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Undulator R & D

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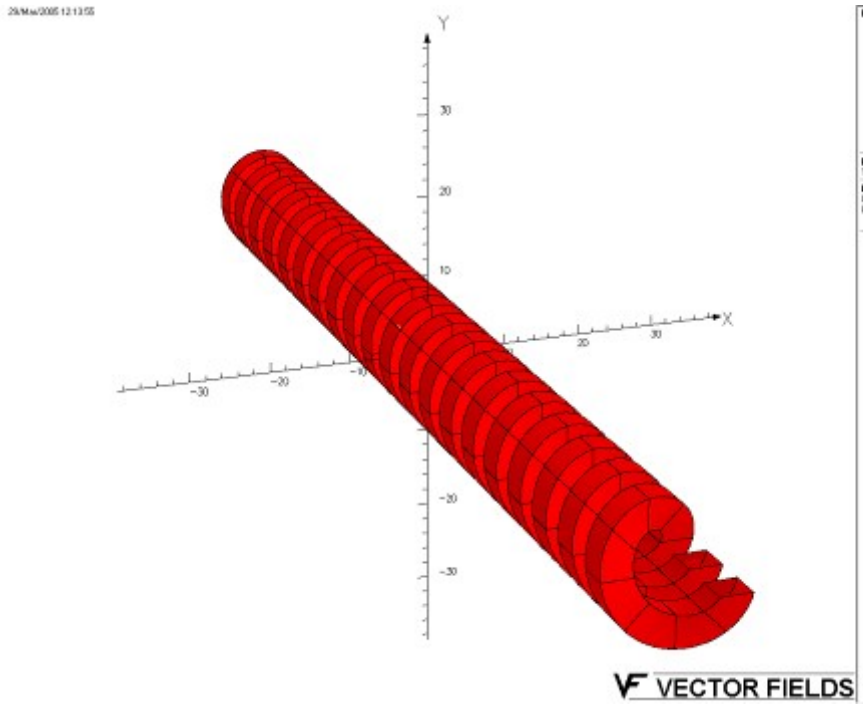
BAW-2 SLAC Jan 2011

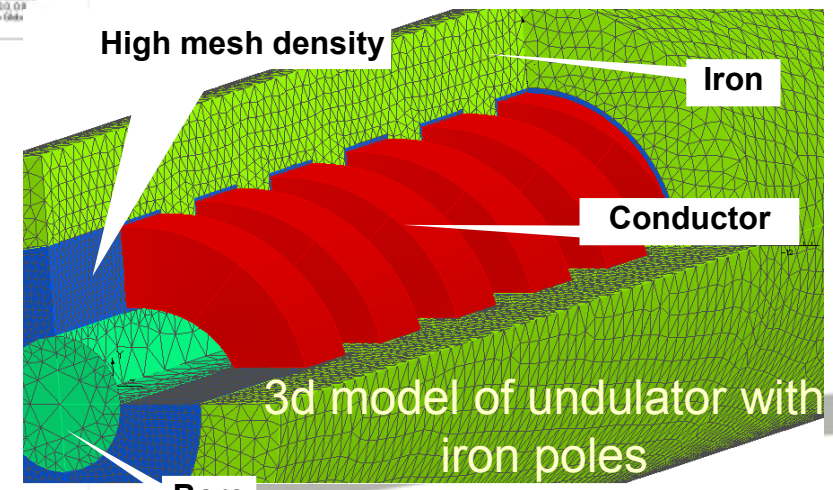
Reminder

- A helical undulator is a core element of the positron source
- The parameters required by the ILC had never been demonstrated before
- Cornell and STFC (Daresbury and RAL) both built short superconducting prototypes
- The results of these short prototypes defined the (RDR) current undulator parameters (11.5mm period, 0.86T)
- **STFC have since built a 4m undulator module that meets the ILC specification**

Basic Magnet Design Features

- **Bifilar Helix with iron poles**
- **NbTi wire**
- Non-magnetic vacuum vessel





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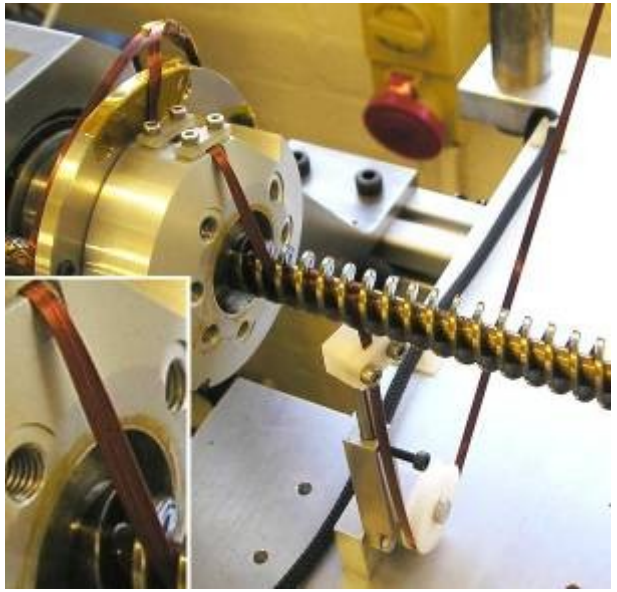
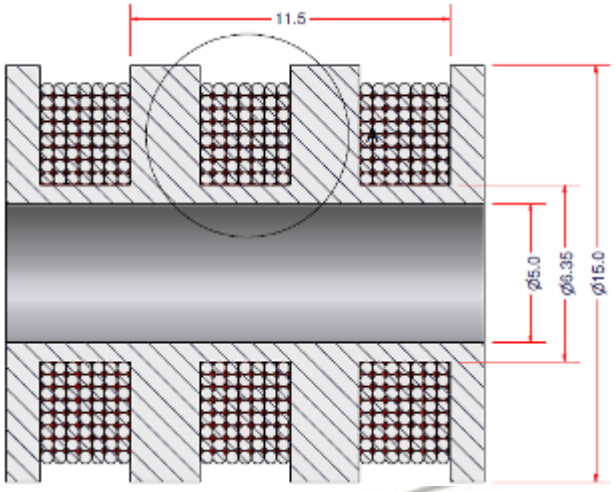
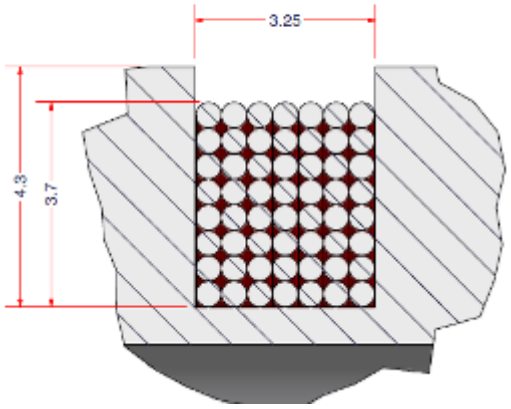
NbTi Winding

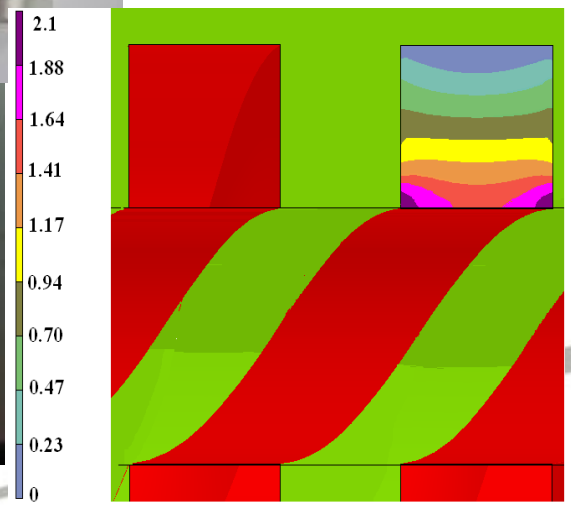
- Wound with **7 wire ribbon**, 8 layers
- Ø0.4 mm NbTi wire, with 25 µm enamel (Ø0.45 mm when insulated)
- 3.25 mm wide winding for 11.5mm period
- Packing factor of 62%







