Undulator-Based Production of Polarized Positrons
A Proposal for the 50-GeV Beam in the FFTB

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http://puhep1.princeton.edu/mcdonald/e166/

The E-166 Project Website:
http://www-project.slac.stanford.edu/lc/local/PolarizedPositrons/index.htm

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Executive Summary
## Contents

1 Introduction 2
  1.1 Effective Polarization .................................................. 2
  1.2 Suppression of Backgrounds via Positron Polarization ................. 3
  1.3 Enhancement of Effective Luminosity .................................. 4
  1.4 Analysis of Physics Beyond the Standard Model ...................... 4
  1.5 Transversely Polarized Beams ......................................... 5
  1.6 Precision Measurement of Beam Polarization ......................... 6

2 The Need for a Demonstration Experiment 8
  2.1 Concept of Polarized Positron Production .......................... 8
  2.2 Calculation of Polarized Electromagnetic Cascades .................. 9

3 The Proposed Experiment in the Final Focus Test Beam 12
  3.1 Overview ................................................................. 12
    3.1.1 Undulator Design Principles .................................... 14
    3.1.2 Overview of the Beam Parameters ............................... 14
    3.1.3 Comparison with Positron Sources for Linear Colliders ........ 14
  3.2 The Beamline ......................................................... 14
    3.2.1 Layout ............................................................ 14
    3.2.2 Beam Parameters ................................................ 14
    3.2.3 Synchrotron Radiation Background ............................. 17
    3.2.4 Collimators ....................................................... 18
    3.2.5 Alignment ......................................................... 18
    3.2.6 Instrumentation .................................................. 18
  3.3 Beam Line Equipment .................................................. 19
  3.4 The Undulator ......................................................... 19
  3.5 Photon Spectrum and Rates ............................................ 21

4 A Run Plan 26
  4.1 Run Plan Summary ..................................................... 26
  4.2 Installation and Check Out Requirements ............................. 26
  4.3 Beam Setup ............................................................ 29
  4.4 Experimental Measurements ............................................ 30
  4.5 Experiment Script ..................................................... 30

5 References 31
List of Figures

1. Effective polarization vs. positron polarization. ......................... 3
2. Selectron pair production with longitudinally polarized beams. .......... 5
3. Search for extra dimension with transversely polarized beams. .......... 6
4. Conceptual scheme for undulator-based production of polarized positrons. 8
5. Longitudinal polarization of positrons from a circularly polarized photon. 10
6. Longitudinal polarization of positrons from a thin target. ................. 10
7. Conceptual layout of the experiment. ................................... 12
8. Conceptual layout of positron production and polarimetry. ............... 13
9. Prototype of the helical undulator. ................................... 20
10. Schematic representation of the undulator with pulsing circuit. ........ 20
11. Mechanical drawing of the undulator. ................................ 21

List of Tables

1. Effective polarization. ............................................. 2
2. Scaling factors for WW and ZZ background suppression. ................. 3
3. Fraction of colliding particles for different beam polarizations. ........ 4
4. TESLA, NLC, FFTB polarized positron parameters. ..................... 15
5. FFTB beam parameters. ........................................... 16
6. E166 beam parameter request. ..................................... 16
7. FFTB beam parameters. ........................................... 17
8. E166 beamline equipment. .......................................... 23
9. Parameters of the helical undulator system. ................................ 24
10. Photon flux from the helical undulator. ................................ 25
11. Photon and positron polarimetry devices and detectors. ............... 27
12. Detector installation and test plan. ................................ 28
1 Introduction

The importance of beam polarization in general has been demonstrated at the Stanford Linear Collider (SLC), where in the last year of its running, 1994/95, an average longitudinal beam polarization \( P_e = 77\% \) was reached and one of the world's best measurements of the weak mixing angle at Z-pole energies was performed.

Moreover, the option of having simultaneously polarized positrons and electrons at a future Linear Collider [2] would lead to:

1. Higher effective polarization,
2. Suppression of backgrounds,
3. Enhancement of the effective luminosity,
4. Precise analysis of any kind of non-standard couplings,
5. The option to use transversely polarized beams,
6. Improved accuracy in measuring the polarization.

Details and examples are summarized in [3] and in the following we list only some key points.

1.1 Effective Polarization

When performing a measurement of a left-right asymmetry with polarized beams at a Linear Collider, the numbers of events \( N_L \) and \( N_R \) for left- and righthanded interactions are related to the physical asymmetry \( A_{LR} \) via an "analyzing power" \( P_{e\bar{e}} \) according to

\[
\frac{N_L - N_R}{N_L + N_R} = P_{e\bar{e}} A_{LR};
\]

where

\[
P_{e\bar{e}} = \frac{P_{e^+} P_{e^-}}{1 + P_{e^-} P_{e^+}}.
\]

In Table 1 we list the corresponding values for the relevant Linear Collider polarizations. The merit of achieving a high effective polarization is that the error in the asymmetry \( A_{LR} \) scales roughly as \( 1/P_{e\bar{e}} \), as shown in Fig. 1.

Table 1: The Effective polarization (2) for various \( e^- \) and \( e^+ \) polarizations.

<table>
<thead>
<tr>
<th>( P_{e^-} )</th>
<th>% 80%</th>
<th>% 90%</th>
</tr>
</thead>
<tbody>
<tr>
<td>( P_{e^+} )</td>
<td>&quot; 60%&quot;</td>
<td>&quot; 40%&quot;</td>
</tr>
<tr>
<td>( j P_{e\bar{e}} )</td>
<td>95%</td>
<td>91%</td>
</tr>
</tbody>
</table>
1.2 Suppression of Backgrounds via Positron Polarization

The dominating background processes are $WW$ and $ZZ$ production and the scaling factors for their rates are given in Table 2. A positron polarization of about $P_{e^+} = 60\%$ would double the suppression of the $WW$ background. Another example for background suppression where the polarization of both beams is needed is single $W^\pm$ background since only $P_{e^+}$ can influence the signal from $W^\pm$.

Table 2: Scaling factors for $WW$ and $ZZ$ background suppression.

<table>
<thead>
<tr>
<th>($P_{e^-} = 80%, P_{e^+} = 0; $ 60%$)</th>
<th>$e^+e^- \ W^+W^- \ e^+e^- \ ZZ$</th>
</tr>
</thead>
<tbody>
<tr>
<td>(+0)</td>
<td>0.2</td>
</tr>
<tr>
<td>(i 0)</td>
<td>1.8</td>
</tr>
<tr>
<td>(+i )</td>
<td>0.1</td>
</tr>
<tr>
<td>(i +)</td>
<td>2.85</td>
</tr>
</tbody>
</table>
1.3 Enhancement of Effective Luminosity

The chiral structure of Standard Model s-channel processes is given by $(V; A)$ couplings, which means that only (LR) and (RL) configurations of the initial $e^e$ contribute. The fraction of colliding particles is therefore

$$\frac{1}{2} (1 \ i \ P_e \ P_{e^+}) \ L_{\text{e\#}};$$

which defines an effective luminosity $L_{\text{e\#}}$. This can only be enhanced when both beams are polarized, as illustrated in Table 3.

Table 3: Fraction of colliding particles ($L_{\text{e\#}}=L$) and the effective polarization ($P_{e\#}$) for different beam polarization configurations, which are characteristic for $(V; A)$ processes in the s-channel [3].

