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Decay of the J/ψ to $\Sigma^0\overline{\Sigma}^0$ Final State

BES Callaboration[1)]

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Abstract With 7.8 million produced J/ψ events collected by the BES detector at the BEPC, the decay $J/\psi\to\Sigma^0\bar{\Sigma}^0$ is analysed. The branching ratio is measured to be $BR(J/\psi\to\Sigma^0\bar{\Sigma}^0) = (0.97\pm0.04\pm0.24)\times10^{-3}$. The angular distribution is of the form $\frac{dN}{d\cos\theta} = N_0(1+\alpha\cos^2\theta)$ with α value of $-0.21\pm0.27\pm0.13$.

Key words Beijing spectrometer, J/ψ particle, Σ^0 particle, angular distribution, branching ratio

1 Introduction

As is well-known, based on the helicity formalism and general conservative principles regarding spin, party, etc, the angular distribution of B in the decay of a neutral vector resonance V into a baryon-antibaryon pair $B\bar{B}$ is of the form[1]

$$\frac{dN}{d\cos\theta} \sim 1+\alpha\cos^2\theta,$$

where θ is the emission angle of B in the V rest frame. The first order calculations[2,3] of perturbative QCD predicted the theoretical value of α at J/ψ energy. Table 1 lists the predicted α values for the decays $J/\psi\to\Lambda\bar{\Lambda}$ and $\Sigma^0\bar{\Sigma}^0$. Several experiments have performed α measurements for $J/\psi\to p\bar{p}$[4—7], $\Lambda\bar{\Lambda}$[6—8], $\Sigma^0\bar{\Sigma}^0$[6,7] and $\Xi^-\Xi^+$[6], including the previously reported results of BES collaboration[8] using 7.8×10^6 produced J/ψ events in the BES detector. Table 2 summarizes the experimental measurements of α and the branching ratio for the decay $J/\psi\to\Lambda\bar{\Lambda}$. It can be seen that for α the BES result is in good agreement with that of DM2[7] as well as the theoretical prediction in Ref.[3].

This paper presents the measurement of α for the decay $J/\psi\to\Sigma^0\bar{\Sigma}^0$, using 7.8×10^6 J/ψ events collected by BES detector, which has been described in detail elsewhere[9,10] and the comparison of its main features with the other detectors is given in the previous paper[8].

Table 1. Theoretical predictions of α for the decays $J/\psi\to\Lambda\bar{\Lambda}, \Sigma^0\bar{\Sigma}^0$.

Channel	Ref.[2]	Ref.[3]	Channel	Ref.[2]	Ref.[3]
$\Lambda\Lambda$	0.32	0.51	$\Sigma^0\bar{\Sigma}^0$	0.31	0.43

Table 2. Experimental measurements of α and BR for the decay $J/\psi\to\Lambda\Lambda$.

Detector	α	$BR(\times10^{-3})$	Events
MARK Ⅱ	0.72 ± 0.36	$1.58\pm0.08\pm0.19$	365
DM2	0.62 ± 0.22	$1.38\pm0.05\pm0.20$	1847
BES	0.52 ± 0.35	$1.08\pm0.06\pm0.24$	631

2 Selection of $\Lambda\bar{\Lambda}$

Since the decay to be searched includes $\Lambda\bar{\Lambda}$ pair in the final state, a set of cuts is used to select $J/\psi \to \Lambda\bar{\Lambda} + X$ events, where X is a system of neutral particle(s) and/or undetected charged particle(s).

The Λ is identified by its $p\pi$ decay mode. Candidates for $J/\psi \to \Lambda\bar{\Lambda} + X$ events are selected by requiring exactly four reconstructed charged tracks in the drift chamber with zero net charge. Tracks with $|\cos\theta_{ch}| < 0.85$ are accepted, where θ_{ch} is the polar angle with respect to the beam direction. Protons are identified by requiring that their time-of-flight (TOF) or the ionization energy loss (dE/dx) in the drift chamber be consistent with the corresponding particle hypothesis, i.e.

