

Search for the Decay $B^0 \rightarrow K^{*+} \rho^-$

The *BABAR* Collaboration

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Abstract

We present the preliminary result of a search for the decay of $B^0 \rightarrow K^{*+} \rho^-$. The data were recorded with the *BABAR* detector at the PEP-II collider and correspond to 123 million $B\bar{B}$ pairs produced in the e^+e^- annihilation through the $\Upsilon(4S)$ resonance. We obtain an upper limit on the branching fraction for this decay of $\mathcal{B}(B^0 \rightarrow K^{*+} \rho^-) < 24 \times 10^{-6}$ (90% C.L.). All results are preliminary.

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1 INTRODUCTION

The study of the B meson decay into charmless hadronic final states plays an important role in the understanding of the origin of CP violation. The B decays to two vector particles are of special interest because their angular distributions reflect both strong- and weak-interaction dynamics [1]. The decay $B \rightarrow K^* \rho$ is dominated by $b \rightarrow s$ penguin contribution, and the tree-level contribution is CKM suppressed in the Standard Model (SM) (see Figure 1). The angular correlation measurement is particularly sensitive to phenomena beyond the SM, potentially present at either loop- or tree-level [2].

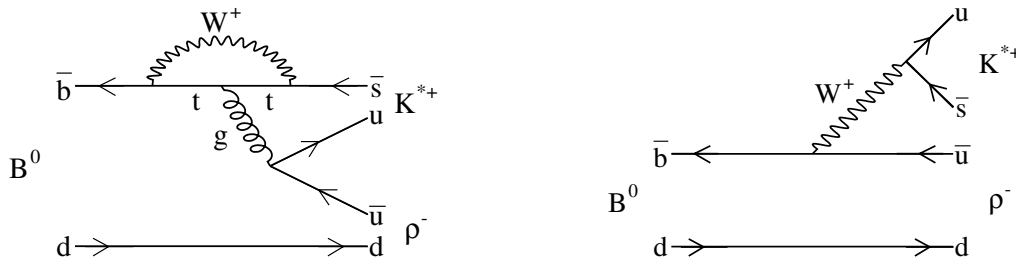


Figure 1: Gluonic penguin and tree diagrams contributing to the process $B^0 \rightarrow K^{*+} \rho^-$. The penguin contribution coming from the diagrams with t and c quarks in the loop dominates since contributions from process with a u quark is suppressed. The tree is a CKM-suppressed diagram.

For measurements with limited statistics, we integrate over the azimuthal angle ϕ between the two decay planes shown in Figure 2. The differential decay rate [1] is

$$\frac{d^2\Gamma}{\Gamma d\cos\theta_{K^{*+}} d\cos\theta_{\rho^-}} = \frac{9}{4} \left(f_L \cos^2\theta_{K^{*+}} \cos^2\theta_{\rho^-} + \frac{1}{4} (1 - f_L) \sin^2\theta_{K^{*+}} \sin^2\theta_{\rho^-} \right) \quad (1)$$

where f_L is the longitudinal polarization fraction component $f_L \equiv \Gamma_L/\Gamma$ [3, 4]. The angles $\theta_{K^{*+}}$ and θ_{ρ^-} are the helicity angles of K^{*+} and ρ^- , which are defined between the charged $K(\pi)$ direction and the direction opposite the B in $K^{*+}(\rho^-)$ rest frame as shown in Figure 2.

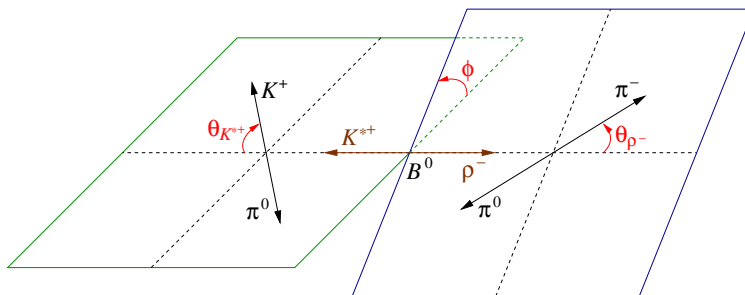


Figure 2: Definition of angles $\theta_{K^{*+}}$, θ_{ρ^-} , and ϕ , for the decay $B^0 \rightarrow K^{*+} \rho^-$. The $K^+ \pi^0$ ($\pi^- \pi^0$) final states are shown in the K^{*+} (ρ^-) rest frame.

