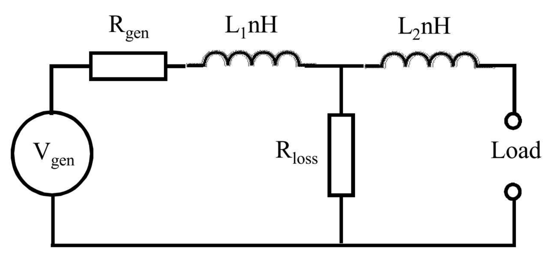
SAND2019-5121D

Sandia National Laboratories

Power Flow Design and Consideration for ICF

Chris Jennings, Matt Gomez, Brian Hutsel, George Laity, Mark Hess, Niki Bennett, Dave Rose, Dale Welch, Andy Perwitzky, Derek Lamppa, Sonal Patel, Mark Johnston

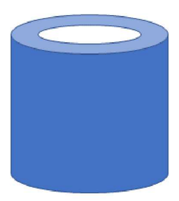
Considerations for driving a target:



- Generator and load are part of a tightly coupled circuit.
- What the generator delivers depends on what the load does
- Must be modelled together to capture coupling
- Maximizing energy coupled is not the same as maximizing current

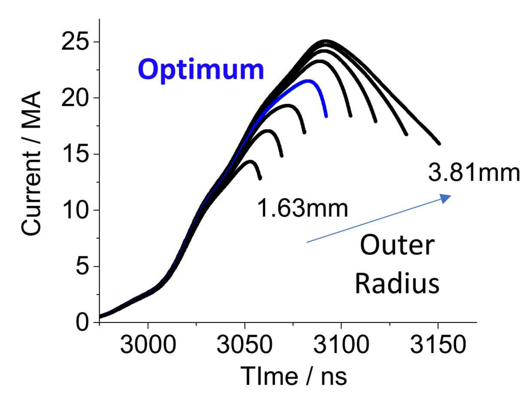
Peak electrical energy delivered is not at peak current obtainable

Radius scan on Aspect Ratio 6 Liners in lossless system

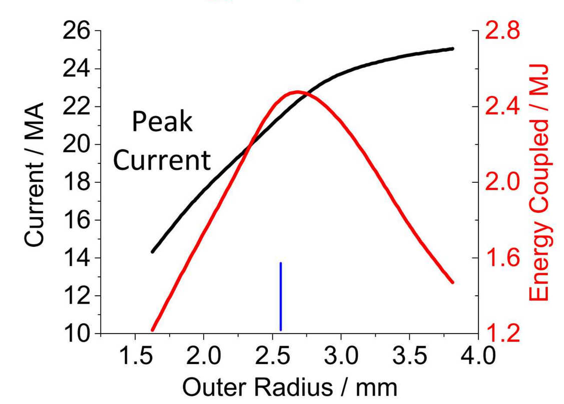


Mass and implosion time increase with radius

Current Delivered



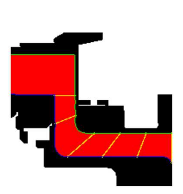
Electrical Energy Coupled to 4mm radius



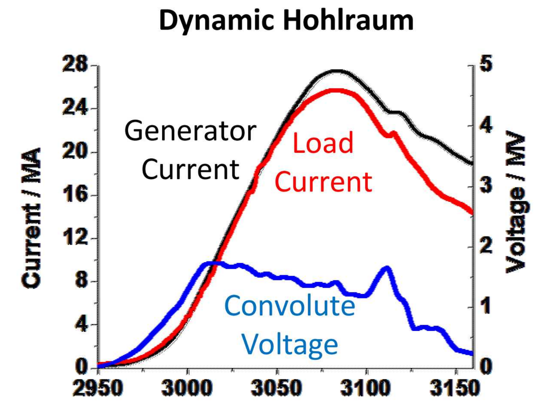
Considerations for managing current losses:

- Some current is lost in transmission lines approaching load volume.
- Z was engineered to better support certain types of load.
- As we move farther away from that design point we risk exacerbating current losses

