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MagNIFico: A Pulsed Magnetic Field System for Magnetized Target Experiments at the National Ignition Facility

M. A. Rhodes, J. M. Solberg, B. G. Logan, L. J. Perkins

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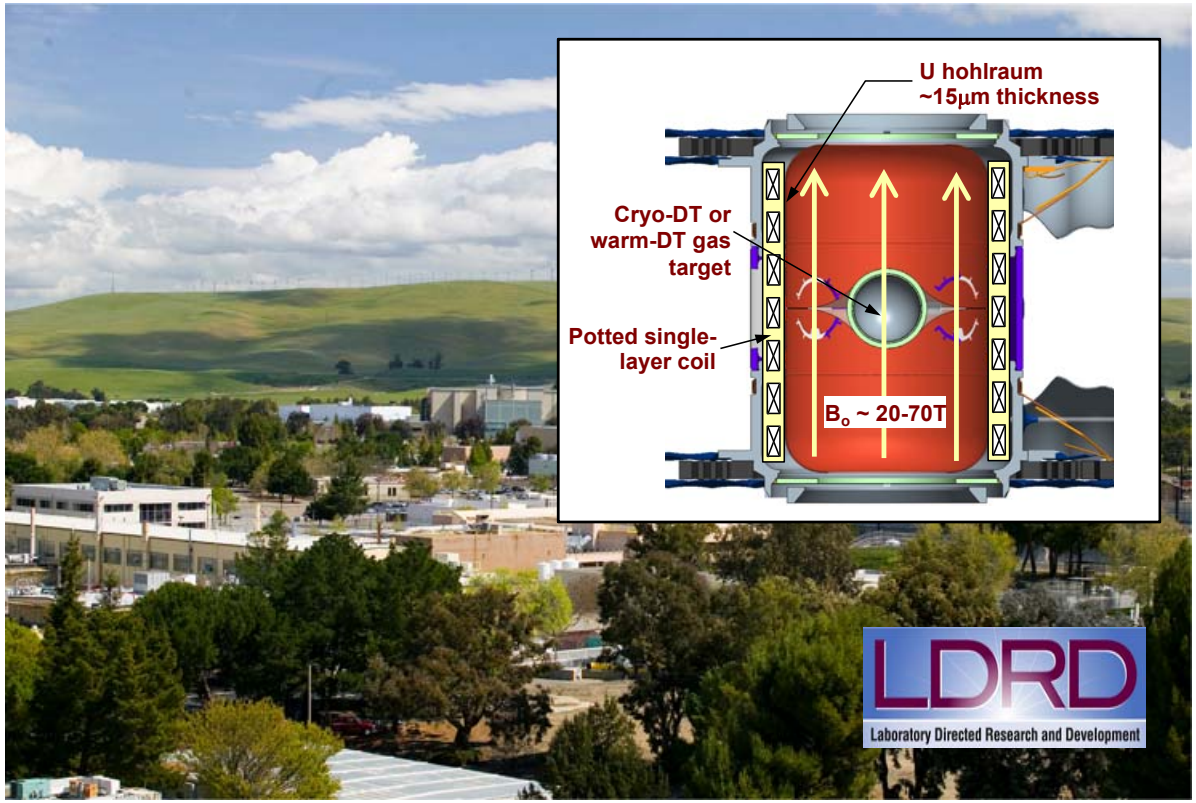
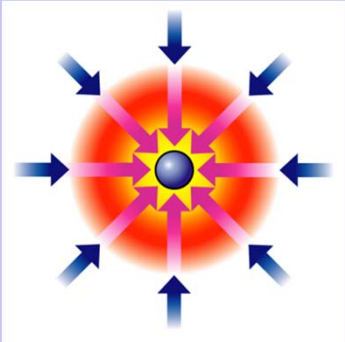
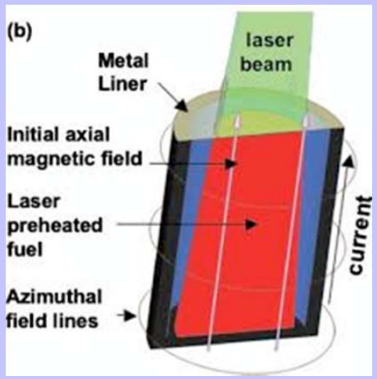
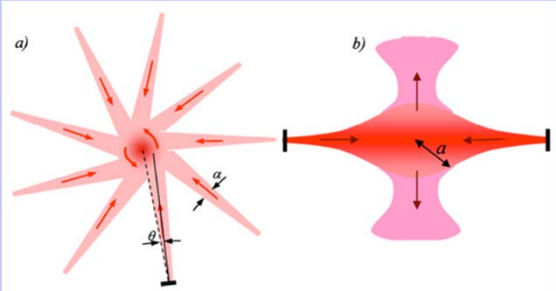


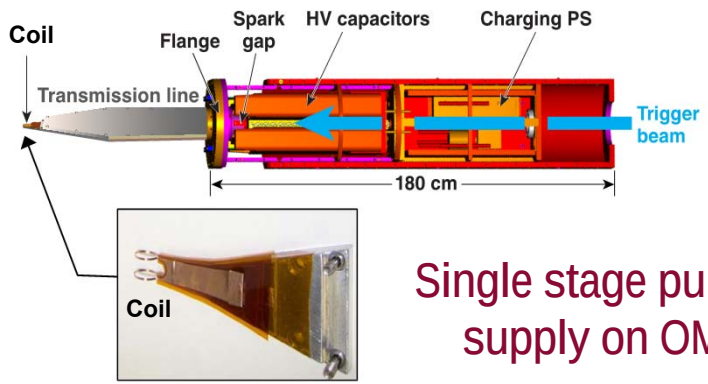
Outline

- Some introduction, orientation, and related work being done elsewhere
- MagNIFico design concepts for NIF
- Modeling of hohlraum heating (ALE3D)
- 3D modeling of the coil (ALE3D)
- Coil optimization schemes
- Conclusion

A flexible pulsed magnetic field system on NIF offers a number of potential applications

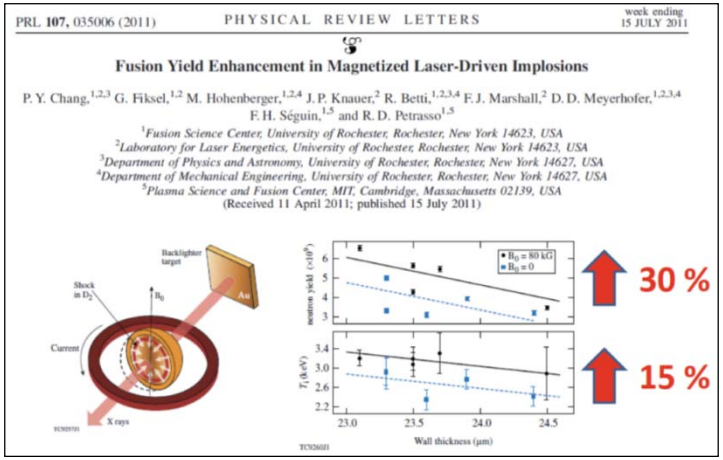
Fusion yield and ignition (prime focus of our LDRD)	MagLIF Supporting Sandia's concept with laser pre-heat at NIF	Basic Science
		
Improved alpha and hot-e confinement, RT stabilization and hohlraum physics *=> Ignition in otherwise submarginal capsules*	*B-field effects on LPI and laser absorption; Sandia collaboration*	*Collisionless shock studies, accretion discs; magnetic reconnection*

LLE (University of Rochester) has already performed laser-driven magnetized implosions on OMEGA.



Single stage pulsed power supply on OMEGA

- Initial coil fields of ~10T were compressed almost a thousand-fold, indicating good flux conservation.
- Enhanced hot spot temperatures and neutron yields were observed in deuterium gas-filled CH capsules under spherical implosion.
- So far, we understand LLE is limited to ~15T over small target volumes



PRL 107, 035006 (2011) PHYSICAL REVIEW LETTERS week ending 15 JULY 2011

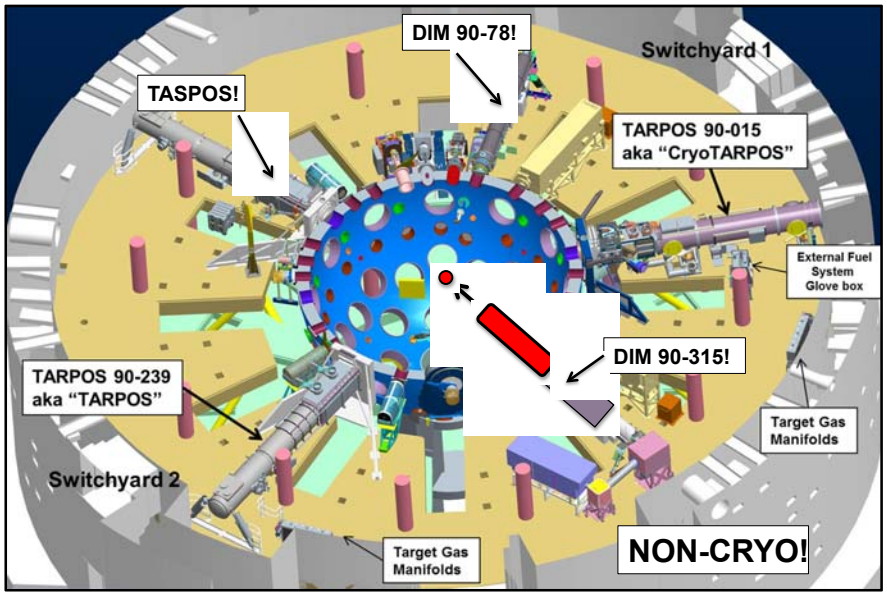
Fusion Yield Enhancement in Magnetized Laser-Driven Implosions

P. Y. Chang,[1,2,3] G. Fiksel,[1,2] M. Hohenberger,[1,2,4] J. P. Knauer,[2] R. Betti,[1,2,3,4] F. J. Marshall,[2] D. D. Meyerhofer,[1,2,3,4] F. H. Séguin,[1,5] and R. D. Petrasso[1,5]

[1]*Fusion Science Center, University of Rochester, Rochester, New York 14623, USA*
[2]*Laboratory for Laser Energetics, University of Rochester, Rochester, New York 14623, USA*
[3]*Department of Physics and Astronomy, University of Rochester, Rochester, New York 14627, USA*
[4]*Department of Mechanical Engineering, University of Rochester, Rochester, New York 14627, USA*
[5]*Plasma Science and Fusion Center, MIT, Cambridge, Massachusetts 02139, USA*
(Received 11 April 2011; published 15 July 2011)

