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J. C. Wang
S. Stone
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Study of $B^o \to \phi K_s$

Abstract

The Decay mode $B^o \to \phi K_s$ can be used to look for physics beyond the Standard Model. We show that the reconstructed signal would be 2400 events per year, with a signal to background ratio of about 6.5. The effects of possible alternative configurations of the pixel detector are also shown.

1 Introduction

The CP asymmetry in the Standard Model for $B^o \to \phi K_s$ is the same as for $B^o \to J/\psi K_s$. The asymmetry is generated by the interference of the $B^o - \overline{B}^o$ mixed decay with the direct unmixed decay (see Fig. 1). In both cases the decay phases are negligible and the mixing phase generates an asymmetry of magnitude $\sin(2\beta)$ times $\sin(\Delta m t)$, where Δm is the $B_H - B_L$ mass difference and t the proper time.

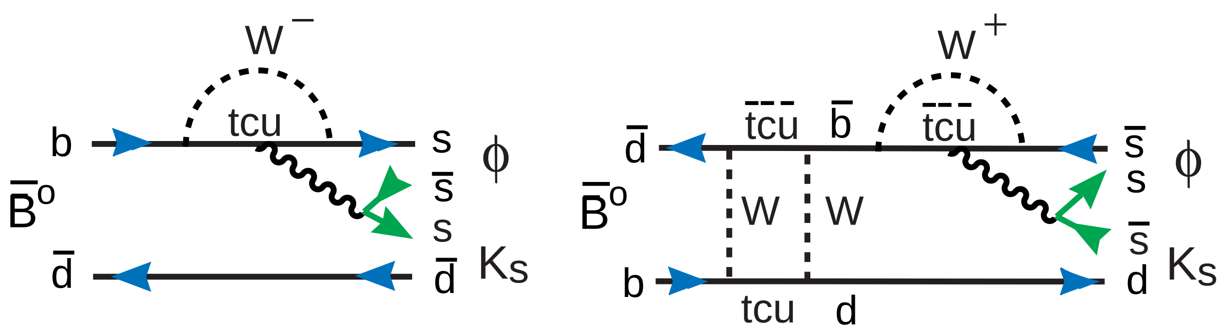

Figure 1: The diagrams of decay $B^o \to \phi K_s$.

In models containing new physics both the mixing amplitude and the decay amplitude can be modified by new phases. However, the $J/\psi K_s$ decay being tree level does not usually pick up any new phase, while the loop level ϕK_s decay is likely to have a new phase. Then the CP asymmetry in $B^o \to J/\psi K_s$ becomes proportional to $\sin(2\beta + \theta_D)$, while in $B^o \to \phi K_s$ we have $\sin(2\beta + \theta_D + \theta_A)$. Thus a measurement of the difference in CP asymmetries between these two modes would definitively demonstrate new physics and measure the decay phase θ_A of the new physics [1].

In this note, we estimate the signal yield and signal to background ratio that can be achieved with BTeV detector. We also show the effect of different pixel detector geometries.

2 Signal selection

The signal we are studying is the decay of $B^o \to \phi K_s$, where $\phi \to K^+K^-$, and $K_s \to \pi^+\pi^-$. The CLEO experiment recently measured $B^o \to \phi K^o$ branching fraction to be $(5.4^{+3.7}_{-2.7} \pm 0.7) \times 10^{-6}$ [2]. The BaBar experiment also published a measurement with the branching fraction of $(8.1^{+3.1}_{-2.5} \pm 0.8) \times 10^{-6}$ [3]. We use the average number of 6.9×10^{-6} in this note. At nominal luminosity, the BTeV experiment will produce about 1.9×10^5 signal events per year.

In this study we use a sample equivalent to one year of running. Signal events are generated using Pythia and QQ, and then passed through the MCFast BTeV detector simulation.

For ϕ reconstruction, we require that both tracks are identified as kaon by the RICH detector. Each track must have more than 20 hits in tracking system and at least 4 hits in silicon detector. The track momentum (p) is required to be greater than 4 GeV/c, with transverse momentum (p_T) greater than 0.2 GeV/c, and at least one of the two tracks has a p_T greater than 0.4 GeV/c.

Since a significant portion of K_s decay outside the pixel detector, we apply looser criteria on the $\pi^\pm$ than on $K^\pm$ selection. Tracks are required to have more than 10 hits in tracking system, the distance of closest approach (DCA) must be larger than 3 standard deviations, $p > 2$ GeV/c, $p_T > 0.2$ GeV/c, and at least one track with $p_T > 0.4$ GeV/c.

