ATLAS ITk Strip Detector

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ATLAS EXPERIMENT

High Luminosity LHC (HL-LHC)

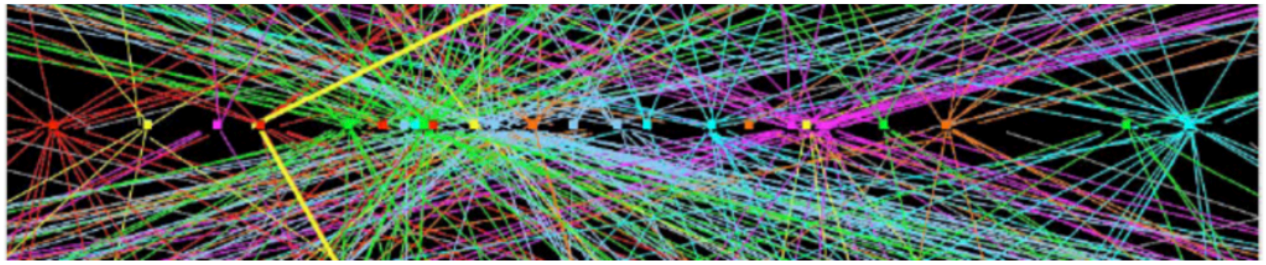
The High-Luminosity upgrade of the LHC is scheduled to begin colliding protons in 2026

- The peak instantaneous luminosity will be up to **7.5×10^{34} cm^{-2}s^{-1}**

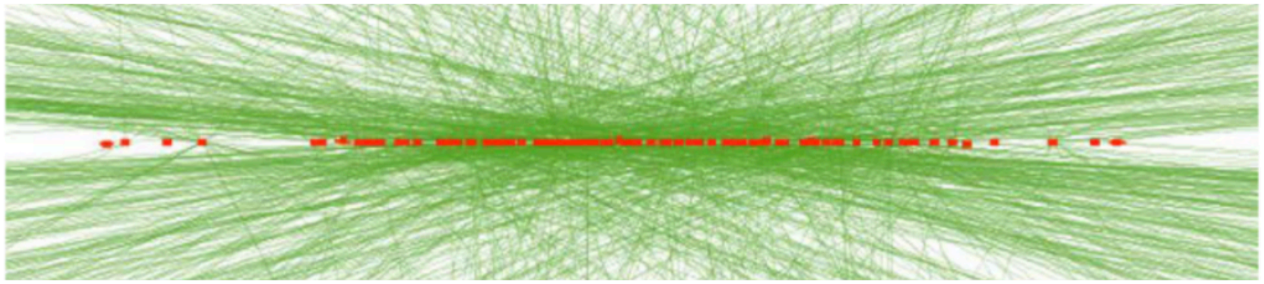
- The mean number of interactions per bunch crossing **μ=200** (currently μ=50)

- 3000 fb^{-1} for 10 years

LHC (25 vertices)



HL-LHC (200 vertices)

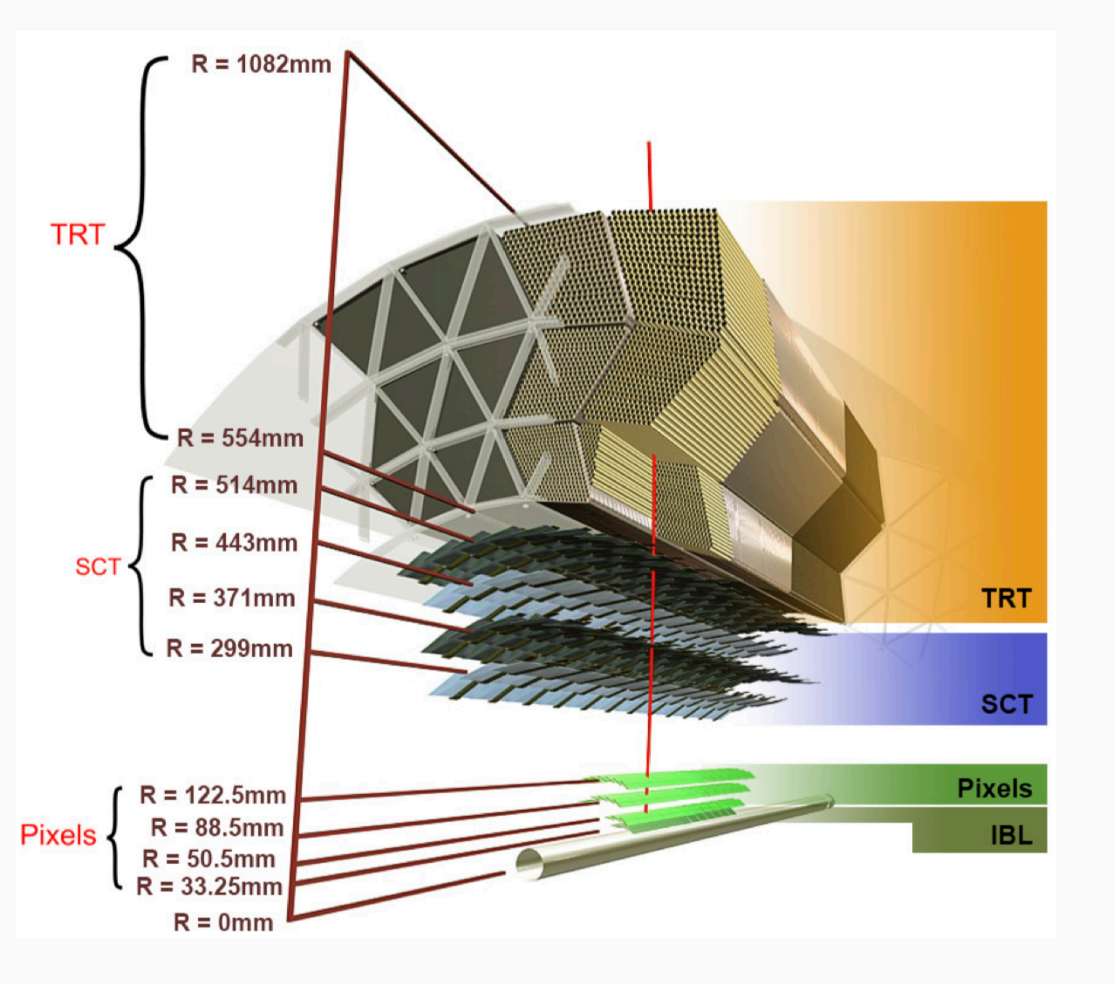


- Higher luminosities benefit searches for new particles, precision measurements and study of rare processes but pose severe challenges to the detectors

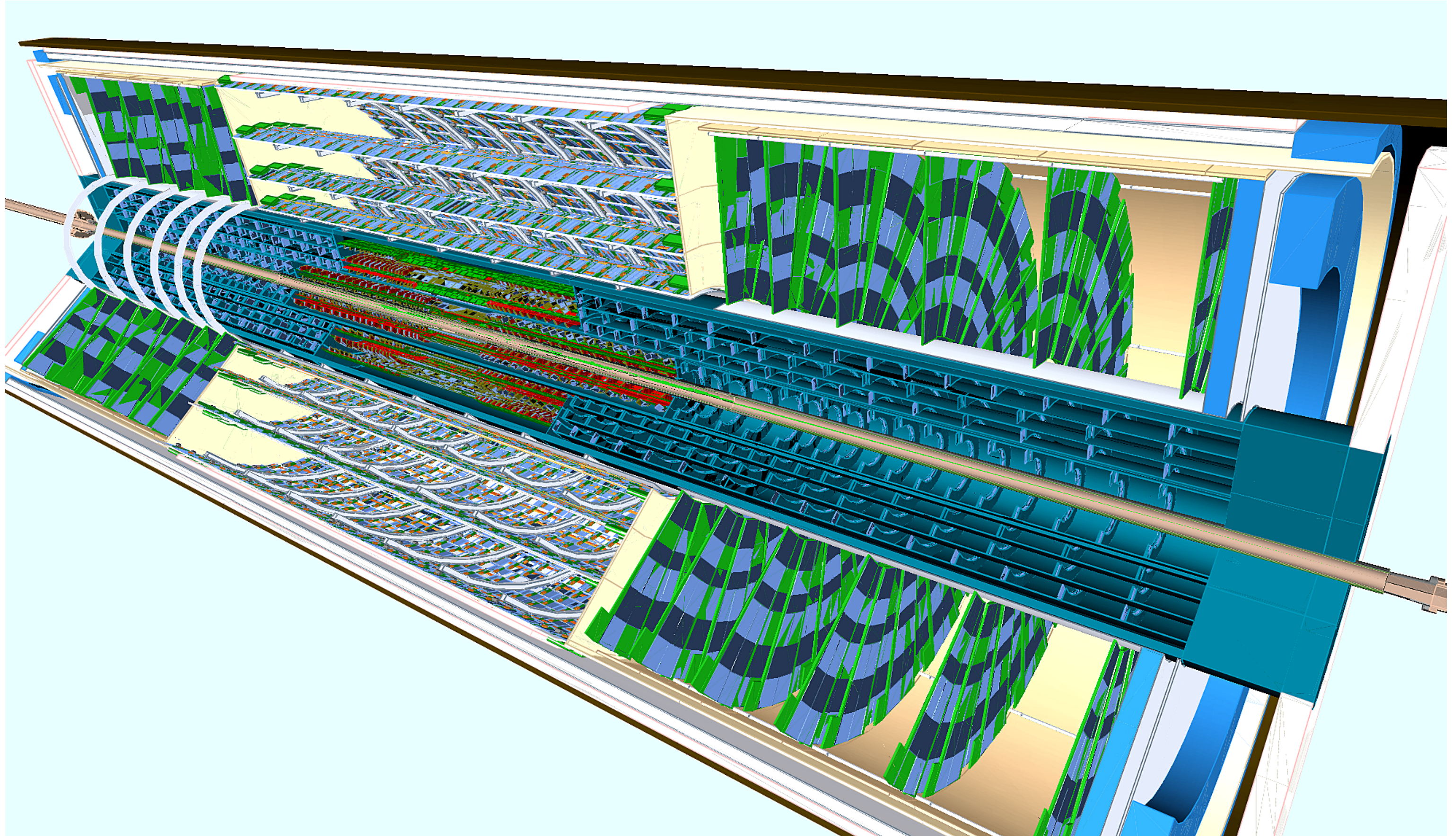
- Specifically the vertex and tracking detectors closest to the interaction region require upgrades to cope with the increased occupancies and radiation damage

The ATLAS Tracking Detectors

Current Inner Detector (ID)



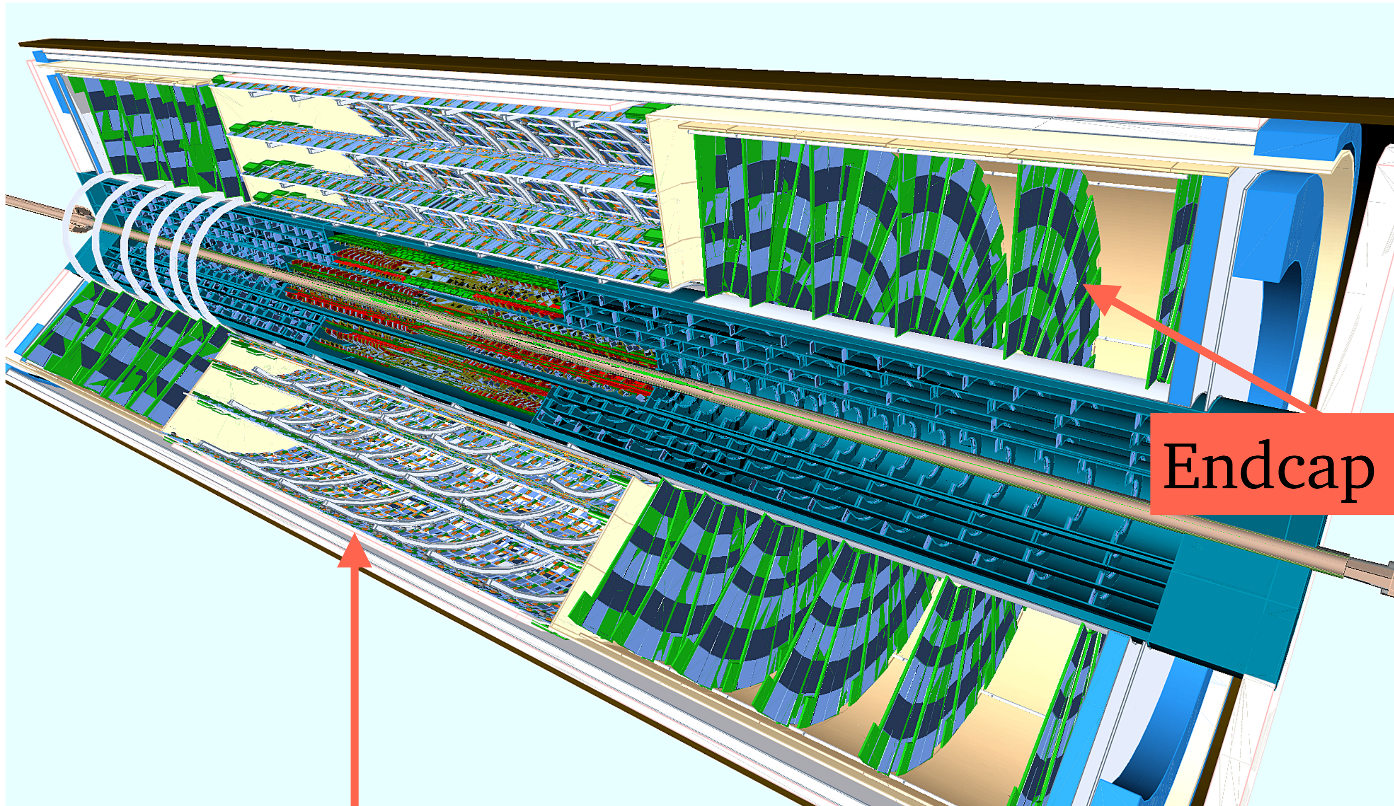
New Inner Tracker (ITk)

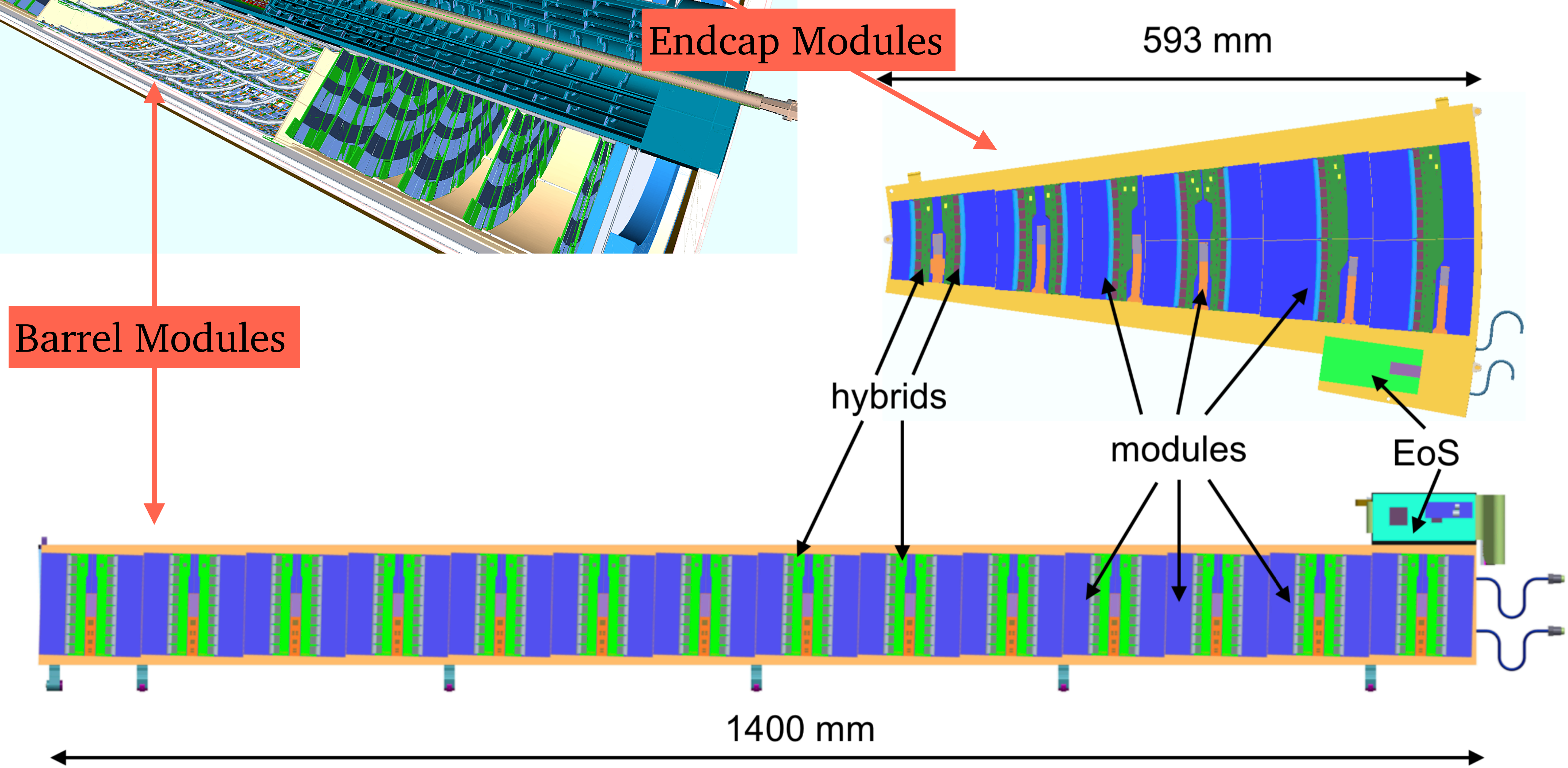


- Currently the Inner Detector uses both silicon layers and a Transition Radiation Tracker
- The new Inner Tracker will be an all-silicon tracker
  - Pixels nearest the interaction region and strips in the outer regions

The ATLAS ITk Strips

- Strips are in the outer regions with both **Barrel** and **Endcap** type modules
- Around ~18000 individual strip modules need to be produced

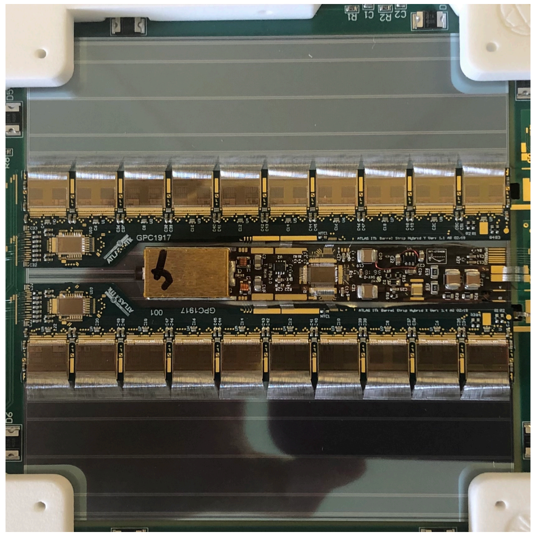




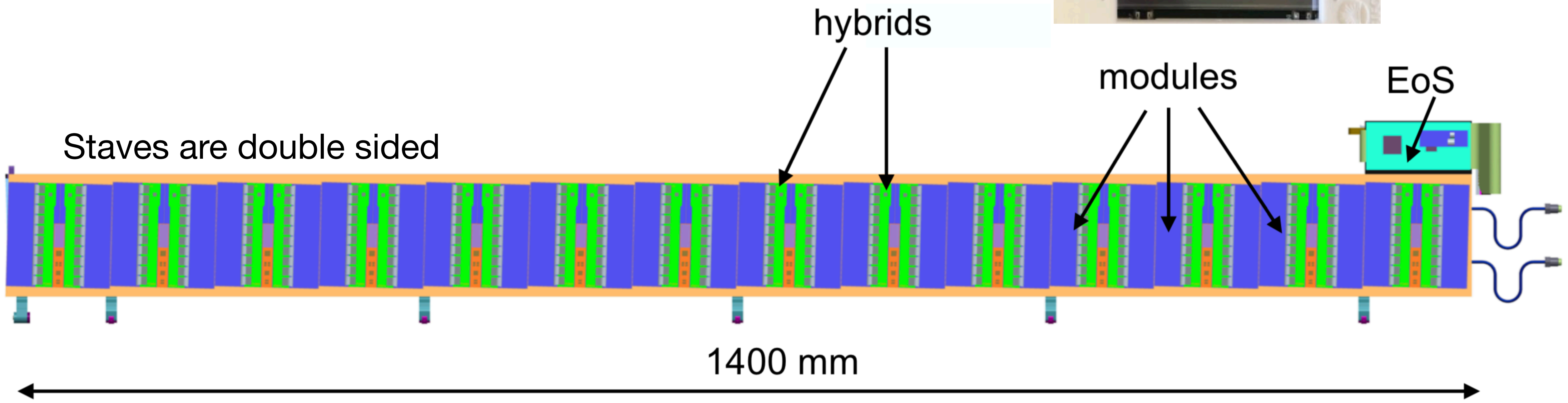
The ATLAS ITk Strip Barrel Modules

Two different types of barrel modules

- 2 layers of Short Strip (**SS**) Modules
    - Used in layers closest to the interaction region

