# Characterizing a Gas-Ionization Platform for Single-Shot Beam Diagnostics

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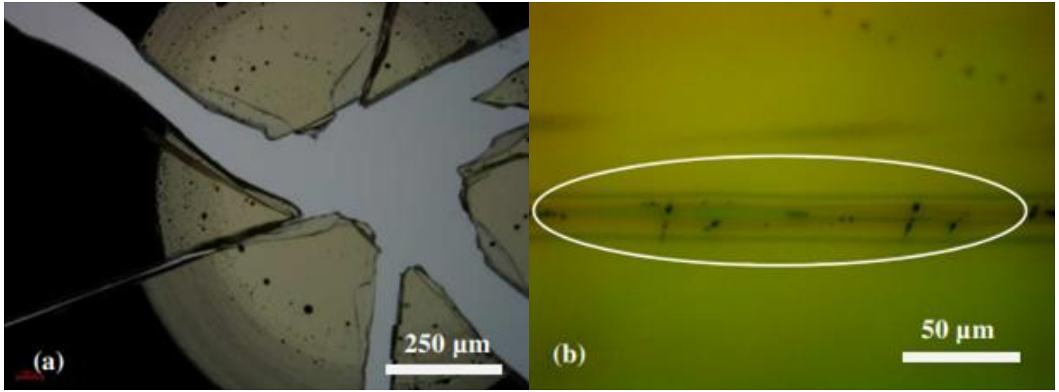
# Talk Outline

- Motivation for ionization-based beam diagnostics
- Design of the gas sheet monitor
- Preliminary experimental results
- Redesign goals and improvements
- Live work

# Motivation for minimally invasive single-shot diagnostics

## High intensity beams cause damage to conventional diagnostics

Koch & Grünert (2023)




**Desired Diagnosable Quantities:**

- **Charge** — 0th moment ($\int \rho \, dx$)
- **Position** — 1st moment ($\langle x \rangle$, beam centroid)
- **Spot size** — 2nd moment ($\langle x^2 \rangle - \langle x \rangle^2$, rms width)

**Injector**

**e- e- e- e-** → **Single-Shot Diagnostic** → **Application (FEL, Wakefield, ect)**

**useful for fast corrections to injector line**

**useful information for shot to shot fluctuation**

# Ionization-Based Monitors (Decades of use in rings & high-intensity accelerators)

**Prior Approaches (detect fluorescence)**

Ionization of trace amounts of residual gas in the vacuum provides information about beam.[1,2,3,4,5]

- In some cases, gas is injected into chamber to boost signal[6]
- Photons emitted in all directions → poor collection efficiency[7,8]
- Low signal: needs long integration over many shots → not truly single-shot[7,8]
- Light cannot respond to EM fields and thus there are no options for velocity mapping

**Our Approach (Detect ions & $e^-$ )**

- Redirected by bias voltage, focused by an electrostatic lens column → much higher collection efficiency
- Detect on a micro-channel plate → boost signal
- Single-shot recovery of charge, position & spot size
- Enables modular magnification and velocity mapping modalities
- Interchangeable gas nozzle allows for custom interaction geometries

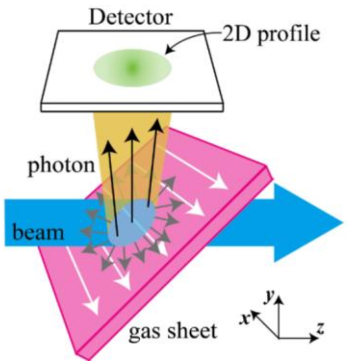




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Image Source [3]

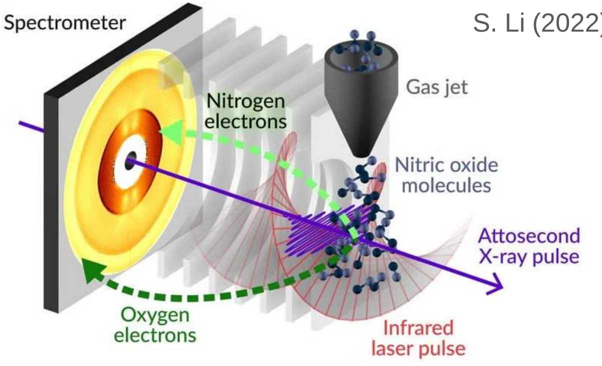
# Beyond transverse diagnostics: a versatile platform

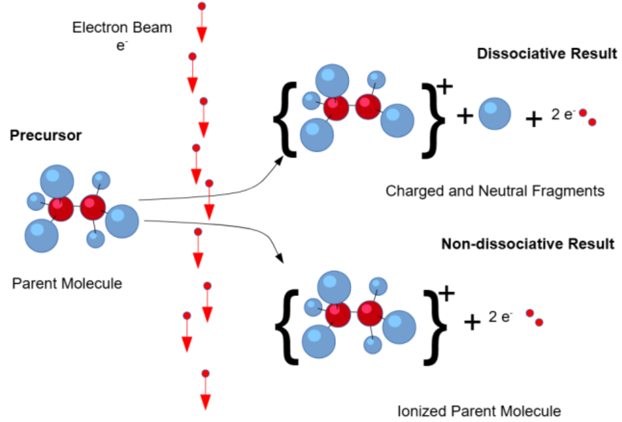
- The ionization mechanism (field vs. impact-ionization) balance is set by the bunch's peak space-charge field, making the ionization signature a sensitive probe of peak current and longitudinal compression

