



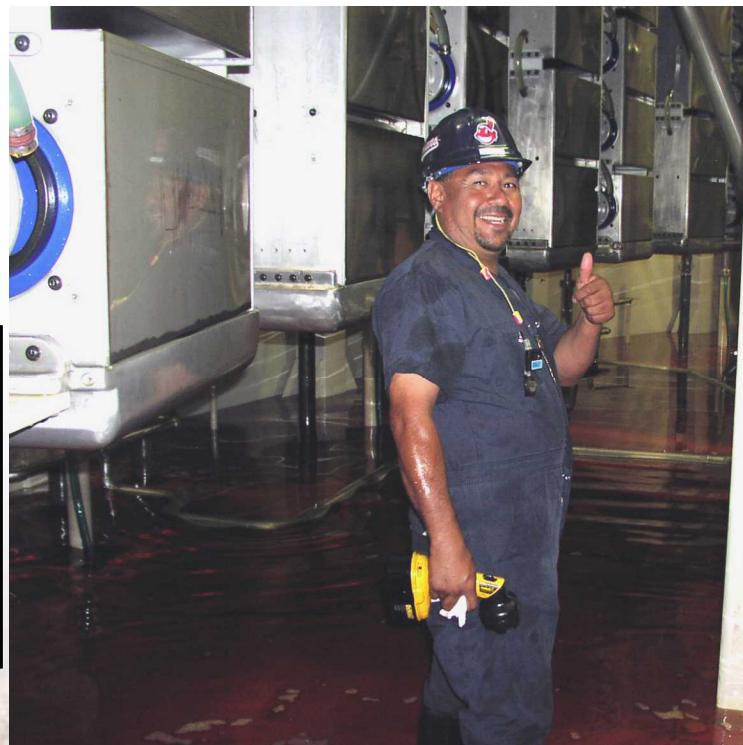
The Z pulsed power driver since refurbishment



Mark Savage

Sandia National Laboratories

Albuquerque, NM, USA



The 13th International Conference on Megagauss

Magnetic Field Generation and Related Topics

Suzhou, China

8 July 2010



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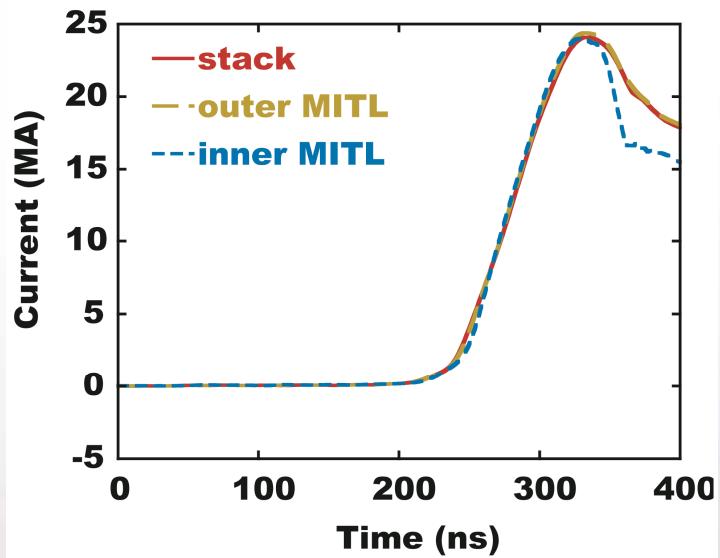


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The Z pulsed power driver reliably delivers 20-25 MA currents to high energy density physics loads



- 85 ns 10%-90% current rise time
- 82 TW forward wave power
- 6.9 MJ forward wave energy

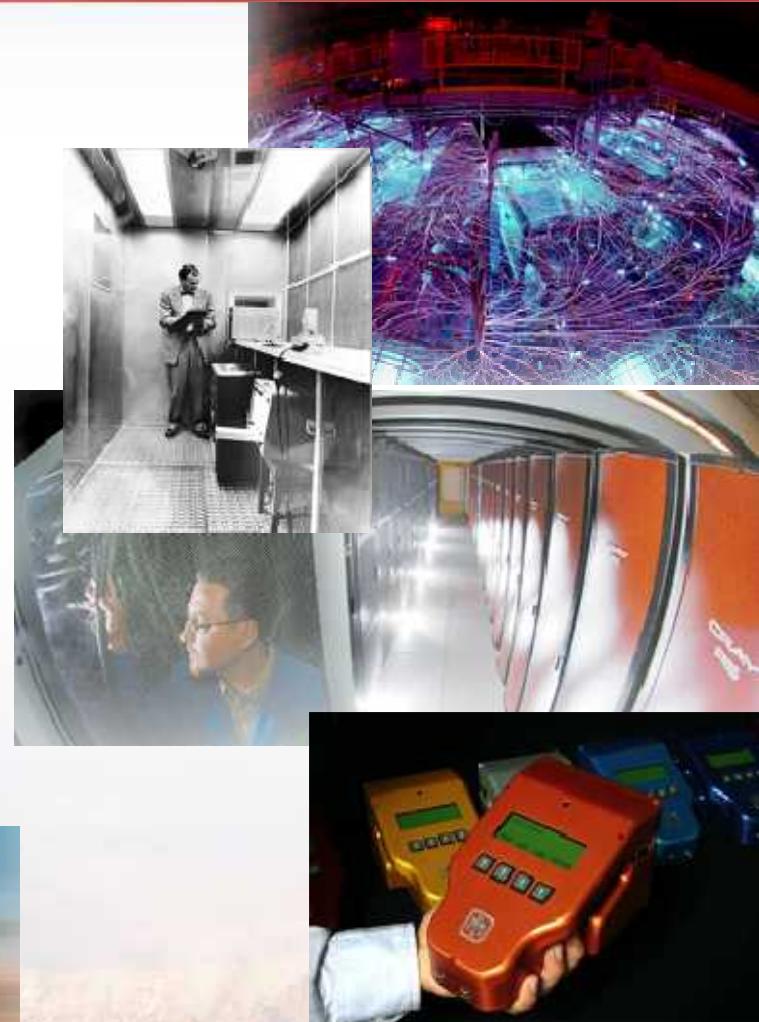
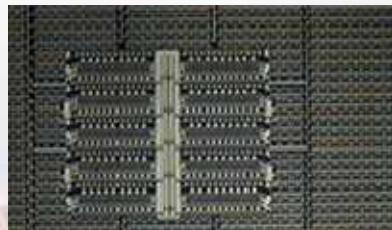


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Sandia's Unique Set of Resources

- World's largest x-ray source
- World's smallest chemical and biological analysis systems
- Tallest solar tower in the United States
- First clean room
- First MEMS in space
- World's largest center for fundamental and applied study of combustion processes
- World's largest federal investment in microsystems technology
- One of the world's fastest general-purpose supercomputers
- World-class team of engineers, chemists, physicists, biologists, mathematicians . . .

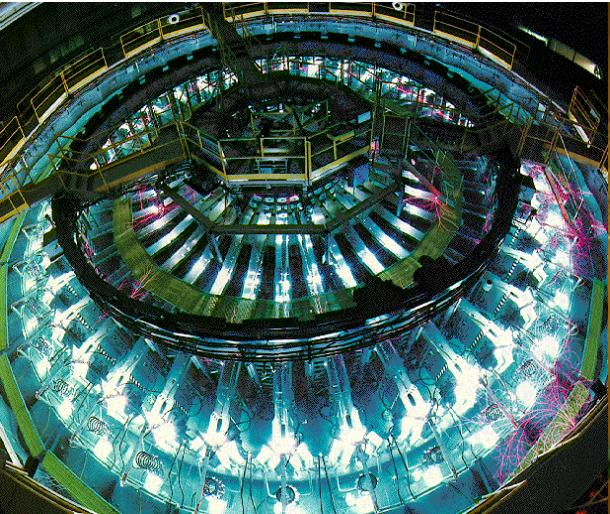


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Capabilities: Extreme Environments

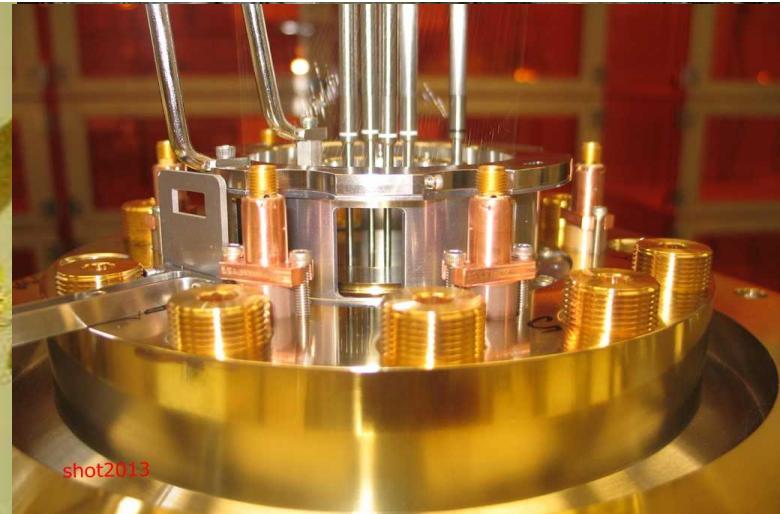
Saturn



Light Initiated High Explosives Facility (LIHE)



ZR k-shell X-ray source



Hermes III



Annular Core Research Reactor (ACRR)



