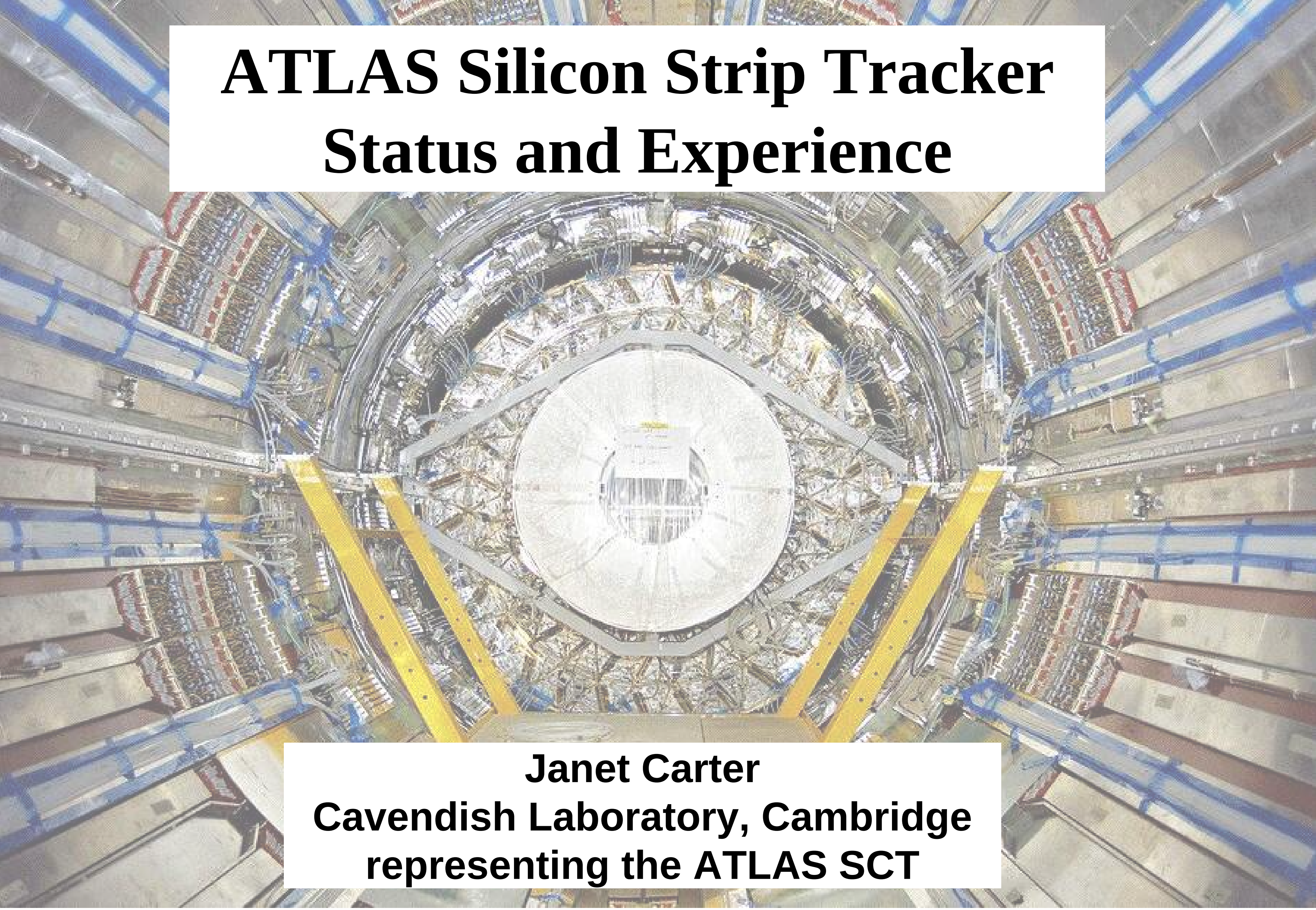


ATLAS Silicon Strip Tracker Status and Experience

Janet Carter
Cavendish Laboratory, Cambridge
representing the ATLAS SCT

ATLAS SEMICONDUCTOR TRACKER (SCT) STATUS & EXPERIENCE

40 Institutes make up the world-wide ATLAS SCT collaboration

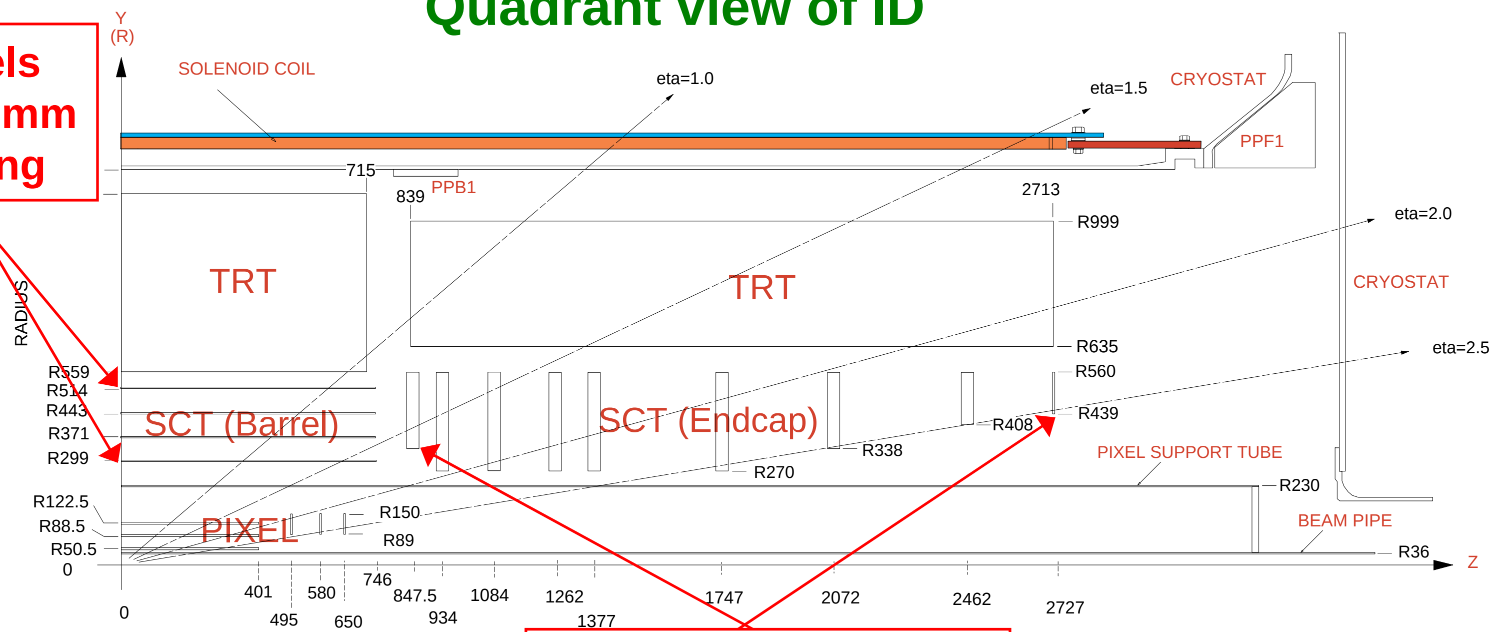
TOPICS:

1. **Overview**
2. **The Barrel and Endcap SCT Modules**
3. **Structures and Services**
4. **Assembly of Modules to Structures and Tests**
5. **Integration of SCT Structures, tests, lessons learnt**
6. **Installation within ATLAS**
7. **Summary**

Overview

- The ATLAS Inner Tracking Detector (ID) consists of:
  - An inner Pixel Detector (covered in earlier talks)
  - The SCT
  - An outer gaseous/polypropylene foil Transition Radiation Detector, the TRT

Quadrant view of ID



4 SCT barrels
299< R < 514 mm
1500 mm long

2 SCT endcaps (A&C)
each with 9 disks

Overview, continued

- **Some SCT Principal Requirements**
  - Survival up to integrated fluence of ~ 2×10^{14} 1 MeV-neutron-equivalent/cm^2 (10 years LHC operation)
  - At least 4 Layer tracking coverage out to $\eta = 2.5$, with 2-D readout
    - Precision/layer ~ 17 μm perpendicular to strip direction, ~ 600 μm orthogonal
  - 40 MHz operation (25 ns LHC bunch-crossing rate)
  - Operational silicon temperature of ~ -7 ^{o}C to limit the increase in depletion voltage due to reverse annealing
  - Robust to temperature cycling -30 ^{o}C < T < +30 ^{o}C
  - Lowest possible material budget, including structures and services
  - Thermal and structural stability for alignment
- **SCT Readout Architecture**
  - Binary readout from custom ABCD3TA DMILL FE ASICs

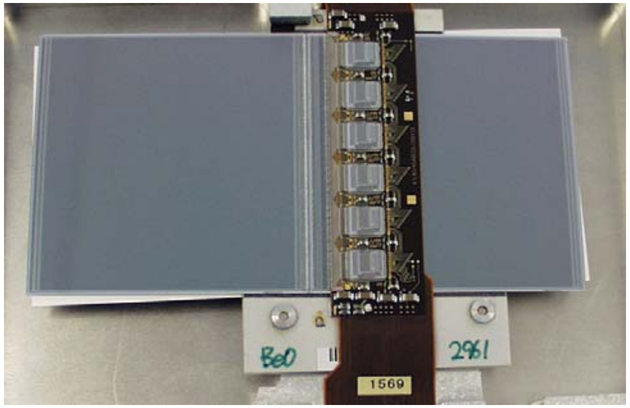
The Barrel and Endcap SCT Modules

Endcap Modules

Outer module Middle module Inner module

3 basic types of wedge-shaped endcap module, 5 sensor shapes, 1 hybrid design, end-tapped readout

Barrel Module



Only 1 type of barrel module, 1 rectangular sensor shape, centre-tapped readout

The Barrel and Endcap SCT Modules - continued

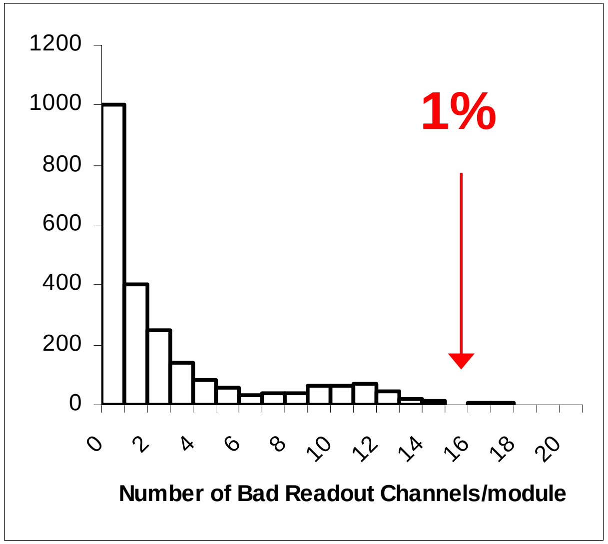
- **Summary of Module Properties:**
  - Back-to back 280 μm thick single-sided p-in-n silicon microstrip sensors, 40 mrad stereo angle
  - Glued around a high thermal conductivity graphite baseboard (barrel) / spine (endcap) to remove heat from sensors
    - No thermal runaway after full irradiation
  - ~ 80 μm strip pitch, giving required spatial resolution
  - Kapton hybrids on carbon-carbon substrates carrying ASICs
  - Total length of silicon in module limited to ~120 mm (ASIC capacitative load, noise performance)
  - ASIC power dissipation ~ 5.5 W nominal, ~7.5 W maximum
    - A critical parameter, dictating evolution of the SCT and evaporative cooling design
  - Electrical specification to 500 V bias
  - > 99% good readout channels and noise occupancy $< 5 \times 10^{-4}$ per channel
  - Tight mechanical internal placement tolerances
    - ~ 5 μm for most critical dimension – difficult to achieve at some construction sites

