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Recent results from BESIII

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Since the major upgrade of the Beijing Electron-Positron Collider and the Beijing Spectrometer was completed in 2008, the BESIII detector has collected the world's largest samples of J/ψ, $\psi(3686)$ and $\psi(3770)$ decays, as well as the data taken around the peak of $\Upsilon(4260)$ resonance. In this report the recent results based on these samples are presented, including observation of the charmonium-like Z_c particles, progresses on the light hadron spectroscopy and measurements of charmonium and charm decays.

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1. Introduction

To meet the challenge of precision measurements of τ-charm physics, a major upgrade of the Beijing Electron-Positron Collider (BEPC) and the Beijing Spectrometer (BES) was completed in 2008 (now called BEPCII and BESIII). Since then the BESIII experiment [1] has collected the world's largest data samples at τ-charm energy region, including 225 million J/ψ events, 106 million $\psi(3686)$ events, 2.9 fb^{-1} at the peak of the $\psi(3770)$ resonance, and 1.8 fb^{-1} around the peak of the Y(4260) resonance, which allow us to study the τ-charm physics with unprecedented precision. In this talk I present a brief review about the recent results that have been obtained from these data samples.

2. Observation of $Z_c(3900)$ [2], $Z_c(3885)$ [3] , $Z_c(4020)$ [4] and $Z_c(4025)$ [5]

Using a 525 pb^{-1} data sample collected at a center-of-mass energy of 4.26 GeV, we reported the observation of a prominent resonance-like charged structure, $Z_c(3900)$, in the $\pi^{\pm}J/\psi$ invariant mass distribution for $e^+e^- \to \pi^+\pi^-J/\psi$ events. With a S-wave Breit-Wigner (BW) function, a fit to the distribution of $M_{\max}(\pi^{\pm}J/\psi)$ [Fig. 1 (a)], the larger one of the two mass combinations $M(\pi^+J/\psi)$ and $M(\pi^-J/\psi)$ in each event, yields $M = 3899.0 \pm 3.6 \pm 4.9$ MeV/c^2 and $\Gamma = 46 \pm 10 \pm 20$ MeV. Shortly after the BESIII announcement, it was confirmed by the Belle [6] and CLEO [7]. This structure couples to charmonium and has an electric charge, which implies a state containing more quarks than just a charm and anti-charm quark.

The $Z_c(3900)$ mass is $\sim$20 MeV/c^2 above the $D\bar{D}^*$ mass threshold, which is suggestive of a virtual $D\bar{D}^*$ molecule-like structure, a charmed-sector analog of the $Z_b(10610)$. Therefore, we performed a study of the process $e^+e^- \to \pi^{\pm}(D\bar{D}^*)^{\mp}$. A distinct charged structure, denoted as $Z_c(3885)$, is observed in the $(D\bar{D}^*)^{\mp}$ invariant mass distribution shown in Fig. 1 (b) and Fig. 1 (c). When fitted to a BW lineshape, the pole mass and width are determined to be $M_{\rm pole} = 3883.9 \pm 1.5 \pm 4.2$ MeV/c^2 and $\Gamma_{\rm pole} = 24.8 \pm 3.3 \pm 11.0$ MeV. The mass and width of $Z_c(3885)$ are 2σ and 1σ, respectively, below those of the $Z_c(3900)$. To investigate its spin-parity, we analyzed the angular distribution of $|\cos\theta_\pi|$ and found it favours a $J^P = 1^+$ quantum number assignment.

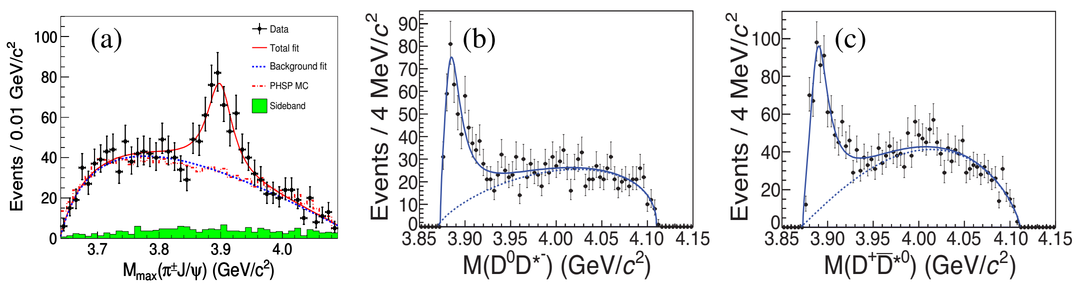

Figure 1: Fit to the $M_{\max}(\pi^{\pm}J/\psi)$(a), the $M(D^0D^{*-})$ (b), $M(D^+\bar{D}^{*0})$ (c).

