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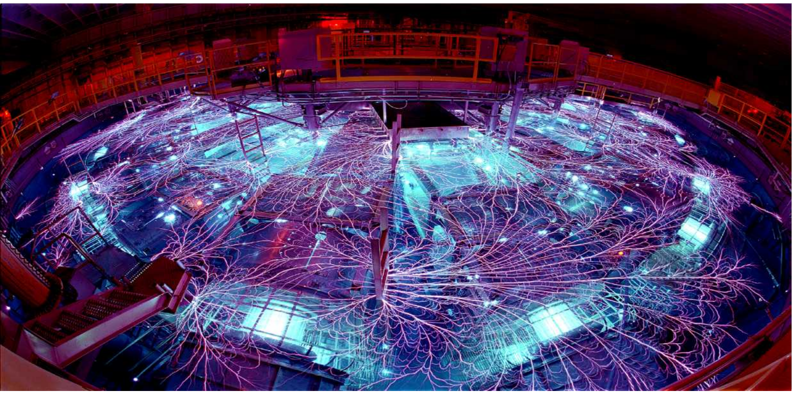

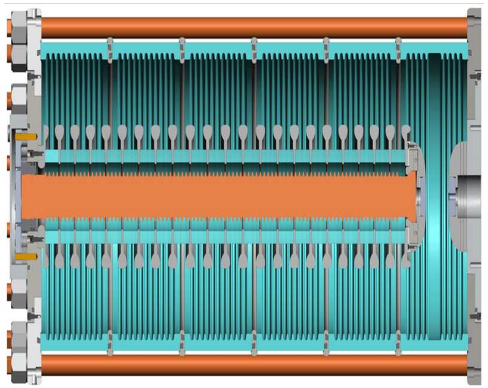

Z Pulsed Power Facility

PERFORMANCE ENHANCEMENTS AND RESULTS OF TESTING A NEW 6.7 MV LASER-TRIGGERED GAS SWITCH SYSTEM ON THE REFURBISHED Z ACCELERATOR

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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Abstract

