Measurement of the beam polarization using the W^+W^- production [1]

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Data driven beam polarization measurements are necessary in order to calibrate the polarimeters. Thanks to the high luminosity available at the future International Linear Collider they will also allow to obtain a better precision on the polarizations than the one given by the polarimeters, at the permill level. Several analysis require this precision [2]. W^+W^- production is sensitive to the beam polarization and has an high cross section, so it fits perfectly to this task.

The status of the analysis reported here represents only the first steps. A large scale production of fully simulated signal and background events is currently on the way. The final results of this analysis will be derived using these high-statistics datasets. Therefore the purpose of the talk is not to give results, but rather to explain how we wish to perform the study, in its two main parts.

In the first part the Blondel scheme [3] will be applied, measuring the total cross section for four different combinations of the beams helicities. An improvement to the Blondel scheme will be studied in the second part, in which other observables from the angular distributions will be exploited. In this second step of the analysis we will determine simultaneously the Triple Gauge Couplings and the polarizations. All these studies will deal only with the longitudinal beam polarizations.

1 Introduction

1.1 Cross section dependence on the beams polarizations

In Figure 1 the Feynman diagrams for the W^+W^- production are shown. In the two s-channels (centre and right) the incoming e^+ and e^- annihilate to give the vector boson mediator. In the Standard Model only the recombination into a vector particle with $J = 1$ is possible, i.e., the beams have to carry opposite helicities. In the case of the t-channel (left), this constraint is no more valid, but the incoming leptons are now coupled to the Ws. Since the W can couple only to left handed electrons and right handed positrons, this channel can be switched off by choosing the wrong sign of the polarizations.

If the beams carry the longitudinal polarizations P_{e^+} and P_{e^-}, the cross section can be subdivided in:

$$\sigma_{P_{e^-}P_{e^+}} = \frac{1}{4}\{(1+P_{e^-})(1+P_{e^+})\sigma_{RR} + (1-P_{e^-})(1-P_{e^+})\sigma_{LL} + \\ + (1+P_{e^-})(1-P_{e^+})\sigma_{RL} + (1-P_{e^-})(1+P_{e^+})\sigma_{LR}\}, \quad (1)$$

where σ_{RL} stands for the total cross section, in case the e^- (e^+) beam is completely right-handed (left-handed) polarized. The other cross sections σ_{LR}, σ_{RR} and σ_{LL} are defined in the same way [2].

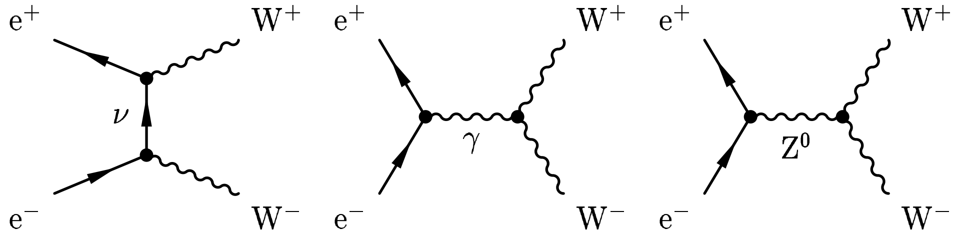

Figure 1: Feynman diagrams for the W$^+$W$^-$ production. On the left the neutrino exchange t-channel, in the centre and on the right the two s-channels with photon or Z exchange.

1.2 Triple Gauge Couplings

Due to the non-abelian nature of the SU(2) group in the SM, triple gauge couplings (TGC) are allowed. They appear in the s-channel of the W^+W^- production, while the t-channel is free from their effect. In the SM the couplings g_1^Z, g_1^γ, κ_γ and κ_Z are 1 at the tree level while all the others are 0 [4]. Both in the SM, via loop effects, and in many of its extentions, deviations from these values are predicted. These deviations might influence both the total cross section and the angular distributions for the W^+W^- production, and have to be considered.

