Lawrence Livermore National Laboratory

Design and Prototyping of the ILC baseline positron target

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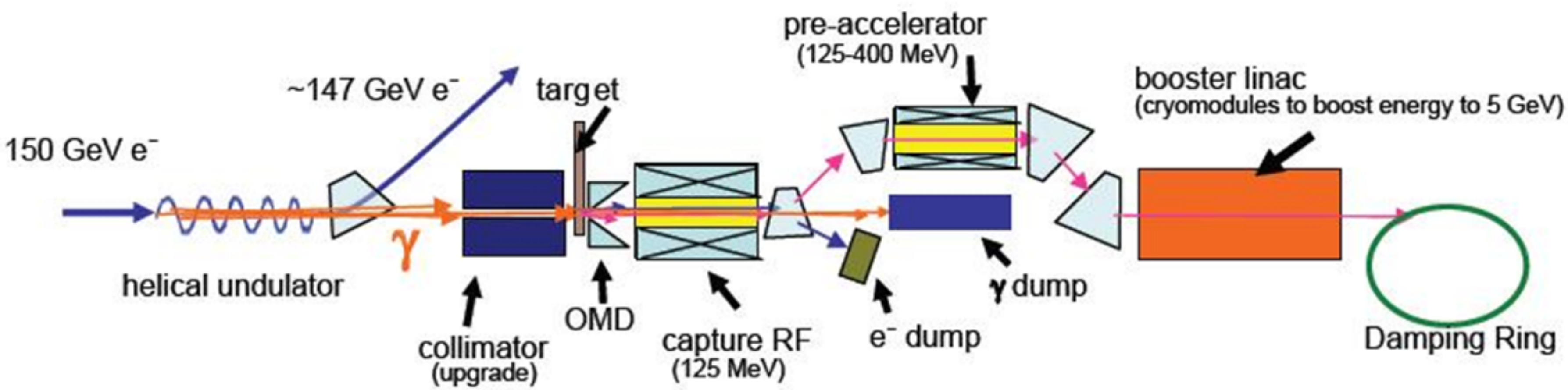
UCRL-XXXX-12345

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

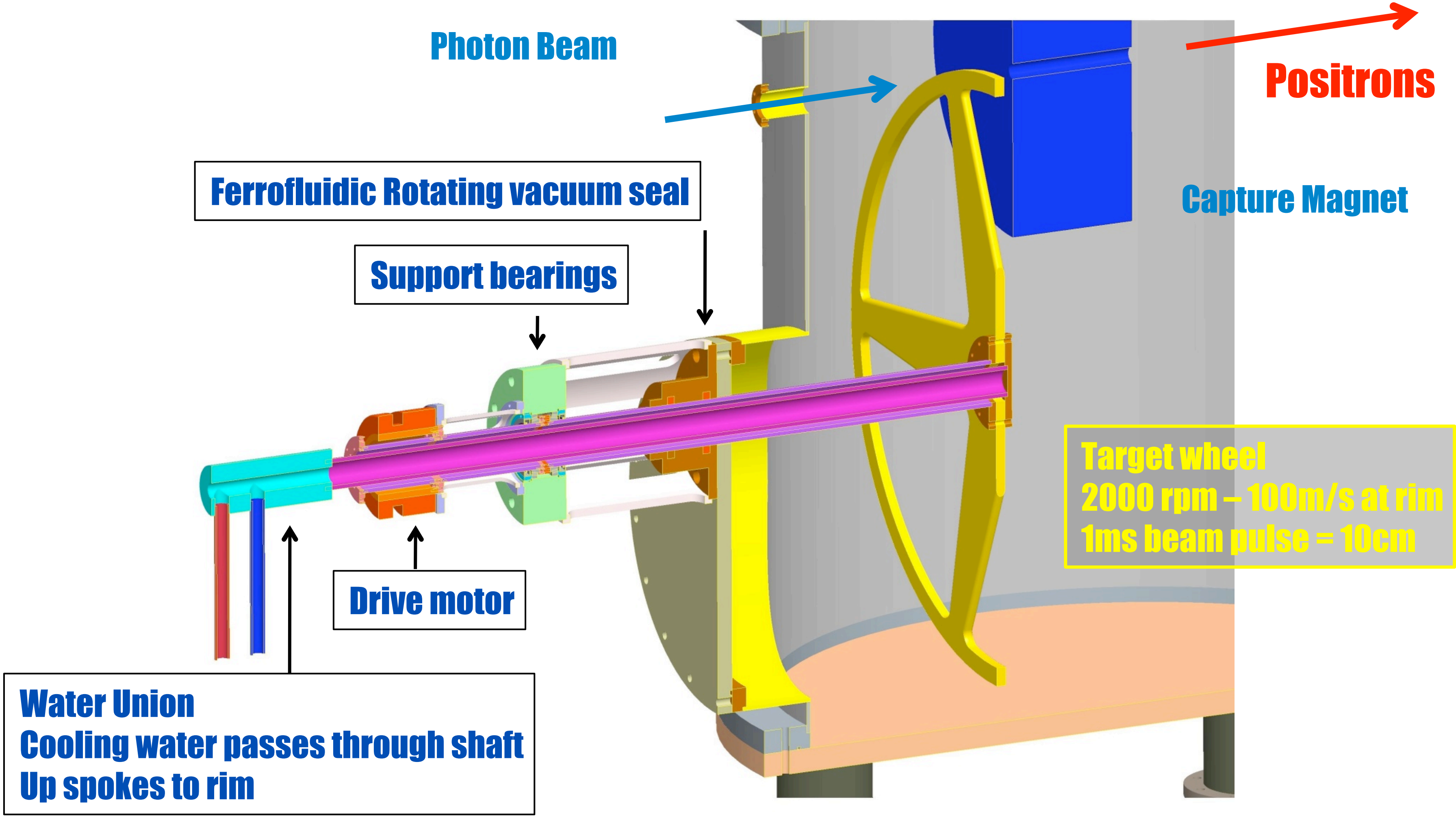
Helical undulator to generate a circularly polarized photon beam

Optical Matching Device to get high capture efficiency

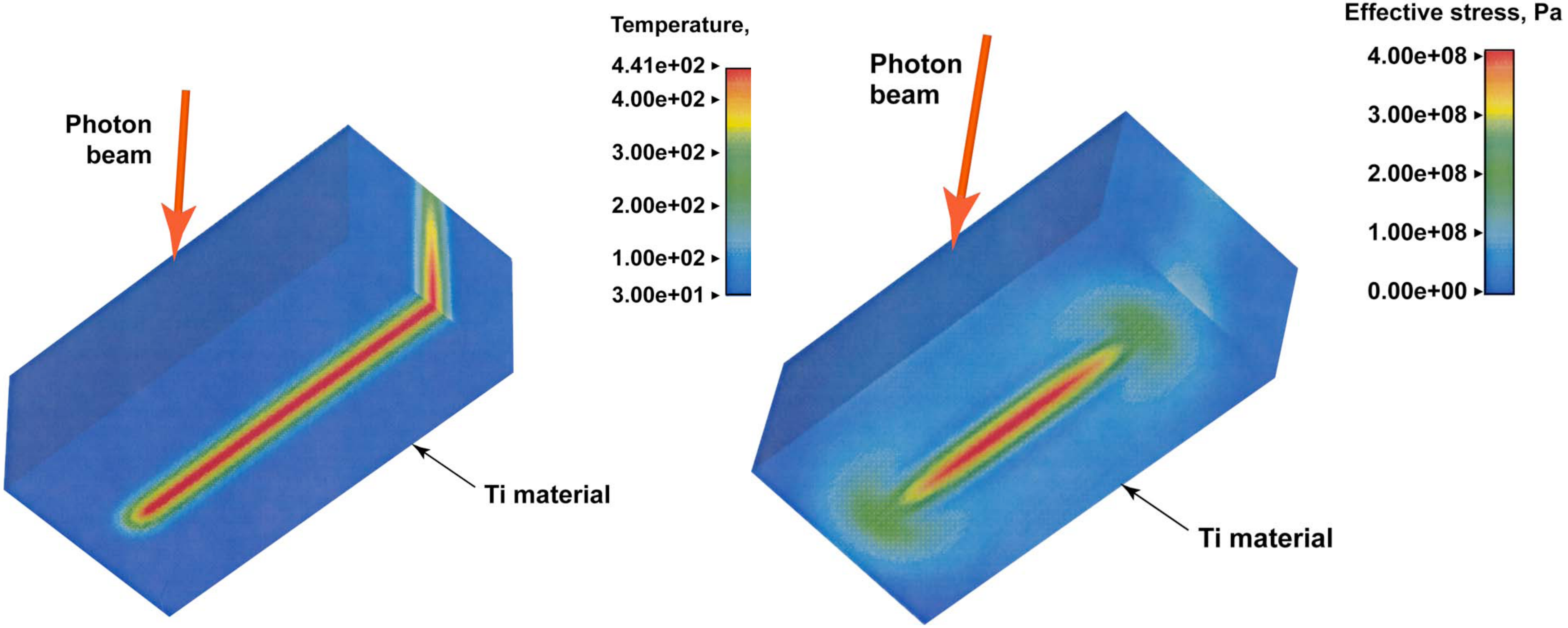


Rotating target to smear out the long 1ms pulse

Basic layout of the target



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



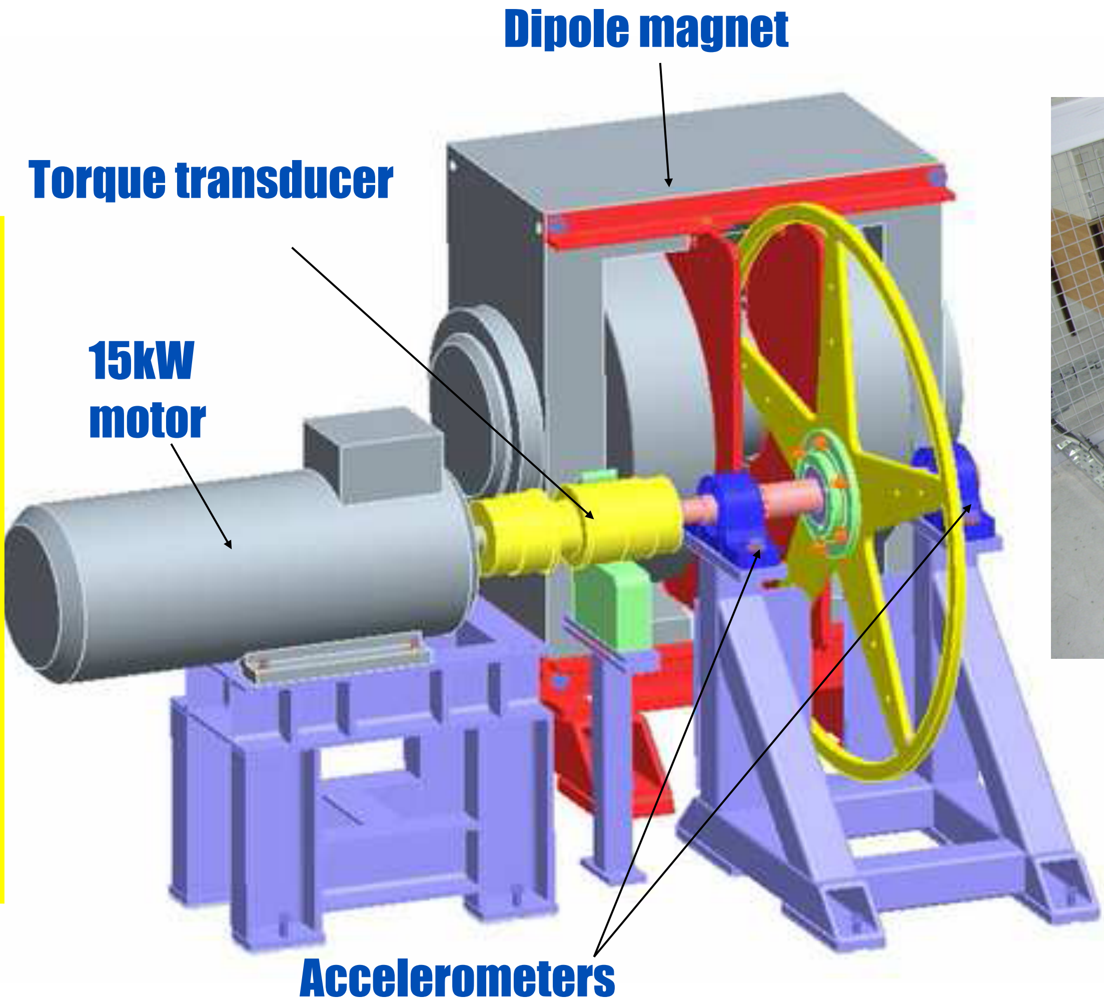
- 100 m/s rim speed
- Maximum temperature is 441C