The ϕ vertex is reconstructed from opposite charged kaon tracks. The vertex fit is required to have acceptable quality ($prob\ (\chi^2) > 0.01$). A ϕ candidate is accepted if the invariant mass is consistent with the nominal value within 3 standard deviations. With the baseline pixel detector geometry, the ϕ mass resolution is about 3.9 MeV. The ϕ candidate is then kinematically fitted using the ϕ mass constraint. The K_s reconstruction is similar with mass resolution about 3.7 MeV. To reconstruct a B^o, all four tracks are required to be from the same hemisphere.

In many other cases like $B \to J/\psi K_s$ decay, the vertex of $J/\psi \to \mu^+\mu^-$ can be used as B decay vertex. In this study, however, we use different method. This is because of the poor resolution of ϕ decay vertex due to the low Q value in $\phi \to K^+K^-$ decay. After boosting into lab frame, the two tracks are nearly in same direction. Although the magnetic field bending separates the two tracks enough to ensure the quality of momentum measurement, the vertex resolution along ϕ boost direction is very poor. The three dimension vertex resolution is about (290, 290, 4800) μm. In comparison, J/ψ vertex resolution is about (26, 26, 250) μm in $B \to J/\psi K_s$ decay, and K_s vertex resolution is about (130, 130, 2000) μm.

Since we have fully reconstructed both ϕ and K_s, we can use their trajectories to form a real B decay vertex. This significantly improves the B vertex resolution to be (63, 69, 1040) μm. This directly reflects in the decay length significance plot as shown in Fig. 2. By requiring significance greater than 3, the detached vertex efficiency is 79% using this vertex method, instead of 39% with only the ϕ vertex.

With further background suppression which will be discussed in next section, the signal reconstructed per year is about 2400, and the B invariant mass resolution is about 18 MeV.

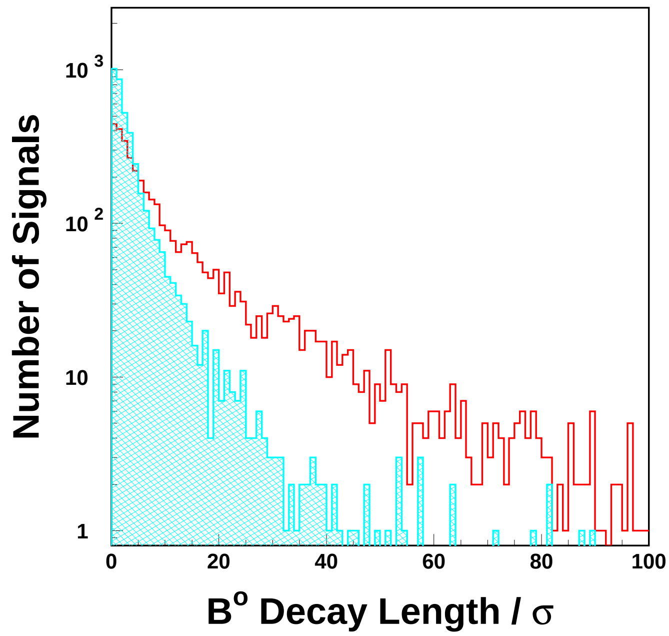

Figure 2: The distributions of decay length over its resolution with two different methods. Using only ϕ vertex as B^o decay vertex is shown in hatched histogram, and using vertex reconstructed from ϕ and K_s trajectories is shown in unhatched histogram.

3 Background estimation

Since we require kaon identification in the RICH detector, and that the two kaons form a good vertex, the fake rate in the ϕ signal is negligible. For K_s, we require that the pions are not from a primary vertex, this minimizes the possibility of fake K_s. And also we require the B^o vertex detached from primary vertex. Thus the main background source is combinations of real ϕ's and K_s's from b decays.

In generic $b\bar{b}$ events, about 80% of ϕ and 83% of K_s are produced at the interaction point either from fragmentation or immediate decay of other prompt particles. They can be eliminated with DCA cut. Although the quality of B vertex and detached B vertex requirement can also suppress the background from this source, the DCA cut is more direct and powerful especially for preselection on background events at the generator level.

In the event preselection, we only consider combination of ϕ and K_s with invariant mass around B^o mass. We do not consider misreconstructed ϕ or K_s. However, the preselected events still contain possible misreconstructed ϕ and K_s. In the reconstruction, we don't require the ϕ and K_s to be real. We found that there is no contribution from misreconstructed ϕ or K_s.

