The ATLAS ITk Strip Detector for the HL-LHC

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on behalf of the **ATLAS Collaboration**

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Outline

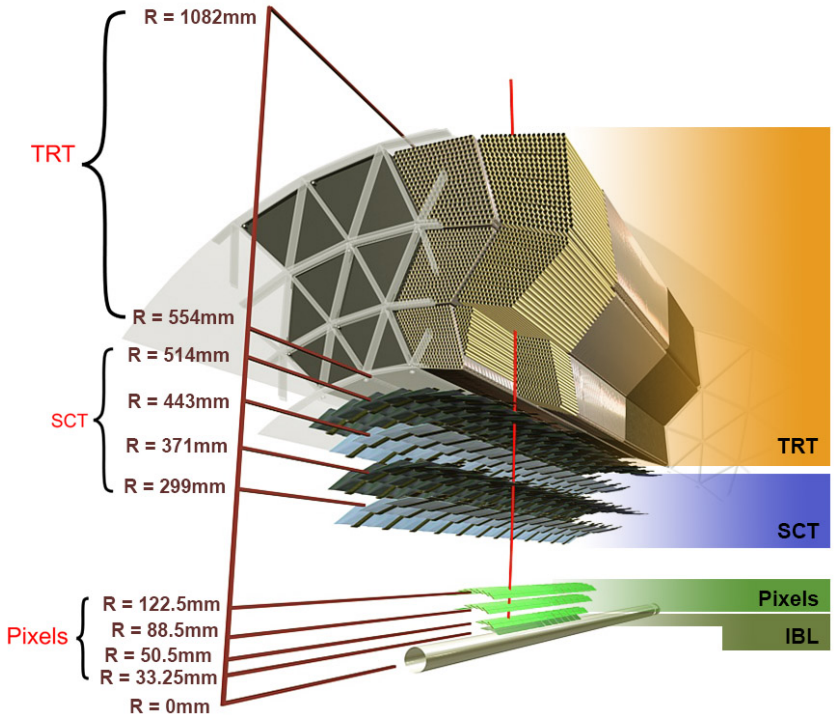
- Motivation for a new tracker
- Meeting the challenges of the HL-LHC
- Building blocks of the ITk strips detector
- Recent results in prototype testing
- Readying for production
- Summary

The High Luminosity LHC

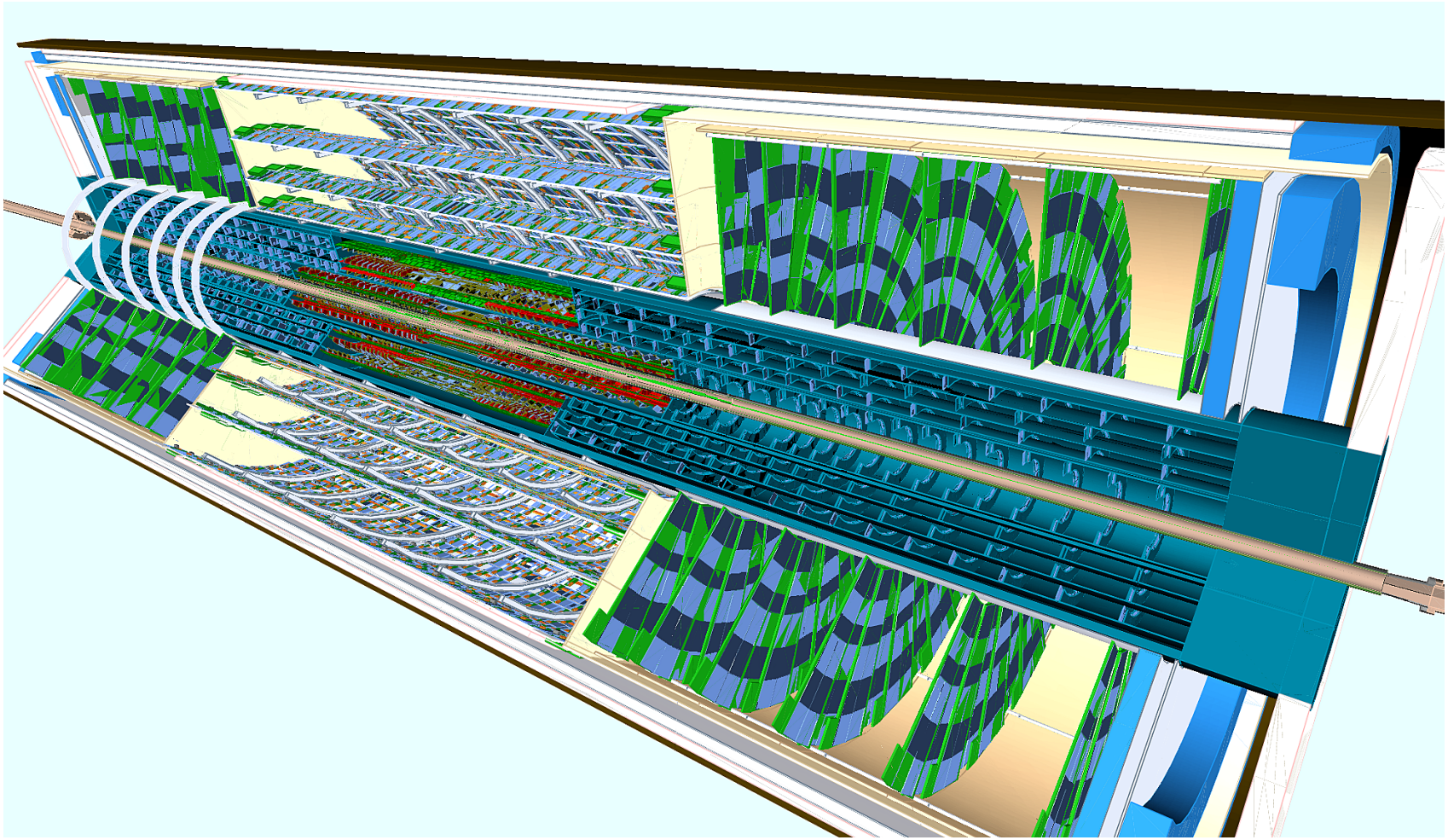
- LHC operating at close to max luminosity possible with current technology → **diminishing returns** to continuing running.
  - 5 years until next doubling of dataset.
- **HL-LHC**: New technologies to achieve 5 to 7 times nominal instantaneous luminosity.
  - Expect 3-4 ab^{-1} delivered per experiment.

The need for a new tracker

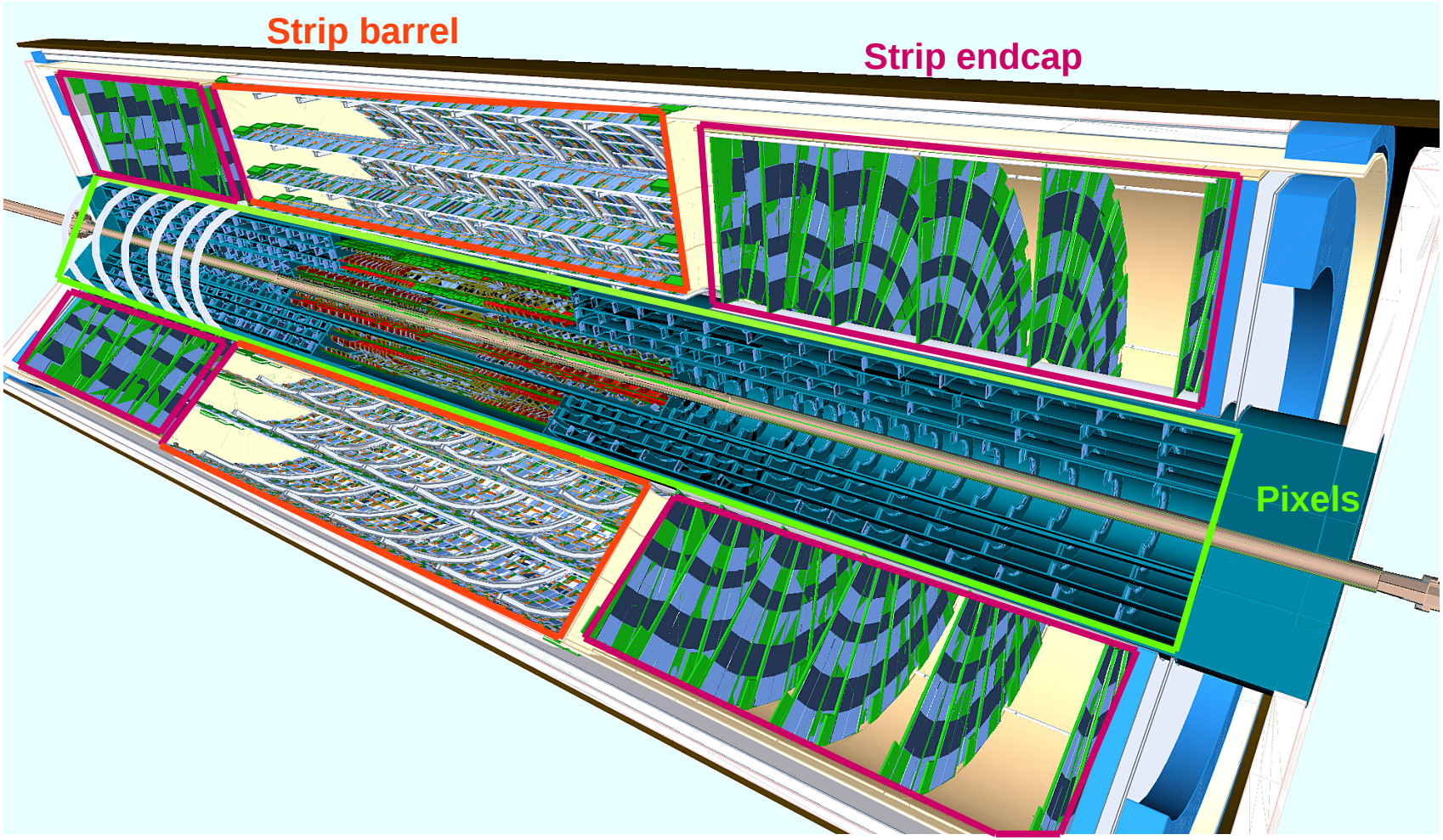
- The ATLAS Inner Detector has performed well in LHC conditions, but will **not be able to cope** with the challenges of the HL-LHC:
  - Radiation damage critical at end of Run 3.
  - Bandwidth saturated.
  - Occupancy too high for tracking.
- **A new tracker is needed**.