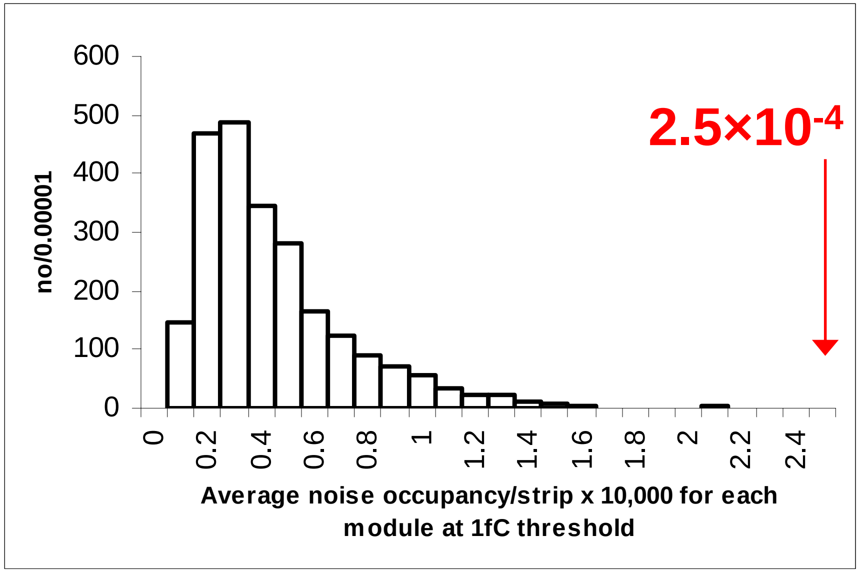
The Barrel and Endcap SCT Modules - continued

- **2112 barrel modules required for installation in ATLAS**
  - **Have been assembled (+ spares) in 4 separate SCT clusters (3 in-house, the largest in industry) over a ~ 2 year period, finishing early 2005**
- **1976 endcap modules required for installation**
  - **Have been assembled (+ spares) in-house within 3 groupings of SCT institutes over ~ 18 months, finishing July 2005**
- **Production yield of modules meeting full ATLAS specifications >~90%**
  - **and a further ~ 5% good for spares**
- **In the end, module production rate was not the limiting factor for the assembly of either the barrel or endcap SCT detectors**
- **But intricate designs, made more difficult by the attempt to minimise material**
  - **eg Barrel module 1.17% X_0 (smeared, normal incidence)**
  - **c.f. ~ 3% X_0 total per barrel layer – dominated by services**

The Barrel and Endcap SCT Modules - continued

- **A few examples of individual module performance:**

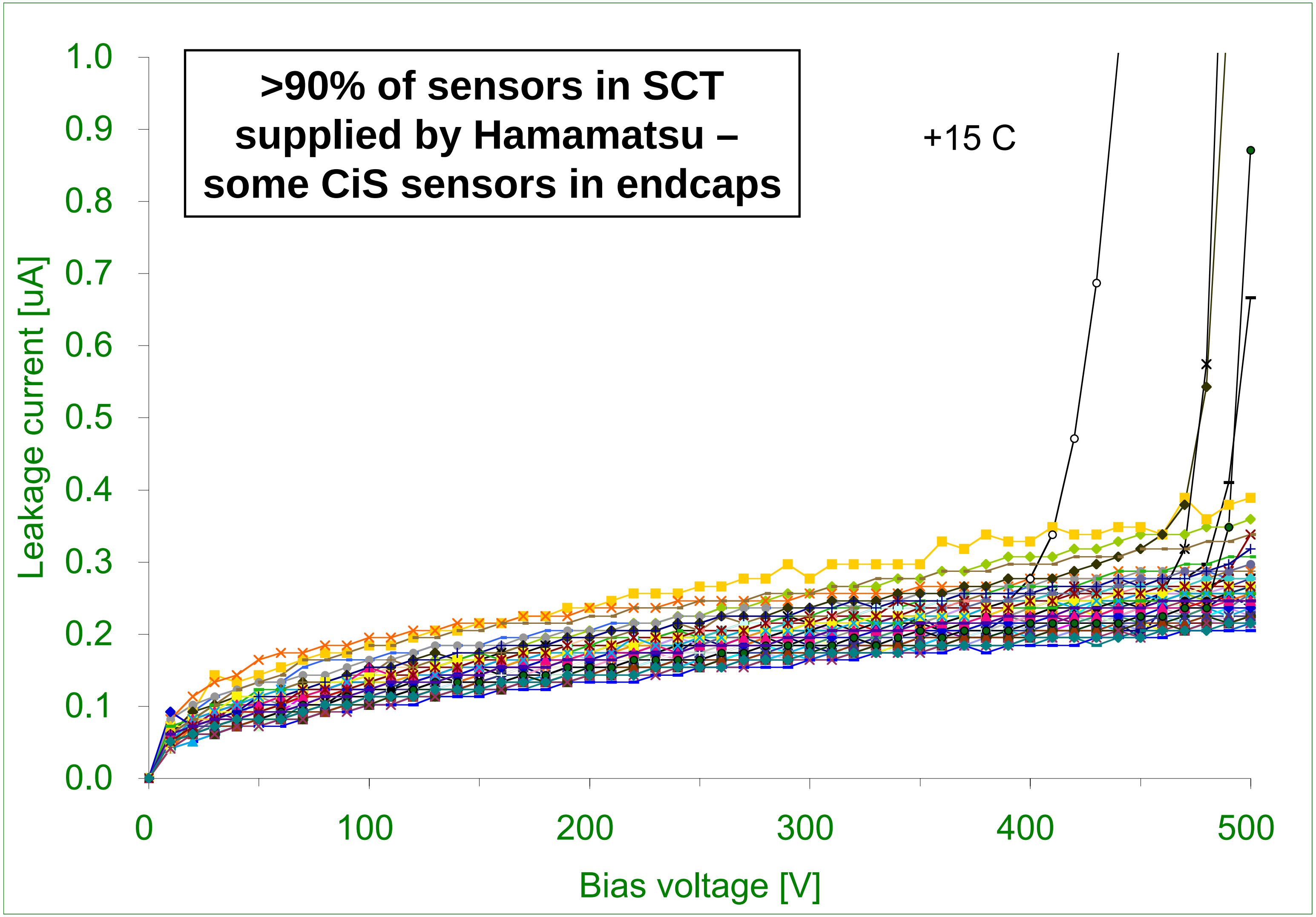




Bad channels/module (barrel)

Average noise occupancy/strip at 1fC binary threshold and ~ 28 ^{0}C

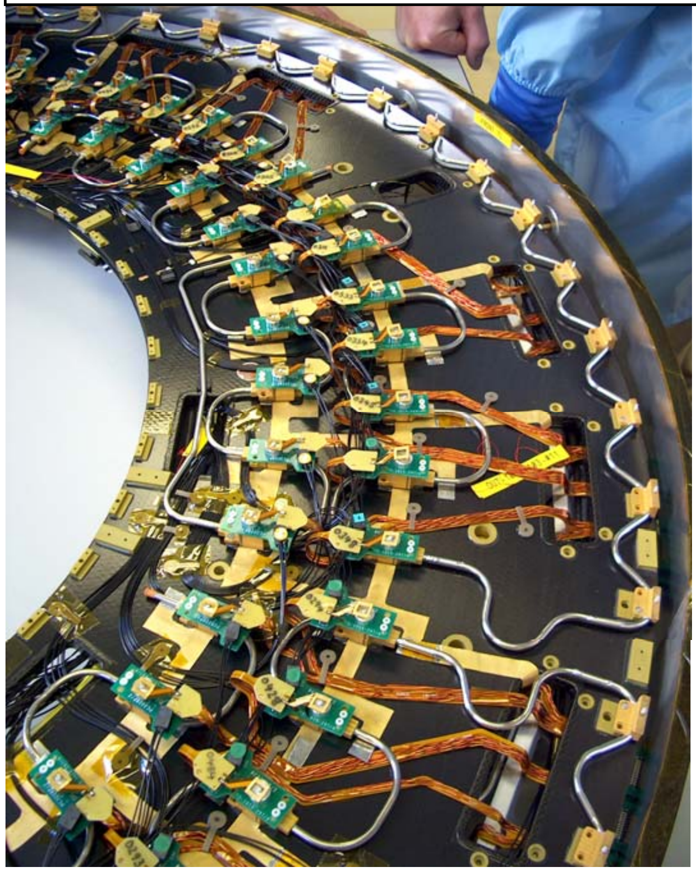
IV curves at 15ºC for 100 modules (Hamamatsu sensors)



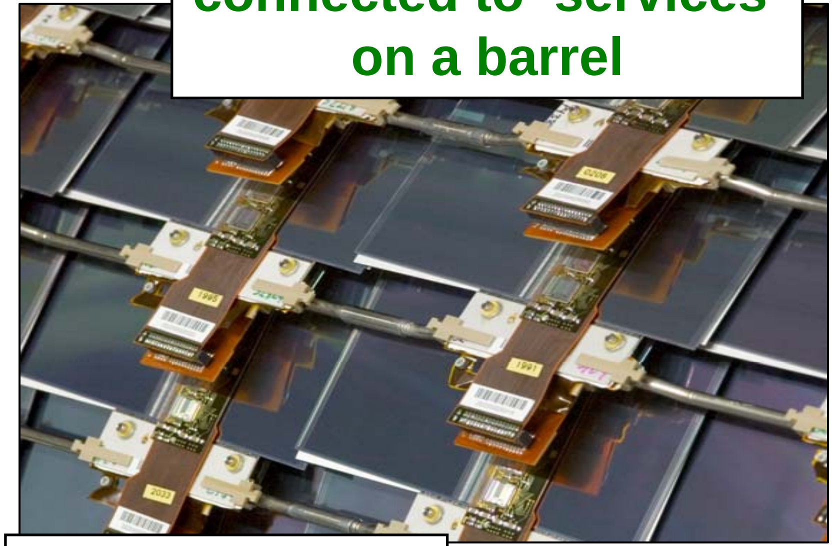
Structures and Services

- Light carbon-fibre structures on which modules individually mounted
  - Cylinders for barrel, disks for endcap
- On-detector Services are:
  - Thin-walled cooling pipes (eg 70 µm Cu-Ni) and module cooling blocks to remove heat through evaporative C_3F_8 cooling system
  - Low mass tapes supplying LV and HV power individually to modules
    - Barrel are Al on kapton – very delicate and prone to cracking
    - Replaced by Cu on kapton for the endcap
  - Optical Fibres for data and TTC transmission and opto-packages containing VCSELs, a PIN diode and custom ASICs
- Designing, manufacturing, handling, assembling these services has been a major undertaking, with many problems
  - Magnitude of the task became apparent as project progressed
  - So far completed successfully
  - But final stage of connection in the pit still lies ahead

