Project Name
LCRD 2.37
Undulator-Based Production of Polarized Positrons
Progress Report of E-166 at FFTB at Stanford Linear Accelerator Center.

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A Demonstration Experiment for Helical Undulator Production of Polarized Positrons at ILC

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University of Tennessee
E166 is a UT contribution to International Linear Collider program

In ILC Baseline positron production is accomplished by use of Undulator due to beam damage in solid targets.
Basic concept is production of intense beam of low energy (0-10MeV) photons by passing a high energy (150 GeV) electron beam through a 200m long undulator. The photons are passed through a thin target and the resulting positrons collected, cooled and accelerated.
If the undulator is replaced by a helical undulator the positrons are circularly polarized. E166 tests this concept with a 1% scale experiment.
Recently due in large part to E166 success, ILC has adopted a helical undulator for the baseline with polarized $e^+$ as an upgrade.
Physics Motivation

- Electroweak processes $e^+e^- \rightarrow WW, Z, ZH$ couple only to $e^-_Le^+_R$ or $e^-_Re^+_L$ (and not $e^-_Le^+_L$ or $e^-_Re^+_R$).
- Slepton and squark production dominantly via $e^-_Re^+_L$.
  \[ \Rightarrow \text{Can double rate using polarized positrons (or suppress rate if both } e^- \text{ and } e^+ \text{ are polarized).} \]
- Effective polarization enhanced, and error decreased, in electroweak asymmetry measurements,
  \[ \frac{(N_L - N_R)}{(N_L + N_R)} = P_{\text{eff}} A_{LR}, \]
  \[ P_{\text{eff}} = \frac{P_- - P_+}{1 - P_- P_+}. \]
Undulator Principle.

- electrons traverse periodic magnetic structure
- photons are emitted
The helical undulator

Helical winding where $I_1$ and $I_2$ are in **opposite directions**.

$\boxed{I_1 = -I_2}$

Helical winding:
- $z$ component of the induced magnetic field cancels
- remaining magnetic field describes a helical profile
γ’s from ILC Helical Undulator

- γ’s per period (with \( K = \frac{eB\lambda}{2\pi mc^2} = 1 \)) \( \approx \alpha = 1/137 \).
- (γ intensity \( \sim K^2 \), but spectrum ragged for \( K > 1 \).)
- 100 γ’s/positron \( \Rightarrow \sim 10,000 \) periods.
- Period \( \sim \) undulator diameter \( \sim 1 \) cm \( \Rightarrow \sim 100 \) m long.
  \( \Rightarrow \) First-order cutoff at \( \sim 10 \) MeV γ’s for 150 GeV e-.
- Helical undulator simpler to fabricate than planar.
E166 undulator designed to duplicate with 50 GeV beam gamma energy and polarization spectrum identical to ILC photons
## E166 Undulator Design

PULSED HELICAL UNDULATOR FOR TEST AT SLAC THE POLARIZED POSITRON PRODUCTION SCHEME. BASIC DESCRIPTION.

Alexander A. Mikhailichenko
CBN 02-10, LCC-106

Table 3: FFTB Helical Undulator System Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Undulators</td>
<td>-</td>
<td>2</td>
</tr>
<tr>
<td>Length</td>
<td>m</td>
<td>1.0</td>
</tr>
<tr>
<td>Inner Diameter</td>
<td>mm</td>
<td>0.889</td>
</tr>
<tr>
<td>Period</td>
<td>mm</td>
<td>2.4</td>
</tr>
<tr>
<td>Field</td>
<td>kG</td>
<td>7.6</td>
</tr>
<tr>
<td>Undulator Parameter, K</td>
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<td>0.17</td>
</tr>
<tr>
<td>Current</td>
<td>Amps</td>
<td>1800</td>
</tr>
<tr>
<td>Pulse Width</td>
<td>µs</td>
<td>30</td>
</tr>
<tr>
<td>Inductance</td>
<td>H</td>
<td>1.8x10^-6</td>
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<tr>
<td>Wire Type</td>
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<td>Cu</td>
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<tr>
<td>Wire Diameter</td>
<td>mm</td>
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<tr>
<td>Resistance</td>
<td>ohms</td>
<td>0.125</td>
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<tr>
<td>Repetition Rate</td>
<td>Hz</td>
<td>30</td>
</tr>
<tr>
<td>Power Dissipation</td>
<td>W</td>
<td>225</td>
</tr>
<tr>
<td>ΔT/pulse</td>
<td>°C</td>
<td>4</td>
</tr>
</tbody>
</table>
Expected Polarization

