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

Serhat Ördek on behalf of the ATLAS ITk Collaboration

Workshop on Future Accelerators
Corfu, 22nd of May 2024

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

ATLAS ITk

Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

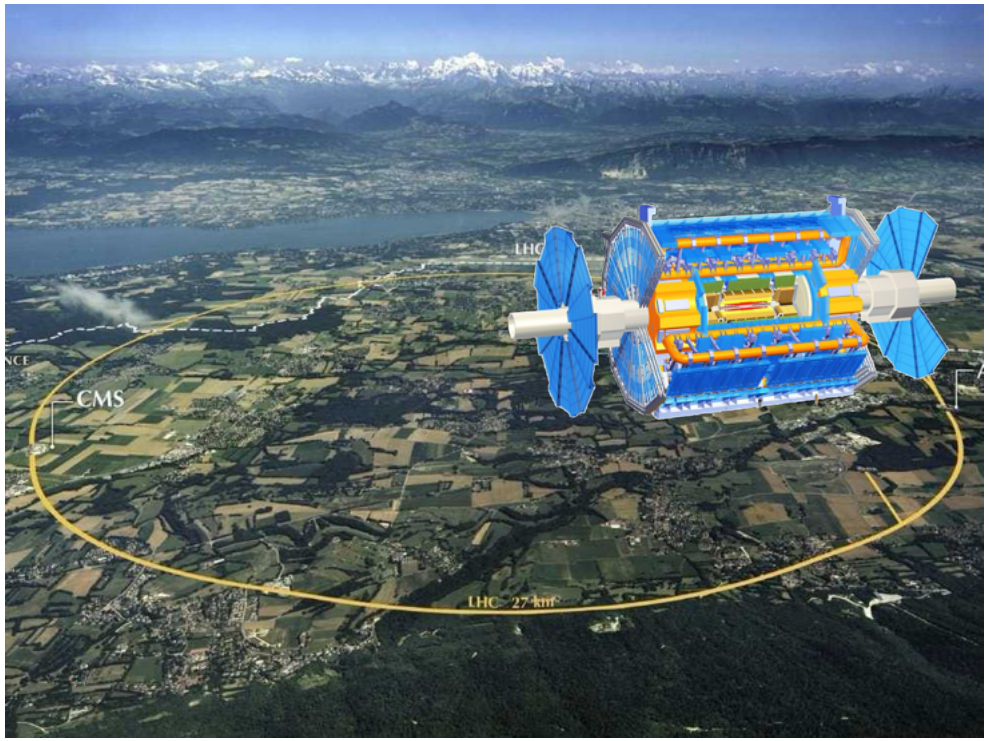
CLUSTER OF EXCELLENCE
QUANTUM UNIVERSE

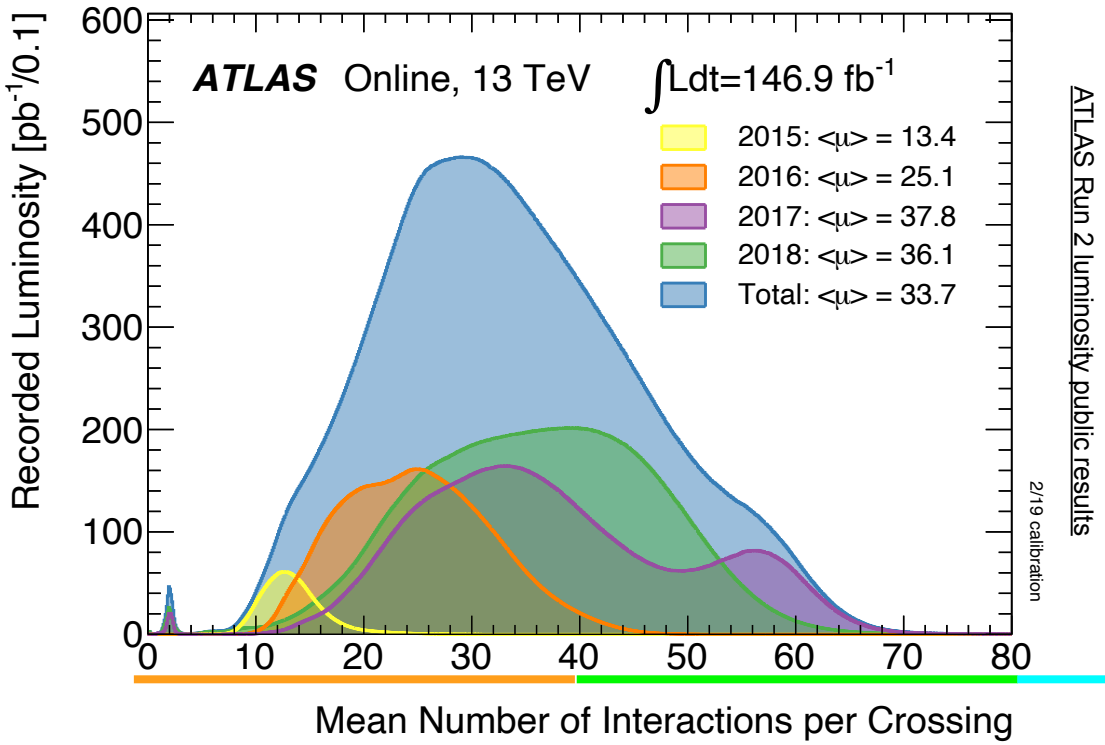
DESY.

The ATLAS experiment

Multi-purpose detector at the LHC

- Detector operated since 2010, collected around 250 fb^{-1} of physics data
- For some processes, e.g. HH production, highest current rate is too low
- Motivates High-Luminosity LHC upgrade to increase collision rate
- Also increases the number of interactions per pp bunch crossing



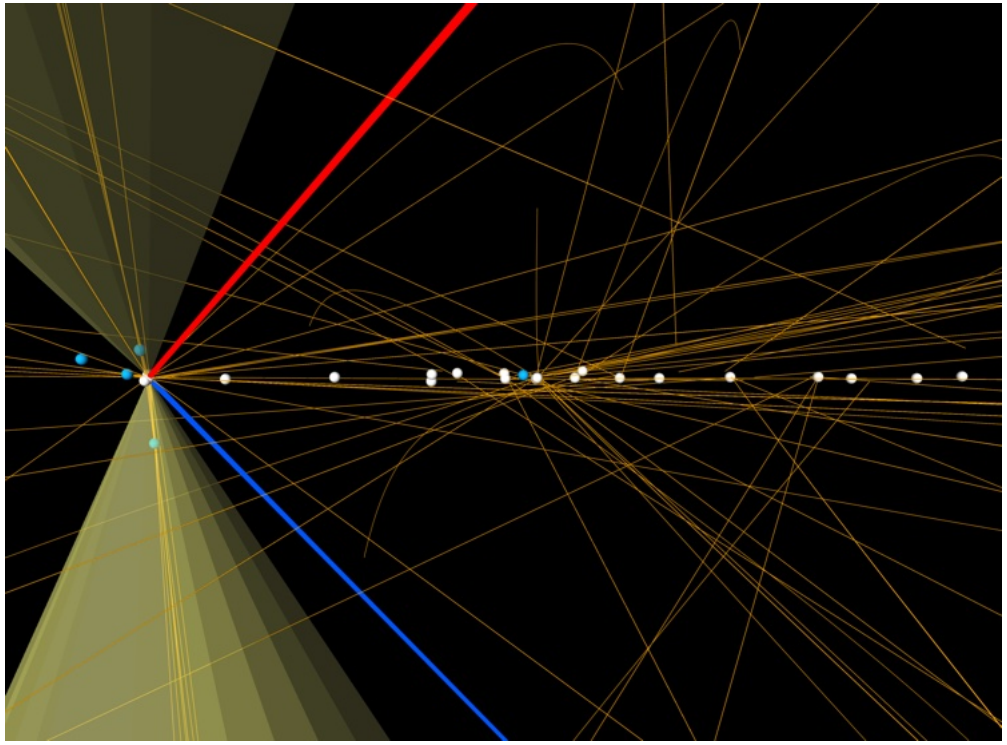


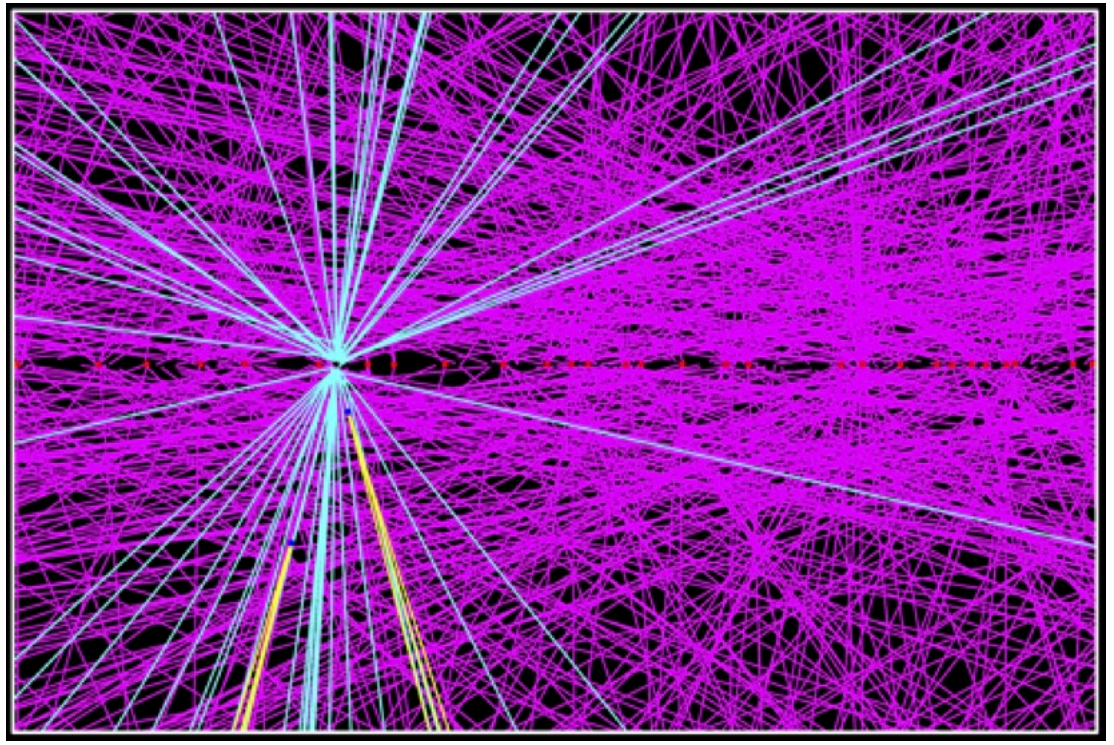
HL-LHC

$\langle \mu \rangle = 200$

What does the pile-up increase mean in practice?

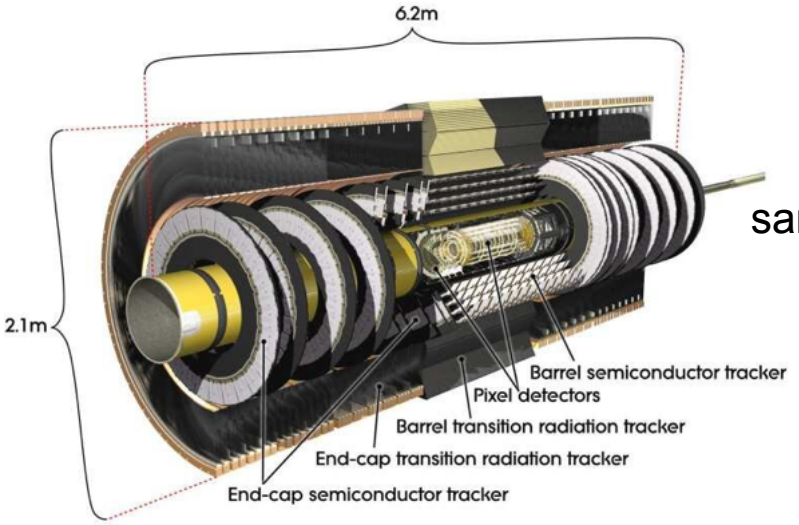
$t\bar{t}$ events at current LHC and HL-LHC pile-up levels



