Lawrence Livermore National Laboratory

Design and Prototyping of the ILC Positron Capture Magnet

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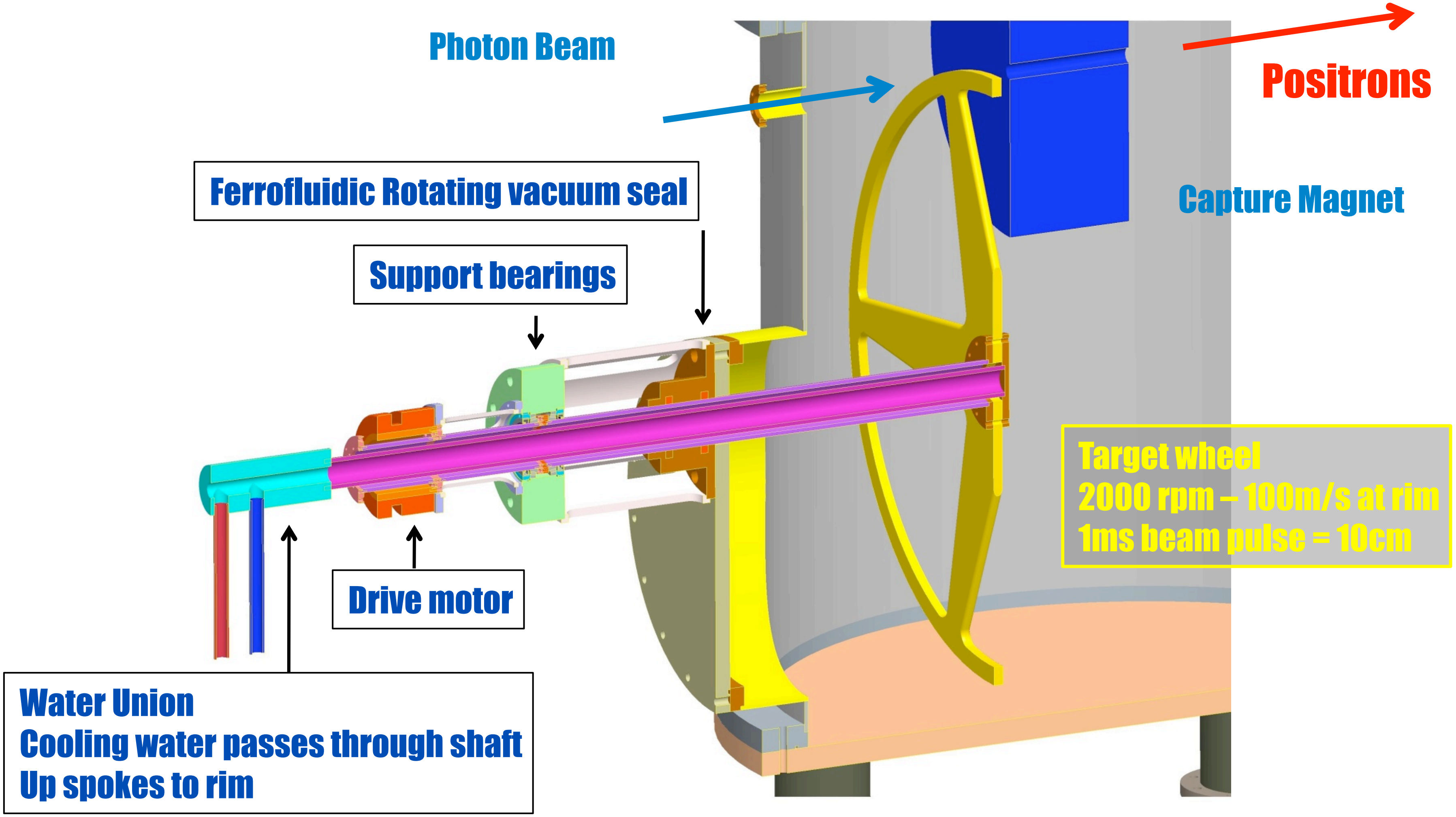
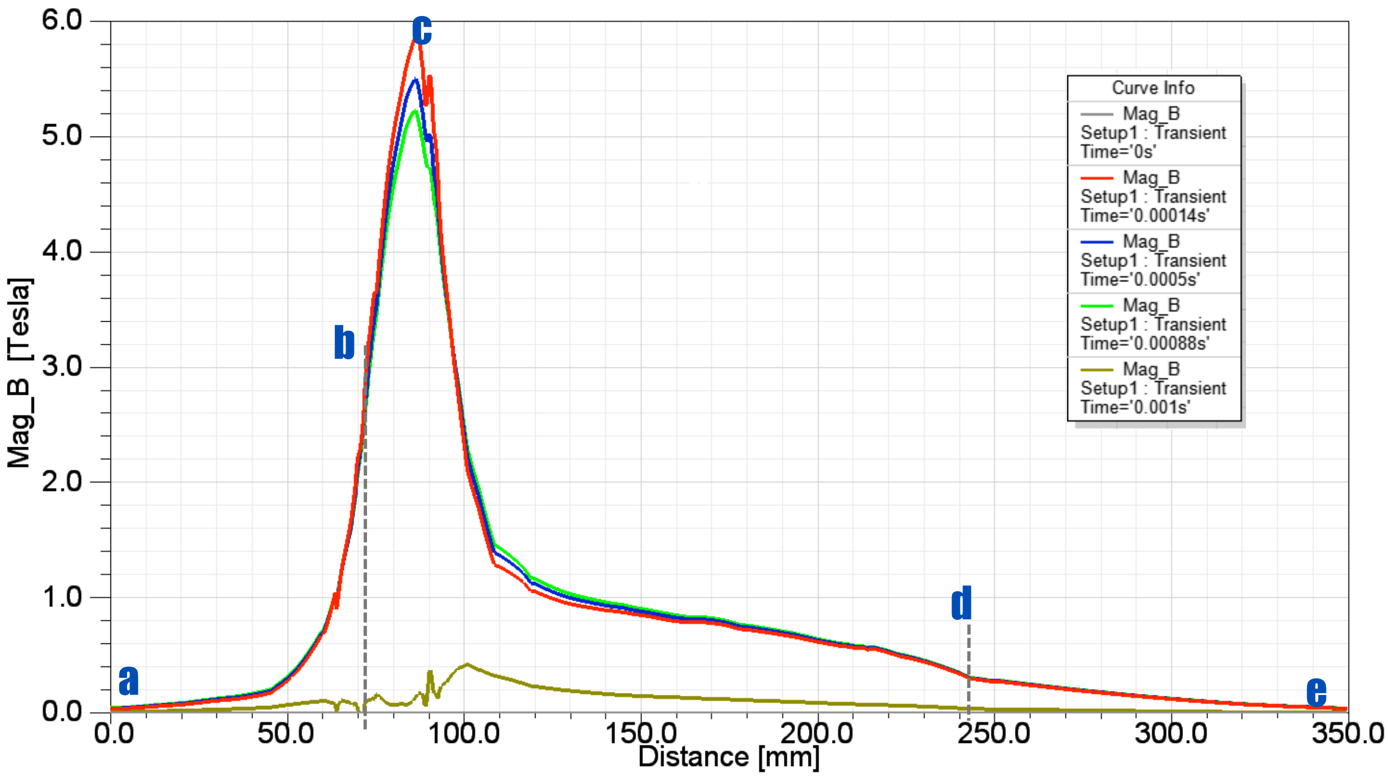
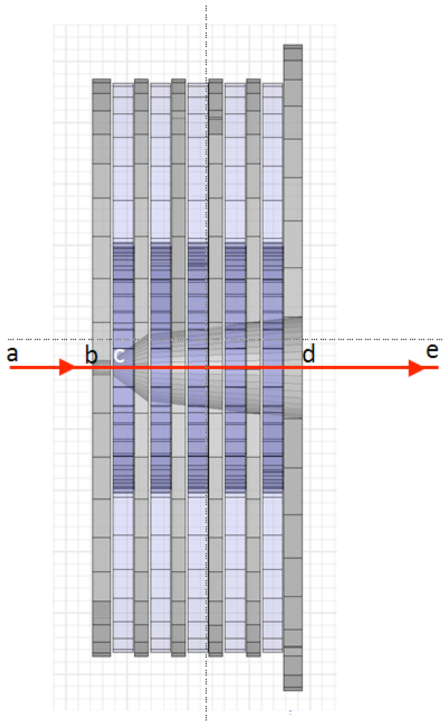
We are doing design and prototyping of the rotating shaft seal and the capture magnet



Pulsed Flux Concentrator to increase capture efficiency and reduce magnetic field at the target