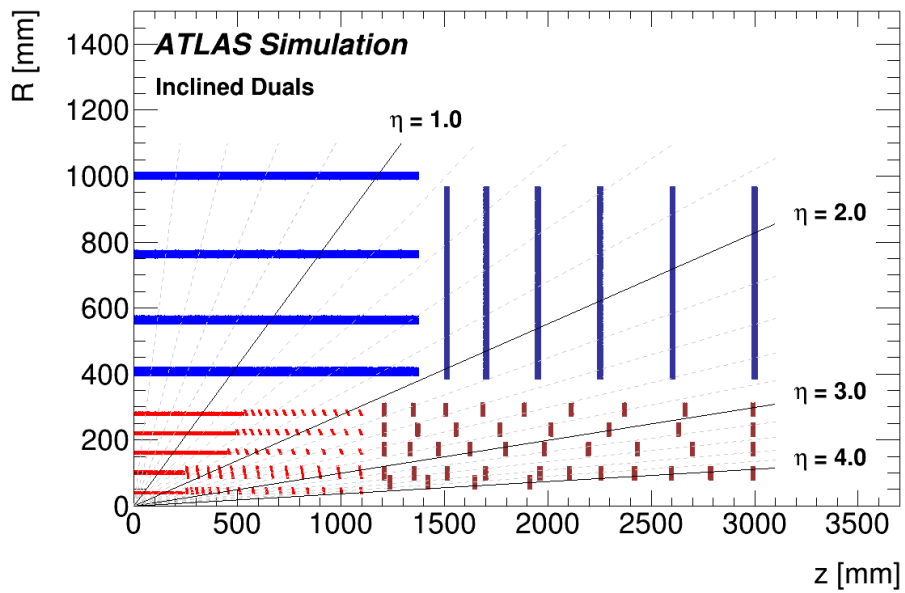
The ATLAS Inner Tracker



The ATLAS Inner Tracker



ITk layout



- Pixels:
  - 5 Barrel layers with inclined sensors in forward regions.
  - Endcaps with individually located rings.

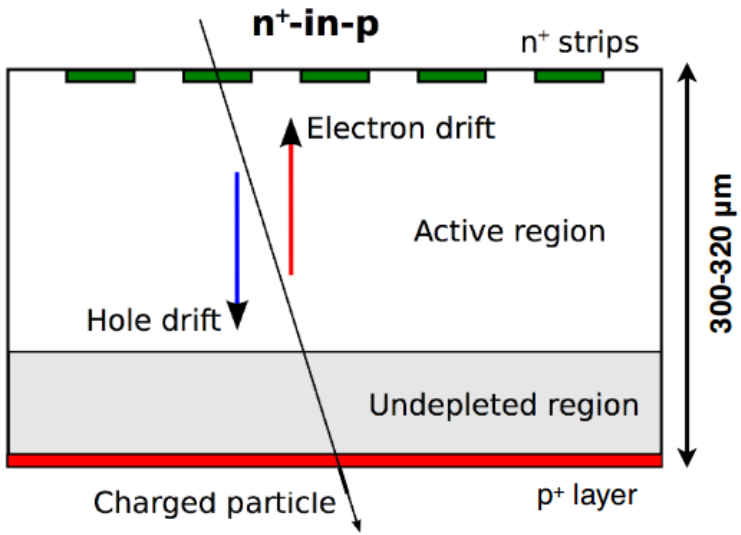
→ Covered by Tobias Flick on Tuesday

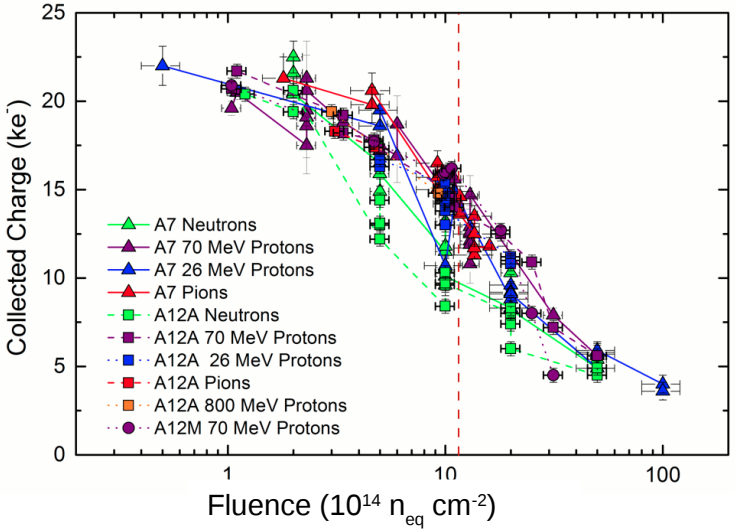
- Strips:
  - 4 Barrel layers in central region.
  - Endcaps composed of six disks.

→ This talk

Meeting the challenges: Radiation

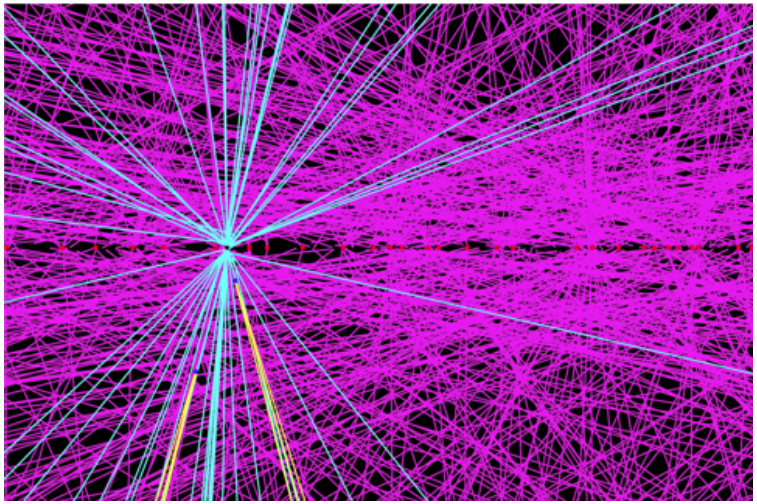
- Sensors must be able to withstand equivalent of 10^{15} neutrons per cm^2 over their lifetime.
- Main improvement: use of **n^+-in-p** silicon sensors.
  - Electrons as charge carriers: **Higher mobility** so less charge trapping.
  - No radiation-induced **type inversion**.
- **Factor 2 increase** in collected charge at end of lifetime compared to p^+-in-n (used in current tracker).



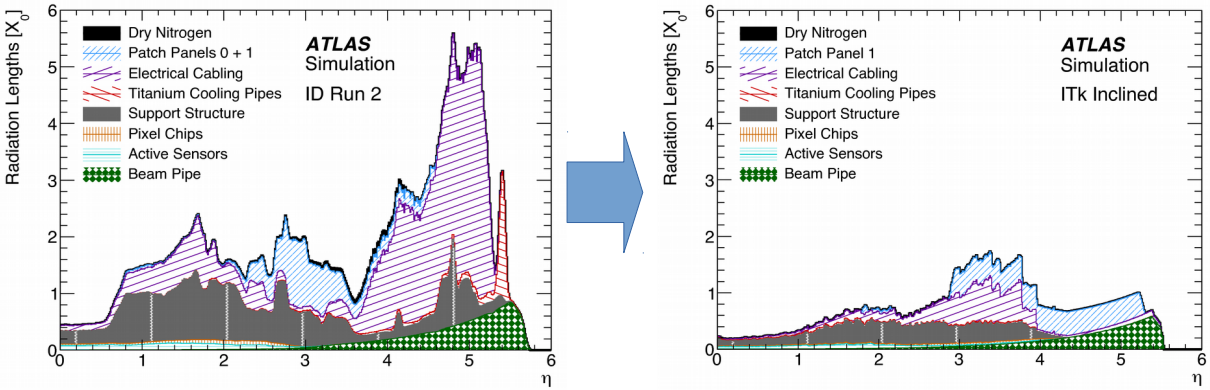


Meeting the challenges: Pileup

- Goal: Maintain or improve tracking performance, as maximum pileup increases from 50 to 200 interactions per bunch crossing.
- Minimum of 13 pixel+strip hits per track, with **increased granularity**.
- 3D spacepoint reconstruction at each layer from 40 mrad stereo angle.
- Significantly reduced **material budget**.
- Regional readout at 1 MHz.
- **Hardware track triggering** capability.

