Underdense Plasma Lens Experiment: Initial Results

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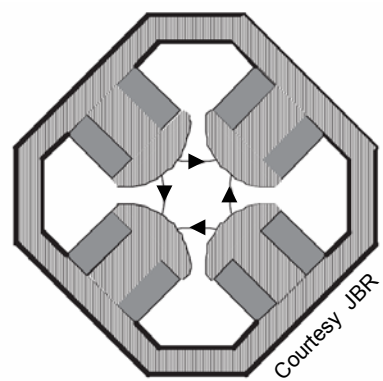
Advanced Electron Beam Lens

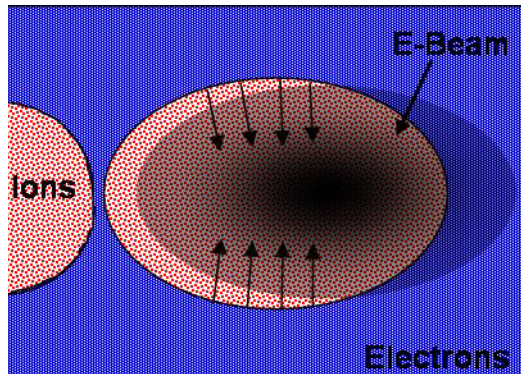
Magnetic Quadrupoles

Uses magnetic forces to focus electron beam in one dimension at a time.



Underdense Plasma Lens

Uses electrostatic forces to focus electron beam in both dimensions.



$$\vec{F}_\perp = q\vec{v} \times \vec{B}_{quad} = ecB'\left(y\hat{y} - x\hat{x}\right)$$

$$B' \approx 250\ \mathrm{T/m}$$

State-of-the-Art Superconducting Quad

$$\vec{F}_\perp = q\vec{E}_{ion} = \frac{e^2 n_p}{2\varepsilon_0}\left(-y\hat{y} - x\hat{x}\right)$$

$$B'_{equivalent} = 3\times10^{-11} n_p\ \mathrm{T/m}$$

Adiabatic Focusing: Adiabatic increase in ***B'***

- Circumvents limits on focusing due to synchrotron radiation induced chromatic aberrations.
- Plasma lens are ideally suited for adiabatic focusing.

Even "weak" plasma lens are immensely strong:

150 T/m at 5×10^{12} cm^{-3}

1500 T/m at 5×10^{13} cm^{-3}

With appropriate parameters 70% - 80% of the beam is focused.