To search for the new decay modes of $Z_c(3900)$, we performed the study of $e^+e^- \to \pi^+\pi^-h_c$ in which $h_c \to \gamma\eta_c$ is reconstructed with η_c's 16 exclusive decay modes. The $M_{\pi^{\pm}h_c}$ distribution summed over the 16 η_c decay modes is shown in Fig. 2 (a), where a narrow structure, referred to as $Z_c(4020)$, is clearly seen, but no significant $Z_c(3900)$ signal is observed. Similar to $Z_c(3900)$,

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the $Z_c(4020)$ also carries an electric charge and couples to charmonium. A fit to the $\pi^{\pm}h_c$ invariant mass spectrum gives $M = (4022.9 \pm 0.8 \pm 2.7)$ MeV$/c^2$ and $\Gamma = (7.9 \pm 2.7 \pm 2.6)$ MeV, respectively, with a statistical significance of greater than 8.9σ.

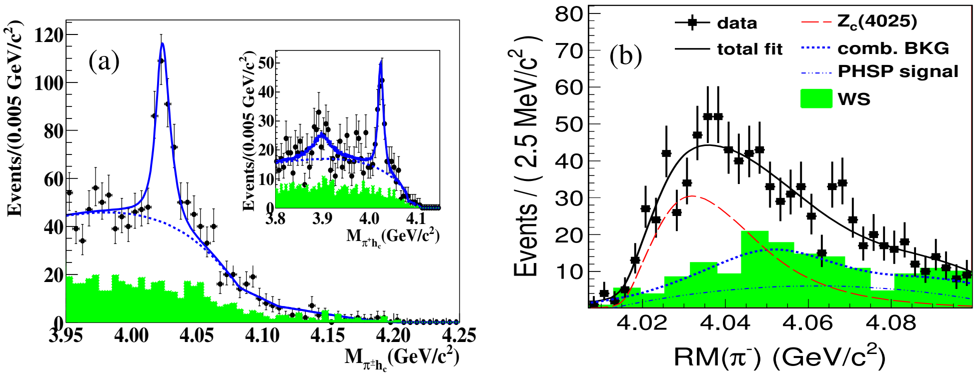

Figure 2: Fit to $M_{\pi^{\pm}h_c}$(a) and π^- recoil mass spectrum (b); the inset shows the sum of the simultaneous fit to the $M_{\pi^+h_c}$ distributions at 4.23 GeV and 4.26 GeV with $Z_c(3900)$ and $Z_c(4020)$.

The narrow $Z_c(4020)$ observed in $e^+e^- \to \pi^+\pi^-h_c$ is very close to $D^*\bar{D}^*$ mass. Therefore, a search of Z_c candidates via their direct decays into $D^*\bar{D}^*$ pairs is strongly motivated. Based on a 827 pb^{-1} data sample taken at a center-of-mass energy of 4.26 GeV, we presented the study of the process $e^+e^- \to (D^*\bar{D}^*)^{\pm}\pi^{\mp}$. A structure near the $(D^*\bar{D}^*)^{\pm}$ threshold, denoted as the $Z_c(4025)$, is seen in the mass spectrum recoiling against $\pi^{\mp}$[Fig. 2(b)]. An unbinned maximum likelihood fit to the spectrum of $RM(\pi^-)$ results in a mass of $(4026.3 \pm 2.6 \pm 3.7)$ MeV/c^2 and a width of $(24.8 \pm 5.6 \pm 7.7)$ MeV. After taking into account the systematic uncertainties, the statistical significance is larger than 10σ.

