PROCEEDINGS OF SCIENCE

New observations of Charmonium decays at BESIII

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With the world's largest $\psi(2S)$ sample collected with BESIII detector, a few new decay modes of $\psi(2S)$, h_c and η_c are observed for the first time, namely $\psi(2S) \to p\bar{p}\phi$, $h_c \to p\bar{p}\pi^+\pi^-$, $h_c \to 2(\pi^+\pi^-)\pi^0$, $\chi_{cJ} \to 4K_S^0$, $\chi_{cJ} \to \phi\phi\eta$, $\chi_{cJ} \to \Sigma^+\bar{p}K_S^0$ and $\psi(2S)$ or $\chi_{cJ} \to \bar{p}K^{*+}\Lambda$. Intermediate states in the three body decays mentioned above are searched, and no new state is observed significantly.

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1. Introduction

Despite the Standard Model of particle physics is very successful in explaining the fundamental interactions, we still do not know how the proton is made up by quarks. In other words, we do not have a calculable tool to deal with the Quantum Chromodynamics (QCD) in the low energy region which is non-perturbative. Charmonium decays provide valuable information to test the new methods developed to solve the problem mention above, due to the mass of the charm quark locates between the perturbative and non-perturbative region of QCD.

BESIII experiment collected $(4.48 \pm 2.9) \times 10^6$ $\psi(2S)$ (also called $\psi(3686)$) events in 2009 and 2012 [1], which enable precision measurements of both S-wave and P-wave Charmonium decays. For the S-wave vector state, $\psi(2S)$, as it's quantum is same as photon, it could be produced directly from electron-positron collision; for the P-wave singlet state, h_c, it is produced from $\psi(2S) \to \pi^0 h_c$, with a branching fraction about 9×10^{-4}; for the P-wave triplet, χ_{cJ}, they could be produced from $\psi(2S) \to \gamma\chi_{cJ}$ with a branching fraction about 10%. Both the π^0 and γ could be reconstructed with good resolution, which enables us to study the P-wave states with low background as the whole decay chains could be reconstructed.

2. New observations

Six recent publications about Charmonium decays will be discussed in this section, and all these processes mentioned are first observed at BESIII.

2.1 $\psi(2S) \to p\bar{p}\phi$

The main motivation of studying $\psi(2S) \to p\bar{p}\phi$ [2] is to search for the $X(p\bar{p})$, which is an intriguing enhancement near the $p\bar{p}$-mass threshold. As shown in Fig. 1, there is no obvious structure on the invariant mass spectrum of $p\bar{p}$ system observed, thus the upper limit on the branching fraction of $\psi(2S) \to X(p\bar{p})\phi \to p\bar{p}\phi$ at set to be 1.82×10^{-7} at 90% confidence level. The branching fraction of $\psi(2S) \to p\bar{p}\phi$ is measured to be $(6.06 \pm 0.38 \pm 0.48) \times 10^{-6}$.

2.2 $h_c \to hadrons$

For the spin-singlet charmonium state $h_c(^1P_1)$, its hadronic decays are not well measured. Three new hadronic decay modes of $h_c(^1P_1)$ are observed at BESIII for the first time [3], namely $h_c(^1P_1) \to p\bar{p}\pi^+\pi^-$, $h_c(^1P_1) \to \pi^+\pi^-\pi^0$, $h_c(^1P_1) \to 2(\pi^+\pi^-)\pi^0$. $h_c(^1P_1) \to 2(\pi^+\pi^-)\pi^0$ and $h_c(^1P_1) \to K^+K^-\pi^+\pi^-$ are searched, but only upper limits are set with current data. These five modes are shown subfigure(I)-(V) of Fig. 2.

2.3 χ_{cJ} decays

For the $^3P_J (J = 0, 1, 2)$ charmonium states $\chi_c J$, new decay modes $\chi_{cJ} \to 4K^0_S$, $\chi_{cJ} \to \phi\phi\eta$, $\chi_{cJ} \to \Sigma^+\bar{p}K^0_S$ and $\chi_{cJ} \to \bar{p}K^{*+}\Lambda$ are observed for first time at BESIII [4–7], as shown in Fig. 3 to Fig. 6. Thanks to the large data sample and great detector performance, these channels with branching fractions at 10^{-4} level are observed clearly. For the three body decays, possible intermediate states are searched, however no one is found significantly. The process of $\psi(3686) \to \bar{p}K^{*+}\Lambda$ is studied also.

