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A Multiple Material Velocimetry Detector for Pulsed Power Flow Studies

M. H. Hess¹, G. R. Laity¹, B. T. Hutsel¹, C. A. Jennings¹, D. H. Dolan¹,
C. R. Aragon¹, K. Tomlinson², K. J. Peterson¹, V. Mehta³

¹Sandia National Laboratories

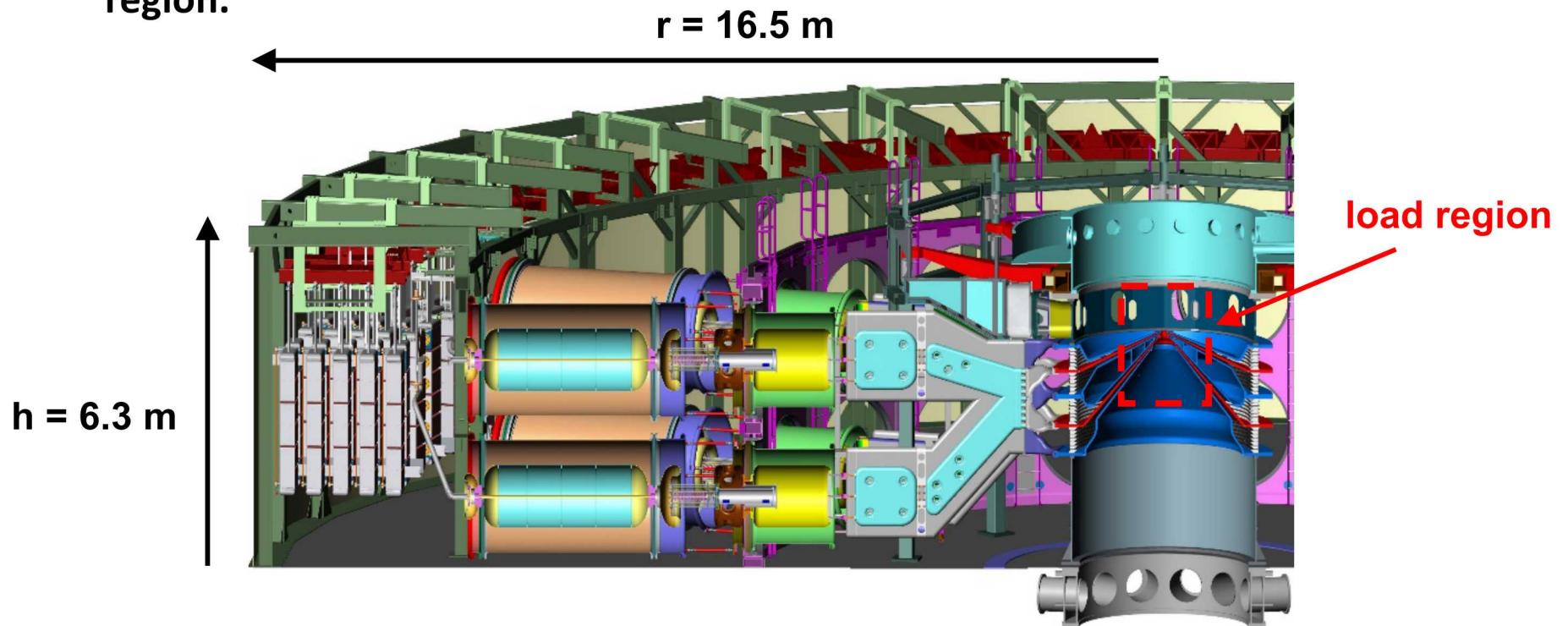
²General Atomics

³Georgia Tech University



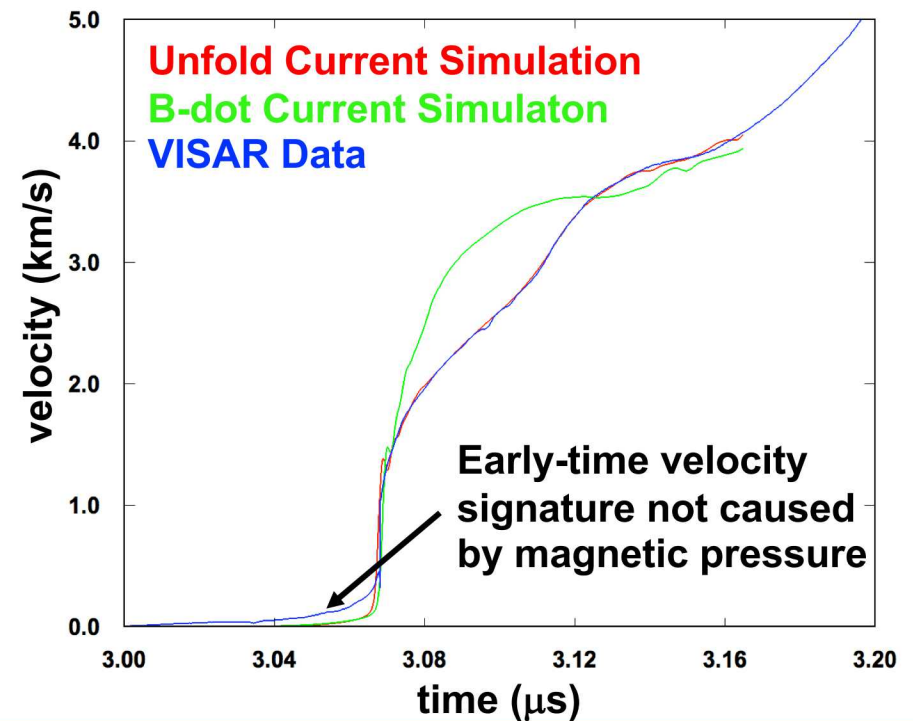