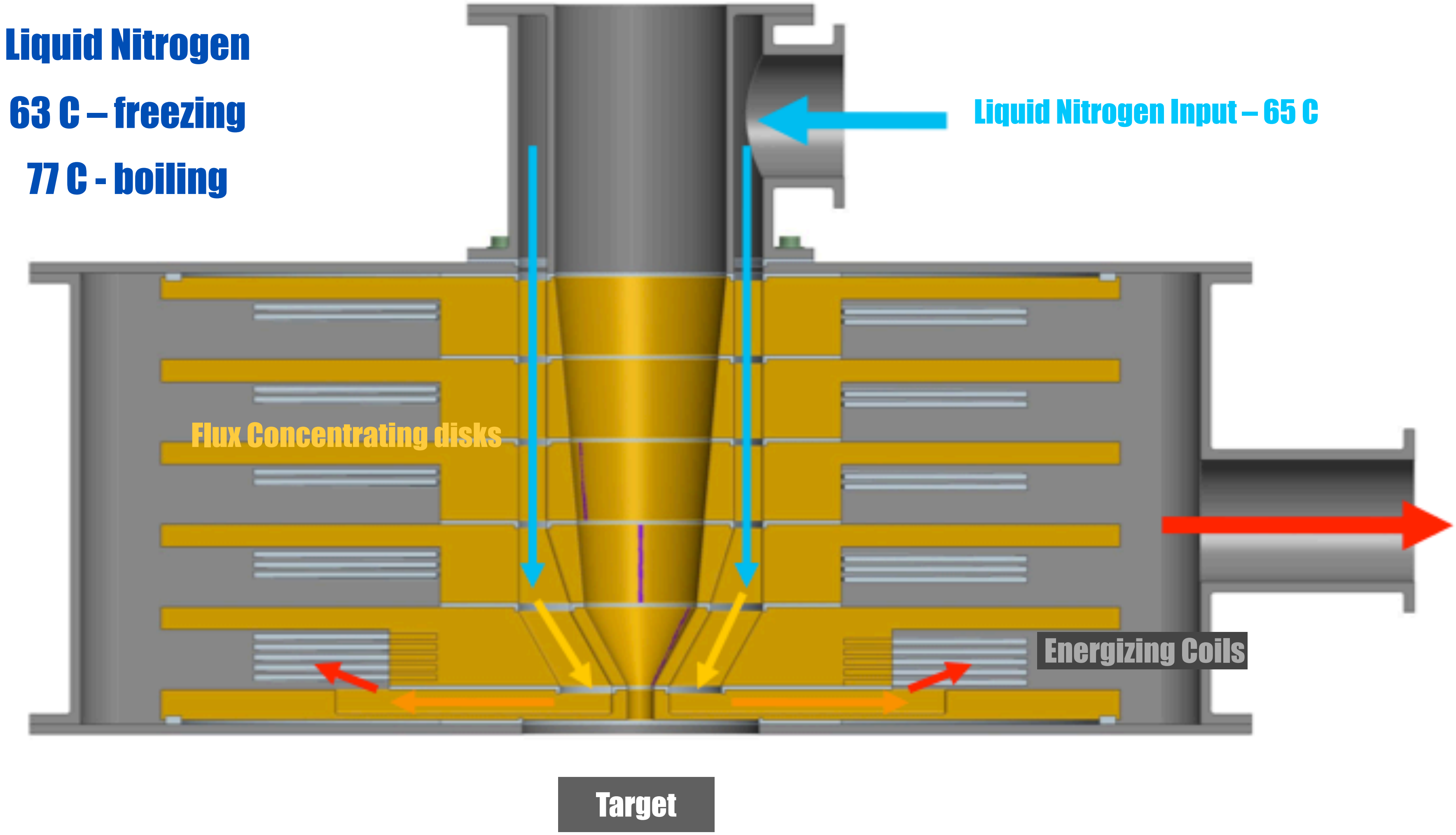




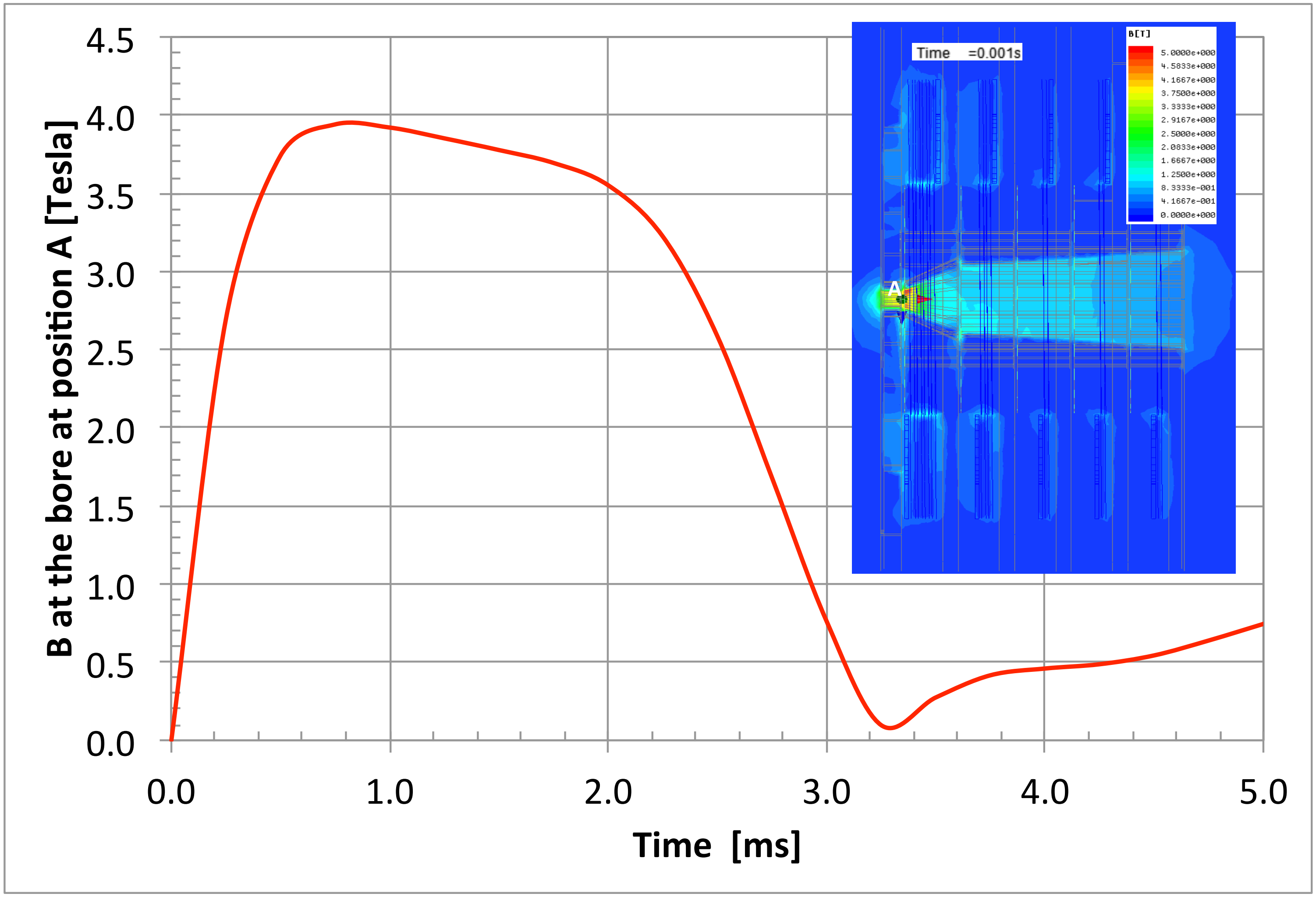
A pulsed flux concentrating magnet is a challenge for the ILC beam structure

- Pulsed flux concentrators are a known technology that work well for short pulses
- We want a constant magnetic field profile over the 1 ms beam pulse
  - Induced currents in the concentrating plates will decay as stored energy is converted into ohmic heating
  - B field strength will decay as L/R
- Nitrogen cooling to minimize R was pursued as a solution
  - Based on a magnet designed by Brechna

The previous concept of the flux concentrator - liquid nitrogen cooled to reduce the droop