Werner Stein, LLNL, Daresbury positron workshop 2005

Target Prototype

Prototype I - eddy current and mechanical stability

Ken Davies - Daresbury Laboratory



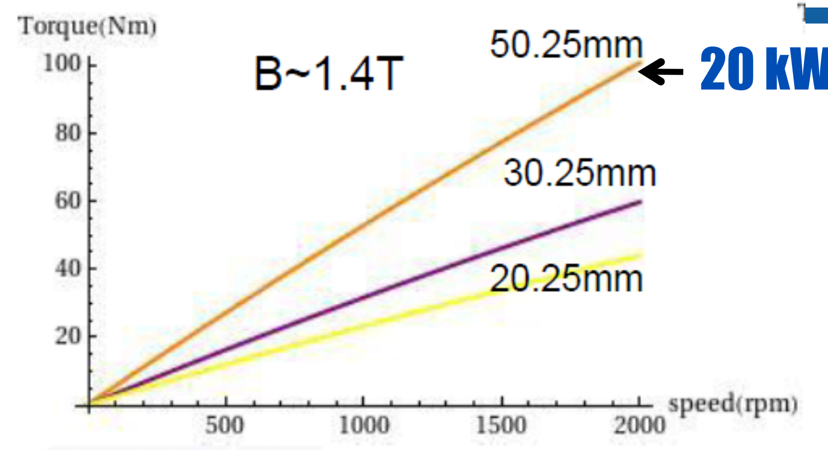
Ian Bailey, ILC collaboration meeting 2010

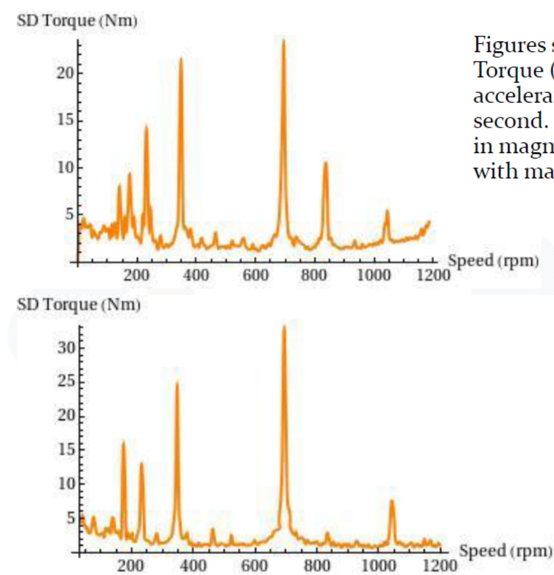
Daresbury Prototype Target wheel
Solid Ti - No cooling

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

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





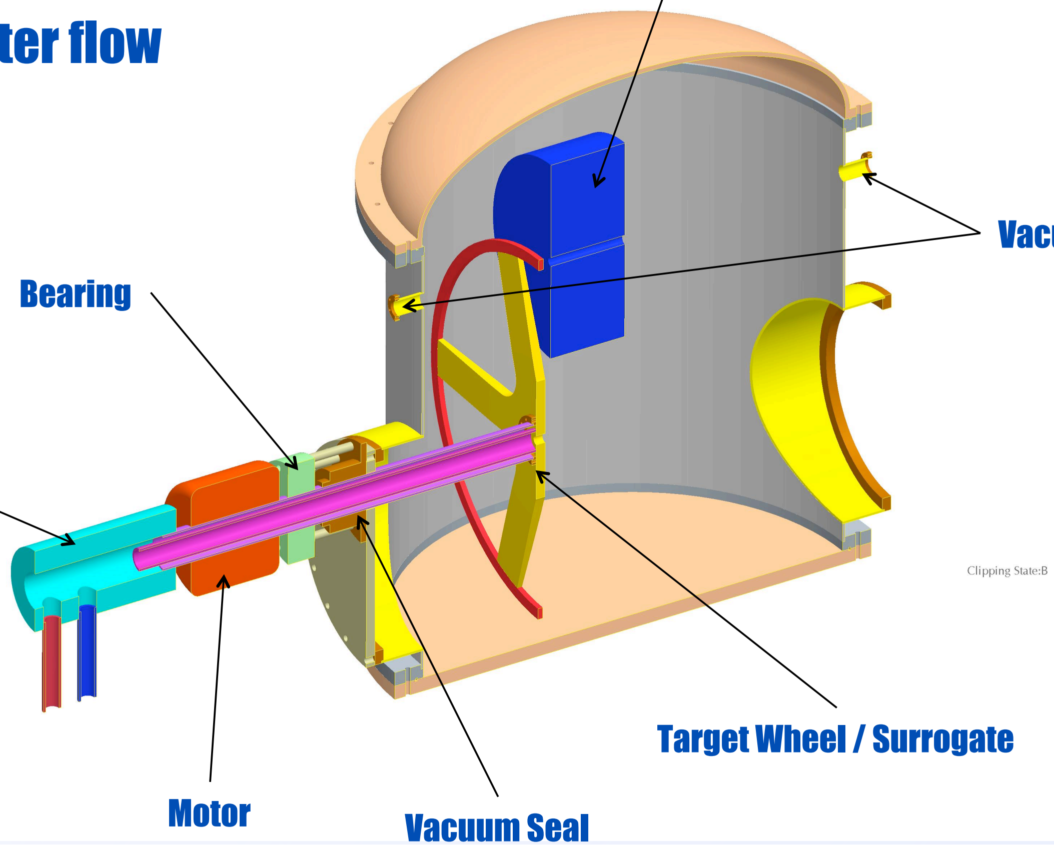
Figures show Standard Deviation in Torque (Nm) measured whilst accelerating at average rate of 6.6 rpm / second. Upper plot obtained with 50A in magnet coils. Lower plot obtained with magnet unpowered.

