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Use of the WSU Pulser to Launch Flyer Plates for EOS and Cratering Studies

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Goals

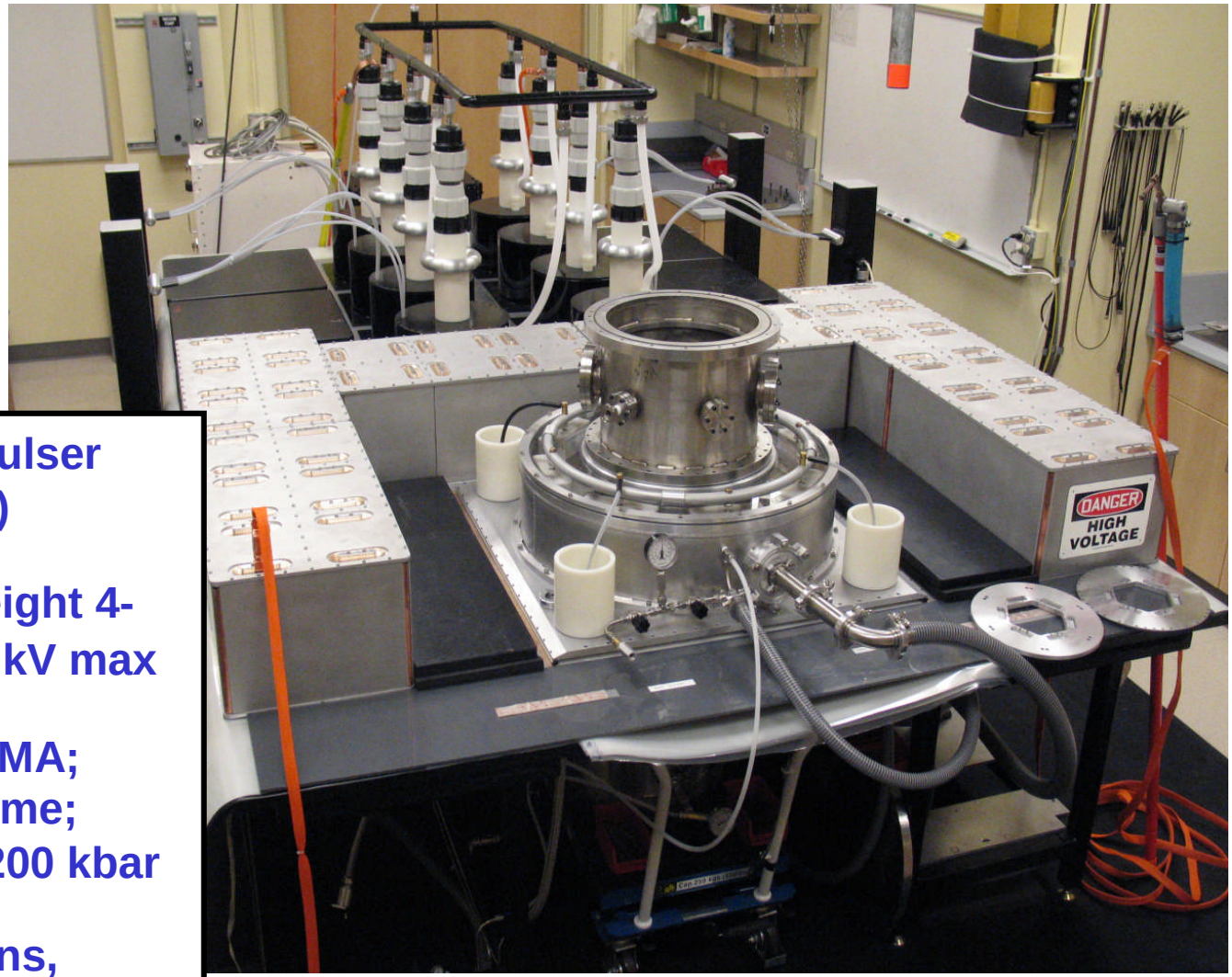
- Launch thick plates with magnetic pressure to velocities of 2-3 km/s over distances of several inches for cratering and other applications
  - Both single and composite flyer plates consisting of Al drive plate and attached flyer plates
- Segment plate into pre-determined fragments

Issues

- Mechanical and thermal stability of magnetically driven plates
- Controllability in fragmenting plates into smaller segments
- Evaluate whether technique can also be used for EOS
- Velocity measurements over large distances

ISP

WSU/ISP Pulser



- ~4 MA compact pulser (~2 shots per day)
- Energy storage, eight 4-μF capacitors, 80 kV max
- Peak current, 3.5 MA; 400 - 500 ns risetime; peak pressure ~ 200 kbar
- Sample dimensions, ~ 2-3 thick x 8-23 mm dia.

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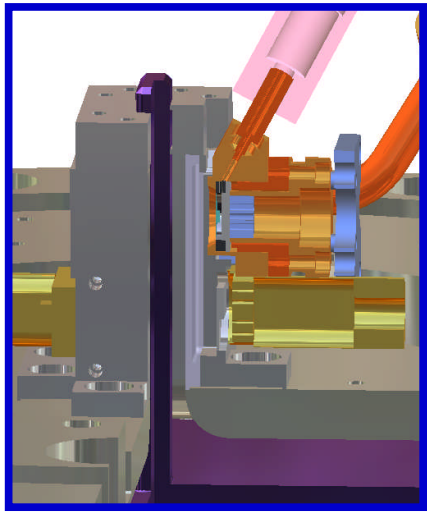
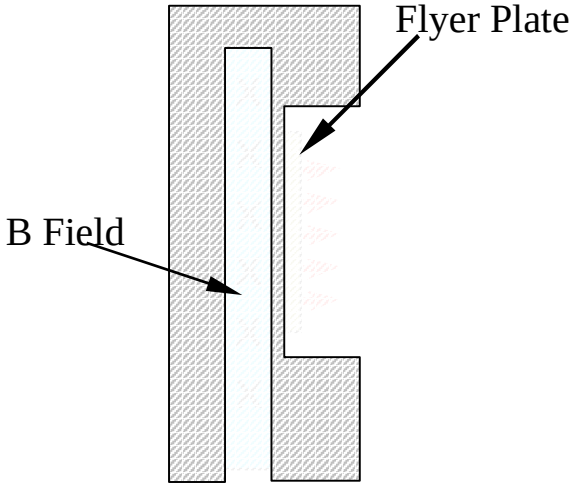
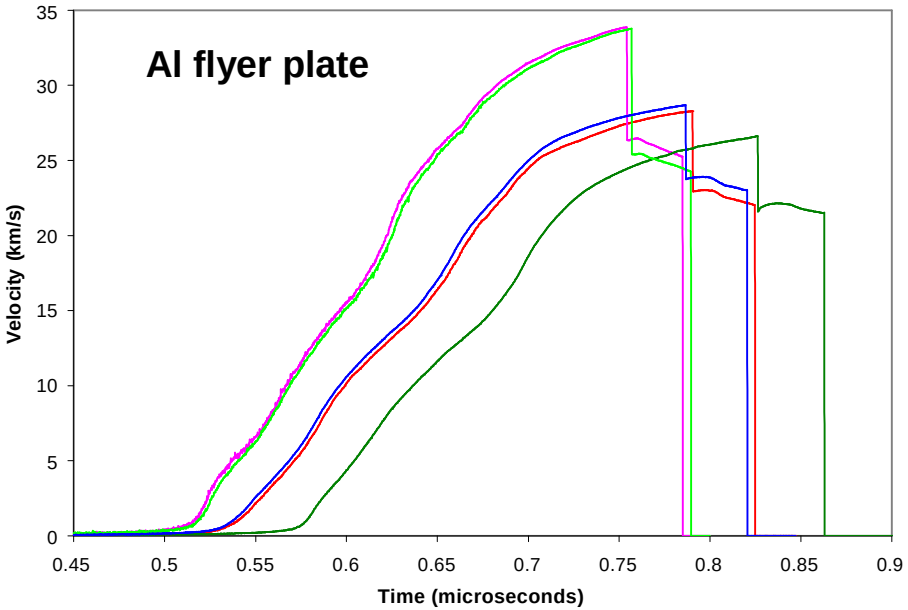
Background – Flyer plates have been successfully launched on Z to high velocities







- Flyer plate velocities of ~34 km/s have been obtained
- Launch distances are typically a few mm

Issues for launching plates over long distances

- Will magnetic field diffusion melt or vaporize the plate over long times?
- Will the plate fragment into multiple segments due to velocity gradients?
- Can VISAR be used to track plates for distances over 25 mm?
- Will plates remain flat for possible EOS experiments?

