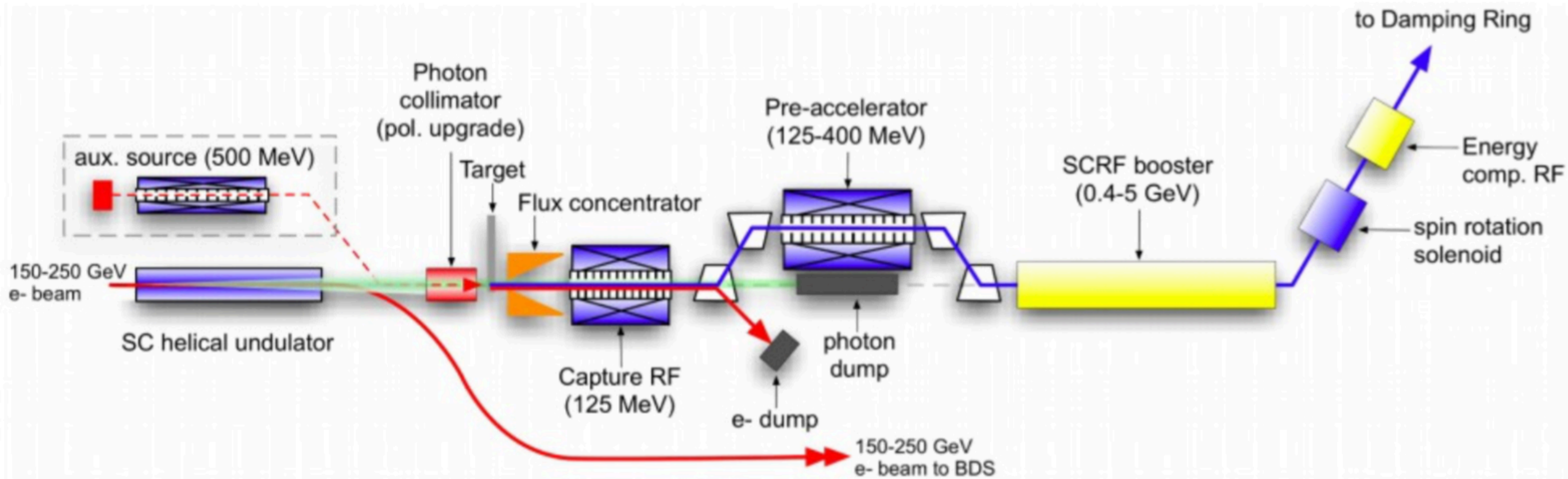
Positron Source Target R&D

Mike Harrison

Positron Production Baseline Design



147m active undulator length, additional 73.5m is reserved for the polarization upgrade.

500m drift space between the undulator and target.

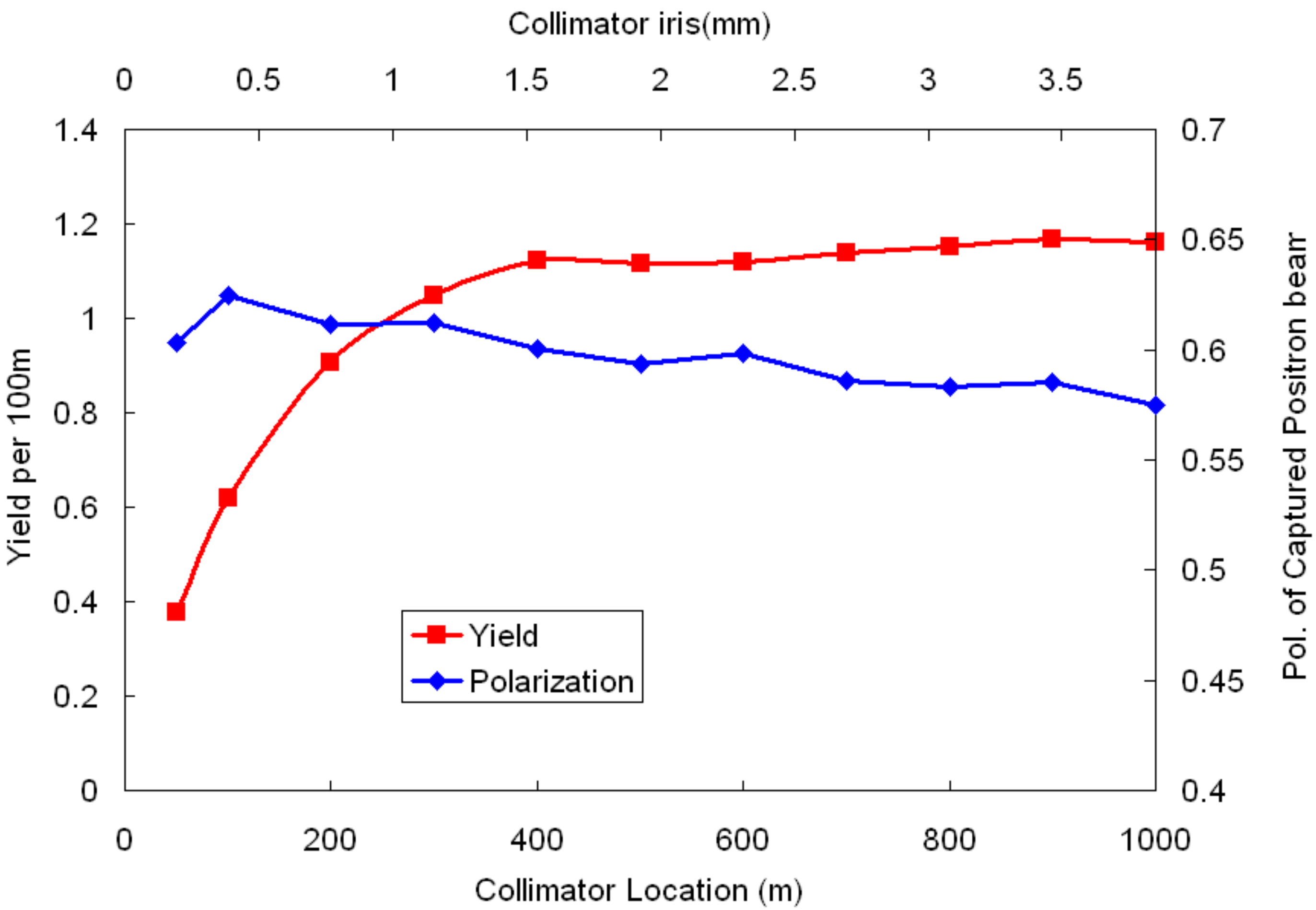
NC RF up to 400 MeV for capturing.

SRF up to 5GeV

Energy Compressor

Spin Rotation solenoid

Polarised Positron Production

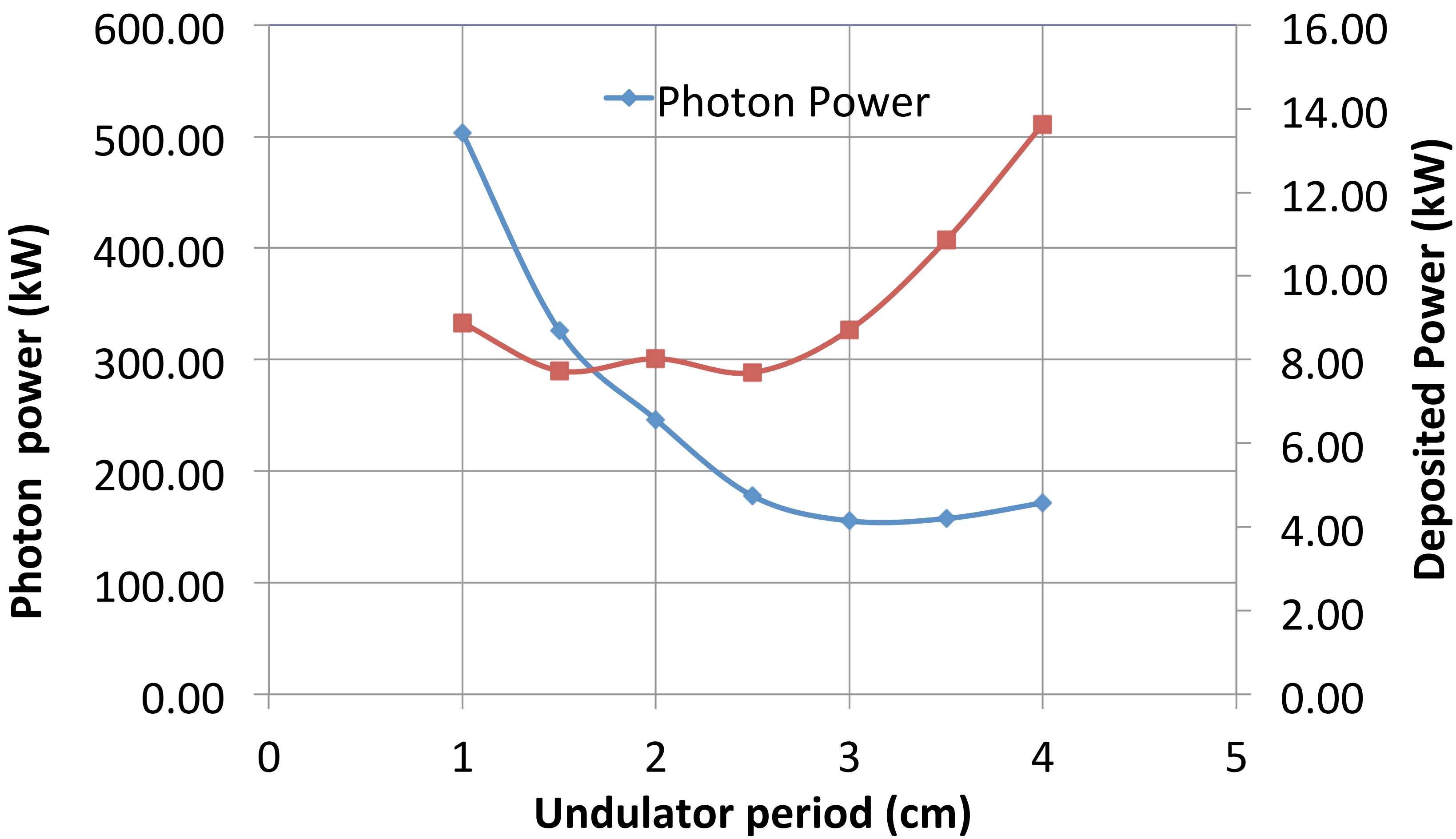


The critical feature of the undulator based source is the ability to generate polarised positrons

Nomura Nov 2015
Mike Harrison

LINEAR COLLIDER COLLABORATION

Photon Power and energy deposition in target per 1.5 positron yield (1 TeV)



The deposited power ~ 14kW undulator has a period of 4cm while the total photon power is about 172kW.

