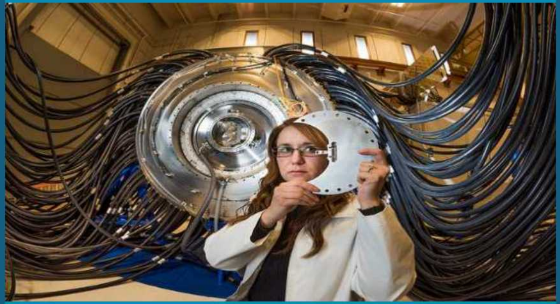
SAND2019-9420C

Fundamental Science Workshop 2019 Breakout Session (Current Delivery)



PRESENTED BY

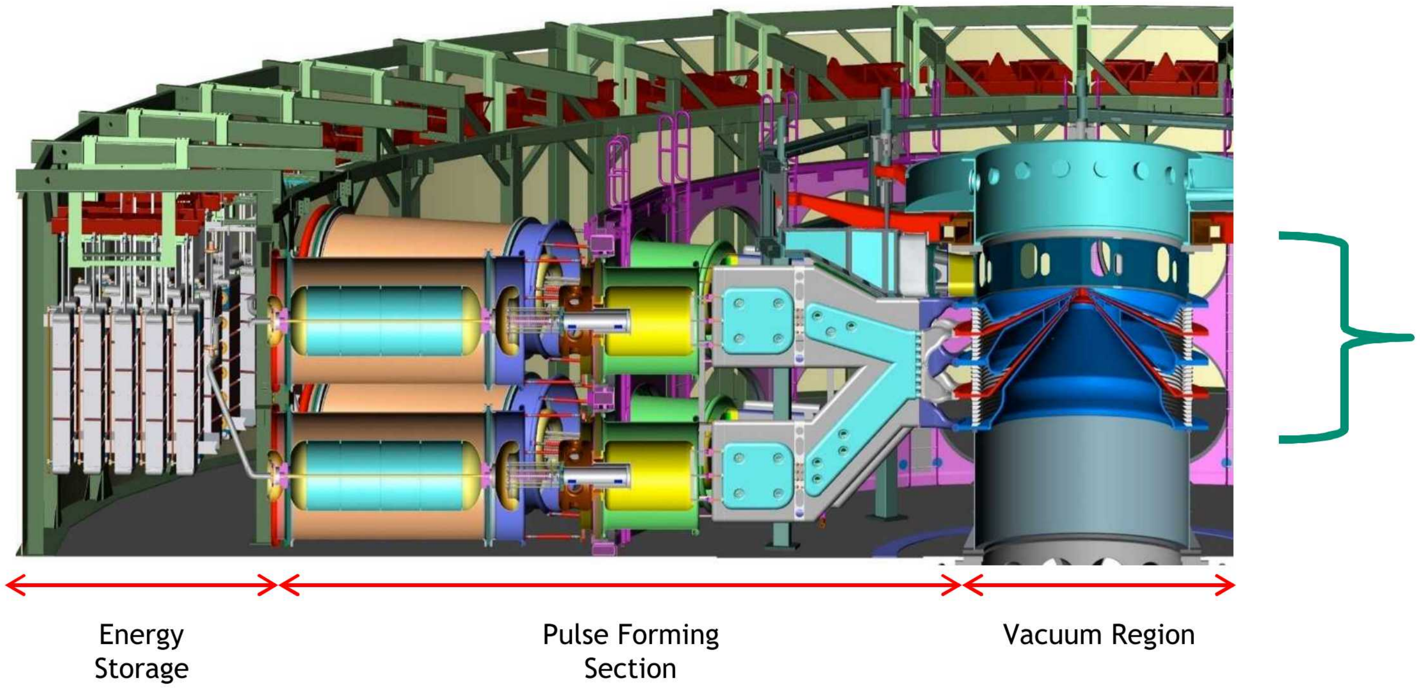
Chris A. Jennings

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

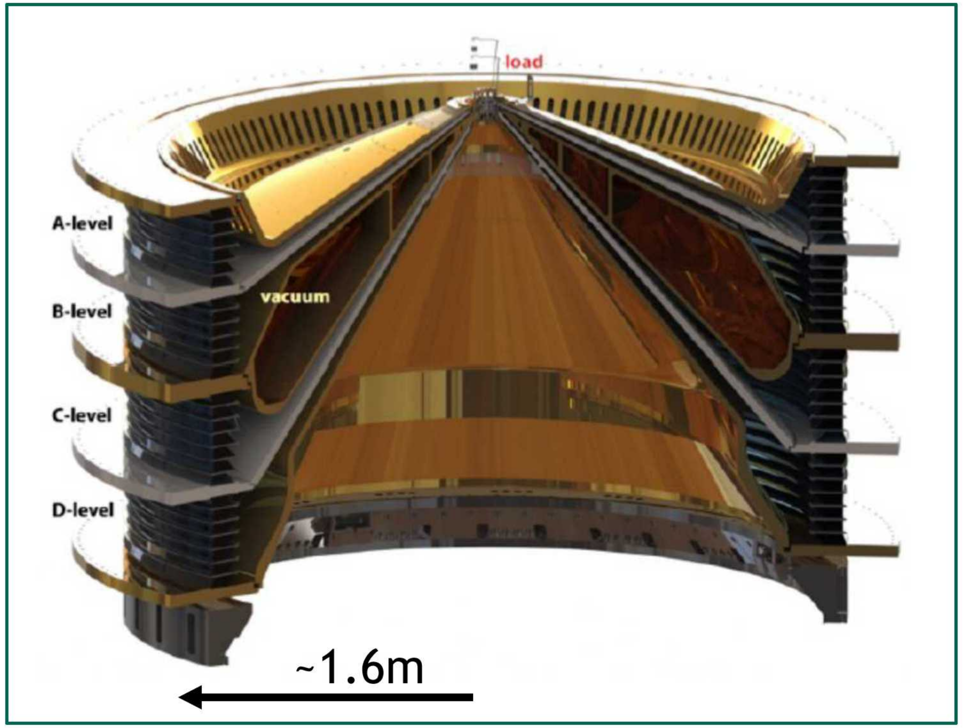
Overview: Current delivery to Maglif targets on Z

- Z architecture (current measurements and locations)
- Current loss processes and their dependencies
- Characterizing distribution of current losses in the system
- Opportunities for improvements in measurements or analysis

