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Ion Dynamics of a BHT-600 Hall Thruster Measured with Time-Resolved Laser-Induced Fluorescence

Christopher V. Young

Andrea Lucca Fabris and Mark Cappelli

Natalia MacDonald-Tenenbaum

William A. Hargus, Jr.

Air Force Research Laboratory | Edwards AFB, CA | January 14, 2016

Motivation

- Build on existing foundation of laser-induced fluorescence expertise, improving time-resolved capabilities
- Bring high spatial resolution, precision, and non-perturbing diagnostic to dynamical studies of Hall thruster oscillations like breathing mode
- Understand time evolution of complex Hall thruster ion flow field in 2D (radial/azimuthal velocities plus axial)
- Provide next level of data for benchmarking and comparison between thruster experiments and simulations

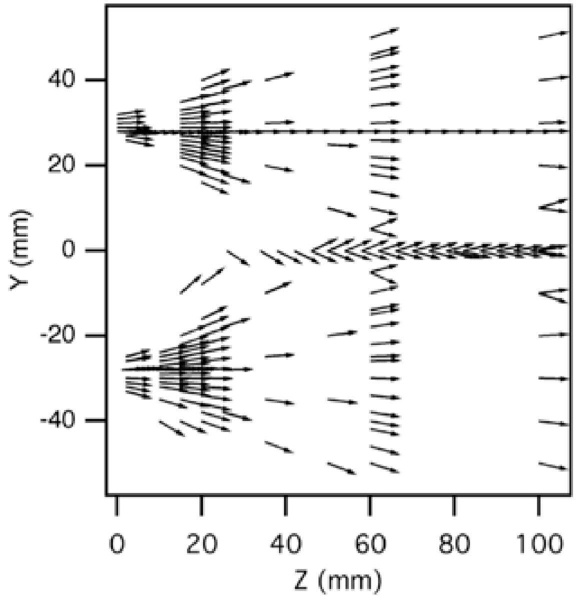
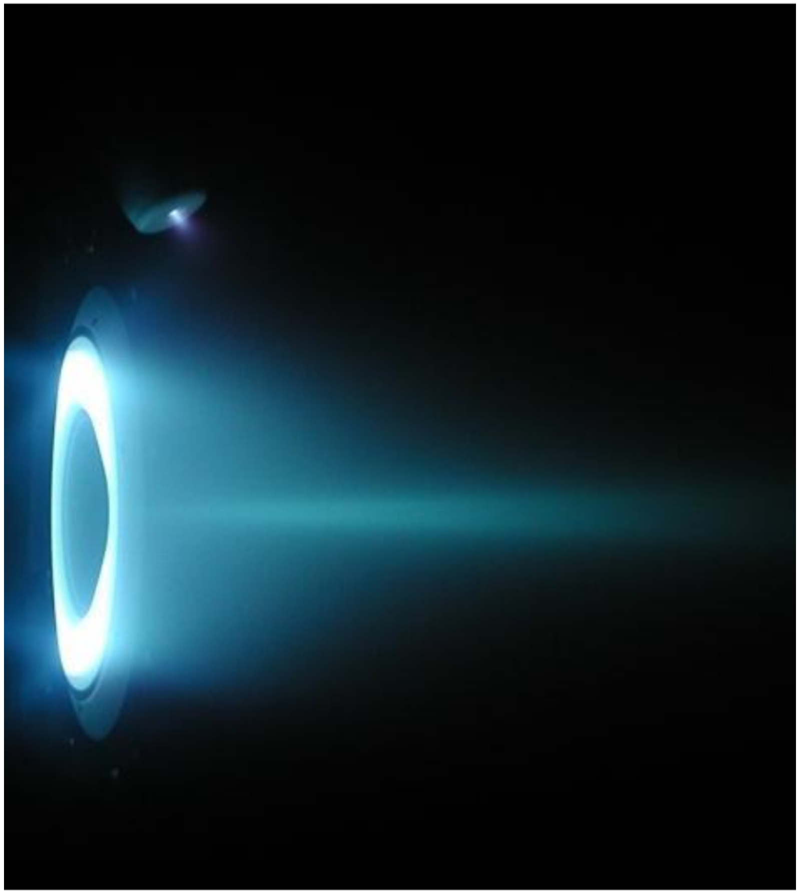


Fig. 5 **Ion velocity vector plot in the *Y*-*Z* plane ($X = 0$).**

W. A. Hargus Jr. and C. S. Charles, J. Propul. Power. **26** (2010) 135

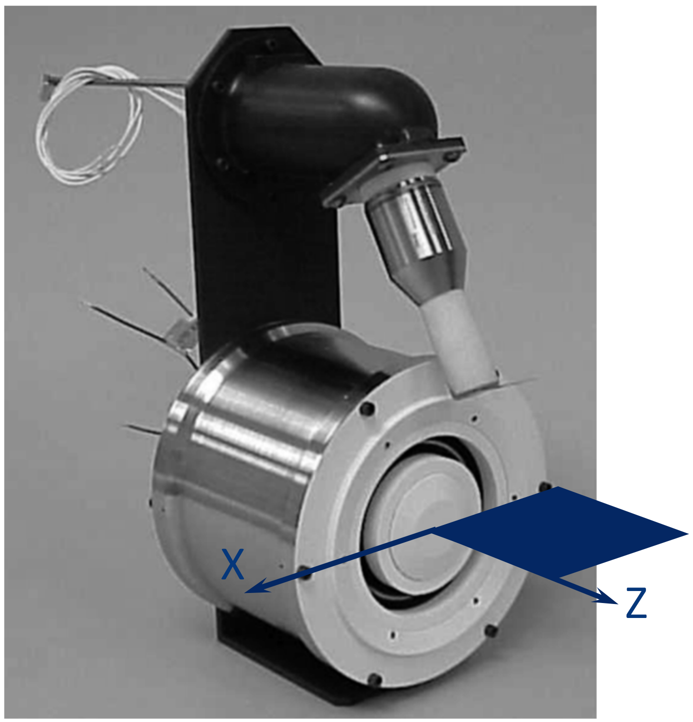
Outline

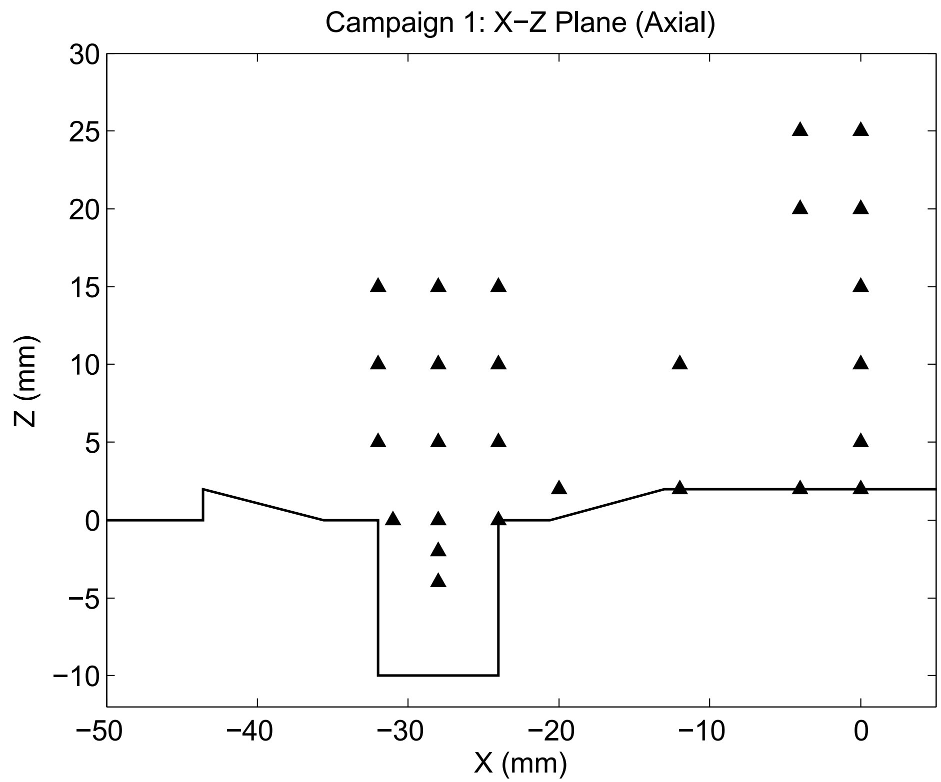
- BHT-600 Measurement Campaign
- Time-Resolved Laser-Induced Fluorescence Method
- Preliminary Results
- Summary



BHT-600 Measurement Campaign

Goal: Map xenon ion velocity vectors in the channel and near-field plume evolving over the 48 kHz breathing mode oscillation.

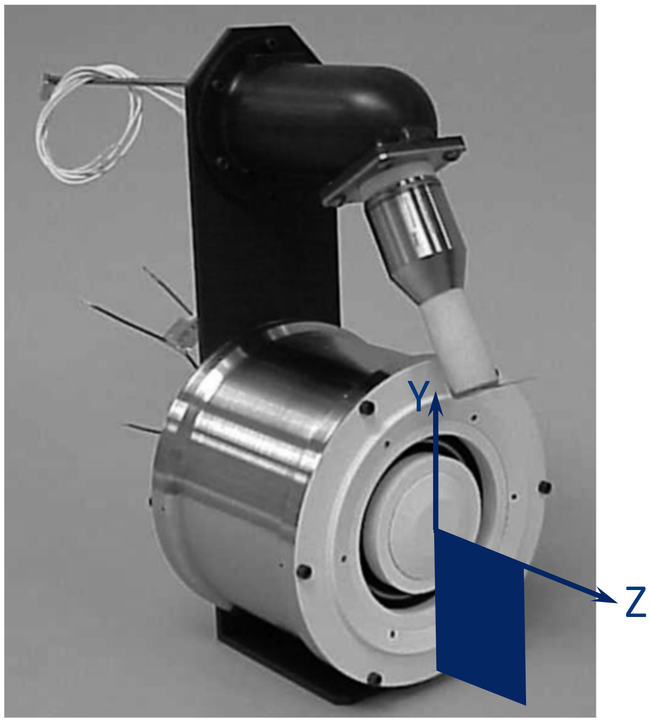


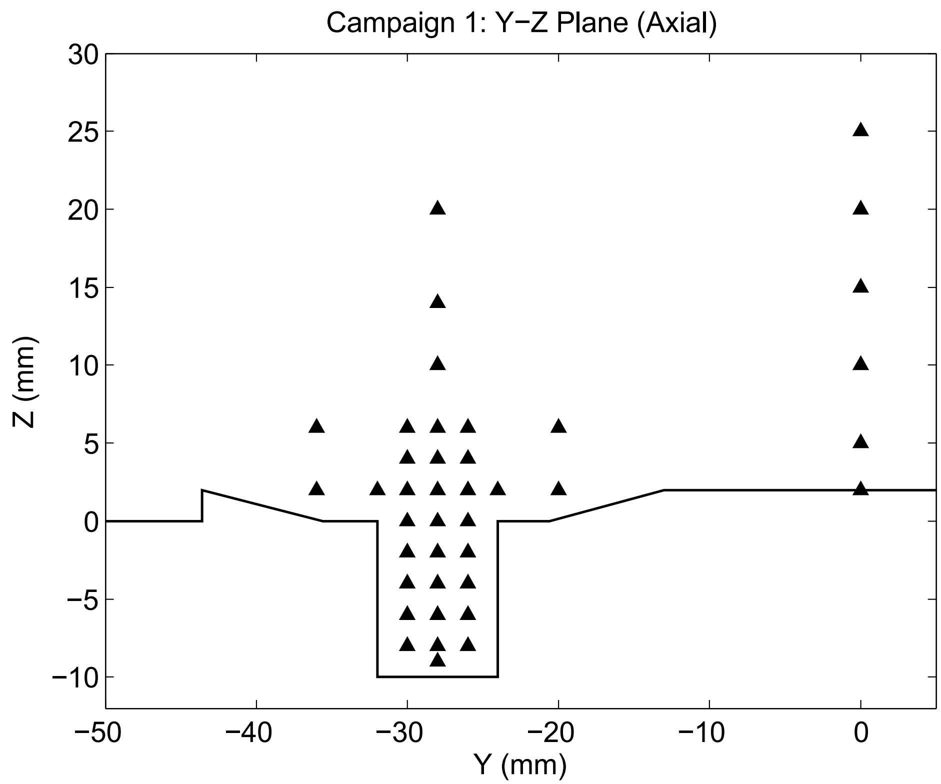


Dataset 1: 26 points in X-Z, axial (04/2015 – 05/2015, 9 days total operation)

BHT-600 Measurement Campaign

Goal: Map xenon ion velocity vectors in the channel and near-field plume evolving over the 48 kHz breathing mode oscillation.

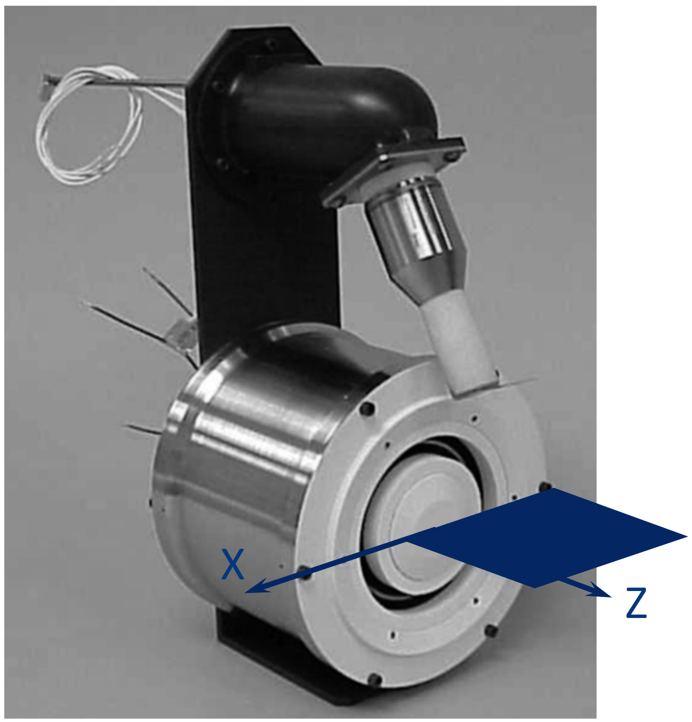


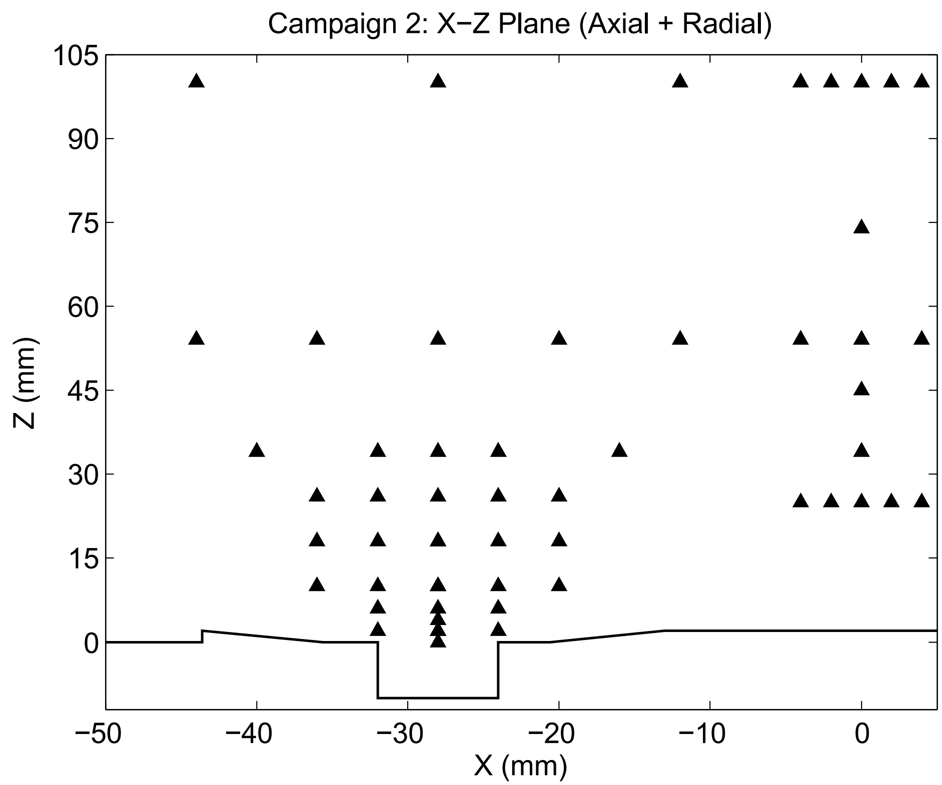


Dataset 2: 34 points in Y-Z, axial (04/2015 – 05/2015, 9 days total operation)

BHT-600 Measurement Campaign

Goal: Map xenon ion velocity vectors in the channel and near-field plume evolving over the 48 kHz breathing mode oscillation.