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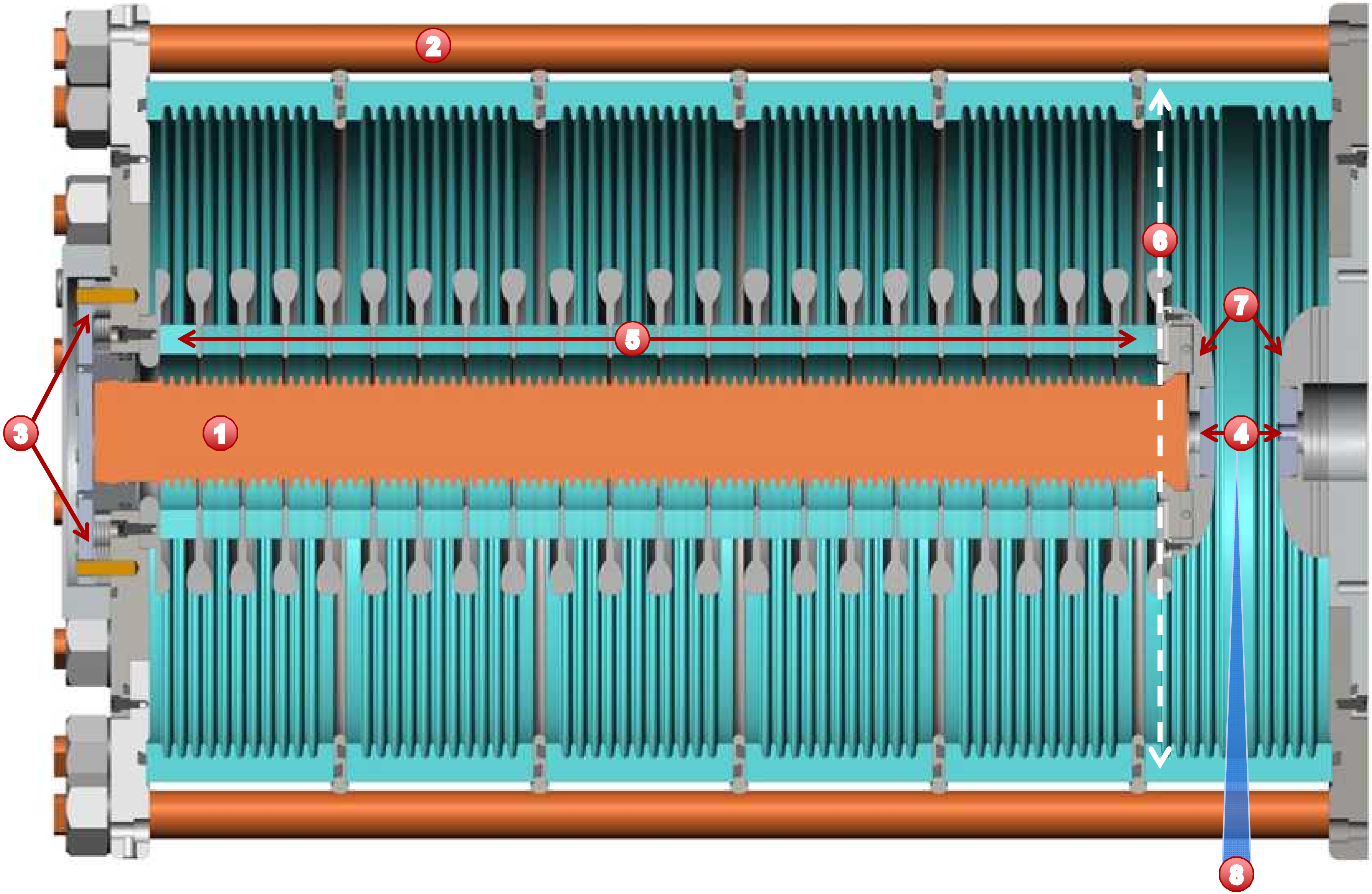
As the last command-triggered switch in the Refurbished Z accelerator at Sandia National Laboratories (SNL), the laser-triggered gas switch (LTGS) system is instrumental in the overall performance of Z and allows for flexibility in pulse shaping for various experimental campaigns. It is desirable to push the operating envelope of the switch to higher voltages and currents to allow for a higher peak power to be delivered to the load while at the same time reducing jitter and pre-fire rate for increased precision and reliability. We have accomplished this in a version of the LTGS that we call the C1.1 with the constraint of keeping the overall switch size consistent with physical space available. The C1.1 LTGS consists of laser-triggered and cascade portions which has been reported on previously.[1] However, the C1.1 eliminates the trigger plate and supports the cascade section in a cantilevered fashion. Improvements to this iteration of the LTGS were mainly mechanical in nature. Other minor electrical improvements were made to reduce regions of electric field enhancement and to reduce the likelihood of tracking by adding scalloping to the center support rod. Materials choice for the center support rod was important due to both the mechanical and electrical requirements placed on this component. Mechanical shock testing of the improved switch was performed on a shaker table available at SNL prior to installation on Z and showed that the improvements resulted in less displacement of the cantilevered end and less rotation of components in the cascade section. All electrical testing of the improved LTGS was performed on the Z machine. To date we have accumulated over 400 shots on C1.1 switches without a pre-fire. Runtime statistics are determined after each shot and show that the C1.1 switches are very tolerant to voltage and pressure variations exhibiting median runtimes of ~43 ns with a jitter (1-σ) of <6 ns on similar shots. The modifications made to and the performance results of the improved LTGS system are detailed in this manuscript.