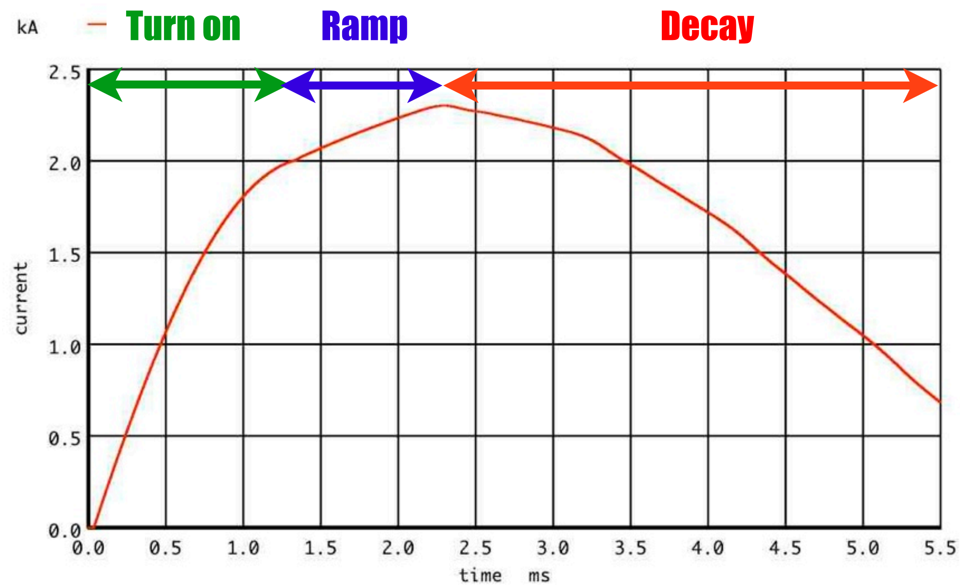


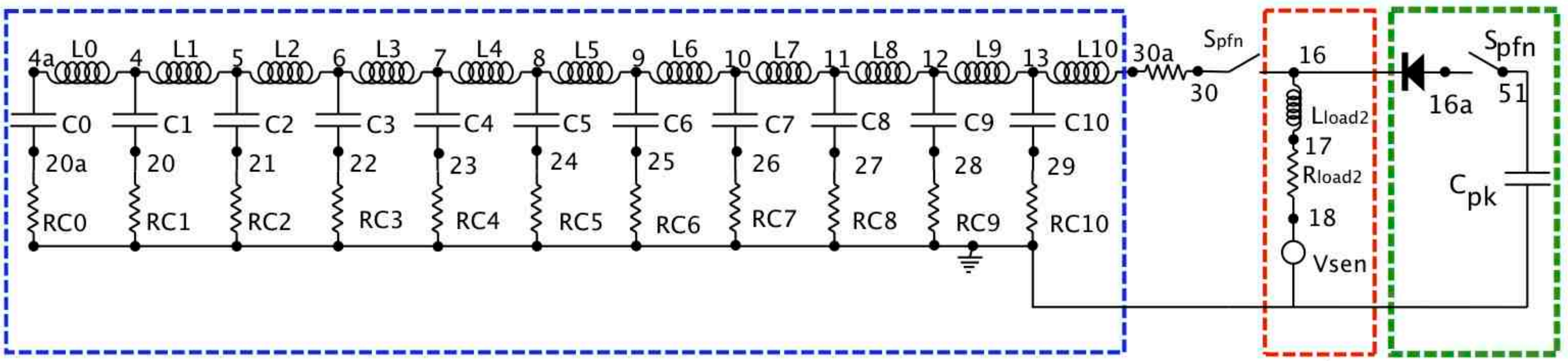
Liquid nitrogen cooling minimizes the problem but there is still a droop to the B field



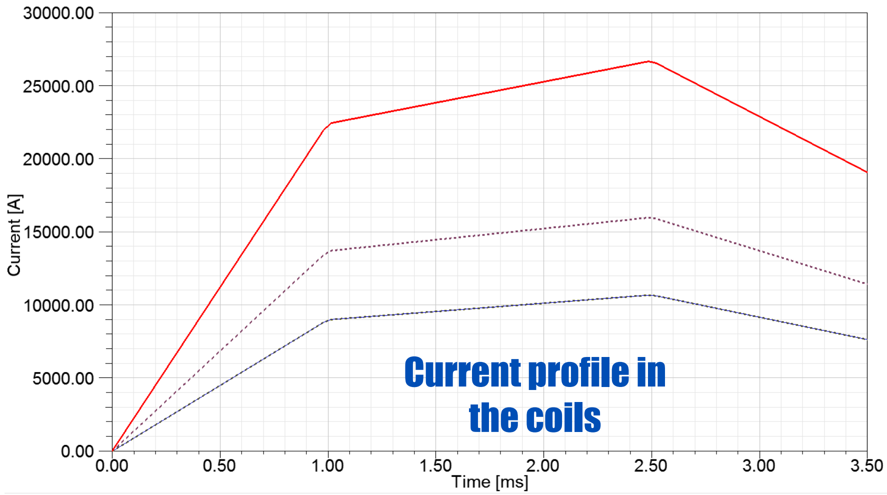
A current ramp can be created by varying the impedances of the pulse forming network

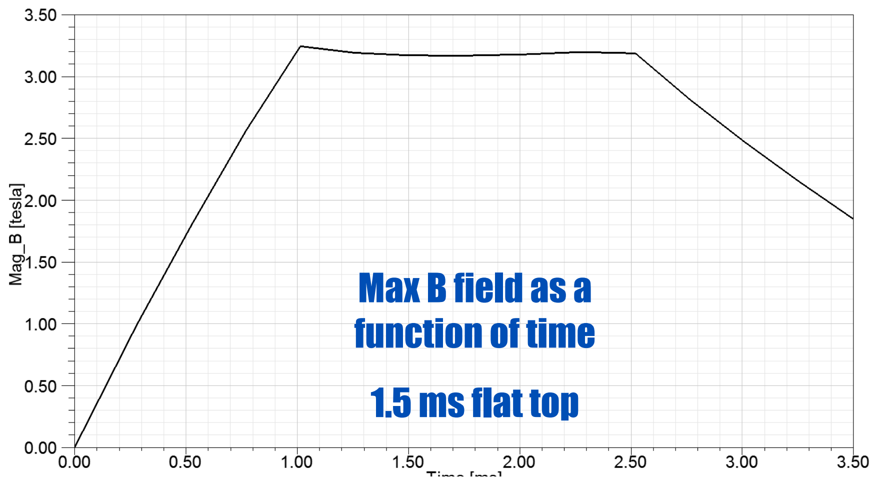
- Splitting the circuit makes a ramp over the 1 ms possible
- We can try to counteract the magnetic field droop using the pulse forming network





A 20% current ramp over 1.5 ms leads to a constant magnetic field during that period





- A current ramp from the pulse forming network can counteract the magnetic field droop - ***even at room temperature***

The design phase space has now expanded

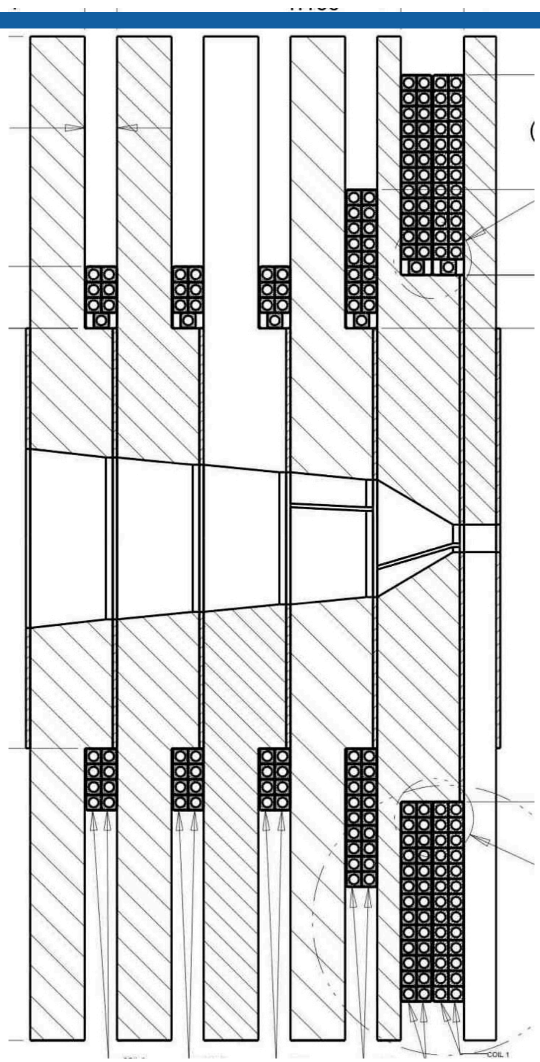
- Liquid Nitrogen was pursued to reduce the droop of the magnetic field over the ILC pulse
- The right pulse forming network can eliminate it, even at room temperature
- So why not go to a room temperature device?

