# The ATLAS ITK Upgrade for the HL-LHC

(with a focus on the Strip detector)

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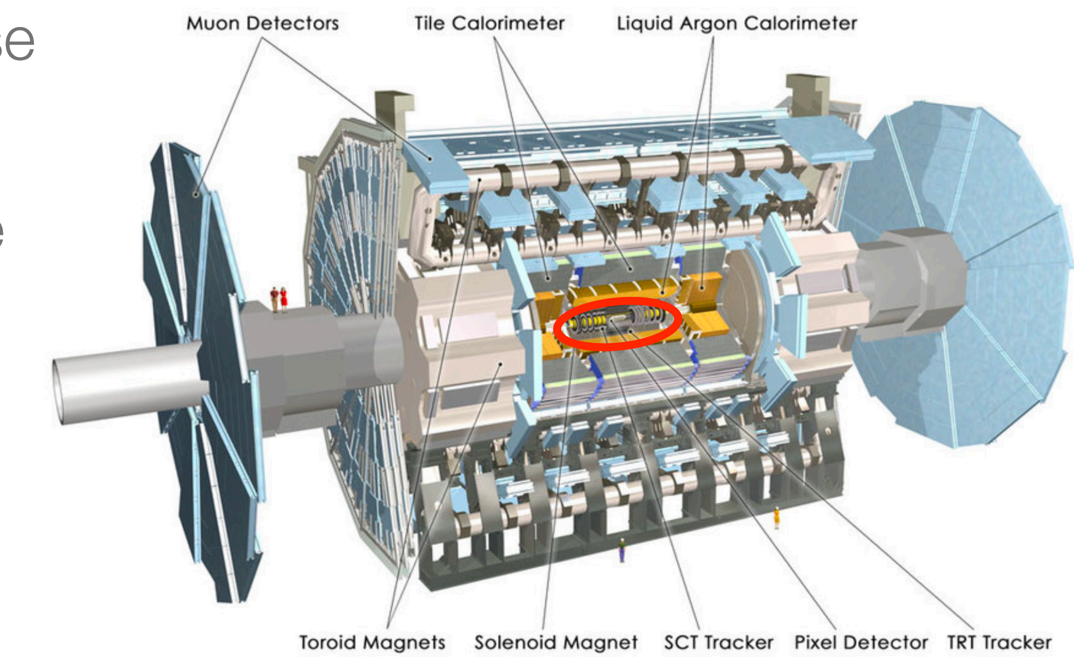
ATLAS ITk

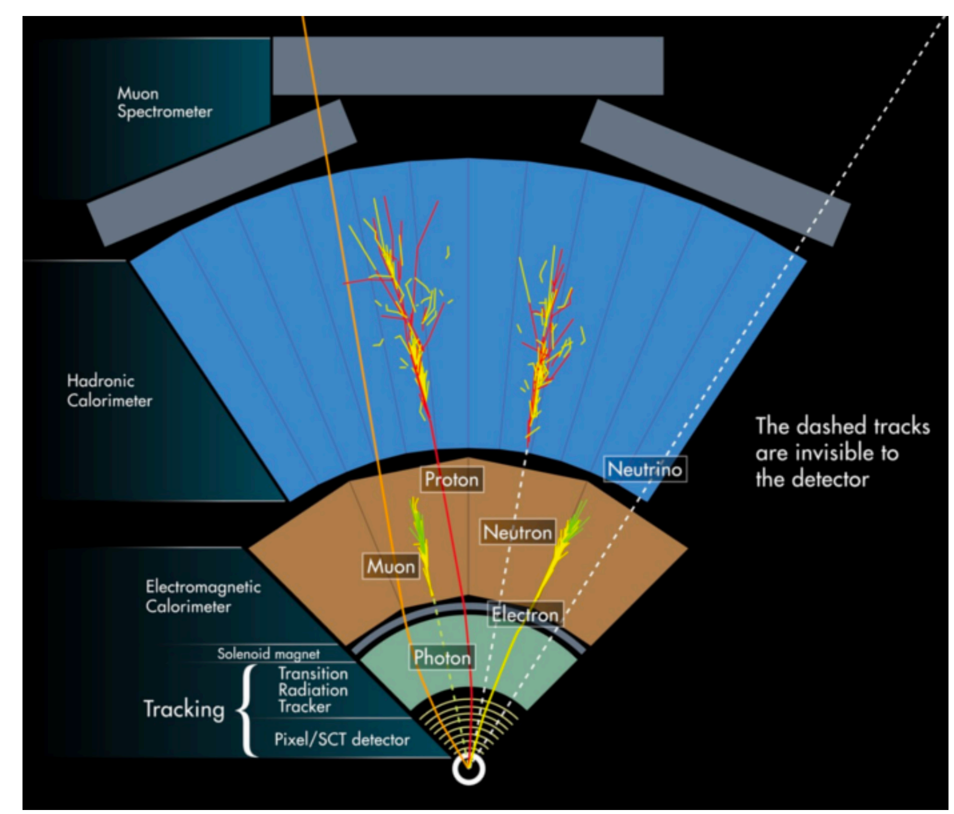
# Outline

- A bit of background on silicon tracking detectors
- The HL-LHC upgrade
- The motivation behind building a new inner tracker
- The ITk layout and design
- The members involved in the project and Canada's role
- How to actually build the detector components
- Outlook / where are we now?

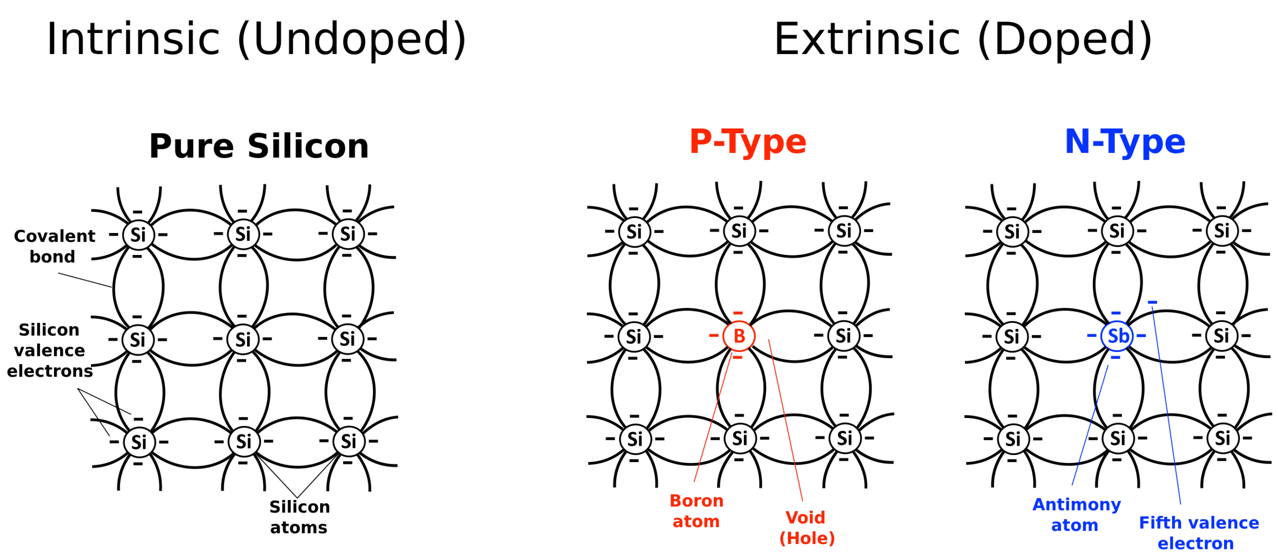
# Silicon trackers in high energy physics

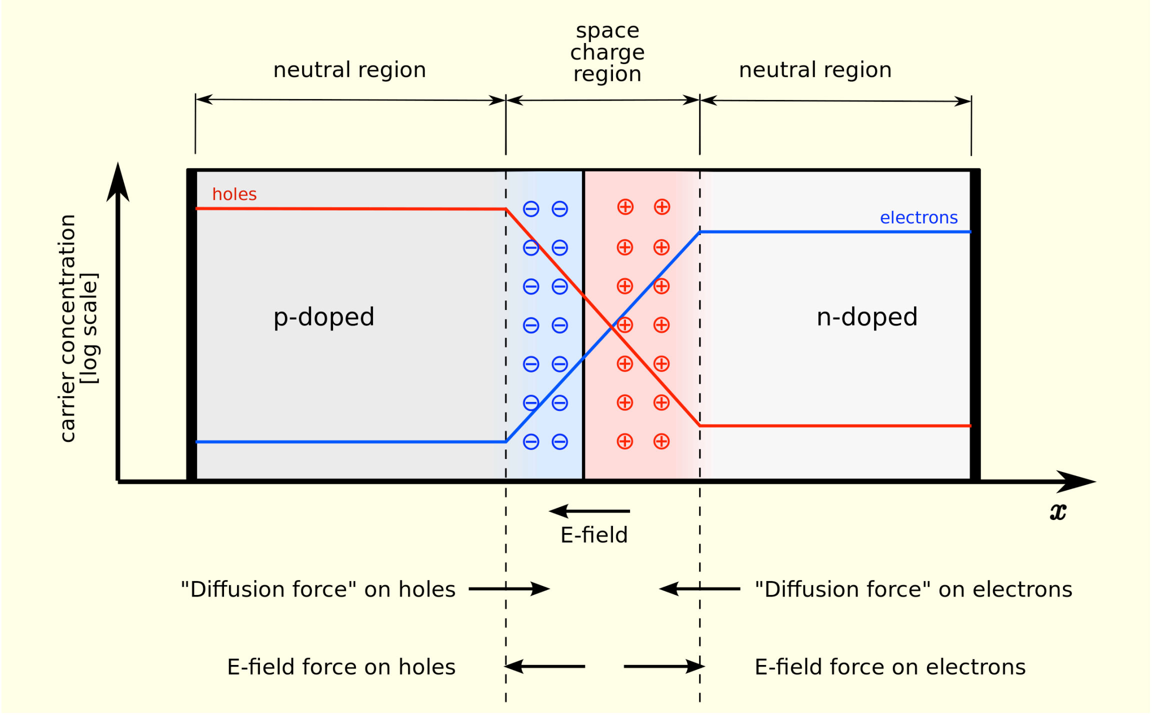
- Trackers are a standard component of general-purpose detectors like ATLAS
- They are placed closest to the interaction point, where the density of particles is the greatest
  - As particles move away from the interaction point, the density of tracks decreases => pixel detector surrounding strip detector
- Trackers provide accurate reconstruction of charged particle tracks
  - Identify charged particles from the primary vertex
  - Identify secondary vertices (pileup events)
  - Identify processes such as photon conversions
  - Also provide measurement of charged particle's momentum, since the tracker is embedded in a magnetic field



# How does a silicon tracker work?

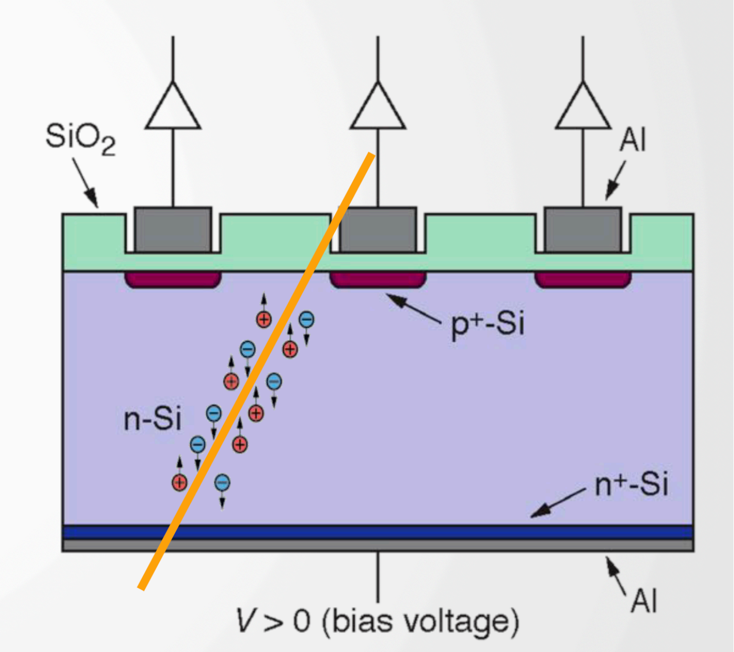


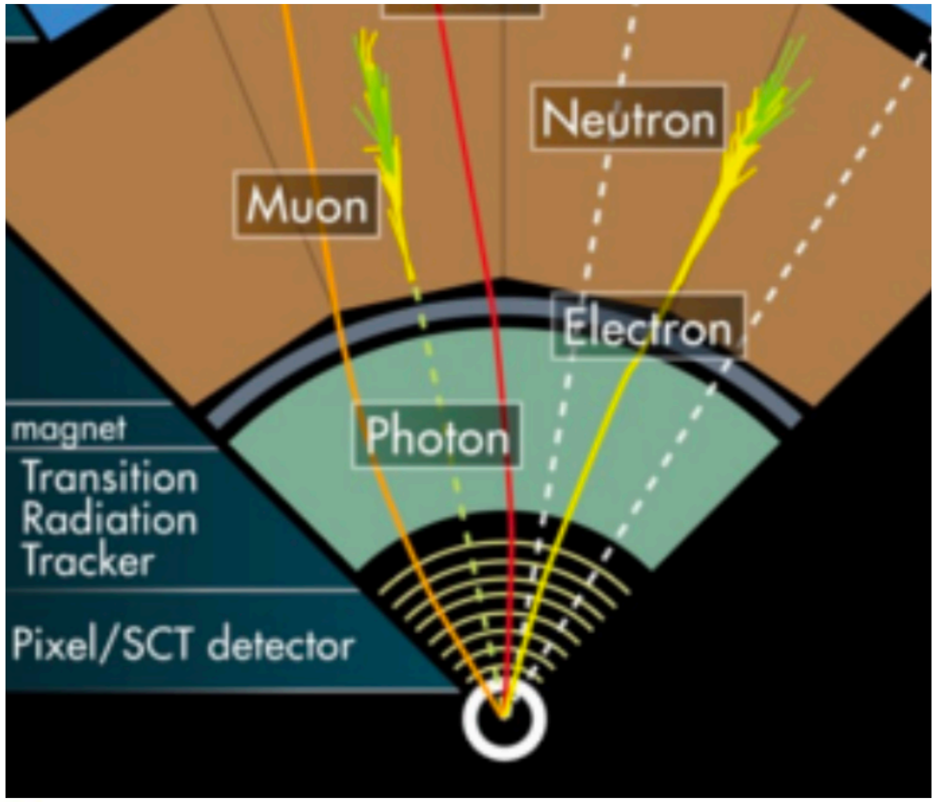




- Silicon detectors are essentially ionisation chambers formed by p-n junctions
  - Silicon on either side of the junction is *doped* so that on one side, atoms with 5 valence electrons are added which donate electrons (n-type), and on the other, atoms with 3 valence electrons are added which form holes (p-type)
  - Joining these together causes diffusion of the charges to the other side of the junction, forming a depletion region
  - Reverse-biasing the junction causes the depletion region to grow

Diagram retrieved from lecture given by Robert Shoefbeck (link)

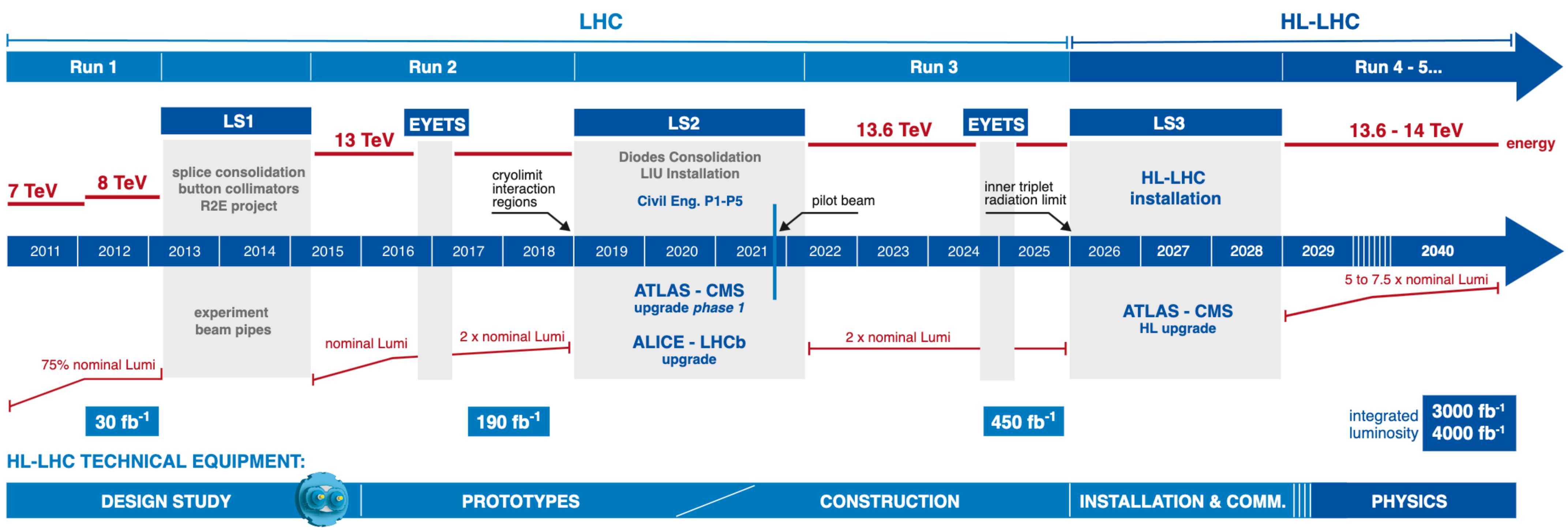
# How does a silicon tracker work?