Cross-Sectional View of the C1.1 LTGS



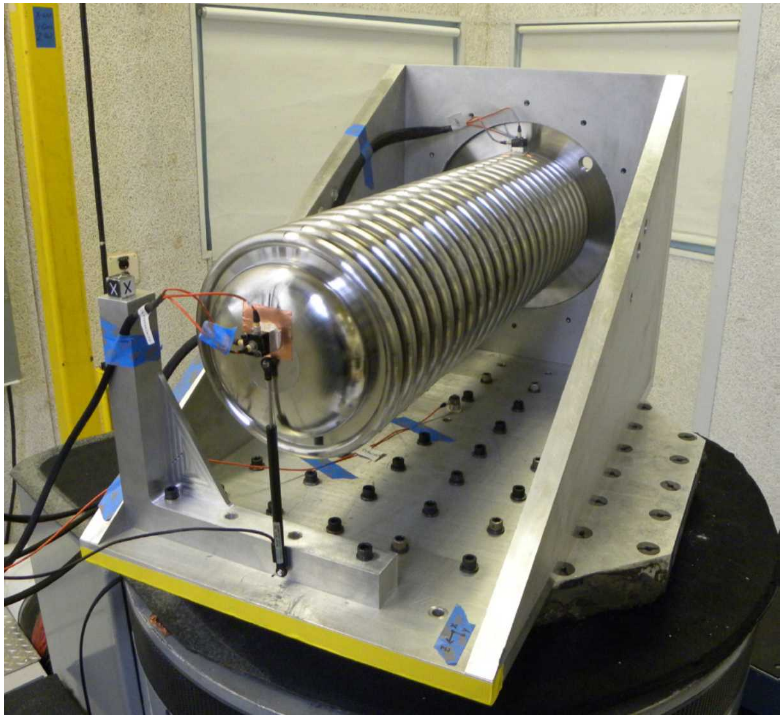
Key Features of the C1.1 LTGS

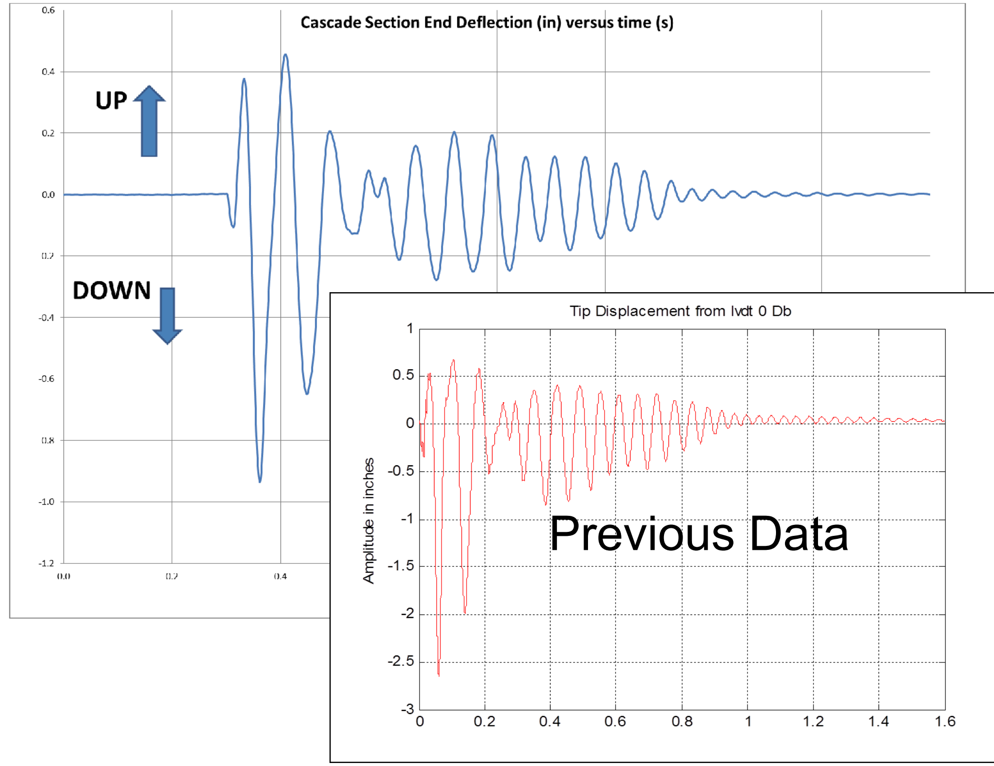
1. Scalloped Torlon 4203 center rod,
2. Torlon 4203 outer housing containment rods,
3. Bellville washer tensioning mechanism,
4. Elkonite 50W3 Tungsten alloy triggered electrode inserts,
5. Varied cascade section electrode spacing for a uniform axial electric field,
6. Elimination of the trigger plate to facilitate cascade section closure,
7. Modified Harrison profile on the triggered electrodes, and
8. Diagnostics

Mechanical Shock Testing

- Initial failures of the C1 LTGS were due to mechanical and debris issues. Point modifications were performed to correct these issues.
- Changes were made to the center rod surface, i.e. scalloping, in order to mitigate electrical flashover on this component.
- A modification was made to the center rod clamping mechanism. Concerns of stress concentration at the clamp were alleviated by design. O-rings were added to prevent debris entry.
- The center rod tensioning mechanism was modified to use more Bellville washer stacks at a larger radius to provide a higher mechanical advantage for supporting the center rod assembly and provide more pretension.
- Analysis of the switch internal pressure during firing necessitated using a stronger material (over Nylon) to hold the switch together during the pressure transient.