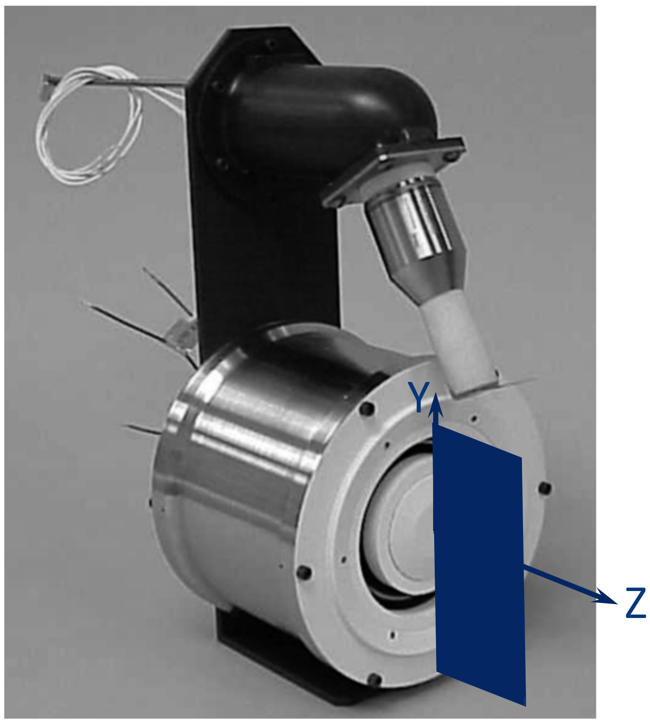


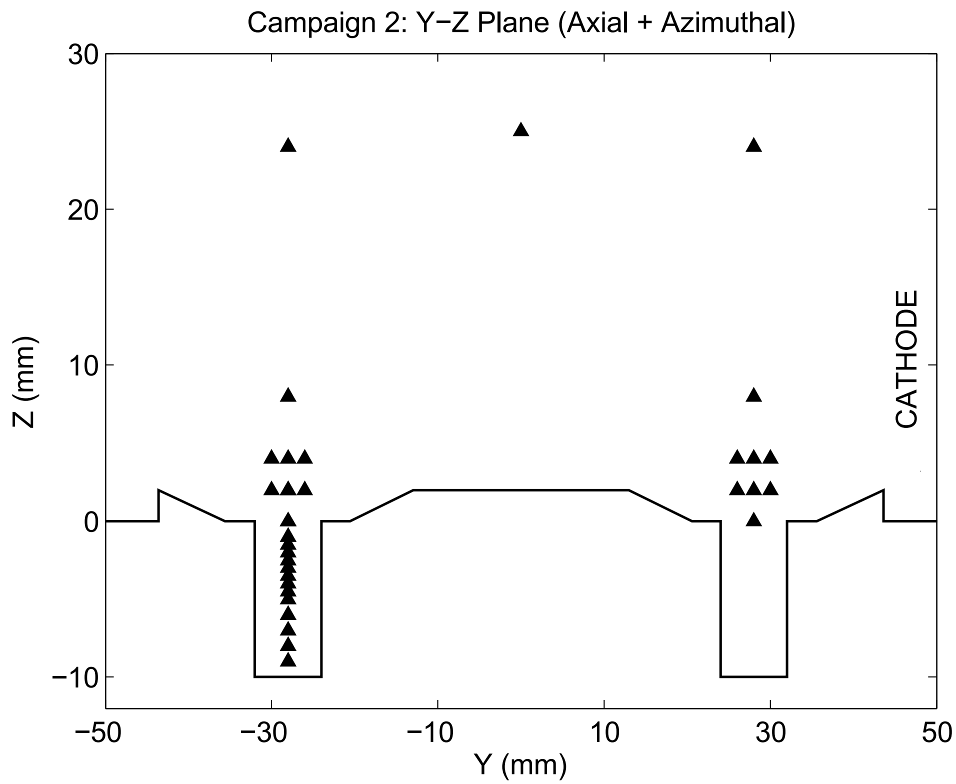


Dataset 3: 55 points in X-Z, axial + radial (11/2015 – 01/2016, 13 days total operation)

BHT-600 Measurement Campaign

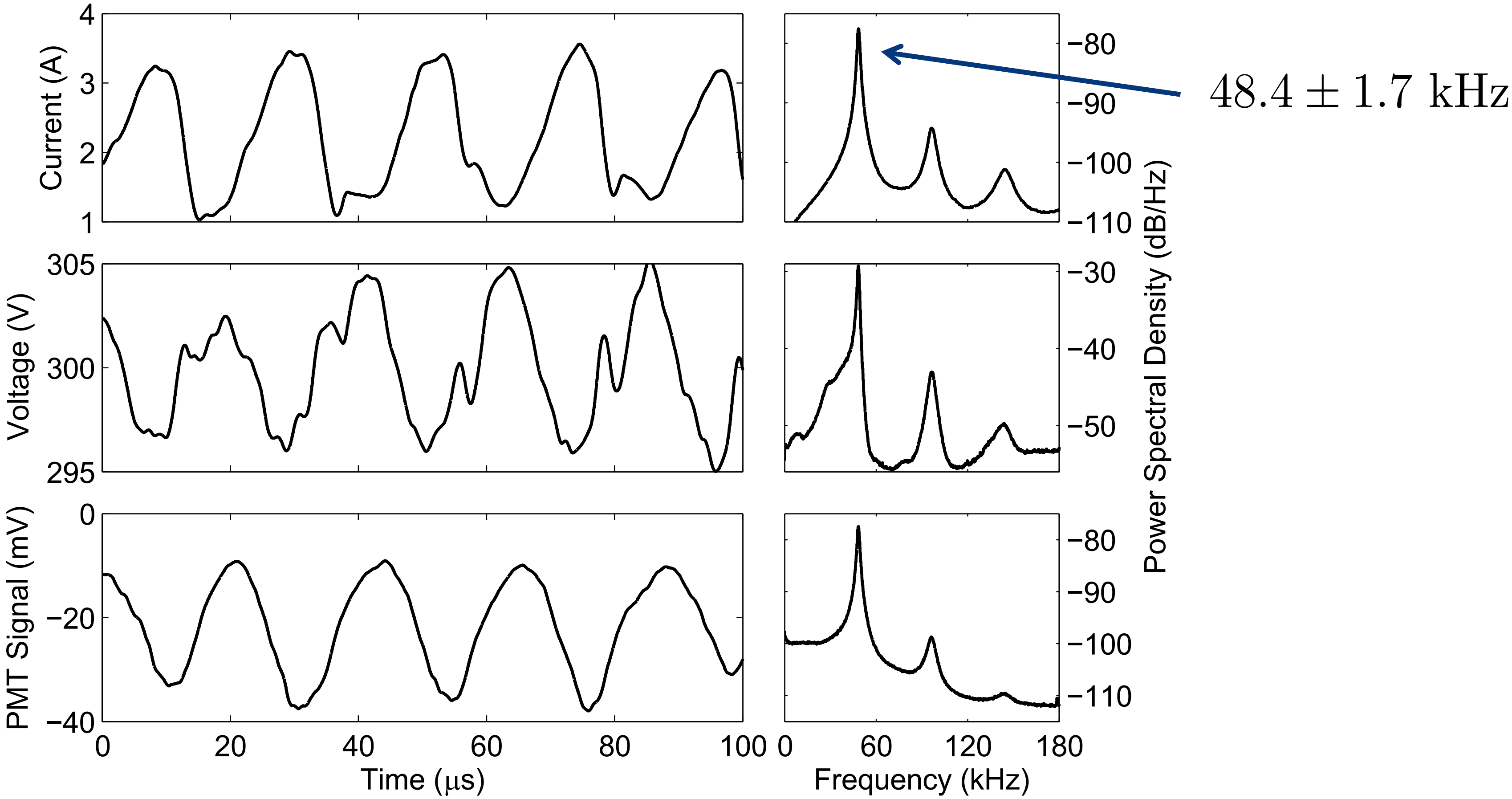
Goal: Map xenon ion velocity vectors in the channel and near-field plume evolving over the 48 kHz breathing mode oscillation.





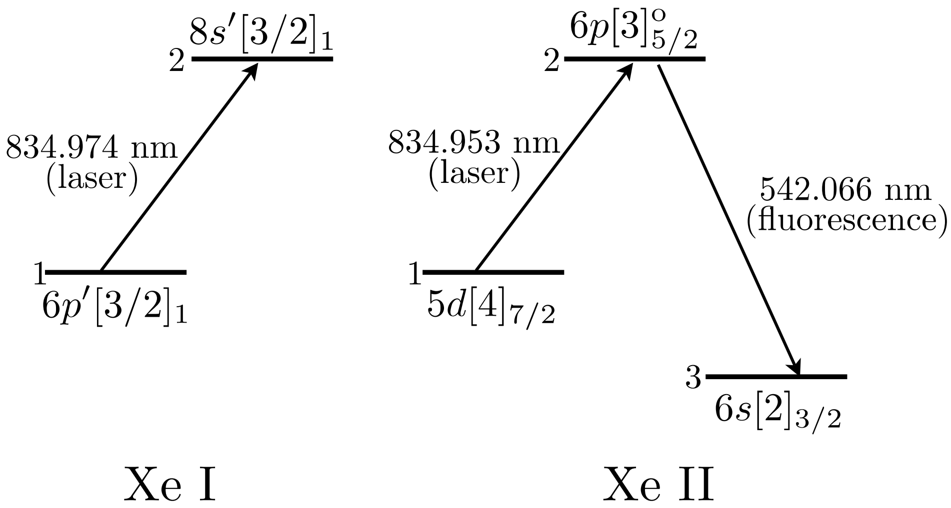
Dataset 4: 16 points in Y-Z, axial + azimuthal; 25 additional axial points in channel and near-field plume (11/2015 – 01/2016, 13 days total operation)

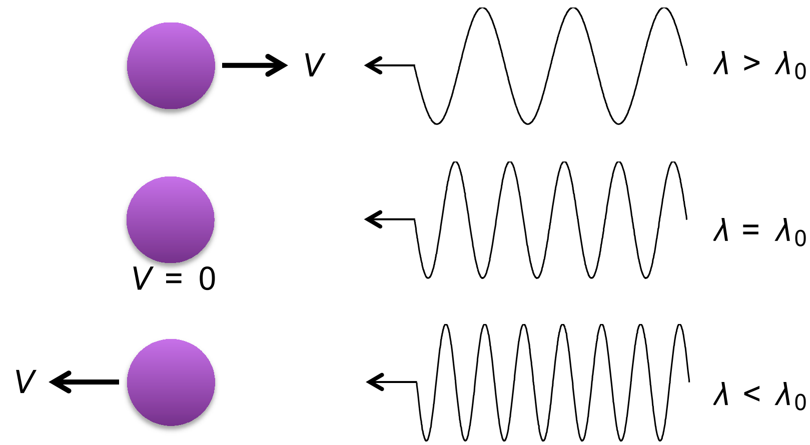
BHT-600 Operating Condition

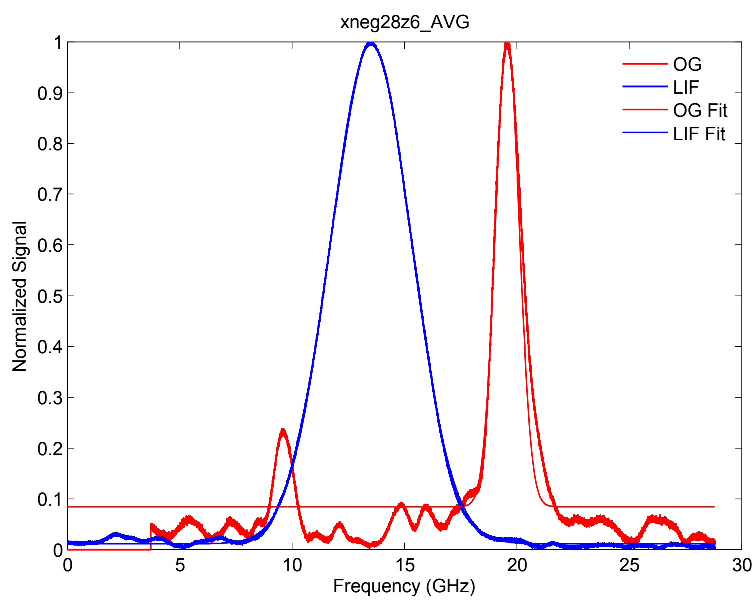


Anode Potential: 300 V	Anode Flow: 22.5 sccm Xe	Magnet 1 Current: 1.75 A
Anode Current: 2.05 – 2.15 A	Cathode Flow: 1.5 sccm Xe	Magnet 2 Current: 1.75 A