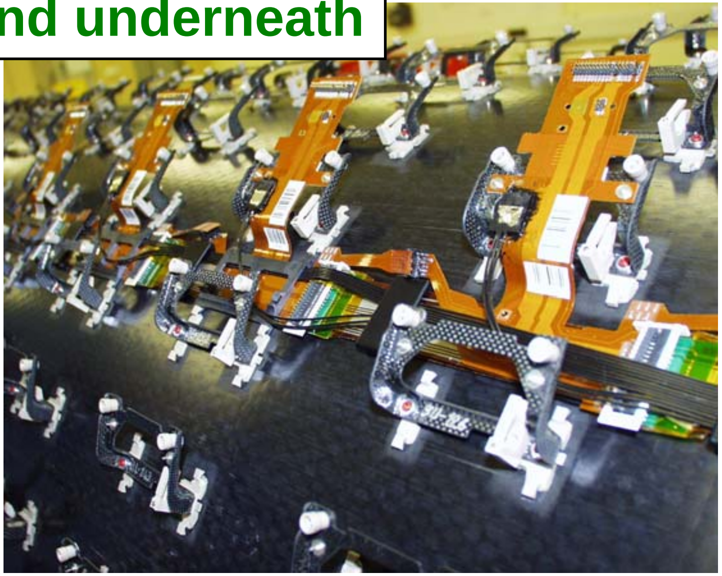
Complexity of services on an endcap disk, before modules mounted



Modules mounted and connected to services on a barrel

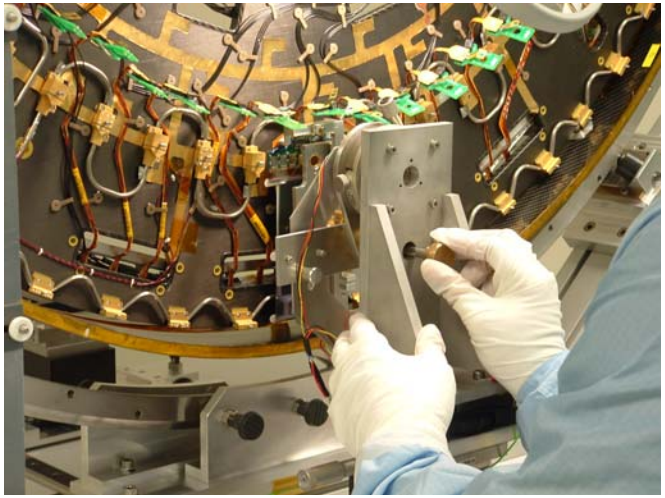


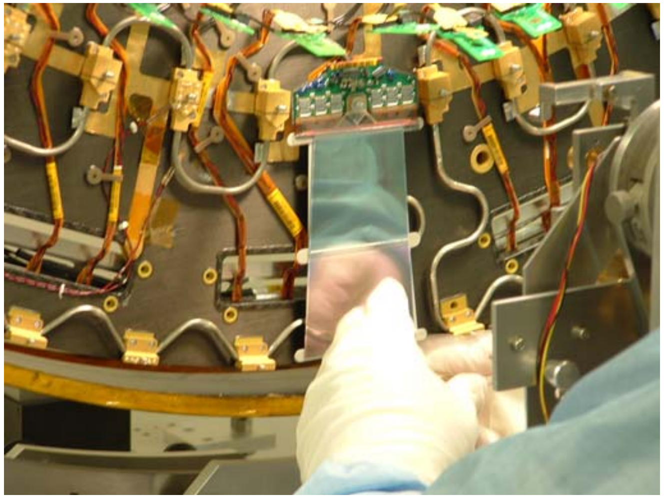
and underneath



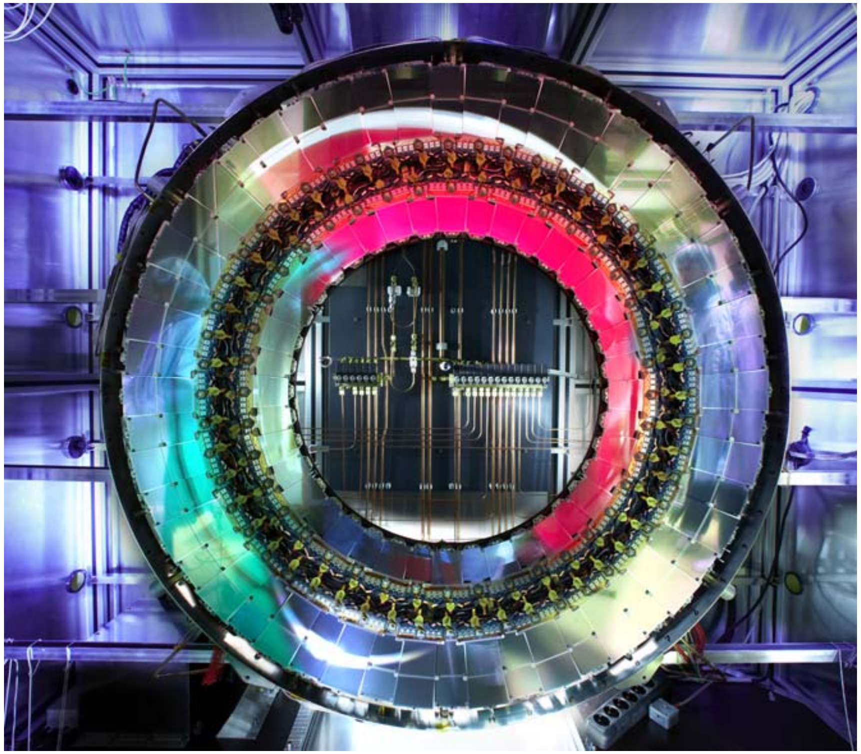
Assembly of Modules to Structures and Tests

- Different approaches taken for barrel and endcaps
  - In the end, time taken was dictated by electrical testing in both cases
- Both very successful
  - The loss of modules through damage while mounting was negligible for both barrel and endcaps
- Endcap – manual mounting tools developed, modules mounted a disk at a time at Liverpool and NIKHEF

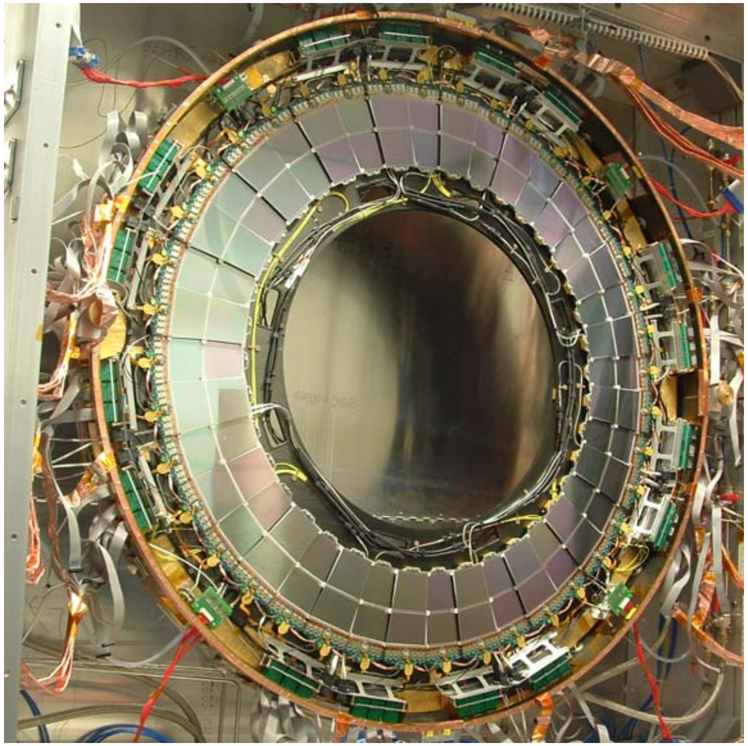




Endcap disks under test



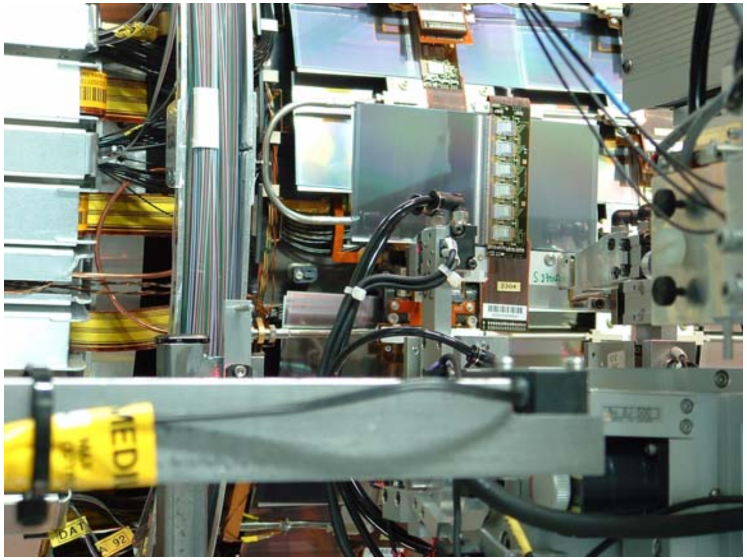
Inner and outer rings of modules
on front-side of an endcap A disk



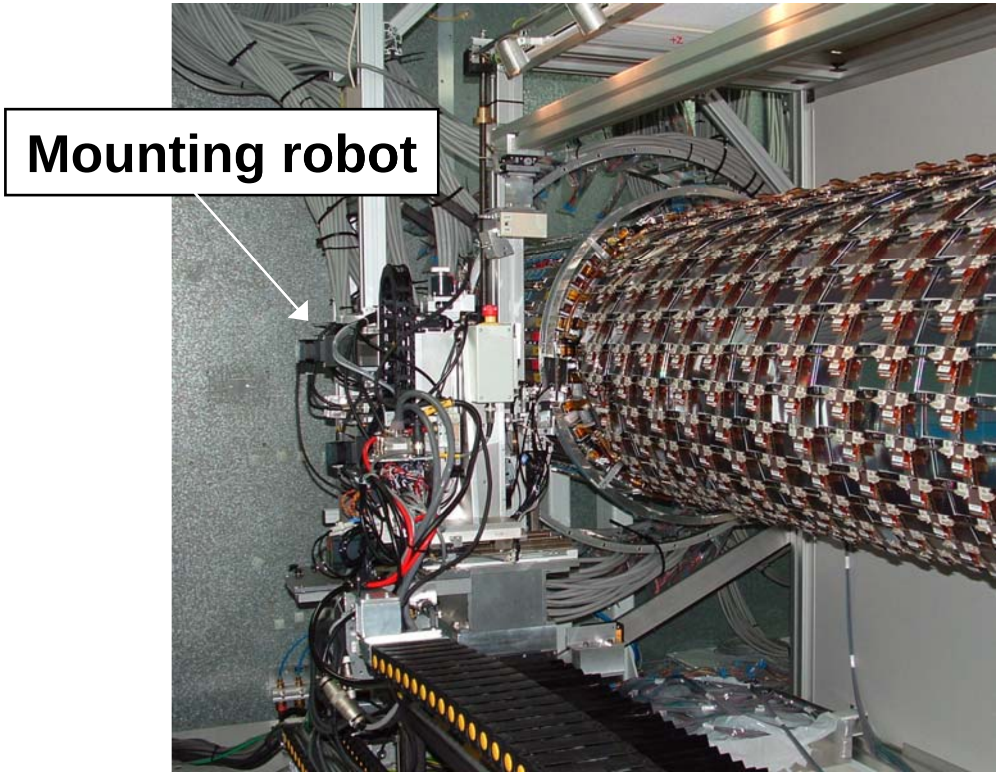
Middle ring of modules on
rear-side of an endcap C disk

