Science & Technology Facilities Council
Technology

Helical Undulator Status and 2009 Progress

Dr Owen Taylor

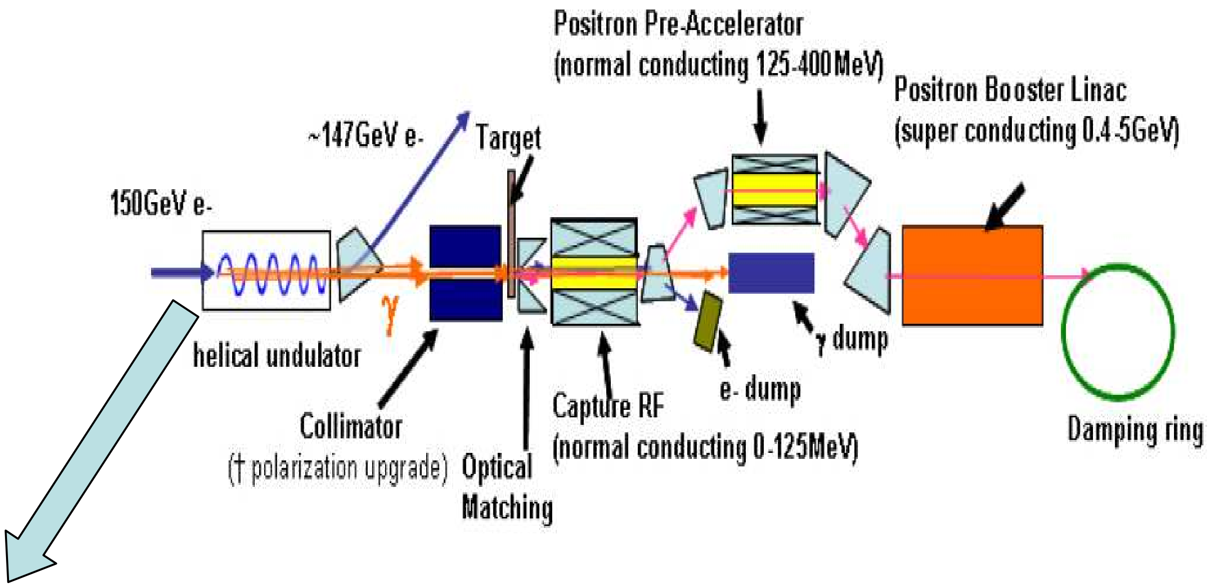
On behalf of the Helical collaboration

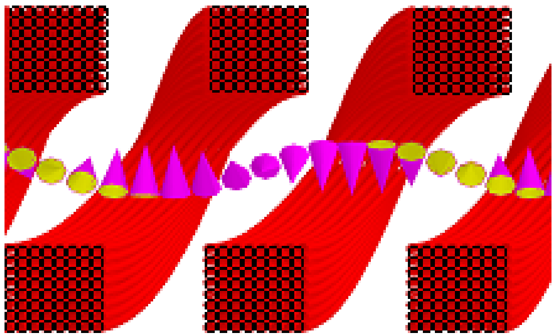
Collaboration members
ASTEC: J.A. Clarke, O.B. Malyshev, D.J. Scott, B. Todd, N Ryder
RAL: E. Baynham, T. Bradshaw, J. Rochford, O. Taylor, A Brummit, G Burton, C Dabinett, S. Carr, A Lintern
University of Liverpool: I.R. Bailey, J.B. Dainton, P. Cooke, T. Greenshaw, L. Malysheva
DESY: D.P. Barber
University of Durham: G.A. Moortgat-Pick
Argonne: Y. Ivansuhenkov

Scope of Presentation

- Introduction
    - Undulator requirements and specification
    - 4 metre module prototype manufactured
- Recap
    - Cryogenic leak
    - Magnet test
- Magnet alignment
- Excessive heat loads
    - Effects of heat load
    - Attempts to fix heat load
- Future plans
    - Show magnet working in cryostat with re-condensation
    - Investigate beam heating effects

ILC requirements





Undulator :

To produce a circularly polarised positron beam

•High energy electron beam through helical undulator

•emission of polarised photons.

•Downstream high Z target, pair production

•Positrons stripped off to produce polarised positron beam.

Intro: Magnet Specification

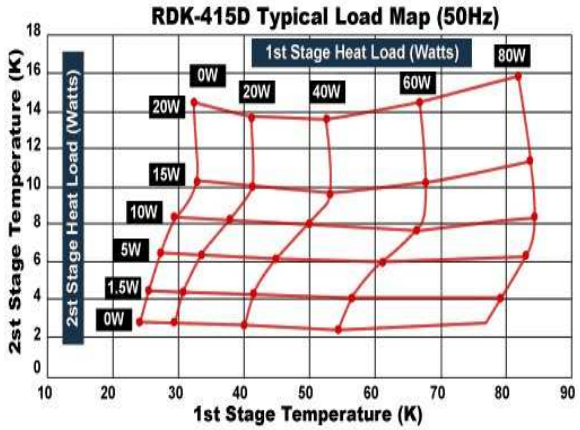
Following a pretty extensive **R&D programme** and **modelling study** the following specification was developed for the undulators:

Undulator Period		11.5 mm
Field on Axis		0.86 T
Peak field homogeneity		<1%
Winding bore		>6mm
Undulator Length		147 m
Nominal current		215A
Critical current		~270A
Manufacturing tolerances		
	winding concentricity	20µm
	winding tolerances	100µm
	straightness	100µm
NbTi wire Cu:Sc ratio		0.9
Winding block		9 layers
		7 wire ribbon

This defines the shortest period undulator we could build with a realistic operating margin.

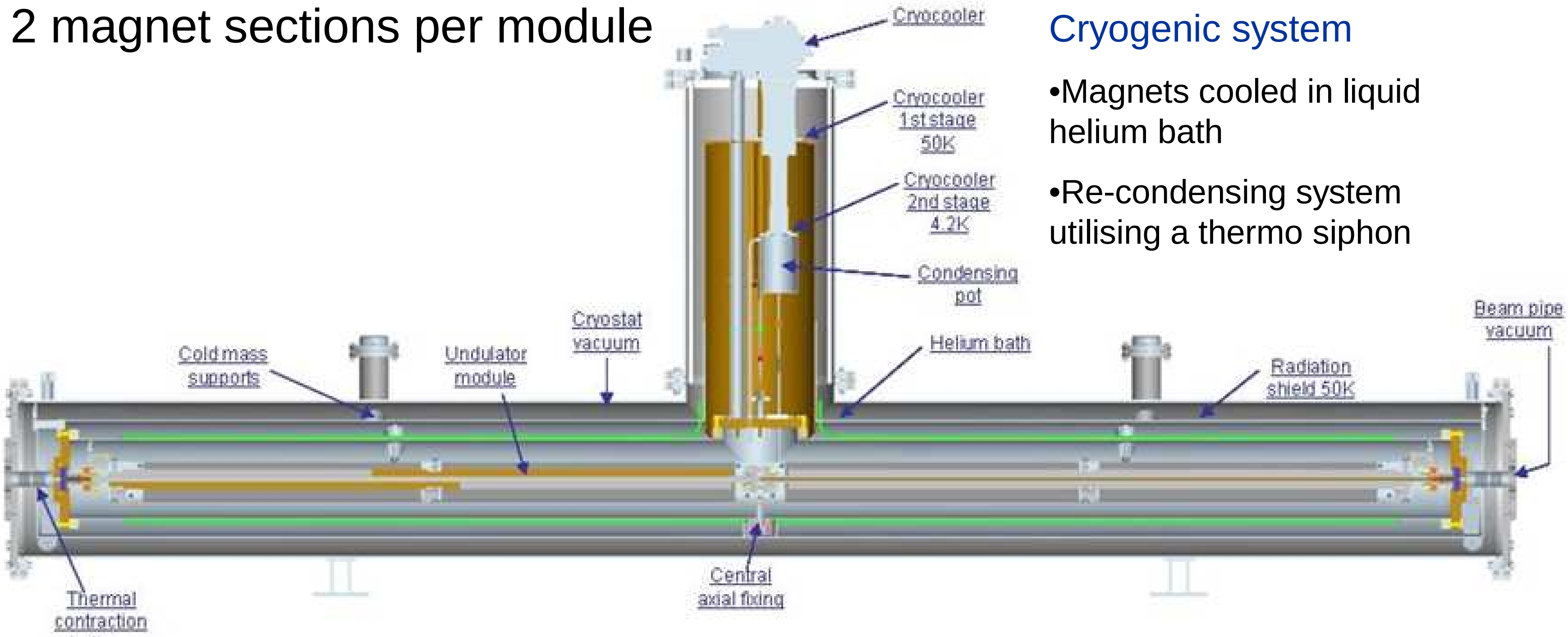
Intro: 4 m Prototype

- 150 m of undulator
- Module length
  - Vacuum considerations < 4 m
  - Collimation < 4 m
  - Magnet R&D 2 m section realistic
- Minimise number of modules
  - 2 magnet sections per module



