Meeting of the JOWOG 32mat
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SAND2010-1617P

Update on Multi-Megabar Ramp Compression at Z

Jean-Paul Davis

with Marcus D. Knudson, Ray W. Lemke, and others

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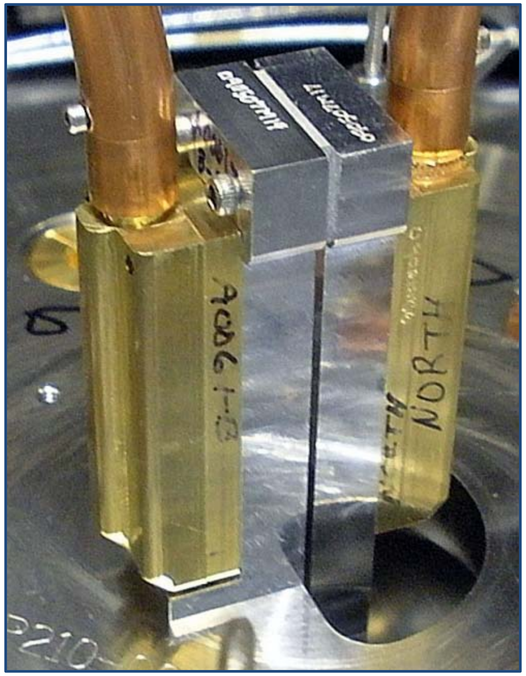

National Nuclear Security Administration

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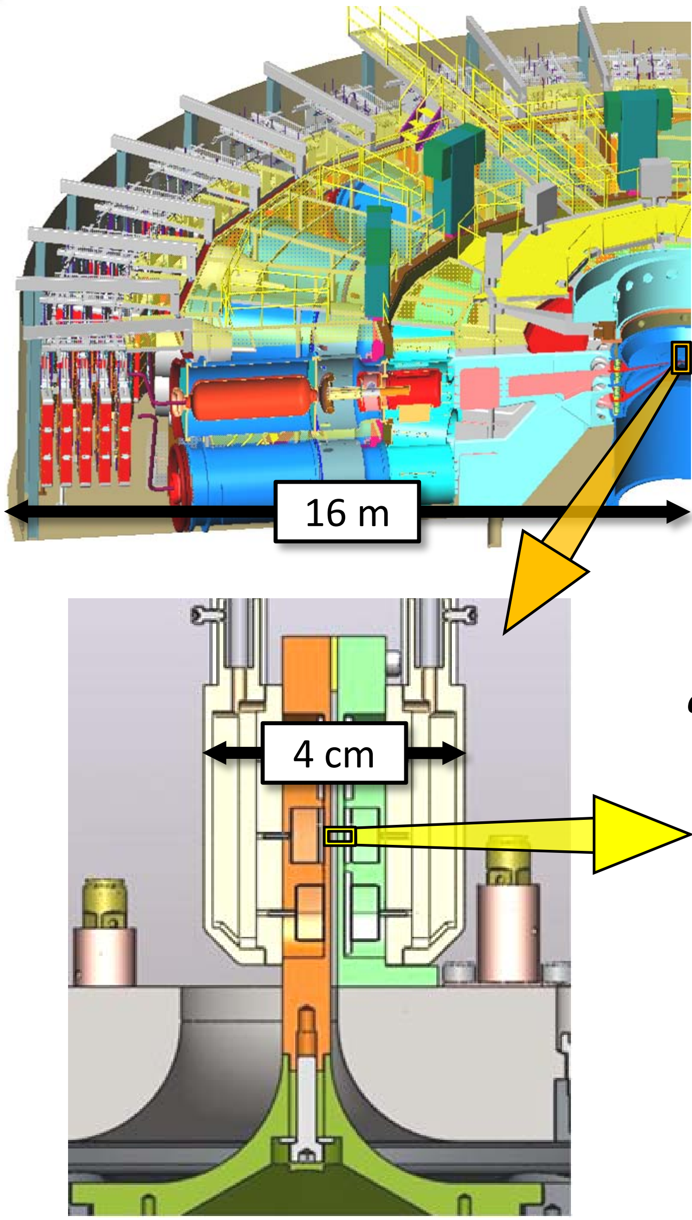
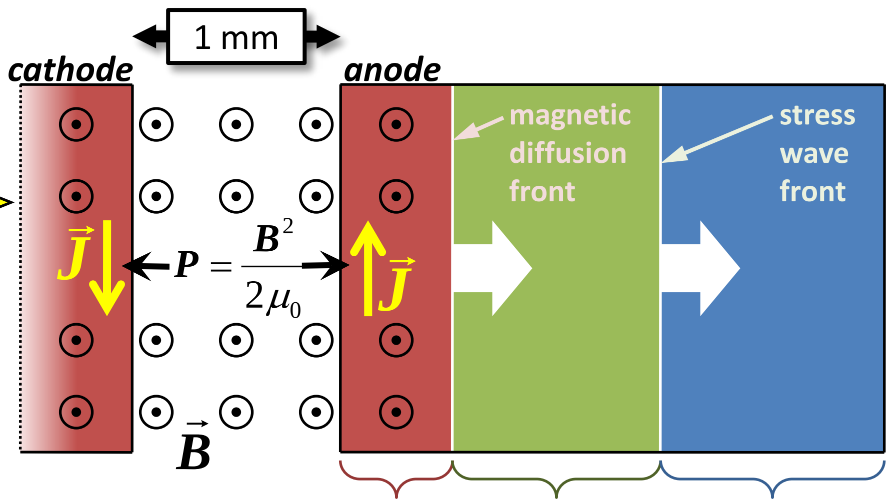
Refurbished Z machine & stripline load enable accurate ramp-compression experiments to > 300 GPa



- current pulse of up to 26 MA delivered to parallel flat-plate electrodes shorted at one end
- magnetic (***J*** x ***B***) force induces ramped stress wave in electrode material
- stress wave propagates into ambient material, de-coupled from magnetic drive
- controllable pulse shape, rise time 100-700 ns
- identical magnetic loading of sample pairs



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OUTLINE

1. Stripline load development (6 slides)

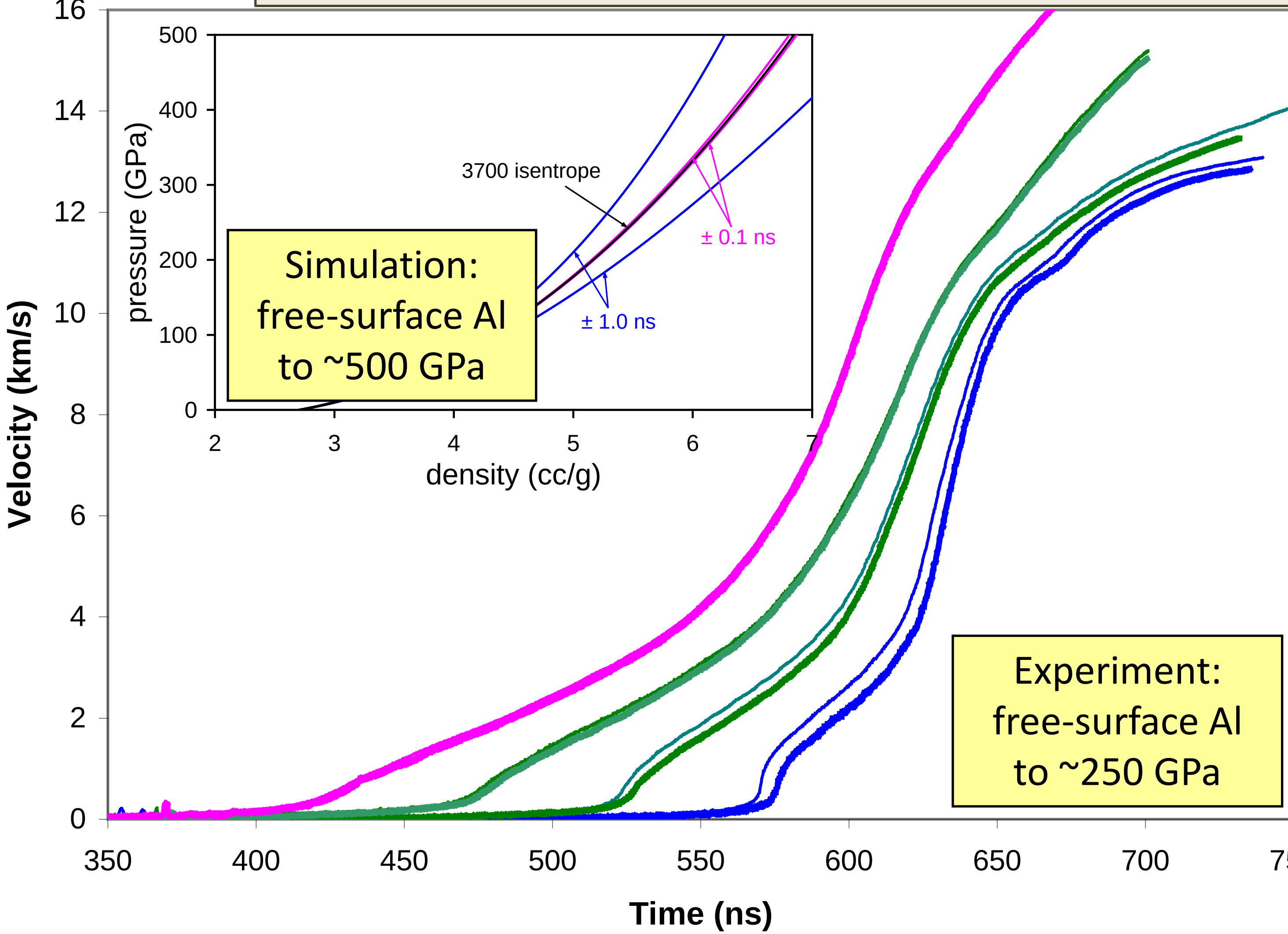
2. Pulse shaping (2 slides)

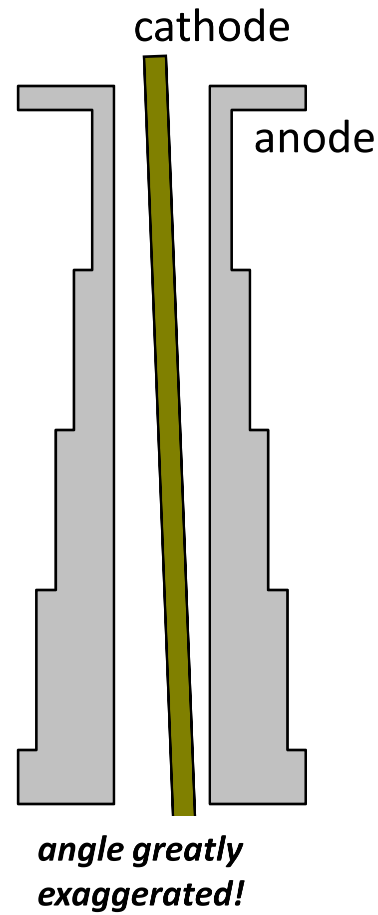
3. Data analysis (4 slides)

4. Preliminary results on tantalum (2 slides)

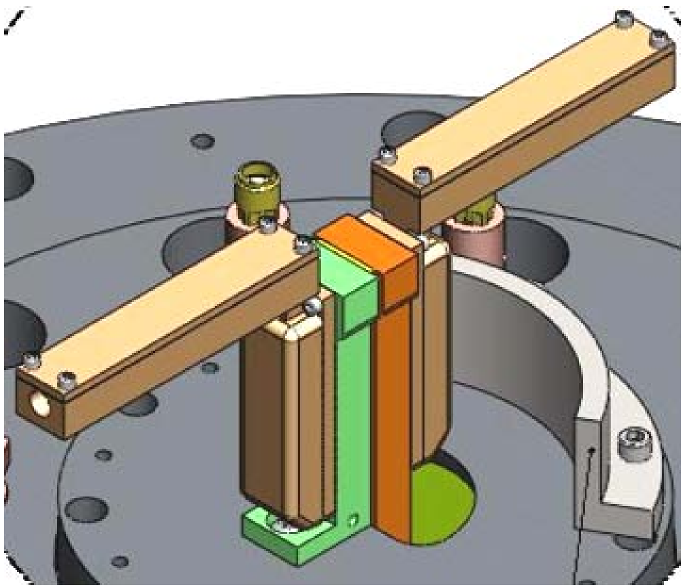
Small misalignments of coaxial anode/cathode geometry can cause significant apparent time shifts

Standard ramp-compression load design on pre-refurbished Z
- samples on separate anodes, two coupled A/K gaps
- 1% uncertainty in stress requires electrodes parallel to < 5 µm across 25 mm

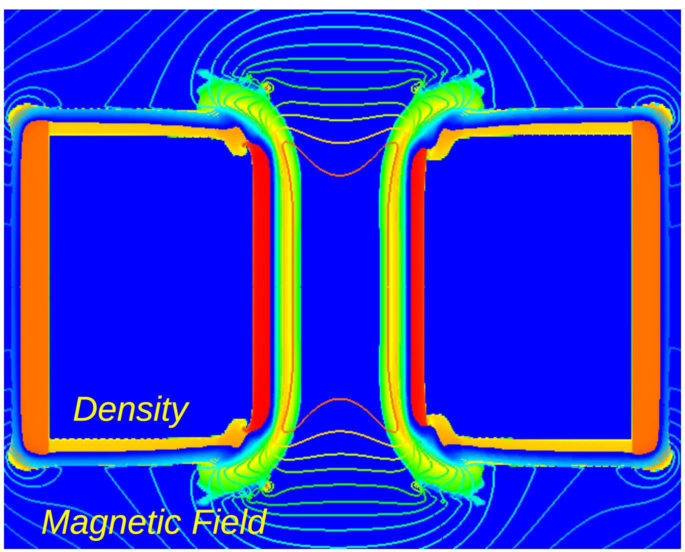




New stripline geometry offers several advantages

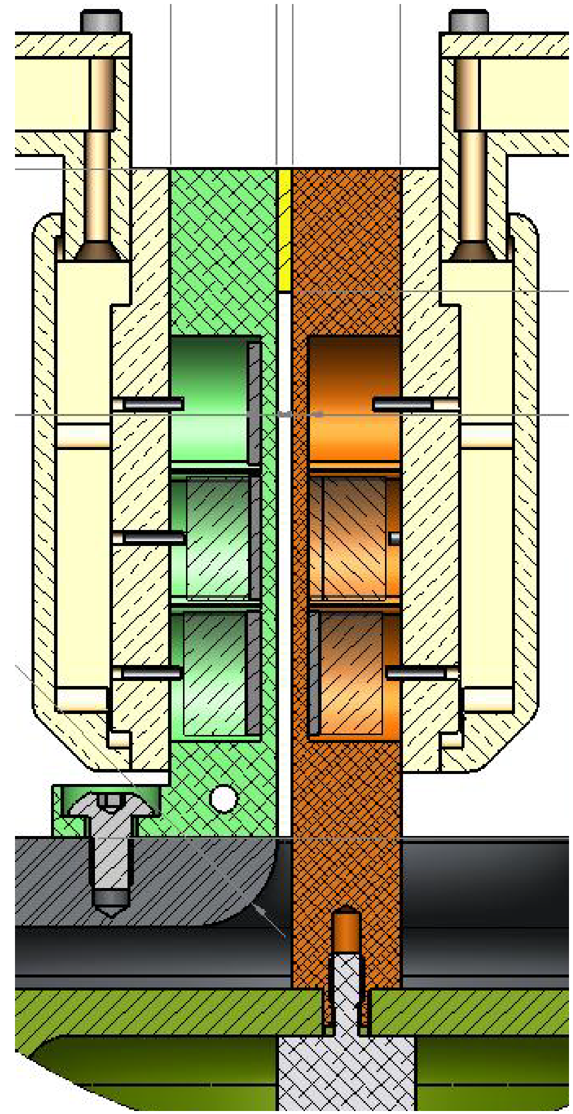


- insensitive to vertical angular misalignment
- single B-field waveform drives two samples
- higher magnetic pressure for given current
- larger lateral extent of uniform 1-D flow

