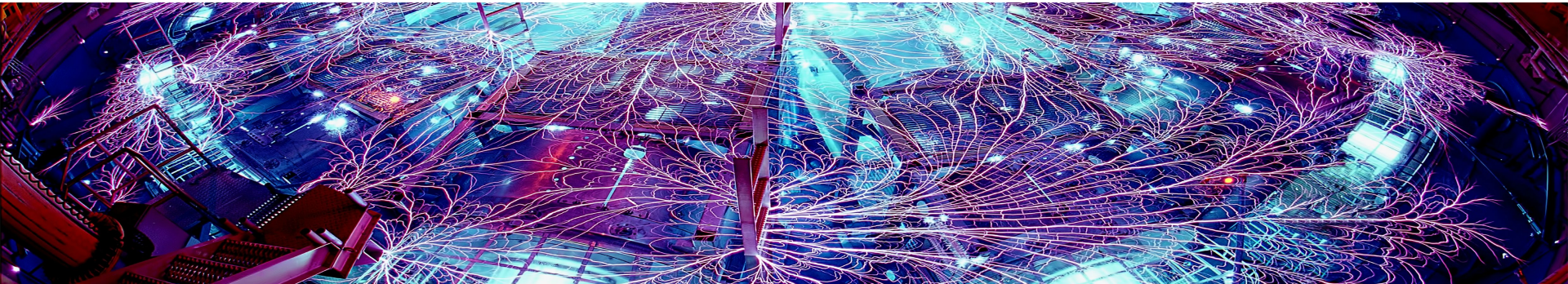


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PDV based technique for probing AK gap plasma in Z Machine target loads

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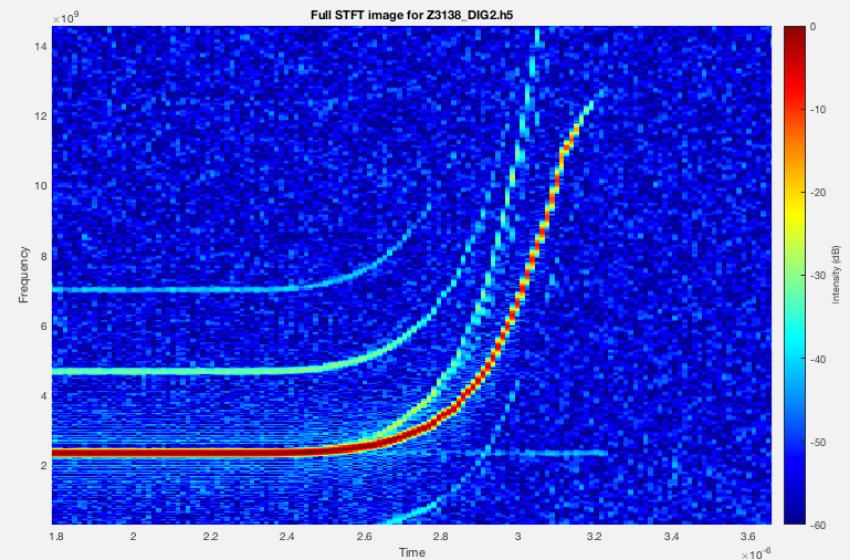
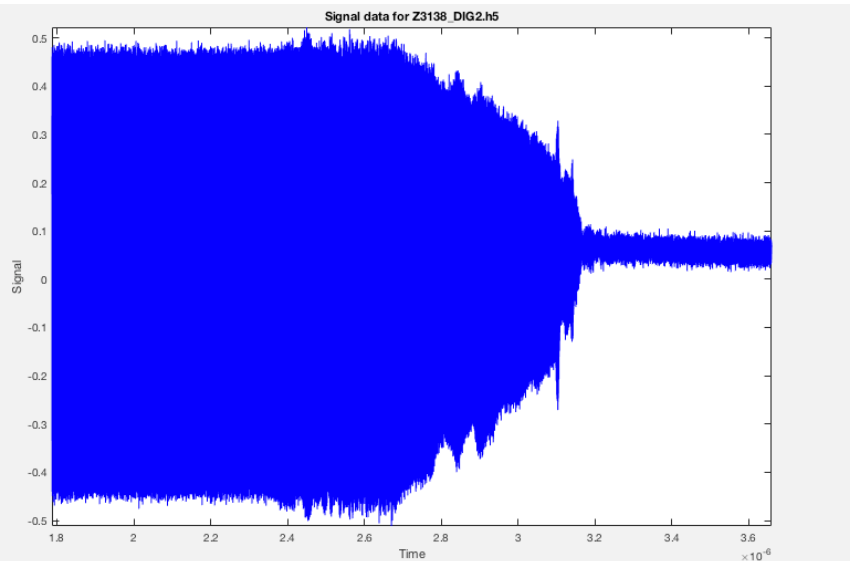


