



## Evidence of $B_s \rightarrow D_{s1}^{\pm}(2536)\mu\nu X$ at DØ

The DØ Collaboration  
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The decay  $B_s \rightarrow D_{s1}^{\pm}(2536)\mu\nu X$  has been observed by DØ through the decay channel  $D_{s1}^{\pm}(2536) \rightarrow D^{*\pm}K_S^0$  with  $D^{*+} \rightarrow D^0\pi^+$ ,  $D^0 \rightarrow K^-\pi^+$  and  $K_S^0 \rightarrow \pi^+\pi^-$  with significance of greater than 3.0 sigma using 485 pb<sup>-1</sup> of integrated luminosity. The observation of this signal demonstrates the potential for DØ to be able to measure production of this state and its properties.

*Preliminary Results for Winter 2005 Conferences*

## I. INTRODUCTION

$D_{s1}^{\pm}(2536)$ , a  $D$  meson consisting of a charm and strange quark in an orbitally excited state, has been detected in the decay of the  $B_s$  meson. In the limit  $m_c \gg \Lambda_{QCD}$ , the quarks in this state have well defined quantum numbers, with  $L = 1$  and  $S = 1/2$  [1]. The resulting  $D_s^{**}$  doublet of narrow width with  $j_q = 3/2$  is made up of the states  $D_{s2}^{\pm}(2573)$  and  $D_{s1}^{\pm}(2536)$ .  $j_q$  is defined as the total angular momentum of the light quark plus all the gluons binding the state.

Being a  $J^P = 1^+$  state, the  $D_{s1}^{\pm}(2536)$  can decay only into a  $D^*$  ( $J^P = 1^-$ ) and  $K$  meson ( $J^P = 0^-$ ) to conserve angular momentum and parity in a D-wave decay (relative angular momentum  $L = 2$ ). Due to the angular momentum barrier, this particle is expected to have a narrow decay width [2]. The state  $D_{s1}^{\pm}(2536)$  is just above the  $D^* K_S^0$  mass threshold.

Table I shows the predicted decay channels for the  $j_q = 3/2$  doublet with expected branching ratios as found in EvtGen [3]. There are no experimental measurements of these branching ratios. We expect to see almost no contribution from the state  $D_{s2}^{\pm}(2573)$ .

State	Decay Products	Fraction
$D_{s1}^{\pm}(2536)$	$D^{*+} K_S^0$	0.5
	$D^{*0} K^+$	0.5
$D_{s2}^{\pm}(2573)$	$D^{*+} K_S^0$	0.05
	$D^{*0} K^+$	0.05
	$D^+ K_S^0$	0.43
	$D^0 K^+$	0.47

TABLE I: Expected decay fractions of  $j_q = 3/2$  doublet [3].

## II. EVENT SELECTION

The offline filter preselected events with a muon and  $D^0$  from all data processed before February 2005. Information only from the muon and tracking systems was used in this analysis. The events were reconstructed without any particular trigger selections; however the majority of the selected events satisfied single muon trigger requirements. The data sample corresponds to an integrated luminosity of 485 pb $^{-1}$ .

Evidence of  $D_{s1}^{\pm}(2536)$  mesons was found in decays of  $B \rightarrow \mu\nu D_s^{**} X$  as resonances in the  $D^{*+} K_S^0$  invariant mass spectrum[?].  $D$  mesons were required to decay subsequently to  $D^{*+} \rightarrow D^0 \pi^+$ ,  $D^0 \rightarrow K^- \pi^+$  and  $K_S^0 \rightarrow \pi^+ \pi^-$ .

The selections for the offline filter are described below.

### A. Selections for muons

Muons were identified using standard  $D\bar{O}$  criteria [4]. For this analysis, muons were required to have hits in more than one muon chamber ( $nseg > 1$ ), to have an associated track in the central tracking system with at least one hit in both SMT and CFT present, and to have transverse momentum  $p_T^{\mu} > 2$  GeV/ $c$ , pseudo-rapidity  $|\eta^{\mu}| < 2$ , and total momentum  $p^{\mu} > 3$  GeV/ $c$ .

All charged particles in the event were clustered into jets using the DURHAM clustering algorithm [5]. Events with more than one identified muon in the same jet were rejected, as well as the events with an identified  $J/\psi \rightarrow \mu^+ \mu^-$  decay.

