LCWS/ILC 2007, Hamburg

Positron Source Target Development Update

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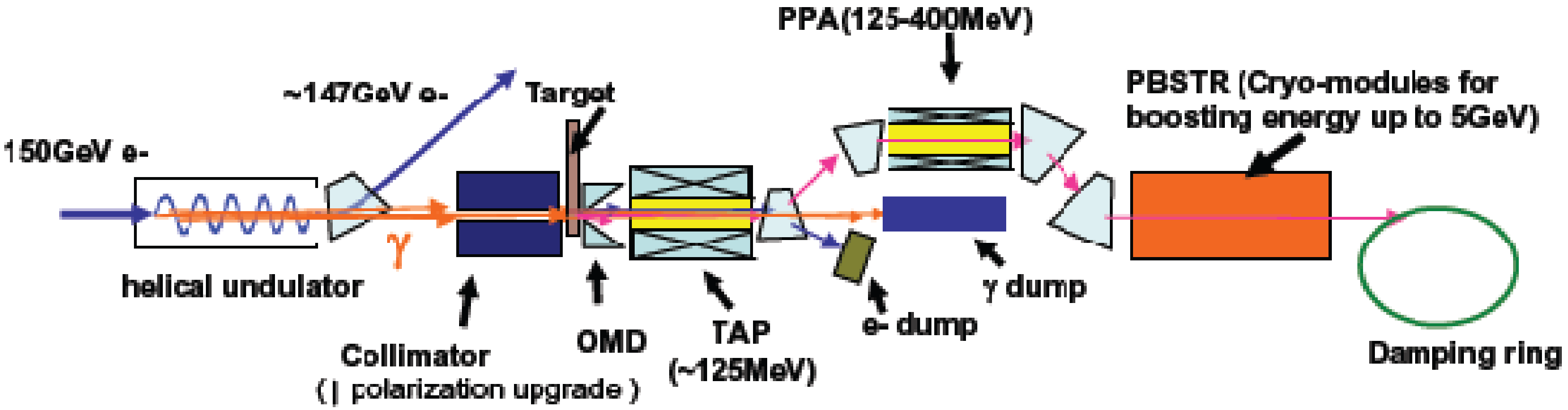
Collaborators

STFC Daresbury Laboratory, STFC Rutherford Appleton Laboratory, STFC ASTeC

ANL, DESY, LLNL, SLAC

ILC RDR Baseline Positron Source

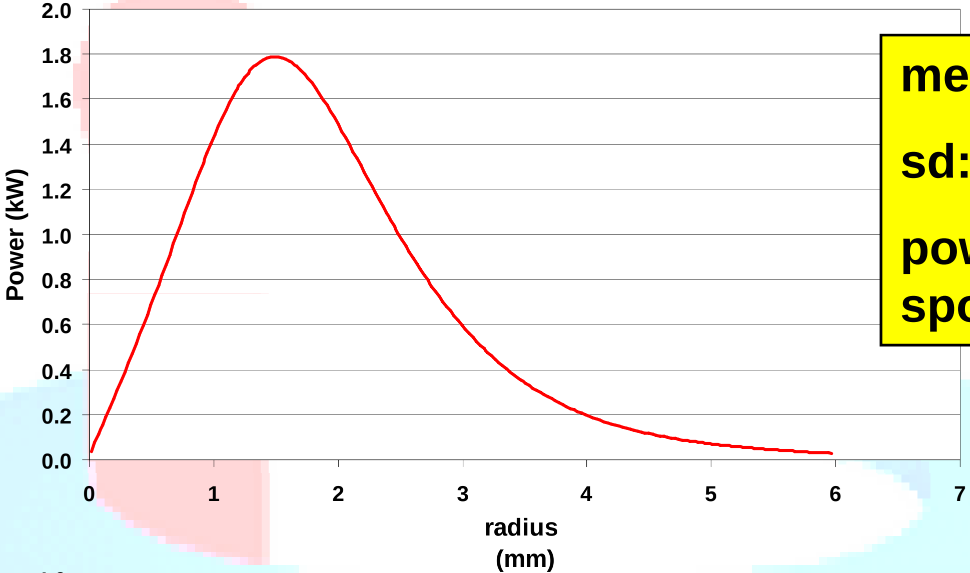


RDR Parameters Relevant for Target

- Centre of undulator to target: 500m
- Active (K=0.92, period=1.21mm) undulator length: 147m
  - Photon beam power: 131kW
  - First harmonic: 10MeV
  - Beam spot: >1.7 mm rms