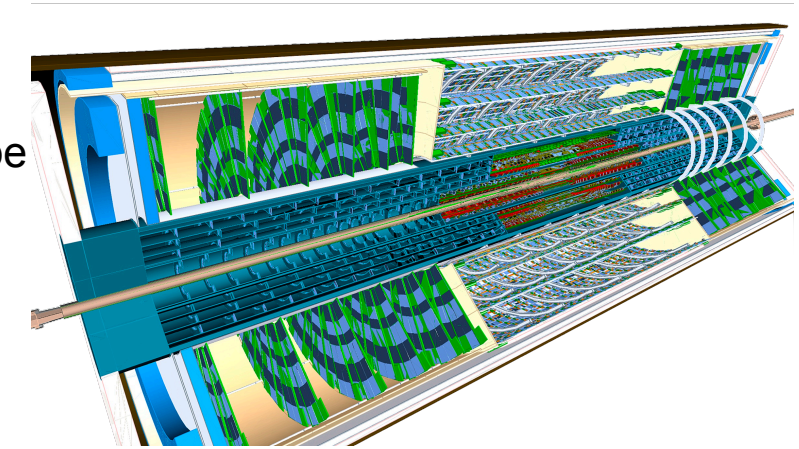


Upgrading the detector

ATLAS Inner Tracker design

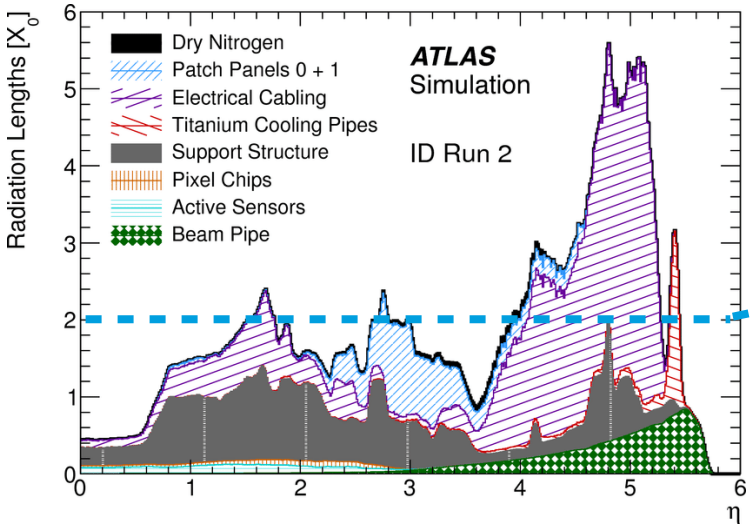


same envelope

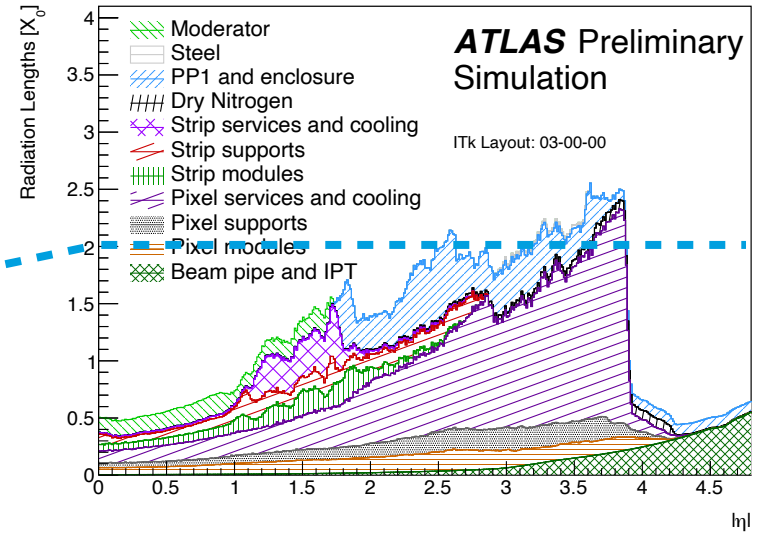


- Current Inner Detector to be swapped out for ITk
- All-silicon detector with two subsystems: pixels and strips
- Higher radiation tolerance
- Faster response
- Increased channel density
- Bigger coverage in η
- Reduced material budget

ITK-2023-001

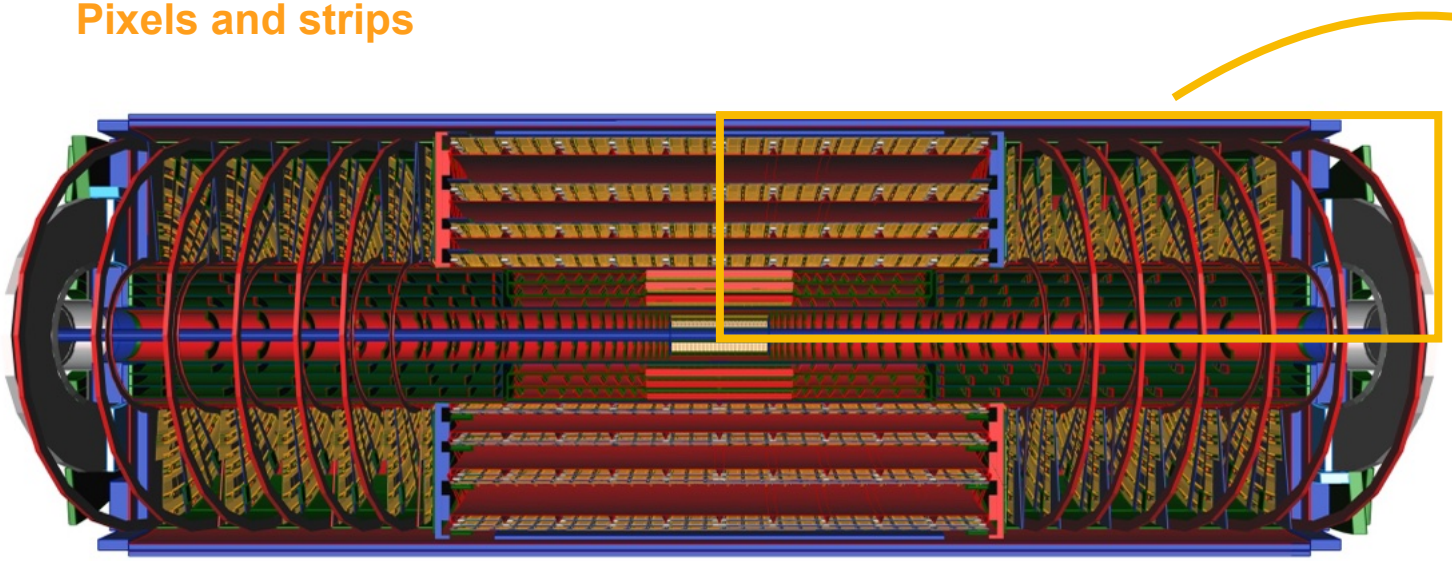


ATLAS-TDR-030



ITk overall layout

Pixels and strips



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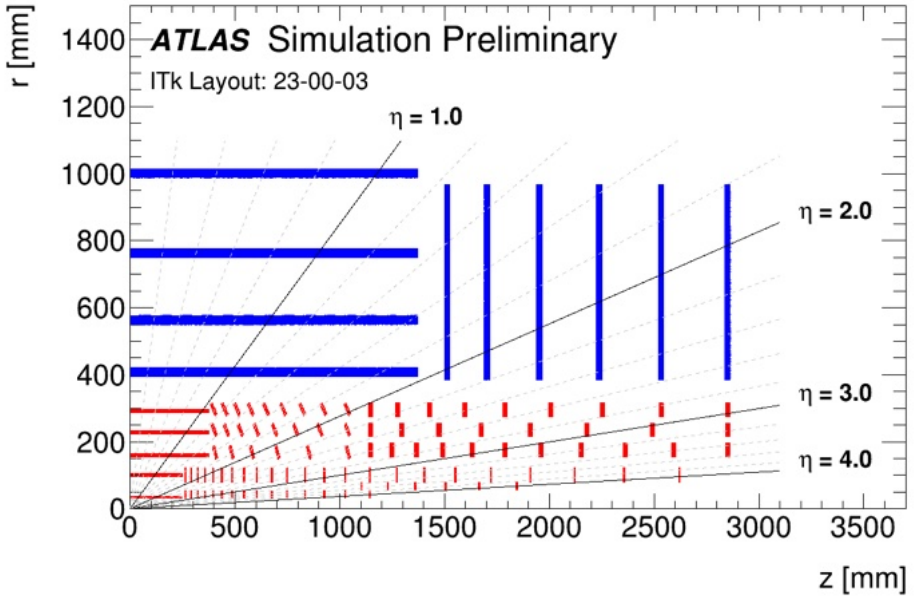
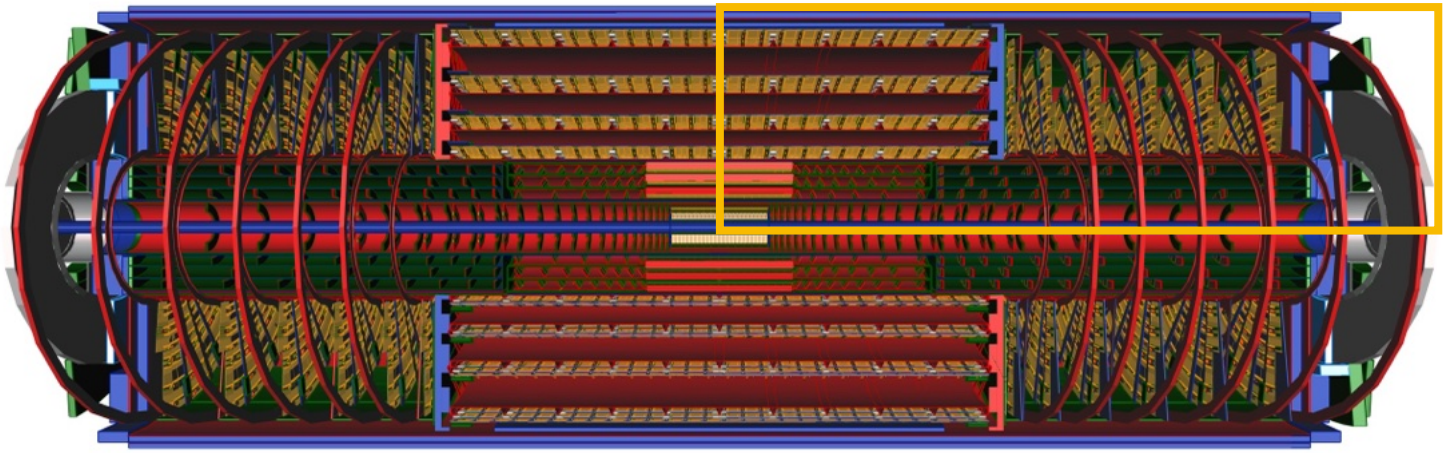


- Pixels are innermost detector layer, strips around it

ITk overall layout

Pixels and strips



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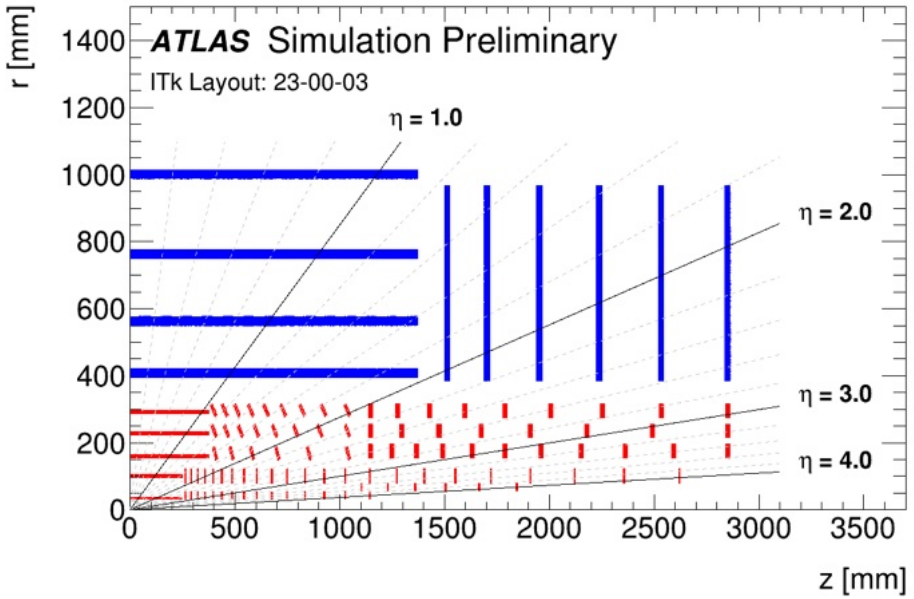

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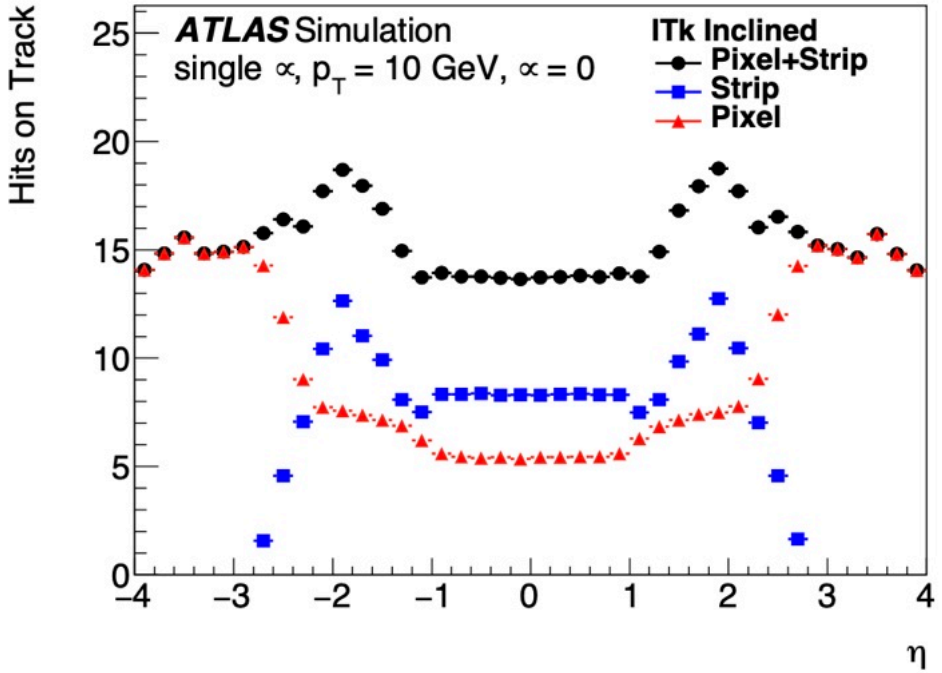
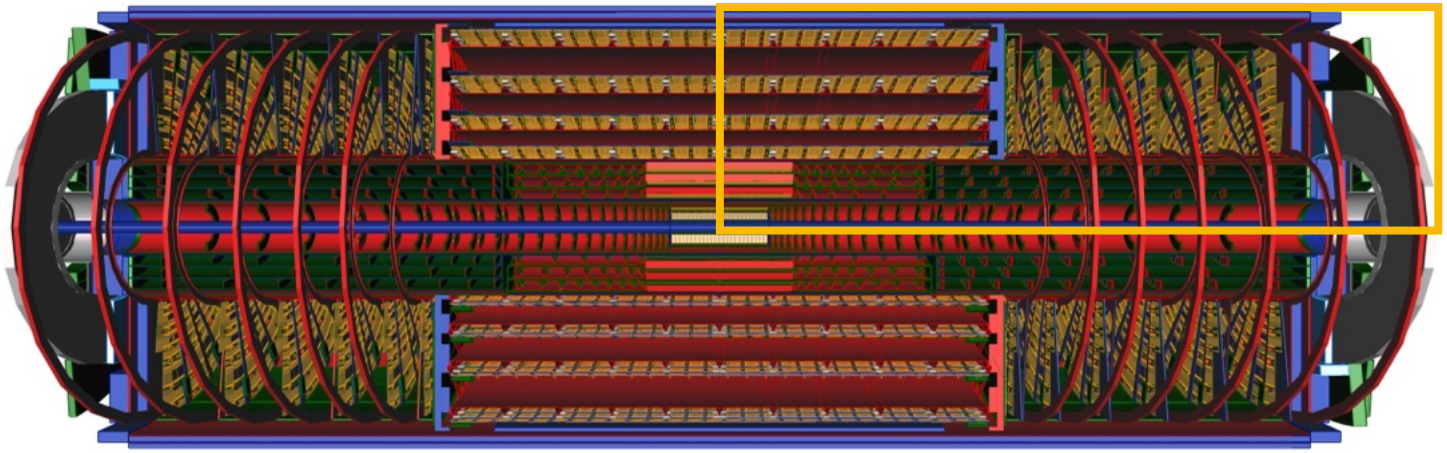