- Streaking the ionization products maps arrival time → transverse position, recovering the single-shot temporal current profile and bunch length

- Resolution of multiple ionization products via different ionization mechanisms. This device also acts as a platform to investigate the physics of different ionization pathway

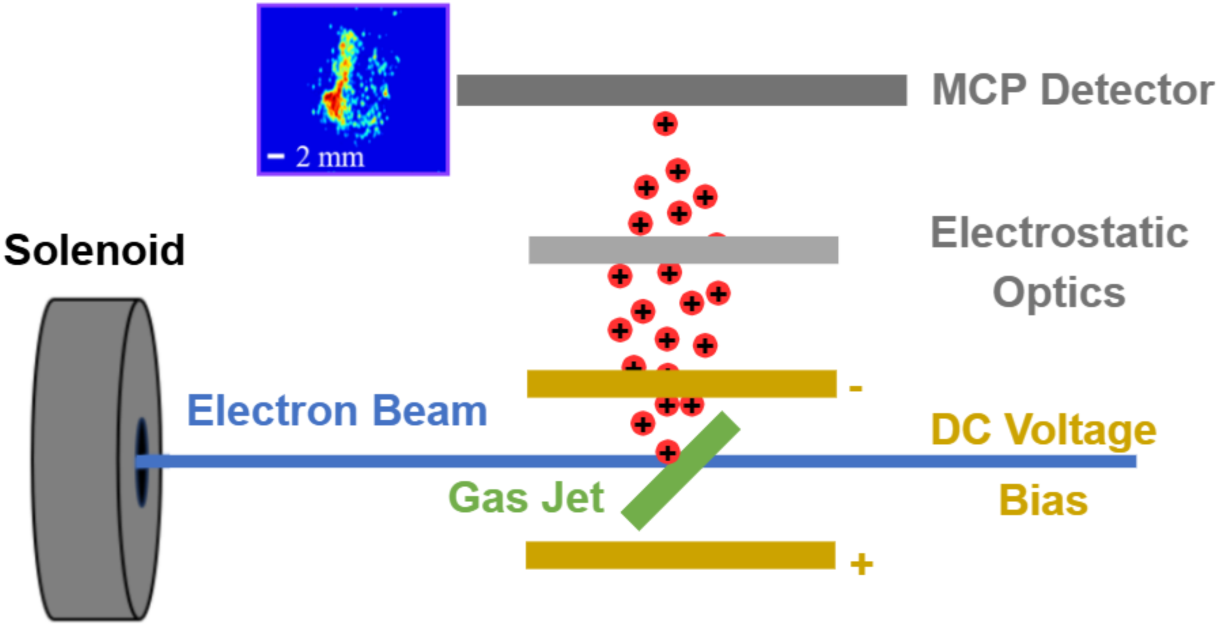
S. Li (2022)



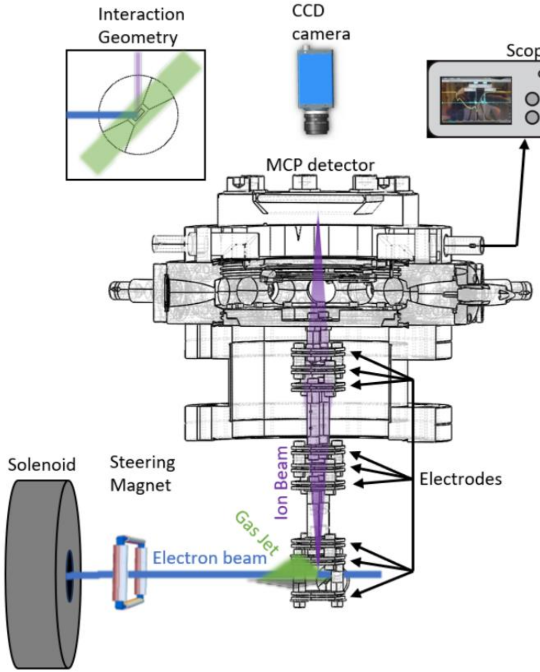



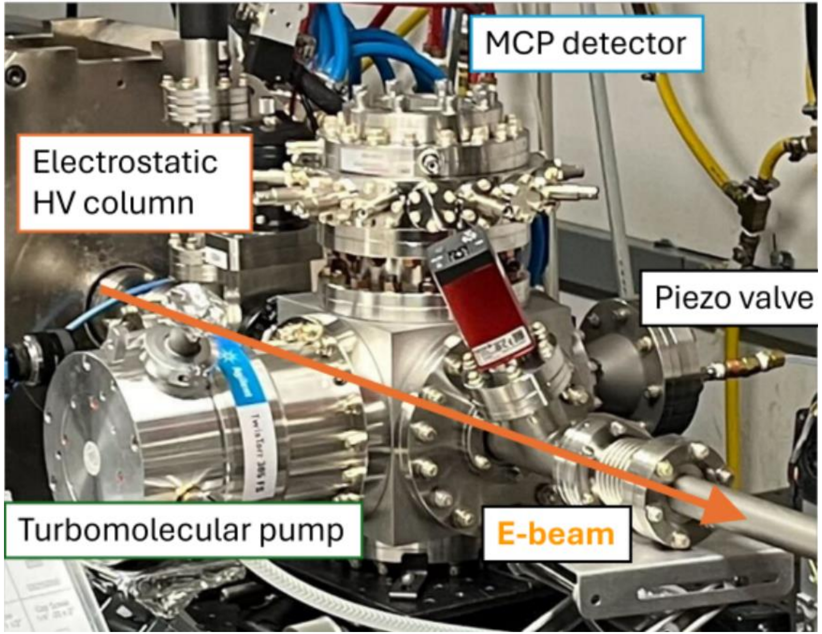
# Gas Sheet Monitor (GSM)

