OVERVIEW AND STATUS OF THE UPGRADED Z PULSED POWER DRIVER

SAND2008-3433C

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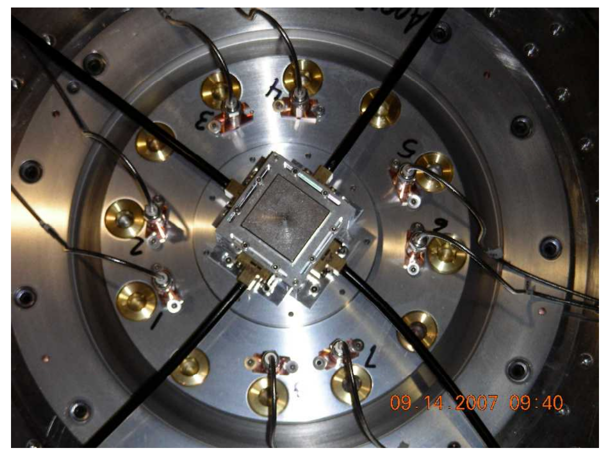

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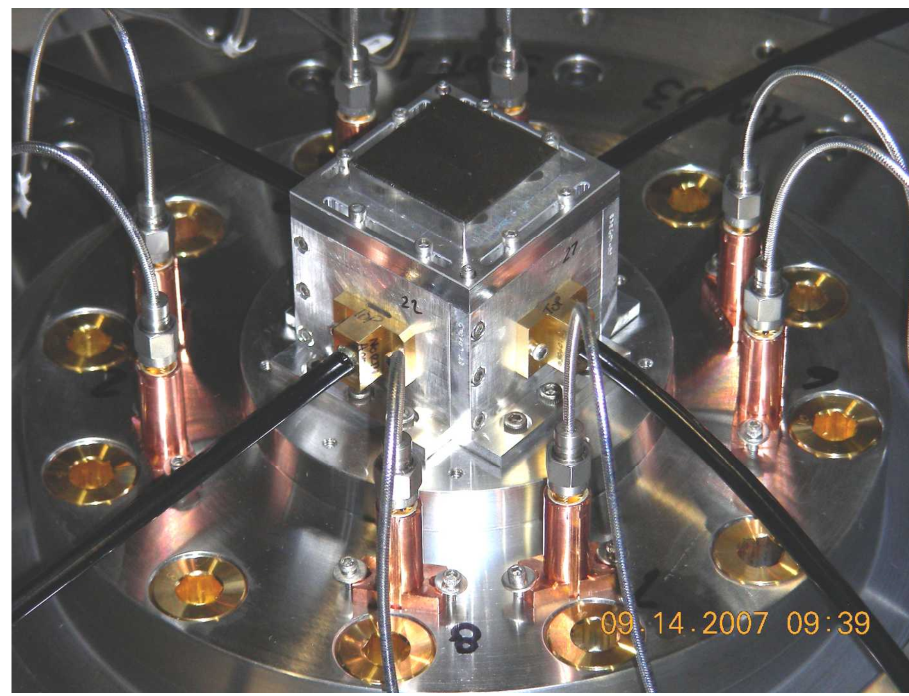
Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

The stored energy of the Z machine has been doubled, and high energy density physics experiments are being done now

- **25 MJ stored in the Marxes at 95 kV charge**
- **18 MJ stored at 80 kV Marx charge**
- **26 MA delivered into a dynamic material properties load in both long-pulse (250 ns) and short-pulse (115 ns) modes**



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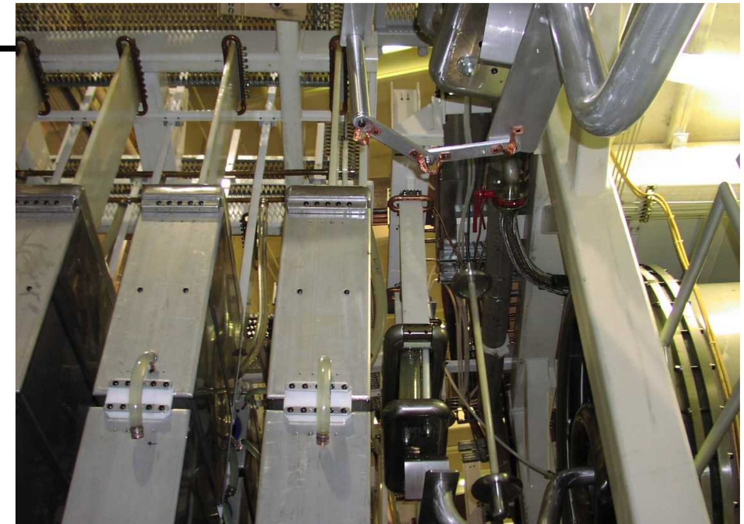
Outline

- Architecture
- Components
- Performance
- Conclusions



ZR is a large effort

Z_{20}/ZR pulsed power team: L. F. Bennett, J.R. Blickem, J.P. Davis, D. E. Bliss, W. T. Clark, R.S. Coats, J. M. Elizondo, K. R. LeChien, H. C. Harjes, W. L. Langston, 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

The ZR crew and staff: G.L. Donovan, D.S. Artery, T.G. Avila, M.J. Baremore, T.L. Bock, R. Chavez, G.D. Coombs, M.E. Dudley, N.L. Grelle, A.D. Jojola, A.K. Kipp, B.A. Lewis, J.J. Lynch, J.A. Mills, L. Molena, J.K. Moore, D.M. Pariza, D.W. Petmecky, S.D. Ploor, C.D. Robinson, E.L. Ross, S.A. Roznowski, T.M. Schweitzer, J.J. Seamen, J.G. Stewart, D.R. Thomas, H.M. Wagoner, S.D. White, J.M. Wilson, D. Woolcott

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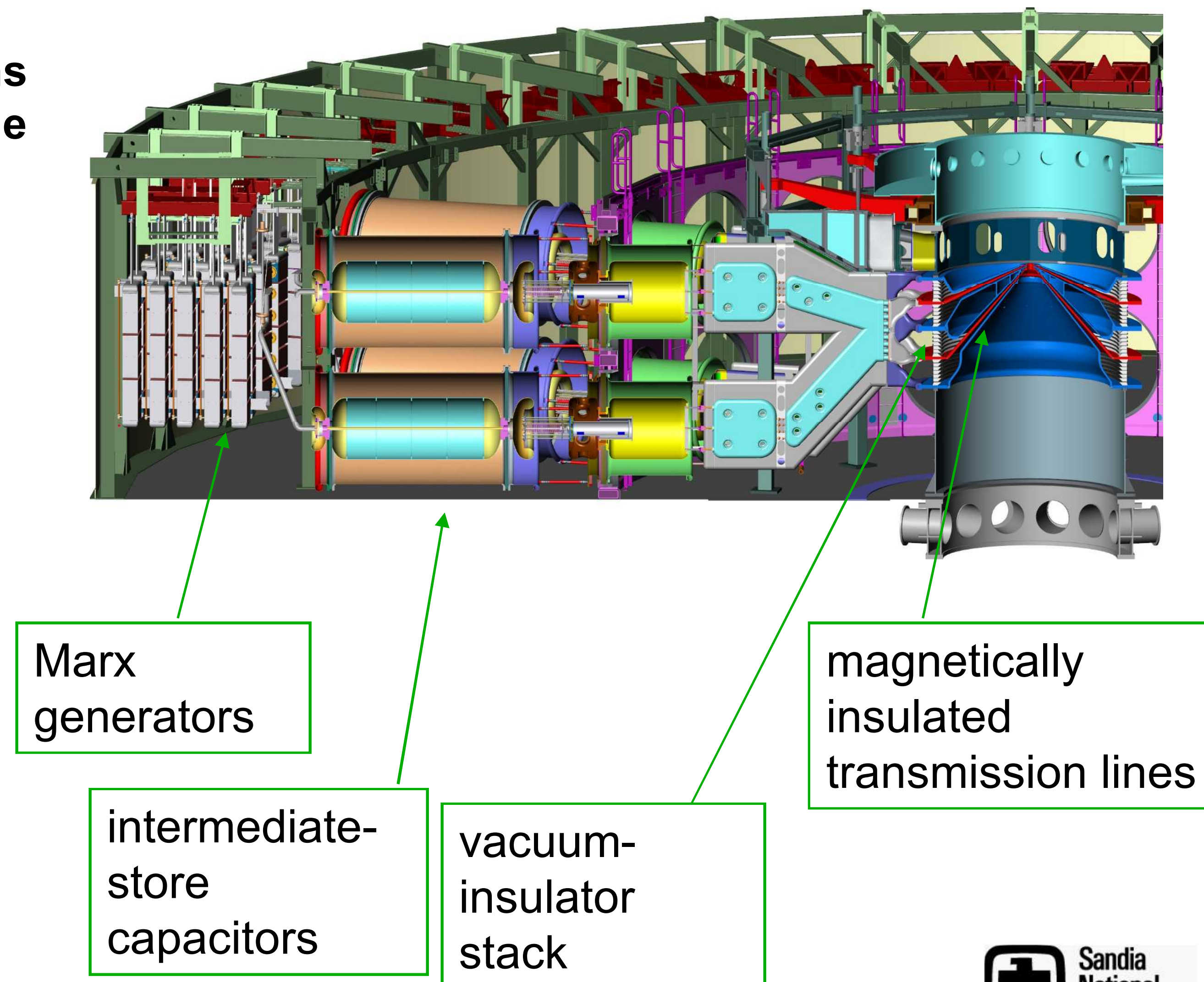
ZR architecture

A successful ZR shot requires operation of many systems with nanosecond accuracy

With all systems charged, a Z shot begins with a 5V signal from the control system:

