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Towards the decays of $\bar{\mathrm{N}}_X(1625)$ in the molecular picture*

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Abstract In this talk, we firstly overview the experimental status of $\bar{\mathrm{N}}_X(1625)$, which is an enhancement structure observed in $\mathrm{K}^-\bar{\Lambda}$ invariant mass spectrum of $\mathrm{J}/\psi\to\mathrm{pK}^-\bar{\Lambda}$ process. Then we present the result of the decay of $\bar{\mathrm{N}}_X(1625)$ under the two molecular assumptions, i.e. S-wave $\bar{\Lambda}\mathrm{K}^-$ and S-wave $\bar{\Sigma}^0\mathrm{K}^-$ molecular states. Several experimental suggestions for $\bar{\mathrm{N}}_X(1625)$ are proposed.

Key words molecular state, strong decay, rescattering mechanism

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1 Introduction

J/ψ decay is an ideal platform for studying the excited baryons and hyperons. With the collected data, the BES experiment has carried out a series of investigations of hadron spectroscopy. Among the new observations of the hadron states, $\bar{\mathrm{N}}_X(1625)$ is an enhancement near $\mathrm{K}^-\bar{\Lambda}$ threshold, which was only reported in several conference proceedings[1—3] under the investigation of $\mathrm{K}^-\bar{\Lambda}$ invariant mass spectrum in $\mathrm{J}/\psi\to\mathrm{pK}^-\bar{\Lambda}$ process. The rough measurement results about the mass and the width of $\bar{\mathrm{N}}_X(1625)$ are m =1500—1650 MeV and Γ =70—110 MeV, respectively. The experiment also indicates that the spin-parity favors $\frac{1}{2}^-$ for $\mathrm{N}_X(1625)$, which denotes the antiparticle of $\bar{\mathrm{N}}_X(1625)$[3]. The $\mathrm{pK}^-\bar{\Lambda}$ Dalitz plot and $\mathrm{K}^-\bar{\Lambda}$ invariant mass spectrum are shown in Figs. 1 and 2. $\mathrm{N}_X(1625)$ enhancement structure was not observed in $\gamma\mathrm{p}\to\mathrm{K}^+\Lambda$ process at SAPHIR[4].

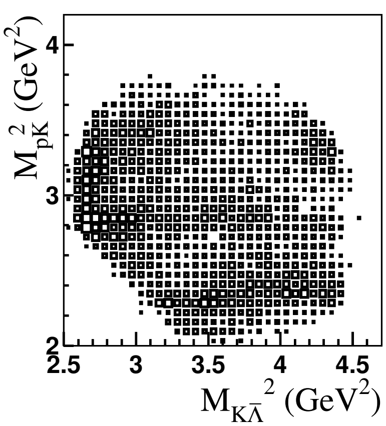

Fig. 1. The Dalitz plot of $\mathrm{J}/\psi\to\mathrm{pK}^-\bar{\Lambda}$ in Ref. [3].

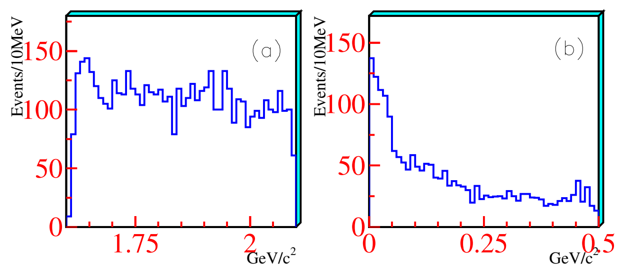

Fig. 2. The invariant mass spectrum (a) $M_{\mathrm{K}^-\bar{\Lambda}}$ from $\mathrm{J}/\psi\to\mathrm{pK}^-\bar{\Lambda}$ and (b) the $M_{\mathrm{K}^-\bar{\Lambda}}-M_{\mathrm{K}^-}-M_{\bar{\Lambda}}$ after the efficiency and phase space correction from Ref. [3].

