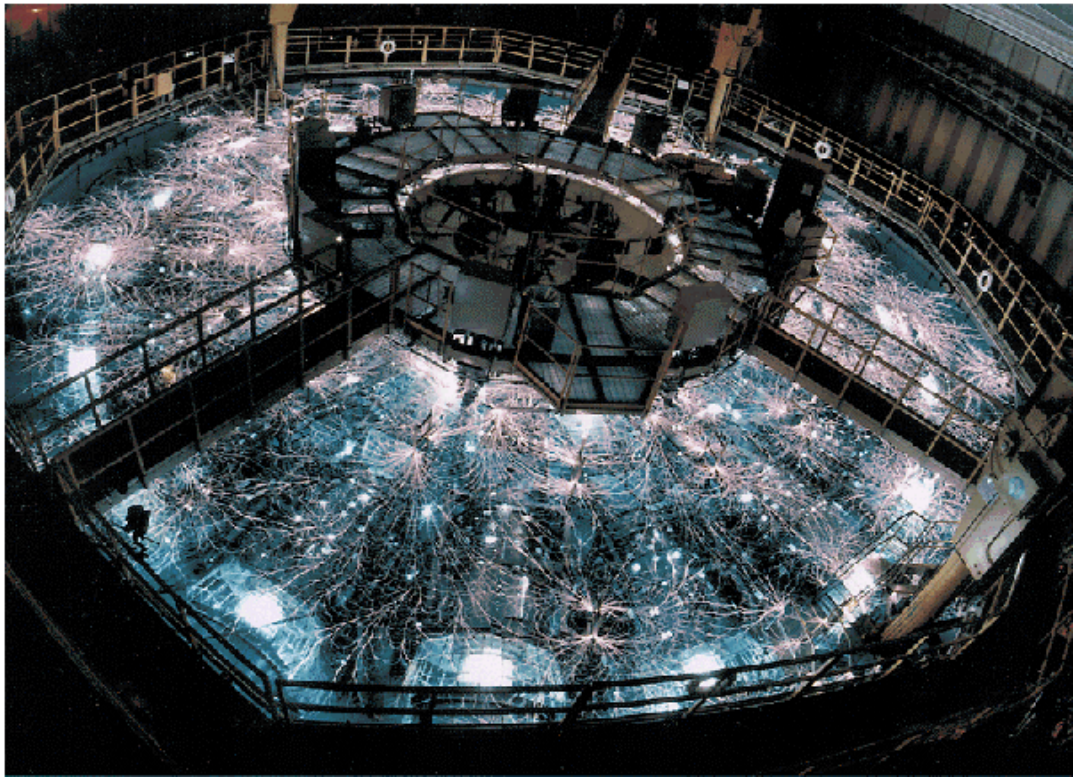
SAND2007-0837C

The 15th International Conference on High-Power Particle Beams (BEAMS'2004)

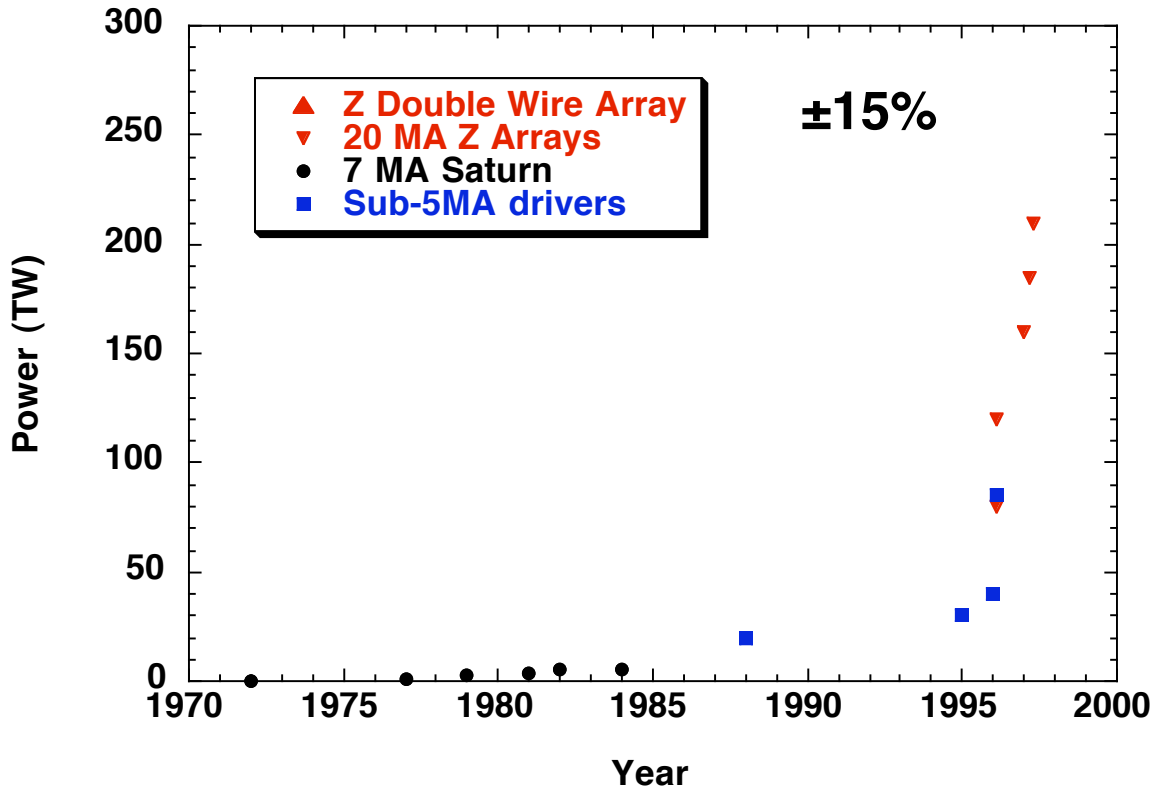
July 18-23, 2004 in Saint-Petersburg, Russia,



Dr. Dillon H. McDaniel, Deputy Director
Pulsed Power Technologies and External Alliances
Phone: (505) 845-7494
Email: dhmcdan@sandia.gov

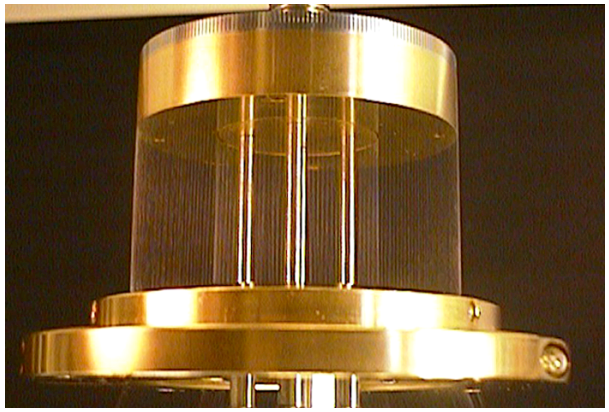
Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under contract DE-AC04-94AL85000.

Improved load dynamics on Saturn and Z have significantly enhanced total x-ray powers

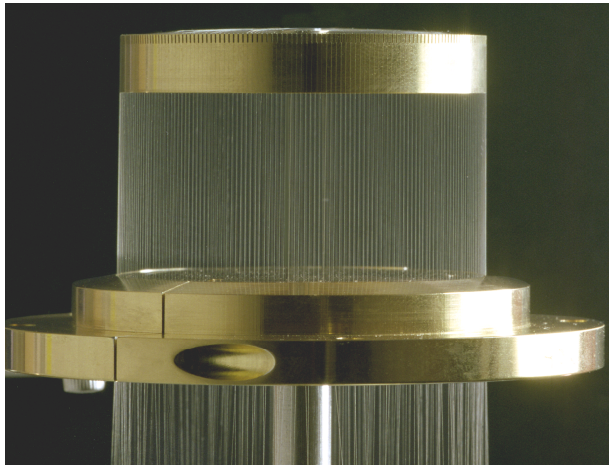


Whitney, et al, Phys Rev E 50, 2166, (1994)
Sanford et al, Phys. Rev. Lett 77, 5063, (1996)
Deeney et al, Phys. Rev E 56, 5945, (1997)
Haines, IEEE Trans. Plasma Sci, 26, 1275, (1998)

40 mm array of 240 wires,
20 mm array of 120 wires



40mm array of 240, 7.5 μm wires



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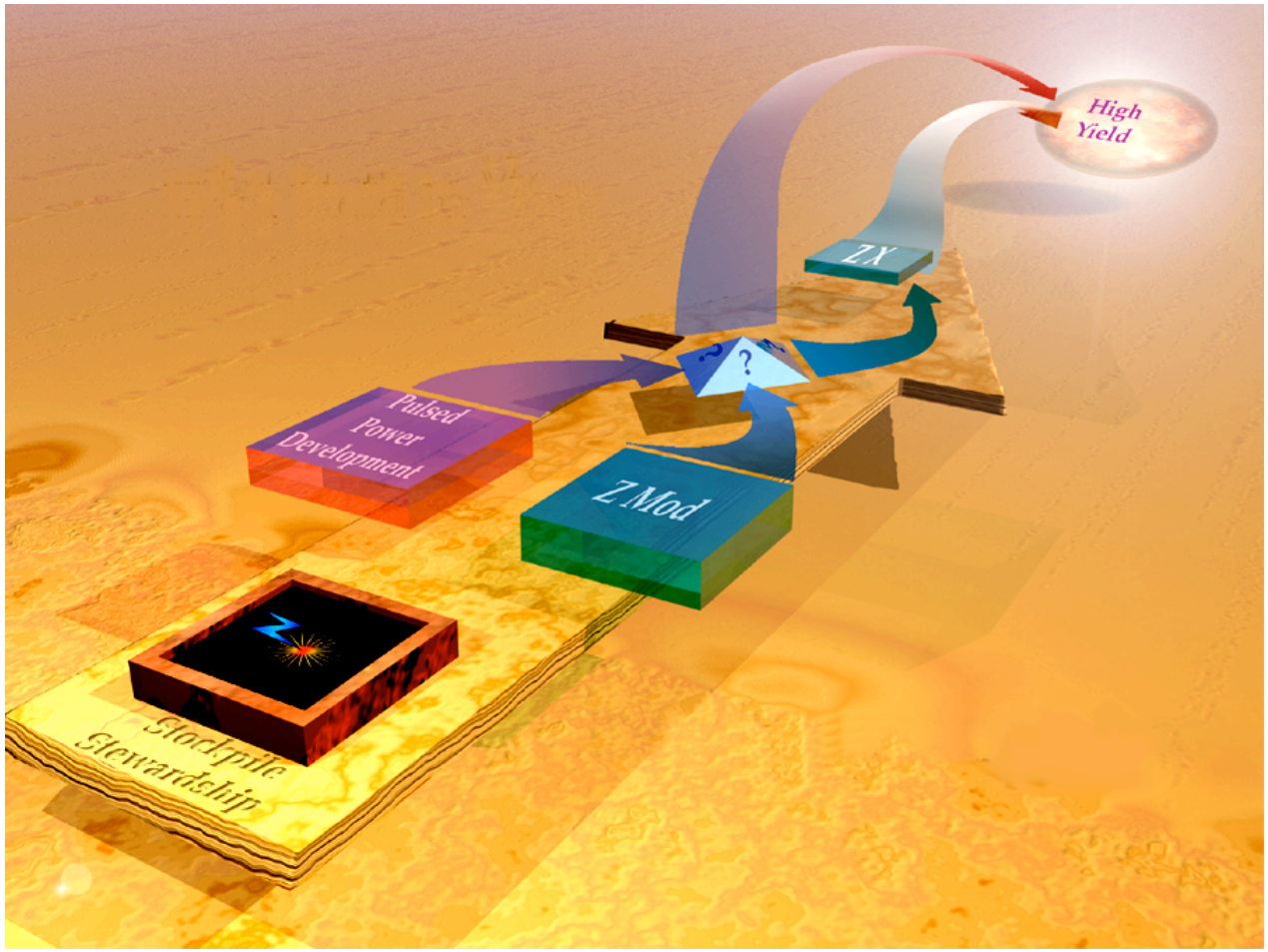
Sandia National Laboratories Pulsed Power Research Program is following a vision to high yield



The evaluation of present technology and its application to high yield is a critical part of this vision. The design for the refurbishment of Z is a result of this evaluation.