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Approach

- Evaluate feasibility of launching intact flyer plates to ~ 2km/s over tens of mm flight distance
- Evaluate the integrity of launched plates with a witness plate, including segmented plates
- Validate experiments with MHD simulations for optimizing and scaling experimental configurations

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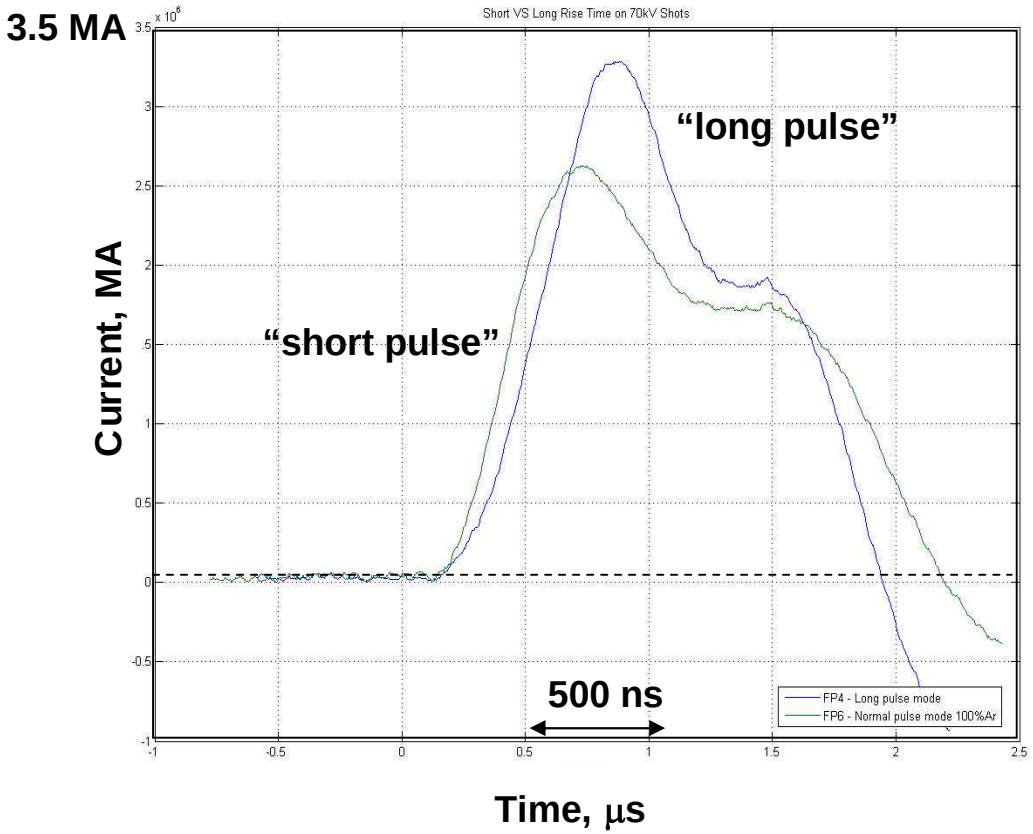
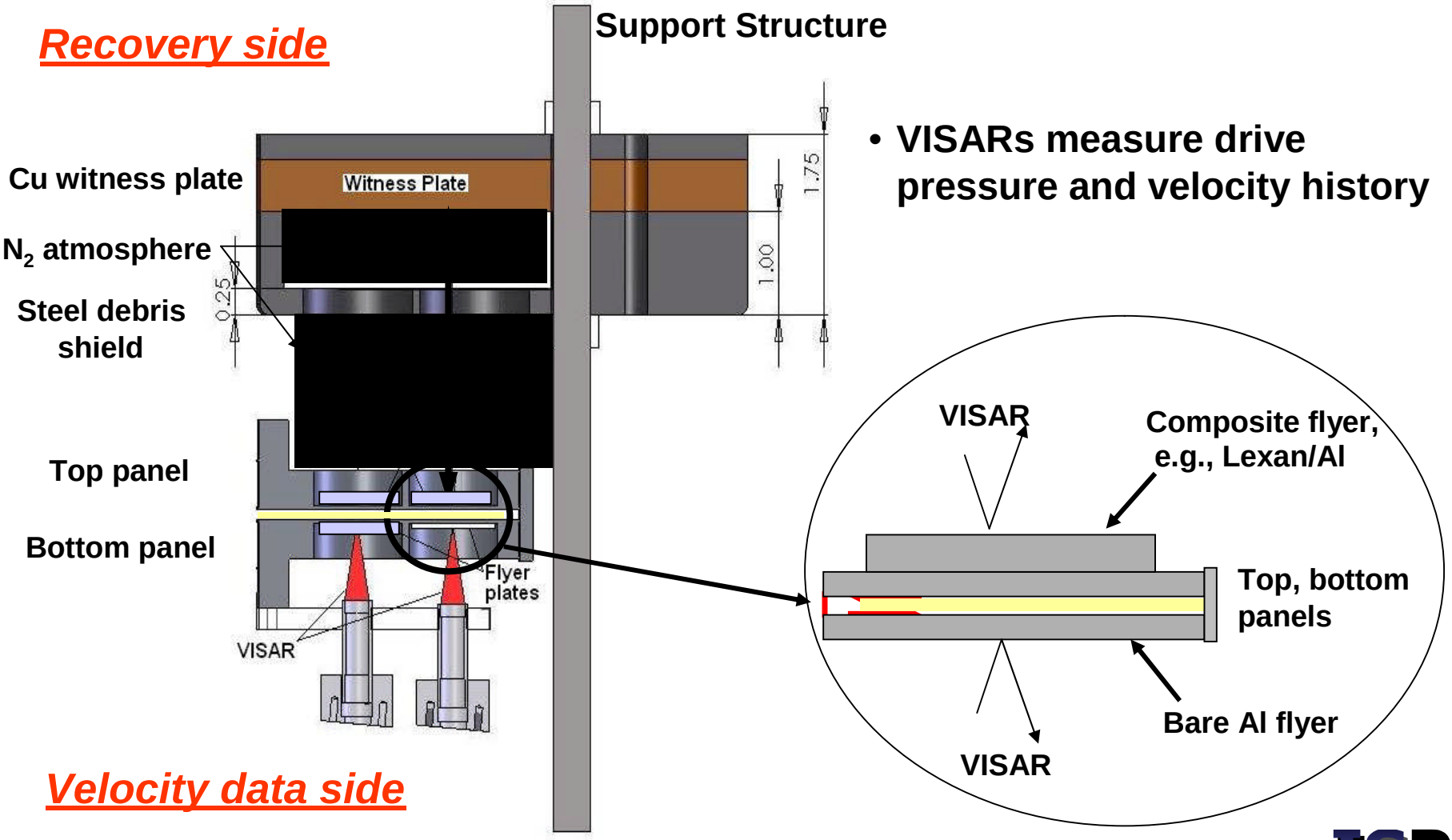
Typical current pulses used to launch flyer plates



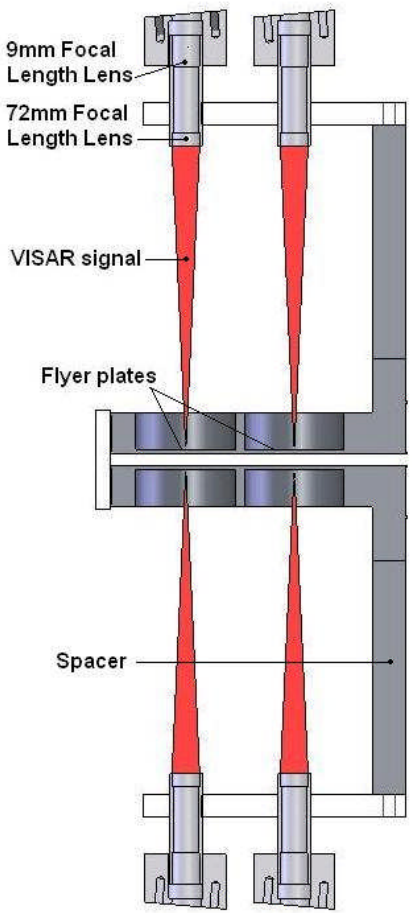
- Peaking caps and switches allow pulse variation
- Current pulses of ~500-800 ns risetime
- Most data have been obtained with short pulse

