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PHYSICS BENEFITS OF POSITRON AND TRANSVERSE POLARIZATION AT A LINEAR ELECTRON POSITRON COLLIDER

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Abstract

Polarization of the incoming beams at a future linear collider is a powerful tool to increase the sensitivity of the machine to new physics processes. While longitudinal electron polarization is considered from the start, positron polarization is technically more involved and thus viewed as an option. The physics case for positron polarization is reviewed. Recently the possibility of transverse polarization was pointed out. Physics possibilities of this option are briefly mentioned.

1 Introduction

Future linear electron positron colliders are the outstanding tool for the precise exploration of physics at the TeV scale connected to electro–weak symmetry breaking and unraveling a solution to the hierarchy problem. In contrast to hadron colliders, the well defined initial state and the cleanliness of the final states allow us to precisely disentangle and measure the properties of both Standard Model (SM) and new physics processes. Polarized incoming beams further increase this capability and are sometimes essential to disentangle the final states. Previous summaries of the physics case for polarized beams can be found in [2, 3].

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While in circular electron positron colliders, polarization is build up in the machine due to the Sokolov–Ternov effect, in linear colliders the lepton source has to provide polarized particles and the polarization has to be preserved during the acceleration. For electrons this has been proven feasible at the Stanford Linear collider where 77% electron polarization has been achieved. The construction of polarized positron sources is intrinsically more complicated. Their production through pair production from polarized photons produced in a helical undulator or from laser photons backscattered from an electron beam are possible technologies. They are discussed in [1].

In the SM, s-channel processes are always initiated by electrons and positrons of opposite helicities ($e^-_L e^+_R$ and $e^-_R e^+_L$) due to the vector nature of the intermediate bosons, the photon and the Z^0 boson. Thus, electron polarization alone already projects out one of the two possible initial configurations and positron polarization does not add fundamentally new information. However, positron polarization increases the effective luminosity, defined as $\mathcal{L}_{eff} = 0.5\,(1 - P_{e^-}P_{e^+})$ due to the suppression of the unwanted RR and LL states. Furthermore, the effective polarization, defined as $P_{eff} = (P_{e^-} - P_{e^+})/(1 - P_{e^-}P_{e^+})$, i.e. the asymmetry between the enhanced and the suppressed configuration, is increased. Both effects increase the measurement precision of the LC w.r.t. to a situation with electron polarization only, provided the same luminosity is achievable. In the following physics examples are given where positron polarization and transverse polarization are important.

2 Physics Case for Longitudinal Positron Polarization

Giga–Z At the LC, high luminosity running at the Z-pole is possible. A significantly improved measurement of the electro–weak mixing angle can be achieved through the measurement of the left–right asymmetry A_{LR} of the e^+e^- annihilation process [5, 4]. A crucial prerequisite for this measurement is a precise determination (better than 0.1%) of the polarization, which is currently impossible from conventional polarimetry. However, with polarized positrons, the polarization can be determined together with A_{LR} from data using the Blondel scheme [6]. Within this scheme, the polarisation can be expressed as a ratio of rates. The achievable precision on A_{LR} is shown in Fig. 1 (left).

Supersymmetry If Supersymmetry is realized in Nature it is the goal of the LC to determine precisely the quantum numbers and couplings of the kinematically accessible SUSY partner particles. An elegant way to disentangle the SUSY partners of the right- and left-handed electrons is through the measurement of the production cross sections of their associated production. Due to the t-channel contribution to these processes the right- and left-handed partners can be uniquely distinguished from the polarization dependence [7], see Fig. 1 (right). Also, an additional handle on the chiral structure of the neutralino sector is obtained from the exploration of positron polarization which can be used to distuguish a minimal SUSY model from extended models [9], see Fig. 2. Pure s–channel processes like $e^+e^- \to \tilde{t}\bar{\tilde{t}}$ benefit from increased effective luminosity and effective polarization due to positron polarization [10]. Finally, if R–parity is not conserved, Spin-0 resonances like $e^+e^- \to \tilde{\nu_\tau}$ can be nicely separated from SM processes in the LL and RR initial configuration [11].