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Outline

1. PDV overview
2. Estimation of plasma number density from transverse flow
3. Z Machine power flow
4. Observed plasma “velocities” and inferred densities

Photon Doppler Velocimetry (PDV)



- PDV is a fiber-based interferometry technique for obtaining highly precise and accurate velocity measurements.
- Popular in the shock physics community, where it is a strong compliment/competitor to VISAR (velocity interferometer system for any reflector).
- Relatively inexpensive systems can be assembled using off-the-shelf components.
- Utilizes a Fourier transform analysis to relate frequency shift (f) and laser wavelength (λ) to apparent velocity (v^*) via:
$$v^* = \frac{\lambda}{2} f$$
- The velocity measured is along the beam path.

Photon Doppler Velocimetry (PDV)

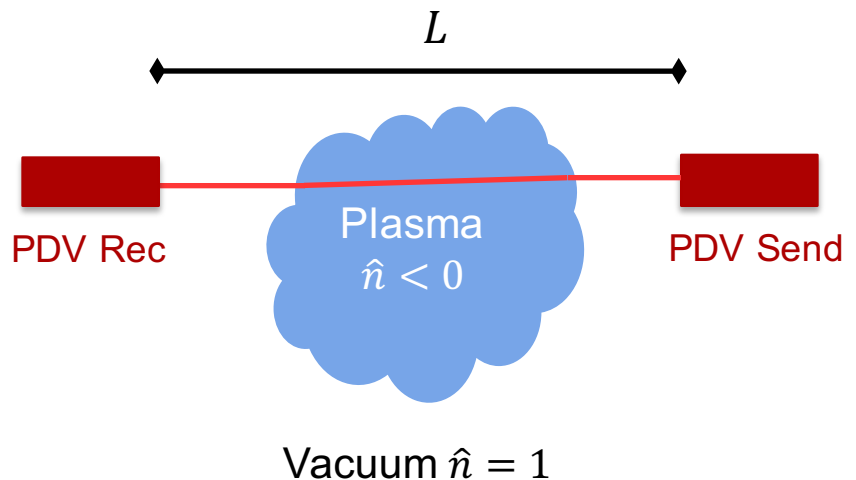
The apparent velocity can be related to the change of the index of refraction encountered by the laser beam as

$$v^* = -\frac{d}{dt} \int n(x, t) dx$$

If a transparent material were to flow perpendicularly across the laser beam, the time varying change to n would be reported as an apparent velocity. For a beam path length L we can approximate

$$v^* \approx -L \frac{d\hat{n}}{dt}$$

with \hat{n} the time average refractive index.



PDV Density Inference Technique

$$v^* \approx -L \frac{d\hat{n}}{dt}$$

Apparent velocity indicates direction of refractive index change:

increasing \hat{n} for $\frac{dv^*}{dt} < 0$

decreasing \hat{n} for $\frac{dv^*}{dt} > 0$

Order magnitude plasma density can be obtained with a few simplifying assumptions. We expect a decreasing \hat{n} as the electron number density N increases up to the critical density N_c (where the plasma becomes opaque).

