PROPOSAL E-150bis
PLASMA LENS EXPERIMENT AT THE FFTB

THE PLASMA LENS COLLABORATION

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WHY PLASMA LENS?

• Linear collider luminosity $\propto 1/\sigma_x \sigma_y$. Stronger final focusing helps. Plasma lens is super strong — of order 1000 Tesla/cm — about 100 times stronger than conventional quadrupoles.

• For SLC/NLC, an enhancement of luminosity by a factor of approximately 5 is possible.

• Possible reduction of the complexity (length) of Final Focusing System (FFS) in linear collider.

• Plasma lens focuses $e^-$ as well as $e^+$ beams.

• Detector backgrounds induced by plasma lens are acceptable.

• Removal of spent $e^-$ beams in $\gamma\gamma$ and $e\gamma$ colliders.
LUMINOSITY ENHANCEMENT IN LINEAR COLLIDERS

- While a linear collider may indeed have been designed with a sufficient luminosity, in practice the actual luminosity delivered at IP may not be always up to the design.

- A plasma lens can serve as an extra kick when needed.

- For certain high energy experiments one may want to operate at a higher luminosity (beyond design) in exchange for a more severe beamstrahlung.
NEED FOR A CHANGE OF PARADIGM IN FINAL FOCUS

• In current approach, beam delivery in a linear collider consists of three major subsystems: Big Bend, Collimation System, and Final Focus System.

• Lengths of BB, CS, and FFS all scales as $E^{3/2}$, where $E$ is beam energy [J. Irwin (1996)].

For example,

$$L_{BB} + L_{CS} + L_{FFS} \approx 5 \text{ km for NLC},$$

$$L_{FFS} \approx \frac{L_{FD}}{\beta_{IP}^*} \sim \left(\frac{B_T}{aE}\right)^{-1/2} \frac{E}{\beta_{IP}^*} \approx 60 \text{ km @15 TeV}.$$

• Super-strong lenses such as plasma lens can in principle eliminate the need for BB, CS, and FFS all together!
PLASMA FOCUSING OF ELECTRON AND POSITRON BEAMS

Collision of $e^+$ and $e^-$ beam in an ionized gas. Snapshots (a) to (d) are for the electron beam; whereas (e) to (h) are for the corresponding positron beam. The horizontal and vertical axes are in units of 1 mm and 10 $\mu$m, respectively.
PHYSICAL MECHANISM

High Energy Beam in Vacuum

Electric Field

Magnetic Field

- **Overdense Plasma Regime:*** $n_p > n_b$
  - $\sigma_z \gg c/\omega_p$, $\sigma_r << c/\omega_p$
  - full charge neutralization
  - perturbation analysis valid: works for $e^-$ and $e^+$ beams

Neutral Plasma

High Energy Beam in Plasma

- **Underdense Plasma Regime:*** $n_p < n_b$
  - physics essentially the same as in the overdense regime

- **Field Suppression Regime:*** $n_p >> n_b$
  - both E and B fields of the beam are suppressed by the plasma
**PREVIOUS EXPERIMENTS**

  - Thick plasma of 35 cm long with \( n_p \approx 0.7 - 7 \times 10^{13} \text{ cm}^{-3} \).
  - A 21 MeV electron beam with \( n_b \approx 2.5 - 4 \times 10^{10} \text{ cm}^{-3} \).
  - Beam size was decreased from \( \sigma = 1.4 \text{ mm} \) to \( \sigma = 0.9 \text{ mm} \), roughly the predicted equilibrium size in a long plasma.

  - Thin plasma lens with plasma density up to \( 1.4 \times 10^{11} \text{ cm}^{-3} \).
  - Focused 18 MeV electron beam with \( n_b \approx 1.2 \times 10^{10} \text{ cm}^{-3} \).
  - Theory of thin plasma lens is confirmed.

  - Thin plasma lens with \( n_p \approx 4 \times 10^{12} \text{ cm}^{-3} \).
  - Focusing was observed for 3.5 MeV electron beam with \( n_b \approx 5 \times 10^{10} \text{ cm}^{-3} \). Beam size decreased from \( \sigma = 3.2 \text{ mm} \) to \( \sigma = 0.6 \text{ mm} \).


These experiments confirmed the plasma lens concept but operated at low electron energies and plasma densities — about \( 10^{-6} \) to \( 10^{-7} \) to that for SLC/NLC.
GOALS OF EXPERIMENT E-150bis

- Study plasma focusing for high energy, high density particle beams in the regime relevant to SLC/NLC.
- Study of plasma beamsstrahlung suppression.
- Better understanding of beam-plasma interactions and benchmarking of computer codes for future plasma lens designs.
- Develop compact, simple, and economical plasma lens designs suitable for high energy collider applications.
PROPOSAL E-150bis

PLASMA LENS EXPERIMENT AT THE FFTB

OVERVIEW OF EXPERIMENT

- Plasma Chamber
- Beam Size Monitors
- Vacuum System
- FFTB
- $e^-$
- Laser
- Focused beam
- Vacuum
## ROUND BEAM FOCUSING