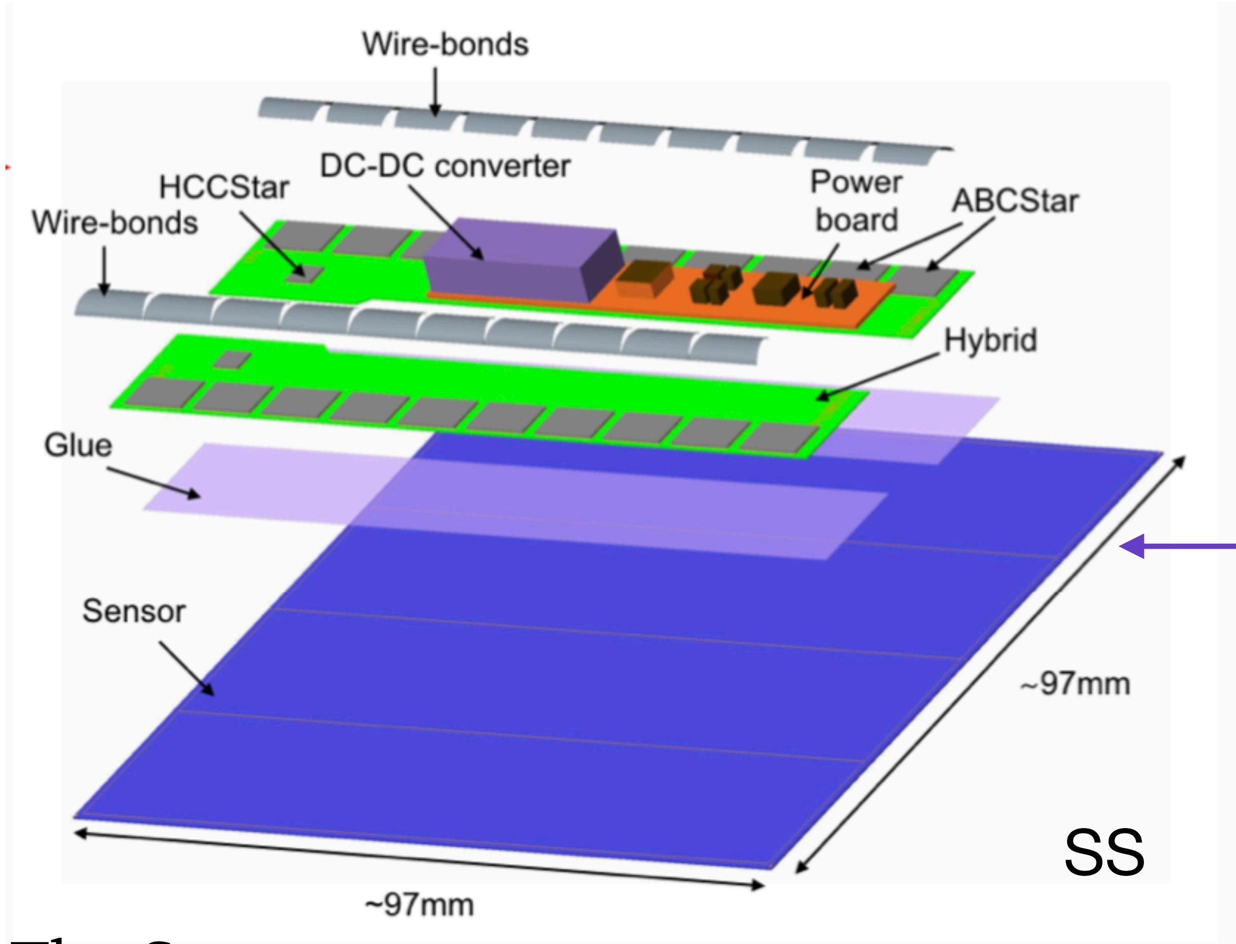


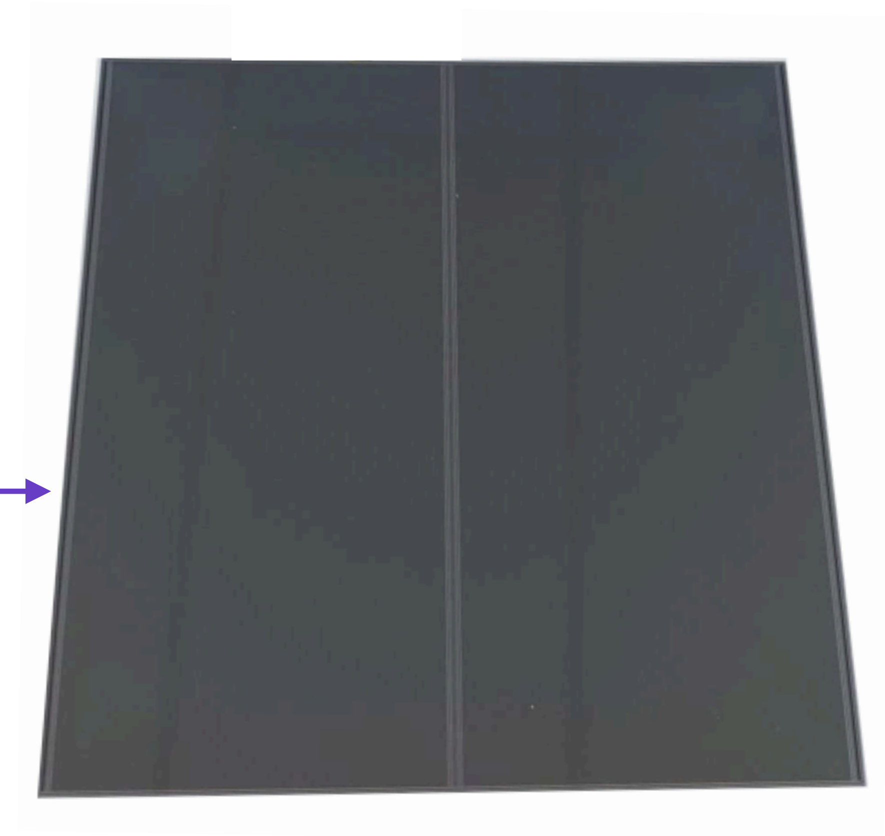
- 2 layers of Long Strip (**LS**) Modules
    - Suitable in the lower occupancy region at larger radii



Barrel Strip Module Design

The basic unit of the ITk Strip Detector is the silicon-strip module





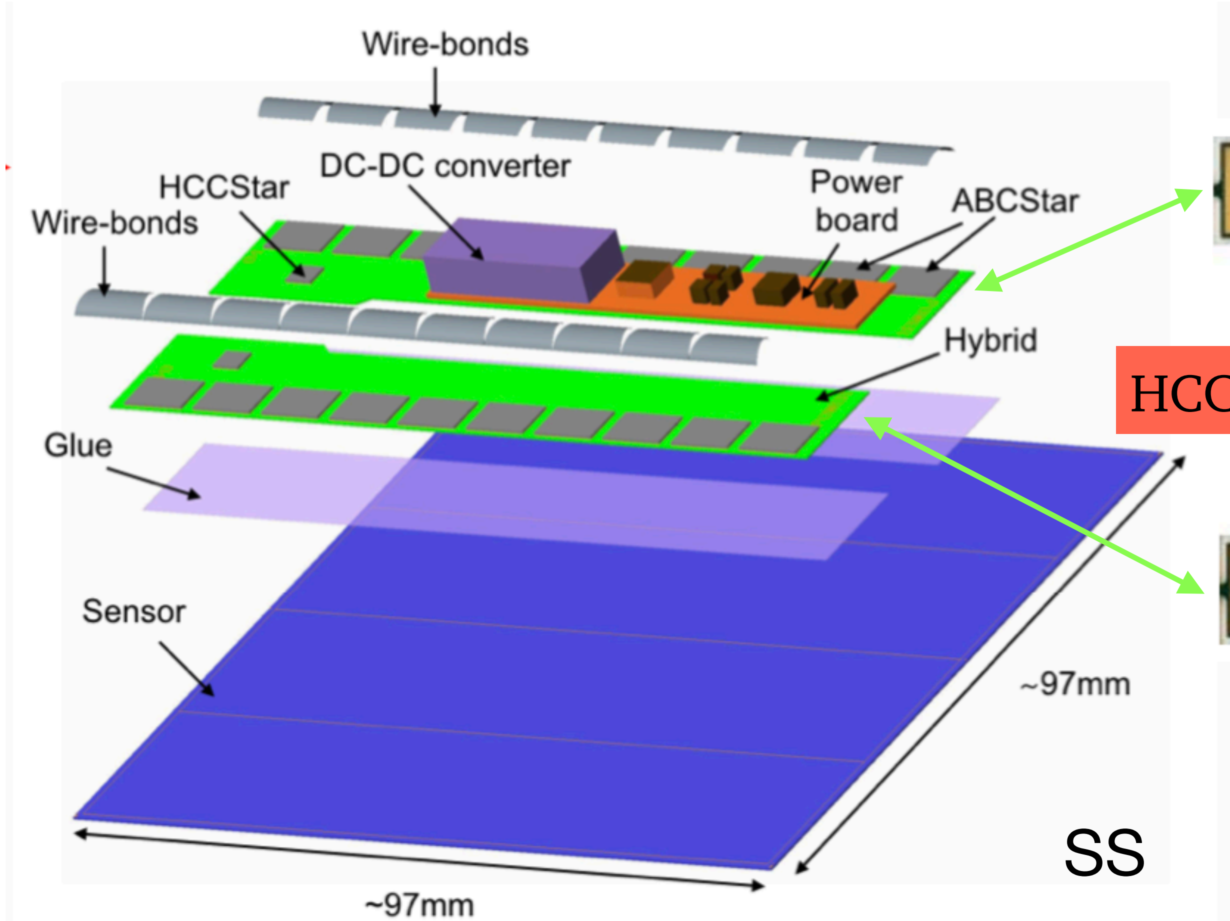
The Sensor

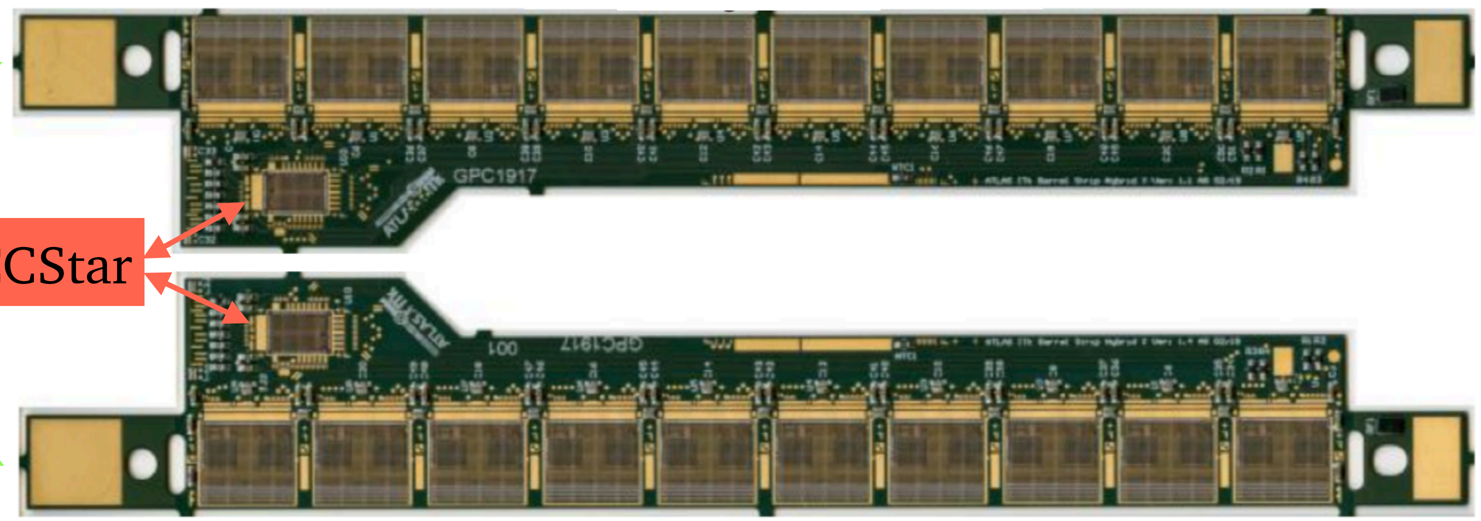
- n^+-on-p strip sensor
- 320 µm thick
- Strip pitch 75.5 µm
- 9.7 cm^2 x 9.7 cm^2

- Short Strip (**SS**) and Long Strip (**LS**) layouts
  - **SS** - 24.1 mm long strips in four segments
  - **LS** - 48.2 mm long strips in two segments

Barrel Strip Module Design

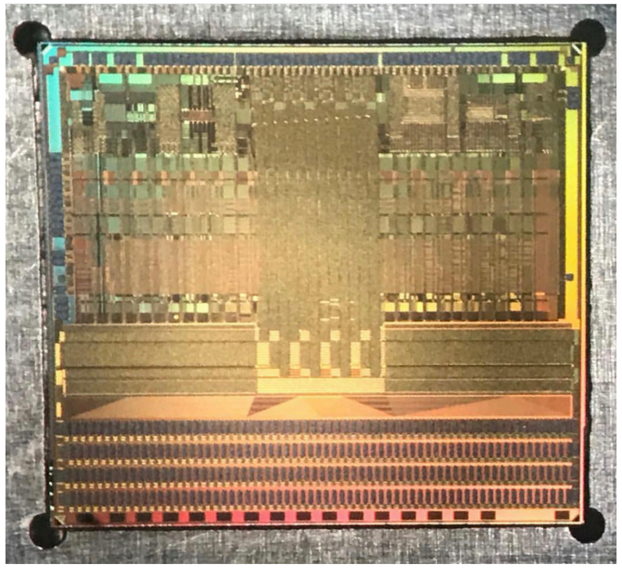
The basic unit of the ITk Strip Detector is the silicon-strip module





HCCStar

ABCStar

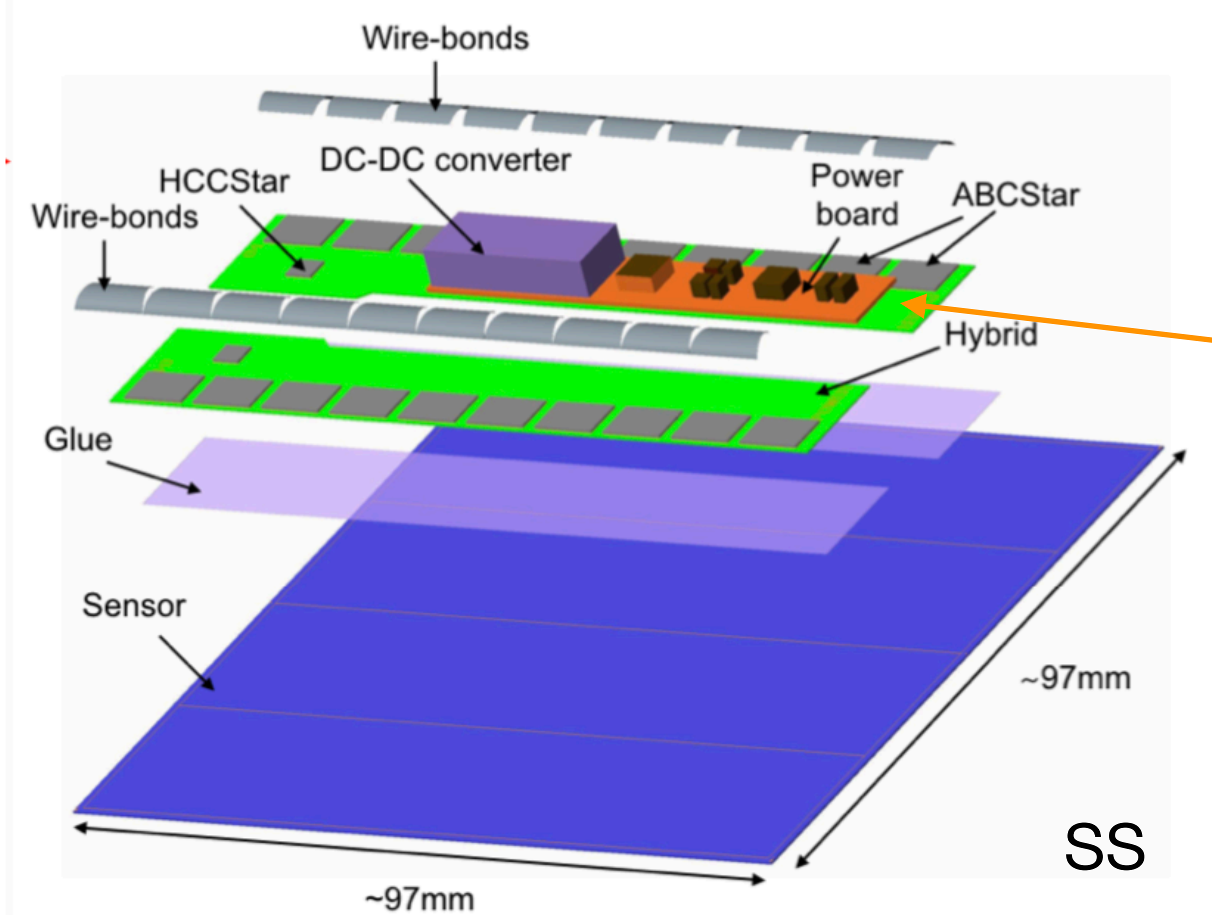


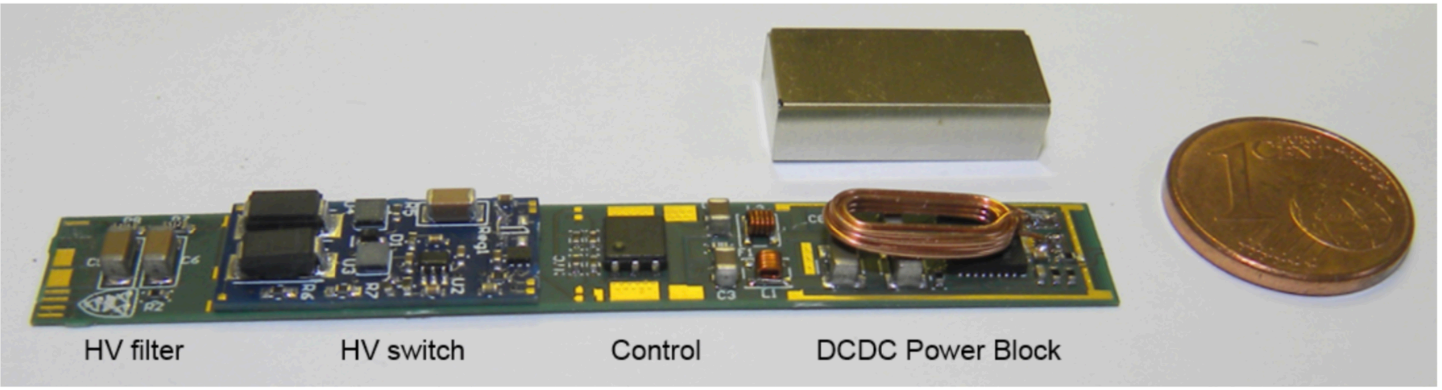
The Hybrids

- **One** hybrid for a **LS** module and **two** for a **SS** module
- 10 ABCStars (ATLAS Binary Chips) per hybrid
    - Converts incoming charge signal into hit information
- 1 HCCStar (Hybrid Controller Chip) per hybrid
    - Interface between ABCStar and bus-tape

