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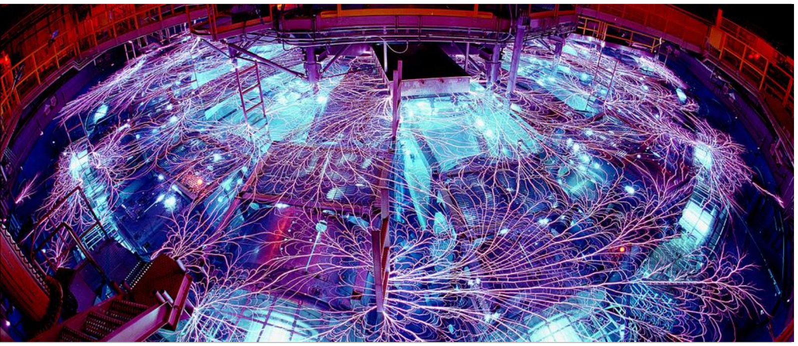

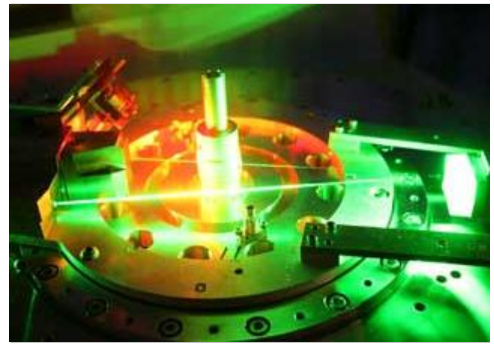

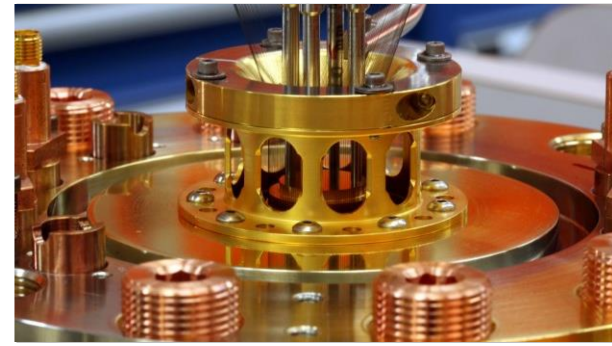

Experimental Platform Development for Studying Vacuum Power Flow Physics at the Sandia Z Accelerator

G. Laity, C. Aragon, D. Dolan, R. Falcon, M. Gomez, M. Hess, B. Hutsel, C. Jennings, M. Johnston, D. Lamppa, S. Patel, A. Porwitzky, P. VanDevender, T. Webb, G. Rochau, W. Stygar, M. Cuneo

Sandia National Laboratories, Albuquerque, NM

2017 IEEE International Pulsed Power Conference, June 18th – 22nd, Brighton, UK

Session Topic: Plasma Z-Pinches, Pulsed X-Ray Sources, High-Power Diodes, Wire Array Implosions

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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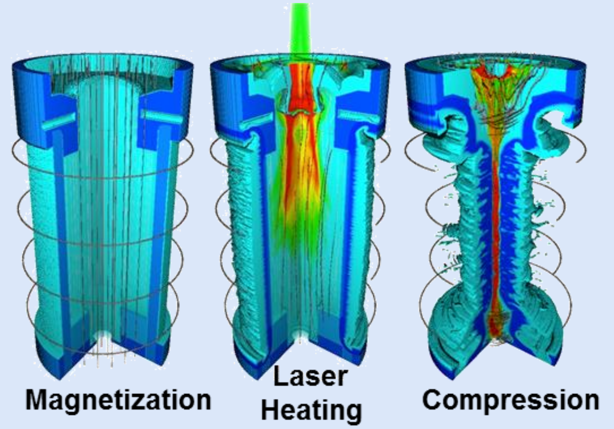
The Z Facility is a National Resource for High Energy Density (HED) Physics Experiments

PPC presentation by Mark Savage for more details!

