DØ Note 4581-CONF

# Reconstruction of the $B_s^0 \to D_s^- \mu^+ X$ ($D_s^- \to K^{*0} K^-$ ) decay at DØ

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The semileptonic $B_s^0 \to D_s^- \mu^+ X$ decay into the $D_s^- \to K^{*0} K^-$ ($K^{*0} \to K^+ \pi^-$) final state was reconstructed at DØ using $\sim$ 200 pb$^{-1}$ of data collected during the April 2002 - September 2003 period. The details of the selection criteria are presented in this note.

*Preliminary Results for DPF 2004*

## I. INTRODUCTION

Measurement of the $B_s^0$ oscillation frequency via $B_s^0 - \bar{B}_s^0$ mixing analyses provides a powerful constraint on the CKM matrix elements. The oscillation frequency is proportional to the mass difference between the mass eigenstates, $\Delta m_s$, and is related to the CKM matrix through $\Delta m_s \sim |V_{tb}V_{ts}|$. When combined with the $B_d^0$ mass difference, $\Delta m_s$ helps in the extraction of $|V_{td}|$, and thereby the $CP$ violating phase.

Reconstructing $B_s^0$ decays into different final states forms the first step in a $B_s^0 - \bar{B}_s^0$ mixing analysis. Two semileptonic $B_s^0 \rightarrow D_s^- \mu^+ X$ [1] decays are currently being studied at DØ — the $D_s^- \rightarrow \phi\pi^-$ mode and the $D_s^- \rightarrow K^{*0}K^-$ mode. Details of the reconstruction of the semileptonic $B_s^0 \rightarrow D_s^- \mu^+ X$ decay into the $D_s^- \rightarrow K^{*0}K^-$ final state using data from the upgraded RunII DØ detector are presented here. This decay mode has a branching ratio ($\mathcal{B} = 3.3 \pm 0.9\%$) that is comparable to the $D_s^- \rightarrow \phi\pi^-$ mode ($\mathcal{B} = 3.6 \pm 0.9\%$) [1] and its reconstruction, therefore, is expected to significantly increase the total $B_s^0 \rightarrow D_s^- \mu^+ X$ yield for use in $B_s^0 - \bar{B}_s^0$ mixing analyses.

## II. DATA SAMPLE

The analysis uses $\sim 200$ pb$^{-1}$ of data collected during the April 2002 - September 2003 period. The large muon acceptance and forward tracking coverage of the DØ detector (pseudorapidity coverage of $|\eta| < 2.0$ for the muon, $|\eta| < 1.7$ for the tracking and $|\eta| < 3.0$ for the silicon subdetectors) were utilized to produce a large sample ($\sim 172$ million events) as input to this analysis.

## III. RECONSTRUCTION

The first step in the reconstruction of the $B_s^0 \rightarrow D_s^- \mu^+ X$ decay involved determining the primary vertex (PV) of the event using the average PV of the run from the beamspot database as the initial seed. Tracks were required to have at least two hits in the SMT detector, two hits in the CFT detector and $\chi^2 < 10.0$. $D_s^- \mu^+$ candidates were obtained using the requirement that the tracks came from the same jet (a geometric cone of $\Delta\mathcal{R} = 2$ was used to define the clustering of charged tracks in jets). The final state reconstruction began with a search for $K^{*0}$ candidates. These candidates were reconstructed in the $K^{*0} \rightarrow K^+\pi^-$ mode. Two oppositely charged tracks with $p_T > 1.0$ GeV/$c$ were assigned the kaon and pion mass and vertexed to produce a $K^{*0}$. These kaon and pion tracks were required to be within 90° from the muon. Further, each $K^{*0}$ candidate was required to have a mass in the 0.75-1.02 GeV/$c^2$ range. The $K^{*0}$ candidate was then combined with another track with $p_T > 1.0$ GeV/$c$ that had a kaon mass assignment and a charge that was opposite to the charge of the kaon from the $K^{*0}$ decay. The combination yielded a $D_s^-$ candidate. Only $D_s^-$ candidates in the mass range $1.5 < m_{D_s^-} < 2.5$ GeV/$c^2$ were kept. The reconstructed $D_s^-$ track was then combined with the muon candidate to produce a $B_s^0$ vertex requiring $2.2 < m_{B_s^0} < 5.5$ GeV/$c^2$. Additionally, the muon and pion were required to have opposite charges to ensure that we picked up the "right-sign" combination ($(K^\pm\pi^\mp)K^\mp\mu^\pm$ combinations).

