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DEVELOPMENT OF A 6.25 MV LASER TRIGGERED GAS SWITCH FOR THE REFURBISHED Z DRIVER

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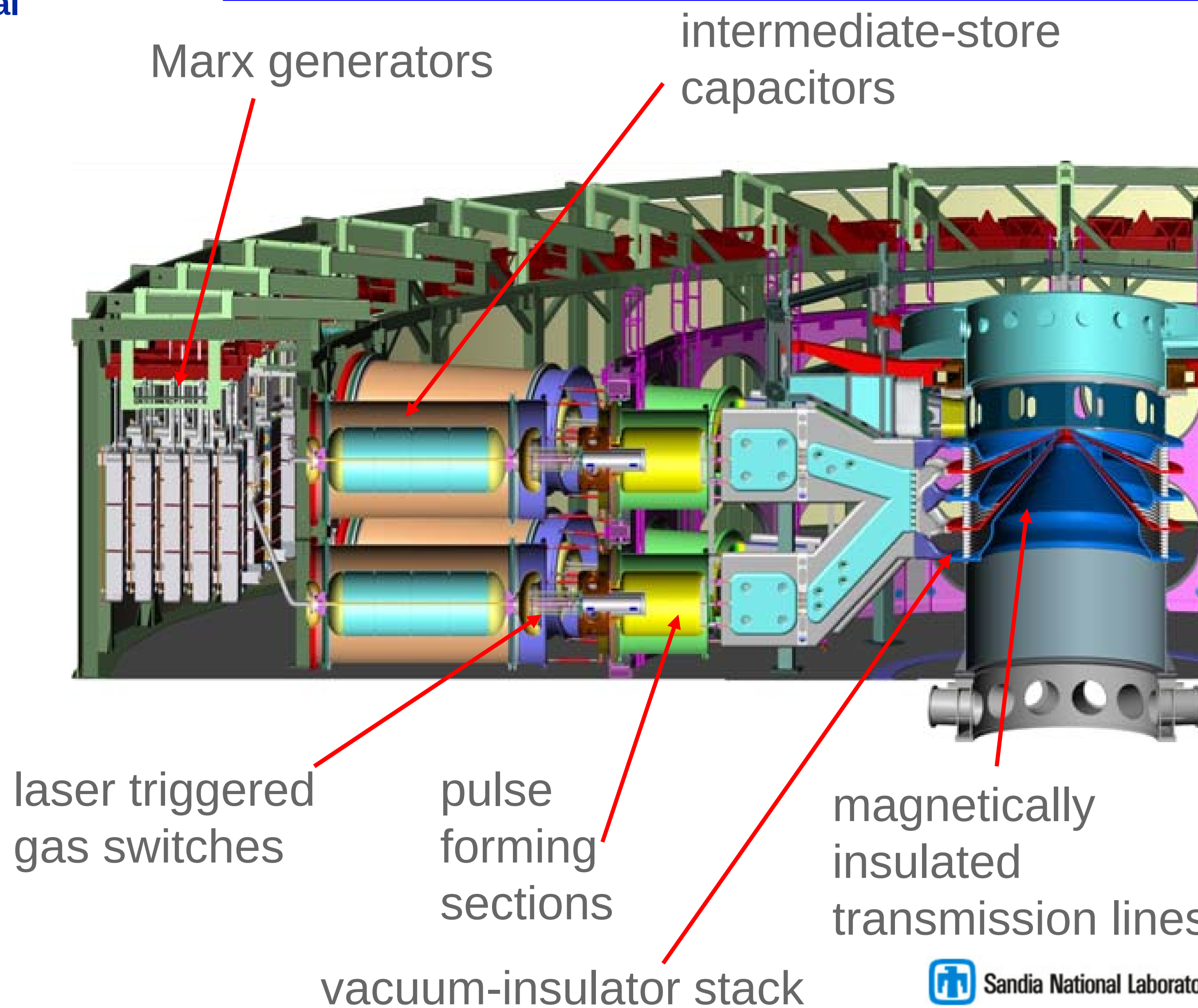
The thirty-six module Z pulsed power system applies 9 MJ of forward going energy in ~100 ns with nanosecond accuracy

All Z pulsed power components were replaced between July 2006 and September 2007

A Z shot begins with a 5V signal from the control system:

- **A system of trigger generators amplify the trigger pulse to 600 kV**
- **The Marx generators are discharged in 1.2 μs, charging the intermediate storage water capacitors**
- **The laser-triggered gas switches control discharge of the intermediate store capacitors with ~5 ns accuracy**
- **The water switches discharge the pulse-forming line in 115 ns with 2 ns accuracy**
- **Load current rises in 115 ns to 26 MA**

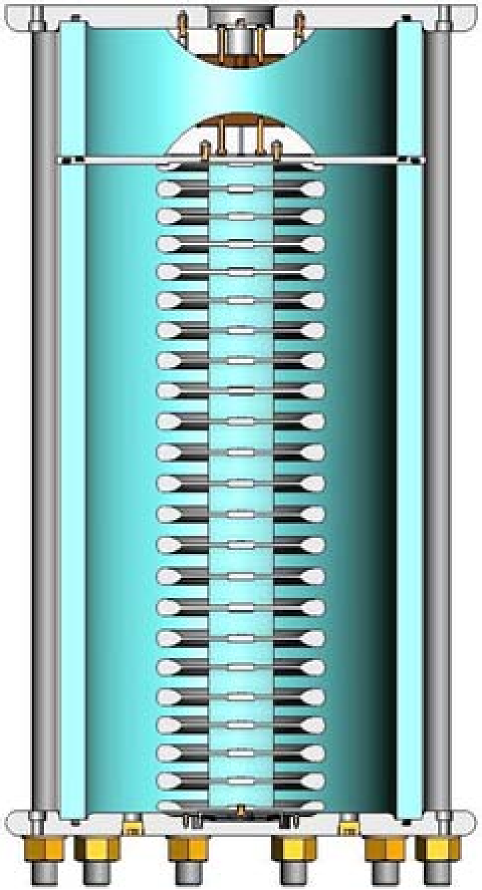


System performance is highly dependant on gas switch operation

- **Forward going wave jitter < 1 ns and repeatability of peak current of ± 1%**
  - Implies less than 6 ns jitter for an individual switch
- **System reliability of 98%**
  - Implies less than a 0.03% probability of individual switch prefire or late fire
- **To obtain 26 MA in 115 ns (wire array load of 20 mm radius, 20 mm long)**
  - Switch voltage: 6.1 MV
  - Switch current: ~800 kA
- **Desired maintenance interval: > 150 shots**

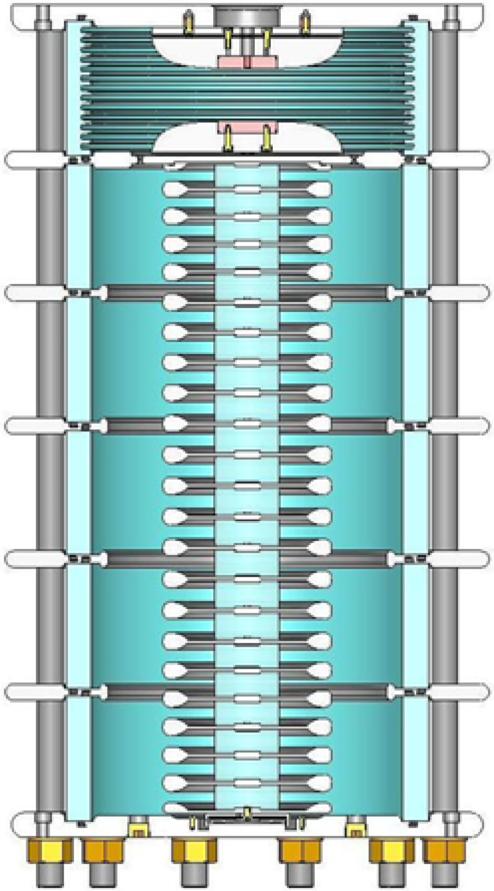
A three-year research effort led to the development of gas switches that meet system performance goals

