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Polarized Positrons at a Future Linear Collider and the Final Focus Test Beam

Achim W. Weidemann
Department of Physics, University of South Carolina,
Columbia, SC 29208, USA

For the E-166 Collaboration *

Abstract

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Stanford Linear Accelerator Center, Stanford University, Stanford, CA 94309

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POLARIZED POSITRONS AT A FUTURE LINEAR COLLIDER AND THE FINAL FOCUS TEST BEAM

ACHIM W. WEIDEMANN [a]
Department of Physics, University of South Carolina, Columbia, SC 29208
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Having both the positron and electron beams polarized in a future linear e^+e^-collider is a decisive improvement for many physics studies at such a machine. The motivation for polarized positrons, and a demonstration experiment for the undulator-based production of polarized positrons are reviewed. This experiment ('E-166') uses the 50 GeV Final Focus Test electron beam at SLAC with a 1 m-long helical undulator to make $\approx 10 MeV$ polarized photons. These photons are then converted in a thin ($\approx$ 0.5 radiation length) target into positrons (and electrons) with about 50% polarization.

1 Introduction

Polarized positrons in e^+e^-collisions in addition to polarized electrons are a powerful tool for many physics studies, for which a few examples are given in Section 2 below. Schemes to provide polarized positrons have been proposed a long time ago[1], but were thought to be difficult to realize.

Polarized positrons can be produced by pair-production from circularly-polarized high-energy photons impinging on a target. The circularly-polarized photons could be made by Compton backscattering of a laser beam off a high-energy electron beam,[3] or by a helical undulator. The latter method is particularly attractive for the proposed TESLA collider, which already uses a positron source based on pair-production from a (planar) undulator in its design.[4] Section 3 presents a demonstration experiment[5] for this method, now under way at the Stanford Linear Accelerator Center.

[a] Address: SLAC, MS 67, 2575 Sand Hill Rd., Menlo Park, CA 94025; e-Mail: achim@SLAC.Stanford.EDU

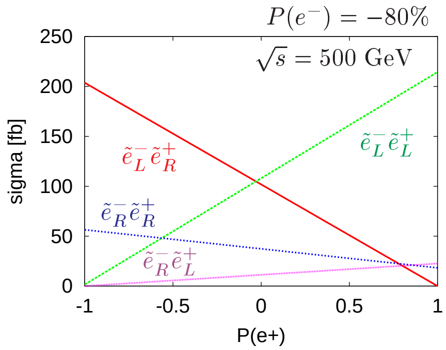

Figure 1: Selectron pair $\tilde{e}^-_L \tilde{e}^+_R$ production cross section as function of positron polarization.[2]

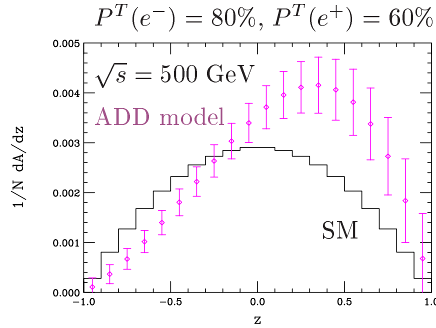

Figure 2: Differential azimuthal asymmetry distribution in the ADD model (asymmetry is signal for graviton spin-2 exchange.[9])

2 Physics Motivation

In the study of the left-right asymmetry of s-channel vector particle exchange the effective polarization is defined as $P_{\text{eff}} = (P_{e^-} - P_{e^+})/(1 - P_{e^-}P_{e^+})$. Increasing P_{eff} will decrease the error in the measurement of this asymmetry, which scales roughly with $1 - P_{\text{eff}}$, as well as that of the polarization itself. In a Linear Collider operating at energies around the Z^0 pole for precision tests of the Standard Model, positron polarization would allow a precise measurement of the polarization from the events themselves in the so-called extended Blondel scheme. An accuracy in the measurement of the electroweak mixing angle of $\delta(\sin^2\theta_{\text{eff}}) = 0.00001$ and of the W-mass of $\delta(M_W) = 6$ MeV seems possible.[11]

WW and ZZ production are the dominant background processes for many new physics searches. A suitable choice of the polarization of both e^+ and e^- beams can enhance or suppress these backgrounds. For example, a positron polarization of about $P_{e^+} = -60\%$ would double the suppression of the WW background compared to $P_{e^+} = 0\%$ (for $P_{e^-} = 80\%$ in both cases).

