2nd SiLC Collaboration meeting.

SILICON TRACKERS MECHANICAL ISSUES:

EXPERIENCE FROM ATLAS

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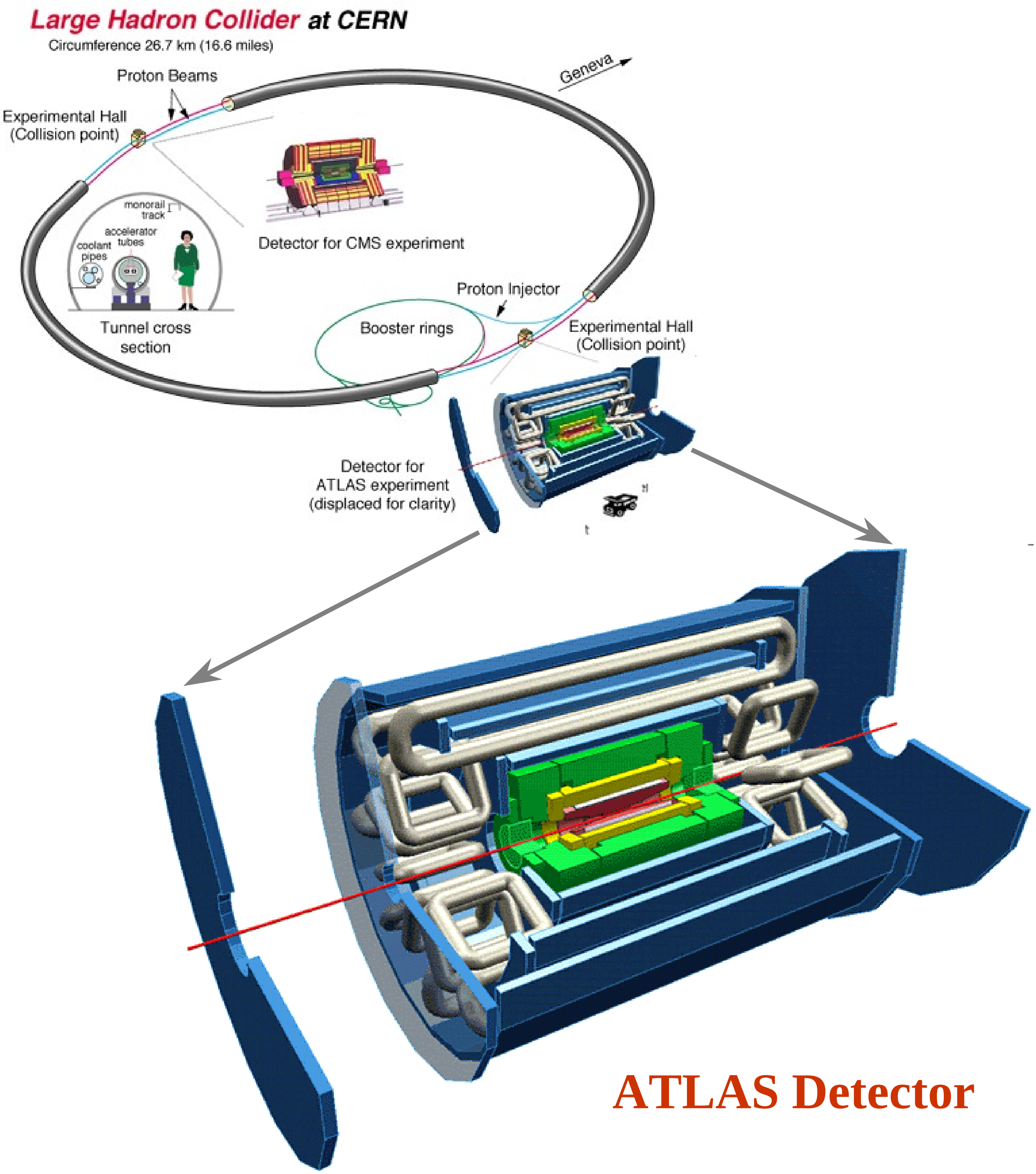
INDEX

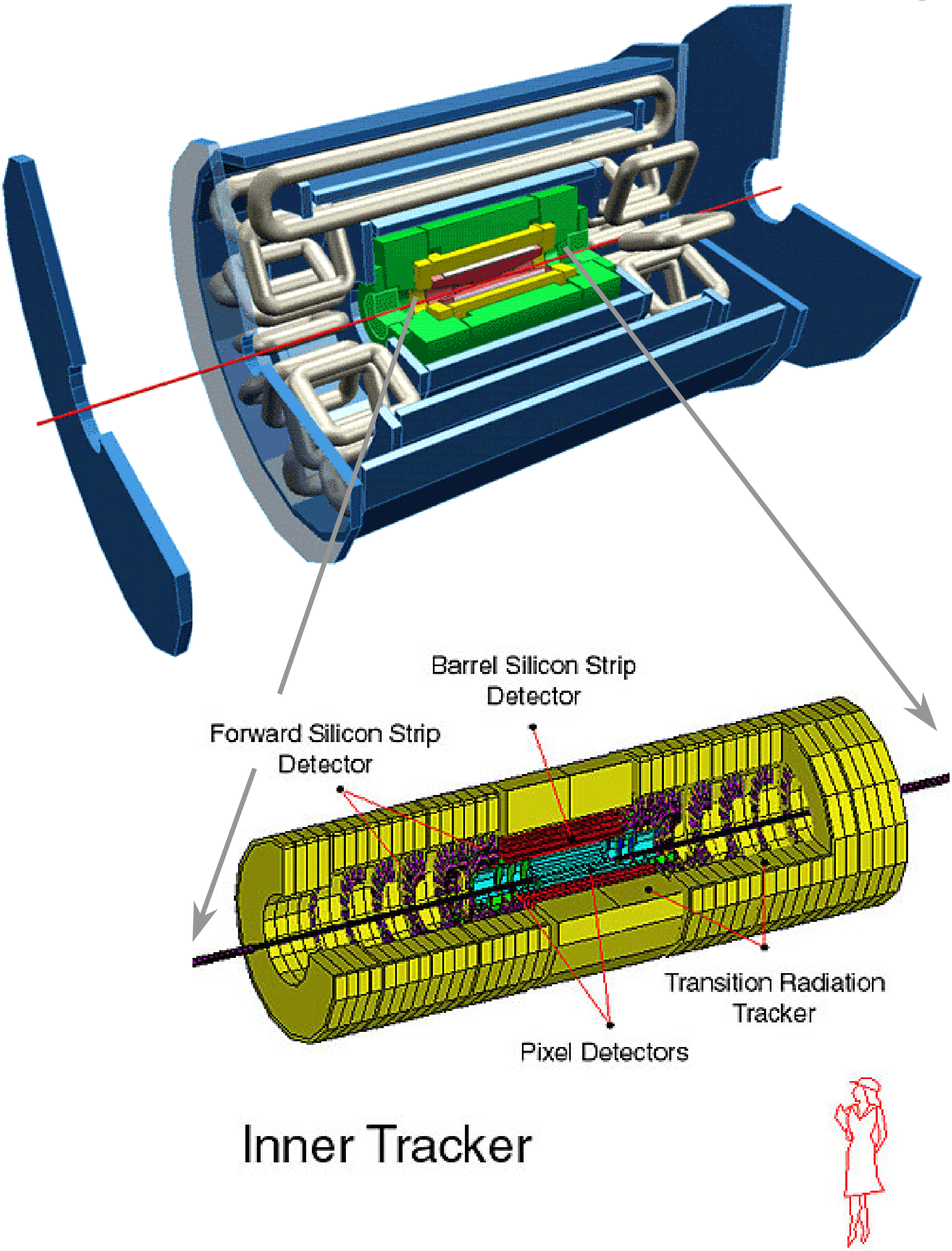
- The Silicon Tracker in ATLAS.
- Type of modules.
- Module design and components.
- Mechanical specifications.
- IFIC contribution.
- Production process.
  - Production steps.
  - Infrastructure.
  - Assembly procedure and jigs.
  - Results.
- Conclusions.