<table>
<thead>
<tr>
<th>Beam Parameters</th>
<th>Case A</th>
<th>Case B</th>
<th>Case C</th>
</tr>
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<tbody>
<tr>
<td>$E_0$ [GeV]</td>
<td>30</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>$N$ [$10^{10}$]</td>
<td>1</td>
<td>1</td>
<td>1</td>
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<tr>
<td>$\varepsilon_n$ [$10^{-5}$ m-rad]</td>
<td>3.0</td>
<td>3.0</td>
<td>3.0</td>
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<tr>
<td>$\beta_0$ [mm]</td>
<td>45</td>
<td>45</td>
<td>45</td>
</tr>
<tr>
<td>$\sigma_0$ [$\mu$m]</td>
<td>4.74</td>
<td>4.74</td>
<td>4.74</td>
</tr>
<tr>
<td>$\beta_0$ [mm]</td>
<td>48.1</td>
<td>48.1</td>
<td>48.1</td>
</tr>
<tr>
<td>$\sigma_0$ [mm]</td>
<td>4.91</td>
<td>4.91</td>
<td>4.91</td>
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<tr>
<td>$\sigma_z$ [mm]</td>
<td>0.47</td>
<td>0.47</td>
<td>0.47</td>
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<tr>
<td>$n_{b0}$ [$10^{16}$ cm$^{-3}$]</td>
<td>5.3</td>
<td>5.3</td>
<td>5.3</td>
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<tr>
<td>Lens Parameters</td>
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<td></td>
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<tr>
<td>$n_p$ [$10^{16}$ cm$^{-3}$]</td>
<td>2</td>
<td>10</td>
<td>100</td>
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<tr>
<td>$k_p \sigma_r$</td>
<td>0.13</td>
<td>0.29</td>
<td>0.92</td>
</tr>
<tr>
<td>$k_p \sigma_z$</td>
<td>12.5</td>
<td>28</td>
<td>88.5</td>
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<tr>
<td>$s_0$ [mm]</td>
<td>-20</td>
<td>-20</td>
<td>-20</td>
</tr>
<tr>
<td>$\ell$ [mm]</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>$f$ [mm]</td>
<td>22.8</td>
<td>17.4</td>
<td>21.6</td>
</tr>
<tr>
<td>Focused Beam</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\beta_r$ [mm]</td>
<td>22.2</td>
<td>12.6</td>
<td>20.4</td>
</tr>
<tr>
<td>$\sigma_r$ [$\mu$m]</td>
<td>2.01</td>
<td>1.53</td>
<td>1.94</td>
</tr>
<tr>
<td>$s^*$ [mm]</td>
<td>2.8</td>
<td>-2.6</td>
<td>1.6</td>
</tr>
</tbody>
</table>
OUTLINE OF E-150bis EXPERIMENTAL SETUP

Laser ~ 1 TW

SHG

Ionization

Cylindrical Optics

Plasma

Optical Delay

Plasma Diagnostics

Wire Scanners

Wire

Detector

Detector

Particle Beam

Spectrometer

Linear Detector Array

Plasma Density from Thomson Scattering

OUTLINE OF E-150bis EXPERIMENTAL SETUP

E-150bis – EPAC 9/97
ISOMETRIC VIEW OF PLASMA CHAMBER DESIGN
SCHEMATIC OF PLASMA TEST CHAMBER

Distance from Lens to Laser Focus is Approximately 1.5 Meter
Artificially coloured image of the plasma produced at the University of Rochester with a laser similar to the one installed for E-144 (and E-150bis) and a cylindrical lens. The laser travels in the Z-direction. The cylindrical lens has a focal length of -66 m and was oriented to defocus the laser slightly in the Y-dimension to form a long focus. The plasma measures in excess of 1 mm FWHM, in the Y-dimension, as shown.
The laser transport for E-150bis will be an extension of that used for E-144

Building 407
1 ps, 1 TW Laser

Planned for E-150bis
Plasma Lens Expt.

Installed Transport for E-144

Plasma Lens

E-144 IP1

FFTB

E-150bis – EPAC 9/97
PICTURE OF E-144 LASER SYSTEM

Missing from Archive
A phase-stabilized, CPA laser system delivers \( \sim 10^{18} \) W/cm\(^2\), 0.5-\( \mu \)m or 1-\( \mu \)m laser pulses at 0.5 Hz with 1.5-ps timing jitter.
The laser energy was $2.4 \pm 0.4 \text{ J}$ over a 1700-shot run.
DIFFERENTIAL PUMPING SYSTEM DESIGN

Wire Scanner

Plasma Lens Chamber

15.5 torr

.1 torr

1X10\(^{-3}\) gm/s

1.5 mm

H\(_2\)

Be

.1 torr

2.5X10\(^{-4}\) torr

8.5X10\(^{-6}\) gm/s

H\(_2\)

Be

1.6X10\(^{-6}\) torr

2.1X10\(^{-8}\) gm/s

H\(_2\)

Be

Solid Beryllium Window

Shintake Laser-Compton Beam Size Monitor

Be

H\(_2\)

8.5X10\(^{-6}\) gm/s

STAGE 3

495 l/s Turbo pump

STAGE 2

495 l/s Turbo pump

STAGE 1

112 l/s Roots pump

1.5 mm

4.76 cm

10 cm

3.81 cm

E-150bis – EPAC 9/97
VIEWS OF PLASMA LENS PROTOTYPE SYSTEM
**PLASMA DIAGNOSTIC**

- Thomson scattering is used.
- Laser is split from ionization laser and then frequency doubled.

