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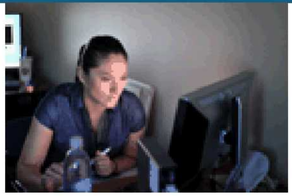
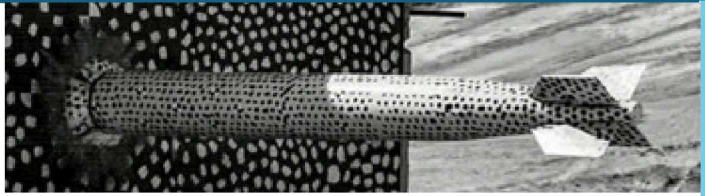
SAND2019-2203C

Uncertainty Quantification of Velocimetry-Based Load Current Inferences for 100 ns Multi-Mega-Amp Pulsed Power Experiments





PRESENTED BY

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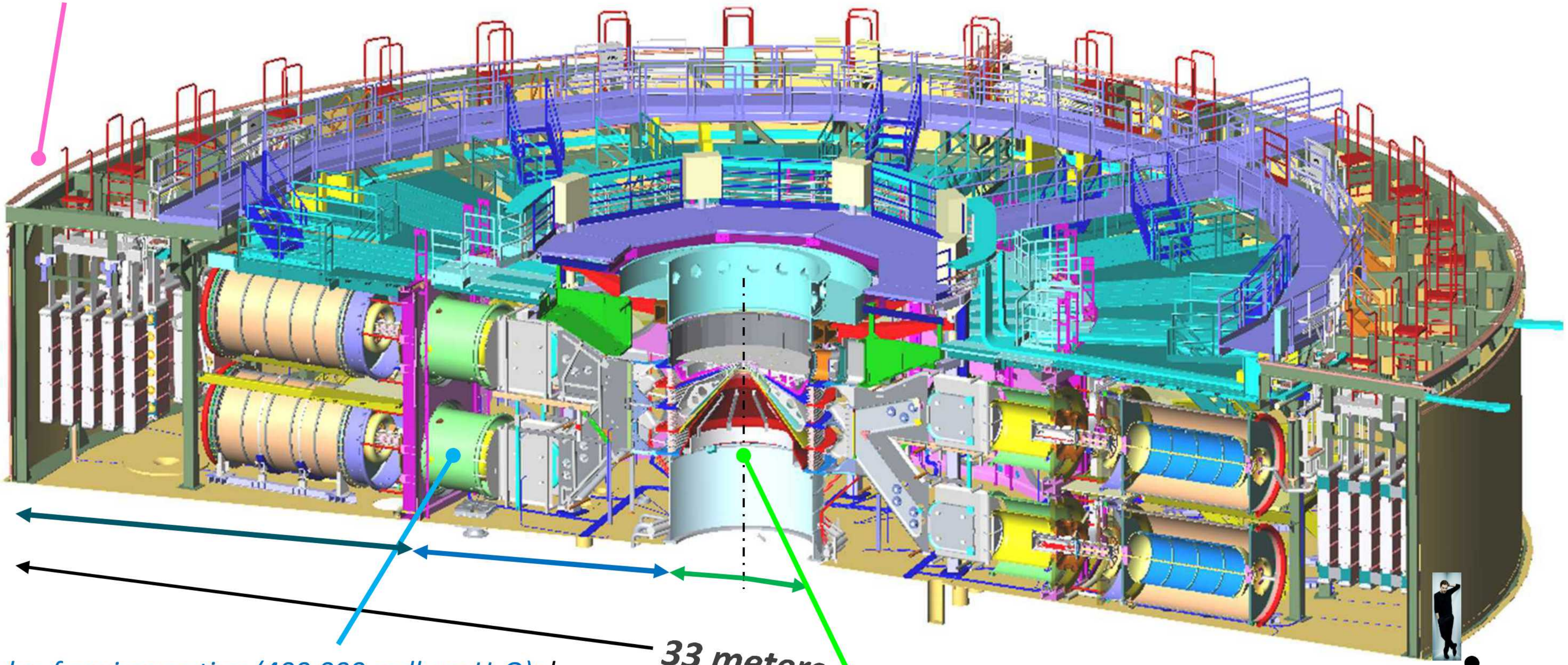
Outline

- Z Machine overview
- B-dots
- Velocimetry-based load current
- Causality and Burn Through times
- Bayesian statistics for UQ
- Results relevant to ICF experiments
- Future work

Z Machine at Sandia

energy storage section (600,000 gallons oil): *stores 23 MJ in 36 banks of 60 capacitors (each 2.3 μF), charged in parallel (90 kV), discharged in series (5.4 MV)*

