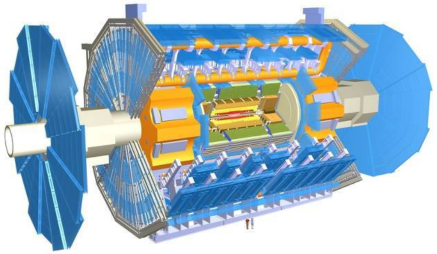
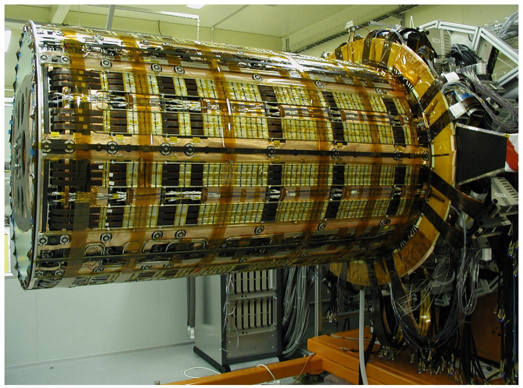


ATLAS SCT End-cap

Stephen Haywood Rutherford Appleton Lab



This Talk

- ATLAS
- Inner Detector
- SCT
- End-cap
  - Silicon Modules
  - Disks
  - Support Structures & Thermal Enclosures
  - Assembling the End-caps
  - Integration at CERN
  - Status
- Tracking in the Inner Detector
- Status
- Conclusions

Focus is Engineering for the SCT End-cap – **JINST 3 P05002 (2008)**

ATLAS

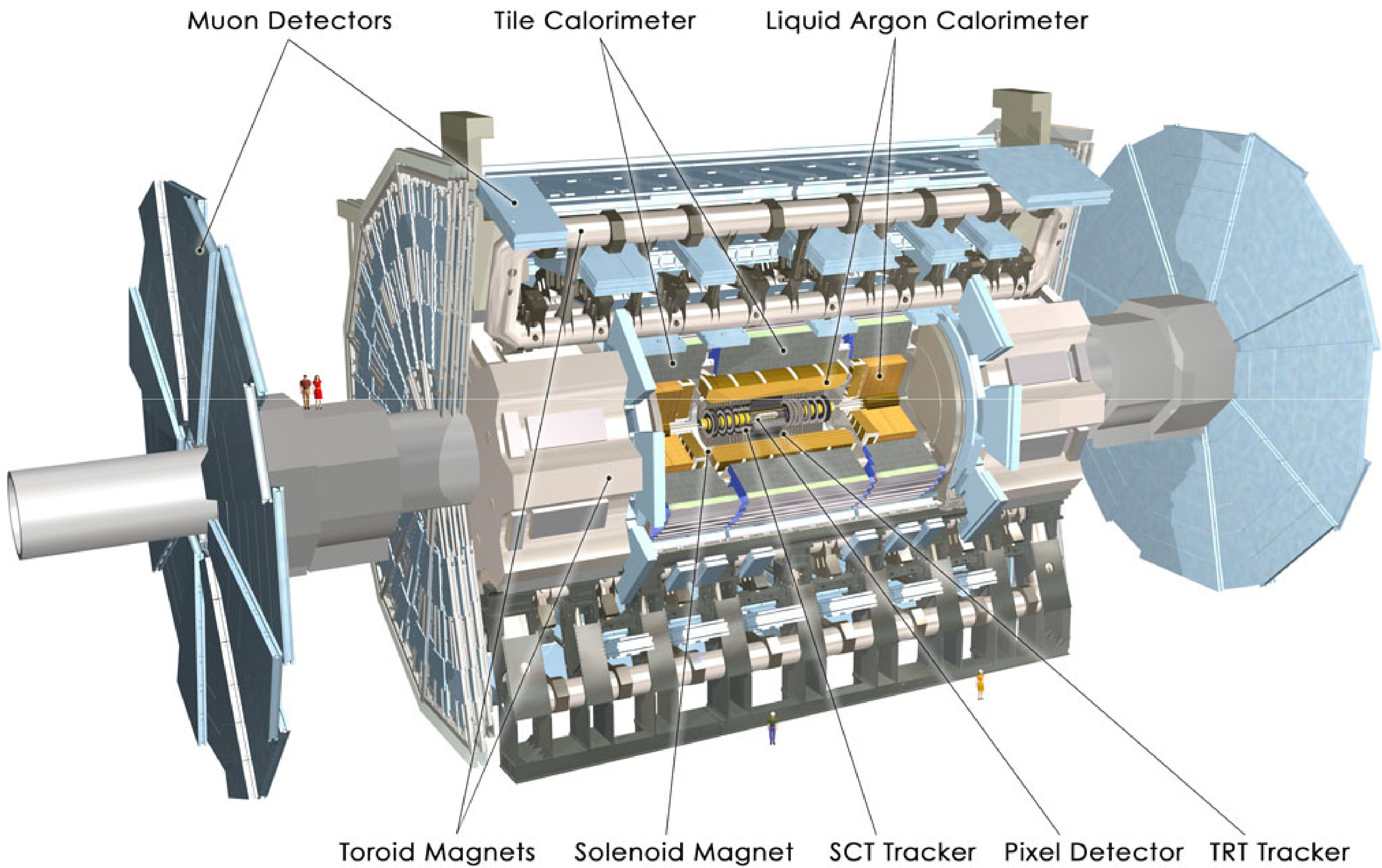
Goals

- Understand the “mass mechanism”: Higgs, Technicolour …
- Investigate physics beyond the Standard Model: SUSY, Extra Dimensions (Black Holes), Additional Symmatries, etc.
- Investigate the Standard Model at 14 TeV: QCD, etc.
- Improve measurements of the Standard Model parameters: M_W, m_{top}, B-sector, etc.

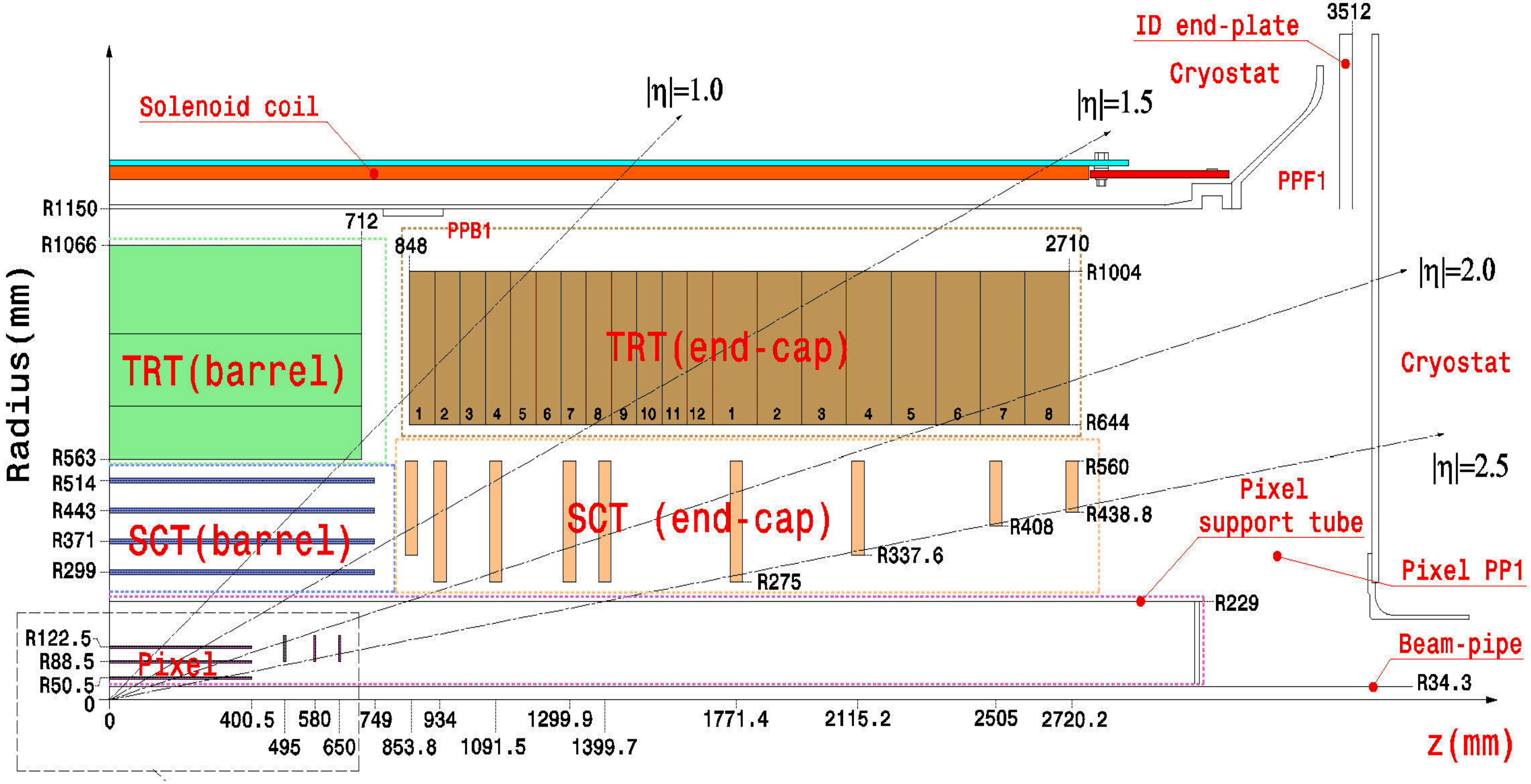
Measurements at LHC:

- $\sqrt{s}$ = 14 TeV
- Design Lumi = 10^{34} $cm^{-2}s^{-1}$

ATLAS Detector



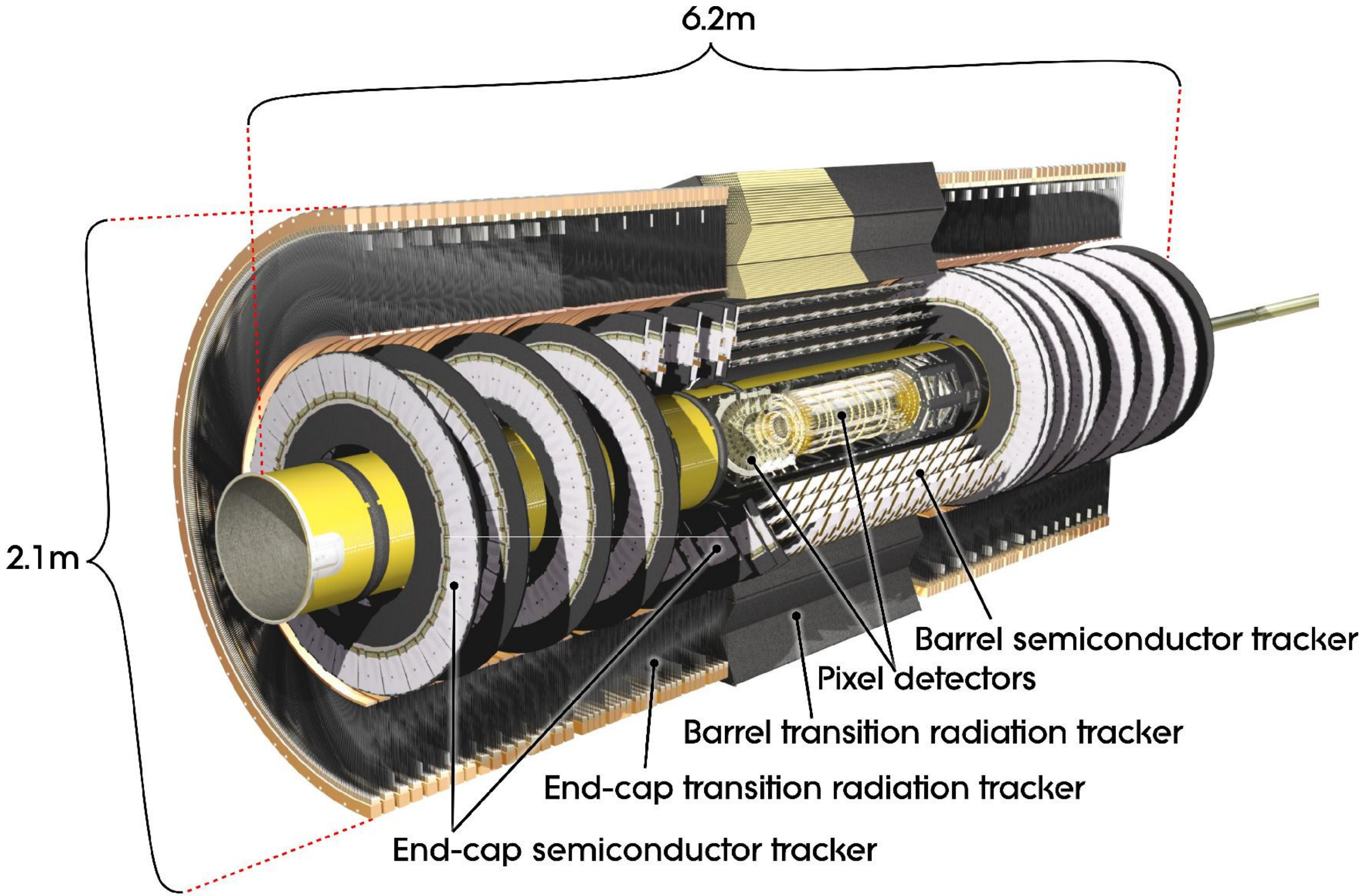
Inner Detector (ID)



$\eta = -\log(\tan\theta/2)$ $\quad\eta = 2.5 \leftrightarrow \theta = 9^{o}$

Radius = 1150 mm Length = 2700 mm

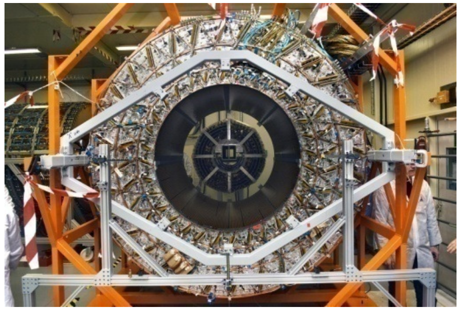
B = 2T Solenoid – non-uniform at ends


6.2m
2.1m
Barrel semiconductor tracker
Pixel detectors
Barrel transition radiation tracker
End-cap transition radiation tracker
End-cap semiconductor tracker

TRT

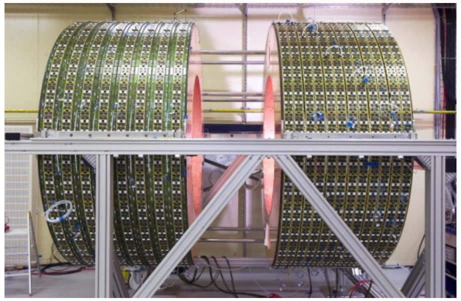
Straw Tracker – continuous tracking

Transition Radiation detected by Xe – distinguish electrons and pions



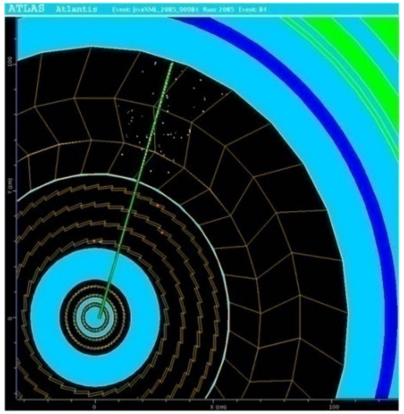
Barrel:

- Effectively 36 layers of straws
- Embedded in “mats” of polypropylene fibres



End-cap:

- Stacks of 16 15 μm polypropylene foils, each separated by 200 μm



Total num straws = 400,000

Pixels

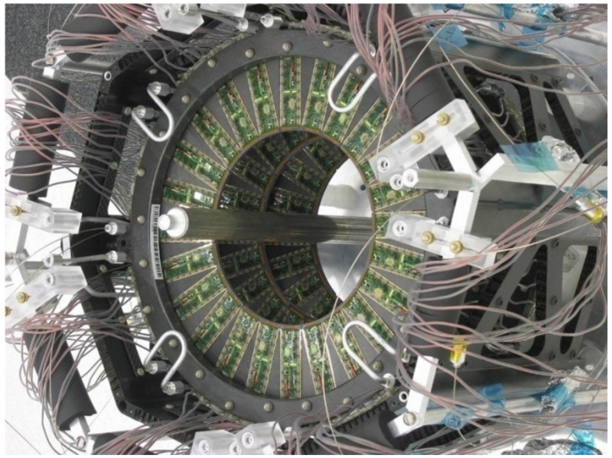
- 50 μm × 400 μm Pixels
- Bump-bonded chips
- 1744 Modules
- 82M channels

Barrel:

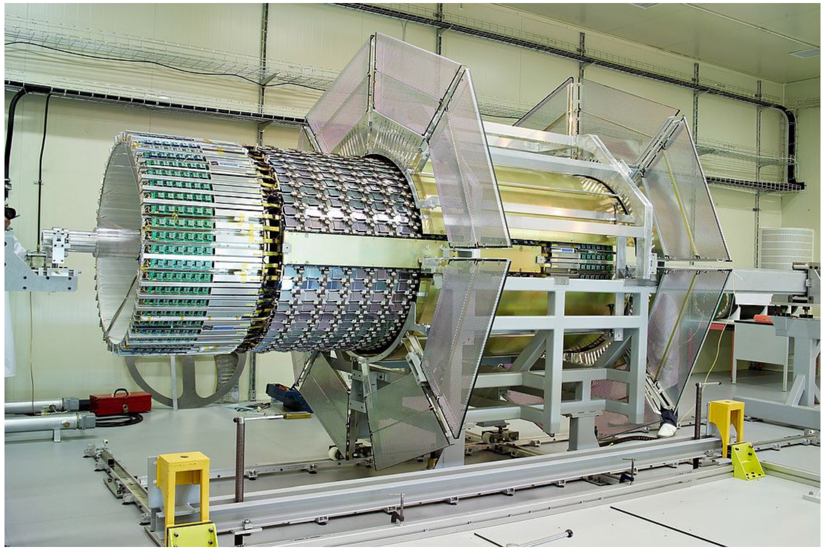
- 3 barrels at R = 5, 9, 12 cm

End-cap:

- 2 × 3 disks



SemiConductor Tracker (SCT)



Barrel:

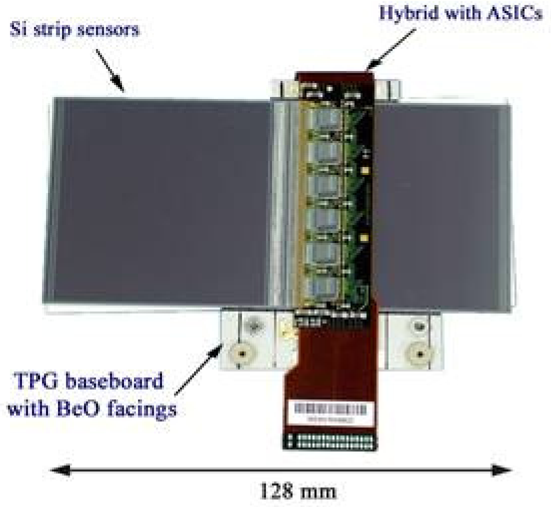
- 4 cylinders
- 2112 Modules

End-cap:

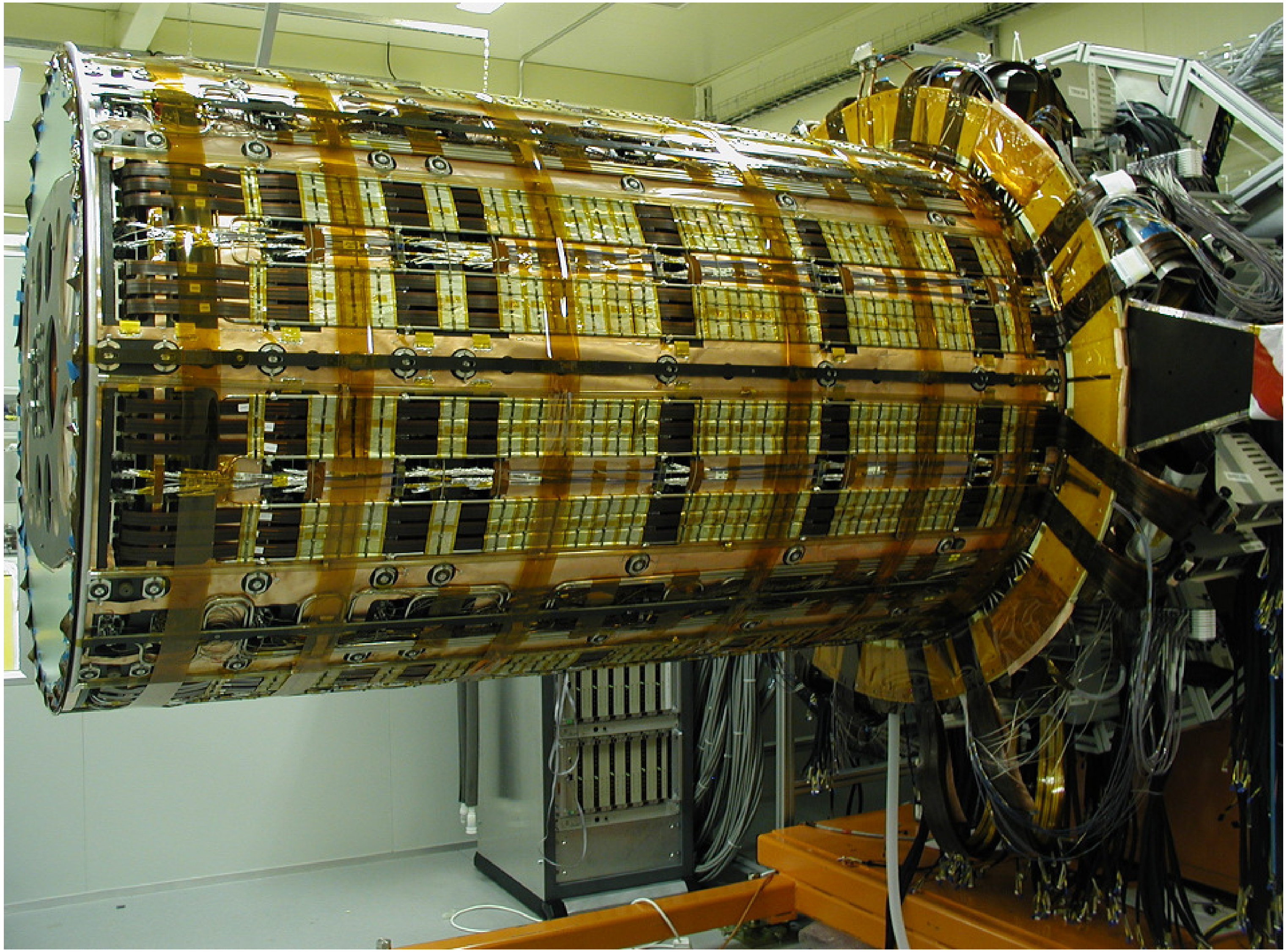
- 2 × 9 disks
- 1976 Modules

Typical Module:

- 2 × 6 cm × 6 cm axial strips
- 2 × 6 cm × 6 cm stereo strips (40 mrad)
- Strips ~80 μm wide
- 6M channels



