Observation of the exclusive decay $B \to e\nu D^*$ and search for $B \to e\nu\pi^0$

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Abstract. The Crystal Ball detector at the $e^+e^-$ storage ring DORIS II has been used to analyze exclusive semileptonic decays of $B$ mesons produced at $\Upsilon(4S)$ energies. The decay $B \to e\nu D^*$ has been observed with a branching ratio of $(7.0 \pm 1.8_{-1.4}^{+1.4})\%$ using the $\pi^0D$ decay mode of the $D^*$. In addition we have searched for the exclusive semileptonic decay $B^\pm \to e^\pm \nu \pi^0$. We find an upper limit on BR($B^\pm \to e^\pm \nu \pi^0$) of 0.22% at the 90% CL.

1 Introduction

Measuring the elements of the Cabibbo-Kobayashi-Maskawa quark mixing matrix [1] in weak decays is an important task in particle physics since the values of these elements are fundamental parameters of the standard model. In a previous paper [2] we have analyzed the inclusive electron spectrum from $B$ meson decays to charmed final states, resulting in a determination of $|V_{cb}|$. Theoretically one expects [3-8] the electron spectrum to be dominated by the final states $e\nu D$ and $e\nu D^*$, contributing approximately 30% and 60% to the total width. A determination of the individual contributions may help to distinguish between different theoretical models.

Inclusive semileptonic $B$ decays to non-charm final states have been studied to extract $|V_{ub}|$. In the beginning...
only upper limits could be derived [2, 9]. Recently both CLEO [10] and ARGUS [11] reported signals from \( b \to u \) transitions in inclusive semileptonic decays resulting in a value [11] of \( |V_{ub}|/|V_{cb}| \approx 0.10 \).

To determine \( |V_{ub}| \) from an experimental measurement, e.g., the branching ratio of semileptonic \( b \to u \) transitions, the hadronic matrix element between the initial state \( B \) meson and the final state meson has to be known. While calculations of the \( b \to c \) hadronic matrix element with different models give reasonable agreement for the inclusive decay rate, the predictions for inclusive \( b \to u \) transitions are much more model dependent [3–8]. More reliable results for \( |V_{ub}| \) may come from measurements of exclusive semileptonic \( B \) meson decays [12–15].

In this article we present two analyses of exclusive semileptonic \( B \) meson decays. The paper is organized as follows: Section 2 gives a short introduction to the experimental setup. In Sect. 3 the observation and analysis of the decay \( B \to e \nu D^* \), \( D^+ \to \pi^0 D \) is reported. The search for \( B^+ \to e^+ \pi^0 \) is presented in Sect. 4. Finally we summarize our results on exclusive \( B \) decays.

## 2 Experimental setup

A detailed description of the Crystal Ball detector at the DORIS II electron-positron storage ring at DESY has been given elsewhere [2]. It is a non-magnetic calorimetric detector consisting of 672 NaI(Tl) crystals of 16 radiation lengths thickness, covering 93% of the full solid angle. The solid angle coverage is increased to 98% of \( 4\pi \) sr by NaI(Tl) endcap crystals. Four double layers of chambers containing in total 800 drift tubes are used to detect charged particles and to measure their directions. For the present analysis the detector’s ability to identify and to measure the energy and direction of electrons and photons from 10 MeV upwards is important. The energy resolution for electrons and photons is given by

\[
\sigma_E/E = (2.7 \pm 0.2)\% \sqrt{E/\text{GeV}}; \quad \text{their directions are measured with an accuracy in the polar angle } \theta \text{ with respect to the beam axis of } \sigma_\theta = 1^\circ \text{ to } 3^\circ, \text{ where the resolution is best for high-energy showers.}
\]

Neutral pions are reconstructed from their decay into two photons. For \( \pi^0 \) energies below about 500 MeV, these two photons are well separated in the calorimeter. For more energetic \( \pi^0 \) mesons the showers of the two photons can overlap in the calorimeter forming only one cluster. At energies above about 1.5 GeV \( \pi^0 \) candidates are selected by analyzing the moments of the shower patterns of neutral energy clusters [16].

## 3 Observation of the decay \( B \to e \nu D^* \to e \nu \pi^0 D \)

We identify the semileptonic \( B \) meson decay chain

\[
B \to e \nu D^* \to e \nu \pi^0 D \tag{1}
\]

by a high-energy electron back-to-back with a slow \( \pi^0 \). Near the electron endpoint energy, the neutrino has low energy and momentum. The semileptonic \( B \) decay then resembles a two-body decay \( B \to e D^* \) with the \( D^* \) recoiling against the electron in the \( B \) rest frame. The \( D^* \) has a sizeable branching ratio for the decay \( D^* \to \pi^0 D \). Due to the small mass difference, \( M_{\pi^0} - M_D \approx 140 \text{ MeV} \), the emitted \( \pi^0 \) has low momentum in the \( D^* \) rest frame \( (p_{\pi^0} \approx 40 \text{ MeV}/c) \). Boosted by the \( D^* \) motion, the \( \pi^0 \) preserves approximately the \( D^* \) direction. The pion is not monochromatic, but still soft \( (p_{\pi^0} \leq 250 \text{ MeV}/c) \) in the laboratory frame. The observation of a soft \( \pi^0 \) recoiling back-to-back with a high energy electron therefore identifies the decay chain (1). The event sample selected in this way includes both charged and neutral \( B \) meson decays.

There are four effects which lead to an opening angle less than \( 180^\circ \) between the directions of the electron and the \( \pi^0 \):

- The momentum carried away by the neutrino. Since the electron spectrum decreases rapidly towards the endpoint one has to compromise between event statistics and the requirement that the electron and slow pion be back-to-back.
- The boost resulting from the non-zero momentum of the \( B \) mesons \( (p_B \approx 340 \text{ MeV}/c) \) produced in the reaction\n
\[
e^+ e^- \to \Upsilon(4S) \to BB. \tag{2}
\]

- The transverse \( \pi^0 \) momentum relative to the \( D^* \) direction.
- The angular resolution of the detector.

Background arises from \( \pi^0 \) mesons produced by the decays of the \( D \) meson in reaction (1), by decays from the second \( B \) meson in reaction (2) and from semileptonic \( BB \) decays to \( D \) mesons.

### 3.1 Data preselection

The Crystal Ball data used in this analysis were taken on the \( \Upsilon(4S) \) resonance, with most of the data (90%) accumulated on the top of the resonance. The integrated luminosity is 92 pb\(^{-1}\). This corresponds to \( N_B = (140.0 \pm 2.8) \times 10^3 \) produced \( B \) mesons [2], where the error is dominated by the luminosity measurement. For background studies, 30 pb\(^{-1}\) of data have been taken in the continuum just below the \( \Upsilon(4S) \) resonance.

Hadronic events are first selected by criteria which are the same as those applied in our inclusive analysis of the electron spectrum [2]. Then we strengthen the multiplicity and topology cuts as follows. Events originating from \( \Upsilon(4S) \) resonance decays are enhanced compared to those from hadronic continuum production by requiring a high multiplicity, i.e., at least 8 local energy maxima in the calorimeter, and non-jetlike events by a cut on the second Fox-Wolfram moment [17]:

\[
H_2 = \frac{\sum_i \sum_j E_{ij} (3 \cos^2 \alpha_{ij} - 1)}{2 \langle \Sigma_k E_k \rangle^2} < 0.40. \tag{3}
\]

The \( E_{ij} \) denote the deposited energies assigned to single particles and the \( \alpha_{ij} \) are the angles between these energy...