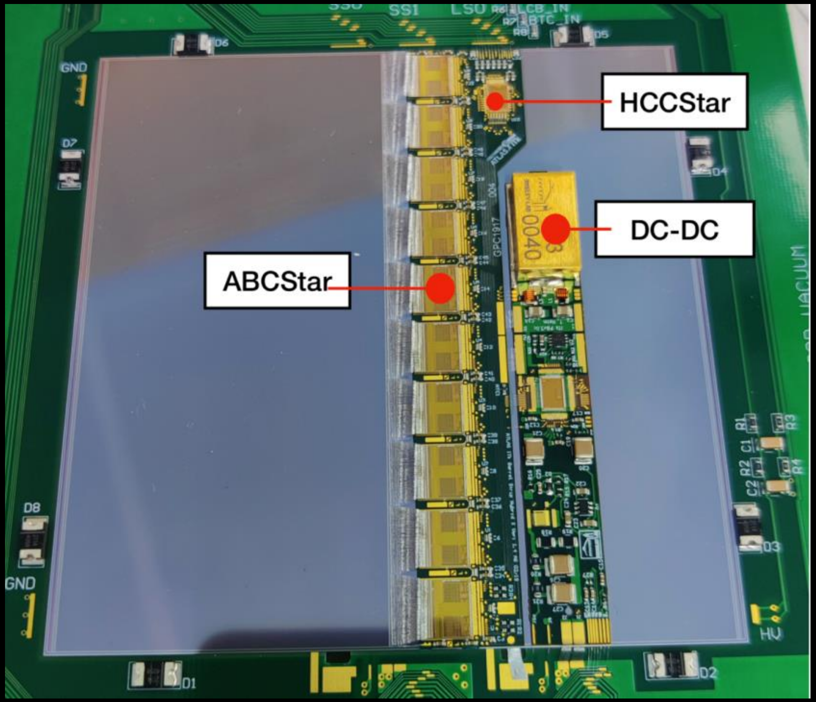
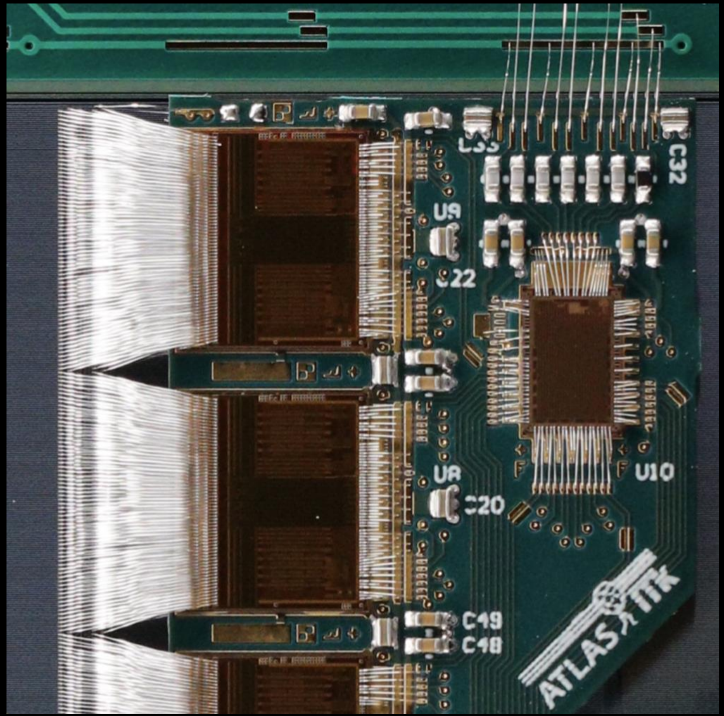
The ATLAS ITk Strip Detector
for the Phase-II LHC Upgrade





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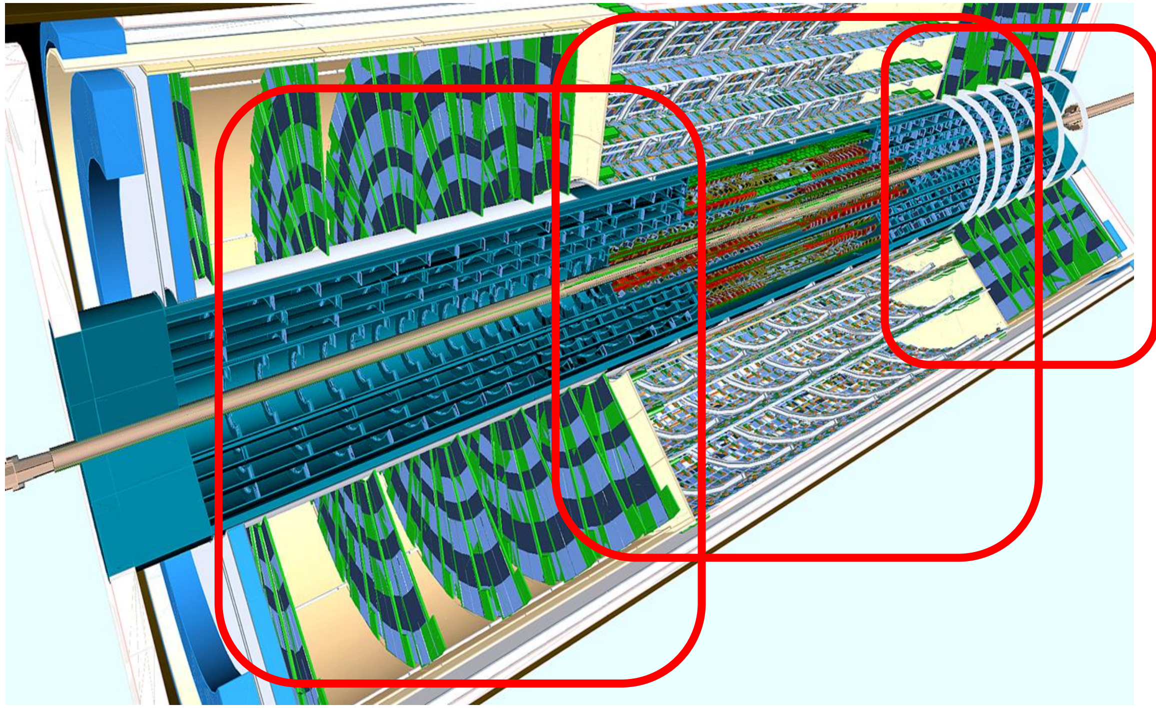
Brandeis University
DIS2023, March 28, 2023

The ITk Detector for the HL-LHC

For the HL-LHC, the ATLAS tracking system will be replaced with all-silicon detector: the Inner Tracker (ITk)



Geometry

- Pixel detector
  - Previous talk
- Strip detector
  - 4 concentric cylindrical layers in barrel
  - 6+6 disks in endcaps

ITk detector designed to withstand harsh HL-LHC environment

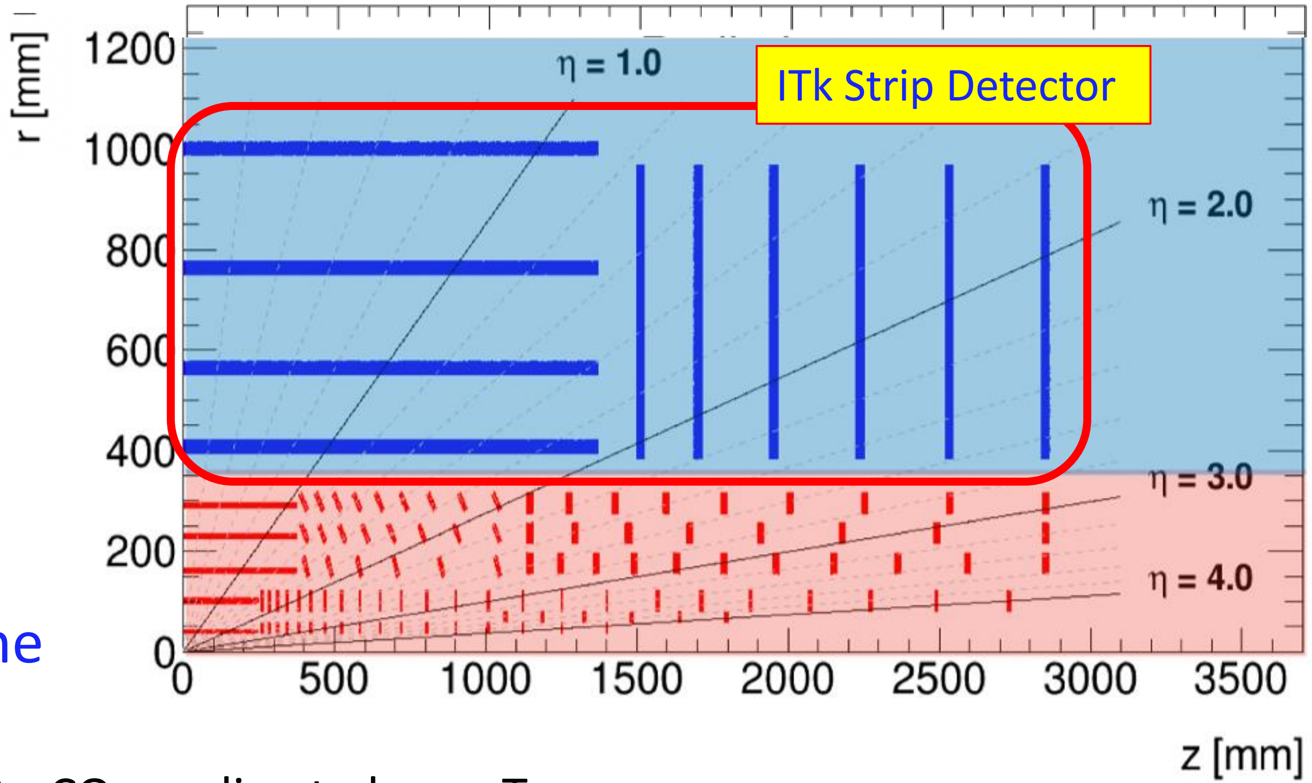
- 4,000 fb^{-1} over 10 years, L_{peak}=7.5x10^{34} $cm^{-2}s^{-1}$, μ~200, 1 MHz L0 trigger rate