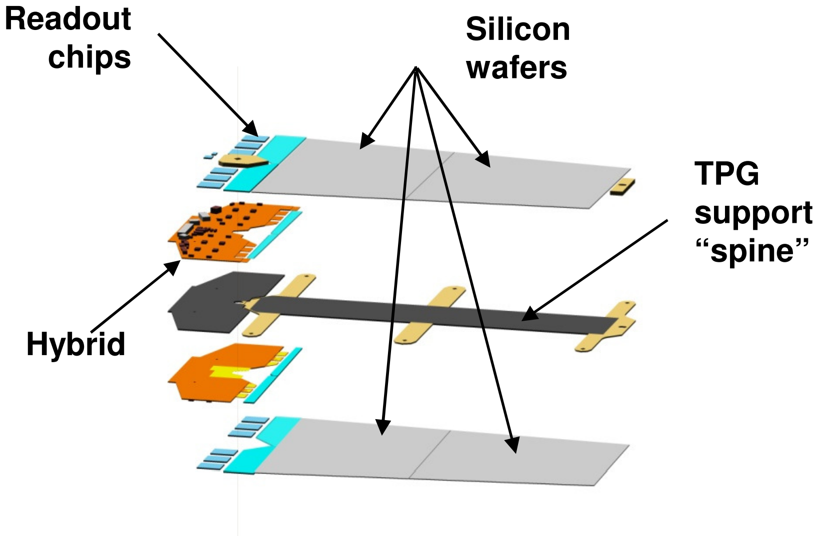
SCT End-cap



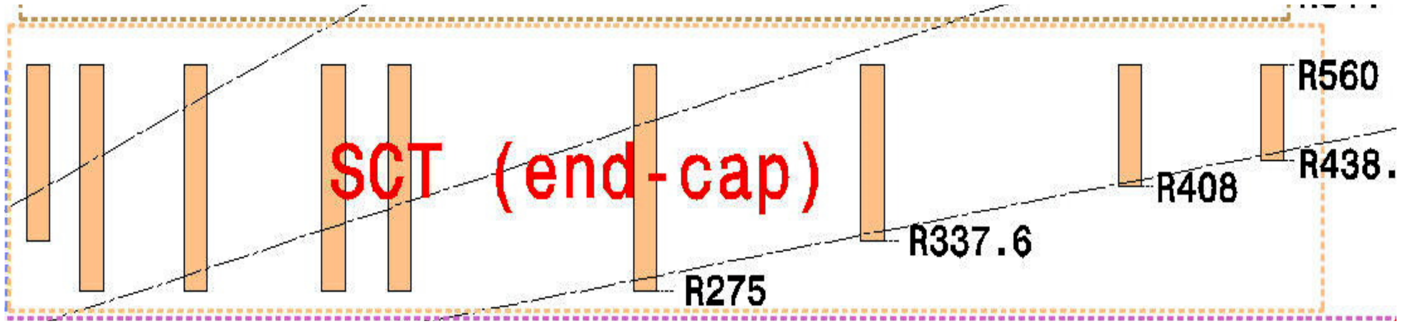
Requirements

- Provide 4 space-points within $|\eta| < 2.5$
- Modules placed on Disks to 70 (Inner) or 220 (Outer) μm
- Disks placed in Cylinder to 100 (x-y) and 1000 (z) μm
- Aligned to O(1) μm; stable to O(1) μm/hour
- Modules kept at –7^{o}C – each End-cap generates 10 kW heat
- End-cap to be kept dry; dew-point O(–30)^{o}C
- Withstand hadron fluences of 2×10^{14} cm^{-2} 1 MeV neutron equiv
- Minimise magnetic materials (Fe,Ni)
- Minimise potential activation (Ag)
- Minimise electrical noise pick-up from ext sources and emission
- Comply with fire-safety requirements
- Reduce mass (radiation & interaction lengths)
- Tolerate Solenoid quench

End-cap Modules



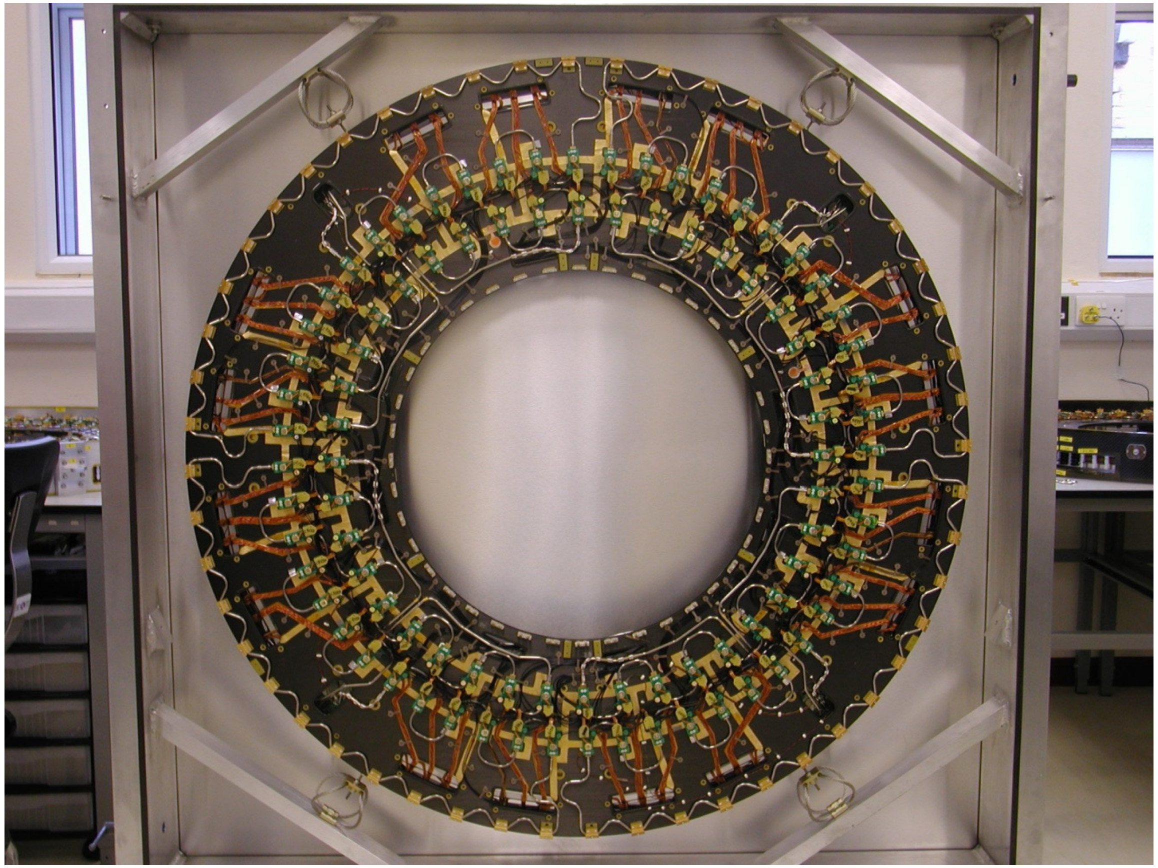
- 6 × 128 channels on each side
- Themal pyrolytic graphite (TPG) spine provides rigidity & cooling path
- Cooling at hybrid and "second point" (opposite end)
- Build precision: O(10) µm; 5 µm in most important params; measured to O(2) µm
- Expected measurement precision: 17 µm × 580 µm – confirmed in Test Beam



- Modules are "key-stone" – phi-strips are radial
- 3 different radii: Outer, Middle, Inner (shorter)
- Disk 8 has "Short Middles"
- Total of 4 different types

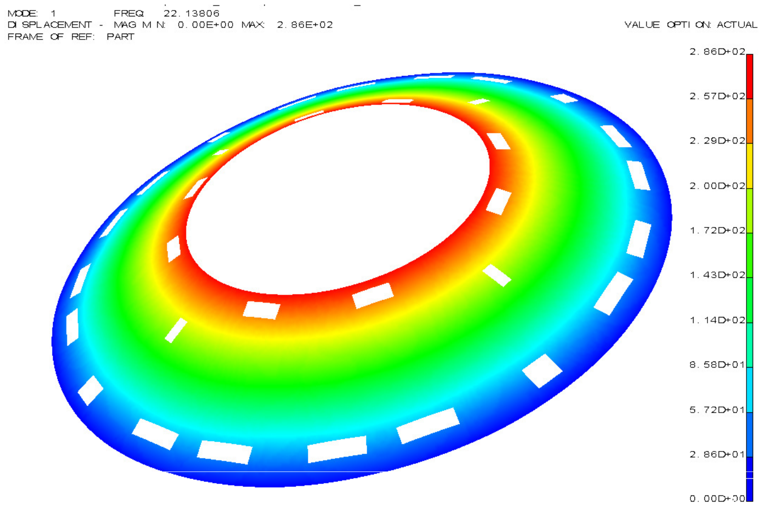
- Stereo alternates orientation (same in Barrel): $u\phi$, ϕv, $u\phi$, ϕv, ...
- Achieved by rotating Modules by $\pm$20 mrad

Disks



- Support Modules
- Support Module Services

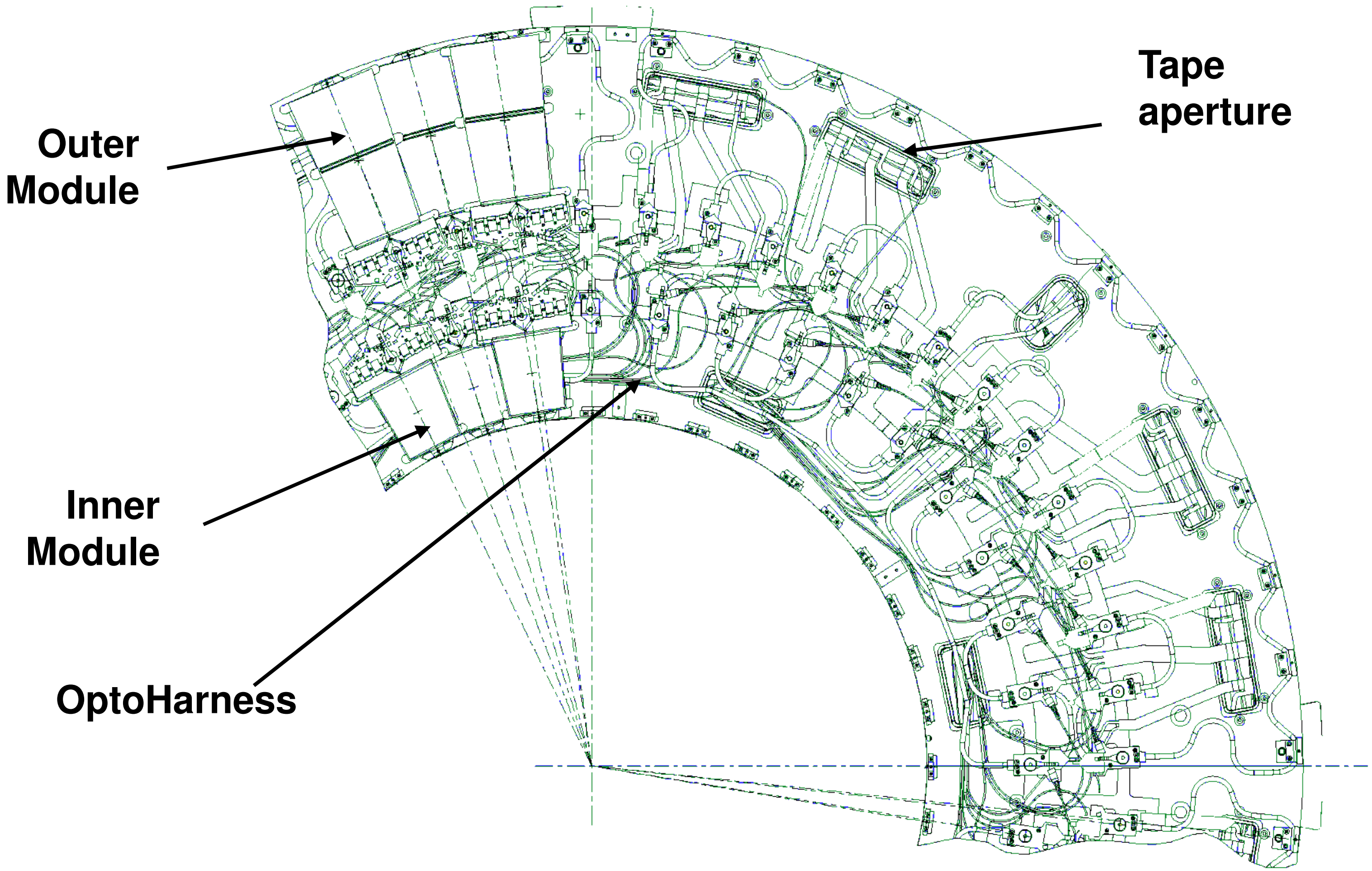
CFRP Disks



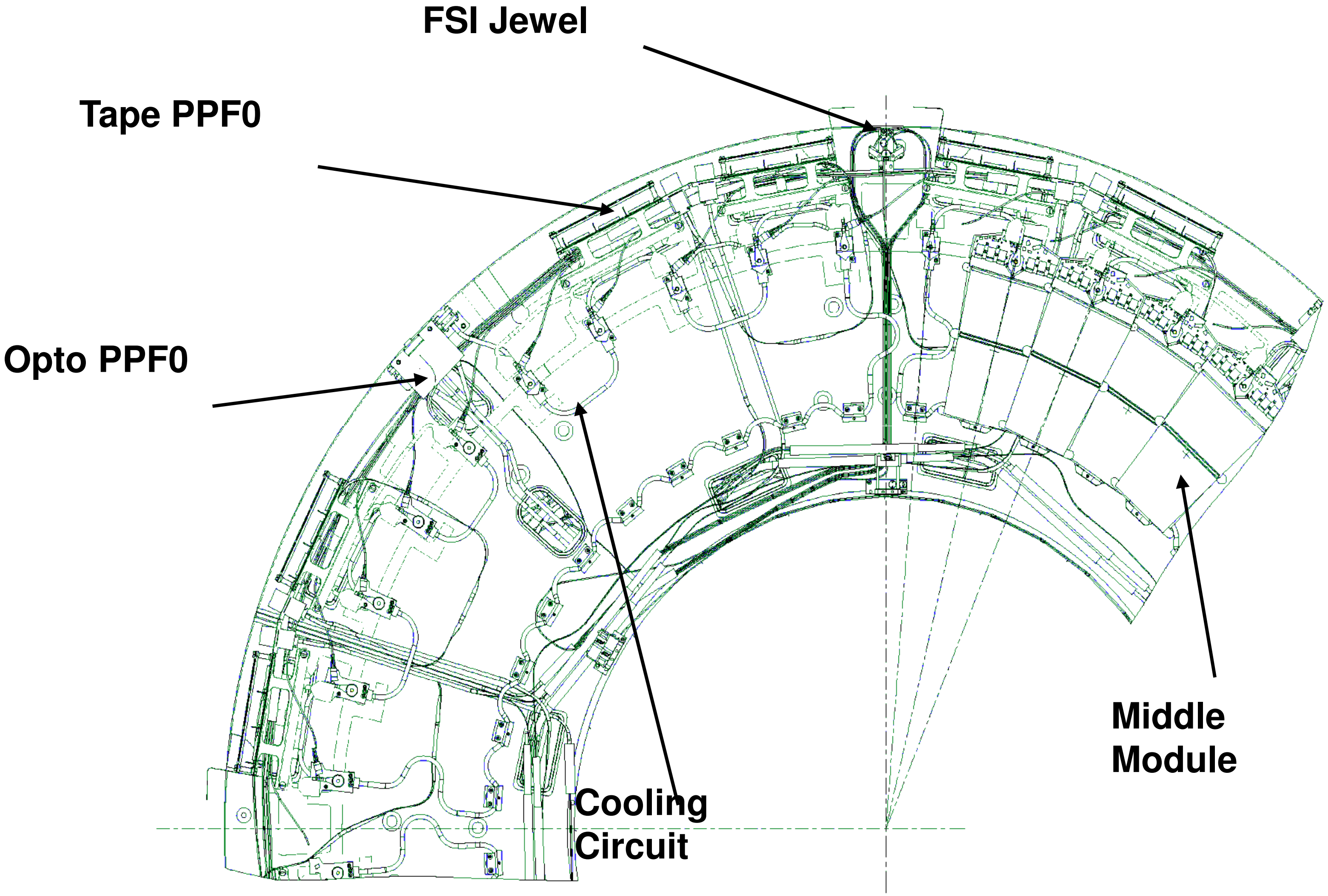
- 180 μm CFRP facesheets: 3 plies at 0, ±60°
- 8.3 mm Korex® honeycombe core
  Korex: aramid fibres with phenolic resin; low moisture absorption

- 1st natural frequency: 22 Hz
- Out of plane distortions expected to be less than 40 μm

Services on Front of Disk



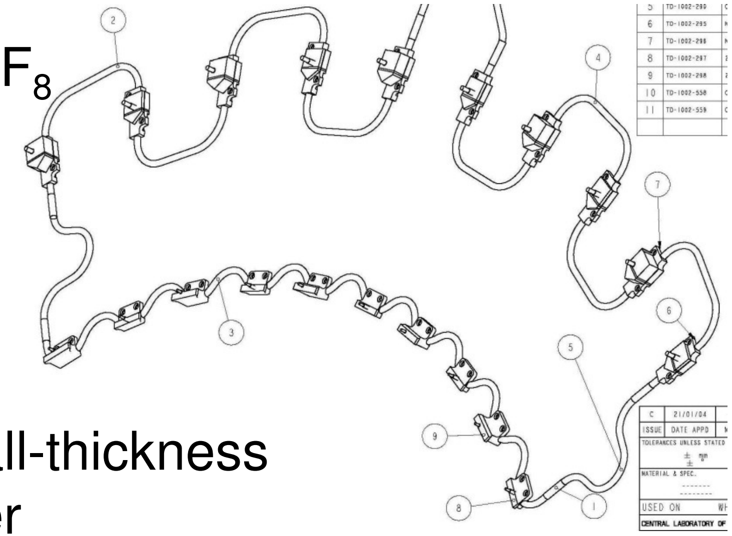
Services on Rear of Disk



On-Disk Cooling Circuits

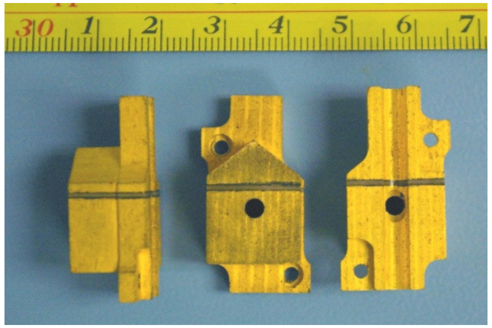
- Modules generate upto 10 W → 10 kW per End-cap
- Must be kept at –7°C to reduce radiation damage to silicon
- Stable temperature essential to reduce thermal motion

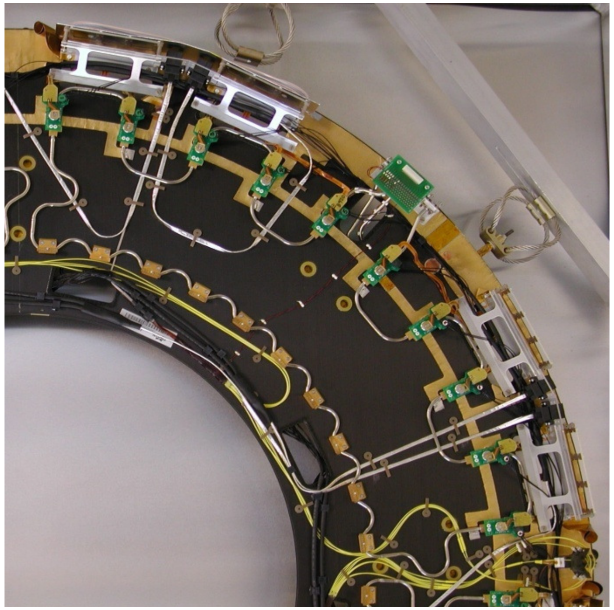
- Use evaporative cooling (latent heat): C_3F_8

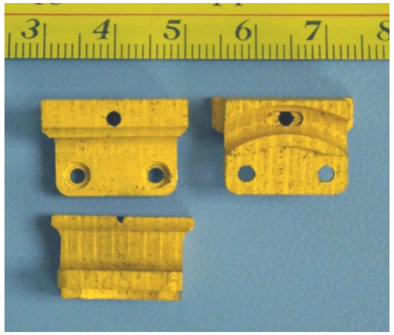


- Tried Al pipes – corrosion problems
- Use CuNi (70:30) 3.7 mm OD, 70 µm wall-thickness
  Good corrosion properties; easy to solder
- "Wiggly" design for stress relief
- Difficult to bend with bend radius of 4×diameter
- Watch holes in wall (from inclusions) → careful QA

- Modules bolted to Pin on Cooling Blocks
- Cooling Blocks made of Carbon-Carbon: 100 W/m/K in good direction
- PEEK insulation between detector and hybrid portion of Block
- Gold-plated to avoid grease absorption



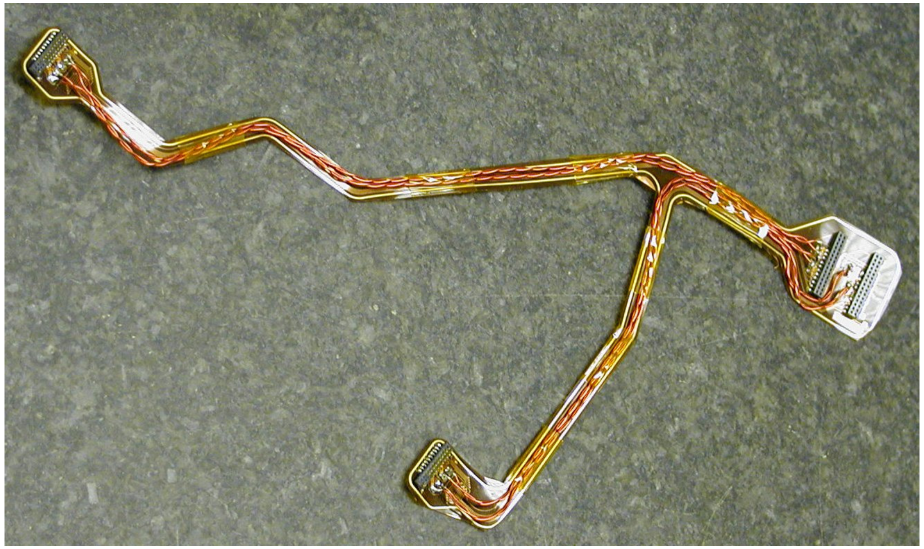




Power Tapes

Supply

- LV digital & analogue power for detector
- HV for detector
- Power for Opto-electronics
- Control lines



- LV power (higher current): copper-clad aluminium twisted pair
- Rest: Cu traces on Polyimide tape (Aluminium too fragile)

