The ATLAS ITk Strip Detector System for the Phase-II LHC Upgrade

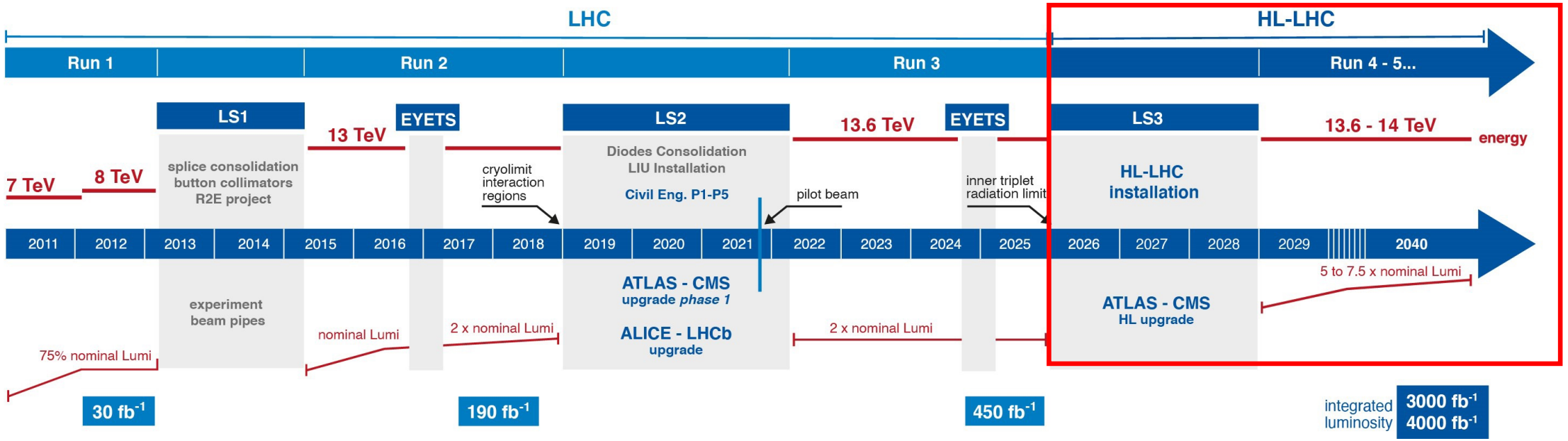
ICNFP2024

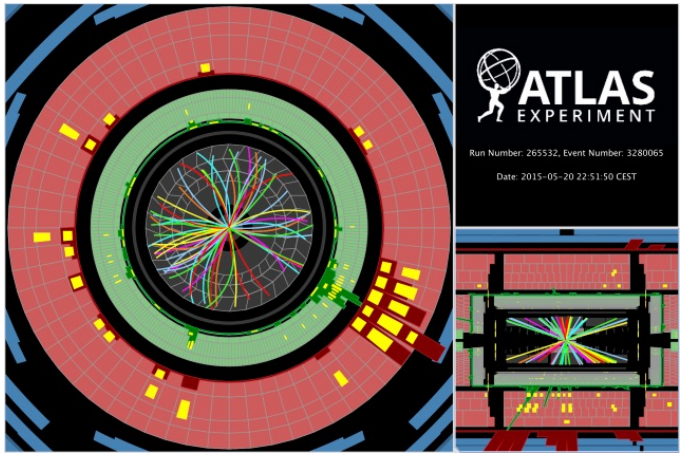
27th August 2024

Emily Duden

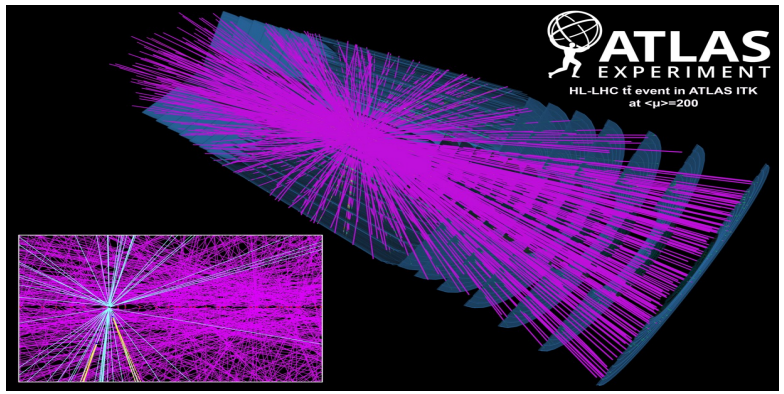
On behalf of the ATLAS Collaboration

High Luminosity LHC





Now: $< \mu > \approx 40$

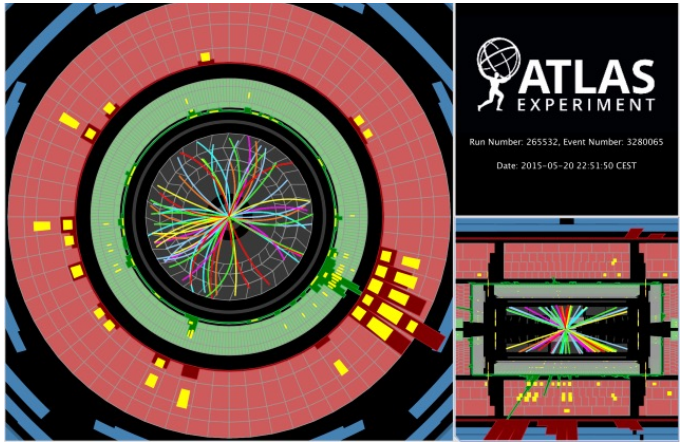


HL-LHC: $< \mu > \approx 200$

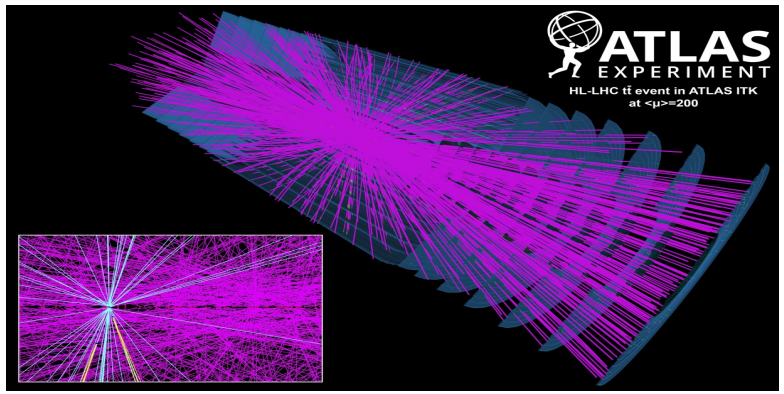
- HL-LHC will have…
  - $L_{peak} \approx 7.5 \times 10^{34} cm^{-2} s^{-1}$
  - $L_{int} \approx 3000\ fb^{-1}$
- Challenges:
  1. Radiation damage
  2. Detector occupancy and bandwidth saturation

High Luminosity LHC

Current tracker will be replaced by the new **all-silicon** *ATLAS Inner Tracker*



