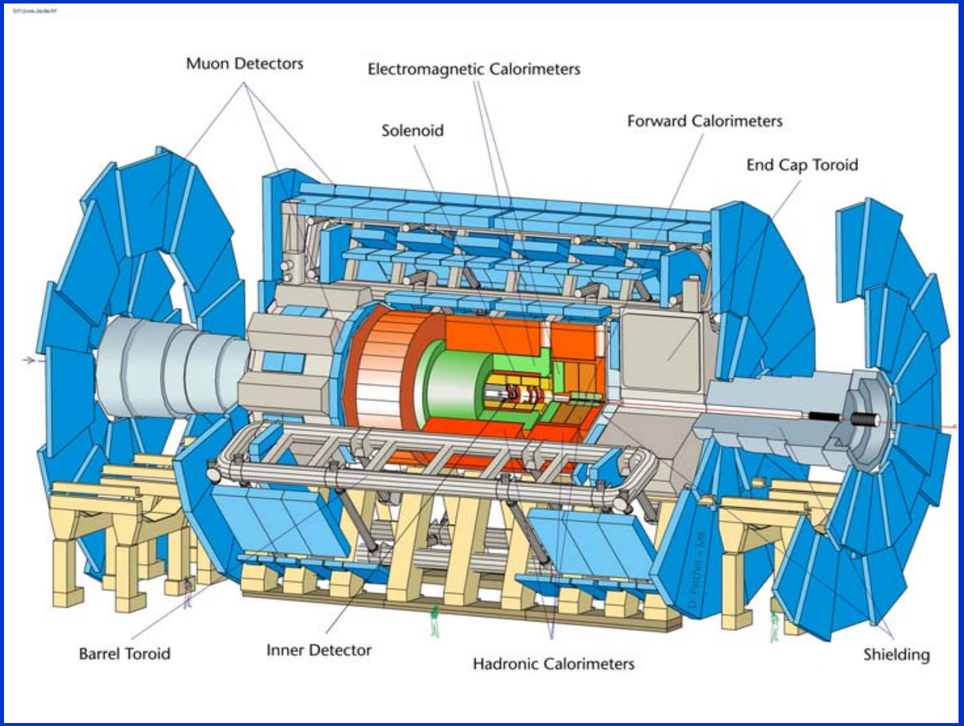
THE ATLAS FORWARD SILICON TRACKER

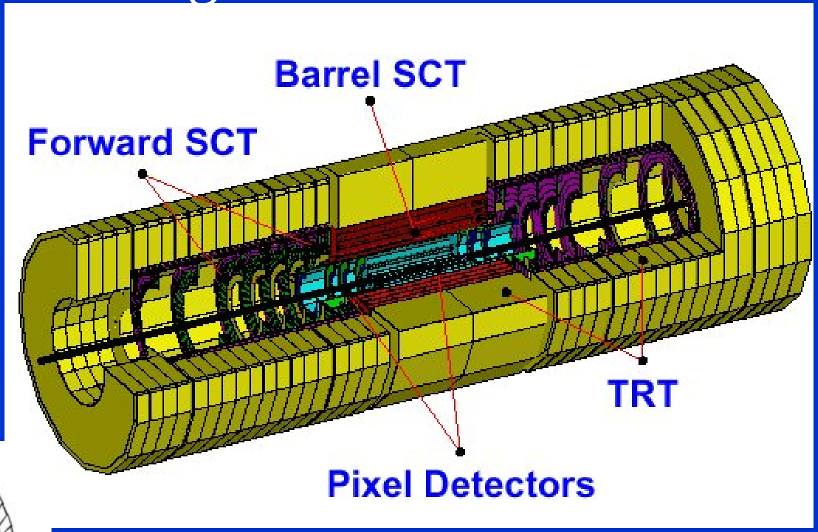
- Overview of the ATLAS SCT
- Module design
- Module production
- Engineering and services
- Macro-assembly and testing
- Summary



Neil Jackson
University of Liverpool

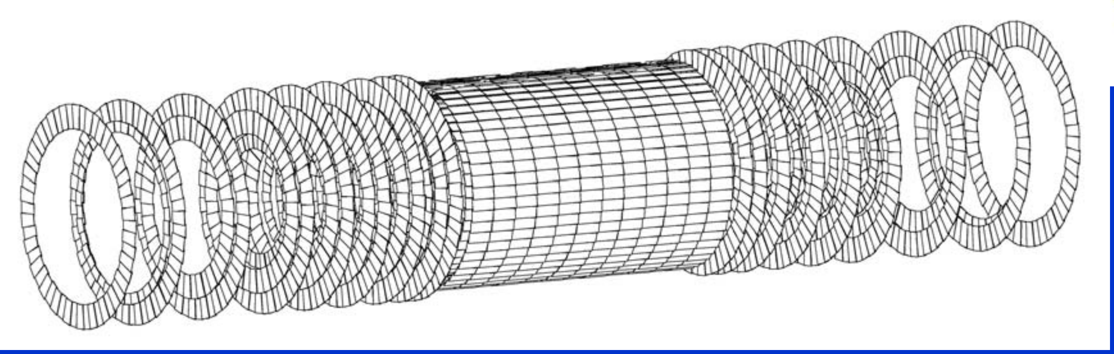
Overview of the SCT

- The SCT forms part of the ATLAS Inner Detector.
- It is constructed using 4088 silicon micro-strip modules arranged as 4 barrels in the central region and 2 x 9 annular wheels in the forward region

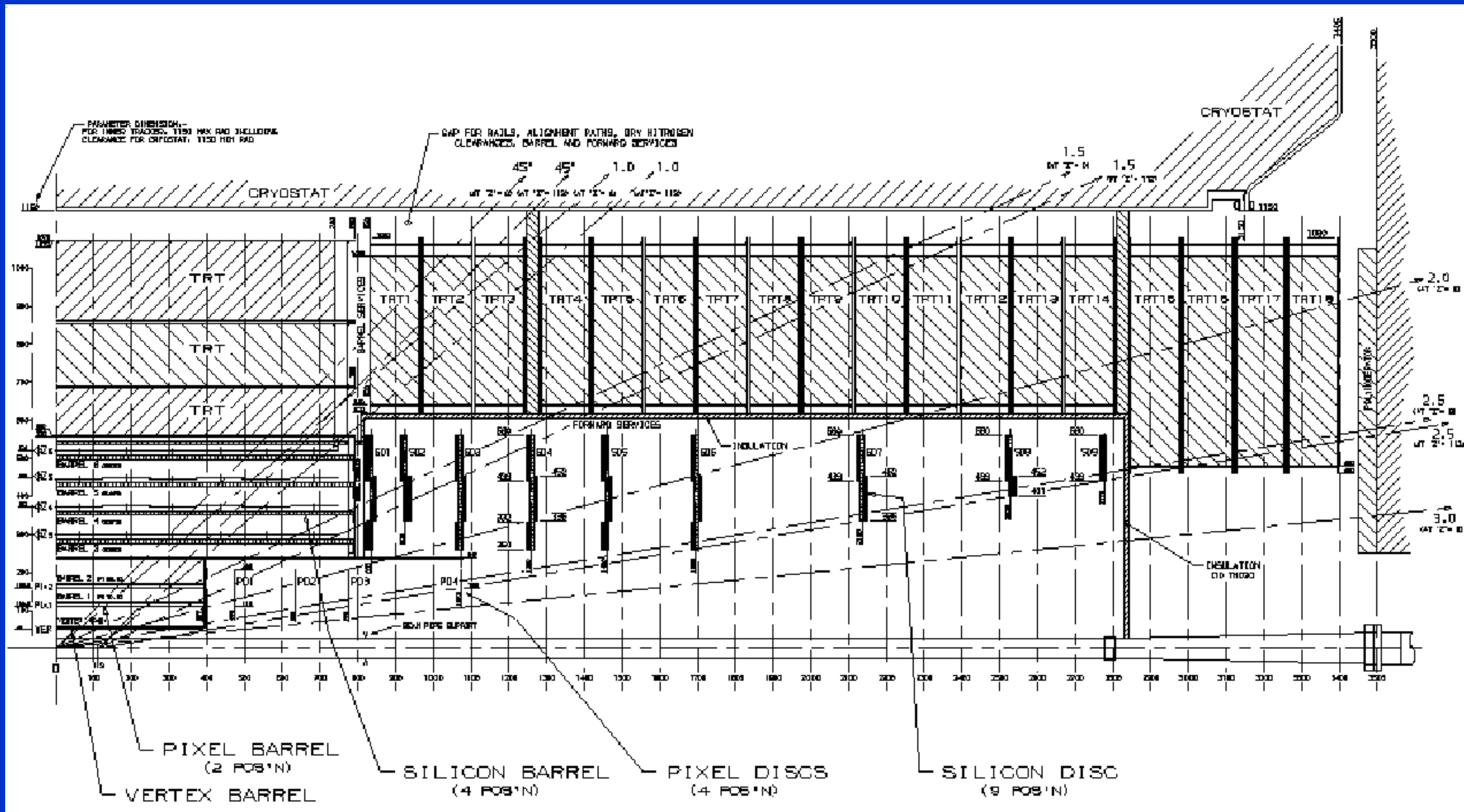


The Inner Detector is in a solenoidal 2T field

SCT



Inner Detector (ID)