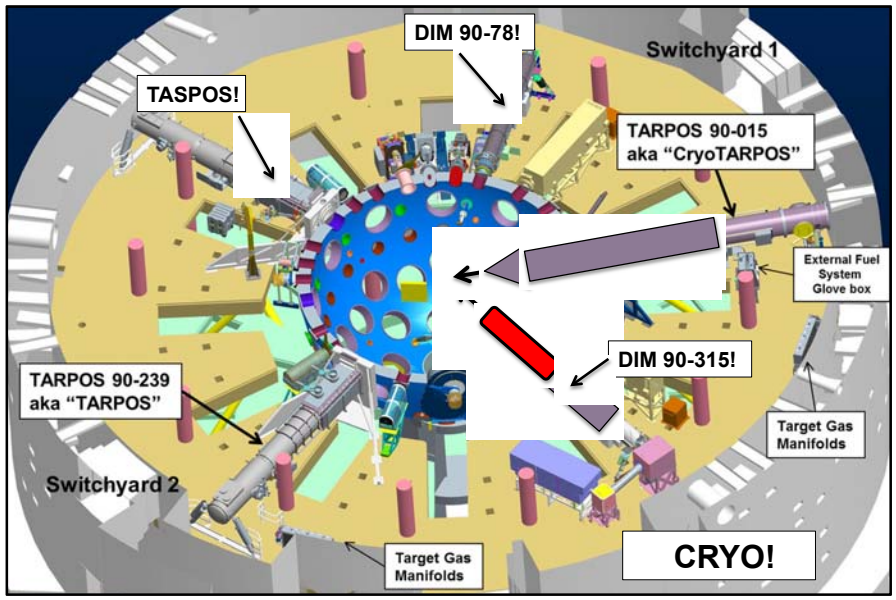
We are studying two approaches for MagNIFico

Power supply in DIM and target attached to DIM (TARPOS not used)



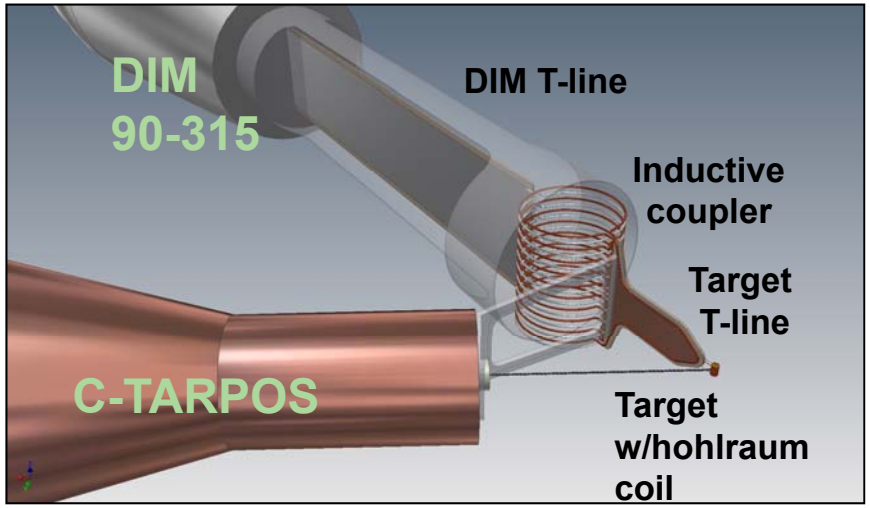
Non-cryo room-temperature targets shot from DIM 90-315

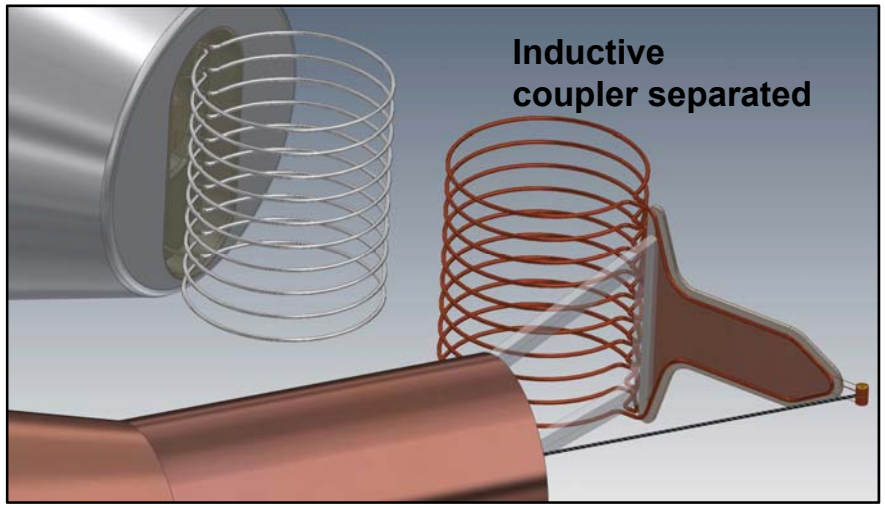
Power supply in DIM and target attached to TARPOS



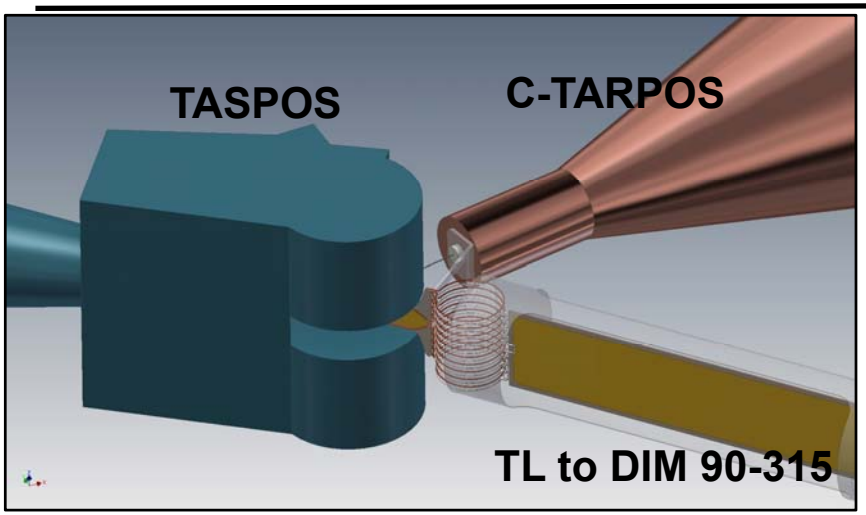
Cryo or non-cryo targets shot from cryo-TARPOS with inductive coupling from DIM

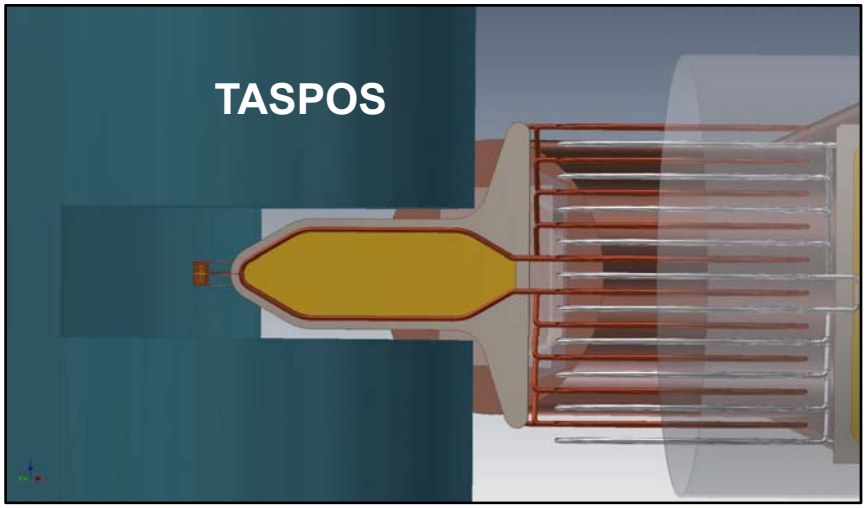
Targets on cryo-TARPOS would require a coupling scheme from DIM to cryo-TARPOS. Present plan is inductive coupling

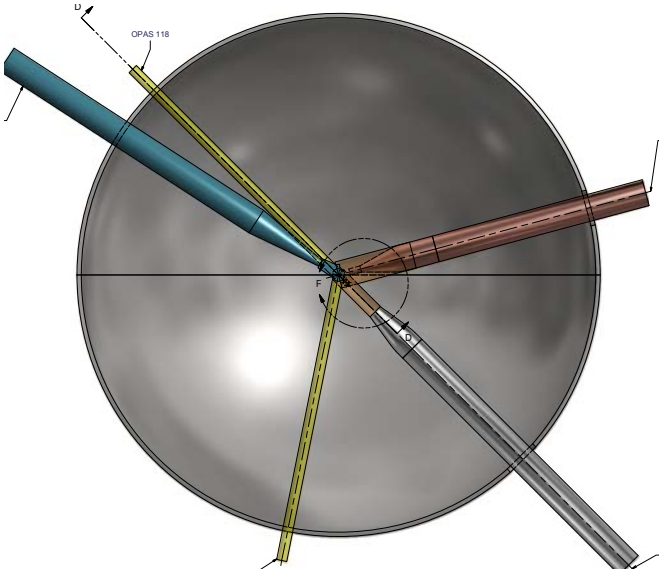


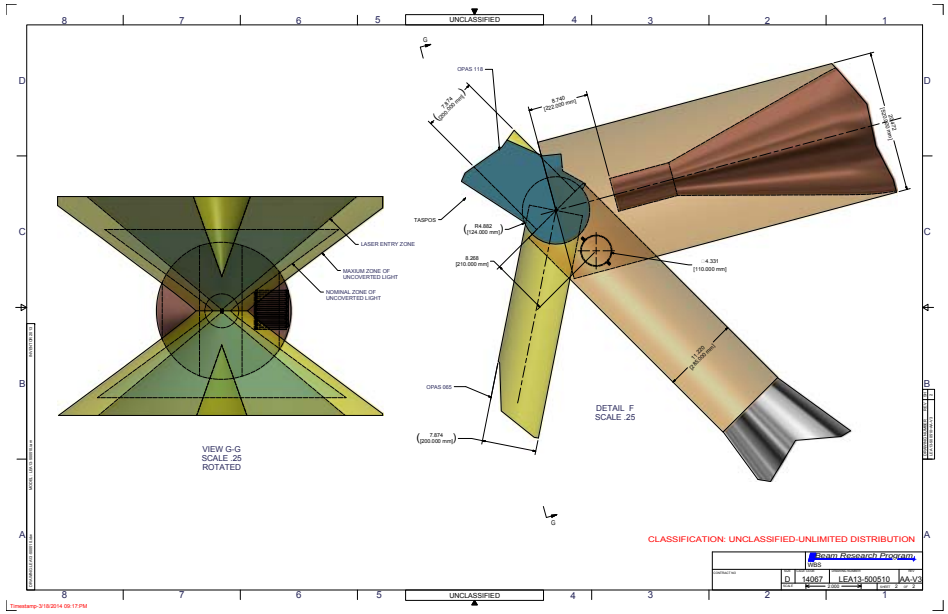


Preliminary NIF integration: Navigating the various NIF stay-out zones is a challenge but no show-stoppers so far

