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Polarisation Measurements With Annihilation Data

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Abstract

The polarisation measurement using polarimeters at the LC is limited at around 0.25%. The large luminosity available offers the possibility to go beyond this value using annihilation data. Methods for the polarisation measurement with these data are presented and experimental aspects are discussed.

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POLARISATION MEASUREMENTS WITH ANNIHILATION DATA

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The polarisation measurement using polarimeters at the LC is limited at around 0.25%. The large luminosity available offers the possibility to go beyond this value using annihilation data. Methods for the polarisation measurement with these data are presented and experimental aspects are discussed.

1 Introduction

Polarisation measurements with polarimeters are limited to a total precision around 0.25%. In addition polarimeters measure either the polarisation of the incoming beam that has not been depolarised by the beam-beam interaction or the one of the outgoing beam which has been depolarised three to four time as much as the interacting particles. On the other hand there are several processes at a linear collider whose polarisation structure is known and which might be used to measure the polarisation directly from data. The large luminosity of the linear collider offers the possibility to reach a precision much better than the polarimeters.

One has, however, to take into account that all methods using annihilation data involve some physics assumptions that have to be considered in the framework of the model in which the data are analysed. The data driven methods also cannot replace completely the polarimeters. The data methods need a large luminosity to get to a precise result while polarimeters are completely systematics limited and statistics is no problem. In any case polarimeters are thus needed for a fast machine tuning. In addition there are some assumptions in the data-methods that have to be verified or corrected with the polarimeters. In all cases the data methods need the assumption that the absolute values of the polarisations of the left and right handed states are the same. If electron and positron polarisation is available the effective polarisations [1], calculated from the two beam polarisations, and the formulae to obtain the polarisation involve linear and quadratic terms of the polarisation values. For these reasons any correlations between the two beam polarisations need to be known from beam-beam simulations and polarimeters.

2 Measurements using W-Production

If only electron polarisation is available not only the Lorenz structure of the used process is needed but the exact helicity structure must be known. This is only fulfilled for the V-A structure of the W-fermion couplings. This coupling can be utilised in two processes at a linear collider, single W production and W-pair production. Both processes have a cross section of several pb so that a few million events are expected.

W-pair production proceeds through a mixture of neutrino t-channel exchange, only determined by the W-fermion couplings, and γ and Z s-channel exchange that involve also triple gauge boson couplings. However, as shown in figure 1, the forward pole is completely determined by the neutrino exchange and insensitive to possible anomalous gauge boson couplings. For this reason it is possible to extract the polarisation and the triple gauge couplings [2] simultaneously from the W-pair data sample. The expected precision is $\Delta\mathcal{P}_{e^-}/\mathcal{P}_{e^-} = 0.1\%$ for a luminosity of $500\,\mathrm{fb}^{-1}$ at $\sqrt{s} = 340\,\mathrm{GeV}$. The correlation with the anomalous gauge couplings is negligible and the only assumption involved is that no right-handed W-fermion couplings appear. Experimental details of the analysis can be found in [1].

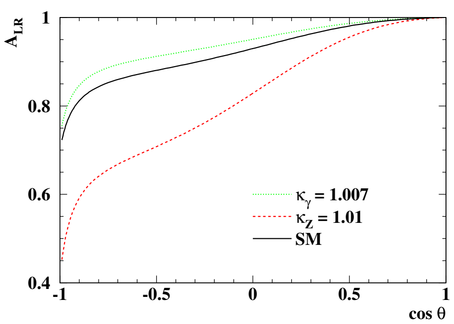

Figure 1: Left-right asymmetry of W-pair production as a function of the polar angle in the Standard Model and with anomalous triple gauge couplings.

If electron and positron polarisation is available, both can be measured simultaneously from the W-pair sample. With equal luminosity at all four helicity combinations and $\mathcal{P}_{e^-} = 0.8$, $\mathcal{P}_{e^+} = 0.6$ one gets $\Delta\mathcal{P}_{e^-}/\mathcal{P}_{e^-} \approx 0.1\%$ and $\Delta\mathcal{P}_{e^+}/\mathcal{P}_{e^+} \approx 0.2\%$ and negligible correlations between the polarisations and between the polarisation and the couplings. If only 10% of the luminosity is spent on the equal helicities the polarisation errors increase by roughly a factor two with -50% correlation between them.

