Near threshold $p\bar{p}$ enhancement in the $J/\psi \rightarrow \omega p\bar{p}$ decay

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**Abstract**

The near-threshold behavior of the $p\bar{p}$ invariant mass spectrum from the $J/\psi \rightarrow \omega p\bar{p}$ decay reported recently by the BES Collaboration is analyzed. Our study demonstrates that there is indeed a clear enhancement in the $p\bar{p}$ invariant mass spectrum near threshold as compared to the phase-space behavior. Moreover, this enhancement is nicely reproduced by the final state interaction in the relevant $(^{13}_S0) p\bar{p}$ partial wave as given by the Jülich nucleon–antinucleon model. Therefore, contrary to the statement by the BES Collaboration, their new data on $J/\psi \rightarrow \omega p\bar{p}$ decay in fact strongly support the FSI interpretation of the $p\bar{p}$ enhancement, seen also in other decay reactions.

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tial waves in the $p\bar{p}$ system. In particular, near threshold the $p\bar{p}$ system can only be in the $^{11}S_0$ state. We use here the standard nomenclature $^{(2I+1)(2S+1)_{1/2}}L_J$ where $I$ and $S$ are the total isospin and spin, respectively. In contrast, for the extensively discussed $J/\psi \rightarrow \gamma p\bar{p}$ decay any combination of the $l = 0$ and $l = 1$ amplitudes is allowed because isospin is not conserved in electromagnetic processes.

Like in our earlier papers [16,17,26], besides the directly measured $p\bar{p}$ invariant mass spectrum, we utilize also the total spin-averaged (dimensionless) $J/\psi \rightarrow \omega p\bar{p}$ reaction amplitude $A$ because that allows us to get rid of trivial kinematical factors. The $J/\psi \rightarrow \omega p\bar{p}$ decay rate is given in terms of $A$ by [29]

$$d\Gamma = \frac{|A|^2}{2\pi^3 m_{J/\psi}^2} \lambda^{1/2}(M^2, m_p^2, m_{\omega}^2) \frac{1}{dM} d\Omega_p d\Omega_\omega,$$

where the Källén function $\lambda$ is defined by $\lambda(x, y, z) = ((x - y - z)^2 - 4yz)/4x$, $M \equiv M(pp)$ is the invariant mass of the $p\bar{p}$ system, $\Omega_p$ is the proton angle in that system, while $\Omega_\omega$ is the $\omega$ angle in the $J/\psi$ rest frame. After averaging over the spin states and integrating over the angles, the differential decay rate is

$$\frac{d\Gamma}{dM} = \frac{\lambda^{1/2}(m_{J/\psi}^2, M^2, m_{\omega}^2)\sqrt{M^2 - 4m_p^2}}{2^6\pi^3 m_{J/\psi}^2} |A|^2.$$  

We use Eq. (2) for extracting $|A|^2$ from the data of the BES Collaboration. The original data [28] are reproduced in Fig. 1 while the extracted values for $|A|^2$ are shown in Fig. 2.

We assume again the validity of the Watson–Migdal approach for the treatment of the FSI effect. It suggests that the reaction amplitude for a production and/or decay reaction that is of short-ranged nature can be factorized in terms of an elementary (basically constant) production amplitude and the $p\bar{p}$ scattering amplitude $T$ of the particles in the final state so that

$$A(M(p\bar{p})) \approx N \cdot T(M(p\bar{p})).$$

(cf. Ref. [16] for further details). Thus, we compare the extracted amplitude $|A|^2$ with the suitably normalized scattering amplitudes $|T|^2$ that result from the Jülich NN model [24] for the $^{11}S_0$ partial wave. Interestingly, that scattering amplitude reproduces the dependence of the experimental $|A|^2$ on the invariant mass almost perfectly in the near-threshold region, cf. the solid curve in Fig. 2. It should be noted that this result is actually a prediction of the model and not a fit. The dashed line represents a constant reaction amplitude and corresponds to the pure phase-space behavior. Obviously the BES data show a clear enhancement as compared to the phase-space behavior in the near-threshold region. This can be also seen from Fig. 1, where the measured $p\bar{p}$ mass spectrum is shown directly. The normalization of the phase space is done in the region $M(p\bar{p}) - 2m_p \approx 100–140$ MeV, where the data indeed follow the phase-space distribution. In principle, one could have also normalized the dashed curve to the lowest data points. Then the first four data points would still be roughly in line with a phase-space behavior, at least within the error bars, but one would end up with a gross overestimation of the data at higher invariant masses and, consequently, be in a situation that one sees and has to explain a suppression in the experimental data in that invariant-mass region.

The BES Collaboration describes the $p\bar{p}$ mass distribution with the polynomial $f(\varepsilon) = N\sqrt{\varepsilon(1 + a_1\varepsilon + a_2\varepsilon^2)}$ with $\varepsilon = M(p\bar{p}) - 2m_p$ (so that the first (constant) term corresponds to the phase-space behavior) and coefficients $a_1$, $a_2$ fitted to the data. The polynomial is meant to represent contributions of non-resonant $\omega p\bar{p}$ events and background, where the latter is suggested to come mainly from the decays of $J/\psi \rightarrow \pi^+\Lambda\Sigma^-\pi^0(\text{c.c.})$ and $\pi^0\Delta^+\Delta^-\pi^0$ as [28]. Since the data exhibit a significant dependence on $\varepsilon$ near the threshold, cf. Figs. 1 and 2, it is obvious that the polynomial likewise produces a significant dependence on the $p\bar{p}$ excess energy $\varepsilon$. Thus, we believe that this polynomial simply parameterizes the $p\bar{p}$ FSI effects. It would be hard to understand if any background, unrelated to the $p\bar{p}$ system, depends so strongly on the $p\bar{p}$ excess energy $\varepsilon$.

Note that the disagreement of our model results with the experiment for invariant masses beyond $M(p\bar{p}) - 2m_p \approx 100$ MeV is...
not a reason of concern and, in particular, does not discredit the interpretation of the data in terms of FSI effects. At those energies we expect that contributions from higher partial waves, not considered here, should start to play a more prominent role.

In summary, we have analyzed the near-threshold data on the $p\bar{p}$ invariant mass spectrum from the $J/\psi \rightarrow \omega p\bar{p}$ decay reported recently by the BES Collaboration. Our study demonstrates that not only in $J/\psi \rightarrow \gamma p\bar{p}$ but also in this reaction there is indeed a noticeable enhancement in the $p\bar{p}$ invariant mass spectrum near threshold as compared to the phase-space behavior. Moreover, this enhancement is nicely reproduced by the final state interaction in the relevant $(^3S_0)$ $p\bar{p}$ partial wave as given by the Jülich $NN$ model [24]. Accordingly, the present result is completely in line with our previous investigations of the $p\bar{p}$ invariant mass spectrum from the $J/\psi \rightarrow \gamma p\bar{p}$ decay [16] measured by the BES Collaboration and the $B^+ \rightarrow K^+ p\bar{p}$ decay [17] measured by the BaBar Collaboration [28], their new data on $J/\psi \rightarrow \omega p\bar{p}$ decay, in fact, strongly support the FSI interpretation of the $p\bar{p}$ enhancement seen in other decay reactions. It goes without saying that, the FSI effects for the various decay reactions should not be expected to be quantitatively the same because due to the different quantum numbers and conservation laws as well as different reaction mechanisms in those decay channels, the final $p\bar{p}$ system can and must be in different partial waves.

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