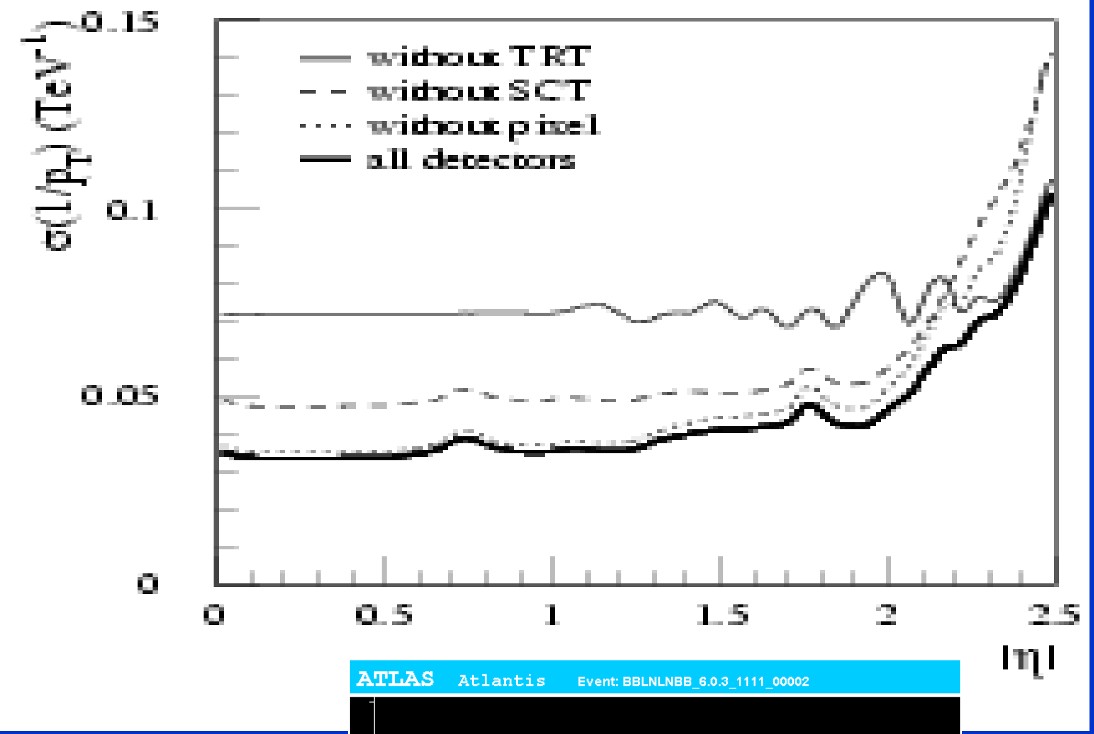


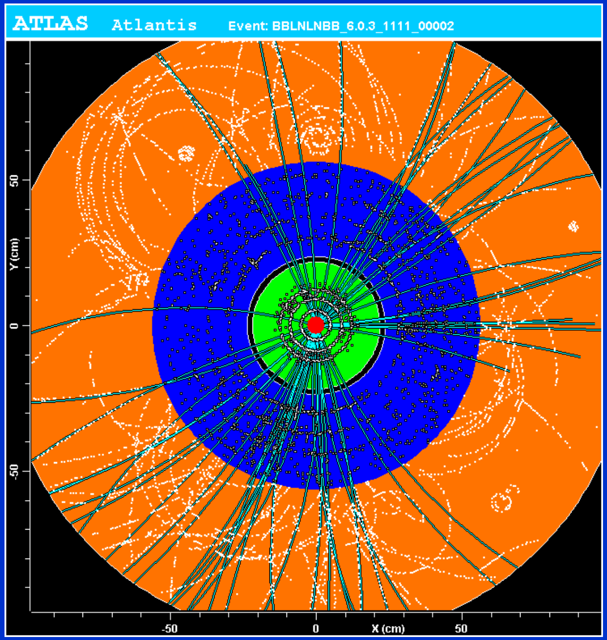
- The modules are arranged to provide 4 space points per track $-2.5 < \eta < 2.5$
- Each module measures two coordinates
  - Detector pitch is 80 μm and +-20 mrad stereo

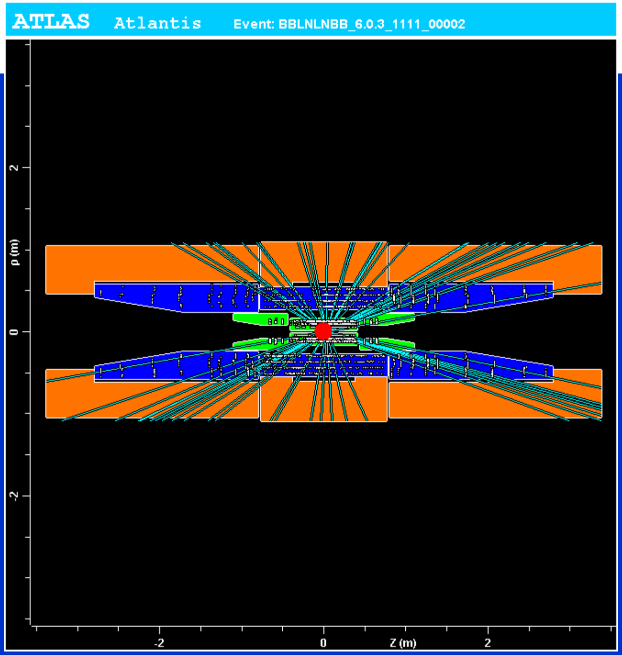
Inner Detector (ID)

Momentum resolution

B = 2 T



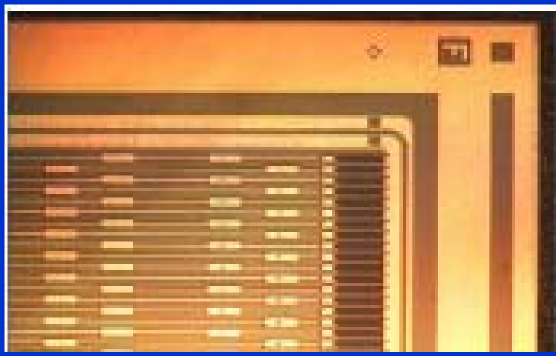




t tbar Higgs event

Sensors

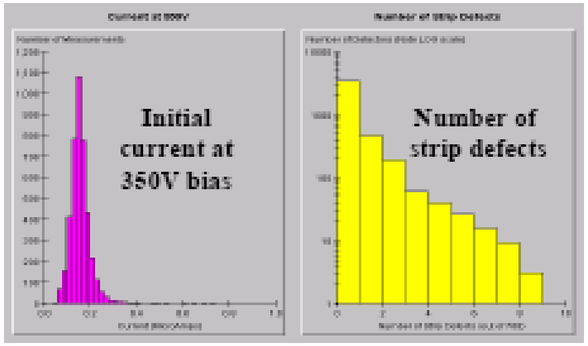
p in n sensors were procured from Hamamatsu and CIS



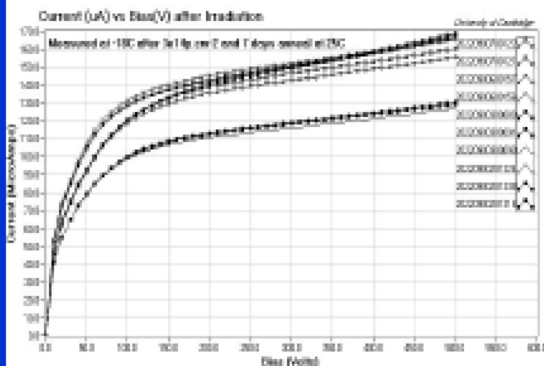
Typical results from the Hamamatsu detectors

Radiation exposure is 3×10^{14} p cm^{-2} at 24 GeV/c (10 yrs LHC)