- Due to complex design (modularity) 21 flavours of tape required

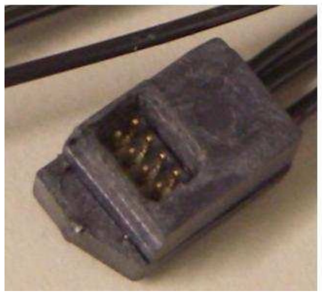
OptoHarnesses

Optical fibres for

- Data from Modules
- Timing/Trigger/Control info to Modules

250 μm fibres clad in 0.9 mm OD furcation tubing

Contained in 12-way ribbons for upto 6 Modules



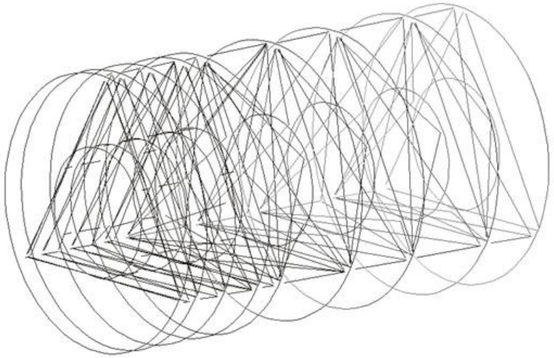
FSI

Frequency Scanning Interferometry provides real-time alignment info

(Interfere light from measured length with light from reference length; scanning frequency allows absolute determination of length)

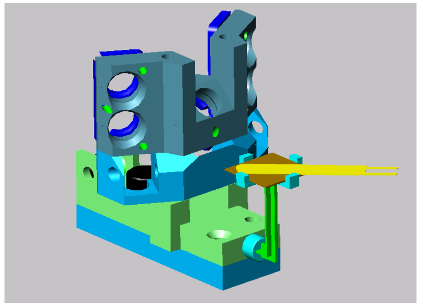
Precision O(1) μm in length

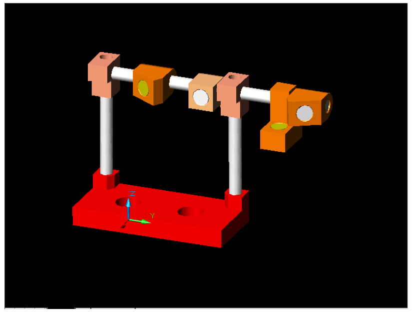
Installed only in SCT

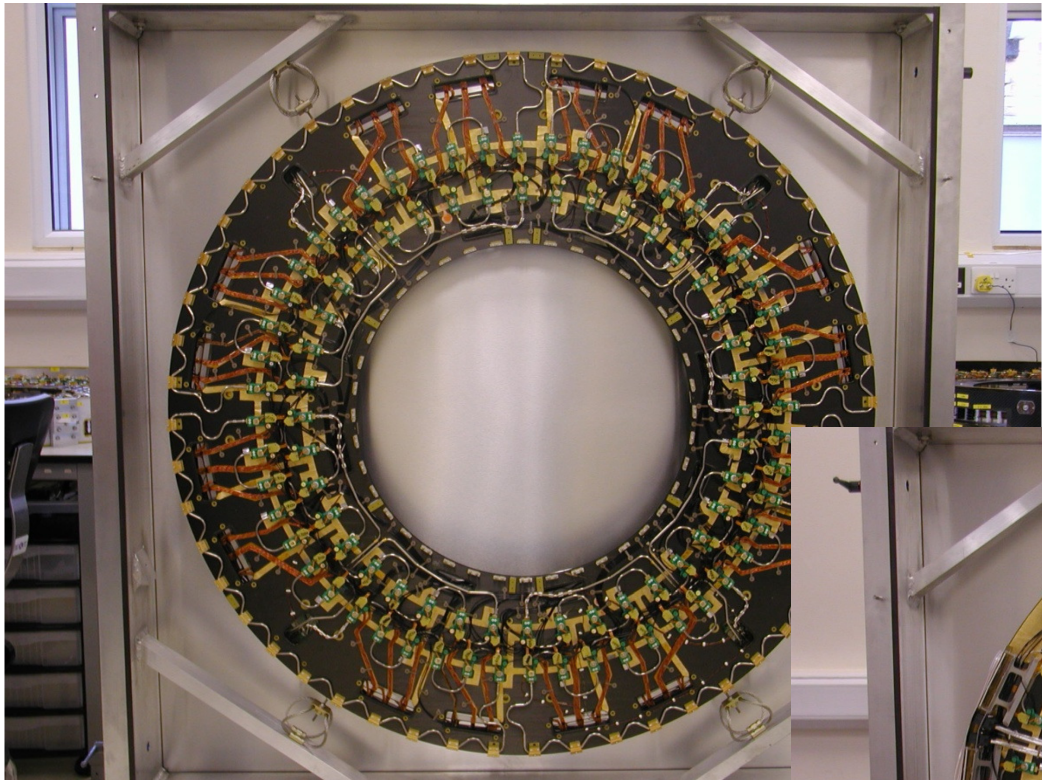


Measures movement … due to thermal & humidity effects, gravitational sag, etc

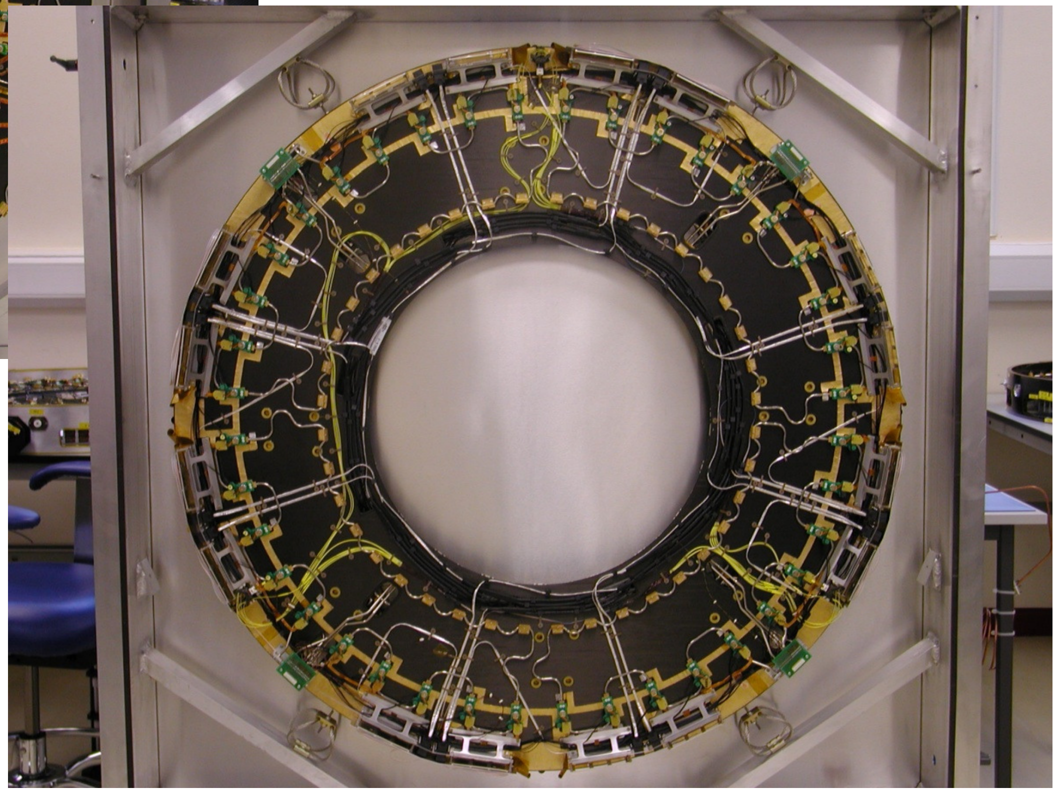
Delicate emitter/receiver fibres in holders & reflectors on Disks







Front

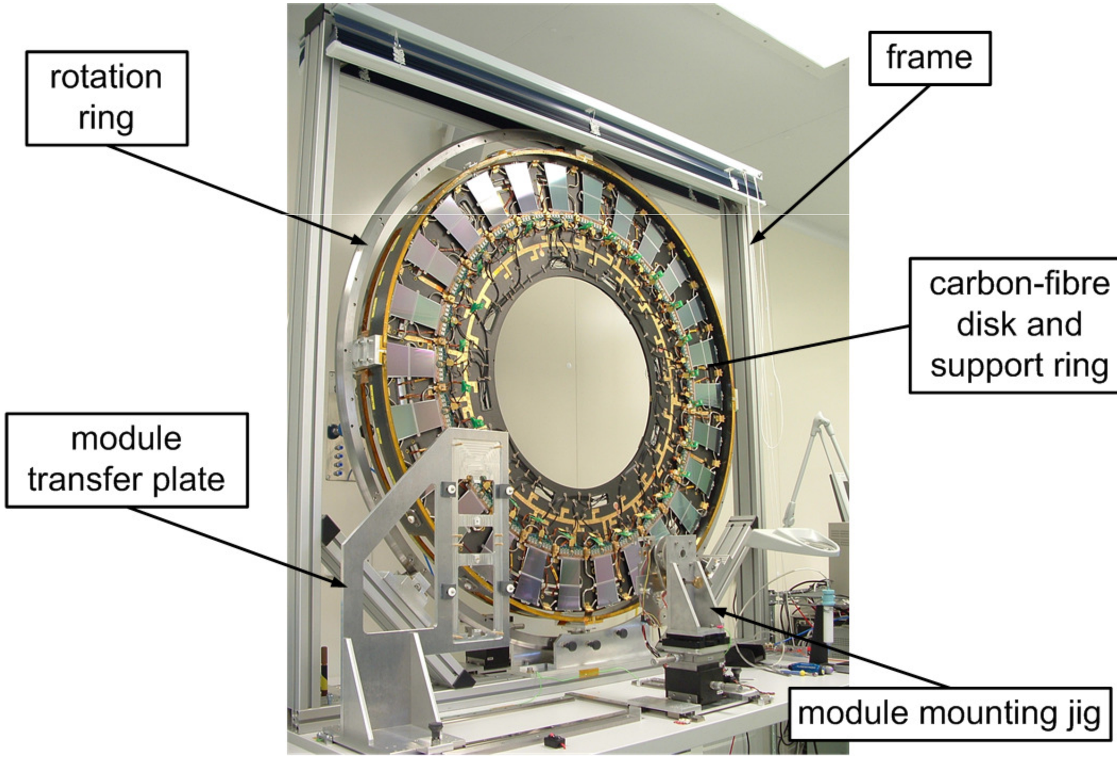


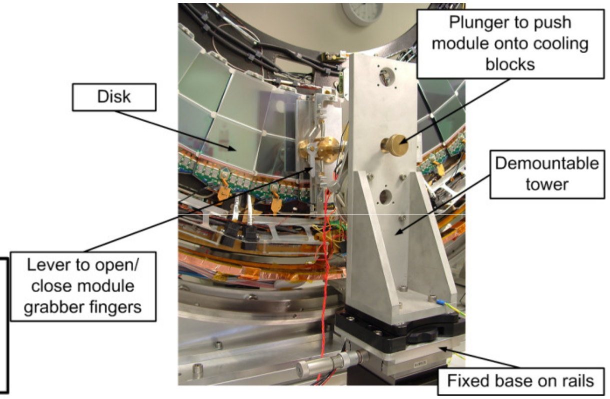
Rear

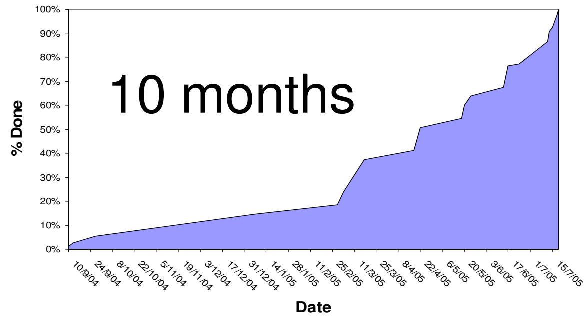
Took 2 years to assemble 9 UK Disks

Module Mounting

- By hand, with tooling (Barrel used robot)
- Thermal grease applied in controlled amount to Cooling Blocks
- Modules held to Block by washer & nut







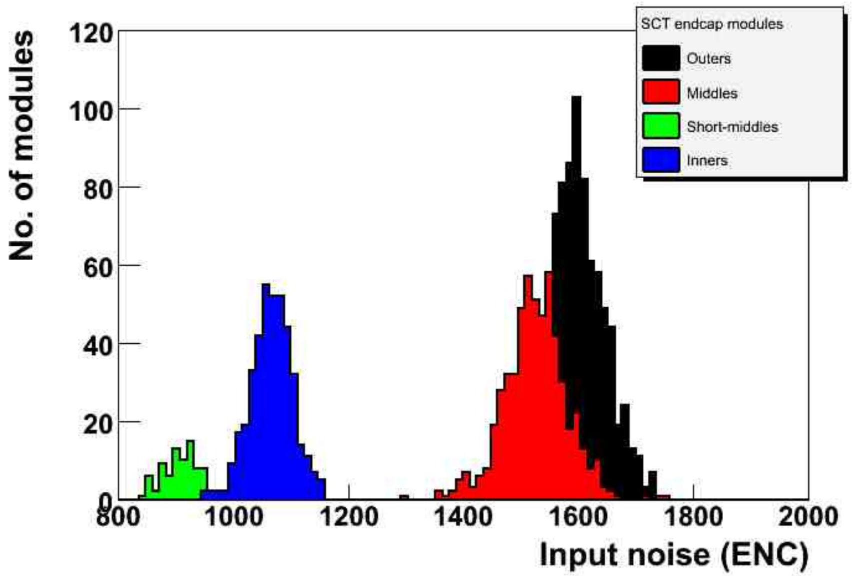
Testing

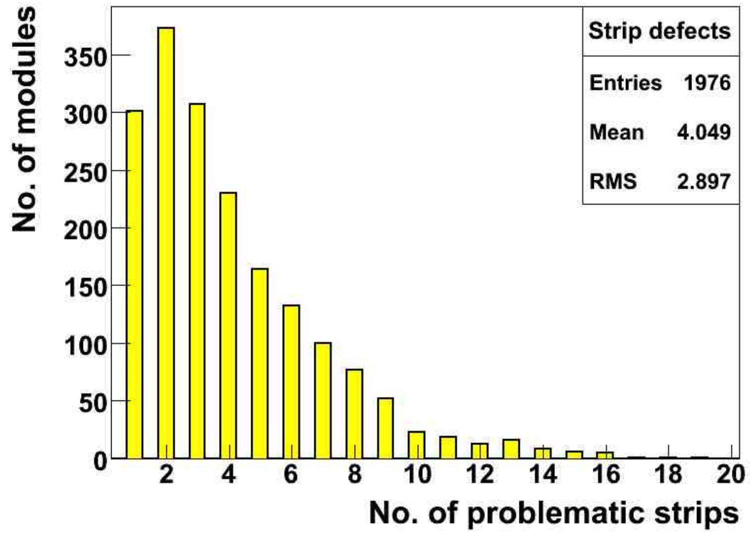
Extensive testing of

- Disks with Services
- Modules
- Modules on Disks

Metrology:

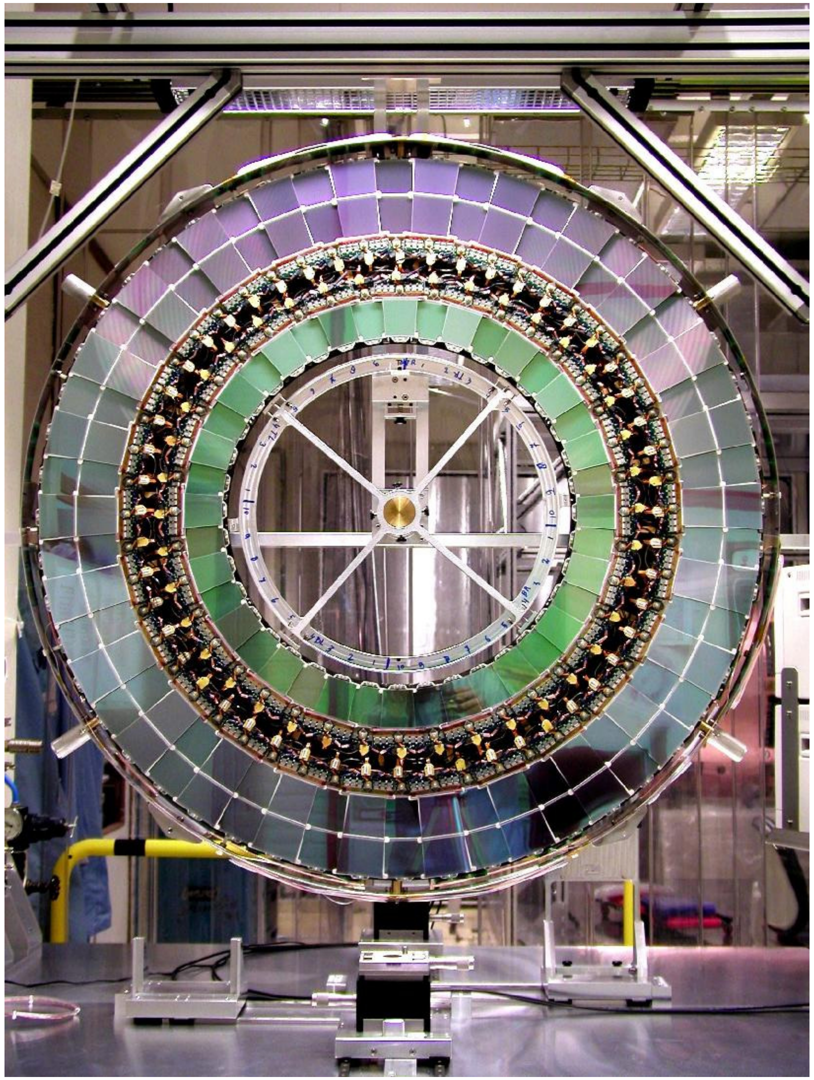
- Require Cooling Block Pins' position to 37, 60, 190 μm for Inner, Middle, Outer Modules (for sufficient overlap)
- Measure with CMM to 10 μm
- Global rotations, but Pin-Pin position in spec for all but one Pin

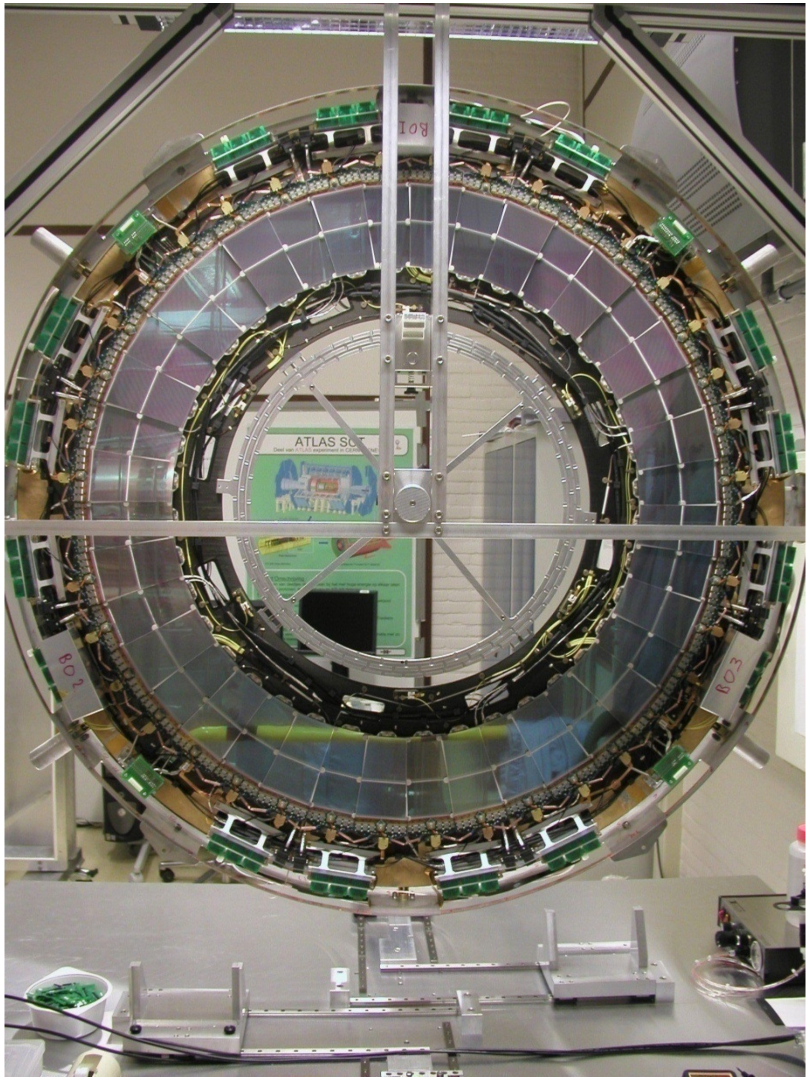




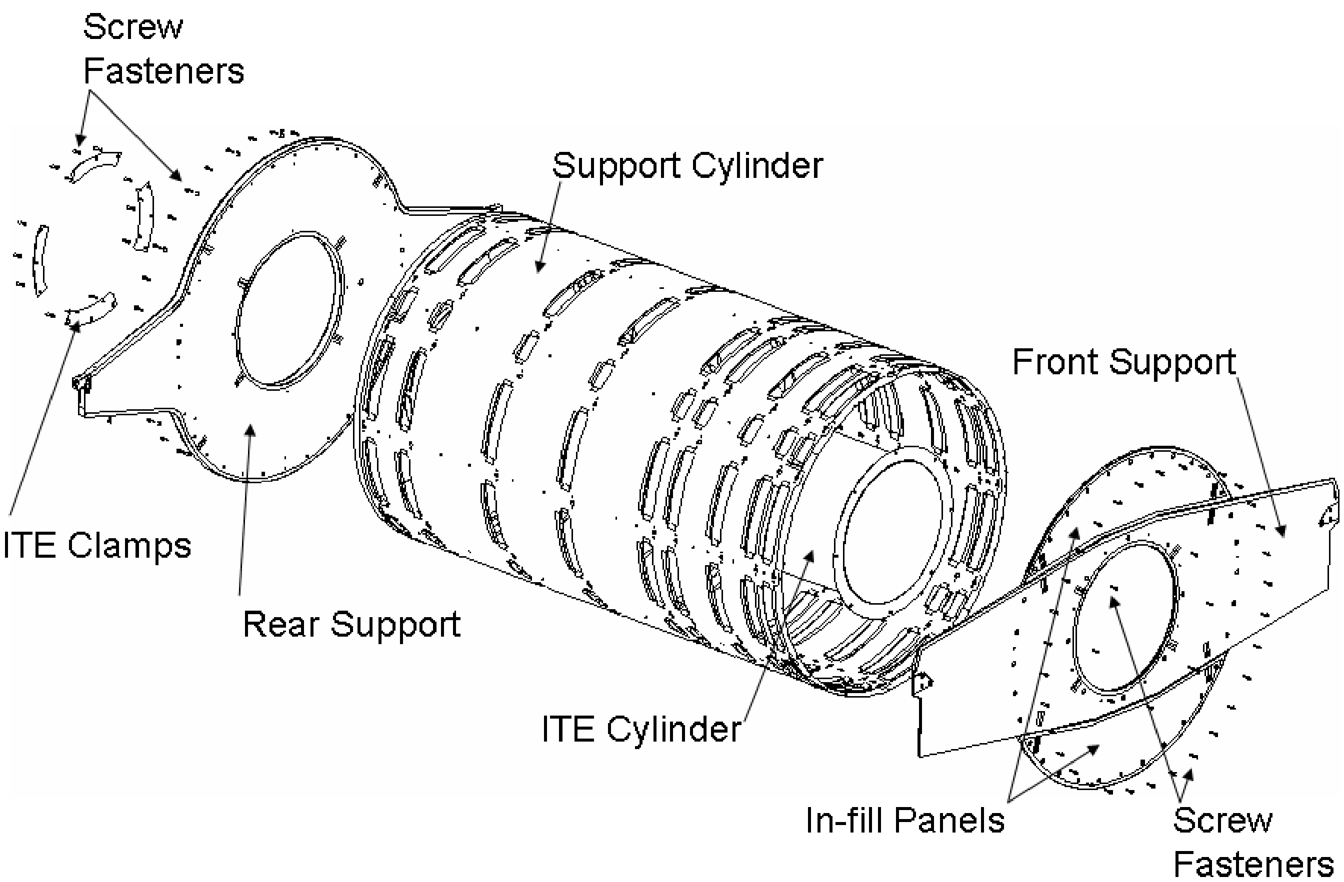
- 8000 “problematic” strips – 0.26% of total, cf spec of 1%
- Mean of 4 out 1536 strips per module
- 80% of these are “dead”; 20% noisy or unbonded

