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Light particle searches at Belle

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We present analysis of new light particle searches at Belle with a data sample of 657×10^6 $B\bar{B}$ pairs collected with the Belle detector at the KEKB e^+e^- collider. At first, we report on a search for the $X(1812)$ state in the decay $B^\pm \to K^\pm \omega\phi$. No significant signal is observed. An upper limit $\mathscr{B}(B^\pm \to K^\pm X(1812), X(1812) \to \omega\phi) < 3.2 \times 10^{-7}$ (90% C.L.) is determined. And also, we constrain the three-body decay branching fraction to be $\mathscr{B}(B^\pm \to K^\pm \omega\phi) < 1.9 \times 10^{-6}$ (90% C.L.). Then, we report on a search for a low mass particle with a mass of 214.3 MeV/c^2 reported by the HyperCP experiment at Fermilab. For this search we use the following decay modes: $B^0 \to K^-\pi^+X^0, X^0 \to \mu^+\mu^-$; $B^0 \to \pi^-\pi^+X^0, X^0 \to \mu^+\mu^-$; $B^0 \to K^{*0}X^0, K^{*0} \to K^+\pi^-, X^0 \to \mu^+\mu^-$; and $B^0 \to \rho^0X^0$, $\rho^0 \to \pi^+\pi^-$, $X^0 \to \mu^+\mu^-$, where X^0 is a pseudo-scalar particle with mass of 214.3 MeV/c^2.

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1. Data Sample and Belle Detector

The following analyzes use 605 fb^{-1} of data containing 657×10^6 $B\overline{B}$ pairs. The data was collected with the Belle detector [1] at the KEKB [2] e^+e^- asymmetric-energy (3.5 GeV on 8.0 GeV) collider operating at a center-of-mass (CM) energy of the $\Upsilon(4S)$ resonance.

The Belle detector is a large-solid-angle spectrometer. It consists of a silicon vertex detector (SVD), a 50-layer central drift chamber (CDC), an array of aerogel threshold Cherenkov counters (ACC), time-of-flight scintillation counters (TOF), and an electromagnetic calorimeter comprised of CsI(Tl) crystals located inside a superconducting solenoid that provides a 1.5 T magnetic field. An iron flux return located outside the coil is instrumented to detect K_L^0 mesons and to identify muons (KLM).

2. Search for the $X(1812)$ in $B^\pm \to K^\pm \omega\phi$

Using a sample of 5.8×10^7 J/ψ events, the BES collaboration observed a near-threshold enhancement in the $\omega\phi$ invariant mass spectrum from the double OZI suppressed $J/\psi \to \gamma\omega\phi$ decay with a statistical significance of more than 10σ [3]. When fitted with a Breit-Wigner, this enhancement, called $X(1812)$, has the property $M = (1812^{+19}_{-26} \pm 18)\mathrm{MeV}/c^2$, $\Gamma = (105 \pm 20 \pm 28)\mathrm{MeV}/c^2$. Many speculations have been made that the $X(1812)$ may be a tetraquark state, hybrid [4], glueball state [5], an effect due to intermediate meson rescatterings [6] or a threshold cusp attracting a resonance [7]. Therefore , we preformed an analysis on $B^\pm \to K^\pm \omega\phi$ to search for this state. On the other hand, this decay proceeds via a $b \to s$ penguin with $s\bar{s}$ and $u\bar{u}$ popping. A similar decay mode $B^+ \to K^+\phi\phi$ is the only observed charmless $B \to VVP$ mode and has a rather large branching fraction $[(4.9^{+2.4}_{-2.2}) \times 10^{-6}]$ [8, 9]. We also measure the $B^\pm \to K^\pm \omega\phi$ three-body decay to investigate decay mechanisms.

The decay cascade $B^\pm \to K^\pm \omega\phi$, $\phi \to K^+K^-$ and $\omega \to \pi^0\pi^+\pi^-$ is reconstructed. We require a momentum in the laboratory frame $p_{\pi^0}^{\mathrm{lab}} > 0.38$ GeV/c to suppress the wrong π^0 background. Because there are three kaons in the final state, one directly from the B-meson decay and the other two from the ϕ decay. To distinguish the two kinds of kaons and reduce multiple candidates, we also require kaons from the ϕ to have momenta $p_{K^\pm} < 1.5$ GeV/c in the CM frame. Finally, candidate $B^\pm \to K^\pm \omega\phi$ decays are identified using the energy difference $\Delta E \equiv E_B - E_{\mathrm{beam}}$ and the beam-energy-constrained mass $M_{\mathrm{bc}} \equiv \sqrt{E_{\mathrm{beam}}^2 - p_B^2}$. We select events satisfying $|\Delta E| < 0.2$ GeV and 5.20 GeV/$c^2 < M_{\mathrm{bc}} <$ 5.29 GeV/c^2.