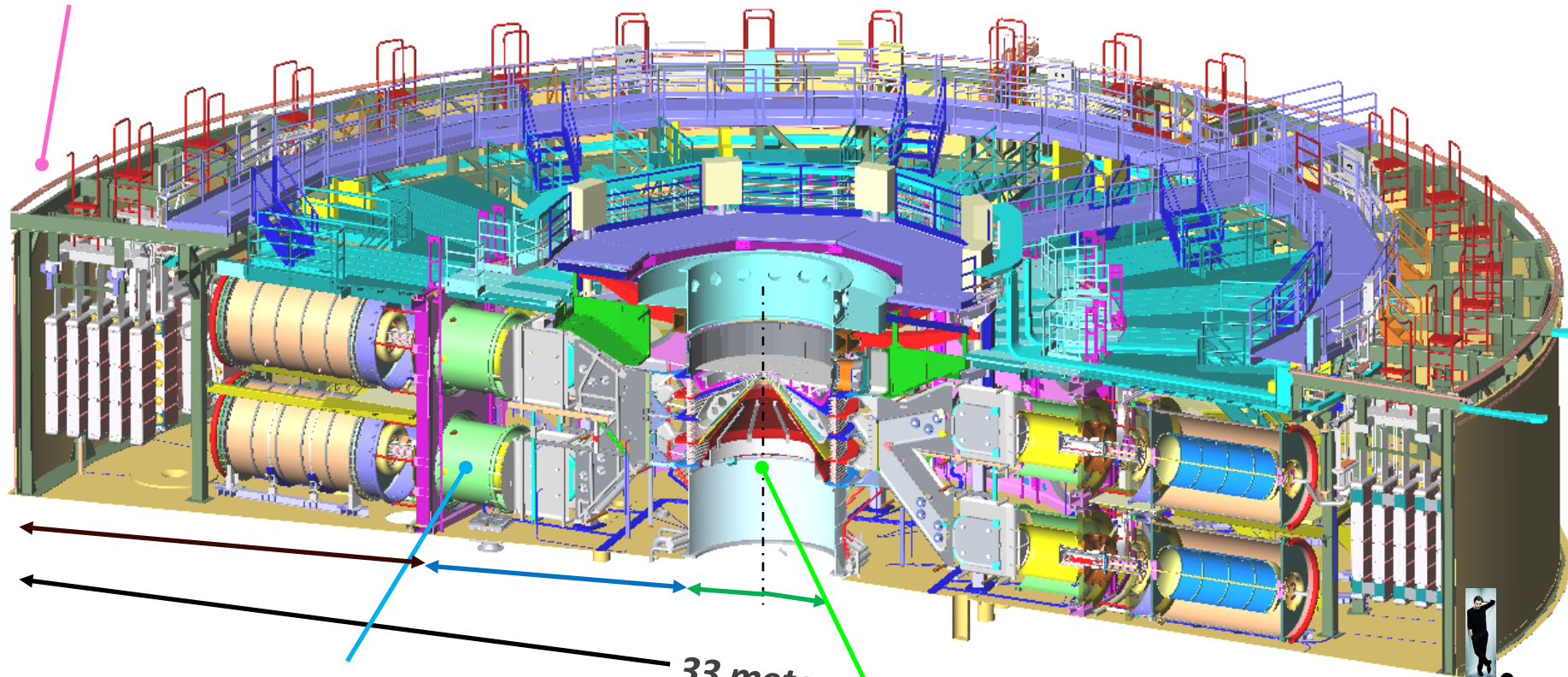
$$n = \sqrt{1 - \frac{N}{N_c}}, \quad N_c = \frac{m \epsilon_0 (2\pi c)^2}{e^2}$$

For the Z Machine PDV configuration, $\lambda = 1550$ nm thus $N_c = 4.6e20$ electrons/cc.

We expect these assumptions to provide order magnitude accurate plasma densities.

