Undulator-Based Positron Source Update

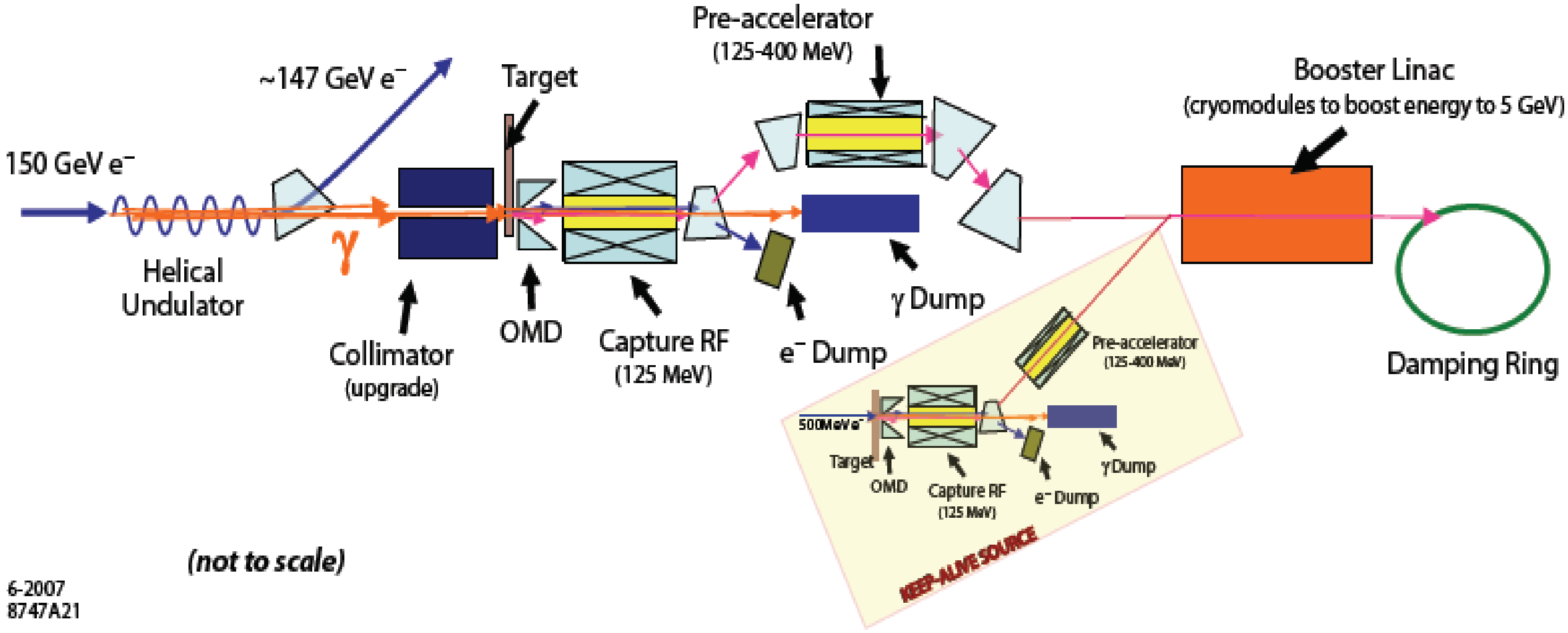
Ian Bailey

Cockcroft Institute/ Lancaster University

on behalf of the HeLiCal collaboration

March, 2010

Baseline (RDR) Positron Source



Talk Overview

- This talk summarises recent activity in the UK towards developing the baseline positron source.
- Topics covered:
  - Undulator prototype
  - Electron trajectories inside undulator
  - Photon collimator update
  - Target prototype
  - Target material tests update

Undulator Magnet Specification

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

K=0.92

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

Owen Taylor (RAL)

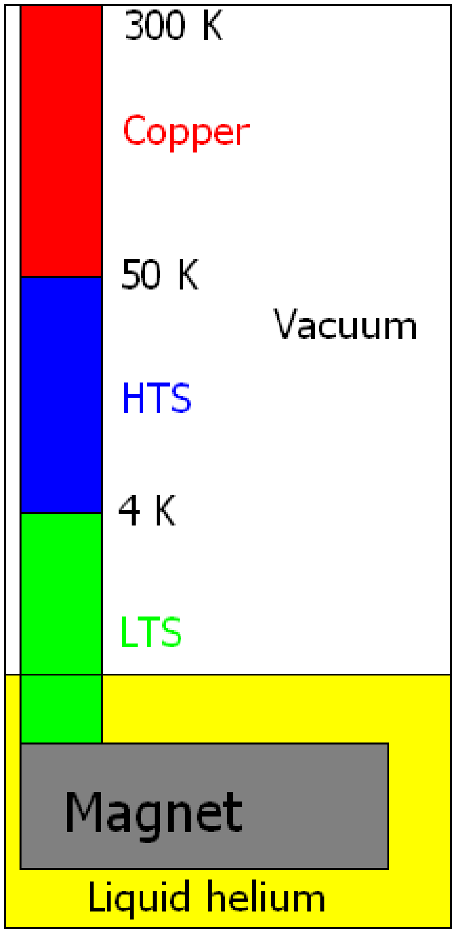
Completed Undulator in Cryomodule

Recent Undulator Prototype Issues

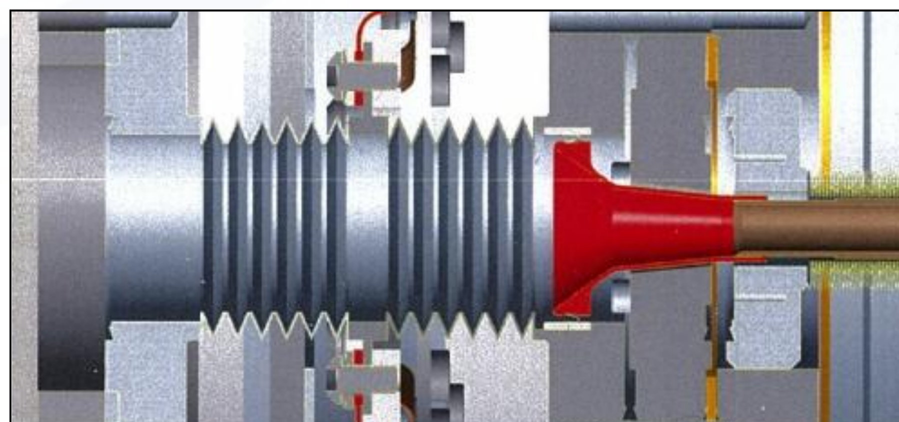
- Initial straightness ±200μm not within ±50μm specification
  - Solution developed using active alignment mechanism giving +/-10μm straightness
- Liquid He leaks through magnet
  - Leak pathways understood and fixed using Cu-Fe bimetal rings
- Excessive (~4W) heat load on He vessel
  - Liquid helium not recondensing
  - Low temperature s/c cables too hot
  - Partial solution found (see next slide)

Heating Issues

- Temperature of LTS (see right) has been too high
- Heat is radiating on to He bath from end flanges (see below)
- MLI (multi-layer insulation) is now being used to reduce heating
- Boil-off of He successfully reduced
- LTS flange will be connected thermally to condenser
- Magnets should be powered within ~2 weeks.