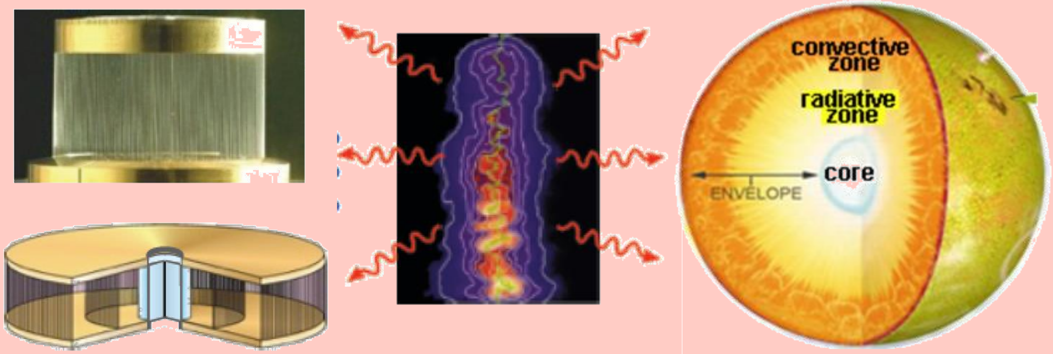
22 MJ stored→1-3 MJ delivered to load

27 MA / 100 ns pulse→ >100 Mbar pressures

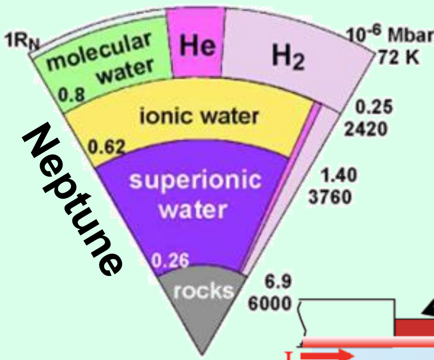
Inertial Confinement Fusion



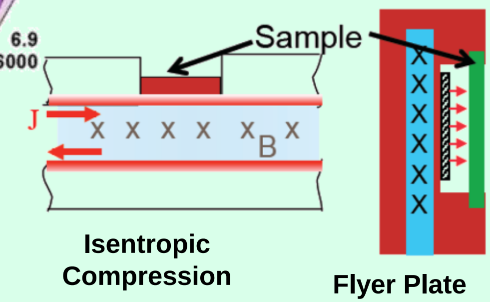
X-Ray Radiation Science & Astrophysics



Dynamic Materials Properties

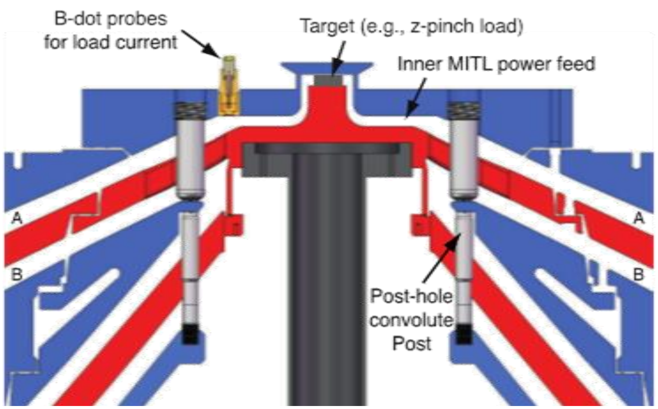


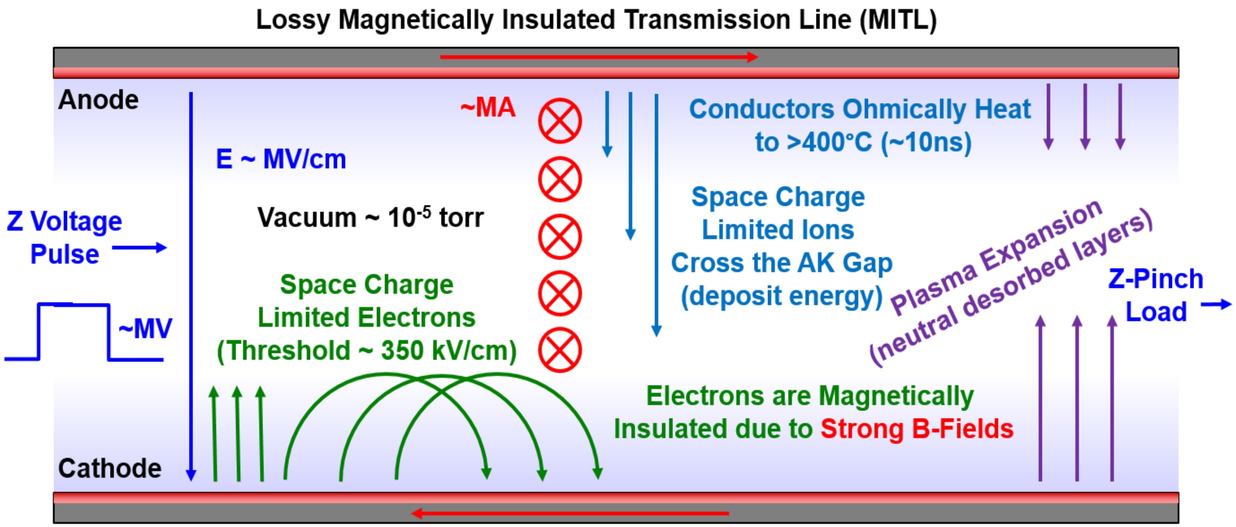
Planetary Science



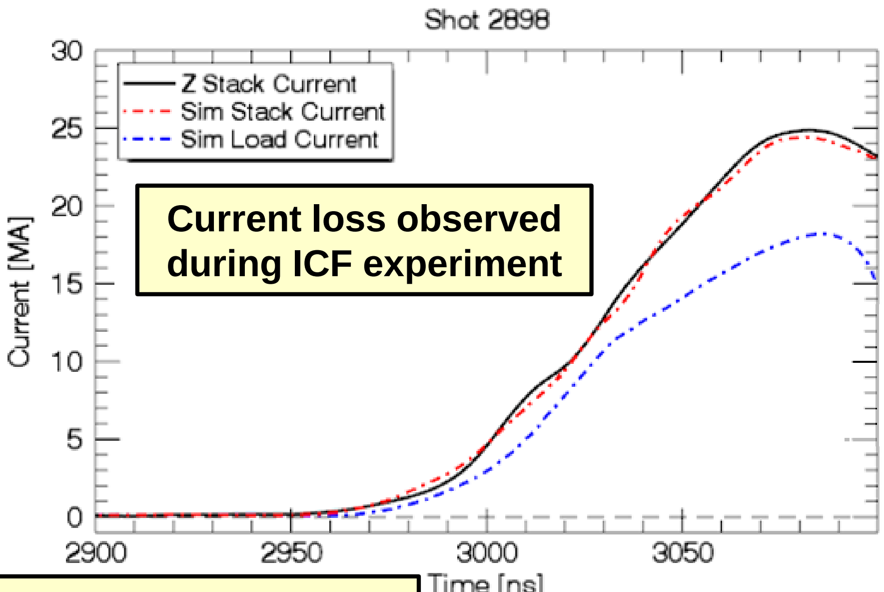
Current loss is limiting energy delivery to a variety of HED experiments at the Sandia Z Facility

Complex 3D power flow geometry at Z





