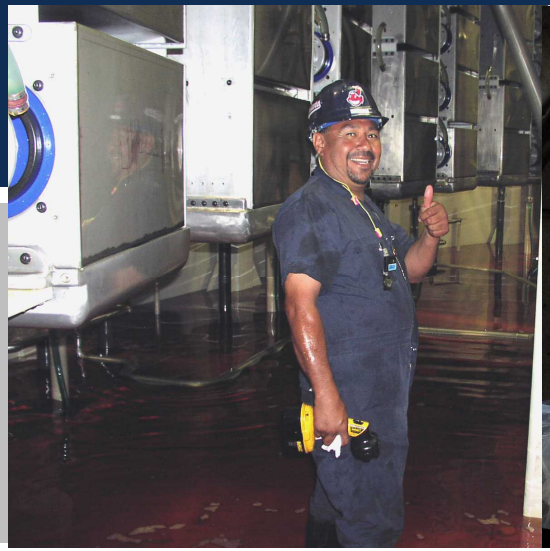
Pulsed power performance of the Z machine:

ten years after the upgrade

SAND2017-7687C



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Summary

- The Z machine is a low-impedance fast driver that delivers megajoules of magnetic energy to cm^3 volumes
- The 110 ns time to peak current requires megavolts from the pulse-forming section:
  - 6 MV Marx generators
  - 6 MV gas switches
  - 6 MV vacuum insulator
- Z can deliver megabar pressures, and hundreds of terawatts of X-rays
- Late-time energy is the scourge of a large machine, and component design and energy diversion are critical

The Z machine has multiple uses

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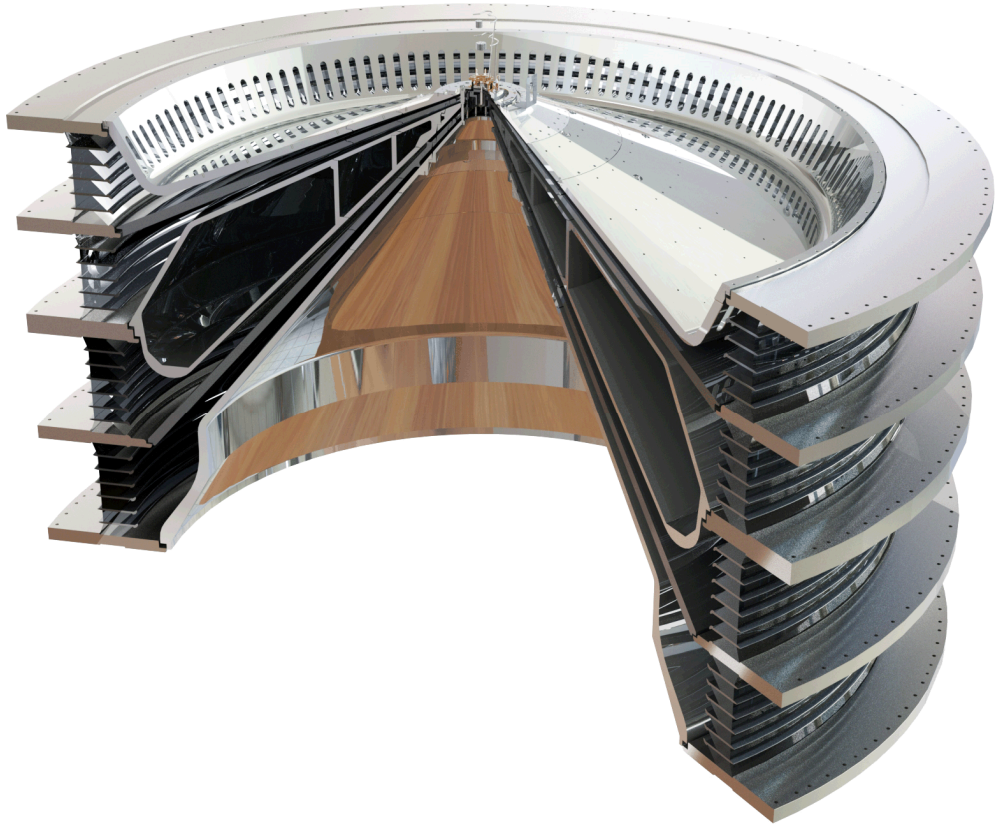
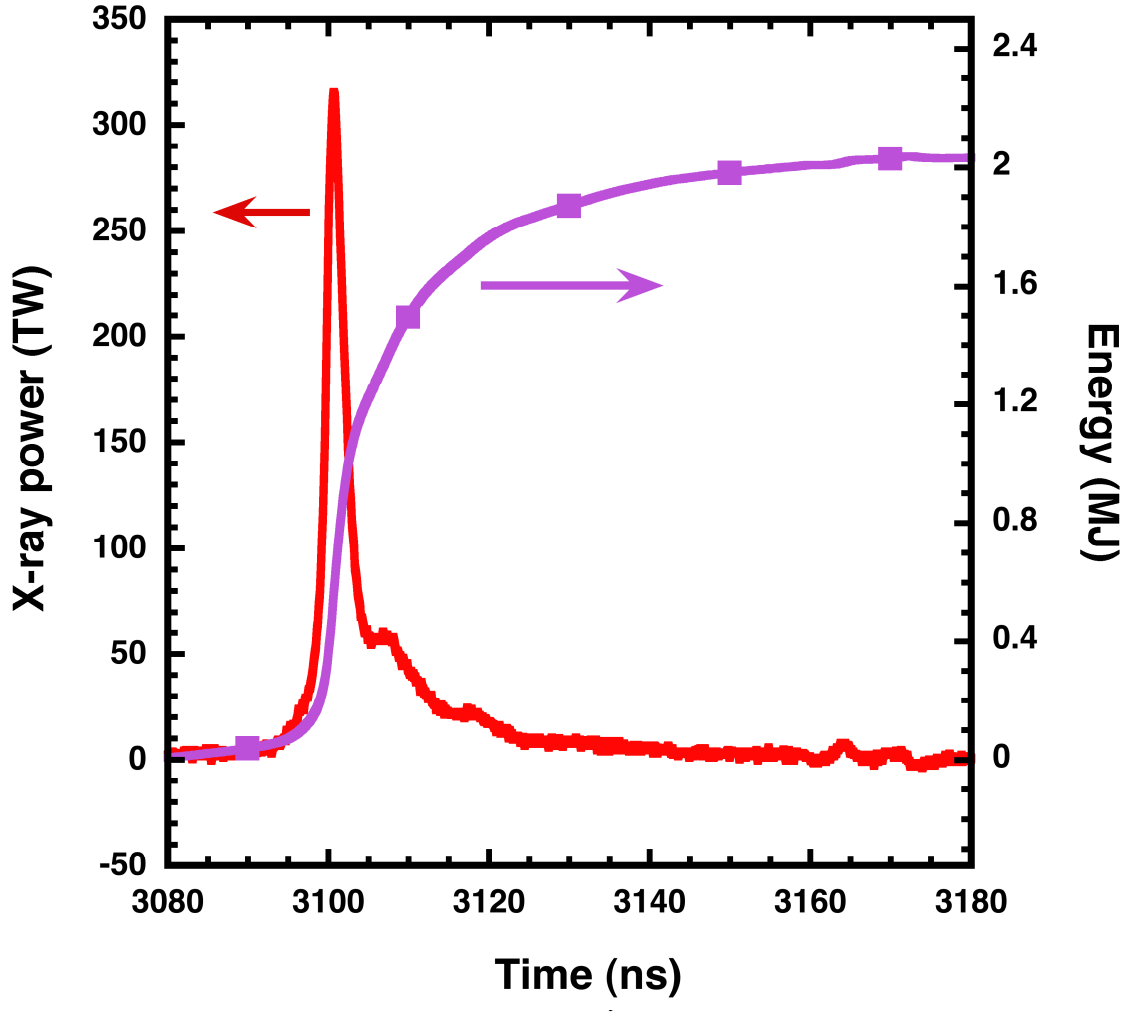
- Megabar pressure source for dynamic compression of solid materials
- Radiation source for effects testing
- Drive source for inertial confinement fusion studies