PoS(ICHEP2020)503

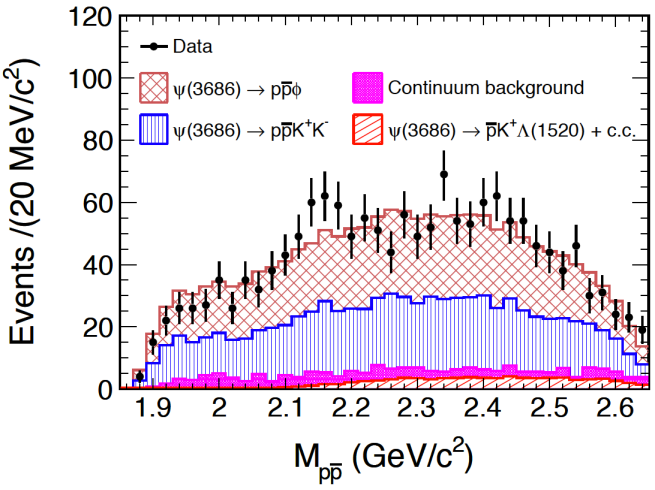

Figure 1: The invariant mass spectrum of $p\bar{p}$ system

3. Summary and prospect

Based on the largest $\psi(3686)$ sample collected at BESIII, some new observations about their decays are reported. BESIII will collect fivefold of current $\psi(3686)$ sample in it's future plan [8], which will enable us to study the charmonium decays in more details.

References

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[8] M. Ablikim *et al.* [BESIII Collaboration], Chin. Phys. C **44**, 040001 (2020)

PoS(ICHEP2020)503

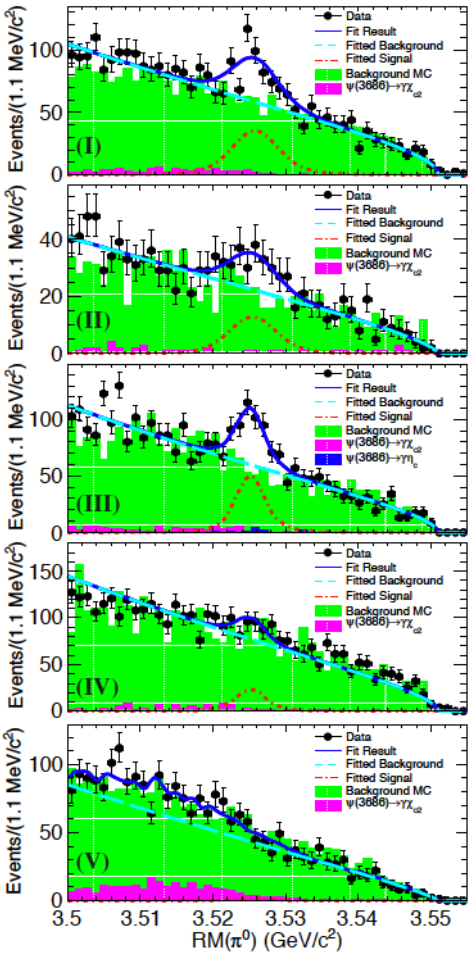

Figure 2: The recoiling mass of π^0 for the five decay modes of $h_c(^1P_1)$

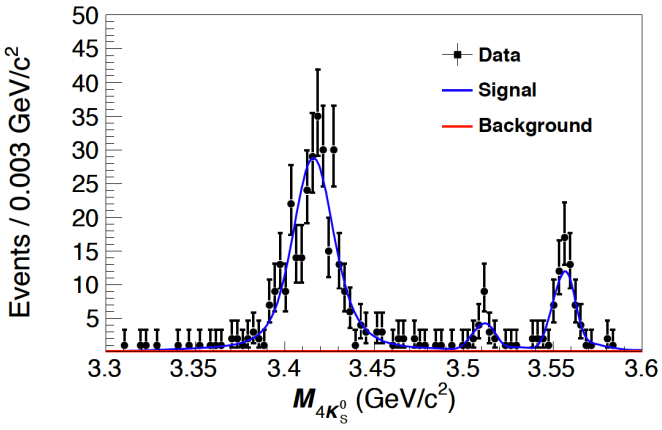

Figure 3: Fit to the $M_{4K_S^0}$ for the candidate events of $\chi_{CJ} \to 4K_S^0$

PoS(ICHEP2020)503

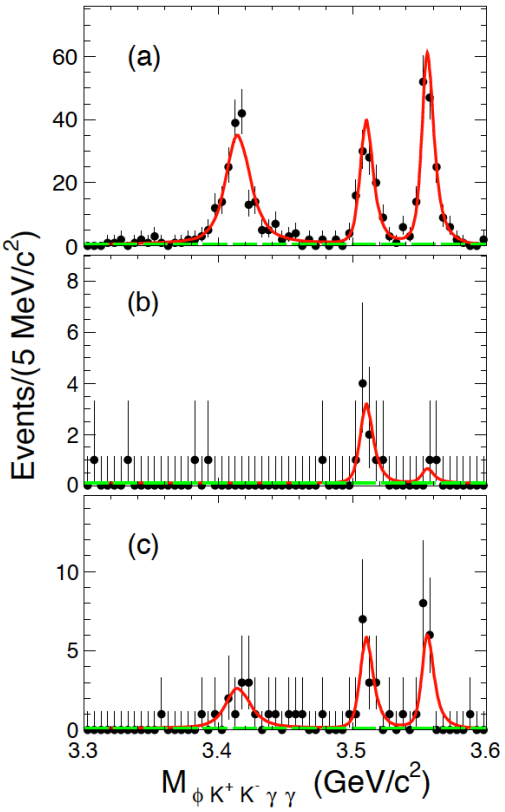

Figure 4: Fit plot for $\chi_{cJ} \to \phi\phi\eta$. (a) is for signal region, (b) and (c) are for the control regions to estimate the background