Finished Disks



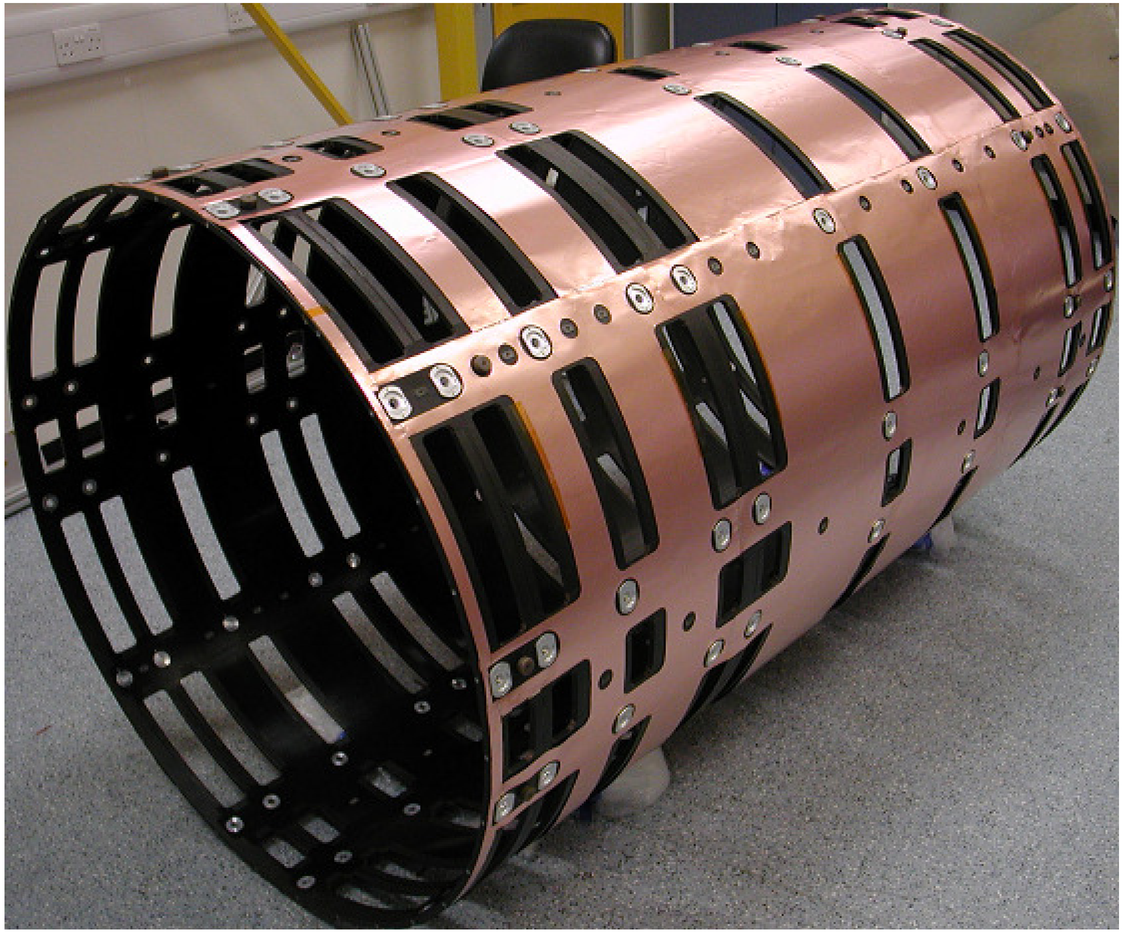


Support Structures



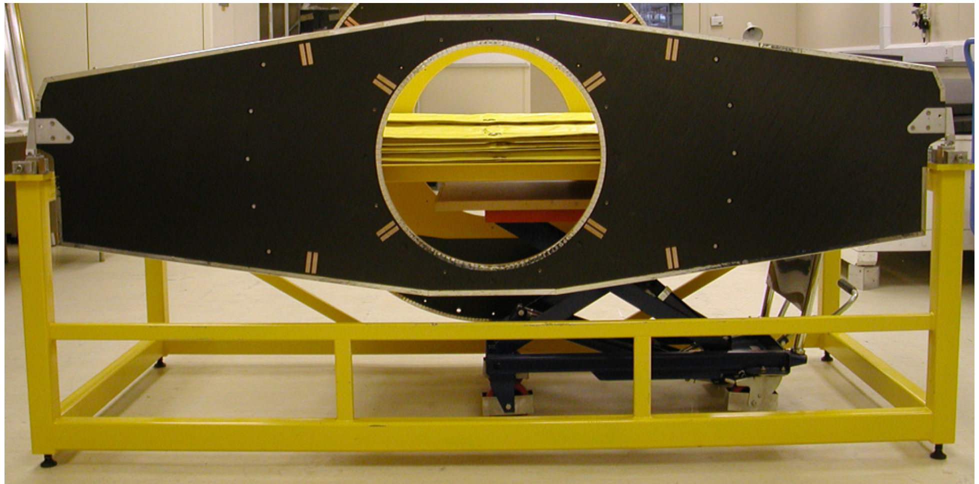
- CFRP composites similar design to Disks: Faceskins & Korex honeycomb
- Cost 2/3 M$ and consumed several years

Support Cylinder

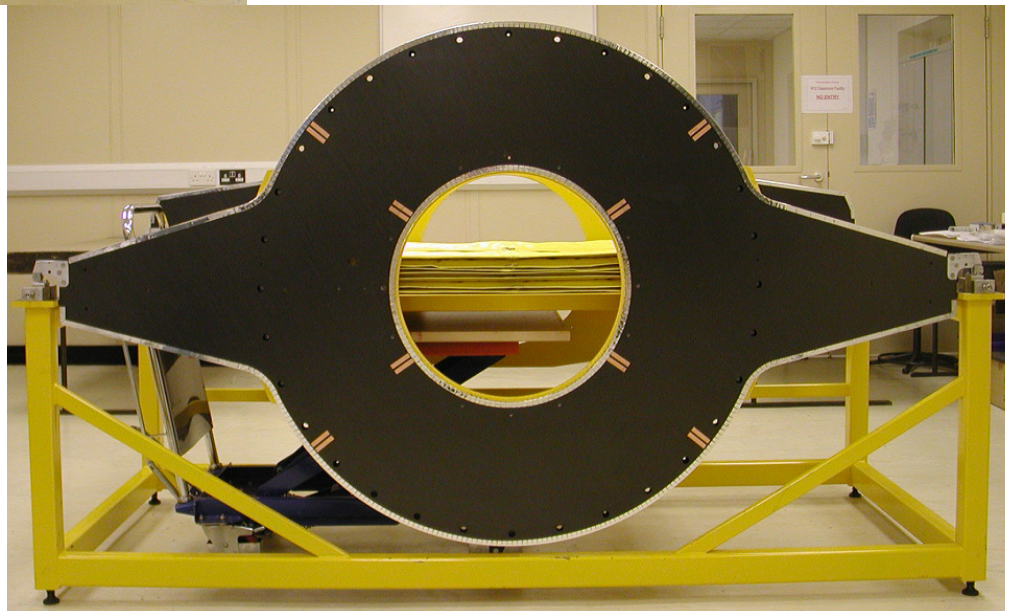


- 9 mm thick
- Inserts accurate to 250 µm to position Disks

Front & Rear Supports

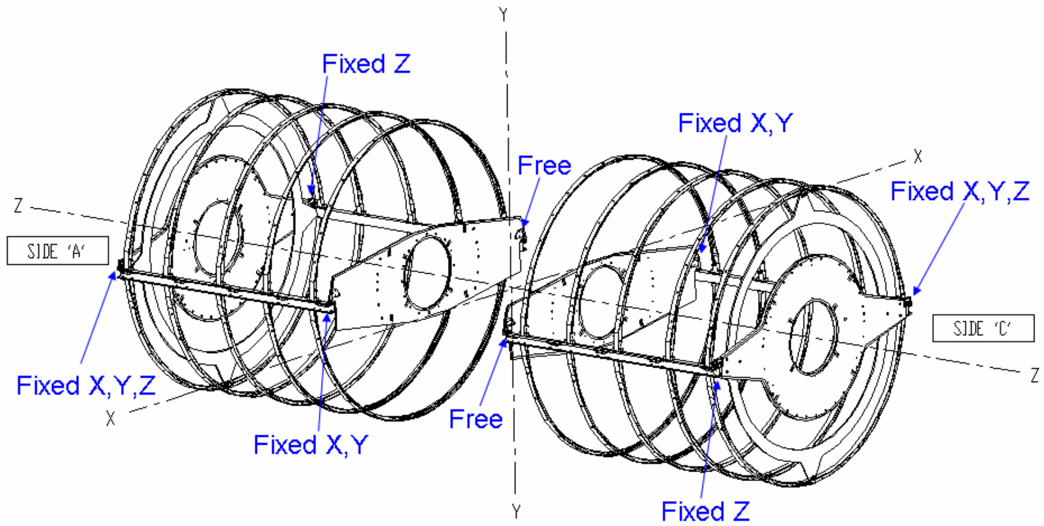


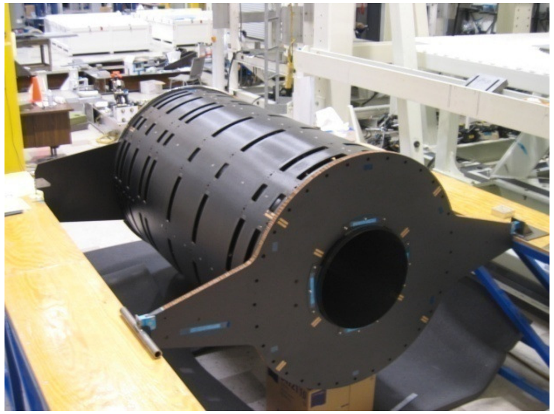
Front: 9 mm thick



Rear: 25 mm thick

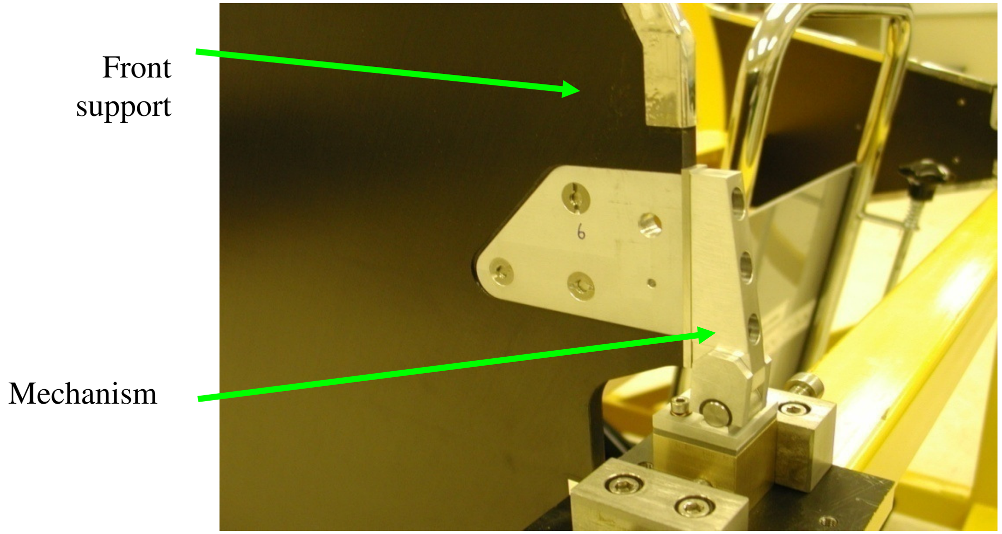
Support



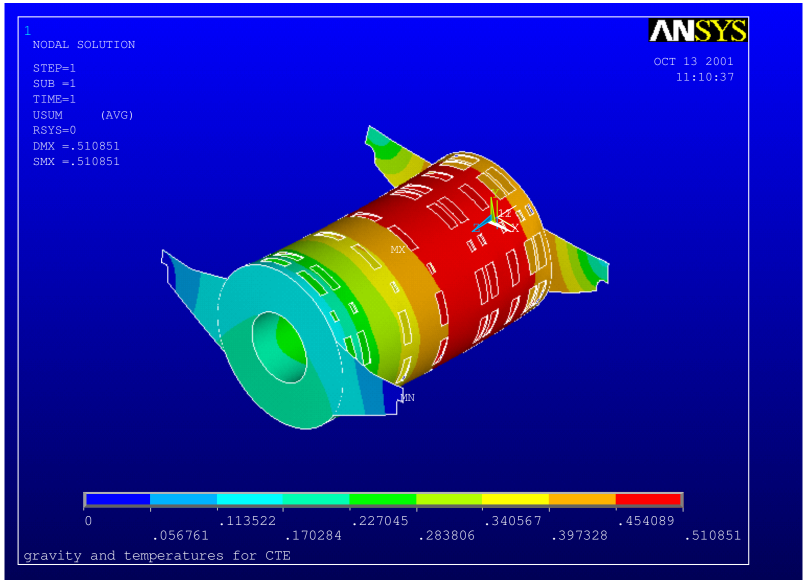


Front & Rear Supports rest on
TRT rails

Supported kinematically
by "Mechanisms"



FEA & Tests



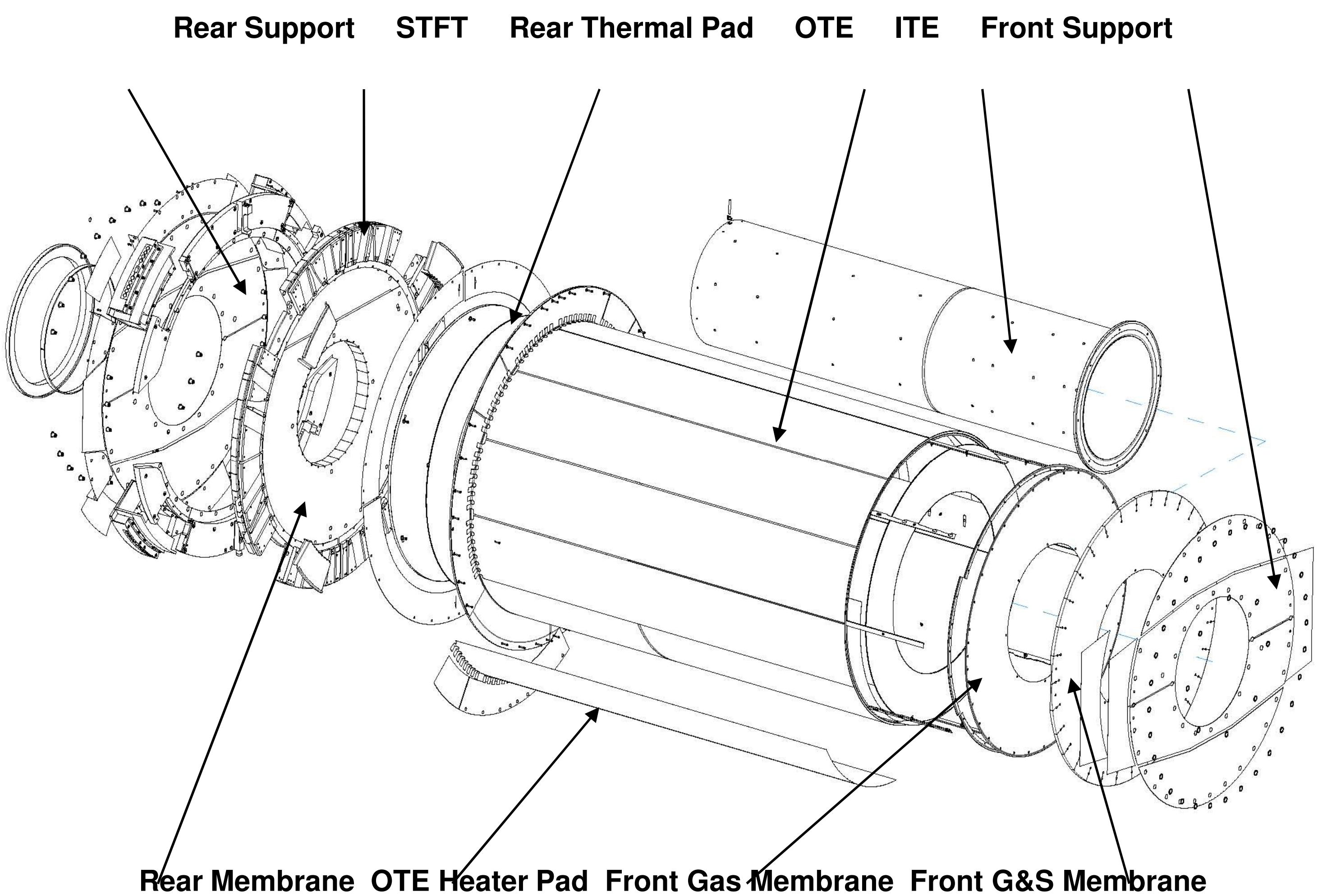
37,000 element model

Effect of gravity & CTE

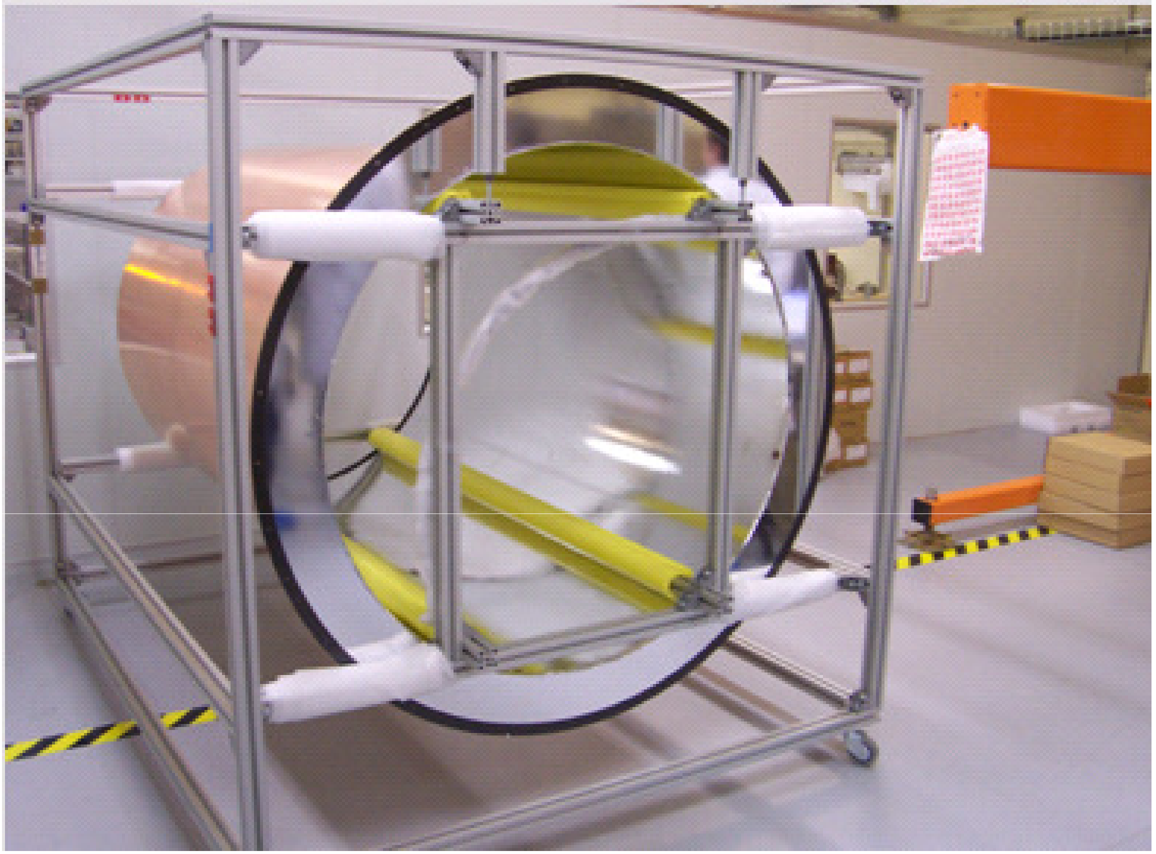
- CTE 1.4×10^{-6} /°C … 30 °C over 2 m → 80 μm   CME = 1.0×10^{-4}
- 1st mode 6 Hz; 2nd mode 24 Hz   Δhumidity=50% @RT
- Taking a conservative vibration spectrum, expect deviations of 3 (40) μm perpendicular (parallel) to axis
- Test sample panels to > 2.5 MPa
- Load structure to ×1.5 working load; measure deflections of 0.74 and 0.87 mm, cf predictions of 0.63 mm

Thermal Enclosures

- Contain SCT environmental gas (N_2) … external gas is CO_2
- Moisture barrier
- Thermal barrier … TRT is at 22.5 °C
- Prevent formation of condensation/ice on outside of SCT
- Faraday shield


Rear Support
STFT
Rear Thermal Pad
OTE
ITE
Front Support
Rear Membrane
OTE Heater Pad
Front Gas Membrane
Front G&S Membrane

Outer Thermal Enclosure

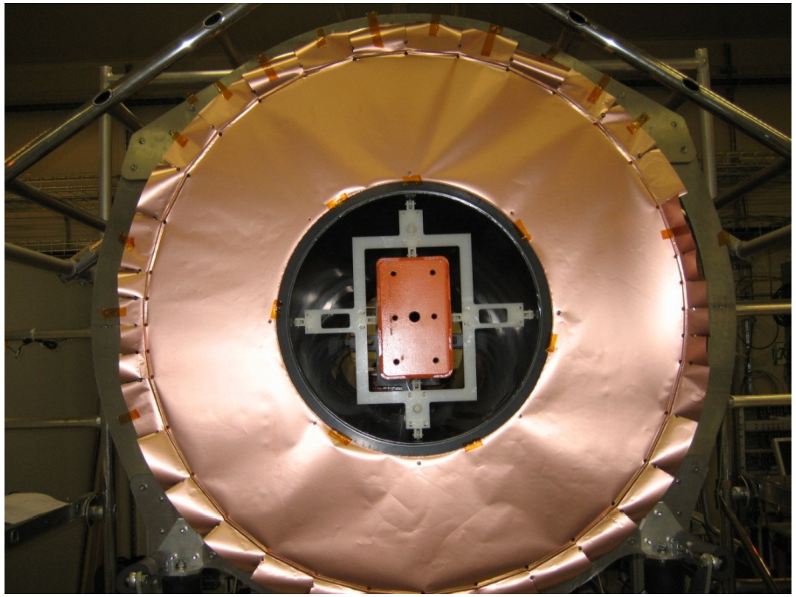


- Sandwich: aluminised polyimide / 8 mm foam / Cu-polyimide
- Use Araldite 2011
- Much prototyping