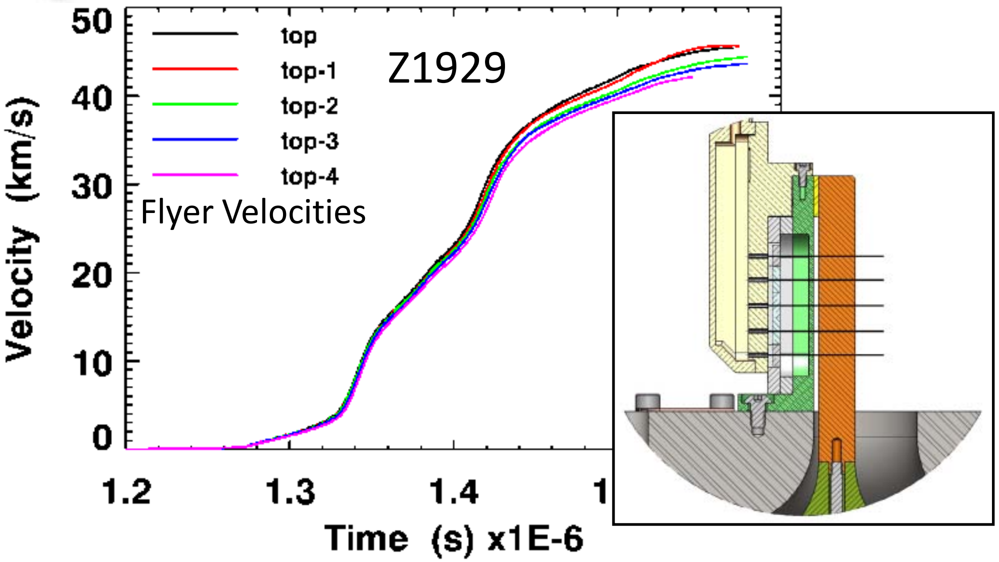


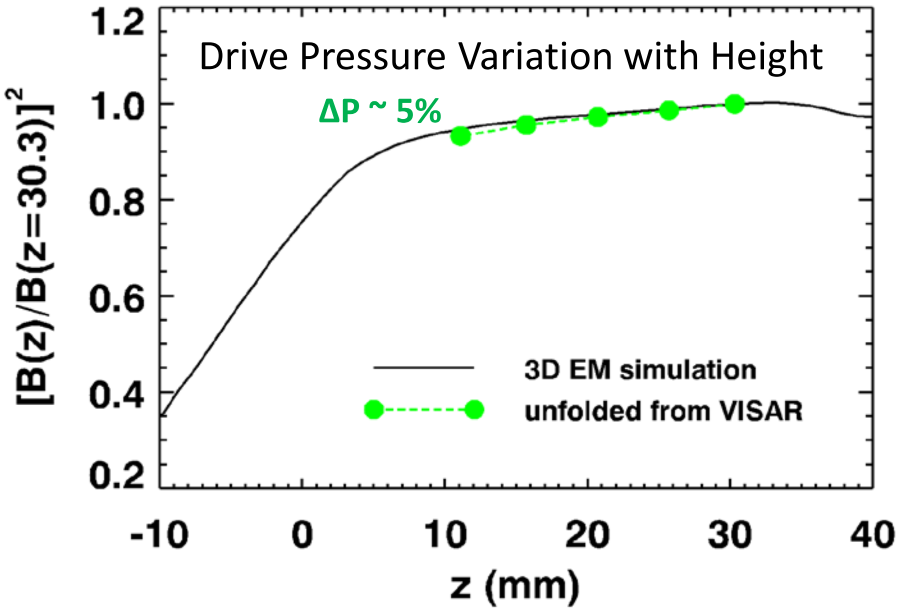
Unconfined B-field:

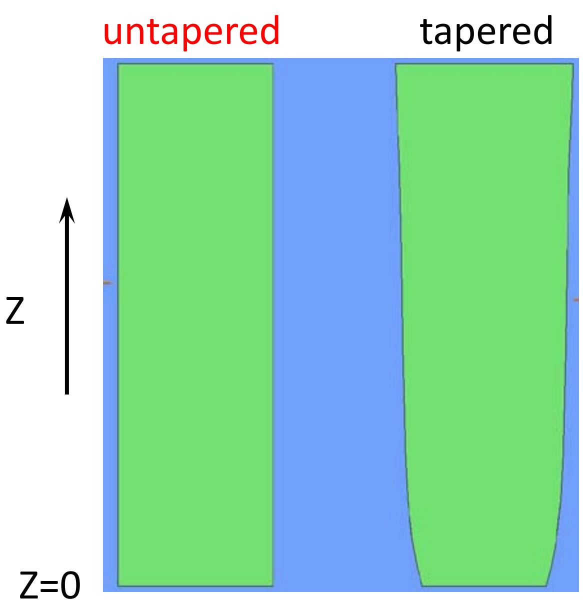
- vertically non-uniform distribution of current inside/outside the gap
- shielding of diagnostics and samples

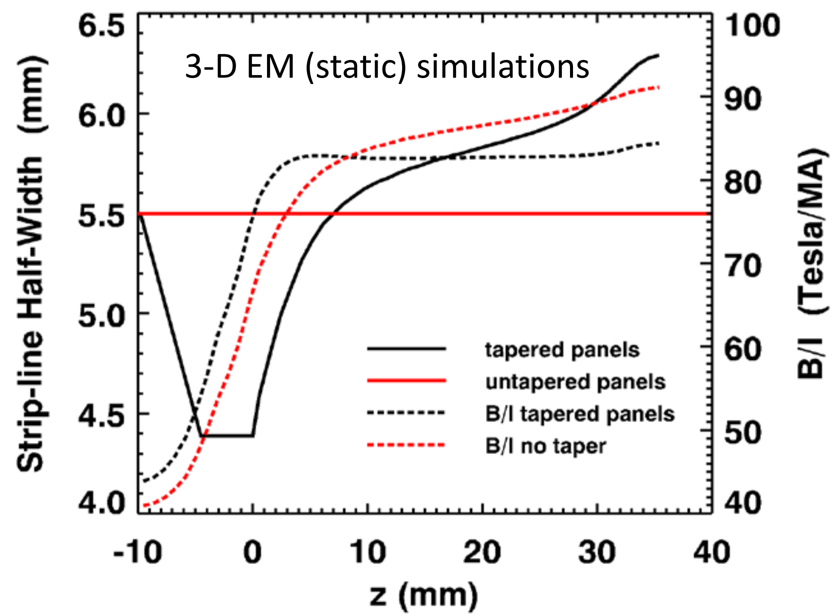


Measurement of vertical non-uniformity of B-field shows need for functional tapering of stripline width

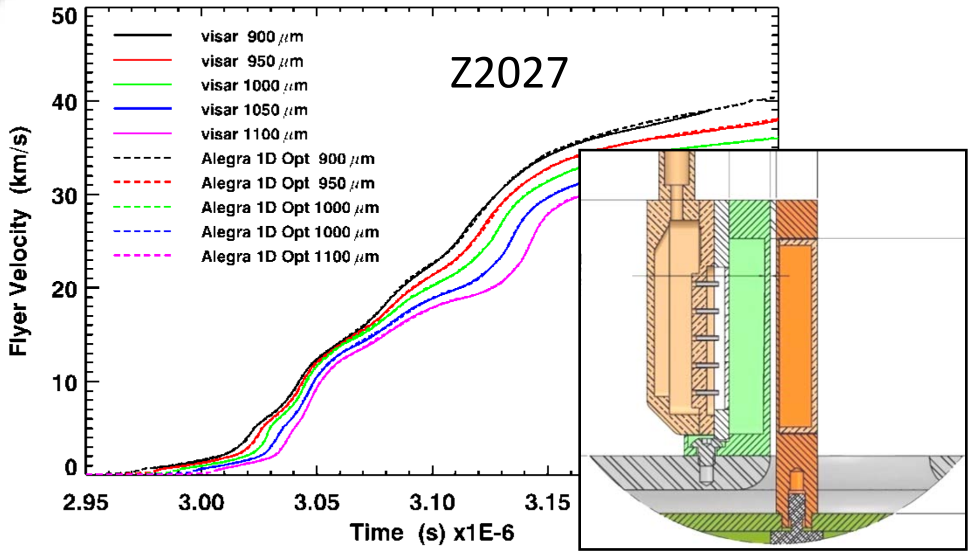


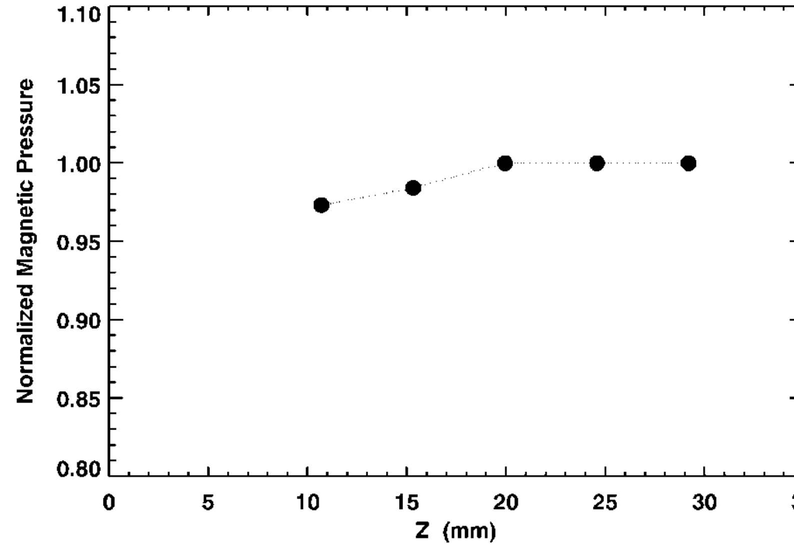


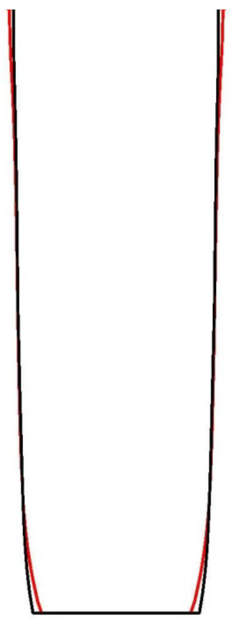




Semi-empirical functional tapering of stripline width should eliminate vertical non-uniformity of B-field

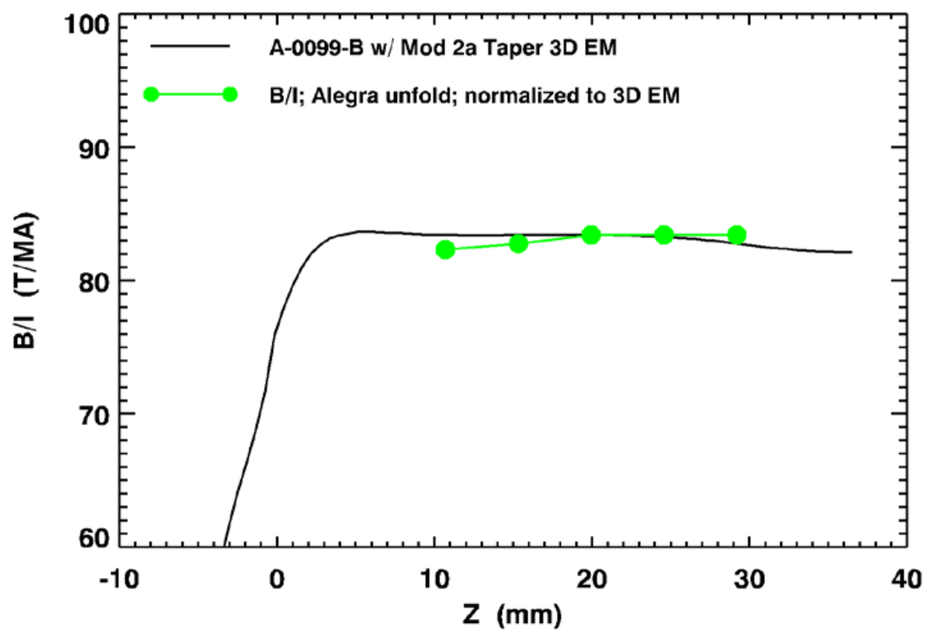






old taper (Z2027)

modified taper (future shots)



