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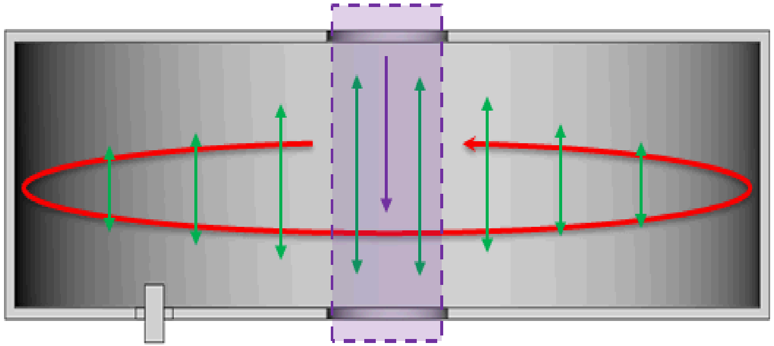

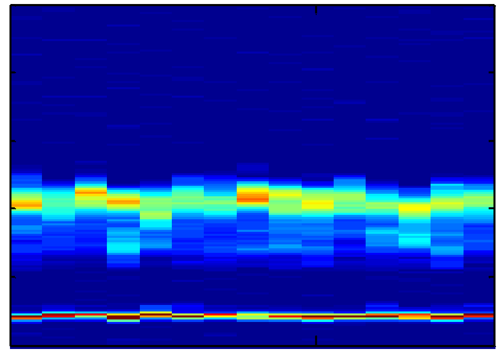

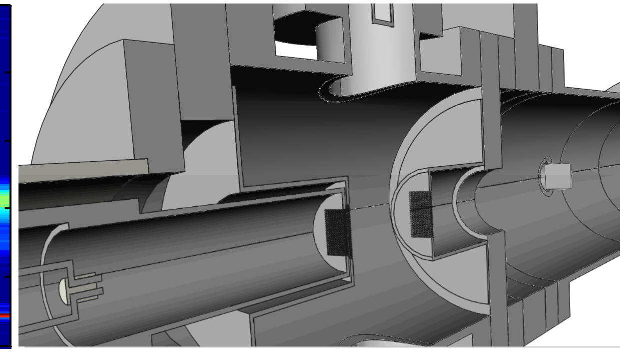

(4O2) A Microwave Resonance Diagnostic for Measuring Characteristics of Pulsed Ion Beams

