The Search for $B \to D\phi(\pi)$

A. J. Lincoln
Department of Physics and Astronomy,
Wayne State University, Detroit, MI, 48201
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The data from CLEO II.V was analyzed to search for the decays $B \to D\phi(\pi)$. The final analysis included a 5 MeV mass cut on ϕ candidates, a $\chi^2 < 5$ cut on mass-fitted D candidates, and a $\chi^2 < 5$ cut on B candidates fitted to the beam energy. No signal was found for modes $B^0 \to D^0\phi$ and $B^0 \to D^{*0}\phi$, and results for modes $B^0 \to \overline{D}^0\phi\pi^0$, $B^0 \to \overline{D}^{*0}\phi\pi^0$, $B^0 \to D^-\phi\pi^+$, $B^0 \to D^{*-}\phi\pi^+$. $B^+ \to \overline{D}^0\phi\pi^+$, and $B^+ \to \overline{D}^{*0}\phi\pi^+$ are inconclusive. Modes $B^+ \to \overline{D}^0\phi\pi^+$, and $B^+ \to \overline{D}^{*0}\phi\pi^+$ seem to carry visible signal, but the low ratio of signal to background prevents determination of a branching fraction. Limits on branching ratios for the modes $B^0 \to D^-\phi\pi^+$, $B^0 \to D^{*-}\phi\pi^+$, $B^+ \to \overline{D}^0\phi\pi^+$, and $B^+ \to \overline{D}^{*0}\phi\pi^+$ have been preliminarily determined to be $(1.4 \pm .68) \cdot 10^{-3}$, $(4.7 \pm 2.3) \cdot 10^{-4}$, $(1.7 \pm .79) \cdot 10^{-3}$, and $(1.5 \pm .87) \cdot 10^{-3}$, respectively.

I. INTRODUCTION

Branching ratios for $B \to D\phi(\pi)$ decay modes have not yet been experimentally investigated. These modes are expected to occur at some rate, of order 10^{-5}, as predicted by the Standard Model, but this small rate and high backgrounds, from both experimental sources and separate complicating processes, make finding reasonable signals from these modes relatively difficult. A major source of background is the decay $B \to DD_s$, after which $D_s \to \phi\pi$, leading to the same final state as four of the modes in this study.

The branching ratios for the $B \to D\pi$ modes have been well established, and these modes were retained in this analysis for rate verification and calibration.

During the course of this project, two separate analyses were done, and each will be described. The first provided a vehicle for trying numerous cuts on the post-skim data, and resulted in no clear signal for any of the relevant modes. The second was skimmed differently, and attempted to initially preserve more of the signal. This second analysis resulted in a possible signal for the modes $B^+ \to \overline{D}^{(*)0}\phi\pi^+$, but no clear signal for the remaining modes.

II. FIRST SKIM AND SELECTION

This analysis was over the entire set of CLEO II.V data, so an initial skim was done to minimize runtime for the rest of the analysis runs, which kept all events consistent with all of the modes in Table I, and their antimatter analogues.

The first skim required, for π^0, that both photons have energy greater than 50 MeV, that the calorimeter energy distribution be consistent with a photon for each (the quantity E9OE25 in CLEO II.V be greater than the cut value that keeps 99% of the photons), and that the reconstructed π^0 be within 3σ of the nominal mass. For all charged tracks, the quantity z0cd (distance along beam axis at point of closest approach to interaction point) must be less than 5 cm. For $K^{\pm}$, dE/dx information was required to be within 2.5σ of the expected value for the track momentum.

In the case of ϕ candidates, the mode $\phi \rightarrow K^+K^-$ was used for reconstruction. Both kaons were required to carry dE/dx information, and mass was required to be within 15 MeV of nominal.

D meson candidates were reconstructed using the modes in Table II, and mass was required to be within 27 MeV of nominal. The modes $D^{*0} \rightarrow D^0\pi^0$ and $D^{*+} \rightarrow D^0\pi^+$ were used for identifying D^*, and the requirement

$$M(D^*) - M(D) - (Q(D^* - D)) < 2\ MeV$$

imposed.