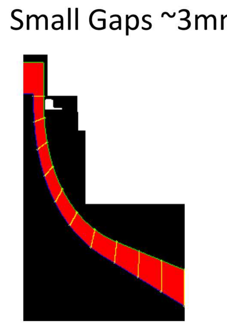
Low inductance ~2.5nH Large Gaps ~6mm



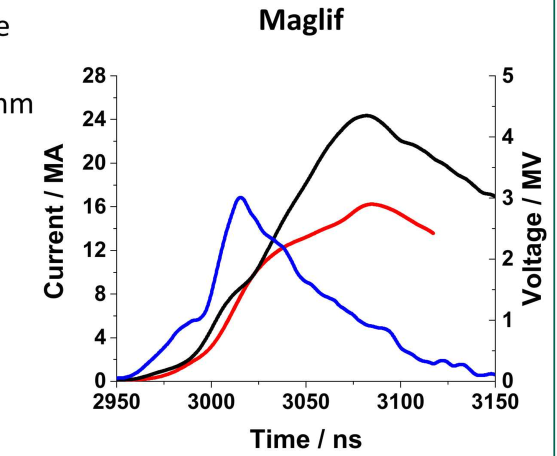
Dynamic Hohlraum



High inductance ~7nH Small Gaps ~3mm



Maglif



We can deliver high currents to Z targets with low loss.
We hypothesize that losses become problematic not because we've gone up in current, but because we've moved to loads that Z was not designed to support.

What does that mean in practice ?

Hypothesized that electron flow is the bad actor:

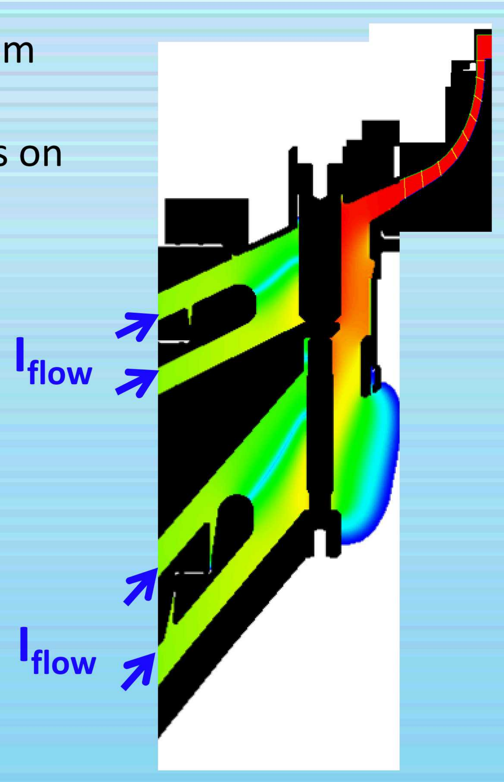
Flow current enters from outer MITL's

- Heats surfaces (turns on anodes)
- Accumulates charge (enhances ion diode loss)