George Laity, Ed Barnat

Sandia National Laboratories, Albuquerque, NM 87185

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U.S. DEPARTMENT OF ENERGY

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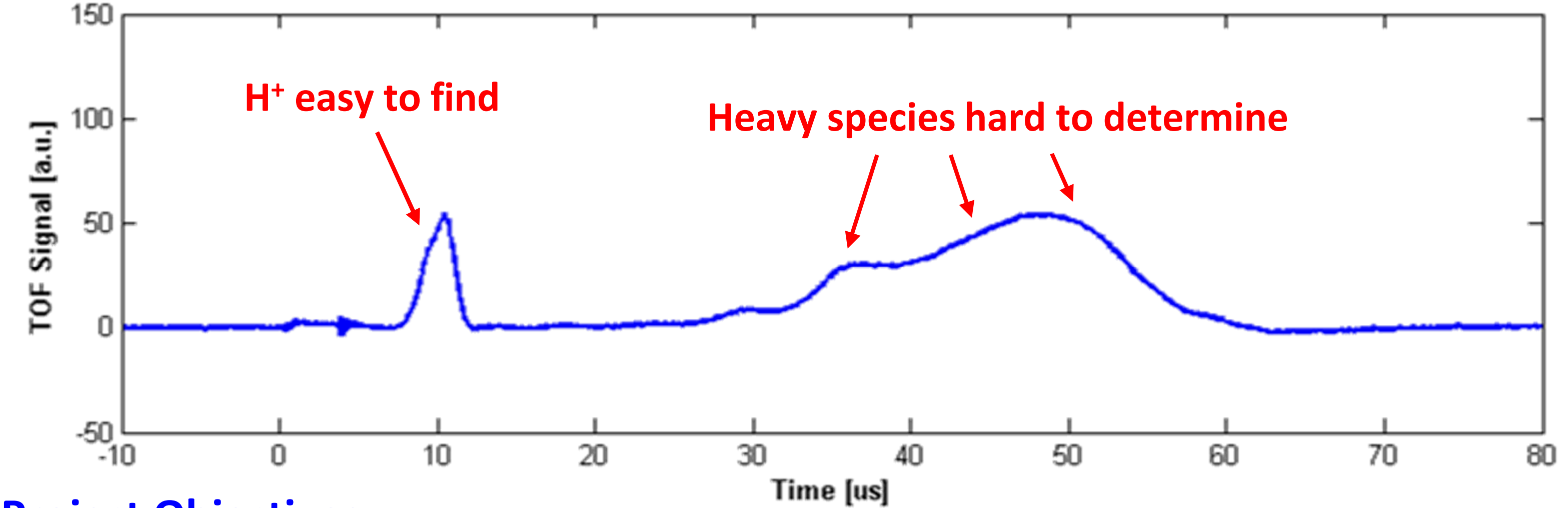
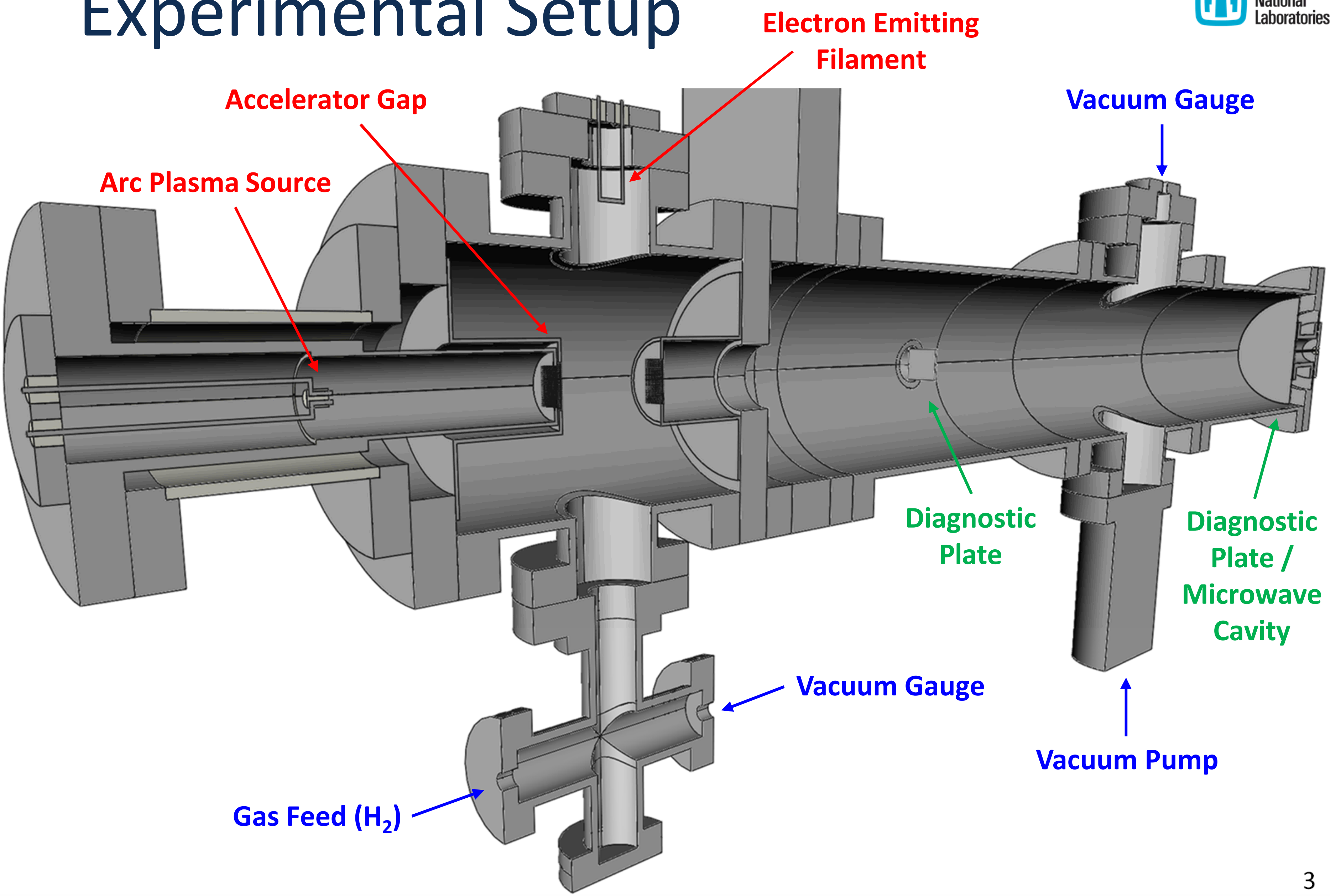
Motivation / Project Objectives

- **Motivation:** Desire to passively measure species / energy / density characteristics of pulsed ion beams, without traditional time-of-flight diagnostic limitations caused by spatial-temporal blurring of slower ions (uncertainty).

