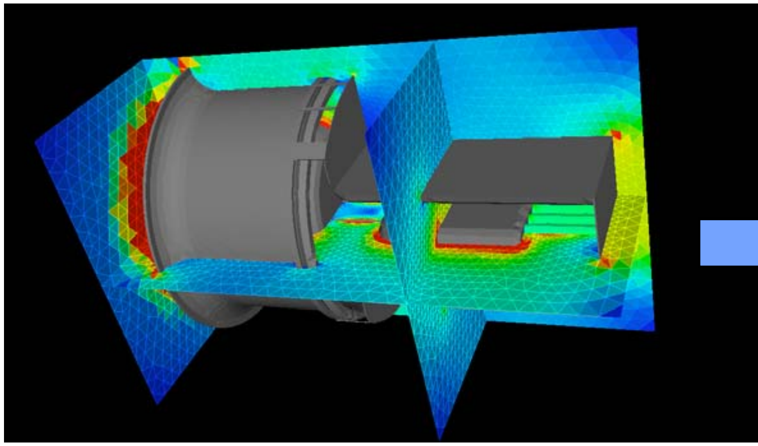
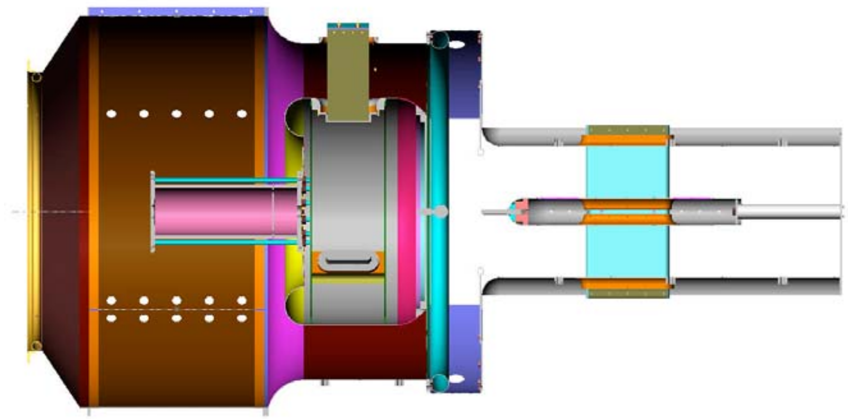
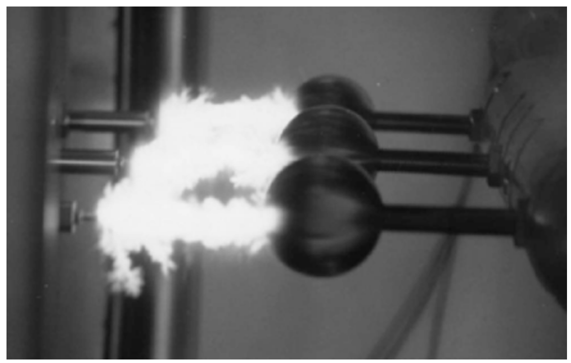
SAND2006-4125P

Pulsed Power Technology Development





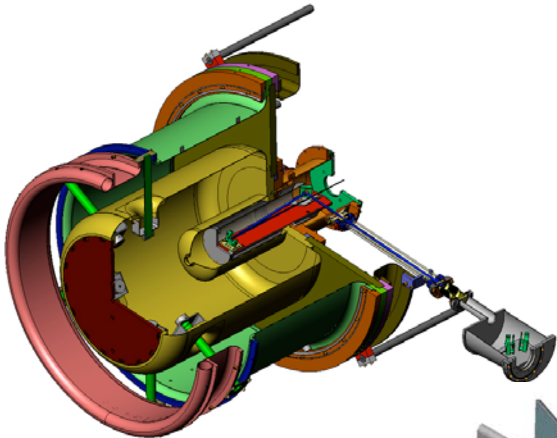


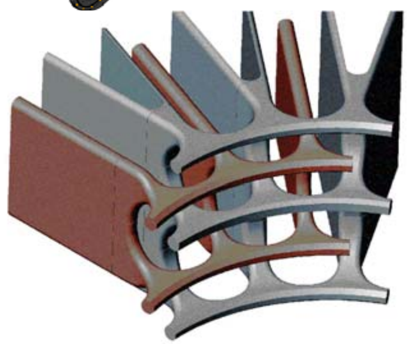
16th International Conference on High Power Particle Beams

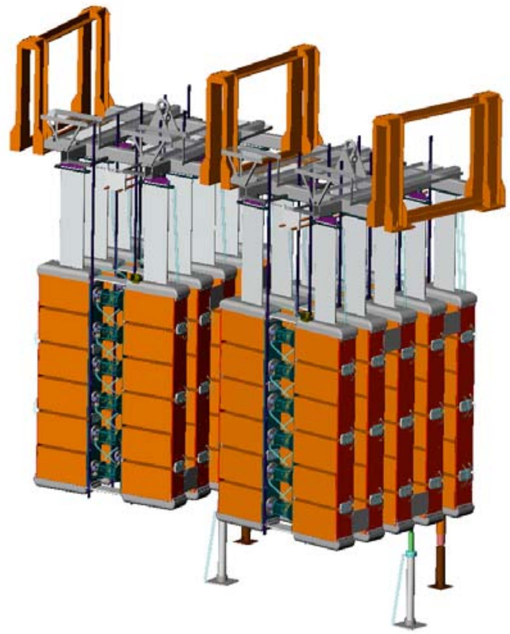
John Maenchen

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.

Some see "pulsed power" as high voltage engineering







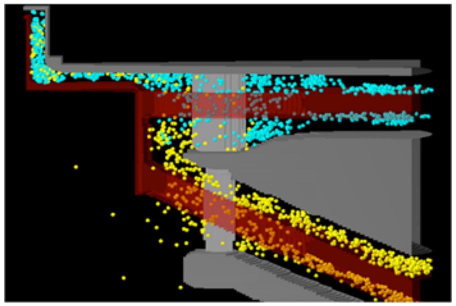
- Early successes led to a rapid transition from science to engineering
  - reliably and efficiently delivering bursts of energy to high energy density loads
- Science now adds control, flexibility, responsiveness, and breadth of applicability

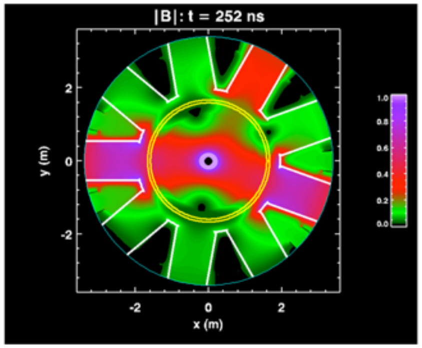
We see Pulsed Power Technology as a suite of core skills and capabilities used to address a wide variety of applications

Pulsed Power Technologies is an integrated skill set

Inter-related theoretical, experimental, and engineering capabilities

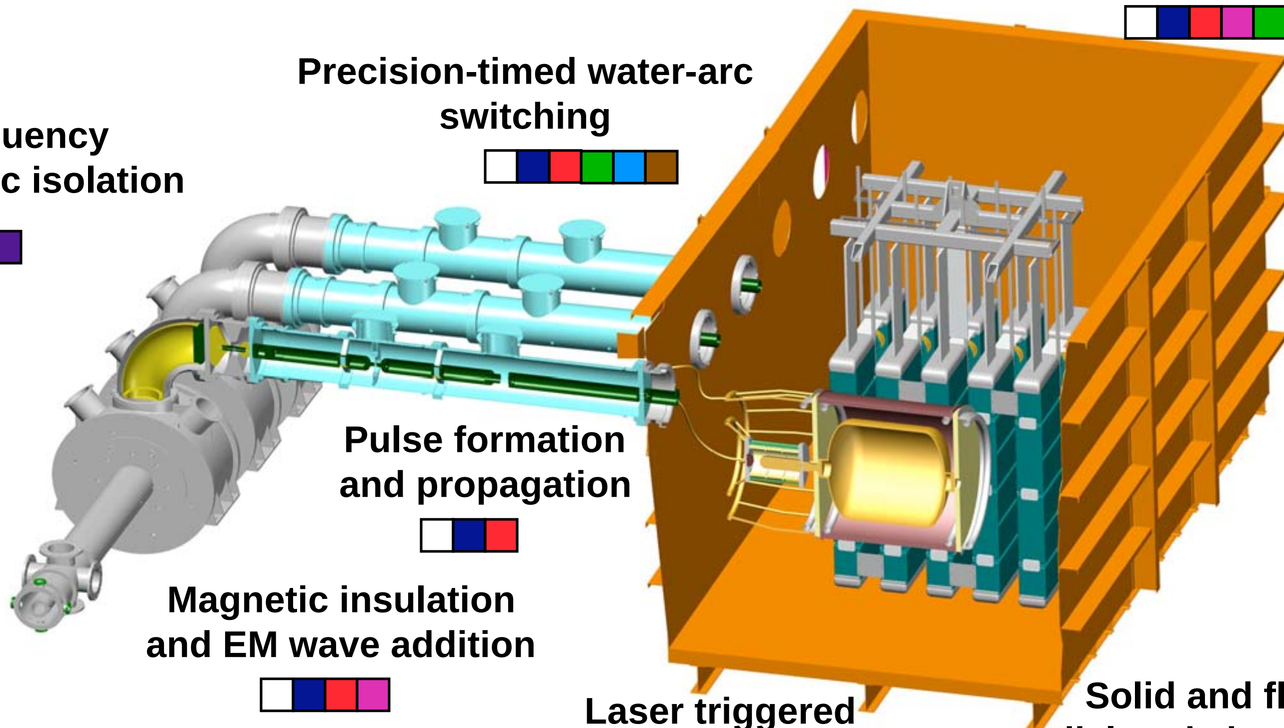
- Electromagnetic fields
- Plasma science
- High-energy-density interactions
- Material properties
- Shock physics
- High voltage dielectric breakdown
- Low inductance, high voltage switching
- Vacuum insulation and power flow
- Intense particle beams
- Magnetically-driven implosion dynamics
- System integration and packaging