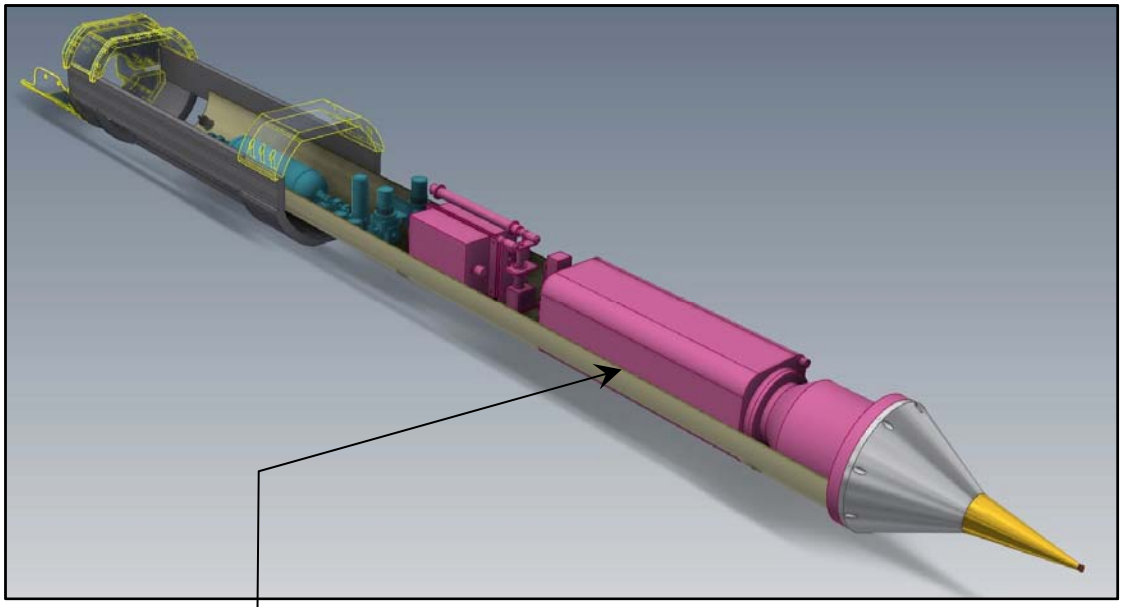


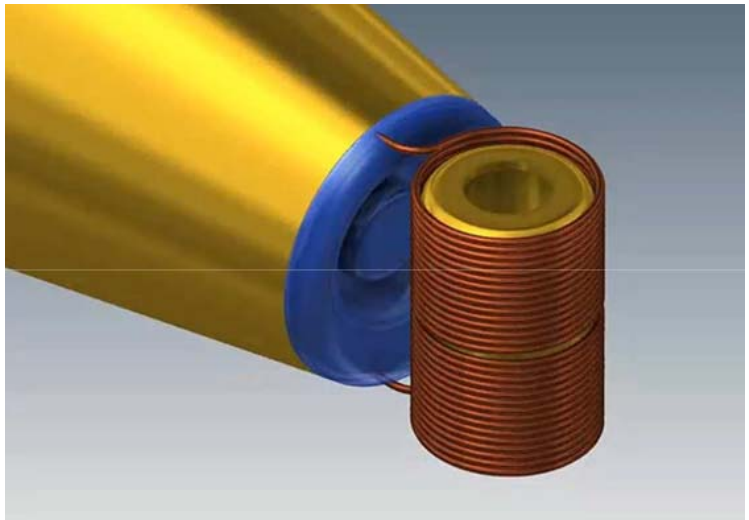


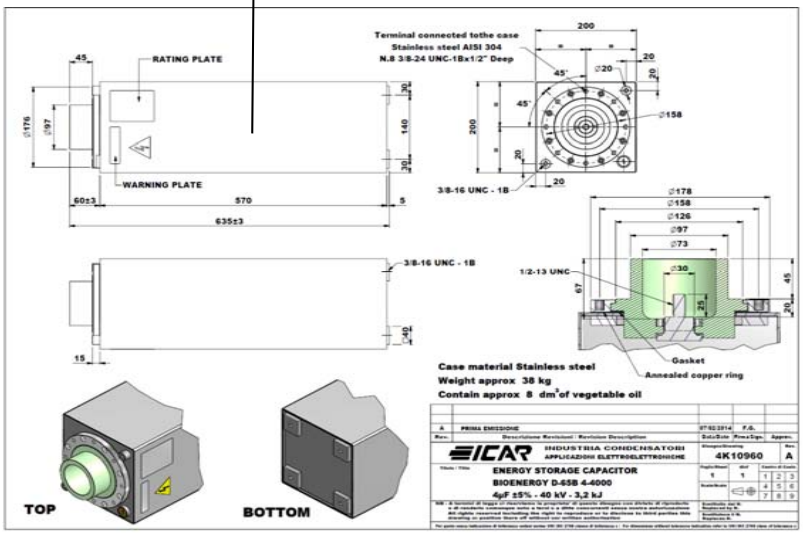




Pulsed power architecture is similar to LLE: Charged capacitor and a spark-gap switch in the DIM

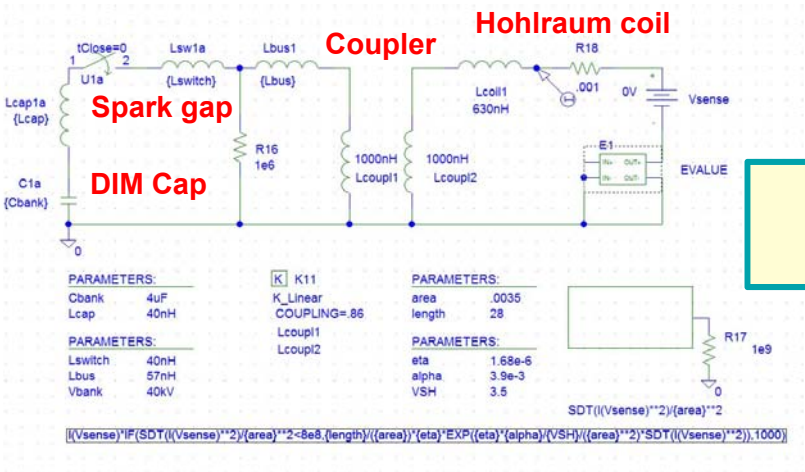




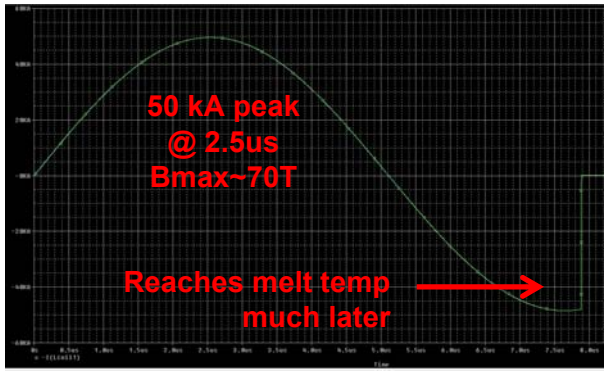


ICAR is producing the required capacitor 4μF @40kV (3.2kJ)

Basic modeling is done with a combination of PSPICE and MAXWELL.



PSPICE circuit models



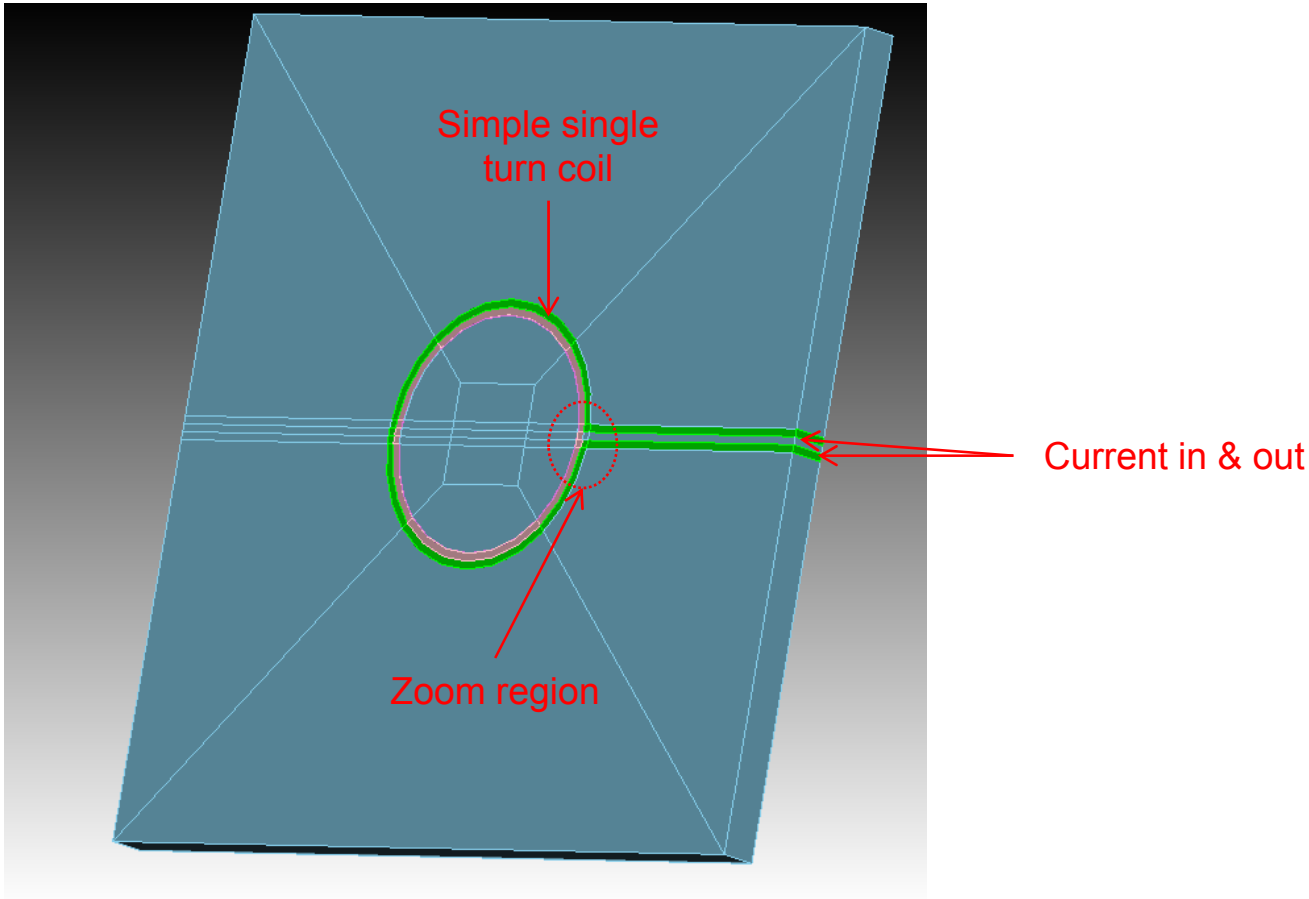
- **ANSOFT MAXWELL gives coil inductance and coil-coupling for the inductive coupler**
- **PSPICE can then model the circuit waveforms.**
- **We have included an Action based resistance model for the coil that accounts coil ohmic heating**