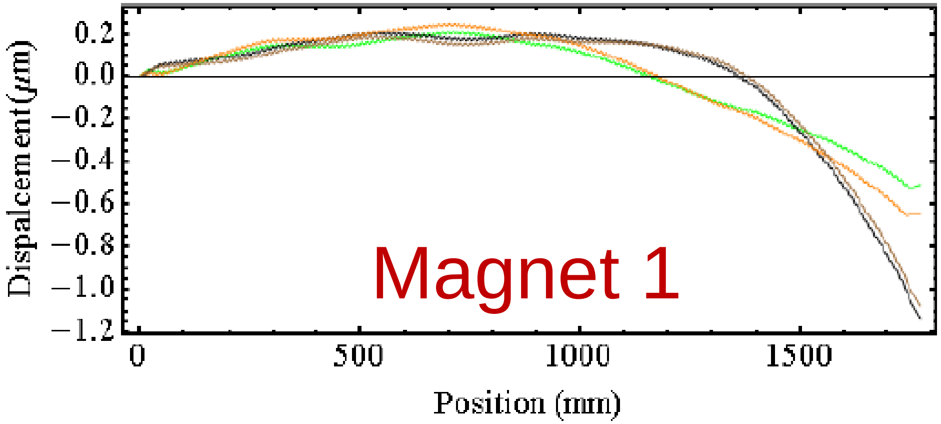
Schematic of turret

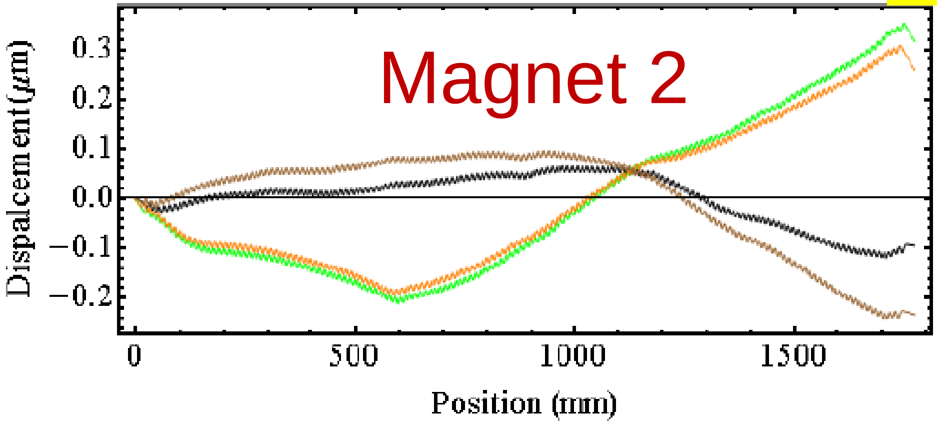


Flange (left) and He bath (right)

Trajectories from Field Data

- Field data is being analysed in detail by Duncan Scott
  - There are multiple, large, data sets at four orthogonal orientations and with two orthogonal Hall probes for each of the two 2m magnets.
- Field data from multiple data sets corrected and combined below
- Angle of trajectory at entrance of magnet optimised to minimise displacement at exit of magnet (i.e. dipole correctors assumed)
- Two lines per plane (e.g. green and orange) correspond to two Hall probes used in the measurements
  - Magnet 2 “better” than magnet 1 for overall displacement
  - Magnet 1 has dipole like behaviour towards the downstream end

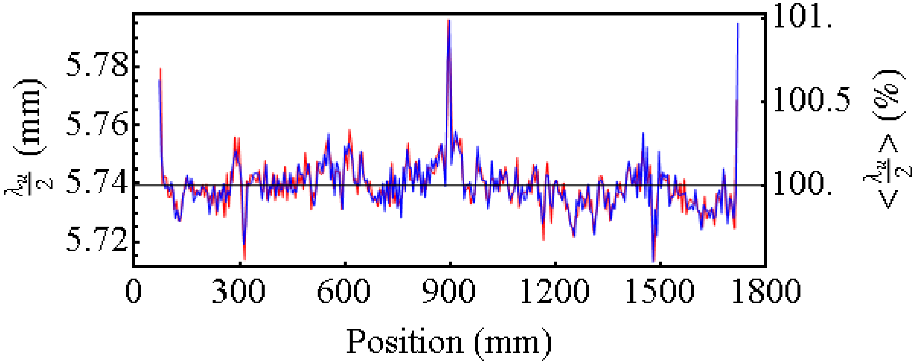




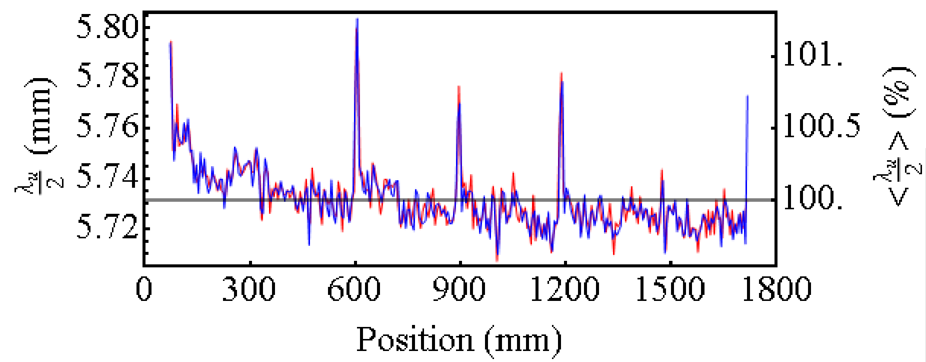
Jim Clarke and Duncan Scott (DL)

Half Period Length

- Half period of magnetic field measured as function of Hall probe position
  - For warm magnet we would expect $\lambda/2=11.5/2 = 5.75$mm
  - Actually expect $\lambda/2 < 5.75$ mm because of thermal contraction
- Measured values are extremely consistent
- However - spikes occur every 300mm due to former manufacturing technique
  - This can be can be corrected in future magnets