Our job is to make Pulsed Power reliable, efficient, and cost effective

Even “simple” Pulsed Power systems are complex



- Circuit
- Electrostatic
- Electromagnetic
- Particle-in-cell
- Hybrid fluid/pic
- Monte Carlo
- Non-linear diffusion
- Radiation transport
- Magneto Hydrodynamic

Performance @ reliability requires knowledge of the boundaries

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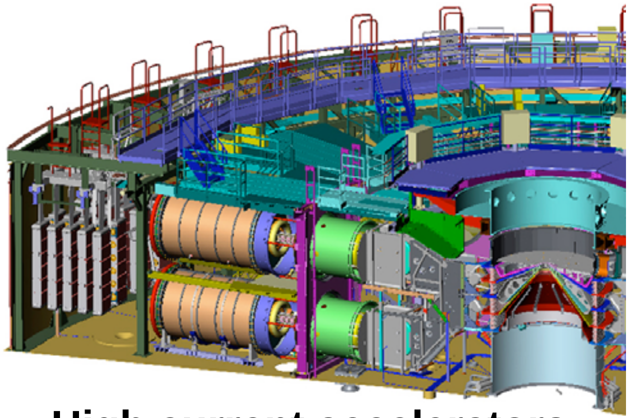
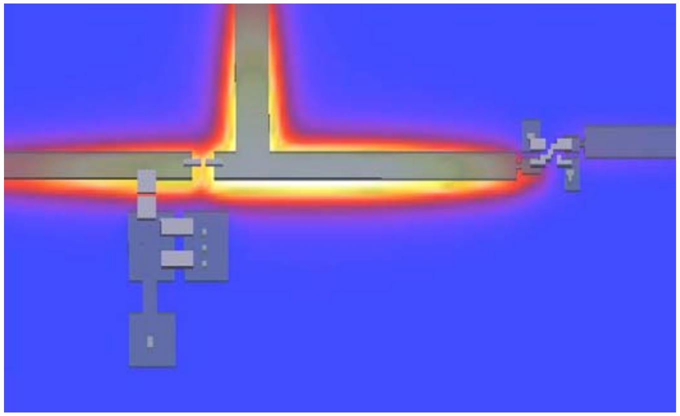
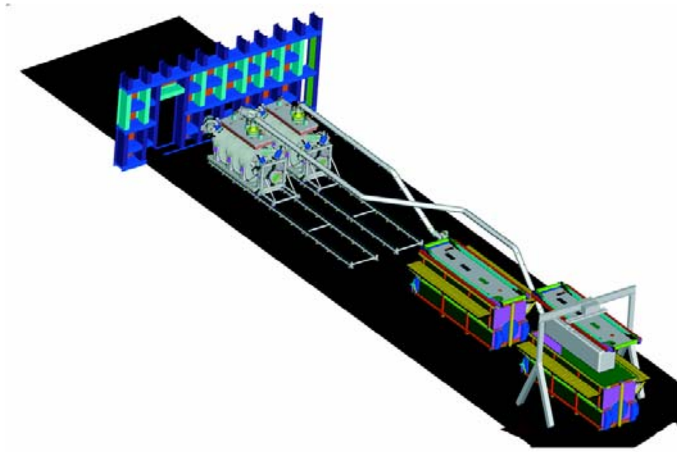
Pulsed Power systems support many missions



High current accelerators



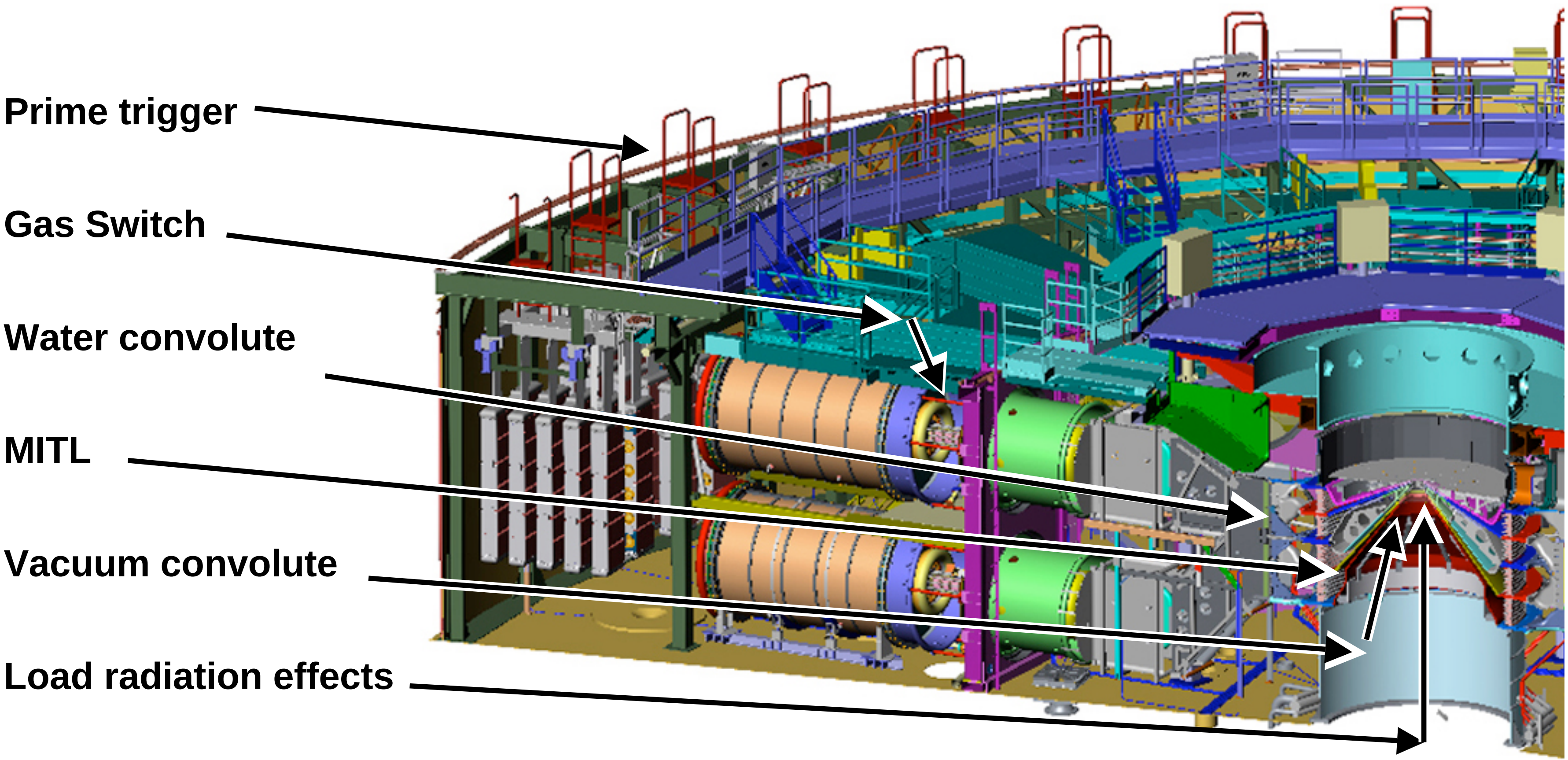
Electromagnetics and pulsed power design of electrical components



Compact pulsed power and advanced x-ray sources for radiography

Pulse shaping and small pulsers for dynamic materials

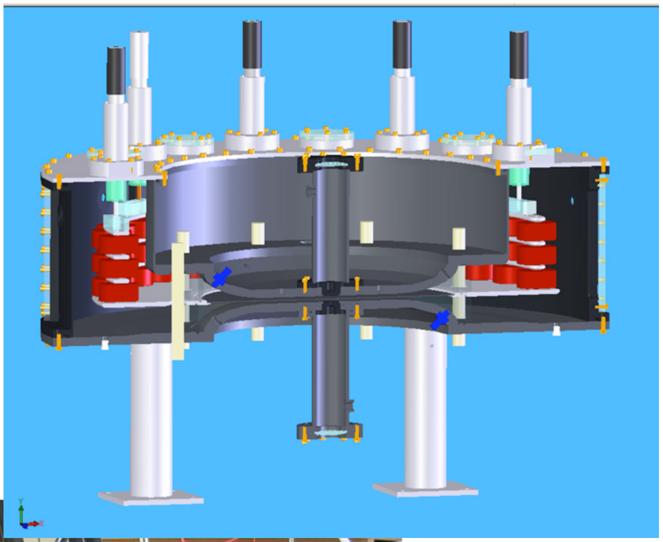
ZR illustrates how pulsed power research increases the precision, performance, and capacity