NbTi Prototypes



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Prototypes Summary

Parameter	Prototype 1	Prototype 2	Prototype 3	Prototype 4	Prototype 5	**Prototype 5'**
Prototype goal	**Winding Technique**	**Mechanical tolerances**	**Reduced period**	**Check effect of iron**	**Increased period**	**improved impregnation**
Length	300 mm	300 mm	300 mm	300 mm	500 mm	**500 mm**
Former material	Aluminium	Aluminium	Aluminium	Iron	Iron	**Iron**
Bore tube	Integral	integral	integral	integral	copper	**copper**
Winding period	14 mm	14 mm	12 mm	12 mm	11.5 mm	**11.5 mm**
Winding bore	6 mm	6 mm	6 mm	6 mm	6.35 mm	**6.35 mm**
Magnet bore	4 mm	4 mm	4 mm	4.5 mm	5.23 mm	**5.23 mm**
SC wire	Cu:SC 1.35:1	Cu:SC 1.35:1	Cu:SC 1.35:1	Cu:SC 1.35:1	Cu:SC 0.9:1	**Cu:SC 0.9:1**
Winding	8-wire ribbon, 8 layers	9-wire ribbon, 8 layers	7-wire ribbon, 8 layers	7-wire ribbon, 8 layers	7-wire ribbon, 8 layers	**7-wire ribbon, 8 layers**

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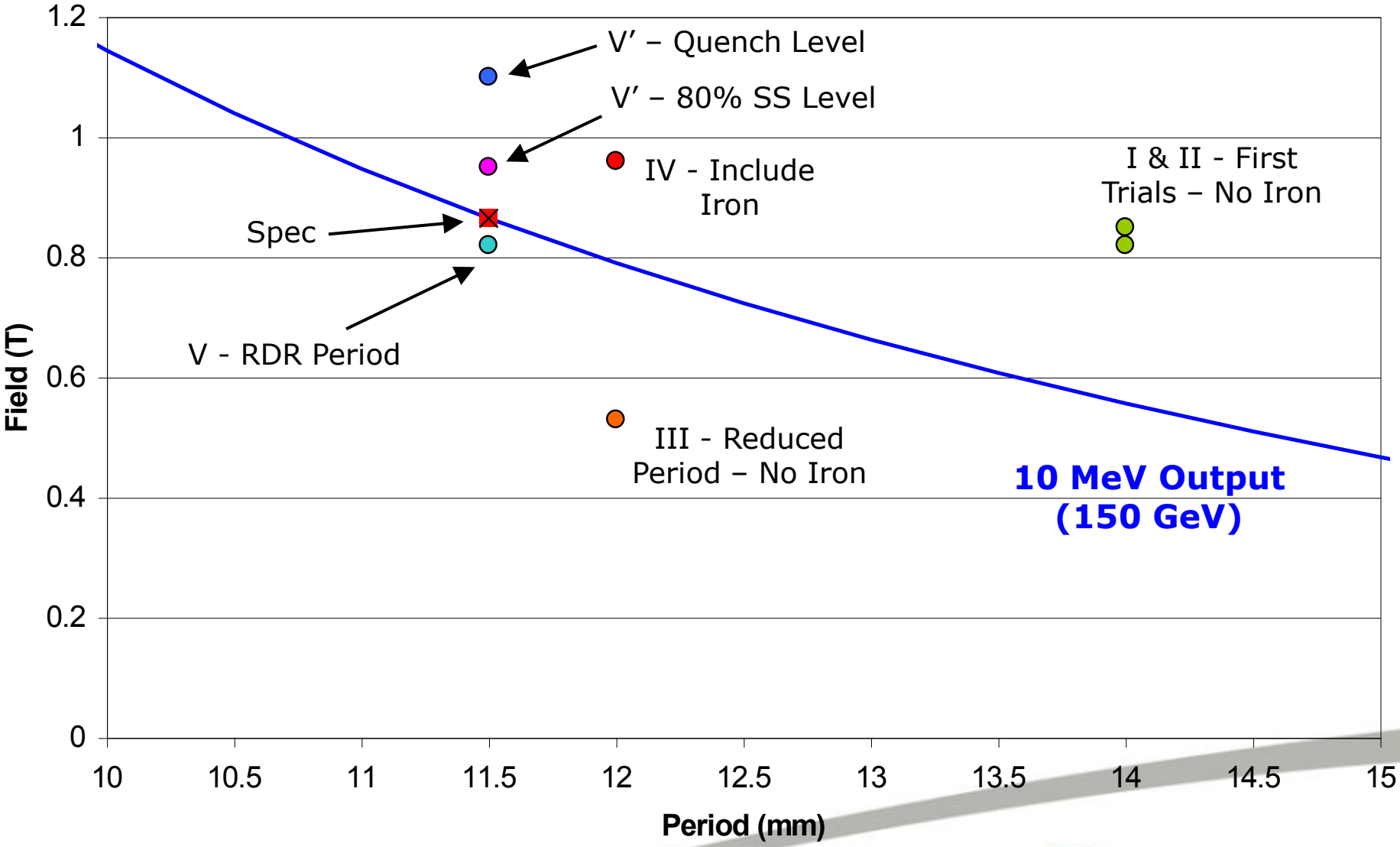
Prototypes Summary



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Full Undulator Parameters (RDR)

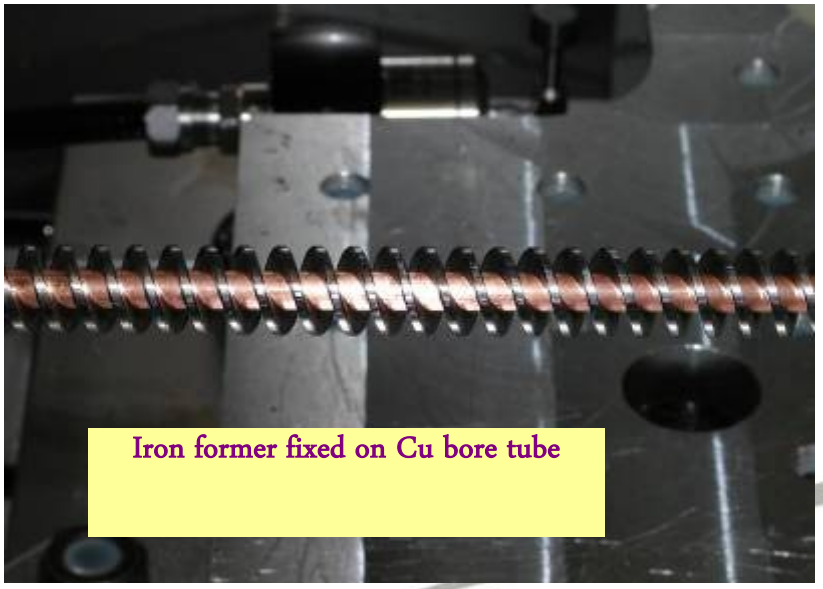
Undulator Parameters	Symbol	Value	Units
Undulator period	λ	1.15	cm
Undulator strength	K	0.92	
Undulator type		helical	
Active undulator length	L_u	147	m
Field on axis	B	0.86	T
Beam aperture		5.85	mm
Photon energy (1^{st} harmonic cutoff)	E_{c10}	10.06	MeV
Photon beam power	P_γ	131	kW