In addition to the four interesting Z_c states, we also report the observation of $X(3872)$ in $e^+e^- \to \gamma\pi^+\pi^-J/\psi$ [8], which was first seen in 2003 by Belle [9] in B decays and then confirmed by the other experiments [10, 11, 12]. Most recently, its spin-parity was determined to be $J^P = 1^+$ by CDF[13] and LHCb [14], respectively. Using data samples collected at center-of-mass energies from 4.009 to 4.420 GeV, the $e^+e^- \to \gamma X(3872)$ was observed for the first time. The measured mass, $M = 3871.9 \pm 0.7 \pm 0.2$ MeV/c^2, is consistent with previous measurements. The products of the cross section $\sigma[e^+e^- \to \gamma X(3872)]$ and the branching fraction $\mathscr{B}[X(3872) \to \pi^+\pi^-J/\psi]$ with respect to different energies are also measured, which suggests the $X(3872)$ might be from the radiative transition of the $Y(4260)$ rather than from the $\psi(4040)$ or $Y(4360)$, but continuum production of $e^+e^- \to \gamma X(3872)$ cannot be ruled out by current data.

3. Progresses on light hadron spectroscopy

Using the 225×10^6 J/ψ events and 106×10^6 $\psi(3686)$ events, we present the recent results on light hadron spectroscopy, including the partial wave analysis (PWA) of J/ψ radiative decays to $p\bar{p}$ [15], $\eta\eta$ [16] and $\omega\phi$ [17], PWA of $\psi(3686) \to p\bar{p}\pi^0$ [18], and η/η' physics.

Since the $p\bar{p}$ mass threshold enhancement was first observed by BESII in $J/\psi \to \gamma p\bar{p}$ about ten years ago, it has been triggered many speculations on its nature. To determine its spin-parity, mass and width, the PWA of $J/\psi \to \gamma p\bar{p}$ with $M_{p\bar{p}} < 2.2$ GeV/c^2 was performed after taking into account the final state interactions using the Julich formulation [19]. The PWA results indicate that the 0^{-+} assignment fit for this structure is better than that for 0^{++} or other J^{PC} assignments. The mass, width and product branching fraction of the $X(p\bar{p})$ are measured to be $M = 1832^{+19+18}_{-5-17} \pm 19$ (model) MeV$/c^2$, $\Gamma = 13 \pm 39^{+10}_{-13} \pm 4$ (model) MeV (a total width of $\Gamma < 76$ MeV$/c^2$ at the 90% C.L) and $\mathscr{B}(J/\psi \to \gamma X)\mathscr{B}(X \to p\bar{p}) = (9.0^{+0.4+1.5}_{-1.1-5.0} \pm 2.3\ \text{(model)}) \times 10^{-5}$, respectively. In addition, we also observed another structure around 1.84 GeV in the $3(\pi^+\pi^-)$ invariant mass spectrum [Fig. 3 (a)] in $J/\psi \to \gamma 3(\pi^+\pi^-)$ [20]. The fit to $M_{3(\pi^+\pi^-)}$ gives $M = 1842.2 \pm 4.2^{+7.1}_{-2.6}$ MeV/c^2 and $\Gamma = 83 \pm 14 \pm 11$ MeV with a statistical significance of 7.6σ. The product branching fraction is determined to be $\mathscr{B}(J/\psi \to \gamma X(1840))\mathscr{B}(X(1840) \to 3(\pi^+\pi^-)) = (2.44 \pm 0.36^{+0.60}_{-0.74}) \times 10^{-5}$. The mass of $X(1840)$ is in agreement with $X(p\bar{p})$, while its width is significantly broader. Therefore, based on these data, one cannot determine whether $X(1840)$ is a new state or the signal of a $3(\pi^+\pi^-)$ decay mode of $X(p\bar{p})$. Further study, including an amplitude analysis to determine the spin and parity of the $X(1840)$, is needed to establish the relationship between these two experimental observations.