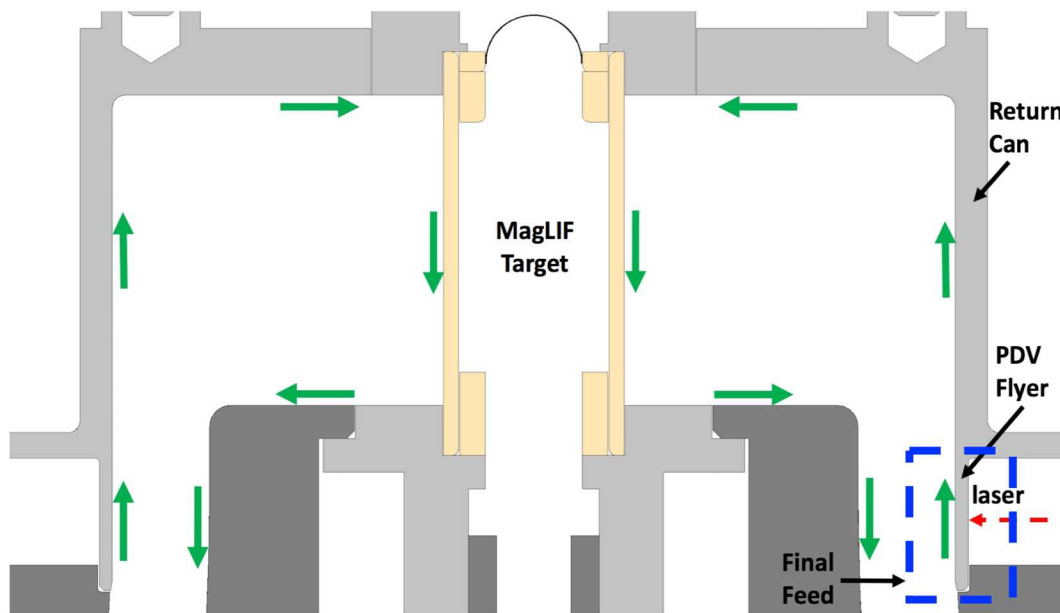
Why are we measuring current near the Z machine load?

- Z machine is the largest pulsed power machine in the world capable of delivering < 30 MA of current.
- We would like to know how much current is actually delivered to the load region, which is very small compared to the entire machine.
- Velocimetry offers the closest measurement that we can make to the load region.



