Analysis Memo

A Measurement of $B(D \to \phi X)$[1]

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Abstract

We report on a preliminary measurement of the branching fraction of the decay $D^+, D^0 \to \phi X$, where X can be any unidentified particles. Using the BES detector, a data sample of 22.3 pb^{-1} has been collected at a center-of-mass energy of 4.03 GeV at the BEPC e^+e^- storage ring. At this energy, the final states $D^*(2010)^+D^-$, $D^*(2007)^0\overline{D}^0$, $D^*(2010)^+D^*(2010)^-$, and $D^*(2007)^0\overline{D}^*(2007)^0$ are abundantly produced. In our analysis inclusive decays of the D^+ and D^0 are reconstructed to form a *singly-tagged* sample which identifies $D^*\overline{D}$ or $D^*\overline{D^*}$ events. In this singly-tagged sample we search for the ϕ meson recoiling against the D^+ or D^0. Based on events reconstructed, we determine the average branching fraction for $D^+, D^0 \to \phi X$. The measured branching fraction is compared to the available measurements of exclusive D^+, D^0 decays into final states containing a ϕ meson.

[1]This note describing the measurement of $B(D \to \phi X)$, to be presented at DPF, 1996.

1 Introduction

Much progress has been made in heavy flavor physics since the discoveries of open charm and bottom[1]. However, the experimental results on inclusive hadronic charm decays are limited[1]. In an era of high precision experiments such as B factories and LHC, accurate measurements of b-flavored particles can benefit from a realistic simulation of charm decays.

This note describes a first measurement of inclusive decay branching fraction for $\mathrm{D} \to \phi \mathrm{X}$, averaged[2] over D^+ and D^0, from an analysis of the BES data collected in $\mathrm{e}^+\mathrm{e}^-$ annihilations at 4.03 GeV. This measurement should serve as a useful check on the existing exclusive D decays involving a ϕ meson in the final state, and will aid in LEP experiments[2], who are using the $\phi\ell$ pair to investigate time-dependent $\mathrm{B}_\mathrm{s}^0\overline{\mathrm{B}_\mathrm{s}^0}$ oscillation, in evaluating backgrounds resulting from decays of B_d^0 and B_u^+.

In $\mathrm{e}^+\mathrm{e}^-$ annihilations at 4.03 GeV center of mass energy, charm mesons D^0 and D^+ are predominantly produced from the final states $\mathrm{D}^*(2010)^+\mathrm{D}^-$, $\mathrm{D}^*(2007)^0\overline{\mathrm{D}}^0$, $\mathrm{D}^*(2010)^+\mathrm{D}^*(2010)^-$, and $\mathrm{D}^*(2007)^0\overline{\mathrm{D}}^*(2007)^0$. Initial state radiation process $\mathrm{e}^+\mathrm{e}^- \to \psi(3\mathrm{s})\gamma$, followed by $\psi(3\mathrm{s}) \to \mathrm{D}\overline{\mathrm{D}}$, and direct reaction $\mathrm{e}^+\mathrm{e}^- \to \mathrm{D}\overline{\mathrm{D}}$ also contribute to D^0, D^+ production. For all these reactions hadrons from sources other than D^0, D^+ decays are too slow to be well reconstructed by the BES detector. Hadrons detected in an identified D event must be from the decay of the $\overline{\mathrm{D}}$. Using the reconstructed inclusive D events as a sample, we can measure the inclusive decays of the D^0 and D^+. In this note we search for the ϕ meson recoiling against a charm meson reconstructed in the same event, and determine the branching fraction $\mathrm{B}(\mathrm{D} \to \phi\mathrm{X})$, averaged over charged and neutral D mesons.

2 The BES Detector and Data Sample

The BES detector has been described in details in[3]. Here we briefly describe detector elements crucial to this measurement.

Tracking is provided by a 10 superlayer main drift chamber (MDC) operated inside a 0.4 T axial magnetic field. Each superlayer contains four layers of sense wires measuring both the position and the ionization energy loss ($\mathrm{dE}/\mathrm{d}x$) of charged particles. The magnetic coil is surrounded by a time-of-flight counter array (TOF) and an electromagnetic calorimeter (ECAL) composed of streamer tubes and lead blocks with a z position resolution of 4 cm. The muon detector system lies outside of the ECAL and consists of four layers of streamer tubes, measuring the coordinates of muons in z and in $r\phi$ with

[2] Throughout this note, charge conjugation is implied.

resolutions of 5 cm and 3 cm, respectively.