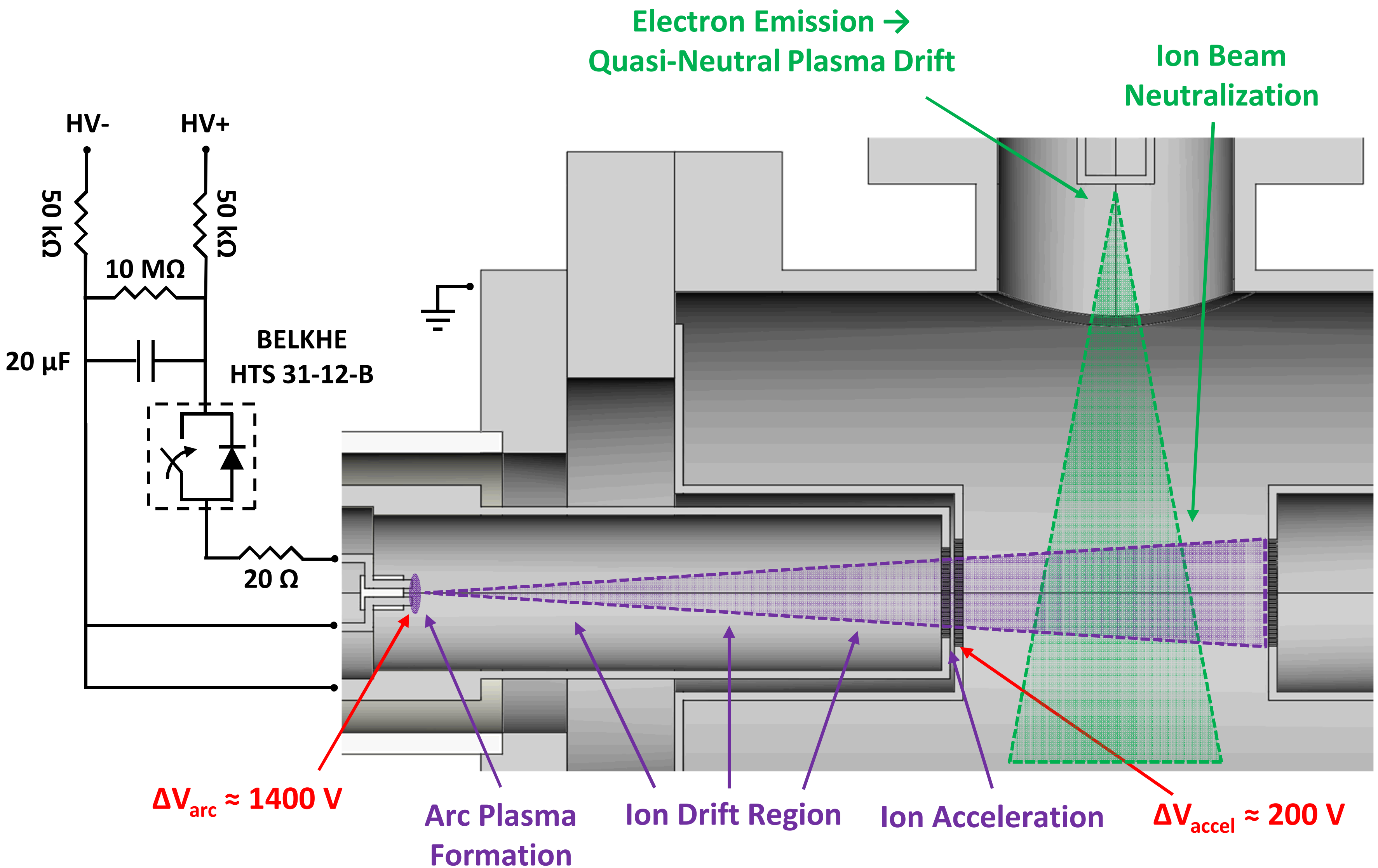


- **Project Objectives:**
  - Demonstrate the physics of **accelerated time-of-flight** as a mechanism for achieving improved dynamic measurement of species / energy / charge state of pulsed ion beams.
  - Demonstrate the ability of a **microwave resonance cavity** to measure temporally resolved plasma densities in pulsed ion beams.