Barrel Strip Module Design

The basic unit of the ITk Strip Detector is the silicon-strip module



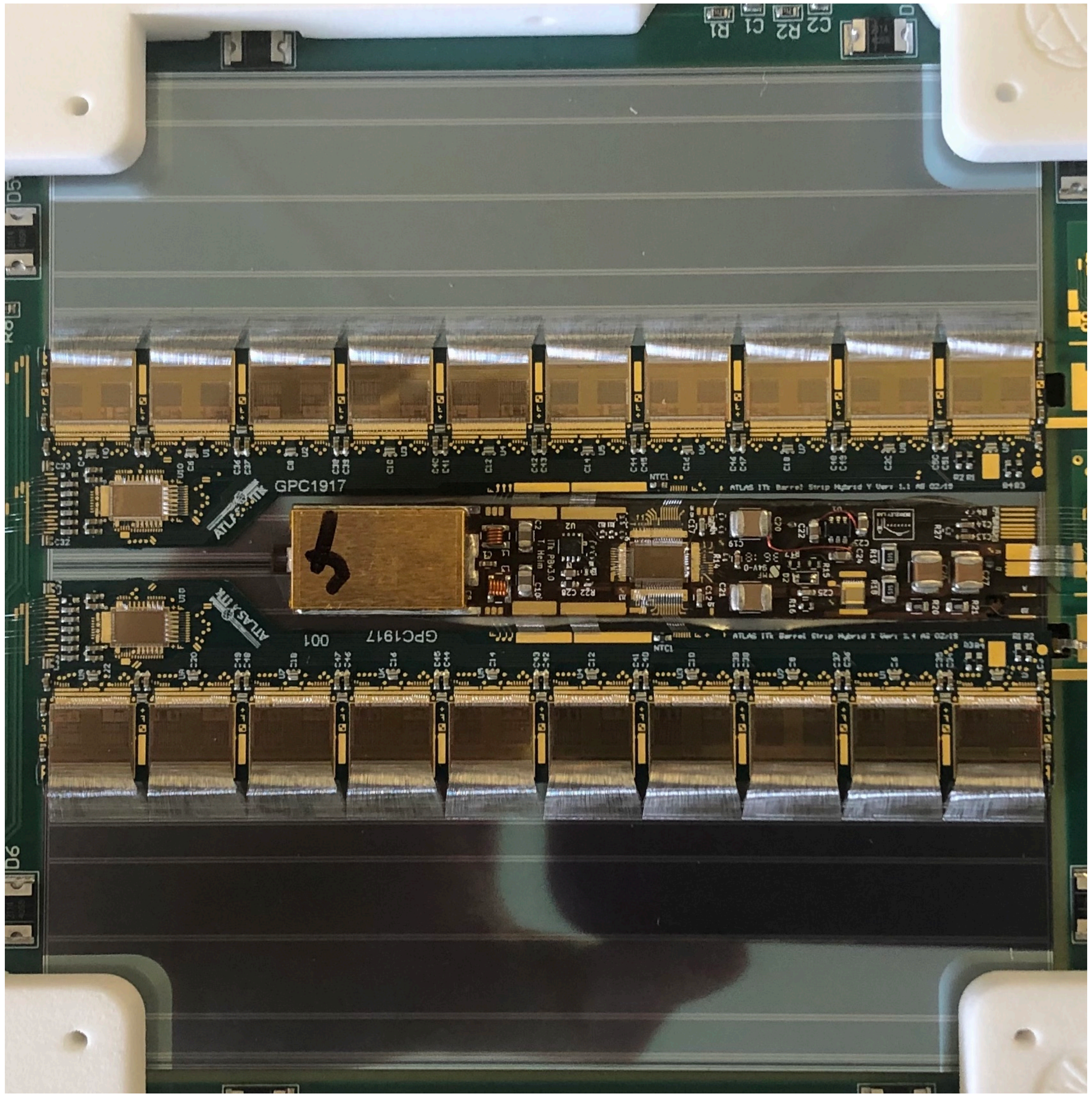


The Power Board

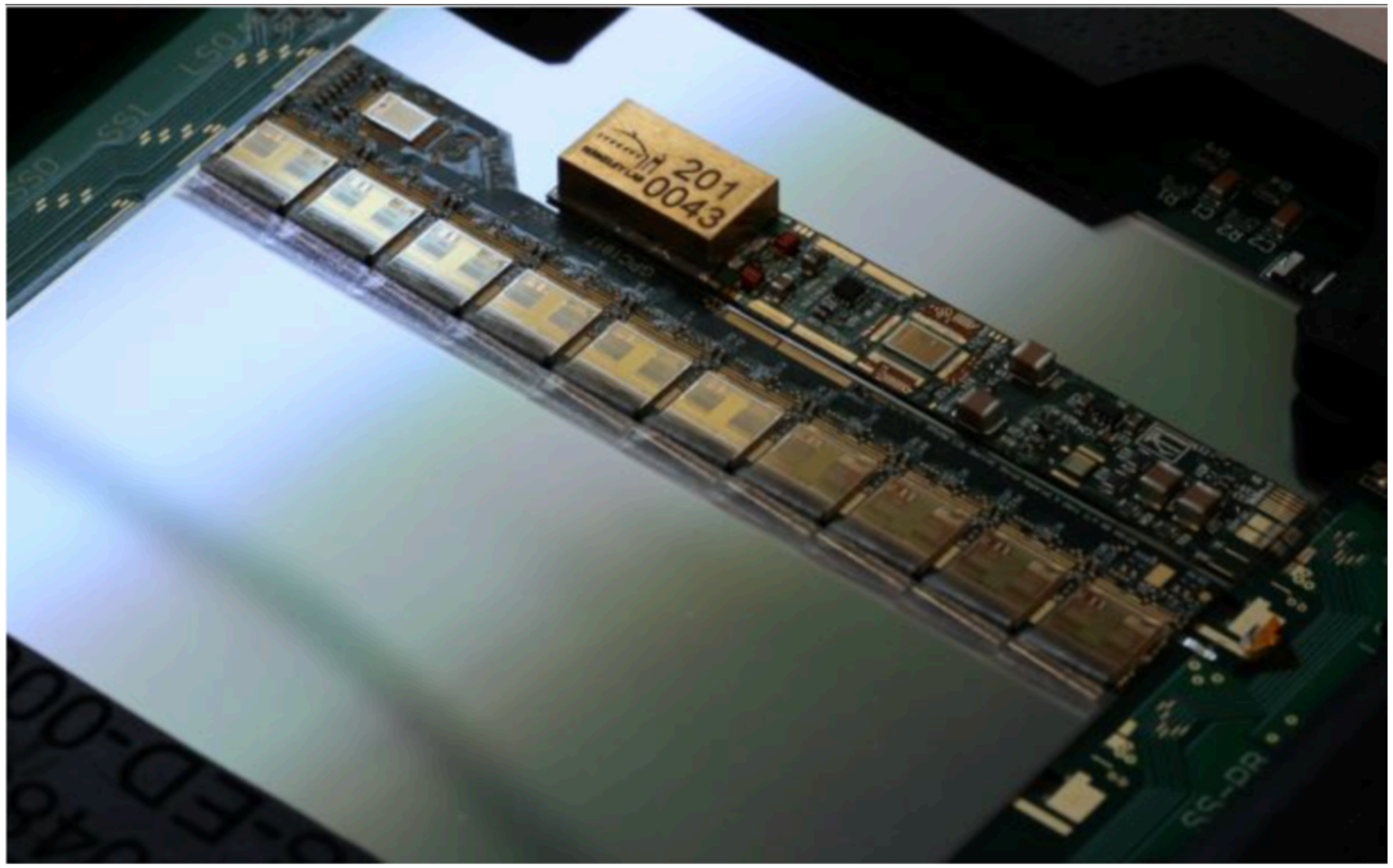
- One per module
- Provides low voltage for the ASICS
- Switchable sensor HV bias
- Hosts an AMAC (Autonomous Monitor And Control)
  - Monitors temperature, voltages and currents

Barrel Strip Module Design

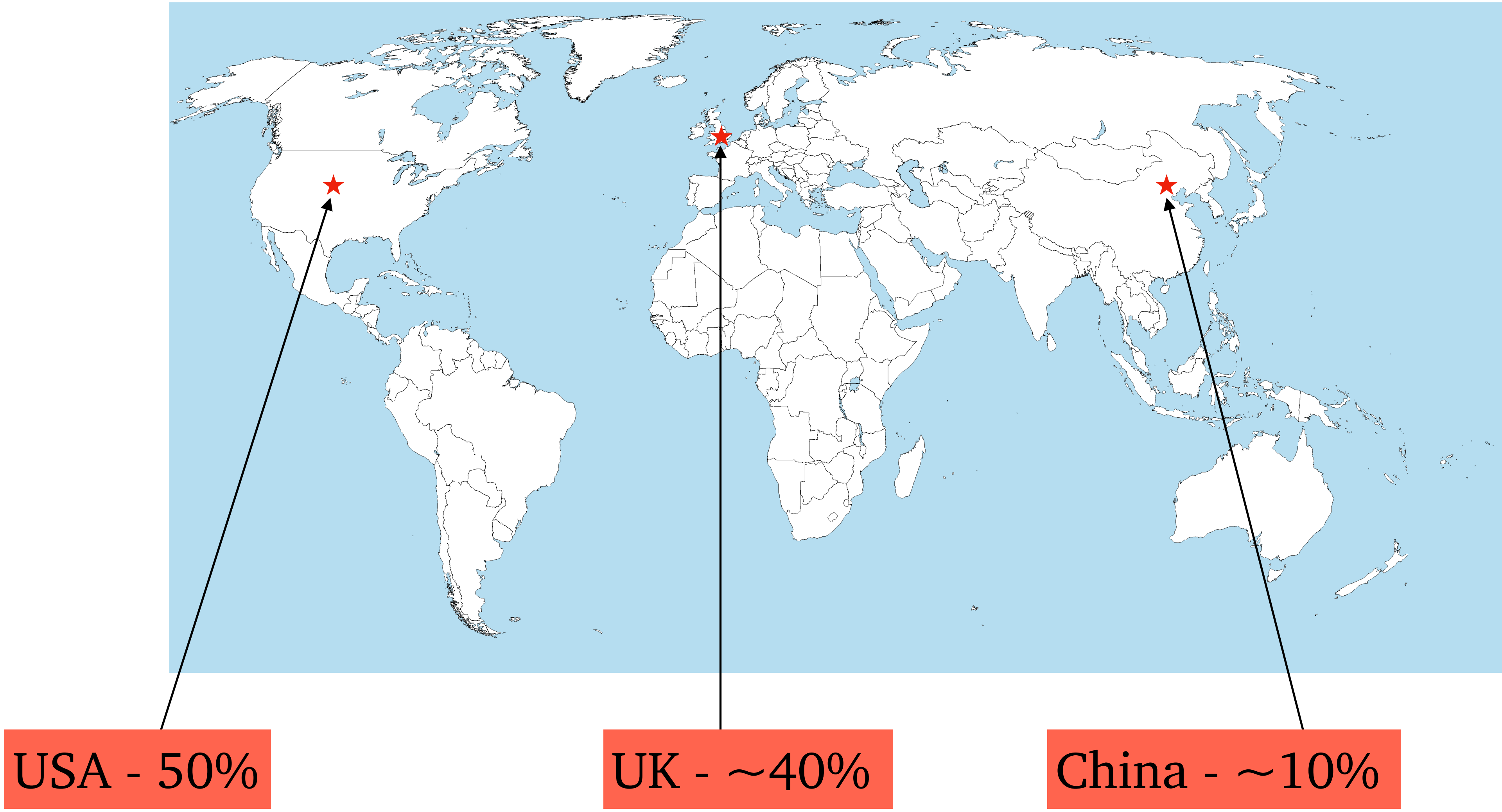
Short Strip (SS) Module



Long Strip (LS) Module



Worldwide Barrel Module Production

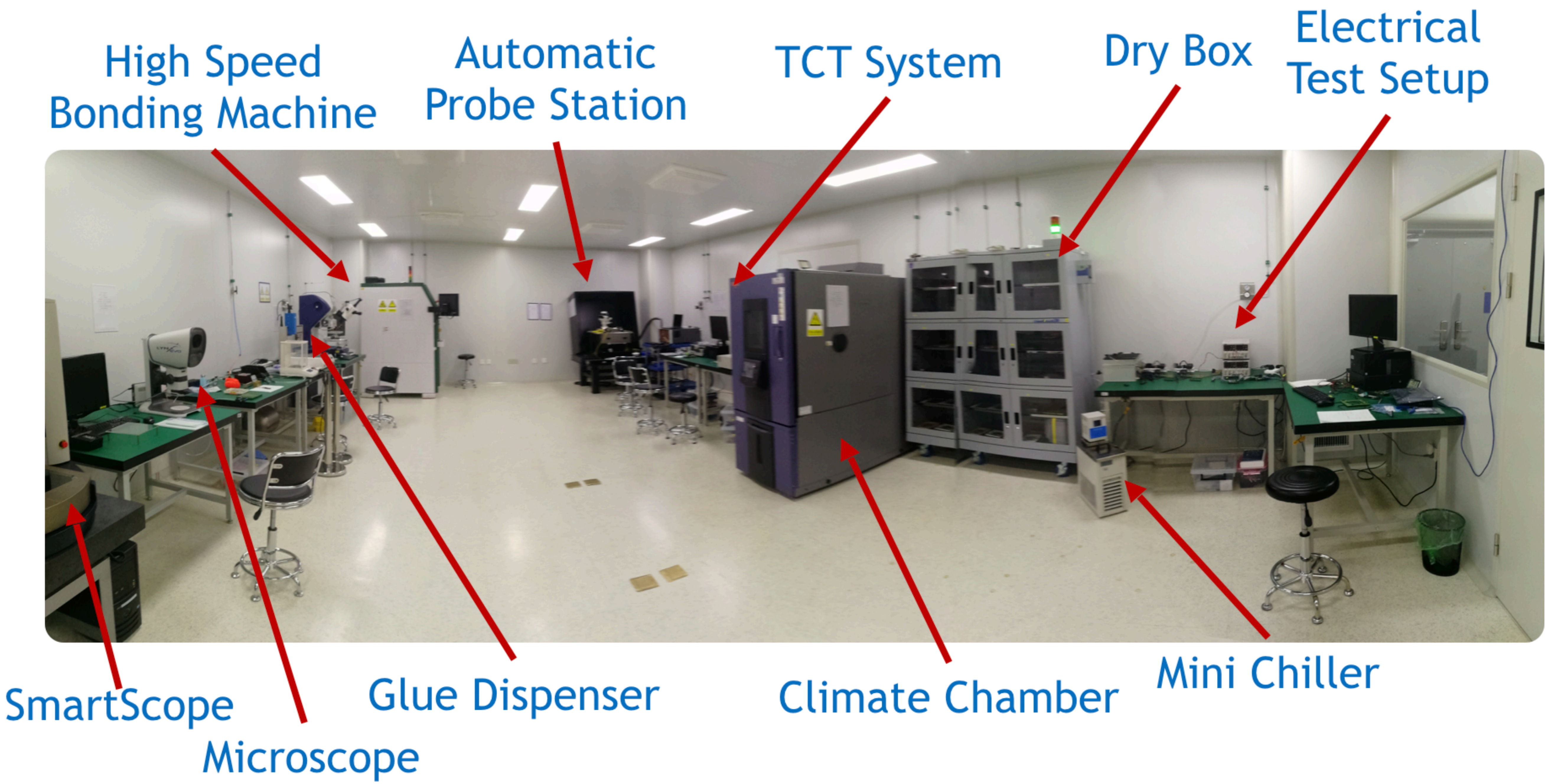


- 12000 barrel modules in total
- China has committed to build 1000 Modules
  - 500 at IHEP
  - 500 at RAL in the UK

Science & Technology Facilities Council
Rutherford Appleton Laboratory

- IHEP aims to have two representatives at RAL at all times

Cleanroom at IHEP



- 80m^2 Class 10,000 clean room opened in April 2019
- Dedicated to ATLAS ITk module production

Cleanroom at RAL (UK)

Smart Scope Glue Robot Module Electrical Testing Area

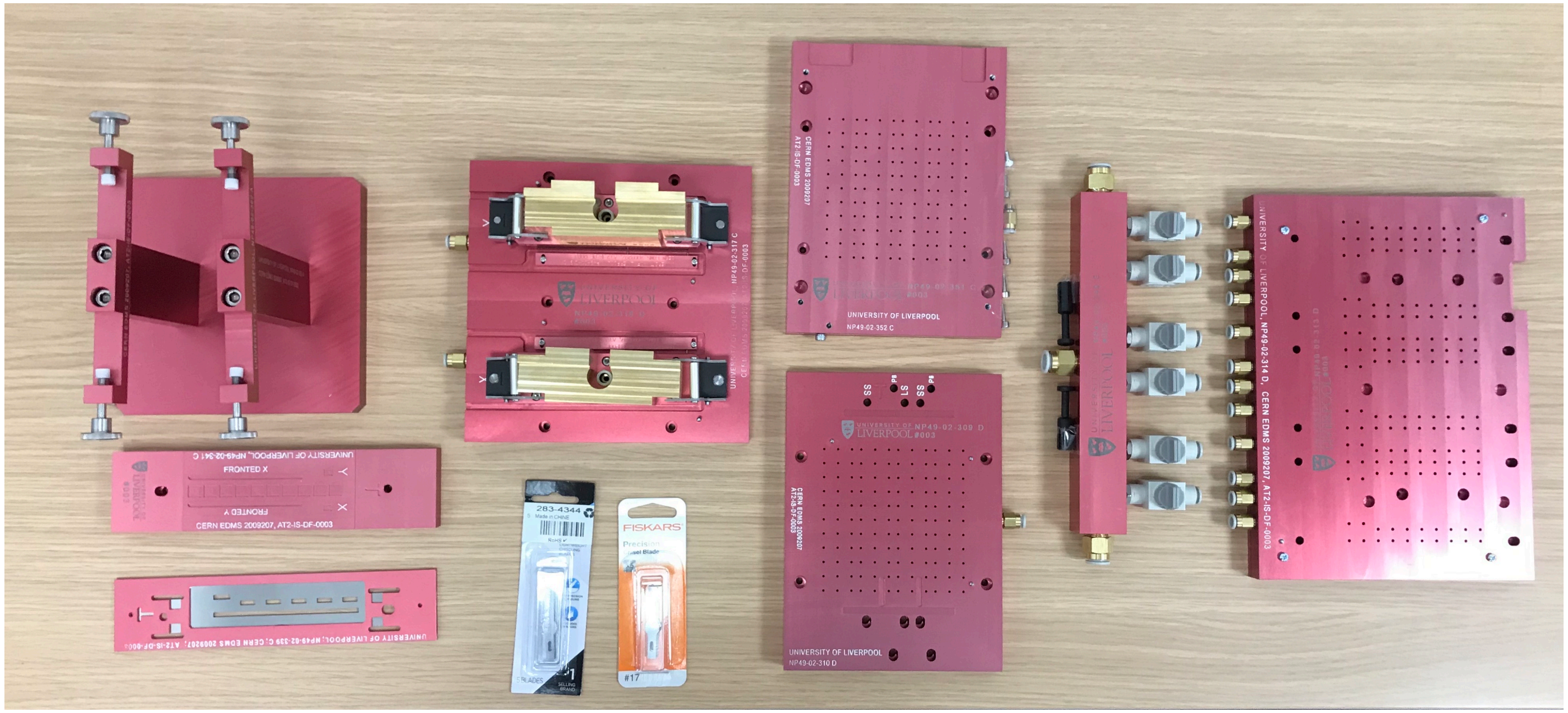
- Currently moving to a newly built cleanroom

Module Assembly Steps

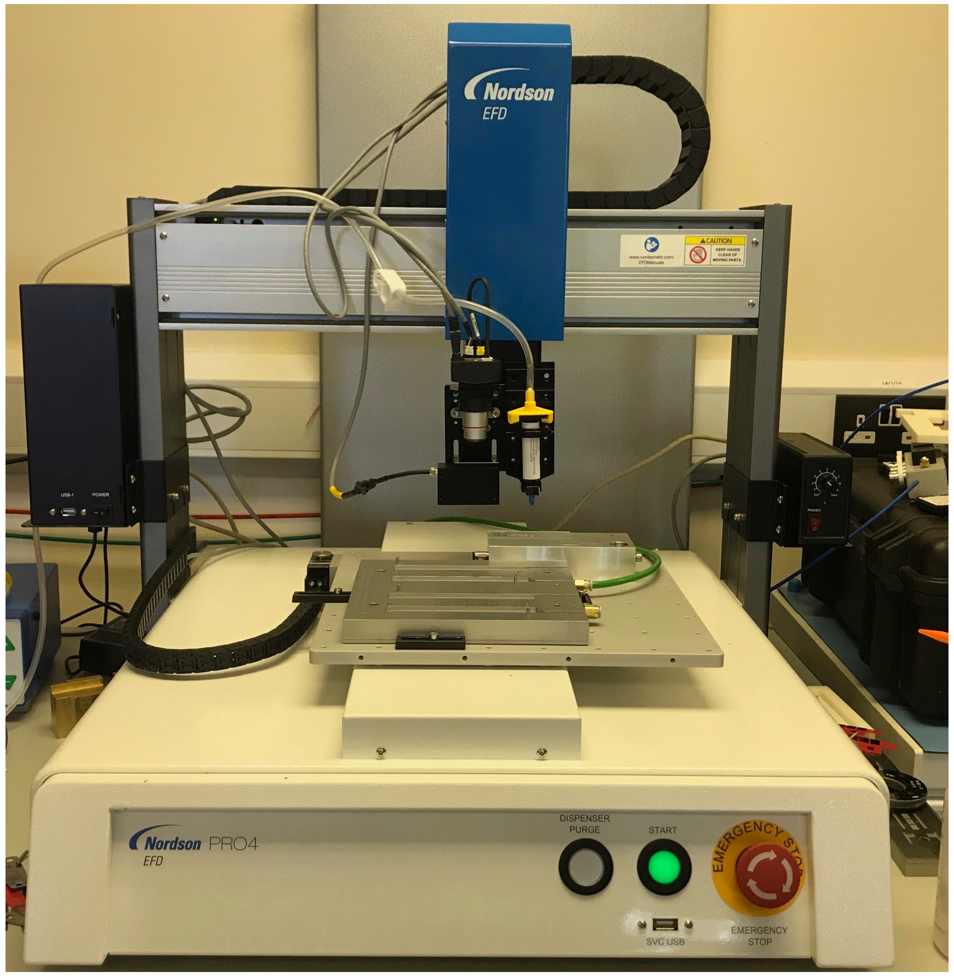
The assembly steps to construct a module are:

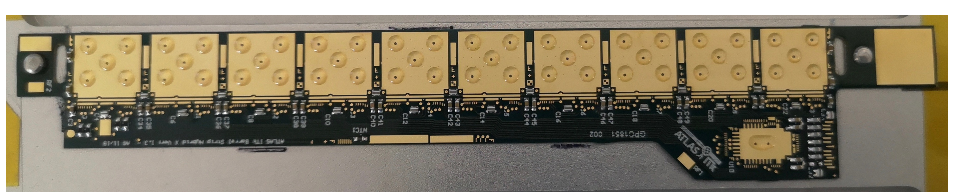
- **Pre-tested ASICs are glued onto hybrids and wire bonded**
- Hybrids are tested electrically
- **Hybrids and power boards are glued to the sensor**
- **ASICs are wire bonded onto sensors**
- Full module is tested