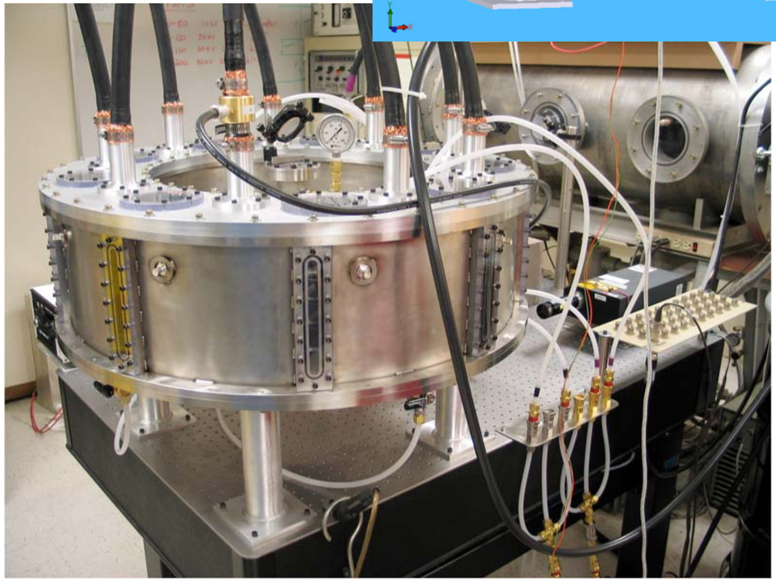


We are developing a fast, low-jitter trigger for ZR

Issue: unreliable 20 year old triggering technology

- PP infrastructure enabled new approaches
- Commercial UV laser closes a low-inductance switch
  - Demonstrated sub-ns jitter over hundred shot runs (~10x improvement)
  - Output risetime ~7 ns (30% improvement)
- Improved precision enables:
  - Pulse shaping for ICE
  - Synchronization with Z-beamlet





We're developing a higher precision and reliability trigger for the next 20 years

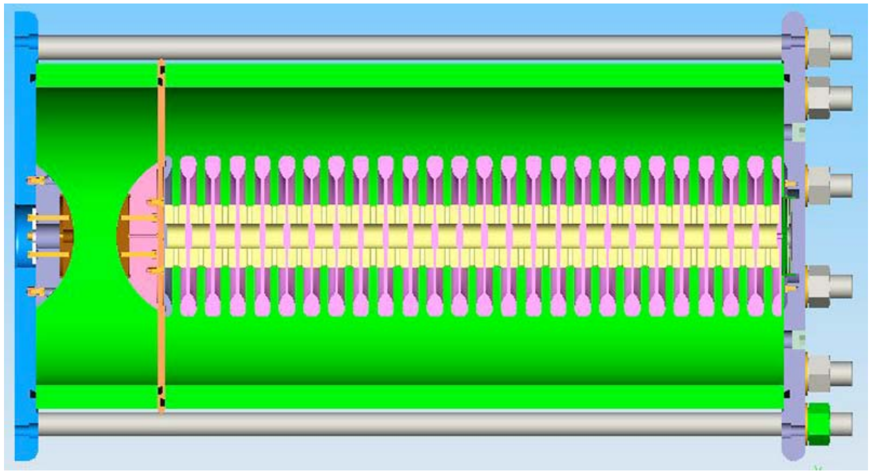
Controlling high voltage and current generation: the Laser Triggered Gas Switch

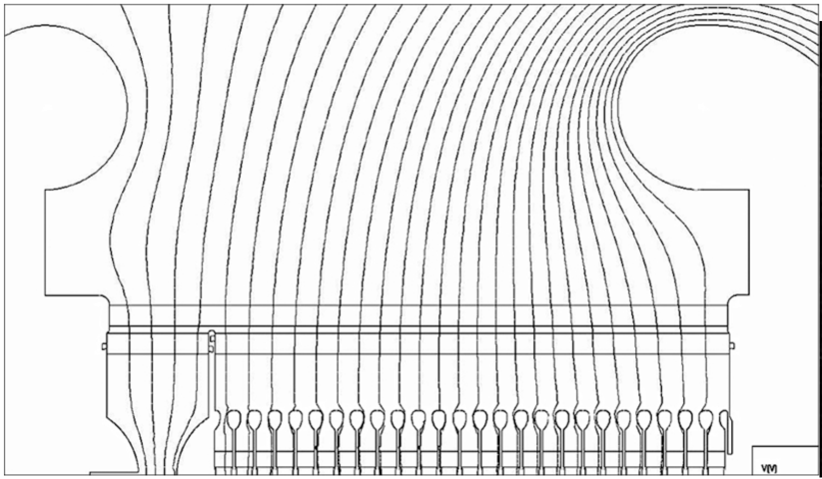
ZR's 6-MV switch needs nanosecond control

Achieved performance (precision and capability), but without adequate lifetime (capacity)

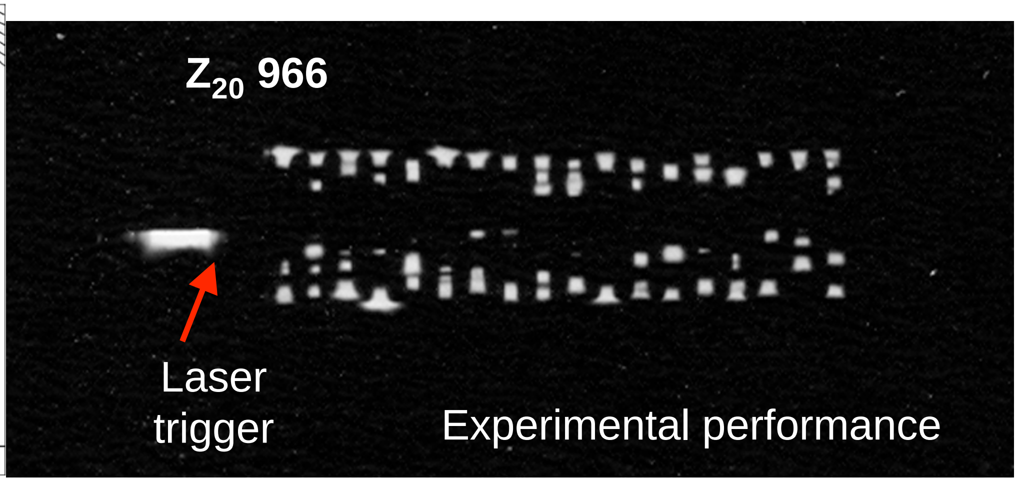
Basic science solution: improve understanding of high voltage switches