Blast tube



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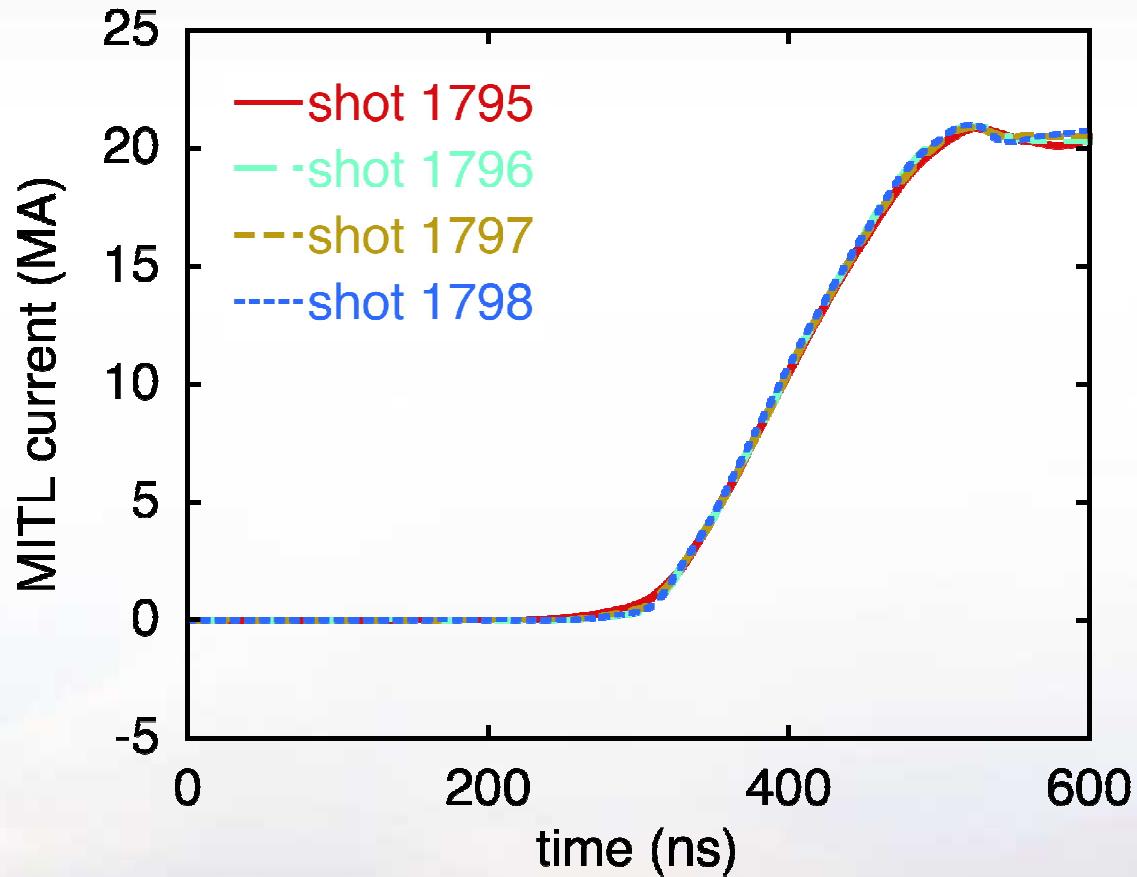
Z Refurbishment



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The goal of the ZR program is to maintain a *reliable* platform for high energy density physics loads

- **Maximize availability of the system**
 - Reduce down time and turnaround time
- **Make the system more precise**
 - Improve shot repeatability and accuracy
- **Maximize performance of the system**
 - Deliver the maximum energy practical

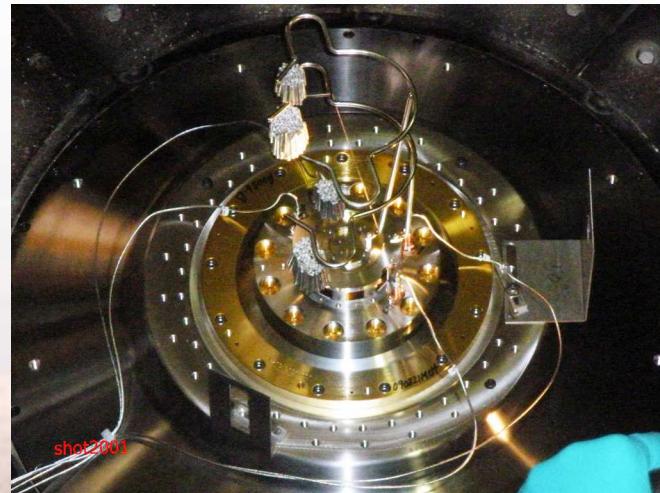
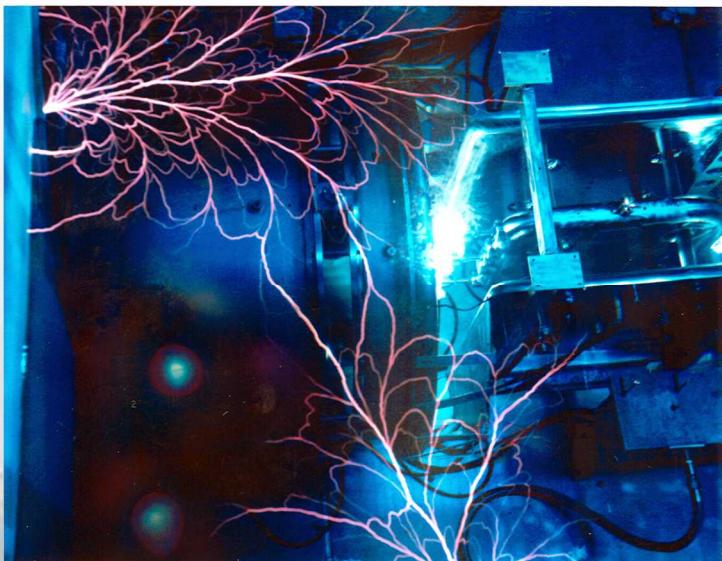
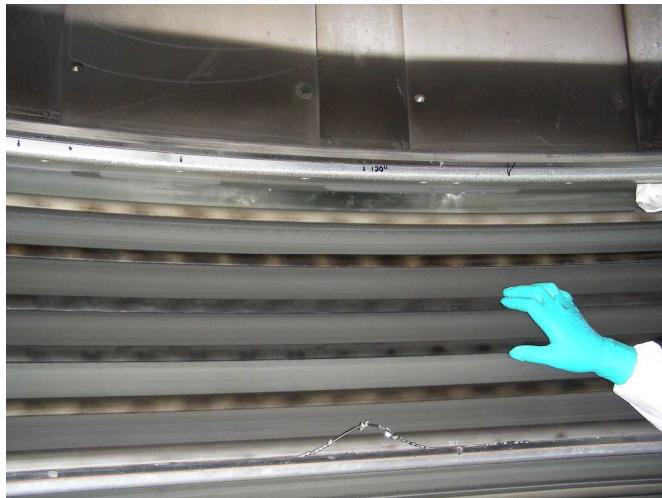


A large driver such as ZR is a balance of performance, reliability, and cost



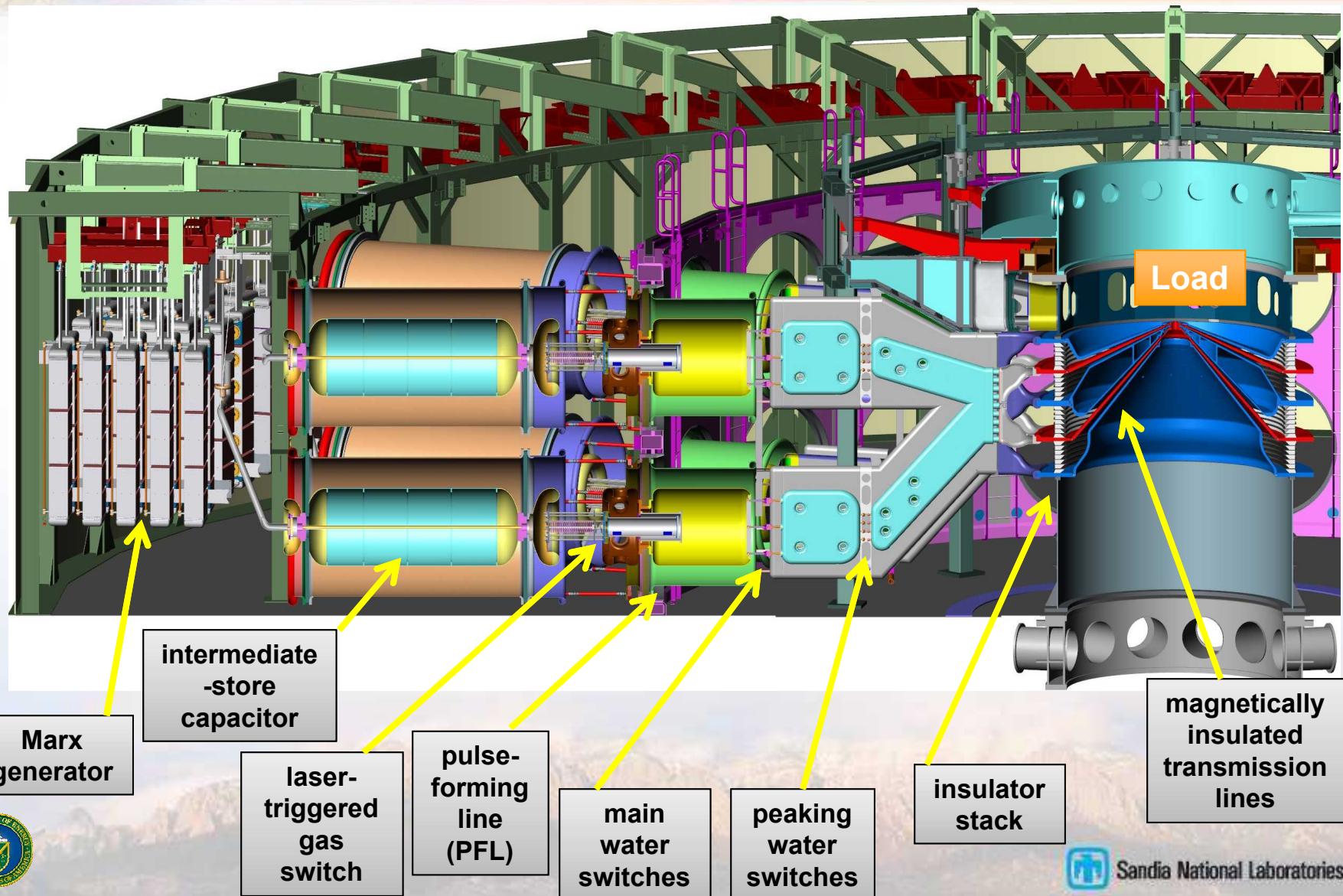
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Z experiments are complicated, and more tests are requested than can be fielded



