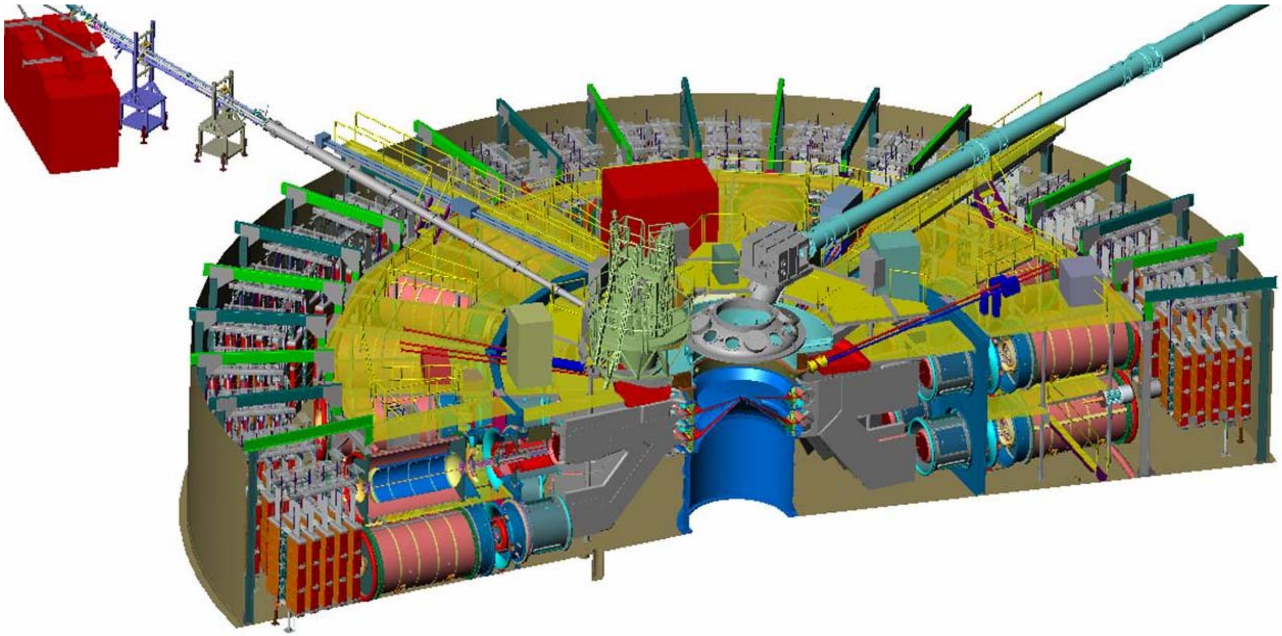
ZR Completion and Status



Drs. Dillon H. McDaniel, Ed Weinbrecht, Mark Savage, Keith LeChien, and Tim Pointon

Workshop and Expert Meeting

On Dense Magnetized Plasmas

ICDMP, Warsaw

December 3 to 4, 2007

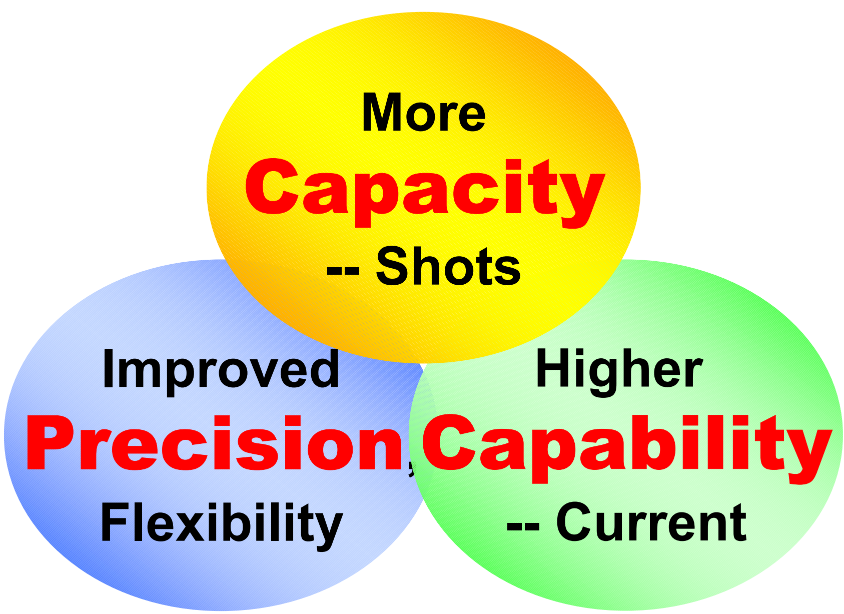
Sandia is a multi-program laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under contract DE-AC04-94AL85000.

Completing and commissioning of ZR was a large effort

L. F. Bennett, D. E. Bliss, W. T. Clark, R.S. Coats, J. M. Elizondo, K. R. LeChien, H. C. Harjes, J. M. Lehr, R.W.Lemke, J. E. Maenchen, D. H. McDaniel, M.F. Pasik, T. D. Pointon, A. C. Owen, D. B. Seidel, D. L. Smith, B. S. Stoltzfus, K. W. Struve, W.A. Stygar, L.K. Warne, L.L. Whinnery, J. R. Woodworth, C. W. Mendel, K.R. Prestwich, R. W. Shoup, D. L. Johnson, V. Anaya, J. P. Corley, G. Feltz, D. Guthrie, K. C. Hodge, J. Lott, T. C Wagoner, P. E. Wakeland

ZR Objectives

- **Extend lifetime and utility of *Z*.**
  - **Increase** shot capacity **to meet demands.**
  - **Increase** precision **for high quality data for code validation.**
  - **Increase** current capability **to meet future temperature, x-ray power and energy, and equation of state requirements.**
- **Exercise SNL's pulsed power research and engineering capabilities – prepare the next generation.**



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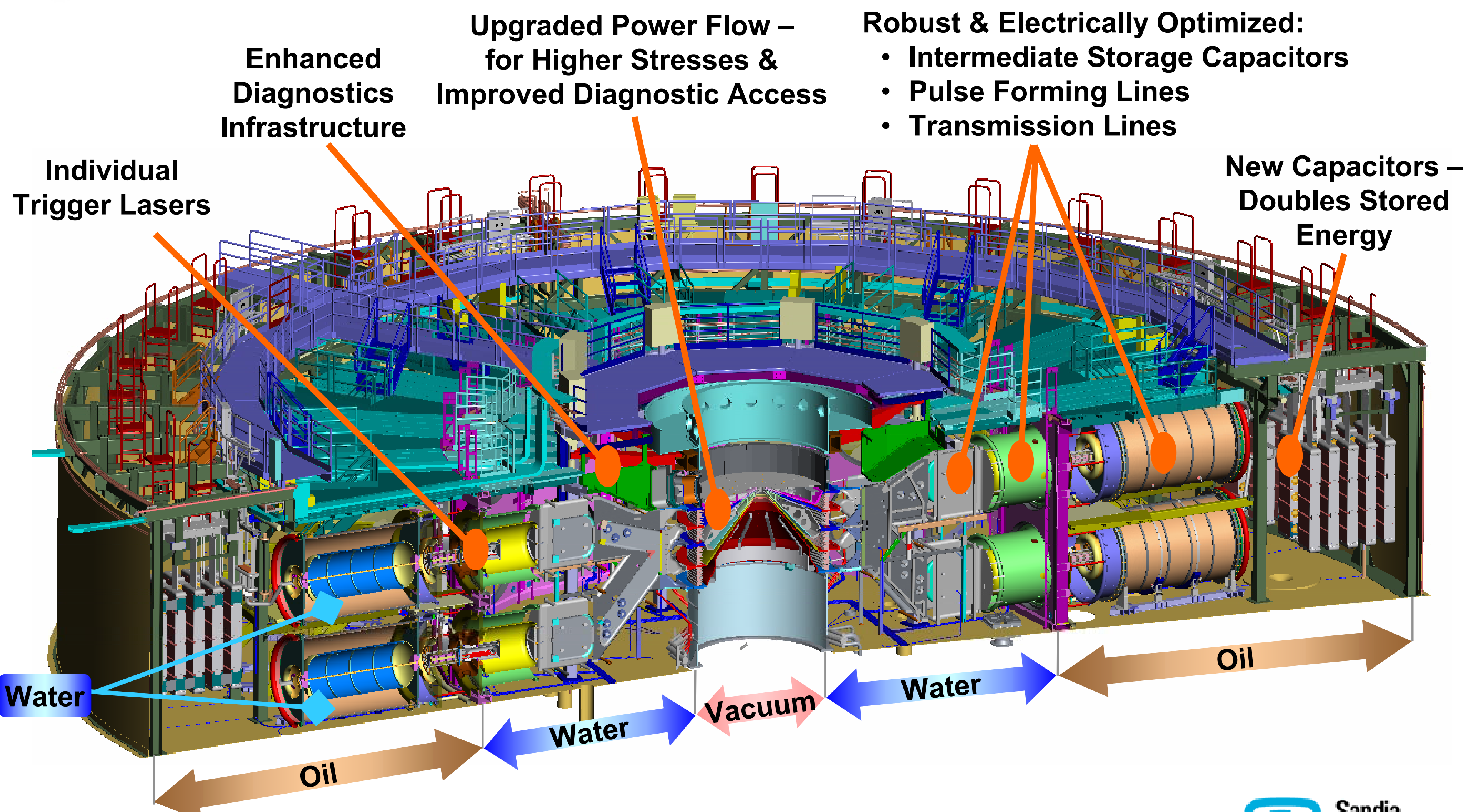
Refurbished Z, September 2007

First shot anticipated in 8/07 – robust user facility



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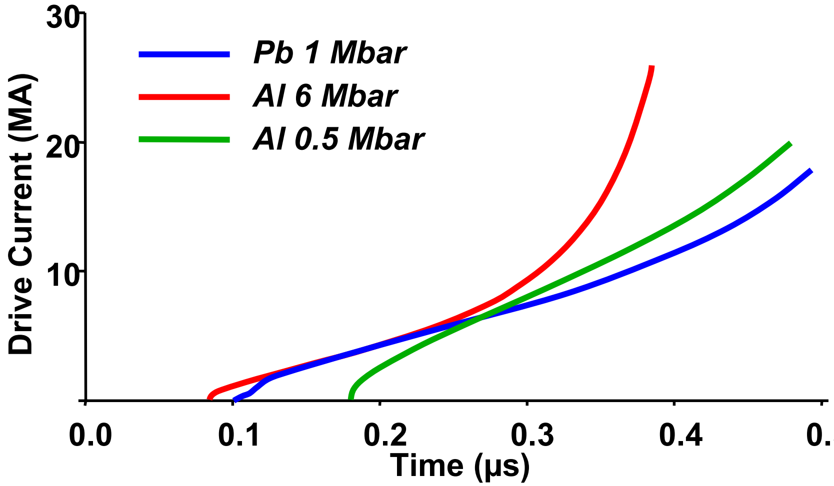
Experimental Benefits

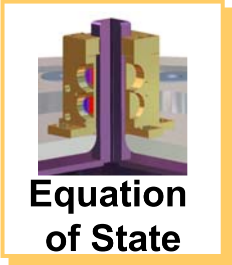
Precision & pulse flexibility will enable:

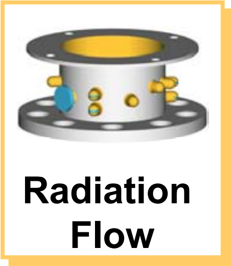
- ***New experimental regimes***
- ***Improved timing with Z Backlighter and Z Petawatt***