- The depletion region is the sensitive region of the detector
- Charged particles passing through form electron-hole pairs which drift in the electric field, inducing a current
- The detector can be made into pixels or strips by segmenting one side of the junction
- The ATLAS tracker is embedded in a magnetic field, which bends charged particles in order to measure their momentum
- A “hit” is recorded whenever a current is induced in a particular pixel or strip of the detector
- Tracks are built out of hits in the inner detector using specialised fitting algorithms

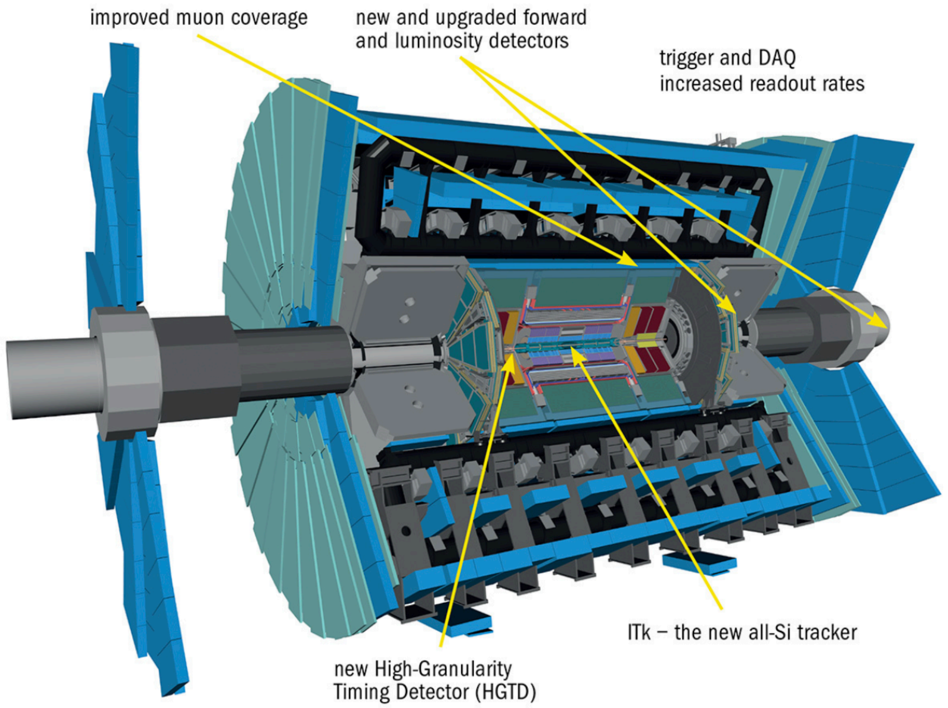
# The HL-LHC upgrade



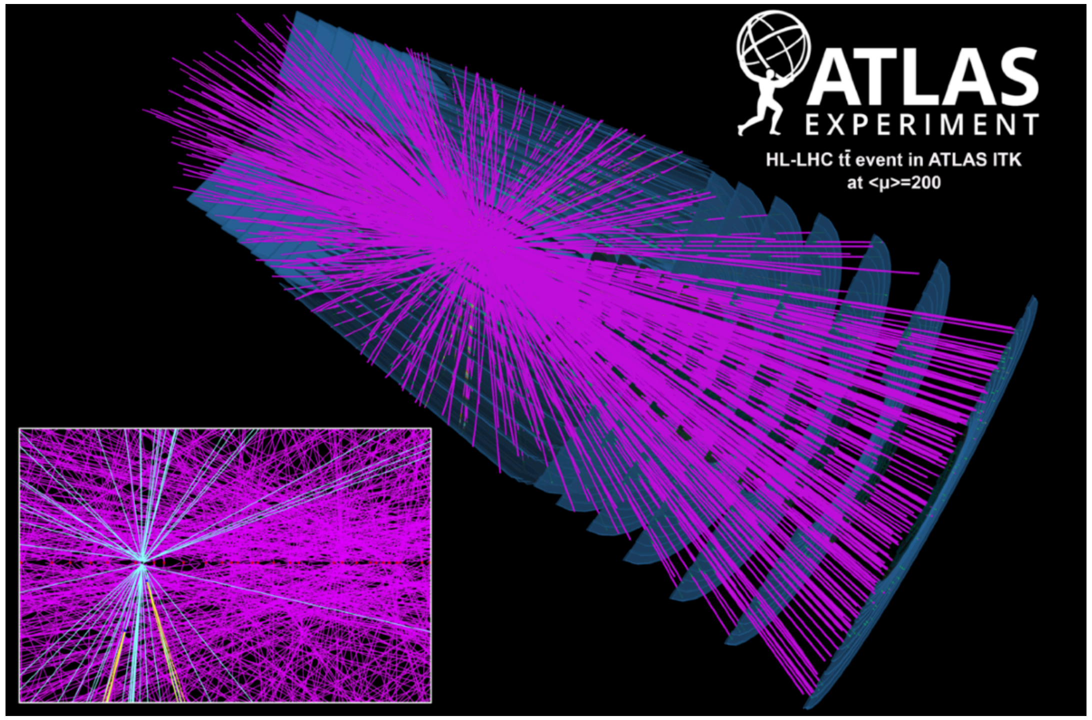

- The High Luminosity* (HL) LHC upgrade will increase the total number of collisions of the collider by a factor of ~10, providing an order of magnitude more data starting in 2029
- This will allow us to measure the Standard Model (SM) in greater detail
  - Measure processes which are not currently accessible by the LHC (due to their small cross sections), for example:
    - Extending the mass reach for exotic searches
    - Precision Higgs boson measurements, including rare decays

# Why do we need to upgrade ATLAS?

- Several components of the ATLAS detector will need to be upgraded to cope with the increased number of interactions expected from the collider (up to 200 simultaneous proton-proton collisions!)

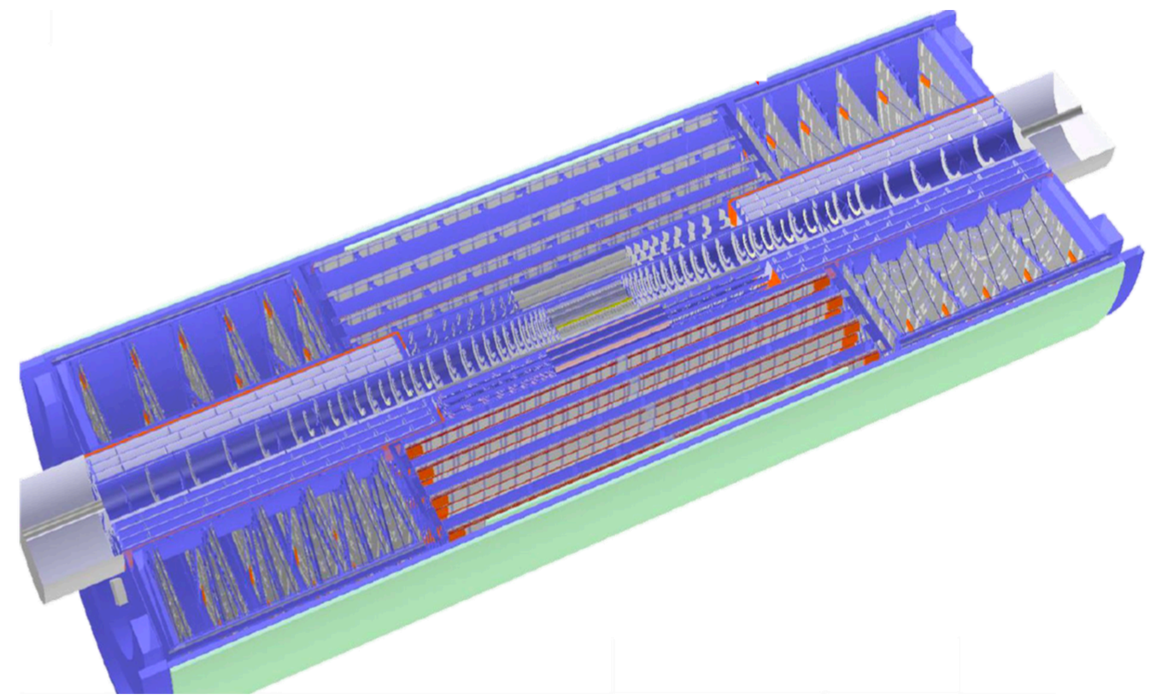



- In particular, the inner detector will no longer function in this high-radiation environment, and so will be completely replaced by a new all-silicon tracker (the ITk)



# The new all-silicon ATLAS inner tracker (ITk)

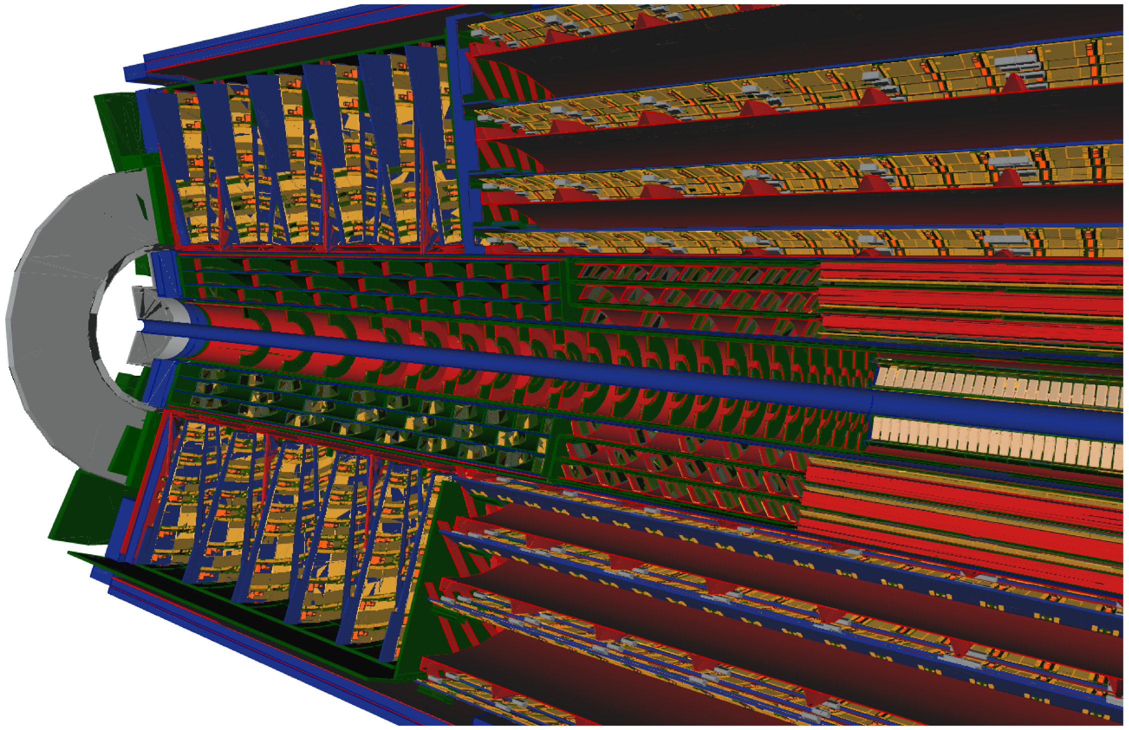
- The new inner detector will be a fully silicon tracker (pixel and strips) and is designed to have:
  - Higher granularity
  - Increased radiation hardness
  - Upgraded readout electronics

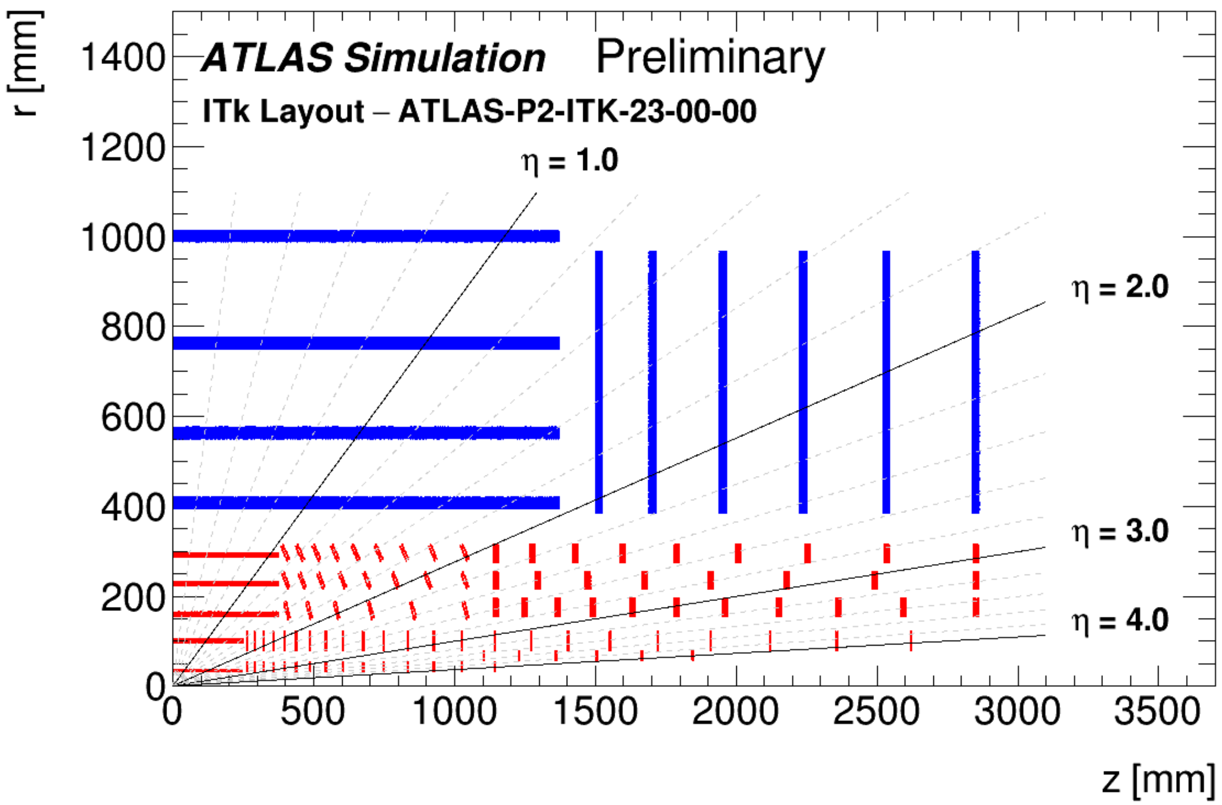


  - Extended coverage in the forward region to increase sensitivity to certain physics processes