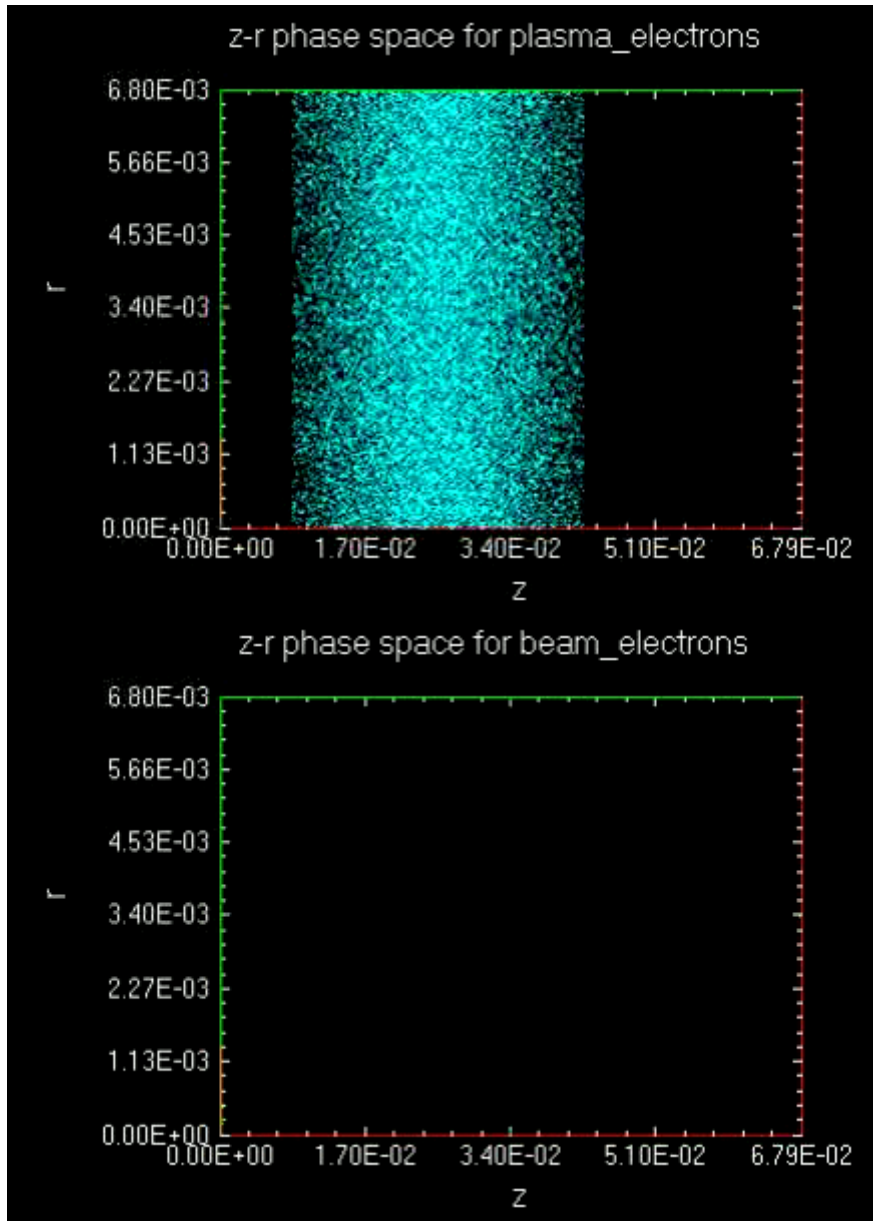
Thin Gaussian Underdense Plasma Lens

This is the first experiment to examine underdense plasma focusing