For $J/\psi \to \gamma\eta\eta$, the PWA results shown in Fig. 3(b) indicate that the scalar contributions are mainly from $f_0(1500)$, $f_0(1710)$ and $f_0(2100)$, while no evident contributions from $f_0(1370)$ and $f_0(1790)$ are seen. Recently, the production rate of the pure gauge scalar glueball in J/ψ radiative decays predicted by the lattice QCD [21] was found to be compatible with the production rate of J/ψ radiative decays to $f_0(1710)$; this suggests that $f_0(1710)$ has a larger overlap with the glueball compared to other glueball candidates (e.g., $f_0(1500)$). In this analysis, the production rates of $f_0(1710)$ and $f_0(2100)$ are both about one order of magnitude larger than that of the $f_0(1500)$, which are consistent with, at least not contrary to, lattice QCD predictions. The tensor components, which are dominantly from $f_2'(1525)$, $f_2(1810)$ and $f_2(2340)$, also have a large contribution in $J/\psi \to \gamma\eta\eta$ decays. The significant contribution from $f_2'(1525)$ is shown as a clear peak in the $\eta\eta$ mass spectrum; a tensor component exists in the mass region from 1.8 GeV/c^2 to 2 GeV/c^2, although we cannot distinguish $f_2(1810)$ from $f_2(1910)$ or $f_2(1950)$; and the PWA requires a strong contribution from $f_2(2340)$, although the possibility of $f_2(2300)$ cannot be ruled out.

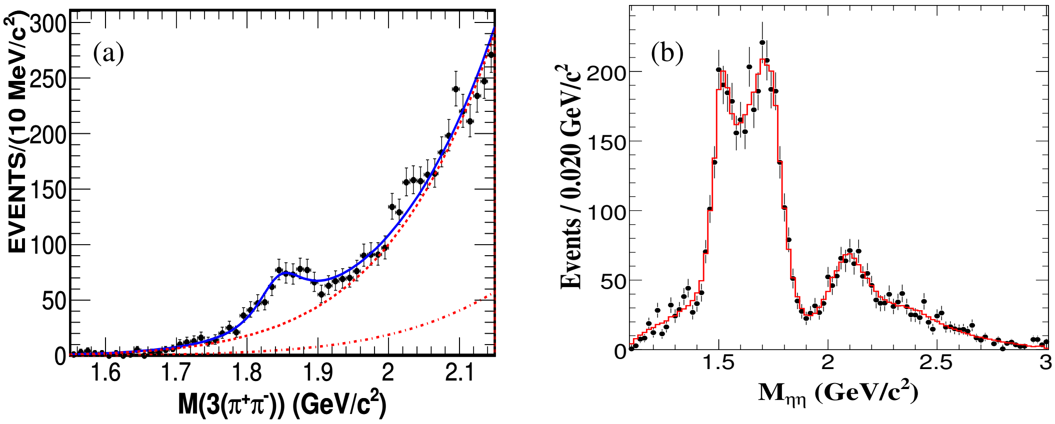

Figure 3: The $3(\pi^+\pi^-)$ mass spectrum (a) and comparisons between data and PWA fit projections: mass spectrum of $\eta\eta$ (b).

A study of the doubly OZI suppressed decays of $J/\psi \to \gamma\omega\phi$ is performed and a strong deviation ($> 30\sigma$) from three-body $J/\psi \to \gamma\omega\phi$ phase space is observed near the $\omega\phi$ mass threshold. Assuming that the enhancement is due to the presence of a resonance $X(1810)$, A PWA with a tensor covariant amplitude found that its spin-parity is 0^{++} and the resonance parameters are determined to be: $M = 1795 \pm 7^{+13}_{-5} \pm 19$(model) MeV/$c^2$ and $\Gamma = 95 \pm 10^{+21}_{-34} \pm 75$(model) MeV, which are consistent with the previous work from BESII [22].

To search for new excited N^* baryons, we performed a PWA of $\psi(3686) \to p\bar{p}\pi^0$ and found that the dominant contributions are from 7 N^* intermediate resonances. Among these N^* resonances, two new resonances are significant, one $1/2^+$ resonance with a mass of $2300^{+40+109}_{-30-0}$ MeV$/c^2$ and width of $340^{+30+110}_{-30-58}$ MeV, and one $5/2^-$ resonance with a mass of 2570^{+19+34}_{-10-10} MeV$/c^2$ and width of 250^{+14+69}_{-24-21} MeV. For the remaining 5 N^* intermediate resonances, the mass and width values from the PWA are consistent with those from established resonances.

