Lawrence Livermore National Laboratory

Design and Prototyping of the ILC baseline target system

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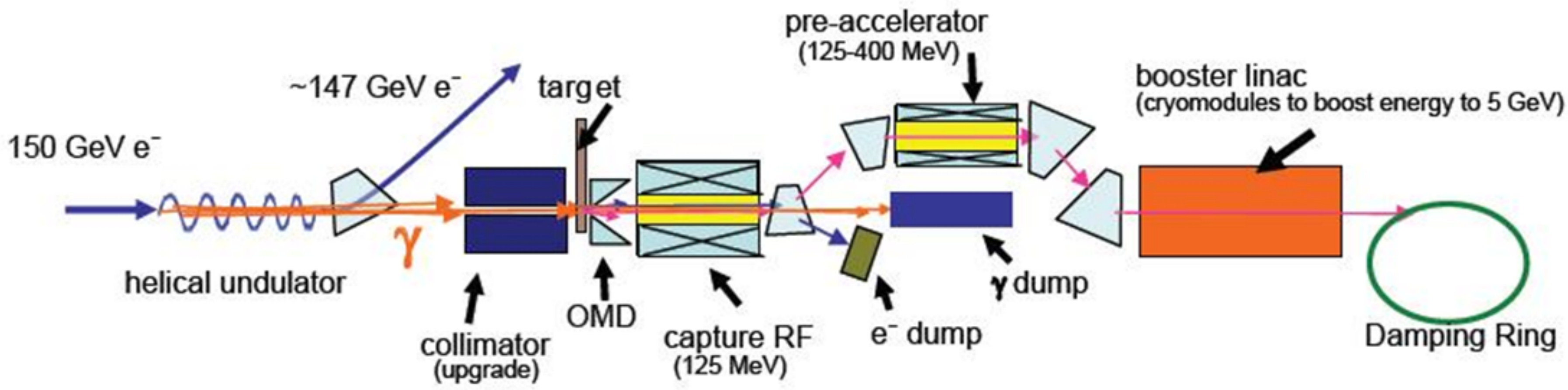
ILC has a new approach to positron generation using helical undulators to create a photon beam

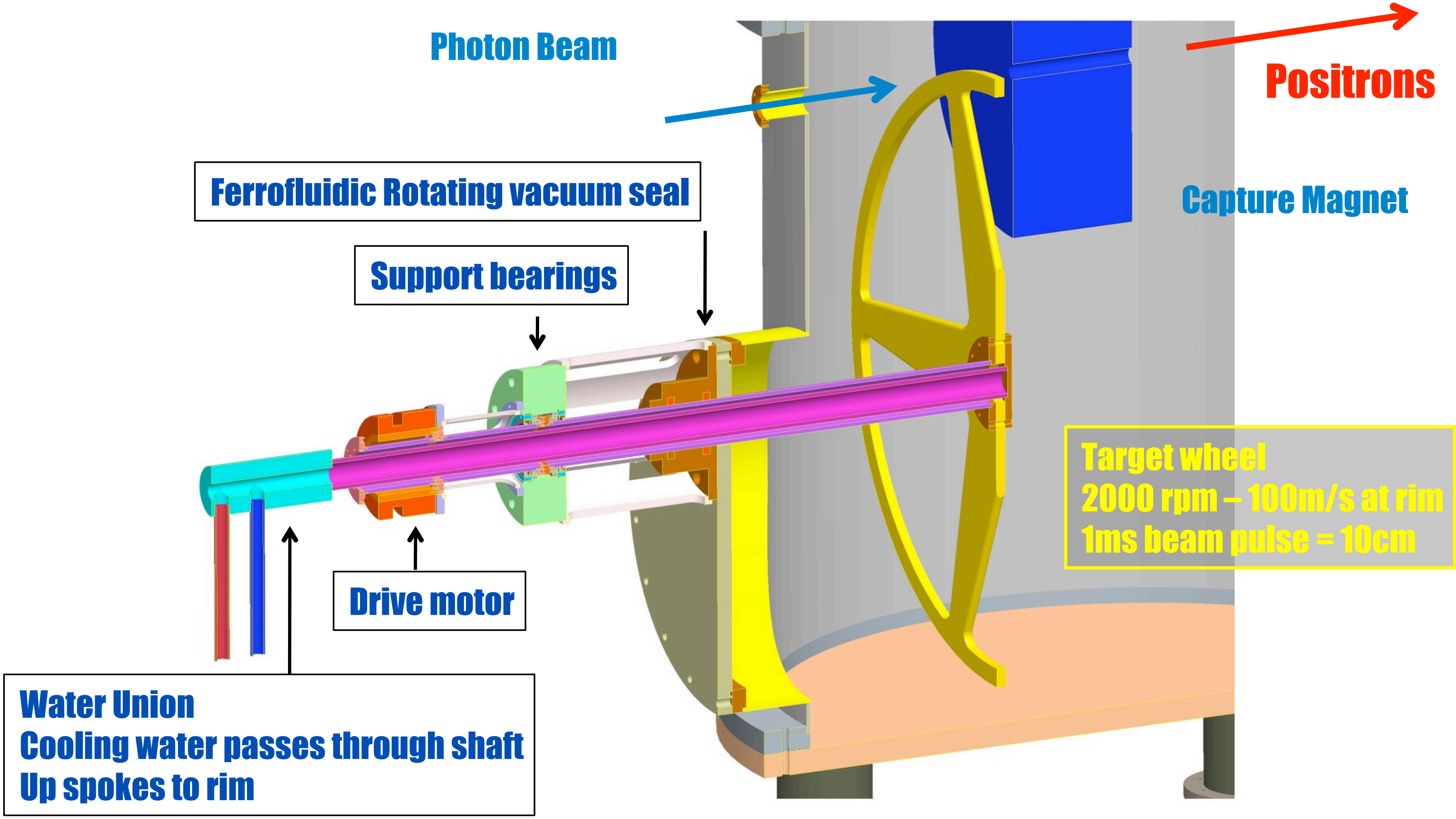
Helical undulator to generate a circularly polarized photon beam

Optical Matching Device to get high capture efficiency

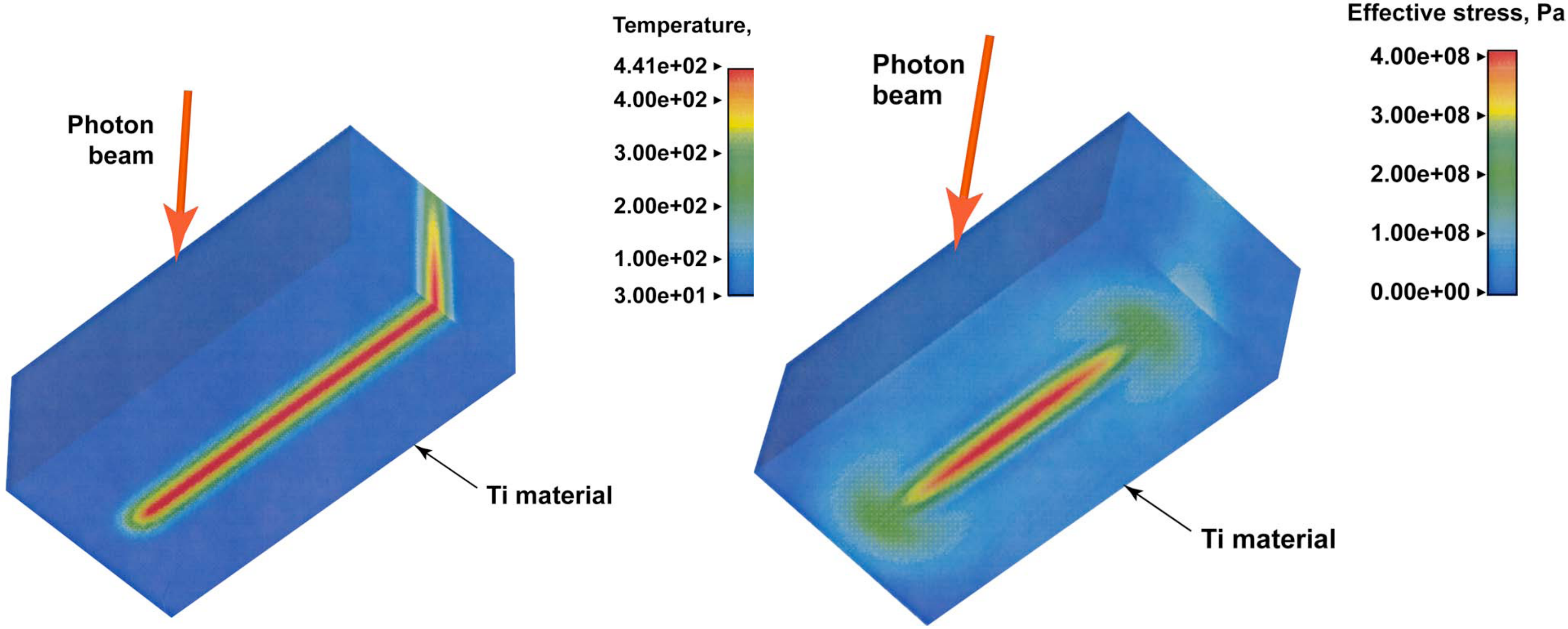


Rotating target to smear out the long 1ms pulse

Basic layout of the target



Rotation disperses the energy of the 1ms pulse over 10cm of the rim

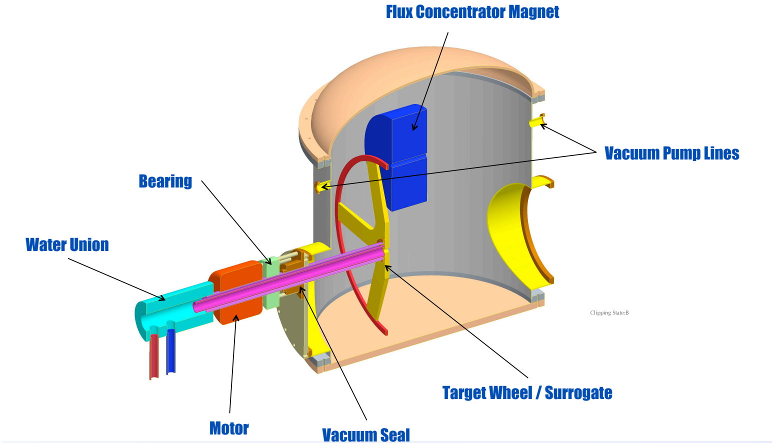


- 100 m/s rim speed
- Maximum temperature is 441C

Werner Stein, LLNL, Daresbury positron workshop 2005

There are many practical concerns with creating a workable system

- Shockwaves in the target
- Thermal stresses
- Rotational stability of the wheel
- Eddy currents from the magnet
- Cooling water in the shaft
- Contamination from outgassing of the ferrofluidic seal
- Operation of a 1ms flat top pulsed flux concentrator

