How we build the detector and ensure that is will work

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In close collaboration with the *HU Berlin* and *DESY-HH*

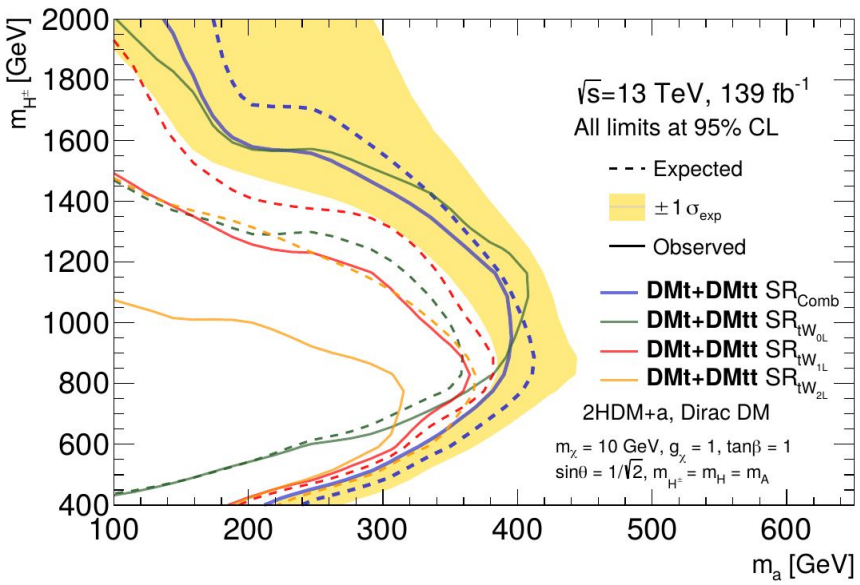
DESY Zeuthen FH Mini Retreat, 12.06.2023

HELMHOLTZ SPITZENFORSCHUNG FÜR GROSSE HERAUSFORDERUNGEN

DESY.

What is this all about?

From my PhD thesis:



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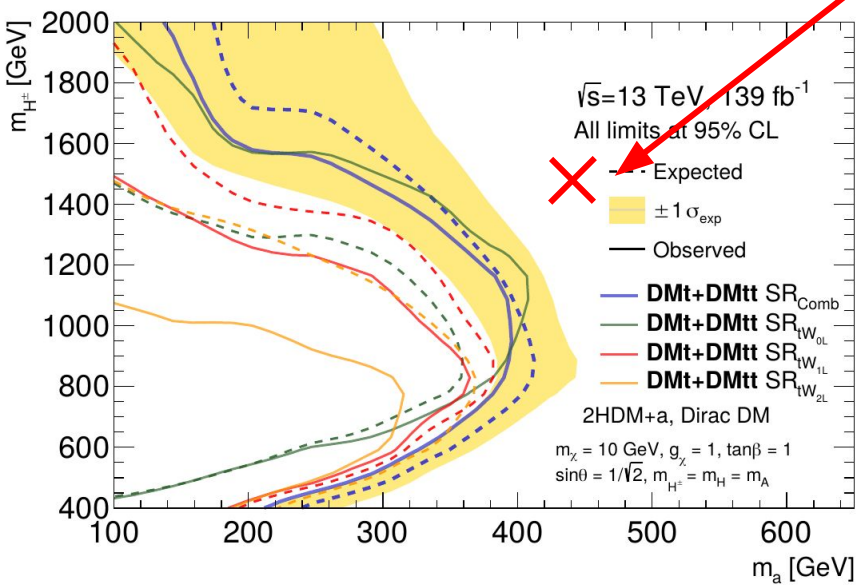

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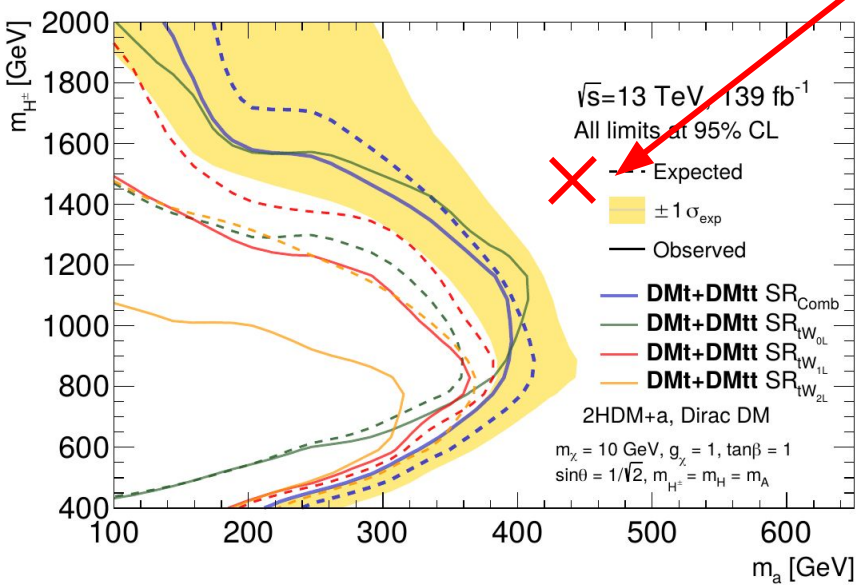

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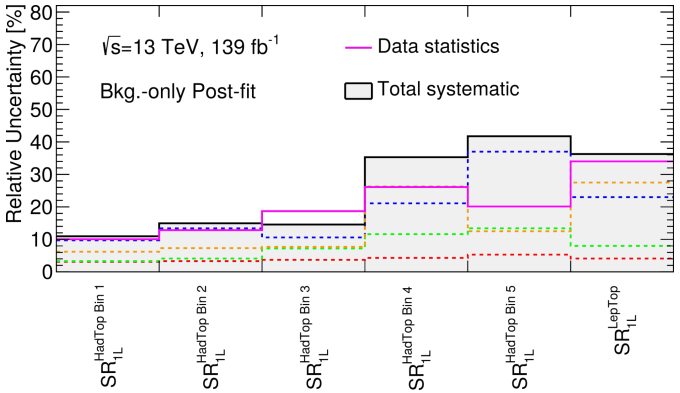

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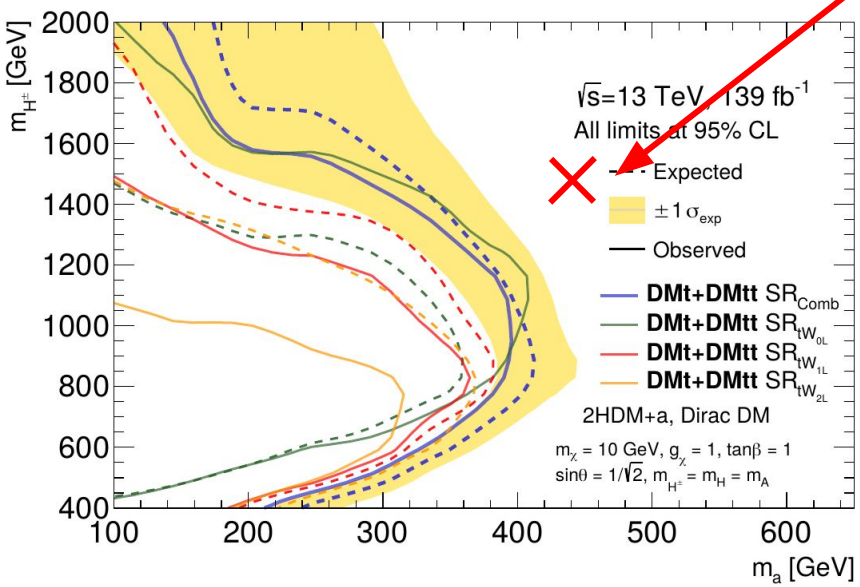

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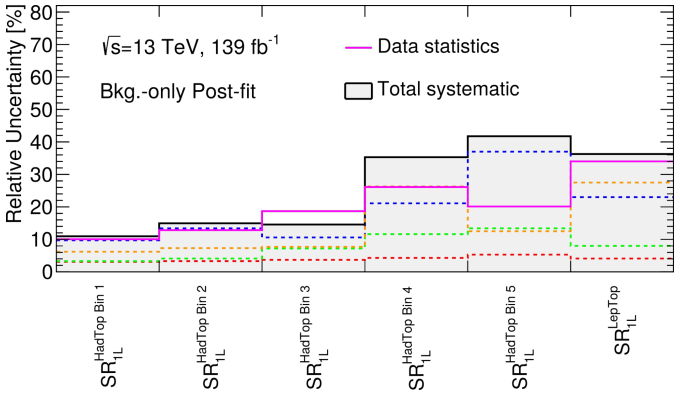

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→ **Collect more data!**
→ **HL-LHC!**

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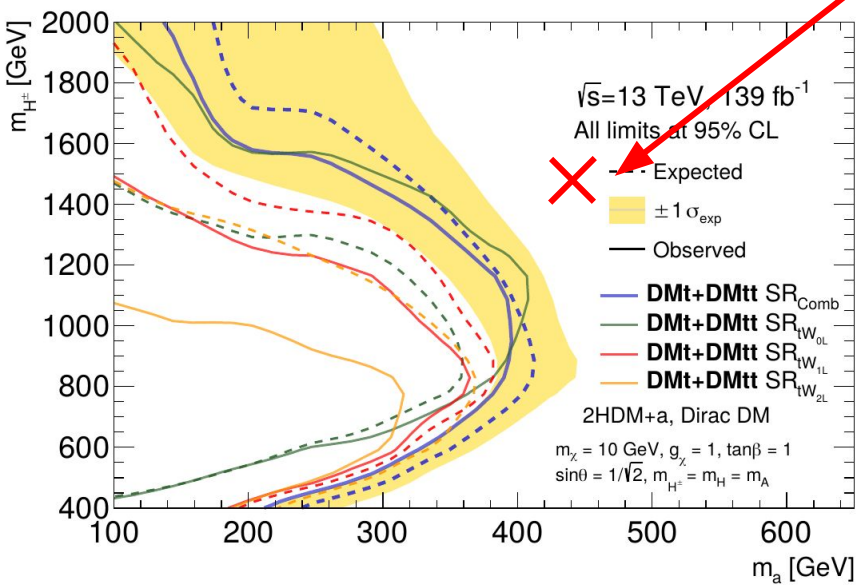

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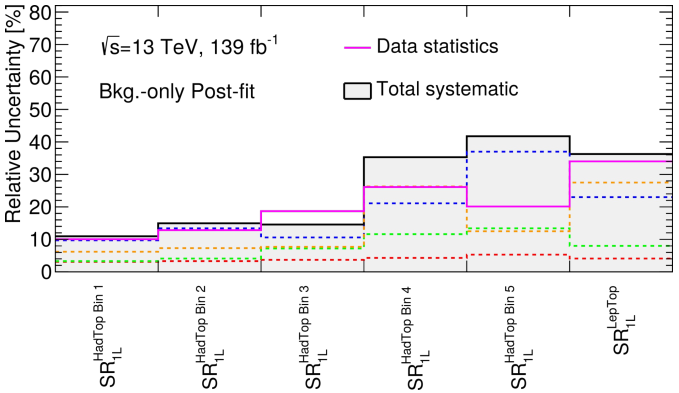

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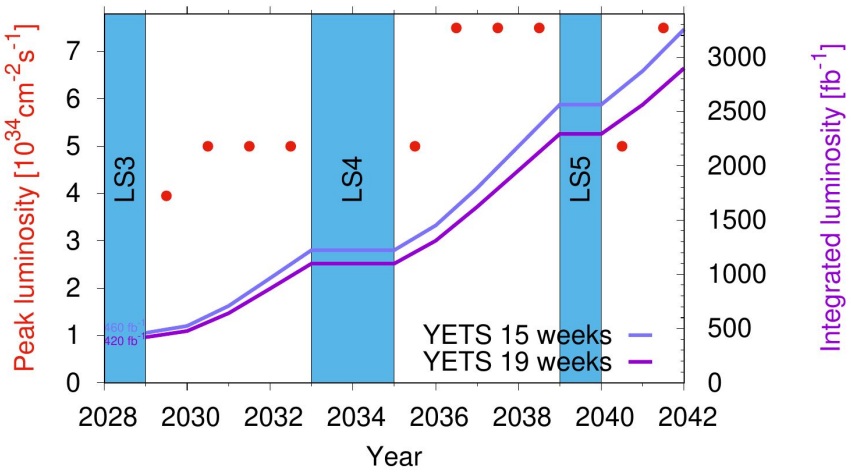
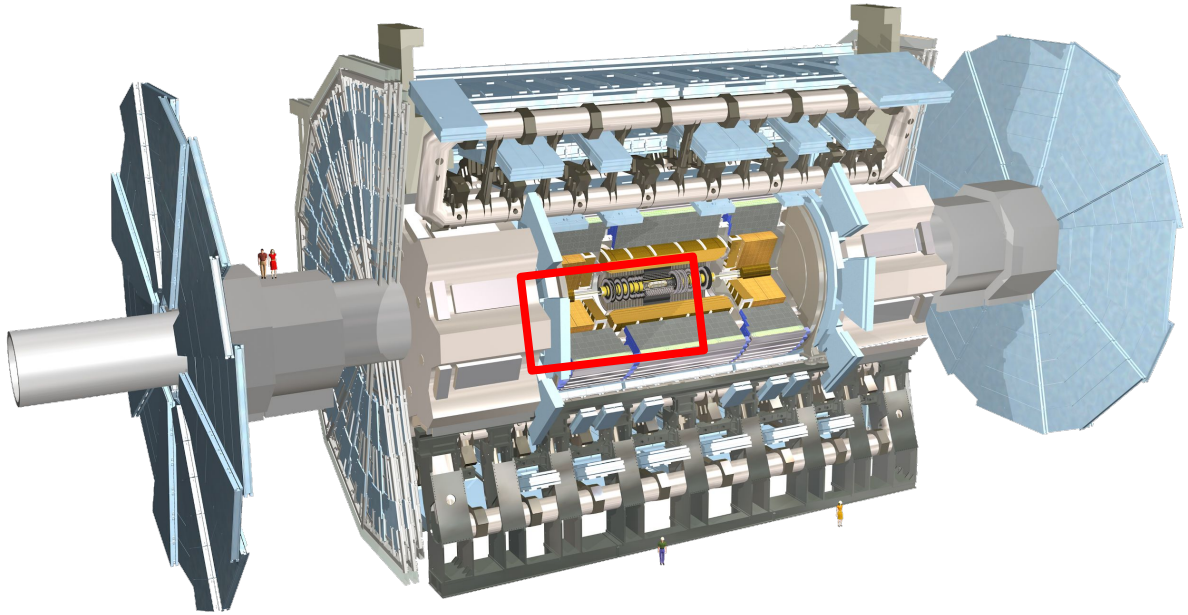


- HL-LHC: collect 10x more data w.r.t. LHC Run-III
- Pile-up increased from ~35 to ~200