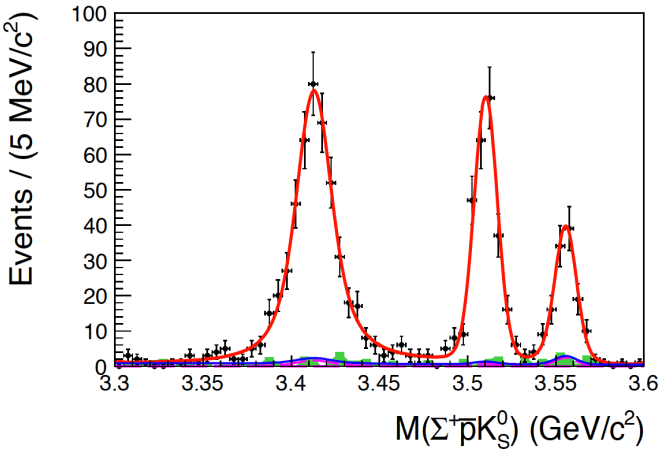

Figure 5: Fit plot for $\chi_{cJ} \to \Sigma^+\bar{p}K_S^0$

PoS(ICHEP2020)503

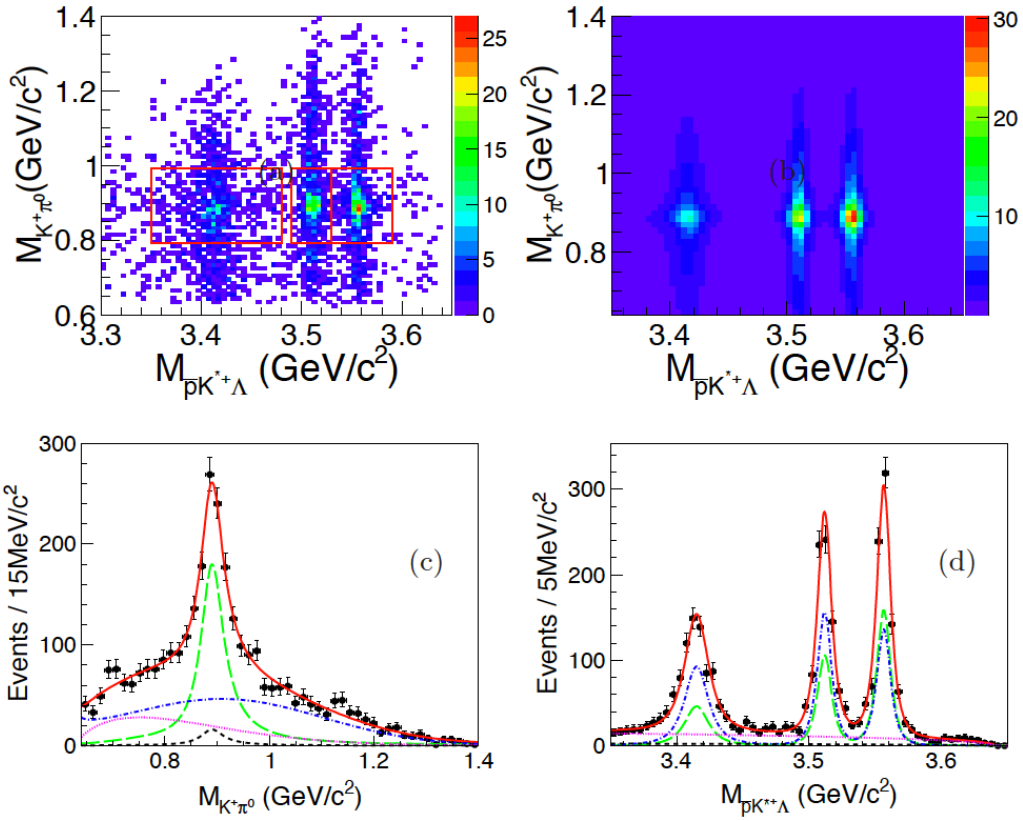

Figure 6: $\chi_{CJ} \to \bar{p}K^{*+}\Lambda$. (a) is the distribution of $M_{K+\pi^0}$ versus $M_{\bar{p}K*+\Lambda}$ from data. (b) is the same distribution from signal Monte Carlo. (c) and (d) are the projections.

PoS(ICHEP2020)503