Undulator to be made of 4m long modules

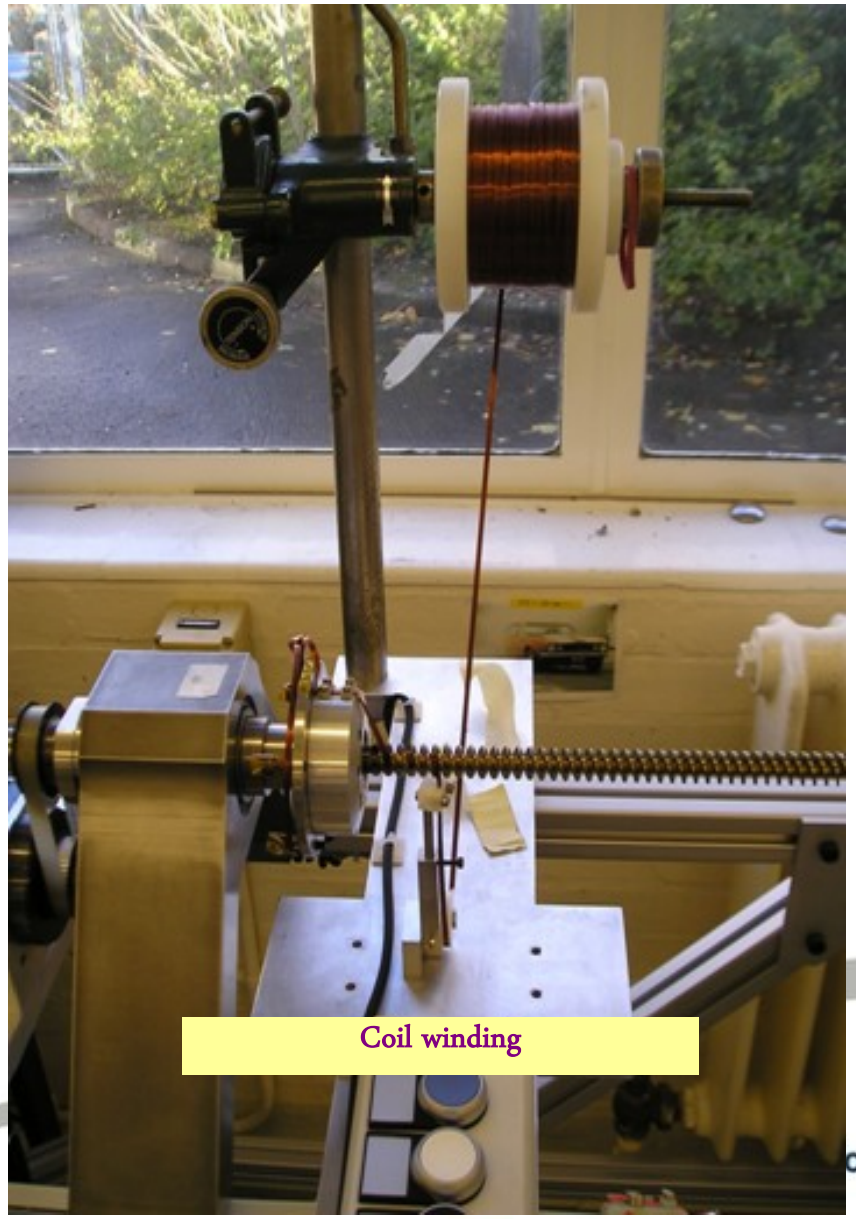
Only the total length has been changed since the RDR

4m Prototype manufacture

4 axis machining

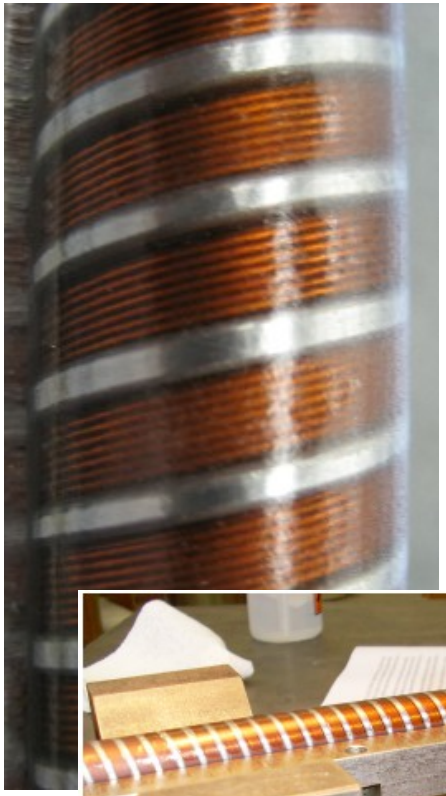


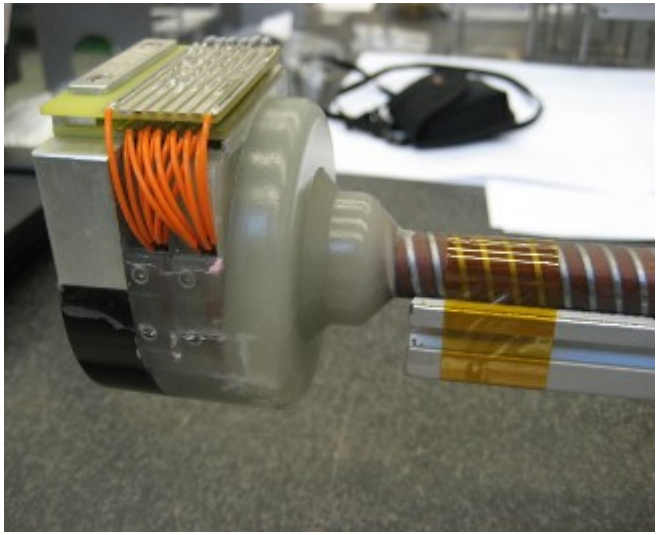
Iron former fixed on Cu bore tube

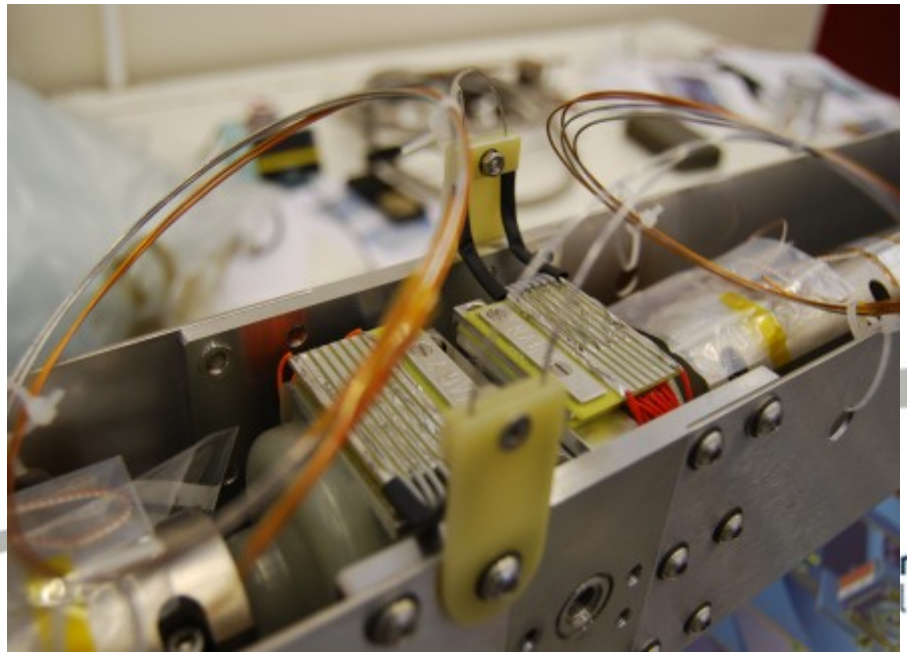


Coil winding

4m Prototype manufacture







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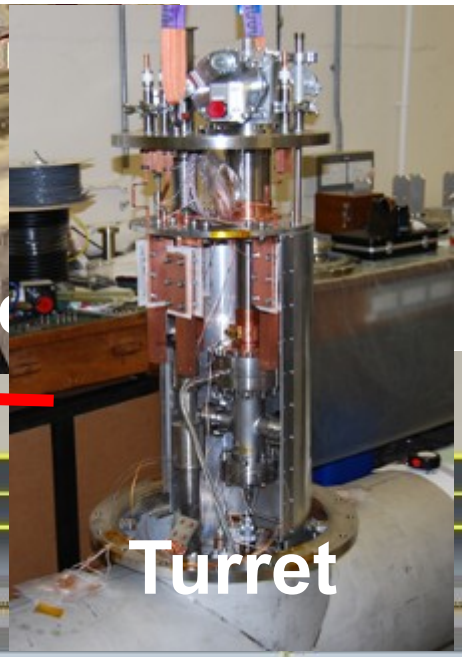
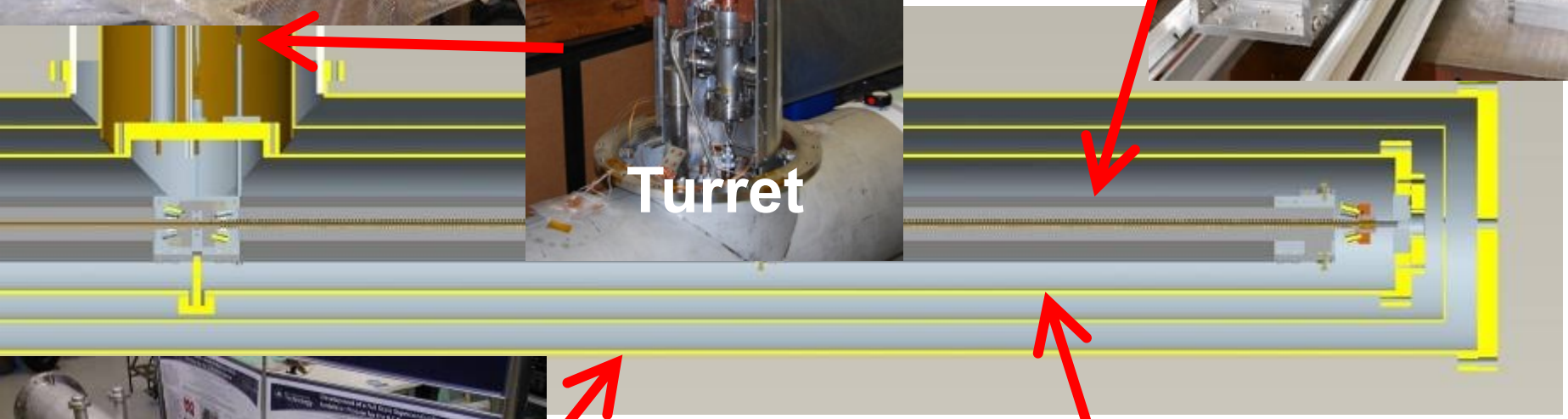
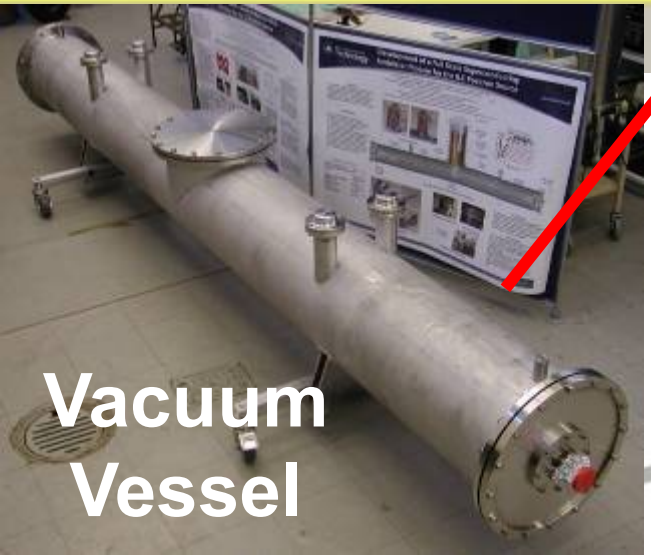
4m Cryomodule Fabrication