Z is expected to perform a high-quality, fully diagnosed physics experiment every working day

Z is all about power



Introduction

- **As an operating user facility, Z allows unique access to performance data on pulsed power mainstay components at extreme levels:**
  - **More than two thousand energy-storage capacitors (85 kV, 160 kA)**
  - **Thirty-six laser triggered SF6-insulated switches (6 MV, 600 kA)**
  - **Thirty-six water insulated transmission lines (6 MV, 700 kA)**
  - **Thirty-six self-closing water switches (3 MV, 700 kA)**
  - **Four water/plastic/vacuum interfaces (150 kV/cm, 7 MA, 21 m^2)**
  - **Post-hole current addition and inductive load (2 MV, 27 MA)**

Z is a system of 36 largely independent modules driving a common load

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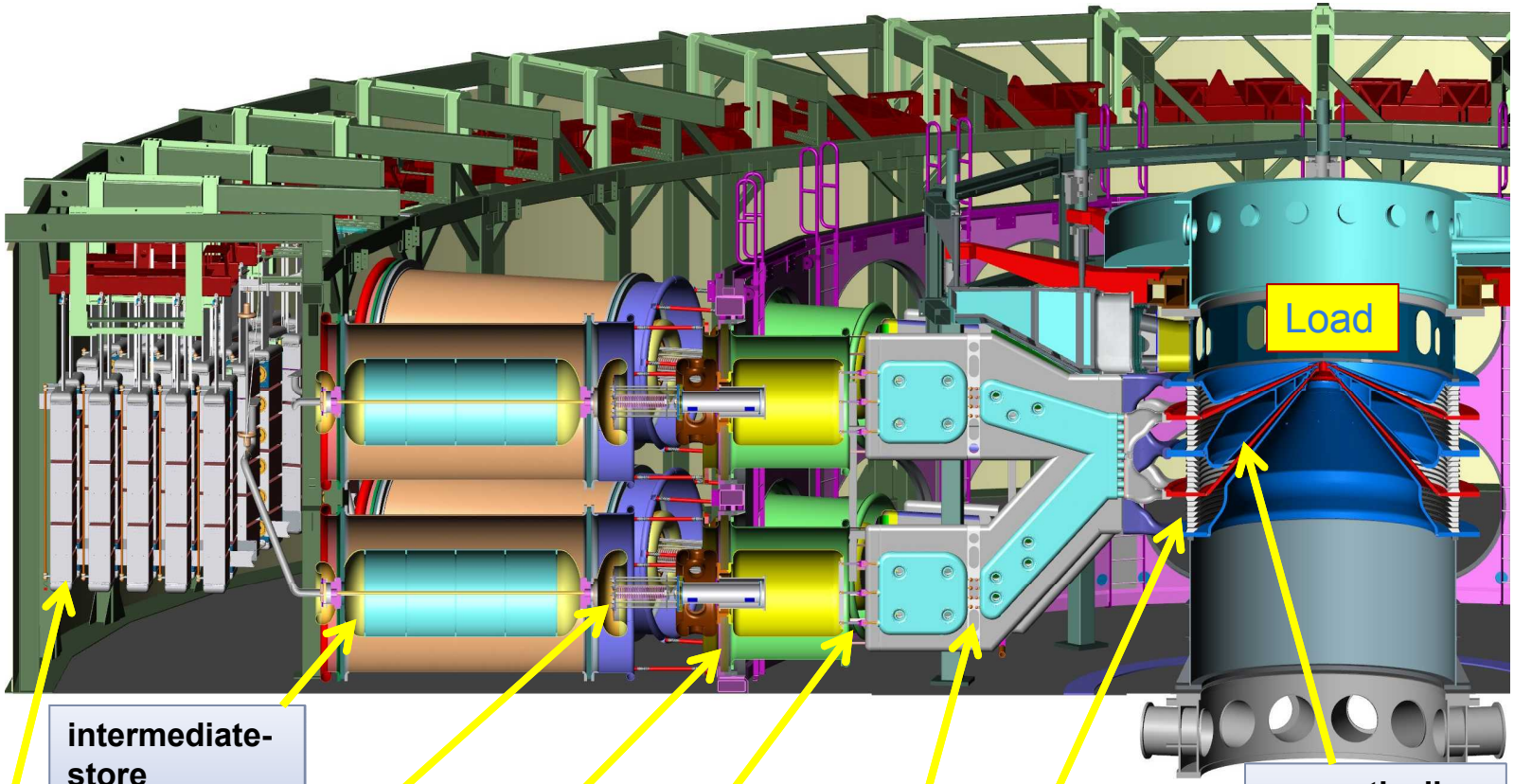


Marx generator

intermediate-store capacitor

laser-triggered gas switch

pulse-forming line (PFL)

