Optimization of CW Polarized Positron Source for JLab

Sami Habet

IJCLab & JLab

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Plan

1. Target optimization

2. Collection system

3. Momentum collimation

4. Longitudinal optimization

5. Conclusion
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Outline

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Target optimization

**Unpolarized mode**

- Efficiency: \( \epsilon = \frac{N_{e^+}}{N_{e^-}} \)

**Polarized mode**

- Figure-of-Merit FoM = \( \epsilon P_{e^+}^2 \)
Target optimization

Unpolarized mode

- Efficiency: \( \epsilon = \frac{N_{e^+}}{N_{e^-}} \)

Polarized mode

- Figure-of-Merit FoM: \( \text{FoM} = \epsilon P^2_{e^+} \)

\( T_c = 120 \text{MeV}, \ t_w = 4 \text{mm}, \ Z = 74, \ \Delta \ p/p = \pm 10\% \)
Target optimization

Unpolarized mode

\[ T_\gamma = 120 \text{MeV}, \quad \Delta \frac{P}{P} = \pm 10\%, \quad Z = 74 \]

Polarized mode

\[ \theta = \pm 10^\circ \]
\[ \theta = \pm 5^\circ \]
\[ \theta = \pm 2.5^\circ \]
Quarter Wave Transformer

- Reduce the transverse angular divergence $x_p = \frac{p_x}{p}$ and $y_p = \frac{p_y}{p}$.
- Rotate the transverse phase space $(x, x_p)$ and $(y, y_p)$ at the exit of the QWT.
- Use a QWT as an energy filter.
- QWT acceptance:
  - Radial acceptance $r_{QWT}^0 = \frac{B_2}{B_1} R$
  - Transverse acceptance $p_{QWT}^t = \frac{eB_1 R}{2}$

$L_1$: Short solenoid length
$B_1$: Magnetig field in $L_1$
$R$: Accelerator aperture
Quarter Wave Transformer

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Goal

- Reduce the longitudinal energy spread of the accepted $e^+$ at $p = 60 \text{ MeV/c}$
- $f = 1497 \text{ Mhz}$
- $E = 1 \text{ MV/m}$
- $L_{cell} = 0.2 \text{ cm}$
- $r_{cell} = 3 \text{ cm}$
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Beam size optimization

**Matching section**

- **Periodic Twiss in FODO:**
  \[ \beta_{x,y_{in}} = \beta_{x,y_{out}} \]

- **Minimum beam size condition:**
  \[ \beta_x = \beta_{x_{MIN}} \rightarrow \alpha_x = 0 \]

\[ B_1 = 2.5 \ T \ B_2 = 0.05 \ T \]

\[ E = 1 \text{ MV/m} \]

\[ P \text{ [MeV/c]} \]
Outline

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Longitudinal optimization: Energy spread and bunch length

- **Compression factor** = 
  
  \[
  \frac{\text{Bunch length}_{\text{Entrance}}}{\text{Bunch length}_{\text{Exit}}} \]

- \( C = \frac{1}{1 + [R_{56} \times \kappa]} \)

- \( \kappa = \frac{d\delta_p}{dz} = \frac{-keV_0}{E_0 + eV_0 \cos \phi} \sin \phi \)

Where:
- \( R_{56} \): Longitudinal chicane element.
- \( k = 2\pi \frac{f}{c} \ [m^{-1}] \)
- \( f \) is the cavity frequency
- \( eV_0 \) Cavity acceleration [MeV]
- \( E_0 \) Central energy [MeV]
- \( \phi \) Cavity phase advance.
Longitudinal optimization: Energy spread and bunch length

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Transmission and Current

Transmission

$\frac{N_{e^+}}{N_{e^+_{Target}}} = 10^0$ to $10^{-1}$

$s [m]$

$P = 123 \text{ MeV/c}$

$\sigma_{dp/p} = 0.68 \%$

$\sigma_z = 1.5 \text{ mm}$

Central momentum [MeV/c]

Current [nA]

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The 2023 International Workshop on Future Linear Colliders (LCWS2023)
summary: Polarized mode