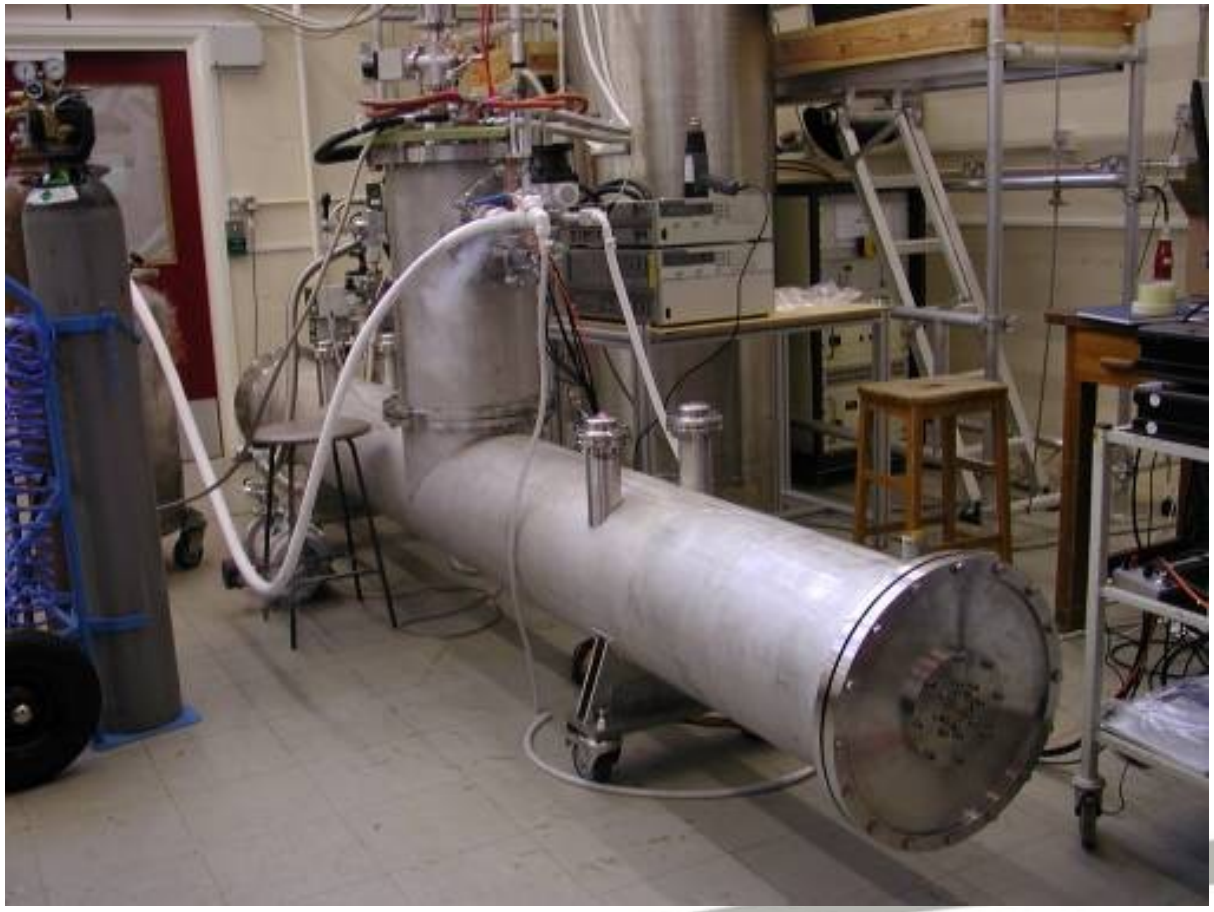






Cryomodule

- A 4m module containing 2 x 1.75m helical undulators (11.5 mm period) was constructed at RAL
- Closed loop cryo system with cryocooler



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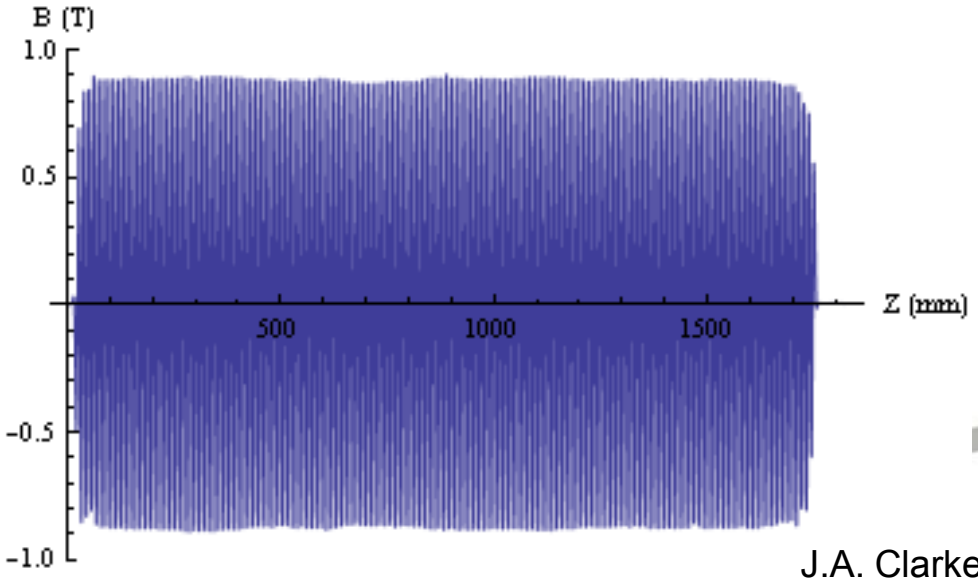
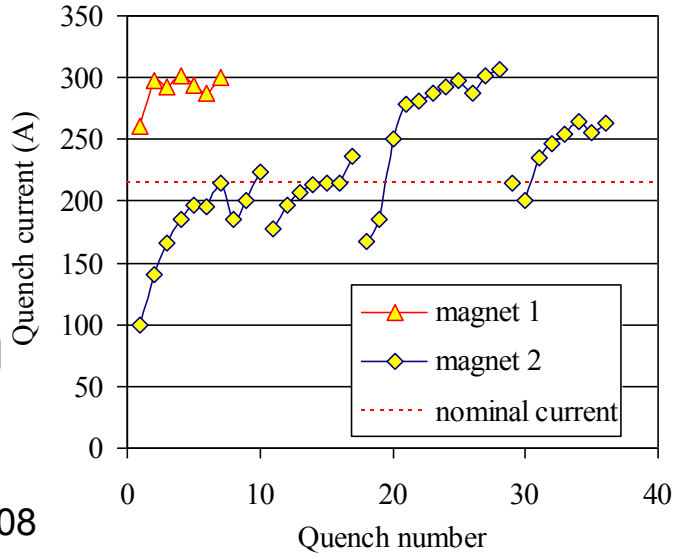
Vertical Tests