This analysis is based on hadronic events recorded with the BES detector during the 1992, 1993 and 1994 runs. A data sample of 22.3 pb^{-1} was collected in e^+e^- annihilations at a center-of-mass energy of 4.03 GeV at the BEPC collider[4]. The BES trigger conditions, and the criteria for the selection of hadronic events have been described elsewhere[5].

3 The Analysis

3.1 Event Selection and Particle Identification

The selection criteria are similar to other charm physics analyses in BES. Charged tracks are selected with the following criteria:

(1) mfit = -19, or 2,

(2) Normalized chi-square of track fit is less than 4 per degree of freedom,

(3) $|d_0|$ <5 cm, $|z|$ <20 cm, where d_0, z are the distances of closest approach on the x-y plane, and in the z direction, respectively,

(4) $|cos\theta|$ <0.8, where θ is the polar angle of the track.

Events with at least two charged tracks, and a total visible energy between 0.5 – 6.0 GeV, are studied in this measurement. Identification of charged hadrons relies on a joint particle confidence level (CL) calculated using measurements from dE/dx, TOF, shower counters and the muon detector, whenever they are available[6]. Charged pions are selected with a requirement of pion CL being more than 1%. Charged kaons are positively identified, for which the kaon CL must be greater than 1%, and the kaon likelihood must be larger than that of the pion. Stronger kaon identification is needed in the analysis because of large pion background in the data.

In addition, a particle specie dependent correction of ionization energy loss in the beam pipe is made for all charged tracks. A small correction of -5.15% is also applied to momenta of all charged tracks to compensate for a shift in the BES magnetic field.

3.2 Monte Carlo Simulations

The routines *dsdgen.f* and *dssgen.f* have been used to generate physics interactions $e^+e^- \to D^*\overline{D}$ and $e^+e^- \to D^*\overline{D^*}$. Several combinations of $D^0\overline{D^0}$, $D^+\overline{D^0}$ and D^+D^- are selected from the intermedia states $D^*\overline{D}$ and $D^*\overline{D^*}$. The D^0 and D^+ mesons are decayed into final states $K^-\pi^+$ and $K^-\pi^+\pi^+$, respectively, which are the modes through which we reconstruct these charm mesons in the measurement. The $\overline{D^0}$ and D^- are decayed into ϕK, $\phi\pi$, $\phi\pi\pi$, and $\phi\mu^-\nu$.

The generated physics events are processed by the BES *sober* package, and are reconstructed using version 8.7 *drunk* program package. These simulated events are analyzed to guide the selection of cuts and to determine the detection efficiencies relevant to the measurement of B(D $\to \phi$X).

3.3 Reconstruction of D^0 and D^+

The D^0 meson is reconstructed in its decay to $K^-\pi^+$. Both particles are positively identified, in order to eliminate double countings of Kπ combinations. For the D^+ meson, its decay $D^+ \to K^-\pi^+\pi^+$ is reconstructed. The kaon is positively identified to reduce combinatorial background.

Figures 1.a-b show the momenta of the $K^-\pi^+$, $K^-\pi^+\pi^+$ pairs that are within $\pm$54 MeV, or $\pm$46 MeV ($\pm 2\sigma$) of the D^0, D^+ masses, respectively. The two most prominent peaks below 650 MeV/c in each figure represent the D^0, D^+ mesons from $e^+e^- \to D^*\overline{D}$ and $e^+e^- \to D^*\overline{D}^*$, respectively. To further suppress combinatorial background, only Kπ pairs within the momentum windows 82 - 254 MeV, and 440 - 624 MeV, and $K^-\pi^+\pi^+$ combinations with momenta falling into 82 - 182 MeV, 453 - 613 MeV are selected in the analysis.