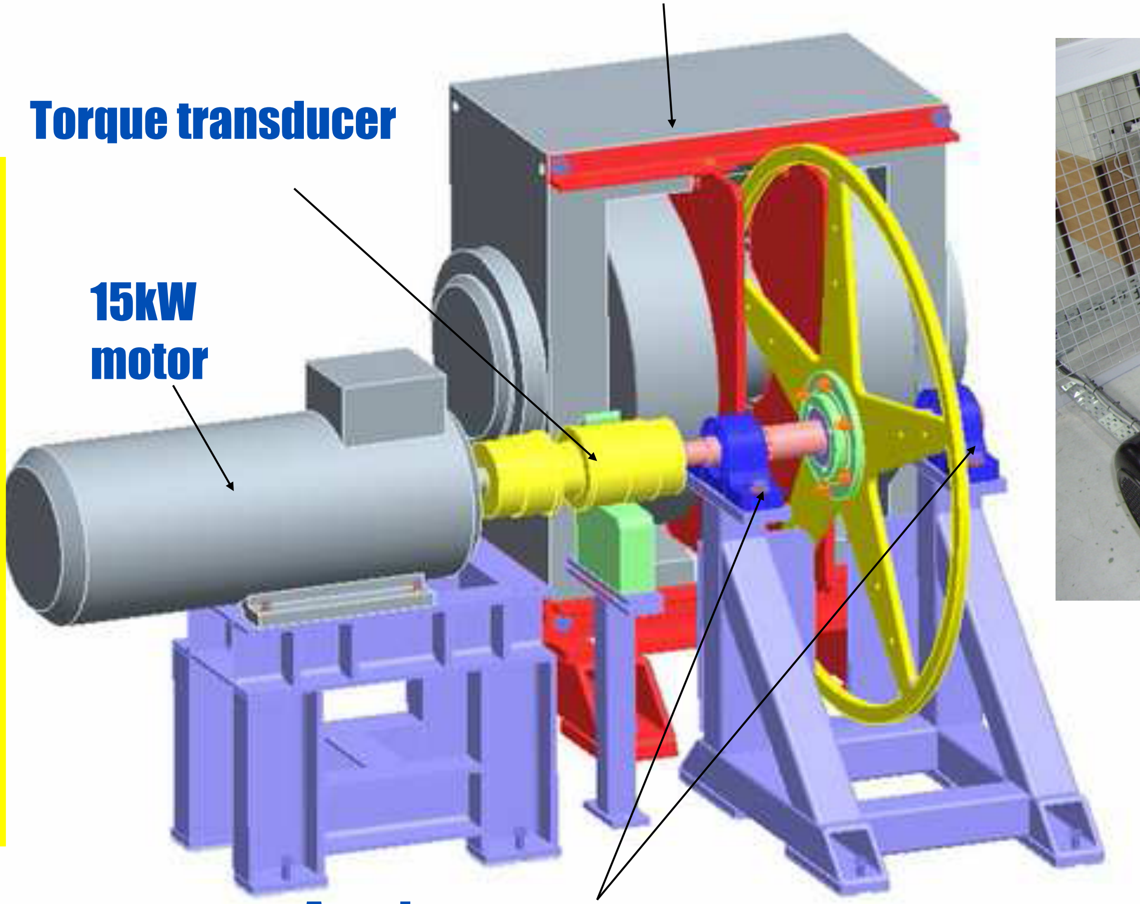


- and for everything ...
- A significant radiation environment
  - design is for 1-year operation then replacement

Target Prototype

Prototype I - eddy current and mechanical stability

Ken Davies - Daresbury Laboratory



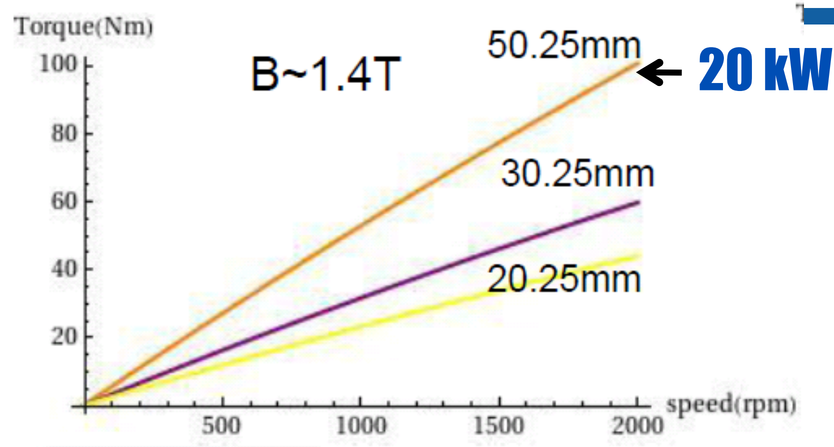
Daresbury Prototype Target wheel
Solid Ti - No cooling

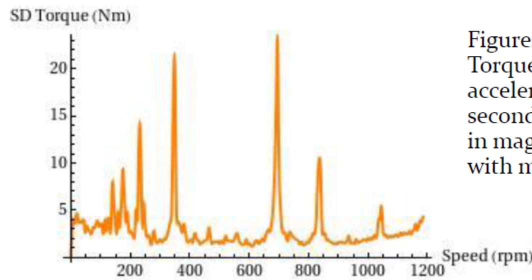
- Test – Rotordynamics
- Test – Mechanical stability
- Benchmark – Eddy current heating from capture magnet

Ian Bailey, ILC collaboration meeting 2010

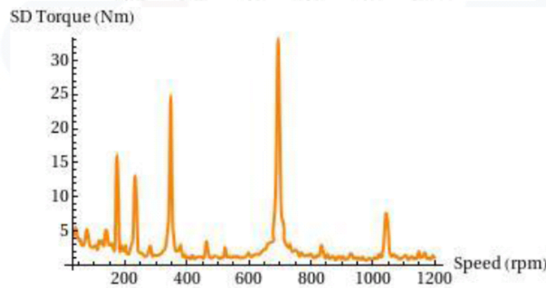
Prototype I has finished data taking and has been a success

- Eddy current losses have been benchmarked. Stray fields from the capture magnet of 1.4T can be accommodated.
  - Eddy current simulations are still not very accurate
- Resonances in the wheel are consistent with predictions
- No problems with the rotating target up to 1800 rpm
  - Higher speeds were not feasible in air





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.