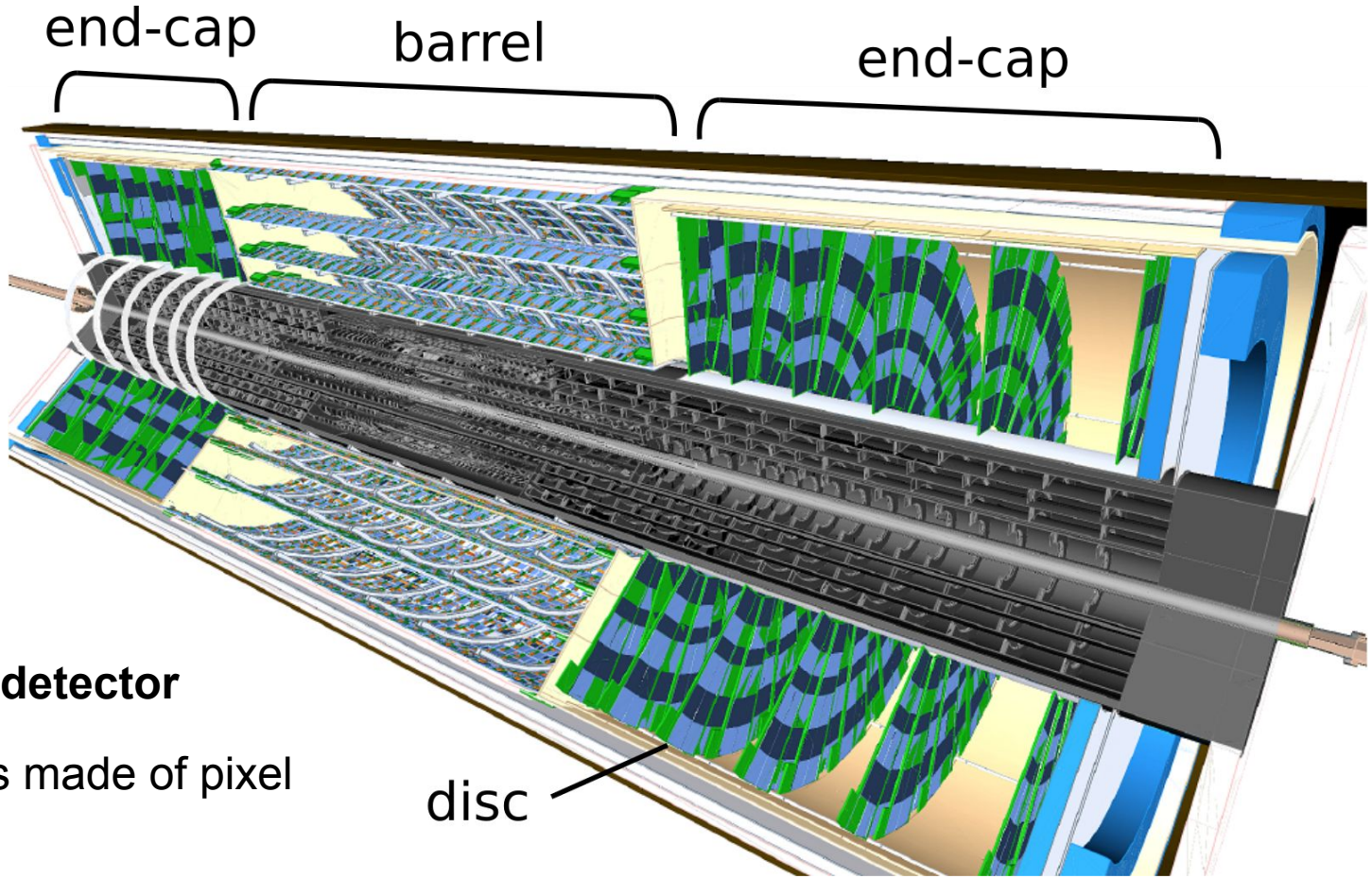
Implications for the ATLAS Inner Detector

- HL-LHC comes with:
  - High track-densities → Parts of the ID will saturate, tracks difficult to reconstruct
  - Increased radiation damage x10 → Not handable by current detector
  - Refined trigger capabilities → Need faster readout, additional buffering, etc.



⇒ Need a new tracking detector!!

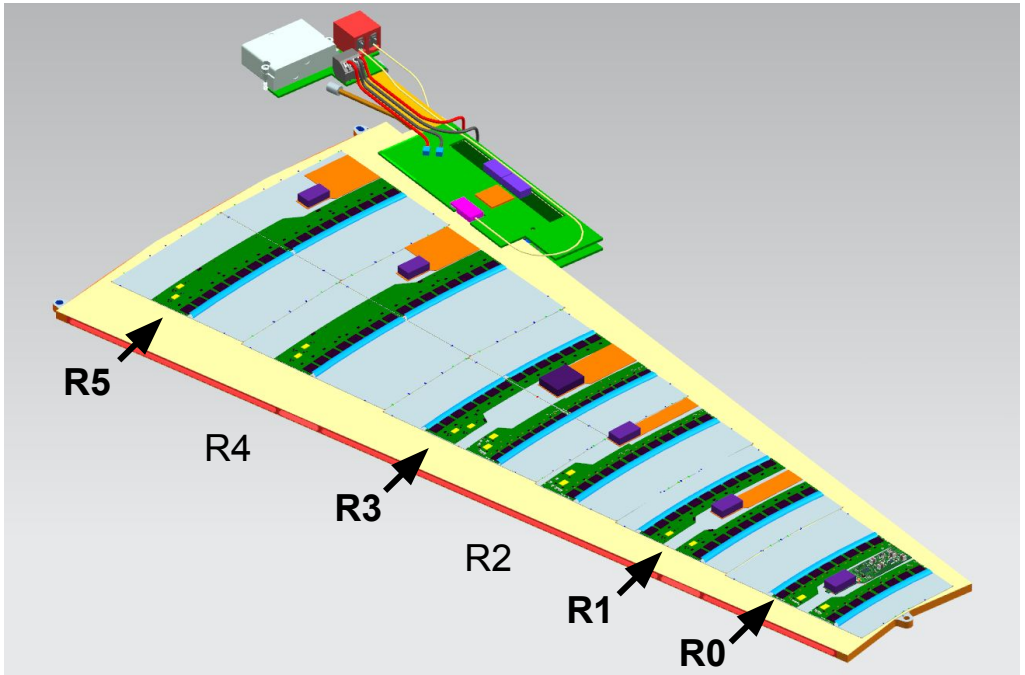
The ATLAS Inner Tracker (ITk)

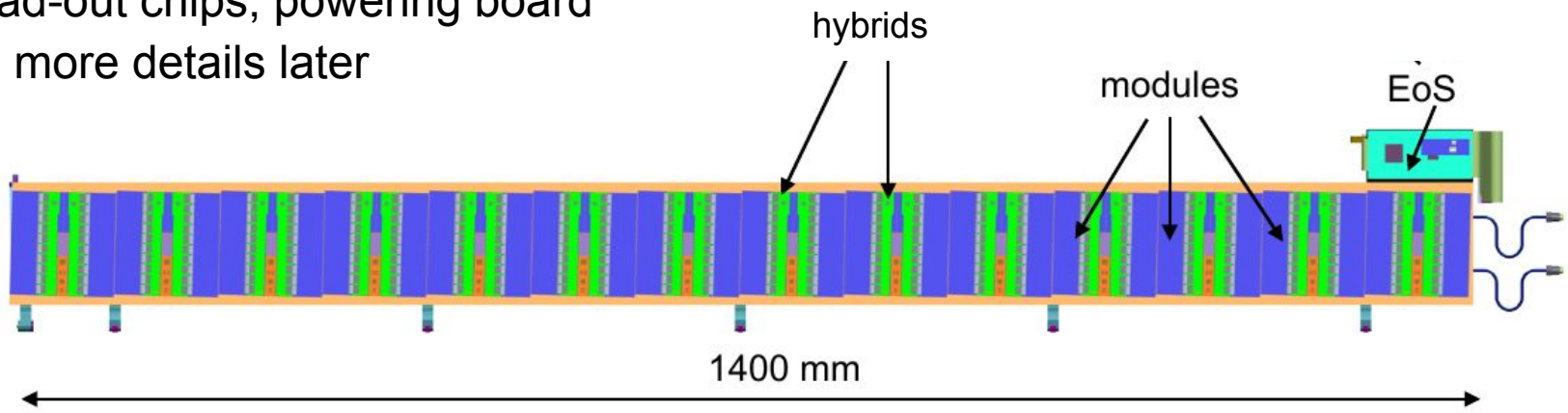


- **All silicon detector**
- Inner layers made of pixel detectors
- Outer layers made of strip detector
- Divided into barrel & two end-caps

The strip detector

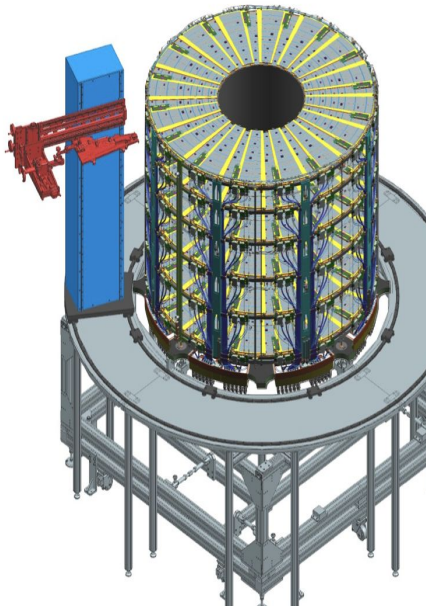
- Builing blocks: stave & petal
  - Divided into modules
- Different modules for different geometries:
  - 2 types in barrel (long-strip, short-strip)
  - 6 types in end-cap(R0-R5)
- Module constituted of sensor, read-out chips, powering board → more details later

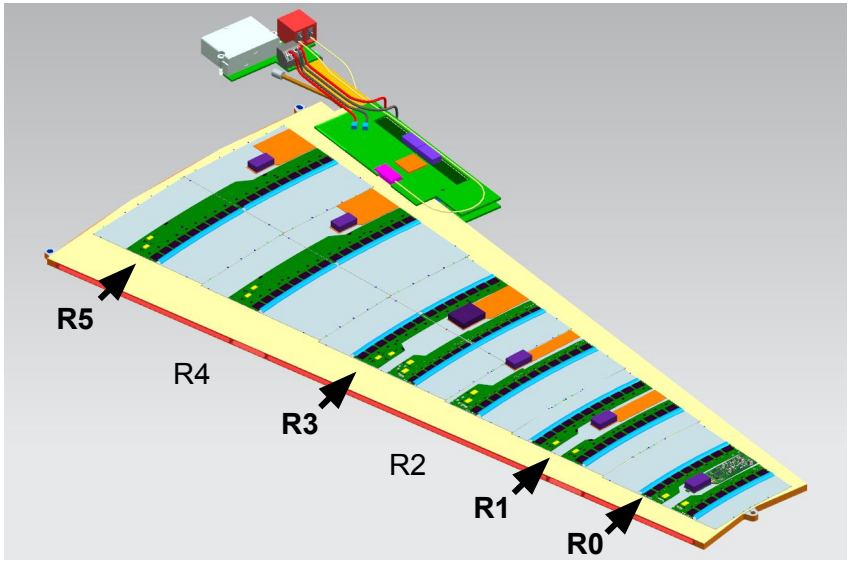




DESY deliverables

- DESY builds
  - End-cap modules (~2500, of these 2000 in Zeuthen) → close collaboration with HU, they build 500 of the modules in our labs
  - Petals (~120, all in Hamburg)
  - …and an entire end-cap

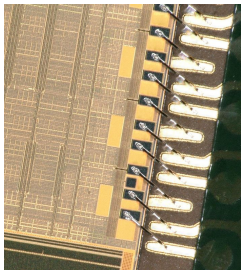


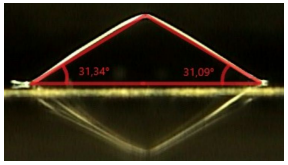


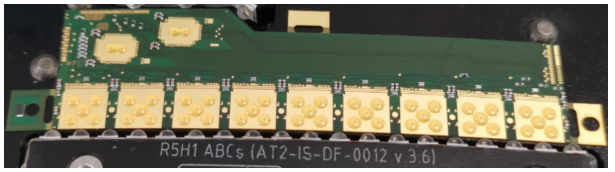
- Why do we build this?
  - Ehm, because it's awesome!
  - But also, because we joined ATLAS late

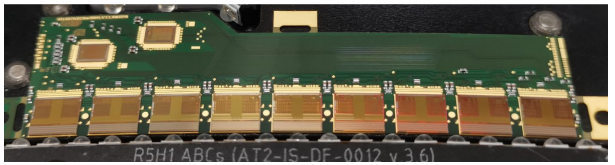
Status

- Status: pre-production
  - Setting up the production line
  - Ensure all is fine to build a detector
- Original plan: visits by internal reviewers
- Now: record data, take videos, reports…
- Time-consuming process, but worth it, find many “bugs” & optimise flow

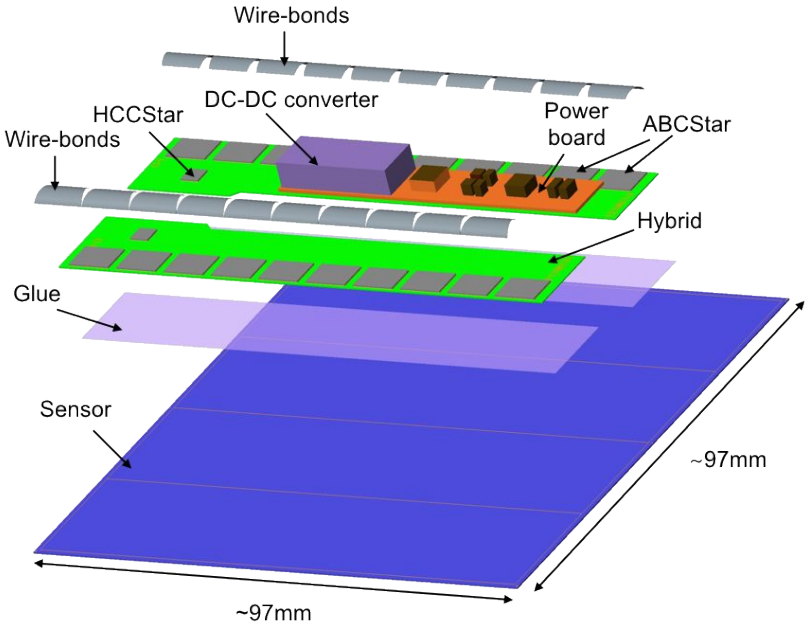




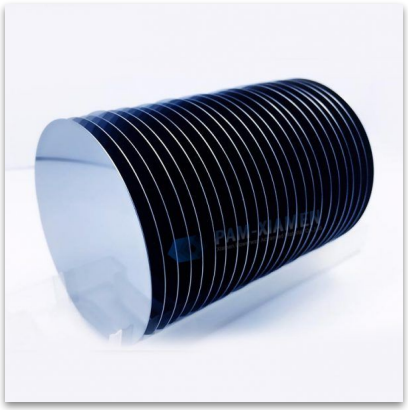


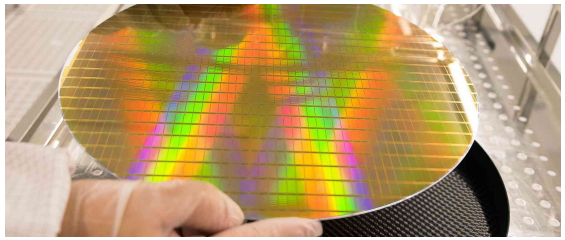


A module - exploded



- 1x Sensor
  - produced in wafers
    → diced by manufacturer
- 2-4x Hybrids, which is
  - 1x PBC → ATLAS-designed, industry-made
  - 7-12x ABC read-out chip
  - 1-2x HCC aggregator chip
  - O(500)x wirebonds (chip-PCB connection)
- O(5000)x wirebonds
  → connect strips to read-out chips
- 1x Powerboard = 1x FEAST power-converter + 1x AMAC control chip + wirebonds
- All chips also come on wafers, diced by companies