Assembly of Modules to Structures and Tests - continued

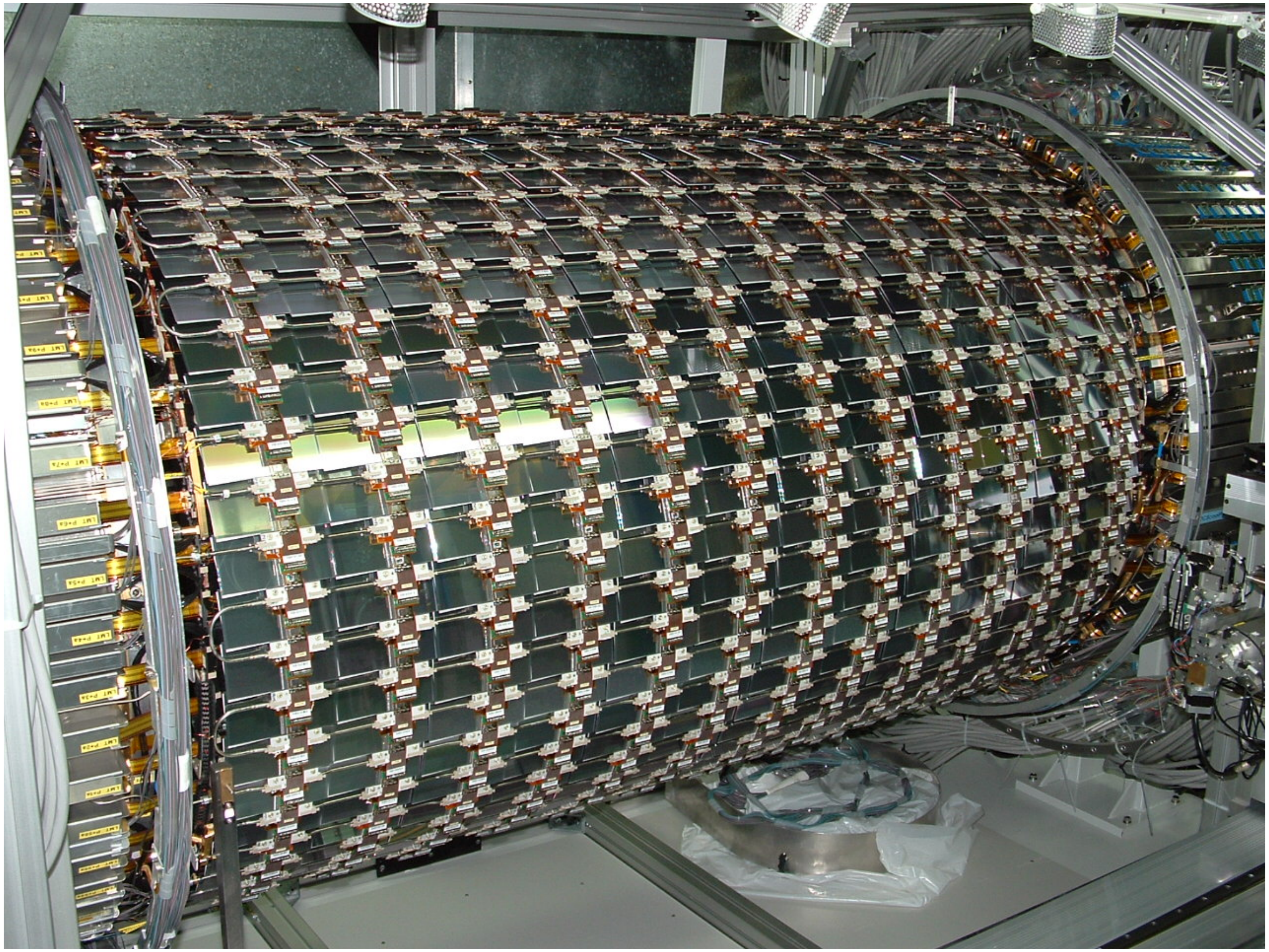
- **Barrel** – a module mounting robot was developed
  - Modules mounted on each barrel a row at a time, at Oxford
  - Total mounting period of 15 months, including tests



Module held in robot jaws ready for mounting



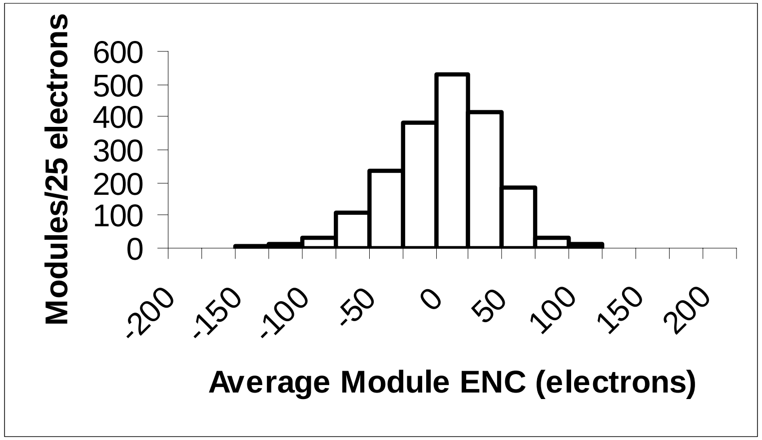
A fully-populated barrel with 672 modules mounted



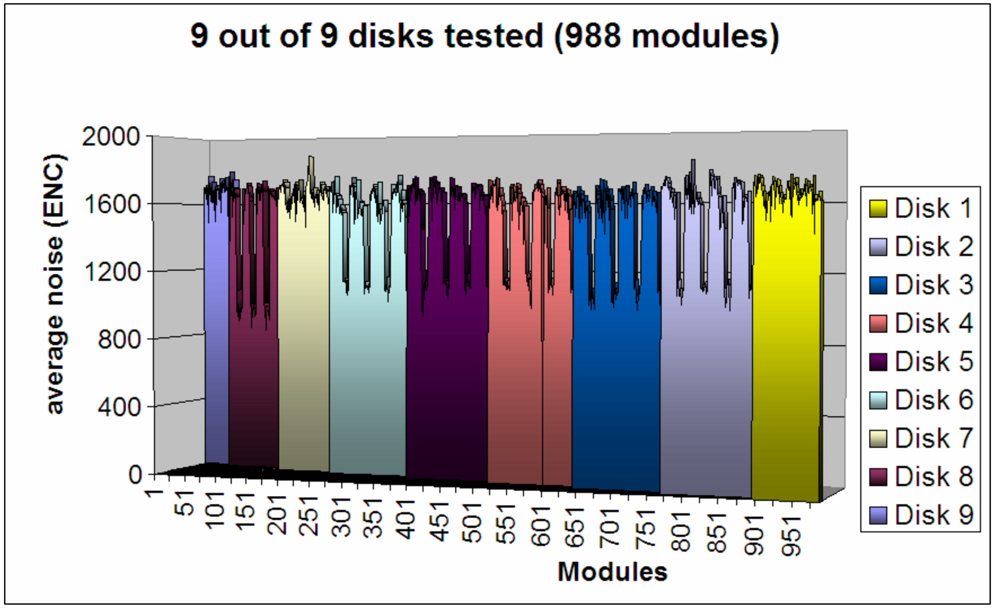
Tests of modules on the structures

- Connected to evaporative cooling plants, final SCT power supplies and readout electronics, prototype of final DAQ, DCS, interlocks
  - Individual disks and individual barrels
- Very encouraging results
  - Module performance after mounting essentially same as before

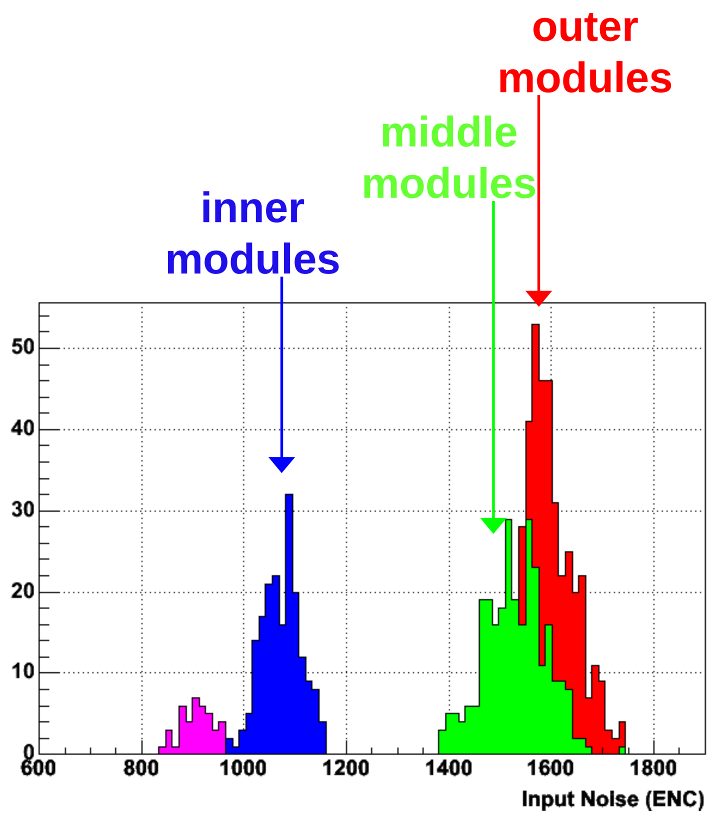
All barrel modules, ~ 28 ^{o}C, ENC (on barrel – in test box) (mean = – 16 electrons) 99.8% good channels



Measured noise of modules on endcap disks



Endcap A

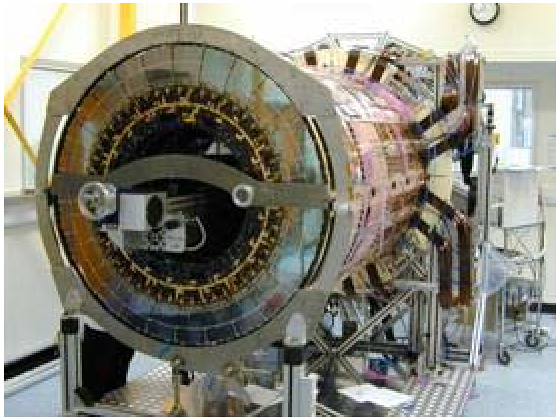


Endcap C

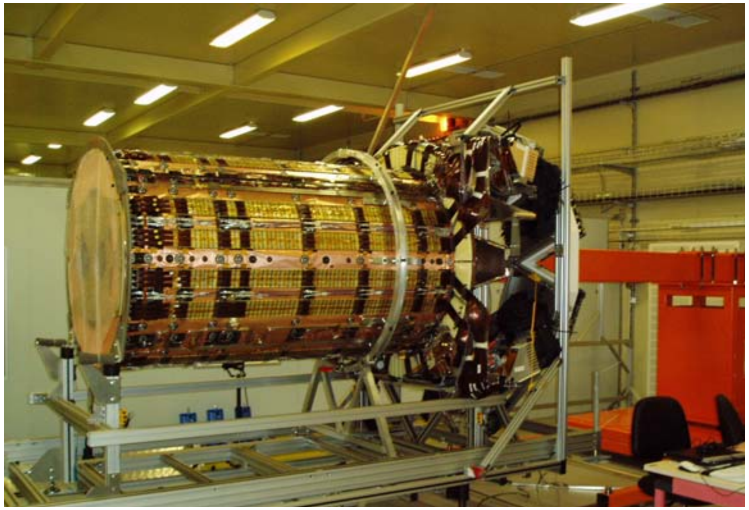
Integration of SCT Structures
The Endcap SCT

- 9 disks aligned inside their support cylinder, services fitted and electrical tests made at Liverpool (endcap C) and NIKHEF (endcap A)
- Endcaps delivered to CERN (SR1 clean room)
  - February 2006 from Liverpool, April 2006 from NIKHEF
- Reception tests (visual, disk alignment, cooling circuits, electrical) showed they both travelled without damage
- Preparation for integration within endcap TRT:
  - Fitting of final mechanical supports, end membranes, inner and outer thermal enclosure cylinders, service feed-throughs, grounding connections, leak tightness….
    - Many small(ish) problems and issues, but no show-stoppers
  - Just completed for endcap C, including electrical test of an octant within the thermal enclosure
    - Peformance of modules unaltered
  - Ongoing for endcap A (completion expected ~ end October)

