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N-pole Effect in Studying N* via J/Ψ→N$\bar{N}$M Decays*

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Abstract: N-pole contributions, especially due to off-shell effect, in J/Ψ→ N$\bar{N}$M decays are carefully studied. It is found that the decay width is sensitive to the form factor. The N-pole contribution as a background is important in the J/Ψ→N$\bar{N}$π decay, ignorable in the J/Ψ→N$\bar{N}$η and N$\bar{N}$η′ decays, and sizable in the J/Ψ→N$\bar{N}$ω decay.

Key words: J/Ψ decay; nucleon excited state; form fovctor

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The nucleon spectrum provides us necessary information for revealing the structure of nucleon[1]. So far, most information on nucleon and its excited states comes from πN elastic and inelastic scattering data.

Up to now, many nucleon resonances have been found. Yet, still some theoretical predicted N* states have not been seen in the πN channel. Whether these so-called "missing resonances" couple weakly to the πN channel so that we should propose other means to search them? Or, if the quark model predicts too many resonances so that the model itself should further be modified? Or, there may exist the hybrid structure or the diquark structure? All these puzzles motivate intensive investigations in both experimental side and the theoretical side[2].

In recent years, 58 million J/Ψ events at BEPC provide an excellent source to study light baryon resonances via a two-stepprocess J/Ψ → N* $\bar{N}$→ MN$\bar{N}$ with many advantages[3]. The corresponding Feynman diagrams are shown in Fig. 1. It is clear that the nucleon-pole diagrams, namely, the intermediate state is nucleon, would also contribute as a background in such a N* study[4].

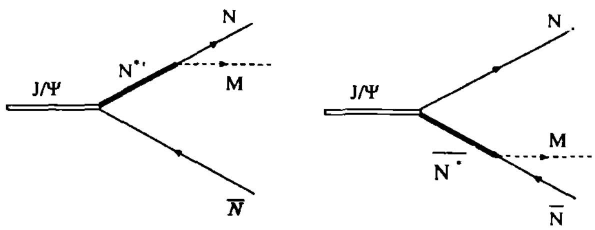

Fig. 1 N*-pole diagrams for J/Ψ→ MN$\bar{N}$ decay.

Pion as a pseudoscalar meson is studied in the J/Ψ→N$\bar{N}$$M_{PS}$ process in the first step. Generally, the J/Ψ→N$\bar{N}$ interaction can be written as

$$H_{\Psi} = \bar{N}[F_M \gamma^{\mu} + \frac{1}{2m} F_0 (p - p')^{\mu}]\, N\, \varepsilon_{\mu}(P_{\Psi}) \,. \quad (1)$$

Two forms of pion-nucleon interaction

$$H_1 = i g_{NN\pi} \bar{N} \gamma_5 \boldsymbol{\tau} N \boldsymbol{\pi}, \text{ (PS-PS)}$$

and

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Biography: Shen Pengnian(1944—), male(Han Nationality), Shanghai, Professor, working on hadron physics, B-B interaction in quark model, NPQCD effect in nucleus.

$$H_1' = \frac{1}{2m} g_{NN\pi} \bar{N} \gamma_5 \gamma_\mu \boldsymbol{\tau} N \partial^\mu \boldsymbol{\pi}, \text{ (PS-PV)} \quad (2)$$

are widely employed in literatures[4]. It can easily be proved that when the intermediate nucleon is on-shell, the decay amplitudes in the PS-PS and PS-PV coupling cases are exactly the same, while the intermediate nucleon goes to off-shell, the decay amplitude in the PS-PS coupling case still remains the same as that in the on-shell case $\mathcal{M}_{PS}$, but has additional terms in the PS-PV coupling case

$$\mathcal{M}_{PV}^{off} = \frac{i g_{NN\pi}}{2m} F_0 \bar{u}(p)\,(p-p')^\mu \varepsilon_\mu \gamma_5 v(p') + \mathcal{M}_{PS} = \mathcal{M}_{PV}, \quad (3)$$

namely, the decay amplitude would receive contributions not only from the on-shell intermediate nucleon, but also from the off-shell one. Our numerical results show that if one takes $|F_0|/|F_M| = 0.12$, the branching ratio (BR) of $\Gamma(J/\Psi\to p\bar{p}\pi^0)/\Gamma(J/\Psi\to p\bar{p})$ is 0.563 in the PS-PS case and 0.529 in the PS-PV case. They are very close to the empirical value of 0.51 ± 0.04[5].

However, the nucleon has inner quark-gluon structure. Due to difficulties in dealing with nonperturbative QCD (NPQCD) effects, hadronic form factor is commonly adopted at the meson-baryon-baryon (MBB′) vertex phenomenologically.