- Pixels are innermost detector layer, strips around them
- Expect more hits from strips at small $|\eta|$

ITk overall layout

Pixels and strips



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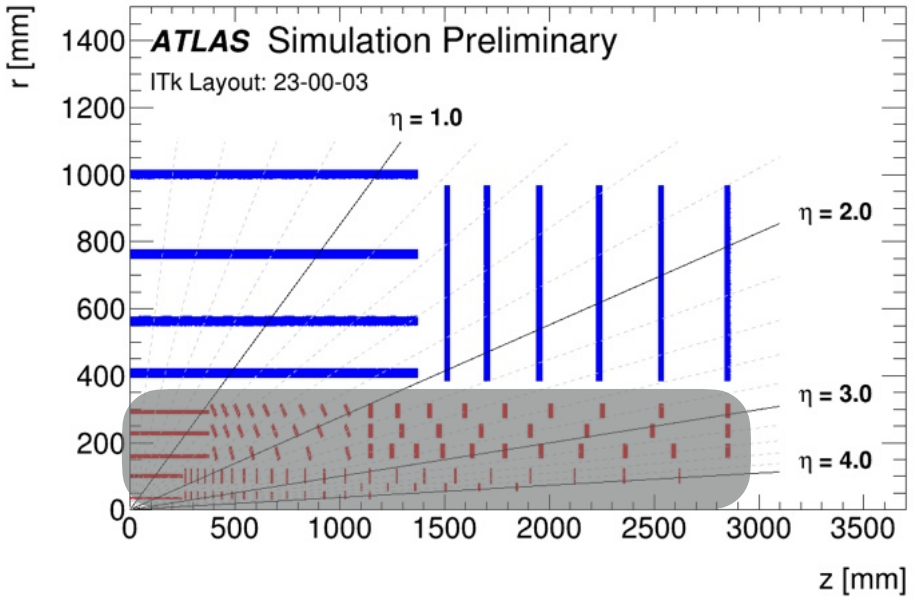

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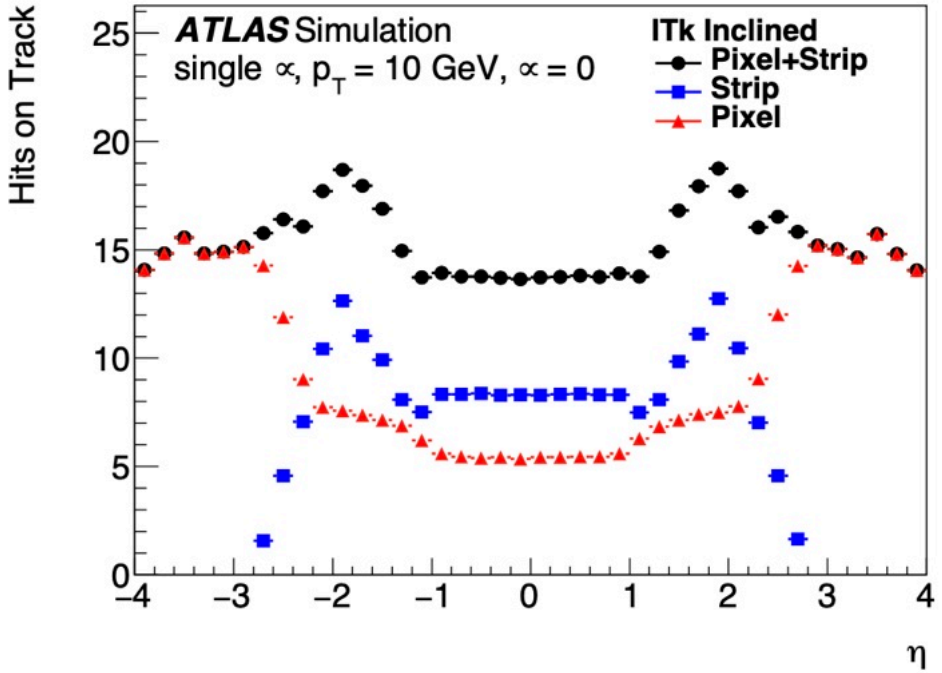

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- Focusing on strip detector, pixels covered in Emily's talk tomorrow

ITk overall layout

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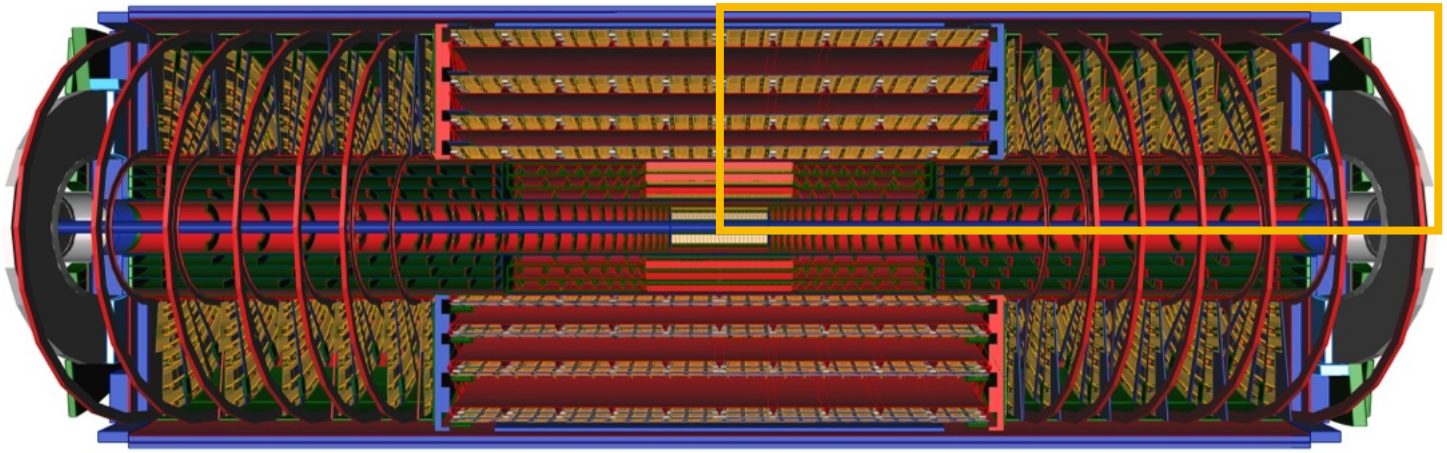

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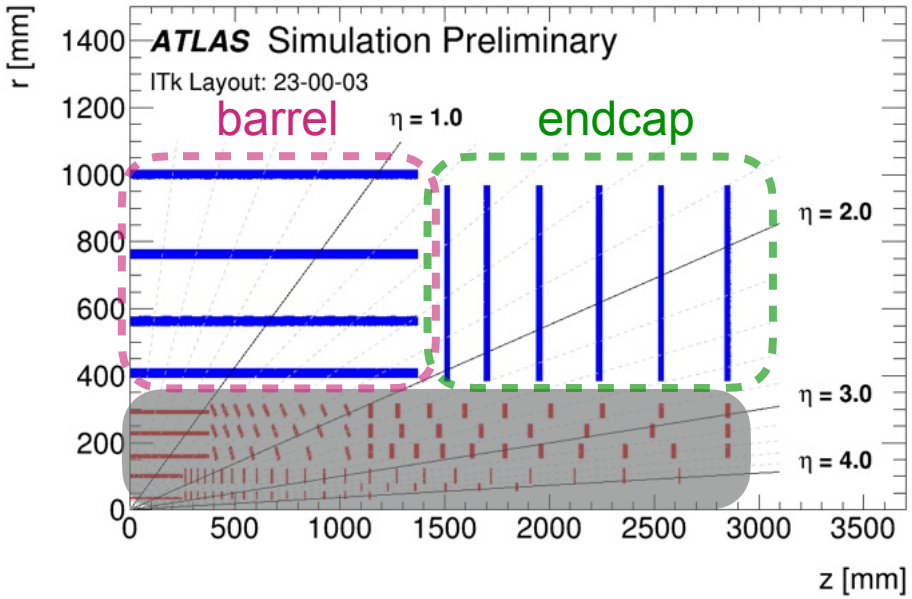

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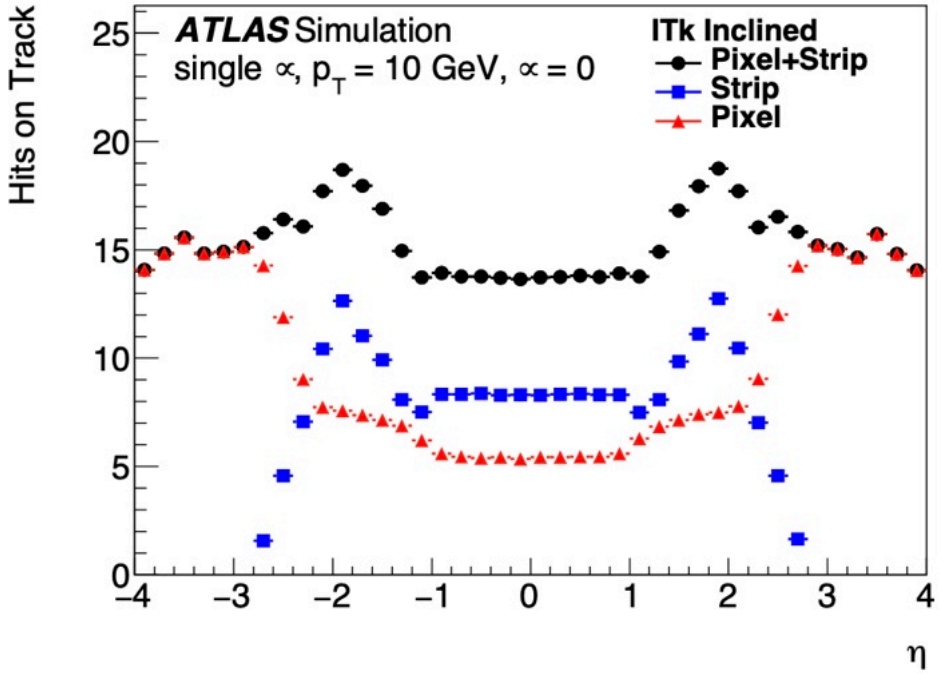

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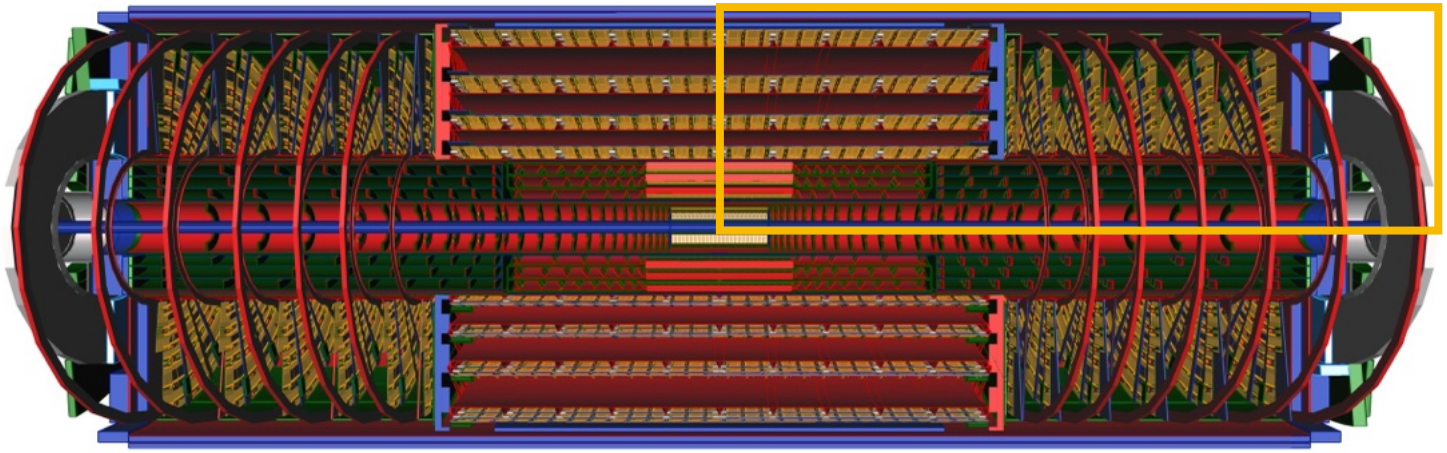
- Strip detector split into barrel and endcap subsystems