The dominant source of background arises from random combinations of particles in continuum $e^+e^- \to q\bar{q}$ events (q=u,d,s,c). To discriminate spherical $B\overline{B}$ events from jet-like $q\bar{q}$ events, we combine event-shape variables into a Fisher discriminant [10], and then form a likelihood ratio R_s. Further continuum background suppression is achieved using b-flavor tagging information. We introduce two parameters to describe the tagging information: the flavor of the tagged meson, q(=$\pm$1), and a flavor-tagging quality factor, r (0$\sim$1). For signal events, q is usually consistent with the flavor opposite to that of the signal B, while it is random for continuum events. Thus, we divide events into six qrF_B bins, where F_B is the charge of the signal B: F_B =+1 (-1) for B^+ (B^-), and determine the optimum R_s selection criteria for each bin. This optimization preserves 57.9% of the signal while rejecting 98.6% of the continuum background. In addition to the dominant continuum background, charmed B decay ($b \to c$) backgrounds are from D^0 and D_s. We use mass veto to exclude these kinds of backgrounds.

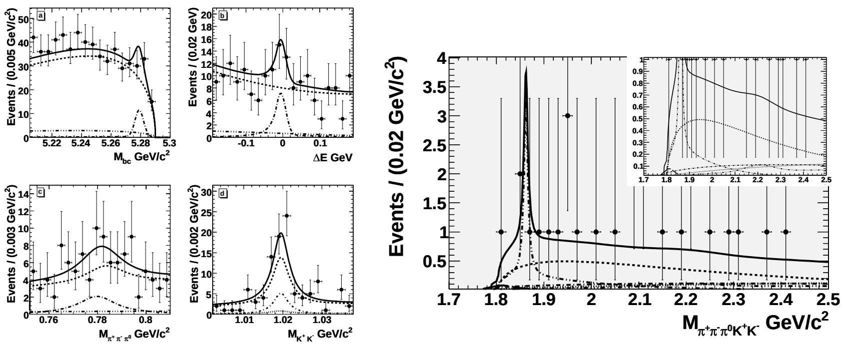

Figure 1: Left: Projection of the data (points with error bars) and fit results onto (a) $M_{\rm bc}$, (b) ΔE, (c) $M_{\pi^+\pi^-\pi^0}$, (d) $M_{K^+K^-}$ with the other variables satisfying $M_{\rm bc} \in (5.27, 5.29)$ GeV$/c^2$, $\Delta E \in (-0.15, 0.05)$ GeV, $M_{\pi^+\pi^-\pi^0} \in (-0.75, 0.81)$ GeV$/c^2$, $M_{K^+K^-} \in (1.00, 1.04)$ GeV$/c^2$: signal (dot-dashed), $q\overline{q}$ (dashed), $B\overline{B}$ (dot-dot-dot-dashed) and total (solid). **Right**: Mass spectrum in the $\omega\phi$ fit with the following components: $B^+ \to K\omega\phi$ three-body (dotted), $B\overline{B}$ (dot-dashed), $q\overline{q}$ (dashed), D^0(dot-dot-dashed), D_s(dot-dot-dot-dashed), $B^\pm \to K^\pm X(1812)$(long-dashed), and total(solid). The spectrum is also shown in the inset with an expanded vertical scale