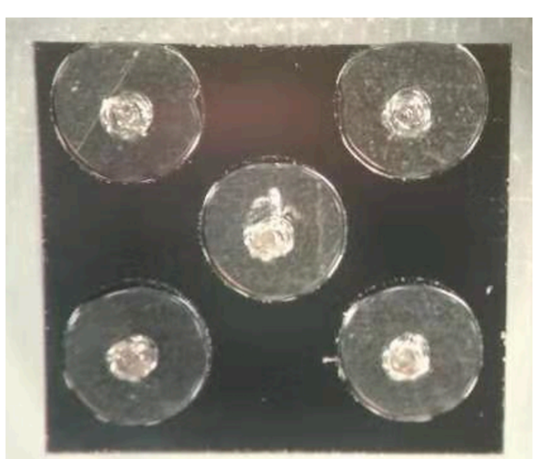
Toolset for Module Assembly



ASIC to Hybrid Gluing

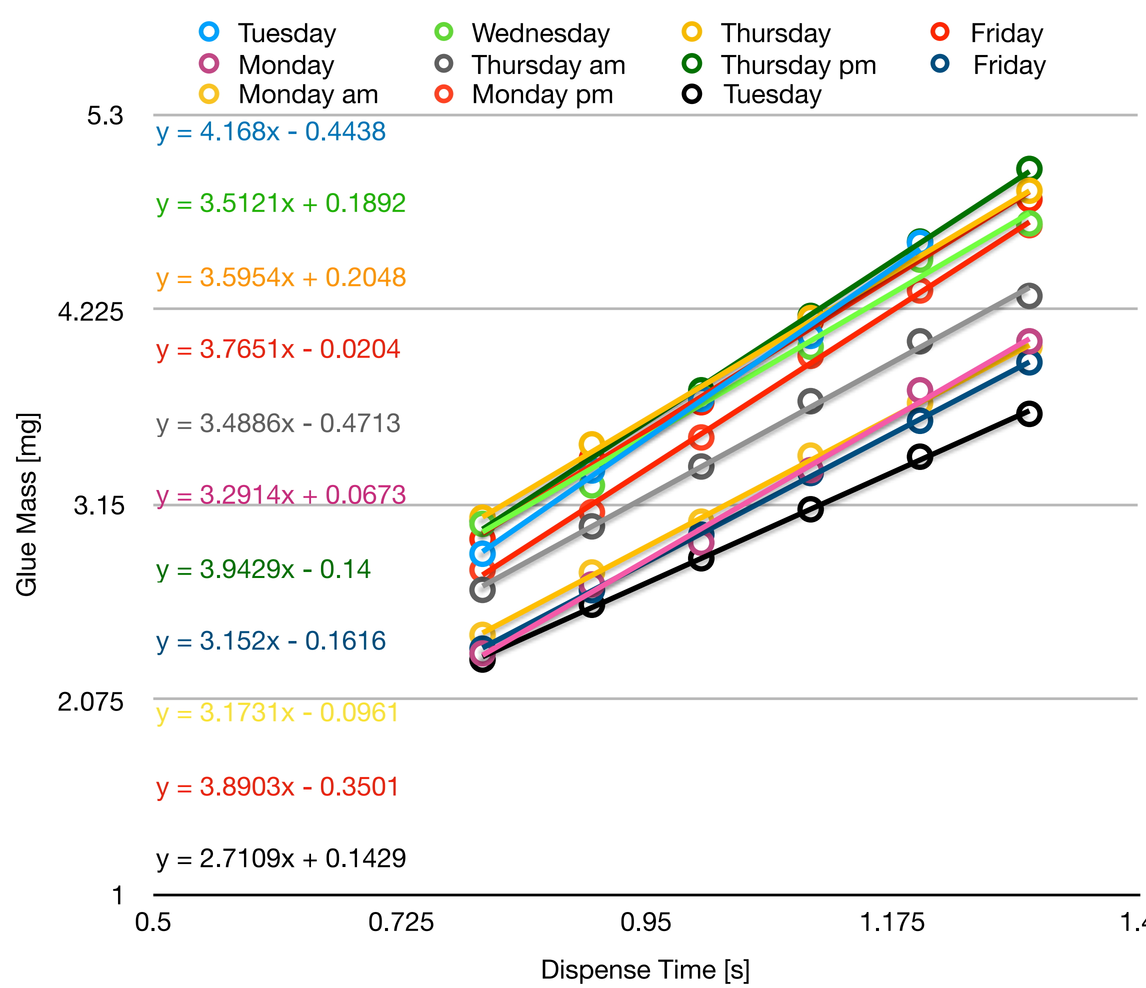






Glue Robot is used to apply glue to the Hybrid

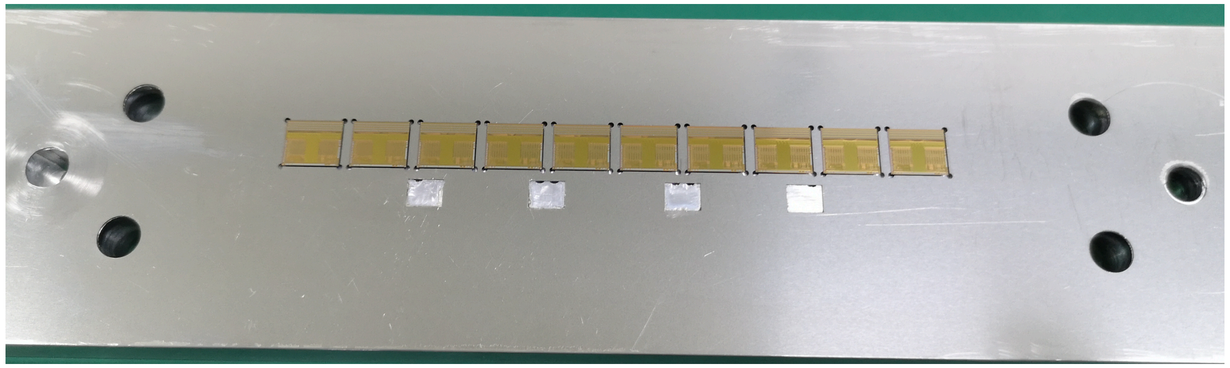
- 5-dot pattern programmed for each ASIC
- Need to calibrate such that each ASIC has ~4.3mg of glue
- Adjust the needle height, dispense time and pressure
- Variations in the calibration depending on the temperature of the room



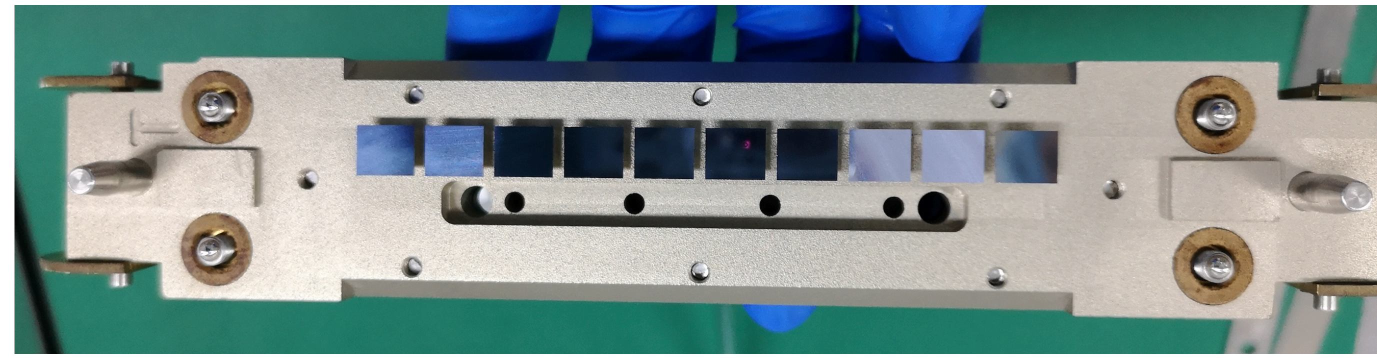
Day	Air Temp [°C]
Tuesday	21.7
Wednesday	21.5
Thursday	21.2
Friday	21.6
Monday	18.5
Thursday am	
Thursday pm	19.7
Friday	18.1
Monday am	17.85
Monday pm	19.1
Tuesday	16.8

ASIC to Hybrid Gluing

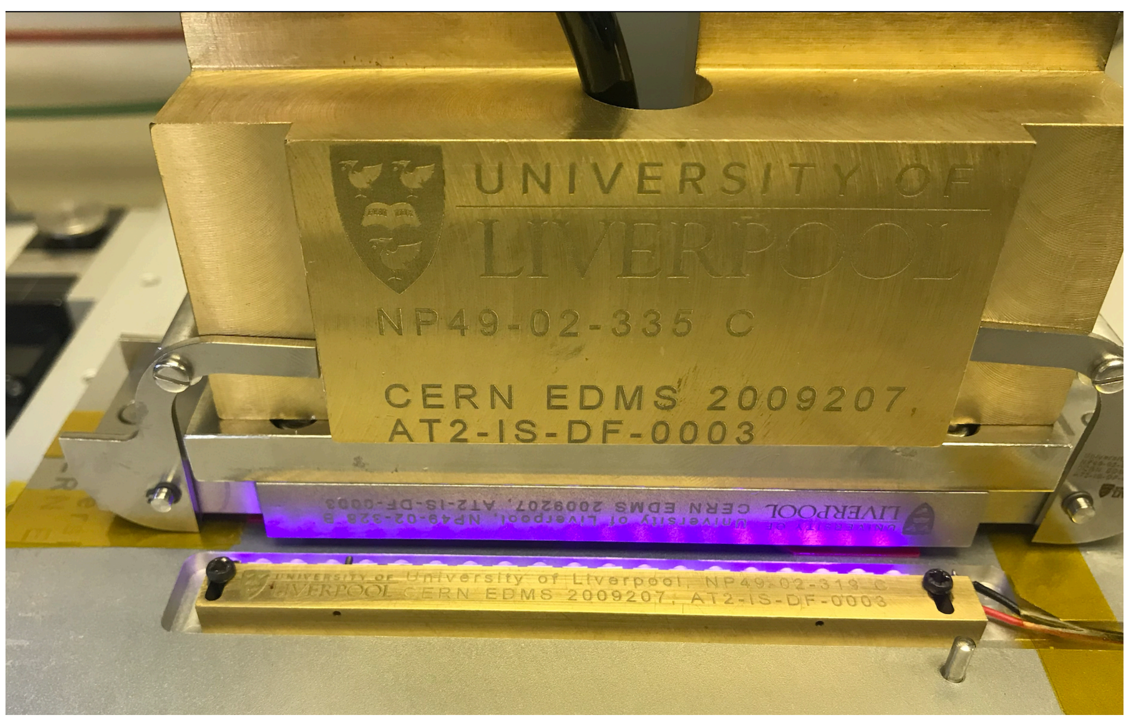
ASICs placed on chip tray



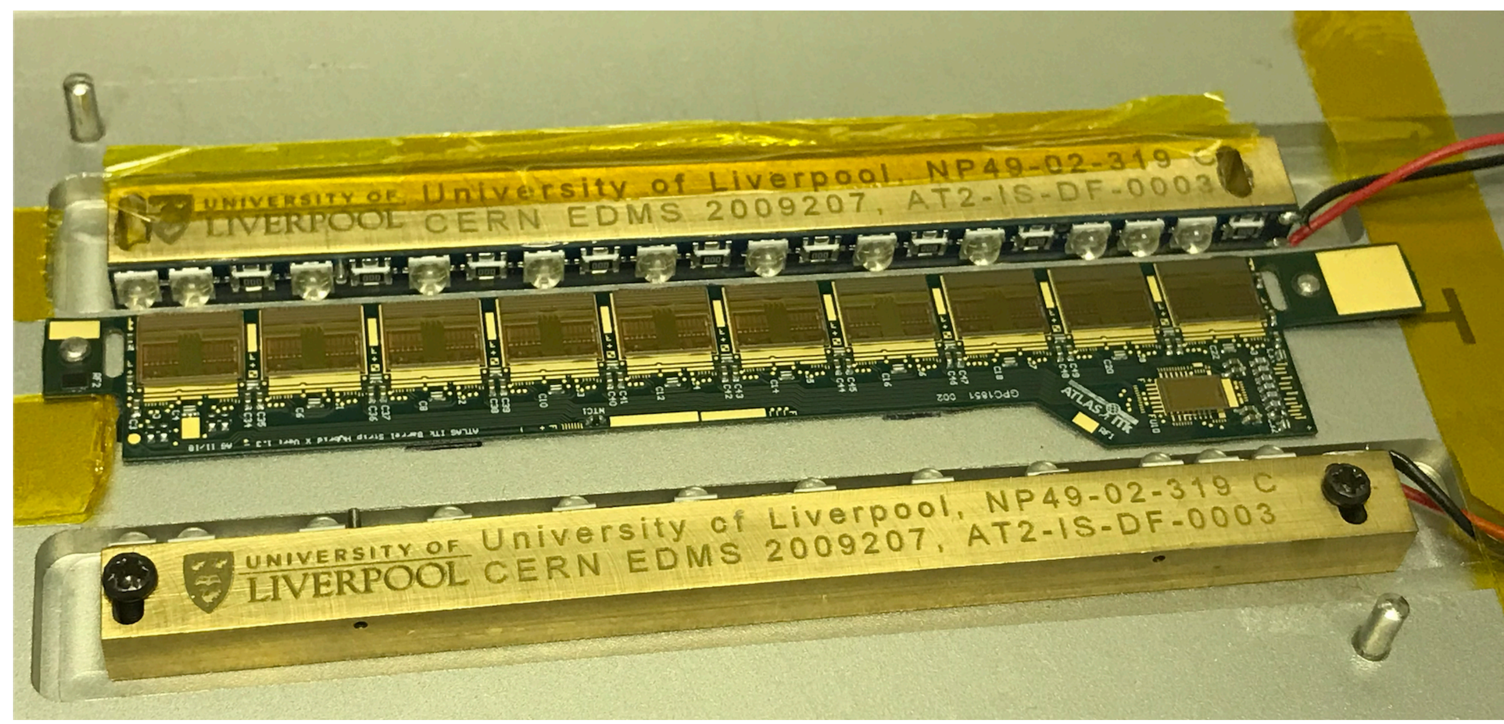
ASICs picked up using vacuum pick up tool



ASICs placed onto hybrid



ASIC fully assembled



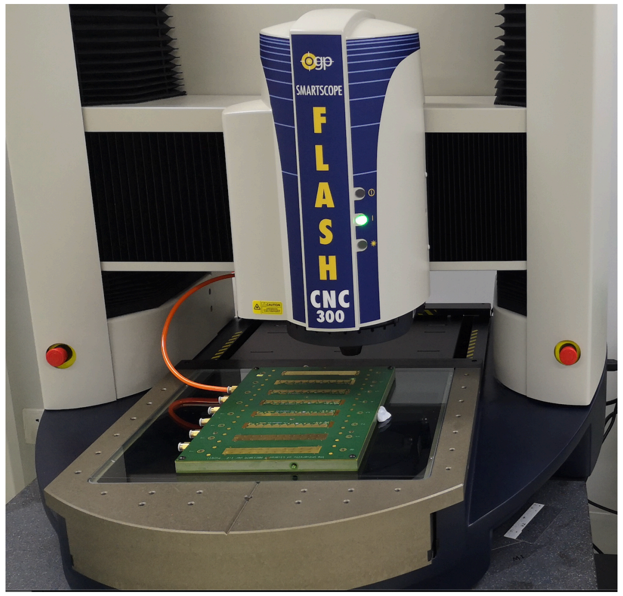
- UV LED lights are used to cure the glue
- A weight is placed on top to ensure consistent glue thickness

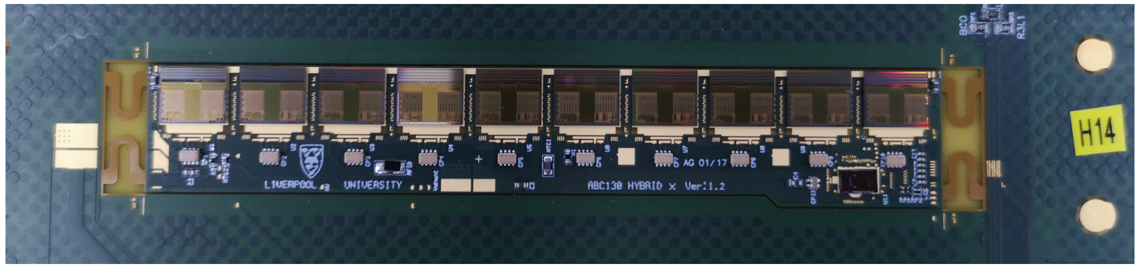
- The hybrid is now ready for ASIC wire bonding

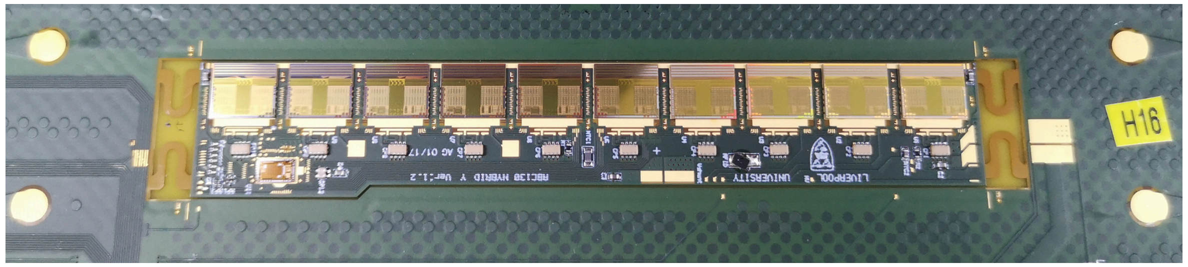
Metrology of the Glue Thicknesses

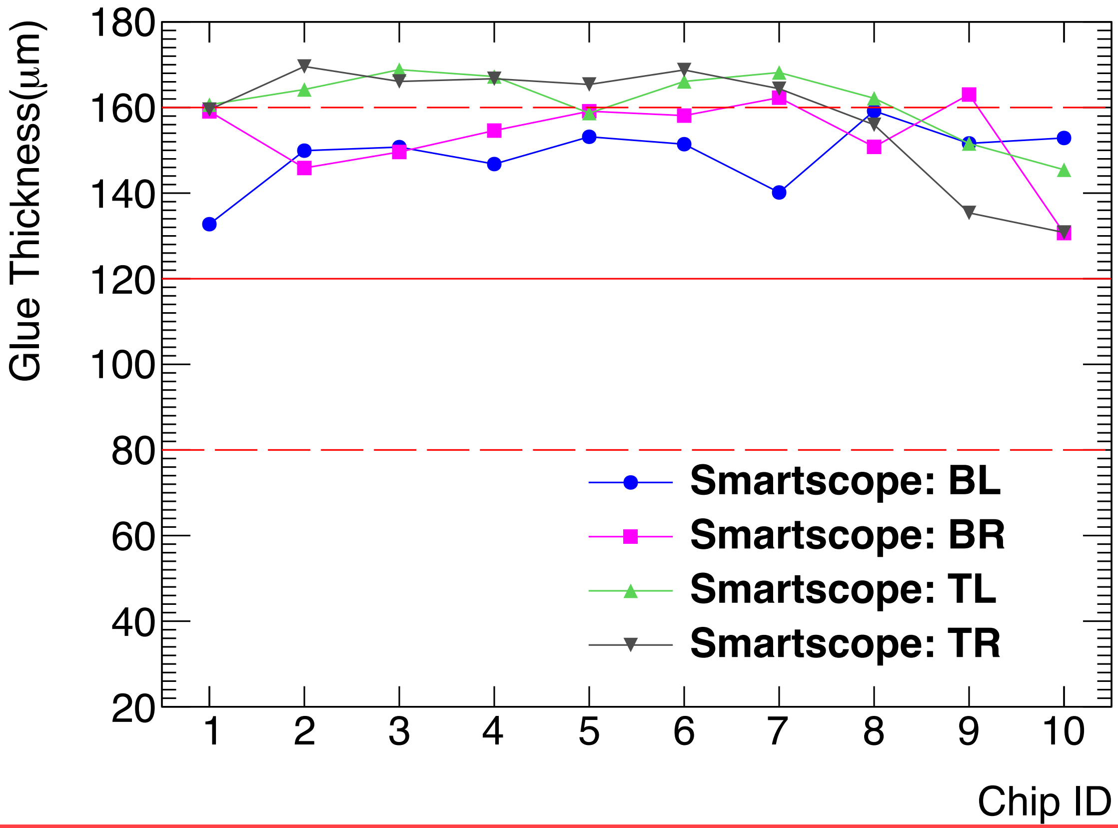
Quality Control

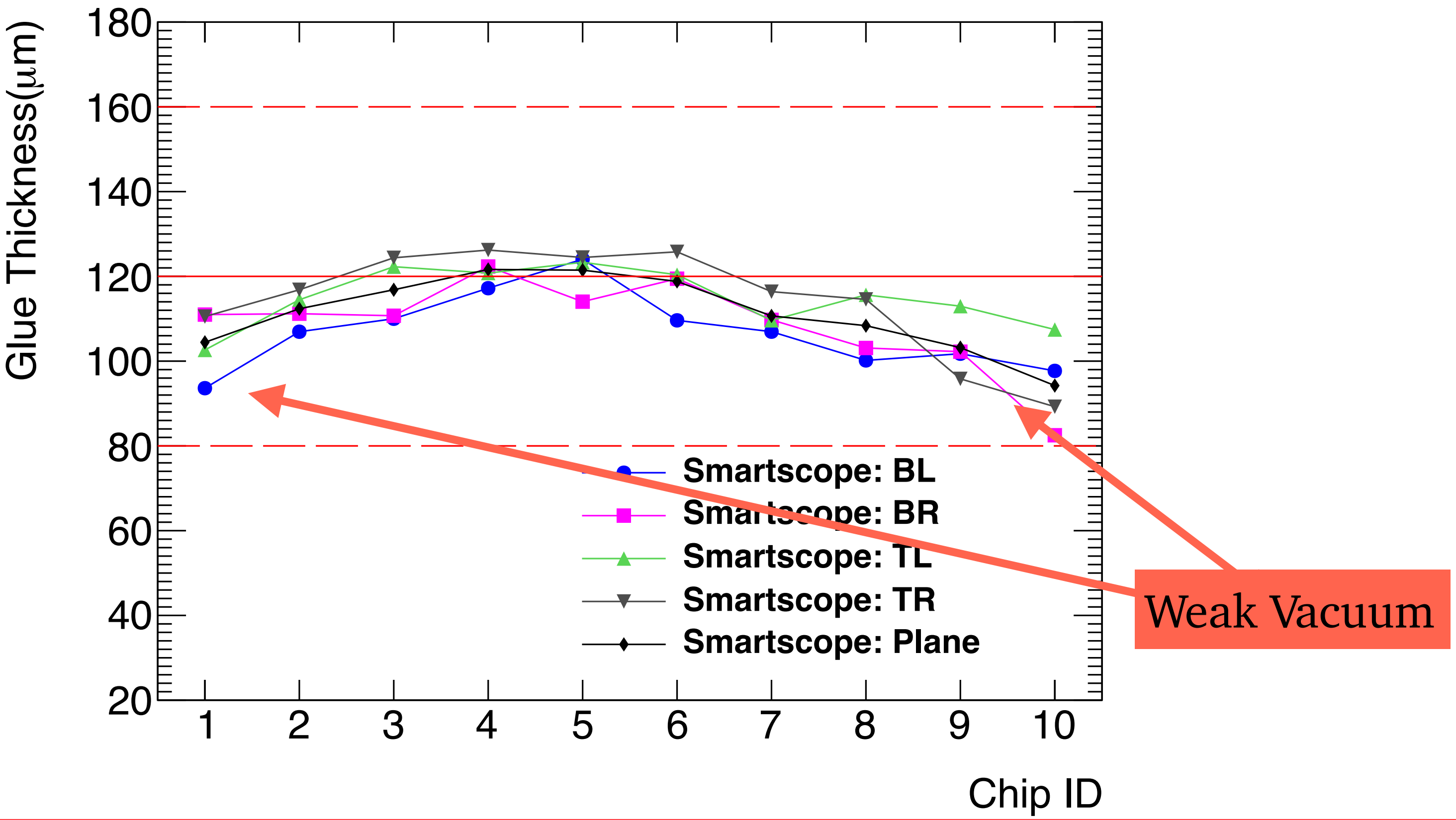
- The tools are designed such that the glue thickness/distance from hybrid to ASIC should be ~120±40μm
- This is checked using a smart scope
- Results shown are using ABC130, predecessor of the ABCStar