### B. Selections for $D^0$

The  $\bar{D}^0$  candidate was constructed from two particles of opposite charge included in the same jet as the reconstructed muon. Both particles should have hits in the SMT and CFT, transverse momentum  $p_T > 0.7$  GeV/ $c$ , and pseudo-rapidity  $|\eta| < 2$ . They were required to form a common  $D$ -vertex with fit  $\chi_D^2 < 9$ . For each particle, the axial [?]  $\epsilon_T$  and stereo [?]  $\epsilon_L$  projections of the track impact parameter with respect to the primary vertex together with the corresponding errors ( $\sigma(\epsilon_T)$ ,  $\sigma(\epsilon_L)$ ) were computed. The combined significance  $\sqrt{(\epsilon_T/\sigma(\epsilon_T))^2 + (\epsilon_L/\sigma(\epsilon_L))^2}$  was required to be greater than 2. The distance  $d_T^D$  between the primary and  $D$  vertex in the axial plane was required to

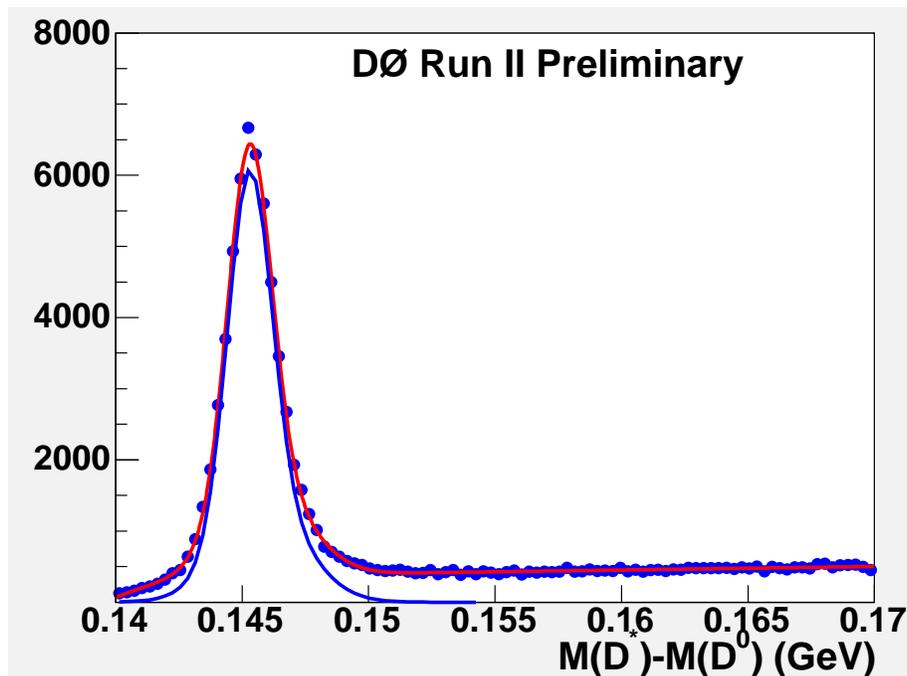


FIG. 1: The mass difference  $M(D^0\pi) - M(D^0)$  for events with  $1.75 < M(D^0) < 1.95$   $\text{GeV}/c^2$ . Total number of  $D^*$  candidates is equal to be  $52670 \pm 330$  (stat.) and was defined as the number of signal events in the  $[0.142-0.149$   $\text{GeV}]$  mass difference window. In the fit function the signal and the background have been approximated respectively by the sum of two Gaussian functions and by the sum of an exponential and first order polynomial function.

exceed 4 standard deviations:  $d_T^D/\sigma(d_T^D) > 4$ . The angle  $\alpha_T^D$  between the  $\bar{D}^0$  momentum and the direction from the primary to the  $\bar{D}^0$  vertex in the axial plane was required to satisfy the condition:  $\cos(\alpha_T^D) > 0.9$ .