Inner Thermal Enclosure

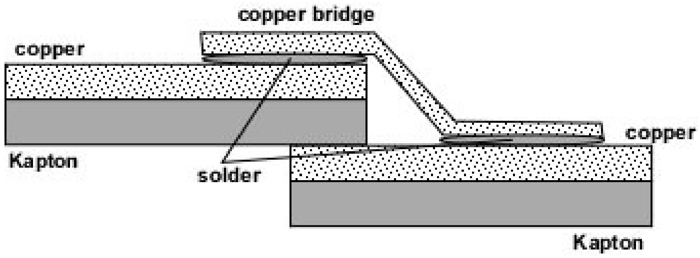
- CFRP laminate cylinder / 5 mm foam / Cu-polyimide
- Includes gas channels with 0.3 mm holes for gas purge

Membranes



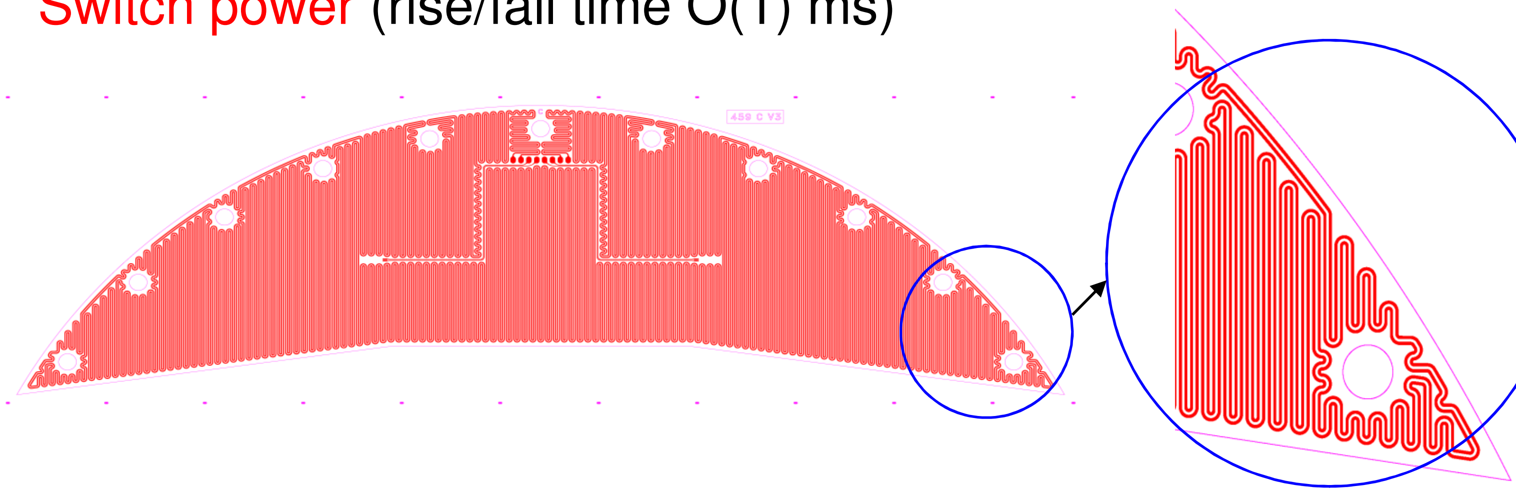
- Gas seals
- Complete Faraday shield

- Connect all Cu-Kapton foils with solder

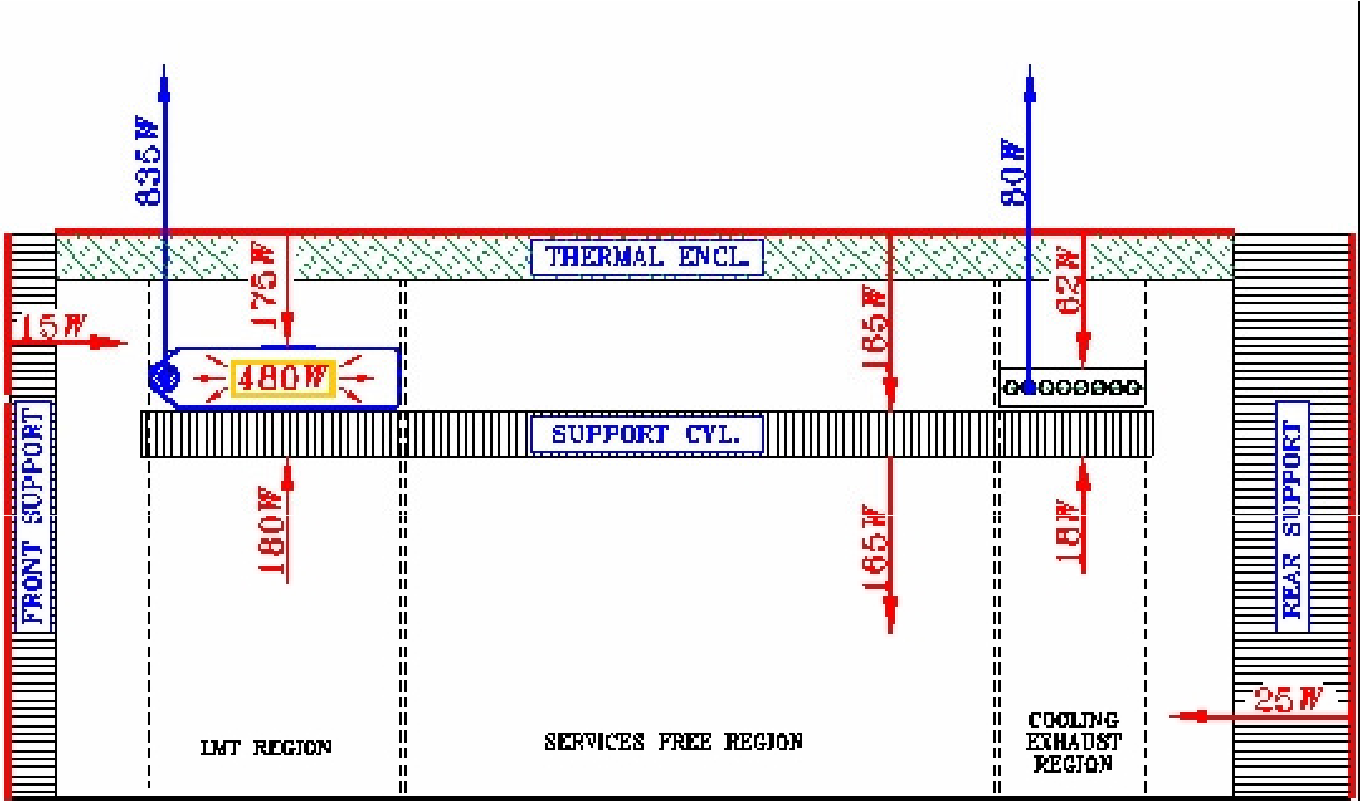


Heater Pads

- Critical component: To ensure keep outside above dew-point and in case moist air gets into Inner Detector, cover outside with heater pads
- 8 μm thick Cu tracks sandwiched between polyimide
- 150 W/m^2 or 300 W/m^2
- Double tracks for redundancy
- Integral thermocouples
- Switch power (rise/fall time O(1) ms)



Heat Flow



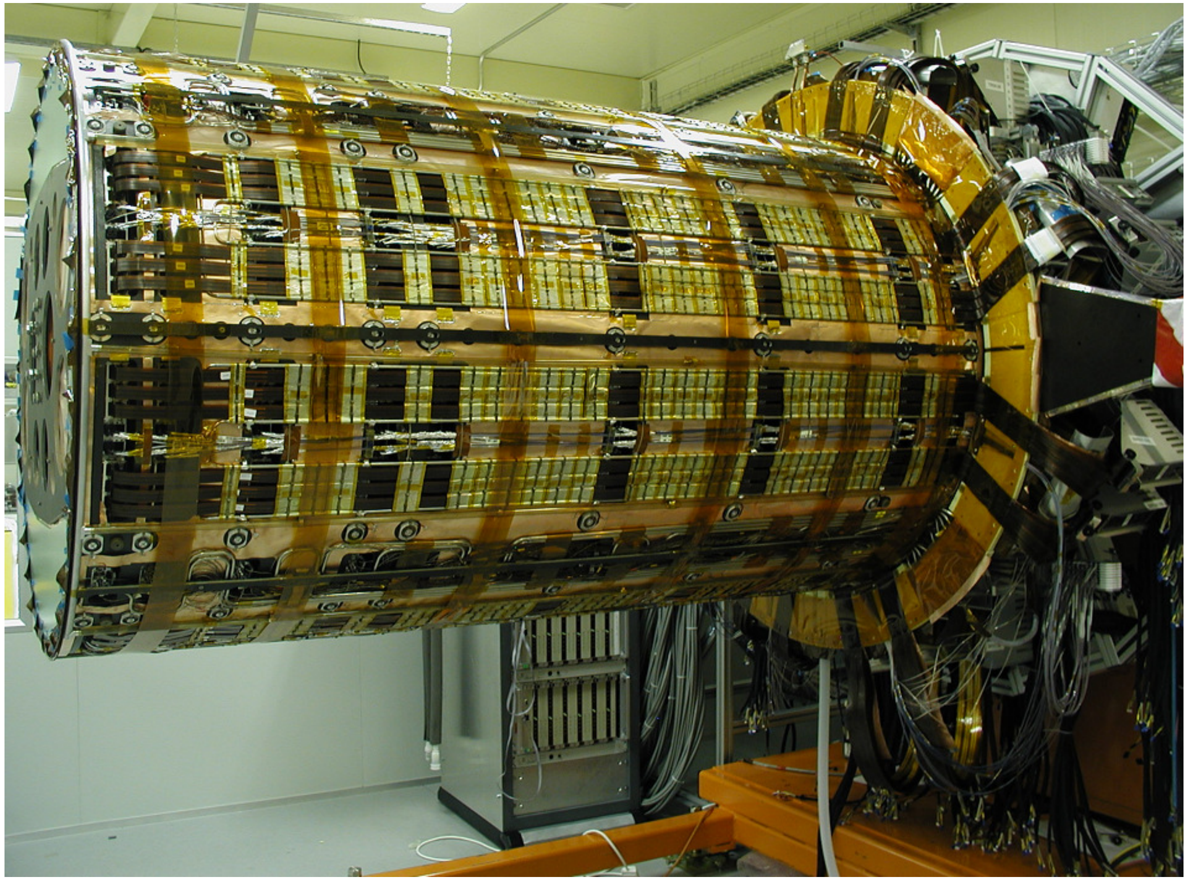
Above ignores Module heating / cooling ~ O(10) kW per End-cap

Net inward flux ~ 200 W – so small perturbation for Module cooling

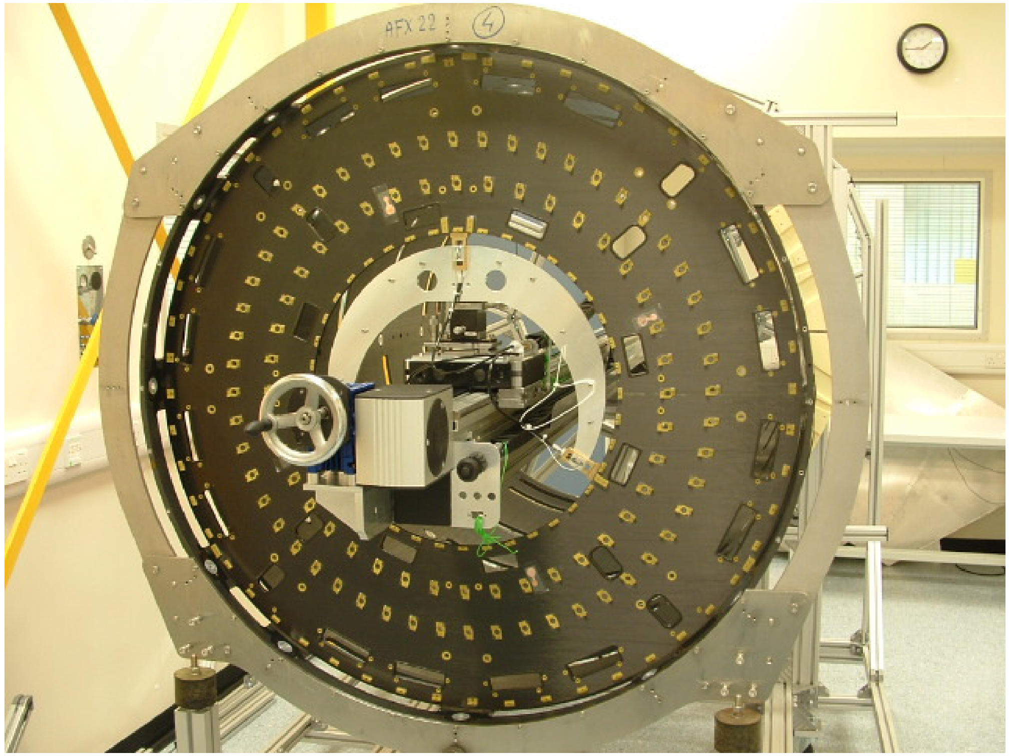
Assembling the End-caps

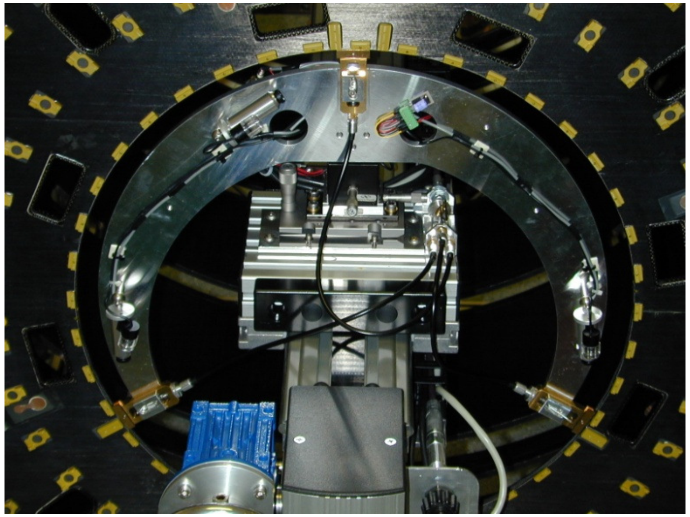
Took place in

- Liverpool
- Nikhef

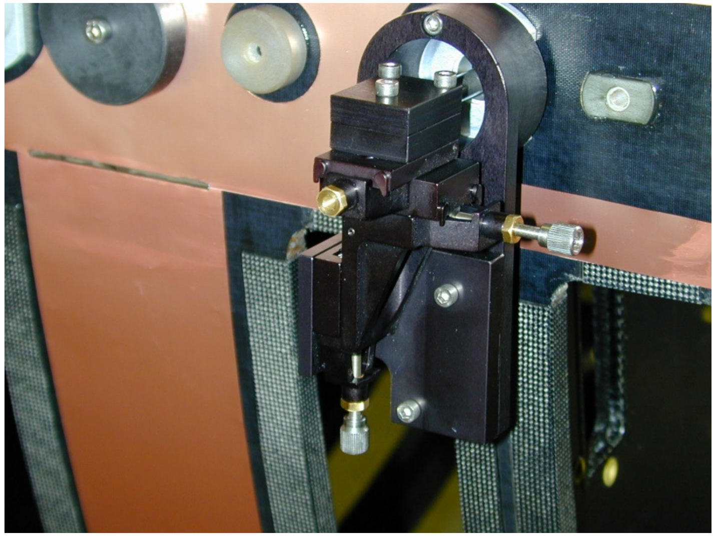


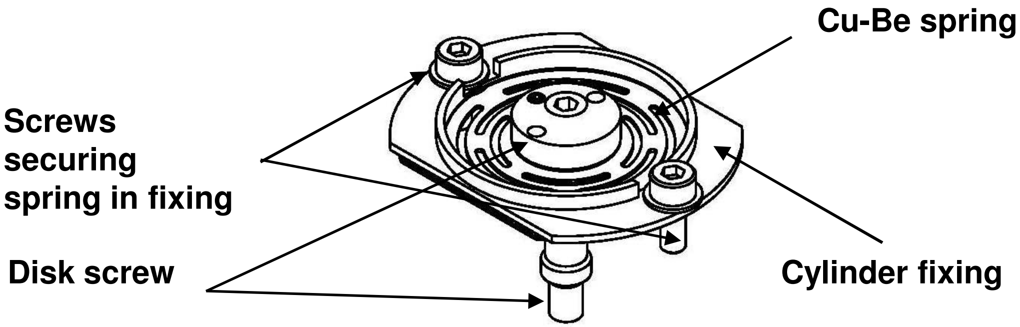
Disk Insertion





Disk “grabbed” at inner radius





Disk “Fixing”

- Located with microscopes longitudinally to 200 μm
- Located with telescopes transversely to ~100 μm
- Cylinder pre-loaded to compensate for subsequent additions of Disks & Services
- Each Disk held by 12 pins around circumference

Services

Power Tapes

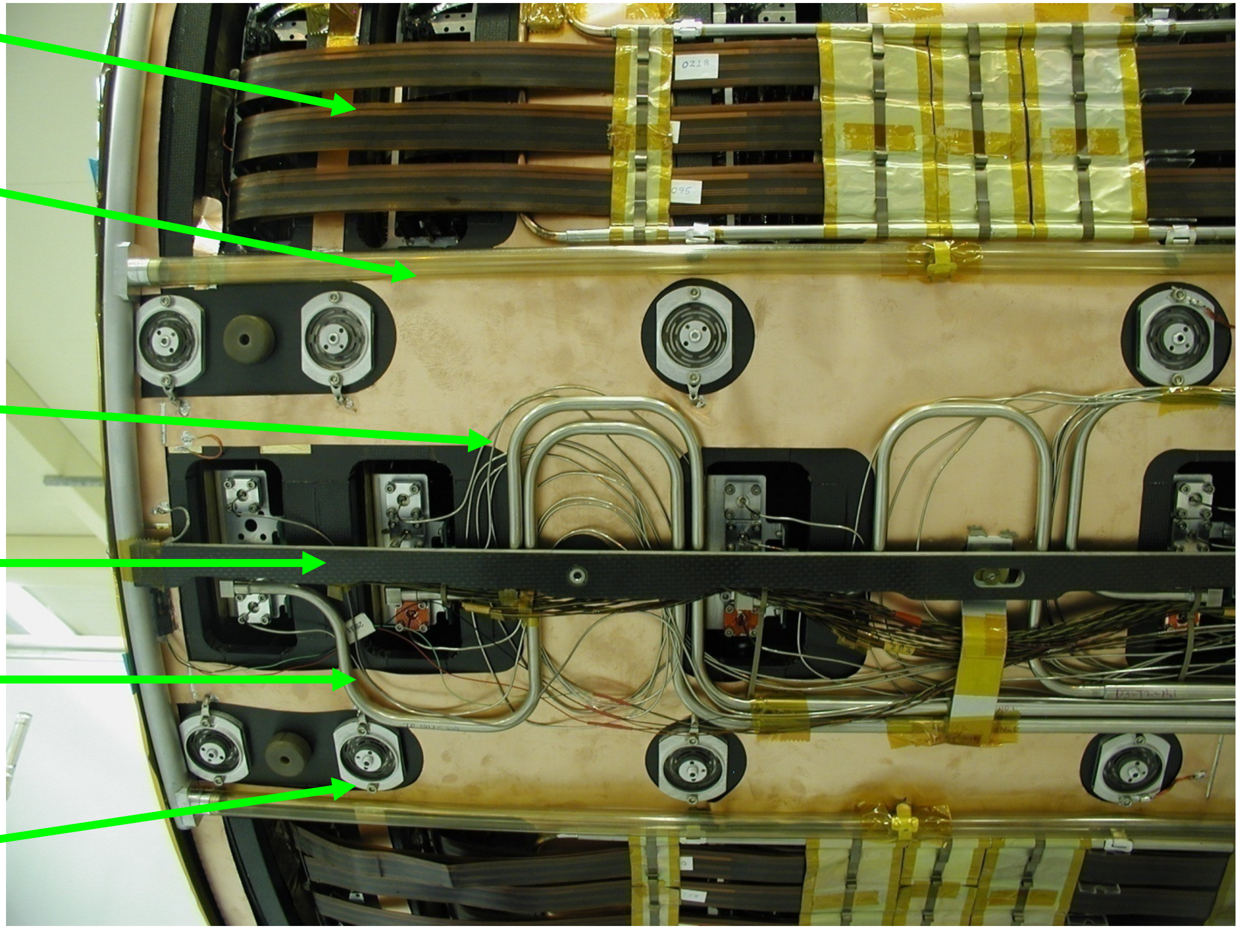
Purge gas return pipes

Module Cooling delivery capillaries

OTE support rail

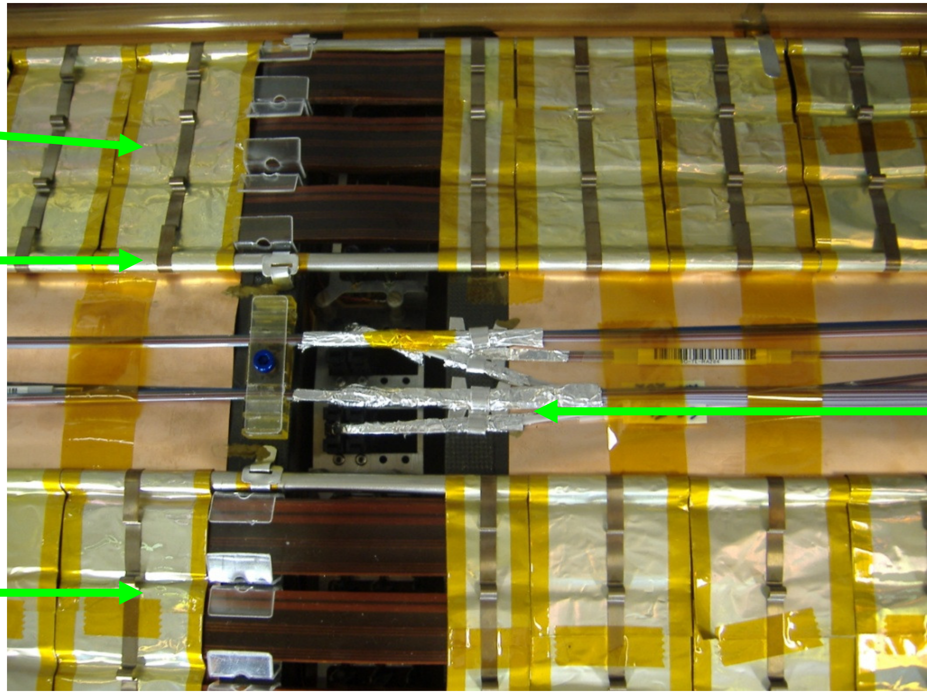
Module Cooling return pipe

Disk Fixings



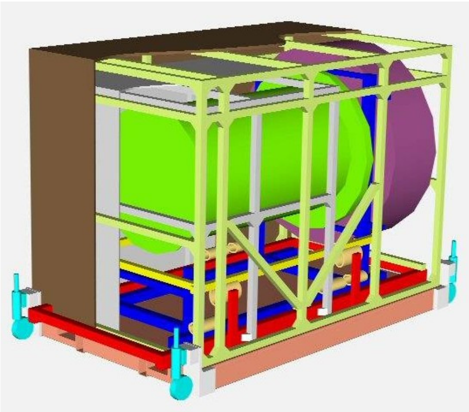
+ Optical Fibres

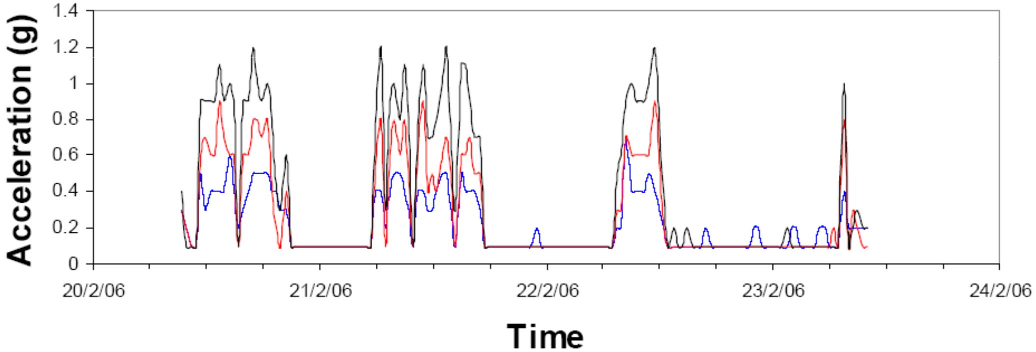
Power Tape Cooling



- Significant heat load
- In absence of cooling, expect temp rise of 50°C at worst
- Wrap in 150 μm Al foil, including dedicated (spare) cooling pipes
- Compress with Cu-Be spring