$$\frac{|t_{meas} - t_{exp}(p)|}{\sigma_t} \leqslant 3,$$

or

$$\frac{|t_{meas} - t_{exp}(p)|}{\sigma_t} < \frac{|t_{meas} - t_{exp}(i)|}{\sigma_t}, \qquad (i = \pi, K),$$

or

$$\frac{\left|\left(\frac{dE}{dx}\right)_{meas} - \left(\frac{dE}{dx}\right)_{exp}(p)\right|}{\sigma_{dE/dx}} \leqslant 3,$$

or

$$\frac{\left|\left(\frac{dE}{dx}\right)_{meas} - \left(\frac{dE}{dx}\right)_{exp}(p)\right|}{\sigma_{dE/dx}} < \frac{\left|\left(\frac{dE}{dx}\right)_{meas} - \left(\frac{dE}{dx}\right)_{exp}(i)\right|}{\sigma_{dE/dx}}, \qquad (i = \pi, K),$$

where t_{meas} is the measured flight time, $t_{exp}(i)$ is the expected flight time for particle hypothesis i, and σ_t is the TOF resolution. The subscripts for dE/dx are of similar meanings.

The events with at least one particle satisfying proton (or anti-proton) hypothesis are selected. The ideal case is that both the number of proton and the number of antiproton are equal to 1. In other cases, the minimum value of $|M_{p\pi^-} - 1.116\text{ GeV}| + |M_{\bar{p}\pi^+} - 1.116\text{ GeV}|$ determines the combination of p, $\bar{p}$, π^+ and π^-. Fig.1 shows the distribution of invariant mass $M_{p\pi}$ for $J/\psi \to p\pi^-\bar{p}\pi^+ + X$ candidates selected in the J/ψ data sample. By fitting it to a gaussian distribution plus a quadrinomial function, a 3.0 MeV r.m.s mass resolution is estimated for the peak. To select a $\Lambda\bar{\Lambda} + X$ event, both of $M_{p\pi^-}$ and $M_{\bar{p}\pi^+}$ invariant masses are required to be within (1116 ± 9)MeV.

3 Selection of the Final State and the Result

The energy distribution of the $\Lambda\bar{\Lambda}$ pair, $E_{\Lambda\bar{\Lambda}}$, for $J/\psi \to \Lambda\bar{\Lambda} + X$ candidates is shown in Fig.2. The enhancement centered at 2.9 GeV is due to the decay $J/\psi \to \Sigma^0\bar{\Sigma}^0$, where $\Sigma^0 \to \Lambda\gamma$. The $\Lambda\bar{\Lambda}$ energy distributions for the Monte Carlo events $J/\psi \to \Lambda\bar{\Lambda}$, $\Sigma^0\bar{\Sigma}^0$, $\Xi^0\bar{\Xi}^0$ and $\Sigma^{0*}\bar{\Sigma}^{0*}$ are shown in Fig.3 with $BR(J/\psi \to \Lambda\bar{\Lambda})$ equal to 1.08×10^{-3} given by BES[8], $BR(J/\psi \to \Sigma^0\bar{\Sigma}^0)$ equal to 0.97×10^{-3} (see the text below), $J/\psi \to \Xi^0\bar{\Xi}^0$ equal to 0.9×10^{-3} given by PDG2000[11] and $BR(J/\psi \to \Sigma^{0*}\bar{\Sigma}^{0*})$ equal to 1.40×10^{-3} which is obtained by fitting $\Lambda\bar{\Lambda}$ pair energy spectrum with the superposition of $\Lambda\bar{\Lambda}$ energy distributions for the four Monte Carlo channels, shown in Fig.2 as dashed line. It can be seen that the agreement between data and Monte Carlo simulation is reasonably well.

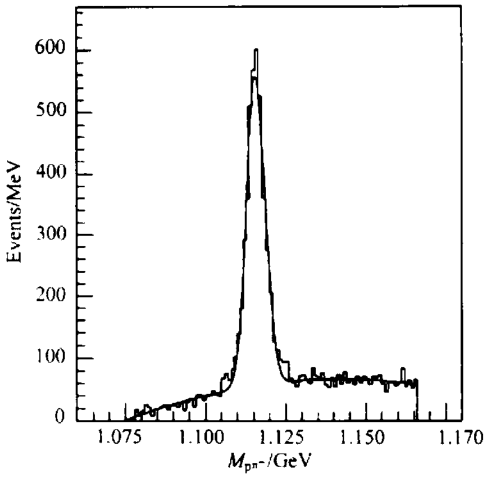

Fig. 1. Invariant mass $M_{p\pi^-}$ distribution in $J/\psi \to p\pi^- \bar{p}\pi^+ + X$ event candidates (histogram). The smooth curve is a fit with a Gaussian plus a quadrinomial.