The Silicon Tracker in ATLAS.(1)

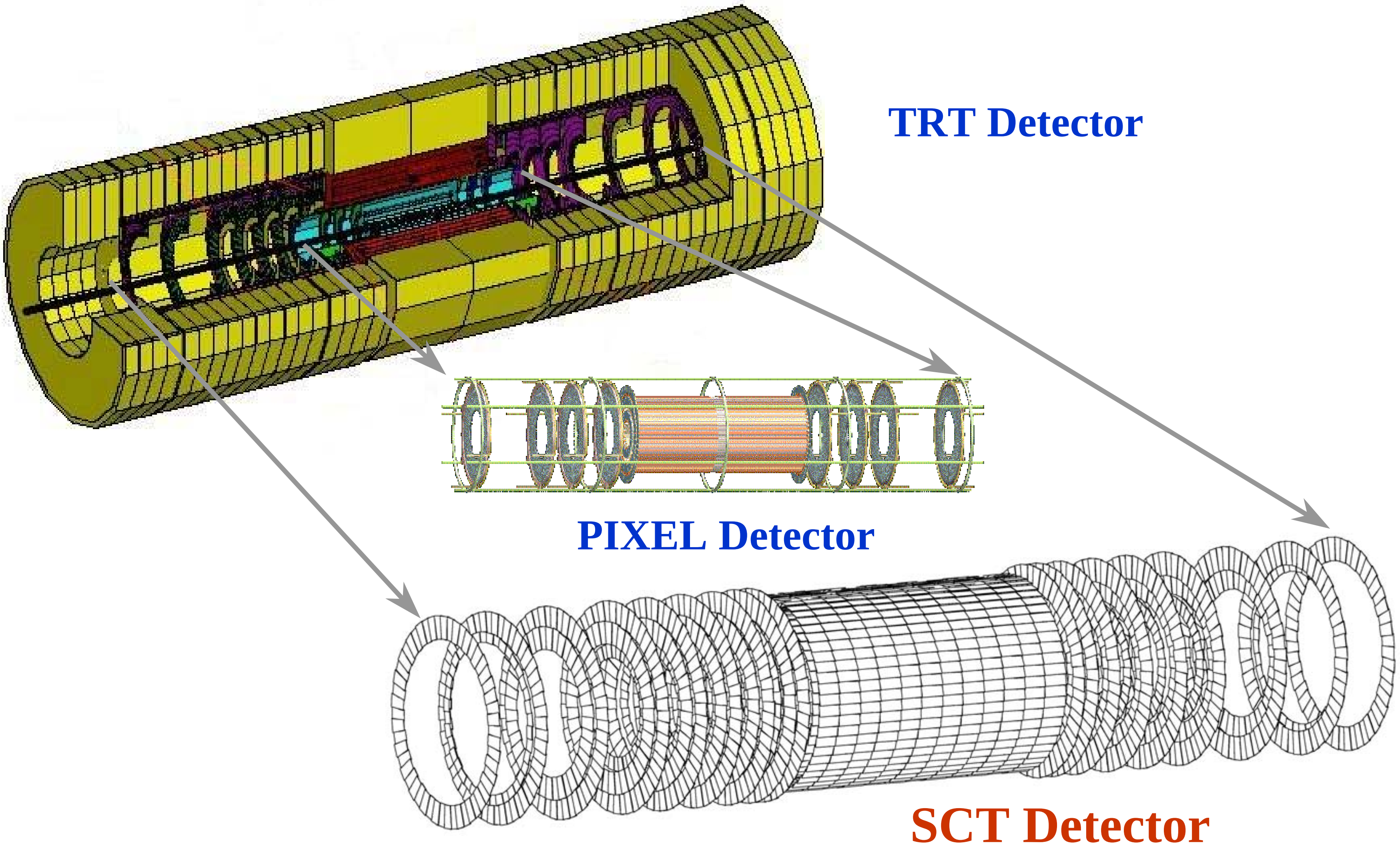


ATLAS Detector

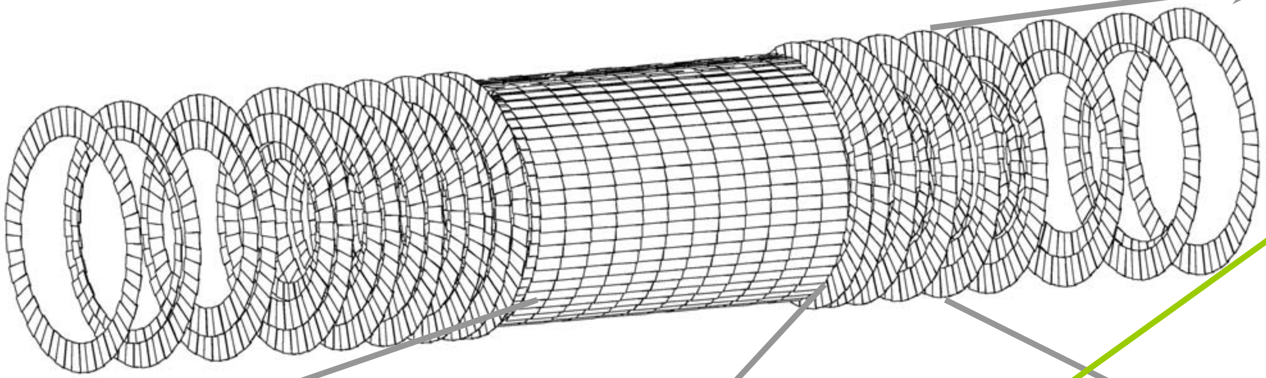
The Silicon Tracker in ATLAS.(2)



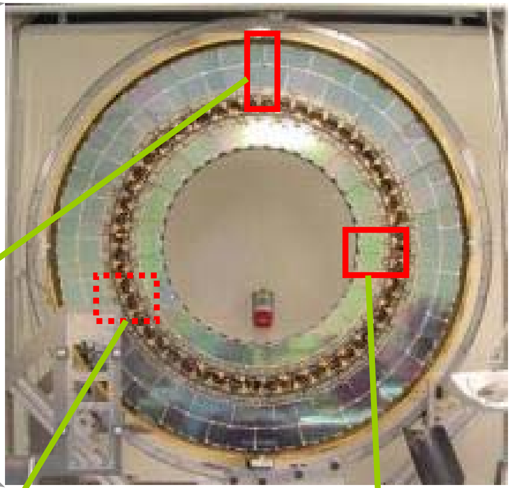
The Silicon Tracker in ATLAS.(3)



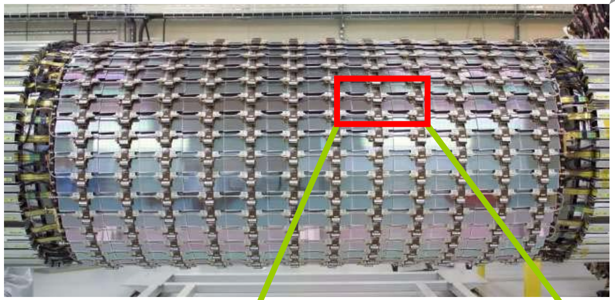
Type of modules

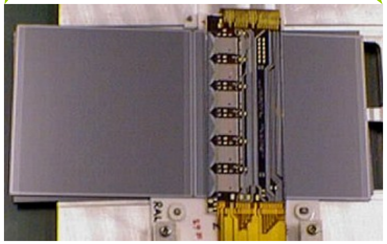


18 Discs



4 Barrels

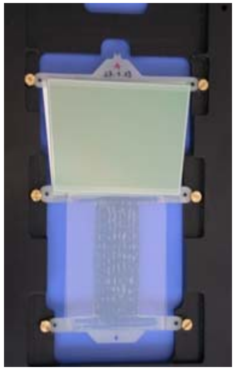




2.112 Barrel Modules

936 Outer

Long



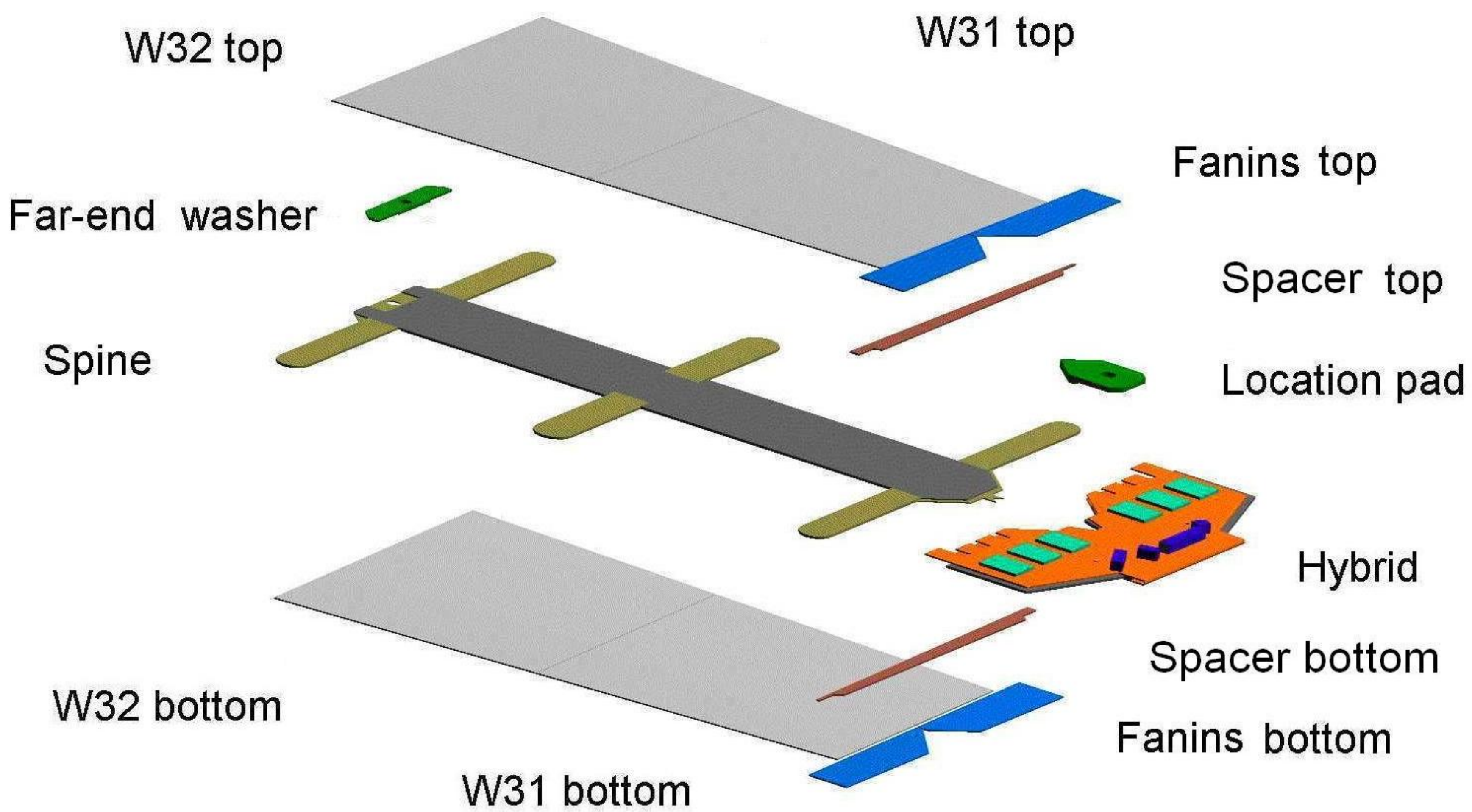
Short

640 Middle

400 Inner

1.976 Forward Modules

Module design and components.



