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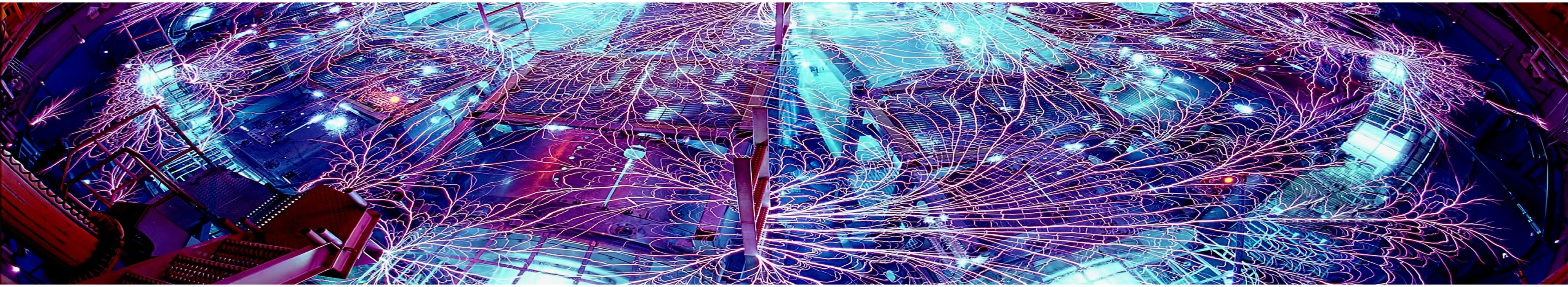

Zero to 1,600 m/s in 40 microns: Sensitive pulse shaping for materials characterization on Z

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U.S. DEPARTMENT OF ENERGY

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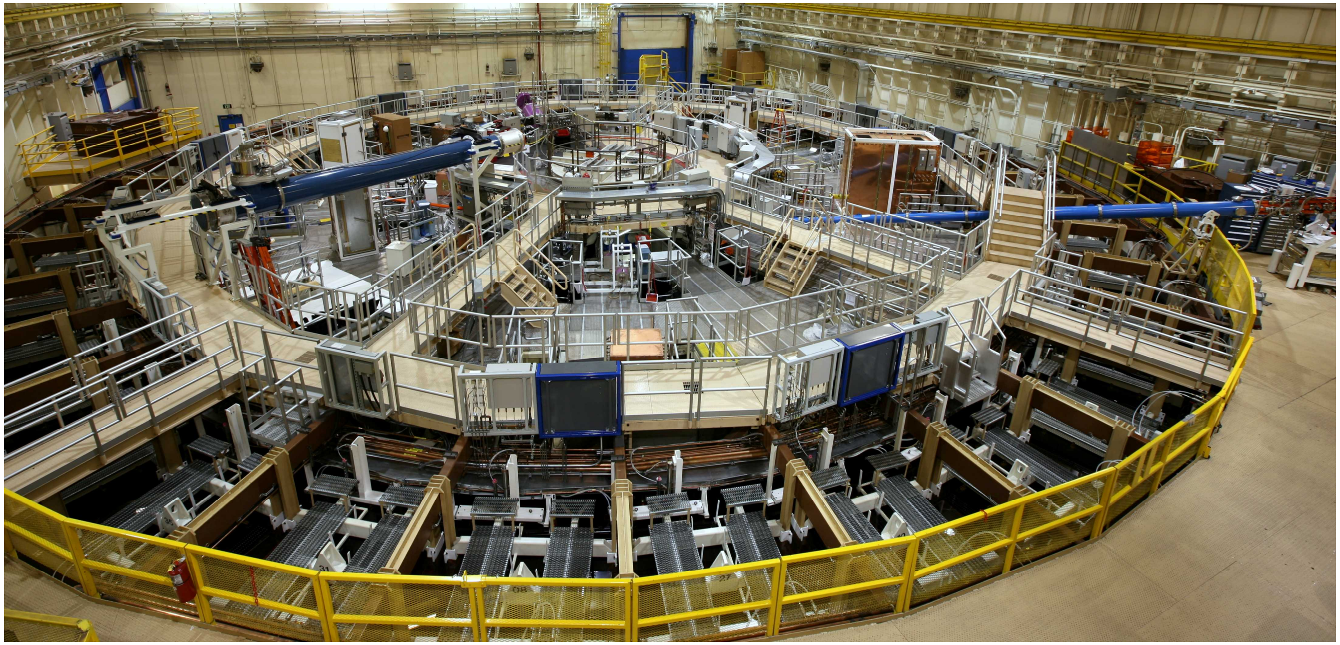
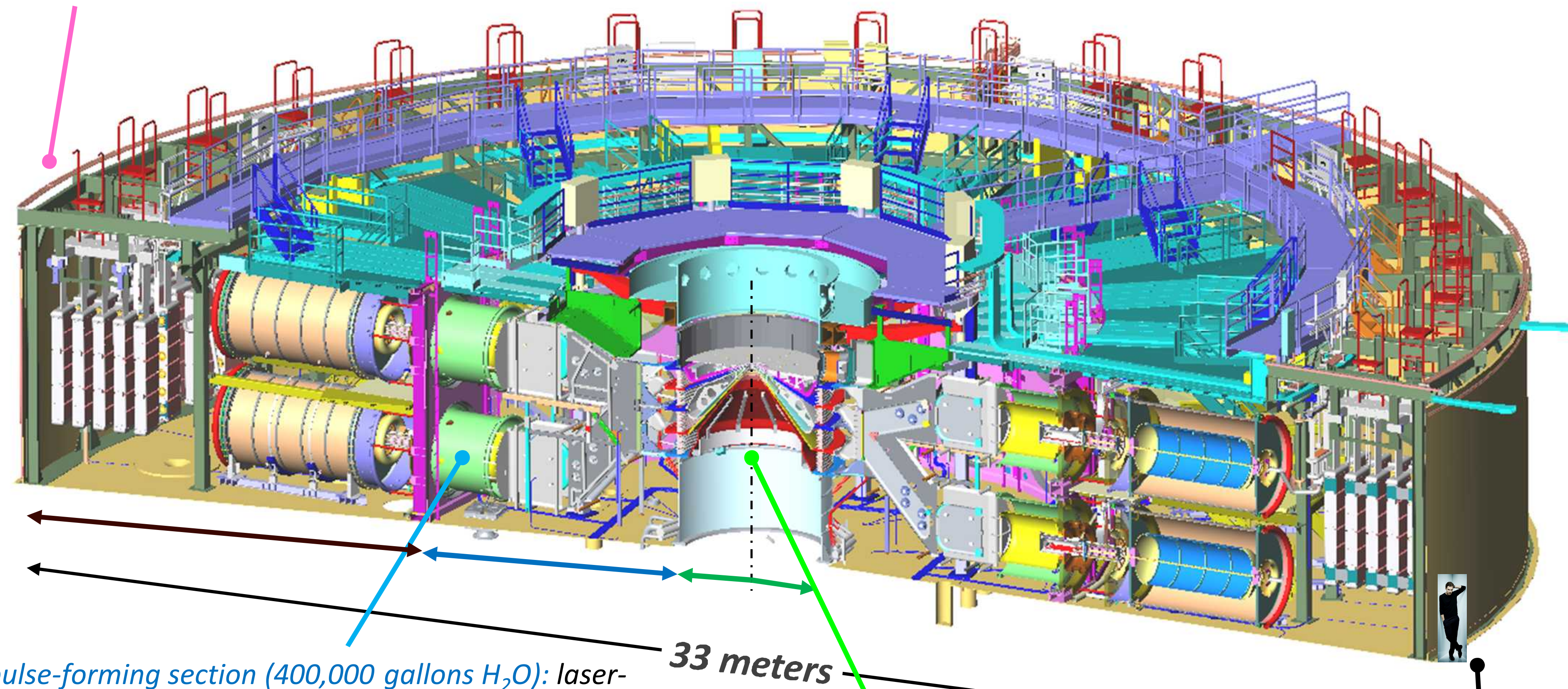
Overview