At Hadron 07 conference, the BES Collaboration reported the preliminary new experiment result of $\bar{\mathrm{N}}_X(1625)$. Its mass and width are well determined as[5]

$$m=1625^{+5+13}_{-7-23}\ \mathrm{MeV},\ \Gamma=43^{+10+28}_{-7-11}\ \mathrm{MeV},$$

respectively. The production rate of $\bar{\mathrm{N}}_X(1625)$ is

$$B[\mathrm{J}/\psi\to\mathrm{p}\bar{\mathrm{N}}_X(1625)]\cdot B[\bar{\mathrm{N}}_X(1625)\to\mathrm{K}^-\bar{\Lambda}]=(9.14^{+1.30+4.24}_{-1.25-8.28})\times10^{-5}.$$

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These more accurate experimental information of $\bar{\mathrm{N}}_X(1625)$ provides us good chance to study the nature of $\bar{\mathrm{N}}_X(1625)$.

If $\bar{\mathrm{N}}_X(1625)$ is a regular baryon, the branching ratio of $\mathrm{J}/\psi \to \mathrm{p}\bar{\mathrm{N}}_X(1625)$ should be comparable with that of $\mathrm{J}/\psi \to \mathrm{p}\bar{\mathrm{p}}$ considering the branching ratio $B(\mathrm{J}/\psi \to \mathrm{p}\bar{\mathrm{p}}) = 2.17\times10^{-3}$[6]. Thus, we can obtain $B[\bar{\mathrm{N}}_X(1625) \to \bar{\Lambda}\mathrm{K}^-] \sim 10\%$, which indicates that there exists the strong coupling between $\bar{\mathrm{N}}_X(1625)$ and $\mathrm{K}^-\bar{\Lambda}$.

This peculiar property of $\bar{\mathrm{N}}_X(1625)$ inspires our interest in exploring its structure, especially in its exotic component. In Ref. [7], we calculated the possible decay modes of $\bar{\mathrm{N}}_X(1625)$ in the two different assumptions of the molecular states, i.e. $\bar{\Lambda}-\mathrm{K}^-$ and $\bar{\Sigma}^0-\mathrm{K}^-$. In the following, we will present the details of the calculation and the numerical result.

2 The decays under the assumptions of $\bar{\Lambda}-\mathrm{K}^-$ and $\bar{\Sigma}^0-\mathrm{K}^-$ molecular states

Since the mass of $\bar{\mathrm{N}}_X(1625)$ is above the threshold of $\bar{\Lambda}$ and K^- under the assumptions of $\bar{\Lambda}-\mathrm{K}^-$ molecular state, thus $\bar{\mathrm{N}}_X(1625)$ can directly decay into $\bar{\Lambda}+\mathrm{K}^-$ (Fig. 3 (a)), which is depicted by the decay amplitude

$$\mathcal{M}[\bar{\mathrm{N}}_X(1625)\to\bar{\Lambda}+\mathrm{K}^-] = \mathrm{i}\mathcal{G}\bar{v}_{\mathrm{N}}\gamma_5 v_{\bar{\Lambda}}. \quad (1)$$

Here $\mathcal{G}$ denotes the coupling constant between $\bar{\mathrm{N}}_X(1625)$ and $\bar{\Lambda}\mathrm{K}^-$. $v_{\bar{\Lambda}}$ and v_{N} are the spinors.