Module design and components (2).

- **Sensors:**

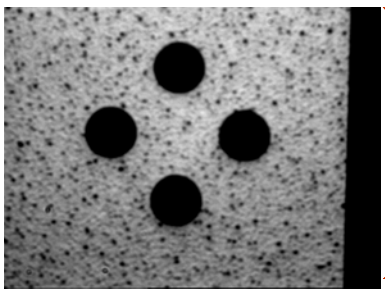
The ATLAS micro-strip sensors are fabricated using p^+ implanted ~20 μm wide strips in high resistivity (ρ > 4 kΩ) n^- substrate, but with a number of features to ensure good operation after heavy irradiation. The strip pitch and width for the forward region varies with the overall device width such that there are **768 read-out plus two edge strips at an average pitch of 80μm**.

		Inner	Middle		Outer	
	Barrel	W12	W21	W22	W31	W32
Length	64.000	61.060	61.085	54.435	65.540	57.515
Outer width	63.360	55.488	66.130	74.847	64.636	71.810
Inner Width	63.630	45.735	55.734	66.152	56.475	64.653
Strip pitch	80	57-69	70-83	83-94	71-81	81-90
Interstrip angle	0	207	207	207	161.5	161.5

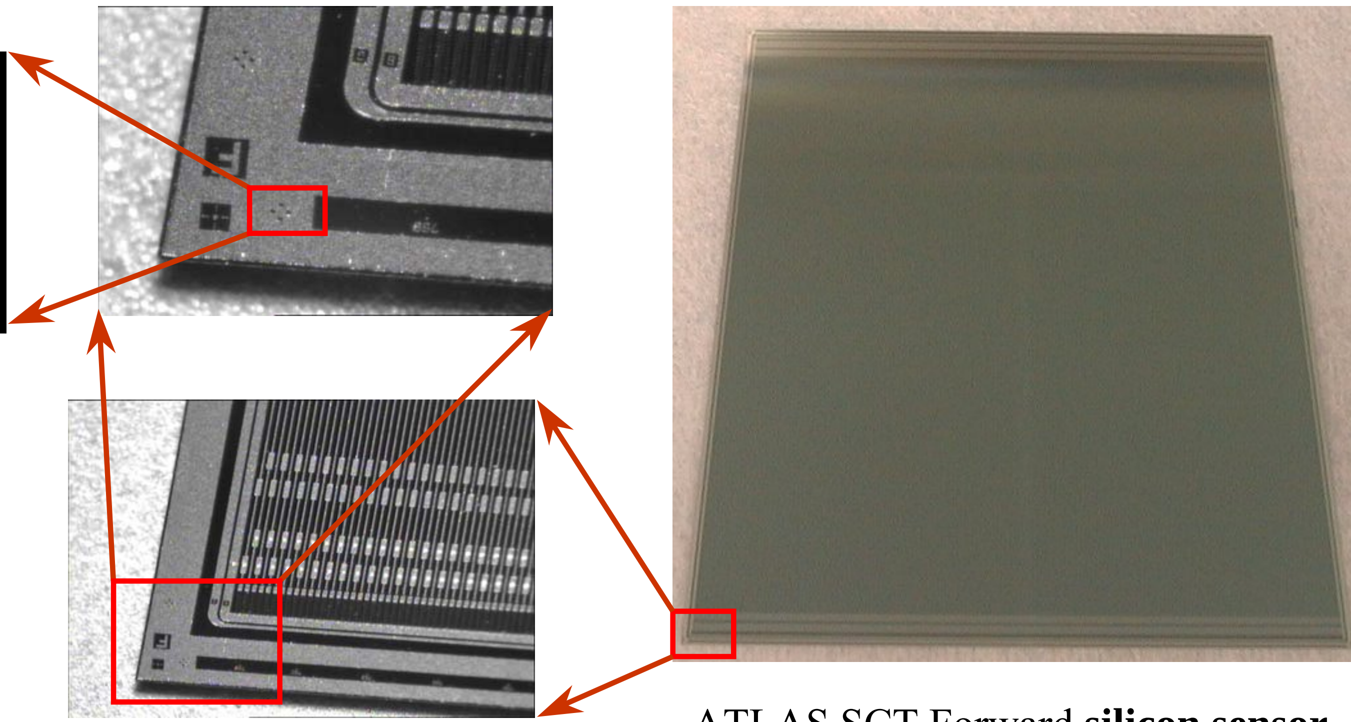
Module design and components (3).

- **Sensors(2):**

The sensors have, on each corner, fiducial marks that we used for alignment. Those fiducial marks consist on 4 spots of 25 μm diameter each separated 50 μm each other. The position of those fiducial marks relative to strip is better than 1 μm.



4 Spots fiducial mark

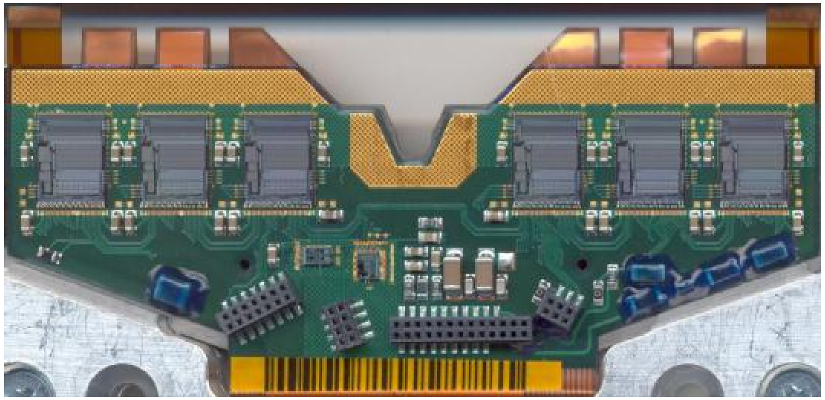


ATLAS SCT Forward **silicon sensor**.

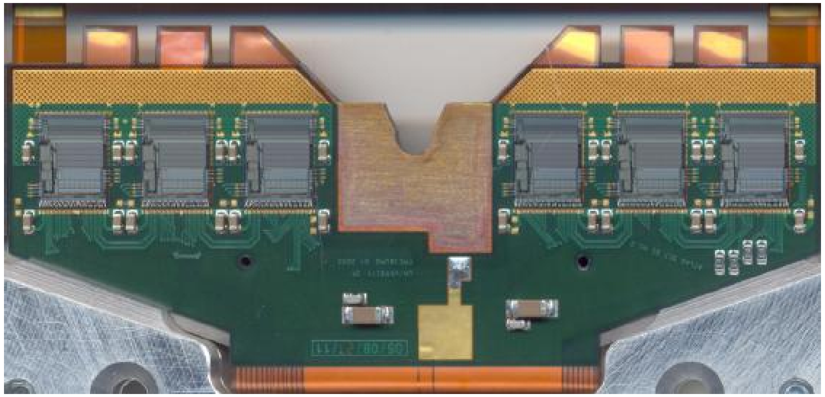
Module design and components (4).

• Hybrid:

For all type forward modules the hybrid design is the same. **The hybrid provides the electrical interface between the module and the disc services**. The basic design of the hybrid is six layers of kapton wrapped around a carbon core. It carries **12 ABCD3TA readout ASICs with 128 channels each**, six on each side of the hybrid, two ASICs for optical communication, DORIC and VDC, on the front side and other SMD components. The sensors are connected via the hybrid to the HV power supplies. A direct contact of the carbon-carbon substrate to the cooling system efficiently removes the heat dissipated from the readout chips.



ATLAS SCT Forward hybrid **front side**.



ATLAS SCT Forward hybrid **back side**.

Module design and components (5).

- **Fan-ins:**

  - Each of the sides of the SCT Forward Module has **768 sensor channels** that are **connected to 6 ABCD3TA chips** for the signal readout.
  - Each chip has 128 channels.
  - The chips are glued in the hybrid with a significant separation from each other.
  - The **pitch of output pads on the sensors** varies **between 140 µm and 190 µm** for the different types of modules.
  - The **pitch of the input pads of the chips is 96 µm**.
  - For the sake of position sensing, the **sensors are glued in the module with an angle of 40 mrad** from each other. This means that the rows of output pads of the sensors face the rows of input pads of the chips with an angle of 20 mrad.