Hohlraum heating due to induced current

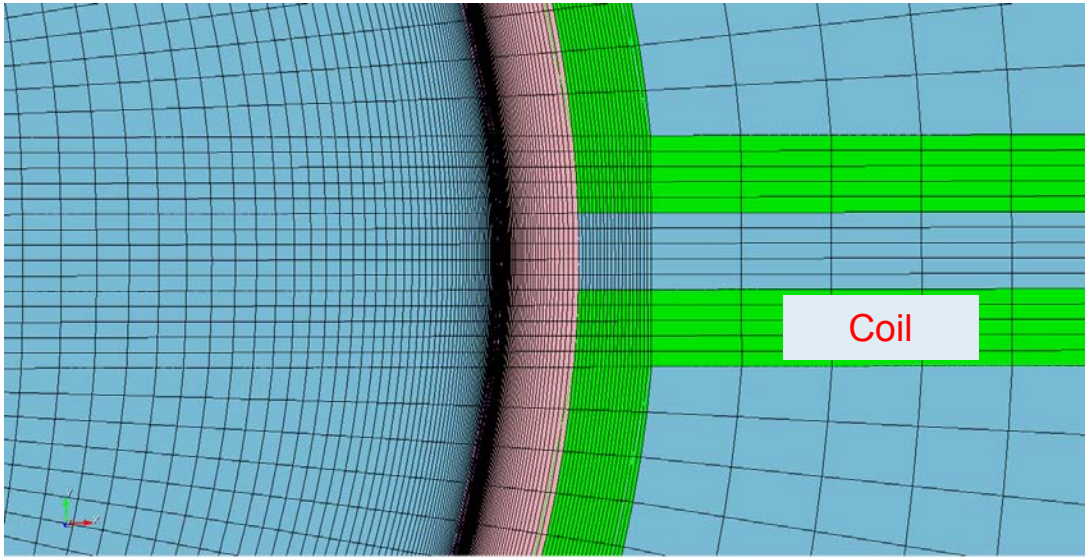
- NIF only has two materials qualified for use as the hohlraum wall: Gold and Uranium both of which are conductors
- A pulsed coil outside the hohlraum drives a current in the hohlraum wall
- The hohlraum layer is heated and is subjected to an inwards JxB force
- ALE3D is well suited to model the electrical, thermal, and hydrodynamic aspects of hohlraum heating
- However, for this type of problem ALE3D requires accurate, temperature dependent material data for a number of material properties
  - Electrical conductivity, heat capacity, EOS, thermal conductivity, and possibly also strength parameters
  - Especially for Uranium and at lower (below melt) temperatures, little data is available.

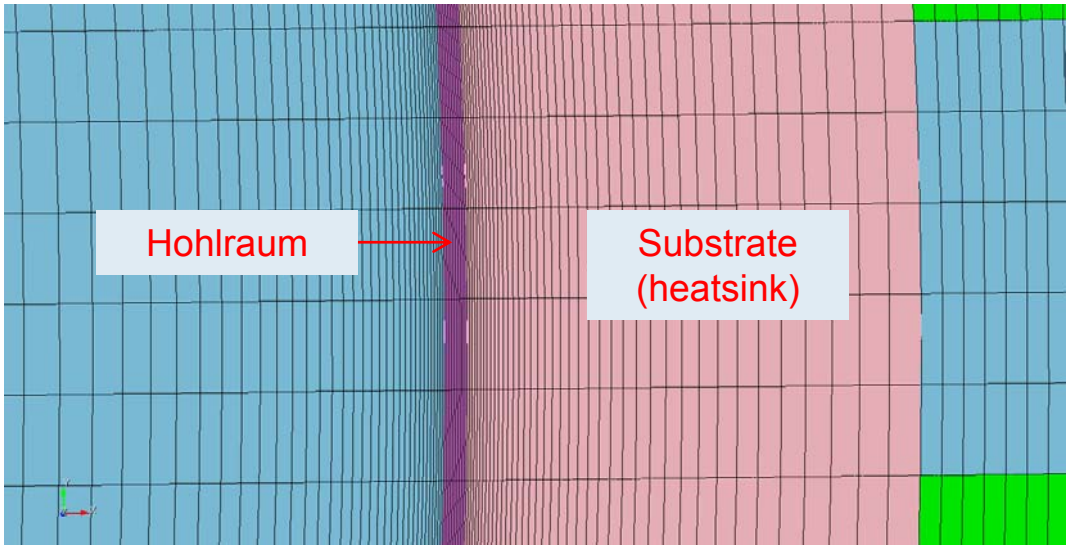
We model hohlraum heating in “2D”.

(ALE3D MHD needs at least 1-cell deep in the z-direction)