- What is the Z Machine?
- Dynamic Materials Properties (DMP) Experiments
- Designing a DMP Experiment (Cerium Shock-Ramp)
- Z3005 Analysis
- Design Robustness Analysis
- Conclusions



The Z Machine

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)

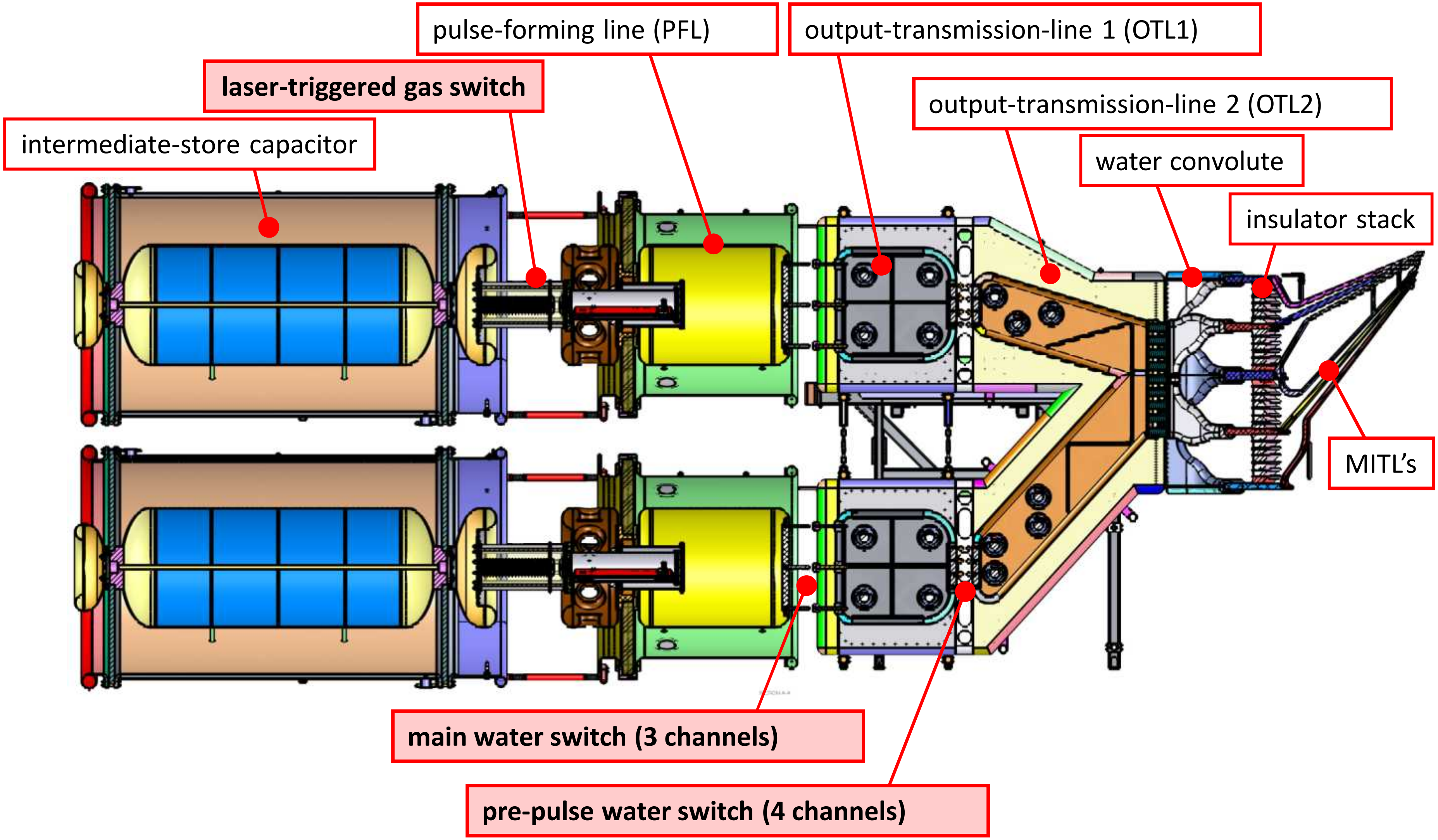


pulse-forming section (400,000 gallons H_2O): laser-triggered SF_6 gas switches & H_20 spark-gap switches compress pulse to 100 ns rise time, tri-plates reduce 36 lines to 18, convolute reduces further to 4 radial feed gaps