Single W production is dominated by W-γ-fusion. Since this process involves the V-A coupling of the W to one of the beam particles a W^- can only be produced from a left-handed electron and a W^+ from a right-handed positron. Measuring the W-charge, the polarisation can thus be obtained for electrons and positrons separately. The outgoing electron usually disappears in the beampipe so that the W charge has to be reconstructed from the W decay products. This means that only leptonic W-decays can be used for the analysis. No detailed simulation study exists yet. The experimental signature is a single lepton in the detector which can be measured with high efficiency and small background. Because of the usually small W energy also the interference with W-pair production should be small. Assuming $\sqrt{s} = 500\,\mathrm{GeV}$, $\mathcal{L} = 1\,\mathrm{ab}^{-1}$ and 100% efficiency for $W^- \rightarrow (e^- \,\mathrm{or}\, \mu^-), \nu$ an error of $\Delta\mathcal{P}_{e^-}/\mathcal{P}_{e^-} \sim 0.15\%$ is expected.

3 The Blondel scheme

If a process $e^+e^- \rightarrow f\overline{f}$ is mediated by pure s-channel vector-particle exchange the cross section for the different polarisation states with electron and positron polarisation available can be written as

$$\sigma \;=\; \sigma_u \left[1 - \mathcal{P}_{e^+}\mathcal{P}_{e^-} + A_{\mathrm{LR}}(\mathcal{P}_{e^+} - \mathcal{P}_{e^-})\right], \tag{1}$$

where $\mathcal{P}_{e^+}$ and $\mathcal{P}_{e^-}$ are the longitudinal polarisations of the positrons and electrons measured in the direction of the particle's velocity. σ_u denotes the unpolarised cross section and A_{LR} the left-right asymmetry. If the signs of the two polarisations can be switched independently four cross sections can be measured for four unknowns. From these cross sections the polarisations can be obtained, if $A_{\mathrm{LR}} \neq 0$. As a drawback of this method some luminosity needs to be spent with the same helicities for both beams which is not very interesting for most physics processes.

To measure the polarisation with this scheme two processes have been considered, $e^+e^- \rightarrow f\overline{f}$ at high energy and radiative return events ($e^+e^- \rightarrow Z\gamma \rightarrow f\overline{f}\gamma$).

At $\sqrt{s} = 340$ the high energy cross section is about 5pb with a left-right asymmetry of 50%. The radiative return cross section is 17pb with $A_{\mathrm{LR}} = 19\%$, however, because of the large Zee background, only around one tenth of that can be used, where the radiative photon is seen in the detector. Both cross sections scale approximately with $1/s$. Details of the analysis can be found in [1].

Assuming $\mathcal{P}_{e^-} = 80\%$, $\mathcal{P}_{e^+} = 60\%$, an integrated luminosity of $500\,\mathrm{fb}^{-1}$ at $\sqrt{s} = 340\,\mathrm{GeV}$ and 50% or 10% of the luminosity spent with both beam polarisations with the same sign table 1 shows the obtainable errors on the two polarisations and their correlation. Due to the scaling of the cross sections the errors are about a factor $\sqrt{2}$ larger at 500 GeV. It should be noted that the relative errors scale approximately with the product of the polarisations.

	$\mathcal{L}_{\pm\pm}/\mathcal{L} = 0.5$			$\mathcal{L}_{\pm\pm}/\mathcal{L} = 0.1$		
	HE	rr	WW	HE	rr	WW
$\Delta\mathcal{P}_{e^-}/\mathcal{P}_{e^-}$ [%]	0.10	0.51	0.07	0.21	1.11	0.11
$\Delta\mathcal{P}_{e^+}/\mathcal{P}_{e^+}$ [%]	0.12	0.53	0.11	0.15	1.13	0.21
corr	-0.49	-0.91	0	-0.56	-0.93	-0.52

Table 1: Relative polarisation error using the Blondel scheme for $\sqrt{s} = 340\,\text{GeV}$, $\mathcal{L} = 500\,\text{fb}^{-1}$, $\mathcal{P}_{\text{e}^-} = 0.8$, $\mathcal{P}_{\text{e}^+} = 0.6$ (HE = High energy events, rr = radiative return, WW = W-pair production).