The Z Machine at Sandia

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



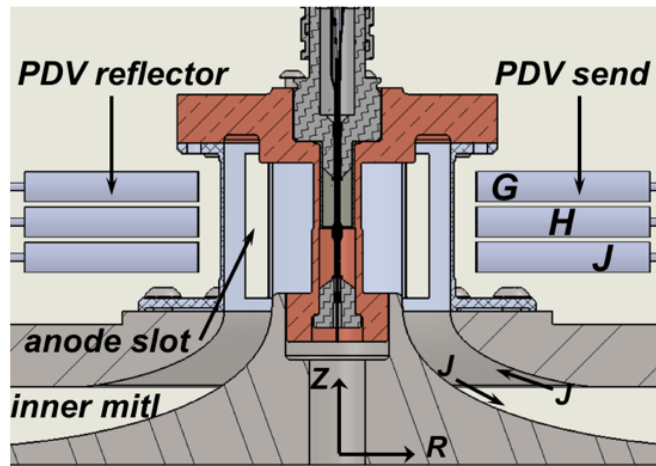
pulse-forming section (400,000 gallons H₂O): laser-triggered SF₆ gas switches & H₂O spark-gap switches compress pulse to 100 ns rise time, tri-plates reduce 36 lines to 18, convolute reduces further to 4 radial feed gaps

33 meters

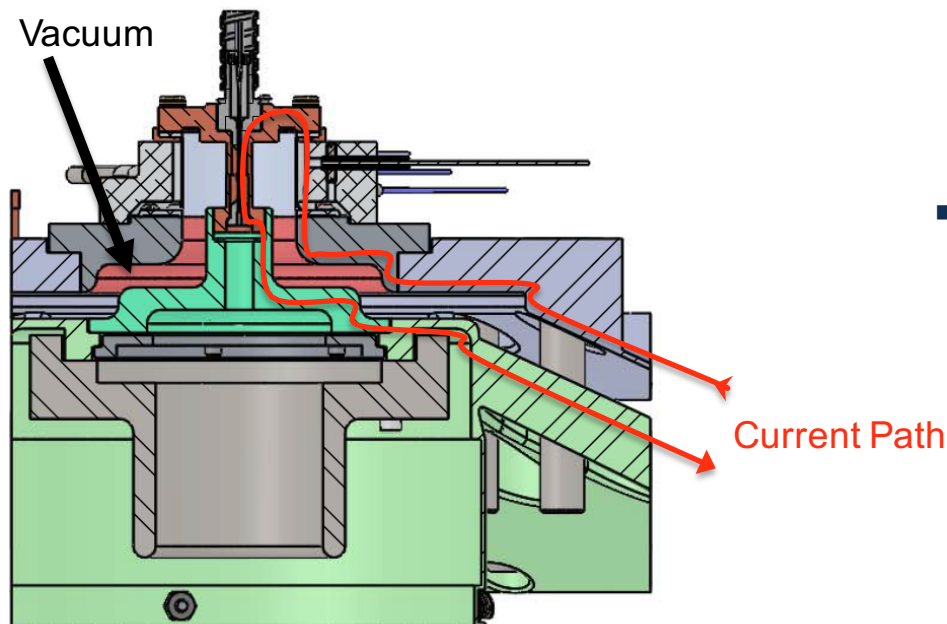
center section (10⁻⁵ torr vacuum): magnetically insulated transmission lines deliver up to 26 MA pulse to load, convolute reduces 4 feed gaps to 1