Magnet 1

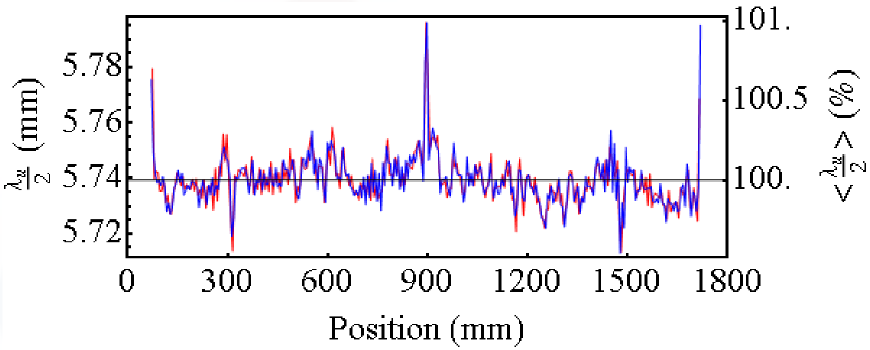


Magnet 2

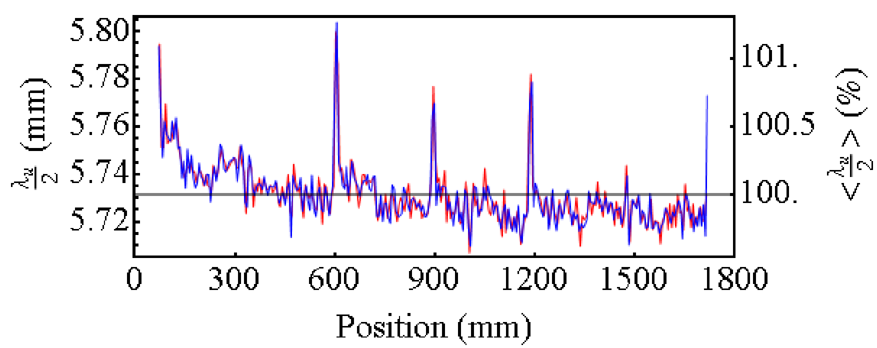
Measured Peak Fields

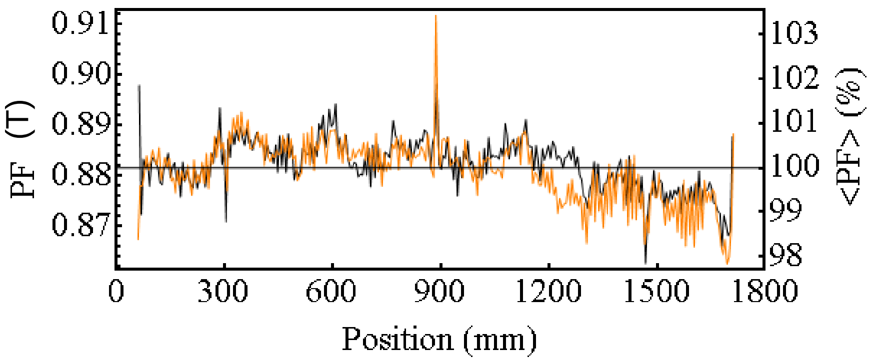
Spikes in half period length also coincide with measured peak field spikes (as expected)

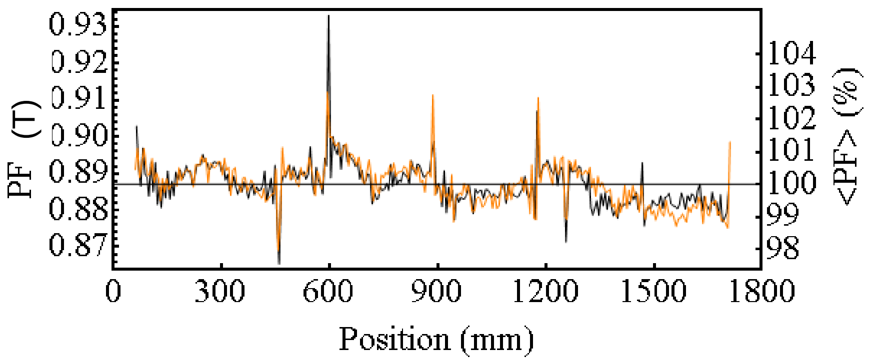
Magnet 1



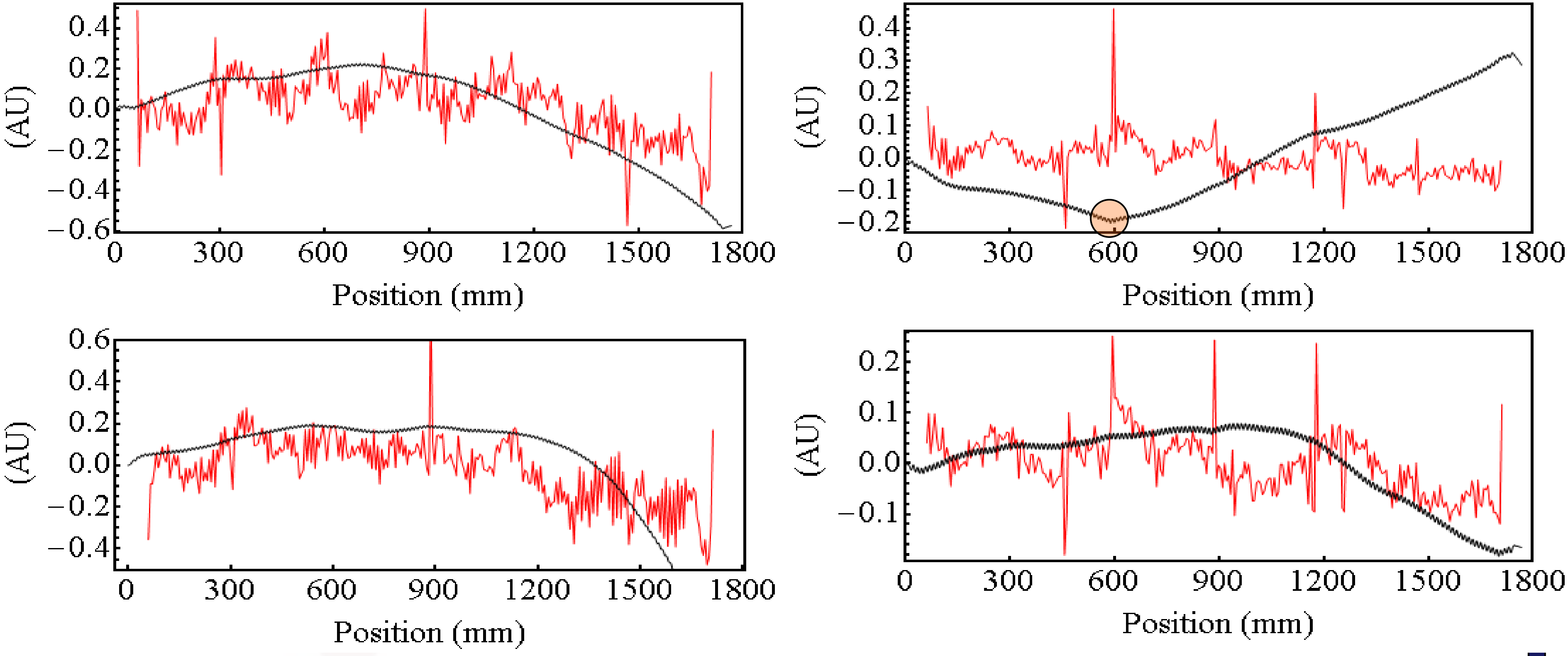
Magnet 2







Correlation between period and trajectory discontinuities



- (Some) period changes do cause changes in trajectory.
- Investigations ongoing to explain dipole behaviour in magnet 1.
- Trajectories being passed to David Newton to calculate SR spectrum