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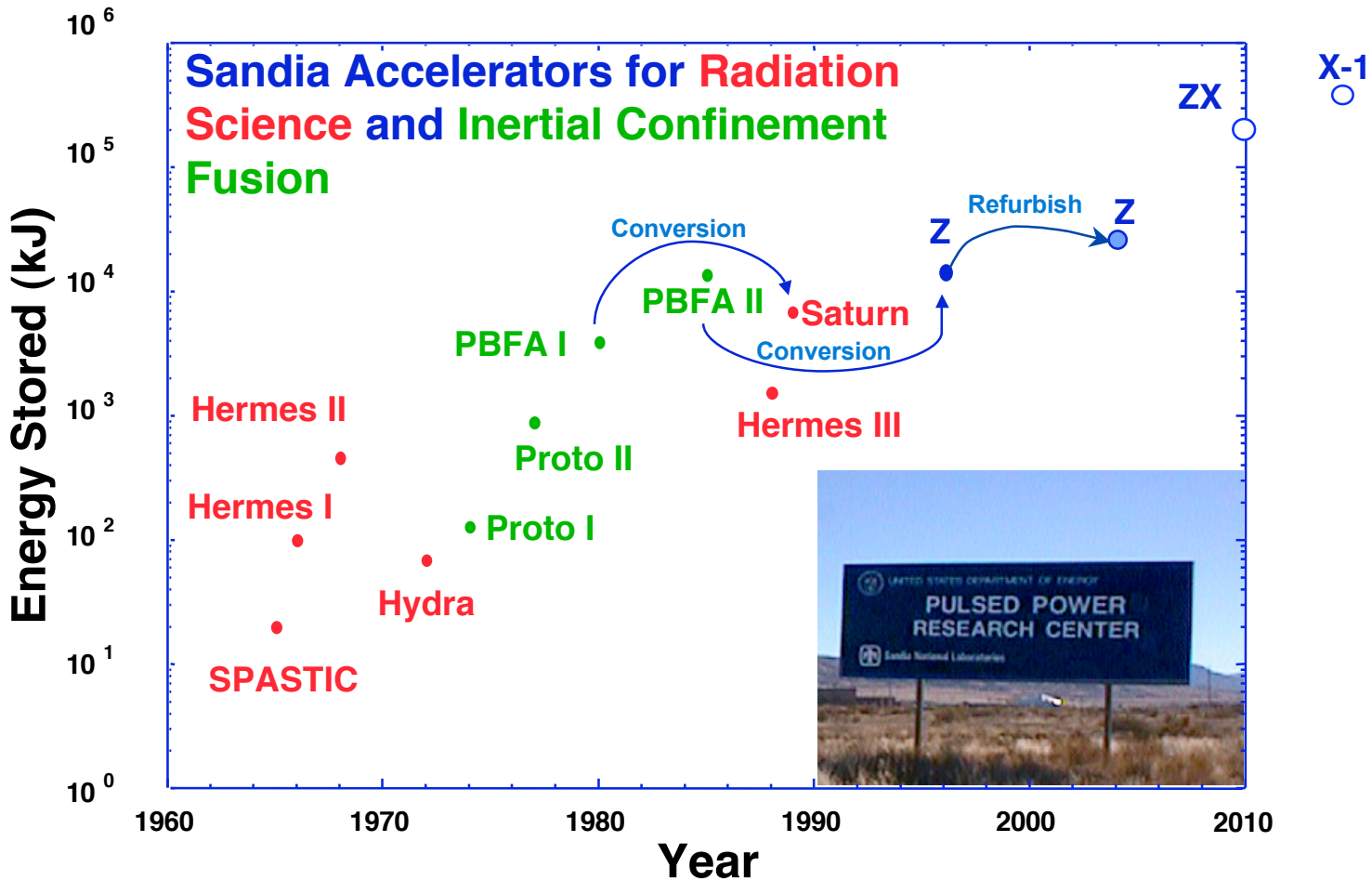
The refurbishment of Z is an important step toward the future



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Increased current is required for High Yield ICF and provides increased capabilities for broad application to NNSA/DOE programs

E Radiated Total / ICF
T_r for ICF VH / DH
P_{pk} for ICE / Flyer plate velocity
In band energy 1 keV / 5 keV / 8 keV

2 x 60 MA

50 MA

26 MA

20 MA

Z
1.6 / 1.0 MJ
75 / 140 eV
2.7 Mbar / 21 km/s
400 / 100 / 20 kJ

Z R
2.7 / 1.7 MJ
90 / 165 eV
10 Mbar / 32 km/s*
800 / 300 / 80 kJ

ZX
10 / 6.3 MJ
145 / 284 eV
31 Mbar / 60 km/s*
2500 / 1500 / 390 kJ

X-1
High Yield
32 / 18 MJ
220 / 310 eV
45 Mbar/ 80 km/s*
7200/4300/1600 kJ

VH = Vacuum Hohlraum
DH = Dynamic Hohlraum
ICE = Isentropic Compression Experiments

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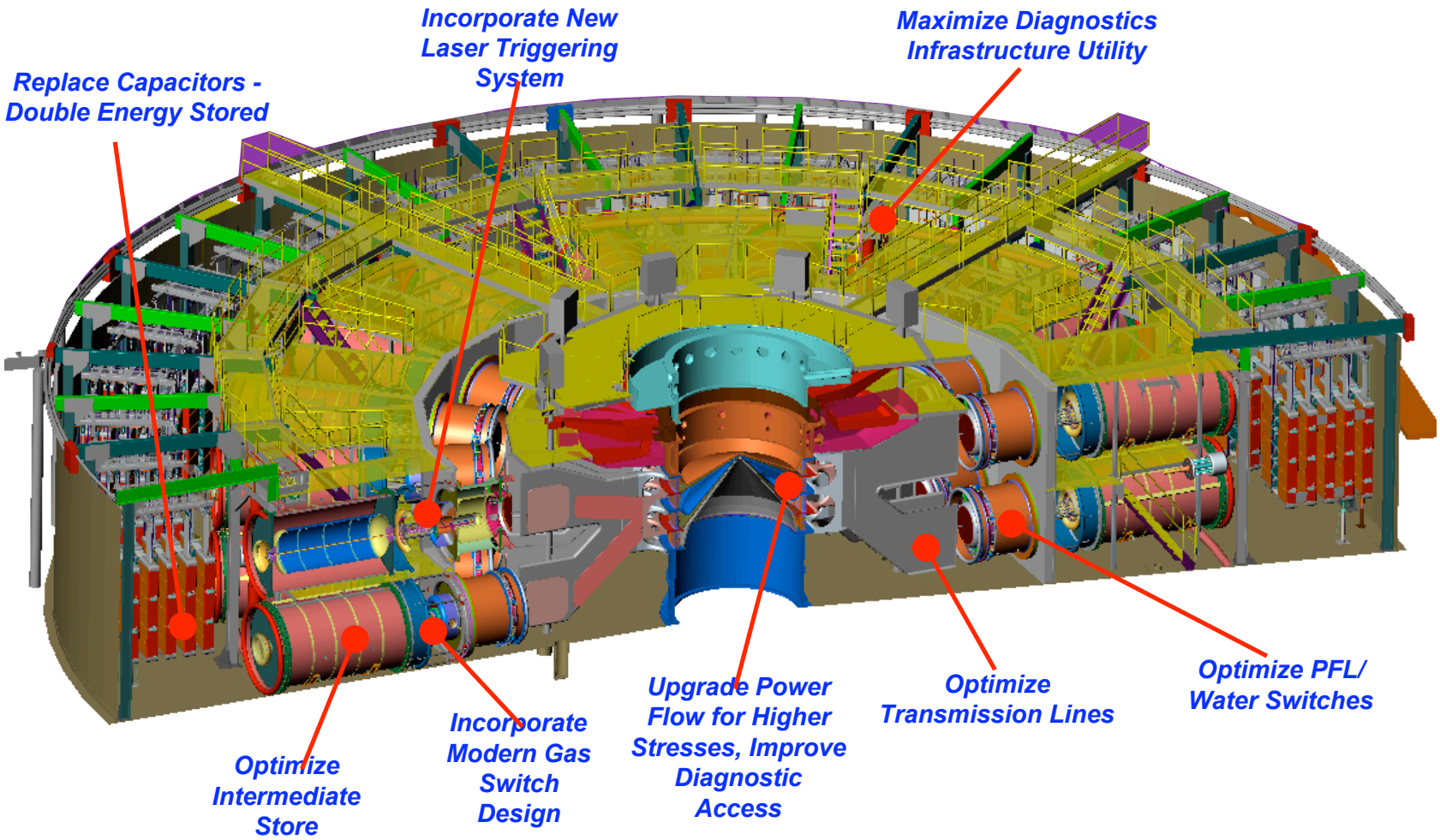
Objectives of the System Assessment Test was to validate the ZR pulse power design



Code prediction capability validated.
The ZR load current shapes are known

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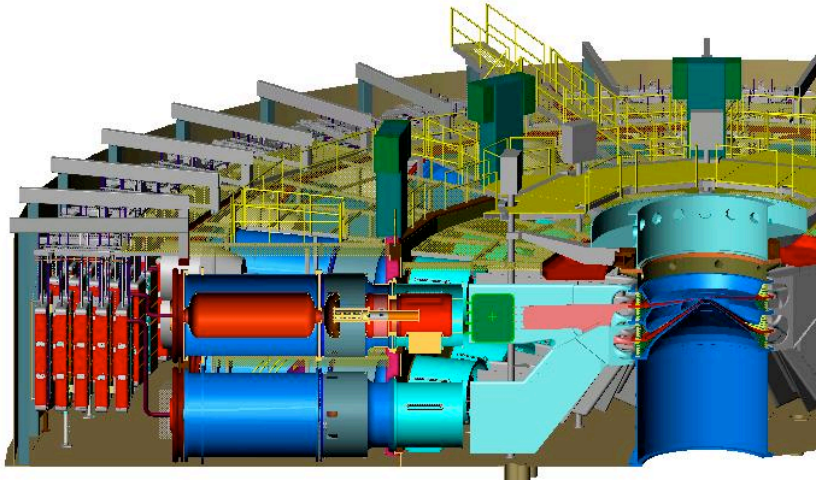
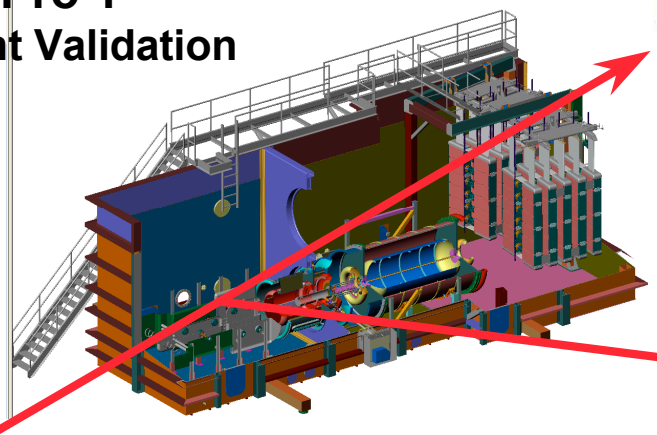
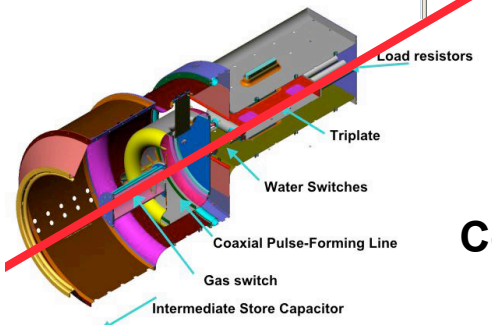
Component R&D for power conditioning is completed. Next is integrated system validation.

ZR
Final Design
Procurement
Assembly
Commissioning

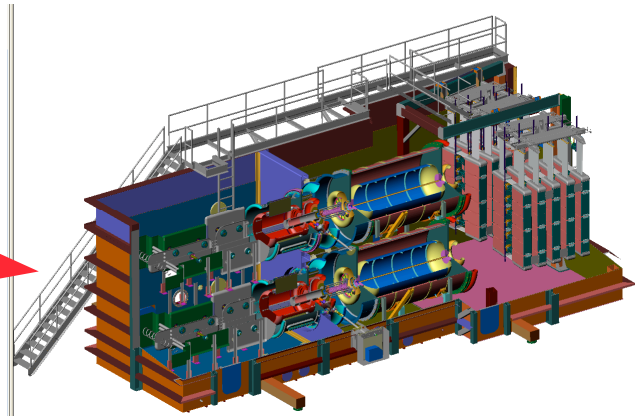


SATPro 1
Component Validation





Z20
Component Development



SATPro 2
Reliability
Maintenance Def.