Shown in Fig. 3.a and 3.b are ϕ and K_s DCA distributions with background and signal events. DCA greater than 3 standard deviations is applied. Please note that most of the prompt ϕ and K_s are rejected at generator level. In a separate test with small amount of events but with all ϕ and K_s considered, the background distribution peaks sharply at 0.

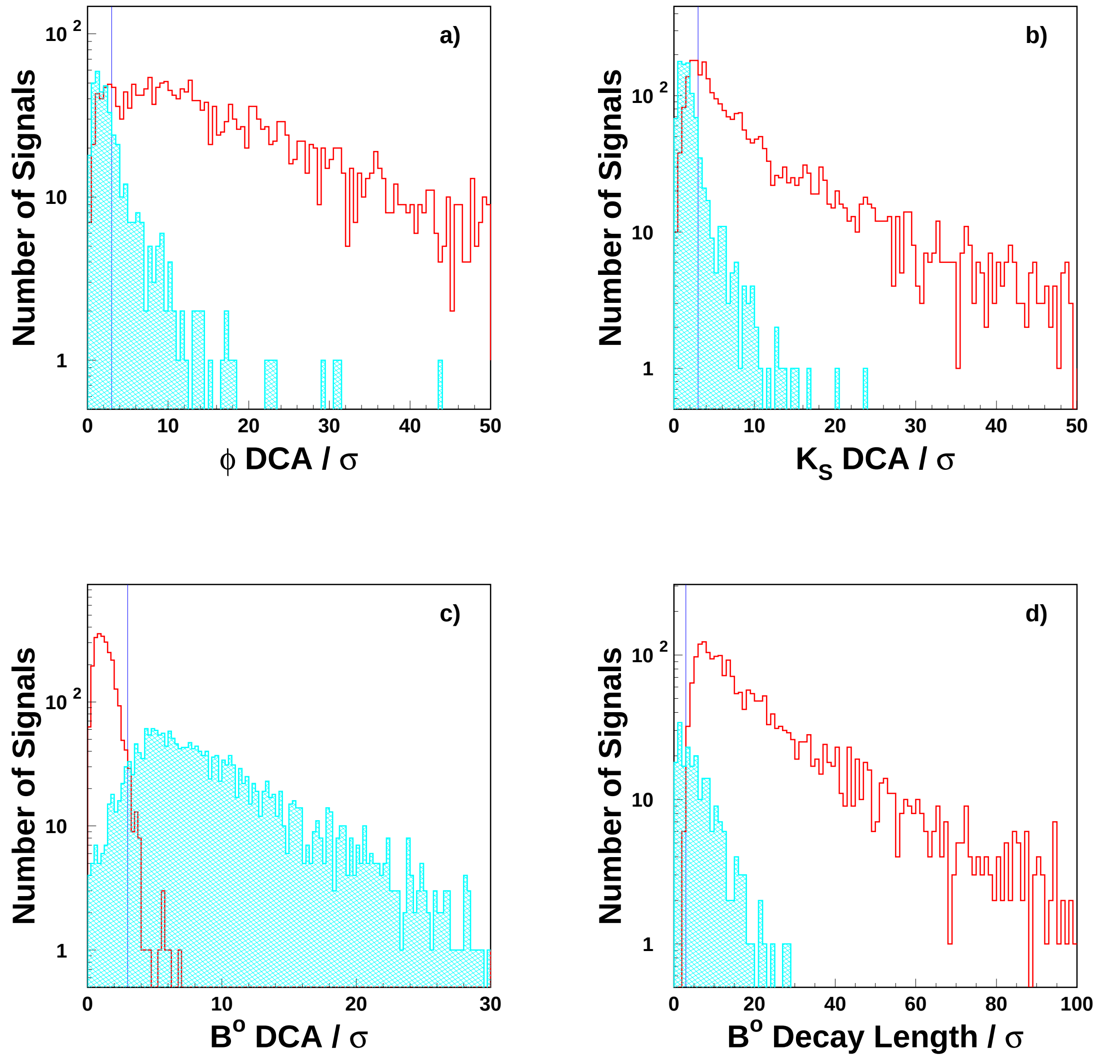

Figure 3: Distributions of four important parameters over their resolution used to suppress the background: distances of closest approach (DCA) with respect to the primary vertex for a) ϕ, b) K_s, and c) B^o, and d) the decay length significance of B^o, where all the rest of selection criteria includes the other three in the plot are applied. Shown in unhatched are signal and hatched for background.

We calculate the DCA for reconstructed B^o with respect to primary vertex. DCA value of zero means that the momentum direction of the reconstructed B^o is consistent with the flight direction determined by vertex reconstructed. As shown in Fig. 3.c, we require that the DCA is consistent with 0 within 3 standard deviations.