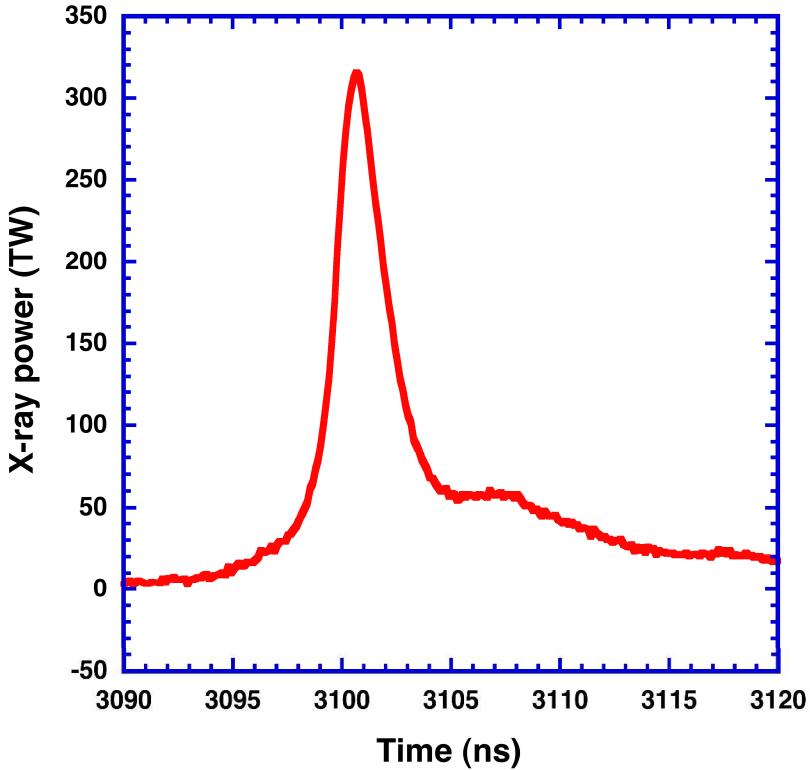
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Z is a large physics facility

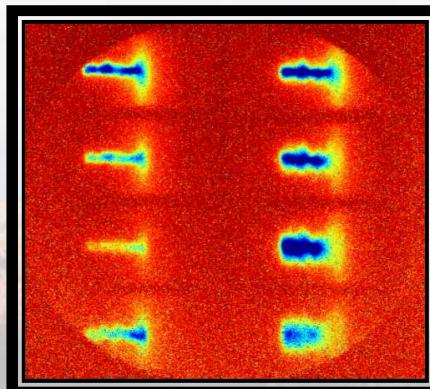
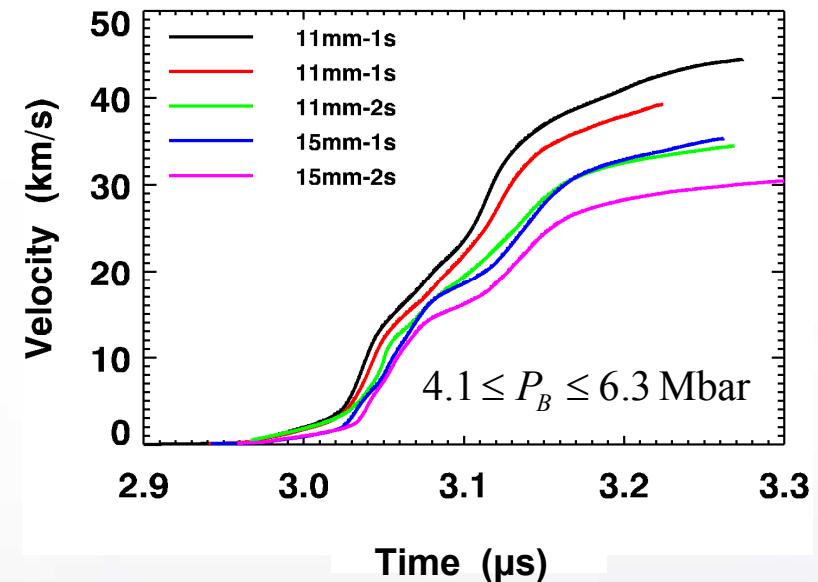


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The high currents of Z can implode plasma liners (z-pinches), and generate tailored megagauss magnetic field temporal profiles