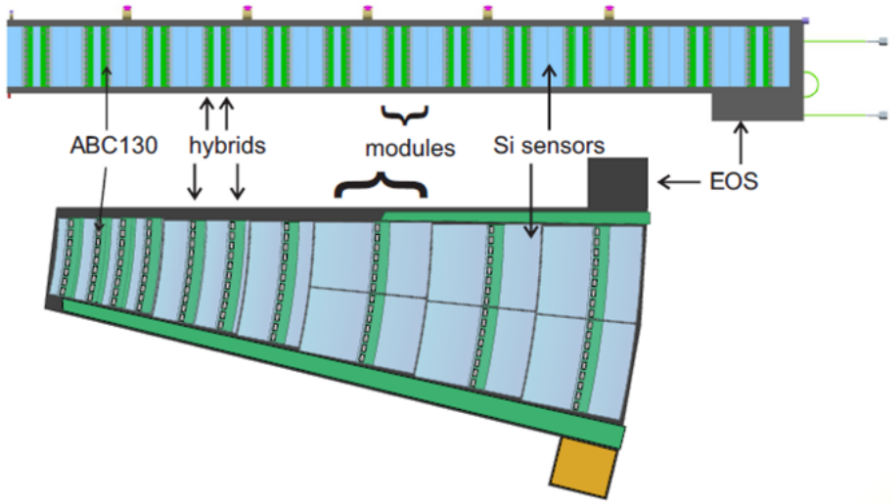


$t\bar{t}$ event @ 140 avg. pileup



Meeting the challenges: Size

- ITk strip detector is an **enormous project**: 165 m² of silicon; 17,888 modules; 59,870,000 channels.
- Only manageable with global, multi-stage construction and integration effort.
- This drives highly **modular design**:



Sensors+ASICS

↓

Modules

↓

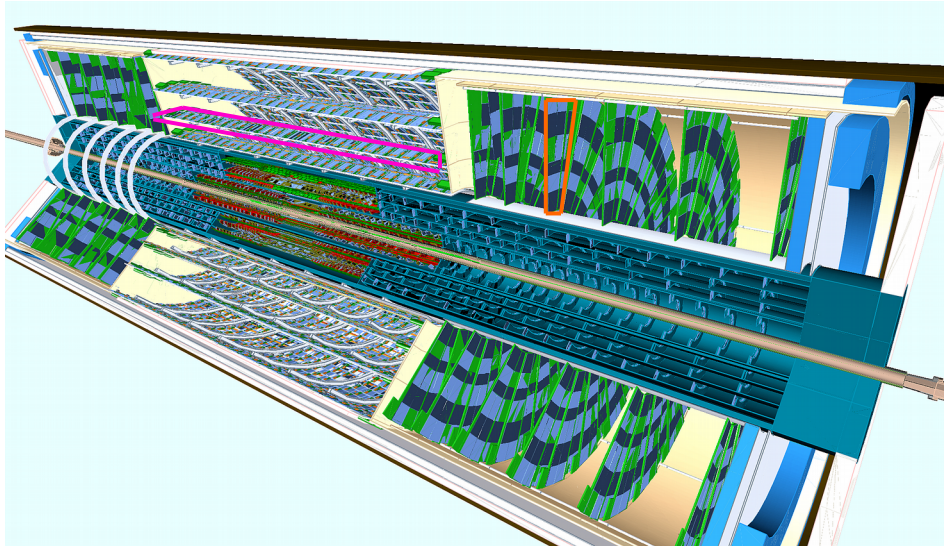
Petals/Staves

↓

Disks/Cylinders

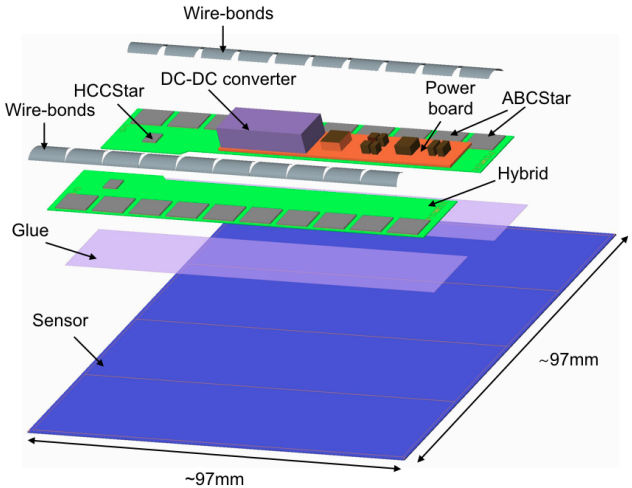
↓

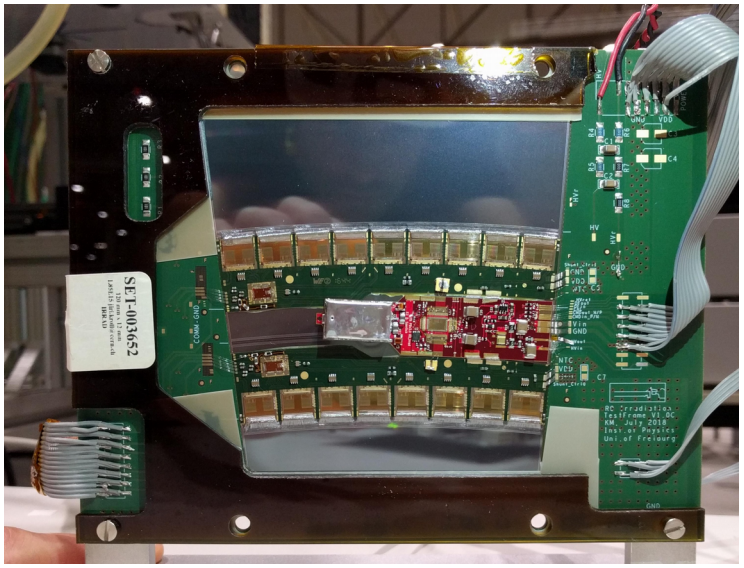
Endcaps/Barrel



ITk strip modules

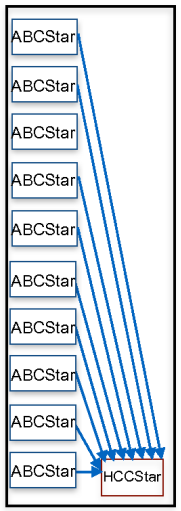
- One rectangular (barrel) or annular (endcap) sensor, ~10 cm².
  - 6 different shapes in endcap.
  - Either 2 or 4 rows of strips depending on expected occupancy.
- 1-2 PCB hybrids containing readout chips (ABC Star) and control chip (HCC Star) glued directly onto sensor.
- Powerboard also glued directly to sensor, containing:
  - Bias HV filter and switch.
  - Monitoring and control chip.
  - DC-DC converter (bPOL12V).

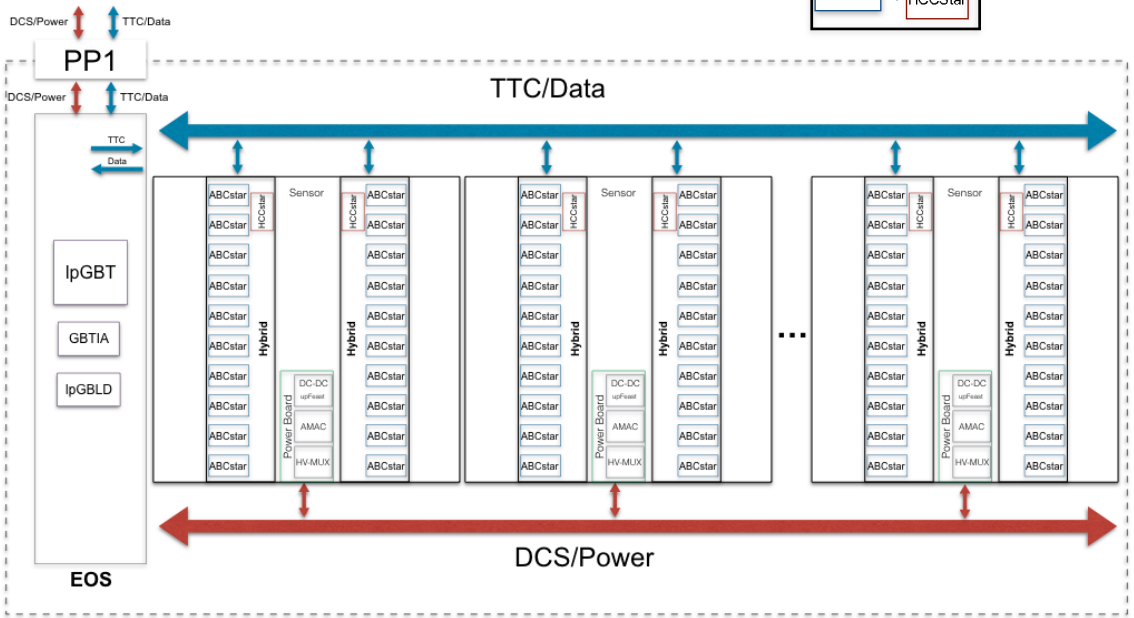




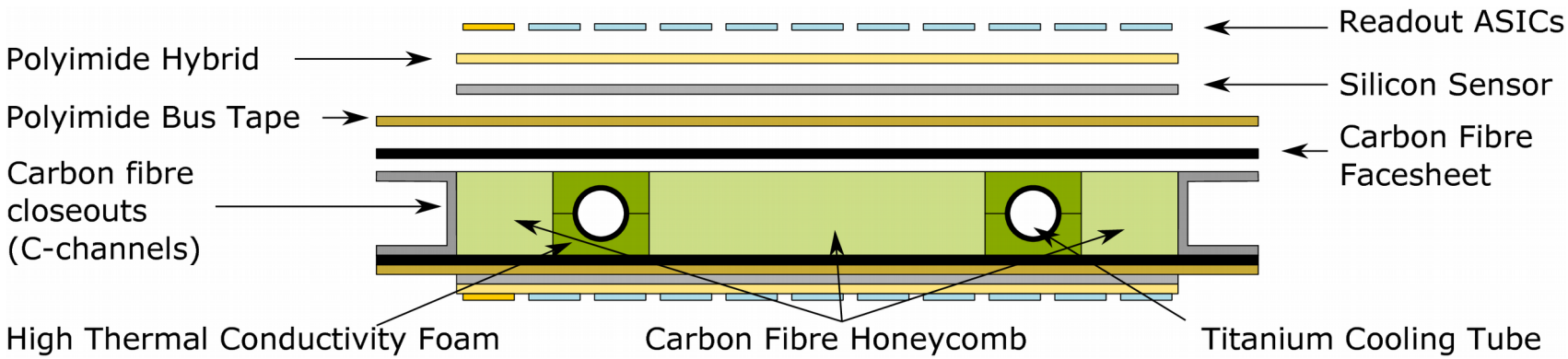
Electronic architecture

- Signals from sensors collected, shaped, and discriminated by **ABCstar** ASIC (ATLAS Binary Chip).
- Each ABCstar sends data to **HCCstar** (Hybrid Control Chip) in parallel configuration.
- HCCstar sends data to **EoS card** (End of Substructure) at up to 640 Mbps, and receives Trigger, Timing, and Control signals at up to 120 Mbps.
- EoS connected to modules via co-cured **bus tape** for data, TTC, detector control, and power.
- EoS contains optical link (VRTX+) and data transceiver/serializer (LpGBT).