Other new physics In models with large extra dimensions (ADD), the production of a Kaluza-Klein tower of gravitons in the process $e^-e^- \to G\gamma$ can be exploited to determine the number of extra dimensions [12]. Here, both electron and positron polarization are crucial to suppress the SM $e^+e^- \to \nu\bar{\nu}\gamma$ production from s- and t-channel processes (Fig. 3 (left)). Fermion pair production at high energies can be used to search for virtual effects from new gauge or contact interactions at large scales. Ultimate sensitivity is obtained from polarization of both beams [13] (Fig. 3 (right)).

3 Transverse Polarization

Recently, it has been pointed out that through the installation of spin rotators also transverse polarization of both beams might be technically feasible. The study of the physics case for transverse polarization has just started and only two examples from the literature will be given: W-pair production with transversely polarized beams provides a possibility to project out the small contribution from longitudinally polarized W-bosons especially at center–of–mass energies far above the production threshold from the measurement of the azimuthal distribution of the W-bosons [14] (Fig. 4). In $e^+e^- \to q\bar{q}$, for transverse polarization, the azimuthal distribution of up- and down–type quarks is different. This might allow their separation in space and thus e.g. a study of difference in their fragmentation [15].

4 Summary

While polarization of the electron beam is considered a baseline option of a future LC, positron polarization is more complicated and thus requires a good physics motivation. Many examples have been worked out where positron polarization is very useful and even mandatory in some cases. Transverse polarization is only useful if both beams can be polarized and the physics case has to be worked out in more detail. Both the physics case and the technical implementation of polarized beams are currently worked out in an international working group (”POWER”) [16].

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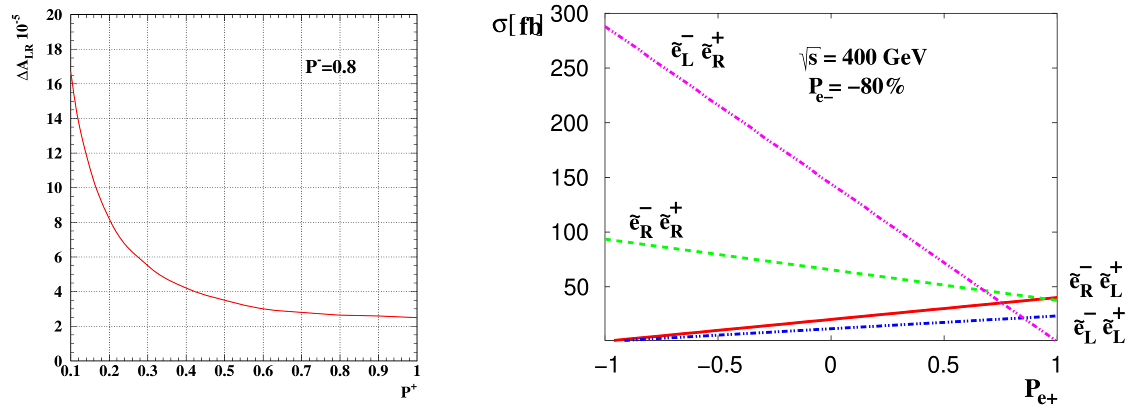

Figure 1: *Left: Precision on the left–right asymmetry from a sample of 10^9 Z^0 decays as a function of the degree of positron polarization using the Blondel scheme. Electron polarization of 80% is assumed [4, 5]. Right: Cross sections for associated production left and right selectrons as a function of the degree of positron polarization. Electron polarization of 80% is assumed. SUSY parameters are described in [7].*