ITk overall layout

Pixels and strips



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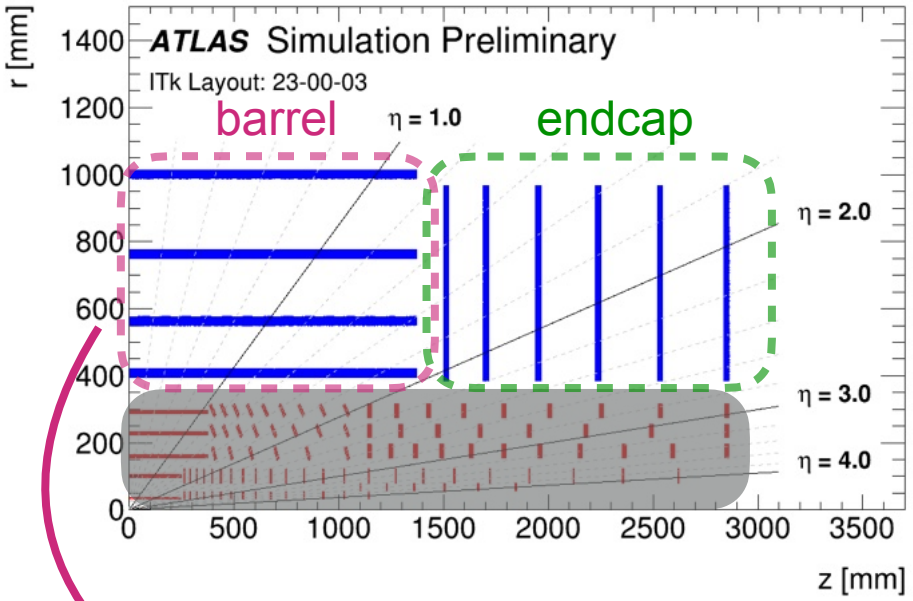

- Pixels are innermost detector layer, strips around it
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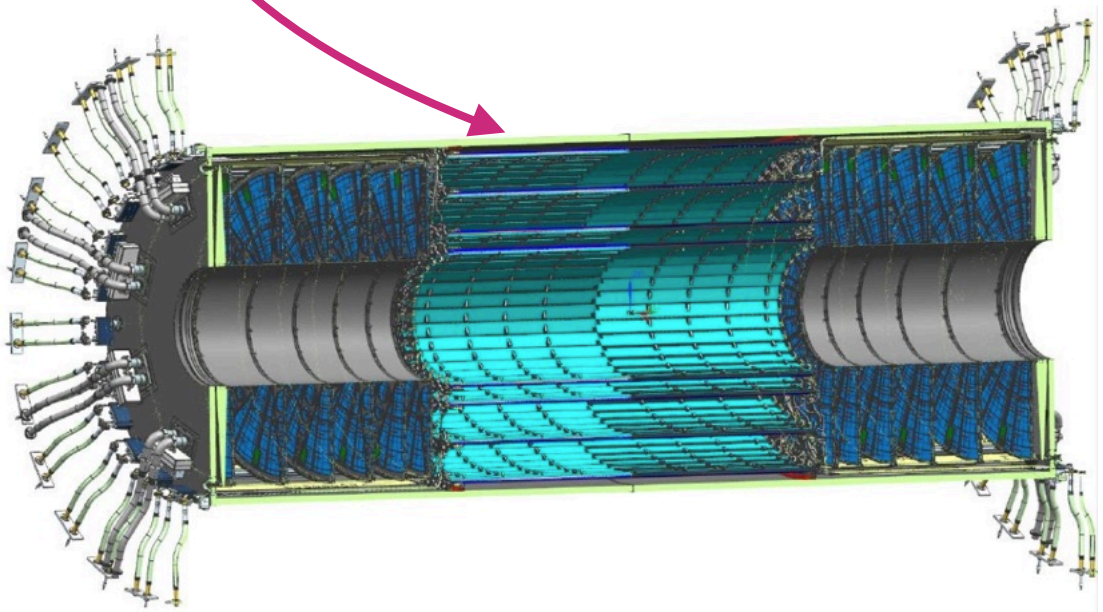
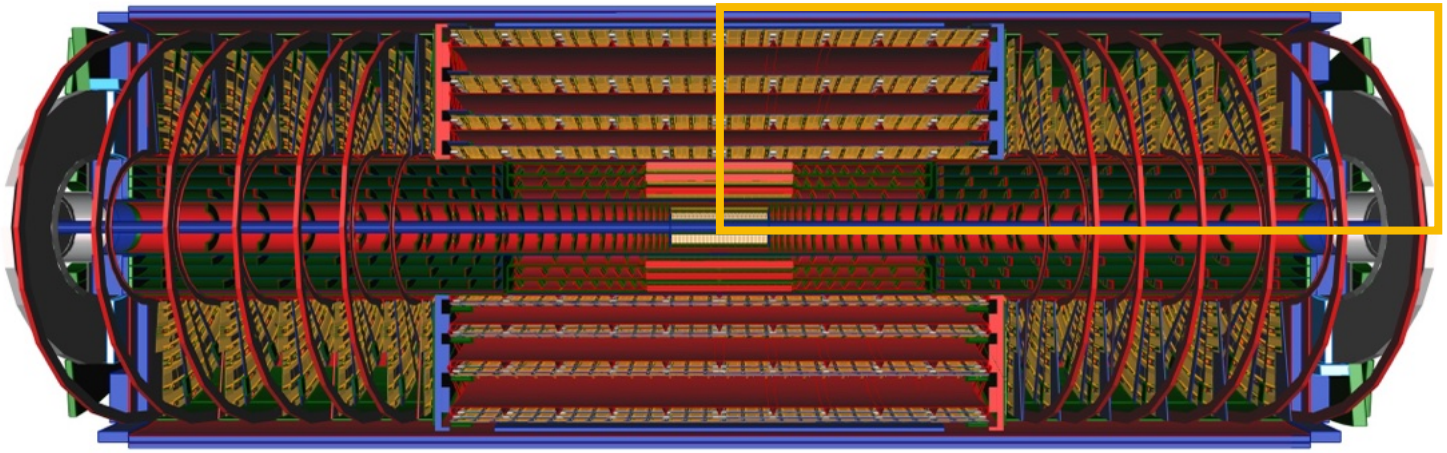
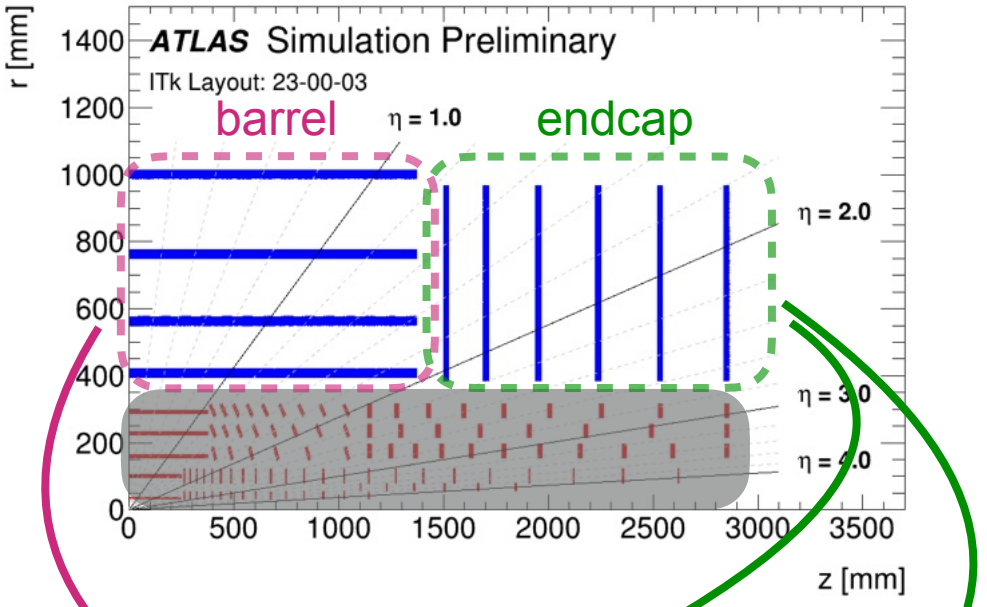
- Focusing on strip detector, pixels covered in Emily's talk tomorrow
- Strip detector split into barrel and endcap subsystems
- Barrel consists of four concentric layers

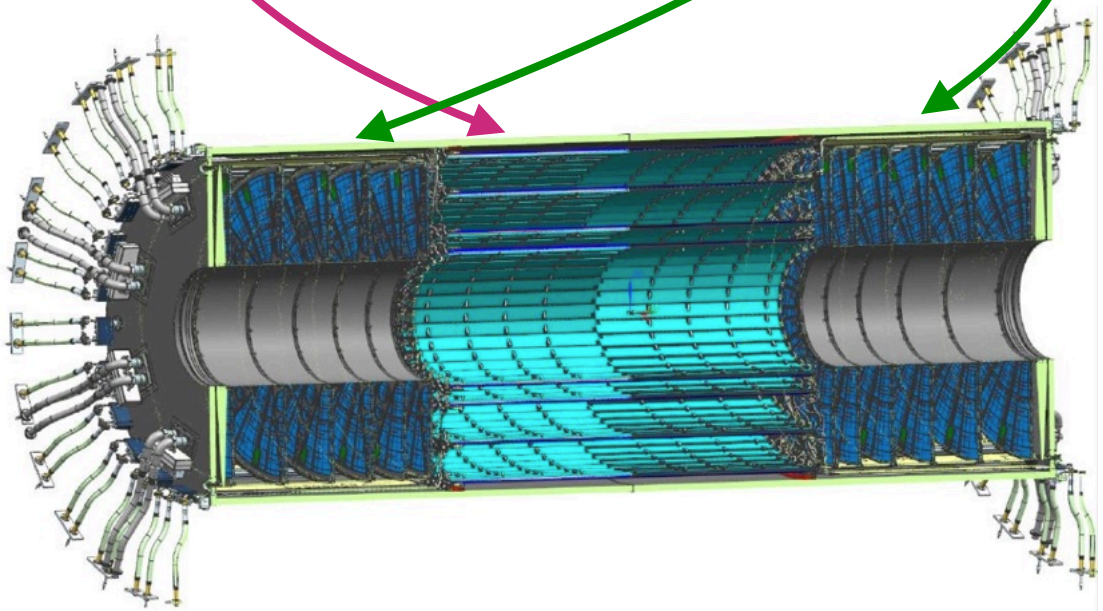


ITk overall layout

Pixels and strips







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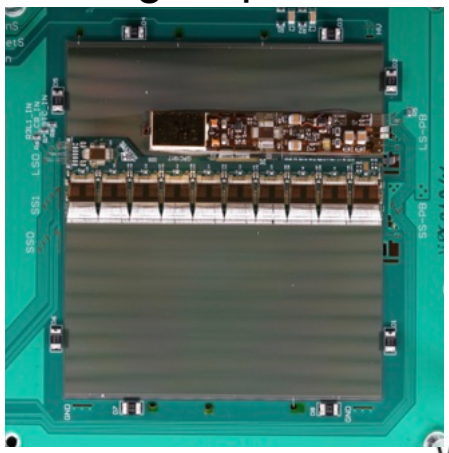
- Strip detector split into barrel and endcap subsystems
- Barrel consists of four concentric layers
- Each endcap consists of six identical discs

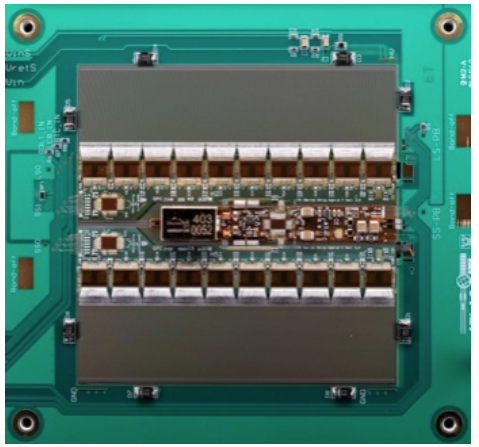
Barrel modules

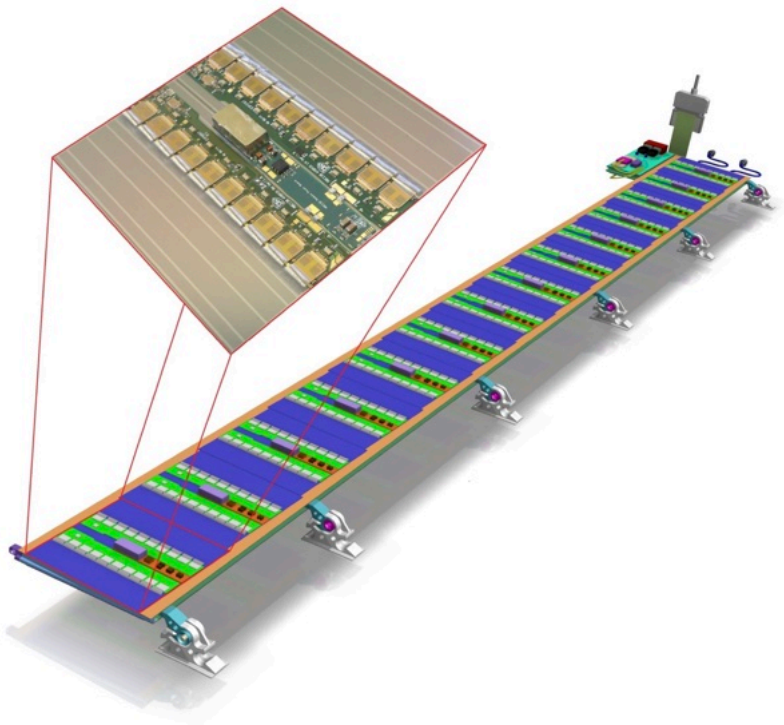
- n^+-in-p silicon sensors, more radiation resistant than p-in-n
- Two types of modules in the barrel: long strip and short strip
- Electronics glued on sensor surface: hybrids and power boards
- Modules are arranged in staves to construct 4 barrel layers
- Short strips in inner, long strips in outer two layers of barrel