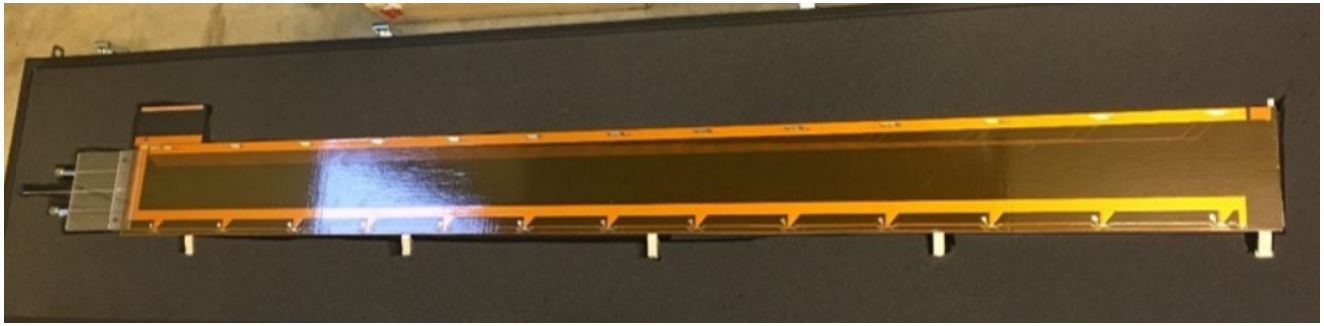




Local support structures

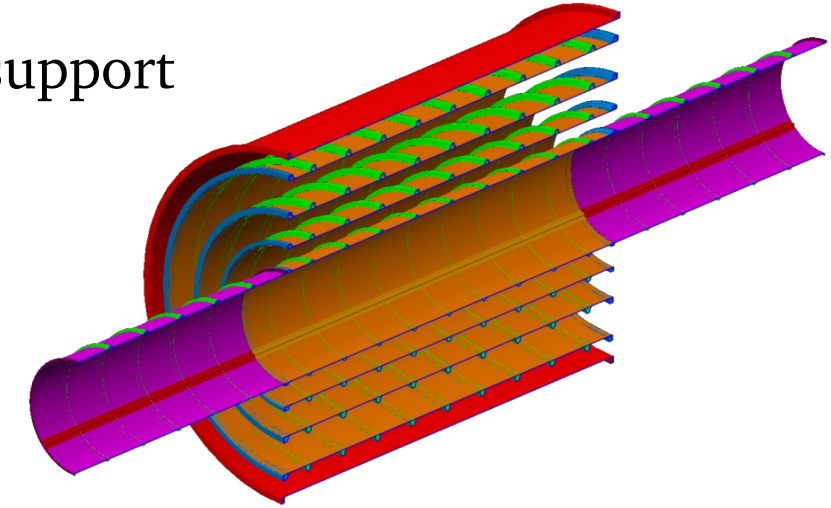


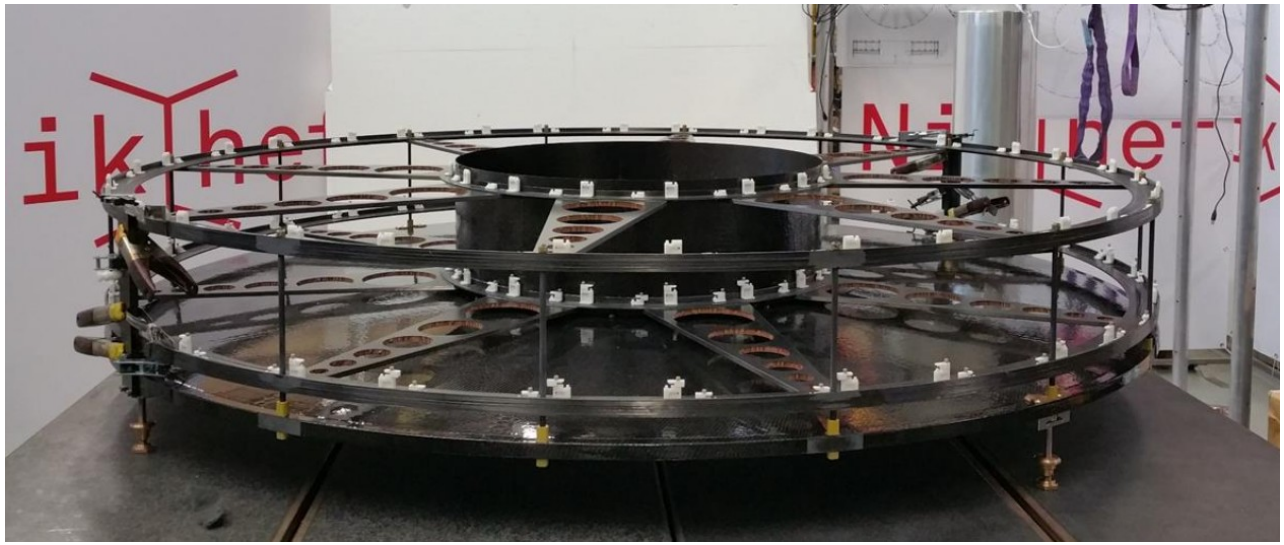
- Modules glued directly on both sides of a low-mass **Carbon Fiber honeycomb** support structure (stave or petal).
- **Evaporative CO_2 cooling** via embedded Titanium tubes.

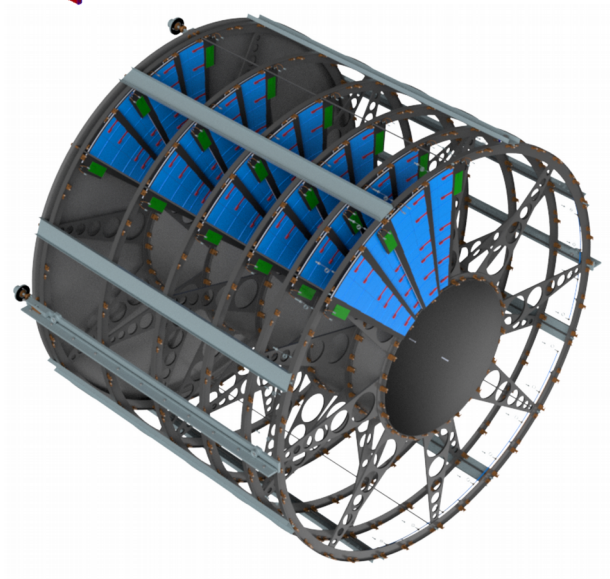


Global support structures

- **Cylinders** and **disks** provide structural support in the barrel and endcap, respectively.
- Designed so that staves and petals are **insertable**.
- Service connections at the end of the structures.