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

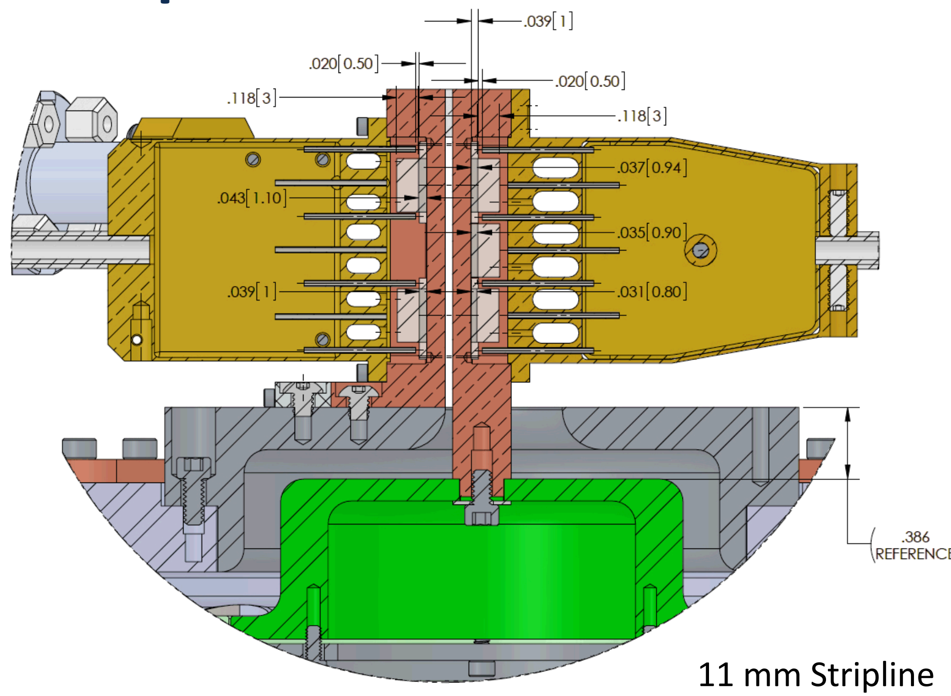
Cumberbatch
for scale

1/18th of Z : Pulse Forming Lines

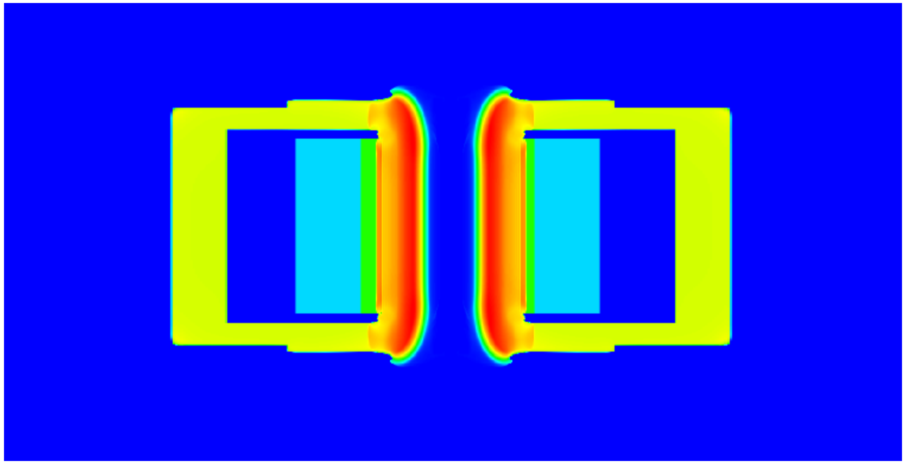


Dynamic Materials Properties

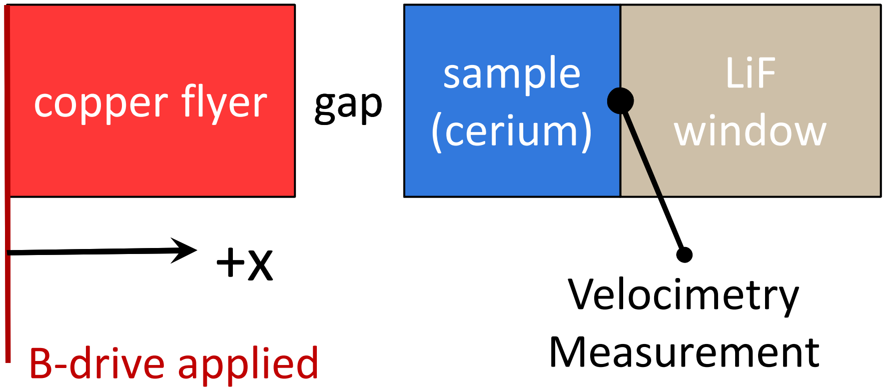
- LTGS timings and switch gap settings allow for great variety in the pulse shape delivered to the load.
- Validated physics and material models required to design, execute, and analyze these experiments.
- Flyer (Shock) experiment: a thin flyer plate is thrown at a sample material at < 42 km/s.