Room Temperature vs Liquid Nitrogen

- About 4 times as much heat deposition in the plates at room temperature
- But water is a much better coolant than liquid nitrogen

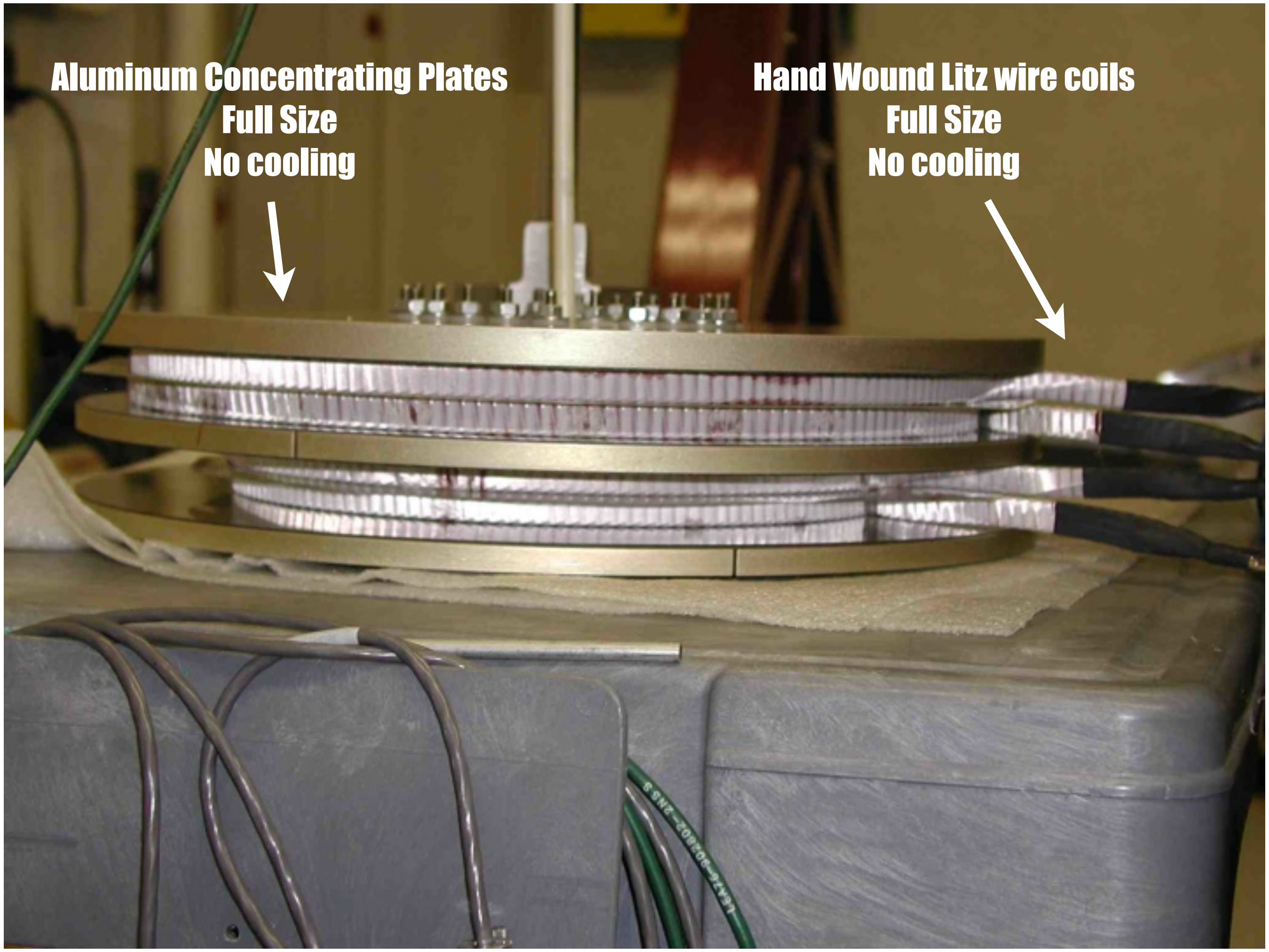
Property:	liquid nitrogen	water
Thermal Conductivity (W / m K):	0.137	0.58
Heat Capacity (J / gm K):	2.054	4.18
Temperature Range, solid to gas: (C)	14	100
Max Gradient (W/m)	1.92	58.0

Water cooling and room temperature greatly simplifies the design



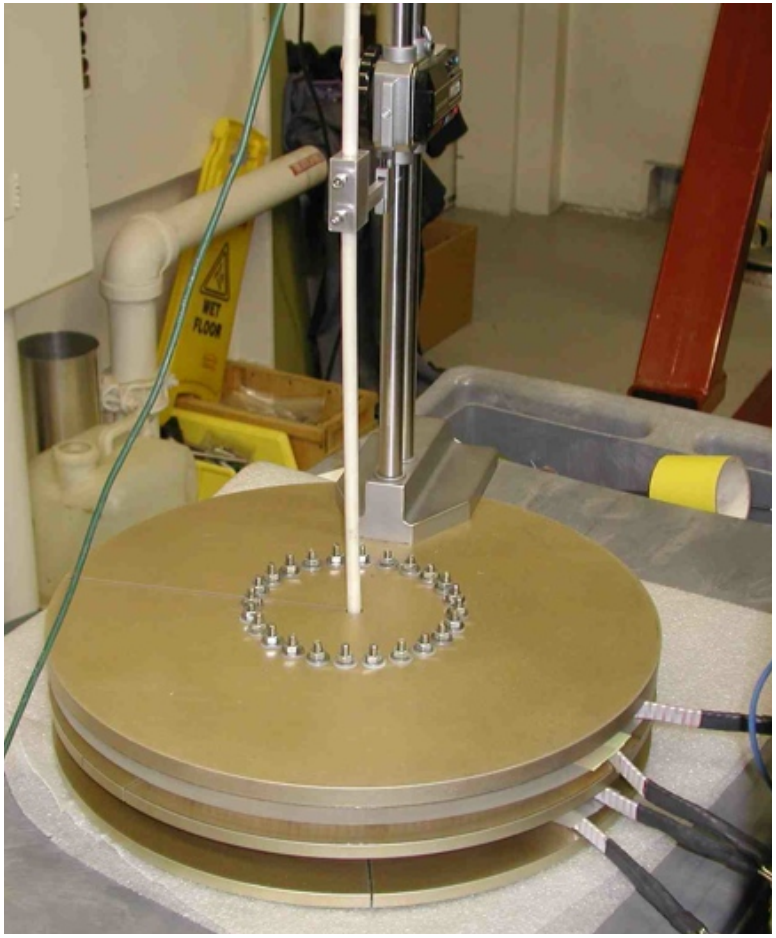
- Device sits in the vacuum
- All power and cooling connections move to the rim
  - Coils are kapton wound, hollow copper, water cooled
  - Plates are OFHC copper with water cooling pipes soldered in
  - Only metal in the high radiation areas
- Plates and coils stack and bolt together