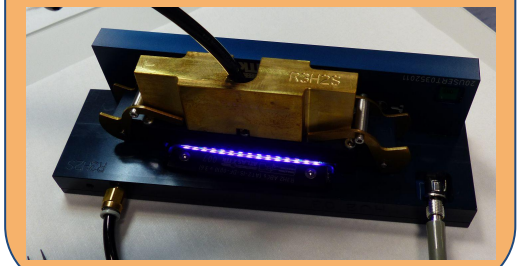


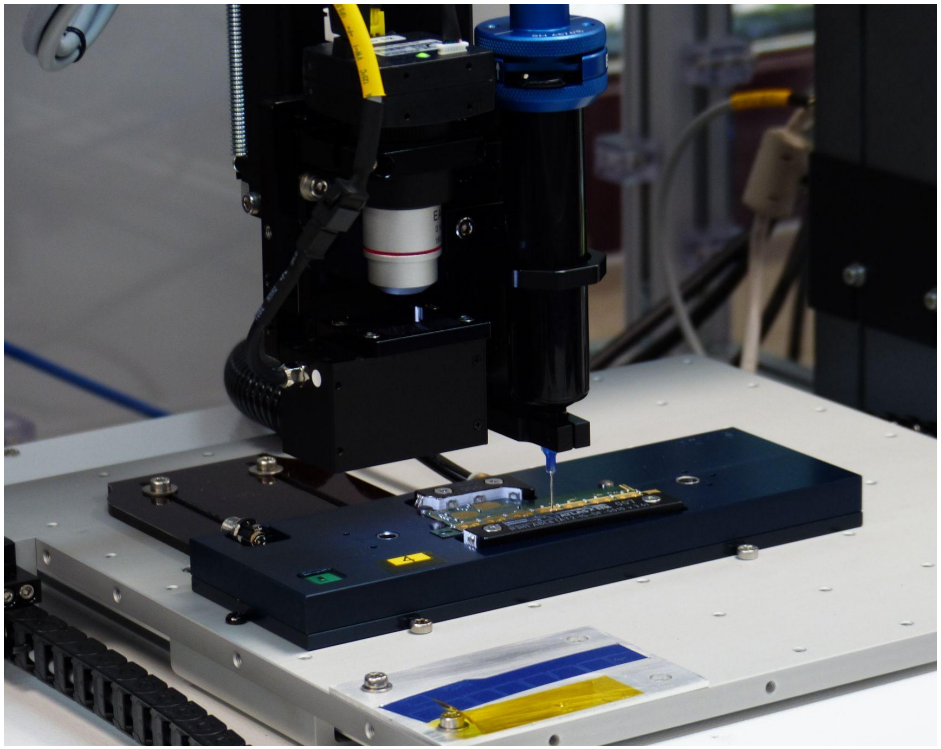


Assembling the pieces

hybrids

Step 1: Glue to hybrid





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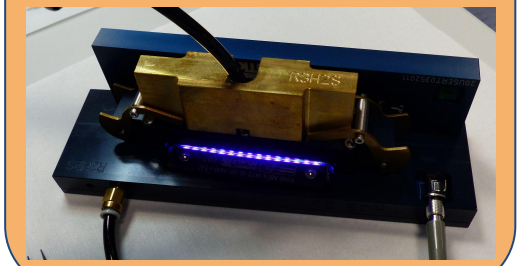

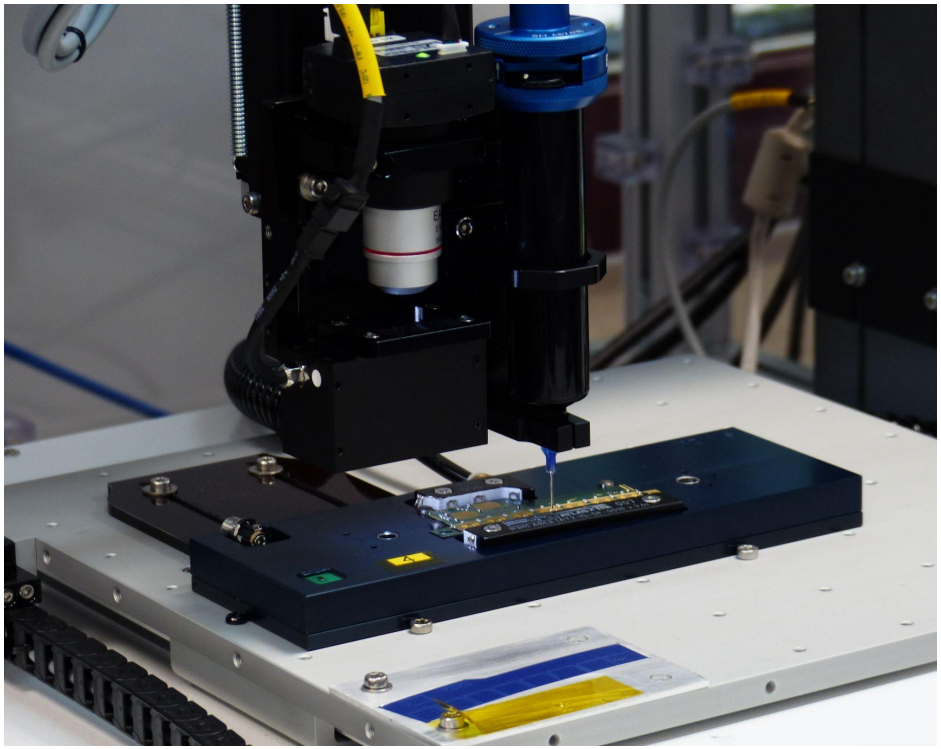

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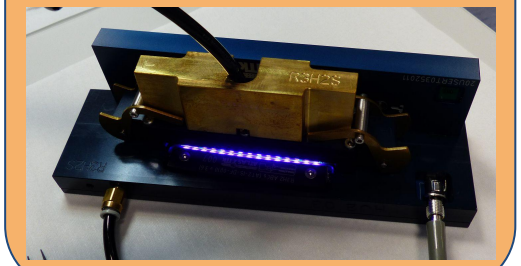

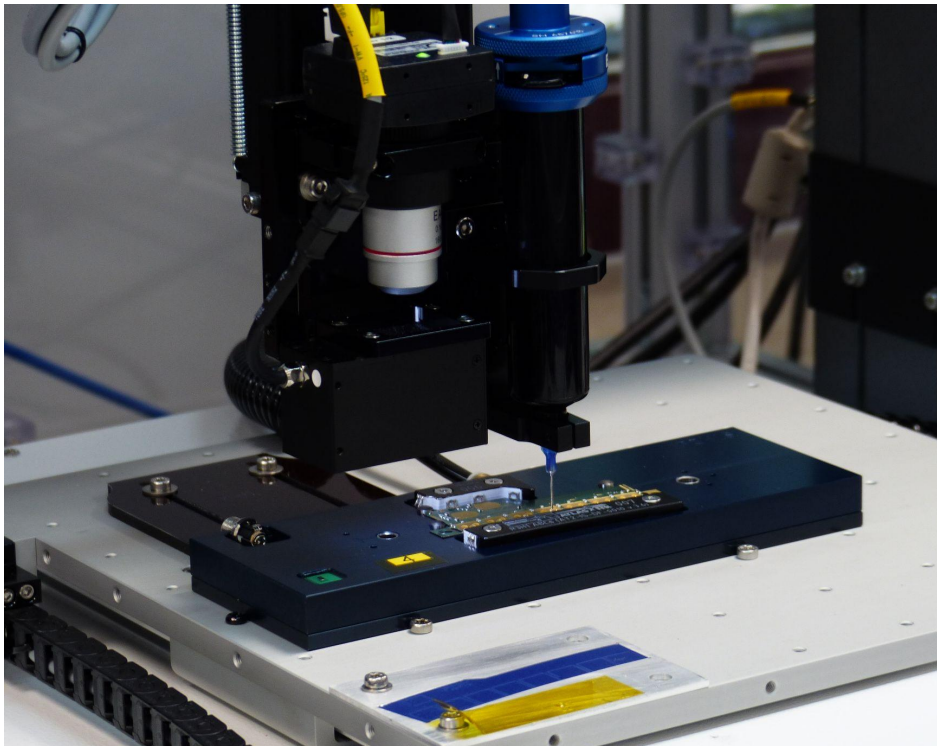

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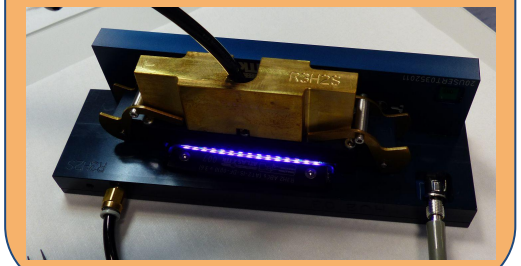

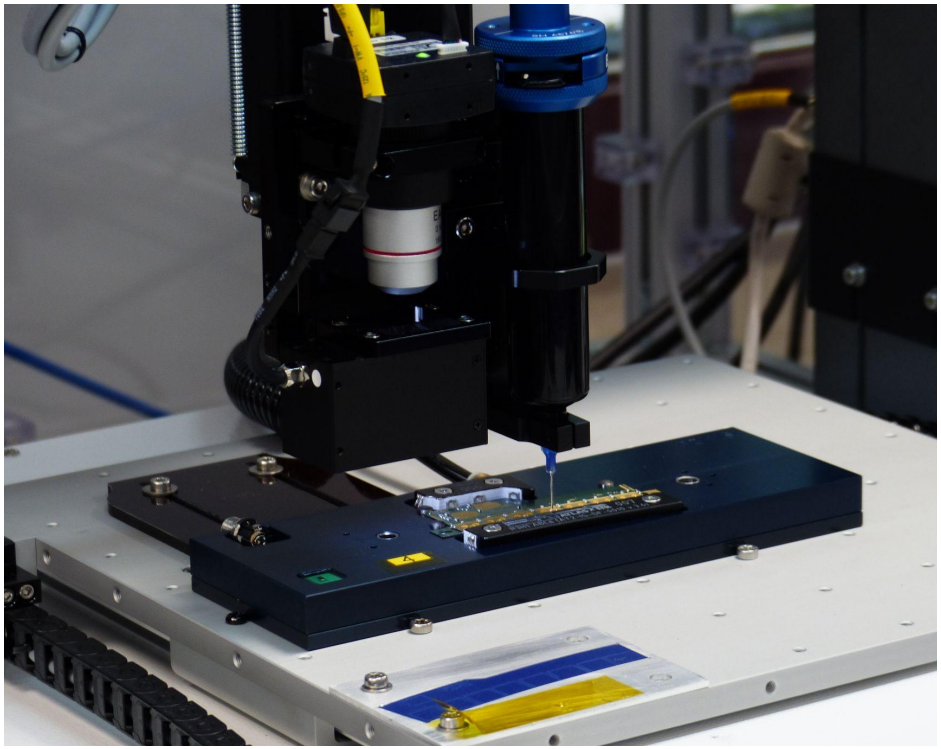

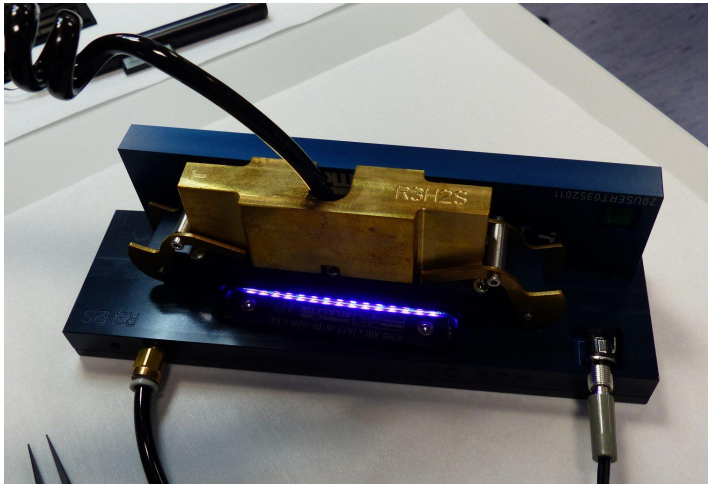

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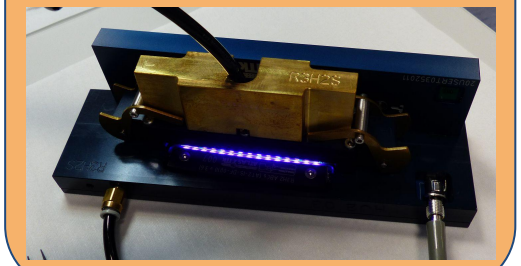

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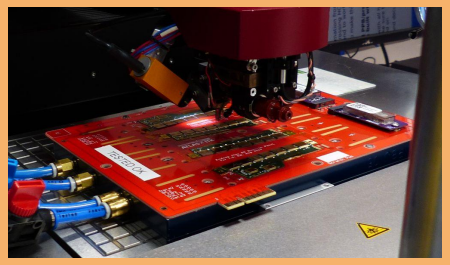

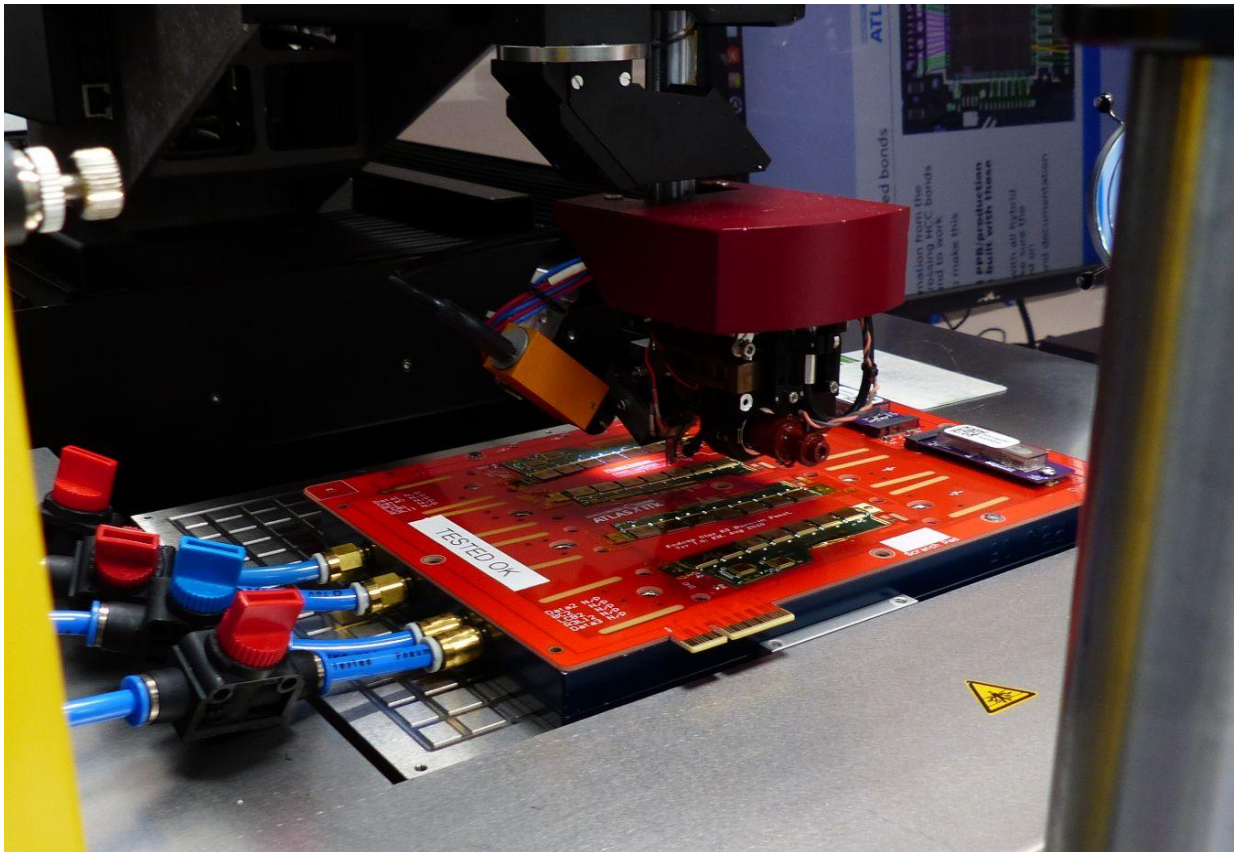

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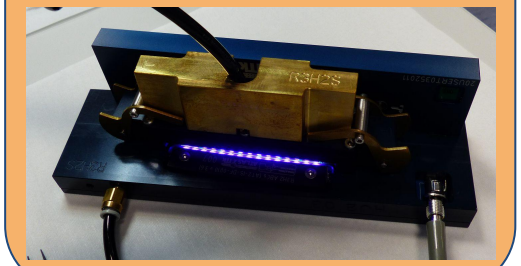

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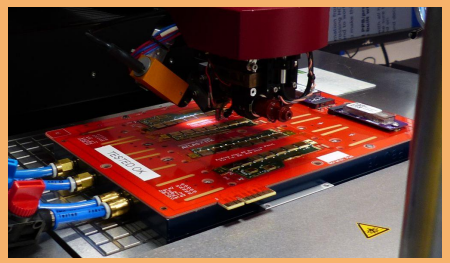