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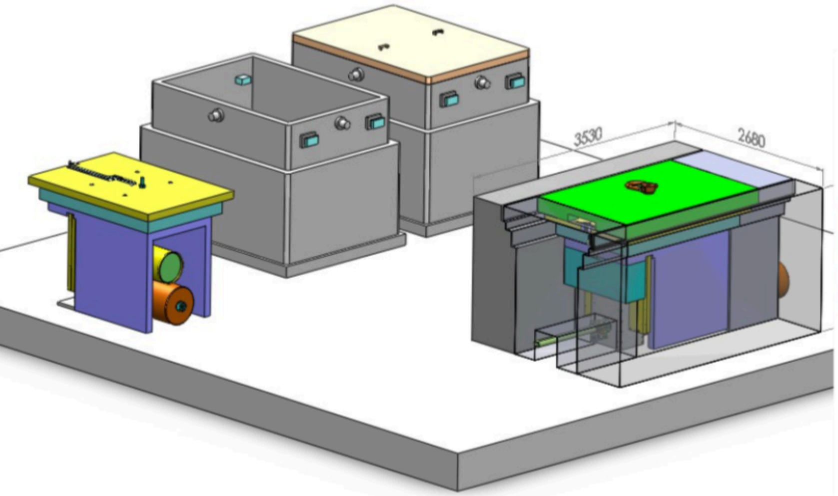
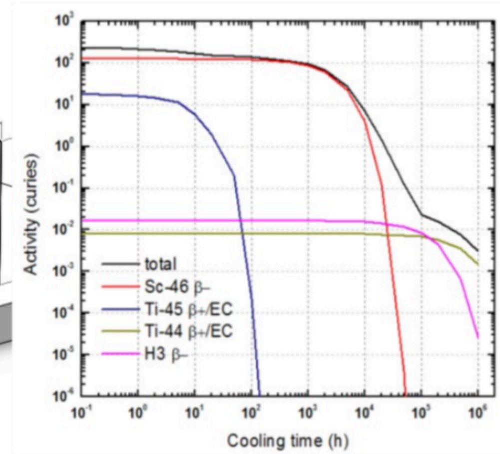
Positron Target Features

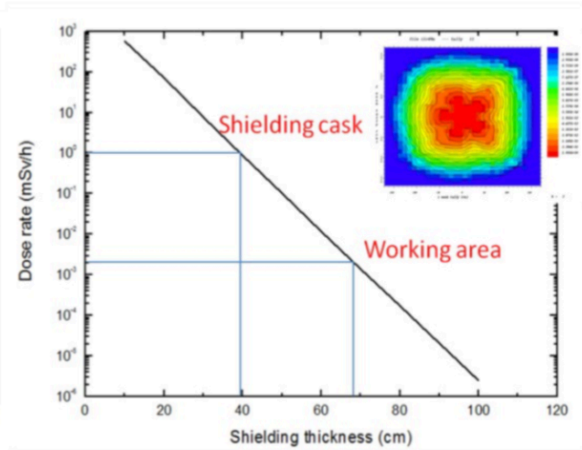
Parameter	Number	Unit
Undulator period	11.5	mm
Undulator aperture	5.85	mm
Undulator Strength *K*	0.92/0.75/0.42	
Drive Beam Energy	150/175/250	GeV
Undulator Type	Helical	
Undulator Section Length	147	m
1st cut off energy	10/16/42	MeV
Photon Beam power	63/55/42	kW
Target material	Ti-6Al-4V	
Target Thickness	0.4/14	X_0/mm
Positron Polarization	30	%

Positron Target Features

Target area shielding and target remote handling







- The target will be highly activated after one year of operation.
- 150kW photon beam, 5000 hours, 1 week after,170 mSv/h at 1m. Concrete shielding of 0.8m thick.
- A remote-handling system is used to replace the target, OMD and the 1st 1.3m NC RF cavities.

Positron Target Features

Wheel rim speed (100m/s, 2000 rpm) determined by instantaneous energy deposition

Rotation reduces pulse energy density (averaged over beam spot) from ~900 J/g to ~24 J/g

Cooled by internal water-cooling channel (~ 10 KW)

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.

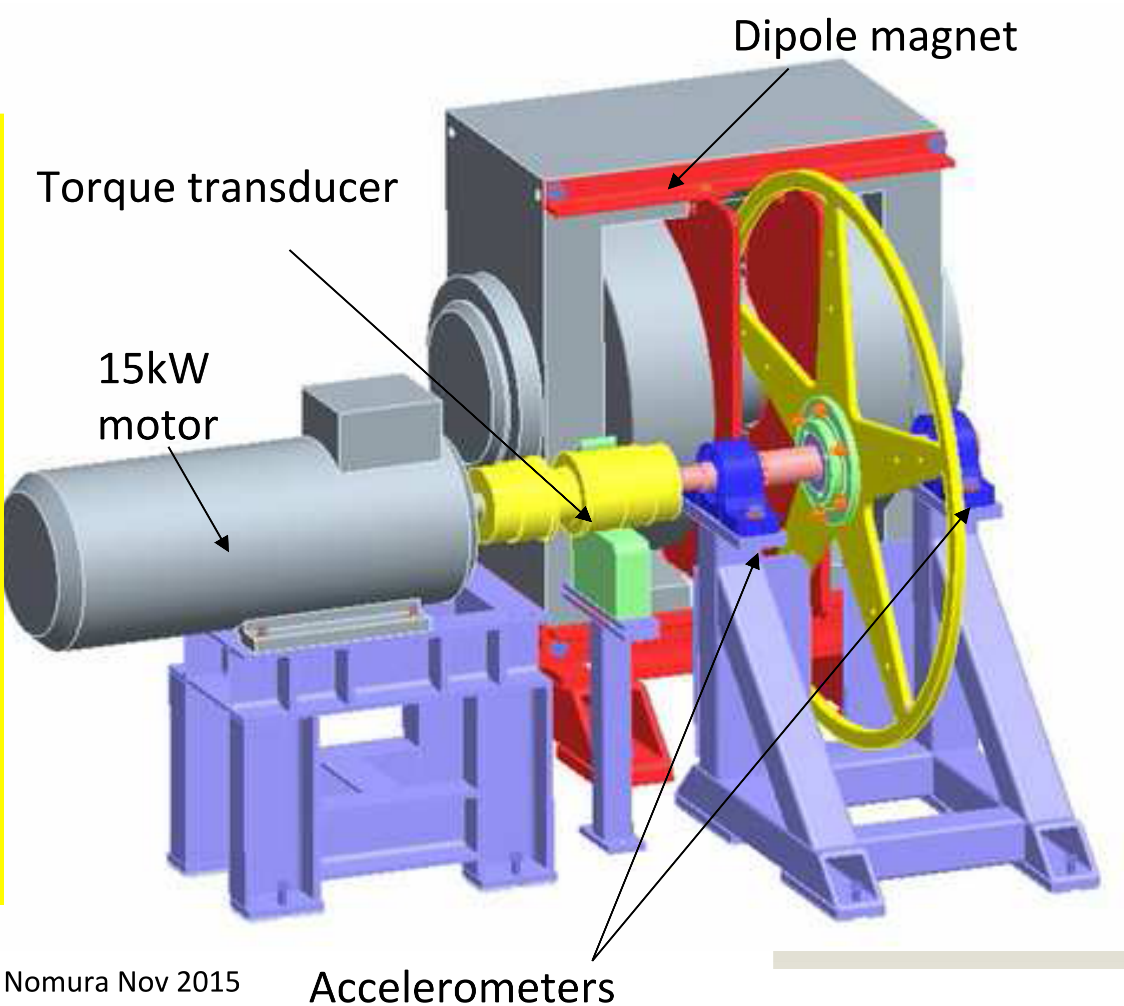
20cm between target and rf cavity.

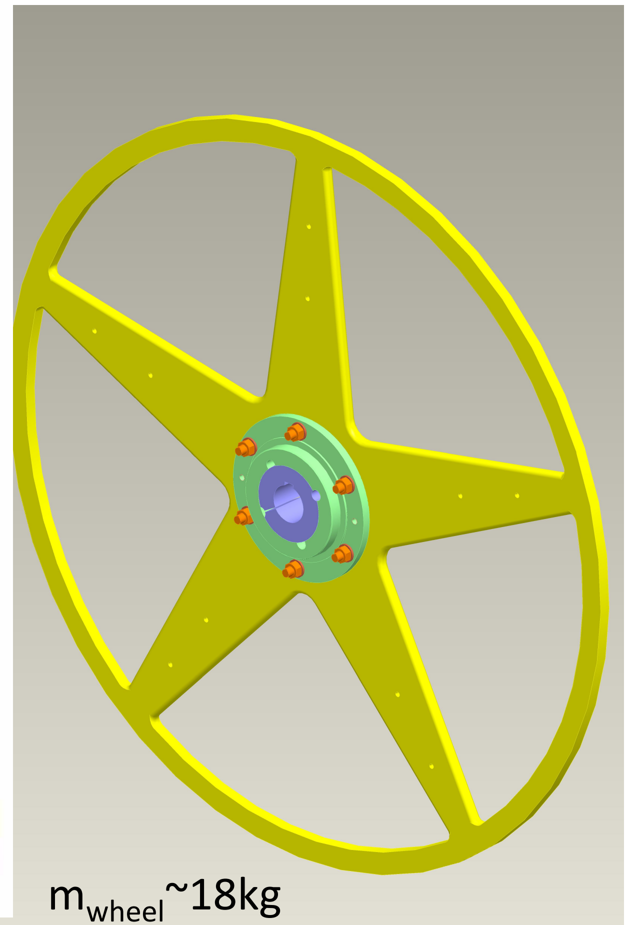
Axial thickness ~0.4 radiation length (14 mm).

Initial R&D in the UK (2008)

Prototype I - eddy current and mechanical stability

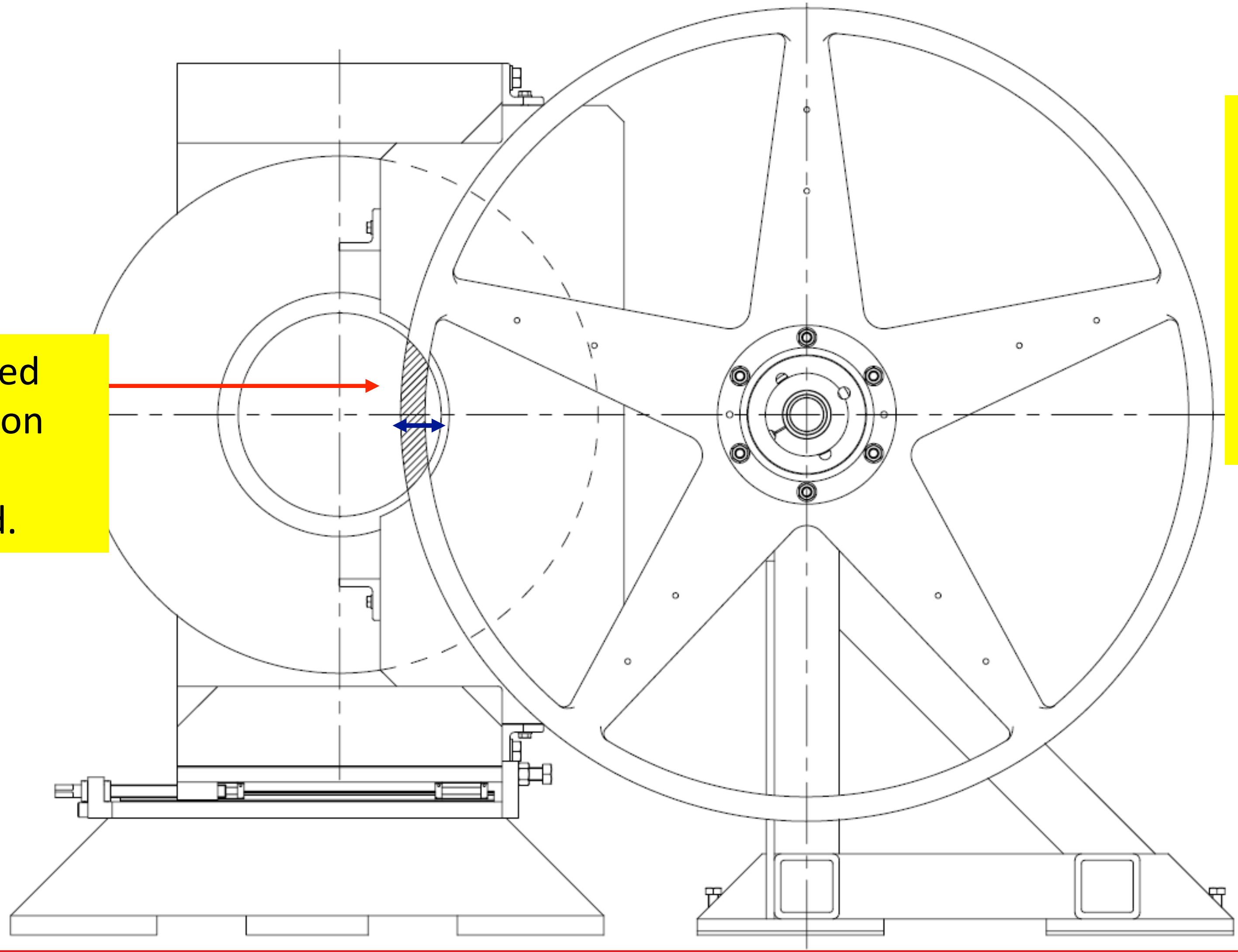
Ken Davies - Daresbury Laboratory





LINEAR COLLIDER COLLABORATION

Immersion Geometry



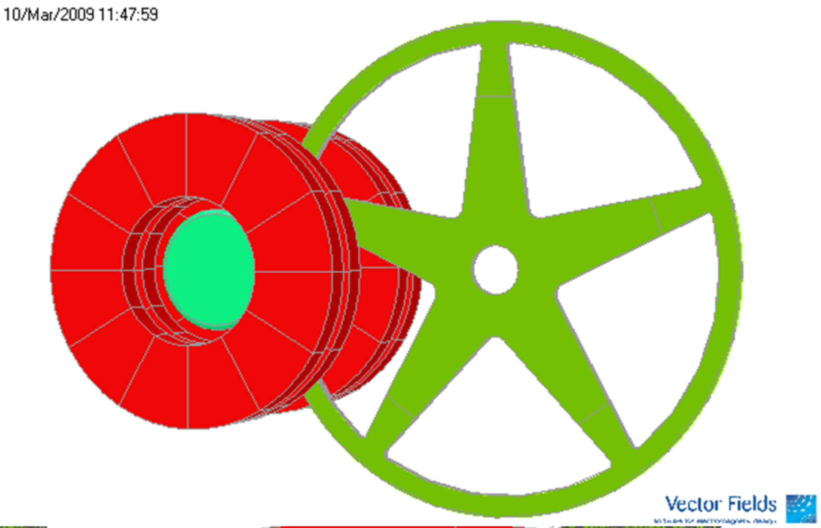
Immersed rim region shown hatched.