Ian Bailey, 6th positron source collaboration meeting 2009

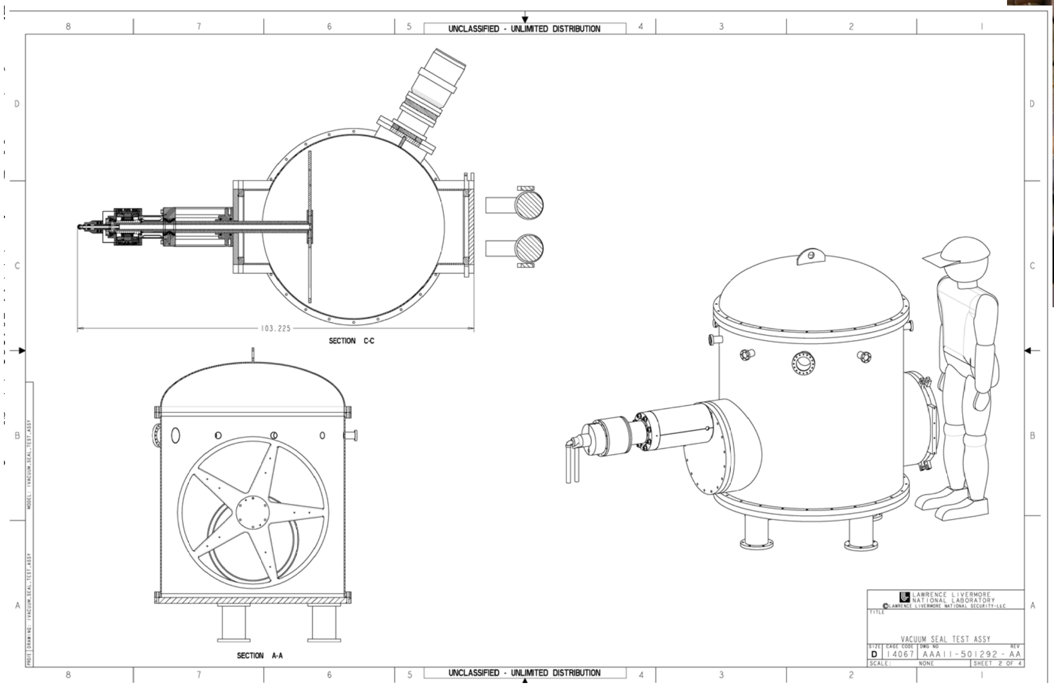
Target Prototype

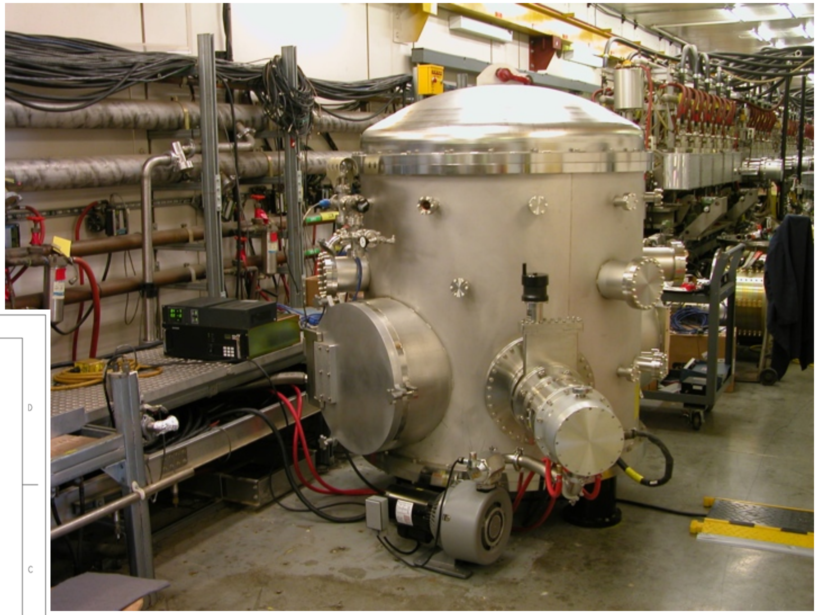
Prototype II - Ferrofluidic Vacuum Seal

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



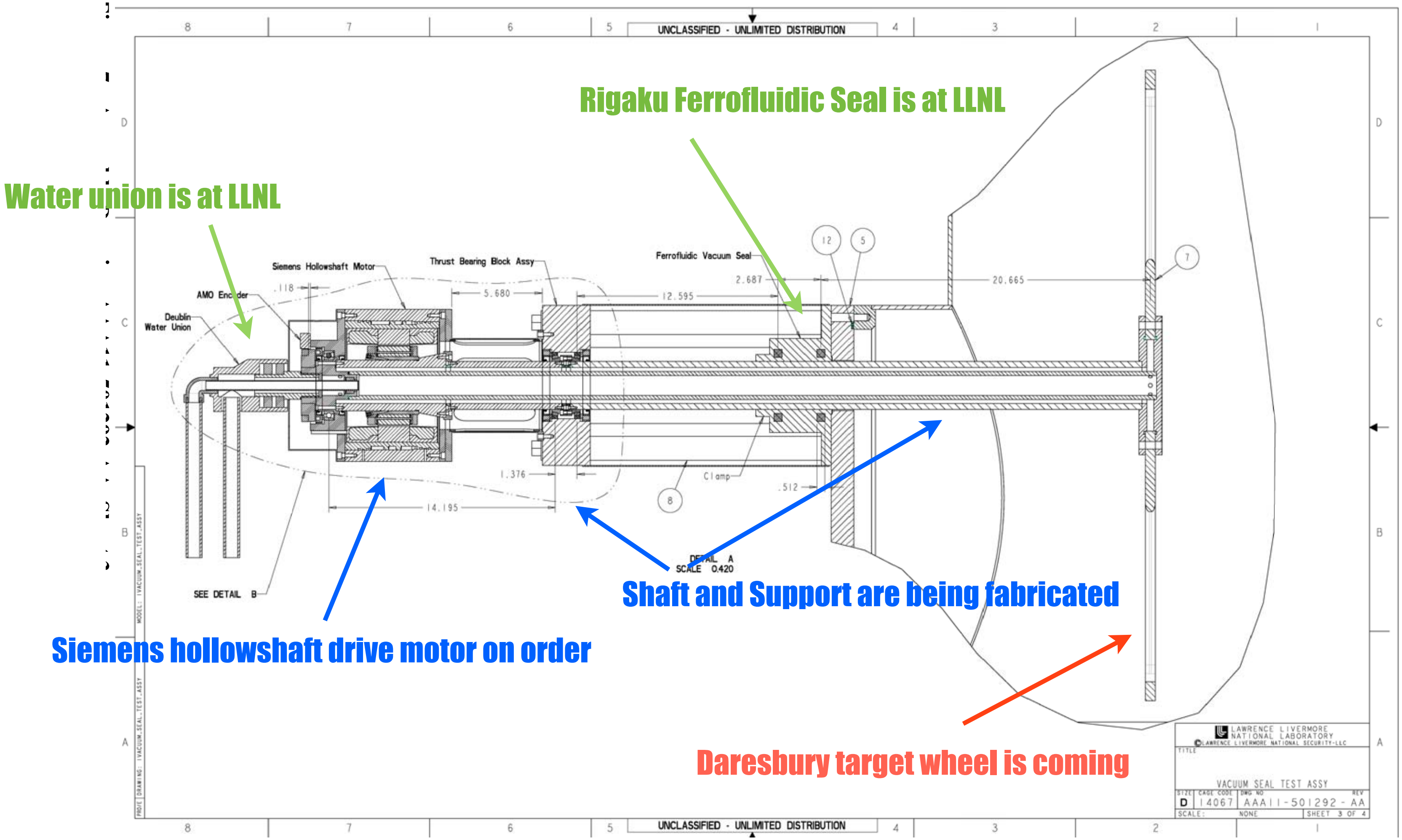
The vacuum tank is setup and under vacuum





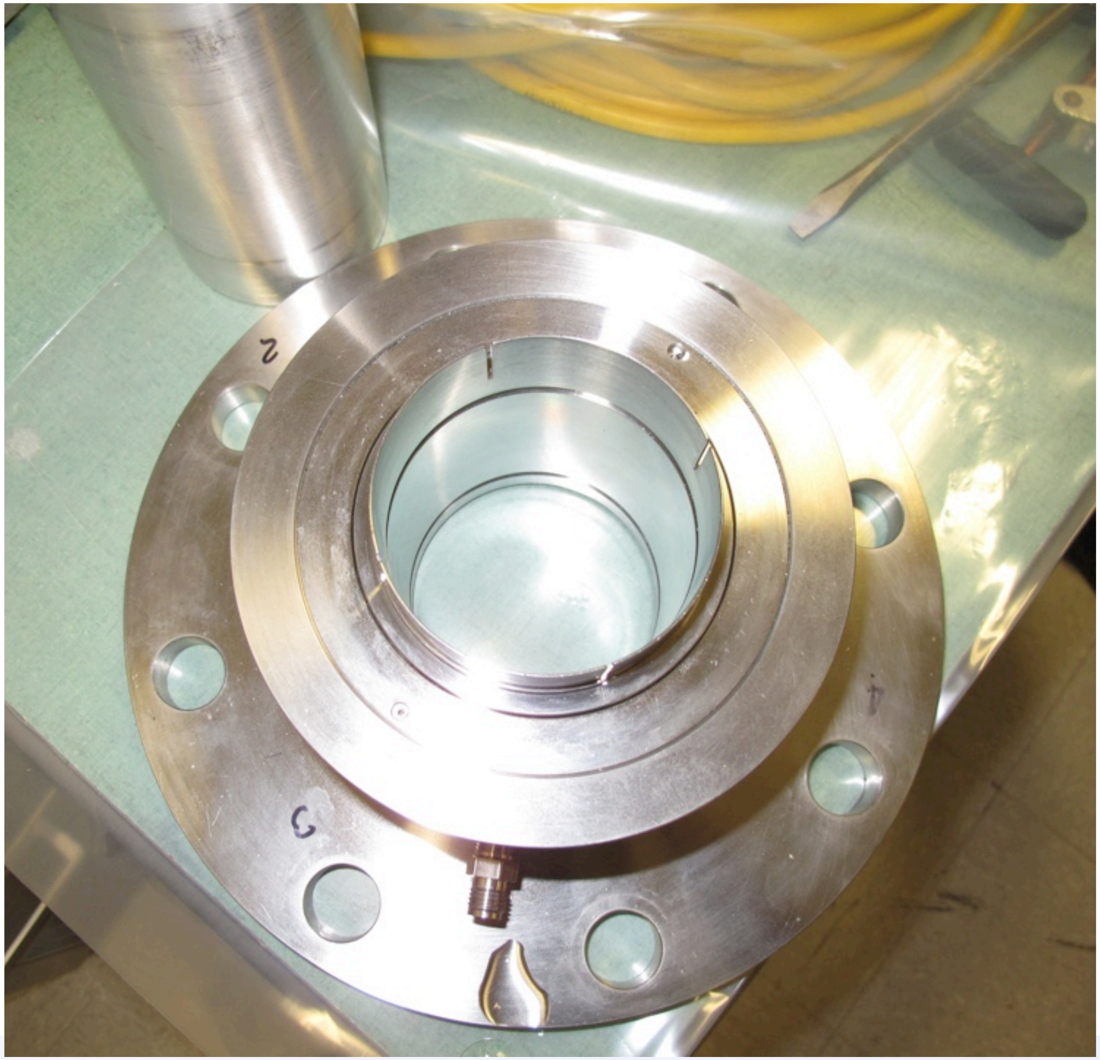
2.2 e-7 Torr without the ferrofluidic seal in place

Full mechanical drawings have been produced and are being machined



Shaft hardware has arrived, construction has begun

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

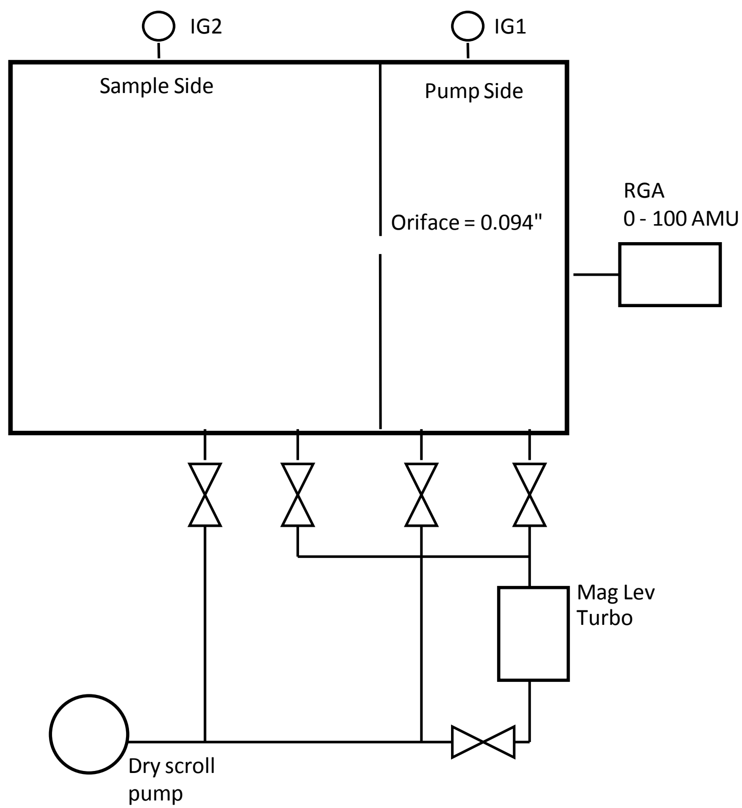
Vacuum Sciences and Engineering Lab Outgassing Measurement Test Stand

Sample Side Volume = 216 Cu. in.