Experimental Setup



Pulse Power / Electrical Setup

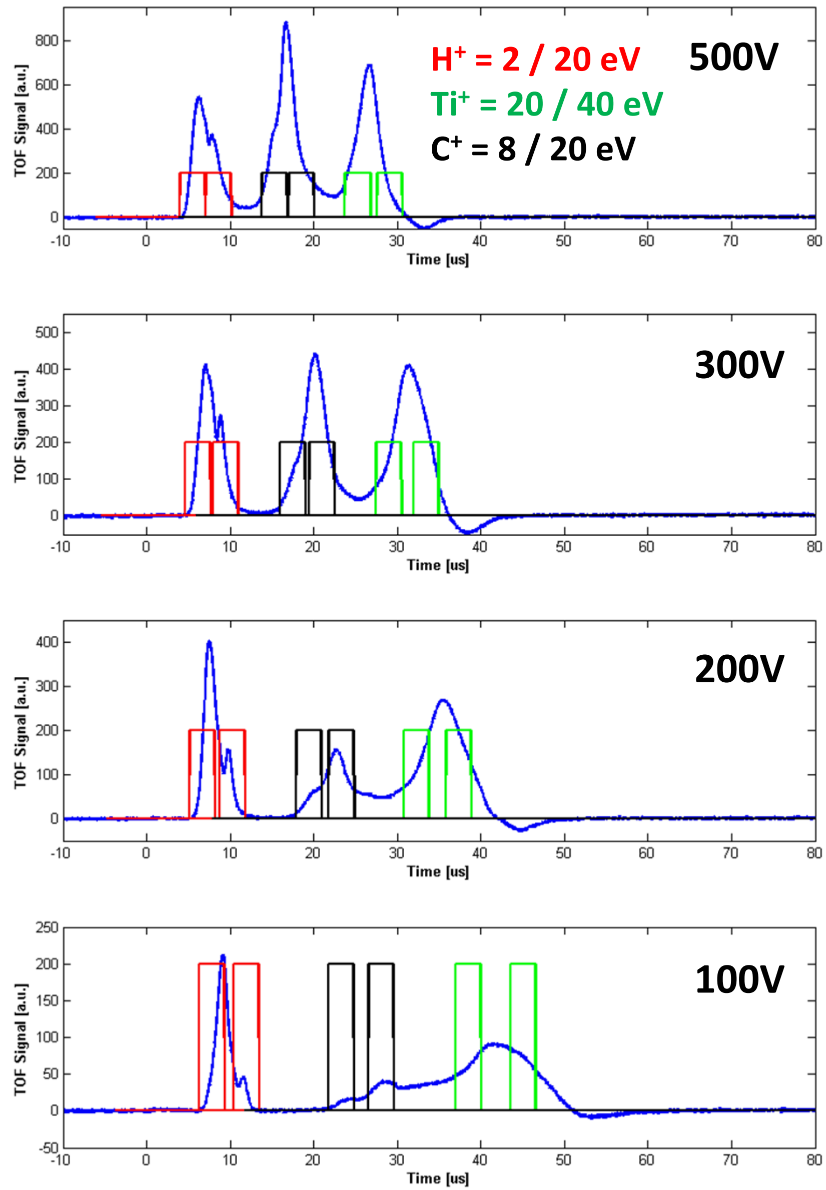


Accelerated TOF Results

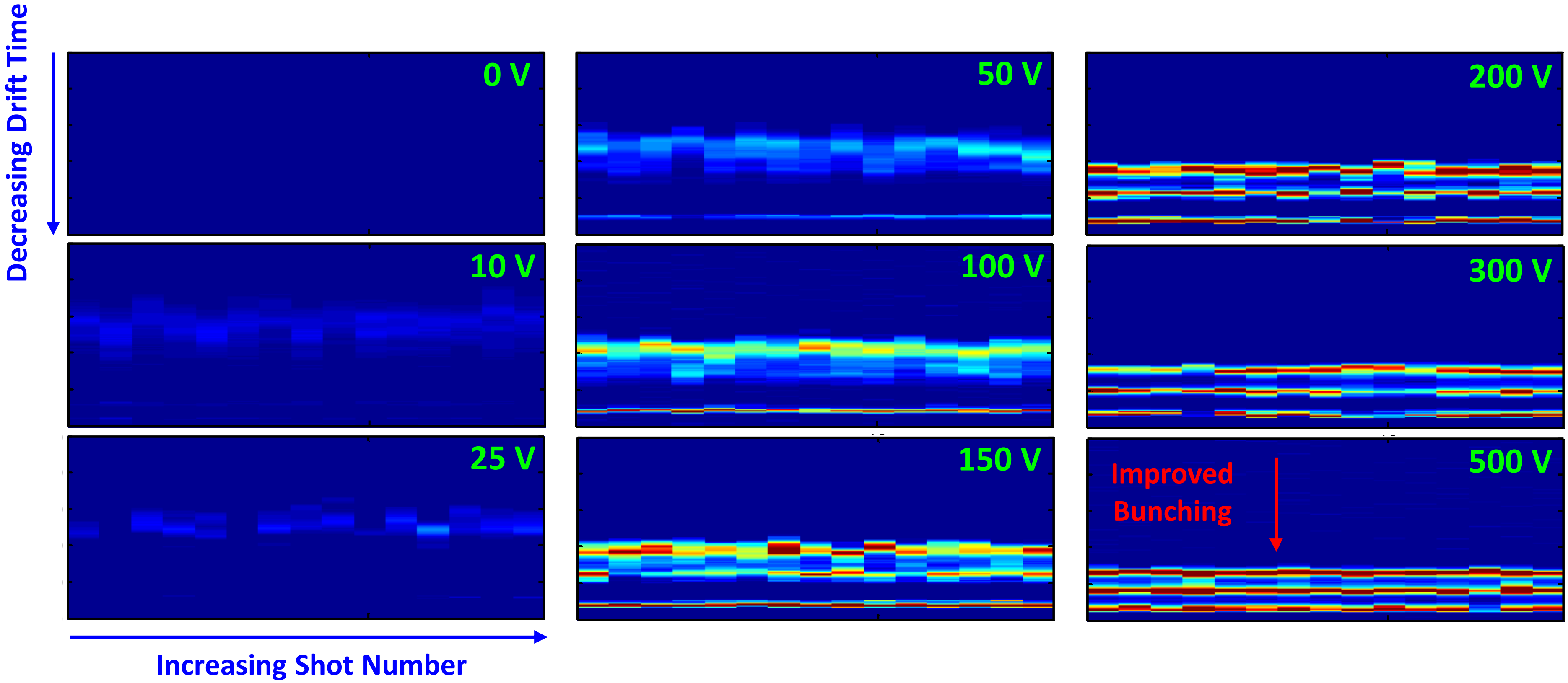
- Series of measurements performed with constant plate bias (+50V) demonstrate that increased acceleration voltage results in increased temporal bunching, and therefore improved resolution for the time-of-flight diagnostic.