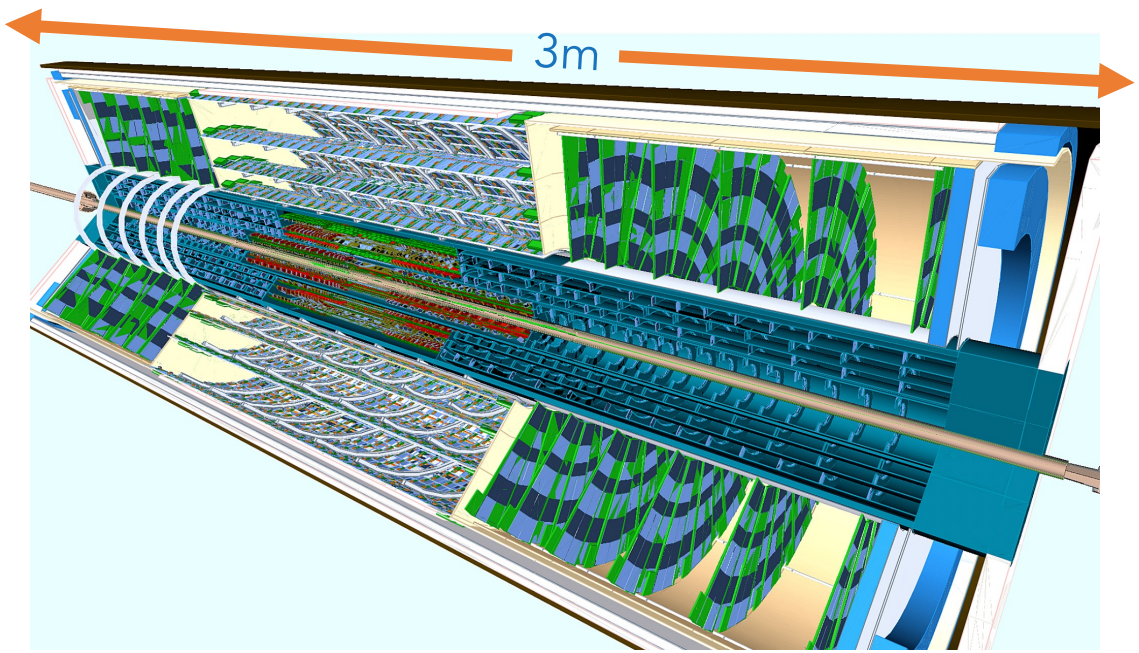
Now: $< \mu > \approx 40$



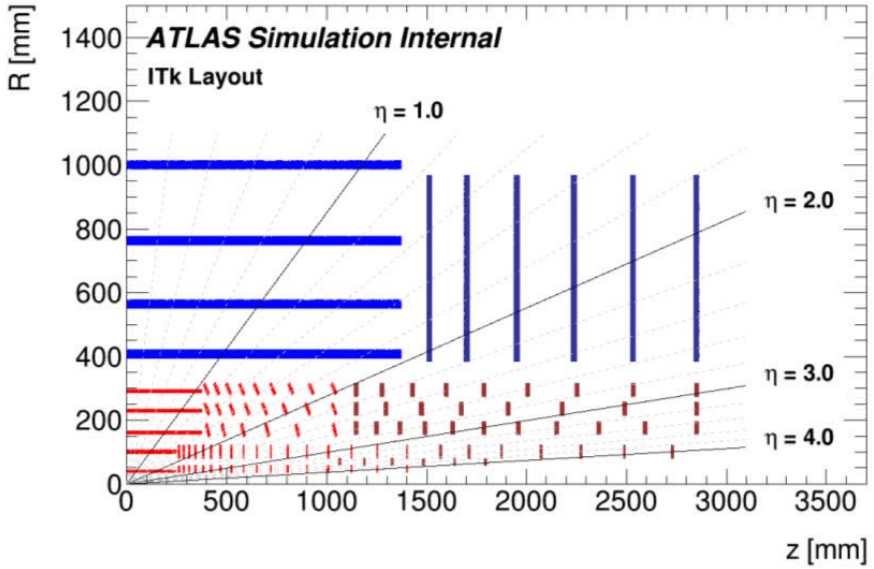
HL-LHC: $< \mu > \approx 200$

- HL-LHC will have…
  - $L_{peak} \approx 7.5 \times 10^{34} cm^{-2} s^{-1}$
  - $L_{int} \approx 3000\ fb^{-1}$
- Challenges:
  1. Radiation damage
  2. Detector occupancy and bandwidth saturation

ITk layout

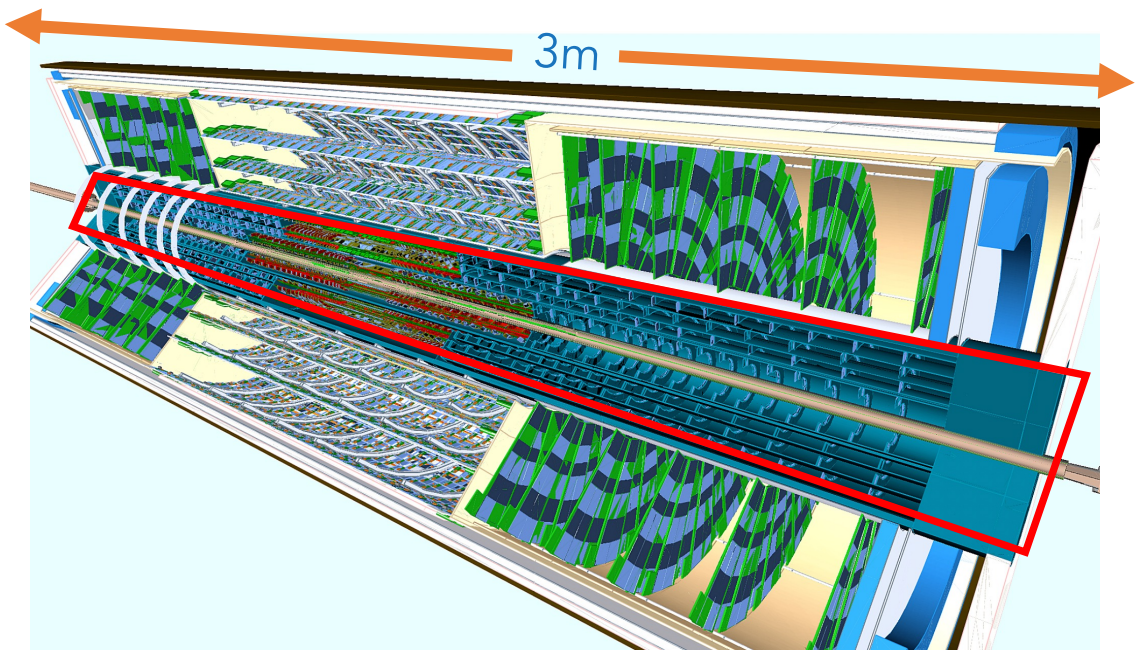


ITk Strips TDR



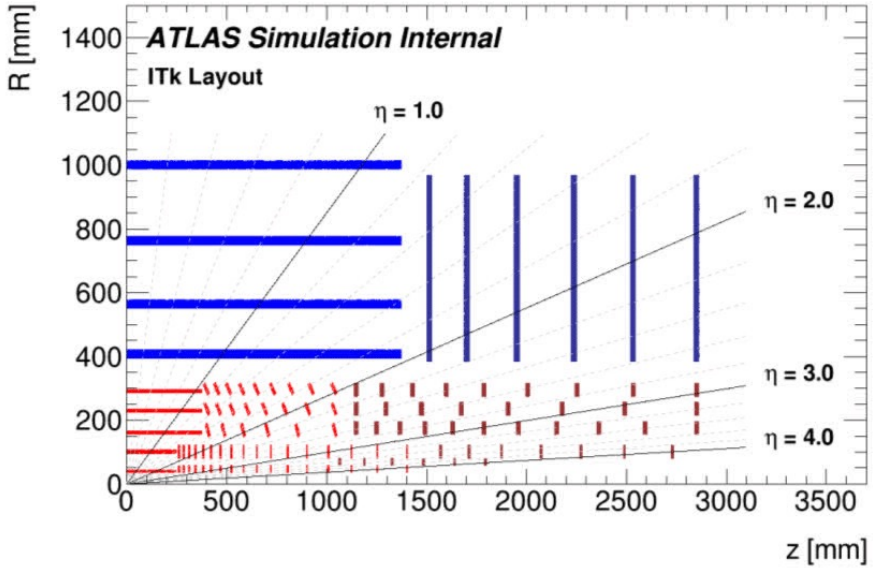
- All-silicon
- Extended η coverage (<4.0)
- Better radiation tolerance, granularity, and trigger rate (1MHz)

ITk layout



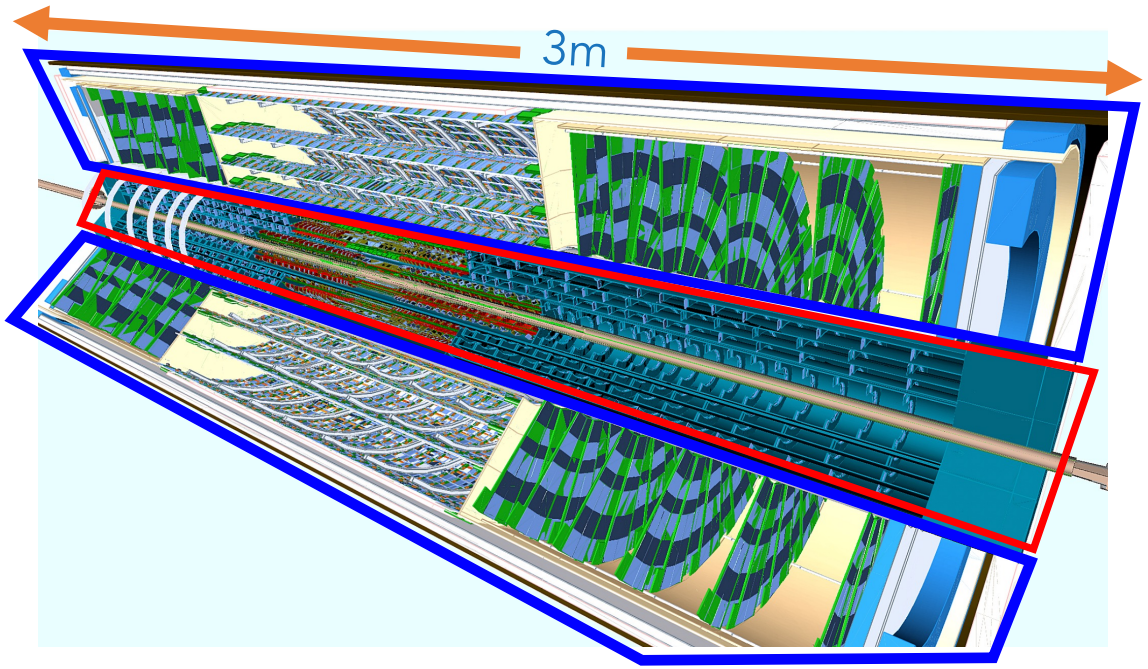
- All-silicon
- Extended η coverage (<4.0)
- Better radiation tolerance, granularity, and trigger rate (1MHz)