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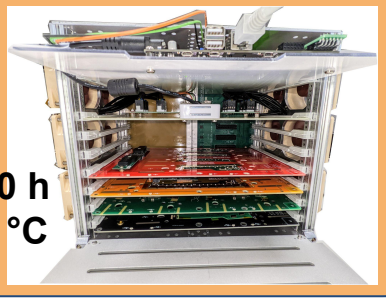
40 °C



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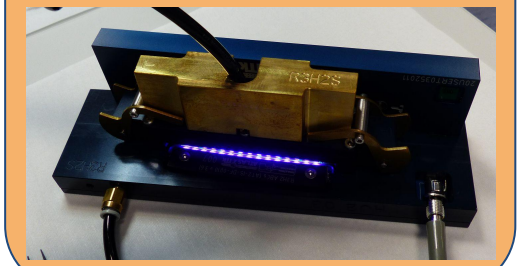

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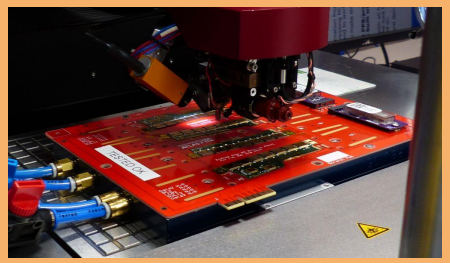

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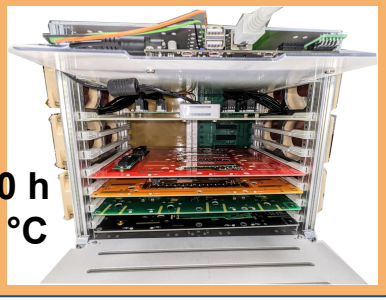

module building

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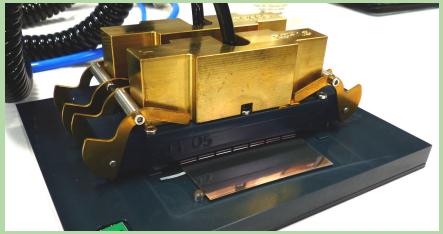

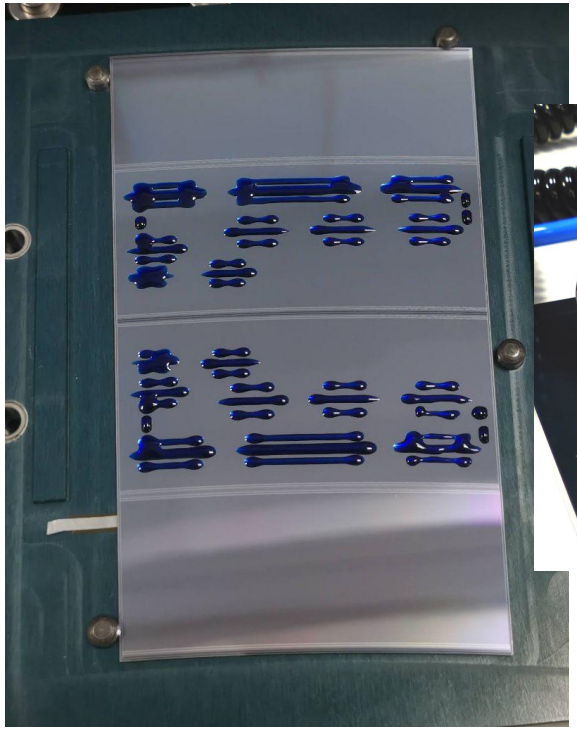

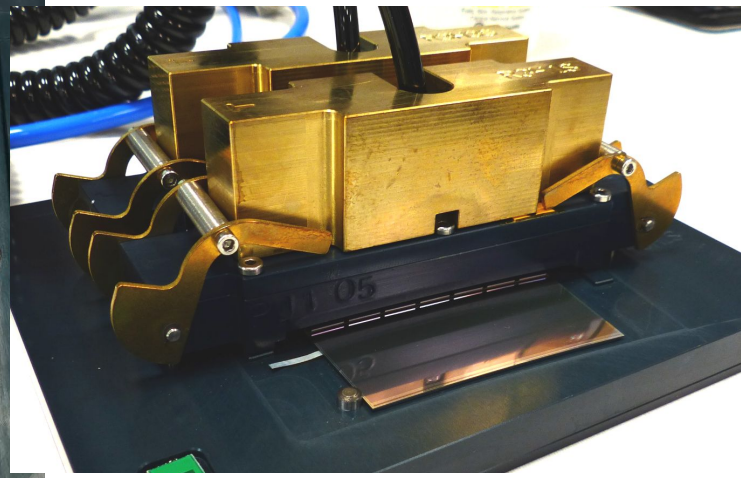

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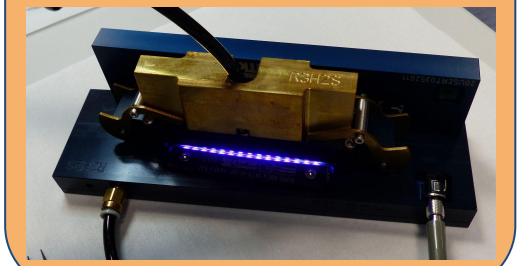

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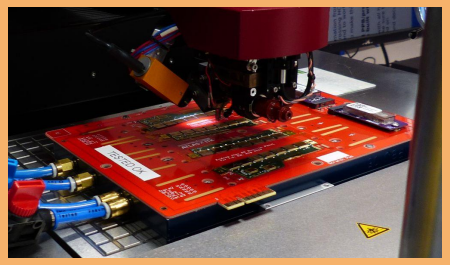

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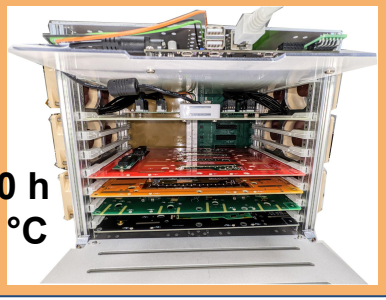

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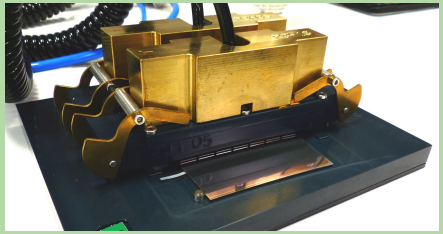
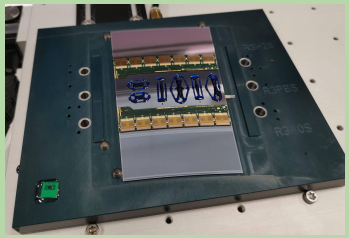
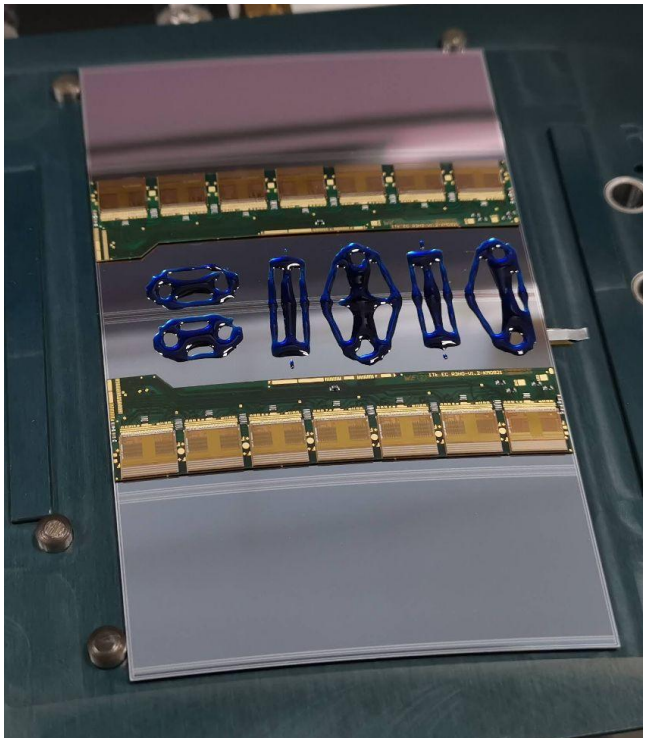


Step 5: Test powerboard & glue to sensor





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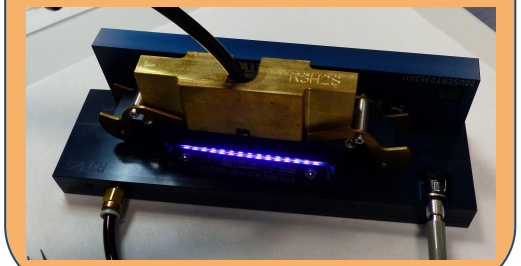

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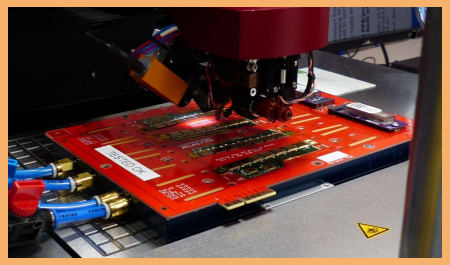

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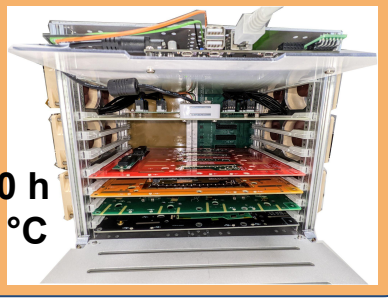

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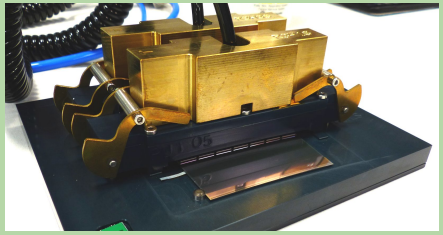

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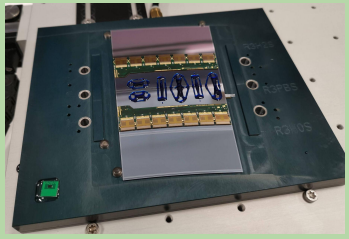
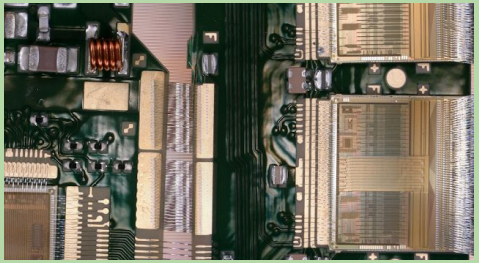
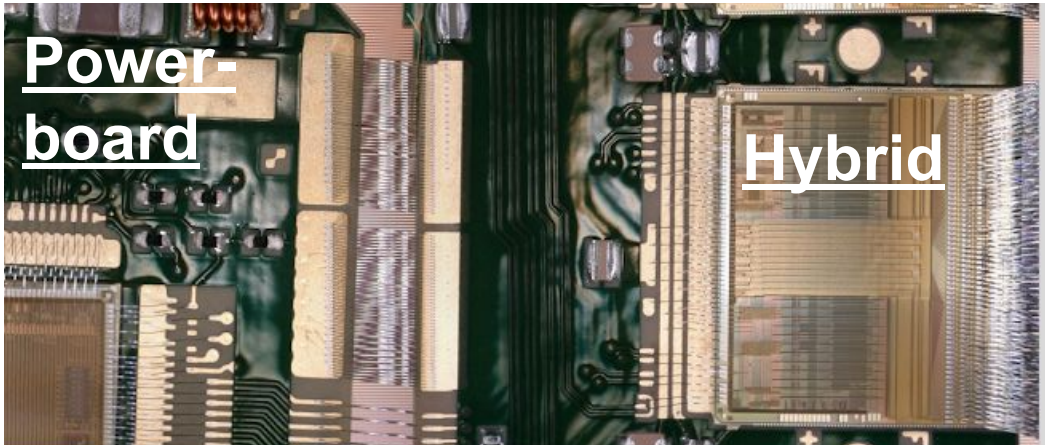


Step 6: Wirebond

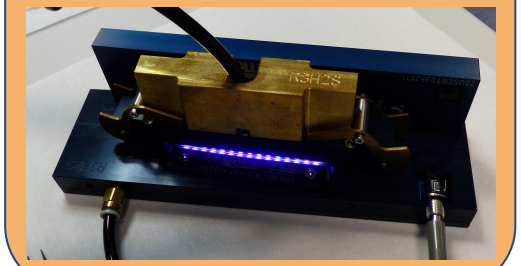




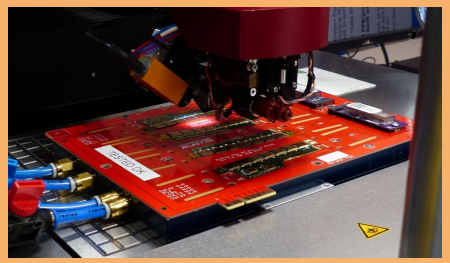
Assembling the pieces

hybrids

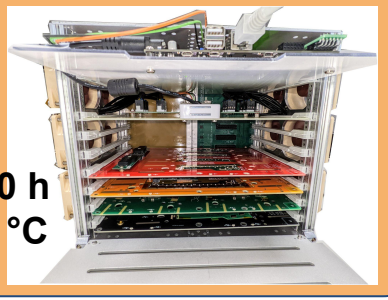
Step 1: Glue to hybrid



Step 2: Wirebond



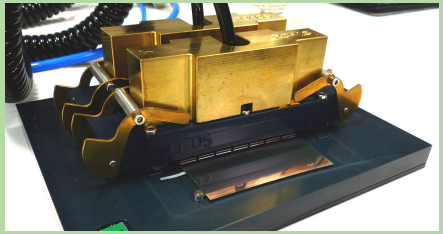
Step 3: Hybrid burn-in



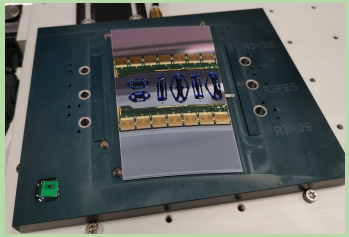
100 h
40 °C

module building

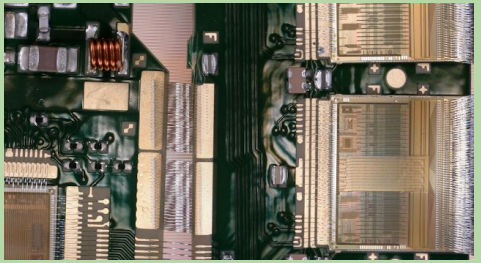
Step 4: Glue hybrids to sensor



Step 5: Test powerboard & glue to sensor

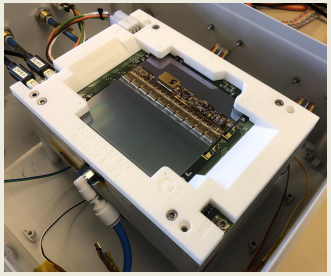


Step 6: Wirebond

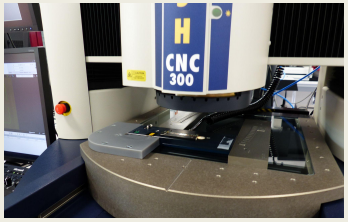


testing & shipment

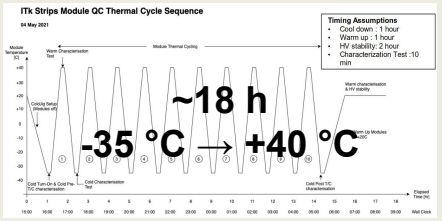
Step 7: Install on frame



Step 8: Test: visual inspection, metrology, etc.