- For low pressure (4.0 mT) H_2 arc plasma, typical drift species can be identified with source energies from 2 - 40 eV.

- Strong emission from carbon ions (C^+) can be measured due to graphite between the arc electrodes used to increase the reproducibility of plasma initiation.

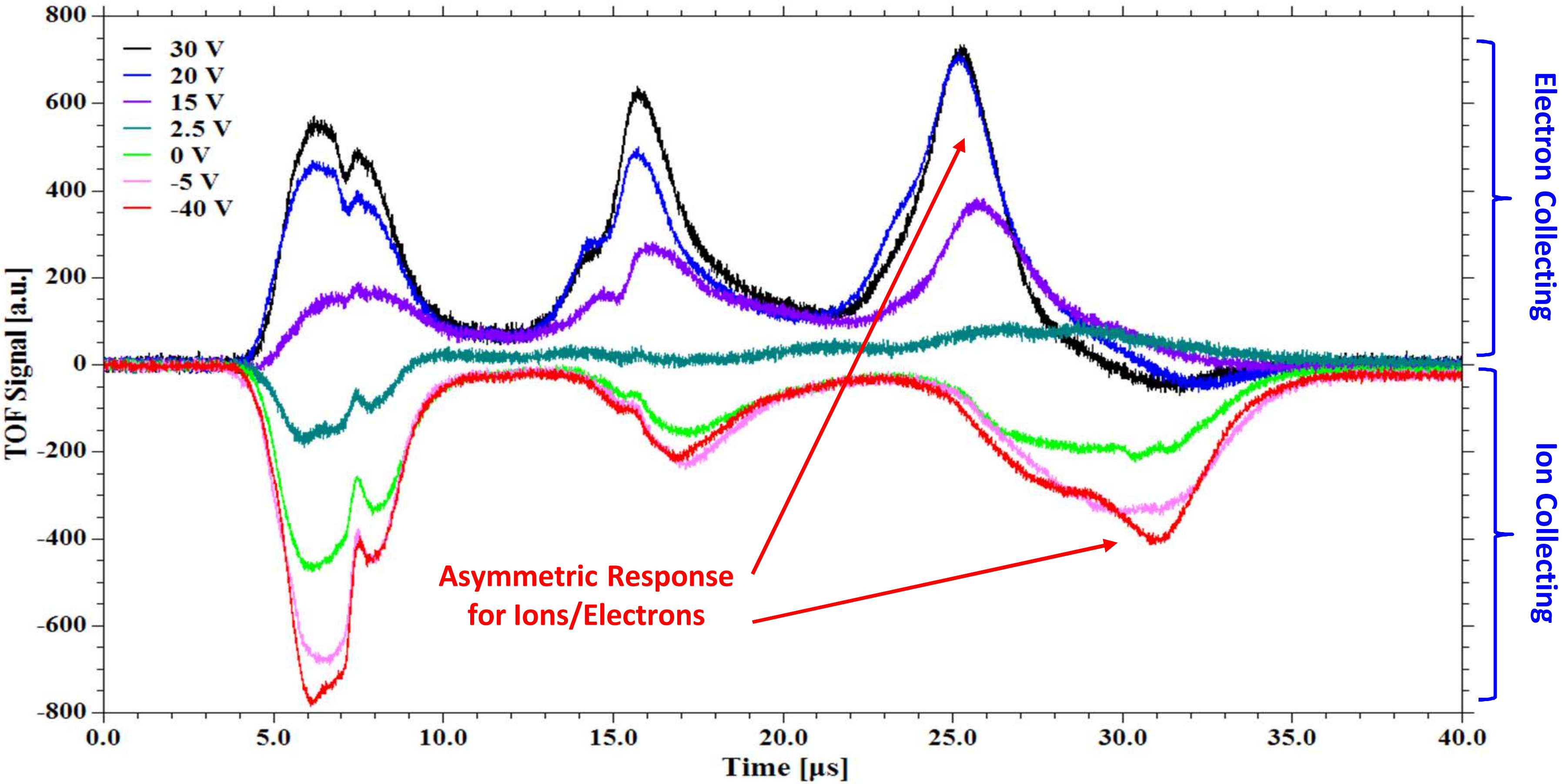


Arc Plasma Reproducibility



- Multiple measurements recorded at each accelerating voltage show that the plasma content is reasonably repeatable, with improved temporal bunching at high accelerator voltage resulting in improved time-of-flight resolution.