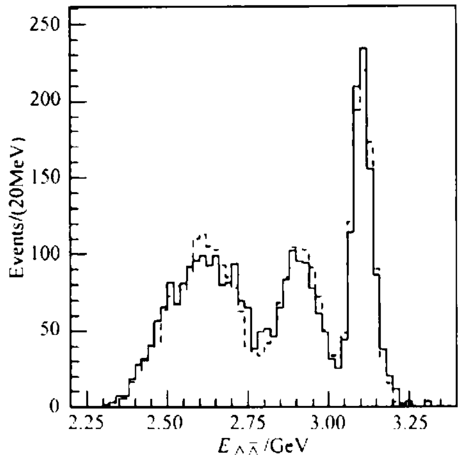

Fig. 2. $\Lambda\bar{\Lambda}$ pair energy distribution. The solid line represents $E_{\Lambda\bar{\Lambda}}$ for data of $J/\psi \to \Lambda\bar{\Lambda} + X$. The dashed line is the superposition of $\Lambda\bar{\Lambda}$ energy distributions for the Monte Carlo events $J/\psi \to \Sigma^{0*}\bar{\Sigma}^{0*}$, $\Xi^0\bar{\Xi}^0$, $\Sigma^0\bar{\Sigma}^0$ and $\Lambda\bar{\Lambda}$ with the branching ratios stated in the text.

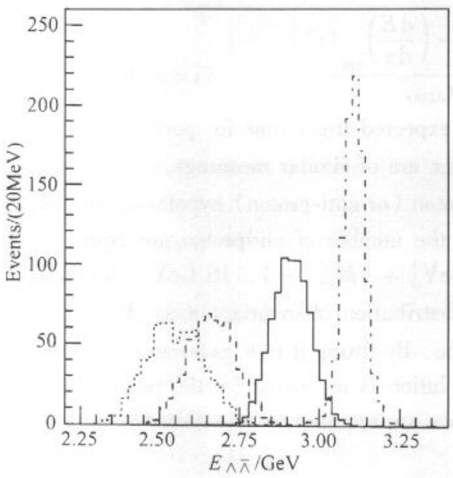

Fig. 3. $\Lambda\bar{\Lambda}$ pair energy distribution. The four bumps from left to right are for the decays $J/\psi \to \Sigma^{0*}\bar{\Sigma}^{0*}$, $\Xi^0\bar{\Xi}^0$, $\Sigma^0\bar{\Sigma}^0$ and $\Lambda\bar{\Lambda}$ from Monte Carlo simulations respectively.

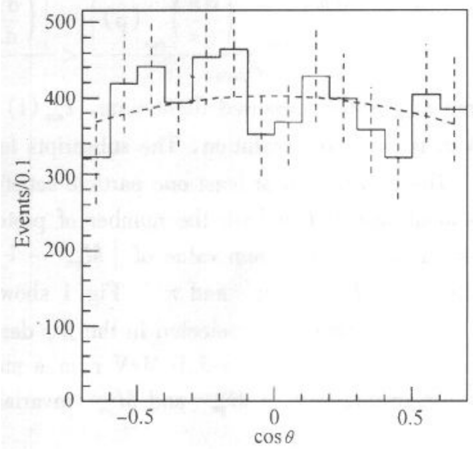

Fig. 4. The angular distribution for the decay $J/\psi \to \Sigma^0\bar{\Sigma}^0$. The curve is the fit described in the text.

642 $J/\psi \to \Sigma^0\bar{\Sigma}^0$ events are left by requiring $2.8 < E_{\Lambda\bar{\Lambda}} < 2.98$ GeV. The contaminations are estimated to be 1.0 % (using BES measurement of the branching ratio[8]) or 1.3 % (using the branching ratio given by PDG2000[11]) for the deca $J/\psi \to \Lambda\bar{\Lambda}$ and 2.3 % for the decay $J/\psi \to \Xi^0\bar{\Xi}^0$ based on Monte Carlo simulation respectively.