Cryogenic system

- Magnets cooled in liquid helium bath
- Re-condensing system utilising a thermo siphon

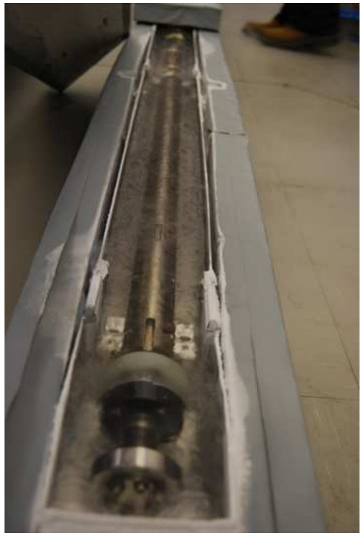


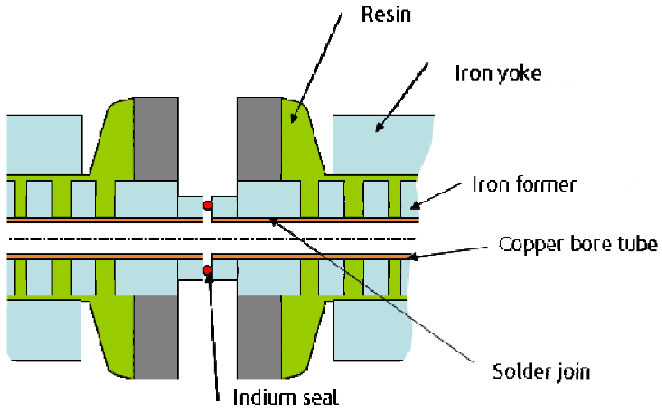
Recap: Cryogenic Leak

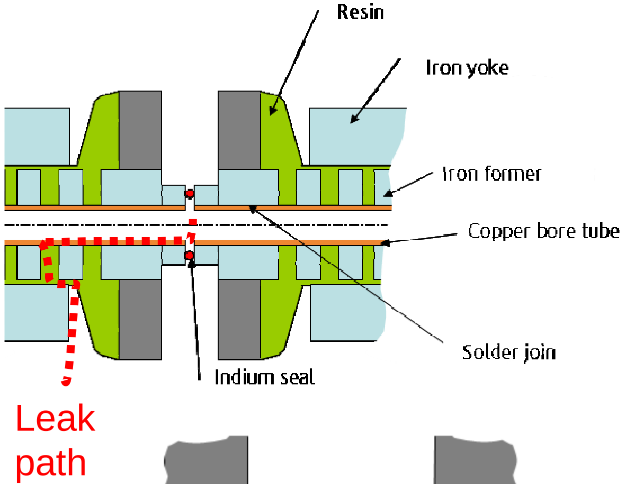
Created a large open Liquid nitrogen bath

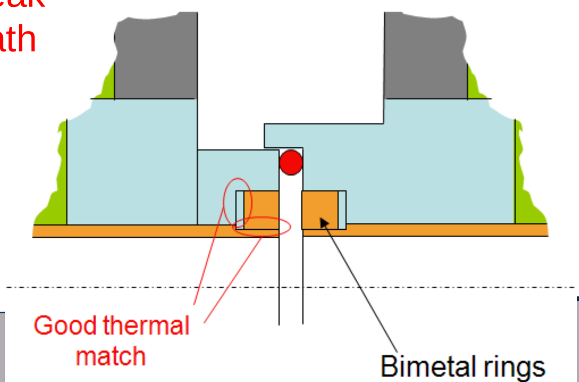
Found a leak at the indium seal between magnets

Fixed this by modifying the clamp arrangement









More worryingly - leak through the magnet structure

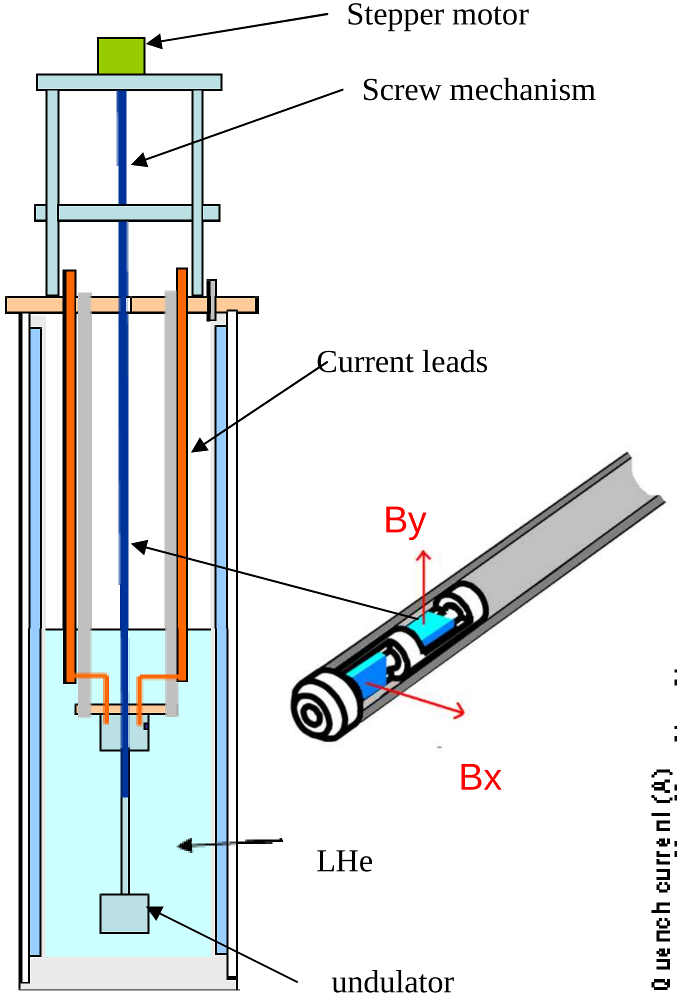
Leak fix with a silver soldered copper-iron Bi metal ring

Implemented this solution on some test pieces and it has survived 20 thermal cycles.

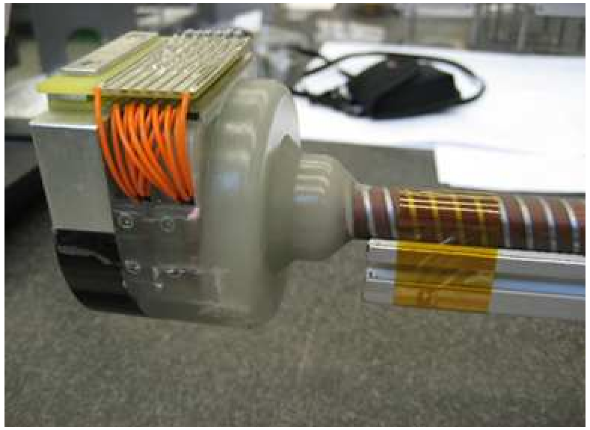
Each magnet joint then thermally cycled and tested 10+ times