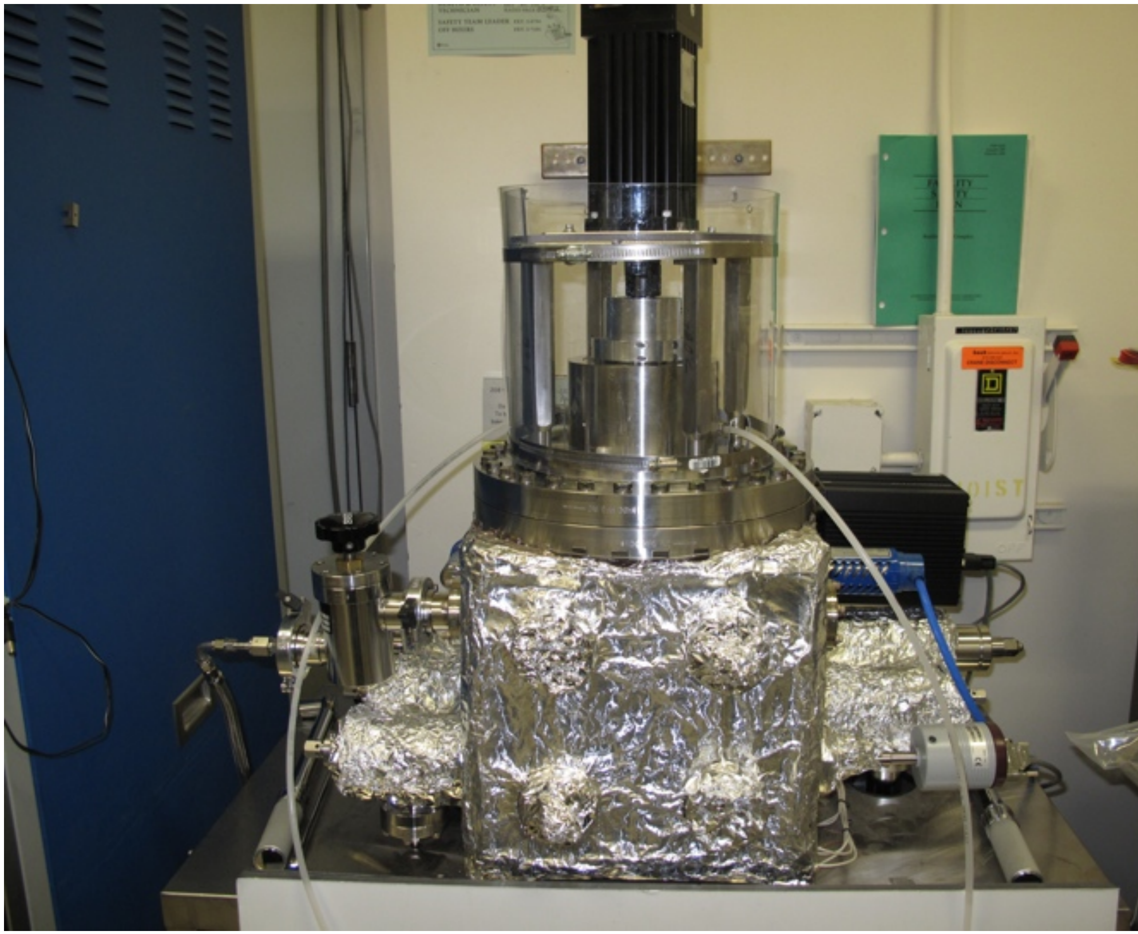
Sample Side Surface Area = 5,575 cm^2

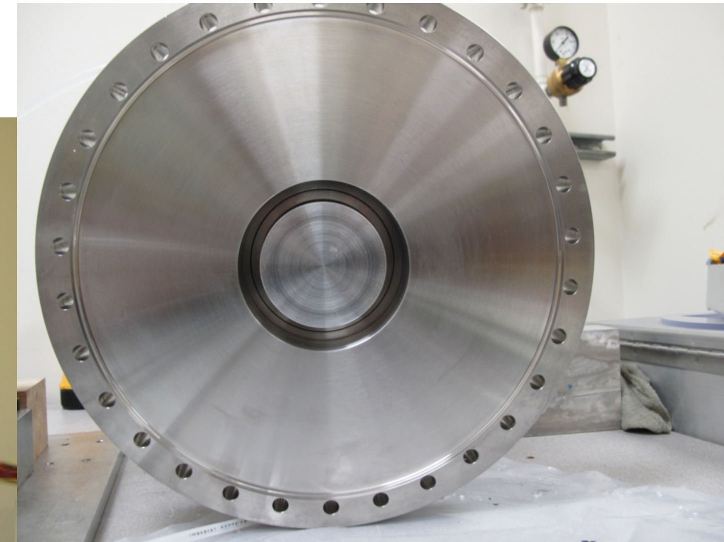
Conductance = 0.52 L/s for air at 20C

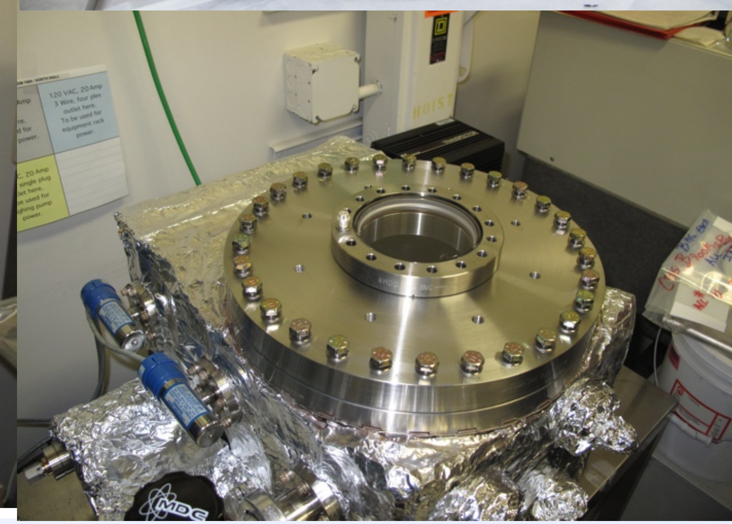
$Q = C(P_{IG2} - P_{IG1})$



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

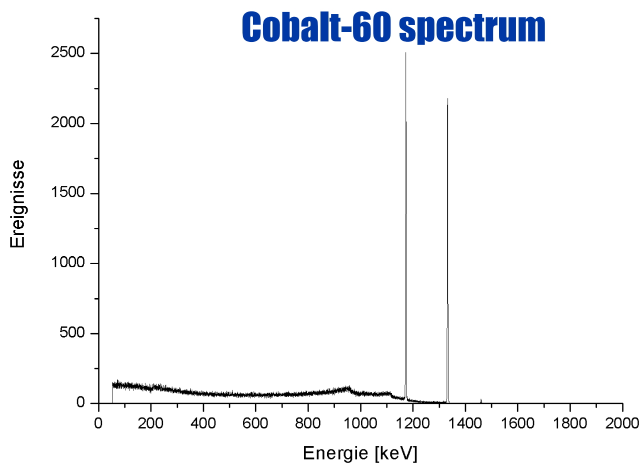






Radiation Damage Testing

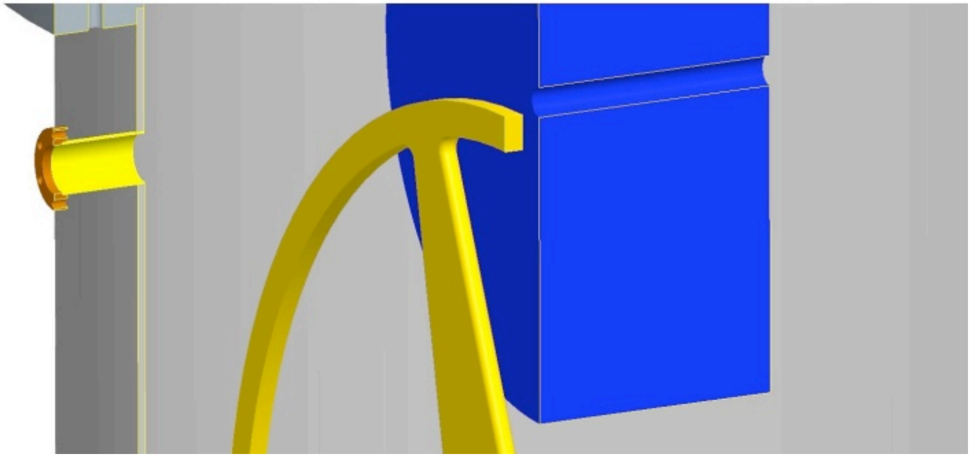
- Ferrofluid is an oil with suspended magnetic particles
- Radiation damage is a concern



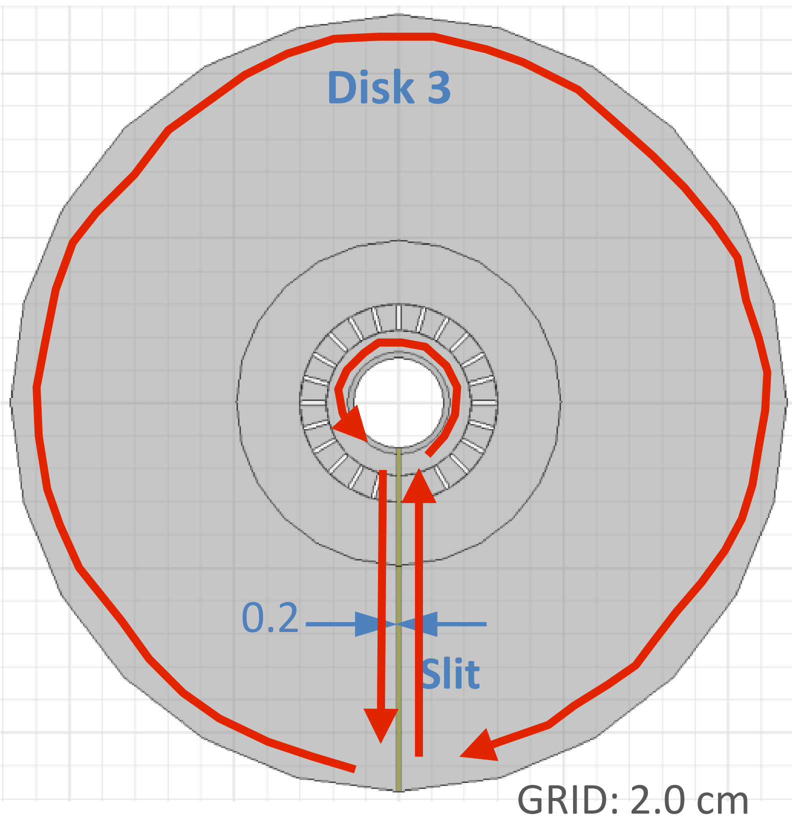
- Cobalt-60 Irradiation facilities exist
  - Only de/dx
  - Below photoneutron threshold – no activation
- Propose to acquire second Rigaku seal for destructive testing
- Facilities exist that can provide 300kGy/hour

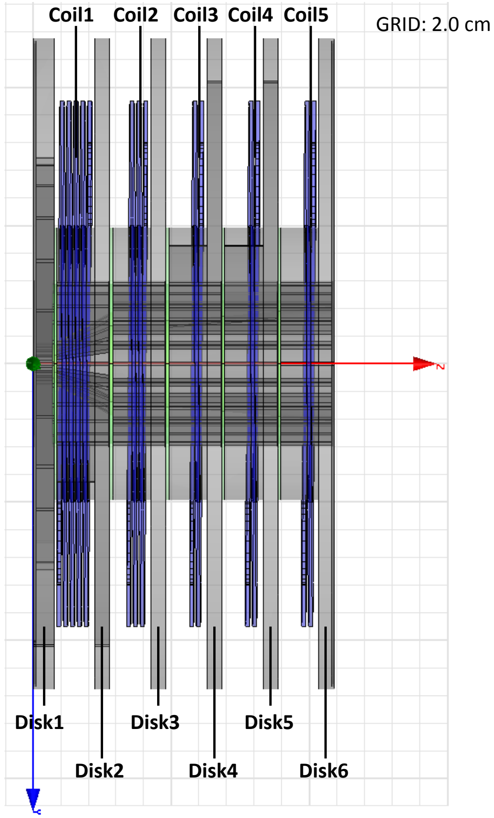
Magnetic Capture Optic is being designed