Mechanical Shock Testing



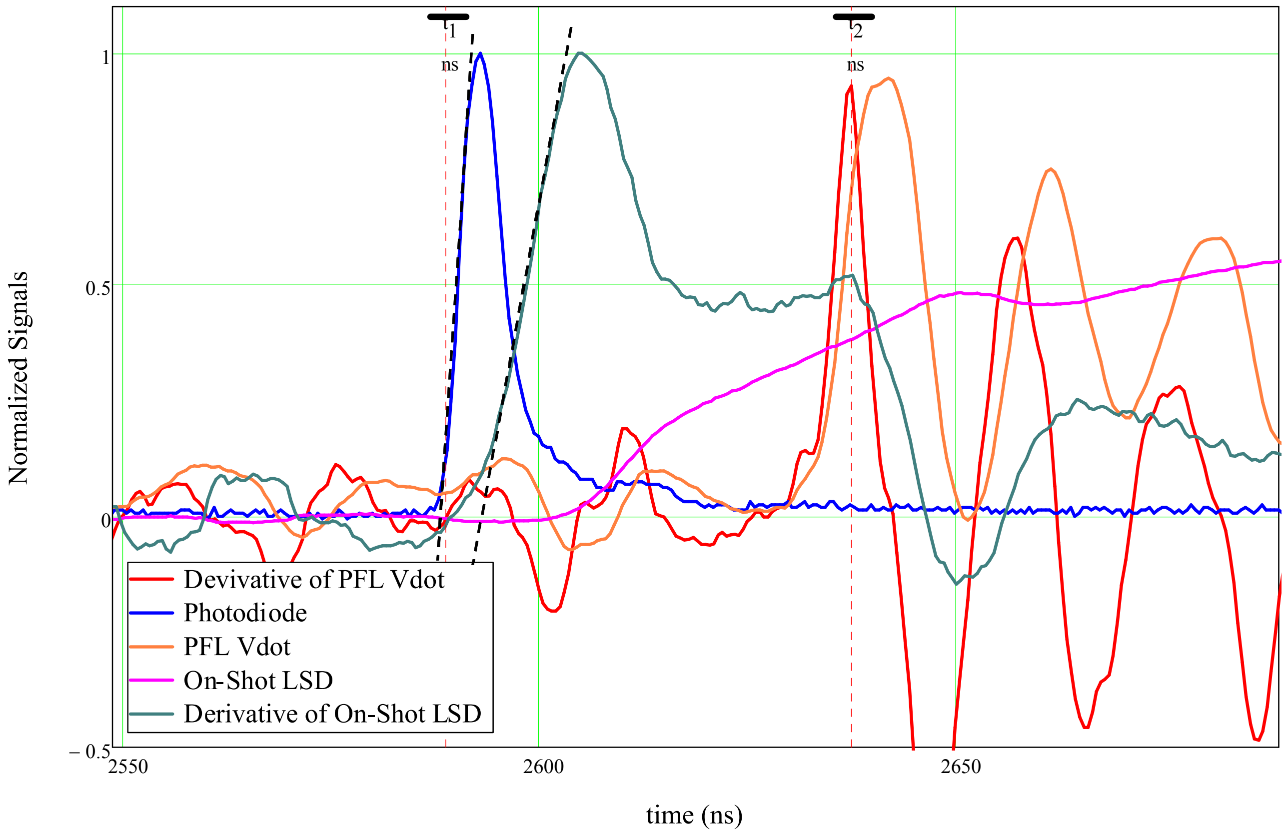


- The applied shock profile was based on g-logger measurements taken on Z.
- In addition to various accelerometers, a linear potentiometer was used to measure the deflection at the unsupported end of the cantilevered section.
- Peak deflection was reduced by more than a factor of two.
- Rotation of components (pucks and electrodes) was also significantly reduced.