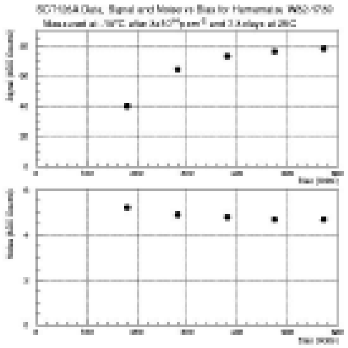
- **Detectors are of excellent quality from Hamamatsu**
- **Pre-Irradiation:**
  - All quantities within specification
  - Very low leakage currents
  - >99.9% good readout strips



- **Post-Irradiation:**
  - Within specification for operation at ~400V bias after 10 years of LHC



Post-irradiation detector leakage current vs bias voltage

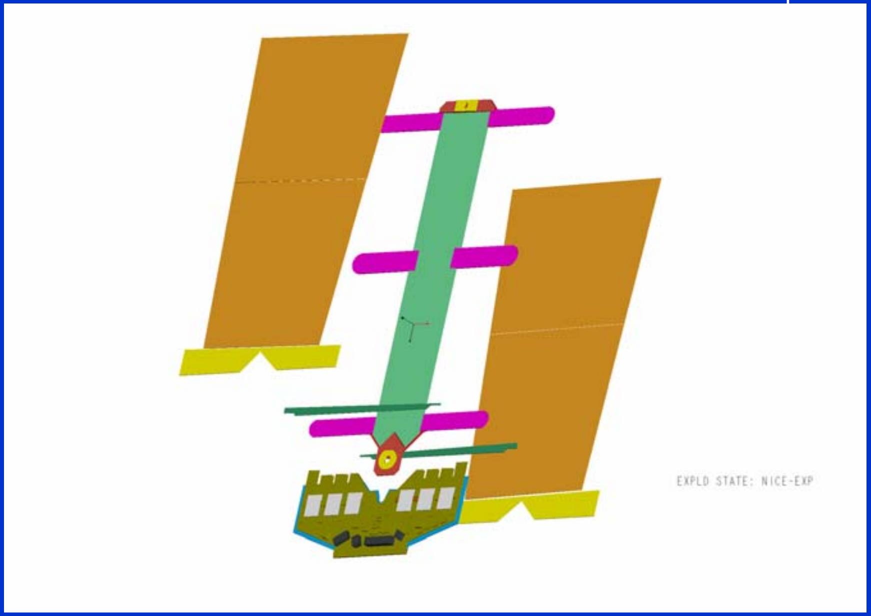


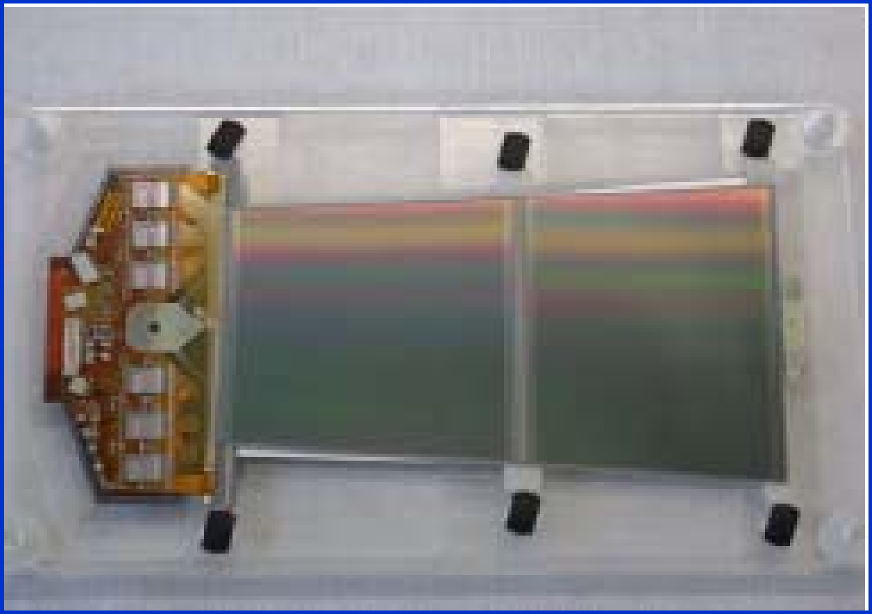
Charge collection vs bias voltage

Noise vs bias

Post-irradiation source measurements with analogue readout

- Modules consist of 4 (2) detectors mounted on a baseboard (barrel) or spine (forward) consisting of Thermal Pyrolytic Graphite + AlN
  - Ensures good thermal performance
- The kapton hybrids are mounted on carbon-carbon substrates
- Modules have 1526 binary readout channels per module
- Spatial resolutions $\sigma_{r\phi} = 16\ \mu m$, $\sigma_R = 580 \mu m$

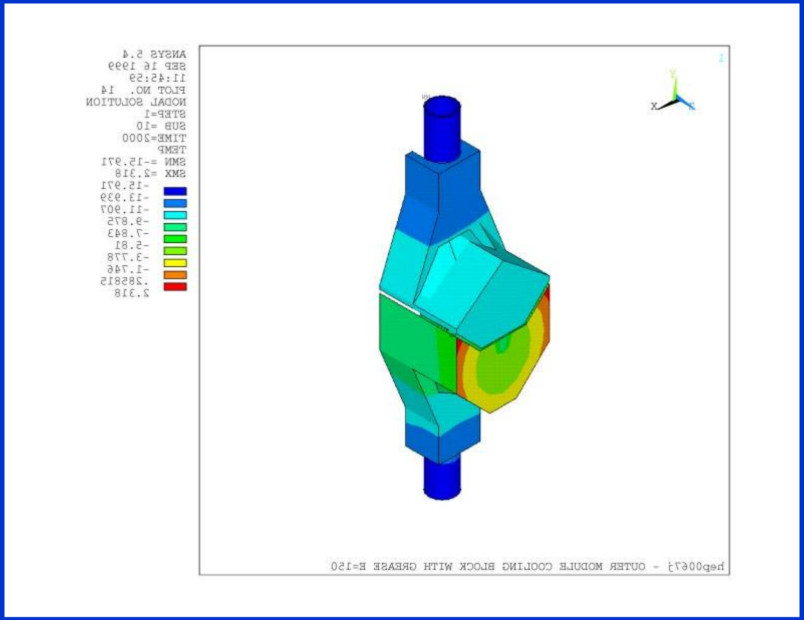


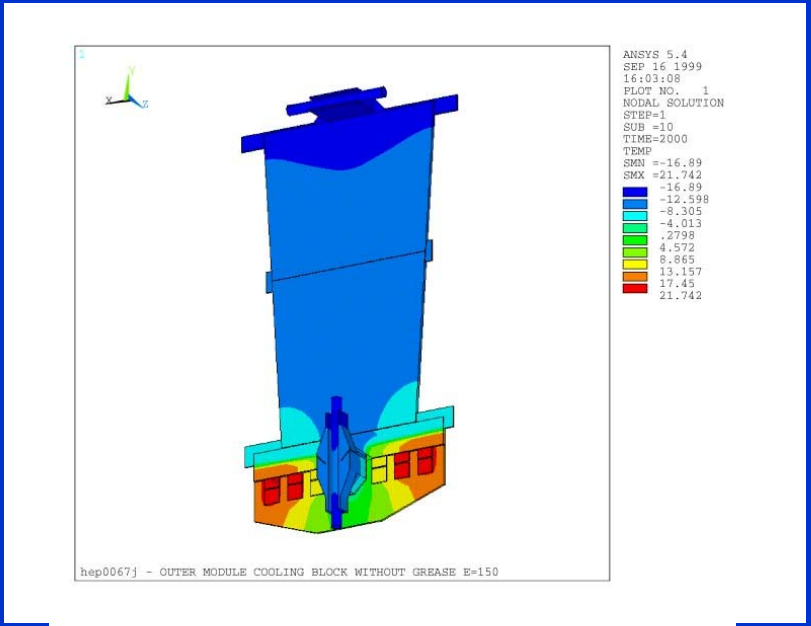


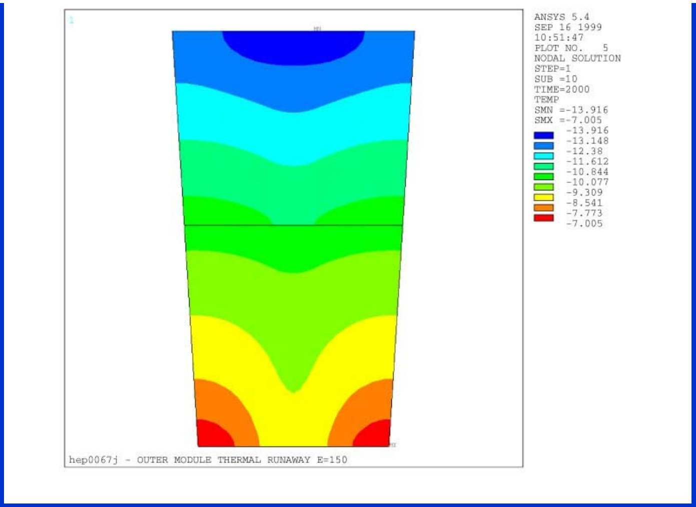
Forward Module

Module types

THERMAL MANAGEMENT







- The design aims to isolate the heat from the hybrid from the silicon
- The carbon-carbon cooling block includes a thermal split