The detection efficiency for the signal events depends on the Λ direction. The Monte Carlo simulation shows that the detection efficiency of the BES detector drops rapidly for the region $|\cos\theta| > 0.7$, where θ is the angle between the Λ direction and positron beam. The efficiency corrected angular distribution for the Λ is shown in Fig.4 with the bin size equal to 0.1. Because the Λ is emitted from Σ^0 within a cone of 4 degree[7] in C.M. frame of J/ψ in the decay $J/\psi\to\Sigma^0\overline{\Sigma}^0$, the Λ angular distribution α is a good approximation to the Σ^0 angular distribution.

Fitting this angular distribution to the theoretical form[1—3]

$$\frac{dN}{d\cos\theta} = N_0(1+\alpha\cos^2\theta)$$

yields

$$\alpha = -0.21 \pm 0.27 \pm 0.13,$$

where 0.27 is the statistical error and 0.13 is the systematic error.

The total detection efficiency ε is obtained to be 8.45 %, which gives the branching ratio

$$BR(J/\psi\to\Sigma^0\overline{\Sigma}^0) = \frac{N}{\varepsilon N_{J/\psi}} = (0.97 \pm 0.04 \pm 0.24)\times 10^{-3},$$

where $N_{J/\psi} = 7.8\times(1\pm0.2)\times10^6$ is the total number of J/ψ events.

The systematic error 0.24 originates from the uncertainties caused by varing the cut conditions and the error of total number of J/ψ events. The contaminations from $J/\psi\to\Lambda\overline{\Lambda}$, $\Sigma^0\overline{\Sigma}^0$ are not subtracted from 642 events, which are also included in the systematic error of the branching ratio.

4 Conclusion and Discussion

Table 3 gives the branching ratio and α value measured by the BES for the decay $J/\psi\to\Sigma^0\overline{\Sigma}^0$ together with those previously reported by Mark Ⅱ and DM2.

The statistics of the events in BES measurement is close to that of DM2. The branching ratio obtained by this experiment is in agreement with that of DM2 within the error, while the shape of the angular distribution is somehow different from those of DM2 and MARK Ⅱ as shown in Table 3. The central α value is negative which is also different from the theoretical expectation[2,3].

Table 3. Experimental measurements of α and BR for $J/\psi\to\Sigma^0\overline{\Sigma}^0$ channel.

Detector	α	$BR(\times10^{-3})$	Events
MARK Ⅱ	0.70 ± 1.10	$1.58 \pm 0.16 \pm 0.25$	90
DM2	0.22 ± 0.31	$1.06 \pm 0.04 \pm 0.23$	884
BES	-0.21 ± 0.30	$0.97 \pm 0.04 \pm 0.24$	642

The reduced barching ratio $|M_B|^2$ is defined to be the branching ratio of $J/\psi\to B\overline{B}$ divided out the phase-space factor:

$$|M_B|^2 = \frac{BR(J/\psi\to B\overline{B})}{\pi p^*/\sqrt{s}},$$

where p^* is the momemtum of the final state particle B in the J/ψ rest frame. Using BES measured branching ratios reported in Ref.[8] and this paper, we give the $|M_B|^2$ values of 0.99 ± 0.23 and 0.97 ± 0.24 for $J/\psi\to\Lambda\overline{\Lambda}$ and $\Sigma^0\overline{\Sigma}^0$ respectively, which are consistent with the J/ψ being a pure $SU(3)_f$ singlet assumption.

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$J/\psi \to \Sigma^0 \overline{\Sigma}^0$ 衰变研究*

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摘要　利用北京正负电子对撞机（BEPC）上的北京谱仪（BES）收集的 7.8×10^6 个 J/ψ 事例，研究了 $J/\psi\to\Sigma^0\bar{\Sigma}^0$ 衰变．其衰变分支比为 $BR(J/\psi\to\Sigma^0\bar{\Sigma}^0)=(0.97\pm0.04\pm0.24)\times10^{-3}$，角分布具有 $\frac{dN}{d\cos\theta}=N_0(1+\alpha\cos^2\theta)$ 的形式，α 值等于 $-0.21\pm0.27\pm0.13$．

关键词　北京谱仪　J/ψ 粒子　Σ^0 粒子　角分布　分支比