For background suppression we tightened some of the above cuts and introduced some additional ones. These cuts are listed below:

- We required $p_\mu > 3$ GeV/$c$, $p_{D_s^- + \mu} > 8$ GeV/$c$ and $p_T^{\mu \text{ rel. } D_s^-} > 1.0$ GeV/$c$, where $p_\mu$ is the muon momentum, $p_{D_s^- + \mu}$ is the momentum of the $D_s^- \mu$ system and $p_T^{\mu \text{ rel. } D_s^-}$ is the muon $p_T$ relative to the $D_s^-$.
- At least one of the kaon or pion tracks was required to have $(\text{dca}/\sigma_{\text{dca}})^2 + (\text{zca}/\sigma_{\text{zca}})^2 > 5$, where dca (zca) is the axial ($z$) component of the track impact parameter with respect to the PV and $\sigma_{\text{dca}}$ ($\sigma_{\text{zca}}$) its uncertainty. The pion track was required to have at least $(\text{dca}/\sigma_{\text{dca}})^2 + (\text{zca}/\sigma_{\text{zca}})^2 > 2$. Additionally, loose cuts were applied on the the maximum allowed dca(zca): $\text{dca}_{\mu,\text{K},\pi} < 0.25$ cm and $\text{zca}_{\mu,\text{K},\pi} < 0.4$ cm .
- We cut on the distance between the PV and the $D_s^-$ decay vertex in the axial ($xy$) plane: $\ell_{D_s}^{xy} / \sigma_{\ell_{D_s}^{xy}} > 4$.
- Except for the cases where the $D_s^-$ meson decay length was consistent with zero, we rejected candidates when the $B_s^0$ meson had travelled further than the $D_s^-$ meson in the xy plane; if $|\ell_{B_s^0}^{xy}| > |\ell_{D_s^-}^{xy}|$, we kept the candidate only if $|\ell_{B_s^0 D_s^-}^{xy}| / \sigma_{\ell_{B_s^0 D_s^-}^{xy}} < 3$.

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[1] Conjugate modes are implied throughout the note.

- We cut on the angle between the $B_s^0$ and $D_s^-$ directions, defined by the PV and the $B_s^0$ and $D_s^-$ vertices: $\cos(\vec{B}_s^0, \vec{D}_s^-) > 0.95$.
- We rejected $D_s^-$ candidates with a negative $xy$-distance from the PV: $\vec{\ell}^{xy}_{D_s^-} \cdot \vec{p}_{D_s^-} > 0$.
- We applied $B_s^0$, $D_s^-$ and $K^{*0}$ vertex fit cuts : $\chi^2 < 20$.
- We tightened the mass cut for the $K^{*0}$ candidate: $0.84 < M_{K^{*0}} < 0.96$ GeV/$c^2$.
- We applied a cut $|\cos\psi| > 0.60$ where $\psi$ is the helicity angle (angle between the kaon coming from the $K^{*0}$ decay and the $D_s$ in the $K^{*0}$ rest frame).

Figure 1 shows the $K^{*0}K^-$ invariant mass distribution in data after applying all the selection cuts. Distributions for both the "right-sign" $D_s^-\mu^+$ combinations ($Q_\mu * Q_\pi < 0$) and the "wrong-sign" $D_s^-\mu^-$ combinations ($Q_\mu * Q_\pi > 0$) are shown. The strategy used for fitting is described in the next section.