Based on the 225 million J/ψ events, we also present the studies on η/η' decays via $J/\psi \to \gamma\eta/\eta'$ or $J/\psi \to \phi\eta/\eta'$. We made an attempt to search for their invisible and weak decays via $J/\psi \to \phi\eta$ and $J/\psi \to \phi\eta'$ [23, 24]. These two-body decays provide a very simple event topology, in which the ϕ meson can be reconstructed easily and cleanly with its dominant decays of $\phi \to K^+K^-$. Since the ϕ and $\eta(\eta')$ are given strong boosts in the J/ψ decay, the invisible decays of the η and η' were investigated with the mass spectra recoiling against ϕ. We find no signal above background for the invisible decays of η and η'. To reduce the systematic uncertainty, the upper limits of the ratios, $\frac{\mathscr{B}(\eta\to invisible)}{\mathscr{B}(\eta\to\gamma\gamma)} < 2.6 \times 10^{-4}$ and $\frac{\mathscr{B}(\eta'\to invisible)}{\mathscr{B}(\eta'\to\gamma\gamma)} < 2.4 \times 10^{-2}$, were obtained first at the 90% confidence level. Then, using the branching fractions of $\eta(\eta') \to \gamma\gamma$, the branching fraction upper limits at the 90% confidence level were determined to be $\mathscr{B}(\eta \to invisible) < 1.0 \times 10^{-4}$ and $\mathscr{B}(\eta' \to invisible) < 5.3 \times 10^{-4}$. For the first time a search for the semileptonic weak decay modes $\eta(\eta') \to \pi^+e^-\bar{\nu}_e$ was performed and no signal was observed. At the 90% confidence level, the semileptonic weak rates were given to be $B(\eta \to \pi^+e^-\bar{\nu}_e + c.c.) < 1.7 \times 10^{-4}$ and $\mathscr{B}(\eta' \to \pi^+e^-\bar{\nu}_e + c.c.) < 2.2 \times 10^{-4}$. The decays of $\eta' \to \pi^+\pi^-e^+e^-$ and $\eta' \to \pi^+\pi^-\mu^+\mu^-$ were also studied via $J/\psi \to \gamma\eta'$ [25]. A clear η' peak is observed in the $M_{\pi^+\pi^-e^+e^-}$mass spectrum, and the branching fraction is measured to be $\mathscr{B}(\eta' \to \pi^+\pi^-e^+e^-) = (2.11 \pm 0.12 \pm 0.14) \times 10^{-3}$, which is in good agreement with theoretical predictions [26] and the previous measurement [27], but is determined with much higher precision. The mass spectra of $M_{\pi^+\pi^-}$ and $M_{e^+e^-}$ are also consistent with the theoretical predictions [26] that $M_{\pi^+\pi^-}$ is dominated by ρ^0 , and $M_{e^+e^-}$ has a peak just above $2m_e$. No η' signal is found in the $M_{\pi^+\pi^-\mu^+\mu^-}$ mass spectrum, and the upper limit is determined to be $\mathscr{B}(\eta' \to \pi^+\pi^-\mu^+\mu^-) < 2.9 \times 10^{-5}$ at the 90% confidence level.

4. Measurement of the h_c and $\eta_c(2S)$ decays

With the 106 million $\psi(3686)$ events, we present the measurements of h_c and $\eta_c(2S)$ decays. The study of $h_c \to \gamma\eta_c$ with η_c subsequently decaying to 16 exclusive decays was performed via $\psi(3686) \to \pi^0 h_c$ [28]. The π^0 recoil mass spectrum is shown in Fig. 4(a), where the clear h_c peak is observed. The simultaneous fit to the π^0 recoil mass spectra of 16 η_c exclusive decays yields $M(h_c) = 3525.31 \pm 0.11 \pm 0.14$ MeV/c^2 and $\Gamma(h_c) = 0.70 \pm 0.28 \pm 0.22$ MeV, which are consistent with and more precise than previous measurements. We also determine the branching

