Observation of Y(4220) and Y(4390) in $e^+e^- \to \pi^+D^0D^{*-}$ cross section between 4.05 and 4.60 GeV with the BESIII detector

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Abstract

The cross section of $e^+e^- \to \pi^+D^0D^{*-}$ at the center-of-mass energies from 4.05 to 4.60 GeV are measured precisely using the data samples collected with the BESIII detector operating at the BEPCII storage ring. Two resonant structures are observed in the cross sections around 4.22 and 4.39 GeV. A fit with two Breit-Wigner functions results in a mass of $(4224.8 \pm 5.6 \pm 4.0)$ MeV/c^2 and a width of $(72.3 \pm 9.1 \pm 0.9)$ MeV for the first resonance*(BESIII preliminary)*, and a mass of $(4400.1 \pm 9.3 \pm 2.1)$ MeV/c^2 and a width of $(181.7 \pm 16.9 \pm 7.4)$ MeV for the second one*(BESIII preliminary)*, where the first errors are statistical and the second ones systematic. The statistical significance of two structure assumption is greater than 10σ over one structure assumption.

Introduction

1. A series of charmonium-like states have been observed in the e^+e^- annihilation processes at BABAR, Belle, CLEO and BESIII experiments.
2. **There is no obvious evidence** for open-charm productions associated with these Y states.
3. BESIII has reported a measurement of the cross section of $e^+e^- \to \pi^+\pi^- J/\psi$ and $e^+e^- \to \omega\chi_{c0}$.
4. $D\bar{D}_1(2420)$ molecule model is proposed to interpret the Y(4260) with a significant smaller mass about 4.22 GeV/c^2, the open-charm production of $e^+e^- \to \pi^+D^0D^{*-}$ is expected to get strongly enhanced above the nominal $D\bar{D}_1(2420)$ threshold.

BESIII Detector

The BESIII Detector includes a *Main Drift Chamber(MDC)*, a *Timer of Flight(TOF)* and a *CsI calorimeter(EMC)*. These components are immersed in a magnetic field of 1 Tesla, provided by a superconducting solenoid, and surrounded by a *Muon counter(MUC)*.

Analysis Method

- Using $K^-\pi^+$ final states to reconstruct D^0 candidates.
- Finding another charged bachelor π^+.
- D^{*-} is inferred from energy-momentum conservation.

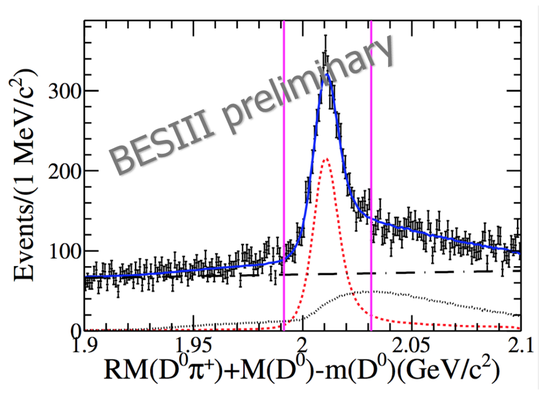

Figure 1: Fit to the distribution of $RM(D^0\pi^+) + M(D^0) - m(D^0)$ for the data sample at $\sqrt{s} = 4.5995$ GeV. The black dots with error bars are data, the solid line(blue) is the total fit, the dashed line(red) is the signal shape, the dotted and dash-dotted lines(black) are the isospin partner background and the linear background. The pink vertical lines are the signal region.

Born Cross Section of $e^+e^- \to \pi^+D^0D^{*-}$

The Born cross section can be calculated with:

$$\sigma^B = \frac{N^{obs}}{\mathcal{L}(1+\delta^r)(1+\delta^v)\mathcal{B}(D^0 \to K^-\pi^+)\epsilon} \quad (1)$$

where N^{obs} is signal yield, $\mathcal{L}$ is the integrated luminosity, $1+\delta^r$ and $1+\delta^v$ are radiative correction factor and vacuum polarization correction factor, ϵ is the detection efficiency for signal process.

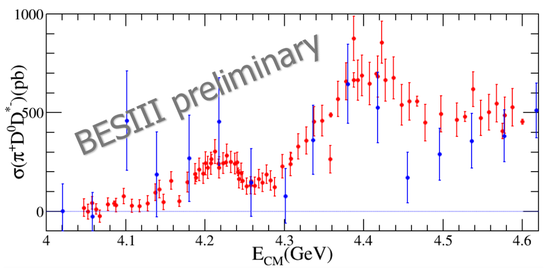

Figure 2: The cross section of $e^+e^- \to \pi^+D^0D^{*-}$(red dots) are consistent with but more precise than those from Belle measurement(blue dots).