In Standard Model s-channel processes, due to its (V−A) couplings, only the (LR) and (RL) configurations of the initial $e^\pm$ contribute. The fraction of colliding particles is therefore $(1 - P_{e^-}P_{e^+})/2 \equiv \mathcal{L}_{\text{eff}}/\mathcal{L}$, which defines an effective luminosity $\mathcal{L}_{\text{eff}}$. If both beams are polarized,with e.g. $P_{e^+} = 60\%$, $P_{e^-} = -80\%$, this $\mathcal{L}_{\text{eff}}$ is 0.74 compared to 0.5 for $P_{e^+} = 0\%$ and any P_{e^-}.[2]

Supersymmetry (SUSY) is a leading candidate for new physics; polarized positrons help to prove the assumptions underlying this theory as model-independent as possible. For example, SUSY transformations associate chiral (anti)fermions to scalars $e^-_{L,R} \leftrightarrow \tilde{e}^-_{L,R}$ but $e^+_{L,R} \leftrightarrow \tilde{e}^+_{R,L}$. Both beams have to be polarized in order to prove these associations. [6] The process $e^+e^- \to \tilde{e}^+\tilde{e}^-$ occurs via γ and Z exchange in the s-channel and via neutralino $\tilde{\chi}^0_i$ 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 out this channel. Fig. 1 shows an example of this; here the selectron masses are assumed to be close together, $m_{\tilde{e}_L} = 200$ GeV, $m_{\tilde{e}_R} = 190$ GeV, so that $\tilde{e}_L$, $\tilde{e}_R$ decay via the same decay channels (other SUSY parameters are taken from the reference scenario SPS1a[7]). From Fig. 1, it is seen that both beams need to be polarized to separate the different $\tilde{e}^-_L\tilde{e}^+_R$, $\tilde{e}^-_L\tilde{e}^+_L$ combinations..

For many SUSY analyses other SUSY processes are the most important background. Positron polarization can again be used to suppress the undesired process, as illustrated for selectron production in [8].

While the examples above used longitudinally-polarized lepton beams, transversely polarized lepton beams may be obtained by a spin-rotator magnet near the interaction point. Only having both beams transversely polarized would allow the measurement of the azimuthal asymmetry for a study of the origins of electroweak symmetry breaking[10] and extra dimensions. Fig.2 shows an example of a signal of extra dimensions in the 'ADD' model.[9]

Table 1 TESLA, NLC, E-166 Parameters

Parameter	TESLA†	NLC‡	E-166
Beam Energy E_e[GeV]	150-250	150	50
N_e/bunch	3×10^{10}	8×10^9	1×10^{10}
N_{bunch}/pulse	2820	190	1
Pulses/s [Hz]	5	120	30
Undulator Type	planar	helical	helical
Undulator Parameter K	1	1	0.17
Undulator Period λ_u [cm]	1.4	1.0	0.24
Undulator Length L [m]	135	132	1
1^{st} Harmonic Cutoff, E_{c10} [MeV]	9-25	11	9.6
dN_γ/dL [γ/m/e^-]	1	2.6	0.37
Target Material	Ti-alloy	Ti-alloy	Ti-alloy,W
Target Thickness[Rad.Length]	0.4	0.5	0.5
Yield e^+/photon [%]	1-5	1.5	0.5
Positrons/bunch	3×10^{10}	8×10^9	2×10^7
Positron Polarization [%]	–	40-70	40-70

†: unpolarized TESLA positron source[4];
‡: proposed polarized positron source

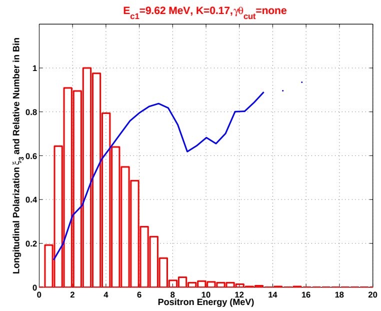

Figure 3: Longitudinal polarization (solid curve, averaged over 0.5MeV bins) and energy spectrum (histogram) of positrons emitted (Horizontal scale: positron energy, range: $0 - 20MeV$). The dip in the polarization at 9 MeV is due to the corresponding dip in photon polarization at about 10 MeV.