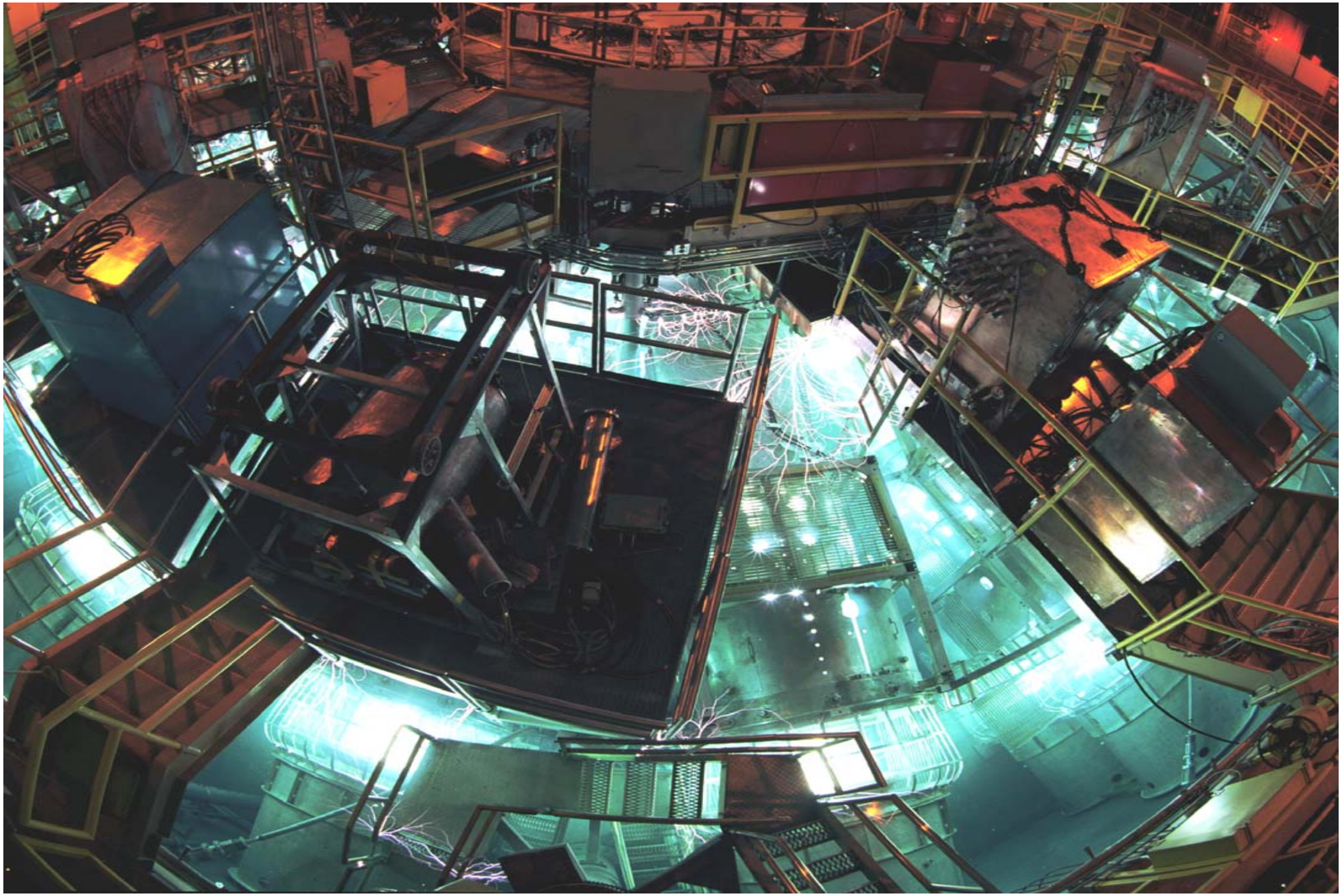
Over *Z*, more current will enable up to:

- ***50% increase - power radiated***
- ***70% increase - energy radiated***
- ***15-20% increase - temperature***
- ***3x increase - peak ICE pressure***
- ***40% increase - flyer plate velocity***





Last *Z* Shot – July 26, 2006



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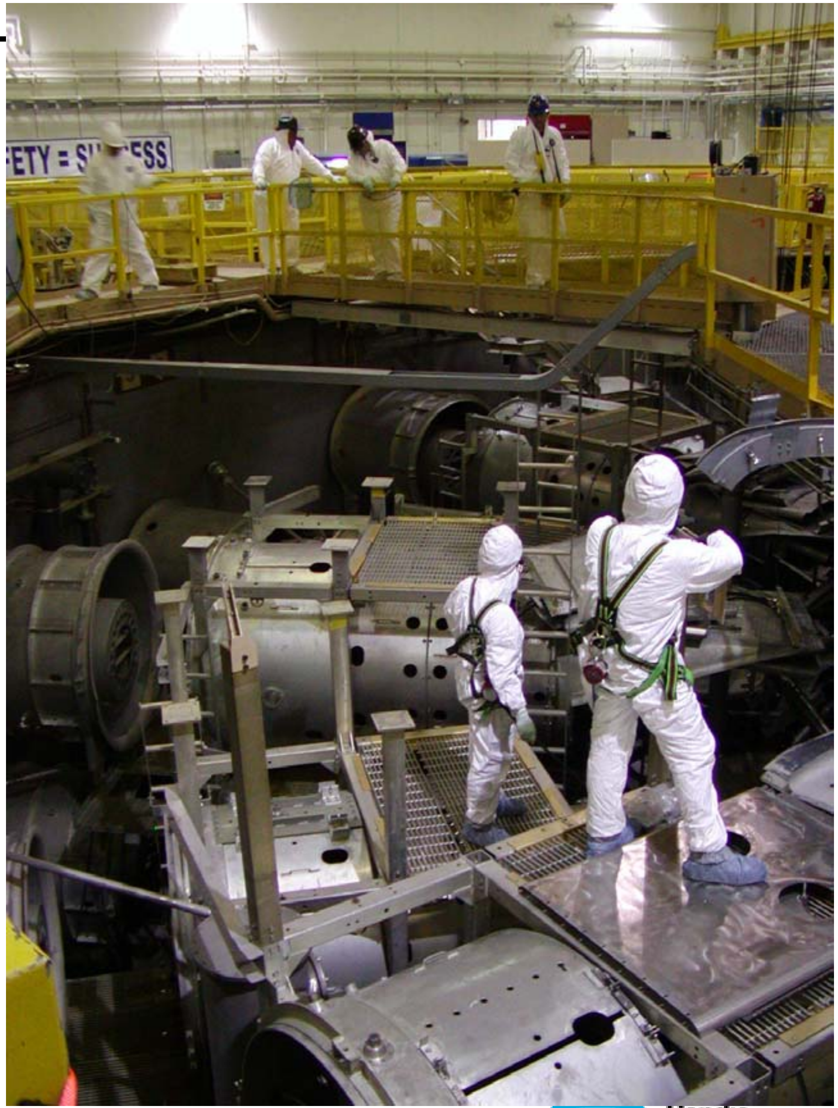
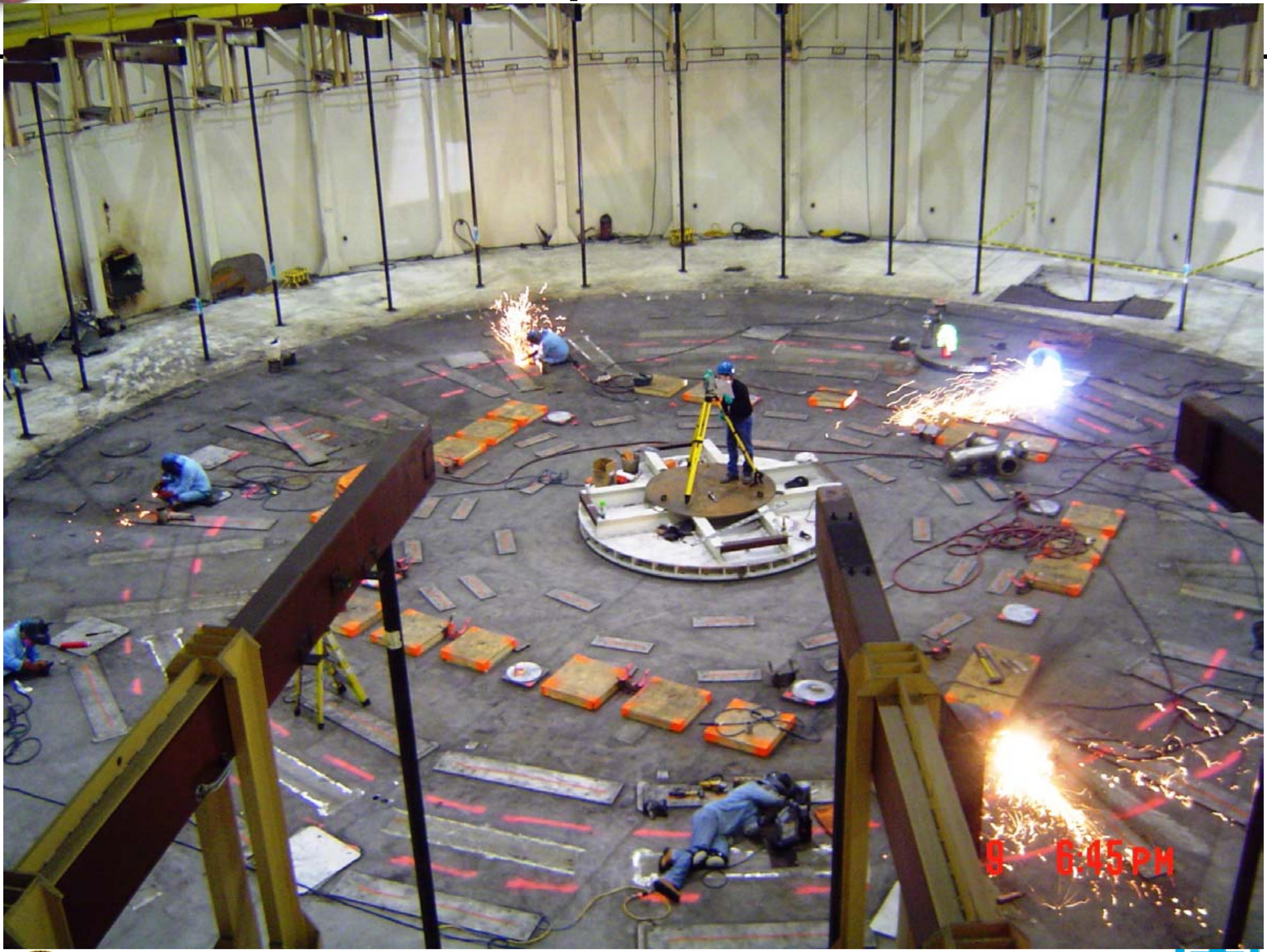
August 2, 2006