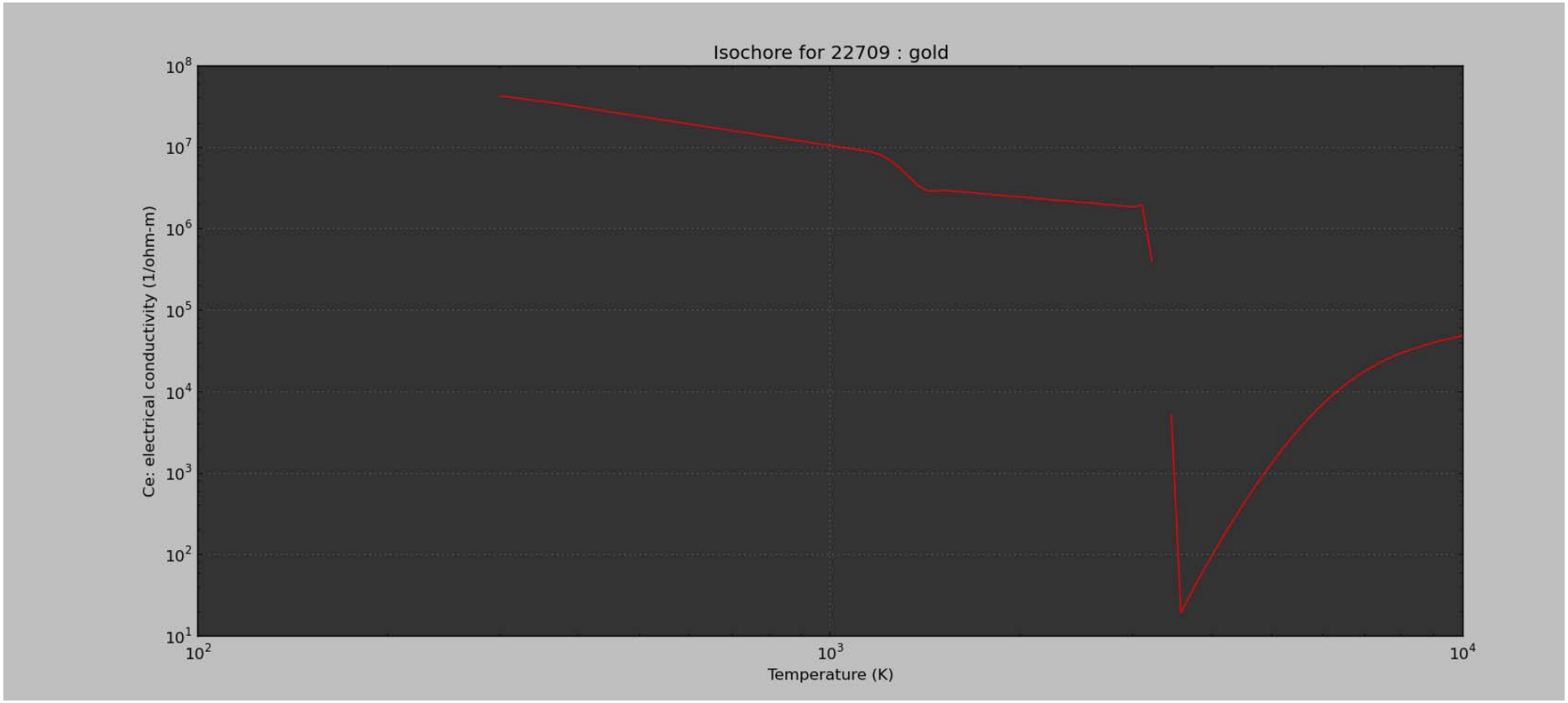


Zoomed in view of the mesh



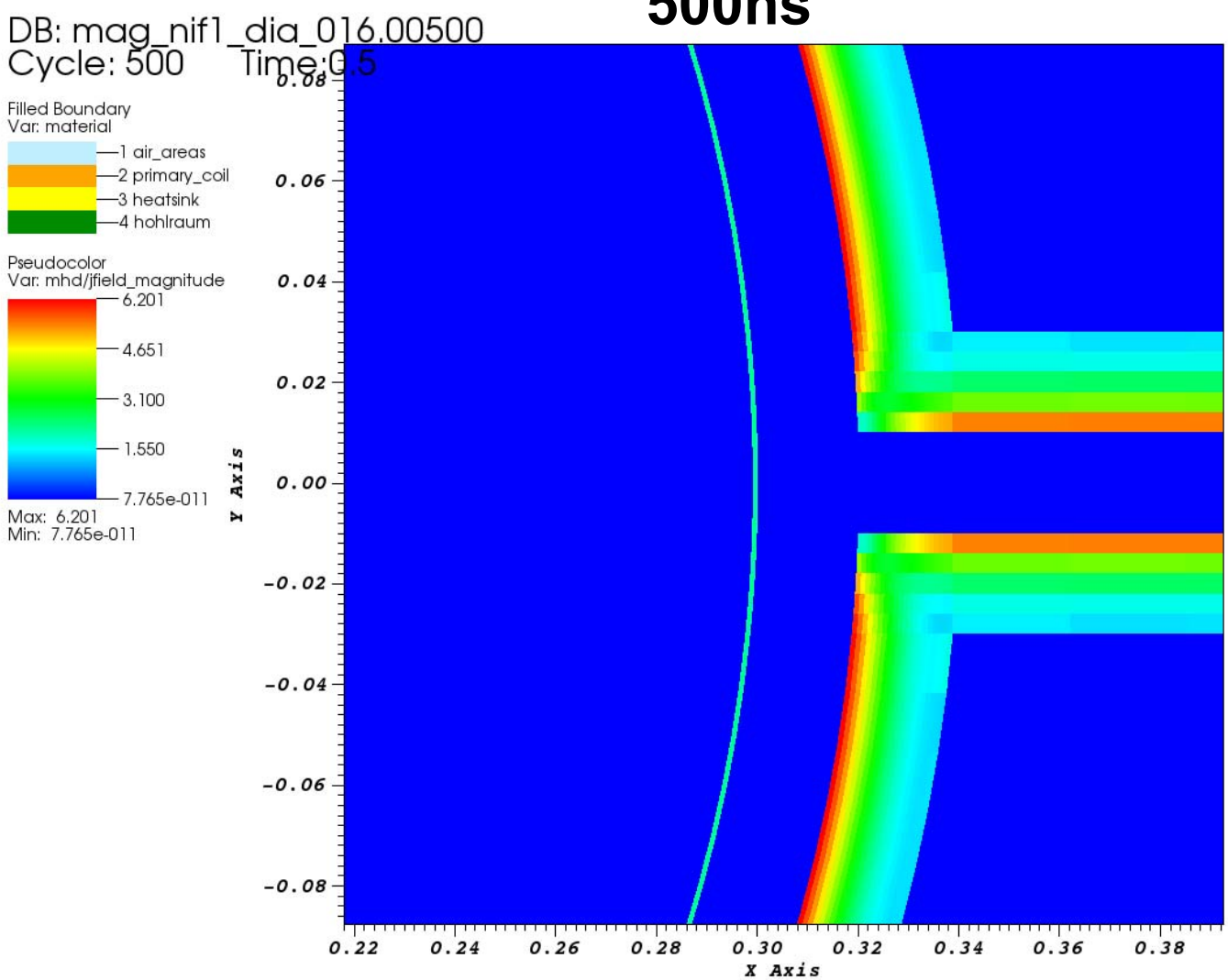


For gold hohlraum models, we use the SESAME 22709 electrical conductivity table

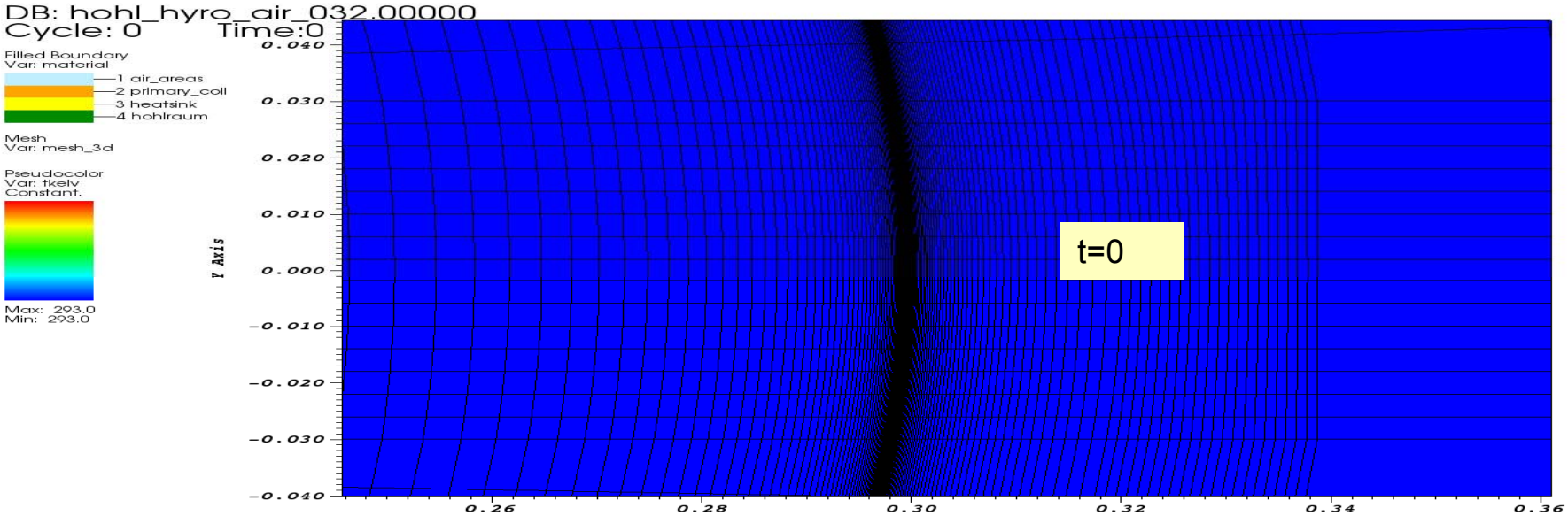


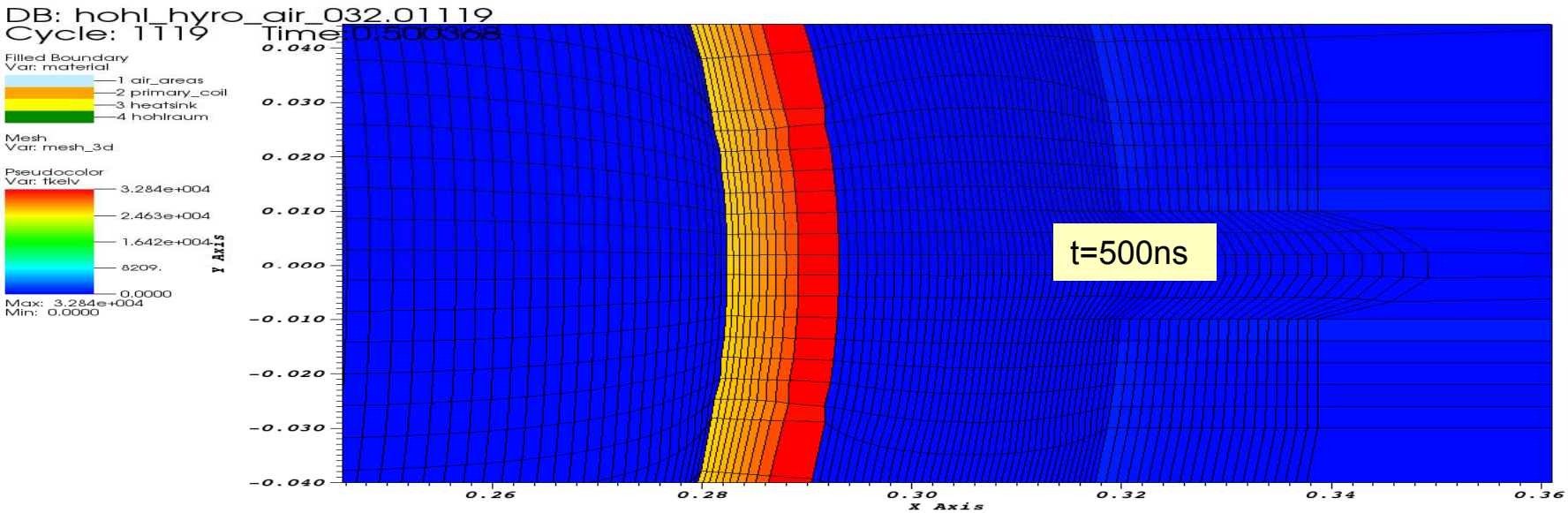
Current density plot with 400ns L/R current waveform shows skin effect in copper and induced hohlraum current

500ns

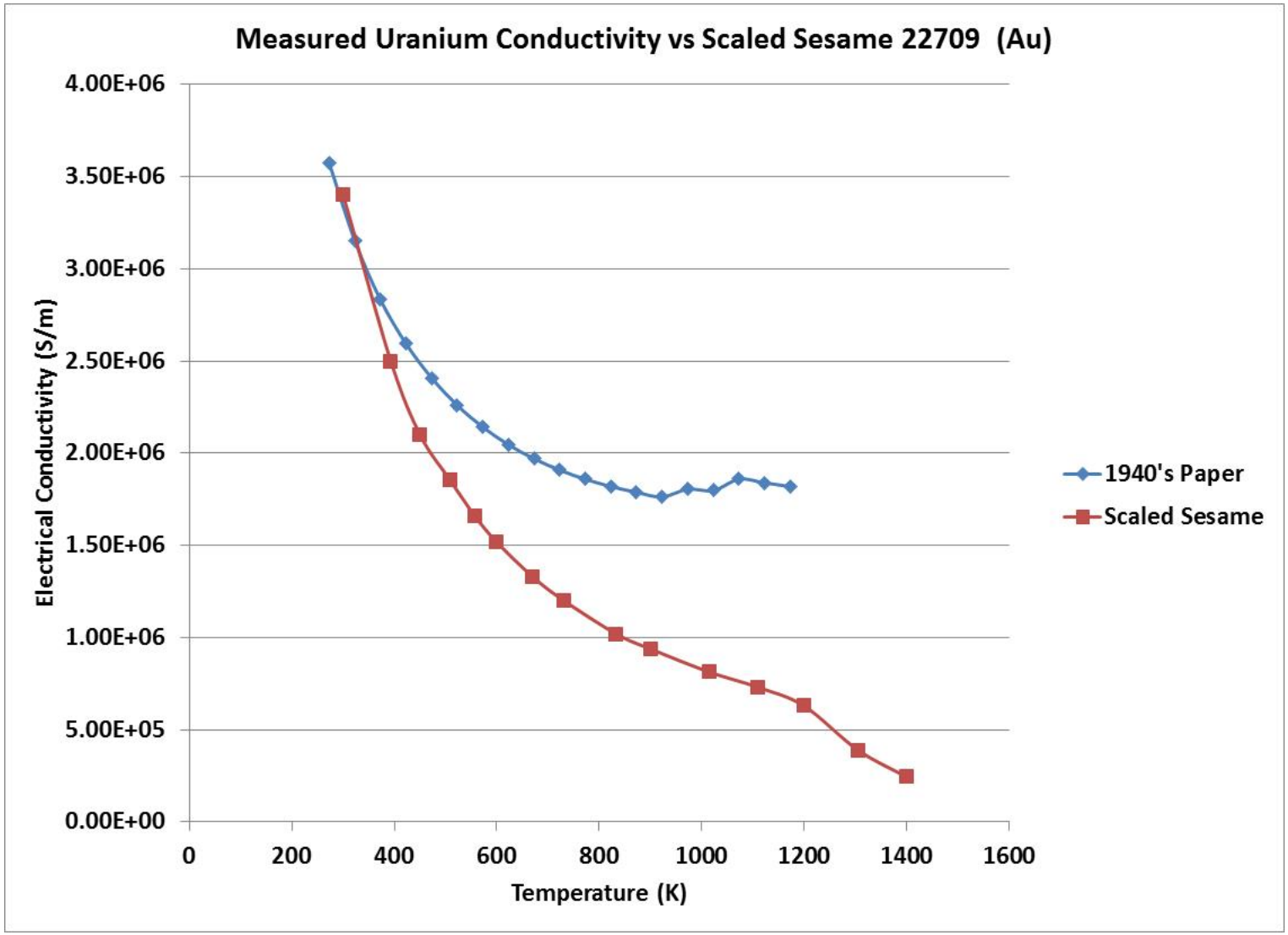


By 500ns gold hohlraum has moved too far and is ridiculously hot (33,000K)