- for ZR
- to support future system requirements



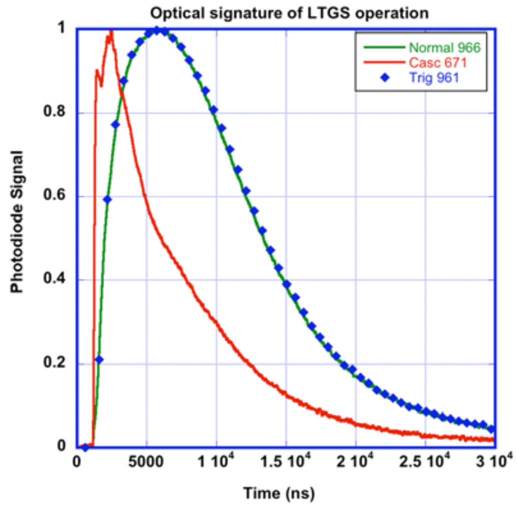


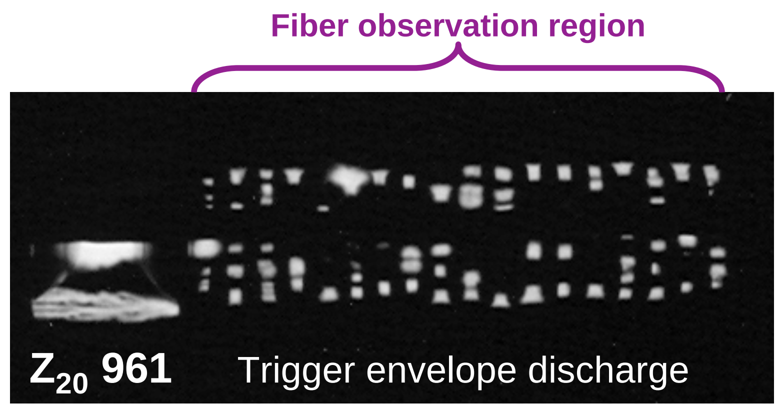
Commercial 2D Estatic model

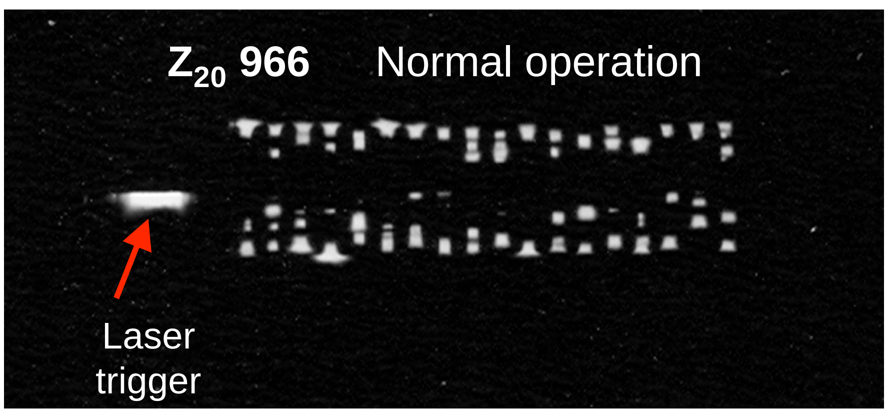


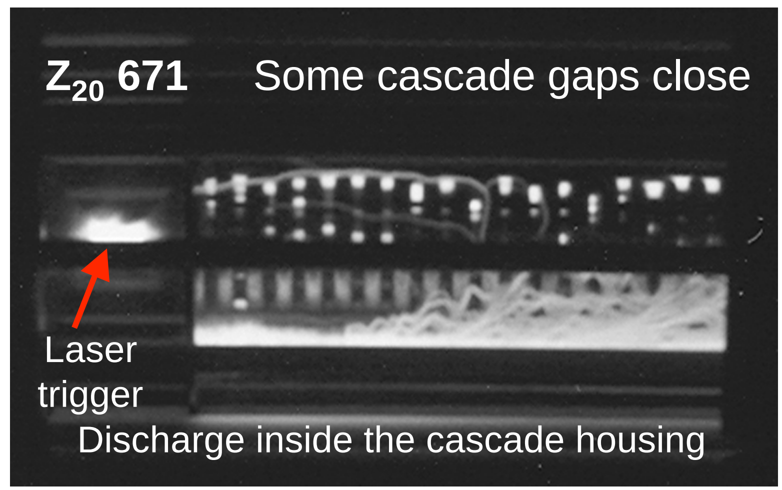
Reliability

Switch Lifetime: signature of an envelope flash









A simple optical measurement can identify envelope failures

A similar fiber system is being developed to verify laser trigger alignment

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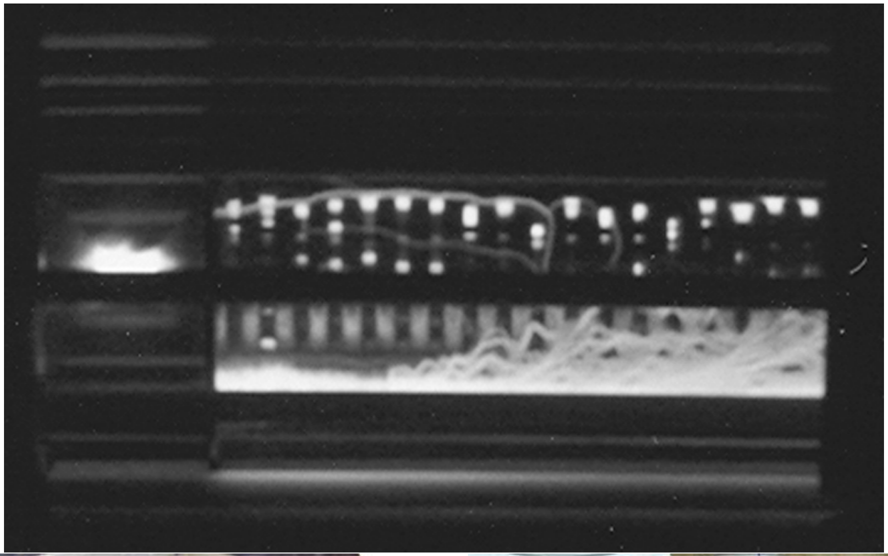
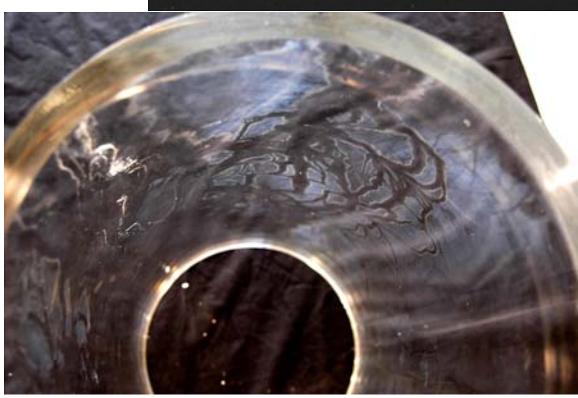
Envelope flashover requires understanding 3D effects





Cascade arc tracks do not follow the pre-breakdown axial fields

Performance is unaffected

Accumulating damage limits switch lifetime, requiring increased maintenance

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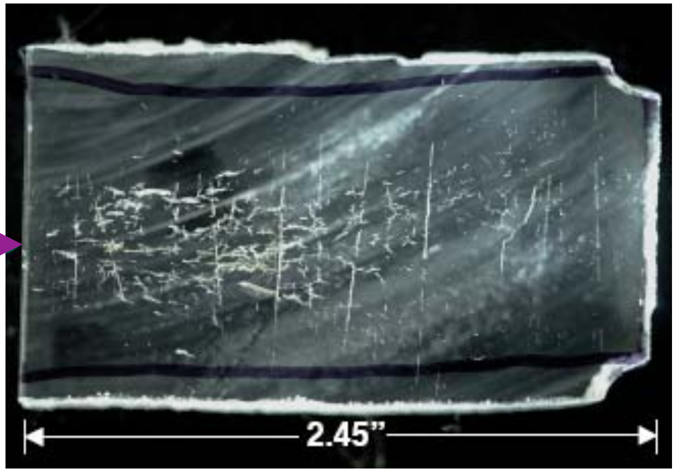
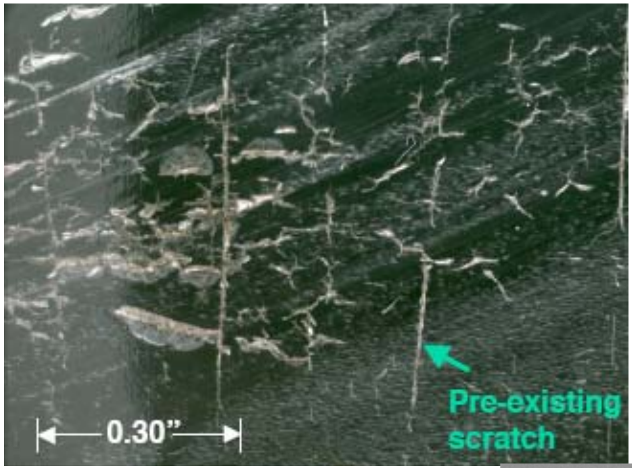
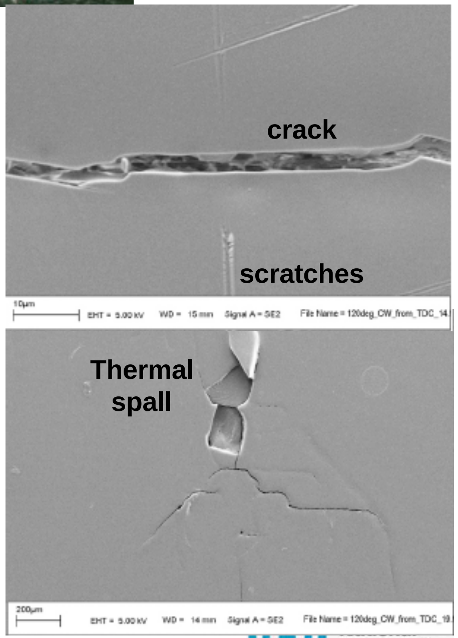
Multidisciplinary research: surface science

Arc at tube end





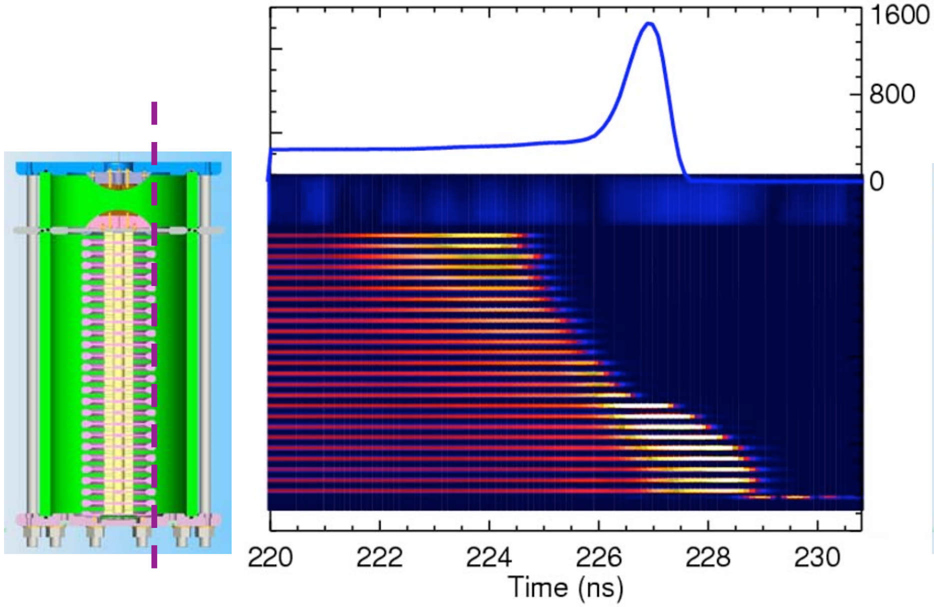
- Cracking follows a dendritic pattern
- Brittle crack growth (to ~ 0.002") and local spallation at junctions.
- Brittle character implies cracking occurred at low temperature, probably as a result of local thermal stresses in the arc path during cool-down.
- **Implies a material surface problem** consistent with infant mortality statistics

