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Measurement of the polarization amplitudes in $B^0 \to J/\psi K^{*0}$ and $B^0 \to \phi K^{*0}$ using the Two Track Trigger

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We present the first measurement of the polarization amplitudes in $B \to VV$ decays using the Two Track Trigger data. In particular we study two B_d^0 decays modes $B^0 \to J/\psi K^{*0}$ and $B^0 \to \phi K^{*0}$ and provide the first measurement of a polarization amplitude in a charmless decay at CDF.

The complete results for the $B^0 \to J/\psi K^{*0}$ decays are:

$$\begin{aligned} |A_0|^2 &= 0.572 \pm 0.026(stat.) \pm 0.018(sys.) \\ |A_\parallel|^2 &= 0.207 \pm 0.032(stat.) \pm 0.007(sys.) \\ arg\{A_\parallel\} &= 2.75 \pm 0.23(stat.) \pm 0.06(sys.) \\ arg\{A_\perp\} &= 2.99 \pm 0.15(stat.) \pm 0.02(sys.) \end{aligned} \tag{1}$$

while for the $B^0 \to \phi K^{*0}$ channel we measure:

$$\begin{aligned} |A_0|^2 &= 0.571 \pm 0.097(stat.) \pm 0.050(sys.) \\ |A_\parallel|^2 &= 0.223 \pm 0.077(stat.) \pm 0.054(sys.) \\ arg\{A_\parallel\} &= 2.97 \pm 0.52(stat.) \pm 0.26(sys.) \\ arg\{A_\perp\} &= 2.77 \pm 0.37(stat.) \pm 0.37(sys.) \end{aligned} \tag{2}$$

I. INTRODUCTION

Analysis of $B \to VV$ decays offers a wide range of experimental observables to test Standard Model and possible extensions of it. In particular, the decays that proceed through the quark level transition $b \to c\bar{c}s$, characterized by high branching ratios, offer the opportunity to study in detail the polarization properties of those decays and additionally, in the case of $B_s^0 \to J/\psi\phi$, they offer a nice way to measure $\Delta\Gamma_s$. Charmless $B \to VV$ decays are no less interesting for the rich range of reactions that can be studied and the potential for extracting CKM parameters and observing CP violation.

Indeed charmless decays mediated by the reaction $b \to s\bar{s}s$ have shown at least two anomalies that are worth further investigation, namely the hint for a contribution other than the usual B_d mixing induced phase in the time dependent CP violation of B_d^0 modes mediated by $b \to s\bar{s}s$, and the longitudinal polarization in $B \to \phi K^*$ that has been measured to be much less than that predicted by theory. With CDF data we can study similar decays of B_s mesons in order to further verify some of these effects. In particular a measurement of the polarization of the $B_s^0 \to \phi\phi$ decay would be a further experimental constraint to investigate whether the $B \to VV$ polarization anomalies might be related to a Standard Model or New Physics effect.

With 180 pb^{-1} of integrated luminosity CDF has been able to show evidence of the $B_s^0 \to \phi\phi$ decay [1]. With 360 pb^{-1} of data a signal of about 40 events of this decay mode has been observed. With such a sample (and even more so with the data taken up to the winter '06 shutdown) a polarization measurement using this decay seems possible. To test the ability to extract the polarization amplitude we use two B_d^0 decays modes $B^0 \to J/\psi K^{*0}$ and $B^0 \to \phi K^{*0}$. The former provide an abundant signal also in the Two Track Trigger (TTT), where events with two opposite-charged displaced tracks are triggered. It allows for detailed test of the procedure and comparison with previous analogous measurement by other experiments and also with CDF but using the J/ψ trigger. The latter is topologically more similar to the $B_s^0 \to \phi\phi$ decay but, given a yield of more than a factor 2 greater, allows us to perform an interesting and competitive measurement already with the present statistics.

