TAGGING B MESONS VIA THE DECAY $B \to D^*l\nu$

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Abstract

We describe a procedure for partial reconstruction of B meson semileptonic decays into the final state $D^{*+}l^-\nu$, and its charge conjugate. The method requires measuring only the lepton (l^-) from the primary B decay and the daughter pion (π_d^+) from the subsequent decay $D^{*+} \to D^0\pi_d^+$. The application of the technique requires superior tracking capability, lepton identification, and special kinematic cuts. This final state has a large branching ratio relative to other B meson decays and is therefore valuable for tagging purposes. In addition to tagging, the technique gives an approximate measurement of the parent B meson momentum.

Introduction

Tagging B mesons at the SSC will be important for a variety of applications. One example is the study of rare decay modes of B mesons. After one B meson is tagged, the potentially rare anti-B partner must be in the appropriate model-dependent part of the phase space. Studying the way tagged B meson pairs populate the phase space will help understand how to go about searching for a rare anti-B associated with a tagged B. Decays of heavy particles, both new and old (e.g., old being Z^0s), into B mesons is another application of B tagging. Thus, the value of B tagging is clear, the challenge is to find good ways to do the job. For many of these studies, it will be important to obtain a cleanly identified B meson rather than simply a B meson enhanced sample of events.

The small branching ratios of B mesons into reconstructable final states makes them difficult to find and few in number. We propose a "partial reconstruction" technique for tagging B mesons that decay into the final state $D^{*+}xl^-\nu$ (and its charged conjugate, hereafter implied), where l^- is either e^- or μ^- and x represents possible additional pions. The interest in tagging this final state is because it represents a large fraction of all B mesons produced, about 5%[1], and it has a relatively clean tagging signature. We rely on the decay $D^{*+} \to D^0\pi_d^+$, and the only decay particles that are used in the analysis are the lepton (l^-) and the daughter pion (π_d^+). This analysis is not effected by additional pions (x) provided that the total hadronic mass including x is not much different than the D^* mass. Studies with $CLEO$ data indicate that we may ignore the extra pion possibility since semileptonic B decays studied at the $\Upsilon(4S)$ show no positive evidence of extra pions[2].

For comparison, we consider some other final state possibilities for B tagging. The best candidate for full reconstruction is the decay involving a Ψ in the final state. The branching ratio for $B \to \Psi + X$ is about 1% and the branching ratio of $\Psi \to e^+e^- + \mu^+\mu^-$ is about 15%. Therefore, roughly 0.1% of B decays occur with inclusive Ψ production, the Ψ forming a lepton pair. However, only a subsample of these will be useful for tagging purposes because the "X" will include final states with undetectable particles[3]. One might try to reconstruct other relatively simple final states such as those with a D or D^*, and only one or two pions. However, once the product of the branching ratios $B \to (D\ or D^{*+}) + \pi(s)$ and $D \to K + \pi(s)$ is taken into account, the the remaining fraction of useful events is less than 0.1%. Moreover, final states with only kaons and pions are likely to be less distinctive for purposes of tagging than those with leptons. Hence, unless it is practical to measure final state pizeros, one finds that reconstructable final states from B decay are extremely rare. Applying our technique offers the possibility of tagging almost two orders of magnitude more B mesons than by seeking out the fully reconstructable final states.

Method for Tagging $D^*l\nu$

An important feature of this technique is that we need to measure only the daughter pion (π_d^+) and the lepton (l^-), as defined above. A schematic picture of the decay is shown in Fig. 1. A secondary vertex is formed by π_d^+ and l^-, and a tertiary vertex is formed by the D^0 where it is shown to decay into a typical final state set of particles. The D^* momentum is obtained by a variation of the "D^* trick". The way this works is that the Q-value for the D^* decay is relatively small, so we use the kinematics that apply in the limit $Q \to 0$ as an approximate measure of the actual situation[4]. The magnitude of the D^{*+} momentum is obtained by scaling up the measured value of the π_d^+ momentum by the kinematic factor (m_D^*/m_π), the ratio of the D^* mass to the π mass. Applying this approximation gives the magnitude of the D^* momentum to an accuracy of about 20%. The D^{*+} direction is taken to be the π_d^+ direction.