Transportation from Liverpool



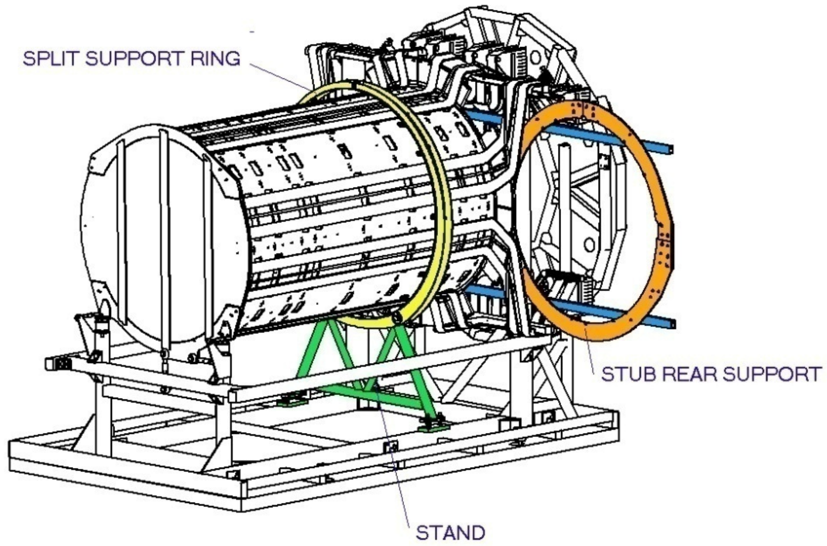


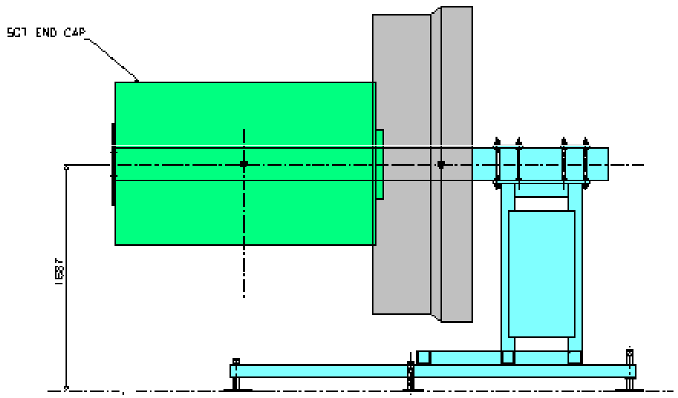
Largest internal acceleration ~1.2 g

- Temperature & humidity controlled, air-sprung lorry
- Serious test run with dummy load
- Carefully monitored
- Insured for 9 MSF

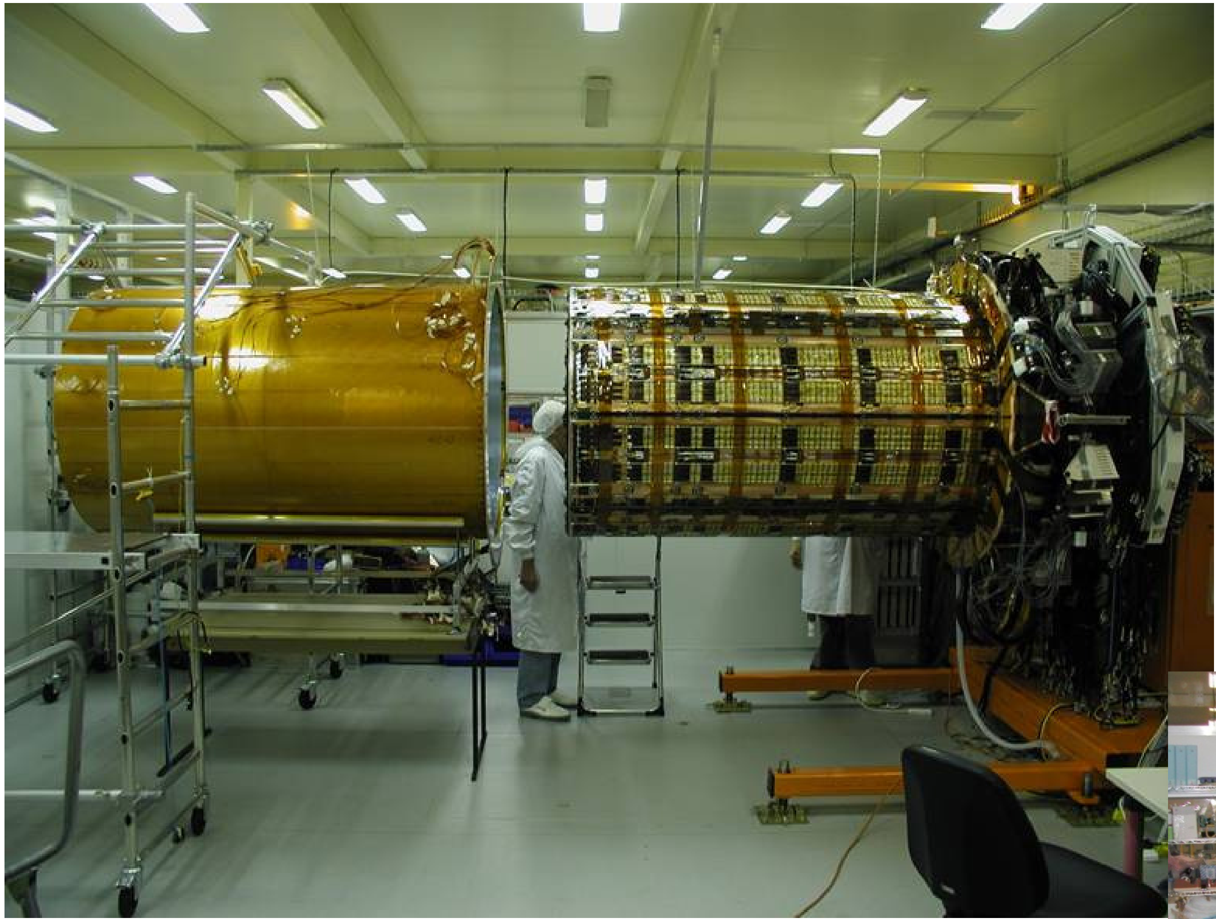
Integration at CERN

- Lots of checks and re-laying of Services at CERN
- Add Rear Support and mount on cantilever beam

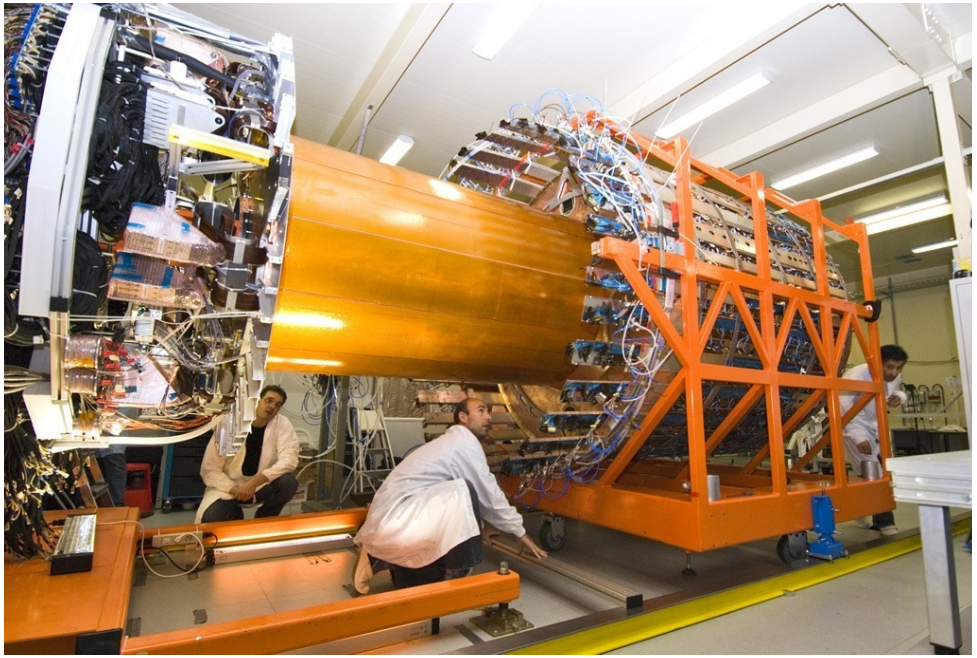




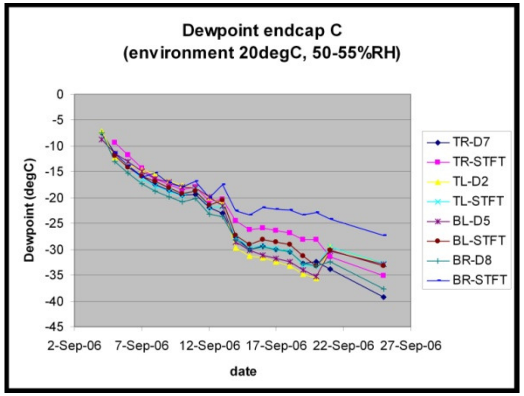
Add Thermal Enclosures



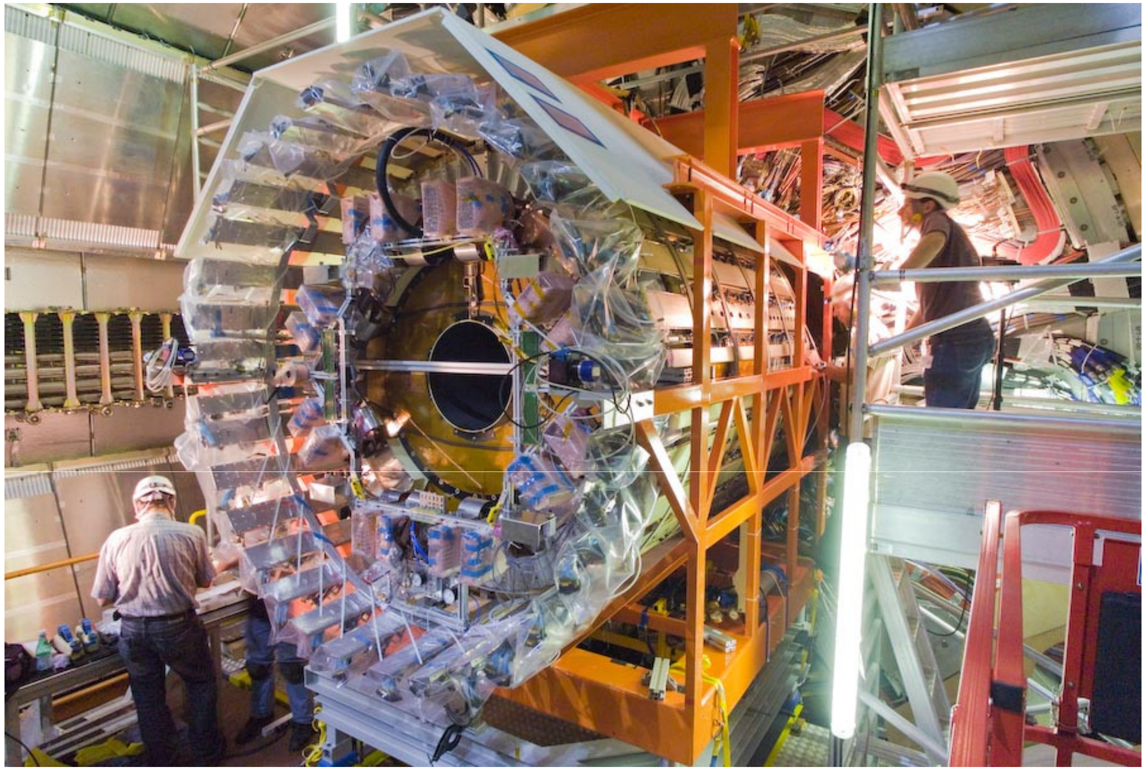
Insert into TRT

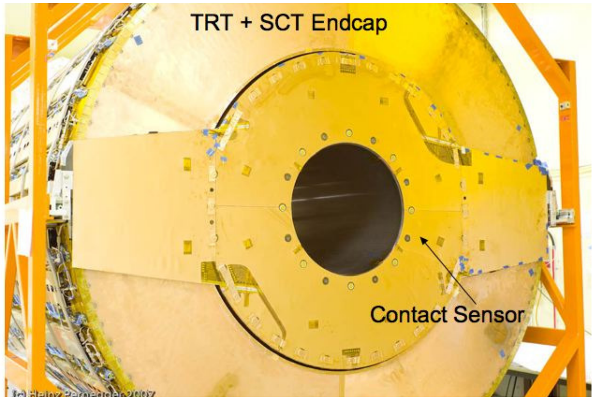


- TRT on rails and slid over the SCT on cantilever beam
- Add Front Support
- Align on TRT Rails
- Seal Thermal Enclosure & dry out
- Electrical tests



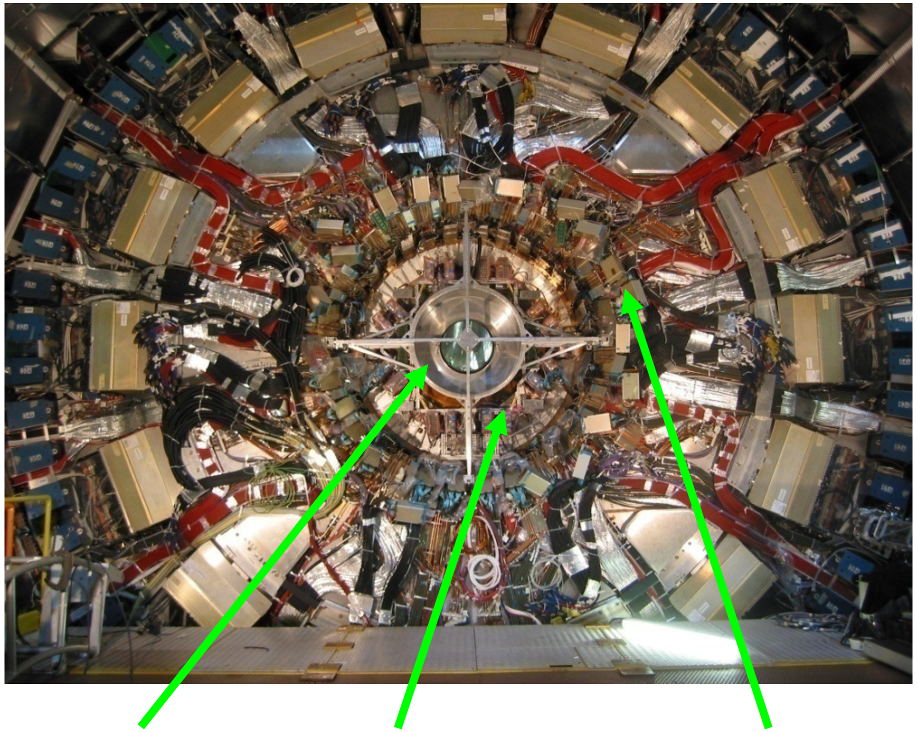
Insert into ATLAS



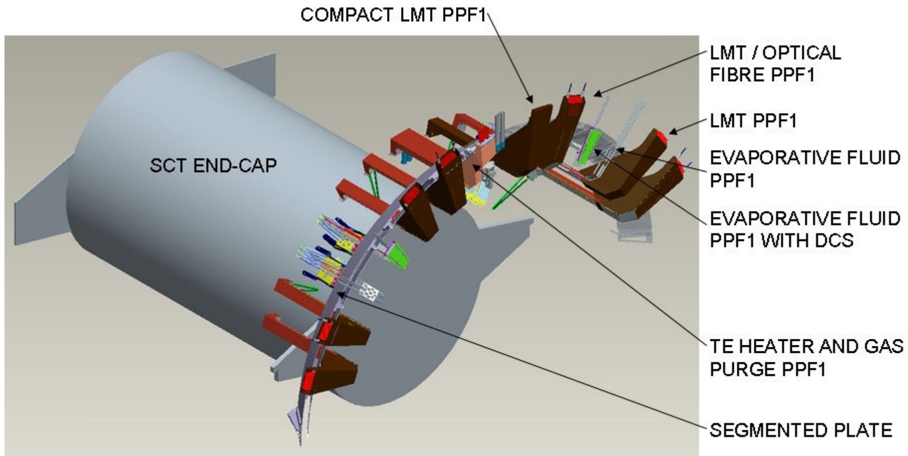


- Use Contact Sensor to work out when in place (up to Barrel)
- Both End-caps make contact 5 mm before nominal – one End-cap 3 mm too long

Services & Patch Panels (PPF1)



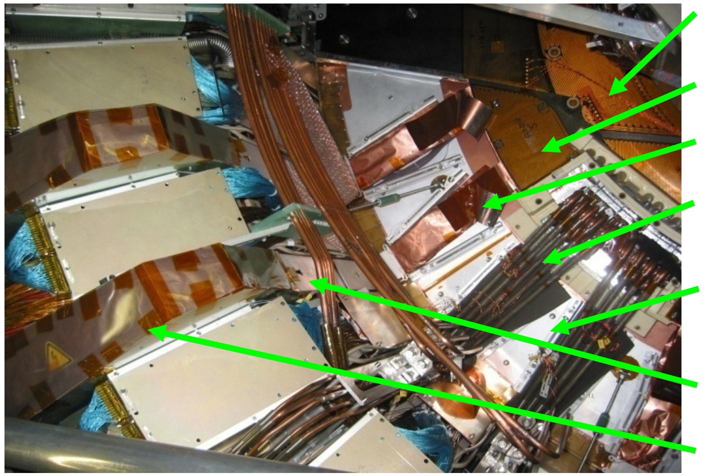
SCT | SCT Services in front of TRT | ID Patch Panels



- Service lengths carefully calculated to avoid deficit/excess
- Cable trays added
- Patch panels at end of Ecal Cryostat

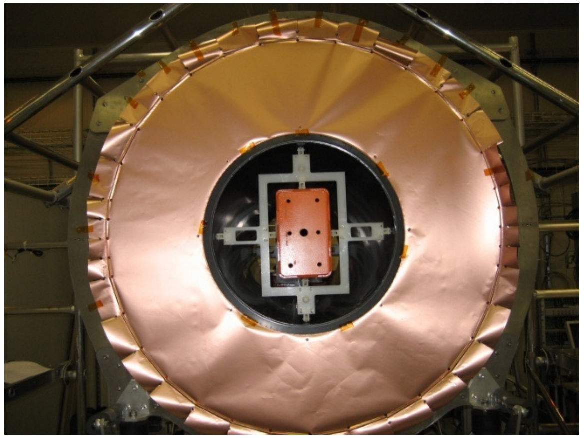
Cooling System

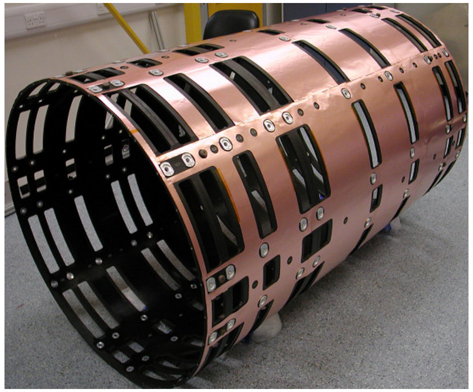
- C_3F_8 liquid enters SCT at room temp
- Leaves as vapour/liquid at around –20 °C
- Heat Exchanger to heat/cooling entering/leaving C_3F_8
- Heat Exchangers occupy space foreseen for cancelled TRT C-wheels
- Must boil off excess fluid, else will cause condensation on un-insulated pipes
- Heaters have been cause of many problems

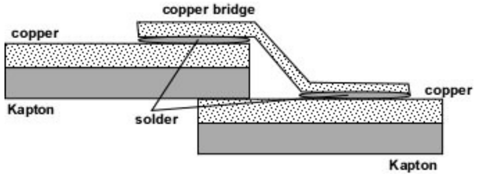


Grounding & Shielding

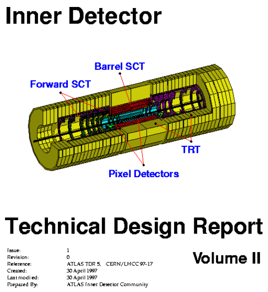
- Can be a make-or-break factor
- Careful consideration:
  Module, Disk, End-cap, Services, Cable Trays, ID, ATLAS
- Solid connections (<< 0.2 Ω) & insulation (> 1 MΩ)
- Avoid apertures > 1 cm × 10 cm where possible
- Use Alochrome 1200 & Fingerstock
- Make measurements before/after insertion into TRT & ATLAS







Timelines

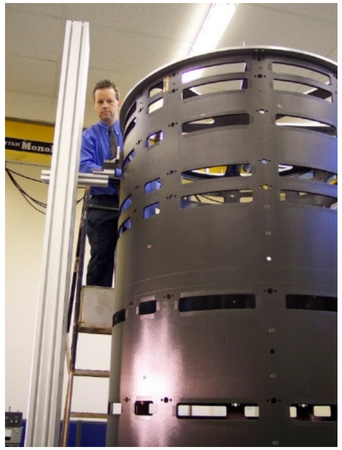

Inner Detector

Barrel SCT
Forward SCT
TRT
Pixel Detectors

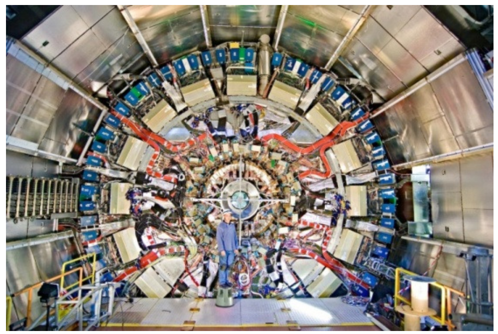
Technical Design Report

Volume II

Issue:	1
Revision:	0
Reference:	ATLAS TDR 5, CERN/LHCC 97-17
Created:	30 April 1997
Last modied:	30 April 1997
Prepared By:	ATLAS Inner Detector Community