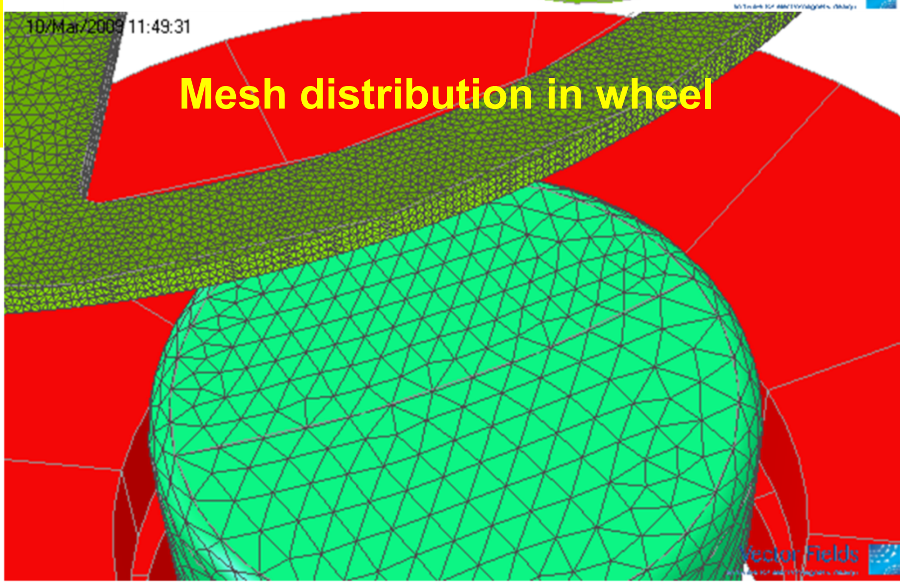
Cross-sectional view of target assembly at full immersion.

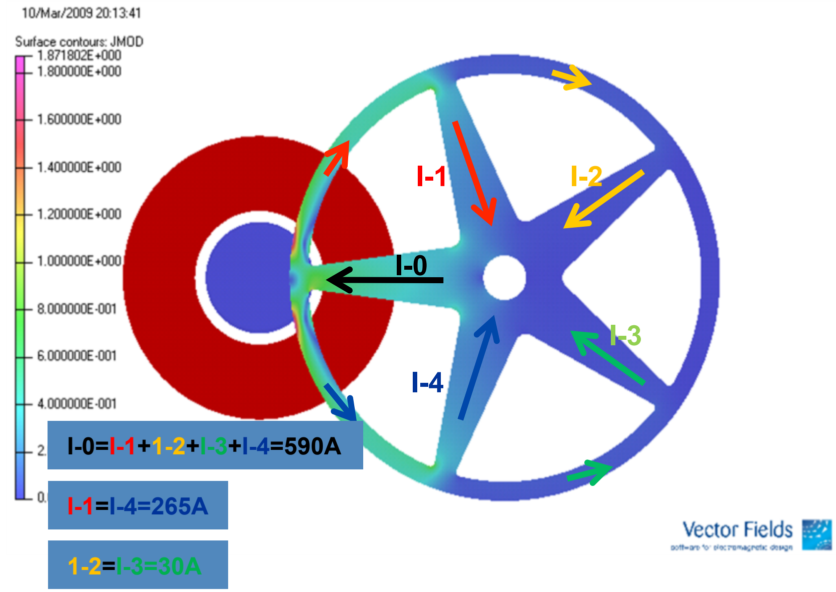
LINEAR COLLIDER COLLABORATION

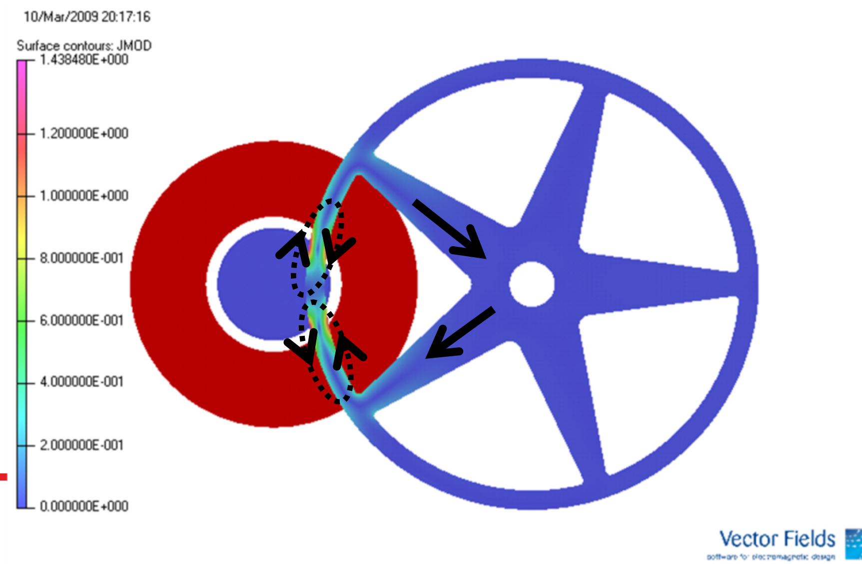
Carmen (spoke) Model Simulations

J. Rochford, RAL

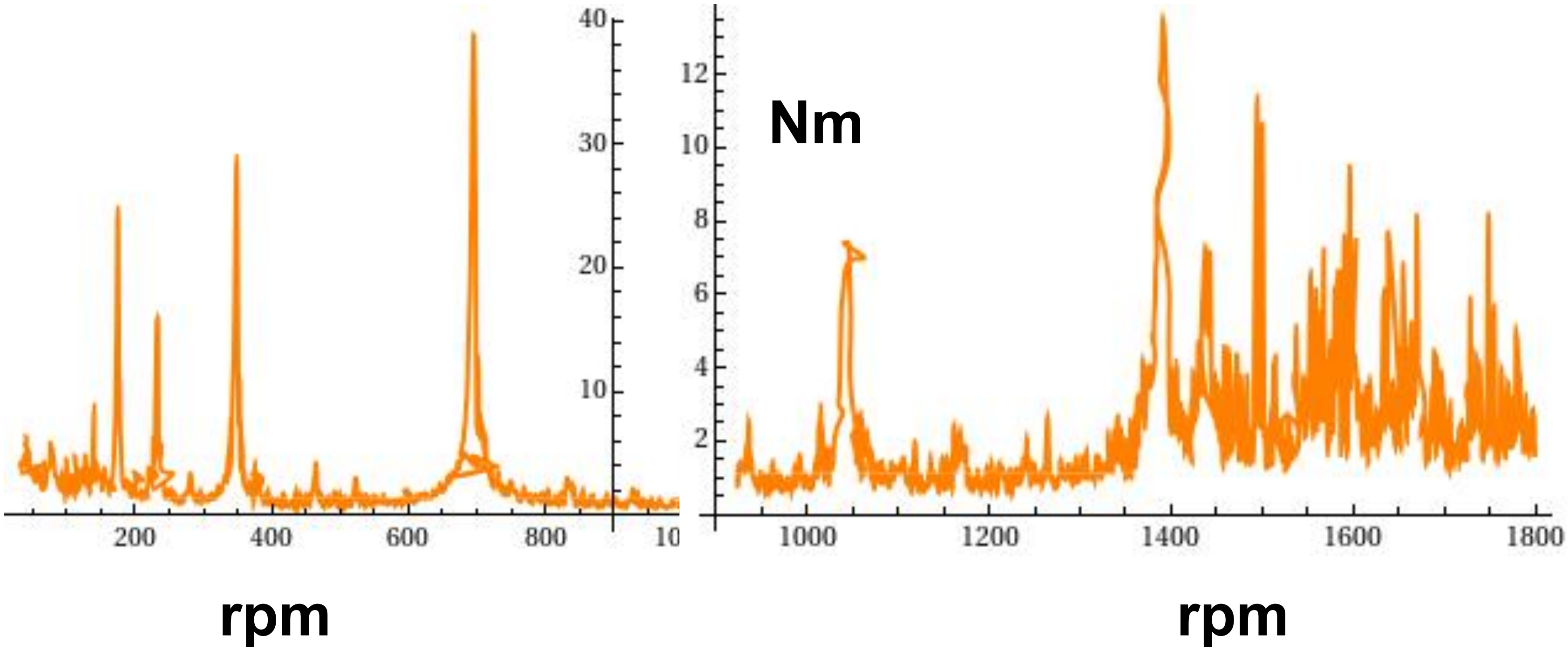








Resonances



Figures show Standard Deviation in Torque (Nm) measured whilst accelerating at average rate of 6.6 rpm / second.

Initial R&D in the UK (2008)

Prototype complete.

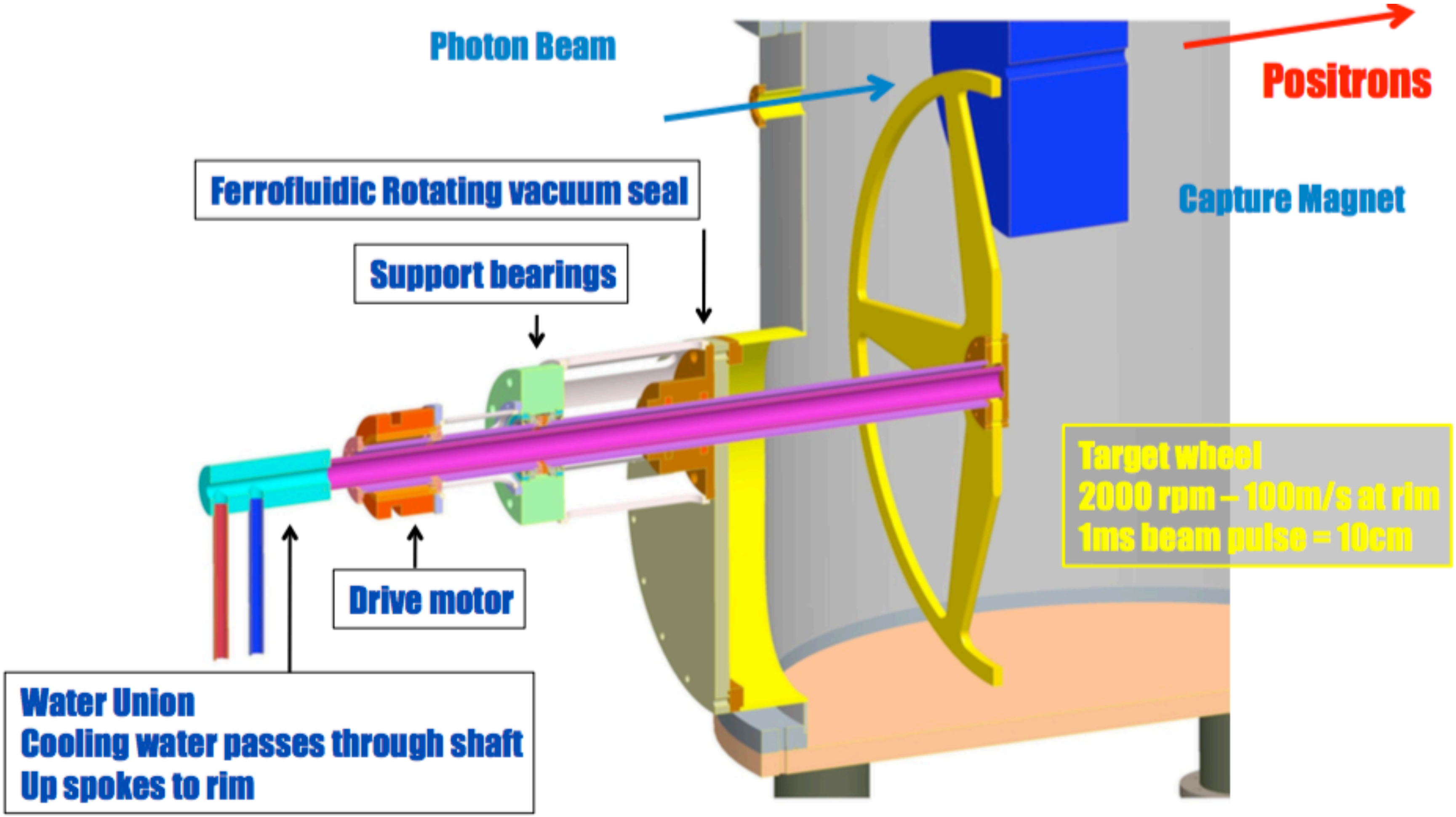
- Data-taking began Nov 08.
- Measurements taken for speeds <1800rpm
- High speeds ⇒ vibration and noise (in air)
  - Attempting to remove spurious speed measurements with low pass filter
- Extrapolating to 2000rpm suggests wheel will be able to operate in immersed fields ~1T without problems.
- Detailed studies of torque Fourier spectra, etc ongoing