- **The primary trigger generator amplifies the trigger pulse to 80kV**
- **The Marx generators are discharged in 1.2μs, charging the intermediate storage water capacitors**
- **The laser-triggered gas switches control discharge of the intermediate store capacitors with ~6ns accuracy**
- **The water switches discharge the pulse-forming line in 120ns with 2ns accuracy**
- **Load current rises in 115 ns to 26 MA**



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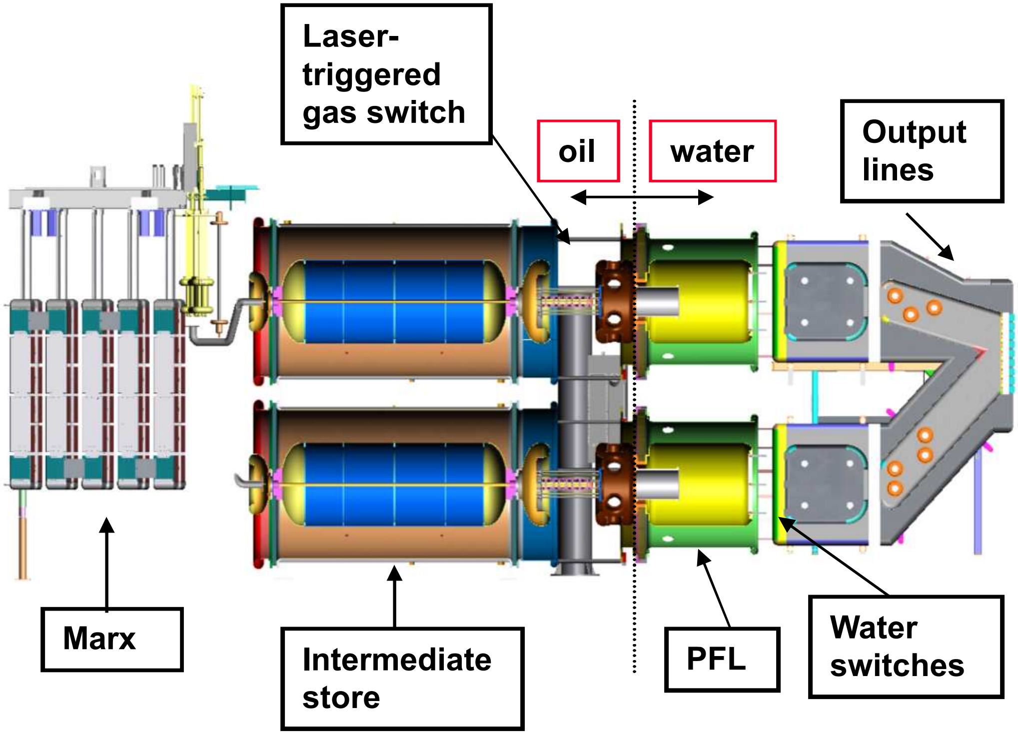
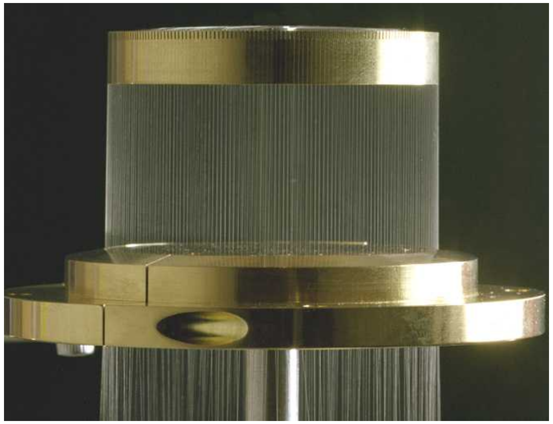
The Z pulsed power system

- Primary energy storage
  - Trigger generators
  - Marx generators
  - Intermediate store capacitor
- Switching
  - Laser-triggered gas switch
  - Water switches
- Water-insulated transmission lines
- Vacuum insulator
- Magnetically-insulated transmission lines, post-hole convolute, and load





Fully charged, ZR has considerable energy available

- At 100 kV (full rated) charge, the Marxes store 28 MJ (6.4 kg TNT equivalent)
- At 6.3 MV, the first compression stage stores 17 MJ
- The wave applied to the vacuum insulator stack has more than 9 MJ *in the first 100 ns of the pulse*
- This is applied to the load with ~1 ns accuracy

ZR has:

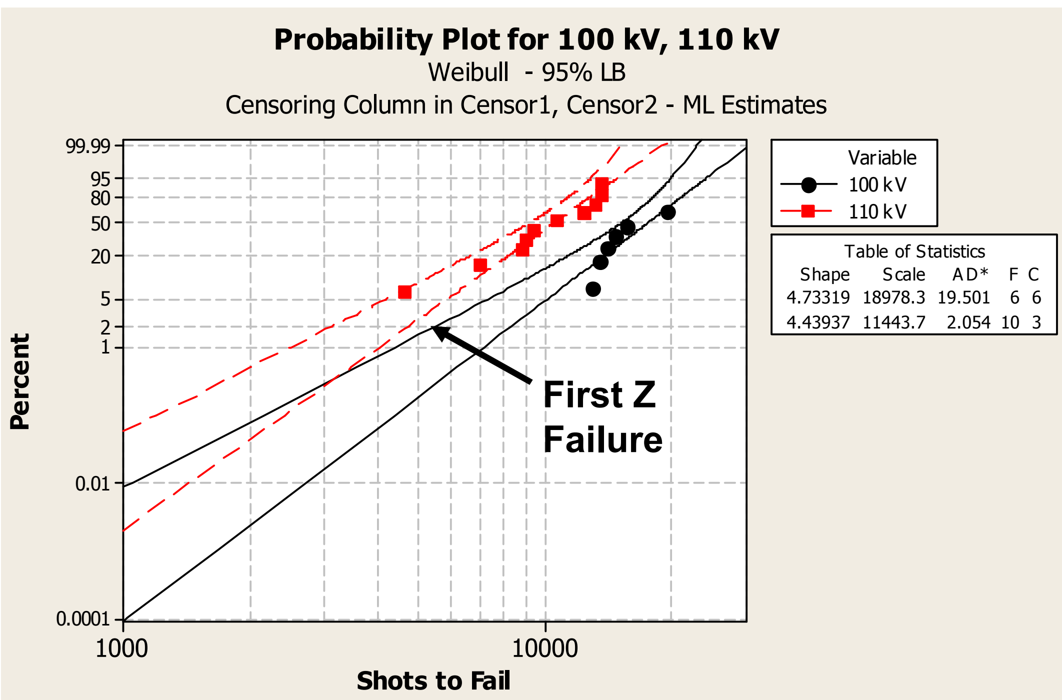
- *2341 DC-charged high-voltage spark gaps*
- *36 pulse-charged multi-megavolt gas switches*
- *252 pulse-charged water switches*
- *36 solid-dielectric switches*

Precision pulsed power requires robust triggering, accurate alignment, and accurate electrical field-shaping in large mechanical assemblies

ZR components

The ZR Marx capacitors were tested for reliability

- Capacitors were tested from several vendors
  - Lifetimes ranged from one shot to 18 thousand shots
  - The facility shot rate is up to 400 shots per year
- The 2.6 μF capacitor reliability is expected to be as high or higher than the 1.3 μF PBFA-II capacitors

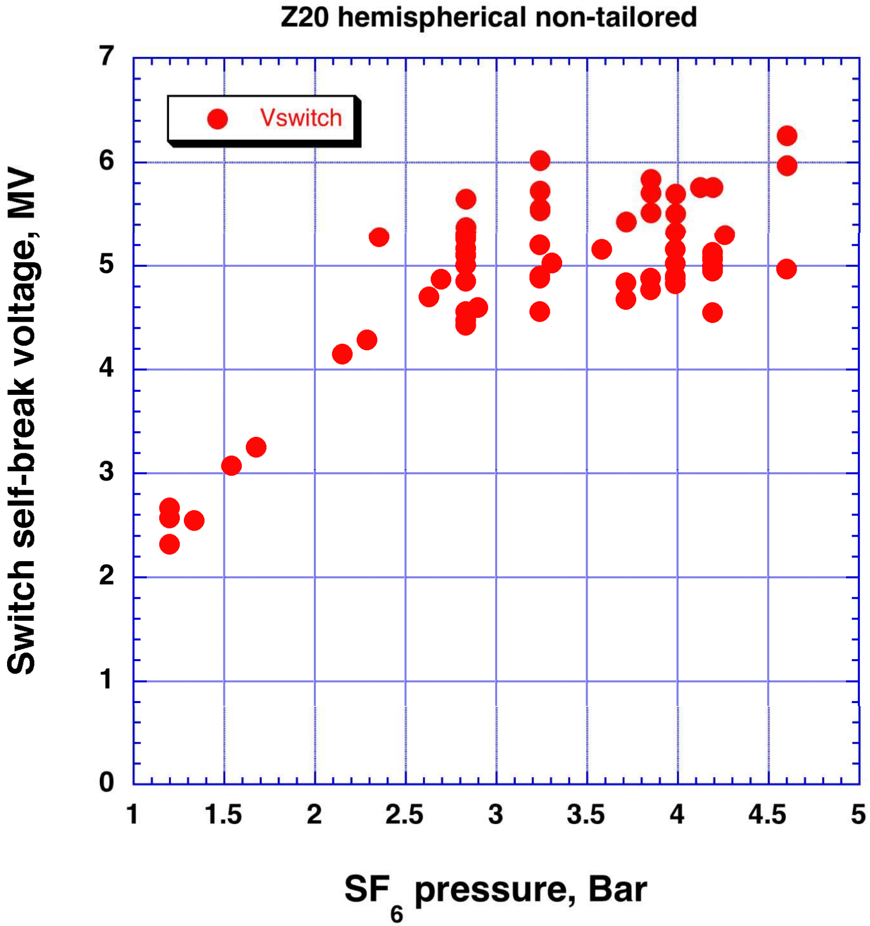


Extrapolating the 100-kV fitted curve, the first lifetime dielectric failure for a Z-sized population will occur at about 4,000 shots at 100kV.