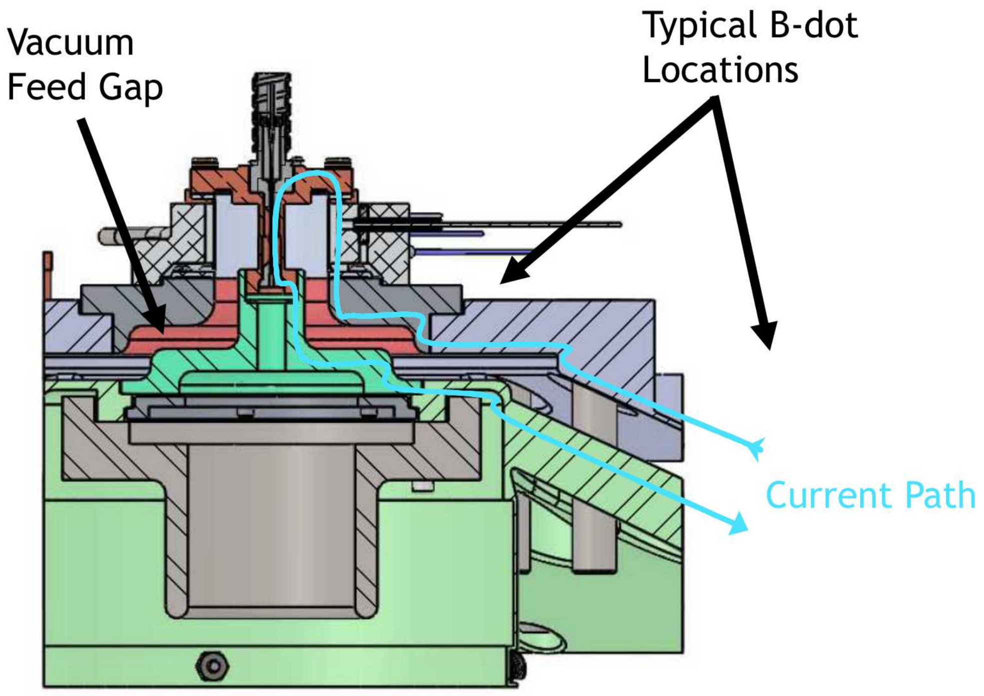


pulse-forming section (400,000 gallons H_2O): *laser-triggered SF_6 gas switches & H_20 spark-gap switches compress pulse to 100 ns rise time, tri-plates reduce 36 lines to 18, convolute reduces further to 4 radial feed gaps*

center section (10^{-5} torr vacuum): *magnetically insulated transmission lines deliver up to 26 MA pulse to load, convolute reduces 4 feed gaps to 1*