Beam Spot Characteristics

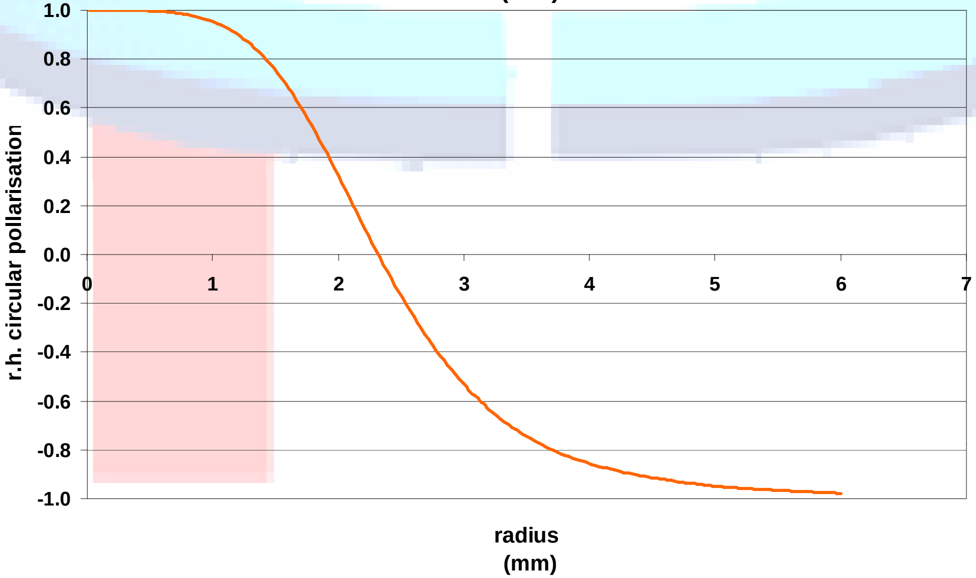
SPECTRA (v7) simulation



mean: 1.9 mm

sd: 1.0 mm

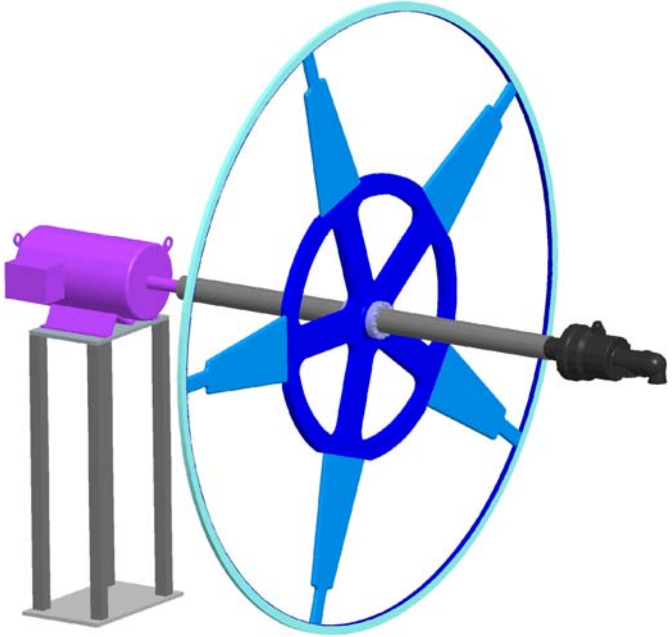
power-weighted beam spot rms: 2.2 mm



(Simple simulation of a continuous undulator without misalignments, collimation or electron beam jitter.)

Baseline 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 ~900J/g to ~24J/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.



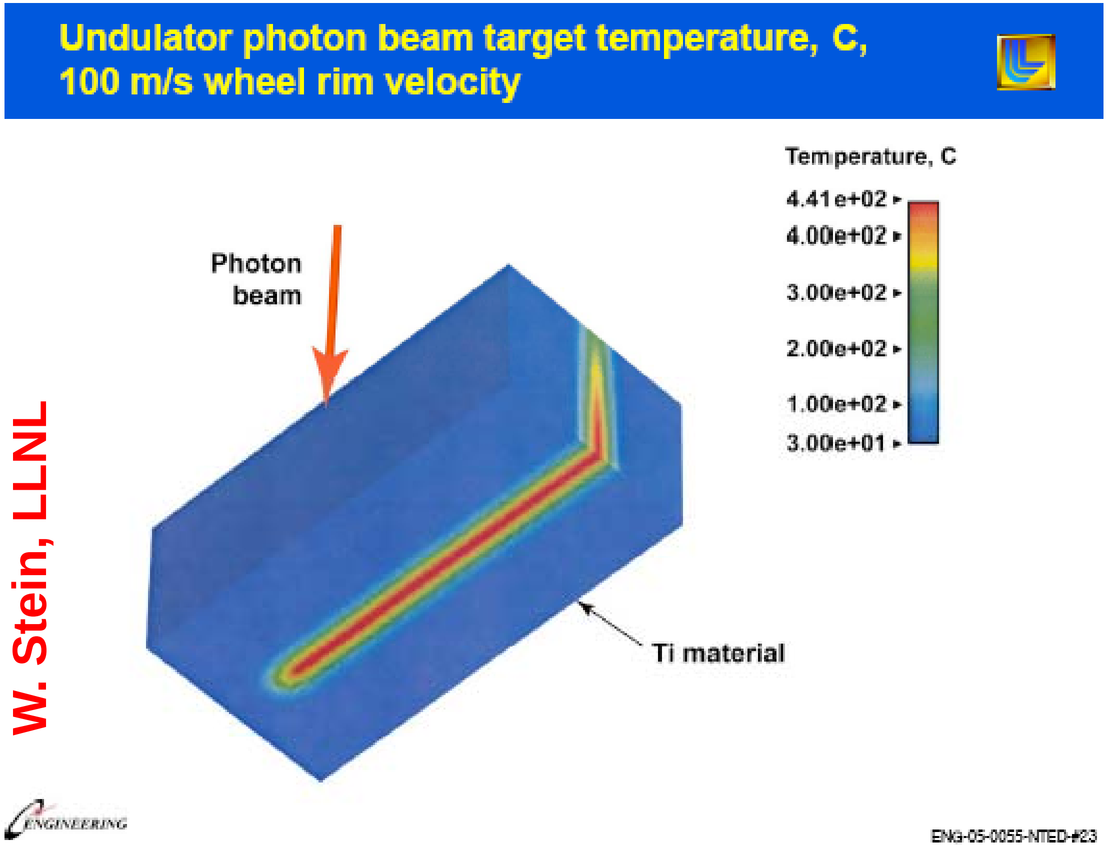
T. Piggott, LLNL

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

Baseline Target Activities

- Design underpinned by simulations
    - – Thermal and structural
    - – Vibrational and rotordynamics
    - – Capture optics effects
    - – Activation and radiation damage
        - (see talk by Andriy Ushakov)
    - – (Polarisation transfer)
- (Remote-handling solutions)
- Alternative target materials
- Target prototyping

Thermal Studies



Undulator photon beam target temperature, C,
100 m/s wheel rim velocity

W. Stein, LLNL

TOPAZ-3D and DYNA-3D simulations

- Rapid energy deposition generates a pressure shock wave
- Maximum stress is experienced at the back surface of the target
- For older beam parameters (small beam spot), peak stress was ~4x10^{8}Pa
- This is a factor of two below the yield stress
- Simulation is being re-evaluated with updated parameters and target design at LLNL.