Final leak check: <1e-12mb/ls in the beam tube vessel at temps <77K

Recap: Magnet Testing

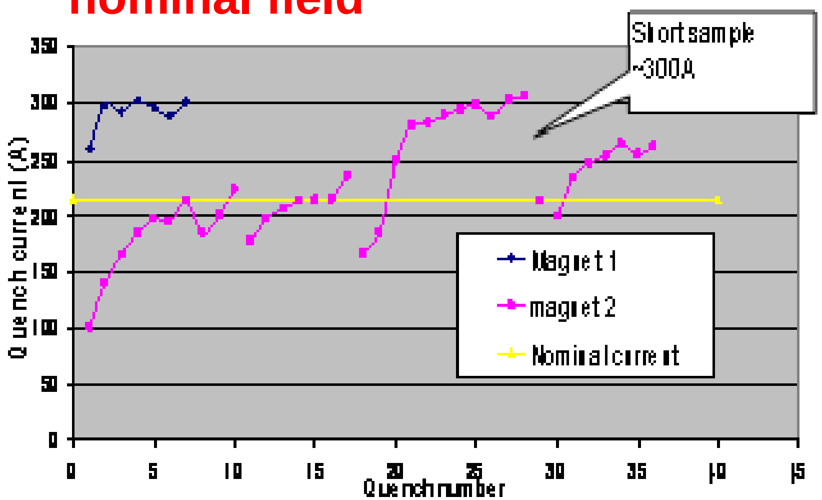


Field maps along the length of the undulator



Magnet rigidity – iron yoke

Quench testing **both magnets deliver nominal field**



Active alignment system

Magnet straightness

•Prototype alignment

+/-200 µm in X

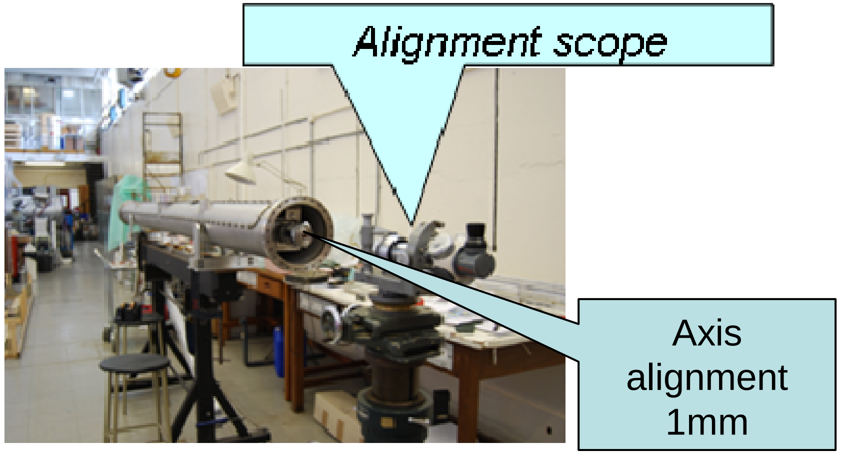
+/-170 µm in Y

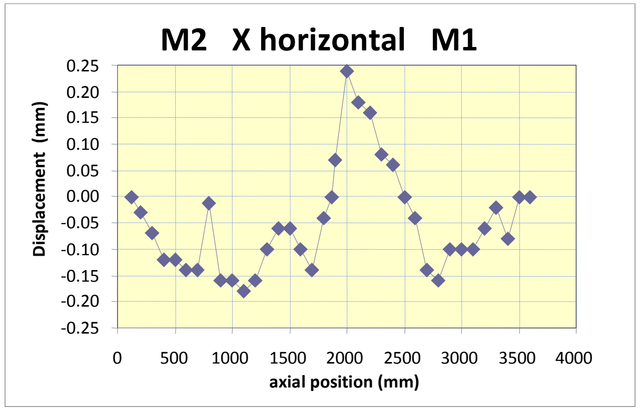
•Not adequate to deliver a straightness of +/-50 µm

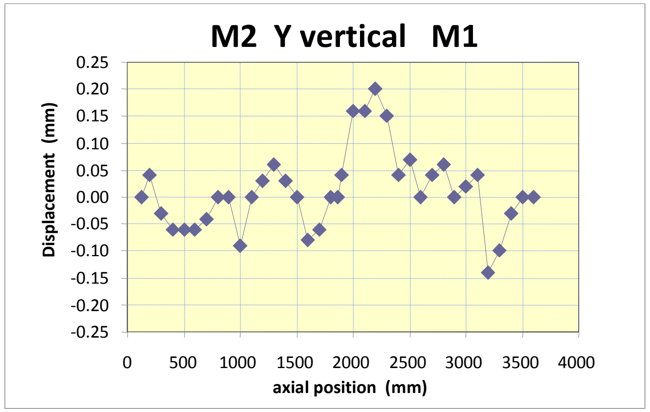
•Developed an active alignment Yoke

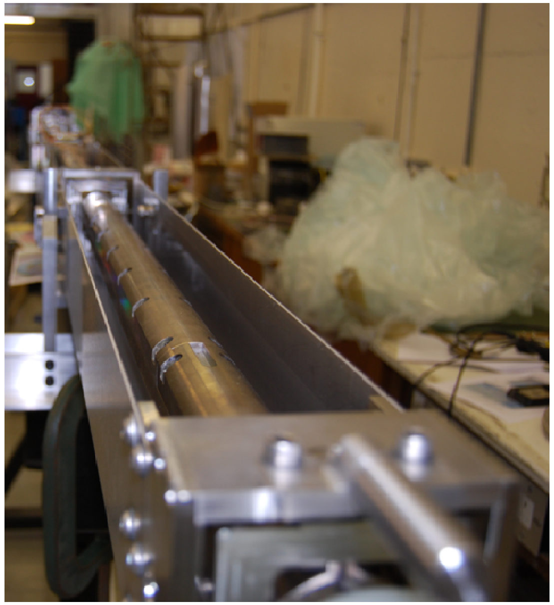
•Allows the straightness of the magnet to be aligned to better than 50 µm.

•In principle the proto type can be retrofitted with this system at a later date.









Active alignment system

Active alignment system

Relies on the flexibility of the magnet

Over sized yoke aperture for the magnet allowing 100 μm clearance

Periodically placed adjustors allowing adjustment in X and Y

After adjustment actuators locked off, a small spring maintains alignment and takes up the thermal contraction when cold

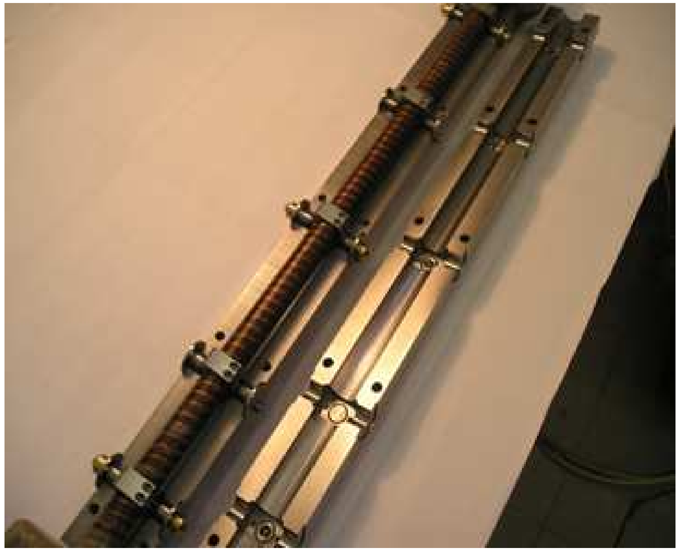
Small contact pads around the magnet to spread contact pressure and avoid damage to winding

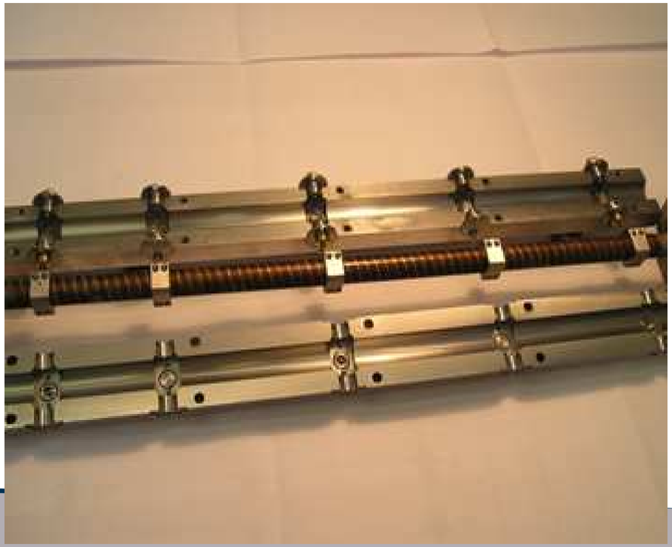
All components are magnetic steel to minimise any losses in the iron circuit

Manufactured 1/2 metre long test section

Getting some metrology data with this at the moment

Our initial tests shows we can position the magnet to within +/- 10 μm at the actuator point





Heat Load

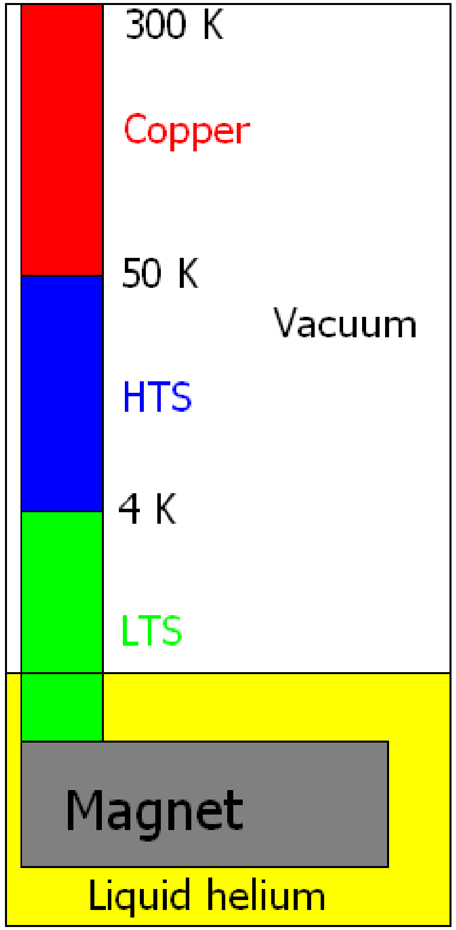
There has been an excessive heat load on the helium bath