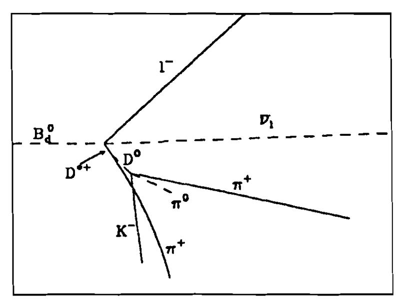

Fig. 1 Sketch of B_d^0 decay into $D^*l\nu$

To isolate candidate (l^-, π_d^+) pairs from the background, we apply the following cuts:

- Require that the lepton have a large transverse momentum relative to the jet axis. This usually means greater than 1 GeV/c.
- With precision tracking, require that the candidate tracks, π_d^+ and l^-, are consistent with coming from a common secondary vertex.
- The lepton and the daughter pion momenta are correlated because they come from a semileptonic B decay. Hence, we require that the mass M_{D^*l} be within prescribed limits determined from monte carlo studies. The cuts we use are: 3.4 GeV $< M_{D^*l} <$ 4.6 GeV.
- The perpendicular components of the pion (π_d^+) and the lepton (l^-) momenta must emerge nearly back-to-back relative to the parent jet axis. This is a consequence of the transverse momentum cut above, and

momentum/energy conservation. We measure the angle between transverse momentum components of l^- and π_d^+ as seen in a plane perpendicular to the jet axis. Monte Carlo studies show that requiring the cosine of this angle to range between -1.0 and -0.7 keeps about 0.85 of the events.

Having selected events as described above, the parent B meson momentum can be estimated by adding the momentum of the D^* to the momentum of the lepton. The momentum of the neutrino is missing in this calculation, but on-the-average this loss amounts to only about 20% of the B momentum. The cut requiring the lepton to have large transverse momentum relative to the jet axis, coupled with momentum/energy conservation, has the effect of minimizing the neutrino momentum.

Clearly, a better measurement of the D^* momentum is obtained if one reconstructs the decay products of the daughter D^0 as well as those of the daughter pion. However, this results in an additional factor of ten or more decrease in statistics due to the small branching ratios of fully reconstructable states, and we defeat our goal of capturing as many events as possible.

Monte Carlo Simulations

A study of this technique for tagging B mesons at the SSC should ultimately be made with a Monte Carlo program that simulates not only the final states at 40 TeV, but incorporates a realistic detector simulation. Lacking this ultimate Monte Carlo, we describe a study of this tagging technique for application at SLC with the SLD detector. In this context, B mesons are produced from Z^0 decays into back-to-back b-quark jets. The SSC enviroment can be expected to include much more complex events that must be unravelled from a high rate background with all the radiation problems anticipated. However, an analysis along the lines described here for Z^0 decays must apply for the SSC as well if there to be any hope for physics based on flavor tagging.

Our detector simulation uses modest assumptions about multiple scattering effects, 5μm position resolution in a precision vertex detector, and good particle identification. With the kinematic cuts described above, we find about 10% of all the $D^*l\nu$ events that result from the decay chain specified. Our cuts are able to reduce the background to a manageable fraction of the signal, but if further background reduction is needed we may tighten the cuts by requiring longer lived decays at the further price of statistics.