- 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

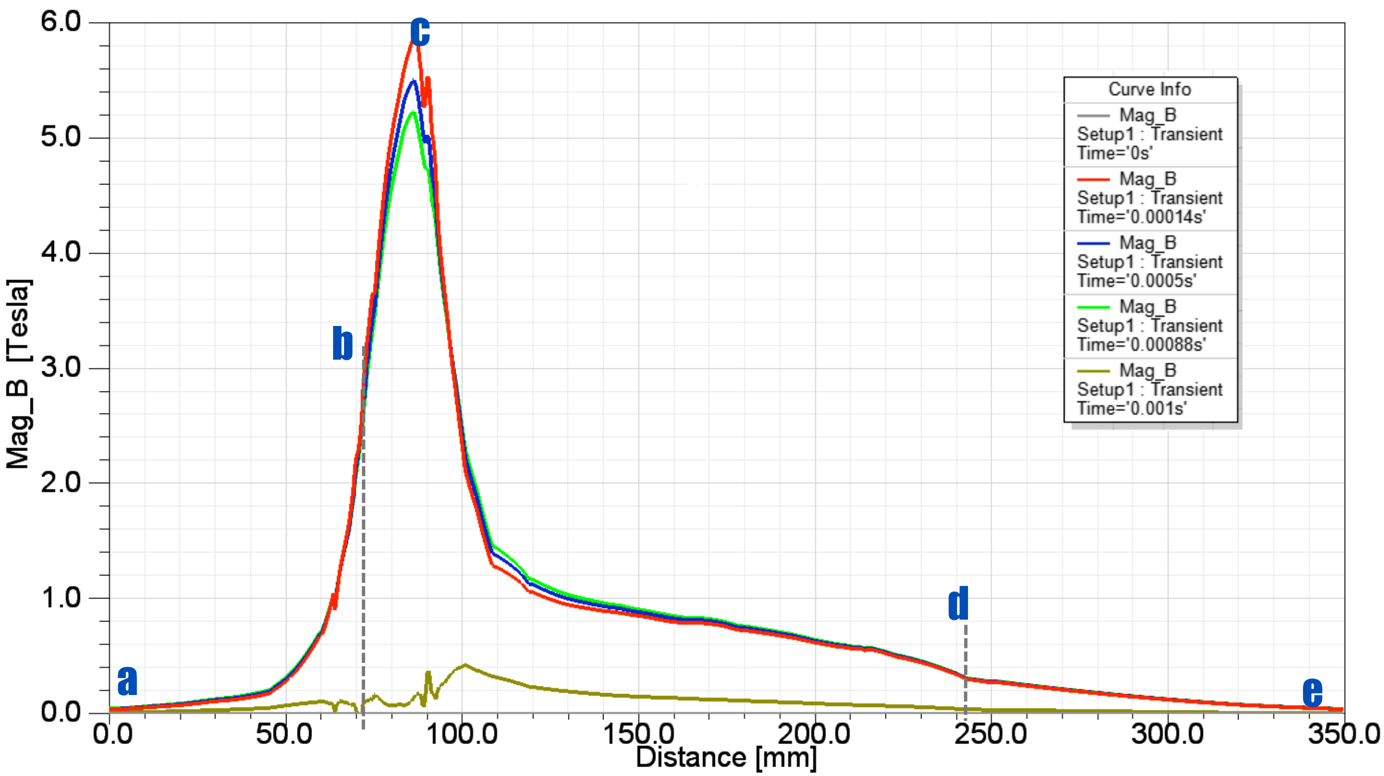


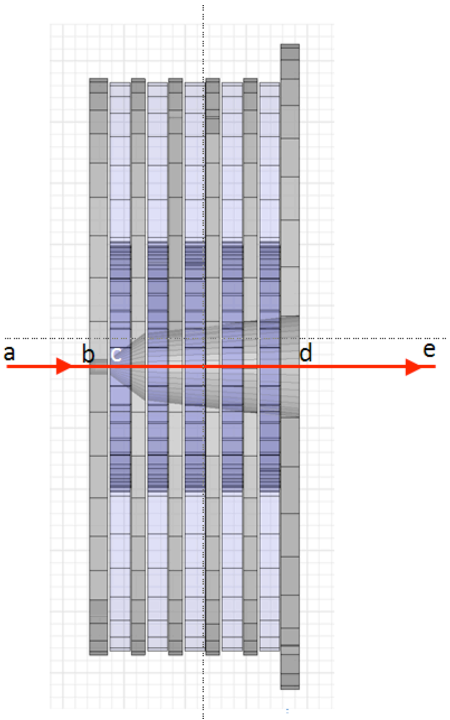


Current induced in a copper disk is forced by a non-conductive slit to flow around the bore

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





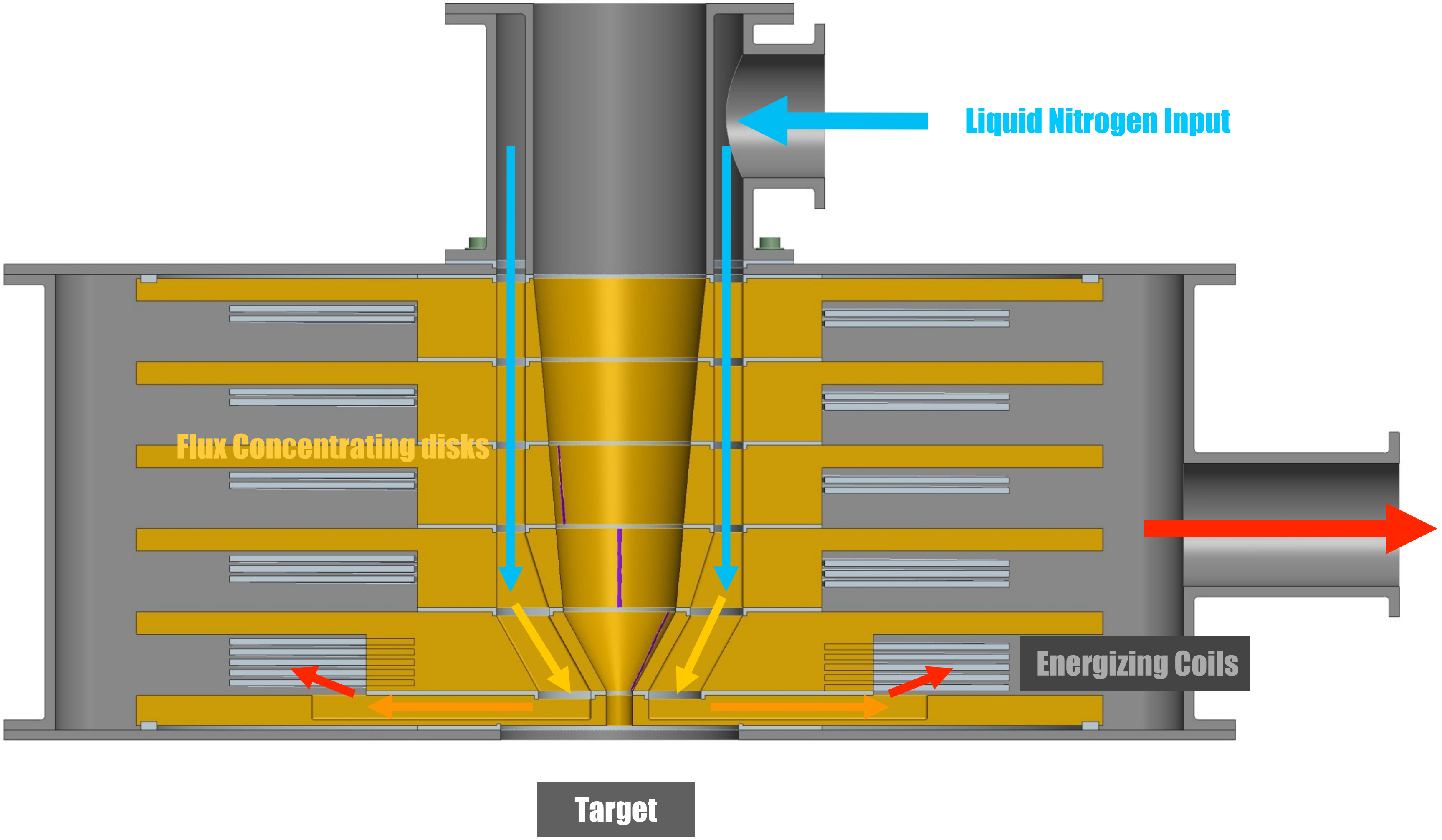
Technical Challenges

- Near the target - high radiation environment

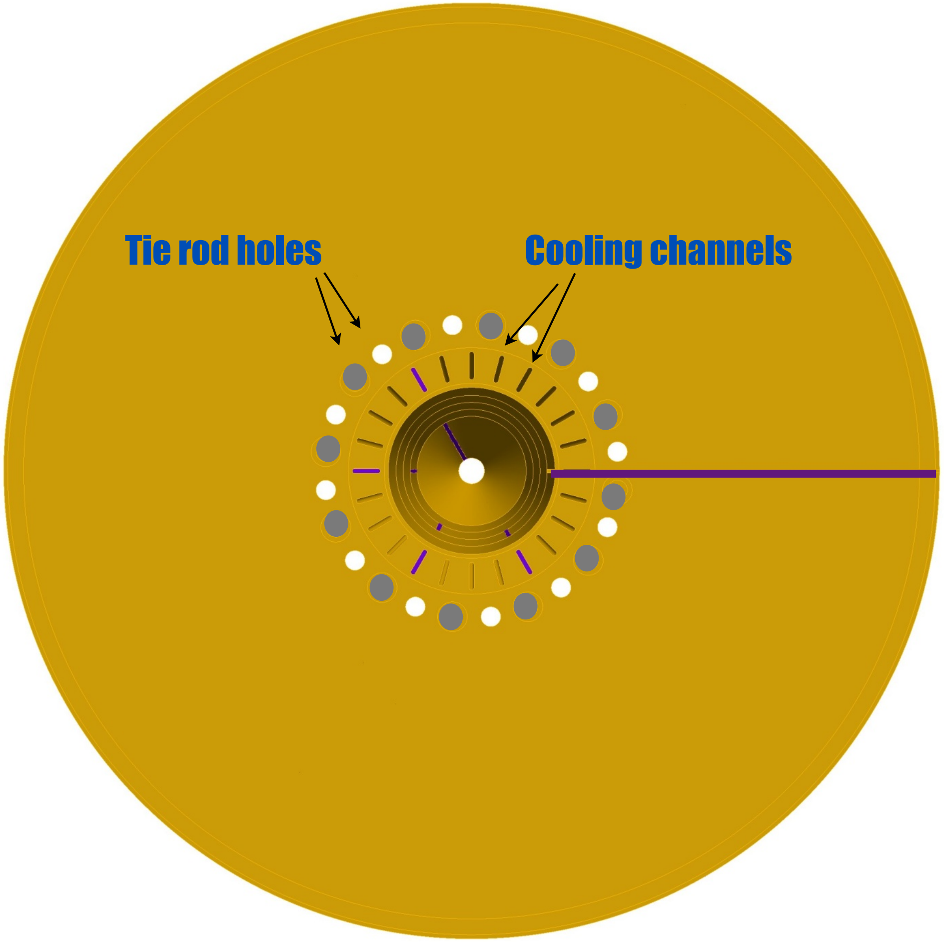
- Pulsed device 5 Hz, 24/7 for 1 year
  - Must survive cyclic stresses

