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Observation of $e^+e^- \to \gamma X(3872), X(3872) \to \pi^+\pi^- J/\psi$

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Using data samples collected with the BESIII detector operating at the BEPCII storage ring at central-of-mass(CM) energies from 4.009 to 4.420 GeV, the $e^+e^- \to \gamma X(3872)$ process is observed with a statistical significance of more than 5σ. The measured mass is in agreement with previous measurements. The products of cross section of $e^+e^- \to \gamma X(3872)$ and the branching fraction $\mathcal{B}(X(3872) \to \pi^+\pi^- J/\psi)$ at CM energies 4.009, 4.229, 4.260, and 4.360 GeV is reported. The results support the possibility that $Y(4260) \to \gamma X(3872)$.

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1. Introduction

The X(3872) was discovered[1] by Belle in $B^\pm \to K^\pm\pi^+\pi^- J/\psi$ in 2003. Since its discovery, $X(3872)$ has simulated great interest in its nature. The LHCb experiment determined[2] the quantum numbers of the $X(3872)$ to be $J^{PC} = 1^{++}$, and CDF also found that the $\pi^+\pi^-$ system was dominated by the $\rho^0(770)$ resonance[3].

Since the mass is near $D\bar{D}^*$ threshold, the $X(3872)$ was interpreted as a good candidate for a hadronic molecule or a tetraquark state. Currently, the $X(3872)$ has only been observed in B meson decays and hadron collisions. BESIII can hunt for it in excited 1^{--} E1 transitions, using the process $e^+e^- \to \gamma X(3872)$.

2. Observation of the $X(3872)$

The process of $e^+e^- \to \gamma X(3872) \to \gamma\pi^+\pi^- J/\psi$, $J/\psi \to l^+l^-$ ($l^+l^- = e^+e^-$ or $\mu^+\mu^-$) is observed with a statistical significance of more than 5σ for the first time with data collected with the BESIII detector operating at the BEPCII storage ring [4] at e^+e^- center-of-mass (CM) energies from $\sqrt{s} = 4.009$ GeV to 4.420 GeV [5] with an integral luminosity of 3301.0 ± 33.1 pb^{-1}.

Figure 1 shows the $\pi^+\pi^- J/\psi$ invariant mass distribution for all data samples. Where $M(\pi^+\pi^- J/\psi) = M(\pi^+\pi^- l^+l^-) - M(l^+l^-) + m(J/\psi)$ is used to reduce the resolution effect of the lepton pairs, and $m(J/\psi)$ is the nominal mass of J/ψ[6]. There is a huge $e^+e^- \to \gamma_{ISR}\psi(2S)$ peak which is used to calibrate and to validate the analysis. In addition, X(3872) can also be clearly seen. Remaining backgrounds mainly come from $e^+e^- \to \gamma_{ISR}\pi^+\pi^- J/\psi$, $\eta\prime J/\psi$ and $\pi^+\pi^-\pi^+\pi^-(\pi^0/\gamma)$ processes. But none of them form peaks around the $X(3872)$ signal region.

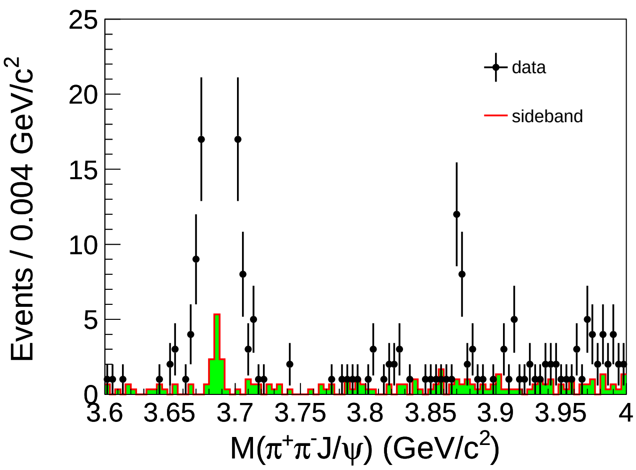

Fig. 1. The invariant mass distribution of $M(\pi^+\pi^- J/\psi)$ for all data samples. Dots with error bars are data, green shaded histograms are normalized J/ψ sideband events.

The mass of X(3872) is determined by fitting the $M(\pi^+\pi^- J/\psi)$ distribution (shown in Fig. 2), which use a MC simulated signal histogram convolved with a Gaussian function representing the difference in the mass resolution between data and MC simulation as the signal shape, and a linear function for the background. The fit result is $M(X(3872)) = (3871.9 \pm 0.7)$ MeV/c^2, $\sigma = 1.14$ MeV/c^2, $N^{obs} = 20.1 \pm 4.5$. The statistical significance of $X(3872)$ is 6.3σ.

Figure 3 shows the $\pi^+\pi^-$ invariant mass distribution for the selected $X(3872)$ candidates, which is dominated by the $\rho^0(770)$ resonance and consistent with the CDF observation[3].