Expected positron polarization vs. positron energy
E166 Collaboration
14 Institutions/57 Participants

E-166 in the FFTB

running parameters:
- beam energy: 46.6 GeV
- rep. Rate: 10 Hz
- N_e/pulse: ~30^{10}
E166 Elements

Low emittance 50 GeV beam from FFTB
Undulator
Counters to measure initial and transmitted photon beam intensity and energy
Target and positron beam transport magnets
Polarization analyzer magnets
CsI calorimeter and positron counter for positron polarization measurement
E-166 Layout  Undulator area (Side view)

- Permanent Magnet
- B-SB magnet
- Collimator (3 mm)
- Undulator
- Synchrotron Stripe
- Collimator (3 mm)

γ (5 MeV, 2×10^9), E_{tot} \sim 10^8 \text{ TeV}

e^- (46.6 \text{ GeV} \times 10^9), E_{tot} \sim 10^8 \text{ TeV}

30 meters upstream
E-166 Detectors area (Top view)

Positron detector area

Photon detector area

\[ 10^3 \gamma \]

\[ \gamma (5 \text{ MeV, } 10^9), \ E_{\text{tot}} \sim 0.5 \times 10^4 \text{ TeV} \]

\[ e^- \]

\[ 0.5 \times X_0, \ W \]
E166 setup in the FFTB
Major participants-4 International Laboratories Cornell, DESY Hamburg, DESY Zeuthen, SLAC and 2 Universities, Princeton and Tennessee.

A. Equipment and Installation

<table>
<thead>
<tr>
<th>Laboratory</th>
<th>Equipment/Installation</th>
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<tbody>
<tr>
<td>Cornell</td>
<td>Undulator and Power Supply</td>
</tr>
<tr>
<td>DESY Hamburg</td>
<td>Polarization Analyzer Magnets</td>
</tr>
<tr>
<td>DESY Zeuthen</td>
<td>CsI Calorimeter and Calibration System for Positron Line</td>
</tr>
<tr>
<td>Princeton</td>
<td>Positron Transport Magnets, Aerogel Photon Counters</td>
</tr>
<tr>
<td>SLAC</td>
<td>Undulator Mover and Support Table, Labview DAQ system, Beamline, Collimators and Vacuum Chambers Target Assembly</td>
</tr>
<tr>
<td>Tennessee</td>
<td>Gammaline SiW Photon Counters, Calorimeter, and Beam Steering</td>
</tr>
<tr>
<td></td>
<td>Counters, Positron Flux Counter, Background Monitoring System (6 SiW Calorimeters, 2 CsI Counters, and assortment of Scintillation Counters)</td>
</tr>
</tbody>
</table>

B. Data Analysis

<table>
<thead>
<tr>
<th>Analysis</th>
<th>Participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Undulator Performance</td>
<td>Cornell, SLAC, Tennessee</td>
</tr>
<tr>
<td>Photon Polarization</td>
<td>Tennessee, DESY Hamburg</td>
</tr>
<tr>
<td>Positron Polarization</td>
<td>DESY Hamburg, DESY Zeuthen, Tel Aviv, Tennessee</td>
</tr>
</tbody>
</table>
Data taking

- Original plan: two running periods in October 2004 and January 2005
- Accident at SLAC -> delay
- June 2005: first run of E-166
- September 2005: second run

Data taking scheme:
- Beam energy 46.6 GeV
- 10 Hz beam
- Undulator at 10 Hz
- Every 2\textsuperscript{nd} pulse - undulator off time
  -> "undulator on"-event followed by "undulator off"-event

\textit{Typical run pattern is a super run of 5-20 cycles, each cycle consisting of 4000 beam pulses followed by analyzer magnet reversal.}
Undulator performance was superb. It worked as expected at turn on, generated the predicted number of photons and showed expected quadratic dependence on undulator magnet current.
FLUX AS FUNCTION OF CURRENT IN UNDULATOR

Below is a signal from #22 as function of current in undulator, obtained in owl run on September 17, 2005. Target – out

![Graph showing flux as function of current](image)

Measured points together with the parabolic approximation.