Cumberbatch
for scale

Plasmas in Cylindrical Load AK Gaps

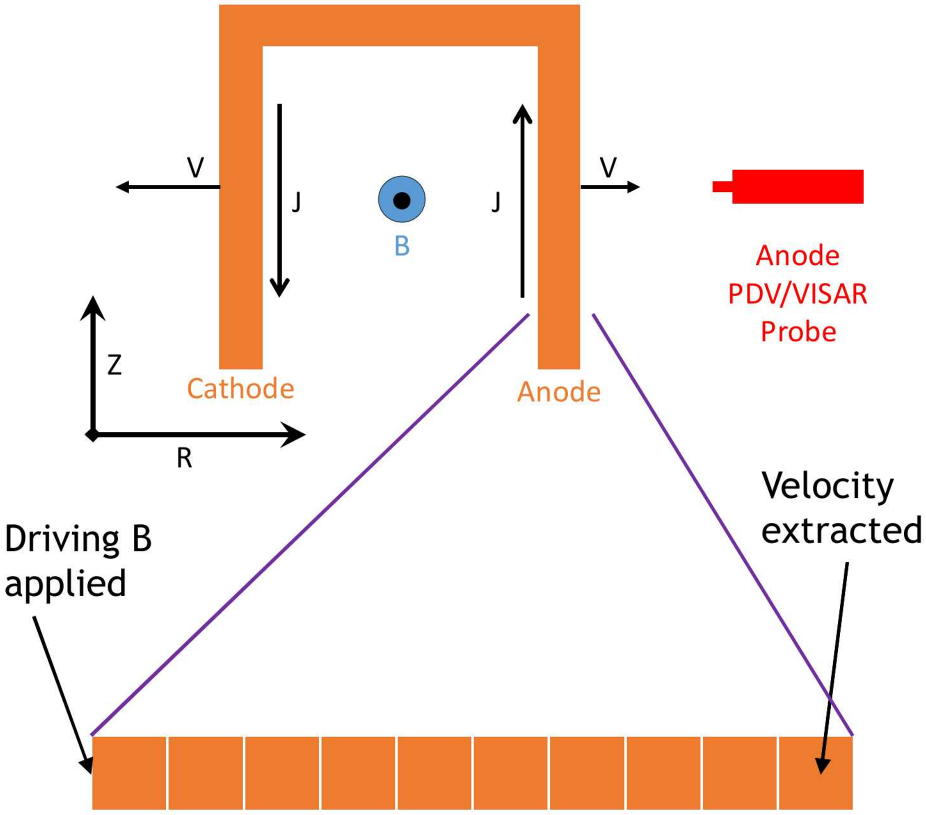


- Magnetic inductance loops (B-dots) are used as standard local current measurement diagnostics on most pulsed power accelerators.
- B-dots require a calibrated *constant* scale factor to convert from local magnetic field to current.
- Plasma generation resulting from high (>10 MA) current can confuse B-dots, resulting in loss of signal quality.
- B-dots are location outside the load region (~3 cm), and plasma has been shown to adversely impact current flow at low radius (<1 cm).*
- Velocimetry-based load current techniques employ multiphysics codes to solve for drive current using a *dynamic* scale factor accounting for material properties. These techniques have been validated in the dynamic materials properties (DMP) program on Z for over a decade.

*Reference to AK gap plasma paper

Velocimetry-based Load Current "Unfolds"

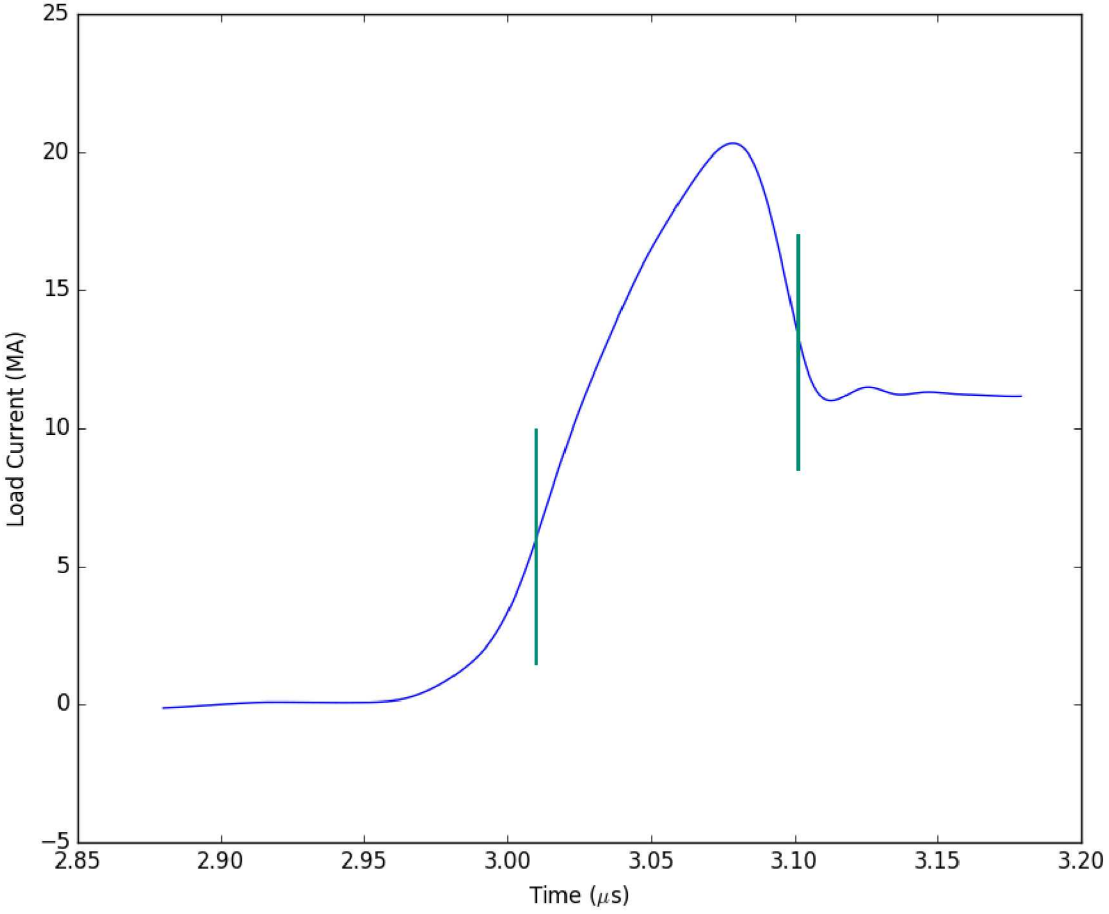
Cylindrical geometry for velocimetry based current inference.