Because the data was taken at the $\Upsilon(4s)$ resonance, and $\Upsilon(4s) \rightarrow B\overline{B}$ more than 96% of the time with very little energy available for B meson motion, B meson candidates were required to have an energy within 150 MeV of the beam energy (E_{beam} defined as $(E(e^-) + E(e+))/2$). Also,

$$\Delta(E_B) < 3\sigma$$

was required, and after fitting the B candidate to beam energy, mass was required to be within 120 MeV of nominal.

TABLE I: Final state modes.

Mode Family	
$B \rightarrow D\pi$	$B^0 \rightarrow D^-\pi^+$, $B^+ \rightarrow \overline{D}^0\pi^+$, $B^0 \rightarrow D^{*-}\pi^+$, $B^+ \rightarrow \overline{D}^{*0}\pi^+$
$B \rightarrow D\phi$	$B^0 \rightarrow \overline{D}^0\phi$, $B^0 \rightarrow \overline{D}^{*0}\phi$
$B \rightarrow D\phi\pi$	$B^+ \rightarrow \overline{D}^0\phi\pi^+$, $B^0 \rightarrow \overline{D}^0\phi\pi^0$, $B^0 \rightarrow D^-\phi\pi^+$,
	$B^+ \rightarrow \overline{D}^{*0}\phi\pi^+$, $B^0 \rightarrow \overline{D}^{*0}\phi\pi^0$, $B^0 \rightarrow D^{*-}\phi\pi^+$

TABLE II: D meson modes used.

Mode Family	Γ/Γ_i	Add. Req.
$D^0 \rightarrow K^-\pi^+$	$(3.80 \pm 0.09)\%$	
$D^0 \rightarrow K^-\pi^+\pi^0$	$(13.0 \pm 0.8)\%$	$p_{\pi^0} > 100$ MeV
$D^0 \rightarrow K^-\pi^+\pi^+\pi^-$	$(7.46 \pm 0.31)\%$	
$D^0 \rightarrow \overline{K}^0\pi^0$	$(2.30 \pm 0.22)\%$	$p_{\pi^0} > 100$ MeV
$D^0 \rightarrow \overline{K}^0\pi^+\pi^-$	$(5.97 \pm 0.35)\%$	
$D^+ \rightarrow K^-\pi^+\pi^+$	$(9.2 \pm 0.6)\%$	
$D^+ \rightarrow \overline{K}^0\pi^+$	$(2.82 \pm 0.19)\%$	

III. FIRST ANALYSIS AND RESULTS

To check for background contribution of charged pions in the set of tracks used to construct ϕ candidates, two sets of ϕ mass plots were produced. The first split ϕ candidates into four momentum ranges: $p_\phi < .5$ GeV, $.5 < p_\phi < 1$ GeV, $1 < p_\phi < 1.5$ GeV, and $p_\phi > 1$ GeV. These plots are shown in Fig. 2. Since dE/dx for pions and kaons overlaps near momenta of 1 GeV (Fig. 1), and noting that the separation between pion and kaon dE/dx information seems to be nearly equal at .8 GeV and 2 GeV, another set of plots with ϕ momentum ranges $p_\phi < .8$ GeV, $.8 < p_\phi < 2$ GeV, and $p_\phi > 2$ GeV, which are shown in Fig. 3. If pions are being substituted for kaons in the construction of ϕ candidates, we would expect the background in mass plots of ϕ with momentum near the overlap dE/dx region to he higher. This is seen in neither of the sets of plots in Fig. 2 and Fig. 3. After this analysis, the mass range around nominal for ϕ candidates was changed to 5 MeV.

For all D^0 and D^+ candidates, mass fitting was introduced to lower background levels. D^0 was forced to have a mass of 1.8645 GeV, and D^+ a mass of 1.8693 GeV. This lead to slight gains in signal to background in all $B \to D\phi\pi$ modes. The mode $B^0 \to D^{*-}\phi\pi^+$ is shown in Fig. 4.

