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.

\[ \vec{F}_\perp = q\vec{v} \times \vec{B}_{quad} = eB'(y\hat{y} - x\hat{x}) \]

\[ B' \approx 250 \frac{T}{m} \]

**State-of-the-Art Superconducting Quad**

**Underdense Plasma Lens**

Uses electrostatic forces to focus electron beam in both dimensions.

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

\[ B'_{\text{equivalent}} = 3 \times 10^{-11} n_p \frac{T}{m} \]

**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 5x10^{12} cm^{-3}
- 1500 T/m at 5x10^{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

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>Peak Plasma Density</td>
<td>$4.8 \times 10^{12}$ cm$^{-3}$</td>
</tr>
<tr>
<td>Plasma Thickness ($\sigma_p$)</td>
<td>9.8 mm</td>
</tr>
<tr>
<td>Beam Charge</td>
<td>12 nC</td>
</tr>
<tr>
<td>Beam Duration ($\sigma_t$)</td>
<td>10.6 psec</td>
</tr>
<tr>
<td>Initial Beam Radius ($\sigma_r$)</td>
<td>450 μm</td>
</tr>
<tr>
<td>Beam Emittance ($\varepsilon_n$)</td>
<td>49 mm-mrad</td>
</tr>
<tr>
<td>Peak Beam Density</td>
<td>$4.9 \times 10^{12}$ cm$^{-3}$</td>
</tr>
<tr>
<td>Focal Length</td>
<td>~2 cm</td>
</tr>
</tbody>
</table>
Thin Gaussian Underdense Plasma Lens
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.
Initial Plasma Focusing Results March 2004

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

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

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.