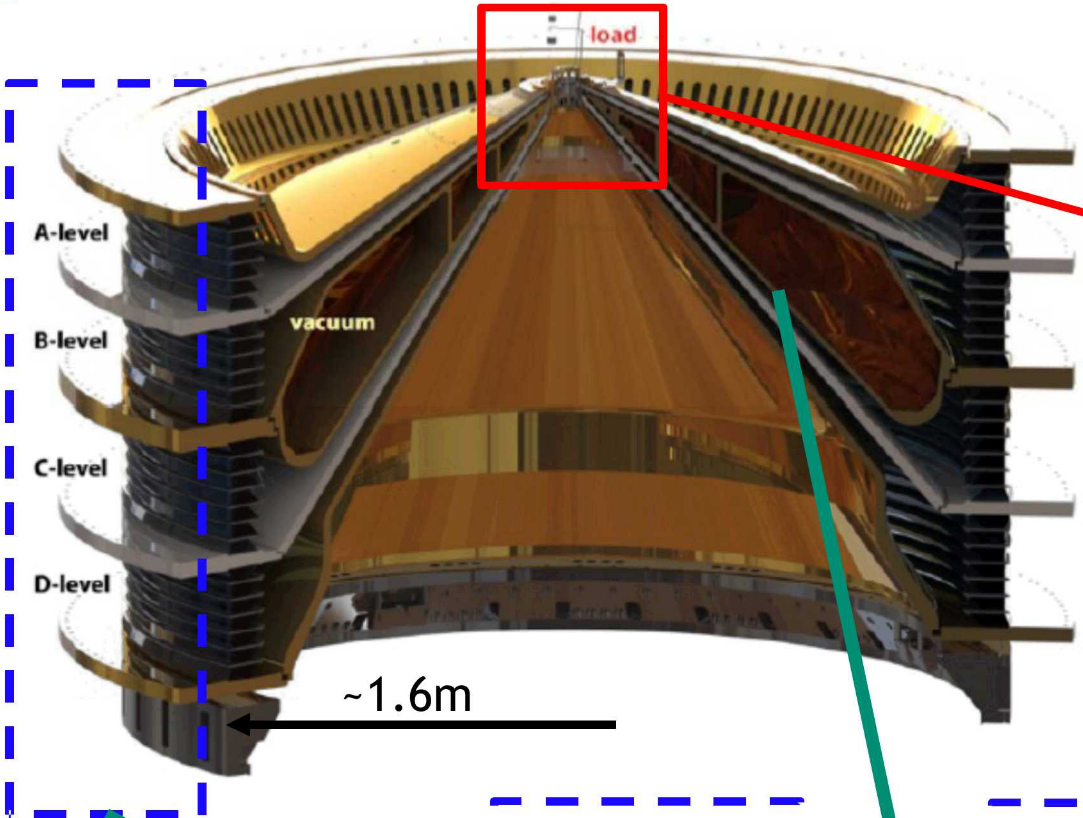
Z architecture



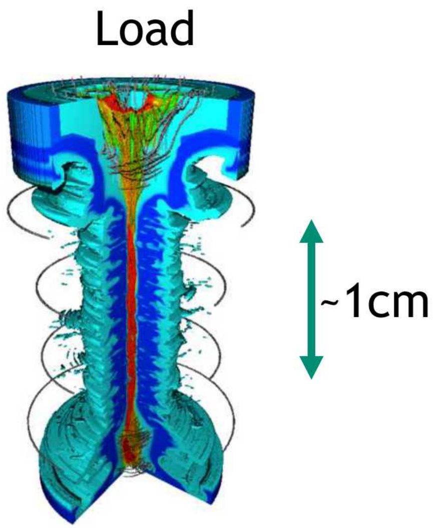
Vacuum section

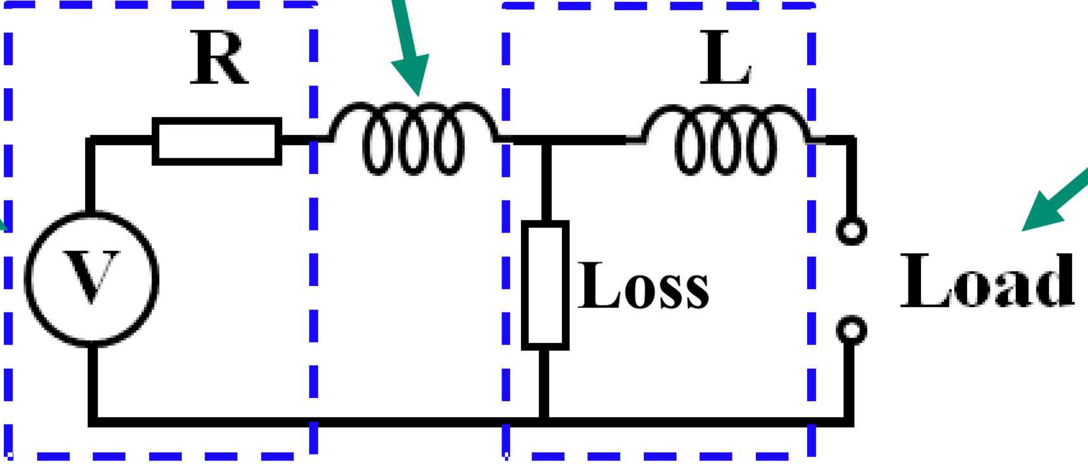


Z vacuum section architecture



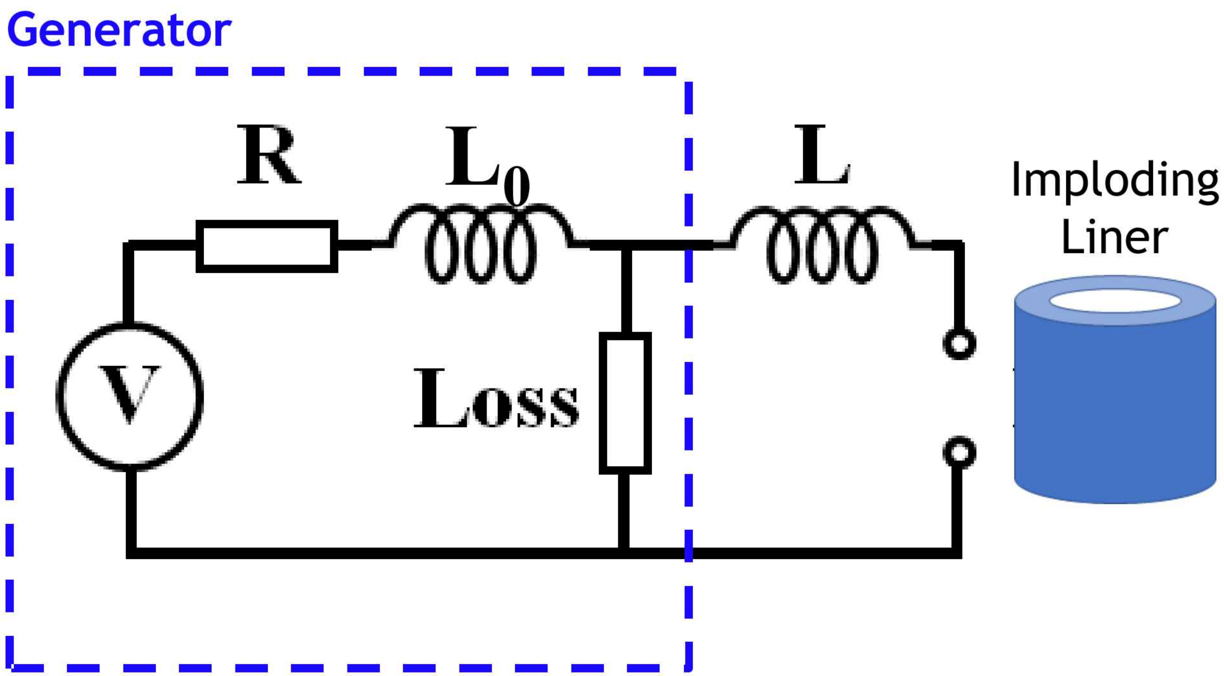
4 lines coupled through a double post hole convolute convolute

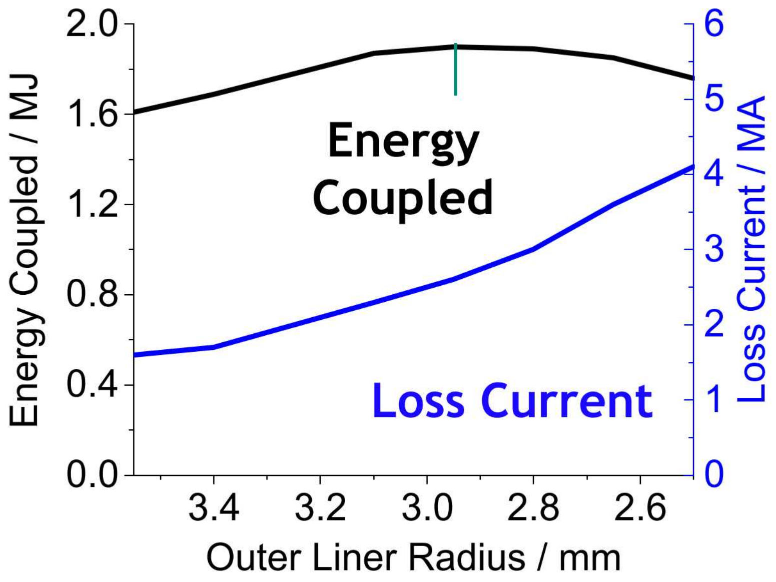




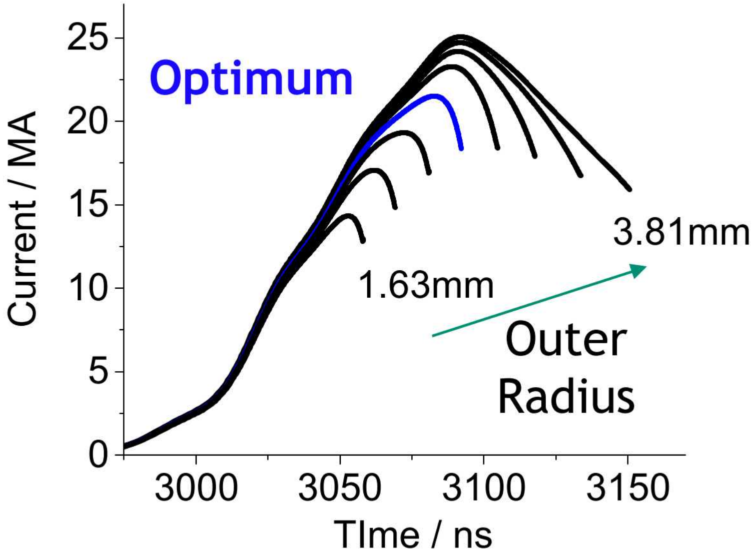
Generator Architecture is not discussed here

Current coupling to a load depends on how the generator responds to the imploding load





Radius scan on Aspect Ratio 6 Liners



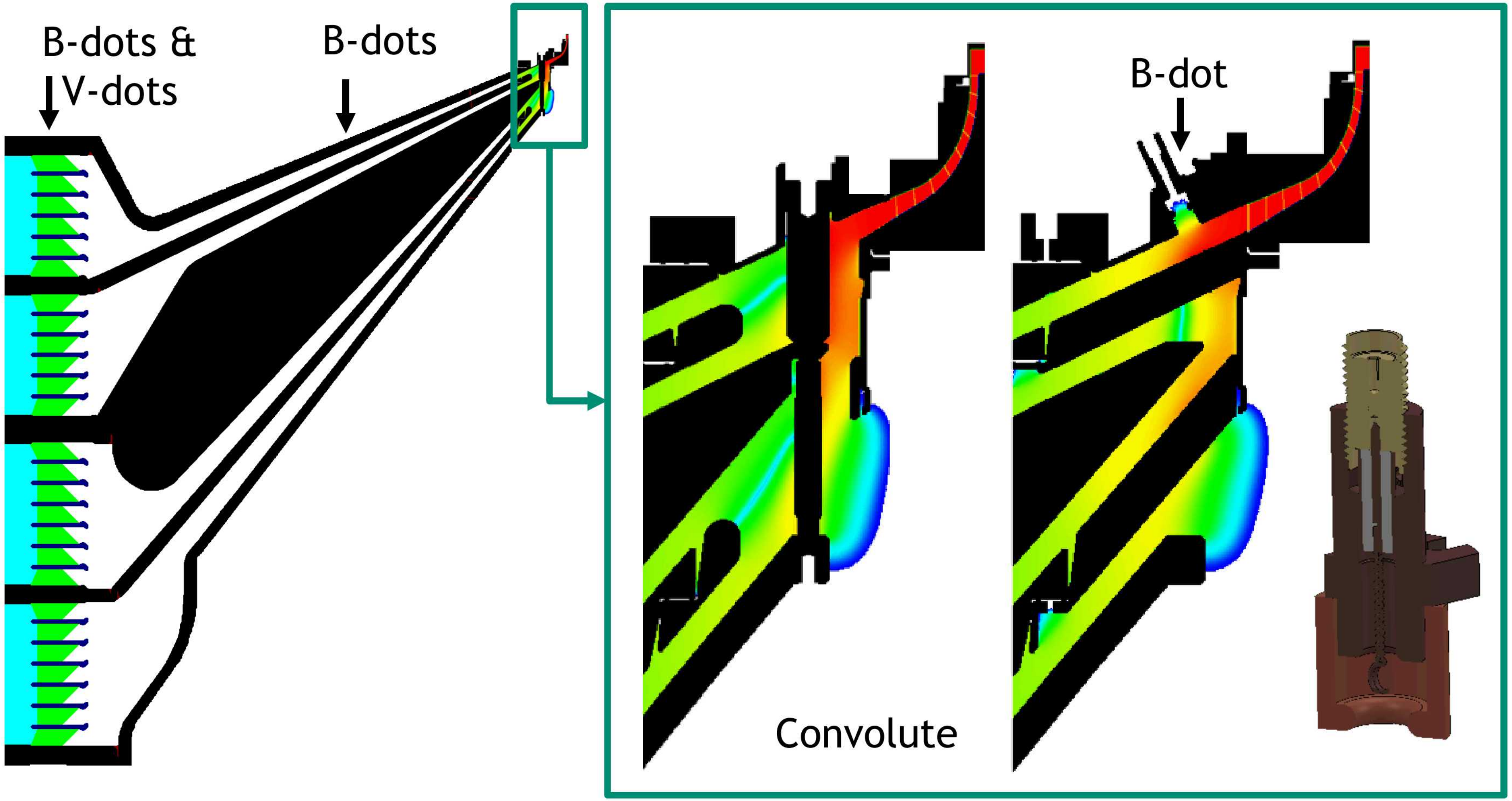
Optimum energy coupled to target volume varies as circuit responds to load