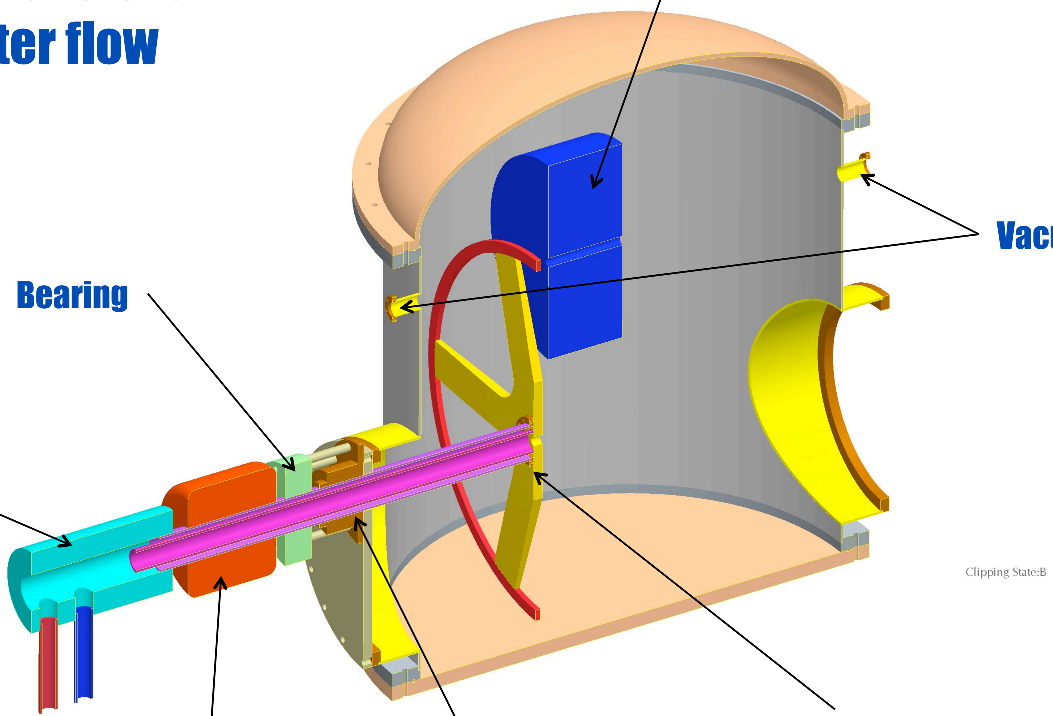


Ian Bailey, 6th positron source collaboration meeting 2009

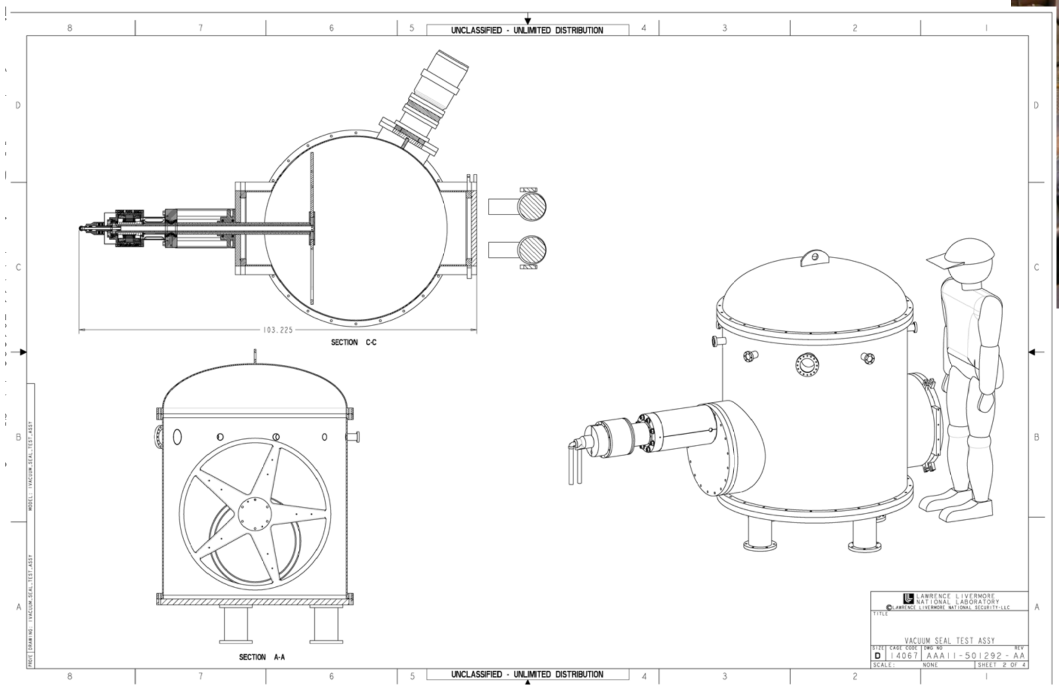
Target Prototype

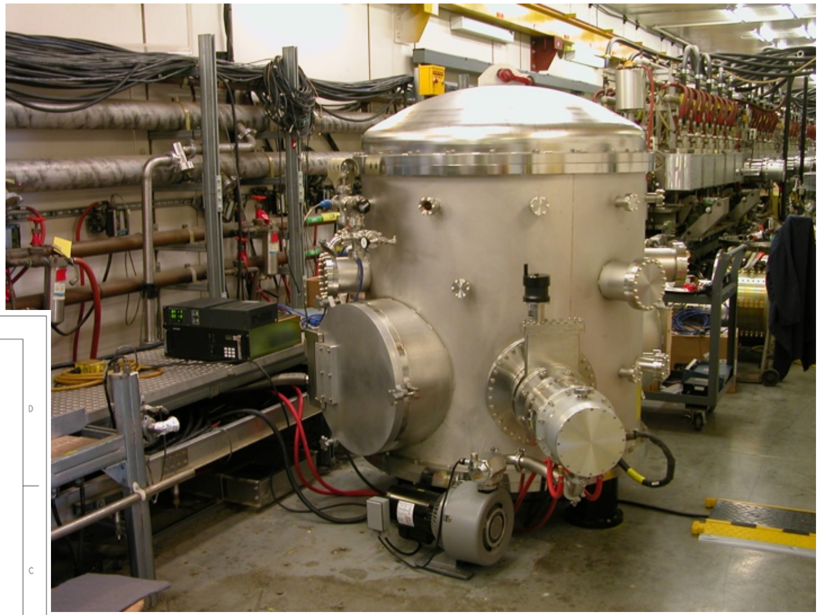
Prototype II - Ferrofluidic Vacuum Seal

Full size prototype of rotating wheel, vacuum seal and shaft with cooling water flow



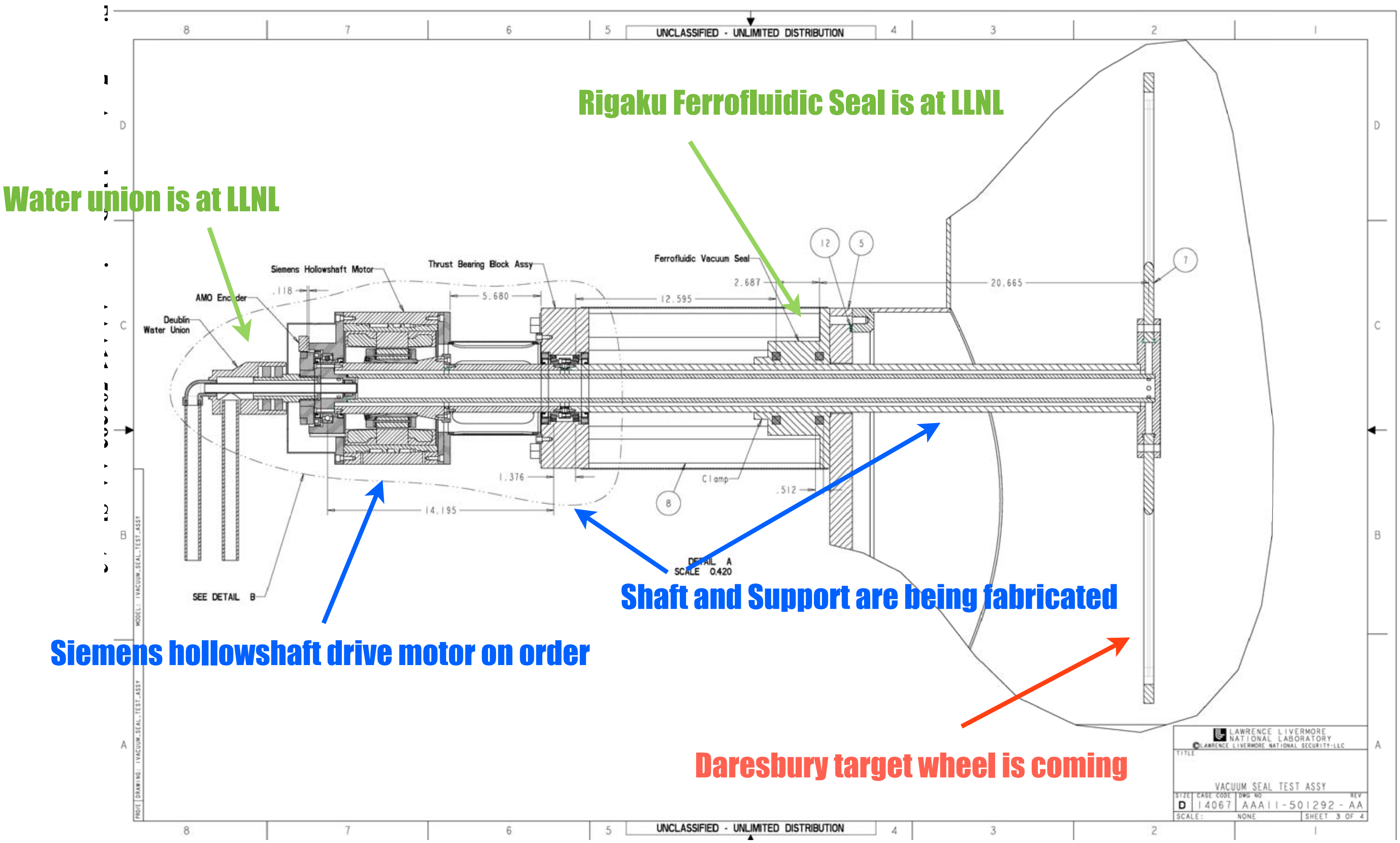
The vacuum tank is setup and under vacuum



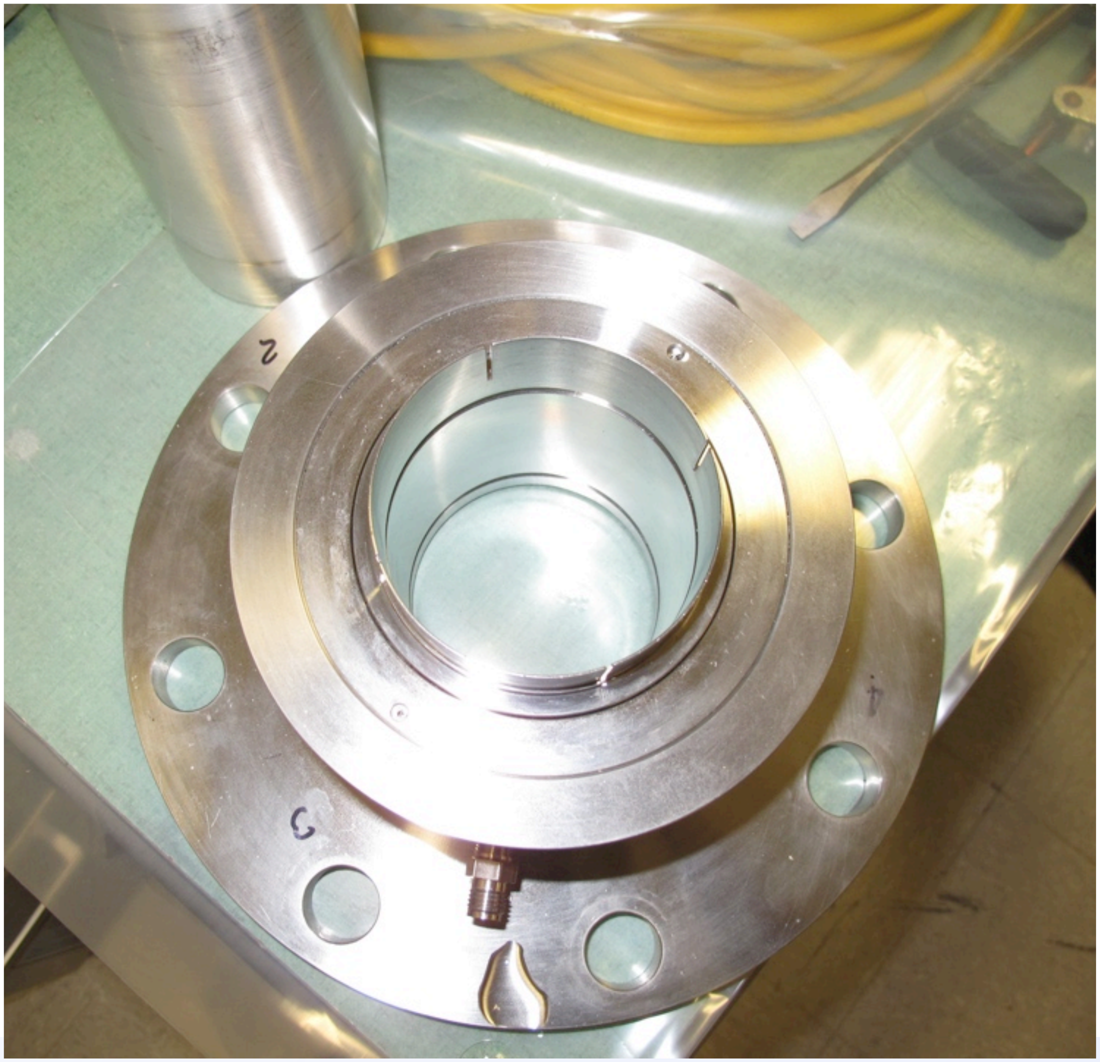


2.2 e-7 Torr without the ferrofluidic seal in place

Full mechanical drawings have been produced and are being machined



While we wait for all components to arrive we have begun initial vacuum testing of the Rigaku Ferrofluidic Seal