August 28, 2006

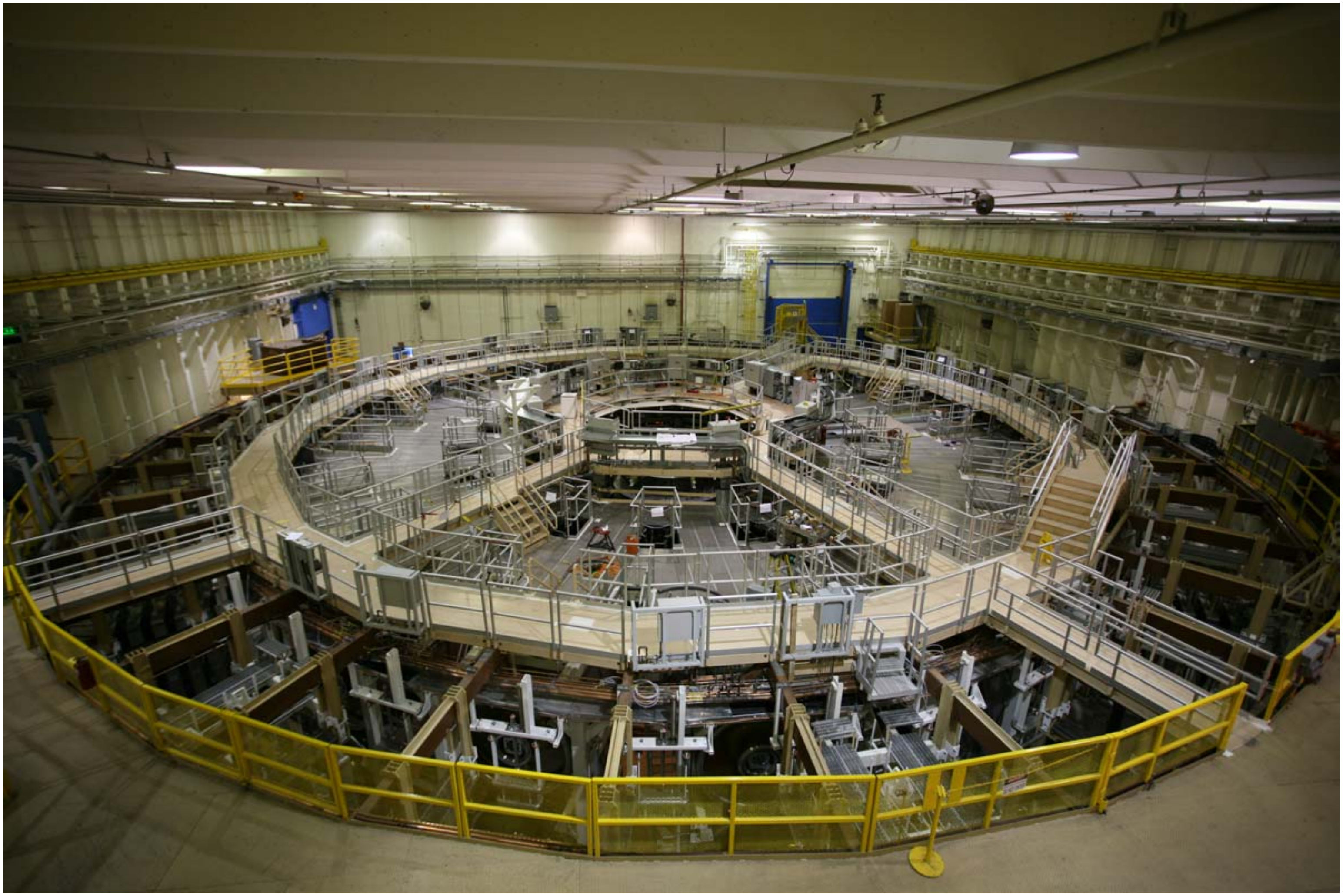
September 18, 2006

September 9, 2006

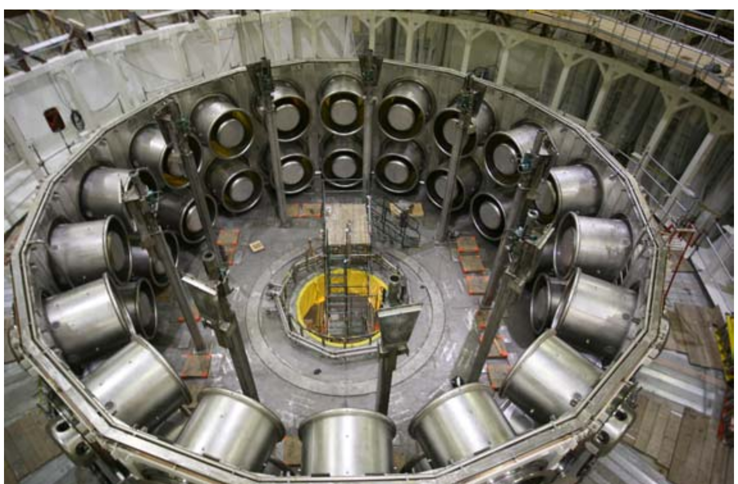


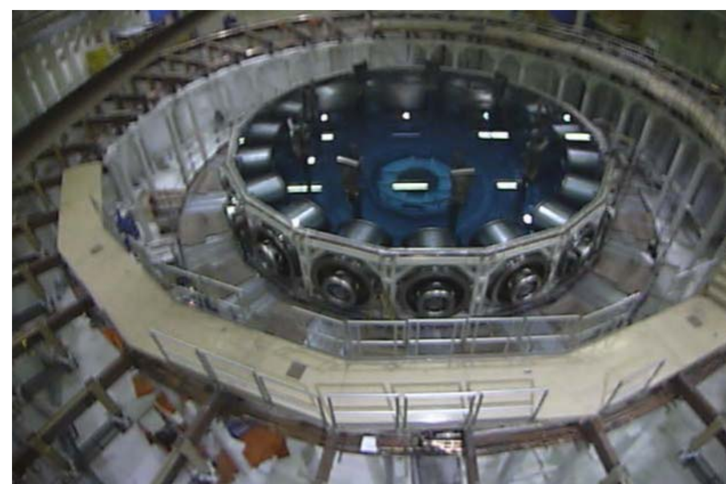
January 26, 2007

June 6, 2007

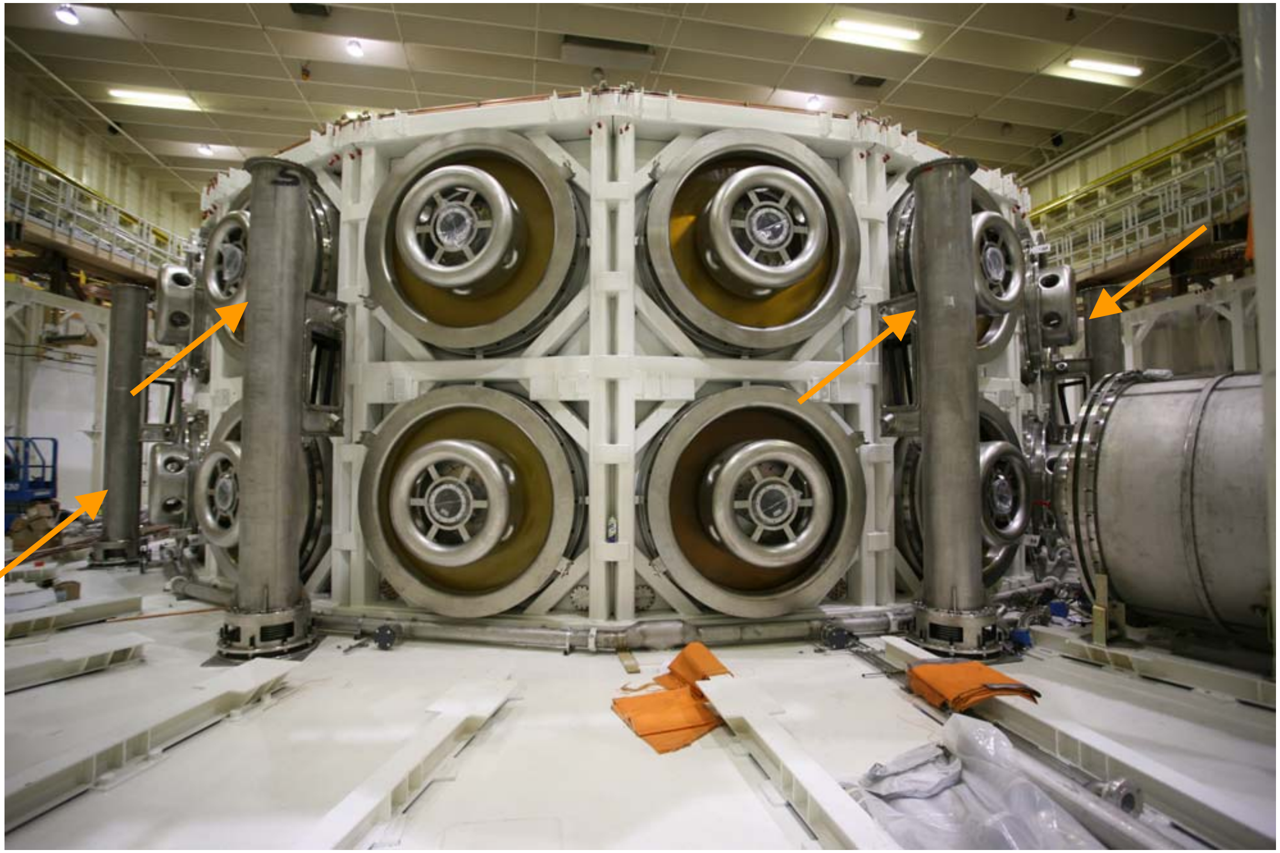


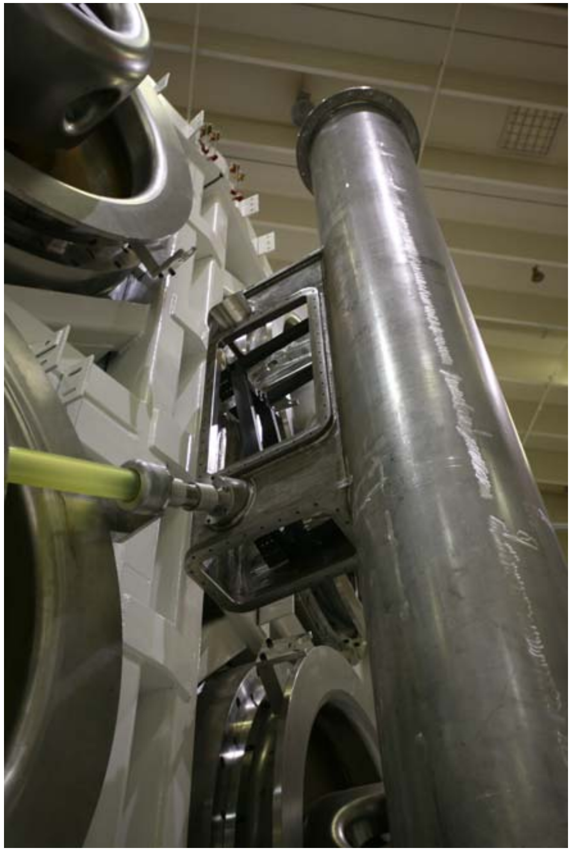
Pulse Forming Lines