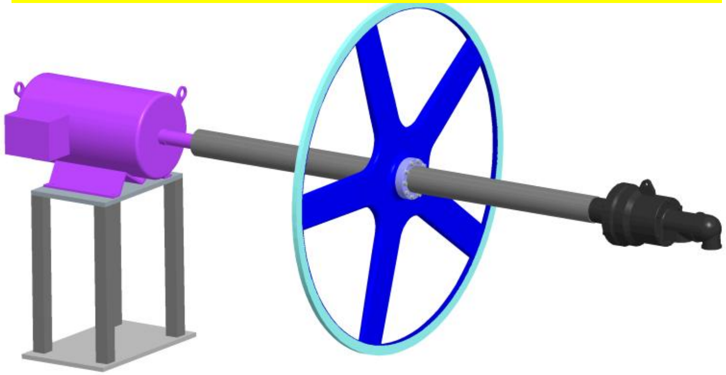
Baseline Photon Collimator

- At the Durham Positron Source meeting (October 2009) it was decided to adopt Alexander Mikhailichenko's design for the photon collimator for use in all baseline simulations.
  - A cylinder of tungsten 9.5cm long with an outer radius of 3cm (spoiler)
  - Followed by a cylinder of pyrolitic graphite 9.5cm long with an outer radius of 3cm (absorber)
  - Both cylinders surrounded by a copper cylinder with outer radius 3.5cm (attached to cooling channels)
  - The inner radius of the tungsten and graphite cylinders is nominally ~ 1.7mm.
- **Please see https://znwiki3.ifh.de/LCpositrons/CategoryCollimator for details and add comments.**

RDR Target Design

- Wheel rim speed (100m/s) fixed by thermal load (~8% of photon beam power)
- Rotation reduces pulse energy density (averaged over beam spot) from ~900 J/g to ~24 J/g
- Cooled by internal water-cooling channel
- Wheel diameter (~1m) fixed by radiation damage and capture optics
- Materials fixed by thermal and mechanical properties and pair-production cross-section (Ti6%Al4%V)
- Wheel geometry (~30mm radial width) constrained by eddy currents.
- 20cm between target and rf cavity.
- Axial thickness ~0.4 radiation lengths.

Target documentation will be uploaded to http://www.ippp.dur.ac.uk/LCsources/Target/ or Zeuthen Wiki.