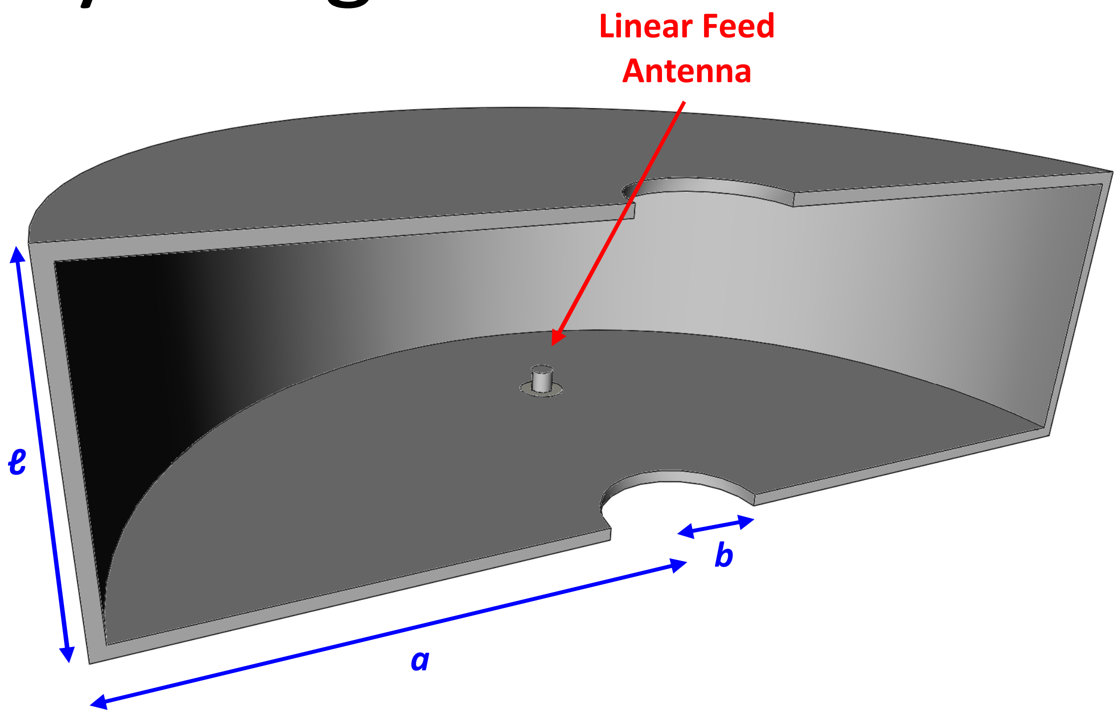
Plate Response Asymmetry



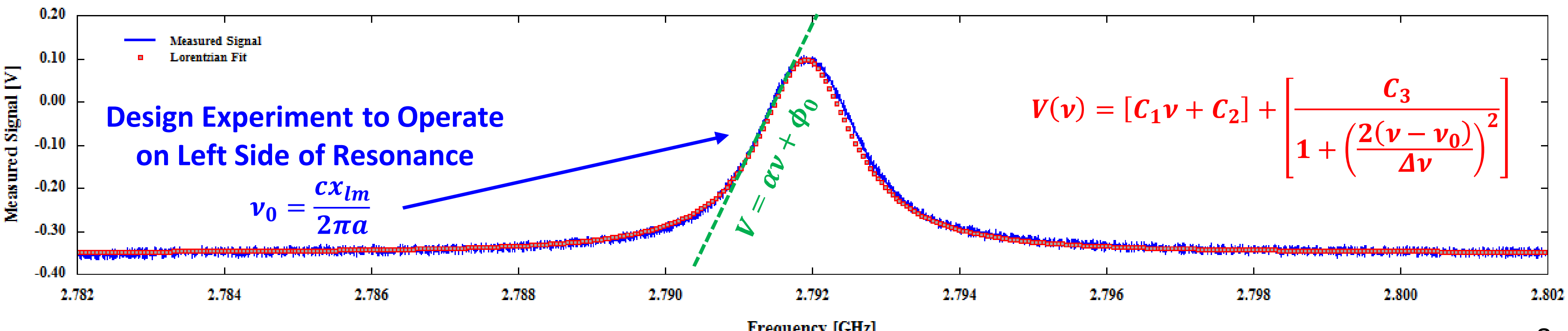
- Adjusting the voltage bias on the detector plate exhibits an asymmetric response for ion/electron collection, caused by various physics related to secondary electron emission, local electric field(s), and surface effects → desire to utilize a passive diagnostic which does not require beam/current collection by probe surfaces.