The χ^2 from mass fitting of D, D^*, and ϕ candidates and the χ^2 from energy fitting of B candidates was required to be less than 4, and in any mode with a D^*,

$$\angle(D^*, D) > .45$$

in the D^* rest frame was required. The background ($M_B < 5.22GeV$) and signal ($M_B > 5.27$) distributions for $\angle(D^*, D)$ is shown in Fig. 5.

As the mode $B^0 \to D^{*-}\phi\pi^+$ seemed the most promising, those events consistent with the intermediate decay $D_s^\pm \to \phi\pi^\pm$, within 25 MeV were removed. This mode, before and after the D_s removal, is shown in Fig. 6.

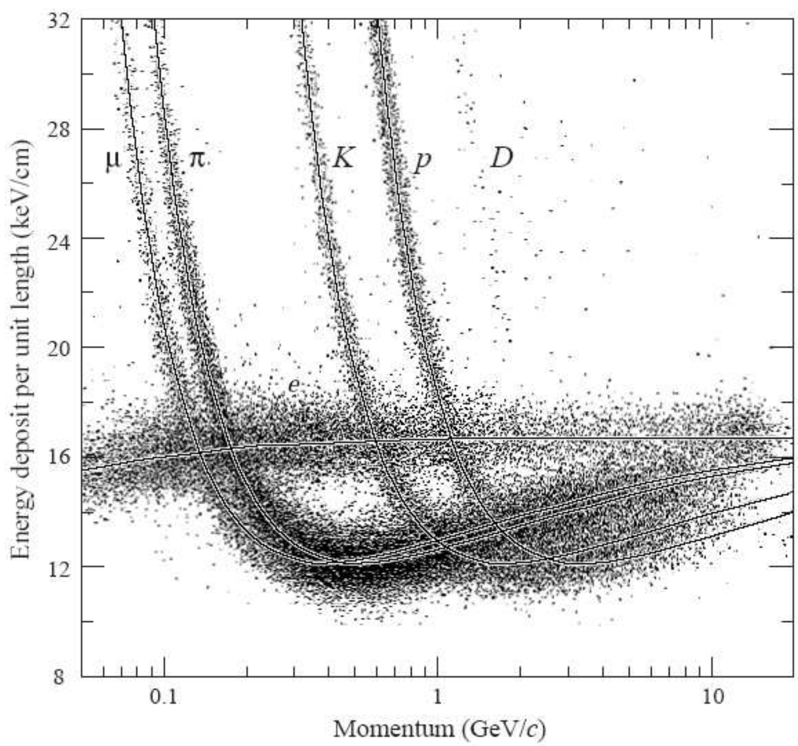

FIG. 1: dE/dx plot for charged particles. Pions and kaons overlap around 1 MeV.[1]