Time-Resolved LIF Method



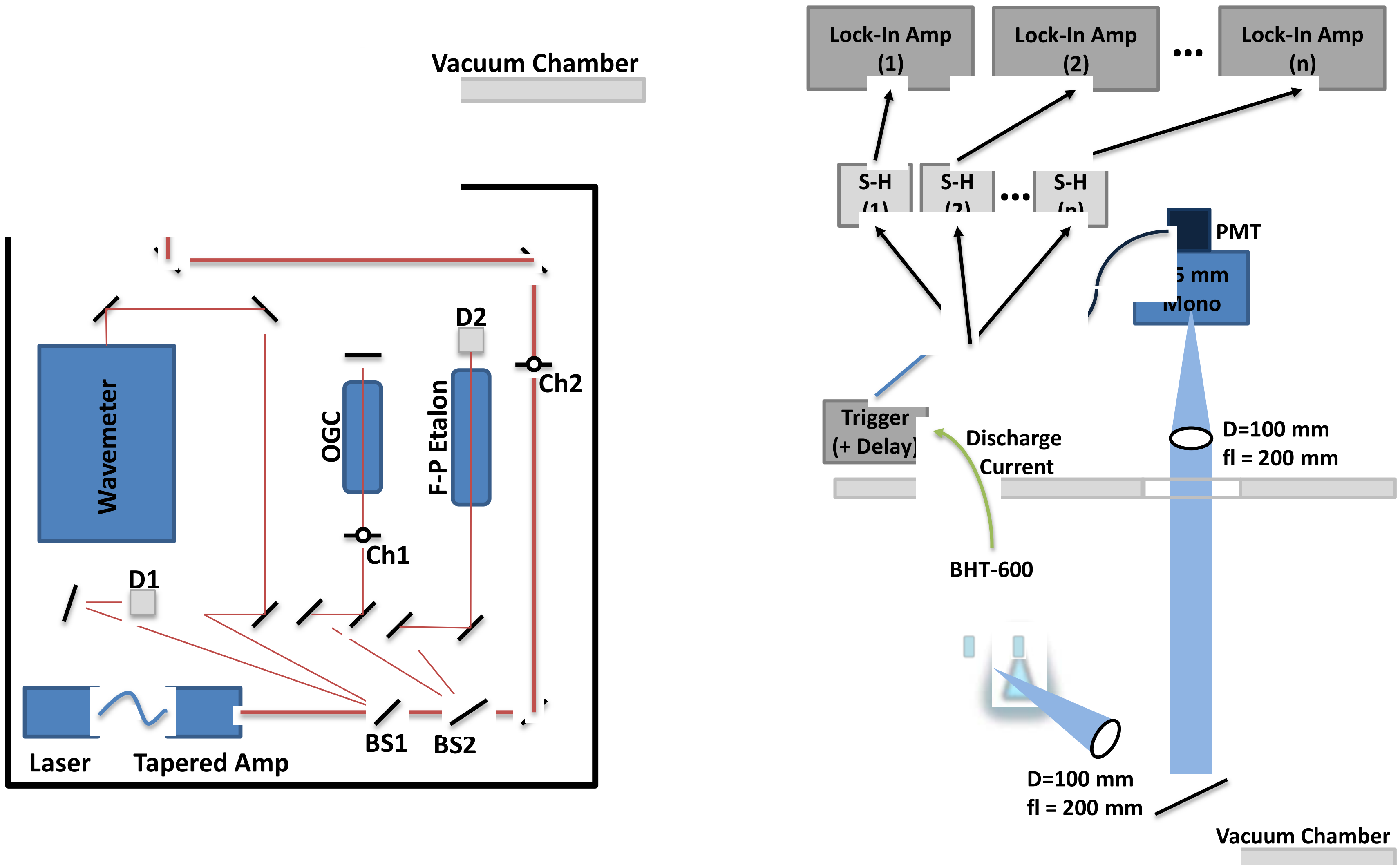




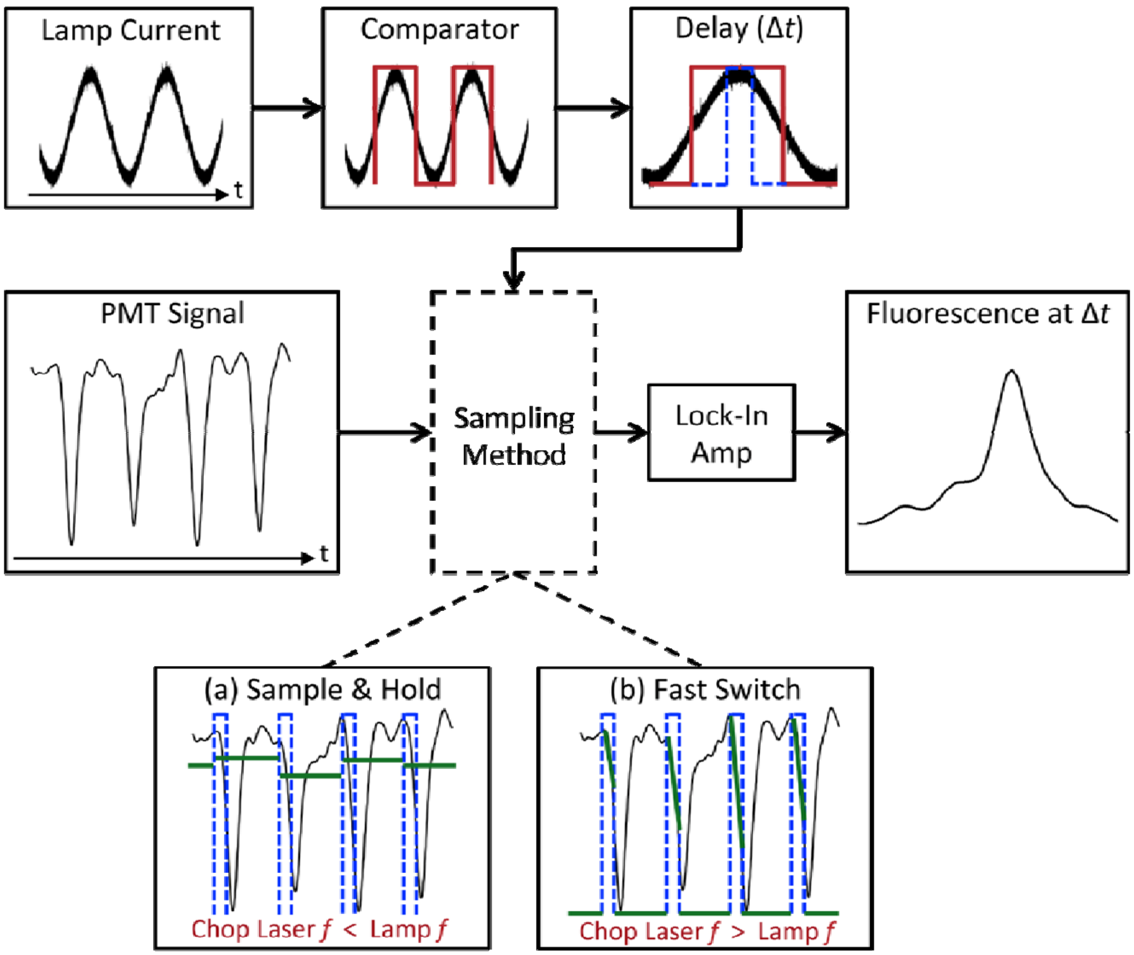
Ion Velocity from Doppler Shift:

$$v = c\frac{\Delta\omega}{\omega}$$

Time-Resolved LIF Method

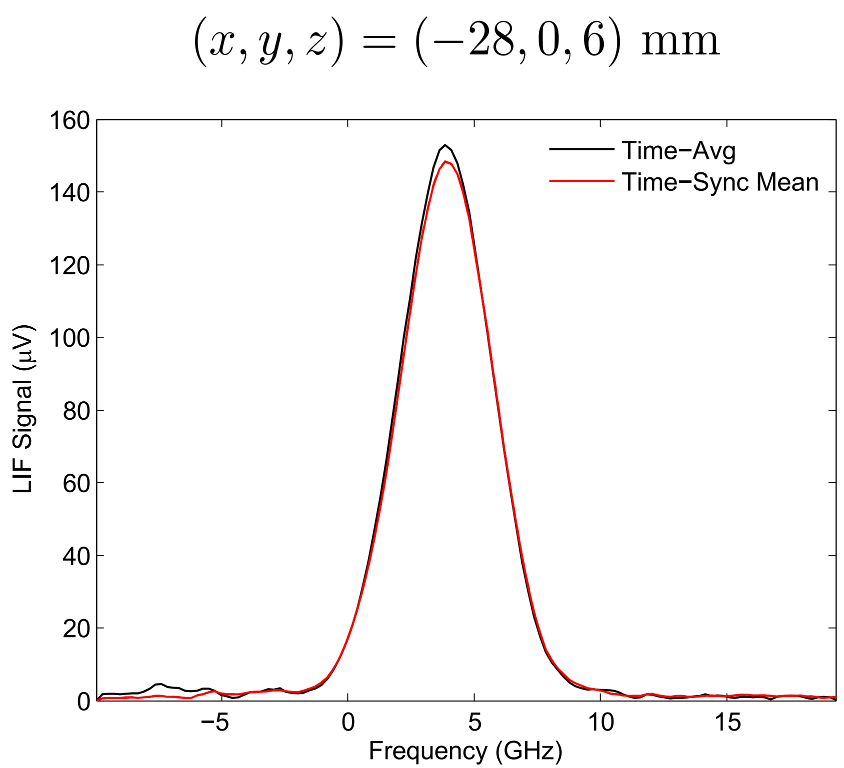


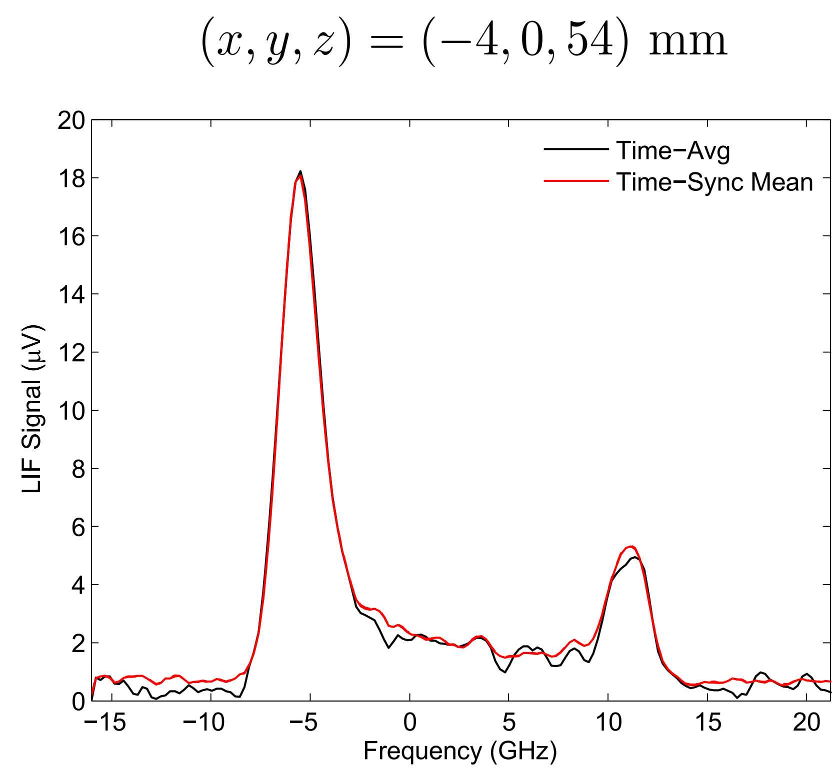
Time-Resolved LIF Method



- **Campaign 1**
  - 1 µs gates
  - 23 time points (0 – 23 µs) + avg
  - 6 lock-ins / SH circuits
  - 4 laser scans / point
- **Campaign 2**
  - 1 µs gates
  - 27 time points (0 – 20 µs) + avg
  - 10 lock-ins / SH circuits
  - 3 laser scans / point

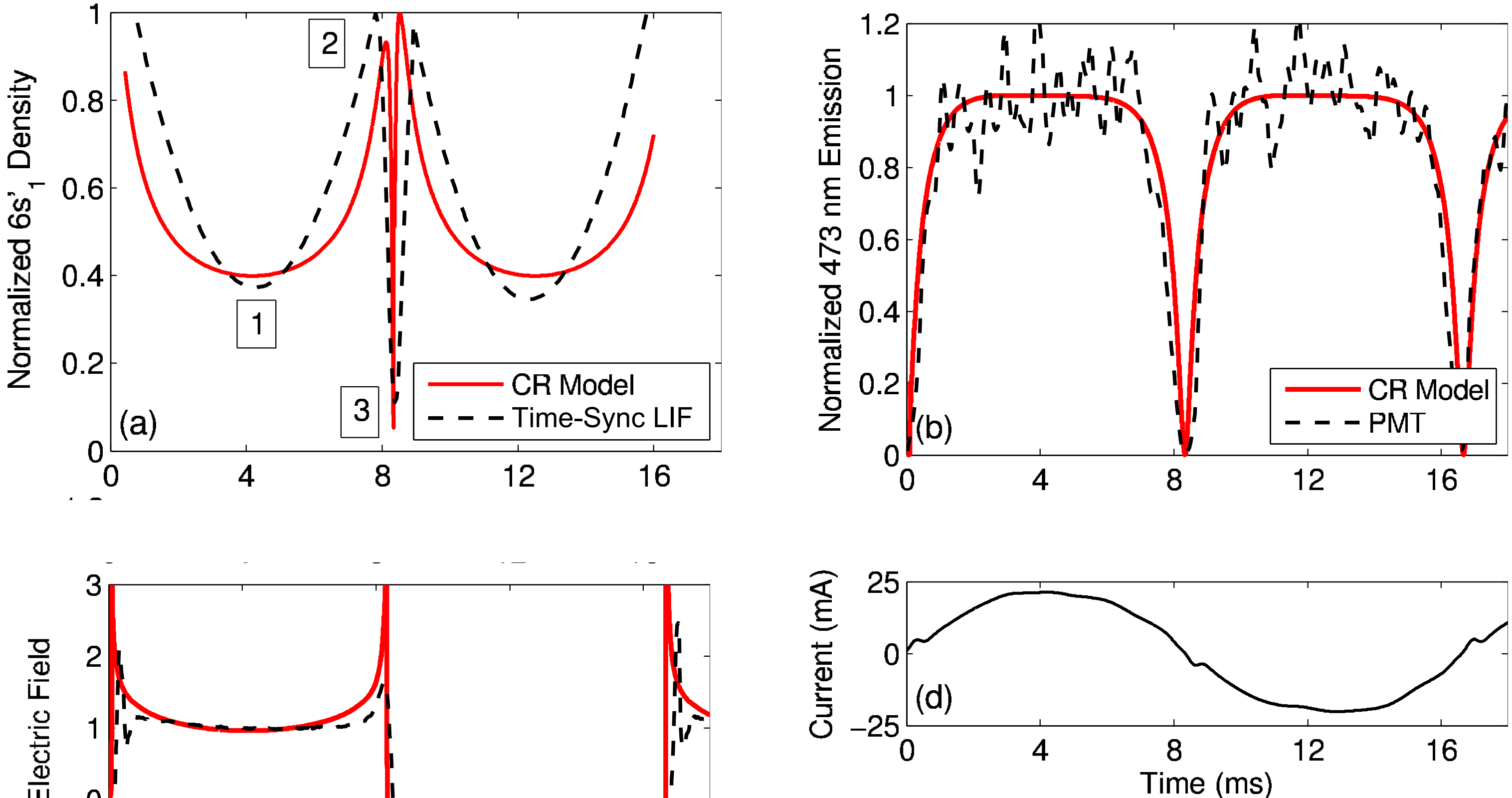
Time-Resolved LIF Method: Validation

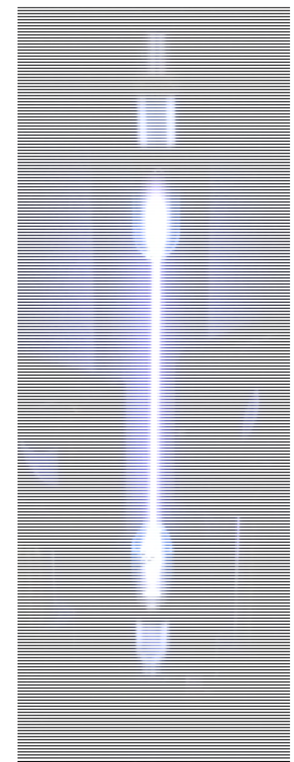




Sanity Check: Averaging the time-resolved traces recovers the time-averaged trace without sample-hold processing