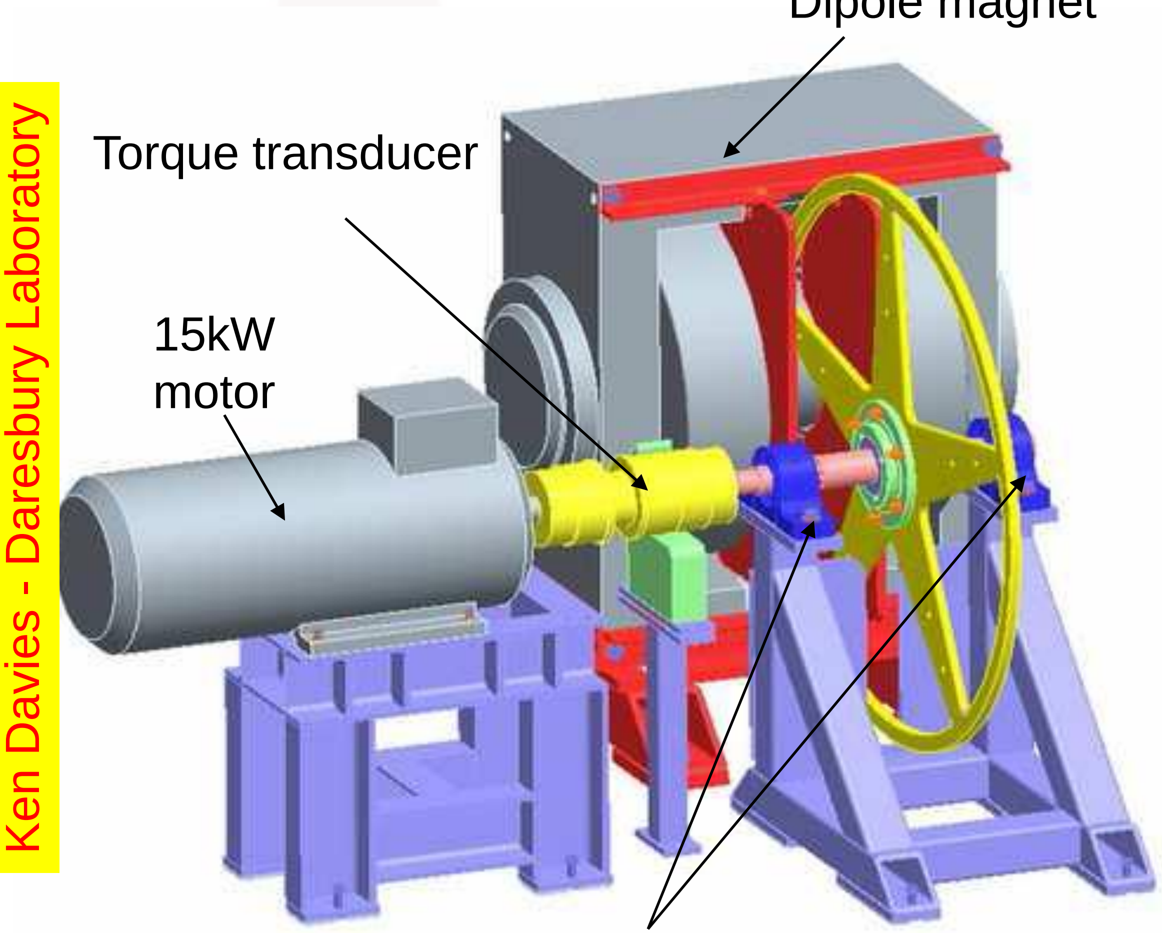
T. Piggott, LLNL

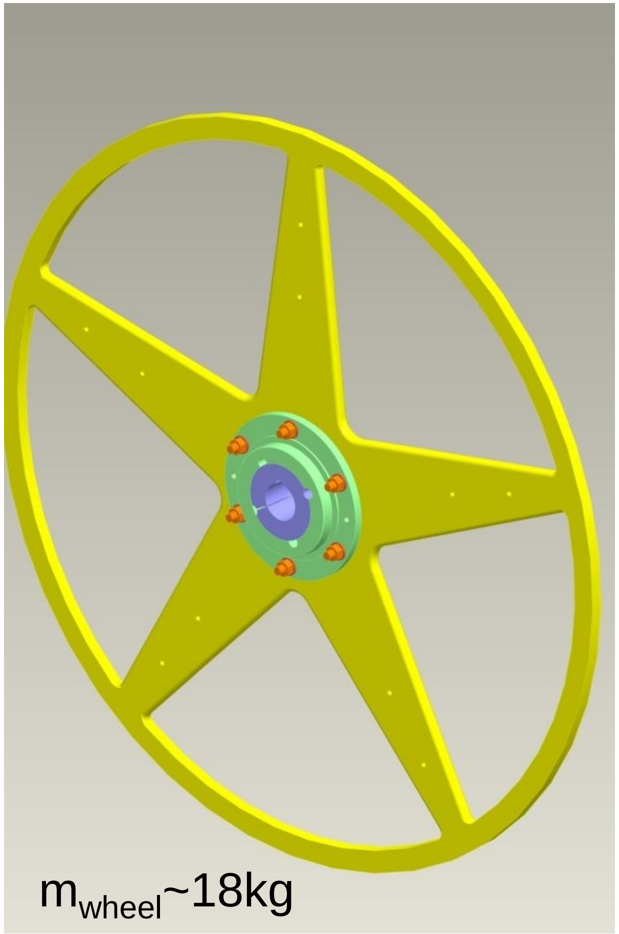
Drive motor and water union are mounted on opposite ends of through-shaft.

Target Prototype Design

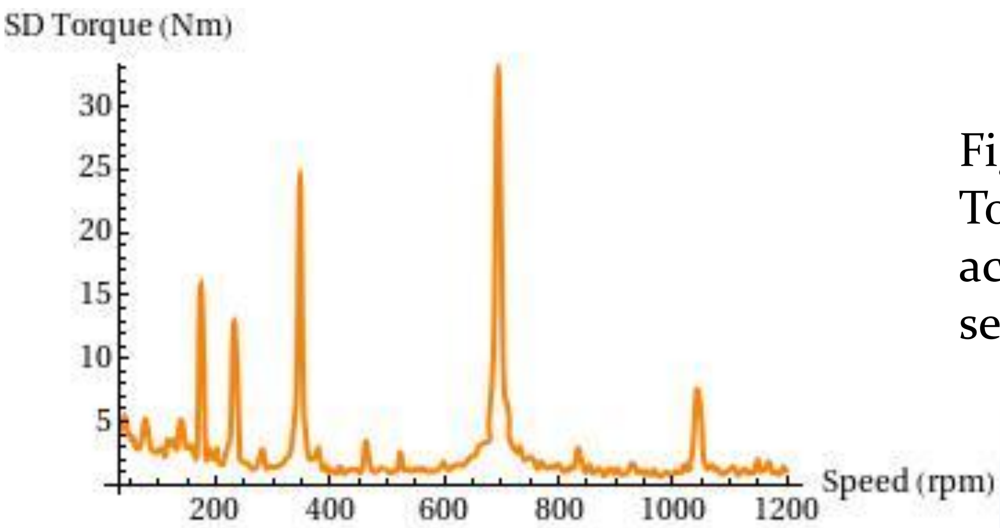
Prototype I - eddy current and mechanical stability

Ken Davies - Daresbury Laboratory

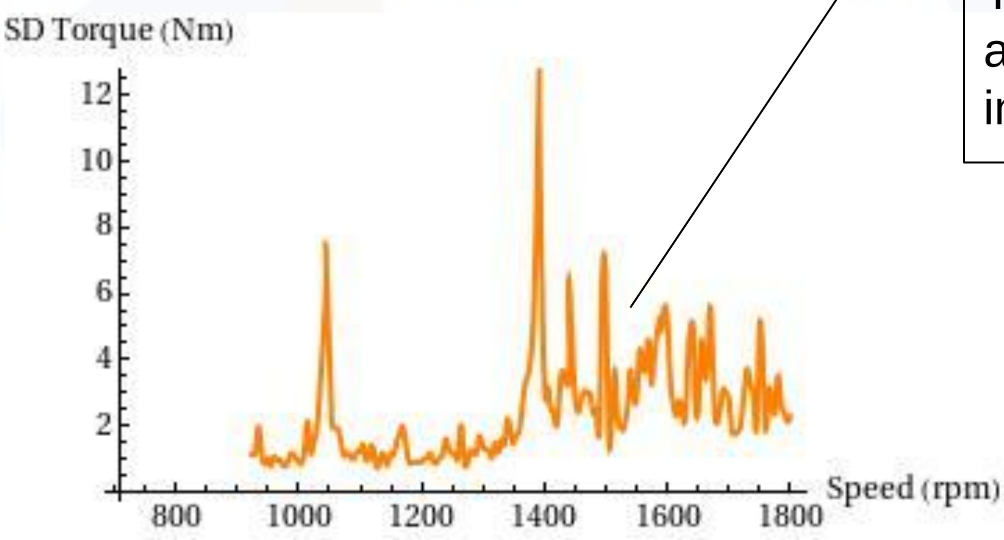




Resonances

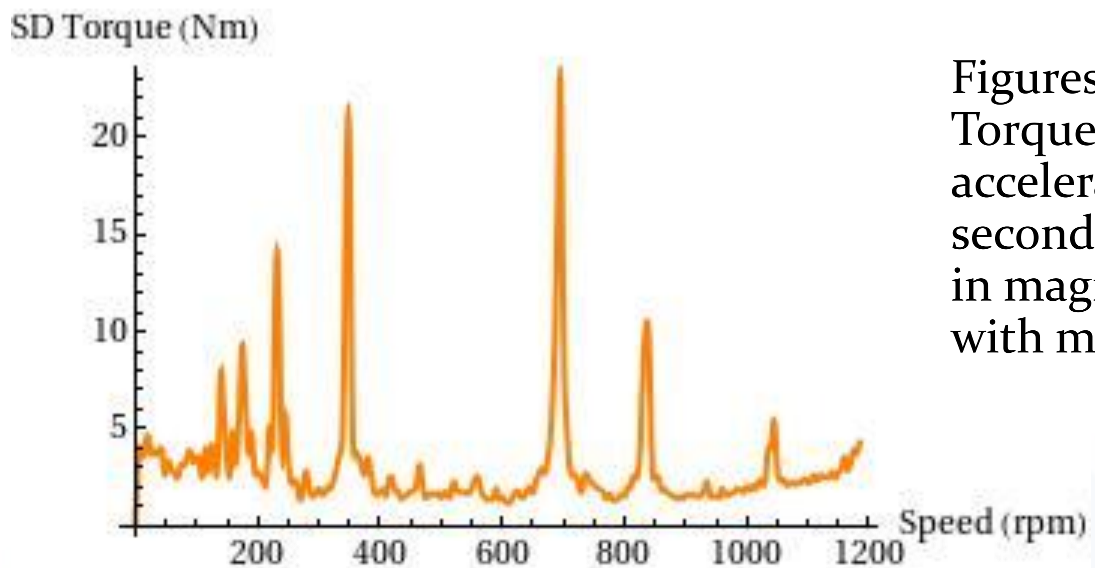


Figures show Standard Deviation in Torque (Nm) measured whilst accelerating at average rate of 6.6 rpm / second with no magnetic field.