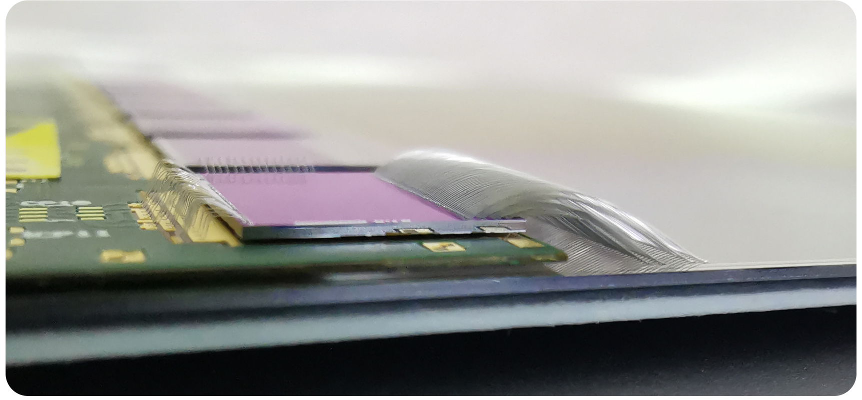




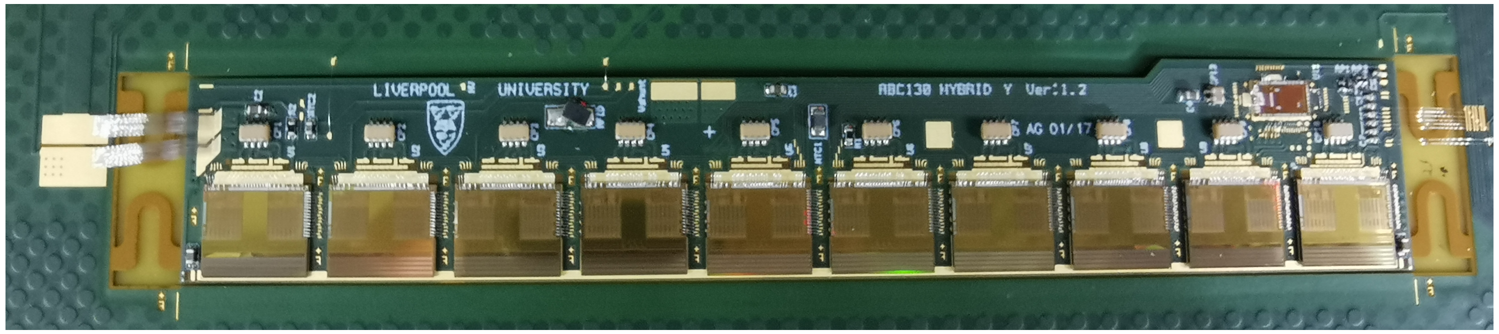




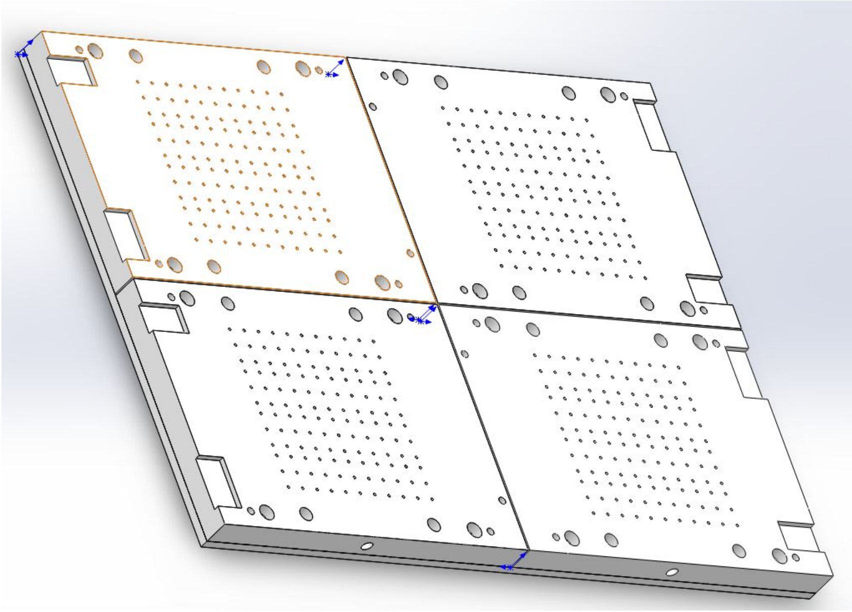
Wire Bonding



- IHEP Postdoc (Yuzhen) trained to wire bond by experts at RAL using the a program designed by Paul Booker
- Successful wire bonded 1st and 2nd electric hybrid at IHEP using ABC130

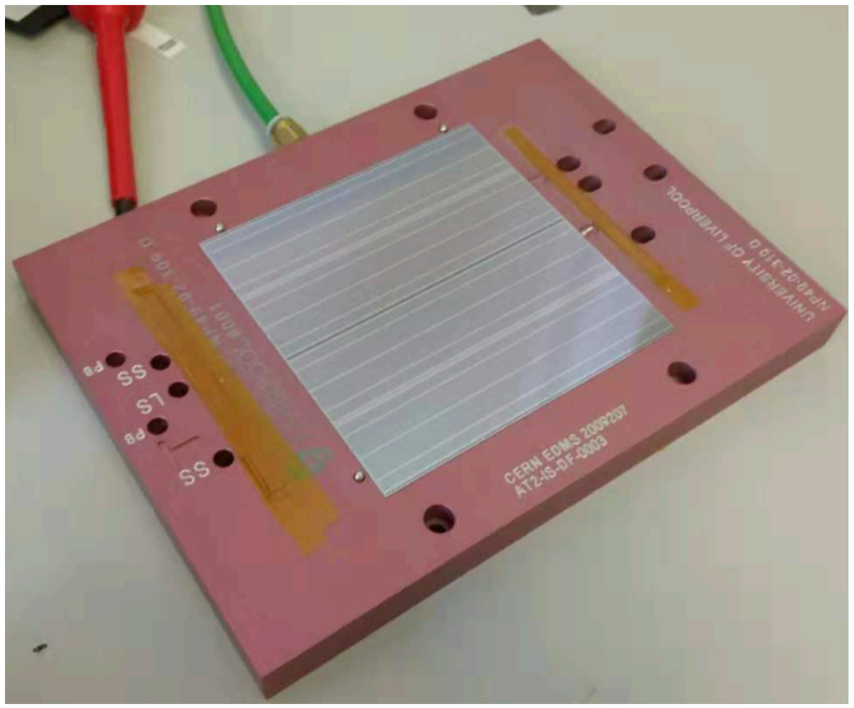


- Bond test machine (DAGE 4000plus) is ready for pull test
- Next steps:
  - Pull test for parameter optimisation
  - Front-end wire bonding for a full module
- Star 2x2 jig: to improve the bonding efficiency and to check the maximum number of modules per day per bonder
- Design 1st version, now circulate for advices and comments

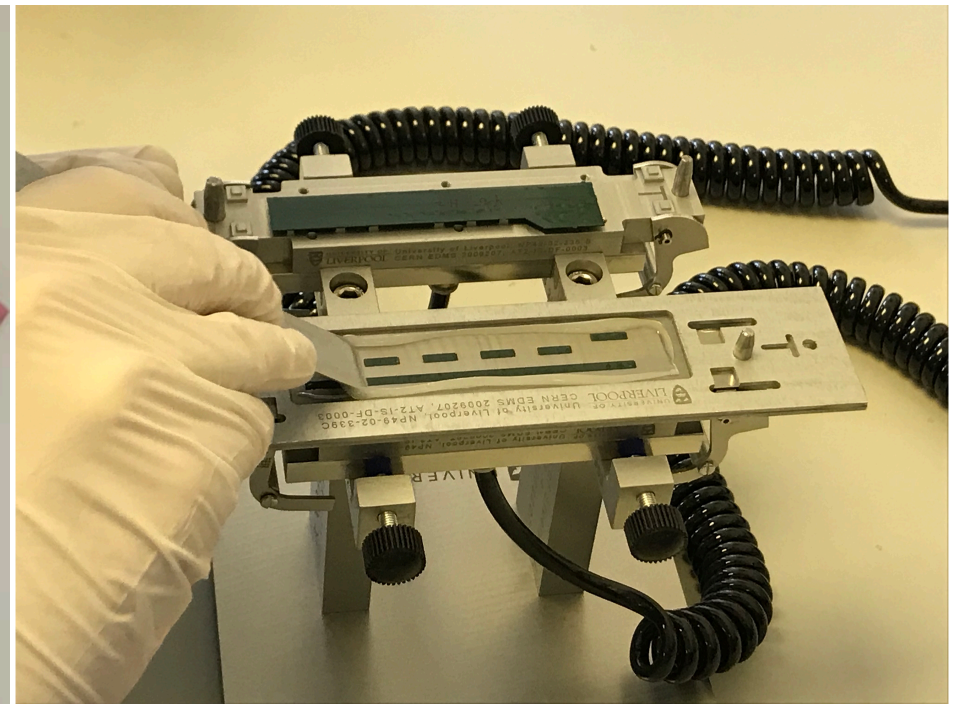


Hybrid to Sensor Assembly

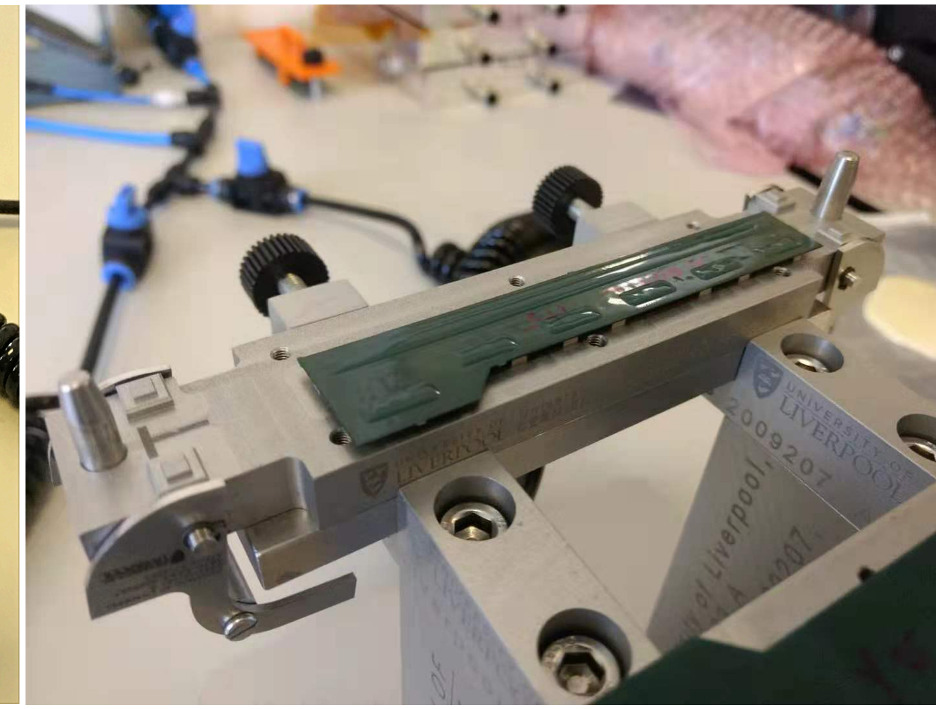
Sensor secured on vacuum plate



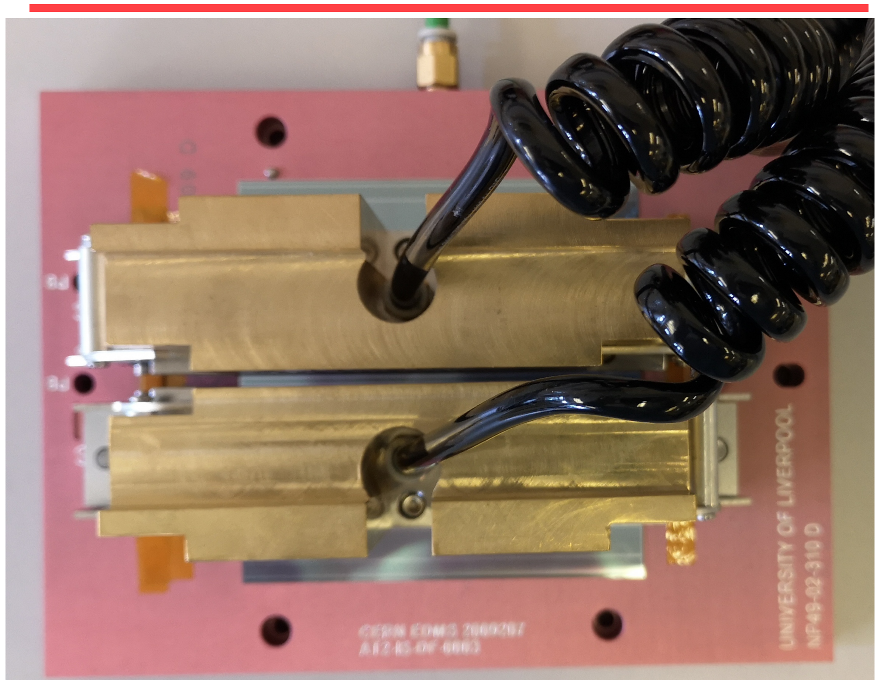
Stencil is then placed on top of the hybrids and glue is applied



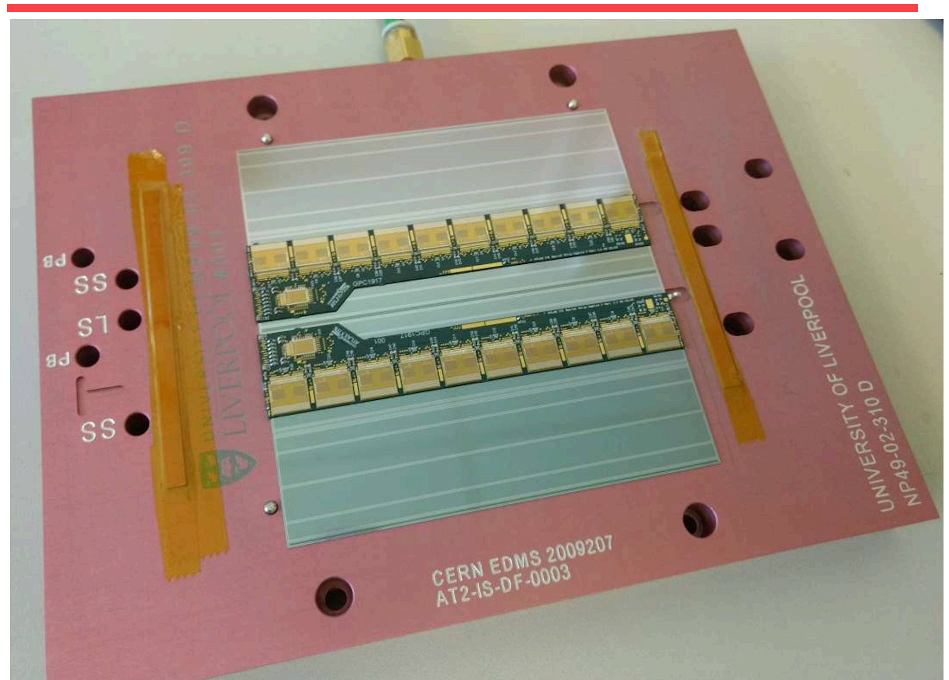
Resulting glue pattern



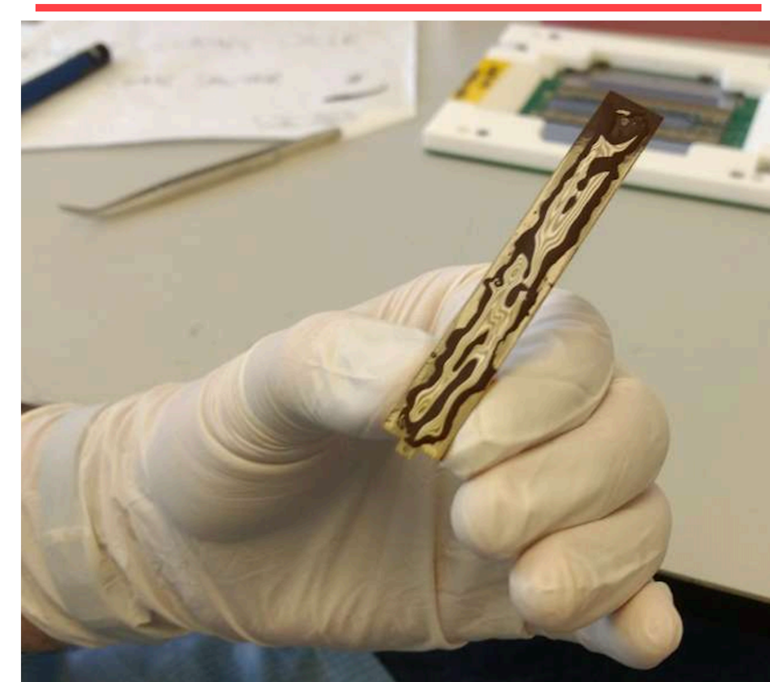
Hybrids are placed on sensor and left over night to cure