Reducing shot-dependant failure modes has been the biggest challenge to providing a suitable switch



June 2005

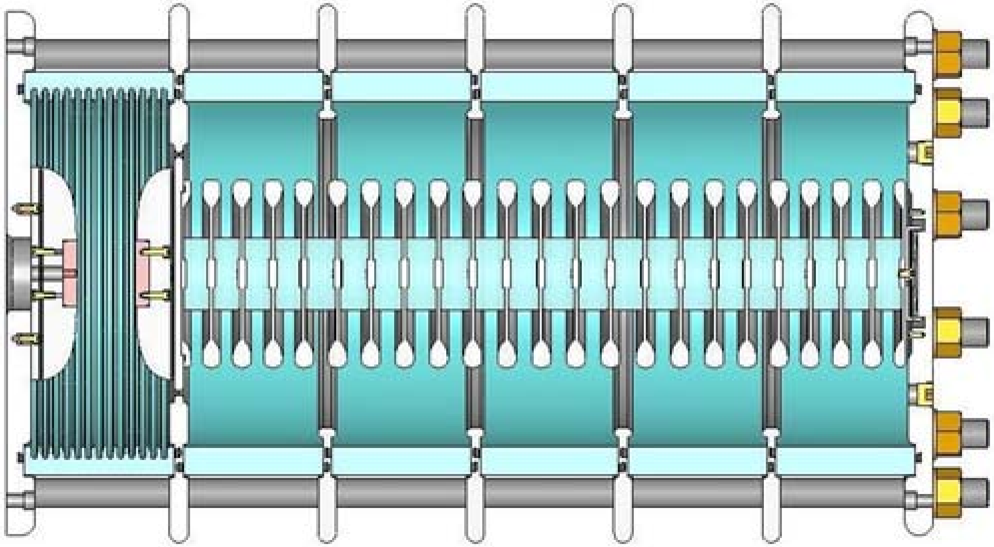
- Flashover of insulators
  - Erosion of electrodes
  - Insulator design
  - Cleaning procedures
- Prefires/no-fires due to limited life components
  - Enhancements due to erosion
  - Optic degradation



June 2008

The present gas switch design will meet near term Z performance goals

performance parameter	original ZR gas switch (5.0 - 6.25 MV)	ZR-A-3 gas switch (6.25 MV)
prefire rate	7%	< 0.1%
jitter	13 ns	5 ns
flashover rate	5%	< 1%
replacement interval	< 30 shots	~120 shots



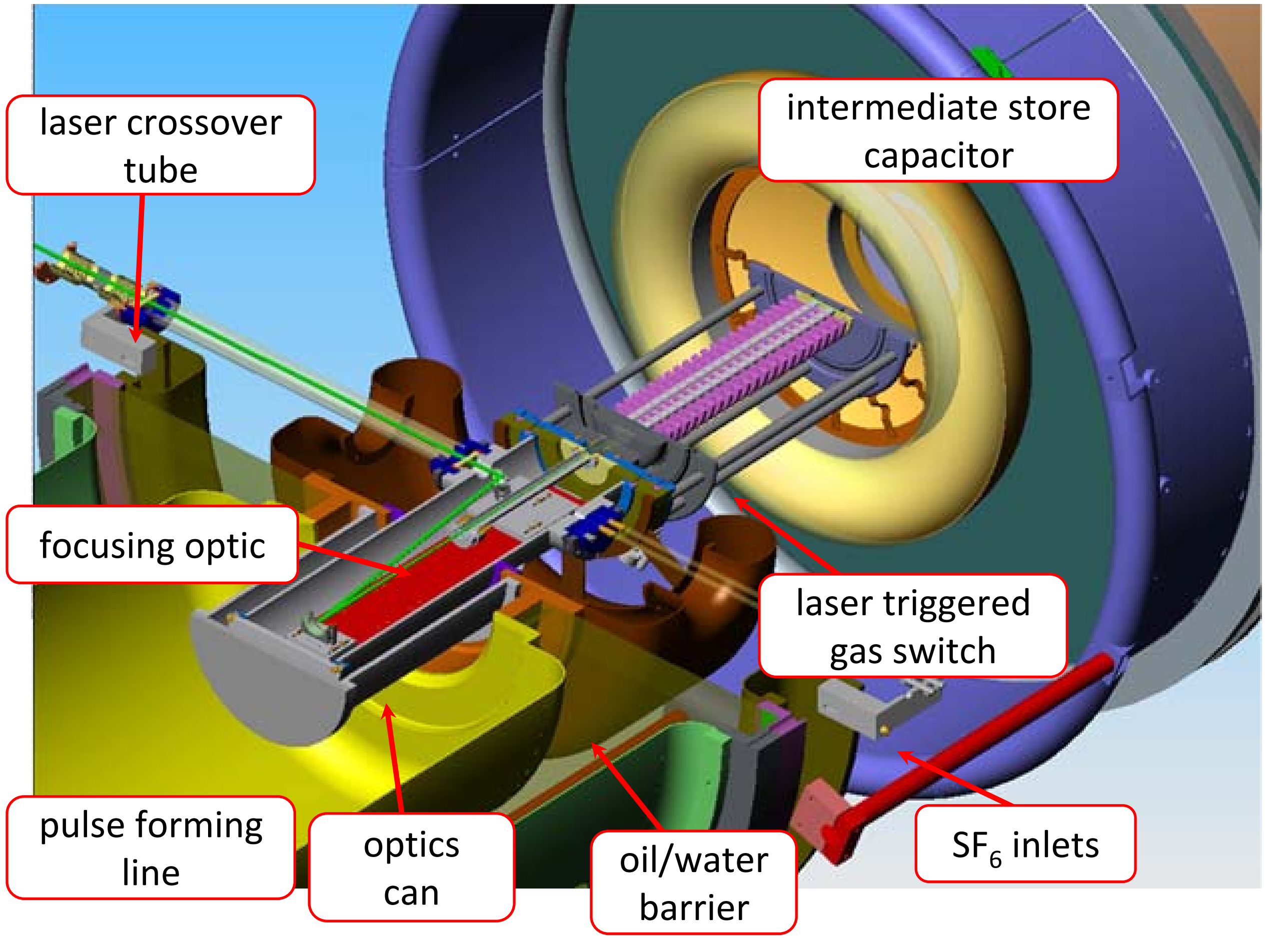
ZR-A-3
laser-triggered
gas switch

K. R. LeChien, M. E. Savage et al., accepted for publication in Phys. Rev. ST Accel. Beams (2008).
K. R. LeChien, M. E. Savage et al., manuscript in preparation (2008).