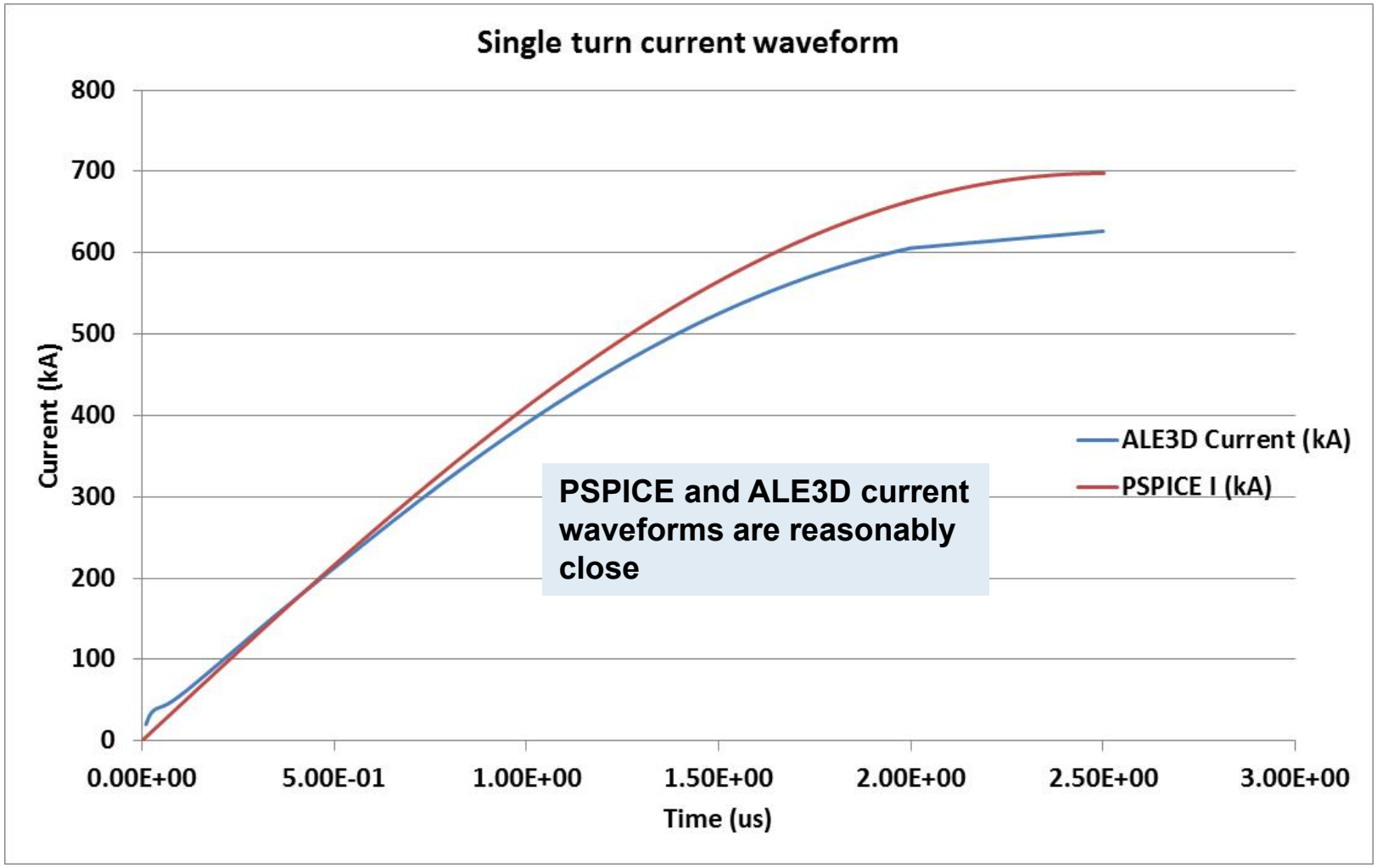




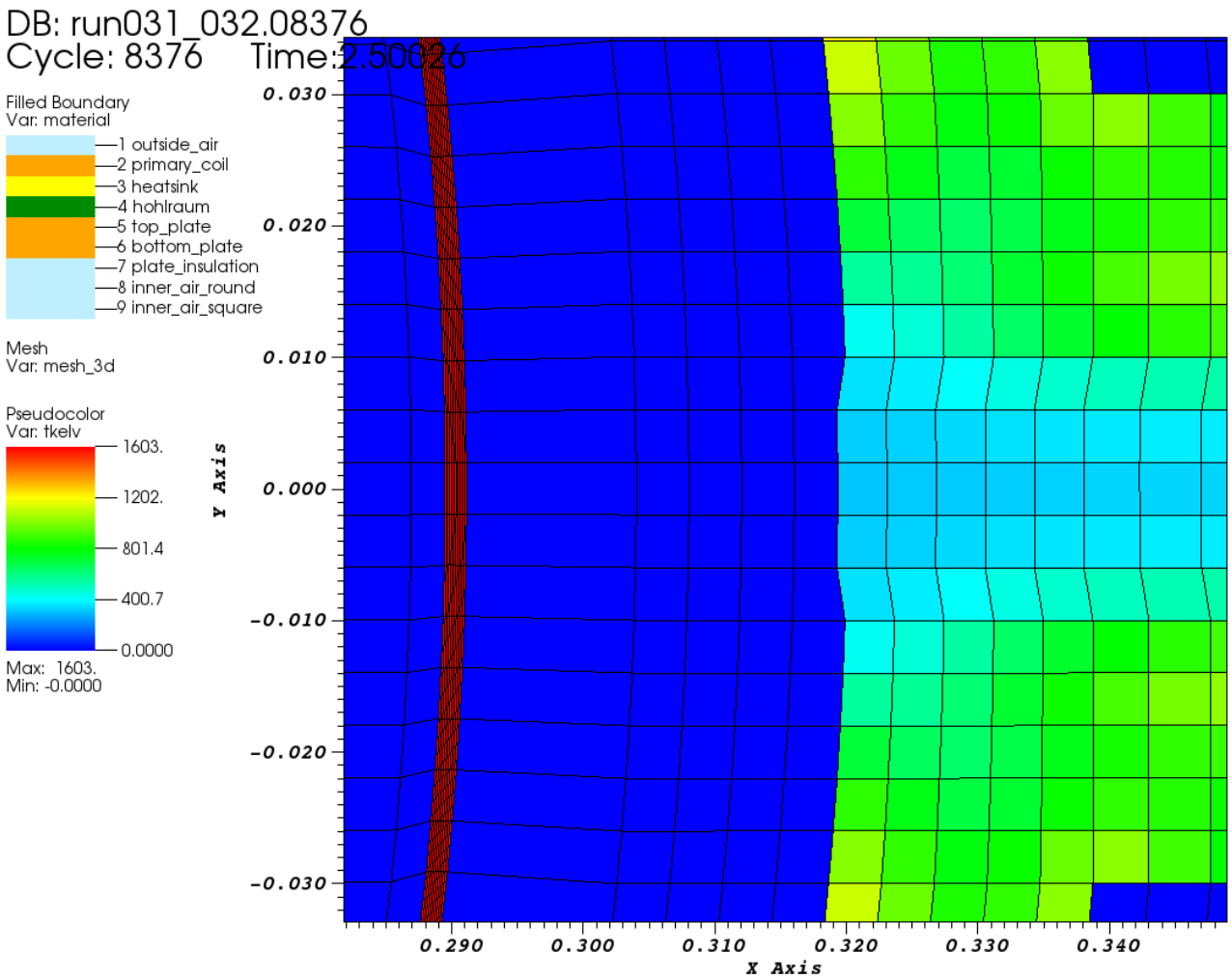
There is surprisingly little data for Uranium electrical conductivity. To model a U hohlraum, we looked at some old conductivity data compared to scaling the Au SESAME table by *.08



Current waveform used for U hohlraum model



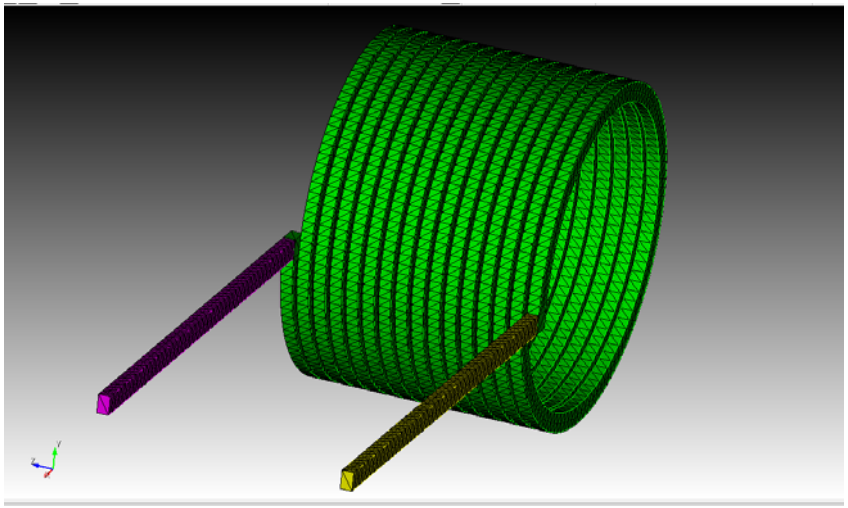
After 2.5us, hohlraum is at 1600K and has moved 100um. This is passed melt for Uranium and maybe moved too far.