# The ITK layout

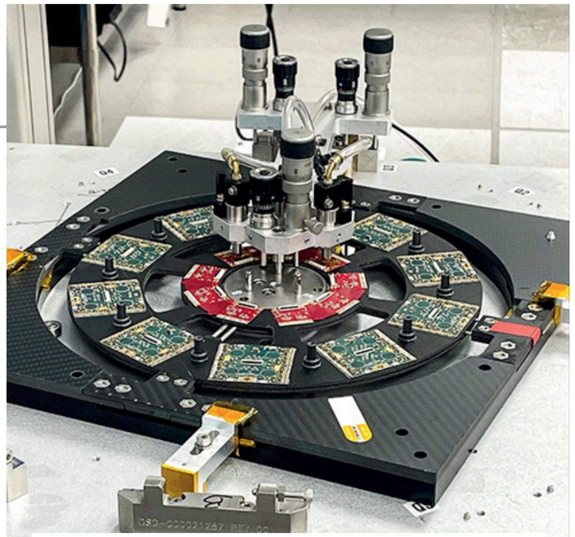
- The ATLAS Inner Tracker (ITk) upgrade will consist of a pixel detector surrounded by a strip detector



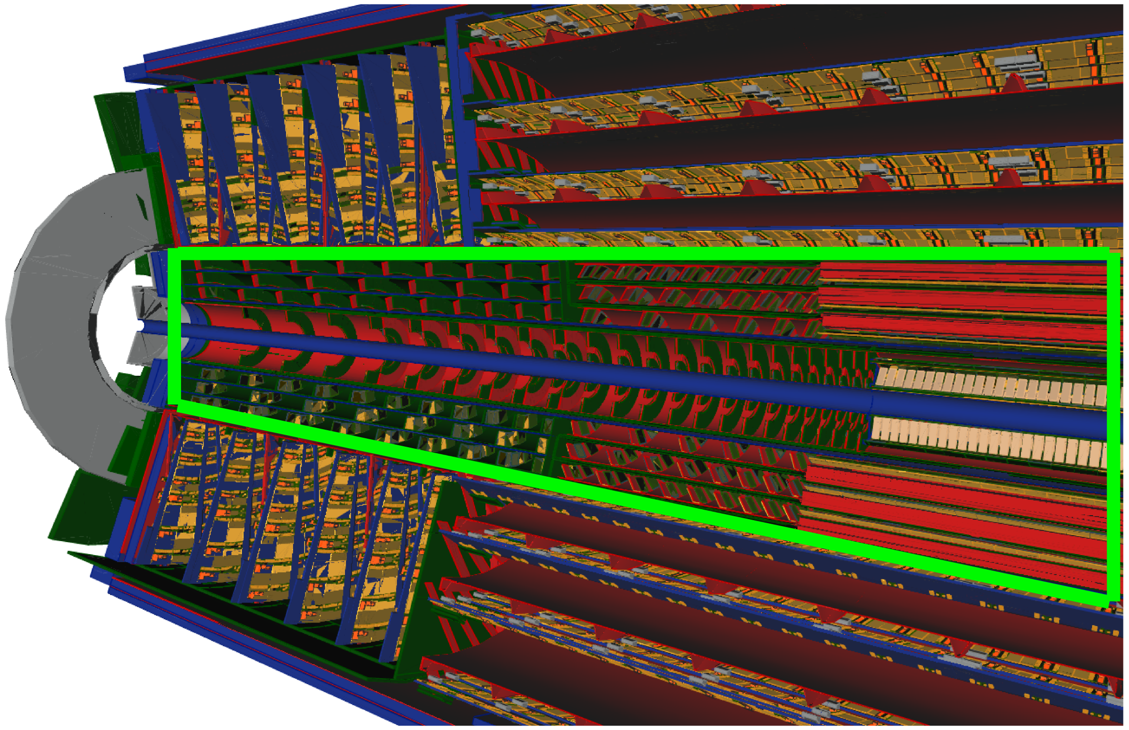


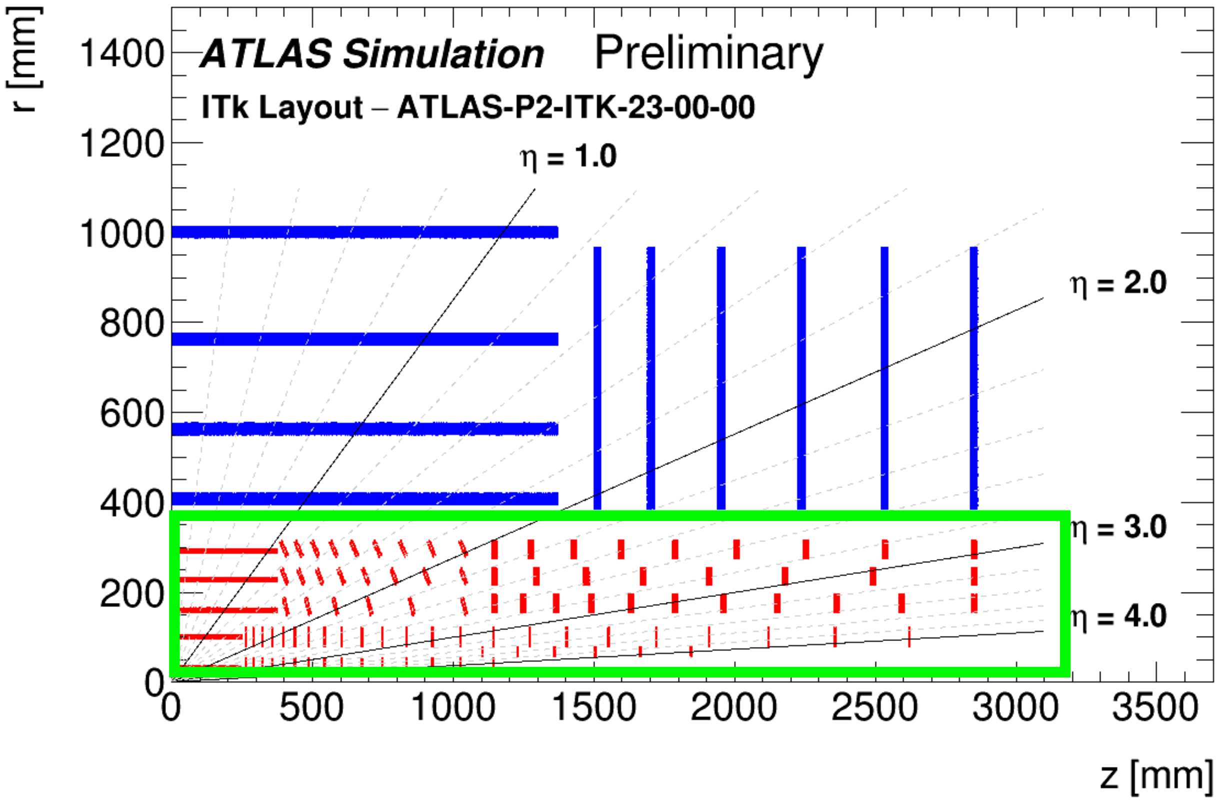
# The ITK layout

- The pixel detector will consist of inner and outer layers of "staves" and "rings", with 60x the number of channels compared to the current inner pixel detector



Prototype pixel end-cap ring

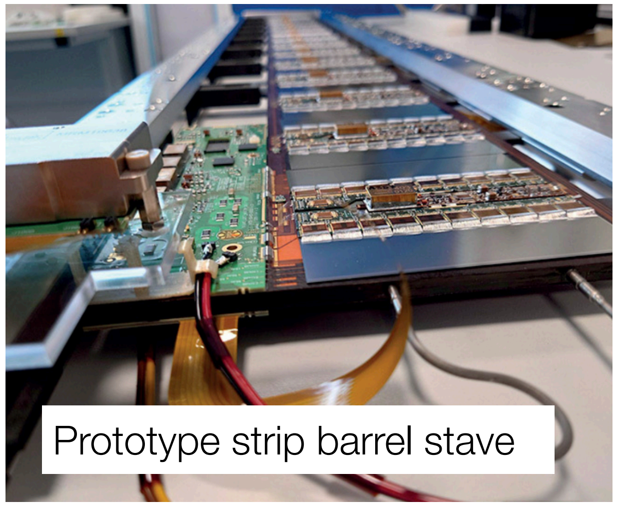




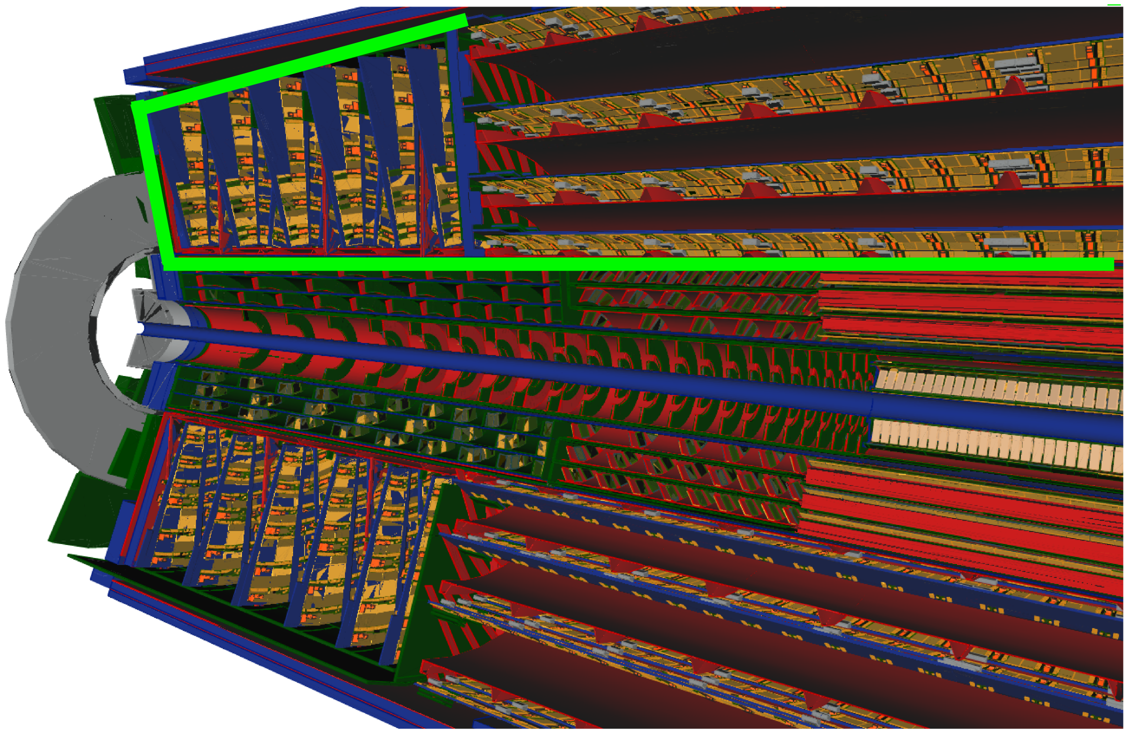

*The pixels will cover an area of 13m² with more than 5 billion readout channels!*

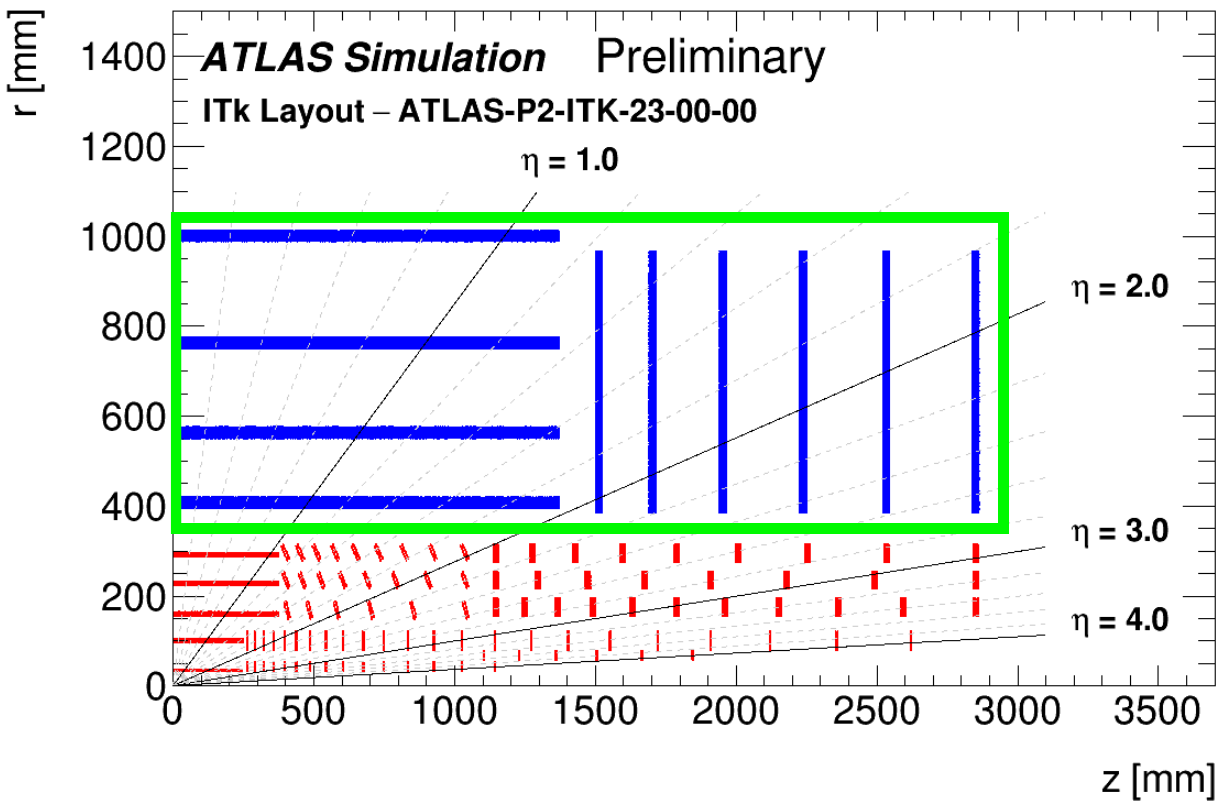
# The ITK layout

- The strip detector will consist of a barrel region built out of staves, and an end-cap region built out of petals, with 10x the number of channels compared to the current inner strip detector