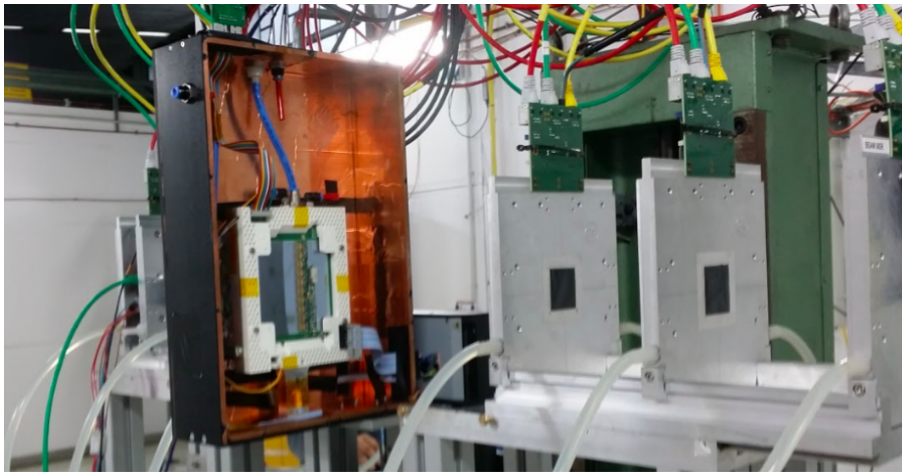


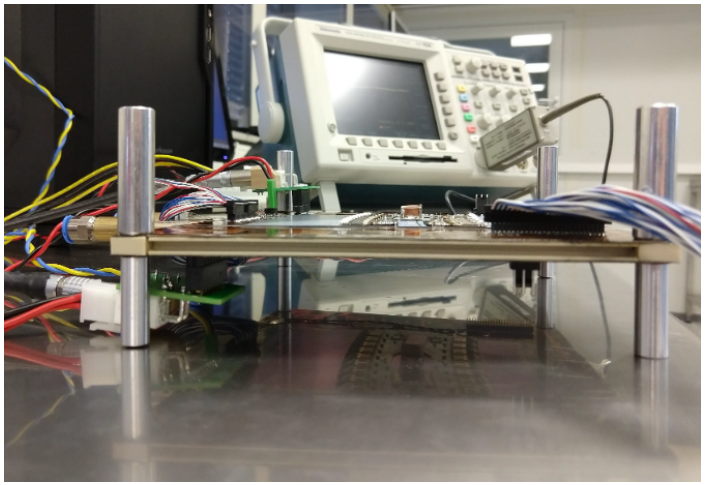




Prototype characterization: Testbeams

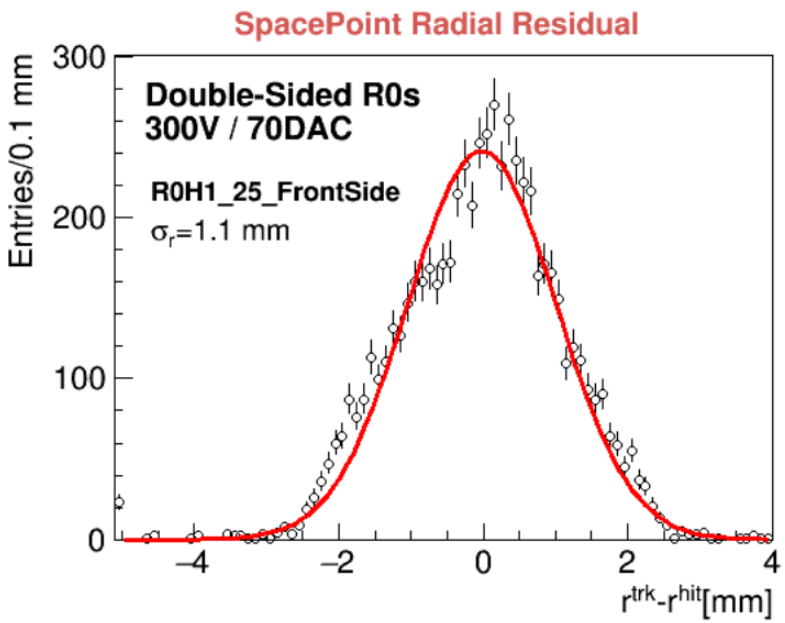
- Series of testbeams carried out at DESY-II and CERN SPS facilities.
- Tracking provided by EUDET telescopes: Six pixel planes with device placed in middle (resolution $\sim$5 μm).
- 2018 highlights:
  - First long-strip modules.
  - First double-sided module.
  - First irradiated module including powerboard.

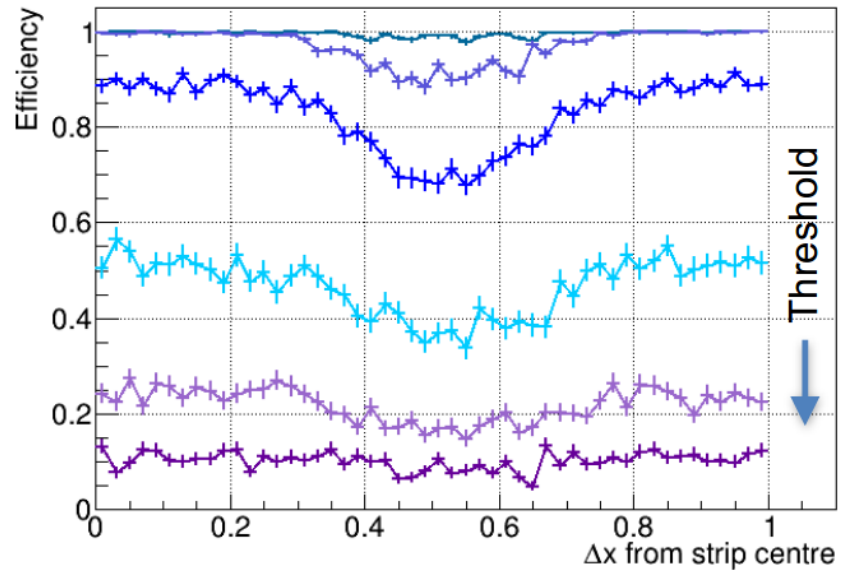




Testbeam results

- Excellent tracking resolution allows us to observe detector performance in great detail.
- Here, efficiency loss versus threshold in **inter-strip region**.

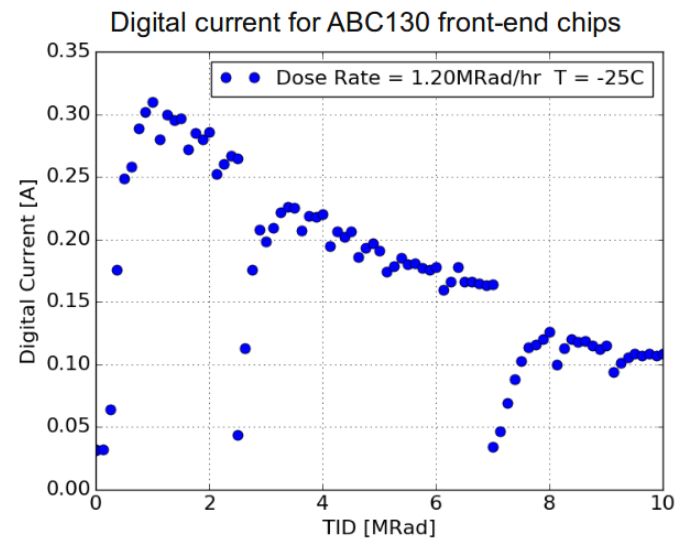


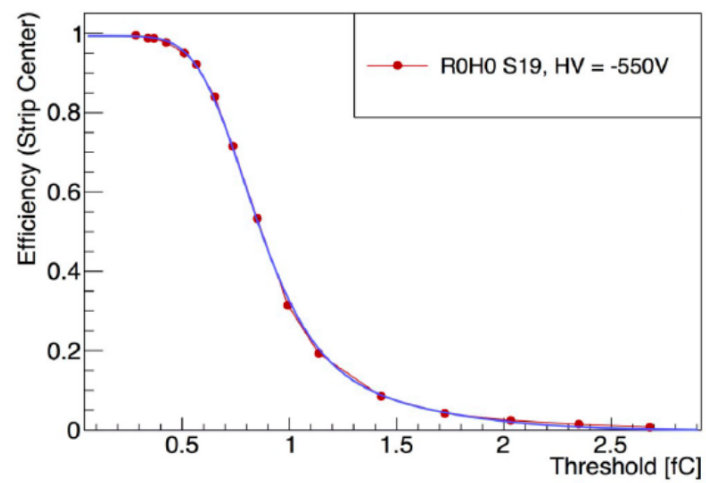


- Double-sided module allows first demonstration of **reconstructed position along the strips** from stereo angle.

Testbeam results

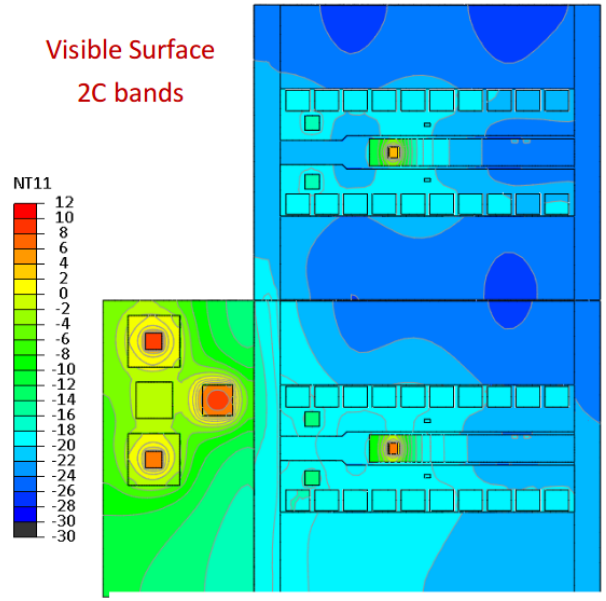
- Endcap module including powerboard irradiated at CERN PS facility to 1.63×10^{15} n_{eq}/cm^2 → 50% higher than maximum expected dose.
- Binary readout: collected charge inferred in testbeam from **threshold scans**.
- After correcting to the expected dose and final electronics chip set, results suggest operability at end of lifetime.
- **To be confirmed** in tests this year!