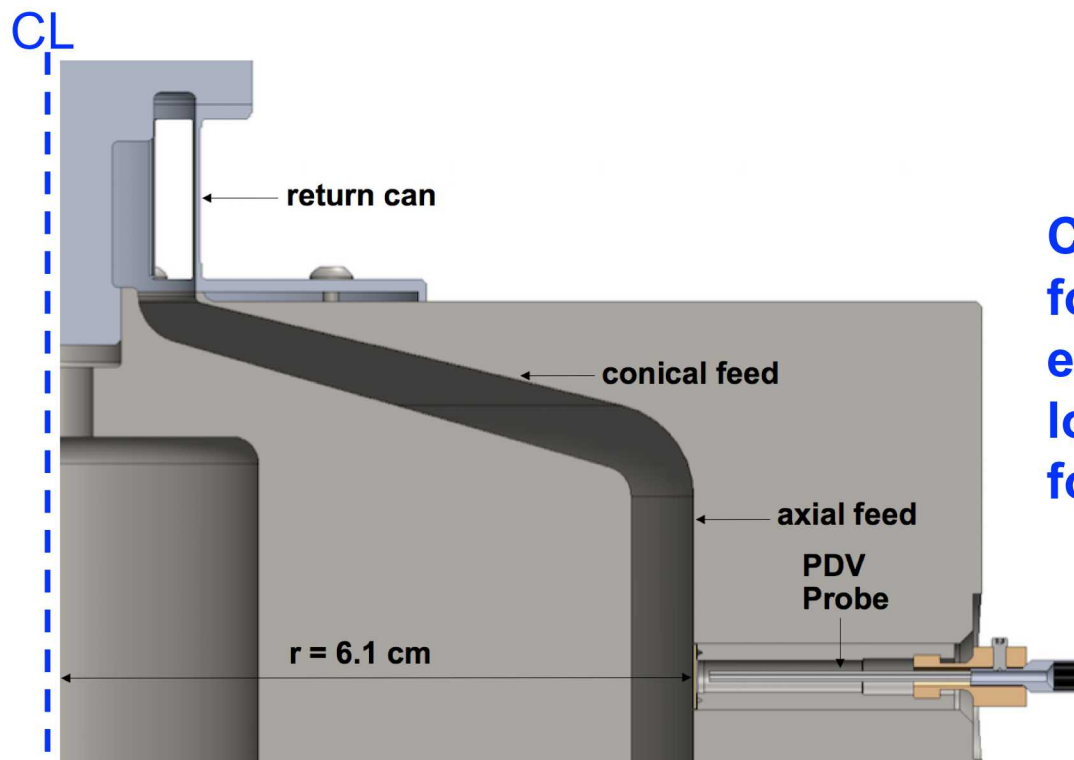
Motivation for Detector

- PDV (Photonic Doppler Velocimetry)/VISAR (Velocity Interferometer System for Any Reflector) diagnostics are routinely fielded on Z Pulsed Power Facility experiments for measuring current delivery by inferring magnetic pressure on metal flyers.
- In 2017* , we showed that flyers used in MagLIF experiments detected additional signal, which was not due to magnetic pressure, but could be caused by radiation hitting the PDV probe fiber**.
- The additional motion was small compared to the motion due to the B-field, but we didn't know what caused it, e.g. electrons or ions.



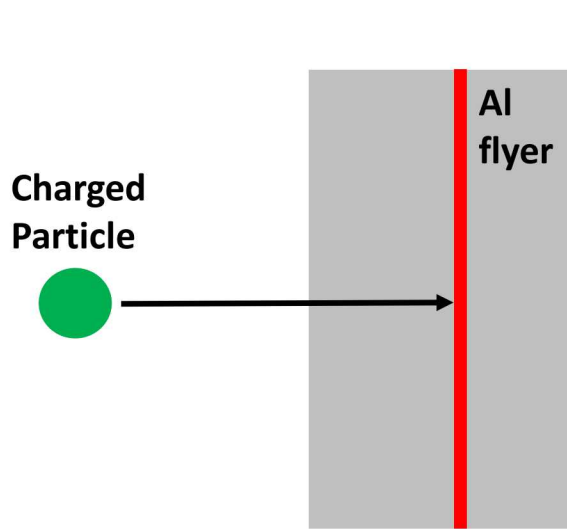
Multi-Material Velocimetry Detector

- We developed a new multi-material PDV flyer measurement for the purpose of clearly detecting non-magnetically driven flyer motion.
- The flyers were located far from the load region so that flyer motion is dominated by particle pressure, and not by magnetic pressure, for a clear measurement.
- The material thicknesses, e.g. Al or Au/Al, in each flyer were chosen for distinguishing species of particles and their corresponding energies.

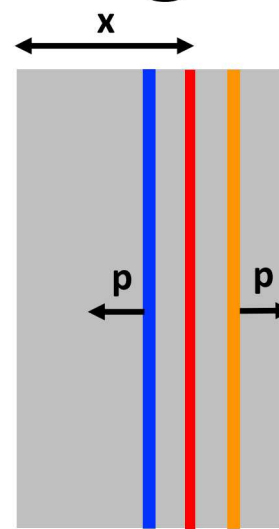


Cross-section of hardware for recent Z power flow experiments showing the location of our PDV probes for detecting particles