- A magnetic fluid is held between the inner and outer ring by permanent magnets
- There is significant torque and heat dissipation
- The ferrofluid can be expected to outgas

We have an existing outgassing test stand that we have modified to test the Rigaku seal

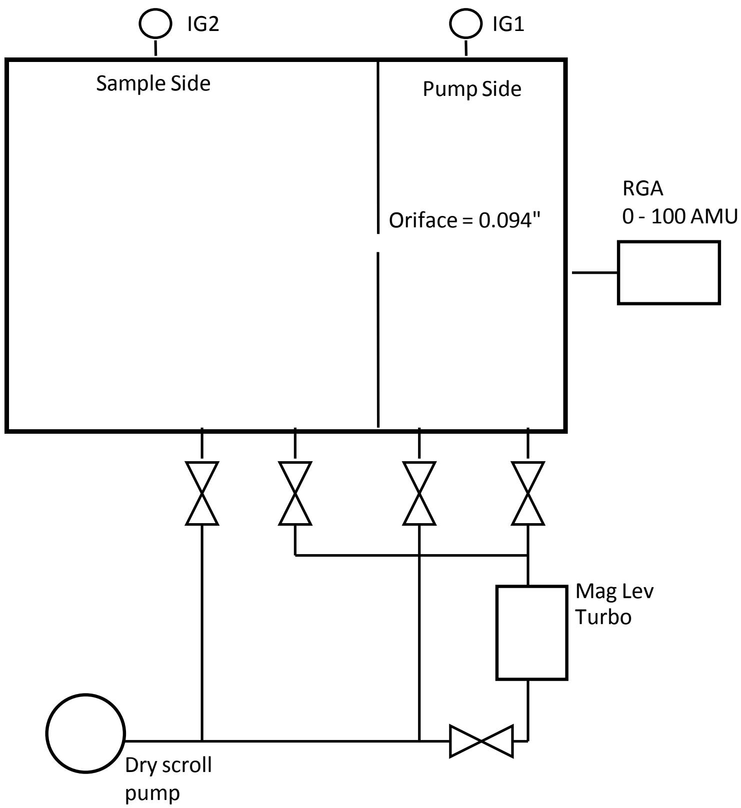
Vacuum Sciences and Engineering Lab Outgassing Measurement Test Stand

Sample Side Volume = 216 Cu. in.

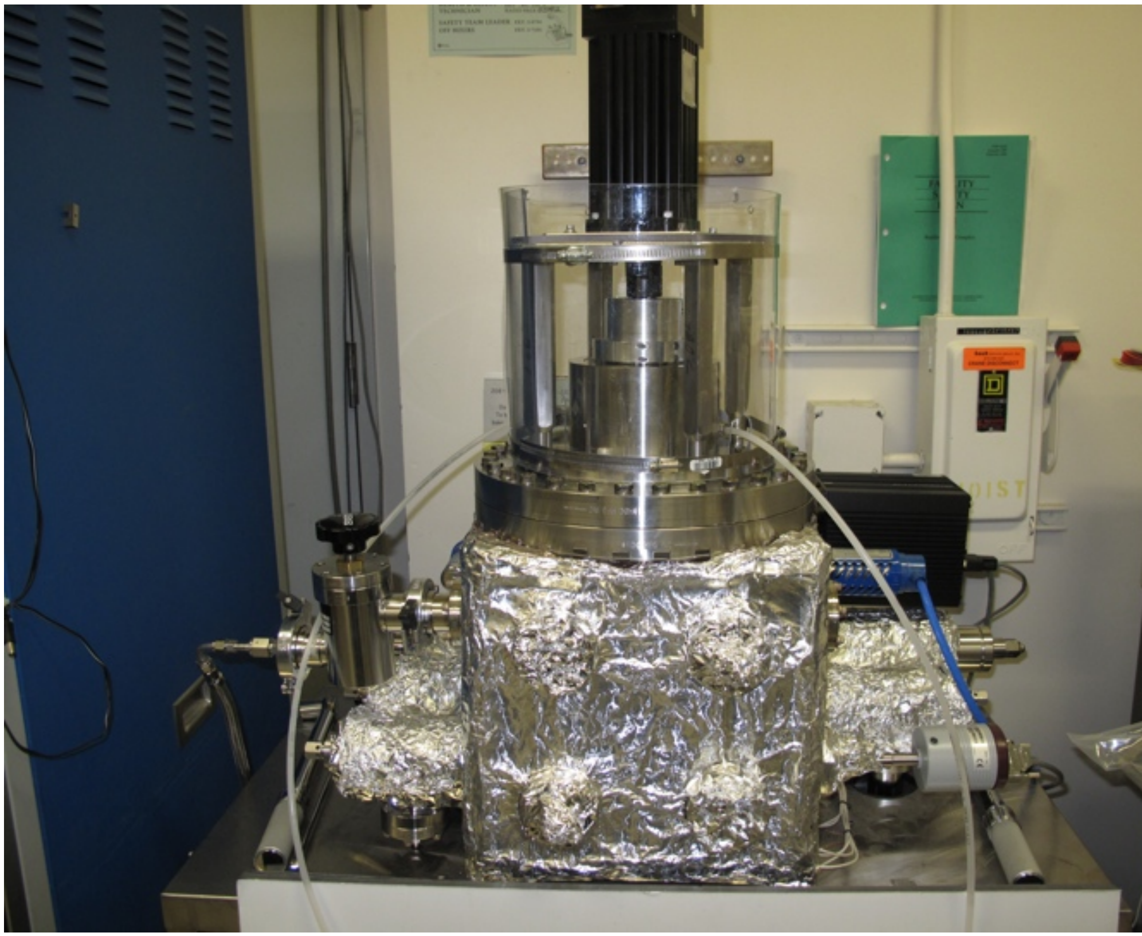
Sample Side Surface Area = 5,575 cm^2

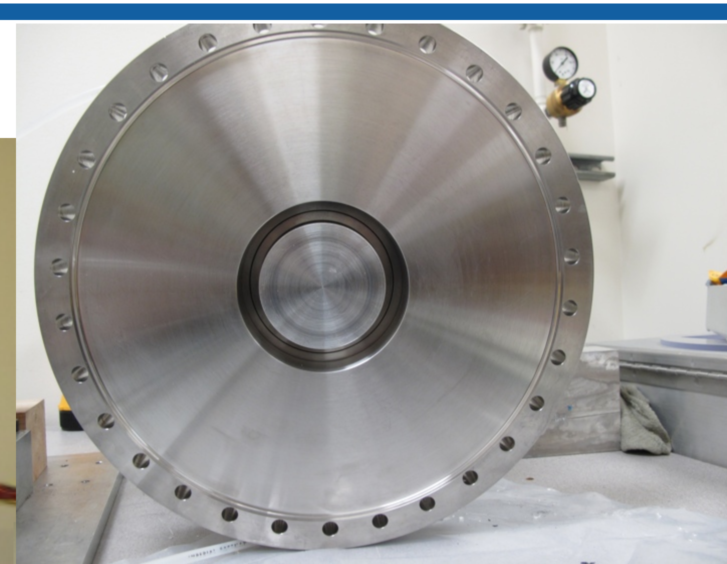
Conductance = 0.52 L/s for air at 20C

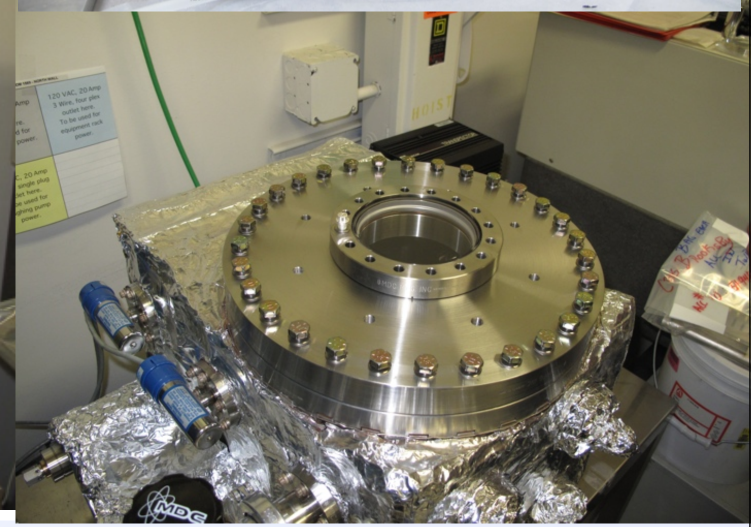
$Q = C(P_{IG2} - P_{IG1})$



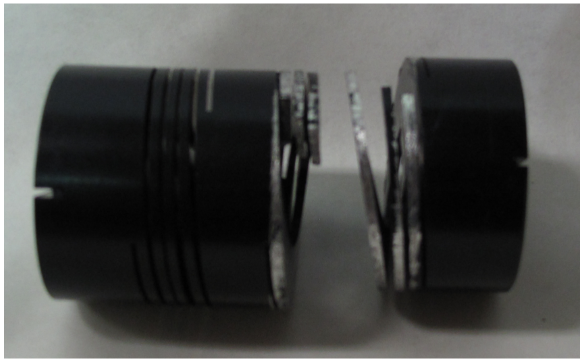
The test stand allows us to rotate the seal up to 2000 RPM with pressure and outgassing measurements