1D Lagrangian simulation geometry. Typical anode 300-600 μm thick, ~10 mm inner radius.

- Velocimetry based techniques allow for current measurements at the load location based on conservation of energy and momentum connected through validated multiphysics codes.
- Anode expansion (or cathode implosion) velocity is measured to sub-nanosecond and 20 m/s precision with PDV/VISAR.
- Non-linear least squares solver connected to multiphysics code used to identify drive magnetic field/current that reproduces the experimental velocity for the given geometry and material makeup.
- For drives free of shock generation (quasi-isentropic compression) we see vanishingly small uncertainties compared to the 20 m/s measurement uncertainty.
- For drives strong enough to allow shock formation, enhanced uncertainties result from the shock destroying drive information. Additionally, strong drives "burn through" the liner quickly, which results in loss of drive information as the majority of the liner transitions to plasma phase.

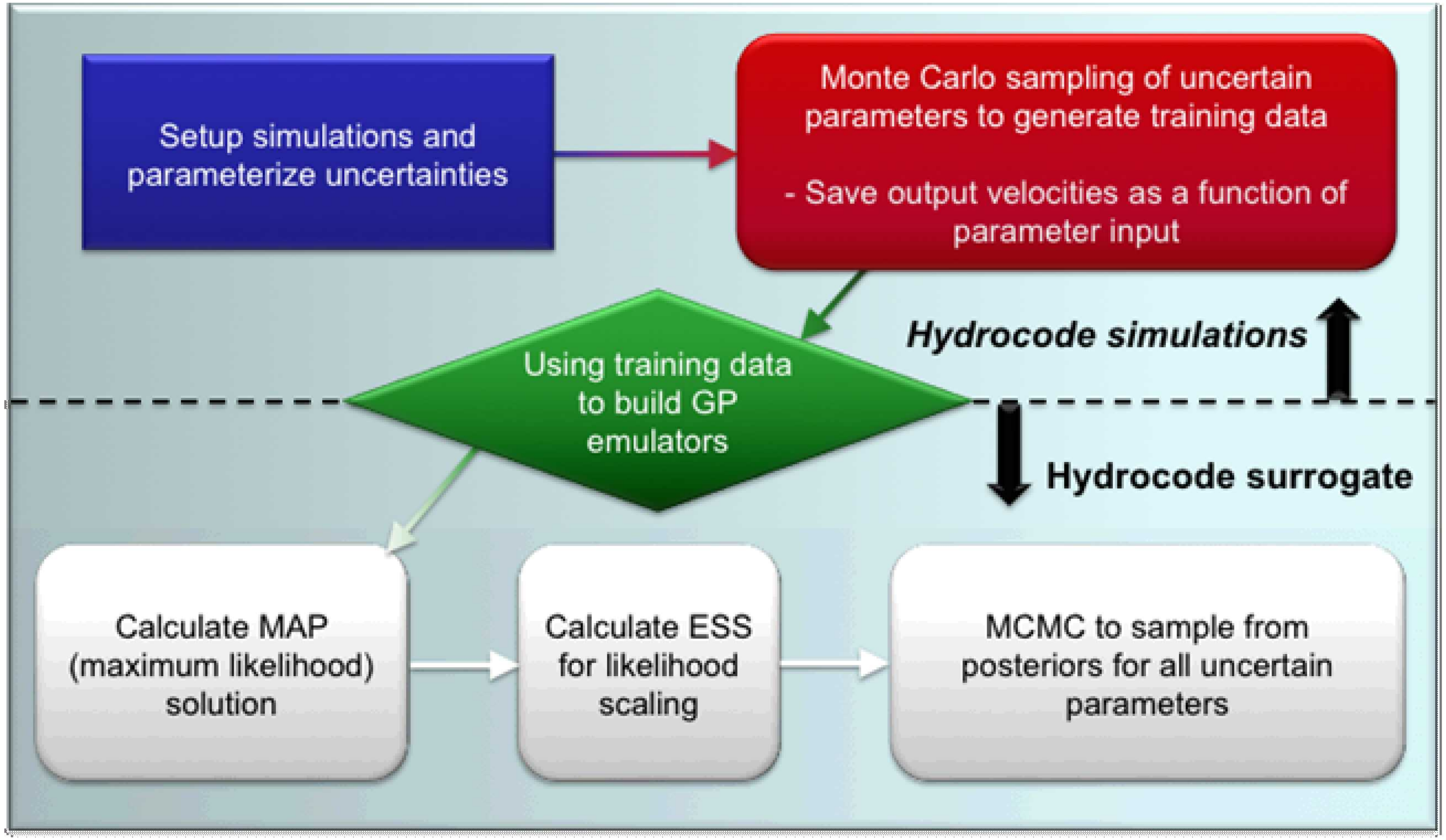
Causality and Burn Through Times



Test case: aluminum liner,
300 μm thick, 6 mm inner radius.

- For a given current pulse, liner inner radius, thickness, and material, there are two critical times that can be uncovered from the unfold: the **Causality** and **Burn Through** times.
- Burn Through is the time at which the current has transitioned the entire liner mass into plasma. This greatly increases the uncertainty since the velocimetry laser is now bouncing off a current carrying plasma front expanding into vacuum. This time is easily extracted from a simulation.
- Causality time corresponds to the point on the current pulse after which current information can be extracted due to the shock formation in the liner. The current drive before that time is responsible for producing the shock, but since there are many solutions to produce the same Hugoniot state we can not in isolation know which was correct. (It is possible to trust the B-dots in this region, which we do in practice, but we ignore here for sanity check of the UQ model.) This time can be extracted from a set of simulations.
- Note: times in velocity space do not directly correlate to times in current space. Velocity times experience a lag due to wave propagation times through the liner. This lag decreases to Burn Through time.