2 Event selection and W mass reconstruction

2.1 Monte Carlo samples

The selection cuts for the analysis have been set up with already available files, corresponding to a detector model and a software version which are inferior to the latest ones released. The reconstruction makes use of the Wolf Particle Flow algorithm. The files are for $\sqrt{s} =$ 500 GeV, unpolarized beams and the LDC detector model concept.

The analysis will take benefit from the large scale production of fully simulated Standard Model processes which is planned to start soon, moving to the latest software version and detector model. Moreover, it will move to a higher statistic, also for the background, and polarized beams.

2.2 Event selection and reconstruction

At the moment we are selecting only the semi-leptonic decay channel (branching ratio 43%), in which one W decays into a quark anti-quark pair, while the other decays into a letpon and neutrino. Some preselection cuts are applied:

- total number of tracks not inferior to 5;
- $P_T > 5$ GeV and total energy < 450 GeV to account for the neutrino;
- visible mass greater than 100 GeV, to reject radiative returns.

Since the taus can decay, and more neutrinos can be present in the final state, we exclude the tau events, to avoid them to disturb the reconstruction of the W invariant mass from the leptonic decay (lepton and missing momentum due to the neutrino). The selection we apply to disentangle the taus makes use of a discriminating variable. The variable is given by the sum:

$$\left(\frac{E_{VIS}}{E_{CM}}\right)^2 + \left(\frac{E_{lepton}}{E_{beam}}\right)^2, \tag{2}$$

where E_{VIS} is the visible energy, E_{CM} is the centre-of-mass energy, E_{lepton} is the lepton energy and E_{beam} is the beam energy. Candidates with a sum smaller than 1 are classified as leptonic τ decays.

Using the Durham algorithm we force three jets: two for the quarks and one for the lepton. The leptonic jet is required to contain one and only one charged track with $p_T >$ 10 GeV and to be isolated. Three tracks are allowed only in case of the electron, since the electron can radiate, and the photon can convert into a pair. Two tracks must therefore have invariant mass almost zero, since they come from the radiated photon, and the third track must be an electron (the ratio between energy and momentum must be almost one, and the track must be charged). A cut on $cos\theta_W >$ -0.95 is also applied, where θ_W is the production angle of the W, i.e., the angle between the incoming e^- and the outgoing W^-. The invariant mass of the Ws is required to be $<$ 150 GeV.

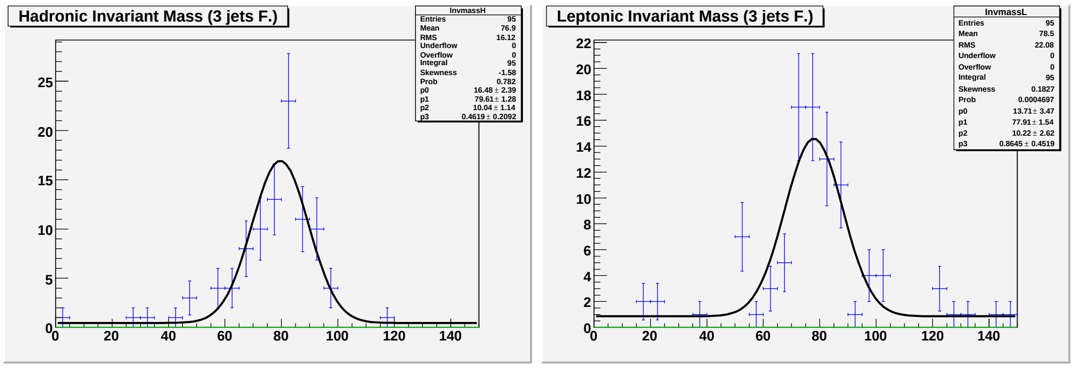

Figure 2: The W invariant mass measured from the hadronic decay (left) and from the leptonic decay (right).

In Figure 2 the results obtained are reported. The background, at the moment only q $\bar{\text{q}}$, is completely eliminated by the selection cuts. This underlines the importance of the new high-statistics sample (see section 2.1).