In the SM, and assuming naive factorization, the polarization is expected to be proportional to $(1 - 4 \times m_\rho^2/m_B^2) > 90\%$ [2], which has been verified experimentally in both $B^+ \rightarrow \rho^+ \rho^0$ and

$B^0 \rightarrow \rho^+ \rho^-$ decays [5, 6, 7]. However, this prediction does not agree with measurements in pure penguin B decays such as $B^+ \rightarrow \phi K^{*+}$ [6] and $B^0 \rightarrow \phi K^{*0}$ [8] as shown in Table 1. Since the pure penguin B decay processes are sensitive to new physics, it is very interesting to look at additional pure penguin or penguin dominated B decays [2].

Table 1: Previous measurements for rates and f_L for $B \rightarrow V_1 V_2$ modes. The first error is statistical and the second error is systematic.

Mode	$\mathcal{B}(10^{-6})$	f_L
$B^+ \rightarrow \rho^0 \rho^+$	$22.5^{+5.7}_{-5.4} \pm 5.8$	$0.97^{+0.03}_{-0.07} \pm 0.04$
$B^0 \rightarrow \rho^+ \rho^-$	$30 \pm 4 \pm 5$	$0.99 \pm 0.03 \pm 0.04$
$B^+ \rightarrow \rho^0 K^{*+}$	$10.6^{+3.0}_{-2.6} \pm 2.4$	$0.96^{+0.04}_{-0.16} \pm 0.04$
$B^0 \rightarrow \phi K^{*0}$	$9.2 \pm 0.9 \pm 0.5$	$0.52 \pm 0.05 \pm 0.02$
$B^+ \rightarrow \phi K^{*+}$	$12.7^{+2.2}_{-2.0} \pm 1.1$	$0.46 \pm 0.12 \pm 0.03$

In this paper we report a search for the $B^0 \rightarrow K^{*+} \rho^-$ decay based on a sample of 123 million $B\bar{B}$ pairs and set a limit on the branching fraction.

2 THE BABAR DETECTOR AND DATASET

The results presented in this paper are based on data collected in 1999–2003 with the *BABAR* detector [9] at the PEP-II asymmetric e^+e^- collider located at the Stanford Linear Accelerator Center (SLAC). An integrated luminosity of 113 fb^{-1} , corresponding to 123 million $B\bar{B}$ pairs, was recorded at the $\Upsilon(4S)$ resonance (“on-resonance”) with the center-of-mass (CM) energy $\sqrt{s} = 10.58 \text{ GeV}$. An additional 12 fb^{-1} were taken about 40 MeV below this energy (“off-resonance”) for the study of continuum backgrounds in which a light or charm quark pair is produced instead of an $\Upsilon(4S)$.

The asymmetric beam configuration in the laboratory frame provides a boost of $\beta\gamma = 0.56$ to the $\Upsilon(4S)$. Charged particles are detected and their momenta measured by the combination of a silicon vertex tracker (SVT), consisting of five layers of double-sided silicon strip sensors, and a 40-layer central drift chamber, both operating in the 1.5-T magnetic field of a solenoid. The tracking system covers 92% of the solid angle in the CM frame.

Charged-particle identification (PID) is provided by the average energy loss (dE/dx) in the tracking devices and by an internally reflecting ring-imaging Cherenkov detector (DIRC) covering the central region. A K/π separation of better than four standard deviations (σ) is achieved for momenta below $3 \text{ GeV}/c$, decreasing to 2.5σ at the highest momenta reached by the B decay final states. Photons and electrons are detected by a CsI(Tl) electromagnetic calorimeter (EMC). The EMC provides good energy and angular resolutions for detection of photons in the range from 30 MeV to 4 GeV. The energy and angular resolutions are 3% and 4 mrad respectively, for a 1 GeV photon. The flux return for the solenoid is composed of multiple layers of iron and resistive plate chambers for the identification of muons and long-lived neutral hadrons.

