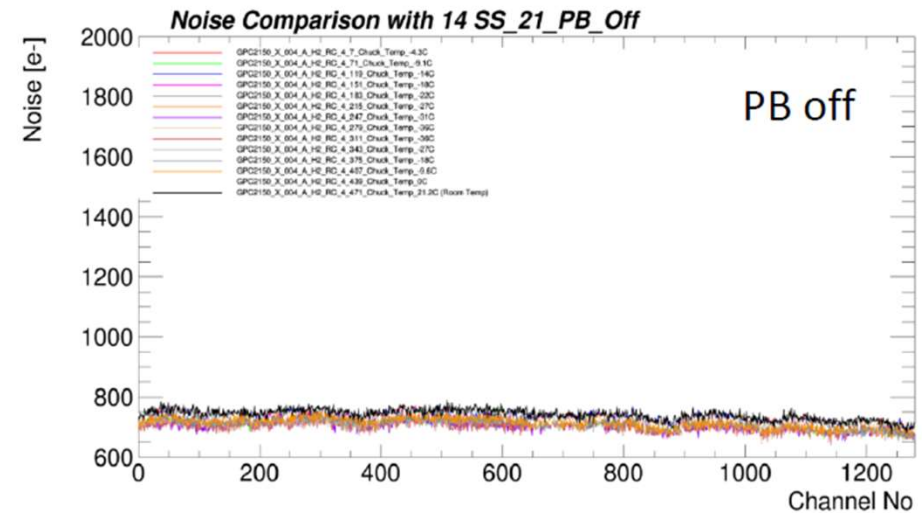
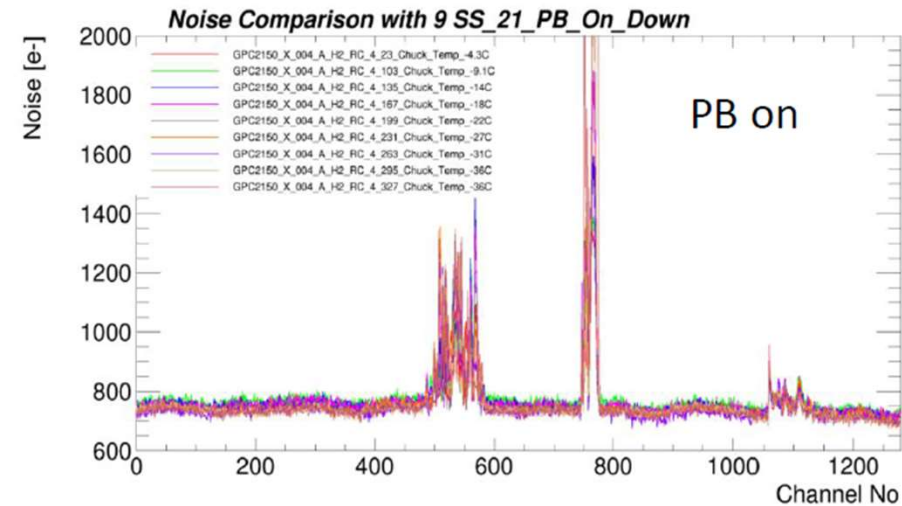
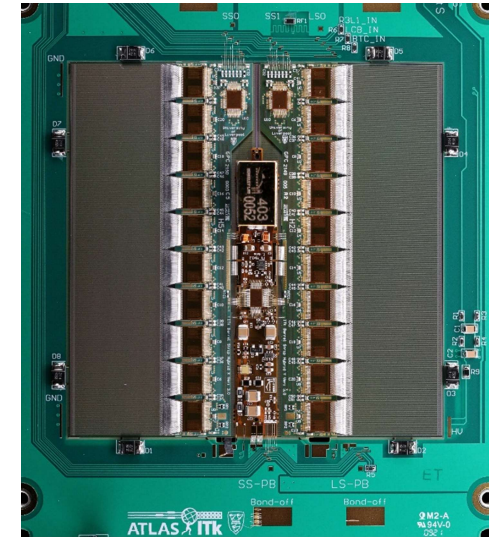