- This has caused a large boil off of liquid helium – should be no boil off in re-condensing system
- Low temperature superconductor section of current lead too hot

There have been many attempts to identify and remove unwanted heat loads

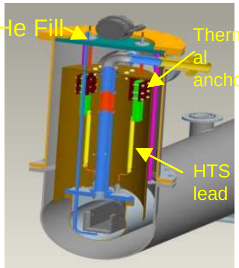
So far, these modifications have made little effect

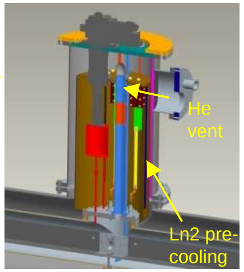
Current lead

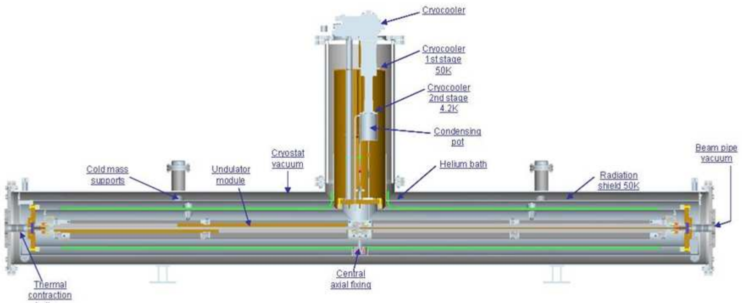


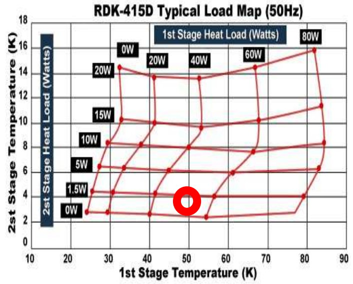
Science & Technology Facilities Council
Technology

Heat load audit









Cryogenic system

- Magnets cooled in liquid helium bath
- Re-condensing system with Sumitomo RDK4150
- Weak thermal link between bath and condenser
- Final stage charge system with liquid

Heat load inventory

- 50 W on rad shield
- 1 W helium bath

0.5 W contingency

Heat Loads

77K

Supports	Bellows	Current Leads			Radiation	Radiation turret
load 130 kg	id 0.01 m	number 4			diameter 0.3 m	diameter 0.3 m
1300 N	od 0.02 m	Q/lead 12			Length 4 m	Length 0.5 m
stress 30 Mpa	convolution 0.004 m	Lead opt 216			Area 3.77 m^2	Area 0.47 m^2
area 43.3 mm^2	L 0.03 m					
length 0.1 m	Leff 0.105 m				q 1 W/m^2	q 1 W/m^2
Int kdt 100 W/m/K	t 0.0005 m					
# supports 4	A 2.36E-05 m^2					
dia 3.71 mm^2	Int kdt 2800 W/m/K					
	# bellows 2					
Q 0.04 W	Q 1.26	Q 48			Q 3.77 W	Q 0.47 W
						total 53.5 W

4.5K

Supports	Bellows	Current Leads	feed thros	Joints turret	Radiation	Radiation turret
load 130 kg	id 0.01	number 4	rho 300K 1.6E-08	resistance 1E-07	diameter 0.2 m	diameter 0.2 m
1300 N	od 0.02	Q/lead 0.065	RRR 100	I 250	Length 4 m	Length 0.5 m
stress 10 Mpa	convolution 0.004	Lead 500	rho 4K 1.6E-10		Area 2.51 m^2	Area 0.31 m^2
area 130 mm^2	L 0.03		rod dia 0.006 m			
length 0.25 m	Leff 0.105 m		rod length 0.04 m		q 0.2 W/m^2	q 0.2 W/m^2
Int kdt 110 W/m/K	t 0.0005		R 2.3E-07 Ohm			
# supports 4	A 2.36E-05 m^2		I 250 A			
dia 6.43 mm^2	Int kdt 300 W/m/K		number 4	number 8		
	# bellows 2					
Q 0.06 W	Q 0.13	Q 0.26	P 0.05659 W	P 0.05 W	Q 0.50 W	Q 0.06 W
						total 1.1 W

no intercept

April 2009 Cool Down

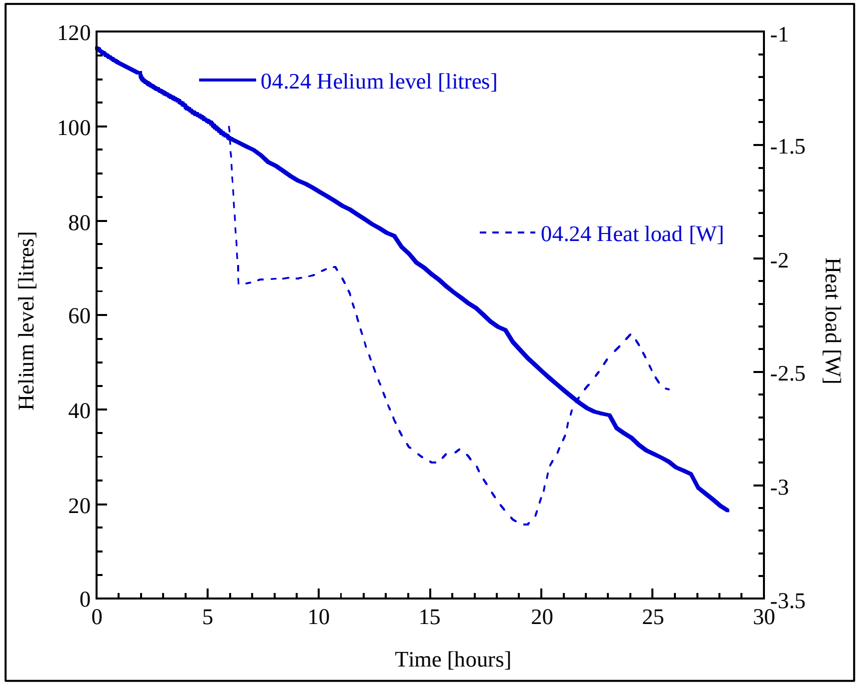
System cooled down in April 2009

2 big issues

- Large liquid helium boil off
- Low Temperature Superconductor (LTS) section of current lead suspected to be at 6 K, not 4 K
- LTS tail would have been normal, damage to tails of both magnets

Fixes

- Ensure HTS ends ~4.2 K
- Implement a shunt to protect LTS lead when normal
- Add some thermometry



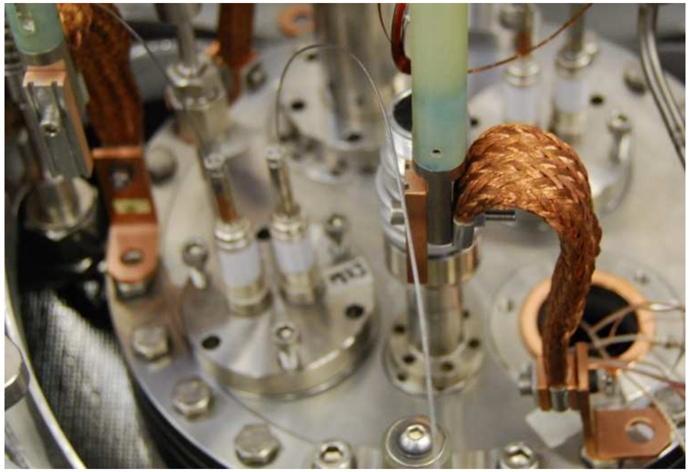
~2.5 W heat load!

