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Magnetic-Field Driver for Magnetized Plasma – Laser Experiments on the Z Beamlet Laser Facility

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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Magnetic-Field Driver for Magnetized Plasma – Laser Experiments on the Z Beamlet Laser Facility

K. W. Struve[1], S. M. Lewis[2], C. S. Speas[1], M. L. Wisher[1], N. Riley[3], R. D. Bengtson[2], and J. L. Porter[1]

[1]Sandia National Laboratories, Albuquerque, NM
[2]Physics Dept., University of Texas, Austin, TX
[3]Lawrence Livermore National Laboratory, Livermore, CA

Outline

Review pulser design and performance when used at the University of Texas

Discuss design requirements and resulting modifications for use with the Z Beamlet Laser (ZBL)

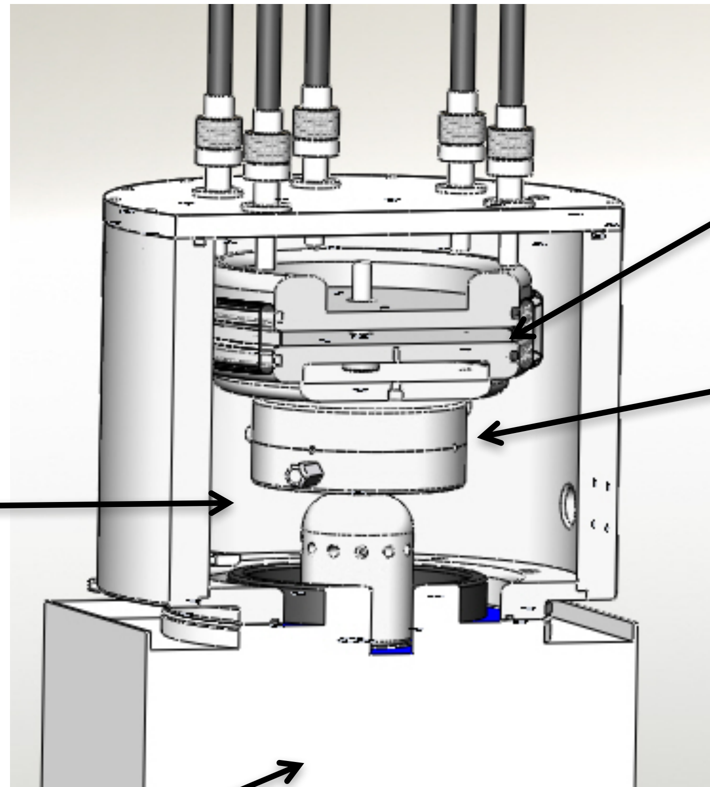
Performance

Problems and solutions

Potential design improvements

Ten capacitor, 2 MA system at UT

Cut-away view of capacitor, switch, and water resistor