<table>
<thead>
<tr>
<th>$P_e$</th>
<th>$P_{e^+}$</th>
<th>RL</th>
<th>LR</th>
<th>RR</th>
<th>LL</th>
<th>$P_{e#}$</th>
<th>$L_{\text{e#}}=L$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
<td>0.0</td>
<td>0.5</td>
</tr>
<tr>
<td>1</td>
<td></td>
<td>0</td>
<td>0.5</td>
<td>0</td>
<td>0.5</td>
<td>1.0</td>
<td>0.5</td>
</tr>
<tr>
<td>0.8</td>
<td></td>
<td>0.05</td>
<td>0.45</td>
<td>0.05</td>
<td>0.45</td>
<td>0.8</td>
<td>0.5</td>
</tr>
<tr>
<td>0.8</td>
<td></td>
<td>0.02</td>
<td>0.72</td>
<td>0.08</td>
<td>0.18</td>
<td>0.95</td>
<td>0.74</td>
</tr>
</tbody>
</table>

1.4 Analysis of Physics Beyond the Standard Model

Beam polarization is in particular important for one of the main issues of a future Linear Collider – not only the discovery but also the precise analysis of the new physics beyond the Standard Model in order to reveal exactly the underlying structure of the model.

Supersymmetry is one of the most motivated possibilities for new physics. However, even its minimal version, the MSSM, leads to about 105 new free parameters. At the Linear Collider one has to determine the SUSY parameters as model independent as possible, as well as to prove the underlying SUSY assumptions, e.g., that the SUSY particles have to carry the same quantum numbers (with the exception of the spin) as their Standard Model partners.

For example, SUSY transformations associate chiral (anti)fermions to scalars $e_{L,R} \ , \ \overline{e}_{L,R}$ but $e^{+}_{L,R} \ , \ \overline{e}^{+}_{L,R}$. In order to prove this association the use of both beam polarized is
necessary [4]. The process $e^+e^- \rightarrow e^+e^-$ occurs via $\gamma$ and $Z$ exchange in the s-channel and via neutralino $\tilde{\chi}_1^0$ exchange in the t-channel. The association can be directly tested only in the t-channel and the use of polarized beams serves to separate this channel. We demonstrate this by isolation of the pair $e_L^\pm e_R^\mp$ by the LL configuration of the initial beams in an example where the selectron masses are close together, $m_{e_L} = 200 \text{ GeV}$, $m_{e_R} = 190 \text{ GeV}$, so that $e_L$, $e_R$ decay via the same decay channels, see Fig. 2. The other SUSY parameters are taken from the reference scenario SPS1a [5]. With $P_{e^-} = 80\%$, $P_{e^+} = 0\%$ the pairs $\frac{3}{4}(e_L^- e_R^+) = 102 \text{ fb}$ and $\frac{3}{4}(e_L^+ e_R^-) = 108 \text{ fb}$ are close together. This will nearly not be changed even if $P_{e^-} = 100\%$ were available, which would result in $\frac{3}{4}(e_L^- e_R^+) = 113 \text{ fb}$ and $\frac{3}{4}(e_L^+ e_R^-) = 119 \text{ fb}$.

However, if we use polarized positrons a separation of the wanted pair $e_L^- e_R^+$ with the test of the chiral quantum number might be possible: $P_{e^-} = 80\%$, $P_{e^+} = 40\%$ result in $\frac{3}{4}(e_L^- e_R^+) = 143 \text{ fb}$ and $\frac{3}{4}(e_L^+ e_R^-) = 66 \text{ fb}$ and with $P_{e^-} = 80\%$, $P_{e^+} = 60\%$ even $\frac{3}{4}(e_L^- e_R^+) = 163 \text{ fb}$, $\frac{3}{4}(e_L^+ e_R^-) = 49 \text{ fb}$ and $\frac{3}{4}(e_L^+ e_R^+) = 44 \text{ fb}$ are obtained, see Fig. 2.

One should also mention that beam polarization provides an elegant and efficient method for the suppression of background SUSY processes to the selectron production studies [6].

1.5 Transversely Polarized Beams

The use transversely polarized beams at a linear collider was afforded additional physics opportunities [7]. The cross section is then given by

$$
\frac{3}{4} = (1 - P_{e^+} P_{e^-}) \frac{3}{4} \text{ unp} + (P_{e^+}^L P_{e^-}^L) \frac{3}{4} \text{ pol } + P_{e^+}^T P_{e^-}^T \frac{3}{4} \text{ pol}; \tag{4}
$$
Access to the physics of the transverse cross section $\frac{3}{4} T_{pol}$ requires that both beams be polarized.

It has been shown in [8] that transversely polarized beams project out $W^+ W^- W^+ W^-$ final states, which are particularly important for studying the origin of electroweak symmetry breaking. When studying the azimuthal asymmetry, which is very pronounced at high energies reaching about 10% and peaks at larger angles, one has direct access to the LL mode of $W W$ production without complicated final-state analyzes.

The azimuthal asymmetry is also a crucial observable when studying signals of extra dimension in the process $e^+ e^- \rightarrow f \bar{f}$ [9]. With the use of transversely polarized beams it is possible to probe spin-2 graviton exchange to about twice the sensitivity of "conventional" methods for analyzing contact interactions! In Fig. 3 the differential azimuthal asymmetry distribution is shown, which is exactly symmetric in the Standard Model and in $Z^0$ models and whose asymmetric distribution is the signal for the graviton spin-2 exchange.

Figure 3: Search for large extra dimensions in the ADD model in $e^+ e^- \rightarrow f \bar{f}$ with transversely polarized beams. Shown is the differential azimuthal asymmetry distribution whose asymmetric distribution is the signal for the graviton spin-2 exchange. From [9].

1.6 Precision Measurement of Beam Polarization

The use of polarized positrons would also permit high-precision electroweak tests of the Standard Model when running the Linear Collider with energies at the $WW$ threshold and at the $Z$ pole. The effective electroweak leptonic mixing angle can be measured via the left-right asymmetry. To reduce the error in measuring the polarization one has to use an extended Blondel Scheme for precision polarimetry and expresses the asymmetries via
polarized rates:

\[ A_{LR} = \frac{\sum (\frac{3}{4} + i \frac{1}{4}) (\frac{3}{4} + i \frac{1}{4})}{(\frac{3}{4} + i \frac{1}{4}) (\frac{3}{4} + i \frac{1}{4})} \]  

(5)

Only with this scheme, where polarization of both beams is required, can we achieve such spectacular accuracy for the electroweak observables as \( \pm (\sin^2 \mu_{\text{ee}}) = 0.00001 \) and \( \pm (M_W) = 6 \text{ MeV} \) [10].
2 The Need for a Demonstration Experiment

2.1 Concept of Polarized Positron Production

A polarized positron source for a Linear Collider was first proposed by Balakin and Mikhailichenko in 1979 in the framework of the VLEPP project [11]. The concept, schematically sketched in Fig. 4, foresees to guide the high energy ($\geq 150$ GeV) electron beam of the linear collider through a long ($\geq 100$ m) helical undulator to produce circularly polarized photons with energies $\geq 10$ MeV.\(^1\) While the electrons are further accelerated and brought into collision after passing through the undulator, the photons are converted in a thin target into electron-positron pairs. Here the polarization state of the photons is transferred to the positrons and electrons (see below for details). Only the on-axis photons of the helical undulator radiation are completely circularly polarized; the degree of polarization is decreasing with increasing emission angle. Hence, the polarization of the photons and of the generated positrons can be increased on the expense of the total number of positrons by collimation. The positrons are captured behind the target similarly to the case of a conventional positron source, and fed into linac.

\(^1\)Alternatively, the undulator could be placed in the electron beam beyond the $e^+e^-$ interaction point, using the "spent" electron beam. The beam quality of the disrupted electron beam is, however, poor due to the strong beam-beam interaction (beamstrahlung). Moreover, the electron beam quality, and hence the positron production efficiency, depend on the details of the collision (offsets etc.), which makes this option even more untenable.

Figure 4: Conceptual scheme for undulator-based production of polarized positrons.

This undulator-based positron source concept offers the additional advantage that the heat load on the target is less than that of a conventional source, and so the former is very well suited for the production of high intensity positron beams [12]. An undulator-based polarized positron sources can in principle be realized independently of the linac technology, i.e., independently of the details of the required pulse structure, because the number of produced positrons scales with the number of the electrons in the drive linac, and the pulse structure of the electrons is directly copied to that of the positrons. In this sense it is an option for all linear collider projects.