Microwave Cavity Design

CAVITY DESIGN PARAMETERS		
LENGTH [cm]	L	2.54
RADIUS [cm]	a	4.10
HOLE RADIUS [cm]	b	0.64
1st BESSEL ZERO [TM_{01}]	x_{lm}	2.405
RESONANCE THEORY [GHz]	ν_0	2.801
RESONANCE EXPERIMENT [GHz]	ν_0	2.792
RESONANCE FWHM [MHz]	$\Delta\nu$	1.55
CAVITY QUALITY FACTOR	Q	1800

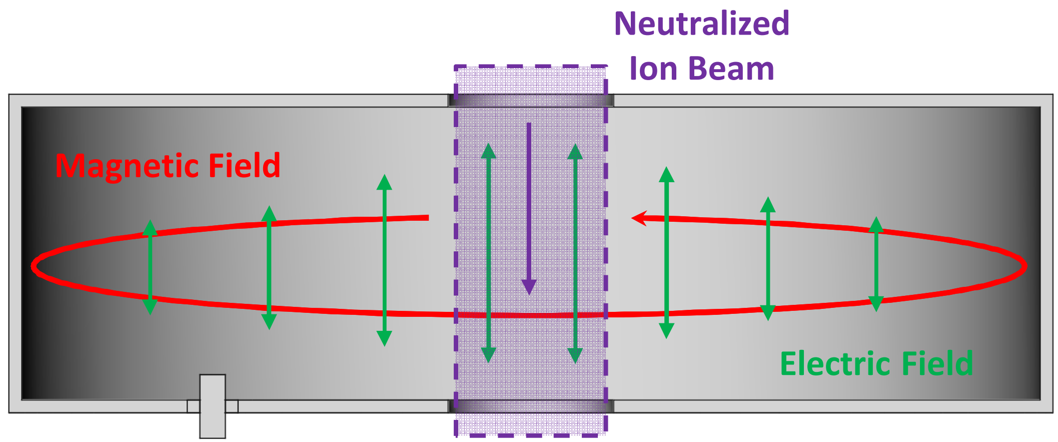


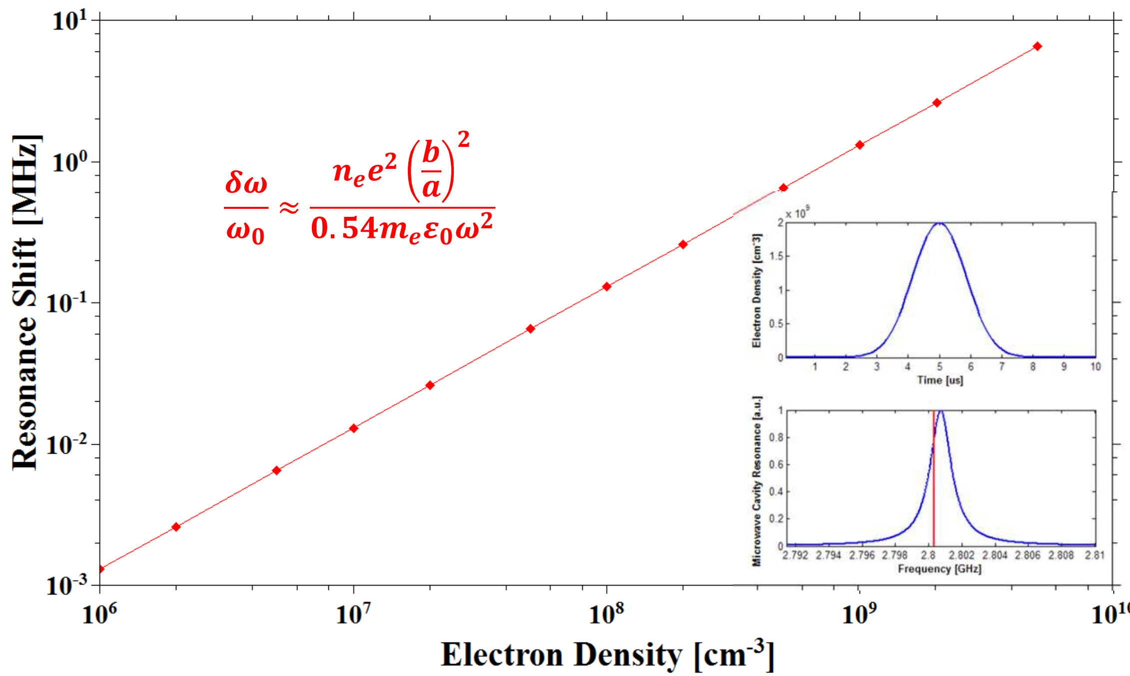
*J.D. Jackson, *Classical Electrodynamics, John Wiley & Sons, (1999).*



Microwave-Plasma Interaction

- As quasi-neutral plasma drifts through the microwave cavity, the resonance is shifted to higher frequencies due to the change in dielectric constant inside the cavity volume.
- The relative shift of resonant frequency is a linear response of average electron density inside the cavity volume, with the slope a function of cavity design parameters.
- By injecting a single frequency below resonance (1/4 FWHM) into the cavity, plasma drift through the device will result in a measurable change in microwave power with fast response time.