Time-Resolved LIF Method: Validation

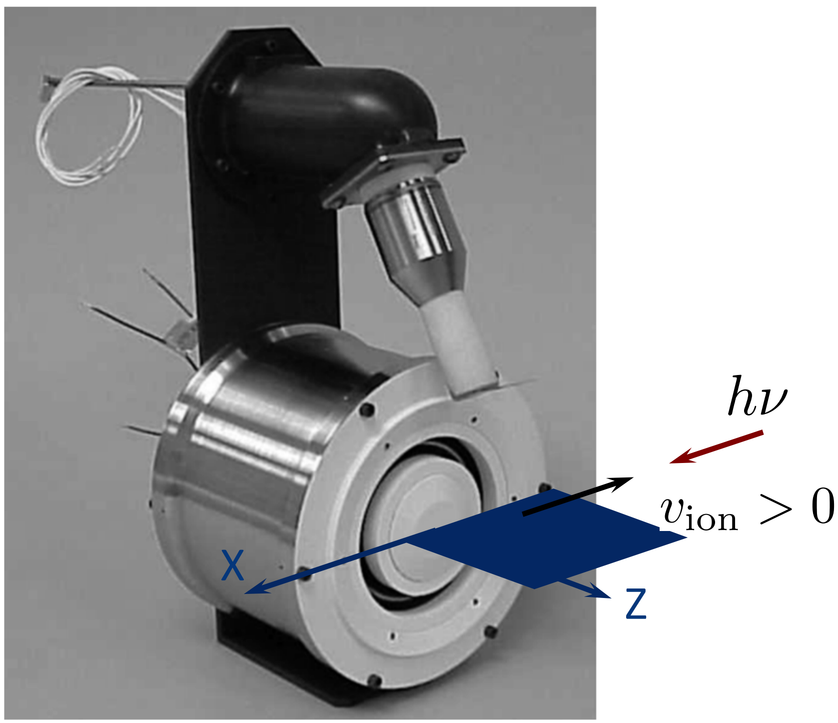


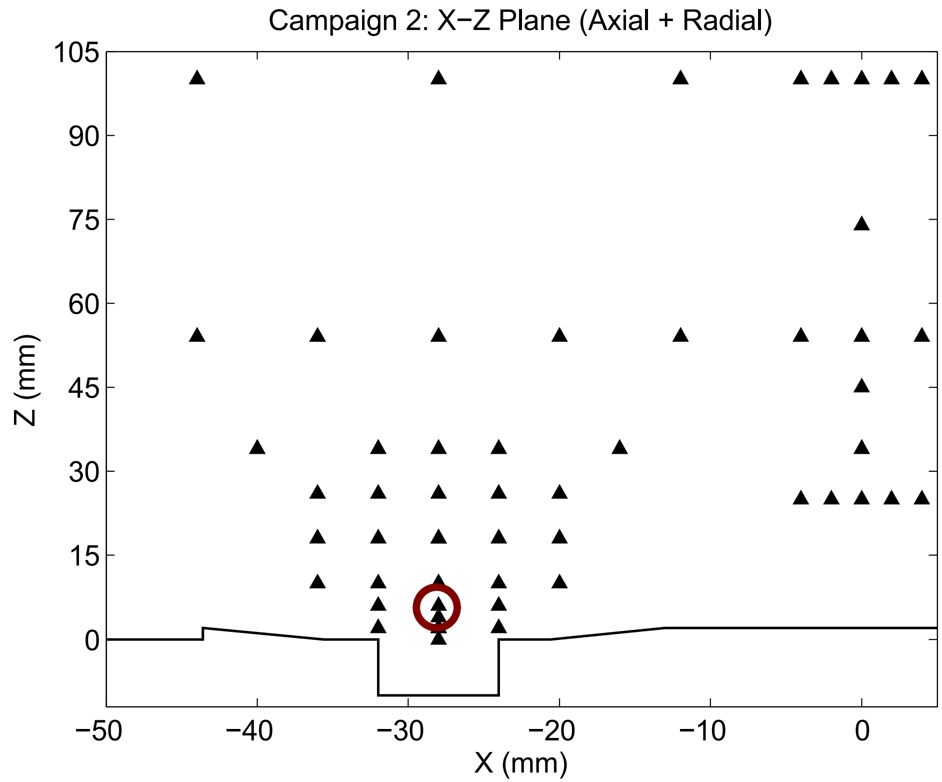


60 Hz Discharge: Collisional radiative model accurately reproduces measured quantities, including relative excited state density obtained from LIF peak intensity

A. Lucca Fabris, C. V. Young, and M. A. Cappelli, Plasma Sources Sci. Technol. **24** (2015) 055013

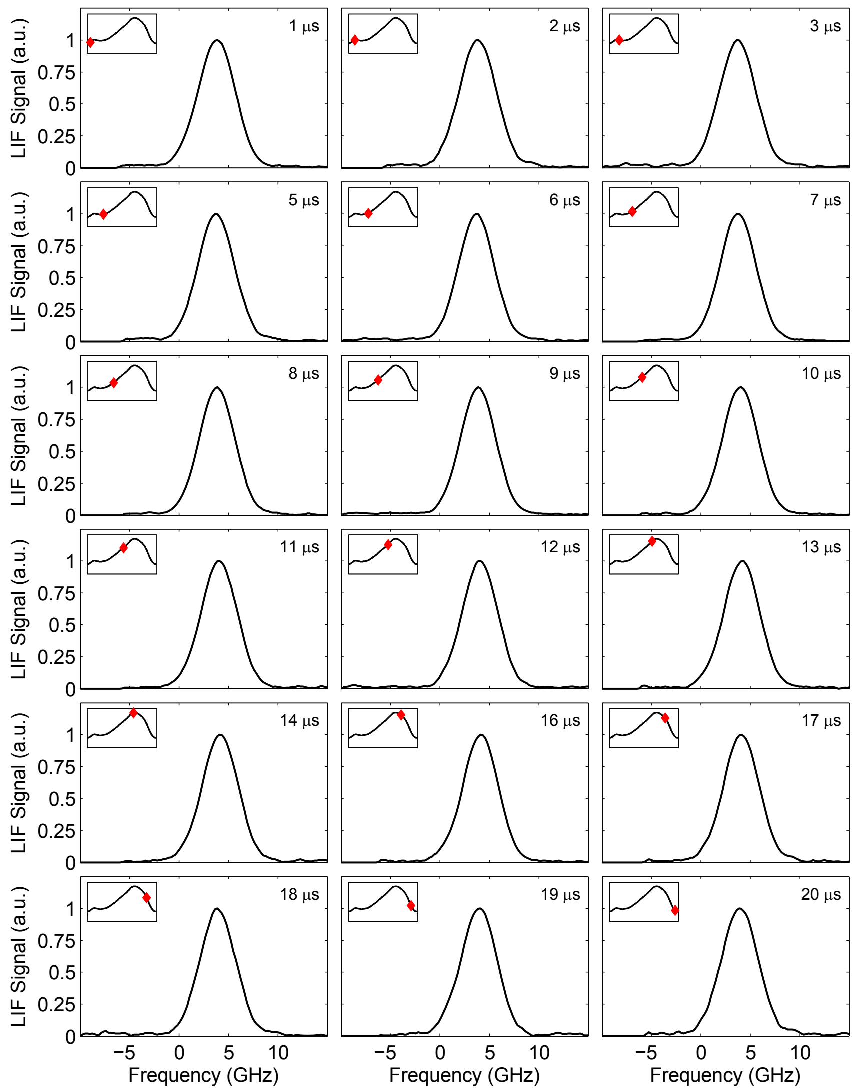
Results: Example Time Series (Radial)

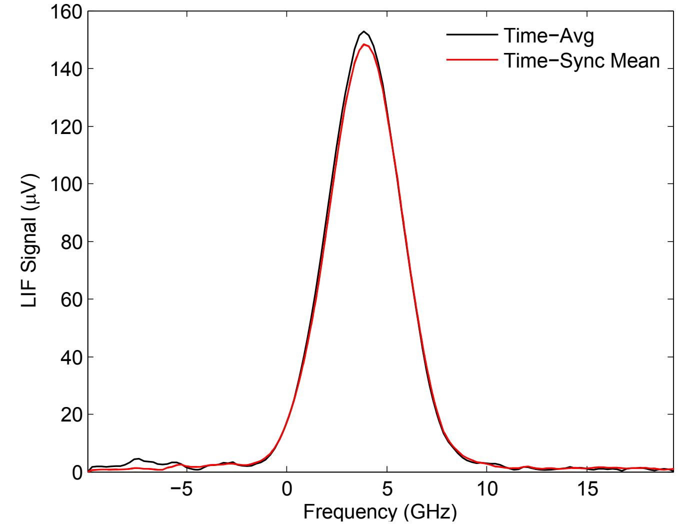


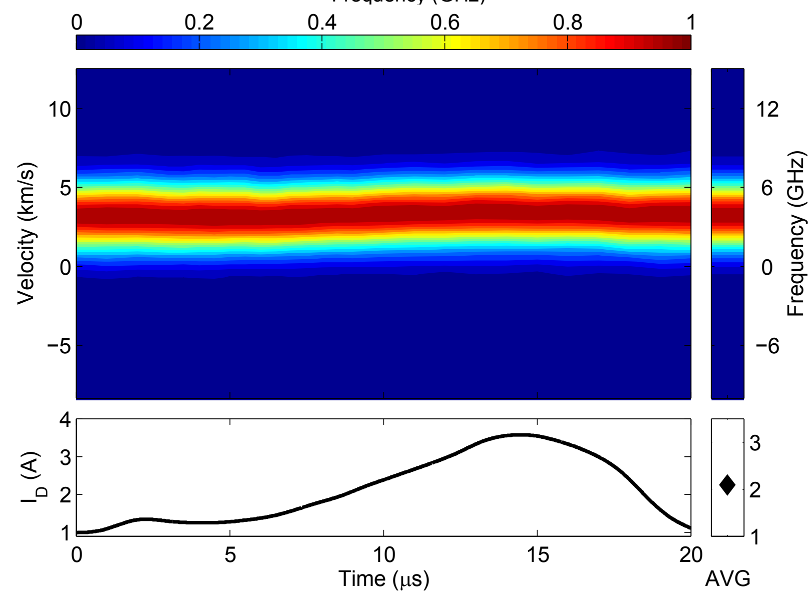


Example Point (Radial): $(x, y, z) = (-28, 0, 6)\ \mathrm{mm}$

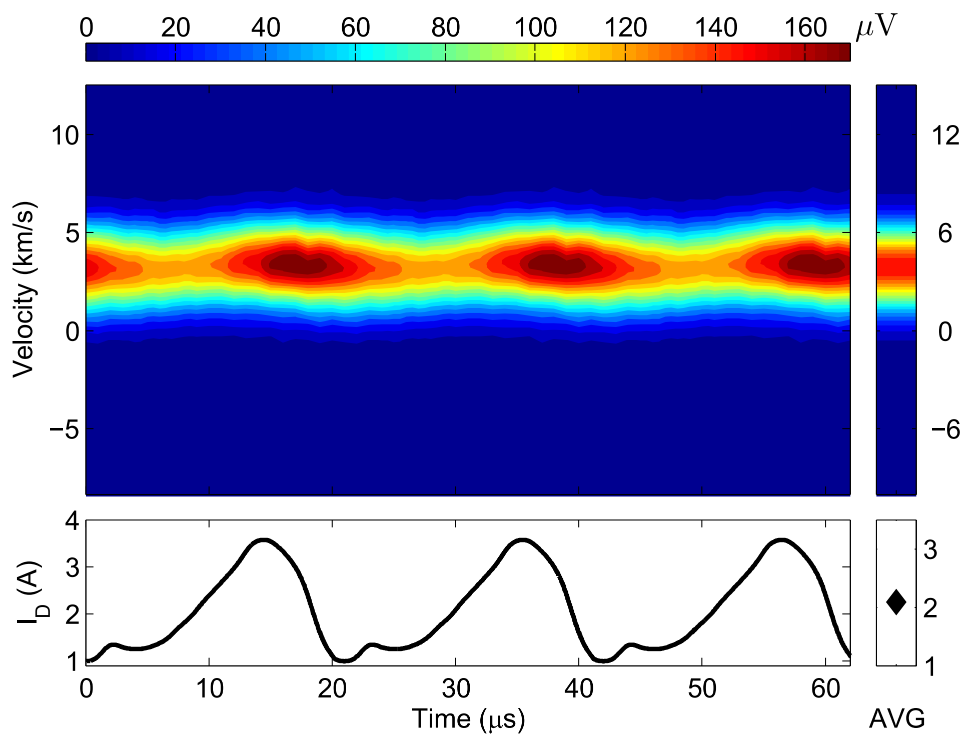
Results: Example Time Series (Radial)

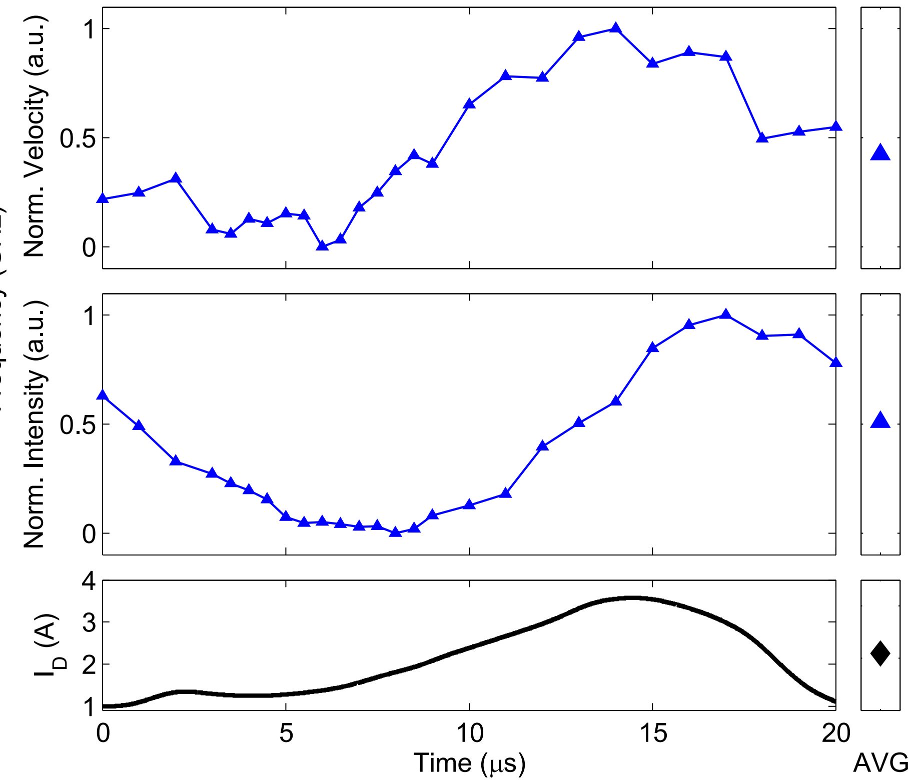






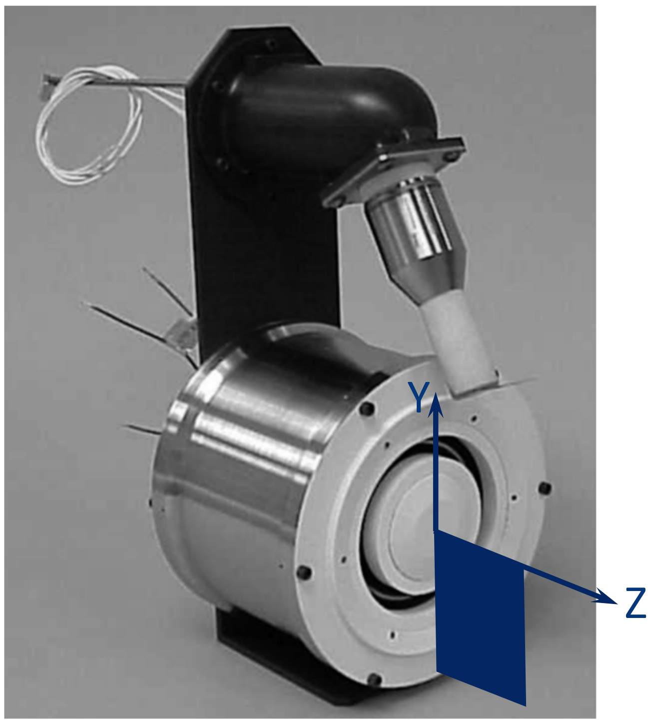
Results: Example Time Series (Radial)

