ANTIPROTON-PROTON RESONANT LIKE CHANNELS IN $J/\psi \rightarrow \gamma p\bar{p}$ DECAYS*

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The BES collaboration has recently observed a strong enhancement close to the proton-antiproton, $p\bar{p}$ threshold in the $J/\psi$ decays into $\gamma p\bar{p}$. Such a structure can be explained by a traditional nucleon-antinucleon, $NN$, model. The near threshold $^{11}S_0$ bound state and/or the well-established $^{13}P_0$ resonant state found in this $NN$ interaction can adequately describe the BES data.

Keywords: $p\bar{p}$ quasi-bound states; traditional $NN$ model; radiative $J/\psi$ decays.

1. Introduction

Existence of near threshold bound states or resonances in nucleon-antinucleon, $NN$, interaction is a challenging matter. Low-energy scattering could indicate the presence of such structures by determining the scattering lengths for $2I+1,2S+1,2J_1$ states. Here $I$ denotes the isospin (0 or 1), $S$ the spin (0 or 1), $L$ the angular momentum and $J$ the total angular momentum. An alternative is to use formation experiments. At the Beijing electron-positron collider, the BES collaboration has observed a resonant-like behavior in the $p\bar{p}$ invariant mass spectrum from radiative $J/\psi \rightarrow \gamma p\bar{p}$ decays. The present work studies the physics of slow $p\bar{p}$ pairs produced in $J/\psi$ decays, using $J^{PC}$ conservation, $P$ being the parity and $C$ the charge conjugation. Here we rely on the Paris $NN$ potential model.

2. Close to Threshold Proton-Antiproton Final State Model

2.1. The low-energy nucleon-antinucleon interaction

The Paris $NN$ interaction is built up from a state dependent optical potential. The long range, $r > 1$ fm, real part is obtained by $G$-parity transformation of the

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Paris $NN$ potential, the two-pion exchange of which is calculated via dispersion relations from pion-nucleon scattering data. The short ranges, $r < 1$ fm, real part and absorptive part, with a form suggested by calculation of $NN$ annihilation into two mesons or resonances, are both determined through fit to the $NN$ data. In the different versions, the short range parameters are readjusted by fitting to new data. The Paris 82 potential, fitted to pre-LEAR (CERN) data, mainly elastic $\bar{p}p$ (isospin 1 + isospin 0) data, has a $\chi^2$/data of 2.8 for 915 data. The Paris 94 potential uses LEAR data, in particular $\bar{p}p \to \bar{n}n$ ($I = 1 - I = 0$) data, and has a $\chi^2$/data of 2.46 for 3295 data. In the Paris 99 version, more recent LEAR data, in particular for $\bar{p}p \to \bar{n}n$, were used leading to a $\chi^2$/data of 2.95 for 3814 data. The Paris 04 model is constrained by fitting to the 1999 data plus the scattering lengths extracted from antiprotonic hydrogen and deuterium data and to the total $\bar{n}p$ cross-section. It has $\chi^2$/data = 3.19 for 3934 data.

2.2. Allowed slow $p\bar{p}$ final states

The $J^{PC}$ conservation ($J^{PC} = 1^{--}$ for $J/\psi$) limits the number of slow $p\bar{p}$ final states. These correspond to pairs of small $M_{p\bar{p}} - 2m_p$ with $M_{p\bar{p}}$ being the invariant $p\bar{p}$ mass and $m_p$ the proton mass. The allowed states are listed in Table 1. Some two-particle analogues are listed in the second column. The last column indicates the relative angular momentum between $\gamma$ or $\pi$ and the $p\bar{p}$ pair $h$. The BES experiment angular distribution favors a pseudoscalar $^1S_0$ or a scalar $^3P_0$ $h$ final state.