Fig. 3.d shows the B^o decay length over its resolution measured between primary vertex and ϕK_s vertex. Since the resolution is about 660 μm, worse than most interesting channels, we currently put a cut at significance of 3. A slightly tighter cut will not reduce the efficiency significantly.

With about 10% of a year run background simulated, we estimate that about 360 background per year. The signal to noise ratio is about 6.5. The B^o invariant mass distribution is shown in Fig. 4, where the background events is properly scaled.

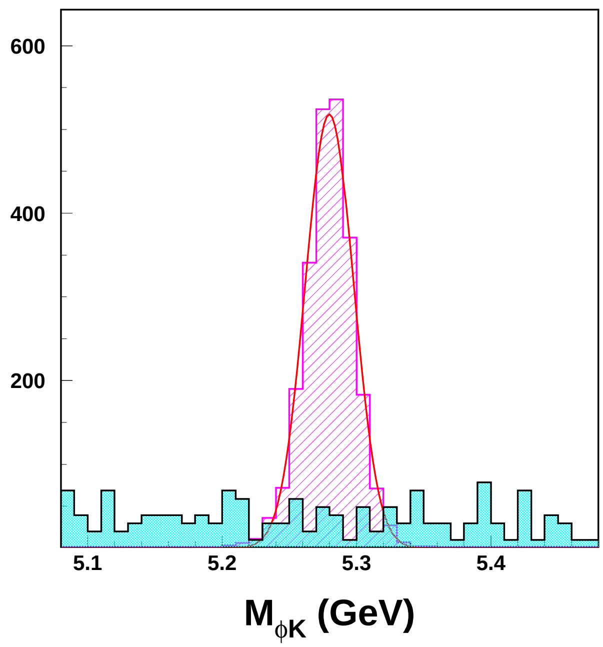

Figure 4: The distribution of ϕK_s invariant mass around B^o mass for signal in hatched and solid for background. The signal is equivalent to one year of running, and the background is properly normalized.

4 Effects of different pixel configurations

The baseline setting of pixel detector is used in the simulation shown in previous sections. In total there are 31 stations with 4.25 cm interval between stations along z direction. Each station consists of two planes measuring x and y respectively. The size of each plane is 10×10 cm^2 with 1.2×1.2 cm^2 square hole in the center.

The effect of the geometry configurations on physics reach has been studied by Penny in decays $B_s \to D_s K$ and $B^o \to K\pi$ [4]. In this section, we study reconstruction efficiency, time resolution, and trigger efficiency in $B^o \to \phi K_s$ decay.

Since in the trigger algorithm, external triplets are searched only in bending view (Y-plane), reducing the size of the non-bend view (X-plane) is expected to have little impact on trigger rate and reconstruction efficiency. In the first test, we reduce the size of X-plane and keep the Y-plane the nominal size. We change the size of X-plane from 10 cm down to 1 cm, where 1 cm really means that there is no X-plane at all. The reconstruction efficiency decreases about 15% from size of 5 to 1 cm. It is nearly constant with size of X-plane between 5 to 10 cm, as shown in Fig. 5.a.