- Targets designed for various HED programs (fusion research, radiation sources, materials experiments, pulse shaped loads) have different impedance parameters
- Low-inductance targets typically perform optimally at the Z Facility (e.g. DH wire arrays)
- Non-ideal current delivery could be caused by a variety of physics processes which are not understood at the predictive level

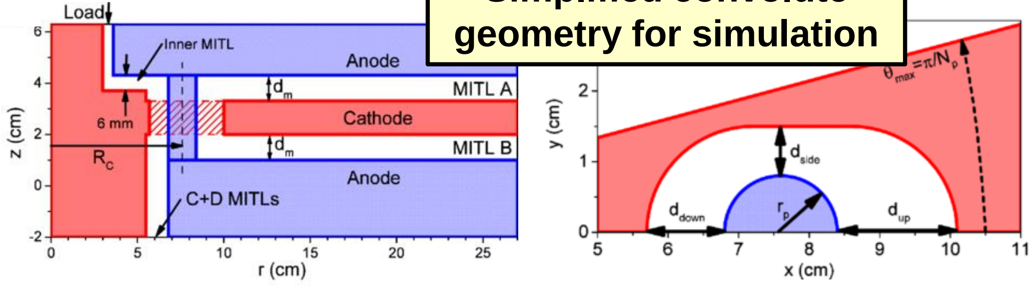


Current loss observed during ICF experiment

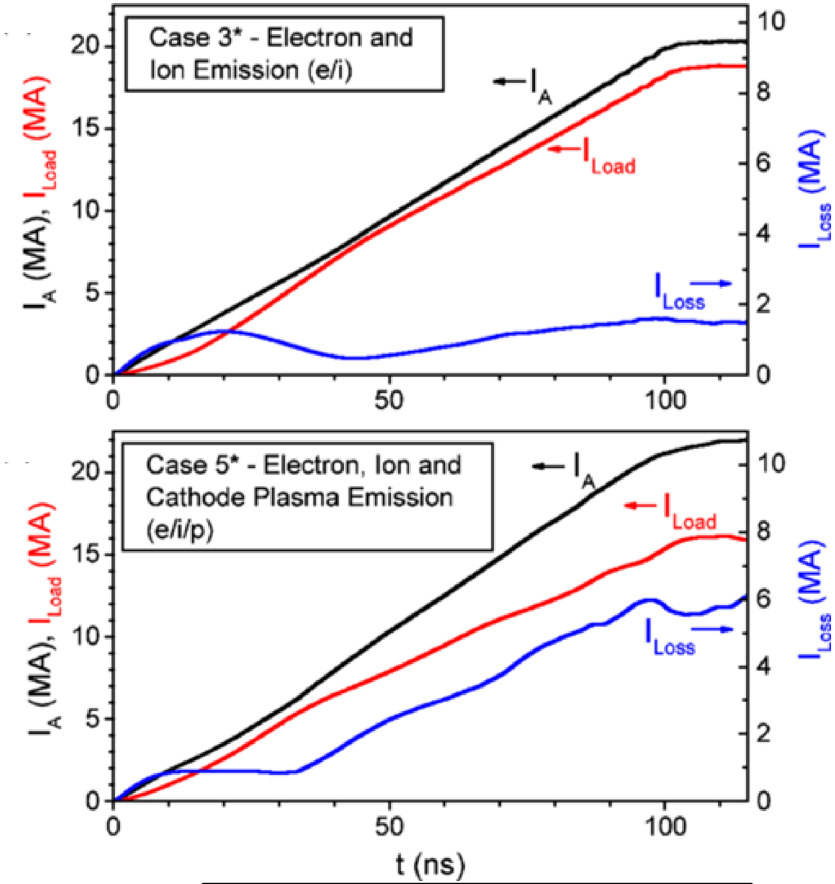
PPC poster by Brian Hutsel for more details!