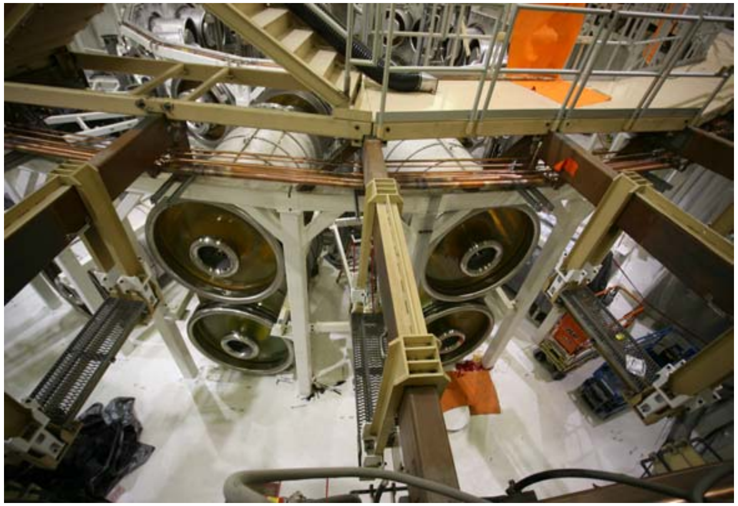


Laser Trigger System Infrastructure





Intermediate Storage Capacitors



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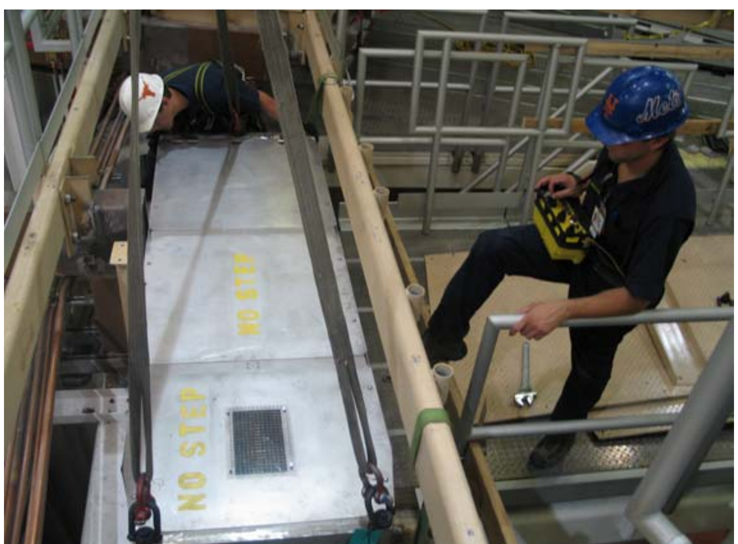
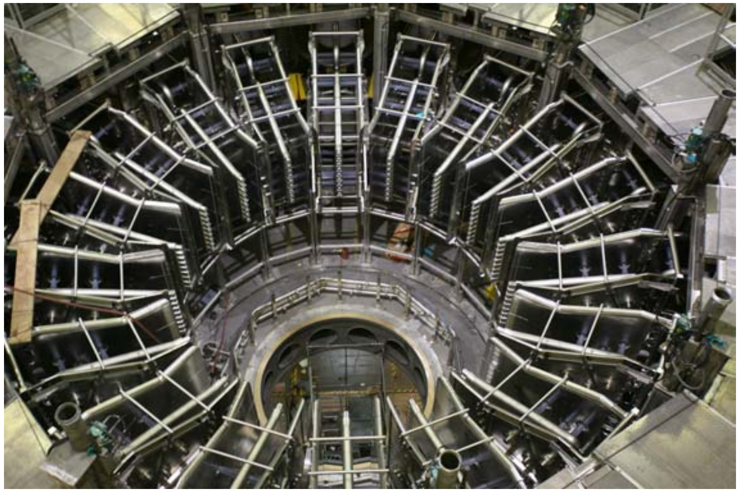
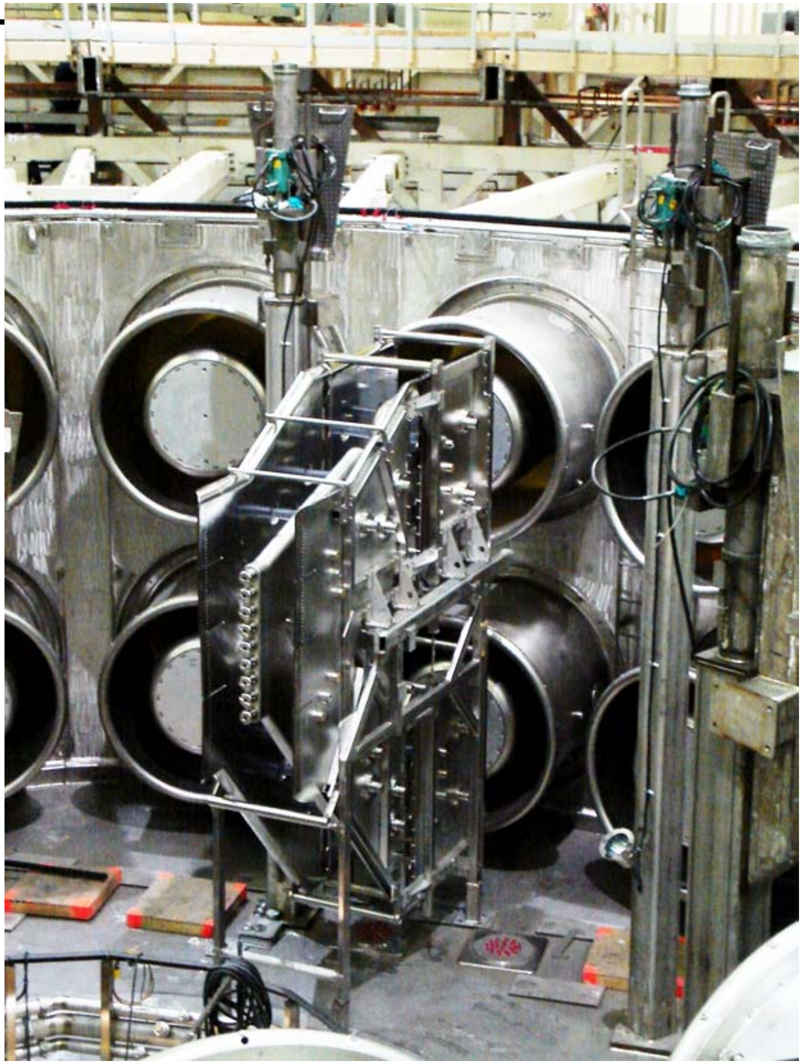
Marx Generators, Energy Diverters, and Marx Trigger Systems