- Electrostatic optics tunable for imaging and velocity mapping
- Imaging ions or electrons possible by inverting polarity of voltage bias



# Gas Sheet Monitor (GSM) schematic

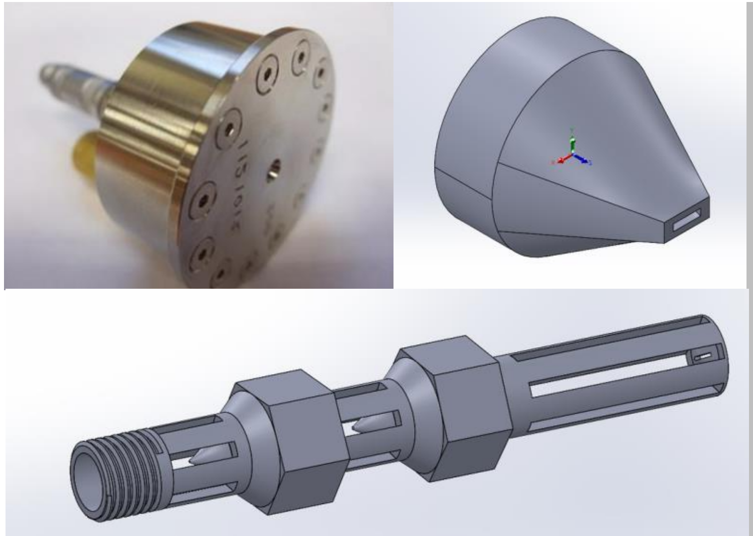


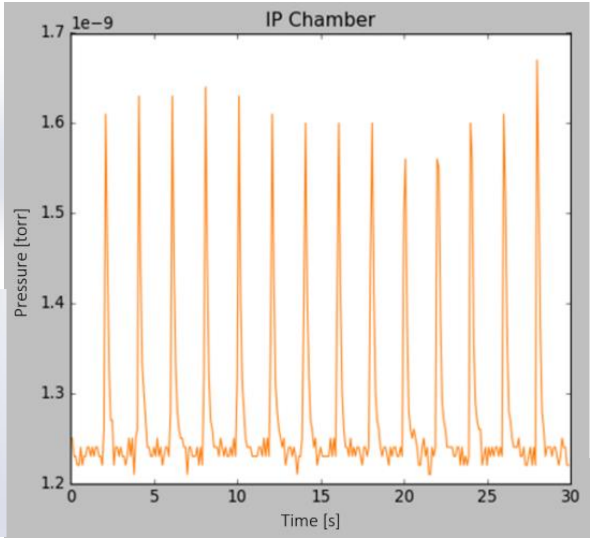




RadiaBeam

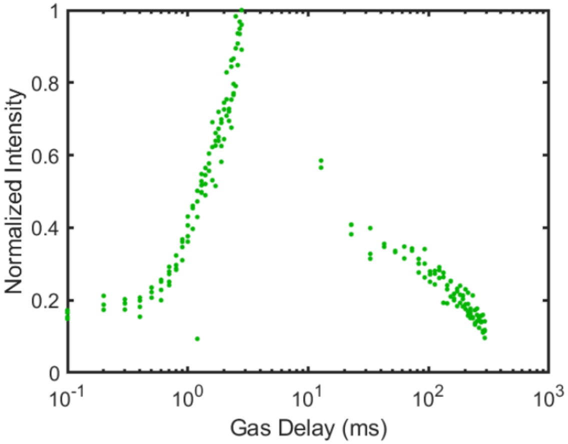
# Gas: shape, timing, and vacuum considerations.

- Piezo valve produces 40-400μs pulses nitrogen gas
- Nozzles shape gas into a sheet ~500μm with density ~ $10^{15}$cm$^{-3}$
- Short pulses decrease load on turbomolecular pumps to maintain vacuum
- Gas trigger is tunable to ensure highest gas density at the beams time of arrival