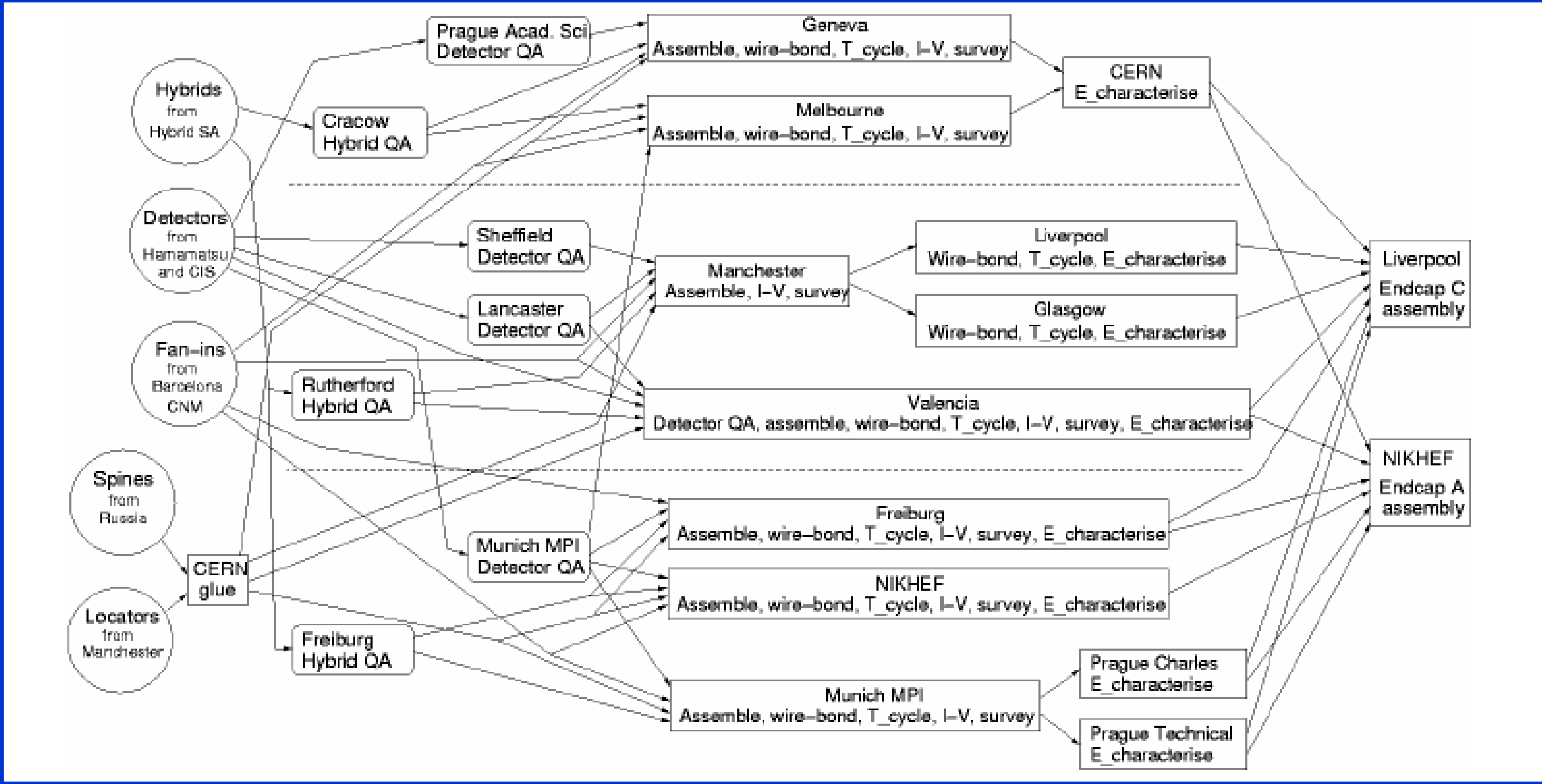
Support structures

- All support structures, cylinders and discs, are produced using a sandwich material constructed with carbon fibre skins and a Korex core in industry
- Cu/Ni cooling pipes, precision mounts for modules, power tapes, opto-fibre harnesses + DCS and alignment components are added

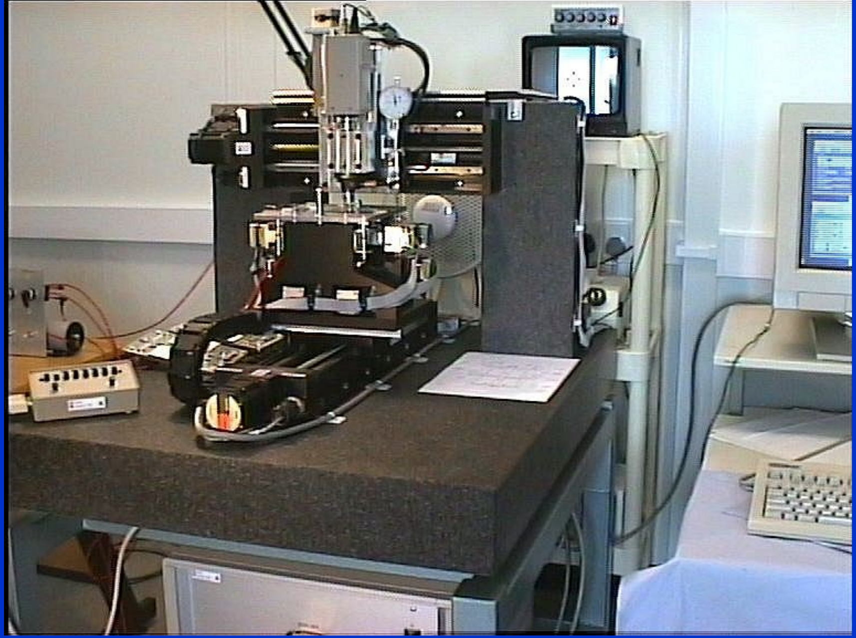
MODULE PRODUCTION

- Production of the modules occurs at several sites worldwide
  - 1976 forward modules + spares were constructed in Australia, Germany, Netherlands, Spain, Switzerland and the UK
- Modules must satisfy many criteria and tolerances – e.g.
  - A range of mechanical tolerances, some < 5 μm
  - Module leakage current < 80 μA at 350V
  - Noise per channel < 1500 ENC
  - Average noise occupancy at 1 fC threshold $< 5 \times 10^{-4}$
  - < 1% bad channels