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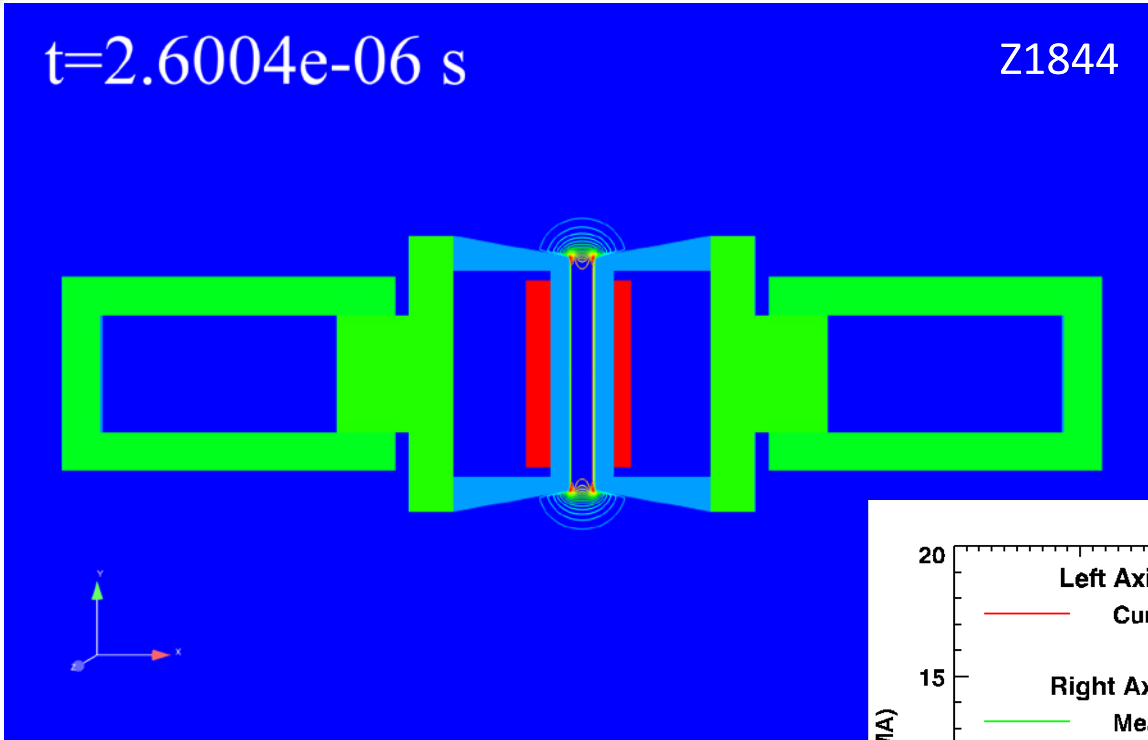
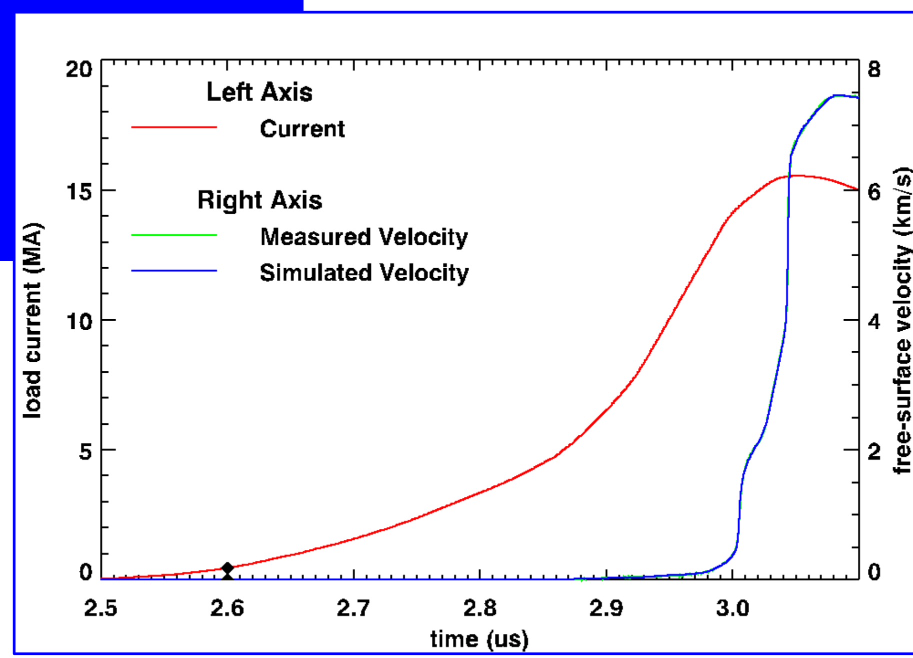
Simulations predict highly uniform B-field in the lateral and normal directions over most of the gap



Magnetic Field (line contours)
Density (filled contours)

2-D Alegra-MHD:
- Resistive MHD
- QMD/LMD conductivity
- Sesame EOS
- Circuit model



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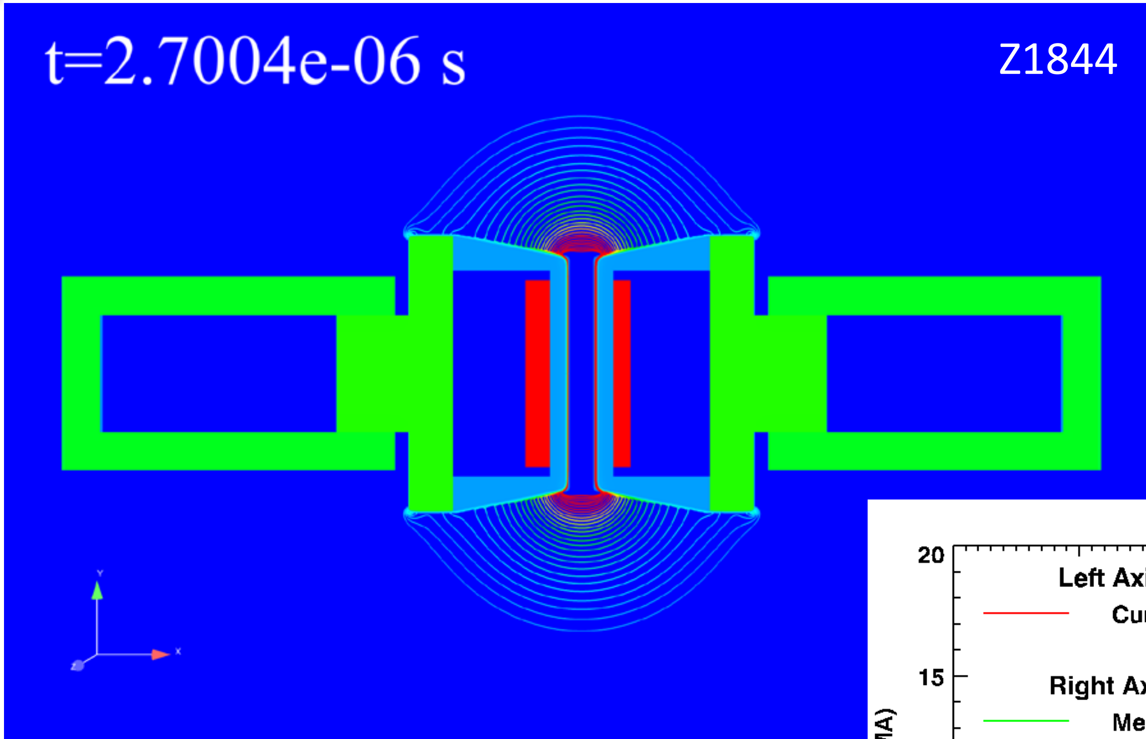

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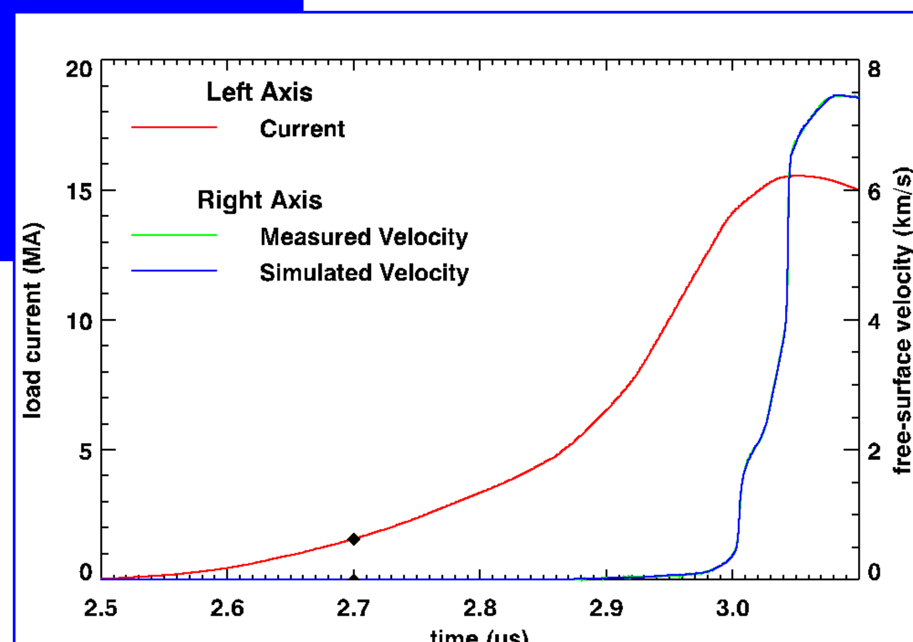

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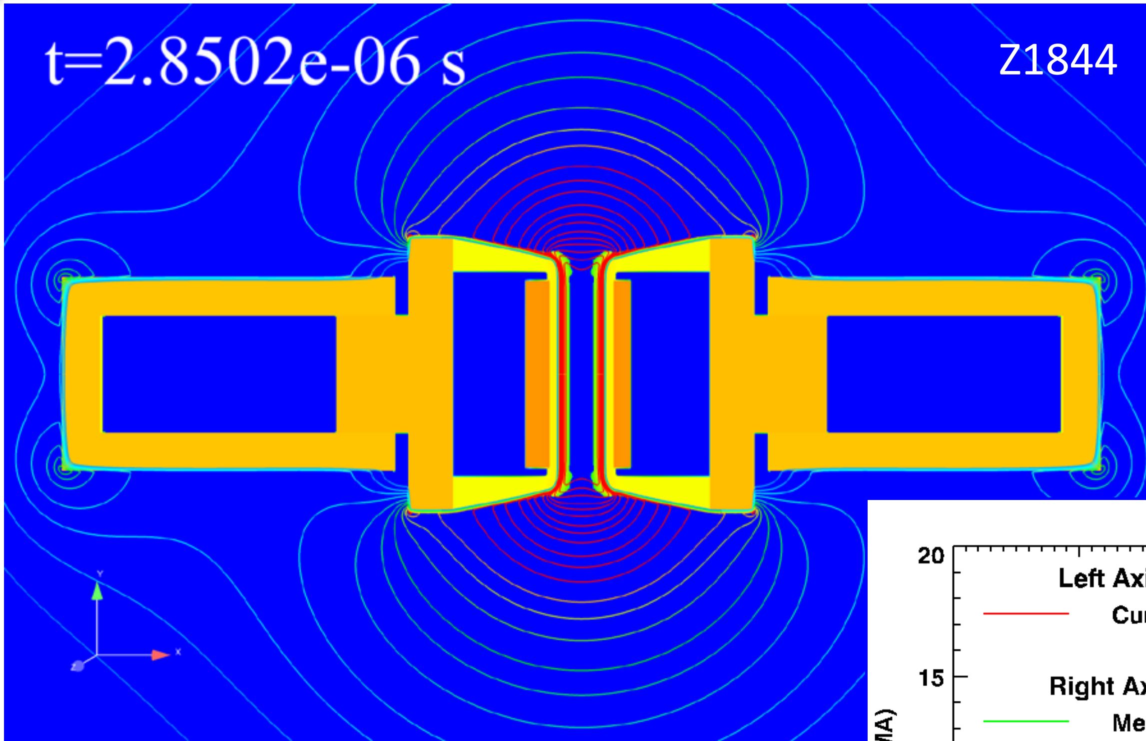

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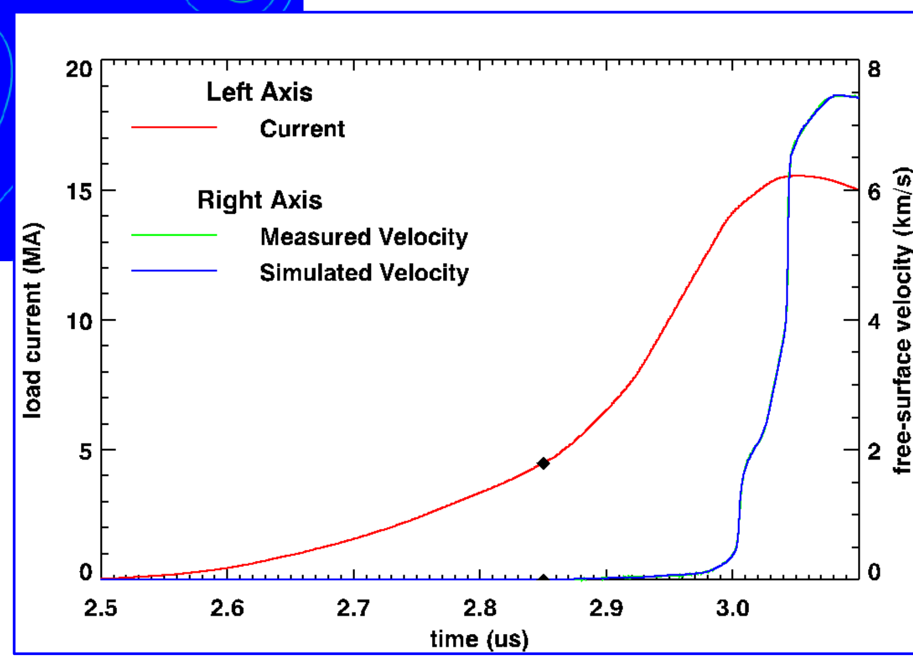