The ITk Strip Detector

Geometry

- Barrel
  - Radius: 40-100 cm; |z|< 1.4m
- Endcaps:
  - 1.5 <|z|< 3.0 m

|η|<2.7



ITk Strip design

- Rooted in current SCT detector with some upgraded technology choices
  - Radiation hard: new n^+-on-p sensors, FE ASICs, CO_2 cooling to lower T
  - Occupancy: shorter strip length in the two inner layers
  - Higher data rate: new readout and data transmission
  - Advanced power and signal distribution: low mass
  - In total: 165 m^2 of strips (vs. 68 m^2 of SCT)

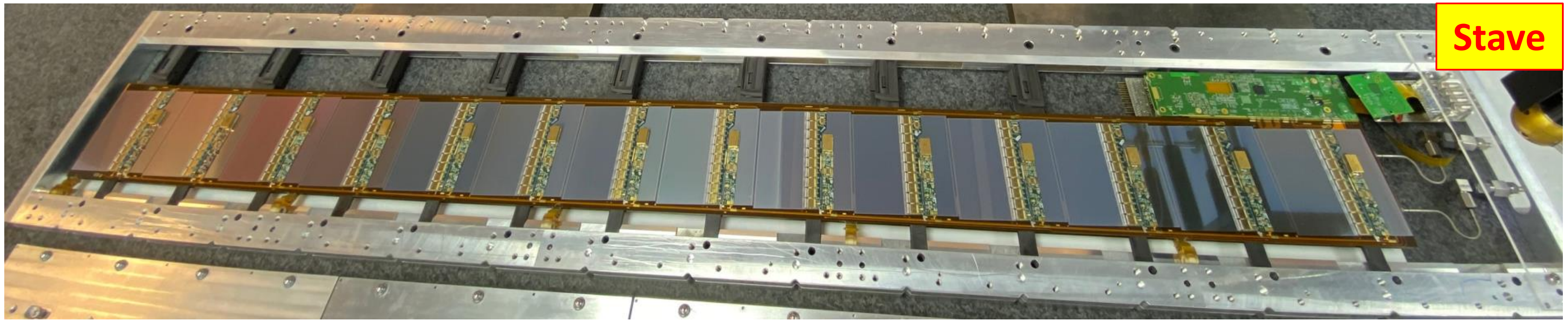
Modular detector units: staves and petals

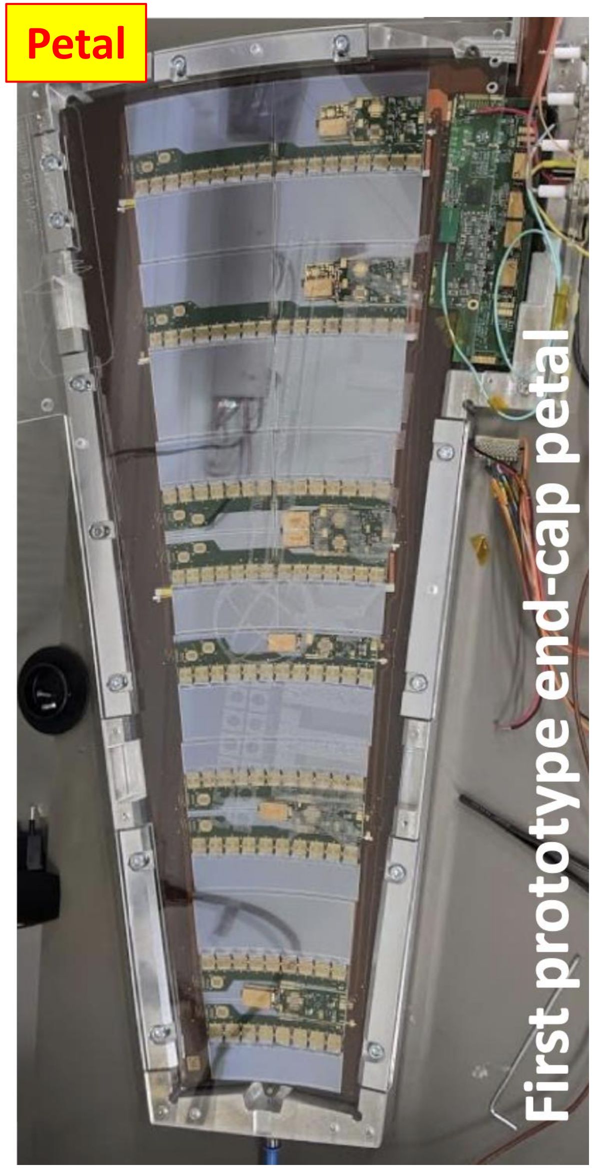
The ITk has a modular structure

- Same detector concept, different geometry in barrel/endcaps
  - Rectangular vs. Trapezoidal

Basic detector units

- Staves in the barrel → cylinders
- Petals in the endcaps → disks





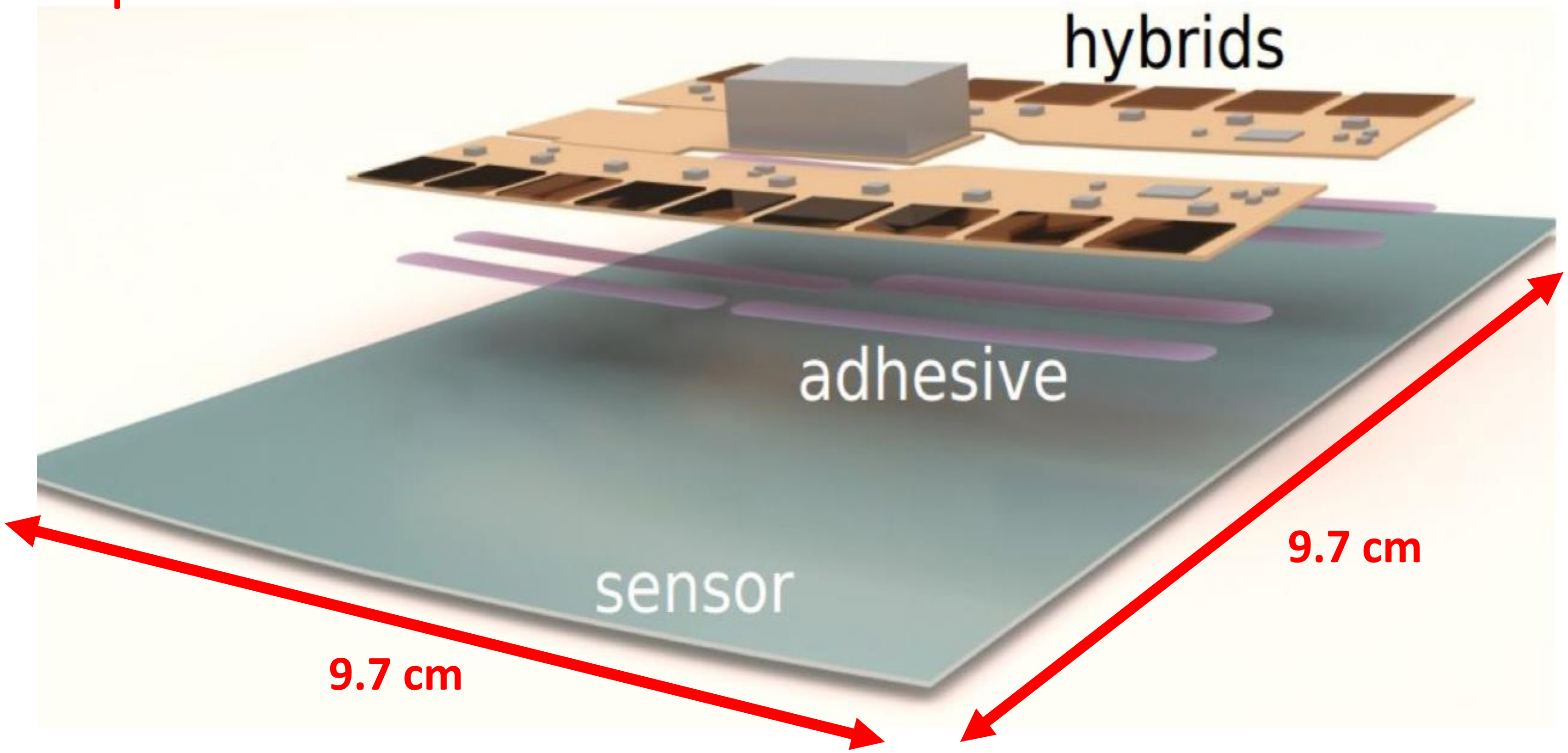
In this talk we will use barrel staves as an example