For a representative loss model:

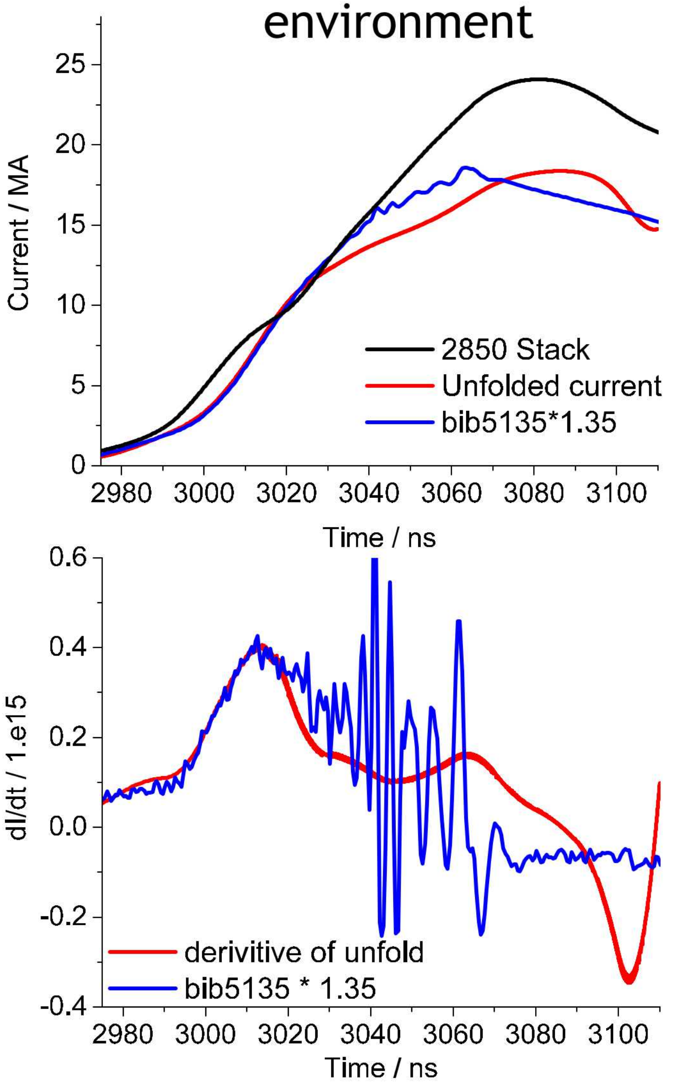
Maximizing energy coupled through target design is not the same as minimizing current loss

Complex power flow physics will always need to be parameterized in simpler circuit model descriptions

Z vacuum section architecture and current measurement locations



Inner B-dots operate in challenging measurement environment

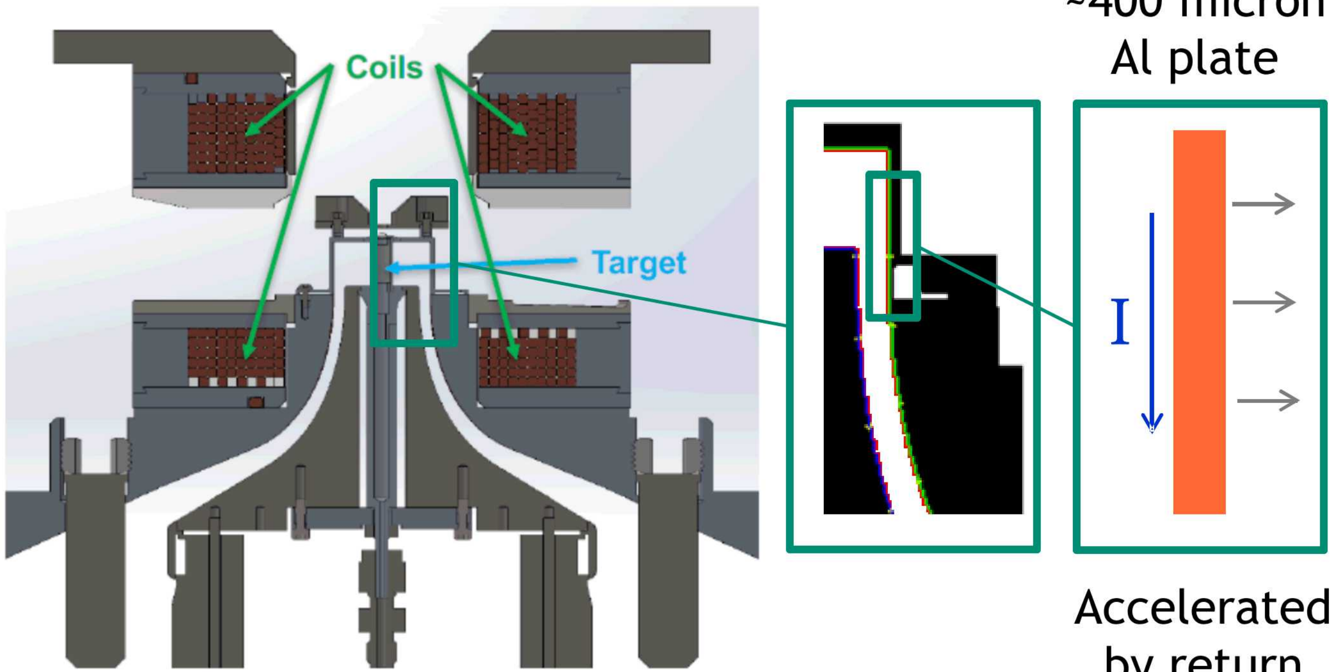


Current measurements at large radius rely on b-dots.
Voltage assessed at water vacuum insulator stack.

16.2 MA delivered to standard 10mm tall Maglif target (Z 2851)

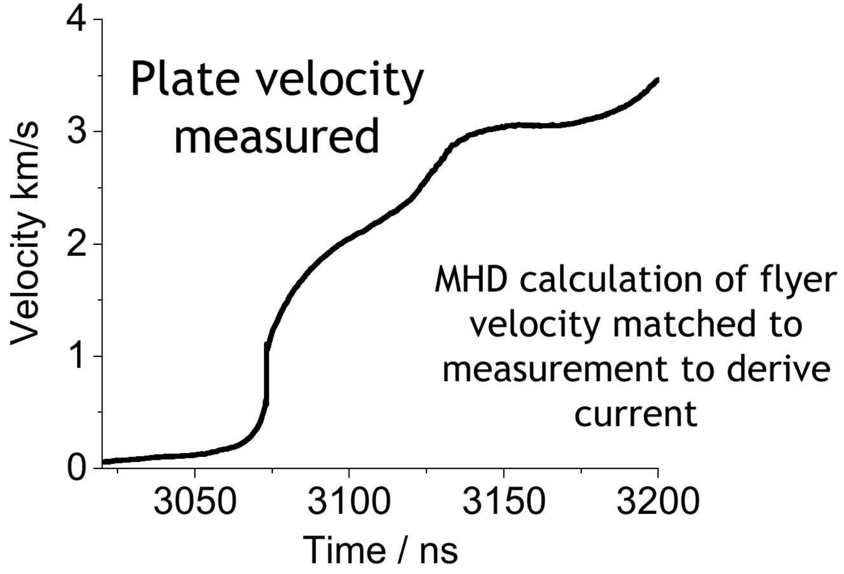
Apply techniques of the Z dynamic material properties program