The most commonly used form factors for meson-nucleon-nucleon vertex are[6].

$$F_1(q^2) = \frac{\Lambda^2 + m^2}{\Lambda^2 + q^2},$$
$$F_2(q^2) = \frac{\Lambda^4 + m^4}{\Lambda^4 + q^4},$$
$$F_3(q^2) = e^{-|q^2 - m^2|/\Lambda^2},$$
$$F_4(q^2) = \frac{1}{1 + (q^2 - m^2)^2/\Lambda^4},$$
$$F_5(q^2) = e^{-(q^2 - q_0^2)/\Lambda^2}. \quad (4)$$

Then, one can easily derive the decay amplitude in the PS-PS and PS-PV coupling cases,

$$\mathcal{M}'_{PV} = \frac{i g_{NN\pi}}{2m} \bar{u}(p)\,\{F_M[F^2(q^2) - F^2(q'^2)]\,\not{\varepsilon} + \frac{F_0}{m}[F^2(q'^2)\,(p\cdot\varepsilon) - F^2(q^2)\,(p'\cdot\varepsilon)]\}\gamma_5 v(p') + \mathcal{M}'_{PS},$$

$$\mathcal{M}'_{PS} = i\, g_{NN\pi}\, \bar{u}(p)\gamma_5 \Big[F_M\Big(\frac{\not{k}\not{\varepsilon}}{2p\cdot k + k^2} F^2(q^2) - \frac{\not{\varepsilon}\not{k}}{2p'\cdot k + k^2} F^2(q'^2)\Big) + \frac{F_0}{m}\not{k}\Big(\frac{p\cdot\varepsilon}{2p'\cdot k + k^2} F^2(q'^2) - \frac{p'\cdot\varepsilon}{2p\cdot k + k^2} F^2(q^2)\Big)\Big] v(p'), \quad (5)$$

respectively. The resultant BRs are shown in Table 1. It is seen that the difference between $\Gamma_{PV}(J/\Psi\to p\bar{p}\pi^0)$ and $\Gamma_{PS}(J/\Psi\to p\bar{p}\pi^0)$ is generally larger

Table 1　The BR of $\Gamma(J/\Psi\to p\bar{p}\pi^0)/\Gamma(J/\Psi\to p\bar{p})$ (%) with various form factors.

F. F.	πN coupling	Λ=0.65 GeV	Λ=1.0 GeV	Λ=1.5 GeV	Λ=2.0 GeV
F_1	PS	3.95(3.73~4.18)	6.81(6.45~7.20)	12.69(12.05~13.38)	19.35(18.40~20.37)
	PV	2.79(2.77~2.82)	5.04(5.01~5.07)	9.96(9.91~9.98)	15.89(15.83~15.91)
F_2	PS	0.34(0.32~0.37)	1.23(1.15~1.31)	7.21(6.82~7.64)	19.64(18.66~20.71)
	PV	0.20(0.19~0.21)	0.76(0.75~0.78)	5.07(5.02~5.11)	15.50(15.45~15.53)
F_3	PS	0.07(0.06~0.07)	1.09(1.02~1.16)	5.83(5.51~6.18)	13.29(12.61~14.02)
	PV	0.04(0.03 ~0.04)	0.66(0.64~0.68)	4.07(4.03~4.10)	10.23(10.18~10.25)
F_4	PS	0.23(0.22~0.25)	3.35(3.15~3.58)	15.03(14.23~15.89)	29.70(29.68~31.26)
	PV	0.13(0.12~0.13)	2.08(2.04~2.14)	10.98(10.92~11.04)	24.30(24.23~24.31)
F_5	PS	2.39(2.25~2.54)	10.25(9.71~10.83)	23.91(22.75~25.16)	34.01(32.40~35.72)
	PV	2.33(2.16~2.81)	9.28(9.37~9.33)	21.98(22.12~21.85)	31.57(31.63~31.44)

than that in the without form factor case. This indicates that introducing a form factor would suppress the contribution at the large momentum transfer region, and consequently, would reduce the N-pole contribution. The numerical results also show that the BRs with different form factor and same Λ value are quite different. In general, a larger Λ value would result in a smaller BR, but large BR difference between the PS-PS and PS-PV cases. Moreover, for a specific form of form factor, the BR becomes larger when a larger value of Λ is taken. However, if one employs a form factor whose momentum dependence is similar to that in the $J/\Psi \to N\bar{N}\pi$ case and whose Λ value has well been determined by the π-N scattering or the pion photoproduction[7], the resultant BR is in the range of 0.08 —0.097, which still present a visible difference.

The corresponding BRs for $\Gamma(J/\Psi \to p\bar{p}\eta) / \Gamma(J/\Psi \to p\bar{p})$ and $\Gamma(J/\Psi \to p\bar{p}\eta') / \Gamma(J/\Psi \to p\bar{p})$ with no form factors considered are generally in the range of 10^{-4}—10^{-5}. If the form factor is considered, the resultant BR would be a few orders smaller. Comparing with the empirical data of $\Gamma(J/\Psi \to p\bar{p}\eta) / \Gamma(J/\Psi \to p\bar{p}) = 0.98 \pm 0.09$ and $\Gamma(J/\Psi \to p\bar{p}\eta') / \Gamma(J/\Psi \to p\bar{p}) = 0.42 \pm 0.19$[5], one finds that the calculated BRs are all smaller than 0.1% of the data.