Step 9: Thermal cycling



~18 h
-35 °C → +40 °C

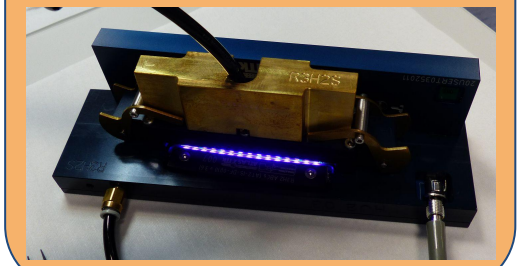
Assembling the pieces

hybrids

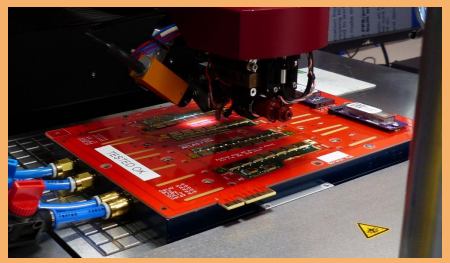
module building

testing & shipment

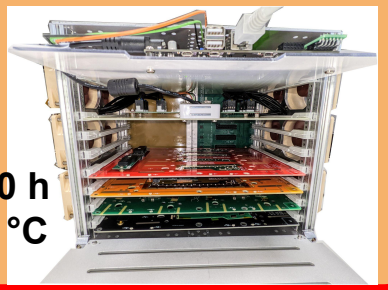
Step 1: Glue to hybrid



Step 2: Wirebond

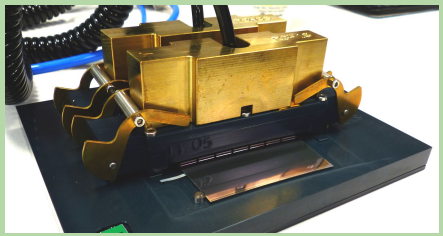


Step 3: Hybrid burn-in

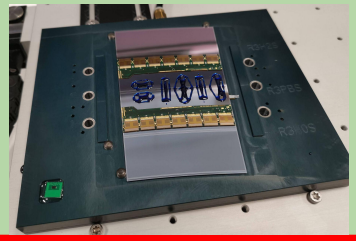


100 h
40 °C

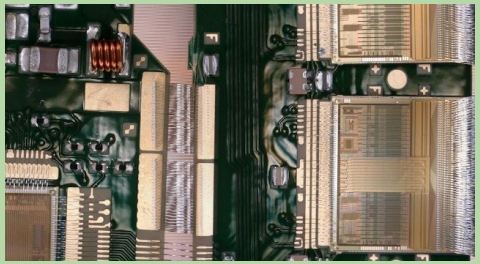
Step 4: Glue hybrids to sensor



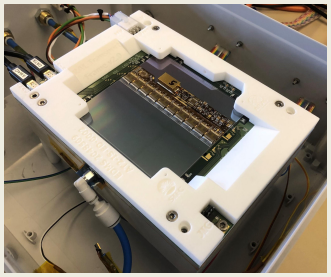
Step 5: Test powerboard & glue to sensor



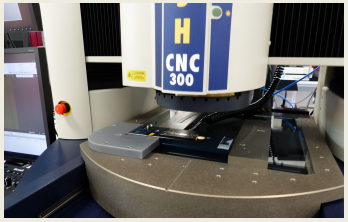
Step 6: Wirebond



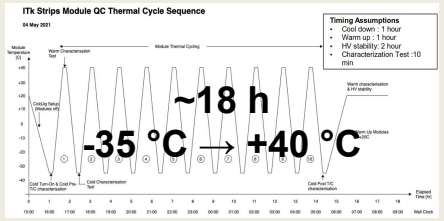
Step 7: Install on frame



Step 8: Test: visual inspection, metrology, etc.



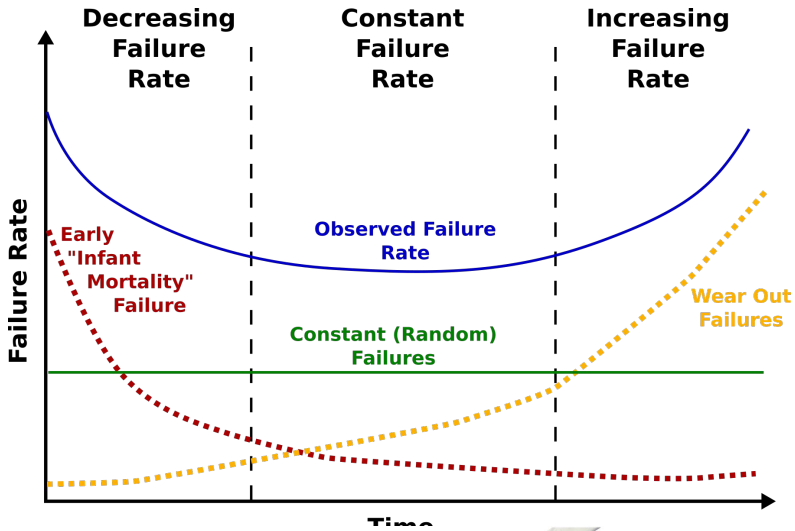
Step 9: Thermal cycling

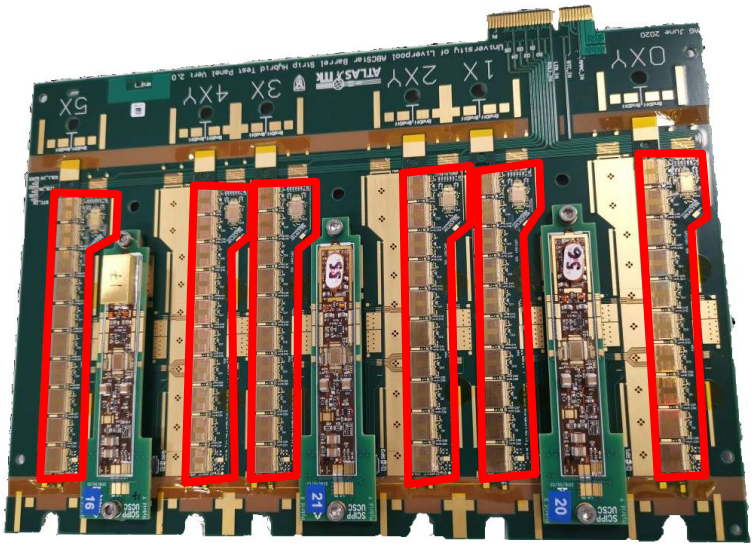


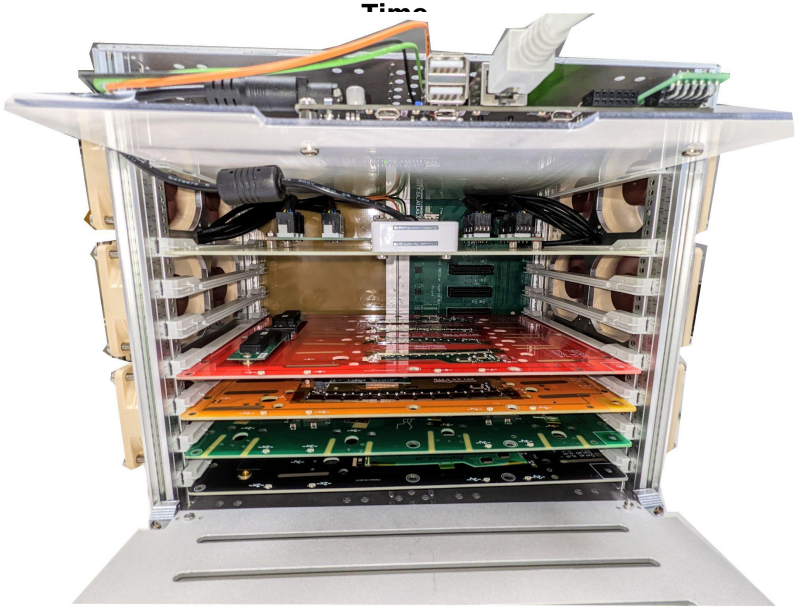
~18 h
-35 °C → +40 °C

What is burn-in?

- Hybrid “burn-in”: sort out broken hybrids due to “infant mortality”, by operating them for some time
- **Stress test for 100 h at 40 °C**
- Standardised, automated setup **developed in Zeuthen** → Burn-in crate



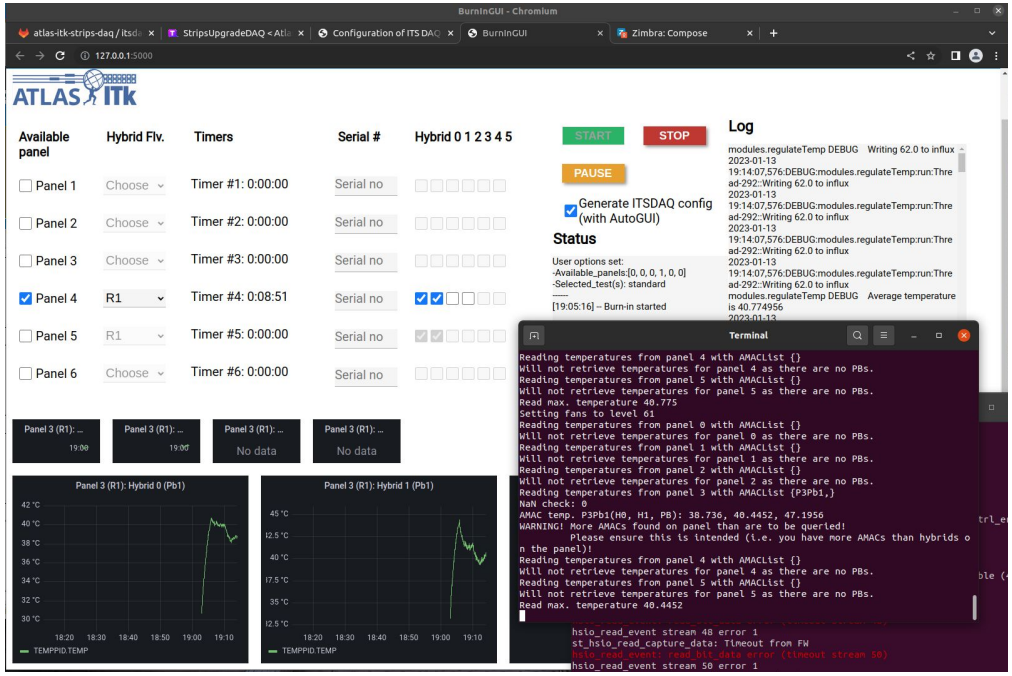


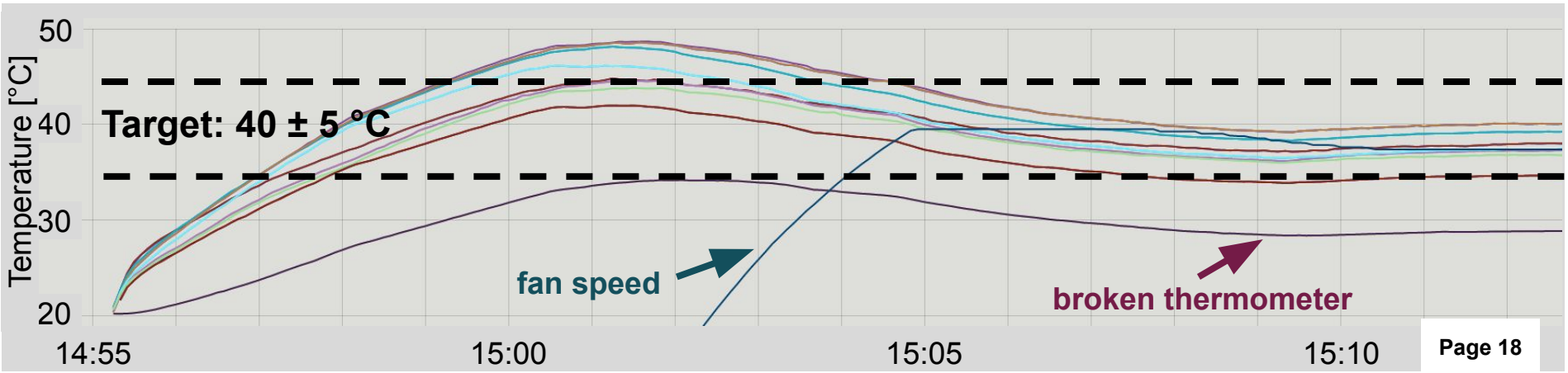


Status burn-in crate

Status:

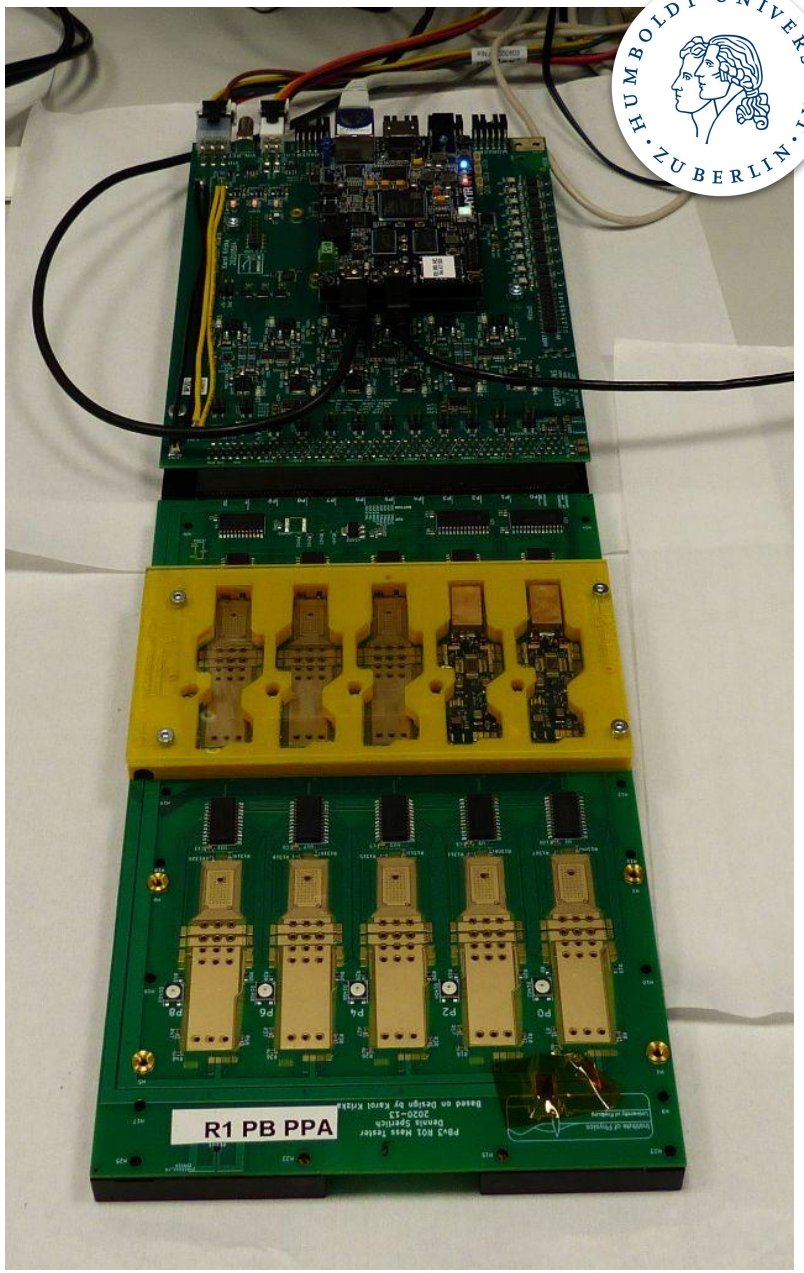
- Designed ✅
- Functionality tested ✅
- Parts shipped to site ✅
- Crates constructed ✅
- Final automatisation ✅
  - Hybrid “plug-and-play”
  - DB upload of results