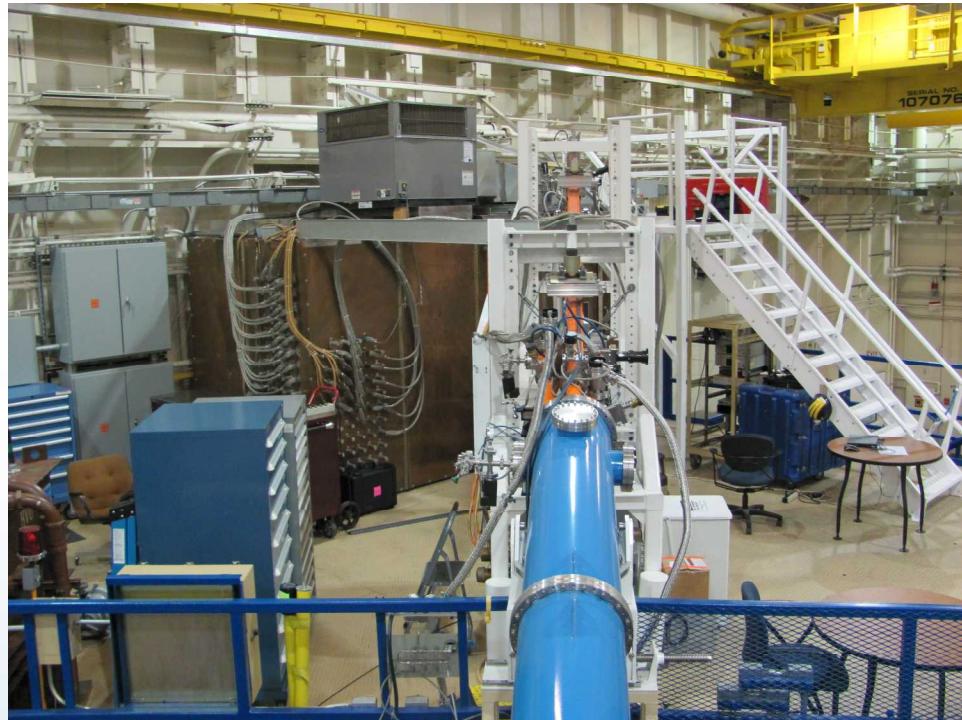


Measured Velocity 900 μm Al Flyer
all Strip-line Geometries



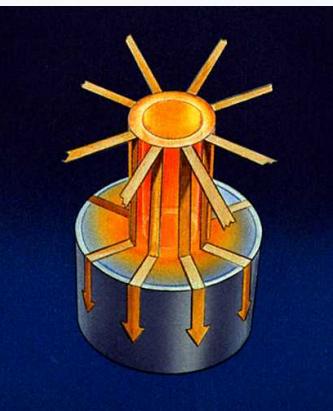
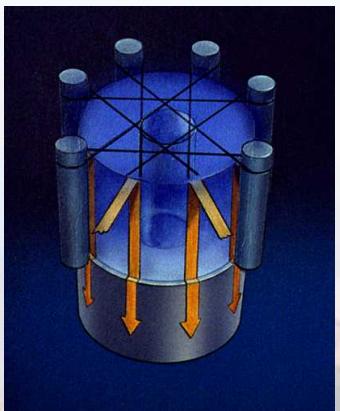
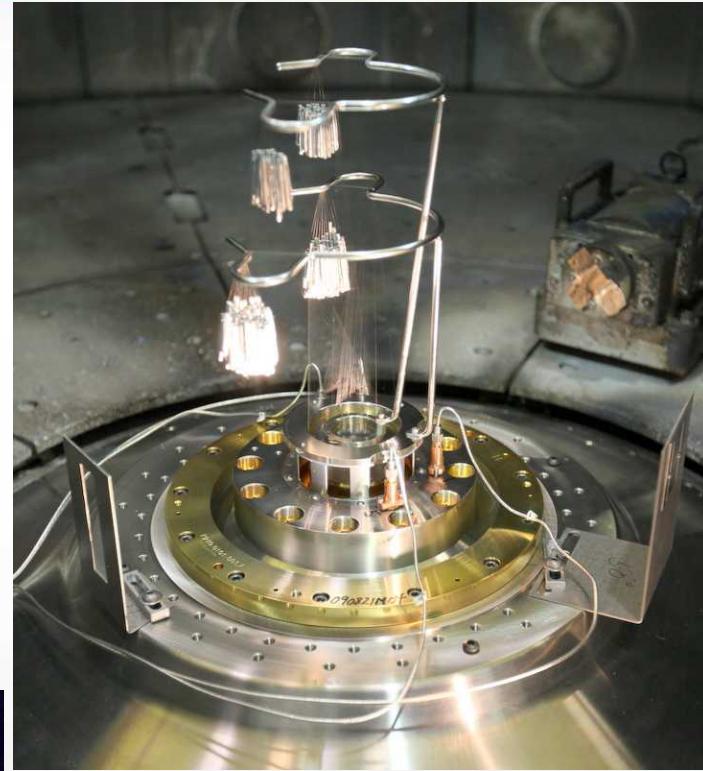
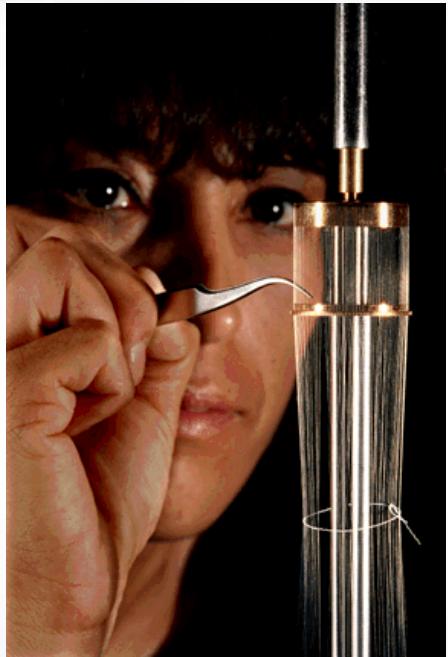
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X-ray power is measured 24 meters from the source



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Wire array z-pinch sources on Z can provide megajoules of black-body X-radiation, or specific k-shell spectra



Initiation

Implosion

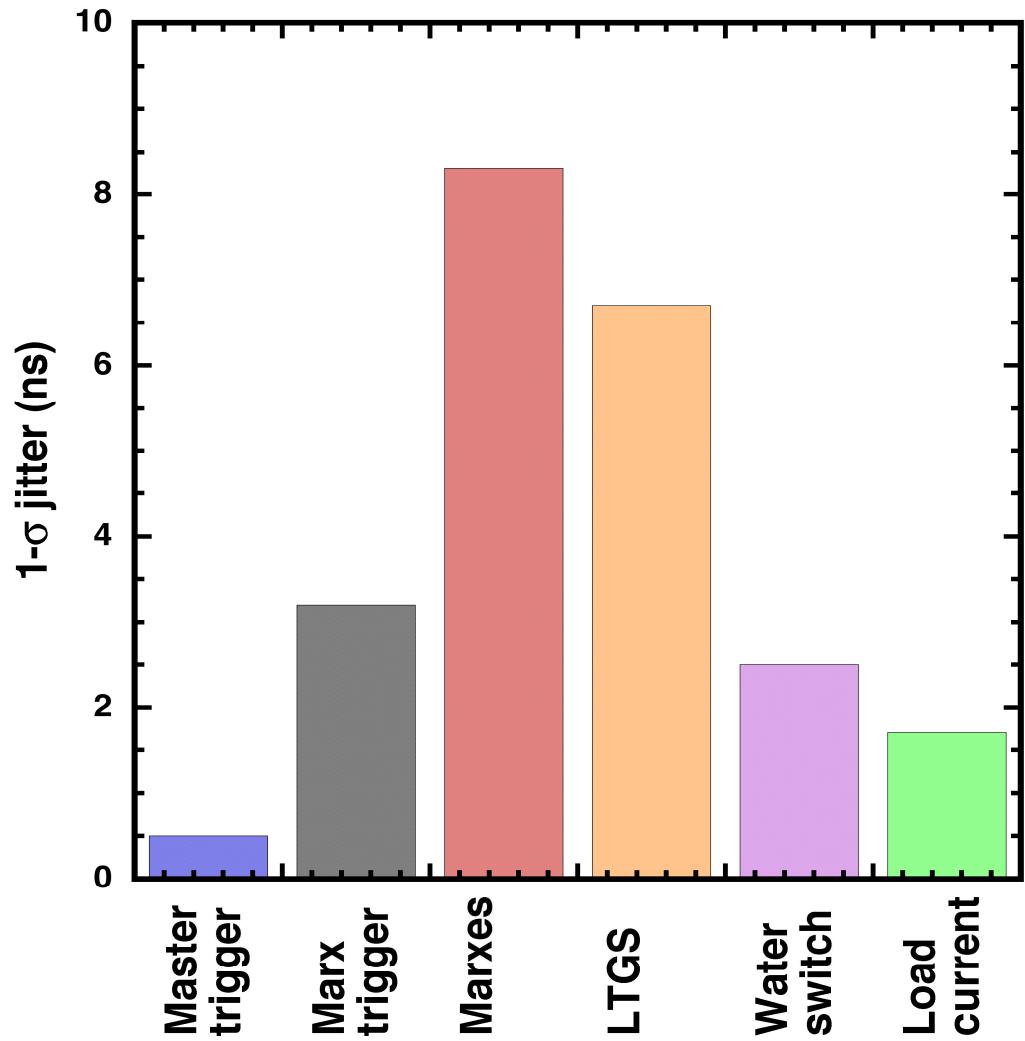
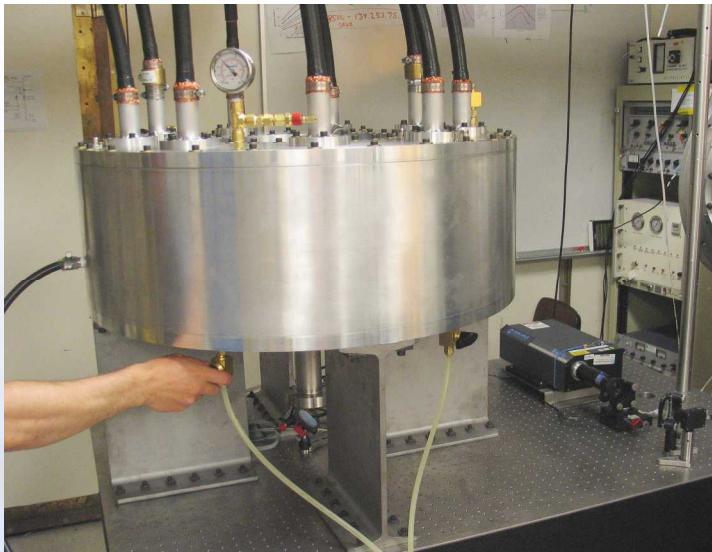
Stagnation