Diagnostics and Runtime Determination

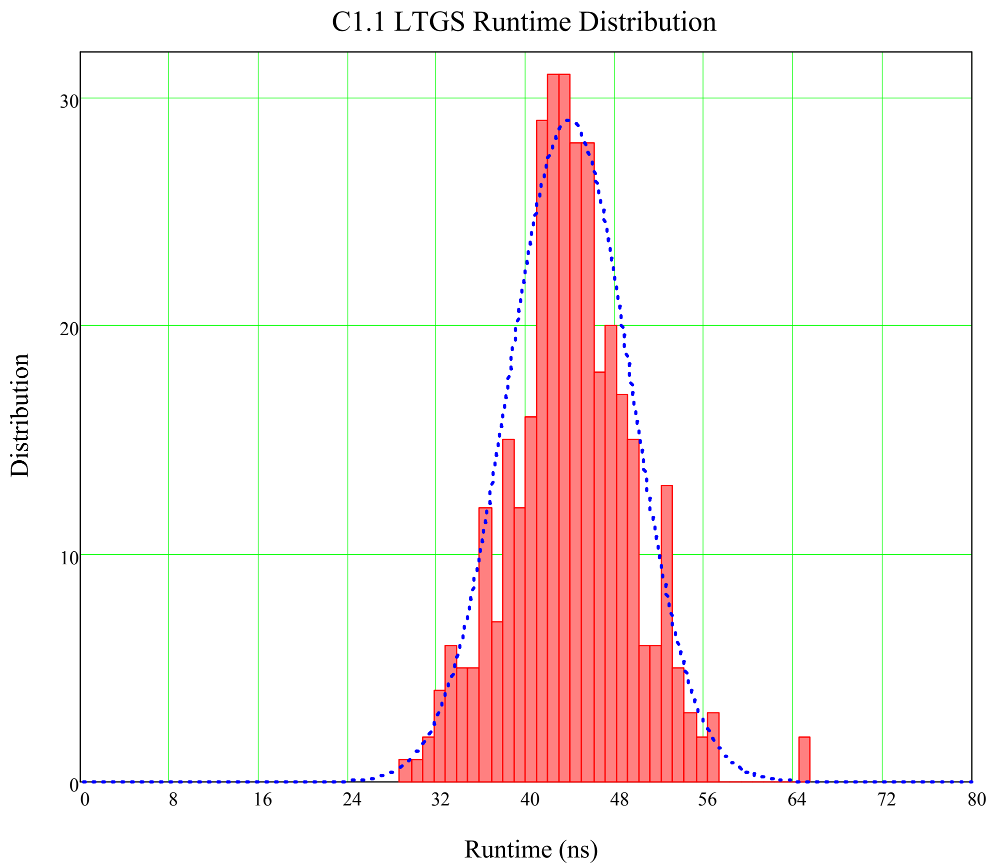
- Each switch has associated with it a laser spark detector (LSD) that is used prior to a shot during “light ups” to verify proper optics alignment and “on-shot” to monitor the triggered section arc channel formation.
- The on-shot LSD signal is used in conjunction with the laser photodiode (PD) and pulse forming line (PFL) D-dot diagnostics to determine switch closure time or “runtime.”
- Use of the PD and PFL voltage diagnostics allows for determination of the total switch runtime.
- Use of the on-shot LSD signal allows splitting the total switch runtime into its triggered and cascade section runtime components.

Runtime Diagnostic Waveforms



- Look at the linear slope on the rising edge of the PD and LSD signals at half maximum and find the zero crossings. The time difference between these zero crossings is the triggered gap runtime.
- Look at the derivative of the PFL D-dot signal and find its peak. This is the closure time of the switch delayed ~13 ns by propagation through a transmission line.
- The time difference between the PD zero crossing and the peak of the derivative of the PFL D-dot is the total switch closure time.