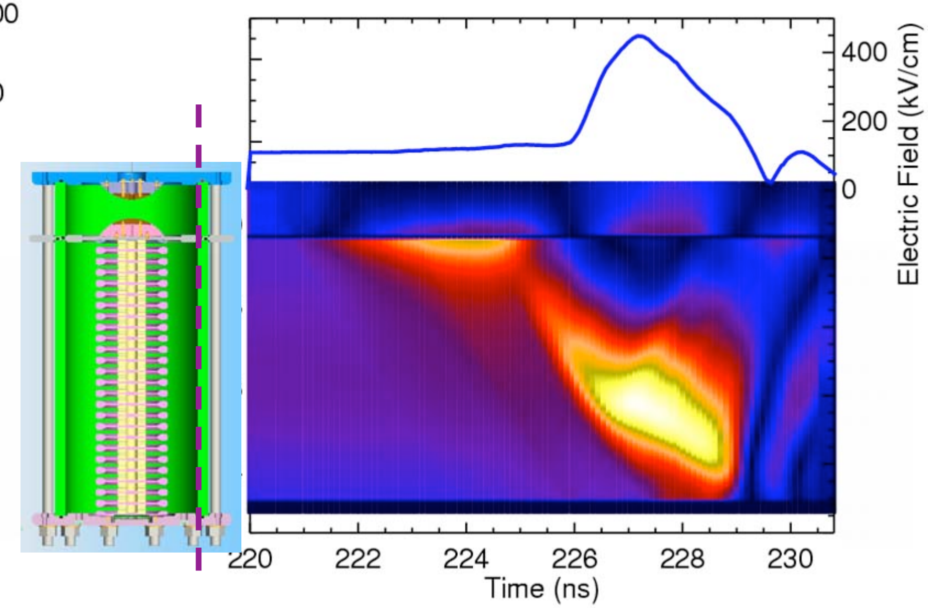


This is basic dielectric science, but in a severe regime

We need this knowledge for ZR and for future systems

Electromagnetic simulations illuminate the dynamics



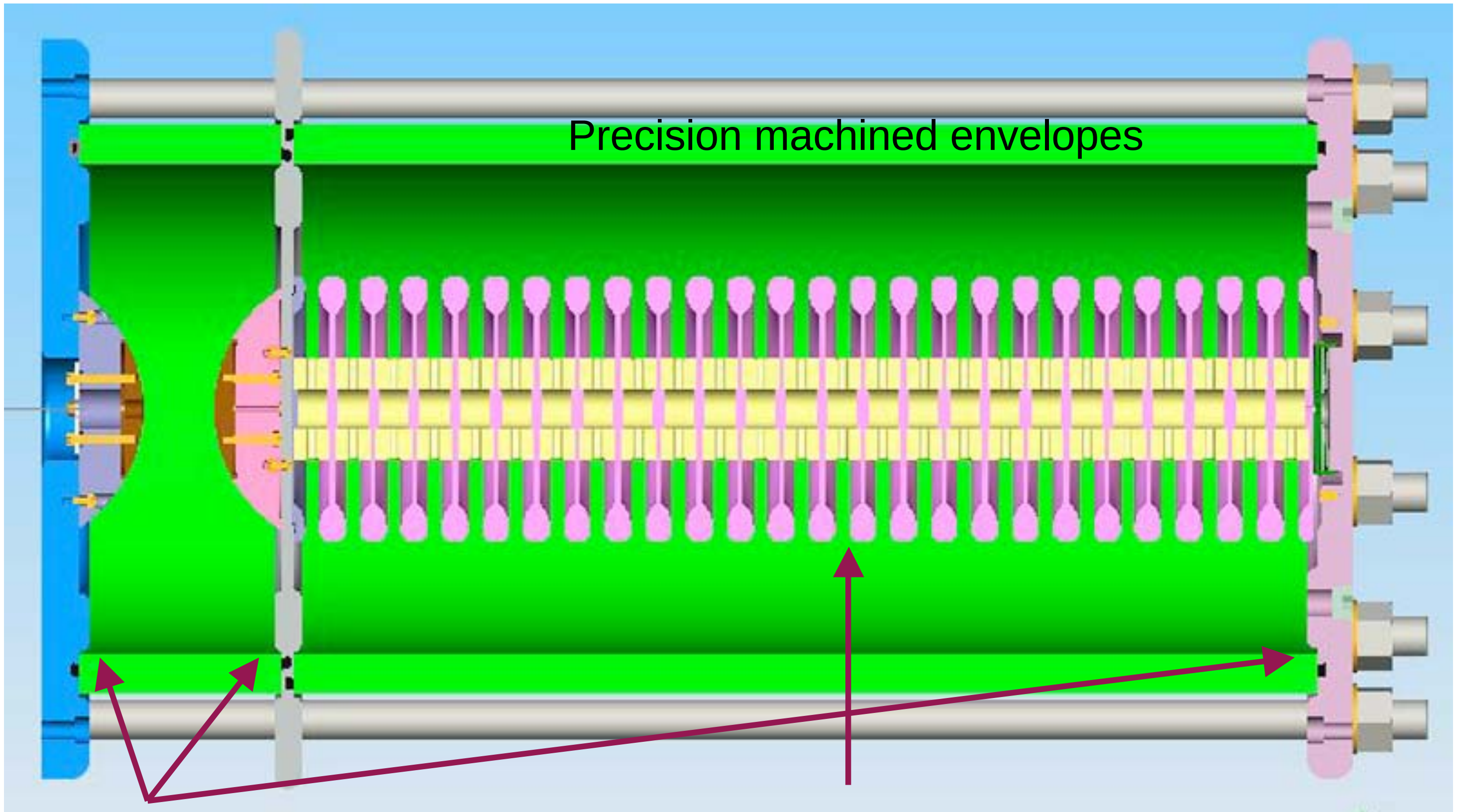


Cascade gap closure is modeled by matching wave propagation to optical streak camera first-light emission

Same wave dynamics stress the insulator during closure
Possibly leading to flashover

Understanding the dynamics will enable high performance, reliability, and lifetime

Near-term ZR LTGS design



Improved laser optics
Reduce trigger runtime jitter

Triple-point shielded junctions
Improved envelope lifetimes

Increased gap spacing, reduced fields
Operate at 30 psig
Reduced prefire probability

Short term improvements provide low prefire and jitter with longer life

Long-term approach to improving the LTGS

A 3 year science program to advance the community's understanding of LTGS for ZR and for future system applications

Sandia:

- Engineering and Manufacturing
- Laser Triggering science
- Optical Diagnostics
- Theory, Modeling, and Simulation
- Switch Test Bed -
  - Laser triggered gap plus several cascades
- Z_{20} - Full-scale tests