The product of the Born-order cross section times the branching ratio $X(3872) \to \pi^+\pi^- J/\psi$ is calculated using $\sigma^B(e^+e^- \to \gamma X(3872)) \times \mathcal{B}(X(3872) \to \pi^+\pi^- J/\psi) = \frac{N^{obs}}{\mathcal{L}_{int}(1+\delta)\epsilon\mathcal{B}}$, where N^{obs} is the number of observed events obtained from the fit to the $M(\pi^+\pi^- J/\psi)$ distribution, $\mathcal{L}_{int}$ is integrated luminosity, ϵ is the detection efficiency, $\mathcal{B}$ is the branching ratio of $J/\psi \to l^+l^-$ and $1+\delta$ is the radiative correction factor. The $(1+\delta)$ factor, detection efficiency, number of $X(3872)$ signal events, and $\sigma^B(e^+e^- \to \gamma X(3872)) \times \mathcal{B}(X(3872) \to \pi^+\pi^- J/\psi)$ at $\sqrt{s} = 4.009$ GeV,

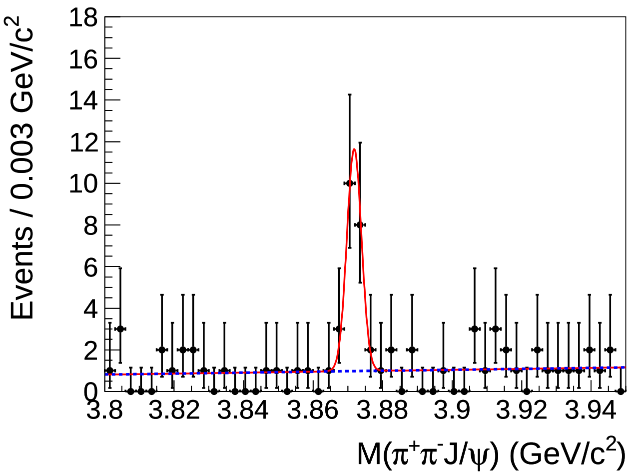

Fig. 2. Fit of the $M(\pi^+\pi^- J/\psi)$ distribution with a MC simulated histogram convolved with a Gaussian function for signal and a linear background function. Dots with error bars are data, the red curve shows the total fit result, while the blue dashed curve shows the background contribution.

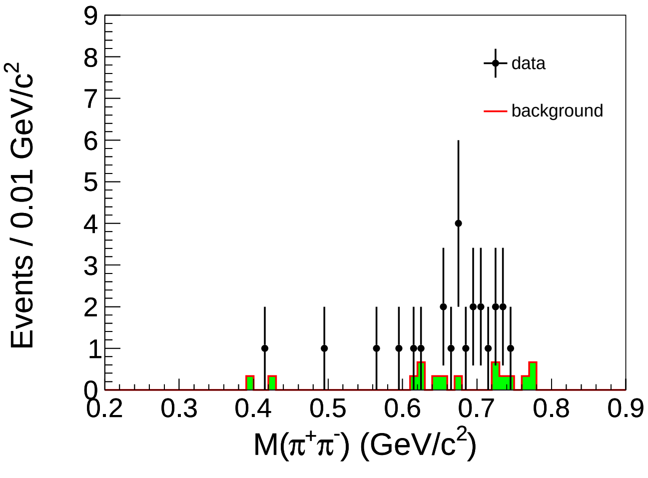

Fig. 3. The $M(\pi^+\pi^-)$ distribution for $X(3872) \to \pi^+\pi^- J/\psi$ candidate events. Dots with error bars are data, and the green shaded histogram is normalized background events in $X(3872)$ sideband region.

4.229 GeV, 4.260 GeV and 4.360 GeV are listed in Table. 1. For 4.009 and 4.360 GeV data, since the $X(3872)$ signal is not significant, upper limits for production yield at the 90% C.L. are given.

Table 1. The number of $X(3872)$ events, radiative correction factor, detection efficiency, measured Born cross section $\sigma^B(e^+e^- \to \gamma X(3872))$ times $\mathcal{B}(X(3872) \to \pi^+\pi^- J/\psi)$ ($\sigma^B \times \mathcal{B}$, where the first errors are statistical and the second are systematic) at different energy points. The upper limits are given at the 90% C.L..

Energy (MeV)	ϵ(%)	1+δ	N^{obs}	$\sigma^B \times \mathcal{B}$ (pb)
4009	25.5	0.861	<1.4	<0.12
4229	31.5	0.799	9.6±3.1	0.29±0.10±0.02
4260	30.5	0.814	8.7±3.0	0.36±0.13±0.03
4360	21.1	1.023	<5.1	<0.39

3. Summary

The process of $e^+e^- \to \gamma X(3872)$ is observed for the first time. The measured mass of the $X(3872)$ is $M(X(3872)) = (3871.9 \pm 0.7 \pm 0.2)$ MeV/c^2, which agrees well with previous measurements[6]. The production rate $\sigma^B(e^+e^- \to \gamma X(3872)) \times \mathcal{B}(X(3872) \to \pi^+\pi^- J/\psi)$ is measured to be (0.29±0.10±0.02) pb at $\sqrt{s} = 4.229$ GeV, (0.36±0.13±0.03) pb at $\sqrt{s} = 4.260$ GeV, < 0.12 pb at $\sqrt{s} = 4.009$ GeV, and < 0.39 pb at $\sqrt{s} = 4.360$ GeV at the 90% C.L., respectively. Where the first errors are statistical and the second are systematic. The observation suggests that the $X(3872)$ might be from the radiative transition of the $Y(4260)$.

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