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Search for the C-parity violating process $J/\psi \to \gamma\gamma$ via $\psi(2S) \to \pi^+\pi^- J/\psi$

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Using $14.0 \times 10^6 \psi(2S)$ events collected with the BES-II detector, the C-parity violating process $J/\psi \to \gamma\gamma$ via $\psi(2S) \to \pi^+\pi^- J/\psi$ is studied. We determine a new upper limit for the $J/\psi \to \gamma\gamma$

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branching ratio of $\mathcal{B}(J/\psi \to \gamma\gamma) < 2.2 \times 10^{-5}$ at the 90% C.L., which is about 20 times lower than the previous measurement.

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I. INTRODUCTION

C-parity violation has been studied in different electromagnetic decays [1,2]. In this paper, we present a search for the C-parity violating decay, $J/\psi \to \gamma\gamma$. In a previous measurement [3], the direct $J/\psi \to \gamma\gamma$ decay was used, and the upper limit measured is $\mathcal{B}(J/\psi \to \gamma\gamma) < 5 \times 10^{-4}$. The obvious disadvantage of using the direct J/ψ decay is the large background from $e^+e^- \to \gamma\gamma$. In this analysis we study this decay via $\psi(2S) \to \pi^+\pi^- J/\psi$, $J/\psi \to \gamma\gamma$. Therefore, the QED background can be strongly suppressed since we observe a $\pi^+\pi^-$ pair plus two photons and do not base our search just on the two γ invariant mass distribution. As a result, the precision is significantly improved, as long as the background from J/ψ decays to neutrals is well understood.

II. THE BES DETECTOR AND MONTE CARLO

The Beijing Spectrometer (BES) is a conventional solenoidal magnet detector that is described in detail in Ref. [4]; BES-II is the upgraded version of the BES detector [5]. A 12-layer vertex chamber (VC) surrounding the beam pipe provides trigger and position information. A 40-layer main drift chamber (MDC), located radially outside the VC, provides trajectory and energy loss (dE/dx) information for charged tracks over 85% of the total solid angle. The momentum resolution is $\sigma_p/p = 0.017\sqrt{1+p^2}$ (p in GeV/c), and the dE/dx resolution for hadron tracks is ~8%. An array of 48 scintillation counters surrounding the MDC measures the time of flight (TOF) of charged tracks with a resolution of ~200 ps for hadrons. Outside of the TOF counters is a 12-radiation-length barrel shower counter (BSC) composed of gas tubes interleaved with lead sheets. This measures the energies of electrons and photons over ~80% of the total solid angle with an energy resolution of $\sigma_E/E = 22\%/\sqrt{E}$ (E in GeV). Outside of the solenoidal coil, which provides a 0.4 T magnetic field over the tracking volume, is an iron flux return that is instrumented with three double layers of counters that identify muons of momentum greater than 0.5 GeV/c.

A GEANT3 based Monte Carlo (MC) program with detailed consideration of the detector performance (such as dead electronic channels) is used to simulate the BES-II detector. The consistency between data and Monte Carlo has been carefully checked in many high purity physics channels, and the agreement is quite reasonable [6]. For $\psi(2S) \to \pi^+\pi^- J/\psi$, $J/\psi \to \gamma\gamma$, the mass of the dipion system is generated according to [7]

$$\frac{d\sigma}{dM_{\pi^+\pi^-}} \propto (\text{phase space}) \times (M^2_{\pi^+\pi^-} - 4m^2_\pi)^2,$$

while the decay $J/\psi \to \gamma\gamma$ decay is generated according to phase space.

III. EVENT SELECTION

The data sample used for this analysis consists of $(14.00 \pm 0.56) \times 10^6 \psi(2S)$ events [8] collected with the BES-II detector at the center-of-mass energy $\sqrt{s} = M_{\psi(2S)} = 3.686$ GeV. Events with two charged tracks and two photons are selected. Each charged track is required to be well fitted by a helix and to have a polar angle, θ, within the fiducial region $|\cos\theta| < 0.8$. To ensure that tracks originate from the interaction region, we require that $V_{xy} = \sqrt{V_x^2 + V_y^2} < 2$ cm and $|V_z| < 20$ cm, where V_x, V_y, and V_z are the x, y, and z coordinates of the point of closest approach of each charged track to the beam axis. In addition, the momentum for each charged track has to be less than 0.5 GeV/c.

