In studies of the decay $B_d^0 \rightarrow J/\psi K^0_S X$ there may be backgrounds due to the decays $B \rightarrow J/\psi K^0_S X$ if $X$ goes undetected or cannot properly be associated with the $B^0$ decay. Decays of any of $B^\pm$, $B_d^0$, or $B_s^0$ can contribute to this background. This problem would be most severe in an analysis in which only the $J/\psi-K^0_S$ mass peak is used as the signal, and no knowledge of the secondary vertices is available.

To estimate the possible problem, we suppose that

$$\Gamma(B^+ \rightarrow J/\psi K^{*+}) = \Gamma(B^0 \rightarrow J/\psi K^{*0}) = 3\Gamma(B^+ \rightarrow J/\psi K^+) = 3\Gamma(B^0 \rightarrow J/\psi K^0).$$

Here we suppose decay to a $K^*$ is 3 times as probable as that for a $K$ because of the multiplicity of spin states. Then to calculate the abundance of $K^0_S$ in these decays we note that

$$\Gamma(K^{*+} \rightarrow \pi^+ K^0_S) = 1/3,$$

$$\Gamma(K^{*0} \rightarrow \pi^0 K^0_S) = 1/6,$$

and, of course,

$$\Gamma(K^0 \rightarrow K^0_S) = 1/2.$$

Then among only those modes listed at the beginning of this paragraph

$$\Gamma(B \rightarrow J/\psi K^0_S X) = 3\Gamma(B_d^0 \rightarrow J/\psi K^0_S).$$

If we also suppose that an extra pion might be added to any of the above decays with probability equal to that of the original decay, we would have

$$\Gamma(B \rightarrow J/\psi X) = 32\Gamma(B_d^0 \rightarrow J/\psi K^0_S),$$

which is close to reported results from CLEO. We then infer that altogether

$$\Gamma(B \rightarrow J/\psi K^0_S X) = 6\Gamma(B_d^0 \rightarrow J/\psi K^0_S).$$
Hence if the invariant mass of the $J/\psi K_S^0$ part of a $J/\psi K_S^0 X$ final state is close to the $B$ mass, the signal of true $B_d^0 \to J/\psi K_S^0$ decays could be hard to see.

If we consider the 3-body decay $B \to \psi K X$, then the invariant mass $M_{\psi K}$ must lie between $M_\psi + M_K$ and $M_B - M_X$. Since $M_X \geq M_\pi$, if we miss the particle(s) $X$, the mass $M_{\psi K}$ must be shifted down from $M_B$ by at least one pion mass.

Our 3-body final state is sometimes reached via a cascade rather than a direct decay. In this case the limits on $M_{\psi K}$ are narrower than the general rule. It turns out that for the cascade $B^0 \to J/\psi K^{*0}; K^{*0} \to K_S^0 \pi^0$, the mass limits are $3.96 \leq M_{\psi K} \leq 5.14 = M_B - M_\pi$ to good accuracy, and that the distribution of masses is roughly uniform over this interval. (See the attached plot.)

Thus we expect that for every true $B^0 \to J/\psi K_S^0$ decay there will be about 6 events of the type $B^0 \to J/\psi K_S^0 X$ with $M_{\psi K}$ spread over a 1.1-GeV interval below the $B$ mass. So long as the $B$-mass resolution is roughly $M_\pi$ or better this will not be a significant background.

The decay $B_s^0 \to J/\psi K_S^0$ will be a background for $B_d^0 \to J/\psi K_S^0$ if the mass resolution is not good enough. This would be very annoying for CP-violation studies. The decay $B_s^0 \to J/\psi K^{*0}$ is slightly troublesome in that the upper end point of the 1.1-GeV-wide spectrum of $M_{\psi K}$ could be very nearly equal to $M_B$, depending on the exact value of $M_{B_s}$. But only a high-statistics experiment would ever have to worry about this!
$B^0 \rightarrow \psi K^{*0}$

$\rightarrow K^0 \pi^0$

$0.0 \rightarrow 6.000$

$3.96 \rightarrow \text{mass missing } n0$

$M(\psi K^0) \approx M_B - M_{\pi}$
Combinatoric Background to $B_d^0 \rightarrow J/\psi K_S^0$

In studies of the decay $B_d^0 \rightarrow J/\psi K_S^0$ there may be backgrounds due to the decays $B \rightarrow J/\psi X$ in which the $J/\psi$ is combined with a $K_S^0$ from the rest of the event to yield an invariant mass near that of the $B$.

This background will be suppressed by a vertex detector in two ways:

1. If the $K_S^0$ can be required to have the same secondary vertex as the $J/\psi$ there will be essentially no combinatoric background. However, since the $K_S^0$ may travel a considerable distance before decaying, the pointing accuracy from its decay tracks may not be sufficient to distinguish whether it originated at the primary or at the $B$ vertex. Monte Carlo simulation is required to clarify this.

2. In many of the decays $B \rightarrow J/\psi X$, the state $X$ will include one or more charged tracks emanating from the $B$ vertex. If these are found in the vertex detector, the event can be removed from the $B_d^0 \rightarrow J/\psi K_S^0$ candidates.

Nonetheless, it is interesting to explore the combinatoric background problem, as this helps answer the question: can we find $B_d^0 \rightarrow J/\psi K_S^0$ at a hadron collider even without a vertex detector?

We have generated a set of 4000 events using ISAJET at 1800-GeV center-of-mass energy, in which each event has one $B_d^0 \rightarrow J/\psi K_S^0$ decay. Figures 1 and 2 show the invariant mass for all $J/\psi - K_S^0$ combinations, and for those not including the $B$-decay products. We see that the signal for $B_d^0 \rightarrow J/\psi K_S^0$ is about 100 times that of the combinatoric background in a 25-MeV/$c^2$ bin. If the mass resolution at the $B$ is 25 MeV/$c^2$, we should consider the background over 4 bins, reducing the signal-to-background ratio to 25/1.

Note that

$$\frac{\Gamma(B \rightarrow J/\psi X)}{\Gamma(B_d^0 \rightarrow J/\psi K_S^0)} \sim 30.$$ 

If so, our calculation indicates that the signal-to-background is effectively 1/1 (since we only generated events with a $B_d^0 \rightarrow J/\psi K_S^0$ decay).

Figure 3 shows the combinatoric background with the restriction that both the $J/\psi$ and the $K_S^0$ are within $-1 < \eta < 1$, as for the CDF acceptance. We see that the signal-to-background is improved by a factor of 4, and hence we estimate that
even without a vertex detector, CDF should be able to reconstruct $B_d^0 \rightarrow J/\psi K_s^0$
with signal-to-background of 4/1 if their mass resolution is 25 MeV/c^2.
Figure 1

4000 ISAJET EVENTS \Gamma_s = 1.8 \text{ TeV}

\omega^0 \rightarrow \psi' K^0 \bar{K}^0 \text{ event}

M(J/\psi-K\text{short}) All K\text{short}
Figure 2

$M(J/\psi-K_{short})$ $K_{short}$ not from $B$ decay
Figure 8
-1 < \eta < 1 \text{ for } \theta / \phi < \frac{3}{5}

\log_{10} M(J/\psi - K_{short}) \text{ All } K_{short}