ITk Strips TDR



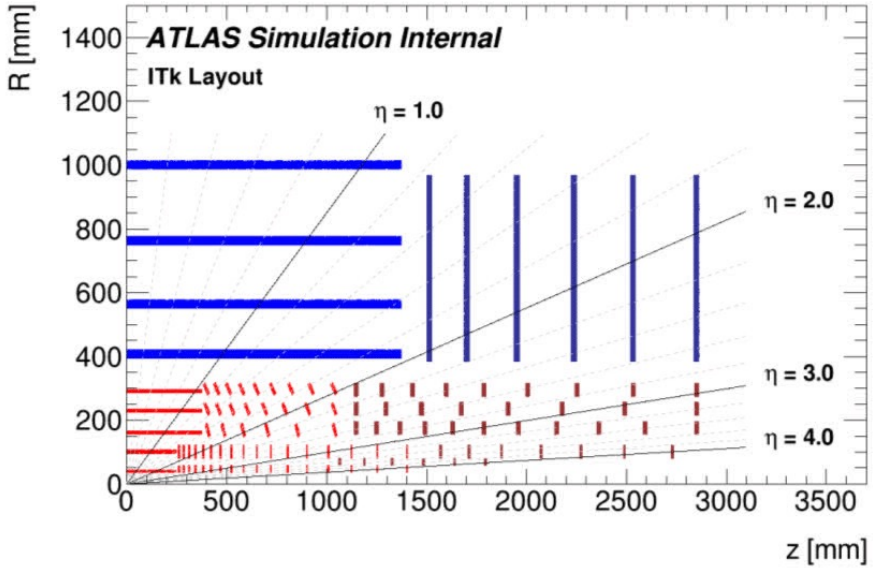
- Pixel detector close to the beamline
  - talk by Martina Ressegotti next week

ITk layout



- All-silicon
- Extended η coverage (<4.0)
- Better radiation tolerance, granularity, and trigger rate (1MHz)

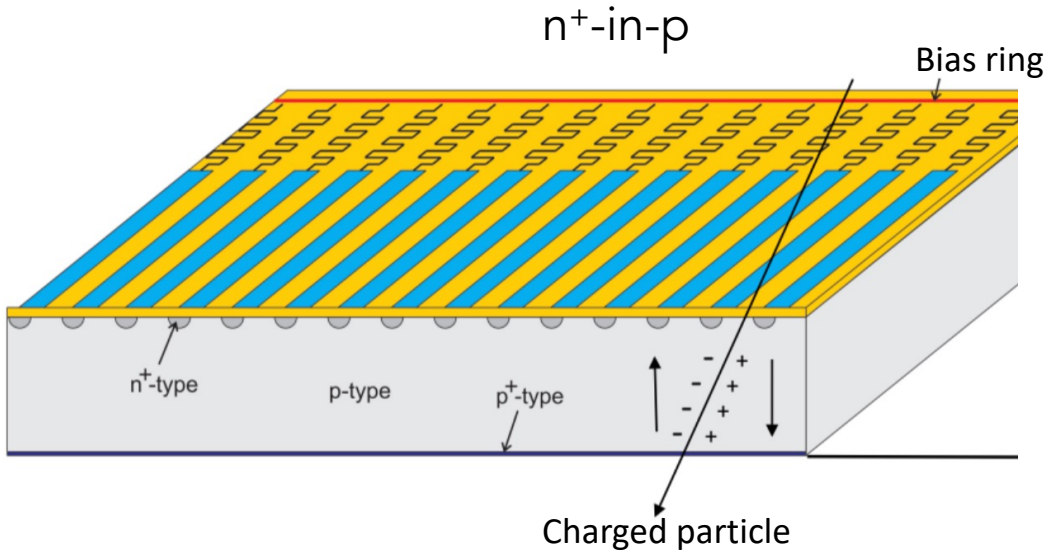
ITk Strips TDR

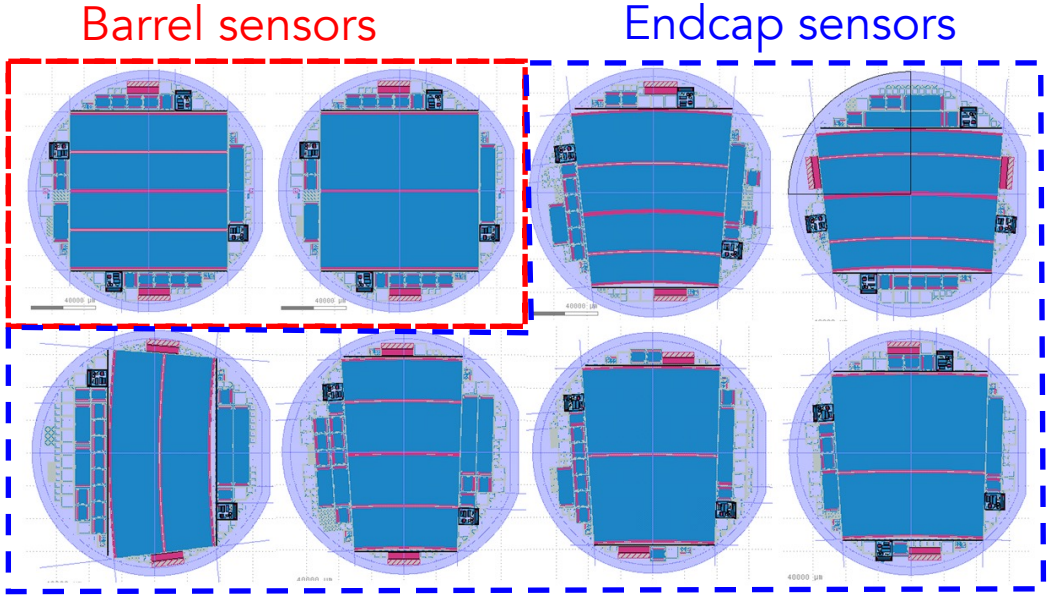


- Pixel detector close to the beamline
  - talk by Martina Ressegotti next week
- Strip detector surrounds pixels
  - 4 barrel layers and 6 endcap disks/forward region
  - 18K modules
  - 65M channels
  - 165 m^2 of silicon

Sensors

- AC coupled strips with n^+ implants in p-type bulk
- Radiation-tolerant up to fluences of $1.6\times10^{16} neq/cm^2$ [expected max $5.4\times10^{14} neq/cm^2$]
- Smaller strip lengths for better occupancy
- In Production since August 2021
- Two types of barrel sensors:
  - Inner 2 layers Short-Strip (2.4 cm)
  - Outer 2 layers Long-Strip (4.8 cm)
  - Active area of $9.7\times9.7 cm^2$ with $75.5 \mu m$ pitch
- 6 endcap sensor geometries
  - 1.5-6cm strip length
  - $70 - 80\ \mu m$ pitch





Power boards

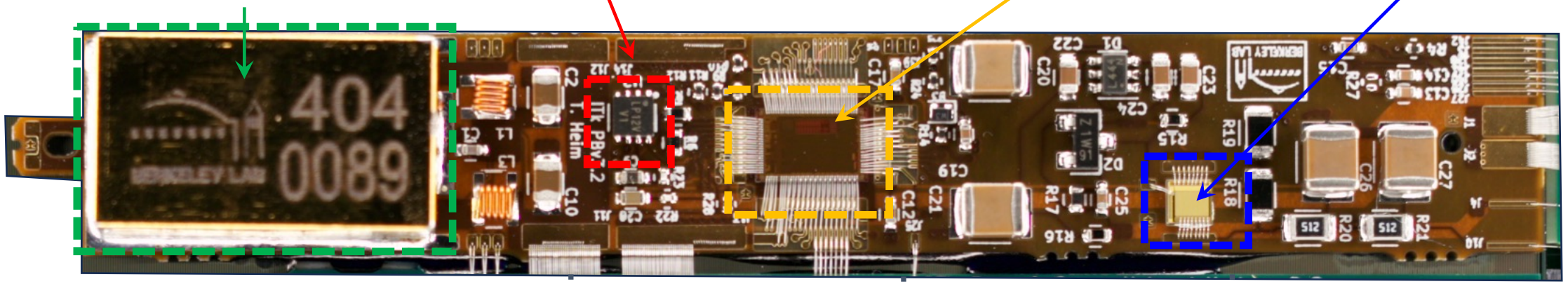
- Powers front-end electronics and monitors and controls sub-detectors