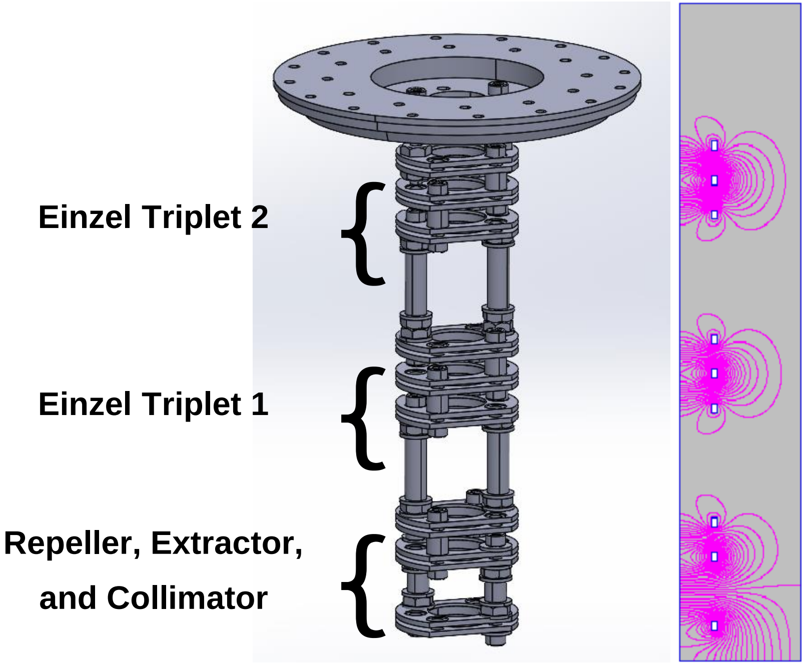

N. Burger (2022)

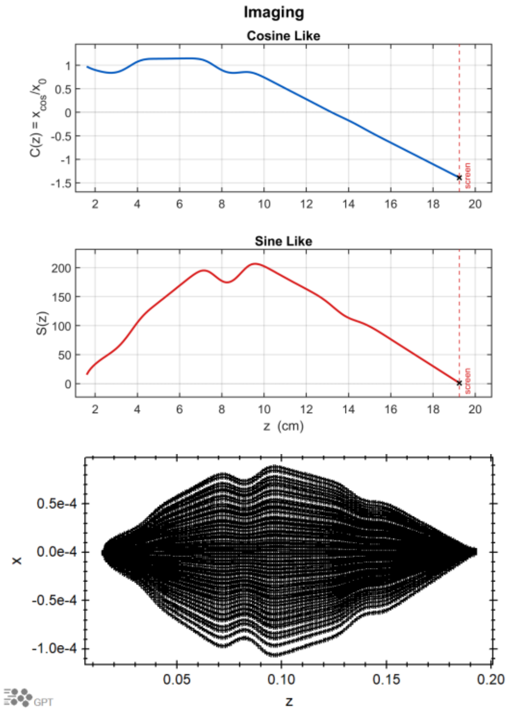


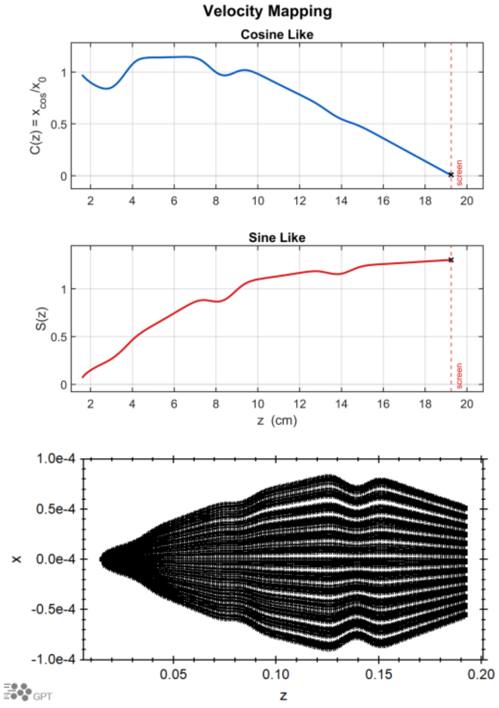

P. Denham (2024)

# Electrostatic Lens Column

- Create fieldmaps in Poisson Superfish then model transport in GPT
- Confirm imaging and velocity mapping with cosine-like and sine-like ray tracing