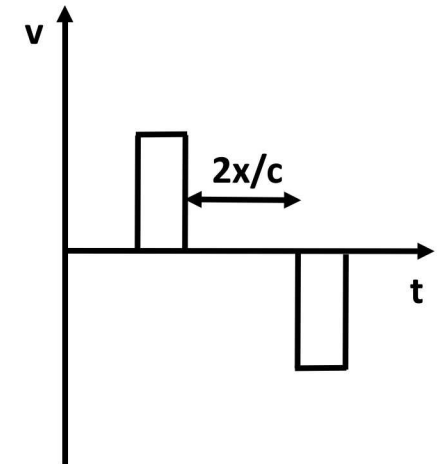
How the PDV Diagnostics Work



particles deposit their energy into the flyer



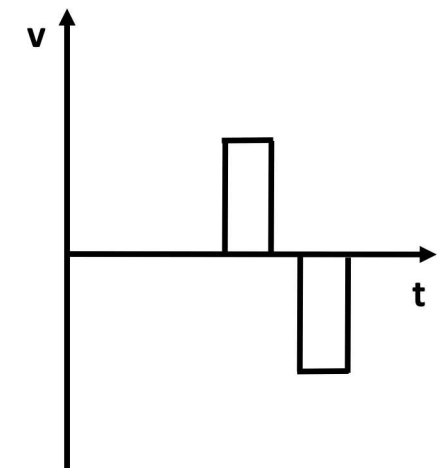
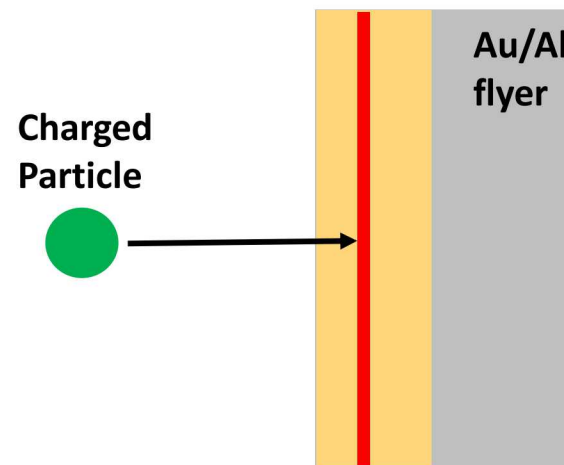
local energy deposition results in two propagating pressure waves carrying opposite momenta



PDV probe measures velocity signals that depend on where the energy was deposited and the flyer sound speed

Flyers made of a Au/Al substrate will have a different location of the energy deposition compared to Al flyers since the two metals have different charged particle stopping powers.

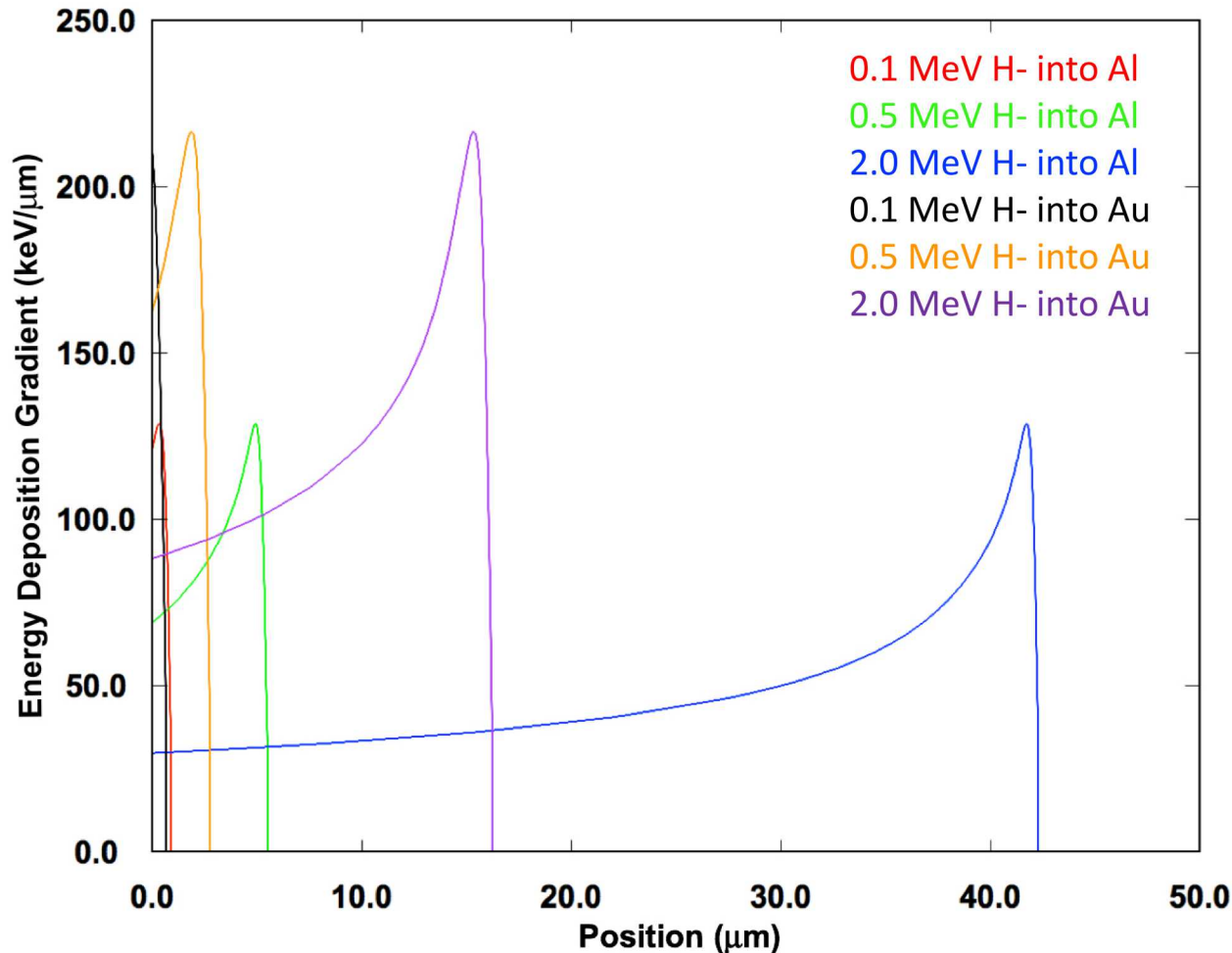
This results in measurable differences in PDV flyer velocities between different flyers.