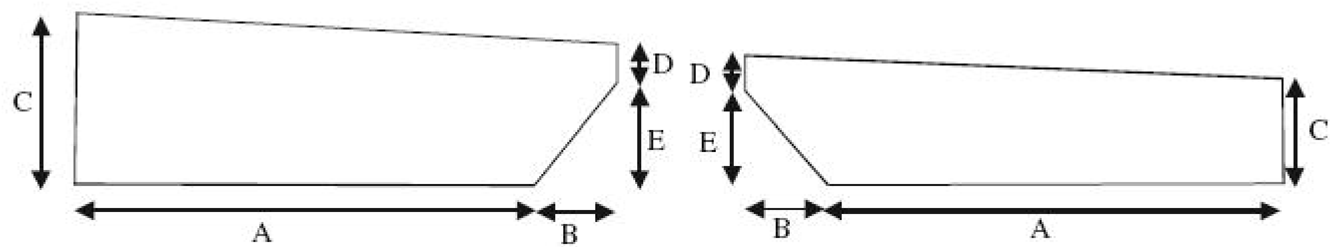
All these factors force the use of pitch adaptors or fan-ins.

The **purpose of the fan-ins** is the **electrical connection** of every channel from the sensors to the readout chips, **adapting the different pad pitch and configuration**. They also **contribute to the mechanical support** between the hybrid and the sensors, and **maintain an effective barrier to heat flow** between these parts.

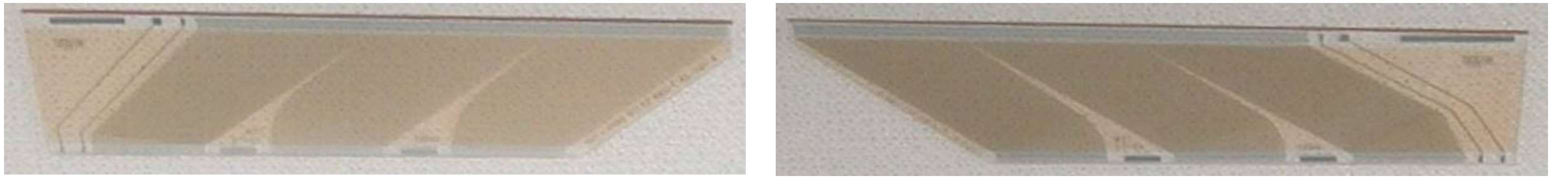
Module design and components (6).

• Fan-ins(2):

There are three different types of fan-ins, one for each type of module: OUTER, MIDDLE, and INNER, and of each of them, there are two kinds: LEFT and RIGHT, for each half of the sensor.



	A	B	A+B	C	D	E	D+E
LEFT	28.95	7.65	36.60	10.19	2.20	7.25	9.45
RIGHT	28.88	10.12	39.00	8.67	1.40	8.05	9.45

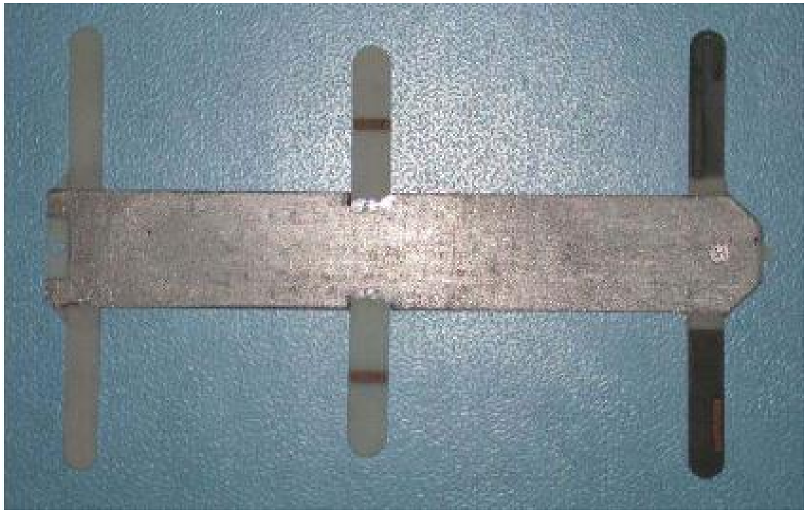


ATLAS SCT Forward Outer Module Pitch Adaptors.

Module design and components (7).

• Spines:

The silicon sensors are glued back to back onto a **support structure** built from thermalised pyrolytic graphite (TPG), with aluminium nitride (AlN), and aluminium oxide (Al2O3), ceramic parts required for mechanical considerations. To minimise the overall material within a module the spine must have **the lowest possible mass**, it must be **mechanically rigid**, and **provide the interface for the module cooling contacts**. There are three different types of Spines, one for each type of module: OUTER, MIDDLE, and INNER.



ATLAS SCT Forward Outer Module Spine.

Module design and components (8).

• Spacers:

- The thickness of carbon -carbon substrate plus the flex kapton printed circuit in the hybrid is around 1 mm.
- The thickness of Spine is 0.5 mm.
- Good bondability and reliable assembly requires the fan-in surface to be parallel to sensors and chips surfaces.

The spacer is a component glued on the spines that **allows the fan-ins to be glue parallel to sensors and chips**, also it is used **to connect the sensors to HV and the spine to ground** and contributes to **maintain an effective barrier to heat flow** between sensors and hybrid.

• Location pad and Far-end washer:

Precision mounting of module on the discs and good cooling contact with cooling blocks need two reliable high precision holes at the mounting points and pressure spread at the contact areas.

The spine do not provide these requirements, so the location pad and the far-end washers are designed to cover these needs.

Mechanical specifications.

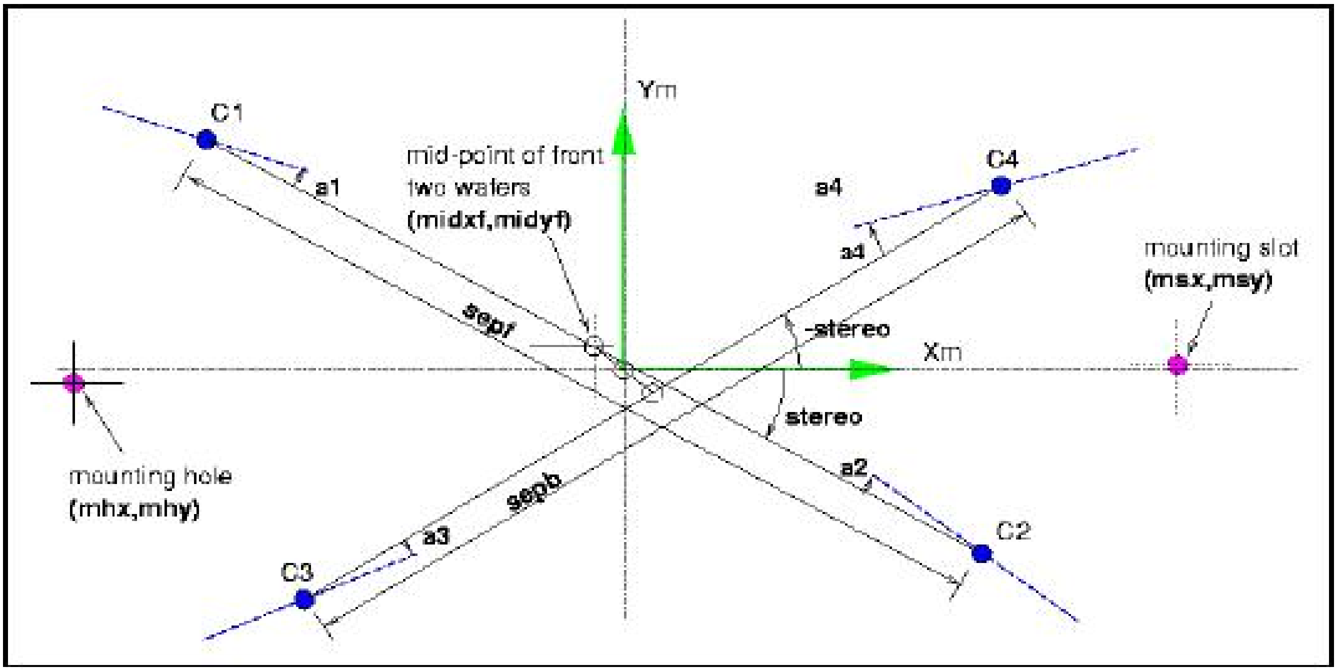


Figure above shows how we describe the geometry of a module in the *xy* plane. Points *C1* to *C4* are the centres of the four detectors. Detector centre is measured by surveying fiducial marks on the detector corners and forming the centre-of-gravity of the four results. We use the centre-of-gravity of the four detector centres to define the module centre, which is the origin of the module coordinate system (*Xm*,*Ym*). The direction of the *Xm* axis is chosen so that it bisects the angle between and line joining *C1* to *C2* and a line joining *C3* to *C4*. The first parameter, (***stereo***), defines the angle between *Xm* and the line joining *C1* to *C2*. The next pair of parameters, (***midxf,midyf***), specify the mid-point of the front pair of wafer centres. Then we specify the separation between the front pair of detectors, (***sepf***), and the back pair, (***sepb***). The angular deviation of each detector centre line from the line joining it to its partner give the four parameters (***a1*** to ***a4***). The remaining four parameters describe the position of the main location hole (***mhx,mhy***) and the far-end location slot (***msx,msy***).