II. ANALYSIS STRATEGY

We analyze the events accumulated via the Two Track Trigger up to August 2004, corresponding to 362 ± 21pb^{-1} of integrated luminosity. To reconstruct both $B^0 \to \phi K^{*0}$and $B^0 \to J/\psi K^{*0}$candidates, each combination of 4 tracks with total charge 0 is fit to a common vertex. To improve the resolution on the invariant mass for the $B^0 \to J/\psi K^{*0}$ reconstruction a constraint to the PDG [8] J/ψ mass is applied to the two muon candidates and at least one of them is required to be associated to a `CdfMuon` object. For the $B^0 \to J/\psi K^{*0}$ candidate reconstruction, the vertex fit with J/ψ mass constraint identify the $\mu^+\mu^-$ pair. We assign to the other track pair both $K\pi$ and πK mass hypothesis and choose the closest invariant mass combination to the K^{*0} mass. For the $B^0 \to \phi K^{*0}$ decays we require one of the neutral track pair to have an invariant K^+K^- mass within a window of ± 7MeV/c^2 around PDG [8] ϕ mass. For the remaining pair we follow the same procedure described above for the $B^0 \to J/\psi K^{*0}$ channel. The procedure for $K\pi$ mass ssociation is not always correct and for a certain fraction of the events we end up swapping $K\pi$ identities. This still produce a signal peak at approximately the correct position but with a much broader width.

B decays of interest are selected applying some kinematic cuts optimized in order to minimize the uncertainty on the final polarization measurement. We use the unbinned maximum likelihood method to extract the polarization amplitudes.

The polarization analysis is carried out in the so-called transversity basis [2]. For the signal part, given the matrix elements of the decay, the angular distribution of the polarized decay defines the likelihood of finding an event with particular set of angles, which is then weighted according to their integrated angular acceptance in the detector. We model the background angular distribution using a similar PDF (probability density function) to signal events with different parameters. A linear distribution in mass is assumed for background events. An additional likelihood term for the mass is also included to allow the fitter to fit for the mass simultaneously, and more importantly, to enhance the separation of signal and background and correctly model the magnitude of signal and background components. To correct for the $K \leftrightarrow \pi$ swapping contamination, we split the signal events into swapped and un-swapped terms and model the swapped distributions using parameters determined by Monte Carlo.

- signal angular distribution:

$$U_{sig}(\vec{\omega}) = \sum_{i=1}^{6} A_i f_i(\vec{\omega}). \tag{3}$$

where: A_i = polarization amplitudes in the transversity basis. f_i = functions of the three angular variables in the transversity basis. The complete angular distributions can be found in literature (see e.g. [2]).

- signal mass distribution:

$$X_{sig}^{obs}(m_j \mid M, \sigma_m) = \frac{1}{\sqrt{2\pi}\sigma_m} e^{-\frac{(m_j-M)^2}{2\sigma_m^2}} \tag{4}$$

- swapped signal mass distribution:

$$\begin{aligned} X_{sig,sw}^{obs}(m) &= (1-f_w)\cdot G(m-(M+\Delta M_s w), \sigma_n)/N_n \\ &+ f_w \cdot G(m-(M+\Delta M_{sw}), \sigma_w)/N_w \end{aligned} \tag{5}$$

where

$$N_{n,w} = \frac{1}{2} Erf\left(\frac{m-(M+\Delta M_{sw})}{\sqrt{2}\cdot\sigma_{n,w}}\right)\Bigg|_{m=5.15}^{m=5.40}. \tag{6}$$

and

$$G(x,y) = \frac{1}{\sqrt{2\pi}y} e^{-\frac{x^2}{2y^2}}. \tag{7}$$

- background angular distribution:

$$U_{sig}(\vec{\omega}) = \sum_{i=1}^{6} B_i f_i(\vec{\omega}). \tag{8}$$

- background mass distribution:

$$X_{sig}^{obs}(m_j \mid M, \sigma_m) = \frac{1}{\sqrt{2\pi}\sigma_m} e^{-\frac{(m_j-M)^2}{2\sigma_m^2}} \tag{9}$$

where M and σ_m are floating in the fit.