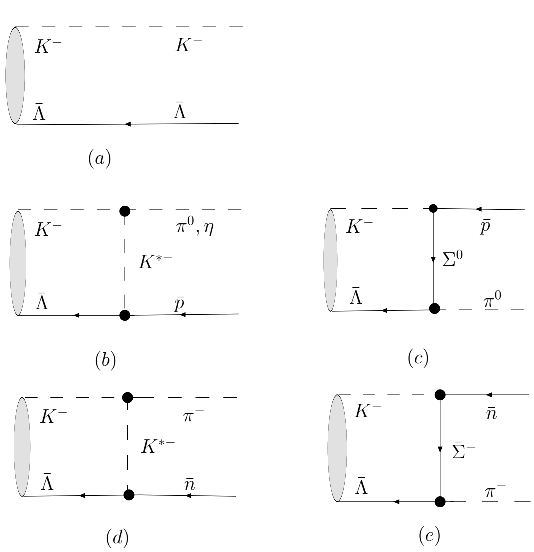

Fig. 3. The decay modes if $\bar{\mathrm{N}}_X(1625)$ is $\bar{\Lambda}-\mathrm{K}^-$ molecular state.

In the rescattering mechanism, the subordinate decays $\bar{\mathrm{N}}_X(1625) \to \pi^0\bar{\mathrm{p}}$, $\eta\bar{\mathrm{p}}$, $\pi^-\bar{\mathrm{n}}$ occur, which are depicted in Fig. 3(c)—(e). The effective Lagrangians relevant to the calculation are[8, 9]:

$$\mathcal{L}_{\mathcal{PPV}} = -\mathrm{i}g_{\mathcal{PPV}}\mathrm{Tr}\big([\mathcal{P},\partial_\mu\mathcal{P}]\mathcal{V}^\mu\big), \quad (2)$$

$$\mathcal{L}_{\mathcal{BBP}} = F_P\mathrm{Tr}\big(\mathcal{P}[\mathcal{B},\bar{\mathcal{B}}]\big)\gamma_5 + D_P\mathrm{Tr}\big(\mathcal{P}\{\mathcal{B},\bar{\mathcal{B}}\}\big)\gamma_5, \quad (3)$$

$$\mathcal{L}_{\mathcal{BBV}} = F_V\mathrm{Tr}\big(\mathcal{V}^\mu[\mathcal{B},\bar{\mathcal{B}}]\big)\gamma_\mu + D_V\mathrm{Tr}\big(\mathcal{V}^\mu\{\mathcal{B},\bar{\mathcal{B}}\}\big)\gamma_\mu, \quad (4)$$

where $\bar{B}$ is the Hermitian conjugate of B. $\mathcal{P}$, $\mathcal{V}$ and B respectively denote the octet pseudoscalar meson, the nonet vector meson and the baryon matrices. F_P and D_P in Eq. (3) and F_V and D_V in Eq. (4) satisfy the relations $F_P/D_P = 0.6$[10] and $F_V/(F_V+D_V) = 1$[11]. In the limit of $SU(3)$ symmetry, by $g_{\mathrm{NN}\pi} = 13.5$ and $g_{\mathrm{NN}\rho} = 3.25$[12], one obtains the meson-baryon coupling constants relevant to our calculation: $g_{PPV} = 6.1$, $F_P = 13.5$, $D_P = 0$, $F_V = 1.2$, $D_V = 2.0$.

Since the intermediate states $\bar{\Lambda}$ and K^- in Fig. 3(b)—(d) are on-shell, one writes out the general amplitude expression corresponding to Fig. 3 (b) and (d) by Cutkosky cutting rules

$$\begin{aligned}\mathcal{M}_1^{(\mathcal{A}_1,\mathcal{C}_1)} = {} & \frac{1}{2}\int\frac{\mathrm{d}^3p_1}{(2\pi)^3 2E_1}\frac{\mathrm{d}^3p_2}{(2\pi)^3 2E_2}\times \\ & (2\pi)^4\delta^4(M_{\mathrm{N}}-p_1-p_2)[\mathrm{i}\mathcal{G}\bar{v}_{\mathrm{N}}\gamma_5 v_{\bar{\Lambda}}]\times \\ & [\mathrm{i}g_1\bar{v}_{\bar{\Lambda}}\gamma_\mu v_{\mathcal{A}_1}][\mathrm{i}g_2(p_1+p_3)_\nu]\frac{\mathrm{i}}{q^2-M^2_{\mathcal{C}_1}}\times \\ & \Big[-g^{\mu\nu}+\frac{q^\mu q^\nu}{M^2_{\mathcal{C}_1}}\Big]\mathcal{F}^2(M_{\mathcal{C}_1},q^2). \end{aligned} \quad (5)$$