- The quench test results show different behaviour between the two identical magnets
- Both do actually reach the same final quench current which agreed well with expectations
- **300A = 1.15T (spec is 0.86T, 215A)**

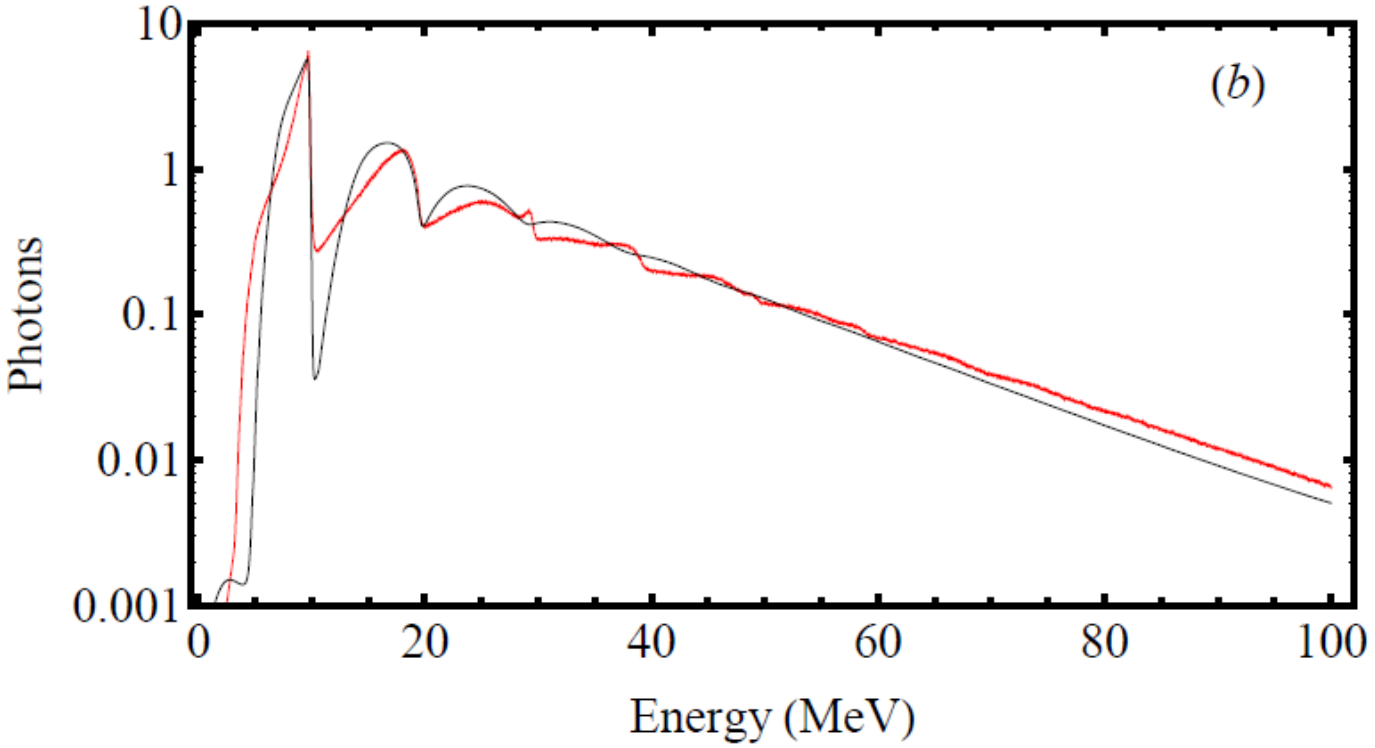




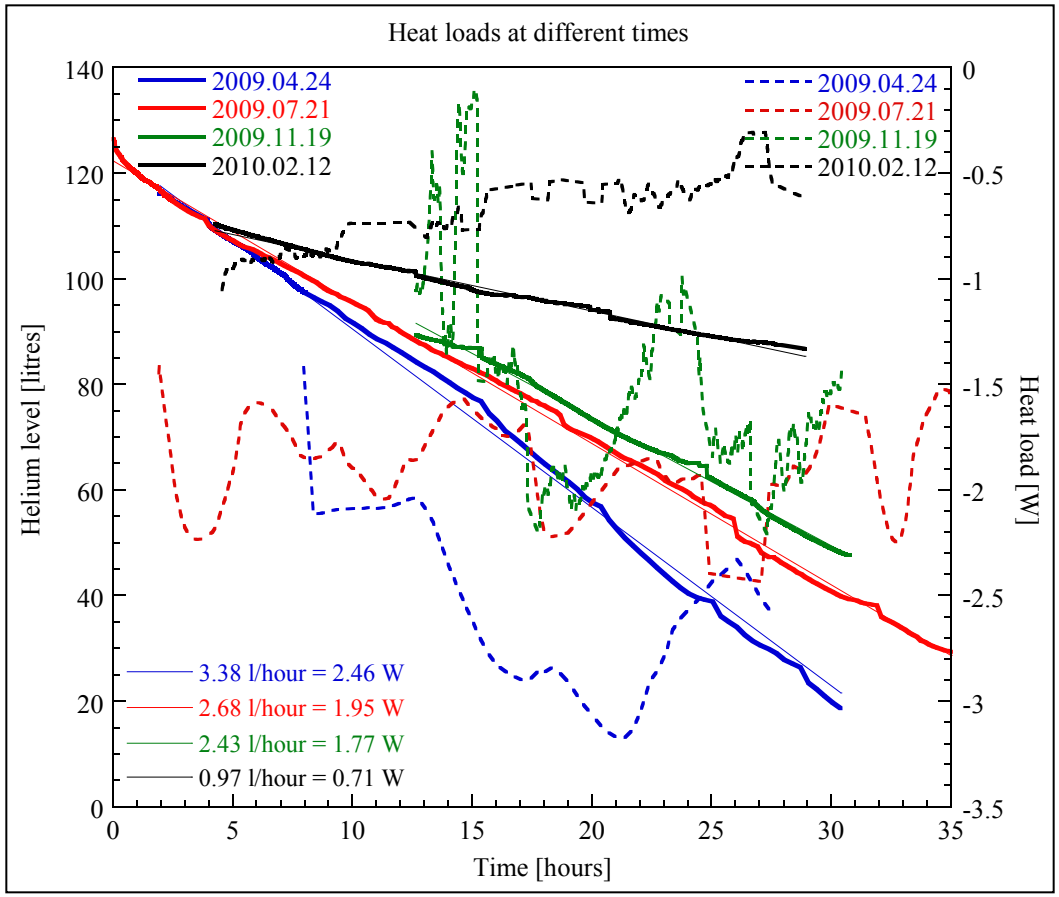
J.A. Clarke et al, EPAC 08

Photon Output

- Photon Flux per 150 GeV electron per unit relative energy bandwidth for the two undulators in series (red) and an ideal undulator with the same average parameters (black)



Module Heat Load Problem



- Heat load higher than anticipated
  - System not recondensing
- Incremental improvements were made slowly with time
  - Main issue was top plate not at **4K**

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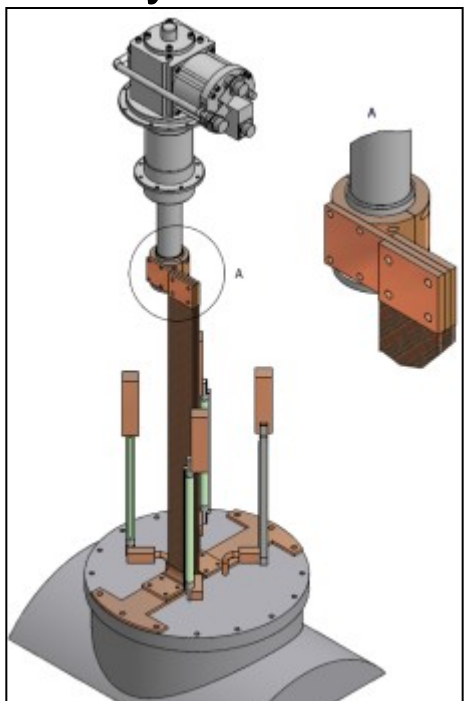
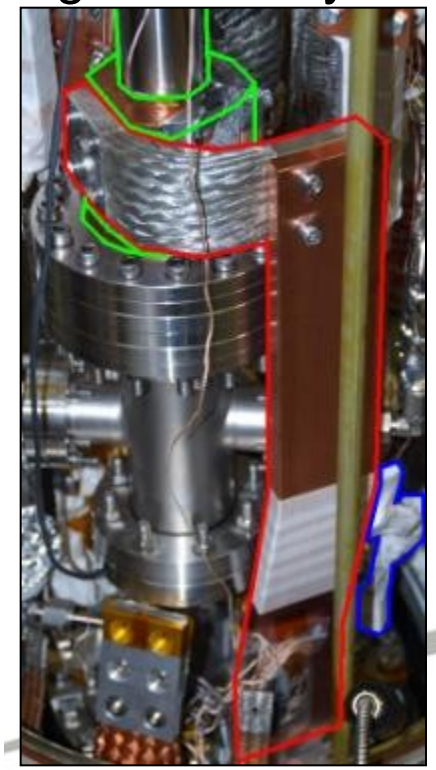
Undulator Cryomodule

