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Measurement of the decay $B^0 \to D^{*-}\ell^+\nu$ and determination of $|V_{cb}|$ at Belle

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We present an analysis of exclusive semileptonic $b \to c$ decays based on data samples collected by the Belle detector at the KEK-B e^+e^- asymmetric collider. Investigation of the decay $B^0 \to D^{*-}\ell^+\nu$ allows precision measurements of the Cabibbo-Kobayashi-Maskawa matrix element $|V_{cb}|$ and the HQET form factor parameters ρ^2, $R_1(1)$ and $R_2(1)$ using untagged $\Upsilon(4S)$ events. Additionally, a test of the form factor parametrization can be performed.

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1. KEKB and the Belle detector

The following analysis was performed using a data sample of about 711 fb^{-1} collected at the $\Upsilon(4S)$ resonance with the Belle detector operating at the KEKB asymmetric-energy e^+e^- collider. The Belle detector is a large-solid-angle magnetic spectrometer that consists of a silicon vertex detector (SVD), a 50-layer central drift chamber (CDC), an array of aerogel Cherenkov counters (ACC), a barrel-like arrangement of time-of-flight scintillation counters (TOF) and an electromagnetic calorimeter comprised of CsI(Tl) crystals (ECL) located inside a superconducting solenoid coil that provides a 1.5 T magnetic field. An iron flux-return located outside the coil is instrumented to detect K_L^0 mesons and to identify muons (KLM). The detector is described in detail in Ref. [1].

Two inner detector configurations were used. A 2.0 cm beampipe and a 3-layer silicon vertex detector was used for the first sample of 152 million $B\bar{B}$ pairs, while a 1.5 cm beampipe, a 4-layer silicon detector and a small-cell inner drift chamber were used to record the remaining 620 million $B\bar{B}$ pairs ([2]).

2. Exclusive $B^0 \to D^{*-}\ell^+\nu$ decays

The quadruple decay width of the decay $B \to D^*\ell\nu$ is a four dimensional function depending on four kinematic variables [3, 4]: $w = v_B \cdot v_{D^*}$ and the three angles $\cos\theta_V$, $\cos\theta_\ell$ and χ, defined in Fig. 1. We use the parametrization defined in Ref. [5], which introduces three free parameters, labeled ρ^2, $R_1(1)$ and $R_2(1)$, to govern the shape of the form factors of the decay.

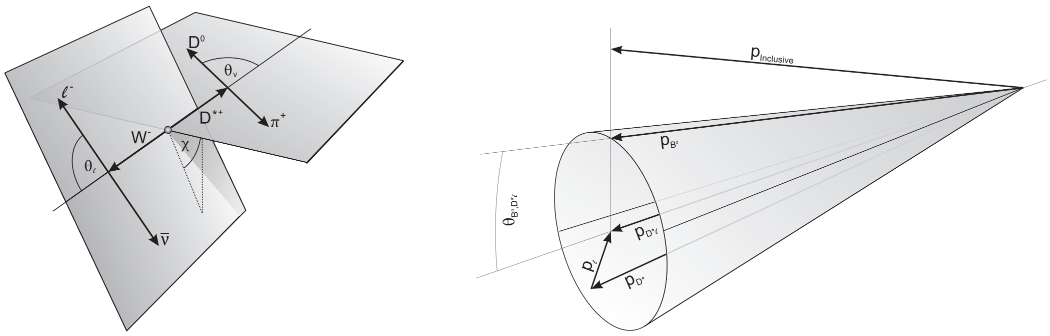

Figure 1: The definition of the four kinematic variables w, $\cos\theta_V$, $\cos\theta_\ell$ and χ and a sketch of the reconstruction of the signal B momentum using momentum conservation.

Preliminary results based on the analysis of B^0 events have been reported before [7], based on a smaller data sample. In the results presented here, the decay cascade[1] $\bar{B}^0 \to D^{*+}\ell^-\bar{\nu}$, $D^{*+} \to D^0\pi_s^+$ and $D^0 \to K^-\pi^+$is reconstructed in the entire $\Upsilon(4S)$ data sample accumulated by the Belle detector. Due to the kinematics of the decay, the momentum of the pion emitted by the D^* meson, π_s^+, does not exceed 350 MeV$/c$ and it is therefore refered to as a "slow" pion. The light lepton ℓ is either an electron or a muon.

Due to momentum conservation, the spatial momentum of the B meson has to lie on a specific cone around the spatial momentum of the $D^*\ell$ system. The inclusive sum of the entire remaining

[1]Charge conjugation is implied throughout this text.

event is used to obtain the best B candidate by orthogonal projection, as sketched in the right hand plot of Fig. 1. Data recorded about 60 MeV below the $\Upsilon(4S)$ resonance is used to investigate background from $q\bar{q}$ decays, while Monte Carlo simulated events are used for a set of additional background components stemming from B decays.