DCDC
- Buck converter
- 11V input, 1.5V output to front-end ASICs
- Al shield

LinPOL
- Linear regulator
- 11V input, 1.4V output to AMAC and 3.3V output to GanFET

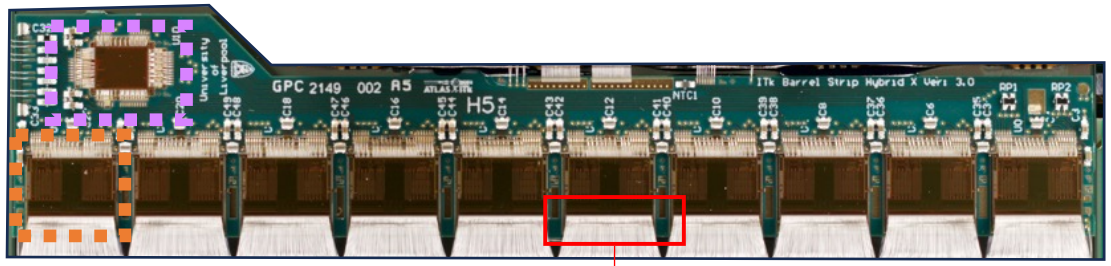
AMACStar
- Monitoring and control
- Measures voltage, current, temperature
- Enables/disables DCDC

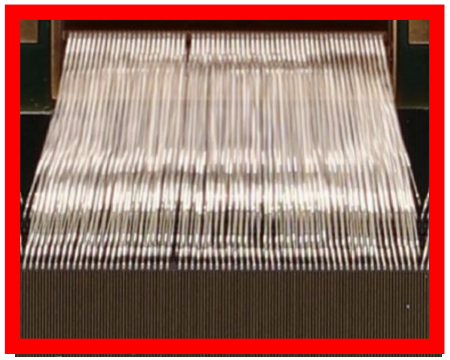
GanFET
- Switch for isolating failed sensors connected to the same HV line



Barrel module PB layout

Hybrids



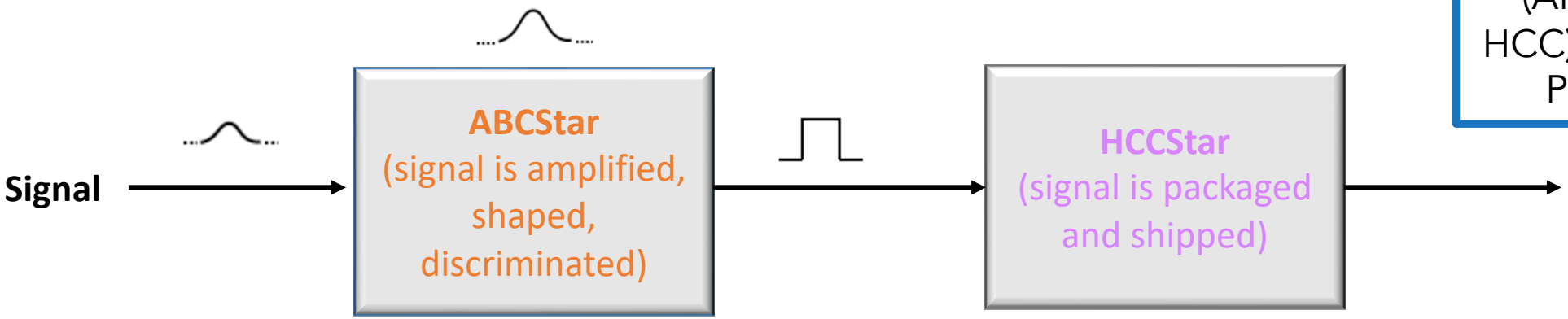


Wire bonds from each strip to ABC

7-12 ATLAS Binary Chips
- Front-end chips
- 256 channels
- Read analog signals from sensor and provide binary per strip readout

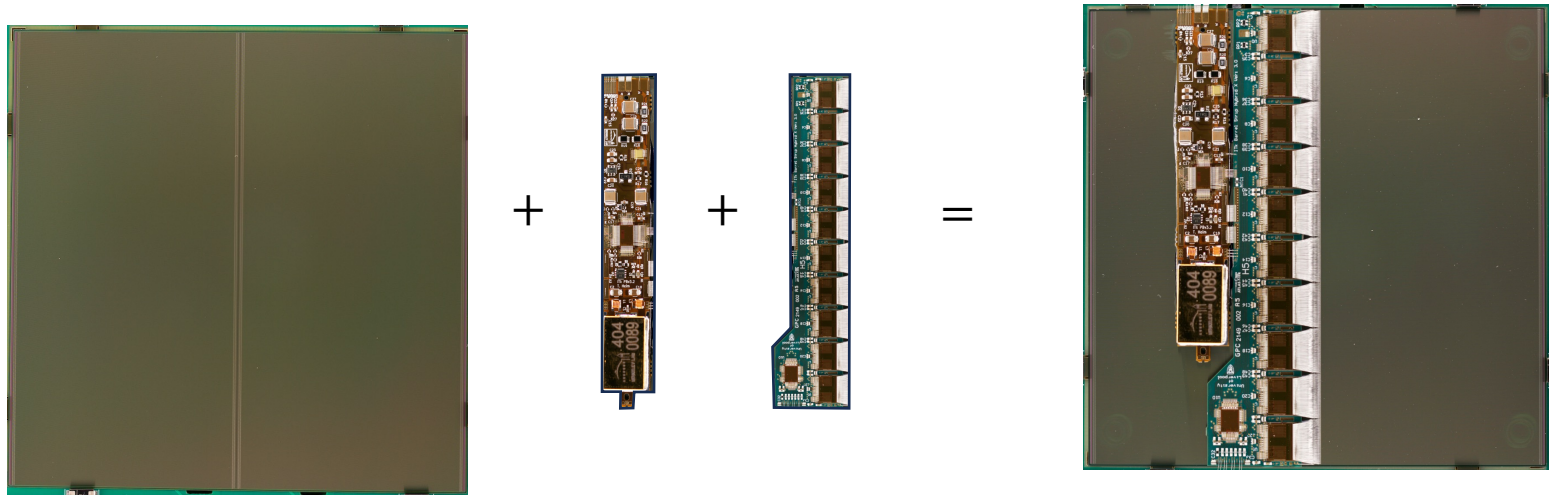
0-2 Hybrid Controller Chips
- Sends data from ABCs out of the sub-detector
- Distributes bunch crossing clock and control signals to ABCs

All 3 ASICs (AMAC, ABC, HCC) are well into Production



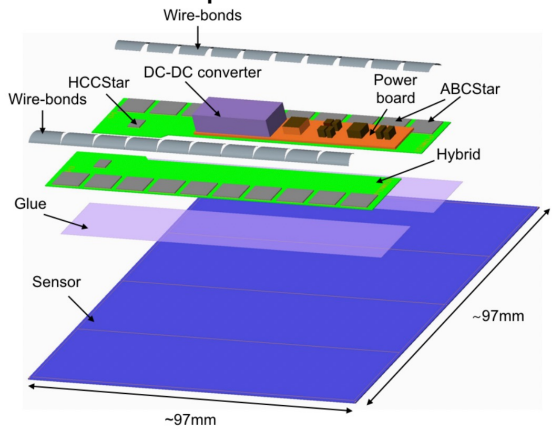
Modules

- 1-2 sensors, 1-4 hybrids, 1 power board
  - Hybrid(s) & power board glued directly onto the sensor
- Biased up to -500V
- Production-ready, contingent upon resolution of "cracking" problem (slide 13)

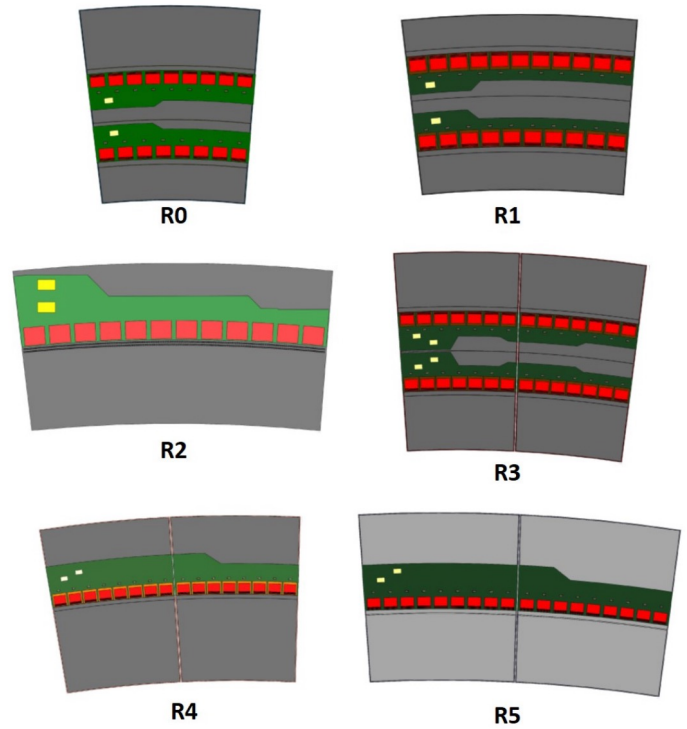


Long Strip Barrel module

Short Strip Barrel module



Endcap modules



ITk Strips TDR

Local support structures

Total staves + petals = 776

Staves (barrel)