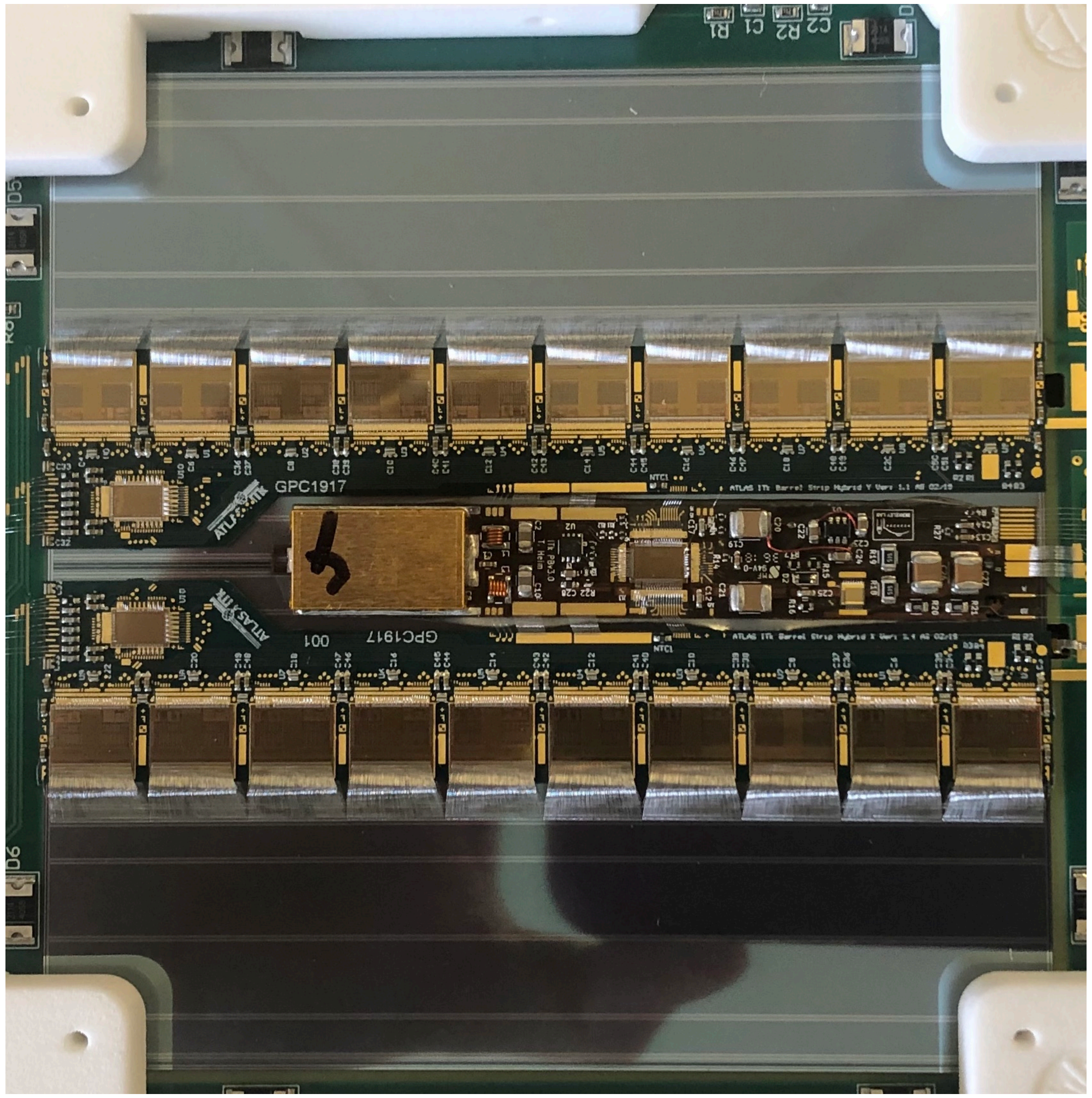
Sensor and hybrids after glue curing

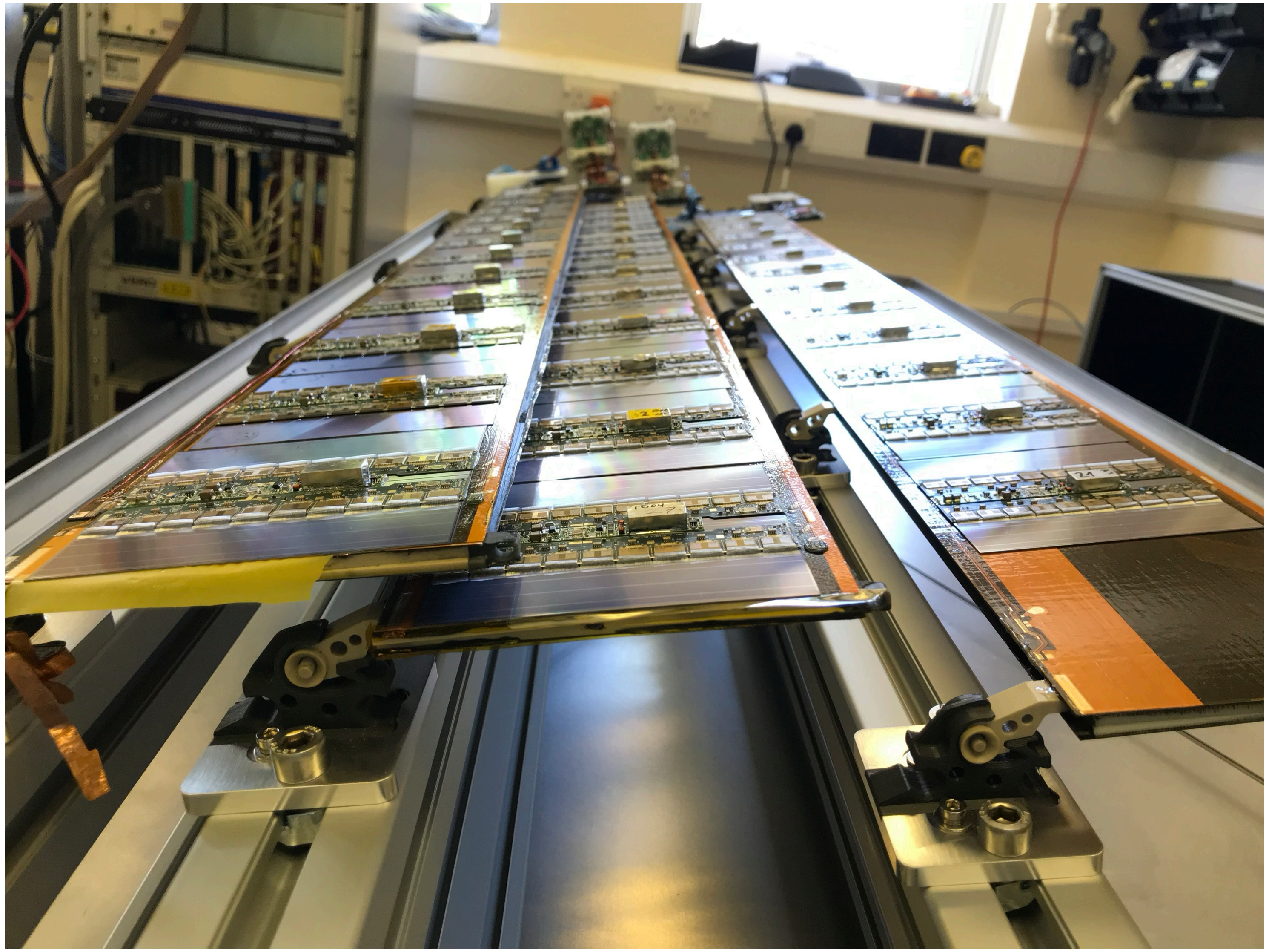


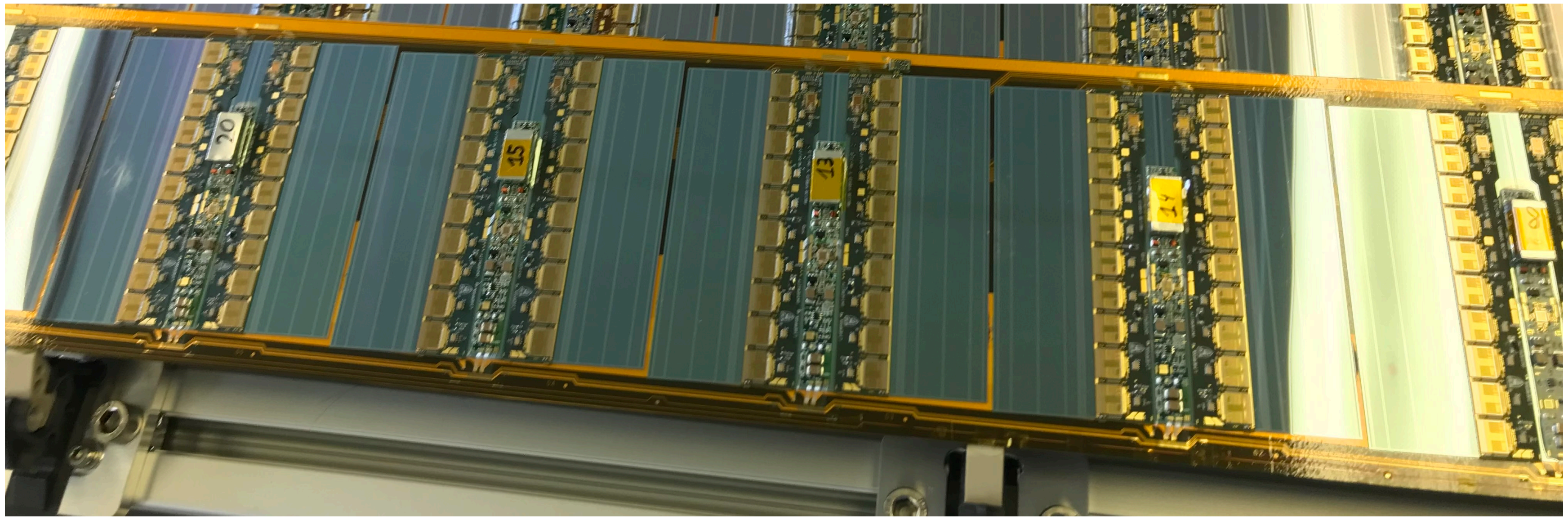
Power board glue applied without stencil



Complete Module and Prototype Staves

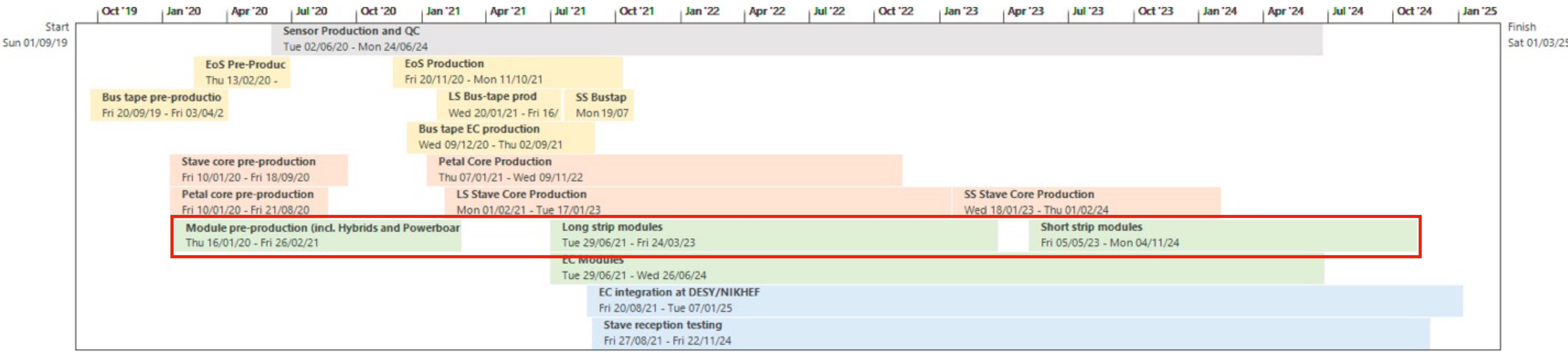






- Once the modules have been assembled, electrically tested and passed Quality Assurance then they will be installed onto staves at RAL

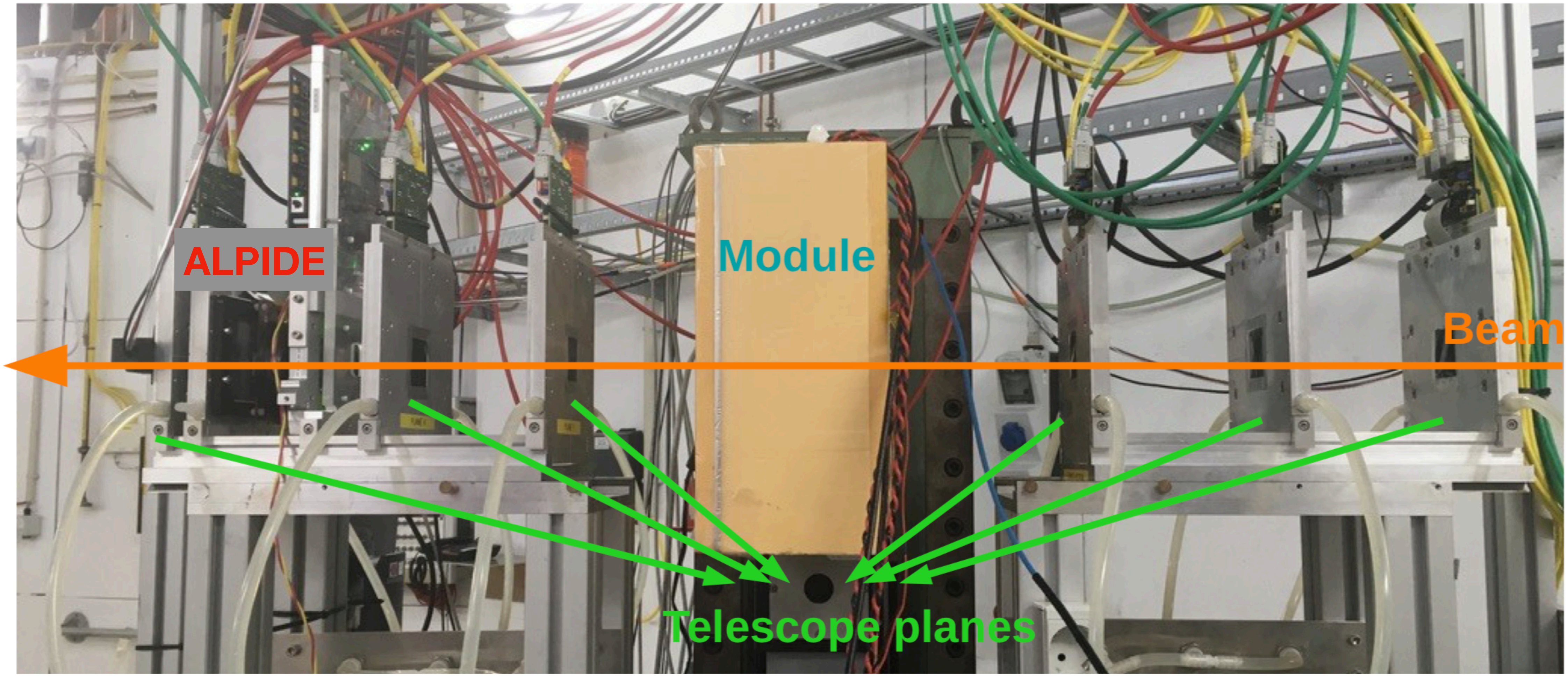
Production Timeline



- The pre-production starts early next year
- **LS** module production begins in the middle of 2021
- Followed by **SS** production in the middle of 2023

Testbeam at DESY

EUDET-type Telescope

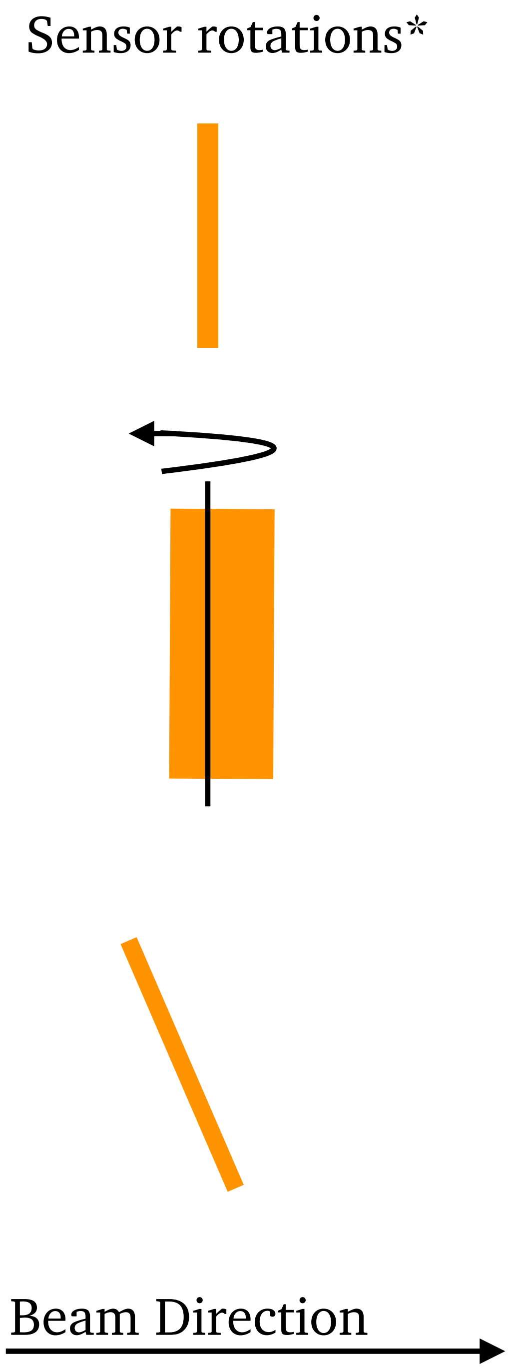


- DESY provides an electron beam with energy up to 6 GeV
- The DUTs are installed in the centre on a rotational stage
- FEI4 is needed for time tagging the telescope tracks (Alpide plane was used for the June testbeam)
- Telescope has a pointing resolution ~5-10 µm

LS Data Studied

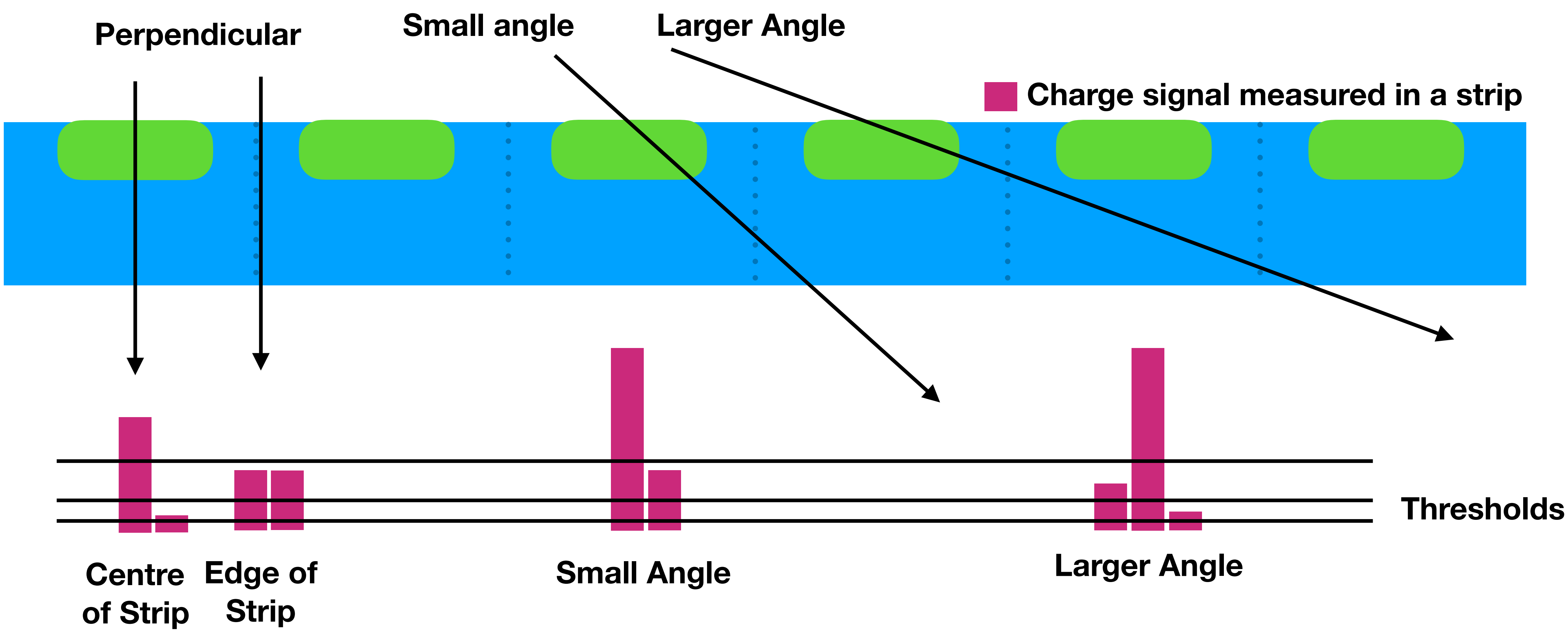
Threshold scans at different angles (400 V)

- Angles studied:
  - **Perpendicular - 0 degree angle**
  - **5 degree angle around the y-axis**
  - **12 degree angle around the y-axis**
  - **23 degree angle around the x-axis (forward angle)**