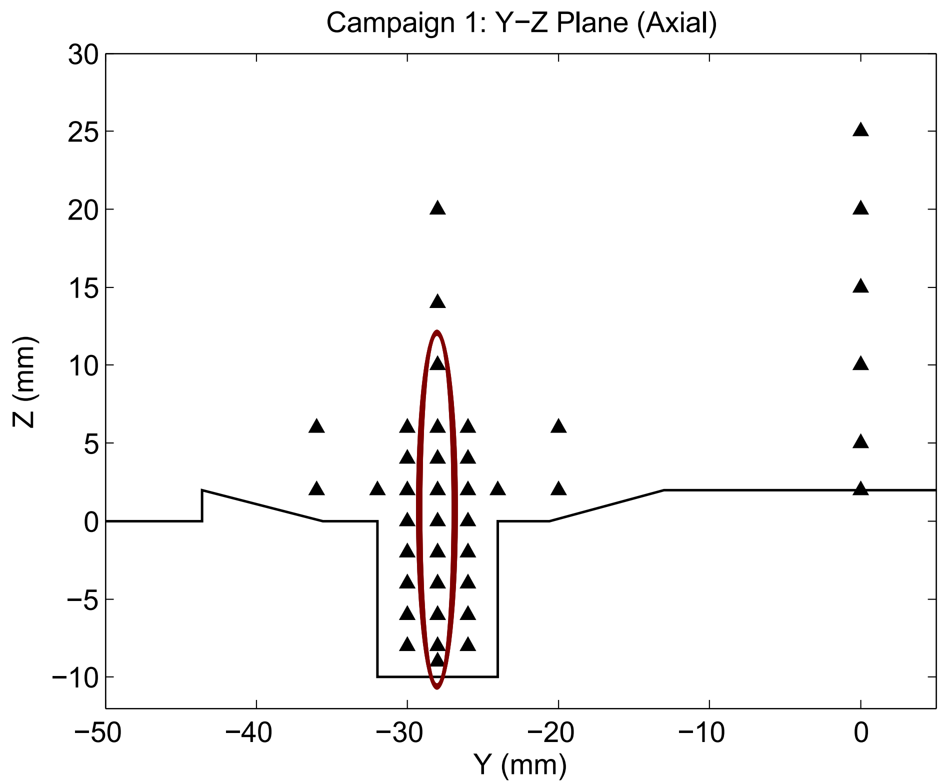




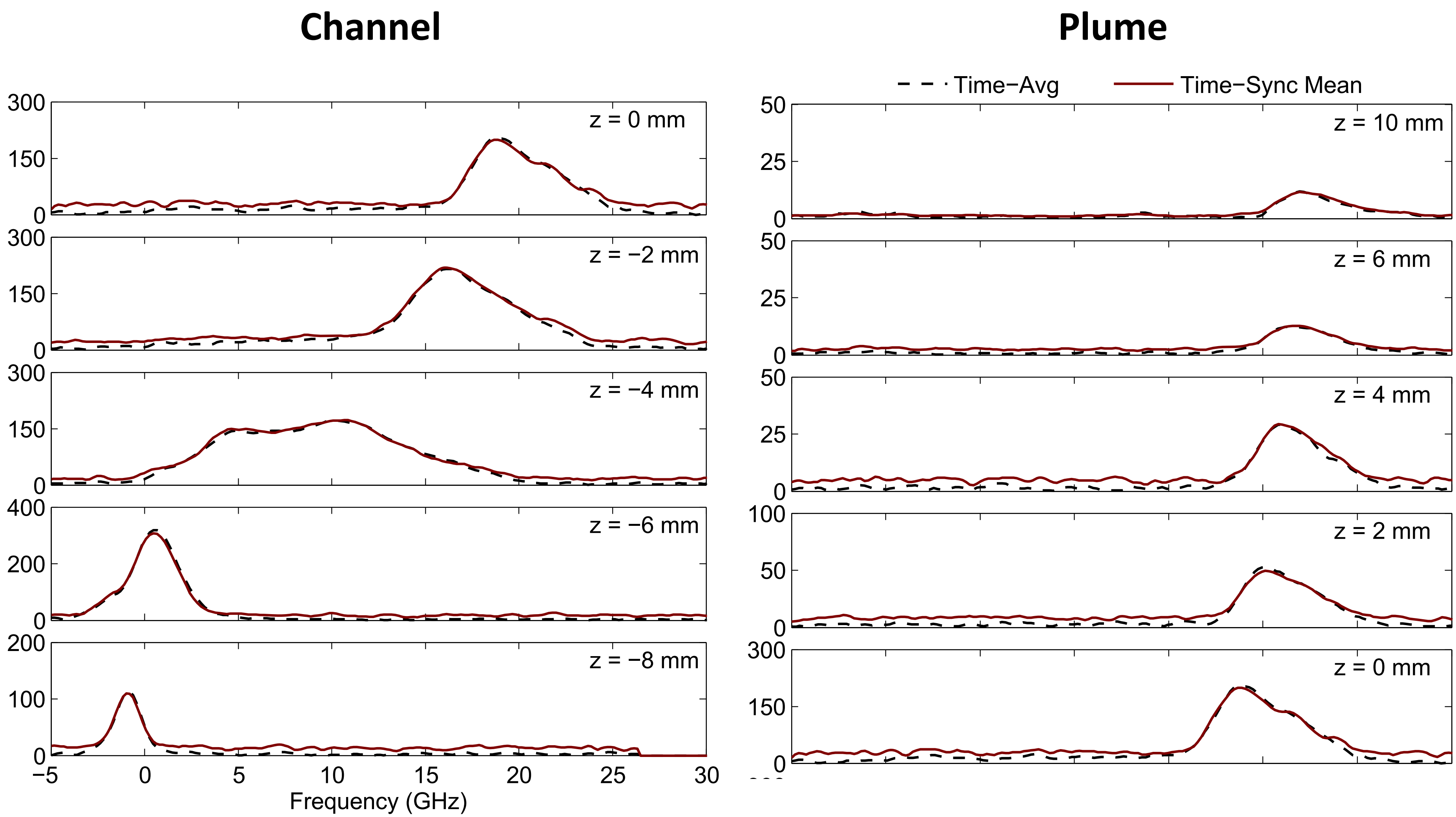
Interesting Behavior: Radial data show small modulation in velocity and intensity correlated with primarily axial breathing mode

Results: Campaign 1 (Channel, Axial)

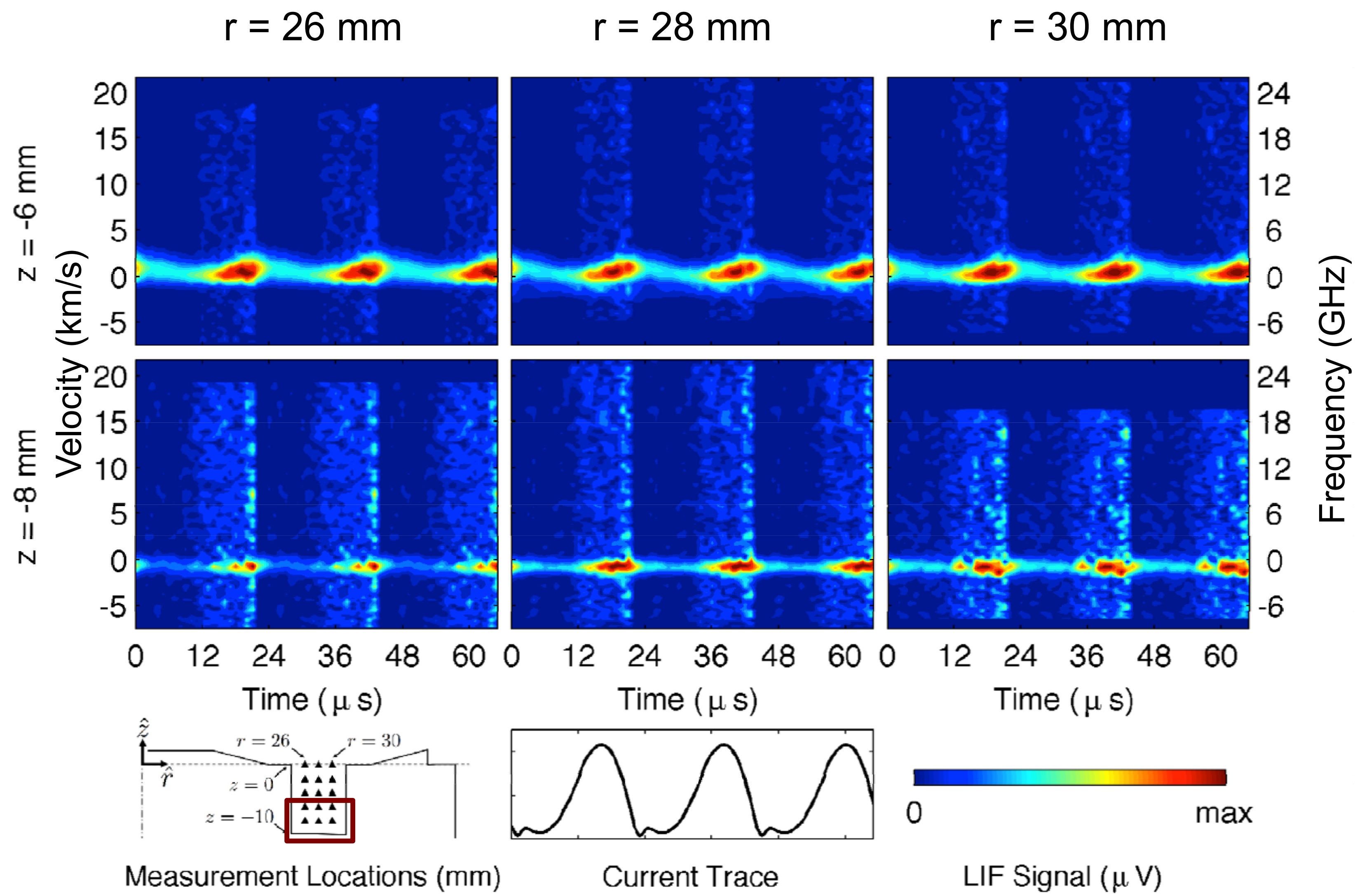




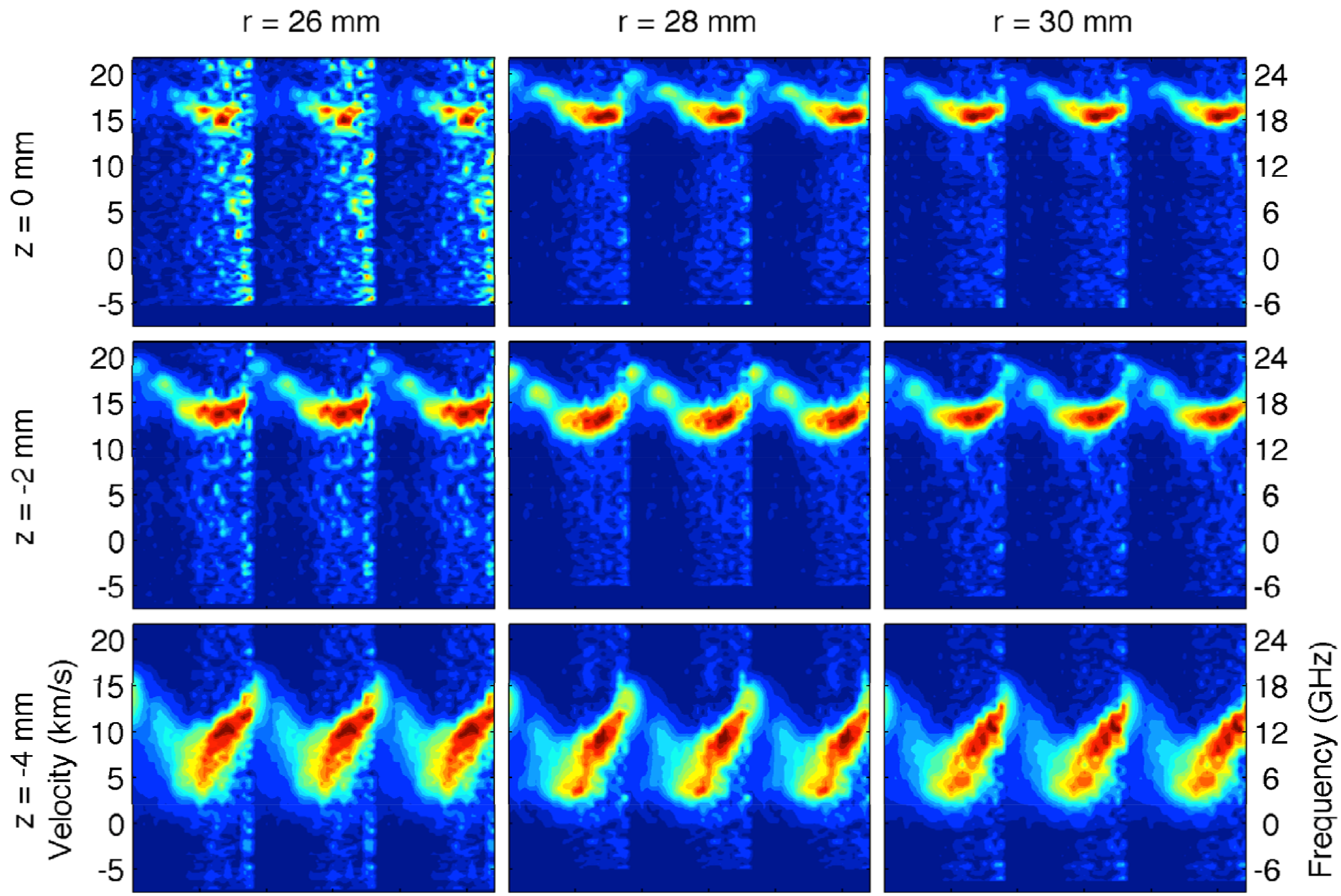
Results: Campaign 1 (Channel, Axial)