CARMEN model

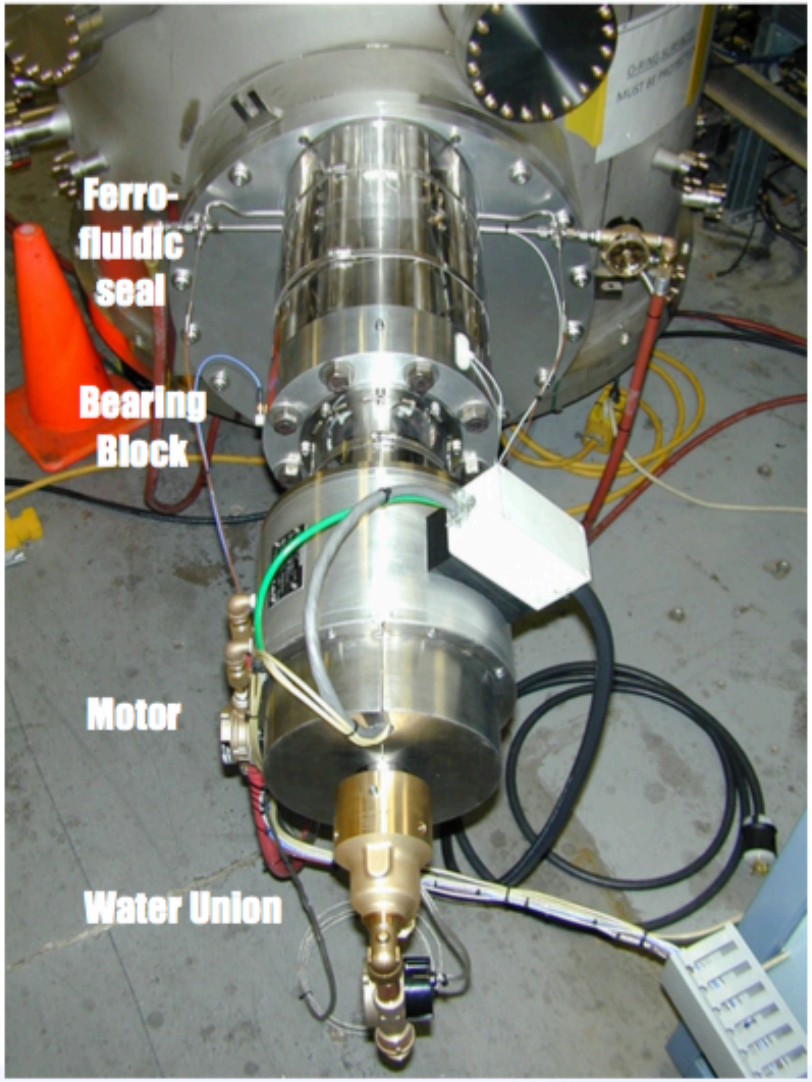
- Consistent with earlier (rim only) ELECTRA model
- In agreement with new LLNL simulation at 10% level
- Predicts large effect from spokes
- Far smaller effect seen in data

UK Funding ceased in 2009

Target R&D at LLNL in the US (2011)



LLNL testing station

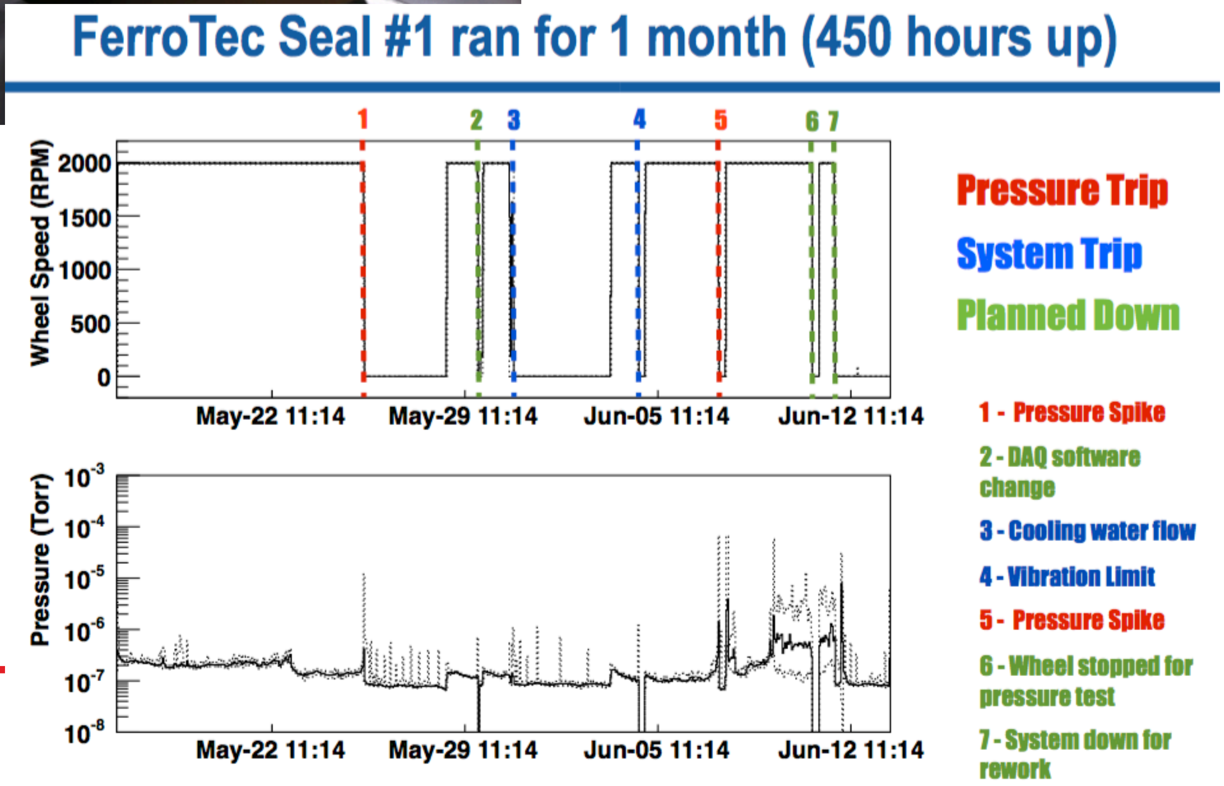


- The DAQ records the system state every 30 seconds.
- Slow control is designed to shut down the wheel if any limits are exceeded
  - Unmanned operation is standard

Target R&D at LLNL in the US (2011)

- Same weight as titanium wheel
- No shielding required for safety

- Cooling water in the shaft has an effect on the balancing
- Not quite as stable a balance point as a solid shaft would have



History of the 5 seals

- Rigaku #1
  - Catastrophic failure after 15 minutes at 2000RPM on the outgassing test stand
  - Rigaku analysis indicates differential expansion of components lead to failure
- Rigaku #1 reworked
  - Switched fluid for low viscosity type
  - Unacceptable behaviors seen on the test stand
- Ferrotec #1
  - Low viscosity fluid
  - Normal operation for 38 hours at 2000 RPM on the outgassing test stand
  - Higher outgassing than Ferrotec expected
  - Ran normally on the test stand until O-ring failure, damaged during rework
- Ferrotec #2
  - Ran rough on the outgassing test stand, better outgassing than Ferrotec #1.
  - Returned to Ferrotec for analysis
- Ferrotec #3
  - Currently mounted on the test stand
  - Good vacuum
  - Vibration spikes

Conclusions from LLNL

- Ferrofluidic seals are not boring, each one has its own individual personality
  - We would prefer them to be anonymously interchangeable and predictable
- They all have outgassing spikes
  - A differential pumping region just after the seal would be a useful modification
- We are pushing them to speeds at which there is significant heat dissipation
  - Off-the-shelf models do not seem to be well designed for this.
  - Improved cooling design is a must for any future system

LLNL R&D ceased in 2013 due to lack of funds

Sliding Contact Cooling (Argonne 2015)

Avoids the need of a rotating vacuum seal.

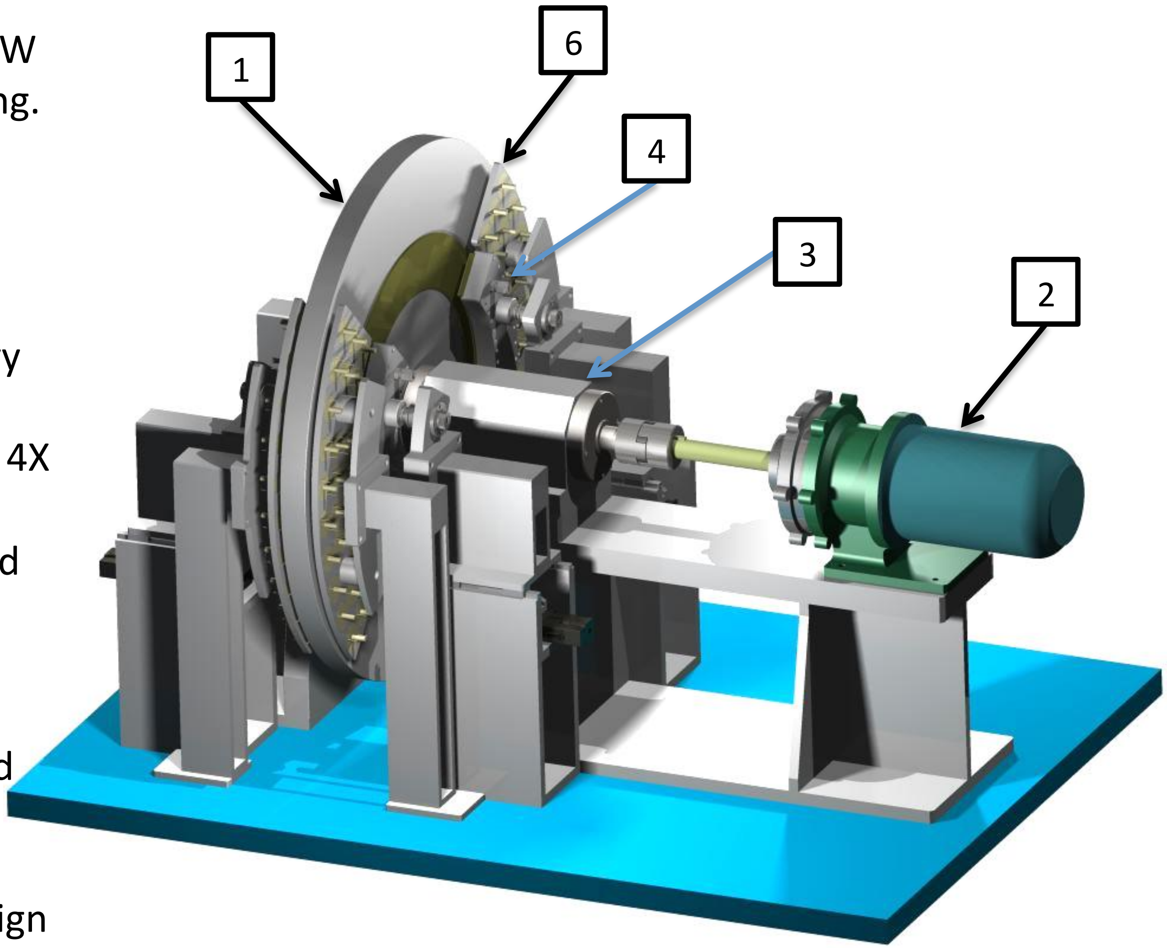
- By sliding contact cooling, the cooling water is flowing through only the stationary cooling pads and thus no rotational water feed through is needed.