Putting all pieces together, we obtain the likelihood function for a B_d event:

$$\begin{aligned} log\mathcal{L} &= \sum_{j=1}^{N_{obs}} log\left\{ f_s \cdot \frac{U_{sg}(\vec{\omega})\cdot X_{sig}(m) + \overline{U}(\mathcal{SW}(\vec{\omega}))R(cos\psi)\cdot X_{sw}(m)}{\sum_i A_i(\xi_i^{un,B^d} + \xi_i^{sw,B^d})} \right. \\ &+ \left. (1-f_s)\cdot\frac{U_{bg}(\vec{\omega})\cdot X_{bg}(m)}{\sum_i B_i \xi_i^{B^s}} \right\}. \end{aligned} \tag{10}$$

where:

$$\xi_i^{un} = \frac{1}{N^{rec,un}} \sum_{j=1}^{N^{rec,un}} f_i(\vec{\omega}_j) \tag{11}$$

$$\xi_i^{sw} = \frac{1}{N^{rec,un}} \sum_{j=1}^{N^{rec,un}} f_i(\mathcal{SW}(\vec{\omega}_j))R(\vec{\omega}_j, \vec{\kappa}_j). \tag{12}$$

are the normalization factors for swapped and unswapped events due to detector acceptance and analysis cut efficiency. The ξ_i coeffients are evaluated using MC samples.

III. SYSTEMATICS

A great effort is made to evaluate all the possible sources of systematics. The most important effect is due to the modellization of the background angular distribution. The background model systematic has been estimated by generating toy MC samples whith background polarizations as measured on data and changing the fit model for background to a constant in the angular variable space. Non-negligible contributions come also from the little disagreement between the MC and the DATA transverse momentum spectrum, the evaluation of the partial-normalization coefficients ξ_i, the $K \leftrightarrow \pi$ swapped events model and the finite resolution on the angular variables. A summary of all the systematic uncertainties is in Table I and II.

Syst. sources	$\|A_0\|^2$	$\|A_\parallel\|^2$	$arg\{A_\parallel\}$	$arg\{A_\perp\}$
background model	±0.017	±0.003	±0.04	±0.003
$K\leftrightarrow\pi$ model	±0.003	±0.003	–	±0.006
angular resolution	±0.003	±0.005	±0.05	±0.021
ξ_i evaluation	±0.002	±0.003	±0.01	±0.004
total	±0.018	±0.007	±0.06	±0.022

TABLE I: *summary of the systematics for $B^0 \to J/\psi K^{*0}$ channel.*

Syst. sources	$\|A_0\|^2$	$\|A_\parallel\|^2$	$arg\{A_\parallel\}$	$arg\{A_\perp\}$
background model	±0.027	±0.054	±0.20	±0.36
$P_t(B)$ spectrum	±0.042	±0.004	±0.16	±0.07
$K\leftrightarrow\pi$ model	±0.001	±0.002	±0.01	±0.004
angular resolution	±0.003	±0.004	±0.05	±0.012
ξ_i evaluation	±0.002	±0.001	±0.004	±0.002
total	±0.050	±0.054	±0.26	±0.37

TABLE II: *summary of the systematics for $B^0 \to \phi K^{*0}$ channel.*

IV. RESULTS

We show the first measurement of the longitudinal polarization in the charmless $B^0 \to \phi K^{*0}$ decay. This value is consistent with what is found at B-factory and close in precision to what have been measured despite a still significantly lower statistic available. More importantly this result confirm that in this $b \to s\bar{s}s$ decay a lower longitudinal polarization is observed contrary to the naive Standard Model and factorization expectation.
The complete results for $B^0 \to J/\psi K^{*0}$ and $B^0 \to \phi K^{*0}$ are summarized in the Table III; the Figure 1 shows the contour plots in the $|A_0|^2$ - $|A_\parallel|^2$ plane with the comparison between our results, the previous CDF results (for $B^0 \to J/\psi K^{*0}$) and the most recent Belle and BaBar numbers ([3–7]); the Figures 2 and 3 show the projection of the unbinned maximum likelihood fit results on the B invariant mass distribution and on the three angular distributions.

	$B^0 \to J/\psi K^{*0}$	$B^0 \to \phi K^{*0}$
Yield	934 ± 24	59 ± 9
$\|A_0\|^2$	$0.572 \pm 0.026 \pm 0.018$	$0.571 \pm 0.097 \pm 0.050$
$\|A_\perp\|^2$	$0.220 \pm 0.032 \pm 0.016$	$0.206 \pm 0.089 \pm 0.045$
$arg\{A_\parallel\}$	$2.75 \pm 0.23 \pm 0.06$	$2.97 \pm 0.52 \pm 0.26$
$arg\{A_\perp\}$	$2.99 \pm 0.15 \pm 0.02$	$2.77 \pm 0.37 \pm 0.37$
$\|A_\parallel\|^2$	$0.207 \pm 0.032 \pm 0.007$	$0.223 \pm 0.077 \pm 0.054$

TABLE III: Preliminary results for $B^0 \to J/\psi K^{*0}$and $B^0 \to \phi K^{*0}$polarization measurement. The first error reported is statistical the second systematic.