Univ. of Missouri - Columbia

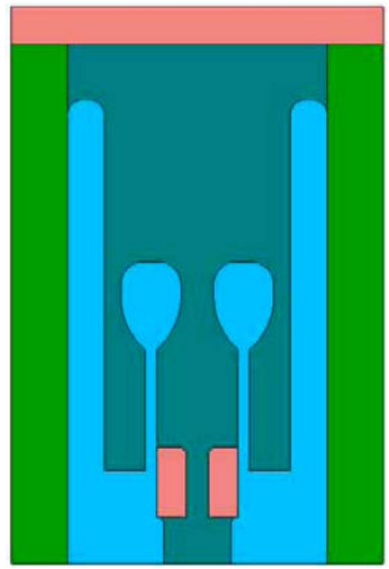
- MUTTS laser triggered gap

University of Strathclyde

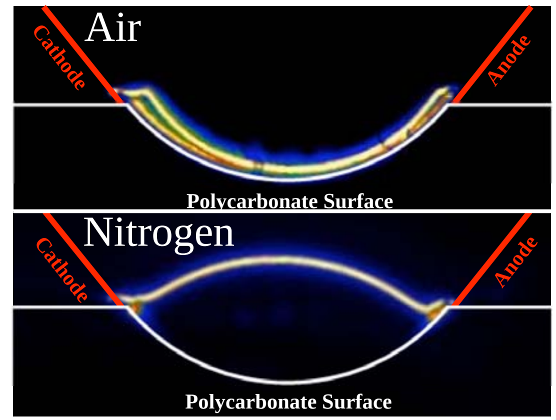
- Cascade gap studies

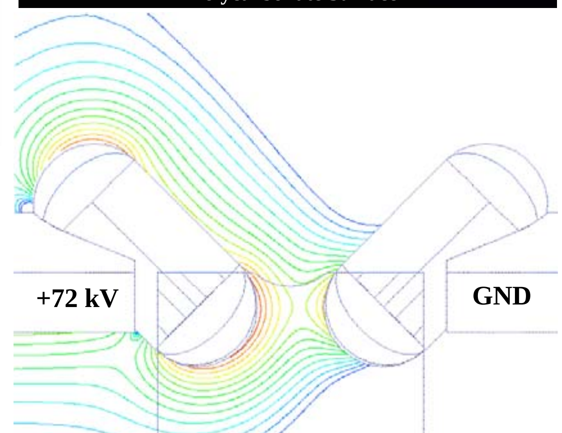
Texas Tech University

- Fundamental breakdown and flashover studies



Strathclyde





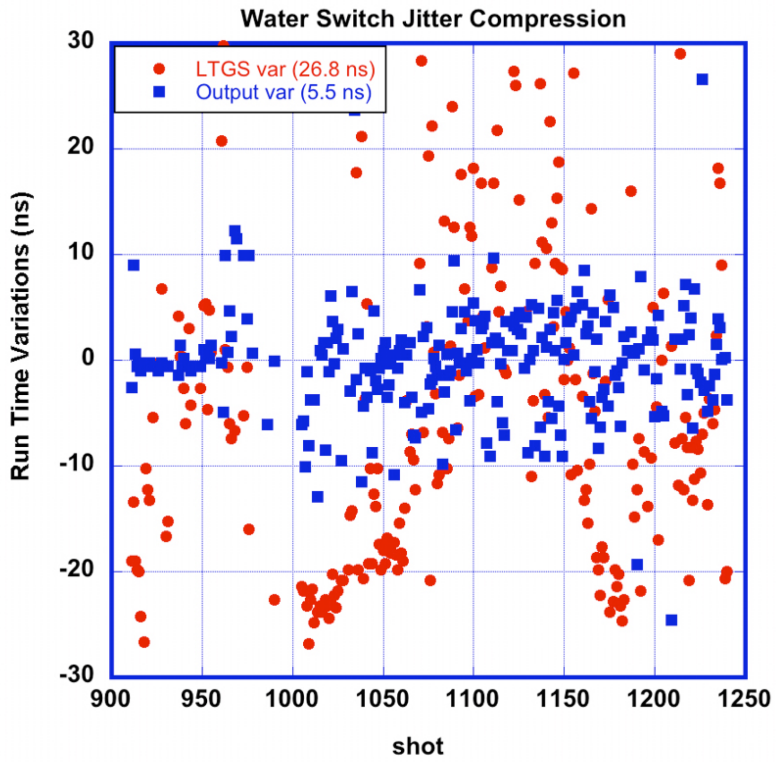
Texas Tech University

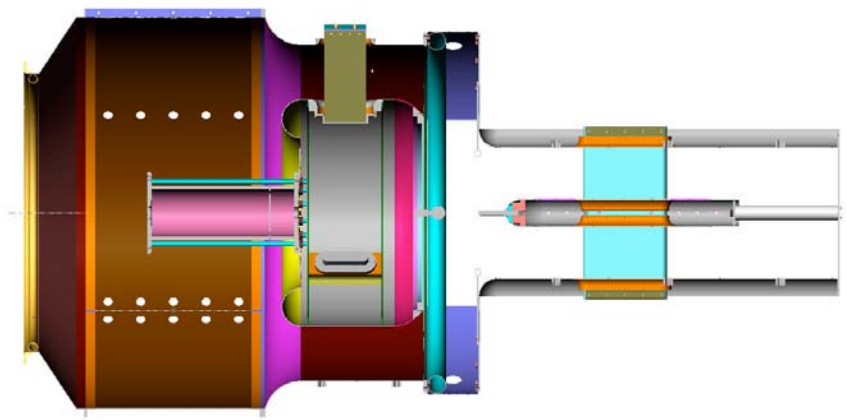
LTGS runtime variations are mitigated by water switches

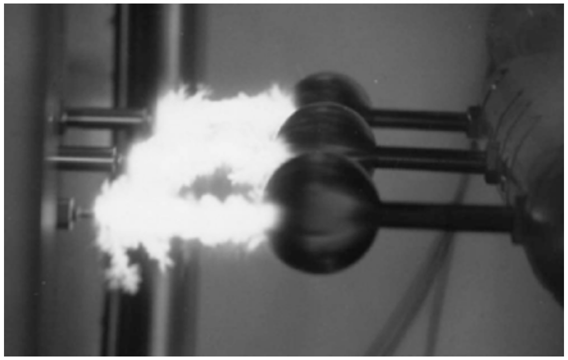
LTGS performance (many drive and switch configurations shown) affects the PFL pulse arrival

Water switches (varied 10x in this data set) compensate to reduce output pulse arrival spread

Even the huge variations from these different developmental LTGS configurations are reduced by the water switches to levels acceptable for ZR







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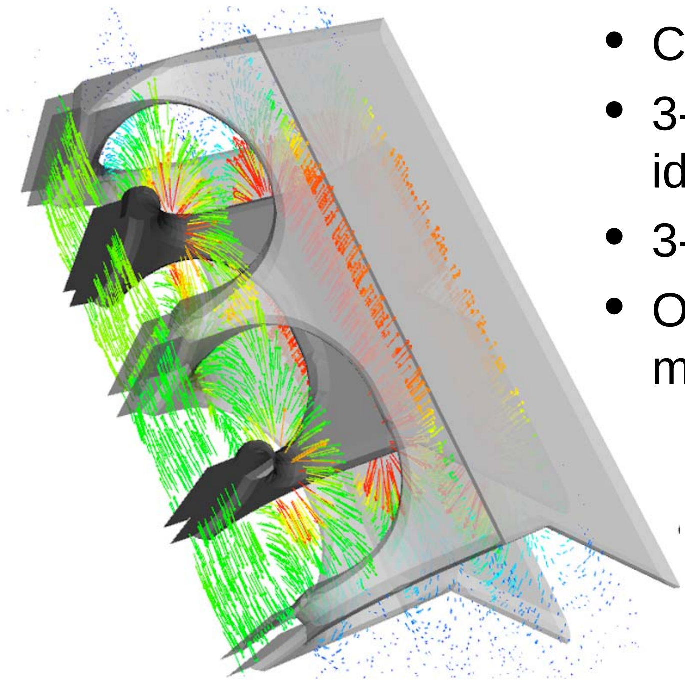
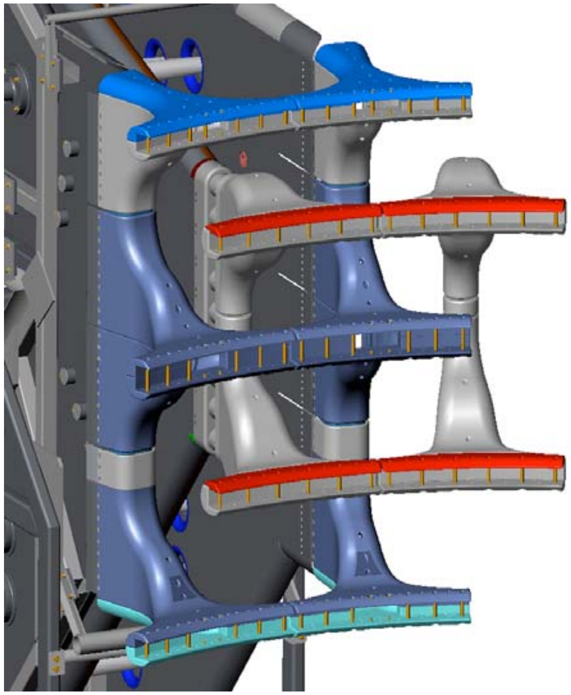
3-D modeling found problems before hardware was built



- Commercial 2-D code gave an erroneous impedance
- 3-D modeling showed a significant current reduction, identifying a design flaw
- 3-D design iterations regained the goal current
- Optimization could still increase performance and may lead to a future hardware insertion

Water convolute - a 3D structure coupling the vertical triplates to the horizontal vacuum insulators



Developing an accurate predictive capability

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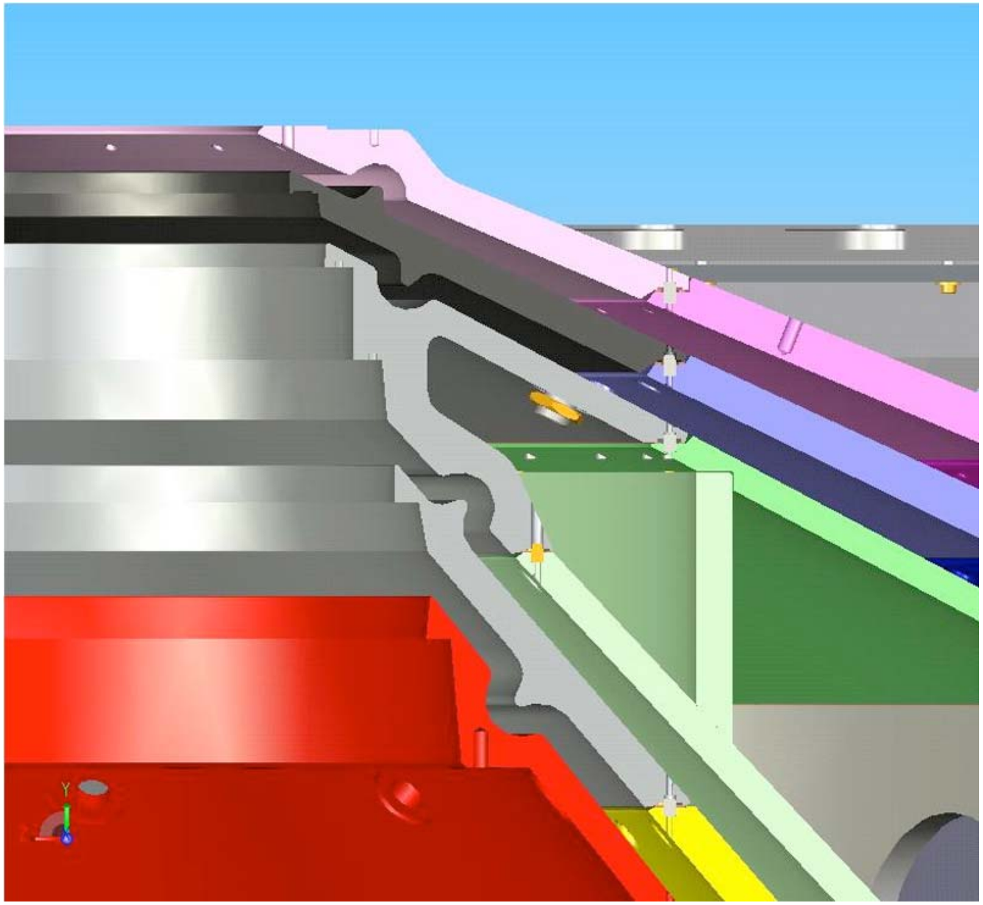
Debris shielding is crucial to protect the vacuum interface