in a true lens configuration with:

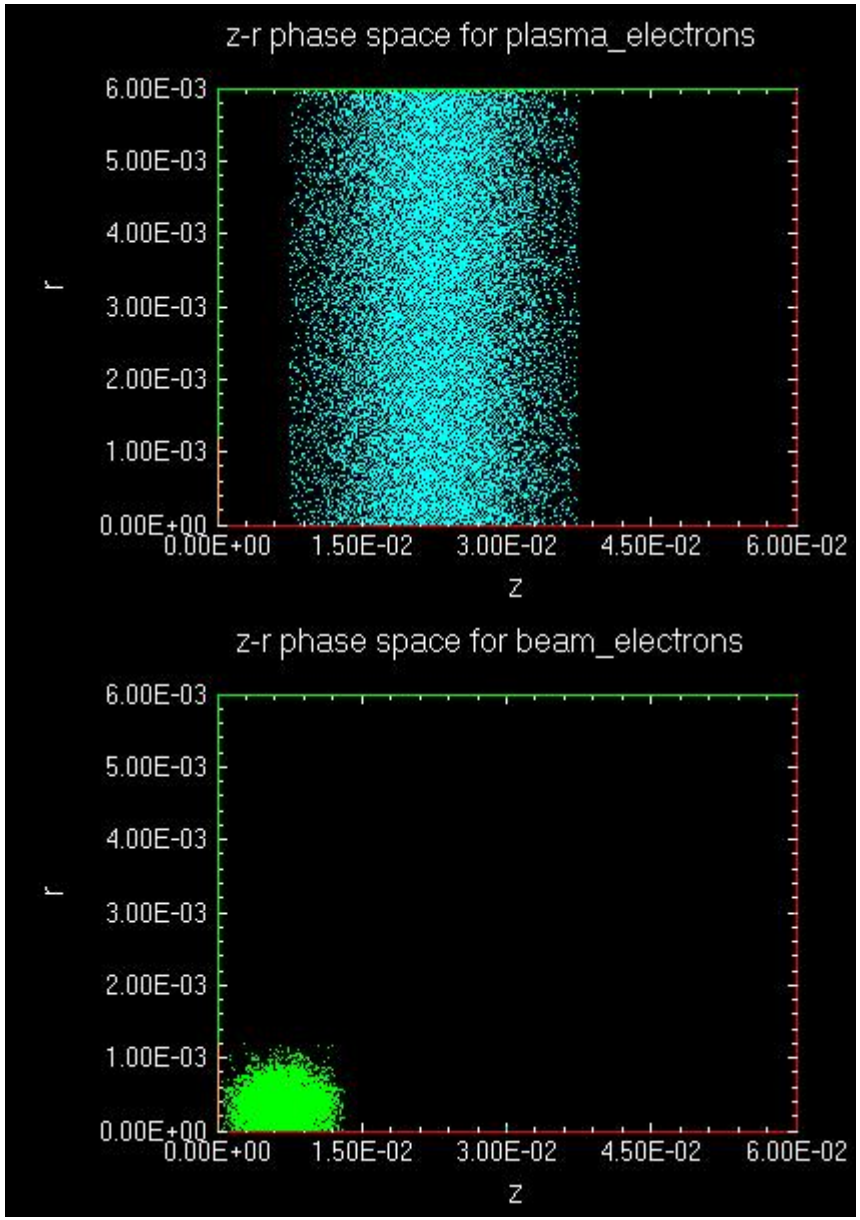
- **Beam Focus Outside Plasma**
- **Variable Lens Position**