Water resistor

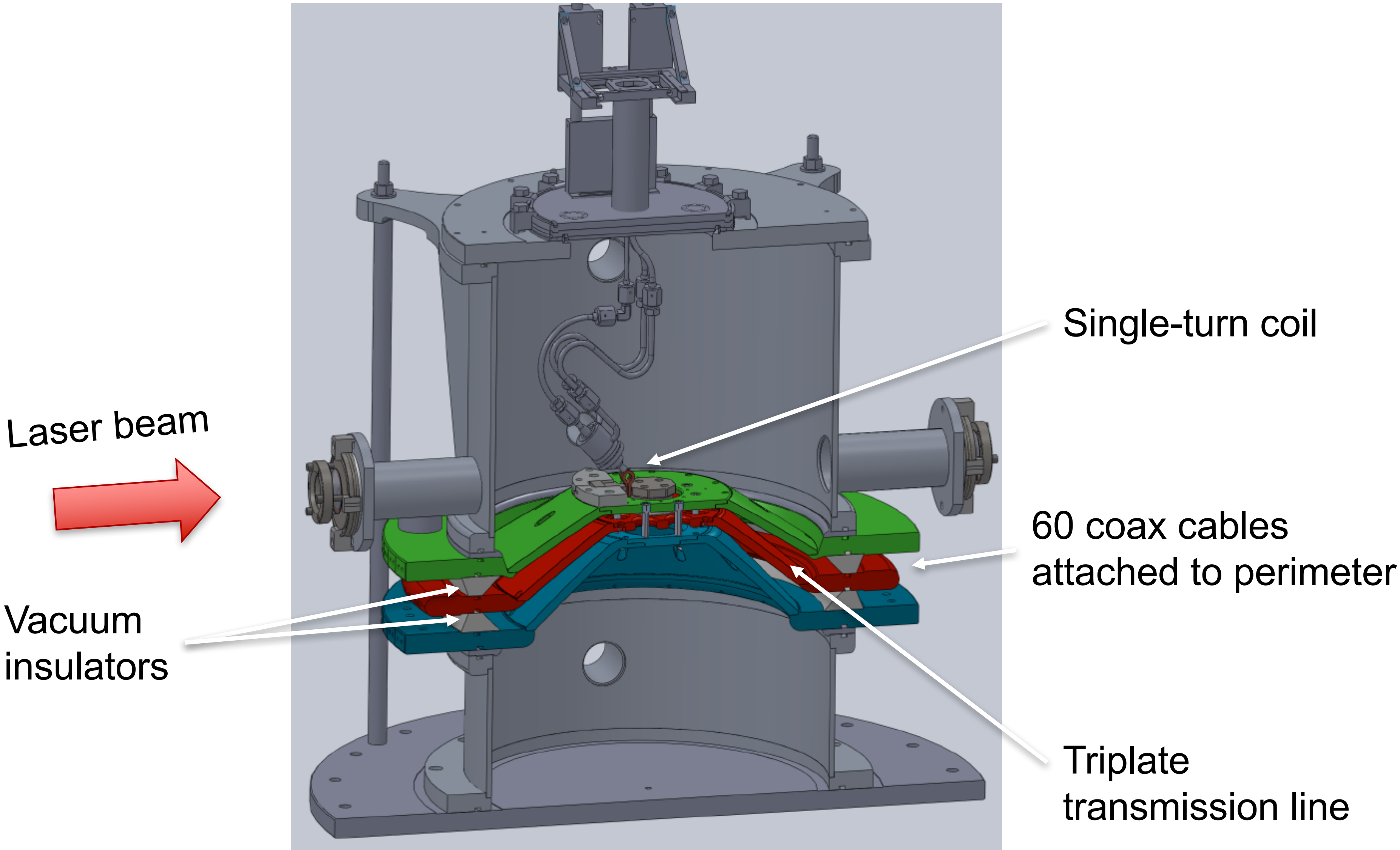
L3 Comm. 40364 gas switch

Volume around switch filled with SF_6

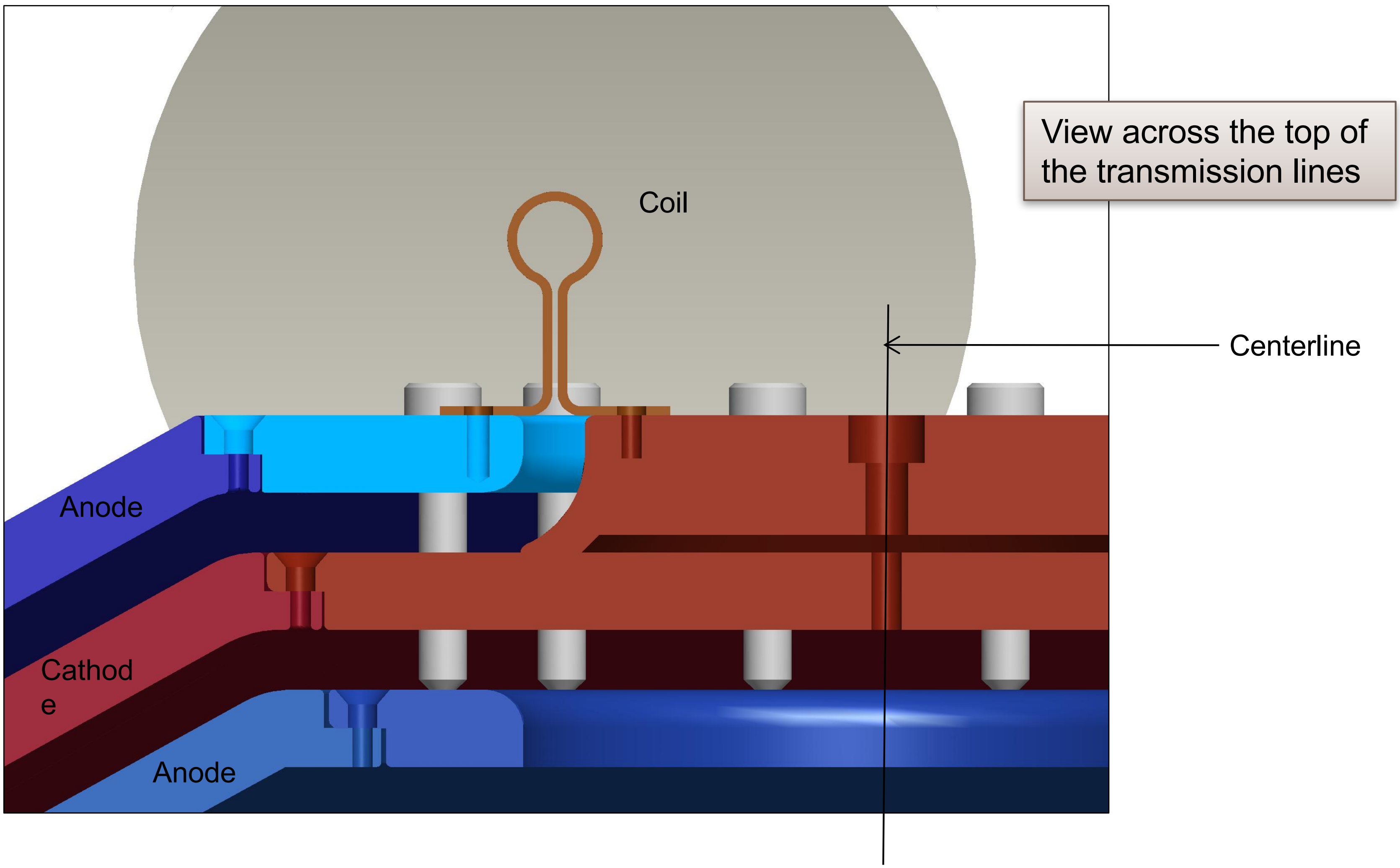
GA 3.1 μF / 100 kV capacitor

The switch must hold off up to 100 kV, and conduct up to 250 kA (0.5 C)

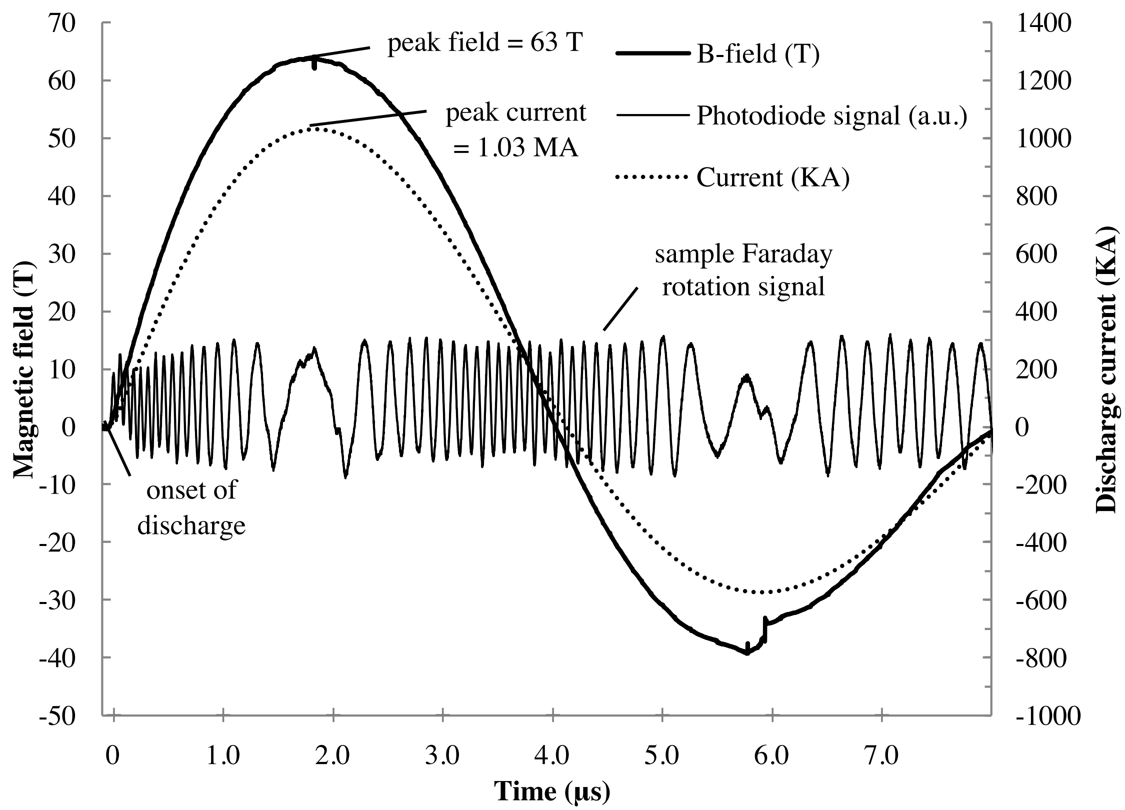
The UT system used a horizontal triplate transmission line



The magnetic coil is a copper strip formed into a loop



This system was successful in delivering over 1 MA, and creating fields up to 0.6 MG



Current limited by electrical breakdown in the triplate and vacuum transmission line sections

This system now back at Sandia for laser/plasma experiments with ZBL

The approach is to adapt the 2 MA pulser for use with the Conchas chamber, using up to six of the pulser modules

- Conchas is one of the several target chamber in the ZBL target bay
- Requires horizontal, one side vacuum feedthrough

Goal is 40 to 50 T

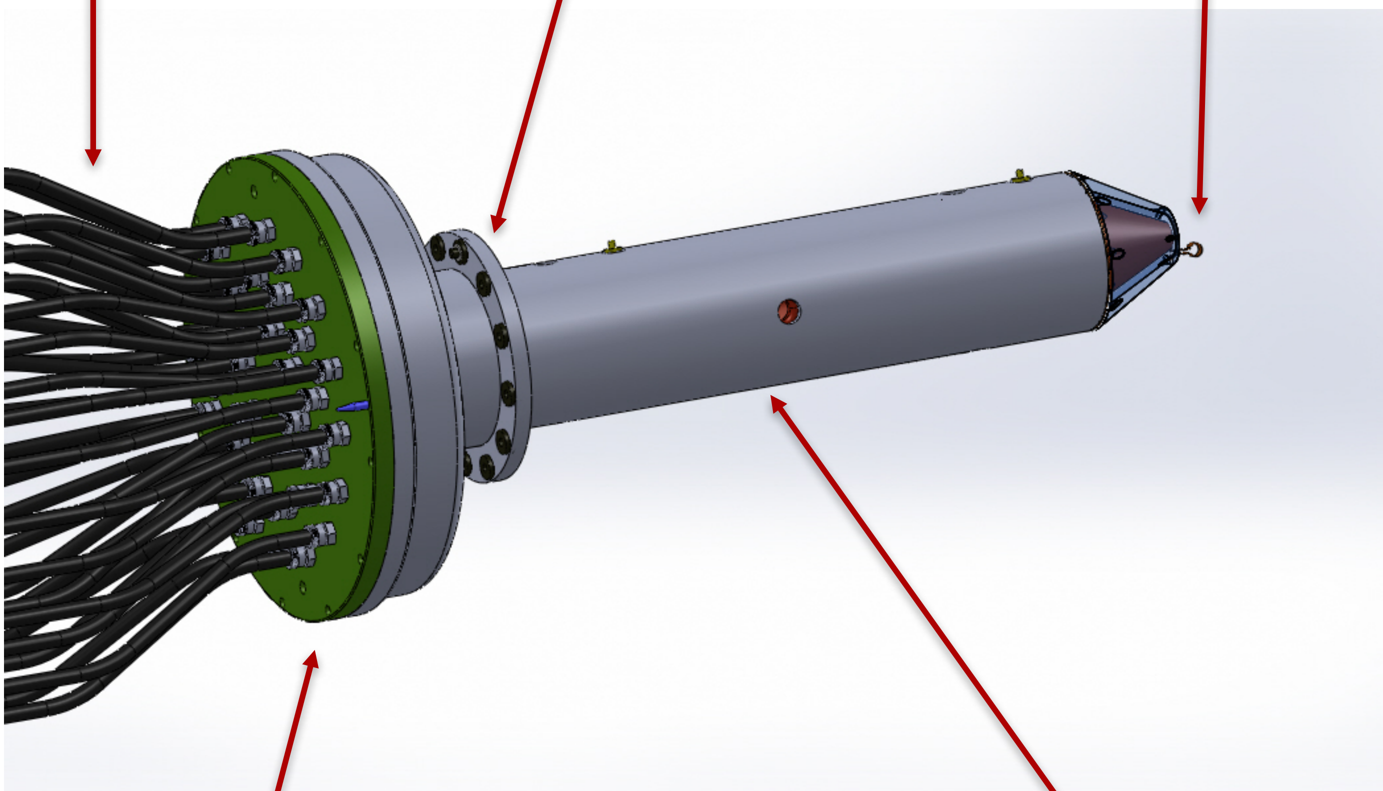
Can be synchronized with firing of the ZBL