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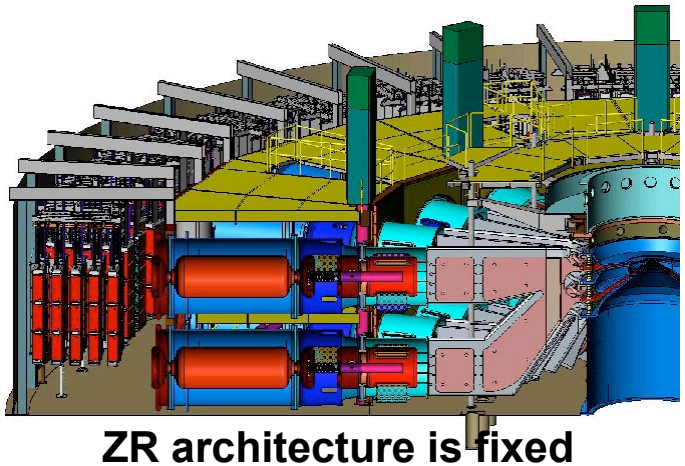
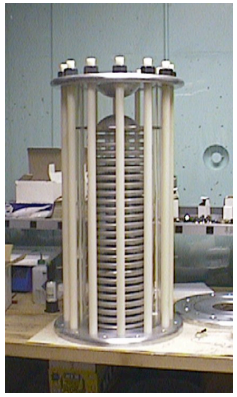
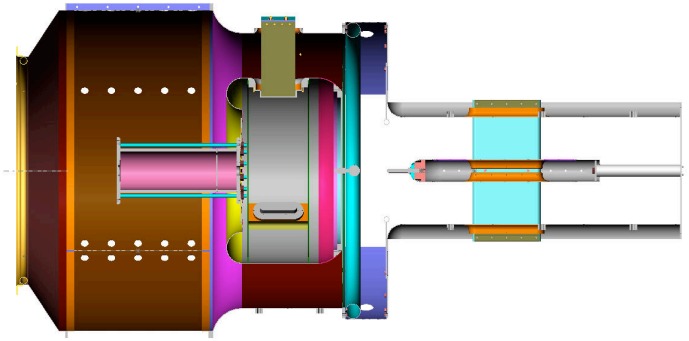
Output of the pulse power development program for ZR has converged to the full ZR design for System Evaluation



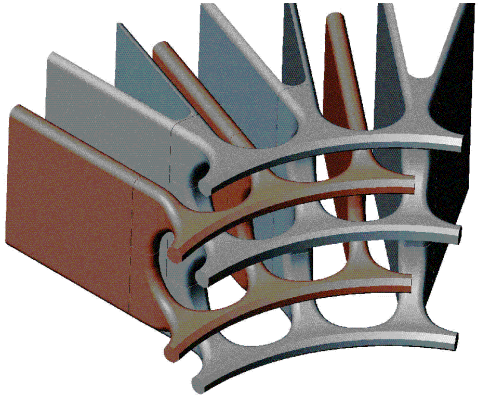
ZR architecture is fixed

Base Line Intermediate Store Gas Switch has been developed at 5.9 MV





Water Switch experiments and EM analysis has defined the pulse forming section



Vertical Triplates to Horizontal Disk has been chosen (Saturn Like)

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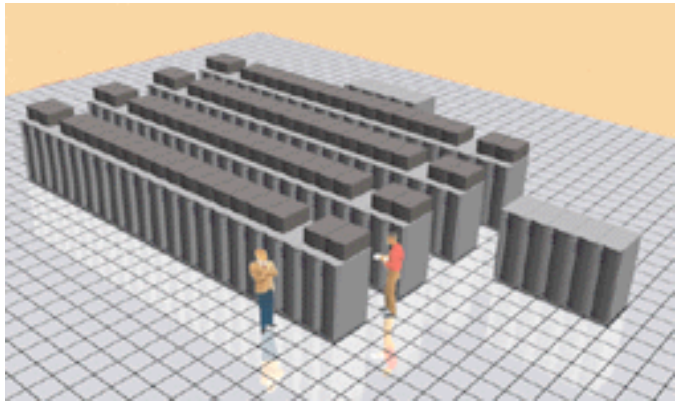
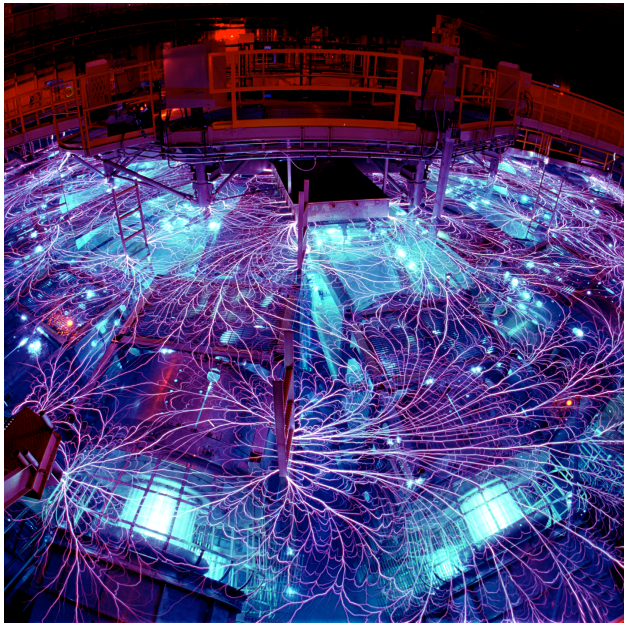
EM and PIC Codes Designed to Utilize Massively-Parallel Computers

- Utilize thousands of processors
- Dynamic load-balancing
- Hybrid grid and solvers
- Coupled physics
- Object-oriented
- Built upon multi-physics software framework



Tera-FLOPS



Tera-watts

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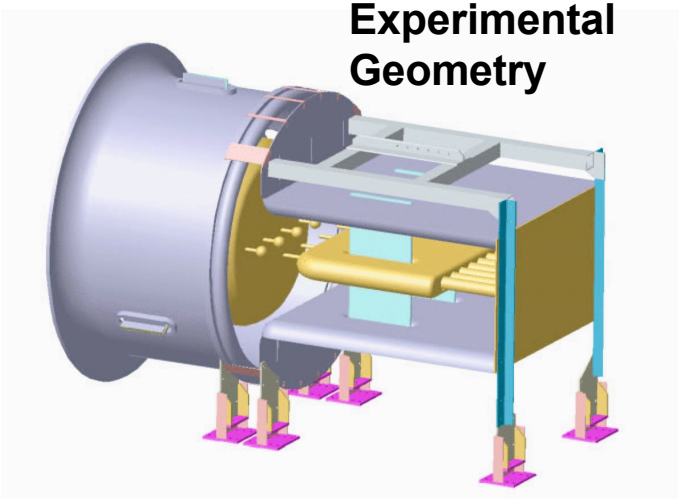
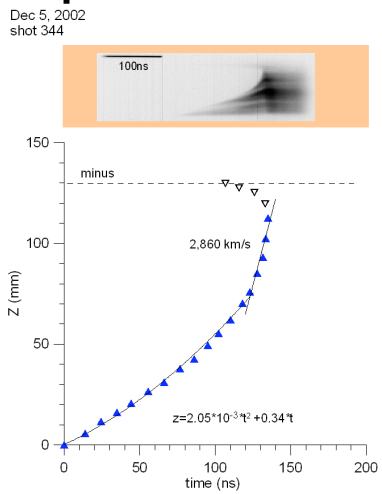
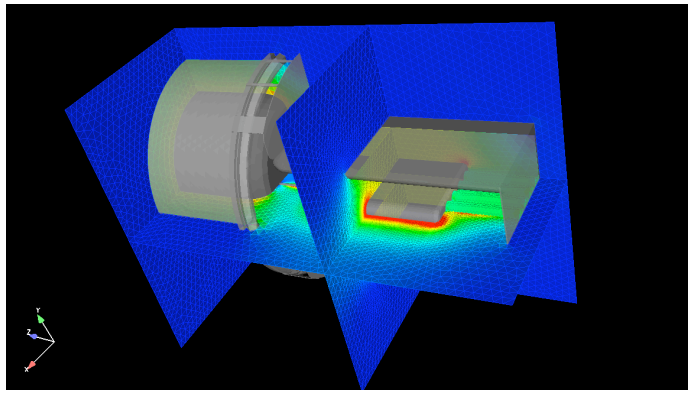
EM codes and analysis used to understand transient behavior of ZR coax - water switch - tri-plate region

Experimental Geometry

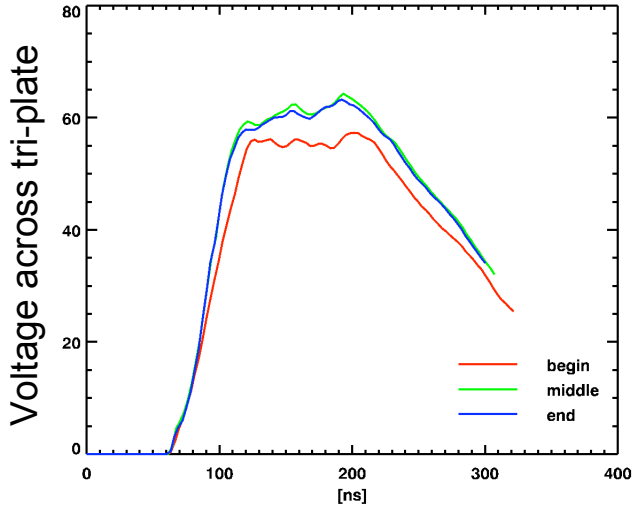


Experimental Data

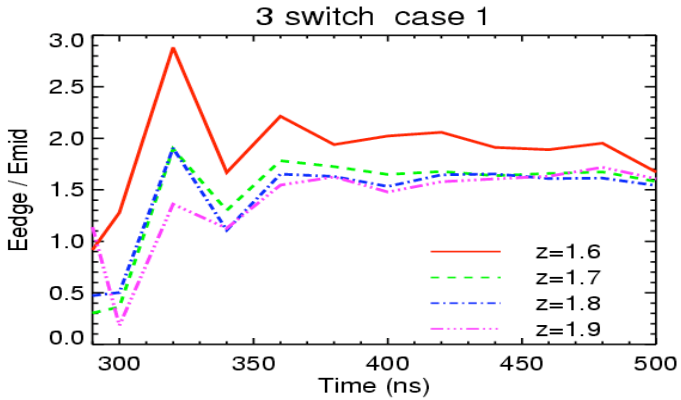




EM Code Results



Analytic EM Modeling



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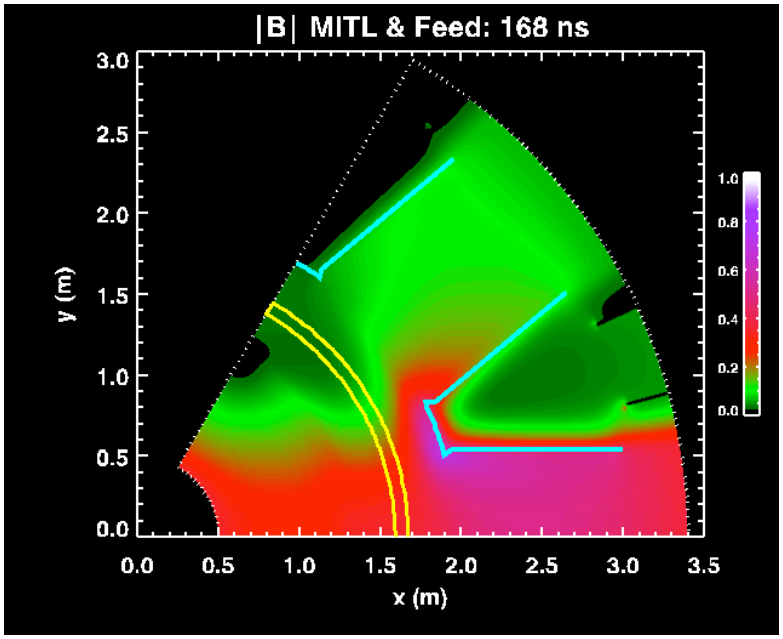
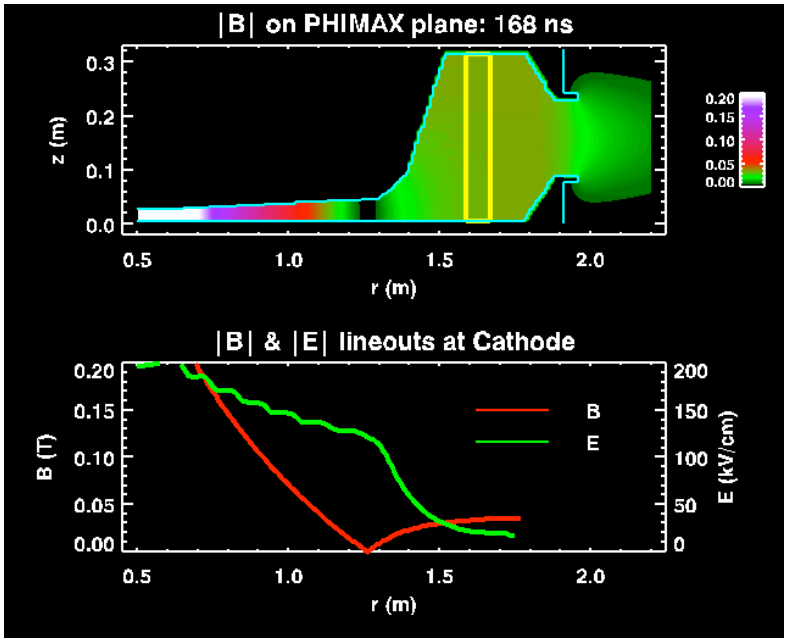
3-D QuickSilver PIC is being used to look at the problems of dynamic magnetic nulls that occur in ICE experiments



Movie showing the movement of the magnetic null that is caused by the requirement of current pulse shaping for ICE



Movie showing details through the position of the magnetic null that is caused by the requirement of current pulse shaping for ICE