main water switches

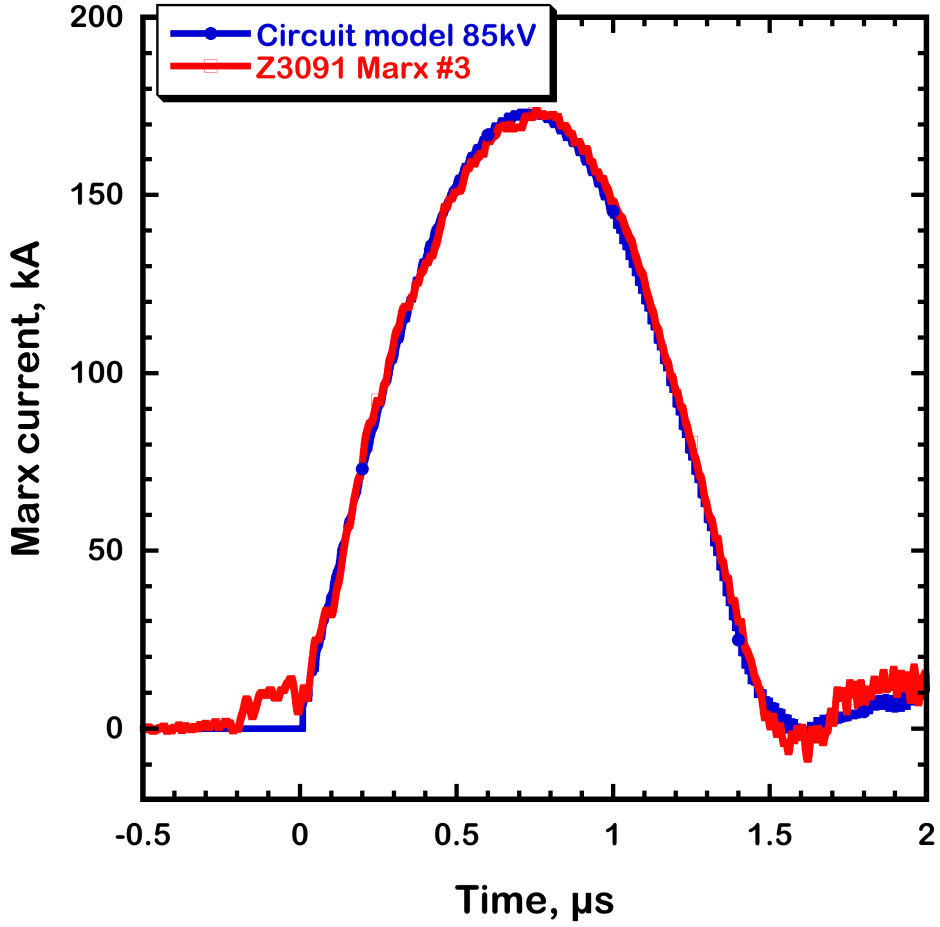
peaking water switches

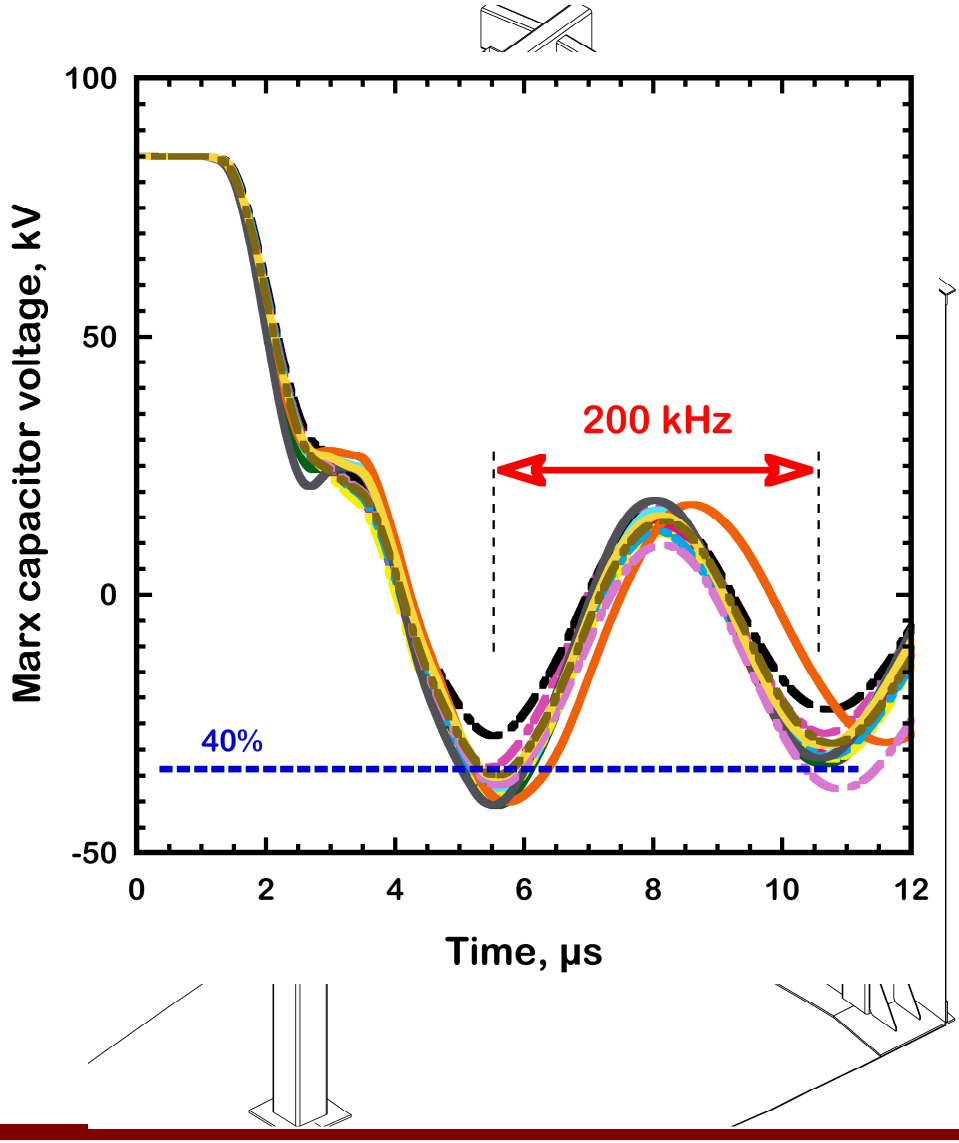
insulator stack

magnetically insulated transmission lines

Marx generators

The Z Marx generators deliver 100s of kJ at 6MV





