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Direct production of χ_{c1} at BESIII

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Abstract. The production of resonances in electron-positron annihilation has only been observed for states with quantum numbers $J^{PC} = 1^{--}$, while $C = +1$ resonances appear only among the decay products. The direct production of the 1^{++} states could happen through two-photon or neutral current. Due to the smallness of the production rate, this process has never been verified experimentally. With the high luminosity and good performance of the BESIII experiment, a search of the direct production of the 1^{++} state in charmonium region, χ_{c1}, is undergoing with dedicated data samples around the χ_{c1} mass. An overview of the data analysis will be presented.

1 Introduction

Up to now, only the production of resonances with the quantum numbers $J^{PC} = 1^{--}$ has been observed in e^+e^- annihilation through a virtual photon, states with other quantum numbers are appeared only among the decay products. In principle, the axial vector states with $J^{PC} = 1^{++}$ could also be produced directly in e^+e^- collider through neutral current or two-photon annihilation. In charmonium region, the contribution from two-photon annihilation dominates the production rate [1]. The production rate, which is proportional to the electronic width, has already been calculated a long time ago [1, 2]. Using unitarity limit, the lower limit of the electronic width of χ_{c1} is calculated to be $\Gamma_{ee} > 0.044$ eV, while in Vector Dominance Model (VDM), the prediction is $\Gamma_{ee} = 0.46$ eV [1]. Recently, the electronic width of χ_{cJ} has been revisited within the VDM [3] and the NRQCD [4] framework, the values from the new estimations are at 0.1 eV level.

Following the strategy used in earlier works [1, 2], the author of [5] extended the study of the direct production of χ_{c1} and χ_{c2} by including the influence of interference between the signal process and the continuum background process. The study focuses on the radiative decay of χ_{cJ} to $\gamma J/\psi$, followed by $J/\psi \to \mu^+\mu^-$, and its interference with the continuum background process, $e^+e^- \to \gamma_{\text{ISR}}\mu^+\mu^-$, where the photon is from radiative corrections. The electronic width from this latest prediction is $\Gamma_{ee} = 0.43$ eV. The interference effect changes the total cross section of $e^+e^- \to \gamma\mu^+\mu^-$ dramatically, as shown in Fig. 1. The peak position of the total cross section shifted towards the lower center-of-mass (c.m.) energy and there is a destructive effect at higher c.m. energy.

Due to the smallness of the production rate, no experimental attempt has been made to verify these predictions. With the high luminosity and excellent performance of the Beijing Electron Positron Collider (BEPCII) and the BESIII detector [6, 7], a study has been launched at the BESIII experiment to search for the direct production of χ_{c1}.

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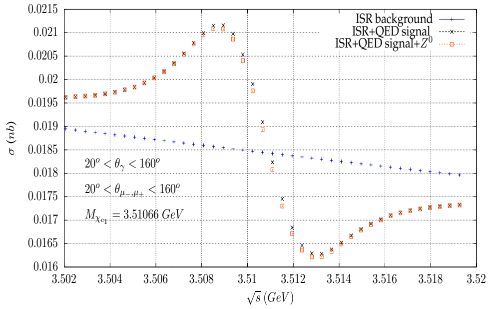

Figure 1. The cross section of $e^+e^- \rightarrow \gamma\mu^+\mu^-$ with interference between the signal process and the continuum background process taken into account, predicted by Ref. [5].

2 The BEPCII and BESIII detector

The BEPCII is a τ-charm factory that works with c.m. energy ($\sqrt{s}$) from 2.0 to 4.6 GeV. The designed luminosity is 1×10^{33} cm$^{-2}s^{-1}$. The energy of the beam can be measured precisely with the beam energy measurement system (BEMS), which is based on the Compton backscattering principle [8]. The accuracy is at $\sim 10^{-5}$ level.

The BESIII detector is a magnetic spectrometer [7] with an acceptance of 93% over 4π solid angle. The cylindrical core of the BESIII detector consists of a helium-based multilayer drift chamber (MDC), a plastic scintillator time-of-flight system (TOF), and a CsI(Tl) electromagnetic calorimeter (EMC), which are all enclosed in a superconducting solenoidal magnet providing a 1.0 T magnetic field. The solenoid is supported by an octagonal flux-return yoke with resistive plate counter muon identifier modules (MUC) interleaved with steel. The charged-particle momentum resolution at 1 GeV/c is 0.5%, and the dE/dx resolution is 6% for the electrons from Bhabha scattering. The EMC measures photon energies with a resolution of 2.5% (5%) at 1 GeV in the barrel (end cap) region. The time resolution of the TOF barrel part is 68 ps, while that of the end cap part is 110 ps. The end cap TOF system is upgraded in 2015 with multi-gap resistive plate chamber technology, providing a time resolution of 60 ps [9]. The position resolution in MUC is about 2 cm.

3 The data samples

Taking both scenarios with and without interference between the signal and continuum background processes into account, a set of data samples contains 5 energy points in the χ_{c1} mass region has been collected in 2017. It contains 2 data samples with large statistics, one at the peak position of the total cross section, as shown in Fig. 1, and one at the nominal χ_{c1} mass [10]. A small statistics sample at $\sqrt{s}$ = 3.49 GeV, which is about 20 MeV lower than the nominal χ_{c1} mass, is collected to study the continuum background process. The study of the continuum background process also uses data samples collected at $\psi(3770)$ peak and $\sqrt{s}$ = 4.178 GeV with integrated luminosity of about 3 fb^{-1} each. The c.m. energy and integrated luminosity of the χ_{c1} data samples are summarized in Table 1. The c.m. energy is measured with the BEMS system, and the integrated luminosity is measured by using the Bhabha events with an uncertainty of ~0.6%.