We obtain the signal yield of three-body decay using a four-dimensional extended unbinned maximum likelihood fit to ΔE, $M_{\rm bc}$, $M_{\pi\pi\pi}$ and M_{KK} (Figure. 1 left). Peaking behavior is observed in ΔE, $M_{\rm bc}$, $M_{\pi\pi\pi}$ and M_{KK}. After taking the systematic errors into account, we give the result $\mathscr{B}(B^\pm \to K^\pm \omega\phi) = (1.15\,^{+0.43}_{-0.38}\,^{+0.14}_{-0.13}) \times 10^{-6} (2.8\sigma)$, and the upper limit $\mathscr{B}(B^\pm \to K^\pm \omega\phi) < 1.9 \times 10^{-6}$. We next study the $\omega\phi$ mass spectrum (Figure. 1 right). In this analysis, we do not use aforementioned mass veto to exclude D^0, D_s background, but fit them simultaneously. In our fitting, the mass and width of $X(1812)$ are taken from the BES measurement and the property of D^0 and D_s is from PDG. No significant signal is observed, so we give a limit on the product branching fraction of $\mathscr{B}(B^\pm \to K^\pm X(1812), X(1812) \to \omega\phi) < 3.2 \times 10^{-7}$ (90% C.L.)

3. Search for $X(214)$

HyperCP experiments at Fermi lab reported an observation of three $\Sigma^+ \to p\mu^+\mu^-$ decays. Because the dimuon masses of observed events were clustered within the detector resolution of 1MeV, some person suggest that these events are two-body decay $\Sigma^+ \to pX(214)$, where $X(214)$ maybe is sgoldstino [11] or low mass Higgs boson [12]. In Gauge Mediated SUSY Breaking (GMSB) model, the decay channels $B^0 \to K^{*0}X^0, X^0 \to \mu^+\mu^-$ and $B^0 \to \rho^0 X^0, X^0 \to \mu^+\mu^-$ are suggested to be studied, while these decay channels are also possible to search low mass Higgs in Next-to-Minimal SUSY Standard Model (NMSSM).

The K^{*0} (ρ^0) is reconstructed with $K^{*0} \to K^+\pi^-$ ($\rho^0 \to K^+\pi^-$) decay channel and required to be within $\pm 1.5\sigma$ ($\pm 1.0\sigma$) of the central value of the fitted mass distribution. ΔE and $M_{\rm bc}$ cuts are applied to B candidates also. According to the result of dimuon mass resolution study, we define the mass window of $X(214)$ as 211.5 MeV$\sim$217.1 MeV. After using MC sample, luminosity of which is corresponding to 1750 fb^{-1}, to study background, we found no background events in the X mass window.

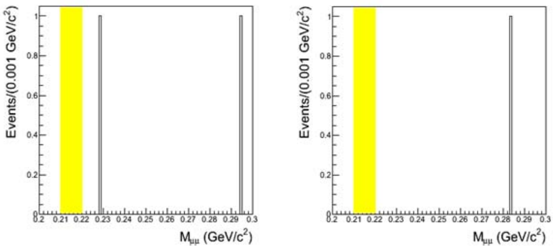

Figure 2: mass spectrum of $\mu^+\mu^-$: $B^0 \to K^{*0}X^0$ (left), $B^0 \to K^{*0}X^0$ (right). Yellow region stands for X(214) mass window

Next, we apply all the analysis process to real data, the mass spectrum of $\mu^+\mu^-$ are given in Figure. 2. No event is observed in the X mass window. And the upper limits are given as $\mathscr{B}(B^0 \to K^{*0}X^0, K^{*0} \to K^+\pi^-, X^0 \to \mu^+\mu^-) < 2.0 \times 10^{-8}$ and $\mathscr{B}(B^0 \to \rho^0 X^0, \rho^0 \to K^+\pi^-, X^0 \to \mu^+\mu^-) < 1.5 \times 10^{-8}$. These results rule out most of allowed branch fraction for sgoldstino interpretation [13].

4. Conclusions

We presented two light particle searches based on data samples collected by the Belle detector at KEKB e^+e^- asymmetric energy collider: No $X(1812)$ event is found and the upper limits of $\mathscr{B}(B^\pm \to K^\pm X(1812), X(1812) \to \omega\phi)$ and $\mathscr{B}(B^\pm \to K^\pm \omega\phi)$ are obtained; No $X(214)$ event is observed and the upper limits of $\mathscr{B}(B^0 \to K^{*0}X^0, K^{*0} \to K^+\pi^-, X^0 \to \mu^+\mu^-)$ and $\mathscr{B}(B^0 \to \rho^0 X^0, \rho^0 \to K^+\pi^-, X^0 \to \mu^+\mu^-)$ are given.

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