Capacitor reliability is important

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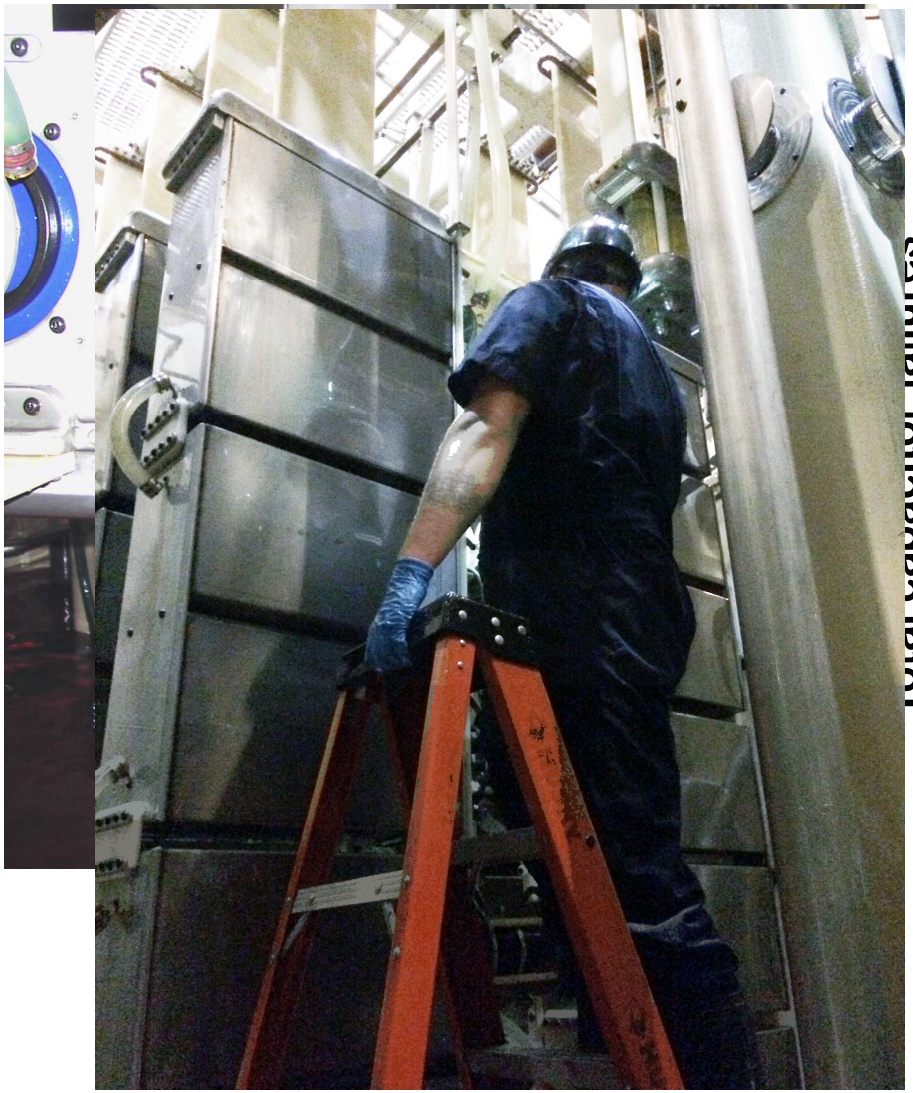
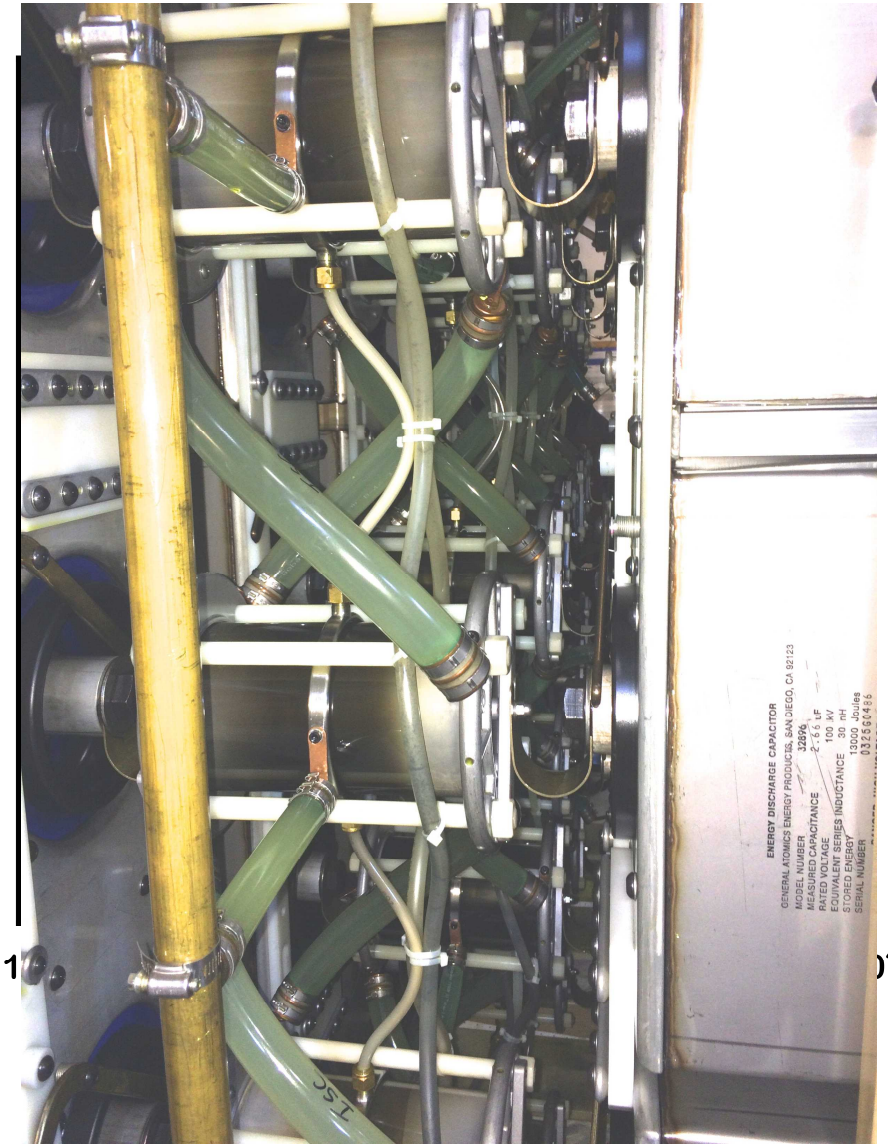
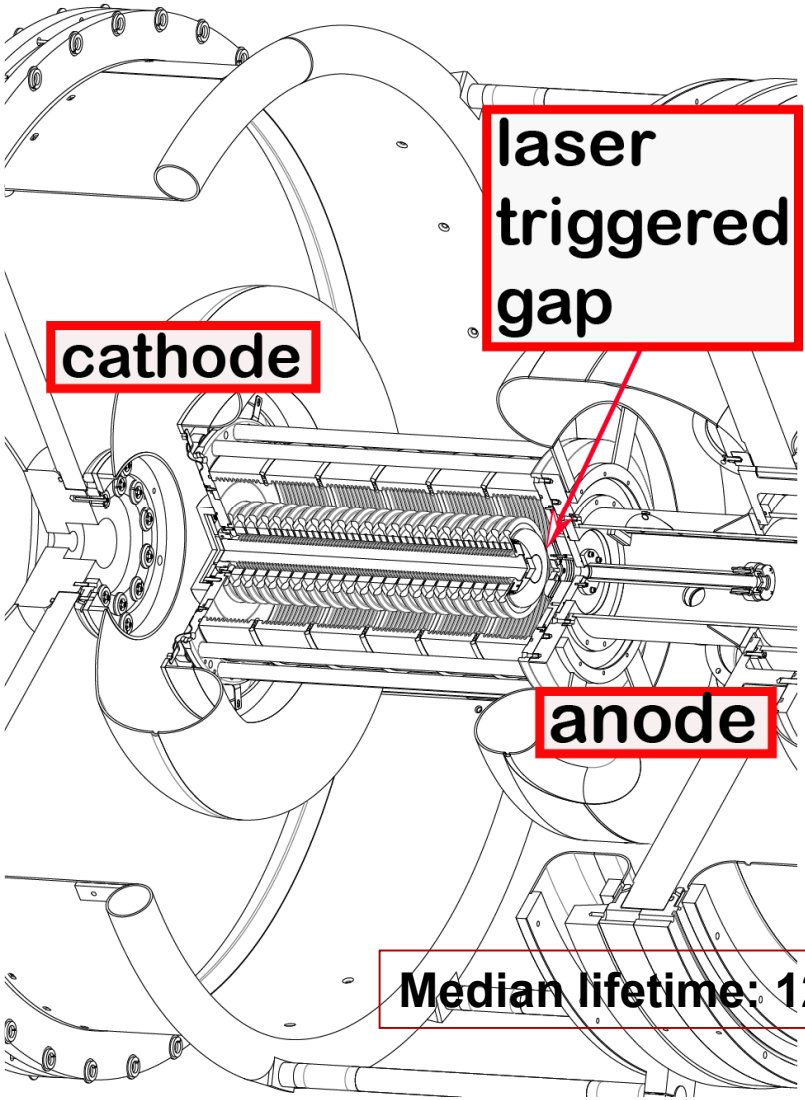
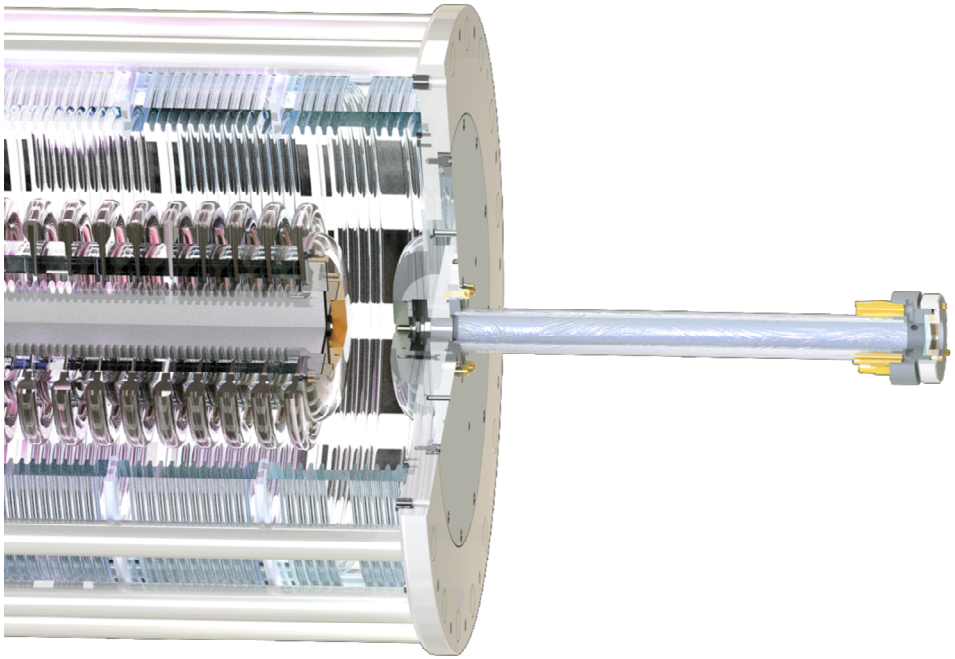