A related approach for the production of polarized positrons is to create circularly polarized photons by means of Compton backscattering of laser light at a high-intensity electron beam [13]. Undulator radiation can be thought of as Compton backscattering of the virtual
photons of the undulator, and hence the photon spectrum and the polarization characteristics of Compton backscattered photons are very similar to those of undulator radiation. The requirements for the pulsed laser system to implement positron production are extremely demanding, so the use of the electron beam + undulator offers significant technical advantages.

The aim of the proposed experiment E-166 is to test the fundamental process of polarization transfer in an electromagnetic cascade. While the basic cross sections for the relevant QED processes were derived in the late 50's, experimental verification of the polarization development in an electromagnetic cascade is still missing. From this point of view, the proposed experiment has some general scientific aspects in addition to its importance for linear colliders.

2.2 Calculation of Polarized Electromagnetic Cascades

The longitudinal polarization of photons produced in a helical undulator depend on the photon energy and the emission angle, as will be discussed in detail below. Here it is sufficient to assume monoenergetic, completely circularly polarized photons with an energy of typically 10 MeV. When such a circularly polarized photon creates an electron-positron pair in the target, the polarization state of the photon is transferred to the outgoing leptons according to the cross sections derived by Olsen and Maximon in 1959 [17]. Positrons with an energy close to the energy of the incoming photons are 100% longitudinally polarized, while positrons with a lower energy have a lower longitudinal polarization (see Fig. 5). At energies below 25% of the photon energy the sign of the positron polarization is opposite to that of the photon.

The probability for the production of positrons is roughly independent of the fractional energy $E_{e^+} = E^-$ in the pair-production process, so that positrons with all energies up to the photon energy are produced (with initial polarization as shown in Fig. 5). However, even in a thin target, low-energy positrons are stopped due to the strong ionization loss at low energies, while high-energy positrons loose a fraction of their energy due to bremsstrahlung. The energy loss by bremsstrahlung is accompanied by a slight loss of polarization; however, the energy loss is stronger than the polarization loss. As a result, the low-energy portion of the positron spectrum is repopulated with positrons from the higher energy portion, and the polarization of positrons of a given energy is higher from a thick than from a thin target [12], as shown in Fig. 6.

For targets thicker than about 0.5 radiation length the polarization decreases again. Hence, positrons are unpolarized in a conventional thick target positron source even if the incoming electrons are polarized. (At very low yield polarized positrons may also be produced from polarized electrons using thin targets [15].)

The basic processes of polarized electromagnetic cascades are of course well known, but understanding of the interplay of all processes in a shower requires simulation with a Monte-Carlo code. The well-known unpolarized Monte-Carlo program EGS 4 [14] has been modified for this purpose and an achievable positron polarization of 40-60% (depending on the running conditions of the Linear Collider) has been predicted. Meanwhile, the shower code of GEANT has been upgraded to include polarization, following the same approach as has been used for EGS 4 [16]. The polarized version of EGS 4 includes the effects for pair production,
Figure 5: Longitudinal polarization of positrons (or electrons) produced by conversion of monochromatic circularly polarized photons in an infinitely thin target, as a function of the ratio of positron to photon energies. From [17].

Figure 6: Longitudinal polarization of positrons produced by conversion of circularly polarized photons in targets of various thickness (in radiation lengths), as a function of the ratio of positron to photon energies.
bremsstrahlung and Compton scattering (with the exception of scattering asymmetries which are not considered) [12]. The effects of other processes on the polarization, e.g., multiple Coulomb scattering, are not taken into account yet. A semi-classical approach is followed, by assigning an average polarization to individual particles. The polarized cross sections of Olsen and Maximon [17] for pair production and bremsstrahlung and of Lipps and Tollhoek [18] for Compton scattering are utilized. Various simplifications have been made in the simulations; for example, a $1/\theta$ angular distribution of the outgoing particles is assumed for the bremsstrahlung and pair production cross sections by Olsen and Maximon, while EGS offers more accurate angular sampling at lower energies. Each approximation seems to be well justified in itself, but the complexity of an electromagnetic cascade makes the comparison with an experiment desirable, so that the decision whether a Linear Collider should be build with or without a polarized positron source can be based on solid grounds.\footnote{Improvements of the polarized Monte-Carlo codes are ongoing, in parallel to the preparation of the experiment, in cooperation with colleagues from Byelorussia.}

The achievable precision of the proposed transmission polarimetry of 5-10\% is sufficient for this purpose, since the predicted polarization for the Linear Collider source has in any case an uncertainty of the same order due to as-yet-unknown running conditions, etc. The precision of the polarization measurement achievable in E-166 will however not be sufficient for a very detailed comparison with the simulation.
3 The Proposed Experiment in the Final Focus Test Beam

3.1 Overview

The goal of the experiment is

1. To measure the yield and polarization of the photons produced by passing an electron beam through a helical undulator.

2. To measure the yield and polarization positrons produced by conversion of undulator photons in a thin target.

3. To compare the results to simulations.

A schematic layout of the experiment is shown in Fig. 7 with emphasis on the particle beams, while Fig. 8 shows the layout of the detectors to measure the flux and polarization of the photons and positrons.

Figure 7: Conceptual layout (not to scale) of the experiment to demonstrate the production of polarized positrons in the SLAC FFTB. 50-GeV electrons enter from the left and are dumped using $D_1$ after traversing the undulator. The positron conversion target as well as the positron and photon diagnostics are located 35 m downstream of the undulator. BPM$_i$ = beam position monitor; HSB$_i$ = hard" soft bend; OTR = optical transition radiation beam profile monitor; Toro = beam current toroid; WS = wire scanner; $A_i$ = aperture limiting collimators; Hcor = horizontal steering magnet; $D_1$ = FFTB primary beam dump bend magnet string; PR$_d$ = dump line beam profile monitor; $PR_t$ = $e^+$ target beam profile monitor; $D_2$ = analyzing magnet.

The experiment uses a low-emittance, 50-GeV electron beam (sec. 3.n) in the SLAC Final Focus Test Beam (FFTB) plus a 1-meter-long, short-period ($\lambda_u = 2.4$-mm, $K = 0.17$), pulsed helical undulator (sec. 3.m), to produce circularly polarized photons of energies up to 10 MeV. These polarized photons are then converted to polarized positrons through pair production in a Ti target which has a nominal thickness of 0.4 rad. len. The polarization
of the photons and positrons are measured by the Compton transmission method using a magnetized iron block [19].

This experiment is a demonstration of undulator-based production of polarized positrons for Linear Colliders at a scale of 1% in length and intensity:

- Photons are produced in the same energy range and polarization characteristics as for a Linear Collider;
- The same target thickness and material are used as in the Linear Collider;
- The polarization of the produced positrons is expected to be in the same range as in a Linear Collider.
- The simulation tools being used to model the experiment are the same as those being used to design the polarized positron system for a Linear Collider: EGS4 and GEANT, both modified to include spin effects for polarized $e^+$ production, and BEAMPATH for collection and transport.

This experiment will provide confidence that a polarized positron source for the next generation of Linear Colliders is based on solid, demonstrated principles all working together at the same time. This experiment, however, will not address detailed systems issues related to polarized positron production for a Collider, such as capture efficiency, target thermal
hydrodynamics, radiation damage in the target, or an undulator prototype suitable for use at a linear collider.

3.1.1 Undulator Design Principles

3.1.2 Overview of the Beam Parameters

3.1.3 Comparison with Positron Sources for Linear Colliders

Table 4 shows a comparison between parameters of the TESLA positron source system [20], the NLC undulator-based positron source option [21], and those of the proposed experiment. The TESLA baseline design uses a planar undulator for unpolarized positron production; the NLC design and FFTB experiment use helical undulators. As seen in Table 4, the characteristic photon energy, $E_{c10}$, for E-166 is very similar to that of both TESLA and NLC. Thus, the positron yield and polarization are also similar to what is expected in the Linear Collider designs. This is accomplished with the use of a much lower energy electron beam by decreasing the undulator period appropriately.