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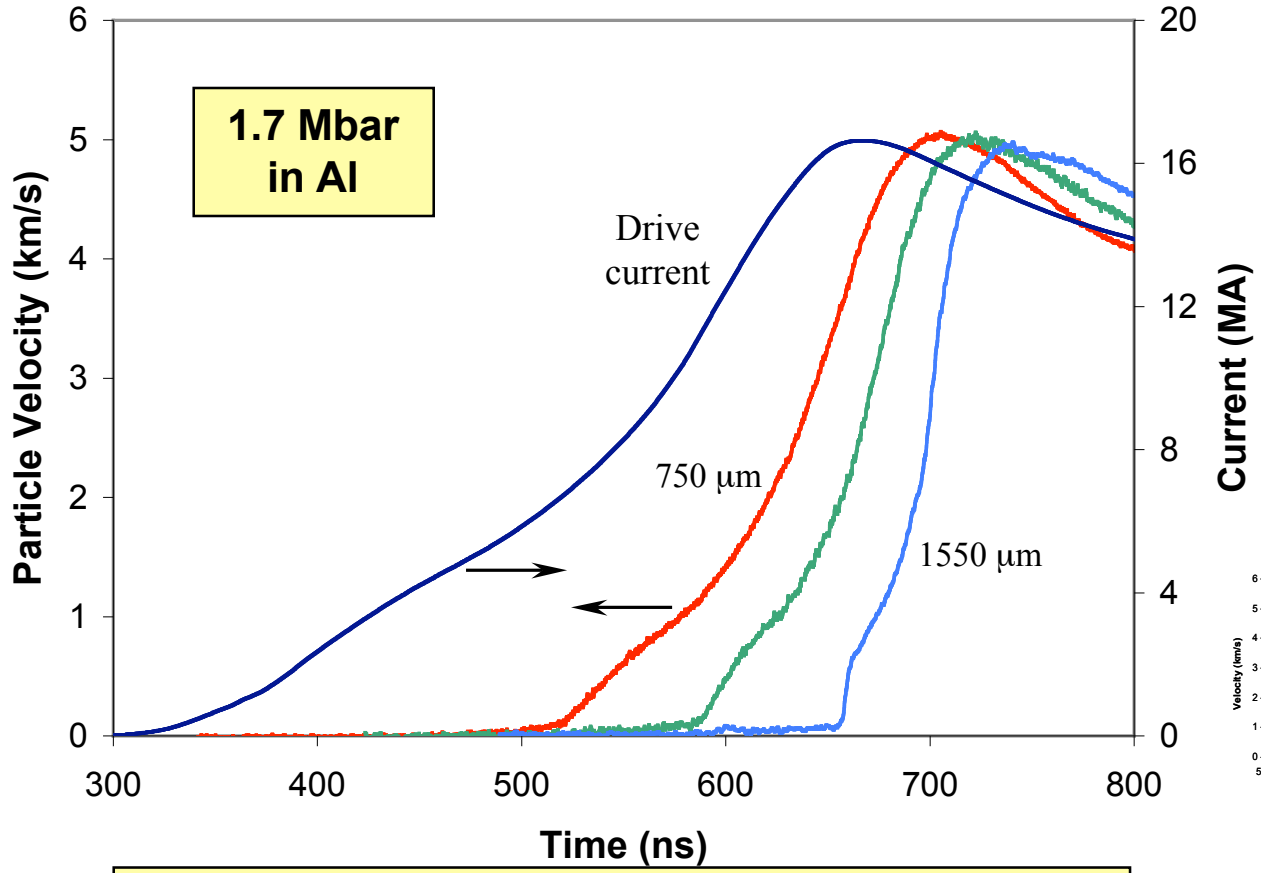
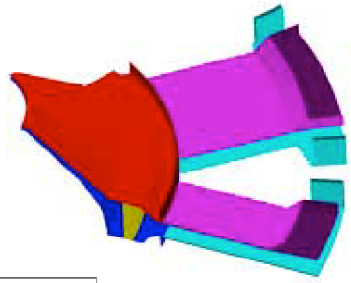
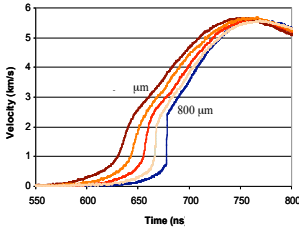
New laser technologies and our 3D PIC modeling capability are enabling pulse shaping







Pulse shaping has extended shockless propagation of 1.7 Mbar ICE wave in aluminum to ~1.5 mm

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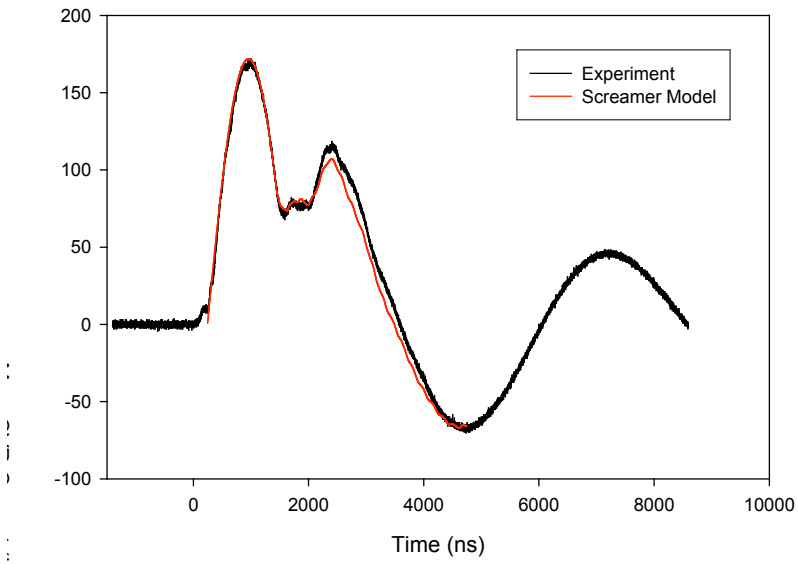
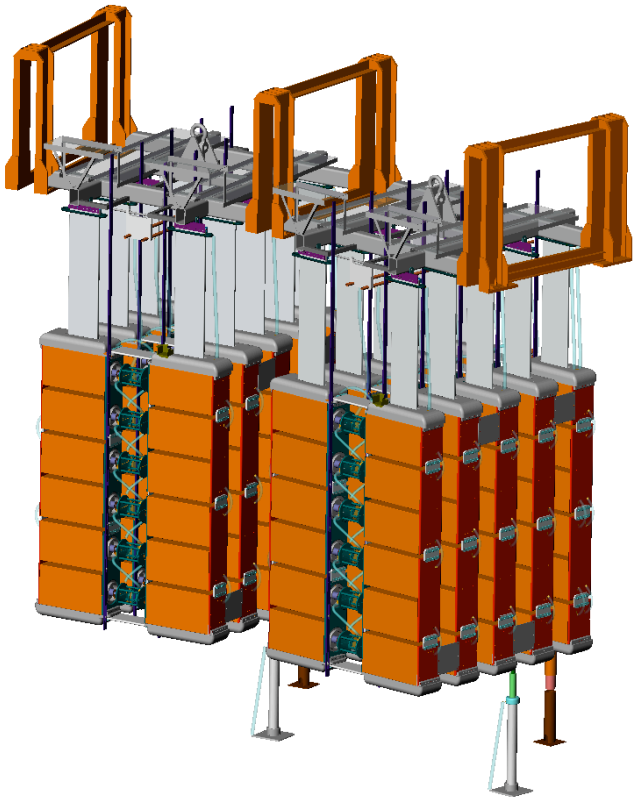
Match to Data: Marx CVRs





Measured:
Rs = 1.4Ω
Ls = 11μH

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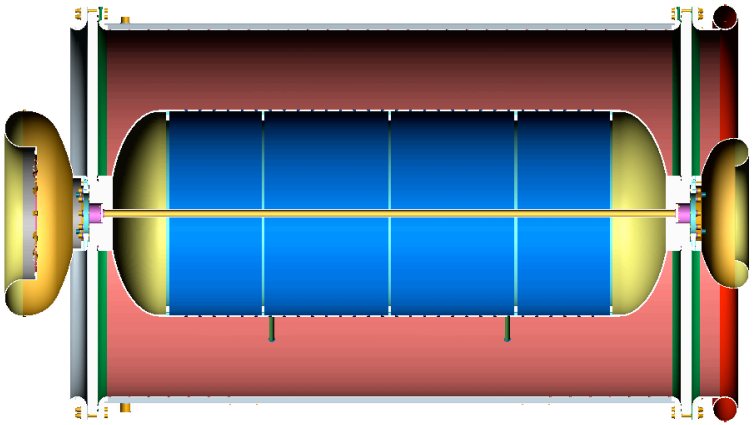
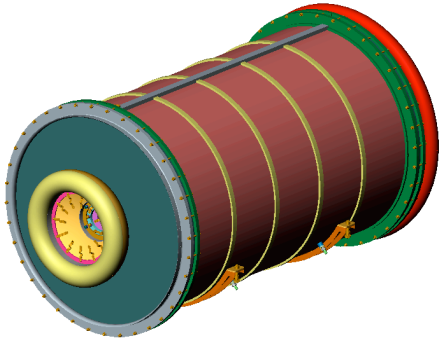
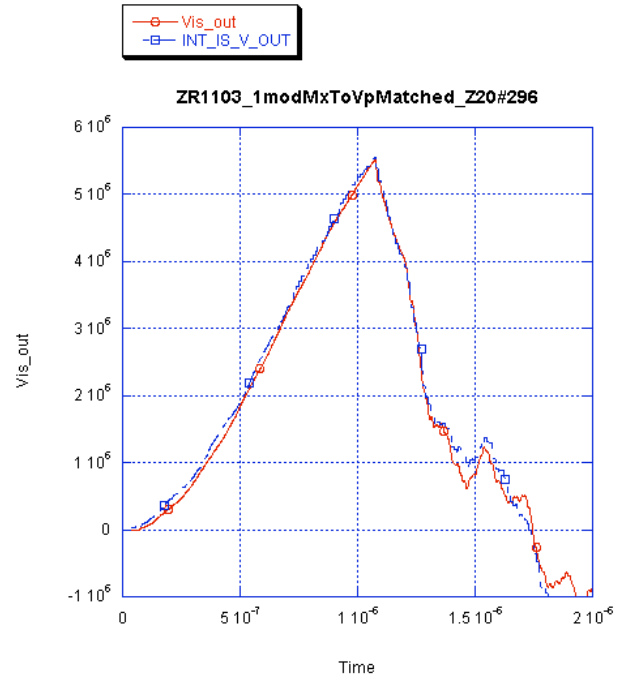
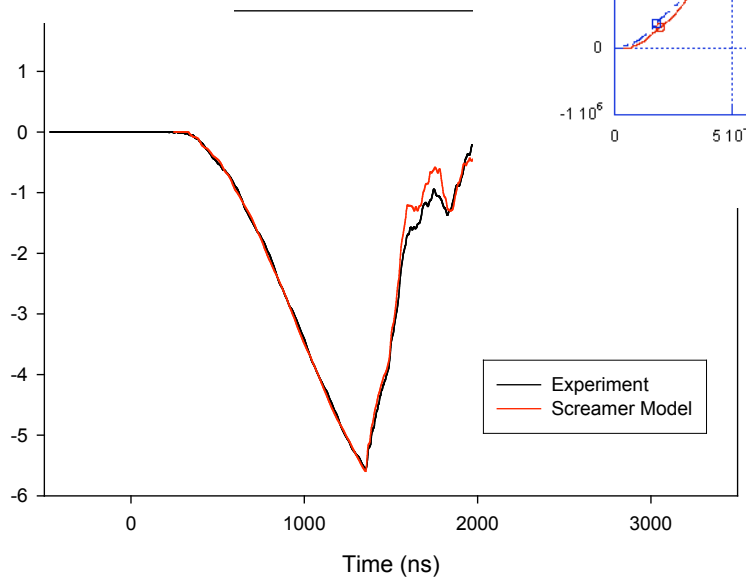
Match to Data:
Intermediate Store Voltage









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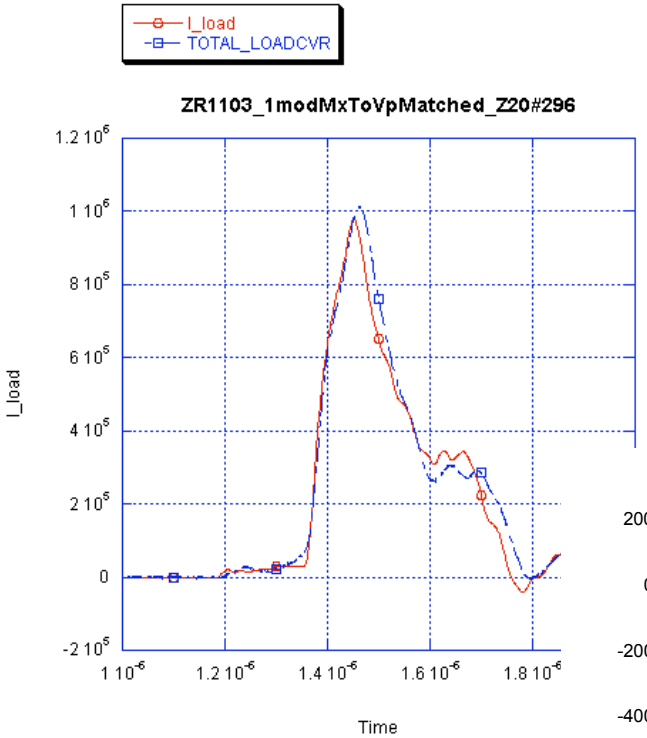
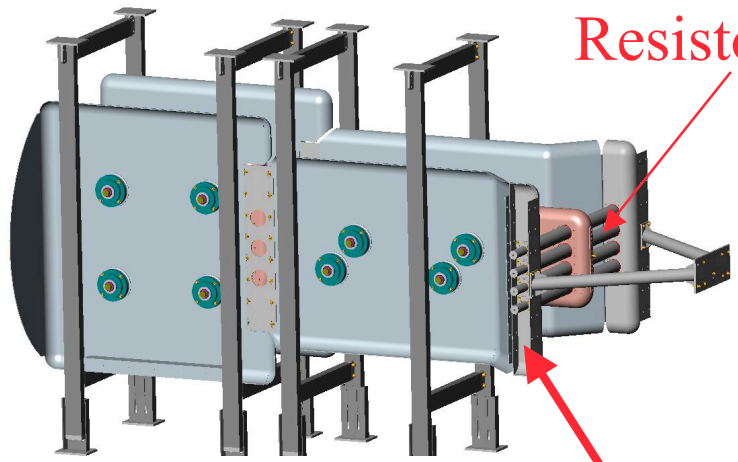
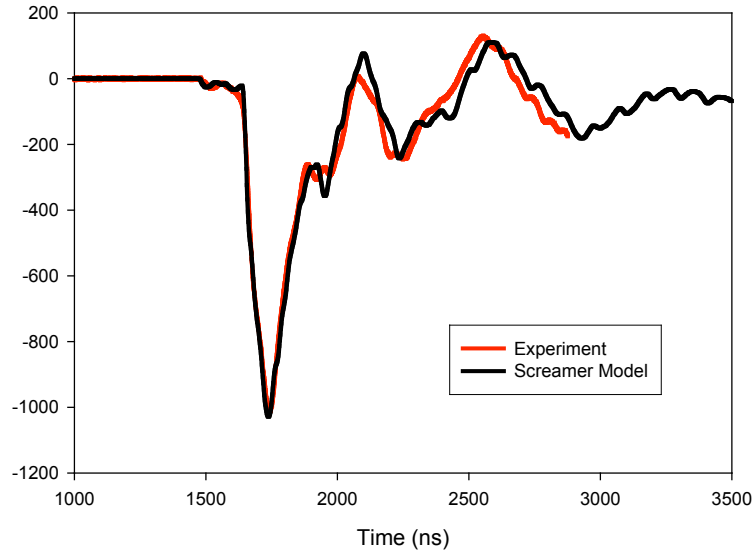
Match to Data:
Total CVR Current