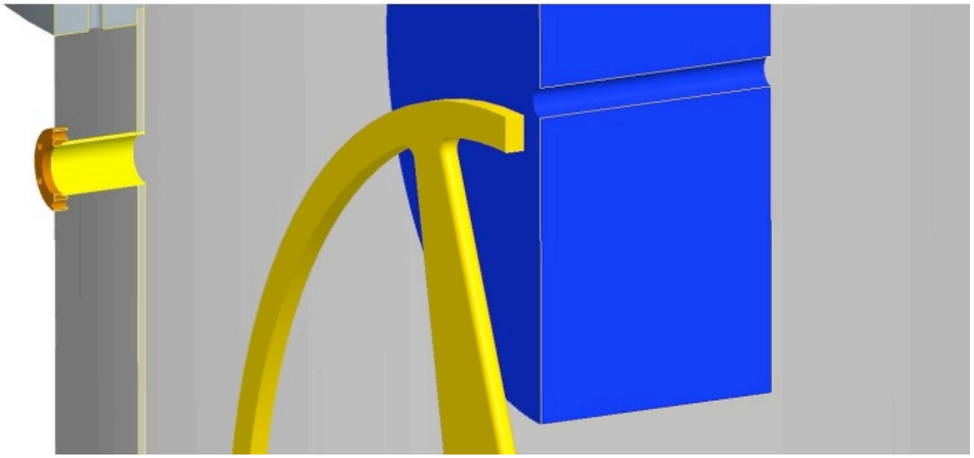
Very Preliminary Initial Results



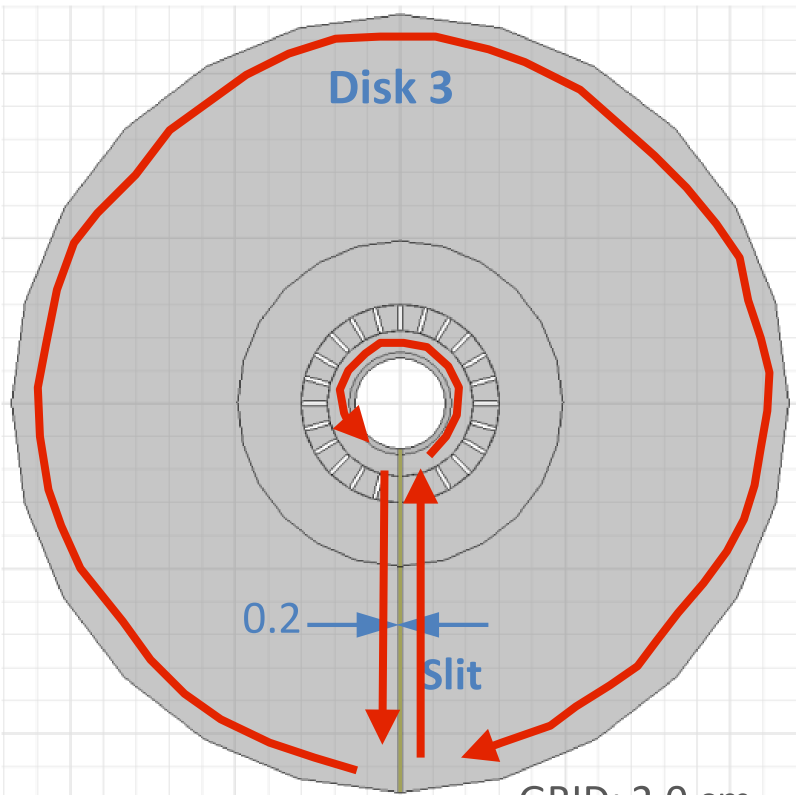
- Seal has been run up to 2000 RPM for short periods
  - Torques of 64 in-lb have been observed
  - Seal outer case temperatures of 55 C
  - Base outgassing rate of 2e-5 Torr L/s at 0 RPM that increases with Rotation and Higher Temperature
- Some start-up problems with the motor.
  - High torque in the ferrofluid seal has caused problems with the motor
  - Couplers have sheared
  - Motor trips are common
- We will need to upgrade to a higher torque motor

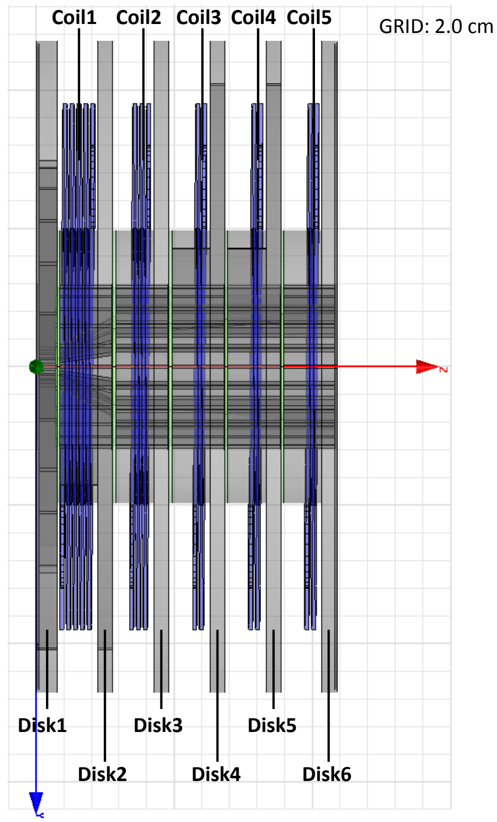
Magnetic Capture Optic is being designed

- Adiabatic matching device after the target increases positron capture
- High fields in the rotating target must be avoided
- The baseline device is a liquid nitrogen cooled, pulsed flux concentrator



Flux Concentrators are a known technology

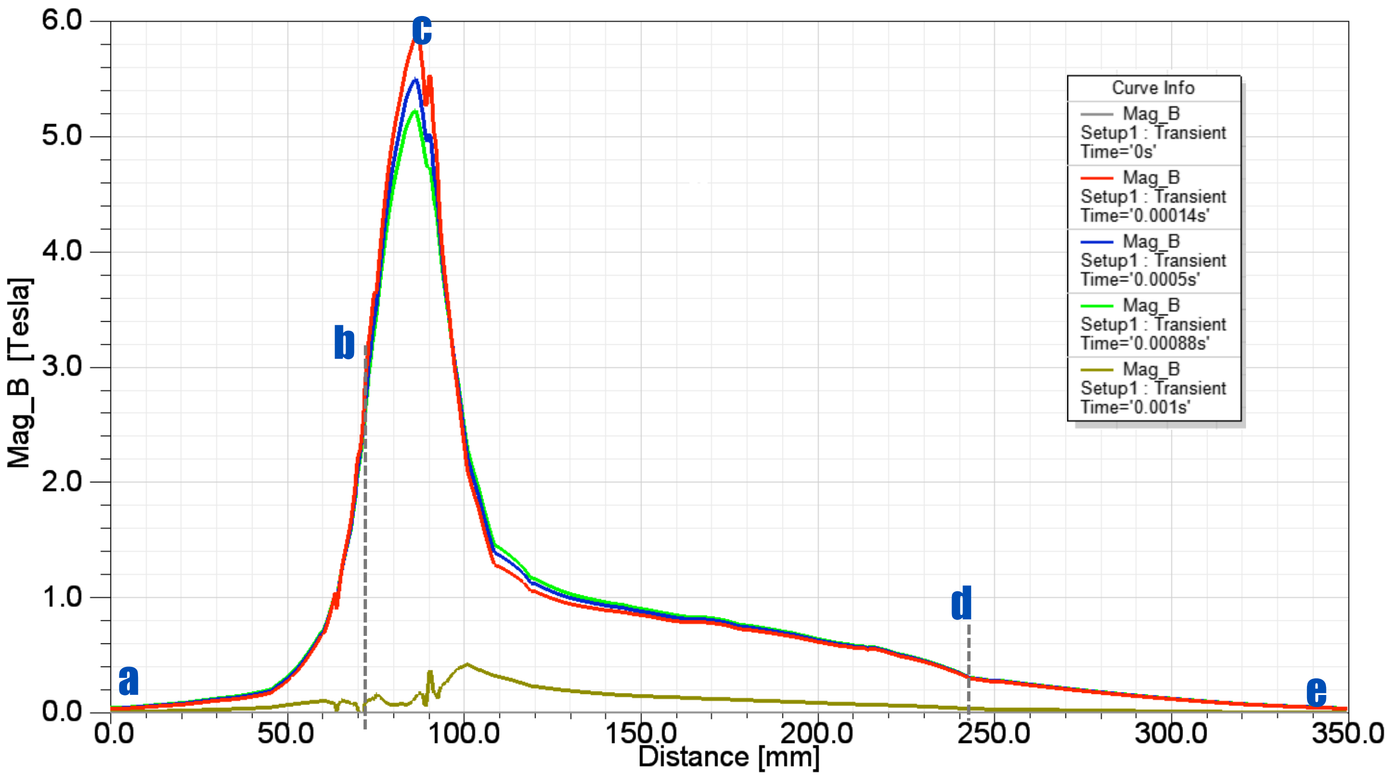


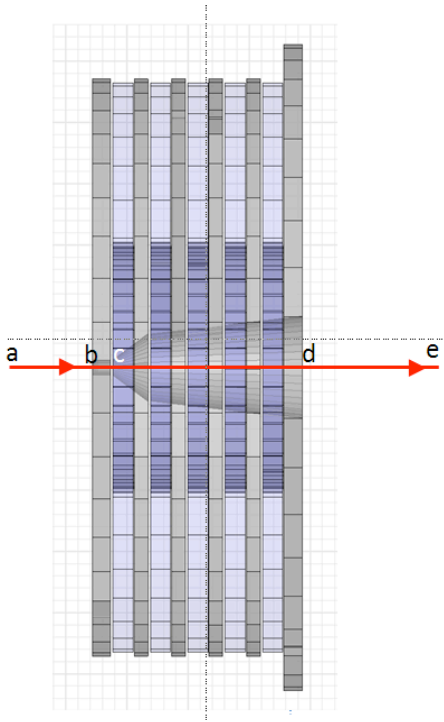


Current induced in a copper disk is forced by a non-conductive slit to flow around the bore

A set of disk with varying bore size are energized by current in copper coils to produce the desired field

High field near the target slowly decreasing with distance provides the best capture performance