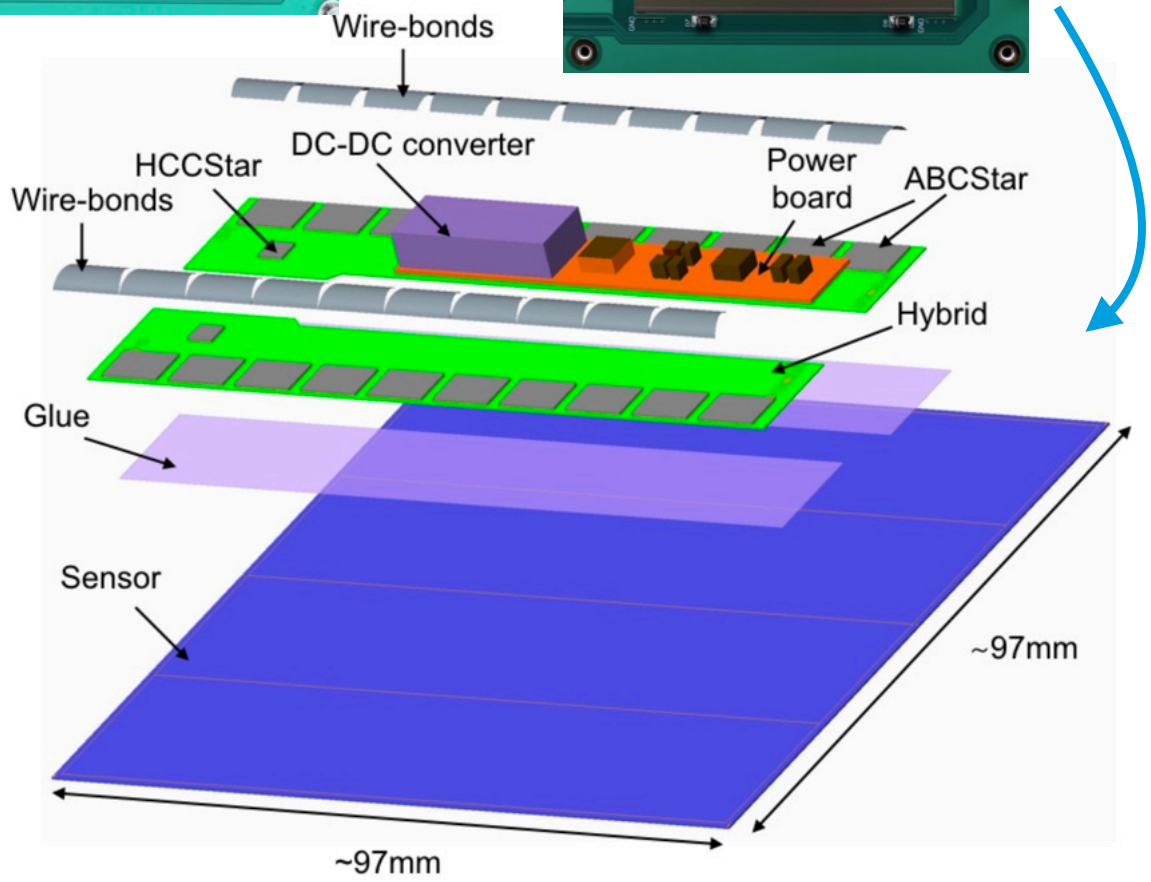
Long strip module



Short strip module

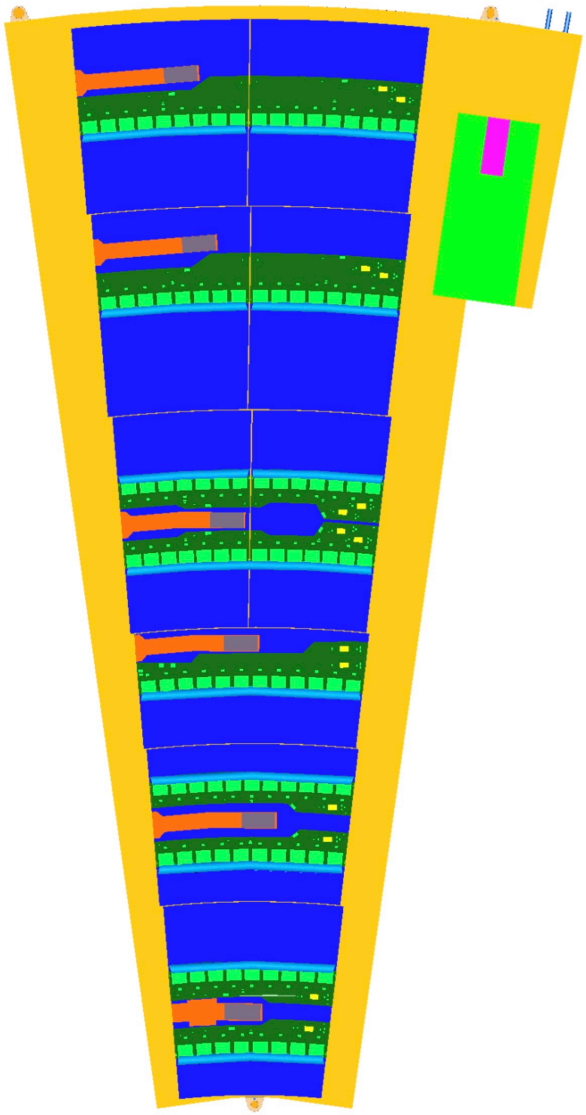






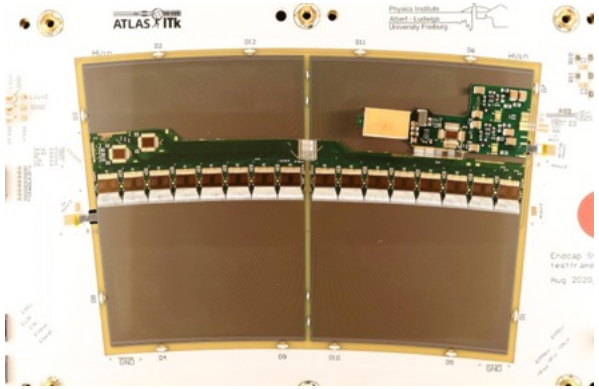
Endcap modules

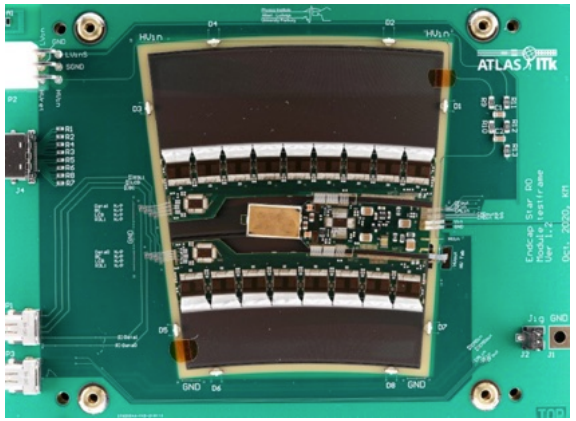
- Consists of 6 discs around beampipe
- Wedge-shaped petals carry the modules
- Need to cover more area at larger distance from centre

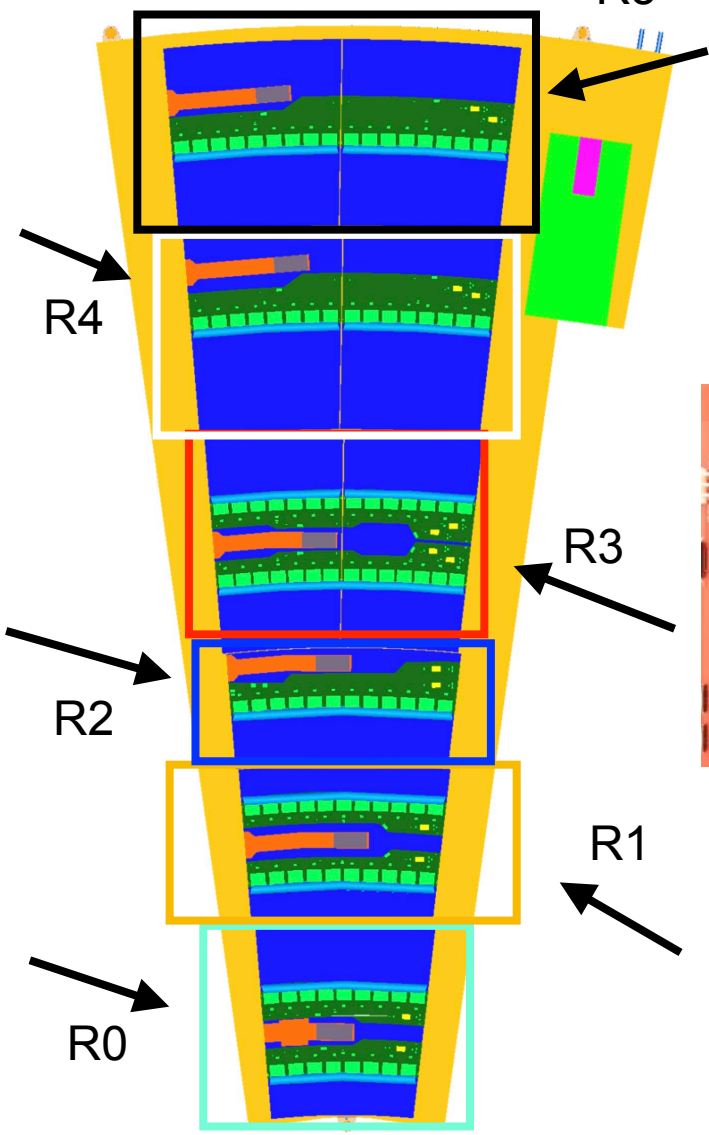


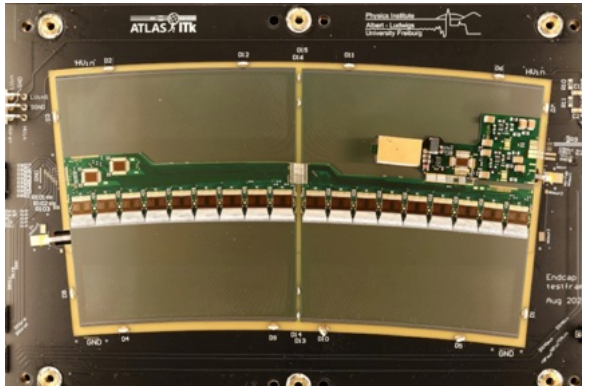
Endcap modules

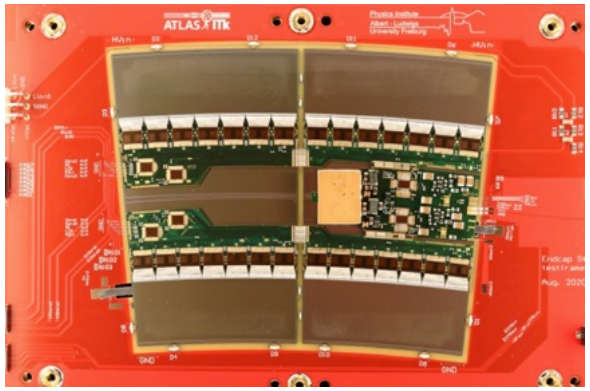
- Consists of 6 discs around beampipe
- Wedge-shaped petals carry the modules
- Need to cover more area at larger distance from centre
- Wider modules further up the petal
- Outer ringmodules consist of two sensors





