Vertex Detection in Strong Electroweak Symmetry Breaking

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Abstract. The study of the process $e^+e^- \to W^+W^-$ at Linear Collider energies presents a good opportunity to investigate anomalous triple gauge boson couplings and $W_L^+W_L^-$ rescattering. The motivation and plans for a helicity analysis of the $e^+e^- \to W_L^+W_L^-$ amplitude, which includes charm flavor tagging, are presented. The SLD collaboration's topological vertex finding algorithm (ZVTOP) has been implemented in the Java based linear collider analyis framework in preparation of this study.

MOTIVATION

The main focus of a next e^+e^- linear collider will certainly be the exploration of the electroweak symmetry breaking. This machine provides a good opportunity to study the strong electroweak symmetry breaking in the process $e^+e^- \to W^+W^-$, which is predominant at center mass energies of 500 GeV and higher.

In case strong electroweak symmetry breaking is realized, the cross section for the reaction $e^+e^- \to W^+W^-$ will show deviations from the standard model expectation in two possible ways: anomalous couplings at the $W^+W^-\gamma$ and W^+W^-Z vertices and $W_L^+W_L^-$ final state rescattering effects.

Strong electroweak symmetry breaking leads to a modification of the chiral Lagrangian, introducing the two real coefficients L_{9L} and L_{9R} as discussed in [1]. These in turn produce the anomalous three-gauge-boson couplings κ_γ, κ_Z and g_1^Z [2].

Final state rescattering can be taken into account by multiplying the standard model $e^+e^- \to W_L^+W_L^-$ cross section with a complex form factor F_T [3]. Since the rescattering process is quite sensitive to a vector resonance, these resonances (a TechniRho for example) can be described by F_T as shown in Figure 43 in [2].

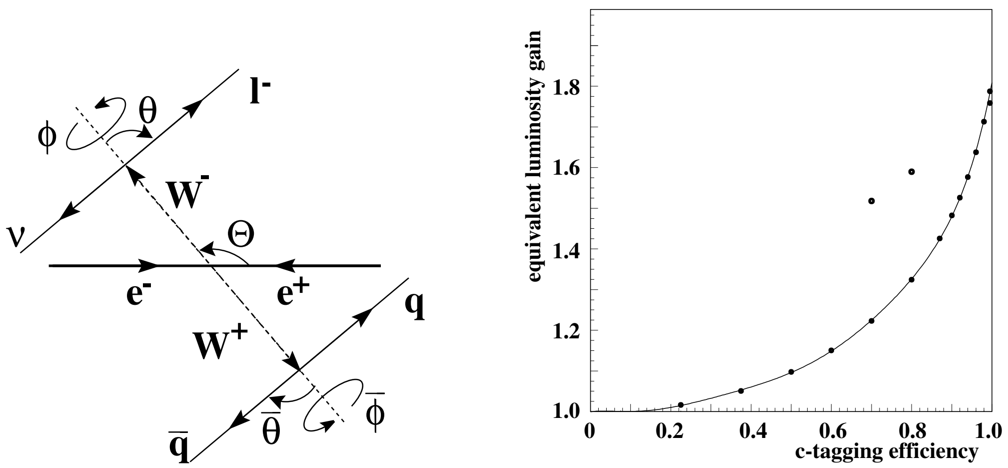

FIGURE 1. Left: Definition of production and decay angles in $e^+e^- \to W^+W^-$. Right: Equivalent luminosity gain as a function of the charm tagging efficiency [4]. The tagging efficiency includes possible mistags. (The two separate data points above the curve are obtained for the low energy theorem (LET) limit.)

HELICITY ANALYSIS OF W^+W^- FINAL STATE

Studies of strong electroweak symmetry breaking effects in the next linear collider environment have been carried out by [1,4]. These studies make use of a helicity angle analysis technique for the W^+W^- state and employ a maximum likelihood formalism to fit alternatively for the two coefficients L_{9L} and L_{9R} or the complex form factor F_T.

In order to achieve the greatest possible sensitivity for anomalous couplings and $W_L^+W_L^-$ rescattering, it is necessary to make use of all information provided by the polarization of the final state W bosons. This can be done by performing a full final state helicity analysis. For example, the W^+W^- scattering is dominated by the T-channel process in the forward direction, as shown in Figure 4 in [3]. Sensitivity to the $W_L^+W_L^-$ rescattering amplitude, whose cross section follows $\sin^2\theta$, is gained in the backward direction.

The five angular quantities used in the maximum likelihood formalism of the helicity analysis are defined in Table 1 and shown in Figure 1. As this analysis is usually carried out with one W decaying leptonically, this decay's helicity angles θ^*

TABLE 1. Definition of the five measured variables.