3 The Blondel scheme

The first method we will use to measure the polarizations will be the Blondel scheme. Given the total cross sections for the four different helicity combinations, σ_{++}, σ_{--}, σ_{+-} and σ_{-+}, where the first sign is the positron helicity and the second sign is the electron one, the polarizations are given by [4]:

$$\mid P_{e^\pm} \mid = \sqrt{\frac{(\sigma_{-+} + \sigma_{+-} - \sigma_{--} - \sigma_{++})(\pm\sigma_{-+} \mp \sigma_{+-} + \sigma_{--} - \sigma_{++})}{(\sigma_{-+} + \sigma_{+-} + \sigma_{--} + \sigma_{++})(\pm\sigma_{-+} \mp \sigma_{+-} - \sigma_{--} + \sigma_{++})}}, \tag{3}$$

assuming that changing the helicity of a beam, only the sign of the polarization changes, but not the absolute value (differences must be given by the polarimeters). Currently only the cross section for the unpolarized case is available, but it is possible to estimate the total cross sections for the polarized case from [4]:

$$\sigma = \sigma_u[1 - P^- P^+ + (P^+ - P^-)A_{LR}]. \tag{4}$$

σ_u is the unpolarized cross-section and A_{LR} is the left-right asymmetry. To give a rough order of magnitude of the amount of luminosity needed to obtain the desired error on the polarizations from the Blondel scheme, we have calculated in this way the cross sections for 80% e^- and 60% e^+ longitudinal polarizations from the already known unpolarized one, and propagated the errors. We have then iterated on different luminosities and applied the Blondel scheme, recalculating every time the final statistical uncertainty on the polarizations obtained. Assuming to spend the same amount of luminosity on each combination of helicities, with 860 fb^{-1} of luminosity, the error on P_{e^-} is around 0.1% and the error on P_{e^+} is 0.2% (Figure 3). This value is very conservative, since the software adopted is inferior to the one which will be available in the new datasets (see section 2.1), but is not surprising. For example, in [5] $\Delta P_{e^-}/P_{e^-} \approx 0.1\%$ and $\Delta P_{e^+}/P_{e^+} \approx 0.2\%$ are expected for P_{e^-} 0.8 and P_{e^+} 0.6, sharing in an equal way 500 fb^{-1} on the different helicity combinations at $\sqrt{s} = 340$ GeV. Considering the strong scaling of the W$^+$W$^-$ cross section, this result is compatible with the one we have obtained at $\sqrt{s} = 500$ GeV. Further improvements to the analysis are expected using also the information from the angular distributions, as explained in the following section.

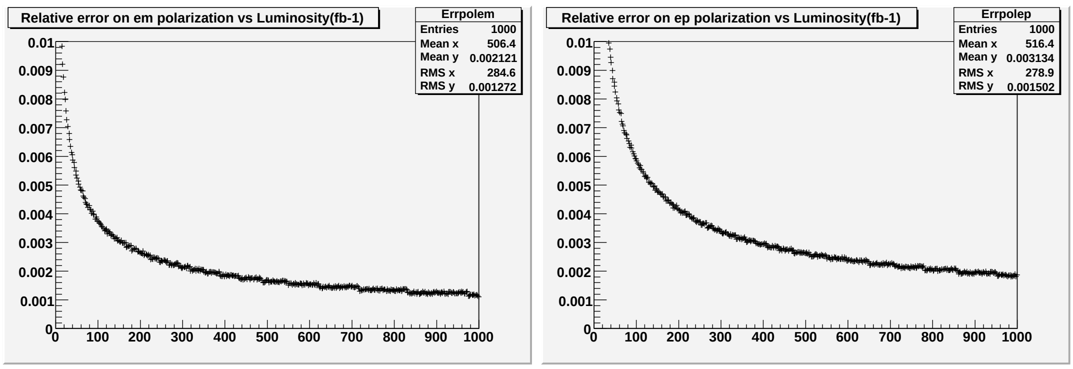

Figure 3: The error on the polarization of the electron beam (left) and the positron one (right) as a function of the luminosity (fb^{-1}). With 860 fb^{-1} of luminosity, the error on P_{e^-} is around 0.1% and the error on P_{e^+} is 0.2%.