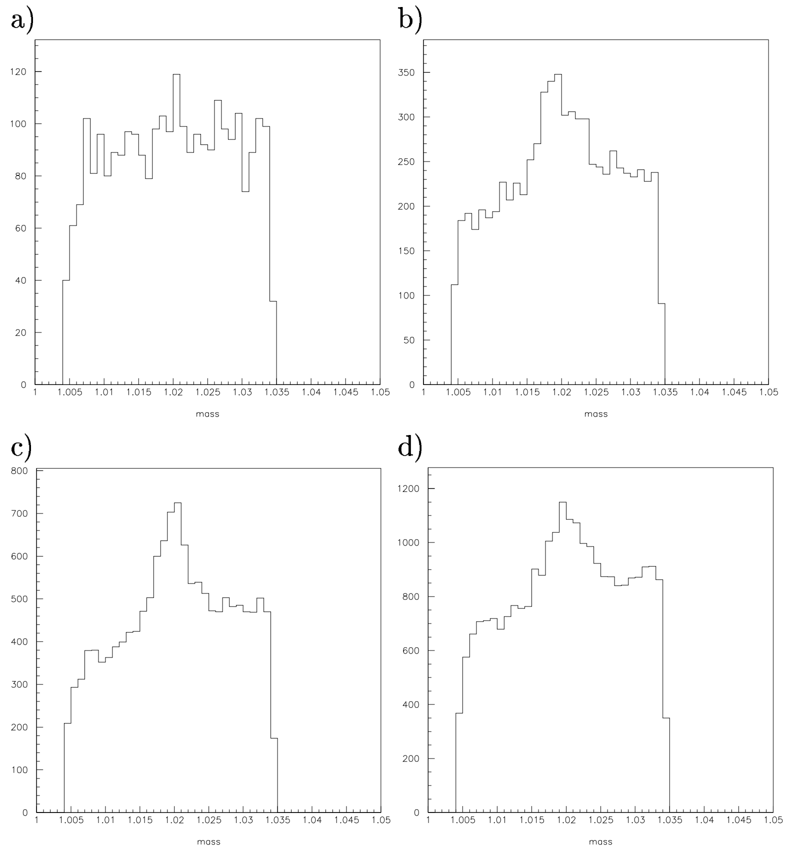

FIG. 2: Masses of ϕ candidates in momentum ranges a) $p_\phi < .5$ GeV, b) $.5 < p_\phi < 1$ GeV, c) $1 < p_\phi < 1.5$ GeV, d) $p_\phi > 1.5$ GeV. The background in plots b) and c) is not higher than the background in a) and d), suggesting that pions are not contaminating the ϕ signal.

IV. SECOND SKIM AND SELECTION

In an attempt to gain signal, a second skim was done. Required was that the χ^2 from mass fitting of D mesons be less than 5, that $D^{*+} \to D^0\pi^+$ candidates be within 1.5 MeV of nominal D^{*+} mass, that $D^{*0} \to D^0\pi^0$ candidates be within 2 MeV of nominal d^{*0} mass, and that χ^2 from energy fitting of B candidates to the beam energy be less than 5. Kaons used to reconstruct ϕ candidates were not required to have dE/dx information, while all intermediate and final state modes shown above still apply.

V. SECOND ANALYSIS AND RESULTS

Again, all events in the modes $B^+ \to D^0\phi\pi^+$, $B^0 \to D^-\phi\pi^+$, $B^+ \to D^{*0}\phi\pi^+$, and $B^0 \to D^-\phi\pi^+$ consistent with $D_s^\pm \to \phi\pi^\pm$ within 25 MeV of nominal D_s mass were removed. In addition, all charged particle tracks are required to have a closest approach to the beam axis less than 1 cm.

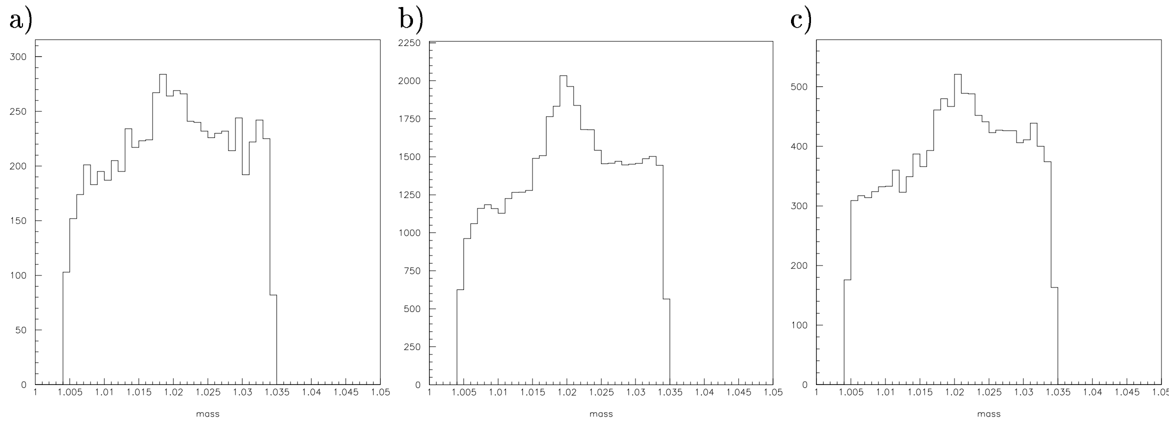

FIG. 3: Masses of ϕ candidates in momentum ranges a) $p_\phi < .8$ GeV, b) $.8 < p_\phi < 2$ GeV, c) $p_\phi > 2$ GeV. The background in plot b) is not higher than the background in a) and c), suggesting that pions are not contaminating the ϕ signal.