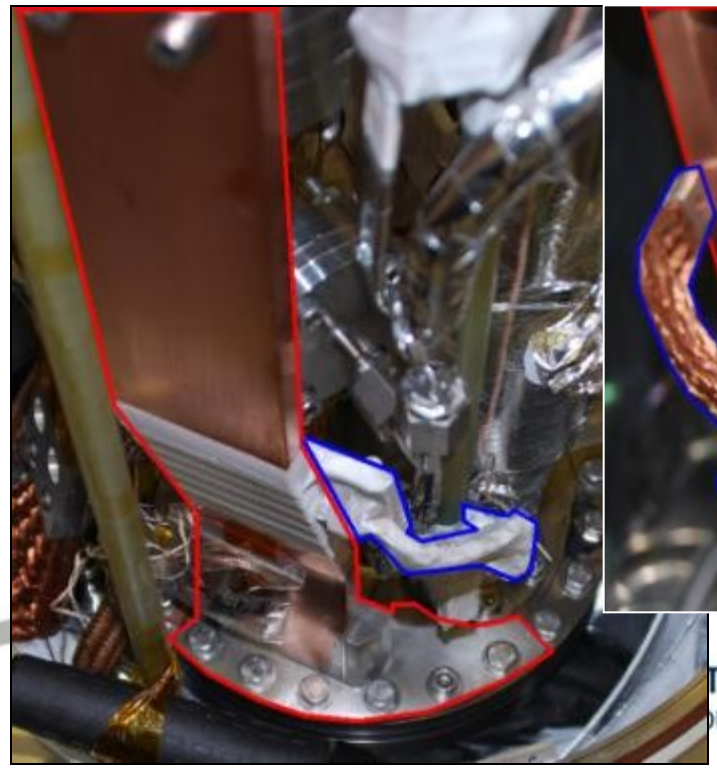
July 2010 – Top plate cooled by cryocooler

It was seen that it did not take much heat input to change temperature of top plate and HTS/LTS join.

Large copper bars have been inserted to cool top plate and HTS/LTS join directly from the 2nd stage of the cryocooler.







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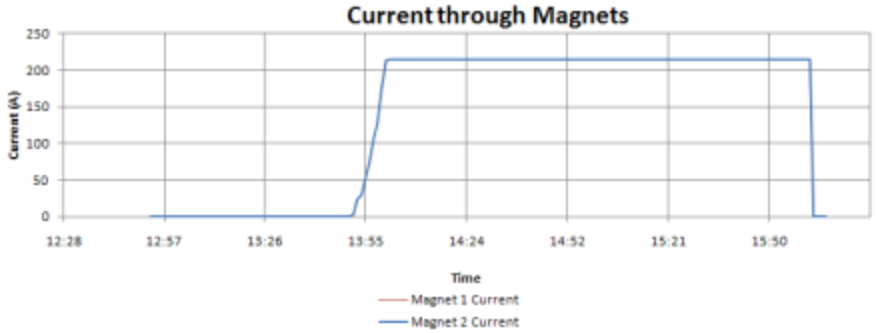
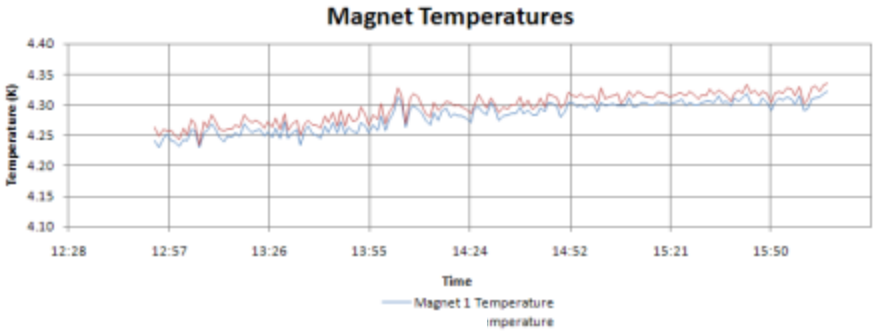
Undulator Cryomodule

- Both undulators now powered individually and together at 215 A (0.86T) – stable operation (during 2 hour test)
- Both also powered at 252A for > 1hour but then lead quenched above top plate
  - Not enough margin on top plate temperature at high current?
  - No magnet quenches so far





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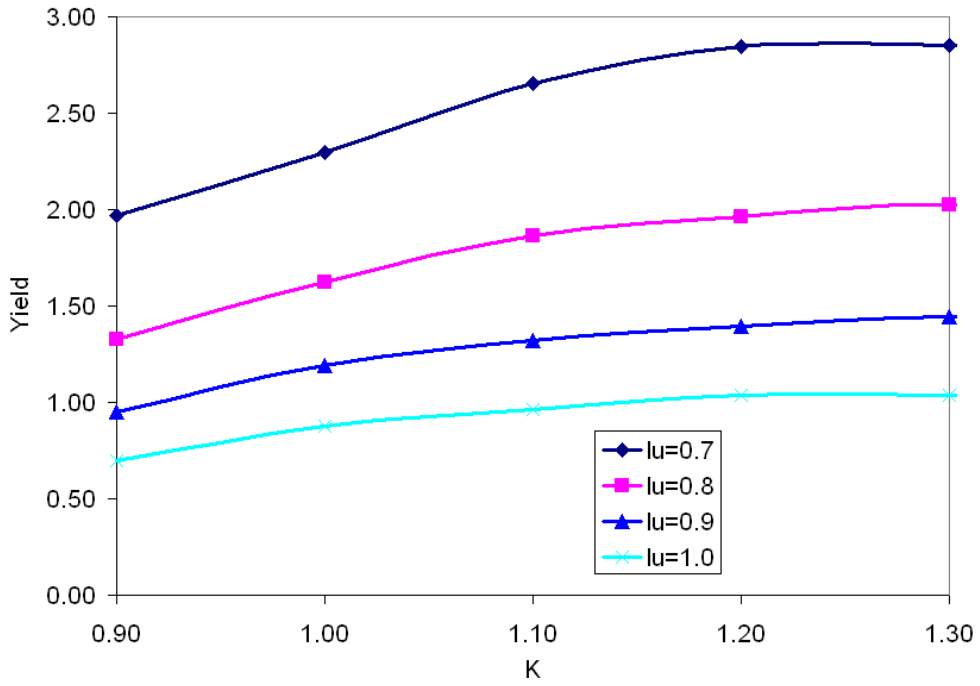
Use Different Undulator Parameters?

- Yield shown for:
  - 231 m long undulator
  - 100 GeV drive beam energy
  - Flux Concentrator
- Shorter period required!