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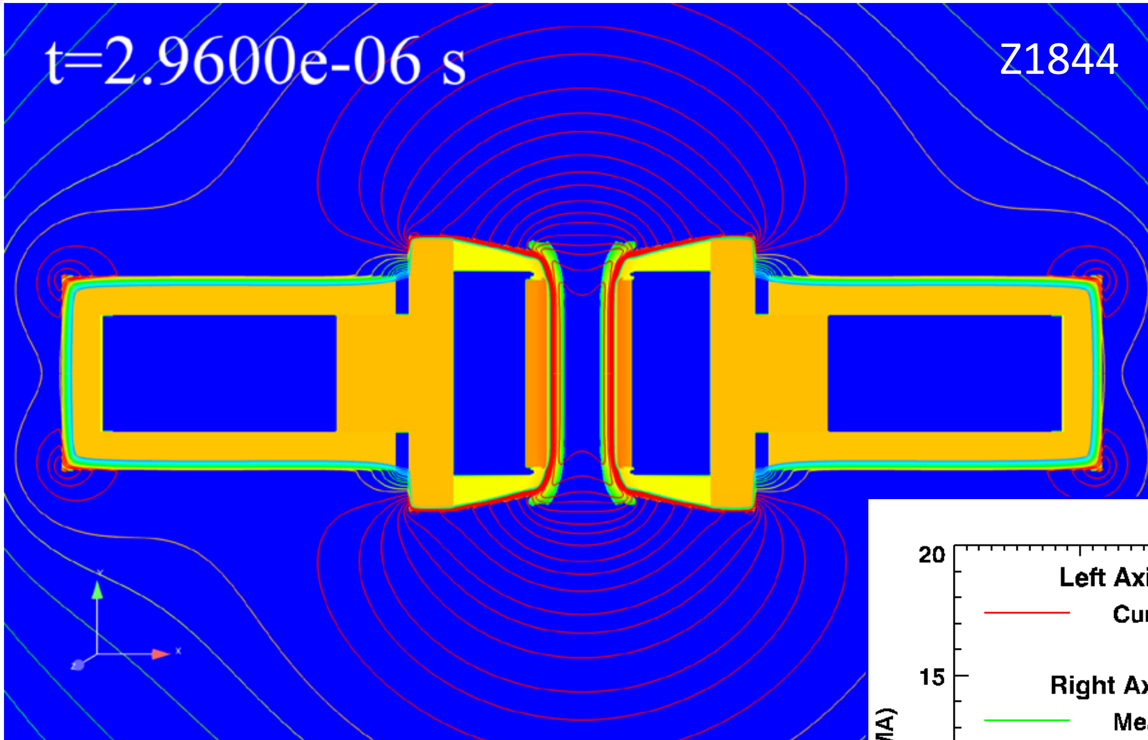

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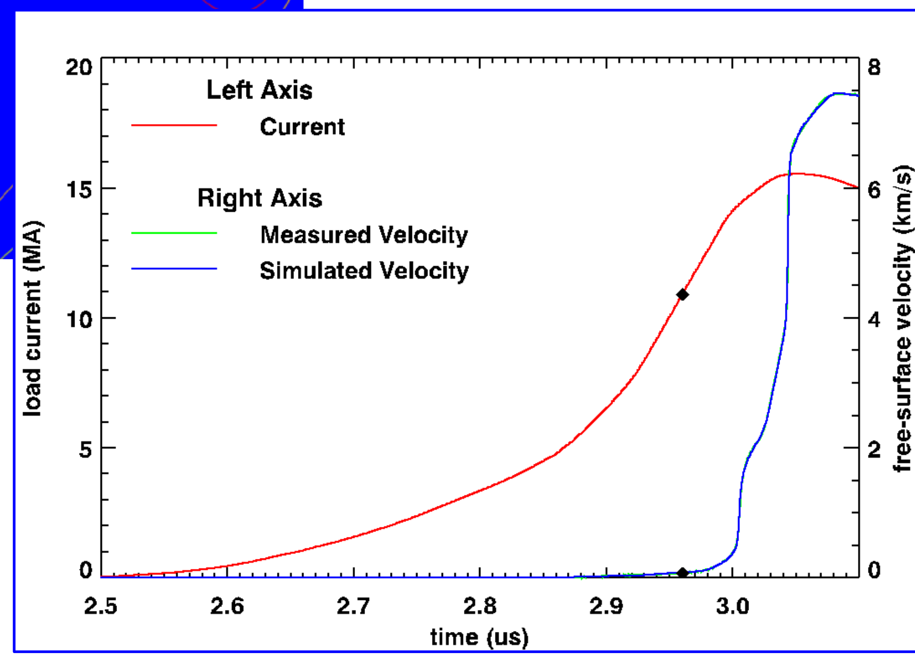

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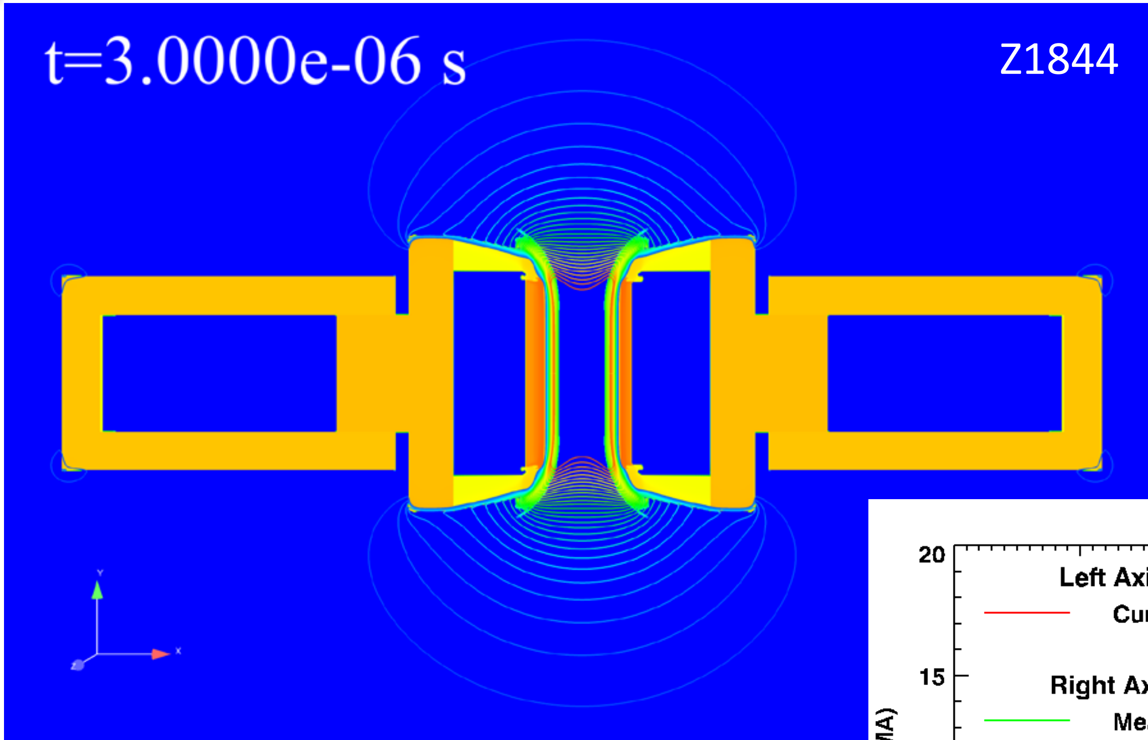

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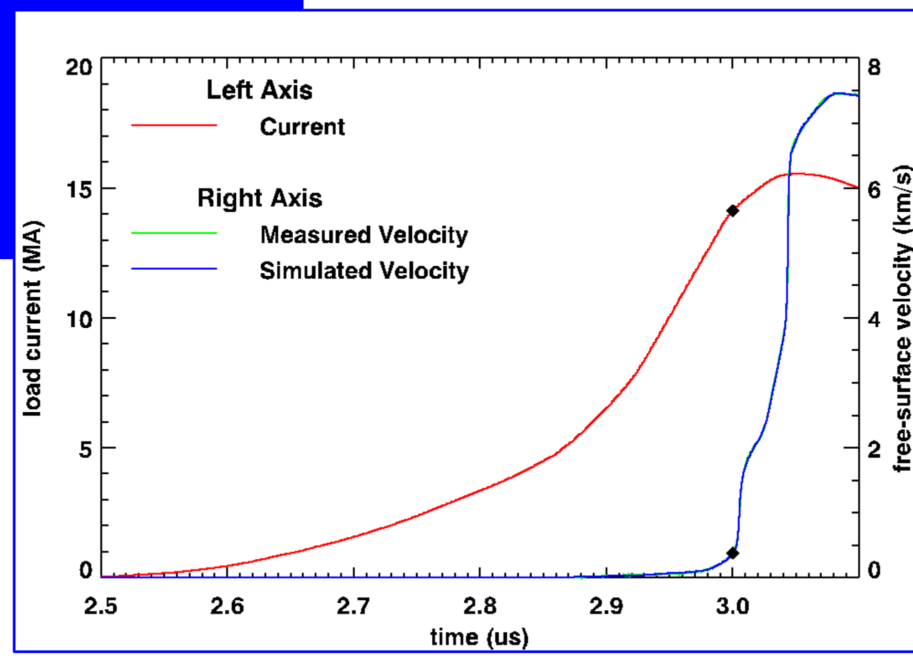

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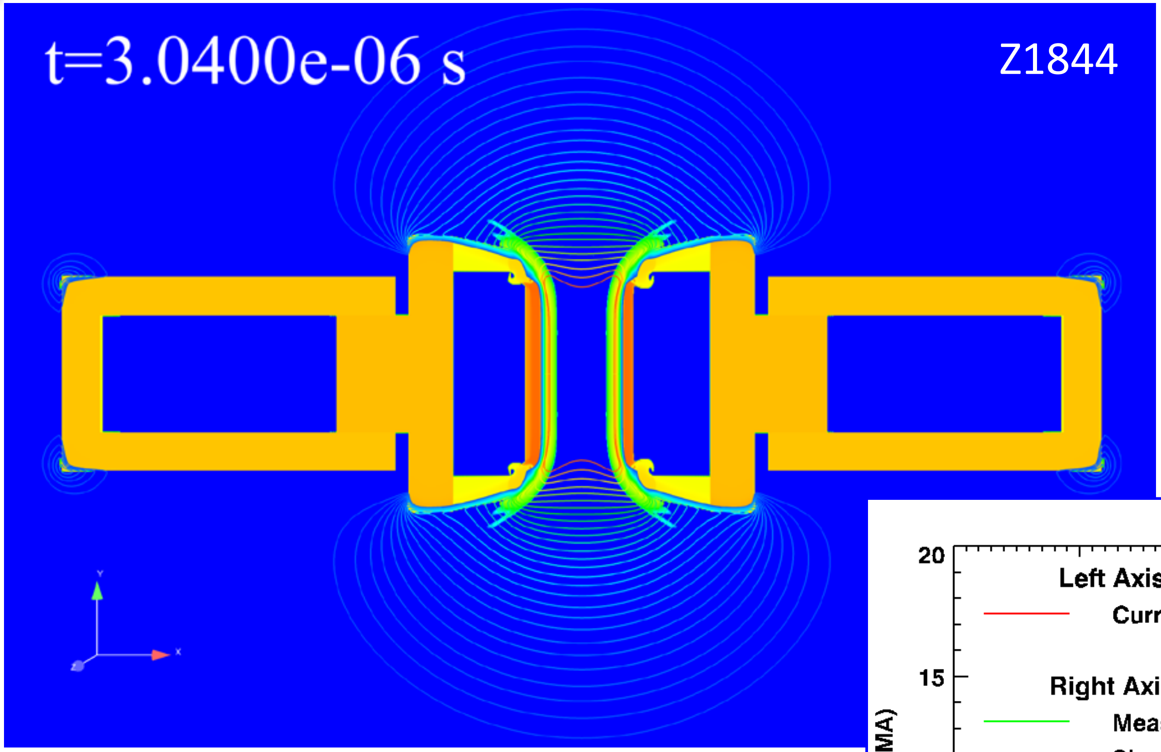

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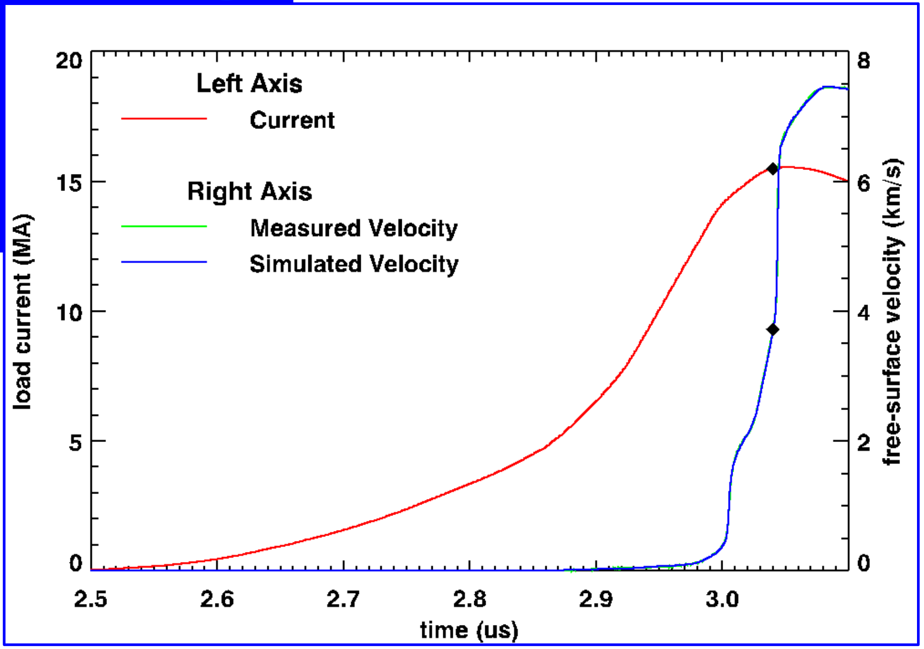