The tracks of muon and  $\bar{D}^0$  candidate were required to form a common  $B$ -vertex with fit  $\chi_B^2 < 9$ . The momentum of the  $B$  candidate was computed as the sum of momenta of the  $\mu$  and  $\bar{D}^0$ . The mass of the  $(\mu^+ \bar{D}^0)$  system was required to fall within  $2.3 < M(\mu^+ \bar{D}^0) < 5.2$   $\text{GeV}/c^2$ . If the distance  $d_T^B$  between the primary and  $B$  vertices in the axial plane exceeded  $4 \cdot \sigma(d_T^B)$ , the angle  $\alpha_T^B$  between the  $B$  momentum and the direction from the primary to  $B$  vertex in the axial plane was demanded to satisfy the condition  $\cos(\alpha_T^B) > 0.95$ . The distance  $d_T^B$  was allowed to be greater than  $d_T^D$ , provided that the distance between the  $B$  and  $D$  vertices  $d_T^{BD}$  was less than  $3 \cdot \sigma(d_T^{BD})$ .

The masses of the kaon and pion were assigned to particles according to the charge of the muon, requiring  $\mu^+ K^+ \pi^-$  final system. In the following the events falling into the  $K\pi$  invariant mass window between 1.75 and 1.95  $\text{GeV}/c^2$  will be referred to as  $\mu^+ \bar{D}^0$  candidates.

### C. Selection for $D^*$

For  $\mu^+ \bar{D}^0$  candidates, we search for an additional slow pion with charge opposite to the charge of muon and with  $p_T > 0.18$   $\text{GeV}/c$ . The mass difference  $\Delta M = M(\bar{D}^0\pi) - M(\bar{D}^0)$  for all such pions when  $1.75 < M(\bar{D}^0) < 1.95$   $\text{GeV}/c^2$  is shown in Fig. 1. The peak corresponding to the production of  $\mu^+ D^{*-}$  is clearly seen. The total number of  $D^*$  candidates in the peak is equal to  $52670 \pm 330$  (stat.) and was defined as the number of signal events in the  $[0.142-0.149$   $\text{GeV}]$  mass difference window. The signal and the background have been modelled by a sum of two Gaussian functions and by the sum of exponential and first-order polynomial functions, respectively.

### D. Selections for $D_{s1}^\pm(2536)$

We are searching for evidence of the  $D_{s1}^\pm(2536)$  through the decay channel  $D_{s1}^\pm(2536) \rightarrow D^{*\pm} K_S^0$ .  $D_{s1}^\pm(2536)$  candidates were found by combining a  $D^*$  candidate with a  $K_S^0$ .  $D^*$  candidates were selected from a mass difference window of  $0.142 < M(D^*) - M(D^0) < 0.149$   $\text{GeV}/c^2$ .

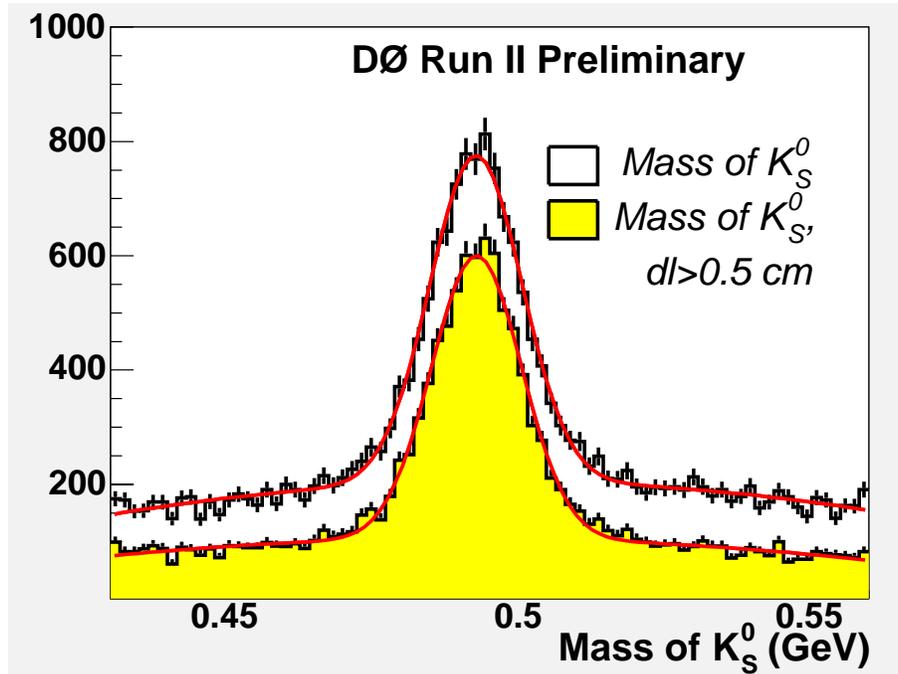


FIG. 2: Mass of  $K_S^0$  plotted both with the requirement that the decay length of the  $K_S^0$  be greater than 0.5 cm and with no decay length cut. These  $K_S^0$  events are plotted after passing  $D^*$  and  $D^0$  cuts. The mass plot was fitted with a Gaussian modeling the signal and a second order polynomial for the background. Without the decay length cut, we see  $7300 \pm 125$  events under the peak. With the cut, we see  $5900 \pm 100$  events in the signal peak.