Capacitor failures should be rare.

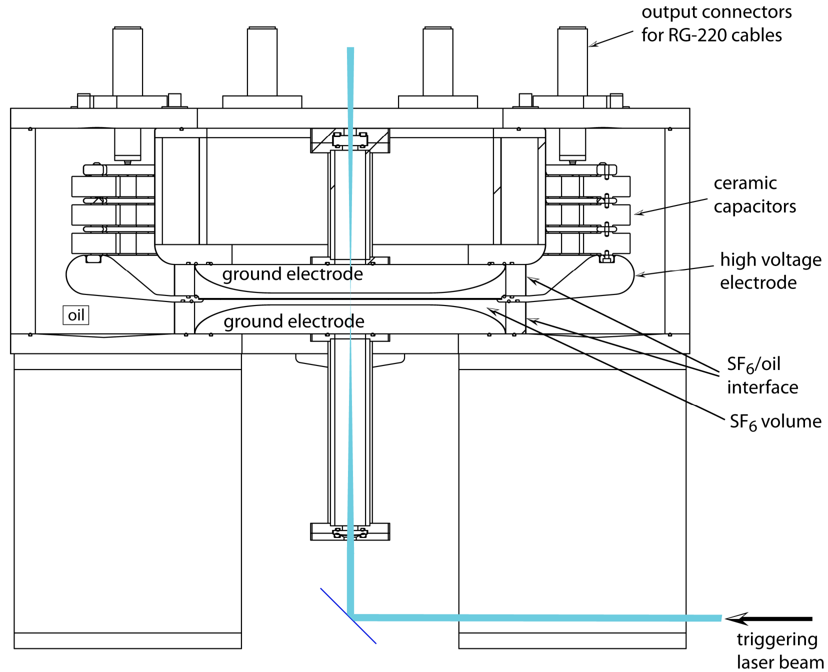
Precision pulsed power to ZR-class facilities means strong triggering and optimized switches

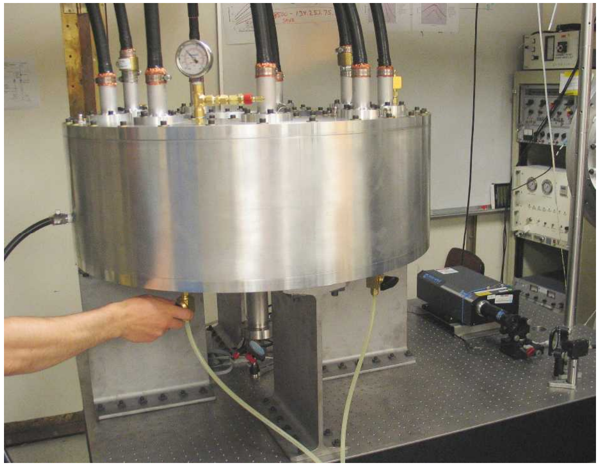
- **Sulfur hexafluoride insulated switches and UV lasers are a good combination**
- **Switches become less stable in high pressure sulfur hexafluoride; usable electric fields are limited to ~200 kV/cm for µs pulse-charged switches**



One of the most challenging systems is the primary trigger generator

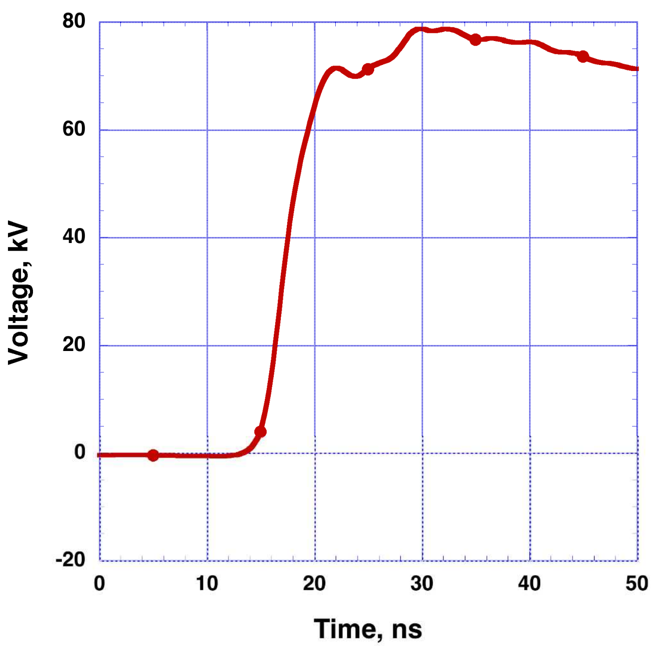
- **The primary trigger generator amplifies the ~5 V command trigger signal to 80 kV**
- **The lack of commercially-available generators mandated development of a novel system**
  - **Total closure spread: 1.1 ns**
  - **Jitter: 560 ps 1-σ(total system)**
  - **Pre-fire rate: <0.1%**
  - **Rise time: 6 ns**
  - **Inductance: *0.15 nH per kilovolt***

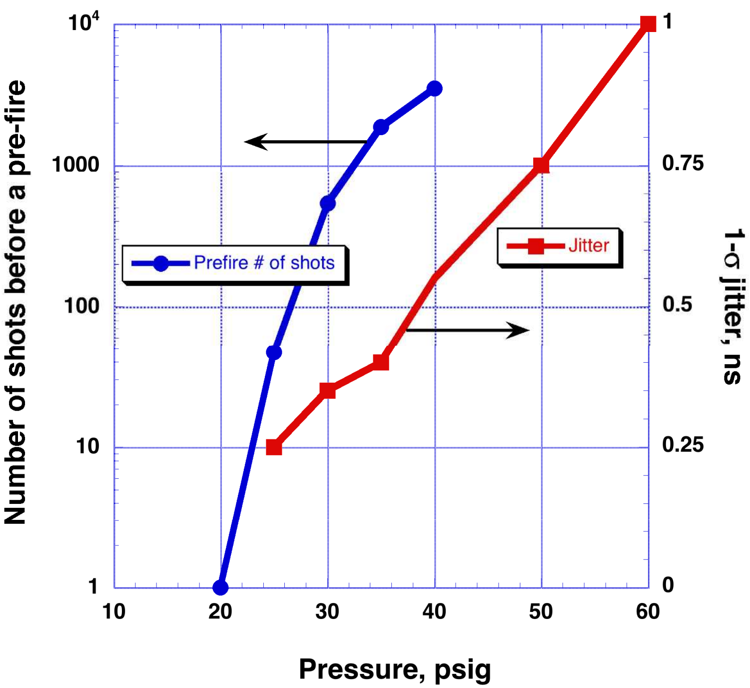




UV laser-triggering is an effective way to create plasma in SF_6 on a ~1 ns time scale

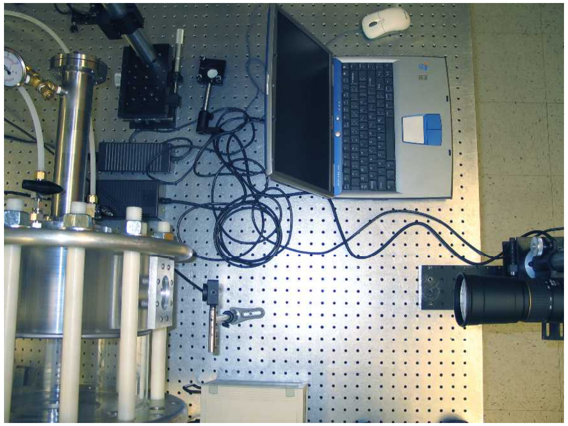
- **The system uses a low-inductance switch geometry with laser triggering to minimize jitter and risetime, and maximize reliability**
- **The system provides *simultaneously:* low jitter, fast risetime, and high reliability**

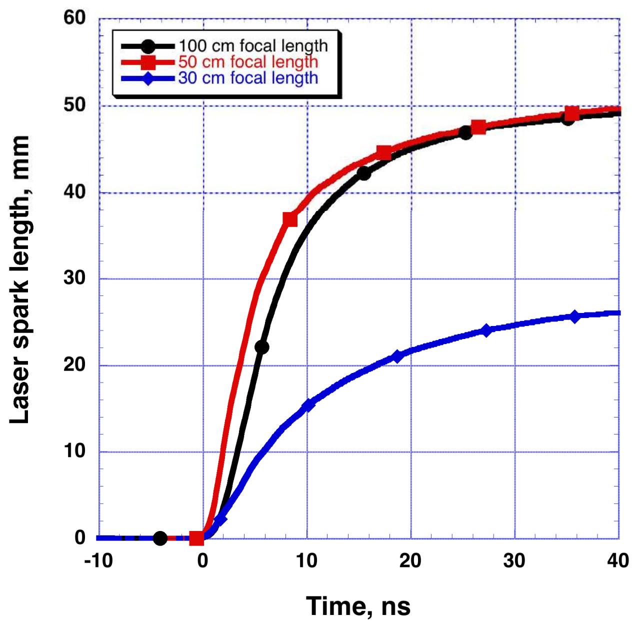


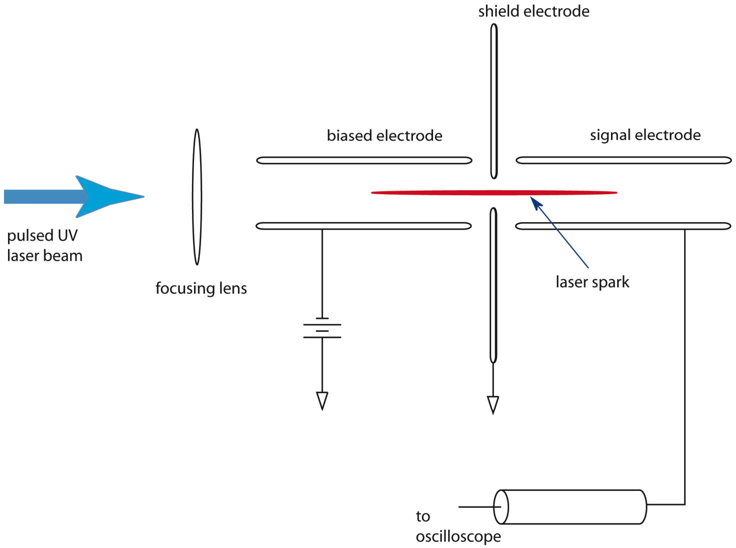


Laser triggering is an important part of precision switching

- Characterizing and optimizing laser triggering is vital to maximizing system performance