* The sensors are mounted such that the strips are vertical

Angular Rotations - y-axis



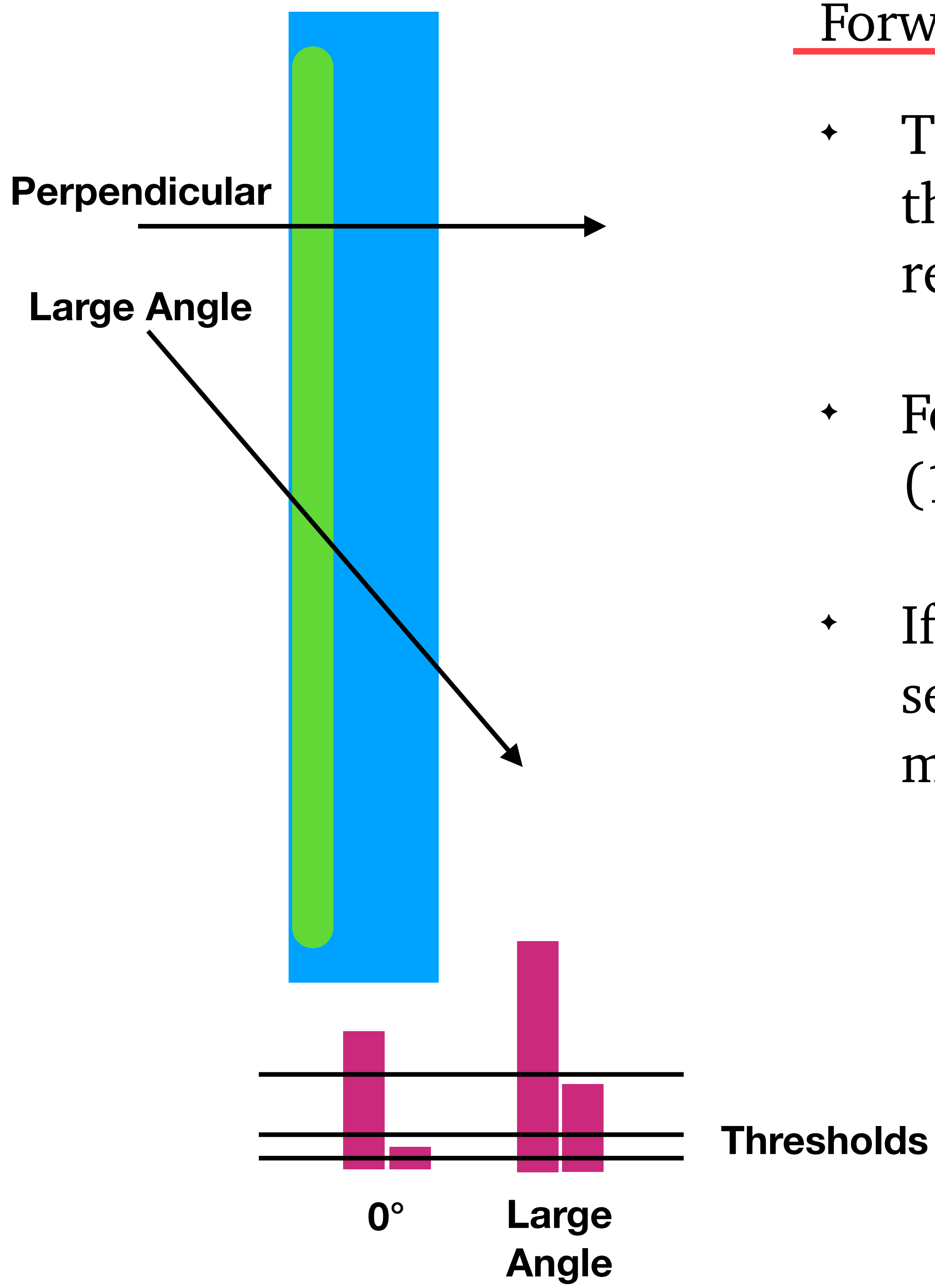
For perpendicular tracks:

- Charge sharing depends on the intra-strip hit position
- If track hits the edge between strips, charge is shared but the charge signals in each strip are smaller and more susceptible to being lost at higher thresholds

For angled tracks:

- Higher probability that the track will traverse more than one strip
- Second or third strips may have very small signals and can be lost easily with increasing thresholds

Angular Rotations - Forward Angle (x-axis)

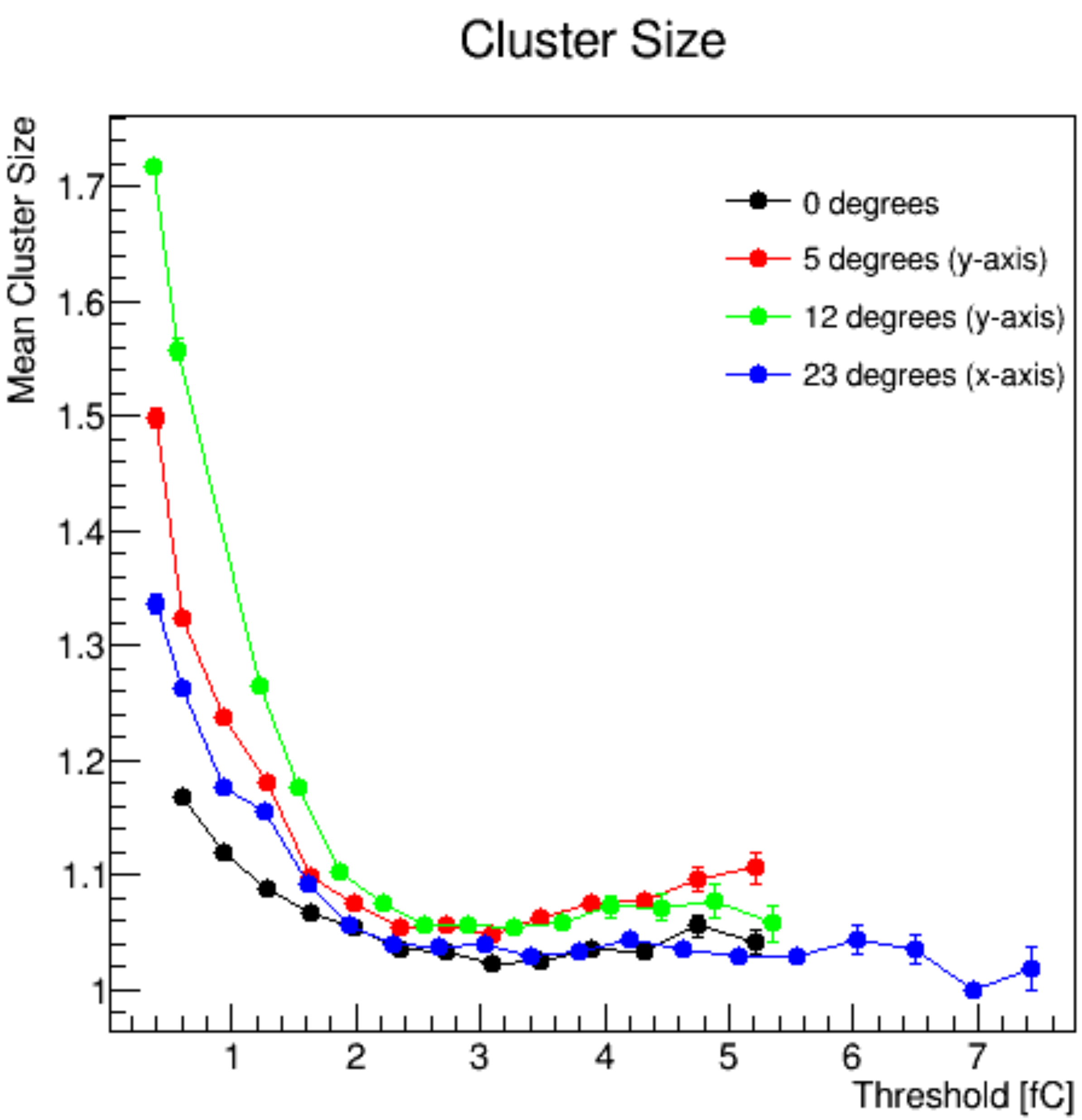


Forward Angles

- The particle tracks have a longer path length through the bulk of the sensor in the direction of the strips resulting in a larger charge collection.
- For 23° the path length increases by ~8.6% (1/cos(23))
- If charge is shared with a neighbouring strip the charge seen on the second strip will be larger than those measured from perpendicular tracks

LS Mean Cluster Size Comparisons

Mean cluster size as a function of the threshold



At low thresholds

- The largest cluster sizes are seen for angles 5° and 12° (y-axis) due to increased charge sharing between strips
- The forward angle (23°) has larger cluster sizes than perpendicular tracks due to the greater charge collection and the second strip seeing more charge

With increasing thresholds

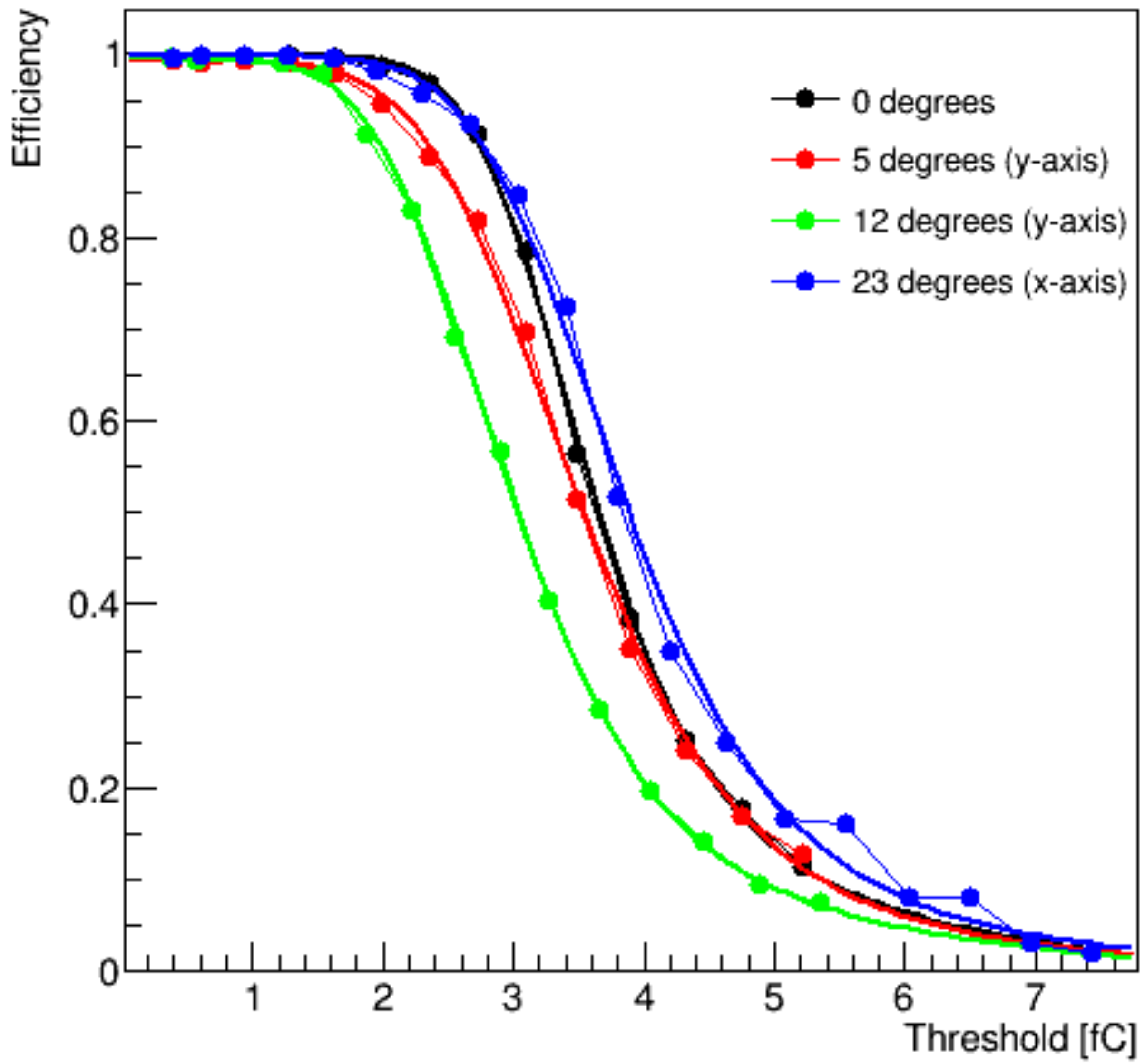
- The cluster sizes tend towards 1 due to smaller charge signals on neighbouring strips being lost

At high thresholds

- The cluster size tends to increase again due to delta rays

LS Efficiency Curve Comparisons

Full Strip



Median Charge

- 0 degrees - 3.654 fC
- 5 degrees - 3.541 fC
- 12 degrees - 3.031 fC
- 23 degrees - 3.890 fC

- The highest efficiencies over the full range of thresholds are for the perpendicular tracks and forward angle tracks
- The majority of charge is collected by one strip
- The forward angle has the overall highest efficiencies due to larger charge collection
  - The charge collection is ~6.1% more than the perpendicular angle. Less than expected.

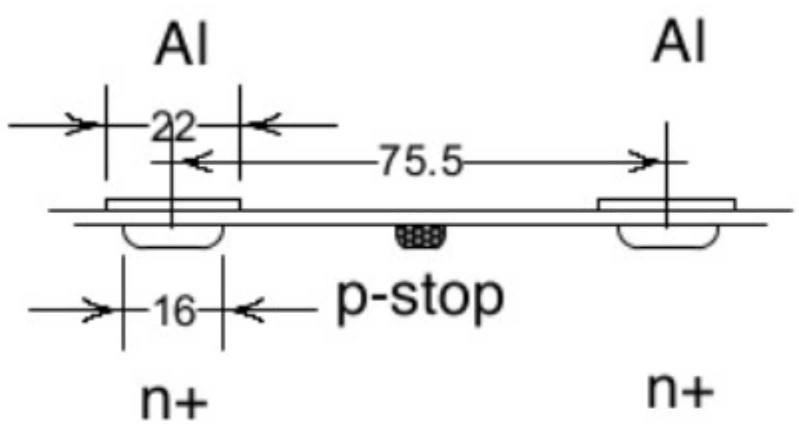
- The tracks that are at angles around the y-axis (5° and 12°) loose efficiencies at a lower thresholds due to charge sharing and the smaller charge signals on each strip

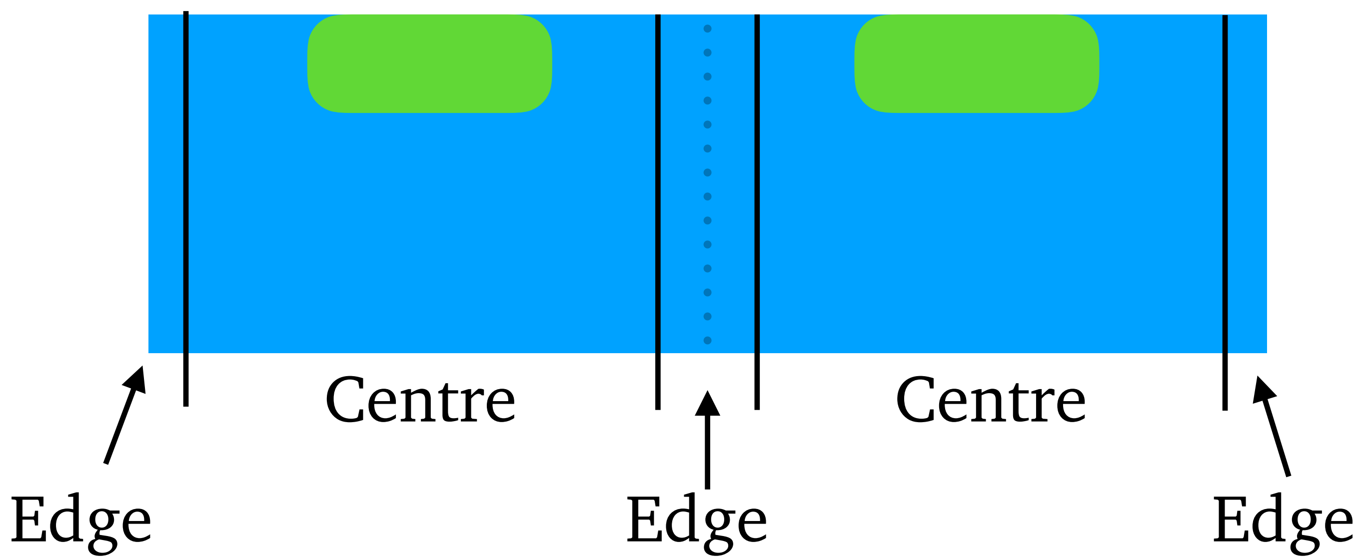
LS Efficiency Curve Comparisons

Strip Centre vs Edge of the Strip

Want to separate the tracks depending on whether they hit the centre or the edge of the strip

- Strip Pitch 75.5 μm
- Implant Size 16 μm
- Aluminium Strip 22 μm

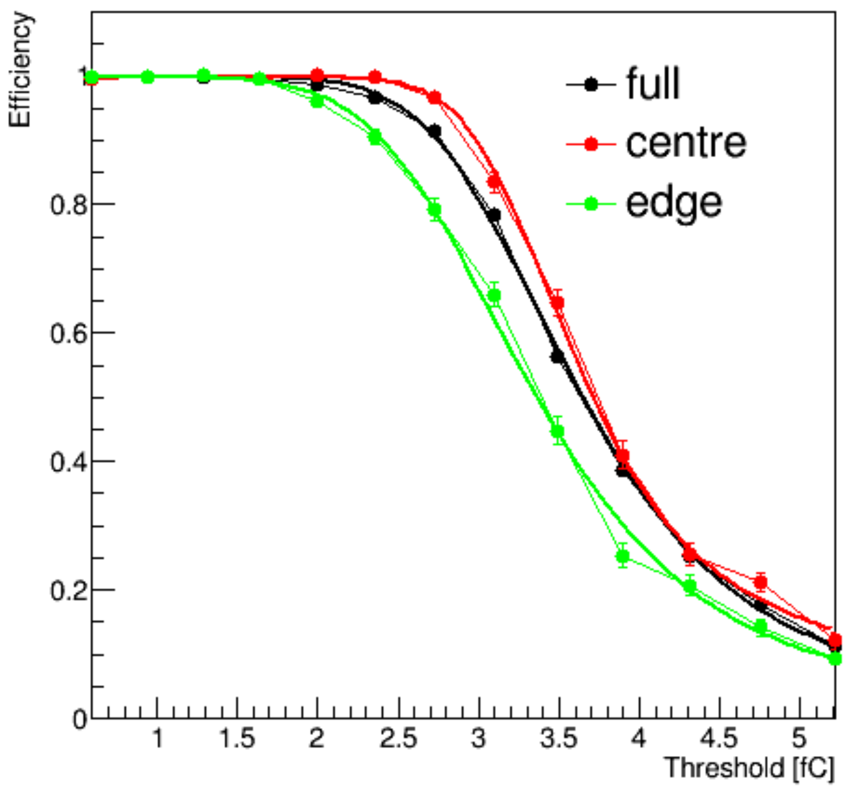




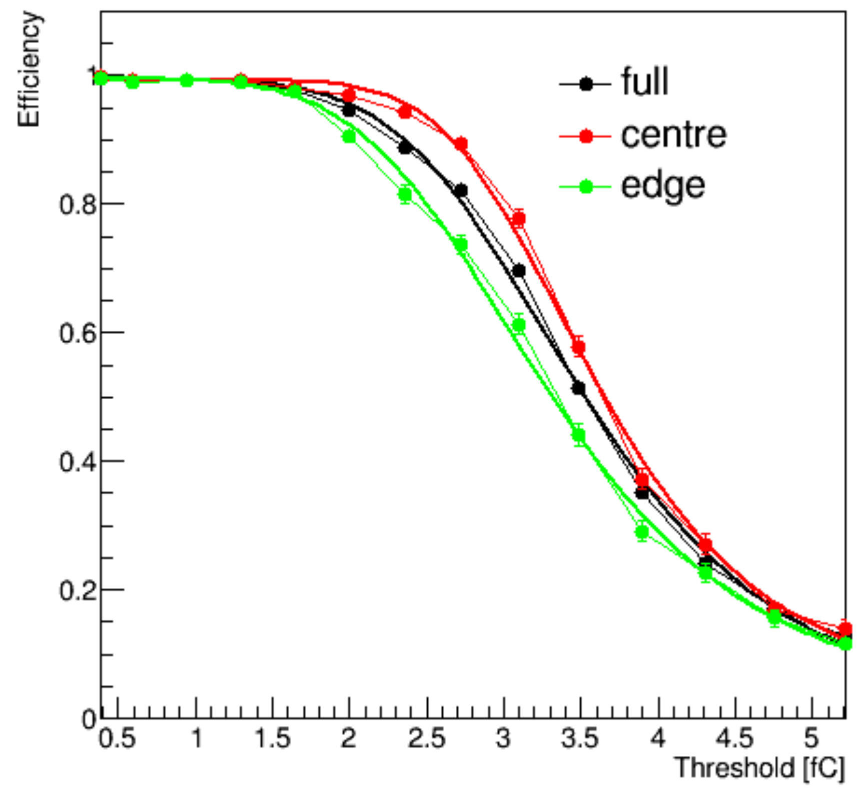
- The edge area is defined as **7.5 μm** from the edge of a strip
- Total edge area for two neighbouring strips is 15 μm