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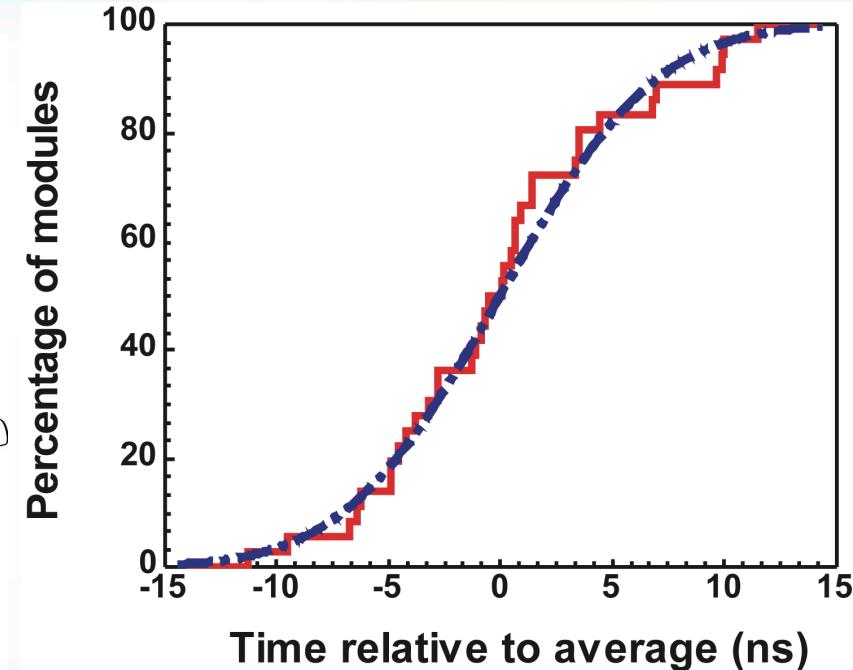
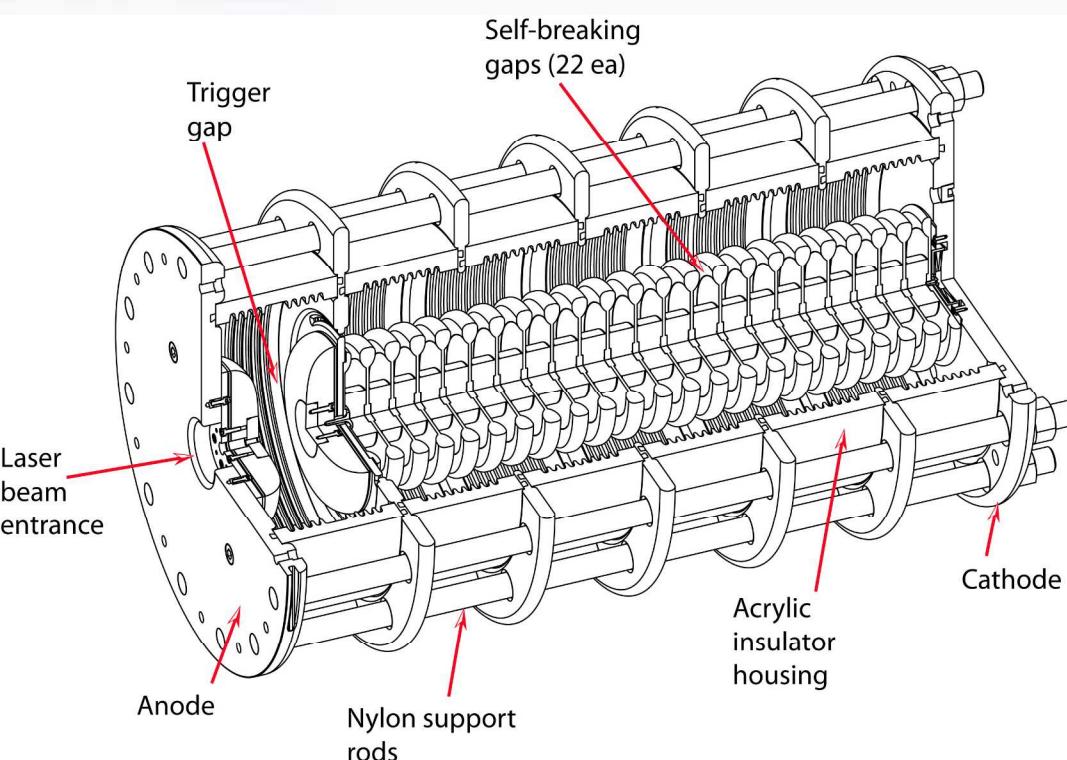
ZR uses an advanced trigger generator and selected operating points for stable operation

- No part of the machine has a $1-\sigma$ jitter greater than 10 ns
- The system is operated at low pre-fire probability
- Reliability has been a major focus



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The laser triggered gas switch enables tailored loading profiles and dominates load current timing



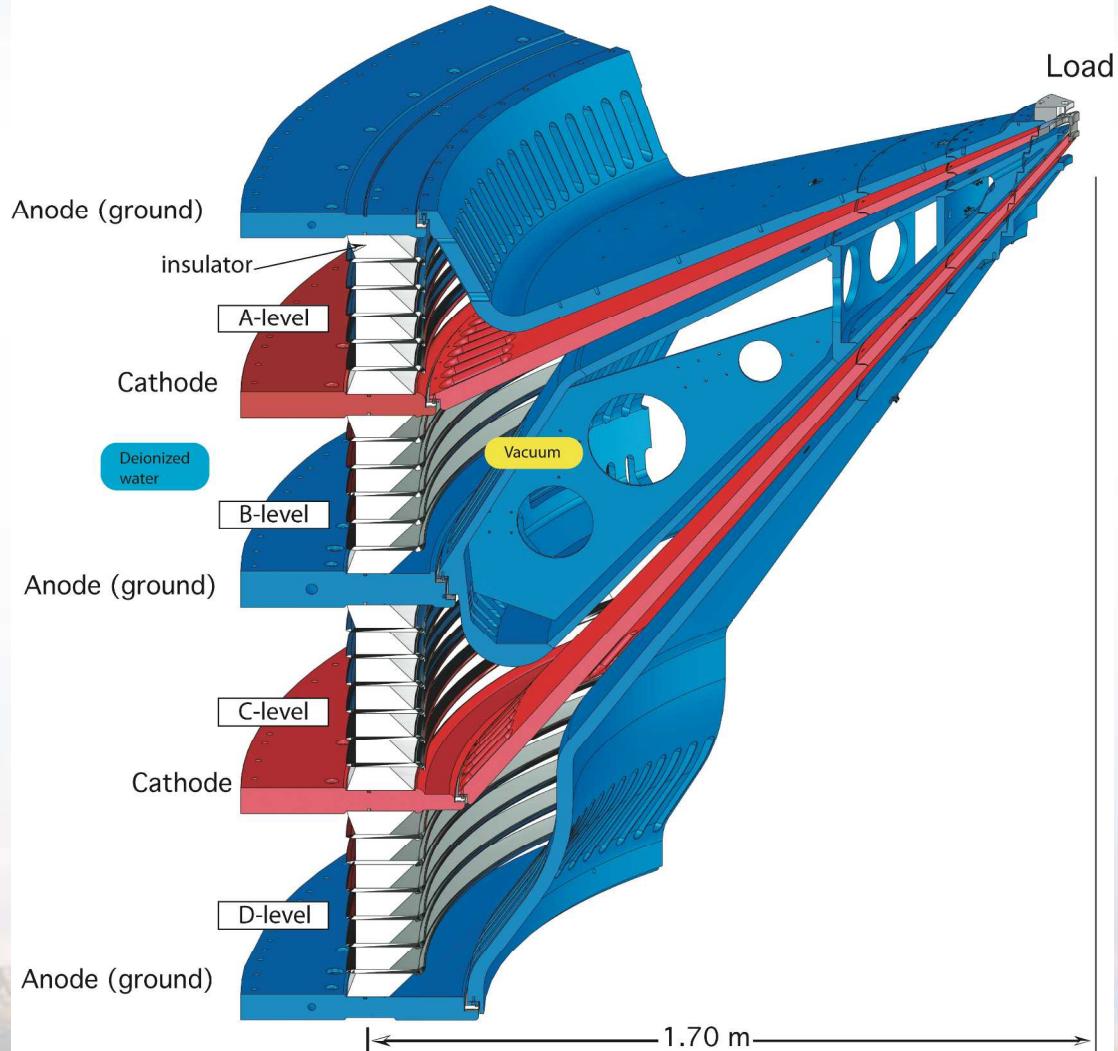
The 12 ns 10-90 spread rise time has a small effect on the 85 ns current rise time



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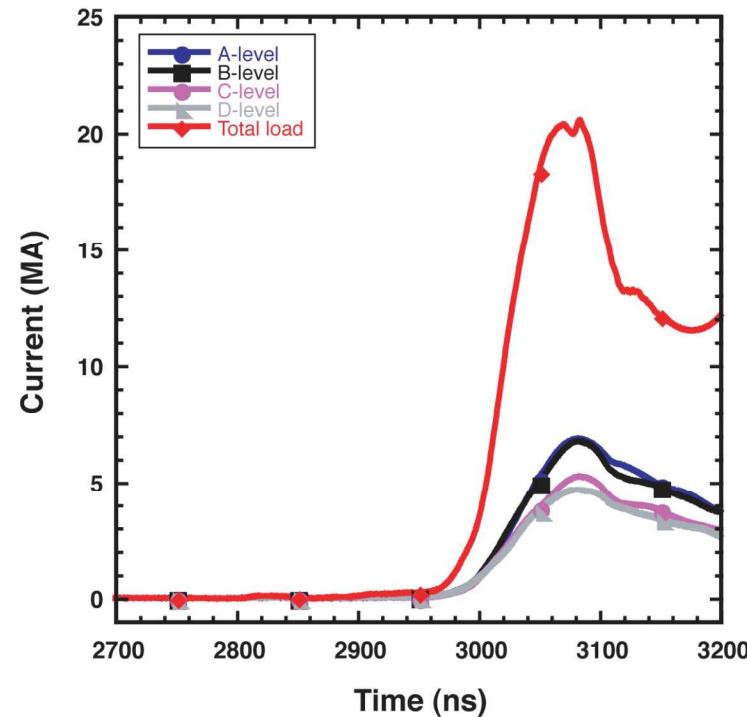
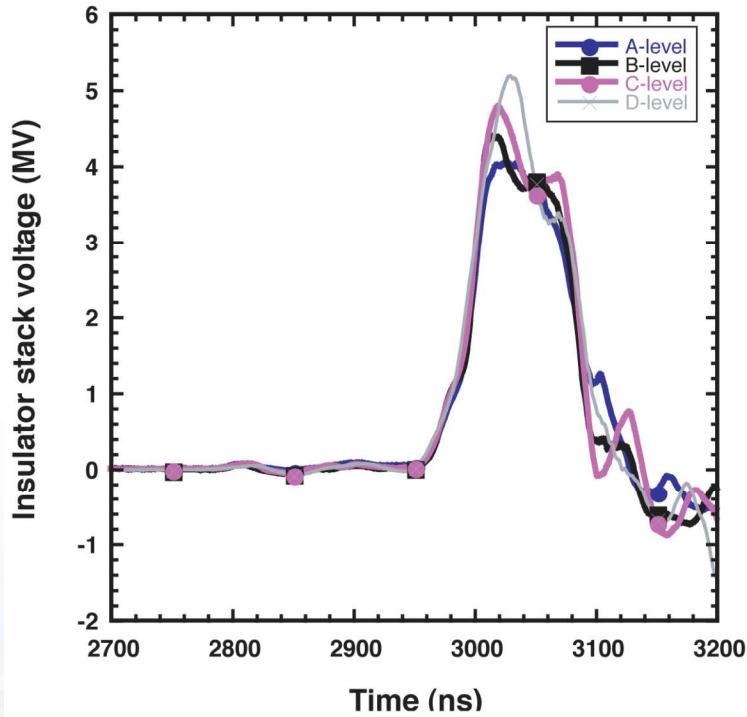
The power flows through a plastic vacuum insulator stack at 135 kV/cm