3.2 The Beamline

3.2.1 Layout

Figure 7 shows the layout of the proposed experiment in the SLAC FFTB. 50-GeV, low emittance electrons are sent through a helical undulator to produce circularly polarized photons. After the undulator, the 50-GeV electrons are bent vertically downward and sent to the FFTB dump. The photons drift in the zero-degree line for a distance of about 35 m where they are either analyzed or converted to positrons in a thin target.

3.2.2 Beam Parameters

Radiation shielding considerations limit the maximum beam power in the FFTB enclosure to less than 2.5 kW. For 50-GeV, 30-Hz operation this corresponds to a beam current of 1 $\times 10^{10}$ e$^+$/pulse. The emittances of the electron beam for fully coupled damping ring operation, and low beam charge, are expected to be about $\sigma_x = \sigma_y = 3:0 \times 10^{-5}$ m-rad or less. For a of 5.2 m, the corresponding beam size is about 4.0 m (rms); the angular divergence of the electron beam at the undulator is smaller than the characteristic angular spread $1/\sigma$ of the undulator radiation (see Table 5).

Table 6 lists the E166 beam request. E166 requires a nominal single bunch beam of 50 GeV at 30 Hz with a charge of 1 $\times 10^{10}$ electrons per bunch, transverse rms emittance in the range of 2 $\times 10^{-5}$ m-radians, and an rms energy spread of 0.3%. It is expected that the beam rate will drop to 1 Hz during PEP II fills, which are expected to take approximately 10% of the scheduled running time.

Table 7 summarizes the E166 beam requirements and calculated photon energy (first harmonic cutoff), angular divergence, and spot size at the converter target for the extremes of the electron emittance range at beam energies of 50 GeV and 47.5 GeV.
Table 4: Parameters of polarized positrons beams at TESLA, NLC and the FFTB.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>TESLA</th>
<th>NLC</th>
<th>FFTB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam energy $E_e$</td>
<td>GeV</td>
<td>150-250</td>
<td>150</td>
<td>50</td>
</tr>
<tr>
<td>$N_e$ (e) / bunch</td>
<td>${ }$</td>
<td>$3 \times 10^{10}$</td>
<td>$8 \times 10^9$</td>
<td>$1 \times 10^{10}$</td>
</tr>
<tr>
<td>$N_{\text{bunch}}$ / pulse</td>
<td>${ }$</td>
<td>2820</td>
<td>190</td>
<td>1</td>
</tr>
<tr>
<td>Pulses/ s</td>
<td>Hz</td>
<td>5</td>
<td>120</td>
<td>30</td>
</tr>
<tr>
<td>Undulator type</td>
<td></td>
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<td>helical</td>
<td>helical</td>
</tr>
<tr>
<td>Undulator strength $K$</td>
<td></td>
<td>1</td>
<td>1</td>
<td>0.17</td>
</tr>
<tr>
<td>Undulator period $\lambda_u$</td>
<td>cm</td>
<td>1.4</td>
<td>1.0</td>
<td>0.24</td>
</tr>
<tr>
<td>$1^{\text{st}}$ Harmonic cut$@$, $E_{c10}$</td>
<td>Mev</td>
<td>9-25</td>
<td>11</td>
<td>9.6</td>
</tr>
<tr>
<td>$dN^+$/$dL$</td>
<td>photons/m/e$^+$</td>
<td>1</td>
<td>2.6</td>
<td>0.37</td>
</tr>
<tr>
<td>Undulator length $L$</td>
<td>m</td>
<td>135</td>
<td>132$^*$</td>
<td>1</td>
</tr>
<tr>
<td>Target material</td>
<td></td>
<td>Ti-alloy</td>
<td>Ti-alloy</td>
<td>Ti-alloy</td>
</tr>
<tr>
<td>Target thickness</td>
<td>rad. len.</td>
<td>0.4</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Yield $e^+$=photon (%)</td>
<td></td>
<td>1-5</td>
<td>1:8$^z$</td>
<td>0.5</td>
</tr>
<tr>
<td>Capture efficiency $%$</td>
<td></td>
<td>25</td>
<td>20</td>
<td>{</td>
</tr>
<tr>
<td>$N^+$/ pulse</td>
<td>${ }$</td>
<td>$8.5 \times 10^{12}$</td>
<td>$1.5 \times 10^{12}$</td>
<td>$2 \times 10^7$</td>
</tr>
<tr>
<td>$N^+$/ bunch</td>
<td>${ }$</td>
<td>$3 \times 10^{10}$</td>
<td>$8 \times 10^9$</td>
<td>$2 \times 10^7$</td>
</tr>
<tr>
<td>Polarization $P^+$</td>
<td>$%$</td>
<td>${ }$</td>
<td>40-70</td>
<td>40-70</td>
</tr>
</tbody>
</table>

A length of 132 m is required for a unity gain $e^-!e^+$ system. A 200 m undulator length of 200 m is under consideration in order to provide 50% overhead in positron production.

Including the effect of photon collimation at $\mu_{\text{cut}} = 1.414$.

The requested beam energy of 50 GeV is necessary to produce the highest possible photon energy. Recent experience with E158 shows that a nominal energy of 50 GeV at the end of the linac is possible at the requested bunch charge of $1 \times 10^{10}$ electrons per bunch with 16 spare klystrons (maximum linac energy of 54 GeV at $1 \times 10^{10}$ electrons per bunch and $\frac{1}{2} = 500$ m). This number of spare klystrons is sufficient for continuous E166 operation with negligible interruption from beam energy issues.
Table 5: FFTB beam parameters.

<table>
<thead>
<tr>
<th>$E_e$</th>
<th>$N_e$</th>
<th>$\sigma_x^2 = \sigma_y^2$</th>
<th>$\varepsilon_x = \varepsilon_y$</th>
<th>$\frac{\sigma_x}{\sigma_y} = \frac{\sigma_y}{\sigma_x}$</th>
<th>$\frac{\sqrt{x^2}}{\sqrt{y^2}} = \frac{\sqrt{x^2}}{\sqrt{y^2}}$</th>
<th>$D$</th>
<th>$(\frac{\sqrt{x^2}}{\sqrt{y^2}} + \frac{\sqrt{y^2}}{\sqrt{x^2}})^{1/2}$</th>
<th>$1$ = $\phi$</th>
</tr>
</thead>
<tbody>
<tr>
<td>GeV</td>
<td>$e^i$</td>
<td>m-rad</td>
<td>m</td>
<td>$1$ m</td>
<td>$1$ rad</td>
<td>m</td>
<td>$1$ rad</td>
<td>$1$ rad</td>
</tr>
<tr>
<td>50</td>
<td>$1 \times 10^{10}$</td>
<td>$3 \times 10^{5}$</td>
<td>5.2, 5.2</td>
<td>40</td>
<td>7.7</td>
<td>35</td>
<td>7.8</td>
<td>10</td>
</tr>
</tbody>
</table>

Table 6: E166 beam parameter request.

<table>
<thead>
<tr>
<th>$E_e$</th>
<th>$f_{\text{rep}}$</th>
<th>$N_e$</th>
<th>$\sigma_x^2 = \sigma_y^2$</th>
<th>$\varepsilon_x; \varepsilon_y$</th>
<th>$\frac{\sigma_x}{\sigma_y}; \frac{\sigma_y}{\sigma_x}$</th>
<th>$\frac{1}{\sqrt{E}} = \phi$</th>
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<tr>
<td>GeV</td>
<td>Hz</td>
<td>$e^i$</td>
<td>m-rad</td>
<td>m</td>
<td>$1$ m</td>
<td>%</td>
</tr>
<tr>
<td>50</td>
<td>30</td>
<td>$1 \times 10^{10}$</td>
<td>$3 \times 10^{5}$</td>
<td>5.2, 5.2</td>
<td>40</td>
<td>0.3</td>
</tr>
</tbody>
</table>

The requested 30-Hz rate and charge of $1 \times 10^{10}$ electrons per bunch matches the FFTB radiation shielding design limit at 50 GeV. Neither the rate nor the charge per bunch goals are not expected to be difficult to achieve. Additional electrical power costs for 30 Hz vs. a lower repetition rate are offset by the water-heater loads required to set the accelerator structure operating temperature. A 1-Hz keep alive rate during PEP II fills is important for maintaining the beam trajectory and quality to ensure rapid resumption of E166 upon completion of ring fills.