According to the latest table of attenuations, the counter #22 has 60 dB\(^1\). Hence the number of quanta going to be

\[
N_p \equiv 175 \cdot 10^{6/20} \cdot 5000 \equiv 8.9 \cdot 10^8,
\]

where 5000 is a calibration coefficient for #22, 175 – is the signal value, see the graph above for 2300 A.

From the other hand, the total number of quanta can be calculated as

\[
N_{\text{theory}} \equiv N_p \frac{4\pi\alpha L}{3} \frac{K^2}{\lambda_n} 1 + K^2,
\]

where \(K = \frac{e\hbar \lambda_n}{2 \pi mc} \propto I\) and \(I\) stands for the current running in undulator. Our undulator has the length \(L \equiv 1000\) mm, period \(\lambda_n \equiv 2.54\); the number of electrons in this measurements was \(N_p \equiv 2 \cdot 10^7\), so \(K\)-factor corresponding to the number of photons (1) according to the formula (2) is

\[
K \equiv 0.196
\]

This value will be précised in further measurements.

A.M.

\(^1\) September 12 readings in Attenuator list.
Measurement of photon polarization

\[ \sigma_{\text{tot}} = \sigma_{\text{phot}} + \sigma_{\text{comp}} + \sigma_{\text{pair}} \quad \text{with} \quad \sigma_{\text{comp}} = \sigma_0 + P_\gamma P_e \sigma_{\text{pol}} \]

\[ T^\pm (L) = e^{-nL \sigma} = e^{-nL(\sigma_{\text{phot}} + \sigma_{\text{pair}} + \sigma_0)} e^{\pm nLP_e P_e \sigma_{\text{pol}}} \quad \text{Transmission} \]

\[ \delta(L) = \frac{T^+ - T^-}{T^+ + T^-} \approx nLP_e P_\gamma \sigma_{\text{pol}} \quad \text{Asymmetry} \]

\[ P_\gamma = \frac{\delta}{nL \sigma_{\text{pol}} P_e} = \frac{\delta}{A_\gamma P_e} \quad \text{Photon Polarisation} \]
Typical photon polarization run (4000 events)

Top. Photon intensity before analyzing magnet
Bottom. Photon intensity after analyzing magnet
Each plot contains both undulator on and off data.
Sequence of runs taken with alternating photon analyzer magnet polarity

Transmission Difference /Sum for Runs of Alternating Analyzer Magnet Polarity

![Graph showing transmission difference over run number](image-url)
Positron Asymmetry is measured by a 9 element CsI calorimeter constructed by DESY. Positrons are transported to positron analyzer magnet, reconverted to polarized photons and asymmetry measured in same way as in photon line.
How we obtain the asymmetries

- subtract background from signal events
- average over certain bg-range
- test statistical methods with toy-monte carlo
- calculate the asymmetry between the two magnetization states
Positron Asymmetries

preliminary

(stat. errors only)
Summary

**E166** completed successful running-October 10, 2005.

**Undulator** produced photons at the expected intensity and showed predicted quadratic dependence on magnet current. Undulator is well understood.

**Photon** polarization was demonstrated and observed asymmetry agreed well with that expected from the predicted undulator spectrum.

**Polarized Positrons** were produced, converted into photons and transmission asymmetry measured. Final results on expected intensity and the average positron polarization as a function of momentum await the completion of simulations incorporating fine details of the positron transport system including a more accurate field map, survey information, shielding and better mechanical detail.

**E166 has provided successful demonstration of feasibility of polarized positron production at ILC.**