The invariant mass distributions of the selected $K^-\pi^+$ and $K^-\pi^+\pi^+$ are shown in Figures 2.a-b, respectively. The $K^-\pi^+$ mass spectrum in Figure 2.a is fitted to two Gaussians, one at the nominal D^0 mass, the other at 1624 MeV. The latter is mostly due to $D^0 \to K^-\pi^+\pi^0$ where the π^0 is undetected. The background is described by a fifth order polynomial distribution. The resulting D^0 mass is 1864.7$\pm$0.7 MeV, the r.m.s. width 27.7$\pm$0.7 MeV, and a total number of 3 252$\pm$86 events. The mass fitted agrees well with the world average of 1864.6$\pm$0.5 MeV. The $K^-\pi^+\pi^+$ mass spectrum is fitted to a Gaussian signal form above a 4th order polynomial background shape. The fit yields 2 862$\pm$100 D^+ events, with a mass of 1869.4$\pm$0.8 MeV/c^2, which can be compared with the world average of 1869.4$\pm$0.4 MeV/c^2.

The fit results are summarized in Table 1. Summing over two D decay modes, we have selected a total of 6 114$\pm$132 D^0, D^+ events.

Table 1. Reconstructed D Mesons in BES Data

D Meson Mode	D Mass (MeV/c^2)	σ_D (MeV/c^2)	Number of D Mesons	χ^2 per d.o.f
$D^0 \to K^-\pi^+$	1864.7$\pm$0.7	27.7$\pm$0.7	3 252$\pm$86	1.24
$D^+ \to K^-\pi^+\pi^+$	1869.4$\pm$0.8	23.3$\pm$0.9	2 862$\pm$100	1.16

3.4 Reconstruction of $\phi \to K^+K^-$

Both kaons are positively identified in the analysis. Photon conversions are rejected by requiring $|\cos\theta_k| < 0.95$, where θ_k is the helicity angle of K^+ in the K^+K^- rest frame, and di-electron mass to be less than 60 MeV. Both quantities are calculated, if possible, at the two track intersection point. When no good vertex is found for the pair, the momenta as calculated at the event vertex are used in calculating di-electron invariant mass. This photon rejection removes most of high momentum conversions which are misidentified as K^+K^- pairs.

The resulting K^+K^- invariant mass distribution is shown in Figure 3. To determine the number of ϕ events, we use a p-wave Breit-Wigner signal form and a two body phase space background distribution to fit to the mass distribution. We obtain 979±44 ϕ events, and a mass of 1019.5±0.2 MeV. The mass fitted is in excellent agreement with the world average of 1019.413±0.008 MeV[1].

To check for possible momentum dependence of the ϕ signal mass, we divide the ϕ signal into five momentum intervals. For each interval, the K^+K^- mass distribution is fitted and the signal mass is obtained. The fit results are listed in Table 2. The masses agree well with the world average value within statistical errors.

Table 2. Reconstructed ϕ signals in five momentum intervals.

p_ϕ (GeV/c)	M_ϕ	N_ϕ
0.0 - 0.50	1017.9±1.2	26±7
0.50 - 0.75	1020.0±0.5	278±24
0.75 - 1.00	1019.5±0.4	366±28
1.00 - 1.50	1019.1±0.5	233±26
1.50 -	1019.6±0.5	83±13
Sum of Above	-	986±47
Inclusive Fit	1019.5±0.2	979±44

To determine the ϕ detection efficiency, we have generated Monte Carlo events $e^+e^- \to D^{*0}\overline{D}^0$, where the $\overline{D}^0$ decays into several possible final states containing a ϕ meson. The decay modes, and the efficiencies are summarized in Table 3. The numbers of ϕ are those that have a K^+K^- invariant mass within ±15 MeV/c^2 of the nominal ϕ mass. The average efficiency for ϕ in $e^+e^- \to D^{*0}\overline{D}^0$ events, including the branching fraction for $\phi \to K^+K^-$, is found to be (8.1±0.2)%. A possible mode dependence of the efficiency is found, which will be included in the systematic error evaluation.