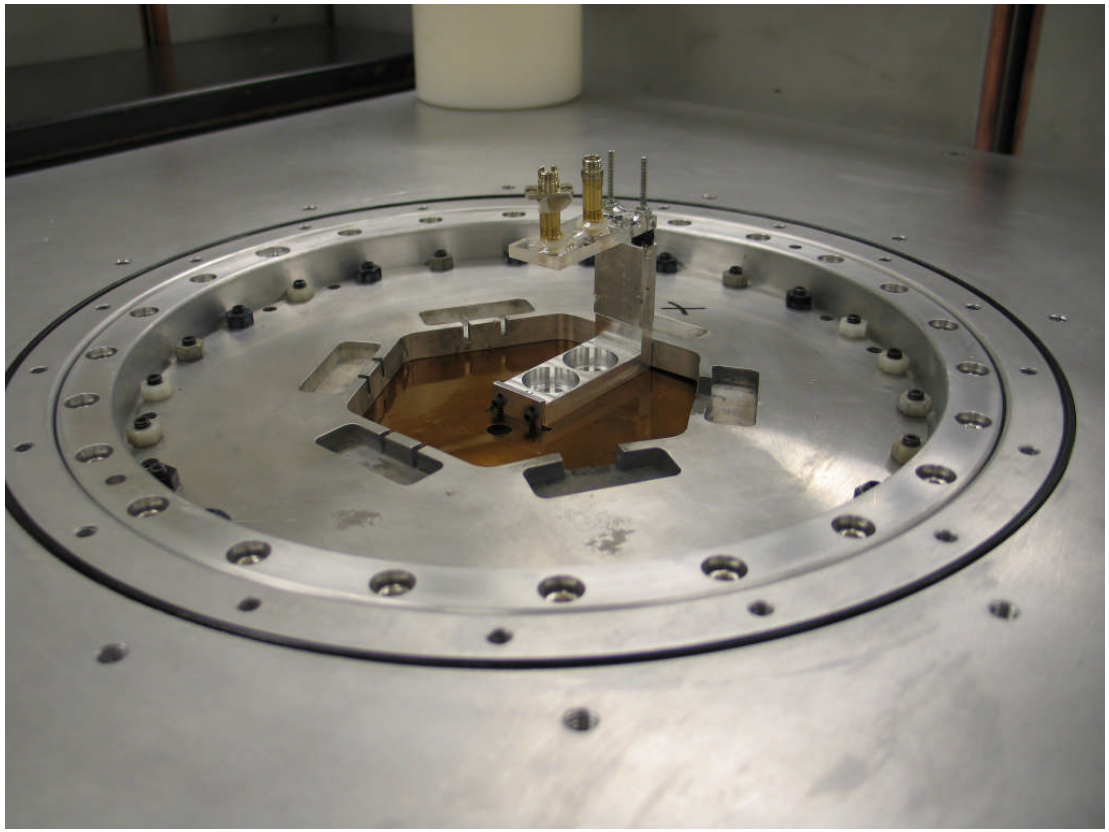
Configuration used to launch and recover flyer plates



- VISARs measure drive pressure and velocity history

Long focal length optics are used to track flyer plates over 10s mm





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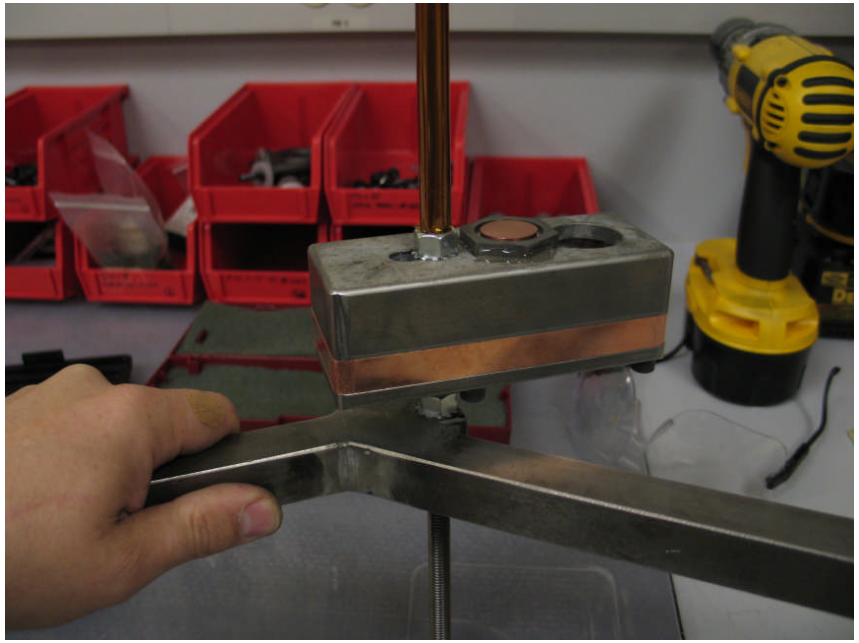
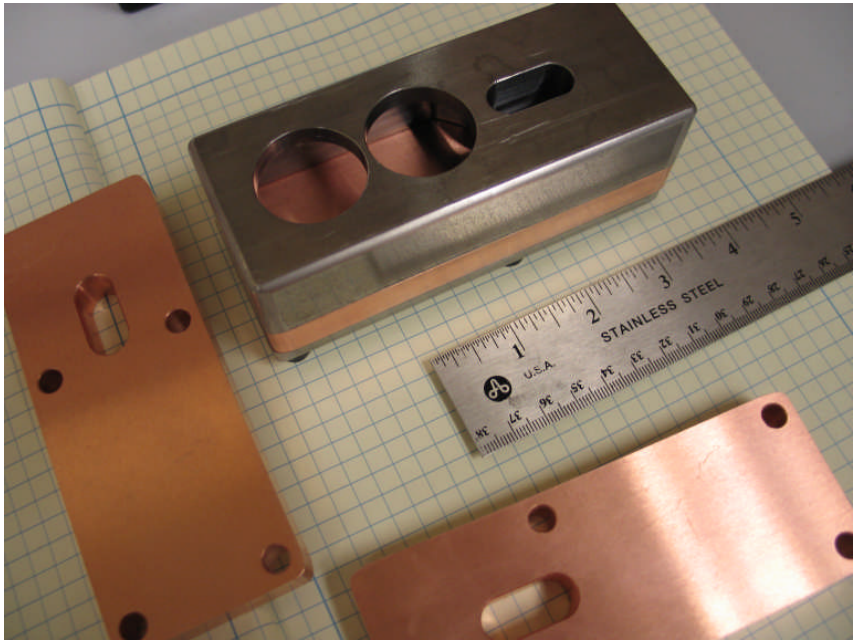
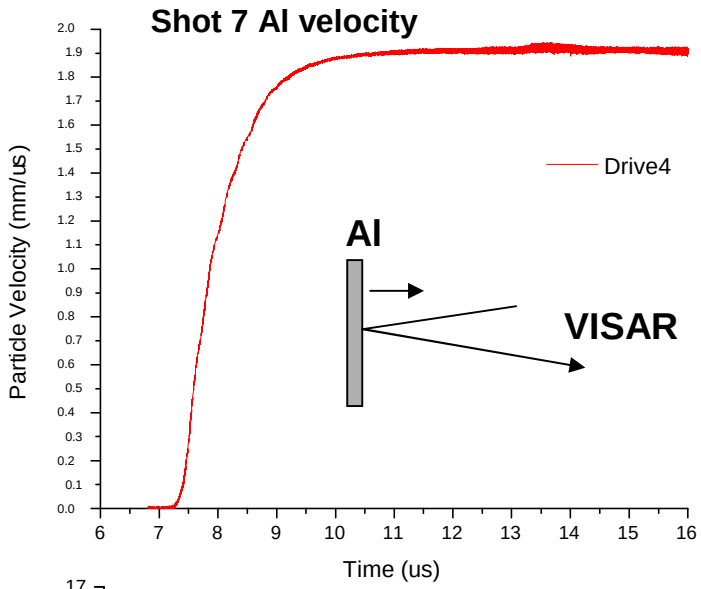
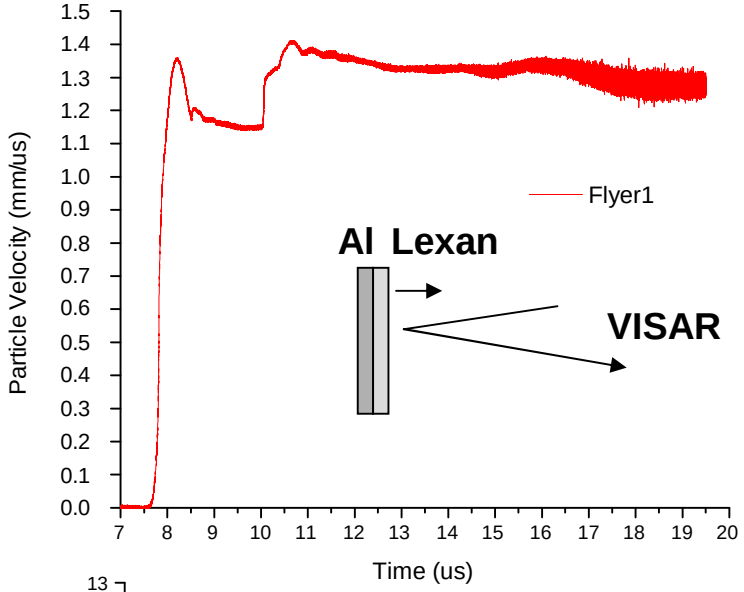
Witness plate assembly with compression bolt & bare assembly