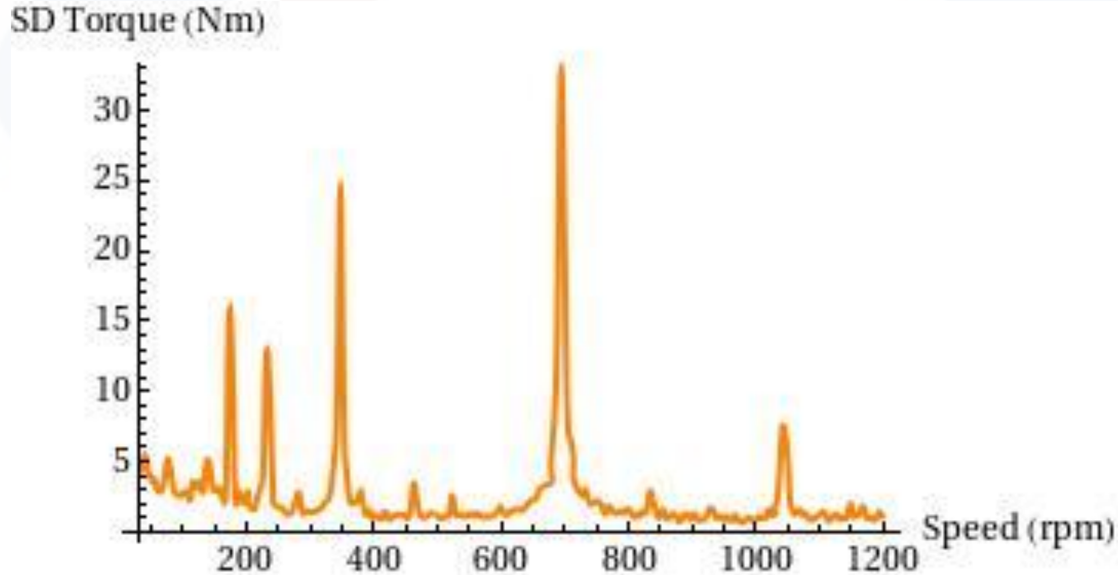


Turbulence at high speeds associated with rotation of wheel in air.

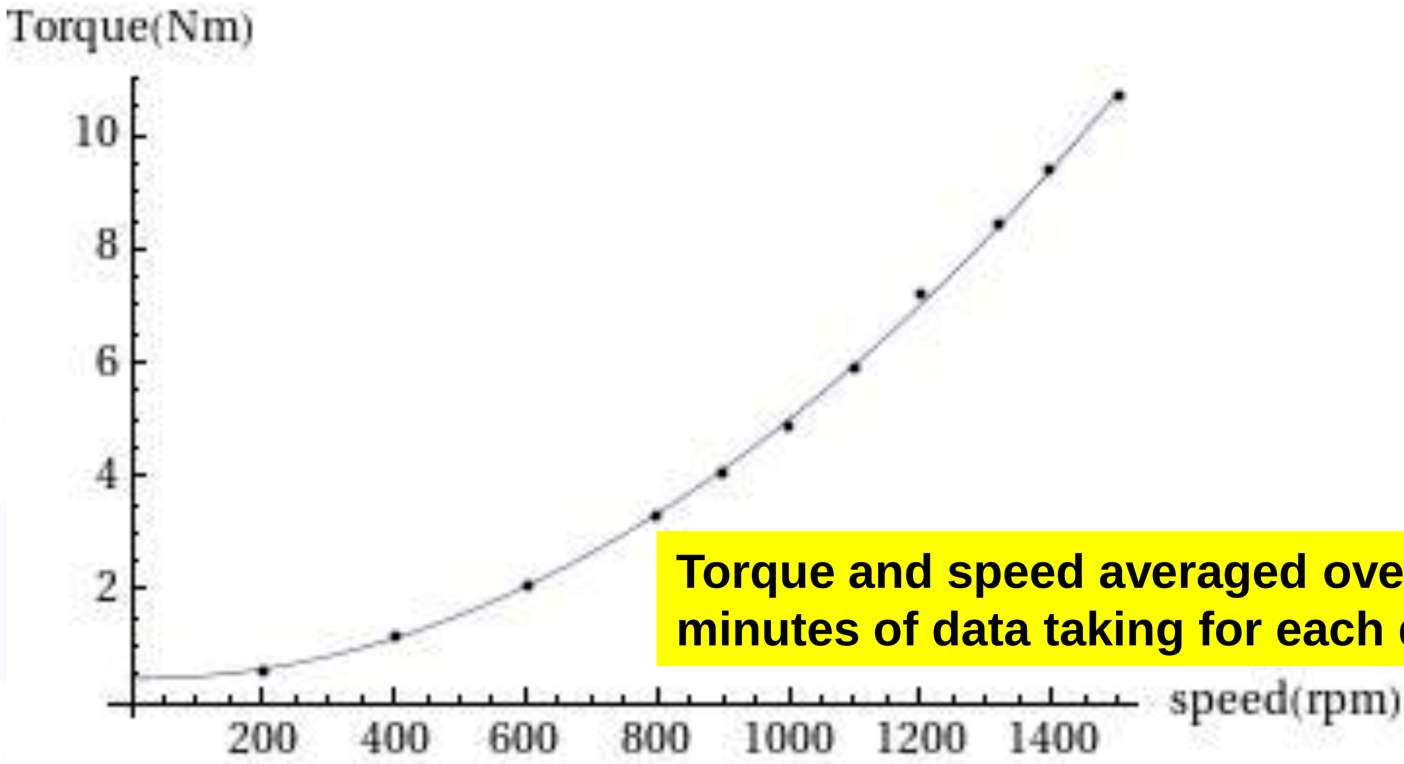
Resonances (2)



Figures show Standard Deviation in Torque (Nm) measured whilst accelerating at average rate of 6.6 rpm / second. Upper plot obtained with 50A in magnet coils. Lower plot obtained with magnet unpowered.