- Ramp experiment: a thick pusher is accelerated so as to quasi-isentropically compress a sample to high pressure.
- Shock-Ramp experiment: a thick flyer impacts a sample and quasi-isentropically compresses it to high pressure.



11 mm Stripline



Z3005: Cerium Shock-Ramp



Copper flyer:	2.500 mm
Flight gap:	0.040 mm
Cerium samples:	0.800 – 1.100 mm
LiF window:	3.000 mm

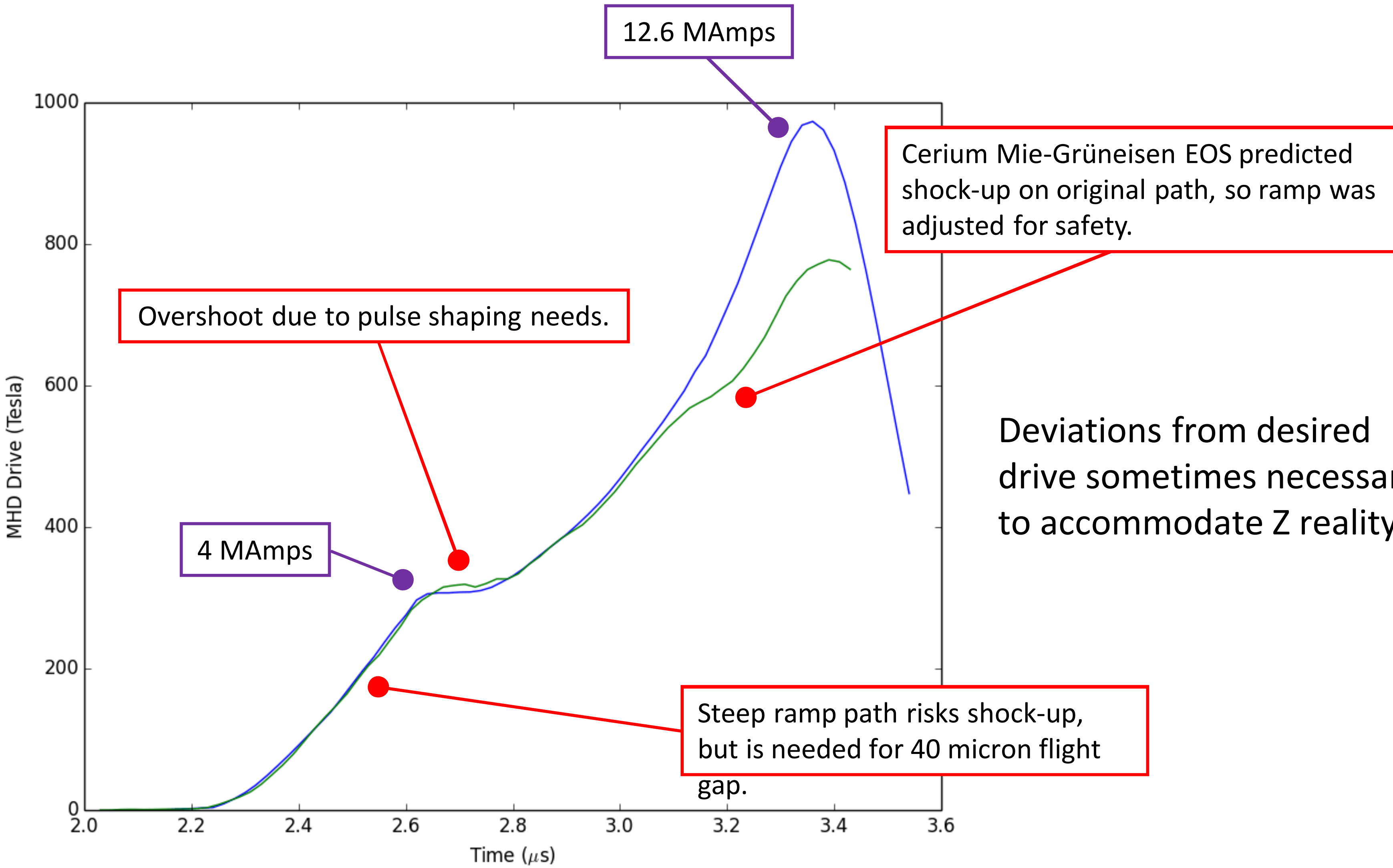
Design considerations:

Shock magnitude (melt the cerium)
Hold shock pressure across thickest sample
Ramp flyer without shocking
Ramp sample without shocking
Reach highest sample pressure possible