Liquid Resistors

CVRs



PPWS closed

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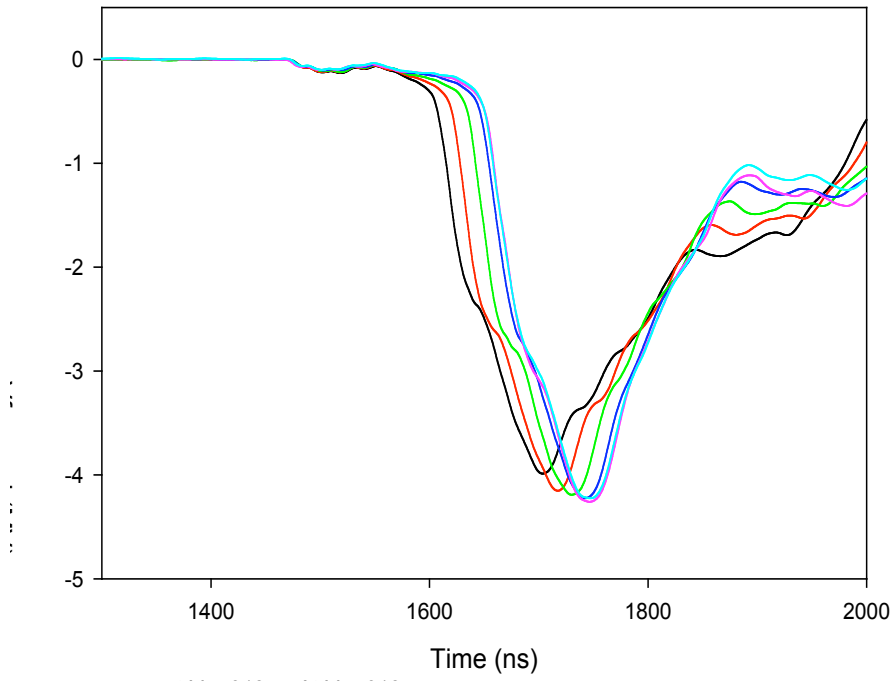
Setting Water Switch Gaps to Optimize Vforward



Gap L (cm)	Peak V_F (MV)
7.6	3.99
9.4	4.15
11.4	4.19
13	4.23
14	4.26
15	4.22

Marx charge voltage = 80 kV
Laser Delay = 415 ns

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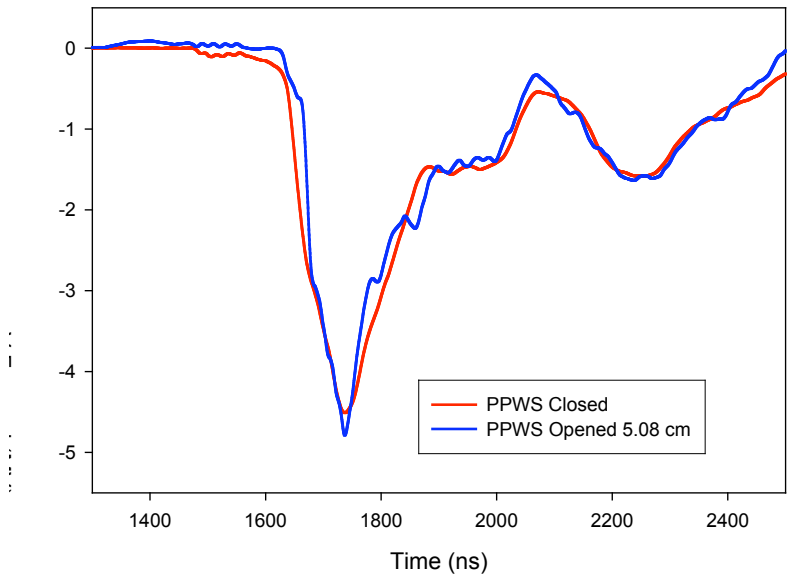
Open up Prepulse Switches Further: Use PPWS as Peaking Switches



Peak Vforward

PPWS Closed: 4.51
PPWS Open: 4.79

Shot #	Laser Delay	Water Gap	Prepulse Gap	WS Time Charge	Vfor|p
352	410	12.7	0	175	4.51
337	345	13	1.27	177	4.5
366	360	12.7	5.08	176	4.79

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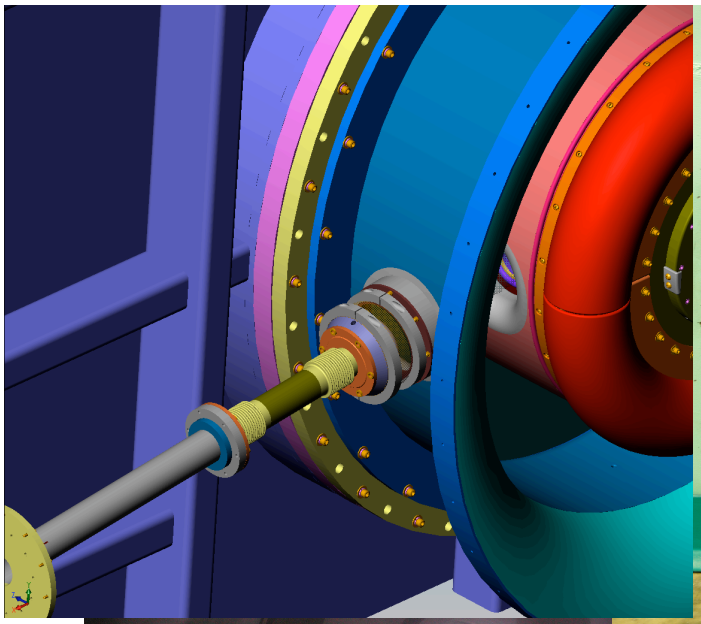
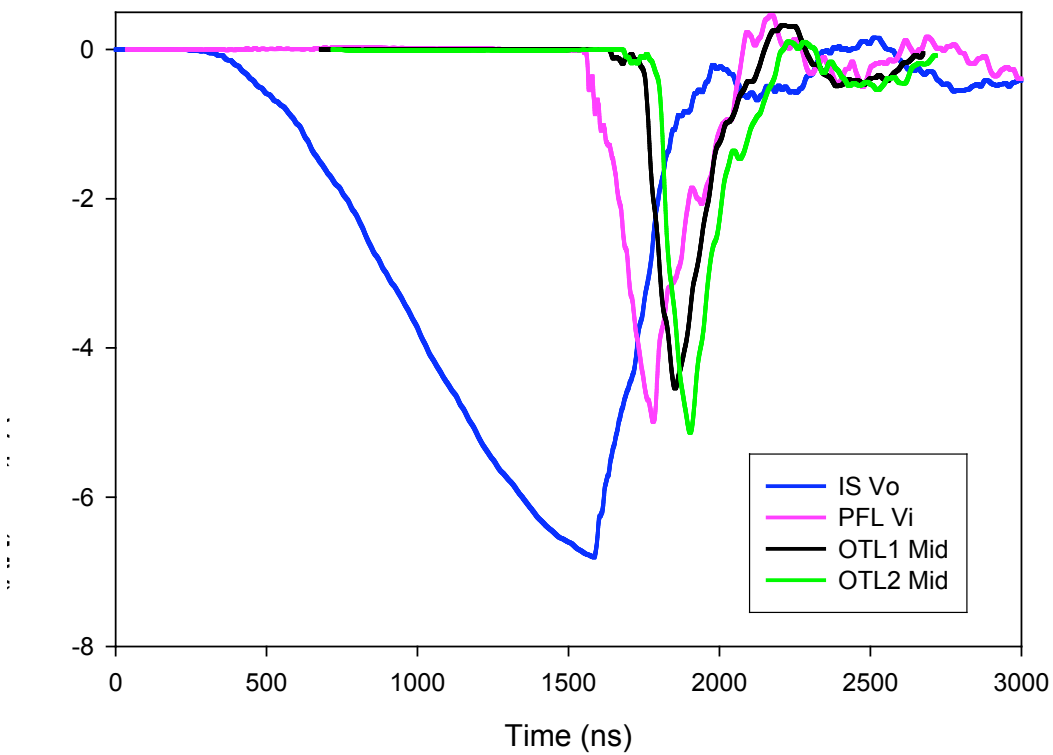
Laser Crossover Tube Failures



- Laser tube started flashing when OTLs installed
- Tube material: Lexan, Bursata, polyeurathane
- Design and fabrication very similar to present Z tubes
- Workable solution is
  - thick-walled polyeurathane
  - glow discharge cleaning

Laser tube has not Flashed in ~ 100 shots

Peak Overstress:
6.81 MV Gas Switch



Peak Voltage (MV)

IS Vo	= 6.81
PFL Vo	= 4.72
OTL1 Vm	= 4.54
OTL2 Vm	= 5.13
Vfor OTL2	= 5.13

Cause: No laser to Gas Switch because of fiber optic receiver.
Gas switch self broke; No damage.

Shot 280

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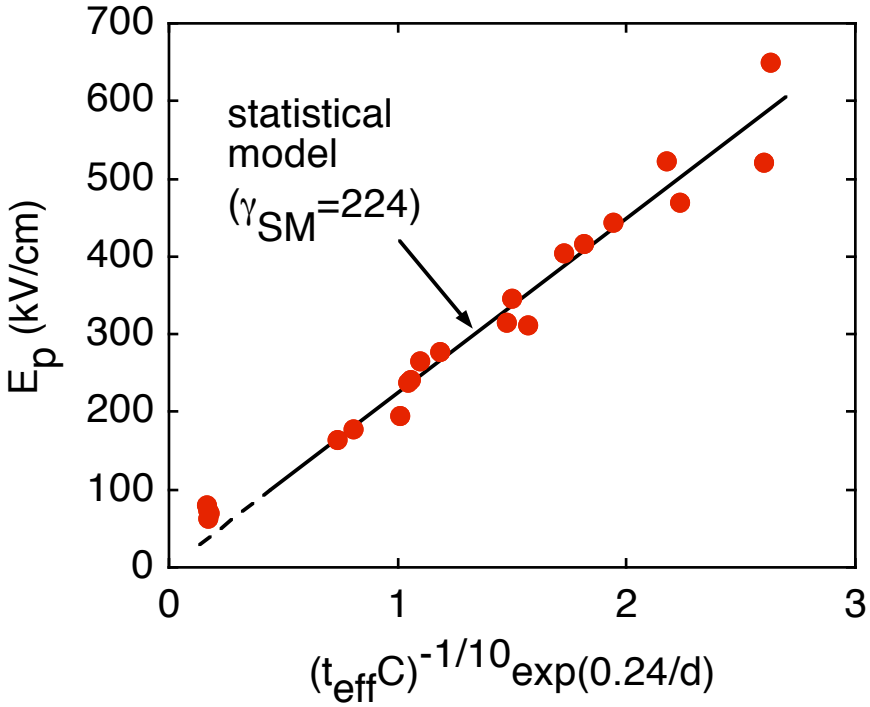
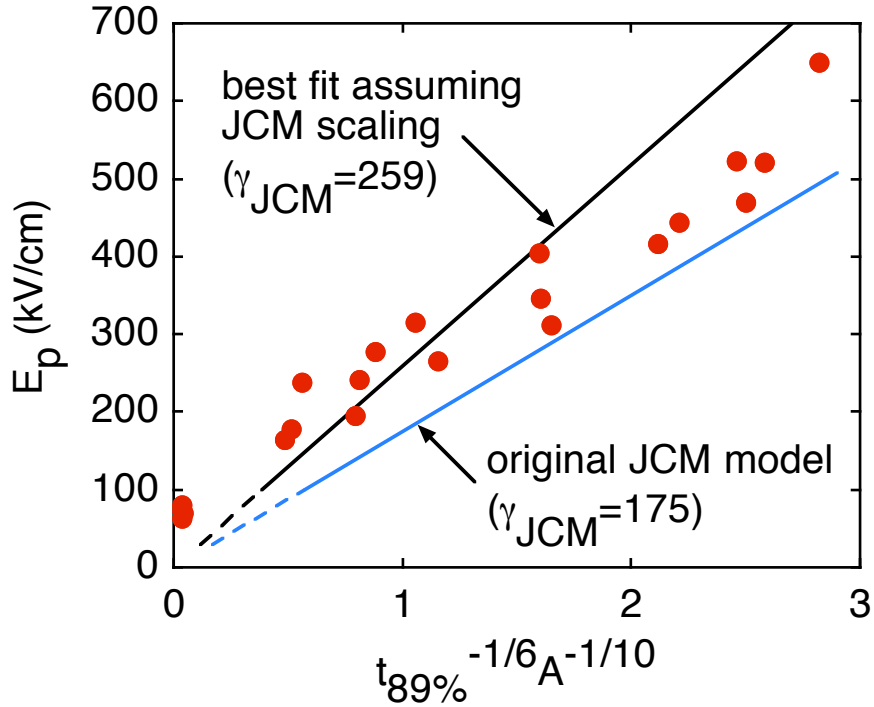
The statistical flashover model [1] is consistent with experiment to within 7% for pulse widths from 0.5 ns to 10 μs.