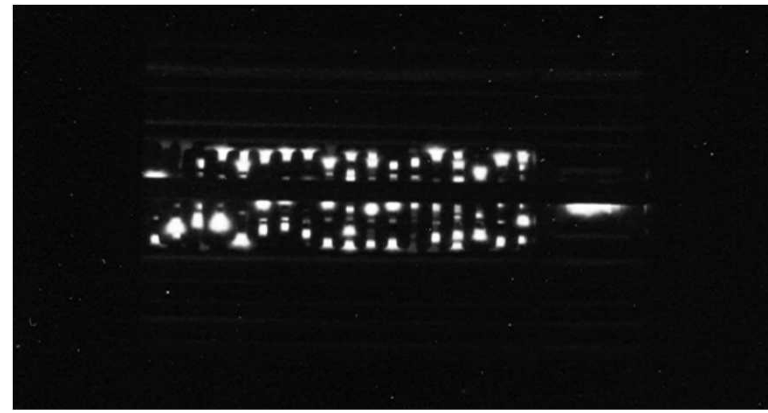


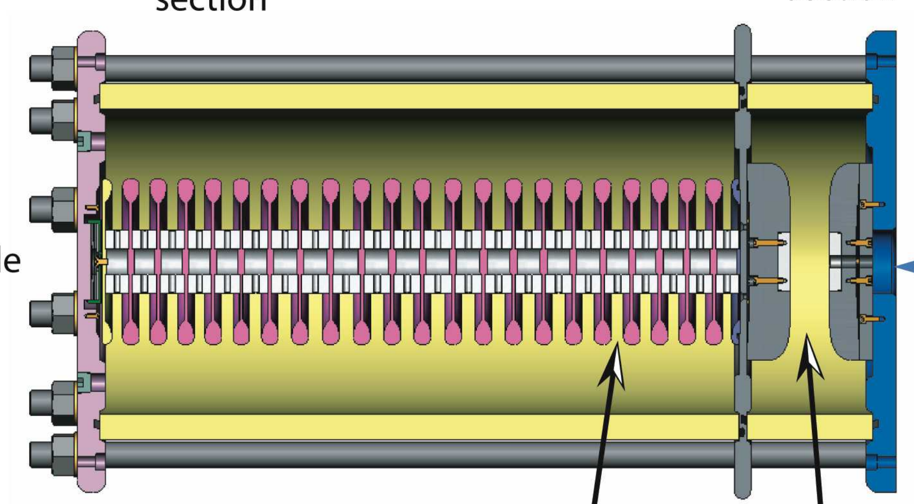


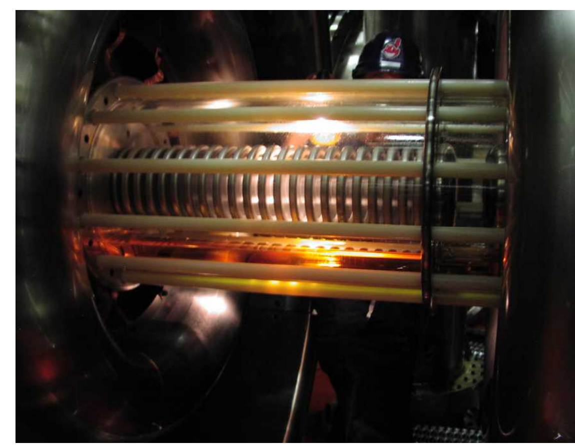


The laser-triggered main gas switches perform the final time synchronization

- **The laser-triggered gas switch sees 6.25 MV rising in 1.2 μs, then conducts 750 kA with nanosecond precision**







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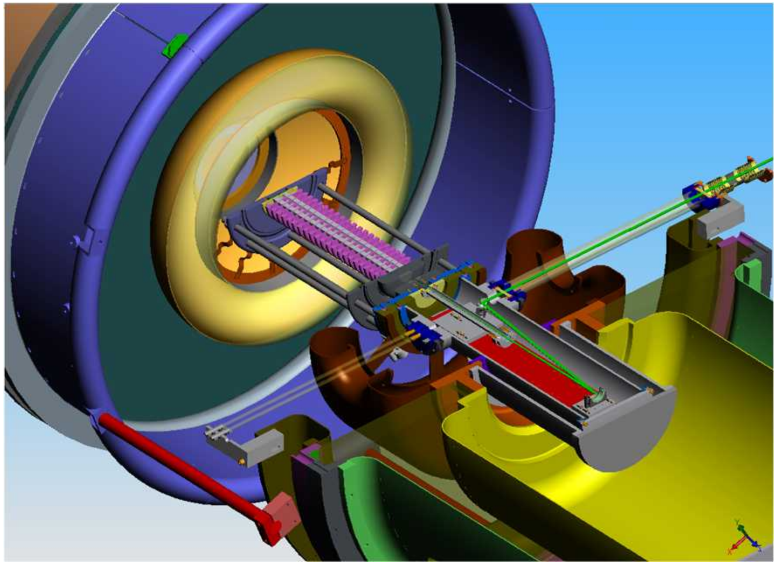
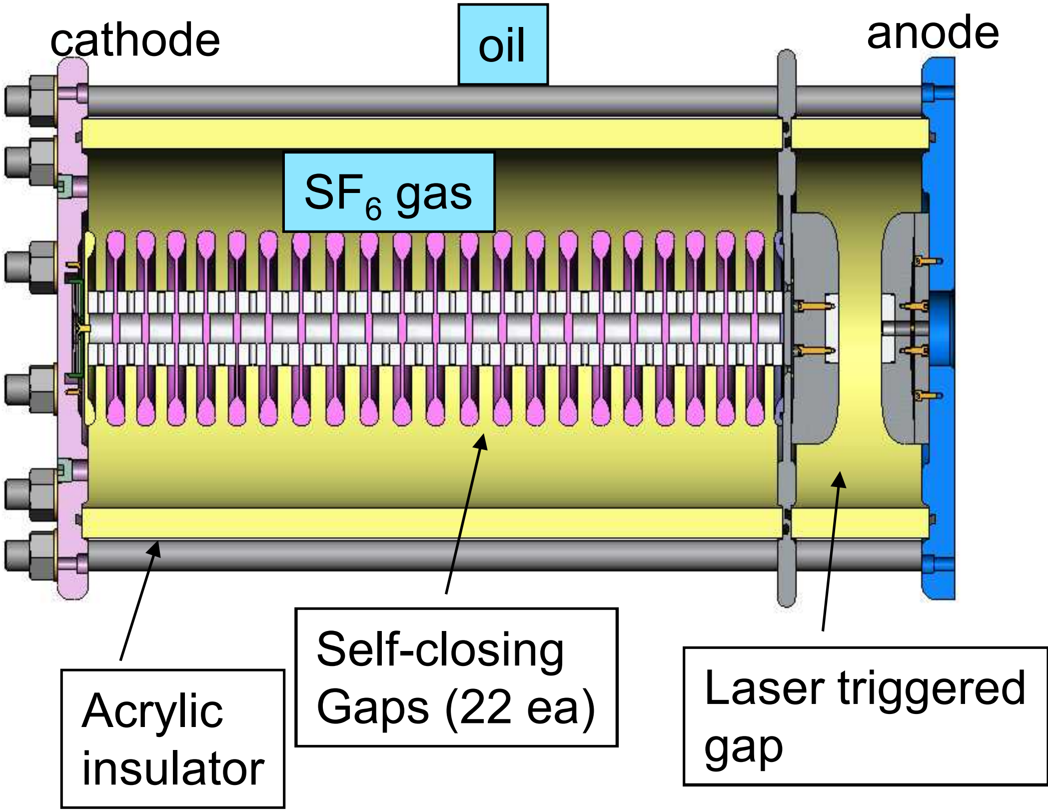
The laser triggered gas switch is the final command-triggered switch