For Fig. 3(c) and (e), the general amplitude expression is

$$\begin{aligned}\mathcal{M}_1^{(\mathcal{A}_2,\mathcal{C}_2)} = {} & \frac{1}{2}\int\frac{\mathrm{d}^3p_1}{(2\pi)^3 2E_1}\frac{\mathrm{d}^3p_2}{(2\pi)^3 2E_2}\times \\ & (2\pi)^4\delta^4(M_{\mathrm{N}}-p_1-p_2)[\mathrm{i}\mathcal{G}\bar{v}_{\mathrm{N}}\gamma_5 v_{\bar{\Lambda}}]\times \\ & [\mathrm{i}g_2'\bar{v}_{\bar{\Lambda}}\gamma_5]\frac{\mathrm{i}(\not{q}+M_{\mathcal{C}_2})}{q^2-M^2_{\mathcal{C}_2}}[\mathrm{i}g_1'\gamma_5 v_{\mathcal{A}_2}]\times \\ & \mathcal{F}^2(M_{\mathcal{C}_2},q^2). \end{aligned} \quad (6)$$

In the above expressions, $\mathcal{C}_i$ and $\mathcal{A}_i$ denote the exchanged particle and the final state baryon, respectively. p_1 and p_2 are respectively the four momenta of K^- and $\bar{\Lambda}$. $\mathcal{F}^2(m_i,q^2)$ denotes the form factor which compensates the off-shell effects of the hadrons at the vertices. In this work, one takes $\mathcal{F}^2(m_i,q^2)$ as the monopole form[13,14] $\mathcal{F}^2(m_i,q^2) = \left(\frac{\xi^2-m_i^2}{\xi^2-q^2}\right)^2$, which plays the role to cut off the end effect. Phenomenological parameter ξ is parameterized as $\xi = m_i + \alpha\Lambda_{\mathrm{QCD}}$, where m_i denotes the mass of exchanged meson[15] and $\Lambda_{QCD} = 220$ MeV. α is a phenomenological parameter and is of order unity.

In the $\bar{\Sigma}^0 - K^-$ molecular picture, $\bar{N}_X(1625)$ does not decay into $\bar{\Sigma}^0$ and K^- because of having not enough phase space. However, decay $\bar{N}_X(1625) \to \bar{\Lambda} + K^-$ occurs by the isospin violation effect, which results in the mixing of Σ^0 with Λ[15] (Fig. 4 (a)). By the Lagrangian

$$\mathcal{L}_{mixing} = g_{mixing}(\bar{\psi}_{\Sigma^0}\psi_\Lambda + \bar{\psi}_\Lambda\psi_{\Sigma^0}),$$

with the coupling constant $g_{mixing} = 0.5 \pm 0.1$ MeV determined by QCD sum rule[15], one writes out the decay amplitude

$$\mathcal{M}[\bar{N}_X(1625) \to \bar{\Sigma}^0 + K^-] = \mathcal{G}\, g_{mixing}\, \bar{v}_N \gamma_5 \frac{i}{\not{p} - M_\Lambda} v_{\bar{\Lambda}}, \quad (7)$$

where p and M_Λ are the four momentum and the mass of $\bar{\Lambda}$, respectively.