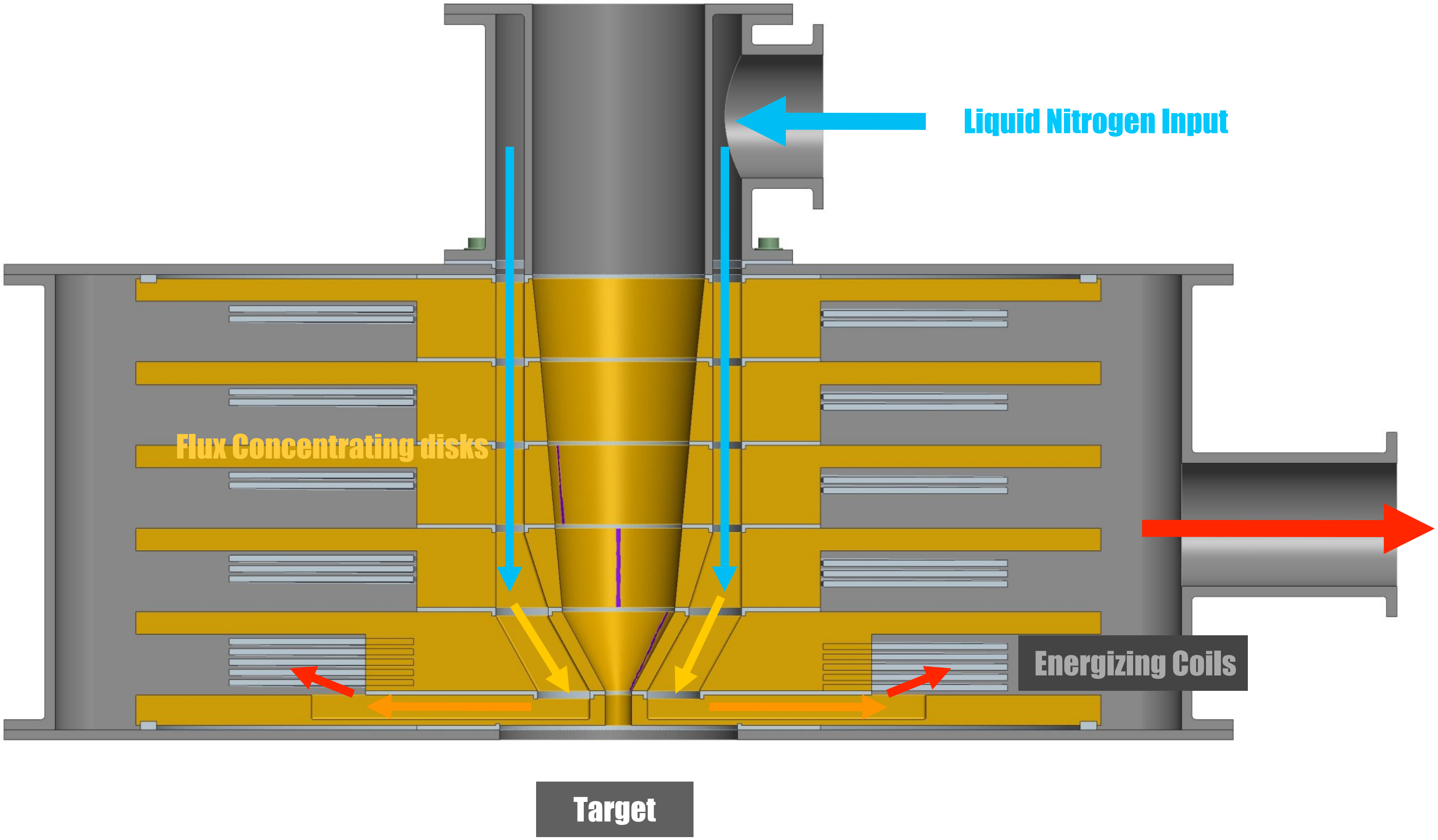




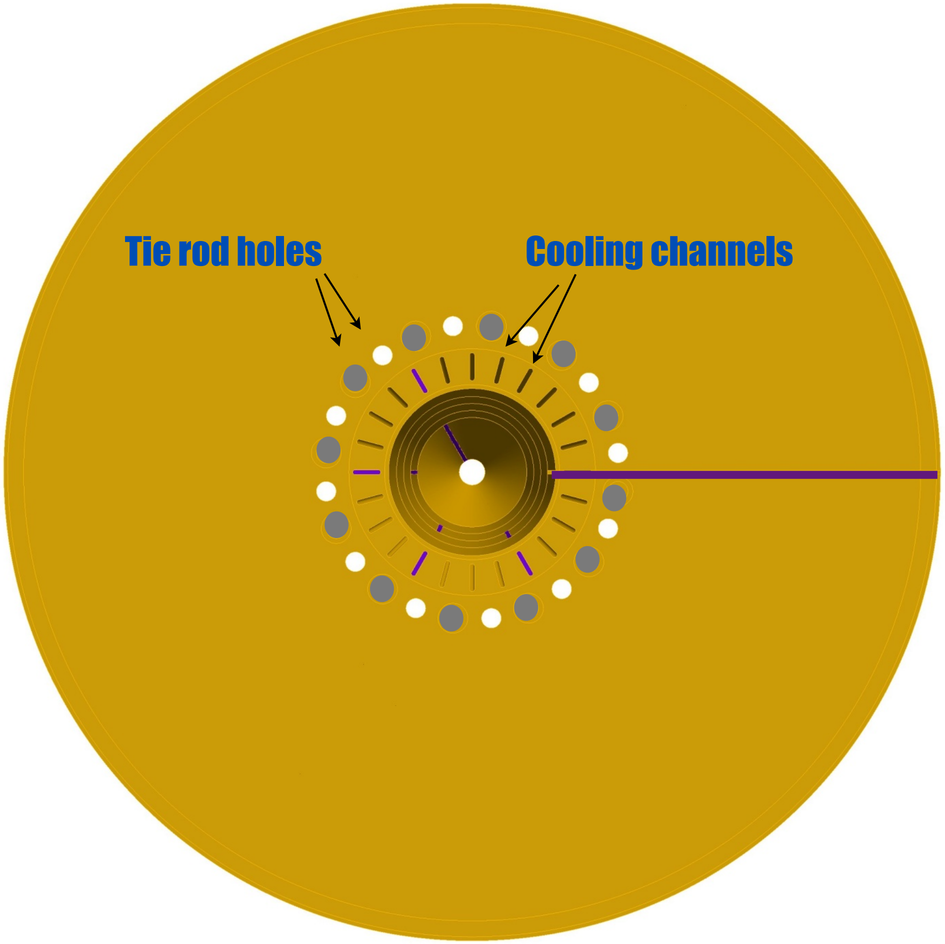
Technical Challenges

- Near the target - high radiation environment
- Pulsed device 5 Hz, 24/7 for 1 year
  - Must survive cyclic stresses
- Cooling flow is needed near the bore
  - location of maximum power dissipation

The current concept of the device



Real Estate around the bore is crowded and is needed for a variety of task



- Cooling channels for liquid nitrogen flow need to be around the bore since that is where the heat is deposited

- Holes for threaded rods to tie the assembly together are needed

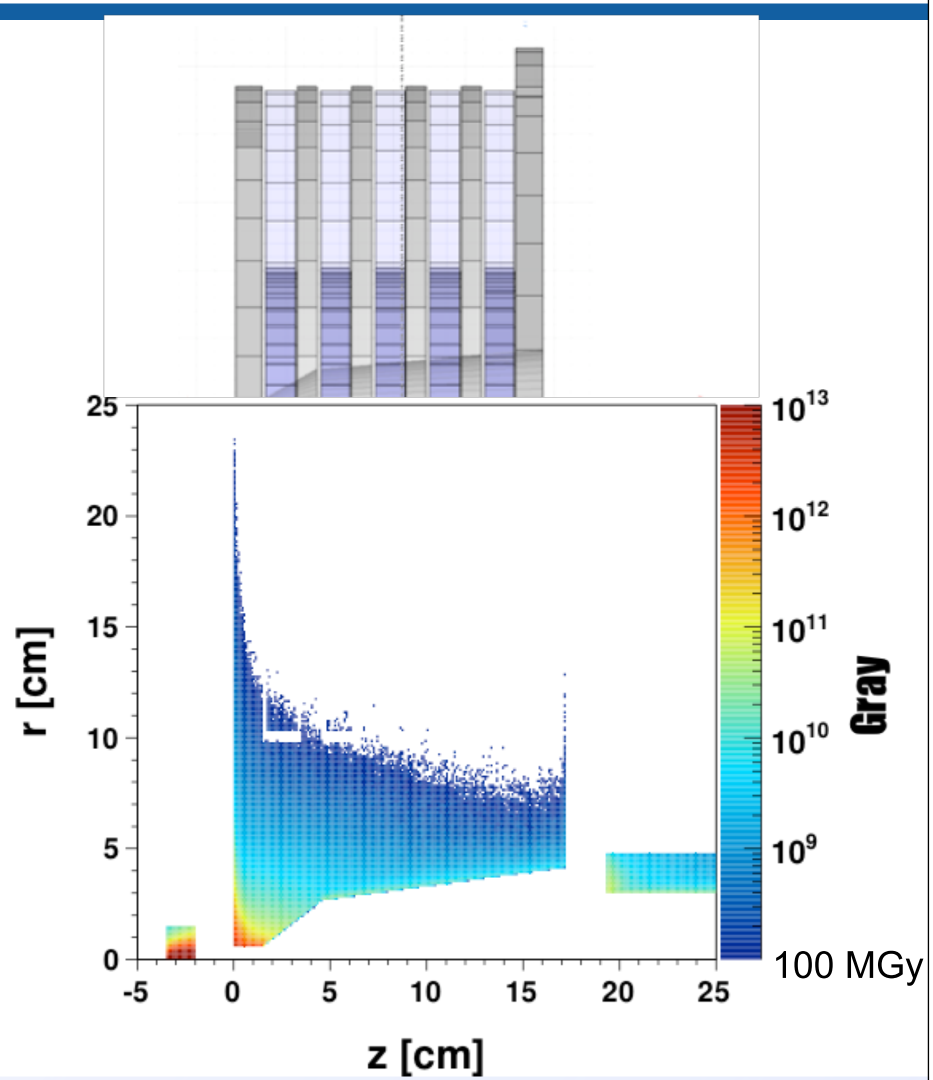
- These regions should not interfere with the current flow around the concentrating disk

Radiation levels preclude organic insulators near the magnet bore

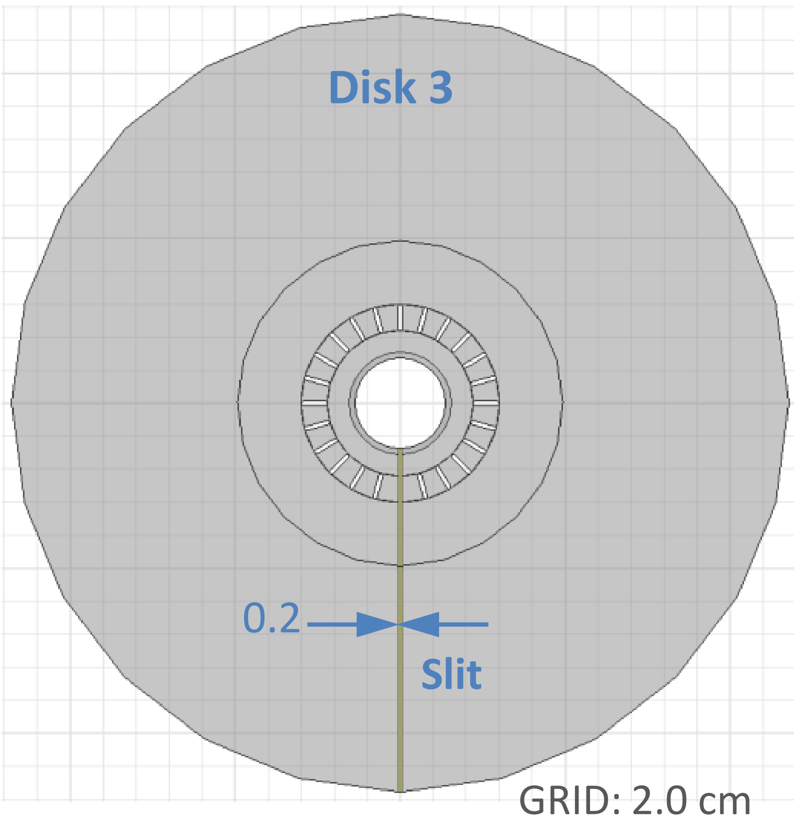
- 100 Mgy is Kapton radiation limit based on work from CERN