$$I_{flow} = \frac{13}{16}\frac{V^2}{I_a Z^2}$$

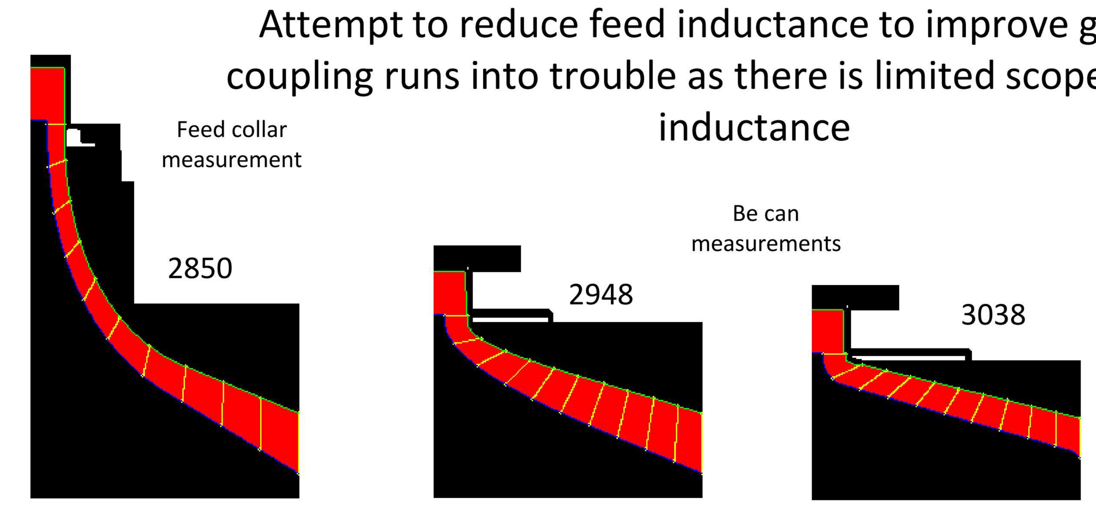
$$V_c = L_f \frac{dI}{dt}$$

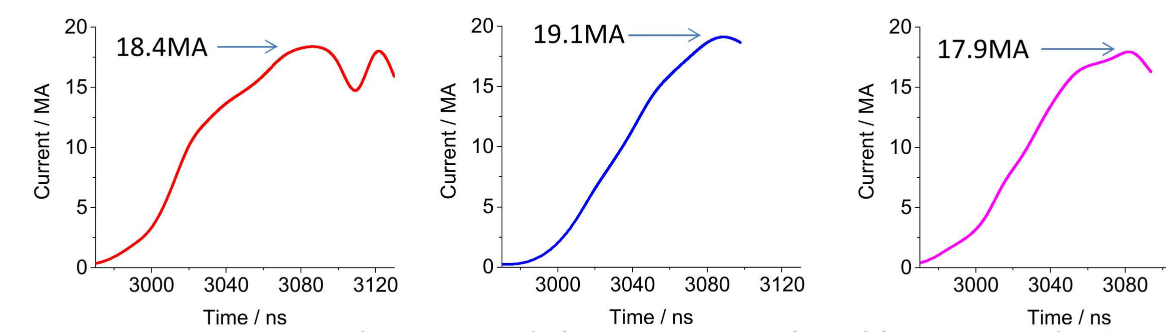
Dependence on initial inductance



- Electron flow is launched from the outer MITL's into the convolute and inner feed.
- Flow current depends on convolute voltage which depends on inductance inside of convolute.
- If flow current is a root cause of other problems we can reduce it by reducing initial inductance inside of convolute.

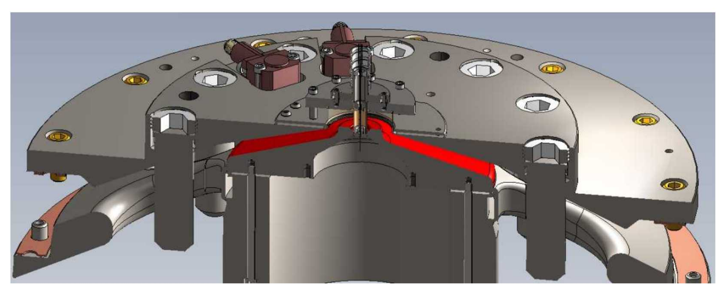
Attempt to reduce feed inductance to improve generator coupling runs into trouble as there is limited scope to reduce inductance

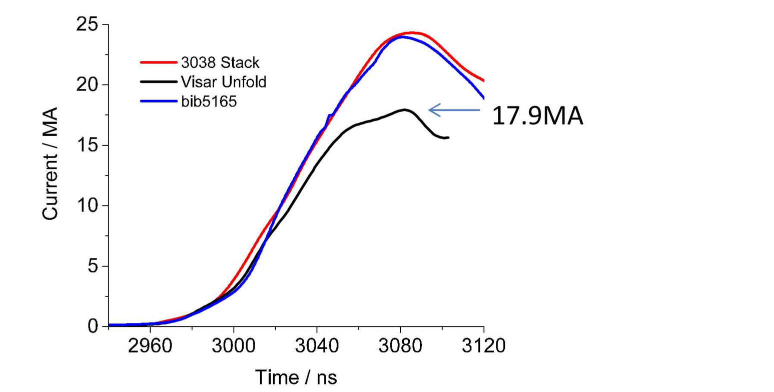




Improved current delivery not realized by just reducing inductance inside of convolute