Prototype strip barrel stave

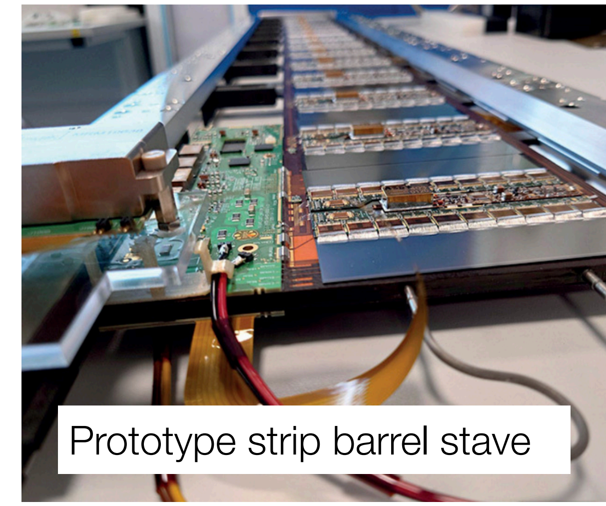




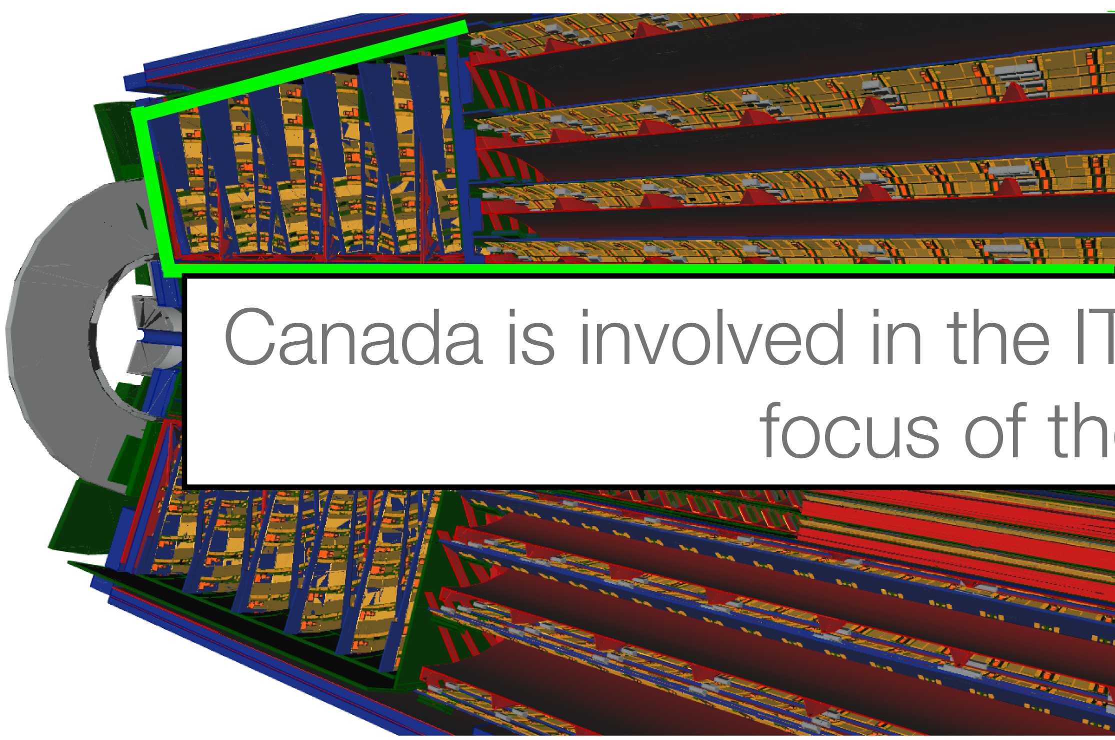

*The strips will cover an area of 160m² with more than 60 million readout channels!*

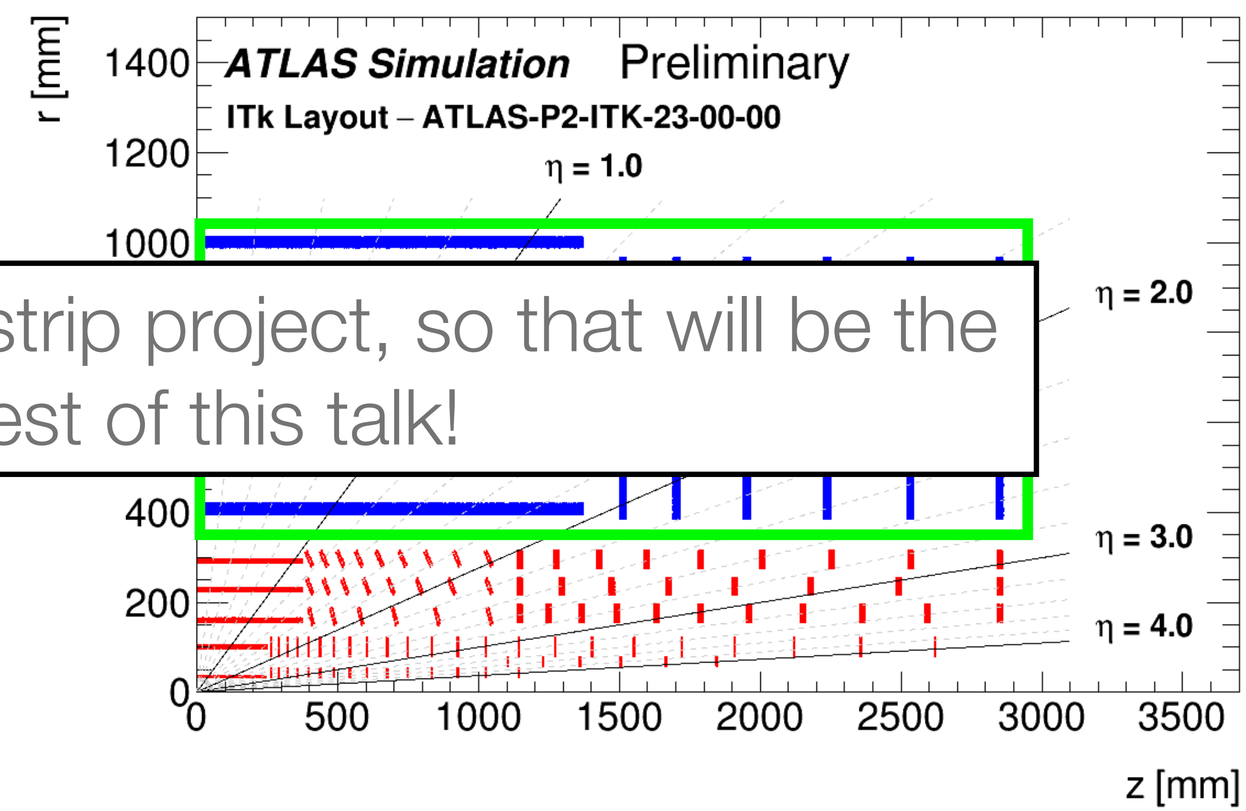
# The ITK layout

- The strip detector will consist of a barrel region built out of staves, and an end-cap region built out of petals, with 10x the number of channels compared to the current inner strip detector



Prototype strip barrel stave



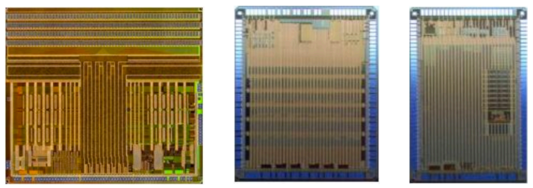



Canada is involved in the ITk strip project, so that will be the focus of the rest of this talk!

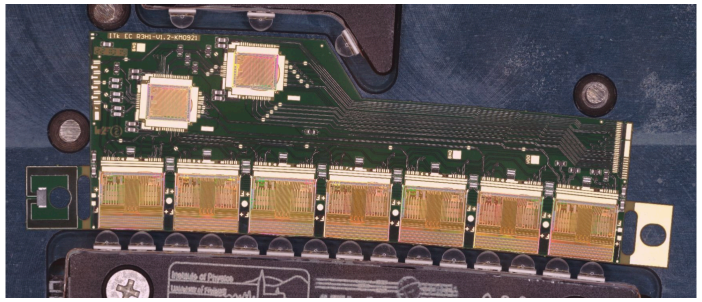
*The strips will cover an area of 160m² with more than 60 million readout channels!*

