The Impact of Particle Identification on $W^\pm$ Helicity Measurements at the Linear Collider

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According to technicolor theories, vector resonance production of longitudinally polarized $W^\pm$ boson pairs is expected at a linear collider with a center-of-energy of 500–1500 GeV. Studying this physics may turn out to be the prime interest of the linear collider program. Based on studies investigating the possibility of enhancing the signal by identifying charm jets in hadronic $W^\pm$ decays, we look into the use of charged particle identification to further increase the sensitivity of this analysis.

1. Introduction

Charged particle identification (PID) is and has been crucial for performing critical measurements at high energy experiments, and may play an important role in the physics pursued at the linear collider. For example, Mercadente and Yamamoto [1] have shown that a PID system may have significant impact on the ability to separate the $e^+e^- \to \mu^+\mu^-$ background from $e^+e^- \to \tilde{\tau}^+\tilde{\tau}^-$ events, if the staus live long enough to decay outside the detector.

Since a dedicated PID system impacts the total project cost, as well as the performance of other detector components, its role in conducting the measurements of interest must be evaluated, and the technology chosen appropriately. Wilson [2] and Yamamoto [3] have studied PID performance when using specific ionization (dE/dx) or a detector of internally reflected Cherenkov light (DIRC). dE/dx is a natural "by-product" of a gaseous tracking system. The dE/dx resolution of a silicon microstrip tracker, however, is significantly poorer than that of gaseous system. Thus, if silicon microstrip technology is chosen for tracking, a dedicated PID system, such as a DIRC or time-of-flight (TOF), may be desired. Such considerations must be taken into account when selecting detector technology. The first step is, of course, to evaluate the physics needs for a PID system, as done in [1].

2. Hadronic $W^\pm$ Helicity Measurement

In this report we study the impact of PID on the helicity measurement of $W^\pm$ bosons decaying hadronicly in $e^+e^- \to W^+W^-$ events. The motivation for this is the detection of increased production of longitudinally polarized $W^\pm$ boson pairs, predicted by technicolor and other theories [4]. The study is based on the work of Walkowiak [5], in which one W decays leptonicly, and the other hadronicly. Measuring the helicity of the hadronic W requires tagging the flavor of the up- or down-type quark jet. The up-type jet is identified by reconstructing the decay vertex of the charmed particle in $W^- \to \bar{c}s$ decays. A jet is considered a c-quark jet if it contains at least two distinct vertices. The effective tagging efficiency is given by

$$Q = \varepsilon\,(2p - 1)^2, \tag{1}$$

where ε is the efficiency for finding a c-quark jet, and p is the purity, i.e., the fraction of tagged events in which a true c-quark jet was correctly tagged. In Ref. [6], $\varepsilon \approx 0.6$ and $p \approx 0.8$ for a center-of-mass energy (E_{CM}) of 500 GeV, resulting in $Q \approx 22\%$. Things are better at $E_{\mathrm{CM}} = 1500$ GeV, where due to larger efficiency and purity, $Q \approx 42\%$.

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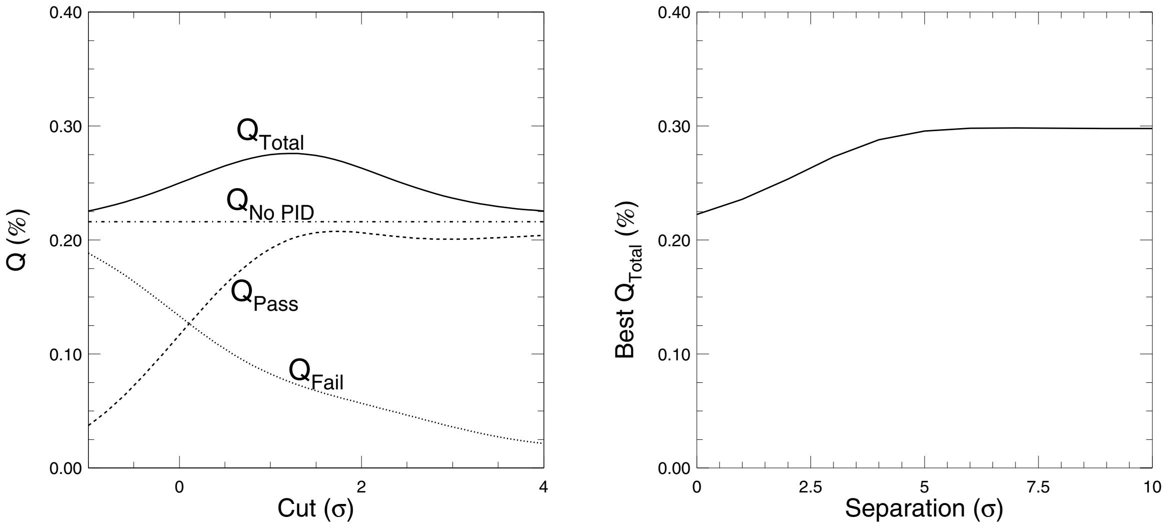

Figure 1: Left: The effective efficiency as a function of the cut applied to the PID observable, for events failing the cut (Q_{Fail}), events passing the cut (Q_{Pass}), and their sum (Q_{Total}). Also shown is the effective efficiency without the use of PID ($Q_{\text{No PID}}$). The distribution of kaons is taken to be centered at 0, and that of pions is centered at 3, yielding a $3\,\sigma$ separation. Right: The largest total effective efficiency obtainable as a function of the $K-\pi$ separation.