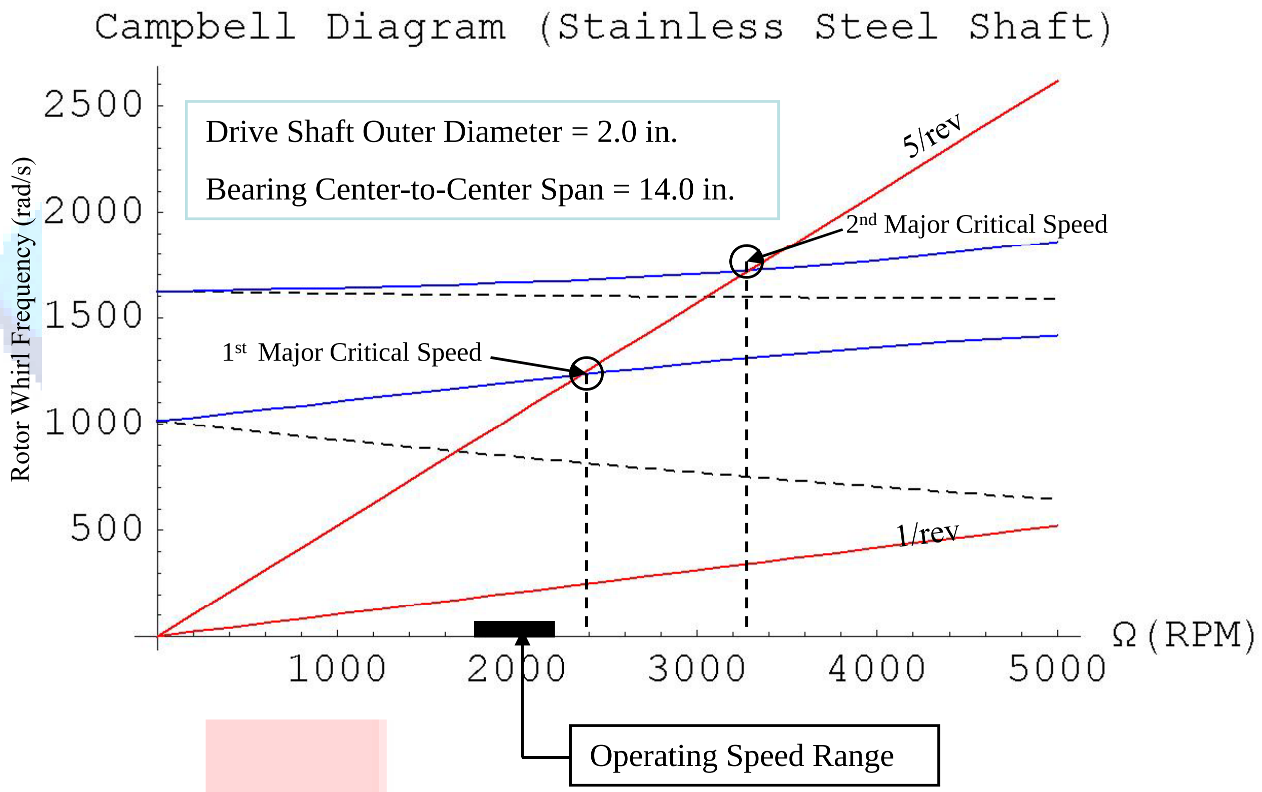
Flywheel Critical Speeds
(Stainless Steel Drive Shaft)

Nominal Design Basis Bearing + Mount Stiffnesses

Support Translational Stiffness = 1,000,000 lbf/in

Support Rotational Stiffness = 10,000 lbf*in/rad

Campbell Diagram (Stainless Steel Shaft)



Drive Shaft Outer Diameter = 2.0 in.

Bearing Center-to-Center Span = 14.0 in.

Operating Speed Range

Sources of Rotor Excitation

- Lorentz Force @ 5/rev
- Unbalance @ 1/rev

Major Critical Speeds

- Tilt Whirl @ 2400 RPM
- Cylindrical Whirl @ 3300 RPM

———	Forward Whirl
- - - -	Backward Whirl

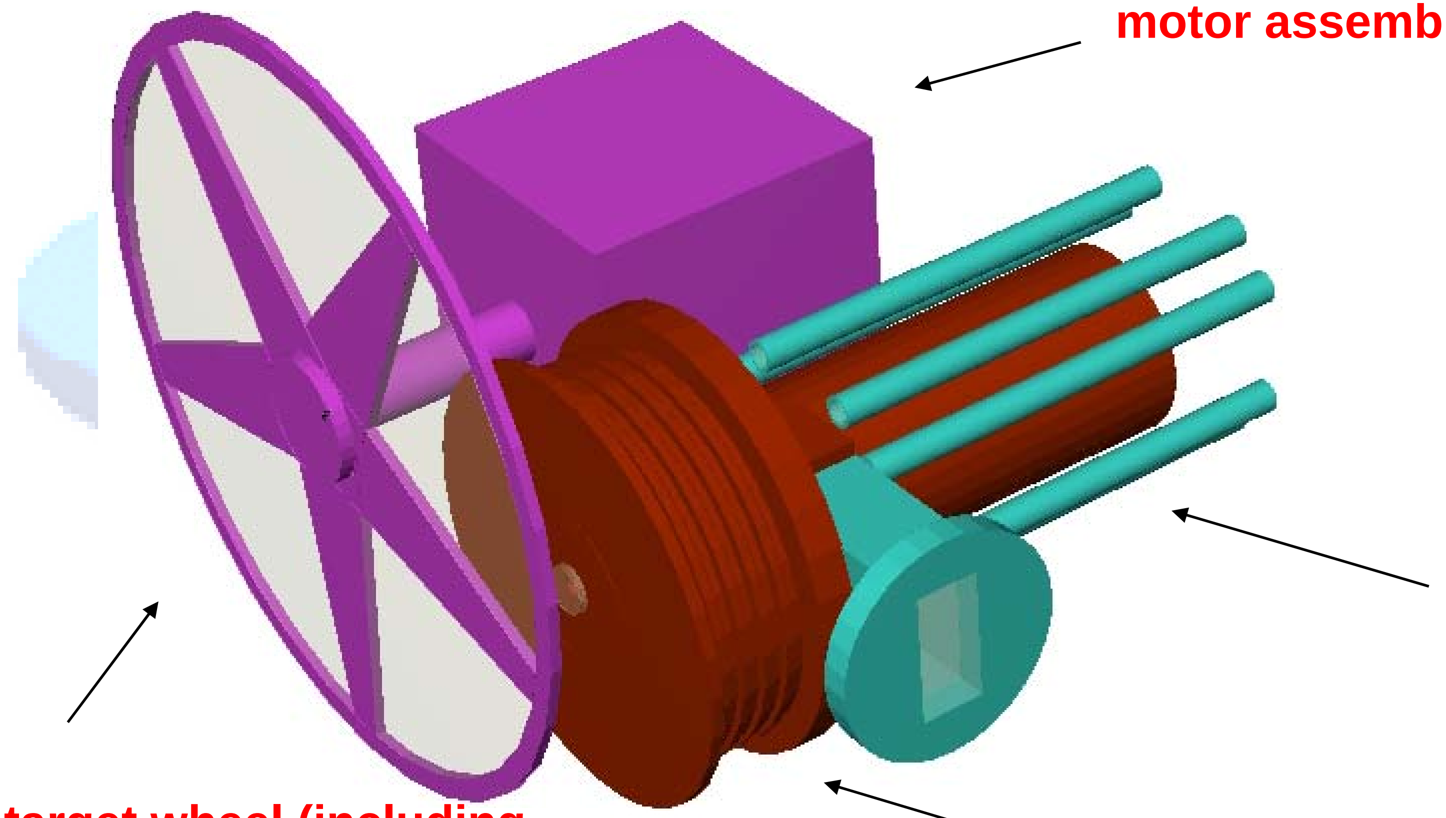
Similar plots exist for Ti drive shafts, etc.