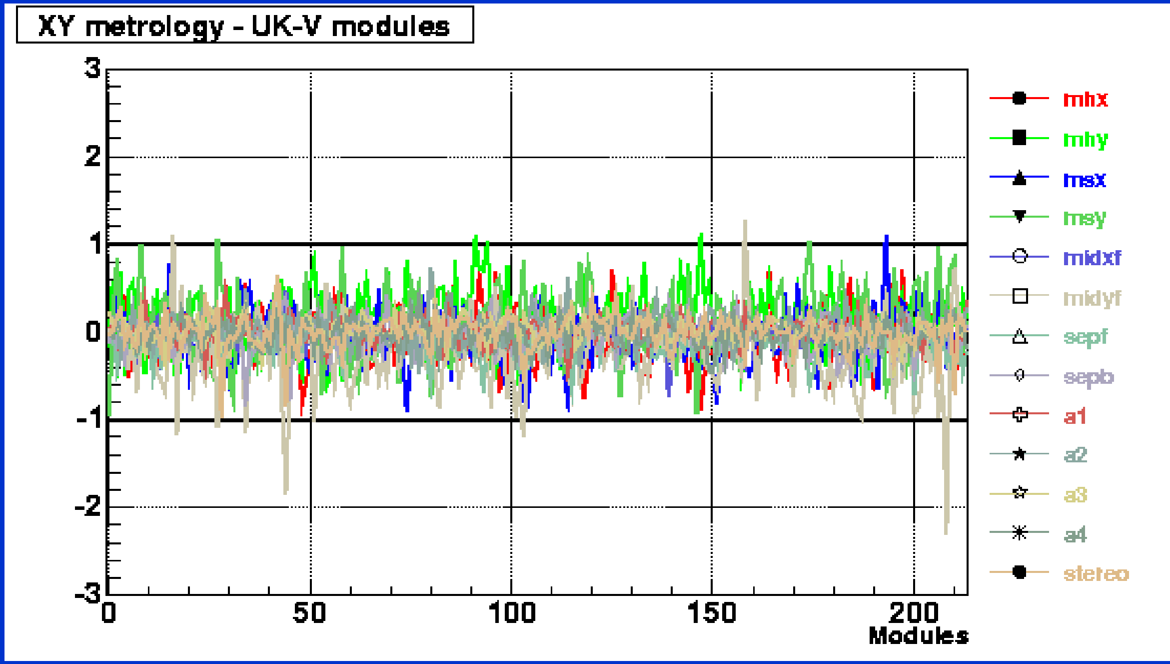
FORWARD SCT ORGANISATION



A forward module assembly station

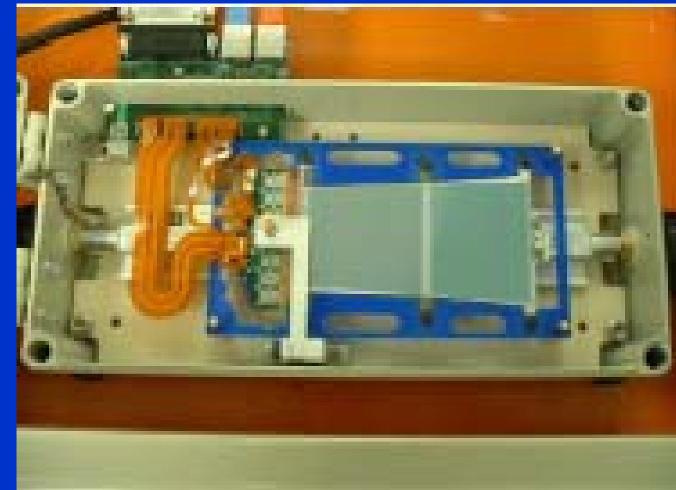


Vertical scale is deviation from nominal in units of tolerance. Horizontal scale is module number.



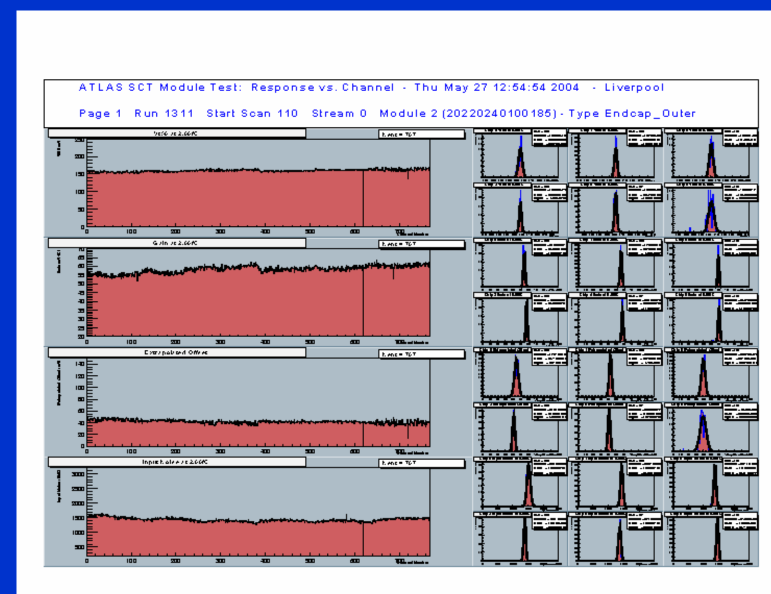
Bonding and testing

Module bonding



Module in testing

Module metrology



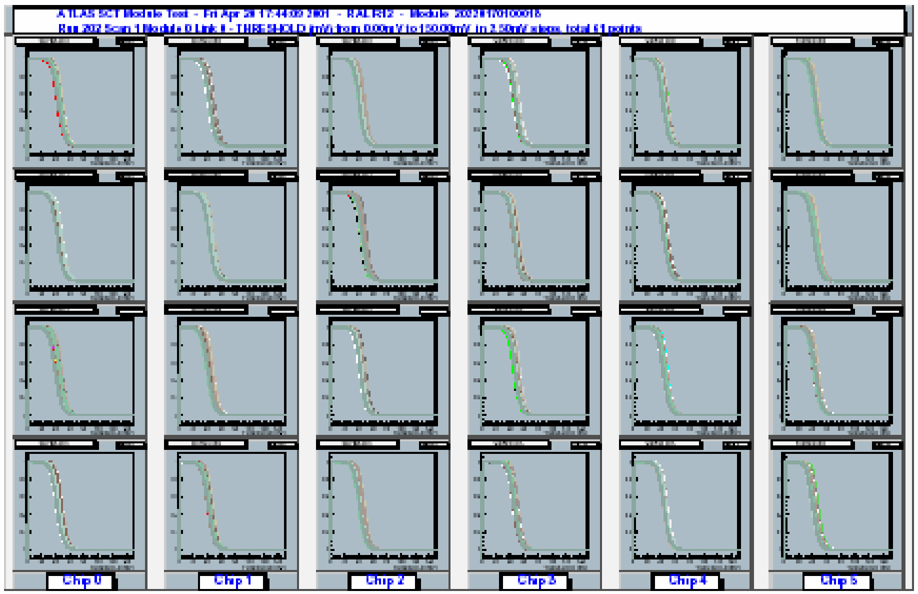
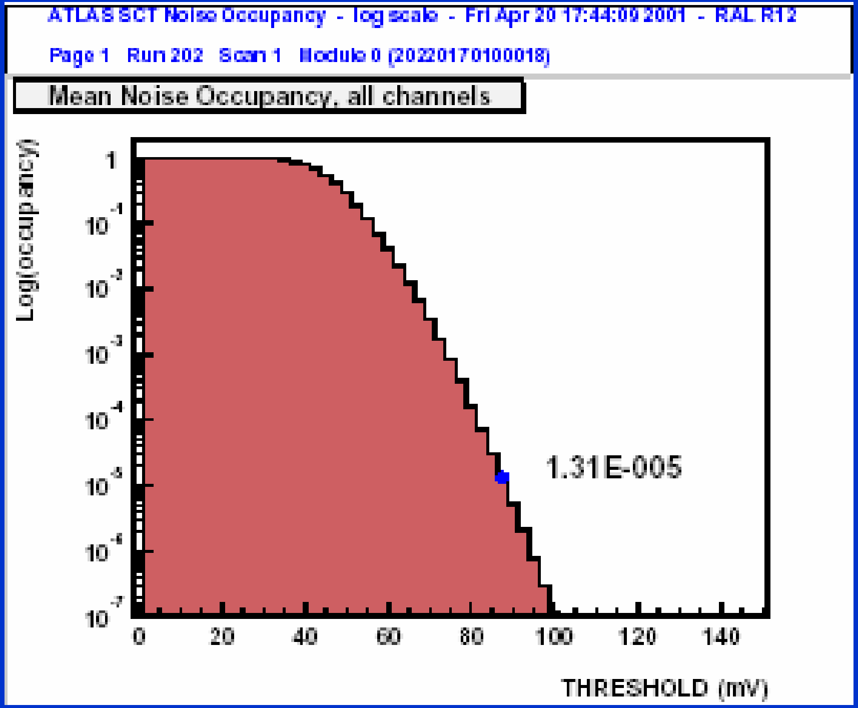


Figure 4: Curves of occupancy versus threshold superimposed for every readout channel of the first readout side of an ABCD3T-A module. Every fourth channel (32 in total) of each ASIC appears in each of the boxes.