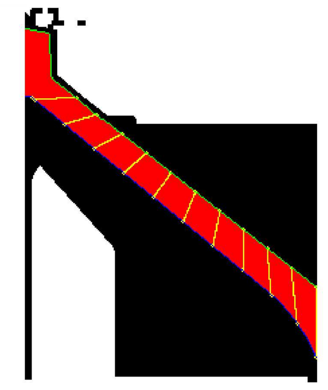
B-dots located inside convolute post at start of feed



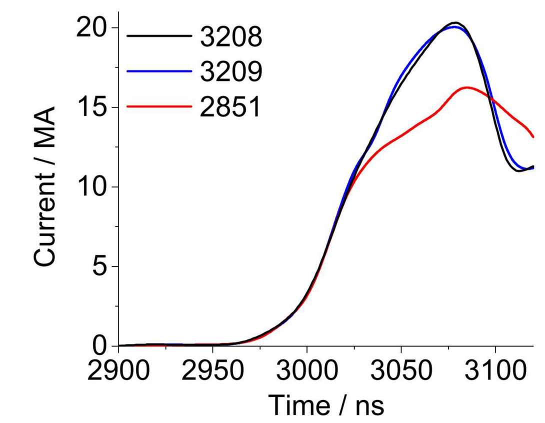


Current measurements indicate significant loss may have just been downstream of b-dots in the feed.

Improvements from maintaining larger feed gaps for better current delivery,



Total: 4.82nH



However this necessitates inductance that still stresses convolute loss

Core approach to scaling systems (target+power feeds) to higher currents:

Leverage accumulated knowledge of how pulsed power operates to advance conservative system designs.

Knowledge captured in "simple" circuit models through physics derived, data constrained terms.

Models are continually tested and refined through data & simulation comparisons

Allows us to follow a conservative system design path to high current while navigating away from root causes of problems

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This approach has successfully enabled current scaling between Saturn(~8) - Z(~22) - ZR(~26)

Examples of experiments that inform understanding

Perform dedicated power flow experiments to study system and test models

Complimentary approach to improve understanding

Develop a detailed understanding of power-flow physics to enable high fidelity system design

Grand Challenge LDRD: Develop validated design codes

Will enable the study, detailed design of specific pulsed power systems

Provides a design path that maximizes performance and flexibility of any future machine

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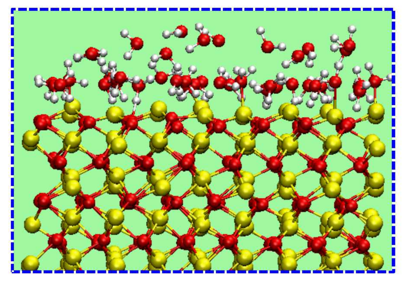
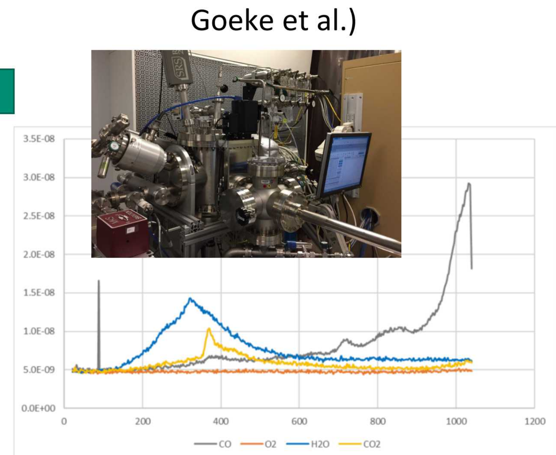
This approach is a more recent undertaking

Advance our Understanding

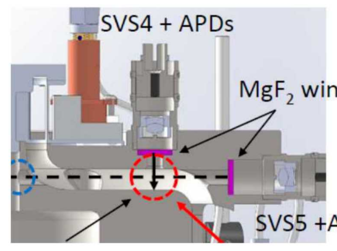


Molecular dynamics surface science (Kevin Leung, Matt Lane et al.)