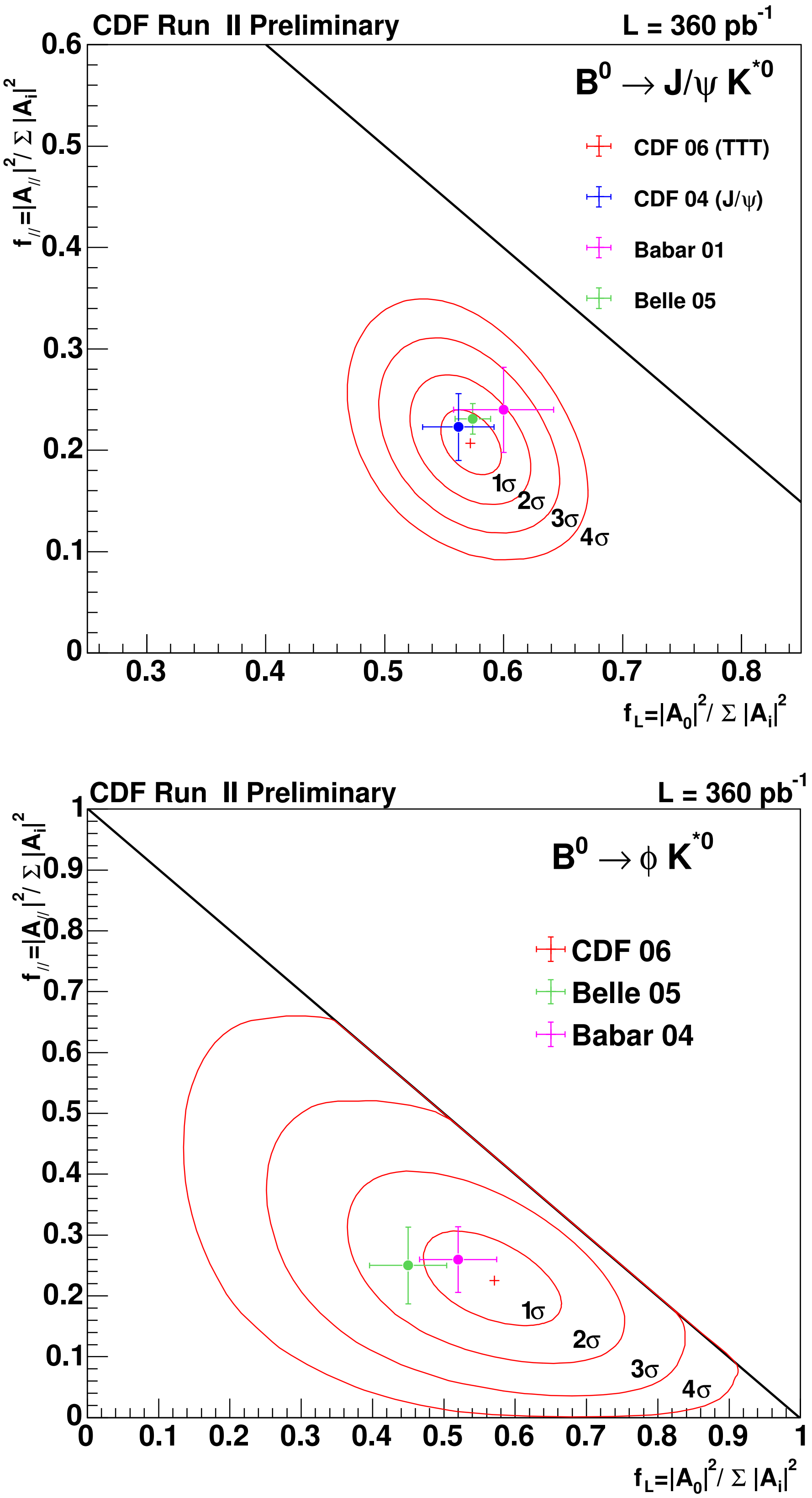

FIG. 1: *Contour plots for* $B^0 \rightarrow J/\psi K^{*0}$ *and* $B^0 \rightarrow \phi K^{*0}$ *with statistical uncertainties and comparison with most recent BaBar and Belle results.*