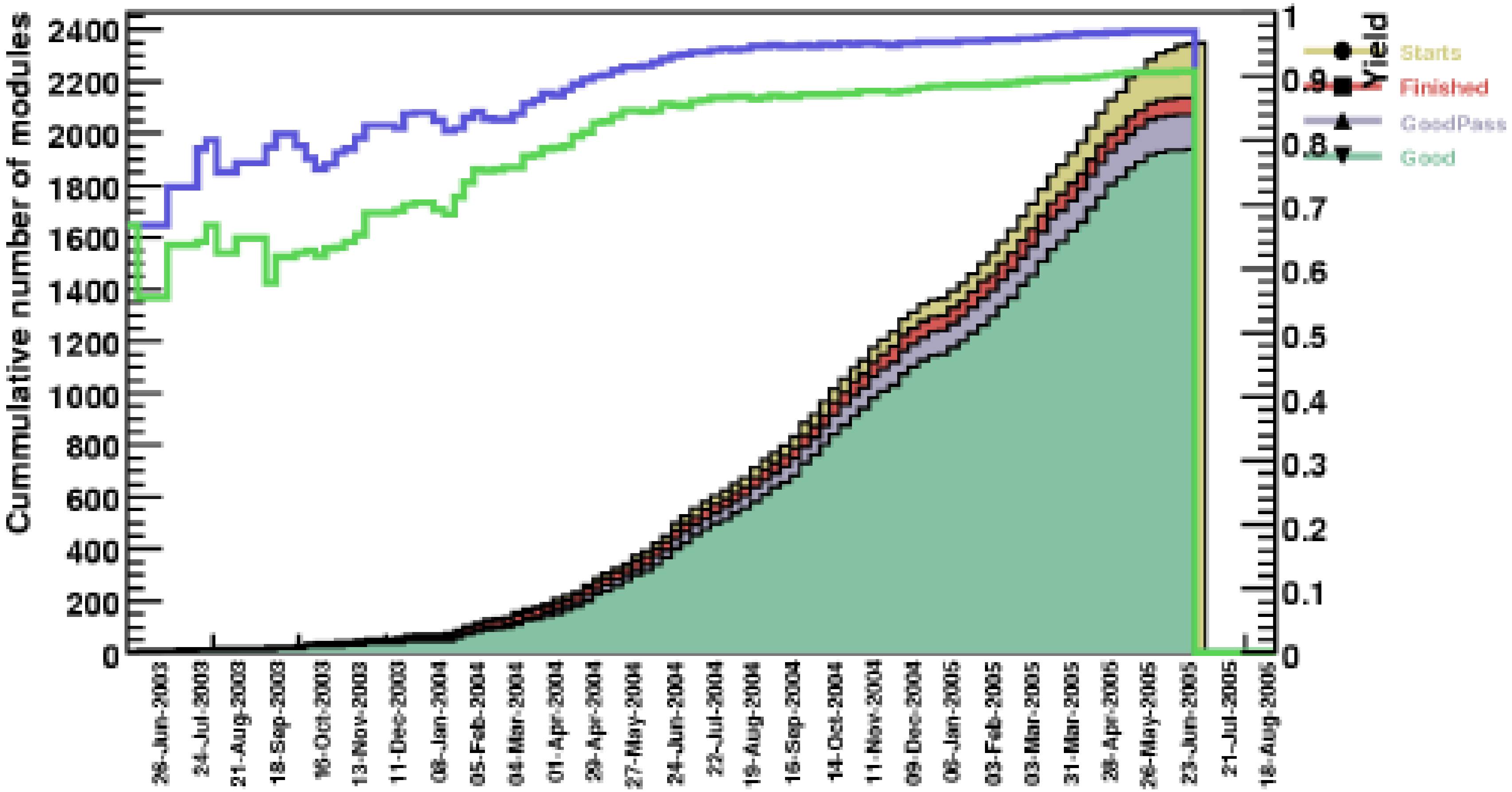
Threshold Scans

Noise Occupancy

FORWARD MODULE YIELDS

- Production allowed for a 20% loss in construction and macro assembly
  - **2368 modules were constructed with a yield of 93%**
- ‘Good’ modules satisfied all specifications -> yield 86.3%
- ~50% of the ‘failures’ were just outside over tight metrology specifications
  - A ‘Pass’ category was defined with some parameters limits increased by 50%

Category	Inner	Middle(S+L)	Outer
Good	394	665	984
Pass	39	58	56
Hold/Rework	46	48	23
Fail	16	5	34
Good+Pass (G+P)	433	723	1040
G+P Required to equip End-Caps	400	640	936

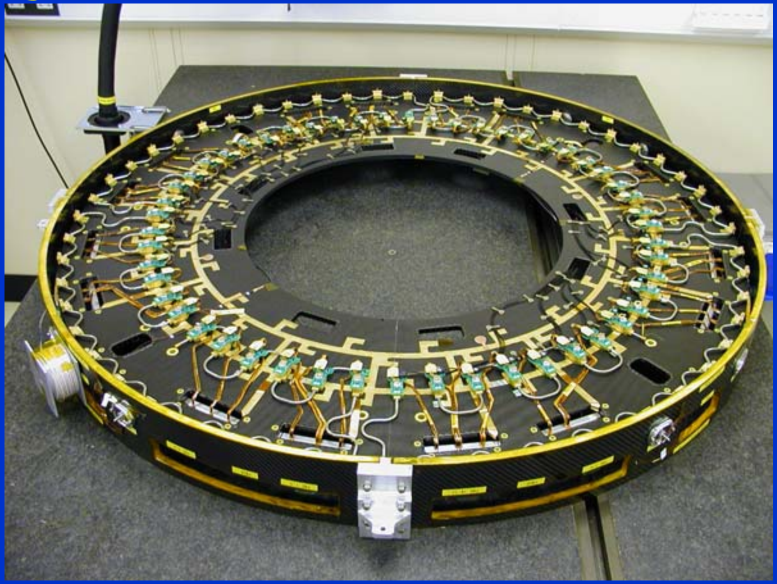

Cummulative number of modules
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
Yield
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Starts
Finished
GoodPass
Good
26-Jun-2003
24-Jul-2003
21-Aug-2003
18-Sep-2003
16-Oct-2003
13-Nov-2003
11-Dec-2003
08-Jan-2004
05-Feb-2004
04-Mar-2004
01-Apr-2004
29-Apr-2004
27-May-2004
24-Jun-2004
22-Jul-2004
19-Aug-2004
16-Sep-2004
14-Oct-2004
11-Nov-2004
09-Dec-2004
06-Jan-2005
03-Feb-2005
03-Mar-2005
31-Mar-2005
28-Apr-2005
26-May-2005
23-Jun-2005
21-Jul-2005
18-Aug-2005

Lessons learned

- The progression from prototyping components to full production can introduce some problems and cause delays
  - e.g. Forward hybrid de-lamination problem
- Do not underestimate the time required to optimise techniques and commission equipment
  - e.g. Module assembly techniques
- Take care in defining specifications
  - Achieving the same quality in multiple sites is not straight forward
- Expect unexpected production problems and allow for the time required to solve them
  - Start with a proper contingency to allow for unexpected problems
  - Rigorous prototyping and QA will minimise unexpected problems