L. Hagler, T. Piggott, LLNL

Activation Simulations

- Majority of work is being carried out at DESY (see Andriy Ushakov’s talk)
- At DL - new target geometry (mostly) migrated to FLUKA
- T-489 FLUKA benchmarking experiment carried out at CERN / SLAC
- Simulations will begin at DL shortly to augment DESY

L. Fernandez-Hernando, DL



motor assembly

n/c rf cavity

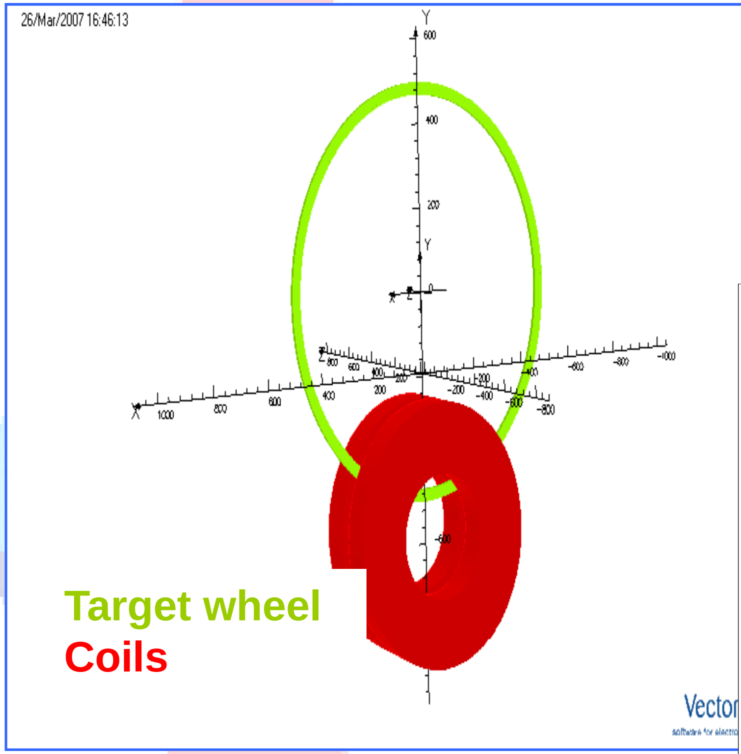
flux concentrator

target wheel (including water channel)

Eddy Current Modelling

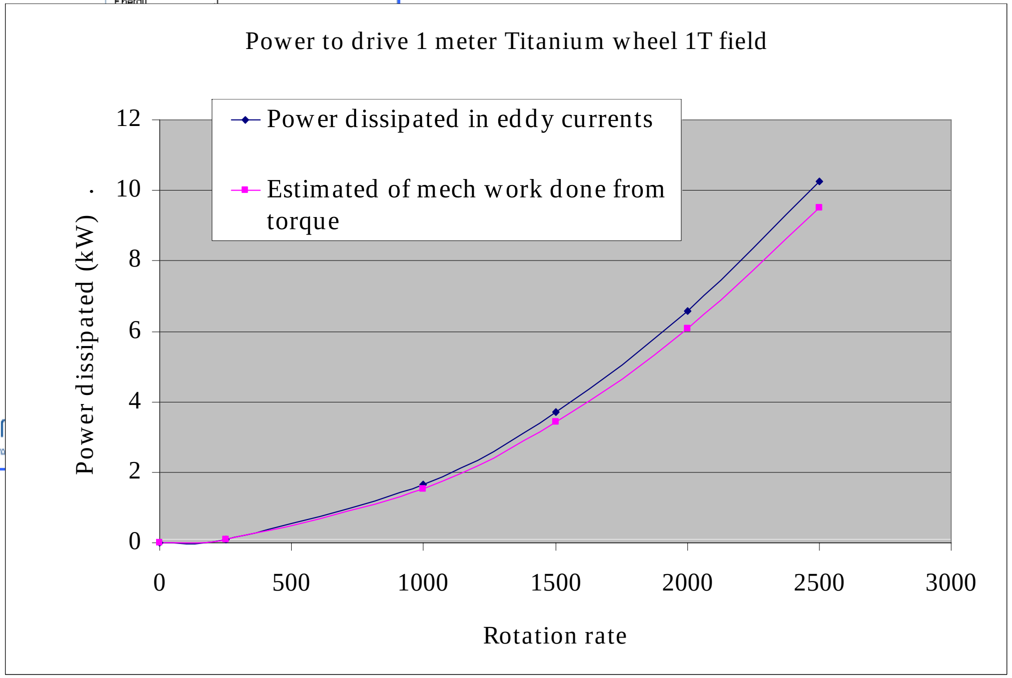
- Capture optics induce eddy currents in the target wheel.
- Eddy current simulations have been carried out by LLNL, Cornell, ANL(FEMLAB) and RAL (OPERA):
  - SLAC Cu disc experiment
  - 2m diameter wheel (older design), s/c OMD field
  - 1m diameter wheel, 1T field, up to 2000rpm
- 2m results were presented at Beijing Positron Source meeting in Jan ’07
  - Eddy current power losses of order 100kW
  - ~factor 4 difference in results from RAL and ANL
- Agreed to study 1m diameter wheel using standardised geometry and parameters.