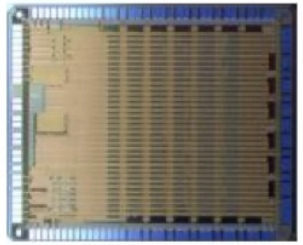




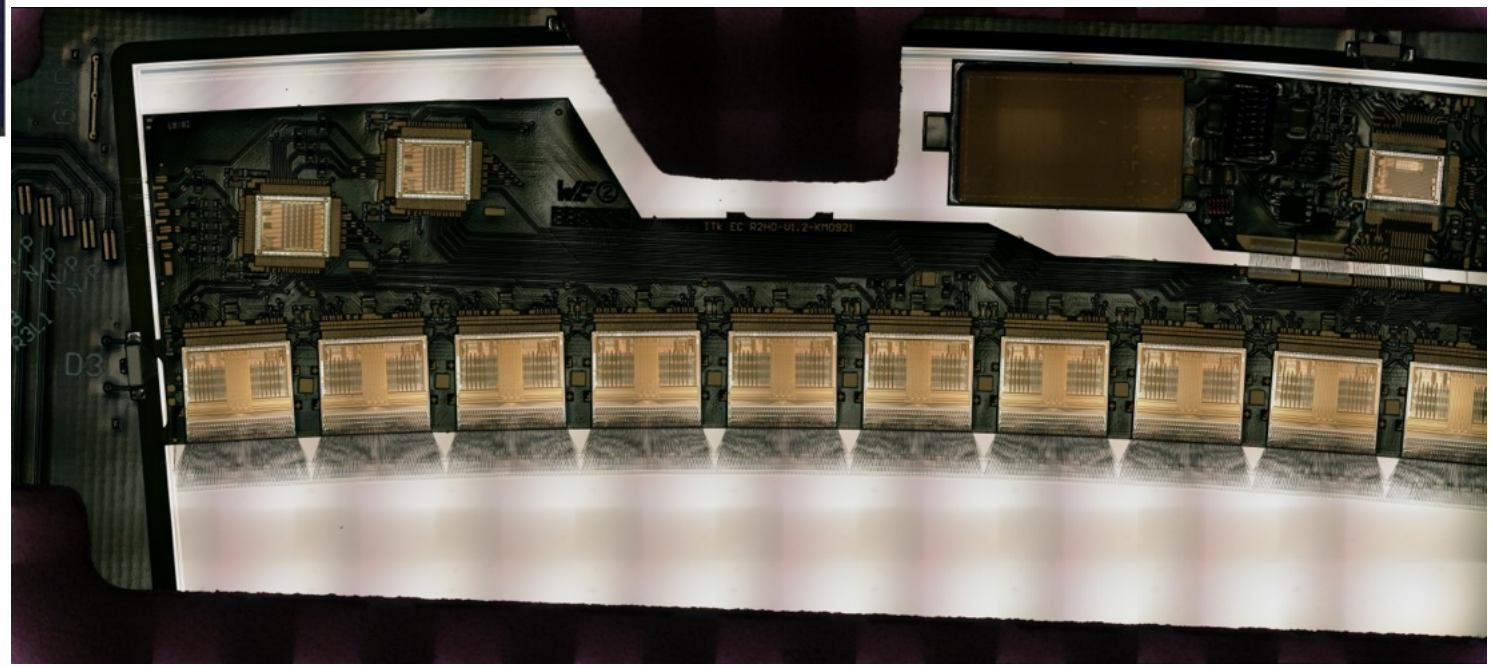


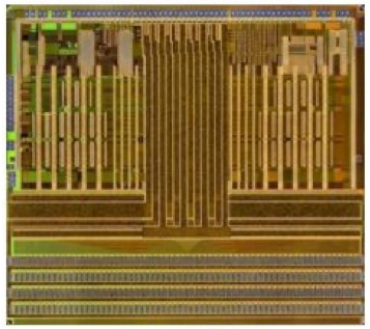
Electronics on a module

HCCStar



AMACStar

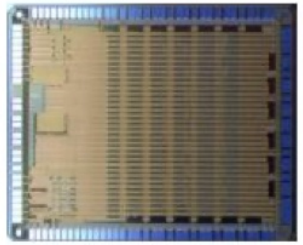




ABCStar

Electronics on a module

HCCStar



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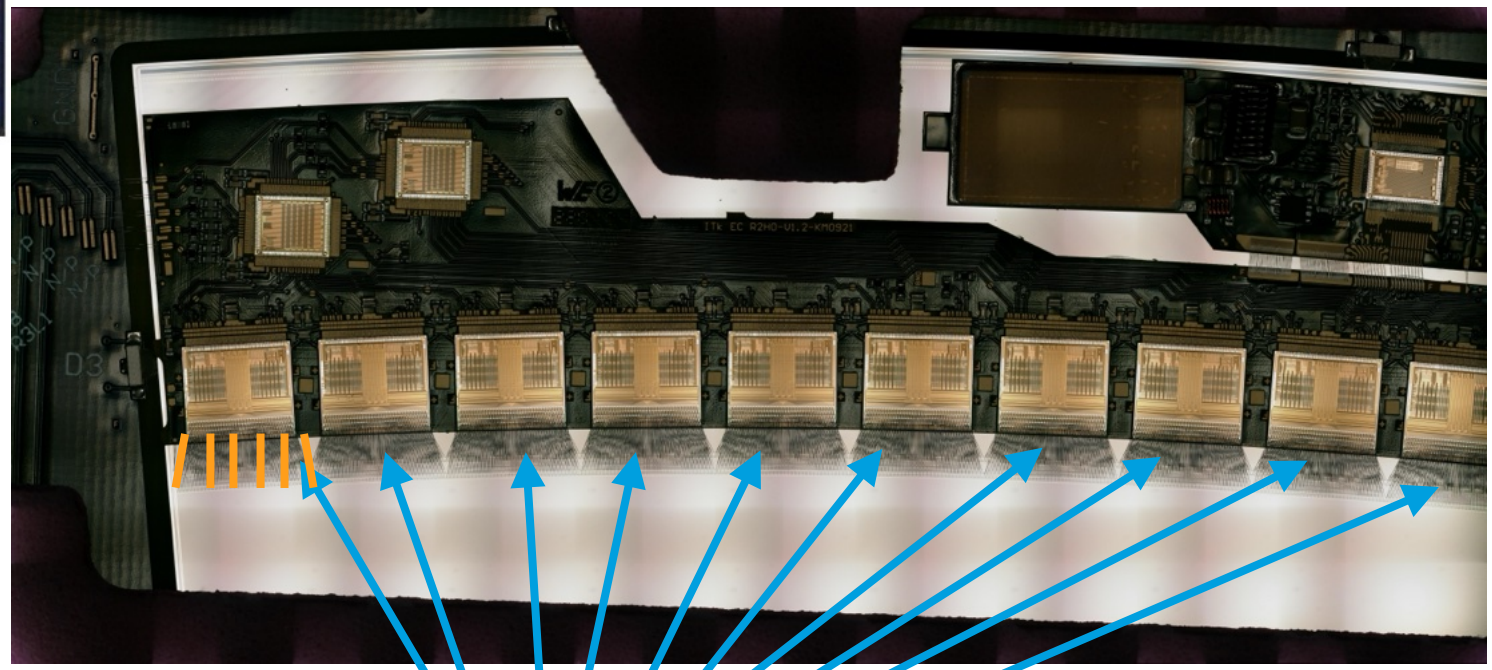
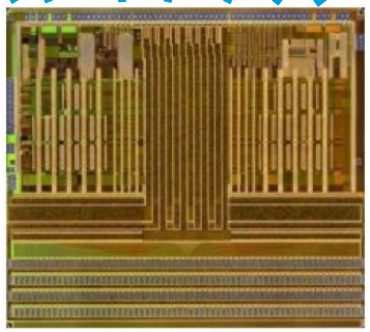


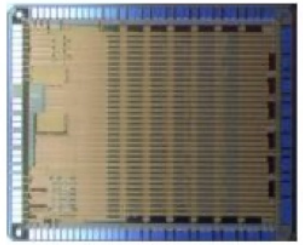


ABCStar

- Frontend chips, read out each channel
- Connected to strips with wirebonds

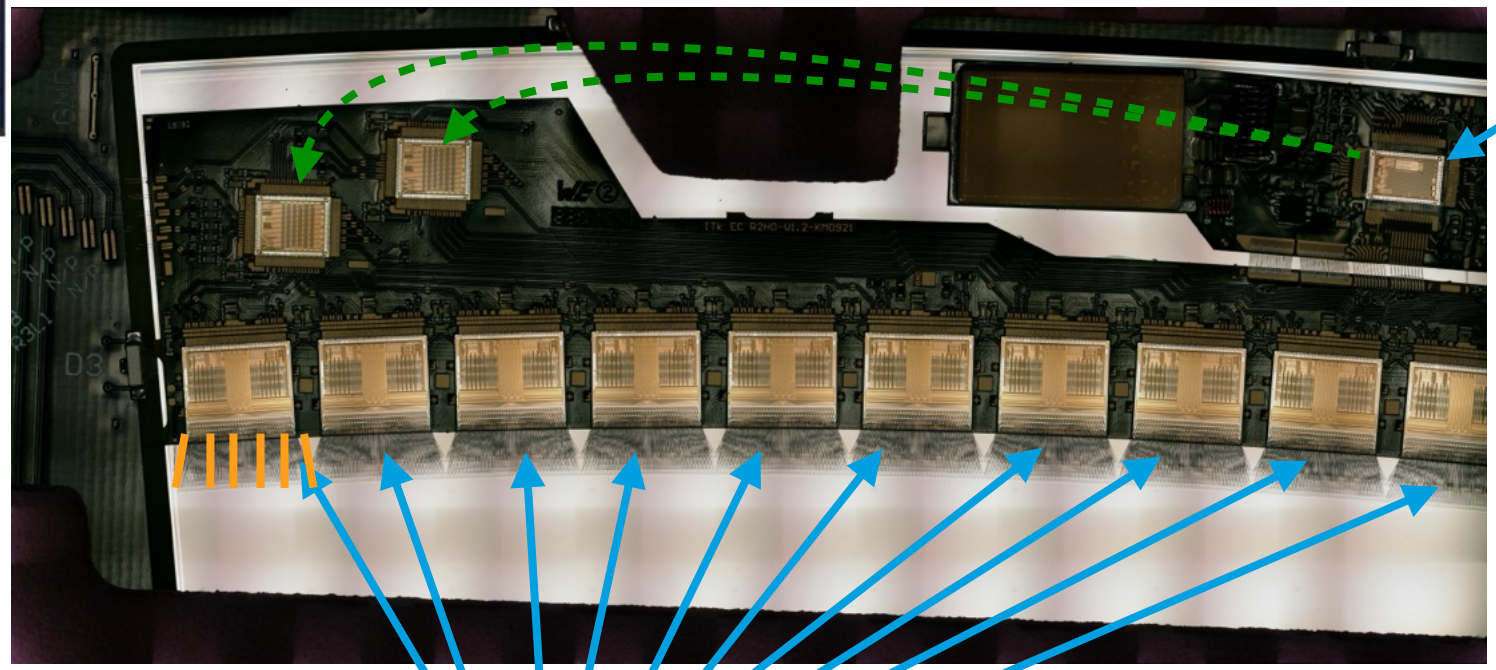
Electronics on a module

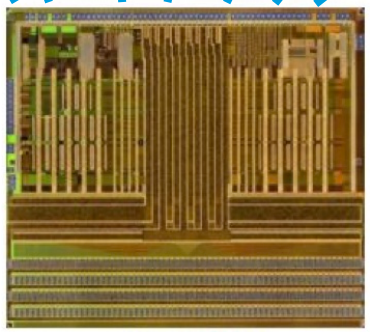
HCCStar



AMACStar

- Controls module
- Distributes power





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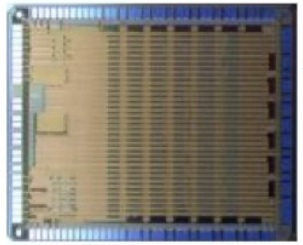
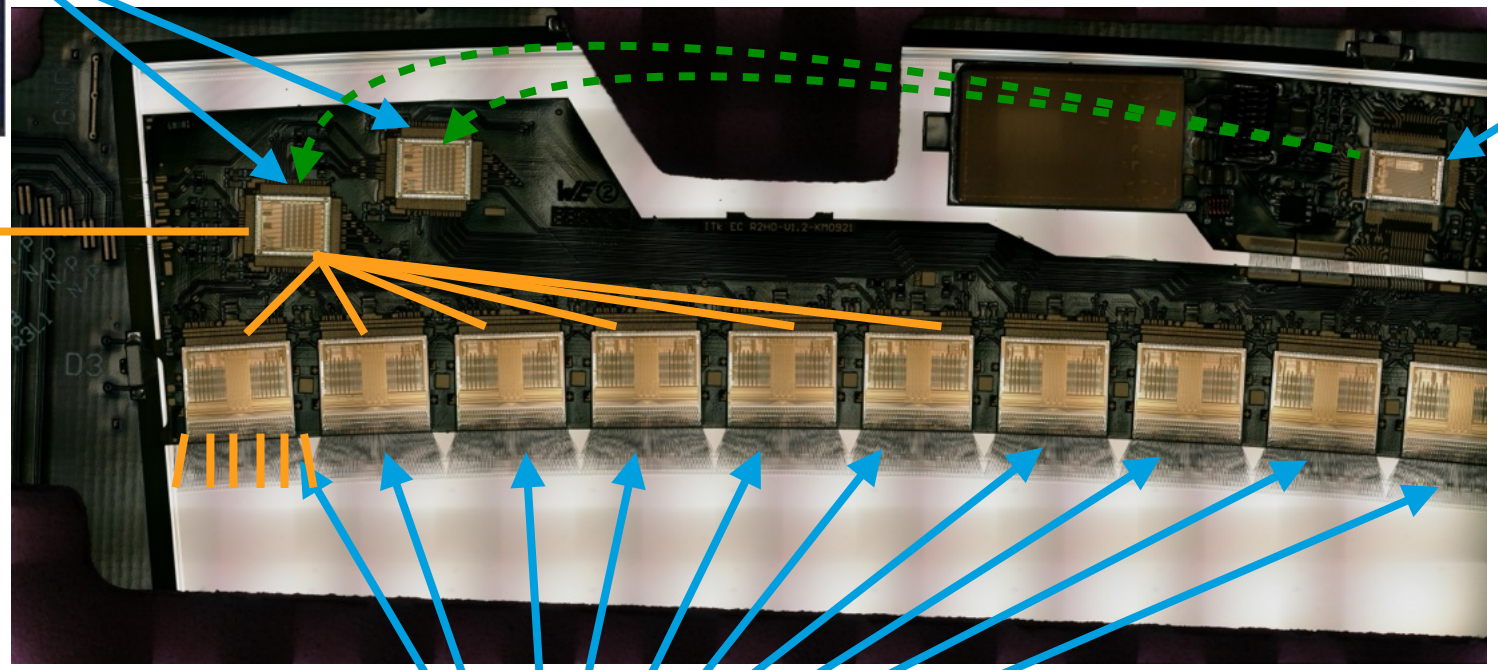
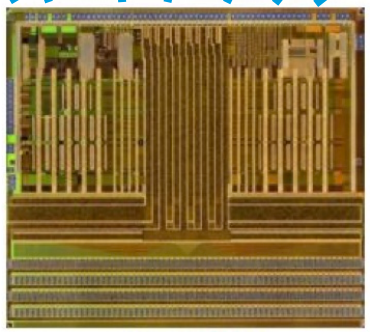


- Collects data from ABCs
- Sends them out for further processing

AMACStar

- Controls module
- Distributes power





ABCStar

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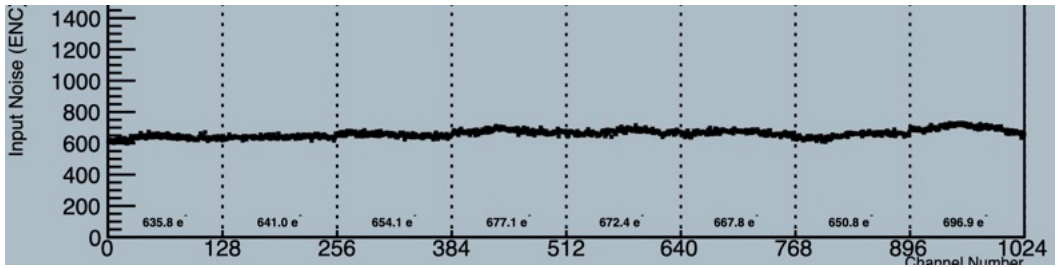
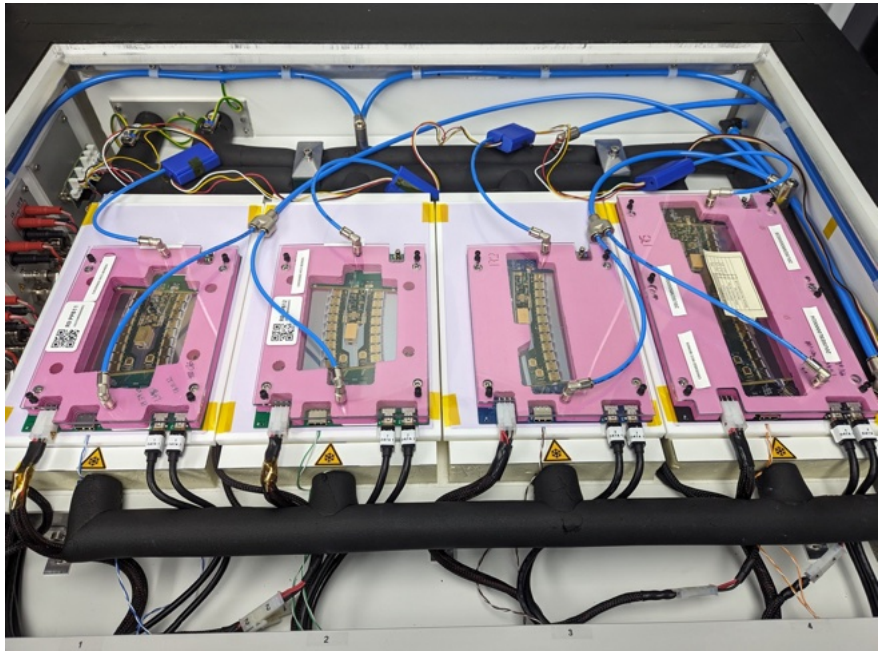
Module quality control