If 1.5 W re-condensing is working, total heat load = 4 W

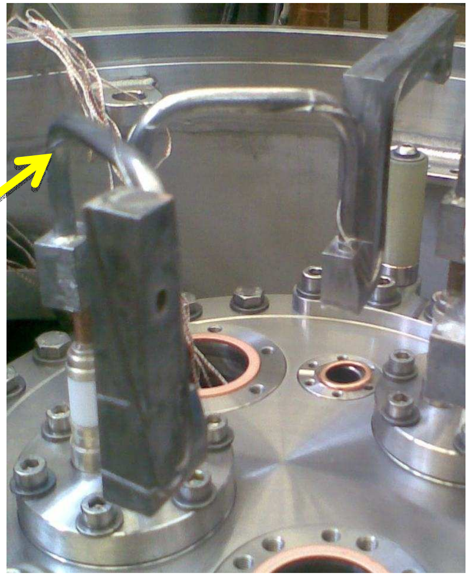
April 2009 - Copper shunts added to LTS cooling improved

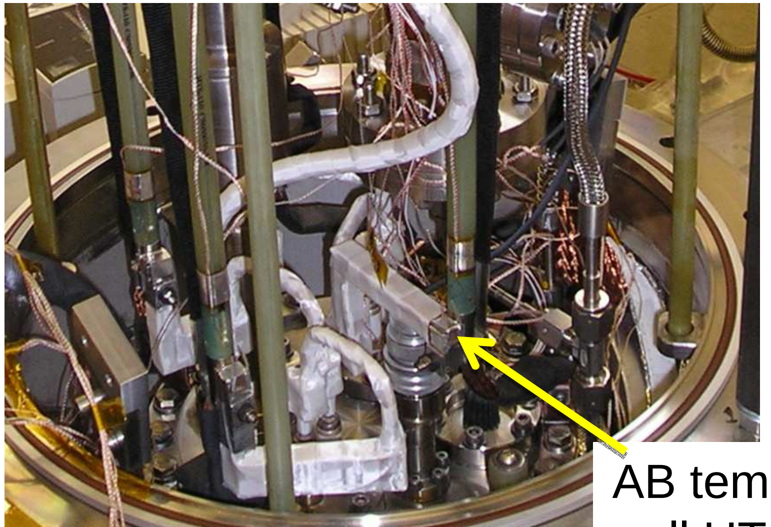
Before April 2009 cool down

- LTS straight from vacuum feed through to HTS
- HTS cooled by braid as shown



LTS cooling and shunt



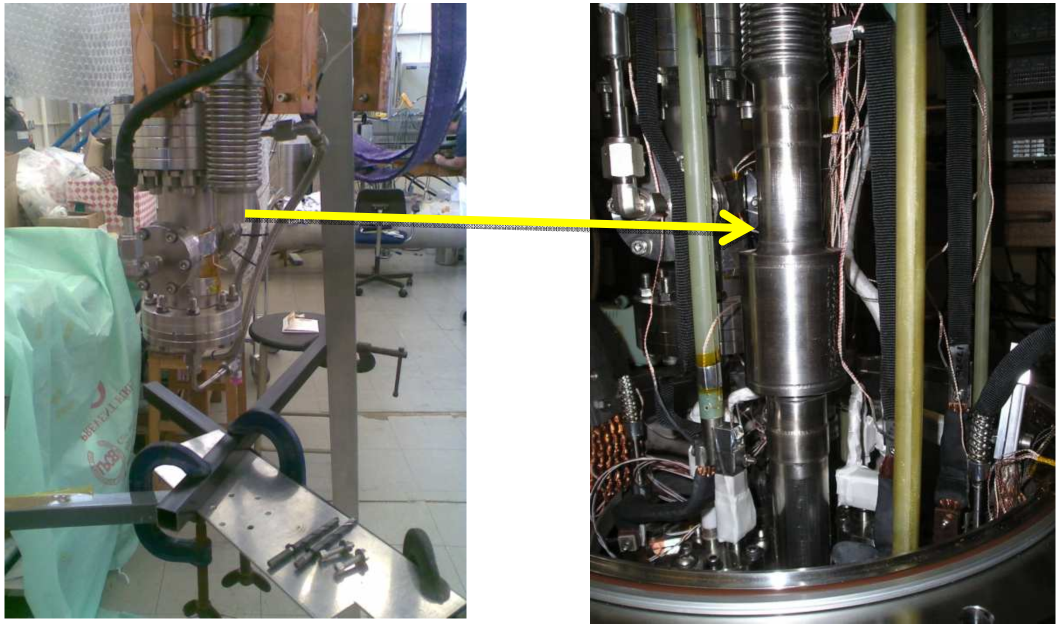


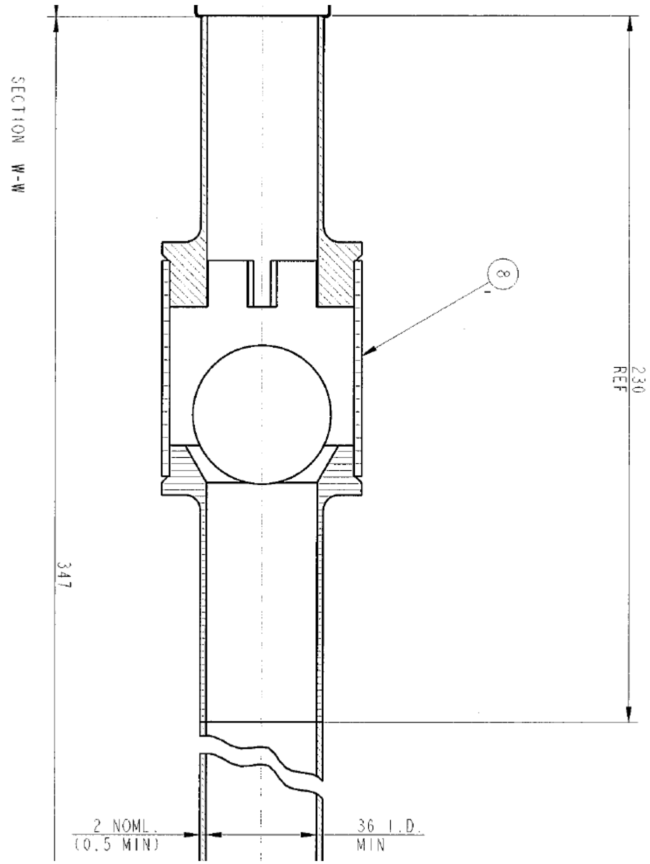
AB temperature sensor - all HTS 4K ends

June 2009 - Helium Vent pipe repair

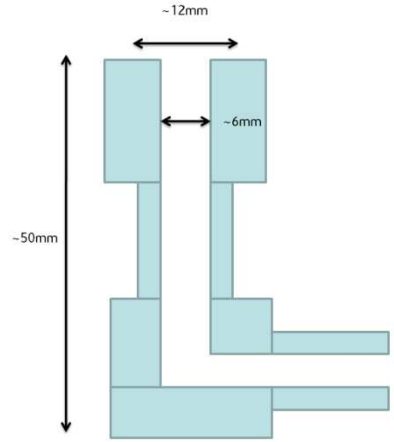
During re-build it was noticed that Helium vent pipe incorrectly manufactured

- The 'Anti-Oscillation Damper' (ATO) was fitted upside-down!
- Allows large convective path from 300 K into 4 K liquid
- This was cut out and re-welded

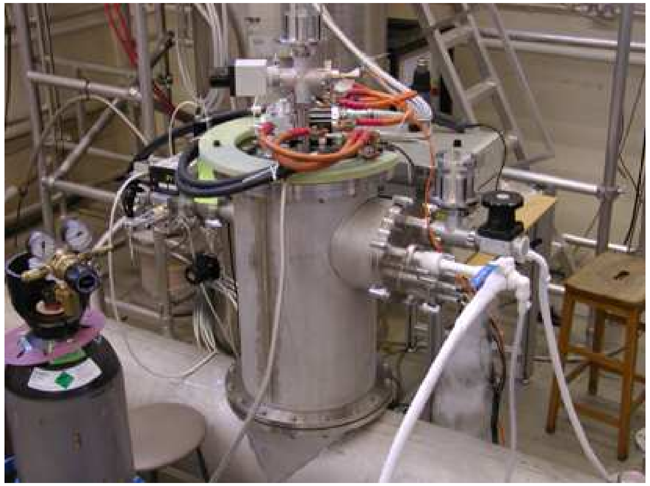




June 2009 - Liquid Nitrogen Pre-Cooling Lines Removed



Liquid n2 line	
Thigh	66
Tlow	4.2
Outer Diam	0.012
Inner Diam	0.006
Length	0.05
x-sect area	8.5E-05
Number	2
Total area	1.70E-04
Int Hi SS	232.640
Int lo SS	0.242
Difference	232.397
Load W	0.79
conduction intoplate	**0.79**



During the subsequent re-build it was decided to disconnect the nitrogen pre-cooling lines