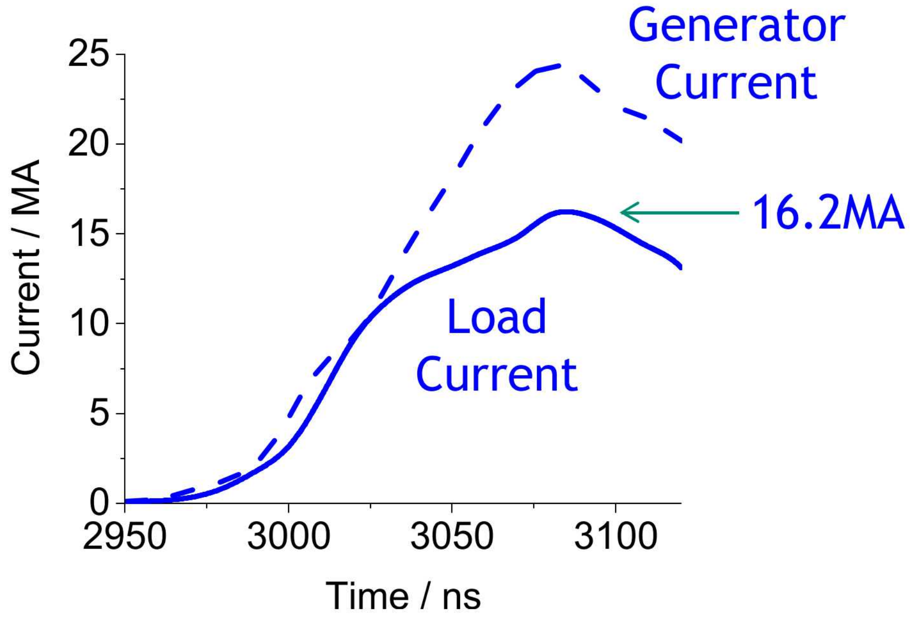
~400 micron Al plate



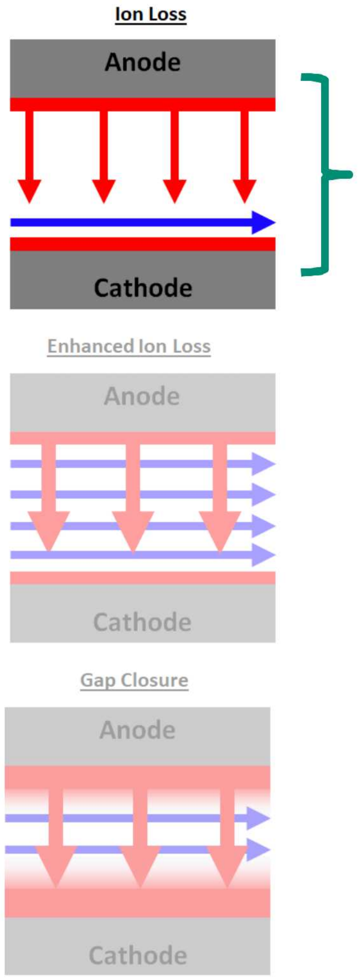
Accelerated by return current

This level of current loss is atypical for Z. Likely resulting from high target inductance and extended feed used to bring electrodes into field coil

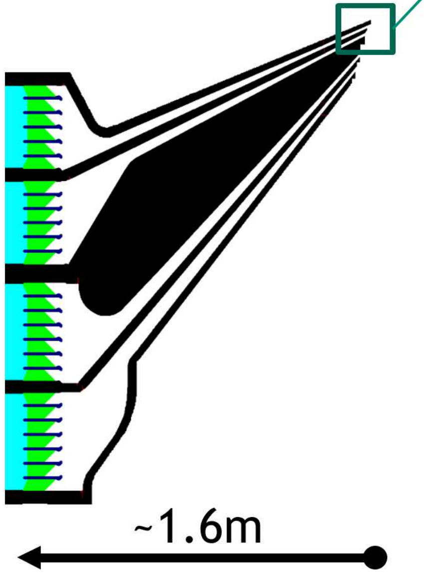




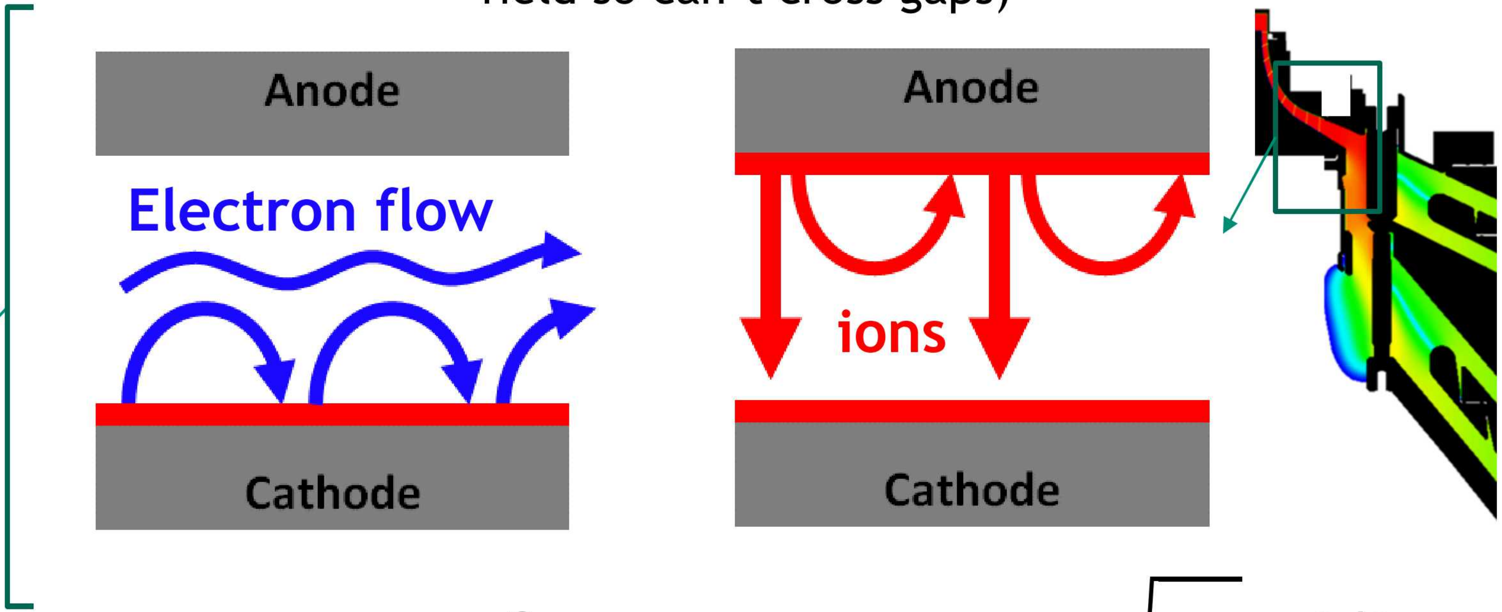
Transmission lines will have electron and ion losses, but system is inherently robust to these losses.



Electron flow currents & ion diode losses are facts of life, but are limited and manageable.



Electrons and eventually light ions are magnetized (gyrate around B field so can't cross gaps)



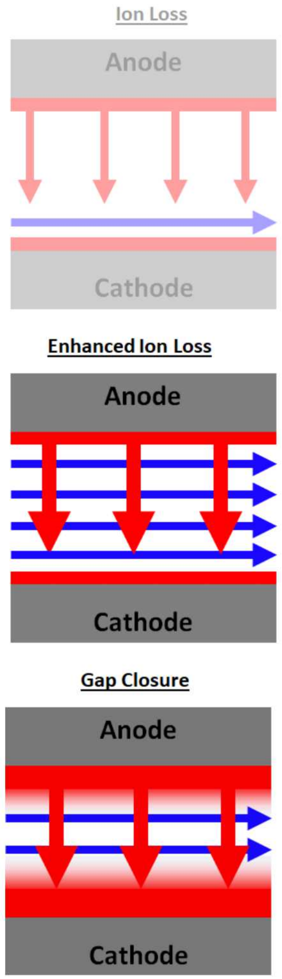
$$I_{flow} = \frac{13}{16}\frac{V^2}{I_a Z^2}$$

$$I_{SCL} = \frac{4\varepsilon_0}{9} A \sqrt{\frac{2q}{m}} \frac{V^{3/2}}{d^2}$$

If injected electron flow is all lost to anode <1 MA in worse case on Z

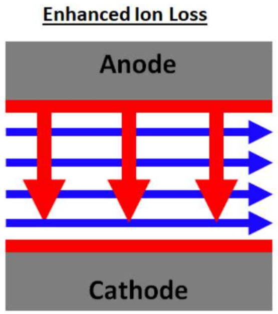
Ion current that does cross gap self limits (space charge limited) to <100 kA

Subsequent enhancement mechanisms can increase current loss, but tend to self limit or saturate



Subsequent processes can enhance losses.

Enhanced ion losses



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

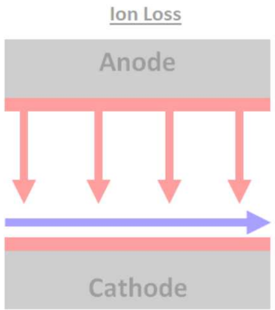
$$I_{Loss} = \eta \frac{4\varepsilon_0}{9} A \sqrt{\frac{2q}{m}} \frac{V^{3/2}}{d^2}$$

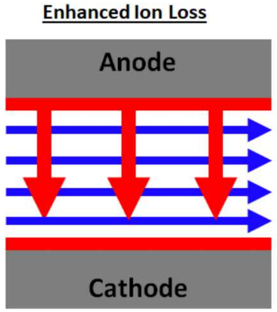
$$V = \frac{d}{dt} L(I_{Total} - I_{Loss})$$

- Negative charge enhances losses
- This reduces elec. flow
- This reduces loss enhancement

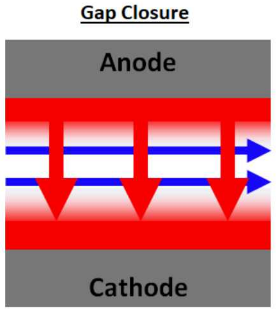
Negative feedback

Subsequent enhancement mechanisms can increase current loss, but tend to self limit or saturate

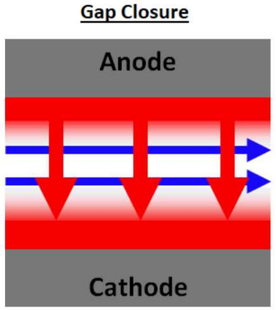




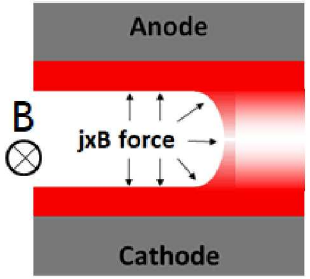
Subsequent processes can enhance losses.