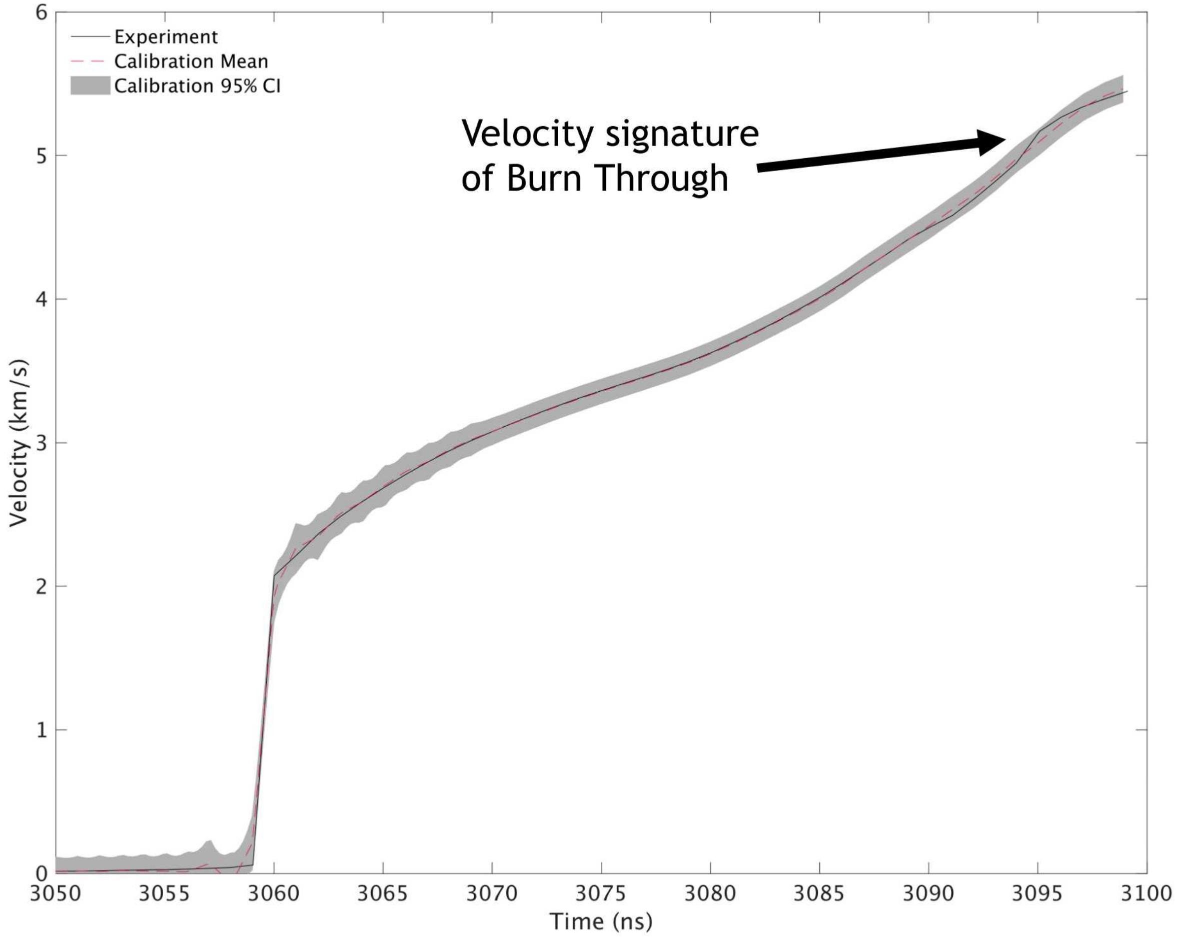
Bayesian Calibration Work Flow

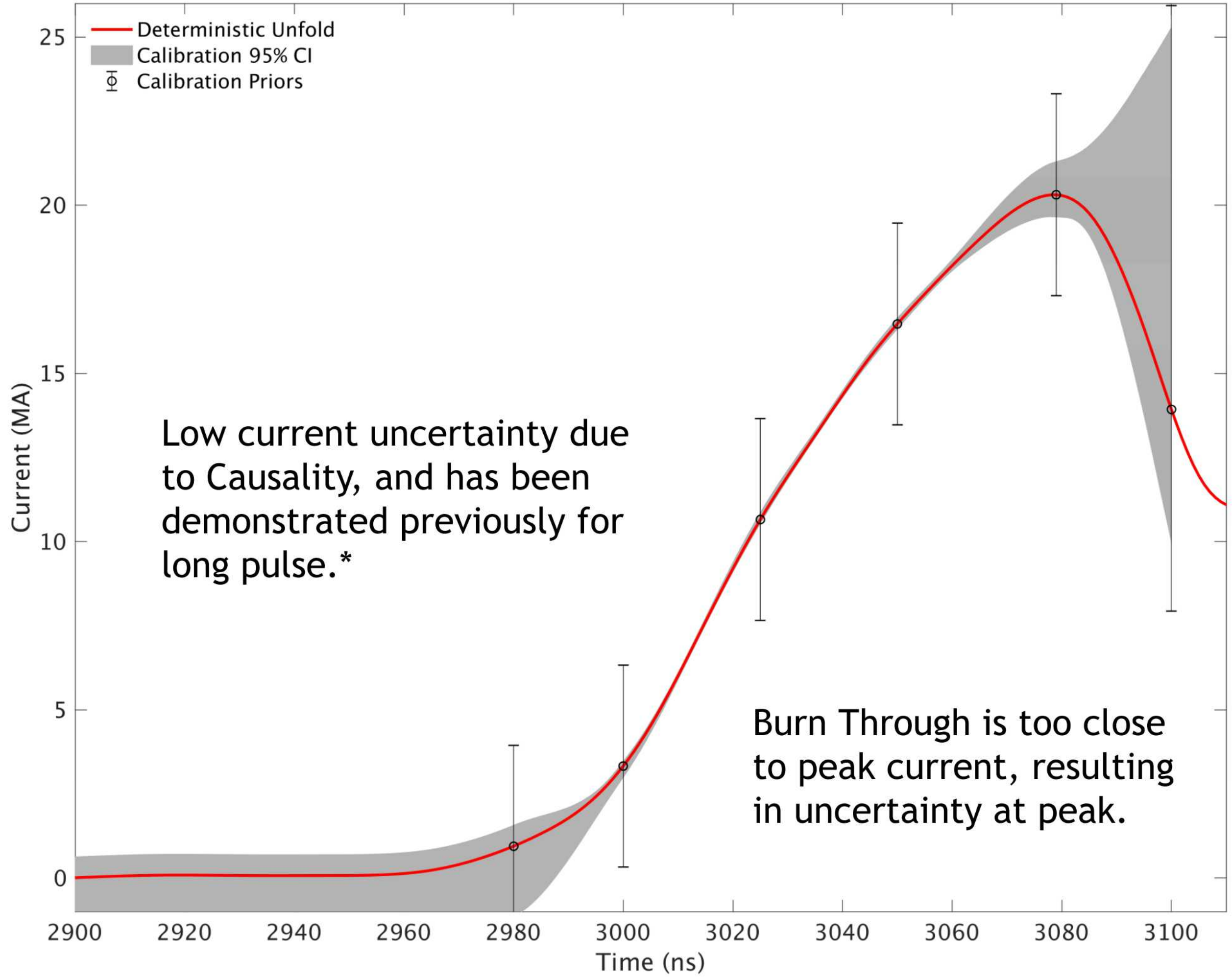


- Bayesian method was used for UQ on current pulse unfold in which the drive was perturbed at various points through a spline fit.
- 10's k multiphysics simulations were run to train Gaussian Process surrogates.
- Markov chain Monte Carlo methods were used with Bayes' theorem to calculate 90% confidence intervals on current with specified confidence intervals on target velocity.
- The results provide insight into observed reproducibility of perturbed current unfolds.