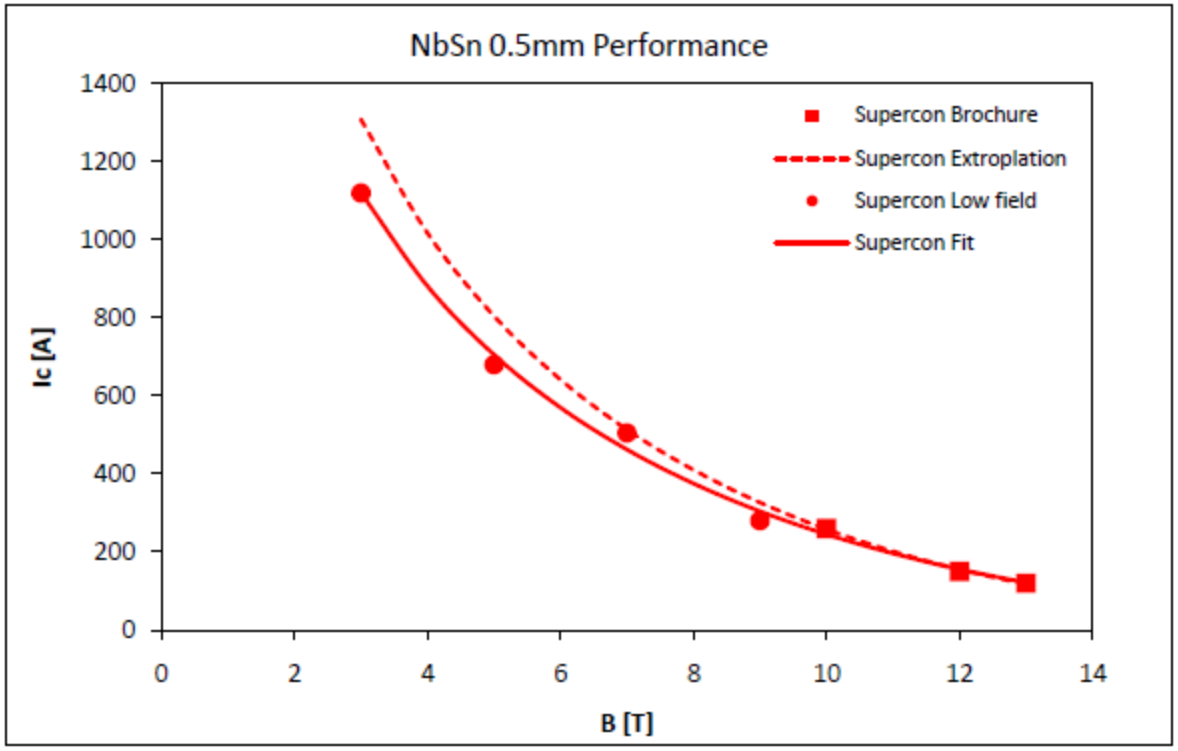
Application of Nb_3Sn

- To generate higher fields or to be able to reduce the period we need to use Nb_3Sn
- Goal would be to reduce period to ~9mm
- **Concerns**
  - Packing factor reduced as insulation is thicker
  - Performance of wire at <5T
  - Insulation of former
  - Can no longer wind with ribbon
  - More difficult material to work with (heat treatment)
- Need Nb_3Sn wire to have small diameter for similar filling factor
- Have purchased 1 km of Ø0.5 mm (Ø0.63 mm with glass braid) wire from OST.

Nb_3Sn Performance

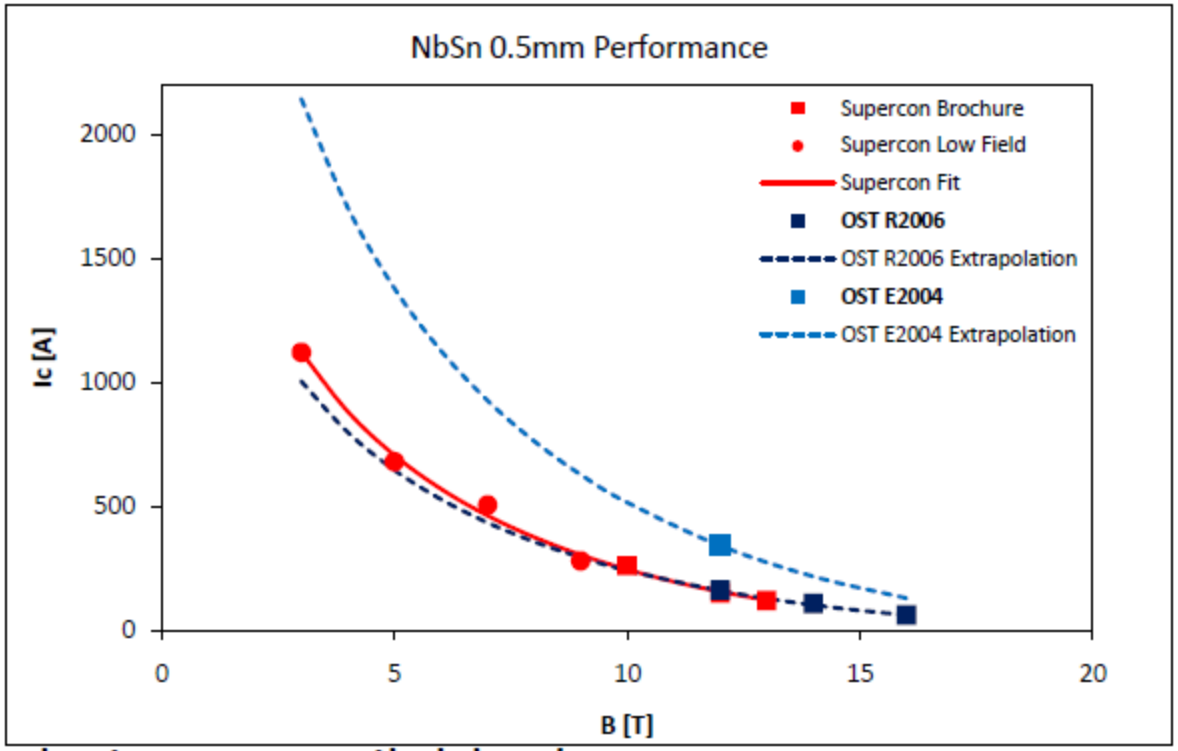
- Nb_3Sn Availability
  - EAS Bruker do not make Nb_3Sn smaller than Ø0.7 mm
  - Supercon Inc. and Oxford Instruments Superconducting Technology (OST) make Ø0.4 mm and Ø0.5 mm respectively
- Nb_3Sn Performance
  - Due to small winding area, need large currents to achieve ~1 T on axis
  - Need to know critical current in winding at ~4 T
  - No companies have data for performance below 9 T
  - Large extrapolation needed – no confidence
  - Supercon Inc. made measurements from 3 T for us

Supercon 0.5mm Internal Tin wire performance



- Solid line shows Kramer fit to all data
- I_c = 1120 A at 3 T, 4.2 K

OST 0.5 mm Nb3Sn Performance, two grades of wire



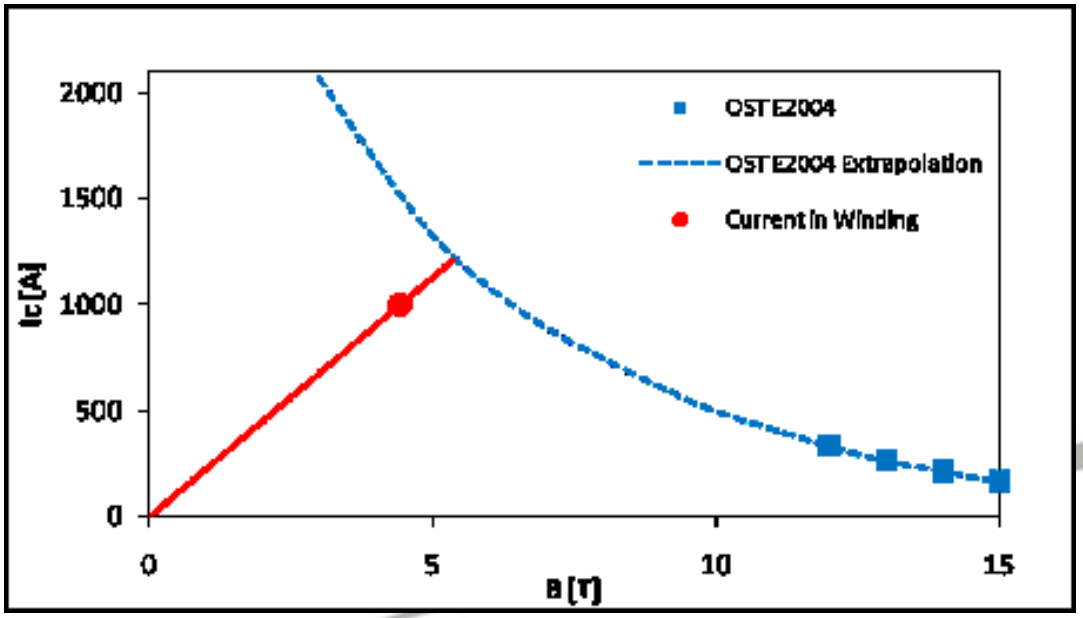
Large extrapolation to available data

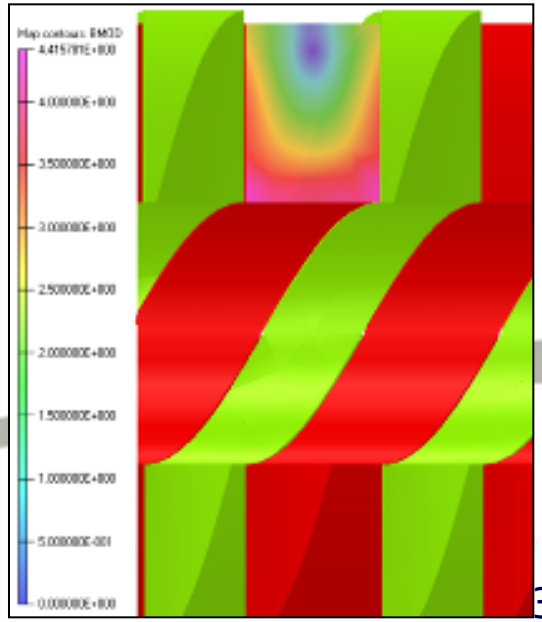
OST R2006: Ic ~ 1000 A at 3 T, 4.2 K (Jc ≈ 1600 A/mm2, 4.2 K 12 T)