No power board – no problem

Identifying the source

Quickly isolated the source of the noise to the power board

- ❖ By powering hybrids externally on modules with known cold noise we were able to turn cold noise on/off via the power board



Vibration → electronics

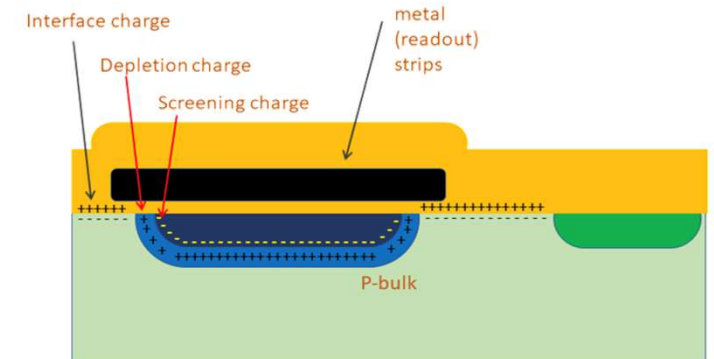
Coupling mechanism?

Coupling mechanism creating the electronics noise not completely understood

❖ Three main theories:

1. CN caused by fixed charges in partially depleted strips on the edges of an implant
 - Unscreened depletion charge on the edge of an implant
 - Vibrations cause oscillations in coupling capacitances translated to increased noise
2. CN caused by changes on the voltage offset across AC coupling capacitors
 - Vibrations cause oscillations in coupling capacitances translated to increased noise
3. Mechanical stress hypothesized as a contributing factor for CN

❖ Tests performed up to now do not allow to fully discard or confirm any of these yet



The good news

Mitigation steps

- ❖ No cold noise seen for end cap modules (all types) for both TrueBlue and FalseBlue
- ❖ No cold noise seen as of yet for barrel LS modules (PPB and production) built with TrueBlue
 - **No CN issues for EC and LS production!**
- ❖ CN does not seem to evolve with irradiation and/or environment
 - So far, minimal changes with gamma irradiations
 - No change seen in a magnetic field- Confirmed with full field magnetic test
- ❖ Vibration of the power board does not seem to be a long term reliability risk

Next steps:

- ❖ Continue studies to understand coupling mechanism
- ❖ Find a viable mitigation for SS modules
 - One of our best hopes is the usage of an endcap-like stack up for the SS power board
- ❖ Understand the impact of (reduced) CN on SS on the detector performance
 - Test beam and simulations

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 - One of our best friends
- ❖ Understand the impact of (reduced) CN on SS on the detector performance
 - Test beam and simulations

**Production could start for EC and LS modules!
...but then...**

Enter sensor cracking

Joining the fun

Late last May, it started to become statistically evident that a fraction of modules were exhibiting early breakdowns after cold temperatures

Most modules seemed to test well at previous stages of QC

- ❖ A few appeared to breakdown after thermal cycling
- ❖ A couple appeared to breakdown during the cold phases of thermal cycling
- ❖ **Most exhibited breakdown after loading to staves**

Indications of potential issues in

- ❖ Barrel and Endcap
- ❖ Different generations of parts (PPA & PPB)

Some of these breakdowns were reversible and associated to known factors, however...