LS Efficiency Curve Comparisons

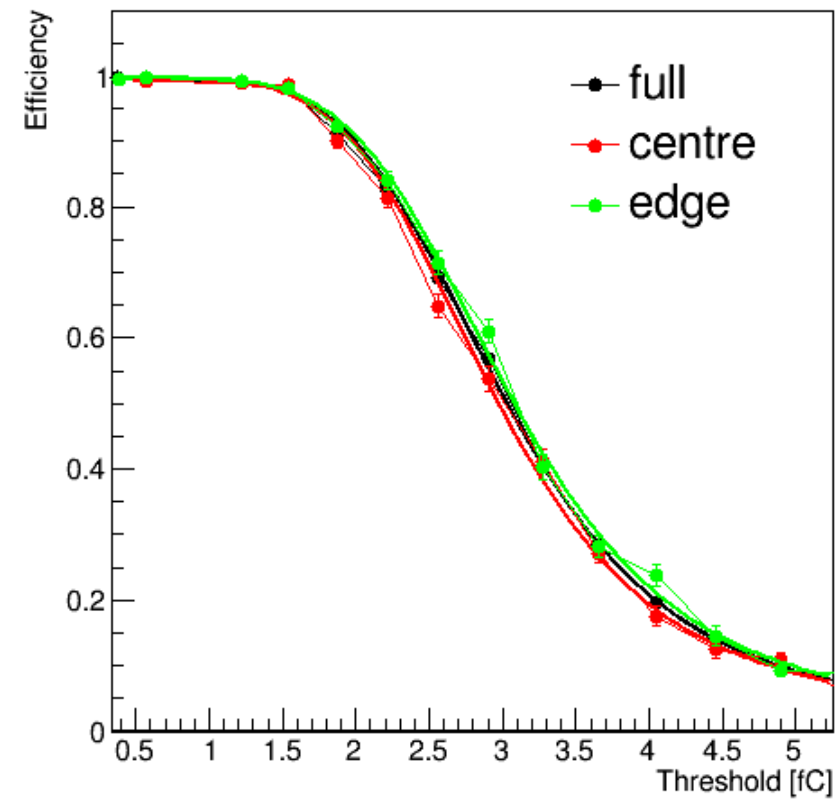
Perpendicular



5 degrees



12 degrees

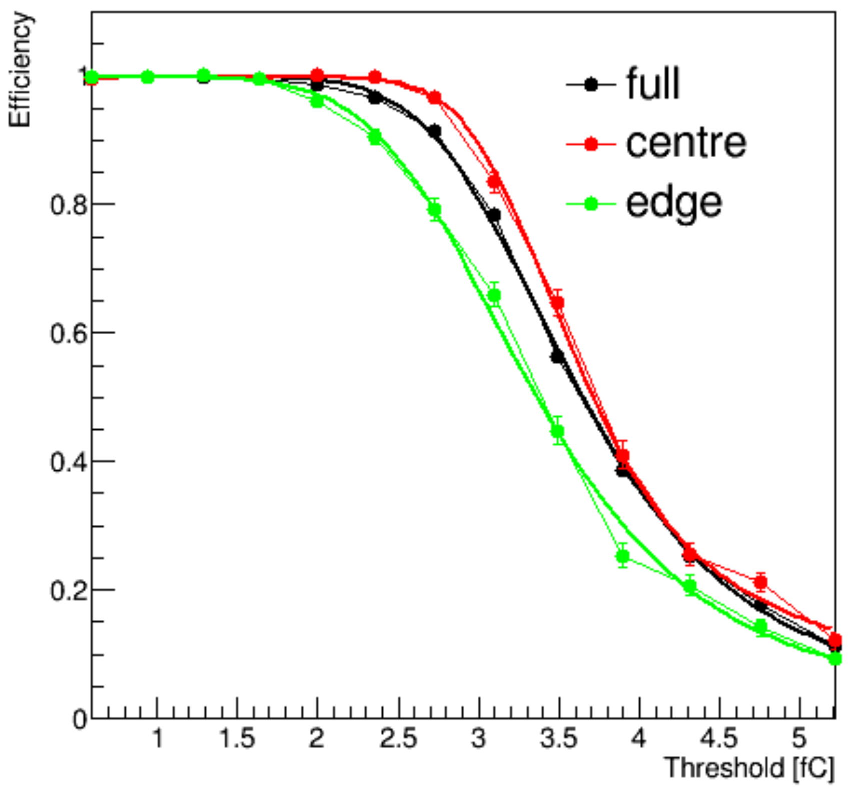


- The highest efficiencies over the larger threshold range is for tracks hitting the centre of a strip
- The lowest efficiencies are seen for tracks hitting the edge of a strip due to the division of the charge between two strips
- As the angles increase the differences between the efficiencies begin to decrease
- For 12 degrees the efficiencies are very similar independent of where the track hits (centre or edge) but the edge is slightly more efficient

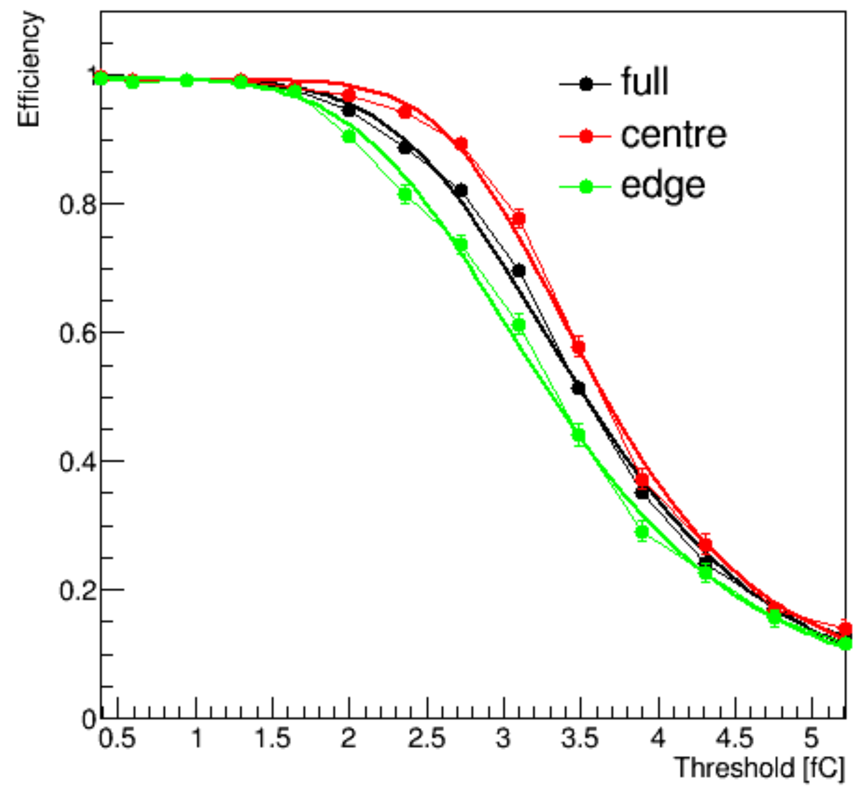
Results are Preliminary

LS Efficiency Curve Comparisons

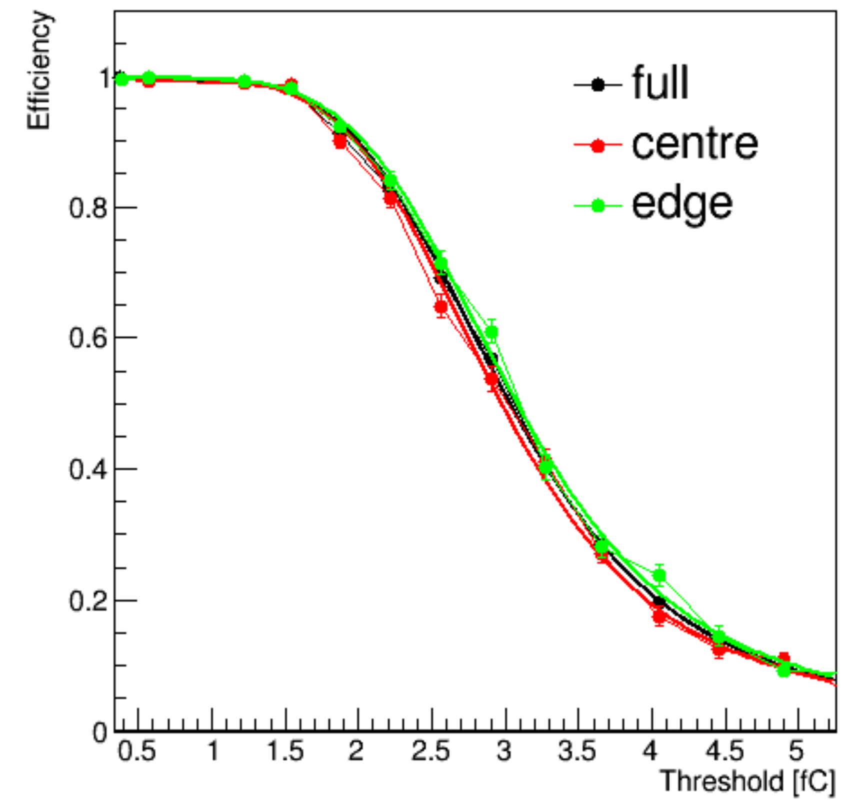
Perpendicular



5 degrees



12 degrees



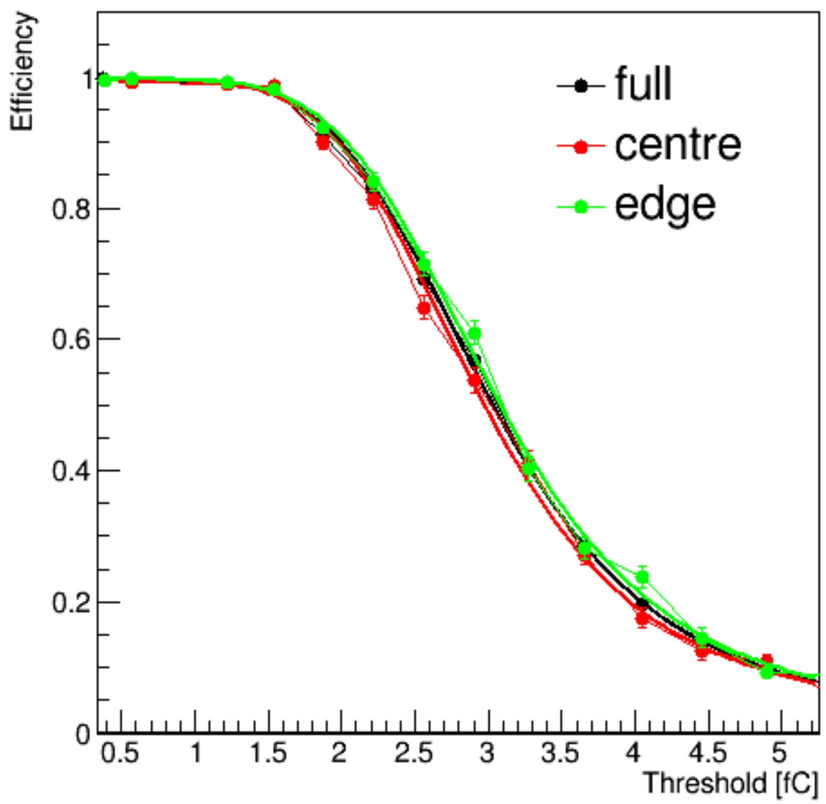
Median Charge

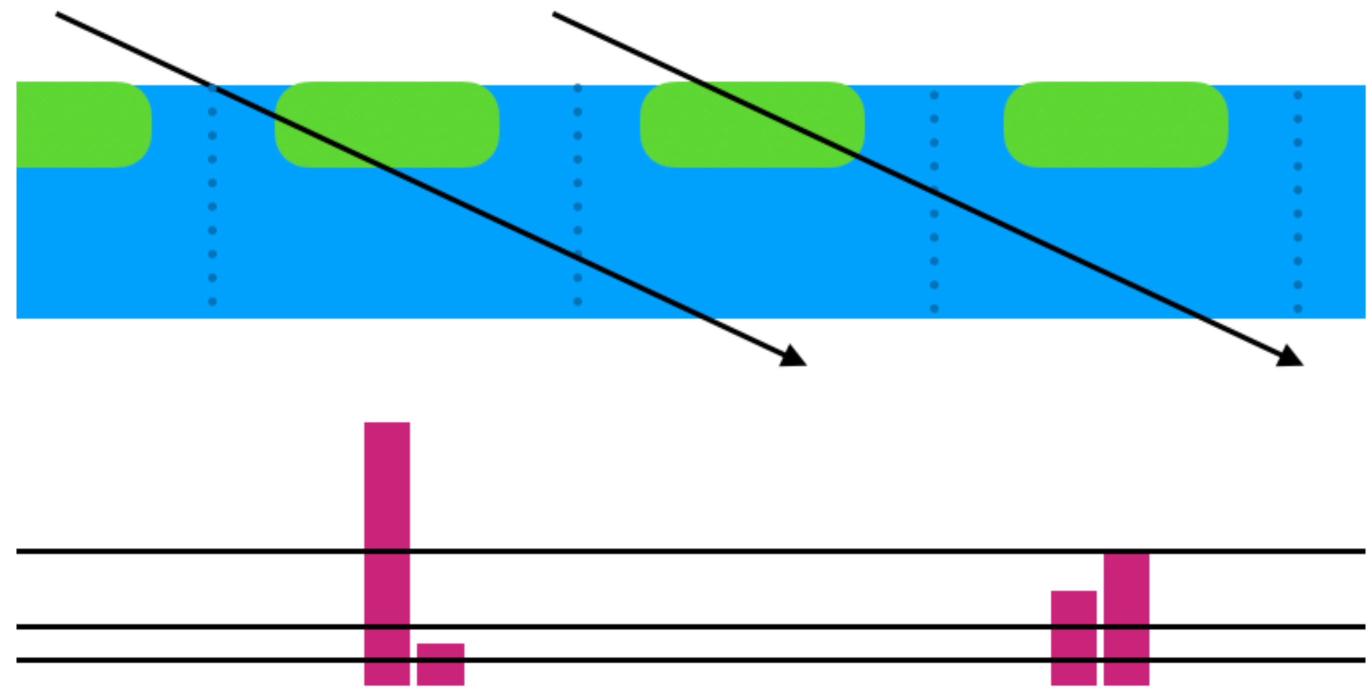
Full Strip:	3.654 fC	3.541 fC	3.031 fC
Centre of Strip:	3.715 fC	3.667 fC	2.974 fC
Edge of Strip:	3.368 fC	3.324 fC	3.078 fC

Results are Preliminary

LS Efficiency Curve Comparisons

12 degrees



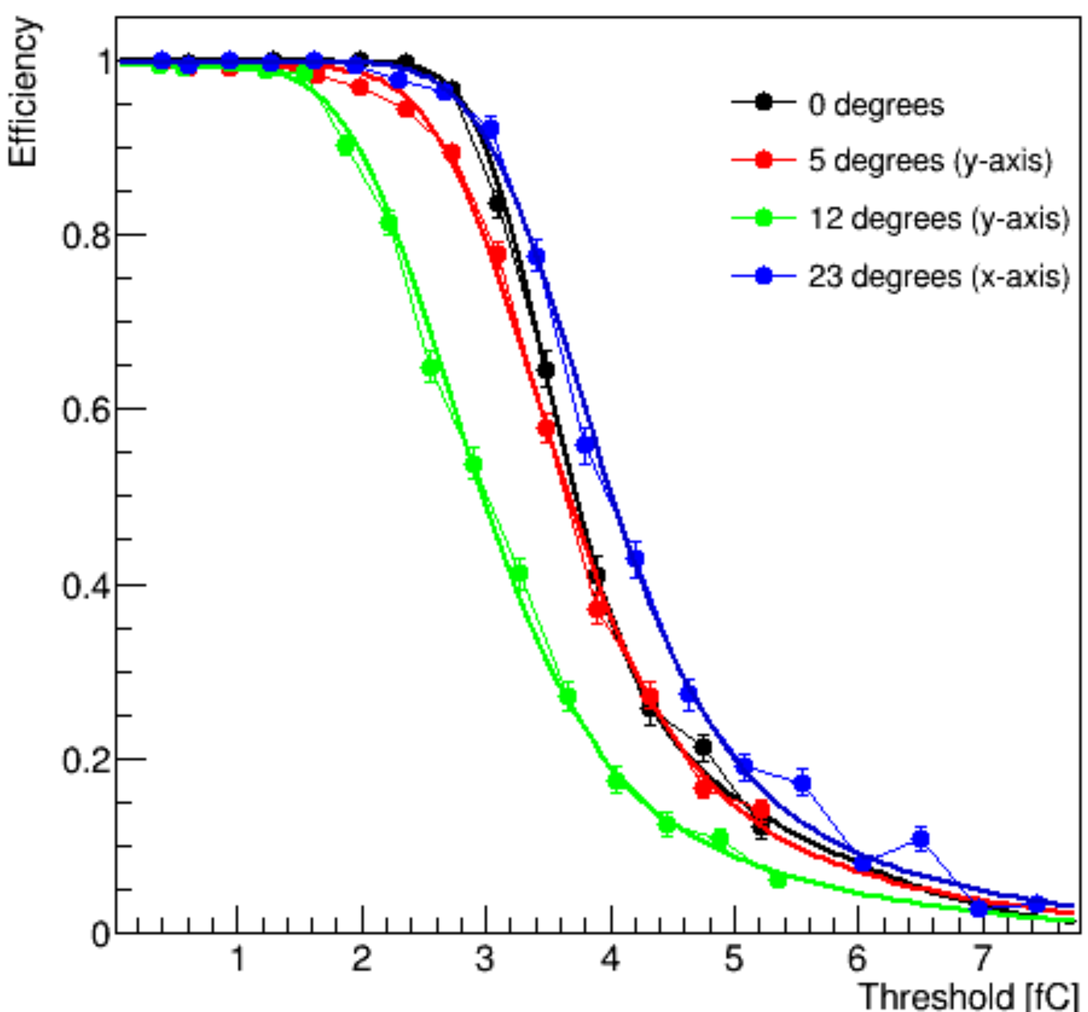


- **Two tracks** that have **identical angles** but different incident inter-strip hit positions have different charge divisions between strips
- At large angles, if the track first hits at the edge of a strip the path length could be mostly through one strip and only a small fraction through a neighbouring strip
- If the track hits in the centre of a strip the path could be through 2 strips and the charge division can be more equal
- This leads to the corners being more efficient than the centre of the strip for tracks at a large angle
- Opposite behaviour to perpendicular tracks
- Need to look at higher angles to confirm and to take a closer look at inter-strip track positions
    - We have some LS angled data still to be look at and many angled threshold scans were taken with the SS module in the September testbeam

LS Efficiency Curve Comparisons

Strip centre and edge angle comparisons

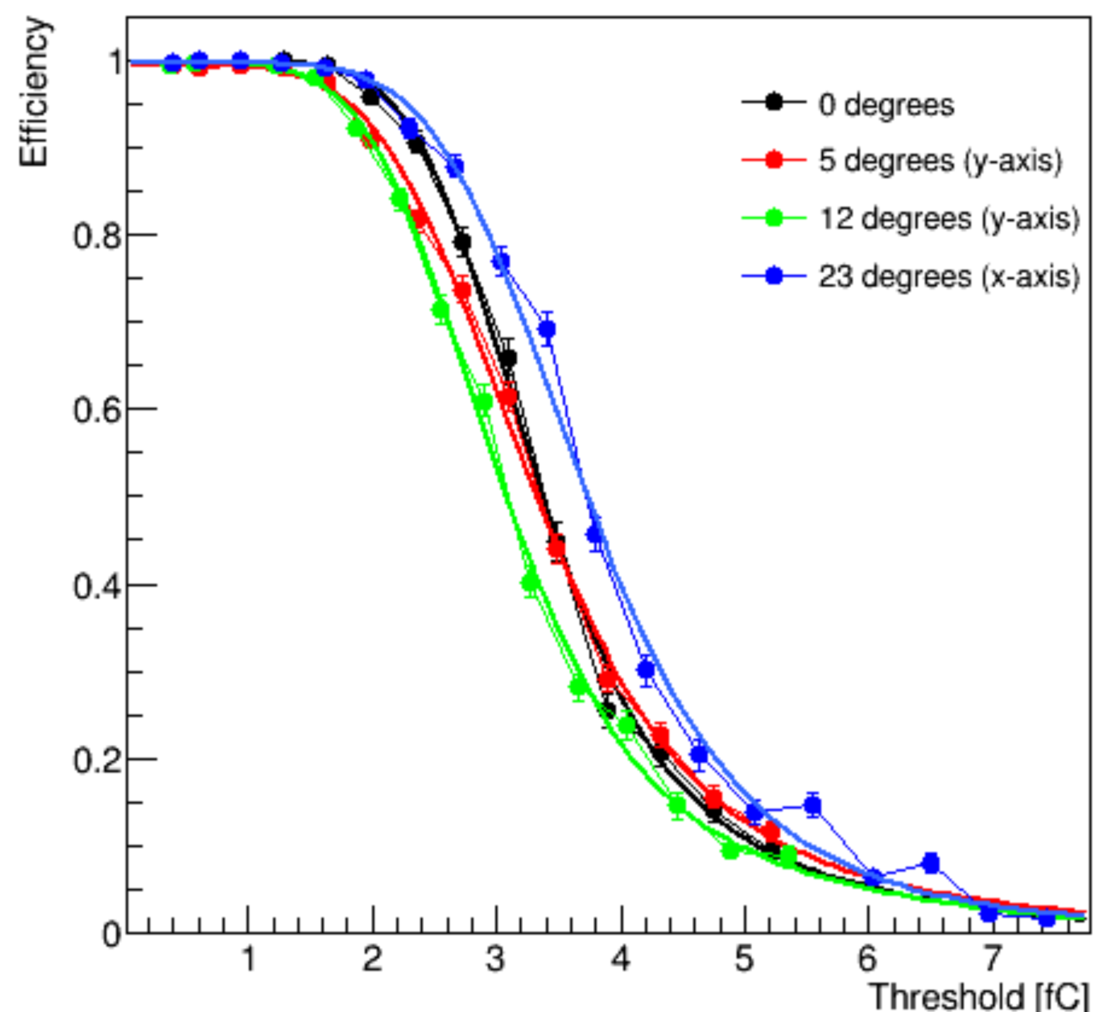
Centre of the Strip



Median Charge

- 0 degrees - 3.715 fC
- 5 degrees - 3.667 fC
- 12 degrees - 2.974 fC
- 23 degrees - 4.020 fC

Edge of the Strip



Median Charge

- 0 degrees - 3.368 fC
- 5 degrees - 3.324 fC
- 12 degrees - 3.078 fC
- 23 degrees - 3.732 fC

Conclusion

- ATLAS is upgrading to an all silicon tracker called the ITk for the HL-LHC
- IHEP is working in collaboration with RAL in the UK to build ~10% of strip barrel modules
- Specialised tooling has been created to build the modules and the procedures are being tested and optimised
- Pre-production begins early next year
- Testbeam is currently ongoing to test different module types
    - The efficiency is found to degrade at lower thresholds when the DUT is placed at angles around the y-axis