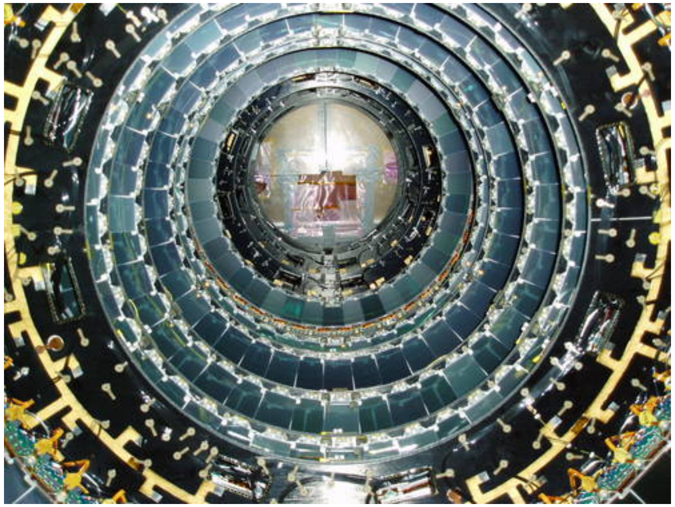
Integration of SCT Structures
The Endcap SCT



View after last disk inserted in support cylinder



Outer support cylinder with services



Beam's eye view of endcap modules

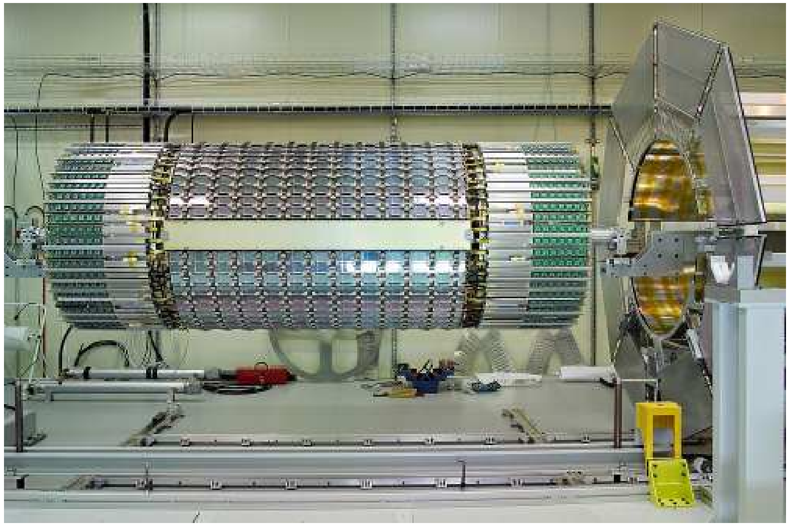
Outer thermal enclosure fitted – ready for insertion into TRT

Integration of SCT Structures
The Endcap SCT

- **Next steps:**
  - **Insertion of endcap C SCT into endcap TRT – this week**
  - **Electrical tests, standalone and combined SCT + TRT (quadrant of whole SCT endcap) from late October**
    - **Following the experience of barrel testing in SR1**
- **Installation of endcap in the pit when ATLAS is ready**
  - **~end January 2007**
    - **When barrel installation signed-off**
- **Endcap A has ~ same installation date, so will have less combined testing with the TRT**

Integration of SCT Structures
The Barrel SCT

- 4 barrels, with modules mounted, travelled separately to CERN
  - Reception tests (undamaged)
- Integration into barrel SCT in SR1 from June 2005 to February 2006
  - Barrels inserted one by one inside the outer thermal enclosure, closed by inner thermal enclosure
- Most of the time taken by service manipulation and connection and final sealing of gas leaks



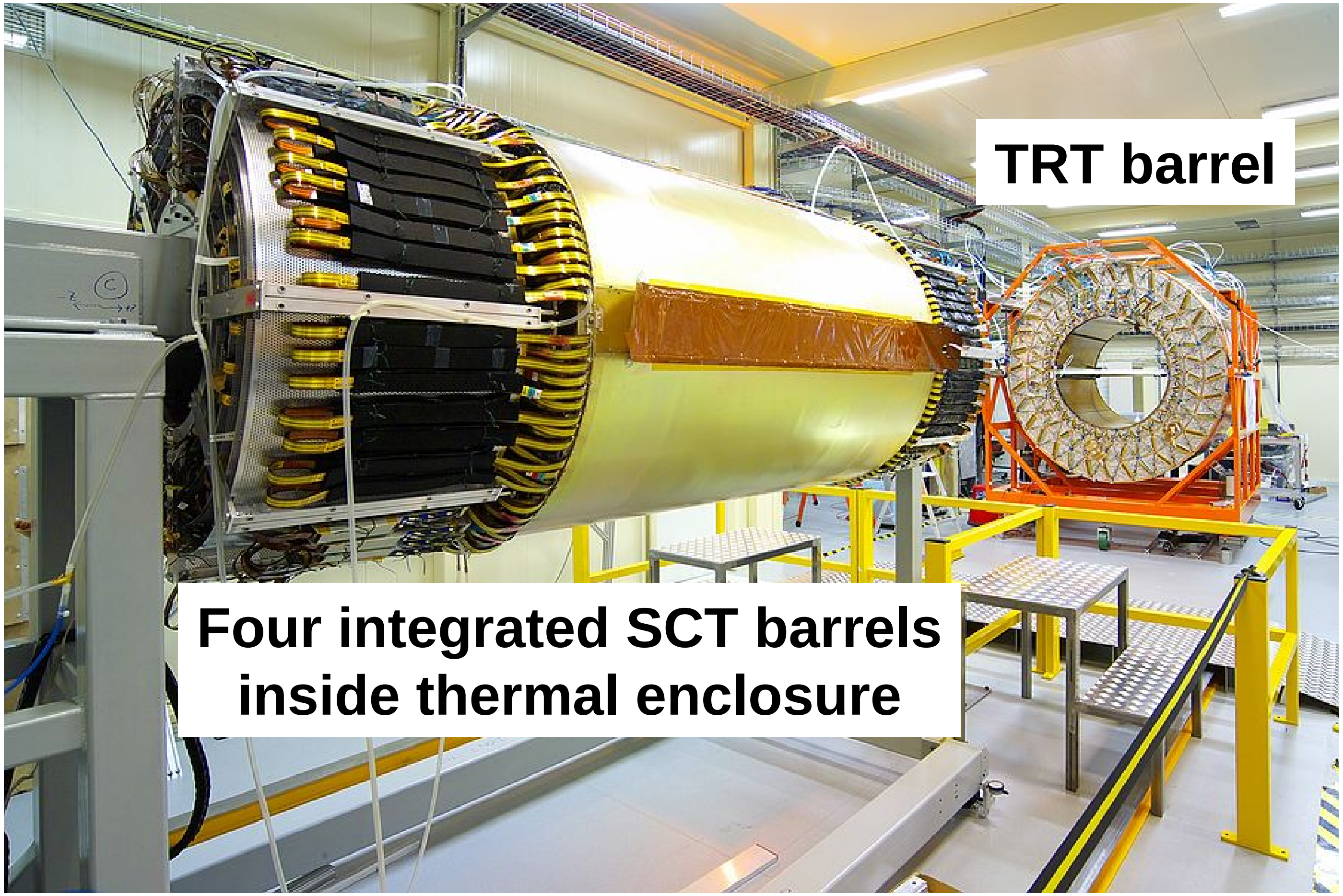
Outer barrel being inserted in outer thermal enclosure

The Barrel SCT

Services unfolded at the ends, barrel by barrel

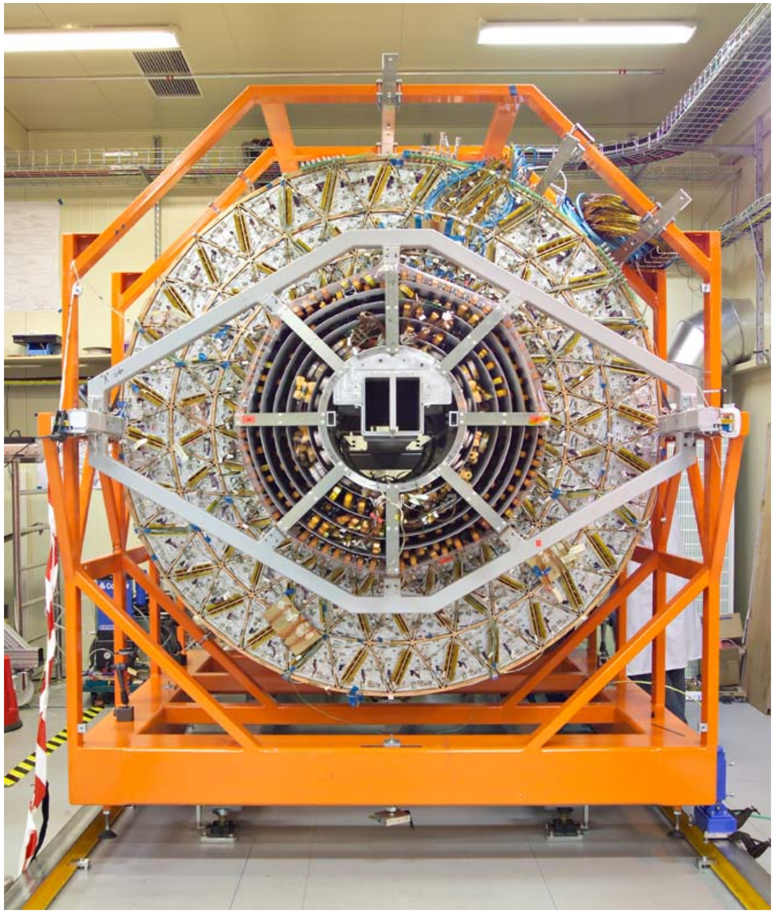
The Barrel SCT

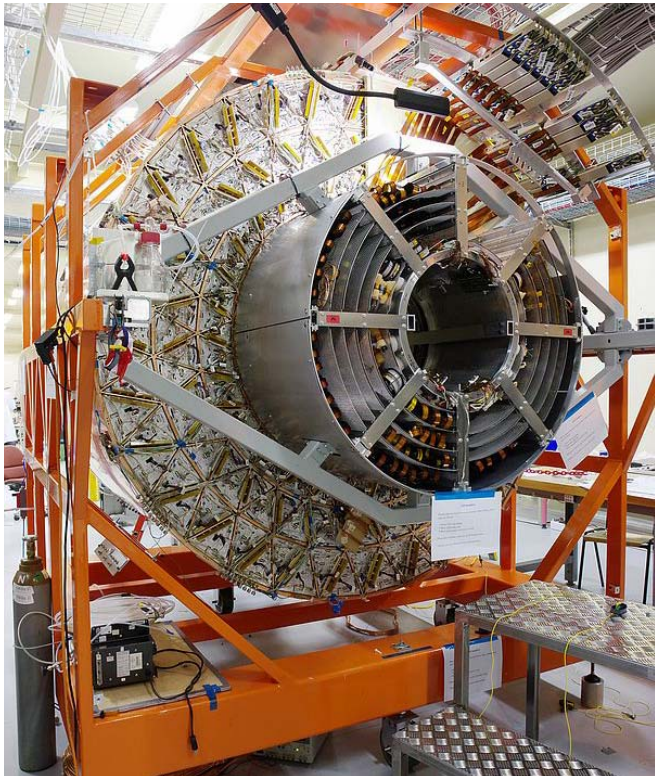
Then services folded back and packed to allow insertion into the TRT