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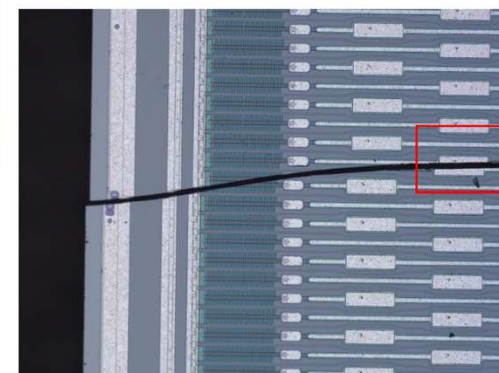
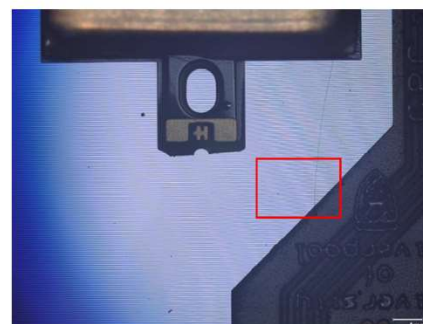
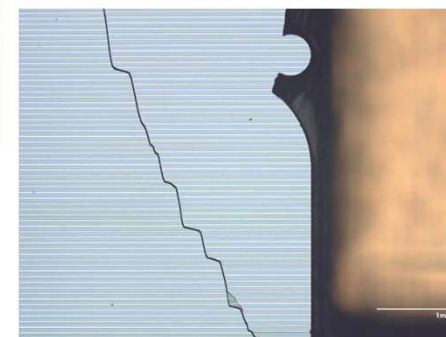
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An Early breakdown $\ll 100$ V with high current was observed associated to cracking of sensors on loaded objects (staves, petals)



Simulations

A powerful diagnostics tool

Strong effort put in place looking at thermo-mechanical simulations of SS, LS and EC modules on staves/petals

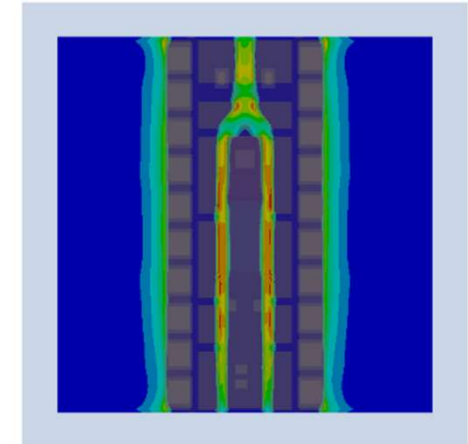
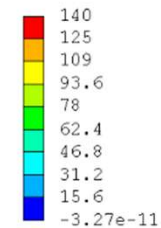
(Many thanks to Giorgio Vallone, Haider Abidi, Eric Anderssen, Bernie Matthews, Masahiro Mori)

While progressively adding more realistic mechanical parameters, simulations reached the same conclusion: **high stress regions coinciding with the observed crack formation regions**

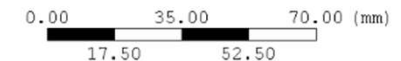
Weekly meetings to discuss results and sequential/parallel approach on what to simulate

Effort ongoing, but already obtained extremely helpful results that are guiding our mitigation efforts

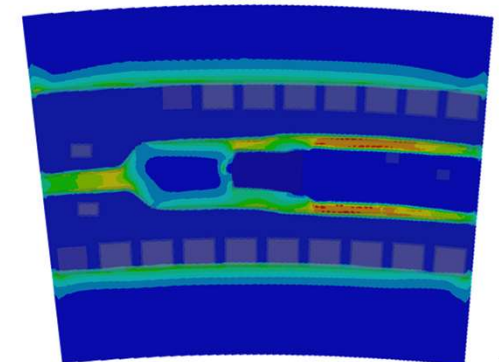
C: SS: Step 1 + 2 + 3 + Thermal
Maximum Principal Stress
Type: Maximum Principal Stress - Top/Bottom - Layer 0
Unit: MPa