The Monte Carlo generator we use assumes $B \to D^*l\nu$ with no additional pions produced in this decay[5]. Additional pions were not seen to have an appreciable effect in studies of this final state from decays of the $\Upsilon(4S)$ [2]. Applying the method described above for estimating the B meson momentum from measurements of the daughter pion and the lepton, we compare this estimate with the true B meson momentum. Figure 2 shows a plot of the difference between the true and the estimated B momentum, divided by the true B momentum, from B mesons that originate from Z^0 decays into two b-quark jets. This shows that on the average 23% of the momentum is lost to the undetected neutrino. The standard deviation of the difference divided by the true momentum is also about 15%, where the this spread comes from the approximations used in this technique. A correlation plot of the true versus the estimated B momentum is shown in Figure 3. These results show that a rough but meaningful estimate of the parent B meson momentum may be obtained by our technique.

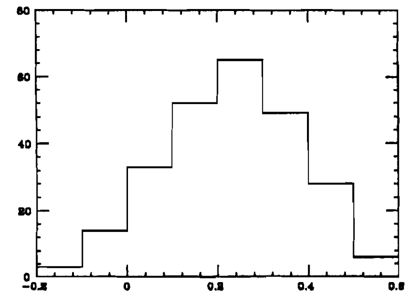

Fig. 2 Histogram of $(P_{true} - P_{est.})/P_{true}$
The mean and standard deviation are:
$\mu = .23$, $\sigma = .15$

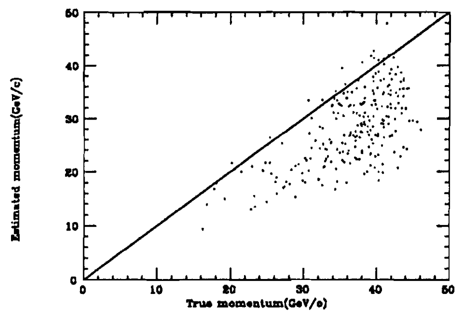

Fig. 3 Scatterplot of $P_{est.}$ vs. P_{true}

Summary and Conclusions

The procedure described above for tagging B mesons via the final state $D^{*+}l^-\nu$ looks promising. The technique is somewhat analogous to "Vee finding", where normally Vees are K^0s or Λ^0s. In the current application, the daughter pion and the lepton form the Vee (see Fig. 1). The combination of particle identification for selecting leptons, and kinematic cuts that cull out our "Vee" events requiring consistency with semileptonic B decay, provides an effective handle on selecting the desired events. The fact that semileptonic branching ratios are large to begin with, and that the D^* subsample is a large fraction of the semileptonic final state, accounts for our estimate that this decay mode represents about 5% of all B decays. The method is also capable of providing a rough measure of the parent B meson momentum. By contrast, the most favorable final states for full reconstruction of B mesons represent less than 0.1% of the total. Hence, for the purpose of tagging Bs and maintaining good statistics, this method seems worth pursuing.

REFERENCES

1. The 5% estimate results from the following assumptions: the ratio of u:d:s quarks are in the ratio of 2:2:1; the branching ratio for semileptonic decays of B mesons is about 0.25; the final state of interest comes only from B_d^0 mesons; the ratio of $D^*/D+D^*$ is about 0.75; the branching ratio of $D^{*+} \to D^0\pi_d^+$ is 0.6.

2. R. Wilson, *b* **Physics**, to be published in Proceedings of 7^{th} Vanderbilt High Energy Physics Conference (May 15 – 17, 1986), World Scientific Publishing Co. (1987), eds. R. S. Panvini and T. J. Weiler; G.B. Word, *Bull. Am. Phys. Soc.* **31**, 790 (1986).
3. *A Study of the Decay* $B \rightarrow \Psi + X$, CLEO preprint, CLNS 86/739.
4. In the $Q \rightarrow 0$ limit, the velocities of the parent D^{*+} and the two daughters, D^0 and π_d^+, are the same. If the velocities are the same, the Lorentz factors are also the same for each particle. From the velocities, $\beta = p/E$, and from the Lorentz factors, $\gamma = E/m$. This leads to the result that the ratio between either the momenta or the energies of any pair of particles is just the ratio of their masses.
5. The event generator used is for these studies is the 1982 version of the LUND Monte Carlo.