Table 3. Detection Efficiency for $\phi \to K^+K^-$

Mode $e^+e^- \to$	$D\to \phi X$ Mode	N_D	N_ϕ	ϕ Detection Efficiency
$D^{*0}\overline{D}^0$ $D^0 \to K^-\pi^+$	$\overline{D}^0 \to \phi\pi^0$	5,624	493	0.088 ± 0.004
$D^{*0}\overline{D}^0$ $D^0 \to K^-\pi^+$	$\overline{D}^0 \to \phi K^0$	5,387	403	0.081 ± 0.004
$D^{*0}\overline{D}^0$ $D^0 \to K^-\pi^+$	$\overline{D}^0 \to \phi\pi^+\pi^-$	11,902	934	0.078 ± 0.003
$D^{*0}\overline{D}^0$ $D^0 \to K^-\pi^+$	$\overline{D}^0 \to \phi\mu^-\nu$	6,430	535	0.084 ± 0.004
Average	-	29,343	2,365	0.0081 ± 0.002

3.5 Reconstruction of Dϕ Events

The charmed mesons and the ϕ are selected as described earlier in the note. For an event in which we have reconstructed a charmed meson D^0 or D^+, which are $K^-\pi^+$ or $K^-\pi^+\pi^+$ combinations with invariant masses within the D mass windows listed in Table 4, a K^+K^- pair recoiling against the D meson is searched for in the rest of the event.

Figures 4.a-c show invariant mass distributions of the K^+K^- pairs selected in the $D^0 \to K^-\pi^+$ and $D^+ \to K^-\pi^+\pi^+$ events, and the sum of the two samples. Defining the ϕ candidate as the K^+K^- pair with a mass within ± 15MeV/c^2 of the nominal ϕ meson mass 1019.5 MeV/c^2, a total of 4 $\phi \to K^+K^-$ candidates are found in Figure 4.c. The breakdown of these 4 events in the D modes are given in Table 4.

Table 4. Mass Windows of D and ϕ Signals

Particle Type Decay Mode	D Mass Window (MeV/c^2)	Fraction within Window	Dϕ Candidates
$D^0 \to K^-\pi^+$	1795 - 1935	95%	3
$D^+ \to K^-\pi^+\pi^+$	1823 - 1915	95%	1

4 Results

The average D^0, D^+ branching fraction for $D \to \phi X$ can be determine from

$$Br(D \rightarrow \phi X) = \frac{N_{D^0\phi} + N_{D^+\phi}}{\varepsilon_D \cdot (N_{D^0} + N_{D^+})}$$

where $\mathrm{N_{D^0\phi}}$, $\mathrm{N_{D^+\phi}}$ are the genuine $\mathrm{D^0}\phi$, and $\mathrm{D^+}\phi$ events reconstructed, ε_D the detection efficiency for ϕ including the $\phi \rightarrow \mathrm{K^+K^-}$ branching fraction, $\mathrm{N_{D^0}}$ and $\mathrm{N_{D^+}}$ are the numbers of inclusive $\mathrm{D^0}$ and $\mathrm{D^+}$ mesons that we observe in the data.

The total number of $\mathrm{D^0}$, $\mathrm{D^+}$ events that we reconstruct in Figures 2.a-b is 6 114±132±54, where the second error is due to fitting uncertainties. The detection efficiency for ϕ has been determined to be (8.1±0.2±1.1)%, where the second error steps from $\mathrm{D} \rightarrow \phi\mathrm{X}$ mode dependence (0.7%) and uncertainties on particle identification and detector resolution (0.8%). The 90% CL upper limit for 4 Dϕ candidates corresponds to 7.99. Assuming Gaussian behavior for all systematic errors, we determine B(D→ ϕX) < 2.0% at 90% CL.

Table 5. Existing Measurements of Exclusive $\mathrm{D^0}$, $\mathrm{D^+} \rightarrow \phi$ Decays (Limits are 90% CL.)

D Meson Type	Decay Mode	B.R. (%)	Experiments
$\mathrm{D^+} \rightarrow$	$\phi\mathrm{K^+}$	$0.039^{+0.022}_{-0.019}$	E691
	$\phi\pi^+$	0.67±0.08	WA82, CLEO, NA14, E691, MK3
	$\phi\pi^+\pi^0$	2.3±1.0	ACCMOR
	$\phi\pi^+\pi^+\pi^-$	<0.2	E691
	$\phi\mathrm{e}^+\nu_\mathrm{e}$	<2.09	MK3
	$\phi\mu^+\nu_\mu$	<3.72	MK3
$\mathrm{D^0} \rightarrow$	$\phi\overline{\mathrm{K}}^0$	0.83±0.12	ARGUS, CLEO, E687
	$\phi\pi^+\pi^-$	0.26±0.07	ACCMOR

This limit can be compared to existing measurements on the exclusive D decays into final states containing a ϕ meson, as summaried in Table 5. Within errors, the exclusive measurements are consistent with our limit of B(D→ ϕX) < 2.0%. Our limit indicates that there is not much room for undetected exclusive B(D→ ϕX) decays.