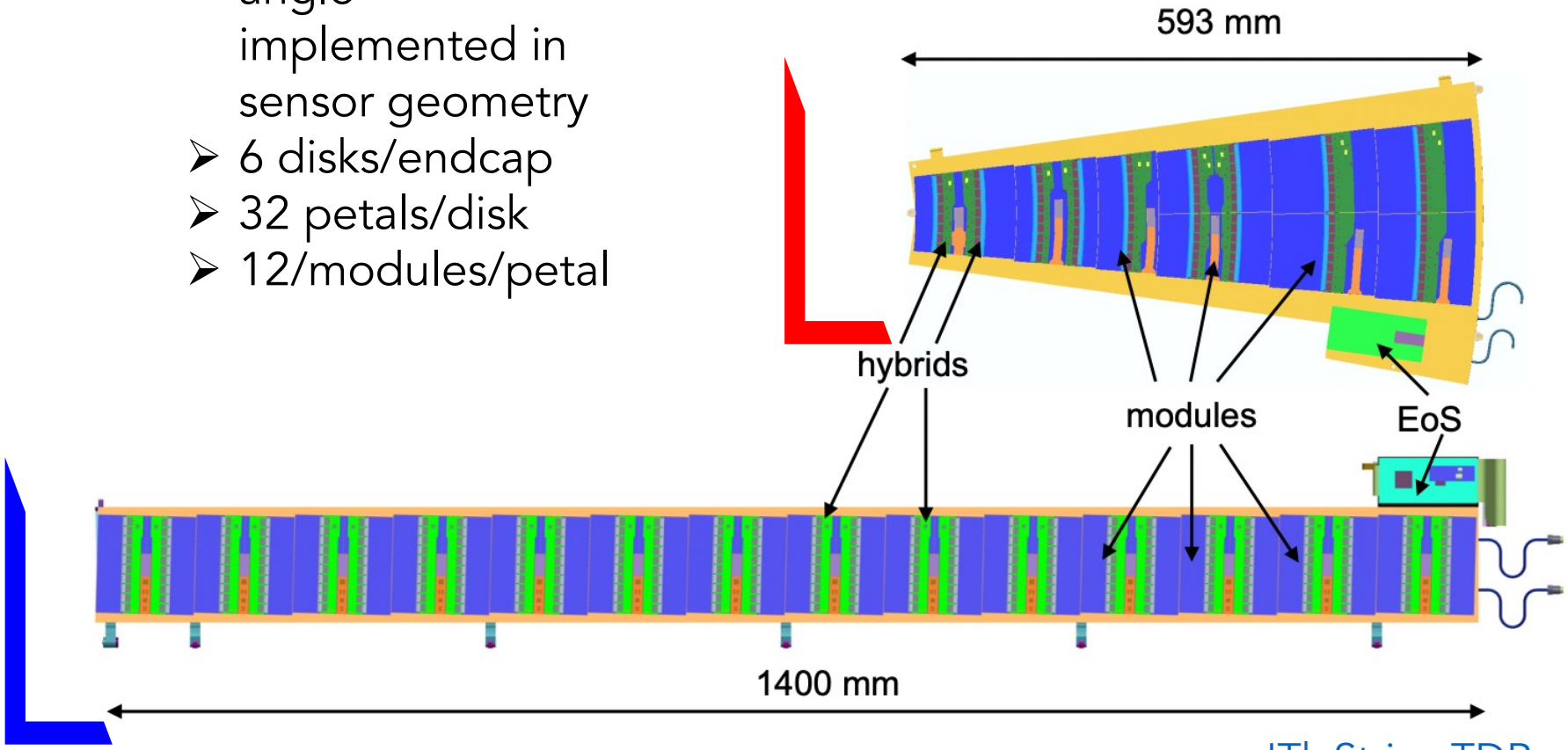
- Modules rotated $\pm 26\ mrad$ wrt beamline
- 28 modules/stave
- 392 total staves

Petals (endcaps)

- $\pm 20\ mrad$ stereo angle implemented in sensor geometry
- 6 disks/endcap
- 32 petals/disk
- 12/modules/petal

End of Substructure Card

- **VTRx+:** fibre-optic driver/receiver package
- **lpGBT:** associated electrical transceivers
  - communicates with off-detector electronics

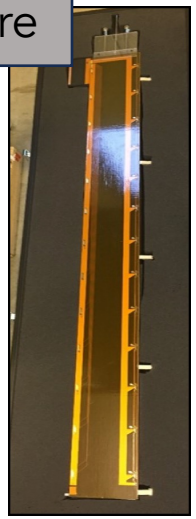


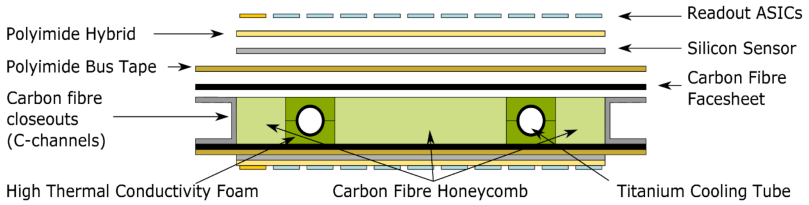
ITk Strips TDR

Local support structures

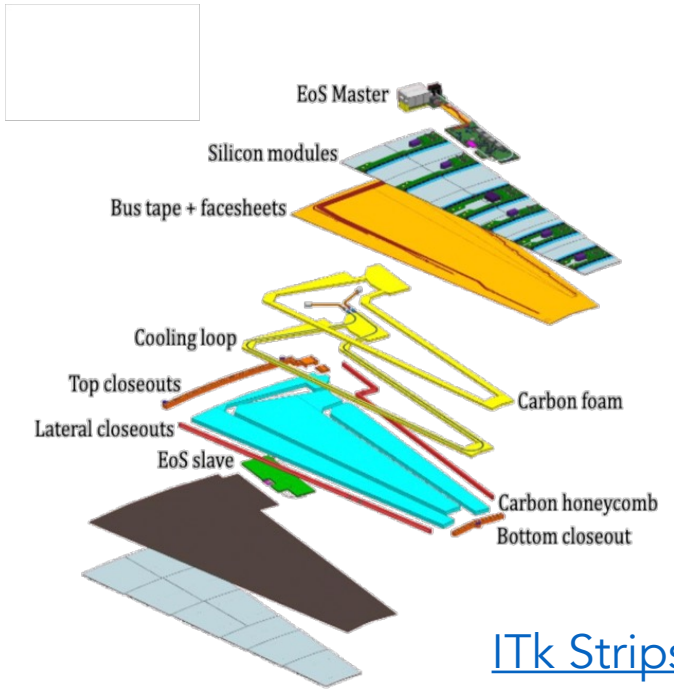
- Modules are glued onto a lightweight carbon fiber support structure (core)
  - Mechanical support and thermal conductivity
  - Ti pipes for cooling
  - Copper/Kapton bus tape routes electrical services for modules