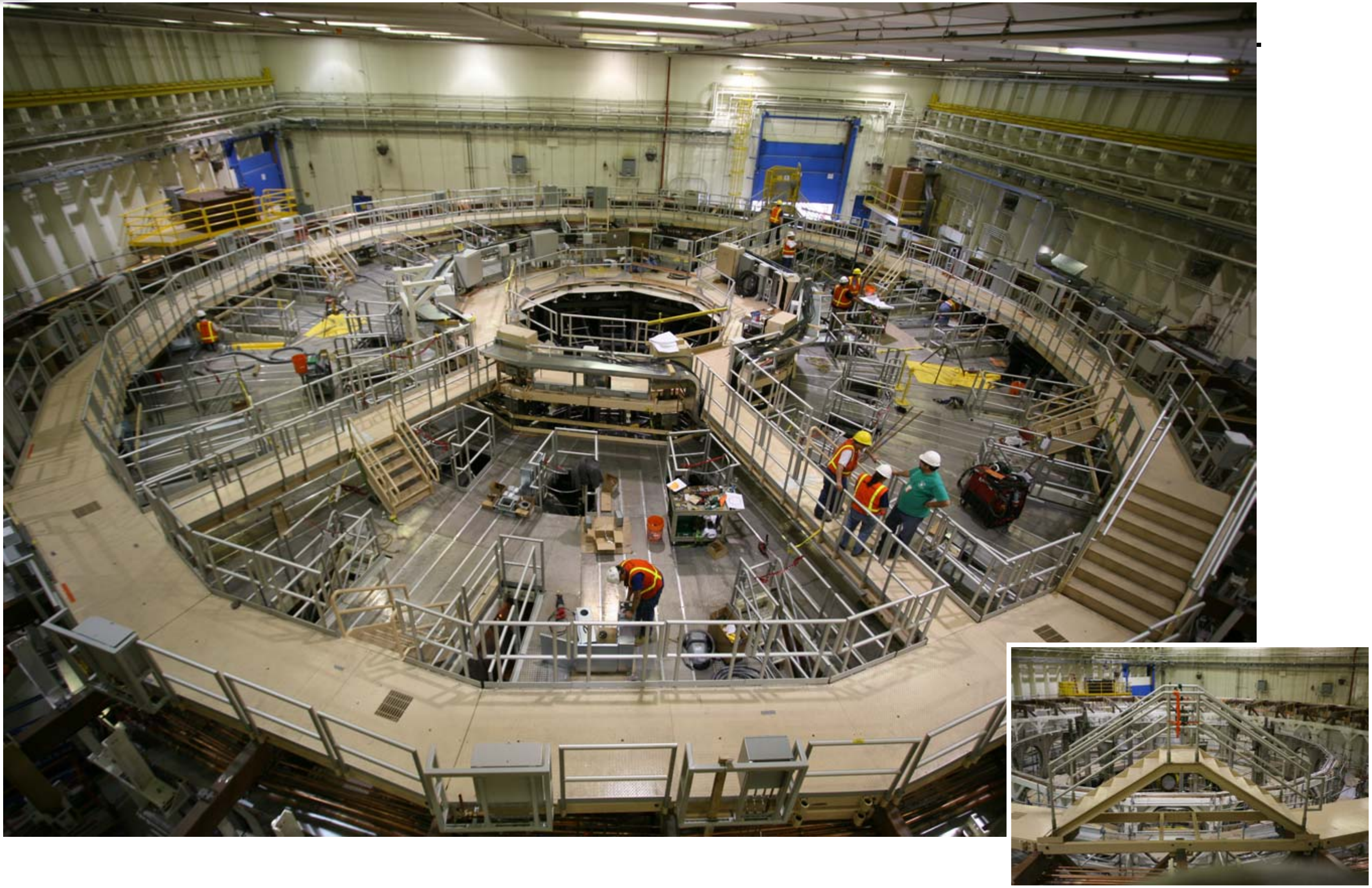


Output Transmission Lines



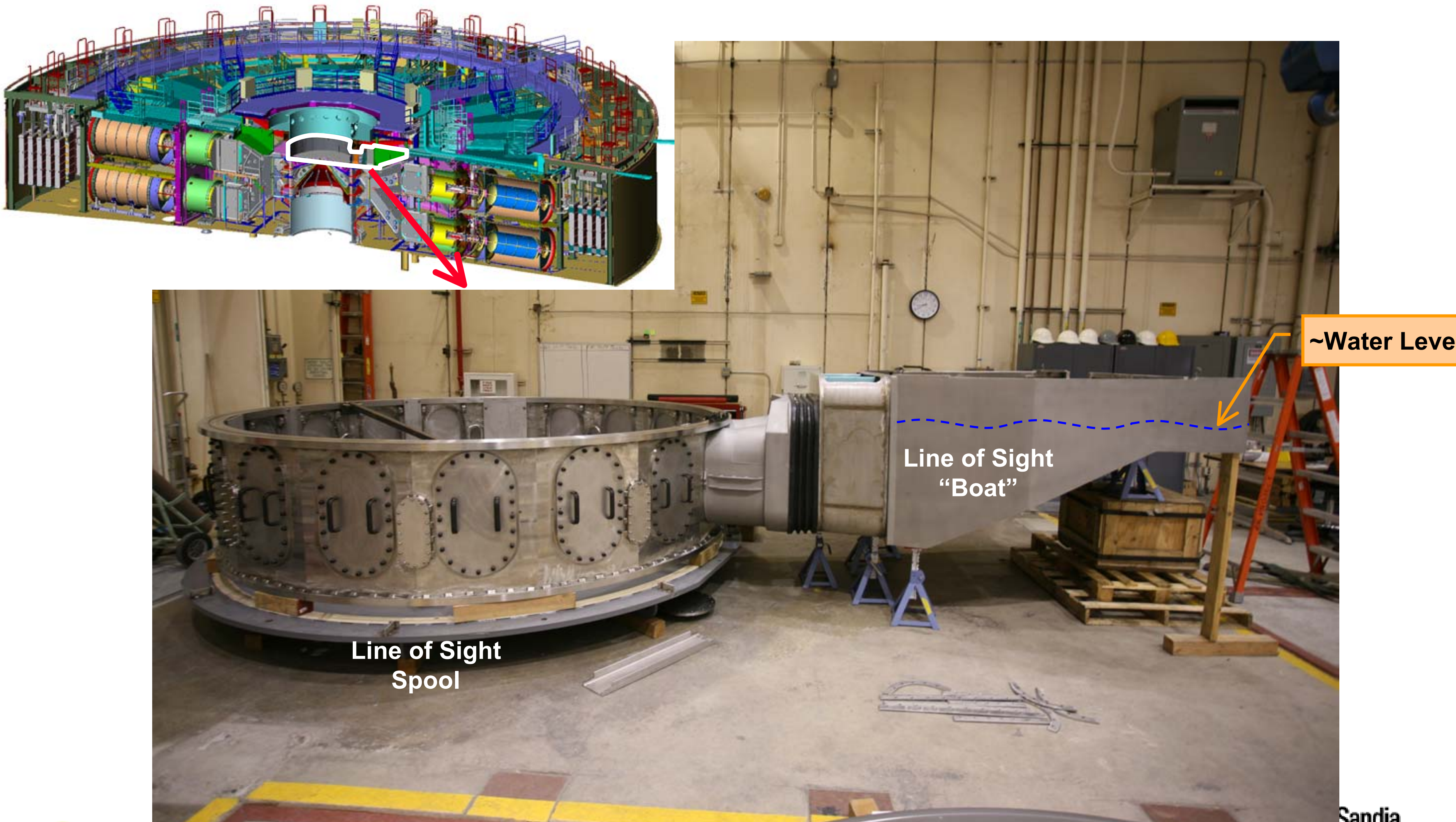


Walkways, Platforms, & Flyovers

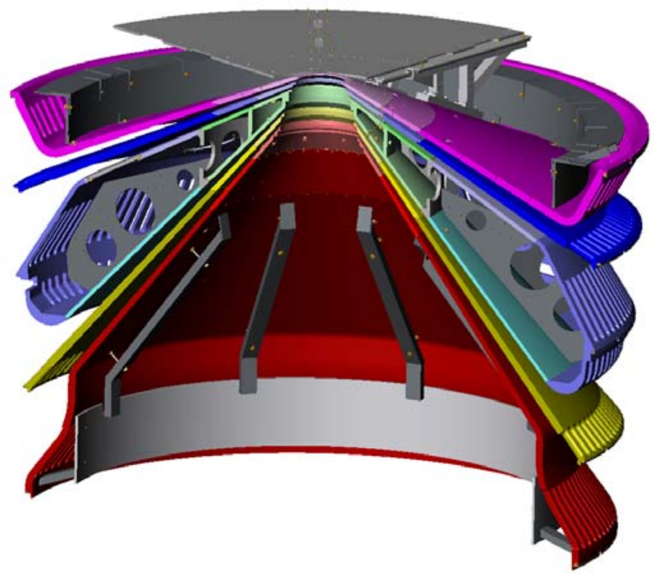


Insulator Stack and Water Convolute

Line of Sight Diagnostic Infrastructure

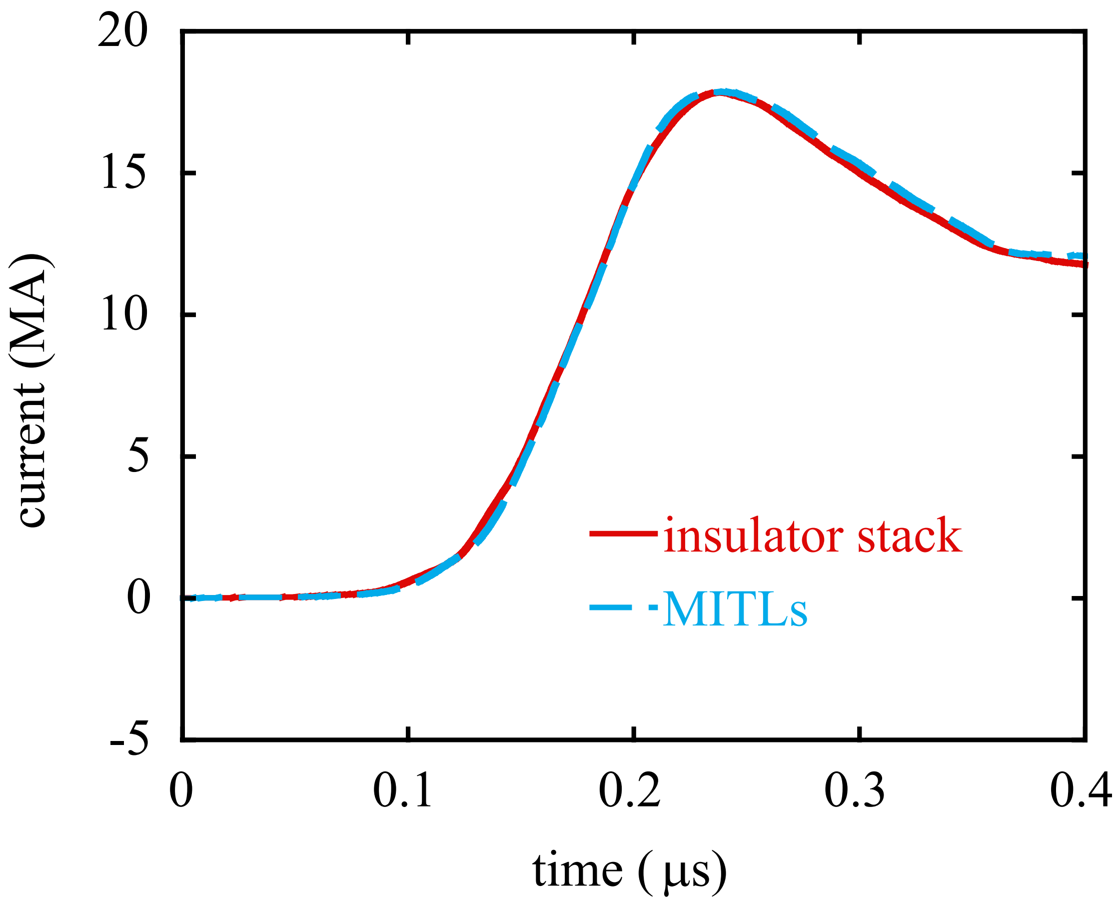


Magnetically Insulated Transmission Lines



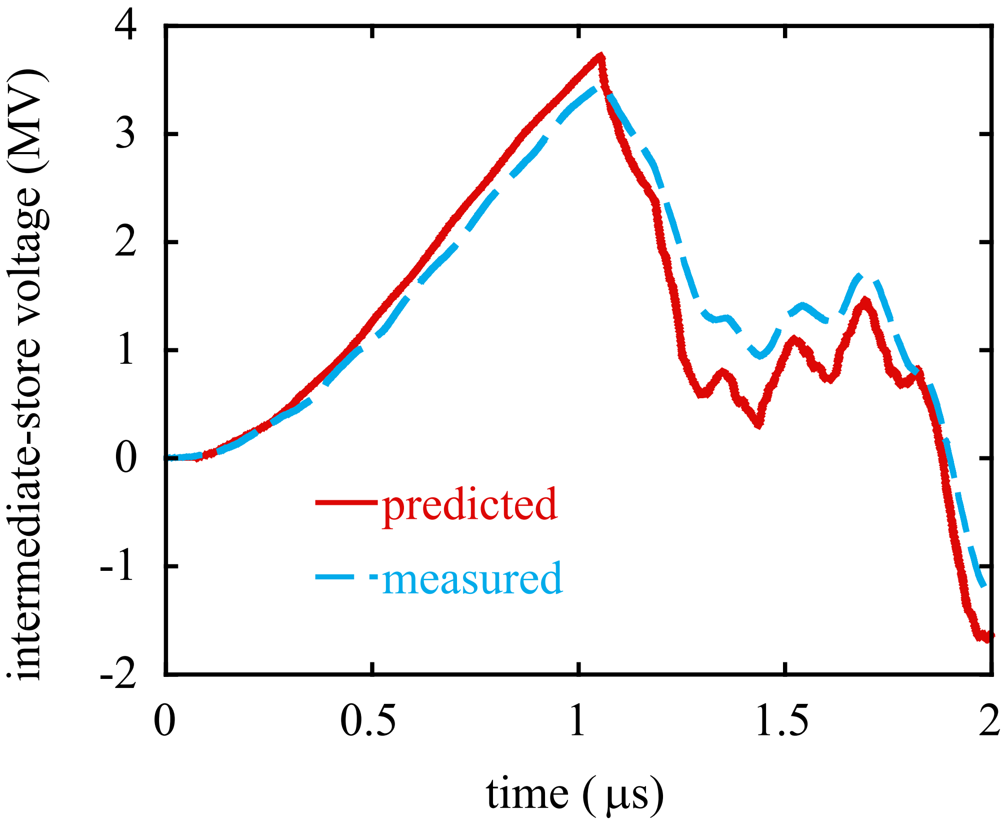
The measured ZR insulator-stack and vacuum transmission line currents agree

As expected, the vacuum insulator stack did not flash, and loss in the magnetically insulated transmission lines is small



Measurements agree with circuit simulation predictions to within reasonable uncertainties

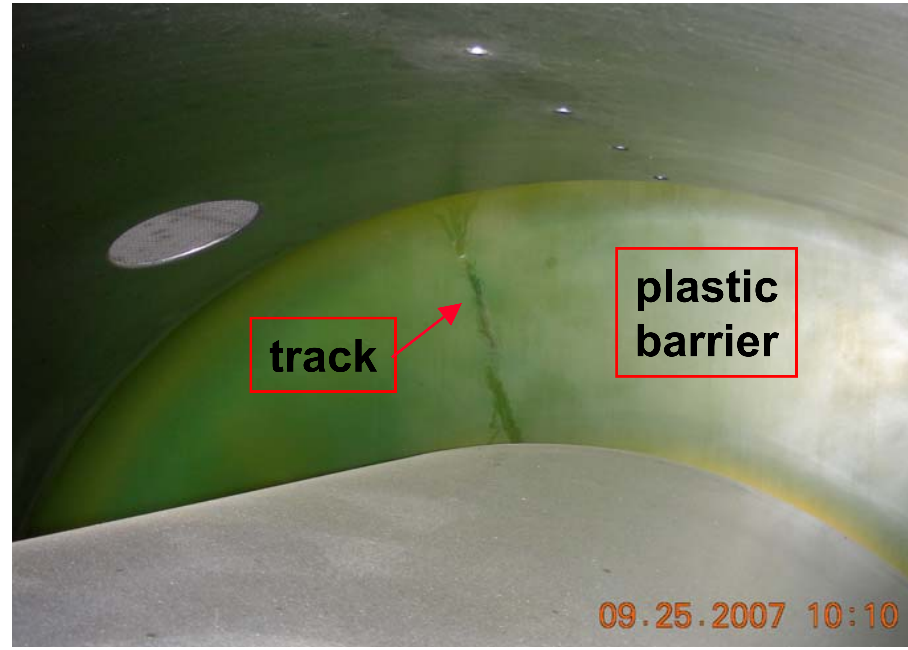
- **We are developing two independent 2D transmission-line circuit models of ZR**
- **We are developing two independent 3D electromagnetic models of the front end of ZR; i.e., two virtual ZR-accelerator models**
- **We are upgrading the power-flow measurements**
- **We expect this work will improve the agreement between modeling and experiment**



Work is in progress to improve both the circuit models and power-flow measurements

The principal issue: debris (from construction) caused the tracking of water-plastic interfaces