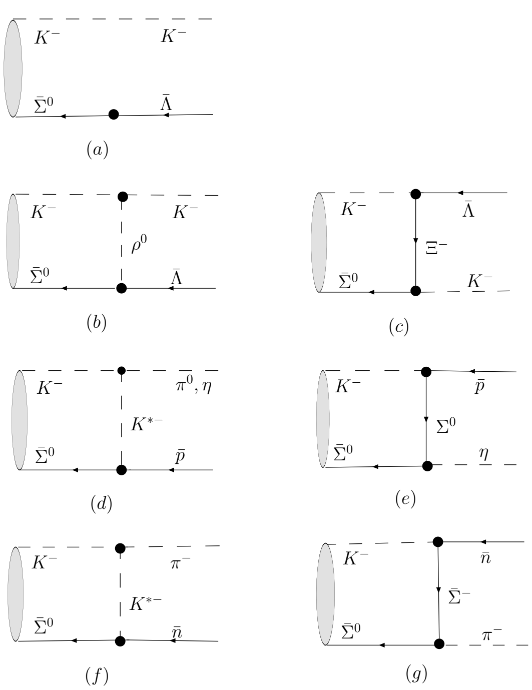

Fig. 4. The decay modes if $\bar{N}_X(1625)$ is $\bar{\Sigma}^0$–K^- molecular state.

For $\bar{\Sigma}^0$–K^- molecular state assumption, $\bar{N}_X(1625)$ still can decay into $\pi^0\bar{p}, \eta\bar{p}, \pi^-\bar{n}$, which are described in Fig. 4(b)—(g). The general expression of Fig. 4(b), (d), (f) is expressed as

$$\mathcal{M}_3^{(\mathcal{A}_3,\mathcal{C}_3)} = \int \frac{d^4q}{(2\pi)^4}[i\mathcal{G}\bar{v}_N\gamma_5]\frac{i}{-\not{p}_2 - M_{\bar{\Sigma}^0}}[ig_3\gamma_\mu v_{\mathcal{A}_3}] \times [ig_4(p_1+p_3)_\nu]\frac{-ig^{\mu\nu}}{q^2 - M_{\mathcal{C}_3}^2}\frac{i}{p_1^2 - M_K^2} \times \mathcal{F}^2(M_{\mathcal{C}_3}, q^2), \quad (8)$$

for Fig. 4(c), (e), (g) the general amplitude expression reads as

$$\mathcal{M}_4^{(\mathcal{A}_4,\mathcal{C}_4)} = \int \frac{d^4q}{(2\pi)^4}[i\mathcal{G}\bar{v}_N\gamma_5]\frac{i(\not{p}_2 - M_{\bar{\Sigma}^0})}{-p_2^2 - M_{\bar{\Sigma}^0}^2}[ig_4'\gamma_5] \times \frac{i(\not{q} + M_{\mathcal{C}_4})}{q^2 - M_{\mathcal{C}_4}^2}[ig_3'\gamma_5 v_{\mathcal{A}_4}] \times \frac{i}{p_1^2 - M_K^2}\mathcal{F}^2(M_{\mathcal{C}_4}, q^2), \quad (9)$$

where p_1 and p_2 denote the four momenta carried by K^- and $\bar{\Sigma}^0$, respectively. $q = p_1 - p_3 = p_4 - p_2$. For the decays depicted in Fig. 4(b)—(g), $\bar{\Sigma}^0$ and K^- are off-shell. The form factor may provide a convergent behavior for the triangle loop integration, which is very similar to the case of the Pauli-Villas renormalization scheme[16—18].

3 Numerical result

In Figs. 5 and 6, we show the ratios of the decay widths of $\bar{N}_X(1625) \to \pi^0\bar{p}$, $\eta\bar{p}$, $\pi^-\bar{n}$ to the decay width of $\bar{N}_X(1625) \to \bar{\Lambda}K^-$ under the assumptions of $\bar{\Lambda} - K^-$ and $\bar{\Sigma}^0 - K^-$ molecular states when taking $\alpha = 1$—3. Fig. 5 and Fig. 6 illustrate that these ratios do not strongly depend on the α. One further obtains the typical values of these ratios taking $\alpha = 1.5$, which are listed in Table 1. Combining these ratios shown in Figs. 5 and 6 with the branching ratio $B[J/\psi \to p\bar{N}_X(1625)] \cdot B[\bar{N}_X(1625) \to K^-\bar{\Lambda}] = (9.14^{+1.30+4.24}_{-1.25-8.28}) \times 10^{-5}$ given by BES[5], one estimates the branching ratio of the subordinate decays of $J/\psi \to p\bar{N}_X(1625) \to p(\pi^0\bar{p}), p(\eta\bar{p}), p(\pi^-\bar{n})$, which are shown in Table 2.