Cumberbatch
for scale

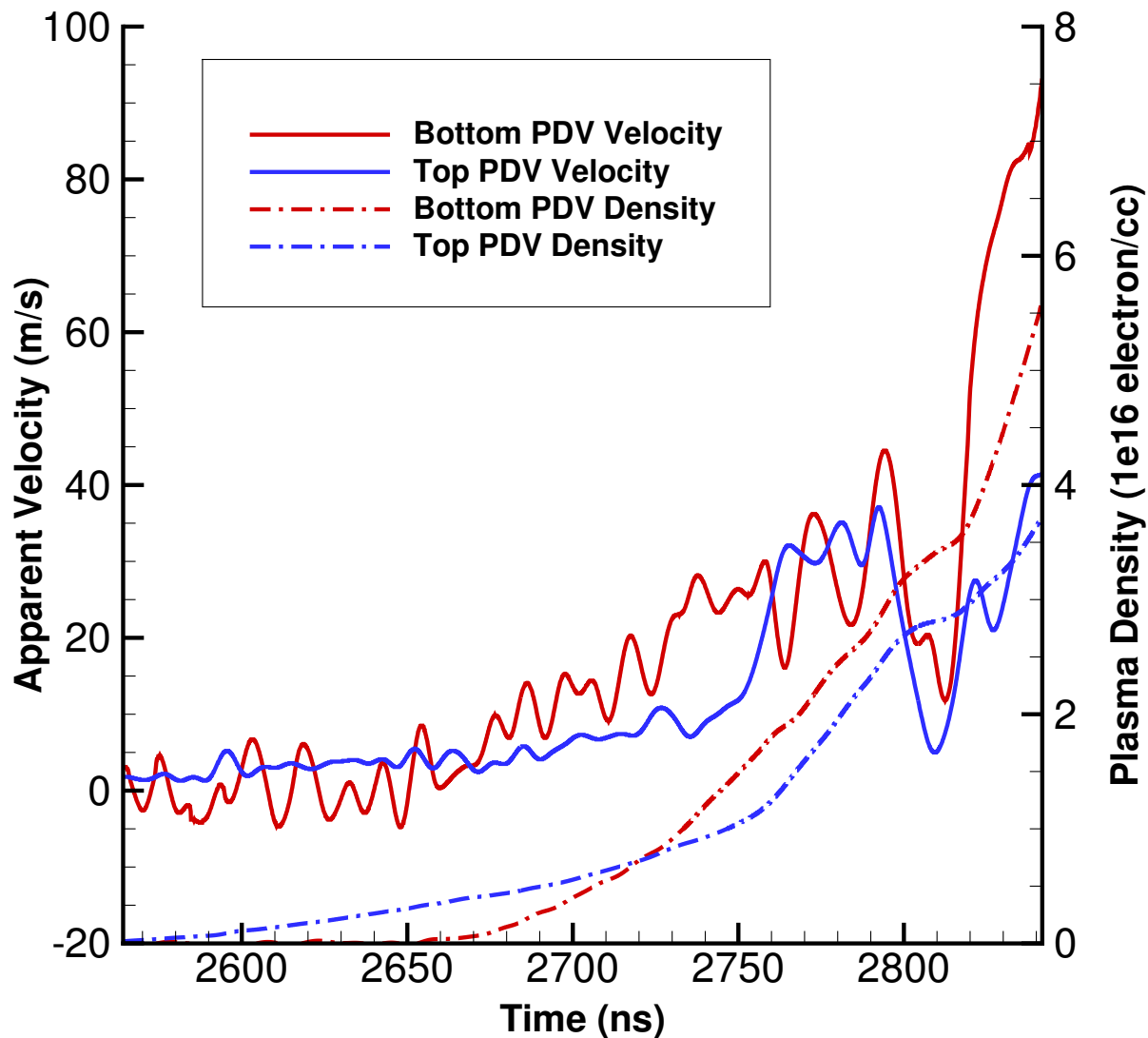
Plasmas in Cylindrical Load AK Gaps



- We have theorized that the arrival/presence of low density plasma in the load AK gap has adversely affected power flow in our cylindrical geometries.
- A slotted anode return can allow for optical access to the load AK gap without impeding power flow or implosion symmetry. This “chordal” PDV diagnostic detects arrival time of load plasmas as well as providing a rough estimate of the plasma density.
- This diagnostic has been deployed on a number of Z experiments and has proven informative.