PDV Diagnostics are Fielded in Pairs for Detecting Similar Power Flow Conditions

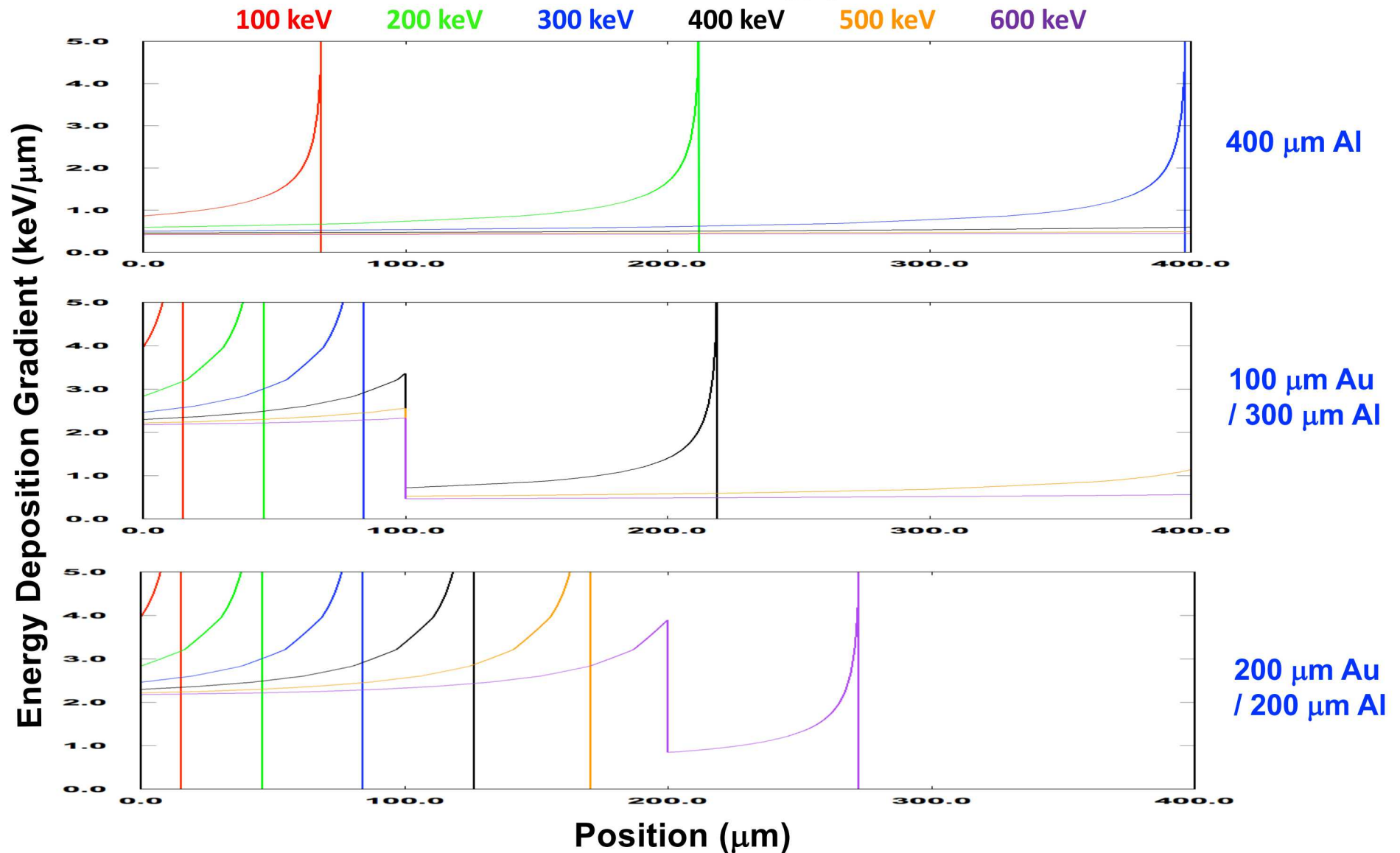
- There were three Z experiments in a recent series that fielded the probes in pairs at the same axial height and radius in the power feed, but at 30° apart.
- Why field the probes in pairs at the same height and radius?
 - If our experiments have azimuthal symmetry, then the two detectors would "see" a similar power flow environment.
- By comparing the velocities of two different flyers (different flyer velocity responses and stopping powers), we are trying to infer the properties of the particles (species, energy, current density, etc.) near the inner power feed surface.
- Three Z experiments
 - Z3184: 400 μm Al and 100 μm Au / 300 μm Al
 - Z3185: 400 μm Al and 200 μm Au / 200 μm Al
 - Z3186: 100 μm Au / 300 μm Al and 200 μm Au / 200 μm Al