Because of the high losses in the selection of the radiative return events the errors on the single polarisations seem rather large. However the large negative correlation reduces the error substantially for the effective polarisations needed in the analysis. As an example for $\mathcal{P}_{\text{eff}} = \frac{\mathcal{P}_{e^-}+\mathcal{P}_{e^+}}{1+\mathcal{P}_{e^-}\mathcal{P}_{e^+}}$, relevant for A_{LR} with s-channel vector exchange, the error is below 0.1% in all cases except for the radiative return with only 10% of the luminosity in the scalar state, where the error is 0.17%.

4 Experimental Aspects

Although the methods presented here measure in the luminosity weighted polarisation directly from the annihilation data, some experimental assumptions are involved. In all cases it is assumed that the absolute values of the polarisation of the left- and right-handed state are the same and possible corrections have to be obtained from polarimeters. If the polarisation is written as $\mathcal{P} = \pm\langle|\mathcal{P}|\rangle + \delta\mathcal{P}$ the shift in the measured polarisation using Ws in the case of electron polarisation only, is given by $\Delta\mathcal{P}/\mathcal{P} = \delta\mathcal{P}$.

Using the Blondel scheme with electron and positron polarisation the corresponding errors are

$$\begin{aligned} \Delta\mathcal{P}_{e^-} &= 1.0\delta\mathcal{P}_{e^-} + 0.6\delta\mathcal{P}_{e^+} \\ \Delta\mathcal{P}_{e^+} &= -0.5\delta\mathcal{P}_{e^-} - 0.7\delta\mathcal{P}_{e^+} \end{aligned}$$

for the high energy events and

$$\begin{aligned} \Delta\mathcal{P}_{e^-} &= 2.4\delta\mathcal{P}_{e^-} + 2.1\delta\mathcal{P}_{e^+} \\ \Delta\mathcal{P}_{e^+} &= -1.7\delta\mathcal{P}_{e^-} - 1.7\delta\mathcal{P}_{e^+} \end{aligned}$$

for the radiative return sample.

The corresponding corrections have to be obtained from polarimeters. This is possible in a Compton polarimeter where the laser polarisation can be flipped easily. To assure that the electron-laser luminosity does not depend on the laser polarisation, or to correct for such effects, one should have a multichannel polarimeter with a large enough lever arm in the analysing power.

If electron and positron polarisation are available, in the formulae for the effective polarisations and for the Blondel scheme products of the two polarisations appear so that one has to understand the correlations between the electron and positron polarisation. In principle there can be a correlation due to the depolarisation in the bunch. Studies with CAIN [3], however, indicate that these correlations are small. Another source of correlation can come from time dependencies or spatial correlations due to the beam delivery system. If half of the luminosity is taken with a polarisation 5% higher and the other half 5% lower than average the polarisations obtained with the Blondel scheme are off by around 0.25% affecting the effective polarisation by the same amount. Measuring the polarisation with polarimeters would only result in a 0.16% error in the effective polarisation.

Time correlations have to be tracked with polarimeters. Spacial correlations due to the beam delivery system have to be obtained from simulations and should be minimised already in the design.

5 Conclusions

With the high luminosity available at a future linear collider it is possible to measure the beam polarisation with annihilation data at the permille level. If only electron polarisation is available, processes that involve the V-A coupling of the electron to the W can be used. If also the positrons are polarised the polarisation can also be obtained from s-channel processes like two-fermion production with completely different assumptions. In all cases, however, polarimeters are still indispensable for fast machine tuning and to obtain some necessary correction factors.

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3. P. Chenand, T. Ohgaki, T. Takahashi, A. Spitkovsky and K. Yokoya, Nucl.Instr.Meth. **A397**, 458 (1997).