Results: Campaign 1 (Channel, Axial)

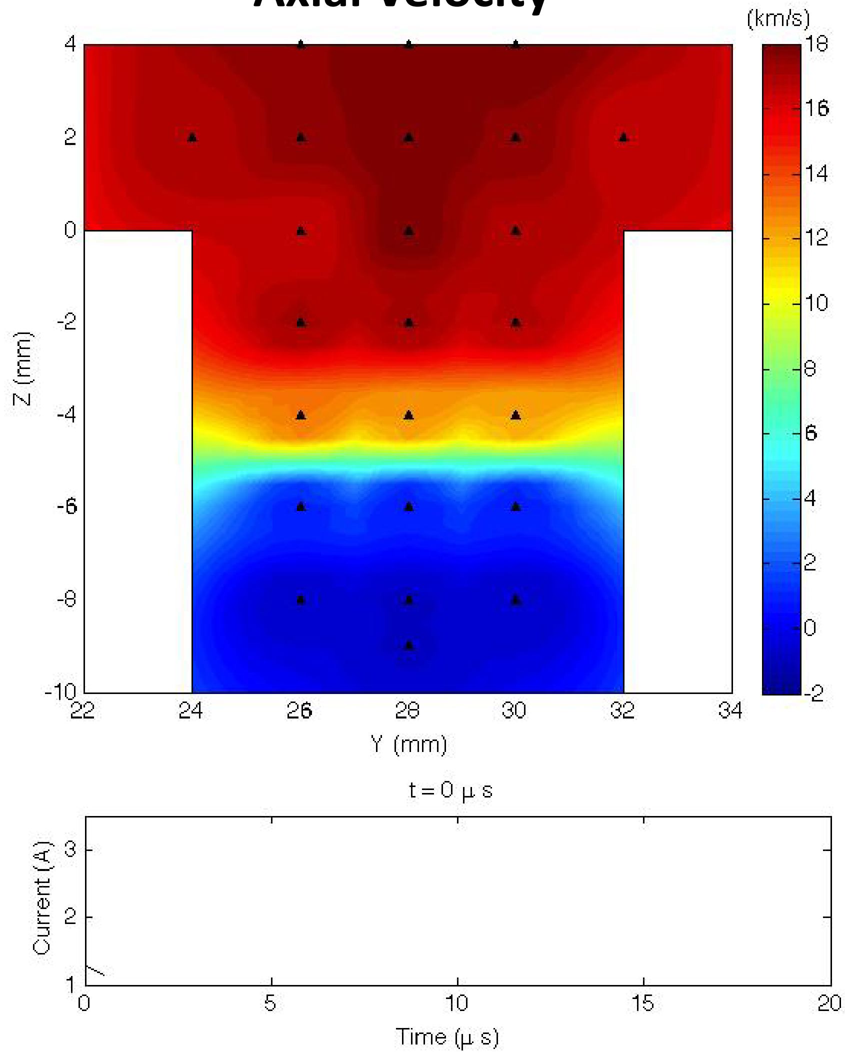


Results: Campaign 1 (Channel, Axial)

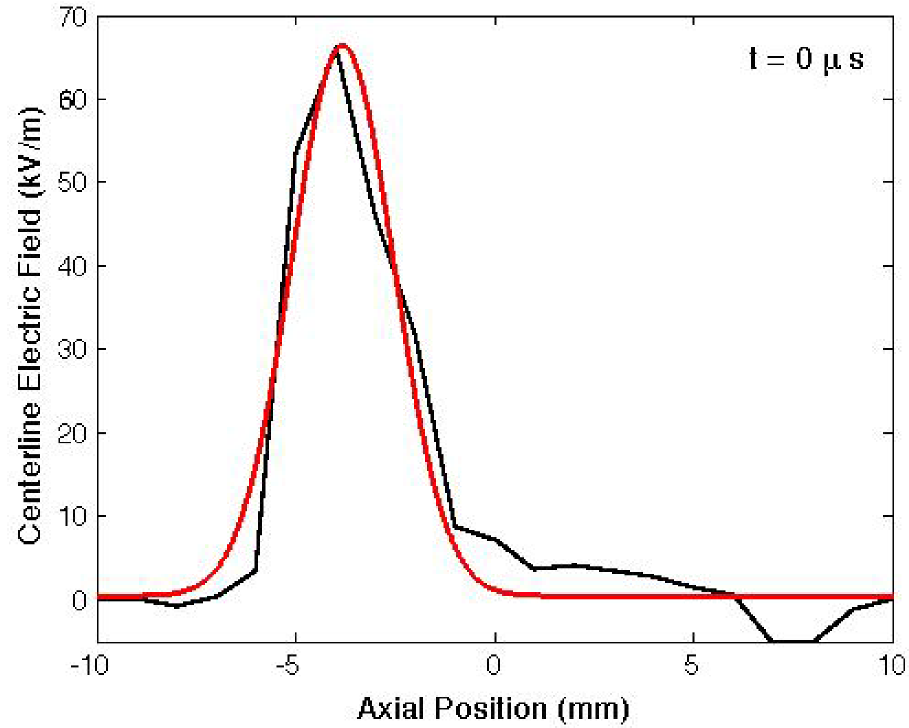


Results: Campaign 1 (Channel, Axial)

Axial Velocity

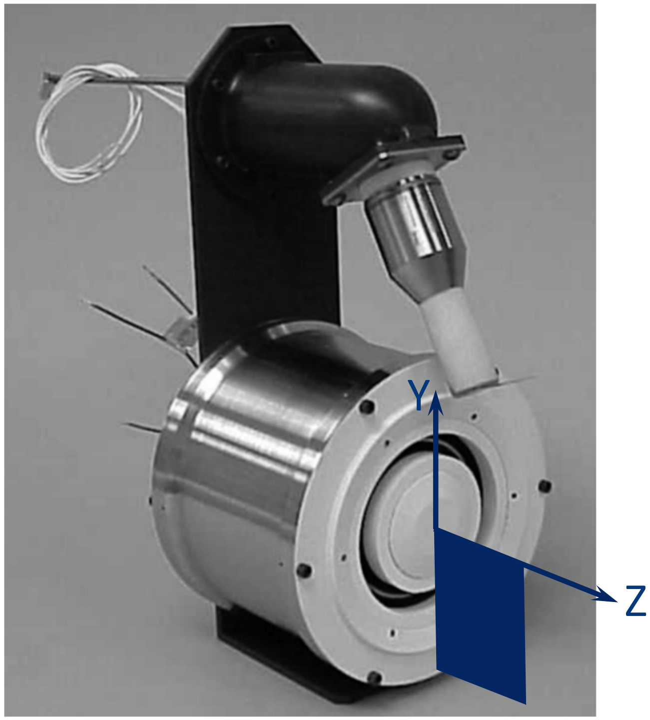


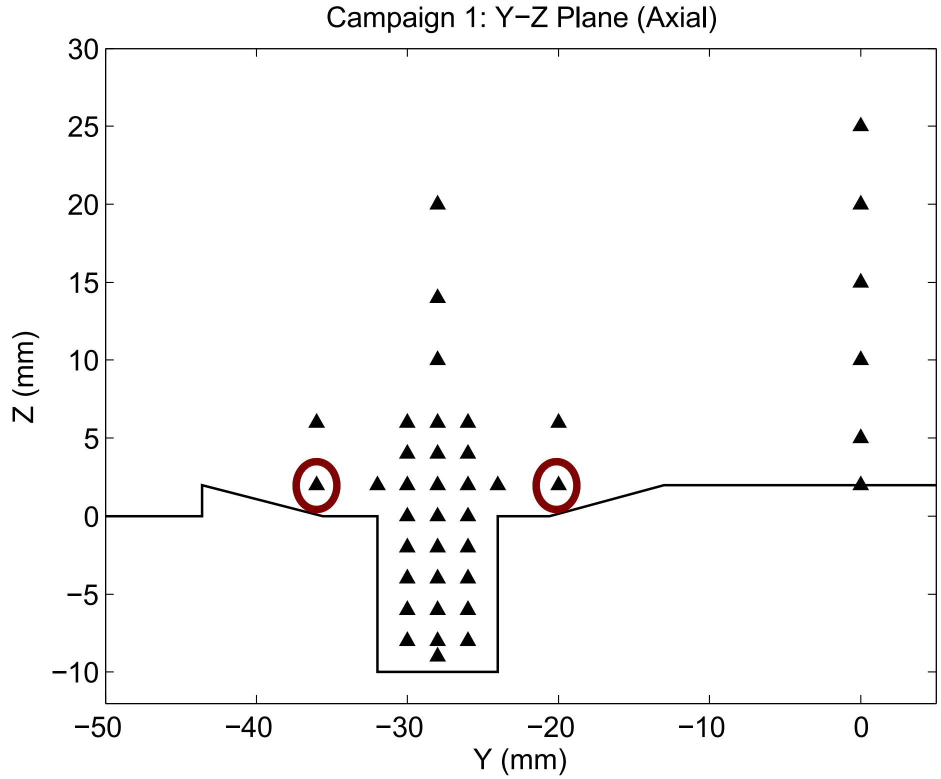
Axial Electric Field



$$E_z = \frac{m_i}{e}\left(\frac{\partial v_z}{\partial t} + v_z \cdot \frac{\partial v_z}{\partial z}\right)$$

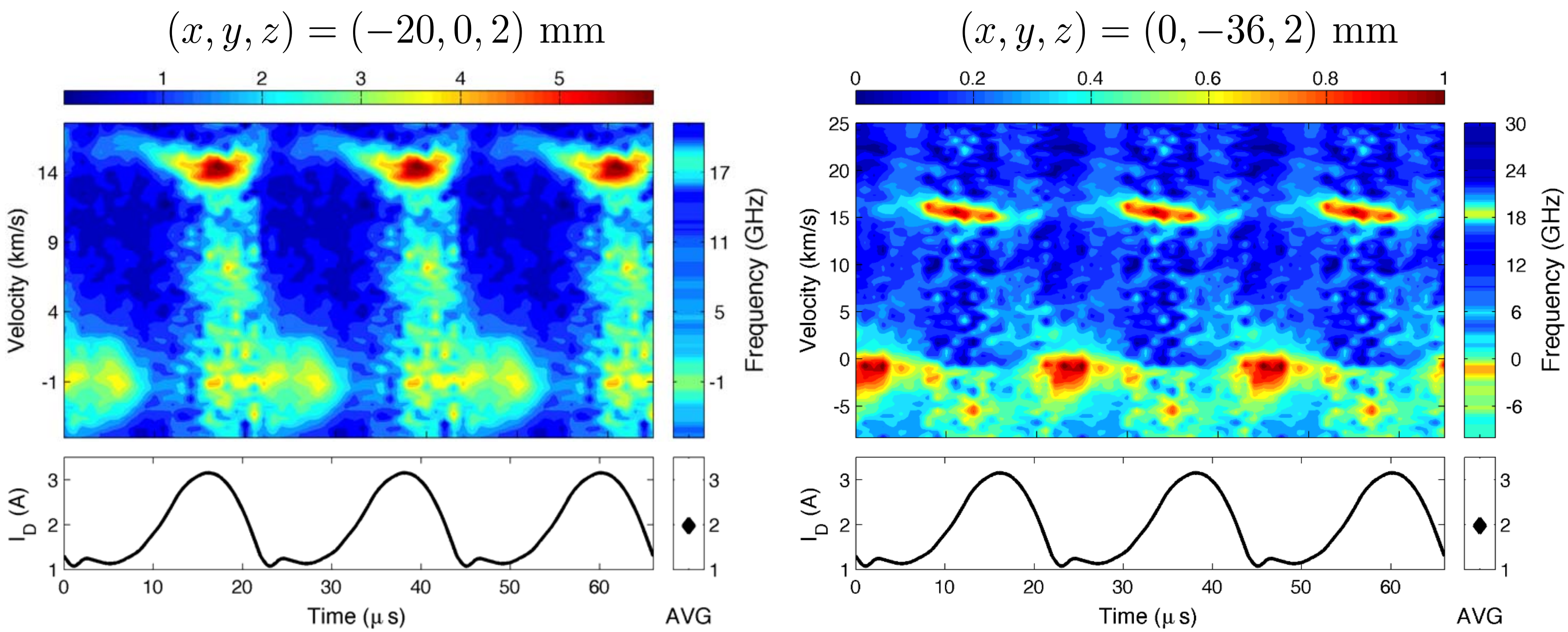
Results: Campaign 1 (Near Field, Axial)



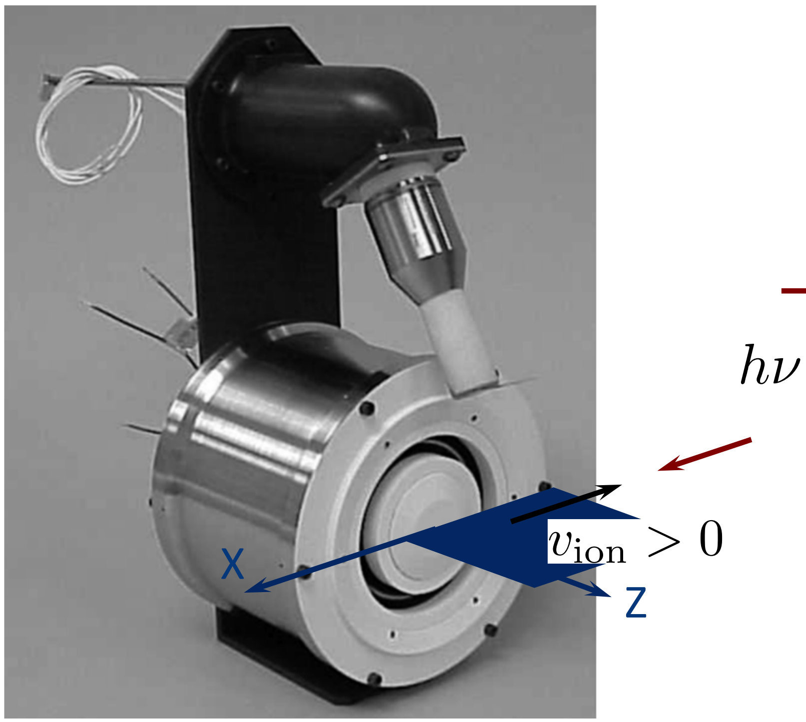


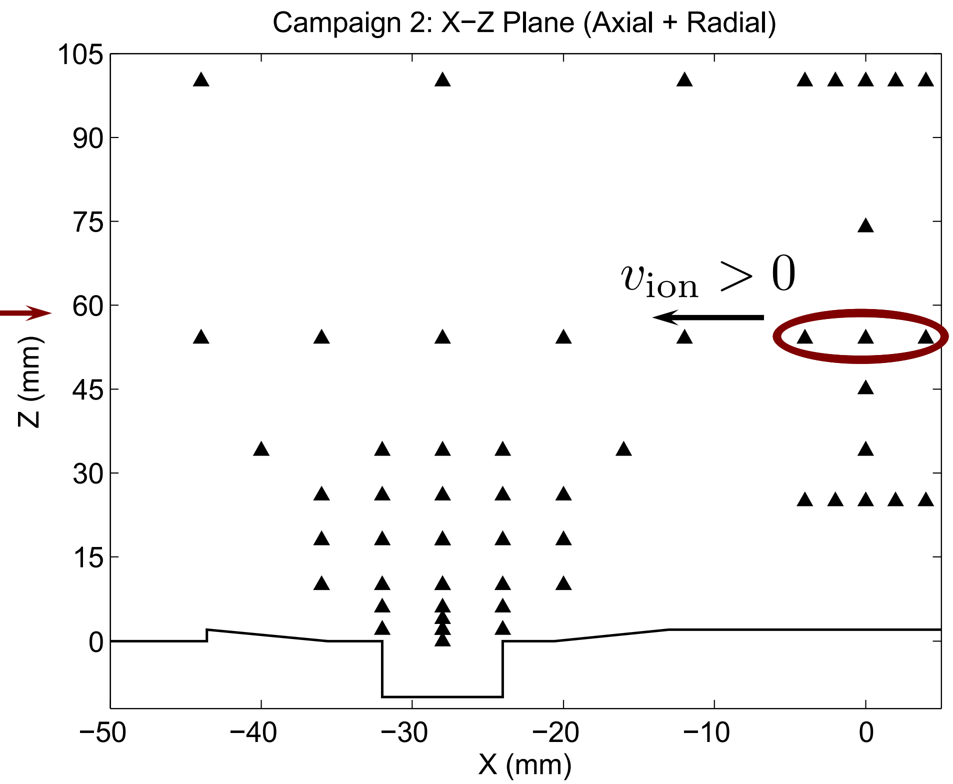
Results: Campaign 1 (Near Field, Axial)