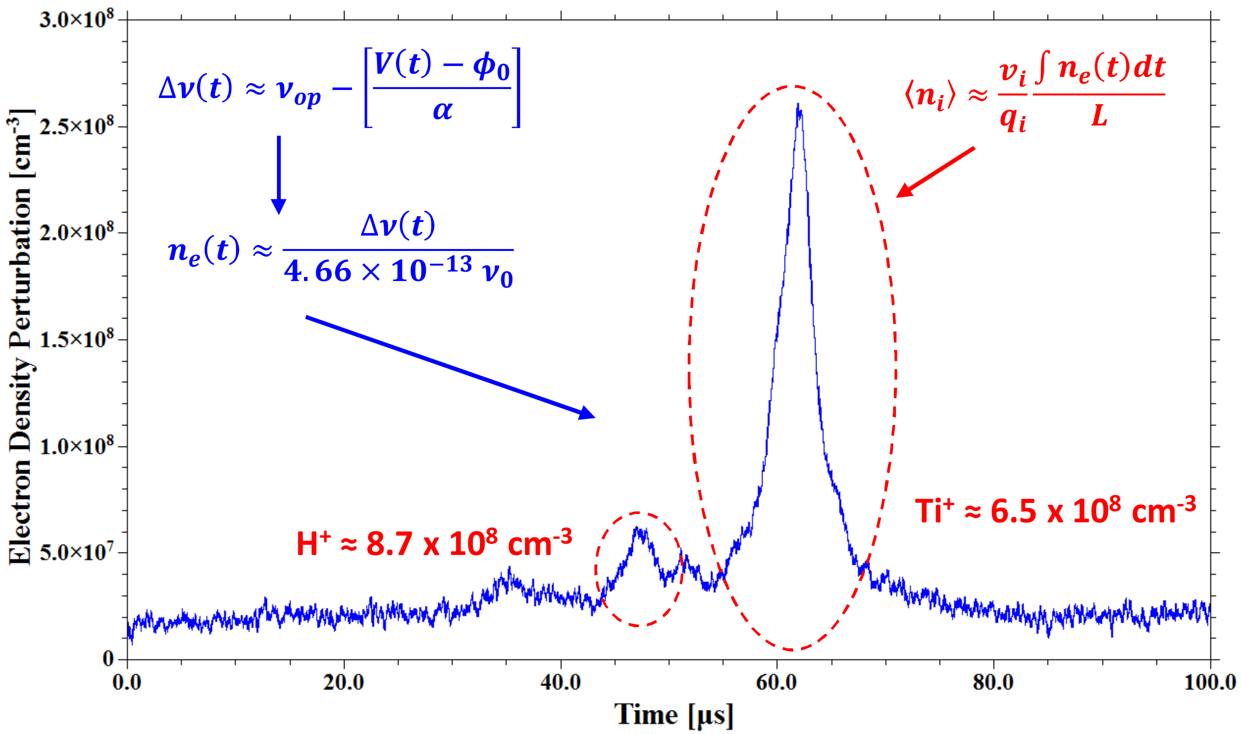
*X. Guochang et al., Rev. Sci. Insrum. 68, 1935, (1997).

Microwave Diagnostic Example

- The measured change in microwave power as a function of frequency shift due to drift plasma is linearly approximated, which results in typical recorded average electron densities of 10^8 cm^{-3} downstream ~1.2 meters from the arc plasma (≈10^{14} cm^{-3} estimated source density).

- The estimated ion density measured by this method depends on the total residence time of ions inside the cavity volume, which is a function of ion velocity and charge.

- For example if ions have ~10 eV source energy, the estimated H^+ density is larger than the Ti^+ density despite the much larger response of slow (heavy) ions.



Conclusions / Future Studies

- **Accelerated TOF:** Initial measurements at accelerator voltages from 25 – 500V demonstrated accelerated time-of-flight as a mechanism for reducing spatial-temporal blur for estimating species, energy, and charge of pulsed ion beams.
- **Microwave Resonance Cavity:** Initial measurements using the microwave resonance cavity demonstrated that ion beam densities on the order 10^8 cm^{-3} can be measured by monitoring the resonance shift as quasi-neutral plasma drifts through the cavity volume.
- **Future Studies:** Initial attempts to implement a combined accelerated TOF-MRC diagnostic resulted in significantly reduced resonance shift recorded in the microwave cavity. Current investigations are focused on understanding the physics surrounding the accelerator gap structure, where possible sheath structures could form via a combination of (1) low density quasi-neutral plasma in the neutralization section as a result of constant electron emission from the heated filament, and (2) the ability of early H^+ ions affecting the plasma near the accelerator mesh before the Ti^+ ions reach the accelerator gap, and (3) space charge limited extraction.