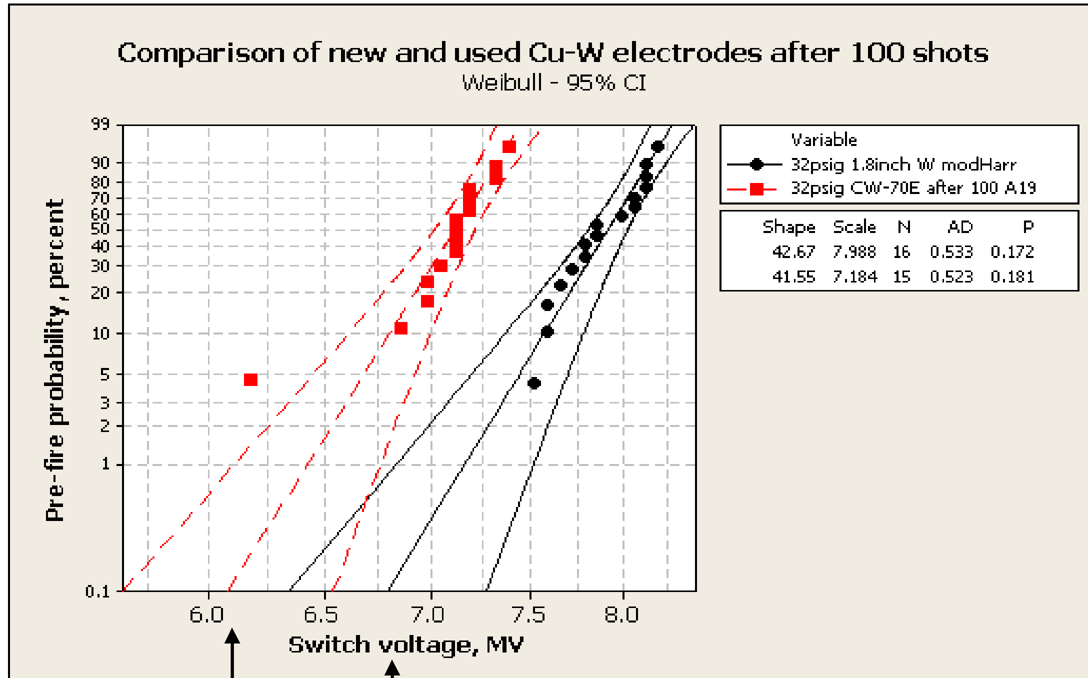
- **Switch must withstand 5.4-6.3 MV before trigger**
- **Switch must conduct 600-800 kA**
- **Total jitter less than 6 ns**
- **Life: >100 shots**





Statistical analysis is used to estimate pre-fire rate from small numbers of self-break tests

- **The ability to quantify the actual effects of erosion (without disassembling the switch) is useful**
- **The predicted pre-fire rate at 5.4 MV is less than 0.05% at a pressure commensurate with 4 ns jitter (3.1 bar)**



After 100 Shots *6.1MV at 0.1%*

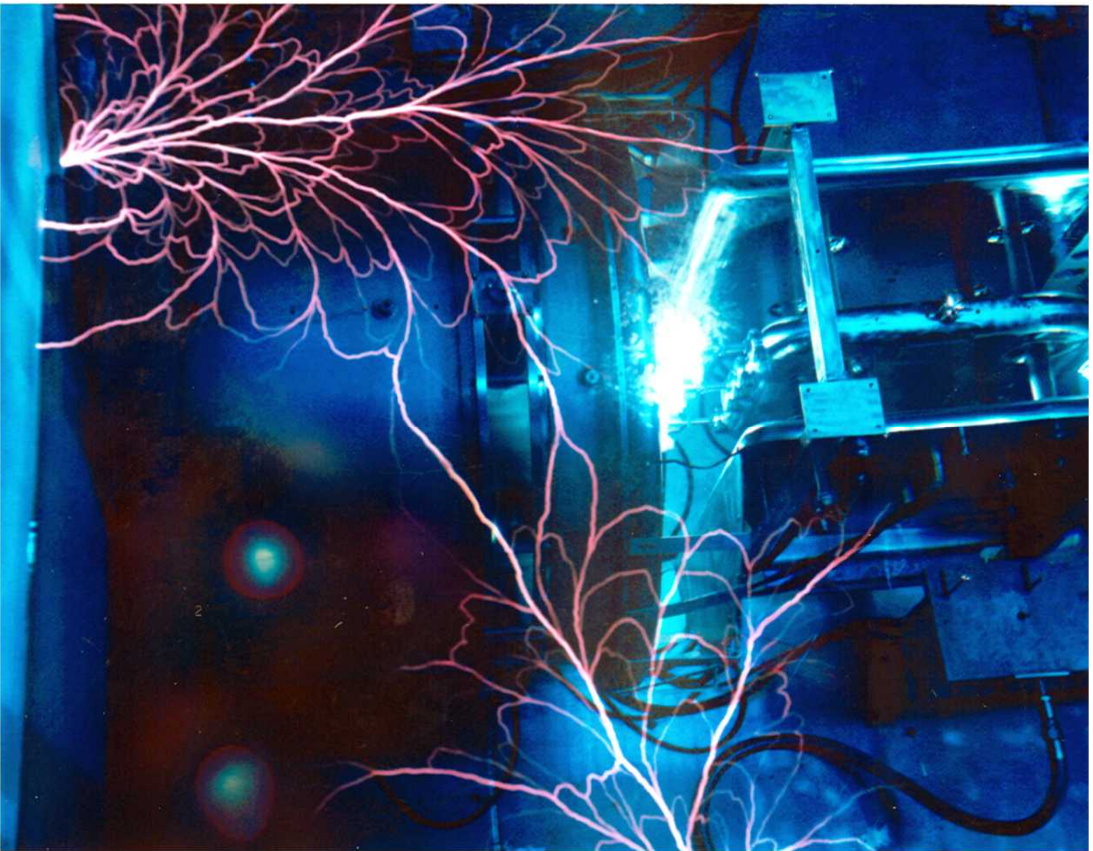
New *6.8MV at 0.1%*

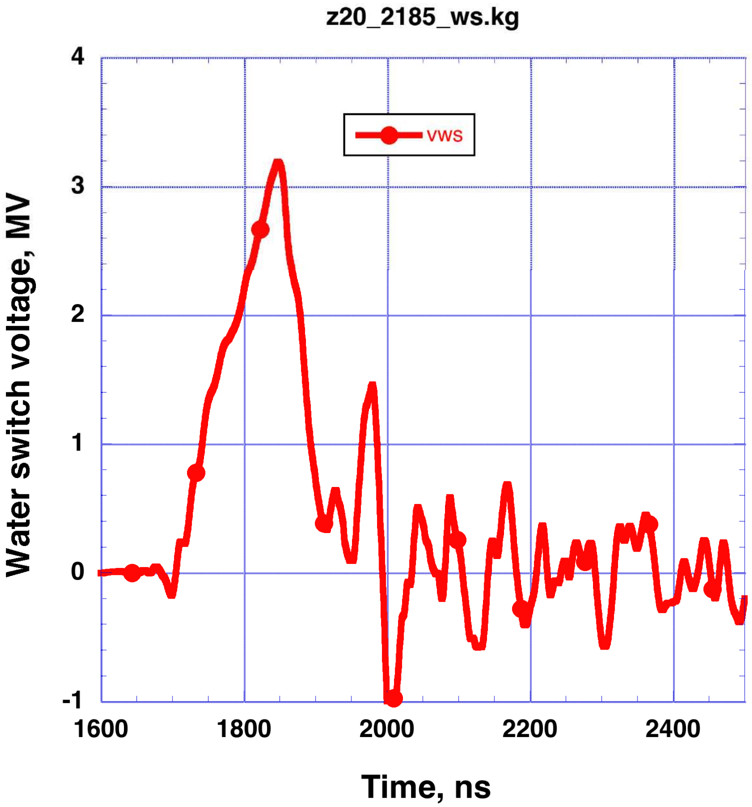
The pulse-forming line is charged through the laser triggered gas switch, and discharged through the water switches

- The 14 nF PFL is discharged through 3 parallel self-closing water switches
- Water switch losses are noticeable
- Jitter: ~3 ns for main and pre-pulse switches