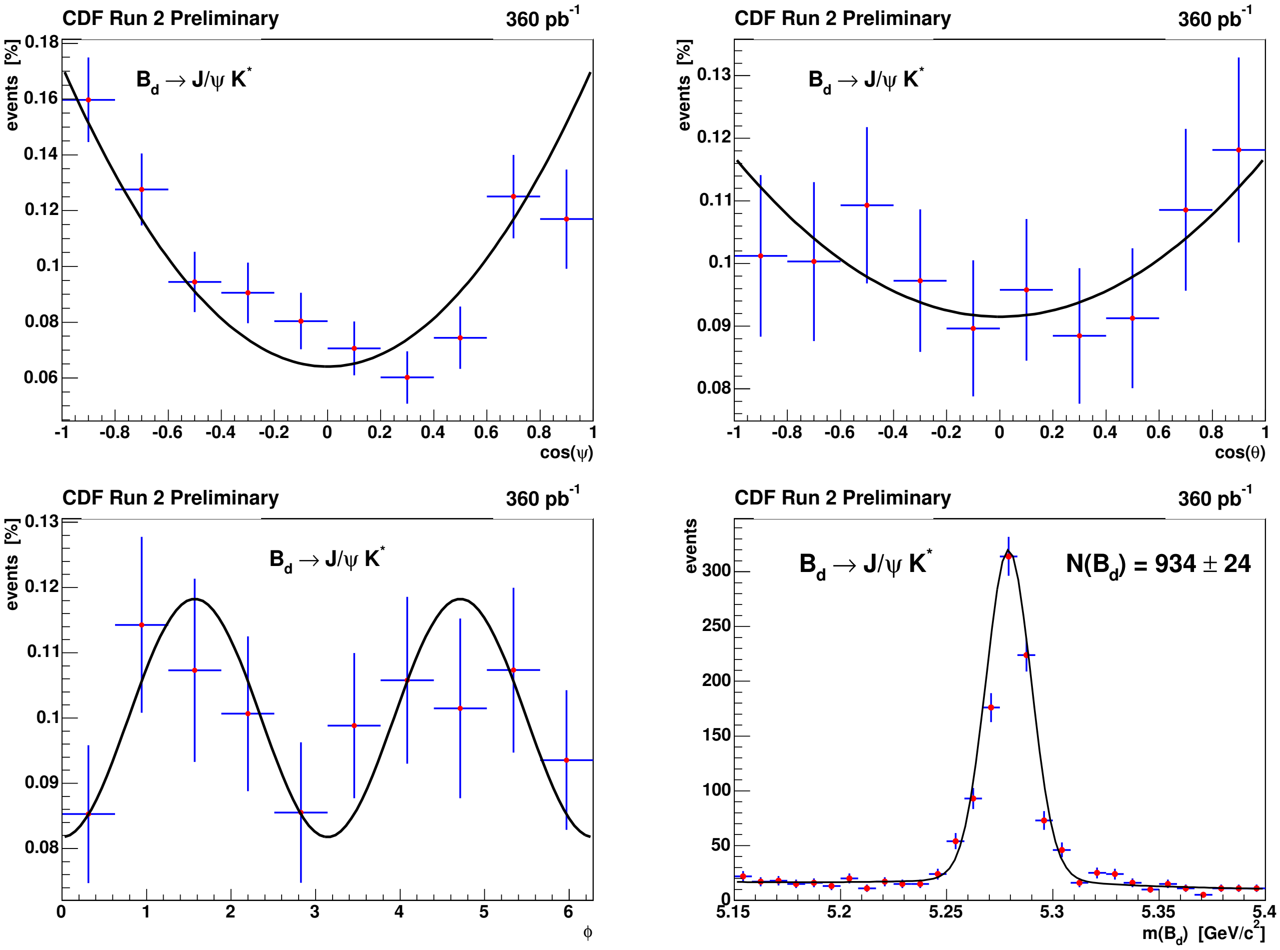

FIG. 2: *Projections of the fit results for the complete Two Track Trigger sample of* $B^0 \to J/\psi K^{*0}$.

