A study of topological vertexing for heavy quark tagging

Toshinori Abe
Stanford Linear Accelerator Center, Stanford University, Stanford, CA 94309

Abstract

We compare heavy quark tagging and anti-tagging efficiencies for vertex detectors with different inner radii using the topological vertex technique developed at the SLC/SLD experiment. Charm tagging benefits by going to very small inner radii.

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1 Introduction

A vertex detector (VTX) is a very powerful particle identification device for the future linear collider experiment. VTX allows not only $b/c$-jet tagging but also anti-$b/c$ jet tagging. Excellent $b/c$-jet tagging is required in studies of Higgs and Top physics. VTX performance depends critically on the innermost radius ($r_{\text{inner}}$) of the detector. Many studies have been done to achieve smaller $r_{\text{inner}}$ in order to get better impact parameter resolution. Current allowable $r_{\text{inner}}$ is expected to be $\sim 1$ cm. However a VTX configuration with $r_{\text{inner}} = 1$ cm is very difficult to achieve and there are presently no physics studies comparing such aggressive designs with more conservative ones. In this paper, we discuss the physics-performance difference between $r_{\text{inner}} = 1$ cm and 2 cm VTX configurations, using the topological vertexing technique developed at the SLC/SLD experiment.

2 Tools

We use the LCD fast simulation and a topological vertexing and a mass tag technique for the study.

The LCD fast simulation [1] is based on the ROOT analysis tool [2] and the C++ programming language to maximally benefit from object oriented programming techniques. In this simulation, track particles are smeared according to their error matrices. The error matrices are given by a look-up table method based on momentum and $\cos \theta$ of charged particles. The error matrices include off-diagonal elements to give added realism. The vertex detector is assumed to have layers at several radii ($r = 2.4$ cm, 3.6 cm, 4.8 cm, 6.0 cm) and resolution of 5 $\mu$m for each layer in both detector configuration. The VTX configuration with $r_{\text{inner}} = 1$ cm has an extra layer of $r = 1.2$ cm with resolution of 5 $\mu$m.

The success of the CCD-based VTX at the SLC/SLD experiment [3, 4] argues strongly that a CCD-based VTX will provide optimal performance in a future linear collider experiment. Taking advantage of the precise 3-D spatial points provided by the VTX, a topological vertexing technique [5] has been developed. The topological vertexing naturally associates tracks with the vertices where they originated and can reconstruct a full $b/c$-meson decay chain, i.e., primary, secondary, and tertiary vertices. Using the reconstructed secondary/tertiary vertex, the invariant mass of the tracks associated with decay is used to identify jet flavor (mass tag technique [6]). This combination of the techniques gives the best heavy-flavor-jet tagging performance in $e^+e^-$ colliding experiments at present. Here it should be noted that the secondary/tertiary vertex reconstruction enables vertex charge information to be determined which gives quark/anti-quark jet identification even for neutral $B$’s [7]. The original vertexing program, called ZVTOP, was written in Prepmort programing language; we translated the code into the C++ language in order to suit the environment of the LCD fast simulation more naturally. Other physics studies which use the program are reported in these proceedings[8, 9].
Table 1: The performance of two different VTX configurations.

<table>
<thead>
<tr>
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<th>$r_{inner} = 1 \text{ cm}$</th>
<th>$r_{inner} = 2 \text{ cm}$</th>
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<tbody>
<tr>
<td>impact parameter resolution</td>
<td>$3.2 \mu \text{m} \oplus 8.5 \mu \text{m}/p\sin^{2/3}$</td>
<td>$3.5 \mu \text{m} \oplus 14 \mu \text{m}/p\sin^{2/3}$</td>
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<td>reconstructed primary vertex resolution</td>
<td>$4.6 \mu\text{m}(xy)$ $3.7 \mu\text{m}(rz)$</td>
<td>$6.9 \mu\text{m}(xy)$ $5.2 \mu\text{m}(rz)$</td>
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<tr>
<td>$b$-jet tagging efficiency and purity</td>
<td>$\epsilon = 63%$ $\Pi = 97%$</td>
<td>$\epsilon = 62%$ $\Pi = 97%$</td>
</tr>
<tr>
<td>$c$-jet tagging efficiency and purity</td>
<td>$\epsilon = 32%$ $\Pi = 83%$</td>
<td>$\epsilon = 27%$ $\Pi = 80%$</td>
</tr>
<tr>
<td>anti-$b/c$ jet tagging efficiency and purity</td>
<td>$\epsilon = 81%$ $\Pi = 91%$</td>
<td>$\epsilon = 78%$ $\Pi = 90%$</td>
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3 Performance

In order to investigate the influence of the VTX configuration, we considered the following variables: (1) impact parameter resolution; (2) reconstructed primary vertex resolution; and (3) $b$-tag, $c$-tag, and anti-$b/c$ tag efficiencies and purities. These studies are done using hadronic decay events at $\sqrt{s} = 91.26$ GeV. The results are summarized in Table 1.

As we expect, $r_{inner} = 1 \text{ cm}$ VTX configuration shows better impact parameter and reconstructed primary vertex resolutions than $r_{inner} = 2 \text{ cm}$. The reconstructed primary vertex resolution, in particular $rz$ resolution, is important to heavy quark physics at giga-Z experiment. We also believe that the resolution will play an important role when we try to discriminate mini-jet backgrounds from Higgs signal events [10]. This idea needs further study.

For jet-flavor identification, we see a result contrary to our naive expectation. Figs. 1 and 2 show the purity against total efficiency plots for $b$-jets and $c$-jets obtained by varying the cut of vertex invariant mass, respectively. From these figures, we can not see significant differences in $b$-jet tagging between the two VTX configurations, but we do see significant improvements for $c$-jet tagging. This can be understood because the maximum $b$ tag efficiency is limited by the fraction of decays which ZVTOP can identify, i.e. those resulting in at least two charged particles. Furthermore, the long $b$ lifetime ensures that most decays are well-separated from the primary; hence improved resolution is not needed to find more decay vertices close to the IP. With improving VTX resolution the $c$-jet efficiency increases faster than the $b$-jet efficiency. We need further study to understand this behavior fully.

In the previous section, we mentioned that the importance of secondary/tertiary vertex reconstruction. This is something that has been overheaded in past linear collider studies. For charged $b$ or $c$ hadrons, vertex charge identifies whether its a quark or anti-quark jet. Fig. 3 illustrates the clear charge separation for $B^+/B^-$ decay vertex. According to Ref. [9], we can know the $t/\bar{t}$-quark direction with efficiency and purity of 78 % and 41 %, respectively, by looking at the charge of the $B$ it decays into, requireing $|\cos\theta_{\text{track}}| < 0.9$.

4 Summary

We have developed a fast simulation code to optimize the detector design for a future linear collider experiment. First results with a topological vertexing technique are presented in this proceeding. The two VTX configurations ($r_{inner} = 1 \text{ cm}$ and $2 \text{ cm}$) do not show significant
Figure 1: Performance of $b$-jet flavor tag.

Figure 2: Performance of $c$-jet flavor tag.
difference for $b$-jet tagging, but do for $c$-jet tagging. This should be investigated with further study.

References

[10] Prof. T. Matsui, private communication.