1m Wheel Eddy Current Simulations



UNITS

Length	mm
Magn Flux Density	T
Magn Field	$A\,m^{-1}$
Magn Scalar Pot	A
Magn Vector Pot	$Wb\,m^{-1}$
Elec Flux Density	$C\,m^{-2}$
Elec Field	$V\,m^{-1}$
Conductivity	$S\,mm^{-1}$
Current Density	$A\,mm^{-2}$
Power	W
Force	N



- •For 1T field at 2000rpm
  - • RAL predicts ~6.6kW
  - •ANL predicts ~9.5kW
  - •Cornell? LLNL?
- •Difference not yet understood…

⇒ Alternative capture optics, alternative materials, prototyping

J. Rochford, RAL

Ceramics as Alternative Target Materials

P. Loveridge, RAL

		Reference Materials		*Machinable Ceramics*		*Nitrides*			
		Titanium Alloy Ti-6Al-4V Grade 5 Annealed	**Isotropic Graphite IG-43**	**“Macor” Machinable Glass-ceramic**	**“Shapal-M” Machinable Aluminium Nitride**	**AlN Aluminium Nitride**	**Si_3N_4 Silicon Nitride (Hot Pressed)**	**“Sialon” Solid Solution**	**BN Boron Nitride**
Heat Capacity	J/kg.K	526	711 @24ºC 2092 @997ºC	790	480	800	680 - 800	620 - 710	800 – 2000
Expansion Coefficient	/K	8.6-9.7 x 10^{-6}	4.8 x 10^{-6}	13 x 10^{-6}	5.2 x 10^{-6}	4.4 x 10^{-6}	3.3 x 10^{-6}	3.3–3.7 x 10^{-6}	1 – 36 x 10^{-6}
Density	Kg/m^3	4430	1820	2520	2950	3330	3110	3240	1900 - 2200
Radiation Length	mm	41	235		93	83	85		211
Thermal Conductivity	W/m.K	6.7	140	1.46	100	175 - 190	15 - 43	20	15 – 50
Electrical Resistivity	Ohm.m	1.78 x 10^{-6}	9.2 x 10^{-6}	>10^{12}	1.8 x 10^{11}	>10^{11}	>10^{10}	>10^{10}	>10^{9}
Max. Use Temperature	ºC	Melting Point ~1600		800	1000 – 1900 In non-oxidising atmosphere	1000 – 1800 In non-oxidising atmosphere	1100 - 1650	1000	950 - 2500
Tensile Strength	MPa	Yield 880 UTS 950	37				400 - 580	400 - 450	
Compressive Strength	MPa	Yield 970	90	345	1000		2000 - 3500	3500	30 – 120
Elastic Modulus	GPa	114	10.8	67	160		280 - 310	280 - 300	20 - 35

Ceramics as Alternative Target Materials

P. Loveridge, RAL

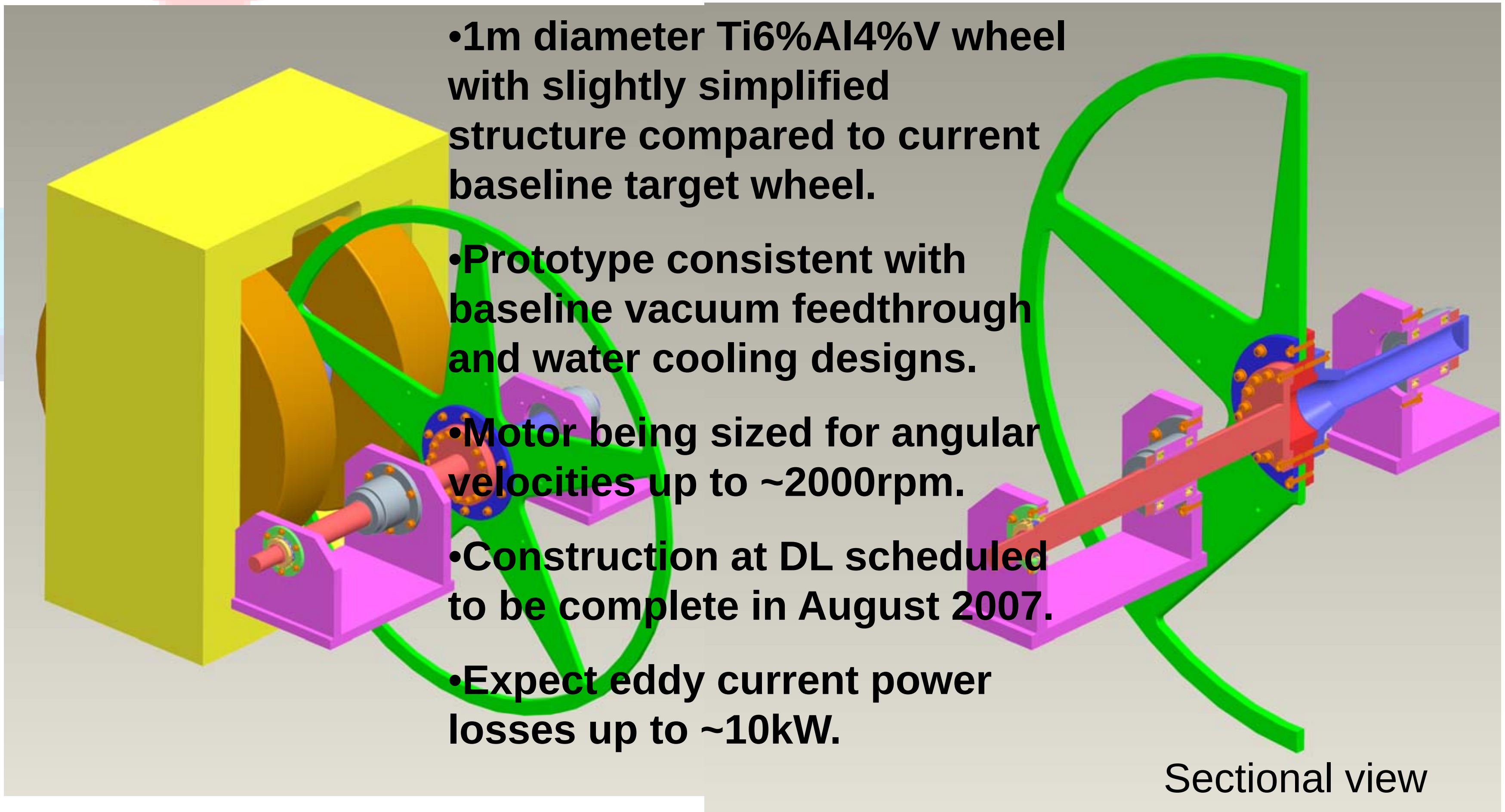
		Carbides				*Oxides*			
		B_4C Boron Carbide (Hot Pressed)	**SiC Silicon Carbide (Reaction Bonded)**	**SiC Silicon Carbide (Hot Pressed)**	**WC 94 / Co 6 Tungsten Carbide / Cobalt**	**BeO 99.5% Beryllia**	**Al_2O_3 99.9% Alumina**	**ZrO_2 / MgO Zirconia (Magnesia stabilised)**	**YO 99.9% Yttrium Oxide**
Heat Capacity	J/kg. K	950	1100	670 - 710	200 - 480	1020 - 1120	880	400 - 500	
Expansion Coefficient	/K	5.6 x 10^{-6}	4.3–4.6 x 10^{-6}	4.5 x 10^{-6}	4.6–5.0 x 10^{-6}	8.4–9.0 x 10^{-6}	8.5 x 10^{-6}	5 – 10 x 10^{-6}	8.1 x 10^{-6}
Density	Kg/m^3	2500	3100	3150	14950	2860	3900	5740	5030
Radiation Length	mm	201	83	81	6	144	72		23
Thermal Conductivity	W/m. K	30 - 90	150 - 200	90 – 160	60 - 80	260 – 300	28	1.5 – 2.5	8 - 12
Electrical Resistivity	Ohm. m	0.001 – 0.1	1 - 10	10 - 1000	2 x 10^{-8}	>10^{12}		See note	10^{12}
Max. Use Temperature	ºC	600 - 800	1350	1500 - 1650		1800 - 1900	1900	1000	Melts at ~2400 ºC
Tensile Strength	MPa	350	310	400	1440			>300	
Compressive Strength	MPa	1400 - 3400	2000 - 3500	1000 - 1700	5300 - 7000	1550 - 1850	>2500	1500 - 2000	
Elastic Modulus	GPa	440 - 470	410	200 - 500	600	340 – 400		200	170