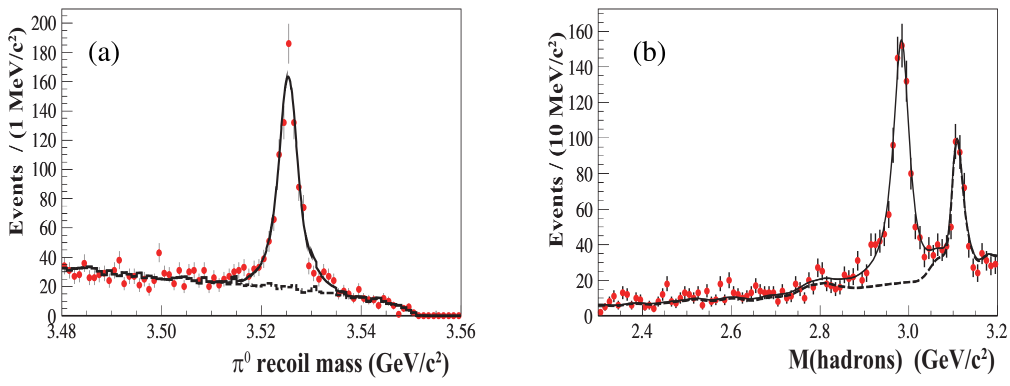

Figure 4: The π^0 recoil mass spectrum (a) and the hadronic mass spectrum (b) in $\psi(3686) \to \pi^0 h_c, h_c \to \gamma\eta_c$.

fractions for the 16 exclusive η_c decay modes, five of which have not been measured previously. New measurements of the η_c line-shape parameters in the $E1$ transition $h_c \to \gamma\eta_c$ are made by selecting candidates in the h_c signal sample and simultaneously fitting the hadronic mass spectra displayed in Fig. 4(b) for the 16 η_c decay channels. The resulting η_c mass and width values are $M(\eta_c) = 2984.49 \pm 1.16 \pm 0.52\,\mathrm{MeV}/c^2$ and $\Gamma(\eta_c) = 36.4 \pm 3.2 \pm 1.7\,\mathrm{MeV}$.

For the first time, the observation of M1 transition $\psi(2S) \to \gamma\eta_c(2S)$ was reported [29, 30]. For $\eta_c(2S) \to K^0_S K^\pm\pi^\mp$, $K^+K^-\pi^0$, the simultaneous fit to $K^0_S K^\pm\pi^\mp$ and $K^+K^-\pi^0$ mass spectra gives $M(\eta_c(2S)) = 3637.6 \pm 2.9 \pm 1.6$ MeV/c^2 and $\Gamma(\eta_c(2S)) = 16.9 \pm 6.4 \pm 4.8$ MeV with a statistical significance of greater than 10σ. The product branching fraction is measured to be $\mathscr{B}(\psi' \to \gamma\eta_c(2S)) \times \mathscr{B}(\eta_c(2S) \to K\bar{K}\pi) = (1.30 \pm 0.20 \pm 0.30) \times 10^{-5}$. Combining our result with a BaBar measurement of $\mathscr{B}(\eta_c(2S) \to K\bar{K}\pi)$ [31], we find the branching fraction of the M1 transition to be $\mathscr{B}(\psi' \to \gamma\eta_c(2S)) = (6.8 \pm 1.1 \pm 4.5) \times 10^{-4}$. For $\eta_c(2S) \to K^0_S K^+\pi^+\pi^-\pi^-$, an evident $\eta_c(2S)$ peak is observed in $M_{K^0_S K^+\pi^+\pi^-\pi^-}$ with a statistical significance of 4σ and the mass and width of $\eta_c(2S)$ are measured be M =3646.9 $\pm$ 1.6 $\pm$ 3.6 MeV/c^2 and Γ = 9.9 $\pm$ 4.8 $\pm$ 2.9 MeV/c^2, which are consistent with the measurements from $\eta_c(2S) \to K^0_S K^\pm\pi^\mp$,$K^+K^-\pi^0$.