# Elements that make up a strip detector

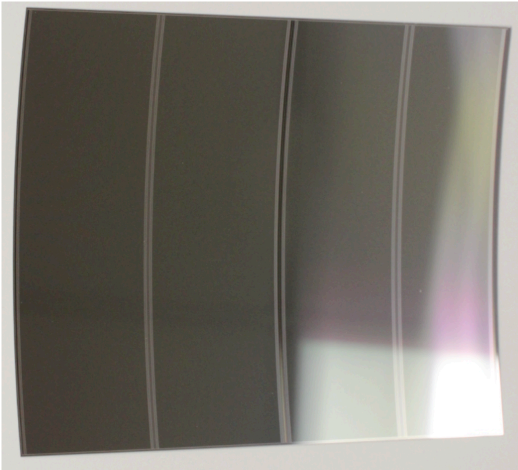
## ASICs
readout chips



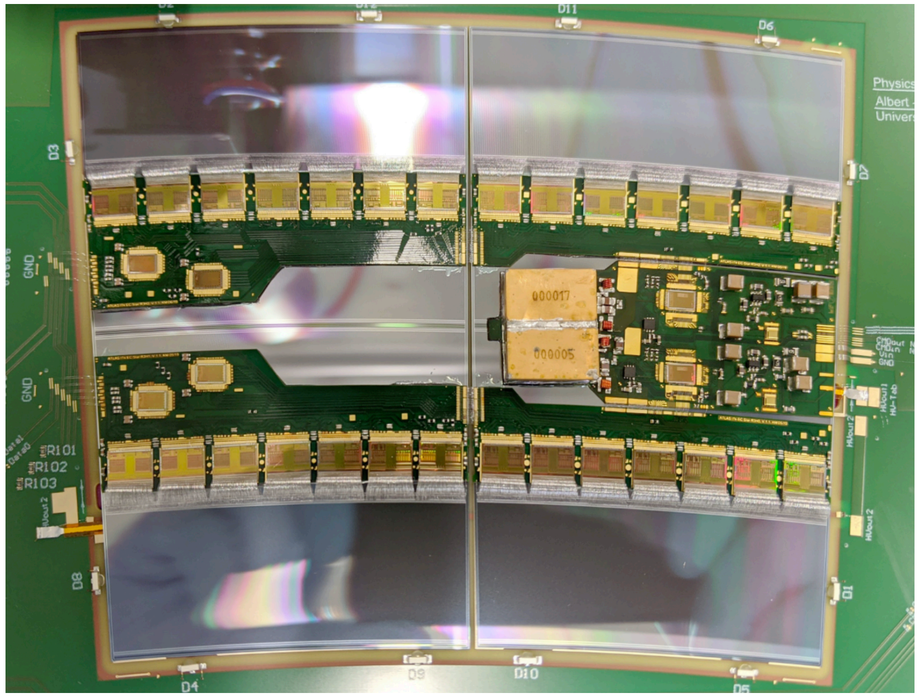
## Hybrids
readout circuits



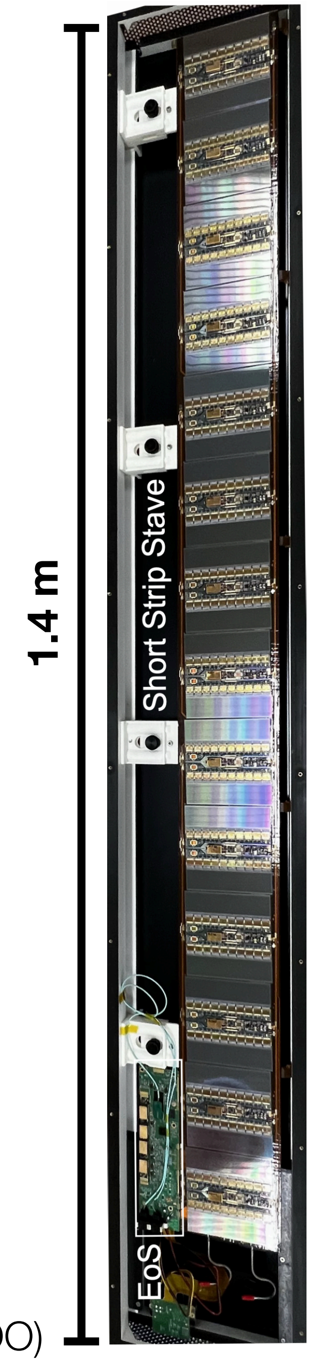
## Sensors
active area

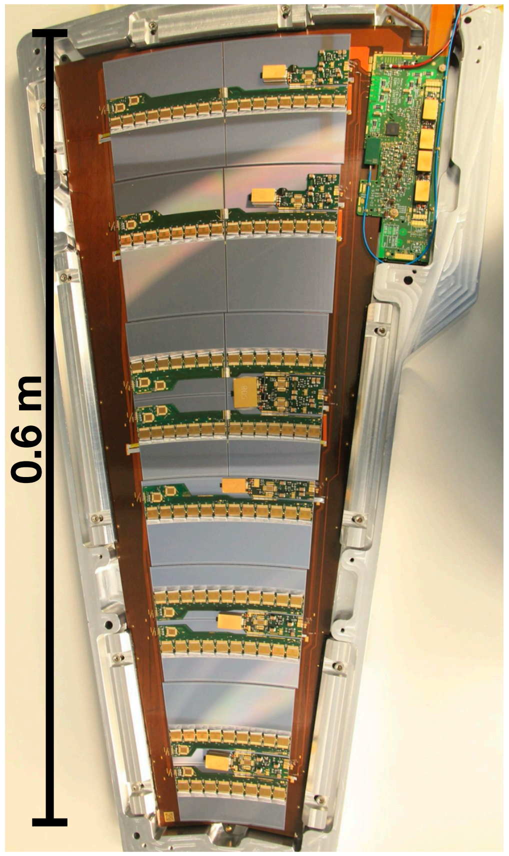


## Modules
single elements making up the detector



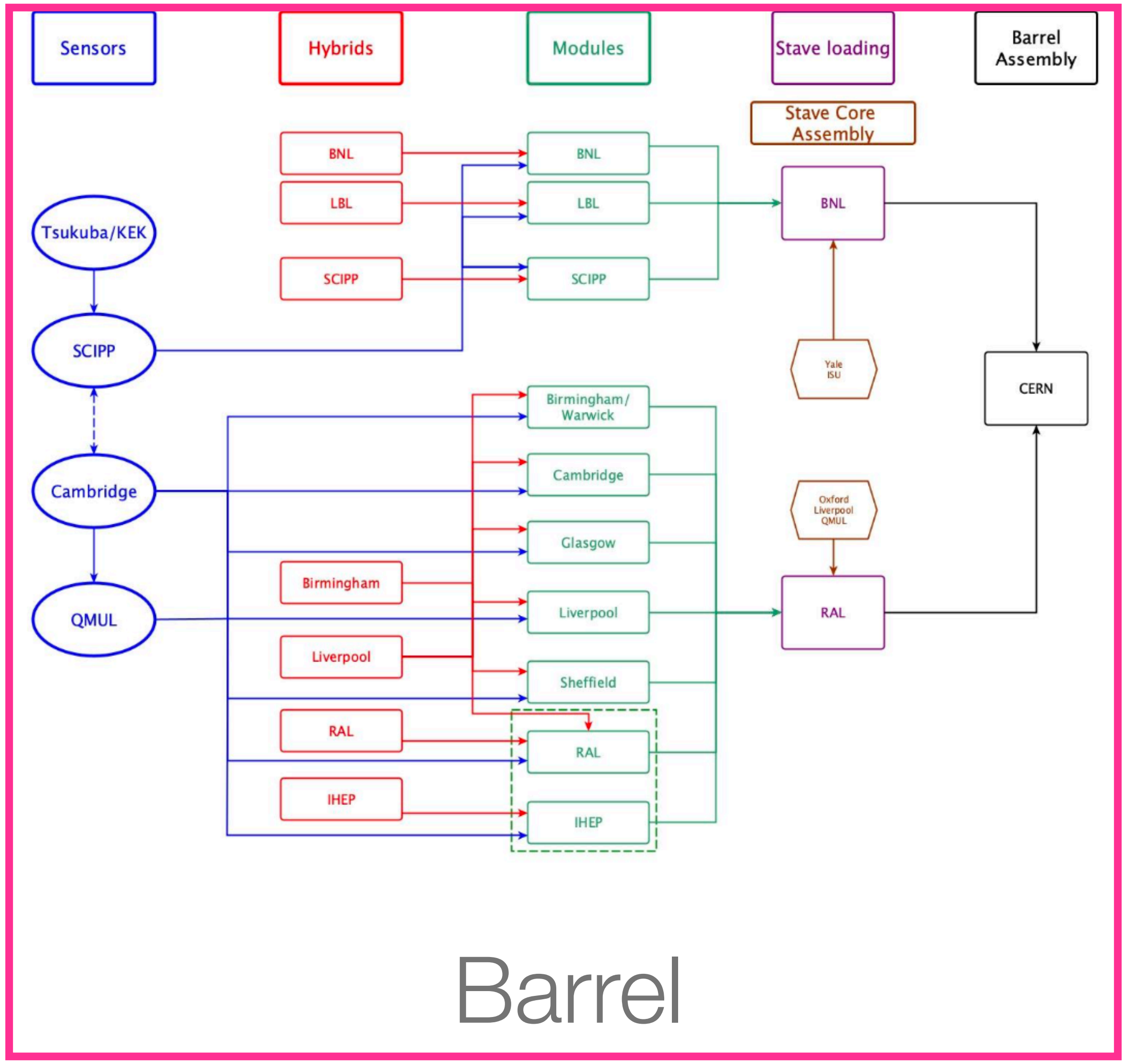
## Staves/Petals
larger structures

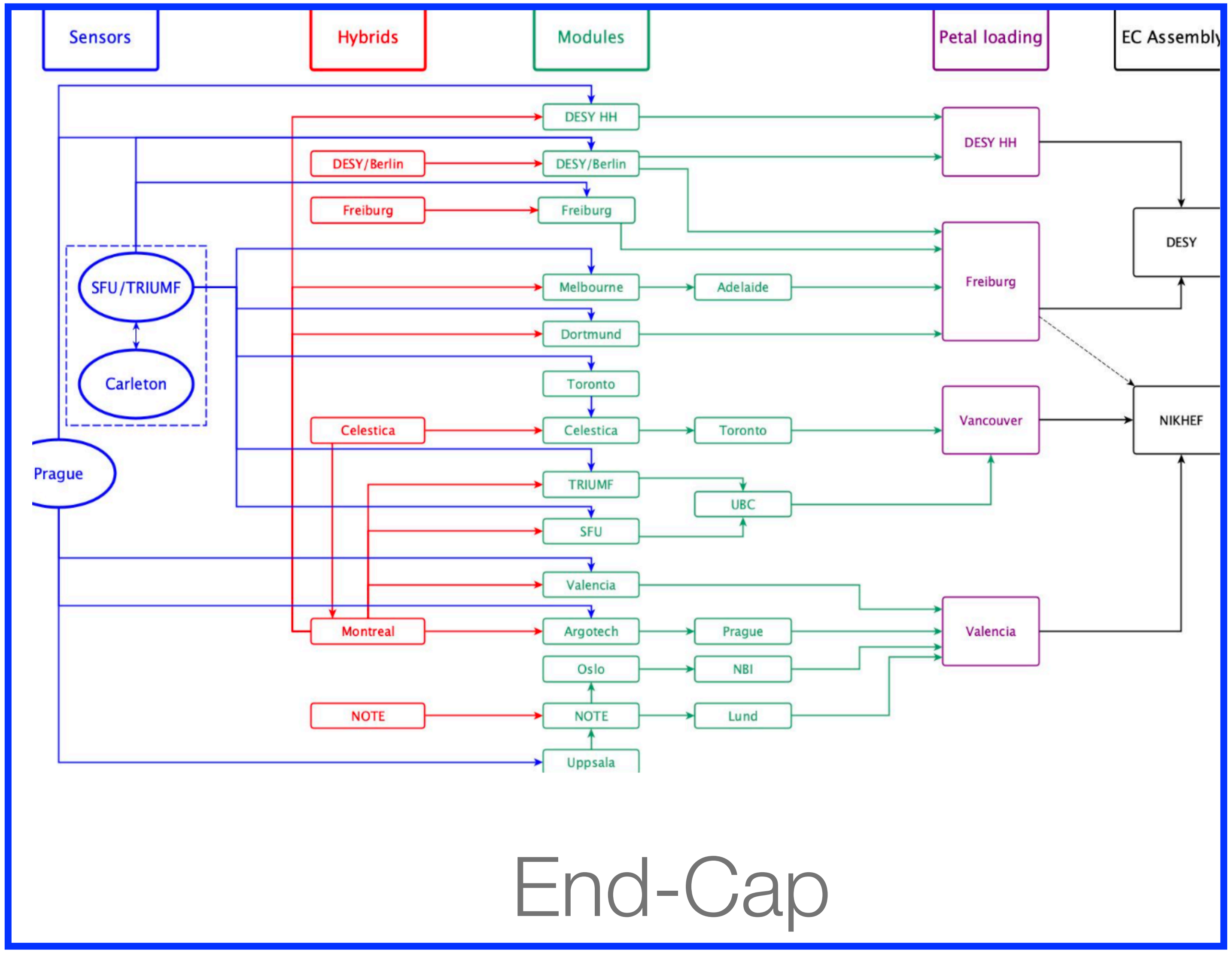


ATLAS ITk

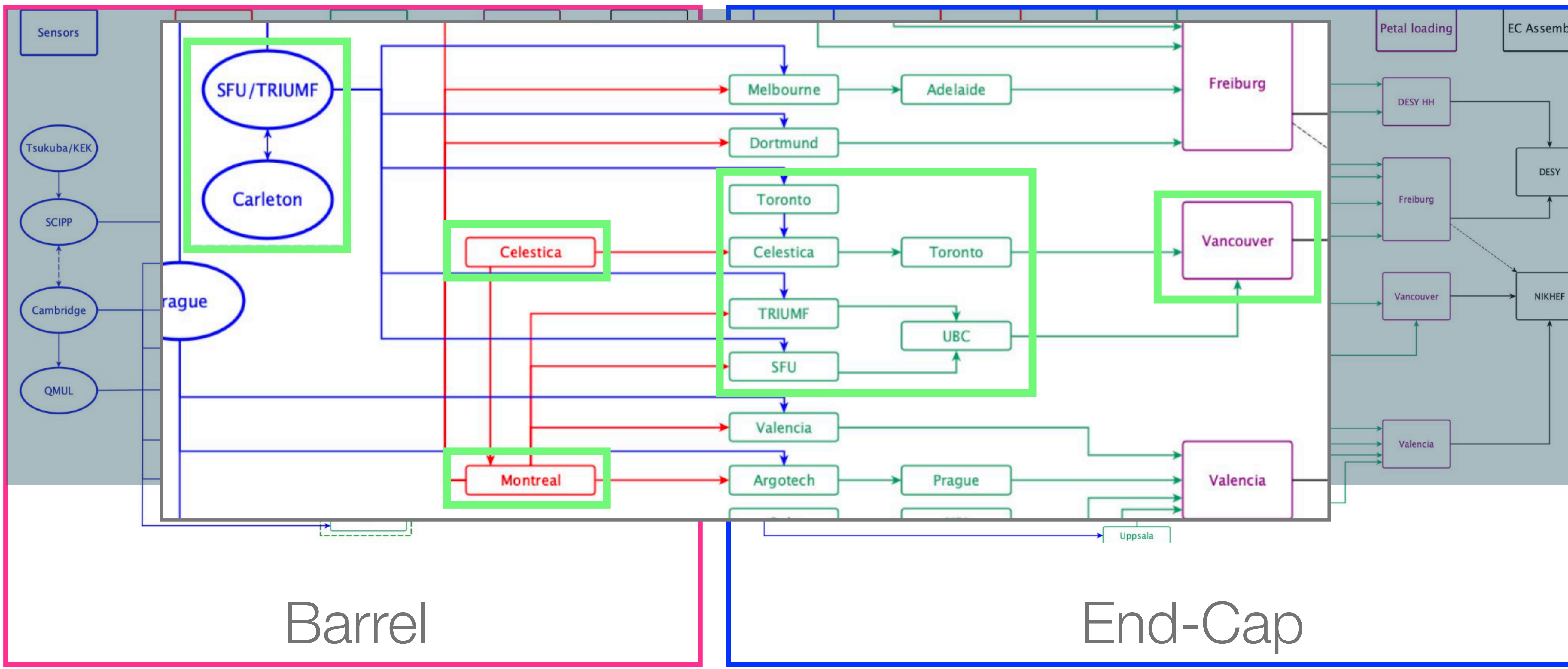
# Who is building the strip detector?



# Who is building the strip detector?

## Canada's involvement:



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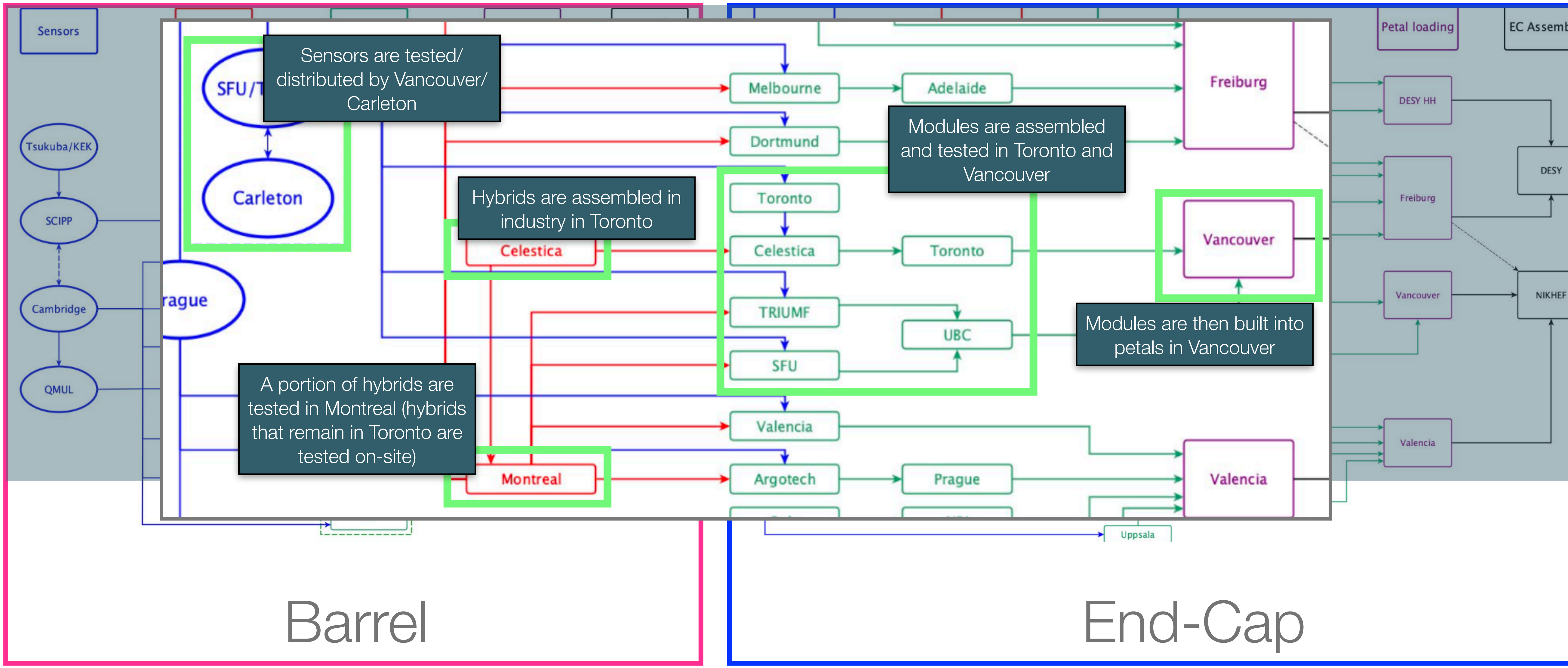
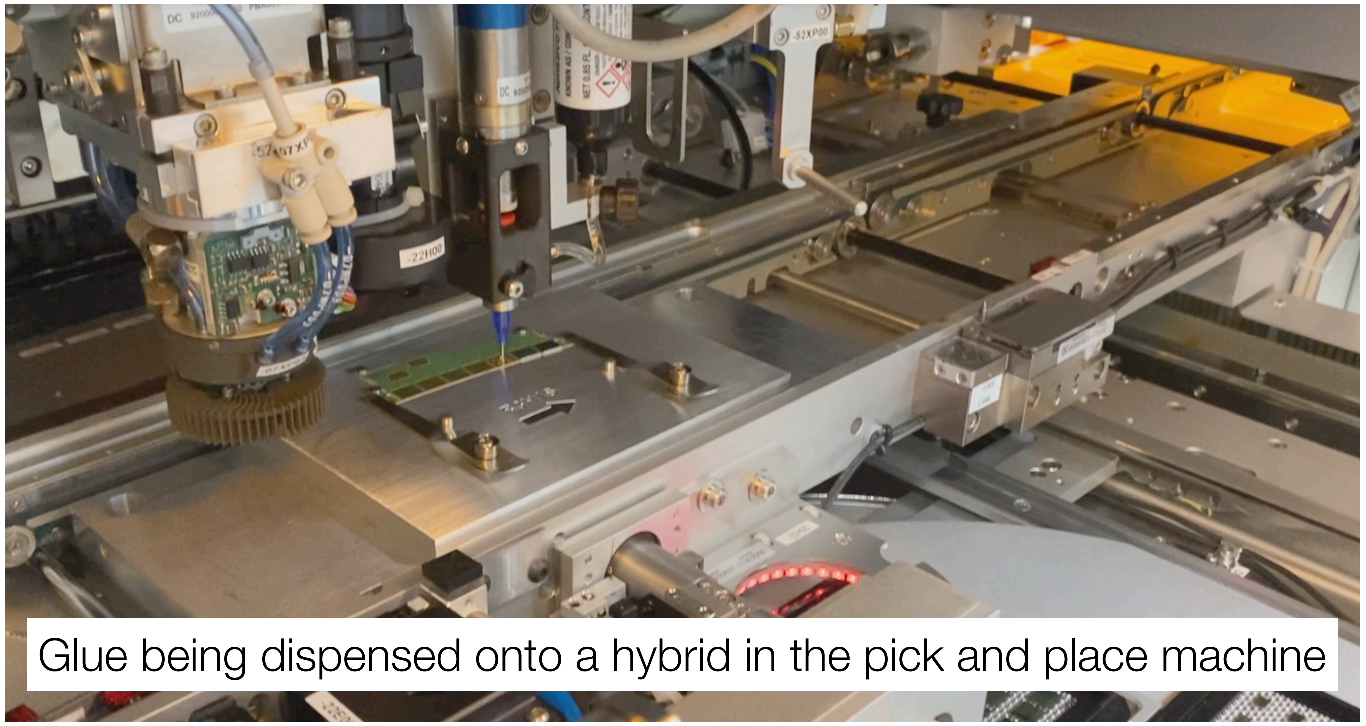
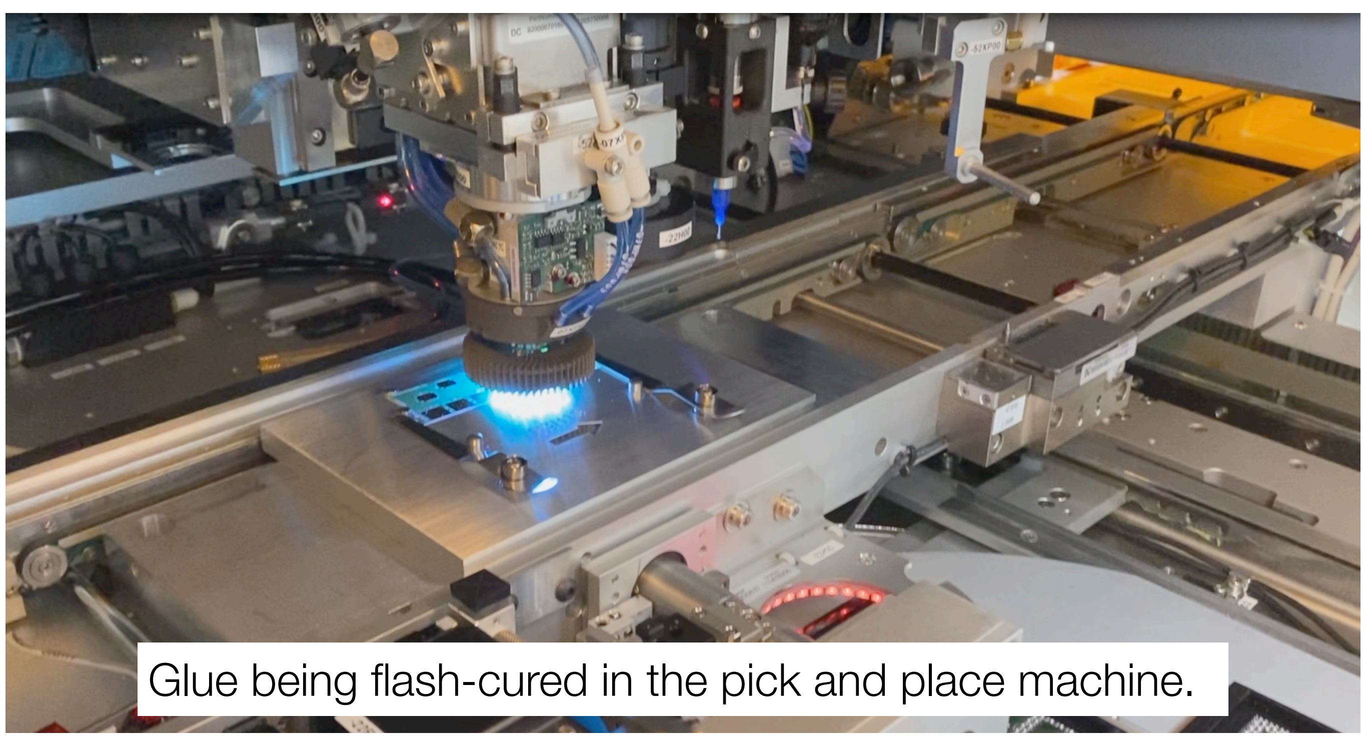
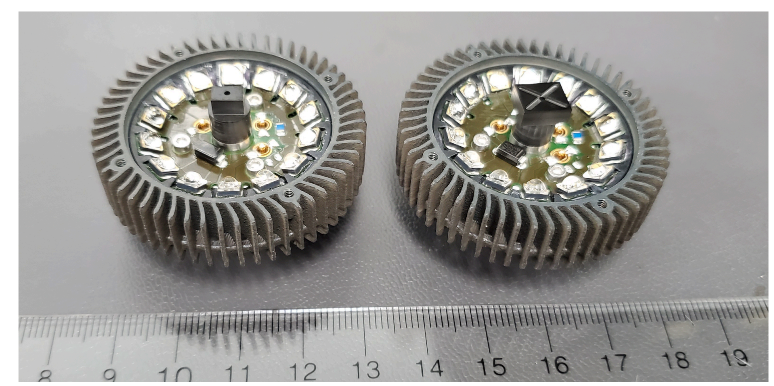