Prototype Target Wheel Experiment

- Aim to construct and test a prototype to establish the mechanical stability of the target wheel assembly in the field of a strong magnet (~1T).
- Does not include internal water-cooling channels.
- Does not include vacuum vessel or vacuum testing.
- Due to begin assembly of wheel at DL in Summer ’07.
- Commissioning and balancing of the prototype wheel should be complete September ’07.
- Experiment scheduled to finish May ’08.
- Will benchmark eddy current and rotordynamic simulations.
- Originally envisaged as the first stage of a series of prototypes…depending on funding.

Target Prototype Design

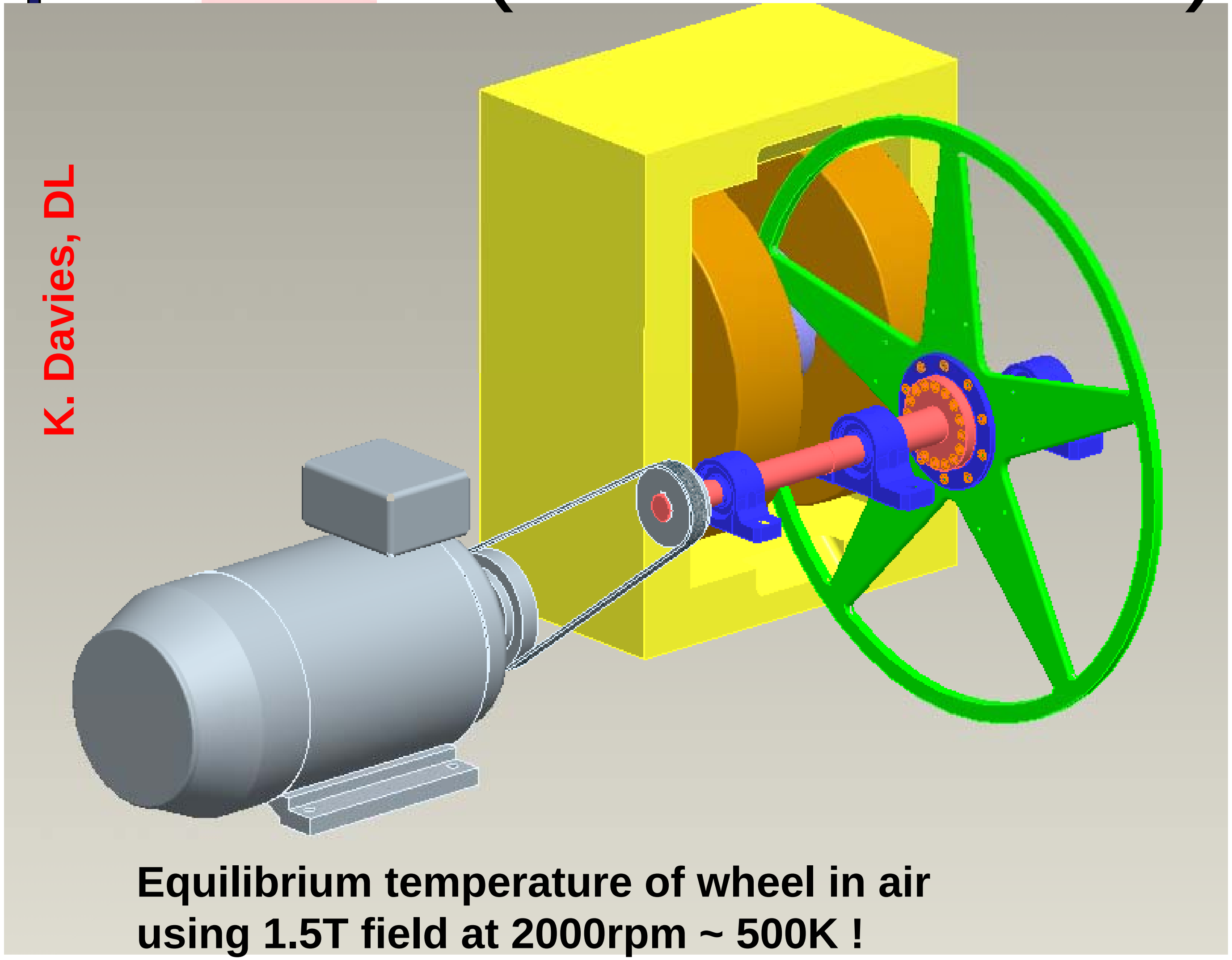
Mechanical stability and eddy current tests