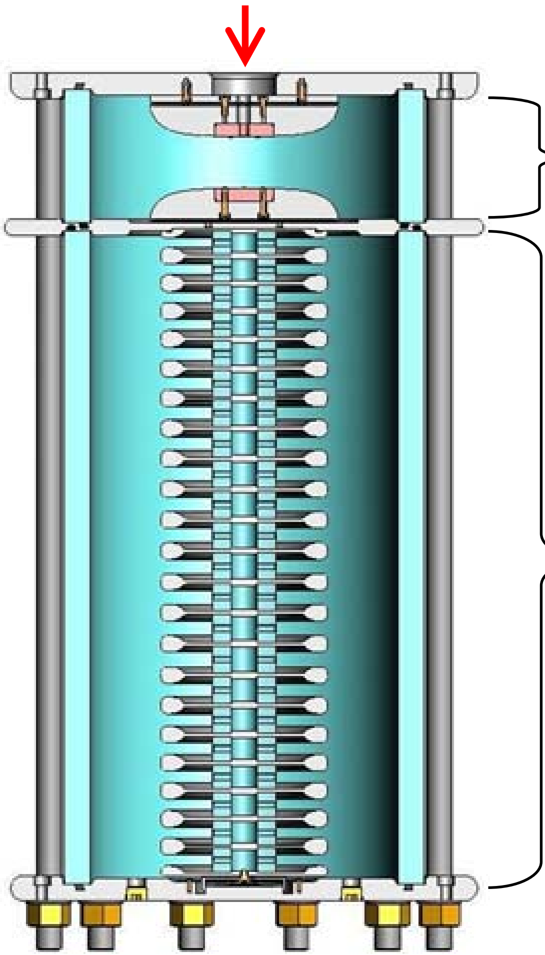
The laser triggered gas switch is the last command fired component in the system

- **Each switch has a dedicated laser**
  - **Nd:YAG**
    E = 35 mJ
    λ = 266 nm
    t= 4 ns FWHM

- **Optical train**
  - **6 mirrors, 3 windows, 1 lens**
  - **11 m total optical path length**

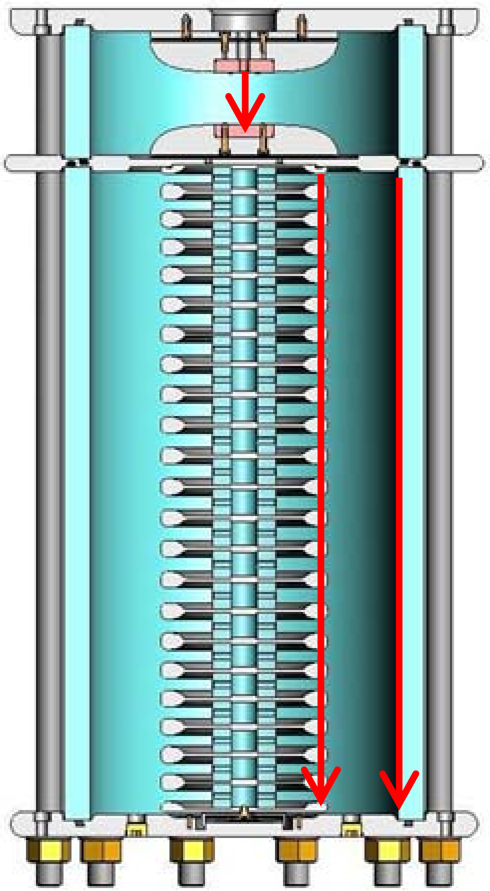


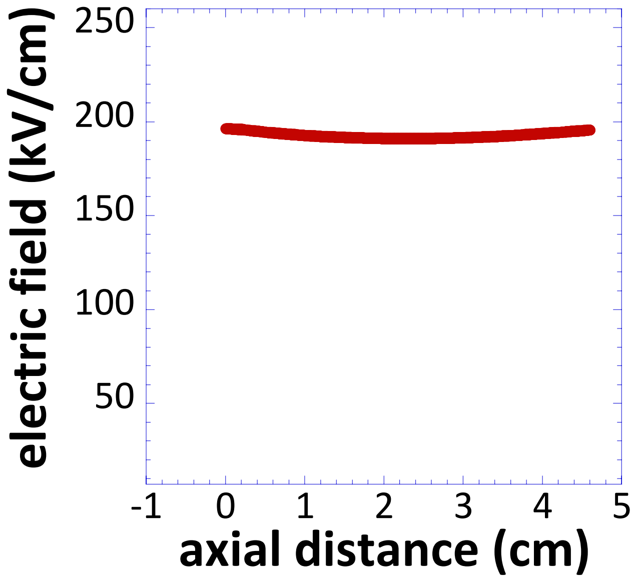
The gas switch is comprised of two series switches; One laser triggered and one electrically overstressed

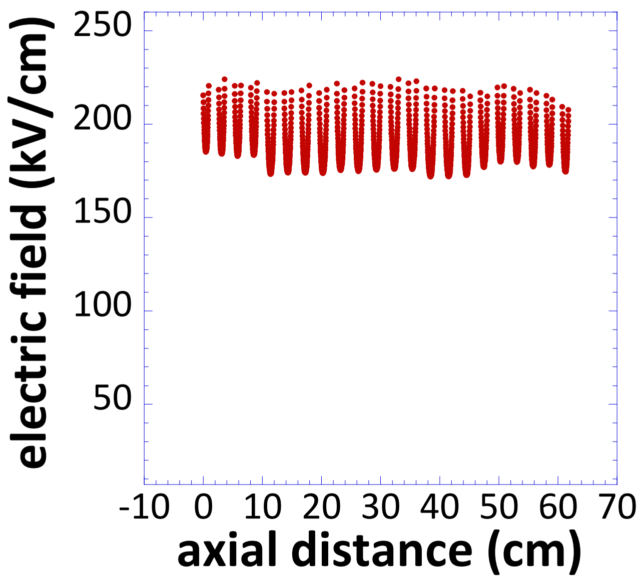


- ~15% of the total voltage is imparted to the trigger gap (~940 kV at 6.25 MV switch voltage)
- Cascade section closure relies on the overstress from the trigger gap
- Cascade section "multi-channels"
- Trigger section and cascade section share a common gas volume

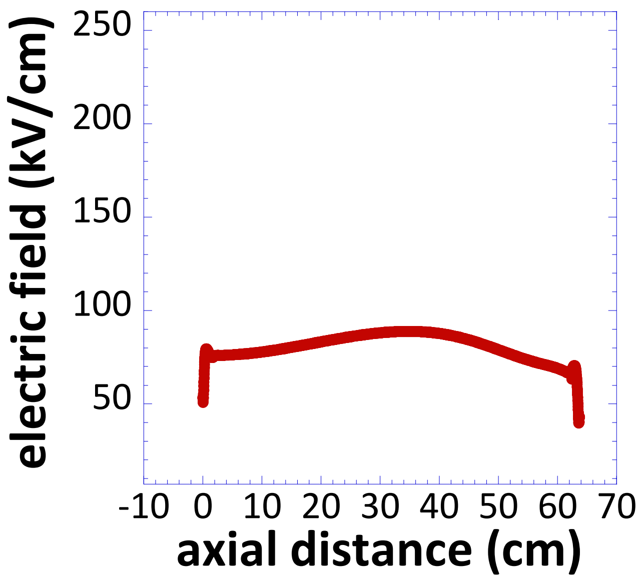
The peak electric field is matched between the trigger and cascade sections before closure



