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The Merits of a $K^{\pm}$ Tag for the BCD

In the EOI we discussed a lepton tag and hinted at other possibilities. Here we examine the possibility of tagging on the sign of a charged Kaon from the decay of the second B in the event. Such a Kaon would not reconstruct to the primary event vertex. This tag might be combined with a secondary-vertex trigger if the latter can be devised. It certainly could be used with a dilepton trigger, which would be useful in enlarging our samples of tagged $B \to J/\psi X$.

Recall the problem with the lepton tag. Only 20% of the B's decay to an electron or muon; the acceptance for these is only about 40% (due to the P_t cut), and the vertexing efficiency is estimated at 33%. Hence only 2.7% of all decays could be tagged this way. [In the EOI, the 2 chances for an interesting B decay per B-$\bar{B}$ pair are included elsewhere in the bookkeeping.] Furthermore, all tagging will be subject to a $p = 20\%$ mistagging probability due to mixing. The proper figure of merit is $1 - 2p = 60\%$, so the fraction of B decays effectively tagged by the lepton tag is only about 1.6%.

The Kaon tag would be based on the sign of the Kaon arising in the decay chain

$$b \to c \to s \to K^- \quad \text{or} \quad \bar{K}^0.$$

This chain occurs $\sim 95\%$ of the time. [In Table 1 below, we suppose this chain occurs 100% of the time.] However, the $b \to c$ transition includes the emission of a W^-, which can decay to a $\bar{c}s$ combination about 33% of the time; then the $\bar{c}$ decays to a $\bar{s}$ essentially 100% of the time. The $s(\bar{s})$ quark emerges as a $K^-(K^+)$ 50% of the time. The presence of a K^+ could lead to a mistag. In the case of multiple Kaons, I suppose we just choose one at random to be the tagging Kaon, and suffer the consequences. Table 1 summarizes the probabilities of various qualities of tags occurring.

Table 1 ignores the small probability that an $s\bar{s}$ pair is created from glue. This, and some of the 'Bad Tags' listed in the Table 1, could likely be suppressed by a momentum cut, not explored here. There is typically an extra Kaon in B_s decays, which would lead to bad tags. However, B_s decays are useless as tags because of their rapid oscillations; this dilution is already accounted for in the 20% mistagging probability due to mixing.

From Table 1 we see that $45/72 = 62\%$ of all B decays could yield a Kaon tag, but that $7/45 = 16\%$ of these would be a mistag. Actually, we must combine the mistags due to the wrong-sign Kaon with the mistags due to mixing. The total mistagging probability is $(16\%)(80\%) + (84\%)(20\%) = 30\%$. The tagging efficiency is then $1 - 2p = 40\%$. I estimate that the geometrical acceptance for the Kaon tag would be more like 70%, as we wouldn't need as strong a P_t cut as for the leptons. The vertexing efficiency is again about 33%. Hence the effective fraction of B events that could have a Kaon tag is $(70\%)(33\%)(40\%) = 9\%$.

Table 1. Estimates of the efficiency of a tag on the particle/antiparticle character of a B meson based on the sign of Kaons in the B decay.

$b \to c \to s \to$	$b \to W^- \to$	Good Tag Prob.	Bad Tag Prob.	No Tag Prob.
K^-	other	1/3		
K^-	$K^+\bar{K}^0$	1/48	1/48	
K^-	K^+K^-	2/72	1/72	
K^-	$K^0\bar{K}^0$	1/24		
K^-	K^0K^-	1/24		
$\bar{K}^0$	other			1/3
$\bar{K}^0$	$K^+\bar{K}^0$		1/24	
$\bar{K}^0$	K^+K^-	1/48	1/48	
$\bar{K}^0$	$K^0\bar{K}^0$			1/24
$\bar{K}^0$	K^0K^-	1/24		
Total		38/72	7/72	27/72

This is six times higher than the lepton tag. It is fairly likely that we could make this tag work for the $B \to J/\psi X$ events, and so the tagged, reconstructed event sample in the EOI should be multiplied by up to 6. This would improve our sensitivity to $\sin 2\varphi_1$ by 2.4, bringing it down to 0.05, as summarized in Table 2.

If a secondary-vertex trigger could be implemented, we might get this improvement in all tagged, reconstructed event samples.

These arguments reinforce the interest in exploring the trigger and tag in a mini-BCD experiment. Of course, we must have Kaon identification to implement the Kaon tag.

Table 2. Update of Table 11 of the EOI to include a Kaon tag for $B_d^0 \to J/\psi K_S^0$. The minimum values of $\sin 2\varphi$ resolvable to three standard deviations in 10^7 sec of running at luminosity of 10^{32} cm^{-2}sec^{-1}. The dilution factor D due to mixing is given by $x_q \coth(\pi/2x_q)/(1+x_q^2)$.

Angle	Mode	Tag	Tagged Events	$1-2p$	b	x_q	D	$\sin 2\varphi_{\min,3\sigma}$
φ_1	$B_d^0 \to J/\psi K_S^0$	$e^\pm$	14,400	0.60	0.1	0.7	0.47	0.094
φ_1	$B_d^0 \to J/\psi K_S^0$	$K^\pm$	110,000	0.40	0.1	0.7	0.47	0.053
φ_2	$B_d^0 \to \pi^+\pi^-$	$e^\pm$	60,000	0.60	1.0	0.7	0.47	0.062
φ_3	$B_s^0 \to \rho^0 K_S^0$	$e^\pm$	400	0.60	1.0	~ 10	0.64	0.55
φ_3	$B_s^0 \to K^+K^-$	$e^\pm$	1,560	0.60	~ 0.1	~ 10	0.64	0.21