The statistical model is consistent with experiment to within a factor of 2 from 0.5 ns to 90 s - a span of over 11 orders of magnitude.

[1] W. A. Stygar et al., accepted for publication in Phys. Rev. ST-AB (2004).

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Using the statistical model, we estimate that ZR-stack-flashover probabilities are acceptable.

ZR-stack level	peak electric field E (kV/cm)	minimum failure probability, assuming ±5% uncertainties in both E and γ_{SM}	nominal failure probability	maximum failure probability, assuming ±5% uncertainties in both E and γ_{SM}
A	140	2.6×10^{-7}	1.2×10^{-5}	3.9×10^{-4}
B	143	5.9×10^{-7}	2.6×10^{-5}	7.4×10^{-4}
C	150	9.6×10^{-7}	5.6×10^{-5}	1.9×10^{-3}
D	150	9.6×10^{-7}	5.6×10^{-5}	1.9×10^{-3}
total stack		2.8×10^{-6}	1.5×10^{-4}	4.9×10^{-3}

Parameters derived from circuit code modeling of Z-R

	Z	85 kV Marx Charge	83 kV Marx Charge
Baseline load I_{peak} (MA)	19	26.3	26
Gas Switch V_{peak} (MV)	4.8	4.9	5.2
Water Switch V_{peak} (MV)	3.0	4.3	4.4
Insulator Stack V_{peak}(MV)	4.2	5.0	5.4
Radiated Energy (MJ) (predicted)	1.8	3.5	3.5
		Predicted 3/02	Operating 5/04

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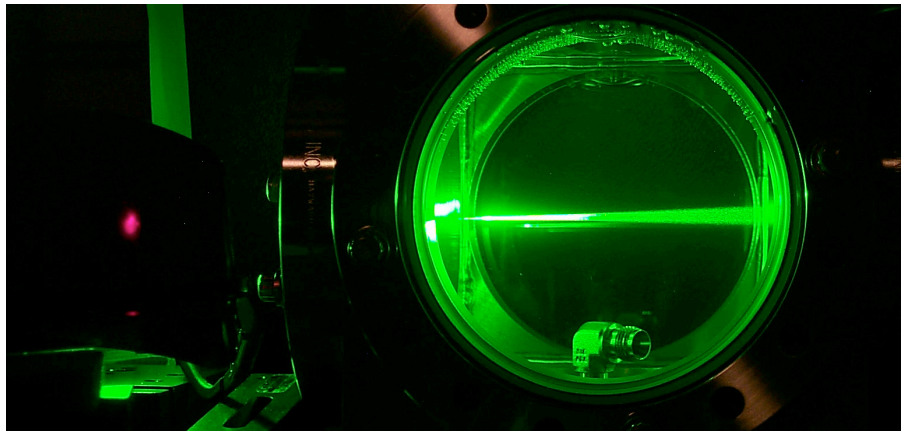
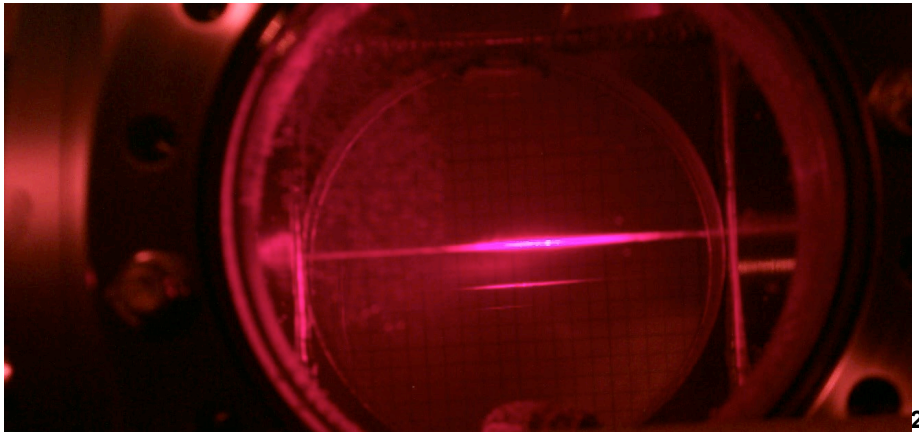
The continued optimization and improvement of the ZR architecture is a continuing mission

Laser-induced Channel-Formation With Green Beam in Water Cell



Red Raman-excited water column extends in both directions from focus.



Future requirements to mate ICF capsule implosions with Petta Watt lasers for investigation of fast ignition experiments will require that the jitter between the Z-pinch x-ray source and the laser will have to be ~ +/- 100 psec.

Sandia LDRD experiment is investigating laser triggered water switching as a solution to this problem.

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Pulsed Power and Z-pinch research is a world wide activity

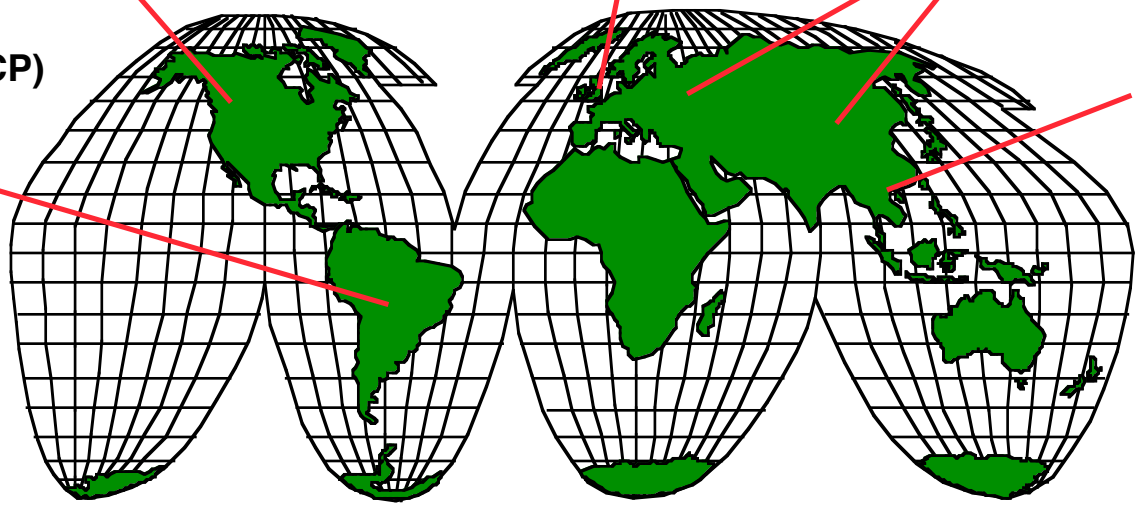
US
UC Irvine(GP, EW)
Physics International(GP, WA)
Maxwell(GP, TP)
Sandia(GP,WA)
AFRL
LANL(DPF, Liner, GP)
LLNL(GP)
AASC(DPF)
SRL(DPF)
Naval Research Laboratories
Arnold Engineering Center

South America
CUS, Chile(EW, XP, CP)
UBA, Argentina
(DPF)

Europe
Imperial College, UK(GP, EW, XP, CP, GEP)
Ecole Polytechnique, Fr(EW, GP, POW)
DGA, Fr(GP, WA, POW on Mag 3)
CEA, Fr(WA, GP)
U. Stuttgart, Gr(DPF)
U. Dusseldorf, Gr(DPF)
Weizman, Israel

Russia and Asia
TRINIT(EW, WA, GP)
HCEI, Tomsk (WA, GP)

Far East
U. Kuala Lumpur
Japan
China
Singapore



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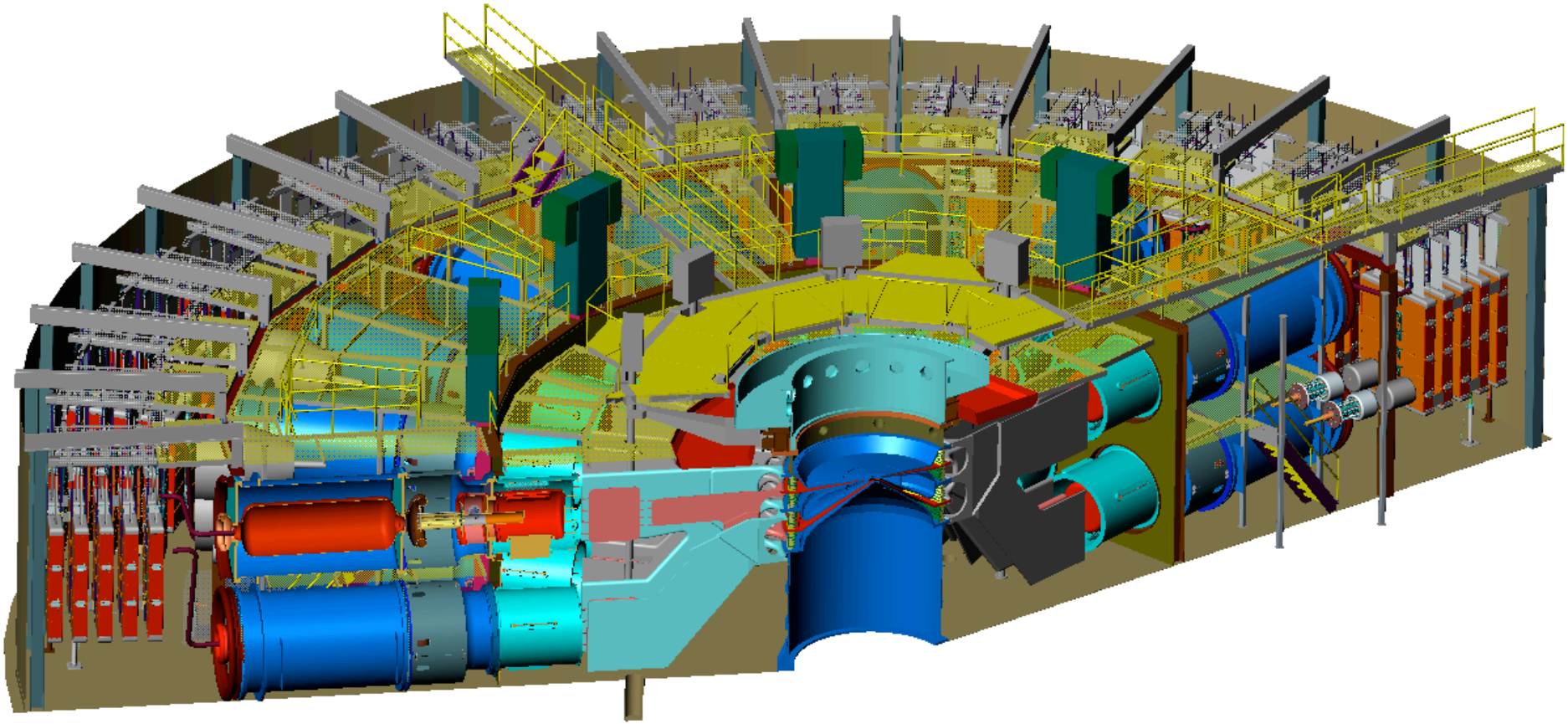
ZR completion in FY06 will provide optimum balance between Capacity, Precision and Capability