The Barrel SCT

- **and 4-barrel integration at CERN and insertion into the TRT successfully completed in February 2006 in SR1**

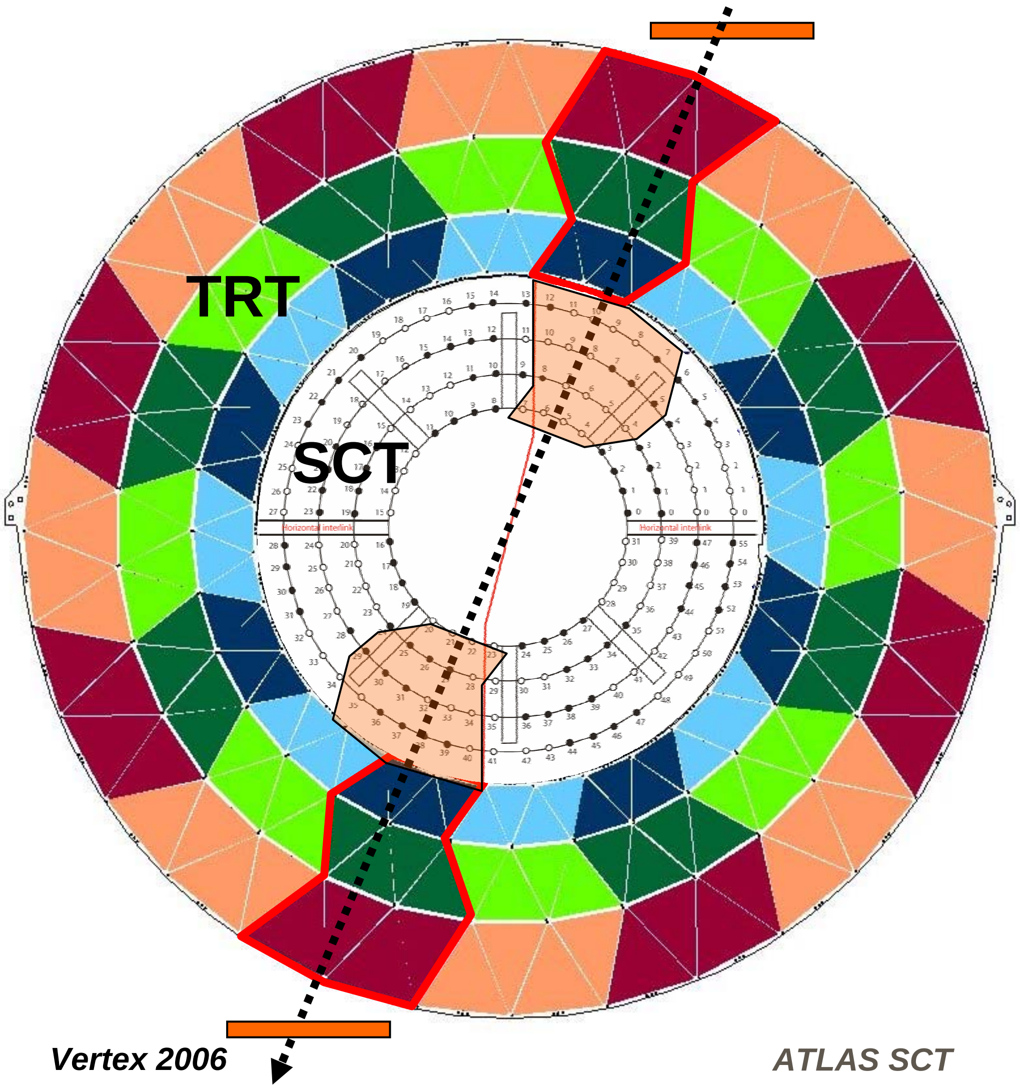




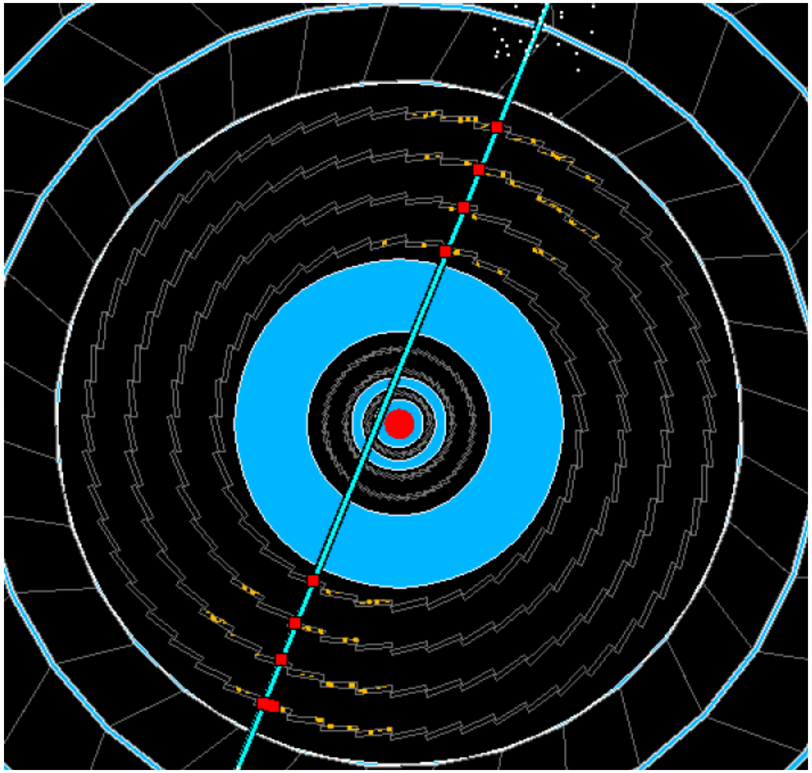
Top and bottom test sectors read out, combined SCT, TRT cosmic data taken

Surface Barrel Readout Test before installation in ATLAS

Schematic configuration
468 SCT modules read out



A recorded cosmic track in the SCT, June 2006



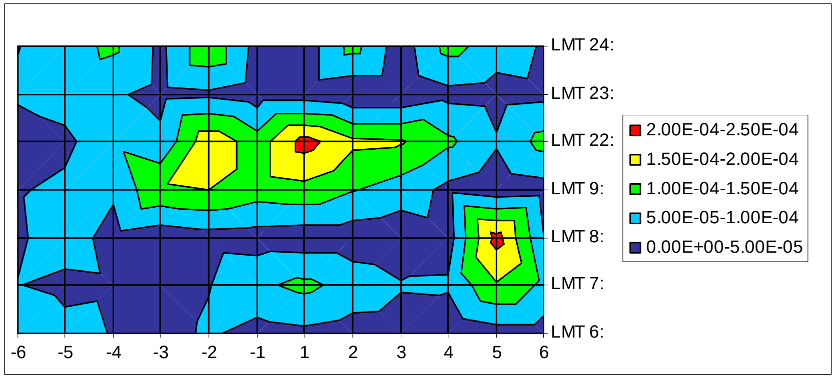
Some Goals of the Barrel Sector Readout Test

- **Operational aspects:**
  - **Gain experience with detector operation**
  - **Development of standalone and combined monitoring tools**
  - **Commission and test combined readout and trigger**
  - **Commission offline software chain with real data**
- **Detector performance aspects:**
  - **TRT performance with SCT inserted and powered**
  - **First test of 4 SCT barrels together, and operation with TRT**
  - **Checks of grounding and shielding for SCT and TRT**
  - **Test synchronous operation and check for cross-talk and noise**
  - **Collect cosmic data for efficiency, alignment & tracking studies**
- **All achieved, at least at the first level**

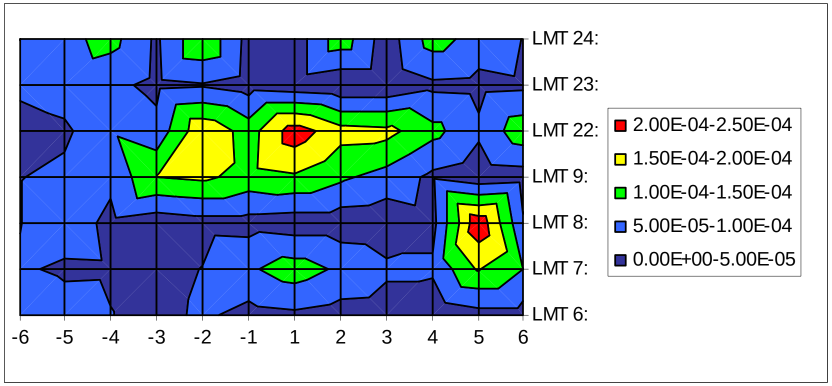
Some achievements and lessons learnt in SR1
Electrical Performance

- **Encouraging results**
  - **No signs of module electrical pick-up**
    - **Between 4 SCT barrels**
    - **Between SCT and TRT**
    - **From external heaters on SCT thermal enclosure**
- **Example – contours of noise occupancy for modules on innermost SCT barrel**

Barrel when operated alone



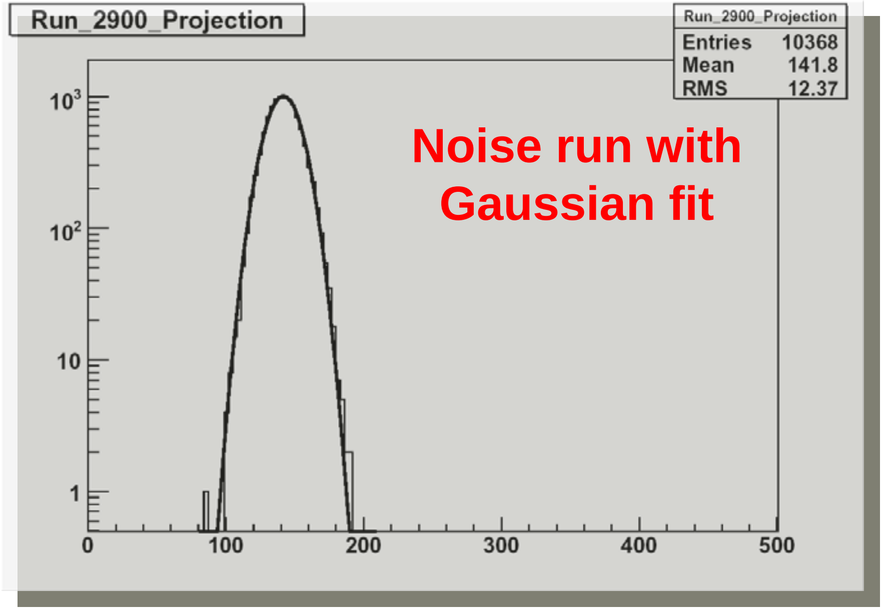
Barrel when operated with all others

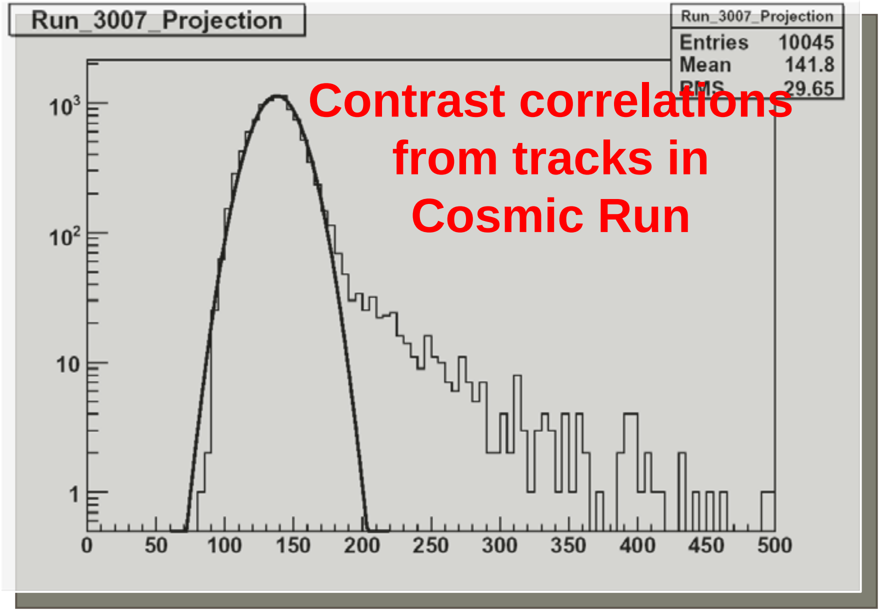


Some achievements and lessons learnt in SR1
Electrical Performance

- **No evidence so far for common mode noise**
  - **No increase in noise occupancy using synchronous triggers**
  - **No correlations between noise hits from chips within a module ("occupancy per event")**
  - **No correlations between noise hits on different modules**