$\sqrt{s}$	$\mathcal{L}$ (pb^{-1})	$N^{\rm obs}$	$1+\delta^{\rm r}$	$1+\delta^{\rm v}$	ϵ (%)	$\sigma^{\rm B}$ (pb)
4.0855	52.6	18.8±5.8	0.725	1.06	30.05	39.6±12.3±3.2
4.1886	43.1	95.5±11.8	0.749	1.07	41.05	172.1±21.3±13.8
4.2077	54.6	191.3±16.1	0.754	1.07	41.73	265.3±22.4±21.2
4.2171	54.1	176.2±15.6	0.765	1.07	41.86	242.5±21.4±19.4
4.2263	1091.7	3885.3±71.7	0.786	1.07	43.25	249.9±4.6±14.5
4.2417	55.6	157.5±15.3	0.858	1.06	39.65	199.1±19.3±15.9
4.2580	825.7	1816.7±56.1	0.903	1.06	38.40	152.3±4.7±8.8
4.3079	44.9	162.6±16.1	0.813	1.06	40.11	267.9±26.5±21.4
4.3583	539.8	3788.2±79.7	0.787	1.05	44.14	488.6±10.3±29.3
4.3874	55.2	509.1±27.7	0.798	1.05	42.01	665.3±36.2±53.2
4.4156	1073.6	10899.1±142.4	0.821	1.05	42.71	698.4±9.1±41.2
4.4671	109.9	868.9±39.9	0.887	1.06	38.34	557.4±25.6±44.6
4.5271	110.0	745.8±39.1	0.931	1.06	36.46	480.0±25.2±38.4
4.5745	47.7	271.4±25.2	0.925	1.06	36.37	406.9±37.8±32.6
4.5995	566.9	3605.2±100.9	0.916	1.06	36.67	454.5±12.7±27.7

Table 1: The results of the measurement of Born cross section of $e^+e^- \to \pi^+D^0D^{*-}$.The first uncertainty is statistical and the second ones are systematic uncertainty.

Fit to the Cross Section

- Using a **least χ^2 method** fit[1] to the cross section to extract possible resonances. The χ^2 is defined as:

$$\chi^2 = \sum_{i=1}^{n_{total}} \frac{(\sigma_i^{dress} - \sigma^{fit}(m_i))^2}{(\Delta\sigma_i^{dress})^2} \quad (2)$$

  where $\sigma_i^{dress} \pm \Delta\sigma_i^{dress}$ is the dressed experimental measurement, $\sigma^{fit}(m_i$ is the cross section value calculated from the model below with the parameters from the fit, m_i is the energy corresponds to the energy point.
- Assuming that the cross section follows the **3-body phase space** and there are **two resonances** at around 4.22 GeV and 4.39 GeV, so we have a fit to the cross section, that is:

$$\sigma^{dress}(m) = |c\cdot\sqrt{PS(m)} + e^{i\phi_1}BW_1(m)\sqrt{PS(m)/PS(M_1)} + e^{i\phi_2}BW_2(m)\sqrt{PS(m)/PS(M_2)}|^2 \quad (3)$$

$$BW_i(m) = \frac{\sqrt{12\pi(\Gamma_{e^+e^-}\mathcal{B}(\pi^+D^0D^{*-}))_i\Gamma_{toti}}}{m^2 - M_i^2 + iM_i\Gamma_{toti}} (i = 1, 2) \quad (4)$$

  where $PS(m)$ is the 3-body phase space factor and $BW_i(m)$ is the Breit-Wigner function.
- The statistical significance of two resonances assumption over one resonance is greater than 10σ. The resonant parameters of Y(4220) and Y(4390) states are consistent with the previous measurements.

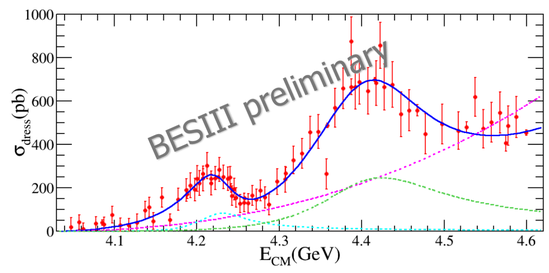

Figure 3: Fit to the Born cross section with a constant(pink dashed triple-dot line) and two constant width relativistic BW functions(green dashed double-dot line and aqua dashed line)

Parameters	SolutionI	SolutionII	SolutionIII	SolutionIV
c (10^{-4})		5.5±0.6		
M_1 (MeV/c^2)		4224.8±5.6		
Γ_1 (MeV)		72.3±9.1		
M_2 (MeV/c^2)		4400.1±9.3		
Γ_2 (MeV)		181.7±16.9		
$\Gamma_1^{\rm el}$ (eV)	62.9±11.5	7.2±1.8	81.6±15.9	9.3±2.7
$\Gamma_2^{\rm el}$ (eV)	88.5±15.8	55.3±8.7	551.9±85.3	344.9±70.6
ϕ_1	-2.1±0.1	2.8±0.3	-0.9±0.1	-2.3±0.2
ϕ_2	1.9±0.3	2.3±0.2	2.3±0.1	-1.9±0.1

Table 2: The parameters of the two resonances in the cross section from the fit.There are four solutions with same fit quality, which have same c, mass and width. The errors are statistical only.

Summary

1. The $e^+e^- \to \pi^+D^0D^{*-}$ cross sections are measured using the data samples collected from 4.05 to 4.60 GeV.
2. Two resonant structures are observed in the cross sections around 4.22 and 4.39 GeV. The parameters are consistent with previous observation on BESIII[2-4] $M(Y(4220)) = (4224.8 \pm 5.6 \pm 4.0)$MeV/$c^2$, $\Gamma(Y(4220)) = (72.3 \pm 9.1 \pm 0.9)$MeV. $M(Y(4390)) = (4400.1 \pm 9.3 \pm 2.1)$MeV/$c^2$, $\Gamma(Y(4390)) = (181.7 \pm 16.9 \pm 7.4)$MeV*(BESIII preliminary)*.
3. These two resonances found in $\pi^+D^0D^{*-}$ final states are new evidences for open-charm production associated with the Y states for **the first time.**
4. The mass of Y(4220) is lower by about 30 MeV/c^2 than that of Y(4260)[5], BUT consistent with the prediction of $D\bar{D}_1(2420)$ molecule interpretation within errors[6].

References

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