- Cooling flow is needed near the bore
  - location of maximum power dissipation

The current concept of the device



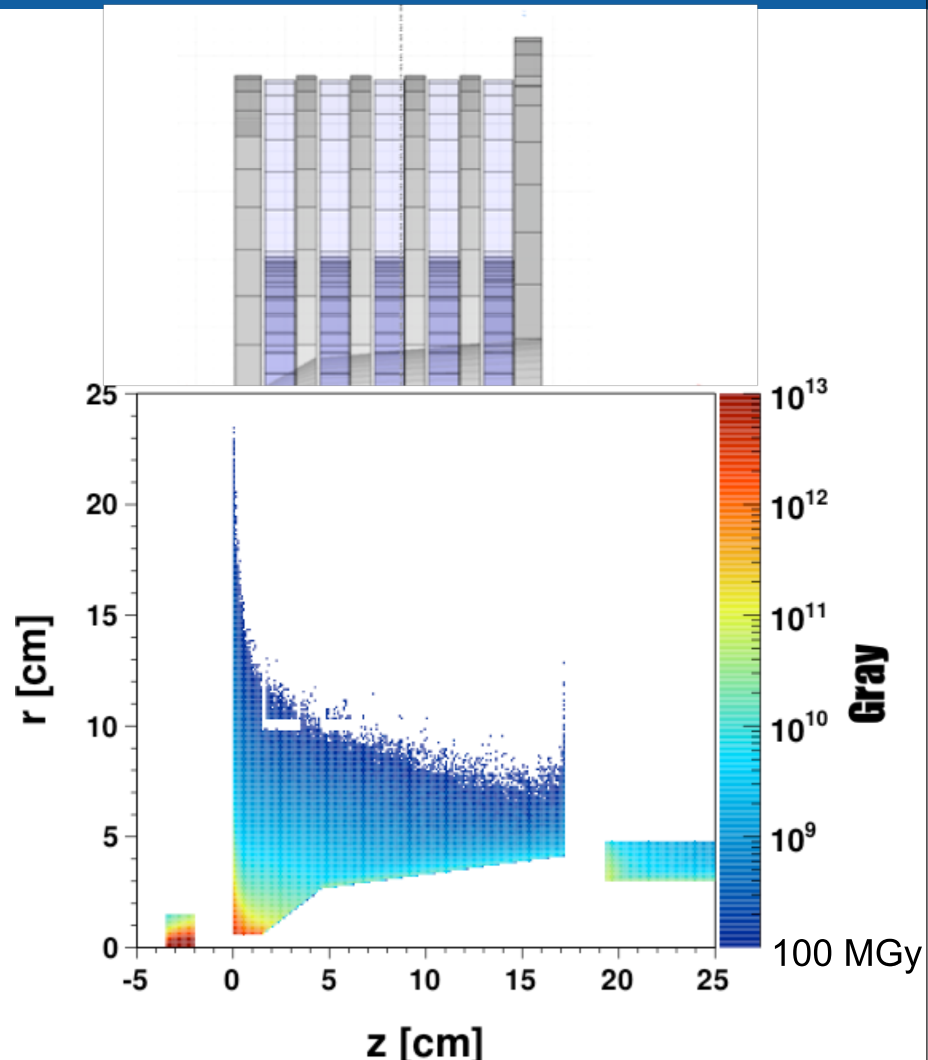
Real Estate around the bore is crowded and is needed for a variety of task



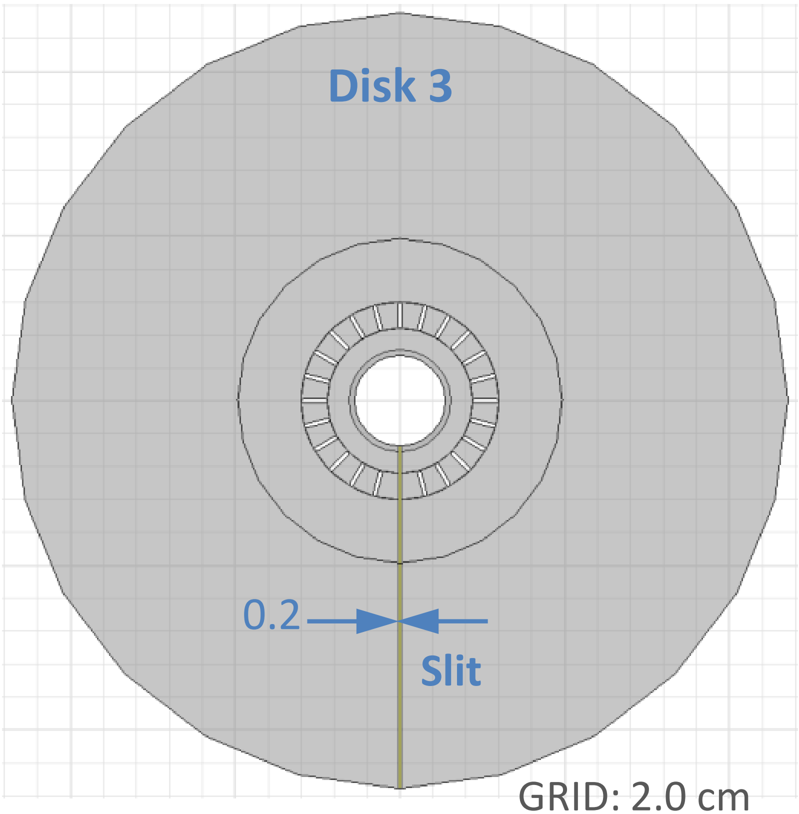
- Cooling channels for liquid nitrogen flow need to be around the bore since that is where the heat is deposited
- Holes for threaded rods to tie the assembly together are needed
- These regions should not interfere with the current flow around the concentrating disk

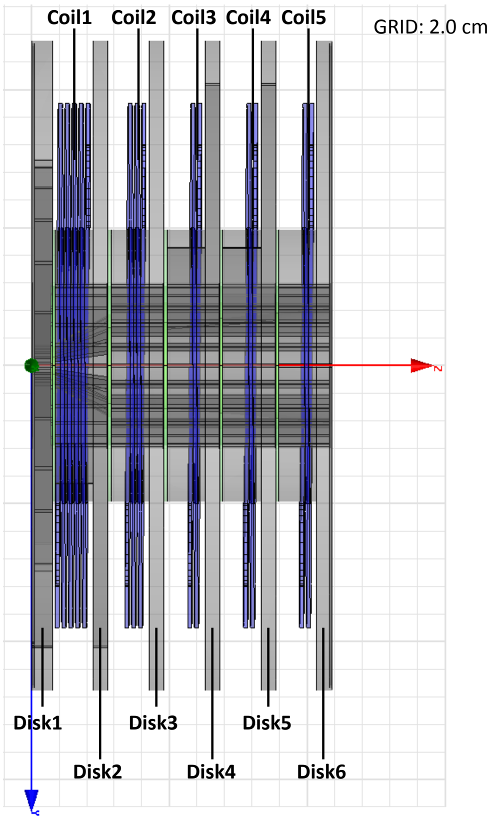
Radiation levels preclude organic insulators near the magnet bore

- 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

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	**-**

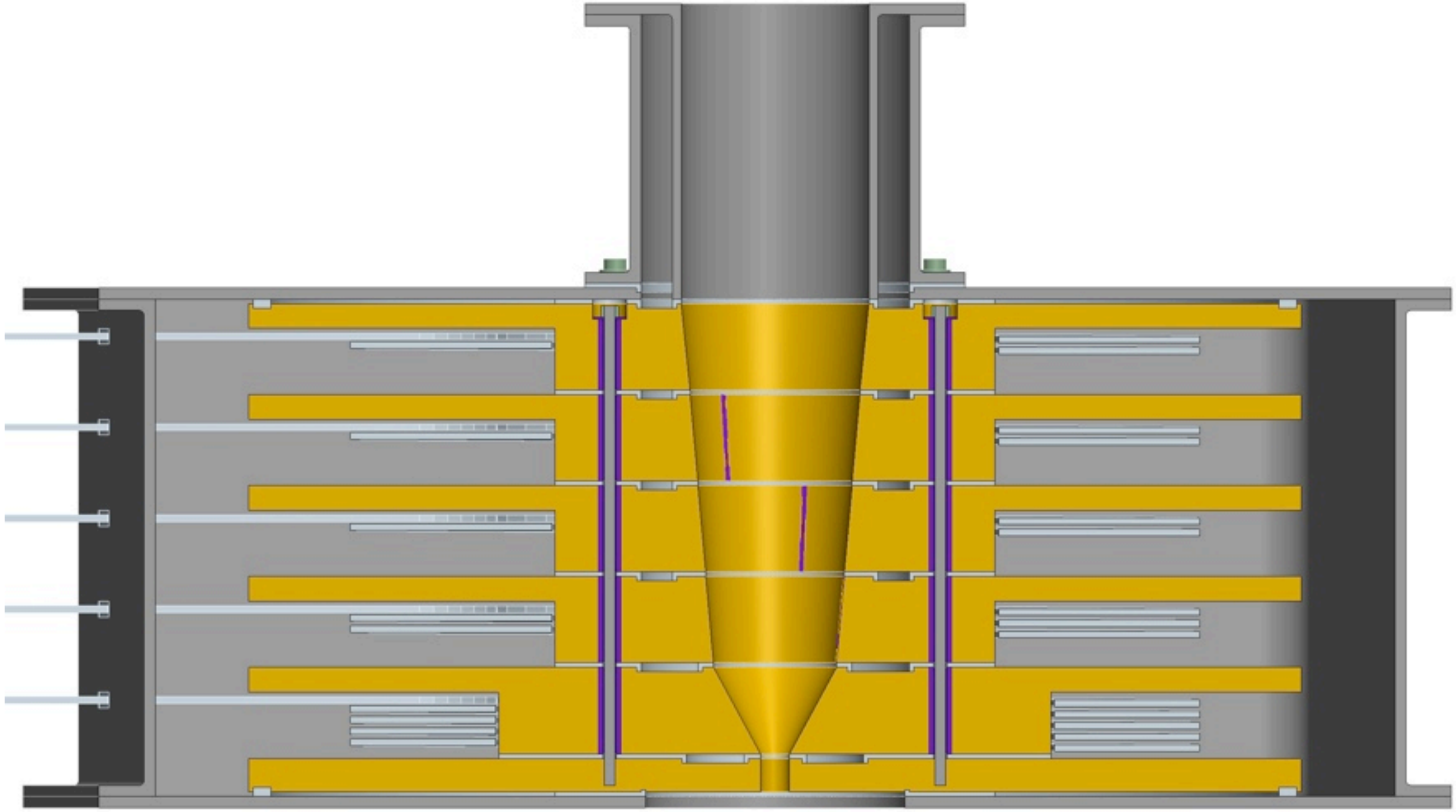
	FS	**K_{Ic}**	**a_t**	**s_{cg}**	**s_{ag}**	**B**
	-	**Pa·√m**	**m**	**Pa**	**Pa**	**T**
Case 1	1.5	6.00E+06	1.98E-05	2.14E+08	1.42E+08	4.3
Case 2	2	6.00E+06	1.98E-05	2.14E+08	1.07E+08	3.2
Case 3	3	6.00E+06	1.98E-05	2.14E+08	7.12E+07	2.1
Case 4	1.5	1.00E+07	5.51E-05	3.56E+08	2.37E+08	7.1
Case 5	2	1.00E+07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