The water switches transfer energy with low jitter

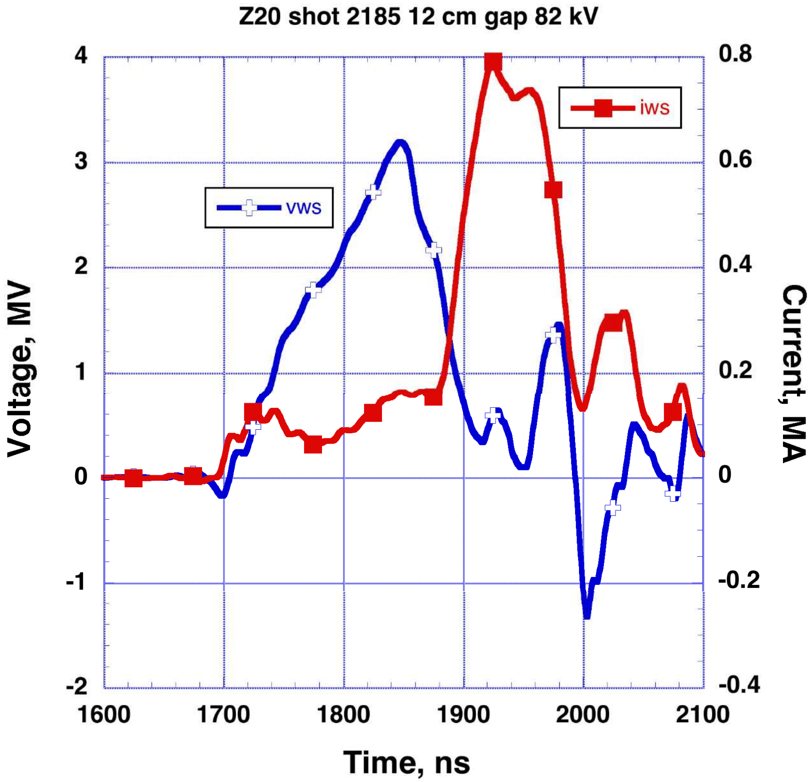
- Jitter: ~3 ns

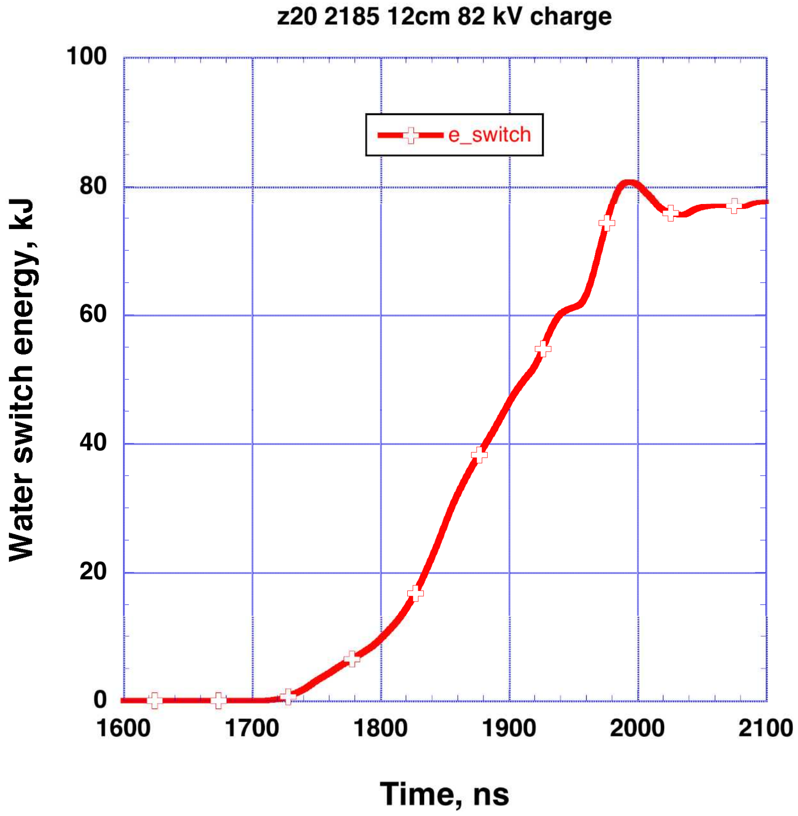




Some energy is dissipated in the water switches

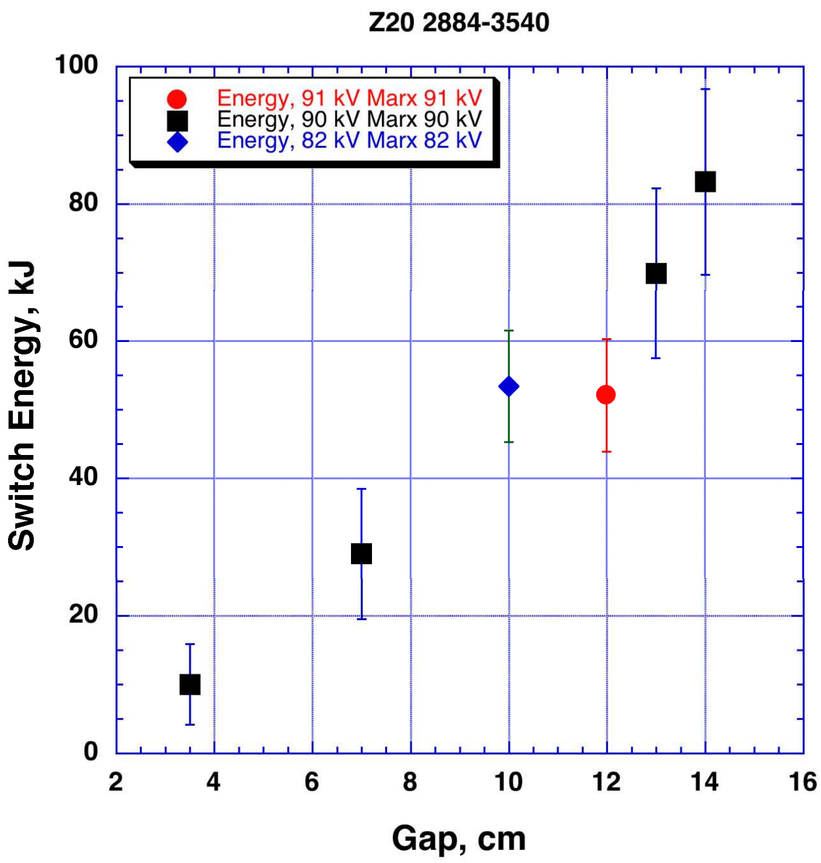
- Data analysis done by transmission-line correcting voltages and currents to the switch location





Water switch energy increases with gap

- **Losses at large gaps are large enough to warrant improvement studies**

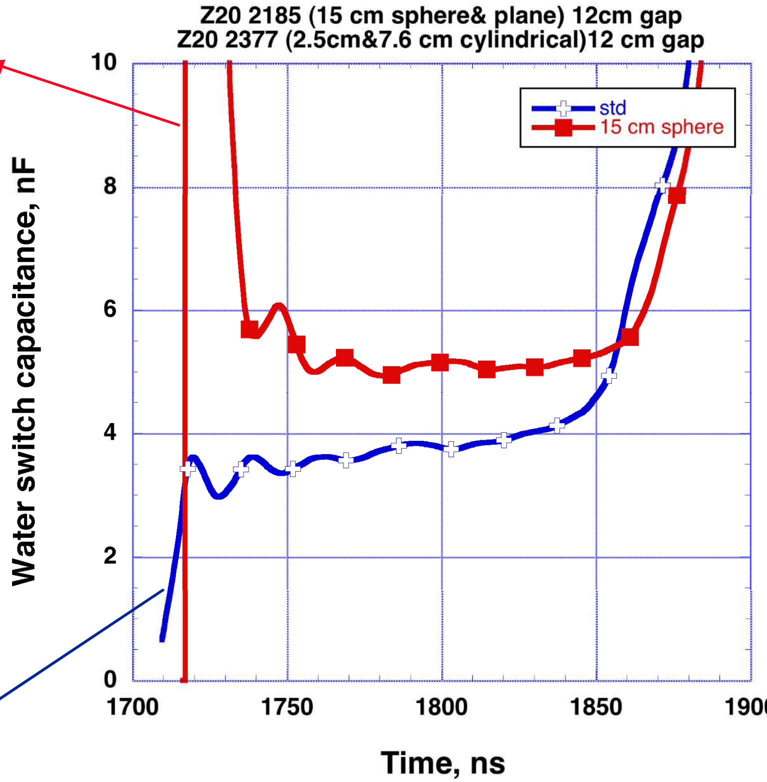


The measured capacitance across the water switch rises as streamers close the gap

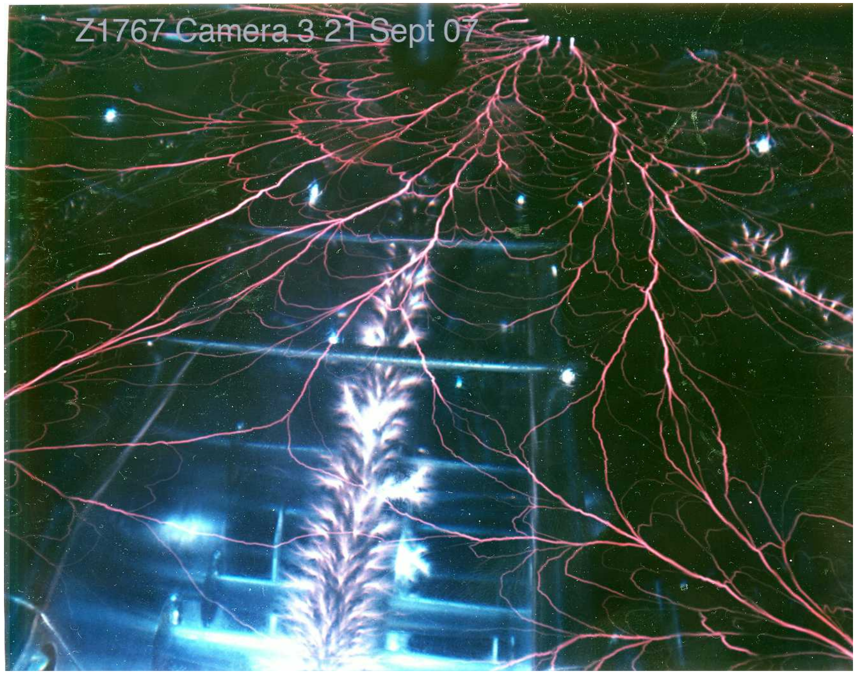
$$I = \frac{d}{dt}(CV)$$

$$C = \frac{\int_{-\infty}^{t} I d\tau}{V}$$

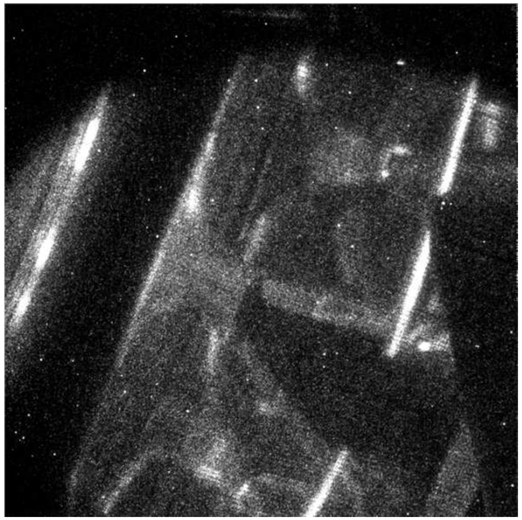
The more enhanced electrodes have lower capacitance initially, but more change in capacitance as streamers grow



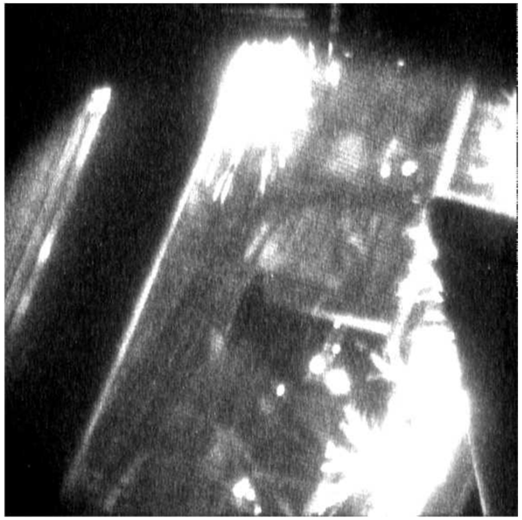
Water streamers occur well after the power pulse