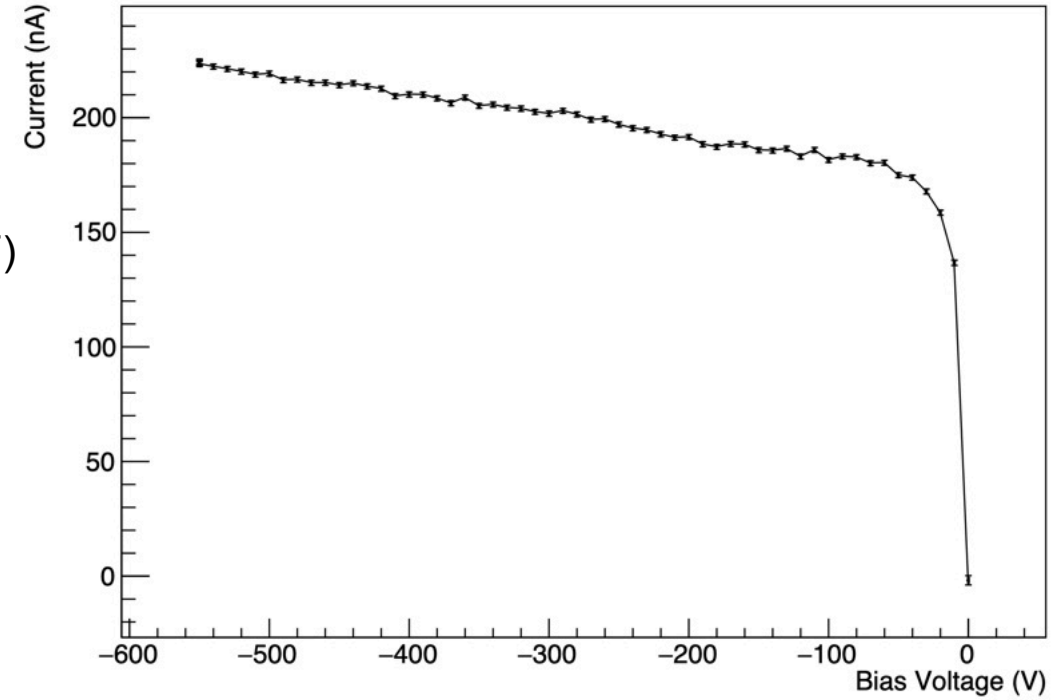
Thermal cycling

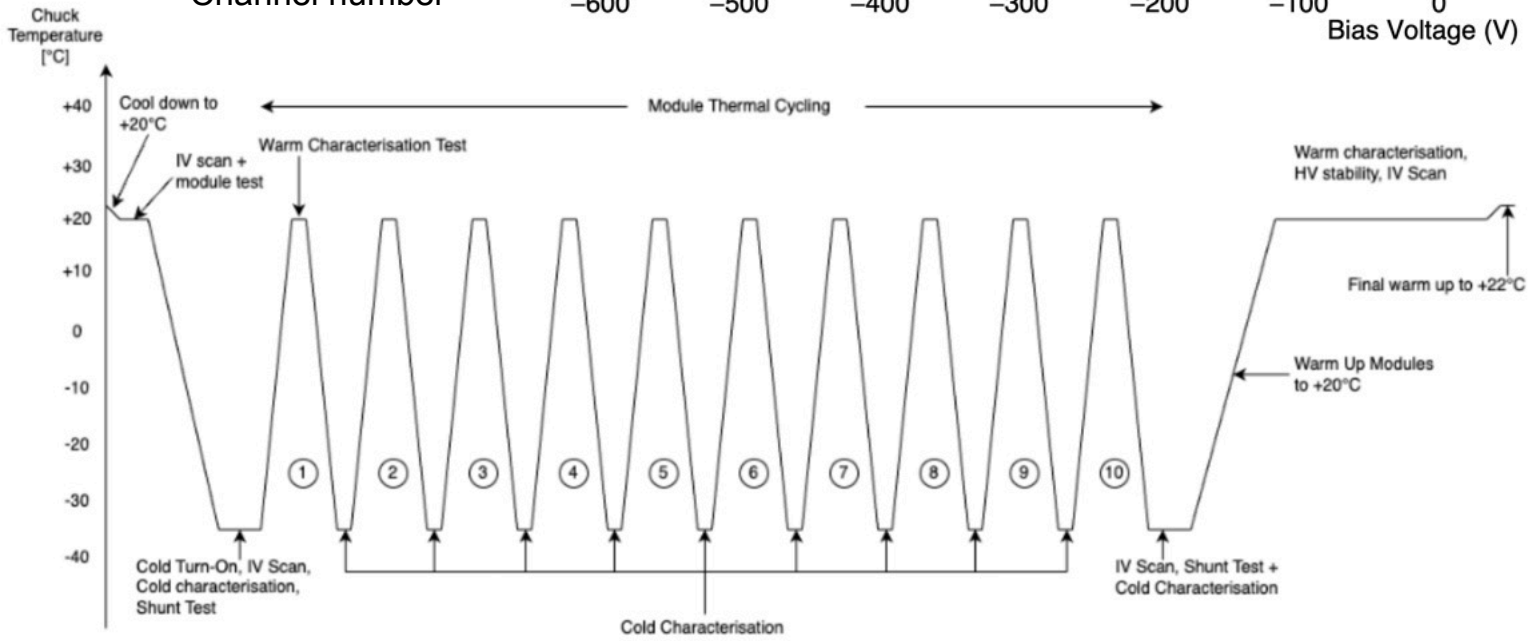
- Main test: electrical performance at $+20°C$ ($+68°F$) and $-35°C$ ($-31°F$)
- 10 times at both temperatures



Channel number



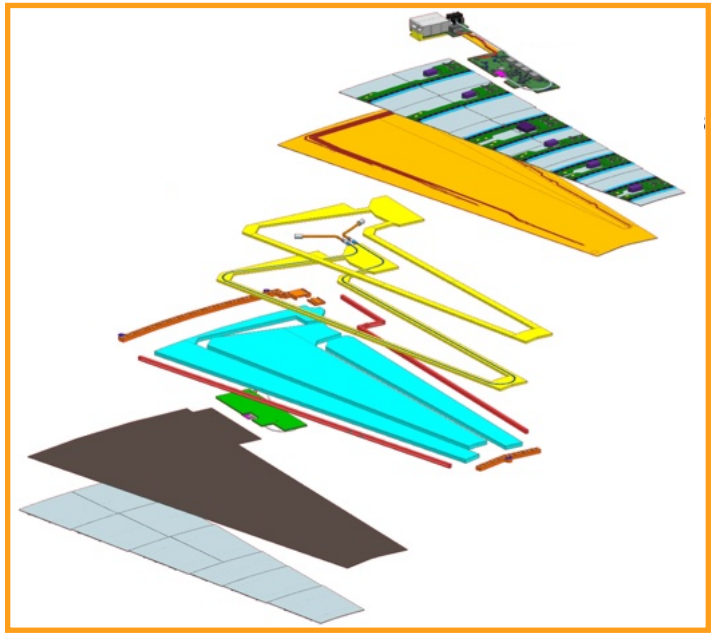


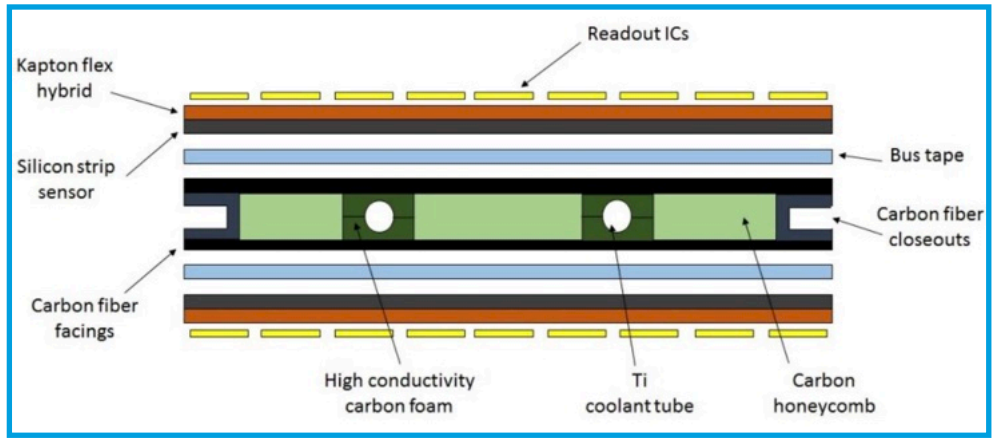


Module support structures

Staves and petals

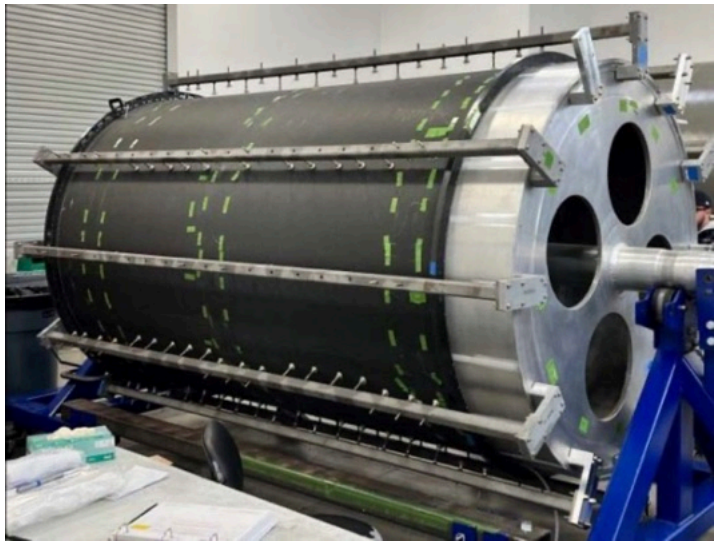
- Modules loaded onto both sides of staves and petals
- Carbon fibre based ⇒ low mass but mechanically stable
- Good thermal and electrical properties, integrated cooling
- “End of substructure” (EoS) cards: single crossing point between what happens inside and outside a stave/petal



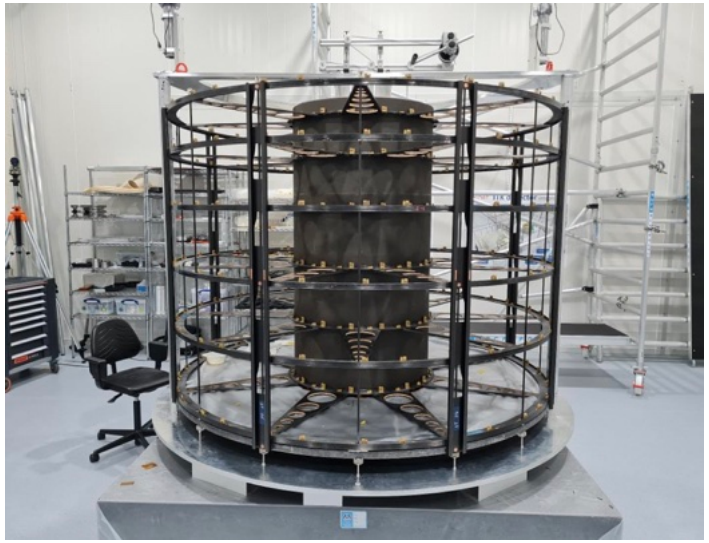


Barrel and endcap integration

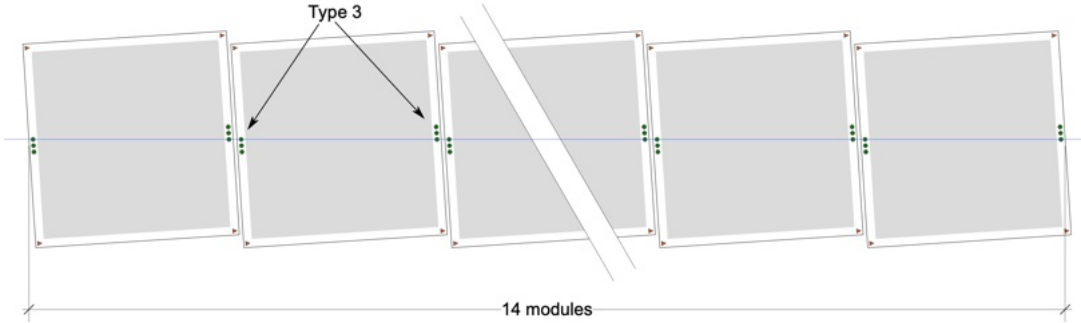
	Number of staves/petals	Number of modules
Barrel @CERN	392	10976
Endcaps @Nikhef & DESY	192*2	3456*2