# How to assemble a hybrid (in industry)

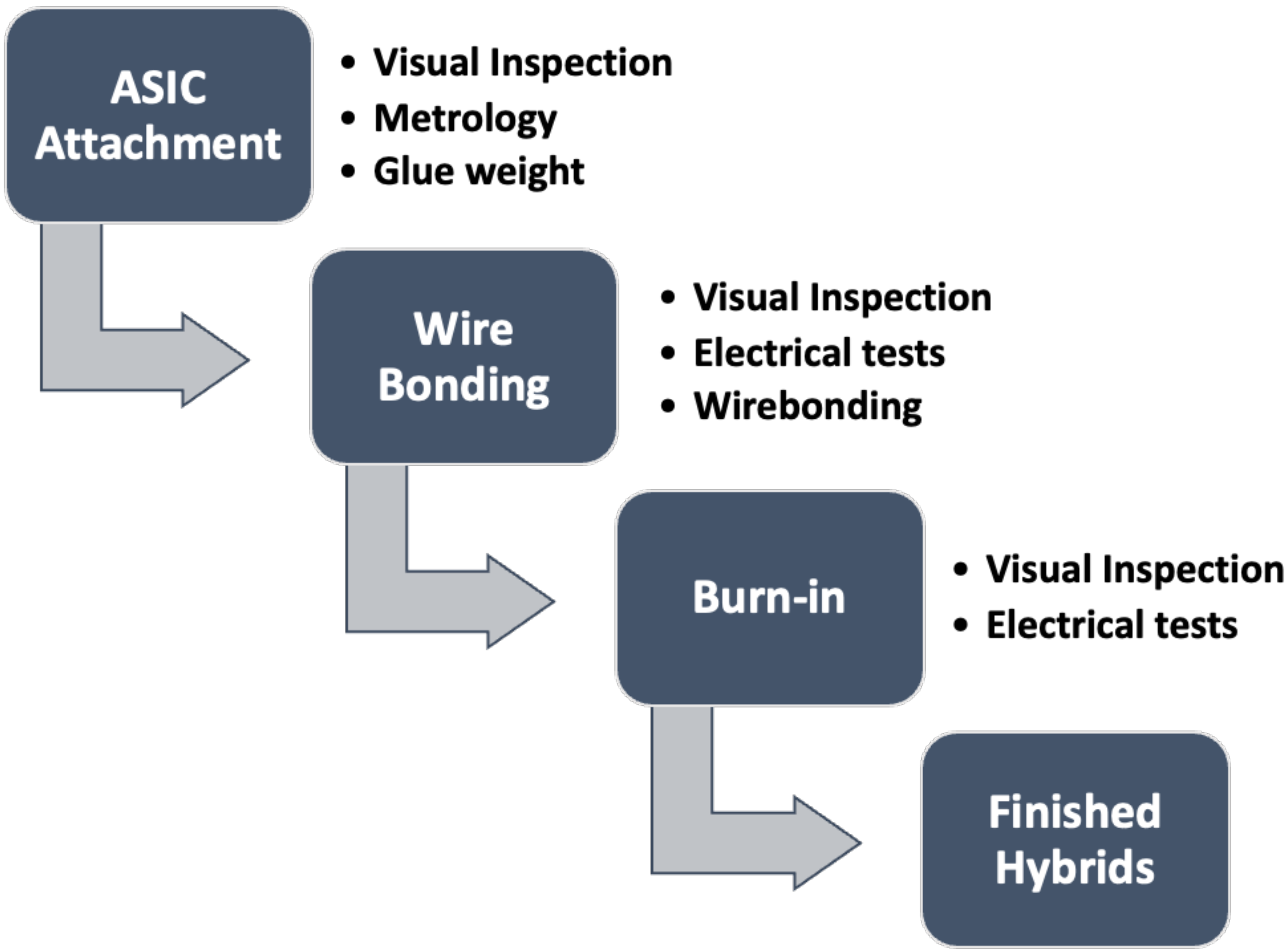

Glue being dispensed onto a hybrid in the pick and place machine


Glue being flash-cured in the pick and place machine.

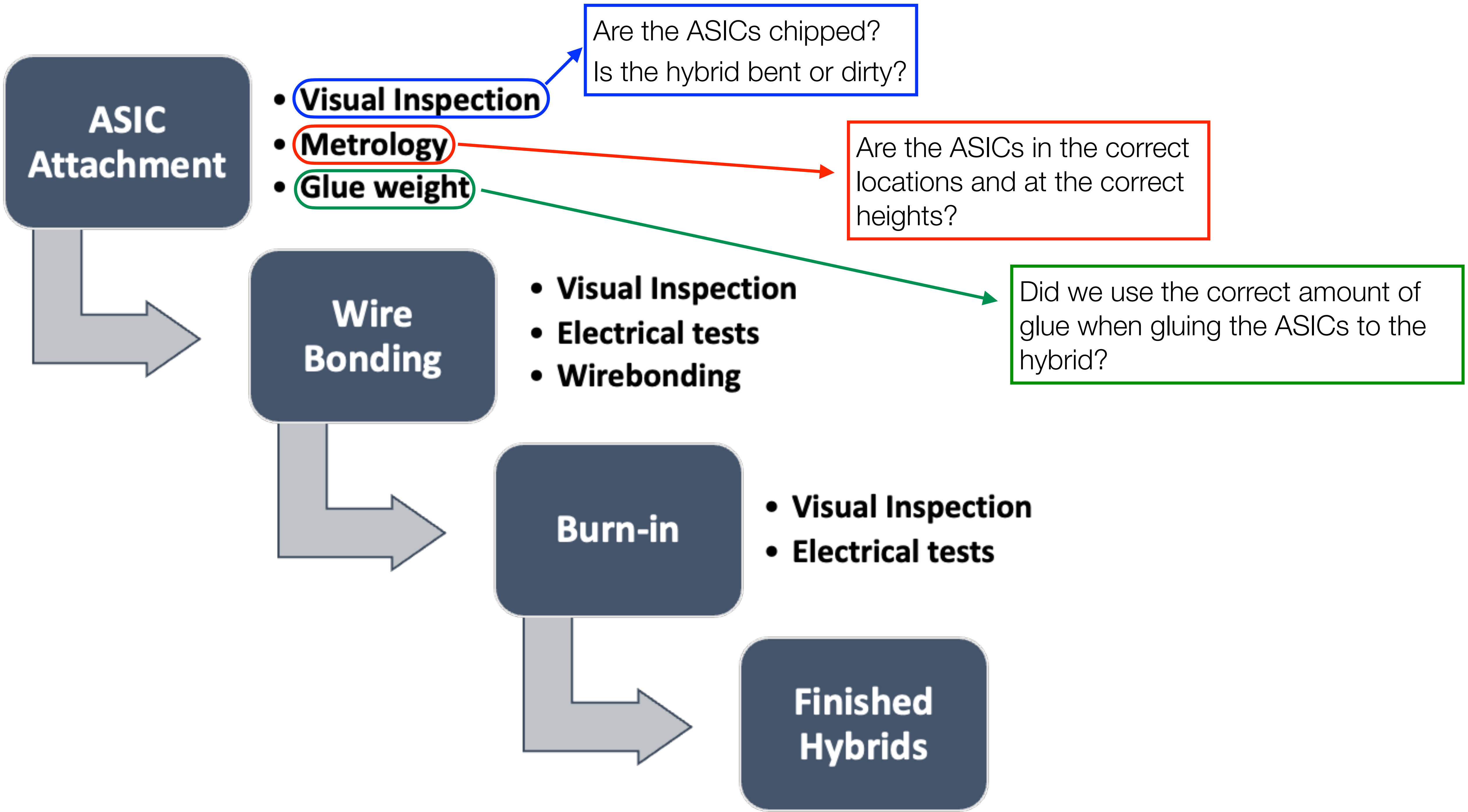
- Hybrids are assembled with our industrial partner Celestica using a pick-and-place machine



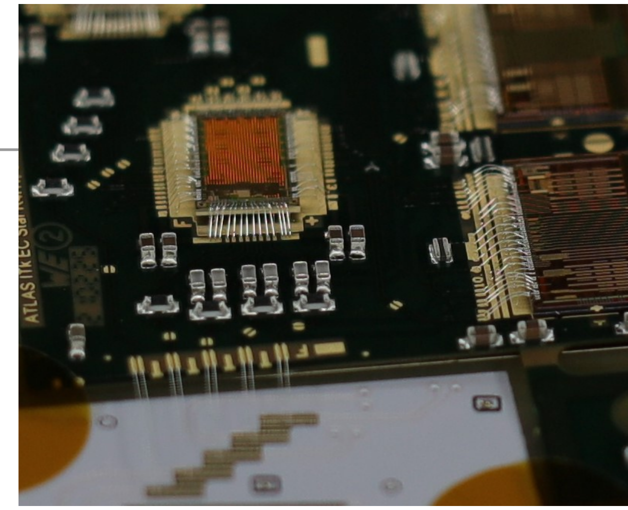
# Hybrid quality control



# Hybrid quality control



# Hybrid quality control



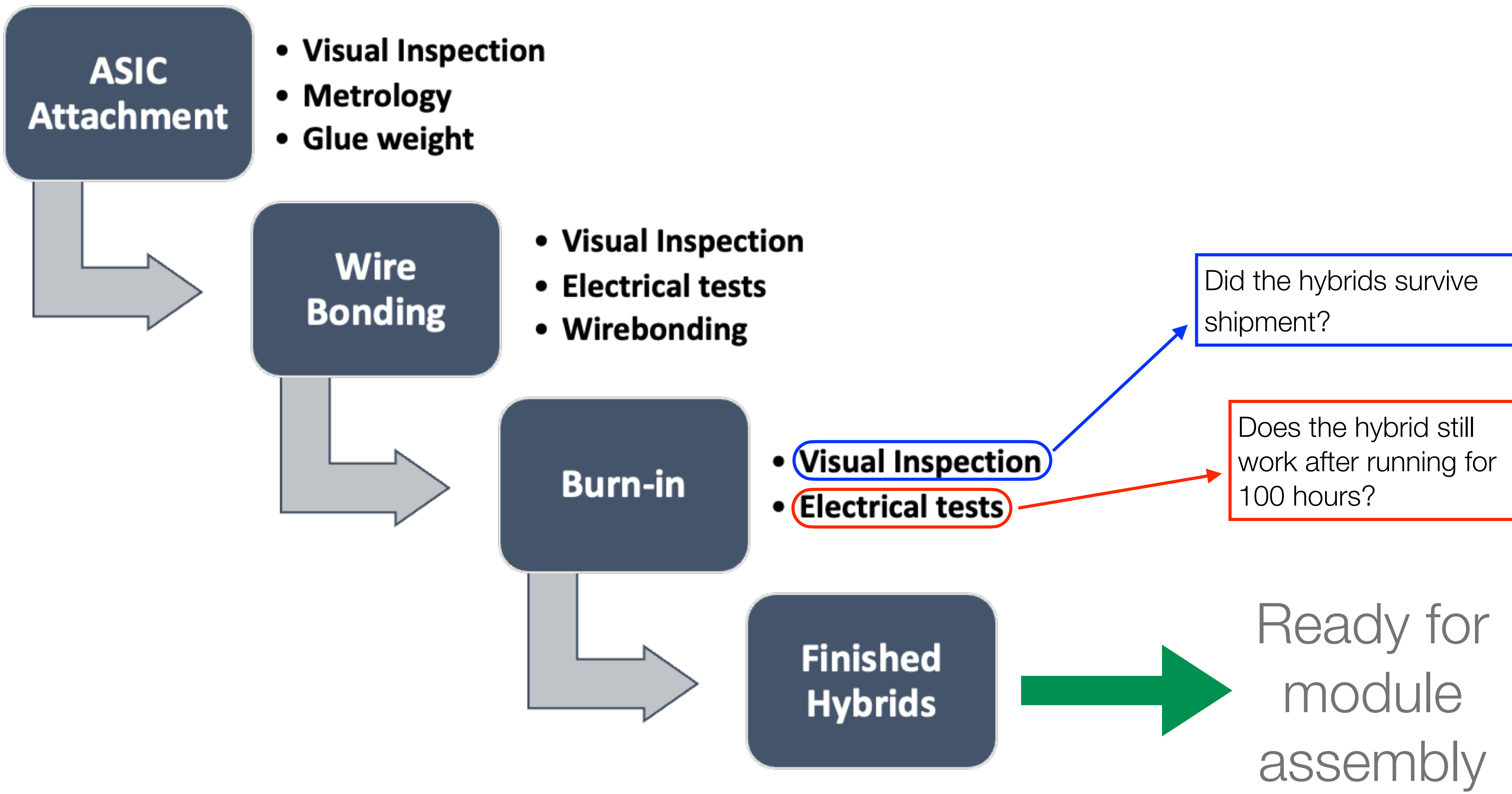
**ASIC Attachment**
- Visual Inspection
- Metrology
- Glue weight

**Wire Bonding**
- Visual Inspection — Are all the wires connected? Do they have the correct shape?
- Electrical tests — Does the hybrid work properly?
- Wirebonding — Did any wire bonds have to be reworked or redone?