Runtime Performance Statistics



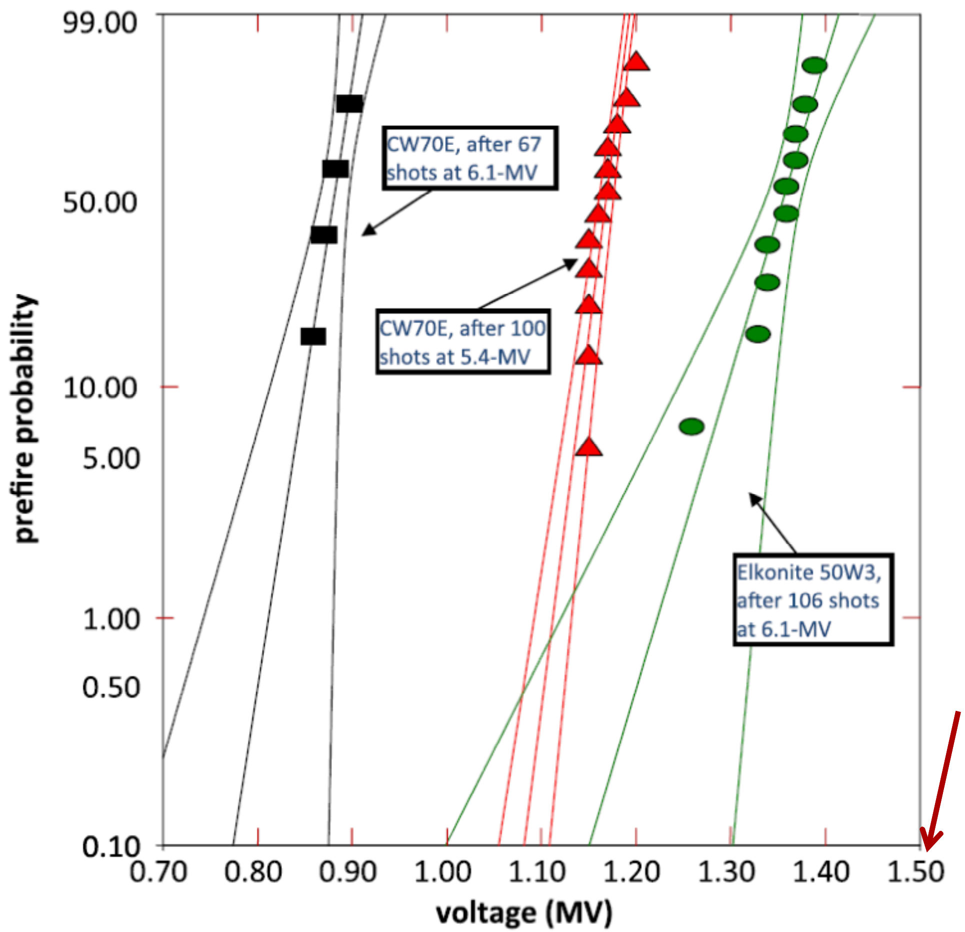
- Total C1.1 Shots: 365
- Marx Voltage Range: 53-85 kV
- Median Runtime: 43.8 ns
- Minimum Runtime: 28.6 ns
- Maximum Runtime: 65.4 ns
- Standard Deviation: 5.5 ns

(as of Shot 2519)

- The longest runtime of 65.4 ns was due to an anomalous condition in which the voltage across the switch was ~5% lower than its pressure setpoint.
- The statistics above cover a wide range of Marx charge voltages, switch pressure setpoints and pulse shapes.

- The runtime jitter for the C1.1 is more than a factor of two less than the A5 switch it will replace.
- The C1.1 switch is also more tolerant to voltage fluctuations on pulse shaped shots.
- The prefire rate at a 6.7 MV operating voltage is expected to be ~0.001%

Prefire Probablility



Voltage is for the triggered gap only which is ~15% of the switch operating voltage

- Weibull reliability statistics were applied to self-closure voltage data to determine the what pressure is appropriate for a given voltage for some desired prefire rate.[1, 2]
- Elkonite 50W3 is a 90% tungsten particulate, 10% infiltrated copper by weight manufactured by CMW, Inc.

References

[1] K. R. LeChien, et al, “6.1-MV, 0.79-MA laser-triggered gas switch for multimodule, multiterawatt pulsed-power accelerators,” Phys. Rev. ST Accel. Beams 13, 030401 (2010) and references therein.

[2] K. R. LeChien, et al., “Development of a 5.4 MV laser triggered gas switch for multimodule multimegampere pulsed power drivers,” Phys. Rev. ST Accel. Beams 11, 060402 (2008)