- By using a magnetic torque coupler, the rotating target will be driven by a motor outside vacuum without mechanical connection and thus no needs of rotational vacuum seal, which has been the unsolved issue for ILC positron source.

Active Sliding Contact Cooling

Overview

1. Rotating 1M dia Target Wheel at 2k rpm (100 m/s) while extracting ~10kW by using active sliding contact cooling.
2. Target wheel is driven by a magnetically coupled drive motor which separates the motor from the vacuum.
3. Stability of wheel controlled by heavy duty machine spindle.
4. Temperature of wheel controlled by 4X Active Sliding Contact Cooling Pads.
5. Cooling Pad's temperature controlled by water/coolant.
6. Heat applied to wheel using UHV radiant filament heaters.
7. Diagnostic feedback: RPM, Temp and Pressure of Cooling Pads, Temp of Target Wheel, Vibration, etc.
8. All material UHV compatible. All design parameters verified by our MathCad program.



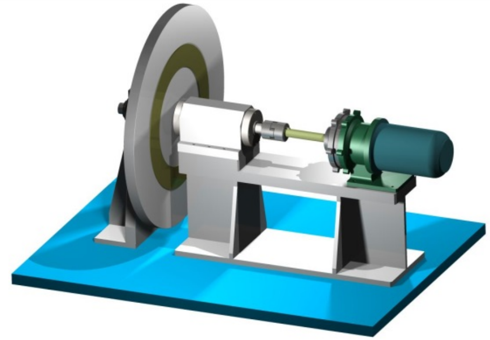
Full Size Target Wheel Ready for Operations in Vacuum

Active Sliding Contact Cooling

Deliverables - Summary

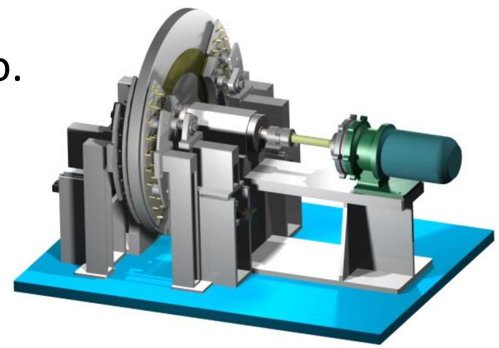
Phase One

- Magnetic coupled motor modified for vacuum.
- Procure spindle and bearings.
- Machined/balance full size wheel.
- Specify materials for contact area.
- Engineering and procurement of Phase Two.



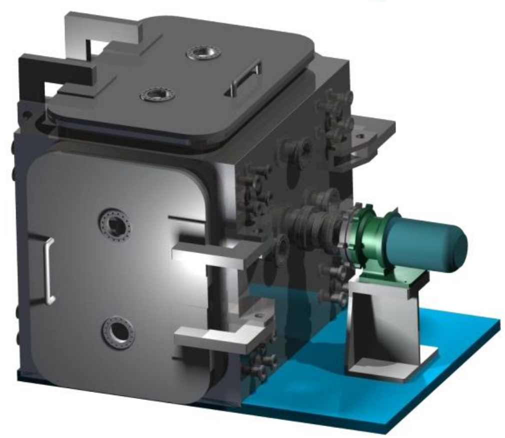
Phase Two

- Implement Contact Materials.
- Install Active Sliding Contact Cooling and Heating systems.
- Engineering and procurement of Phase Three.



Phase Three

- All systems working together in vacuum.



Focus

We will focus on each phase of deliverables as a building block toward the ultimate goal of a fully functional rotating target for the ILC. The phased approach allows for flexibility to improve the systems as we move forward and provides a realistic expectation of results. Our ability to complete this project in a given time frame is commensurate with the level of funding.

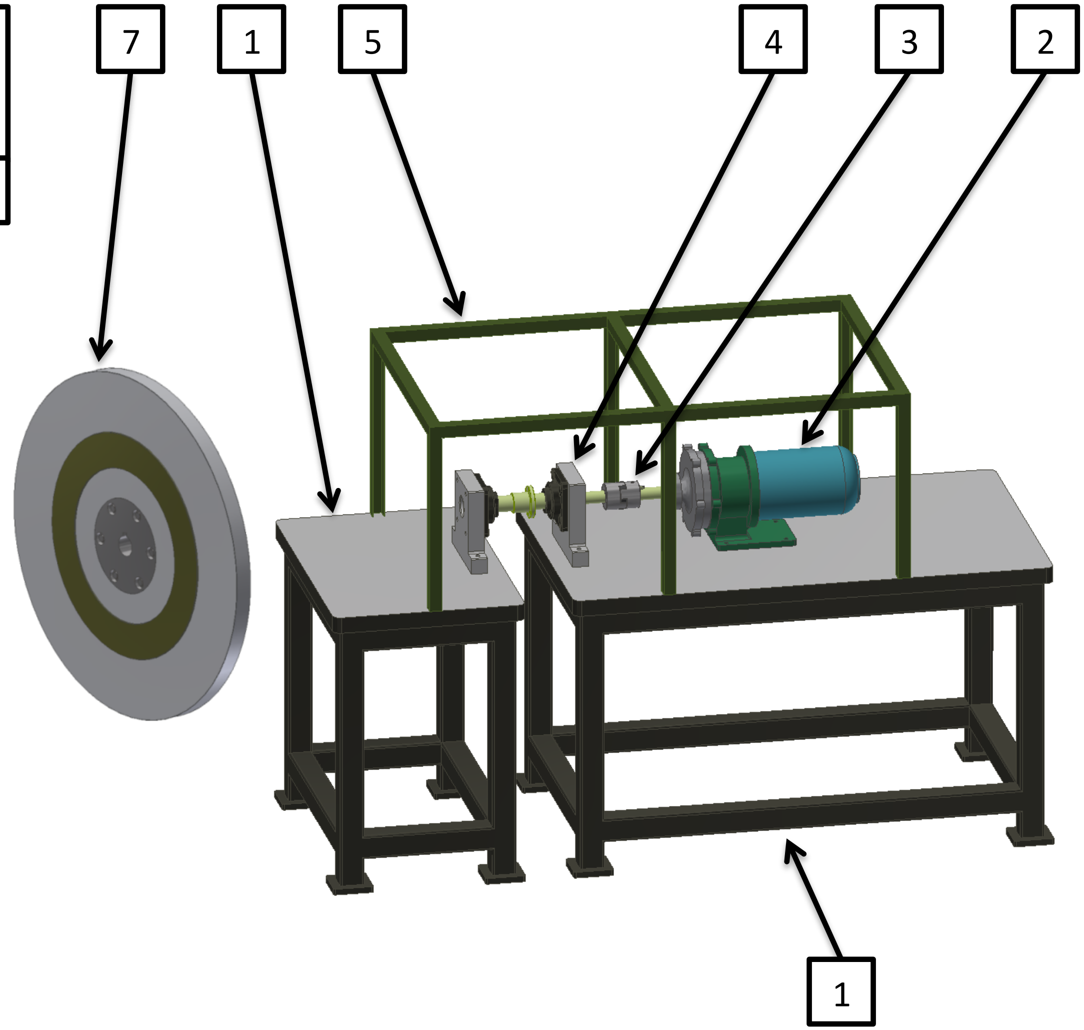
Active Sliding Contact Cooling - Phase 1

Deliverables for Phase 1 - Drive System Test - Completed By Mid-August,2015

- Vacuum Compatible Drive System
- Test: Motor and Controls
- Purchase Test Target Wheel

TO DO

1. Use existing table in 366 and purchase new table. Move to end of exterior of the AWA bunker. Refinish top surface, prep for use, and secure to floor.
2. Receive Magnatex - Magnadrive MP221 Motor, Modified for Vacuum. Control system for motor. Secure motor to table. Run dry to verify internal bearing temperature.
3. Manufacture custom shafts to adapt to motor, wheel, and bearings. Purchase couplings.
4. Purchase bearings and support material. Machine and secure to table, align with motor, mark, and drill and tap table.
5. Build safety cage: Unistrut and Lexan.
6. Test Drive System
7. Procure Test Wheel
8. WPC Documentation

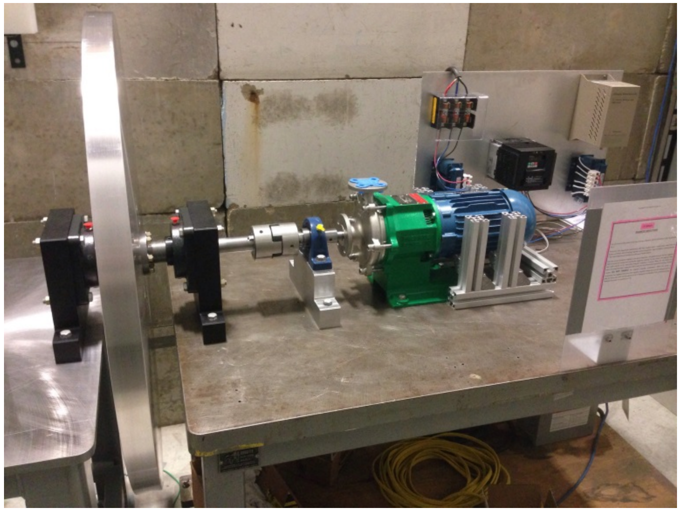


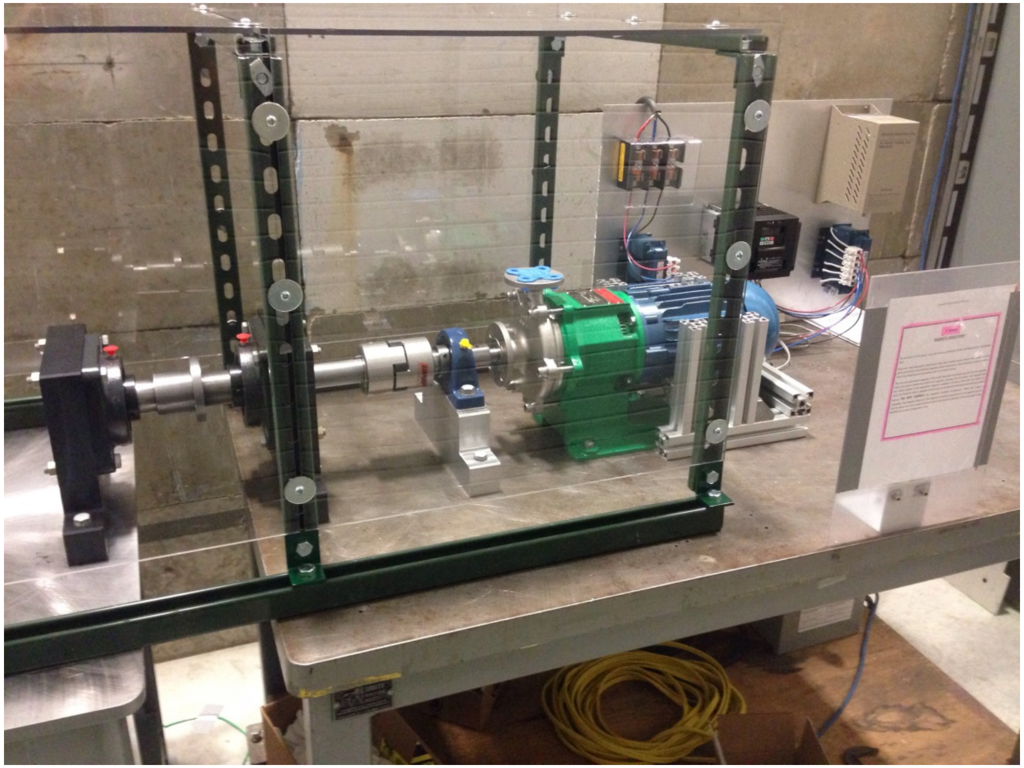
Active Sliding Contact Cooling - Phase 1