Laser triggered gas switches

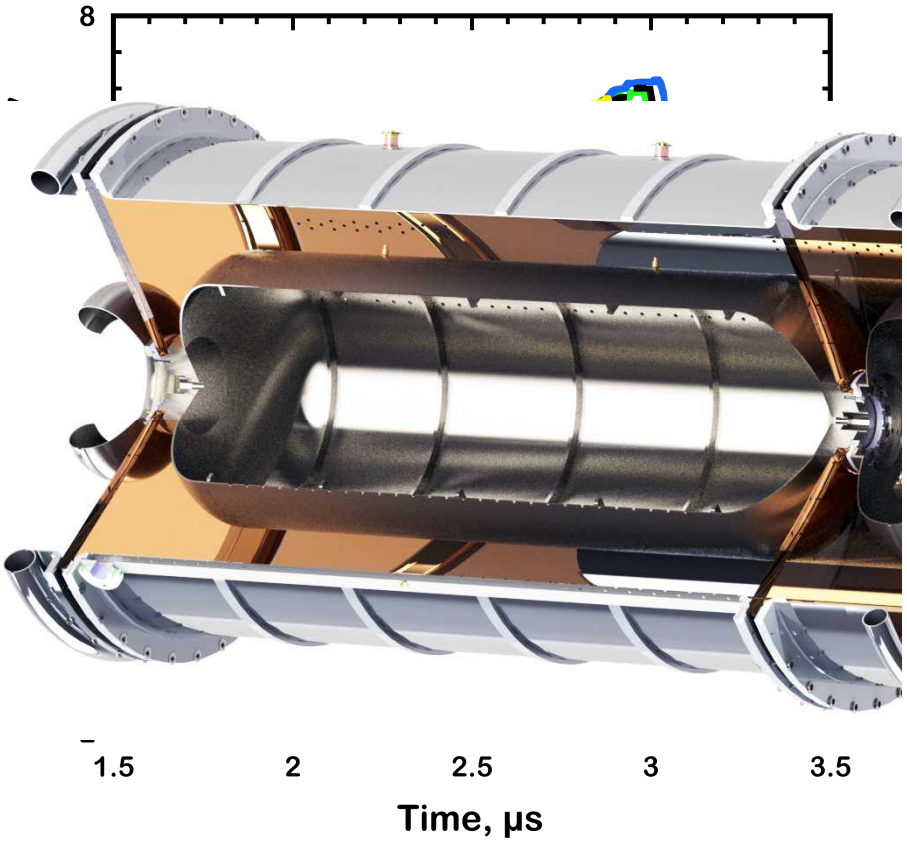
The 6 MV laser triggered gas switch determines load current timing and pulse shape