### Table 1. The slow $p\bar{p}$ pairs states permitted in the radiative $J/\psi \to \gamma p\bar{p}$.

| decay mode | analogue | $J^{PC}[\gamma or \pi]$ | $J^{PC}[p\bar{p}]$ | $h(p\bar{p})$ | relative $\ell$ |
|------------|----------|-------------------------|-------------------|---------------|----------------|
| $\gamma p\bar{p}(^1S_0)$ | $\gamma f(1444)$ | $1^{--}$ | $0^{--}$ | pseudoscalar | 1 |
| $\gamma p\bar{p}(^3P_0)$ | $\gamma f_0(1710)$ | $1^{--}$ | $0^{++}$ | scalar | 0 |
| $\gamma p\bar{p}(^3P_1)$ | $\gamma f_1(1825)$ | $1^{--}$ | $1^{++}$ | pseudovector | 0 |

2.3. Specific final-state interaction model

The transition amplitude from a channel $i$ to a channel $f$, in a multichannel system at low energy described by a S-wave K matrix, can be written as $T_{if} = A_{if}(1 + iq_f A_{ff})^{-1}$. Here $A_{if}$ is a transition length, $A_{ff}$ the scattering length in the channel $f$ and $q_f$ the momentum in this channel. The $f$ channel scattering amplitude can also be expressed as $T_{ff} = A_{ff}(1 + iq_f A_{ff})^{-1}$. For a P wave close to threshold, $A_{ff} = A^P_{ff}/q_f^2$ and $A_{if} = A^P_{if}/q_f^2$, where $A^P_{ff}$ is the scattering volume. Up to terms in $q_f^2$ one has $T_{if} = (A_{if}/A_{ff})T_{ff} = CT_{ff}/q_f^2 = Ct_L$. The quantity $C = A_{if}q_f^2/A_{ff}$ represents the unknown formation amplitude and $|t_L|^2 = |T_{ff}/q_f|^2$ is the final state interaction factor in a given $p\bar{p}$ partial wave. In terms of the phase shifts $\delta_L$ and inelasticities $\eta_L$ of a given $NN$ interaction one has $t_L = (\eta_L e^{2i\delta_L} - 1)/(2i q_f^{2L+1})$. The function $C$ is parametrized by $|C(x)|^2 = q_f(c_0 + c_1 x)$ where $x = M_{p\bar{p}} - 2m_p$ and $q_f = [x(m_p + x/4)]^{1/2}$. 

3. Results and Conclusions

The final state interaction factors $|t_L|^2$ for the $^1S_0$ and $^3P_0$ states and for the different versions of the Paris $NN$ are compared to the BES data$^{[2]}$ in Figs. 1 and 2. The $c_0$ and $c_1$ parameters are determined by requiring $|T_{if}|^2$ of Paris 04 to be close to the events distribution as given in Fig. 3 of Ref. 2 at $x = 7$ MeV and $x = 66.2$ MeV. For $^1S_0$, $c_0 = 1.18599$, $c_1 = 0.00299$ and for $^3P_0$, $c_0 = 2.5206$, $c_1 = 0.0269$. As seen in Fig. 1, the data is well reproduced by the Paris 04 $NN$ interaction. This interaction has a $^{11}S_0$ bound state located at $x = -4.8$ MeV and with a width $\Gamma$ of 52.5 MeV. Paris 99 has also a bound state at $x = -69$ MeV with $\Gamma = 46$ MeV. There are no bound states for Paris 94 or Paris 82. All Paris models have a $^{13}P_0$ resonance of mass $\sim 1876$ MeV and $\Gamma \sim 10$ MeV. They all reproduce the near threshold BES enhancement as seen in Fig. 2.

In conclusion, the near threshold $p\bar{p}$ enhancement seen in BES collaboration$^{[2]}$ can find a natural explanation from a traditional model of $\bar{p}p$ interaction. The $^{11}S_0$ bound state$^{[6]}$ needs confirmation. The well established $^{13}P_0$ resonance originates from the strong attraction of the one-pion exchange$^{[11]}$. Each of these states gives a reasonable representation of the BES radiative $J/\psi \rightarrow \gamma p\bar{p}$ decay data. They correspond to the S or P wave Breit Wigner resonance functions considered by BES collaboration in their fit to the data.$^{[3]}$

![Fig. 1. The $^1S_0$ final state factor compared to BES data$^{[2]}$](image-url)
Fig. 2. The $^3P_0$ final state factor compared to BES data.

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