Accomplishments for Phase 1 - Drive System Test - Completed By Mid-August,2015

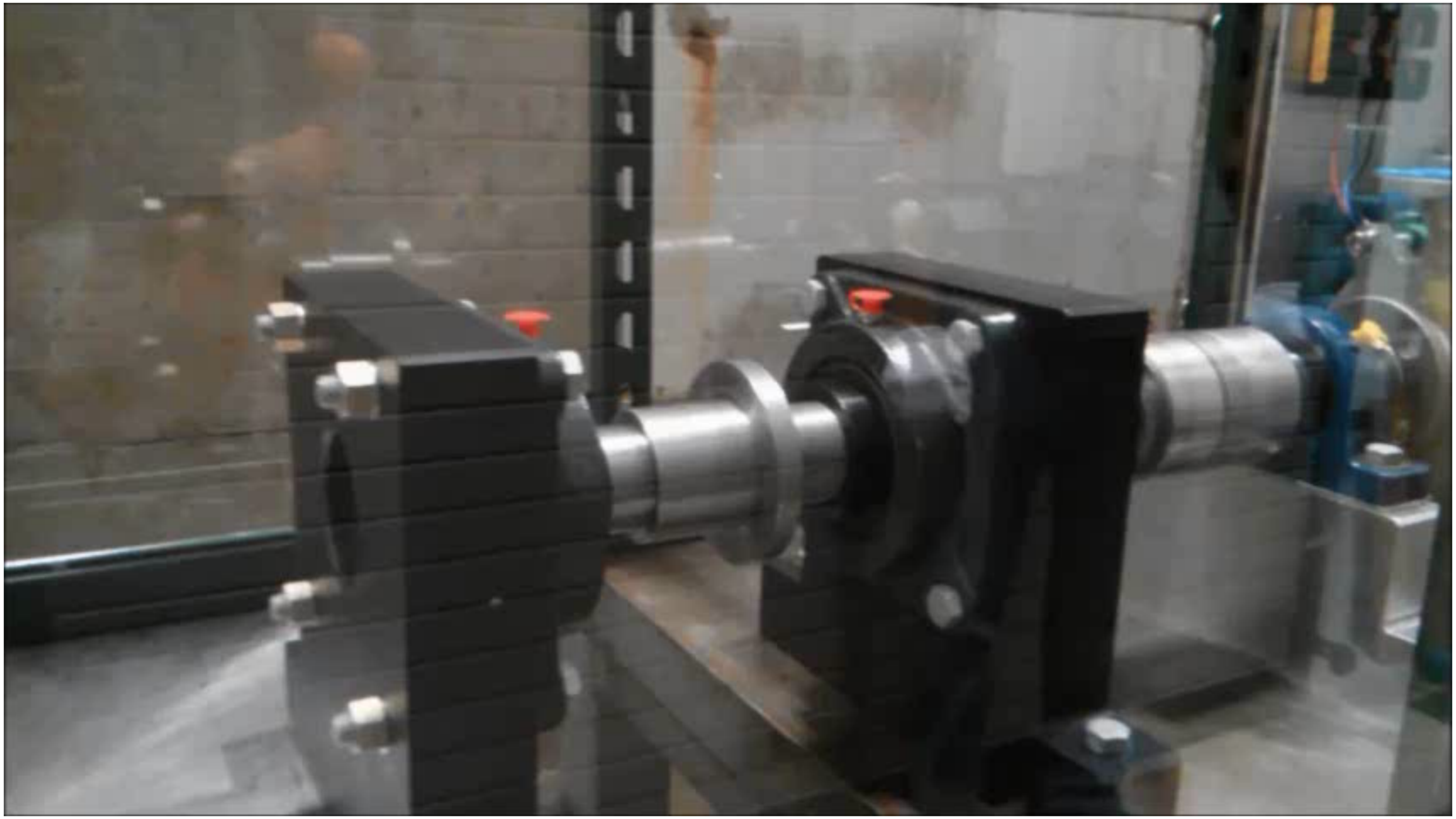
- Vacuum Compatible Drive System
- Test: Motor and Controls
- Purchase Test Target Wheel

COMPLETED





Full Speed Test of Shaft Assemblies



Due to safety regulation, we can not spin the wheel until a bunker/engineering approved safety enclosure has been setup and safety documents approved.

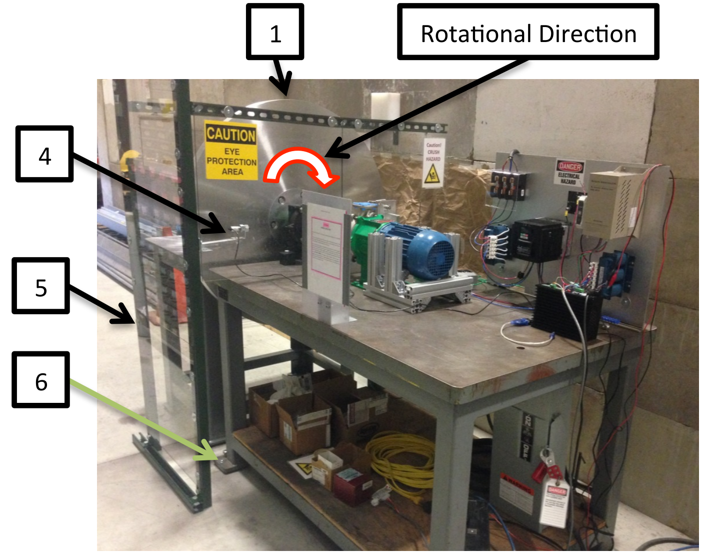
Low speed testing

About 25 minutes of test run of the test wheel has proved that the commercially available magnetic torque coupler and motor we bought is capable to drive the ~350lbs test wheel. This test also confirmed that we can control the start and stop of the spinning wheel.

Tasks and Basic Operations

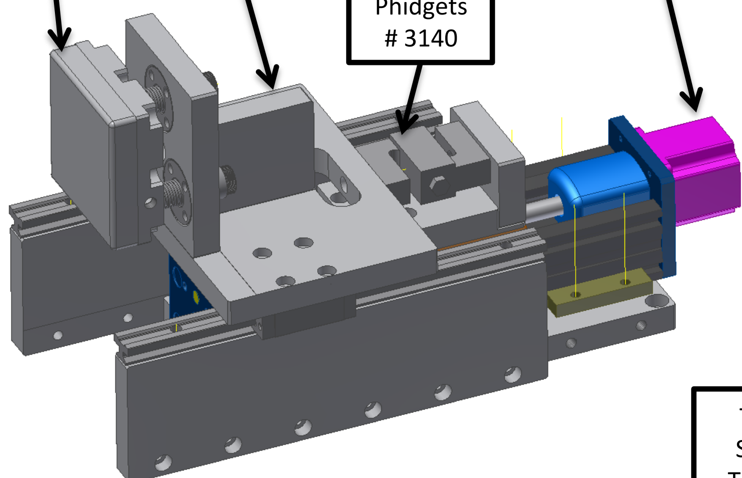
We are tasked to:
1. Rotate the target wheel at ~100 RPM.
2. Apply a metal to metal contact using Sliding Contact Cooling.
3. Control the temperature of the wheel.

1. These tasks will be completed with the target wheel assembly in it's current location with the wheel running at a very low rpm (~100 rpm).
2. We will implement our Sliding Contact Cooling design which is a mechanism that applies a controlled frictional force to both sides of the target wheel simultaneously. The Sliding Contact Cooling units will use a linear actuator with a micro-stepper motor that actuates a spring loaded 304 stainless steel contact pad. The contact pad uses chilled water to overcome frictional heating and control the temperature of the contact area. The target wheel's temperature is controlled as it's contact area slides past the cooling pad. To reduce the coefficient of friction and the chance of galling, the contact area is it is lubricated with MoS_2 (DOW Molykote D-321 R). The control system will monitor the frictional force by using a load cell that is integrated to the contact cooling unit.
3. The motor will wind slowly up from low power to its operational speed. The frictional force will be applied after the motor/wheel achieves its operational speed. The power to the motor will be adjusted to maintain its operational speed.
4. We will use a laser tachometer to monitor the wheels RPM.
5. We have installed a Unistrut and Lexan machine guard and safety keep-out around the target wheel and contact cooling units.
6. The shaft bearings that support the wheel are bolted to the tables and the tables are anchored to the floor.



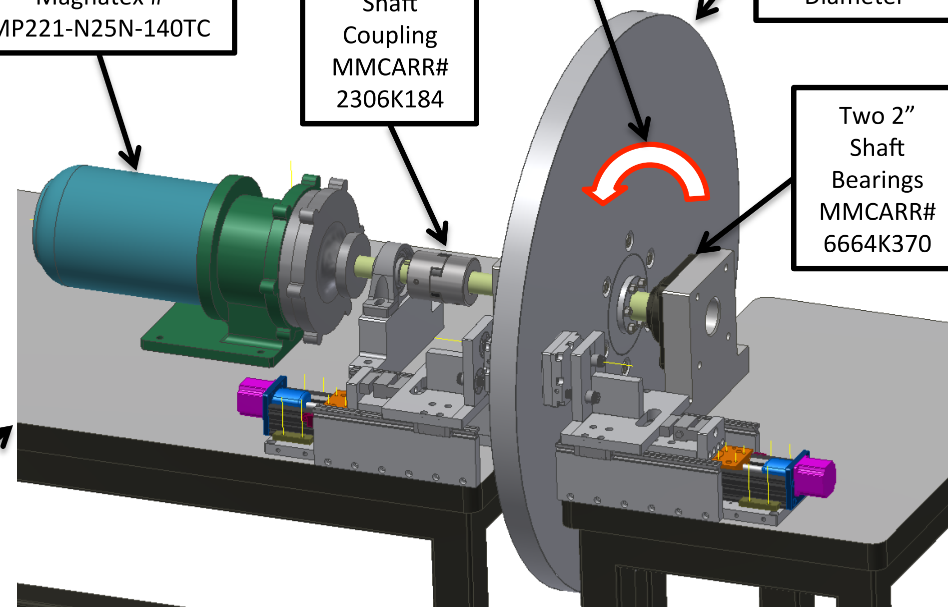
ILC Rotating Target ASCC- Phase 1.1.5

Mechanical Design and Operation



Active Sliding Contact Cooling Assembly | Fig 1

1. The linear actuator applies a linear force to the load cell.
2. The load cell transfers that force to the carriage.
3. The carriage moves the spring loaded contact pads into contact with the rotating target.
4. The load cell provides feedback as to the amount of force (LBS) that contact pads are applying to the wheel.
5. The target amount of force is 3-5 LBS.
6. Molykote dry lubrication spray is used to reduce friction between the contact pads.