Time integrated



100 ns after peak power

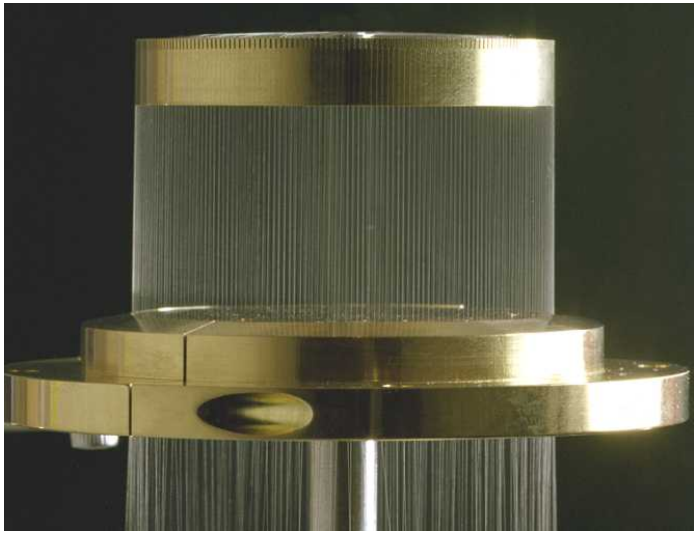


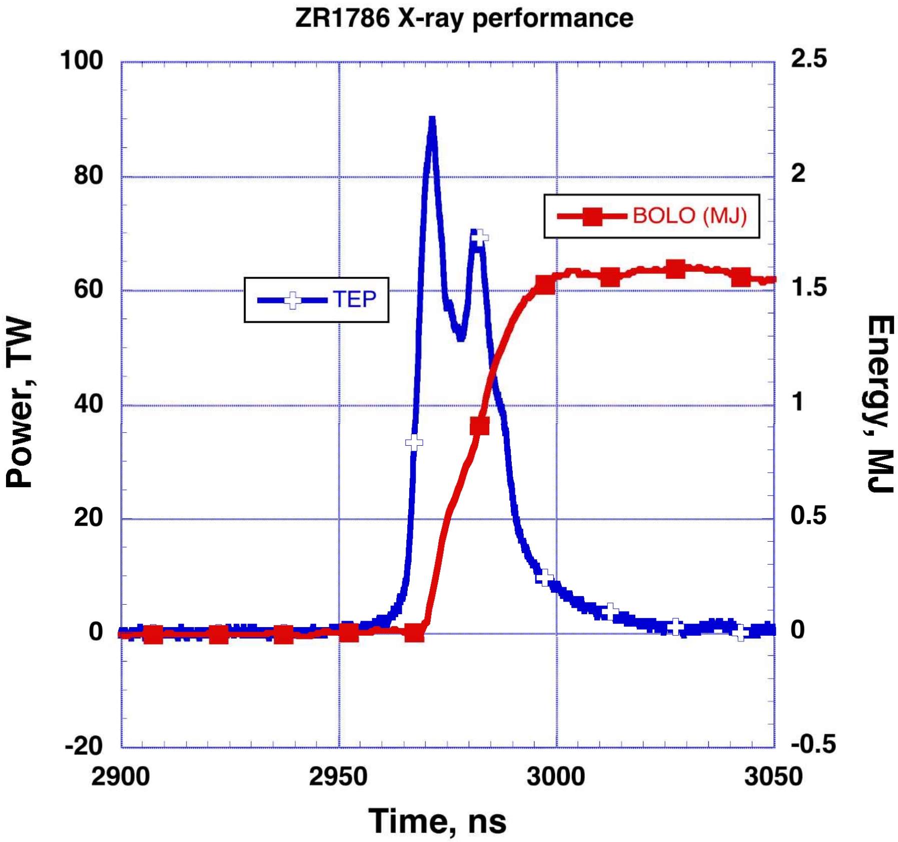
500 ns after peak power

ZR performance

ZR has produced 1.6 MJ of X-ray energy at 88TW

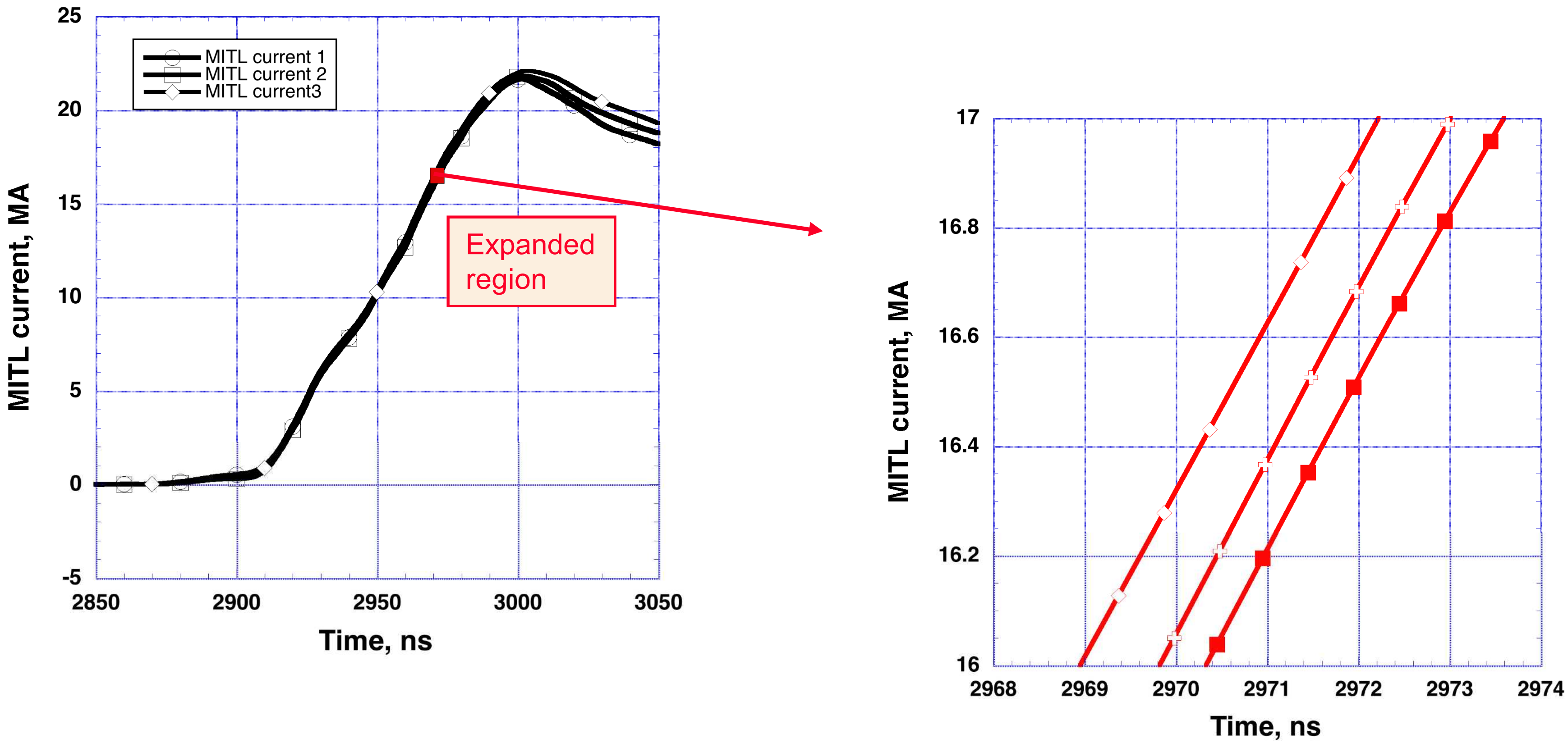
- Effort is ongoing to optimize the load for the drive circuit