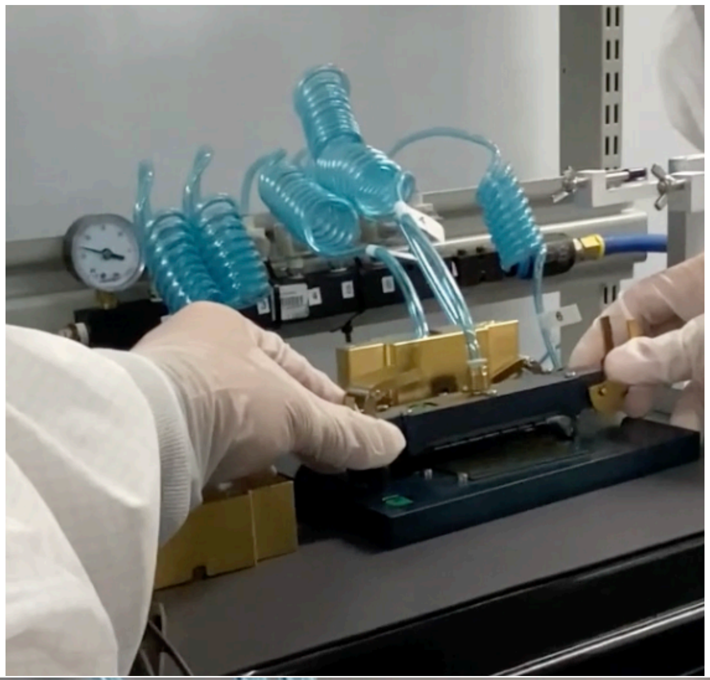
**Burn-in**
- Visual Inspection
- Electrical tests