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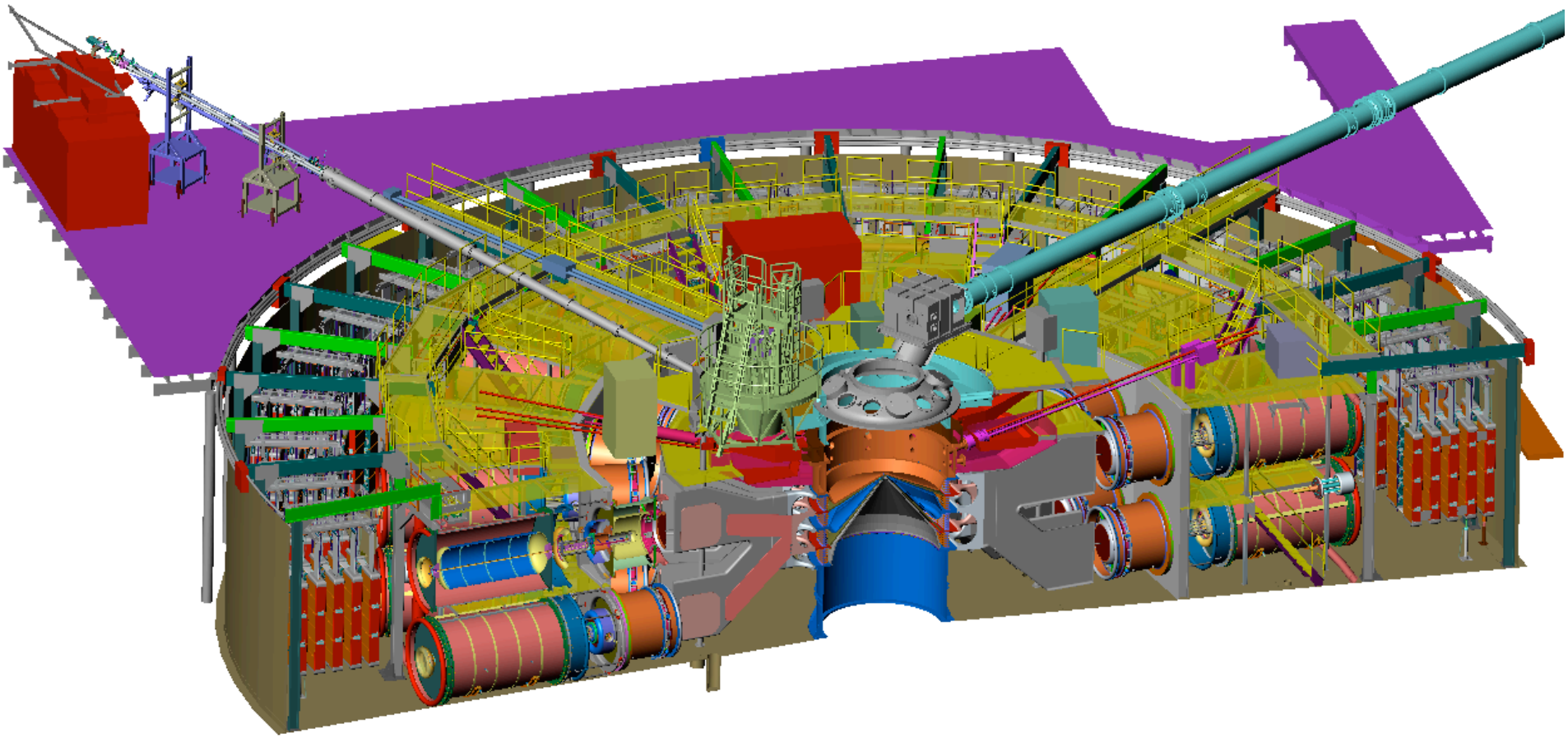
ZR Technical Review 5/19-20/04
SNL is technically ready to begin final design of ZR



Refurbishment

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Increased Capability Provided by 26 MA Impacts Multiple Users

Capability	Z today	After Refurbishment
Power Radiated (Nested Arrays)	230 TW	350 TW
Energy Radiated (Single Array)	1.6 MJ	2.7 MJ
T_r for Radiation Physics VH/DH	140 / 220 eV	165 / 260 eV
T_r for ICF VH/DH	75 / 140 eV	90 / 165 eV
P_{pk} for ICE	2.7 Mbar	>10 Mbar
Flyer plate velocity	21 km/s	> 32 km/s
In band energy 1 keV(Al), 5 keV(Ti), 8 keV(Cu)	400 / 100 / 20 kJ	800 / 300 / 80 kJ

VH = Vacuum Hohlraum
DH = Dynamic Hohlraum
ICE = Isentropic Compression Experiments

Back Up Slides

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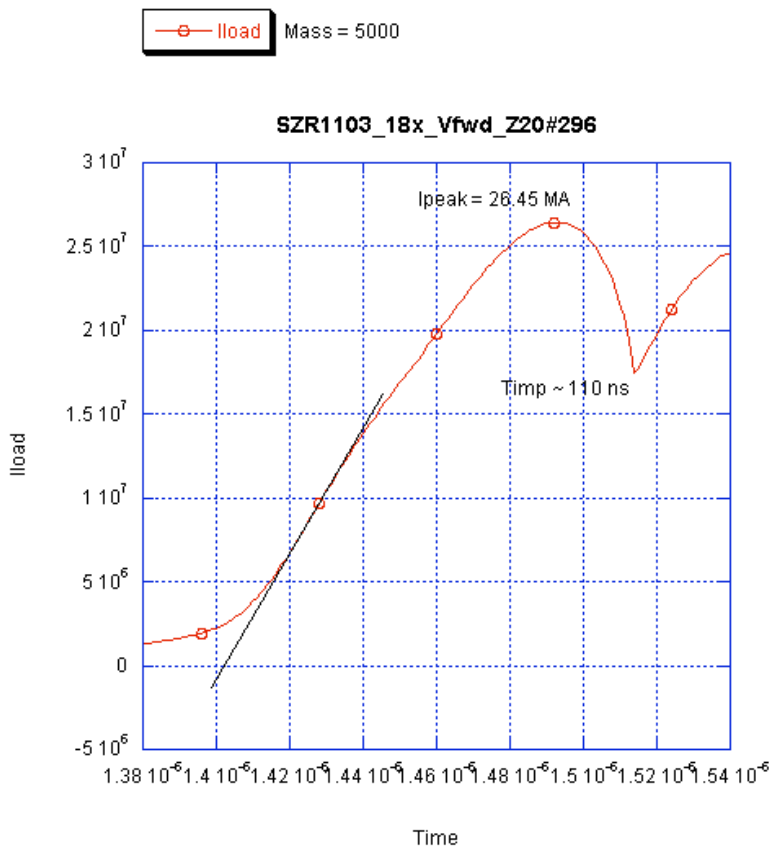
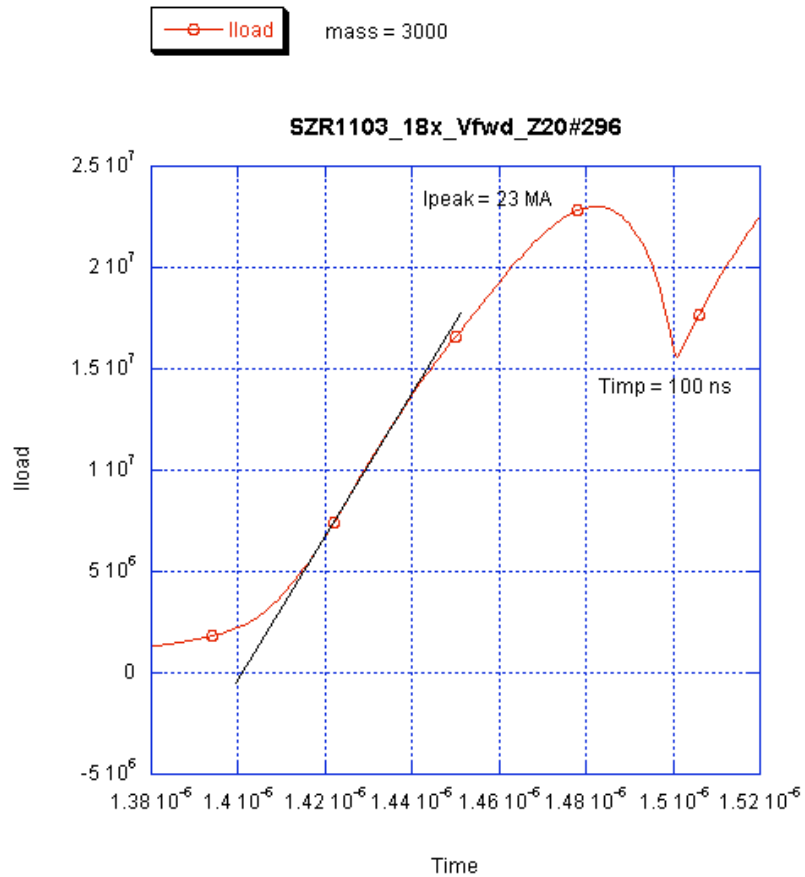
Scaling of SATPro V-forward to Z-R





TP6677d16x20 stack model

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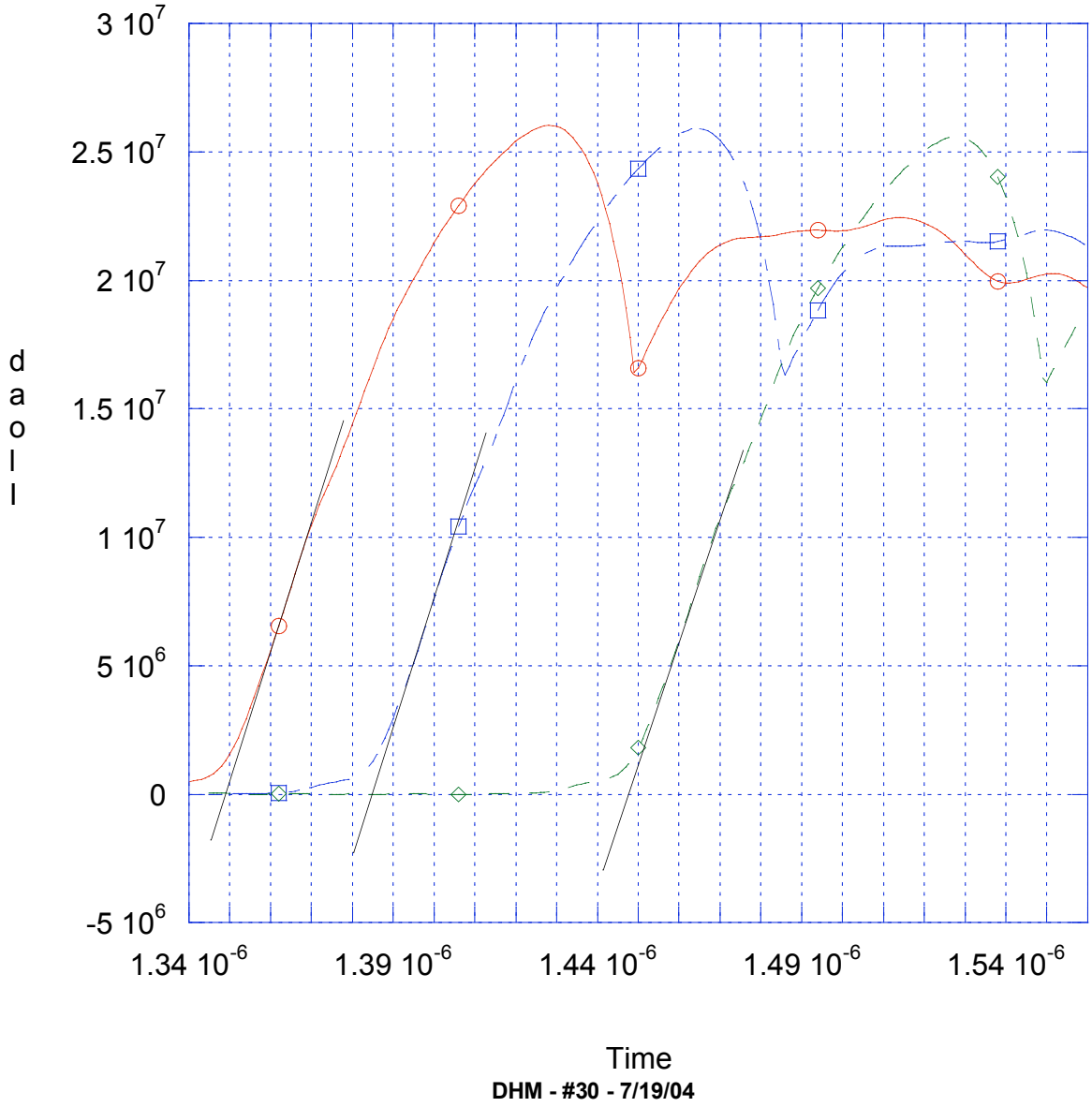
Iload	88kV - Timp=100ns	Ipeak=26MA
Iload	85kV - Timp=101ns	Ipeak=25.9MA
Iload	80kV - Timp=102ns	Ipeak=25.6MA