ATLAS ITk-Strips
Internal



High stresses in similar locations
for barrel and EC modules

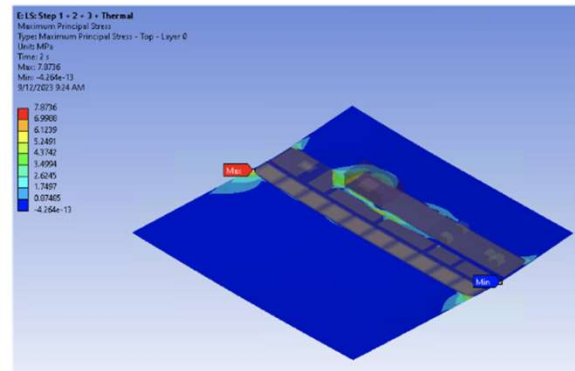


Simulation steps

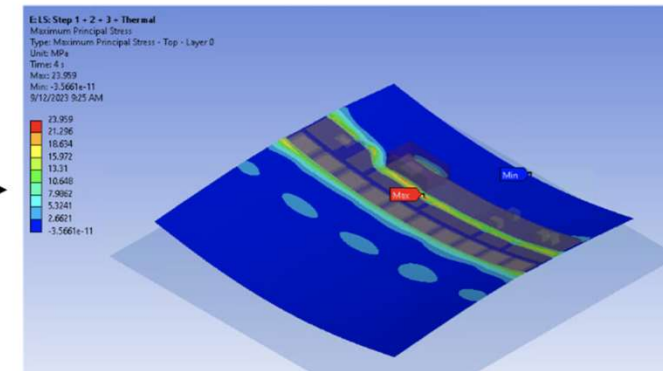
Identifying the biggest danger

Step 0:
Build module
Zero deformation/zero stress

Step 1:
Thermal cycle past glass transition - induce a bow



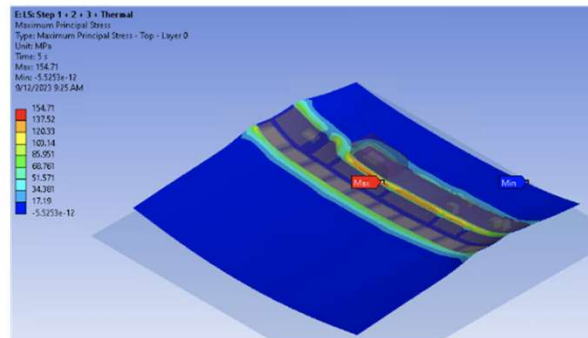
Step 2:
Mount on the stave with opposite bow



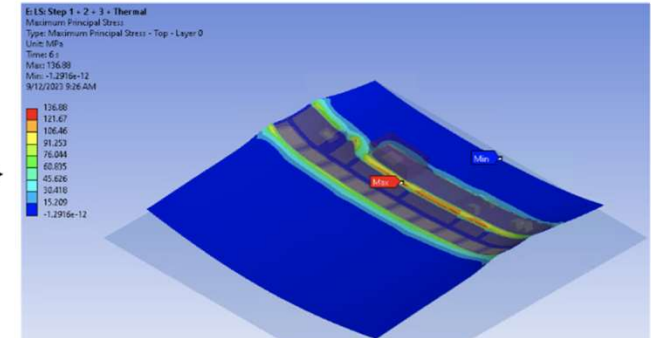
Assuming sensor breaking at ~120 MPa,
incremental impact of each step:

- ❖ Module QC: ~ 5%
- ❖ Stave mounting: ~ 10%
- ❖ Stave cooling to -35 C: ~ **105%**
- ❖ Stave cold and powered: ~-10%

Step 3:
Cold and not powered

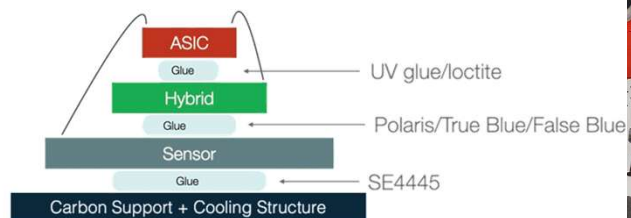
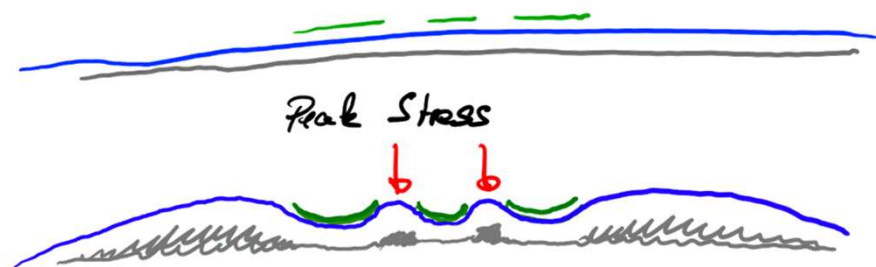