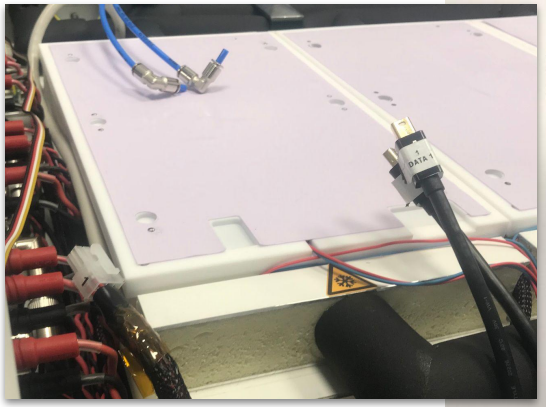
Powerboard testing

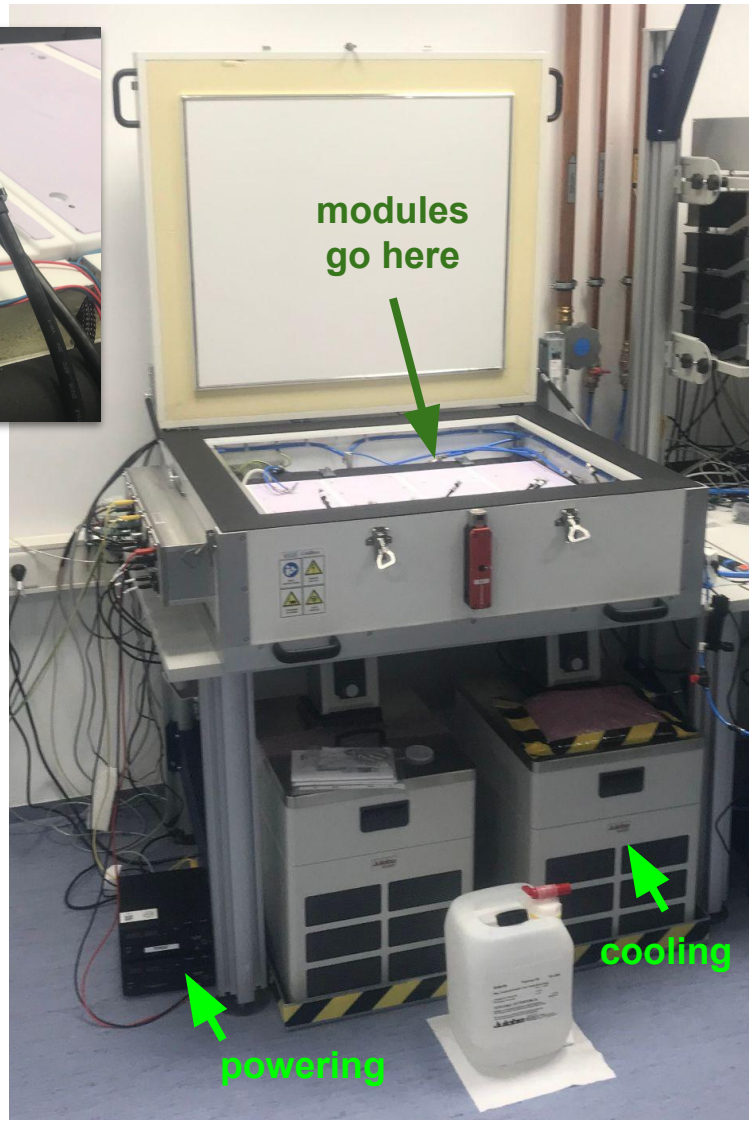
- Powerboards built in Freiburg & shipped to DESY
- Before installing in detector: test
- Use mass-testing setup to make testing efficient
- Designed by HU / Freiburg / BNL
- Status:
  - All parts designed ✅
  - Functionality tested ✅
  - Shipped to sites ✅
  - Plug-and-play software ⏳
    - DESY-Z jumping in to finalise this



Thermal cycling setup

- Cycle module 10x from – 35 °C to + 40 °C:
  - Ensure mechanical & electrical stability
- Work closely with DESY-HH





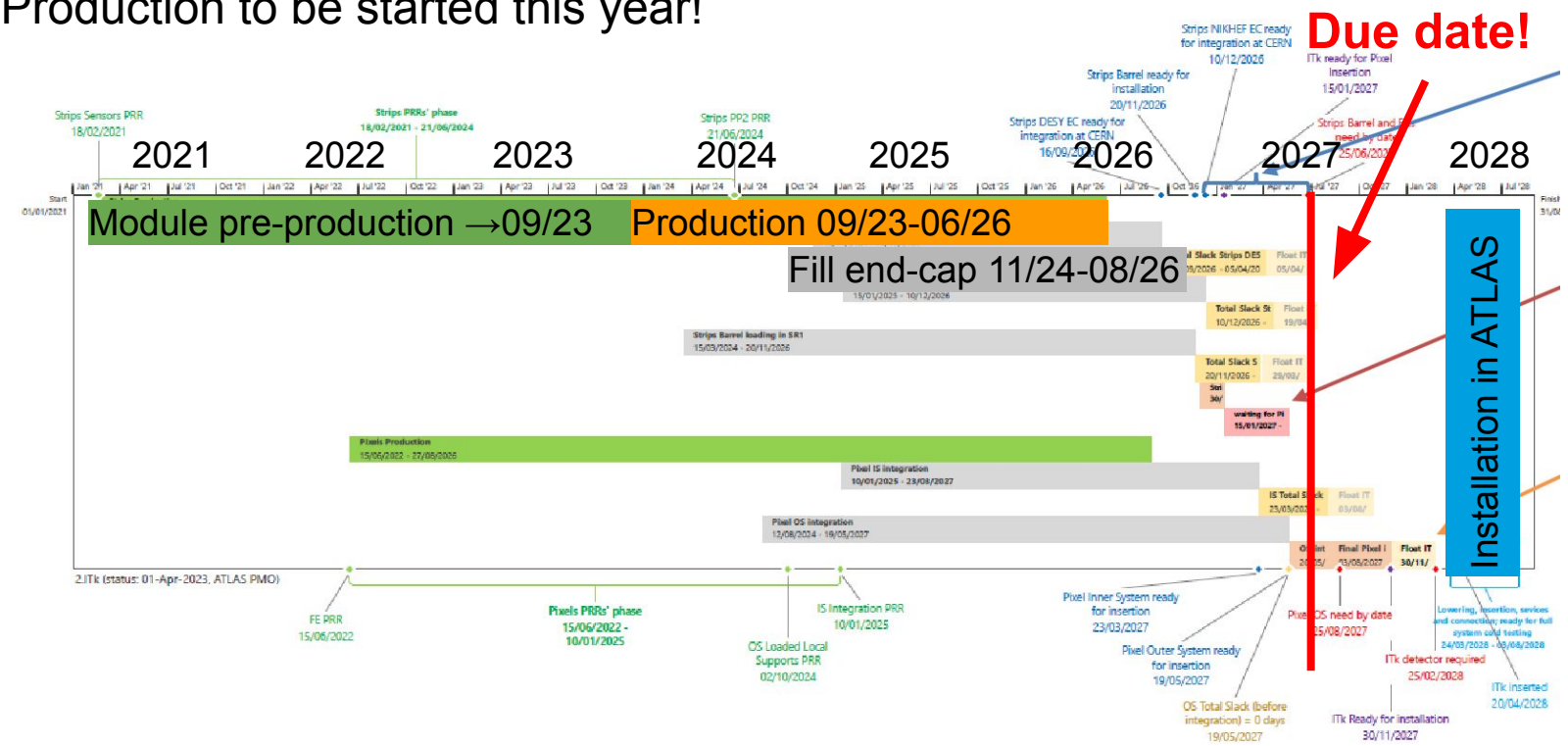
Module
Peltiers
Cold plate

Status

- Box designed & tested ✅
- Boxes transported to sites ✅
- Boxes ready to use ✅
- Final automatisation ✅
  - Modules “plug-and-play”
  - Automatic running of full test cycle

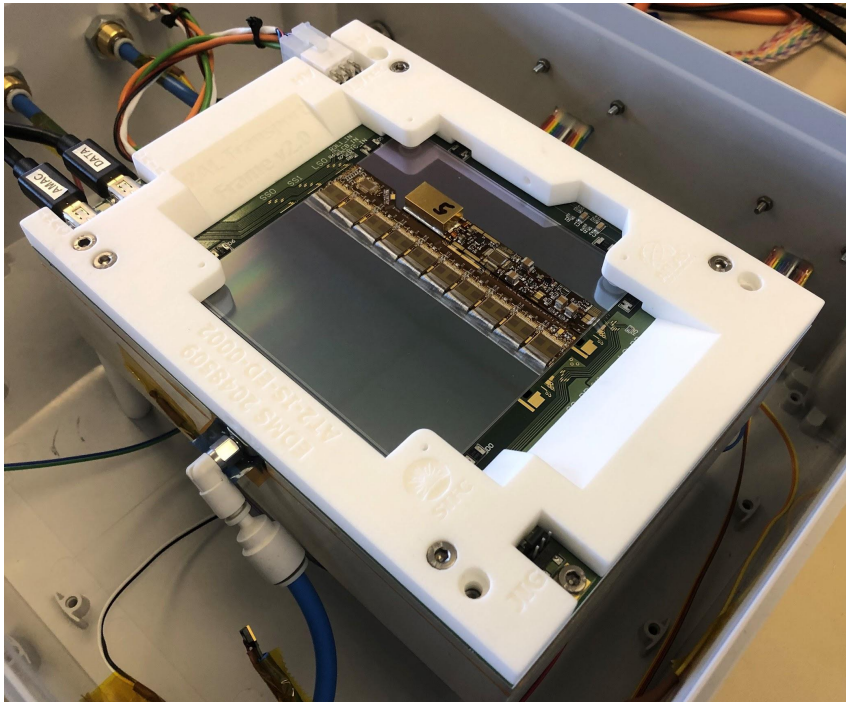
Summary

- ATLAS inner tracker to be upgraded to cope with HL-LHC conditions
- DESY heavily involved in building ITk
- ~2000 modules to be built in Zeuthen until 2026
- Currently qualifying the production line & finalising quality control setups
- Production to be started this year!



When the modules are done…

- They are installed on module frame and packed
- This involves air-evacuation (i.e. shipped in vacuum)
- **Is necessary, as sensors are very sensitive to humidity**
- → Ilona's talk



Thank you

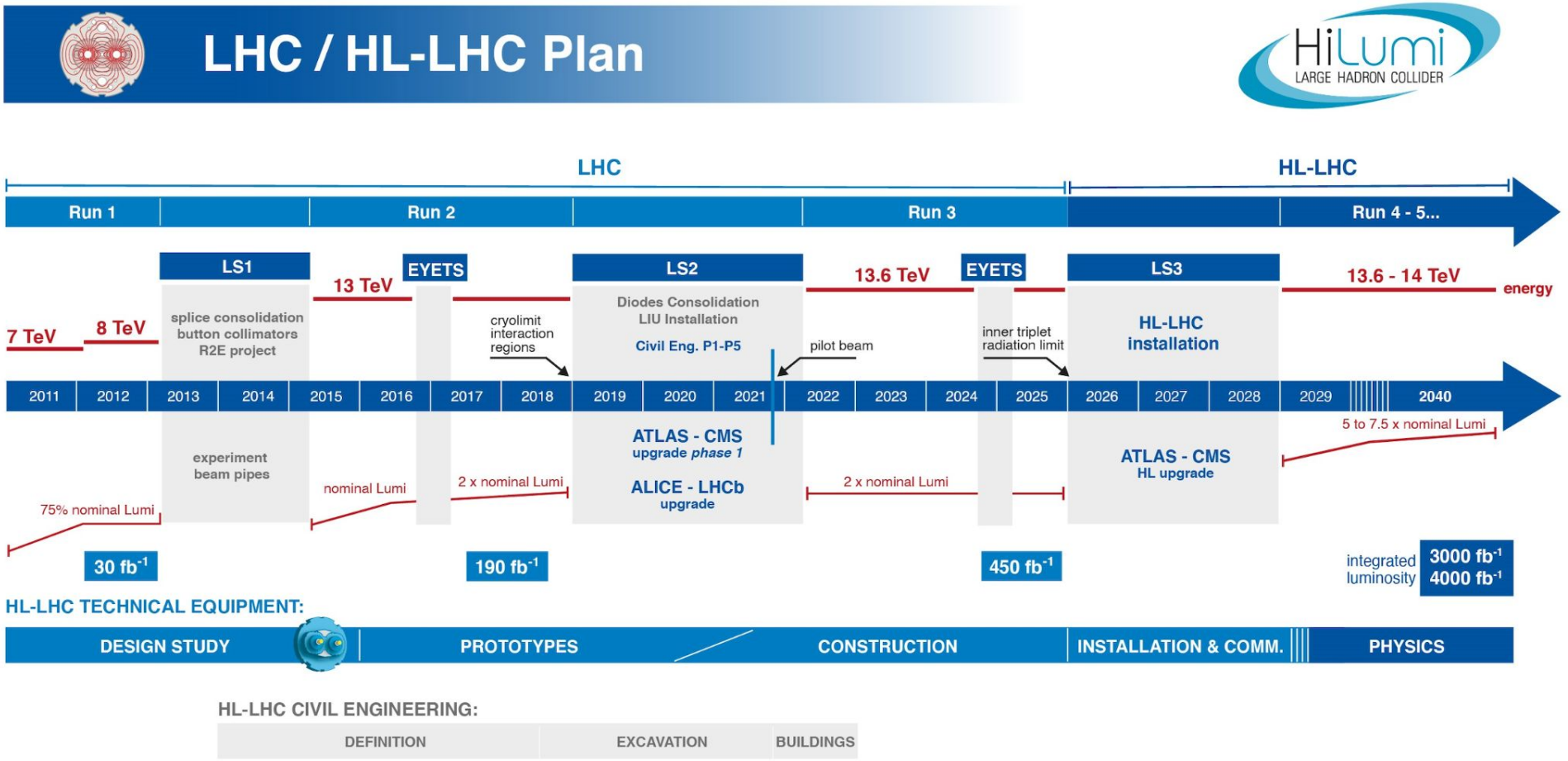
Backup slides

DESY Deliverables

Need to deliver more than 4600 parts ….

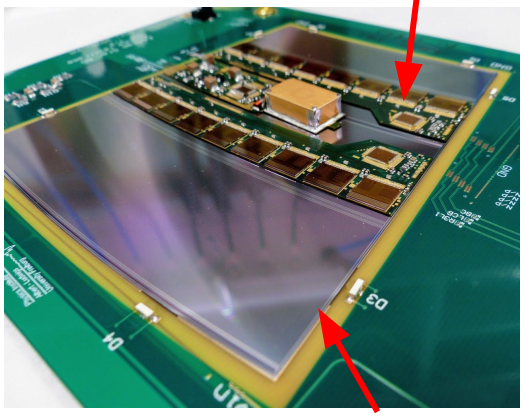
- **Petal cores (400)**
  - Planning based on delivering parts for all cores for BOTH end-caps
    - Co-cured facings, Titanium pipes with welded insulating breaks, smaller parts
  - Main process of building the petals taken over by company AVS (Spain)
- **Endcap modules (2000 +500)**
  - Split into 3/4 in Zeuthen and 1/4 in Hamburg
  - 500 modules for the HU delivery
  - Backup for each other
- **End of Substructure (EoS) cards (1630)**
  - Custom board to be produced
- **Fully instrumented petals (100-125)**
  - ~ 50% of an end-cap
- **End-cap integration structure (1)**
  - Structure will be built at NIKHEF
    - DESY involved in overall design and producing some of the carbon fiber components (service trays)
- **Fully instrumented end-cap (1)**
  - In close collaboration with Berlin, Dortmund and Freiburg

LHC / HL-LHC schedule

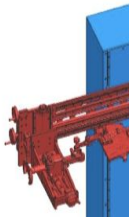


ATLAS ITk Strip Tracker Upgrade

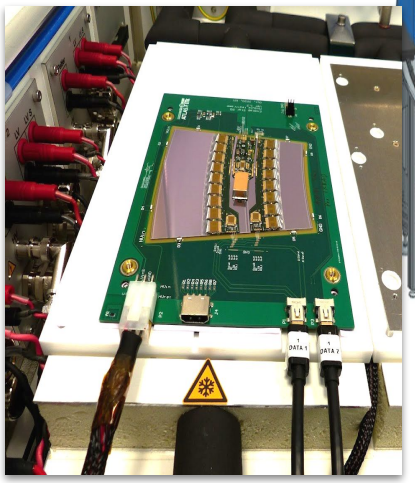
at DESY - Zeuthen Campus



- **Micro-Intro: why ATLAS upgrade @ DESY**
  - LHC: higher luminosity with “HL-LHC” Upgrade
  - at HL-LHC, current ATLAS tracking detector will not
    - withstand radiation nor
    - be able to separate dense tracks in time and space
  - ATLAS needs new tracker
    - higher radiation hardness and
    - higher granularity and
    - faster readout (and new trigger) capabilities