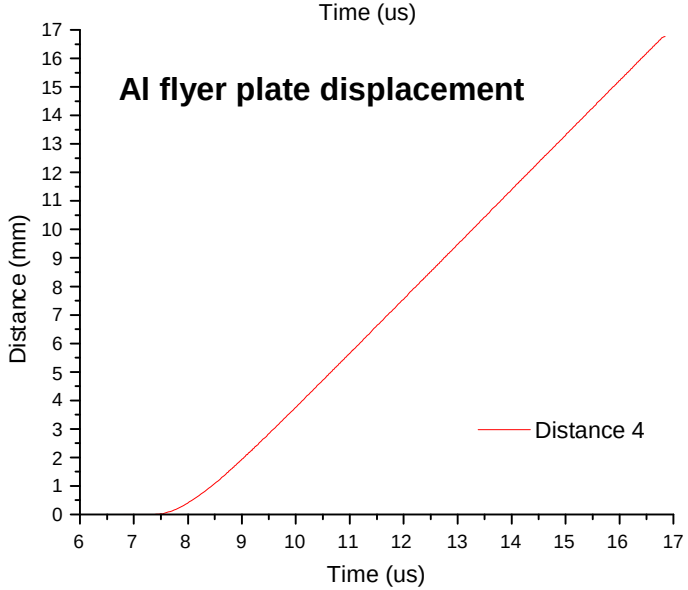


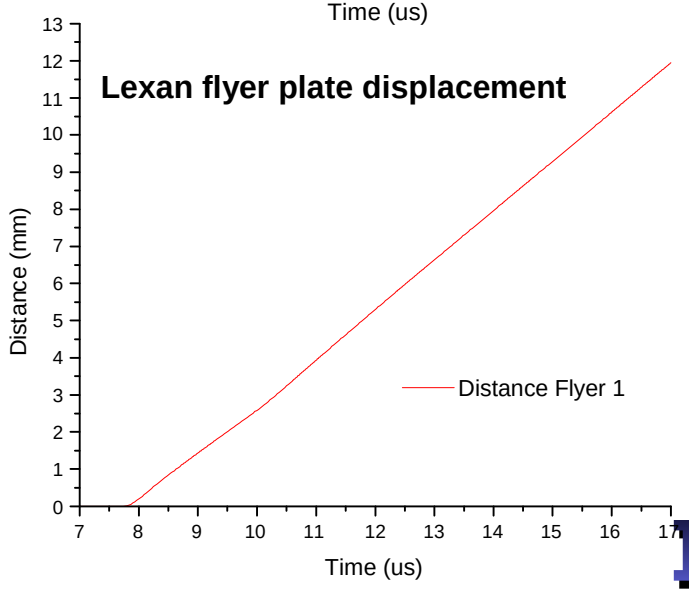


Typical measured flyer plate velocities

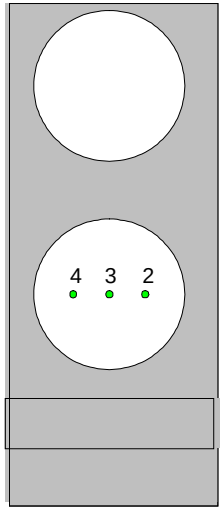


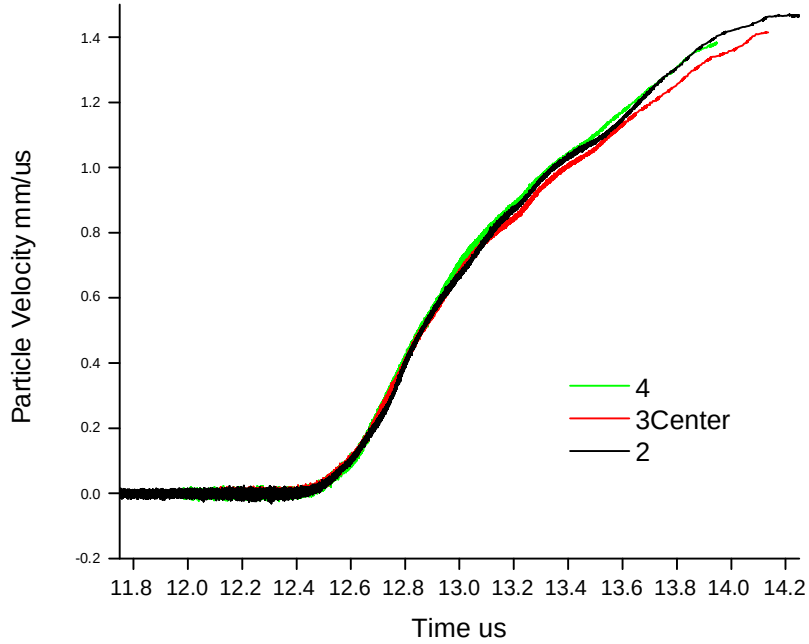


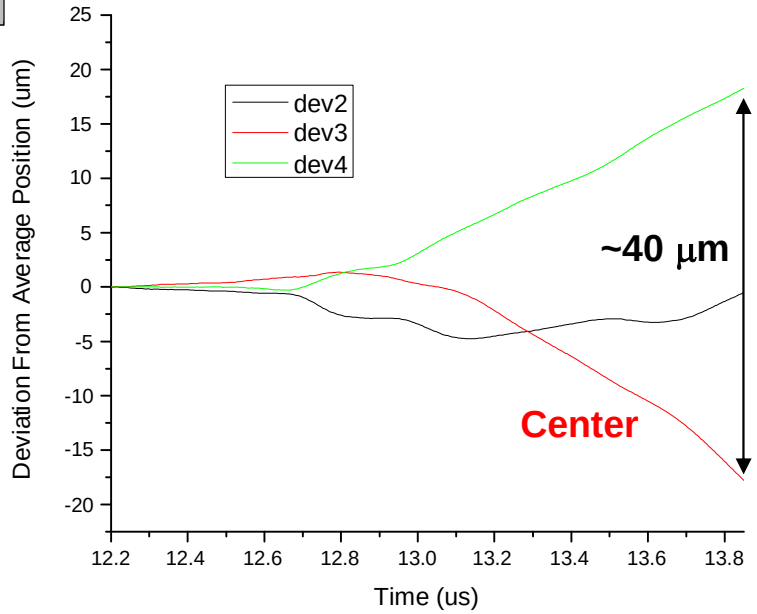




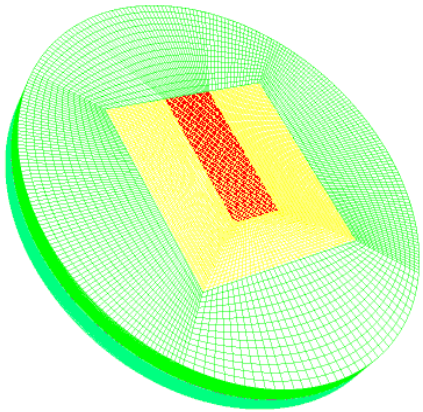
VISAR measurements indicate departure from uniformity later in time

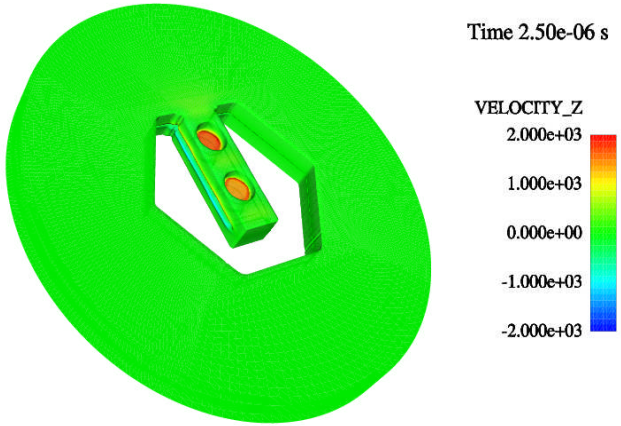






A 3D/2D radiation MHD code has been used to design and analyze experiments





- Unstructured finite-element based
- Eulerian/Lagrangian/ALE
- Object oriented
- Massively parallel
- Multi-material
- Coupled physics
  - Hydrodynamics
  - Magnetics
  - Thermal conduction
  - Radiation (not used this application)
- Material models
  - LANL Sesame & other EOS
  - Lee-More-Desjarlais conductivity

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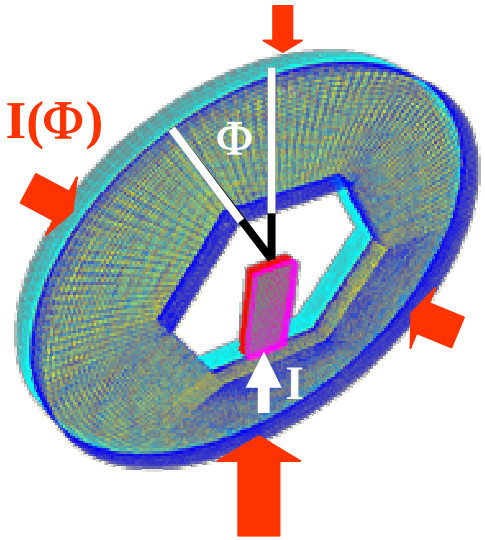
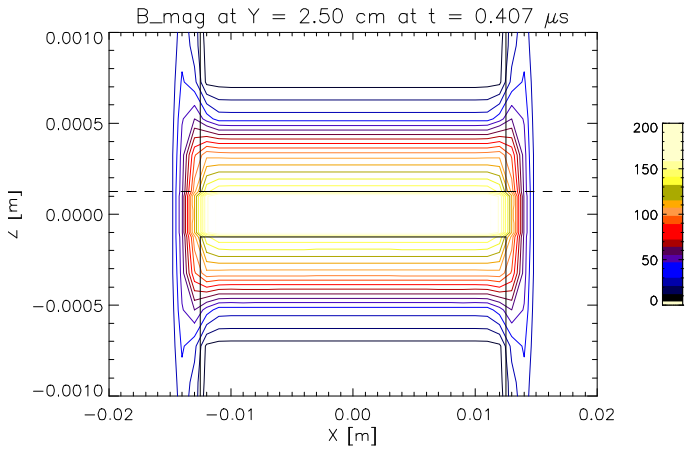
Several 1D, 2D, 3D simulations of the pulser were performed