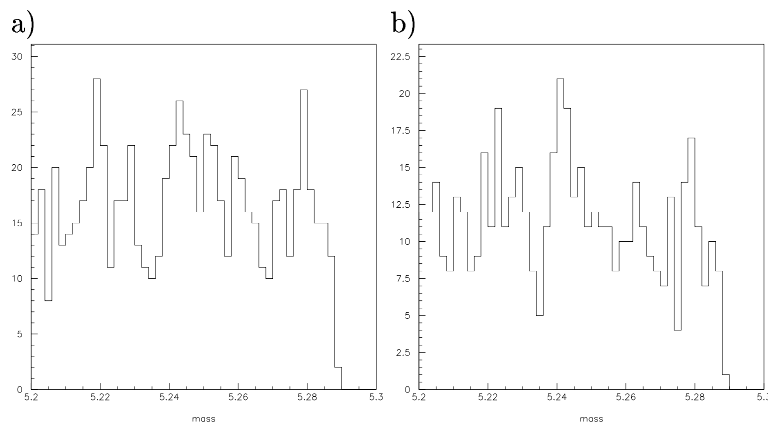

FIG. 4: a) the mode $B^0 \to D^{*-}\phi\pi^+$ before D mass fitting, and b) after D mass fitting.

Final plots are shown in Fig. 7 ($B \to D\pi$ modes), Fig. 8 ($B^0 \to D^{(*)0}\phi$ modes), Fig. 9 ($B \to D\phi\pi$ modes), and Fig. 10 ($B \to DD_s, D_s \to \phi\pi$ modes).

VI. RESULTS

Table 3 contains the limit of the number of events in the signal peak for each mode of interest at 95% C.L.

Table 4 contains upper limits for branching ratios of selected modes at 95% C.L.

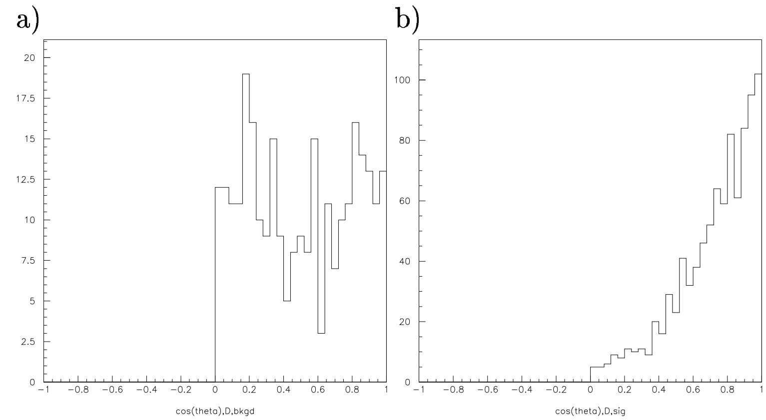

FIG. 5: a) $\angle(D^*, D)$ for background B candidates, and b) for signal B candidates.

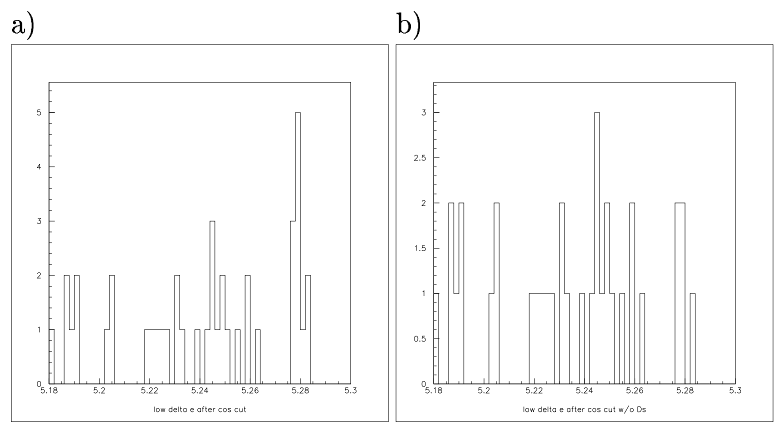

FIG. 6: a) the mode $B^0 \to D^{*-}\phi\pi^+$ before removal of $D_s \to \phi\pi$, and b) after.