Interesting Behavior: Double axial ion populations near edge of channel



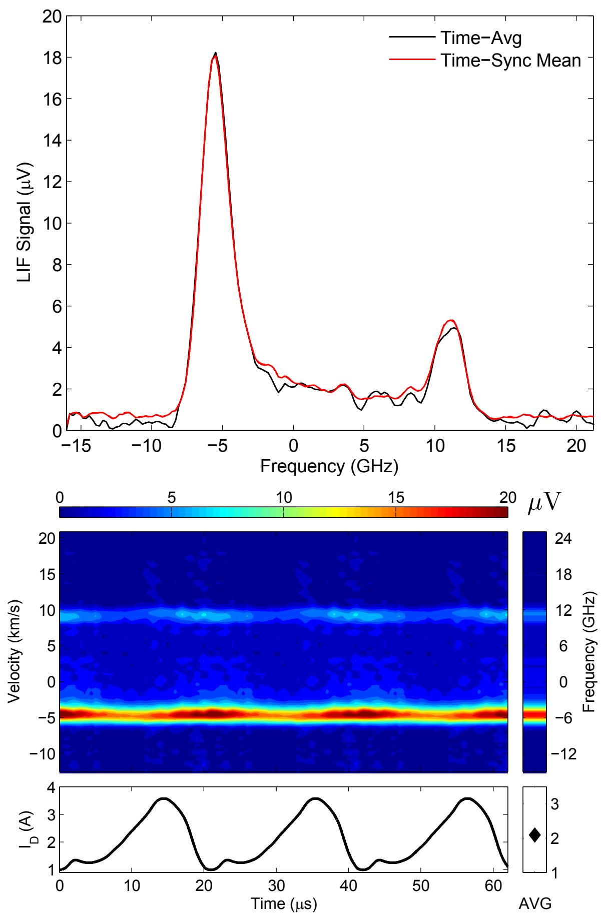
Results: Campaign 2 (Central Jet)



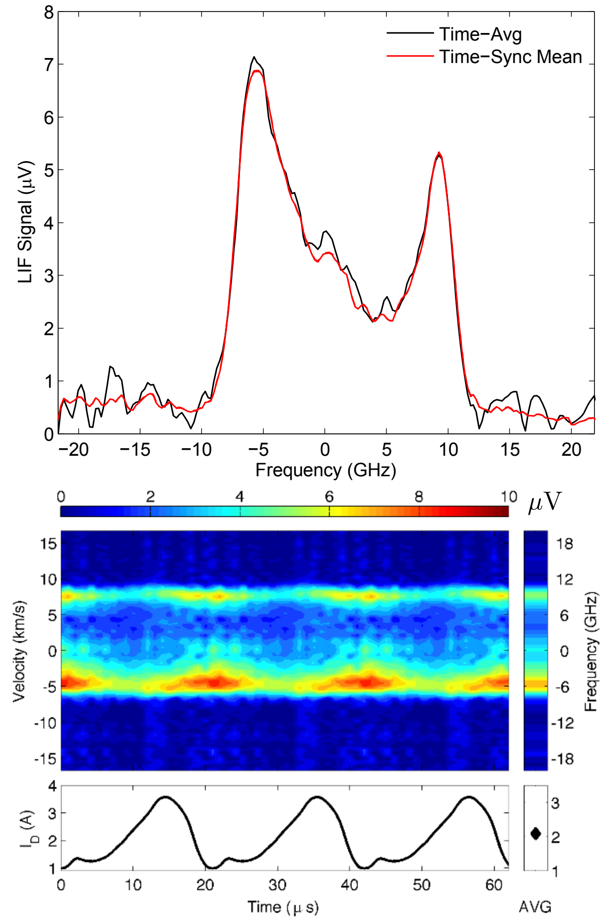


Results: Campaign 2 (Central Jet, Radial)

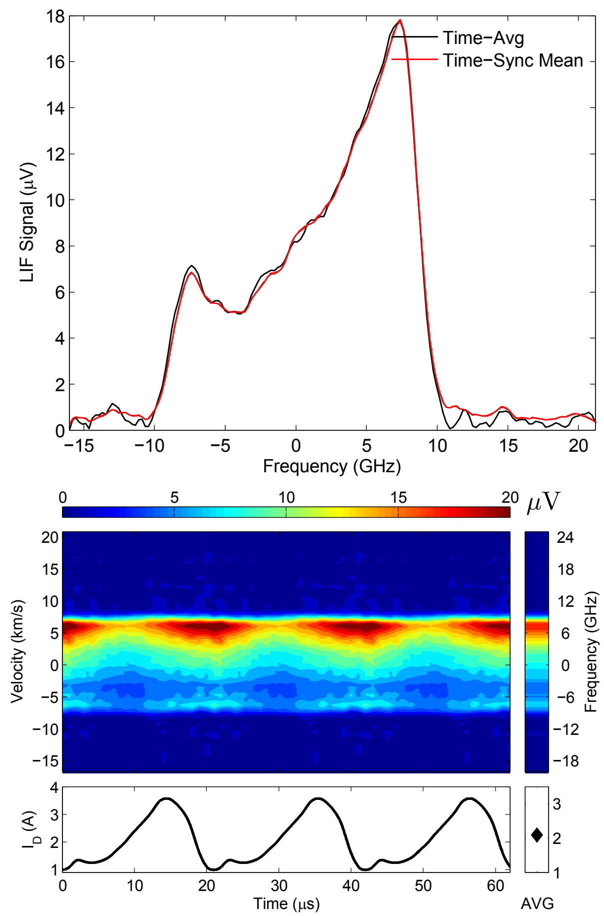
Radial Data: Complex flow field along thruster axis with crossing beams



$(x, y, z) = (-4, 0, 54)$ mm



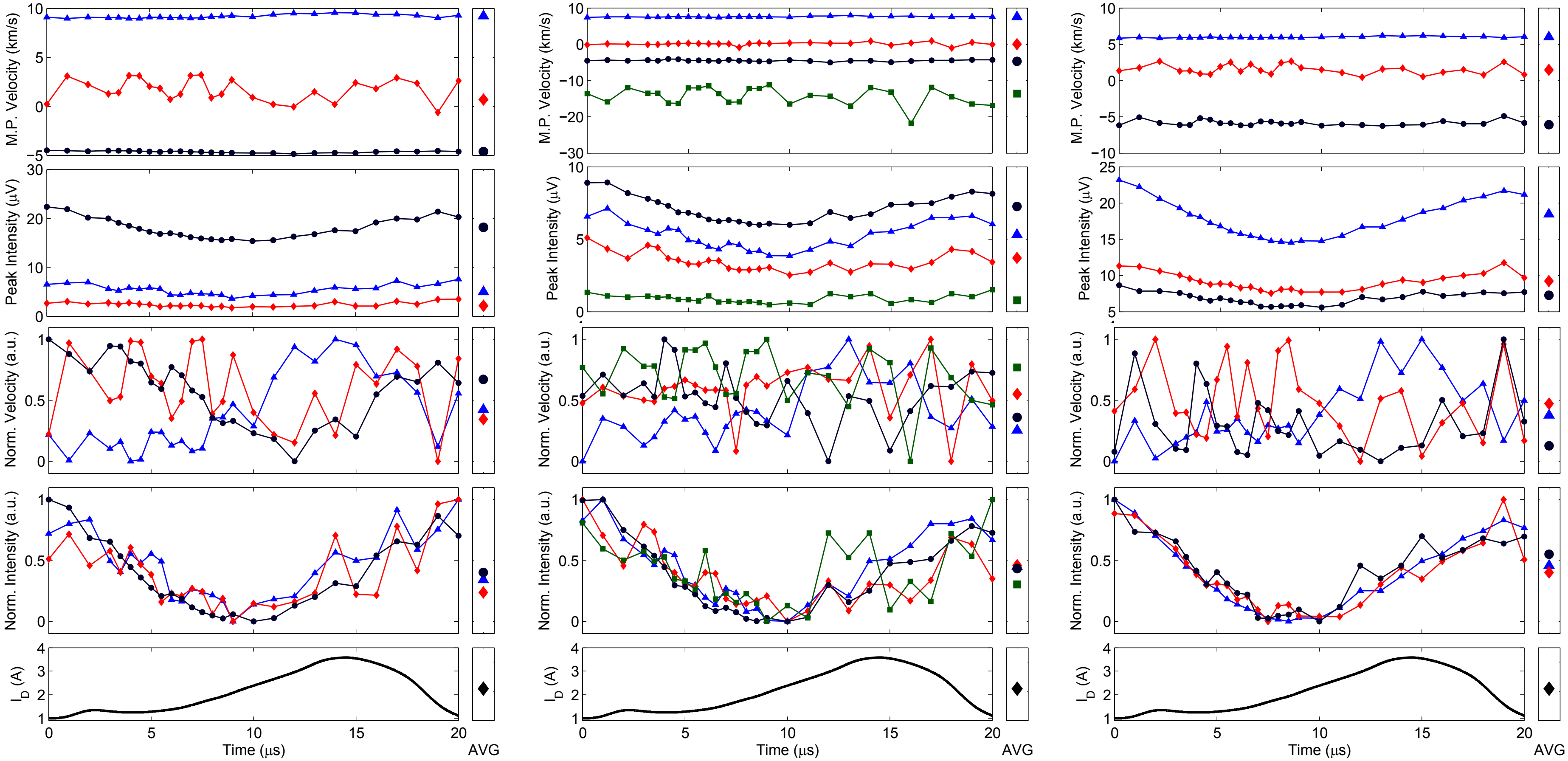
$(x, y, z) = (0, 0, 54)$ mm



$(x, y, z) = (4, 0, 54)$ mm

Results: Campaign 2 (Central Jet, Radial)

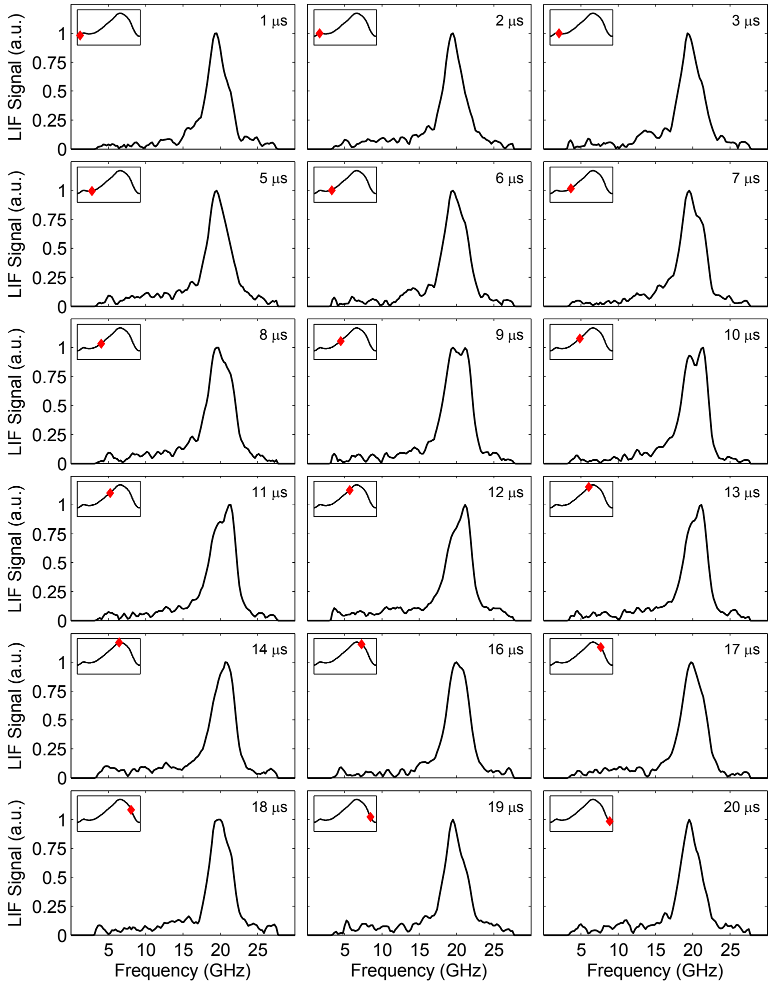
Radial Data: Similar intensity trends, but opposite velocity trends?