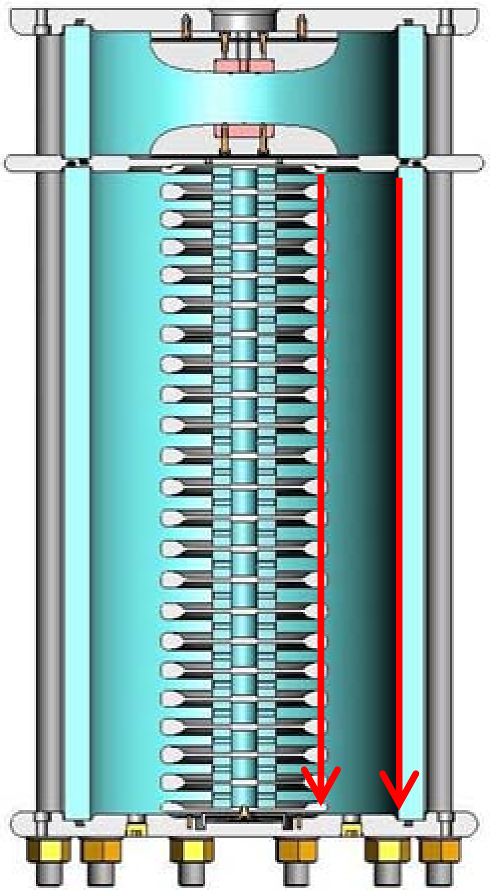


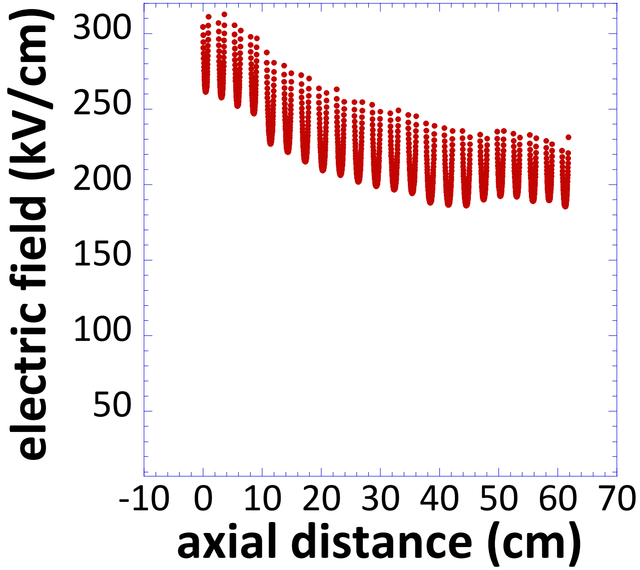


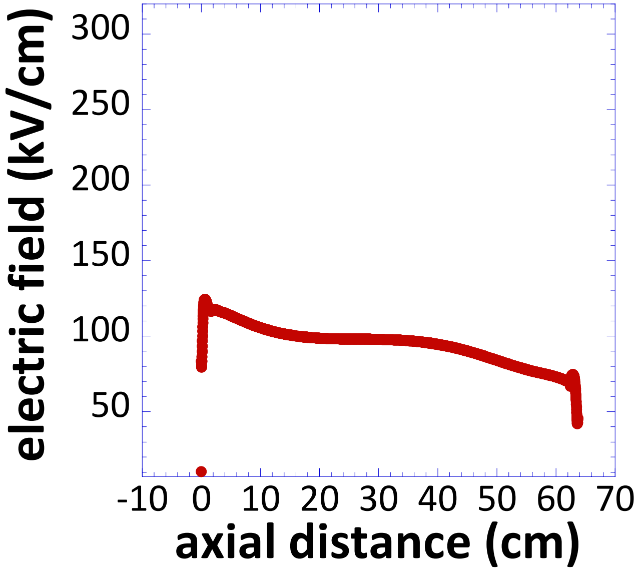
- Trigger gap field is uniform
- Cascade field is uniform
- Cascade insulator field is ~0.5 gap field



The peak electric field increases throughout the cascade section upon trigger closure

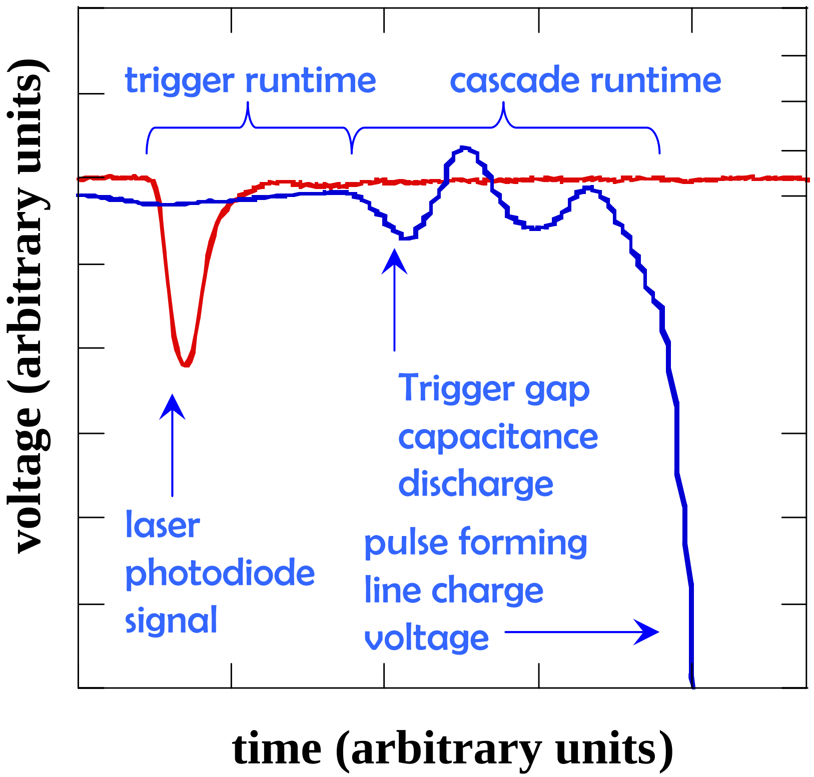






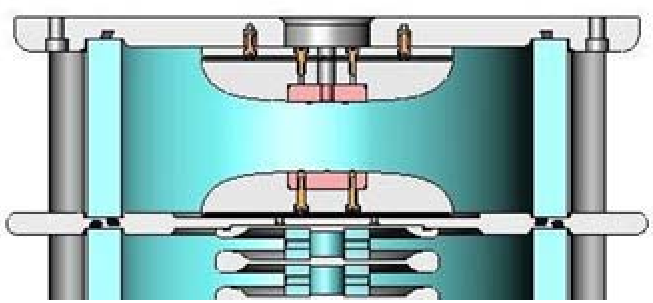
- **Electric field magnitude increases approximately 45% when triggered**
- **Overstress wave is partially impressed on 18 of the 22 gaps**

Electrical closure of the switch is monitored by voltage, photomultiplier, and streak camera diagnostics



- Runtime and jitter for the trigger and cascade section are fully identifiable.
- The ability to clearly observe each sections closure has led to major advances in our understanding of laser triggered gas switches in a multi-megavolt environment.
- Trigger section failure modes and cascade section failure modes are separable with these diagnostics