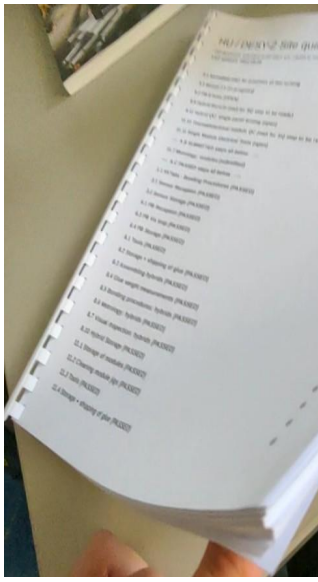
  - DESY joined ATLAS late, without contributing to ATLAS dev and construction
    - required that large labs do this, to be accepted into collaboration
    - we fulfill this “dept” retroactively with contribution to tracker upgrade (aka *obligation to international collab*)



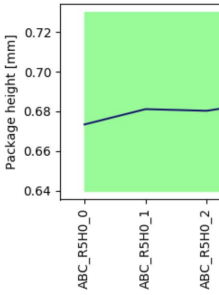
  - DESY-Z contributed significantly to dev of new tracking detector
  - DESY-Z will build large fraction of new tracker
    - entered pre-production
    - ITk uses the pre-production modules to build petals and staves to test a larger fraction of the final detector

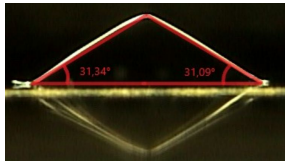
ATLAS ITk Strip Tracker Upgrade

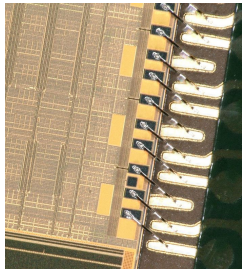
at DESY - Zeuthen Campus

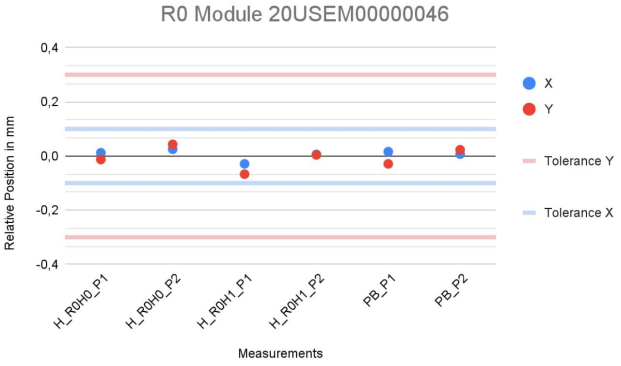


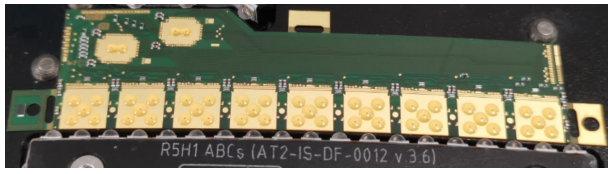
- **Status - gearing up for production**
  - Well advanced in “qualification” for production
  - Covid: qualify >20 labs worldwide in “remote” way
    - had planned site visits, spend few days at each lab
    - now record data, shoot videos, … and put into documents
      - Zeuthen alone: wrote 145 pages (85% done)
    - significant time and work investment
      - worth it, play through every step in production and document, finding “bugs” in the process and learning in detail requirements to ensure coherent required quality at all labs

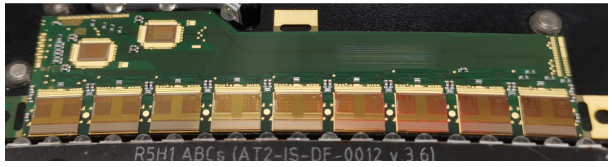










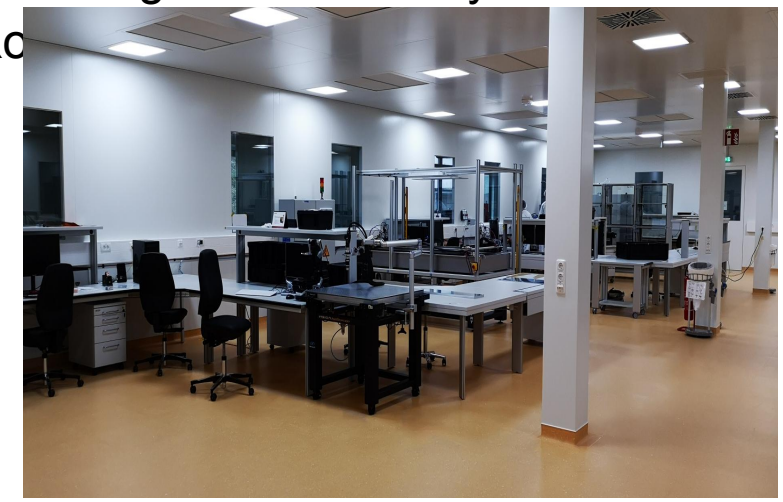


ATLAS ITk Strip Tracker Upgrade

DESY wide laboratories and clean rooms operational, undergoing site qualification

Zeuthen ATLAS upgrade production lab

Hamburg DAF assembly and QC Clean Ro

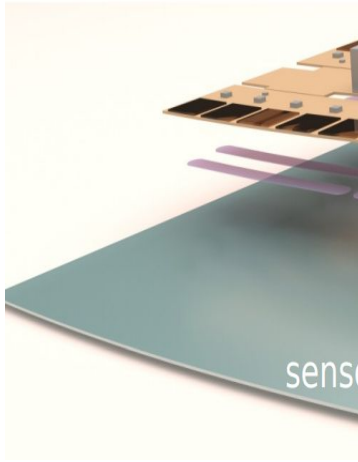


Hamburg DAF module/petal building Clean Roon

Hamburg DAF Integration Clean Room

ATLAS ITk Strip Tracker Upgrade

at DESY - Zeuthen Campus

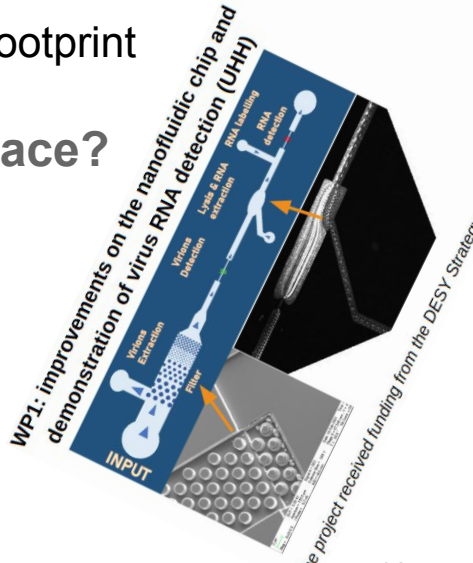


- **1. Where are our scientific and technological gold mines?**
  - The real gold mine is 4000fb^{-1} HL-LHC data that we work towards
  - Challenge to operate detectors at huge radiation levels at HL-LHC led to technological advancements, e.g.:
    - radiation hard components
      - silicon detectors
      - electronics (analogue and digital readout, powering (DCDC converters), environmental monitoring, flex circuits …)
      - construction components (composites (e.g. carbon), adhesives, …)
    - efficient powering schemes (e.g. DCDC conversion or serial powering)
    - CO2 cooling
- **2. What are our future applications fields?**
  - upgrade technology has many direct applications (e.g. in medical imaging, nuclear safety, satellites near the sun, …)
    - wherever high radiation fields and/or large temperature changes are expected and high detection sensitivity at low noise is required
  - future detectors will build upon what we developed for the HL-LHC (as we have build upon previous detectors)
  - data reduction techniques, online reconstruction and high throughput methods have a WIDE field of application (incl Astronomy)
  - efficient powering methods as well
- **3. What are our (== ATLAS Upgrade @ Zeuthen) mission-critical research infrastructures?**
  - short term the cleanroom and the cleanroom requirements

ATLAS ITk Strip Tracker Upgrade

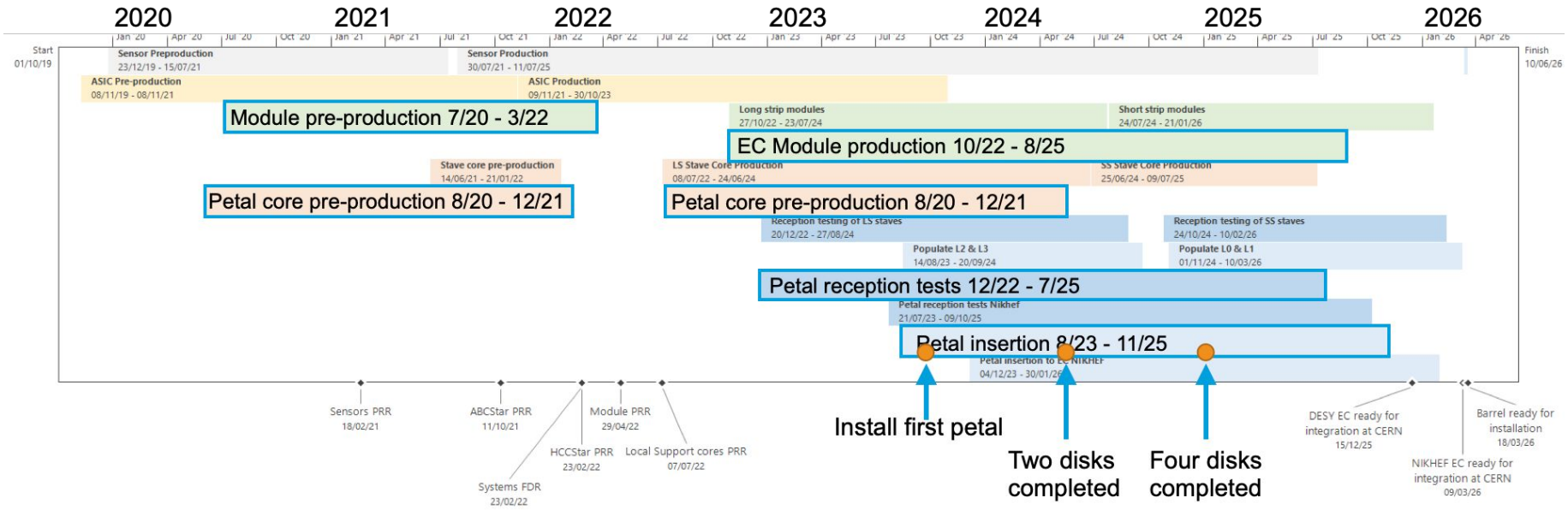
at DESY - Zeuthen Campus

- **4. What are further RIS (research infrastructure) with high discovery potential?**
  - ideally a plasma accelerator driven collider @ DESY :)
  - next higher energy collider - succeeding LHC
- **5. What are DESY obligations in international collaborations?**
  - in the context here, clearly
    - construct ~2000 modules and
    - deliver one of two endcaps CERN by Q2-2026
- **6. How can we increase the societal impact of the lab?**
  - ATLAS group (HH) develops cheap “DNA analysis tool” (nanoflu)
    e.g. as reliable detector for viruses (e.g. covid)
  - mind set: decisions checked for alternatives with smaller CO2 footprint
  - more remote collaboration (zoom, remote det ops, …)
- **7. How do we set up our service groups, deal with lab space?**
  - the “engineering matrix” appears a good start to me
    - think about ways to “automate” “booking” process
      - an online version of the matrix with immediate feedback to the person who adds a request?
  - as for lab space - we need more land!
    - if need to share, important to have protected zones, ensured that individual setups are protected against involuntary modifications



ATLAS ITk Schedule

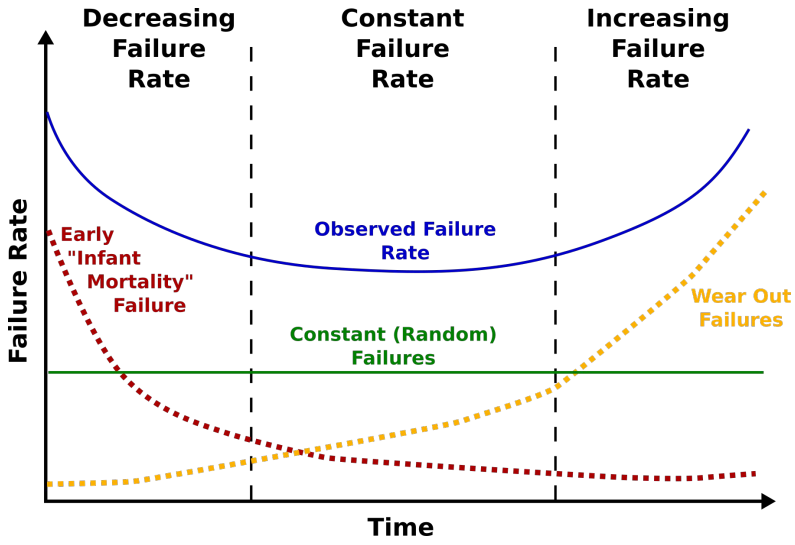
Highlighted on DESY Deliverables (Status: PRC - May 2022)

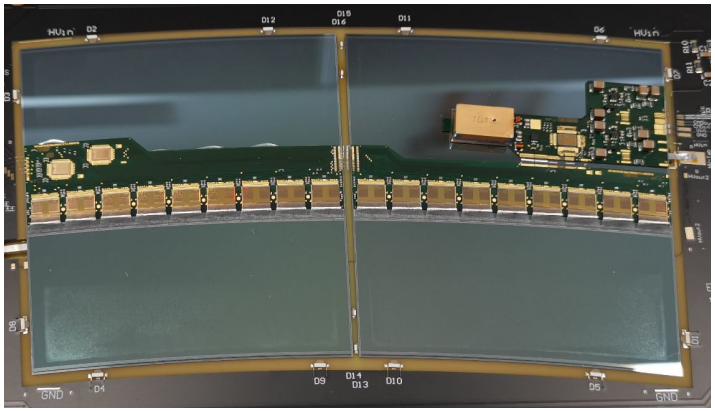


- Overall - strong impact due to Covid-19 - many delays in all areas
- Hard to disentangle “normal” delays and Covid-delays, but estimates assume at least 70% of delays due to lockdowns etc.
- Running with 50% top speed compared to “normal” times
- Many reviews ongoing

What is burn-in?