3 ANALYSIS METHOD

Monte Carlo (MC) simulations [10] of the signal decay modes, continuum and $B\bar{B}$ backgrounds are used to establish the event selection criteria. We reconstruct $B^0 \rightarrow K^{*+}\rho^-$ candidates from the decay products of the $K^{*+} \rightarrow K^+\pi^0$ and $\rho^- \rightarrow \pi^-\pi^0$ (the charge conjugate states are implied in this paper). Charged-track candidates are required to originate from the interaction point: distance of closest approach to the interaction point less than 10 cm along the beams direction and less than 1.5 cm in the plane transverse to the beams direction. We require that the track from the ρ^- decay has particle identification information inconsistent with the electron, kaon, or proton hypotheses; and the track from the K^{*+} decay should agree with the kaon hypothesis. We reconstruct π^0 mesons from pairs of photons, where each photon must have an energy greater than 50 MeV in the laboratory frame and must exhibit a lateral profile of energy deposition in the electromagnetic calorimeter consistent with an electromagnetic shower [9]. The π^0 candidates must have a mass that satisfies $0.11 < m(\gamma\gamma) < 0.16 \text{ GeV}/c^2$. The mass of the reconstructed ρ^- and K^{*+} candidates must satisfy $0.396 < m(\pi^-\pi^0) < 1.146 \text{ GeV}/c^2$ and $0.767 < m(K^+\pi^0) < 1.017 \text{ GeV}/c^2$, respectively. Combinatorial backgrounds dominate near $|\cos(\theta_V)| = 1$ (V denotes K^{*+} or ρ^-). Backgrounds from B decays, like $B^0 \rightarrow K^{*+}(892)\pi^-$, with an additional low energy π^0 from the rest of the event (ROE), tend to concentrate at negative values of $\cos(\theta_V)$. The $K^{*+} \rightarrow K^+\pi^0$ and $\rho^- \rightarrow \pi^-\pi^0$ helicity angles are restricted to the region $-0.8 < \cos(\theta_V) < 0.98$ to suppress combinatorial background and reduce acceptance uncertainties due to low-momentum pion reconstruction.

The B -meson candidates are identified from two nearly independent kinematic observables [9], the beam energy-substituted mass $m_{\text{ES}} \equiv [(s/2 + \mathbf{p}_i \cdot \mathbf{p}_B)^2/E_i^2 - \mathbf{p}_B^2]^{1/2}$ and the energy difference $\Delta E \equiv (E_i E_B - \mathbf{p}_i \cdot \mathbf{p}_B - s/2)/\sqrt{s}$, where $(E_i, \mathbf{p}_i)$ is the four-momentum of the e^+e^- initial state, and $(E_B, \mathbf{p}_B)$ is the four-momentum of the reconstructed B candidate, all defined in the laboratory frame. For signal events, the m_{ES} distribution peaks at the B mass and the ΔE distribution peaks near zero. We accept candidates that satisfy $5.21 < m_{\text{ES}} < 5.29 \text{ GeV}/c^2$ and $-0.12 < \Delta E < 0.15 \text{ GeV}$. The asymmetric ΔE window suppresses background from higher-multiplicity B decays.

In this analysis, B^0 decays to charm modes, such as $B^0 \rightarrow \bar{D}^0\pi^0$ with $\bar{D}^0 \rightarrow K^+\pi^-\pi^0$ have the same final state as signal. If the tracks from these B decays are used to reconstruct the K^{*+} and ρ^- mesons, these events will have peaking ΔE and m_{ES} distributions under the signal region. We apply the requirements $|m(K^+\pi^-) - m(\bar{D}^0)| > 0.02 \text{ GeV}/c^2$ and $|m(K^+\pi^-\pi^0) - m(\bar{D}^0)| > 0.04 \text{ GeV}/c^2$ to suppress these peaking backgrounds, where $m(\bar{D}^0)$ is the nominal mass of $\bar{D}^0$ meson [12]. After $\bar{D}^0$ veto 95%(99%) of longitudinal(transverse) signal events are retained.

Signal candidates may pass the selection even if one or more of the tracks or π^0 s assigned to the $K^{*+}\rho^-$ state actually comes from the other B in the event. These self-cross-feed (SCF) candidates comprise 37% (21%) of the accepted signal for longitudinal (transverse) signal and are included as signal in the fit.

Continuum $e^+e^- \rightarrow q\bar{q}$ ($q = u, d, s, c$) events are the dominant background. To discriminate signal from continuum we use a neural network (NN) to combine six variables: the Fisher of the Legendre monomials [11]; the sum of transverse momenta in the ROE relative to the z axis; the cosine of the angle between the direction of the B and the collision axis (z) in the CM frame; the cosine of the angle between the B thrust axis and the z axis; the cosine of the angle between the B -thrust axis and the thrust axis of the ROE; the decay angle of one of the π^0 s (defined in the same way as the K^*/ρ decay angle, θ_V), randomly selected. The final sample of signal candidates is selected with a cut on the NN output that retains $\sim 93\%$ (54%) of the signal (continuum).