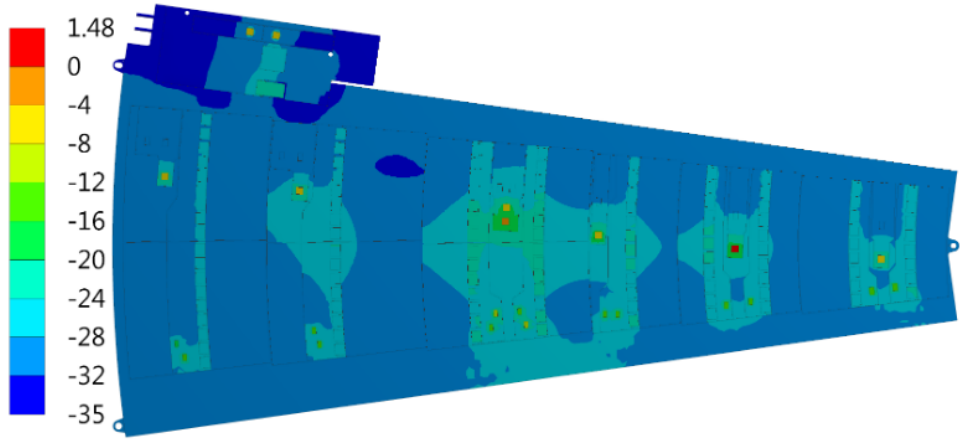




Thermal characterization

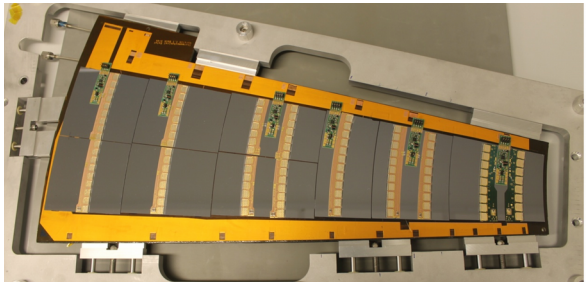
- Thermal properties of staves and petals simulated using Finite Element Analysis.
- At end of lifetime, **no thermal runaway** expected for CO_2 T_{evap} < -15 C (nominal is -35 C).
- Possibility to begin with higher cooling temperatures (e.g. 0 C) is under investigation.

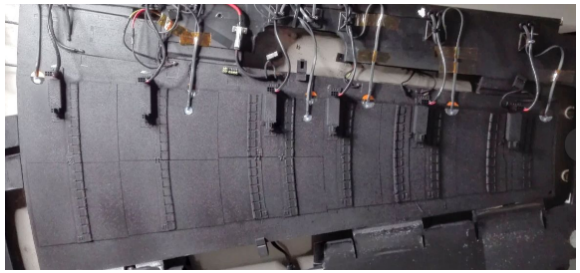


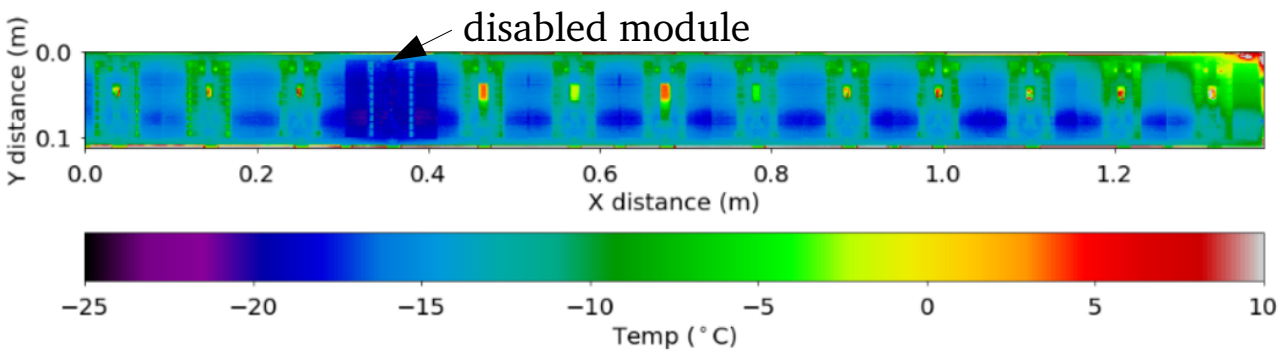


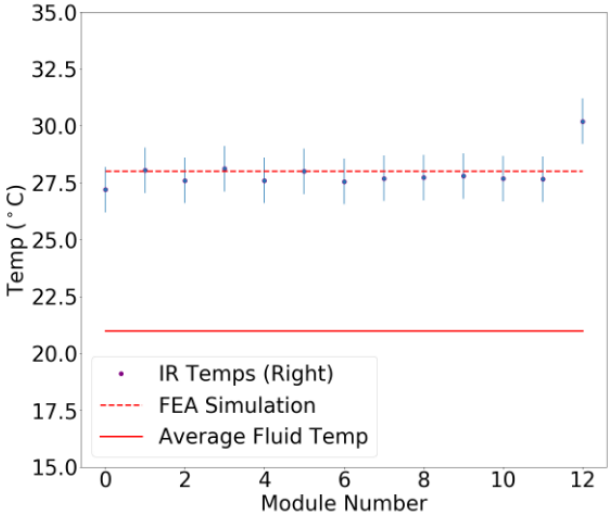
Thermomechanical prototypes

- FEA validated using thermomechanical stave and petal prototypes: real cores, but bare silicon and heaters instead of ASICs.
- Painted black to ensure constant emissivity.
- **Excellent agreement** observed between data and FEA simulation.



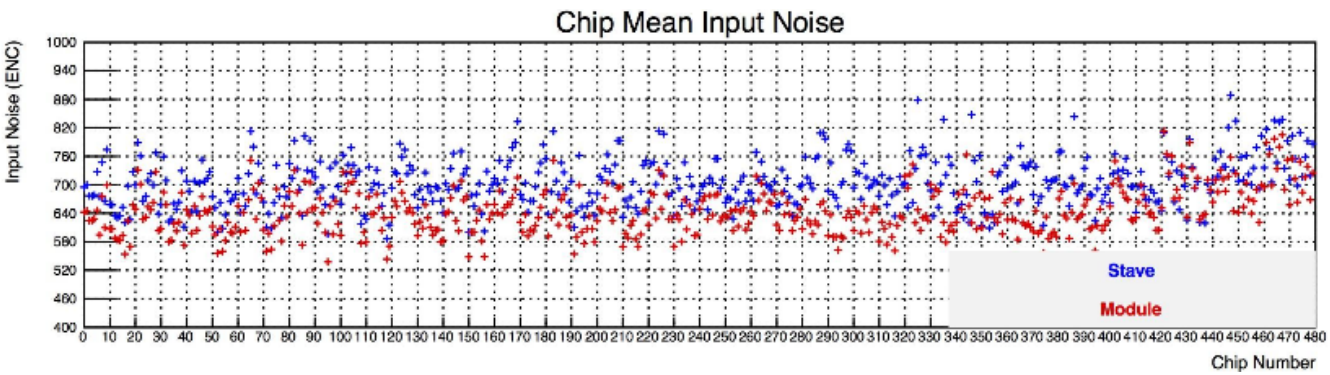


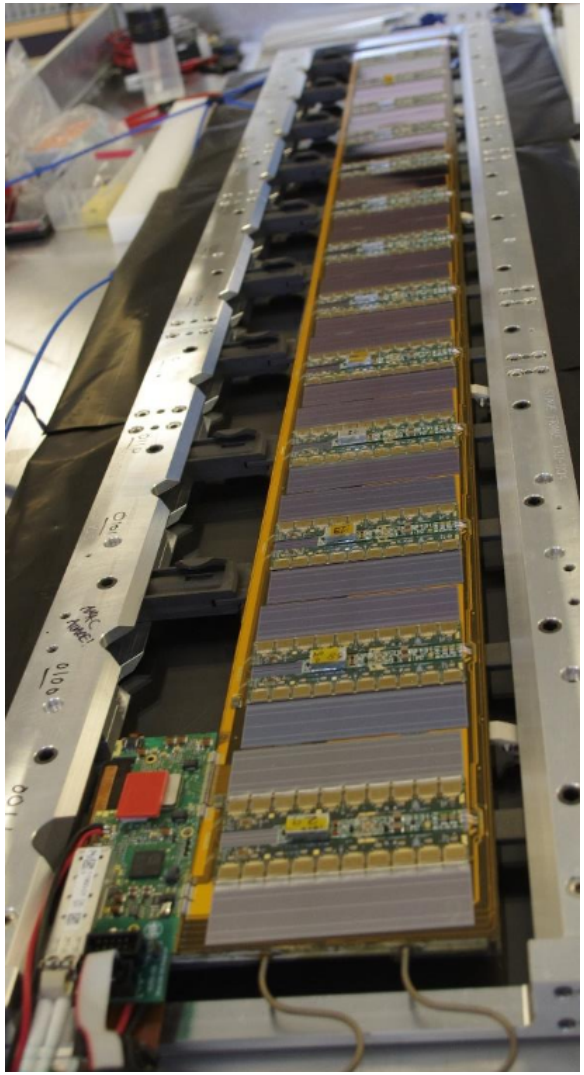




Towards larger structures

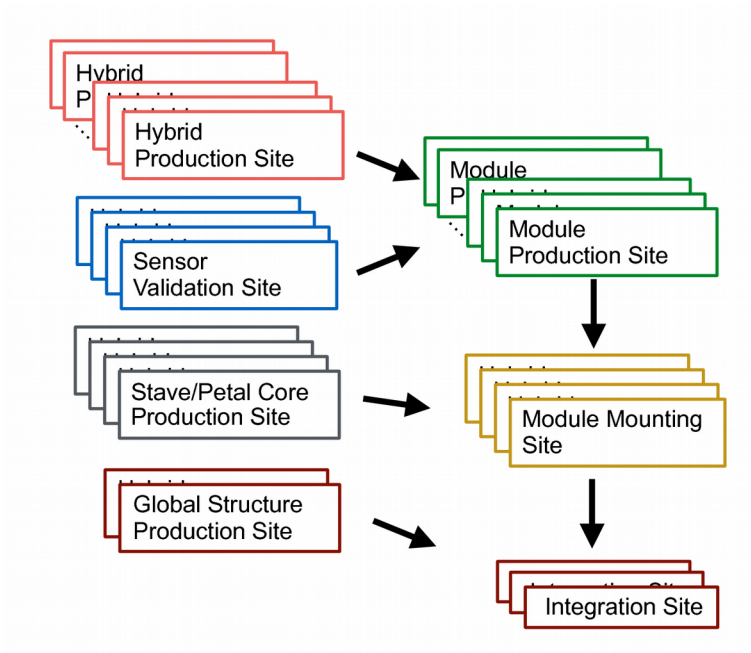
- First **fully populated staves** built with real modules or mix of real and mechanical modules.
- Small increase in noise seen on stave, within acceptable limits.
- Next steps include electro-mechanical petal and multi-stave systems test.