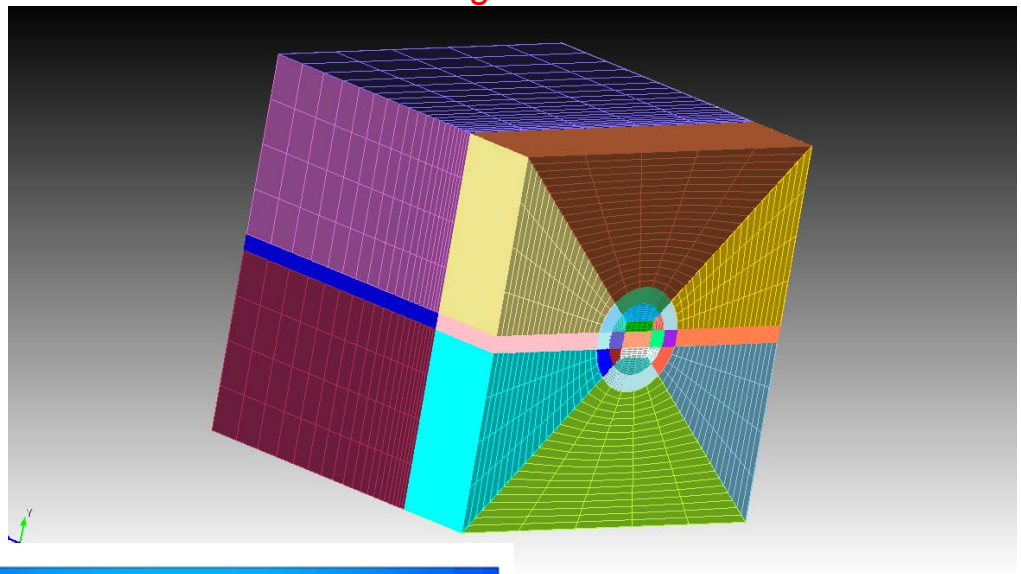
Maybe we should consider non metallic hohlraum materials

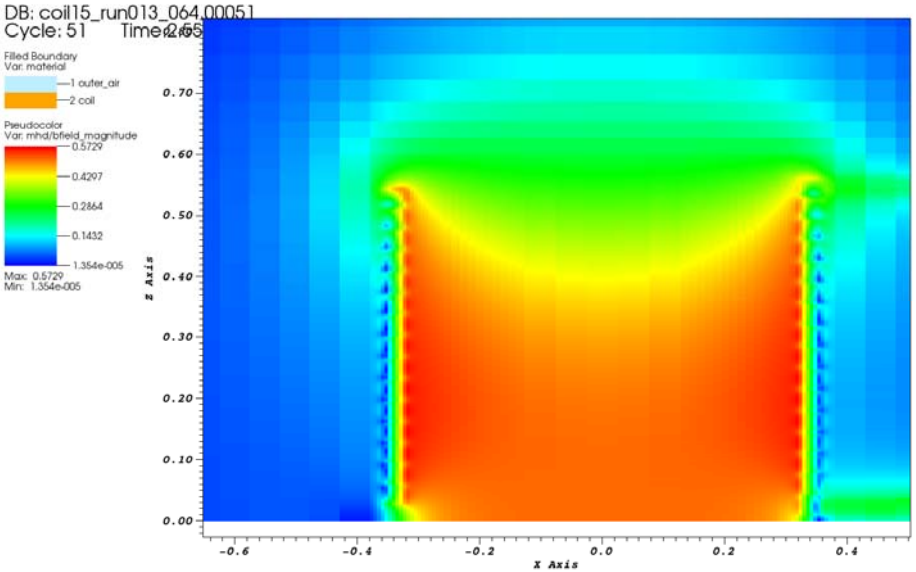
We have developed a full ALE 3D model for the hohlraum coils. So far we have only used it to check the magnetics but we can turn on hydro and strength, if needed

coil



Surrounding mesh

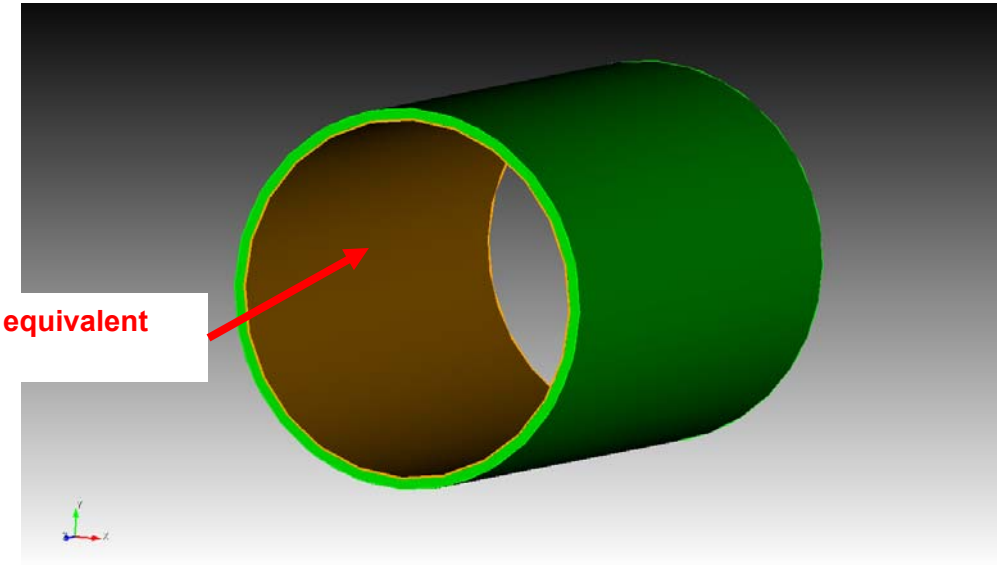




Field plot gives the expected field

Both ALE3D and the simpler PSPICE model suggest we can get to 50T without melting the wire. What about containing the coil?

- For now, we are just using a simple pressurized tube model
- 50T produces a pressure of 1000 MPa
- Kevlar composite has a tensile strength of around 3500 MPa. Also looking at Zylon
- For 2mm, tube stress=1600 MPa, so looks OK at 50T anyway



Coil optimization

- Lets say we vary just the wire gauge and wind single layer coils of the same length (10mm) and diameter (6mm). Is there an optimum?

- As wire get bigger, number of turns gets lower, so required current goes up to get the same field.

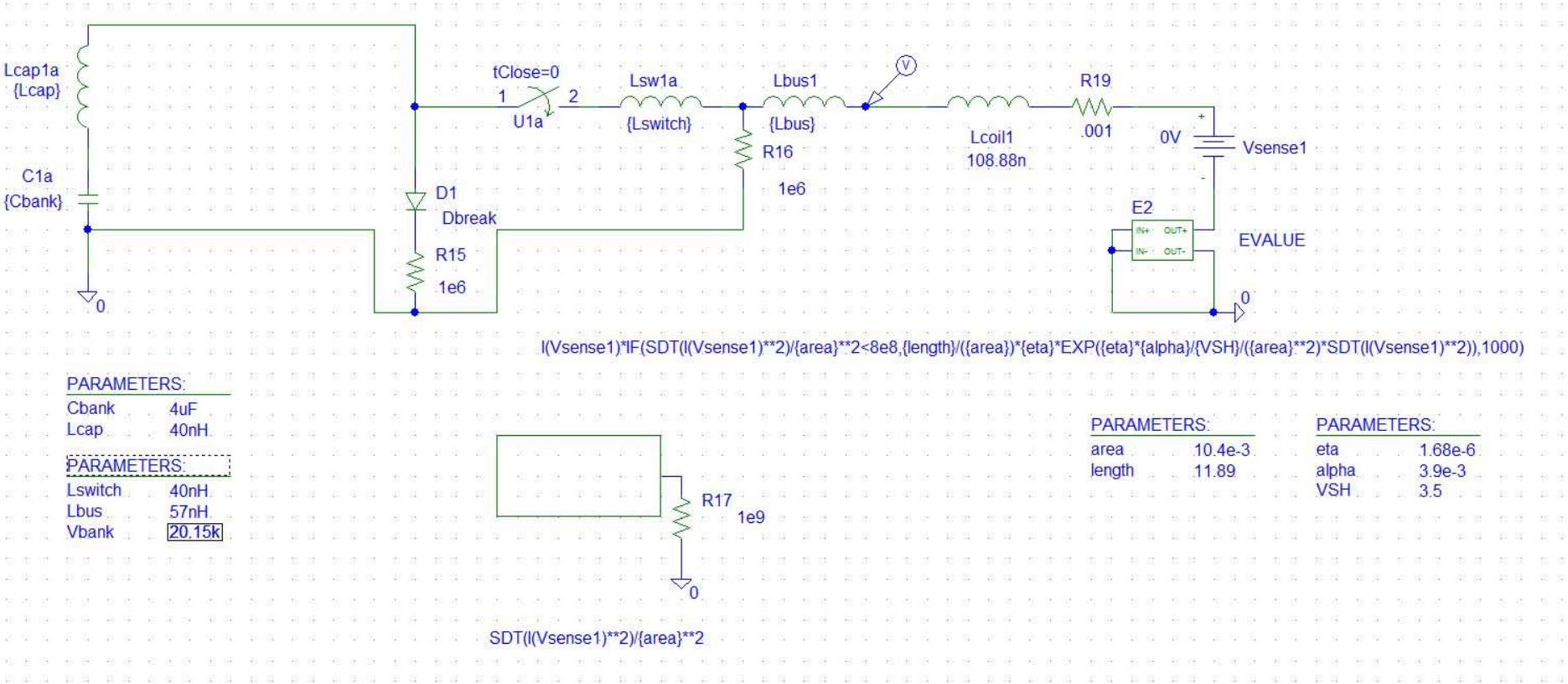
- The wire gets bigger in cross-section and shorter. How does that effect the wire temperature at peak field (specific action)? Do we win with bigger or smaller wire?