Issue: Detonation of the z-pinch load sends debris up the vacuum lines

MITL transition shapes

- Block debris from damaging the insulators
- minimize vacuum electron flow losses

An experimental evaluation on Z confirmed the design analysis



Significant reliability and performance improvement for ZR

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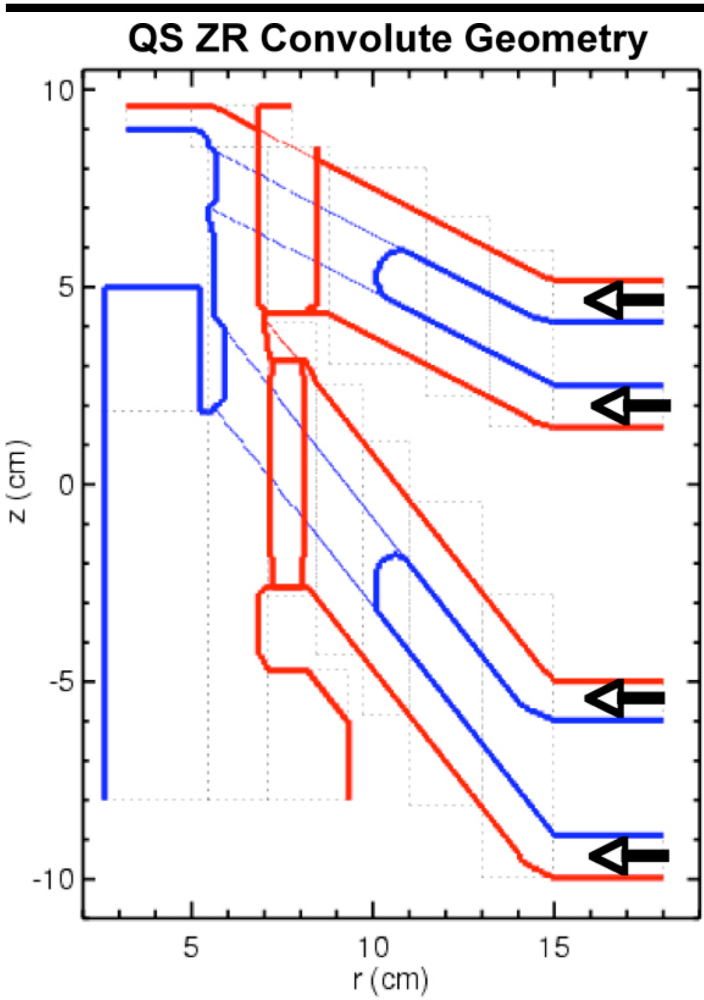
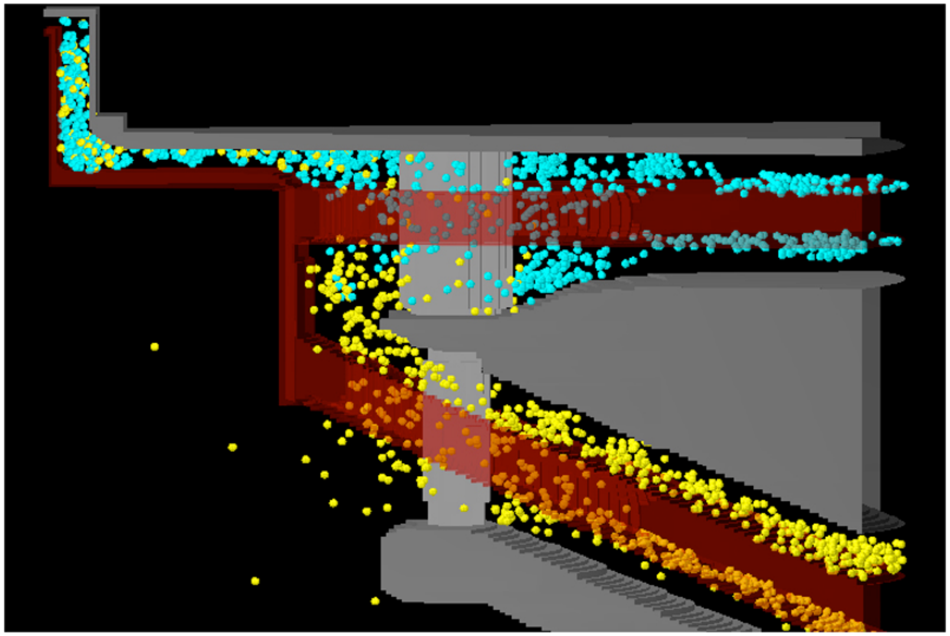
Complex vacuum convolute requires 3D PIC modeling



Double post-hole
four-level-into-one vacuum convolute

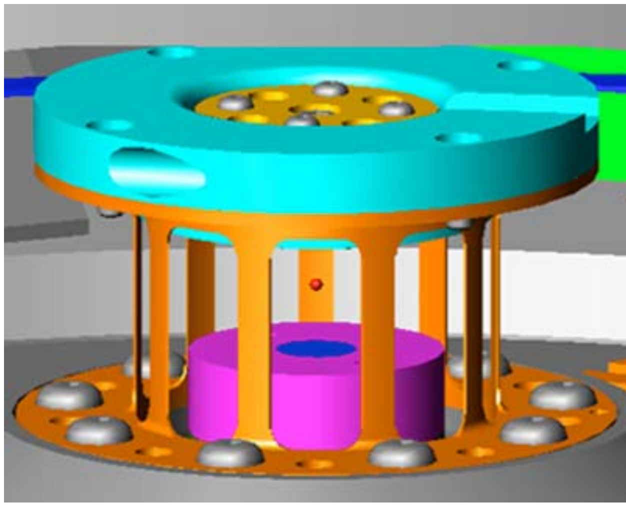


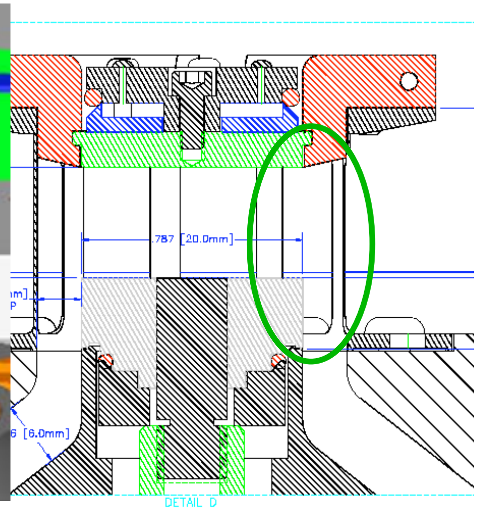
3-D particle-in-cell codes:

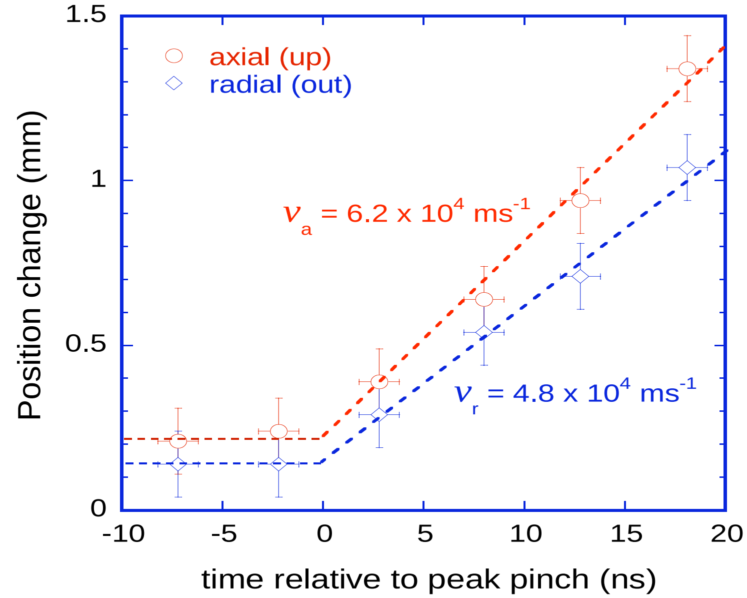
- benchmarked against Z data
- provide predictions for ZR performance
- provide a key skill set for the future