- Apr 97 ID TDR
- Nov 01 EC FDR
  - Nov 01 Start Tendering process for Support Structures
  - Sep 02 Work Starts on Support Structures
  - Jul 04 Support Structures completed
- Sep 03 Disc Services PRR
- Jan 05 TE PRR
- Feb 06 EC-C Transported from Liverpool to CERN
- Jun 07 EC-A Inserted in ATLAS
- Feb 08 End-caps signed off; first Cosmic



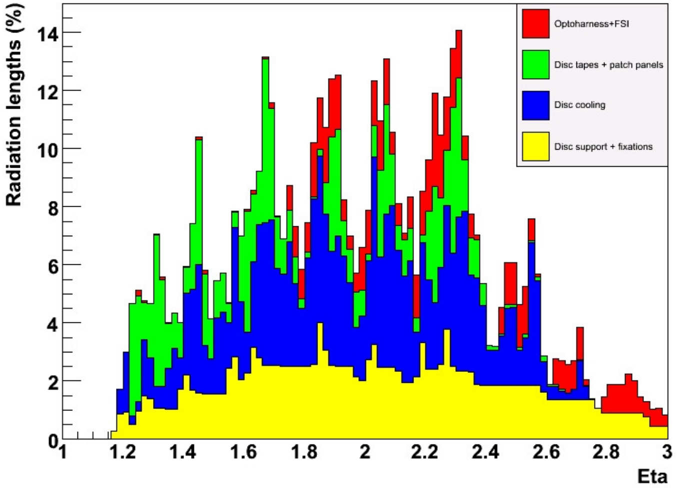
Mass

- Target for error is 1% – more critical at lower radii (tracking volume)
- Very careful bottom-up estimates of component masses
- Disk (without Modules) correct to 1.4%
- Mass supported by Front & Rear Supports is 178 kg, cf initial design estimate of 168 kg
- Difference between two End-caps (some +'s and –'s) is < 1 kg
- Attempt to weigh SCT (inside TRT) was inconclusive

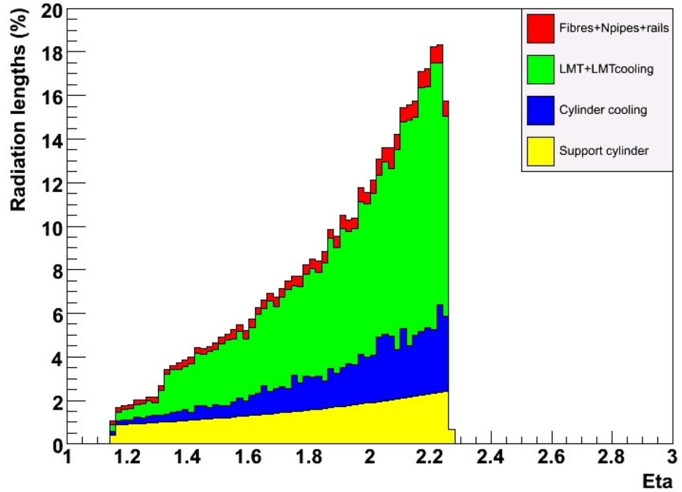
Component	**Mass (kg)**
Modules	24
Disks	33
Support Cylinder, Services & OTE	57
Other Support Structures	23
Rest of Services	88
PPF1 Patch Panels	35
Total	**259**

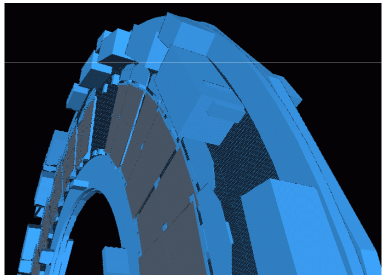
Radiation Lengths

Disk

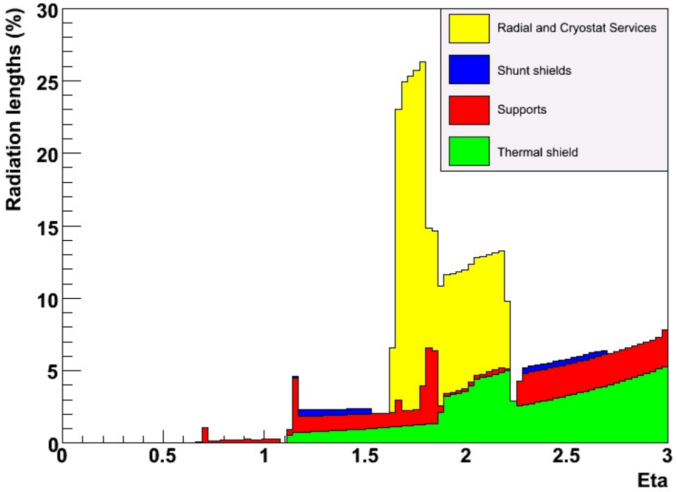


Cylinder & Services

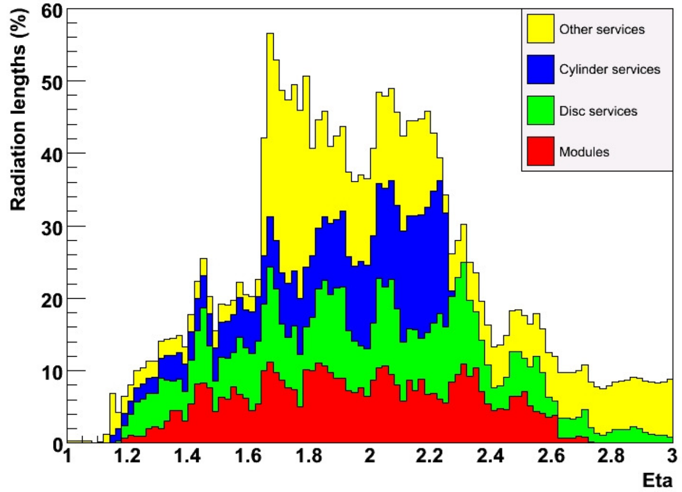




Other Services etc



Total (except PPF1)



RAL Contributions

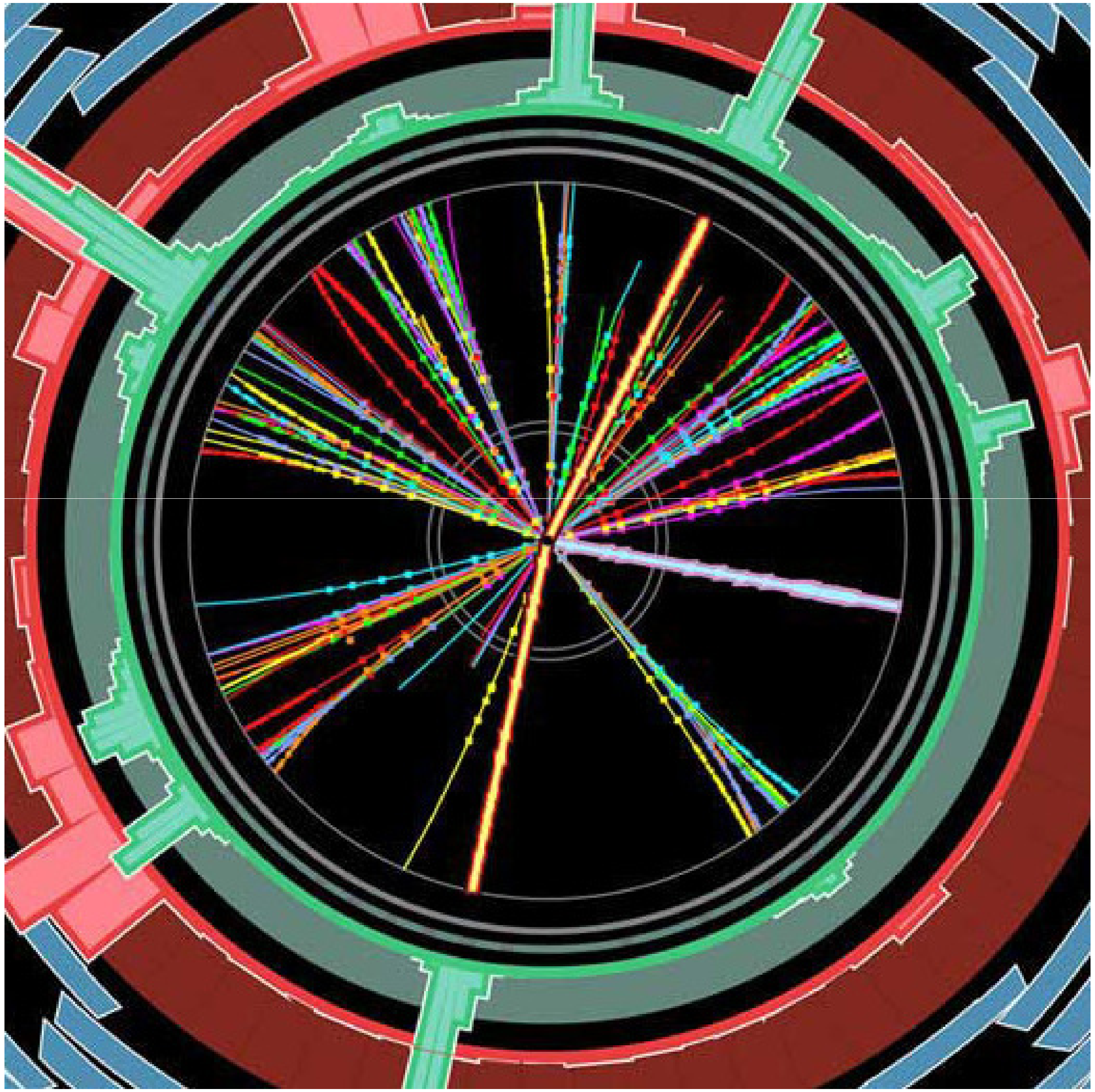
Barrel:

- 600 Modules
- On-Cylinder Cooling Circuits
- Services $\rightarrow$ Cylinders
- Thermal Enclosure design & manufacture
- Mass

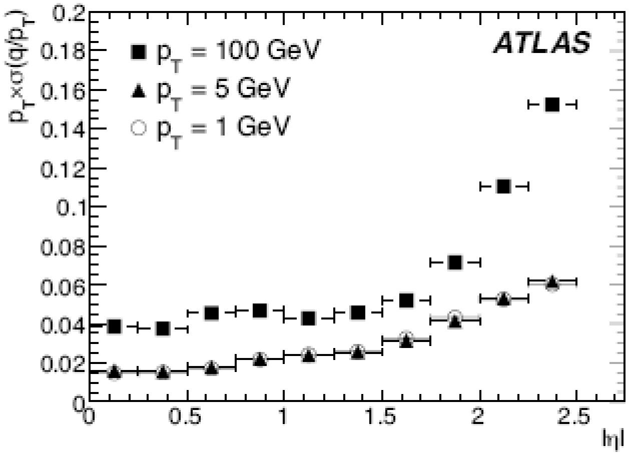
End-cap:

- On-Disk Cooling Circuits
- Services $\rightarrow$ 9 Disks
- Support Structures design & procurement
- Thermal Enclosure design
- UK Transportation & Insurance
- Off-Disk Cooling Circuits, Services routing & Patch Panels
- Mass

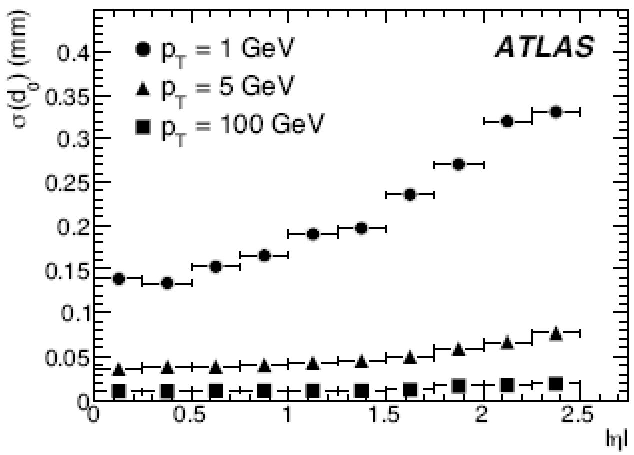
Tracking Performance



Track Parameter Resolutions



Momentum resolution
$p_T \times \sigma(1/p_T)$



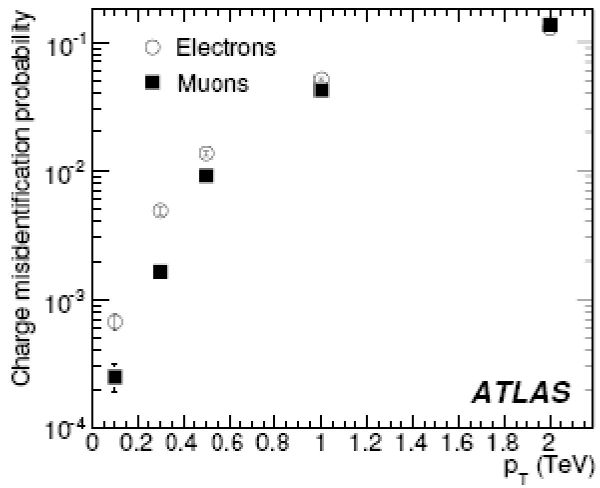
Impact parameter resolution
$\sigma(d_0)$

Barrel:

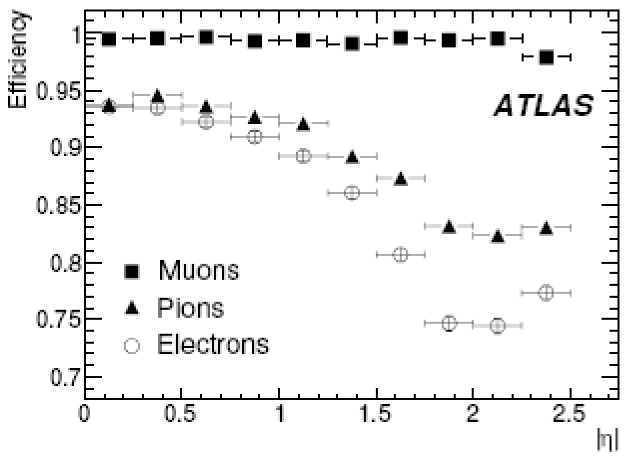
$\sigma(1/p_T)$ = 0.34 × (1⊕44 GeV/p_T) TeV^{-1}

$\sigma(d_0)$ = 10 × (1⊕14 GeV/p_T) μm

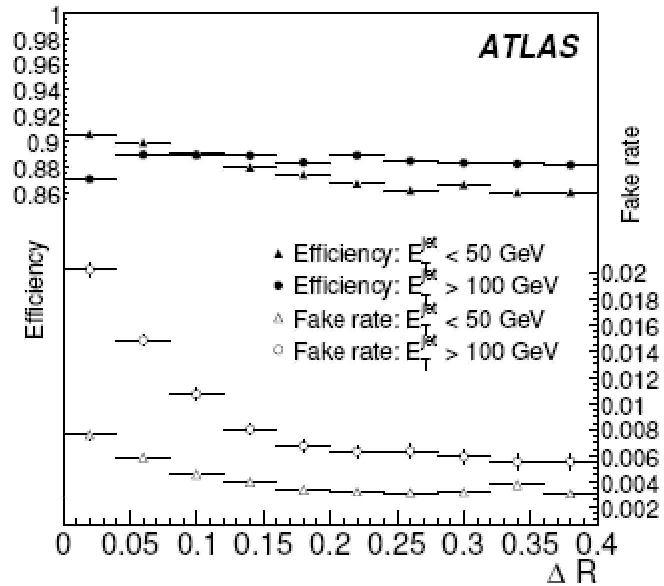
Charge mis-id probability



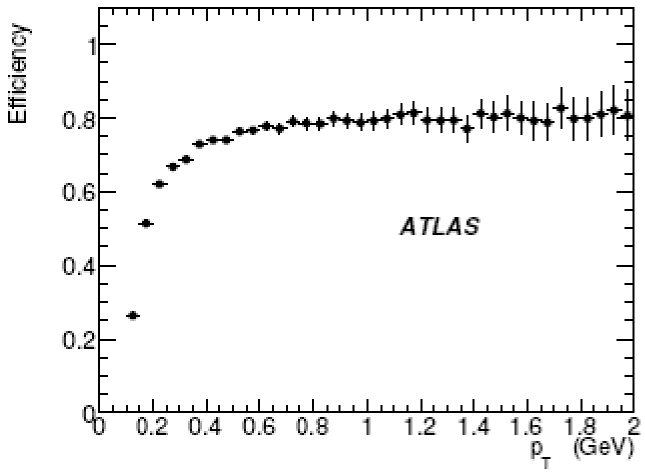
Reconstruction Efficiency



5 GeV μ, π, e

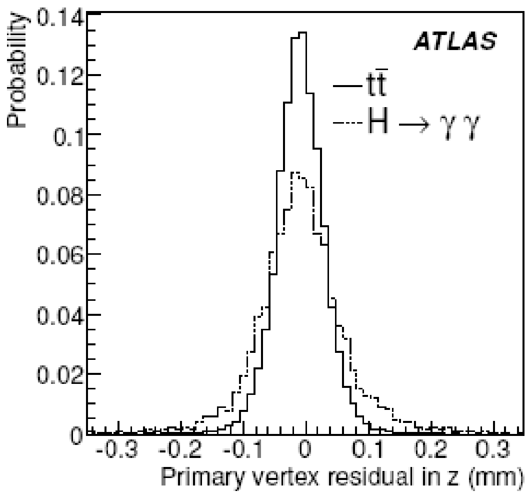


Tracks in b-jet from ttbar events, as function of distance from core of jet



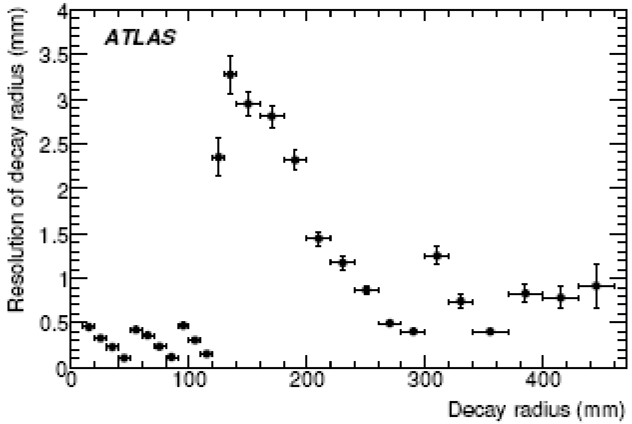
Tracks in Min Bias events

Vertex Reconstruction



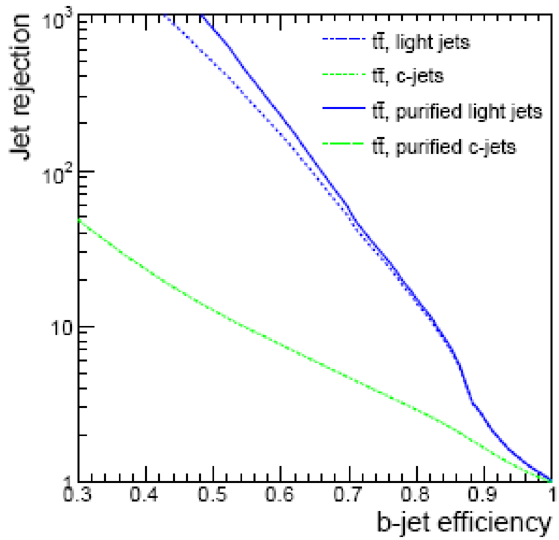
Z vertex resolution

40 µm (ttbar), 70 µm (Higgs)

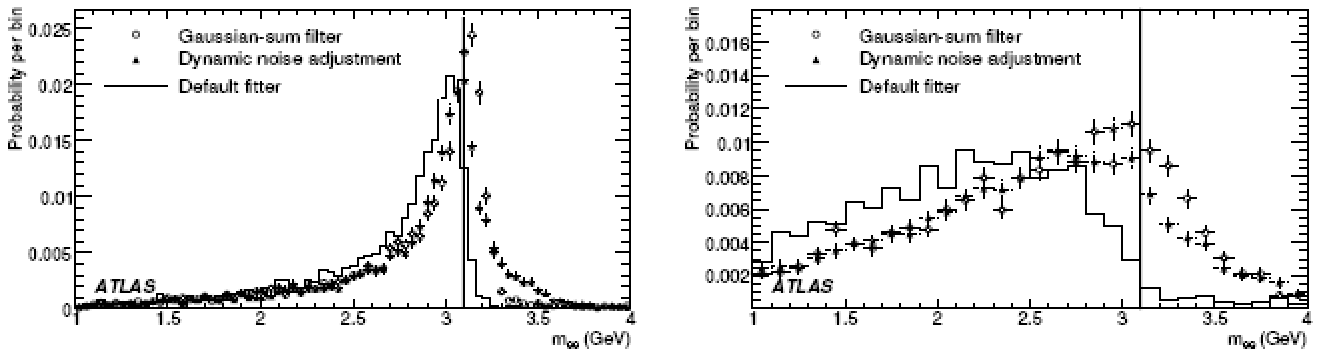


Radial resolution for K_s decays

B-tagging in ttbar events

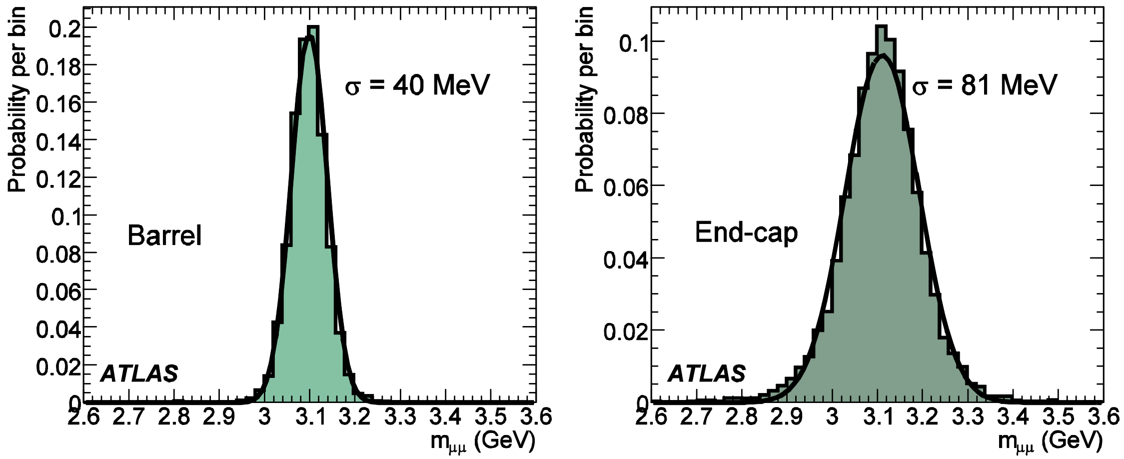


Electrons & Conversion Photons

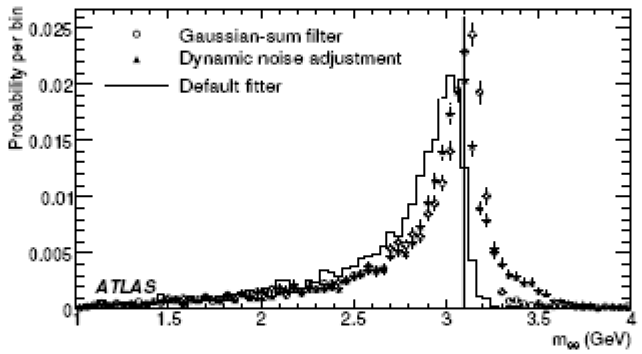


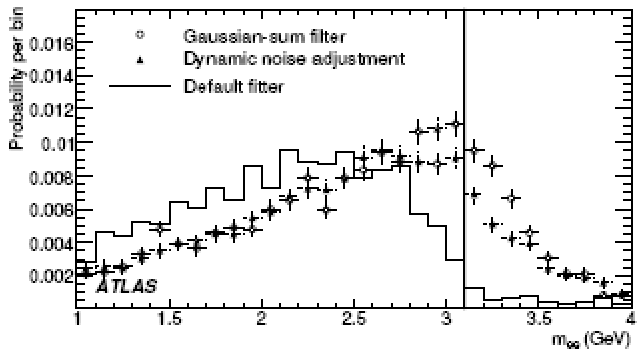
J/ψ mass resolution in Barrel (left) & End-cap (right)