Mechanical specifications(2).

The module assembly specifications are derived from next table:

	Total error budget	Detector alignment within module
r.φ	12	4
z	200	67

The thin flat shape of modules with tight *z* tolerance allows us to decouple the *z* (out-of-plane) specification from the *xy* (in-plane) specification. Next table shows the nominal values of parameters described above and the assembly tolerances that are allowed on each parameter. The tolerances on *stereo, midyf* and *a1* to *a4* are chosen to just satisfy the 4 micron *r-φ* specification. The tolerances on *msy* and *mhy* are chosen as small as can reasonably be achieved, to minimise the loss of overlap between adjacent modules in the *r-φ* direction.

Parameter (unit)	Tolerance	Nominal values: Outer	Middle	Short-mid	Inner
mhx (mm)	0.020	-78.136	71.708	41.764	45.060
mhy (mm)	0.020	0.000	0.000	0.000	0.000
msx (mm)	0.100	62.244	-66.672	-96.616	-34.320
msy (mm)	0.020	0.000	0.000	0.000	0.000
midxf (mm)	0.010	0.000	0.000	0.000	0.000
midyf (mm)	0.005	-0.040	-0.053	-0.652	0.000
sepf, sepb (mm)	0.010	61.668	59.900	*	*
a1 - a4 (mrad)	0.130	0.000	0.000	*	*
stereo (mrad)	0.130	-20.000	-20.000	-20.000	-20.000

IFIC contribution.

The IFIC contribution to ATLAS SCT was established at the beginning as the production and testing of the modules for two discs with 20% contingency:

- 124 Outer modules.
- 96 middle modules.

220 modules completely assembled bonded and tested.

During the production phase, we had to recover delays accumulated during the design and development phase. We had to improve our production rate (from 3 modules/week up to 8 modules/week) so that we took part of the production of other sites. We produced 62 more middle modules.

282 modules completely assembled bonded and tested and 30 more module bonding from other site.

The expected Yield was around 85% during module assembly.

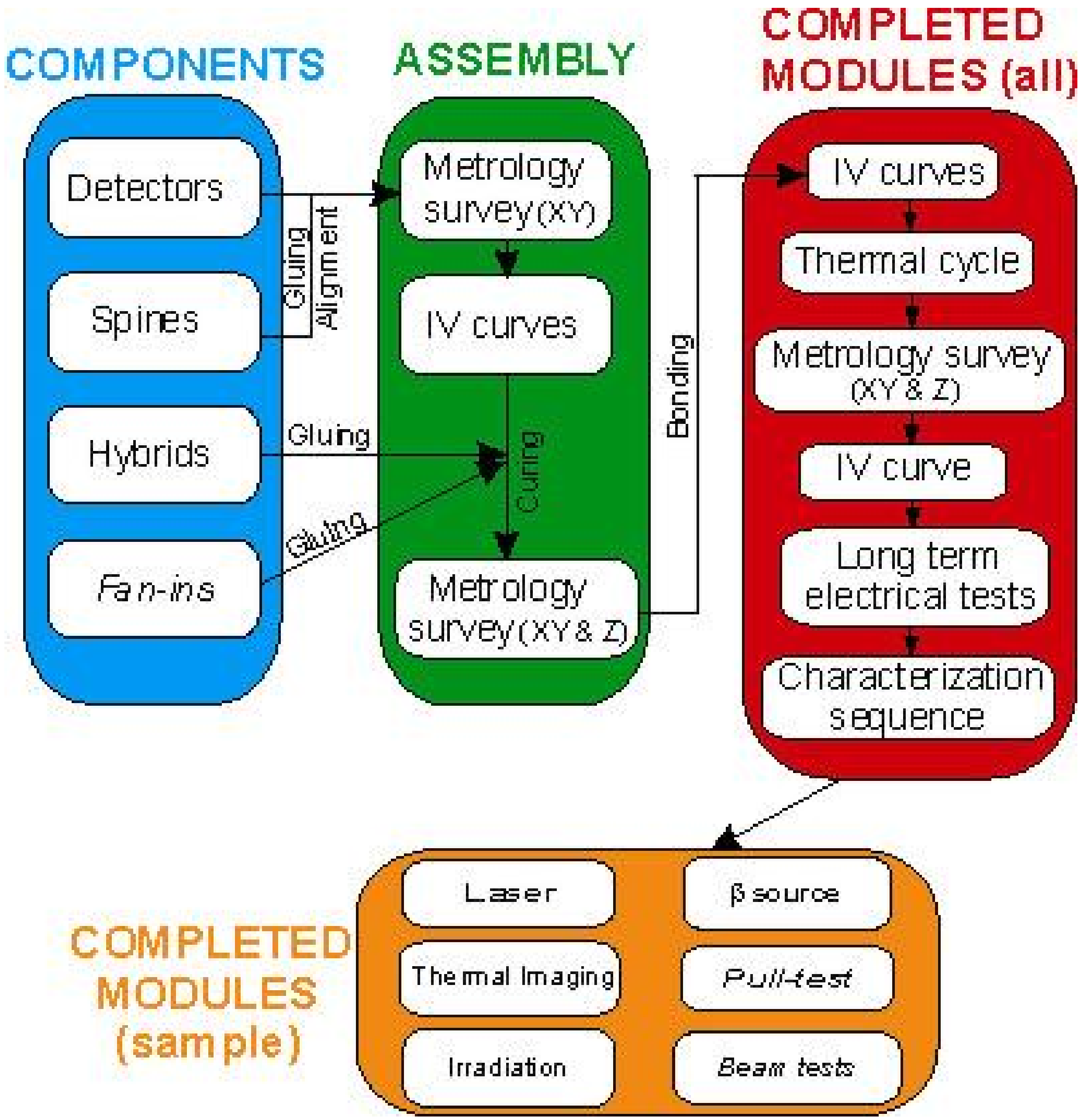
OUR YIELD WAS:

92,4% for middles.

94,4% for Outers.

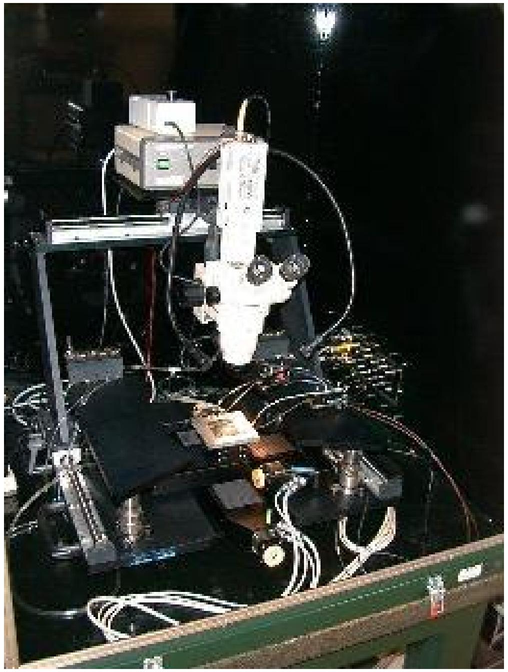
Production process.

- **Production steps.**



Production process (2).

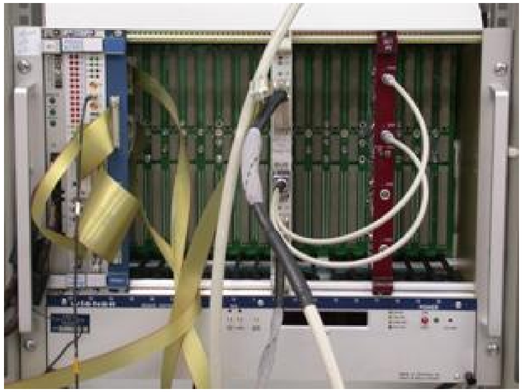
- **Infrastructure.**



Probe station for sensor characterization & module IV curves.

Alignment machine module alignment.

Glue dispenser for module gluing

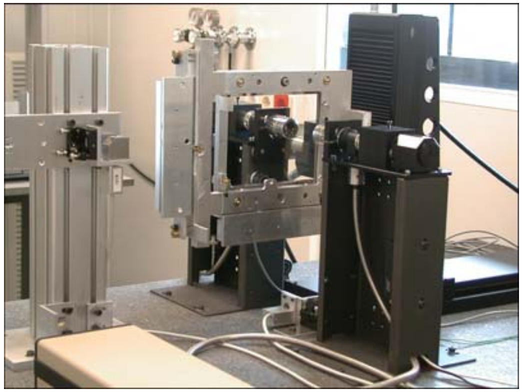


Electronic set up for hybrid & module characterization.

Bonding machine for module bonding.

Production process (3).

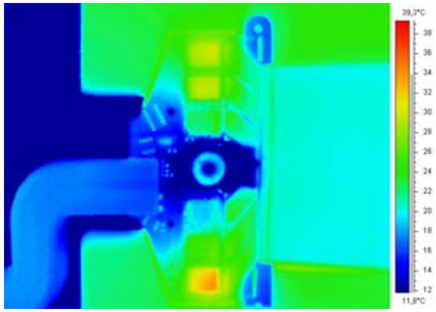
• Infrastructure (2).



Metrology machine for module X,Y,Z metrology.