Distributions of hits per event with 1fC binary threshold

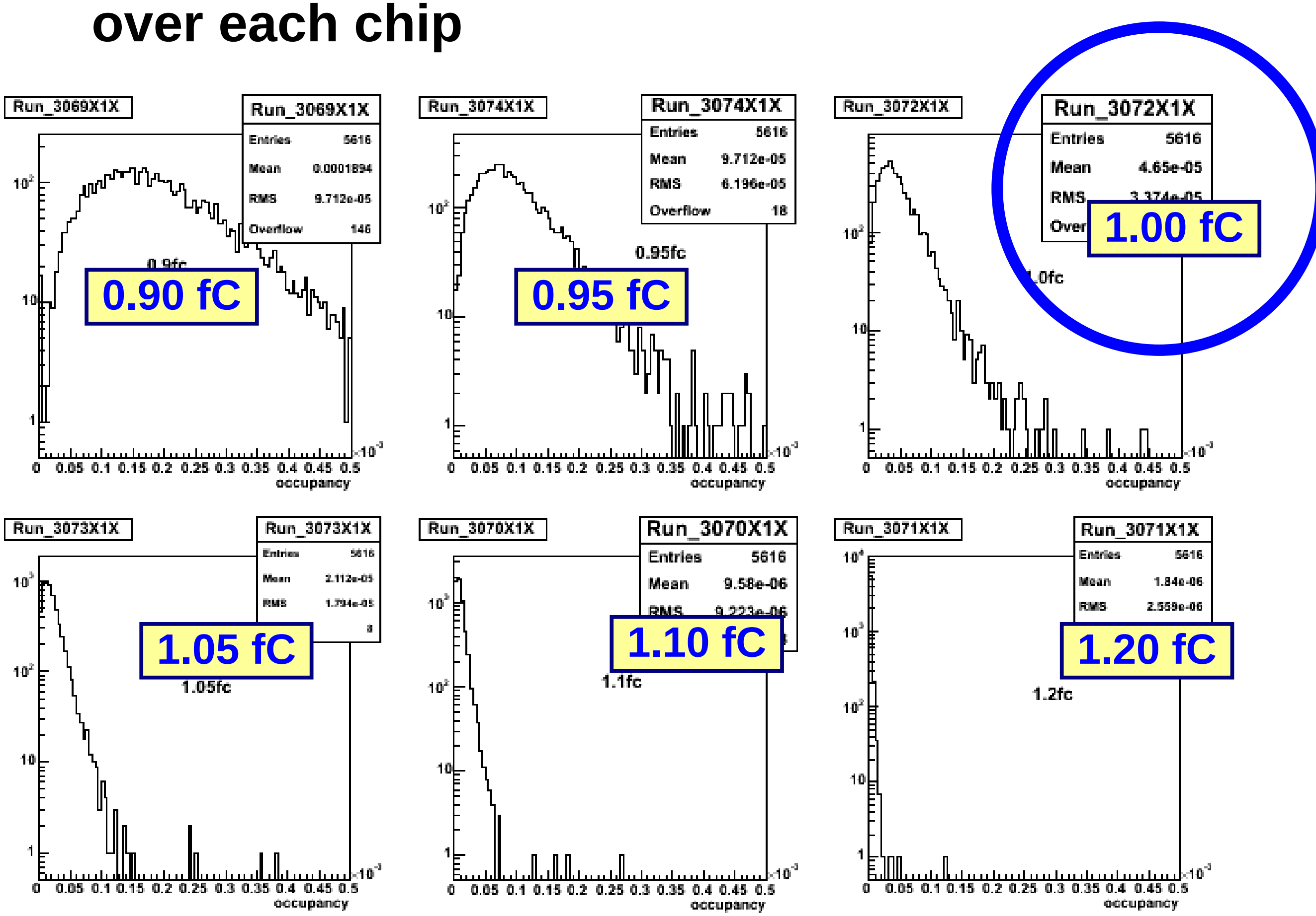




Some achievements and lessons learnt in SR1

Electrical Performance

- Noise Occupancy as a function of binary threshold, averaged over each chip



4.65×10^{-5}

↓

4.13×10^{-5}

at end of run

Very similar to previous results with single barrels (spec 5×10^{-4})

J.R. Carter

Some achievements and lessons learnt in SR1
Electrical Performance

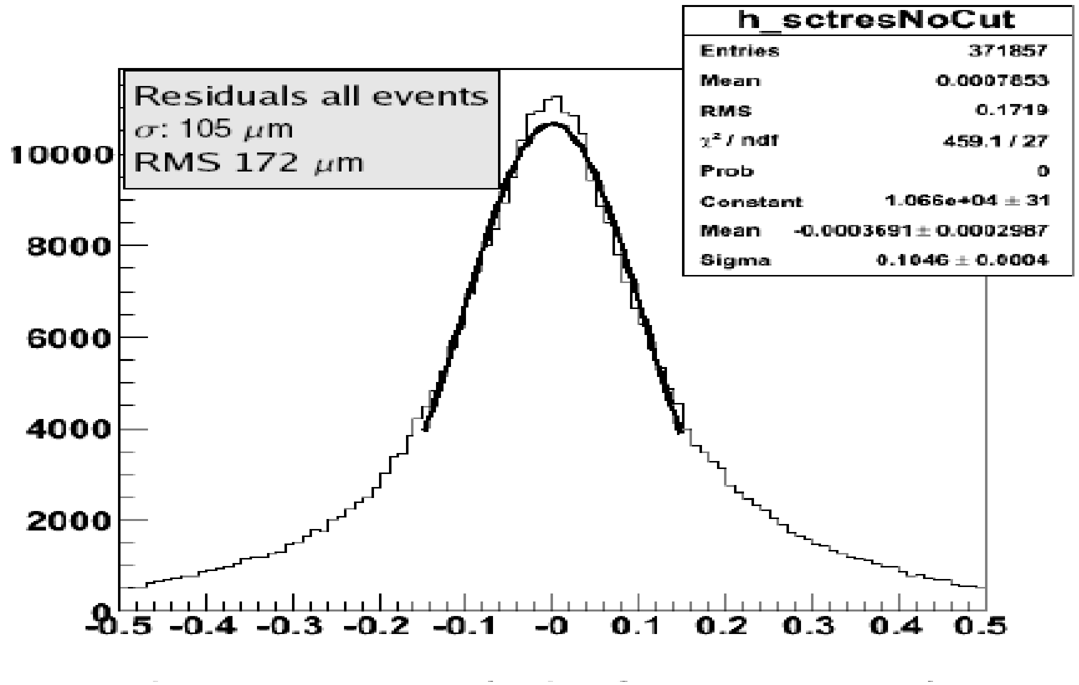
- **ENC input noise very similar to values for modules before mounting (after applying temperature correction)**
- **Module efficiency in cosmic data, from initial tracking, >99%, as expected**
  - **See later talk of Maria Jose Costa**

- **In summary:**
  - **No major problem seen so far with the electrical performance of the integrated barrel**

- **Barrel tests after integration in ATLAS will be with**
  - **All 2112 barrel modules (factor 4.5 more) and complete TRT**
  - **Final grounding and shielding scheme**

Some achievements and lessons learnt in SR1
Mechanical Placement Precision

- **Mechanical Construction Precision found to be better than module placement build tolerances (~200 µm):**
  - **SCT Residuals from cosmic data, without alignment**

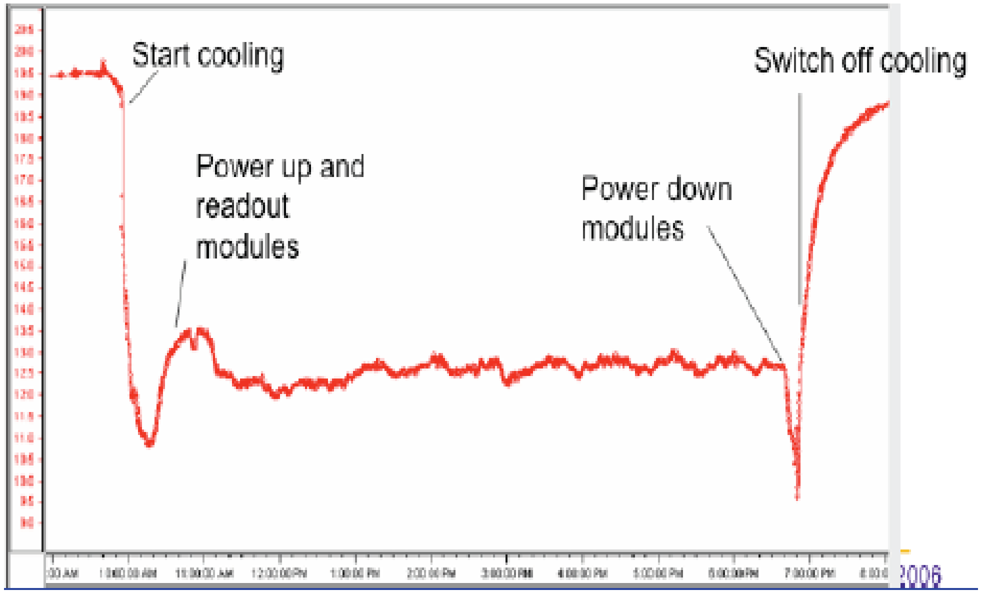


- **Now detailed alignment studies in progress (see later talk of Pawel Bruckman De Renstrom)**

Some achievements and lessons learnt in SR1
Operational Experience - Module Cooling

- **The evaporative cooling system worked stably and well**
  - C_3F_8, fairly similar to final system, run 'warm'

Temperature on cooling pipe during 8 hr run



- **But filtering needed improvement**
  - One cooling capillary (0.76 mm diameter) had to be un-blocked
  - Appropriate improvements installed in the final ATLAS system

Some achievements and lessons learnt in SR1
Operational Experience – Readout, Powering, DAQ, DCS

- **Final SCT power supplies and readout electronics being used**
  - As throughout the integration phases
  - But long, stable, data-taking runs attempted for the first time with the cosmic data
    - For example, allows study of low level of HV and LV trips, and appropriate firmware modifications
- **Timing in of modules required for the first time for cosmic data**
  - Module-module timing from fibre lengths
  - Overall timing from coincidences between top and bottom ASICs in individual modules in the ROD DSP code
- **First exercise of data-taking in physics mode, instead of calibration, and passing SCT+TRT data up the acquisition chain**
  - Monitoring at the event filter level and offline exercised for first time
  - Data formats and configurations for offline analysis, use of databases

Some achievements and lessons learnt in SR1
Operational Experience – Readout, Powering, DAQ, DCS