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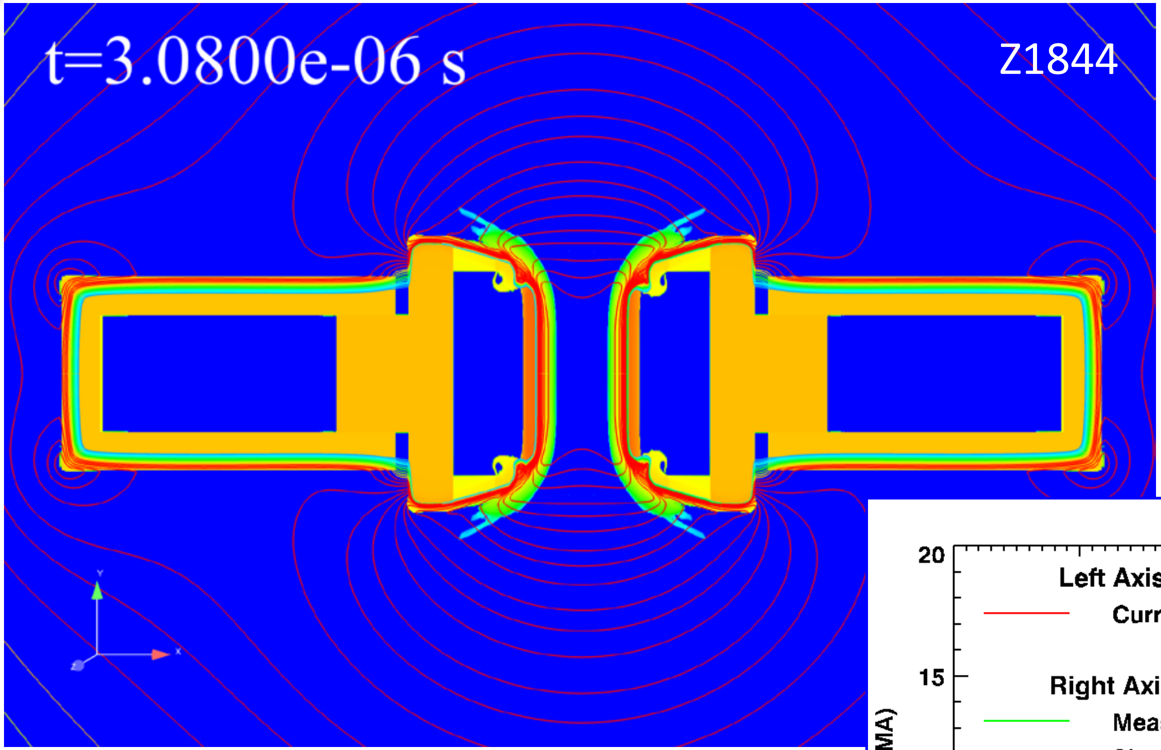

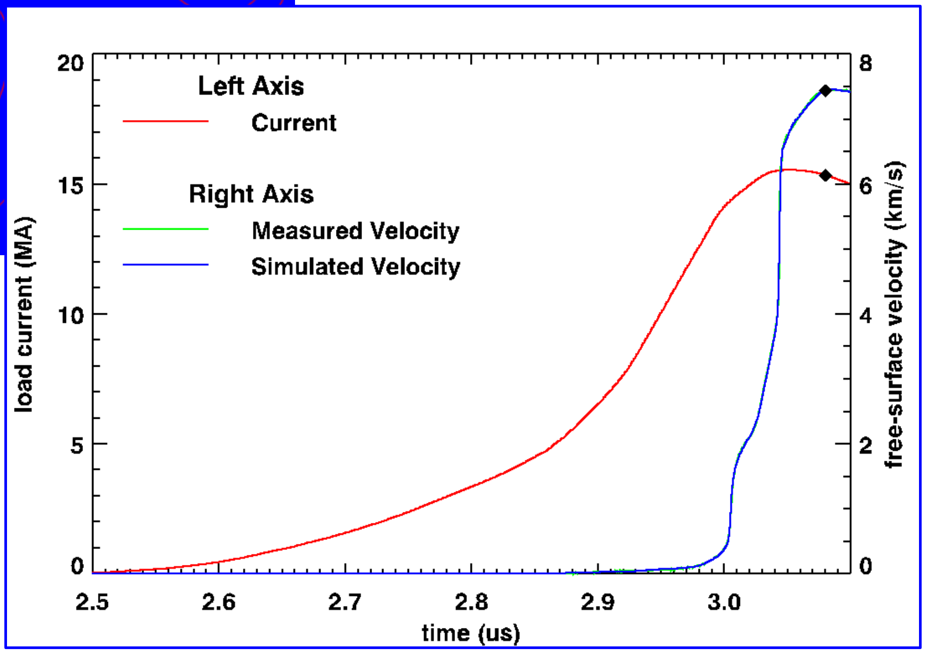

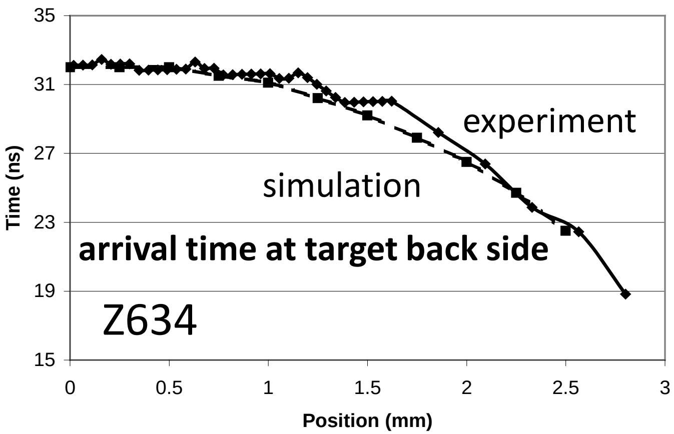

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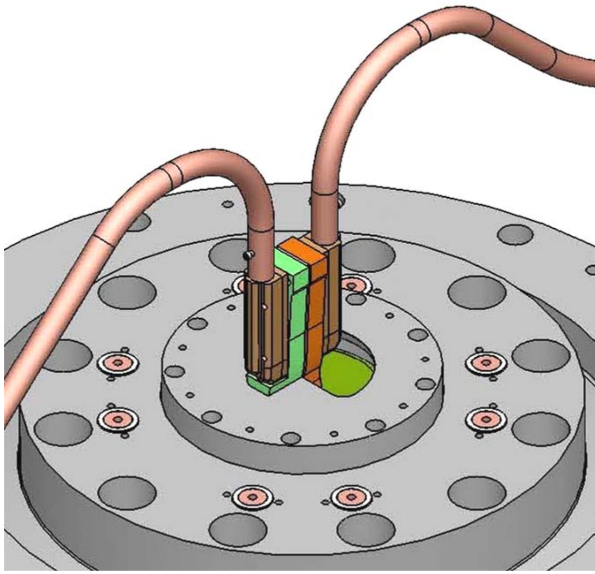
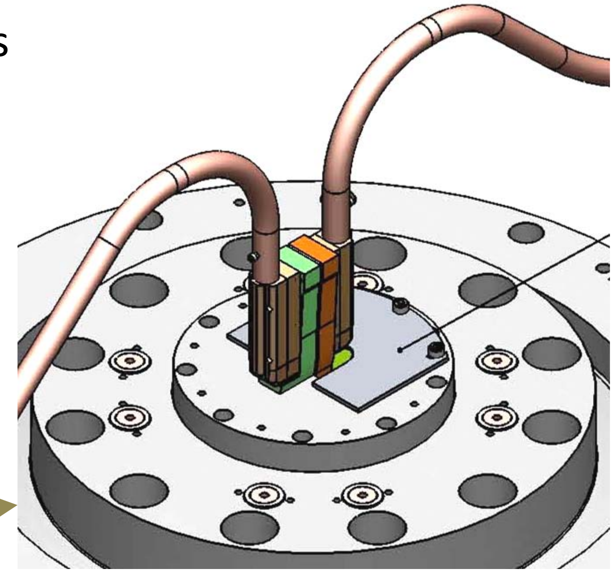
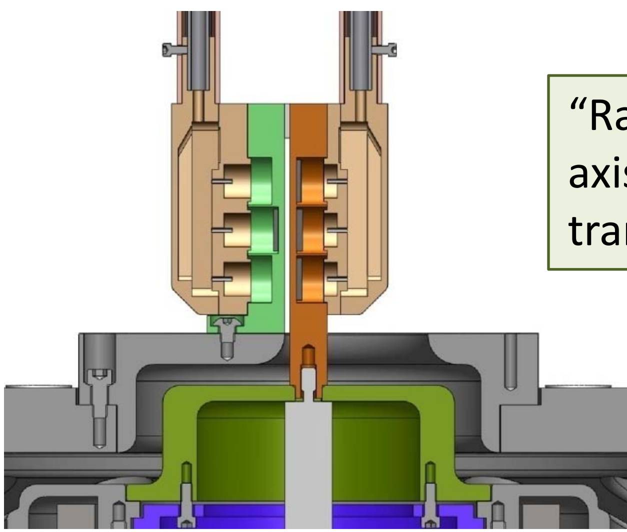
VISAR fiber darkening issues have been addressed



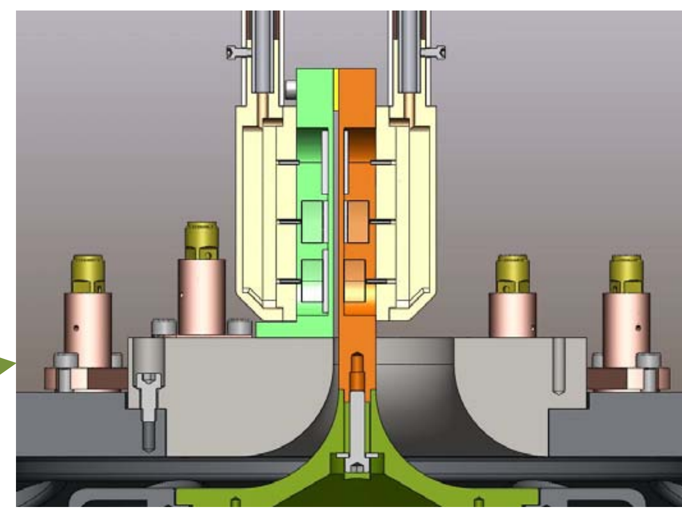
X-rays generated at corners inside inner-MITL feed?

“D-hole” anode opening decreased to 4-mm minimum A-K distance

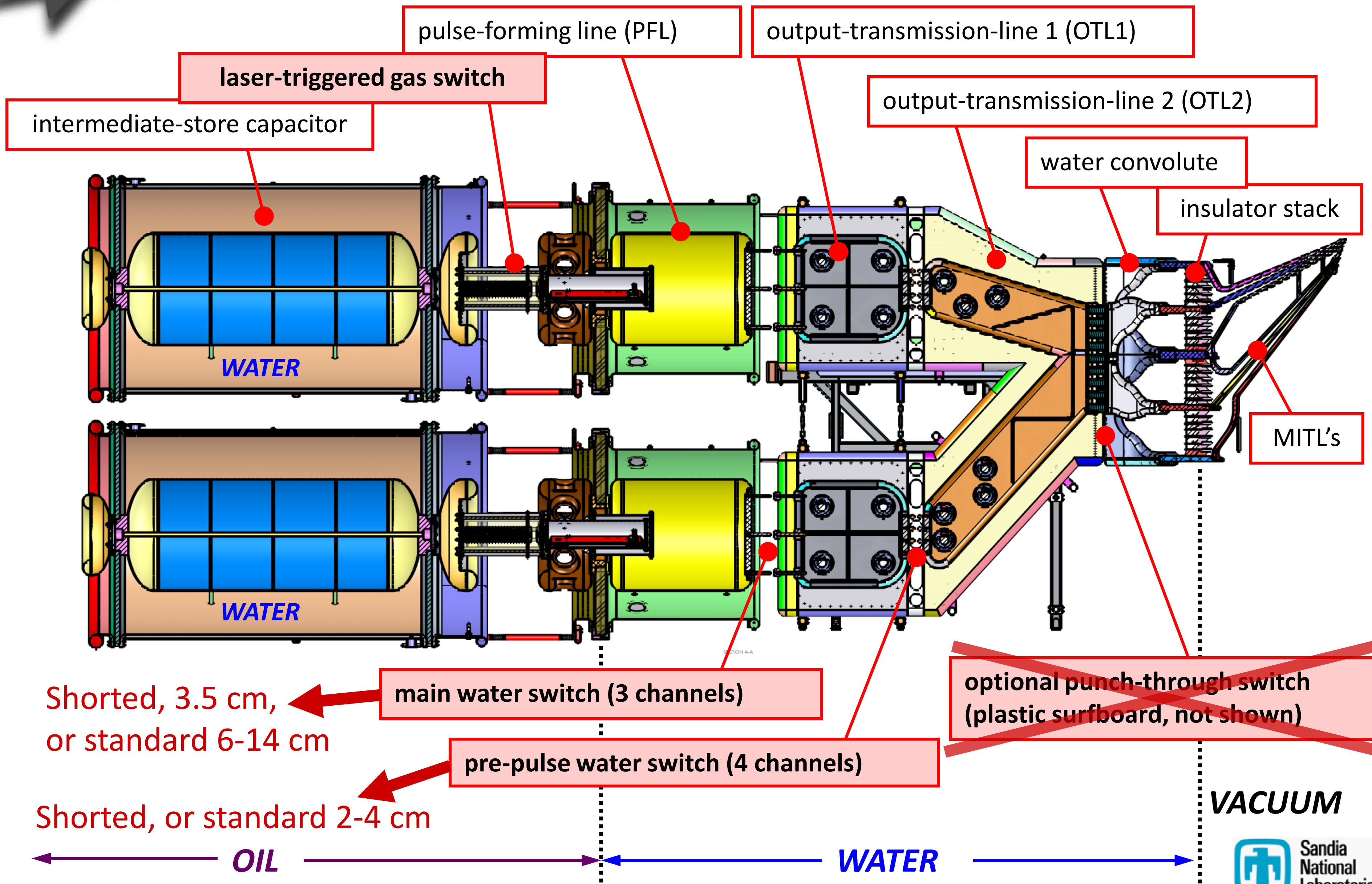




“Radial” feed for axisymmetric-to-stripline transition



Shaped pulses are obtained by staggering gas-switch times and modifying water switches