We built a test stack of 3 Aluminum concentrating plates and 2 Litz-wire coils

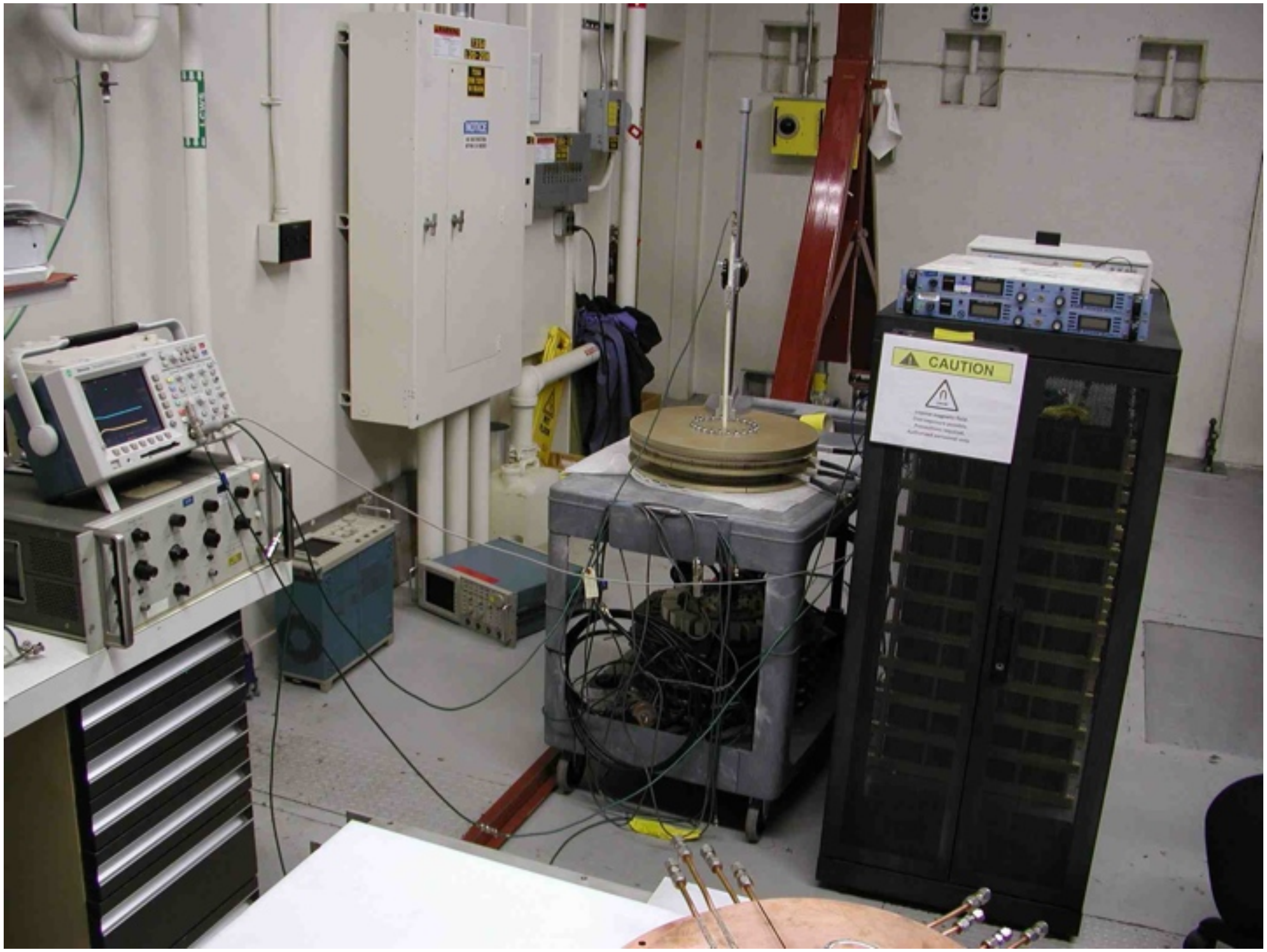


We use a wire loop to measure the time-dependent magnetic field in the bore

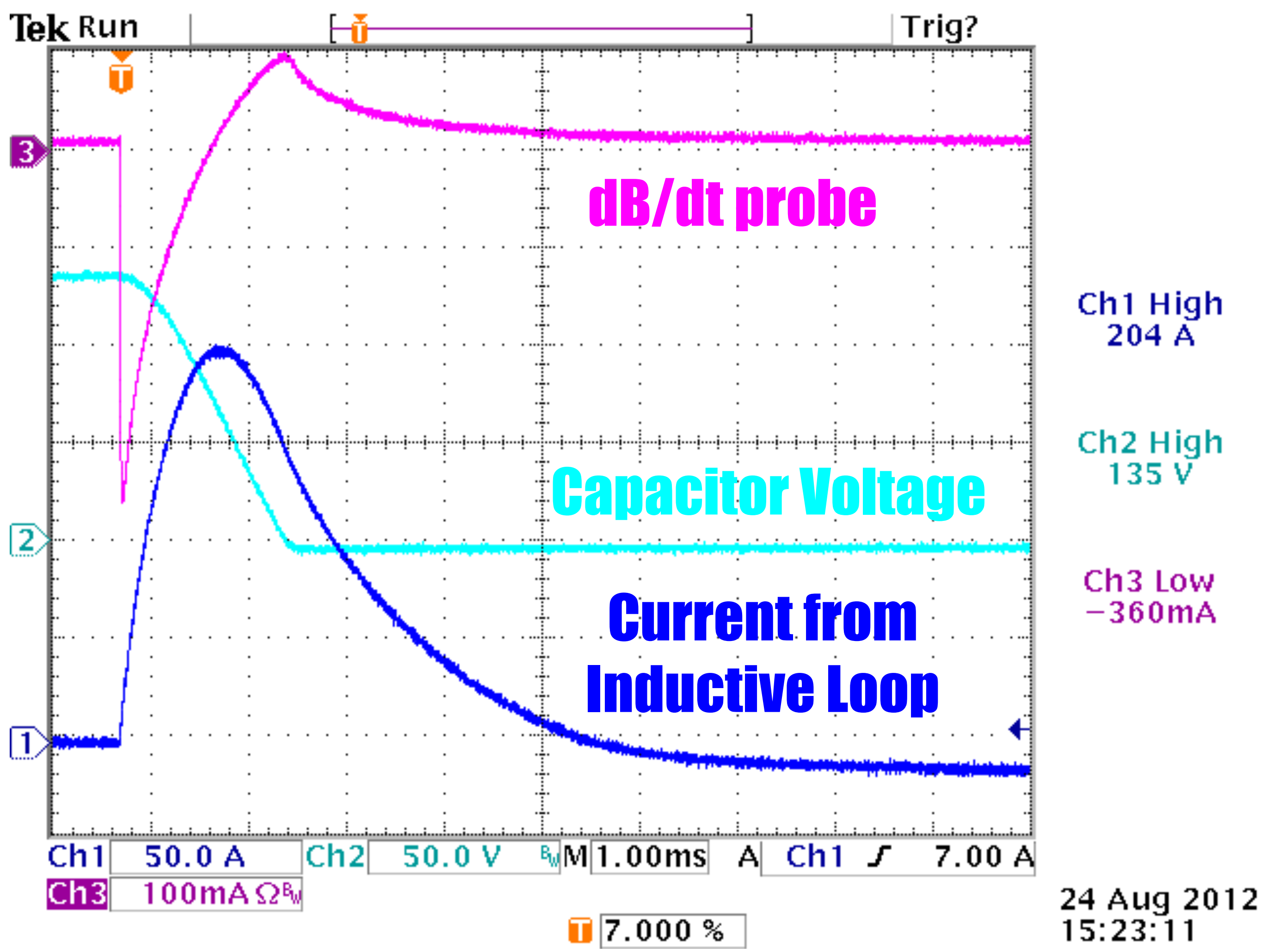
- Wire loop:
  - 5 turns
  - 3/8” diameter = 7.12×10^{-5} m^2
  - B(T) = 2809 x Volt-seconds



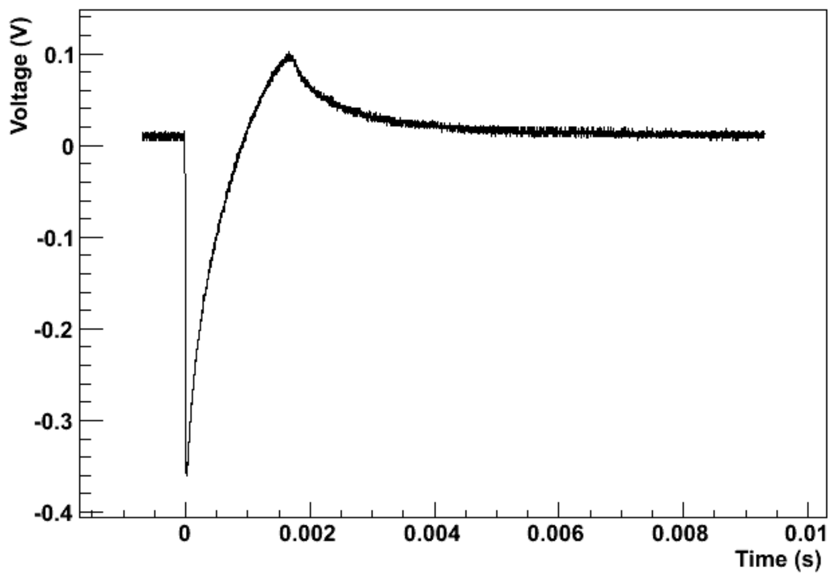
Capacitor stack configured for a single pulse