Horizontal drive configuration

Six cables for each capacitor/switch module

Vacuum flange

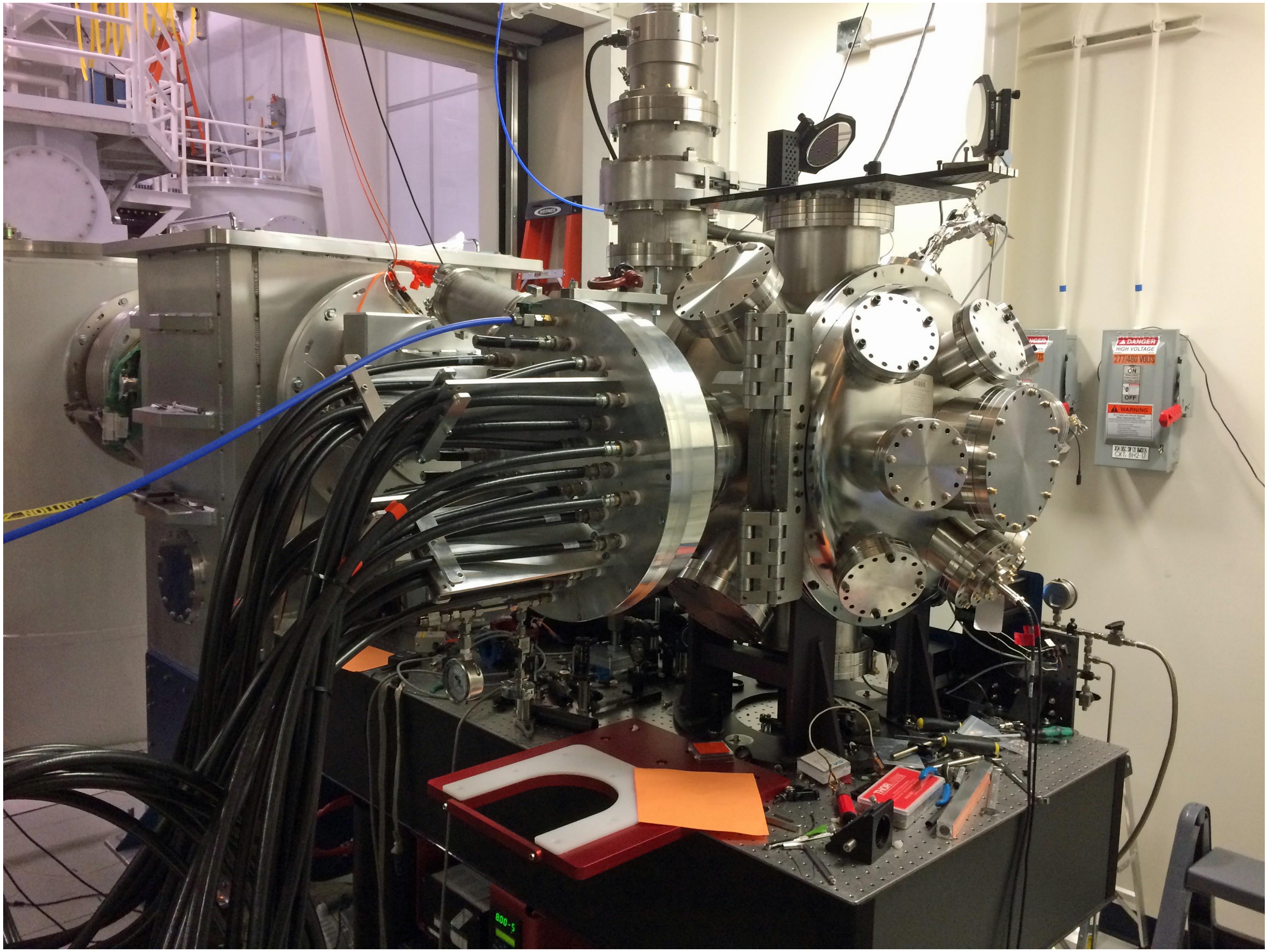
Single-turn magnetic field coil



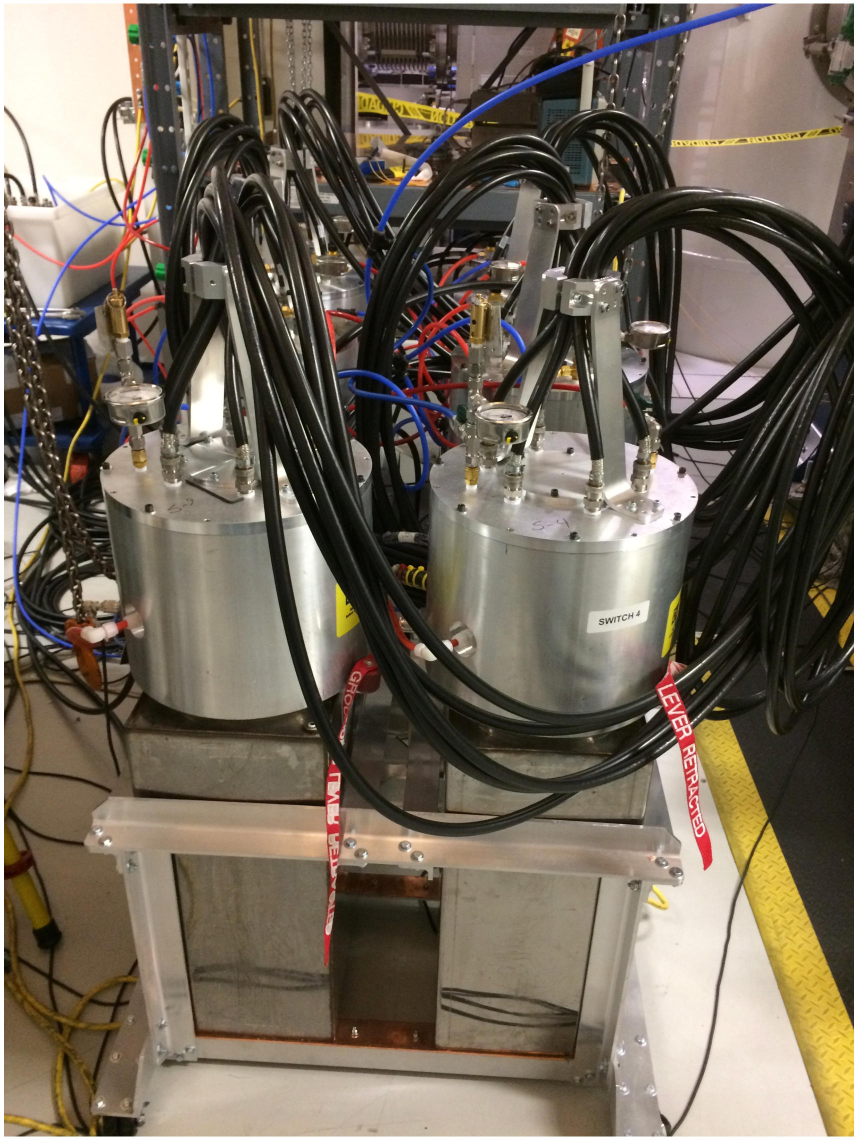
"Mushroom" - where currents are collected