VII. ACKNOWLEDGMENTS

It is my pleasure to acknowledge G. Bonvicini, of Wayne State University, for providing me with an engaging and exciting project, for spending his valuable time walking me through my first data analysis, and for enduring my constant interruptions. I also wish to thank R. Galik, Cornell University, for organizing what is, by far, the best summer experience I have had.

[1] S. Eidelman et al., Phys. Lett. B 592, 1 (2004).

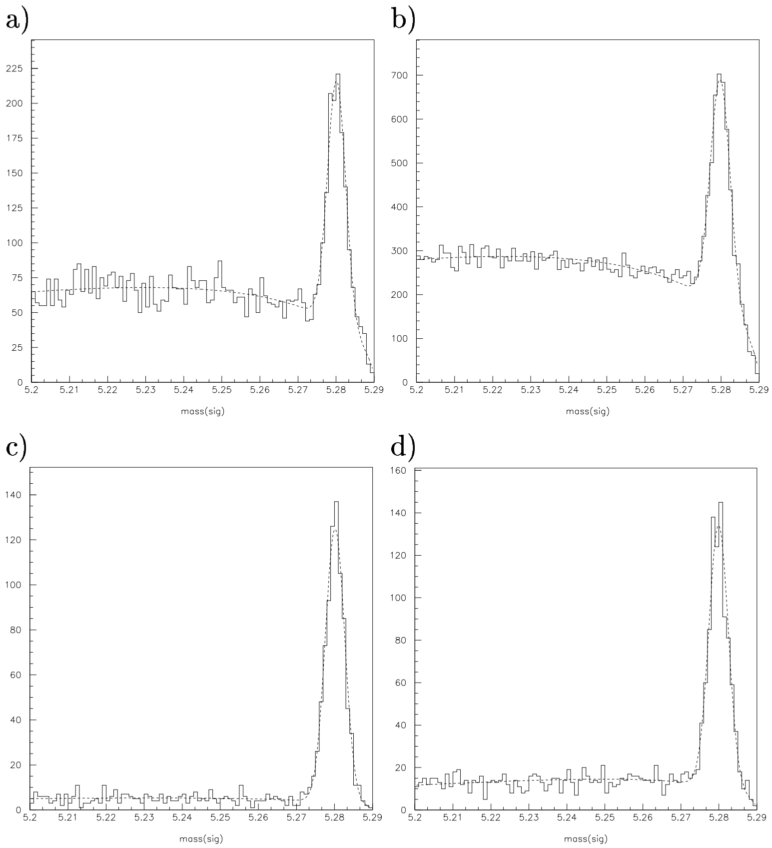

FIG. 7: a) $B^0 \to D^- \pi^+$, b) $B^+ \to D^0 \pi^+$, c)$B^0 \to D^{*-} \pi^+$, d) $B^+ \to D^{*0} \pi^+$

TABLE III: Upper limits on number of peak events.