Typical Design Procedure:

1. 1D hydro design (no MHD)
2. Hydro pressure converted to B field through validated 1D MHD simulations
3. 2D MHD used to iteratively find Z pulse shape that produces desired B field in A-K gap
4. "Pulse shaping"; machine configuration identified that produces desired current pulse (if possible)

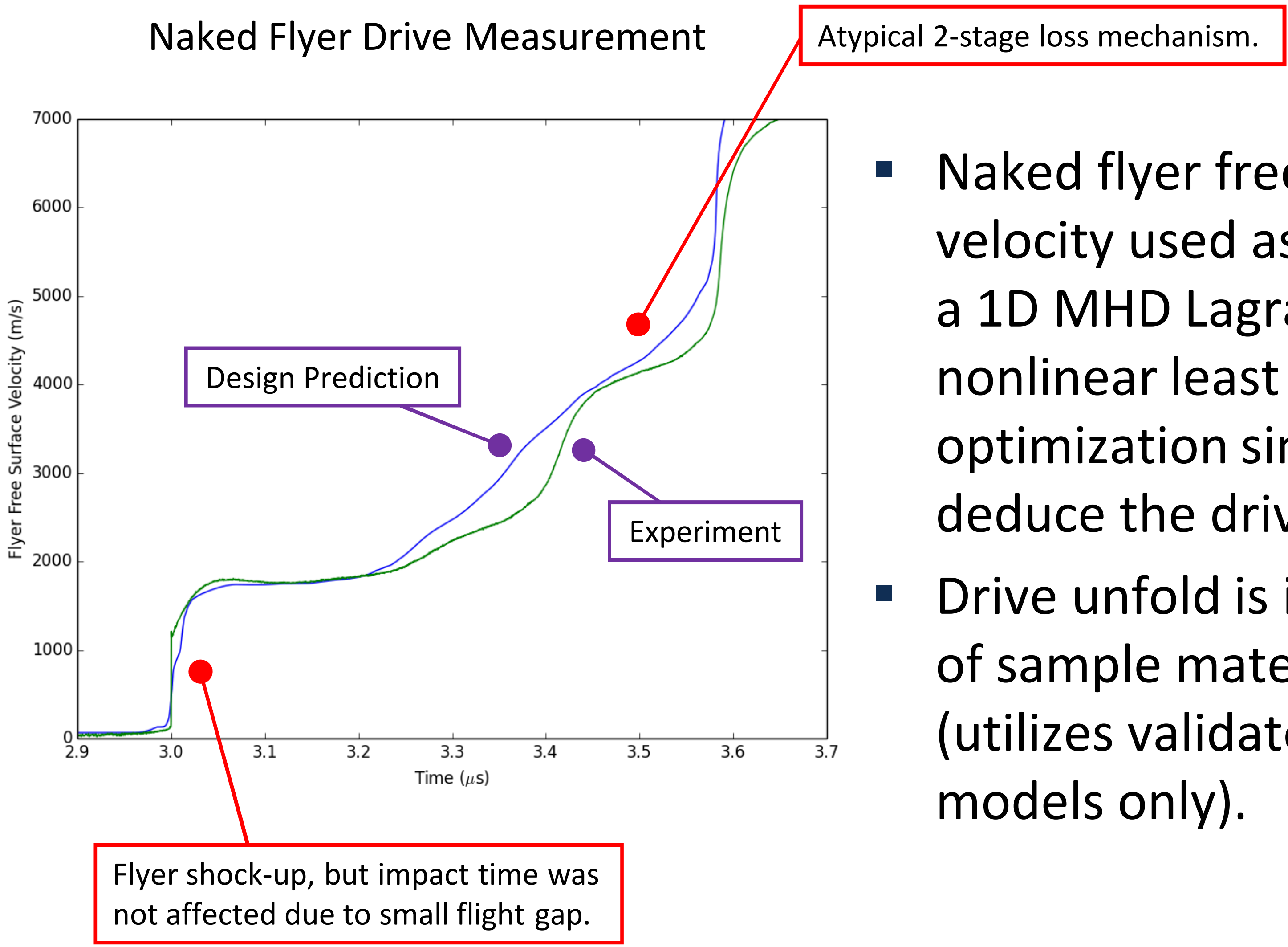
Designing the MHD Drive



Deviations from desired drive sometimes necessary to accommodate Z reality.