Stave core





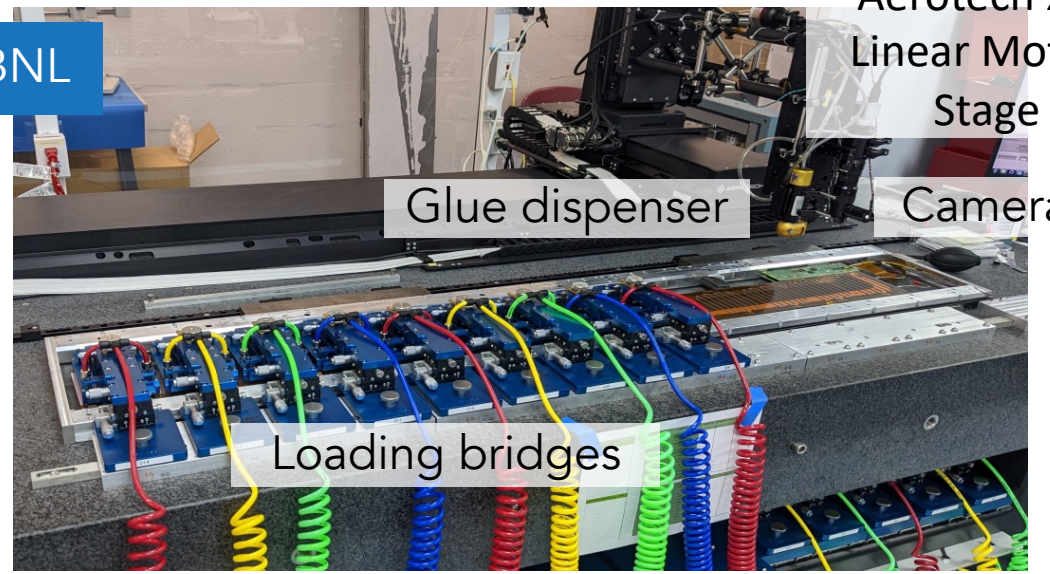
Petal core

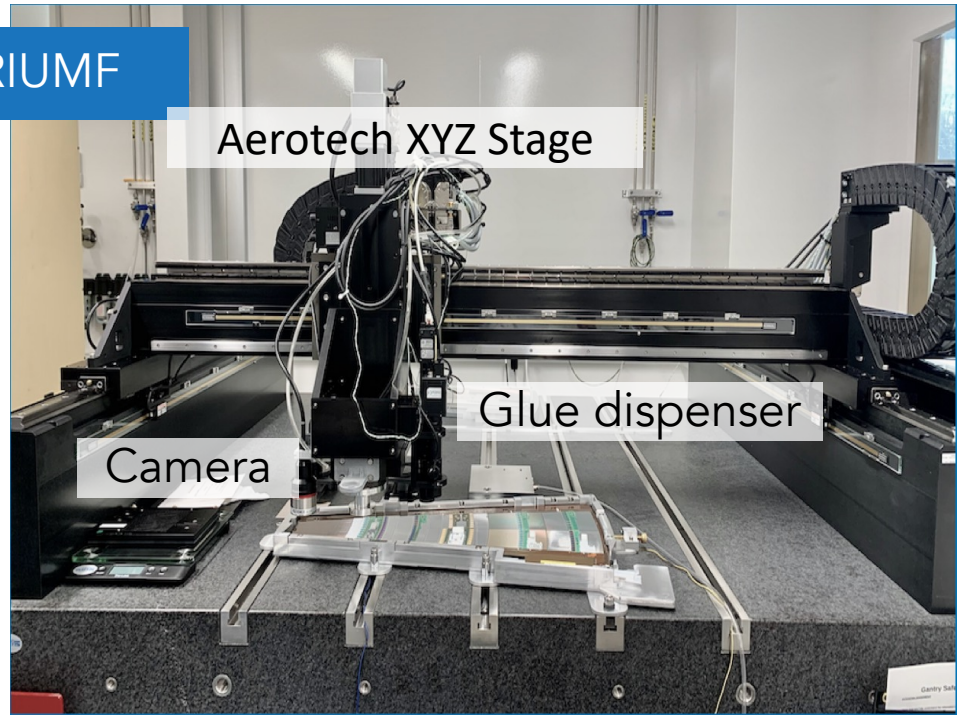


ITk Strips TDR

Stave/petal loading

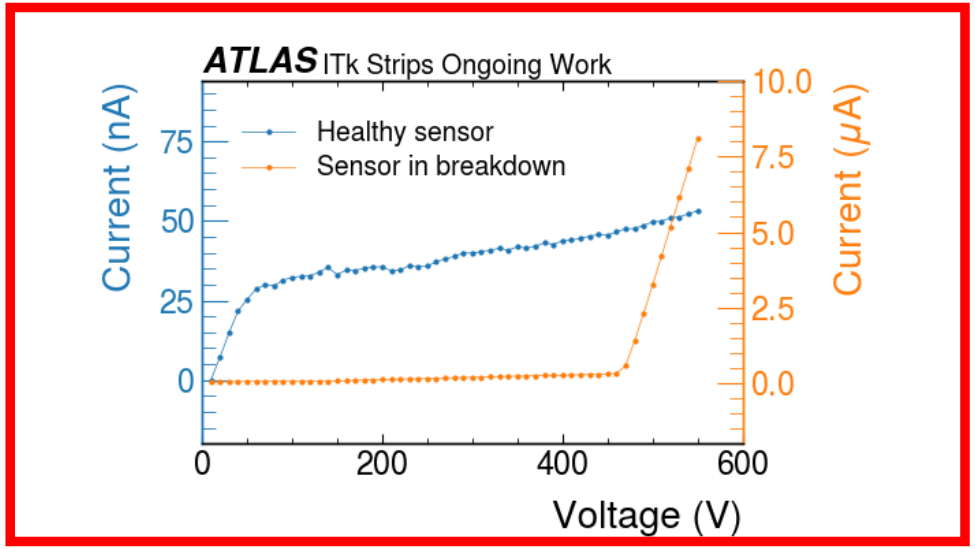
- Barrel loading sites: BNL, RAL
  - Different glue patterns + loading bridges
- Petal loading sites: DESY, Freiburg, Valencia, TRIUMF
  - Some difference in procedures, i.e. metrology
- General loading procedure
  - ➢Glue dispensed
  - ➢Modules placed within 50 μm accuracy
  - ➢Final XYZ metrology scan

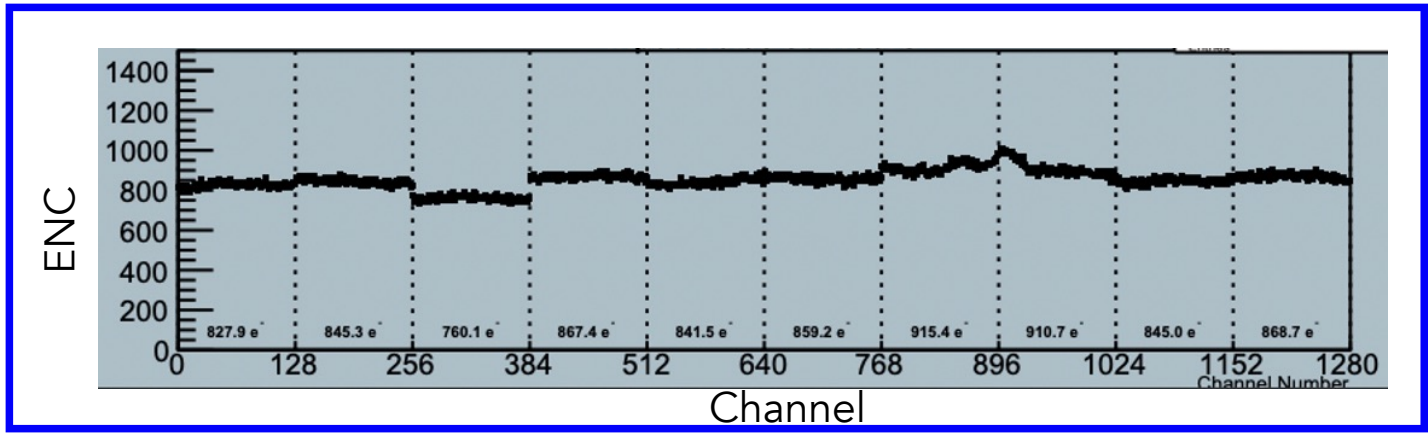




Quality control

- Modules + staves/petals must be extensively tested at every stage
  - Visual inspections + metrology
  - Hybrid burn-in
  - IV curves + electrical tests
  - Thermal cycling
- Electrical tests for QC
  - HVret current as a function of bias voltage (IV scans)
  - Calibrate front-end timing
  - Ensure channel uniform response
  - Characterize noise





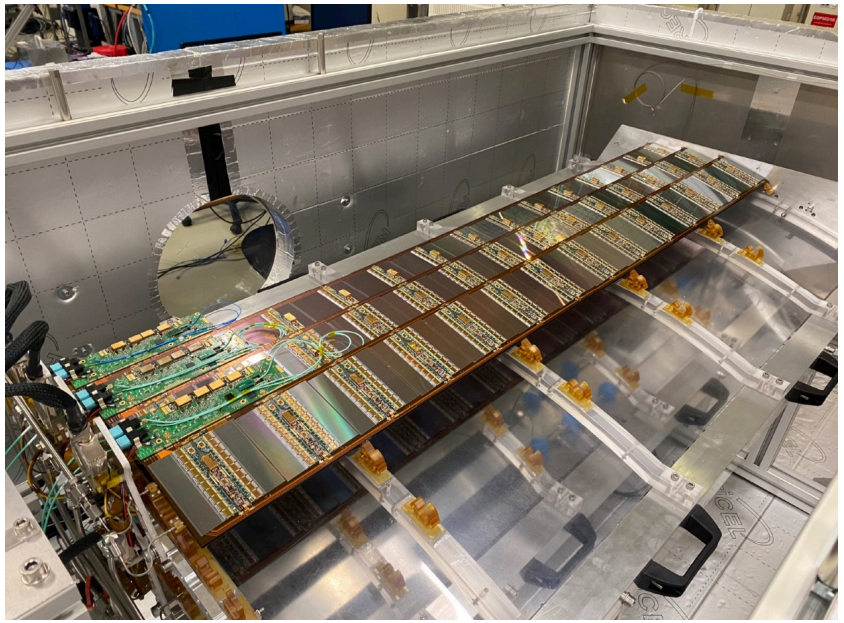
Tests done at room temp and -35 °C

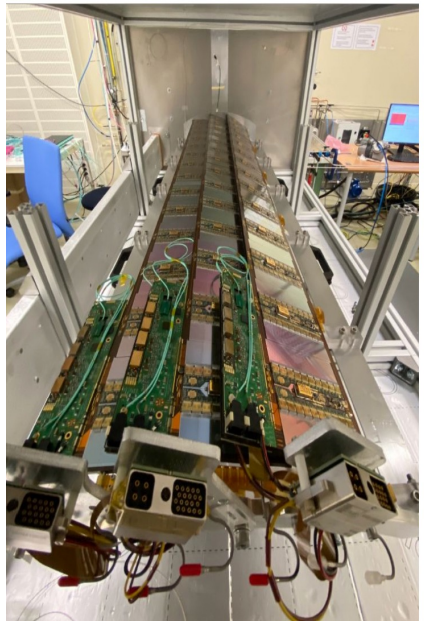
System tests

- Tests production chain with final parts and cooling
  - Powering chain, cooling infrastructure, electrical services, interlocks, DAQ systems…
- Used for long term DAQ and DCS development