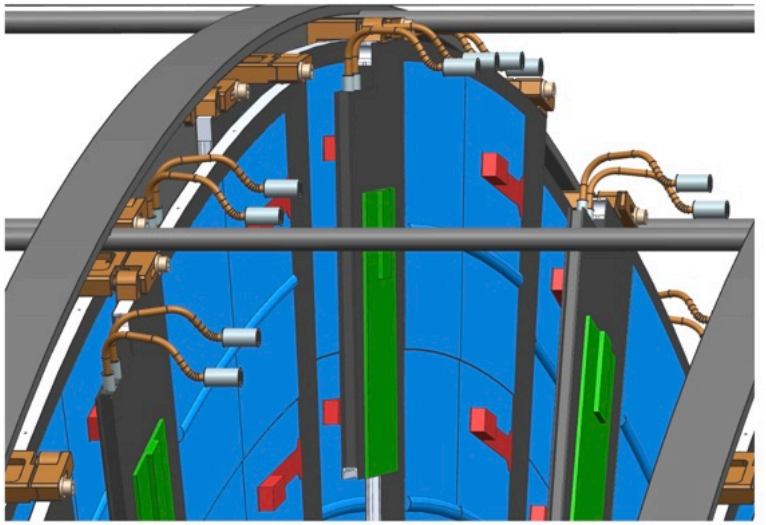


Outermost cylinder of barrel



Endcap structure

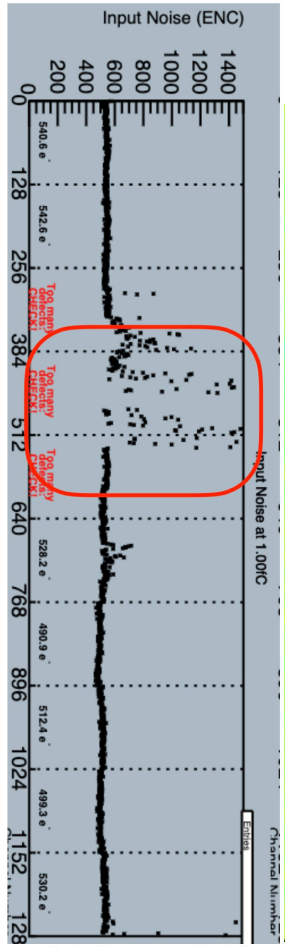


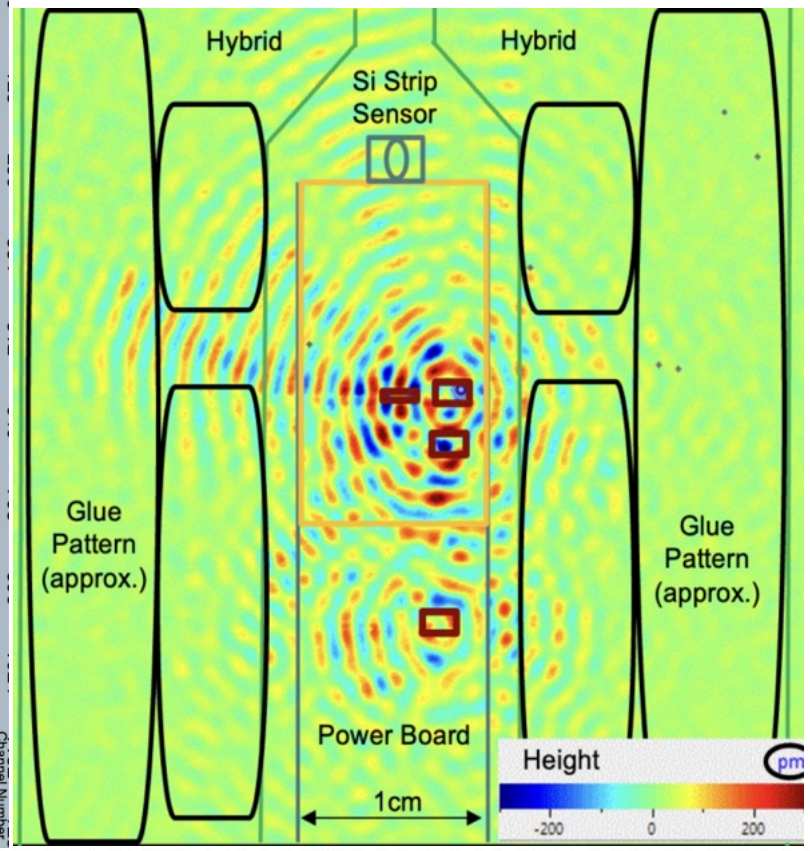


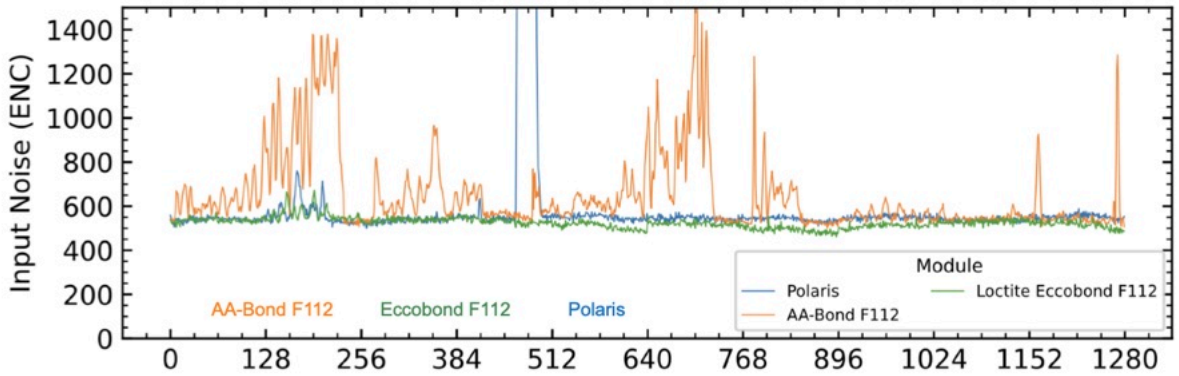
Stereo information by:
- tilting modules on staves
- tilting and overlapping petals in endcap discs

Module challenge: “cold noise”

- In 2022, technical problem with barrel modules found
- While working fine at room temperature, high noise spikes observed when testing modules at $-20°C$
- Caused by vibrations of capacitors on power board which travelled through glue into sensors and affected ABCs
- Mitigation strategy: change glue used on sensor
- After this change: no longer happens in long strip nor endcap modules
  - Residual noise on short strip modules, studies of mitigation strategies and performance implications ongoing

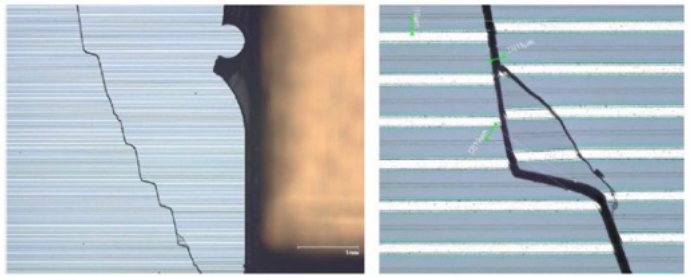


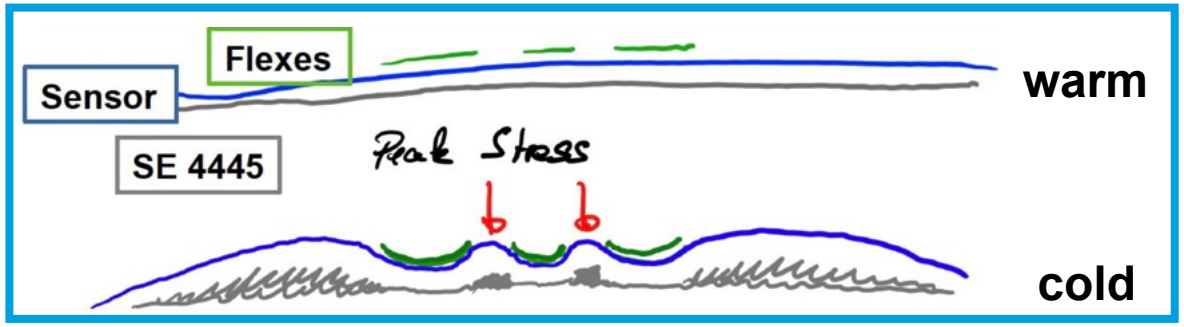




Module challenge: sensor cracking

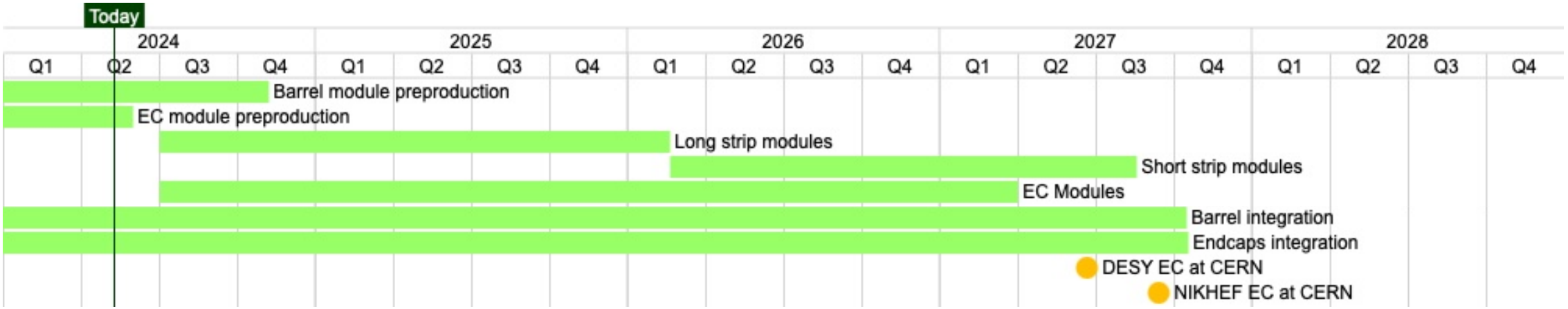
- Happens when cold testing fully loaded staves or petals
  - After cooling down to $-35°C$ and testing electrical performance, found early breakdown in modules
- Modules did not have this before ⇒ sensors got fractured after loading
- At cold temperatures, hybrid/power board flexes curl up more strongly than a sensor (CTE mismatch)
- Free sensor can follow, but stave/petal keeps it in place
- ⇒ Sensor gets locally bent, leading to mechanical stress
- Currently exploring mitigation strategies (not mutually exclusive):
  - Harder glue under sensor to prevent bending
  - Larger gaps between flexes to reduce curvature
  - Intermediate layer (“interposer”) between flexes and sensor (also helps with cold noise)





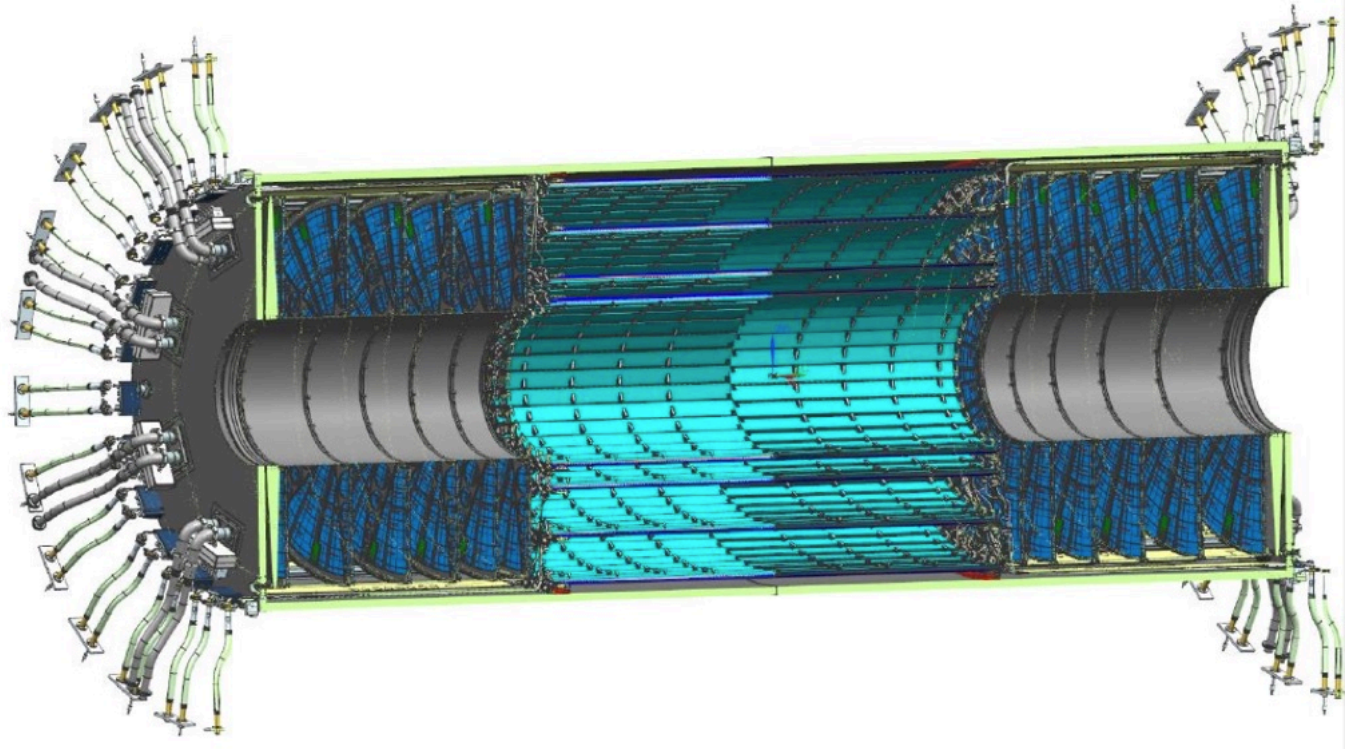
Construction status and timeline

- Production of sensors, chips and local/global support structures well underway
- Transitioning from preproduction to full production for modules
- Ready for integration of staves/petals into barrel/endcaps



Conclusion

- Currently building fully silicon-based tracking detector for ATLAS during HL-LHC phase
- Lighter, faster, more precise and more radiation resistant than current Inner Detector
- Production of different components well underway, preparing for integration
- While technical problems were found during pre-production, promising mitigation techniques are identified
- Mass production phase starting soon!



Backup