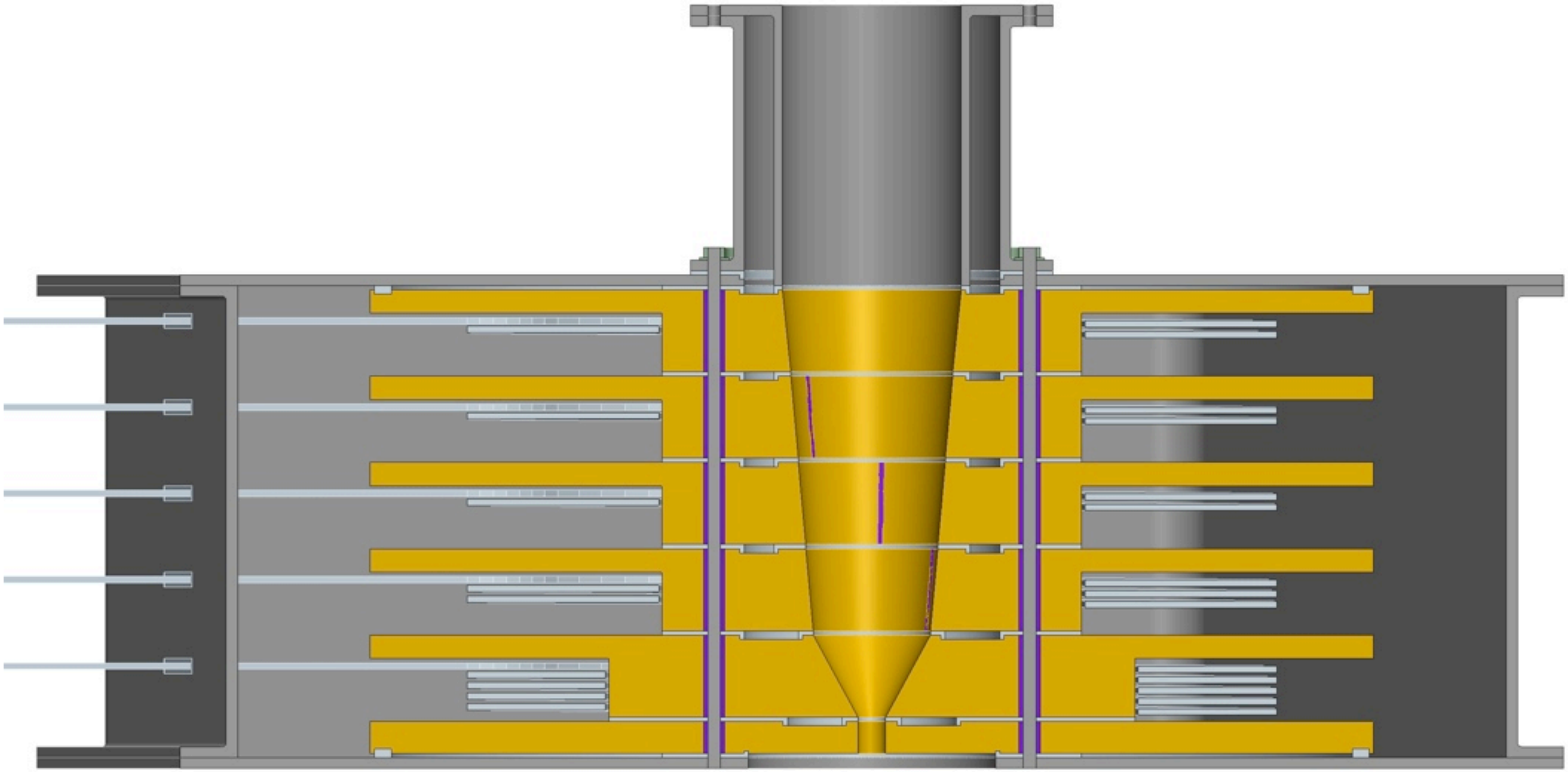
B_0	Reference peak magnetic flux density
σ_0	Reference ZTA stress
s_f	ZTA flexural strength
a	Assumed flaw (crack) size
F	Flaw stress multiplier
FS	Factor of Safety
K_{Ic}	ZTA fracture toughness (Mode I)
a_t	Transition flaw size (use LEFM for flaws larger than this)
s_{cg}	Critical gross section stress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

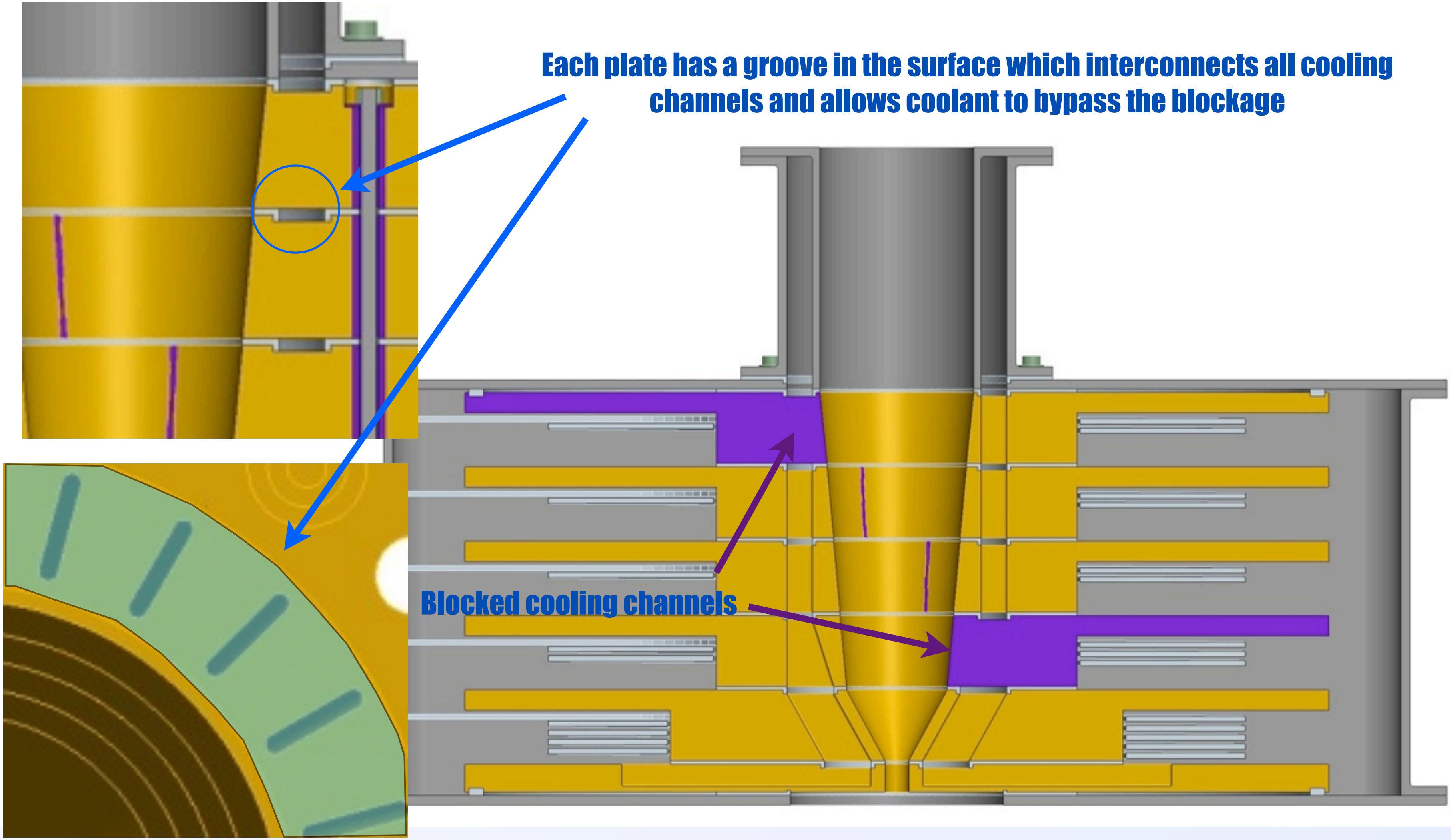
One set of tie rods provides the compressive force to seal the concentrating plates together



The other connects to the outer casing



Some of the ZTA gap fillers block a single cooling channel

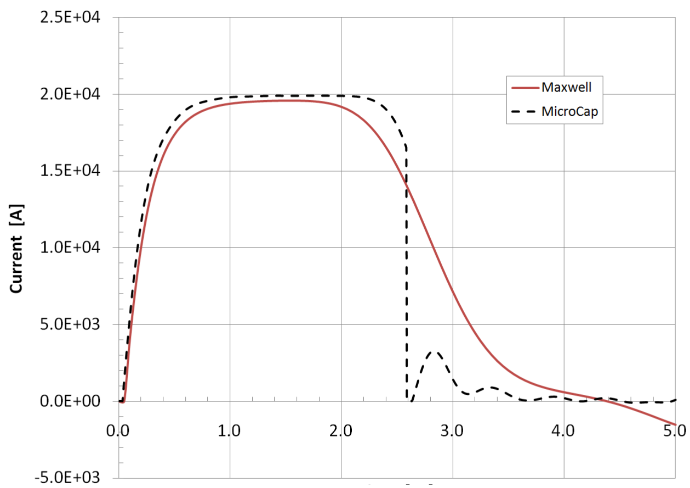


The Pulse Forming Network for the Flux Concentrator is a challenge to optimize

- We want:
  - One milllisecond flat top
  - Fast turn on
  - Minimize capital cost of the pulser (capacitors)
  - Minimize operating cost (Joules / pulse)