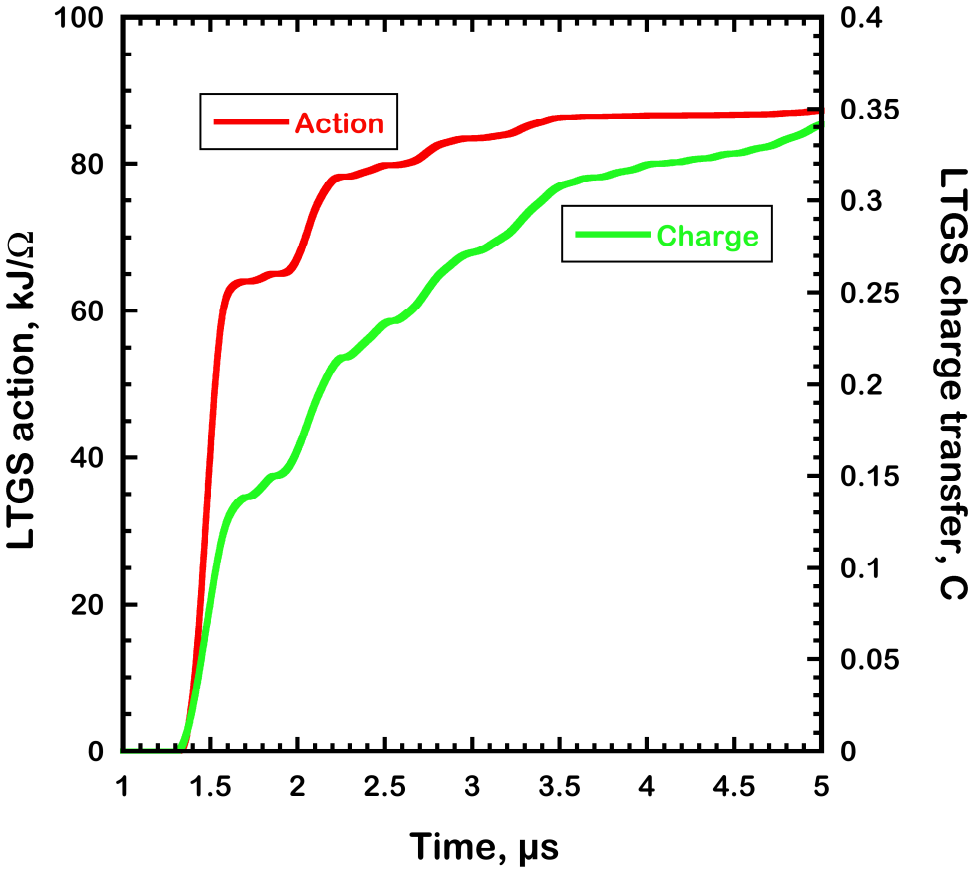




Median lifetime: 127 shots at full energy

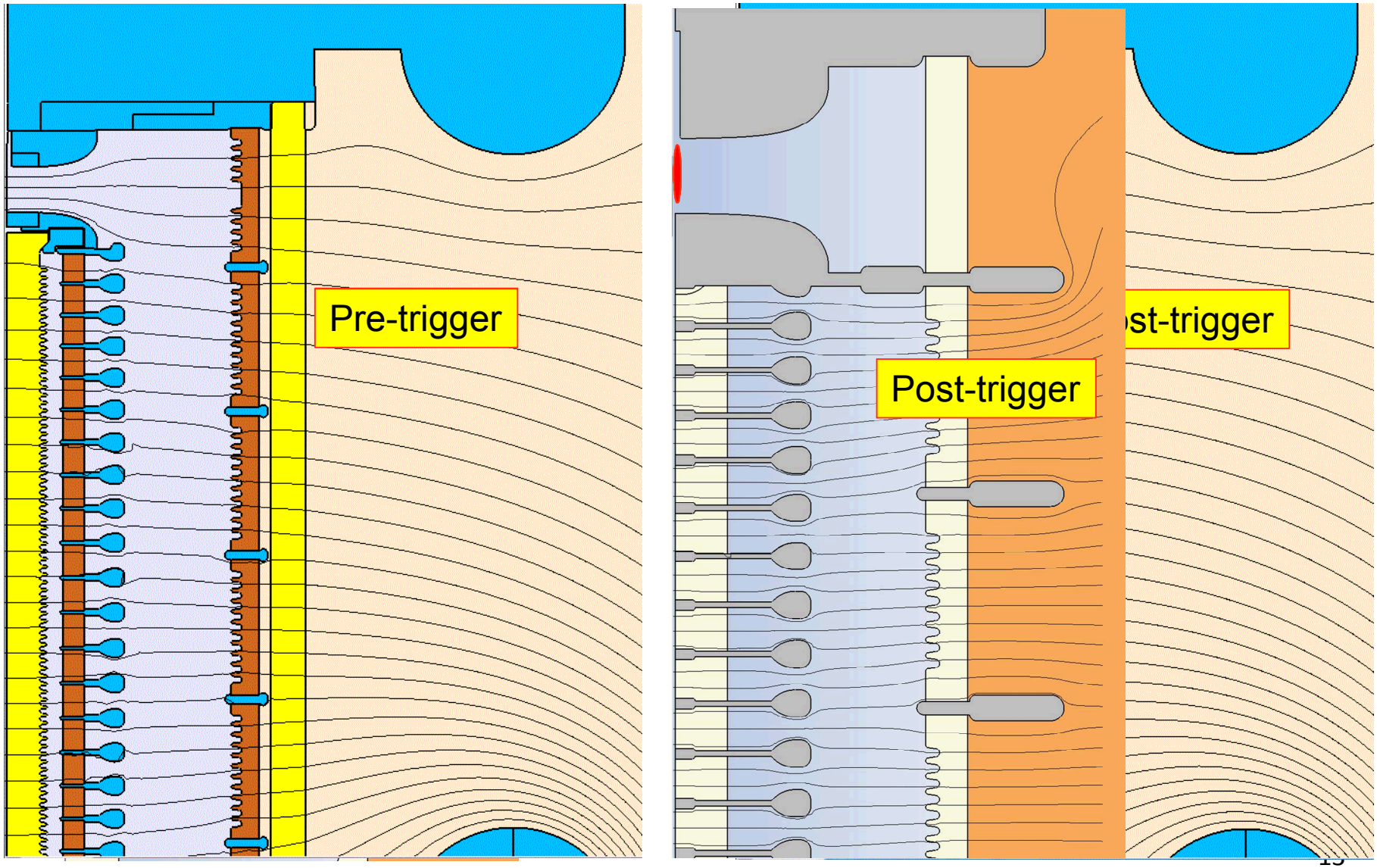
The LTGS withstands 6 MV and 600 kA





Ratio of charge time to 1-σ jitter: ~300

A new LTGS triggers more reliably



Gas switch spread does not appreciably contribute to load current rise time

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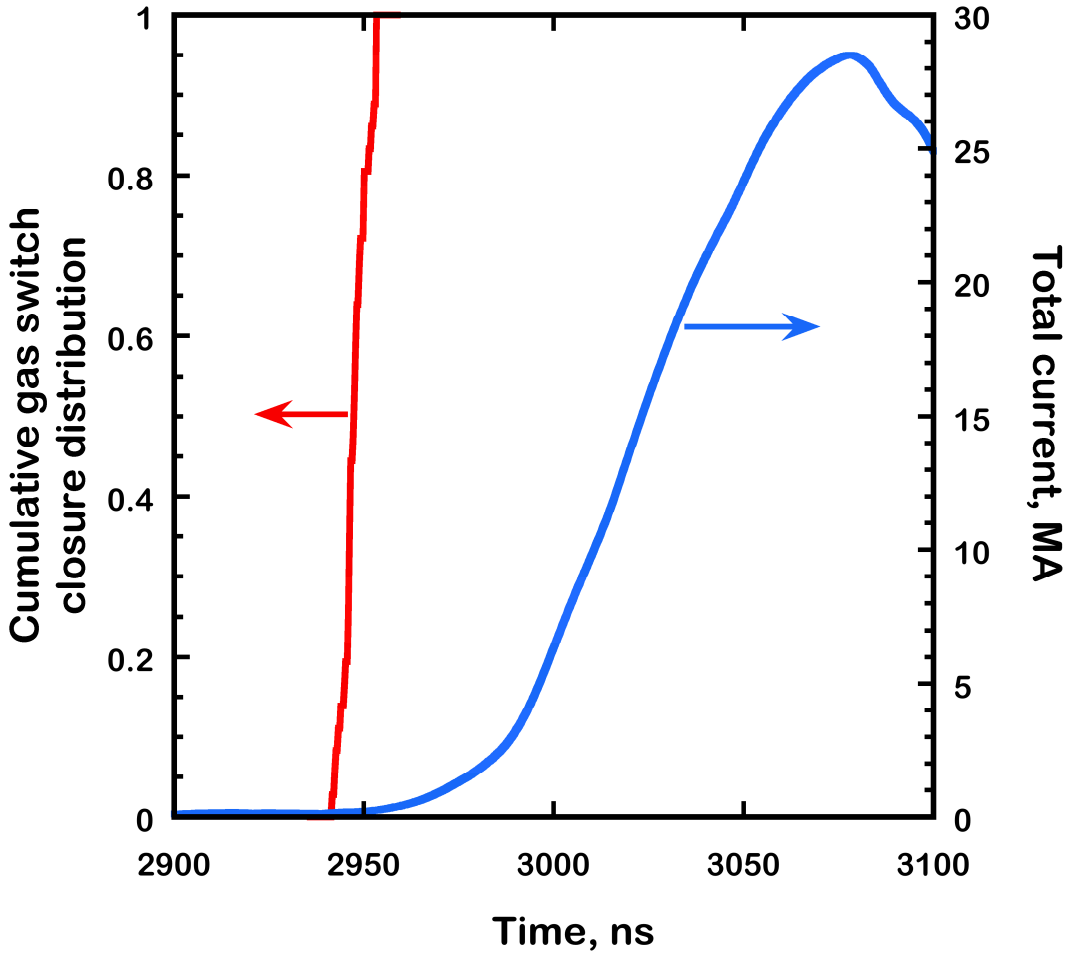
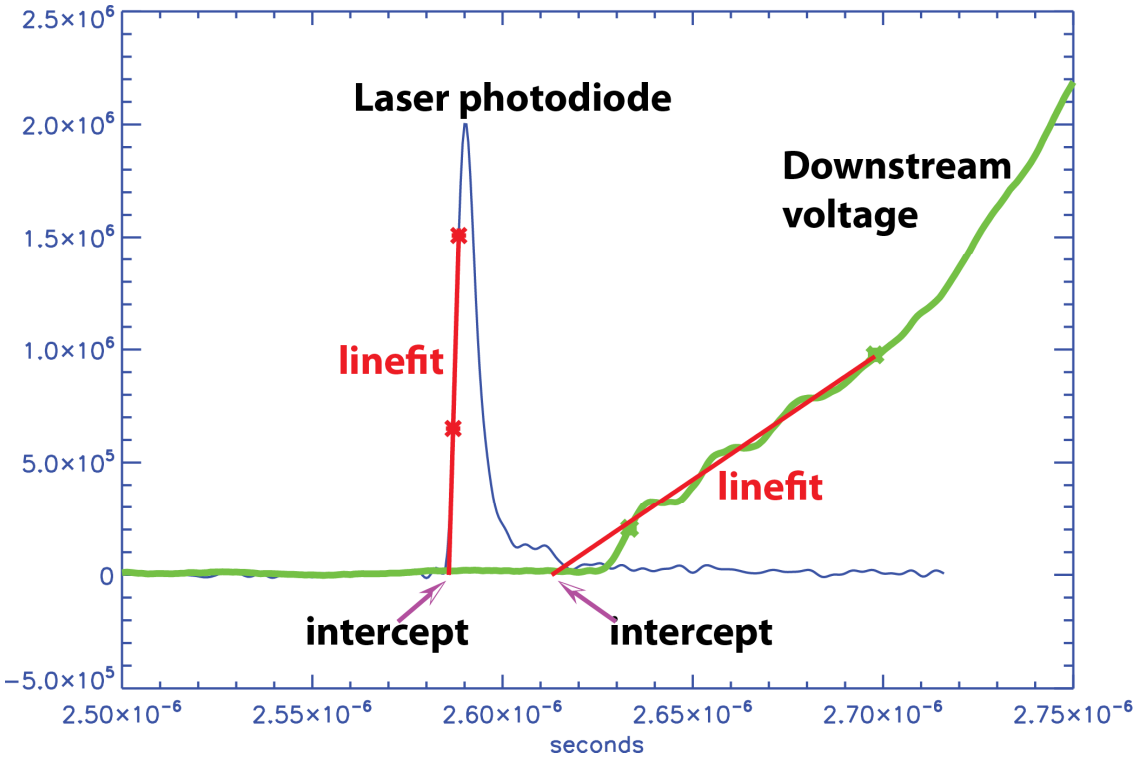
10%-90% rise times:

- **Total current: 68.7 ns**
- **Gas switch closure: 10.4 ns**
- ***Quadrature difference: 67.9 ns***



Accurate data analysis guides maintenance work on Z

- Visual review of every signal is tedious, error-prone and unnecessary
- Generally, we compare each signal to a reference (known good signal, circuit model, or analytic calculation) and use the entire waveform
- In every case, we use multiple waveform points and fit calculations to assess the result