- 1m diameter Ti6%Al4%V wheel with slightly simplified structure compared to current baseline target wheel.
- Prototype consistent with baseline vacuum feedthrough and water cooling designs.
- Motor being sized for angular velocities up to ~2000rpm.
- Construction at DL scheduled to be complete in August 2007.
- Expect eddy current power losses up to ~10kW.

Sectional view

Prototype Target Wheel (with Belt Drive)



K. Davies, DL

Equilibrium temperature of wheel in air using 1.5T field at 2000rpm ~ 500K !

Shows vacuum feedthroughs replaced with cheaper (and stiffer) Plummer block assemblies.

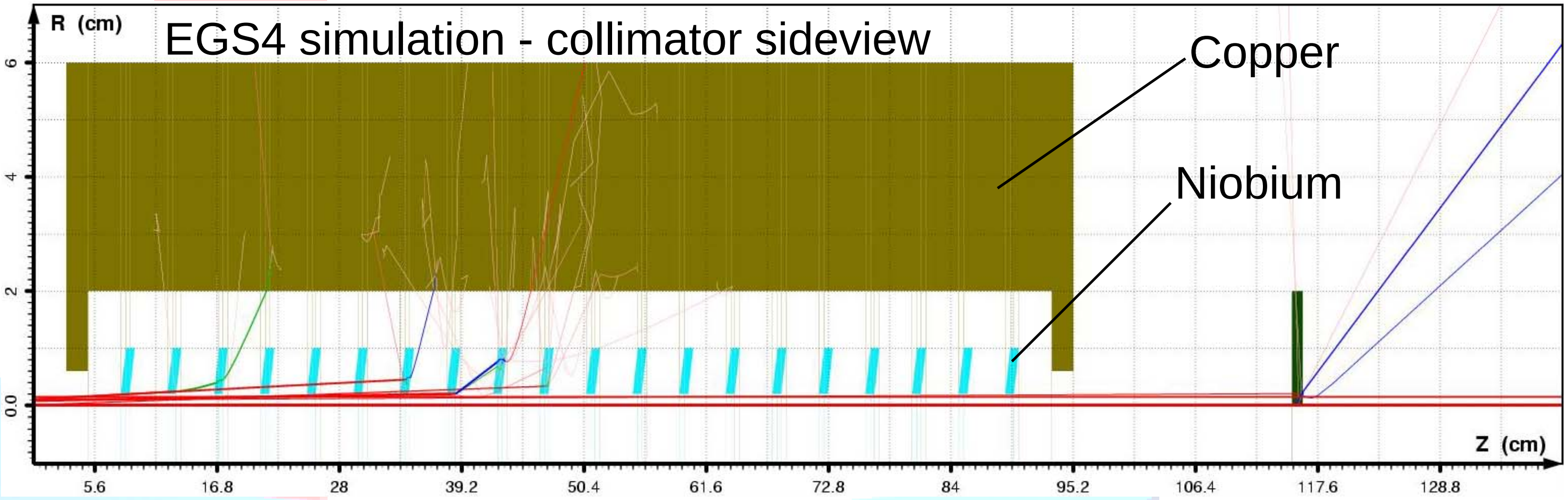
It has not yet been decided whether to use a direct-drive or belt-drive motor.

Instrumentation includes: torque sensor, remote temperature gauges and accelerometers.

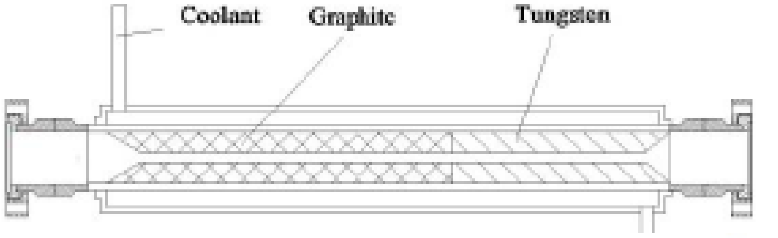
Target Prototyping Status

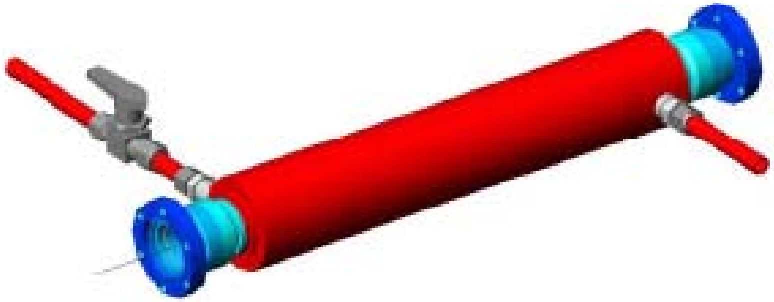
- Project is funded
- Space has been allocated at DL
- Magnet has been sourced
  - model 3474-140 GMW water-cooled electromagnet
  - variable pole gap (0mm->160mm)
- Design should be complete ~mid-June
- Design consistent with
  - Water-cooled rotating vacuum feedthroughs (Rigaku RMS-F1-HS-50-W-C MagnaSeal)
  - Rotating water union (Deublin 55 series)
- Instrumentation and DAQ being designed (Andy Gallagher - DL, Leo Jenner - Liverpool)
- Draft document outlining experimental programme has been written and circulated