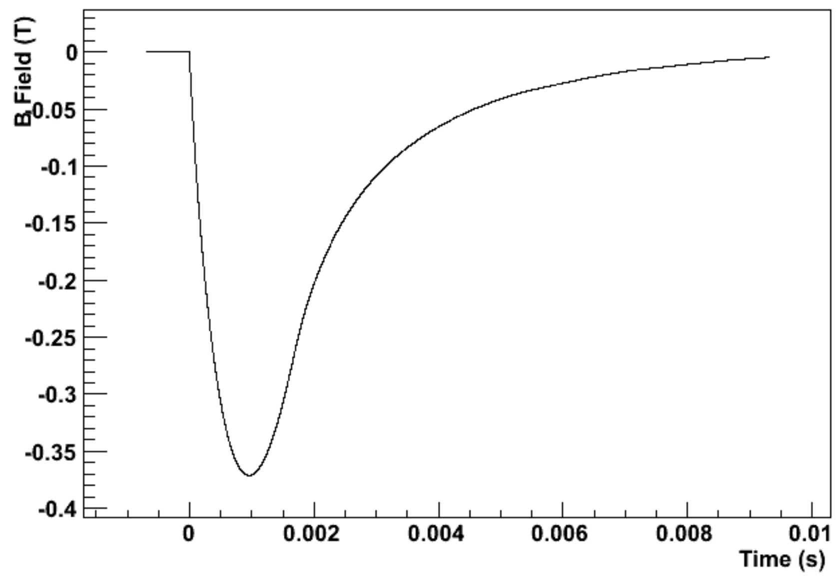


Example measurements from 200A peak pulse

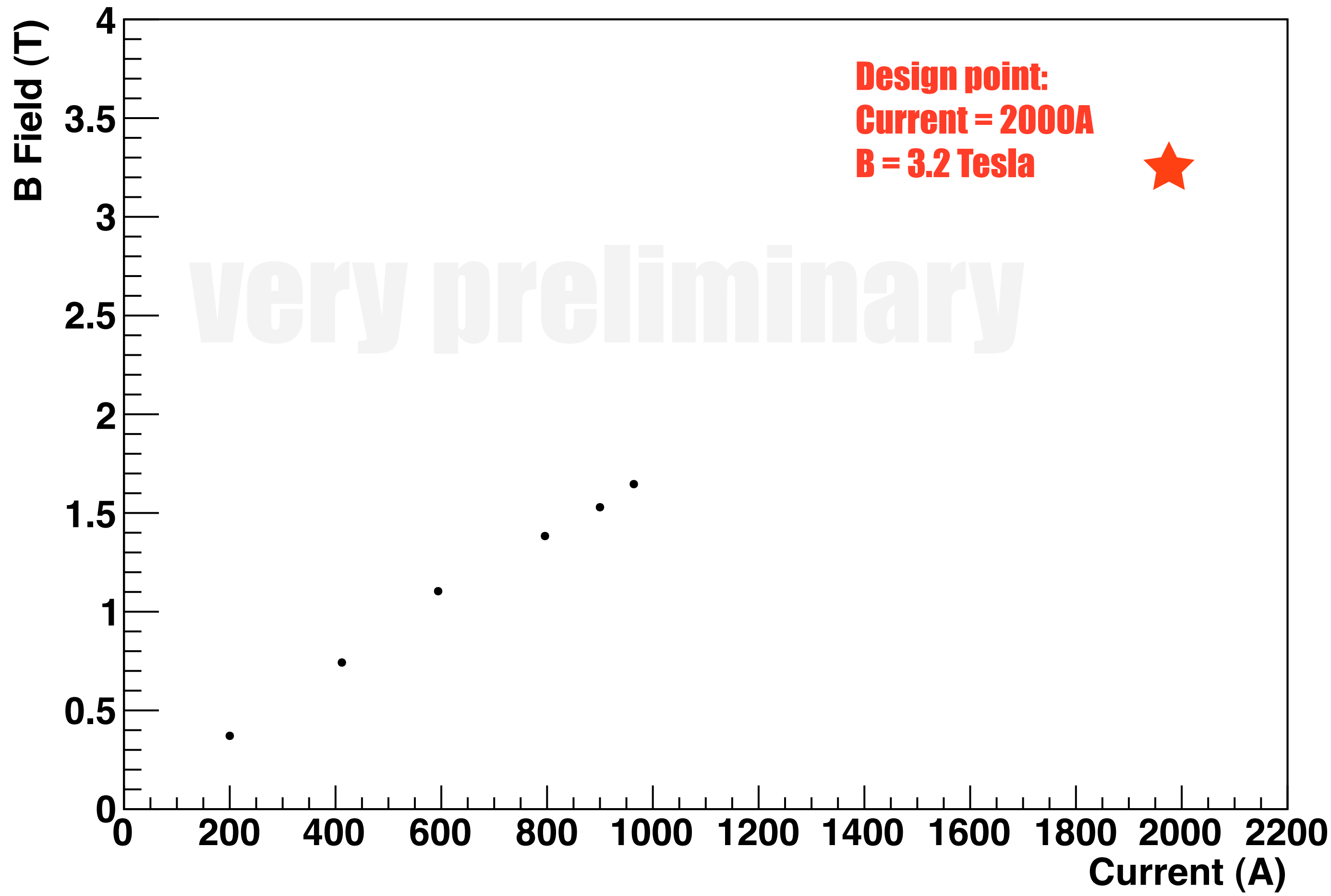


The voltage of the dB/dt probe is integrated over time to measure the time dependent B Field

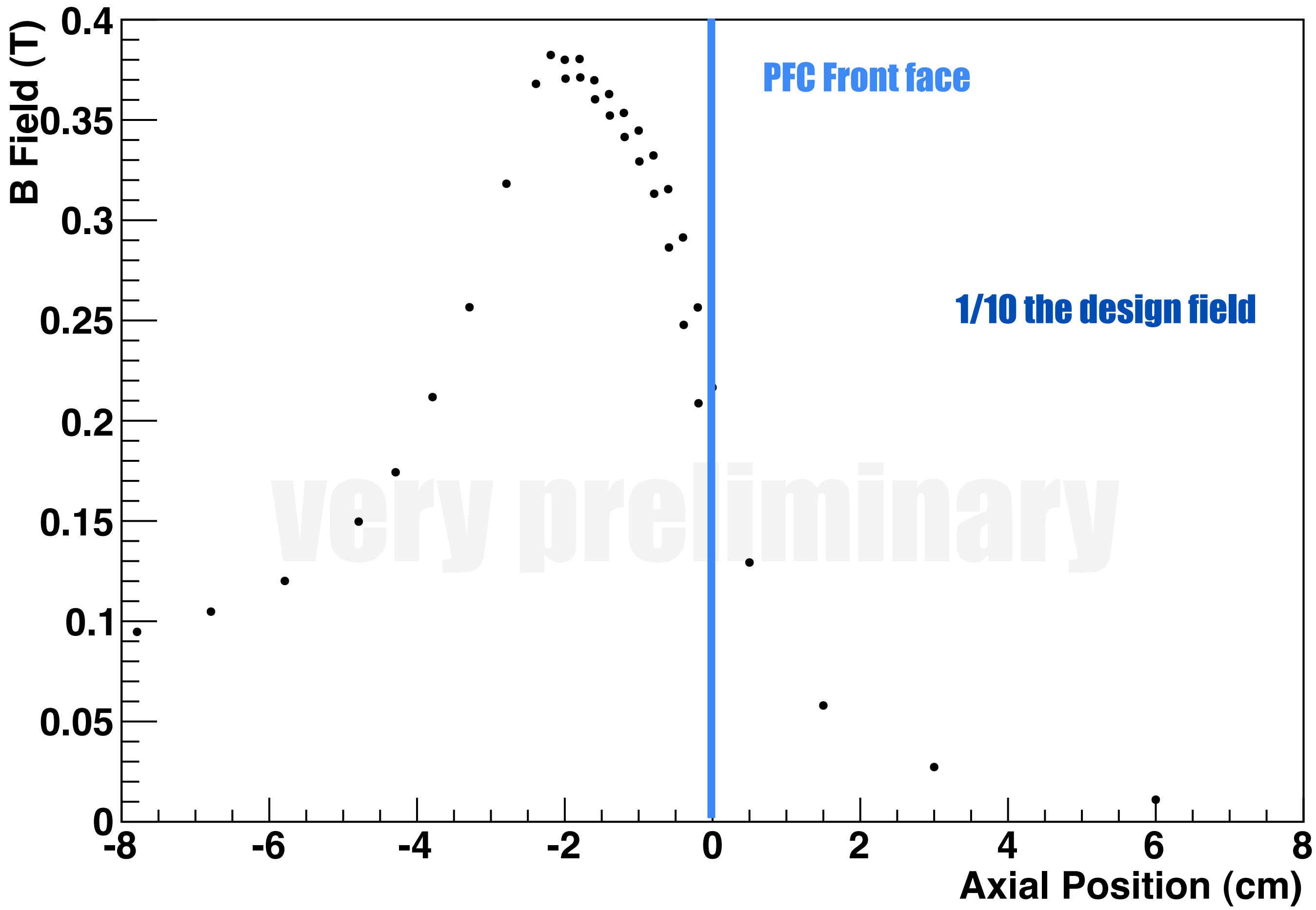




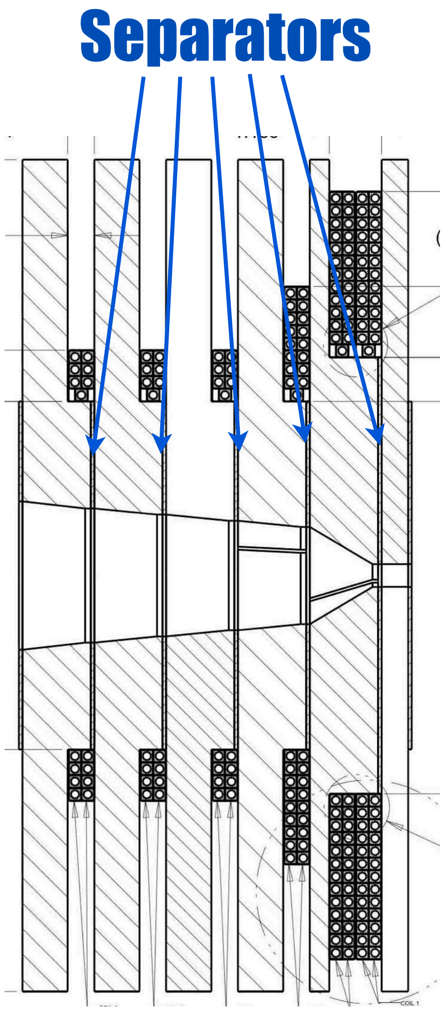
Measured peak axial magnetic field out to 1000A peak current