Corresponding plots for Muons



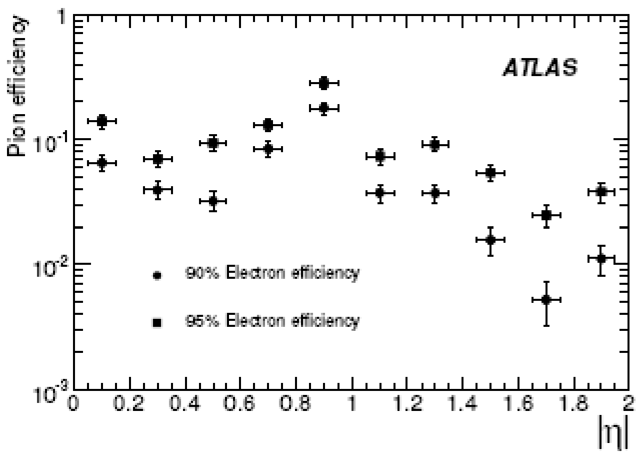
Electrons & Conversion Photons



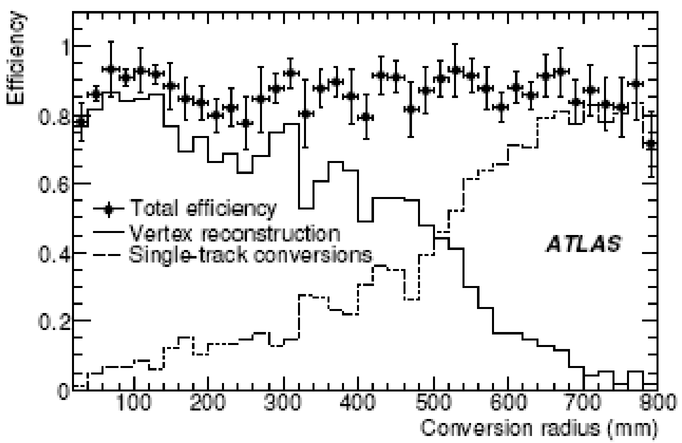


J/ψ mass resolution in Barrel (left) & End-cap (right)

Pion rejection in TRT



Conversion identification



Status

- ATLAS was ready for Collisions on Sunday 21 Sep, but ... ☹
- I am not aware of any serious problems with any of subdetectors

Inner Detector

TRT

- Some dead HV cards

Pixels

- 11 (4) dead (problematic) modules
- 36 modules unusable on Disks due to problems with 3 cooling loops
- Currently, can operate 95% of Pixels – hope to recover even more

SCT

- Leak rates of N_2 exceed spec, but are tolerable: dry-out achieved, so operate with lower overpressure (Barrel SCT has large leak rate)
- One Module Cooling Circuit on Disk 9 has large leak of C_3F_8 and is inoperable – loss of 13 Modules ... not terrible
- One Module Cooling Circuit on Disk 1 has Heater problem and is currently inoperable – loss of 23 Modules ... not great – now fixed

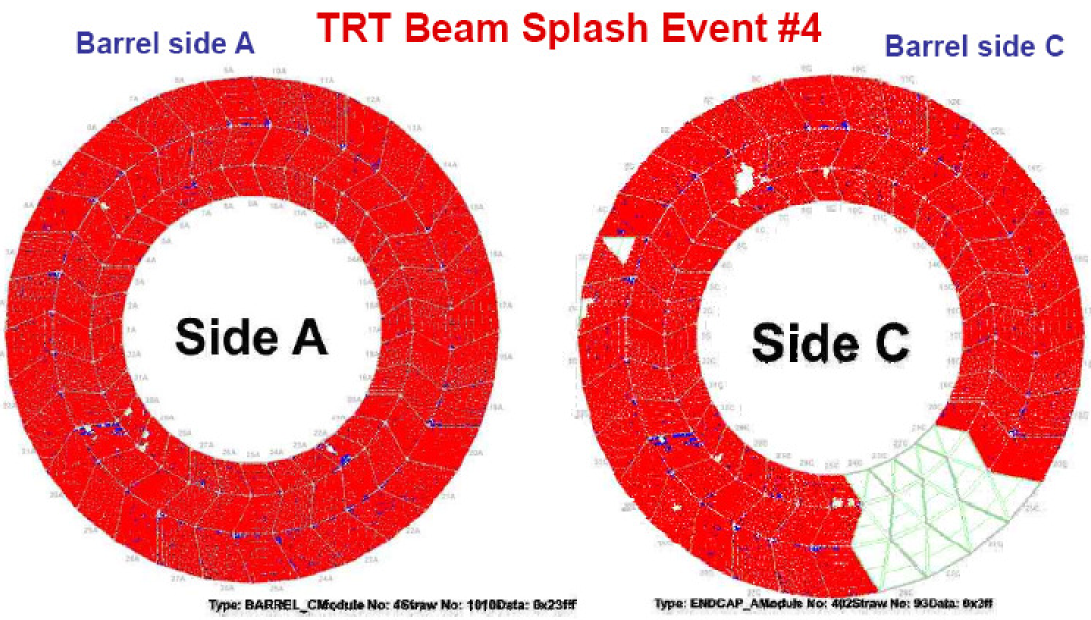
SCT Summary

	Barrel	End-cap A	End-cap C
Total Num Modules	2112	988	988
Modules not functional	3	0	1
Modules not cooled (2008)	0	0	36→13
Dead Strips (%)	0.2	0.3	0.3
Chips lost	13	0	0
Functional channels (%)	99.6	99.7	96.0→98.3

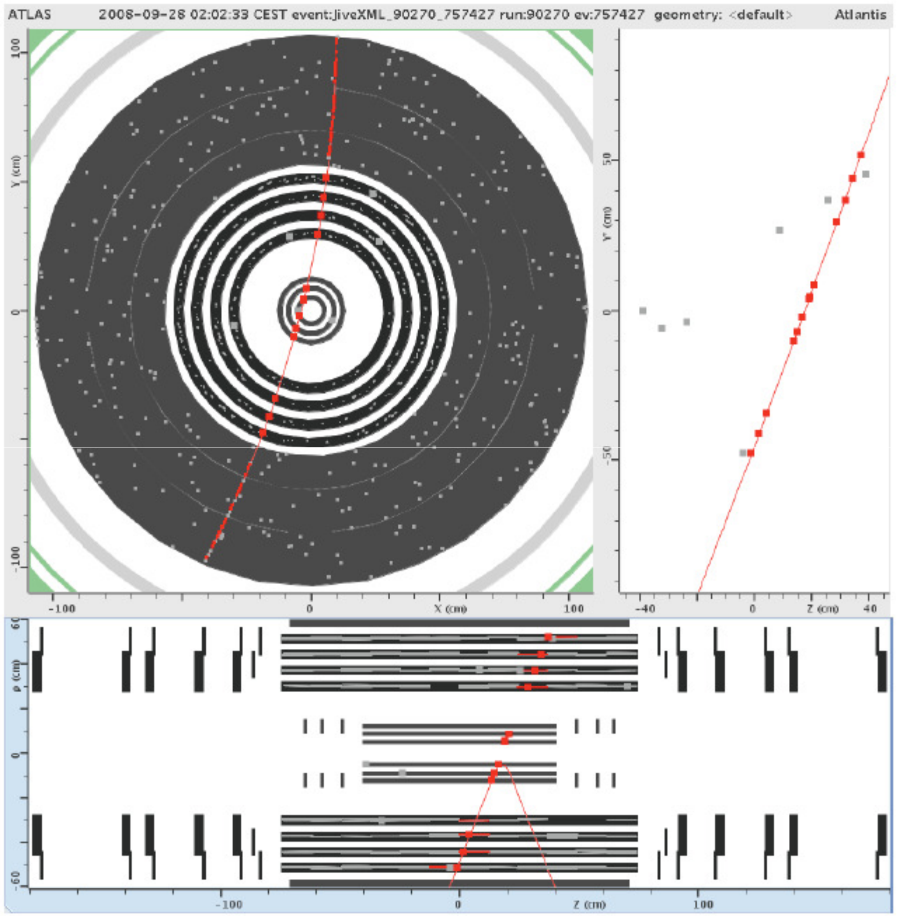
Inner Detector Commissioning

Huge amount of testing, more recently with:

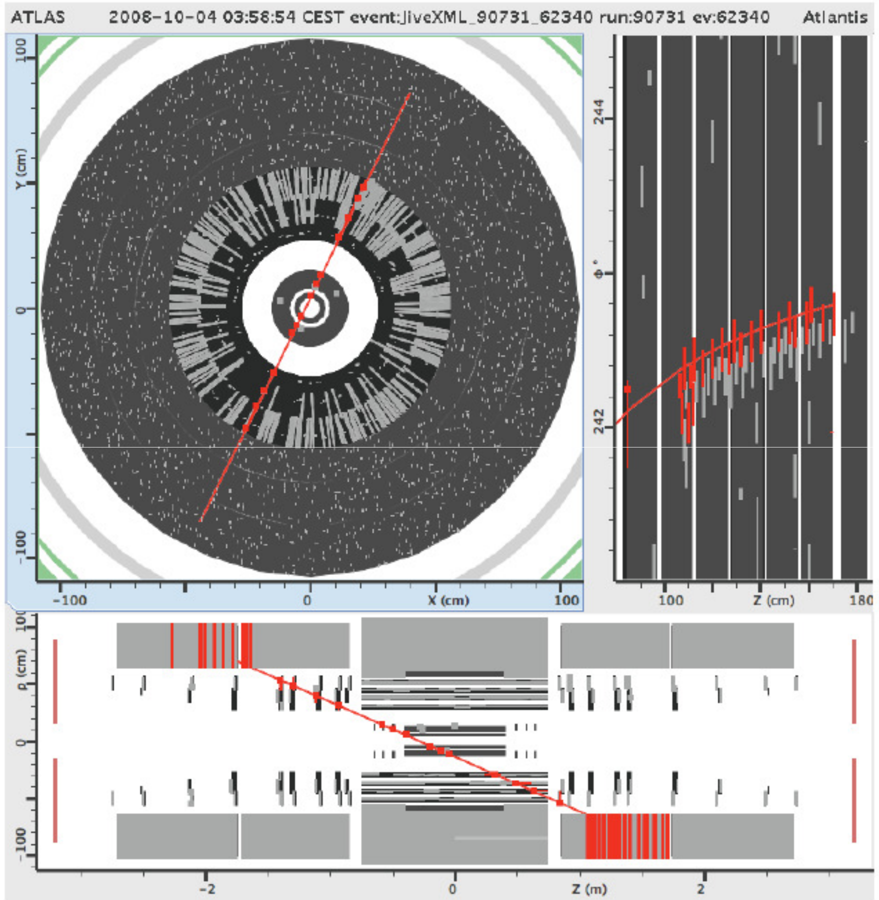
- Cosmics – very useful for Alignment
- Beam "splash" – very useful for timing:
  "Unique opportunity to time whole the detector at once in one event!
  This saves may be months of work."
- Beam-gas – nice for Software Reconstruction, but not many events



Cosmics

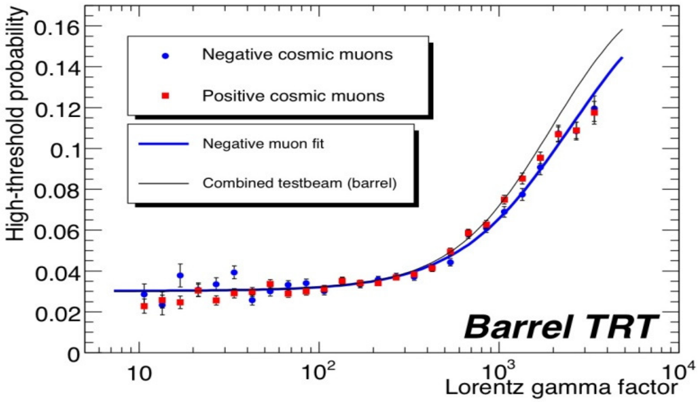


TRT, SCT & Pix Barrels

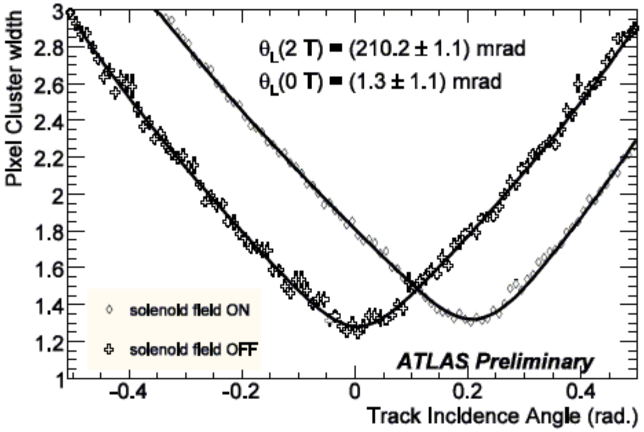


SCT End-cap

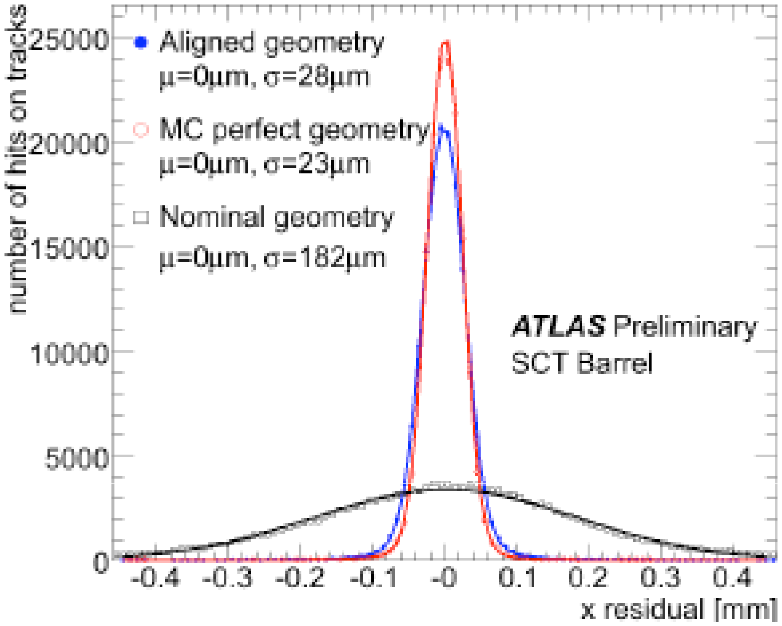
Cosmics: Measurements



TRT HT Probability

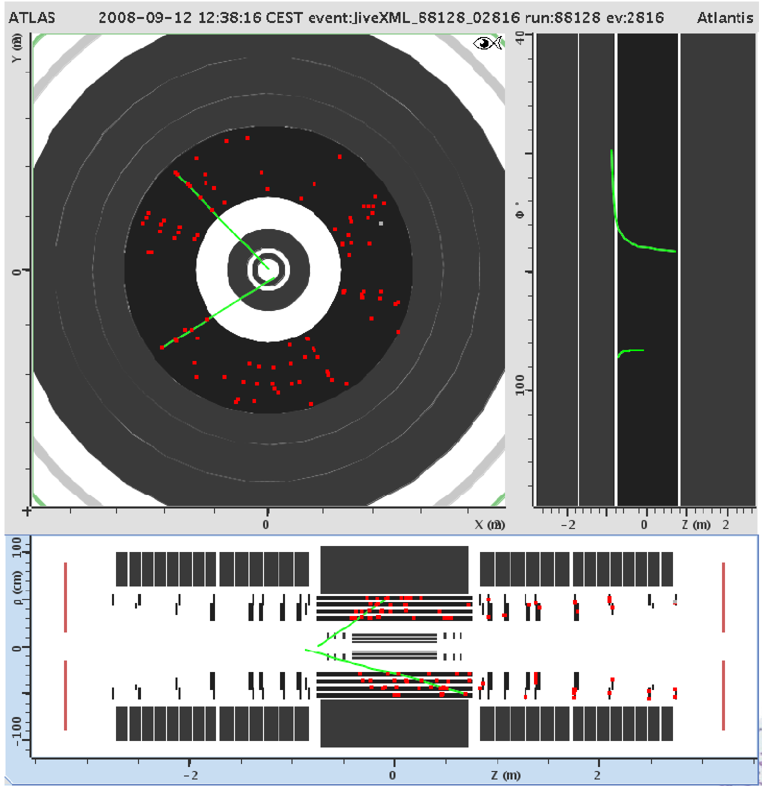


Pixel Lorentz angle

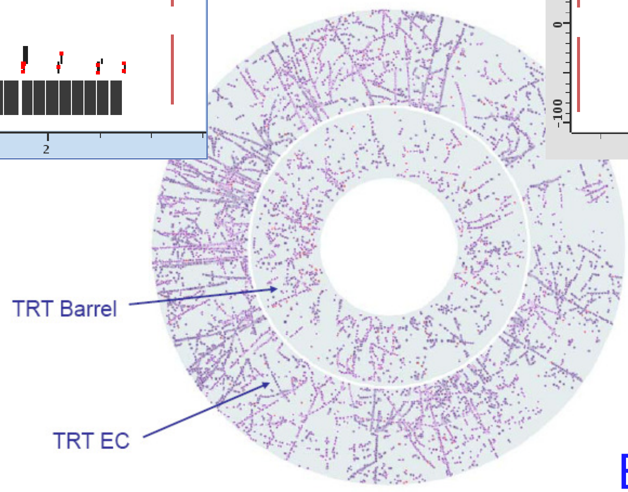


SCT Alignment

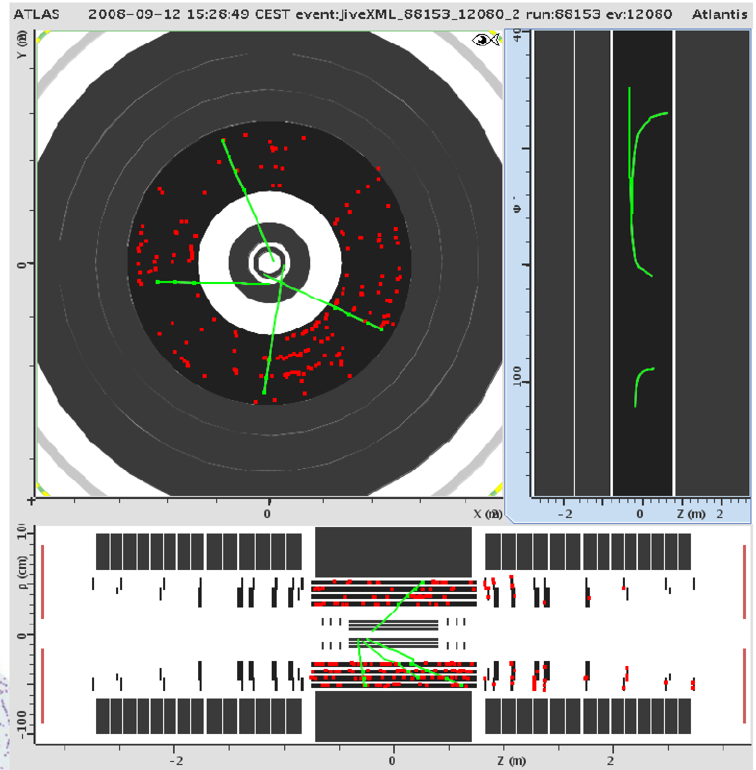
Single Beam



Beam-gas in SCT



Beam-gas in TRT



Interaction in Beam-pipe

Conclusions

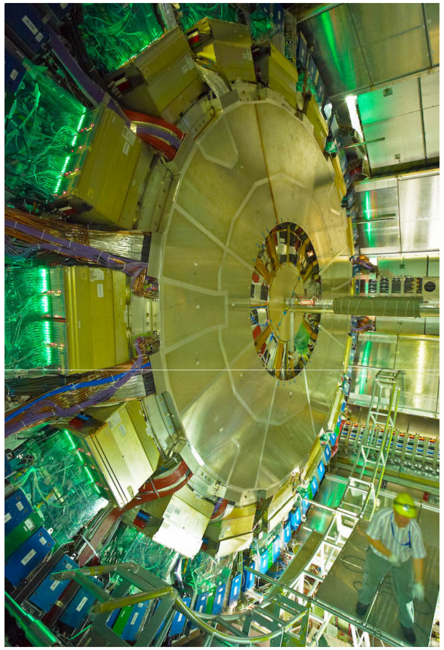
Two ATLAS SCT End-caps have been constructed, meeting almost all of the specs.

The project has taken ~15 years, with ~6 years required for Construction and Assembly.

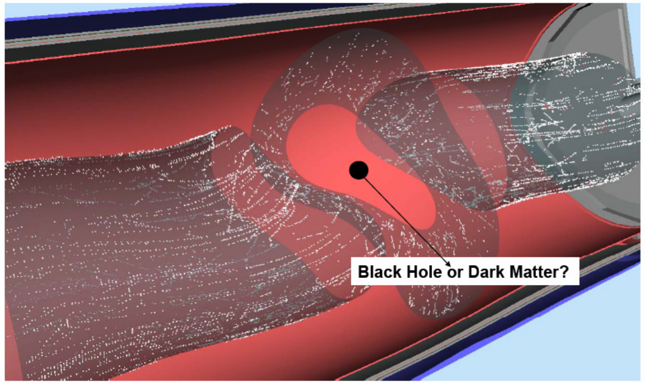
~200 people have worked on the End-caps.

The insured value of the hardware was 9 MCHF for each End-cap.

Apart from one two Cooling Circuit problems, the End-caps are close to fully functional.

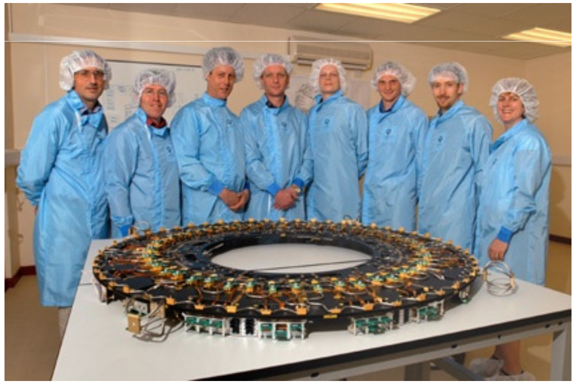


The ATLAS Inner Detector is ready to receive LHC collisions and the Software is in place to reconstruct the First Data.



Acknowledgments

- Work of many institutes: Modules, Services
- Engineering especially: Liverpool, Nikhef, RAL, CERN
- Underlying Paper benefitted from input from:



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Graham Rolfe
John Spencer (SSTD)
Dave Wilshire