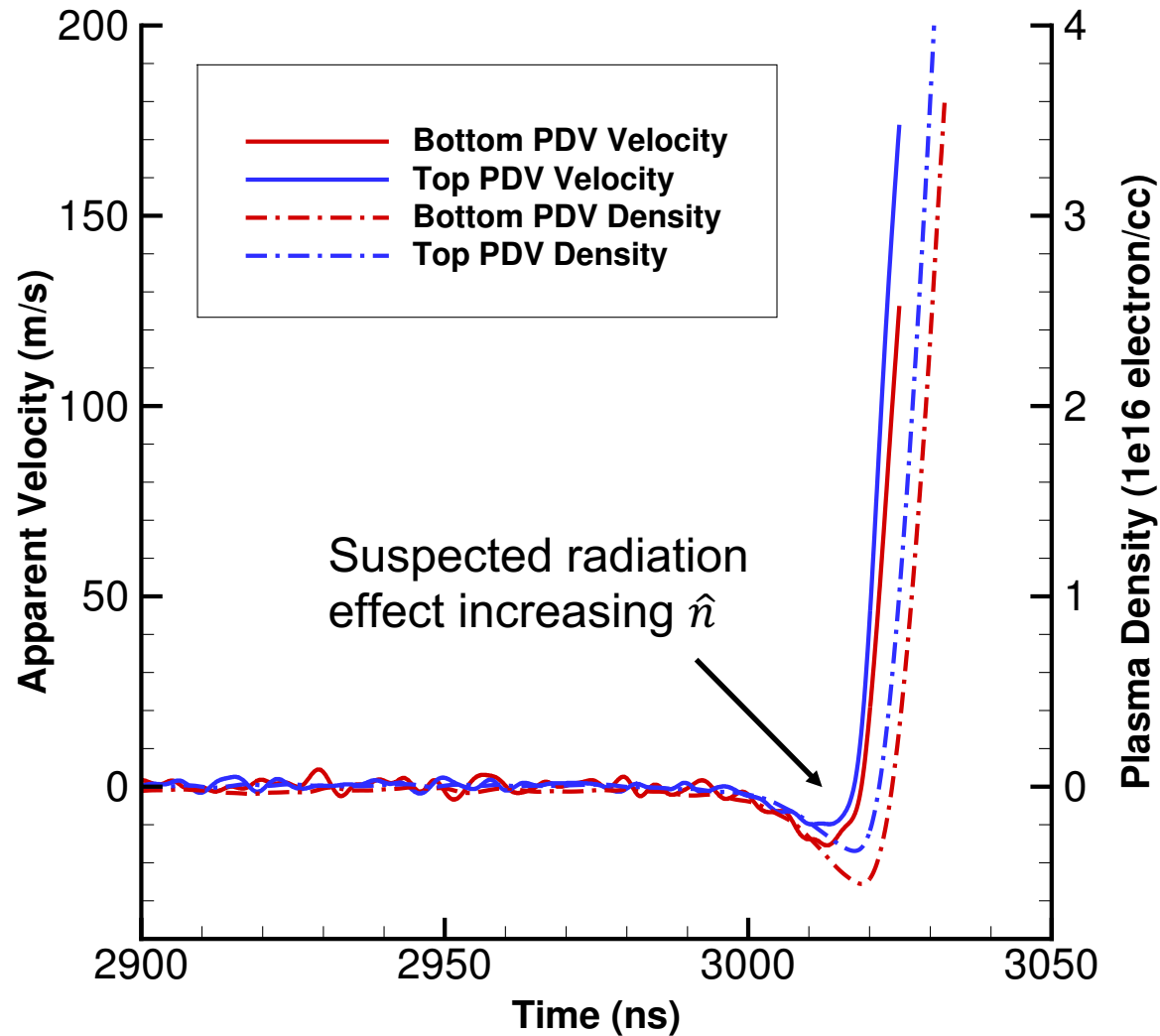


Long Pulse Plasma Detection



800 ns current rise time

Short Pulse Plasma Detection



100 ns current rise time

Simple Method, Complex Insight

- Densities are consistent with what we expect in the AK gap. These densities are not relevant under the MHD assumption, but inclusion of the Hall term (Extended MHD) shows that they may have measureable impact on experiments. (A series of PRLs are being submitted on this topic.)
- Densities at cutoff are approximately $0.1 * N_c$, implying beam deflection is resulting in light cutoff.
- Coordinating load current (both I and dI/dt) with plasma arrival time and secondary diagnostics is yielding insight into power flow physics.
- Because this is a fiber based method, probes can be deployed in tight spaces such as the upper feed, potentially coordinating plasma transit through a pulsed power machine.
- Appears to be a promising diagnostic for plasma physics applications.

Thank you

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