Plasma gap closure



Electrode plasma expansion is diagnosed to be slow over timescale of experiments (and gaps kept sufficient)

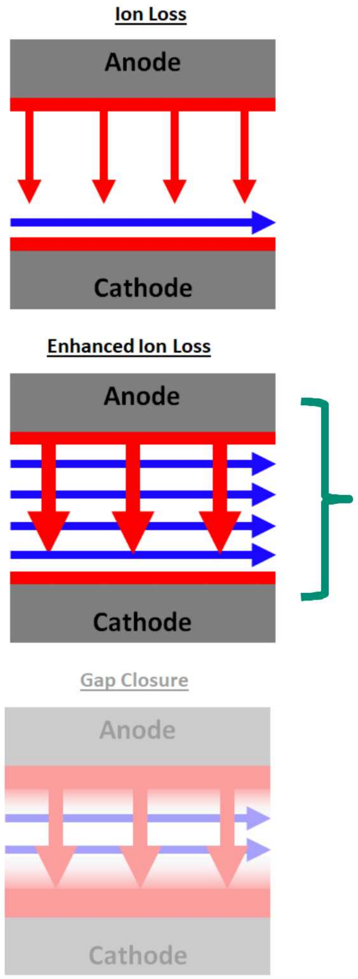


Magnetic pressure at small radius can clear gaps

Low density plasma cannot carry arbitrarily large current density (anomalous resistivity)

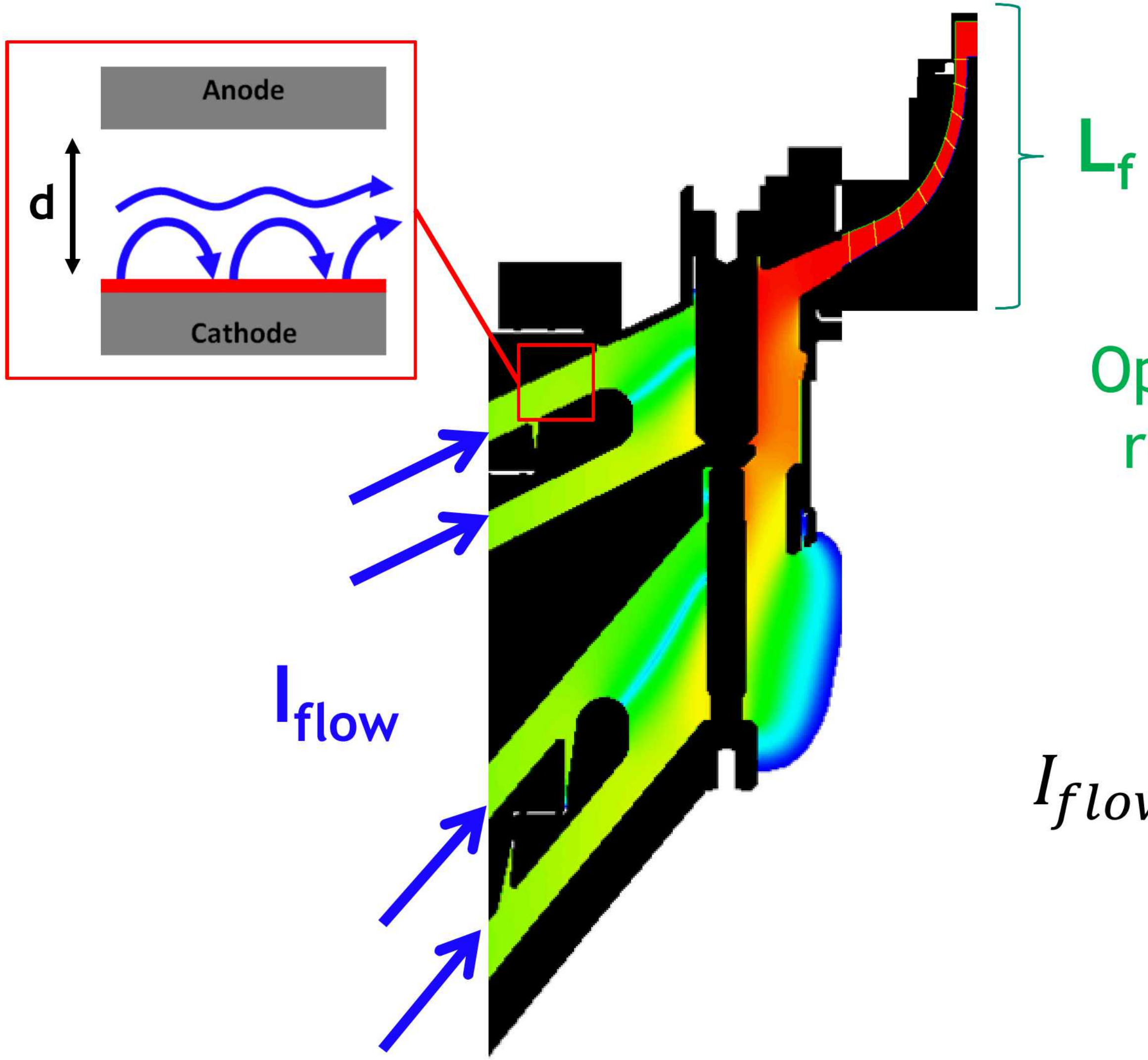
- Ion acoustic turbulence limiting current on 1e17/cc 2eV plasma filling entire inner-MITL is ~3.5 MA
- Conductive plasma shorting gaps can self clear through large jxB (Although this can result in plasma accelerated towards target volume)

We reduce loss enhancement through load design (reducing inductance)



Ion currents can be enhanced by accumulation of negative charge from electron flow

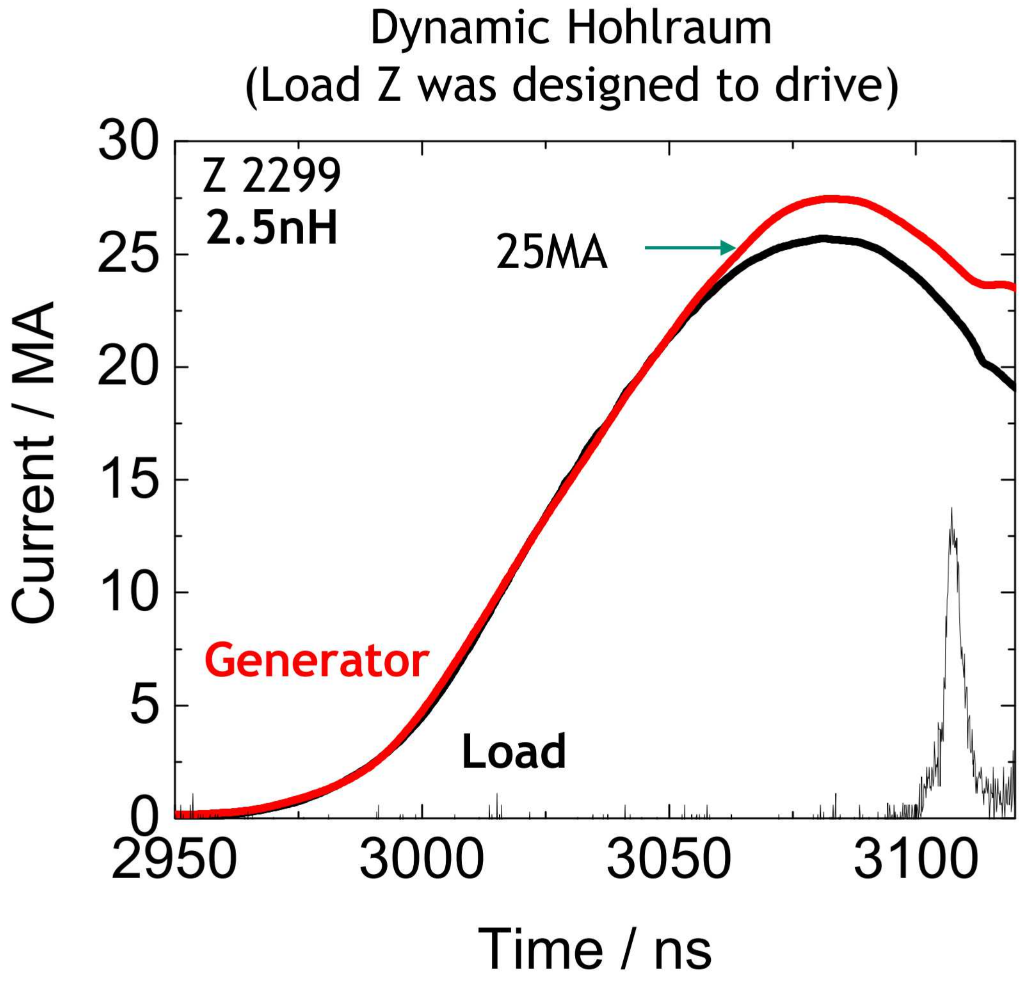
Electron flow is launched from the outer MITL's into the convolute and inner feed:

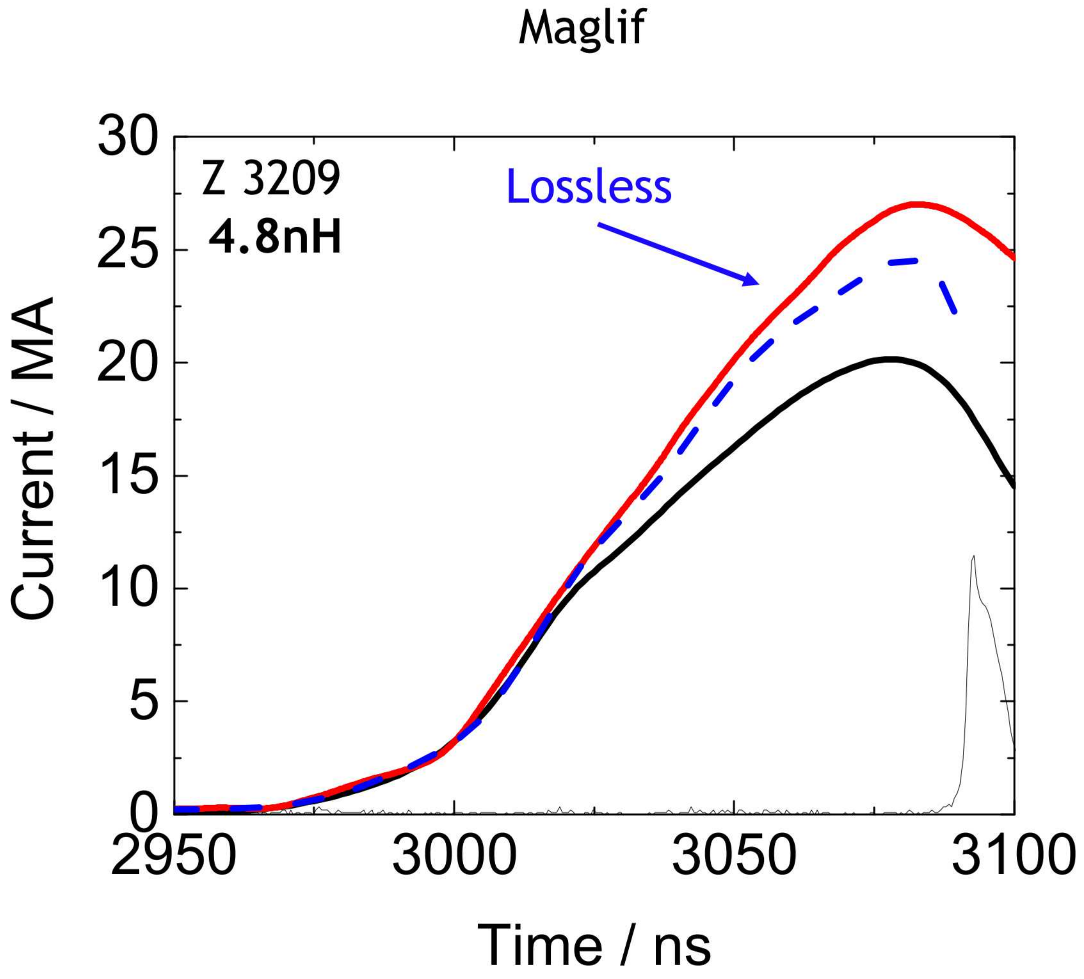


Optimize Load by reducing initial inductance

$$I_{flow} \propto \frac{\left(L_f \frac{dI}{dt}\right)^2}{I_a \left(\frac{d}{r}\right)^2}$$

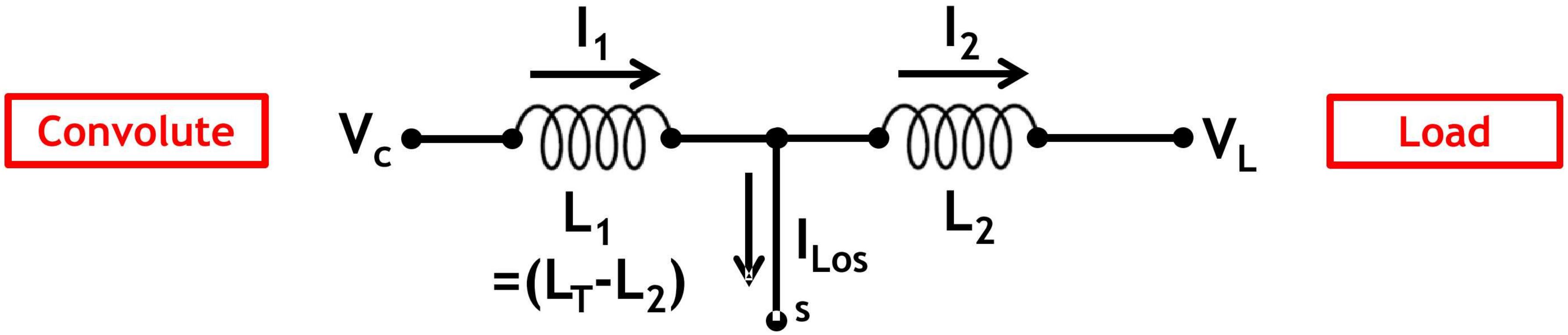
Lowering initial inductance is seem to significantly improve current coupling





Visar/PDV measurements in conjunction with a circuit model can better characterize current losses ?

Representation of final section of the feed through to the load



Assume that:

- From visar/pdv we know I_2 and dI_2/dt
- From Z electrical data we know I_1 and dI_1/dt and V_c
- From taking I_2 and using it to drive an MHD calculation of the load implosion we have V_L
- From hardware we know the final inductance $L_T = L_1 + L_2$

If we know all those things, then the unknown becomes the location of the current loss L_2

$$L_2 = \frac{\left[V_L - V_C + L_T \frac{dI_1}{dt} \right]}{\left[\frac{dI_1}{dt} - \frac{dI_2}{dt} \right]}$$

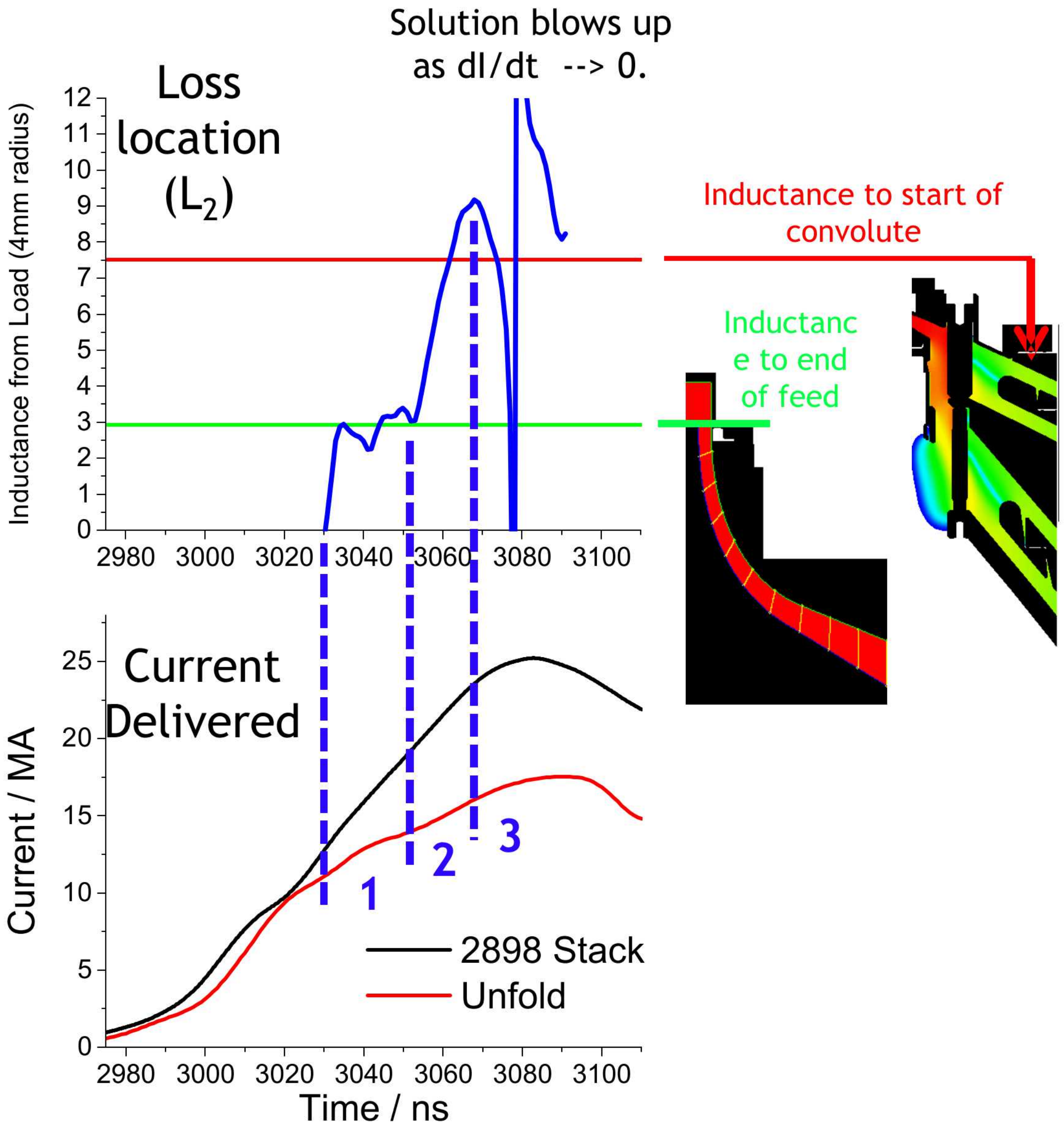
This style of layered analysis could benefit from more comprehensive data analysis techniques.