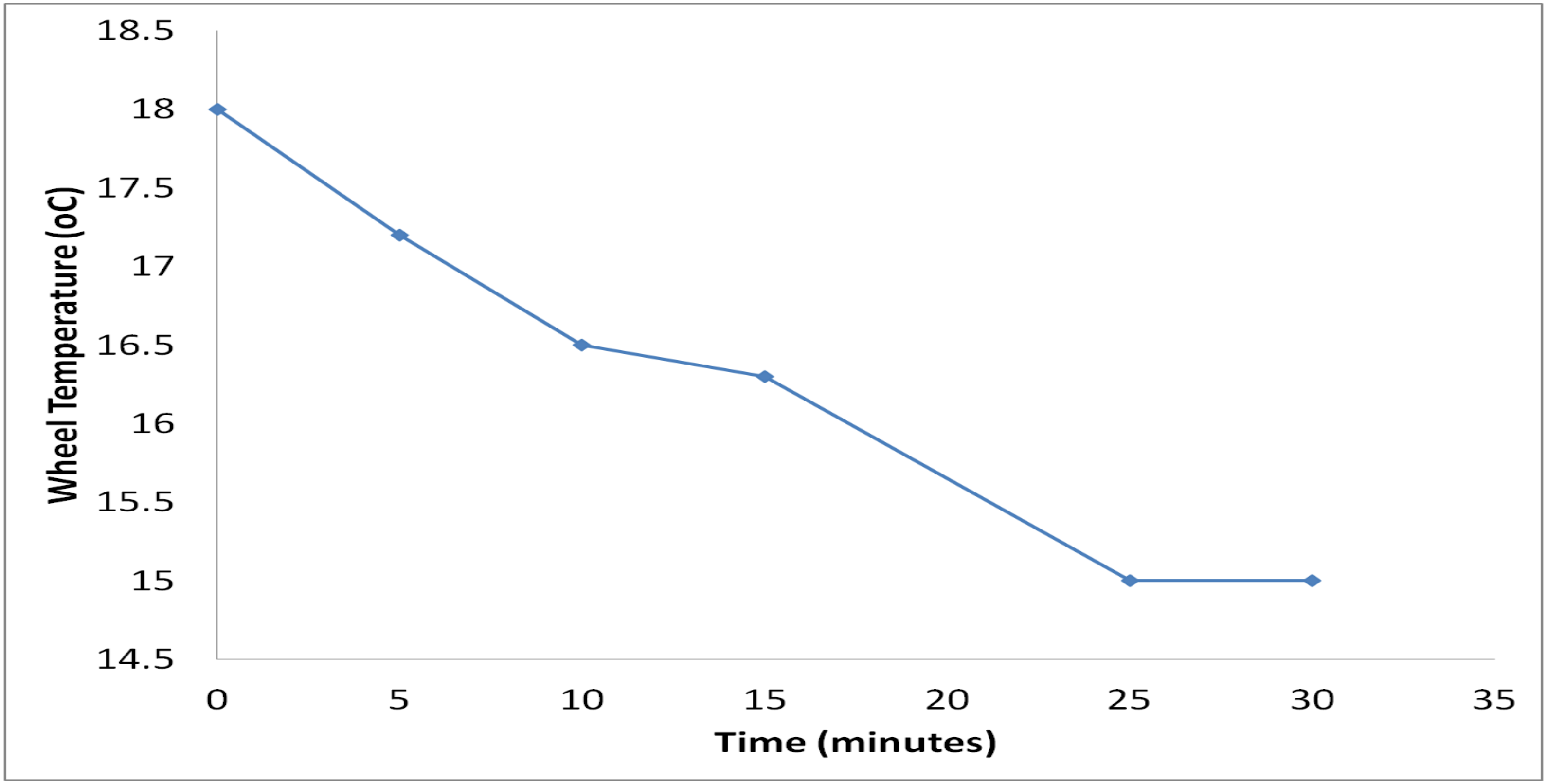


ILC Rotating Target Assembly | Fig 2

1. The motor rotates a steel shaft that passes through the target wheel.
2. The shaft is connected to a connecting plate with grade 8 3/8-UNC steel bolts which in turn is connected to the target wheel with grade 8 1/2-UNC steel bolts.
3. The target wheel and shaft (~350lbs) is captured on both sides by cast iron flange mounted steel ball bearings, each with a dynamic load capacity of 9700lbs.
4. The wheel will be rotated toward the AWA bunker wall (~11ft thick concrete) at ~100RPM (7200 joules) which is monitored by a laser sensor tachometer.
5. The cooling pads will be actuated to contact the rotating target wheel and will use chilled water, fed at ~2 gallon/minute, to control the temperature of the target wheel.

Test run with cooling pads at ~100RPM

Cooling Demonstrated

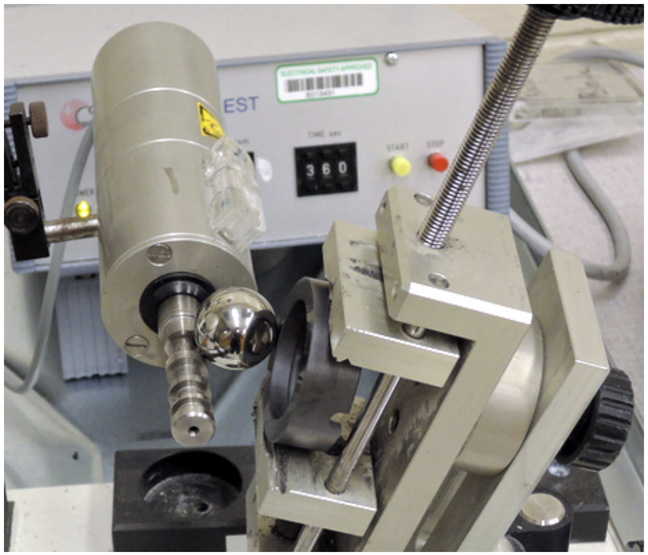


During the ~30 minutes of test with contact cooling, a hand held IR thermal meter was used for measuring the temperature of the wheel. We stopped after we observed no additional cooling. We have observed 3 degrees C cooling to spinning wheel.

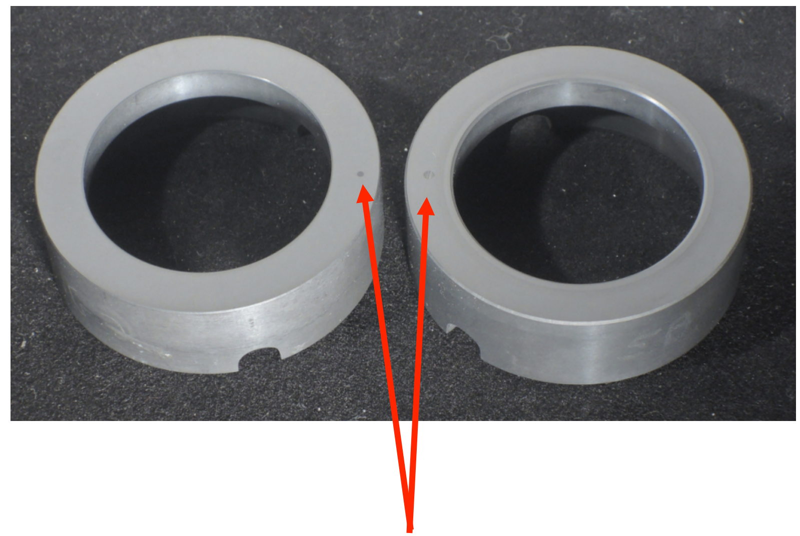
Tribology study of low friction materials

- Goal:
  - perform sliding tests of candidate materials using vacuum-compatible dry solid lubricant and report friction and wear data
  - Use existing vacuum tribometer operating at maximum speed to replicate vacuum environment
  - Ascertain that materials will perform for year-long duration
- Materials:
  - SiC rings lapped to sub wavelength flatness for counterfaces, with MoS_2 (either powder or solid) for lubrication
- Current status:
  - Have done some initial test, tribology group is refining their apparatus.

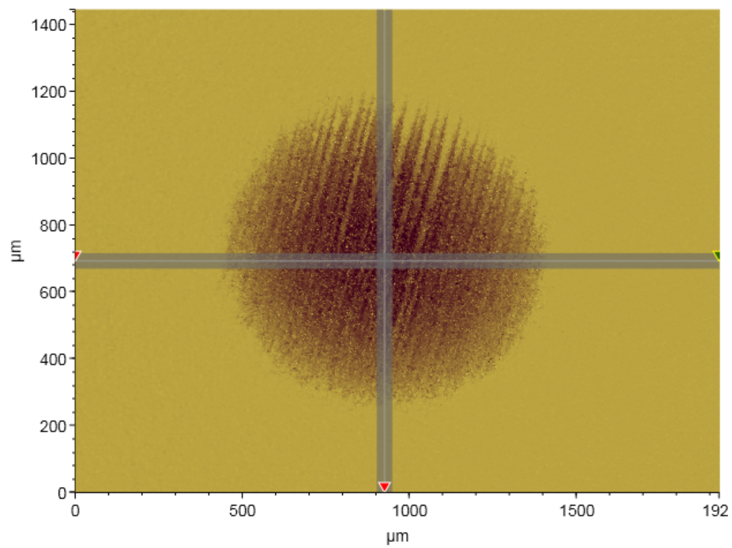
Vacuum Testing

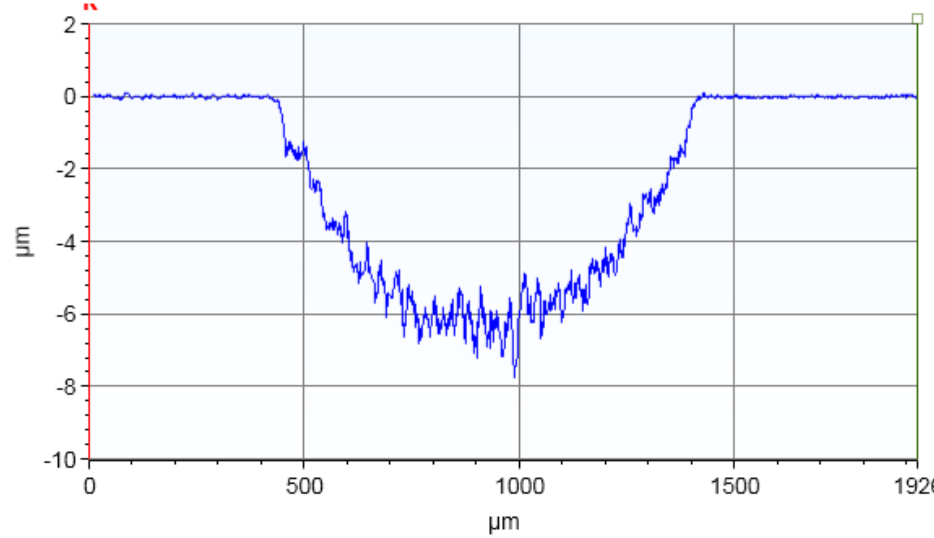


Calotest machine was used to put small dimples into ring surfaces to serve as reference level for wear measurement



Reference dimples are small black spots





This pseudo-color WLI image shows a dimple on the flat surface of the ring with light=high, and dark= low

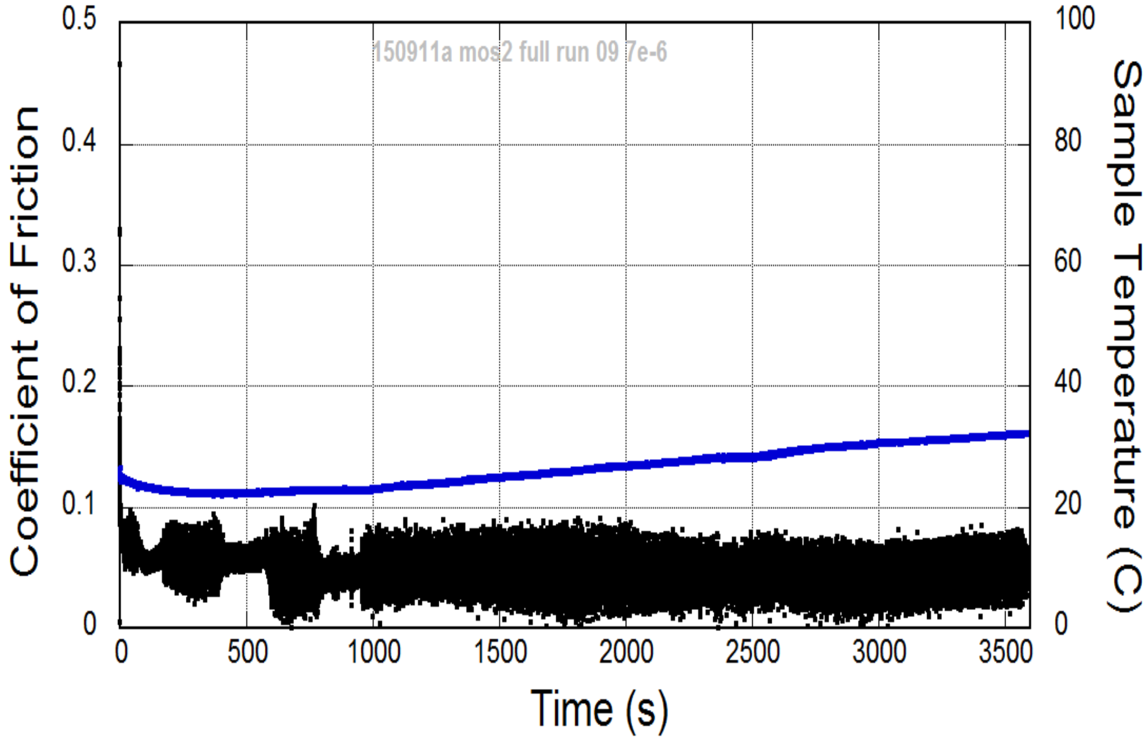
The depth of the dimple is about 6.5 µm

If the top surface experiences wear then the depth will decrease

The initial wearing test is inconclusive. The depth increased by about 1µm after test. Need to run test for longer time.