5 Summary

Based on a sample of 6 114±132±54 $\mathrm{D^0}$, $\mathrm{D^+}$ events observed in the BES data, we have searched for inclusive decay D→ ϕX. A total of 4 $\mathrm{D^0}\phi$, $\mathrm{D^+}\phi$ candidates are found, which lead to a 90% CL upper limit of B(D→ ϕX) < 2.0%, averaged over $\mathrm{D^0}$ and $\mathrm{D^+}$. Comparing to the existing measurements on exclusive D decays into ϕ containing states this limit indicates little room for unobserved exclusive B(D→ ϕX) type decays.

References

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[6] M. Kelsey, "BES Particle Identification with the TRACKID Package" BES Note 94-005, December 8, 1994.

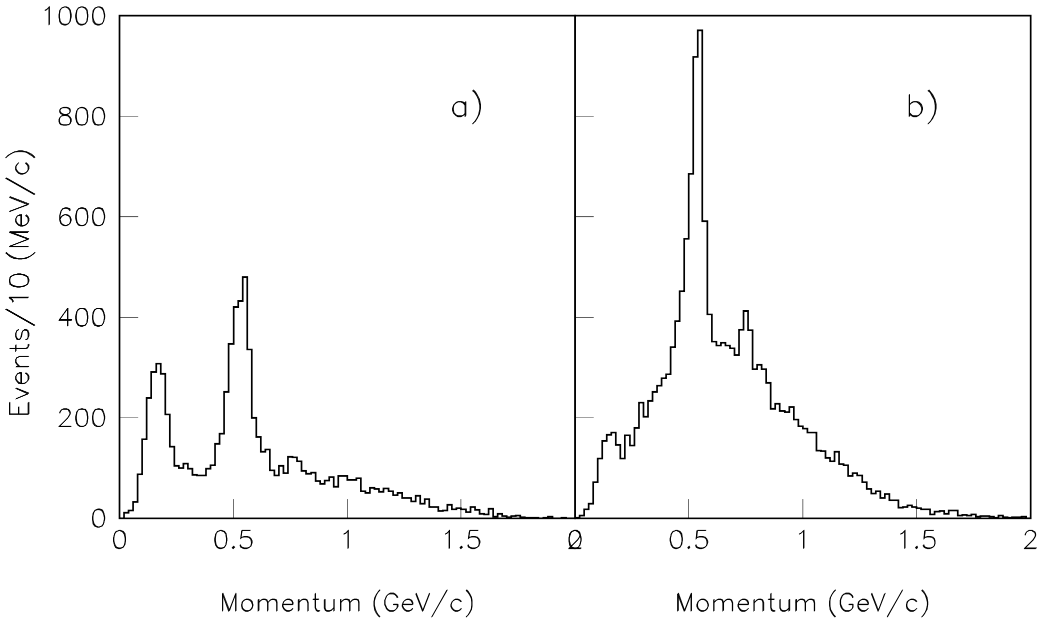

Figure 1: Momentum distributions of (a) $K^-\pi^+$ pairs with masses consistent with the D^0, and (b) $K^-\pi^+\pi^+$ pairs with masses consistent with the D^+.