- The 1.7 meter radius, 4 level feed is low inductance
 - ~9 nH to 15 cm dia



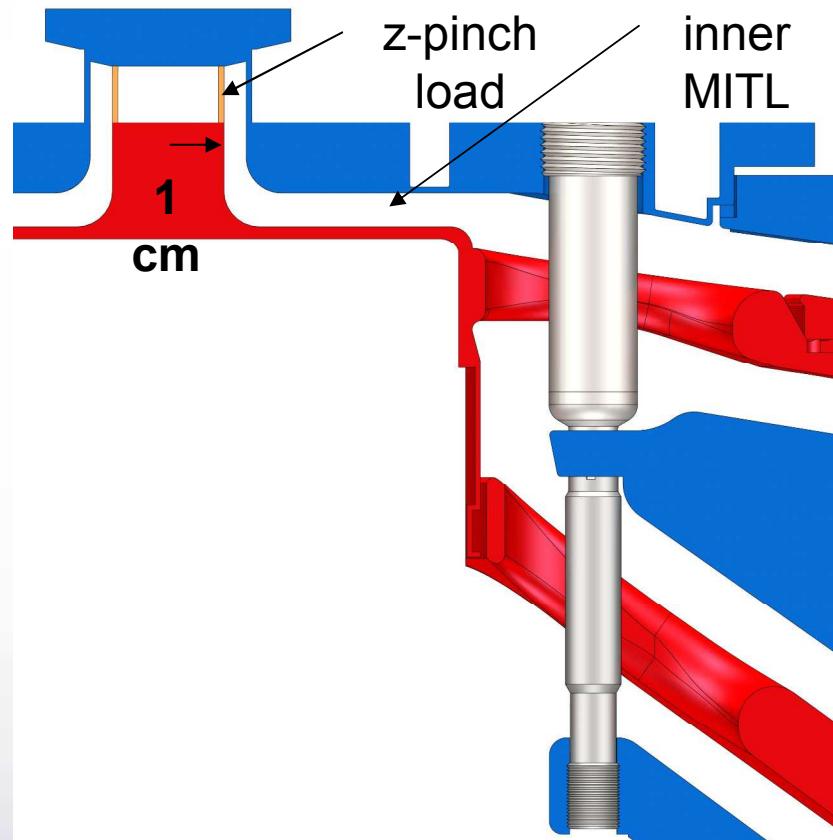
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The vacuum insulator transmits 75 terawatts



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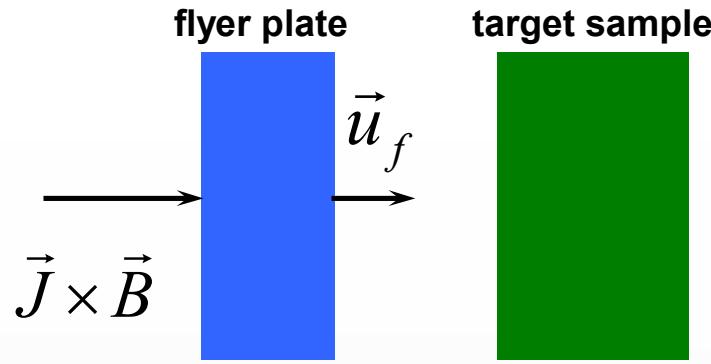
The four level currents are combined in the post-hole convolute



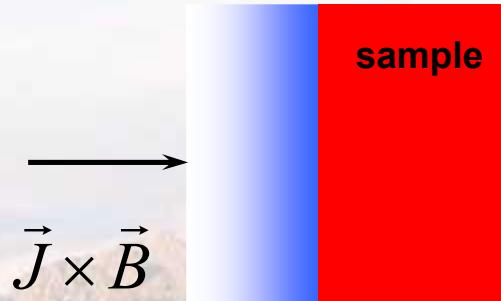
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Flyer plate impact yields a point on Hugoniot; ICE yields an isentrope to a peak pressure

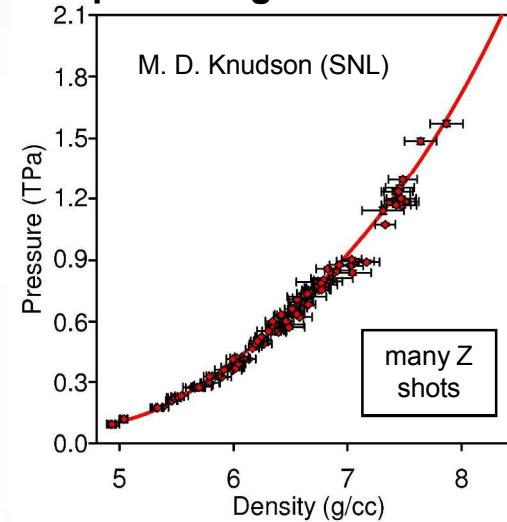
Plate Impact Experiment (Hugoniot)



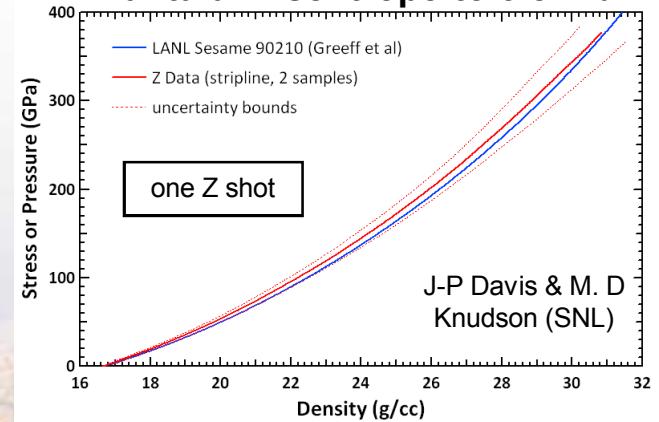
Isentropic Compression Experiment (ICE)



α -quartz Hugoniot to 15.7 Mb



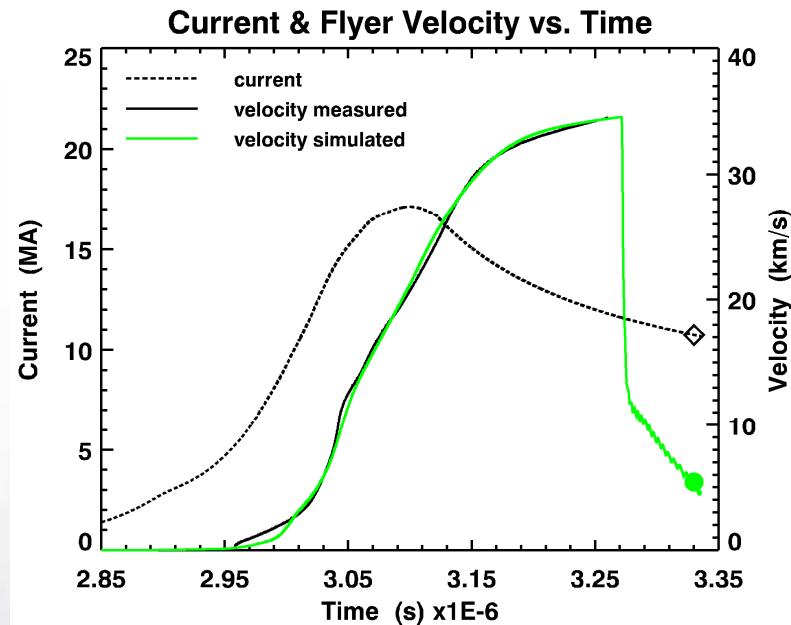
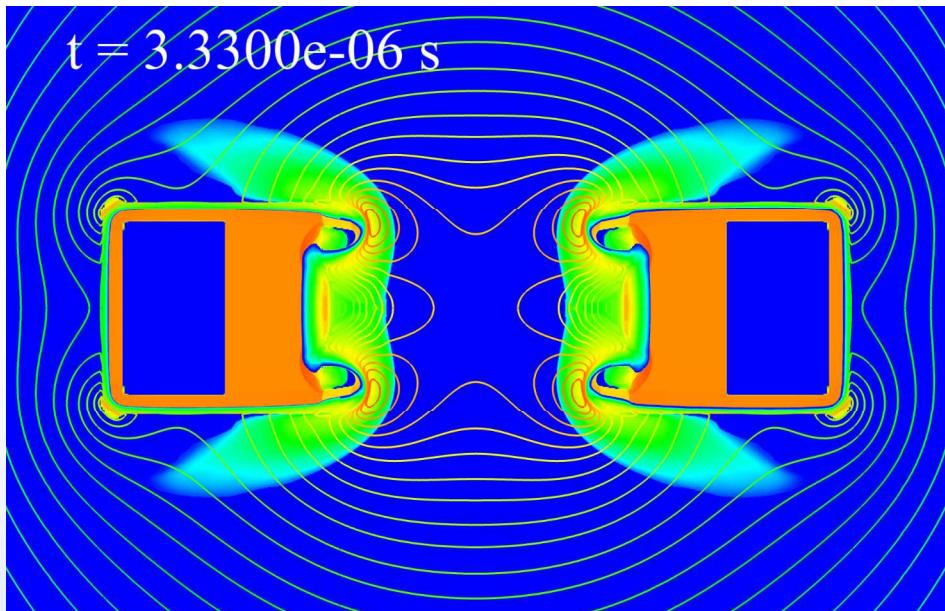
Tantalum isentrope to 3.8 Mb