- **Material models**
  - Elastic-plastic models with failure
  - Lee-More-Desjarlais conductivity
  - Experiment design
- **1-D simulations**
  - Validation of experimental results
  - Scaling to larger dimensions
- **2-D, 3-D simulations**
  - Uniformity of drive
  - Efficiency and scaling factors for 1-D

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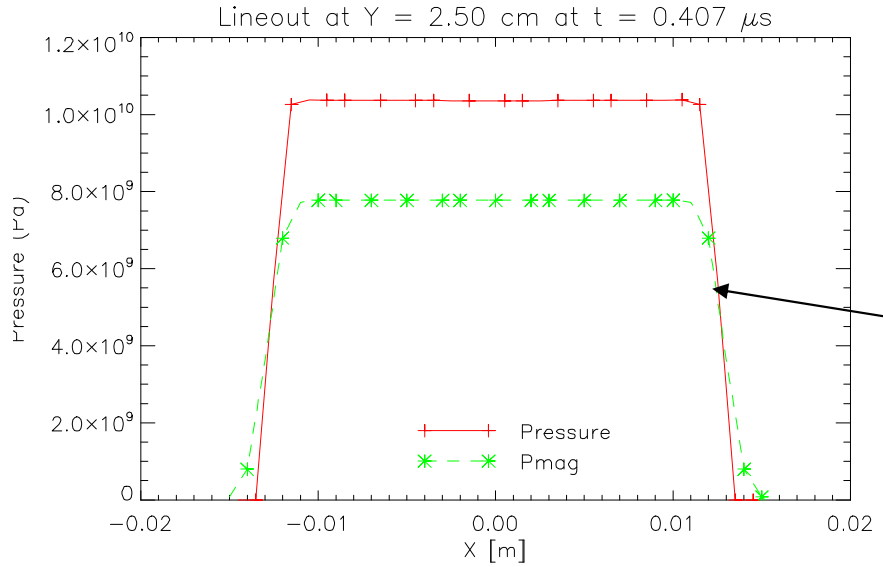
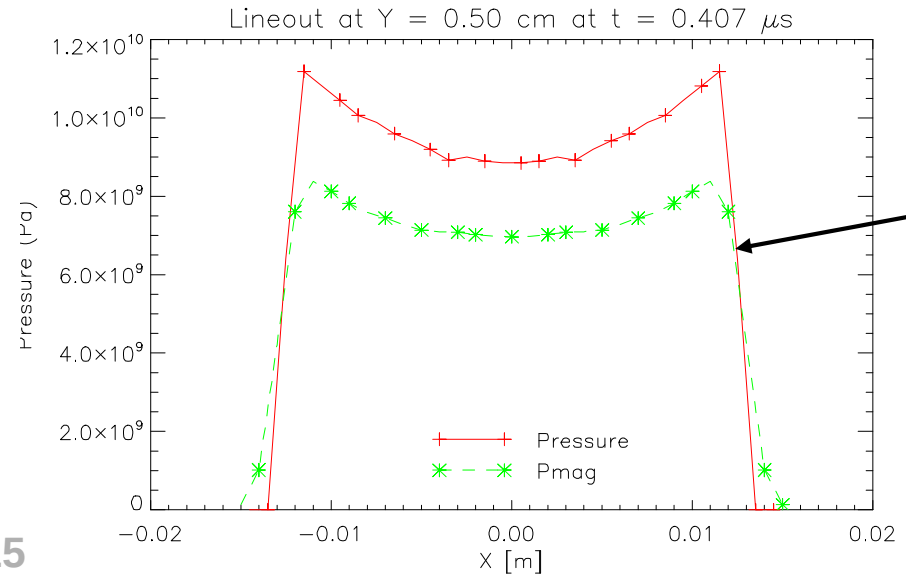
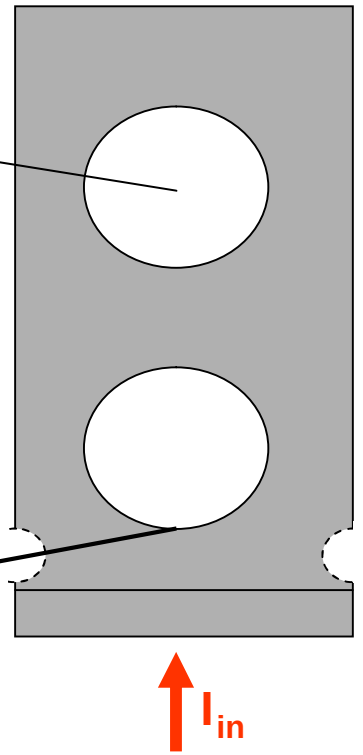
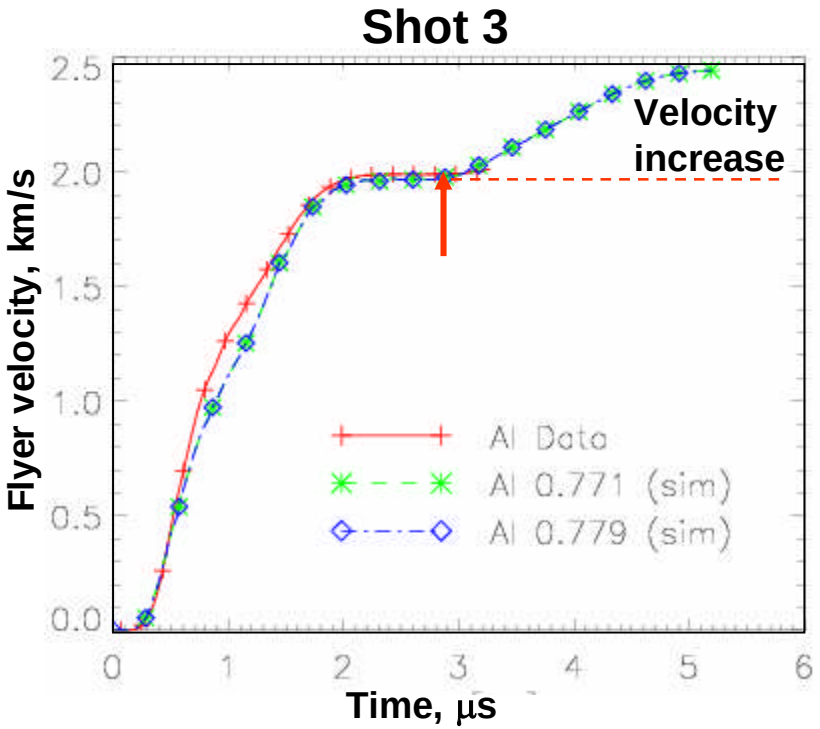
MHD simulations show effect of spatial current evolution