ITk Strip Modules

Module: basic building block of the ITk detector

Each barrel module comprises:

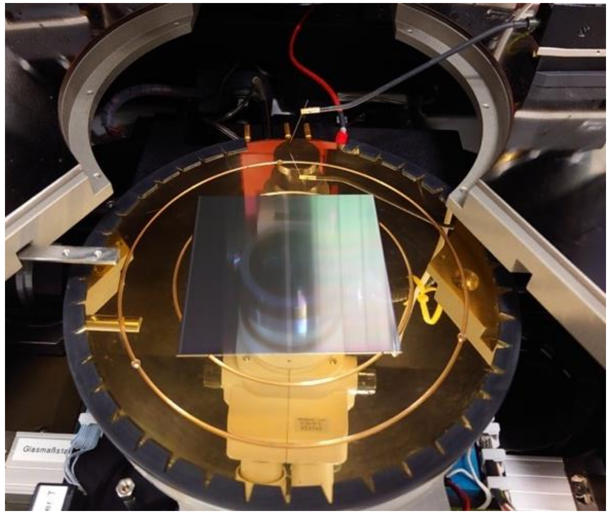
- 1 Si Sensor
- 1 (or 2) Hybrid(s)
- 1 Power Board

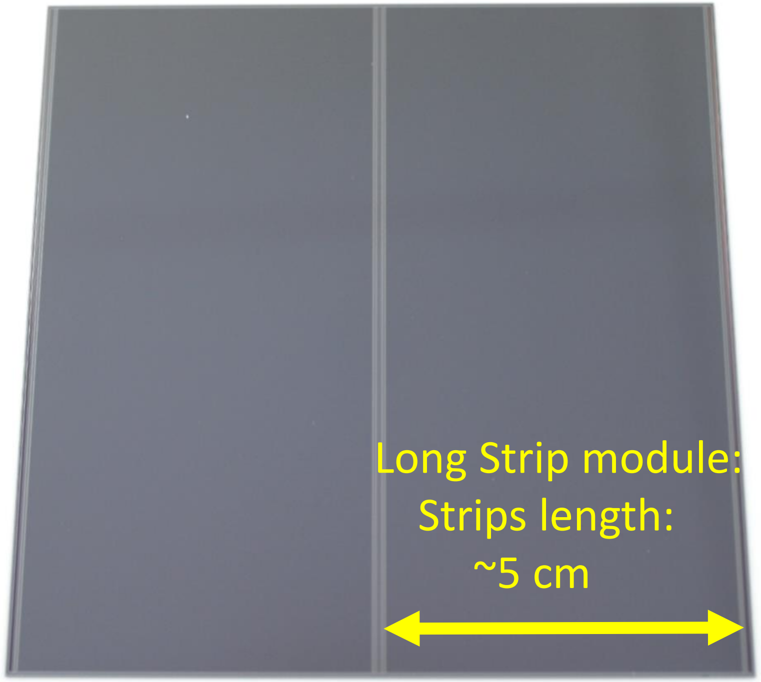


ITk Strip Module ingredient #1:
ITk Strip Sensors

Si Sensors by HPK

- n^+-on-p, 320 μm thick
- 9.7 X 9.7 cm^2
- Strip pitch: 75.5 μm
- 2 designs in the barrel:
  - Long Strips (5cm)
  - Short Strips (2.5cm)
- 6 designs in the endcaps to fit petal geometry





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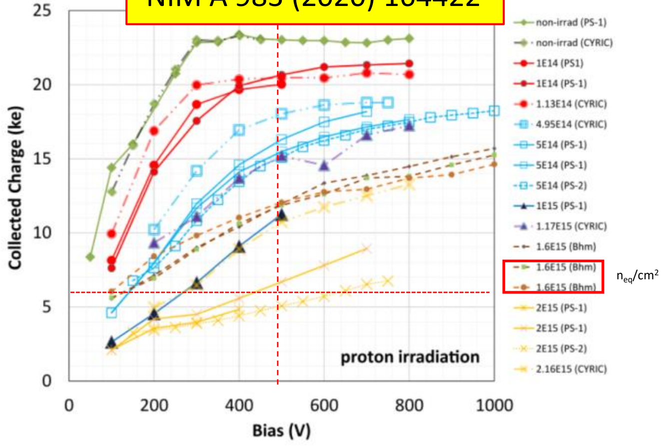
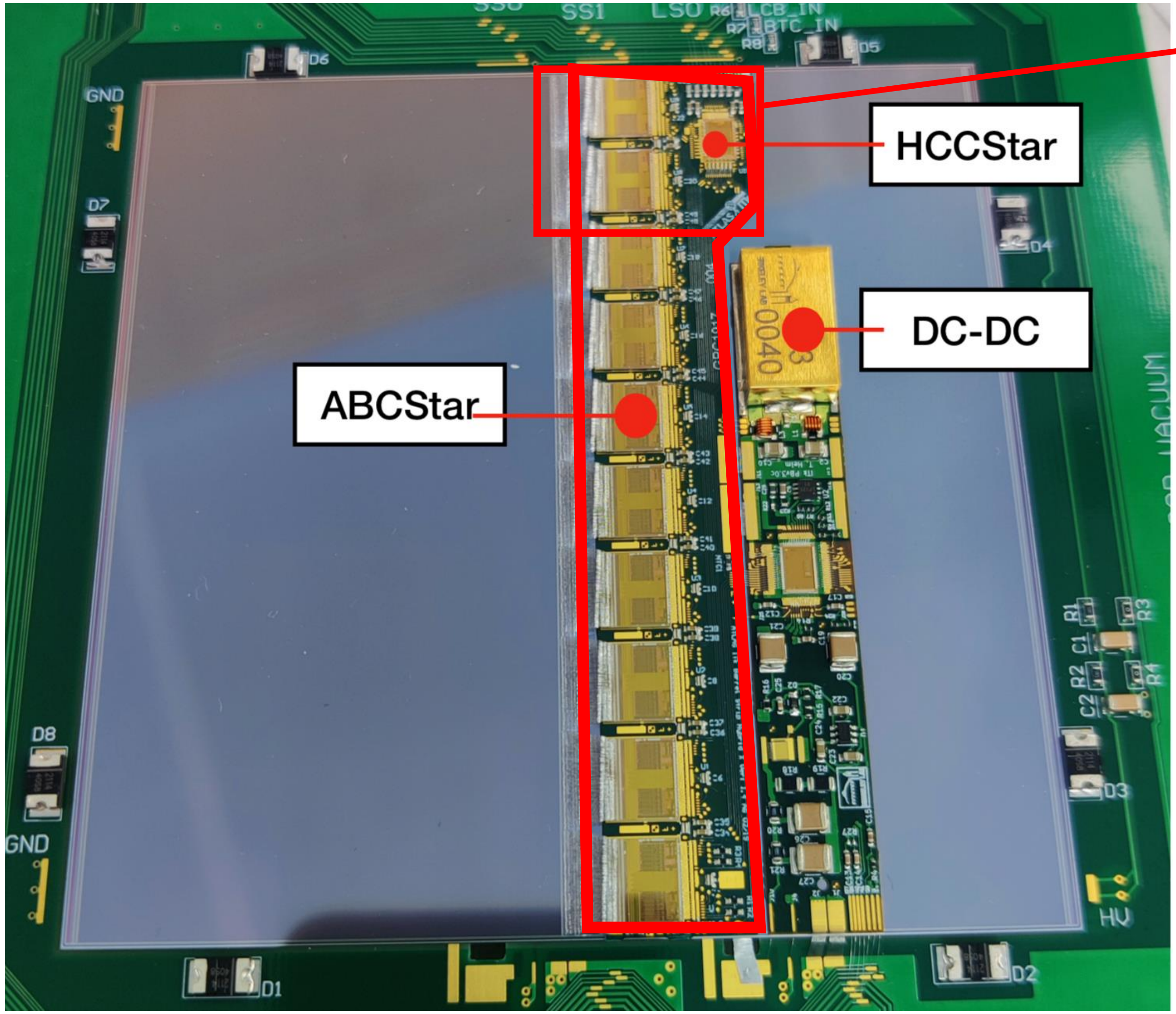
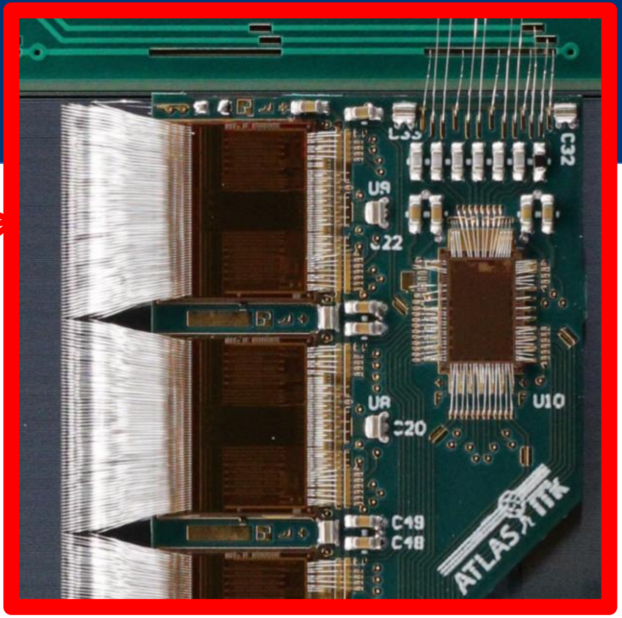