Laser triggered gas switch run time calculation

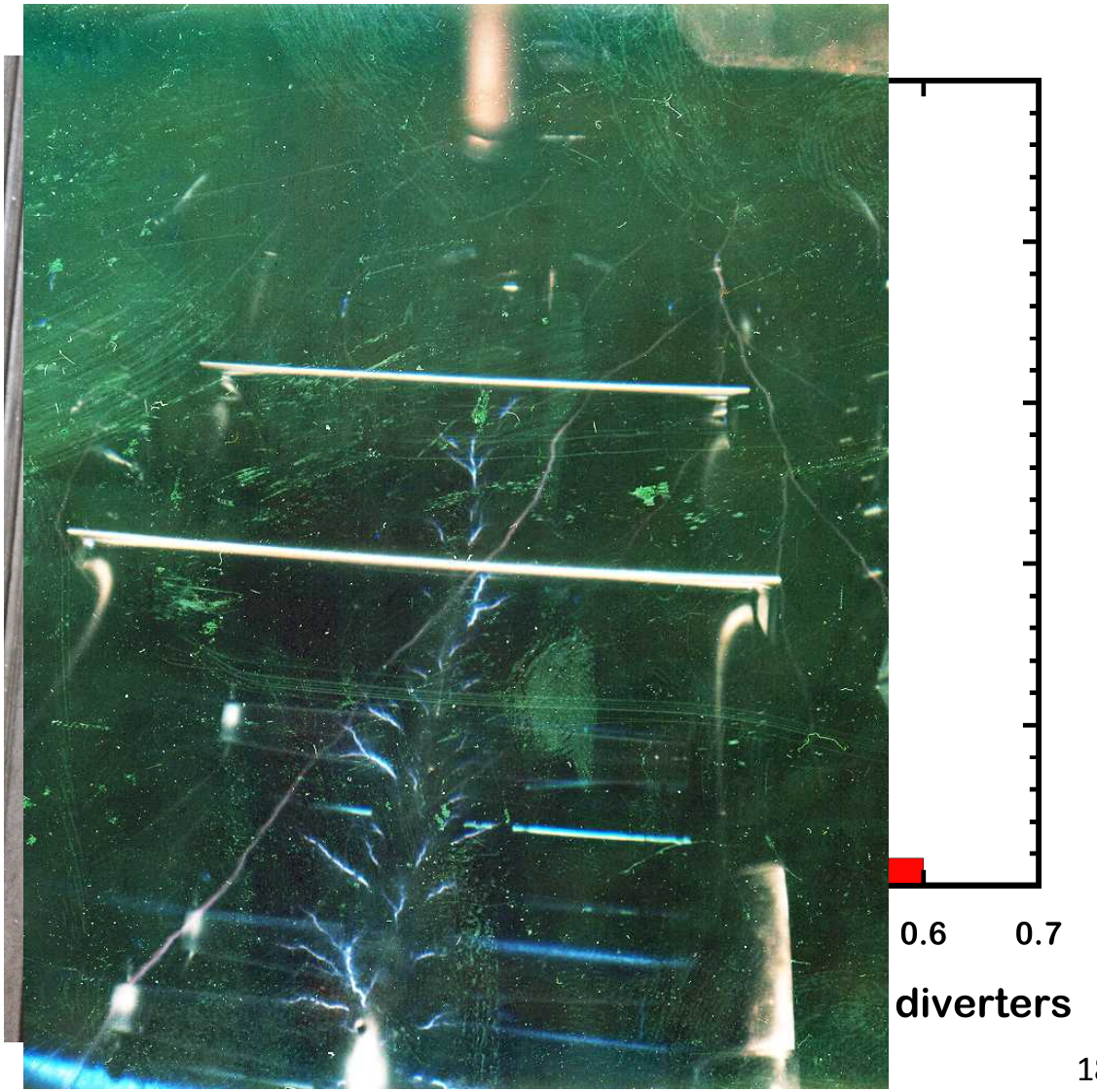
Water pulse-forming section

Late-time breakdown can damage metal structure

- **Breakdown that affects the shot is rare, but damaged parts must be replaced**

To enhance reliability, Z uses nonlinear energy diverters

- Late-time energy is not beneficial and can cause damage that must be repaired before the next shot



Water-vacuum interface

The water-vacuum interface operates with large mechanical stress

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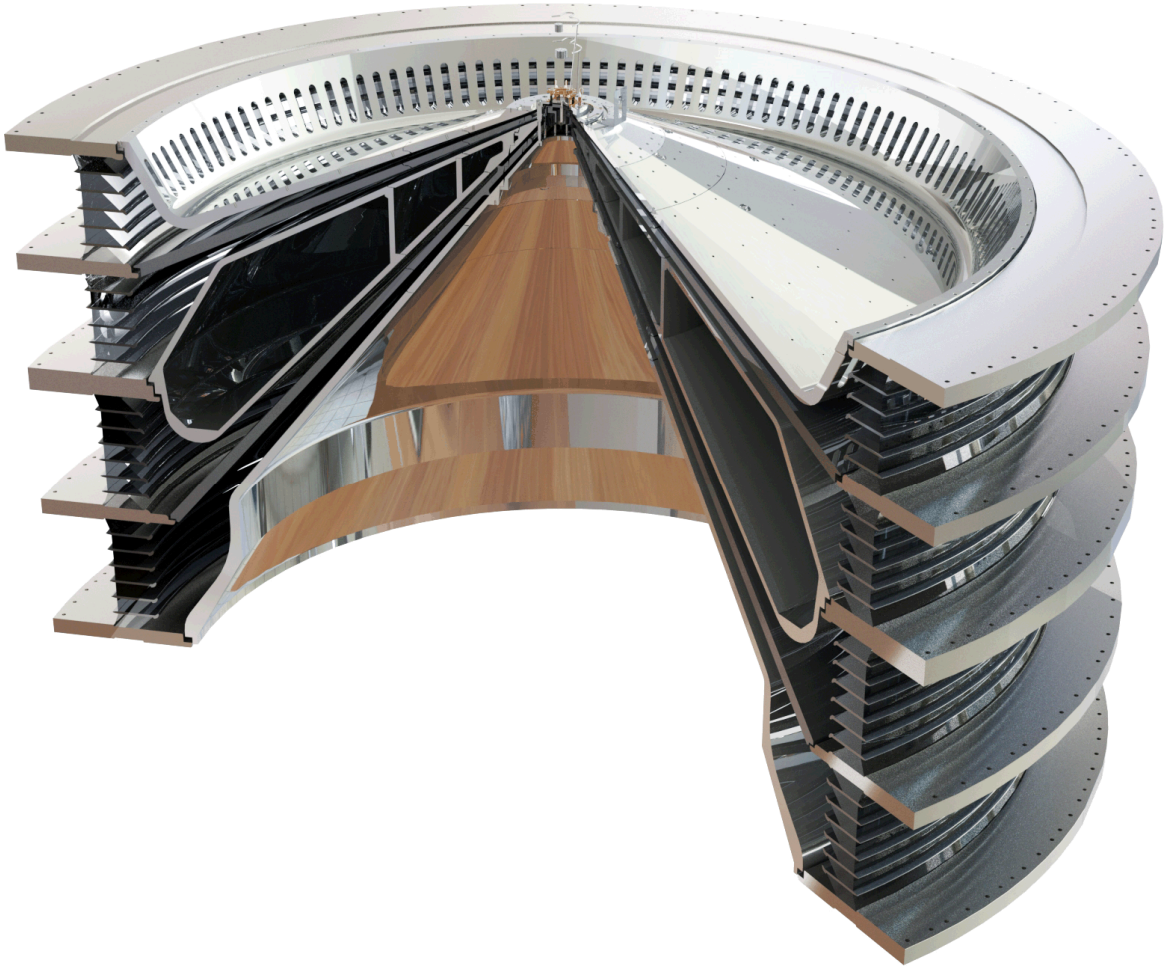
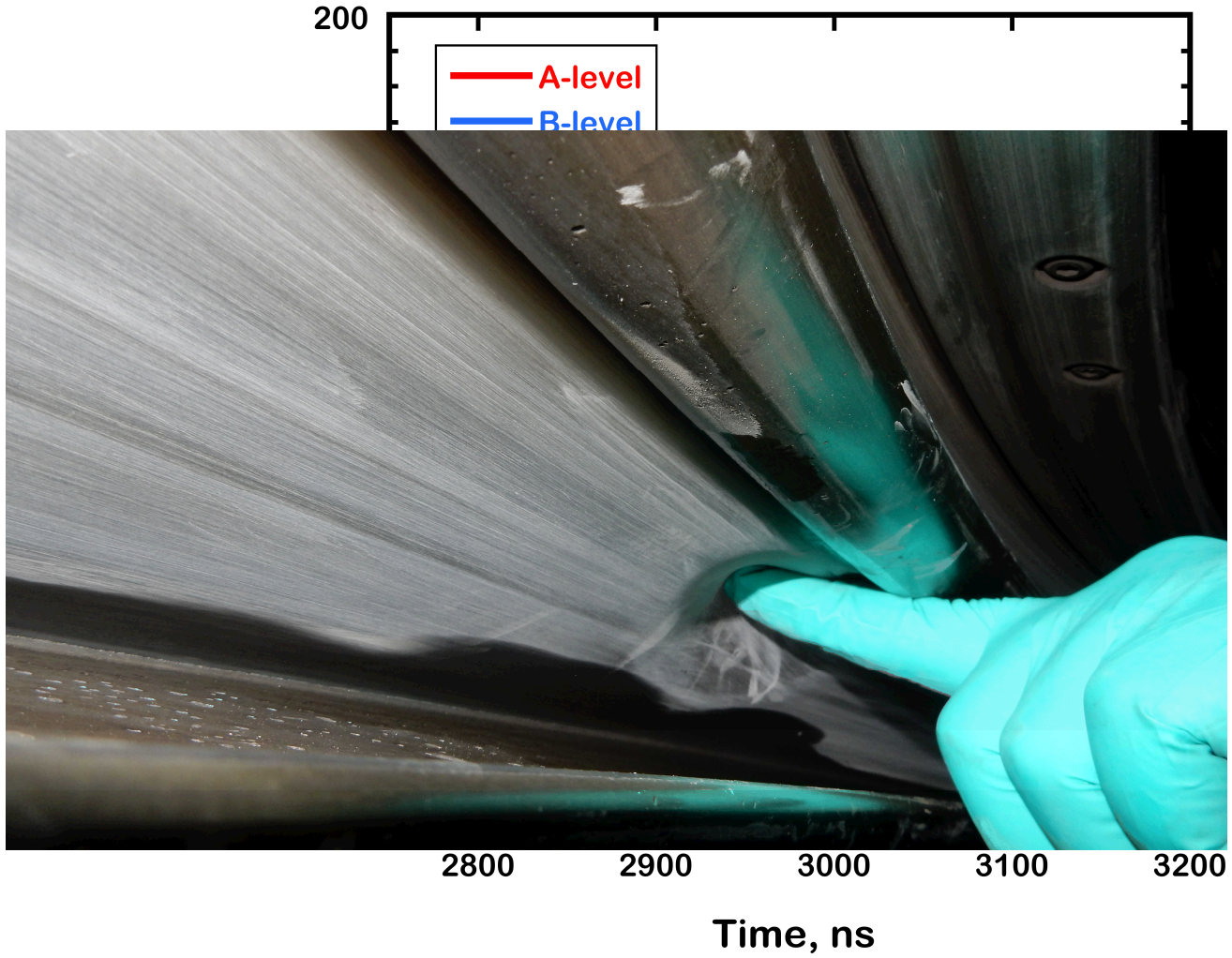
- 3.5 m diameter
- 1 MN axial vacuum load
- 60 kN compression
- 2 MN radial force on plastic
- 5G, 40 Hz acceleration of the entire assembly