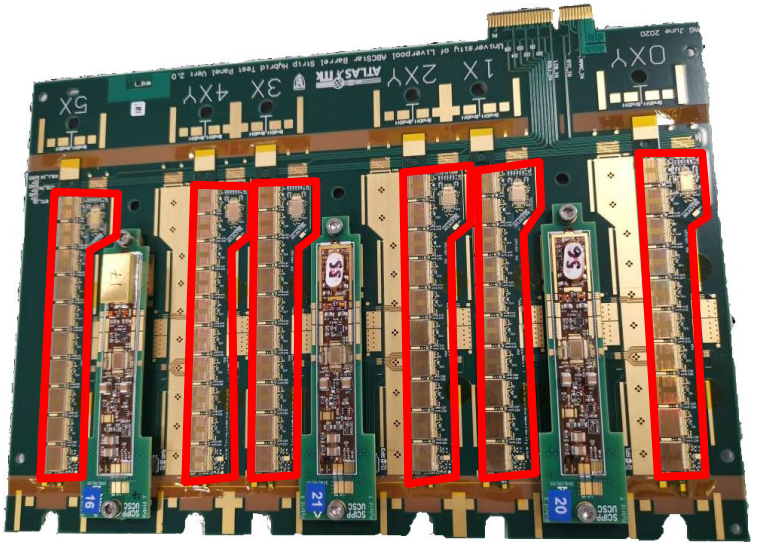
- Hybrid “burn-in”: sort out broken hybrids due to “infant mortality”, by operating them for some time
- Stress test for 100 h at 40 °C
- Done for each of the ~25000 hybrids, produced at >10 sites
- Standardised, automated setup makes burn-in efficient
  → Burn-in crate

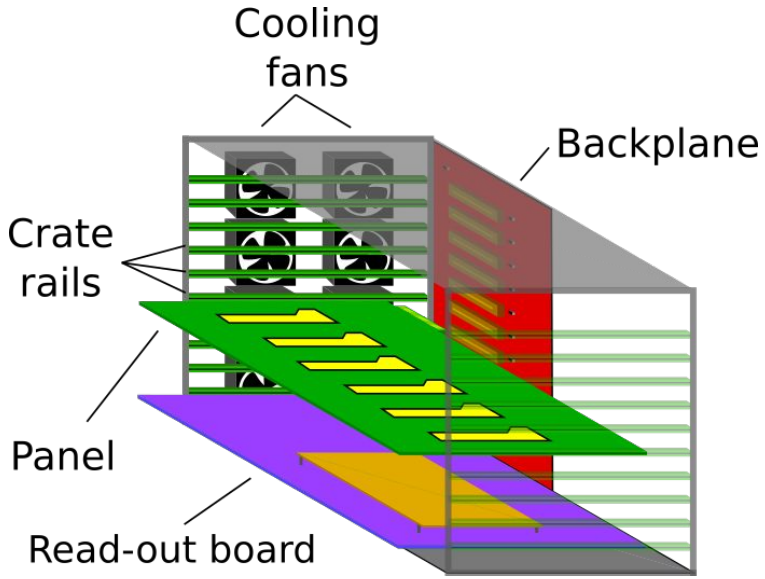


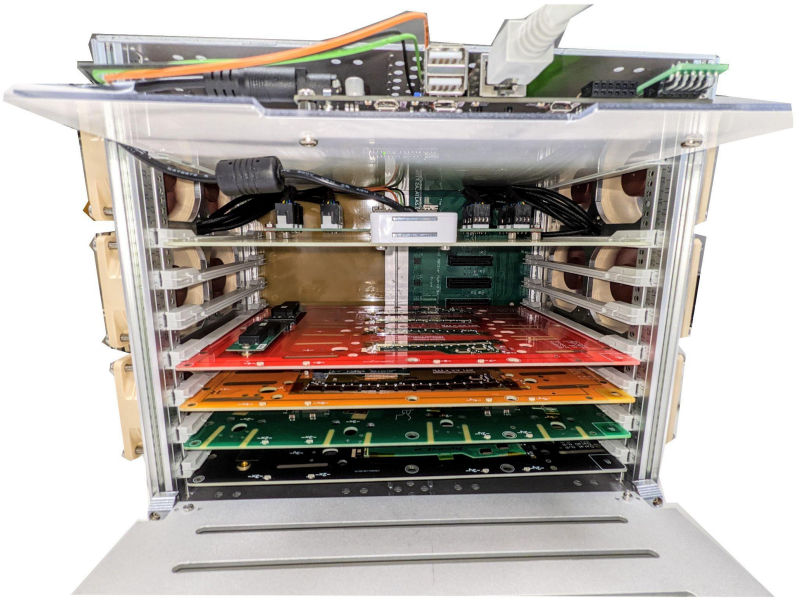


The burn-in crate

- Hybrids mounted on “hybrid panels”
  - 2-6 hybrids per panel
  - Up to six panels per crate
- Panels plug into backplane (PCIe)
- PID controlled fan-cooling

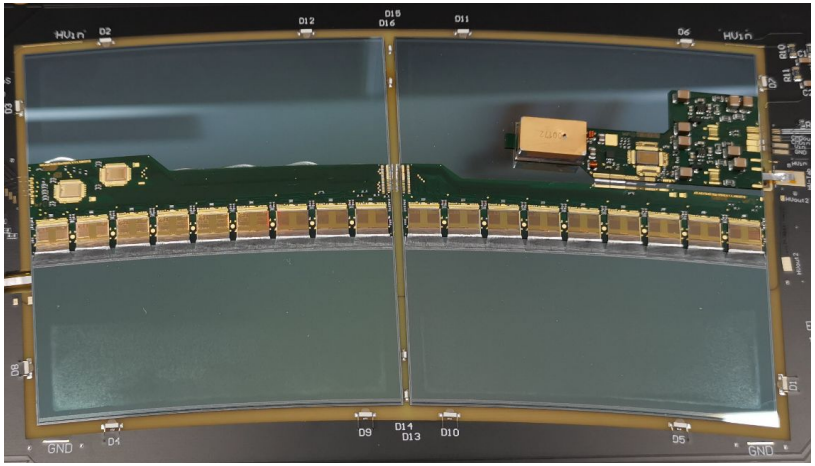


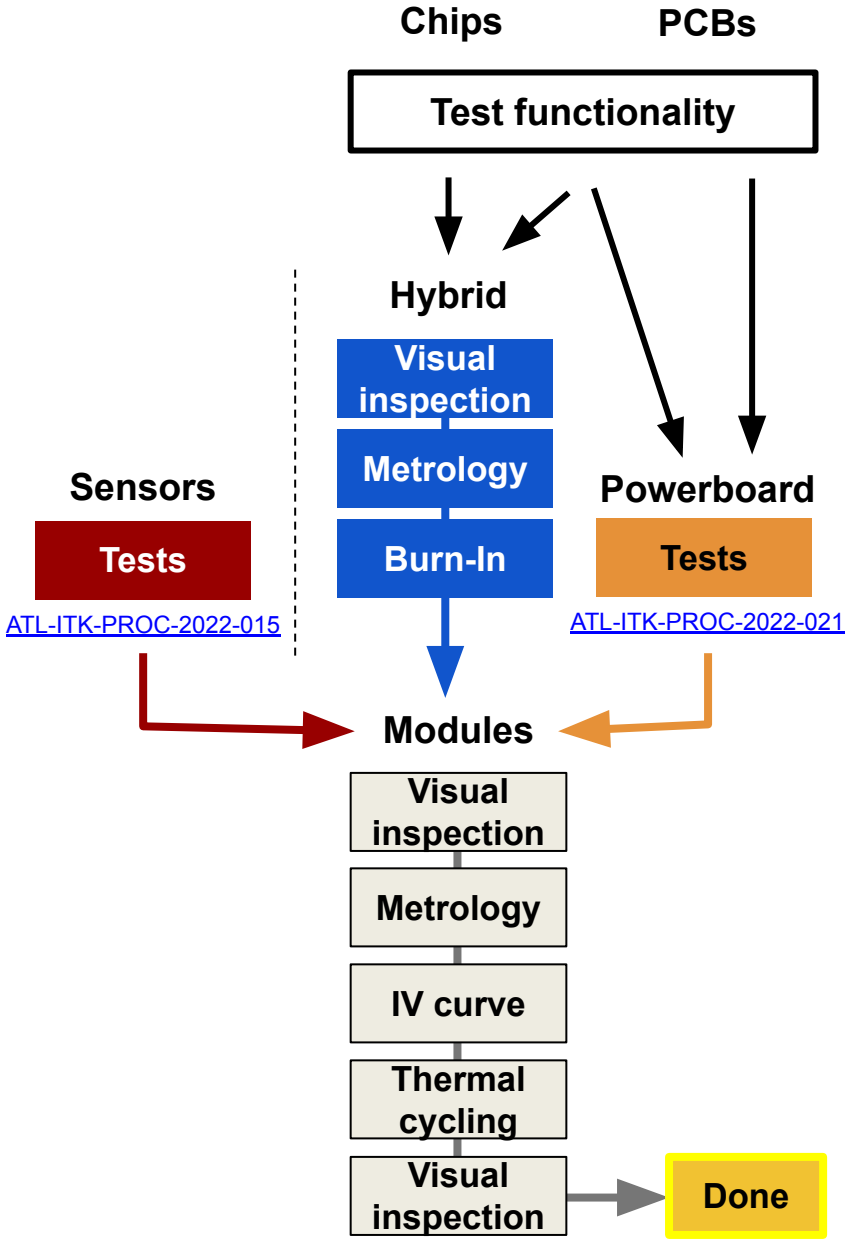




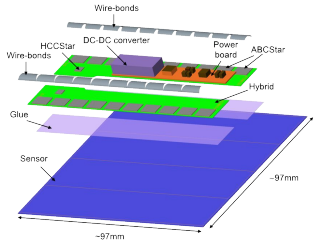
Module requirements

- To build ITk & (indirectly) fulfill physics requirements
- ITk strip modules must fulfill quality requirements, e.g.
  - well-defined geometry
  - fully functional
  - long-lasting (cannot replace)
- Extensive testing of module and components before installation



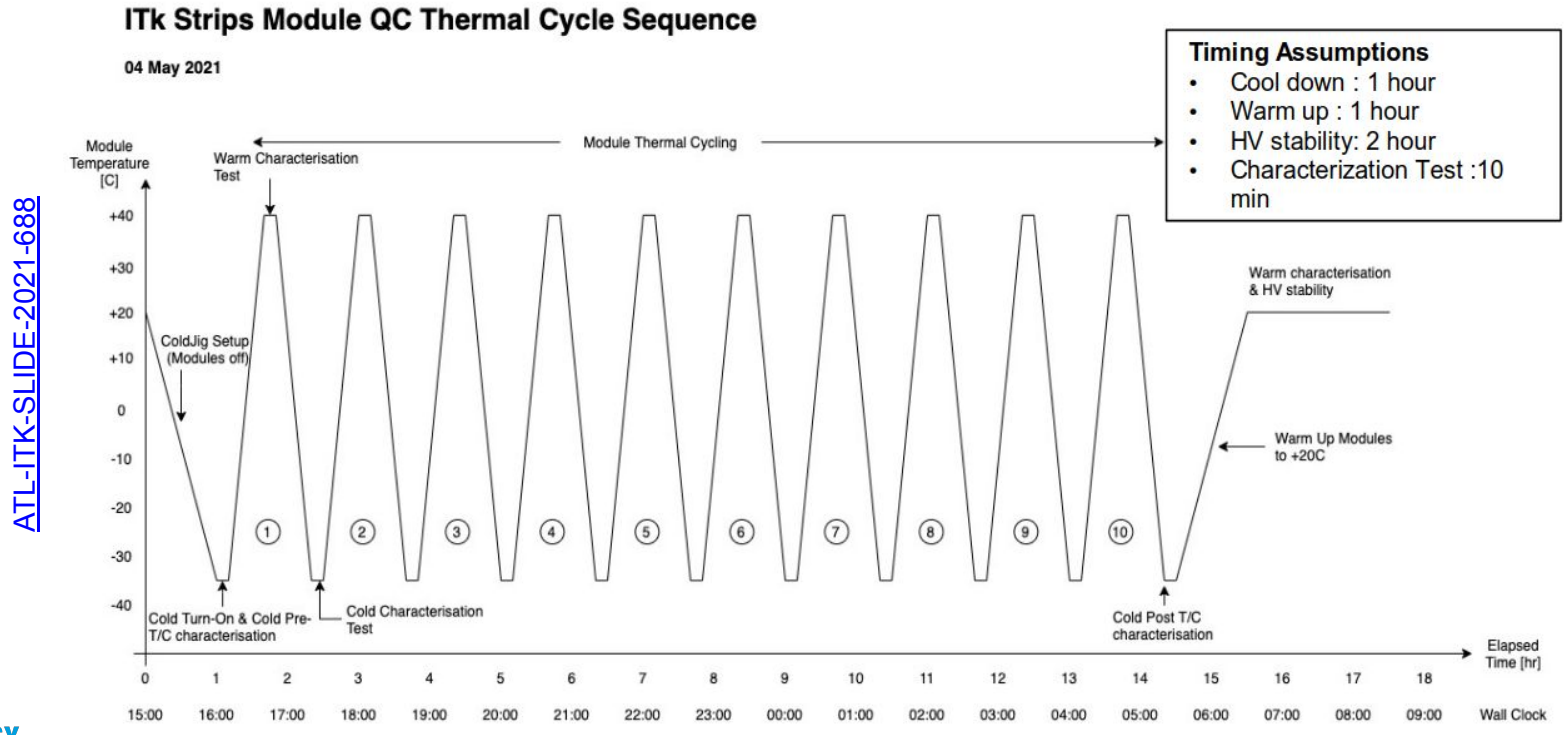


Module thermal cycling tests



- Radiation damage → leakage current → increases temperature

- Prevent thermal runaway by cooling detector as low as to T = – 35 °C
- Cycle module 10x from – 35 °C to + 40 °C:
  - Ensure mechanical stability & test electrical properties



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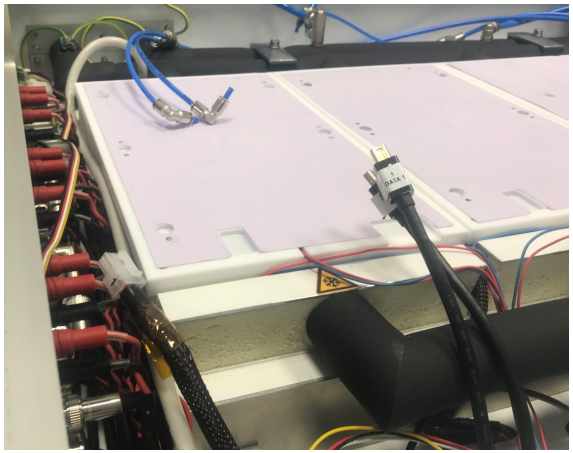
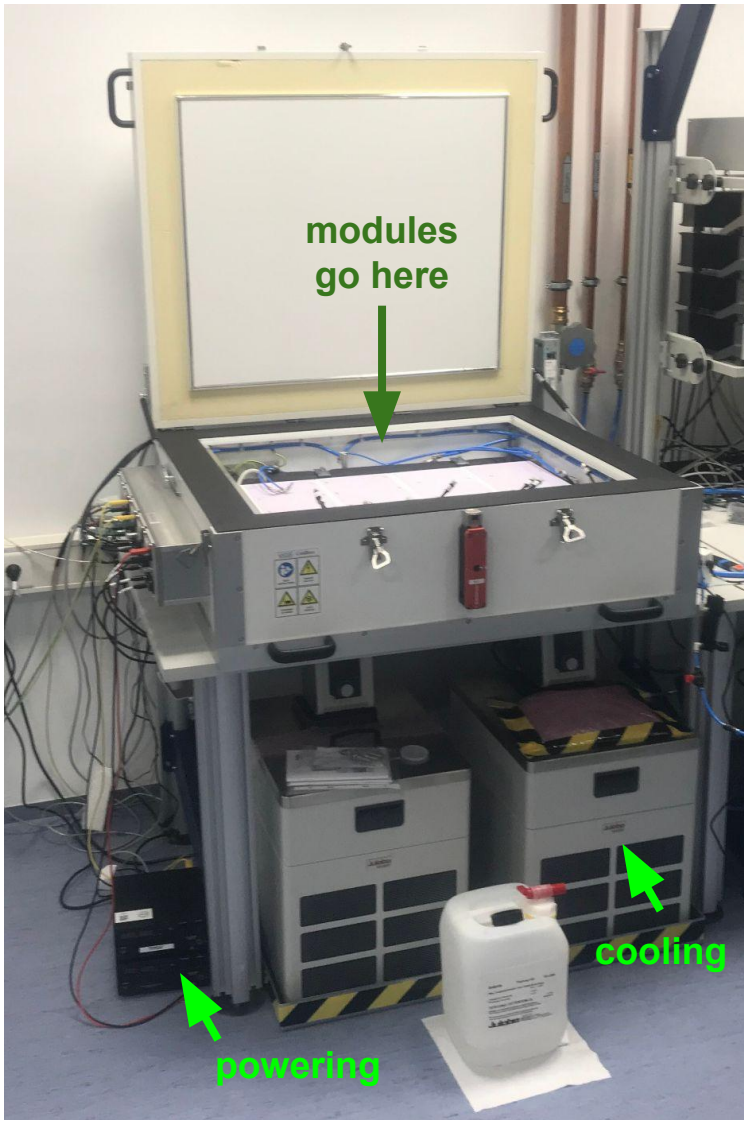
Thermal cycling setup



Module
Peltiers
Cold plate



Status

- Box designed & tested ✅
- Boxes transported to sites ✅
- Boxes ready to use ⌛
- Final automatisation ⌛
  - Auto recognition of modules
  - Automatic running of full test cycle

Contact

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