Modeling Challenges Exist for Advancing the Physics Understanding of Current Loss on Z

- It is difficult to model (requires PIC treatment) the actual Z convolute geometry, therefore simple MITL geometries* are used to understand scaling relationships and phenomenological physics:
  - Space Charge Limited Electron Emission from Cathode Surfaces (>350kV/cm)
  - Space Charge Limited Ion Emission from Anode Surfaces
  - Neutral Desorption / Plasma Formation near Electrode Surfaces (>400°C)
  - Negative Ion Emission / Generation in Anode-Cathode Gaps**
  - Magnetic Nulls in Convolute Geometries



Simplified convolute geometry for simulation



****PPC poster by Andrew Fierro for more details!**

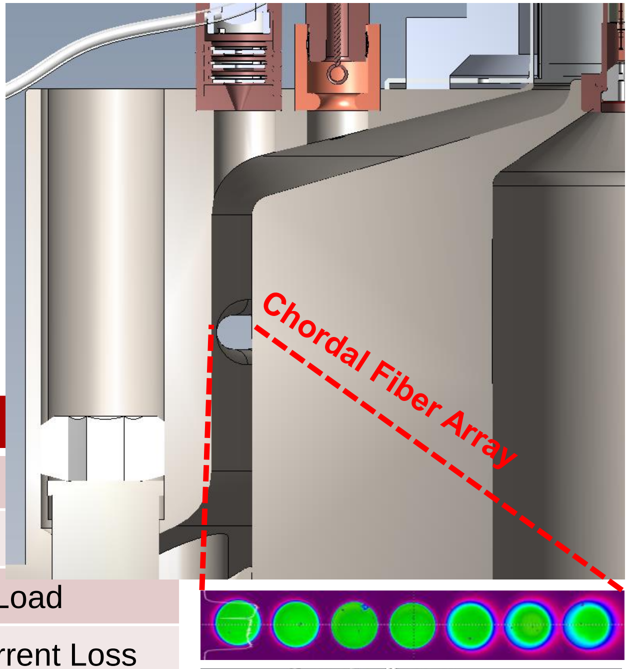
Sandia has established a "Power Flow Physics & Spectroscopy" group to explore the relevant theories

- **Quantitatively understand the physics, and ultimate limits, of MITL plasma evolution / dynamics in the convolute, radial feed, and load regions on ZR.**
  - Examples: magnetic nulls, plasma expansion velocities, plasma gap closure, etc.
- **Determine the characteristics of electrode surface condition in MITL geometries, and determine which characteristics are important for subsequent plasma formation at these interfaces.**
  - Examples: surface and/or bulk neutral desorption, skin depth / surface heating, etc.
- **Separate the fundamental generation mechanisms, and relative importance, of ion vs. electron currents in vacuum power flow MITL geometries.**
  - Examples: negative ion current, enhanced space-charge-limited flows, etc.
- **Determine the importance of transient plasma effects which propagate from one area of the power flow architecture into a downstream location (or vice versa)**
  - Examples: plasma plume from radial feed into the load, beams from convolute into radial feed, electron flows from the outer MITLs into the convolute, etc.

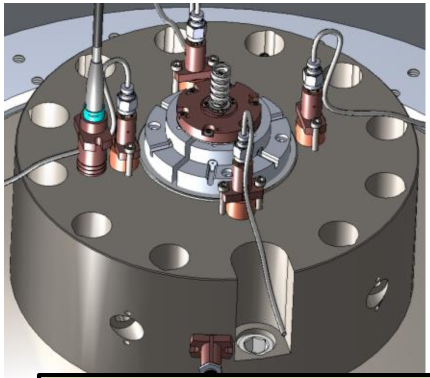
We have dedicated experiments planned to investigate this!

We have developed a new experimental platform to provide power flow diagnostic access on Z

- **Motivation**: Can we improve our understanding of fundamental power flow physics to inform the design of next generation pulsed power machines (Z-Next)?
- **Approach**: We have allocated experimental machine time to explore the basic physics of vacuum power flow, and are developing targeted diagnostics for this study.