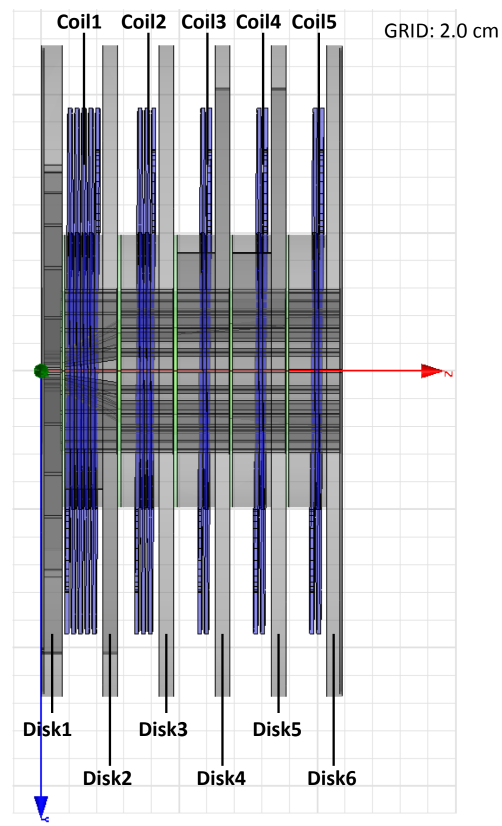
- Calculation from Ushakov shows area where inorganic insulators will be needed

- Energizing coils will use Kapton
  - First and second coil will be moved out in radius for greater shielding



Zirconia Toughened Alumina (ZTA) will be used as an inorganic insulator

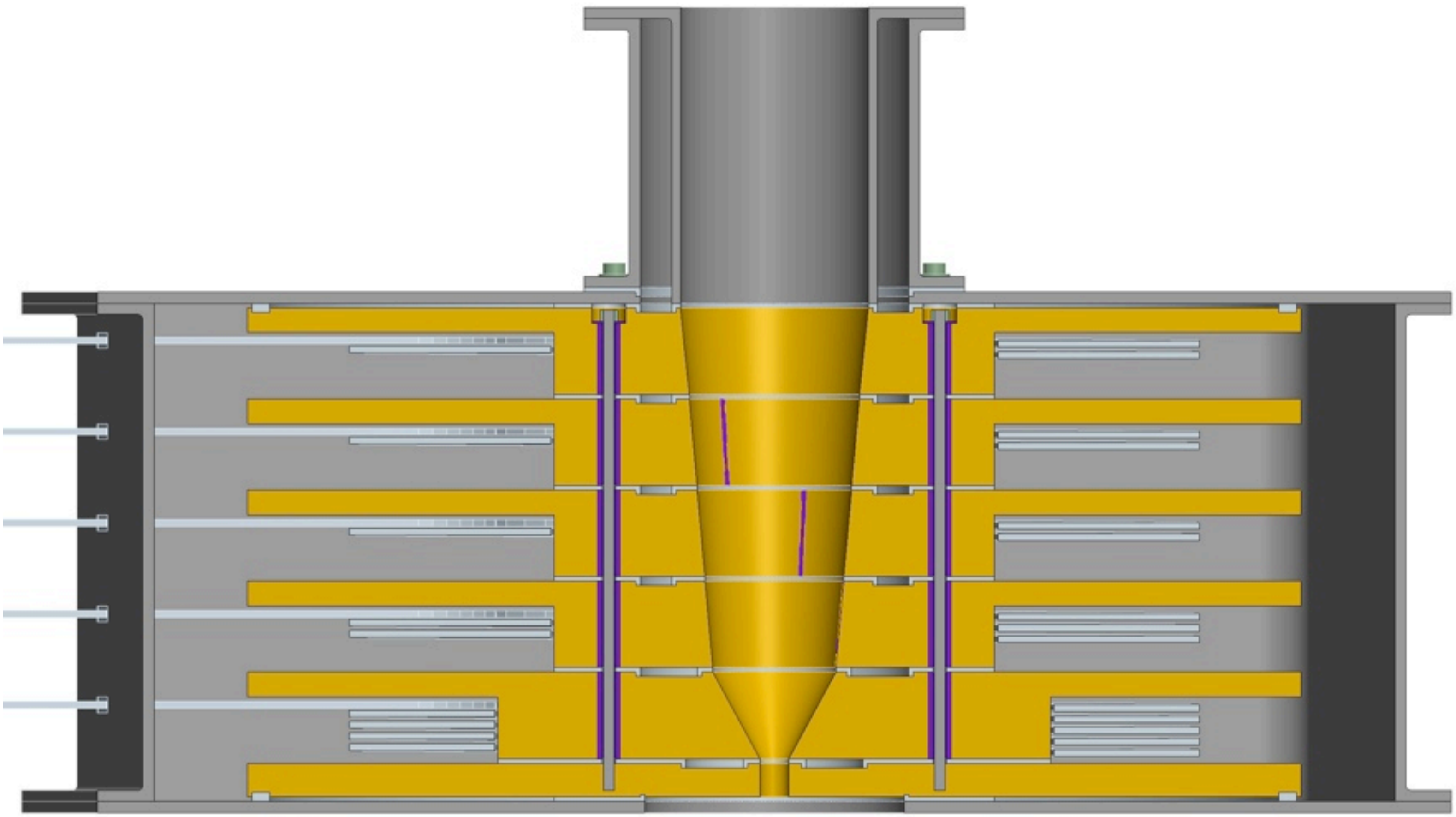




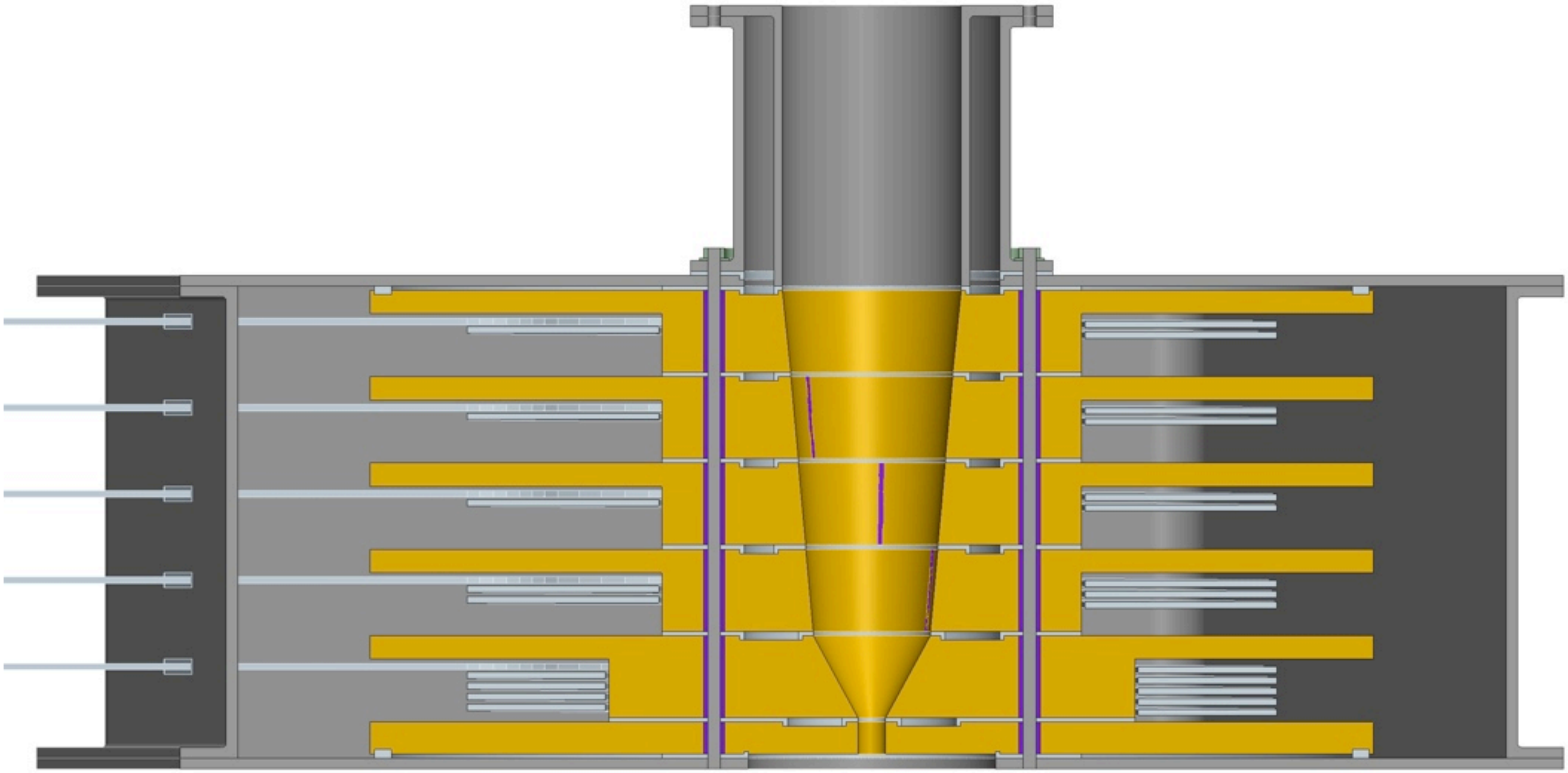
ZTA will be bonded into the gaps in the concentrating plates

ZTA disks will separate the concentrating plates with Flexible Graphite disks to form the vacuum seal