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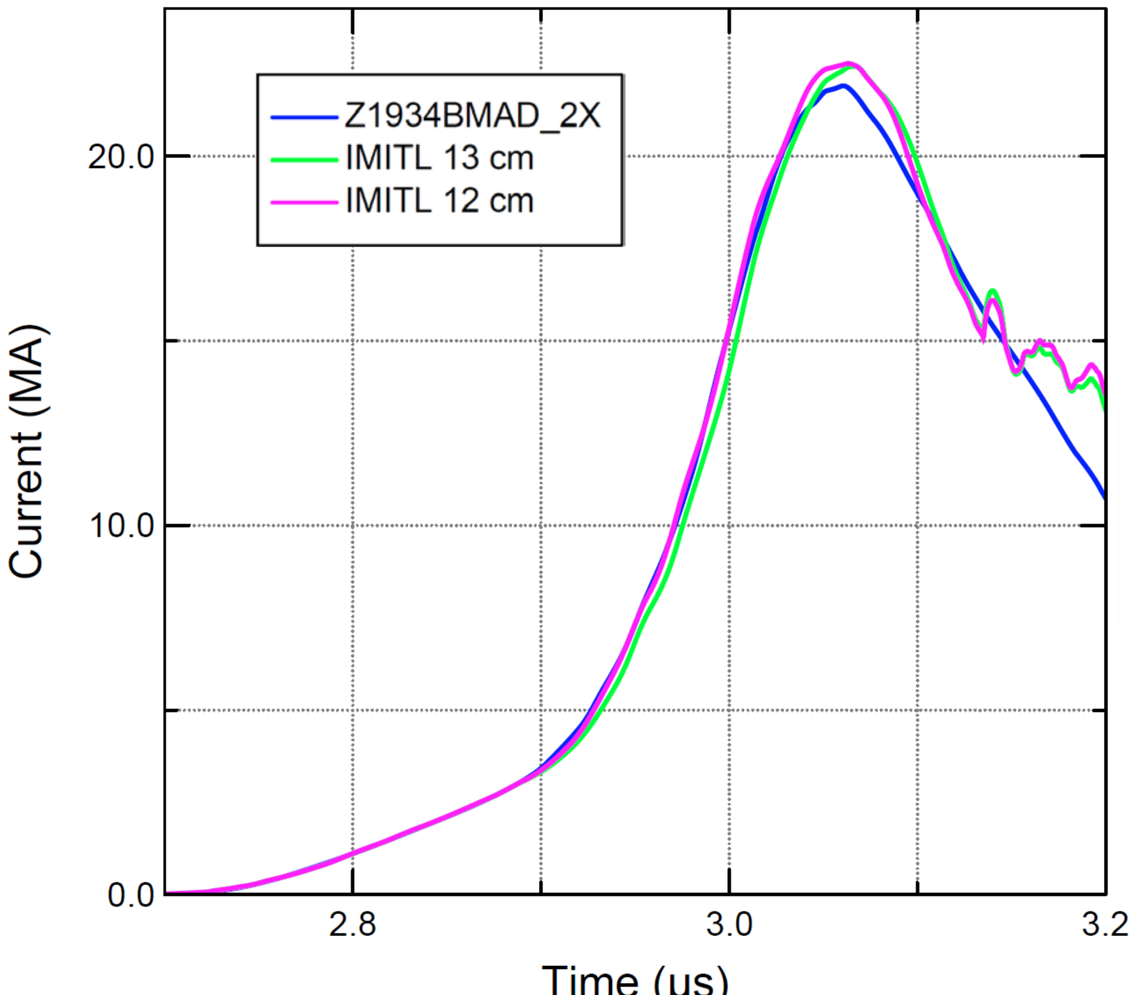
Recent improvements to the Bertha circuit model of Z have increased accuracy of predictions

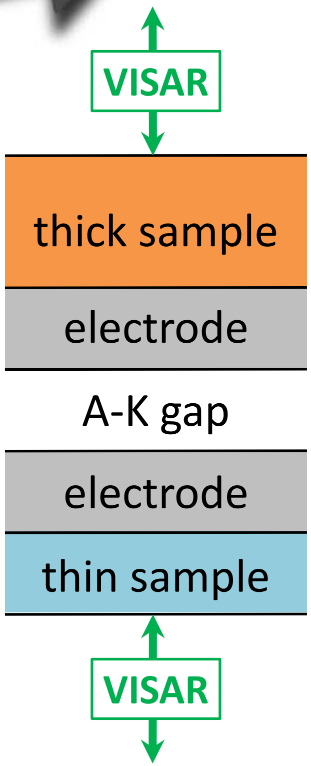
Recovers effect of 1-cm change in main water-switch gaps of 30 short-pulse lines!

85-kV standard = 13cm gap
Z1934 at 12cm instead
(standard for 80-KV on Z1933)



- working with L-3 Communications on final version of model
- calibrate pulse-forming section against flat-MITL shots
- will include 2-D transmission-line sections (OTL2, stack and outer MITLs)

Inverse Lagrangian analysis of velocity from two samples gives quasi-isentropic stress-density response



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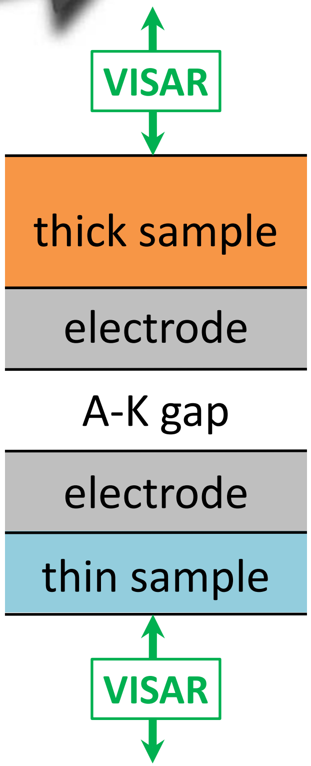


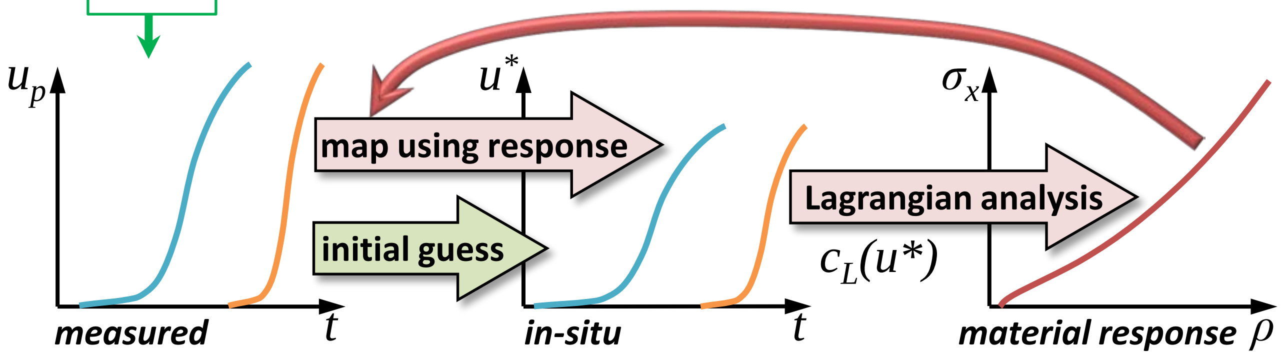
1. measure velocity at back faces of two different-thickness samples

2. make initial guess of in-situ $u^*(t)$ at each measurement location

3. determine material response by Lagrangian analysis of in-situ $u^*(t)$

4. use material response to map measured $u_p(t)$ to in-situ $u^*(t)$

5. repeat steps 3-4 until material response converges



- assumes isentropic, simple-wave behavior
- **valid ONLY while electrode/sample interface states identical**

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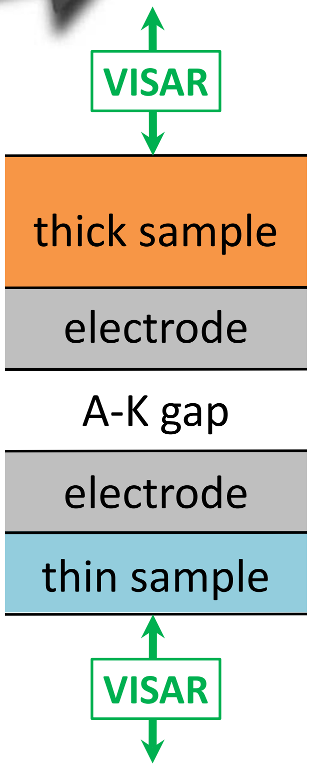

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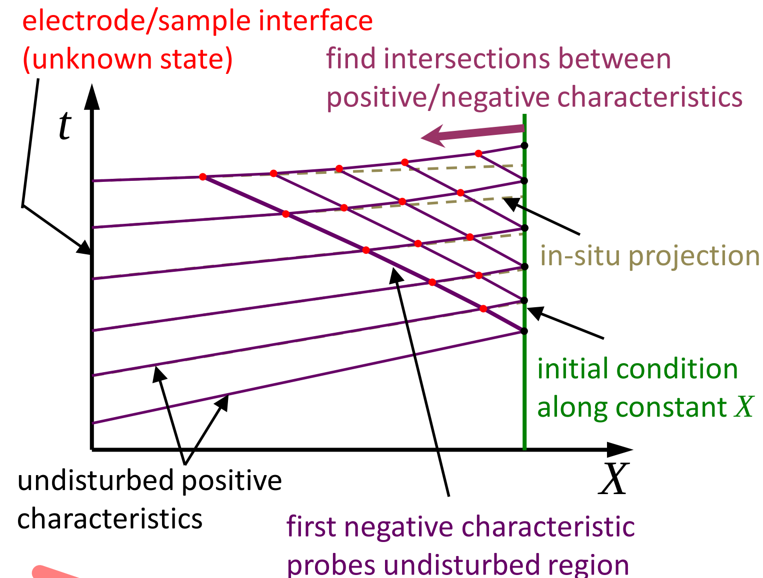
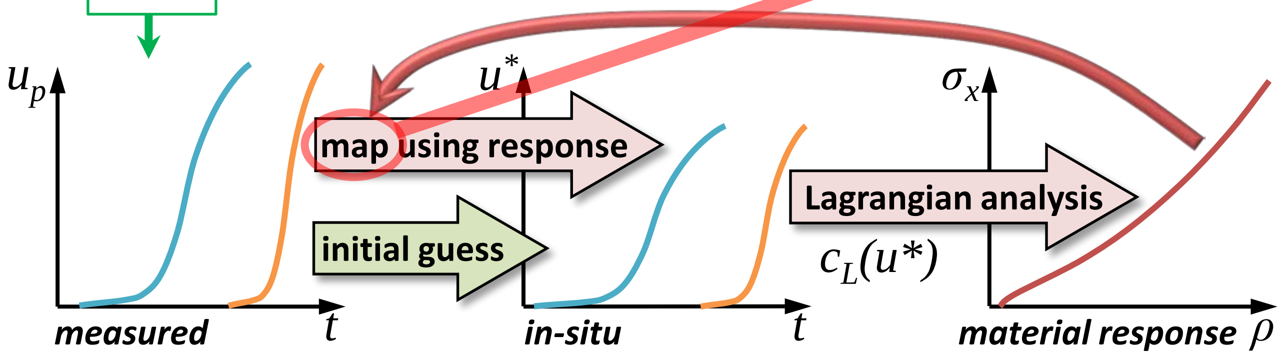


- use Riemann invariants to solve intersections between
  1. negative characteristics projected forward in time
  2. positive characteristics projected backward in time
- project points on 1st negative characteristic forward to measurement position



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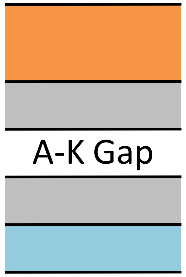
Two-sample approach is limited in accuracy and maximum stress by pulse shape and reverberation

- uncertainty in $c_L = \Delta X / \Delta t$ depends on relative uncertainty in thickness difference
  - must maximize difference in thickness between samples



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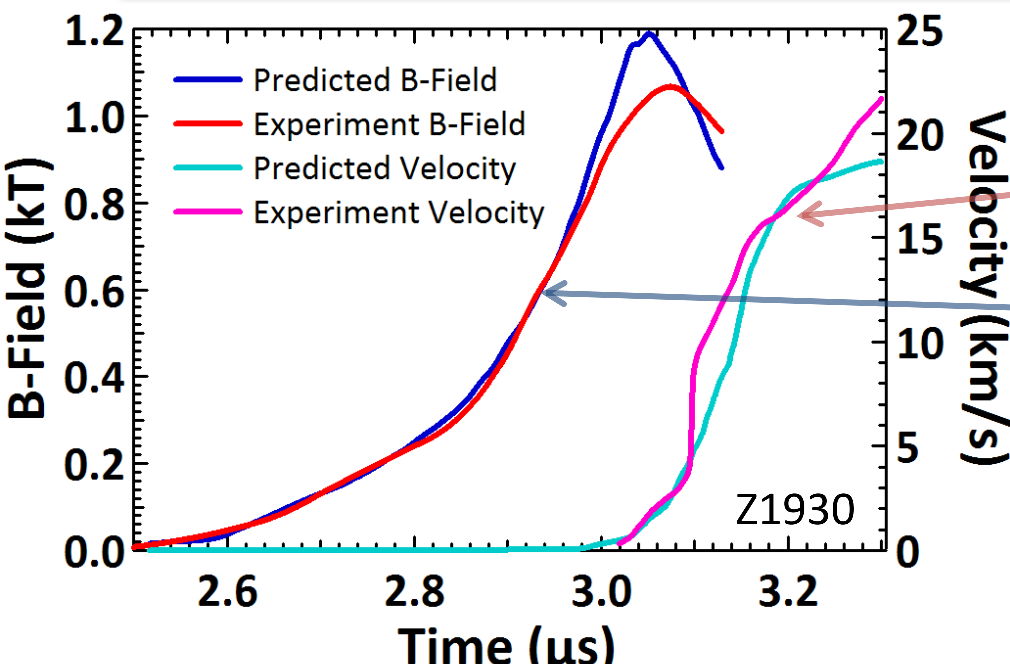
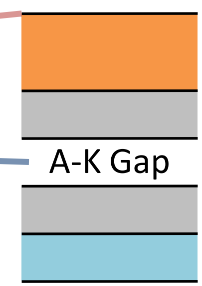
- requirement for 1-D shock-free loading limits **maximum thickness**
  - imprecision in pulse shaping makes ideal shock-up distance difficult to attain