Location	Diagnostic	Physics Information
Target	Return Can PDV/VISAR	Load Current
Target	Radial (internal) PDV	Liner Velocity / Load Current
Target	PDV Chordal Fiber Array	Plasma Motion / Density near Load
Radial Feed	Radial Optical Pyrometry	Cathode Temperature / Ion Current Loss
Radial Feed	Mini-XRD Pyrometry	Cathode Temperature / Ion Current Loss
Radial Feed	Chordal Optical Spectroscopy	Plasma Velocity / Density / Temperature
Convolute	Axial Optical Spectroscopy	Plasma Velocity / Density / Temperature
Convolute	Faraday Cup Anode Post	Electron / Negative Ion Current Loss
Convolute	Anode Post Magnetic Spectrometer	Electron / Negative Ion Energy Spectrum
Convolute	Cathode-side Scintillator Fibers	Ion Current Loss (Time-Resolved)
Convolute	Cathode-side Film Detectors	Ion Current Loss (Time-Integrated)



Raised Feed for Diagnostic Access

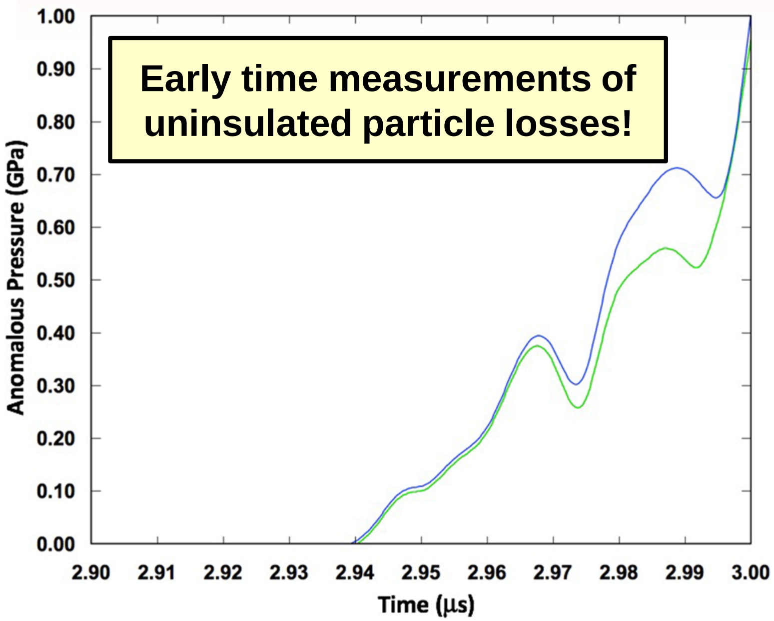
Example: New Power Flow Diagnostics near Load

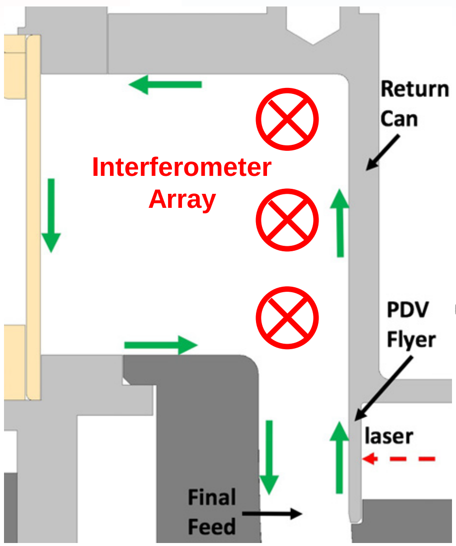
Particle Pressure via Laser Velocimetry

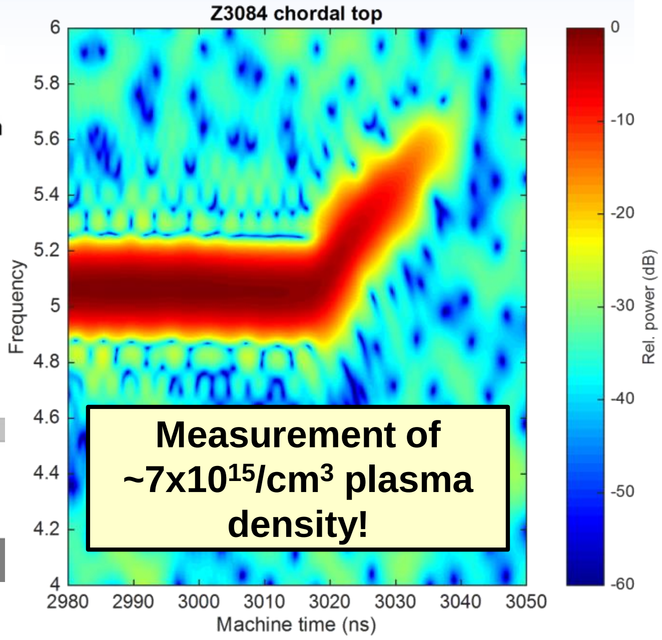
- Laser velocimetry based load current diagnostics have been extended* to measure early-time surface pressures
- The measured pressures cannot be sourced by magnetic pressure at such early times in the current pulse

Plasma Density via Interferometry

- Laser interferometry based techniques deployed in single- and double-pass configurations between liner and anode
- Fiber arrays can be deployed to observe plasma motion and measure time-resolved plasma densities







*M. Hess et al., *Phys. Plasmas*, Vol. 24, 013119, (2017).

