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

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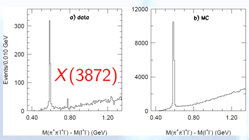
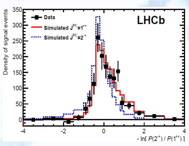
1 Abstract

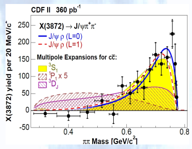
Using data samples collected with the BESIII detector operating at the BEPCII storage ring at central-of-mass(CM) energies from 4.009 to 4.420 GeV, the $e^+e^-\to\gamma X(3872)$ process is observed with a statistical significance of more than 5σ. The **measured mass** is in agreement with previous measurements. The **cross section** of $e^+e^-\to\gamma X(3872)$ at CM energies 4.009, 4.230, 4.260, and 4.360 GeV are reported. The results support the possibility that $Y(4260)\to\gamma X(3872)$.

2 Introduction

- X(3872) was **discovered** by Belle in $B^\pm\to K^\pm\pi^+\pi^- J/\psi$ in 2003 (left).
- LHCb determined it has quantum numbers **$J^{PC} = 1^{++}$** using $B^+\to X(3872)K^+$ and $X(3872)\to\pi^+\pi^- J/\psi$ (middle).
- CDF investigated the $\pi^+\pi^-$ mass spectrum (right) in $X(3872)$ decays, and found it is dominated by the $\rho^0(770)$ resonance.







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

3 Data sample and MC simulation

CM energies and luminosities:

Energy (GeV)	Luminosity (pb⁻¹)	Energy (GeV)	Luminosity (pb⁻¹)
4.009	482	4.260	827
4.190	43.0	4.310	44.9
4.210	54.7	4.360	545
4.220	54.6	4.390	55.1
4.230	533	4.420	44.7
4.245	56.0		

Error of the CM energy is ±1.0 MeV, measured using Compton back scattering technique

Uncertainty of the integrated luminosity is 1.0%, measured using Bhabha events.

Signal MC :

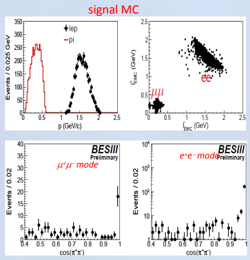
$e^+e^-\to\gamma X(3872)$ at each CM energy point with $X(3872)\to\rho^0 J/\psi$, $J/\psi\to(\gamma)\mu\mu/ee$, $\rho^0\to\pi^+\pi^-$

Inlcusive MC : 500 pb^{-1} at 4.26 GeV

Background : $Y(4260)\to\eta' J/\psi(\eta'\to\gamma\rho^0/\pi^+\pi^-\eta)$, $e^+e^-\to\pi^+\pi^- J/\psi$

4 Event selection for $e^+e^-\to\gamma X(3872)\to\gamma\pi^+\pi^- J/\psi$, $J/\psi\to(\gamma)\mu^+\mu^-/e^+e^-$

- 4 charged tracks with 0 net charge. $|R_{xy}| < 1$cm, $|R_z| < 10$cm, $|\cos\theta| < 0.93$ for each track.
- Particle separation
  - π : momentum (p) < 1 GeV/c
  - e : p > 1 GeV/c && energy (E) > 1.1 GeV
  - μ : p > 1 GeV/c && E < 0.35 GeV
- The largest energy photon
  - $0 < t < 700$ ns, $1 < N_\gamma < 5$
  - E > 0.025 GeV as $|\cos\theta|$<0.8 and E > 0.05GeV as 0.86<$|\cos\theta|$<0.92
  - 20° away from any charged track
- 4C kinematic fit χ^2<60
- $M(\gamma\pi^+\pi^-)$ > 0.6GeV, reject $\eta J/\psi$ events

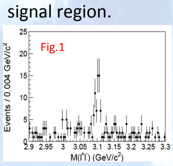


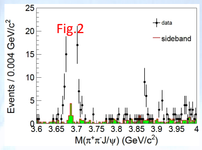
- $\cos\theta_{\pi\pi}$ < 0.98 reject $\gamma^*\to e^+e^-$

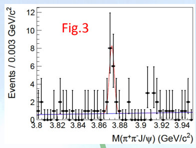
5 Data analysis

✓ After imposing all requirements, there's a **clear J/ψ signal** in the l^+l^- invariant mass distribution when $3.80 < M(\pi^+\pi^- J/\psi) < 3.95$ (**Fig.1**). We require the J/ψ mass window to be $3.08 < M(l^+l^-) < 3.12$ GeV/c^2 and sidebands as $3.0 < M(l^+l^-) < 3.06$ GeV/c^2 and $3.14 < M(l^+l^-) < 3.20$ GeV/c^2.