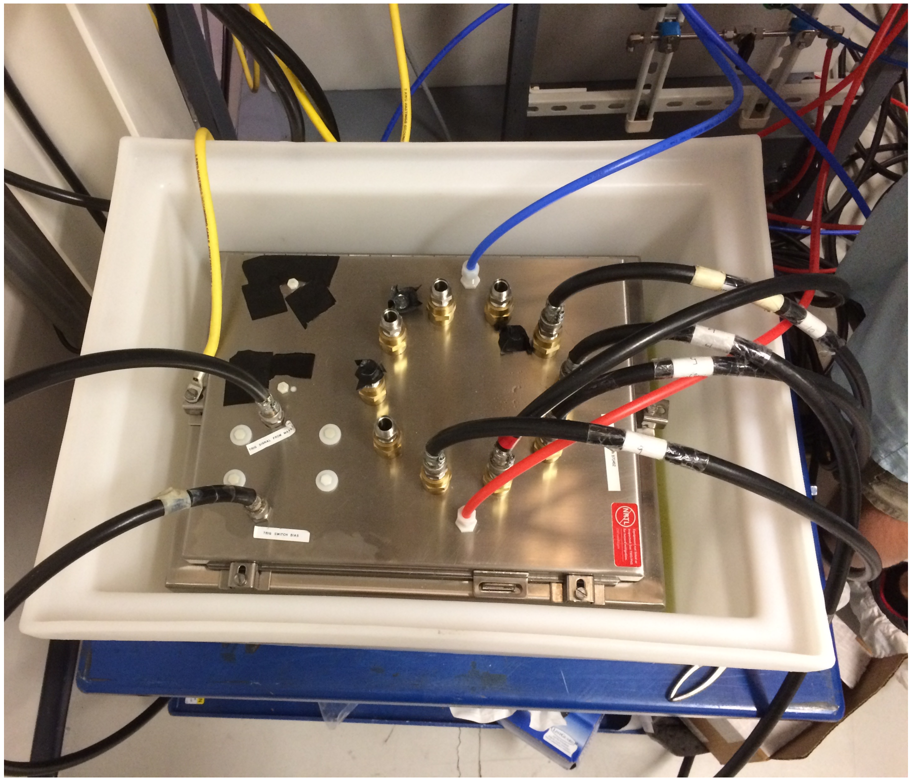
Coaxial vacuum transmission line

Conchas chamber in the ZBL target bay

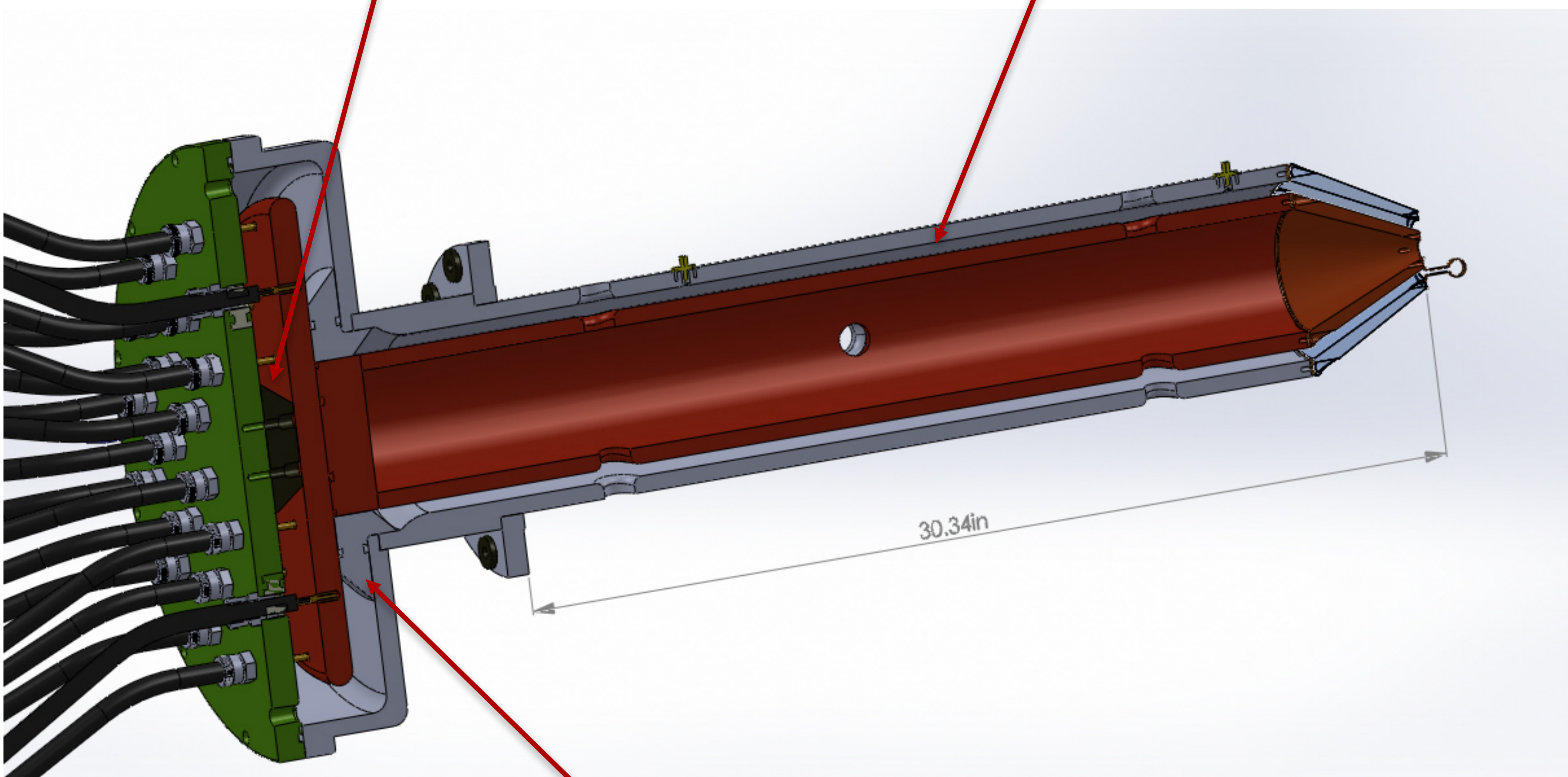


Capacitor/switch modules, trigger bias box

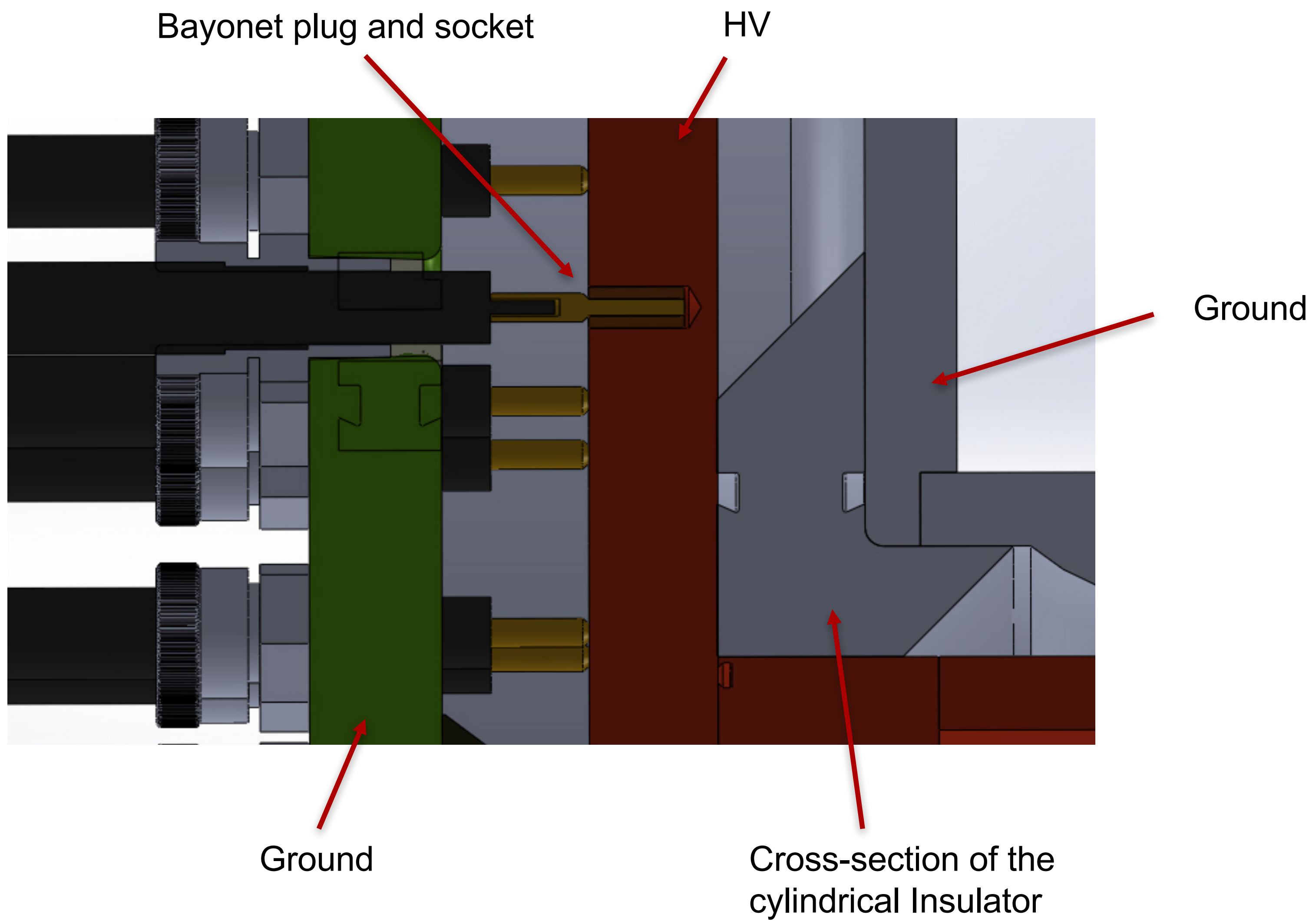