Sensor production is ongoing: ≈ 40%

ITk Strip Module ingredient #2: Hybrids





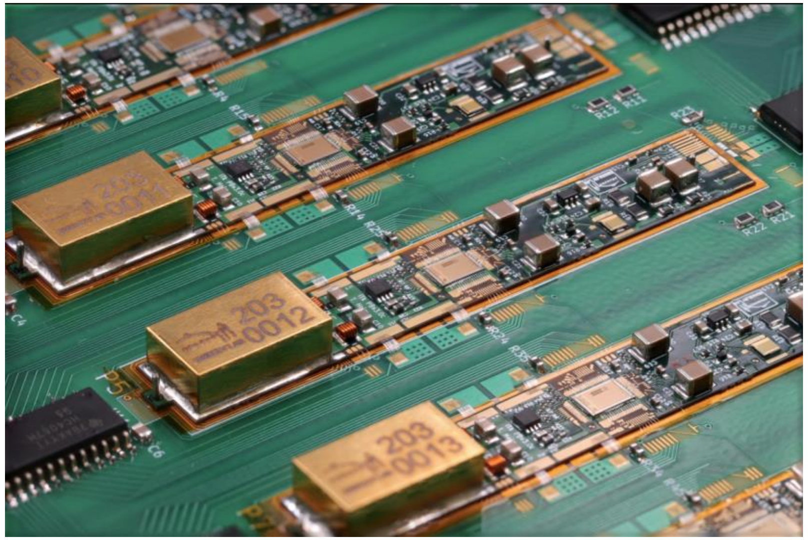
Each FE ASIC has 256 Al wirebonds in 4 rows

Flexible PC boards each carrying:

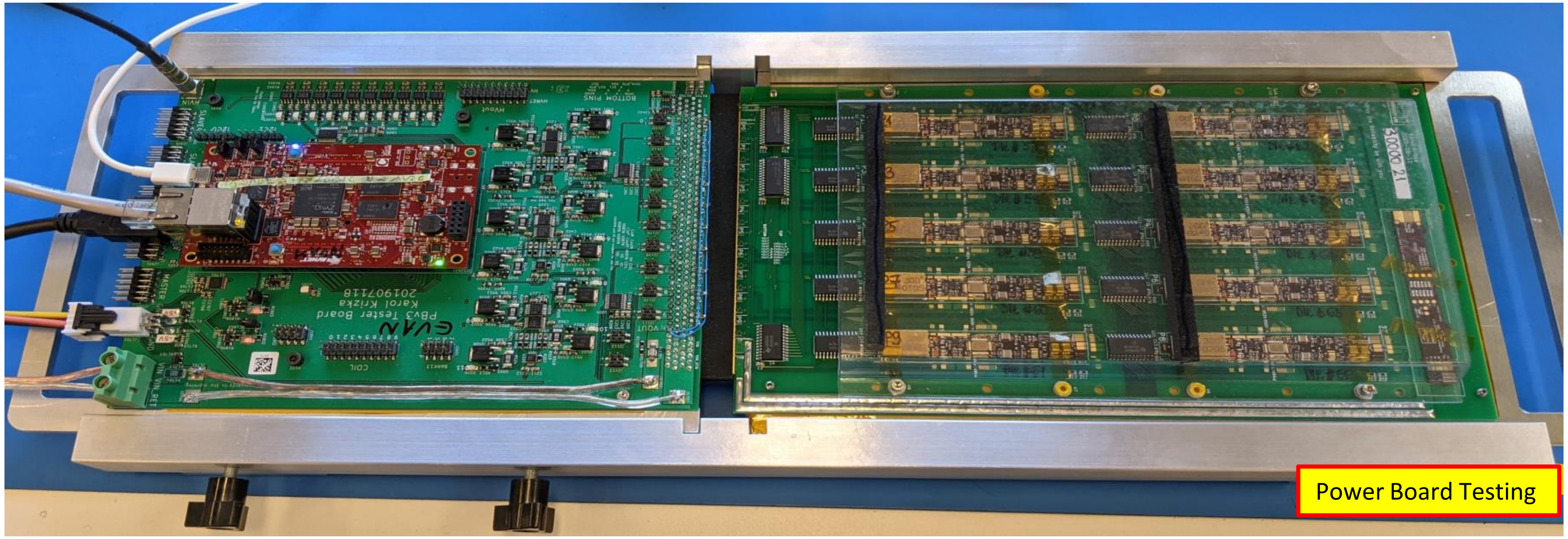
- 10 FE readout chips (ABCstar)
  - 256 channels/chip
    → 2560/5160 channels per LS(SS) module
- 1 Hybrid Controller Chip (HCCstar)
  - Interface between FE chips and electrical signal on bus tapes

Power Boards

Power Board: PC board that distributes power and controls to modules



- DC-DC converter (BPOL12V): 11V → 1.5V to ABCstar/HCCstar
- Linear regulator LinPol12V: 11V → 1.4/3.3V to AMAC
- HV filter and switch (HV-Mux)
- Autonomous Chip for Monitoring And Control (AMACstar)
  - Monitors currents, temperatures, voltages