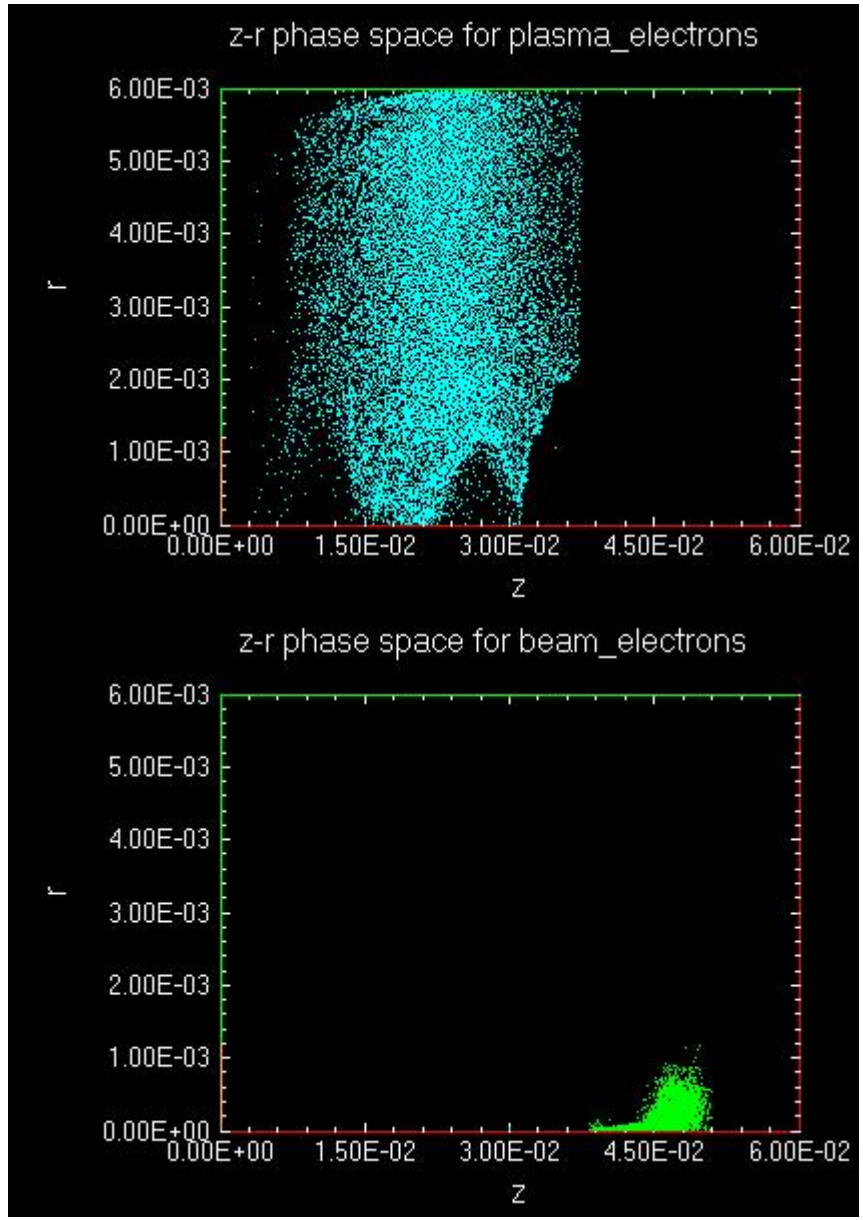
Achieved Experimental Parameters

Peak Plasma Density	4.8×10^{12} cm^{-3}
Plasma Thickness (σ_p)	9.8 mm
Beam Charge	12 nC
Beam Duration (σ_t)	10.6 psec
Initial Beam Radius (σ_r)	450 μm
Beam Emittance (ε_n)	49 mm-mrad
Peak Beam Density	4.9×10^{12} cm^{-3}
Focal Length	~2 cm