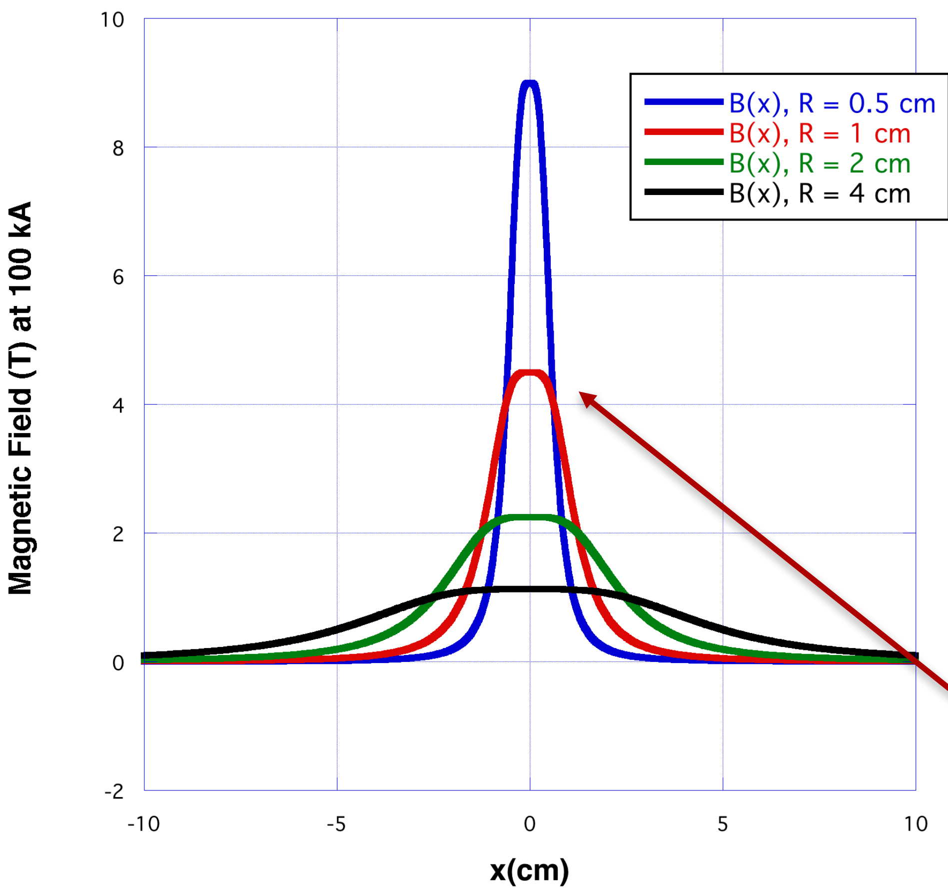
Cutaway drawing of mushroom and feed stalk



Vacuum insulator and cable connections



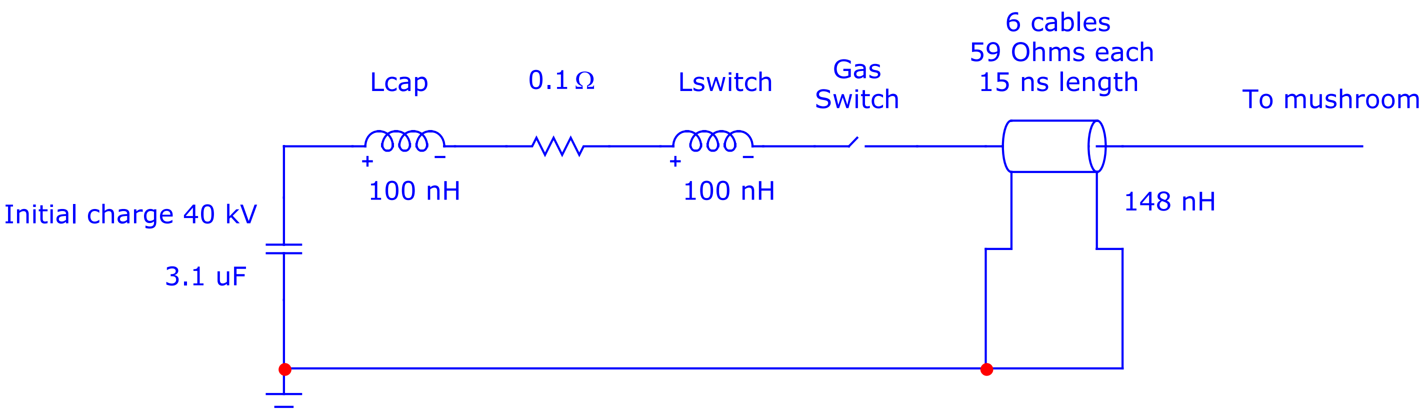
Expected field from a split-current Helmholtz coil vs radius with a 100-kA peak drive current