Power Board Testing

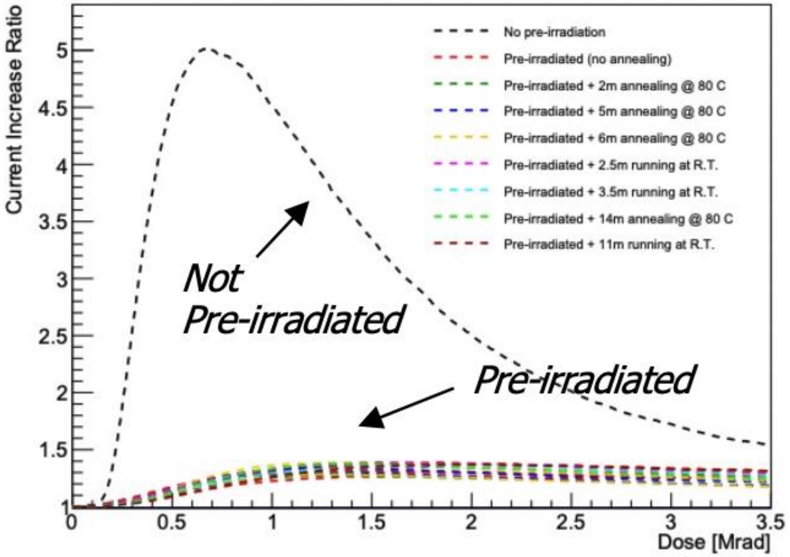
ITk Strip custom ASICs

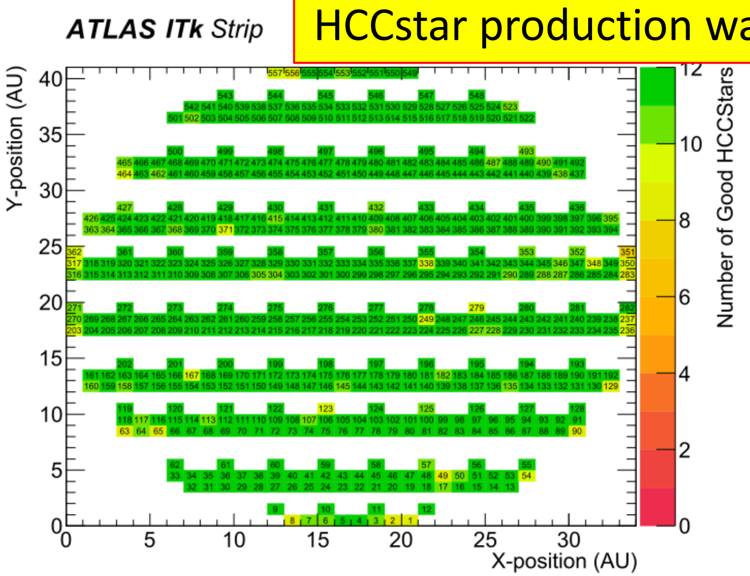
All custom ASICS (ABCstar, HCCstar, AMACstar) made by Global Foundry using 130nm technology

- Pre-irradiation to avoid TID bump
- Extensive simulation to prevent issues due to working in high-radiation environment
    - Triplication of logic to improve SEE protection
    - Final design validated in several test beams

All custom ASICs are now in production

- 15-67% in hand depending on ASIC
- Probing yields ≈ 90-96%





HCCstar production wafer

Module pre-production and QC

Extensive pre-production campaign

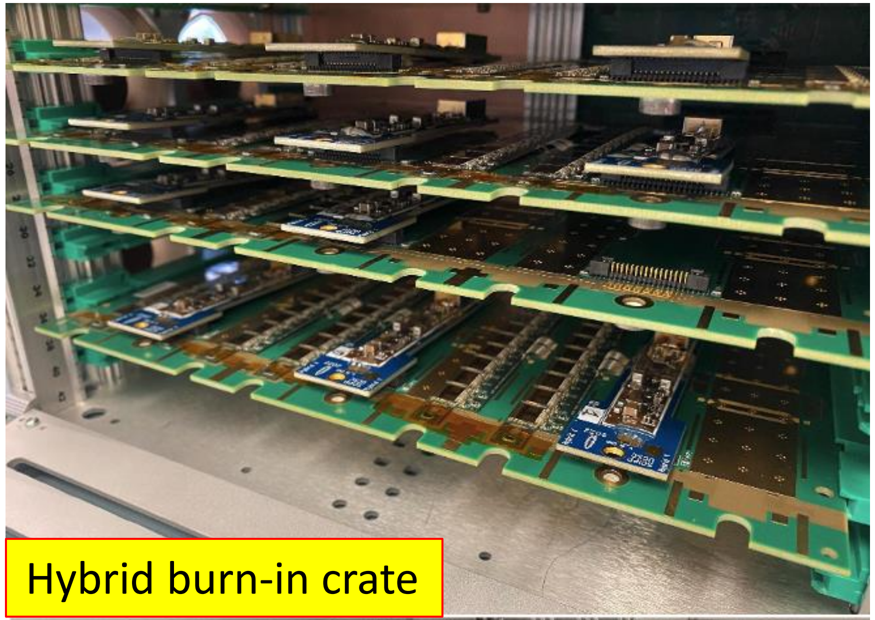
- 5-10% of entire production

Goals

- Qualify 21 sites in 4 continents
- Qualify each component
- Establish rigorous QC procedures
- Stress-test modules/staves/petals at high statistics

QC procedures

- Hybrid burn-in:
  - 100 hours at 40C
- Module thermal cycling:
  - 10x cycling between Room Temperature and -35C



Hybrid burn-in crate

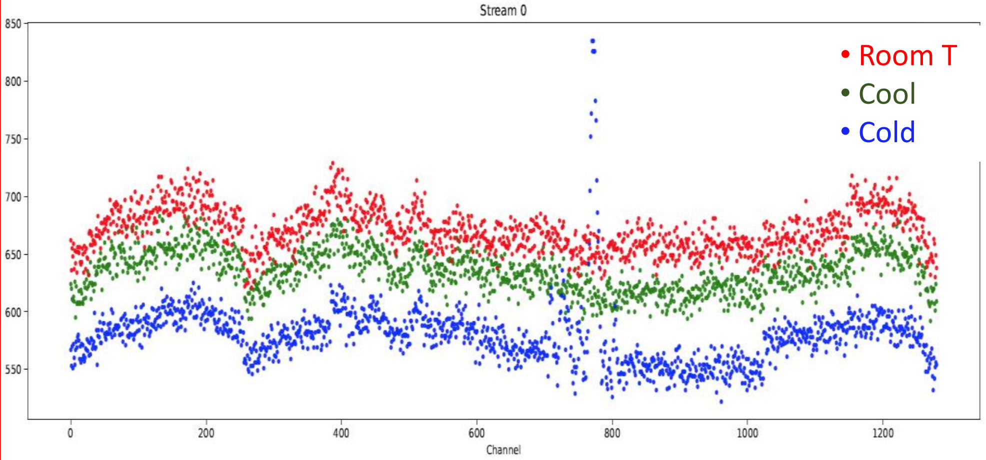
Cold box for Module Thermal Cycling

The Strips Cold Noise

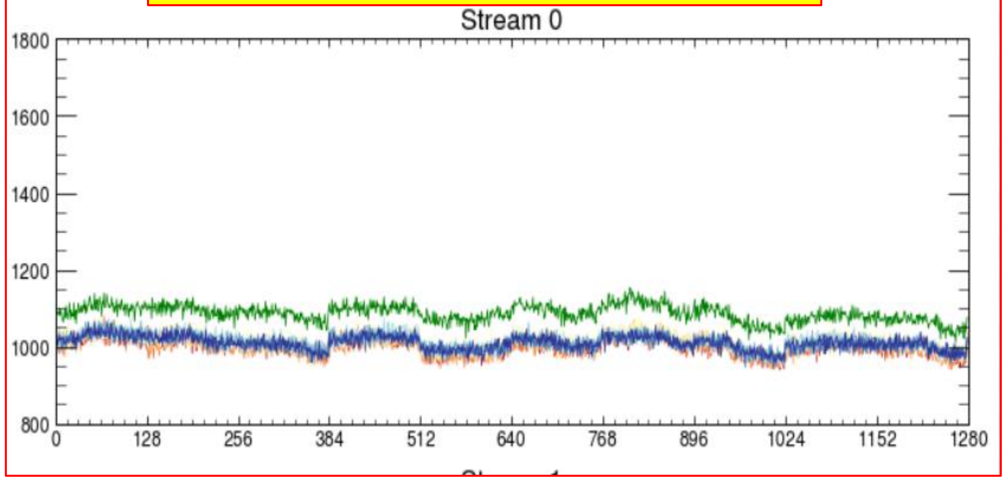
Rigorous testing during pre-production revealed unexpected problem: "Cold Noise"

- Temperature-dependent noise appearing in some region of modules when operating $\lesssim -20$C
- Huge effort to understand its origin
  - Probably induced by piezo-electric effect on glue under Hybrids caused by mechanical vibrations of components on Power Boards at low T
- Mitigation strategy: use different glue to secure Hybrids and Powerboards
  - True Blue (Eccobond F112) or Dow SE4445