Barrel system test @ CERN

- Hosts up to 8 staves
- 4 already installed





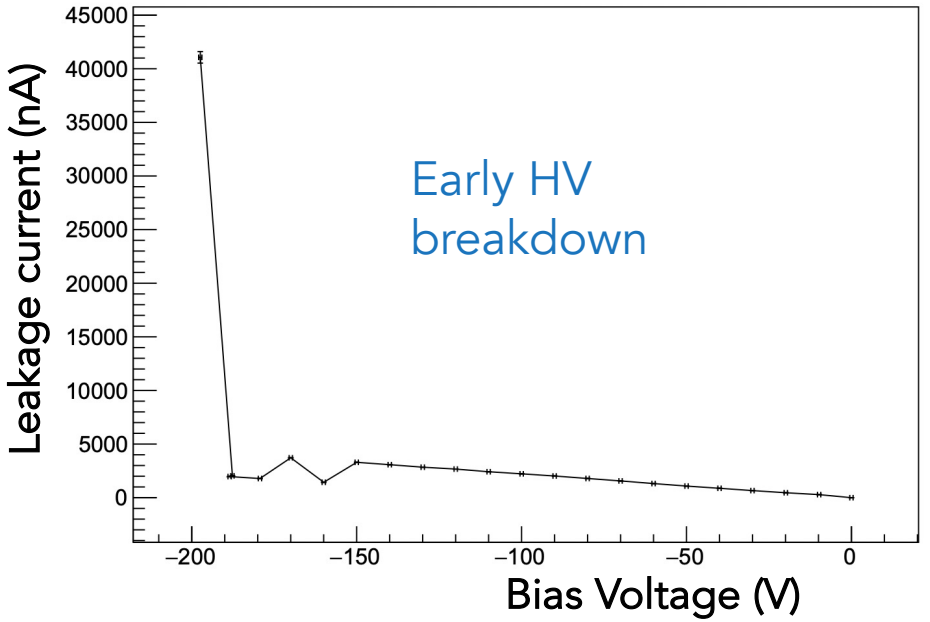
Endcap system test @ DESY

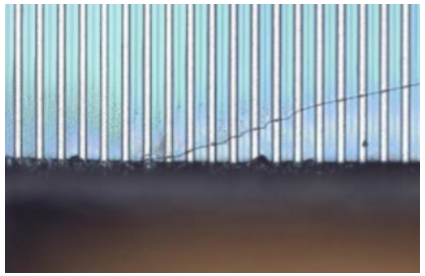
- Hosts up to 12 petals
- 1 installed

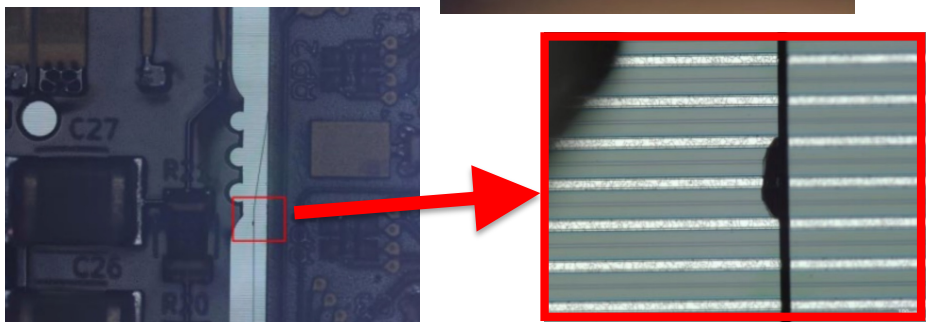
Sensor cracking

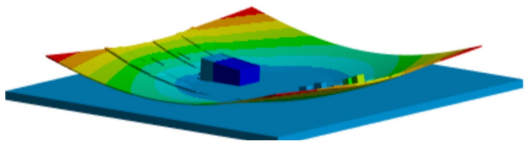
- Early HV breakdown on a fraction of modules during stave and petal cold tests, accompanied by noisy channels
  - Developed only after mounting on cores
  - Cracks typically around hybrid(s) and power board
- Coefficient of thermal expansion (CTE) mismatch between electronics, glue, and sensor
  - Hybrids and power board contract more than the sensor, causing curling
  - Sensor cannot curl up when glued to the support structure
- Module production halted while testing remediation strategies

Electrical signatures of cracks

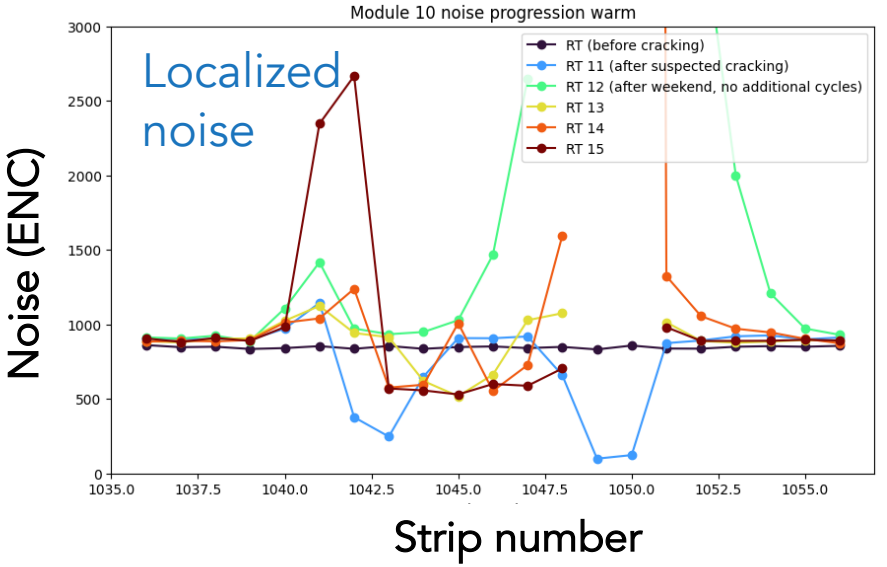








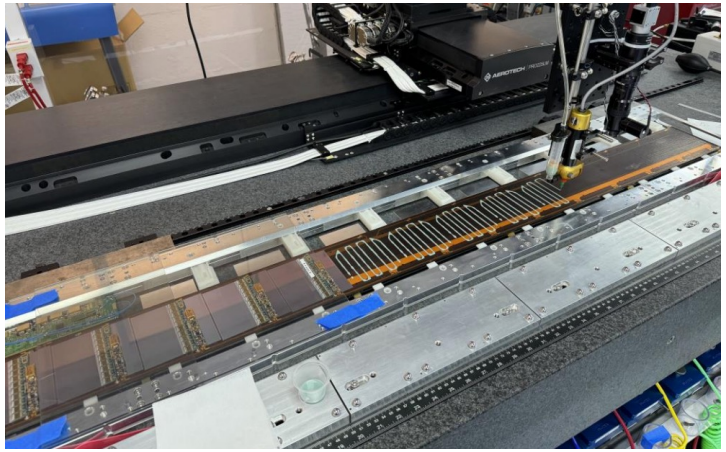
Free sensor (before stave loading)



Sensor cracking remediation

Hysol loading glue

- Use more rigid hysol glue to load modules onto staves/petals
- Stress reduction in simulation O(50%)
- Staves and petals still exhibit cracking when cycles 10 times to -35 °C