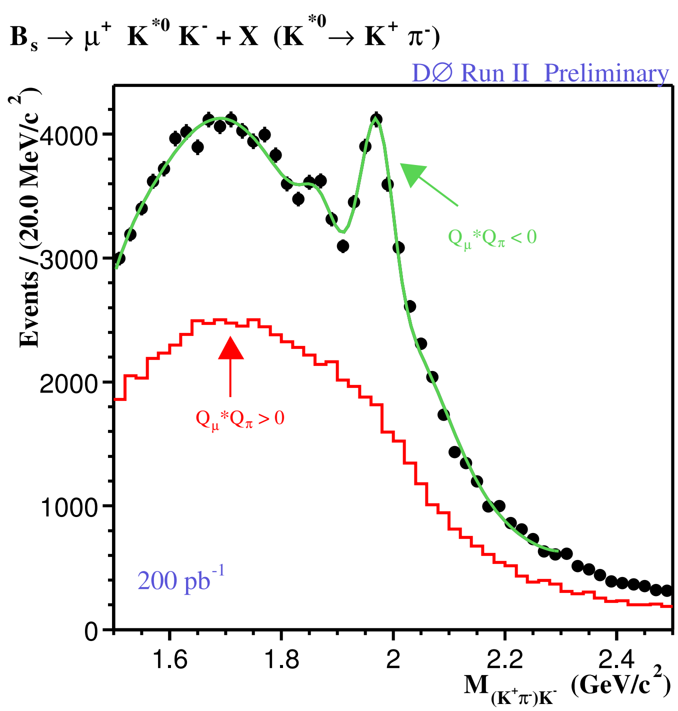


FIG. 1: Distribution of the mass of $D_s^- \to K^{*0}K^-$ candidates in data ($\sim 200$ pb$^{-1}$) after all the selection cuts. Both "right-sign" ($Q_\mu * Q_\pi < 0$) and "wrong-sign" ($Q_\mu * Q_\pi > 0$) combinations are shown.

## IV. FITTING STRATEGY

A gaussian was used to describe the $D_s^- \to K^{*0}K^-$ signal in data and the mean and width ($\sigma$) of this gaussian along with the normalization were obtained from the total fit. The results from fitting the "wrong-sign" combinations with a polynomial of degree four were taken as the initial seed for the background parameters when fitting the total (signal+ combinatorial background). All the background parameters were then allowed to float in the total fit. Additionally, to extract an accurate normalization, the following potential reflections were studied using Monte Carlo samples and then parameterized in the total fit:

- $D^- \to K^+\pi^-\pi^-$ [$\mathcal{B} = 9.1 \pm 0.6\%$]
  A Monte Carlo sample for the Dalitz decay which took into account all the underlying amplitudes ($K^{*0}(892)\pi^-$, $K^{*0}(1430)\pi^-$ and $K^{*0}(1680)\pi^-$ resonances and $K^+\pi^-\pi^-_{\text{non-resonant}}$) and the interference between them was generated and used for the study. The mode which poses the biggest background is $K^{*0}(892)\pi^-$ ($\mathcal{B} = 1.28 \pm$

0.13%), where the pion could be mis-identified as a kaon. The other resonances should have smaller impact since we imposed a cut on the mass of the $K^+\pi^-$ combination. Given that we accept all $K^+\pi^-$ combinations in the $K^{*0}$ mass region, the non-resonant contribution could also make an impact since its branching fraction is quite large ($\mathcal{B} \sim 8.6\%$). However, the mass region occupied by the $K^{*0}$ is much smaller than the phase space available to the $K^+\pi^-$ combinations, and thus the impact should be small. The $|\cos\psi| > 0.60$ helicity cut should further reduce the non-resonant contribution. The $D_s^- \to K^{*0}K^-$ reconstruction code was run on this sample and the shape of the $D^-$ reflection thus obtained from Monte Carlo was used when fitting data.