Example: New Power Flow Diagnostics Inner MITL

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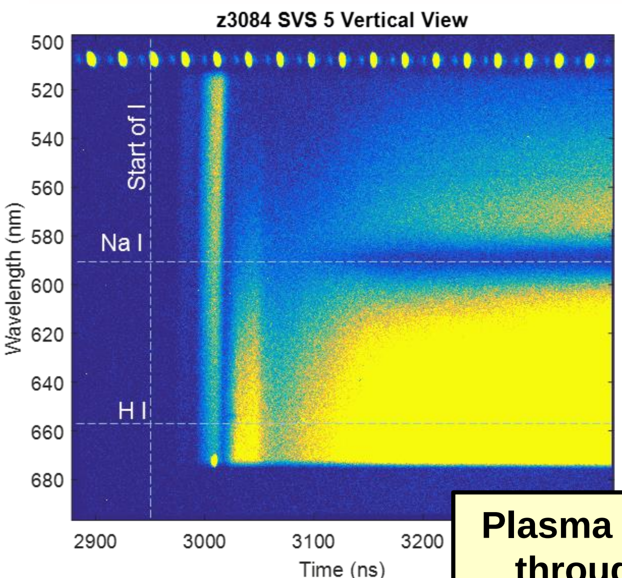
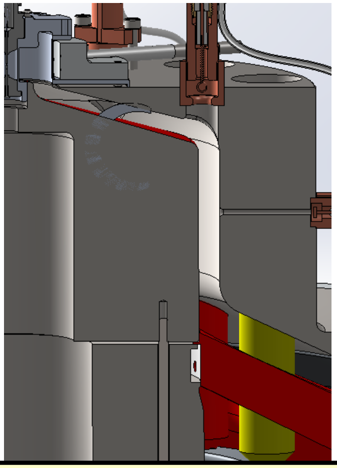
Plasma Parameters via Spectroscopy

- Spectroscopic diagnostics developed* for the Z convolute have been extended to study electrode surfaces in the inner MITL
- New raised feed power flow platform allows for axial, radial, and chordal views of power flow surfaces (analysis ongoing from first experiments May 2017)

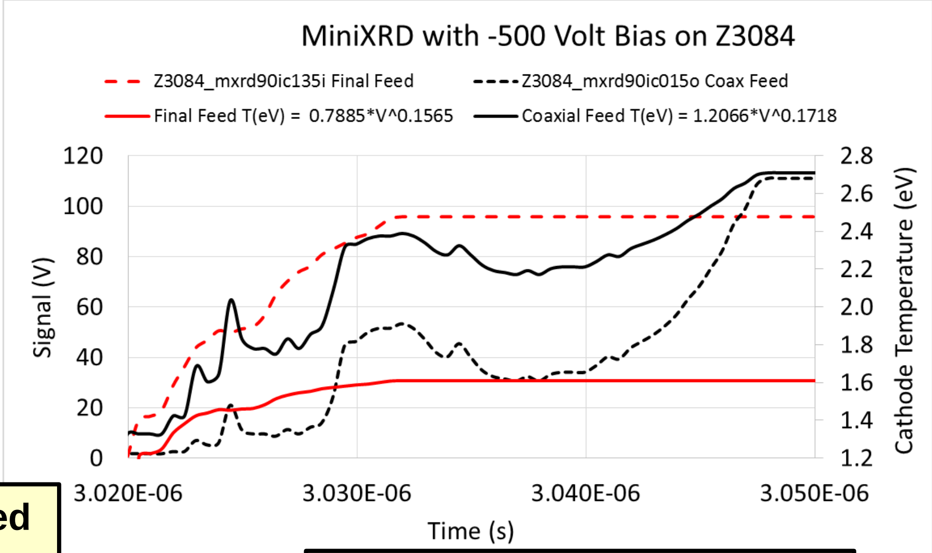
Cathode Temperature via XRD

- Determining the temperature of cathode surfaces would provide a major advance in bounding particle loss models
- We have developed new temperature diagnostics using x-ray diode (XRD) techniques to measure the evolution of surface temperatures





Plasma Evolves in Axial Feed throughout Current Pulse



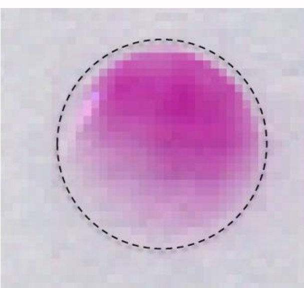
Observed 1-3 eV cathode temperatures → ion heating!