$$B_{peak} = \frac{\mu_o I}{2R}\left(\frac{4}{5}\right)^{3/2}$$

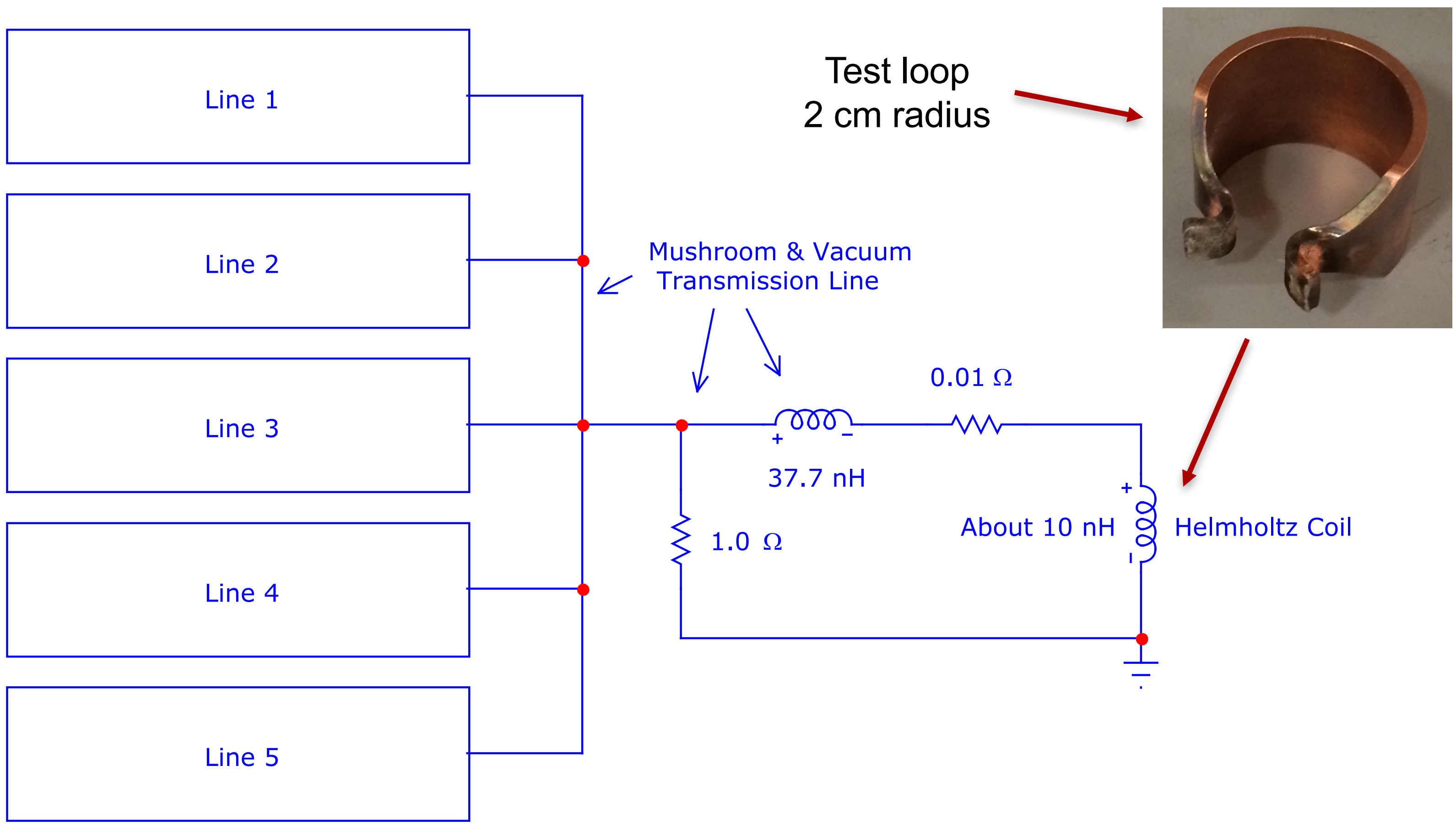
4.5 T, 1 cm radius, 100 kA

Circuit model of the capacitor and switch



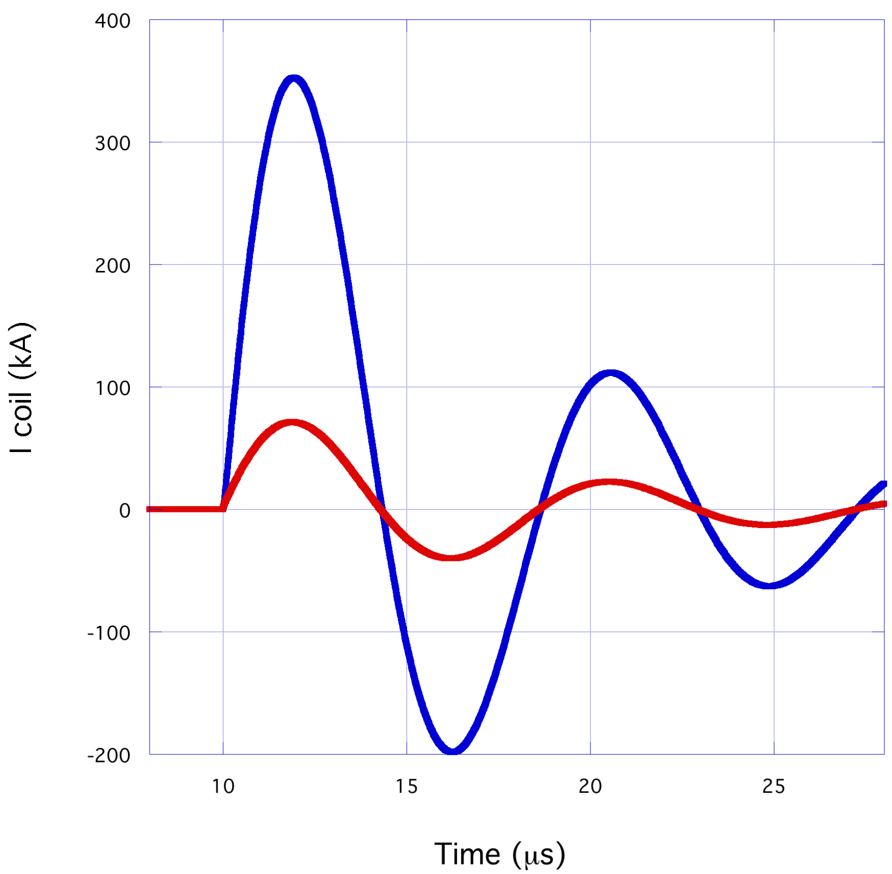
Inductance values chosen to match ringing frequency of measurements. These values are higher than expected.

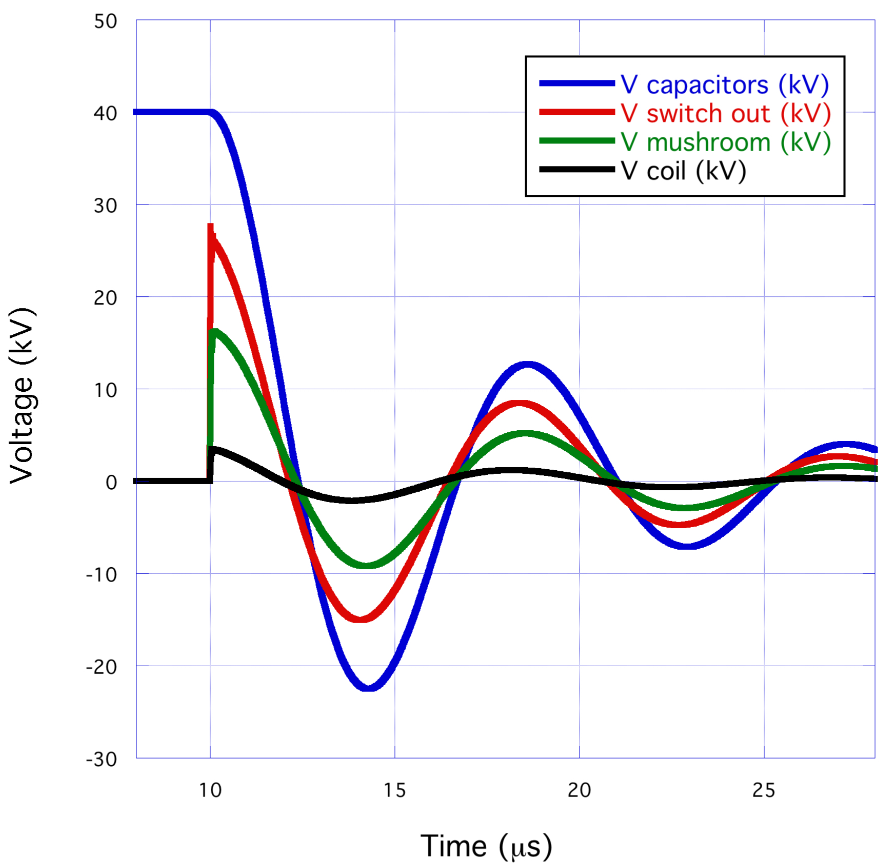
Add up to six lines in parallel



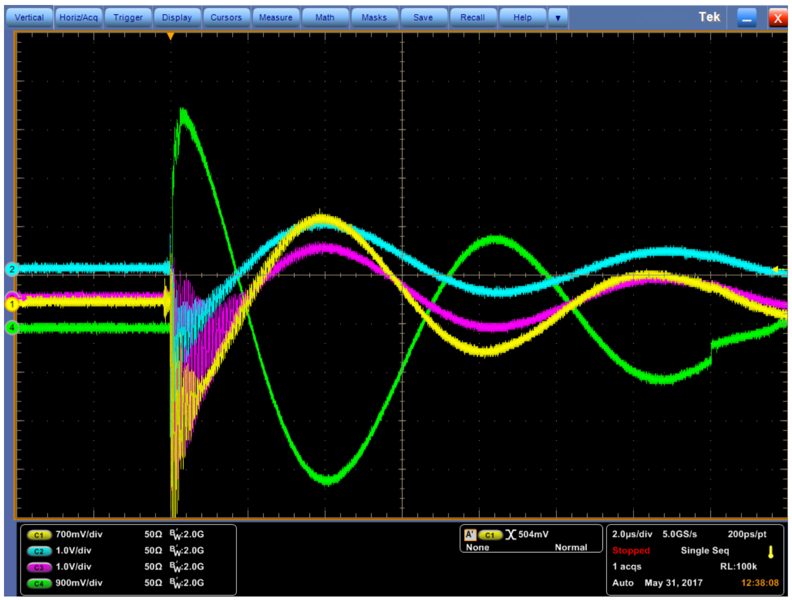
Example of a five line configuration

Expected current and voltage for a 5-module configuration with a 40 kV capacitor charge voltage