<table>
<thead>
<tr>
<th>Ce+BAF Parameter</th>
<th>e+ model</th>
<th>Target value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sigma_{dp/p}$ [%]</td>
<td>0.68</td>
<td>± 1%</td>
</tr>
<tr>
<td>$\sigma_z$ [ps]</td>
<td>4</td>
<td>≤ 4</td>
</tr>
<tr>
<td>N $\epsilon_n$ [mm mrad]</td>
<td>140</td>
<td>≤ 40</td>
</tr>
<tr>
<td>Mean Momentum [MeV/c]</td>
<td>123</td>
<td>123</td>
</tr>
<tr>
<td>$e^+$ ($P &gt; 60%$)</td>
<td>170 nA</td>
<td>50 nA</td>
</tr>
</tbody>
</table>
Unpolarized mode: Transmission current

### Positron Injector for Un-Polarized mode

- **Transmission** $\frac{N_{e^+}}{N_{e^+_{\text{target}}}}$
- **$P = 123$ MeV/c**
- **$\sigma_{dp/p} = 0.53\%$**
- **$\sigma_z = 0.7$ mm**

- $s$ [m] from 0 to 40
- Current [nA] from $10^1$ to $10^7$
- Momentum [MeV/c] from $10^1$ to $10^7$

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<th>Ce+BAF Parameter</th>
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<tr>
<td>(\sigma_{dp/p}) [%]</td>
<td>0.5</td>
<td>(\pm 1)%</td>
</tr>
<tr>
<td>(\sigma_z) [ps]</td>
<td>2</td>
<td>(\leq 4)</td>
</tr>
<tr>
<td>(N \epsilon_n) [mm mrad]</td>
<td>123</td>
<td>(\leq 40)</td>
</tr>
<tr>
<td>Mean Momentum [MeV/c]</td>
<td>123</td>
<td>123</td>
</tr>
<tr>
<td>(e^+ (P &gt; 20%))</td>
<td>700 nA</td>
<td>1 (\mu)A</td>
</tr>
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Conclusion

- The performance of the positron system is heavily dependent on the central momentum. The central momentum should be set to 15 MeV/c to obtain a high yield of positrons, while a high polarization requires a central momentum of 60 MeV/c.

- The QWT plays a crucial role in selecting the desired momentum and reducing the spread of transverse angles.

- Including the electron beam after the target could be an interesting way to test our layout.

- Our positron injector is unique because it operates using a CW mode, which is challenging compared to other positron sources.
Acknowledgements

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THANK YOU FOR YOUR ATTENTION!
Twiss functions

QWT Polarized 2023 30Million e^ - E = 1MV/m B_2 = 0.05T
Beam size

QWT Polarized 2023 30Million e⁻ E = 1MV/m B₂ = 0.05T

\( \sigma_x [m] \)

\( s [m] \)

\( 0 \quad 5 \quad 10 \quad 15 \quad 20 \quad 25 \quad 30 \quad 35 \quad 40 \)
Normalized emittance

QWT Polarized 2023 30Million e− E = 1MV/m B2 = 0.05T

Normalized x = 0.00148770437816591 [m]
Normalized y = 0.0014545048748436 [m]
Transmission and current

QWT Polarized 2023 30 Million e⁻ \( E = 1 \text{MV/m} \) \( B_2 = 0.05T \)

- Transmission \( N_{e^-}/N_{\text{source}} \)
- Efficiency \( N_{e^-}/N_e \)
- Current [nA]

- \( B_1 = 2.5T \) \( B_2 = 0.05T \)
Momentum collimation

\[ B_1 = 2.5 \quad T \quad B_2 = 0.05T \]

- Entrance Chicane
- Middle: Collimator Entrance
- Middle: Collimator Exit

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Angular distribution
Transverse space

- The transmitted positrons are within the acceptance of the QWT
- \( p_t^{QWT} = \frac{eB_1R}{2} \). = 10.31°
- \( r_0^{QWT} = \frac{B_2}{B_1} R = 0.6 \text{ mm} \)
Un-Polarized mode: Positron Capture

- Reduce the magnetic field in the first solenoid.
- Rotate the transverse phase space \((x, x_p)\) and \((y, y_p)\) at the exit of the QWT.
- Use the same QWT as an energy filter.
- QWT acceptance:
  - Radial acceptance
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- \(L_1 = 0.24 \text{ cm}:\) Short solenoid length
- \(B_1 = 0.96 \text{ T}:\) Magnetic field over \(L_1\)
- \(R = 3 \text{ cm}:\) Accelerator aperture
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The longitudinal energy spread $\frac{dp}{p}$ is reduced by accelerating from 22 MeV/c to 123 MeV/c.

The accelerating section is utilized to produce the required energy chirp.

The same compression chicane is employed to effectively reduce bunch length.