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At impact, flyer free surface nearly planar, $\sim 100 \mu\text{m}$ Al still solid despite 33 Gg acceleration & B -field $\sim 1100 \text{ T}$

MHD simulation 2-sided, 11 mm strip-line, 900 μm Al flyers, density & magnetic field



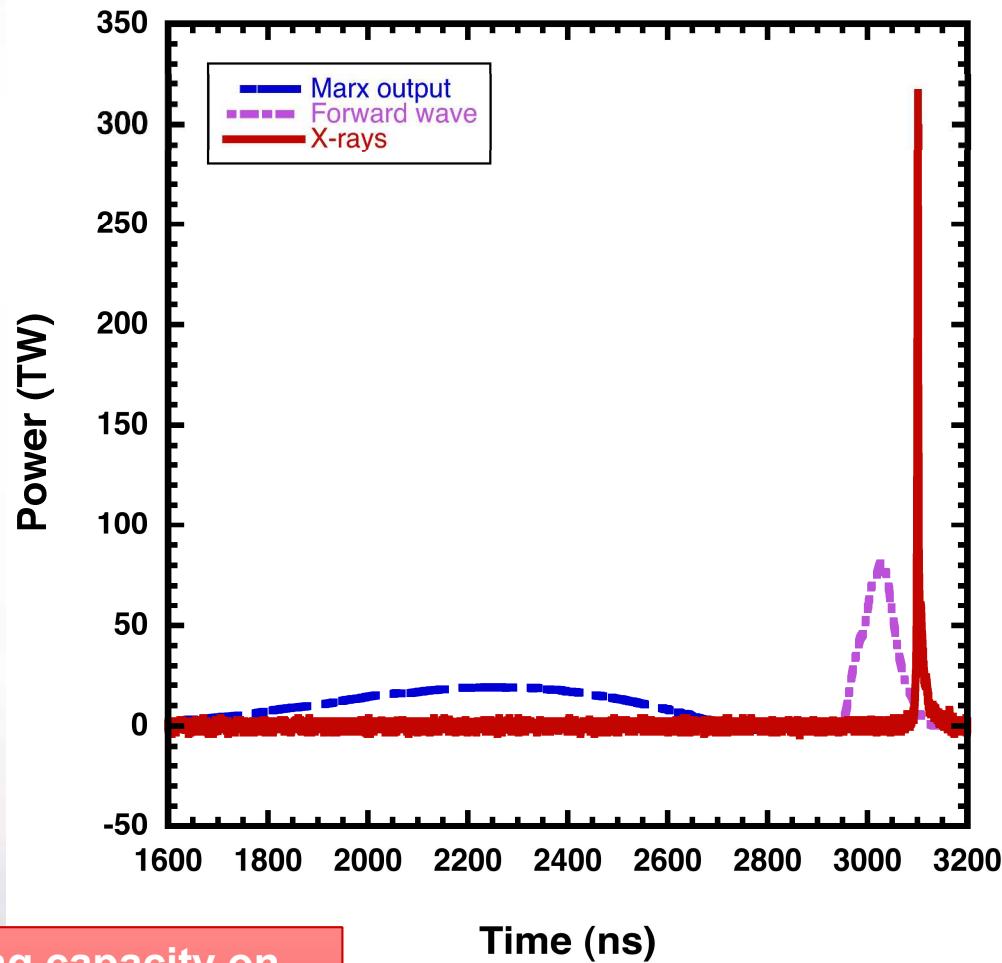
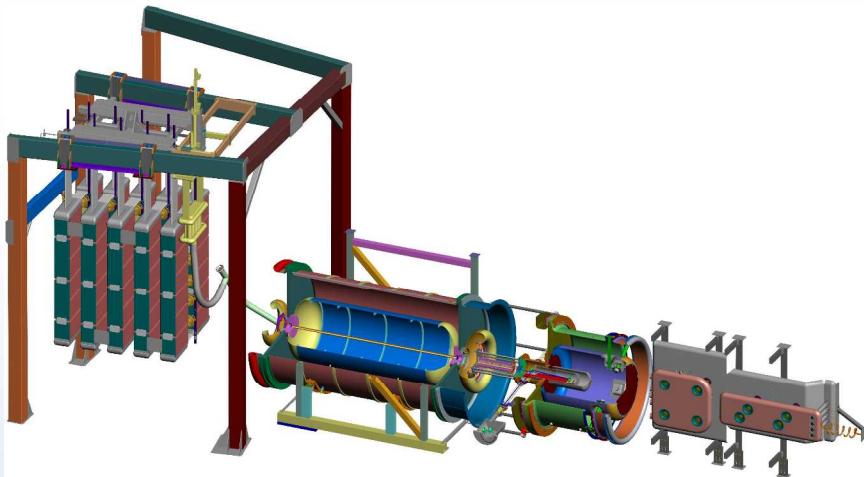
State of flyer plate at impact is deduced from the numerical simulation.



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Z uses 4 stages of pulse compression to temporally and spatially compress megajoules of electrical power

- Marx power: 19 Terawatts
- Forward wave power: 82 Terawatts
- Load X-ray power: 320 Terawatts

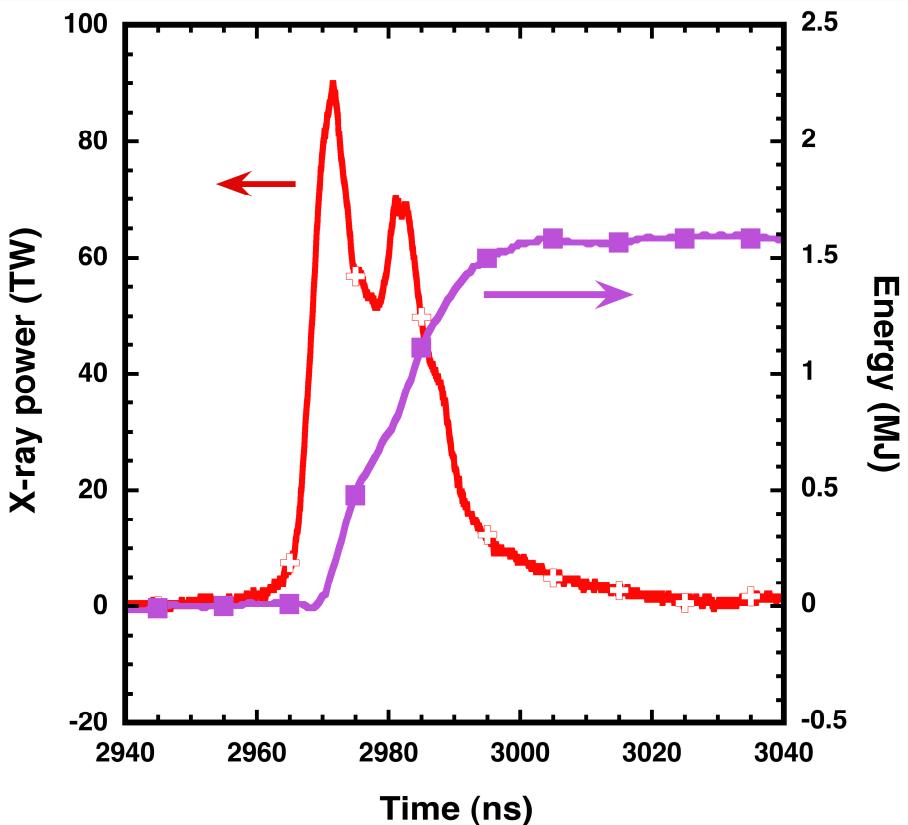


Total electrical generating capacity on earth: 4.7 TW

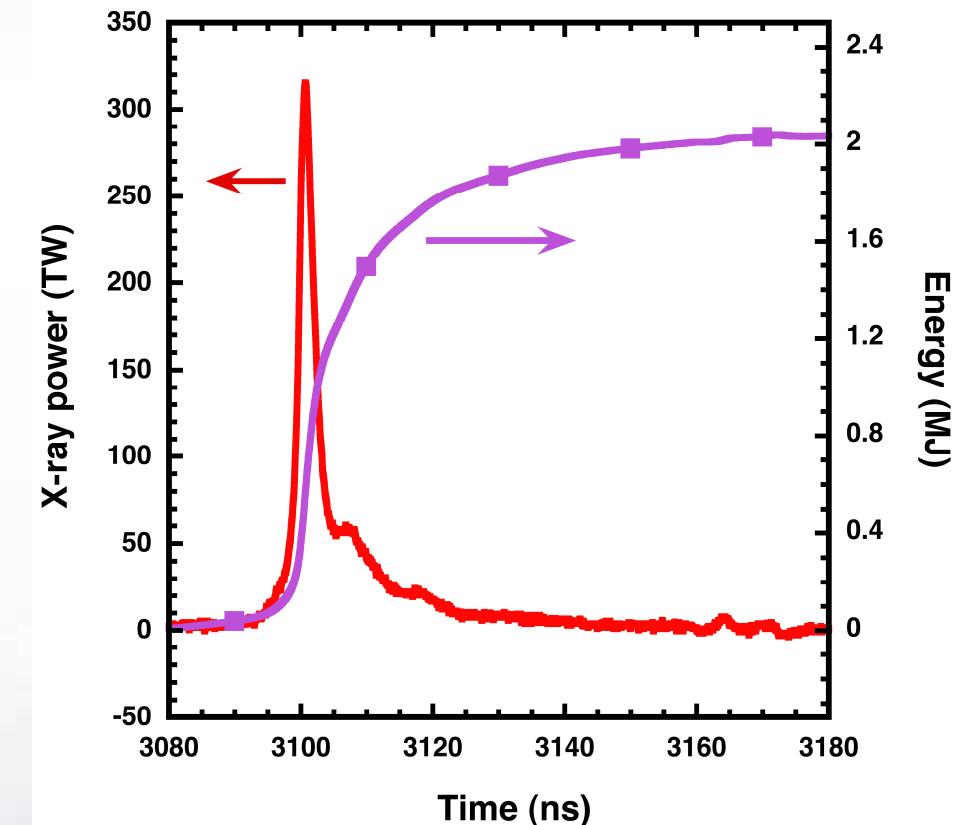


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Progress in X-ray power has been great