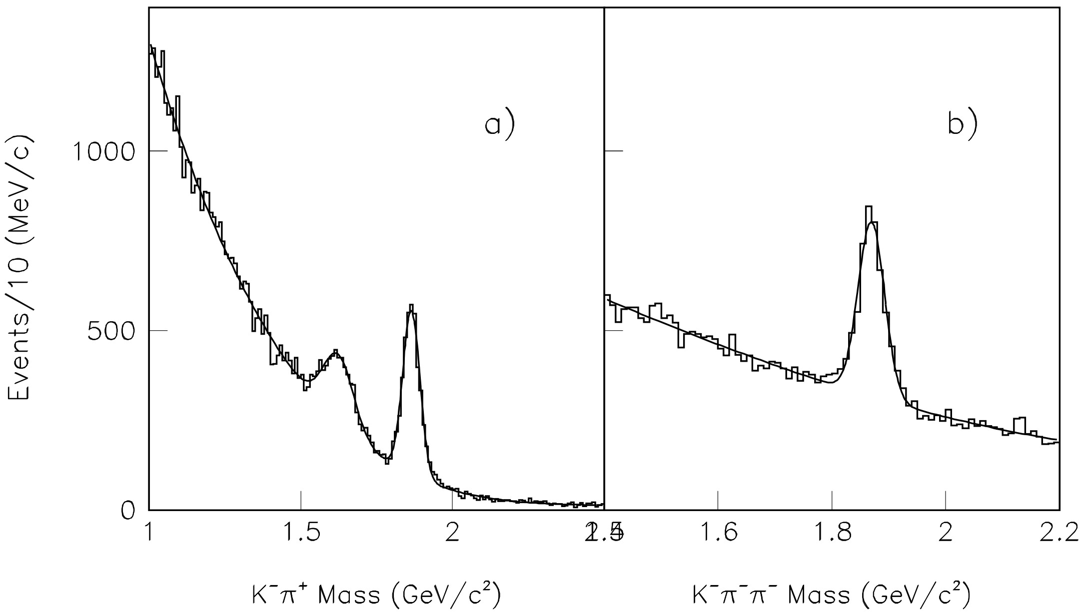

Figure 2: Invariant mass distribution of selected (a) $K^-\pi^+$ combinations, and (b) $K^-\pi^+\pi^+$ combinations.