Step 4:
Cold and powered



“Displacement” plot

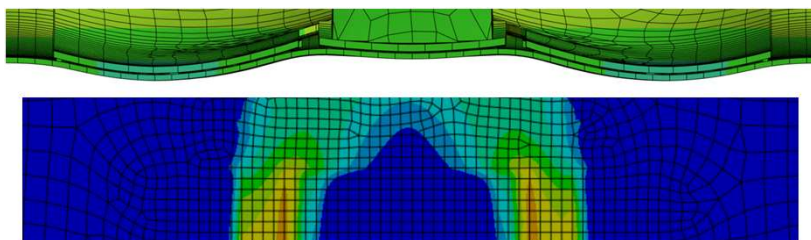
The breaking mechanism



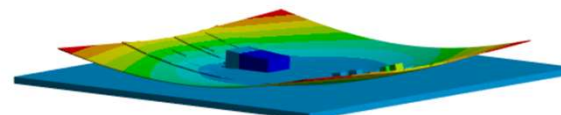
CTE mismatches cause electronics components to bend upwards, which cause sensor regions in between to bend downwards, as SE4445 does not constrain the shape, causing peak stresses

One of the biggest issues appears to be the usage of a “stiff” glue (TrueBlue) above the sensor vs. a “soft” glue (SE4445) below the sensor

Sensor bonded to stave



Free sensor

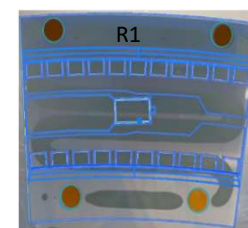
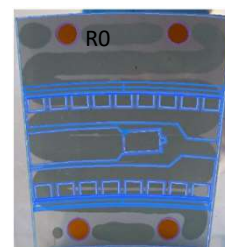
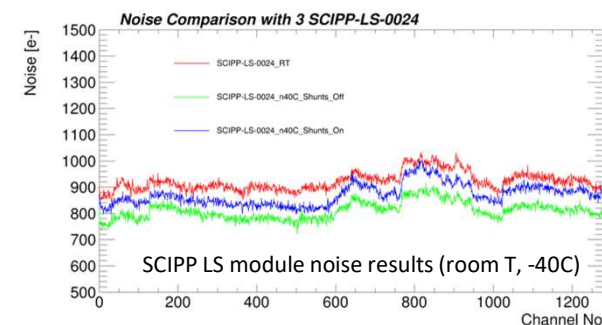
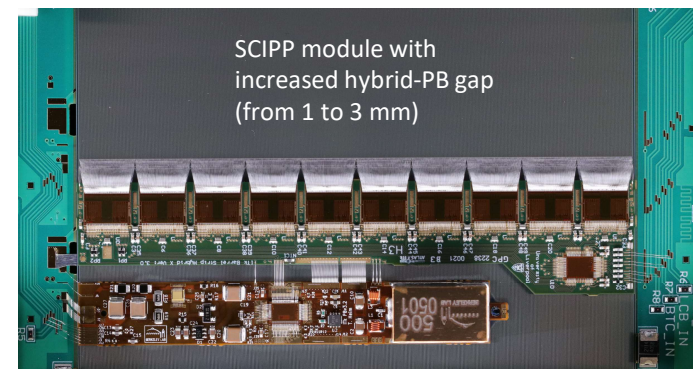


Mitigations

Multiple avenues to pursue

A number of possible mitigations are being pursued at the moment guided by the simulation results:

1. **Usage of a (100x) stiffer glue** between sensors and local supports
 - ❖ Hysol 9396 loaded with Al_2O_3 powder
 - ❖ Dispensing studies promising, first stave and petal sides imminent
2. **Increasing the gap** between electronics components
 - ❖ Only possible in LS, R4 and R5 modules (to first order)!
 - ❖ First two LS modules with wide built, good performance (also, no CN!)
3. Usage of **thinner hybrids/PBs**
 - ❖ Coupled to CN mitigation!
 - ❖ Only possible to barrel modules
 - ❖ Possibly unrealistic copper reduction to have a significant stress reduction
4. **Modified glue patterns** to ensure glue coverage below gaps
5. Others: Filling in gaps on top surface, modified thicknesses