When multiple B candidates can be formed, we select the one that minimizes the sum of the χ^2 of the reconstructed π^0 masses from the nominal π^0 mass. For those with the same lowest χ^2 , we keep the first one.

The efficiency of the selection is 6.8% (13.9%) for longitudinally (transversely) polarized signal as determined with MC simulations. After the full selections, we obtain 14251 events in the data sample, which are dominated by combinatoric backgrounds: roughly 92% from $q\bar{q}$ and 7.7% from $B\bar{B}$.

We use MC-simulated events to study the cross-feed from other B decays. The charmless modes are grouped into thirteen classes with similar kinematic and topological properties. Two additional classes account for the neutral and charged $b \rightarrow c$ decays. For each of the background classes, a component is introduced into the likelihood below, with a fixed number of events. In the selected $K^{*+}\rho^-$ sample we expect 56 ± 27 charmless background events and 1005 $b \rightarrow c$ events.

We use an unbinned, extended maximum-likelihood (ML) fit to extract the signal yield. The likelihood for each B candidate i is defined as

$$\mathcal{L}_i = e^{-N'} \prod_{i=1}^N \left\{ N^{sig} \mathcal{P}_i^{sig} + N^{q\bar{q}} \mathcal{P}_i^{q\bar{q}} + \sum_{j=1} n_j \mathcal{P}_{ji}^B \right\} \quad (2)$$

where N' is the sum of the signal and continuum yields and the fixed B -background yields, N^{sig} is the number of signal events of type $K^{*+}\rho^-$ in the entire sample. $N^{q\bar{q}}$ is the number of continuum background events and is floated in the fit. The numbers of events n_j in the B background category j are all fixed to their MC expectations. The probability density function (PDF) $\mathcal{P}$ is the product of the PDFs of seven discriminating variables. The signal PDF is thus given by $\mathcal{P}^{sig} = \mathcal{P}(m_{ES}) \cdot \mathcal{P}(\Delta E) \cdot \mathcal{P}(NN) \cdot \mathcal{P}(\cos(\theta_{K^{*+}})) \cdot \mathcal{P}(M_{V1}) \cdot \mathcal{P}(\cos(\theta_{\rho^-})) \cdot \mathcal{P}(M_{V2})$, where M_{V1} (M_{V2}) is the mass of K^{*+} (ρ^-) meson, and $\mathcal{P}(\cos(\theta_{K^{*+}}))$, $\mathcal{P}(\cos(\theta_{\rho^-}))$ is the signal helicity PDF which is expressed as a function of the longitudinal polarization (see Eq. 1). The ideal angular distribution is multiplied by the detector acceptance function. We obtain the acceptance function from a simultaneous fit to a sample of MC events with transverse and longitudinal polarization. The PDF of the continuum contribution is denoted $\mathcal{P}^{q\bar{q}}$. The $\mathcal{P}_j^B$ corresponds to the PDF of the B -background category j . The signal events are decomposed into two parts with distinct distributions: signal events that are correctly reconstructed and those mis-reconstructed, namely, SCF events. The SCF fractions for longitudinal and transverse signal are estimated by MC simulation. The m_{ES} , ΔE , NN , $\cos(\theta_{K^{*+}})$, M_{V1} , $\cos(\theta_{\rho^-})$ and M_{V2} PDFs for signal and B background are taken from the simulation. The continuum-background m_{ES} , ΔE , NN , $\cos(\theta_{K^{*+}})$ and $\cos(\theta_{\rho^-})$ PDF parameters are floated in the fit to data. The distributions of the continuum as a function of M_{V1} and M_{V2} are described by a non-parametric PDF [13] derived from m_{ES} and ΔE data sidebands. A total of 12 parameters, including signal yield and continuum background yield, are varied in the fit.

4 SYSTEMATIC UNCERTAINTIES

The contributions to the systematic error on the signal parameters are summarized in Table 2. The uncertainties due to the signal model are obtained from varying the signal PDF parameters, which are fixed in the fit, within their estimated errors and assign the effects on the signal yield as systematic error. We perform fits on large MC samples with the measured proportions of $K^{*+}\rho^-$ signal, continuum and B backgrounds. The bias observed in these tests is due to imperfections of

the PDF model: *e.g.*, unaccounted correlations between the discriminating variables of the signal and B -background PDFs. The bias is assigned as a systematic uncertainty of the fit procedure. The expected event yields from the B background modes are varied according to the uncertainties in the measured or estimated branching fractions.