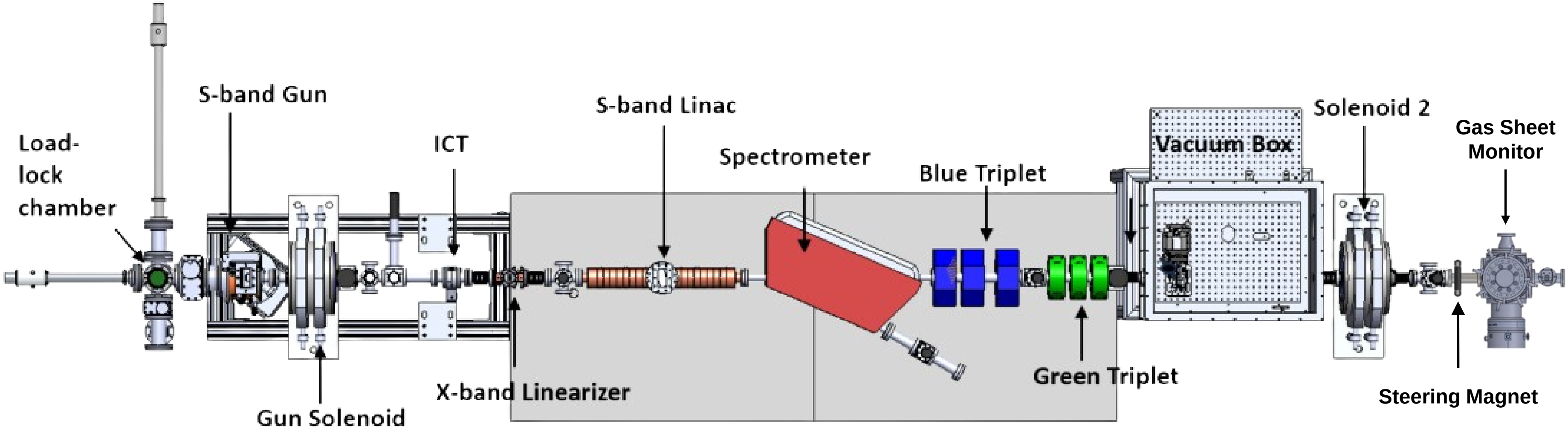


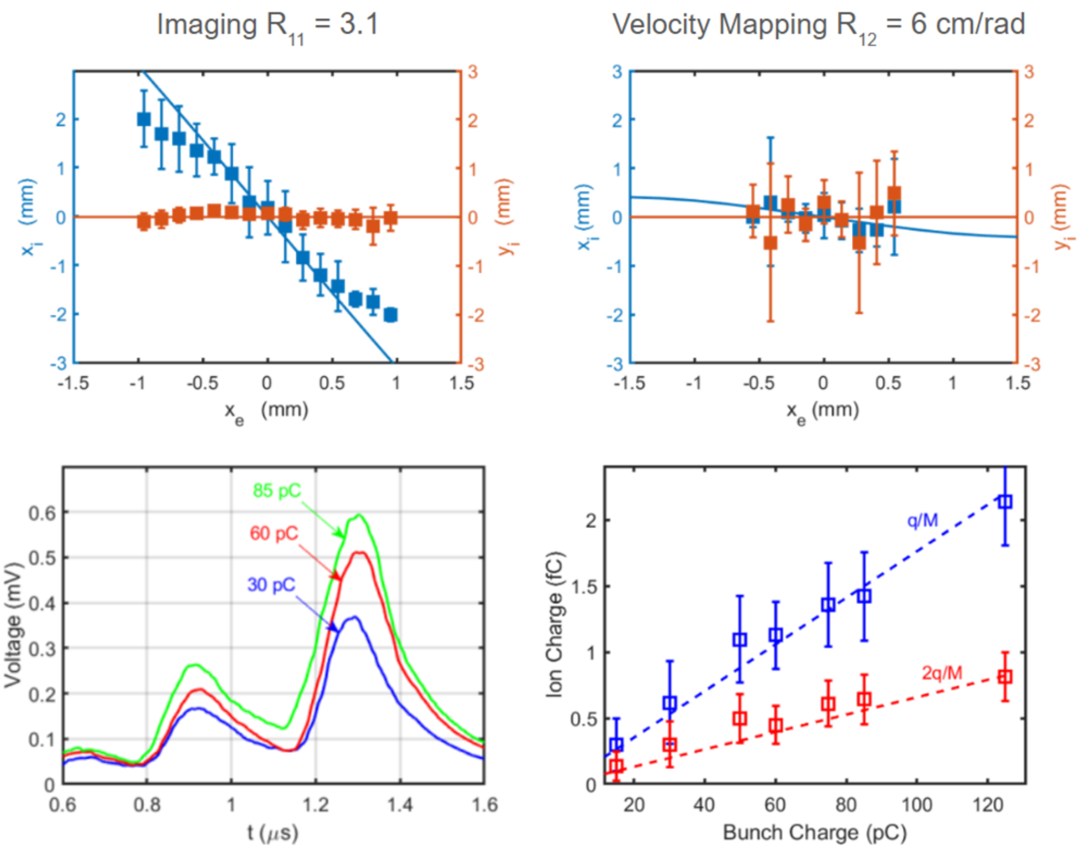



# PEGASUS Beamline (8 MeV · 1 fC–500 pC · tunable transverse and temporal size)

- **Ti:sapphire drive laser** — 780 nm, 40 fs; frequency-converted to UV onto a high QE photocathode
- **S-band RF photogun** — 75 MV/m gradient → 3.2 MeV, up to 500 pC/bunch; differential pumping keeps gun at ≤$10^{-9}$ Torr for cathode
- **Solenoid 1 + booster linac** — focus and accelerate beam to 7 MeV
- **Solenoid 2 + steering magnet** — transverse focus into the interaction chamber; steering sets the e-beam / gas-jet interaction point
- **Gas Sheet Monitor** — diagnosis of beam charge, position and spot size



# Preliminary experimental results




P. Denham (2024)

- Sweeping the beam through the jet confirmed imaging ($R_{11} = 3.1$) and velocity-mapping ($R_{12} = 6$ cm/rad) modes.
- Ion charge scales linearly with bunch charge; two scope peaks → singly and doubly ionized nitrogen.

Promising results, with areas for improvement.

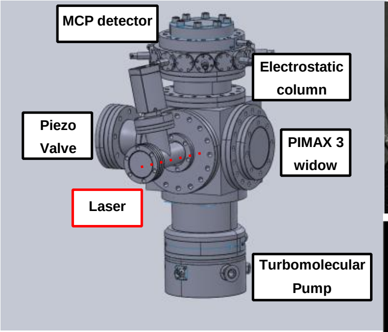
- The gas-jet shape is largely unknown. Thus measurements can be clouded by the change in gas density rather than a change in beam dynamics
- Magnification and R12 for velocity mapping are both too low for desired applications

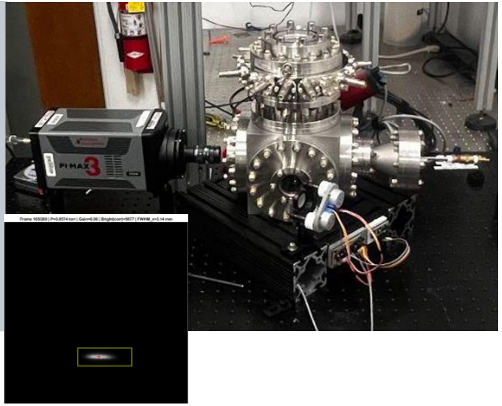
# Diagnostic for mapping the gas density profile