For the  $K_S^0$ , the decay length was required to be greater than 0.5 cm. In making this cut, one loses 19% of the  $K_S^0$  signal, but 52% of the background is also eliminated (Fig. 2).  $K_S^0$  candidates were chosen from a mass window of  $0.47 < M(K_S^0) < 0.52$   $\text{GeV}/c^2$  and the  $p_T$  of the  $K_S^0$  was required to be greater than 1  $\text{GeV}/c$ . Additional cuts were also made. All particles used in the reconstructed decay chain were required to have more than 5 CFT hits.

To compute the  $D_{s1}^\pm(2536)$  invariant mass, a mass constraint was applied using the PDG  $D^*$  mass in the  $D_{s1}^\pm(2536)$  mass calculations instead of the invariant mass of the  $K\pi\pi$  system and a mass constraint was also placed on the  $K_S^0$ .

### III. RESULTS

A central value and width for the  $D_{s1}^\pm(2536)$  was found by plotting the mass and fitting it with a gaussian function for the signal and an exponential with a threshold cutoff at  $M(D^*) + M(K_S^0)$  to model the background(Fig. 3). The fit gives a central value for the gaussian of  $2.536 \pm 0.001$   $\text{GeV}/c^2$  with a width of  $1.9 \pm 0.5$   $\text{MeV}/c^2$ . Integrating over the signal yields  $18.5 \pm 5.5$  events for a significance of 3.4 sigma. The errors on all values are statistical only. Systematic errors are being investigated.

A background only fit was applied to the plot of the  $D^*K_S^0$  mass by fitting with an exponential with a threshold cutoff at  $M(D^*) + M(K_S^0)$ (Fig. 4). The range that is defined as the signal region,  $2.53 < M(D_{s1}^\pm(2536)) < 2.54$   $\text{GeV}/c^2$ , was excluded from this fit. The signal yield was determined by summing the difference between the mass at each bin in the signal region and the background value at that bin. Following this procedure, the yield is found to be  $17.8 \pm 5.1$  events. The error on this result is statistical only. The significance is determined to be 3.4 sigma. The error was also calculated from the error on the fit parameters, and this gave a yield of  $17.8 \pm 4.3$  events for a significance of 4.1 sigma.

### IV. CONCLUSION

The decay  $B_s \rightarrow D_{s1}^\pm(2536)\mu\nu X$  has been observed by DØ through the decay channel  $D_{s1}^\pm(2536) \rightarrow D^{*\pm}K_S^0$  with  $D^{*+} \rightarrow D^0\pi^+$ ,  $D^0 \rightarrow K^-\pi^+$  and  $K_S^0 \rightarrow \pi^+\pi^-$  with significance of greater than 3.0 sigma using  $485 \text{ pb}^{-1}$  of integrated