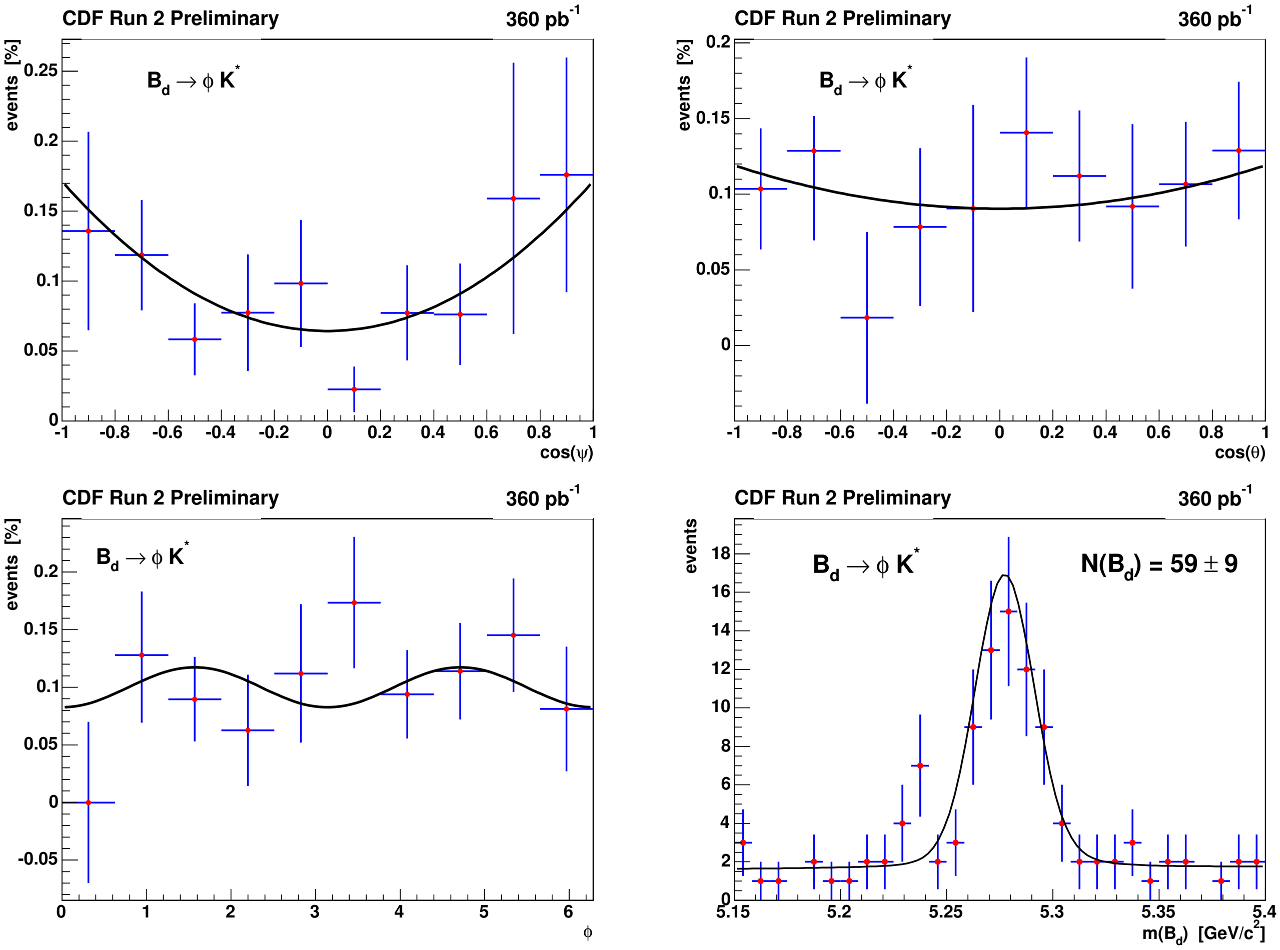

FIG. 3: *Projections of the fit results for the complete Two Track Trigger sample of* $B^0 \to \phi K^{*0}$.

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