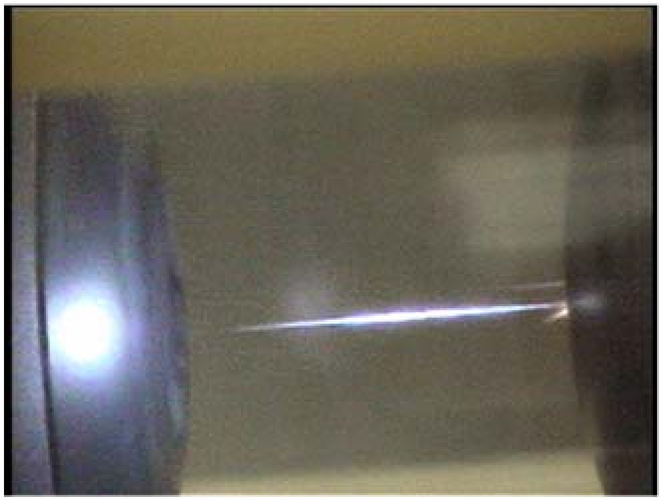
Trigger section

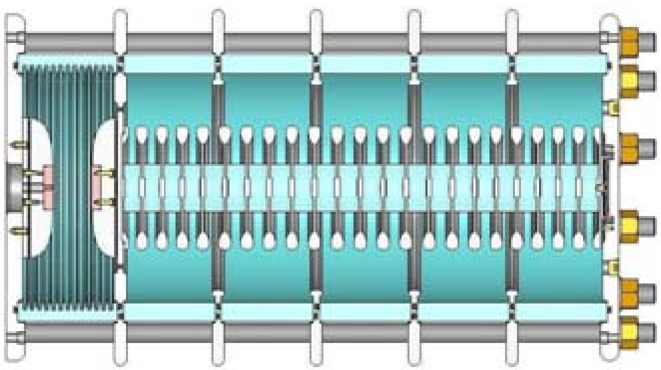


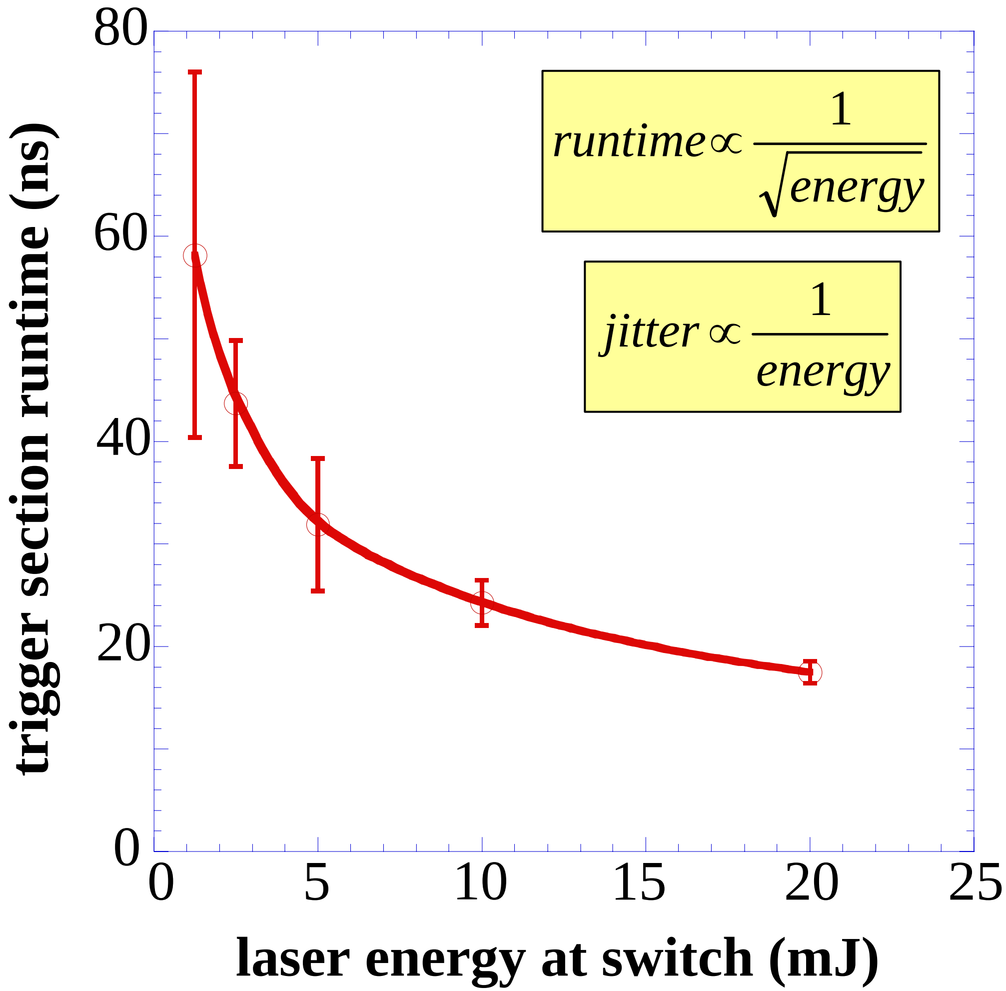
- **Laser parameters**
- **Trigger electrode material (single channel)**
- **Optic line of sight**

The trigger section is designed for sub-nanosecond jitter performance

- ***Trigger jitter is ~ 1 ns at a gap distance commensurate with a prefire probability of <0.01%***



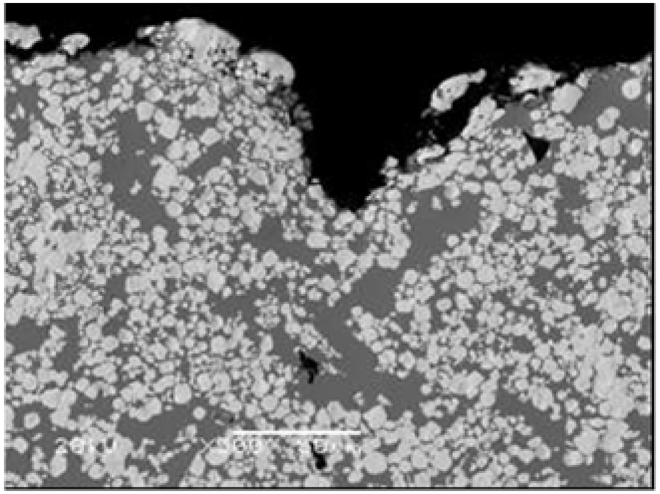


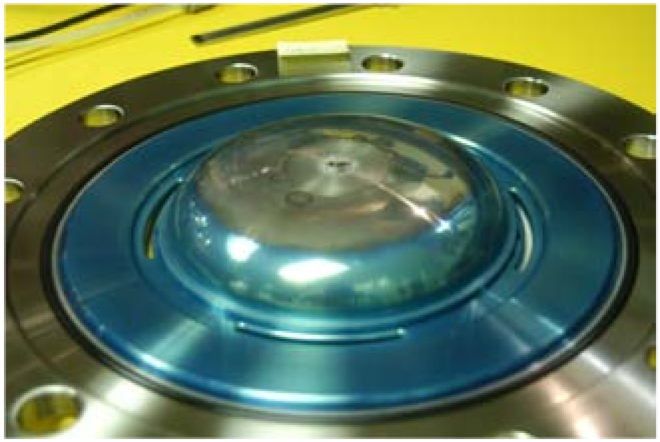


Appropriate selection of trigger electrode material led to suitable performance at 6.25 MV, 800 kA

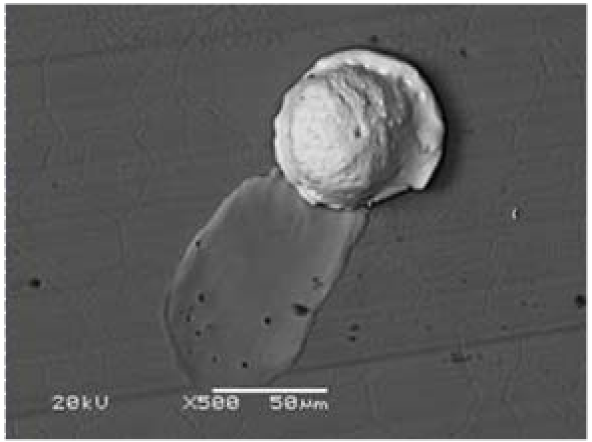
- **The flashover rate was reduced an order of magnitude; from 8% with stainless steel to < 1% using Elkonite 50W3**