A limiting constraint for E166 is the 0.885 mm I.D. aperture of the undulator. To prevent background generation due to beam interception, a beam size of $40 \times 10^{-3}$ m rms has been adopted. This gives an undulator radius-to-beam size ratio of 11 $\frac{3}{4}$. To achieve this beam size at 50 GeV, the $\varepsilon$ function at IP1 must be set to the range of 7.8 m to 3.9 m for $\sigma_z^2 = 2 \times 10^{-5}$ m-rad. The computer code DIMAD has been run to find magnet values for the function at IP1 of 10 m and 2.5 m. The required magnet strengths are well within the magnet fabrication specifications and power supply operating ranges. Emittance at the lower end of the request, $\sigma_z^2 = 2 \times 10^{-5}$ m-rad, is preferred for ease of attaining the 40 m rms beam size through the undulator. A nominal value of $\sigma_z^2 = 3 \times 10^{-5}$ m-rad is listed in Table 6.

An rms energy spread of $\frac{1}{\sqrt{E}} = \phi$ = 0.3% is a factor of 1.5-2 times larger than expected for the nominal bunch current with an rms bunch length of $\frac{1}{\sqrt{z}} = 500 \times 10^{-3}$ m. This requirement on the energy spread is to limit the possibility of background generation in the FFTB due to beam loss in regions of large dispersion. Little is known about the exact details of backgrounds due to transmission of large energy spreads through the FFTB, but it is prudent to keep the energy spread $\frac{1}{\sqrt{E}} = \phi$ to as low a value as reasonable. Since the dispersion through the IP1 area is negligible, energy spread is not a concern in regards to the beam focusing nor potential background generation in the vicinity of the undulator.

E164 was run in March, 2003 with a nominal beam current of $1 \times 10^{10}$ electrons per...
Table 7: FFTB beam parameters for an undulator strength parameter of $K = 0.17$ and distance from undulator to positron production target of $D = 35$ m.

$1^\omega = 1^\varphi_\omega = 1^\varphi_\omega = \frac{2}{\sqrt{3}} D^2 + \frac{2}{\sqrt{3}} \varphi_\omega$ and $\varphi_\omega = D^2$.

<table>
<thead>
<tr>
<th>$E_{e}$ (GeV)</th>
<th>$E_{e_{10}}$ (MeV)</th>
<th>$\varphi_\omega$ (m-rad)</th>
<th>$\varphi_\omega$ (m)</th>
<th>$\varphi_{\omega_{0}}$ (m)</th>
<th>$\varphi_{\omega_{0}}$ (m)</th>
<th>$1^\varphi_\omega$</th>
<th>$1^\varphi_{e_\omega}$</th>
<th>$\varphi_{\omega}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>9.62</td>
<td>2 $\times 10^5$</td>
<td>7.8; 7.8</td>
<td>40; 5.1</td>
<td>10.2; 11.5</td>
<td>402</td>
<td></td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>9.62</td>
<td>4 $\times 10^5$</td>
<td>3.9; 3.9</td>
<td>40; 10.2</td>
<td>10.2; 14.5</td>
<td>507</td>
<td></td>
<td></td>
</tr>
<tr>
<td>47.5</td>
<td>8.68</td>
<td>2 $\times 10^5$</td>
<td>7.4; 7.4</td>
<td>40; 5.4</td>
<td>10.8; 12.1</td>
<td>423</td>
<td></td>
<td></td>
</tr>
<tr>
<td>47.5</td>
<td>8.68</td>
<td>4 $\times 10^5$</td>
<td>3.7; 3.7</td>
<td>40; 10.8</td>
<td>10.8; 15.3</td>
<td>534</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

bunch and measured emittances of $\varphi_\omega = 3 \times 6 \times 10^5$ m-rad and $\varphi_\omega = 0.4 \times 10^5$ m-rad. Coupling in the damping ring would bring these emittances to $\varphi_\omega = 2 \times 10^5$ m-rad. The energy spread of the E164 beam was about 0.6% due to the 100 m rms bunch length. A more typical bunch length of 500 m rms would have an rms energy spread of less than 0.2%. The longer bunch length does result in increased transverse wake fields, which are not expected to be problematic at the requested beam current of $1 \times 10^{10}$ electrons per bunch.

Multiple access to the FFTB housing will be required after the beam has been turned on. These entries are to install the undulator after initial beam setup and for detector background shielding adjustments. During access, the 50-GeV beam is put onto the tune up dump in the beam switchyard. Additionally, all power supplies and magnets remain energized during an FFTB entry. These two features, along with existing FFTB beam steering feedback systems, ensure rapid beam recovery after an access.

In summary, the requested beam and optics requirements are within the design specifications of the linac and FFTB. Furthermore, these criteria are less stringent than recent (March, 2003) operating experience.

3.2.3 Synchrotron Radiation Background

To avoid noise in the detectors from synchrotron radiation by electrons in upstream beam transport magnets and in the dump line magnets, a pair of soft bends is included in the electron beamline just before and after the undulator (see Fig. 7). These bends have the same polarity and give a vertical downward kick to the electron beam. This is similar to the geometry that was used successfully in the E144 experiment [22], albeit only one set of "hard" soft bends are used for E166 whereas E144 used both "hard" soft bends and "soft" soft bends. Table 10 lists expected photon parameters from the undulator and bend magnets in the immediate vicinity of the experiment. The expected flux from the undulator is significantly higher in photon energy and number. In Table 10, $\hbar/c$ is the critical energy of the synchrotron radiation emitted by the bends; $\xi L_{(3\varphi_{\omega})}$ is the length of bend required to produce a $3^\omega$ angular deflection in the beam; and the $\xi N_\omega$ and $\xi P_B$ are the radiated...
ux and power from the bends for the $L(3\pi)$ length segment of bend.

3.2.4 Collimators

Fig. 7 shows two aperture-limiting collimators for the experiment, $A_u$ that protects the undulator from possible mis-steering of the primary electron beam, and $A_t$ that defines the photon beam used to create the polarized positrons. These devices are 30-cm-long ($\approx 20$ rad. len.) cylinders of copper with a 0.85-mm ID through hole for electron beam transmission in $A_u$, while collimator $A_t$ has a 3-mm ID aperture for photon beam transmission.

Collimator $A_u$ is water cooled because of the possibility of primary beam interception; collimator $A_t$ does not require water cooling.

$A_u$ is required to protect the undulator assembly from being hit head-on by the primary electron beam. With $A_u$, failure of the soft bends could result in a glancing incidence of the electron beam on the undulator. Preliminary calculations indicate that such interception would not damage the undulator in a single shot; protection ion chambers located at the undulator will cause the beam to be turned off after detection of a single shot fault.

Collimator $A_t$ is located just upstream of the undulator-photon conversion target, and serves to limit extraneous halo (both photons and charged particles) from entering into the detector region of the experiment.

3.2.5 Alignment

Absolute component alignment tolerances of 100 $\mu$m (rms) in the transverse dimensions for the beam-line devices are required for the experiment. Collimator $A_u$ is rigidly mounted with the undulator to prevent a relative misalignment between the collimator and undulator. With the exception of the photon collimator, $A_t$, none of the devices requires remote mover capability.