Mode	$N_{ev} <$
$B^0 \to \overline{D}^0 \phi$	66.327
$B^0 \to \overline{D}^{*0} \phi$	29.765
$B^+ \to \overline{D}^0 \phi \pi^+$	172.95
$B^0 \to \overline{D}^0 \phi \pi^0$	83.202
$B^0 \to D^- \phi \pi^+$	188.30
$B^+ \to \overline{D}^{*0} \phi \pi^+$	43.426
$B^0 \to \overline{D}^{*0} \phi \pi^0$	27.857
$B^0 \to D^{*-} \phi \pi^+$	13.892

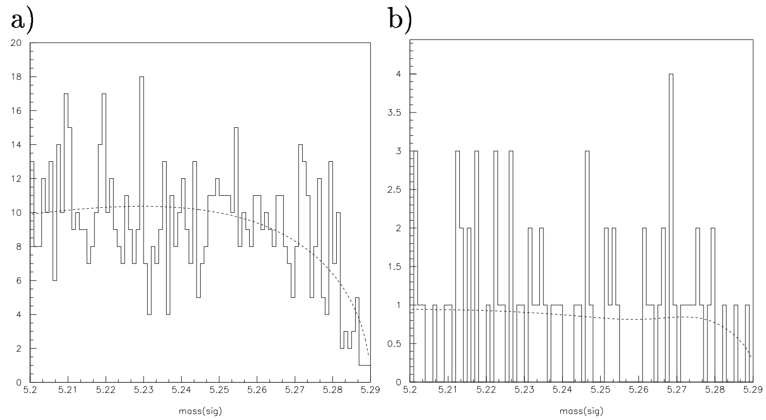

FIG. 8: a) $B^0 \to D^0\phi$, b) $B^0 \to D^{*0}\phi$

TABLE IV: Upper limits on branching ratio.

Mode	$Br <$
$B^0 \to D^- \phi\pi^+$	$(1.4 \pm .68) \cdot 10^{-3}$
$B^0 \to D^{*-} \phi\pi^+$	$(4.7 \pm 2.3) \cdot 10^{-4}$
$B^+ \to \overline{D}^0 \phi\pi^+$	$(1.7 \pm .79) \cdot 10^{-3}$
$B^+ \to \overline{D}^{*0} \phi\pi^+$	$(1.5 \pm .87) \cdot 10^{-3}$