Identical shots show good repeatability of the load current

- Three identical (machine configuration) shots



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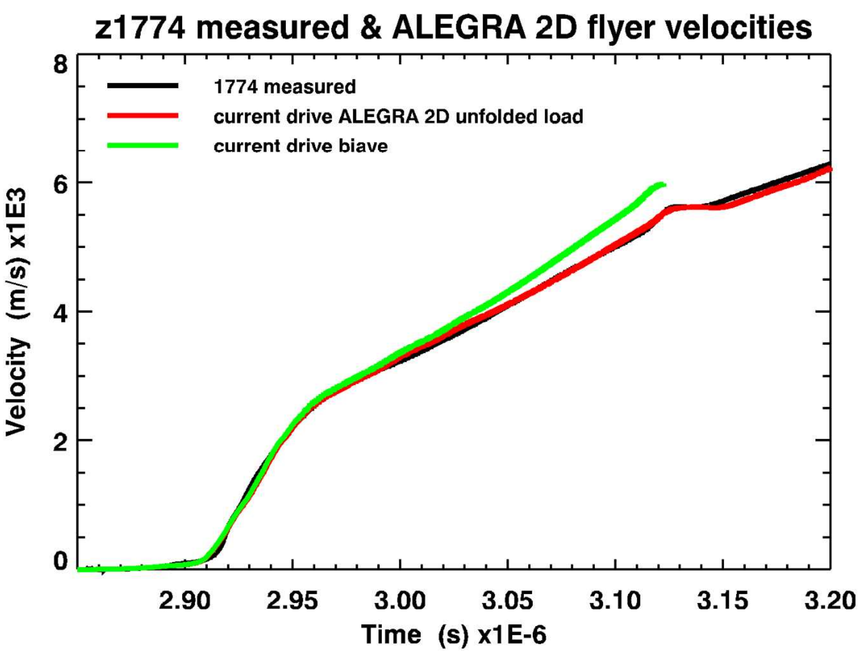
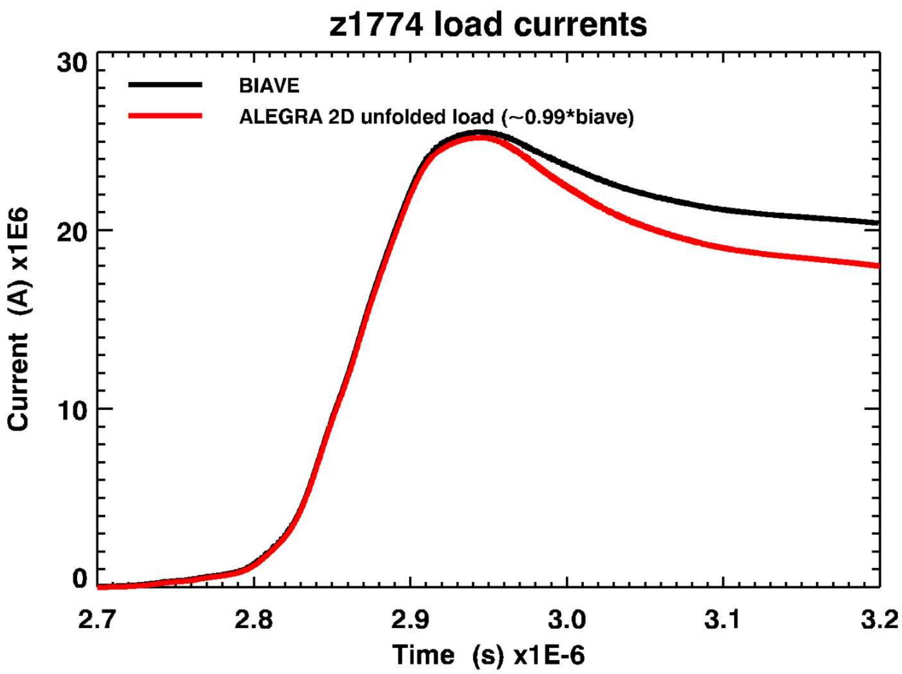
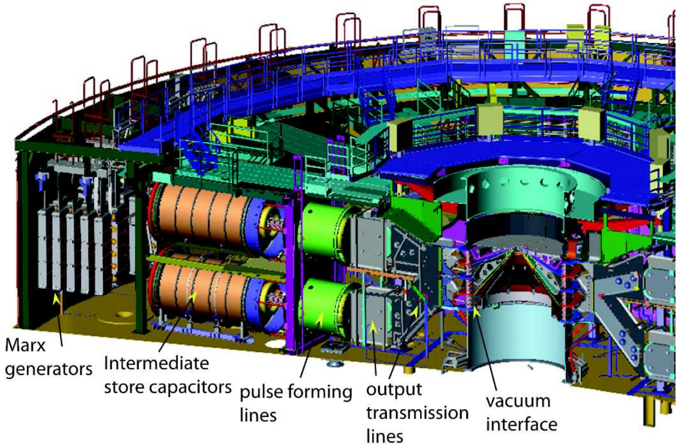
ICE shots allow current measurement *at the load*

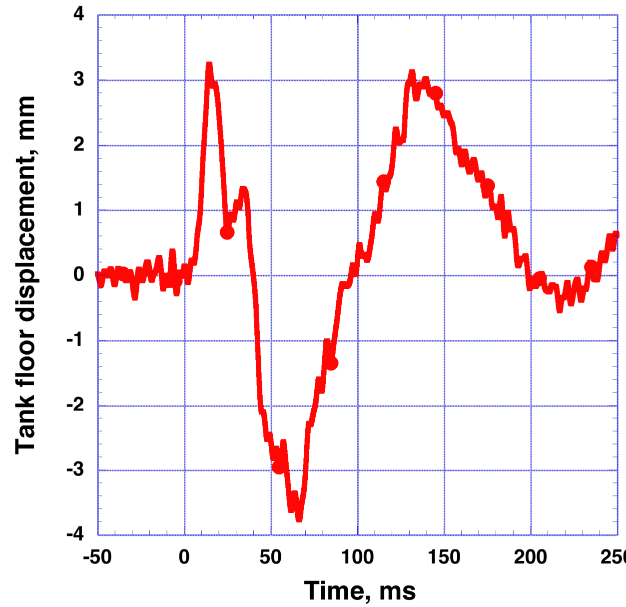


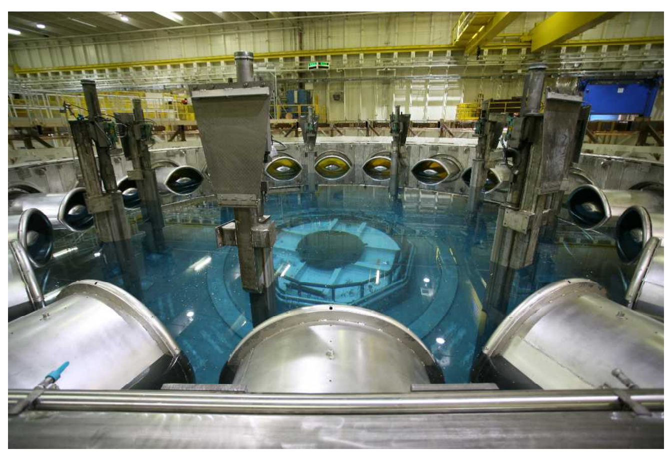


On ZR1774, the load Bdots agree with the flyer unfold to ~2%

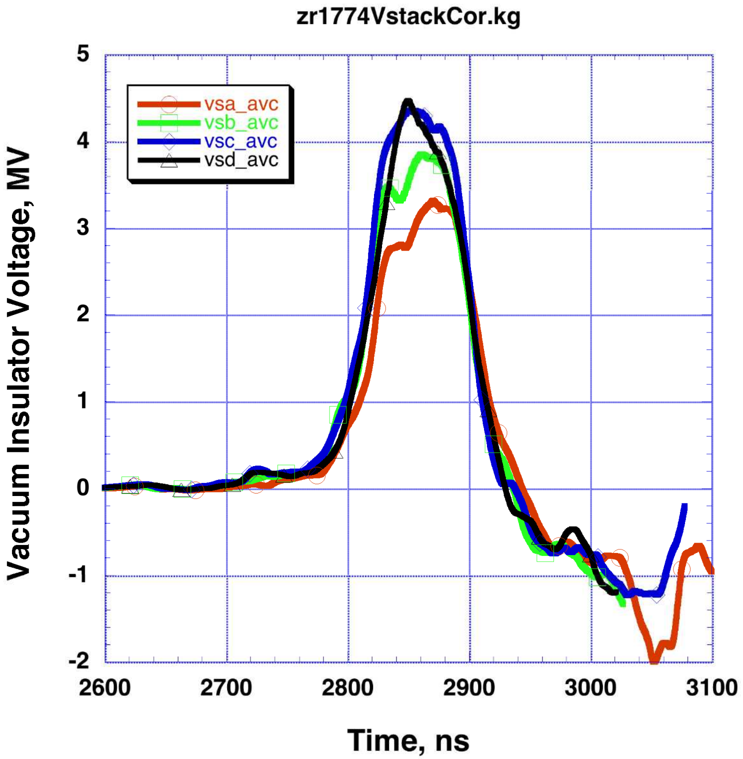
The large amount of energy causes motion of the massive tank

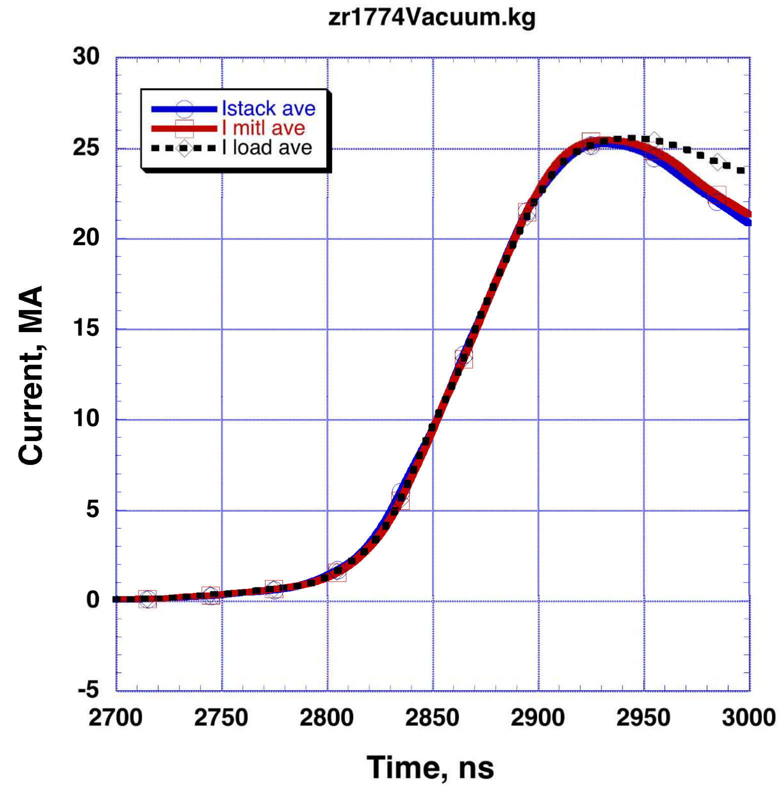






ZR acquires more than 600 fast waveforms on every experiment





Data quality allows improved understanding of the system

Summary

- The Z machine has been rebuilt to increase energy and improve reliability
- The system is being optimized as high energy density experiments are beginning
- Peak load currents of 26 MA have been achieved in short (115 ns) and long (250 ns) modes of the machine
- Reliable and accurate switching are crucial for a system with thousands of individual switches
- Continual improvement in understanding and operation of the switching will allow further improvement of the system