- **The lifetime of the final optic was increased by an order of magnitude; from 50 shots with Mallory 1000 to > 200 shots with Elkonite 50W3.**





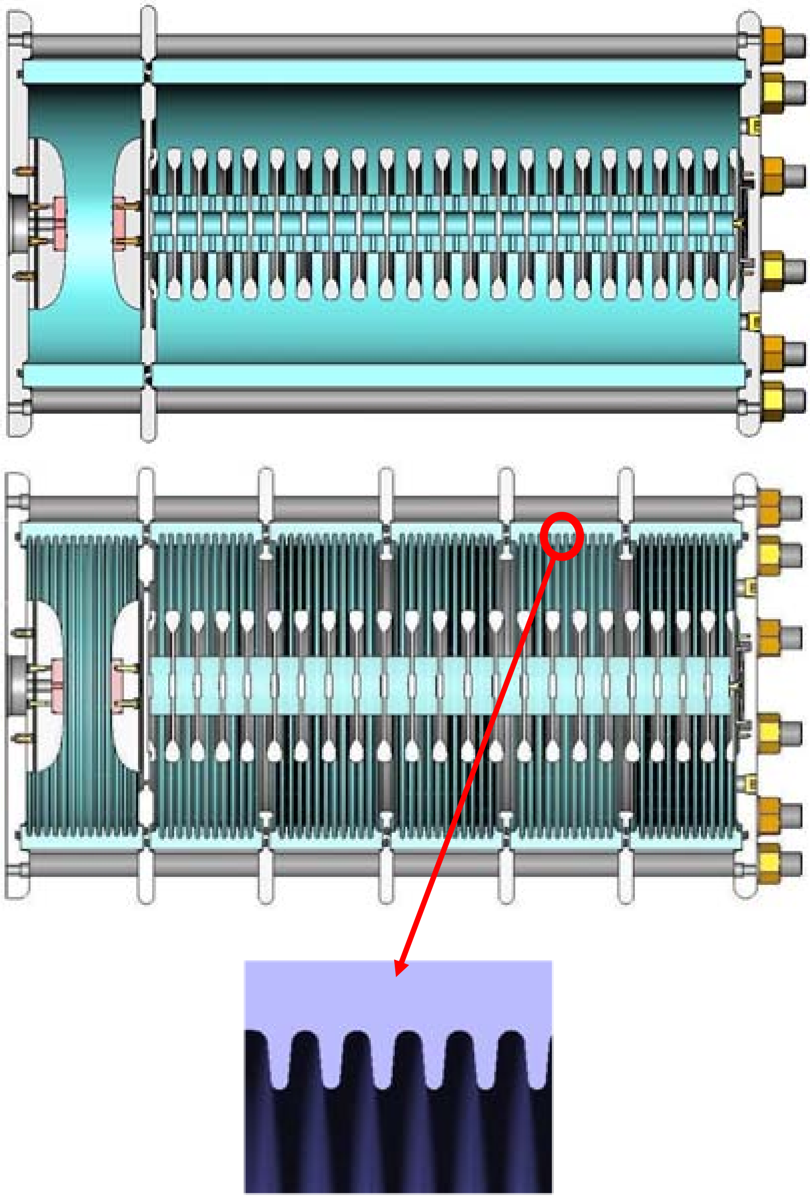
Molybdenum trigger electrodes: byproducts coated insulators and led to flashing (43 shots)

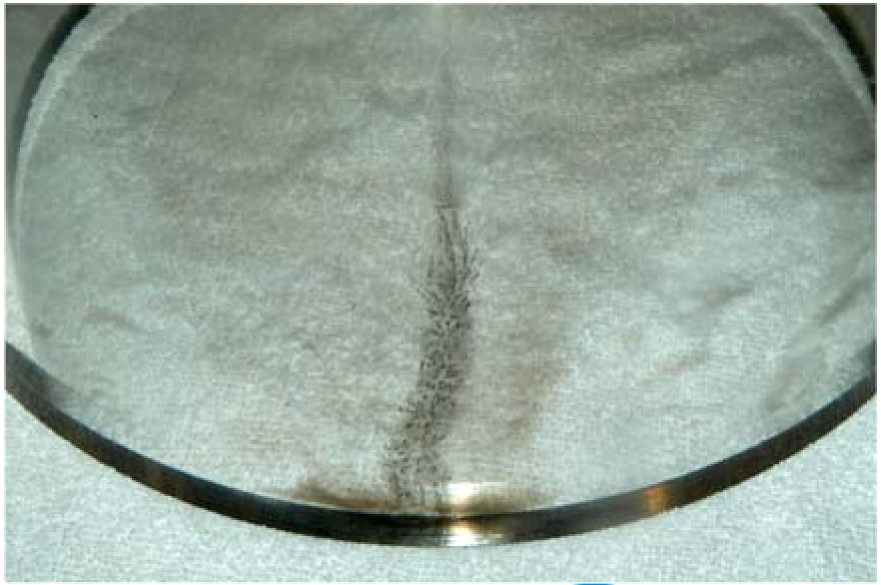


HD-17 Cu-W: electrodes material was deposited in large pieces and led to flashover (40 shots)

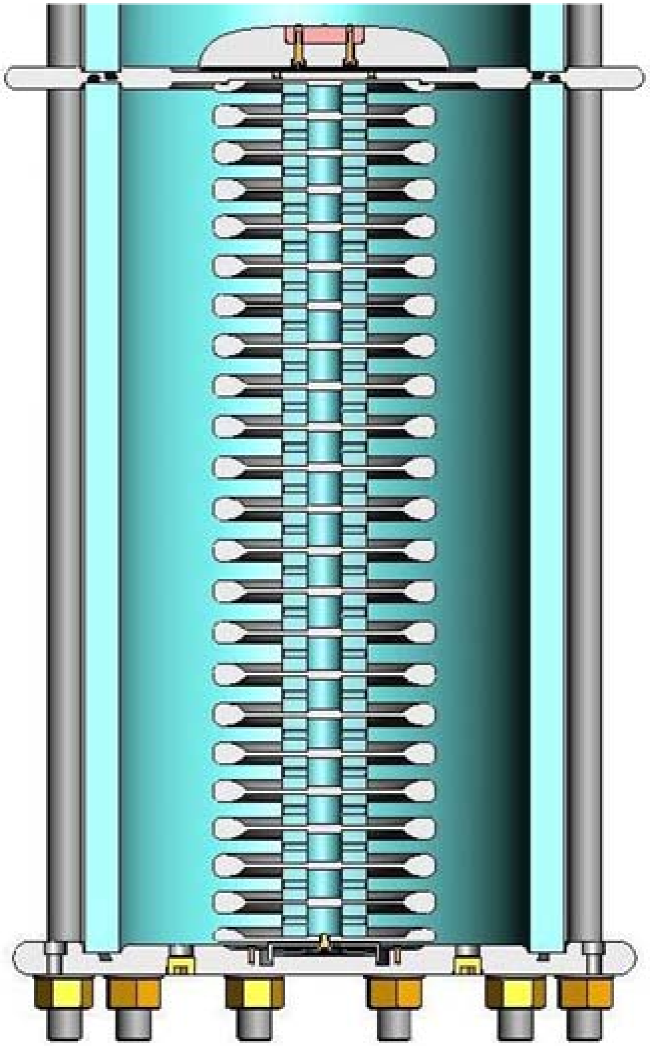
Mallory Cu-W: electrode material coated optics and reacted unfavorably with UV (30 shots)

Scalloping and segmenting monolithic insulators increased reliable gas switch performance by two orders of magnitude