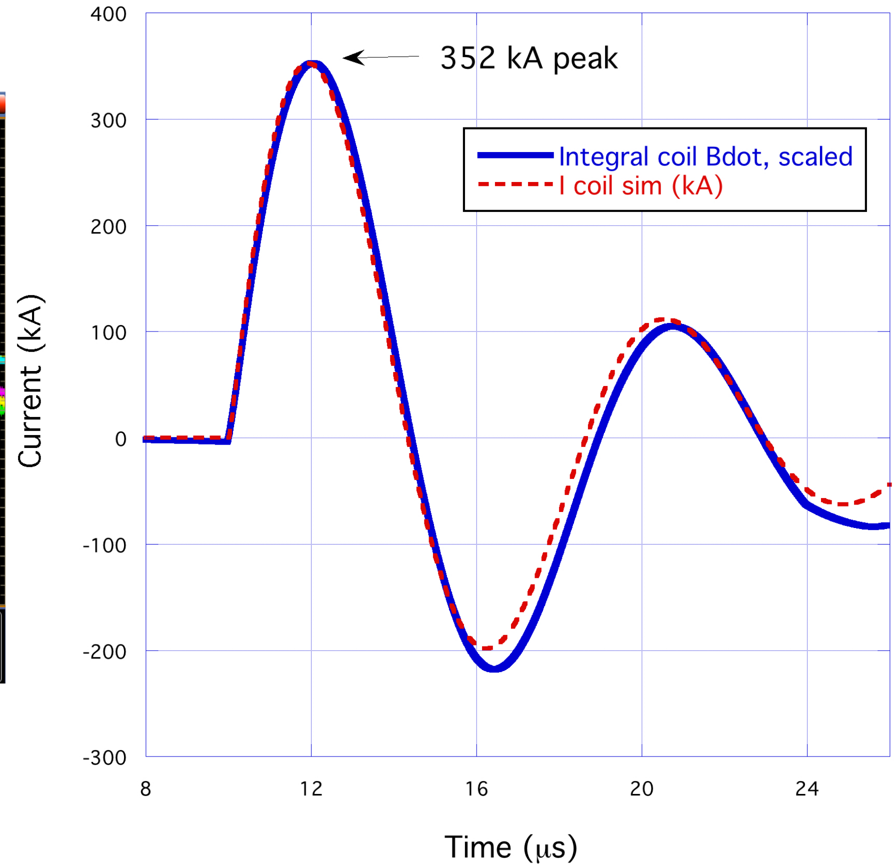




Recent shots in air at 40 kV confirm the prediction



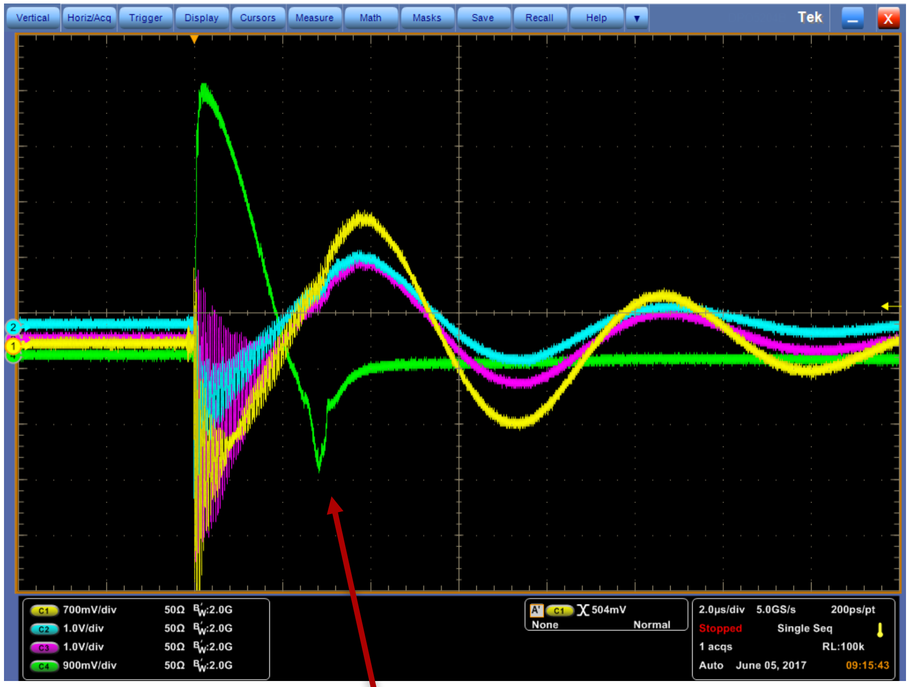
Bdot signals of the magnetic field in the coil (green), and currents in three of the drive modules. Voltages proportional to the derivative of the currents and the B field.



Integral of the Bdot signal (green trace) scaled to the peak current of the simulation

With vacuum we often get breakdown in the transmission line

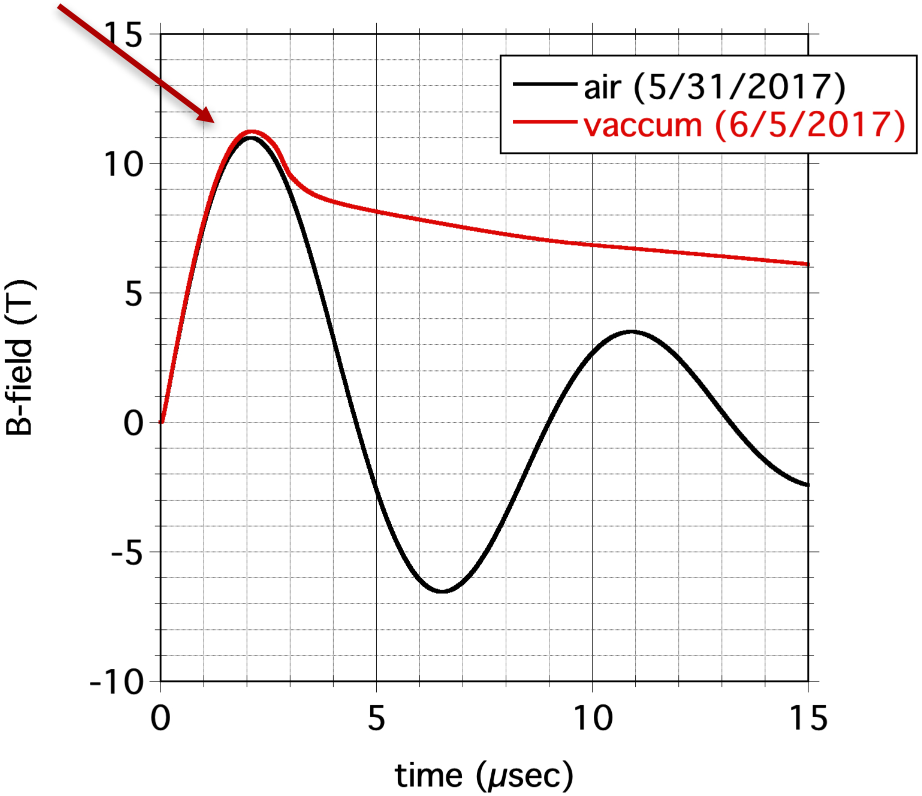
Bdot signals
Green trace is coil Bdot



Vacuum breakdown
at this time

Coil Bdot integrated
and calibration applied

Peak field 11.3 T



How do we get to 40 to 50 T?