- 28 insulator rods (out of 270 total) tracked on the first ZR shot
- 22 rods tracked on the second
- 2 pulse-forming-line (PFL) oil-water barriers (out of 36) tracked on the second shot
- Work is in progress to make repairs, and remove the debris from the accelerator tank



tracked PFL oil-water barrier

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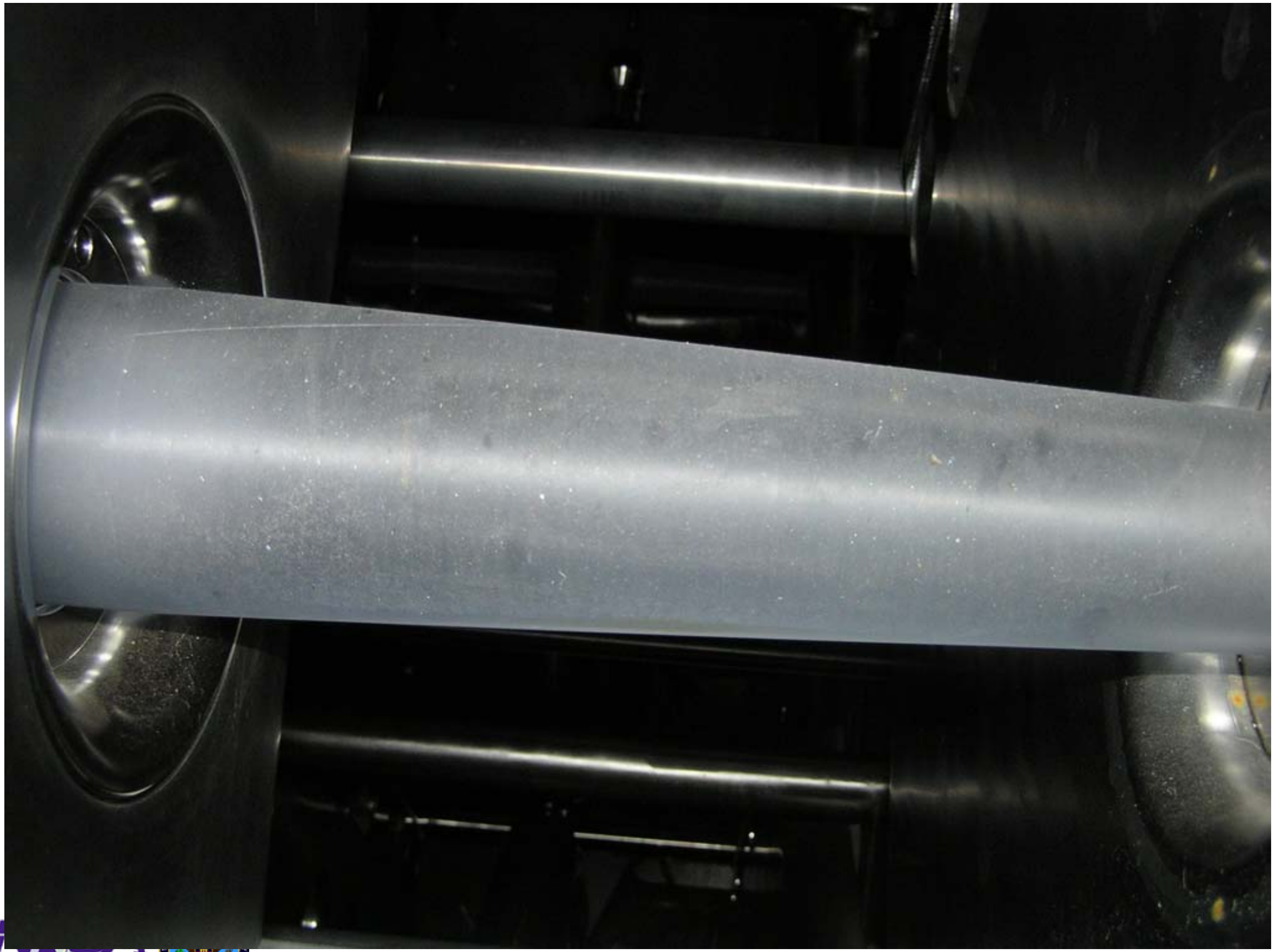
The tracking on the first two shots is not surprising given the amount of debris

- Dust, grinding residue, and solid metal chips are present in the water and oil sections



Debris was shaken down by Marx testing and the first shot

Cleaning is the highest priority at the facility

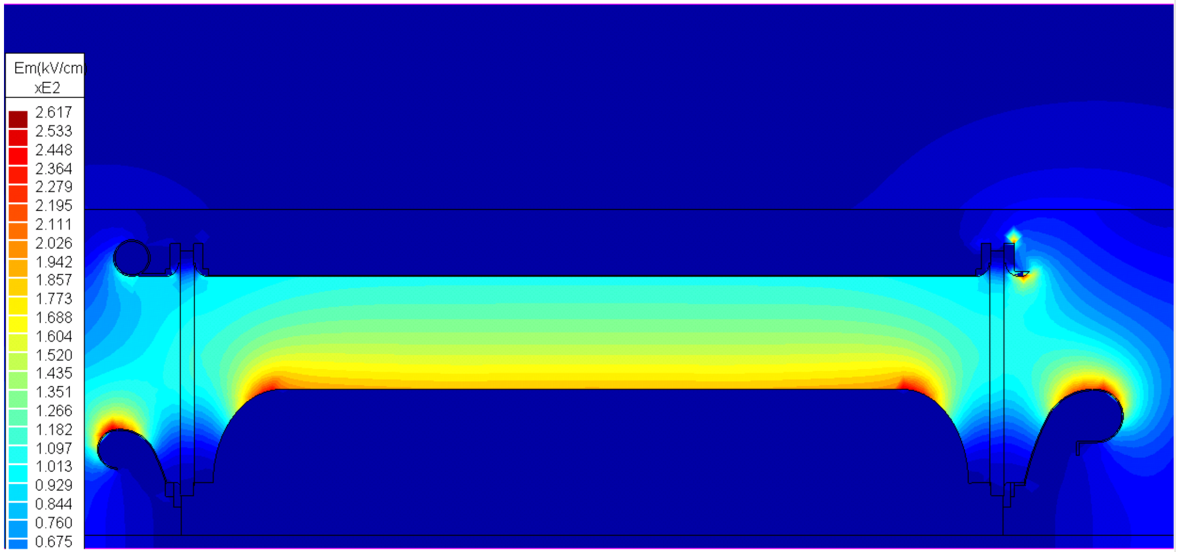
The commissioning of ZR is in progress

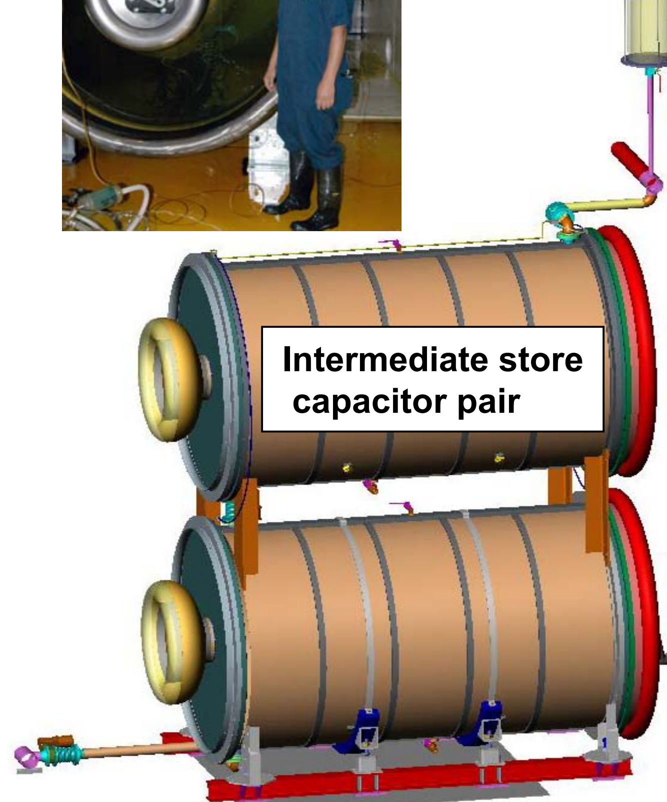
Over the next three months we expect to:

- **Complete the calibration of power-flow diagnostics throughout the accelerator**
- **Conduct large-area insulator-stack-flashover experiments**
- **Install a fast-SF_6-gas-purge system for the gas switches**
- **Gradually increase the Marx-charge voltage from 60 to 82 kV**
- **Perform plutonium-confinement experiments**
- **Conduct an initial set of dynamic-materials experiments**
- **Conduct an initial set of z-pinch-physics experiments**

load hardware for
dynamic-materials experiment

The intermediate store capacitors are reliable at ZR voltages





Breakdown at peak voltage effective time is 0.6 µs at which breakdown V/d is 160 kV/cm (~6.4 MV). Z_{20} intermediate store has survived shots at ~7 MV peak.

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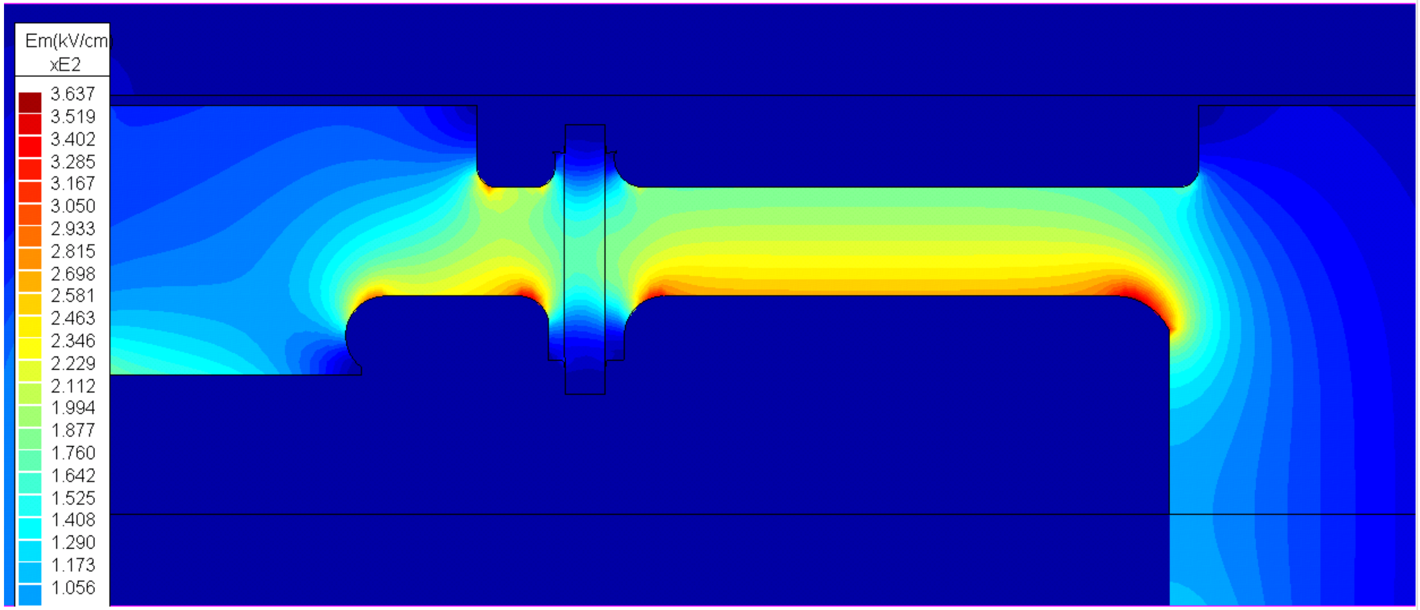
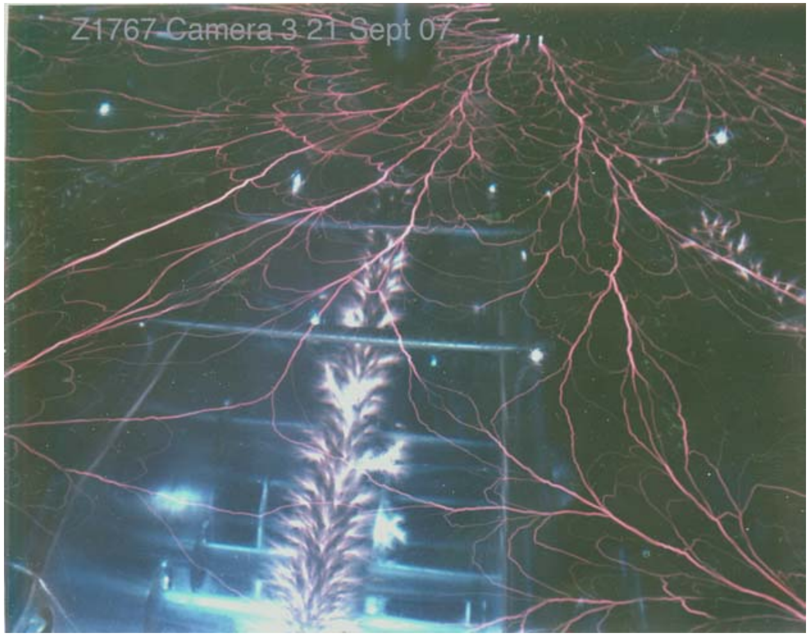
The pulse-forming line charges to ~5 MV in 250 ns