The parameters $\mathscr{F}(1)\,|V_{cb}|$, ρ^2, $R_1(1)$ and $R_2(1)$ are obtained by a binned least squares fit to the four one-dimensional marginal distributions of the decay width. The bin-to-bin correlations between these one dimensional histograms have to be considered. A χ^2 function is formed for each of the two channels (e and μ) separately and the sum of these two χ^2's is minimized numerically using the MINUIT package [6]. Systematic uncertainties are investigated by repeating the fit procedure for pseudo-experiments obtained by varying various systematic parameters within their respective uncertainties. Four sub-samples of data are investigated separately, to ensure that no systematic bias is introduced either due to the different detector setups mentioned above or due to the usage of different tracking algorithms, which have been applied to the data. The results obtained in these statistically independent samples are averaged using the algorithm used by the Heavy Flavor Averaging Group to obtain the world average of $|V_{cb}|$ from exclusive semileptonic decays. This approach incorporates both statistical and systematic uncertainties as well as possible correlations between the measurements.

The final results obtained are:

$$\begin{aligned}
\mathscr{F}(1)|V_{cb}| &= (34.5 \pm 0.2 \pm 1.0) \times 10^{-3}, \\
\rho^2 &= 1.214 \pm 0.034 \pm 0.009, \\
R_1(1) &= 1.401 \pm 0.034 \pm 0.018, \\
R_2(1) &= 0.864 \pm 0.024 \pm 0.008,
\end{aligned}$$

where the first error is the statistical uncertainty and the second is the systematic uncertainty. These values correspond to a branching fraction $\mathscr{B}(B^0 \to D^{*-}\ell^+\nu) = (4.56 \pm 0.03 \pm 0.26)\%$. The χ^2 probability of the averaging procedure is $P_{\chi^2} = 28.2\%$, showing good agreement between the four sub-samples. A plot of results of the fit to one of the sub-samples is shown in Fig. 2.

Additionally, a cross check of the parametrization used to define the form factor parameters is performed by extracting the shapes of the longitudinal (G^L) and transversal (G^T) helicity functions of the decay. These functions are given by product of the helicity amplitudes of the decay and kinematic functions. There is good agreement between this cross check and the result by the parametrized fit, as shown in Fig. 3.

3. Conclusions

We presented an analysis of the decay $B^0 \to D^{*-}\ell^+\nu$ based on data collected by the Belle detector at the KEKB e^+e^- asymmetric energy collider. This analysis allows the determination of $\mathscr{F}(1)\,|V_{cb}|$ and the form factor parameters ρ^2, $R_1(1)$ and $R_2(1)$.

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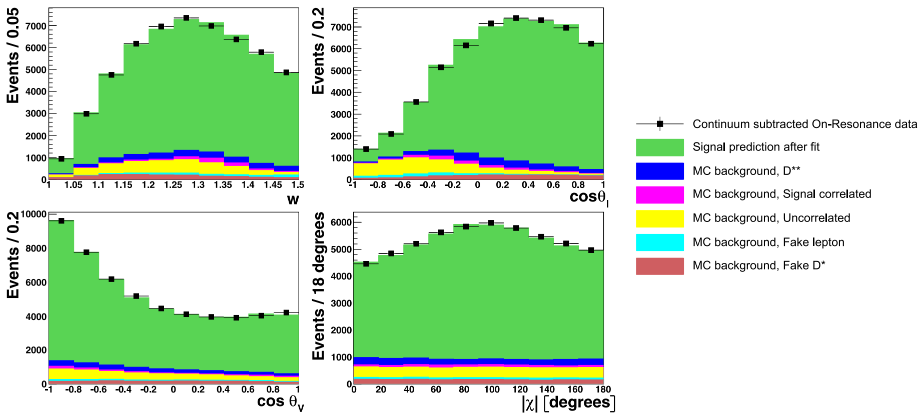

Figure 2: Result of the fit of the four kinematic variables in a sample of 274 fb^{-1}. The points with error bars are continuum subtracted on-resonance data. The histograms are the signal and the different background components.

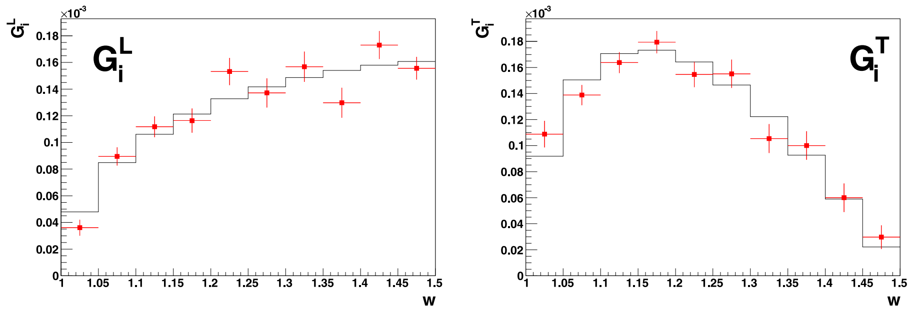

Figure 3: Results of the fit of the helicity functions (red crosses) compared to the prediction obtained by using the parameters obtained by using the parametrization prescription by Caprini, Lellouch and Neubert (solid black line). The left plot shows the results for the longituginal part, G_i^L, the right one for the transversal part G_i^T. Only the statistical error is shown.

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