6 mm inner radius, 300 µm thick

Velocity uncertainty of ±20 m/s results in 2σ window of 80 m/s

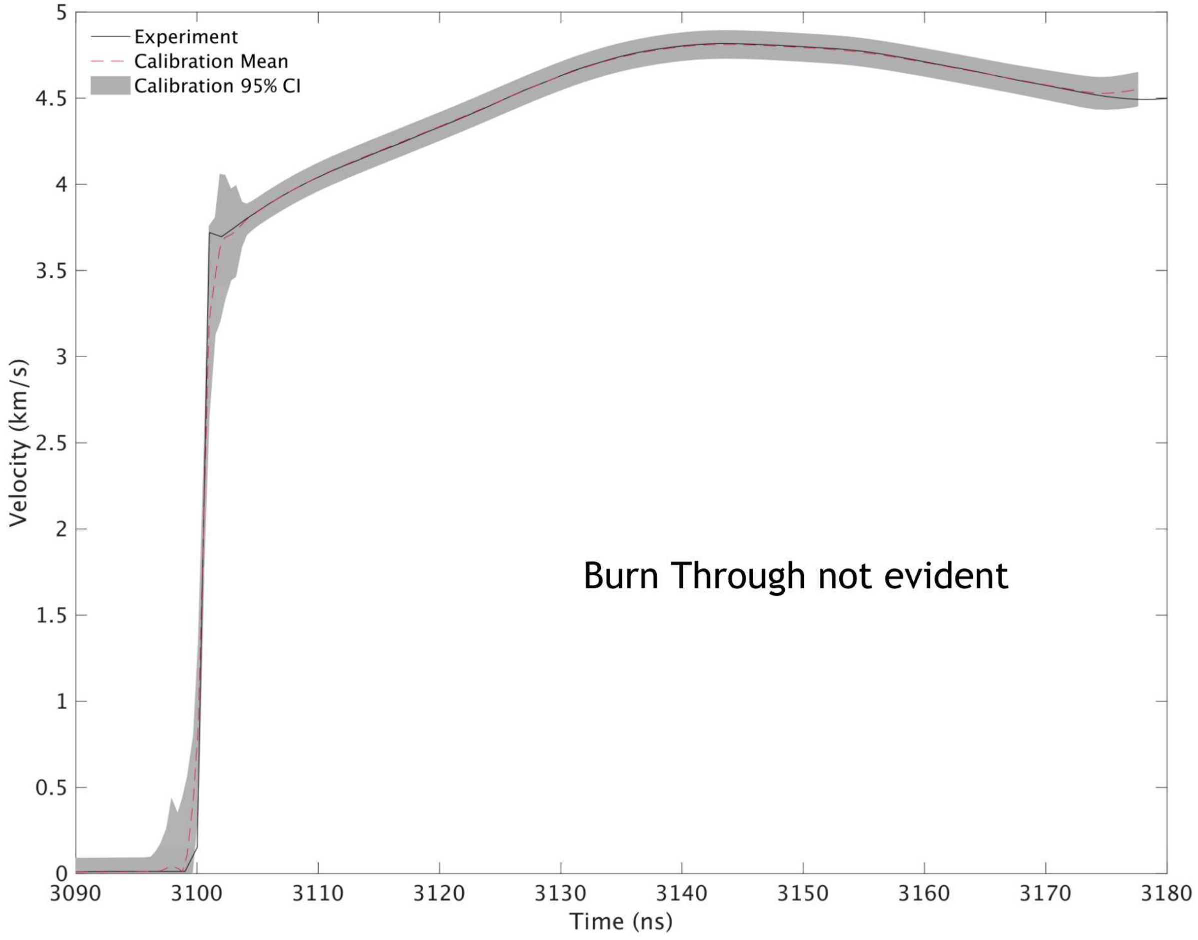


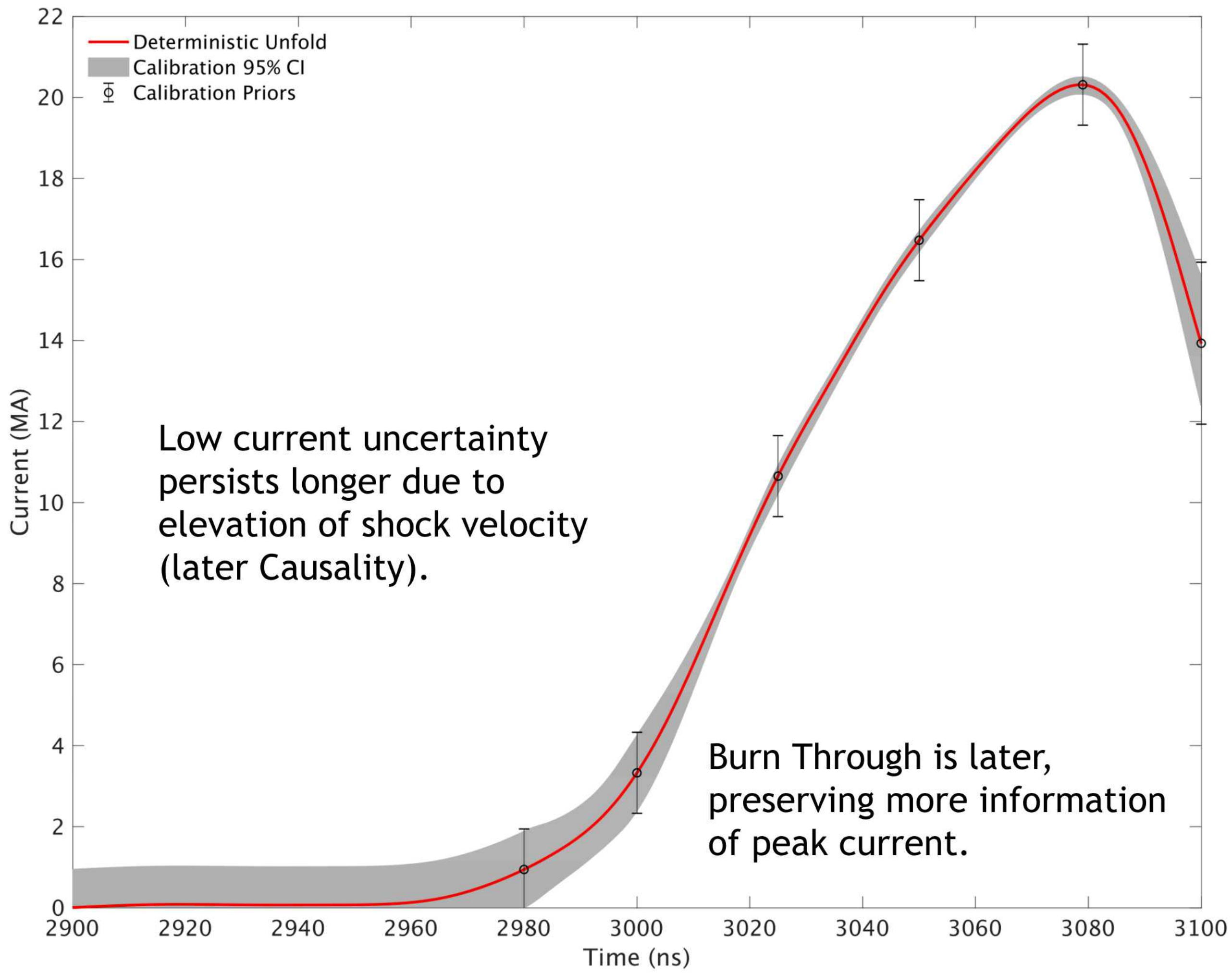


*Reference to low current uncertainty

6 mm inner radius, 550 μm thick

Velocity uncertainty of ±20 m/s
results in 2σ window of 80 m/s





Conclusions and Future Work

- Velocimetry-based techniques can provide highly accurate (±200 kA) load current above 10 MA.
- B-dots often fail in the 20 MA regime, and even when they don't they are recording current ~3 cm from the load, within which radius loss mechanisms have been shown to manifest.
- Design of load structures requires a balance of early time current and late time (peak) current desires.
- As always, UQ is required to prevent undue confidence from being applied to results.
- The Bayesian work is continuing for benefit of the Z Magnetic Direct Drive Inertial Confinement Fusion (ICF) program, where load currents are used to drive predictive and postdictive multiphysics simulations of cylindrically convergent target geometries.

Thank you for your time.

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