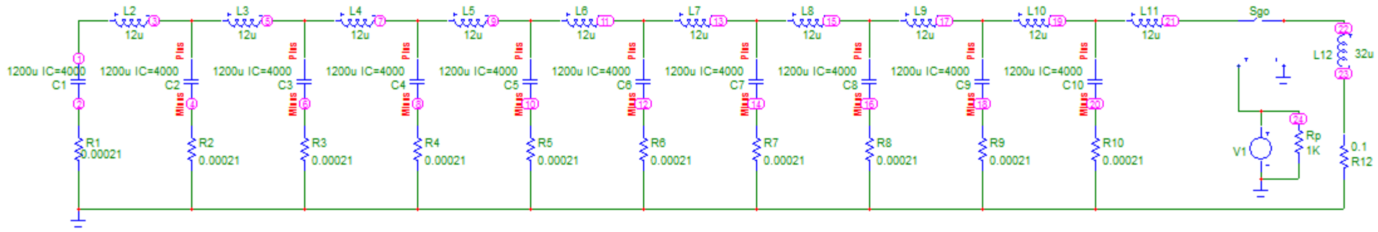
- We need power during the initial turn on
- At the flat top we need current but little power

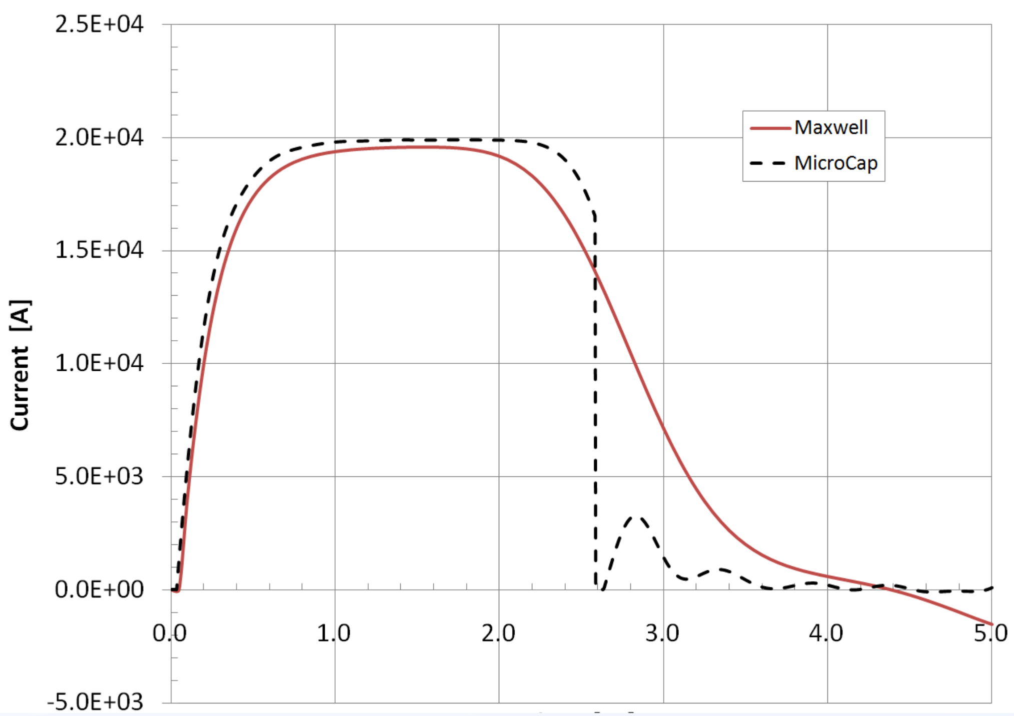
- Number of turns of the primary coils is a free parameter of the design



First design was 20kA – 2ms flat top pulser, Flux concentrator with minimum number of turns

Verification of Current from Maxwell with Equivalent Microcap Circuit

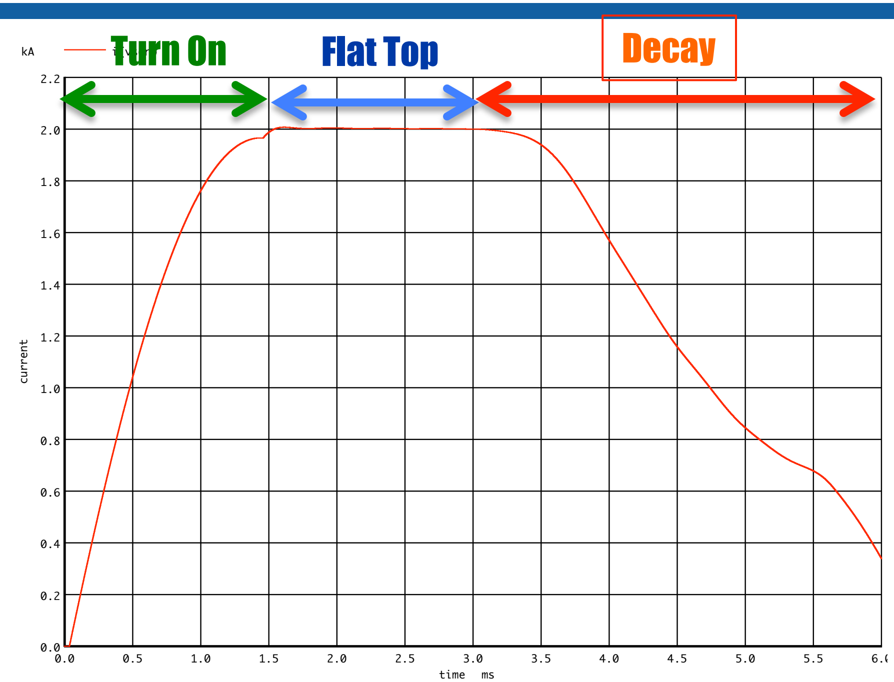


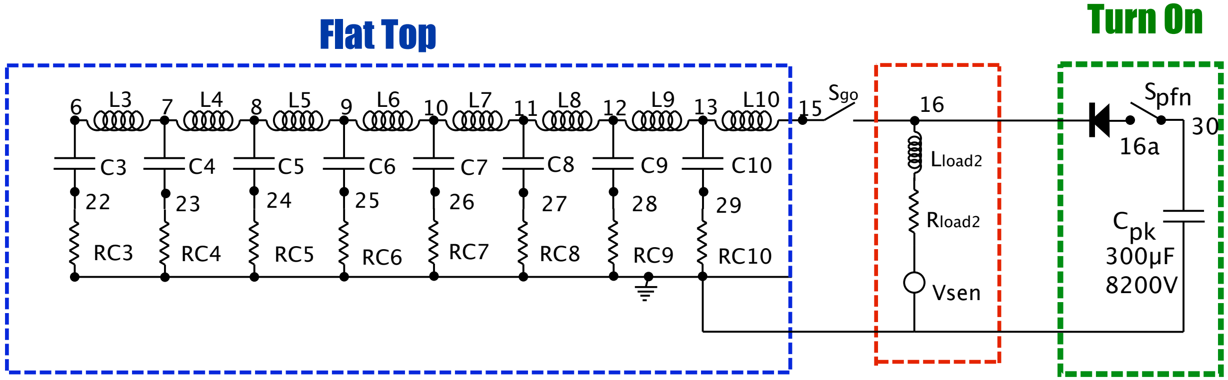


- 96kJ/pulse
  - 480kW at 5Hz
- 12,000 microFarads of capacitors at 4000V
  - 48 C/pulse

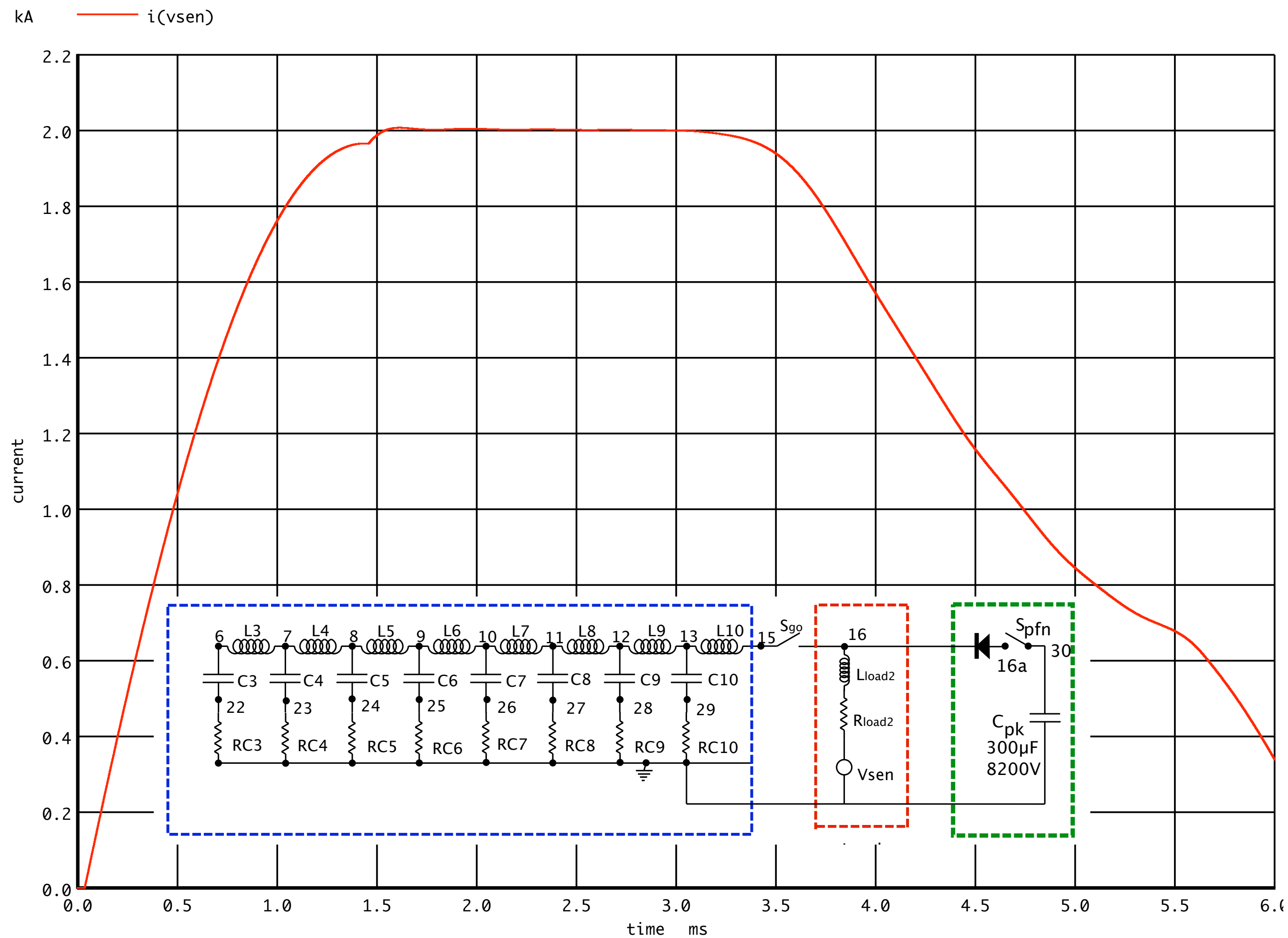
Separate turn-on phase from flat top in the pulse forming network

- Turn-on circuit fires first
- At peak, flat top circuit fires
- Allows to have higher number of turns – lower peak current





Design for 10x turns – 2kA peak current reduces capital and operational cost in pulser



- 17kJ/pulse
  - 85kW at 5Hz
- 1,600 microF at 4000V

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