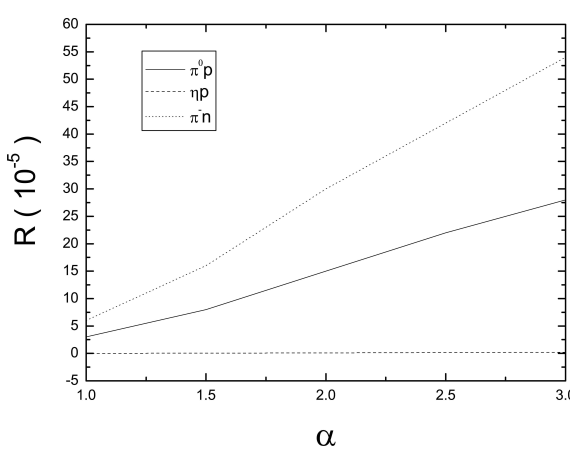

Fig. 5. The ratios of $\bar{N}_X(1625) \to \pi^0\bar{p}, \eta\bar{p}, \pi^-\bar{n}$ decay widths to $\bar{N}_X(1625) \to \bar{\Lambda}K^-$ decay width under the assumption of $\bar{\Lambda} - K^-$ molecular state.

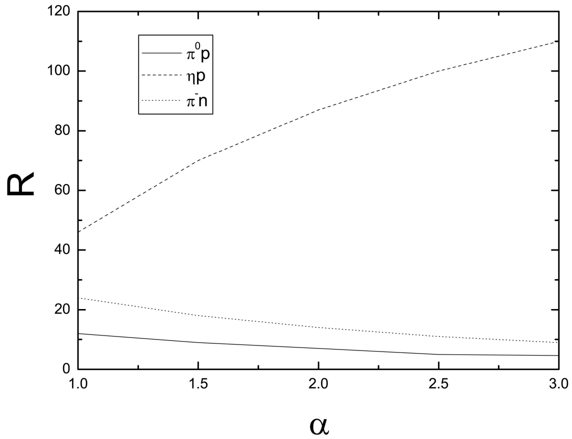

Fig. 6. The ratios of $\bar{N}_X(1625) \to \pi^0\bar{p}, \eta\bar{p}, \pi^-\bar{n}$ decay widths to $\bar{N}_X(1625) \to \bar{\Lambda}K^-$ decay width in $\bar{\Sigma}^0 - K^-$ molecular state picture.

Table 1. The ratios of the decay widths of $\bar{N}_X(1625) \to \pi^0\bar{p}$, $\eta\bar{p}$, $\pi^-\bar{n}$ to the decay width of $\bar{N}_X(1625) \to \bar{\Lambda}K^-$ in different molecular assumptions with $\alpha = 1.5$.

	$\frac{\Gamma(\pi^0\bar{p})}{\Gamma(K^-\bar{\Lambda})}$	$\frac{\Gamma(\eta\bar{p})}{\Gamma(K^-\bar{\Lambda})}$	$\frac{\Gamma(\pi^-\bar{n})}{\Gamma(K^-\bar{\Lambda})}$
$\bar{\Lambda} - K^-$	1×10^{-4}	5×10^{-7}	2×10^{-4}
$\bar{\Sigma}^0 - K^-$	9	70	18