A neutral cluster is considered to be a photon candidate if it is located within the BSC fiducial region ($|\cos\theta| < 0.75$), the energy deposited in the BSC is greater than 0.5 GeV, the first hit appears in the first 6 radiation lengths, the angle between the cluster and the nearest charged track is more than 15°, and the angle between the direction of cluster development and the direction of the photon emission is less than 40°.

A four constraint (4C) kinematic fit under the $\psi(2S) \to \pi^+\pi^-\gamma\gamma$ hypothesis is performed, and the χ^2 of this fit is required to be less than 9. Figure 1 shows the distribution of mass recoiling against the $\pi^+\pi^-$ for the surviving events. The MC indicates the detection efficiency for this channel is 16.0%.

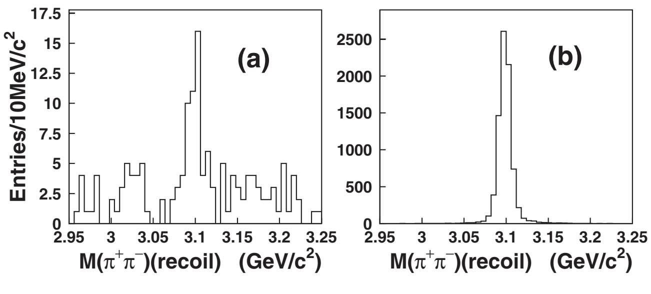

FIG. 1. The distribution of mass recoiling against $\pi^+\pi^-$ after event selection. (a) data and (b) MC.

TABLE I. Peaking background events from different channels. The “Sum of four channnels” includes $\gamma f_2(1810)$, $\gamma f_0(2020)$, $\gamma f_2(2150)$, and $\gamma f_4(2050)$.

Peaking background ($\psi(2S) \to \pi^+\pi^- J/\psi, J/\psi \to$)	Number of events
$\gamma\pi^0$	$8.3^{+1.7}_{-1.2}$
$\gamma\eta$	16.4 ± 1.4
$\gamma\eta'$	1.5 ± 0.2
$\gamma f_2(1270) \to \gamma\pi^0\pi^0$	1.7 ± 0.3
$\gamma f_0(1500) \to \gamma\pi^0\pi^0$	Negligible
$\gamma f_0(1710) \to \gamma\pi^0\pi^0$	0.4 ± 0.3
Sum of four channels	2.0 ± 1.0
Total	30.4 ± 2.4

IV. PEAKING BACKGROUND STUDY

The important background comes from $\psi(2S) \to \pi^+\pi^- J/\psi$, $J/\psi \to$ neutrals, which produces a peak in the mass recoiling against the $\pi^+\pi^-$. Among these background channels, the most contributions are from the decays in which the final state contains three photons such as $J/\psi \to \gamma P$ (P denotes π^0, η, η'), $P \to \gamma\gamma$. In addition, some background arises from five photon final states such as $J/\psi \to \gamma f_2(1270)$, $f_2(1270) \to \pi^0\pi^0$, etc. The efficiencies for other potential background channels in which the number of photons is more than five, for example, $J/\psi \to \gamma\eta'$, $\eta' \to \pi^0\pi^0\eta$, $\eta \to \gamma\gamma$, are found to be on the order of $\sim$0.01% and therefore negligible. Taking into account the measured branching ratios of $\mathcal{B}(J/\psi \to \gamma\pi^0, \gamma\eta, \gamma\eta')$ [9] and the combined branching ratios of $\mathcal{B}(J/\psi \to X, X \to \pi^0\pi^0)$ [here X denotes $f_2(1270)$, $f_0(1500)$, and $f_0(1710)$] [10], the normalized numbers of background events are determined and listed in Table I. The contribution from other potential background channels such as $J/\psi \to \gamma f_2(1810)$, $\gamma f_0(2020)$, $\gamma f_2(2150)$, and $\gamma f_4(2050)$ should not be larger than that from $J/\psi \to \gamma f_2(1270)$ according to the partial wave analysis result in Ref. [10]. Conservatively, 2.0 ± 1.0 events are estimated as the background from these four channels.