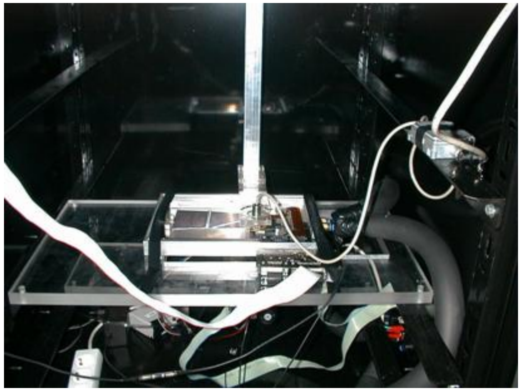
Pull tester for bond tests.

Long term set up for 6 module long term functionality test.



IR camera for module cooling tests.

Climate chamber for module termocycling test.



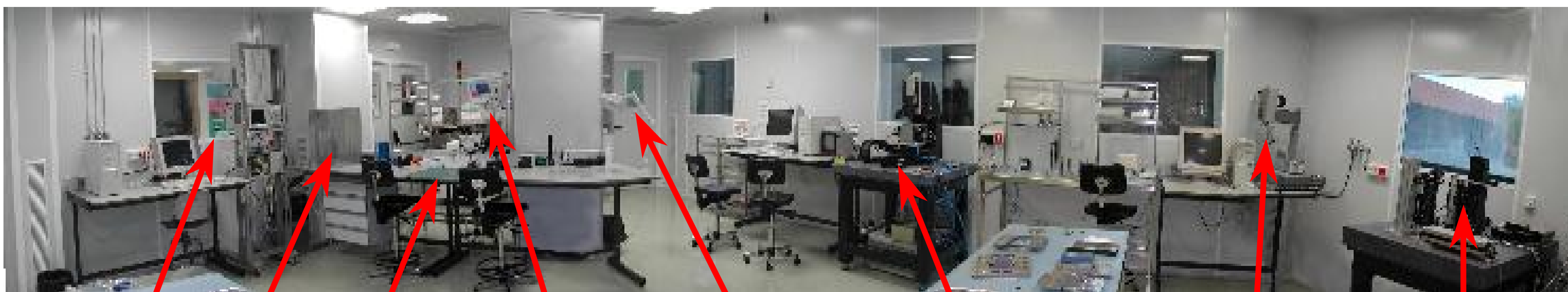
laser station for module particle detection test.

Production process (4).

• Infrastructure (3).

Most of the infrastructure shown is inside of a clean room of class 10000 with temperature and humidity control. That is required in order to preserve detectors characteristics and avoid electronics malfunction due to dirty.

Clean room laboratory overview.



Electronics and ***Long term set ups***.

Microscope for visual inspection

Bonding machines (at the end of the room)

Access to ***Probe station*** area (next door room)

Alignment machine

Glue dispenser

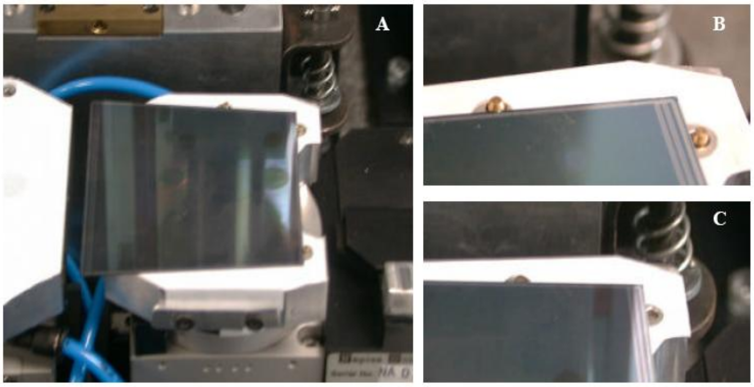
Metrology machine

Production process (5).

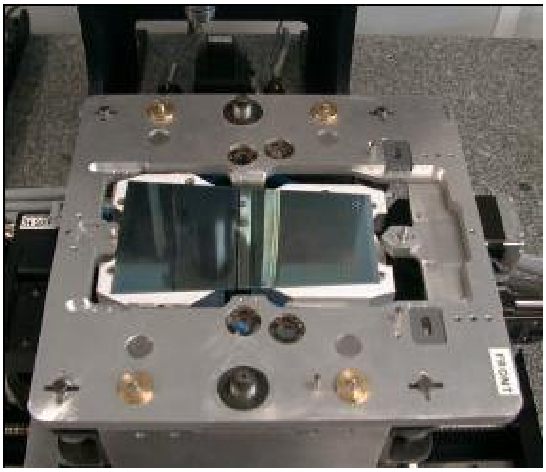
•Assembly procedure and jigs.

Components arrive at module assembly sites having all passed their own quality assurance, so it is only necessary to do a **visual inspection** to catch any damage that could have occurred in transit from the QA site to the assembly site.

The first step is to **align the pairs of detectors** that will make up the front and back faces of the module. A pair of detectors is placed on a pair of vacuum chucks, each of which is mounted on a compact XYΘ stage integrated with a measuring microscope. The detector positions were measured using fiducial marks in the aluminium layer, near the detector corners. Recognition and measurement of fiducials and movement of the stages and microscope were controlled by a LabVIEW programme, which was able **to place a pair of detectors at the required position within 1 μm** after a small number of iterations.



Detector pre-aligned on the vacuum chucks on the **alignment machine**



One side detectors aligned on the **alignment machine** relative to the "***turn plate***" jig

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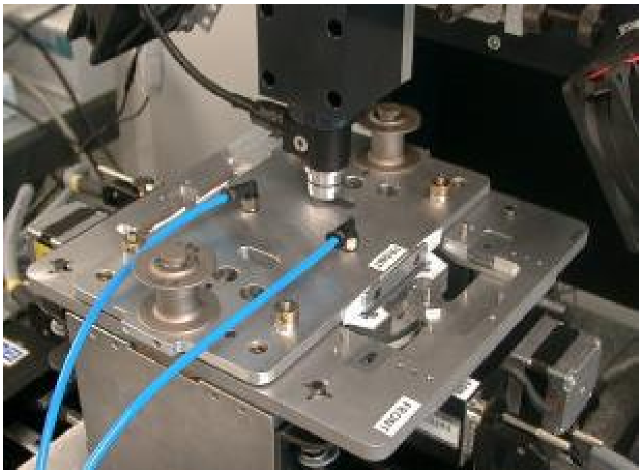
Production process (6).

•Assembly procedure and jigs (2).

After alignment, a pair of detectors is **moved to another vacuum chuck** which will transfer them to their final positions on the module. The move is done by placing the transfer chuck so that it rests on the pair of detectors, then switching the vacuum off at the alignment chucks and on at the transfer chuck. Viewing holes above the detector fiducials in the transfer chuck allow measurement of the detector positions after the vacuum switch; **if the detectors are now misaligned by more than 2 µm the alignment and transfer steps have to be repeated**.

Transferring detector to "***transfer plate***" jig after fiducial measurement



The *xy* position of the transfer chuck in this and later assembly steps is defined by plain contact bearings of hardened steel pressed together with a spring, giving **reproducibility better than 1 µm.**

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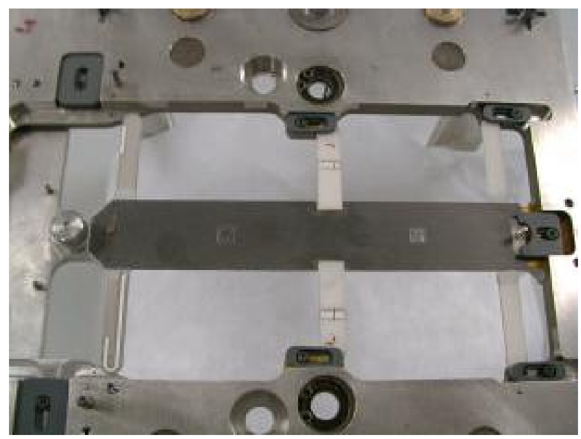
Production process (7).

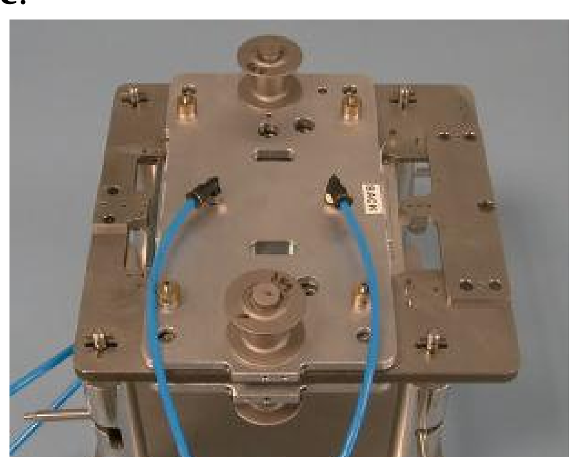
•Assembly procedure and jigs (3).

Glue (Araldite 2011) is then distributed onto both sides of the spine in the form of a few lines using a simple XYZ robot and a pressure-time dispenser. The aim is to achieve **maximum coverage of glue between detectors and spine**, while avoiding an excess that can squeeze out onto the front face of the detectors. A number of small spots of electrically conducting glue (Tra-duct) are added by hand to distribute the detector bias voltage from a trace on one wing of the spine to the back planes of all four detectors.



