POSITRON SOURCE OPTIONS FOR LINEAR COLLIDERS

Klaus Floettmann

DESY

EPAC 04
Contents:

- Basic design considerations
- Source Characteristics
- Polarized Positron Sources
How to build a Positron Source?

Primary Beam  Target  Capture Optics

Photons 10-20 MeV
thin target: 0.4 $X_0$

Electrons 0.1-10 GeV
thick target: 4-6 $X_0$
Target Damage at the SLC Converter Target
## Parameters of existing and planned positron sources

<table>
<thead>
<tr>
<th>Source</th>
<th>Rep Rate</th>
<th># of Bunches per Pulse</th>
<th># of Positrons per Bunch</th>
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<tr>
<td>TESLA</td>
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<tr>
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The Problem: Target Heating

\[ \Delta T = 2N_{pos} \eta \frac{E_{dep}}{c \cdot A} \]

\[ E_{dep} = 2 \frac{\text{MeV} \cdot \text{cm}}{\text{g}} \]

\( \frac{1}{\eta} = \text{capture efficiency} \)

\( c = \text{heat capacity} \)

\( A = \text{source area} \)
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Example of the rotating target for TESLA:

- 0.8 m diameter
- 1250 revolutions per minute
- 52 m/s on the circumference
- 4 cm in a pulse train of 0.8 ms
NLC Positron Target System Layout

RF Separator

4 Targets & Capture Optics

RF Combiner

6 GeV $e^-$

250 MeV $e^+$
The Problem: Target Heating

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Heat Capacity of the Target Material

Low Z materials have a higher heat capacity (Dulong Petit Rule)

but

high Z materials give a higher positron yield.
The escape depth $S_{\text{Escape}}$ from which a positron of energy $E_{\text{pos}}$ can reach the target surface is estimated as:

$$S_{\text{Escape}} \div X_0 = \frac{E_{\text{pos}}}{E_{\text{dep}} \cdot \rho \cdot X_0}$$

$$E_{\text{dep}} = 2 \frac{\text{MeVcm}^2}{\text{g}}$$

$$\rho = \text{density of the material}$$
## Escape depth for 10 MeV positrons:

<table>
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<tr>
<th>Material</th>
<th>$Z$</th>
<th>$S_{\text{Escape}}/X_0$</th>
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<tbody>
<tr>
<td>W</td>
<td>74</td>
<td>0.74</td>
</tr>
<tr>
<td>Cu</td>
<td>29</td>
<td>0.39</td>
</tr>
<tr>
<td>Ti</td>
<td>22</td>
<td>0.31</td>
</tr>
<tr>
<td>Al</td>
<td>13</td>
<td>0.21</td>
</tr>
</tbody>
</table>
Positron Yield vs. Target Thickness for a Photon based Source
Radiation Damage Material Test at BNL

collaborative effort of SLAC and other labs
The Problem: Target Heating

\[ \Delta T = 2 N_{pos} \eta \frac{E_{dep}}{c \cdot A} \]

\[ E_{dep} = 2 \frac{\text{MeV} \cdot \text{cm}}{g} \]

\[ \frac{1}{\eta} = \text{capture efficiency} \]

\[ c = \text{heat capacity} \]

\[ A = \text{source area} \]
How to Increase the Capture Efficiency?

Increase the acceptance of the capture optics

- requires a Predamping ring with large acceptance

Improve the positron emittance

- photon based positron source with thin target
Transverse momenta

- Conventional source
- Thin target source

Number of positrons [arb. units] vs. Transverse momentum [MeV/c]
The capture optics

\[ B(z) = \frac{B_i}{1 + g \cdot z} \]

\[ g \cdot \frac{P}{e \cdot B_i} \ll 1 \]

- low frequency (L-band)
  - large iris radius
  - long wave length
Source characteristics: Energy distribution

The graph shows the distribution of positrons at different energies in various locations:
- Positrons at the target
- Positrons in the linac
- Positrons in the damping ring

The y-axis represents the number of positrons per unit energy [1/MeV], while the x-axis represents the energy [MeV]. The graph indicates the energy distribution of positrons across different sections of the system.
Source characteristics: Longitudinal beam shape

![Graph showing the number of positrons vs. rf-phase (1.3 GHz) in degrees.](image)
Source characteristics: Transverse beam shape

![Graph showing transverse beam shape with a Gauss fit.](image_url)
Polarized Positron Sources

For the production of polarized positrons circularly polarized photons are required.