SZR1103_18x_TP6677d16x20_88kV4400mass_975-222-60



DHM - #30 - 7/19/04

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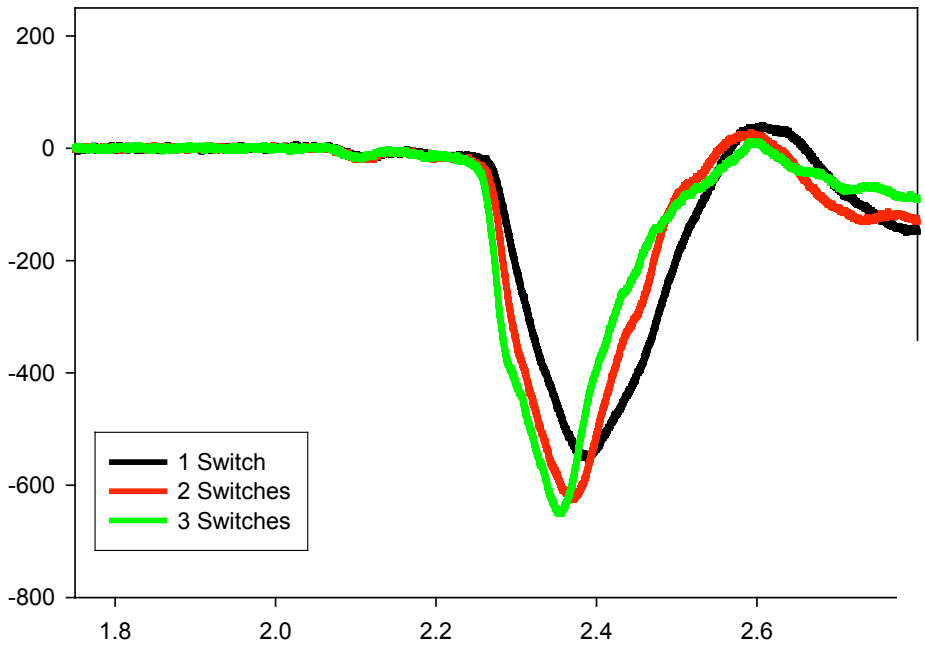
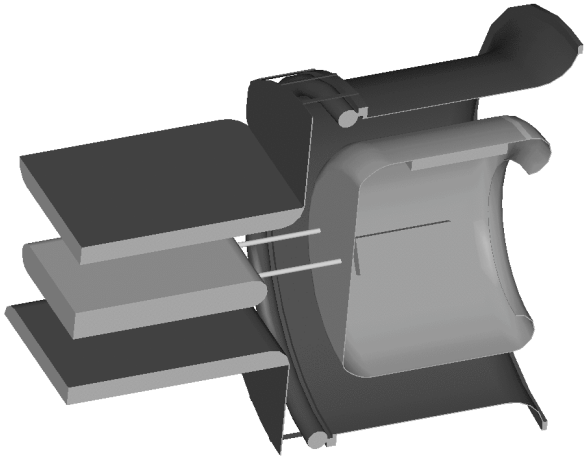
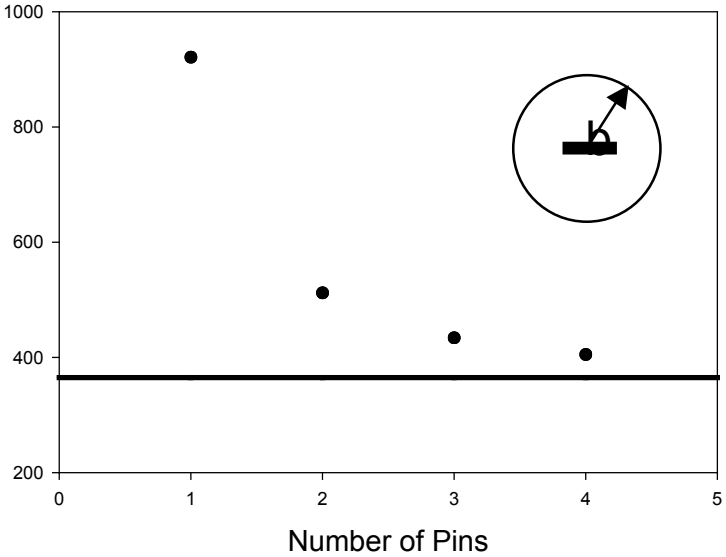
Number of Switches







# Sw	Ip (kA)	tr (ns)
1	553	86
2	626	77
3	651	76

Inductance is not linear with # of switches

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Water Switch Model

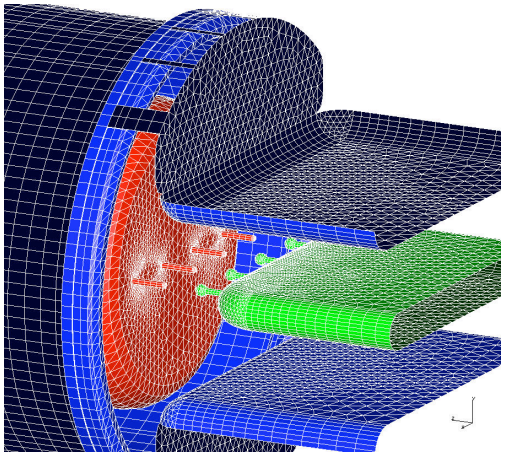
$$R(t) = (Zpfl + Zotl1) * \frac{e^{-t/\tau}}{1 - e^{-t/\tau}} + R_{final}$$

τ = JCM Resistive Phase time constant (ns)

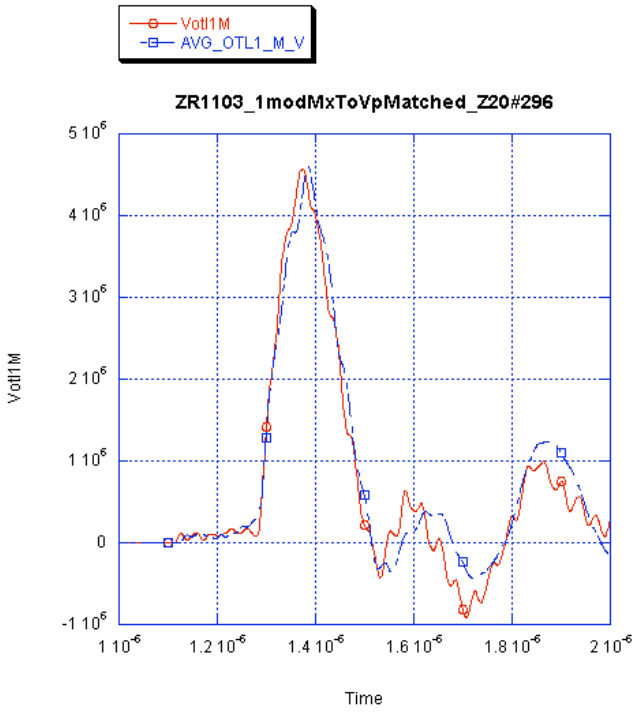
$\tau = 5 / (E^{4/3} * Z^{1/3})$

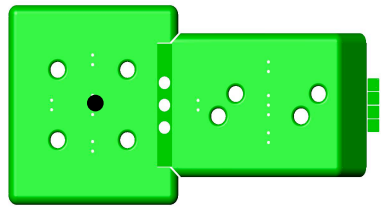
E = average electric field (MV/cm)

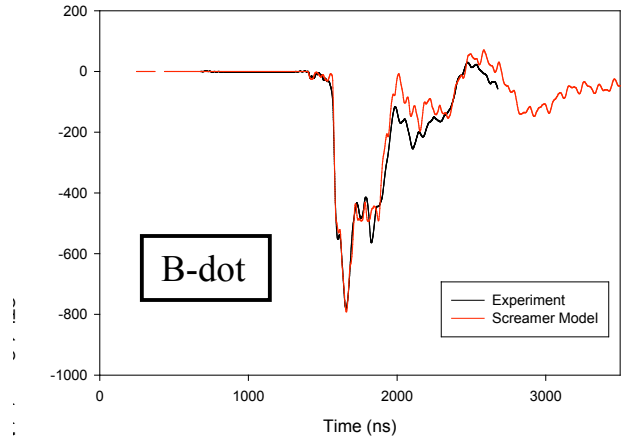
$\tau = 11$ ns

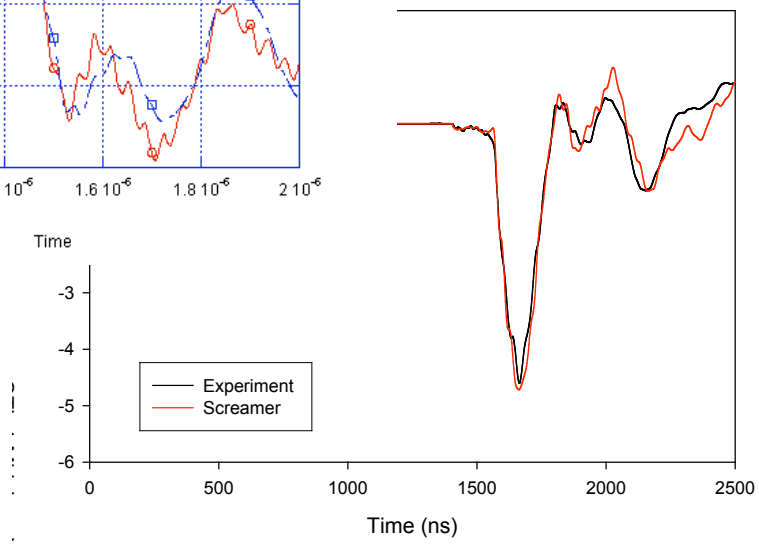


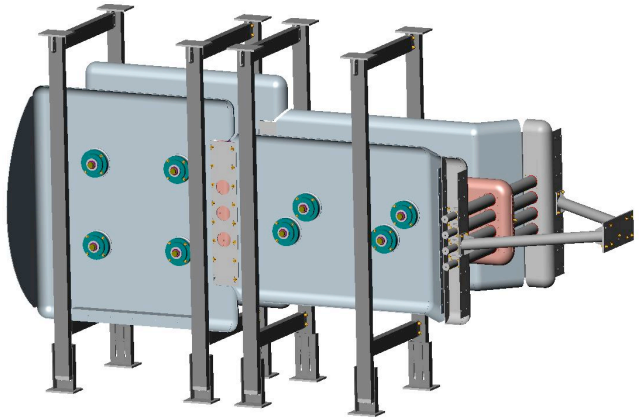
Match to Data:
OTL 1 Midplane V-dot & B-dot





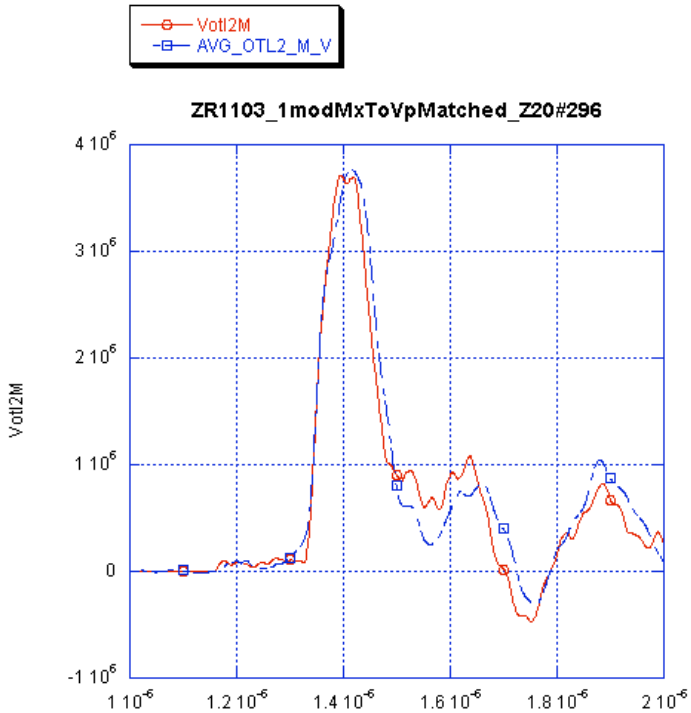


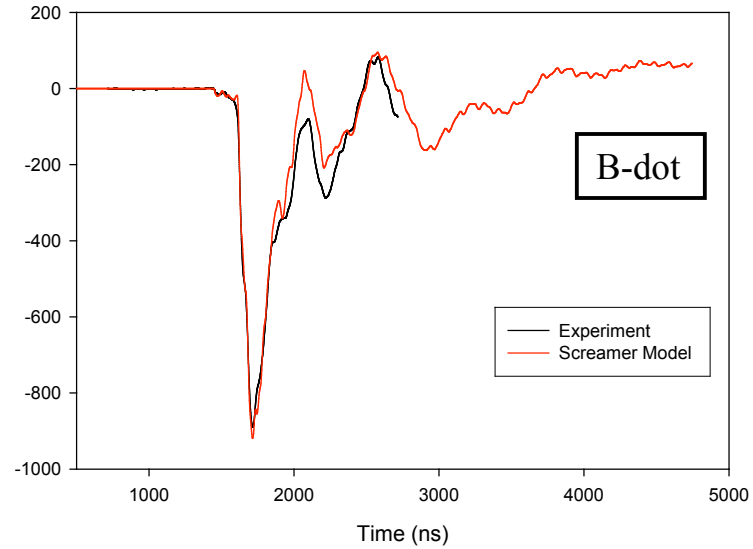


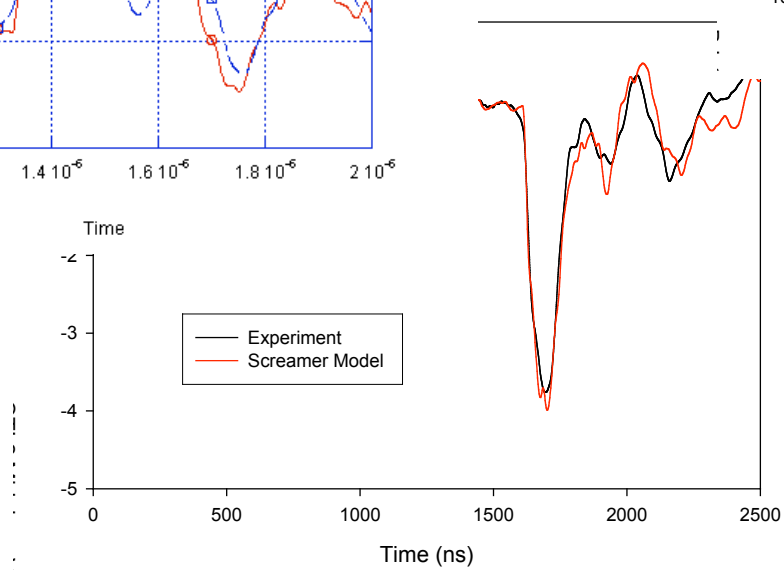


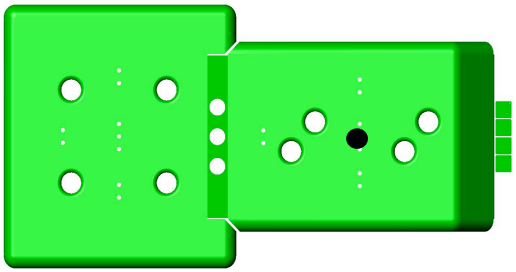
PPWS closed

Match to Data:
OTL2 Midplane V-dot & B-dot









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