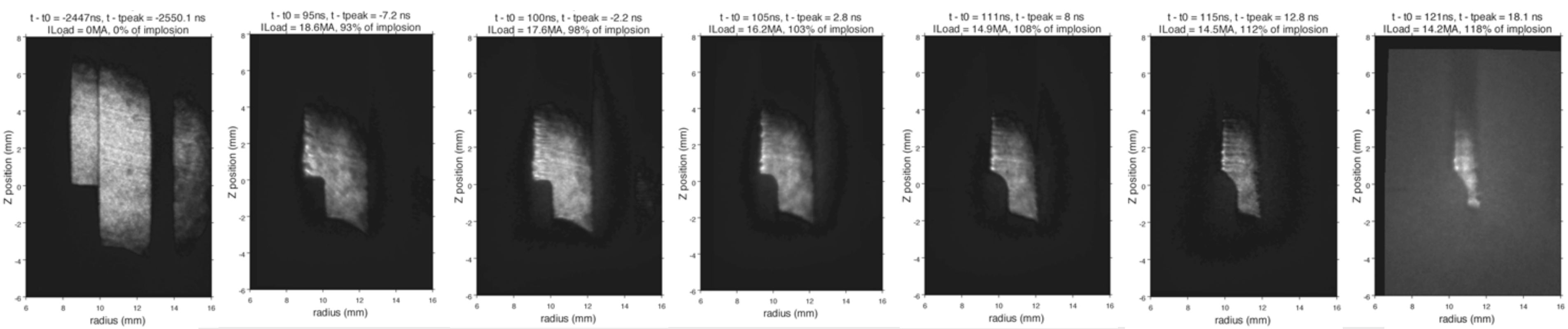
Performance

We find that radiation pressure can overwhelm magnetic insulation









Careful measurements show the limits on power flow gaps

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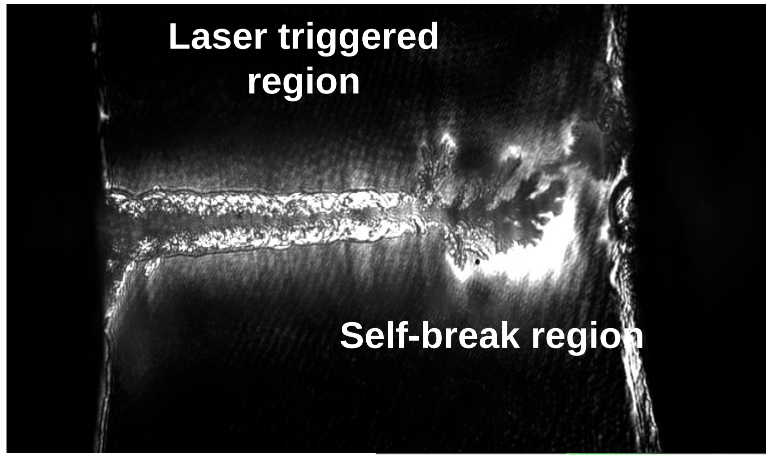
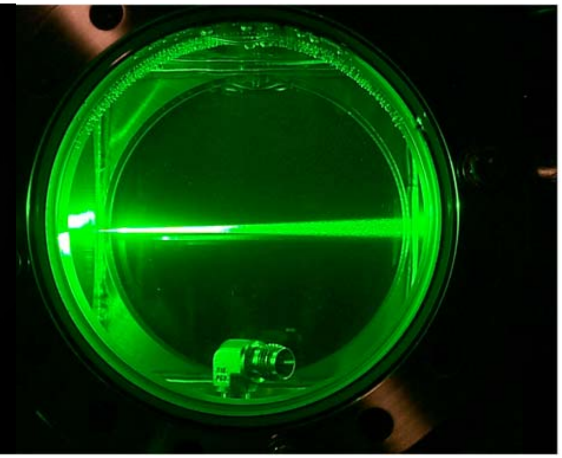
Advanced Pulsed Power Technology development

Laser triggering of water advanced capability development





Russian architecture Linear Transformer Driver assessment for Radiography, Z-pinch, and other possible applications

Advanced development in Pulsed Power assess potential contributions for the future

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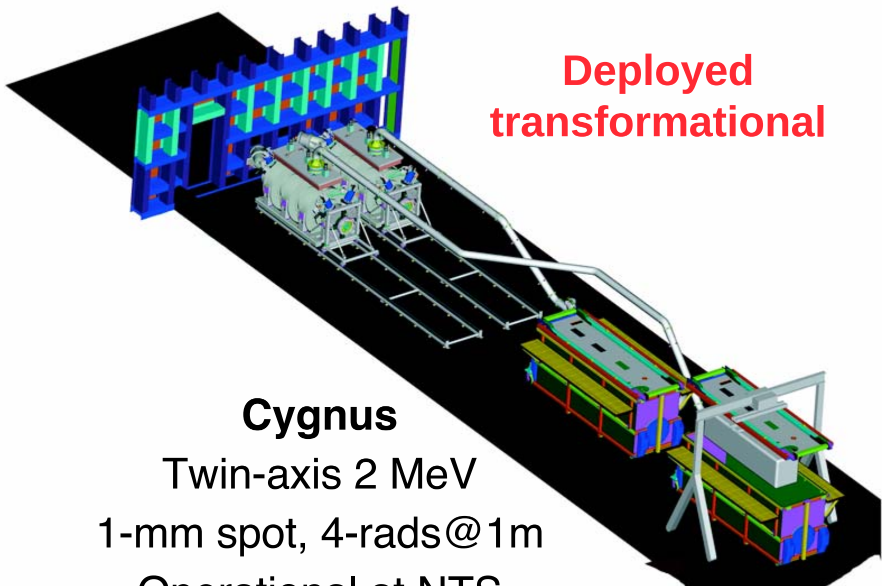
Pulsed Power Technology applications - 1



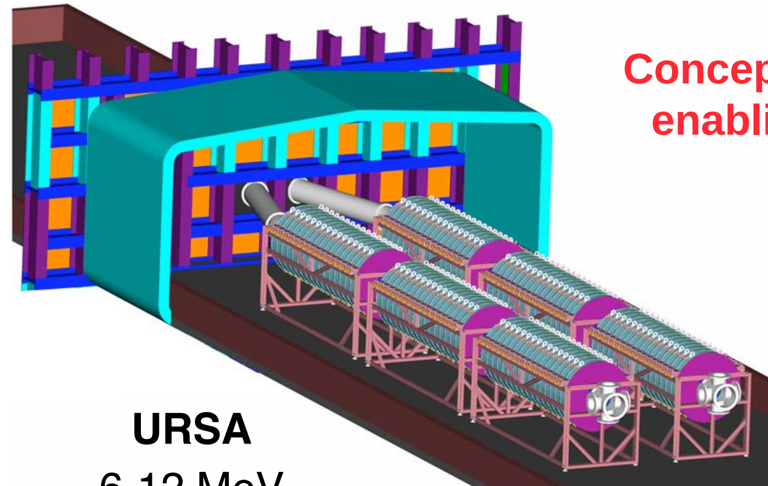
Deployed transformational

Cygnus

Twin-axis 2 MeV

1-mm spot, 4-rads@1m

Operational at NTS

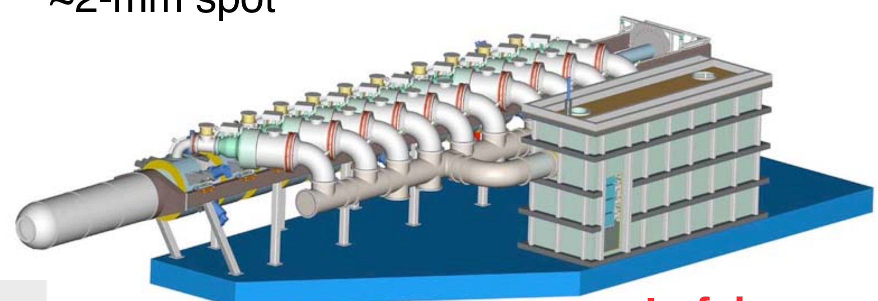


Conceptual enabling

URSA

6-12 MeV

~2-mm spot



Hydrus UK

14 MeV, ~2-mm spot

3-axis hydrotest capability

In fab transformational

Our job is to enable radiography, not do it.

In partnership with a user this becomes transformational.

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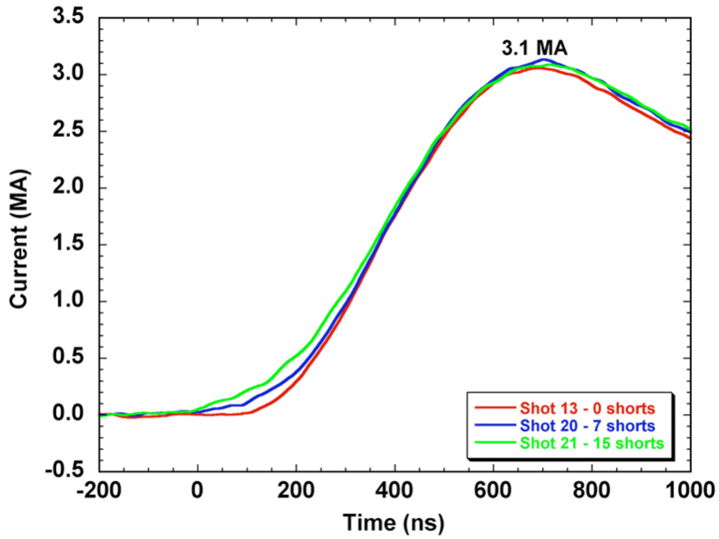
Pulsed Power Technology applications - 2

Commercial systems are build upon past pulsed-power technology investments.

- **These address near-term needs.**



Pulse shaping and higher pressures are needed so we are investing in:

- **User friendly operations**
- **Low maintenance and versatile drivers**
- **Genetic self-programming pulse shape algorithms**

Pulsed Power Technology can improve ICE driver reliability and flexibility

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Conclusion: Pulsed Power is an enabling technology for transformation

We are applying Pulsed Power to support:

- ZR for performance and reliability
- Radiographic x-ray sources
- Isentropic compression and flyer plate capabilities
- Dynamic system performance assessment
- Micro-system component certification and validation

Pulsed Power will always be a cost effective and efficient method for delivery of large energies to high intensity loads

Developing a responsive portfolio for known and anticipated needs

Scientific approach underpins an adaptive capability for the future

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