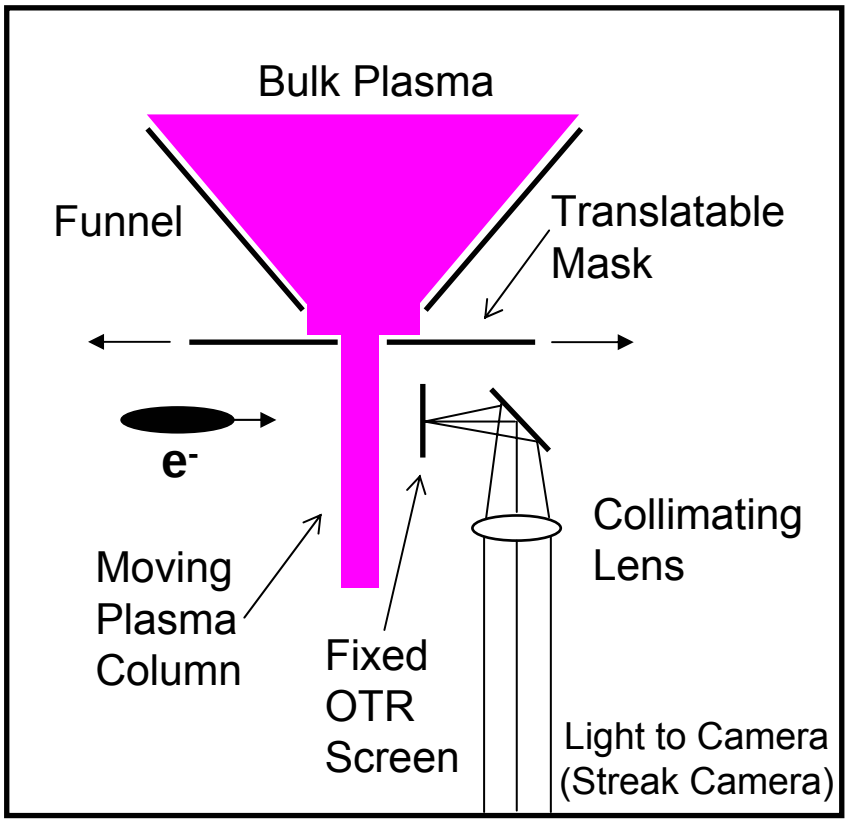
Thin Gaussian Underdense Plasma Lens



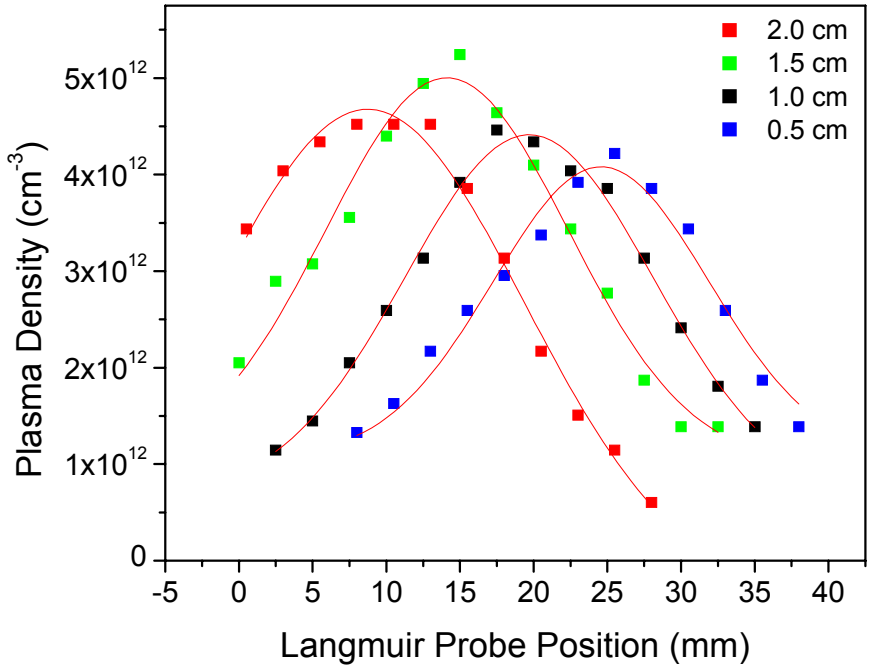


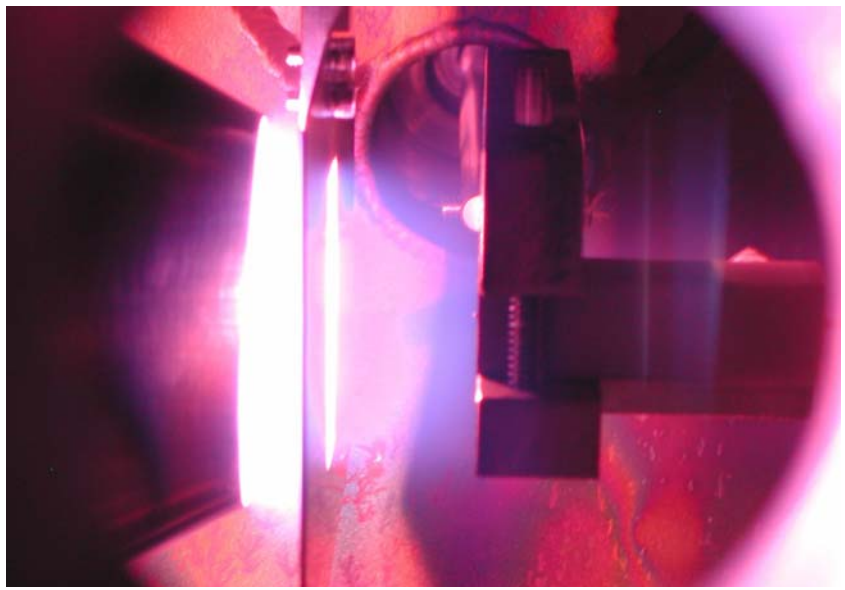
Plasma Lens Apparatus

A 1 cm wide moving window is placed in front of the fixed 6 cm plasma column. The resulting translatable plasma column is used to focus the beam onto a fixed OTR screen.