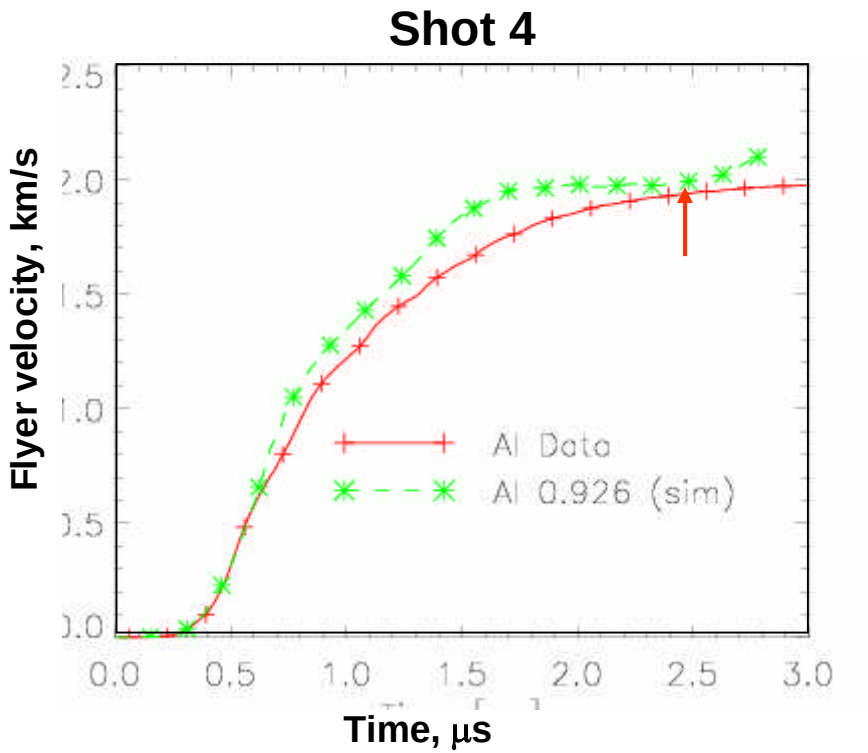






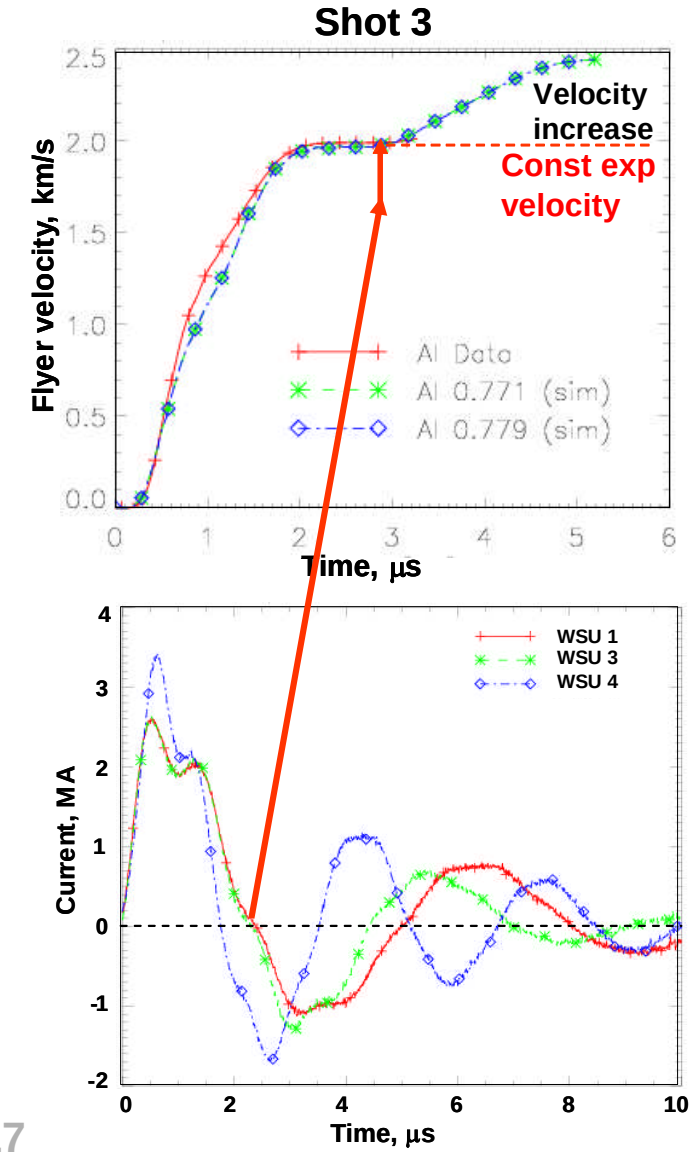
Comparison of calculated and experimental flyer plate velocities

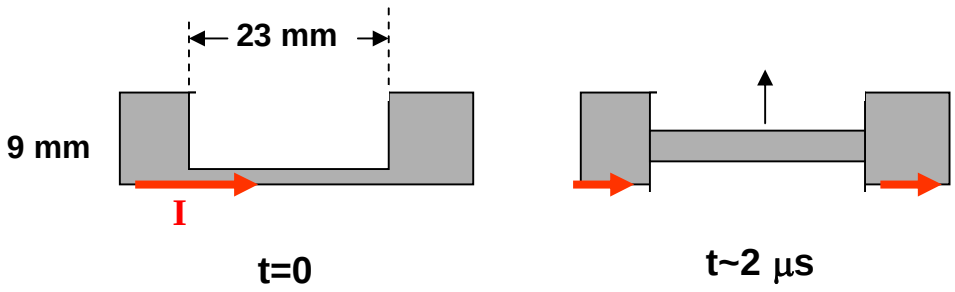




- **Experimental and calculated velocities diverge at ~ 3 μs**

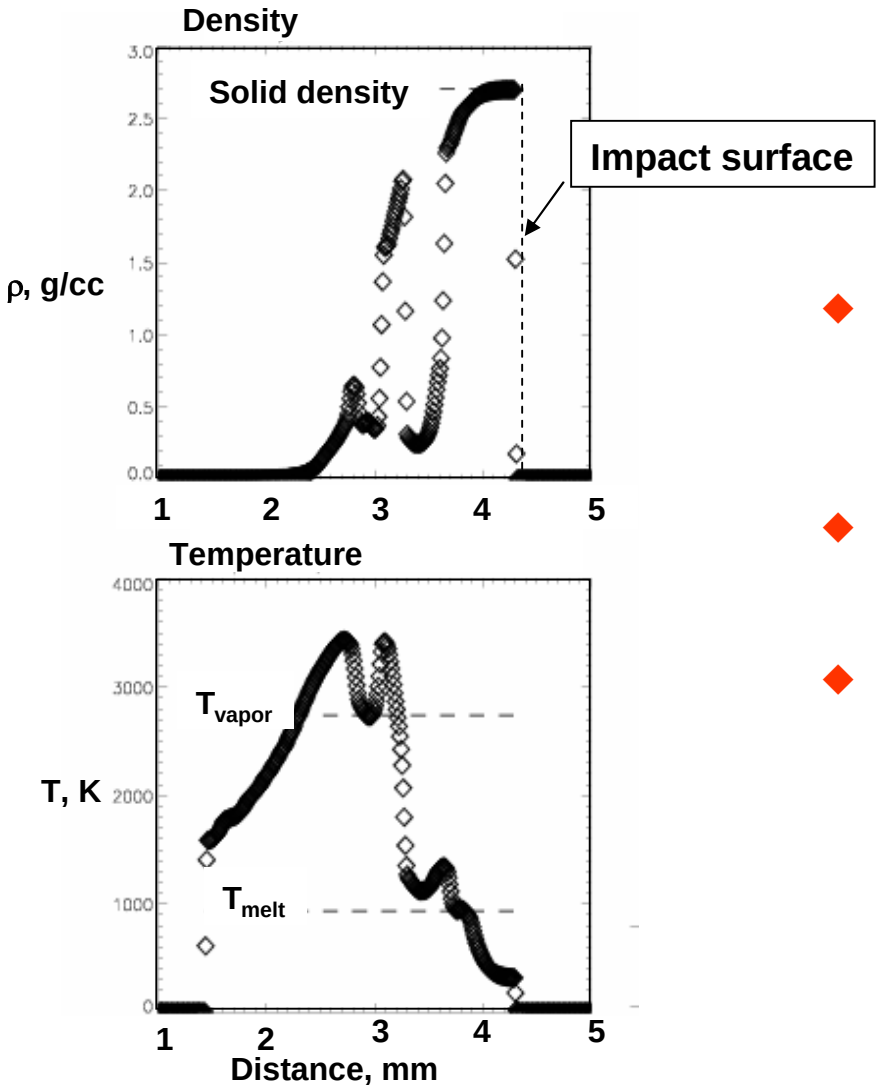
Loss of the current drive may be occurring at about later in time due to plate motion





- Increased 1- D calculated velocity is thought to be due to negative current ringing
- Departure of results suggests current detachment from flyer drive surface and flow around hole
- 3-D MHD needed to resolve issue

1-D MHD simulations also identify region of the plate that remains in the solid phase



- Near ambient conditions at the impact surface
- No change in state after about 3 μs
- Solid density phase is about 0.5 mm thick

Recovered flyer plates in a witness plate were used to confirm plate integrity

- Single 1-mm thick, 23 mm diameter aluminum flyer plates were launched to 1.7 mm and recovered on a copper witness plate
- Aluminum flyer plates remained intact with an estimated 50% of the thickness in the solid phase
- A single crater of about 0.5 mm depth was produced