Typical pattern of Cold Noise, SS



Noise @ various T, LS, True Blue

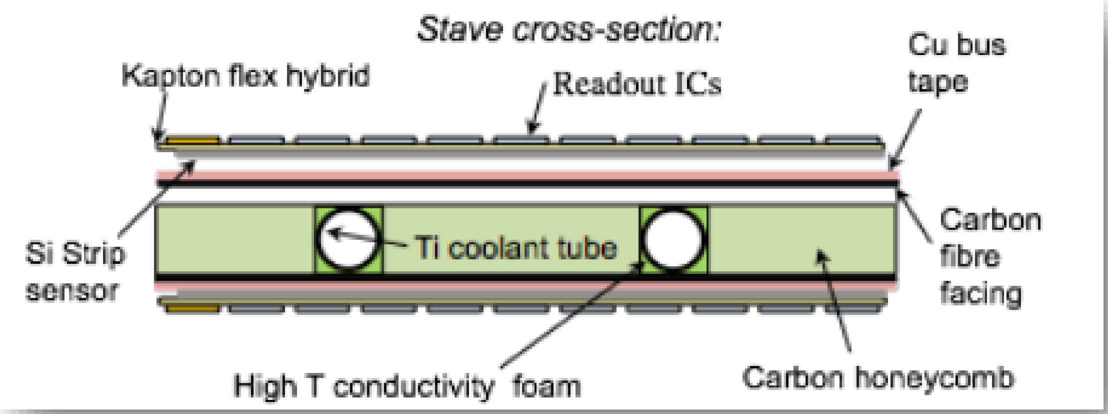


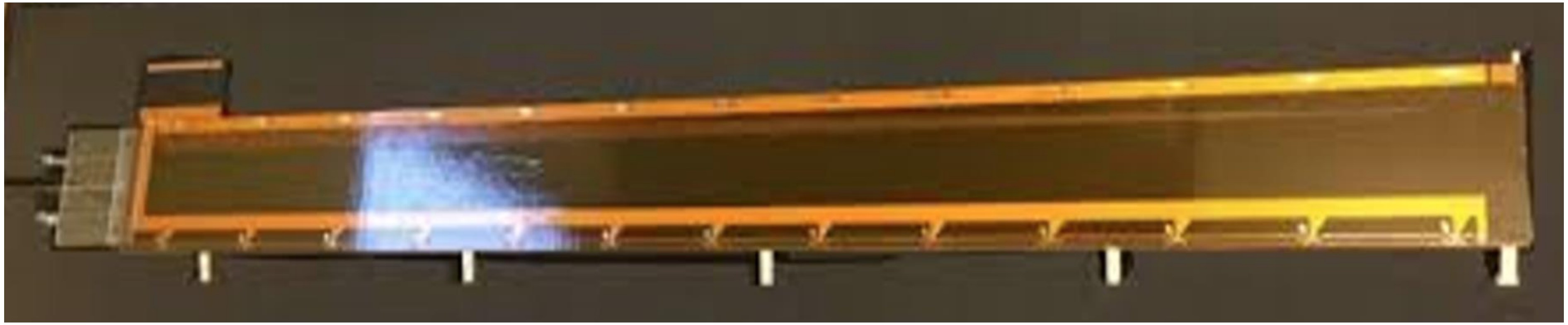
Stave Cores

Modules are assembled on support structures known as Stave Cores

Each stave core (140 x 10 cm^2) provides:

- Mechanical support using minimal material
  - Carbon-fiber/honeycomb/foam composite structure
- Copper/Kapton co-cured Bus Tapes
  - Distribute power, controls, carry signal
- Cooling
  - Ti cooling pipes carry CO_2 at −40C

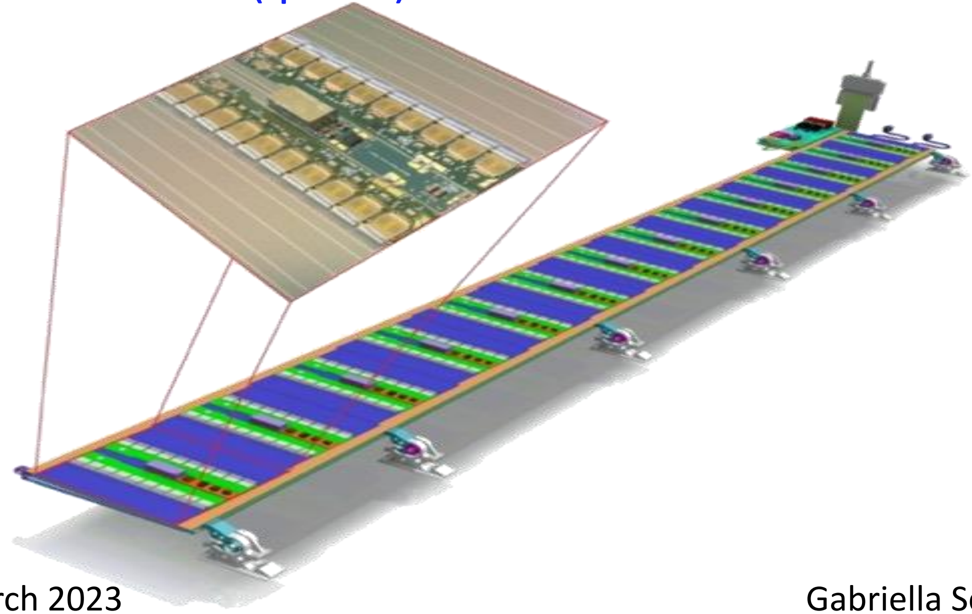


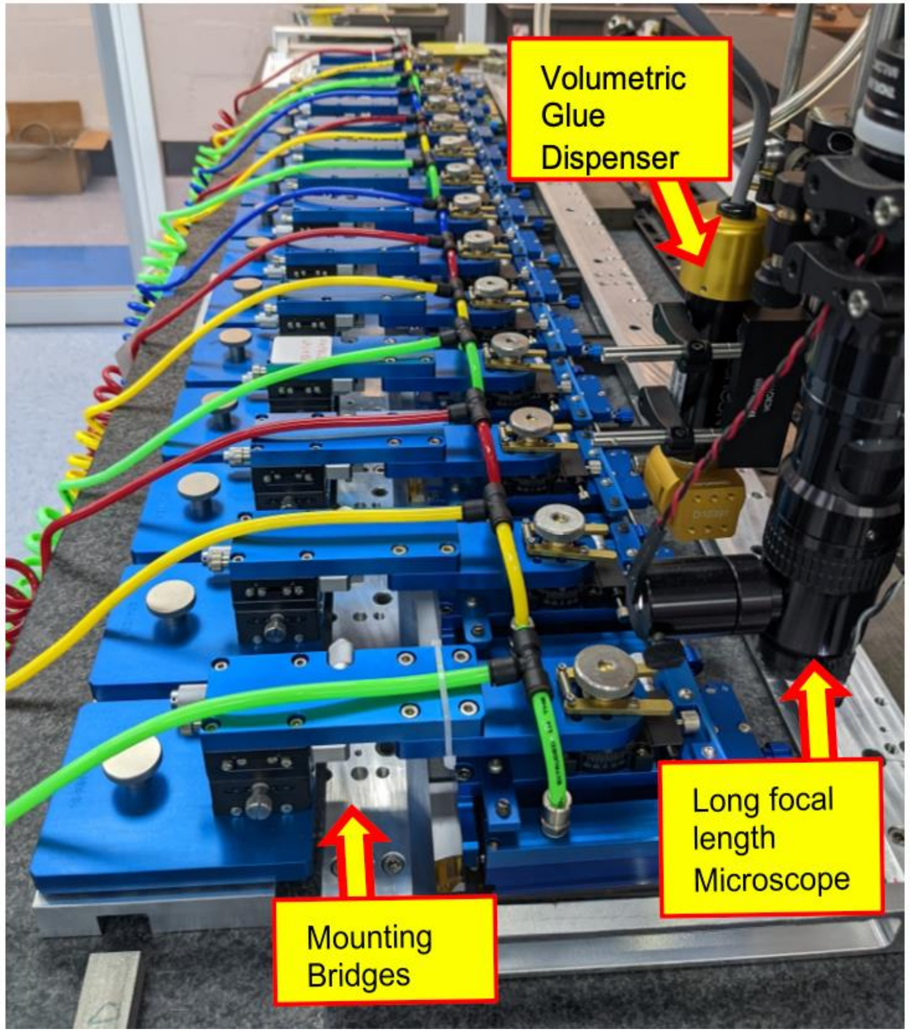


Stave Assembly

Si modules shipped to BNL/RAL where they are assembled on Stave Cores

- 28 modules are glued on each stave core
  - Positioned to ±50 μm using precision tooling and a camera mounted on an XYZ stage
  - ±26 mrad stereo angle
- End-of-Stave card hosts radiation-hard fiber-optic driver/receiver package (VTRx+) and associated electrical transceivers (lpGBT)