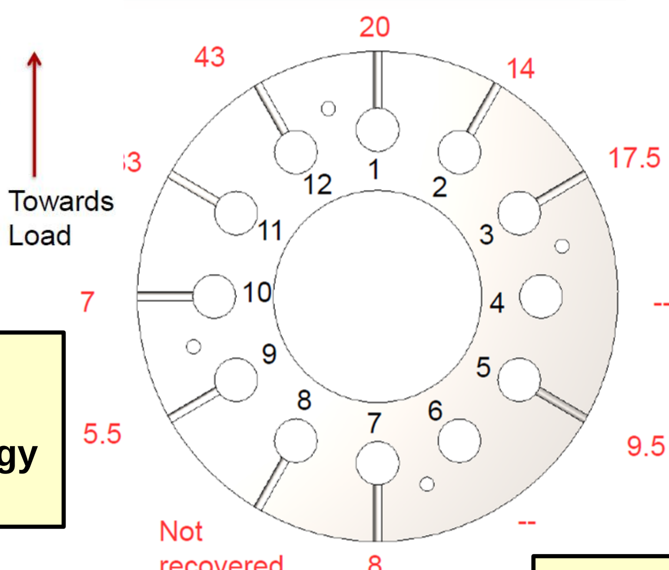
*M. Gomez et al., *Phys. Rev. Accel. Beams.*, Vol. 20, 010401, (2017).

Example: New Power Flow Diagnostics in Z Convolute

Positive Ion Flux via Radiochromic Film

- Cathode-side diagnostics are difficult on large pulsed power accelerators due to noise issues
- 1st generation cathode-side diagnostics have been developed using integrated proton dose on radiochromic films

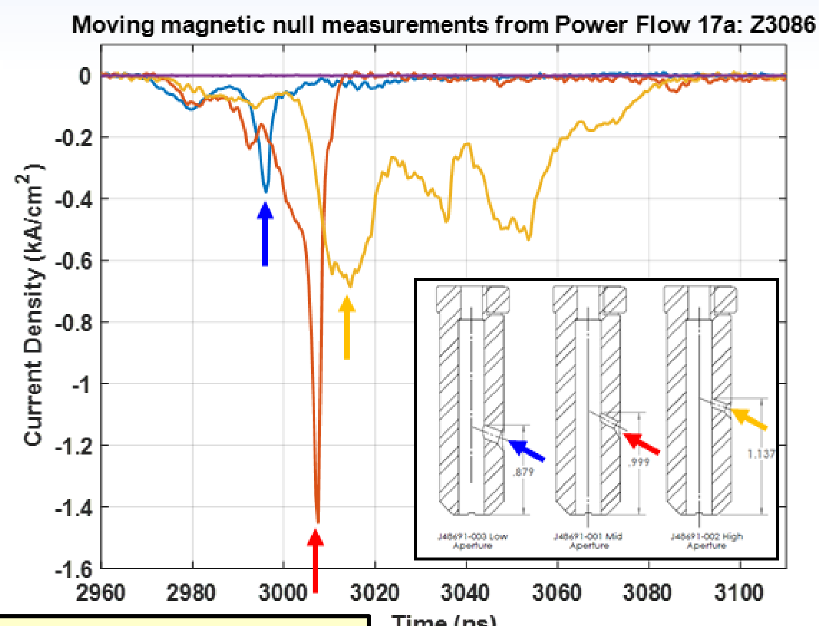




Observation of proton flux with 0.6 - 1.6 MeV energy in convolute!