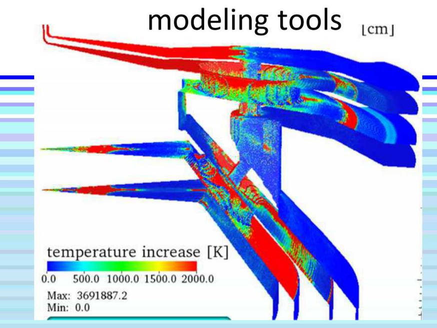
Surface desorption characterization (Ron Goeke et al.)



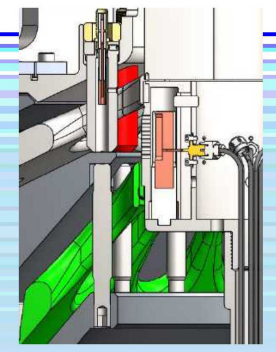
Spectroscopic characterization of electrode surface plasmas (Mark Johnston *et al*)



Development of hybrid PIC/Fluid modeling tools

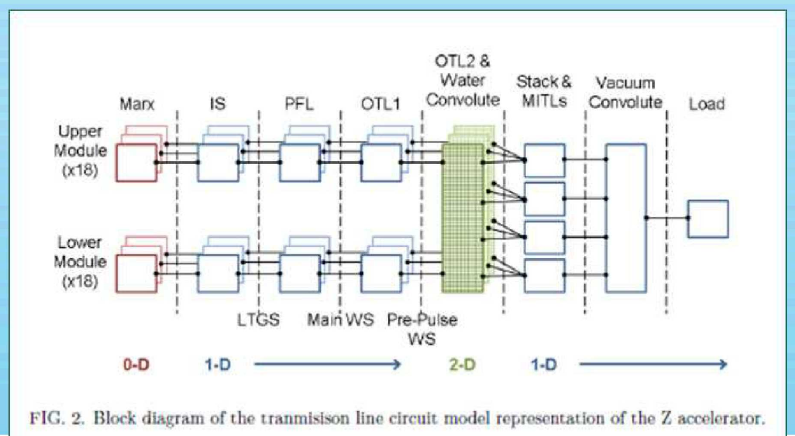


Characterization of particle losses (faraday cup electron and ion measurements) D. Lamppa, T. Webb et al

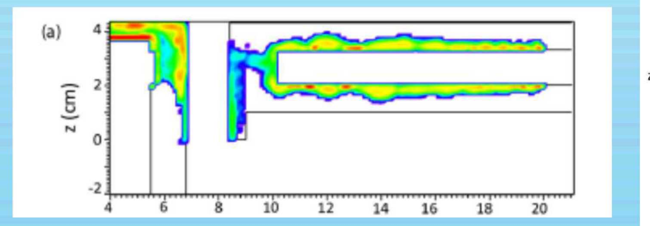


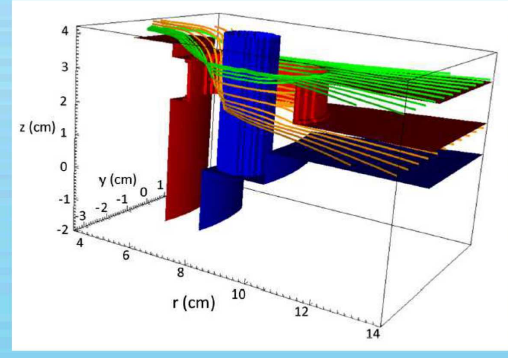
Captured in models

Loss mechanisms captured in Brian Hutsel Z current loss circuit model



Targeted numerical studies on reduced systems to inform circuit models and motivate experiments





Messages:

- Pulsed power systems are tightly coupled to their targets. They deliver current more effectively to loads they were designed to support.
- We understand how to navigate away from power delivery problems, but that is not always possible for targets we want to field.
- We can try and better match future machines to loads of interest. We can also develop a more detailed understanding of power flow physics so we have flexibility to efficiently operate away from ideal loads.

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