OST E2004: Ic ~ 2000 A at 3 T, 4.2 K (Jc ≈ 2900 A/mm2, 4.2 K 12 T)

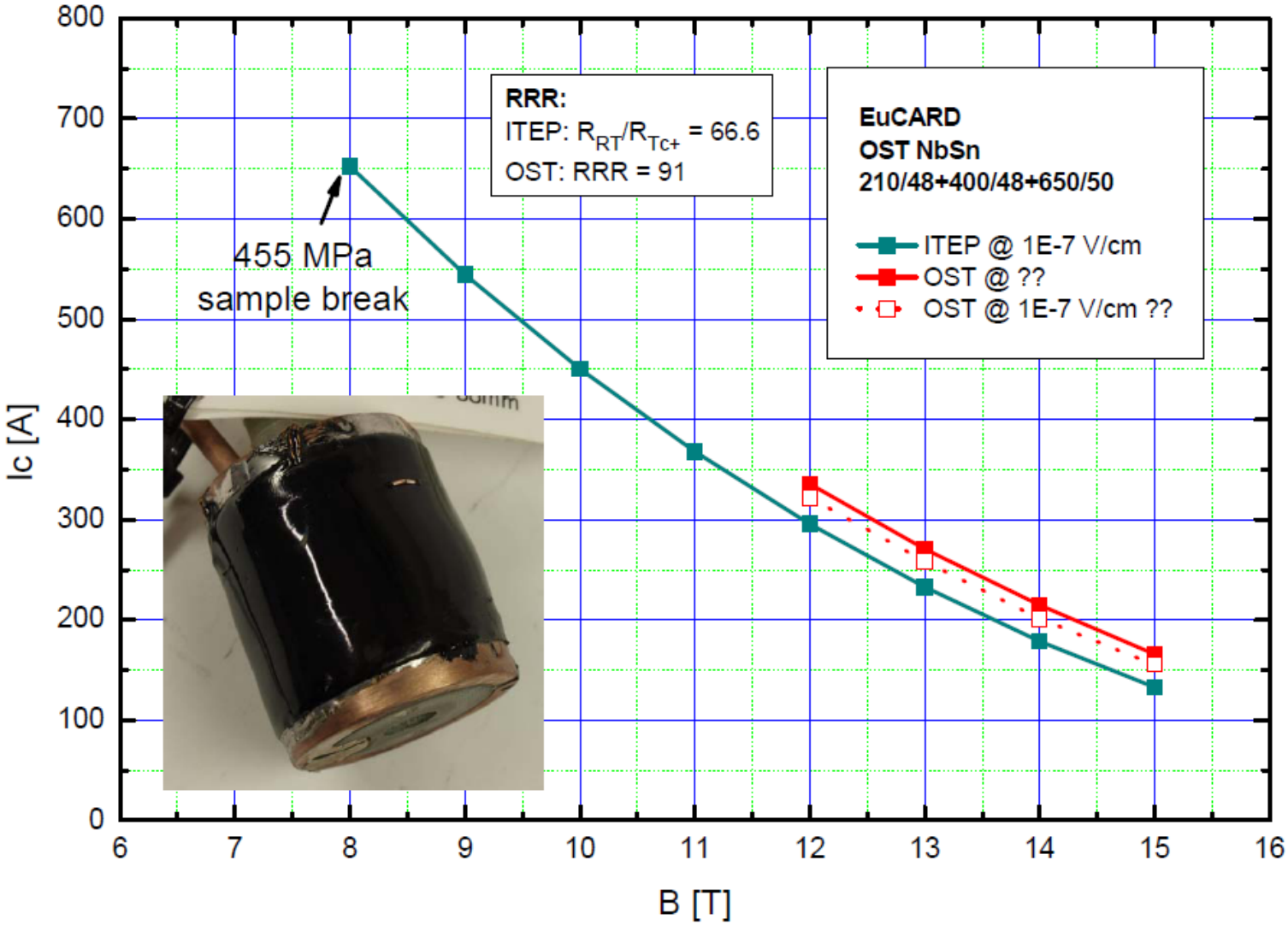
FEA Modelling

- Winding ID: Ø6.35 mm as before
- Field on axis: 1.54 T for 11.5mm period (cf 0.86T)
- Peak field in conductor: 4.4 T
- Operating at 82% of I_c
- Wire performance measurements have started at KIT



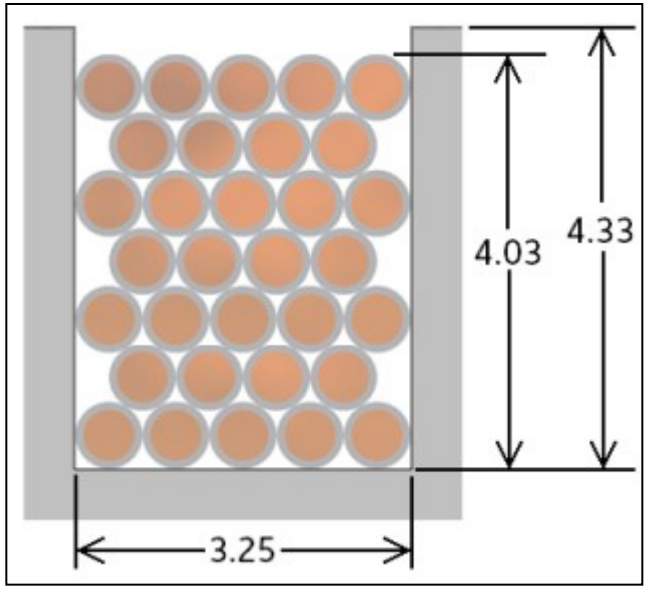


Results: Comparison to OST-data (HT “A”)



Trial Winding

- Need to do a trial winding to confirm groove dimensions
- Aluminium former has been made with the dimensions shown
- Will be 32 wires in winding
- 11.5 mm period
- Will be wound, potted and sectioned to check groove width etc



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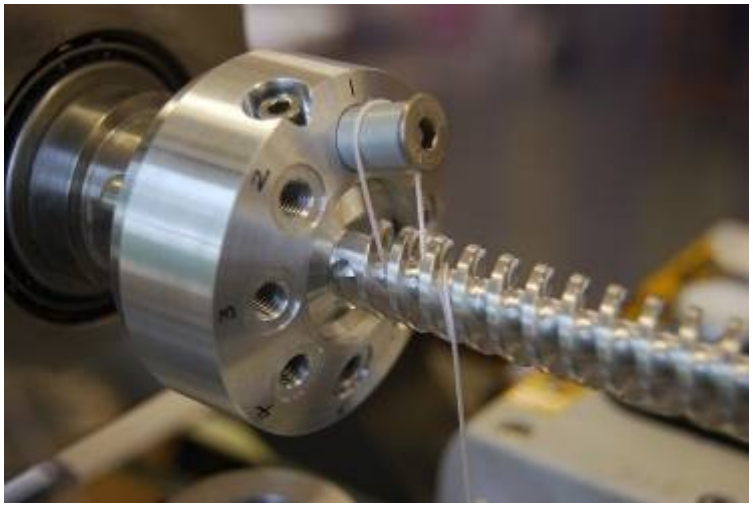
Trial Winding Started



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Summary

- A SC Helical Undulator Cryomodule with the current ILC parameters has been constructed and tested successfully using NbTi wire at RAL
- A project to develop Nb_3Sn short prototypes with enhanced parameters has now started in the UK 

- The wire has been procured and is being tested at low field by KIT
- The benefit to the ILC of a reduced period undulator using Nb_3Sn could be significant at low energies (<150 GeV)