- Could potentially add 0.8 W heat load

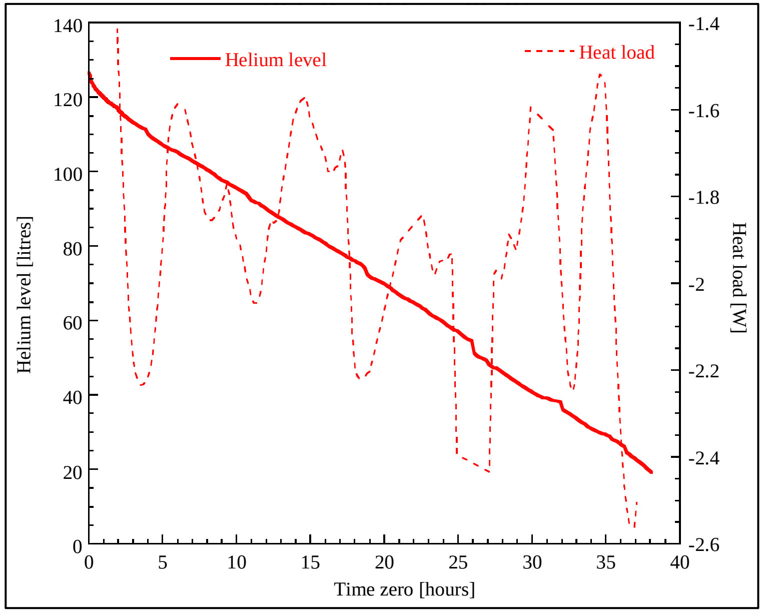
Does not include conduction down N2 ice

Science & Technology Facilities Council
Technology

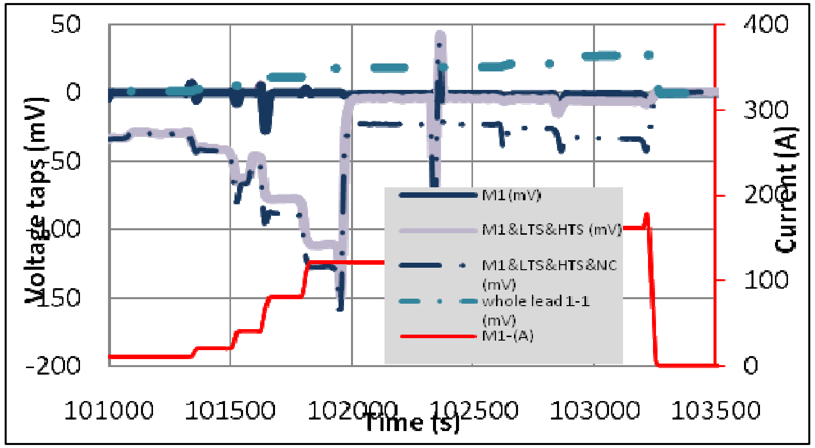
July 2009 Cool Down

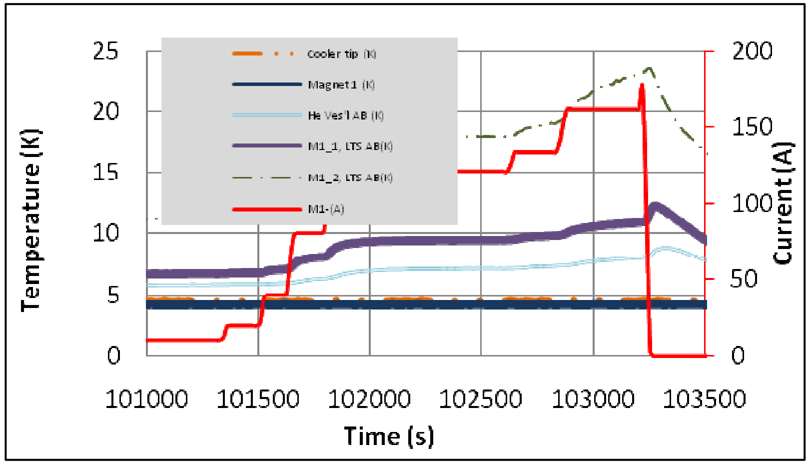
System cooled down in July 2009

Re-condensation does not work -
system pressurizing rapidly



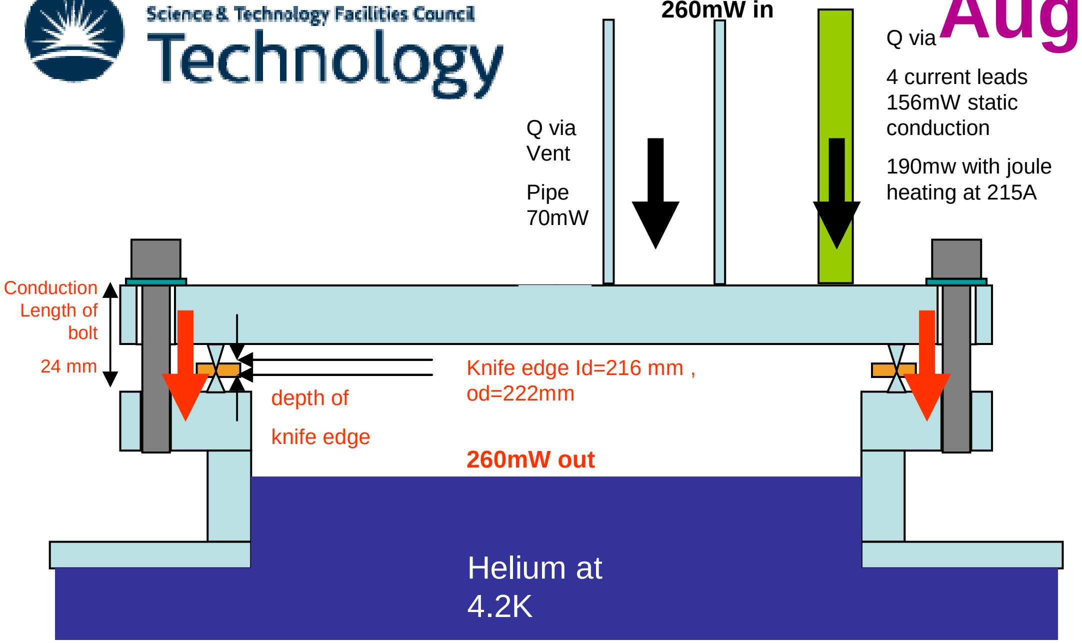
Still ~2 W (3.5 W total) heat load!





- All voltage developed was across LTS
- Temp of LTS shunt was 7 K plus
- Helium bath top plate also 7 K plus
- **LTS damaged again**

August - 2009 Heat load on helium bath top plate



For equilibrium the load through the bolts and knife edge must = 260 mW

For this to happen temp of top plate is ~7 K. Very similar to that seen by A-Bradleys

Current leads	
Thigh	60
Tlow	6
op current (A)	215
Number	4
Cond @ 215A	0.039
Joule heat @215A	0.009
Cond @ 320A	0.058
Joule heat @320A	0.022
Load W	0.19

Liquid He vent (60k-4k)	
Thigh	60
Tlow	6
Outer Diam	0.04
Inner Diam	0.036
Length	0.659
x-sect area	2.4E-04
Number	1
Total area	2.39E-04
Int Hi SS	193.508
Int lo SS	0.667
Difference	192.841
Load W	0.07

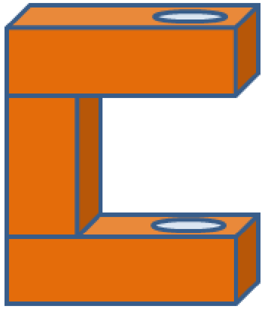
conduction intoplate 0.26

StSt knife edge	
Thigh	6.8
Tlow	4.2
Outer Diam	0.222
Inner Diam	0.216
Length	0.0065
x-sect area	2.1E-03
Number	1
degradation for touching contact	1
Total area	2.06E-03
Int Hi SS	0.951
Int lo SS	0.242
Difference	0.709
Load W	0.23