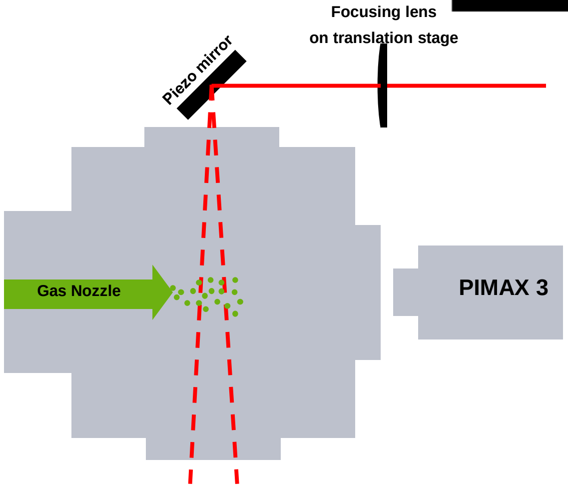
- 25cm focusing optic is used to focus 800nm, 0.5mJ, 40fs, laser pulse to 14µm. Intensity above multiphoton ionization threshold
- Plasma Ions and electrons recombine, emitting light
- PIMAX 3 intensified camera images the recombination spark
- Piezo mirror sweeps the laser focus in two directions combined with a translation stage for a 3D scan

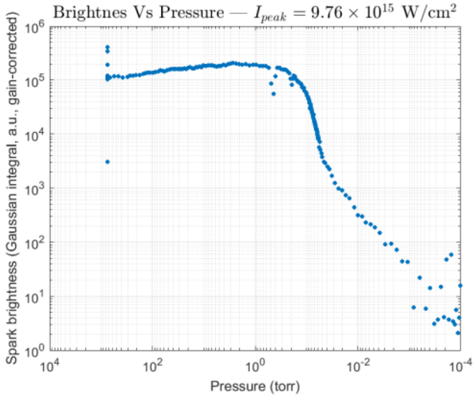
Plasma Brightness to Pressure Calibration:

- Decrease background pressure in chamber and image plasma
- Ideal gas law gives us a calibration from integrated brightness to local particle density



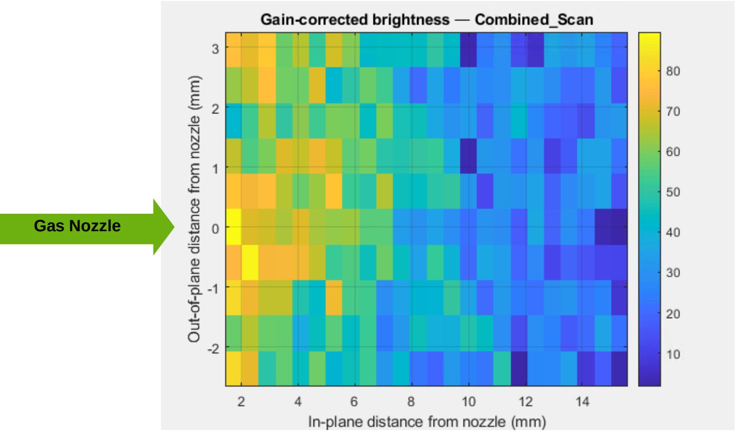



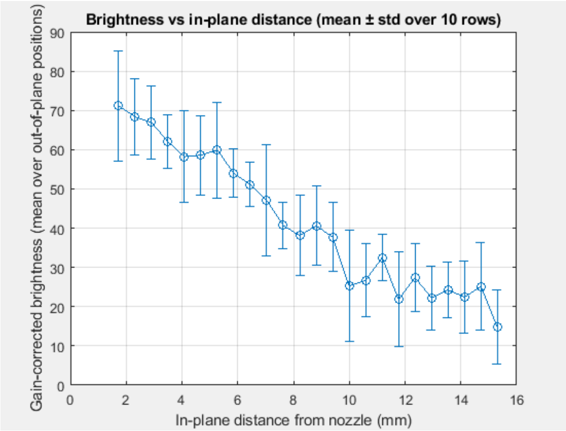


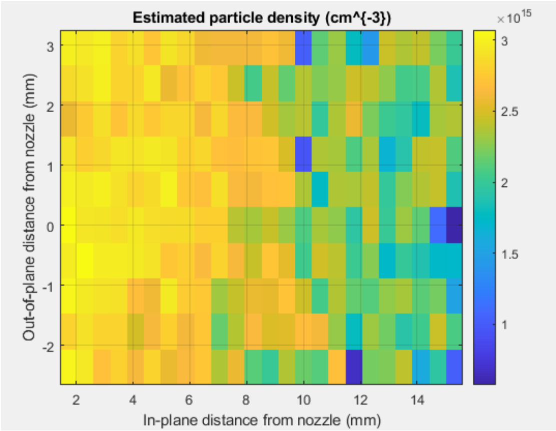



# 2D Laser spot scan for density mapping

- Verified density of gas jet to be ~ $10^{15}cm^{-3}$
- Demonstrated a change in particle density as a function of distance from the nozzle (to be verified with flow simulations)
- Provides a platform to test nozzle design for optimizing gas shape