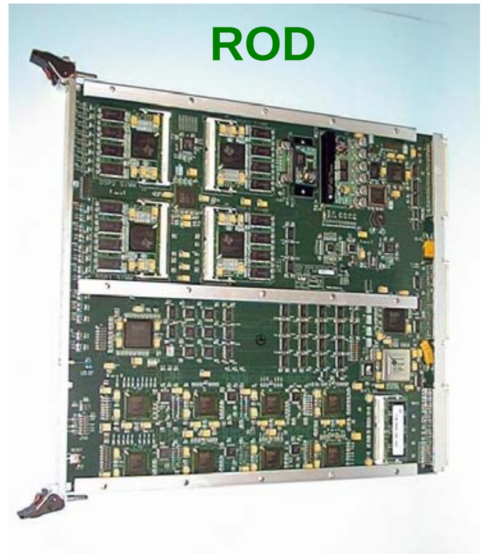
- Very useful exercise, much focussed effort
  - Successful cosmic data collected (~450k events)
- Now preparing for next phase of larger-scale operation down the pit, starting January 2007, requiring:
  - Further automation of module set-up and turn-on procedures
  - Further auto recovery for modules
  - Multi-crate readout
  - Installation of final interlock systems
  - Development of DCS State Machine and DSS systems for final cooling system, full powering, all environmental monitors
    - Definition of all actions to be taken
    - Risk analysis for SCT in progress
  - Improved inner detector monitoring and parallel analysis
  - Development of database usage
  - etc, etc…

Installation of the Barrel within ATLAS

- **Installation of services (cables, fibres, cooling pipes and plant, gas)**
  - **Magnitude of task severely underestimated in initial planning**
  - **Huge effort deployed over past year for inner detector services**
- **Barrel detector has been waiting for > 2 months for services to be ready for its final installation, and for magnetic field survey**
  - **Start of service connection to barrel TRT now imminent**
- **All SCT off-detector electronics now installed and connected**
- **Power supply installation in progress**

September 2006 - The full SCT readout electronics were installed and connected in ATLAS

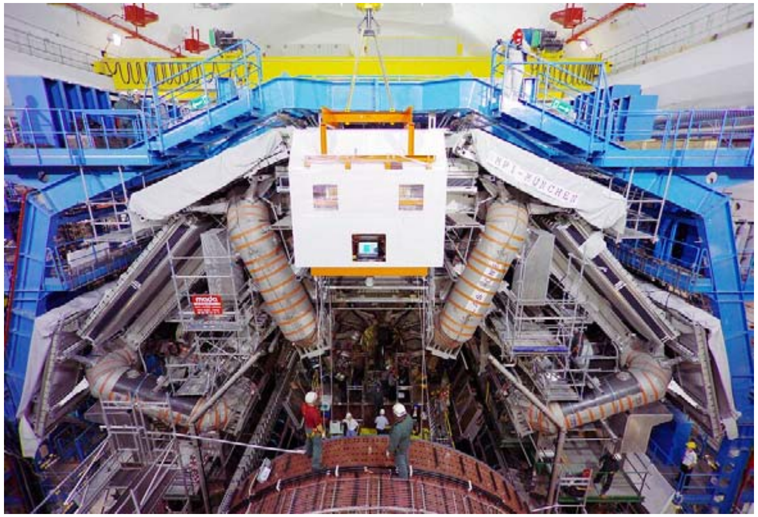
Front of Barrel ROD +TTC Crates

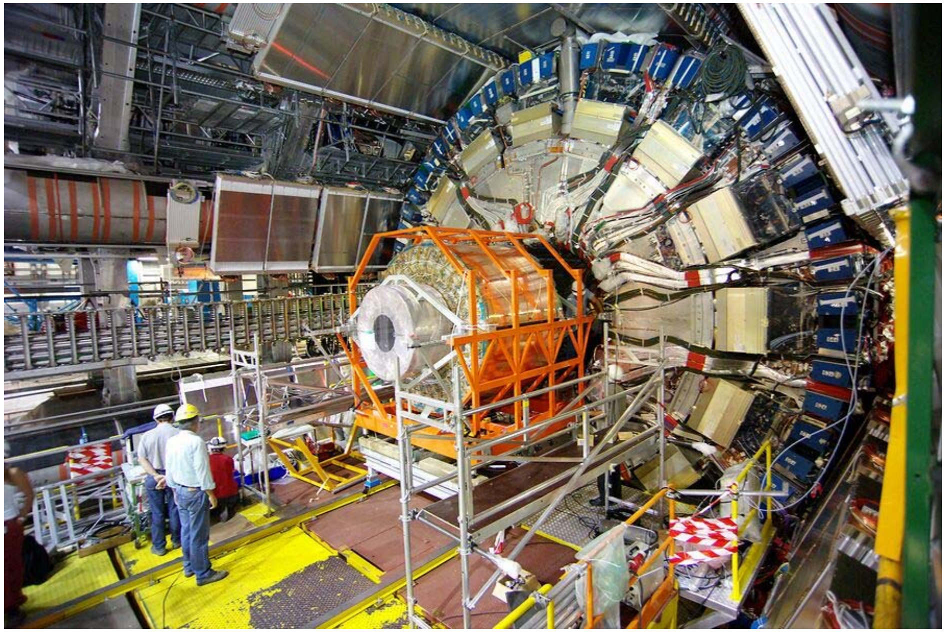


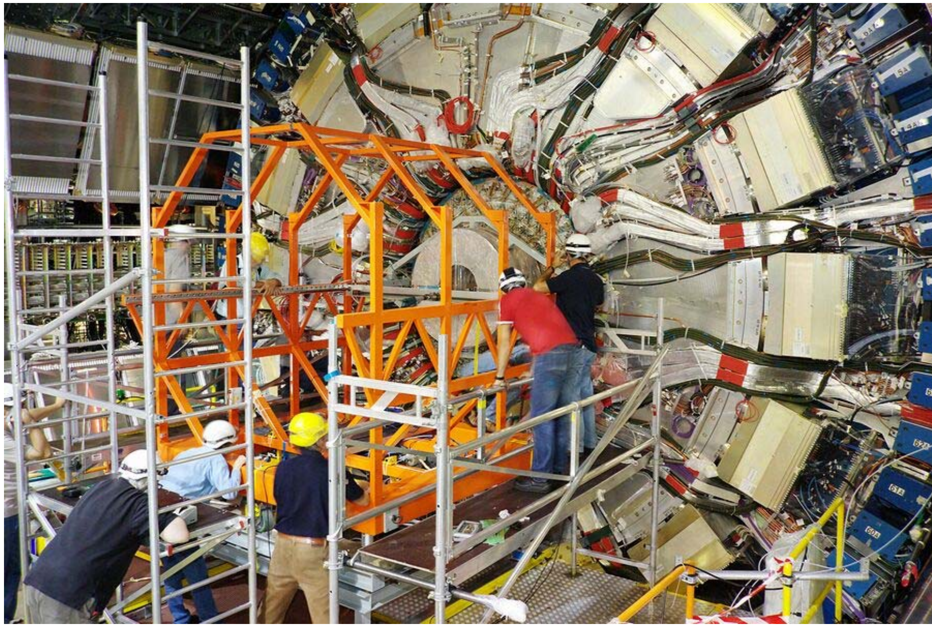
BOC

Fibre connections to BOCs at rear

August 2006 - the Barrel SCT+TRT were installed within ATLAS

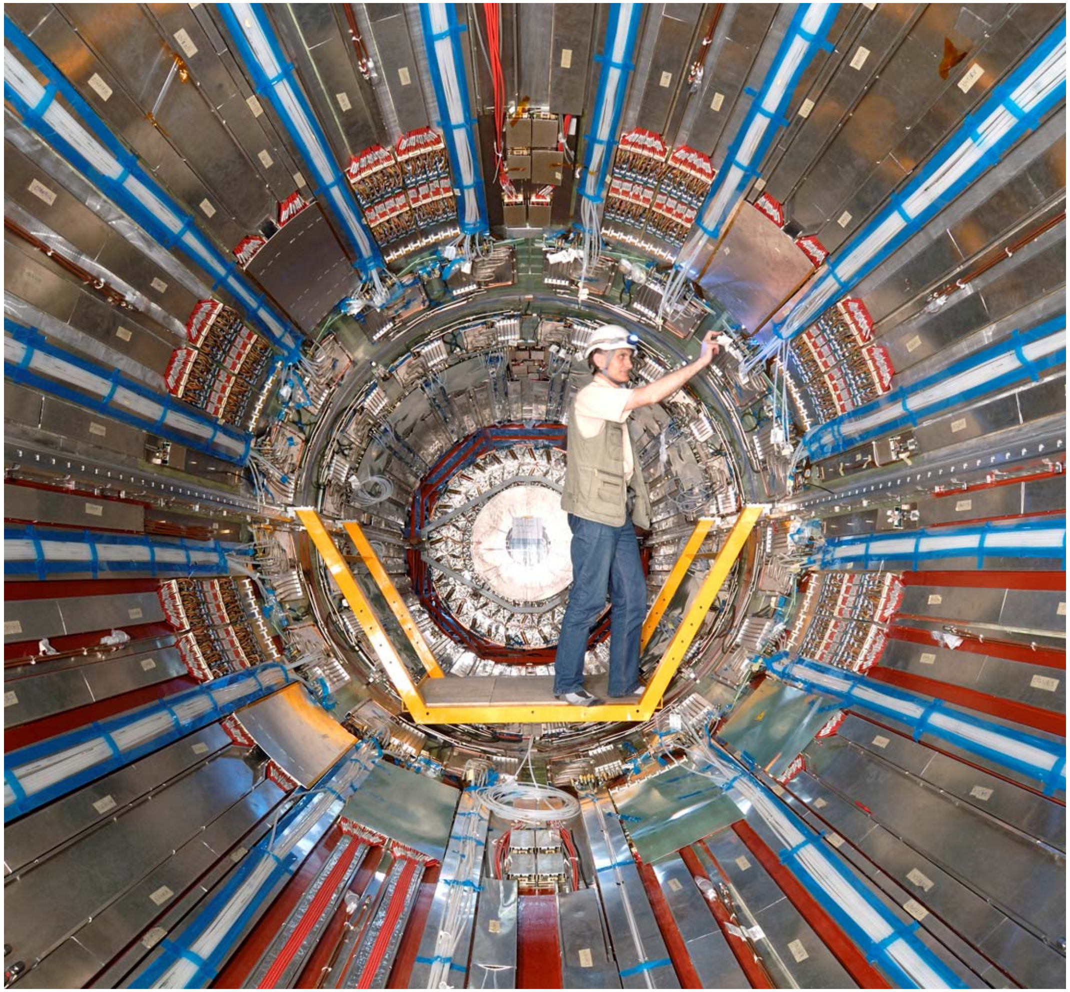






Present Status and near-term Plans

The Present



Plans

- Barrel moved to final z=0 position planned for end September
- Then TRT connection and test
- Followed by SCT connection and functional test, scheduled over 11 weeks, ending during January 2007
- Followed by installation of both endcaps
- and in parallel, operational commissioning of barrel SCT + TRT

Summary

- Integration and installation for the barrel SCT is entering its final phase
  - The critical unwrapping and connection of the delicate services
  - The installation of fragile heat-exchangers and connection of the evaporative cooling system
  - Then rapidly checking performance before access is lost when the endcaps are installed
- The endcaps are following as planned
  - We will soon see their operation within the TRT
- So far, so good – the performance of the modules is maintained
  - Despite the many problems requiring solution
    - Often related to service issues
- First steps taken in commissioning with combined SCT+TRT barrel running in SR1 and cosmic data-taking
- Ahead the huge and challenging programme of commissioning the whole SCT detector within ATLAS
  - Cosmic data in 2007, then first LHC beams