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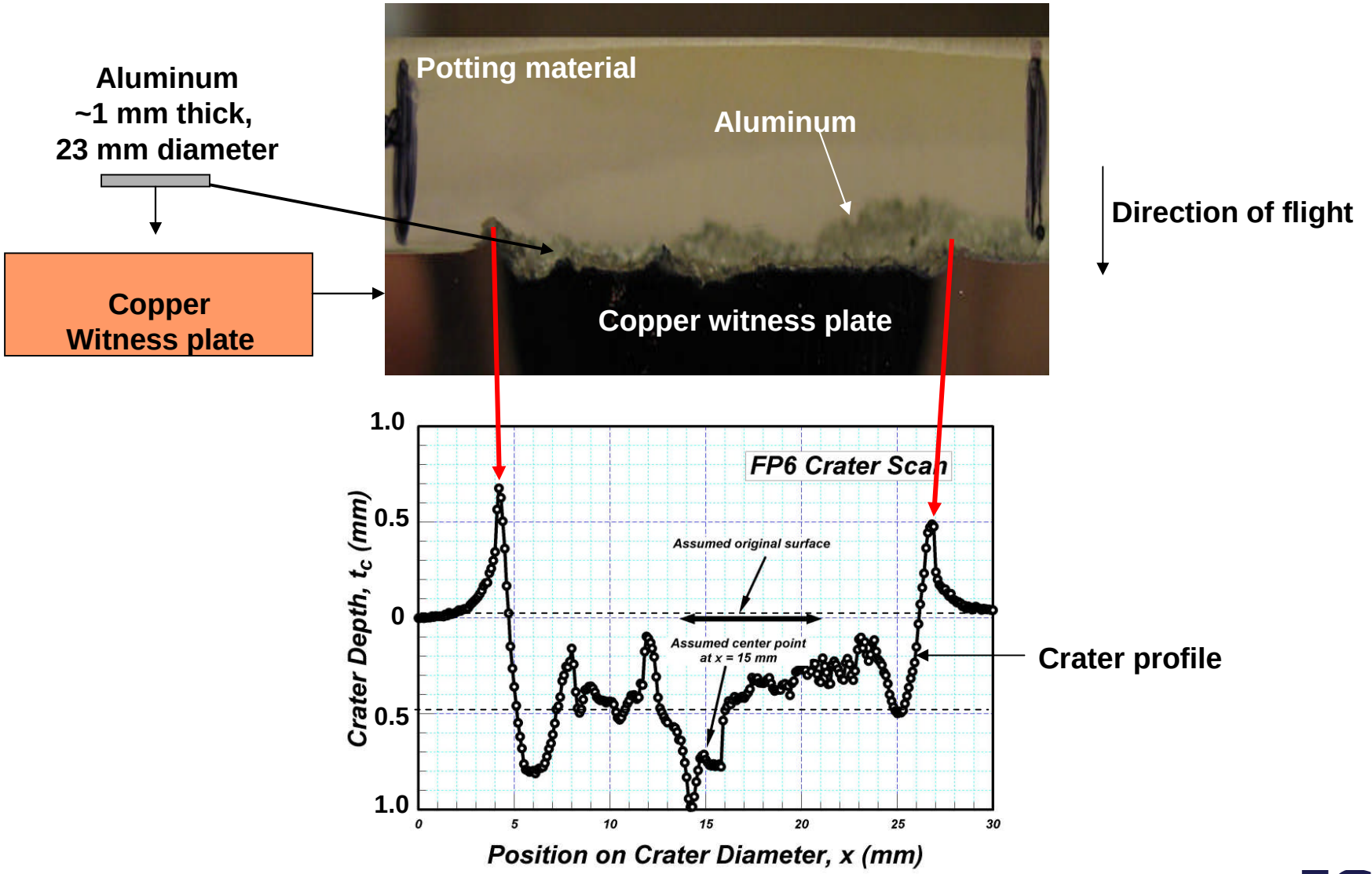
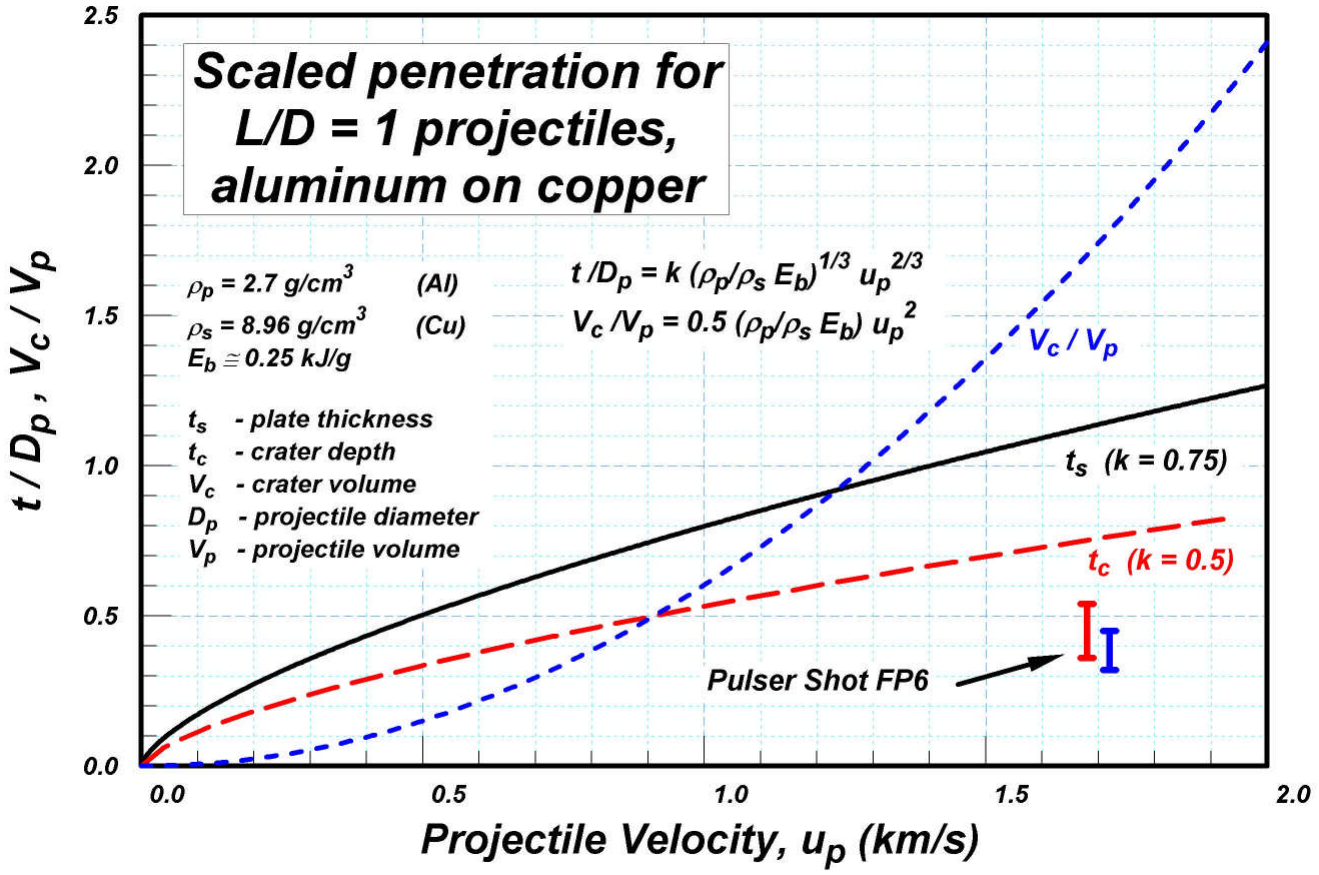
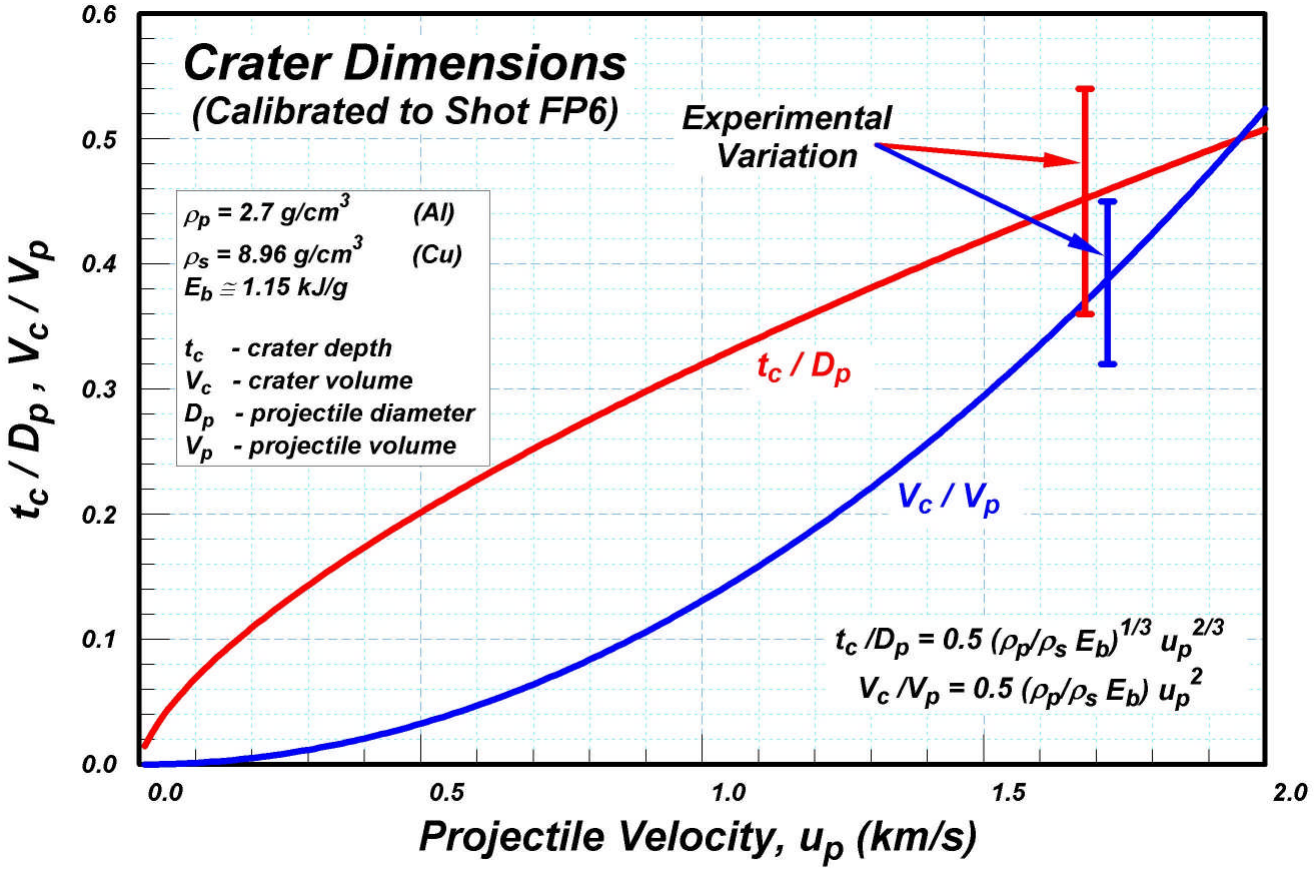
Flyer-witness plate configuration after impact