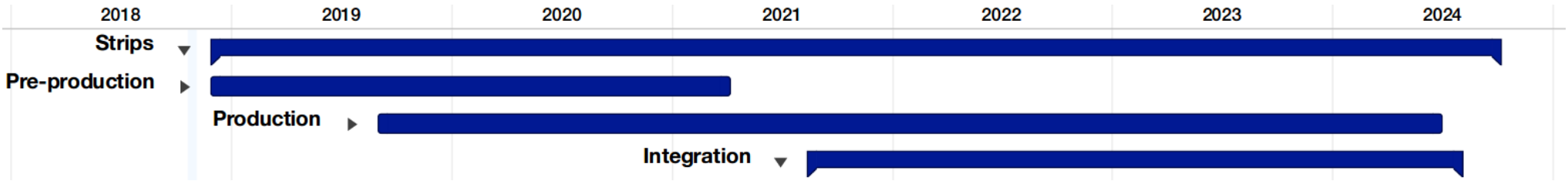




Preparing for production

- Project is in a **phase transition**: many-year R&D phase drawing to a close, 5-year construction phase beginning.
- Pre-production begins this year: 5% of materials delivered to establish procedures, qualify sites.
- To be followed by production from 2020 to 2024.





Summary

- After many years of extensive designing, prototyping, and testing, we are confident the ITk strips detector will be able to meet the challenges of the HL-LHC.
- Now begins the next challenge: constructing, installing, and commissioning the detector in time for beams in 2026.
- It is a difficult task, but this team knows how to work together.

Acknowledgements

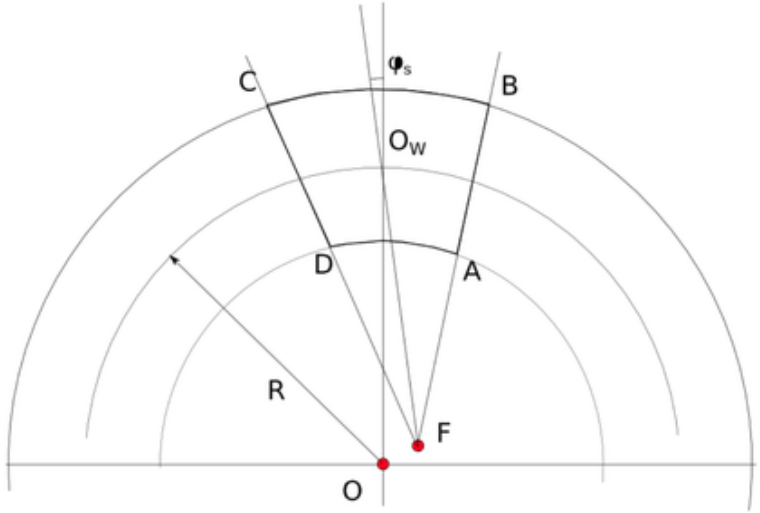
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 654168

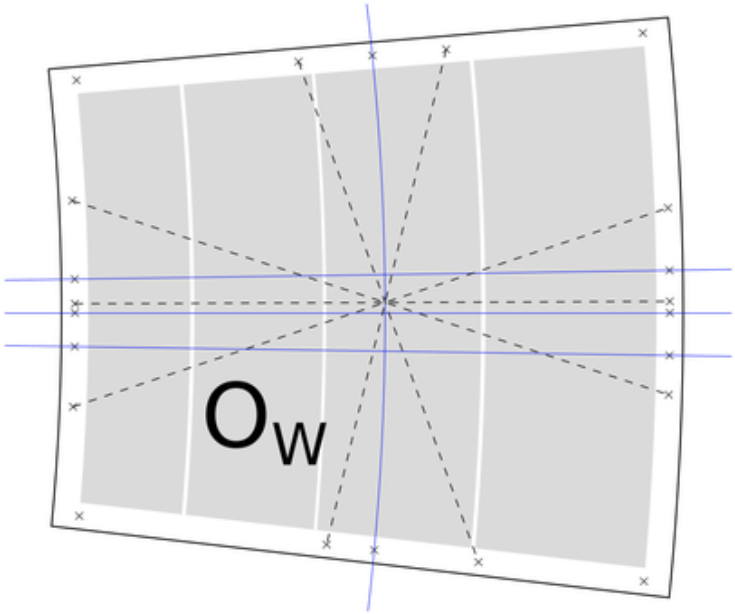
AIDA 2020

Some of the measurements leading to these results have been performed at the Test Beam Facility at DESY Hamburg (Germany), a member of the Helmholtz Association (HGF); and at the CERN SPS Test Beam Facility. We gratefully thank the operators of these facilities.