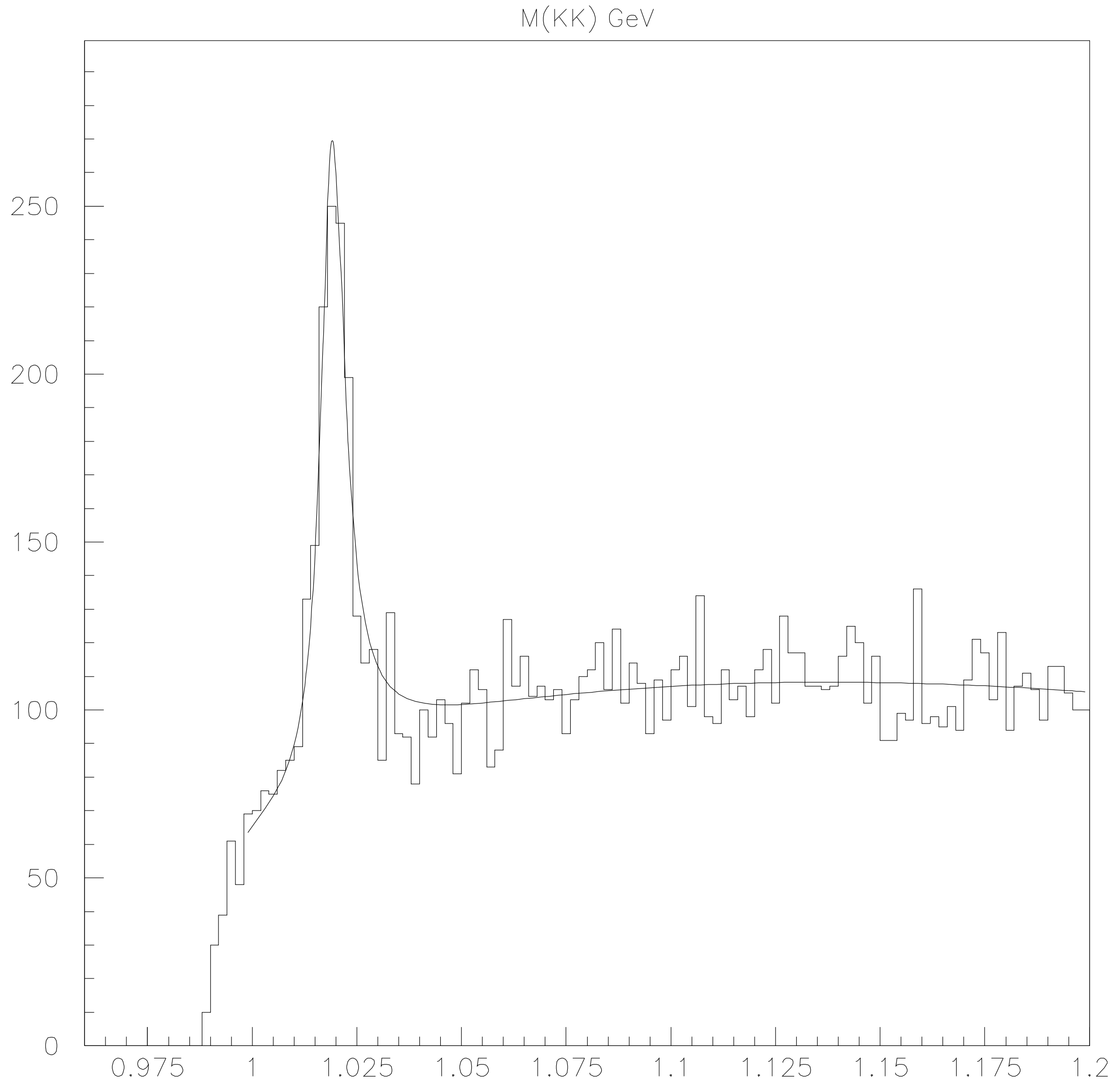

Figure 3: Invariant mass distribution of selected K^+K^- pairs. The signal function used in the fit is a p-wave B.W. function.

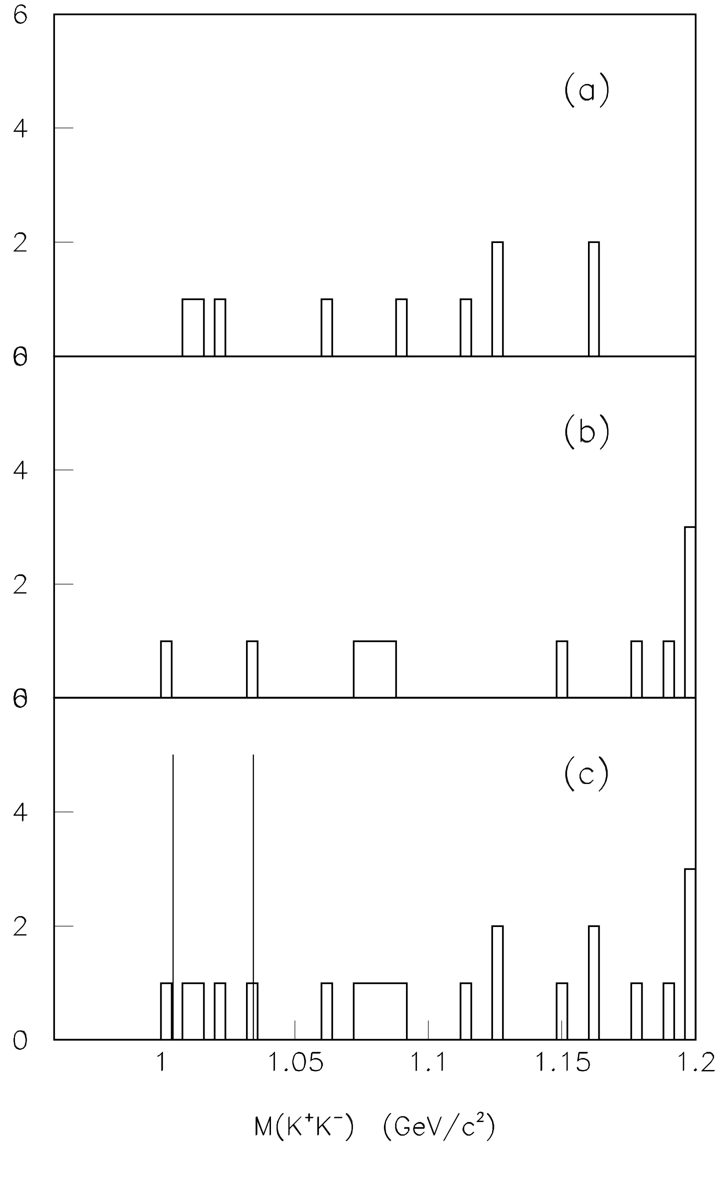

Figure 4: Invariant mass distribution of K^+K^- pairs recoiling against a D candidate. (a) $D^0 \to K^-\pi^+$, (b) $D^+ \to K^-\pi^+\pi^+$, and (c) sum of the two modes. The mass interval between the vertical lines is the ϕ signal region.