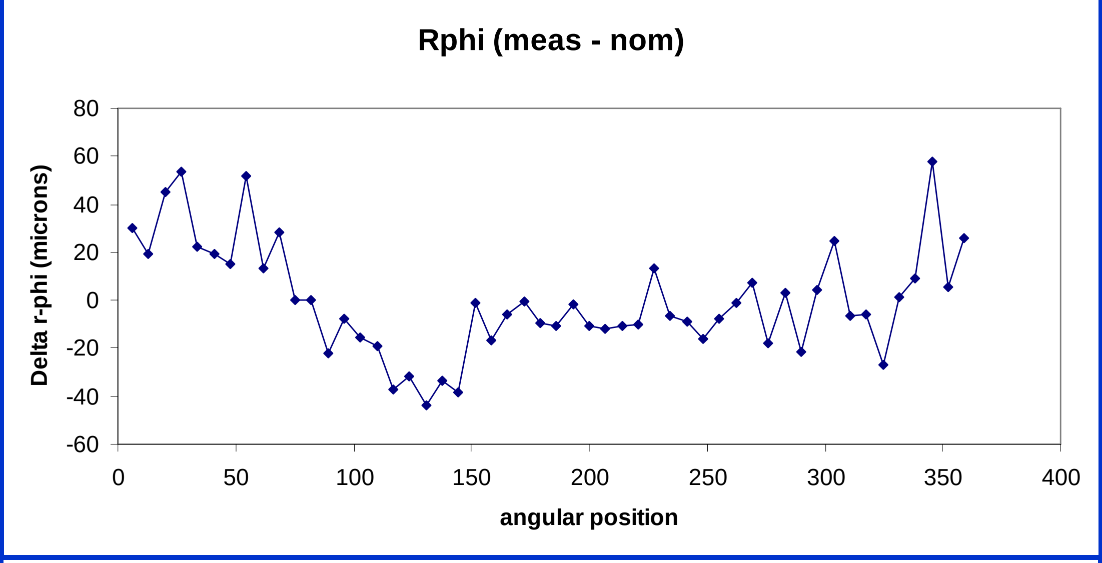
Engineering assembly and services

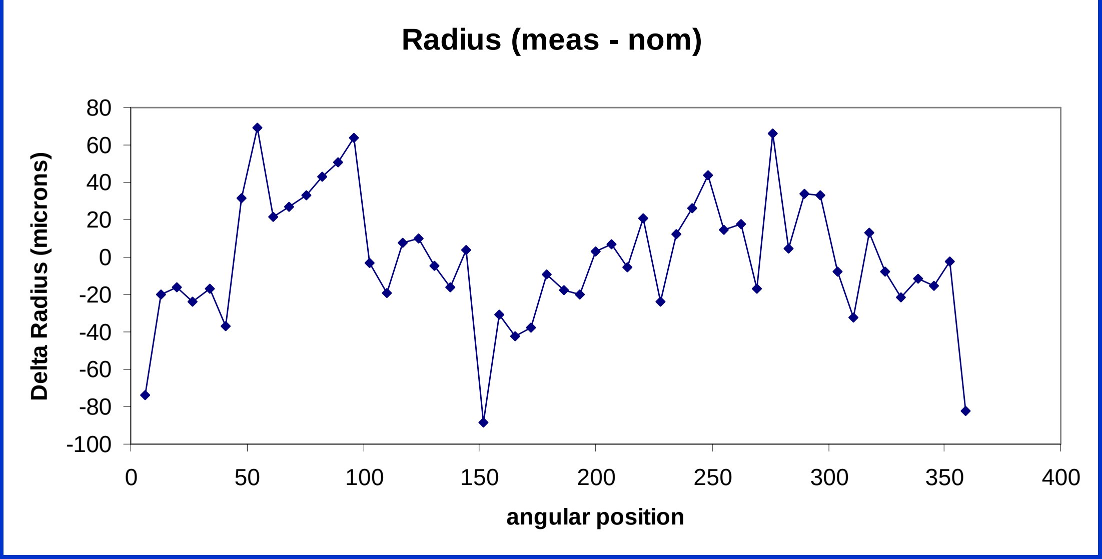
Preparation of discs



- Mounting pads and closeouts are glued onto the disc
- The pads are machined plane
- Patch panels and grounding foils are added
- Services are added
  - Low mass tapes
  - C-C mounting blocks soldered onto Cu/Ni pipes are mounted with high precision
  - Optical fibre harnesses, alignment components and DCS

Metrology results for mounting pin positions for disc 9C





The measurements are repeatable (to ± 5 μm) after thermal cycling

The disc is within specifications

Lessons learned

- Developing new solutions is time consuming
  - e.g. bending and soldering Cu/Ni pipes and developing C-C cooling blocks
- Take care with design of kapton components
  - Design of tracks, attachment of connectors and stiffening where required
- The end-cap support cylinders when delivered were not up to specification and needed modifications involving delays

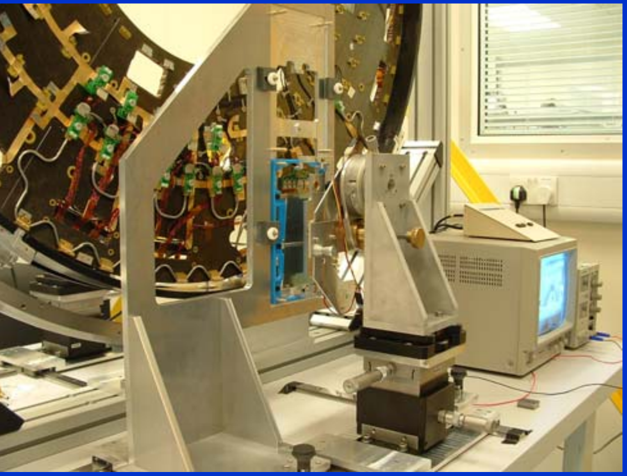
Macro-assembly

General infrastructure

- The macro-assembly is performed in clean conditions (typically class 10000)
- An evaporative cooling plant based on C_3F_8 is required to cool large numbers of modules
- Special tooling is required to mount modules
  - A manual mounting jig for the end-cap
- Special tooling is required to mount discs into the support
- Testing must be done at –7C
  - Requires final power supplies, DCS and DAQ

Mounting modules onto discs

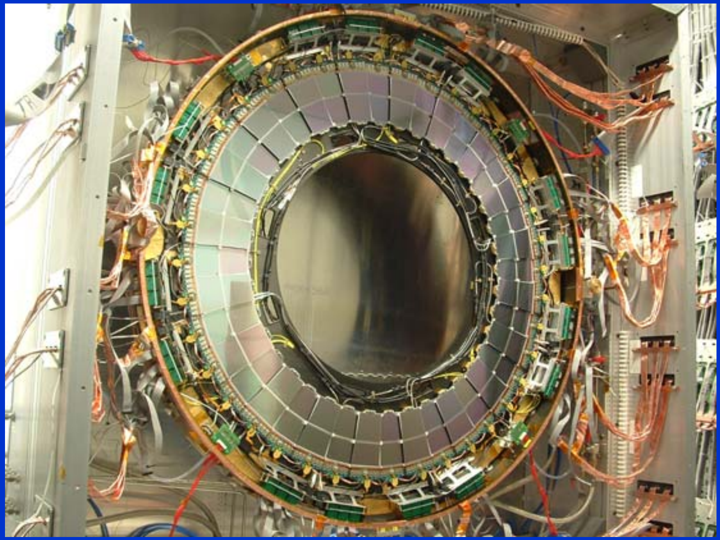
- The disc is mounted in a rotating vertical frame
- Thermal grease is applied to the cooling blocks
- The module is extracted from its frame
- The frame is removed and the module is lined up with the mounting blocks
  - Using the x/y/θ stages monitored with cameras
- The module is positioned and attached

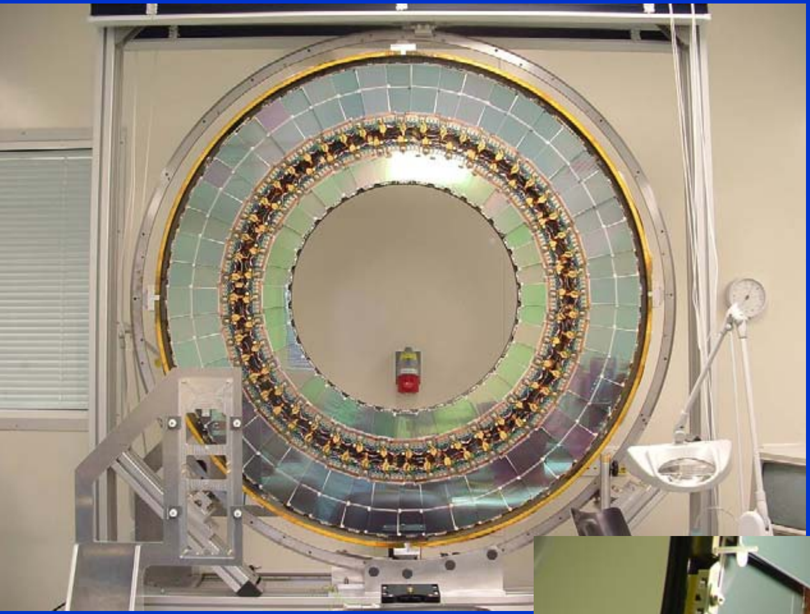


- Lower modules are added first and then tested electronically and thermally at –7C. Upper modules next.