Spine on the "***trun plate***" jig for glue dispending.

The two pairs of **detectors on the "transfer plate" jigs are sandwiched around the spine in the "*turn plate*" jig and left clamped there overnight for the glue to cure**.



Spine and detectors sandwiched on the "***trun plate***" jig for glue to cure.

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Production process (8).

•Assembly procedure and jigs (4).

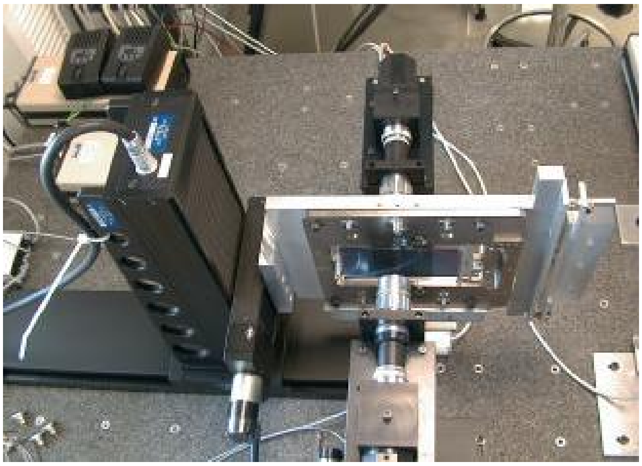
Part of the "*turn plate*" jig is shaped like the cooling blocks that will eventually support the module. The spine is clamped onto these blocks, defining its position in the *z* direction and ensuring that it will make good contact with the real blocks.

The *xy* position of the spine within the frame is controlled at the hybrid end by a V shaped tooth pressed against a pin and at the other end by the slot washer fitting over a precision pin. The "transfer plate" position in the *z* direction is set such that module will have its nominal thickness.

The **final step is to glue on the hybrid, fan-ins and main location washer**. The hybrid is clamped against the cooling block template, to ensure that it will be coplanar with the matching surface of the spine. Its *xy* location is defined by a U shaped notch fitting against the same pin as the V tooth of the spine.

The **fan-ins are held on vacuum chucks**, similar to the transfer chuck but with less precision. When the glue cure the **module is then** removed from the "*turn plate*" jigs and **placed in a transport frame for testing, wire-bonding and thermal cycling**.

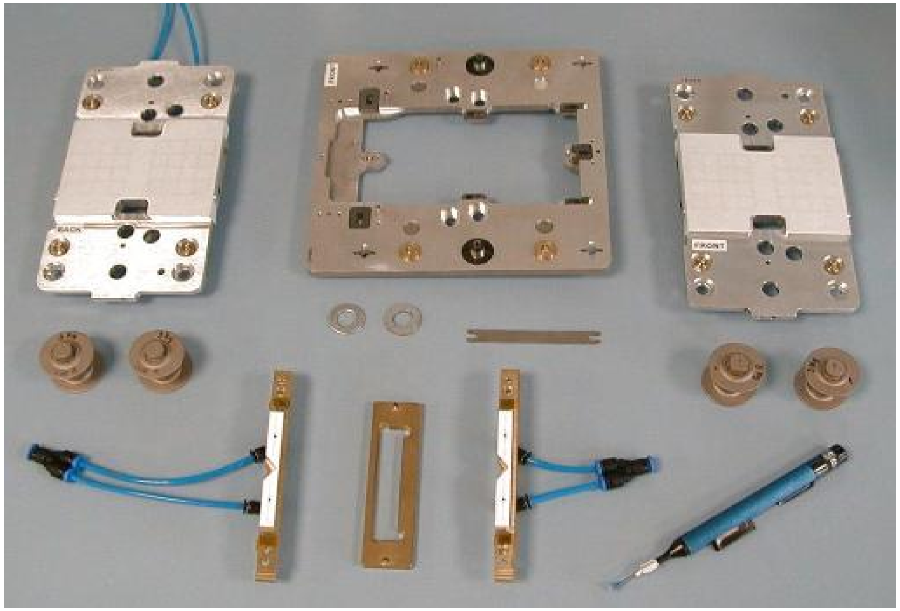
Module during metrology inspection.



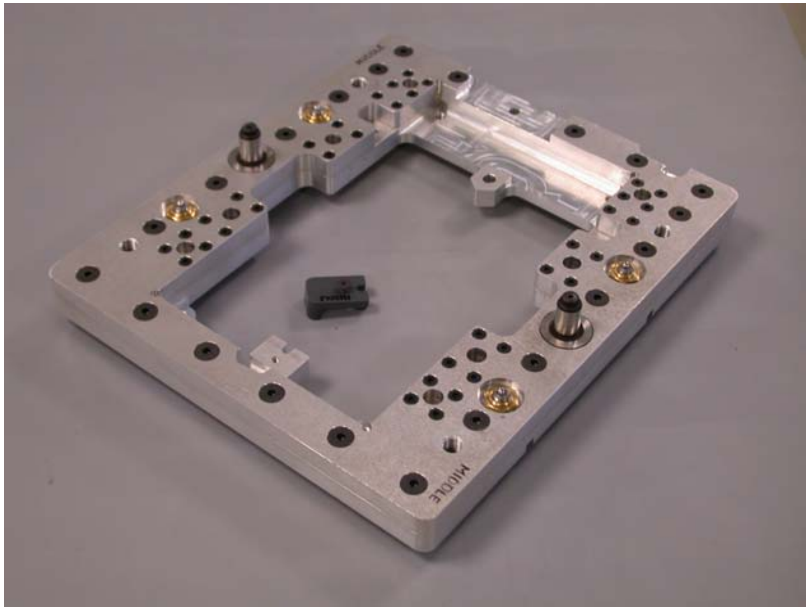
Production process (9).

•Assembly procedure and jigs (5).

All jigs for the assembly and for module metrology have been designed and manufactured at IFIC in collaboration with Manchester University.



Alignment jigs.



Metrology jig.

Production process (10).

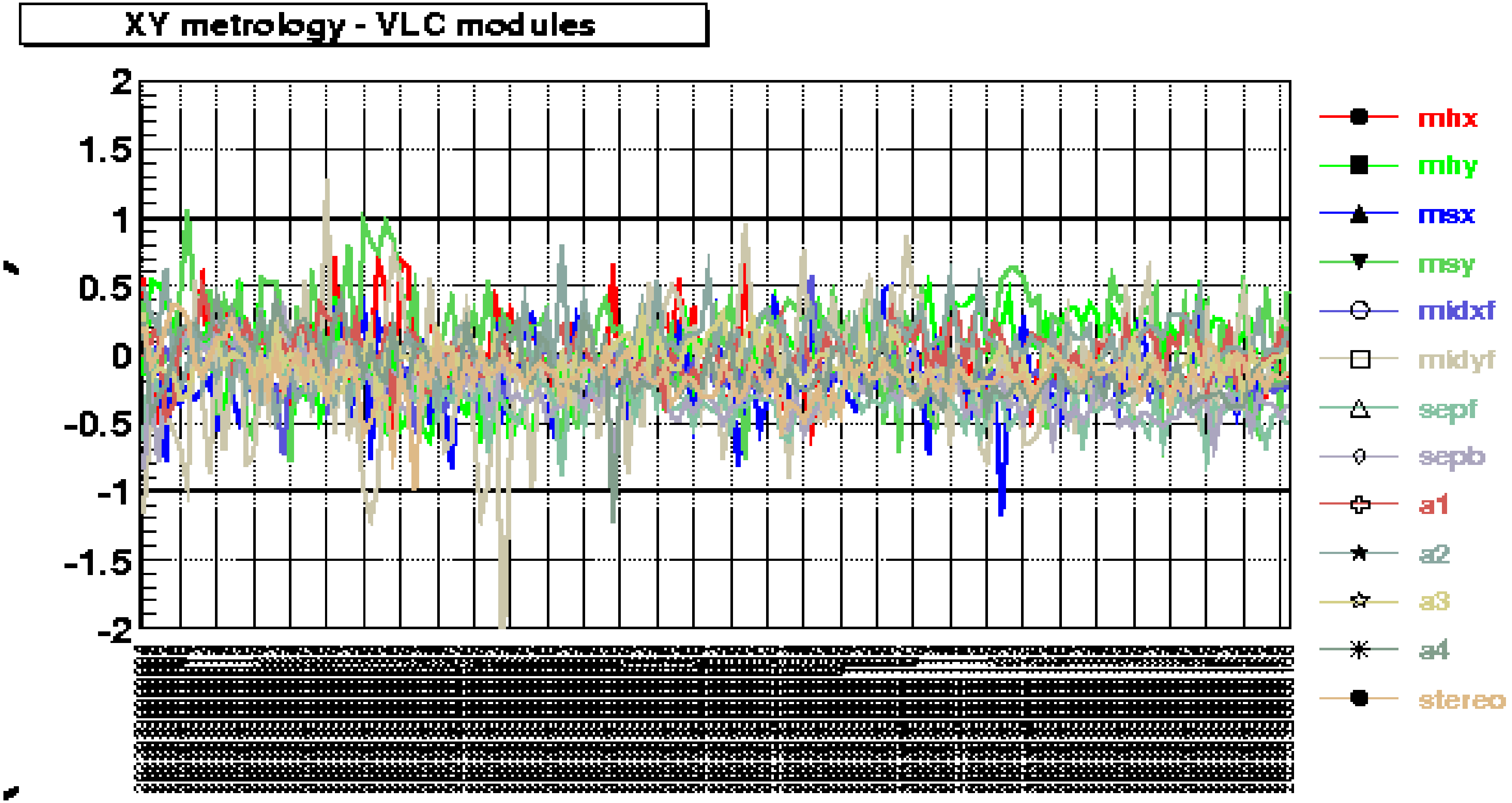
- **Results.**

The table below shows some statistics and an estimate of the production yield.