Characterising Frictional Forces



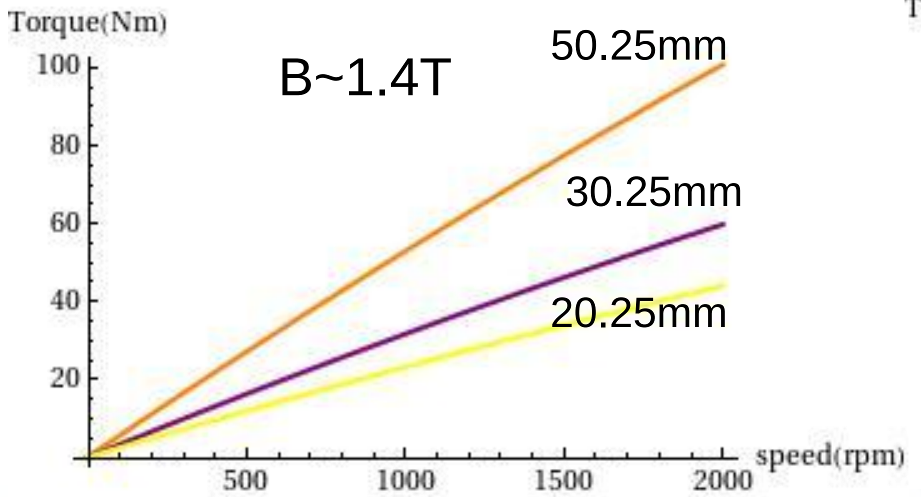
Torque and speed averaged over three minutes of data taking for each data point.

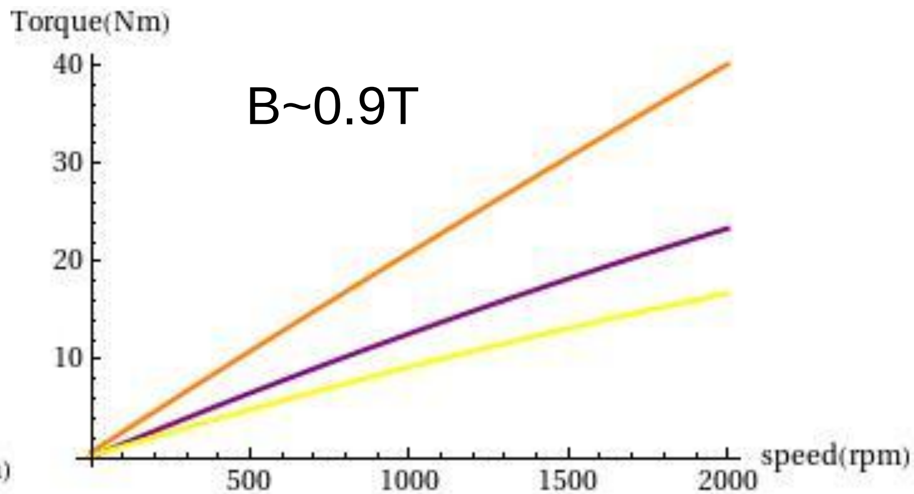
Data obtained with magnet off. Line shows quadratic fit to data points.

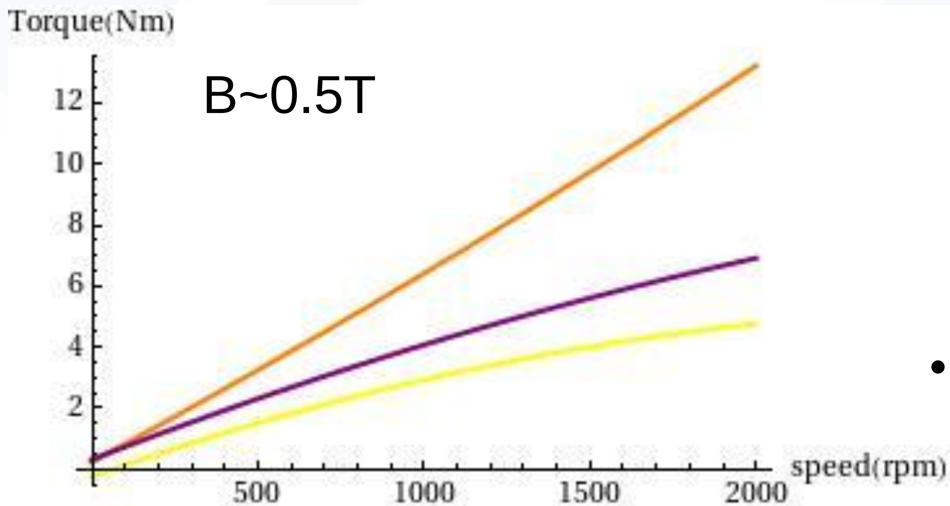
Wheel is not generally operated above 1500 rpm due to noise..

Extrapolates to ~19Nm at 2000rpm, but behaviour may change at higher velocity as bearings heat up.