Because of the long lever arm ($\approx 35$ m) from the end of the undulator to the measurement area, remote movers for $A_t$ are incorporated into the design. The 100-$\mu$m tolerance does, however, require consideration in the design of various supports and has been taken into account. As expected, the tolerances along the beam line are very loose and are essentially set by what is required to match up and seal the vacuum chambers.

3.2.6 Instrumentation

A variety of beam-line instrumentation is shown in the layout (Fig. 7). In addition to their role during beam set up, the profile monitors will be used to monitor the beam quality over the duration of the experiment.

Three beam-position monitors (BPMs) will be used in the automated beam-steering feedback to keep the beam away from the undulator and directed onto the dump.

A beam-current toroid (Toro) is used to measure the electron current on a pulse-to-pulse basis with an absolute accuracy of a few percent and a relative accuracy of a few tenths of a percent.

Four transverse beam-profile monitors (OTR, WS, $PR_d$, and $PR_t$) are shown. The OTR and WS are used in the initial optical set up of the beam line to adjust to the requisite beam size through the undulator. Monitor $PR_t$ has been included in front of collimator
A target for observation of the photon beam. PR is a fixed position dump line screen used for observing the electron beam as it enters the dump. The profile monitors OTR and PR are invasive monitors. Wire scanner WS provides non-invasive beam-size monitoring; however, backgrounds in the detector are likely to increase when WS is scanned through the beam.

So-called LIONS (long ion chambers) are located along the beam line wall and are used to detect secondaries caused by possible beam interception. A discrete protection ion chamber will be installed next to the undulator to detect beam loss in the undulator.

The precision and accuracy of the required instrumentation does not exceed the normal performance of the standard FFTB equipment. All of the beam-line hardware (power supplies and instrumentation) will be controlled and monitored through the existing SLAC accelerator control system.

### 3.3 Beam Line Equipment

Figures 7 and 8 show the layout of the E166 beam line in the vicinity of IP1, and 35 m downstream of IP1, respectively. The devices BPM1, HSB1, OTR, Toro, and PR are presently installed at the desired E166 locations, while WS, BPM2, Au, the undulator, and HSB2 will require new installation (including cabling). Monitor BPM3 is presently installed but will be moved up stream by about 0.3 m; the existing cable for BPM3 will reach to the new position. The dump magnet string D1 presently consists of 6 permanent magnet dipoles, of which two are presently degaussed. For 50-GeV operation, a seventh permanent dipole magnet will be added at the downstream end of the D1 string, and all seven magnets re-energized. A power supply and cabling for this is already installed in the FFTB.

The magnet HSB2 is an existing device, but not presently installed in the FFTB; cables need to be pulled and a power supply will be borrowed from the SLC or SLAC? NFFS what is NFFS?. Monitor BPM2 and associated electronics modules will be borrowed from the SLAC NFFS and replaced upon completion of E166. A set of BPM cables will be pulled. Rack space and empty camac slots are available in the Bldg. 407 for the needed additional power-supply and control modules.

The SPPS diffraction grating chamber and associated vacuum windows (not shown) are presently located about 20 m downstream of the dump magnet string D1, and will be removed and replaced with a vacuum spool piece.

Profile monitor PR, collimator Au, and the Target are new installations. PR will be borrowed from the SLAC NFFS and replaced upon completion of E166. The target actuator is a simple in/out device. New cabling is required for these devices.

Need some text about the spectrometer and polarimeter...

Table 8 gives a status summary of the E166 beam line equipment.

### 3.4 The Undulator

The undulator shown in Fig. 7 is 1-m-long [23]. It consists of a copper wire bilar helix, wound on a 1.068-mm-OD, stainless-steel support tube; the ID of the tube is 0.889 mm. The undulator ID is thus 11 times the rms beam size of 40 μm (see Section 3.2.2). The period of the undulator is 2.4 mm. A 0.6-mm-diameter wire has been chosen. Fig. 9 shows a 23-cm-long prototype model built to test the winding procedure, support constraints, and
voltage handling capability of the device [?]. As shown in the figure, three G10 rods and rings hold the helical coil in place.

Figure 9: One end of a 23-cm-long prototype of the helical undulator [?].

The on-axis field in the undulator is 0.76 T for 2300-A excitation, resulting in an undulator parameter of $K = 0.17$ (see Eq. 7. The presence of the stainless-steel support tube reduces the field by < 3%. Modeling of the undulator has been done using MERMAID [24].

For a 30-$s$-long current pulse, the temperature rise is about 3$^\circ$C/pulse and the average power dissipation for 30-Hz operation is about 260 W. The undulator is immersed in an oil bath for cooling. A water cooled heat exchanger loop is required to remove the heat from the oil.

Table 9 lists various undulator system parameters. Fig. 10 shows a schematic of the undulator configuration and the associated pulse-forming network. Fig. 11 shows the undulator vacuum vessel with the power supply connections entering at the center of the envelope.

Figure 10: Schematic representation of the undulator with pulsing circuit. From [23].
Figure 11: The 1-m-long helical undulator is mounted in a 1.13-m-long vacuum vessel; the power supply feed-through is located at the middle of the vessel. From [23].

3.5 Photon Spectrum and Rates

For small values of $K$, the number of photons $dN/\text{d}L$ emitted per meter from the helical undulator is

$$\frac{dN}{dL} = \frac{4\sqrt{\pi} \cdot \beta}{3} \frac{K^2}{u[\text{mm}]1 + K^2} \text{ photons=m=e}^i; \quad (6)$$

where $\beta$ is the fine structure constant, $u$ is the undulator period and $K$ is the dimensionless undulator-strength parameter defined by,

$$K = \frac{2\sqrt{\pi}eB_0 \cdot u}{mc^2} = 0.9344B_0[\text{T}, u[\text{cm}]; \quad (7)$$

The average energy of the undulator photons is one half the cut-off energy $E_{c10}$ of the first-harmonic radiation, whose value for small values of $K$ is

$$E_{c10} = 2E_{\text{avg}} = 9.5 \times 10^3 \frac{E_e^2[\text{GeV}]}{u[\text{mm}](1 + K^2)} \text{ MeV}; \quad (8)$$

where $E_e$ is the electron beam energy.

The radiated power $dP/\text{d}L$ per meter of undulator is

$$\frac{dP}{\text{d}L} = q\zeta E_n = 2.32 \times 10^4 \frac{E_e^2[\text{GeV}]K^2}{u[\text{mm}]} \cdot n_e[\text{e} \times 10^{10}]f_{\text{rep}}[\text{Hz}] \text{ W=m}; \quad (9)$$

in which $n_e$ is the number of electrons per pulse and $f_{\text{rep}}$ is the pulse repetition rate.

The conversion yield of photons to positrons by a thin target is calculated using the EGS4 code [14], modified to allow introduction of arbitrary photon spectra and polarization as data inputs. In addition, the modified version allows the user to input a gaussian transverse beam of arbitrary size. In the case of 0.5 rad. len. of Ti, the outgoing beam size is dominated by multiple scattering of the positrons in the target, rather than by size of the undulator photon beam (about 450 $^\circ$ m (rms) for the parameters listed in Table 5).

The expected photon flux and power are listed in Table 10 for an undulator length of $L_u = 1 \text{ m}$.

For the parameters of E-166, Fig. ??a on p. ?? shows the expected photon number spectrum and Fig. ??b on p. ?? shows the corresponding circular polarization spectrum.
The low $K$ value limits the flux to essentially only the first harmonic. To produce the curves in Fig. ??a and ??b, the undulator radiation has been integrated over all emission angles up to $\theta = 2$. Since the characteristic opening angle of the radiation is $1 = \frac{1}{4} \times 10^1 \text{ rad}$, the finite aperture of the undulator does not affect the calculation.