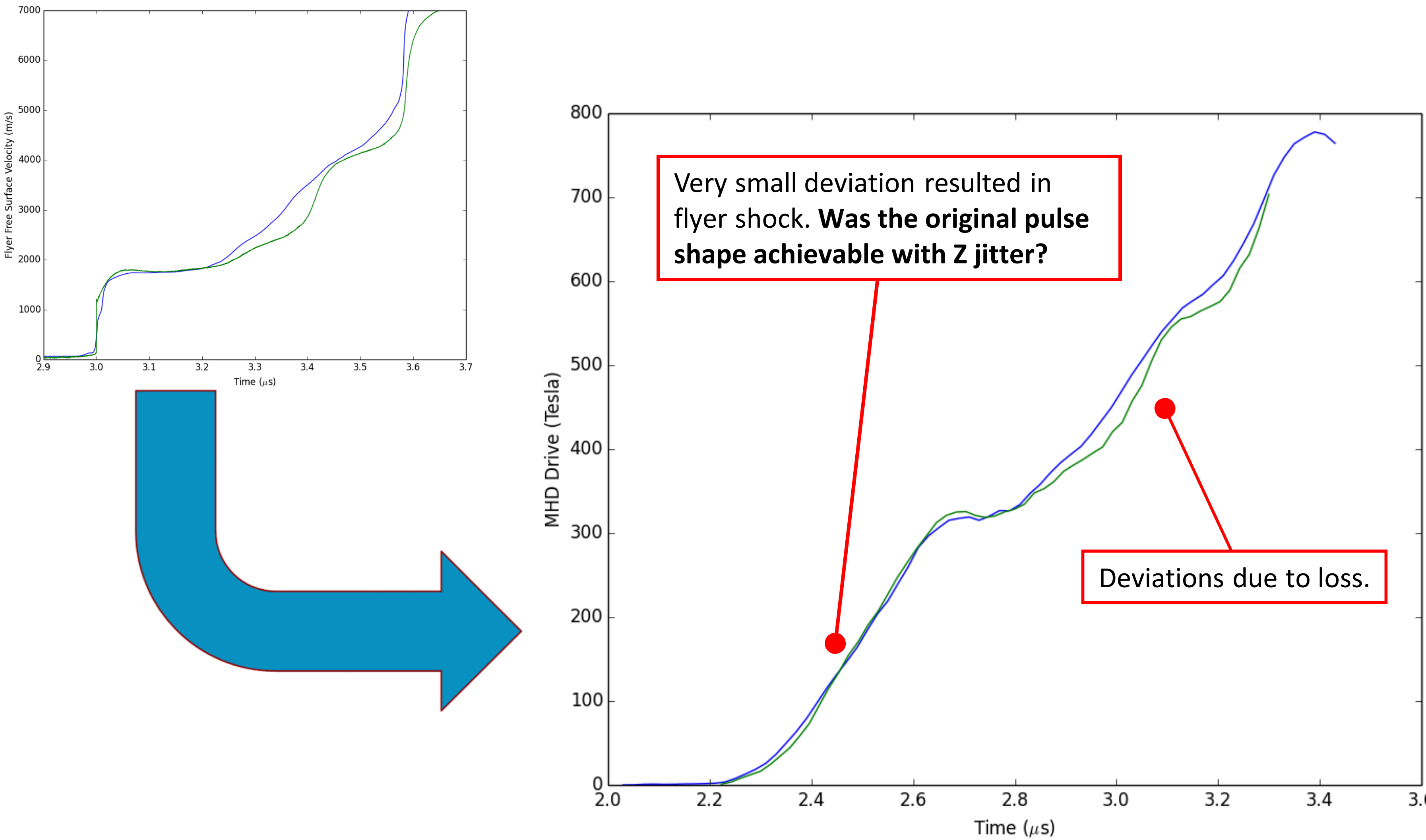
Z3005 Analysis

Naked Flyer Drive Measurement



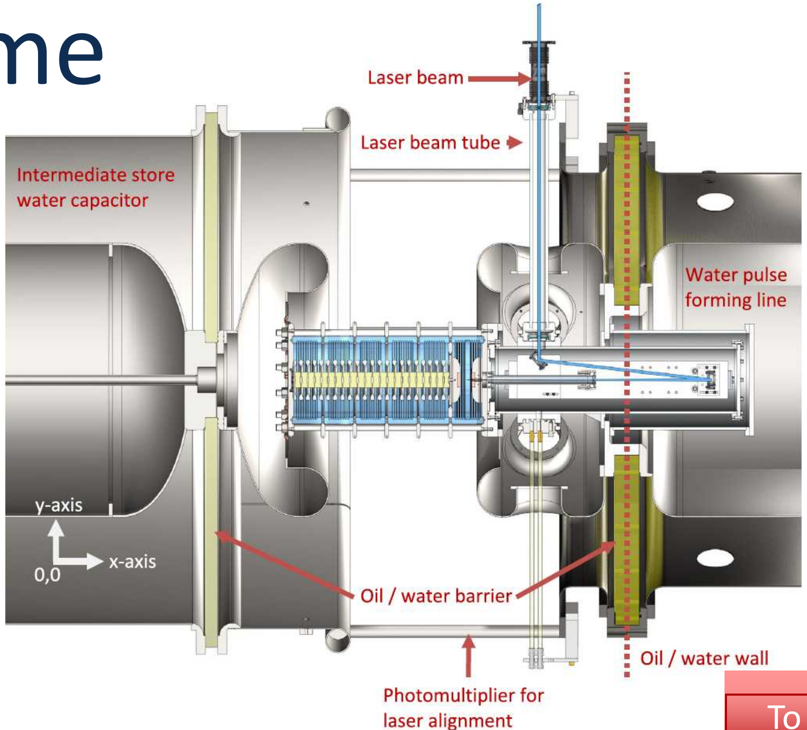
- Naked flyer free surface velocity used as a target in a a 1D MHD Lagrangian nonlinear least squares optimization simulation to deduce the drive.
- Drive unfold is independent of sample material models (utilizes validated copper models only).