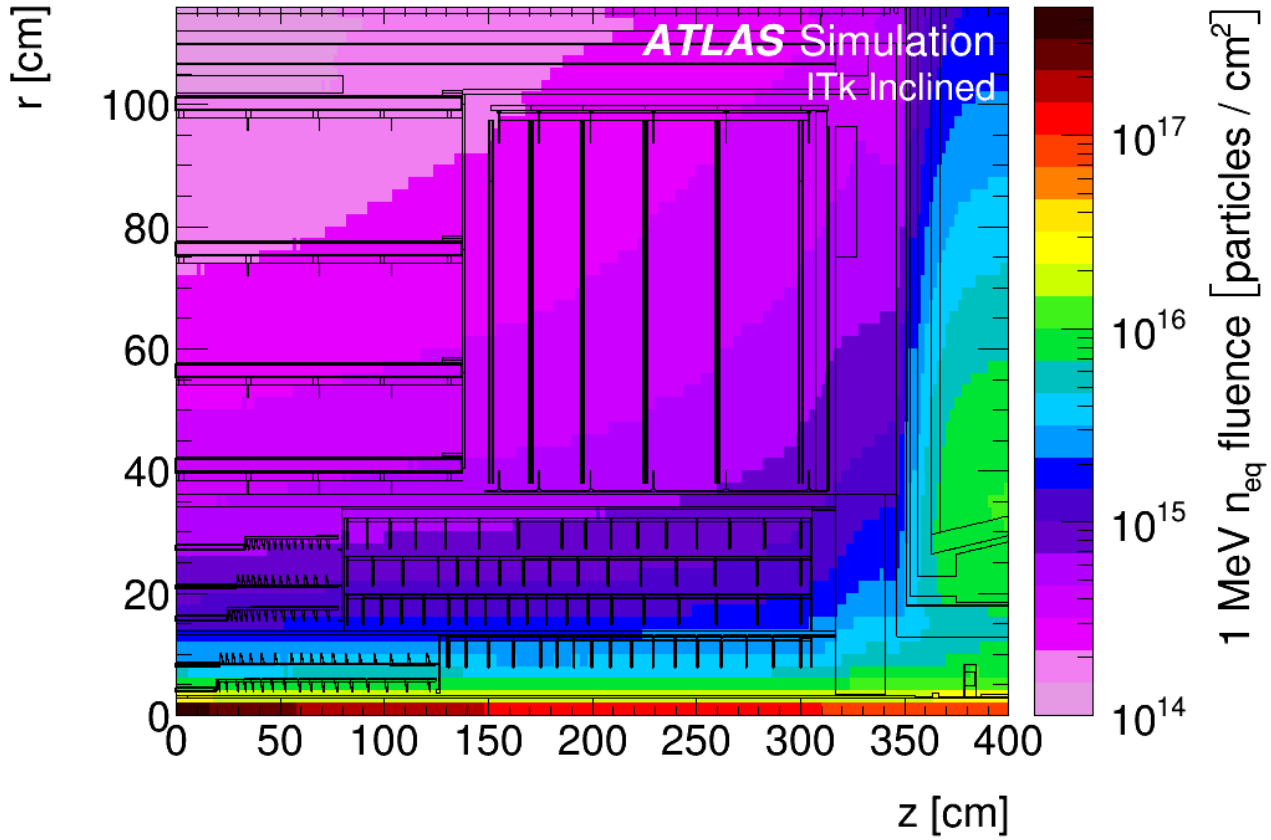
Backup slides

Stereo annulus geometry



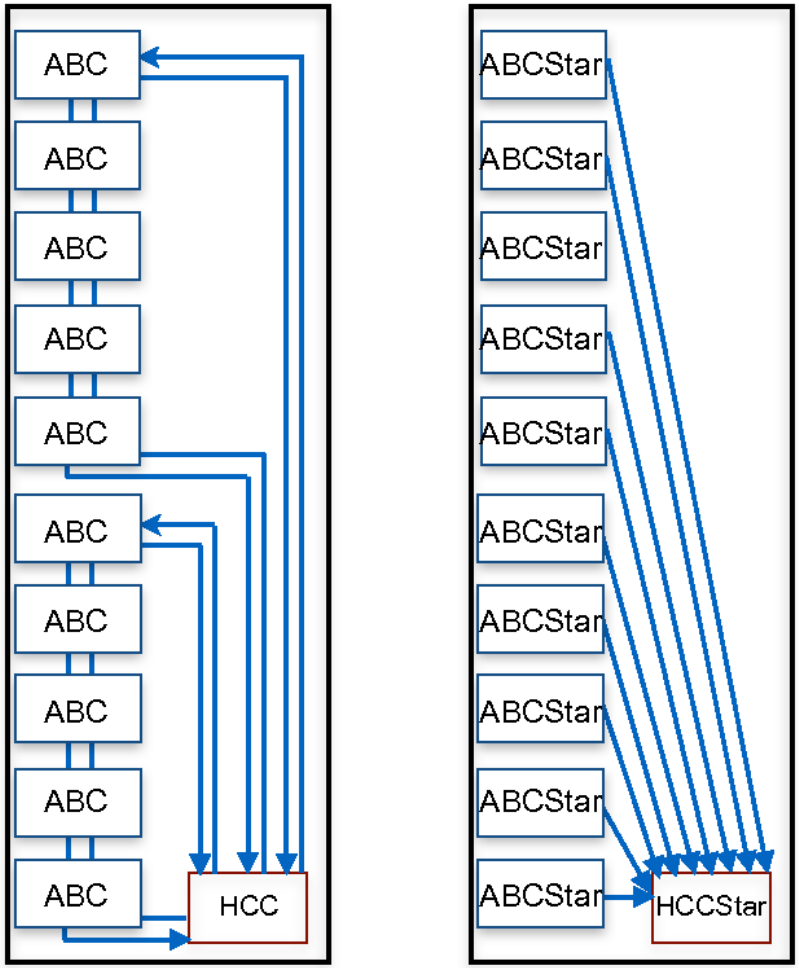


Radiation fluence

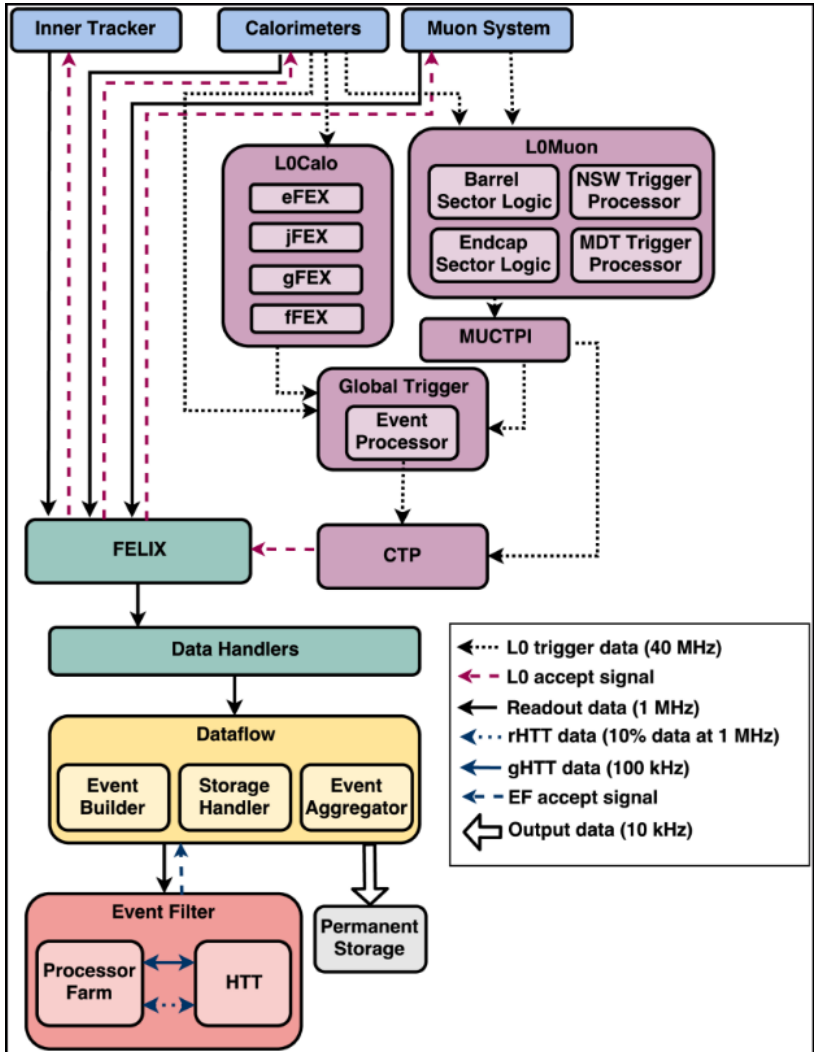


For 3000 fb^{-1}

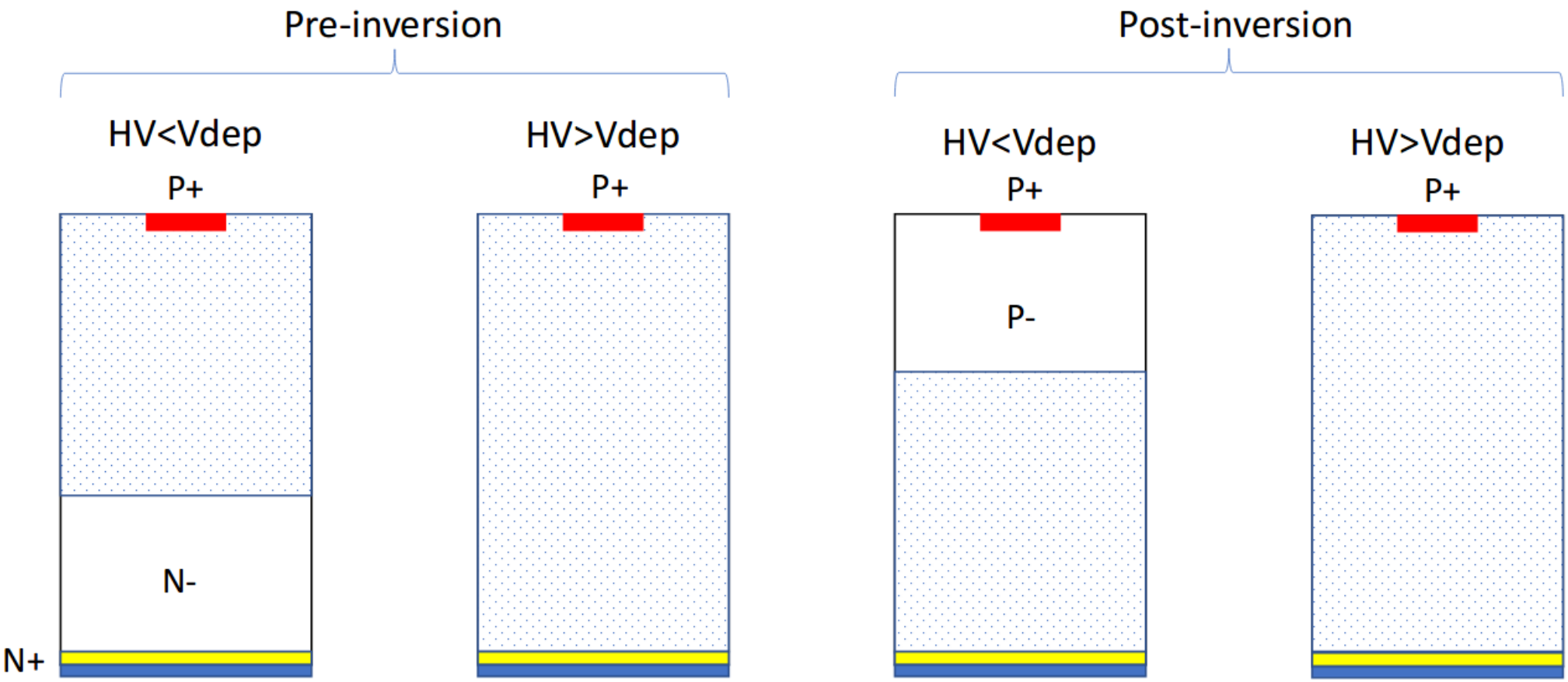
Star architecture



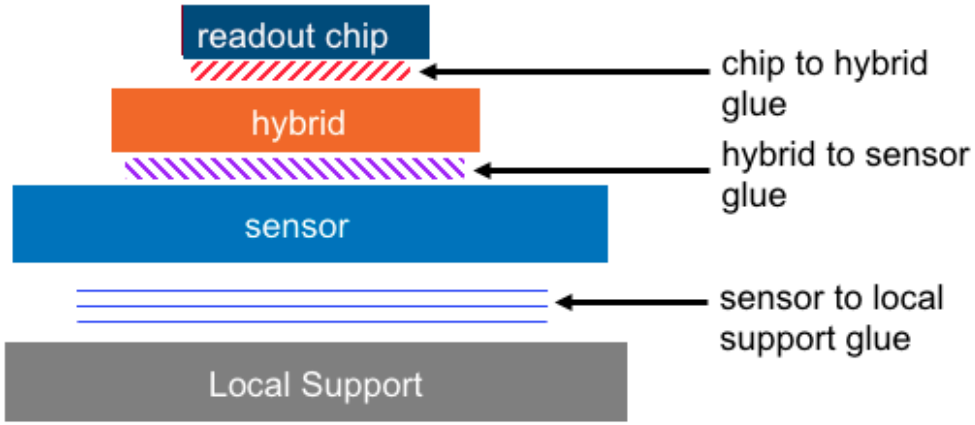
Phase 2 TDAQ


Inner Tracker
Calorimeters
Muon System
L0Calo
eFEX
jFEX
gFEX
fFEX
L0Muon
Barrel Sector Logic
NSW Trigger Processor
Endcap Sector Logic
MDT Trigger Processor
MUCTPI
Global Trigger
Event Processor
FELIX
CTP
Data Handlers
Dataflow
Event Builder
Storage Handler
Event Aggregator
Event Filter
Processor Farm
HTT
Permanent Storage
L0 trigger data (40 MHz)
L0 accept signal
Readout data (1 MHz)
rHTT data (10% data at 1 MHz)
gHTT data (100 kHz)
EF accept signal
Output data (10 kHz)

Type inversion in p^+-in-n silicon



Glue!



Loctite 3525

Polaris PF-7006

Dow SE 4445