Schematic of the Experiment



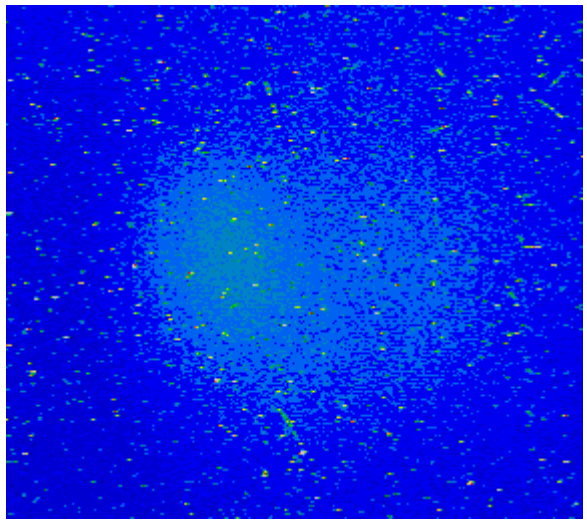


Photograph of Measurement in Progress

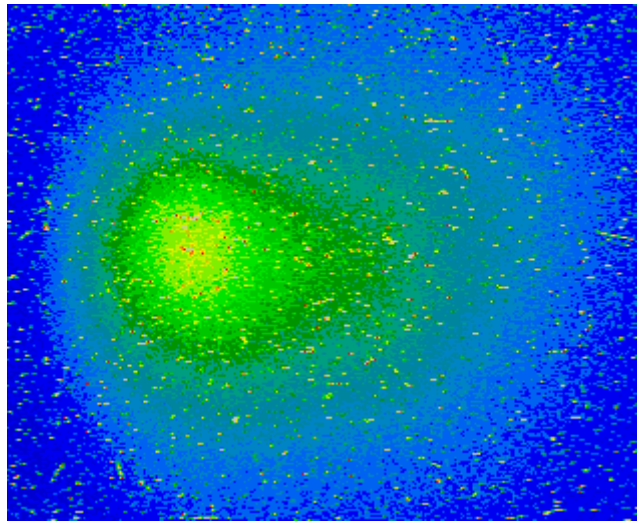
Initial Plasma Focusing Results March 2004

Beam Spot Before:
x FWHM = 1573 μm
y FWHM = 1066 μm
$n_b = 5 \times 10^{12}\ cm^{-3}$

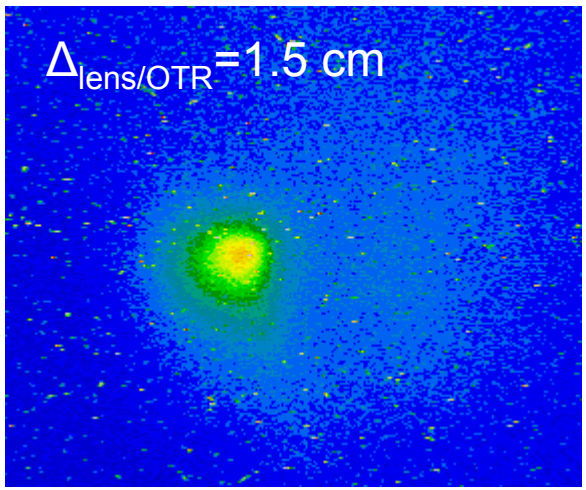
Beam Spot After (Ave.):
x FWHM = 554 μm
y FWHM = 437 μm
$n_b = 3.4 \times 10^{13}\ cm^{-3}$