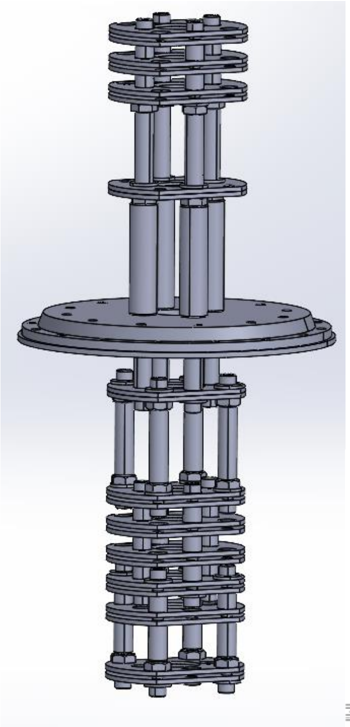


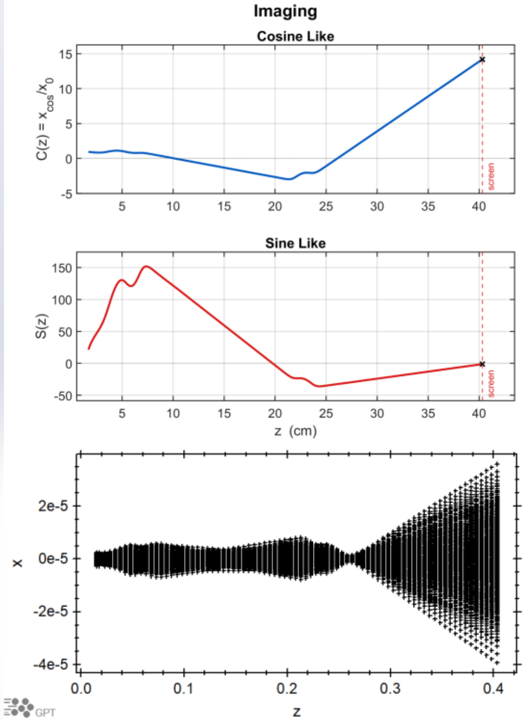



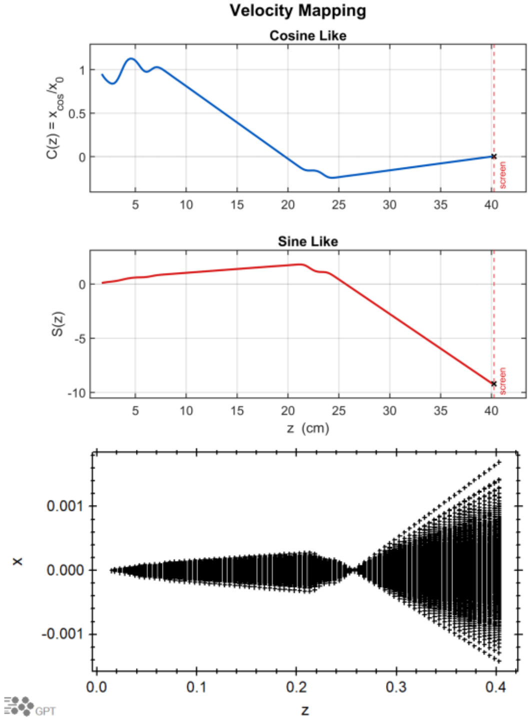



# Redesigning Lens Column

- Lens distances extended and optimized for $R_{11} \sim 14$ and $R_{12} \sim -64.5$cm/rad
- Transverse spacing between supports widend to prevent dielectric polarization of ceramic skeleton and additional supports added for alignment






Imaging and Velocity mapping are verified by tracking Sine-Like and Cosine-Like rays

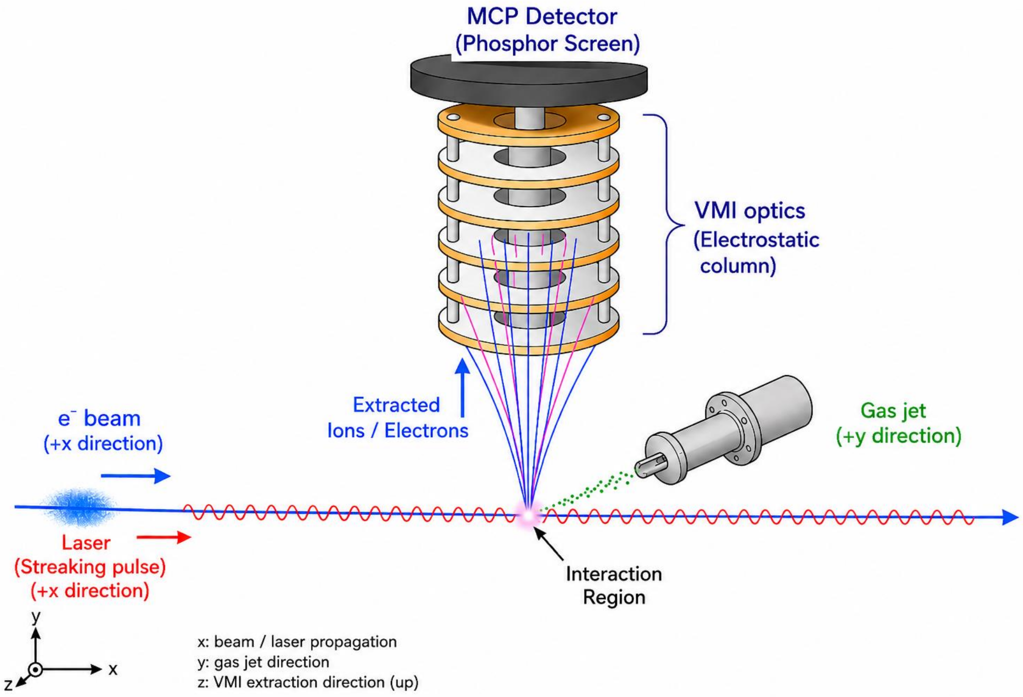
Transport of a 1µm rms 100 mrad beam in an imaging configuration or Velocity mapping configuration