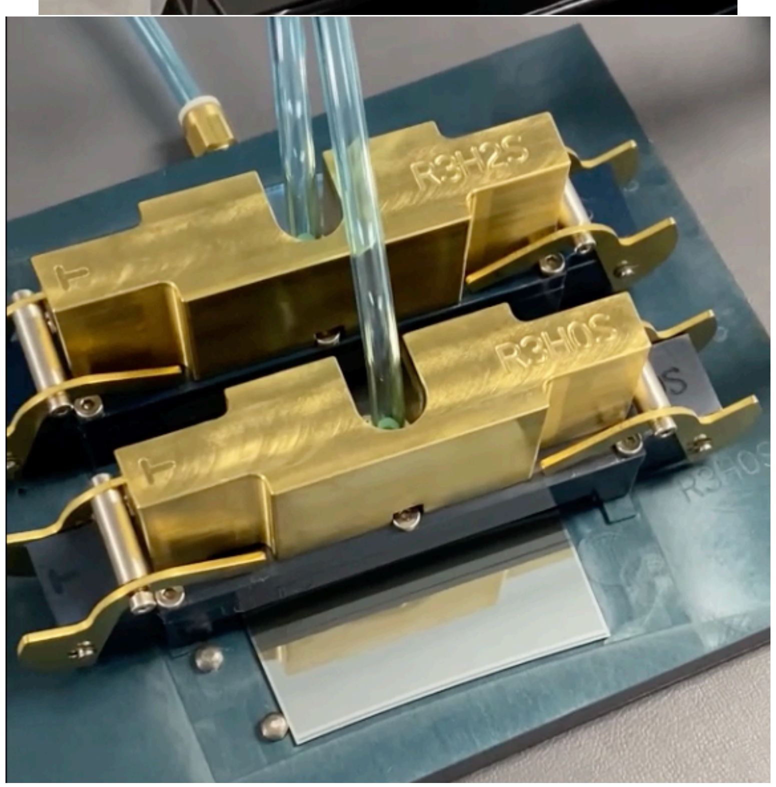
**Finished Hybrids**

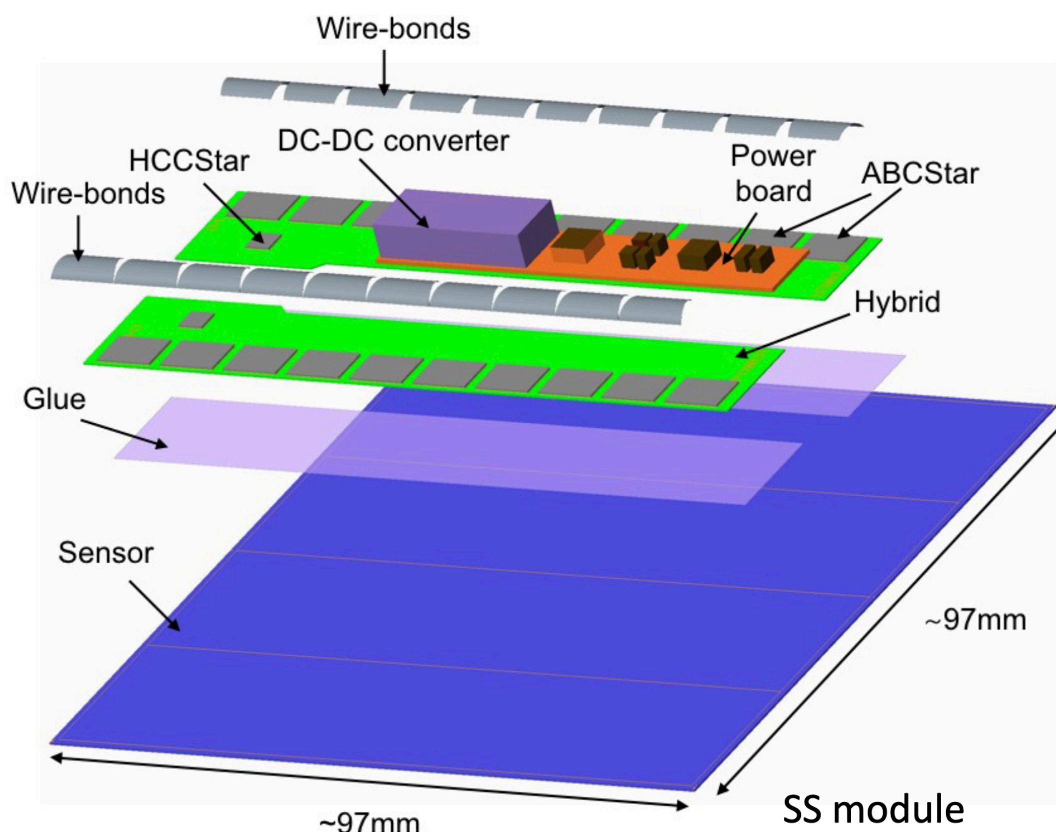
# Hybrid quality control

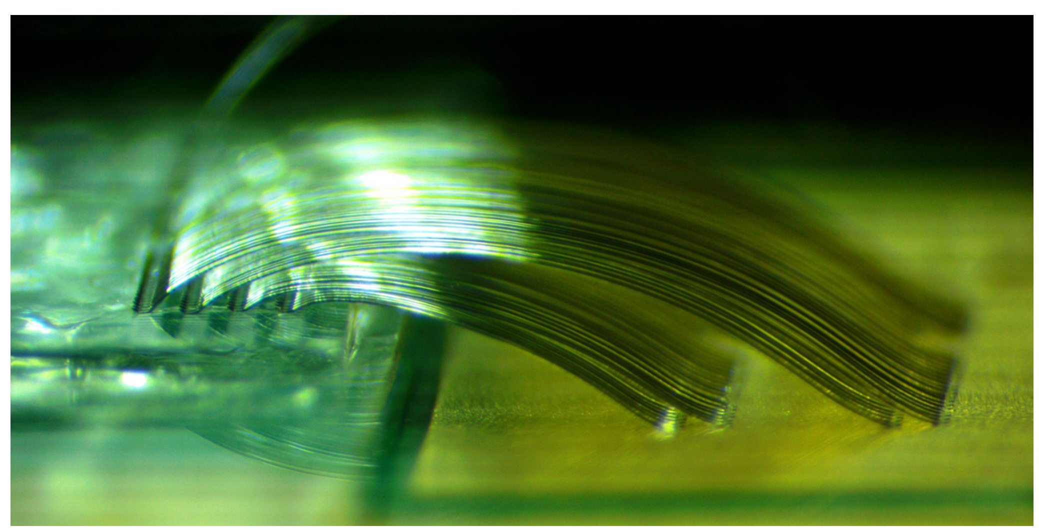


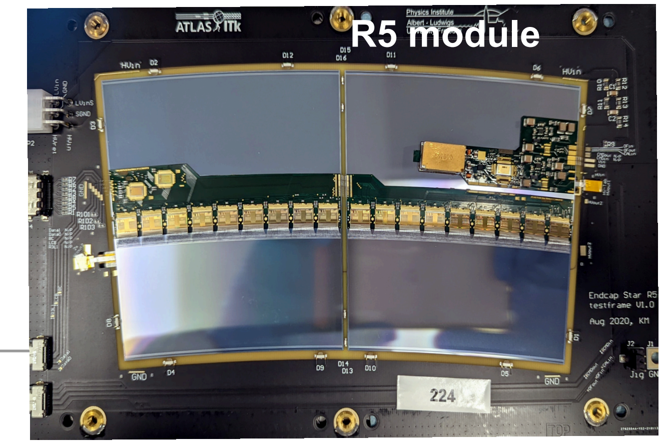
# How to assemble a module



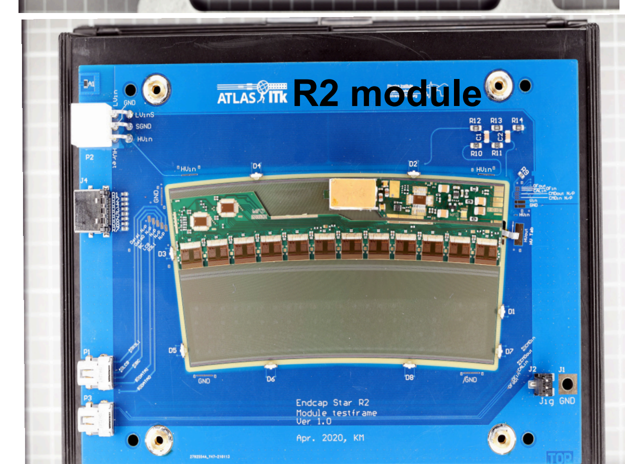


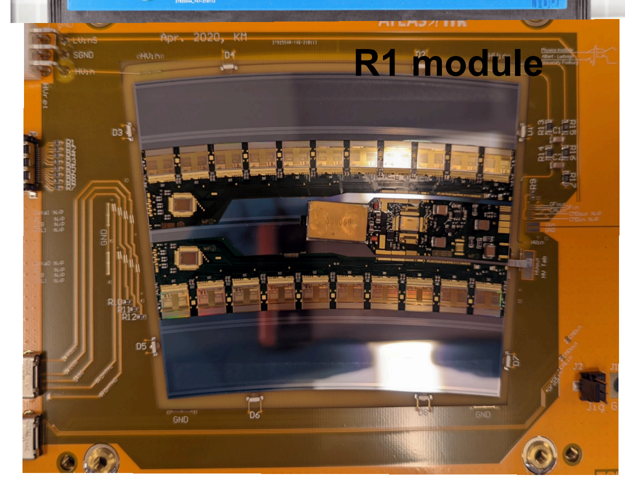




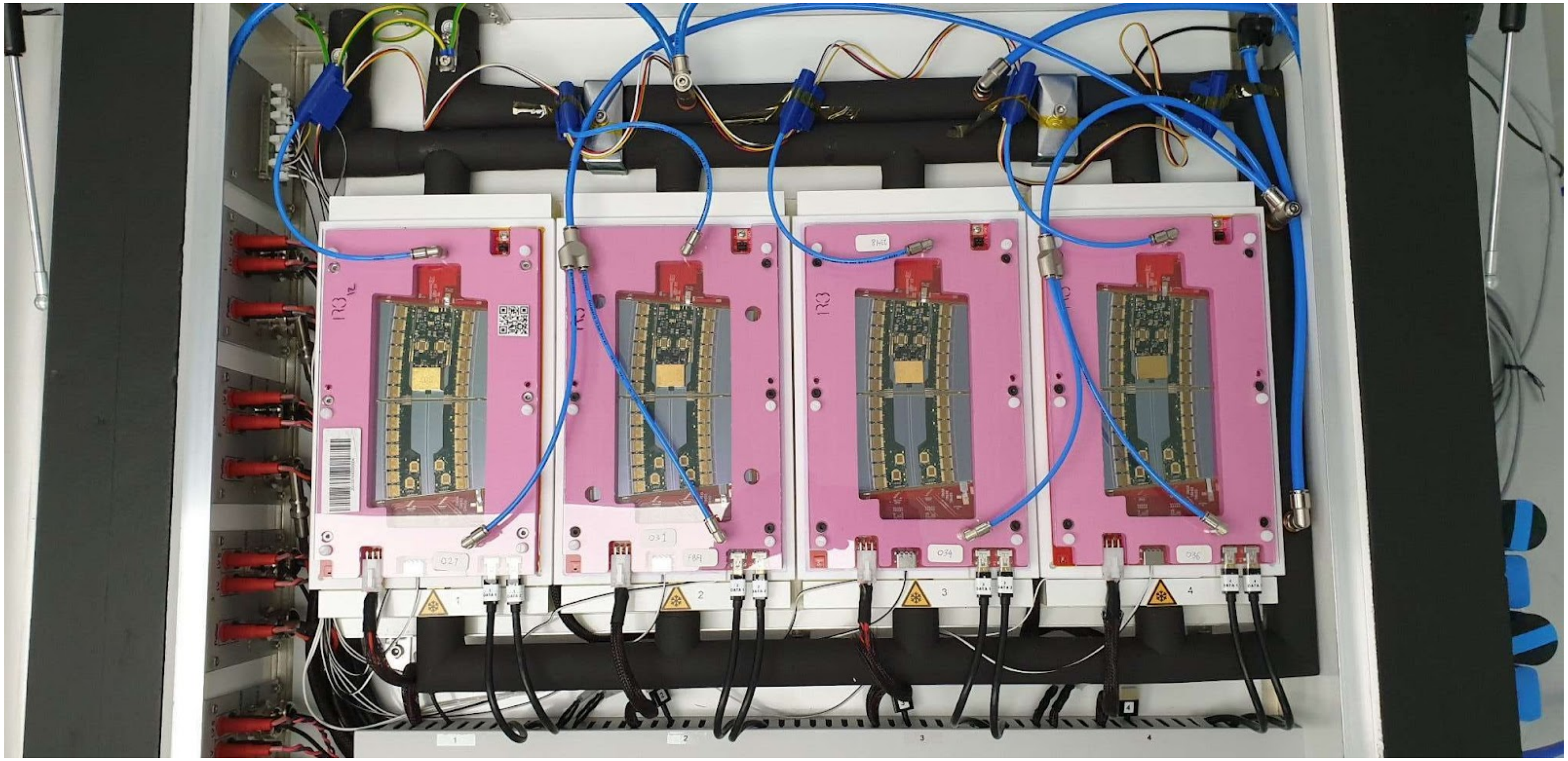




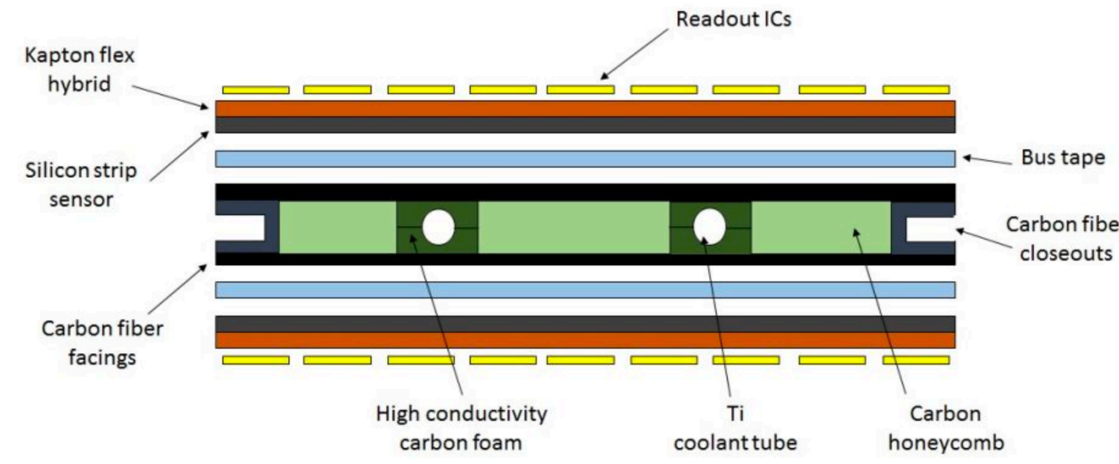
# Module quality control

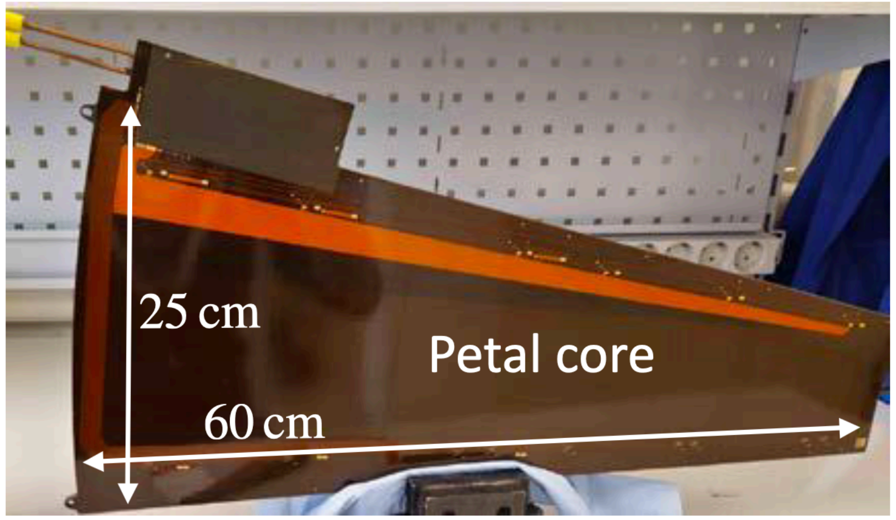
- Very similar to hybrid QC! (i.e.: visual inspection, glue weights, metrology, wire bonding, etc)
    - Main difference: module thermal cycling instead of burn-in

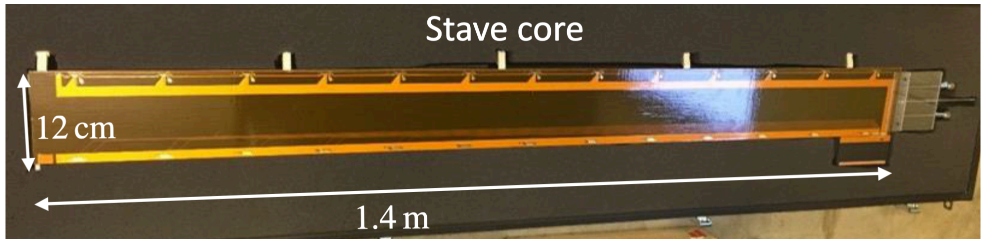


# Support structures

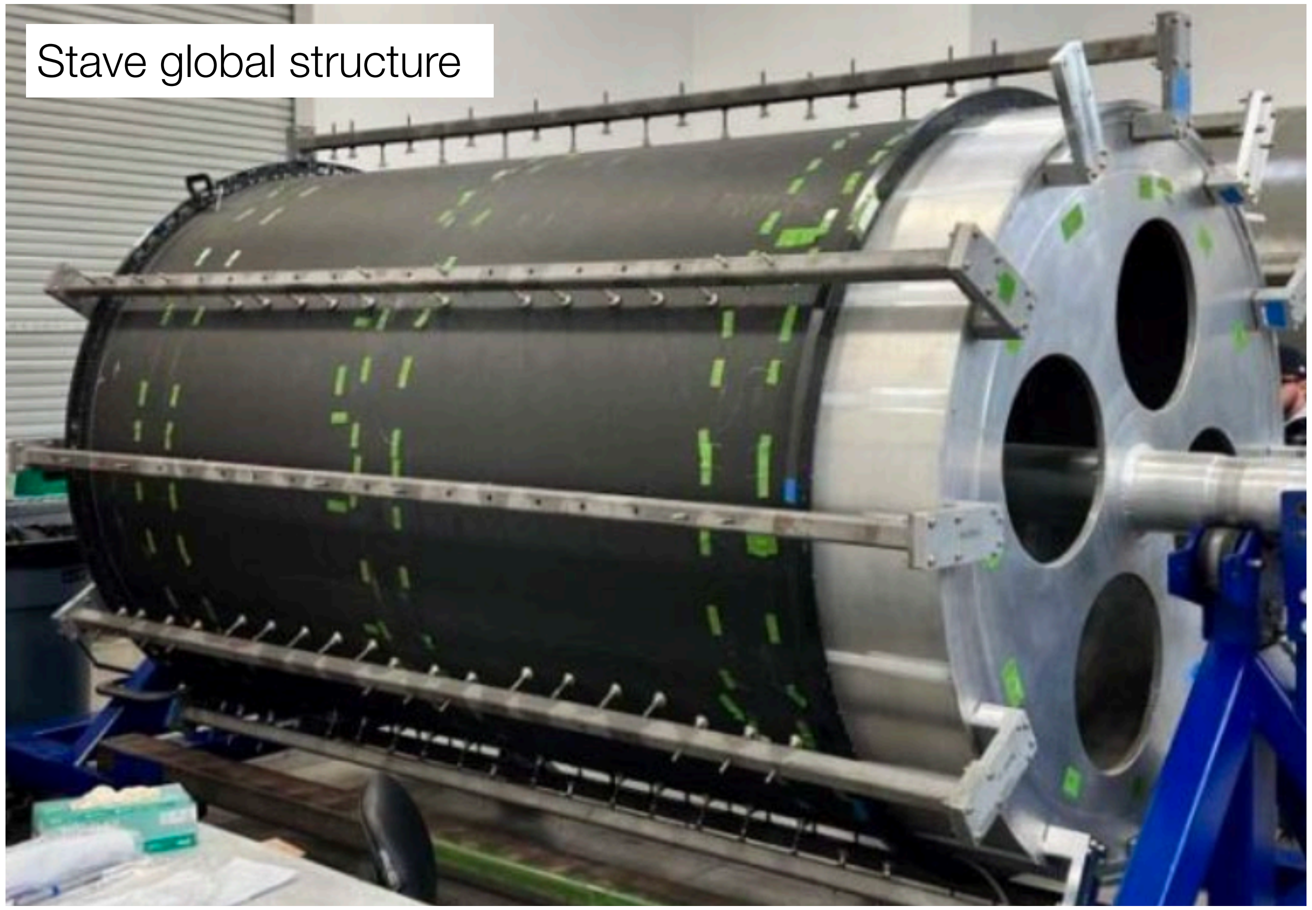
- Carbon fibre structures support the modules in staves (barrel) or petals (end-cap) and host common electrical and cooling services
    - Staves consist of a total of 28 modules (14 on either side of the support structure)
        - Modules are rotated by 26 mrad relative to the stave axis
    - Petals are trapezoidal structures which consist of all 6 of the differently-shaped end-cap modules
        - Strips are rotated by 20 mrad relative to the centre of the sensor

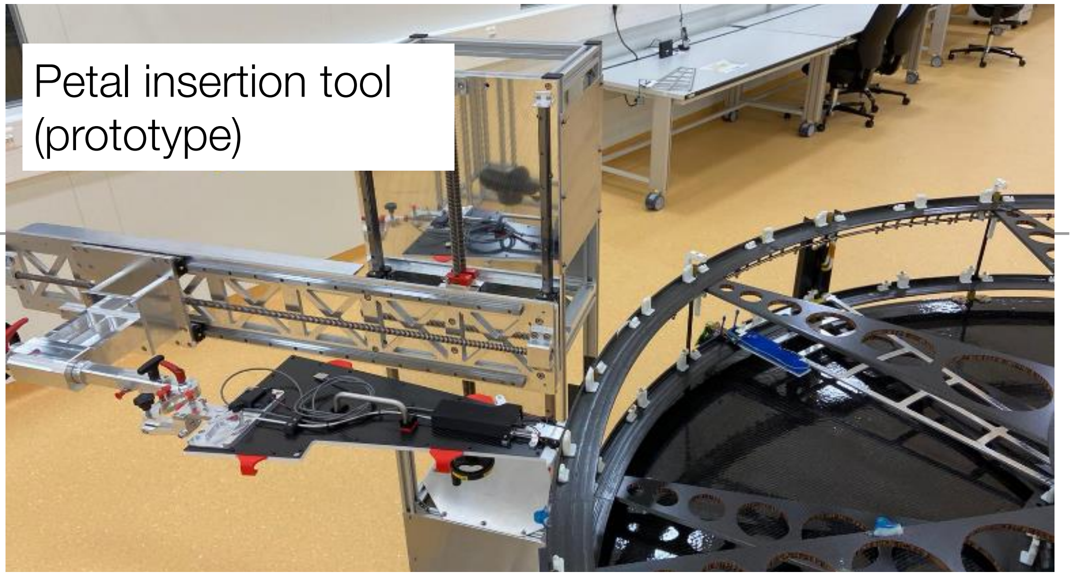


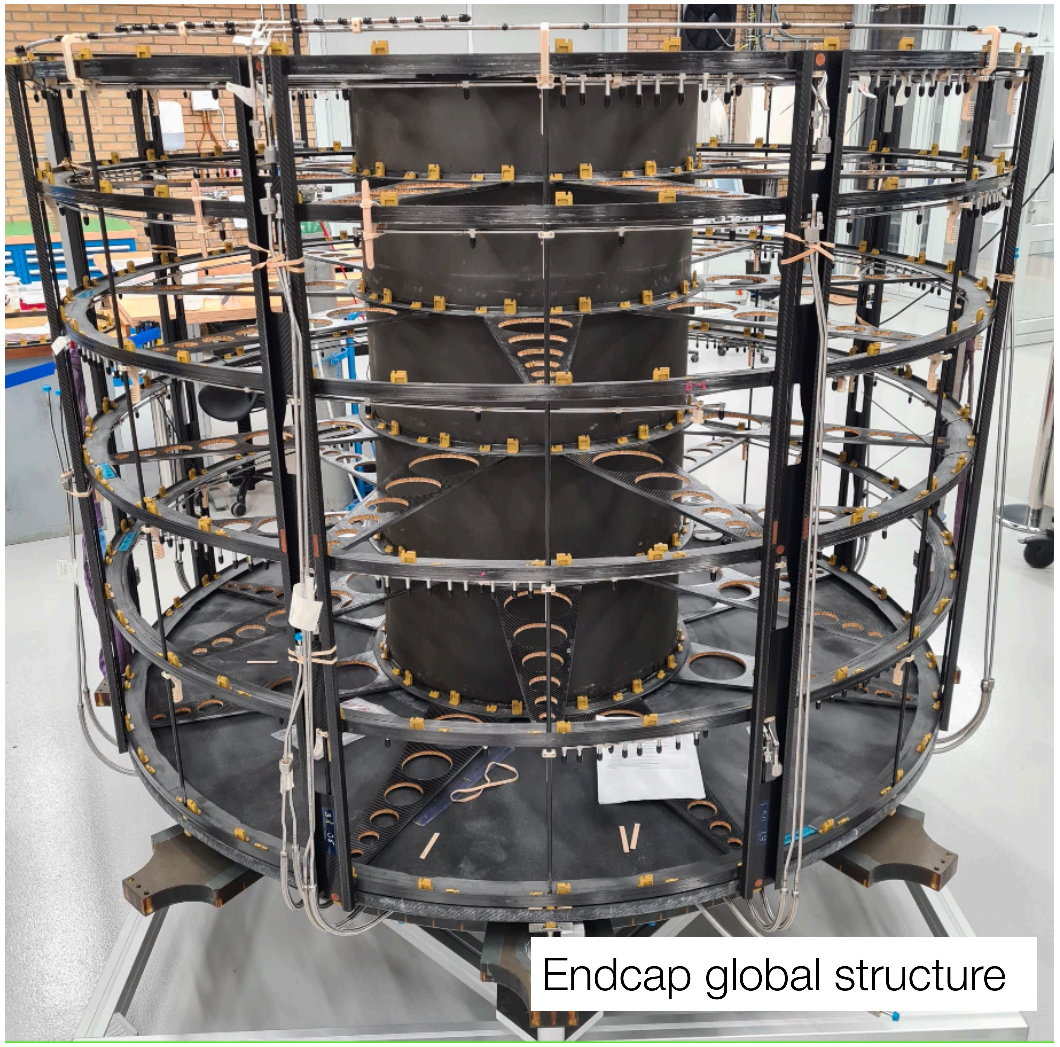



# Global structures


Stave global structure

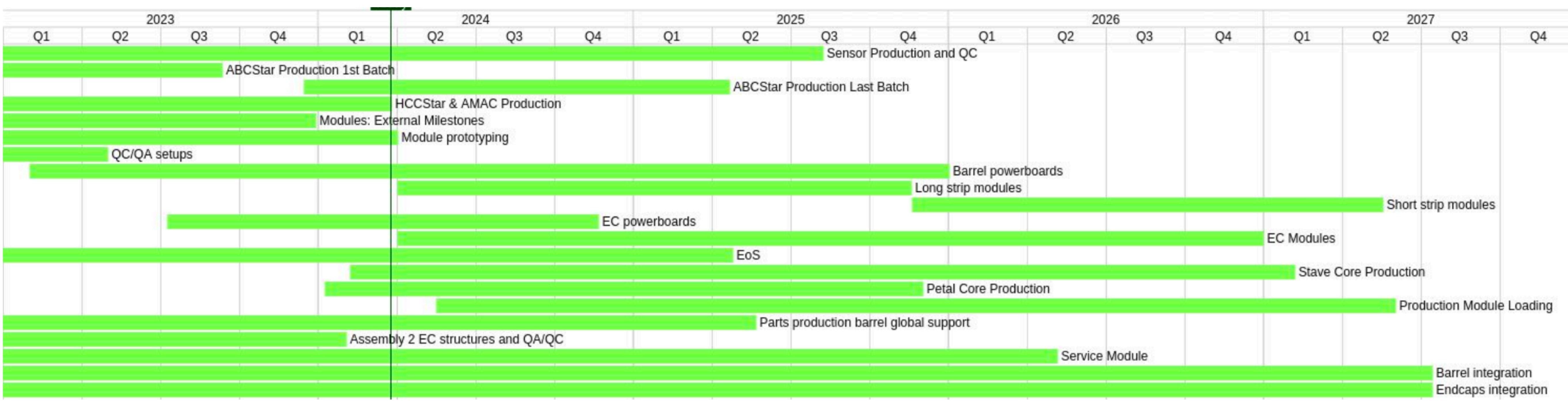

Petal insertion tool (prototype)


Endcap global structure

- Barrel integration is at CERN, petal integration at DESY (Germany) and NIKHEF (Netherlands)
- Staves and petals are inserted into the global structures using special insertion tools

# Where are we now?

- We are currently in the ~middle of production
    - Sensors are well underway
    - ASICs are almost done
    - Hybrids/modules are slowly ramping up
    - Local supports and global structures are ongoing
    - Integration is ready to start (once staves/petals are available)



Questions?

# Further reading

- The High-Luminosity LHC
- A new ATLAs for the high-luminosity era
- Exploring the scientific potential of the ATLAS experiment at the High-Luminosity LHC