5. Measurement of charm decays

Although $D^+ \to \mu^+\nu_\mu$ has smaller branching fraction than $D^+ \to \tau^+\nu_\tau$, it is the the simplest and cleanest decay mode for measuring the pseudoscalar decay constant f_{D^+} because of the additional neutrino produced in τ decays. Based on the data, corresponding to an integrated luminosity of 2.92 fb^{-1}, accumulated at $\sqrt{s} = 3.773$ GeV, we present the preliminary results on the study of $D^+ \to \mu^+\nu_\mu$ in which the D^+ is tagged with its nine decay modes: $K^-\pi^+\pi^+$, $K^0_S\pi^+$, $K^0_S K^+$, $K^+K^-\pi^+$, $K^-\pi+\pi^+\pi^0$, $\pi^+\pi^+\pi^-$, $K^0_S\pi^+\pi^0$, $K^-\pi^+\pi^+\pi^+\pi^-$, and $K^0_S\pi^+\pi^+\pi^-$. The signal for $D^+ \to \mu^+\nu_\mu$ is observed in the distribution of $M^2_{miss} = E^2_{miss} - p^2_{miss}$, where E_{miss} and p_{miss} are the missing energy and momentum due to the undetectable neutrino in the detector. The M^2_{miss} is displayed in Fig. 5 where the a remarkably clean peak around zero is seen. The branching fraction is measured to be $\mathscr{B}(D^+ \to \mu^+ \nu_\mu) = (3.74 \pm 0.21 \pm 0.06) \times 10^{-4}$ and the weak decay constant is calculated to be $f_{D^+} = (203.91 \pm 5.72 \pm 1.97)$ MeV.

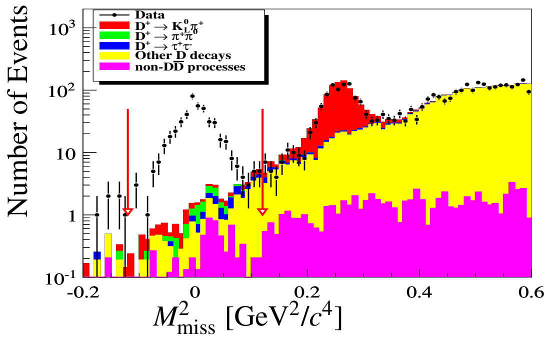

Figure 5: The M^2_{miss} distribution for selected single μ^+ candidates.

The semileptonic D decay measurements are a good laboratory for testing theories of QCD. Using one-third of the 2.92 fb^{-1} data, a partially-blind analysis has been done with the $D^0 \to K^- e^+ \nu$ and $D^0 \to \pi^- e^+ \nu$ decays. The signal events with a missing ν are inferred using the variable $U = E_{miss} - |P_{miss}|$. Given the signal yields obtained from fitting U distributions and signal efficiencies obtained from signal Monte Carlo, the absolute branching fractions are measured to be $\mathscr{B}(\bar{D}^0 \to K^+ e^- \nu) = (3.542 \pm 0.030 \pm 0.067)\%$ and $\mathscr{B}(\bar{D}^0 \to \pi^+ e^- \nu) = (0.288 \pm 0.008 \pm 0.005)\%$, which are consistent with the previous measurements from CLEO-c [32].

Charmed meson three-body decays proceed dominantly via quasi-two-body decays containing an intermediate resonance that subsequently decays into two particles. The analysis of these resonant decays using Dalitz plot techniques enables one to study the dynamical properties of various resonances. In this talk, we present the Dalitz analysis of $D^+ \to K^0_S \pi^+ \pi^0$[33] and found that the Dalitz plot could be well described by a combination of six quasi-two-body decay channels ($K^0_S \rho^+$, $K^0_S \rho(1450)^+$, $\overline{K}^{*0} \pi^+$, $\overline{K}_0(1430)^0 \pi^+$, $\overline{K}(1680)^0 \pi^+$, $\overline{\kappa}^0 \pi^+$) plus a small non-resonant component.

6. Summary

Based on the data samples taken at the BESIII detector from 2008 to 2012, the recent results on the searches of charmonium-like Z_c particles, light hadron spectroscopy, charmonium decays and charm decays are presented, which illustrate the rich physics in the τ-charm region. Currently, the BESIII detector and BEPCII are collecting data for R measurement and plan to take data at the center-of-mass energy of 4.6 GeV. More promising results are expected to be coming soon.

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