- What about voltage breakdown between turns. Lots of competing effects
  - Bigger wire leads to fewer turns so maybe more volts per turn
  - but voltage division with fixed upstream inductance tends to reduce voltage on the coil
  - Larger wire also has lower field enhancement

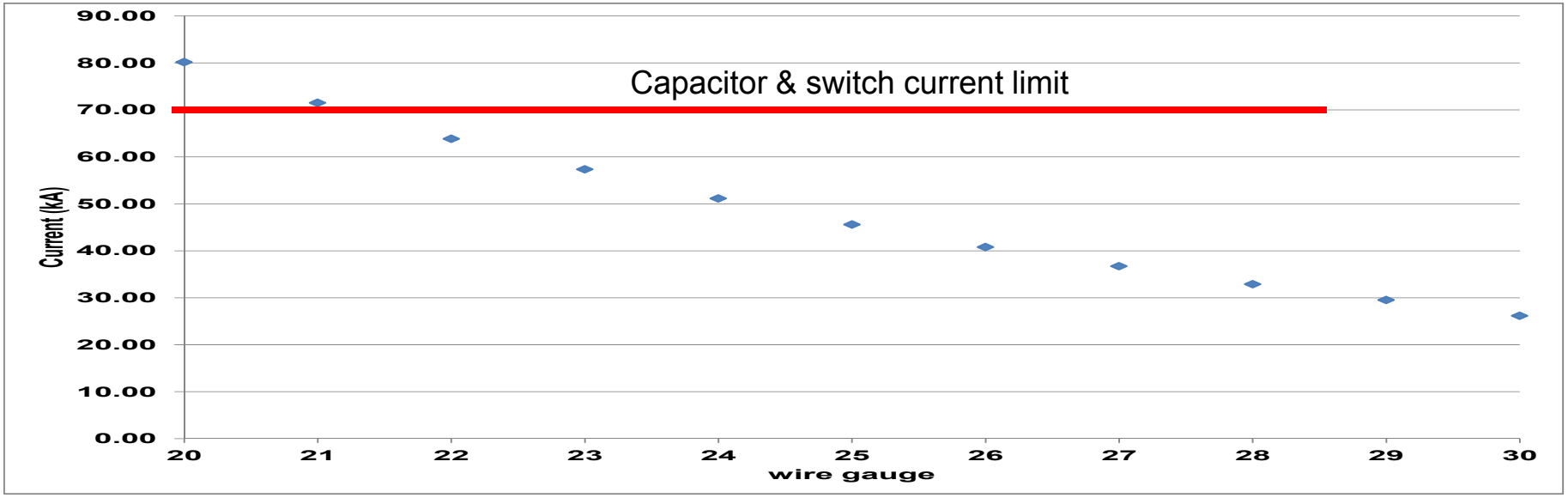
Some wire dimensional details

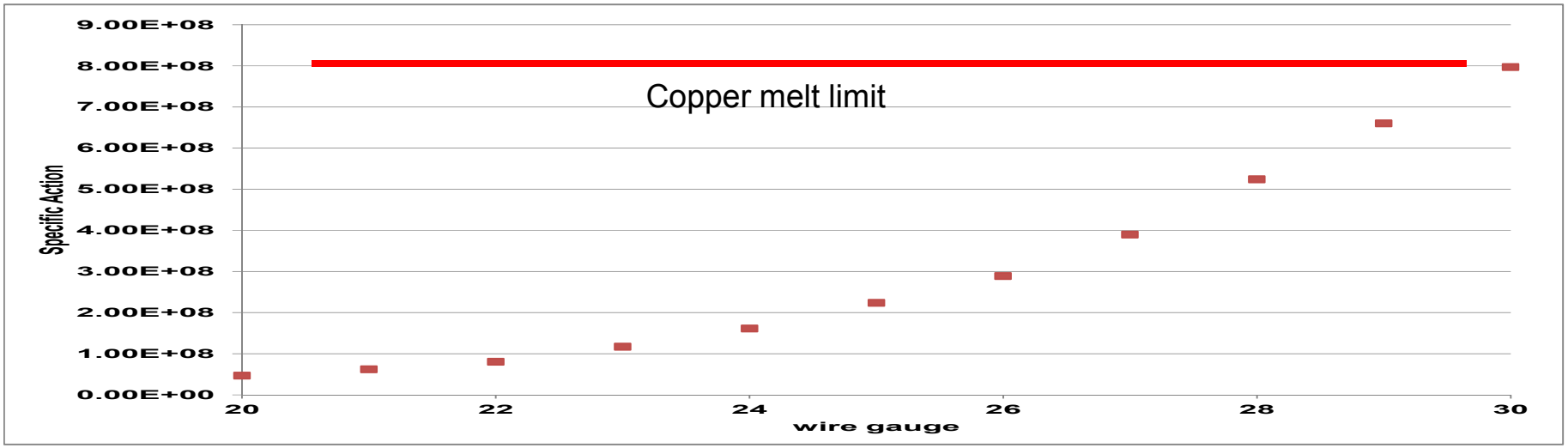
wire gauge	full dia (in)	wire dia (in)	insulation (mil)
30	0.0109	0.01	0.45
29	0.0123	0.0113	0.5
28	0.0137	0.0126	0.55
27	0.0153	0.0142	0.55
26	0.017	0.0159	0.55
25	0.019	0.0177	0.65
24	0.0213	0.0199	0.7
23	0.0239	0.0224	0.75
22	0.0266	0.0253	0.65
21	0.0298	0.0285	0.65
20	0.0334	0.032	0.7

Here is the circuit model used to see how things vary with wire gauge.

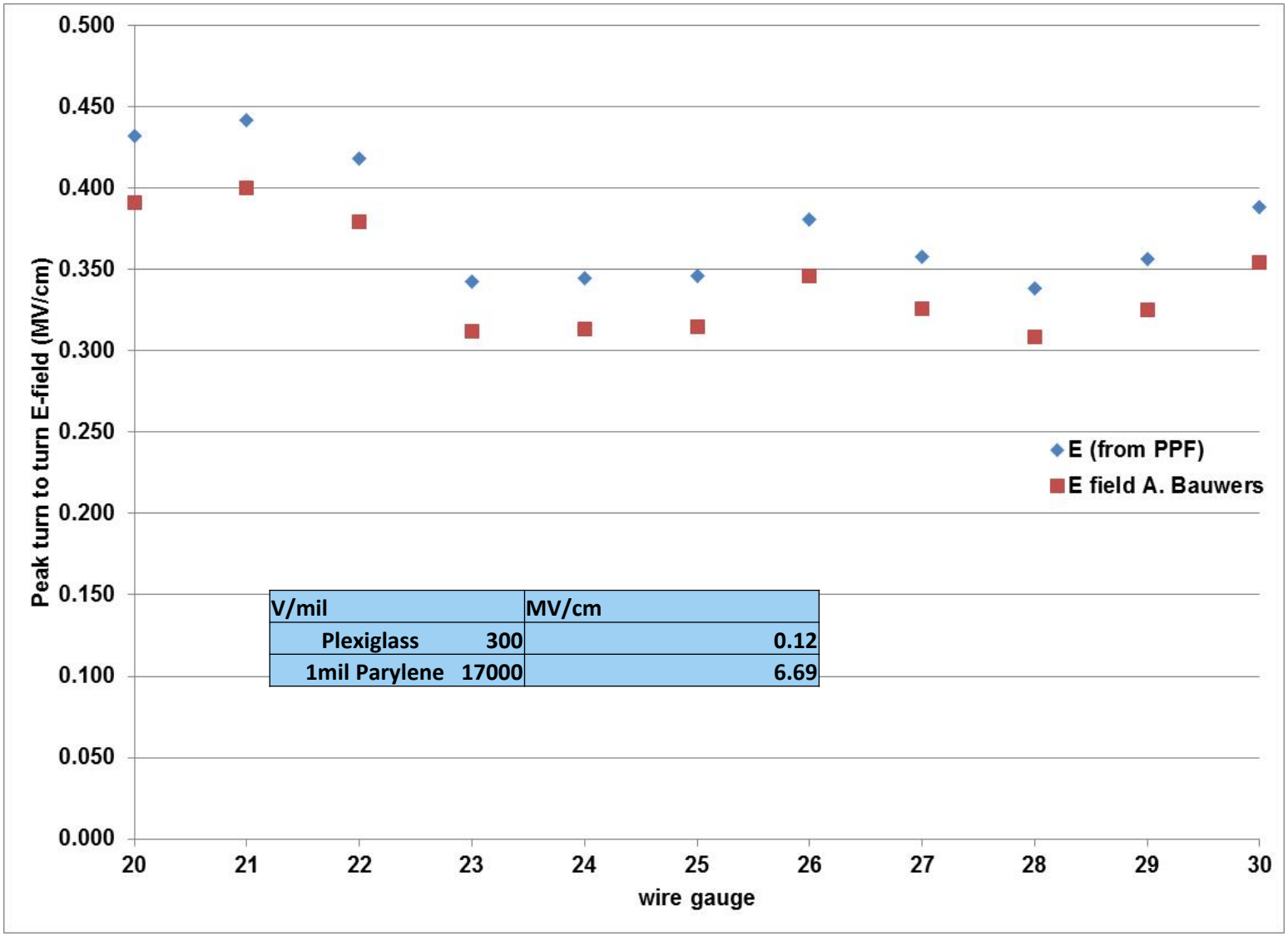


Current and Action vs wire gauge for 50T





Turn to turn E-field slightly favors medium to small wire. Thin polymer films good to 4 MV/cm so we have almost 10x margin even for largest wire.



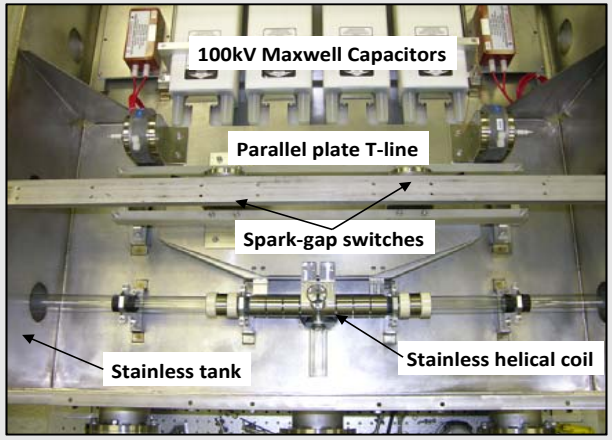
V/mil		MV/cm
Plexiglass	300	0.12
1mil Parylene	17000	6.69

What about higher fields?

- At 70T you need more amp-turns. The optimum wire size get smaller (24-25 gauge) and runs closer to the action limit.

- At 100T there is no wire size that stays below both the cururent limit and the action-to-melt.
  - For example, 28-gauge wire would produce 100T with 65kA but the action would be 1.3e9
  - Do we need to stay below melt? We really don’t know. Experiments!
  - Or we would need a different pulsed power system to operate at more than 70kA

We are re-purposing an existing facility to test coil designs



- **Originally built as the LIFE Xenon Theta Pinch**
- **Containment tank, capacitors, HVPS, fast scopes, vacuum, etc. all on hand**

Conclusion

- In the first year of a new LDRD for magnetizing NIF shots, we have made substantial progress
- We developed concepts for targets mounted to either the DIM or TARPOS. We invented the inductive coupling scheme for the TARPOS version. In both cases, the pulsed power supply is in the DIM
- We used ALE3D to study hohlraum heating by induced current and identified this as a potentially serious problem.
- We developed a full 3D model of one coil design in ALE3D which could be extended to look at containment but a simpler pressurized tube is probably good enough
- We developed a scheme to optimize the coil design finding that using the largest wire possible while staying below the rated capacitor current leads to the least specific action. The breakdown voltage between turns looks manageable.
- We are starting prototype experiments as we speak