On p. ??, Fig. ??a and ??b show the spectrum and polarization of positrons as a function of energy, produced in 0.5 rad. len. of Ti by the photons of Fig. ??a and ??b. The EGS4 code was used to simulate the positron production shown in Fig. ??.
<table>
<thead>
<tr>
<th>Device</th>
<th>Description</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>BPM$_1$</td>
<td>FFTB BPM</td>
<td>Installed</td>
</tr>
<tr>
<td>HSB$_1$</td>
<td>FFTB B04A</td>
<td>Installed</td>
</tr>
<tr>
<td>OTR</td>
<td>FFTB OTR beam profile monitor</td>
<td>Installed</td>
</tr>
<tr>
<td>Toro</td>
<td>FFTB Beam Toroid Current Monitor</td>
<td>Installed</td>
</tr>
<tr>
<td>BPM$_2$</td>
<td>SLC FFS BPM</td>
<td>Relocate from SLAC NFFSy</td>
</tr>
<tr>
<td>WS</td>
<td>FFTB Wire Scanner beam profile monitor</td>
<td>Needs Installation</td>
</tr>
<tr>
<td>A$_u$</td>
<td>Undulator protection collimator</td>
<td>Newy</td>
</tr>
<tr>
<td>Undulator</td>
<td>1-m helical undulator</td>
<td>Newy</td>
</tr>
<tr>
<td>BPM$_3$</td>
<td>FFTB BPM</td>
<td>Installed, needs repositioning</td>
</tr>
<tr>
<td>Hcor</td>
<td>FFTB horizontal corrector</td>
<td>Installed, needs repositioning</td>
</tr>
<tr>
<td>HSB$_2$</td>
<td>FFTB B04B</td>
<td>Exists, needs reinstallation</td>
</tr>
<tr>
<td>D$_1$</td>
<td>FFTB Dump magnet string</td>
<td>Needs augmentation</td>
</tr>
<tr>
<td>PR$_d$</td>
<td>FFTB Dump Screen</td>
<td>Installed</td>
</tr>
<tr>
<td>PR$_t$</td>
<td>E166 target screen</td>
<td>Relocate from SLC NFFSy</td>
</tr>
<tr>
<td>A$_t$</td>
<td>E166 target collimator</td>
<td>Newy</td>
</tr>
<tr>
<td>Target</td>
<td>Target actuator</td>
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<tr>
<td>D$_2$</td>
<td>E166 $e^+$ spectrometer</td>
<td>Newy</td>
</tr>
<tr>
<td>$^\circ$ Diag</td>
<td>E166 photon diagnostics</td>
<td>Newy</td>
</tr>
<tr>
<td>$e^+$ Diag</td>
<td>E166 positron diagnostics</td>
<td>Newy</td>
</tr>
<tr>
<td>e$^-$ Dump</td>
<td>E166 electron dump</td>
<td>Newy</td>
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</tbody>
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*Requires cabling*
Table 9: Parameters of the helical undulator system.

<table>
<thead>
<tr>
<th>Parameter</th>
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<th>Value</th>
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</thead>
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</tr>
<tr>
<td>Length</td>
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<td>K Undulator Parameter</td>
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<td>Current</td>
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<td>Peak Voltage</td>
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<tr>
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<td>260</td>
</tr>
<tr>
<td>(\Delta T / \text{pulse})</td>
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<td>2.7</td>
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Table 10: Photon flux from the helical undulator.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
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<th>D1 Bend</th>
<th>HS Bend</th>
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</thead>
<tbody>
<tr>
<td>(E_e)</td>
<td>GeV</td>
<td>50</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>(n_e)</td>
<td>(\text{e}^{10})</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>(f_{\text{rep}})</td>
<td>Hz</td>
<td>30</td>
<td>3dc</td>
<td>dc</td>
</tr>
<tr>
<td>(P_e)</td>
<td>kW</td>
<td>2.4</td>
<td>2.4</td>
<td>2.4</td>
</tr>
<tr>
<td>(B_0)</td>
<td>kG</td>
<td>7.58</td>
<td>4.45</td>
<td>0.660</td>
</tr>
<tr>
<td>(K)</td>
<td></td>
<td>0.17</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>(dN = dL)</td>
<td>photons/m/ei</td>
<td>0.37</td>
<td>2.75</td>
<td>0.41</td>
</tr>
<tr>
<td>(E_{c10})</td>
<td>MeV</td>
<td>9.62</td>
<td>(0.739)</td>
<td>(0.110)</td>
</tr>
<tr>
<td>(E_{\text{avg}})</td>
<td>MeV</td>
<td>4.81</td>
<td>0.228</td>
<td>0.034</td>
</tr>
<tr>
<td>(dP_{u:B} = dL)</td>
<td>mW/m</td>
<td>87</td>
<td>30</td>
<td>0.7</td>
</tr>
<tr>
<td>(L_u, \zeta L (3=\theta))</td>
<td>m</td>
<td>1</td>
<td>0.01</td>
<td>0.08</td>
</tr>
<tr>
<td>(\phi N)</td>
<td>photons/s</td>
<td>1:1 (\text{e}^{11})</td>
<td>9:5 (\text{e}^{9})</td>
<td>9:5 (\text{e}^{9})</td>
</tr>
<tr>
<td>(\phi P_u; \phi P_B)</td>
<td>mW</td>
<td>87</td>
<td>0.35</td>
<td>0.05</td>
</tr>
</tbody>
</table>
4  A Run Plan

4.1 Run Plan Summary

E166 requests 6 weeks of beam time in the SLAC FFTB for installation, checkout, set up, and operations. This request is based on the assumptions that the beam at the end of the linac meets the nominal beam quality requirements for the experiment and that a valid FFTB configuration exists for transport through the FFTB and onto the FFTB dump. These assumptions are reasonably met if E166 is scheduled during the operating cycle in which the FFTB has been used for other experiments. The assumptions are notably not valid immediately after a long accelerator shutdown and during the time that PEP II is initially being brought online.

This 6 week request is broken into a 3-week block for installation, checkout, setup, and initial operations followed by a 3-week block of data taking. The initial 3 week period is broken into: 1.5 weeks of installation and prebeam checkout; 0.5 weeks of checkout with beam; 0.5 weeks of beam tuning in the FFTB (primarily beam size tuning at the location of the undulator and upstream collimation for background reduction); and 0.5 weeks of initial data taking interspersed with tuning, background reduction, and detector shielding. The 3-week data run will be spent approximately: 1/3 on photon beam measurements and 2/3 on positron beam measurements.

Removal of the E166 equipment has not been included in this request. A period of 2-3 days is required to remove E166 equipment and to reinstall equipment removed for the E166 cycle. This removal/reinstallation period can coincide with the installation of the next experiment if the scheduled activity does not occupy the same locations as E166 apparatus.

Further details of the beam requirements, beam line equipment, installation and checkout, beam set up, the experimental measurements, as well as the script for the experiment are discussed in the following sections.

4.2 Installation and Check Out Requirements

Open access to the FFTB enclosure from the IP1 region to the downstream end of the housing is required for a period of 1.5 weeks for installation and prebeam check out. Another 0.5 week of checkout with beam is required prior to commencement of full operations for the experiment.

A block of 5 consecutive day shifts (Monday-Friday) are needed for installation and prebeam check out of beam line devices in the vicinity of IP1 and the primary beam dump line. This is standard beam line work including installation, alignment, cabling, and pump out to be performed by SLAC sta®. E166 physicists will work each swing shift to test the functionality of the installed devices from the computer control system through to the beam line hardware. Each new system will be tested and calibrated prior to staging for installation. Because of the 1-millimeter apertures of undulator and its protection collimator, care will be exercised to ensure that the alignment of these devices is done properly.

Downstream of the primary dump line, the SPPS di®action grating box will be replaced with a vacuum spool piece. This is a straightforward task.

A period of 1.5 weeks is required for installation and prebeam check out of the positron
target system, spectrometer and positron diagnostics as well as the photon diagnostics. This work will be done by SLAC sta® with E166 physicists working on swing shift to check the functionality of the installations.