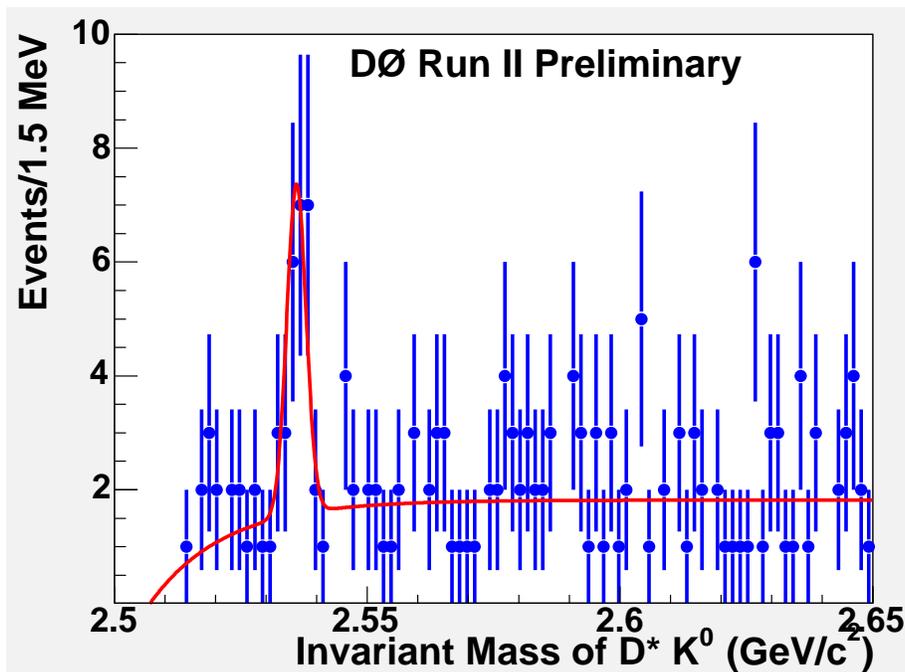


FIG. 3: Invariant mass of  $D^* K_S$ . Shown is the result of the fit of the  $D^* K_S$  mass with a Gaussian function plus an exponential function with a threshold cut-off at  $M(D^*) + M(K_S^0)$  to model the background. The total number of candidates in the peak is  $18.5 \pm 5.5$ .

luminosity. The observation of this signal demonstrates the potential for  $DØ$  to be able to measure production of this state and its properties.

The significance of the observed signal has been determined by two methods and has been found to be greater than 3 sigma in both cases. The observation of this signal demonstrates the potential for  $DØ$  to be able to measure properties of this state and its production.

Systematic uncertainties are being investigated as well as the continued generation of Monte Carlo for further exploration of cut selection, mass resolution and determination of signal efficiencies.

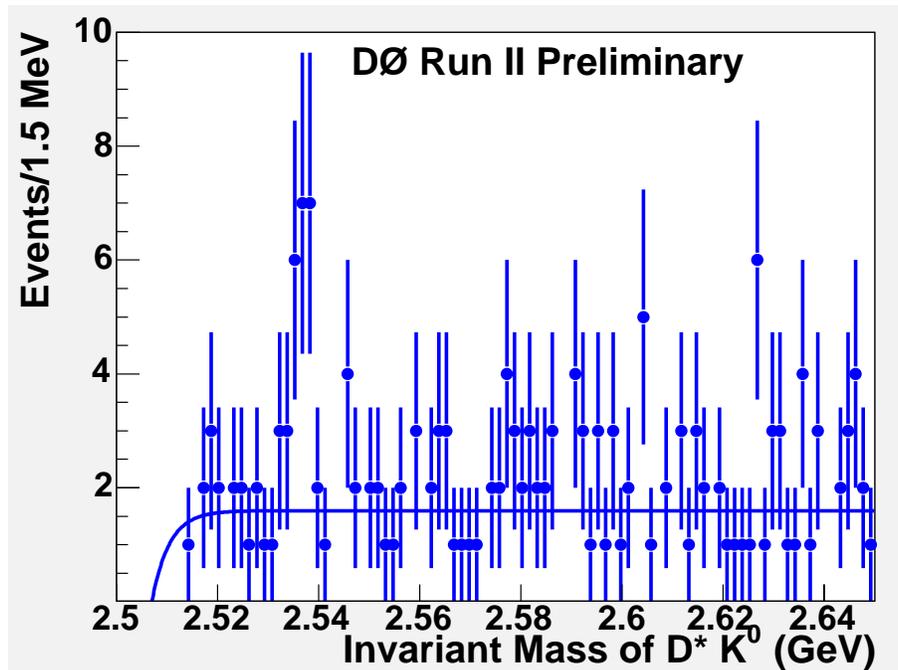


FIG. 4: Shown is the result of the fit of the  $D^*K_S$  mass with an exponential function with a threshold cut-off at  $M(D^*) + M(K_S^0)$ . Events in the signal windows, defined to be  $2.53 < M(D_{s1}^\pm(2536)) < 2.54$   $\text{GeV}/c^2$ , were excluded from the fit.

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□ Charge conjugate states are implied throughout the note.  
□ In the plane perpendicular to the beam direction.  
□ In the plane parallel to the beam direction.