Table 2: Summary of the systematic uncertainties in the measurement of the $B^0 \rightarrow K^{*+}\rho^-$ branching fraction.

Source	Uncertainty
Fit uncertainties (in Events)	
Signal model	$+2.3$ -1.9
Fit procedure bias	4.2
B backgrounds	1.7
Total fit error	5.1
Multiplicative [%]	
Track finding	2.4
Neutral correction	10.3
Number of $B\bar{B}$ pairs	1.1
Particle ID	1.1
Total multiplicative uncertainties	10.7%
Non-resonant charmless background	$+0.0\%$ -39.0%

In this analysis, we do not include a fit component for other B decays with the same final-state particles selected within the K^* or ρ resonance mass window, such as the non-resonant decays $B^0 \rightarrow K^+\pi^-\pi^0\pi^0$, $B^0 \rightarrow \rho^-K^+\pi^0$ and $B^0 \rightarrow K^{*+}\pi^-\pi^0$. The selection requirements alone suppress the $B^0 \rightarrow K^+\pi^-\pi^0\pi^0$ ($B^0 \rightarrow \rho^-K^+\pi^0$ and $B^0 \rightarrow K^{*+}\pi^-\pi^0$) efficiency by two (one) orders of magnitude relative to $B^0 \rightarrow K^{*+}\rho^-$. The contribution of these decays to the fit results is also significantly suppressed by the mass and helicity-angle information in the fit; they are examined in the context of mass and helicity-angle distributions, as discussed below.

To check the sensitivity of our results to the presence of non-resonant $B^0 \rightarrow K^+\pi^-\pi^0\pi^0$, $B^0 \rightarrow \rho^-K^+\pi^0$ and $B^0 \rightarrow K^{*+}\pi^-\pi^0$ decays, we explicitly include a fit component for them, assuming a phase-space decay model. The associated systematic error is estimated by the difference in the data fit result when the yields of these background modes are floated or fixed to zero. We obtain an asymmetric error of -22 events (-39%) on the signal yield, which is systematically overestimated when these non-resonant background modes are not modeled in the ML fit. This systematic error is preliminary estimation, and is presented separately from the other systematics, with the label "non-resonant". Interference effects between the resonant and non-resonant components are ignored in this fit.

The systematic uncertainties in the efficiency are due to track finding (2.4% for two tracks), particle identification (1.1% for two tracks), and π^0 reconstruction (10.3% for two π^0 s). Smaller systematic uncertainties arise from event-selection criteria, MC statistics, and the number of B mesons in the sample.

5 PHYSICS RESULTS

From the ML fit, we find the signal yield $N_{sig} = 58 \pm 19(stat)$. The results are summarized in Table 3. It is checked that we obtain the most conservative estimate for the upper limit on the branching fraction when 70% longitudinal polarized signal is used in the fit. Using the above results, together with the selection efficiency, the branching fractions of $\mathcal{B}(K^{*+} \rightarrow K^+\pi^0)$, $\mathcal{B}(\rho^- \rightarrow \pi^-\pi^0)$, $\mathcal{B}(\pi^0 \rightarrow \gamma\gamma)$, we obtain a central value of the branching fraction, $\mathcal{B}(B^0 \rightarrow K^{*+}\rho^-) = [16.3 \pm 5.4(stat) \pm 2.3(syst)_{-6.3}^{+0.0}(non - resonant)] \times 10^{-6}$. The impact of the uncertainties on $\mathcal{B}(K^{*+} \rightarrow K^+\pi^0)$, $\mathcal{B}(\rho^- \rightarrow \pi^-\pi^0)$, $\mathcal{B}(\pi^0 \rightarrow \gamma\gamma)$ is negligible compared to the other systematic errors.

In Table 3, the statistical error on the branching fraction results from the statistical errors on the signal yield. The systematic uncertainty on the branching fraction results from the propagation of the systematic uncertainties on signal yield and effective selection efficiency. Finally, the non-resonant systematics on signal yield is propagated to the branching fraction.