We mapped out the axial magnetic field in the bore as a function of position for a 200A pulse



All measurements were done with Stainless Steel separators between the concentrating plates



- Original design had Zirconia Toughened Alumina insulators between the concentrating plates
  - Potential problem with fracturing under 5 Hz repetitive stress
- Measurements show that Stainless Steel is sufficiently insulating to achieve the peak magnetic field.
  - More robust to repetitive stress and radiation

We are done with the aluminum dummy and are moving on to the copper stack with cooling loops

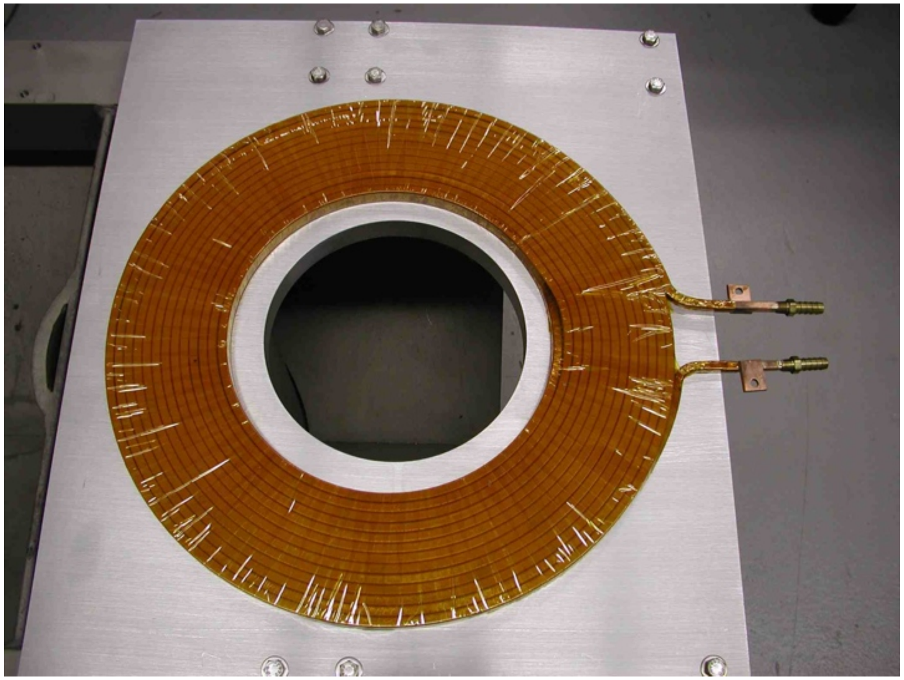
- Using the aluminum dummy we have:
  - Verified the magnetic field versus current
  - Validated the use of Stainless Steel as a separator material

- Copper has the correct resistivity to test:
  - The energy deposition
  - The 1 ms flat top magnetic field

- We have a design for the cooling but will not be able to test it in the current program

Coils are kapton wrapped, center cooled copper, up-set winds, cooling is not a problem

- Wire dimensions:
  - 7 mm x 7 mm square
  - 4.5 mm dia inner hole
  - resistivity 1.68e-8 Ωm
  - skin depth between 5-6.5 mm
- Largest 25 turn coil
  - 27.8 m long wire
  - will dissipate ~800W
  - 5 mL/s flow - 30 cm/s - 18 kPa
  - 50 K ΔT = 900 W



Cooling of the concentrating plate must remove the ohmic heating around the bore

- Cooling lines should go where the heat is.
- A loop should run around the region of the coil image current.
- Up and down the side of the slit
- Around the bore

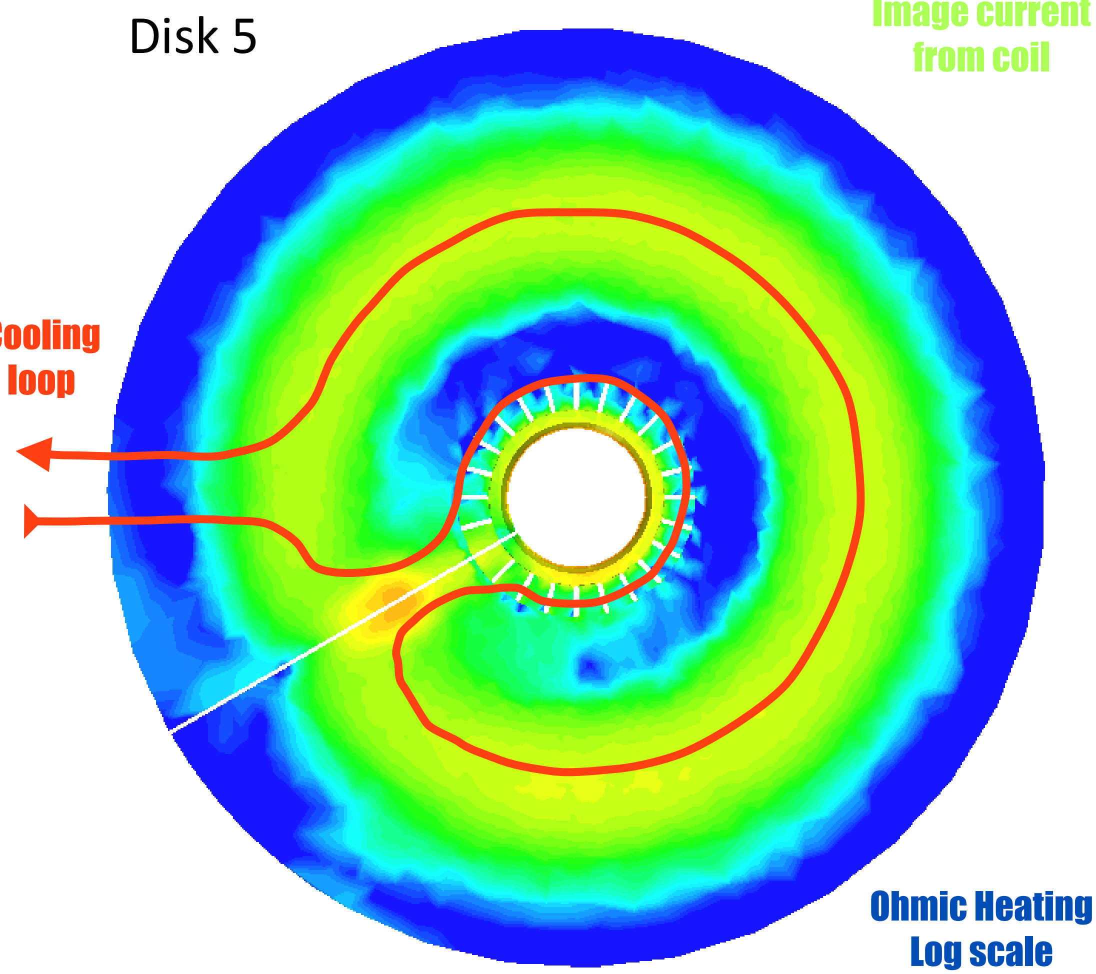
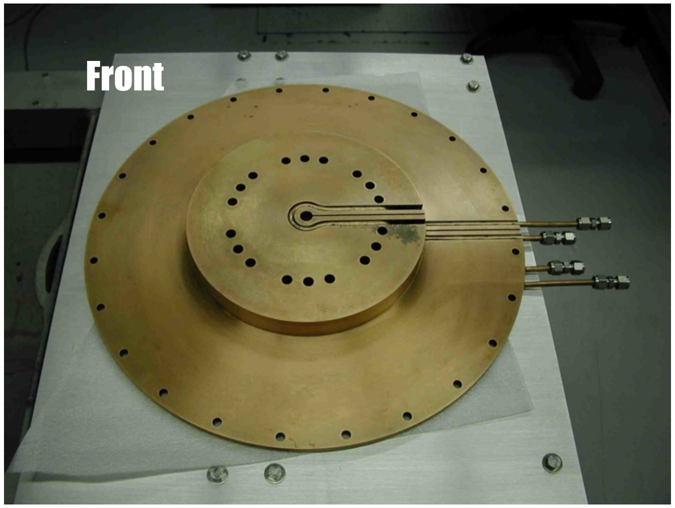