Type	Built	Good	Pass	Hold	Fail	Efficiency (G+P)
Middle	157	137	8	9	3	92,36 %
Outer	125	109	9	6	1	94,40 %

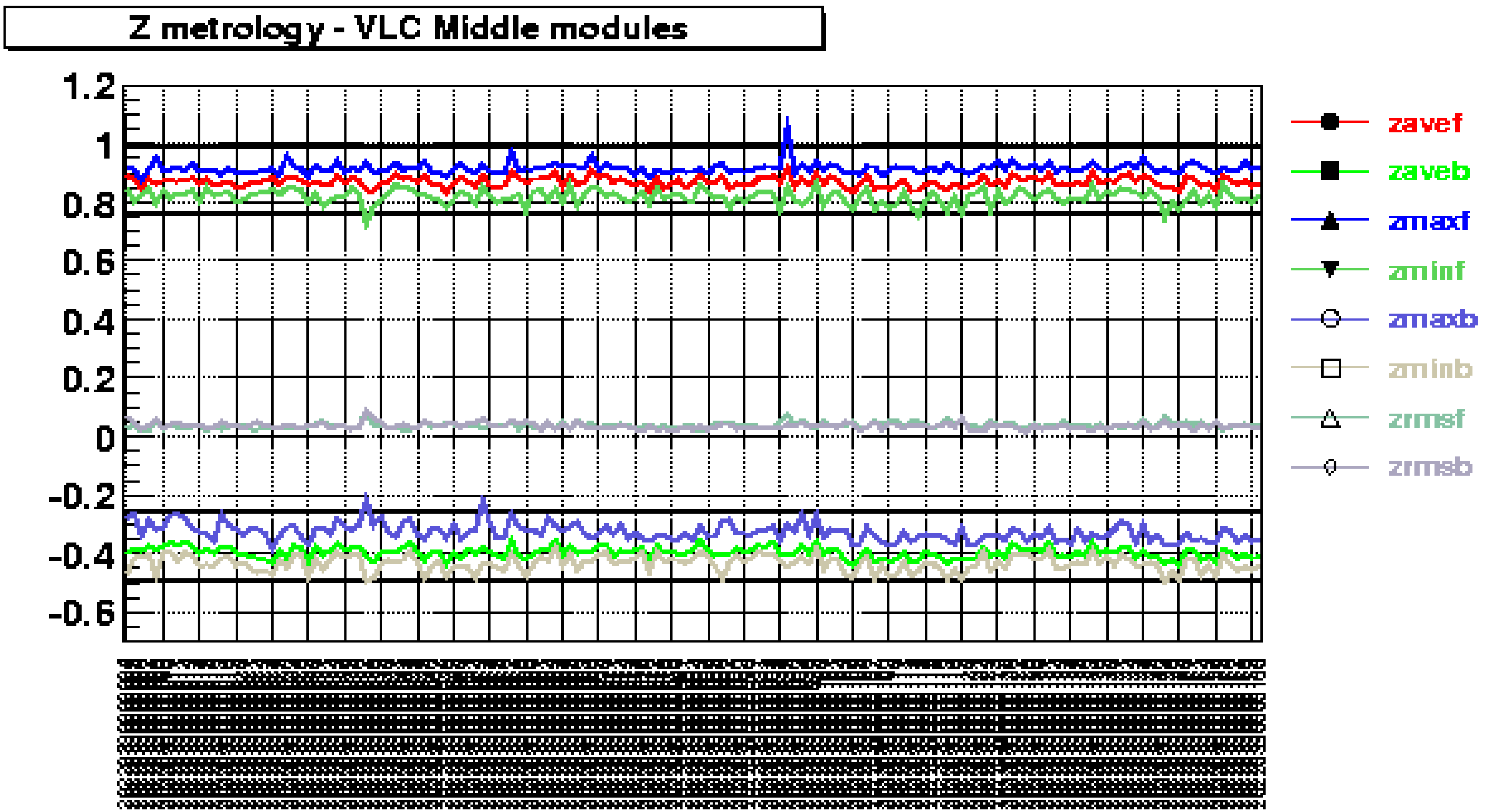
Production process (11).

- **Results (2).**



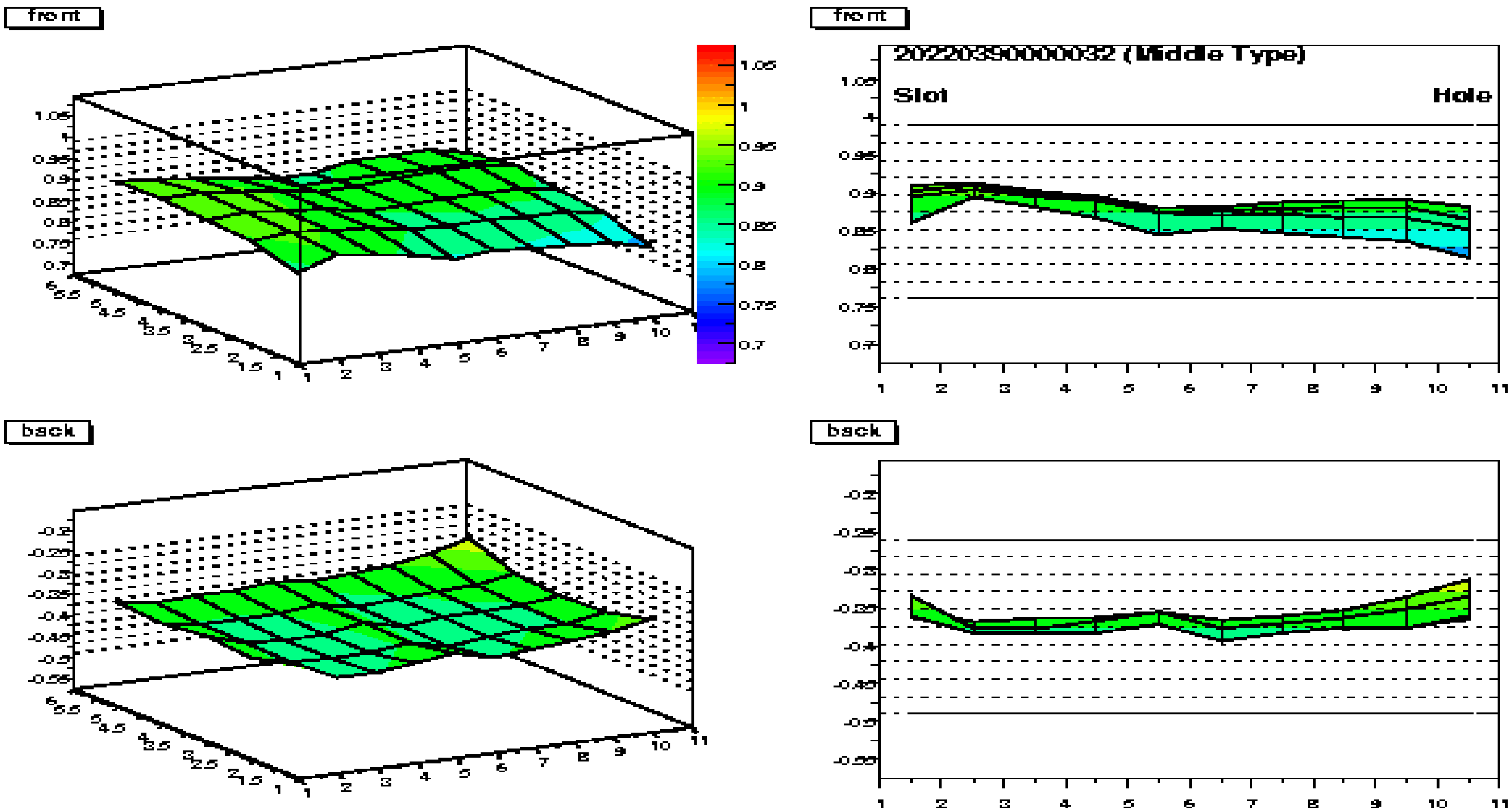
Production process (12).

- **Results (3).**



Production process (13).

- **Results (4).**



Typical Z profile plot for ATLAS SCT forward modules.

Conclusions.

- The production of the ATLAS SCT modules has been a successful, long and complex process that needed about 24 months for completion.
- The production was planned with a contingency of 20% allowing for loses of 15% during module assembly and a further 5% when mounting modules on discs.
- More than 2350 SCT endcap modules have been built with a yield of 93%, despite the complexity of the design and the tight mechanical specifications.
- The SCT group at IFIC has produced 282 (12%) of these modules with a yield of 93,4%.
- 14 institutes with a wide geographical spread have participated in the process in a remarkably collaborative way which has been key to this success.
- Modules has to be designed as simple as possible bearing in mind not only experiment requirements but also the production complexity, time and cost involved.