Tribology test result of MoS2 in vacuum

Test results show that small amounts of MoS2 are effective for lubrication in vacuum.

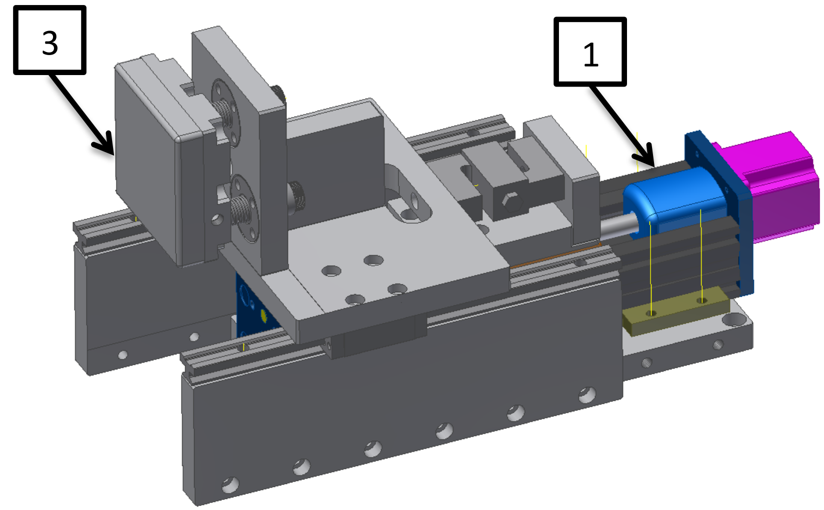


	Ring 1	Ring 2
New MoS2 on ring	2.54 mg	4.91 mg
MoS2 transferred to paper	2.08 mg	4.09 mg
MoS2 remaining on ring	0.36 mg	0.4 mg
Unaccounted for	0.1 mg	0.41 mg

Friction was low (μ = 0.05) and temperature was modest (35C) for 1 hour duration

Phase 2 Contact Cooling and Heating Element Details

The contact cooling units that are currently constructed are for Phase 1.1. After we finish Phase 1.1, we will evaluate the cooling units and make any and all necessary modifications. Here are a few that we already anticipate.



1. Purchase vacuum compatible actuators. (due to the longer lead times of the vacuum compatible versions we were unable to purchase them for Phase 1.1)

2. Modify the assembly so it is more compact in the direction shown.

3. Assess the performance for the spring loaded cooling pads.

4. Clean all parts for vacuum.

5. We will also need to evaluate heating elements for inside the vacuum. We have a ceramic heater in mind, but, will need to develop.

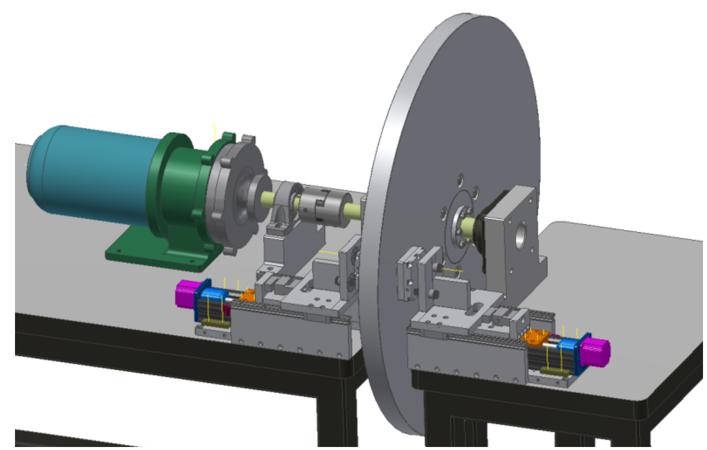


Image from Phase 1.1

Phase 2 Vacuum Chamber Details

The main goal of Phase 2 is to extract heat from a full speed (2000 rpm) target wheel while the wheel is in vacuum. Since rough vacuum is good enough we will only need an o-ring seal. Even with this simplified requirement it is not trivial to fit this apparatus inside a vacuum chamber. Here is my proposal.

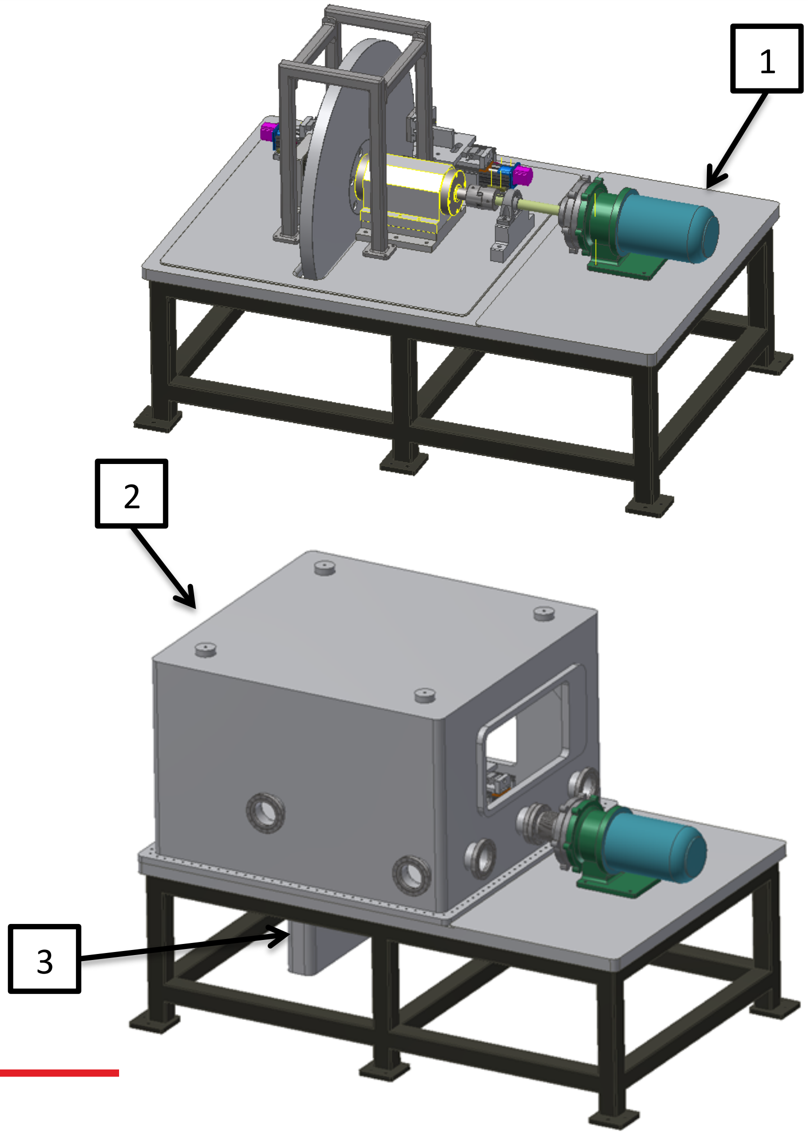
1. The operation and configuration of this apparatus is unique, so, it needs a unique solution. We want to integrate the vacuum chamber to the support table. The table will have an aluminum top bolted to a steel frame. The table top will have finished areas for the vacuum seals and will provide for support for all other components.

2. The main vacuum chamber will have lifting eyes, access ports for feed thru's and remote monitoring, and access panels so we do not have to remove the chamber to work on key areas of the apparatus.

3. The lower chamber will enclose the bottom part of the wheel and be used for pumping.

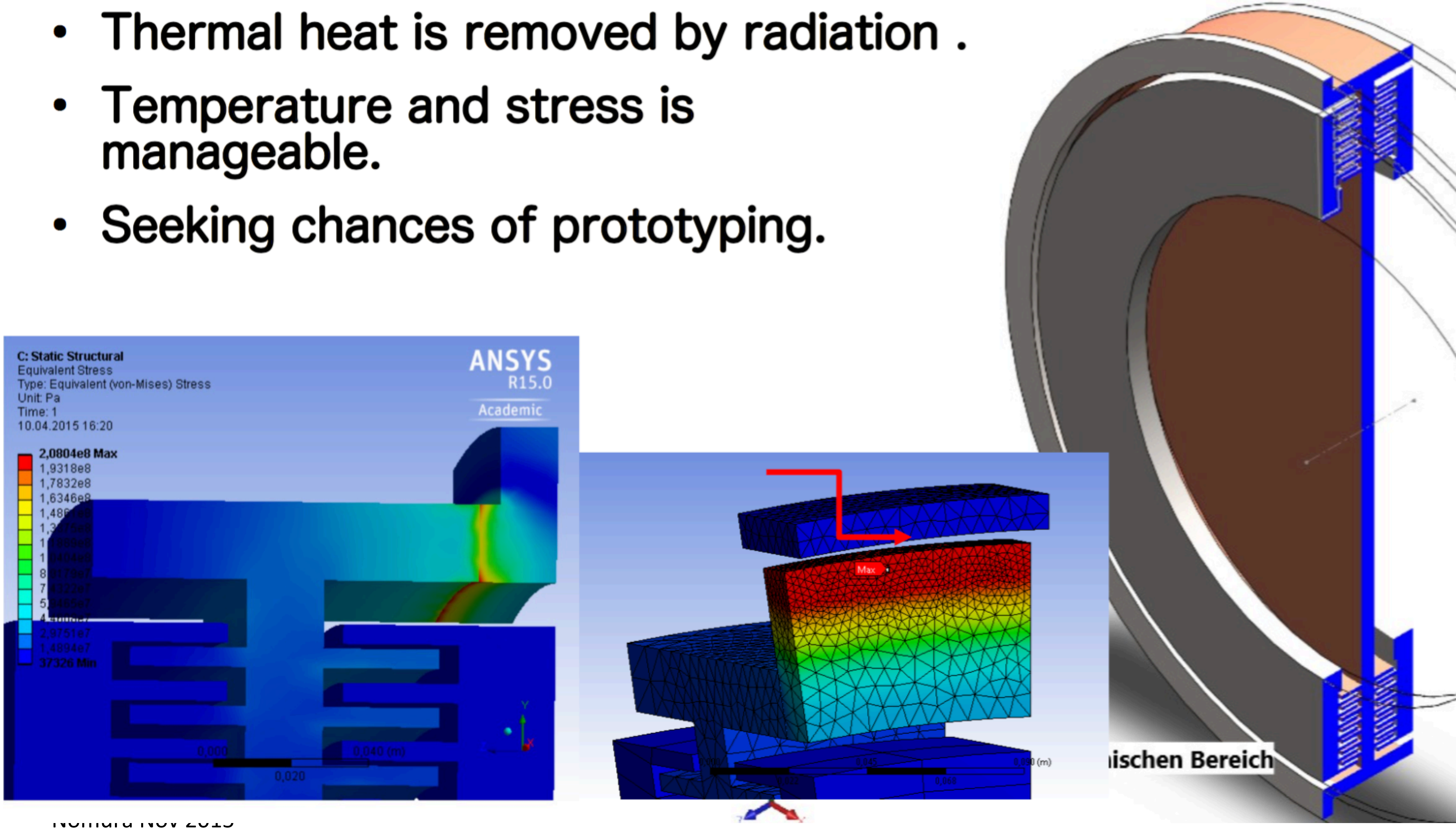
4. We will need to have some engineering analysis done to verify some small details, but, this concept is very doable.

5. We consulted with MDC and they are willing to supply the three piece vacuum chamber as a turn-key project. There are plenty of other options as well, but, the turn-key option would include vacuum stress analysis, testing, cleaning, etc.



Radiation Cooling Target (DESY/CERN)

- Thermal heat is removed by radiation .
- Temperature and stress is manageable.
- Seeking chances of prototyping.



Positron Production Target Summary

- Initial testing in the UK has validated ~2000 rpm in a magnetic field for a prototype target wheel. (Daresbury)
- Vacuum seals based on a ferro-fluidic design do not look viable (Lawrence Livermore)
- Initial results have proven the concept of sliding contact cooling (Argonne)
- The next phase of the R&D at Argonne will validate many of the remaining design issues (2000 rpm, 10kW, computer control, vacuum, friction coefficient, heat transfer rates, etc......)
- We will need a fully tested prototype
- At some point we need to address radiation/remote handling