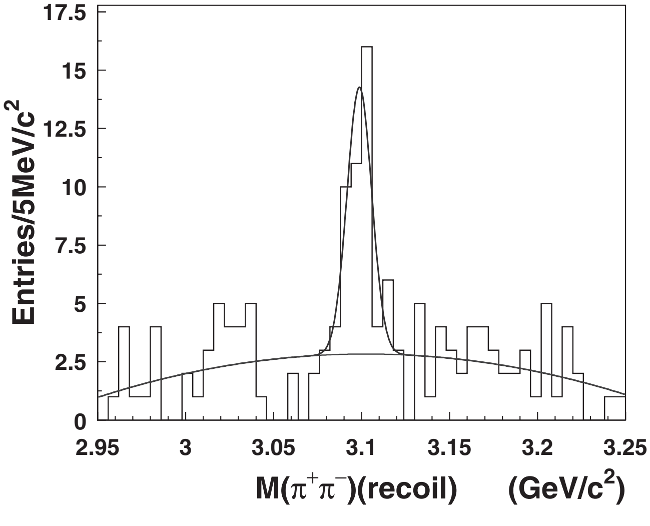

FIG. 2. The distribution of mass recoiling from the $\pi^+\pi^-$ after event selection. The curves shows the fit described in the text.

V. MASS SPECTRUM FIT

A fit with a Breit-Wigner function convoluted with a Gaussian resolution function yields the number of J/ψ events, 33.4 ± 6.6. Here, the function to describe the background shape is a second-order polynomial. Figure 2 shows the fit results.

VI. SYSTEMATIC ERROR

The systematic error on this branching ratio measurement includes the uncertainties in the MDC tracking efficiency, photon efficiency, kinematic fit, binning, fit range, background shape, the number of $\psi(2S)$ events, etc.

A. MDC tracking efficiency and photon efficiency

For charged tracks, the uncertainty of the tracking efficiency is determined by comparing data and MC, and an error of 2% is found for each track [6]. A similar comparison has also been performed for photons, and the difference is also about 2% for a single photon [6].

B. Kinematic fit

The final state in the investigated channel is the same as in $\psi(2S) \to \pi^+\pi^-\pi^0$ where an error of 6% is given due to the uncertainty from kinematic fit [11] Similarly, the same error is assumed in this analysis due to the uncertainty from the 4C fit.

C. Binning, fit range, and background shape

When the bin width is changed from 25 to 50 MeV$/c^2$ and the fit range is changed from 3.2–3.7 to 3.1–3.7 GeV$/c^2$, the differences of the numbers of the fitted signal events is 5.2%. This is considered as a systematic error. The uncertainty caused by using a different background shape is negligible.

TABLE II. Systematic error (%).

Source	(%)
Track efficiency	4
Photon efficiency	4
Kinematic fit	6
Binning and fit range	5.2
Background shape	Negligible
$\mathcal{B}(\psi(2S) \to \pi^+\pi^- J/\psi)$	1.9
$\psi(2S)$ total number	4
Total	10.7

D. Total systematic error

The total systematic error, determined by the sum of all sources added in quadrature, is listed in Table II.

VII. UPPER LIMIT OF $\mathcal{B}(J/\psi \to \gamma\gamma)$

The signal region for $J/\psi \to \gamma\gamma$ is taken from 3.08 to 3.12 GeV/c^2 in $\pi^+\pi^-$ recoiling mass distribution, which is J/ψ mass plus and minus three standard deviation in the mass resolution. The total number of events in the signal region is 52. The peaking background is 30.4 and the smooth background is $52 - 33.4 = 18.6$ according to fit result. Therefore, the expected number of total background events is 49. With the Bayesian method [12], the upper limit on the number of $J/\psi \to \gamma\gamma$ events is estimated to be 15.74 at the 90% confidence level, in which the systematic errors of the signal detection efficiency (10.7%) and the background expectation (5.0%, this uncertainty is obtained by 2.4 events from peaking background out of the total 49 events) have been taken into account with the assumption that these two errors are independent of each other. Therefore, the upper limit on $\mathcal{B}(J/\psi \to \gamma\gamma)$ is

$$\mathcal{B}(J/\psi \to \gamma\gamma) < \frac{N_{\text{obs}}^{UL}}{N_{\psi(2S)} \cdot \mathcal{B}(\psi(2S) \to \pi^+\pi^- J/\psi) \cdot \epsilon} = \frac{15.74}{14M \cdot 31.8\% \cdot 16.0\%} = 2.2 \times 10^{-5}, \quad (1)$$

where N_{obs}^{UL} is the upper limit on the number of events for $J/\psi \to \gamma\gamma$, $N_{\psi(2S)}$ is the total number of $\psi(2S)$ events, and ϵ is the detection efficiency.

VIII. SUMMARY

The upper limit for the branching ratio $\mathcal{B}(J/\psi \to \gamma\gamma)$ at the 90% confidence level has been measured via $\psi(2S) \to \pi^+\pi^- J/\psi$. Our upper limit for the C-violating decay is about 20 times lower than previous measurements. It indicates that there is no obvious C-parity violation.

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