Effect of B Field on Average Torque

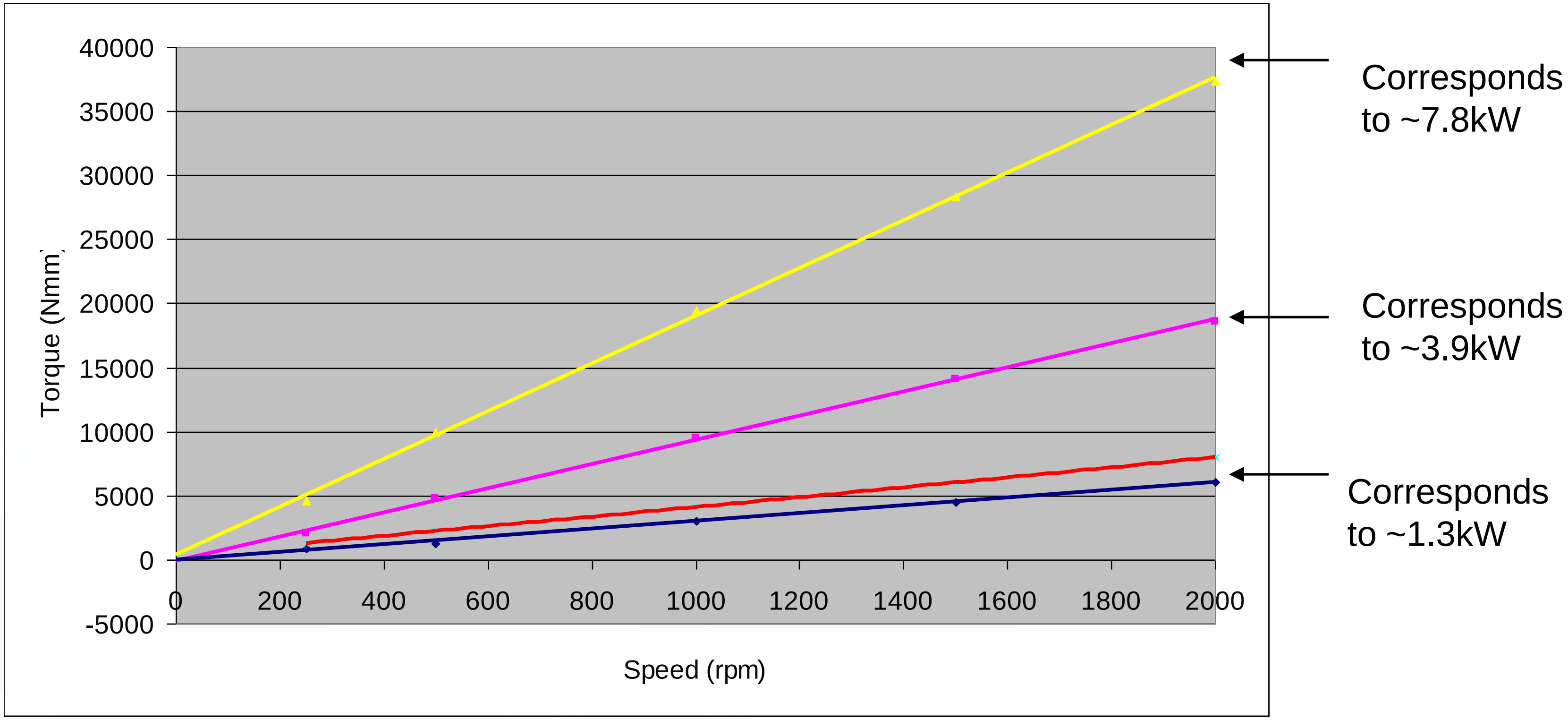






- The plots show a quadratic fit to the measured torques (≤ 1200rpm) where the effects due to bearing friction have been removed.
- The colours represent different immersion depths of the wheel in the field.

CARMEN Model Prediction



Peak (yellow), average (magenta) and minimum (blue) torques as predicted by the CARMEN model for rim immersed in a field of peak strength 0.489T.

The red line shows the current best fit from the data. Spoke effects appear to be far smaller than indicated by the CARMEN model.

Target Material Issues

- Inconsistency between torque measurements and simulations in eddy current measurements.
  - **Might** be a target material issue.
  - Conductivity tests being carried out at Lancaster University.
- Shockwave effects
    - FlexPDE simulation at Durham (Stefan Hesselbach) ongoing
    - Ansys simulation expected from DL (Luis Fernandez-Hernando)
    - Material tests being carried out by ILC collimator group using tungsten and titanium alloy samples at ATF2.

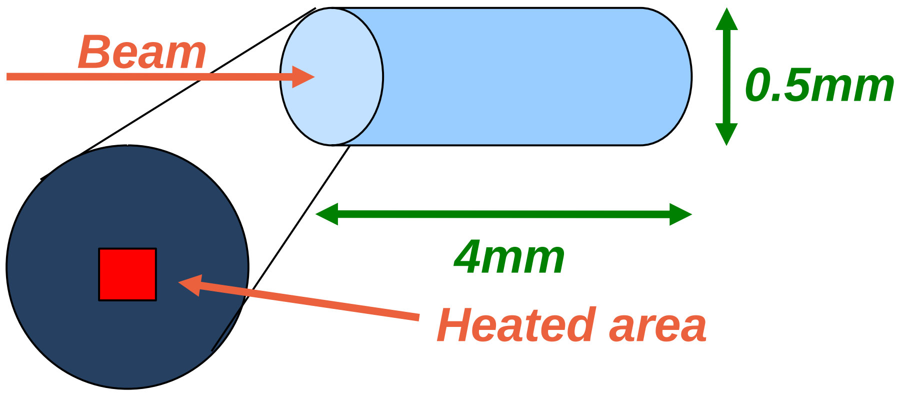
See PAC09 proceedings
http://trshare.triumf.ca/~pac09proc/Proceedings/papers/we6rfp034.pdf

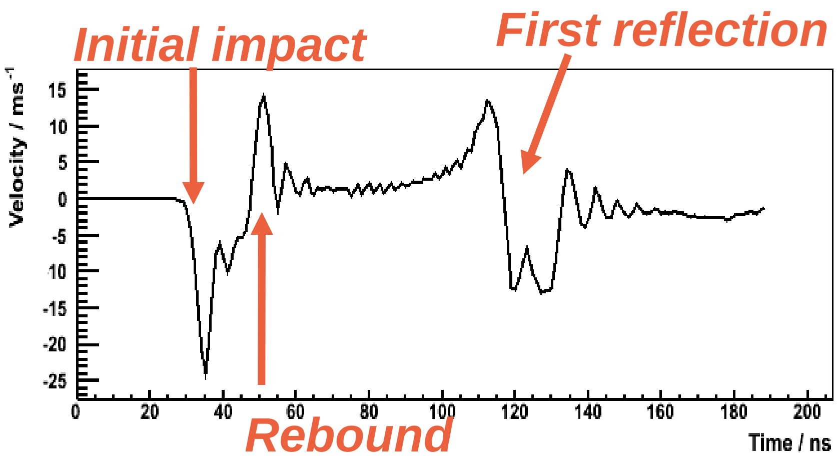
Damage Studies – Target & Simulation

Preparing to run beam tests at ATF2 to measure the shock waves produced from beam impacts on a cylindrical target. This data will be used to verify simulations produced using Autodyn and Ansys.

Target Geometry:

4mm length x 0.5mm diameter cylinder
Made of a Titanium alloy (Ti-6Al-4V)
Length limited by ATF2 restriction of 0.3% energy absorption





Simulations:

5x5um elements used
Deposited 1.96E+05 kJ/m3 (840 increase)
To simplify the geometry, 100umx100um square was used
Shockwave peaks of 25m/s over 5ns time-scales are predicted

Summary

- Undulator
  - Prototype working well apart from heat problem.
    - Expect magnets to be powered in next few weeks.
    - Magnet field quality mostly excellent. Small variations in field at 300mm intervals due to manufacturing process may cause electron trajectory kinks. Can be fixed.
    - Improved trajectories will be used to calculate new synchrotron radiation spectra
- Photon Collimator
  - Please see Zeuthen Wiki page

Target summary

- Prototype
  - Data-taking began Nov 08 and is mostly complete.
  - All measurements taken for speeds <1800rpm
  - Higher speeds $\Rightarrow$ vibration and noise (in air)
  - Extrapolating to 2000rpm shows that wheel will be able to operate in immersed fields ~1T without problems.
  - Detailed studies of torque Fourier spectra, etc ongoing
- Eddy current models
  - CARMEN consistent with earlier (rim only) ELECTRA model
  - CARMEN in agreement with new LLNL simulation at 10% level
  - Prediction of large effect from spokes not seen in data!
  - Carrying out conductivity material tests at Lancaster and further magnetic field measurements at DL to try to resolve this.
- Material tests
  - Plan to use collimator data from ATF2 (in 2010?) to calibrate beam-induced shock wave simulations.