Checkout with beam is required to ensure that all beamline devices are functioning as speci¯ed. This includes cross calibration of the diagnostic devices with beam in comparison to expected performance. A period of 0.5 weeks is allocated for this activity. Less time is required if the prebeam checkout has been done properly. For checkout, a 10 Hz electron beam in the FFTB dump is required; as discussed below, the E166 undulator will not be placed in the beam line for the initial checkout.

Several detectors need to be installed, cabled up, and commissioned during the 1.5 weeks of prebeam installation time. These are the devices and detectors associated with the photon and positron polarimetry shown in Table 11.

Table 11: Photon and positron polarimetry devices and detectors.

<table>
<thead>
<tr>
<th>Photon Polarimetry</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incident photon °ux monitor</td>
</tr>
<tr>
<td>Iron block w/ support and mover</td>
</tr>
<tr>
<td>Transmitted photon °ux monitor</td>
</tr>
<tr>
<td>Positron Target Mover</td>
</tr>
<tr>
<td>Positron Extraction Line Dipole Pair</td>
</tr>
<tr>
<td>Positron Polarimetry</td>
</tr>
<tr>
<td>Positron-to-Photon converter target</td>
</tr>
<tr>
<td>Converted photon °ux monitor</td>
</tr>
<tr>
<td>Iron block w/ support and mover</td>
</tr>
<tr>
<td>Transmitted photon °ux monitor</td>
</tr>
<tr>
<td>Positron Target Mover</td>
</tr>
</tbody>
</table>

Detectors also require: HV Power Supplies; Front-end read-out electronics (with LV power); and Cabling from FFTB housing to Data Acquisition electronics in neighboring building.

The detectors will be brought to SLAC, in assembled form, with the associated read-out electronics by the collaborators who produced them. Tables and similar structures to put these detectors on will most likely be procured at SLAC and built and possibly installed ahead of time.

The mechanical installation is expected to be rather uncontroversial; however the physical space available must be managed very carefully due to the limited space in the FFTB tunnel.
After the mechanical installation, and before turning on the beam, a mechanical survey of the beam line components and detectors may be useful; however this can be done any time after the mechanical installation, and before beam turn on, and concurrently with data-acquisition integration and tests (see below).

For the connection of the detectors with their power supplies, and the data-acquisition and control system, cables must be strung from Bldg. 407 into the FFTB; most of this may also be accomplished well before E166 beam time; otherwise it can be accomplished in less than a shift, concurrently with other mechanical installation.

After the installation and connection of the detectors, one needs about 3 shifts without beam for the integration of the detectors into the data-acquisition (DAQ) system, and at least one shift with beam for additional tests. This task is also simplified by the fact that the detectors are expected to be tested on a similar DAQ system beforehand (currently LabView).

Table 12 summarizes the installation and test plan for the detectors.

<table>
<thead>
<tr>
<th>Day</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Install supports</td>
</tr>
<tr>
<td>2-4</td>
<td>Install detectors, iron blocks, cables, alignment survey</td>
</tr>
<tr>
<td>4-5</td>
<td>Connect detectors to HV/LV and DAQ</td>
</tr>
<tr>
<td>5-8</td>
<td>Test electronic readouts, DAQ system</td>
</tr>
</tbody>
</table>

Note that some tests might be performed by physicists during the weekend preceding beam delivery.

The commissioning of the detectors is fairly straightforward, after they and their associated electronics have been cabled up, connected with the appropriate power supplies (HV/LV), and linked to the readout electronics and the data-acquisition system in Bldg. 407. High-voltage settings for PMT’s and depletion voltages for silicon detectors, e.g., have been determined beforehand.

The following paragraph is somewhat redundant with the above. The main problem then is the integration of the detectors into the DAQ system. This problem is alleviated by the fact that the detectors and read-out electronics will have been tested and readout before using the same system (LabView), even if elsewhere. The DAQ system, of course, will also have been programmed previously, with the appropriate hooks to link in the detectors. The detector integration will most likely take at least one shift before beam time, but can be performed concurrently with final installation.

A further 1-2 shifts is required for detector and DAQ commissioning with beam, for the final setting of trigger times, and possible last xes of DAQ software and recognition and repair of possibly dead channels.
4.3 Beam Setup

1. Starting with a low emittance beam at end of linac, raise the energy to 50 GeV; steer, tune, and save configurations.

2. Scale up last known good FFTB configuration to 50 GeV; start with last saved FFTB "gold" BPM orbit. With undulator removed, and a nominal 2-cm-I.D. beam pipe installed, steer beam to dump. We expect less than one shift will be need to re-establish beam from switchyard through to the FFTB dump at the new energy.

3. Spend 1 shift checking diagnostics with beam (we expect everything to work as per prebeam checkout.)

4. Tune up the nominal 40-¹ m rms spot size by loading in the DIMAD configuration and using OTR profile monitor and wire scanner. Once the beam has been focused onto the wire scanner, the beam waist can be shifted downstream by about 1 m to the center of the undulator using standard operating procedures. Estimated tuneup time after nominal beam is on dump: 2 calendar days.

5. Once tuned, save reference orbits for steering feedbacks, save gold orbit, magnet settings.

6. Shut off beam and install undulator: 1 shift.

7. Bring back beams at low rate until full transmission through the undulator is achieved.

8. Increase repetition rate to 10 Hz for diagnostics.

9. Run up undulator current (should have negligible effect on beam), and look for undulator photons at PR₁.

Linac tuning and raising of the beam energy can be done in parallel with the 1.5 weeks of installation. Klystron/SLED tuning is accomplished on standby and can be done prior to the first beam to E166. When the FFTB is in Controlled Access, the full energy linac beam is parked on 52SL1 and 52SL2 using dipole 50B1; screen PR55 allows observation of the energy-resolved beam.

In summary, prior to E166, modulators, klystrons, and SLED systems are tuned for a 50-GeV beam at 30 Hz. Low-emittance beam is established at 50 GeV during the 1.5-week installation period. Three days are required to bring the 50-GeV beam to FFTB dump, checkout diagnostics, and tune a small spot at IP1 with the undulator moved o the beamline. The undulator is moved onto the beamline on the fourth morning of beam operation and E166 is ready to begin measurements.

The first week of beam operations, including the initial three days of beam tuneup, will be spent making preliminary data runs, testing equipment, and repairing as necessary. The last 3 weeks are dedicated to data collection.
4.4 Experimental Measurements

NEEDS HELP!!!! And Definition!! The minimum E166 measurements are: photon flux and photon polarization at an undulator parameter of $K = 0.17$, and positron flux and polarization at an undulator parameter of $K = 0.17$ using a 0.5-rad. len.-thick Ti converter with the passband of the beam spectrometer set to $6:5 \pm 2$ MeV/$c$. Having achieved this, photon flux and polarization will be measured as a function of the undulator parameter $K$. Also, positron flux and polarization will be measured as a function of momentum for a 0.5 rad. len.-thick Ti converter at $K = 0.17$. Finally, the effect of target thickness will be measured at $K = 0.17$ and a positron momentum band of $6:5 \pm 2$ MeV/$c$ for Ti targets of 0.1 and 0.25 rad. len. and for W targets of 0.1, 0.25, and 0.5 rad. len.

It is estimated that approximately one-third of the time will be spent on photon beam measurements and two-thirds of the time will be spent on positron characterization. NEED SOME DISCUSSION REGARDING THE NATURE OF THE SYSTEMATICS: WHAT TO LOOK FOR, WHAT IS THE EFFECT, WHAT TO DO ABOUT IT.

4.5 Experiment Script

Developed from the foregoing: install, checkout, checkout w/ beam, tuneup beam, install undulator, tune up detectors, collect and analyze data, reduce backgrounds, iterate. Question: are we testing different materials, different thickness materials. I suggest we hold off until we get a valid data set for the first set of material.
5 References


[7] See also the links on http://www.ippp.dur.ac.uk/~gudrid/power/.


[24] MERMAID/3D, SIM Inc., Novosibirsk, P.O. Box 402, Russia.

32