3 E-166

The experiment E-166 at the SLAC Final Focus Test Beam (FFTB) is designed to test undulator-based production of polarized positrons for a future high-energy linear collider.[5] In this experiment, the low-emittance 50 GeV FFTB electron beam will pass through the bore of a one-meter-long helical undulator to generate circularly-polarized photons of a few MeV, which are then converted in a thin target to generate longitudinally-polarized positrons by pair-production. The positrons are then selected by a magnetic spectrometer, and their polarization measured.Many parameters of this experiment are similar to those actually required at a future linear collider, except for undulator length, electron beam energy E_e, and the number of positrons produced per pulse, as shown in Table 1.

The undulator consists of a 0.6-mm diameter copper wire bifilar helix wound on a stainless steel support tube with inner diameter 0.89 mm, undulator parameter $K = 0.09B_0[T]\lambda_U[mm] = 0.17$ and period $\lambda_U = 2.4mm$; these parameters were chosen to obtain a sufficient photon intensity, namely $dN_\gamma/dL = (30.6/\lambda_u[\mathrm{mm}])(K^2/(1+K^2) = 0.37\mathrm{photons/m}/e^-$. The photons range in energy up to about $E_{c10} \approx 24[\mathrm{MeV}](E_e/50[\mathrm{GeV}])^2/(\lambda_u[\mathrm{mm}](1+K^2)) = 9.6$ MeV, the maximum energy of first harmonic radiation.

When a circularly polarized photon creates an electron-positron pair in a thin target, the photon polarization is transferred to the outgoing leptons.Positrons with an energy close to the energy of the incoming photons are 100% longitudinally polarized, while those with a lower energy have a lower longitudinal polarization. Figure 3 gives the longitudinal polarization (solid curve) and energy spectrum (histogram) of positrons emitted from a 0.5-radiation-length-thick Titanium target irradiated with photons of the energy and polarization spectra for the chosen undulator design. The polarization of the total sample is about 53% and the conversion efficiency from γ-rays to positrons about 0.5%. The measurement of the circular polarization of high-energy photons is based on the spin dependence of Compton scattering off atomic electrons. Here the transmission of photons through a thick magnetized iron cylinder is used.(Scattering removes photons from the flux.) The transmission probability has a polarization-dependent term; the asymmetry (1-6%) of the transmitted photon flux for two iron magnetization directions is then directly proportional to the photon polarization. The photon polarimeter, includes an aerogel Cerenkov detector before and after the magnetized iron absorber, and a total-absorption Silicon-Tungsten (SiW) sampling calorimeter. The areogel detectors are only sensitive to photons with an energy above ≈ 5 MeV; therefore, they give a photon number asymmetry independent of lower-energy photon backgrounds, while the SiW calorimeter records the energy-integrated

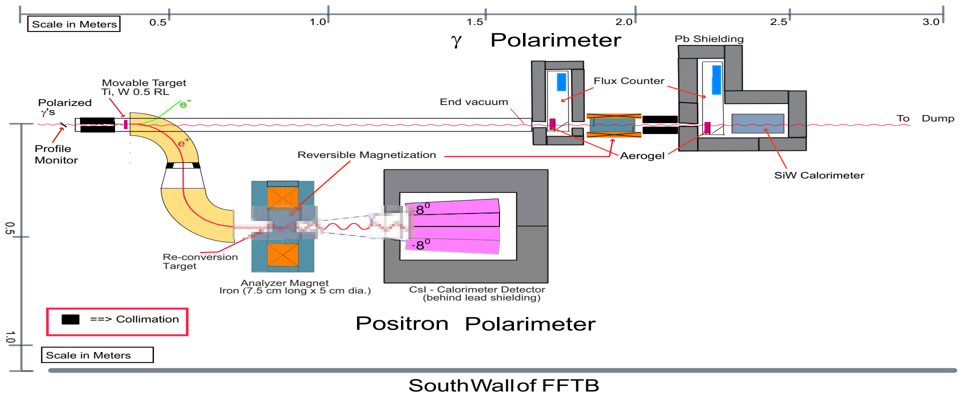

Figure 4: Conceptual layout of the E–166 positron generation and photon and positron diagnostic systems. Photon beam enters from top left; if no target is inserted, it continues to the photon polarimeter (upper right of Figure); if the target is inserted, the produced positrons are transported (downward in Fig.) to the positron polarimeter.

photon spectrum and energy-weighted asymmetry. When the positron production target is inserted into the undulator photon beam line, the produced positrons are collected and displaced from the photon beam by a positron transport line, with an efficiency of about 2%.