StSt bolts	
Thigh	6.8
Tlow	4.2
Outer Diam	0.008
Inner Diam	0
Length	0.024
x-sect area	5.0E-05
Number	24
degradation for touchin	1
Total area	1.21E-03
Int Hi SS	0.951
Int lo SS	0.242
Difference	0.709
Load W	0.04

conduction outofplate 0.26

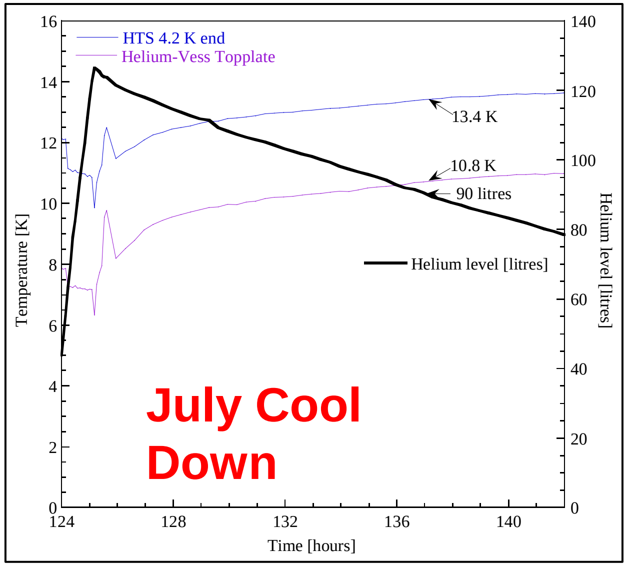
August 2009 - Copper 'C' clamps added to top plate

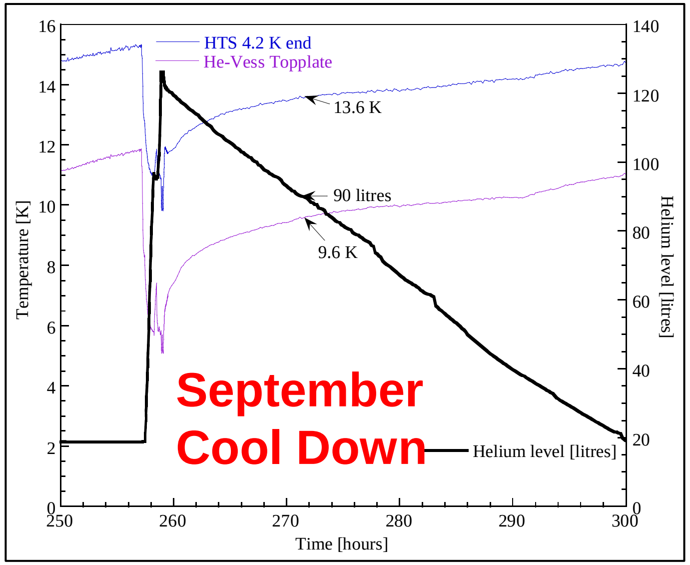


StSt knife edge		StSt bolts		Copper clamps	
Thigh	4.33	Thigh	4.33	Thigh	4.33
Tlow	4.2	Tlow	4.2	Tlow	4.2
Outer Diam	0.222	Outer Diam	0.006	dx	0.003
Inner Diam	0.216	Inner Diam	0	dy	0.02
Length	0.0065	Length	0.024	Length	0.05
x-sect area	2.1E-03	x-sect area	2.8E-05	x-sect area	6.0E-05
Number	1	Number	24	Number	6
degradation for touching contact	1	degradation for touching contact	1	degradation for touching contact	1
Total area	2.06E-03	Total area	6.79E-04	Total area	3.60E-04
Int Hi SS	0.264	Int Hi SS	0.264	Int Hi OFHC	90.700
Int lo SS	0.242	Int lo SS	0.242	Int lo OFHC	57.405
Difference	0.022	Difference	0.022	Difference	33.295
Load W	0.01	Load W	0.001	Load W	0.24
conduction outofplate	0.25				

With copper 'C' clamps, top plate should be no more than 4.3 K

September 2009 Cool Down

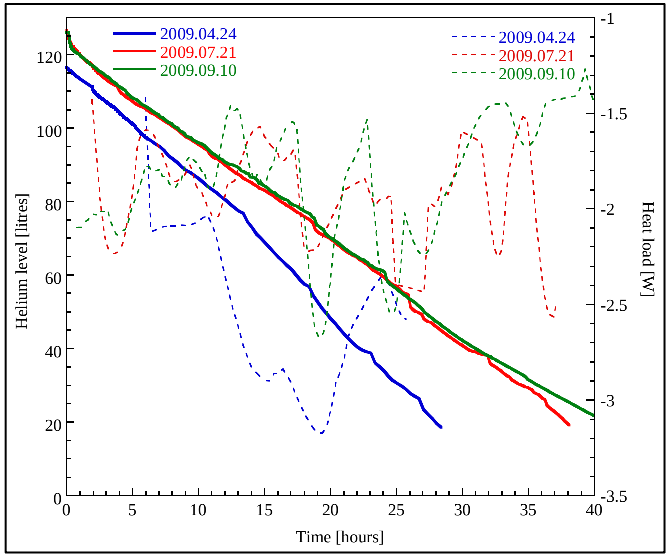




No Difference!

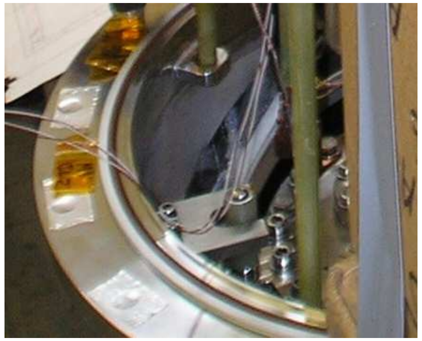
Top plate and LTS shunt at same temperature

Knife edge theory not correct



- Boil off has not been altered
- Always ~ 2 W above that of the cold heat re-condensation

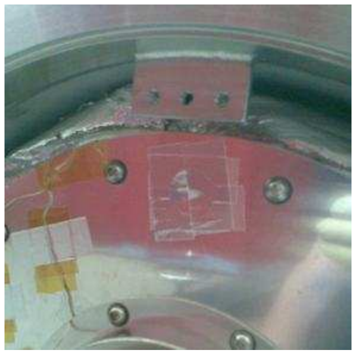
Where is the heat leak?
Helium bath location pins

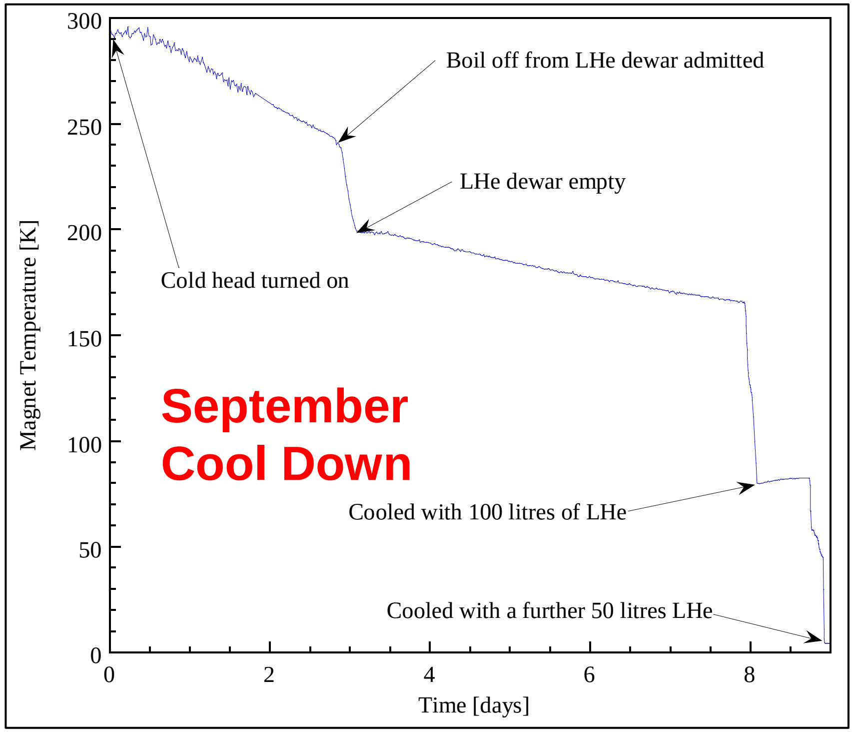

To minimise heat leak into helium bath, the helium bath location pins were removed