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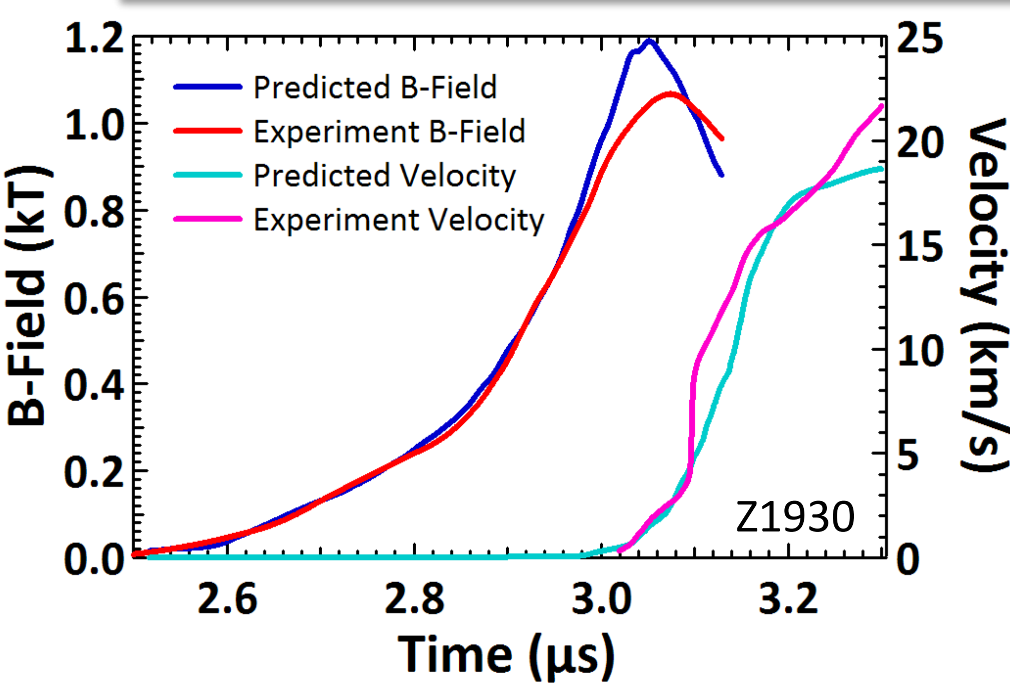
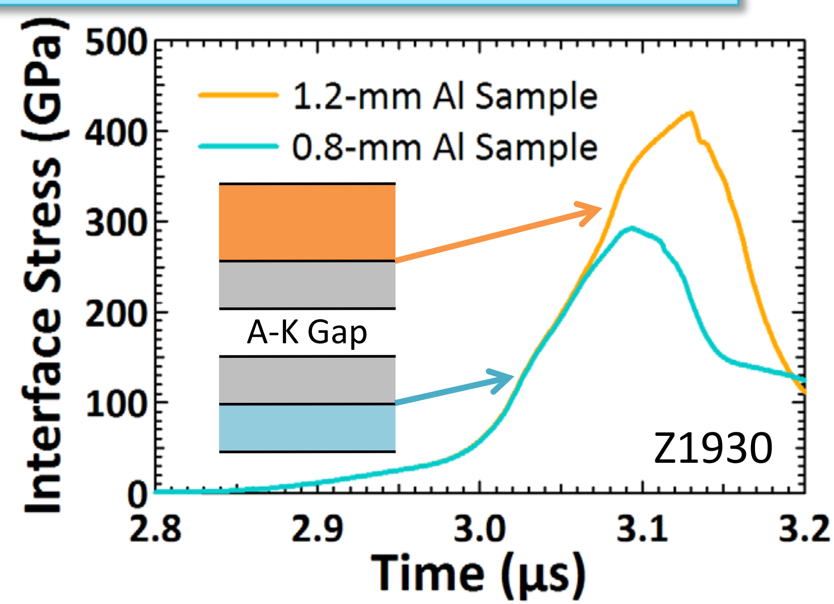
- requirement for 1-D shock-free loading limits **maximum thickness**
  - imprecision in pulse shaping makes ideal shock-up distance difficult to attain
- arrival of back-surface reflection at sample's front surface (reverberation) limits **minimum thickness** to achieve desired stress state
- increasing rise time to delay shock formation in thick sample reduces peak stress at front surface of thin sample





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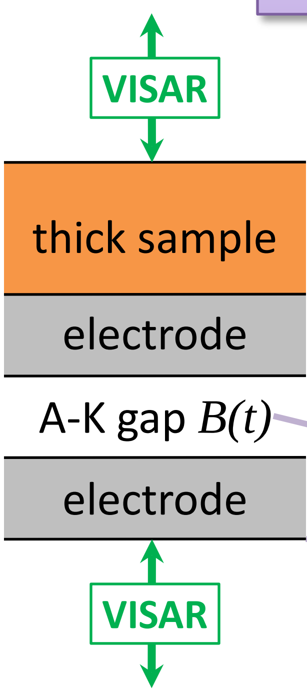
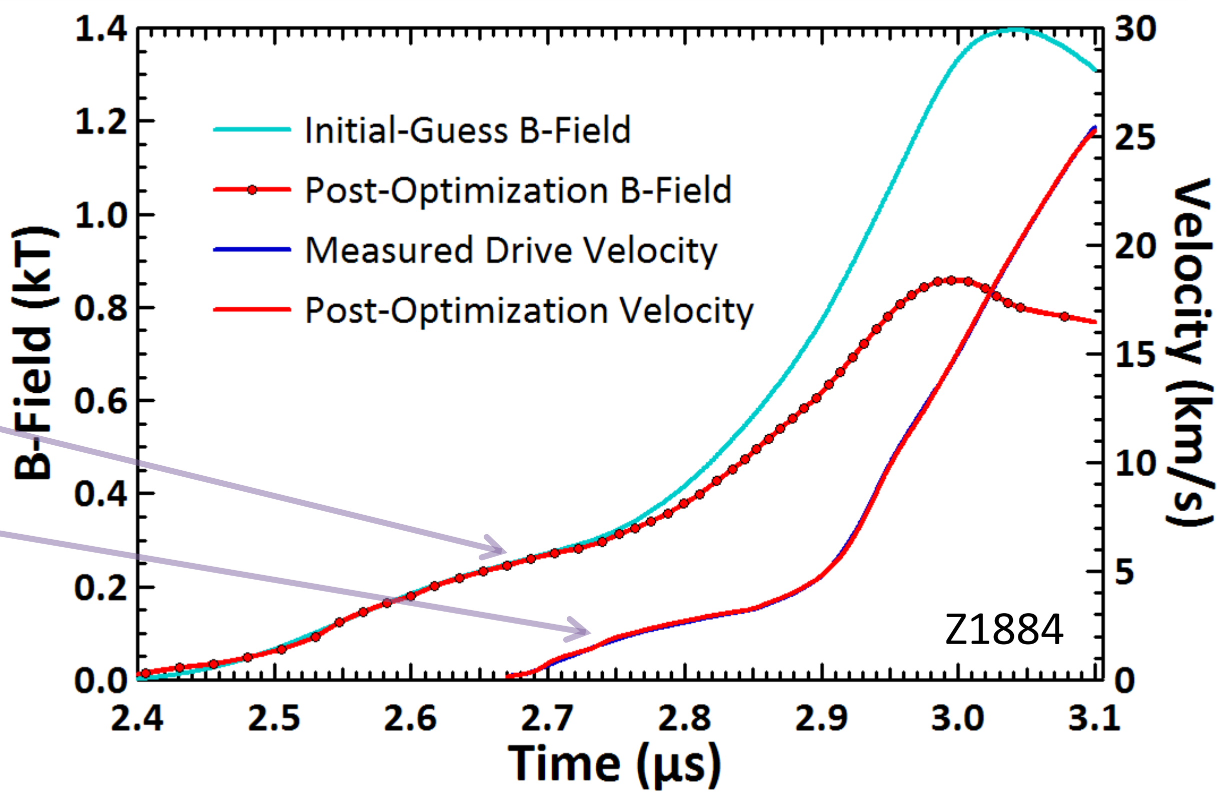
Optimization technique determines magnetic-field history in A-K gap from electrode "drive" measurement

- Dakota optimization framework drives Alegra 1-D MHD simulations
- *B(t)* represented by constrained cubic spline (25-50 points) with time shift and stretch factors
- objective function is metric of isometry between simulated and experimental velocity history at electrode back surface

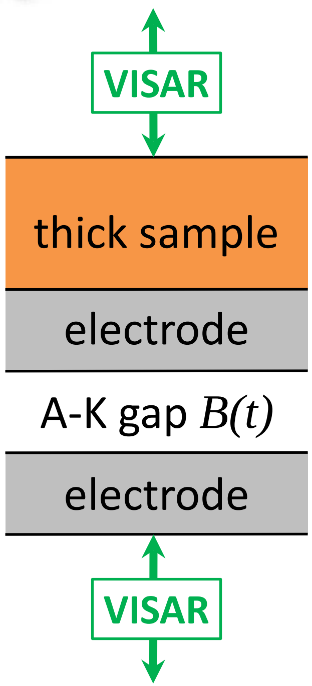




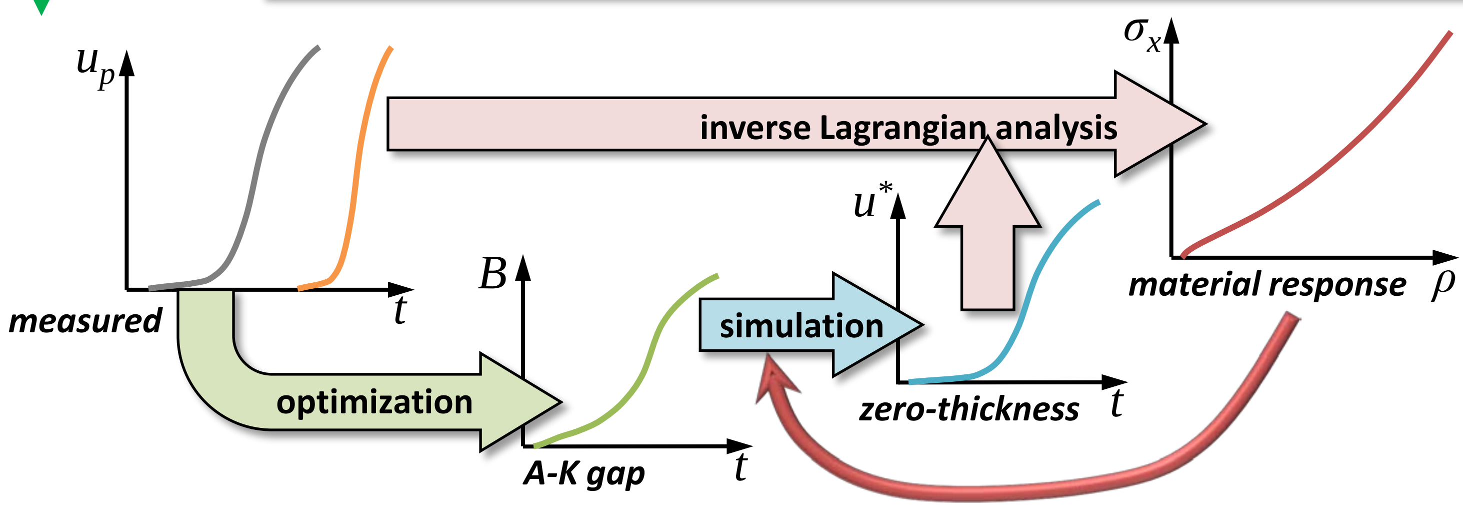
MHD simulations:

- high confidence in aluminum EOS and conductivity models
- high spatial resolution (2.5-µm cells)

Single sample yields quasi-isentrope by iterating inverse Lagrangian analysis with simulated "zero-thickness" velocity



1. measure velocity at back faces of sample and opposite electrode
2. use optimization to determine $B(t)$ from electrode measurement
3. use $B(t)$ and first-guess sample EOS (Sesame table + strength) to simulate electrode/sample interface "zero-thickness" velocity
4. perform inverse Lagrangian analysis on simulated "zero-thickness" velocity and measured back-face velocity of sample
5. convert resulting $\sigma_x(\rho)$ curve to full tabular EOS by assuming constant c_V and Γ/V, equating stress to pressure (strength folded into EOS)
6. use $B(t)$ and new tabular EOS to simulate electrode/sample interface
7. repeat steps 4-6 until material response converges