Energy Deposition of Ions Keeps Ions Near the Flyer Surface



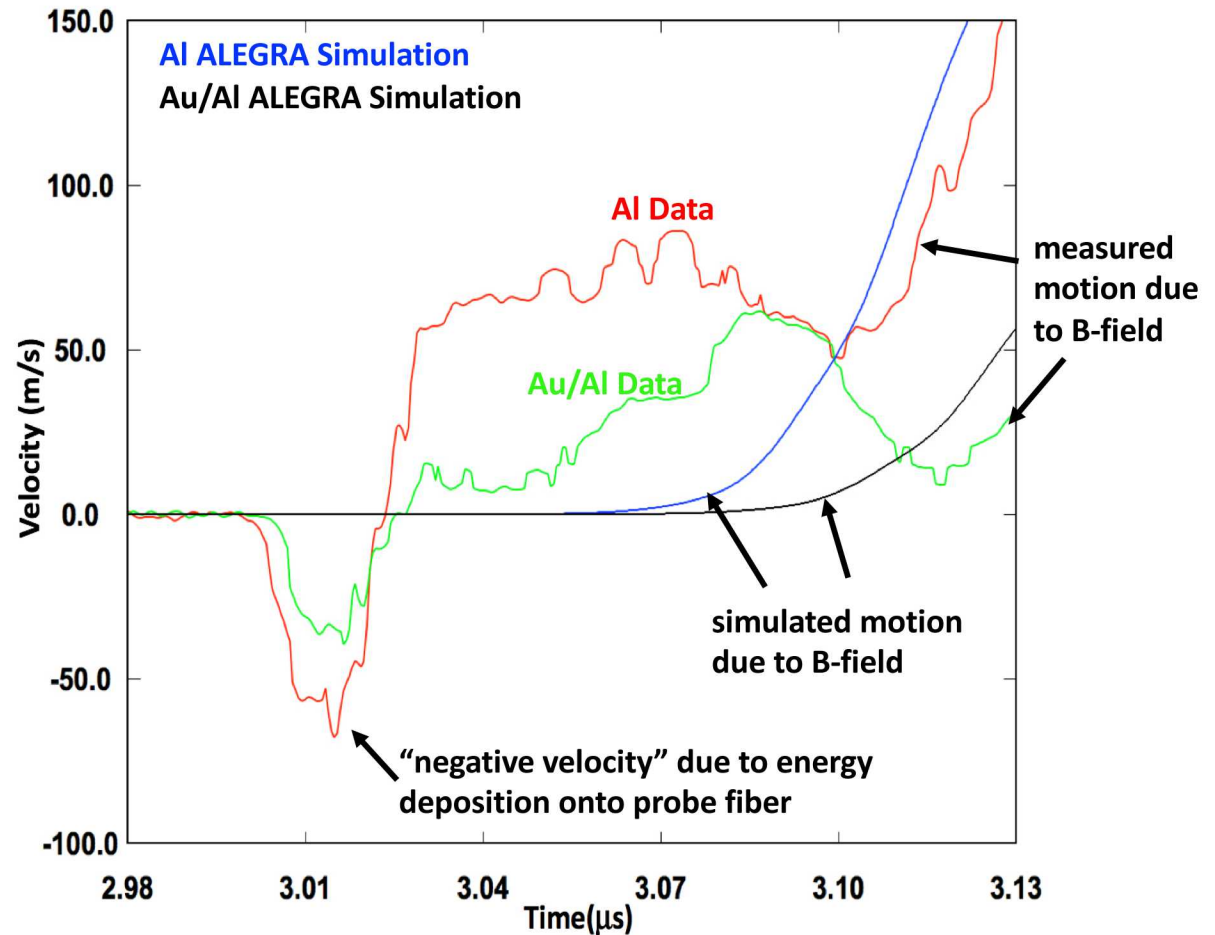
- Using well-known stopping power tables*, we can calculate the energy deposition for ions into Al and Au.
- In general, Au has a higher stopping power than Al.
- The power feed voltage does not exceed 2.0 MeV.
- Since the flyer thicknesses are 400 μm thick, ions will mainly deposit their energy near the surface <10% of the flyer bulk mass.