✓ Remaining **backgrounds** mainly come from $e^+e^-\to(\gamma_{ISR})\pi^+\pi^- J/\psi$, $\eta' J/\psi$ and $\pi^+\pi^-\pi^+\pi^-(\pi^0/\gamma)$ processes. But none of them form peaks around X(3872) signal region.

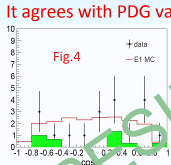






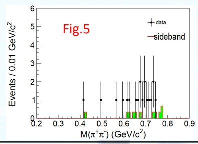
✓ Fig.2) Huge $e^+e^-\to\gamma_{ISR}\psi(2S)$ is used to **calibrate and validate** the analysis.

✓ Fig.3) **Fit** to the $M(\pi^+\pi^- J/\psi)$ distribution with a Gaussian function for signal and a linear background term and get the **preliminary result:** $M(X(3872)) = (3872.1\pm0.8)$ MeV/c^2, $\sigma = 2.4\pm0.7$ MeV/c^2, $N_{obs} = 15.0\pm3.9$. It agrees with PDG value. The statistical significance of X(3872) is 5.3σ.



✓ Fig.4) **Angular distribution** of X(3872) together with pure E1 transition MC, green histogram is sideband background. It means the observed X(3872) signal can not be from detector effects.

✓ Fig.5) The $\pi^+\pi^-$ invariant mass distribution is dominated by the $\rho^0(770)$ resonance, which agrees with the CDF observation (box2 right plot).



6 Systematic errors

1). **X(3872) mass** measurement

Source	Mass (MeV/c²)	Estimated thoughts
Absolute mass scale	0.2	difference of fitted $\psi(2S)$ mass and PDG value
Fit model	0.1	use Breit-Wigner convolve Gaussian to fit X(3872)
Background shape	0.1	use background shape from $(\gamma_{ISR})\pi^+\pi^- J/\psi$, $\eta' J/\psi$
Total	0.3	

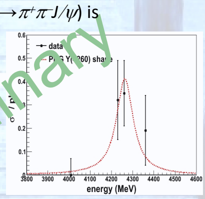
2). **X(3872) cross section** measurement

Source	Error (%)	Estimated thoughts
Luminosity	1.0	bhabha events
Tracking	4.0	
Photon	1.0	$J/\psi\to\rho\pi$
Background shape	0.2	use background shape from $\eta' J/\psi$
Y(4260) line-shape	0.6	largest difference between Belle and BABAR
Kinematic fit	1.5	pure $\gamma_{ISR}\psi(2S)$ sample
J/ψ mass window	0.8	pure $\gamma_{ISR}\psi(2S)$ sample
Branching ratios of $J/\psi\to l^+l^-$	1.0	PDG value
Others	1.0	
Total	4.9	

7 Summary and preliminary result

- **Observe** $e^+e^-\to\gamma X(3872)$ for the first time with significance > 5σ.
- **Measured mass of the $X(3872)$** is $M(X(3872)) = (3872.1\pm0.8\pm0.3)$ MeV/c^2, agrees with previous measurements well.
- **Cross section** of $\sigma^B[e^+e^-\to\gamma X(3872)]\times B(X(3872)\to\pi^+\pi^- J/\psi)$ is

Energy (MeV)	Efficiency (%)	1+δ	N_{evts}	σ^B(pb⁻¹)
4230	31.3	0.799	4.7±2.2	0.32±0.15±0.02
4260	30.2	0.814	8.3±2.9	0.35±0.12±0.02
4009	26.1	0.861	<1.5	<0.13 (90% C.L.)
4360	21.1	1.023	<5.2	<0.39 (90% C.L.)



These results suggest that $X(3872)$ may comes from $Y(4260)$ decays.

- $\sigma^B[e^+e^-\to\gamma X(3872)]\times B(X(3872)\to\pi^+\pi^- J/\psi)$ / $\sigma^B[e^+e^-\to\pi^+\pi^- J/\psi]$ = $(5.6\pm2.0)\times10^{-3}$ at 4.26 GeV, if we take $B(X(3872)\to\pi^+\pi^- J/\psi)$ ~ 5%, then

$$\frac{\sigma(e^+e^-\to\gamma X(3872))}{\sigma(e^+e^-\to\pi^+\pi^- J/\psi)}\sim 11.2\%$$

indicates that Y(4260) has a large E1 transition rate to the X(3872).