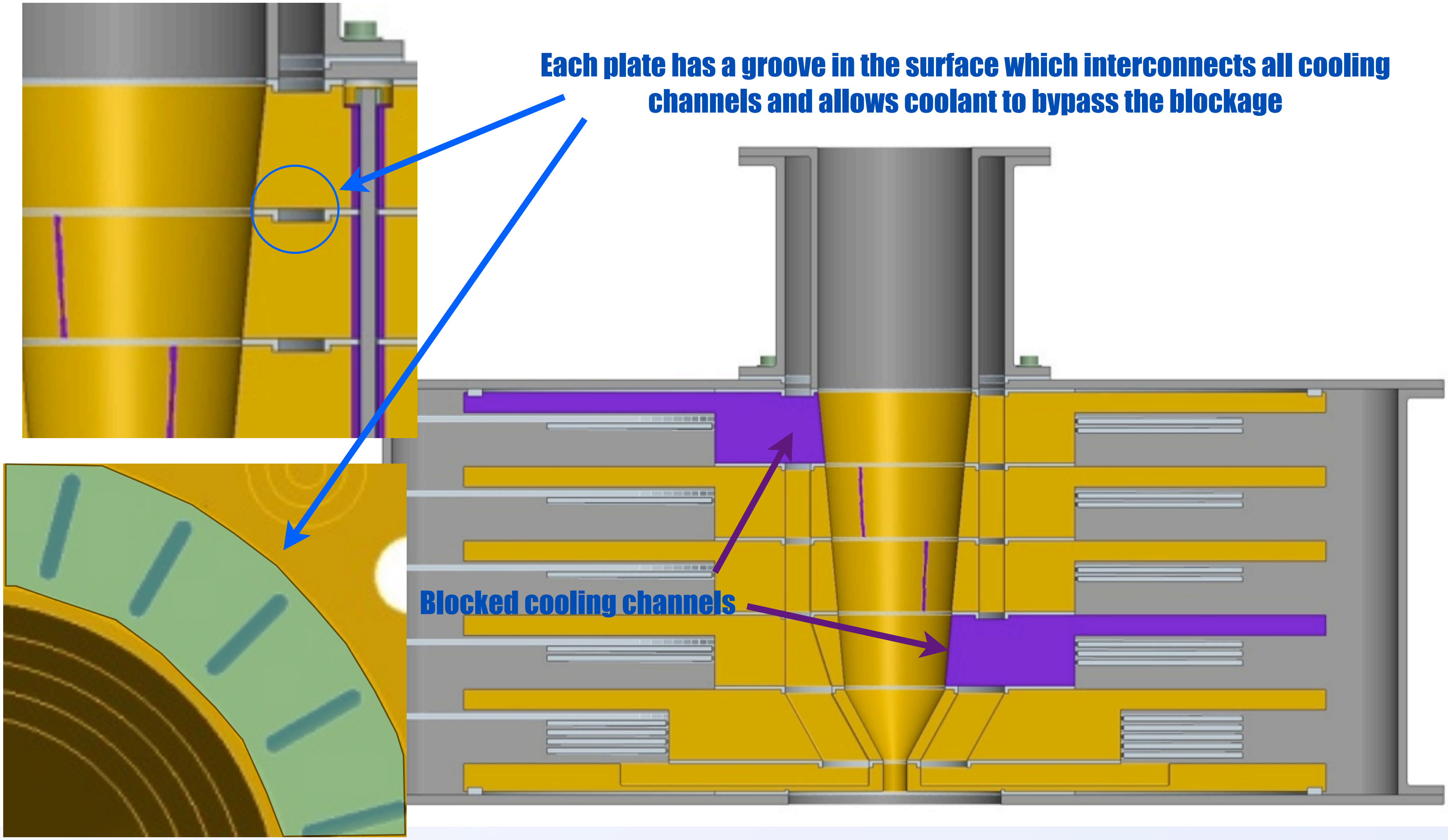
One set of tie rods provides the compressive force to seal the concentrating plates together



The other connects to the outer casing

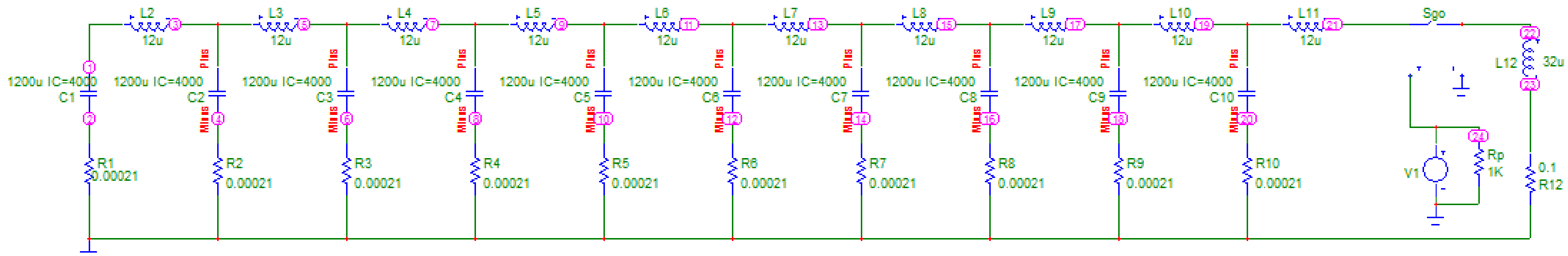


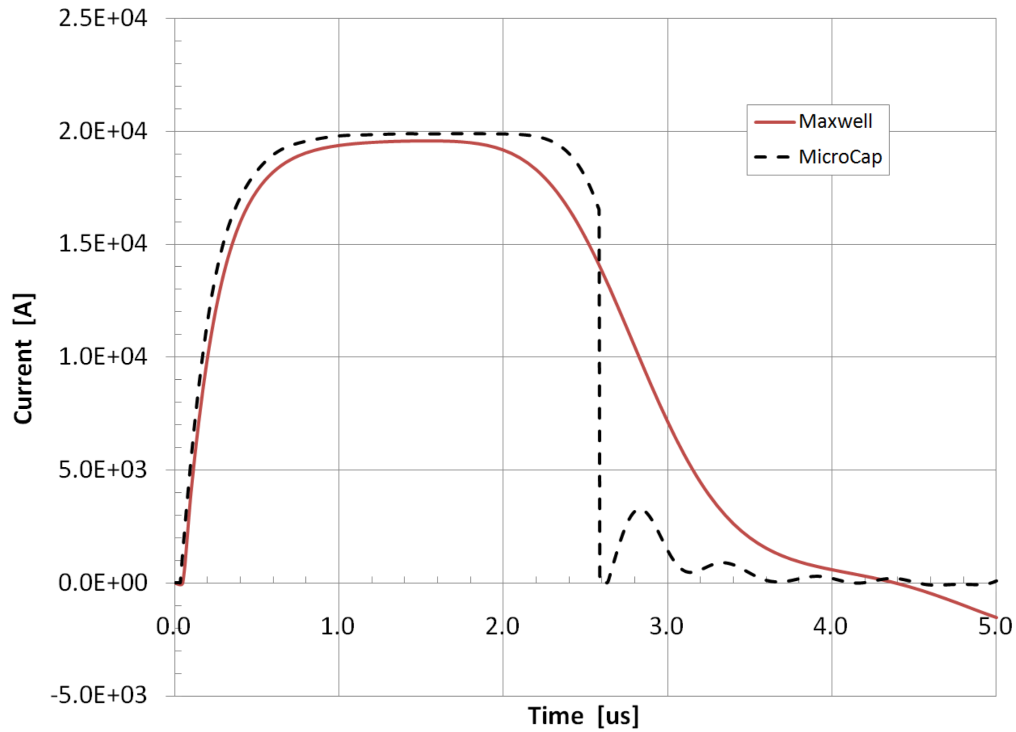
Some of the ZTA gap fillers block a single cooling channel



Pulse forming network has been designed and integrated into the FEA model to achieve 1ms flat top

Verification of Current from Maxwell with Equivalent Microcap Circuit





Achievable fields are limited by mechanical stresses

B_0	4.2	**T**
σ_0	1.40E+08	**Pa**
s_f	7.60E+08	**Pa**
a	2.00E-04	**m**
F	1.12	**-**

	FS	**K_{Ic}**	**a_t**	**s_{cg}**	**s_{ag}**	**B**
	-	**Pa·√m**	**m**	**Pa**	**Pa**	**T**
Case 1	1.5	6.00E+06	1.98E-05	2.14E+08	1.42E+08	4.3
Case 2	2	6.00E+06	1.98E-05	2.14E+08	1.07E+08	3.2
Case 3	3	6.00E+06	1.98E-05	2.14E+08	7.12E+07	2.1
Case 4	1.5	1.00E+07	5.51E-05	3.56E+08	2.37E+08	7.1
Case 5	2	1.00E+07	5.51E-05	3.56E+08	1.78E+08	5.3
Case 6	3	1.00E+07	5.51E-05	3.56E+08	1.19E+08	3.6

Key:

B_0	Reference peak magnetic flux density
σ_0	Reference ZTA stress
s_f	ZTA flexural strength
a	Assumed flaw (crack) size
F	Flaw stress multiplier
FS	Factor of Safety
K_{Ic}	ZTA fracture toughness (Mode I)
a_t	Transition flaw size (use LEFM for flaws larger than this)
s_{cg}	Critical gross section stress (max principal?)
s_{cg}	Allowable gross section stress with FS (max principal stress from FEA?)
B	Peak allowable magnetic field (flux density)

- Mechanical stresses in the ZTA gap filler become the limiting factor in the achievable field
- Management decision needed on acceptable risk vs. field choice

Prototyping plan

- Conceptual design is maturing
  - Final energizing coil design is needed
  - Engineering drawings for manufacture are next
- Staged prototyping scheme
  - Build full device - demonstrate good seal performance
  - Build pulser network
  - Demonstrate room temperature performance at low repetition rate
  - Cool to liquid nitrogen temperature and demonstrate full field and 1 ms flat top at low repetition rate
  - Full repetition rate requires significant cooling plant

Conclusions

- The ILC will require two orders of magnitude more positrons than the previous SLC
  - This is pushing the performance of the baseline positron target system near the limit of what can be physically achieved
- The ILC prototyping activity is attempting to address the technical risks of the baseline system
  - The Daresbury prototype target test has shown good rotordynamics and acceptable eddy current effects
  - Demonstration of acceptable vacuum performance with the ferrofluidic seal is underway
  - Detailed design of the magnetic capture optic is concluding and prototyping will soon begin