- **More modules** – 6 instead of 5 produces 20 % higher field. 11 T ⇨ 14 T
- **Higher voltage** – 60 kV instead of 40 kV, 50% higher. 11 T ⇨ 17 T
  - *If we could operate at 90 kV, over 2x higher. Capacitor limit 100 kV.*
- **Smaller coil radi**us – 1 cm instead of 2 cm,100% higher. 11 T ⇨ 22 T
- **Two turns instead of single turn** – 2x higher for same size coil

Potential higher field configurations:

1 cm radius coil, 60 kV charge voltage, six modules ⇨ 41 T

Two turn coil, 1 cm radius, 5 modules, 40 kV charge voltage ⇨ 45 T

Some of the problems that have been or will be addressed

Insulator flashing -- modified insulator

Breakdown in the vacuum transmission line -- surface finish, eliminate field enhancements

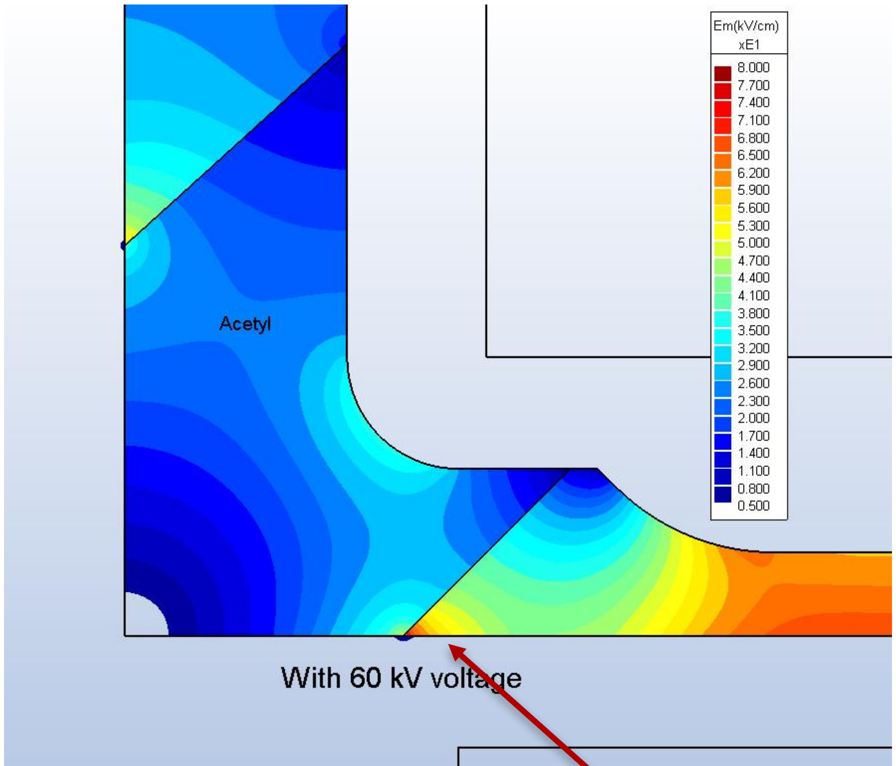
Shorting of coil at its feed -- move the insulator to the cone

Arcing at cable feed connections -- replace bayonet and socket connections with higher-current capable design

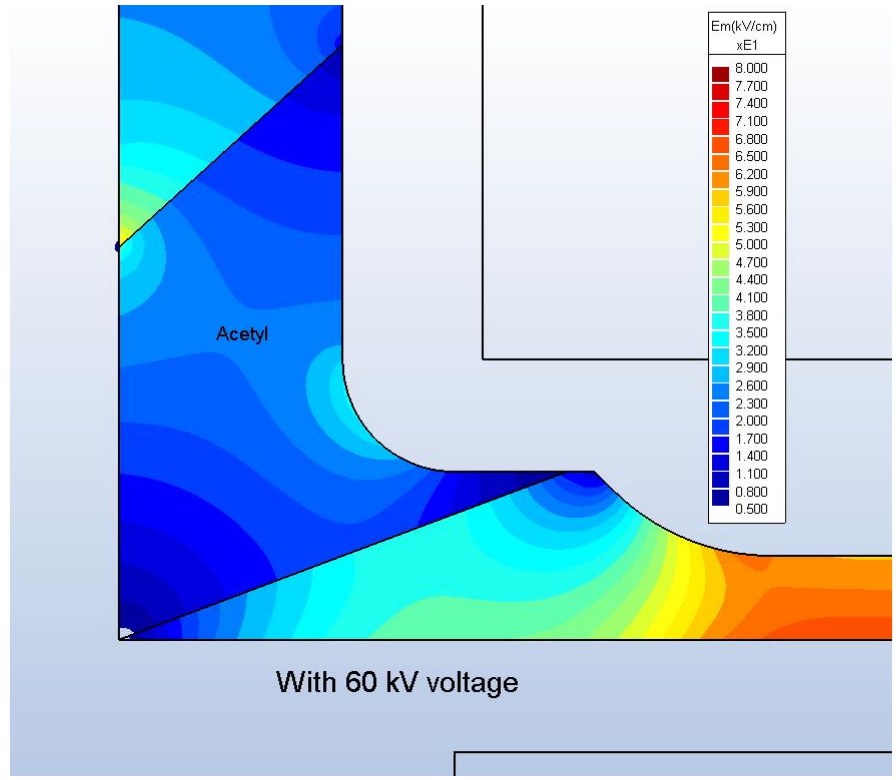
Irregular triggering – added capacitance to the trigger circuit for a higher current trigger

We were able to eliminate flashing of the vacuum insulator with a simple modification

Original



Modified barrier



Anode triple point fields too high

A future design for higher magnetic fields would include the following design improvements

Lower inductance switch-and-series-resistor configuration
- Could increase currents by 50%
- Use to switch newer, higher-energy-density capacitors

Move vacuum insulator to coil input
- Would eliminate vacuum transmission line
- Allow higher voltages – potential 100 % increase in current

Enhanced trigger system
- Trigger voltage independent of capacitor charge voltage

Multi-turn magnetic field coils
- Develop multiple-turn, single-use coil designs that can withstand voltage without shorting

Conclusions

We have been able to adapt the 10-capacitor, 2 MA magnetic coil driver for use with the ZBL laser in a 6-capacitor configuration

Because of vacuum breakdown, peak operating voltage has been about ½ of its capability

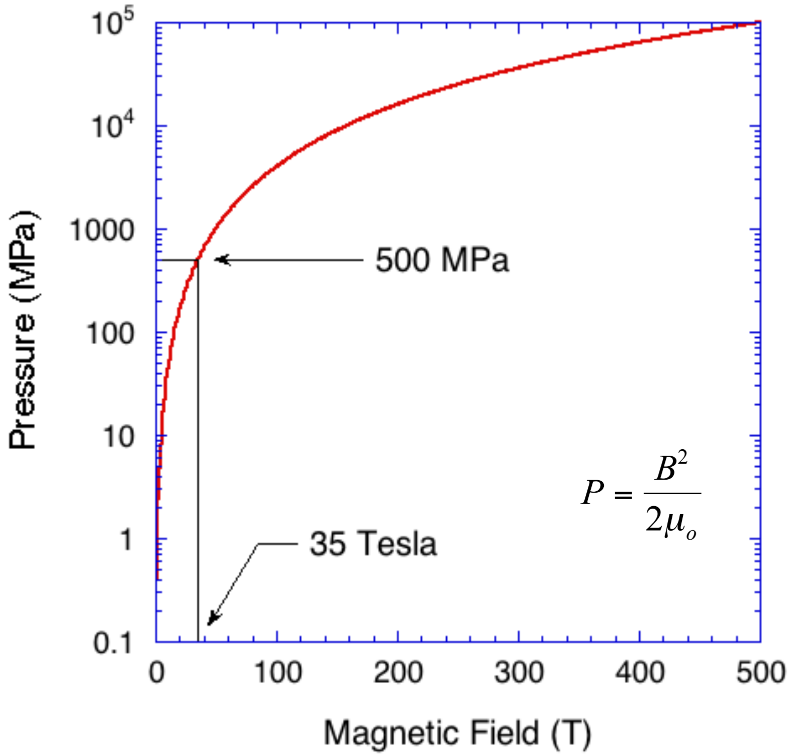
Even with this limitation, production of 40 to 50 T magnetic fields feasible.

Biggest problems to date are related to vacuum breakdown at the feed to the magnetic coil, and inconsistent triggering of the modules

Design modifications offer the possibility of higher voltage operation, and the potential of magnetic field strength exceeding 100 T

Backup slides

Magnetic pressure can be severe with these fields, and motivate choice of single-turn, single-use coils



Materials normally used in the construction of high field magnets

Material	Yield Strength MPa	Ultimate Strength MPa
Plain carbon steel AISI-SAE 1020		450
Stainless steel type 304	240 - 300	550 - 650
High-strength alloy steel, ASTM A514	690	760
Copper 99.9%, annealed	70	220
Copper 99.9%, hard	300	340
Yellow brass	200	550
Zylon fiber		4500
Glass fiber		3400
Carbon fiber		5650

With fields above about 35 T (0.35 MG) magnetic pressure is high enough to destroy most materials. At 200 T (2 MG) nothing will survive.