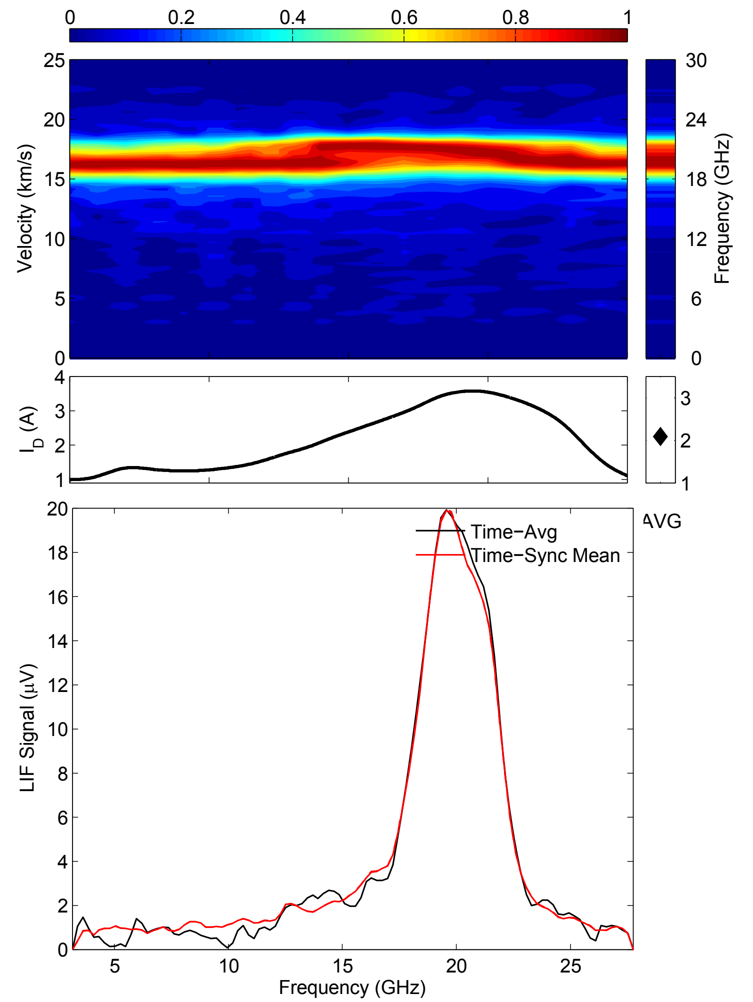


$(x, y, z) = (-4, 0, 54)$ mm $\quad (x, y, z) = (0, 0, 54)$ mm $\quad (x, y, z) = (4, 0, 54)$ mm

Results: Campaign 2 (Central Jet, Axial)

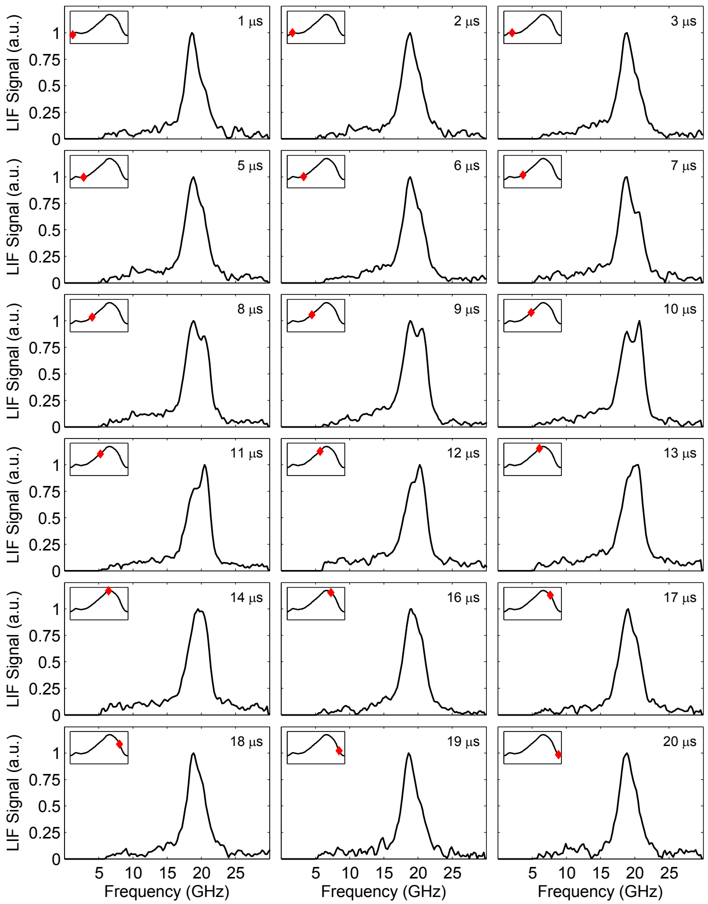
Axial Data: One main population with a hint of two? $(x, y, z) = (0, 0, 54)\ \mathrm{mm}$



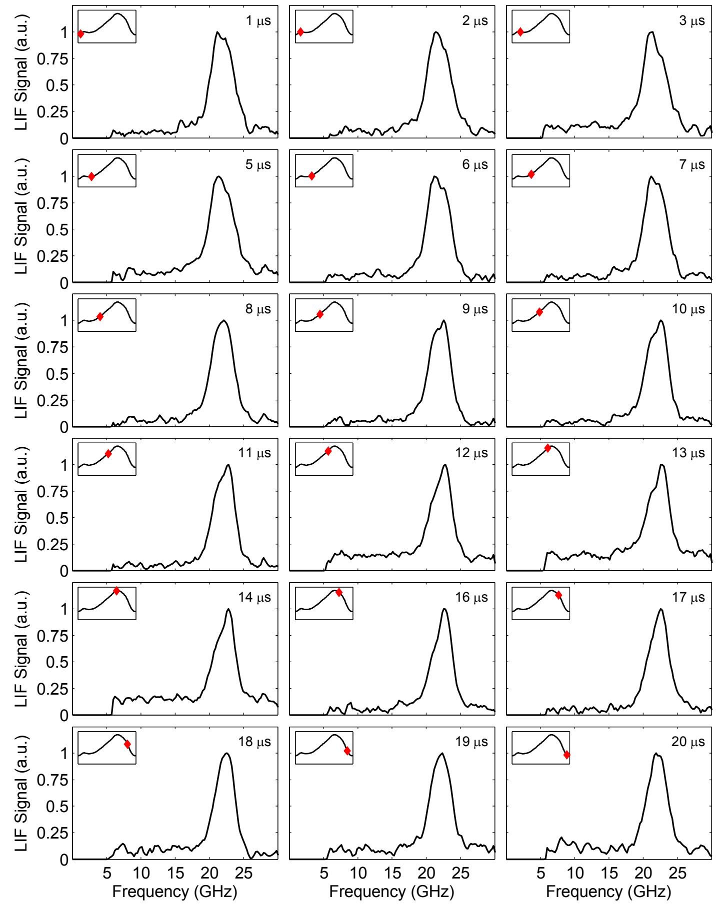


Results: Campaign 2 (Central Jet, Axial)

Axial Data: Double peak behavior apparent all along central jet



$$(x, y, z) = (0, 0, 45)\ \text{mm}$$



$$(x, y, z) = (0, 0, 100)\ \text{mm}$$

Summary

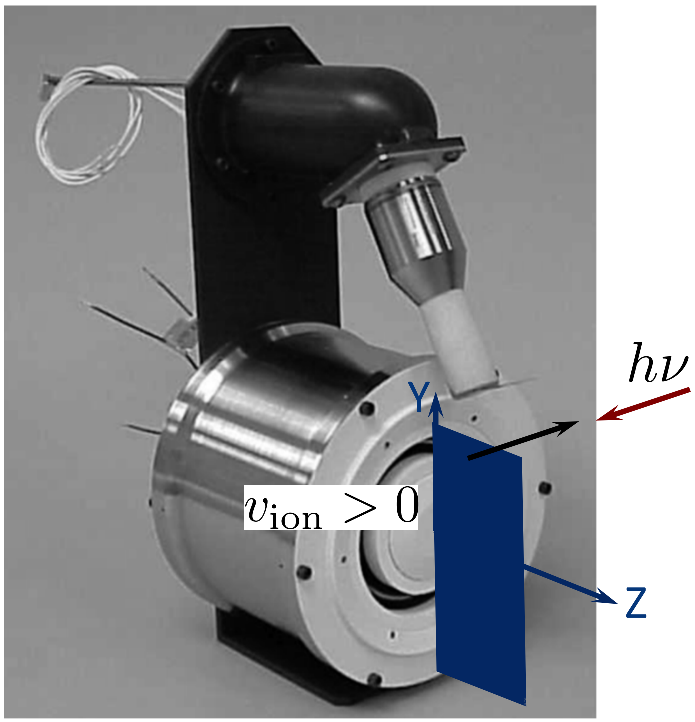
- Radial (azimuthal) and axial, time-resolved LIF velocity data has been taken in the channel and near-field plume of a BHT-600
- Parallelized sample-hold circuits enabled full time-series acquired at >150 spatial points (axial, with radial/azimuthal at 71) in 22 test days
- Modulations in ion velocity and LIF intensity (excited state ion population) observed in both axial and radial data at breathing mode frequency of 48 kHz
- Data analysis is ongoing, but interesting features like multiple, time-dependent ion populations are already apparent
- Time-resolved ion velocity data can provide benchmark for Hall thruster simulations that should capture realistic dynamics

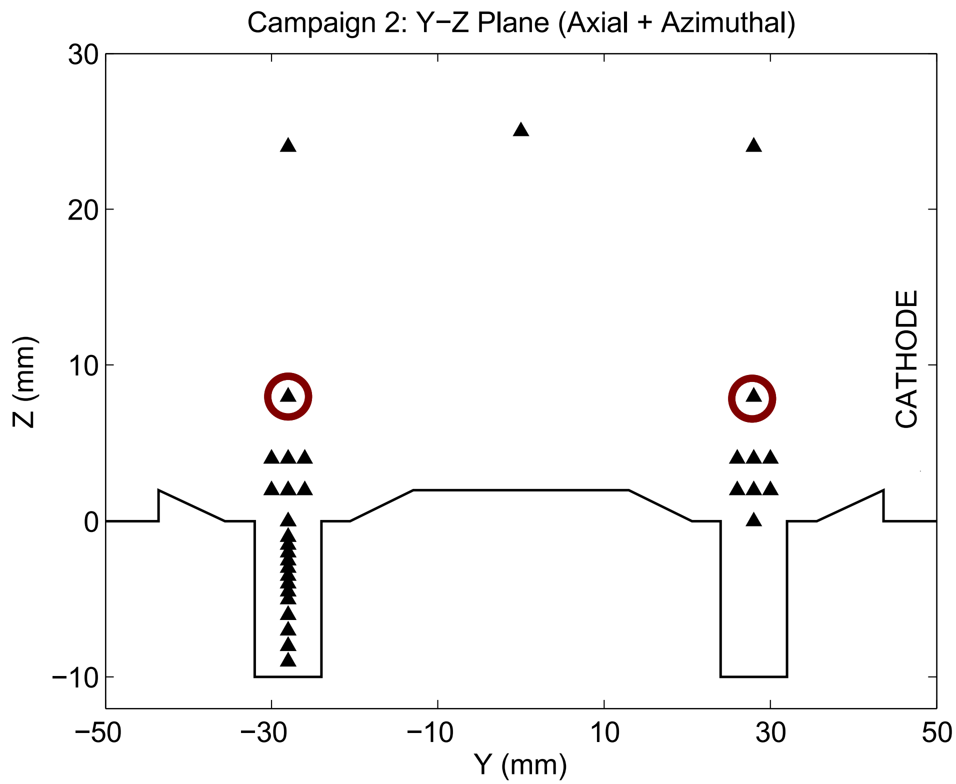
Questions?

- Radial (azimuthal) and axial, time-resolved LIF velocity data has been taken in the channel and near-field plume of a BHT-600
- Parallelized sample-hold circuits enabled full time-series acquired at >150 spatial points (axial, with radial/azimuthal at 71) in 22 test days
- Modulations in ion velocity and LIF intensity (excited state ion population) observed in both axial and radial data at breathing mode frequency of 48 kHz
- Data analysis is ongoing, but interesting features like multiple, time-dependent ion populations are already apparent
- Time-resolved ion velocity data can provide benchmark for Hall thruster simulations that should capture realistic dynamics

BACKUP

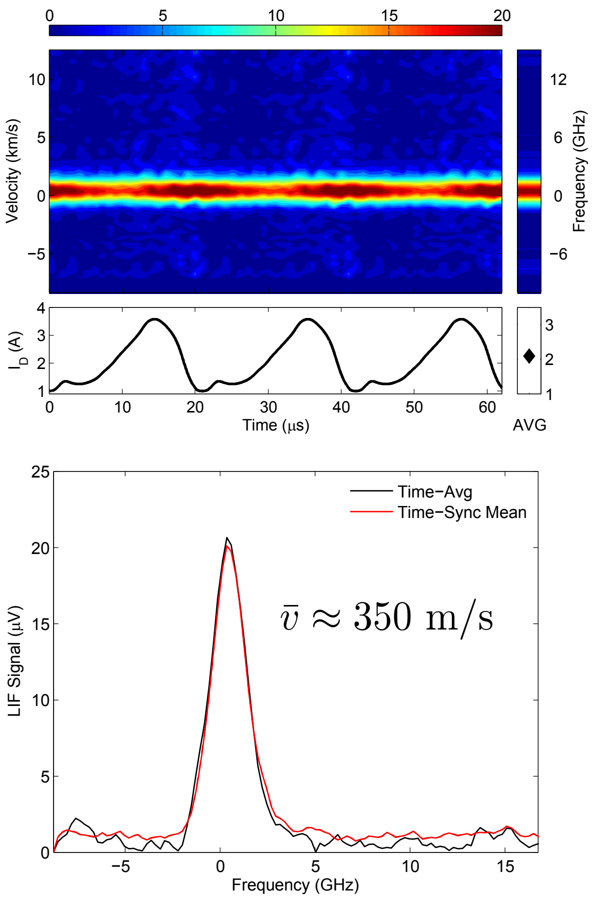
Results: Campaign 2 (Azimuthal Velocities)



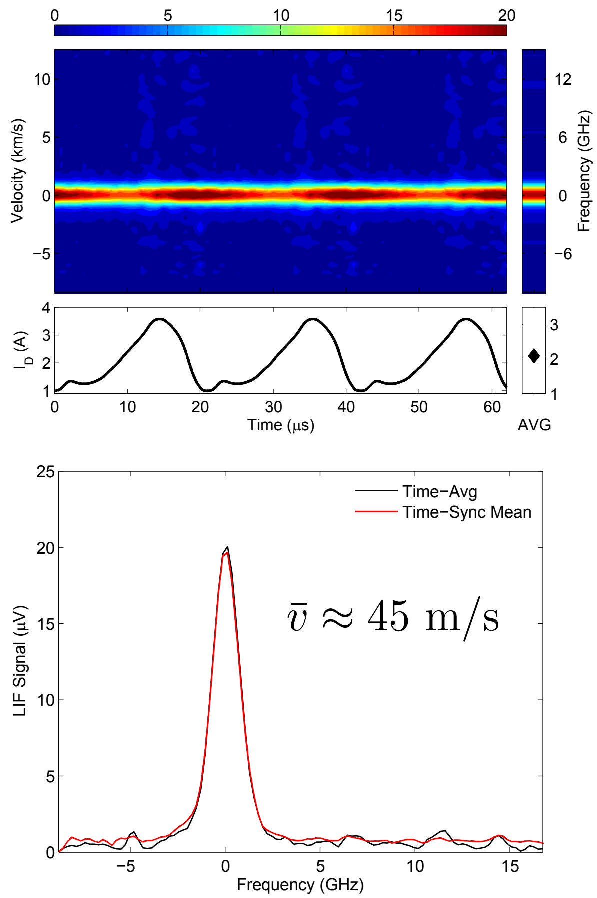


Results: Campaign 2 (Azimuthal Velocities)

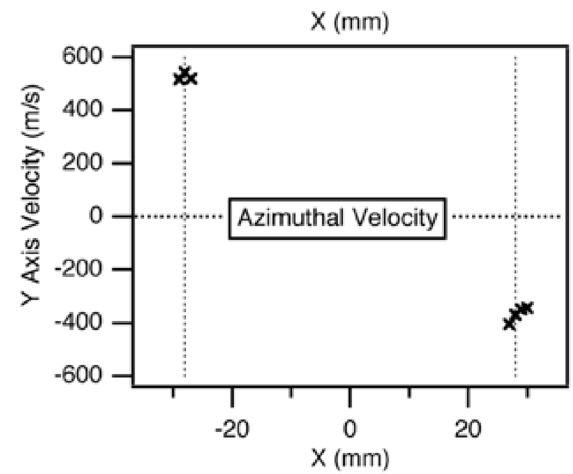
Azimuthal Velocities: Small velocity component within measurement uncertainty



$(x, y, z) = (0, 28, 8)$ mm



$(x, y, z) = (0, -28, 8)$ mm



(Hargus and Charles, 2010)

W. A. Hargus Jr. and C. S. Charles, J. Propul. Power. **26** (2010) 135