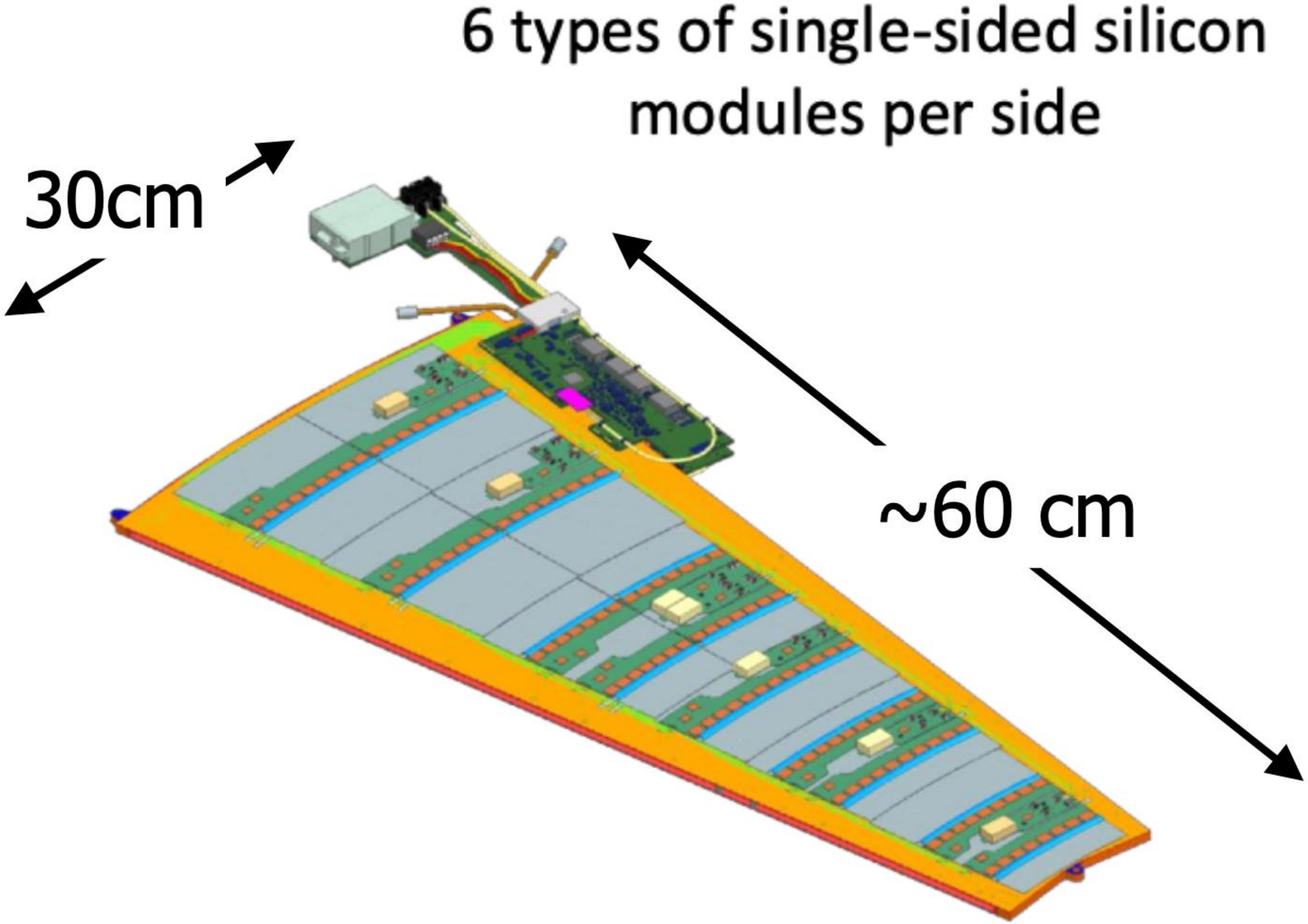




Petal Assembly

Endcap Petals are assembled with a similar procedure

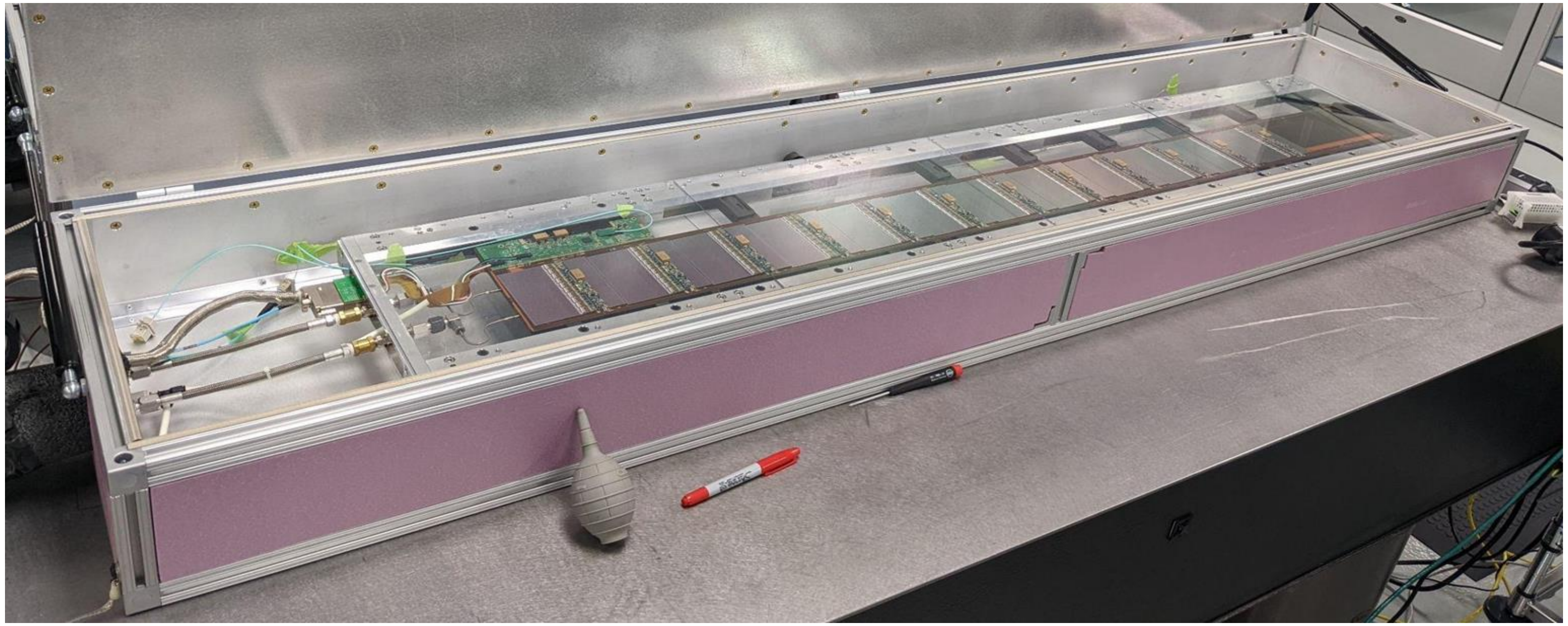
- 12 fan-shaped sensor modules on each petal
    - 6 per side (R1, R2, ..., R6)
    - Each module has a different geometry
        - Shorter strips at inner radii
- Stereo angle of 20 mrad implemented in sensor geometry

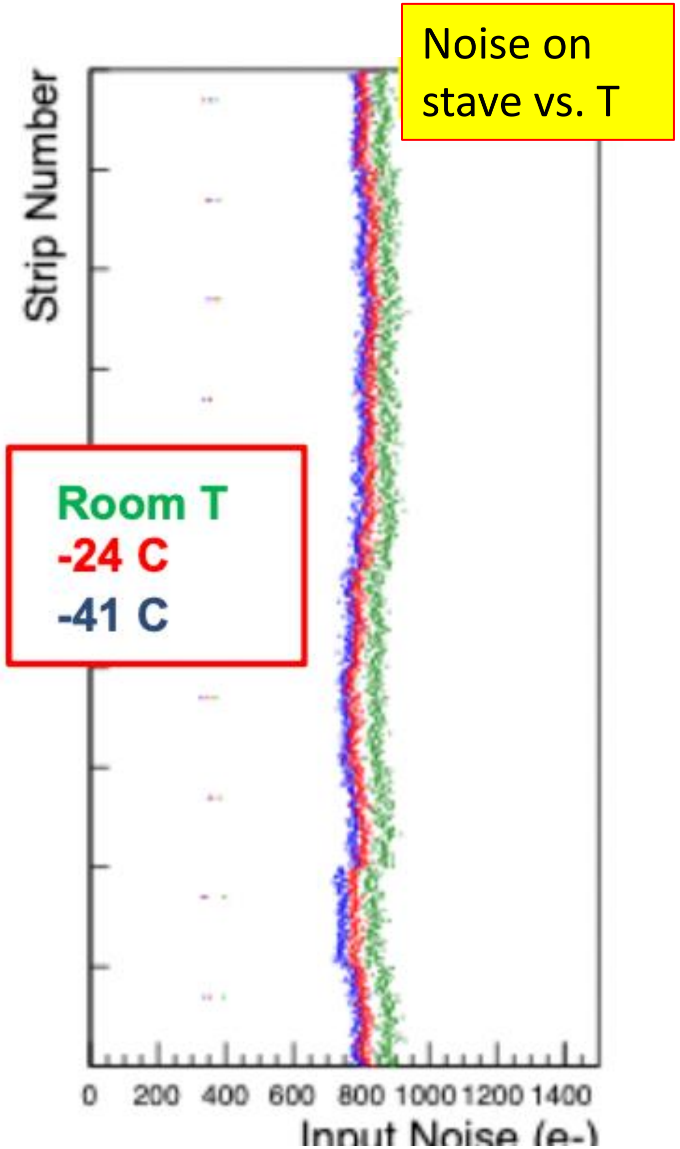


Staves/Petals Quality Control

QC tests include

- Thermo-mechanical studies
- Stress tests and thermal cycling at −35C
- Electrical test — IV curve, gain, noise, dead channels



