Positron Production
Experiments at SABER

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3/15/06
1) Why Produce Positrons at SABER?

2) Positron Simulation Model

3) Simulation Predictions
Why Produce Positrons?

- The method for producing positrons for future linear colliders has yet to be determined.

- The initial SABER beam will not be the highest quality as the new beam line will need to be “debugged”. This offers a great opportunity to study plasma effects that do not require low emittance and small transverse beams.

- Betatron X-ray production almost prefers this regime.
Positron Production from Betatron X-rays

- If $I_{peak}$ of the $e^-$ beam is large enough, the vapor medium will field ionize.
- If $n_b >> n_p$, plasma electrons are blown-out, leaving a pure ion column.
- Ion column acts as a “Plasma Wiggler” leading to X-ray synchrotron radiation.

\[ N_p = 3 \times 10^{17} \text{ cm}^{-3}, \gamma = 56000, r_o = 10 \mu\text{m}, \]
\[ B_\theta/r = 9 \text{ MT/m}, \lambda_\beta = 2 \text{ cm} \]

1) **Wiggler strength:**

\[ K = \frac{\gamma \omega_\beta}{c} r_o = 173 \]

2) **Critical frequency on-axis ($K >> 1$):**

\[ \omega_c = \frac{3 \omega^2 \gamma^3}{2c} r_o = 49.6 \text{MeV} \]

3) **Particle energy loss:**

\[ \frac{dE}{dz} = \frac{1}{3} r_e m_e c^2 \gamma^2 k^2 K^2 = 4.3 \text{GeV/m} \]

Figure 1: Measured vs. Computed $e^+$
Spectra: $N_p = 1 \times 10^{17}$, $r_x = 7 \mu\text{m}$ and $r_y = 5 \mu\text{m}$
with $N_b = 7.2 \times 10^9$ electrons in the ion column

\[ \triangle \text{ Measured } e^+ \text{ Spectrum} \]

\[ \text{Computed } e^+ \text{ Spectrum} \]
1) Brute Force Computation of Lienard-Wiechert potentials (Esarey et al.).

2) Saddle-Point theory for practical computation of the potentials.

3) EGS4 for positron production calculations.

a) Input betatron trajectories into the potentials: Result? -> Multiple infinite Bessel Sums

b) Critical Harmonic number scales as \( K^3 = (\gamma k \beta r)^3 \). Impractical resolution!!

\[ \gamma \gg K = \gamma k \beta r \gg 1 \]

1) Only when \( k \) and \( p \) are pointed in the same direction do you get a radiation contribution.

2) The instantaneous time at this “Saddle-Point” has a characteristic radius of curvature.

3) This gives a characteristic “synchrotron-like” radiation spectrum, and approximates the radiation field to that of a particle moving in a circular path.

Assumption: The electron deflection angle (\( p_x/p_z \)) should be much larger than the angular spread of the radiation (1/\( \gamma \)) – (Kostyukov et al, Phys Plasmas, 10, 2003)
Radiated Energy Agreement

- The following shows a chart of Chao’s Theoretical Energy vs. Integrated Calculated Energy

Table 1: Error Between Theory and Calculation

<table>
<thead>
<tr>
<th>Plasma Density</th>
<th>Chao Theory (MeV)</th>
<th>Calculated (MeV)</th>
<th>% Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.00E+17</td>
<td>66.5</td>
<td>66.0</td>
<td>0.751879699</td>
</tr>
<tr>
<td>2.00E+17</td>
<td>188.1</td>
<td>187.8</td>
<td>0.159489633</td>
</tr>
<tr>
<td>3.00E+17</td>
<td>346</td>
<td>348</td>
<td>0.578034682</td>
</tr>
<tr>
<td>1E17 Gaussian</td>
<td>1.307e12</td>
<td>1.315e12</td>
<td>0.605235093</td>
</tr>
</tbody>
</table>

- Integral is performed in the following steps.
  - Calculate the Lienard-Wiechert Potential
  - Integrate over frequency at each position
  - Integrate over solid angle

\[
E = \int \frac{\partial P(\theta, \phi)}{\partial \Omega} \partial \Omega
\]

\[
\frac{\partial^2 I}{\partial \omega \partial \Omega} = \int \frac{\partial^2 I(\omega, \theta, \phi)}{\partial \omega \partial \Omega} \partial \omega
\]
Figure 3: Schematic of Long Plasma Simulation

Procedure for simulating 1-m plasma case:
1) Choose a length for each bin.
2) Calculate the loss to the wake for each bin length.
3) Compute the number of saddle-points within each bin.
4) Compute the synchrotron spectrum.
5) Subtract the energy loss (wakefield+radiation).
6) Use new $\gamma$ for particle for the next bin.
Can we increase the yield of the SLC source using betatron X-rays? Use a Cs plasma (lower ionization potential).

- $E_e = 28.5$ GeV, $N_b = 1 \times 10^4$, $N_p = 2 \times 10^{17}$ cm$^{-3}$, $r_{xy} = 15$ microns, $\text{wakeloss} = 15$ GeV/m, $L_p = 1$ m
- Both X-rays and e$^-$ hit the target. Average electron is roughly 10 GeV when it hits the target.
- Positrons are collected 10 cm downstream in a radius of 5 mm
- Results for 2-20 MeV positrons (ideal for collection)
Experiment #2

- Using a thin target (.5 rl W), can we get a comparable yield?

$E_e = 28.5 \text{ GeV}, N_b = 1 \times 10^7, N_p = 2 \times 10^{17} \text{ cm}^{-3}, r_{xy} = 15 \text{ microns, wakeloss} = 15 \text{ GeV/m, } L_p = 1 \text{m}$
- X-rays only.
- Positrons are collected 10cm downstream in a radius of 5mm
- Results for 2-20 MeV positrons (ideal for collection). These results are impressive for a thin target positron source

Table 3: Positrons / incident $e^-$ for plasma IN and OUT cases (2-20 MeV)

<table>
<thead>
<tr>
<th>Case</th>
<th>$e^+$ collected/$e^-$</th>
</tr>
</thead>
<tbody>
<tr>
<td>150 GeV in 150m wiggler (.5rl W)</td>
<td>1.5 w/ flux concentrator</td>
</tr>
<tr>
<td>28.5 GeV w/ 1m plasma (.5 rl W)</td>
<td>.5 w/o flux concentrator</td>
</tr>
</tbody>
</table>
1) We have shown simulations for increasing the yield of positron sources using betatron X-rays from a plasma.

2) Two experiments were presented.

3) A Cs-plasma would be necessary to achieve a full ion column with large transverse radii beams.

4) These would be ideal initial experiments for SABER.