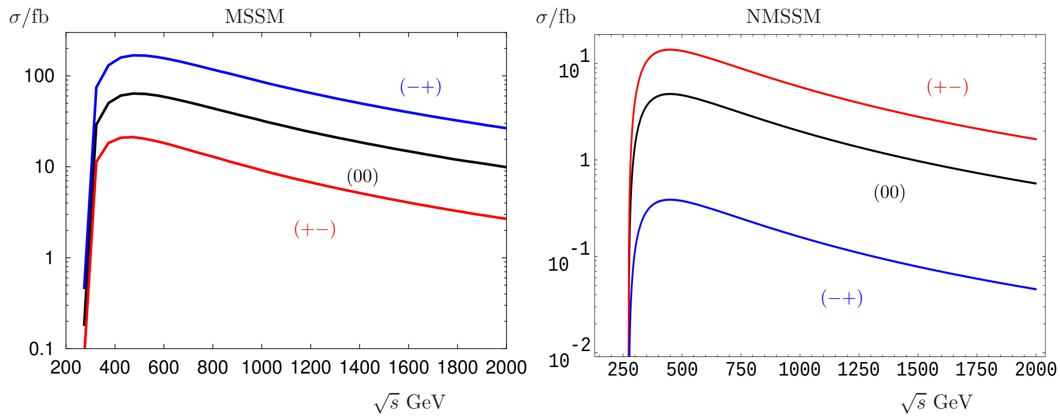

Figure 2: *Cross sections for neutralino production, $e^+e^- \to \chi^0_1\chi^0_2$, as a function of the center–of–mass energy for LR-, RL- and unpolarized beams. Left: MSSM, Right: NMSSM. For details see [9, 8].*

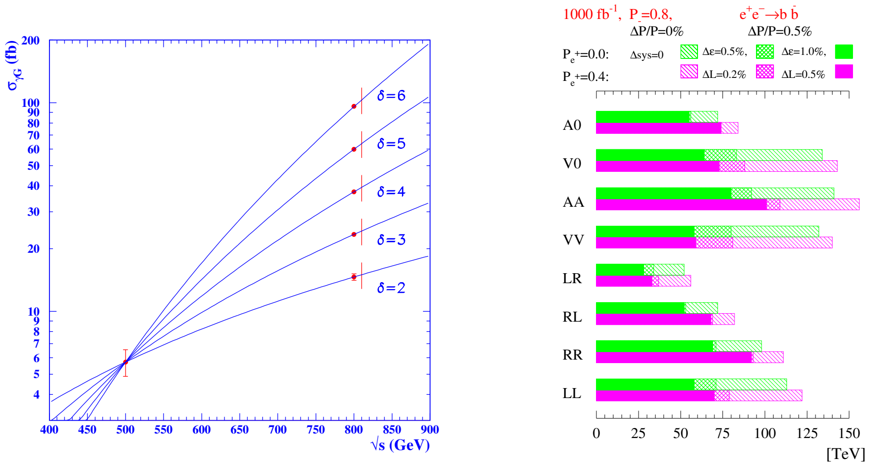

Figure 3: *Left: Cross section for single photon production from $e^+e^- \to G\gamma$ in the ADD model as a function of the center–of–mass energy. The error bars show the achievable precision with 500 fb−1 at 500 GeV and 1000 fb^{-1} at 800 GeV [12, 4]. Right: Achievable sensitivity limits for contact interactions for various coupling structures with and without positron polarization [13].*

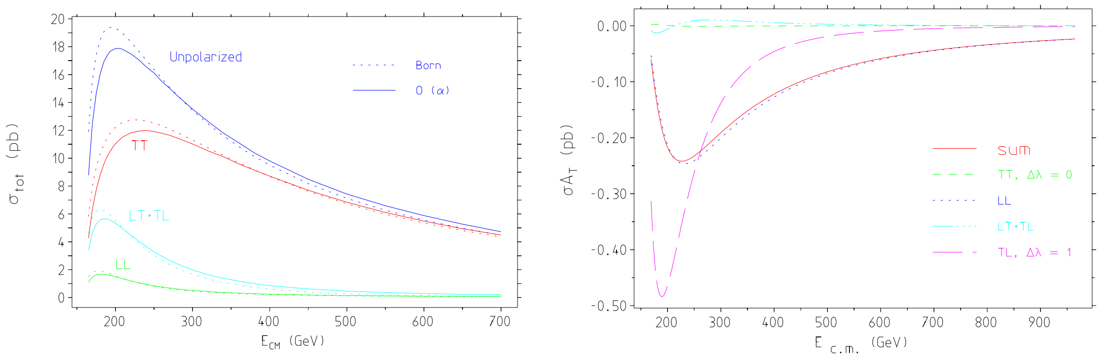

Figure 4: *W–pair production with transversely polarized beams. Left: cross section as a function of center–of–mass energy. Right: Azimuthal asymmetry as a function of center–of–mass energy [14].*