Application of Plasma Lenses as Optical Matching Device for Positron Sources at linear colliders

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Motivation -
Plasma Lens for Optical Matching

**Motivation:**
To achieve a two thousandfold increase in luminosity from the SLC ($3 \times 10^{30}$ cm$^{-2}$s$^{-1}$) to the proposed ILC ($7.5 \times 10^{30}$ cm$^{-2}$s$^{-1}$), it is necessary to push all technological boundaries. One area of improvement in particular is the particle number, which is primarily determined by the capture section and specifically by its optical matching device. This is where the application of a plasma lens could potentially open up new possibilities.

**Sources:**

*Plasma Lens optimizations Only with 1st SWT*
## Advantages of Plasma Lenses over conventional OMDs

<table>
<thead>
<tr>
<th></th>
<th>Current ILC Options</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Quarter Wave Transformer (QWT)</td>
<td>Flux Concentrator (FC)</td>
<td>Plasma Lens (PL)</td>
</tr>
<tr>
<td>Dephasing</td>
<td>- helical</td>
<td>- helical</td>
<td>+ sinusoidal</td>
</tr>
<tr>
<td>Chromaticity</td>
<td>- high</td>
<td>+ low</td>
<td>+ low</td>
</tr>
<tr>
<td>Eddy current in rotating target</td>
<td>+ manageable</td>
<td>- problematic for fast rotation</td>
<td>++ spatially confined field</td>
</tr>
</tbody>
</table>

**QWT proposed for ILC**
Principle of an Active Plasma Lens

gas (e.g. H₂)
capillary

gas inlet
ring electrode

ring electrode
gas inlet

ring electrode

ring electrode

ring electrode

ring electrode
ring electrode

ring electrode
ring electrode

ring electrode

ionized gas

ring electrode

Plasma

electric discharge current

~kA

~kV

G

ring electrode

~kA

~kV

G

E

I

e+/e-
Optimization Results of Tapered Active Plasma Lens as OMD

41.7% captured $e^+$ within DR energy acceptance of .75% (14 mm long. Cut) → ~50% improvement over ILC’s current proposed OMD (QWT) design

Optimized Parameters at $I_0 = 3000$ A

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Optimal Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>PL Length</td>
<td>$z_{\text{max}}$</td>
<td>6 cm</td>
</tr>
<tr>
<td>Opening Radius</td>
<td>$R_0$</td>
<td>3.8 mm</td>
</tr>
<tr>
<td>Tapering Order</td>
<td>$n$</td>
<td>1</td>
</tr>
<tr>
<td>Tapering Strength</td>
<td>$g$</td>
<td>136 m$^{-1}$</td>
</tr>
<tr>
<td>PL-SWT distance</td>
<td>$d$</td>
<td>1 cm</td>
</tr>
<tr>
<td>SWT Phase</td>
<td>$\phi_0$</td>
<td>220°</td>
</tr>
</tbody>
</table>

Tapered PL cavity profile: $R(z) = R_0 (1 + gz)^n$

Captured Yield Stability of the Optimum

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>-10% offset</th>
<th>+10% offset</th>
</tr>
</thead>
<tbody>
<tr>
<td>PL Length</td>
<td>$z_{\text{max}}$</td>
<td>-0.3% yield</td>
<td>-0.2% yield</td>
</tr>
<tr>
<td>Opening Radius</td>
<td>$R_0$</td>
<td>-0.1% yield</td>
<td>-1.1% yield</td>
</tr>
<tr>
<td>Tapering Strength</td>
<td>$g$</td>
<td>-0.2% yield</td>
<td>-0.3% yield</td>
</tr>
<tr>
<td>Current strength</td>
<td>$I_0$</td>
<td>-1.5% yield</td>
<td>+1.2% yield</td>
</tr>
<tr>
<td>PL-SWT distance</td>
<td>$d$</td>
<td>+0.2% yield</td>
<td>-0.2% yield</td>
</tr>
<tr>
<td>SWT Phase</td>
<td>$\phi_0$</td>
<td>-0.5% yield</td>
<td>-0.4% yield</td>
</tr>
</tbody>
</table>
The azimuthal magnetic field of the plasma lens leads to a sinusoidal trajectory (helical for QWT), which results in an effectively shorter path and therefore smaller longitudinal spread, the so called dephasing.
Summary
- Theoretical advantages of PLs over conventional OMDs in Dephasing, Chromaticity & Target eddy currents
- PL with ~50% more $e^+$ yield over ILC’s currently proposed OMD
- Stability of $e^+$ yield within ±2% for single parameter deviations of ±10%

Outlook
- Simulation with entire pre-accelerator structure
- Current ILC plan: 4y prelab phase (starting April 2022)
- Exploring technical details by prototyping a Plasma Lens as OMD
  - could have impact on final ILC design