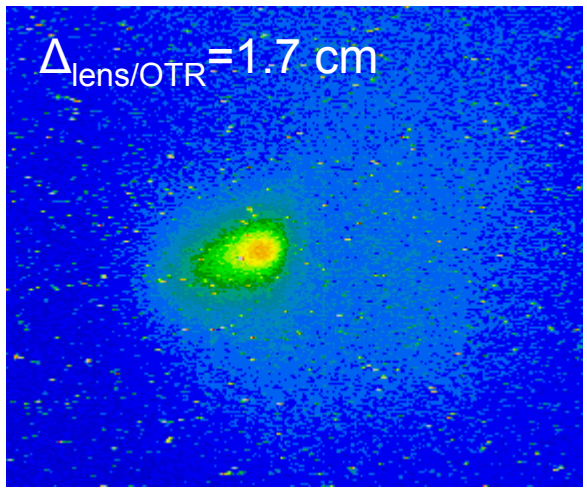


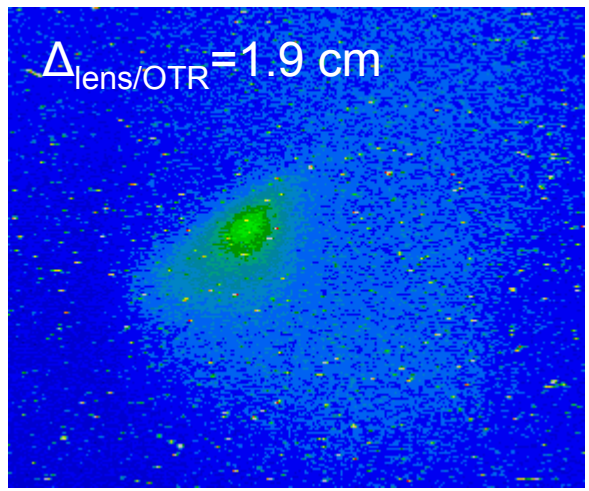
Plasma Off – One Pulse



Plasma Off – 5 Pulses

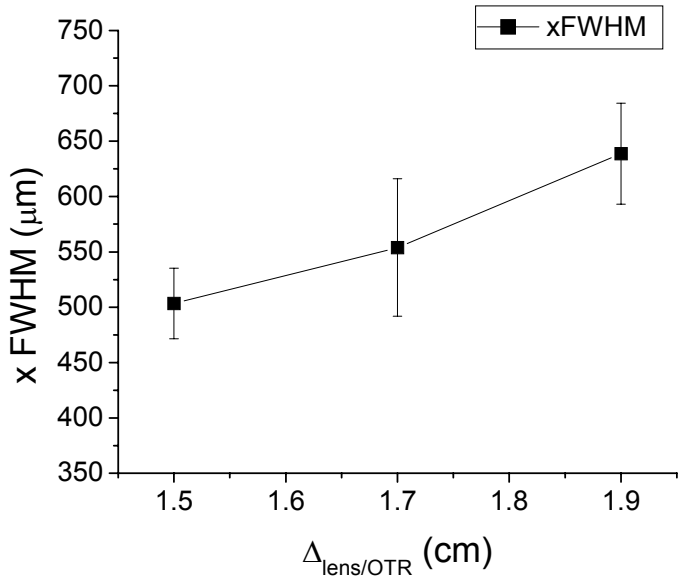


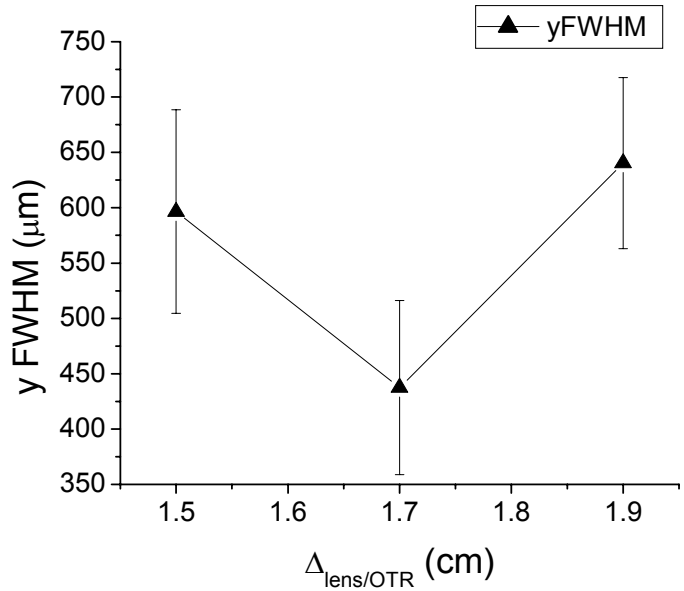




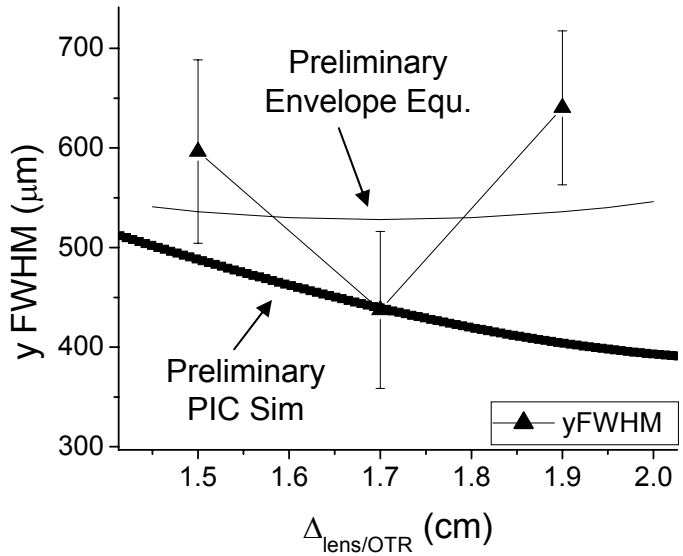
Plasma On – One Electron Pulse

Analysis of Focused Spot Sizes



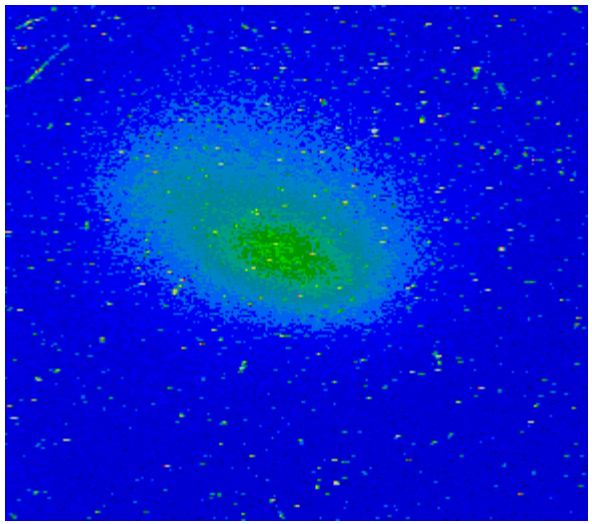


- Focusing data generally as expected
- Spot size variation with lens/OTR spacing indicates mismatch in x and y convergence.
- The collection of more data, both integrated and time resolved, should allow better matching to theory.