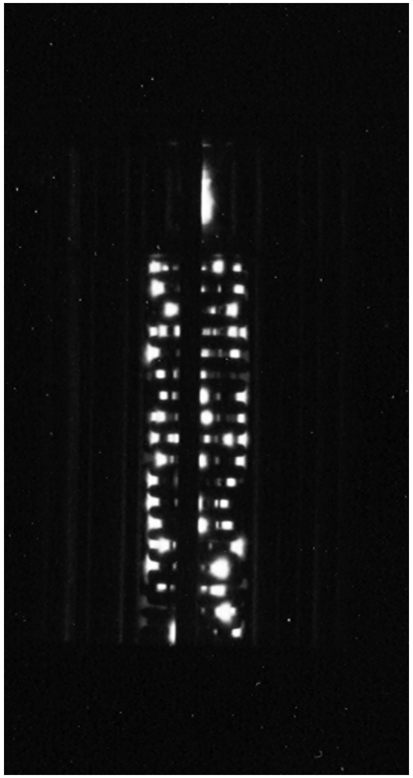




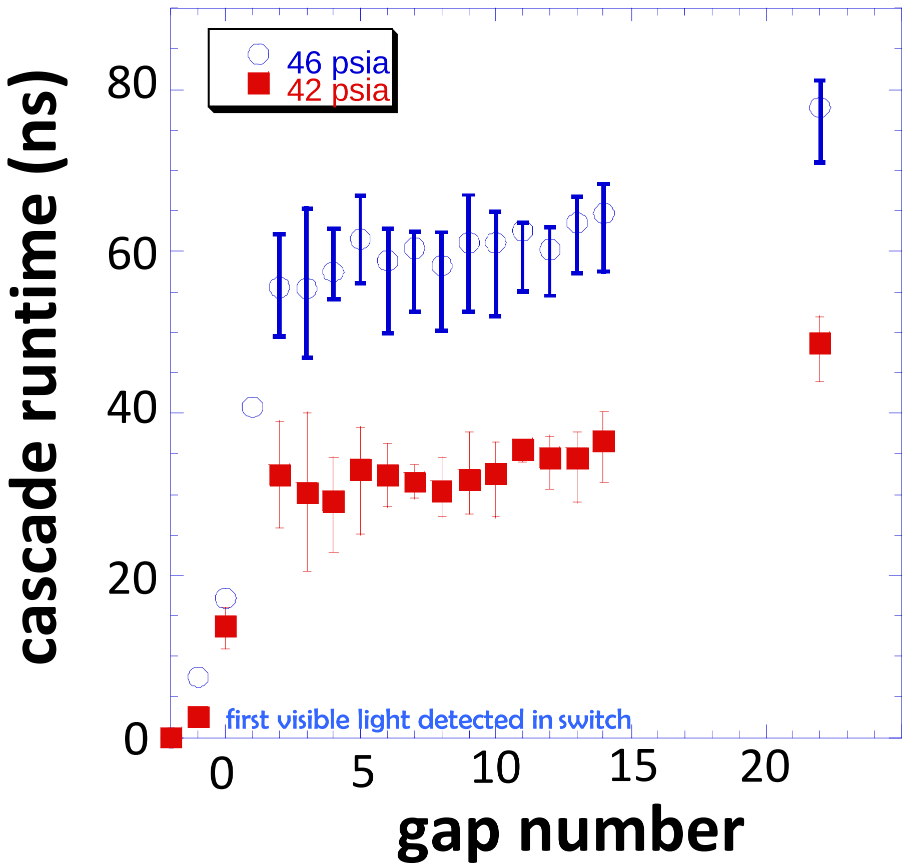
Cascade section

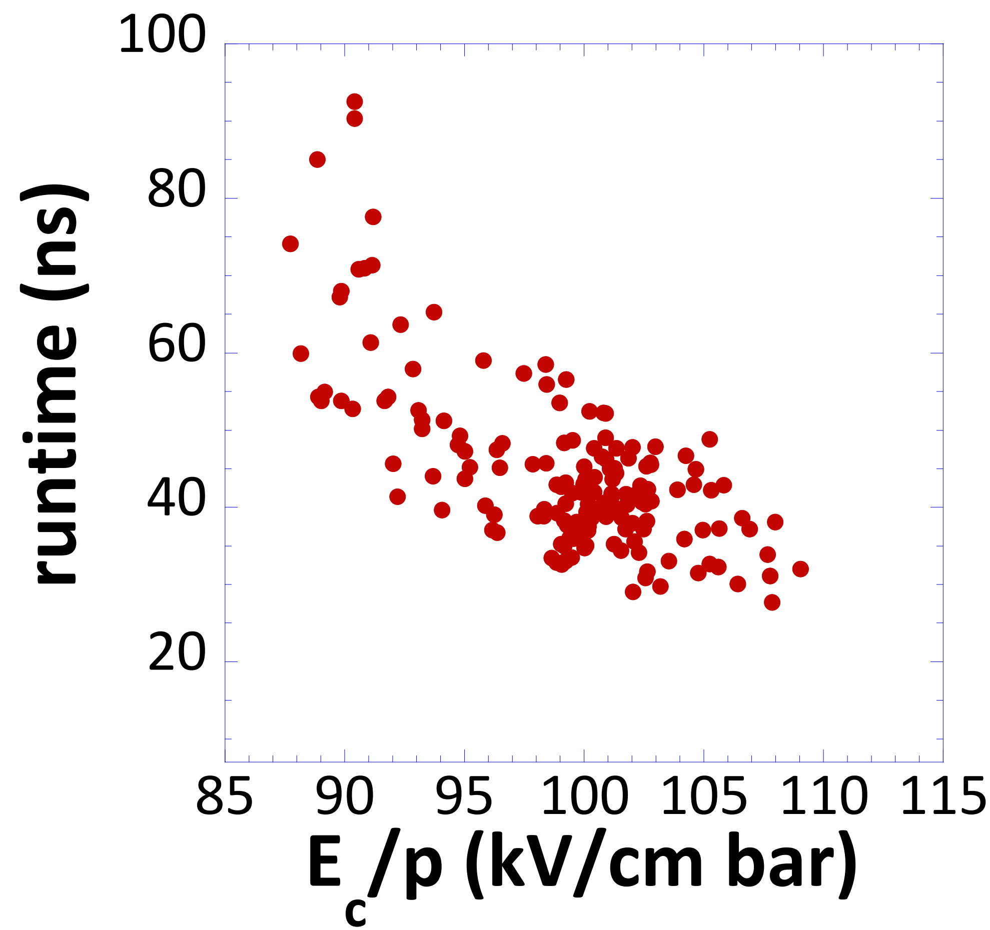


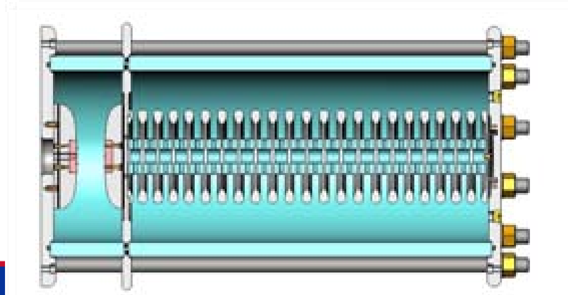
- **Electrically overstressed**
- **Multi-channeling**



The magnitude of the overstress and the geometry of the switch determines the operation of the cascade section