# Plans for streaking experiments

- Plasma electrons are born at different times as the electron beam passes through the gas.
- A co-propagated laser gives electrons transverse momentum corresponding to the vector potential

$$\vec{P}_x = e\vec{A}(t_b)$$

$$\vec{A}(t) = \frac{\vec{E}_0}{\omega} exp\left(\frac{t_b}{\tau}\right) sin\left(\omega t_b + \frac{\pi}{2}\right)$$

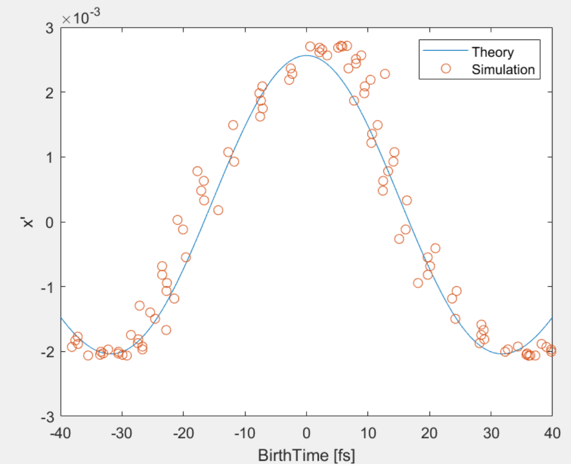


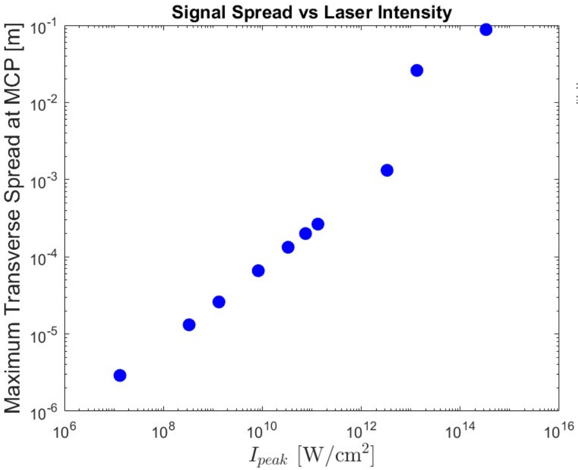
# Streaking with laser: GPT simulations

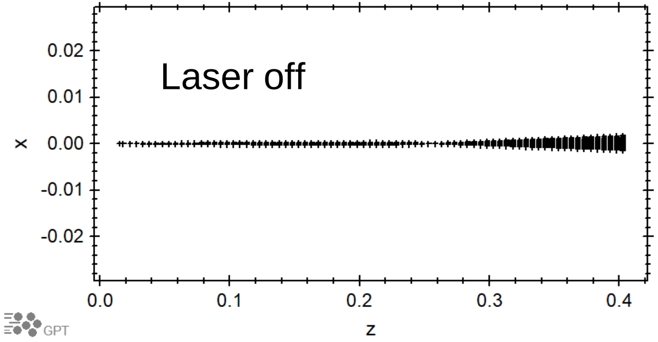
- GPT laser-streaking: kick ∝ vector potential and spread ∝ √intensity, matching the analytic model.

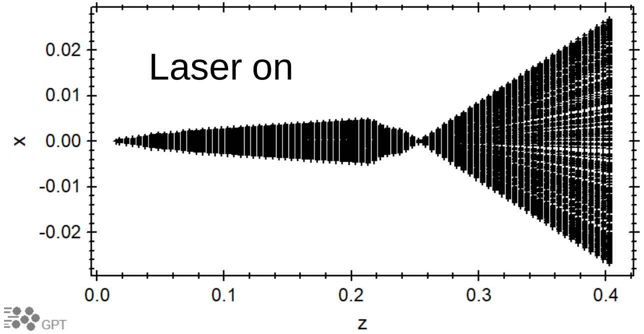
$$\vec{P}_x = e\vec{A}(t_b)$$

$$\vec{A}(t) = \frac{\vec{E}_0}{\omega} exp\left(\frac{t_b}{\tau}\right) sin\left(\omega t_b + \frac{\pi}{2}\right)$$



## Conclusions

- Hardware and preliminary experiments completed before my time at UCLA
- Uncertainty in gas shape made diagnostics unreliable and we desire to use the GSM as a platform for many experiments

## Live work

- Preliminary Streaking experiment via ionization with a UV laser and streaking with an IR laser. Proof of concept for laser streaking experiment planned for fall/winter at PEGASUS
- Build new column for higher resolution
- Long plasma channels via laser filamentation

# Thank you

## Image References:

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