Electronic and thermal tests of discs at operating temperature (C_3F_8 coolant at -25C

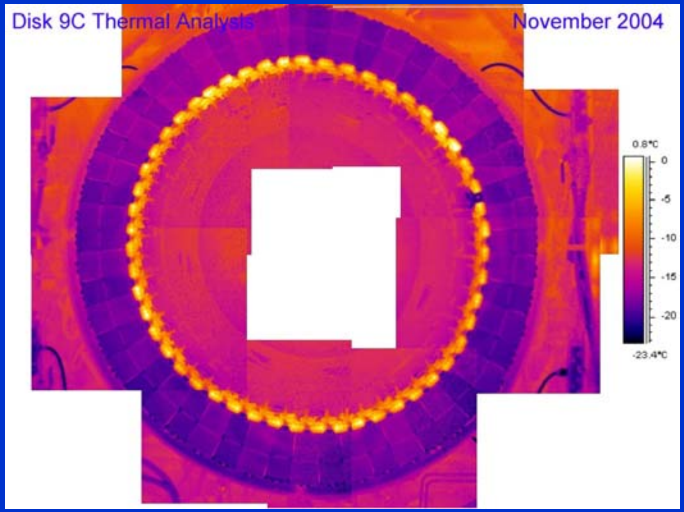
A disc under test in the environmental chamber





A completed end-cap SCT disk

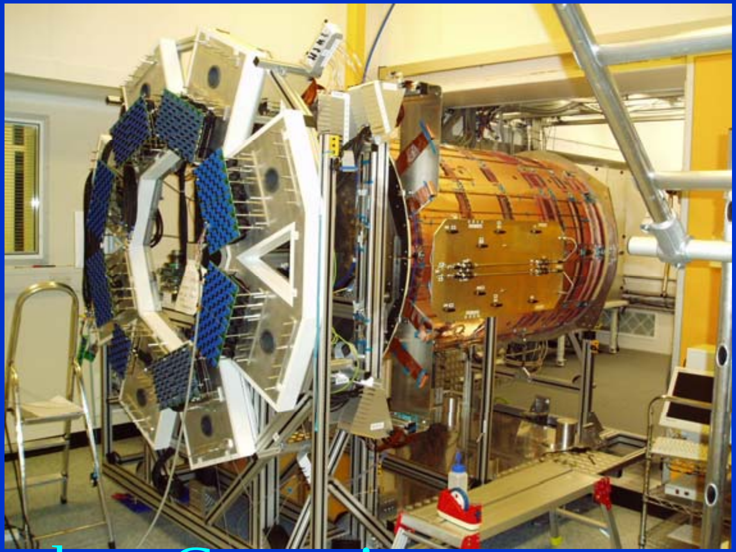
Close up view



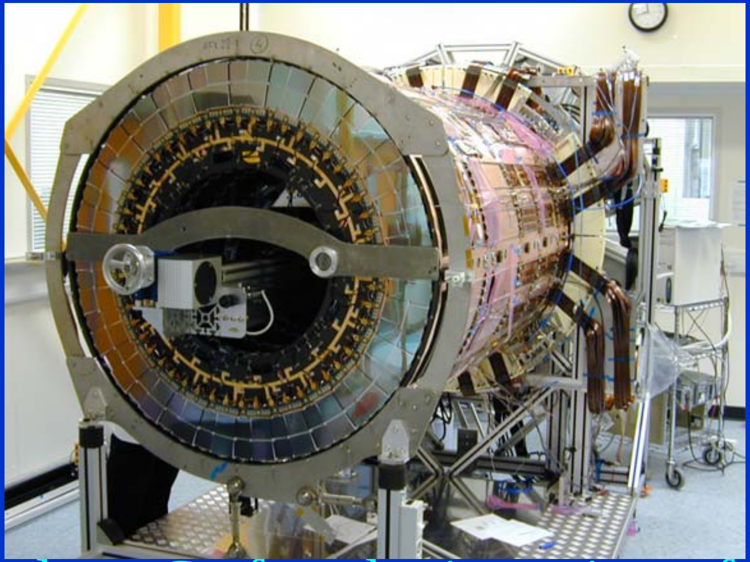
Thermal tests

Mounting discs into the support cylinder

- The disc is extracted from the test frame frame and attached to the tooling to insert it into the cylinder
- After insertion the services are added to the end-cap which is then moved to the cold room for testing.
- The cooling pipes, fibres, low mass tapes and DCS are connected and the disc is readout at –7C.

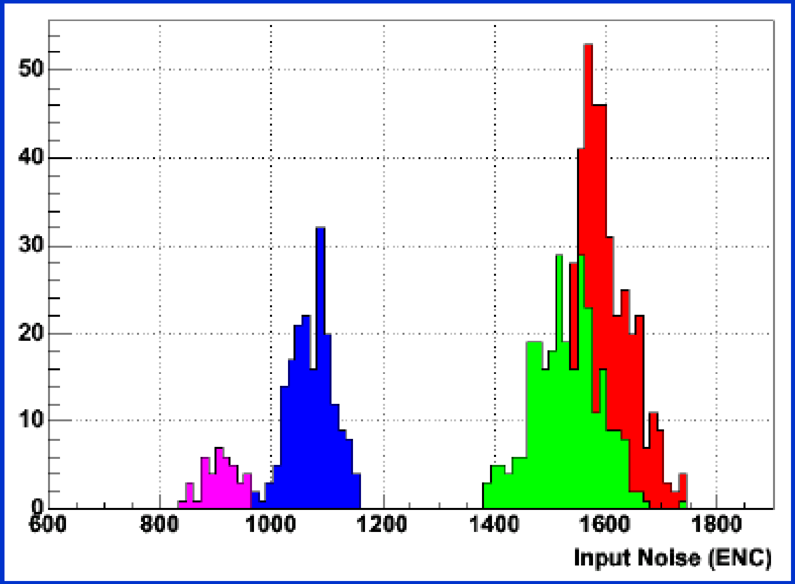


Endcap C entering environmental chamber



Endcap C after the insertion of the last disc

Tests were performed on each disc separately and on quadrants of discs 7,8 and 9 simultaneously



Average Input Noise (ENC) at ~0C:

- **Outers: 1576**
- **Middles: 1529**
- **Inners: 1070**
- **Short Middles: 907**

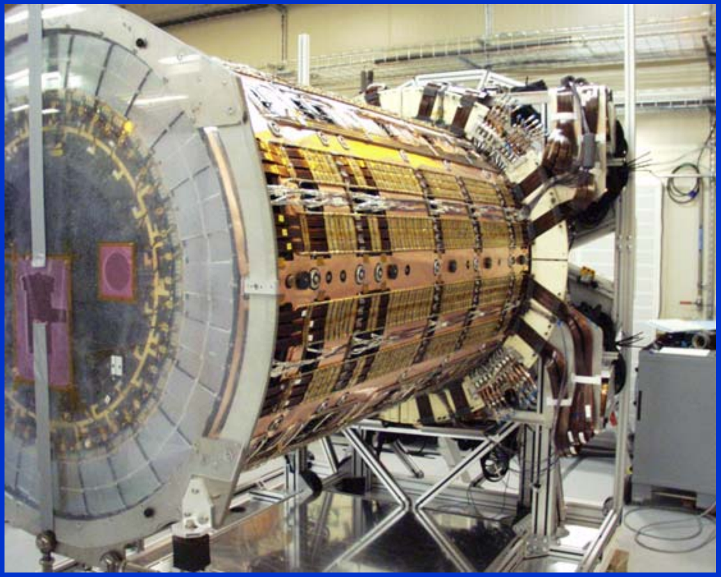
Noise measurements from the 9 discs

A total of 99.73% channels are fully functional

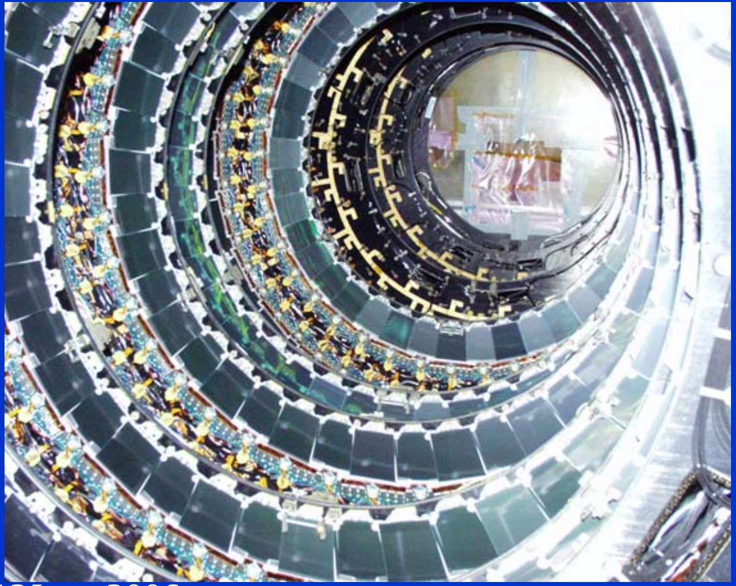
Endcap C arrives at CERN

Unloading

Endcap C in SR1



Transfer to SR1



Inside view

Current Status

- Acceptance tests are completed
- Mechanical work is underway
  - Mounted on cantilever stand
  - Support wings and thermal enclosures are being added
- Insertion into TRT in September
- Installation in ATLAS in November

SUMMARY

- ATLAS SCT Endcap C has been completed and shipped to CERN
  - Module production was completed on time with a successful yield
  - Acceptance testing in Liverpool and at CERN was completed
  - The completion of the mechanical structure, installation inside the TRT and joint testing will precede installation in ATLAS
- Several problems have been solved on route
  - No show stoppers
  - But usually caused delays and resource implications
- The schedule for completion remains tight but the collaboration is now looking forward to the first physics