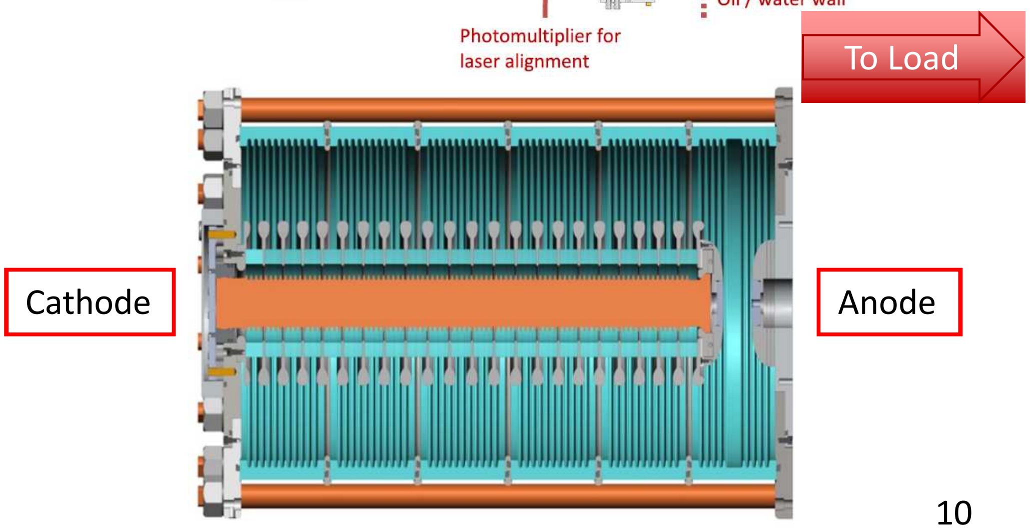
MHD Drive Identified



Jitter: Uncertainty in prediction of LTGS breakdown time

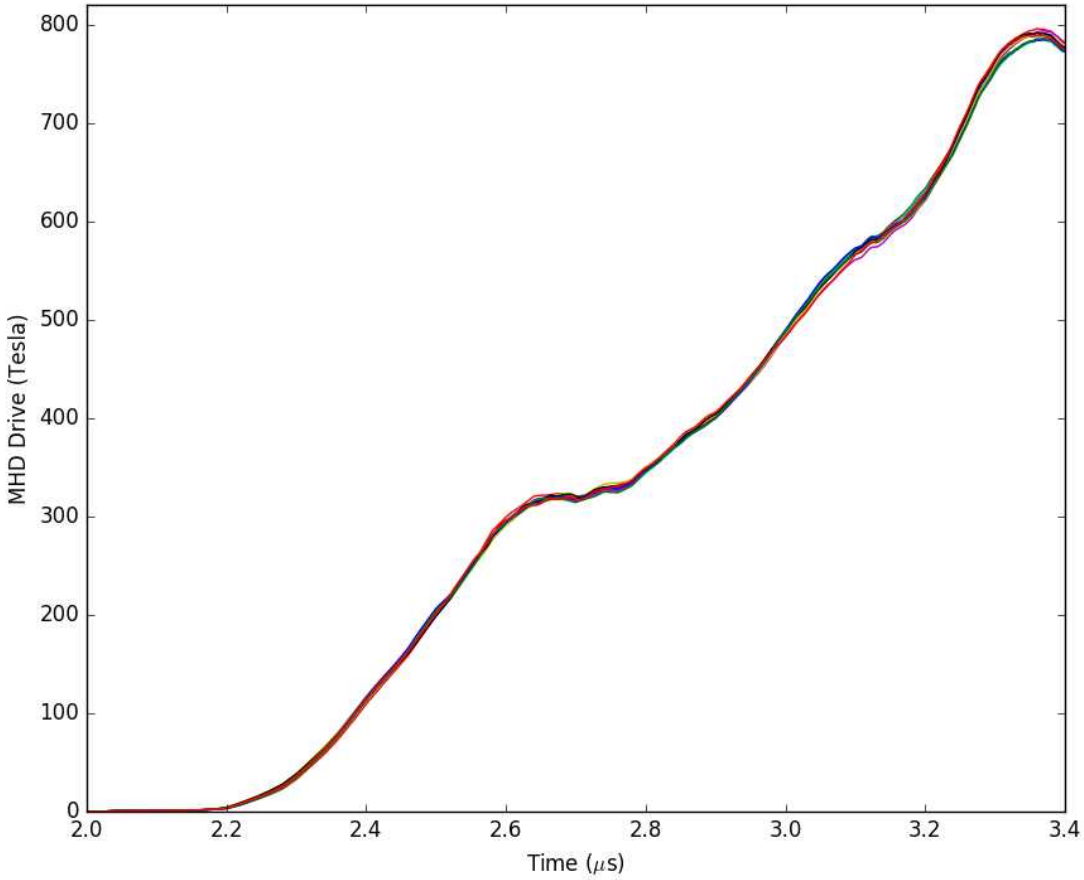
- SF_6 psia determines early breakdown time (advance time) of up to ~ 675 ns
- Biggest source of timing uncertainty in pulse line
- LTGS one sigma of 5 ns
- Developed a framework to randomly perturb pulse line timings, simulate the resulting pulse shape, quantify pulse shape robustness RE jitter.