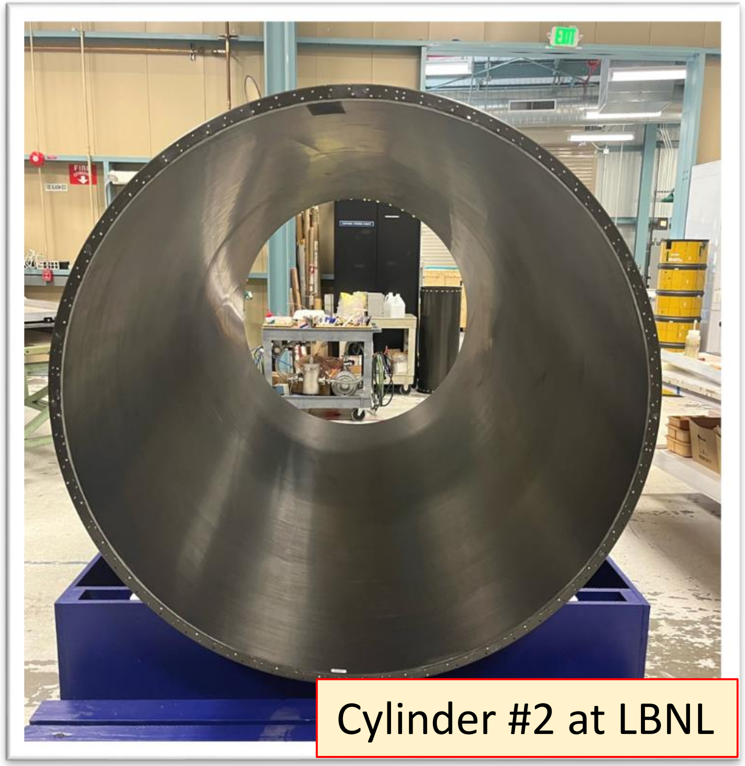


Strips Global Mechanics

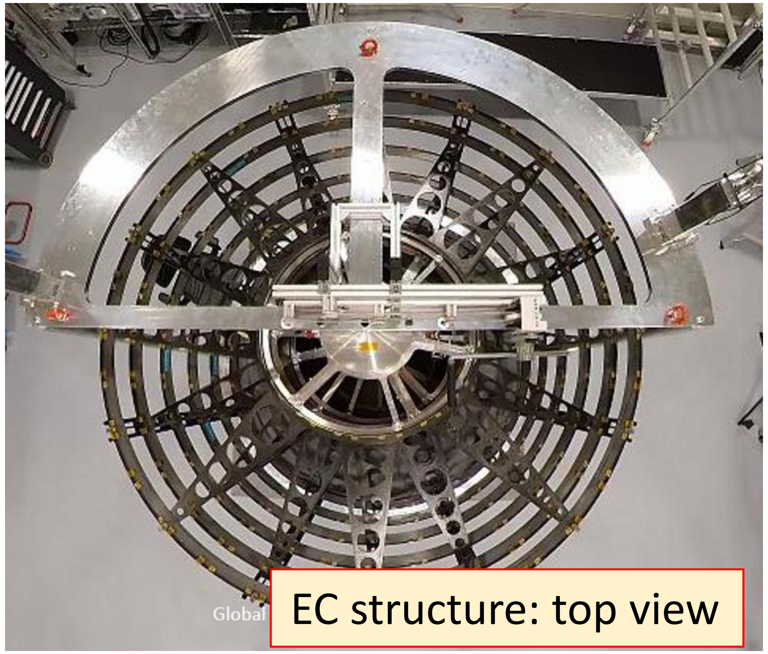
- Staves will be inserted in four concentric Carbon cylinders
    - Cylinders #3 and 2 in hand, #3 being outfitted
- Petals in carbon wheels with blades for each disk
    - EC super-frames delivered DESY→Nikhef

EC structure: side view

Cylinder #3 being outfitted in Oxford



Cylinder #2 at LBNL



EC structure: top view

System Tests

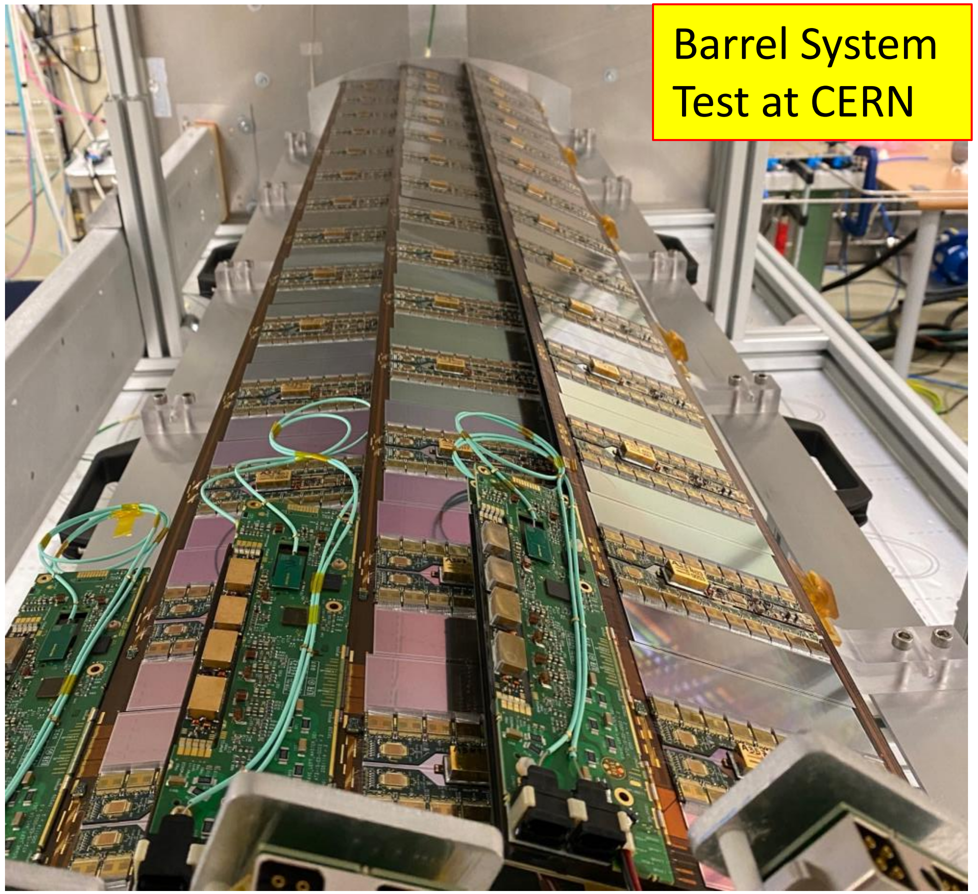
Goal: validate full production chain with final parts and cooling before production starts

- Powering chain, fiber optics, DAQ, cooling, mechanical supports, interlock, detector controls
- Eventually it will provide hardware platform for future DAQ and DCS development

Barrel: ongoing at CERN with 4→ 8 staves

Endcap: ongoing at DESY with up to 12 petals

Endcap System Test at DESY



Barrel System Test at CERN

Conclusion

The ITk Strip Detector is about to enter the full Production phase

- Production has started and is going well in several areas
  - Already in hand: ~40% of Si sensors and ~15-67% of all custom ASICs
  - Contracts for key materials (e.g.: foam) and components (e.g: hybrids) have been placed
- Pre-production is well advanced for all the other key items
  - Tens of pre-production Modules have been built and mechanically/electrically stress-tested
  - Several pre-production staves/petals have been built and operated
    - Including 4 currently used in the System Tests at CERN
- Not entirely smooth sailing lately…
  - It took several months to understand the “Cold Noise” problem
  - Identified remediation strategy; now getting ready for final Production Readiness Review in May 2023

The ITk Strips Collaboration looks forward to start Module/Stave/Petal production in Summer 2023!

- Production will take 3.5 years
- Assembly of the detector at CERN (barrel) and Nikhef/DESY (endcaps) proceeding in parallel
  - In 2027 the full detector will be ready to be lowered in the ATLAS pit

Looking forward to (New!) physics at the HL-LHC!