Methods to produce circularly polarized photons of 10-60 MeV are:

• radiation from a helical undulator
• Compton backscattering of laser light off an electron beam
Polarization Transfer in Pair Production
Polarization loss due to Bremsstrahlung
Undulator Based Positron Source

250 GeV electron beam

undulator ~100 m

to the IP

e^-

γ beam

target 0.4 X_0

Ti–alloy

Adiabatic Matching Device

solenoids

accelerating structure

to Damping Ring
Super Conducting Design

- Ribbon-wire wound in a double helix
Helical Undulator

- Rotating Dipole Field in the Transverse Planes
- Electrons follow a “helical” path
- Circularly polarised radiation is emitted
Number of Photons vs. Energy

First harmonic of helical undulator radiation

- Number of photons [arb. units]
- Photon energy / energy of the first harmonic
Polarization vs. Energy

First harmonic of helical undulator radiation

circular polarization
transverse polarization

polarization vs. photon energy / energy of the first harmonic
Polarization vs. Emission angle

First harmonic of helical undulator radiation

- **circular polarization**
- **transverse polarization**

![Graph showing polarization vs. emission angle]

K. Floettmann

EPAC, July 5-9, 2004
Model of the Prototype Helical Undulator at Daresbury
Model of the Prototype Helical Undulator at Daresbury
Compton Backscattering based Positron Source
GLC Polarized Positron Source Design

- RF-Gun
- 3 GeV Linac
- 3 GeV DR
- BC
- 2.8 GeV Linac
- 3 GeV DR
- CO2 lasers
- Conversion target
- Capture section
- 1.98 GeV Pre-DR
- 1.98 GeV DR
- BC
- 1.98 GeV Linac

- Electron beam 5.8 GeV
- High current and low emittance
- Collision points (Parabolic mirrors)
- γ-rays
Multi Collision Point Layout
GLC Collision Region

10 collision sections, with 20 collision points each:

200 collision points
E-166 Demonstration Experiment for a Polarized Positron Source

About 47 members from 17 institutions:
Brunel, CERN, Cornell, DESY, Daresbury, Durham, Jefferson, Humboldt, KEK, Princeton, South Carolina, SLAC, Tel Aviv, Tokyo M.U., Tennessee, Wasada, Yerevan
E-166 Demonstration Experiment for a Polarized Positron Source

- Final Focus Test Beam (FFTB) at SLAC with 50 GeV Electrons.
- 1 m long helical undulator produces circular polarized radiation of up to 10 MeV.
## Undulator Parameter for Polarized Positron Source

<table>
<thead>
<tr>
<th>Parameter</th>
<th>TESLA</th>
<th>E-166</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>~150 m</td>
<td>1 m</td>
</tr>
<tr>
<td>Beam</td>
<td>200 GeV</td>
<td>50 GeV</td>
</tr>
<tr>
<td>Period</td>
<td>14 mm</td>
<td>2.4 mm</td>
</tr>
<tr>
<td>B-field</td>
<td>0.7 T</td>
<td>0.76 T</td>
</tr>
<tr>
<td>Energy of first Harmonic</td>
<td>20 MeV</td>
<td>9.6 MeV</td>
</tr>
<tr>
<td>Positrons/bunch</td>
<td>$3 \cdot 10^{10}$</td>
<td>$2 \cdot 10^{7}$</td>
</tr>
</tbody>
</table>
Pulsed Undulator for E-166

- Inner diameter 0.89 mm
- Magnetic field: 0.76 T
- Pulsed current: 2.3 kA
- Rate 30 Hz
• Conversion of photons to positrons in 0.5 $X_0$ Ti-target
• Measurement of polarization of photons and positrons by Compton transmission method
• Expected polarization $\sim$50%
E-166 Demonstration Experiment for a Polarized Positron Source

- E166 is a demonstration of production of polarized positrons for future linear colliders
- Uses the 50 GeV FFTB at SLAC
- Approved by SLAC in June 2003
- All components or prototypes work properly
- Installation of total experiment in FFTB tunnel in August 2004
- First data taking run in October 2004
- Second data taking in February 2005
\textbf{Experiment@KEK}

- \textit{e}^− \text{beam} 1.28 \text{ GeV}
- YAG laser 2nd harmonic \((\lambda = 532 \text{ nm}, E = 2.33 \text{ eV})\)
- Thin conversion target
- \(\gamma\)-ray \(E_{\text{max}} = 56 \text{ MeV}\)
- \(e^− e^+\) pair creation
- \(e^−\)
$\gamma$-ray: production, detection, and polarimetry at ATF Extraction line

- Compton chamber
- Collision Point
- Compton
- Bend
- Magnet: Magnetized Iron
- Air Cherenkov Counter
- Laser Beam $\lambda = 532$ nm
1.) Production of polarized $\gamma$‘s and polarized $e^+$
   - pol. $\gamma$: finished 2002
   - pol $e^+$: underway

2.) Polarimetry
   - polarimetry of short pulse & high intensity $\gamma$
     rays established
   - same method applicable for polarized positrons
Acknowledgement

I would like to thank John Sheppard (SLAC), Tsunehiko Omori (KEK) and Duncan Scott (Daresbury) for providing figures and information.