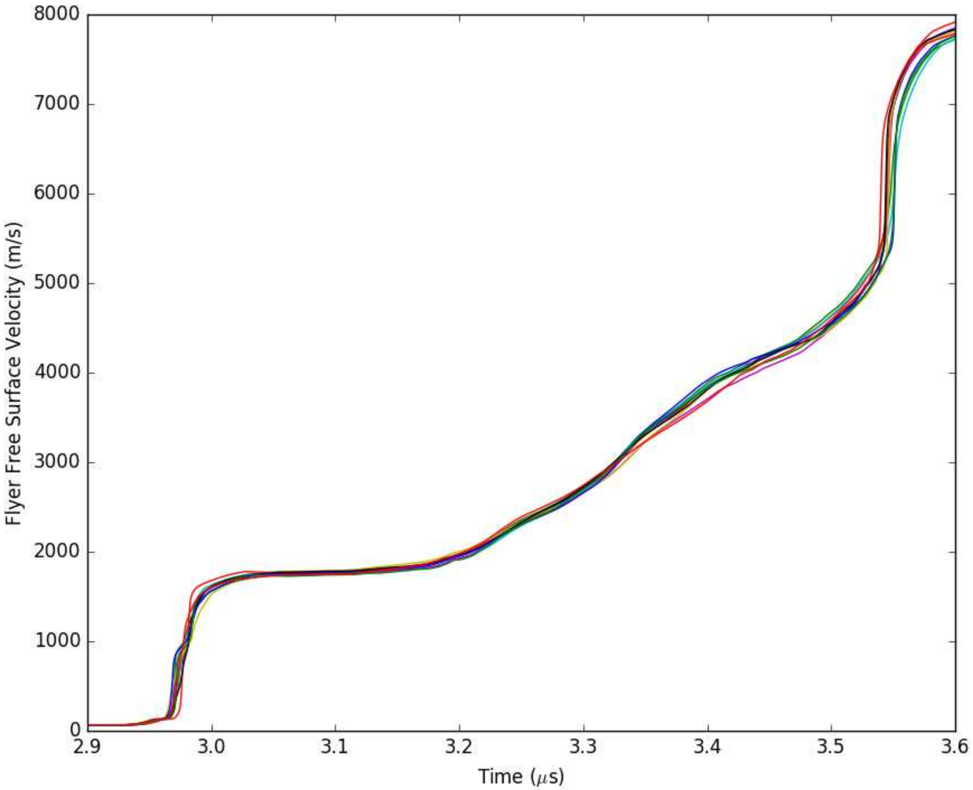
Statistical Variation in Pulse Shape

- Because the circuit model is fast, 1000 random variations can be run on a workstation in a few hours.
- How variations in MHD drive affect DMP experimental goals is not clear.
- Select 10 random pulses and propagate through the DMP model framework.



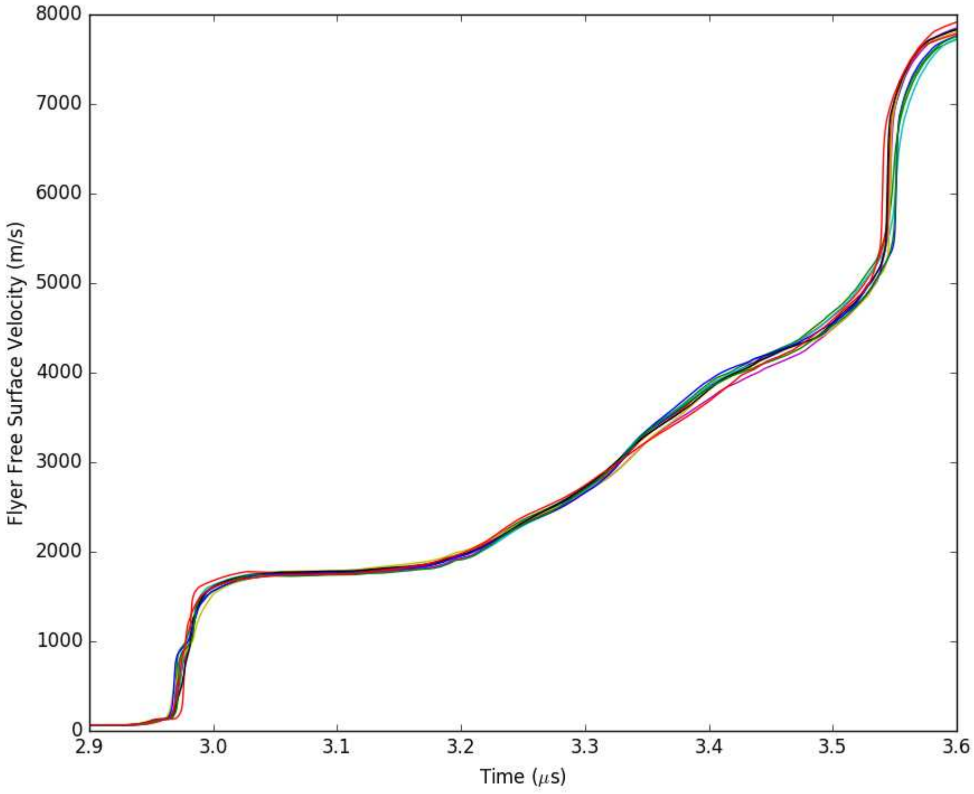
Jitter effect on DMP objectives

- Jitter effect on velocity profile is larger than might be expected.
- 6/10 of these pulses resulted in flyer shock-up, 4/10 had no adverse characteristics.
- Due to the small flight gap, none of the shocked flyers impacted early, or altered the target sample pressure or hold; this is not typical of most shock-ramp designs.



Jitter effect on DMP objectives (2)

- Flyer impact may occur up to 5 ns early (one sigma)
- Flyer free surface velocity during pressure hold varies by < 100 m/s
- Results in a predicted shock pressure in the cerium of 21-26 GPa
- Shock melt is 18 GPa
- The pulse shape is robust, thanks to specifics of this hardware design



Conclusions

- Sensitive pulse shaping on Z is possible if machine jitter is taken into account during the design phase.
- This new code infrastructure for jitter analysis has been adopted by a number of Z shot designers.
- New hardware and software capabilities are under development to enable a wider variety of DMP experiments on Z.