2898 indicates substantial loss first turning on at the end of the feed (close to load), with convolute loss turning on later

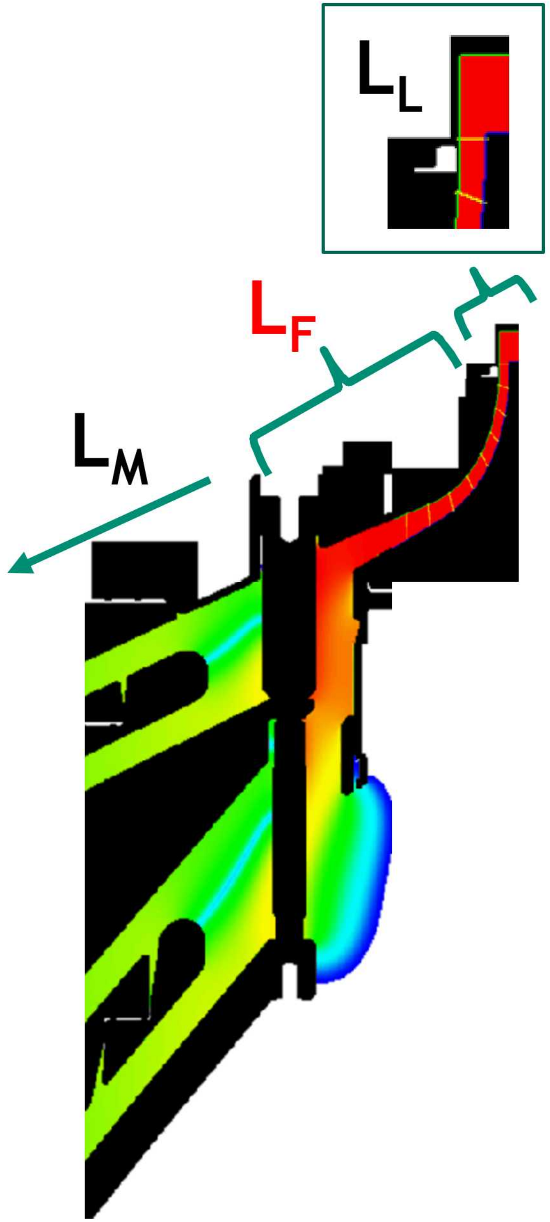
For standard Maglif configuration on 7.5mm tall target:

1. Large current loss starts in the final feed (inner MITL), in close proximity to the load.
2. Convolute loss turns on ~20ns later.
3. Around peak current the solution blows up so can't constrain loss location.

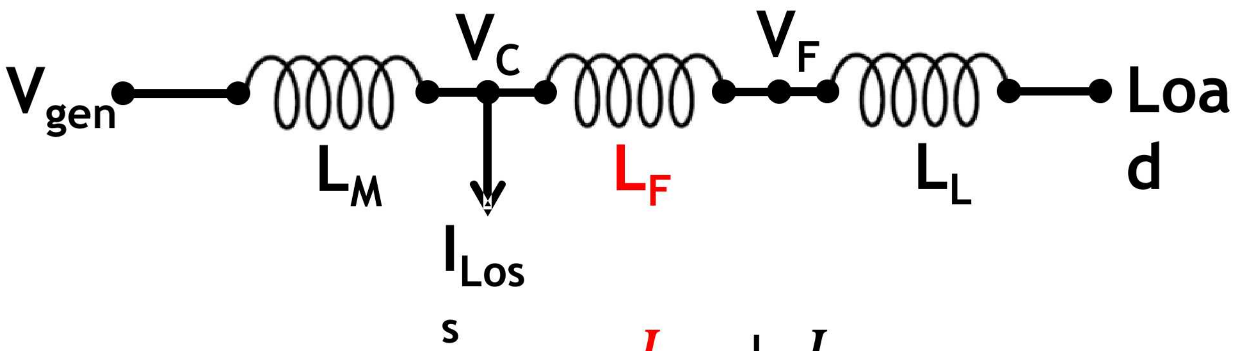
Maglif targets see very high current losses that start early in time. But high initial inductance creating problems in the convolute may not be the route cause. We might instead be shorting across the narrow feed gaps close to the load early in time.



Depending on loss location, reducing feed inductance may help or hurt

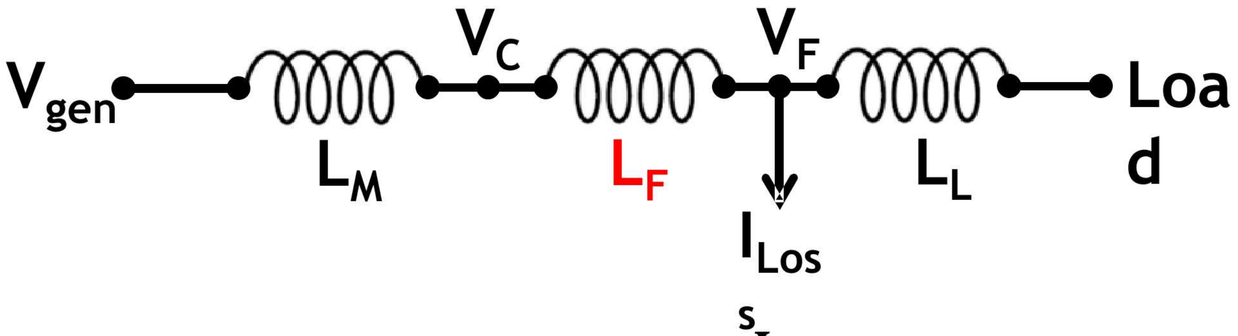


Loss Located in Convolute



$$V_c = V_{gen}\frac{L_F + L_L}{(L_F + L_L + L_{MITL})}$$

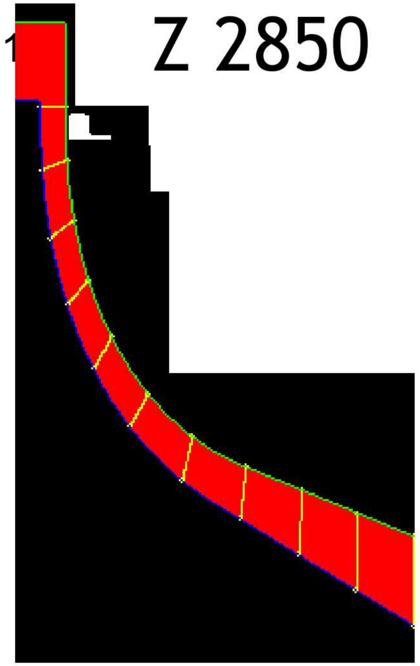
Loss Located in Feed

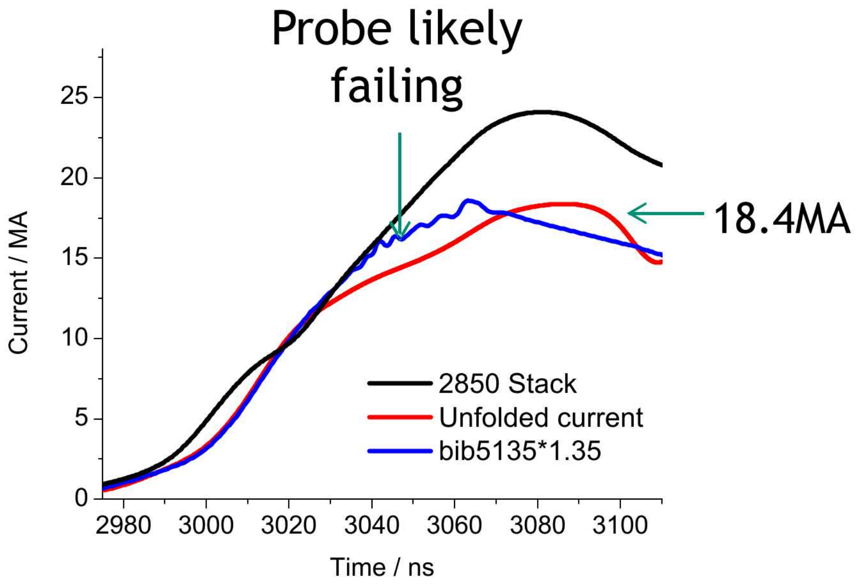


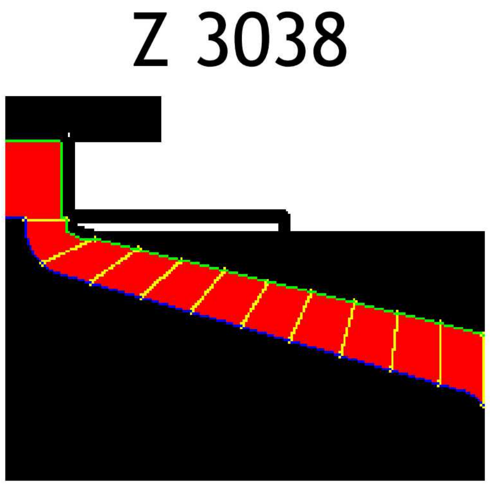
$$V_F = V_{gen}\frac{L_L}{(L_F + L_L + L_{MITL})}$$

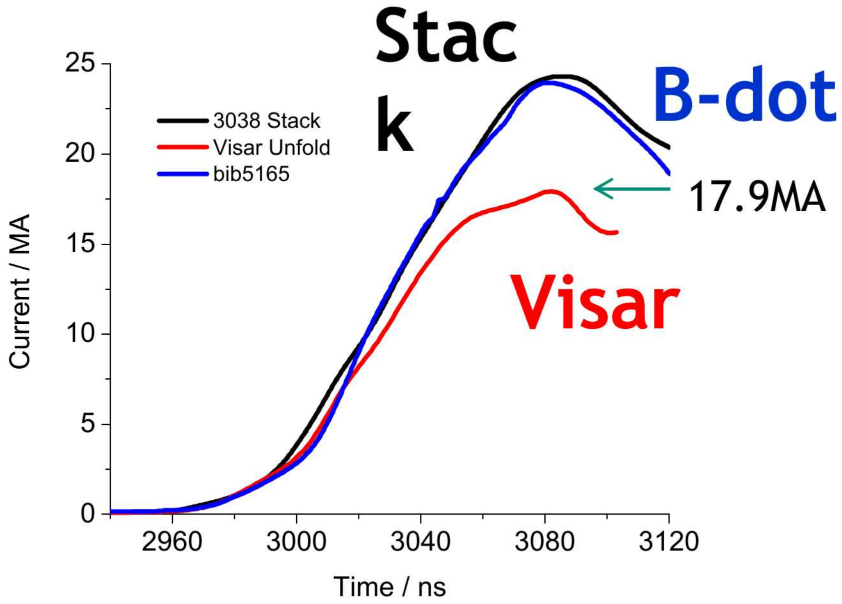
We must ensure higher currents are making it to the load