**BEAM DIAGNOSTIC**

- Wire scanners with micron-sized carbon fibers.
- Proven technology — at SLC and FFTB.
- Existing bremsstrahlung monitors at the FFTB are used.
WIRE SCANNER

Vertical beam profile.
After correction for wire thickness, beam width

$$0.66 \pm 0.18 \ \mu m$$

From Clive Field, NIM A360, 467 (1995).
### ESTIMATED BEAM TIME REQUIREMENT

<table>
<thead>
<tr>
<th>Case</th>
<th>Description</th>
<th>Plasma</th>
<th>Beam Size Monitor</th>
<th>Shift†</th>
</tr>
</thead>
<tbody>
<tr>
<td>Set-up</td>
<td>installation and alignment</td>
<td>– –</td>
<td>– –</td>
<td>two month</td>
</tr>
<tr>
<td>Check-out</td>
<td>all systems &amp; components: control, laser, vacuum, plasma, etc.</td>
<td>laser ionized</td>
<td>– –</td>
<td>three weeks</td>
</tr>
<tr>
<td>A</td>
<td>underdense lens, round beam focusing</td>
<td>laser ionized</td>
<td>wire scanner</td>
<td>7</td>
</tr>
<tr>
<td>B</td>
<td>overdense lens, round beam focusing</td>
<td>laser ionized</td>
<td>wire scanner</td>
<td>7</td>
</tr>
<tr>
<td>C</td>
<td>total compensation of beam fields</td>
<td>laser ionized</td>
<td>wire scanner</td>
<td>7</td>
</tr>
</tbody>
</table>

† In units of 8-hour shifts, unless stated otherwise.
RECOMMENDATIONS BY EPAC AND RESPONSES

• Viable beam size monitor for the experiment.
  Established wire scanner technology will be used in E-150bis. Exotic beam size monitor not needed.

• Production of high density plasma suitable for the experiment.
  Has been produced at University of Rochester with a laser similar to the one for E-144 and E-150bis.

• Study the high energy detector backgrounds from a plasma lens.
  Detailed calculations made and found acceptable to all major components in a model NLC detector, as reported in Appendix A of the E-150bis Proposal.
# Backgrounds from Plasma Lens in NLC*

<table>
<thead>
<tr>
<th>Background Source</th>
<th>Cross Section (cm(^{-2}))</th>
<th>Vertex Detector</th>
<th>Drift Chamber</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bhabha and Møller</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Elastic ep:  e</td>
<td>$0.103 \times 10^{-45}$</td>
<td>negligible</td>
<td>negligible</td>
</tr>
<tr>
<td></td>
<td>p</td>
<td>negligible</td>
<td>negligible</td>
</tr>
<tr>
<td>Inelastic ep:  e</td>
<td>$0.132 \times 10^{-33}$</td>
<td>negligible</td>
<td>negligible</td>
</tr>
<tr>
<td></td>
<td>charged hadrons</td>
<td>0.018</td>
<td>0.018</td>
</tr>
<tr>
<td>Inelastic (\gamma p):</td>
<td>charged hadrons</td>
<td>0.12</td>
<td>0.12</td>
</tr>
<tr>
<td>Synchrotron Radiation</td>
<td>$0.995 \times 10^{-25}$</td>
<td>138 (\gamma s)</td>
<td>174 (\gamma s)</td>
</tr>
<tr>
<td>Compton with (\gamma) from plasma focusing</td>
<td>$0.548 \times 10^{-25}$</td>
<td>66 (\gamma s)</td>
<td>120 (\gamma s)</td>
</tr>
<tr>
<td>Compton with (\gamma) from bremsstrahlung</td>
<td>$0.119 \times 10^{-24}$</td>
<td>36 (\gamma s)</td>
<td>18 (\gamma s)</td>
</tr>
</tbody>
</table>

*Calculations are for per bunch crossing. Each bunch has $0.65 \times 10^{10}$ particles. The plasma lens has a density of $2 \times 10^{18}$ cm\(^{-3}\) and a thickness of 3 mm.
SUMMARY

• E-150bis will confirm that substantial luminosity enhancement and/or relaxation of the conventional FFS may be attained by a plasma lens in the parameter regimes of SLC/NLC.

• Plasma suppression of beamsstrahlung will be studied experimentally for the first time.

• The knowledge gained in E-150bis will serve as the basis for engineering designs of plasma lenses in linear colliders.