Figure 3 shows the result of the fit projected onto the m_{ES} , ΔE , M_{V1} and M_{V2} observables. The histograms show the data after a cut on the quantity $\mathcal{P}_{sig}/(\mathcal{P}_{sig} + \mathcal{P}_{cont})$ has been applied, where $\mathcal{P}_{sig}$ and $\mathcal{P}_{cont}$ are the probabilities for a given event to be signal and continuum background, respectively, and are evaluated using all observables except for the one that is being plotted.

Because of the limited statistical significance of the observed signal, we choose to quote as our preliminary result an upper limit on the branching fraction. Taking systematic uncertainties into account, an upper limit of 24×10^{-6} at 90% confidence level (C.L.) is set for the $B^0 \rightarrow K^{*+}\rho^-$ branching fraction.

Table 3: Summary of the fit results: Signal yield (N_{sig}), effective selection efficiency (ε), branching fraction ($\mathcal{B}$), upper limit at 90% confidence level and significance of the measurement, expressed as number of standard deviation (σ s). The first error corresponds to the statistical uncertainty and the second one to the systematic uncertainty, and the third is the systematic uncertainty from non-resonant contributions.

Quantity	Measured Value
N_{sig}	$58 \pm 19(stat)$
$\varepsilon(\%)$	8.9 ± 1.0
$\mathcal{B}(\times 10^{-6})$	$16.3 \pm 5.4(stat) \pm 2.3(syst)_{-6.3}^{+0.0}(non - resonant)$
$U.L.(\times 10^{-6})$	24 (22 statistical only)
Significance (σ)	3.2 (3.7 statistical only)

6 SUMMARY

We have searched for the decay $B^0 \rightarrow K^{*+}\rho^-$ using a maximum likelihood technique in a data sample equivalent 113 fb^{-1} of integrated luminosity. From a fitted signal yield of $58 \pm 19(stat)$, we obtain a branching fraction is $\mathcal{B}(B^0 \rightarrow K^{*+}\rho^-) = [16.3 \pm 5.4(stat) \pm 2.3(syst)_{-6.3}^{+0.0}(non - resonant)] \times 10^{-6}$. We get a preliminary upper limit on the $B^0 \rightarrow K^{*+}\rho^-$ branching fraction at 90% C.L. is:

$$\mathcal{B}(B^0 \rightarrow K^{*+}\rho^-) < 24 \times 10^{-6}.$$

All results are preliminary.

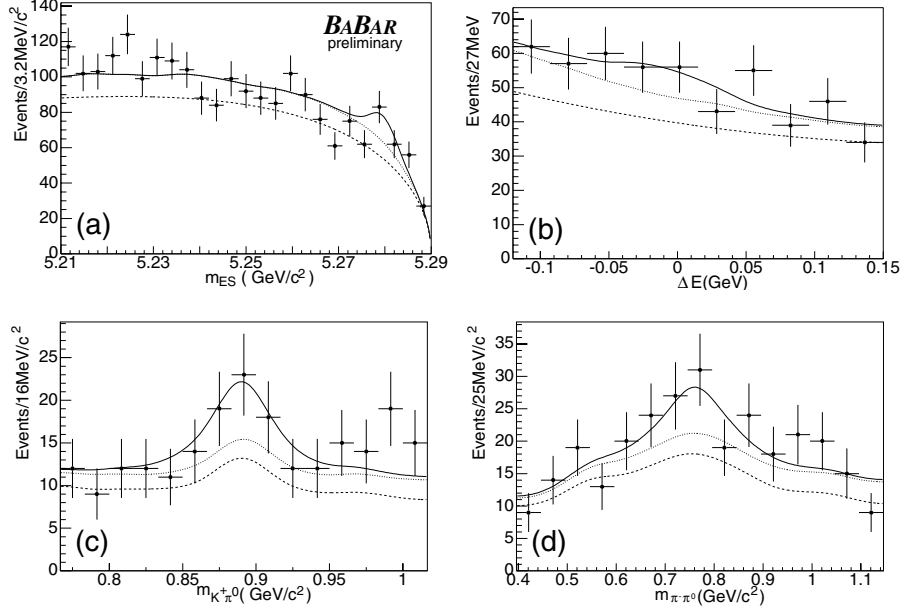


Figure 3: The (a) m_{ES} , (b) ΔE , (c) K^* mass, (d) ρ mass distribution for signal enriched samples of the data. The dashed line is the projection of the continuum background, the dotted line is the projection of the sum of backgrounds and the solid line is the projection of the fit result.

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