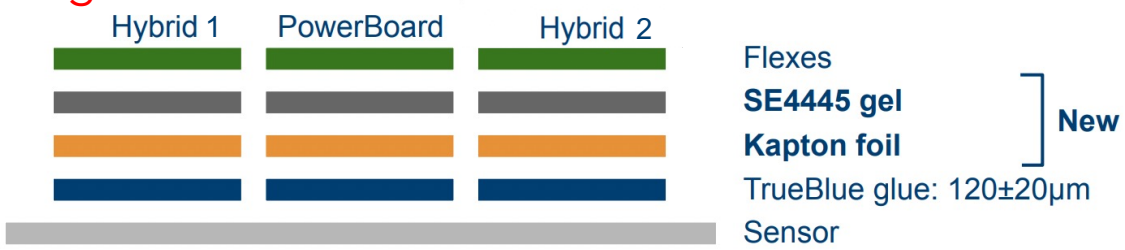
Stave loading with Hysol @ BNL

Wide gap modules

- Increase gap between hybrid and power board
- Not applicable to all module types
- Stress reduction in simulation O(10%)
- Hysol + wide gap module stave cycled 50x to -35 °C without cracks
  - Followed by cracking at -45 °C

Interposers

- Kapton interfaces between hybrid/power board flex & glue
- Stress reduction in simulation O(85-90%)
- Interposer modules, staves, + petals in development
- One interposer stave side cycled 10x to -45 °C without cracks



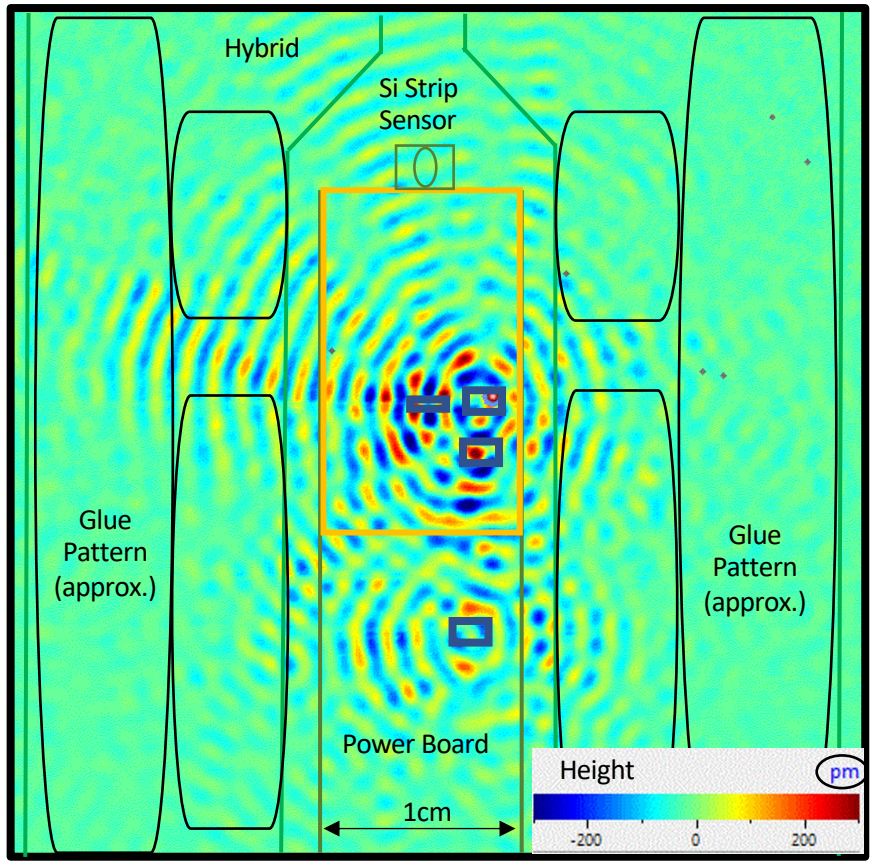
Interposer structure

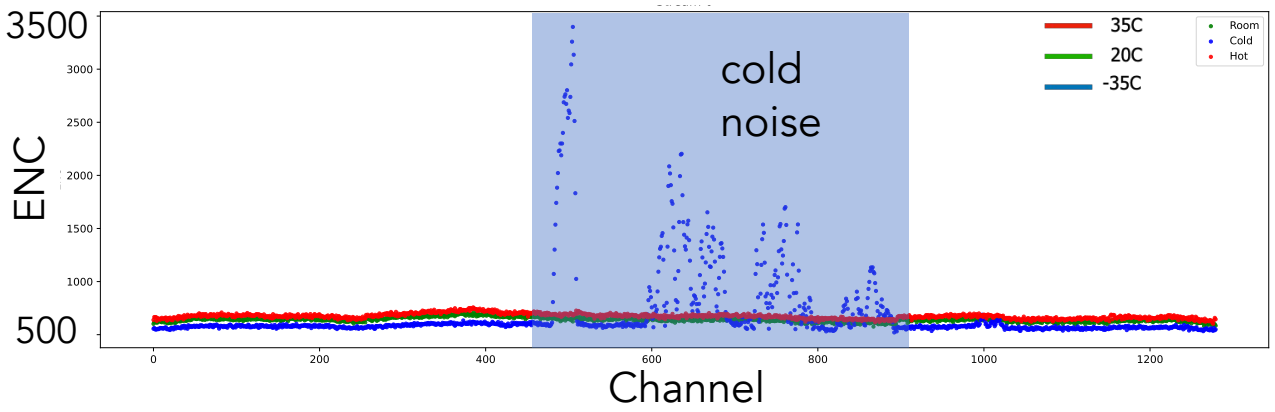
Cold noise

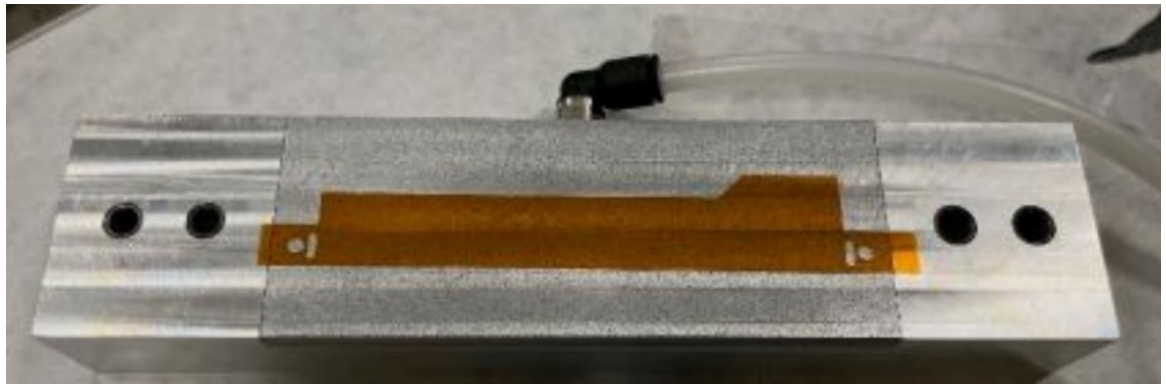
Matt Kurth and Ian Dyckes TWEPP2023 talk

- High noise below 0°C observed during module QC
  - Only strips under PB and hybrid affected
- Source determined to be capacitor vibrations on PB

Interposers for crack mitigation have been shown to eliminate cold noise!





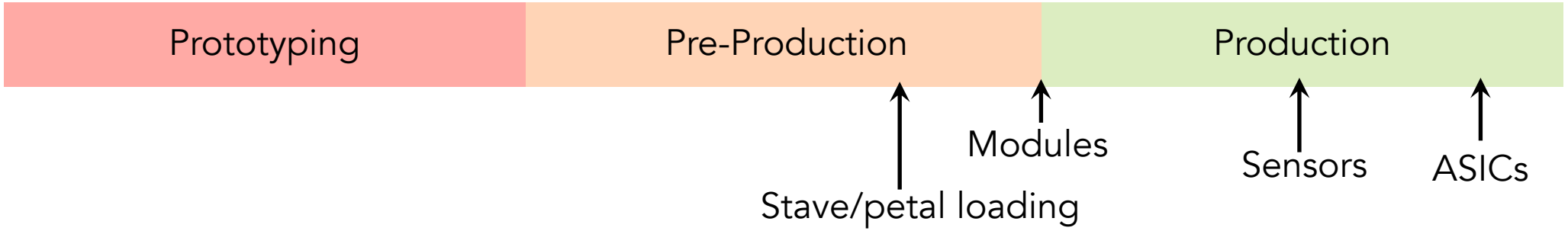


Kapton interposer for barrel module

Conclusions

- ITk will deliver similar or better tracking performance in the harsh HL-LHC environment
- Lots of work done so far
  - Years of prototyping and pre-production
  - Developed rigorous QC procedures and solved many problems along the way
- We are almost fully in production!
  - ITk Strips is in production or entering production for all components
  - ASICs and most sensors already manufactured
- Solving lingering issues
  - Cold noise mitigated
  - Cracking: promising use of interposers
- Let's build our detector! ☺

Looking forward to Production and Installation!



Backup: stave noise plots

Noise plots for one side of an LS barrel stave (14 modules)