Table 1. The c.m. energy ($\sqrt{s}$) and integrated luminosity ($\mathcal{L}$) of the data samples.

Number of points	$\sqrt{s}$ (MeV)	$\mathcal{L}$ (pb^{-1})
1	3490.0	12.1
2	3508.0	181.8
3	3509.7	39.3
4	3510.4	183.6
5	3514.6	40.9

4 Analysis strategy

In this study, the χ_{c1} signal is reconstructed through its radiative decay $\chi_{c1} \to \gamma J/\psi$ with $J/\psi \to \mu^+\mu^-$. The continuum background events from the ISR processes of $e^+e^- \to \gamma_{\rm ISR} J/\psi \to \gamma_{\rm ISR}\mu^+\mu^-$ and non-resonant $e^+e^- \to \gamma_{\rm ISR}\mu^+\mu^-$ under the J/ψ peak are irreducible. The analysis strategy is to develop the selection criteria and prove that the ISR background events can be well described by the MC generator, PHOKHARA [11], using the data samples at $\sqrt{s}$ = 3.49 GeV and the two high statistics data samples above the χ_{c1} mass. Then the 4 data samples around the χ_{c1} mass are studied to search for discrepancy between data and background MC prediction around the J/ψ peak. In case of no interference, excess of J/ψ events beyond the irreducible background events is expected at $\sqrt{s}$ = 3.510 GeV, while in case of interference as predicted in [5], excess of J/ψ events is expected at $\sqrt{s}$ = 3.508 GeV and insufficiency of J/ψ events is expected at $\sqrt{s}$ = 3.514 GeV. Combing the 4 energy points around the χ_{c1} mass, the interference between the signal and the background processes can be studied.

5 Event selection and number of events estimation

Candidate events are required to have two charged tracks, with zero net charge, and at least one photon within the detector volume. A four-constraint (4C) kinematic fit is performed by constraining the total four momentum to that of the initial beams. If there is more than one photon candidate in an event, the one with the least $\chi^2_{\rm 4C}$ is retained. The background events from Bhabha process is rejected by requiring the energy deposition of the charged track in EMC to be smaller than 0.4 GeV. After the selection, the background ratio is smaller than 0.1% and flatly distributed in the $\mu^+\mu^-$ invariant mass distribution in the range of 2.9 to 3.2 GeV/c^2. Good agreements between data and MC simulation of the irreducible background events are observed at $\sqrt{s}$ = 3.49 GeV, ψ(3770), and $\sqrt{s}$ = 4.178 GeV in the $\mu^+\mu^-$ invariant mass distribution.

This has also been demonstrated in the previous BESIII publications of the Γ_{ee} of J/ψ [12] and the π form factor measurement [13] using data sample at ψ(3770). The Γ_{ee} of J/ψ is measured with the $e^+e^- \to \gamma_{\rm ISR}\mu^+\mu^-$ process, which is the irreducible background process of this study. The consistence of the Γ_{ee} of J/ψ measured from the BESIII measurement and the world average value [10] indicates a reliable J/ψ simulation from the PHOKHARA generator. In the π form factor measurement, the process of $e^+e^- \to \gamma_{\rm ISR}\mu^+\mu^-$ is the dominant background process. A direct comparison between data and MC simulation of the background process shows good agreement in a wide mass range, as shown in Fig. 2.

Using the cross section predicted in [5] and taking the detection efficiency ($\sim$ 60%) into account, the expected number of events from background only or background and signal process are summarized in Table 2.

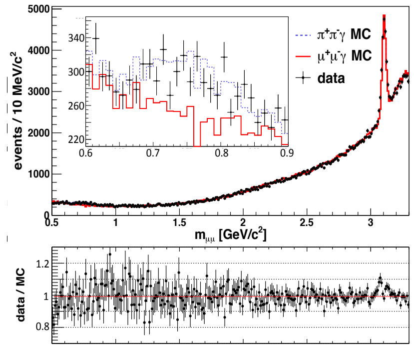

Figure 2. The comparison of $\mu^+\mu^-$ invariant mass distribution between data and MC simulation of $e^+e^- \to \gamma_{\rm ISR}\mu^+\mu^-$ after selecting μ and applying the efficiency corrections [13].

Table 2. The number of background events ($N^{\rm ISR}$) and the number of signal and background events ($N^{{\rm ISR}+\chi_{c1}}$) estimated with the prediction in [5].

Number of points	$\sqrt{s}$ (MeV)	$N^{\rm ISR}$	$N^{{\rm ISR}+\chi_{c1}}$
2	3508.0	2025 ± 45	2286 ± 48
3	3509.7	436 ± 21	483 ± 22
4	3510.4	2043 ± 45	2132 ± 46
5	3514.6	450 ± 21	411 ± 20

6 Conclusion

The direct production of a 1^{++} state in e^+e^- annihilation process has been studied experimentally for the first time at BESIII. Dedicated data samples around the χ_{c1} mass at 5 energy points have been collected with a total integrated luminosity of 456 pb^{-1}. Study of the irreducible continuum background process with data samples far below or above the χ_{c1} mass region shows that the MC simulation can describe data very well. The analysis is in progress, the signal of $e^+e^- \to \chi_{c1}$ as well as the possible interference effect will be verified. If the χ_{c1} can be observed from this study, it will provide new perspective for the study of the properties of the $C = +1$ states in e^+e^- collider, not only for traditional quarkonium, but also for exotic quarkonium states.

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