Scaling relations for crater formation were used to check self-consistency



Estimated crater depth is consistent with reported penetration parameters



Consistent with MHD simulations of ~ ½ mm remaining plate thickness

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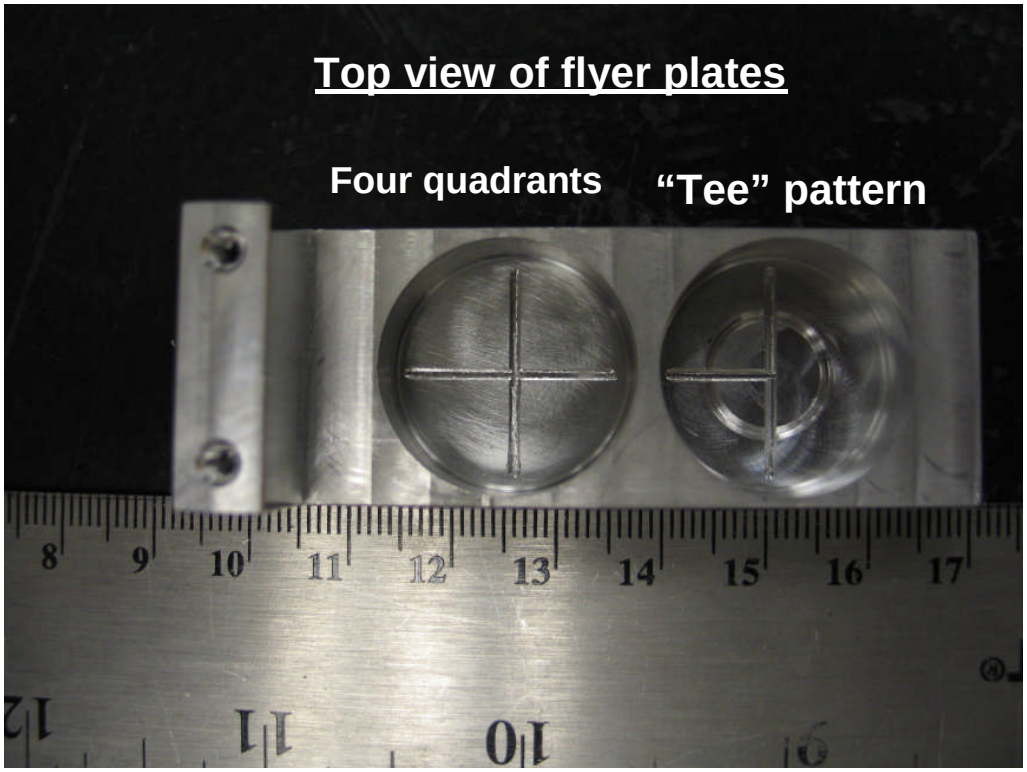
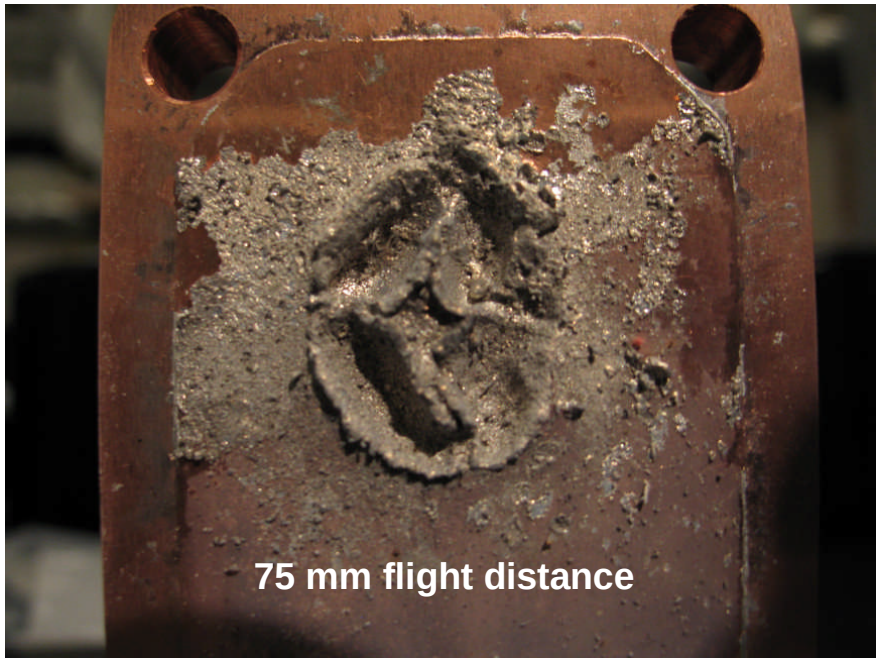
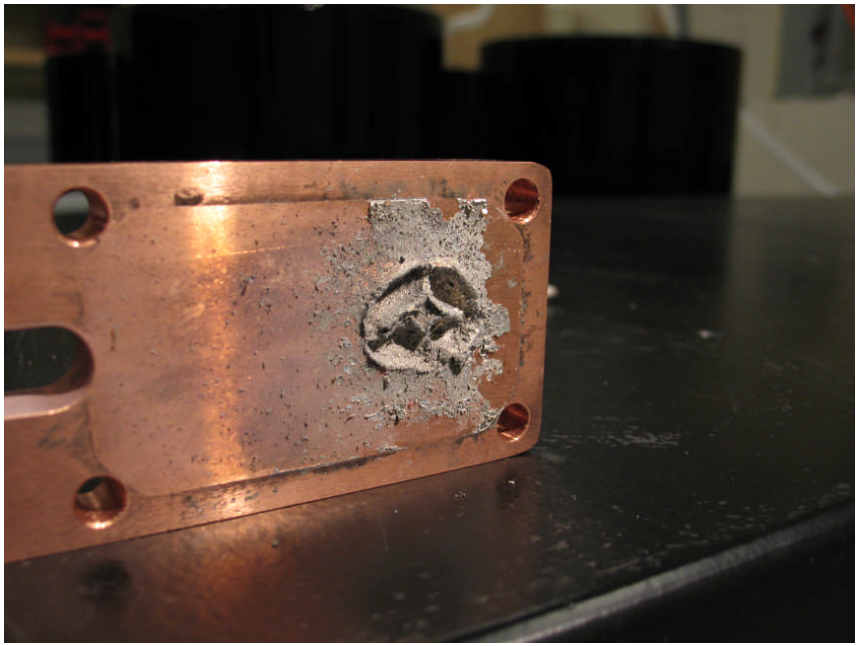
Aluminum flyer plates were scored with 250 μm grooves to produce individual fragments



- 250 mm groves machined into flyer plate
- Two different patterns:
  - Four sections
  - Three sections
- Flight distance of about 75 mm

Recovered witness plate from four quartered plate





- Individual impacts with low angular dispersion are apparent, indicating minimal fragmentation into smaller pieces
- Deeper penetration in individual impact areas of fragments

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Summary and Next Steps

- Stable single and composite flyer plates can be launched over several inches
- Segmented plates appear to remain intact
- MHD simulations validate experimental results

Next steps

- Extend the flyer plate launch distance and velocity
- Evaluate integrity of other flyer plates (sapphire, quartz, other metals)
- Examine scaling issues for larger sizes

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