Energy Deposition of e- Varies With Energy



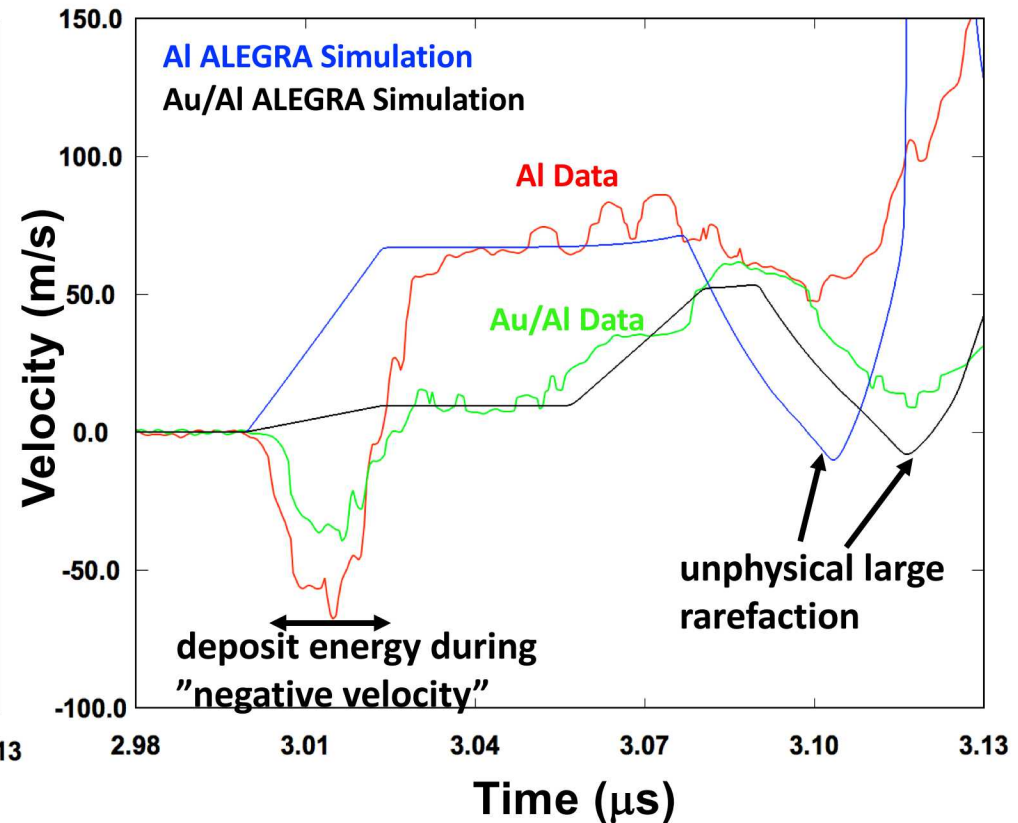
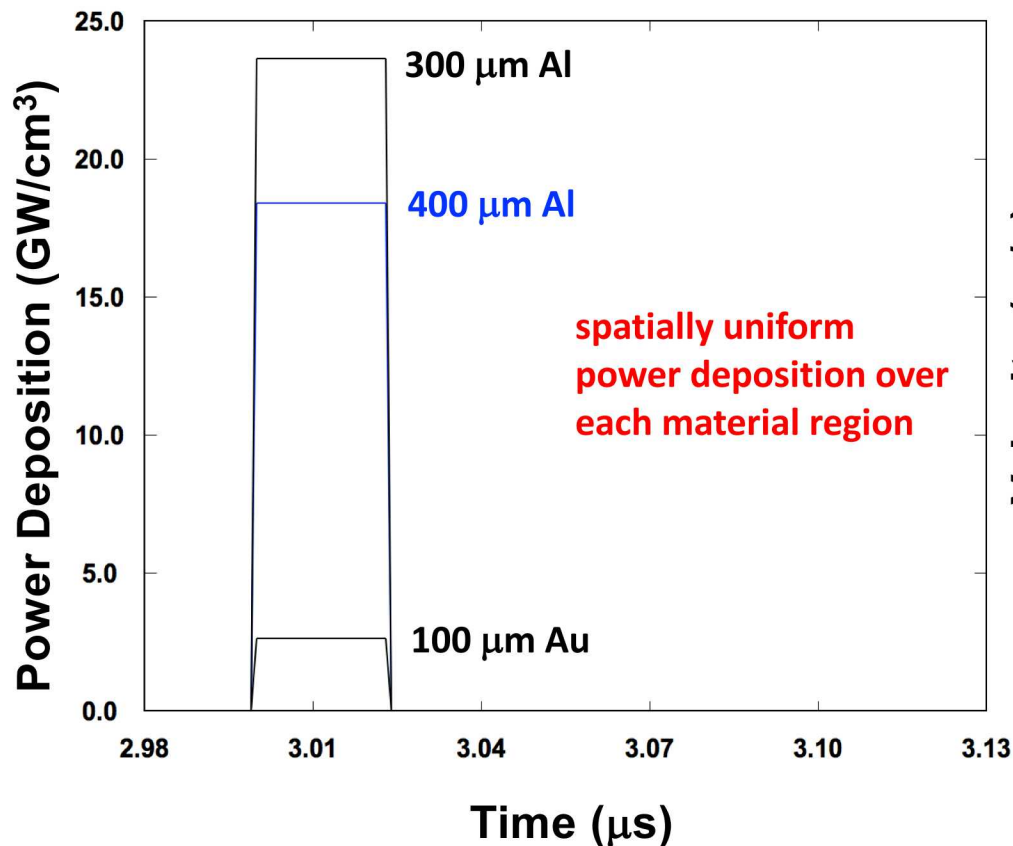
Data from Shot Z3184 Shows Particle Energy Deposition

- Data clearly shows a signal not due to B-field flyer motion.
- Data also shows the presence of a “negative velocity” signal which indicates energy deposition onto the PDV probe fiber.
- Since ions can only penetrate 10% into the flyer, the “negative velocity” signal cannot be due to ions.
- Electrons with energies > 400 keV are the most likely candidate for “negative velocity” signal.