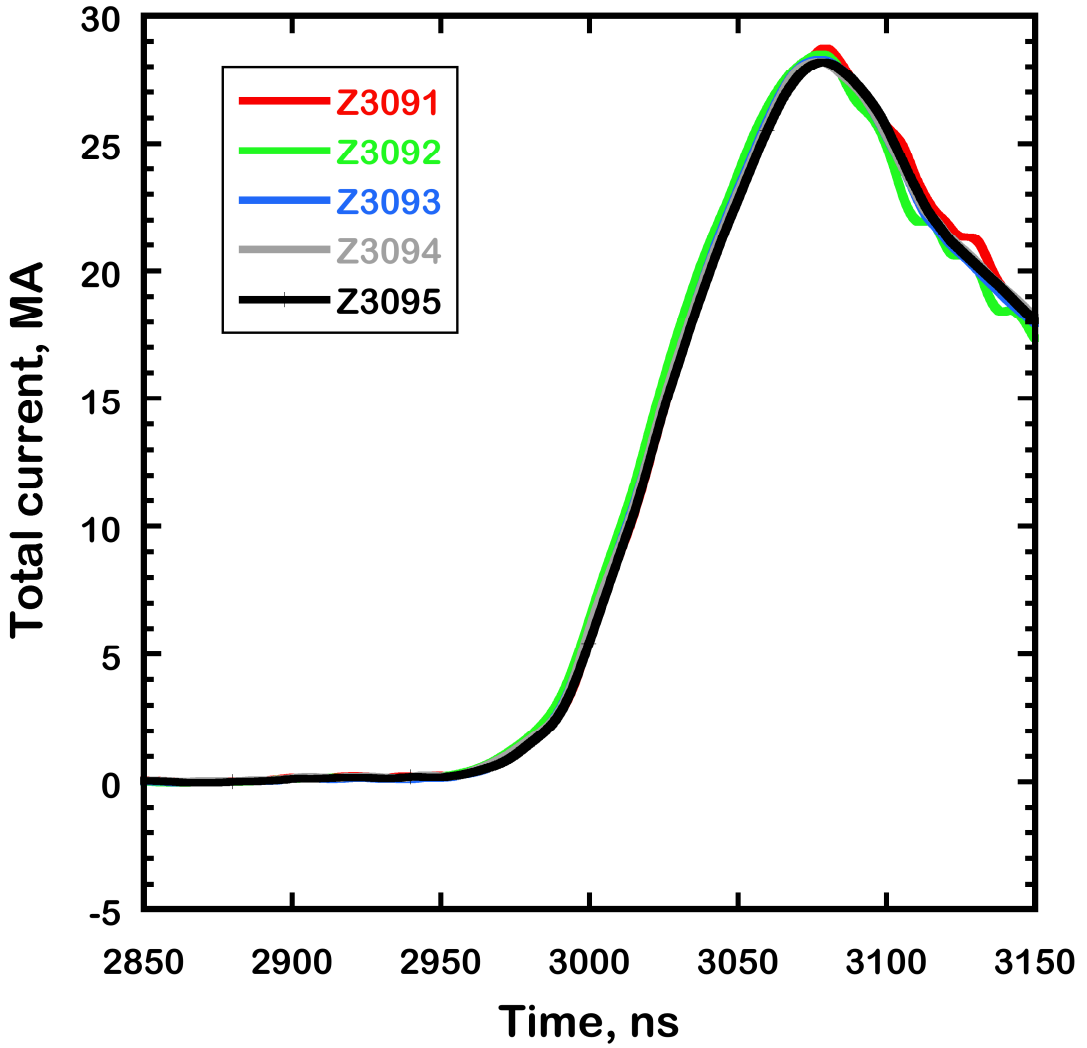
The Z water-vacuum interface operates at 150 kV/cm peak field

- Before Z data, it was not known what insulator stress could be tolerated on damaged insulators



The delivered current is reproducible

- **Five nominally identical experiments**
  - **Timing 900 ps 1-σ**
  - **Amplitude 0.24% 1-σ**



Conclusions

- Operating Z is a learning experience because it is unique
- Z provides a useful combination of high magnetic pressure, fast rise time, variable pulse shapes and a shot every day
- Z shots can be reproducible to the nanosecond and 1% level
- Six-MV triggered gas switches have been developed to be reliable and low jitter
- The water-vacuum interface operates routinely at 150 kV/cm

Keeping Z working

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