4 Angular distributions

The total cross sections are not the only observables available. Also the angular distributions can be exploited: the W production angle θ_W and the decay fermion angles in the rest frame of the W. The total cross sections as well as the angular distributions, are influenced by the

TGCs. However, as shown in Figure 4, the forward region of the production is completely dominated by the neutrino exchange and insensitive to the anomalous couplings.

For this reason it is possible to extract the polarizations and the triple gauge couplings simultaneously from the W-pair data. To study the extraction procedure it is necessary to work with several polarizations and several TGCs. 100% polarization files can be easily combined to get different polarizations. To obtain different samples with different values of the couplings it is not convenient to generate every time different files, it is more convenient to weight the Monte Carlo events as a function of the couplings. The total cross section σ_{rew} will then be given by:

$$\sigma_{rew} = \frac{\sigma_{gen}}{N_{gen}} \sum_i w_i, \tag{5}$$

where w_i is the weight for the i^{th} event. σ_{gen} is the cross-section and N_{gen} the number of events of the Monte Carlo sample. A previous study, performed in fast simulation, is reported in [4]. For one anomalous coupling, 60% e$^+$ and 80% e$^-$ polarizations, for $\Delta\sigma/\sigma$ = 1% to 0.25%, $\Delta P_{e^-}/P_{e^-} = 0.2\%$ to 0.05% and $\Delta P_{e^+}/P_{e^+} = 0.31\%$ to 0.08% at 800 GeV.

5 Conclusions

As soon as the outcome from the large scale production of fully simulated Standard Model processes will be available, the selection will be improved moving to a full statistic, also for the background, and to the latest software version. Pandora will be used instead of Wolf as Particle Flow algorithm.

This study will show that, thanks to the high luminosity available at the future International Linear Collider, data driven polarization measurements allow to obtain a high precision, of the order of the permill. Still the polarimeters will be very important, for the fast tunings and to measure deviations from the avarage values given by these methods.

References

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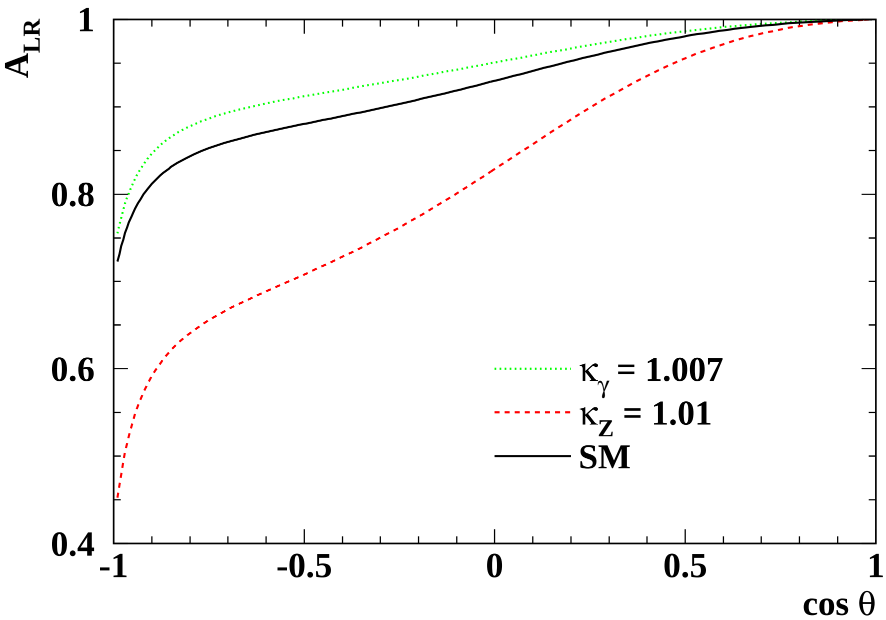

Figure 4: Left-right asymmetry of the W-pair production as a function of the polar angle, in the Standard Model and for two anomalous values of the triple-gauge couplings.