Hysol dispensing studies (BNL, Vancouver)

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2. Increasing

All these studies are very much in flux, a lot of testing is expected in the next weeks/months

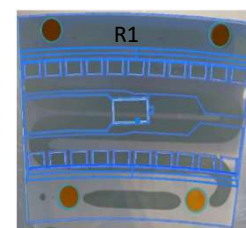
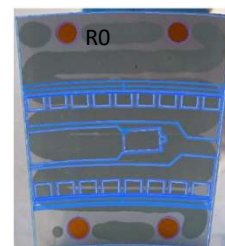
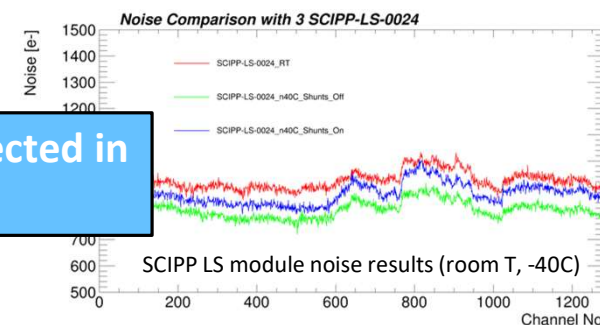
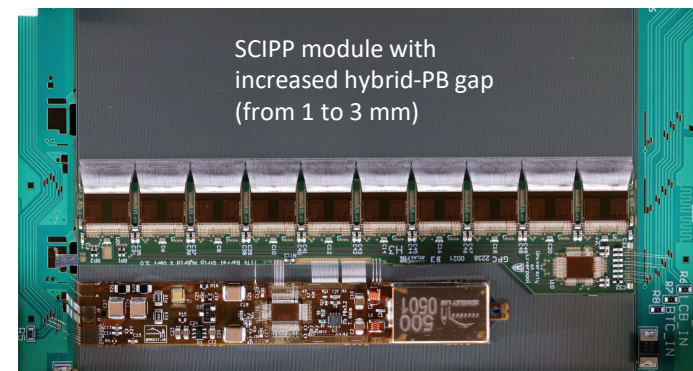
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Hysol dispensing studies (BNL, Vancouver)

Summary

The final stages of pre-production have been extremely challenging for the ITk strips community

Two major standing issues prevented initiating module production

Huge effort and progress in understanding and mitigating **cold noise**

- ❖ To first order, cold noise does not prevent the start of production
- ❖ Further solutions are being explored for short strip modules

Sensor cracking is right now the biggest concern and it remains a standing issue delaying the project

- ❖ A similar effort to solve it is in place as for CN
- ❖ Multiple mitigation avenues are being explored with high priority, some of them very promising
 - Most likely, a combination of them will be needed to give us enough confidence