Photon Collimator


EGS4 simulation - collimator sideview

N. Golubeva and V. Balandin, DESY





A. Mikhailichenko, Cornell

Purpose of collimator

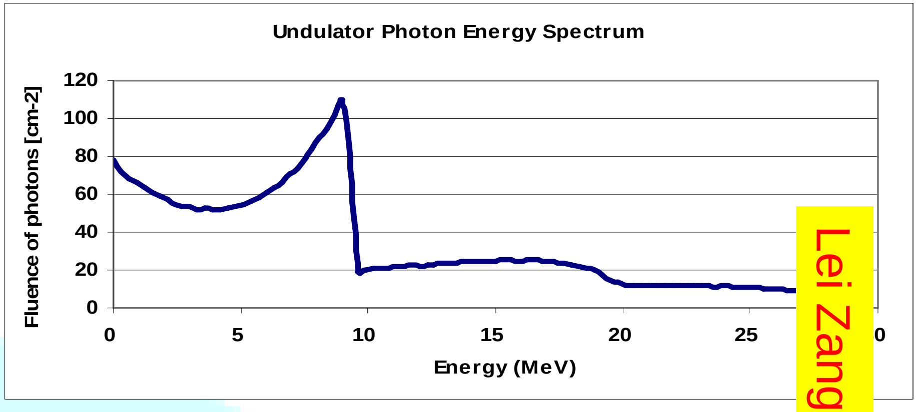
- Scrape beam
- Adjust beam polarisation

FLUKA Photon Collimator Simulations

Simulations started in FLUKA

Calculating energy deposition, peak and average heating.

Investigating cooling solutions.



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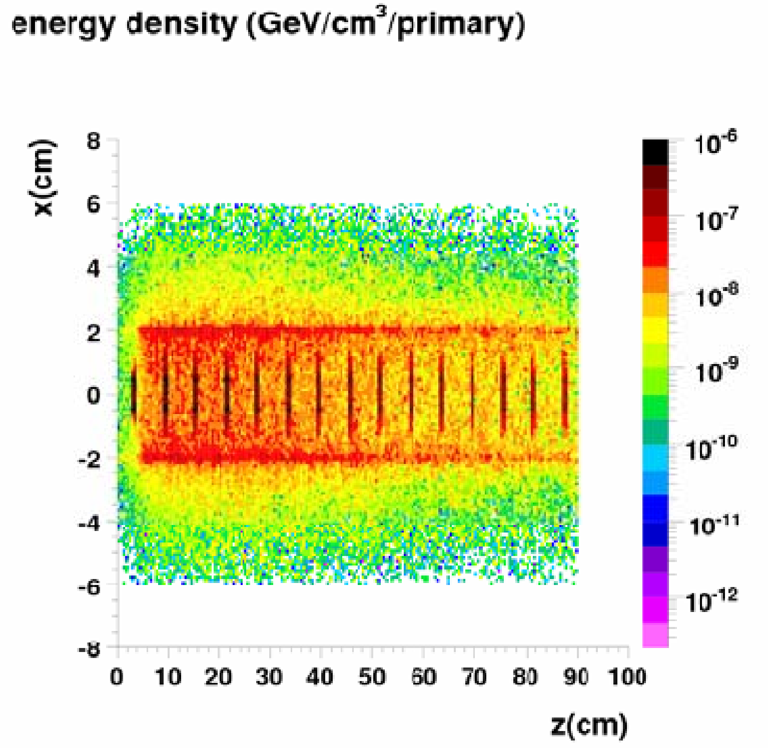

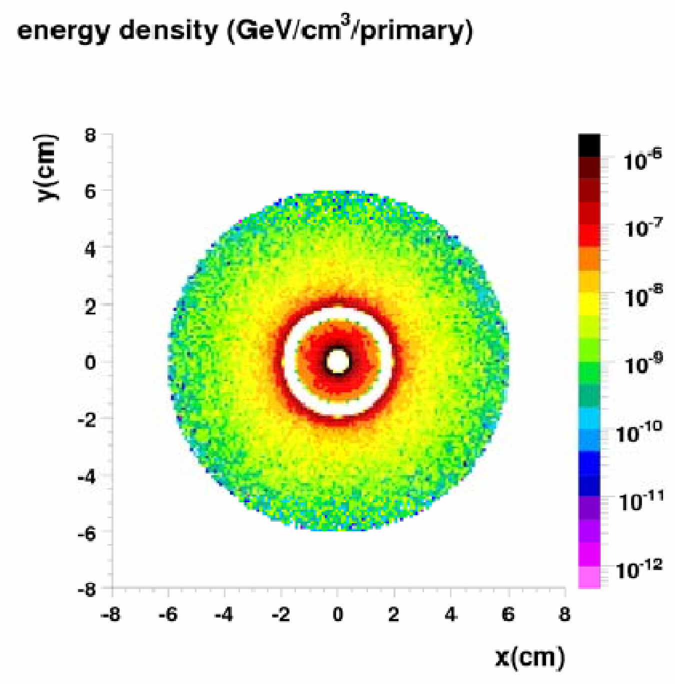

Lei Zang, University of Liverpool

Summary and Future Activities

SIMULATIONS

- Thermal + structural
  - Updated studies underway at LLNL
  - Larger beam spot may relax constraints on wheel speed
- Rotordynamics
  - Ongoing studies for both prototype wheel and baseline design
- Capture optics effects / eddy currents
  - Need to resolve mismatch between RAL and ANL results.
  - Simulations of pulsed magnets and CARMEN simulation of spoke effects are expected soon.

REMOTE-HANDLING

- Current vertical r.h. design will be written up as a report Summer '07
- Little UK funding available to fund this activity at RAL for the coming financial year.

TARGET-PROTOTYPING

•Design for prototype to measure eddy current effects in target rim is well-advanced.

•Solutions need to be found to keep the magnet cool when operating at high field (radiative and conductive heating of pole caps).

•Instrumentation needs to be finalised.

•Experiment should be taking data in Autumn '07.