Shot 1786
90 TW
1.6 MJ



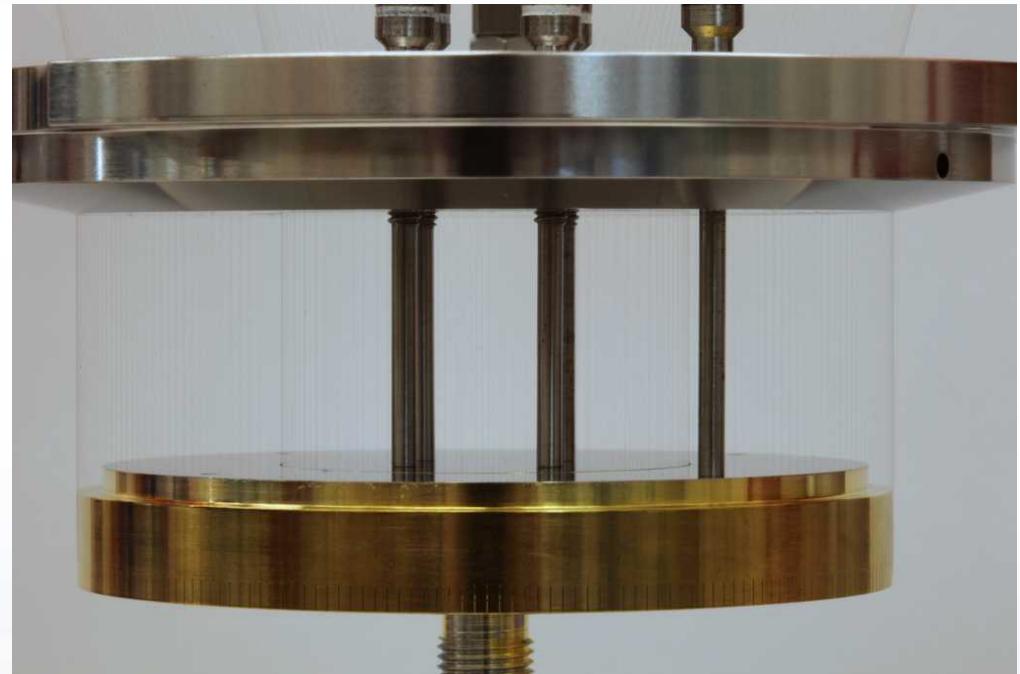
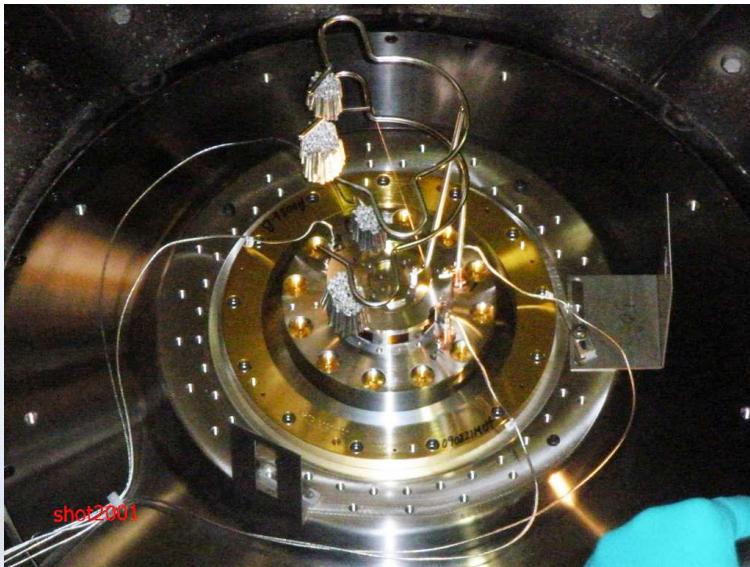
Shot 1997
320 TW
2 MJ



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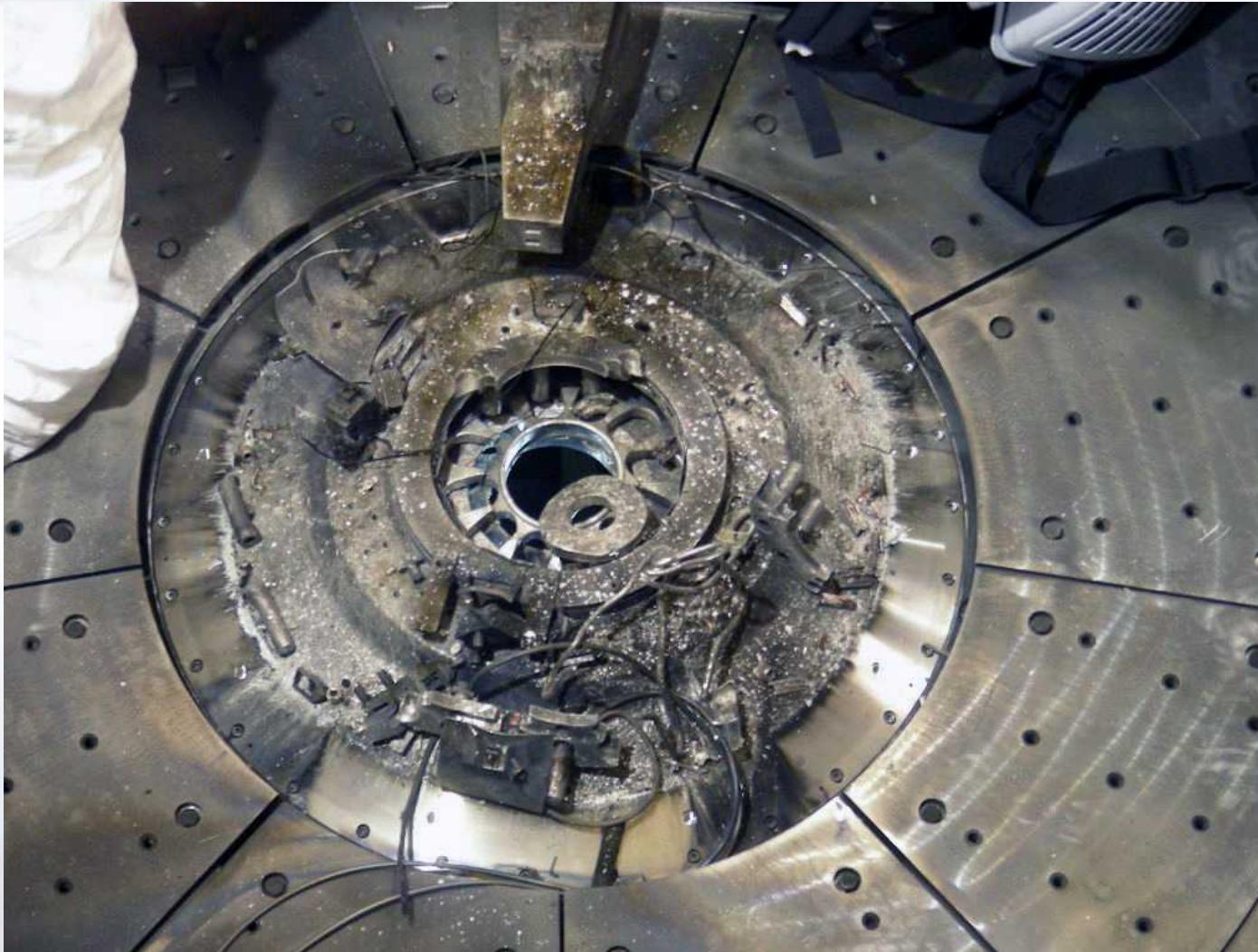
Double nested tungsten wire arrays use 2.5 mg total mass

- 65 mm outer array diameter
- 33 mm diameter inner array
- 5 μm wire diameter
- 330 total wires



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High current z-pinch drivers deliver Mbar pressures to conductors and plasma



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Conclusions

- The Z pulsed power driver was rebuilt in 2007
- The new system is being used for a variety of studies requiring megajoules per cubic cm
 - inertial confinement fusion research, material properties studies at megabar pressures, astrophysical research, and radiation source development
- 25 MA currents into 2.5 nH imploding loads can be delivered with nanosecond accuracy and 1% amplitude repeatability
- Tailored current temporal profiles allow TPa pressures without shocks in samples
- Flyer plates have been driven to 40 km/s from 1200 Tesla fields while remaining partially solid
- Wire arrays produce hundreds of terawatts of X-ray power



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