In principle, enough helicity information is obtained from the leptonicly decaying W to conduct this analysis. However, measuring the helicity angle of the hadronic W increases the sensitivity. This increase is only significant if the effective efficiency Q of $\bar{c}s$ decays can be made greater than about 60%. It is therefore worthwhile to try to increase Q using PID.

3. PID Charm Tagging

One way to PID-tag the c-quark jet is to detect a kaon of the correct charge (determined by the charge of the leptonic W decay) originating from the charm candidate vertex. Events in which such a kaon is identified have a higher purity. Since charm tagging using vertex reconstruction is still possible for all other events, they are also useful, and are not discarded. Thus, this use of PID always increases the effective efficiency. This is true even if $K-\pi$ separation is poor, but good separation may result in a substantial improvement.

To study this possibility, we assume that the PID observable is normally distributed with unit r.m.s., with a particular separation between kaons and pions. We then calculate the PID efficiencies of $K^-\pi^+$ (signal) and $\pi^-\pi^+$ (background) vertices, requiring that at least one of the tracks pass a given cut on the PID observable. For simplicity, vertices composed of more than two tracks, which yield lower purities, are ignored in this study. Also ignored are rare background vertices containing a true kaon. It is assumed that 39% of all signal vertices contain a charged kaon, averaging the production rates in D^0 and D^+ decays. Using Eq. (1), the effective efficiency is calculated for vertices that pass or fail the cut. The sum of these effective efficiencies is the total effective efficiency.

The effective efficiencies are shown in Figure 1 for a $K-\pi$ separation of 3 standard deviations (σ). This separation yields a maximum total effective efficiency $Q_{\text{Total}} = 27.6\%$, an improvement of 25% over the no-PID value. Also shown in Figure 1 is the best Q_{Total} obtainable for different $K-\pi$ separations. It is clear from this plot that even near-perfect PID makes relatively modest improvements. The reason for this is that the charged kaon yield is only 39%, limiting the fraction of events that can be PID-tagged.

Having determined the $K-\pi$ separations needed for charm tagging in this context, we briefly examine the PID technologies capable of such separation over the relevant momentum range. The momentum spectra of signal kaons and the main background pions are shown in Figure 2. A device capable of 4.5% dE/dx resolution, such as the ALEPH [7] time projection chamber (TPC), provides 2–3 σ separation over most of the spectrum. The resolution of a pressurized TPC may

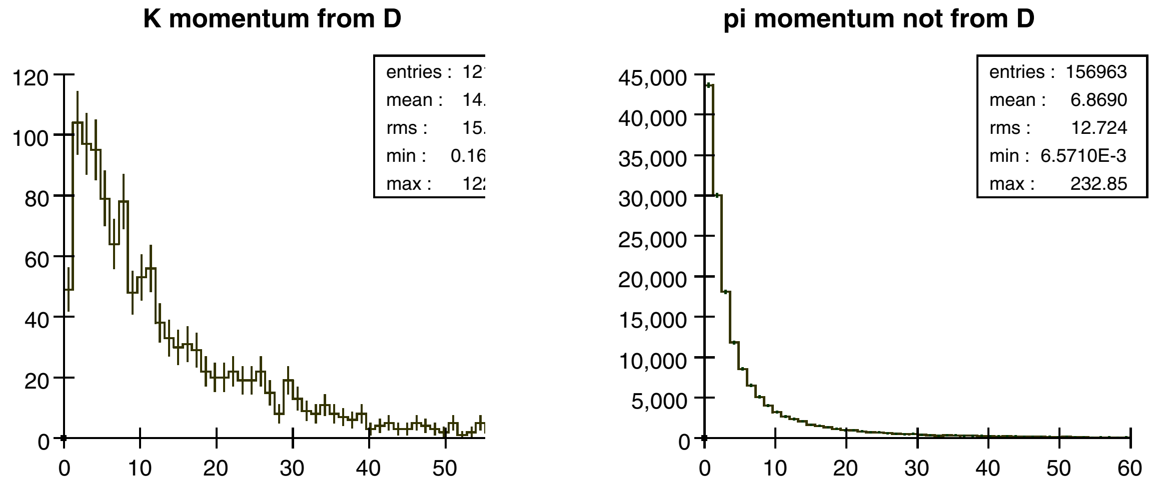

Figure 2: The momentum spectrum of charged kaons originating from D meson decays (left) and charged pions not originating from D meson decays (right).

be as low as 2.5%, increasing the separation to the optimal 4–5 σ. DIRC technology, on the other hand, can only be extended up to about 8 GeV [8], which is clearly insufficient for this analysis.

4. Discussion and Conclusions

With some simplifying assumptions, we have shown that use of kaon identification can improve the charm tagging efficiency in the $W^{\pm}$ helicity analysis by up to about 35%. This is a worthwhile improvement, especially given that the necessary separation could be provided by the charged particle tracker. Since this is not enough to make a decisive difference for this particular analysis, it does not warrant a dedicated PID system. We note that the different momentum spectra of signal kaons and background pions (Figure 2) may also be exploited to effectively increase the separation.

Kaon identification may be used in additional ways to enhance this analysis. The SLD collaboration used their CRID to identify hard kaons with high efficiency and purity, using them to tag s-quark jets [9]. With more limited PID capabilities, a linear collider detector would not do as well, but could nonetheless improve the analysis by adding some degree of s-quark tagging. Further detailed studies are needed in order to determine the feasibility of this approach with dE/dx. Finally, PID-enhanced c- and s-quark jet tagging may be used to further increase the total efficiency, by including events in which both W bosons decay hadronicly. Thus, rather than serving as the knight in a suit of armor, PID may be used along with other methods to incrementally increase the sensitivity of this and other analyses.

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