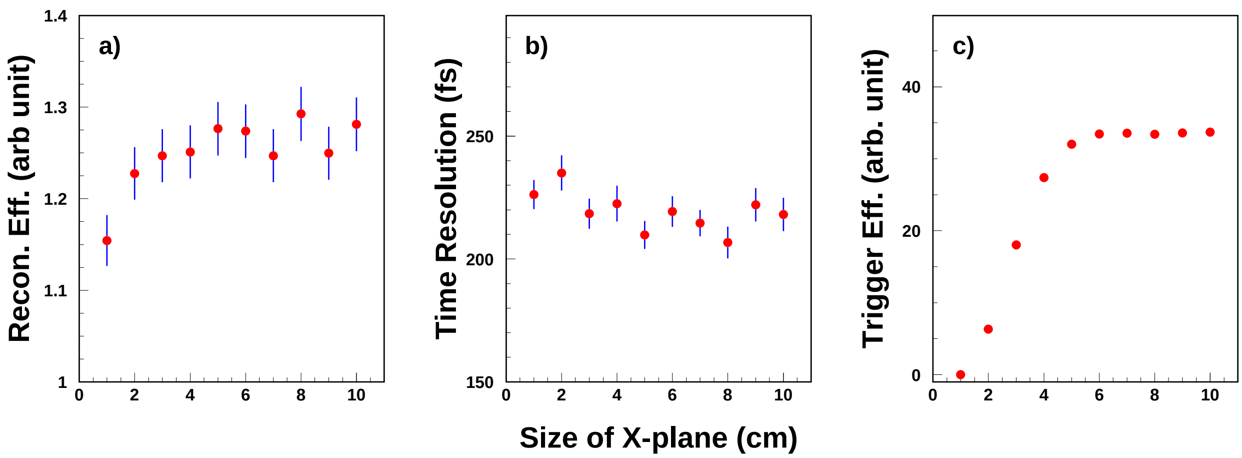

Figure 5: The effect of X-plane pixel detector size on a) $B^o \to \phi K_s$ reconstruction efficiency, b) B decay time resolution, and c) trigger efficiency.

In Fig. 5.b we show the B decay time resolution, where the decay time is defined as $t = L \times M/p$. The resolution does not deteriorate much when decreasing the size of X-plane. The reason is that the decay length error is dominated by vertex error on z direction which is still confined by y resolution when x-resolution is poor. Checking the primary vertex, we found the x resolution worsen by a factor of two when no X-plane presented, while the y resolution is nearly untouched and z resolution worsen by 38%.

The trigger efficiency has a sharp decrease from 5 cm to 1 cm as shown in Fig. 5.c. This is because that in trigger algorithm, hits in the non-bend view are required to reject fake tracks.

In the second test, we keep the size of X-plane and Y-plane be the same, and change the size of both planes, shown in Fig. 6. The reconstruction efficiency and time resolution changes more significantly than with only X-plane size varies.

When reducing the size of both planes, there are less hits and thus the trigger efficiency is reduced. With increasing the size, at certain level the number of hits is enough for trigger and the efficiency is relatively constant. With even larger size, the effect of multiple scattering and secondary interaction deteriorate the reconstruction and thus the trigger efficiency drops. It is interesting to see that the optimal size is about 11 cm.

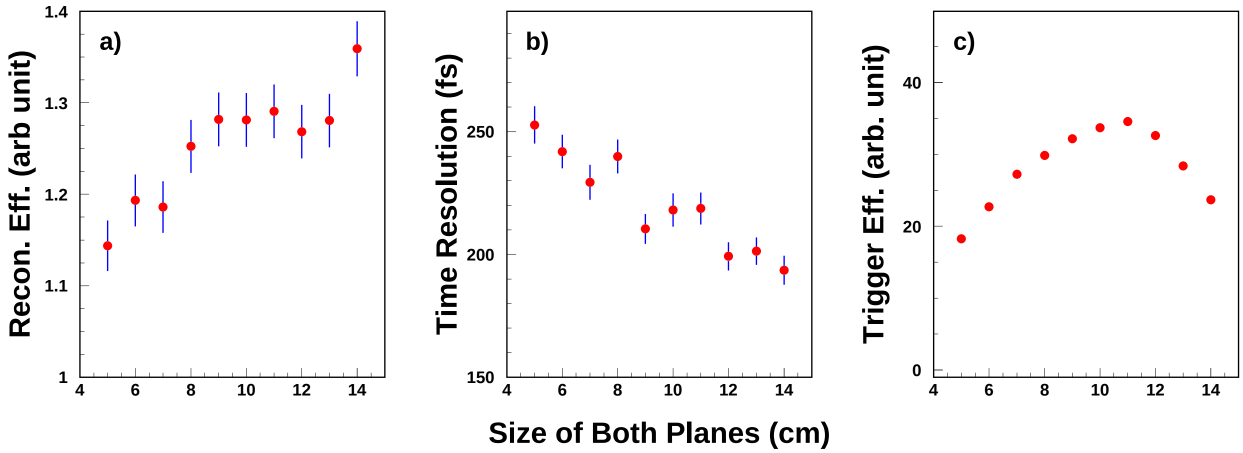

Figure 6: The effect of pixel detector size of both planes on a) $B^o \to \phi K_s$ reconstruction efficiency, b) B decay time resolution, and c) trigger efficiency.

5 Conclusions

With baseline setting of BTeV detector, we can reconstruct about 2400 $B^o \to \phi K_s, \phi \to K^+K^-$, and $K_s \to \pi^+\pi^-$ signals. The signal to background ratio is estimated to be about 6.5.

The pixel detector geometry has impact on reconstruction efficiency, time resolution and trigger efficiency. However, this is a very special mode with very bad time resolution, the smaller size of X-plane does not degrade the resolution and efficiency much. We need to study more modes to decide whether it is a wise choice.

References

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