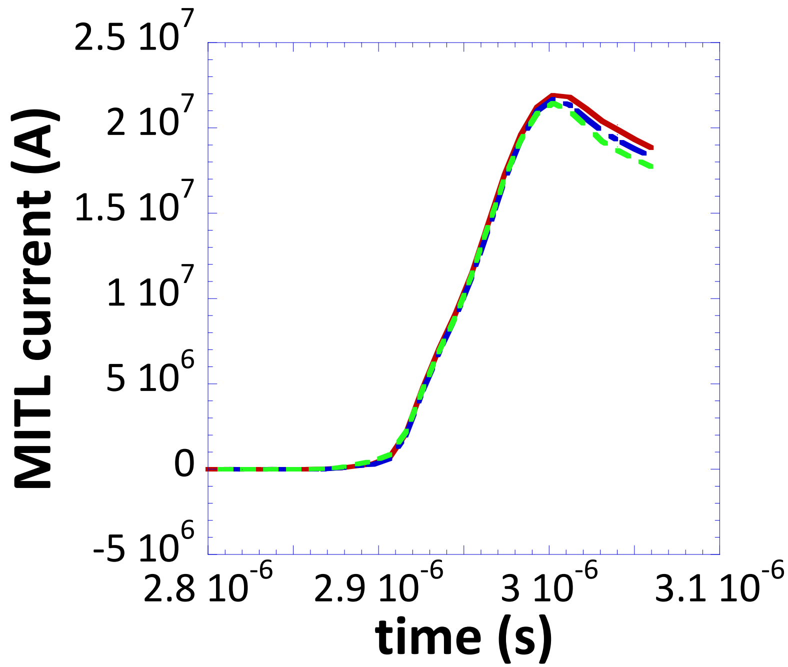






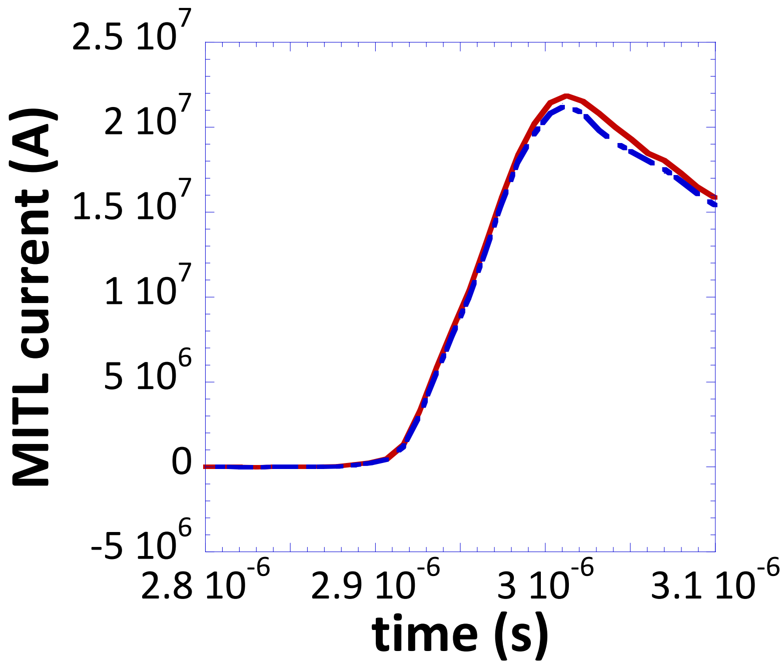
- *Cascade jitter is < 5 ns at a pressure commensurate with a prefire probability of < 0.1% at 6.25 MV*

The MITL current jitter is of order 1 ns with the present gas switch design



$$\sigma = 0.401\, ns$$

- **V = 5.2 MV**
- **P = 39 psia**
- **Ec/p= 99 - 108 kV/cm bar**

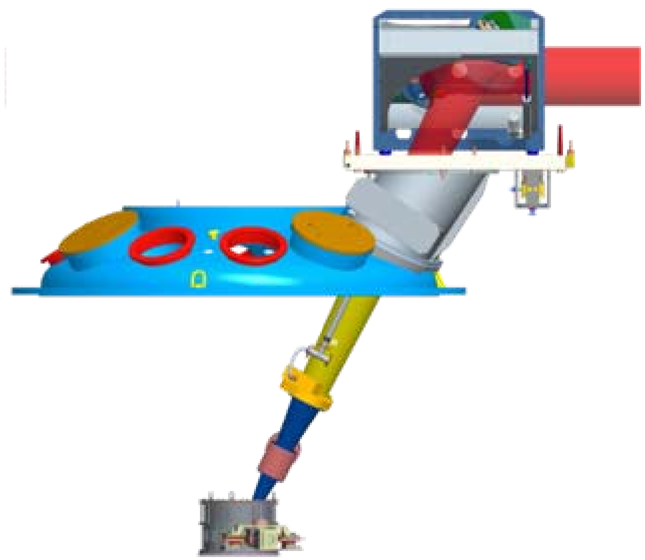


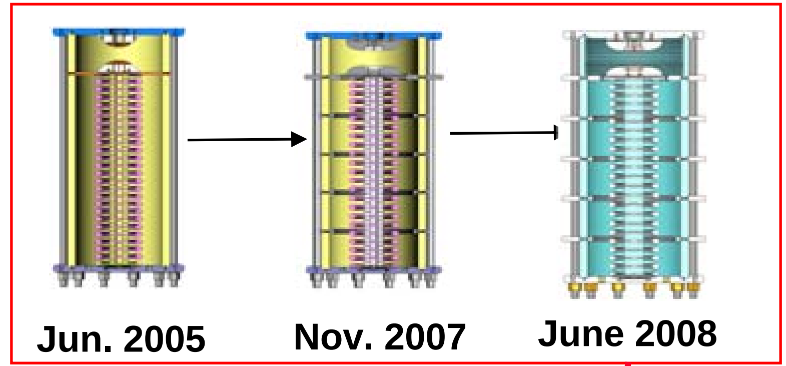
$$\sigma = 0.308\, ns$$

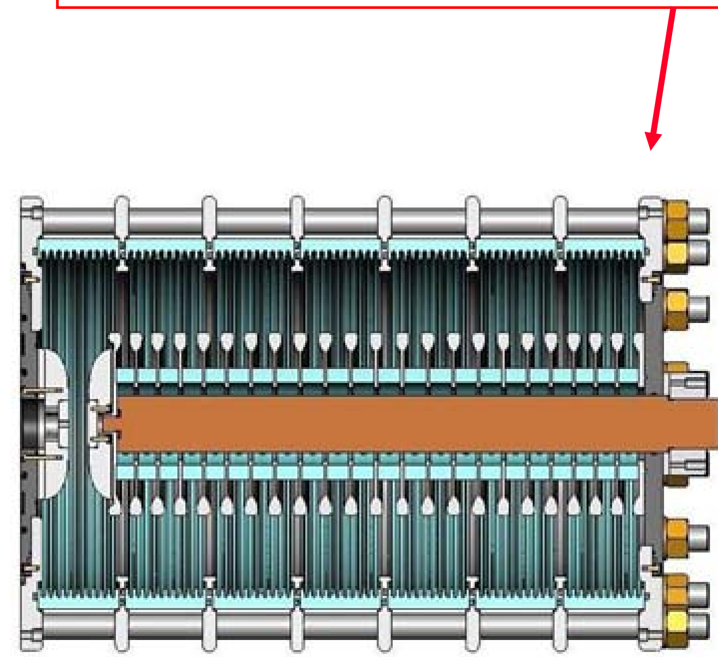
- **V = 5.2 MV**
- **P = 39 - 42 psia**
- **Ec/p= 100 kV/cm bar**

Summary

- A reduction of single switch jitter of less than 3 ns is required to obtain precise radiographs using Z-Petawatt and increases backlighting accuracy for Z-Beamlet







January 2009

- Requires a different topology
  - Testing beginning June 1