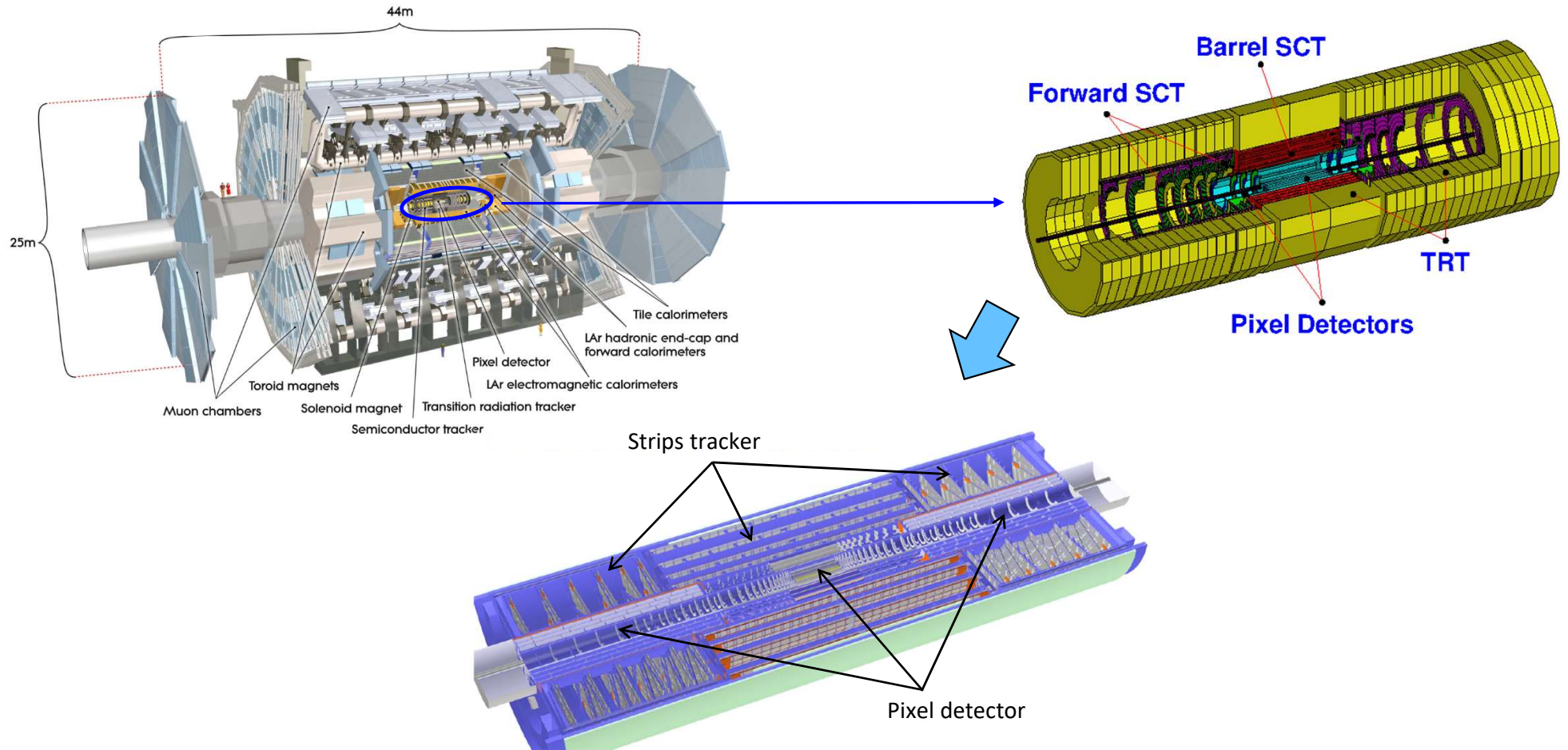
On a positive note, production is underway and running smoothly for many other activities!

- ❖ Sensors, ASICs, Endcap bus tapes and Local supports, EoS, Global structures,...

Thank you

The new silicon tracker

Replacing the old Inner Detector by a new all-silicon Inner Tracker (ITk)



Standing issues at the ITk

Kicking off production

The schedule of the ITk construction is built by design to drive its “critical path” during the first stages via the strips module assembly

- ❖ Allows the main industrial components to be early in hand (sensors, front-end and power ASICs, hybrids)
- ❖ Many module production sites that can cover the needs avoiding bottlenecks
- ❖ Quick expertise buildup across the community

A number of key design detector decisions need to be taken “early” and extensive prototyping needs to follow to cover all possible failure scenarios

- ❖ The more complex the module, the more important the prototyping
- ❖ ITk prototyping has been running for many years for that purpose, with easily $O(1k)$ prototype modules built

Despite this, **not one, but two massive standing issues** have surfaced on the verge of module production, with the very last pre-production version of components which (we are almost sure) were not present in any earlier prototyping stage:

- ❖ **Cold noise**, discovered ~June 2022
- ❖ **Sensor cracking on loaded modules**, discovered ~ May 2023

Two taskforces were quickly formed within the ITk strips community and a huge effort has been devoted to understand and solve/mitigate both issues