Variable	Description
$\cos\Theta$	cosine of W^- production angle with respect to e^- in e^+e^- rest frame
$\cos\bar{\theta}^*$	cosine of polar angle of lepton in it'sW rest frame
Φ^*	azimuthal angle of lepton in it's W rest frame
$\cos\theta^*$	cosine of polar angle of quark jets in it's W rest frame
$\bar{\Phi}^*$	azimuthal angle of quark jets in it's W rest frame

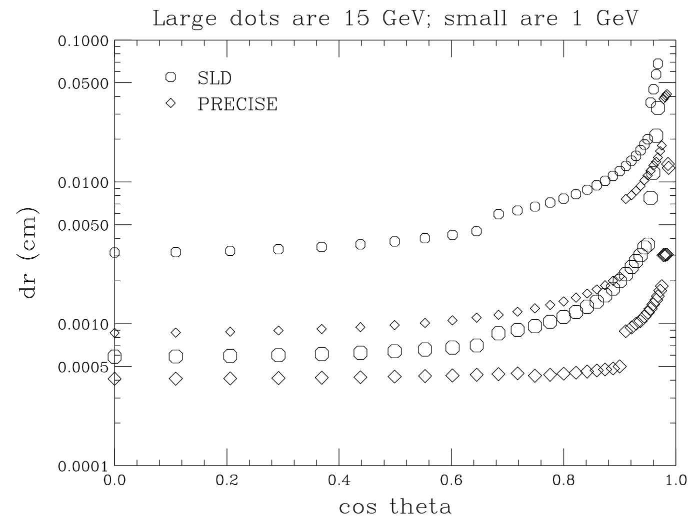

FIGURE 2. Radial tracking resolution as a function of the cosine of the polar angle Θ for 15 GeV (large symbols) and 1 GeV (small symbols) for the SLD detector and the LCD design [8]. (The precise detector design is very similar to the large LCD design.)

and Φ^* are determined unambigiously, since the lepton is expected to be identified. In absence of any flavor tagging however, there is an ambiguity in the hadronic side's W decay angles $\bar{\theta}^*$ and which is dealt with by averaging the two possible solutions:

$$\bar{\mathbf{H}}^{\bar{\lambda}}_{\bar{\lambda}'} = \left[\bar{\mathbf{D}}^{\bar{\lambda}}_{\bar{\lambda}'}(\cos\bar{\theta}^*, \bar{\Phi}^*) + \bar{\mathbf{D}}^{\bar{\lambda}}_{\bar{\lambda}'}(-\cos\bar{\theta}^*, \bar{\Phi}^* + \pi)\right]$$

The parameters $\bar{\lambda}$ and $\bar{\lambda}'$ denote the different possible helicity states for the chiral matrix elements $\bar{\mathbf{D}}^{\bar{\lambda}}_{\bar{\lambda}'}$.

THE CASE FOR CHARM TAGGING

In case the ambiguity in the determination of $\bar{\theta}^*$ and $\bar{\Phi}$ can be resolved by flavor tagging one of the two hadronic jets, the sensitivity of the will be enhanced. As shown by [4] in Figure 1 (right) an equivalent luminosity gain of up to a factor 1.8 could be gained if the charm tagging were perfect.

The goal of the study suggested here is to quantify the possible gain if charm tagging is employed to $e^+e^- \rightarrow W^+W^-$ decays in the current linear collider detector (LCD) design models.

As for the expected charm tagging efficiency the analysis with the LCD design should achieve higher values than is currently achieved with sophisticated analysis methods by the SLD collaboration. Using a topological vertex finding algorithm in combination with a neural net for the (bottom and) charm tagging, analyses of the SLD collaboration achieve up to 23% charm tagging efficiency in a B meson contaminated environment [5]. Since the tracking resolution for the LCD detector design is much better than for the SLD detector (see Figure 2) a significant increase in the charm tagging efficiency is expected. It will be interesting to investigate, whether aggressive vertexing scenarios as recently suggested [7] would provide for another substential improvement.

In addition, charm tagging allows to make partial use of double hadronically decaying $e^+e^- \to W^+W^-$ events by adding to the event sample with one W boson decaying leptonically those events with a both W bosons decaying into a charm final state. Combinatorically, this would gain an additional maximum 1.5 times more in statistics in case of perfect charm tagging. Of course, this depends not only on the charm tagging efficiency but on the ability to determine the charge identity of at least one W boson by using jet or vertex charge methods, as the advantage of the clear charge marking from the leptonic W decay is no longer available.

We plan to study the charm tagging capabilities for the process $e^+e^- \to W^+W^-$ for the LCD designs using fast Monte Carlo simulation techniques and topological vertexing. This study will quantify the achievable gain in equivalent luminosity, investigate the possiblility of using fully hadronic final states and eventually consider agressive vertexing scenarios. In preparation, the SLD collaboration's topological vertex finding algorithm ZVTOP [6] has been implemented in the Java based LCD analysis framework [9].

SUMMARY

The next linear collider will provide an excellent environment to search for effects possibly induced by strong electroweak symmetry breaking in the process $e^+e^- \to W^+W^-$. The corresponding analysis, which relies primarily on the determination of the helicities in the W^+W^- final state, will profit from charm quark tagging capabilities of the LCD detector. To quantify the gain from charm tagging and to benchmark different detector designs, an analysis based on fast Monte Carlo simulation and topological vertex finding will be carried out.

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