Plate 2 has two separate cooling loops

- Front loop:
  - Runs along slit and around the bore
- Back loop:
  - Runs around the bore and in the region of the coil image currents



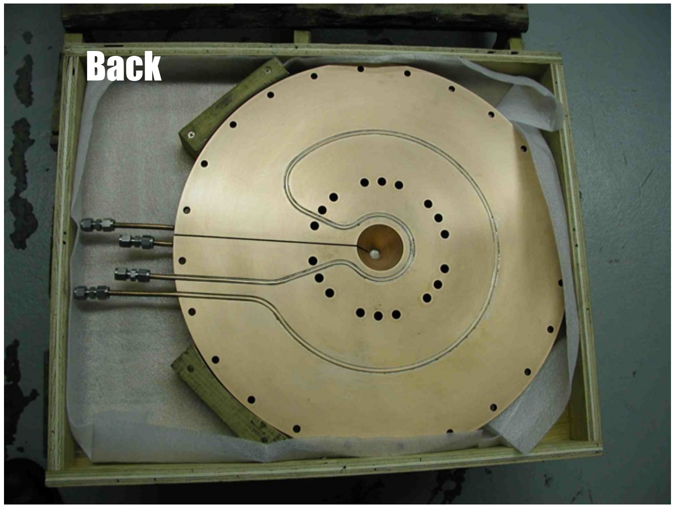


Plate 2 with 50 turn energizing coils in place

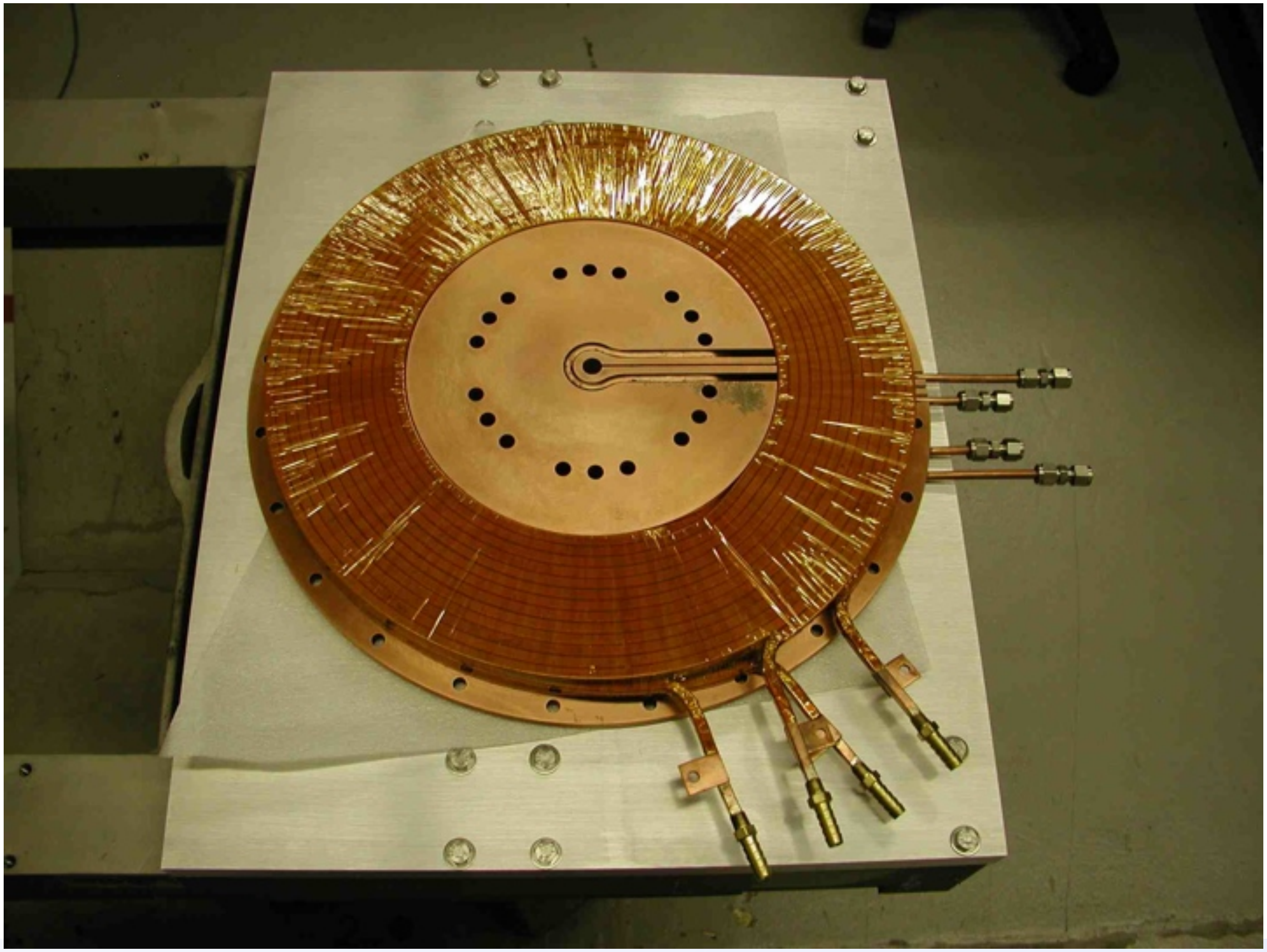
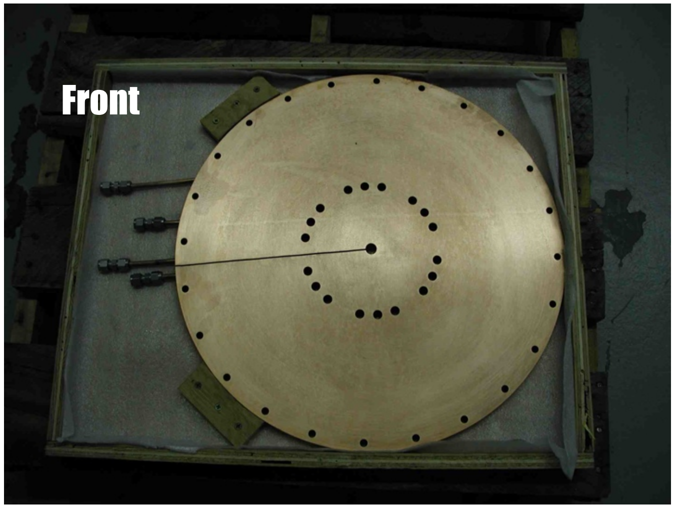
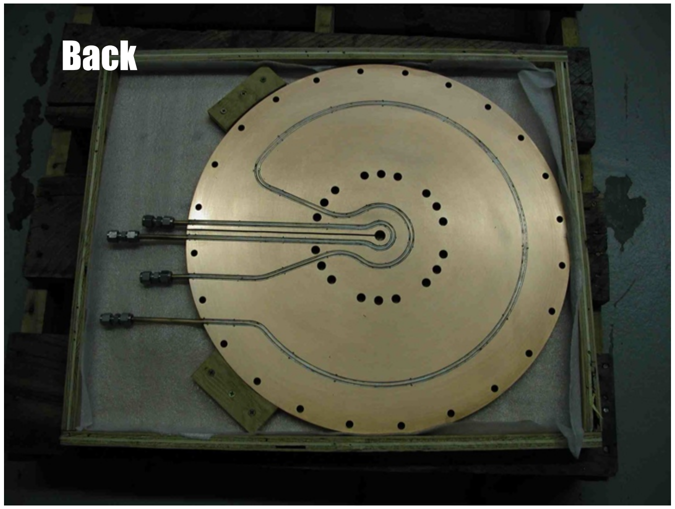


Plate 1 has both cooling loops on the back

- Front:
  - Bare metal to provide maximum shielding against beam particles



- Back:
  - One loop around bore and along slit
  - One loop around the bore and in the image current region



The 3 copper concentrating plate and 2 center cooled copper coil test stack

Final Measurements

- Calibrate our magnetic field probe
- Assemble the copper plate stack
  - Pulse at full 2000A current
- Reconfigure the capacitor stack into a Pulse Forming Network with the ramped pulse
  - Observe the flat-top magnetic field over 1 ms
  - Measure energy loss in the stack
- 5 Hz operation will not be possible
  - full test of the cooling will not happen in this program

Final Simulations

- The magnetic fields and energy deposition of the final configuration has been simulated
- Heat flow and temperatures with the final cooling will be calculated
- Forces and stresses will be calculated

Work that should still be done

- The slit in the first plate allows a path for radiation to travel from the target to the kapton insulator in the coils
  - Shielding for the slit needs to be designed
- Particle energy deposition in the plate 1 cooling lines should be evaluated for shock wave damage
- Existing prototype should be run at 5 Hz, full current for an extended period