Preliminary Fluid Analysis Produces Qualitative Flyer Motion

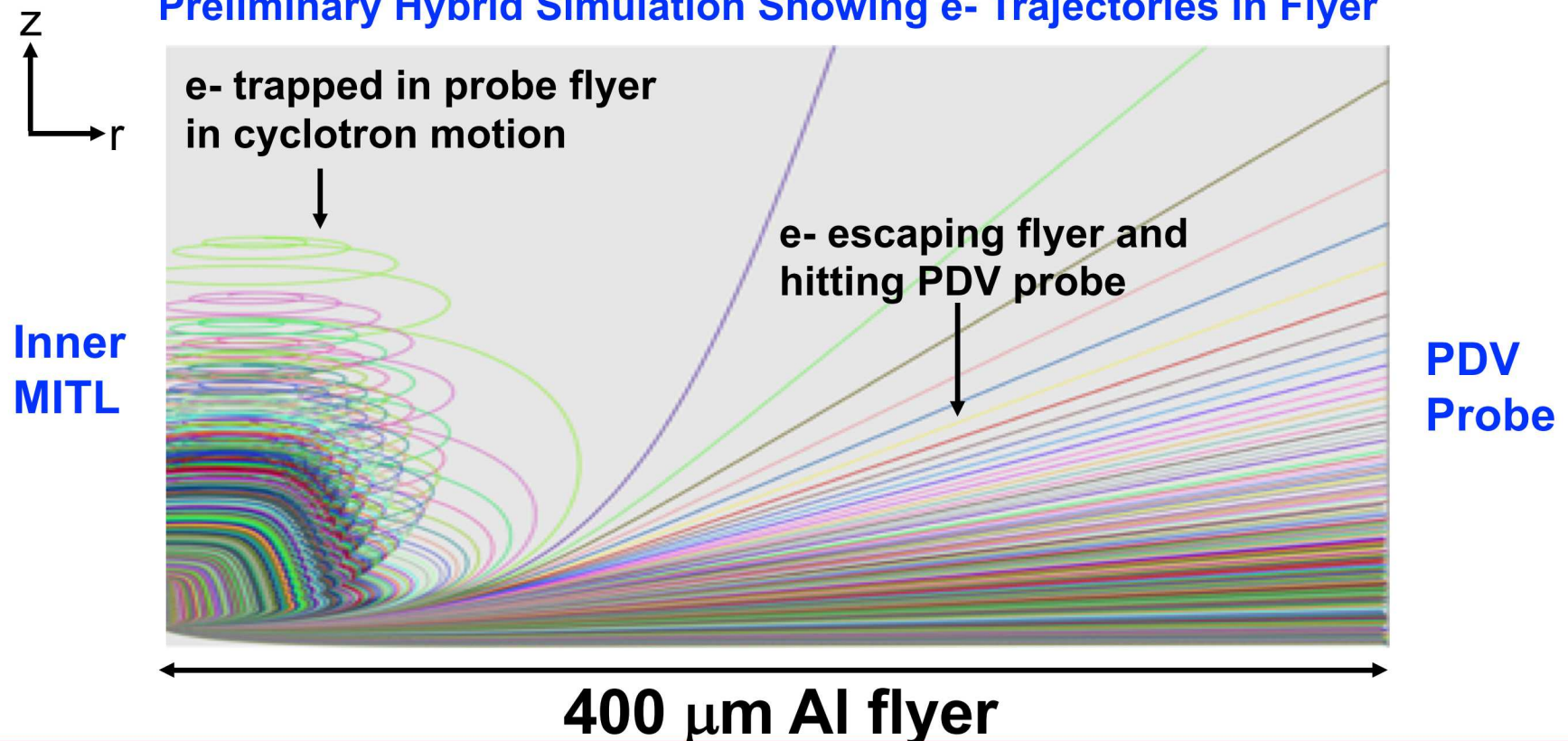
- We use a simple nontrivial model which deposits energy uniformly in each material during the measured “negative velocity” signal.
- Aspects of the early time motion are recovered, but rarefaction waves cause large discrepancies in the later time motion.



Future Modeling Direction: Hybrid Kinetic/Fluid Modeling

- A fluid code does not connect the flyer motion with the essential physics of the charged particle dynamics in the power feed.
- A hybrid code allows for a complete understanding of the charged particle energy deposition process into the flyer, and utilizes a self-consistent picture of the charged particle kinetics in the inner MITL.

Preliminary Hybrid Simulation Showing e- Trajectories in Flyer



Summary

- We have designed and fielded a novel PDV diagnostic, which we believe is capable of detecting particles on the anode side of the inner MITL at the Z Pulsed Power Facility.
- The diagnostic shows a positive velocity signal, which is not due to magnetic pressure, and in addition a negative velocity signal, which is not due to ions. The signal is likely due to electrons.
- We have performed preliminary ALEGRA fluid simulations of the flyer to understand the time-dependent energy deposited, and are expanding our simulation efforts to incorporate hybrid modeling.
- More data/analysis will continue as this diagnostic is fielded on future Z power flow experiments.