The polarization of these positrons is then measured by a two-step process; first, they are reconverted by a 0.175cm-thick Tungsten target into polarized photons, and then the polarization of these photons is measured, again by transmission polarimetry through a magnetized iron cylinder, as discussed above. The emerging photons, with a typical energy of about 1 MeV, and about 1000 per pulse, are then measured in a CsI crystal calorimeter. Geant simulations have shown that systematic errors in the polarization measurements are of the order of $\Delta P/P \approx$ 5%; they are dominated by the (limited) knowledge of the effective polarization of the atomic electrons in the iron. More details can be found in [5]

At this time (October 2004) E-166 is scheduled to run in January 2005. Obtaining and measuring of positron polarization of better than 50 % will demonstrate the feasibility of undulator-based production of polarized positrons for a future linear collider.

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* **List of Authors:**

G. Alexander[DE,TA], P. Anthony[SL], V. Bharadwaj[SL], Y. K. Batygin[SL], T. Behnke[DE], S. C. Berridge[UT], G. R. Bower[SL], W.M. Bugg[UT], R. Carr[SL],E. Chudakov[JL], J. Clarke[DA], J. E. Clendenin[SL], F.-J. Decker[SL], Y. Efremenko[UT], T. Fieguth[SL], K. Flöttmann[DE], M. Fukuda[TO], V. Gharibyan[DE], T. Handler[UT], C. Hast[SL], T. Hirose[WA], R. H. Iverson[SL], Y. Kamychkov[UT], H. Kolanoski[HU], K. Laihem[DE], T. Lohse[HU], C. Lu[PR], K. T. McDonald[PR], N. Meyners[DE], R. Michaels[JL], A. A. Mikhailichenko[CO], K. Mönig[DE], G. Moortgat-Pick[DU], M. H. Munro[SL], M. Olson[SL], T. Omori[KE], D. Onoprienko[BR], N. Pavel[HU], E. Reinherz[TA], R. Pitthan[SL], R. Poeschl[DE], S. Riemann[DE], L. Rinolfi[CE], K.-P. Schüler[DE], D. Scott[DA], T. Schweizer[HU], J. C. Sheppard[SL] S. Spanier[UT], A. Stahl[DE], Z. M. Szalata[SL], J. Turner[SL], D. Walz[SL], A. W. Weidemann[SC], J. Weisend[SL]

[BR] Brunel University, Uxbridge, Middlesex UB8 3PH, United Kingdom;
[CE] CERN, CH-1211 Geneva 23, Switzerland;
[CO] Cornell University, Ithaca, NY 14853;
[DA] Daresbury Laboratory,Daresbury, Warrington, Cheshire, United Kingdom;
[DE] DESY, D-22603 Hamburg, Germany;
[DU] University of Durham, Durham DH1 3HP, United Kingdom;
[JL] Thomas Jefferson National Accelerator Facility, Newport News, VA 23606;
[HU] Humboldt University, Berlin, Germany;
[KE] KEK, Tsukuba-shi, Ibaraki, Japan;
[PR] Joseph Henry Laboratory, Princeton University, Princeton, NJ 08544;
[SC] University of South Carolina, Columbia, SC 29208;
[SL] Stanford Linear Accelerator Center, Stanford, CA 94309;
[TA] University of Tel Aviv, Tel Aviv 69978, Israel;
[TO] Tokyo Metropolitan University, Hachioji-shi, Tokyo, Japan;
[UT] University of Tennessee, Knoxville, TN 37996;
[WA] Waseda University, 389-5 Shimooyamada-machi,Machida,Tokyo 194-0202.