If M is a vector meson, say ω, due to relative weaker tensor coupling, we only keep the vector coupling in the $J/\Psi \to p\bar{p}\omega$ calculation

$$H'_{\omega NN} = g_{\omega NN}\bar{N}(x)\gamma^{\alpha}N(x)\omega_{\alpha}(x)\ . \qquad (6)$$

Then, the decay amplitude of $J/\Psi \to p\bar{p}\omega$ with form factor reads

$$\begin{aligned}\mathcal{M} = {} & g_{\omega pp}\bar{u}(p,s)\cdot \\ & \left\{F_M\left[\frac{2p\cdot e+\not{e}\not{k}}{2p\cdot k+k^2}F^2(q^2)\not{\epsilon}-\right.\right. \\ & \left.\not{\epsilon}\frac{2p'\cdot e+\not{k}\not{e}}{2p'\cdot k+k^2}F^2(q'^2)\right]- \\ & \frac{F_0}{m}\left[(p'\cdot\varepsilon)\frac{2p\cdot e+\not{e}\not{k}}{2p\cdot k+k^2}F^2(q^2)+\right. \\ & \left.\left.(p\cdot\varepsilon)\frac{2p'\cdot e+\not{k}\not{e}}{2p'\cdot k+k^2}F^2(q'^2)\right]\right\}v(p',s')\ . \qquad (7)\end{aligned}$$

Comparing with the BR data of 0.61 ± 0.12 in PDG[5], we find that the resultant BRs are generally less than 10% of the data.

As a conclusion, in studying N^* via $J/\Psi \to p\bar{p}\pi^0$ decay, the N-pole contribution is about 10%—20% of the data, so that the N-pole diagram contribution must be accounted. In the $J/\Psi \to p\bar{p}\eta$ and $p\bar{p}\eta'$ processes, the proton-pole contribution is tiny compared with the data, so can safely be ignored. In the $J/\Psi \to p\bar{p}\omega$ decay, the proton-pole contribution is less than 10% of the data, thus the N-pole contribution should carefully be considered in extracting N^* properties.

References:

[1] Burkert V D. Nucl Phys, 1997, **A623**: 59c.

[2] Capstick S, Page P R. Phys Rev, 1999, **D60**: 111 501; Capstick S, Roberts W. Prog Part Nucl Phys, 2000, **45**: S241.

[3] Zou B S. Nucl Phys, 2000, **A675**: 167.

[4] Sinha R, Okubo S. Phys Rev, 1984, **D30**: 2 333.

[5] Particle Data Group. Euro Phys J, 2000, **C15**: 1.

[6] Liang W H, Shen P N, Zou B S. to be appaered in Euro Phys J, 2004.

[7] Oh Y, Titov A I, Lee T S H. Phys Rev, 2001, **C63**: 25 201.

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Study on Roper Structure as Hybrid from J/Ψ Decays*

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Abstract: The structure of Roper resonance is studied as hybrid states through decays $J/\Psi\to p\bar{N}^*$, $N^*\bar{N}^*$ by calculating the angular distributions and decay widths. The results show that the angular distribution parameters for decays $J/\Psi\to p\bar{N}^*$, $N^*\bar{N}^*$ are almost equal if the Roper is identified as a pure hybrid state, while their decay width are less the 1% of that for the decay $J/\Psi\to p\bar{p}$, and the variance of the ratio $\Gamma(J/\Psi\to N^*p)/\Gamma(J/\Psi\to p\bar{p})$ and $\Gamma(J/\Psi\to N^*\bar{N}^*)/\Gamma(J/\Psi\to p\bar{p})$ with the mixing parameter are presented, and also the scheme to identify the Roper structure in J/Ψ decays is discussed.

Key words: Roper structure; hybrid; J/Ψ

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通过 $J/\Psi\to N\bar{N}M$ 衰变研究 N^* 时的核子极点效应*

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摘　要：研究了 $J/\Psi\to p\bar{p}\pi$ 衰变过程中核子极点图的贡献，特别是由离壳效应带来的贡献. 发现衰变宽度对形状因子是敏感的. 在通过用 $J/\Psi\to p\bar{p}\pi$ 衰变研究 N^* 时，核子极点图作为背景道的贡献是非常重要的；在通过 $J/\Psi\to p\bar{p}\eta$ 和 $p\bar{p}\eta$ 研究 N^* 时，核子极点图的贡献可忽略不计；在通过 $J/\Psi\to p\bar{p}\omega$ 研究 N^* 时，核子极点图有明显的贡献.

关 键 词：J/Ψ 衰变；核子激发态

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