Negative Particle Flux via Faraday Cup

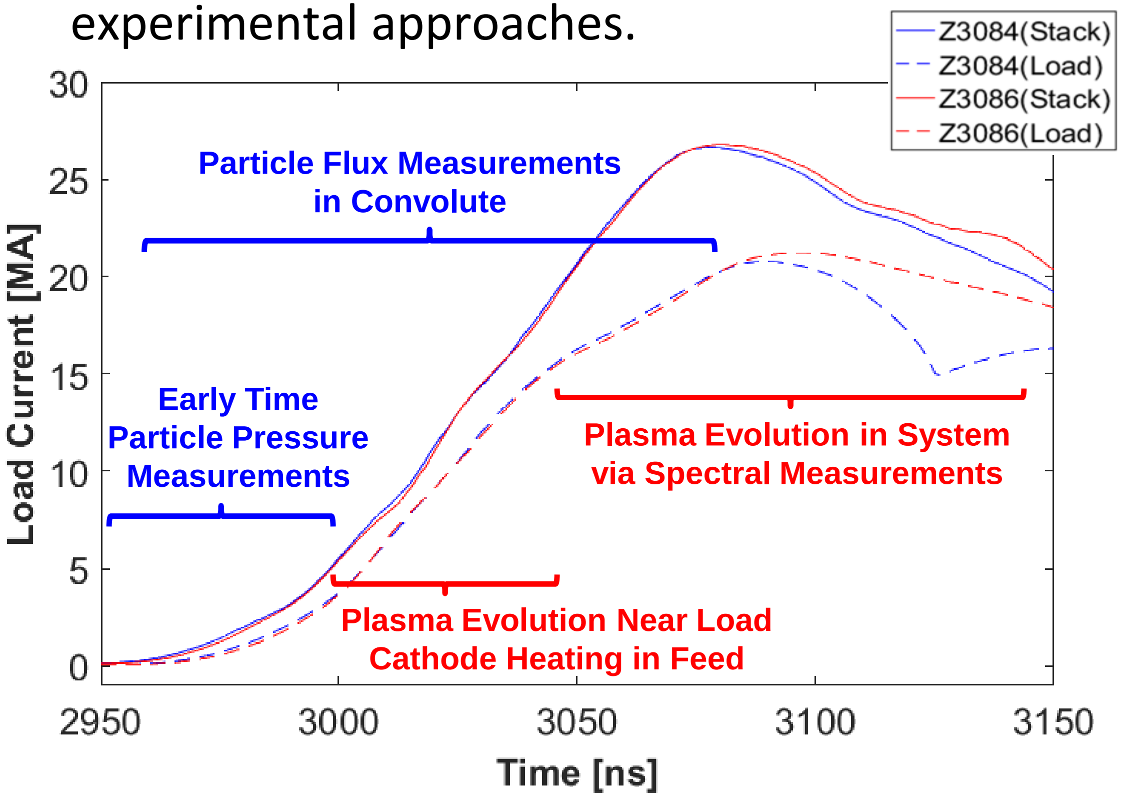
- We have developed electrical diagnostics to measure negative particle flux into anode posts in the Z convolute
- *Observations of particle flux differences inside/outside of the magnetic nulls, movement of magnetic nulls, etc.



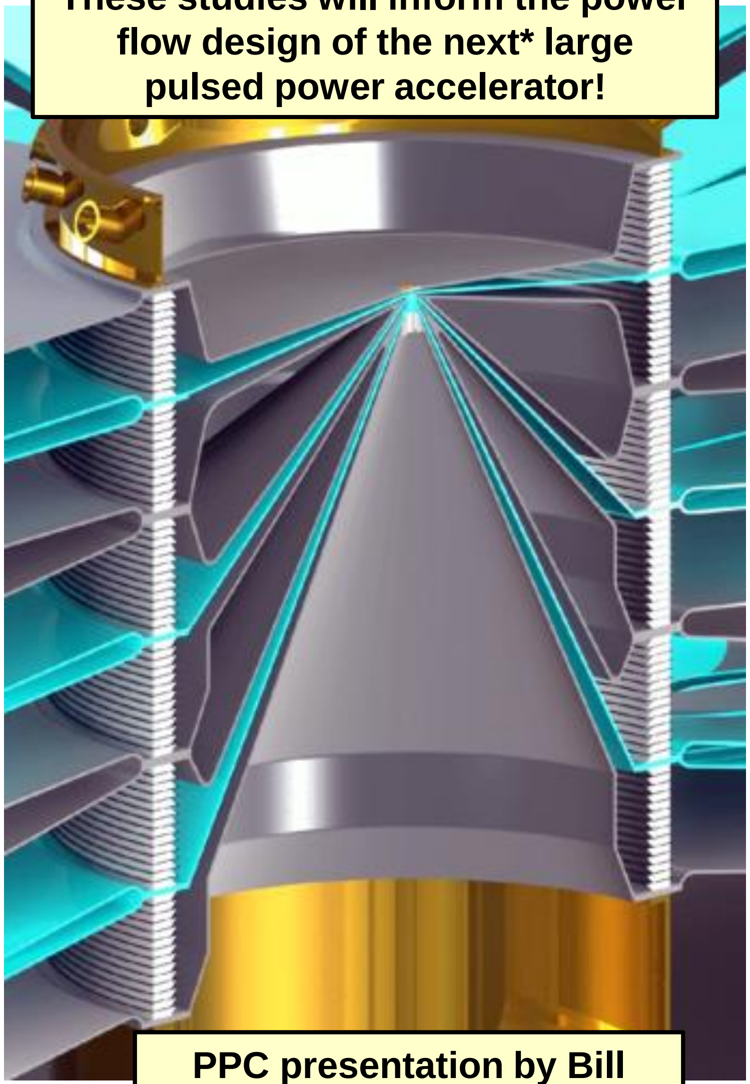
***PPC presentation by Derek Lamppa for more details!**

Conclusions

- ✓ Current loss is a active research challenge for large pulse power generators, and will continue to be investigated as new pulsed power concepts are explored.
- ✓ At Sandia, we are addressing the current loss challenge with a combination of modeling and experimental approaches.



These studies will inform the power flow design of the next* large pulsed power accelerator!



PPC presentation by Bill Stygar for more details!