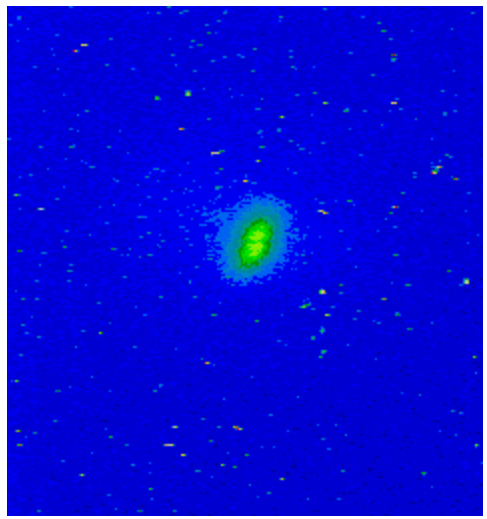


Plasma Focusing of High Aspect Ratio Beams

- The International Liner Collider will use a 100:1 aspect ratio beam in order to mitigate detrimental beam/beam affects.
- We intend to examine plasma focusing of beams with the largest aspect ratio that we can produce during this experiment.



Before:
x FWHM = 2000 μm
y FWHM = 1200 μm



After:
x FWHM = 380 μm
y FWHM = 560 μm

Initial results from the underdense plasma focusing of a 1.5 aspect ratio beam.