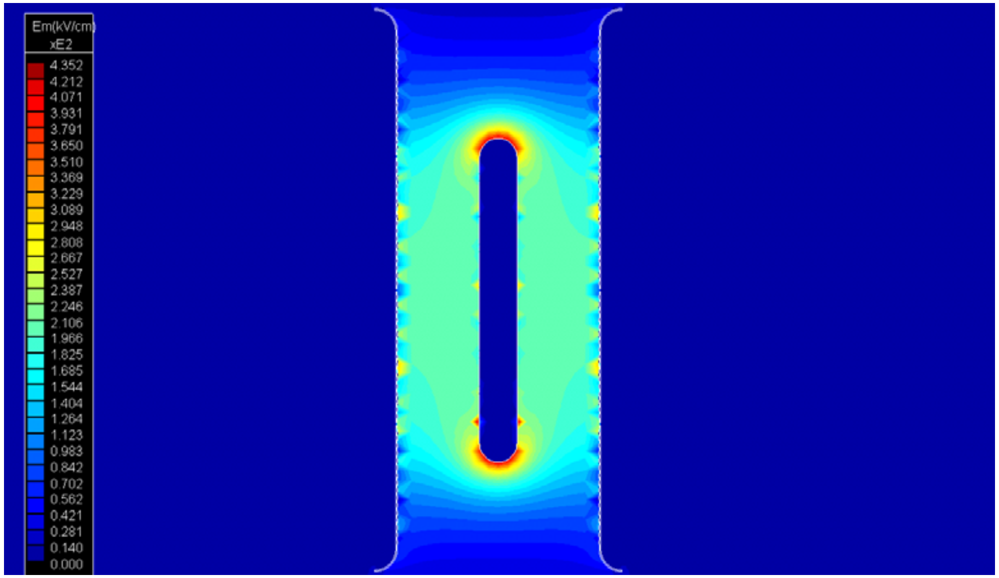
- ~6 MV is acceptable for the effective time for water breakdown
- Barrier had no flashes at 5 MV and 2000 shots on Z_{20}
- Presently, water switch losses offset higher PFL voltage



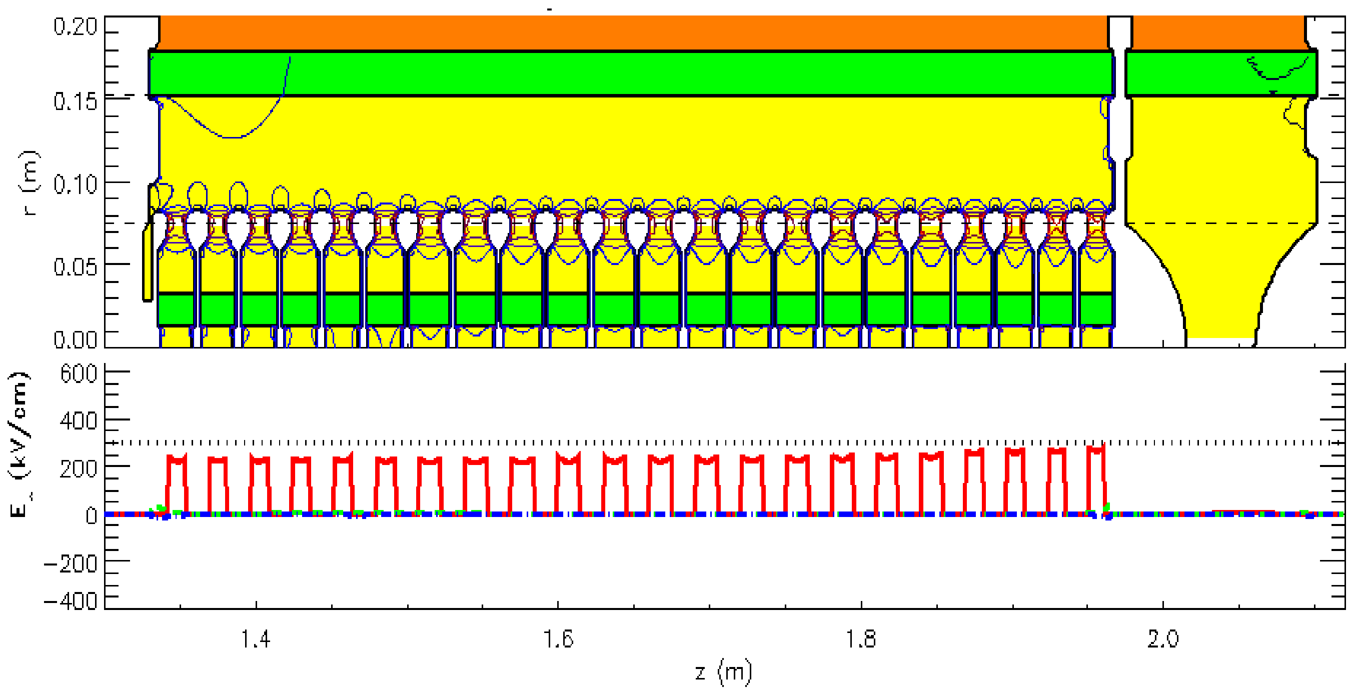
The output transmission lines carry power to the water-vacuum insulator

First ZR shots were ICE and the vacuum insulator didn’t flash so energy was in the water for ~1μs





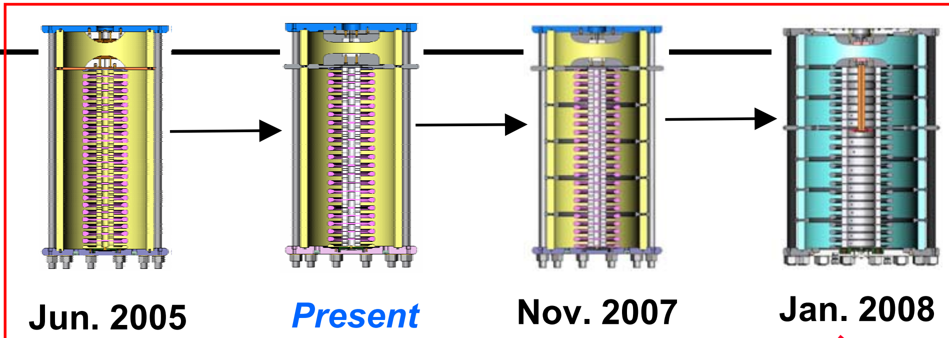
The simulations model the transient EM behavior in the switch as it closes



- **Automated geometry setup: rapidly test different configurations**
- **Detailed evolution of the electric field in each cascade gap, and on the switch housing**

Improvement program for the Laser Trigger Gas Switch continues

- **Recent advances in materials understanding, testing methodology, data analysis, and cleaning and handling protocols have greatly improved our physical knowledge of multi-megavolt laser triggered gas switches**
- **The present gas switch has been fired for two ZR shots and performed as anticipated**
- **There is an interim modification to reduce random failure modes**
- **An optimized design has been developed with a goal of less than 3 ns jitter, a 6.3 MV operating level, a life of ~150 shots, and a reduction in random failures such as low voltage prefires and housing flashes**



Parameter	Gas switch goals	Present gas switch	FY08 Optimized
voltage	6.3 MV	5.4 MV	6.3 MV
prefire rate	<0.03 %	< 0.1 %	<0.03 %
jitter (ns)	< 6 ns	**5 ns**	< 6 ns
optics life	> 200 shots	**~ 800 shots**	> 200 shots
flashover rate	0.03 %	< 1 %	0.03 %
replacement interval	> 100 shots	**> 100 shots**	> 100 shots

Initiating Testing Nov. 07

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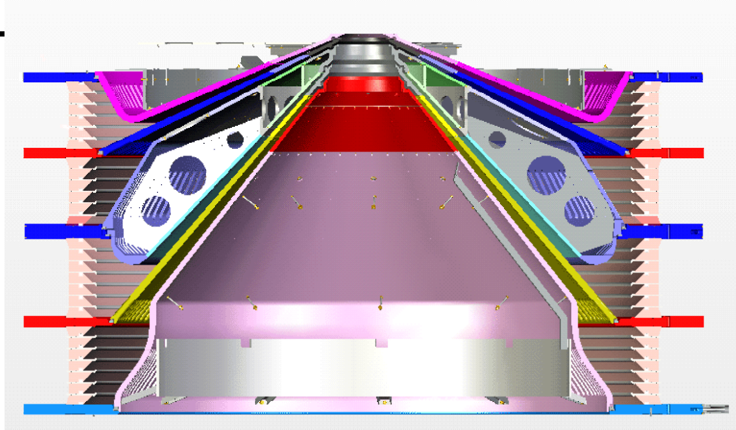
The magnetically insulated transmission lines deliver energy from the vacuum insulator to the load



- New ZR magnetically insulated transmission lines based on the old Z design
- The ZR magnetically insulated transmission lines were built and assembled with sub-mm tolerances
- Debris shield to protect vacuum insulator

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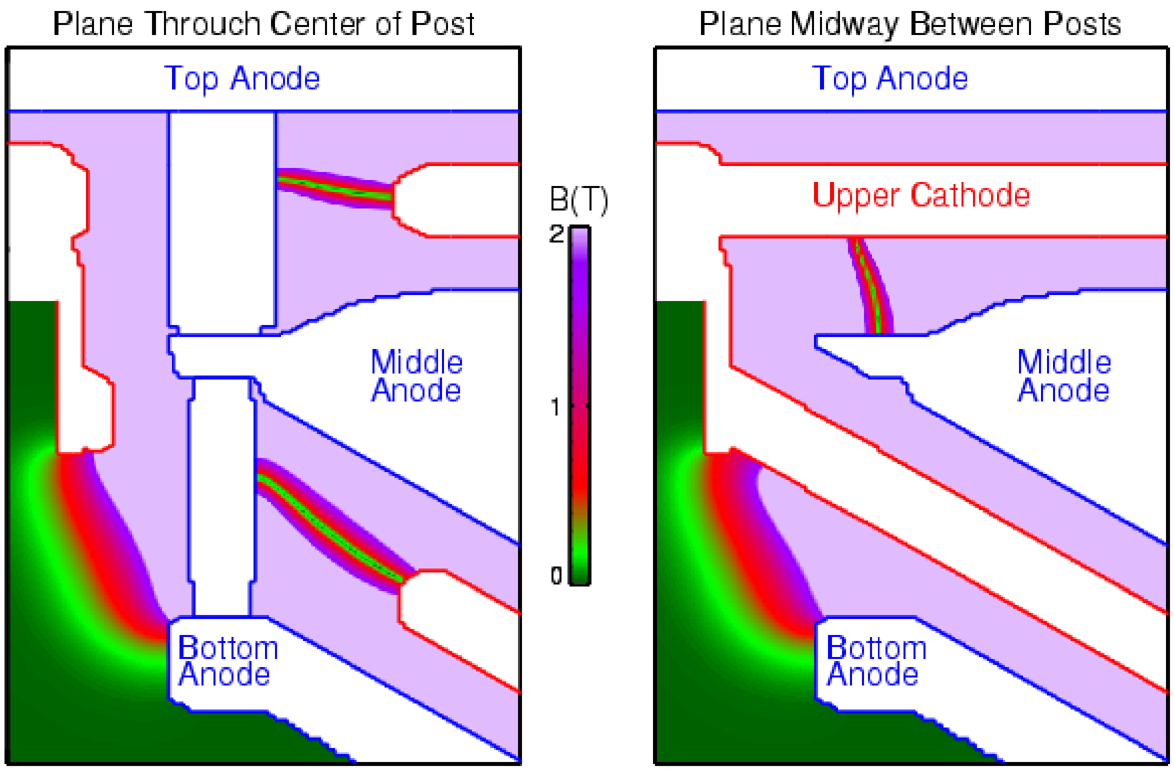
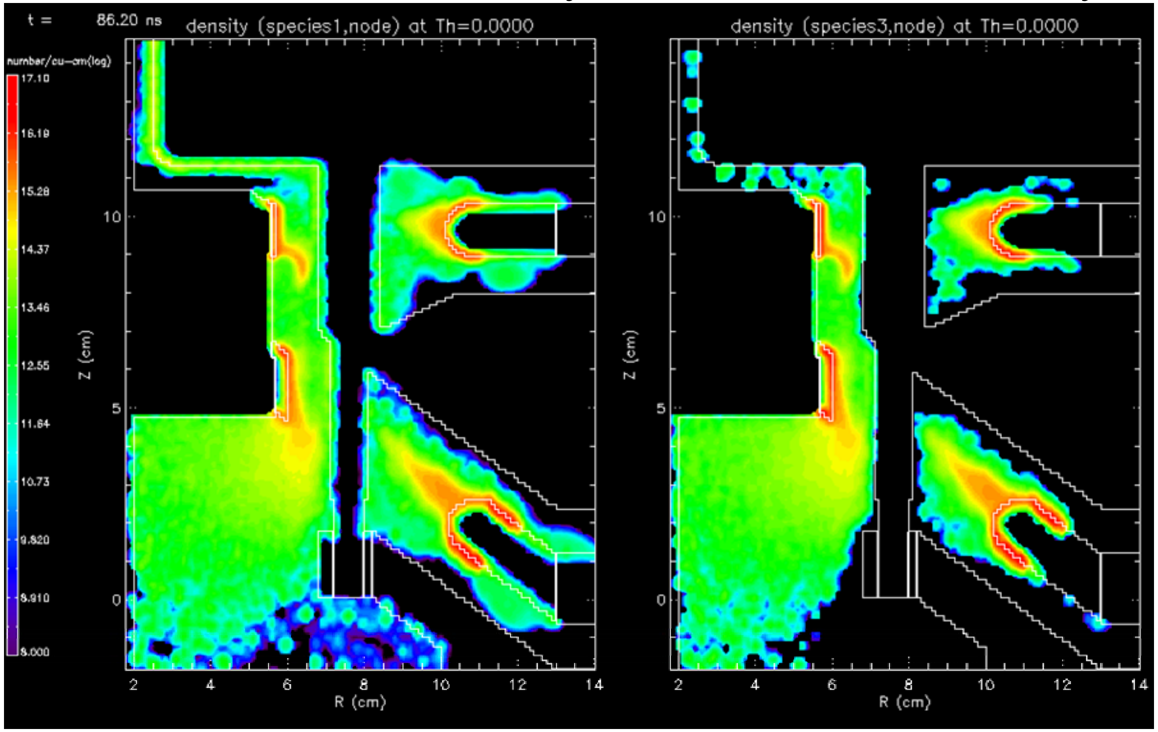
Magnetic nulls in the convolute