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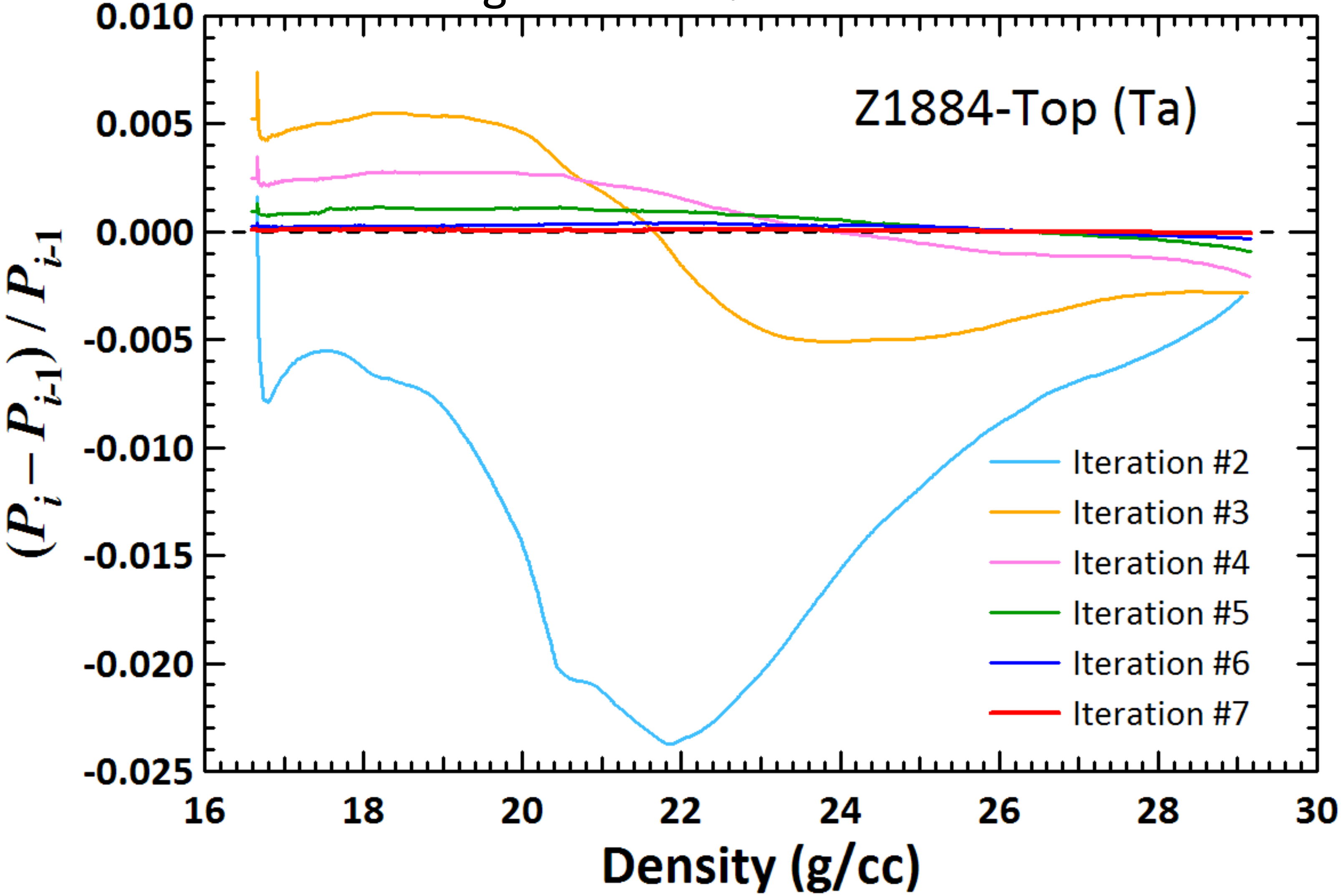
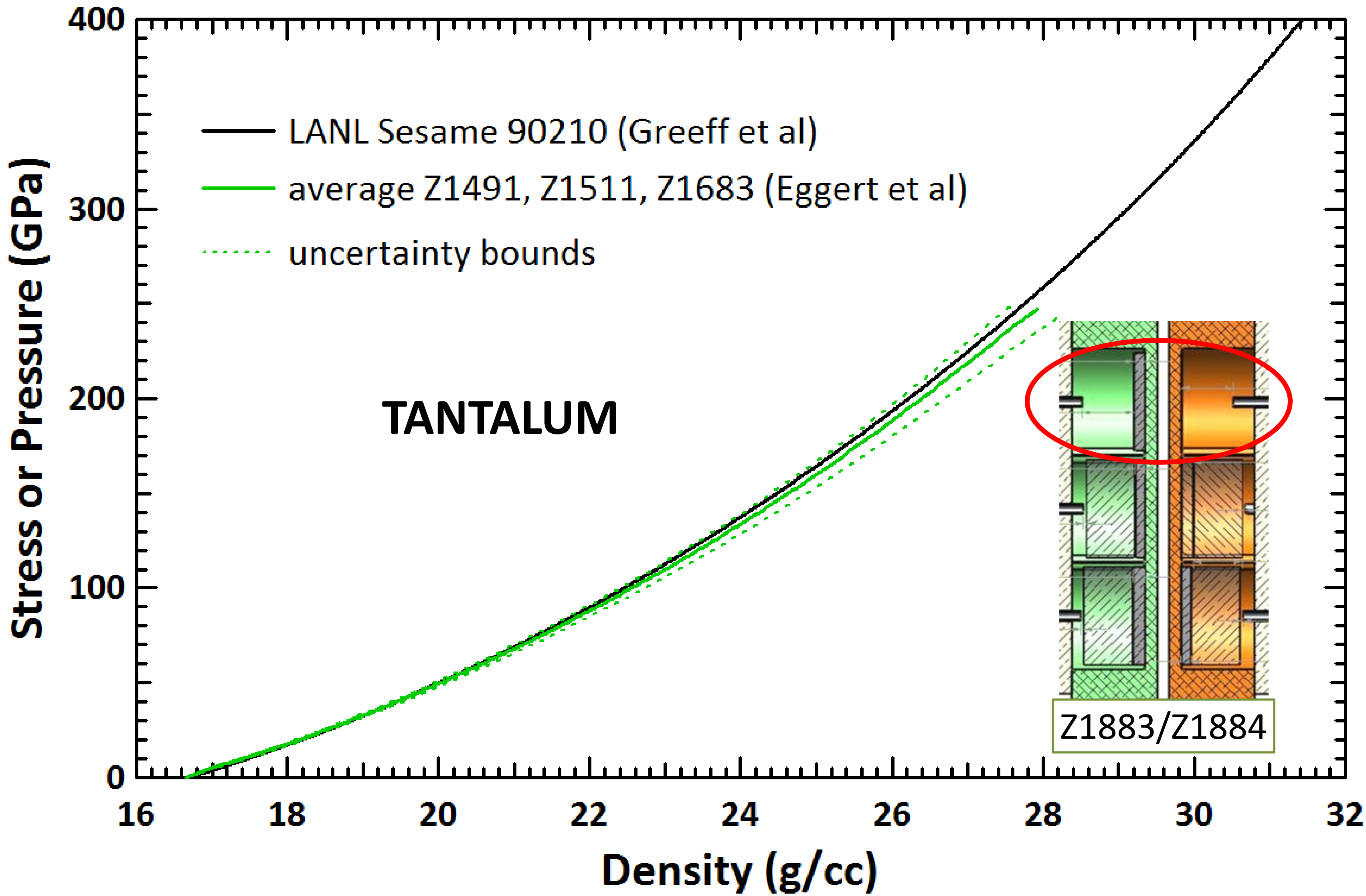
Outer loop of single-sample approach converges

result changes < 0.015% from 6th to 7th iteration



Single-sample measurement of tantalum to 320 GPa decreases uncertainty over two-sample measurement



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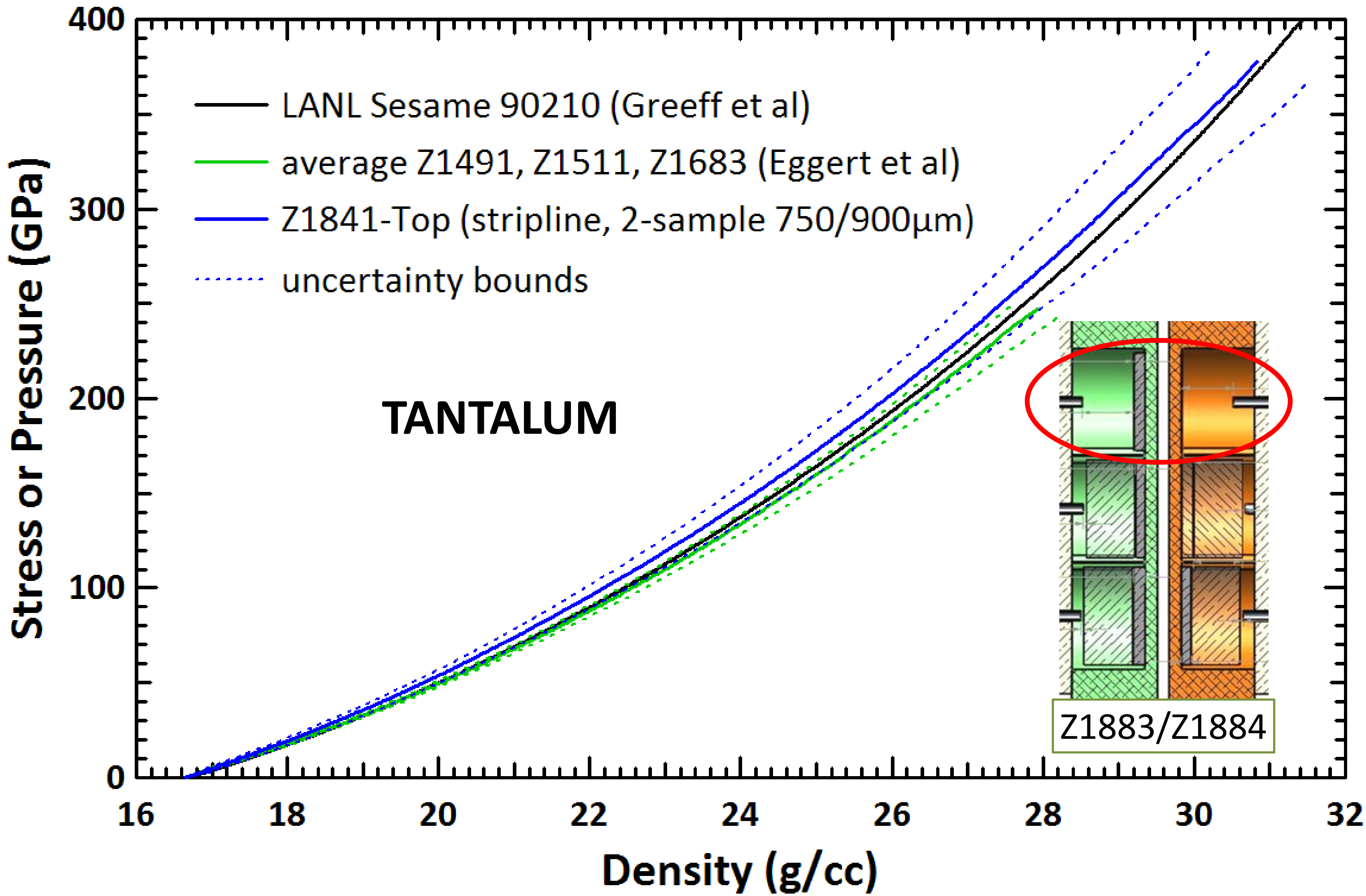

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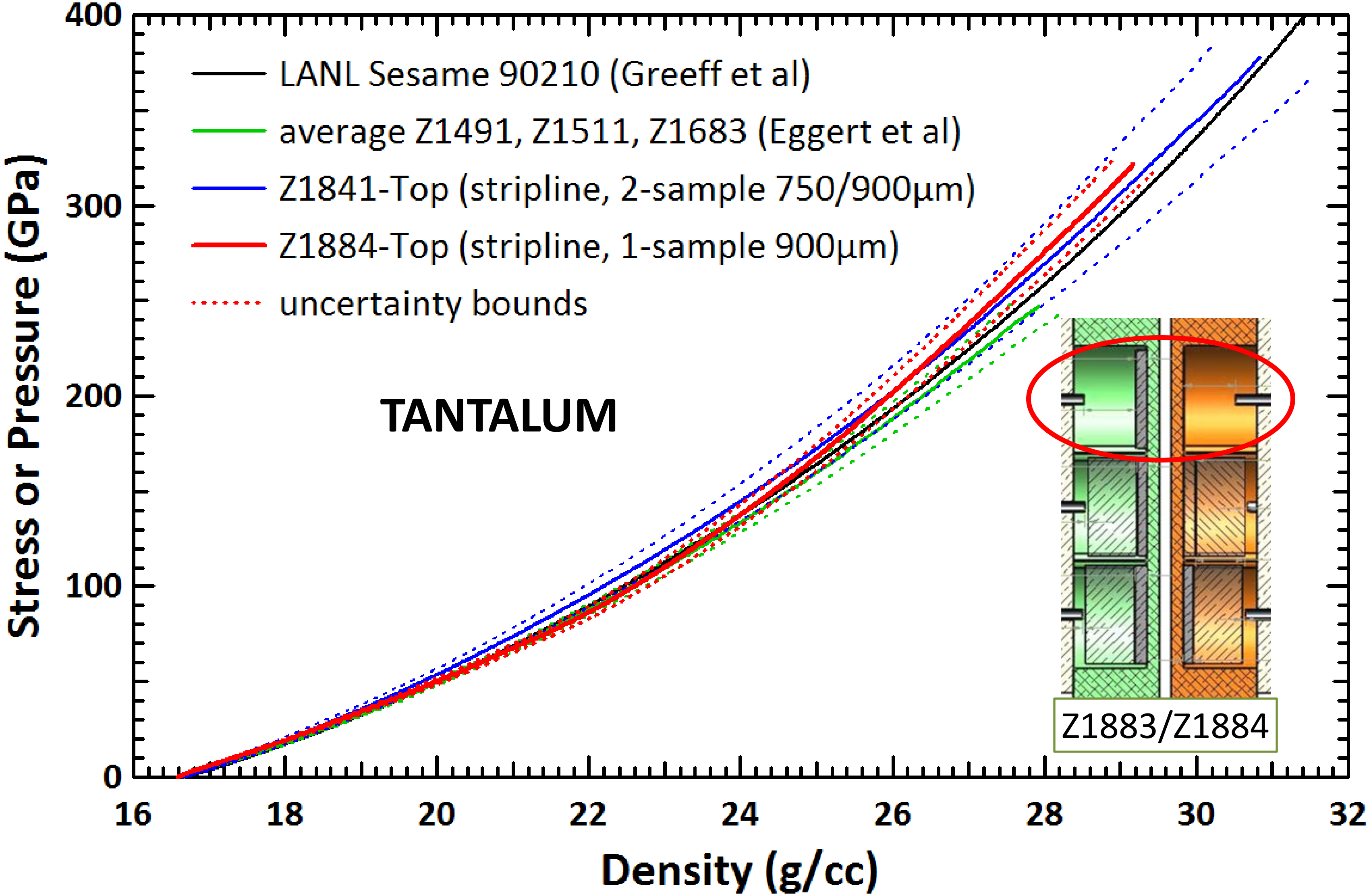
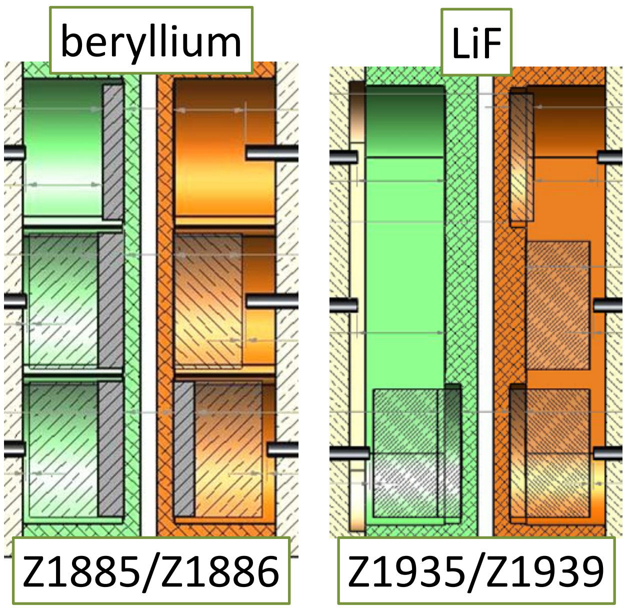


Further work is planned to fully establish a capability for multi-megabar ramp compression measurements

- Analyze additional single-sample and two-sample data sets on Ta, Be, LiF, Al, Cu, and Au
- Use independently measured strength to correct quasi-isentrope to isentrope
- Extract LiF index-of-refraction window correction
- Quantify sensitivity of results to
    1. aluminum EOS used for B-field optimization
    2. LiF EOS used for windowed samples
    3. B-field gradients across sample diameter



- The stripline load with the single-sample analysis approach has the **<u>potential</u>** to measure quasi-isentropic loading paths to multi-megabar pressures with uncertainties of ~1% in density and ~3% in stress
- Recent design and pulse-shaping improvements suggest measurements to > 5 Mbar are possible on high-Z materials at full machine charge voltage