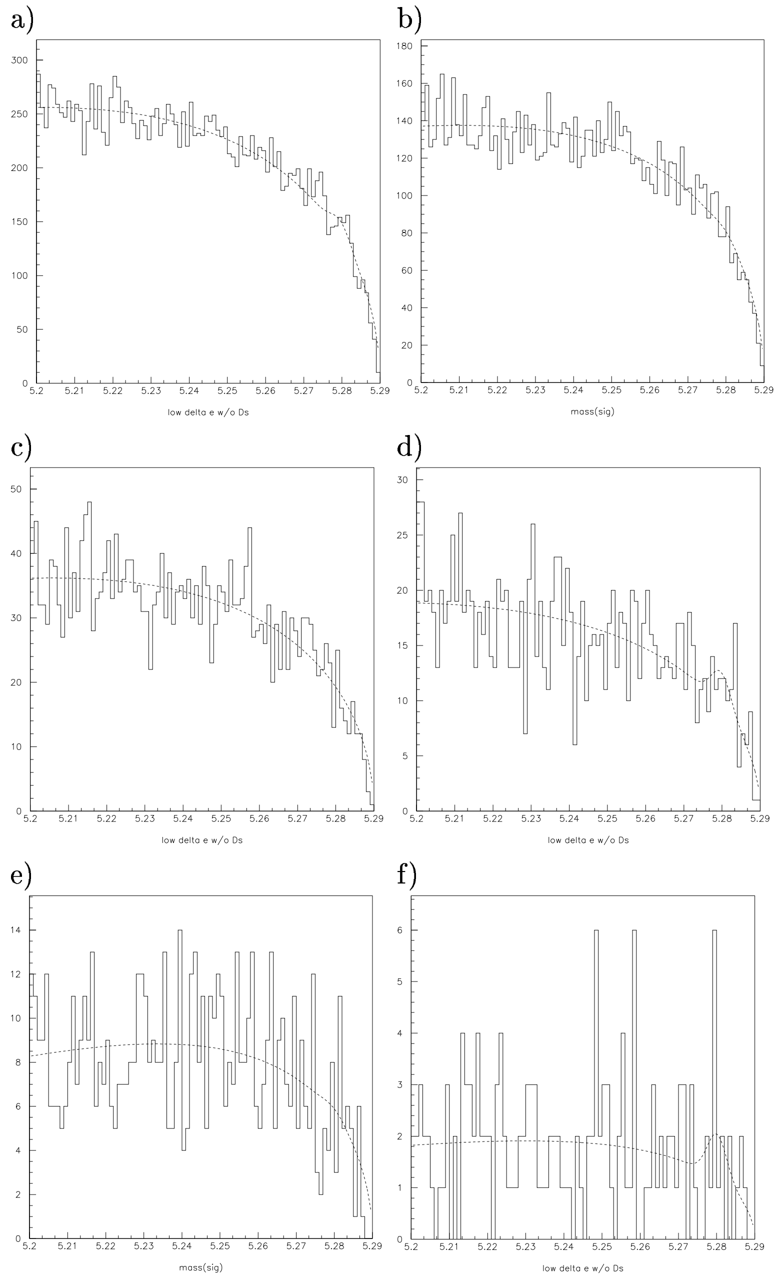

FIG. 9: a) $B^+ \to \overline{D}^0 \phi \pi^+$, b) $B^0 \to \overline{D}^0 \phi \pi^0$, c)$B^0 \to D^- \phi \pi^+$, d) $B^+ \to \overline{D}^{*0} \phi \pi^+$ e)$B^0 \to \overline{D}^{*0} \phi \pi^0$, f) $B^0 \to D^{*-} \phi \pi^+$

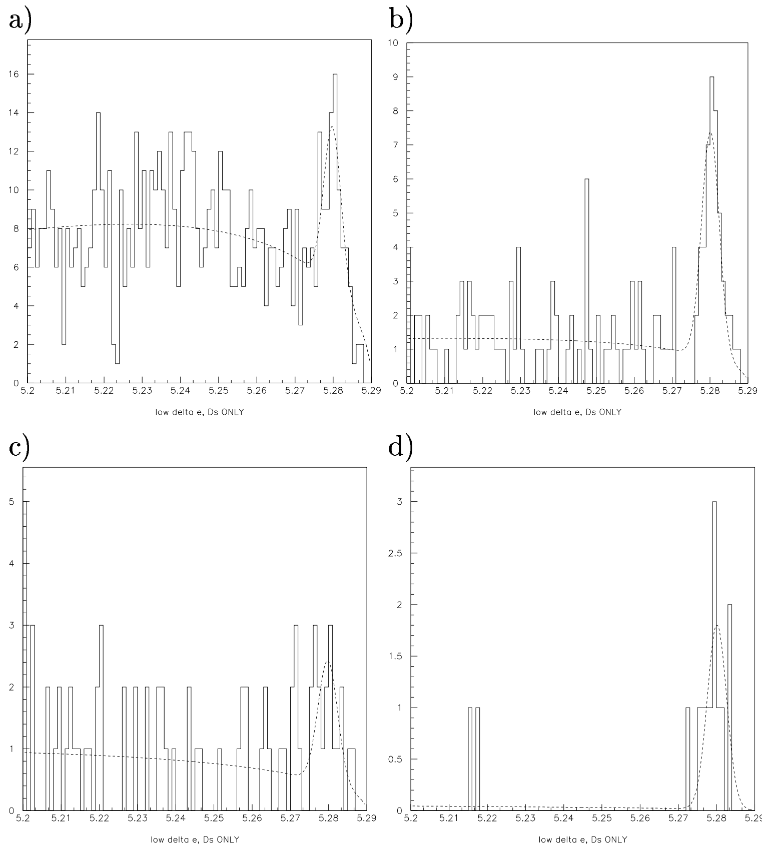

FIG. 10: a) $B^+ \to \overline{D}^0 D_s^+, D_s \to \phi\pi^+$, b) $B^0 \to D^- D_s^+, D_s \to \phi\pi^+$, c)$B^+ \to \overline{D}^{*0} D_s^+, D_s \to \phi\pi^+$, d) $B^0 \to D^{*-} D_s^+, D_s \to \phi\pi^+$