- There will be electron losses at the nulls: “loss of magnetic insulation”
  - How much? How fast does the anode surface heat?

LSP 3-D convolute simulations have been done with anode and cathode plasmas

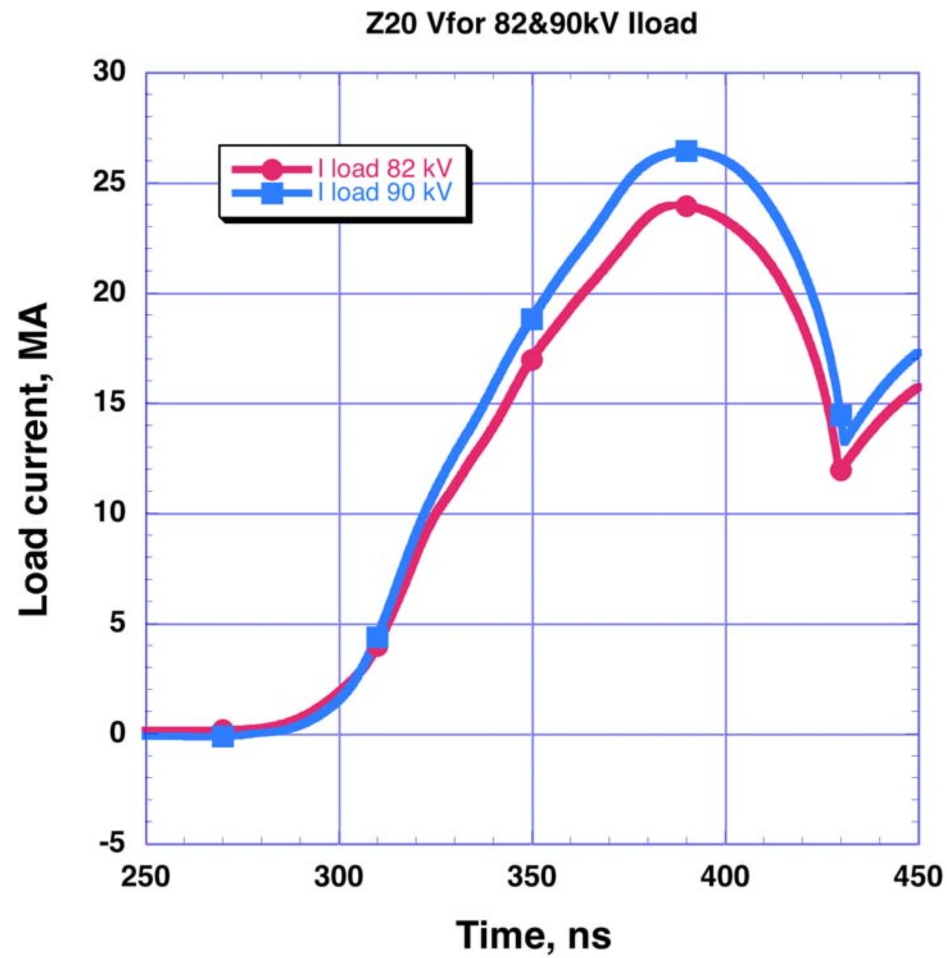
Cathode Electron Density   Cathode Ion Density



- **Cathode plasmas turned on when E-field exceeds threshold; Anode plasmas turned on when surf. temperature exceeds threshold**
- **Coulomb collisions included: plasma drift across magnetic field**

Circuit modeling predicts 26 MA into the baseline load at 90 kV Marx charge

- **Expect 26 MA at 90 kV and 23 MA at 82 kV Marx charge**
  - **Using Z_{20} forward wave with baseline water switches**
  - **82 kV is 5.3 MV gas switch**
  - **90 kV is 6.1 MV gas switch**



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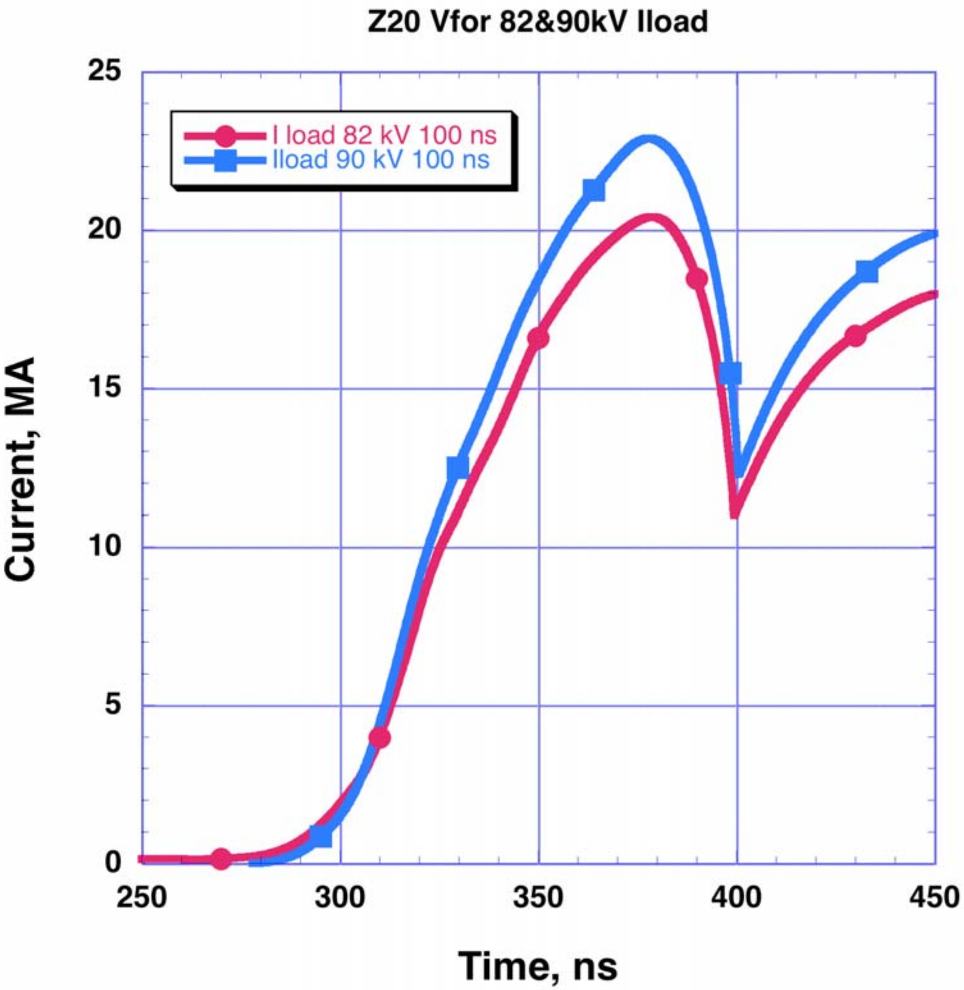
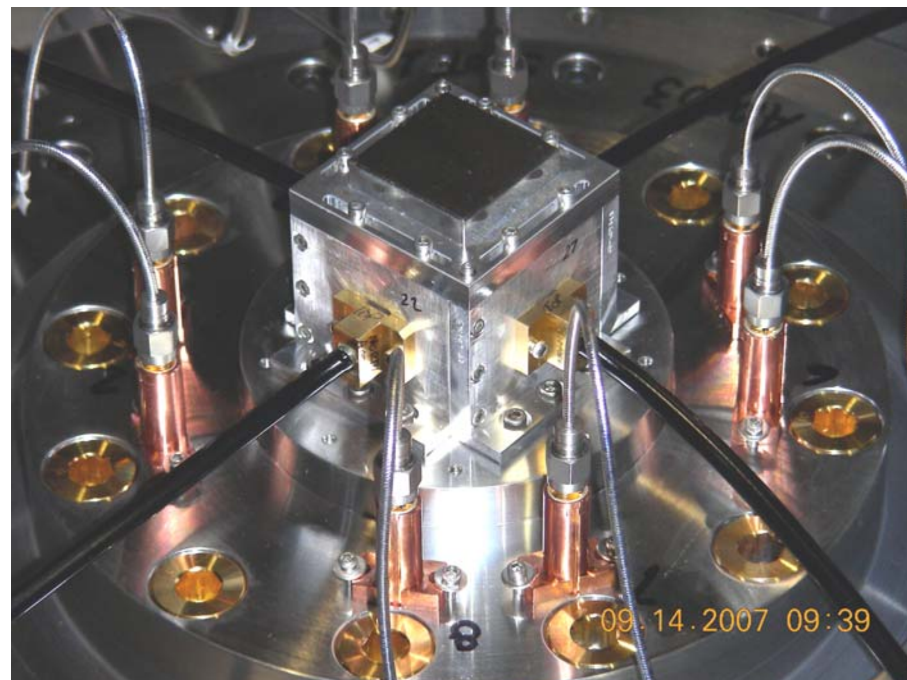
At 100 ns implosion time ZR will deliver 23 MA at 90 kV and 20 MA at 82 kV

- Uses forward-going waveform from Z20 and baseline water switches



The ZR machine fired two full system shots in September, delivering high current to a load

- 10 MJ stored in the Marxes at 60kV charge
- 17 MA in the load
- All the Marxes, all the laser triggered gas switches, all the water switches and the full vacuum section, including a fully-diagnosed isentropic compression load



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