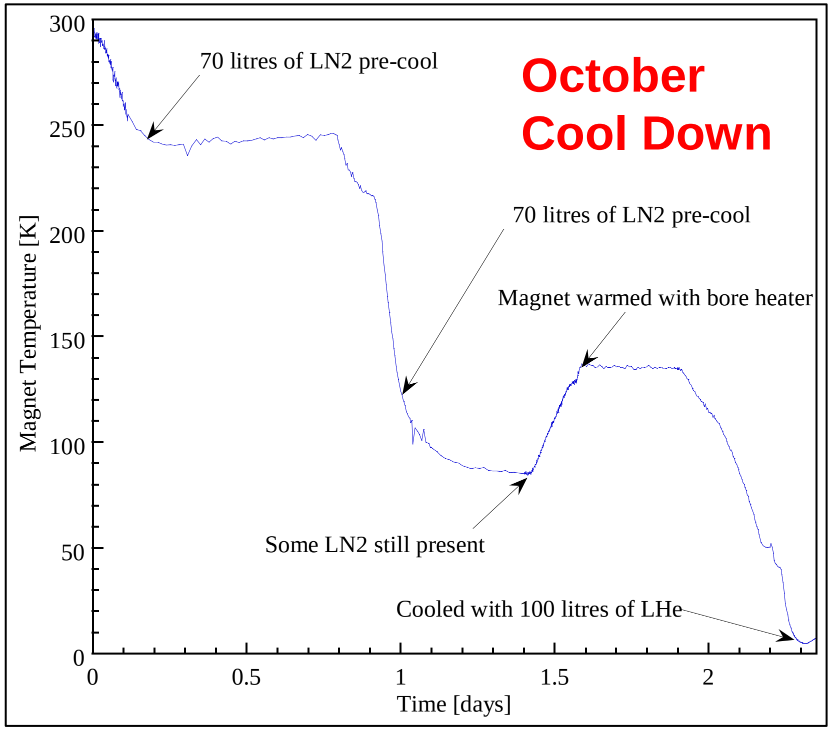
The heat load from radiation through two 7 cm x 3 cm holes at 300 K amounts to ~2.0 W

The thermal conductivity
~1 W worst case

October 2009 Cool Down
Different methods of pre-cooling





The magnet was pre-cooled with the re-condensing cold head

- 9 days to cool magnet to 4 K
- 150 litres of liquid helium used to reach 4 K

The magnet was pre-cooled with liquid nitrogen

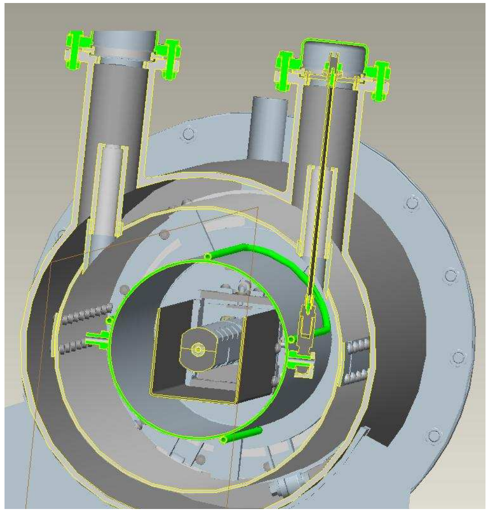
- 2.5 days to cool magnet to 4 K
- 100 litres of liquid helium used to reach 4 K

However, due to re-condensing design, difficult to remove nitrogen and a blockage occurred – system had to be warmed again

Current status

Carbon magnet support rods have failed

One end of magnet dropped by ~15 mm - Bonded joints on both CF rods had failed at 4 K end.



Pre production rods were tested to >1.5 kN at 77 K

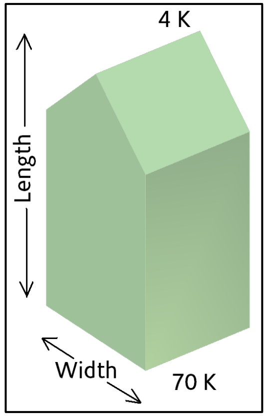
Once carbon rods are fixed, will cool down again

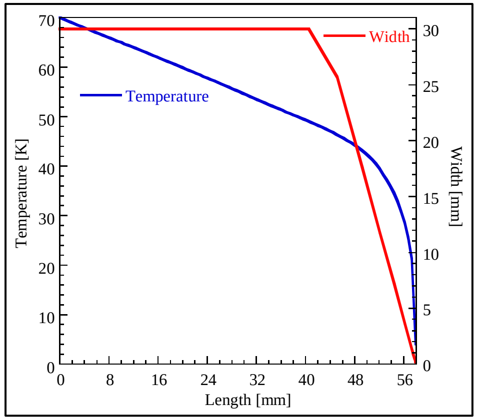
- Check boil off (i.e. heat load)
- Test magnet
- Investigate bore heating effects

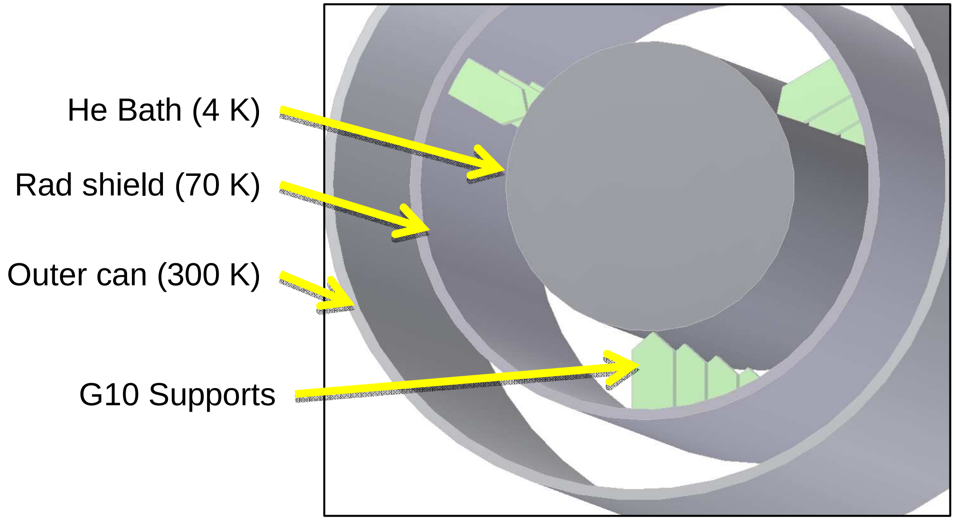
Where is the heat leak?
Other Concerns

Some worry, radiation shield supports from helium bath may have a larger heat load than originally calculated

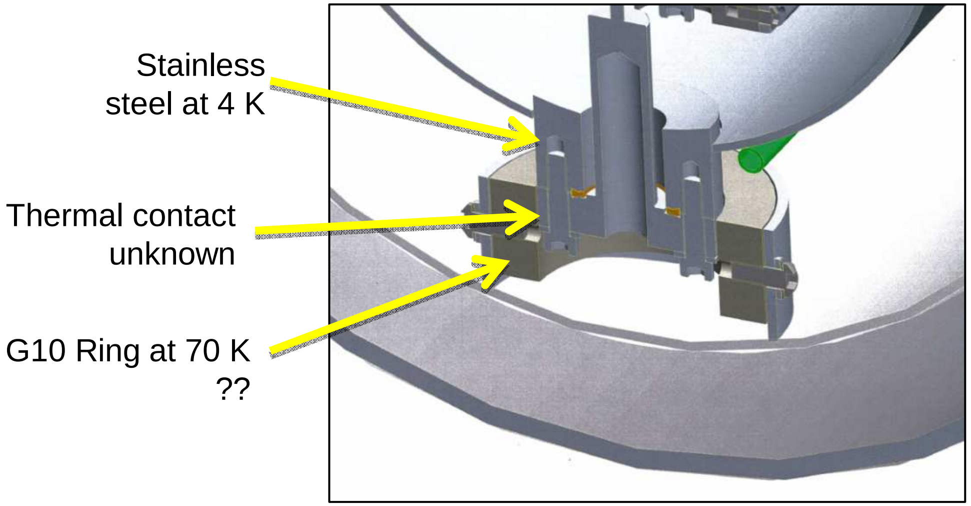
- ~0.13 W each
- ~1.5 W for 12 in total
- This is worst case scenario, probably much less – MLI barrier







Central support ring has an unknown heat load



Future plans - "Beam heating" test

"Beam heating" test planned

Chain of resistors in evacuated bore to simulate beam heating effects

From Duncan's thesis the calculated heat loads span range 0.1 W to 1.4 W per module

Current experiment can apply 0 to 2.5 W inside the bore of the magnet

The intention is to run the magnets at their nominal field wind up the power in steps until the magnet quenches

This gives a measure of the peak power the magnets can sustain

Summary

4 metre prototype has been built

- Each 2 metre magnet reaches beyond design field
- The magnets have a straightness of +/-200 µm
- This is greater than the +/-50 µm required
- With an active alignment system, +/-10 µm achievable

Cryogenic issues

- There have been ‘cryogenic’ leaks that have now been fixed
- There is a heat leak greater than originally expected causing
  - -High helium boil off
  - -Low temperature superconductor too warm to pass operating current

Fixes

- Many attempts to fix heat leak
- None successful so far – latest ideas seem more plausible

Future work

- Show magnet running in cryostat with re-condensation
- Bore heater tests to simulate beam heating effects