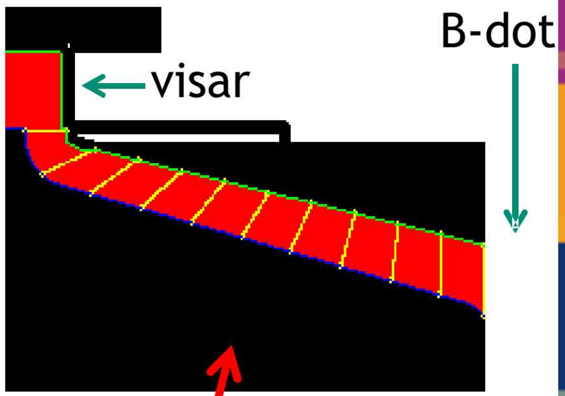
- From convolute b-dot perspective it appears lowering inductance significantly improved current delivery
- From visar perspective less current was delivered to the load

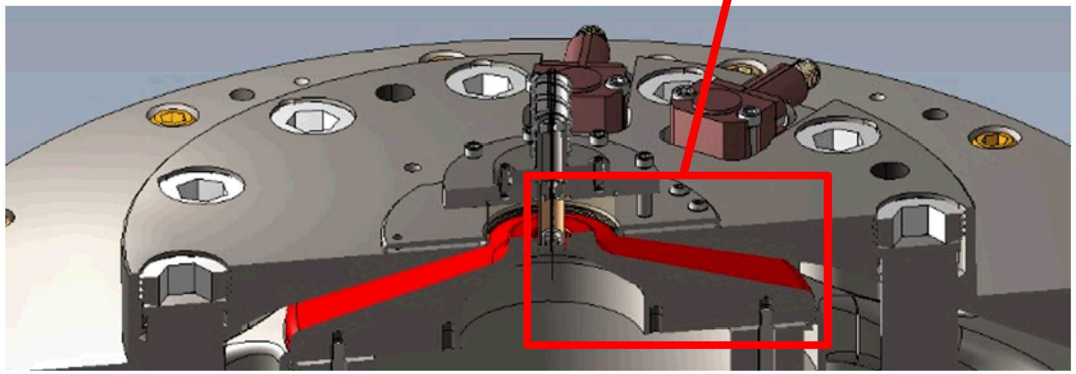








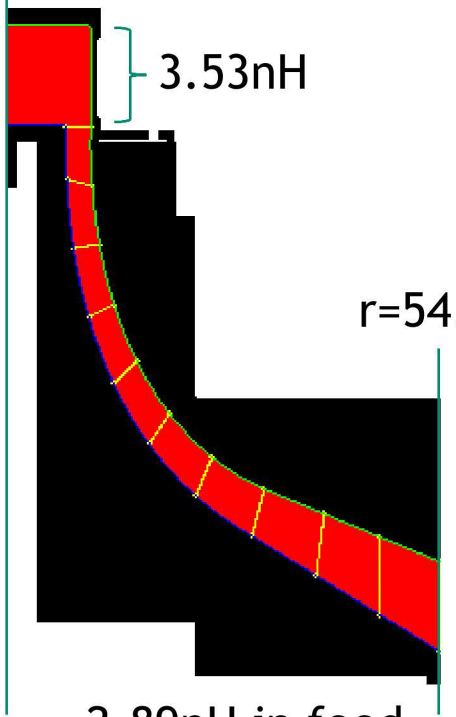




Details of feed geometry are important in determining current coupling to load

Standard Maglif Raised

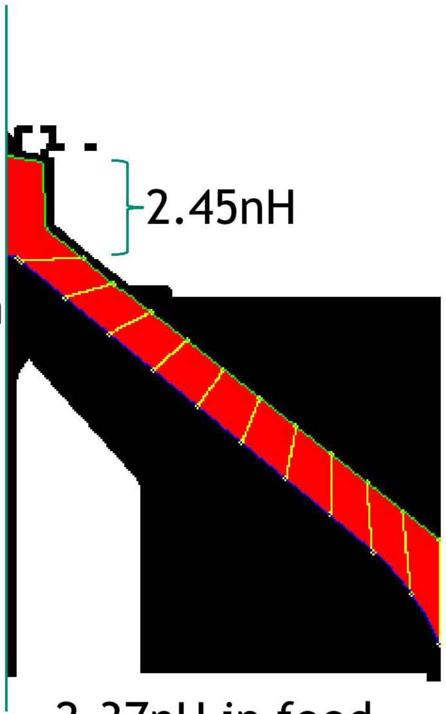
r=3mm



2.89nH in feed elements

Total: 6.42

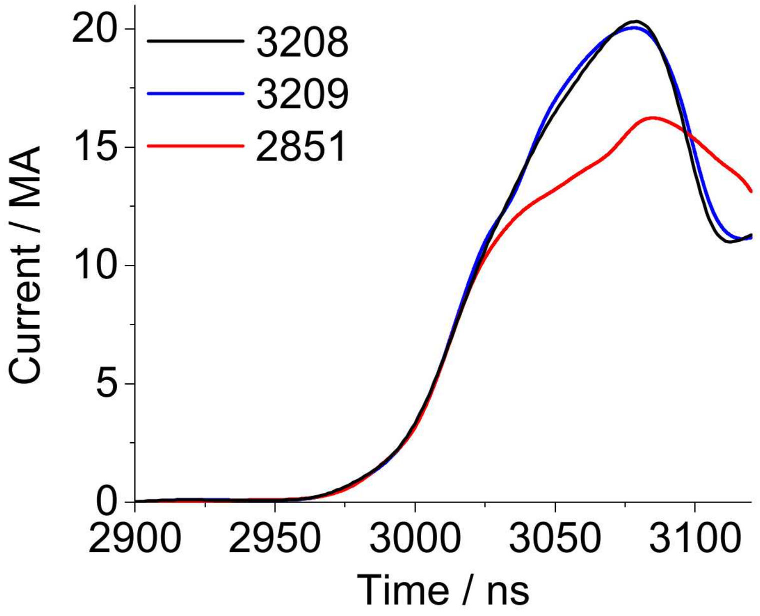
Maglif Integration 18a



2.37nH in feed elements

Total: 4.82nH

Feed reconfigured and charge increased from 80 to 85kV



Standard hardware from 2707 drawing

Electrical energy coupled to Maglif liners is dominated by late time (post peak) energy coupling

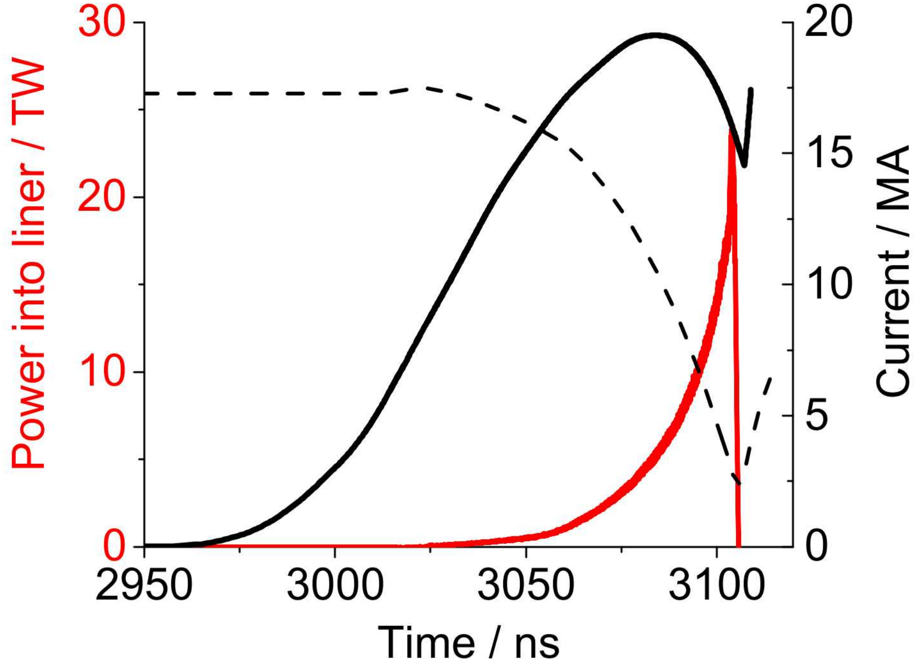
Energy delivered

$$\int IV\,dt = \frac{1}{2}LI^2 + \int I^2 \frac{dL}{dt}dt$$

Electrical Energy Delivered | Magnetic Energy | Work done on the liner

Rate at which work is done on the liner depends on L-dot

$$I^2 \frac{dL}{dt} = -I^2 \frac{l\mu_0}{2\pi}\frac{v}{r}$$



To more directly quantify energy coupling we cannot rely just on peak currents.
Assessment of rate of current drop, or voltage assessment at the load location would be valuable.

Conclusion

- Current measurements on Z are challenging (as are power energy measurements)
- Current coupling can be improved through choice of initial load inductance.
- Electrode plasmas can enhance losses (their properties need to be better understood)
- Inner electrode geometry is important (limits reduction of inductance)