- $D^- \to K^{*0}K^-(K^{*0} \to K^+\pi^-)$ $[\mathcal{B} = (2.8 \pm 0.4) \times 10^{-3}]$
  This decay has a final state identical to the $D_s^- \to K^{*0}K^-$ signal. Therefore, when fitting data, this mode was parameterized by a gaussian with its mean fixed at the $D^\pm$ mass and a width equal to that of the $D_s^- \to K^{*0}K^-$ gaussian. The normalization of the gaussian was obtained from the final fit.

- $D_s^- \to K^{*0}K^-\pi^0$ and $D_s^- \to K^{*0}K^{*-}(K^{*-} \to \bar{K}^0\pi^-)$
  For completeness we also considered the above decay modes. Neither was expected to peak in the signal region, but including them allowed for a better understanding of the shape below the $D_s^-$ peak.

We also studied possible contamination arising from other $D_s^-$ decay modes, namely $D_s^- \to \phi\pi^-$ and the non-resonant $D_s^- \to K^+K^-\pi^-$ decays. We estimate that $\sim$ 300 such events could be mis-reconstructed as the signal. However, since these events do not affect the yield for mixing studies, we have not parameterized them in the total fit.

Figure 2 shows the same $D_s^- \to K^{*0}K^-$ invariant mass distribution as was shown in Figure 1. In this plot the contribution of all the reflections discussed above are shown separately. The total fit gave an estimated $4933 \pm 376$ $D_s^- \to K^{*0}K^-$ signal events centered at 1.966 GeV/$c^2$, and a width of $\sim 30\ MeV$.

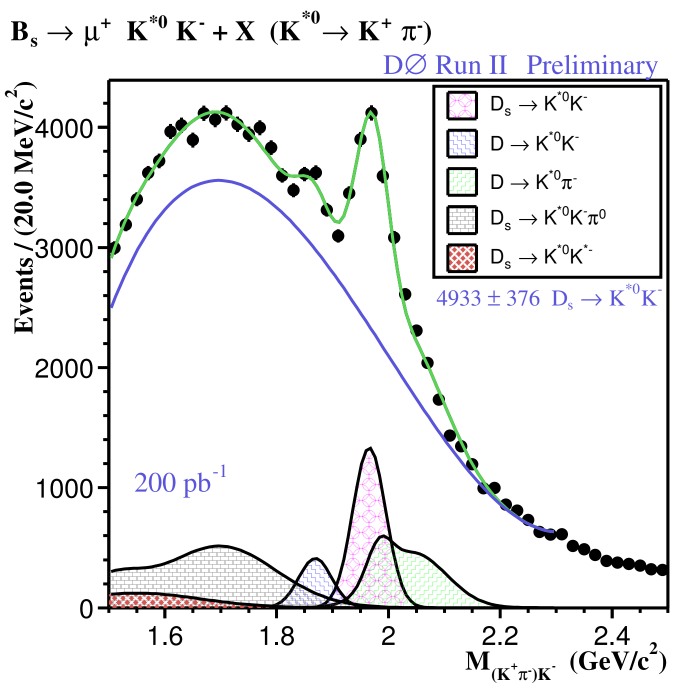


FIG. 2: Distribution of the mass of $D_s^- \to K^{*0}K^-$ candidates in data ($\sim 200$ pb$^{-1}$). There is a clear $D_s^- \to K^{*0}K^-$ signal peak at 1.966 GeV/$c^2$. The various reflections and their individual contribution to the total fit are given by the legend description.

## V. SUMMARY

The $B_s^0 \to D_s^-\mu^+X$ decay into the $D_s^- \to K^{*0}K^-$ $(K^{*0} \to K^+\pi^-)$ final state was reconstructed at DØ using $\sim$ 200 pb$^{-1}$ of data. A total of $4933 \pm 376$ signal events ( $\sim$ 25 events per pb$^{-1}$ on average) were obtained using the selection criteria described in this note.

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[1] The Review of Particle Physics by the Particle Data Group, S.Eidelman *et al.*, Phys. Lett. **B592**, 1 (2004).