4 Discussion and conclusion

Assuming $\bar{N}_X(1625)$ as $\bar{\Lambda} - K^-$ molecular state, $K^-\bar{\Lambda}$ is the dominant decay mode of $\bar{N}_X(1625)$. The branching ratio of $\bar{N}_X(1625) \to K^-\bar{\Lambda}$ is far larger than the branching ratios of $\bar{N}_X(1625) \to \pi^0\bar{p}, \eta\bar{p}, \pi^-\bar{n}$, which can explain why $\bar{N}_X(1625)$ was firstly observed in the mass spectrum of $K^-\bar{\Lambda}$. And we notice that the smallest measurable branching ratio for J/ψ decay listed in the Particle Data Book[6] is about 10^{-5}. Thus, it is difficult to measure $J/\psi \to p\bar{N}_X(1625) \to p(\pi^0\bar{p}), p(\eta\bar{p}), p(\pi^-\bar{n})$ in further experiments.

Under the assumption of S-wave $\bar{\Sigma}^0 - K^-$ molecular state for $\bar{N}_X(1625)$, $\bar{N}_X(1625)$ can not decay to $\bar{\Sigma}^0K^-$ due to having not enough phase space. The $\Lambda - \Sigma^0$ mixing mechanism and final state interaction effect result in the decay $\bar{N}_X(1625) \to \bar{\Lambda}K^-$. The branching ratio of $\bar{N}_X(1625) \to \bar{\Lambda}K^-$ is about one or two order smaller than that of $\bar{N}_X(1625) \to \pi^0\bar{p}, \eta\bar{p}, \pi^-\bar{n}$. The sum of the branching ratios of $\bar{N}_X(1625) \to \pi^0\bar{p}, \eta\bar{p}, \pi^-\bar{n}$ listed in Table 2 is about 10^{-2}. Such a large branching ratio is unreasonable for J/ψ decay. The BES collaboration has already studied $J/\psi \to p\pi^-\bar{n}$ in Ref. [19] and $J/\psi \to p(\eta\bar{p})$ in Ref. [20]. The branching ratios respectively corresponding to $J/\psi \to p\pi^-\bar{n}$ and $J/\psi \to p\eta\bar{p}$ are 2.4×10^{-3} and 2.1×10^{-3}[19, 20]. Although these experimental values are comparable with our numerical result of the corresponding channel, the former experiments did not find the structure consistent with $\bar{N}_X(1625)$, which seems to show that the evidence against S-wave $\bar{\Sigma}^0 - K^-$ molecular picture is gradually accumulating[7].

As indicated in Ref. [5], there exists very strong coupling between $\bar{N}_X(1625)$ and $\bar{\Lambda}K^-$. At present other decay modes of $\bar{N}_X(1625)$ are still missing[5]. Thus the assumption of S-wave $\bar{\Lambda} - K^-$ molecular state is more favorable than that of S-wave $\bar{\Sigma}^0 - K^-$ molecular state for $\bar{N}_X(1625)$. The result of Ref. [21], which is from the calculation within the framework of the chiral $SU(3)$ quark model by solving a resonating group method (RGM) equation, indicates that the ΛK system is unbound. Whether there exists the S-wave $\bar{\Lambda} - K^-$ molecular state is still an open issue. The dynamics study of S-wave $\bar{\Lambda}$–K^- system by other phenomenological models is encouraged.

Table 2. The branching ratios of $J/\psi \to p\bar{N}_X(1625) \to p(\pi^0\bar{p}), p(\eta\bar{p}), p(\pi^-\bar{n})$ in two different molecular state pictures for $\bar{N}_X(1625)$.

	$\bar{\Lambda} - K^-$ system	$\bar{\Sigma}^0 - K^-$ system
$J/\psi \to p\bar{N}_X(1625) \to p(\pi^0\bar{p})$	$1\times10^{-8} \sim 3\times10^{-8}$	$\sim 1\times10^{-3}$
$J/\psi \to p\bar{N}_X(1625) \to p(\eta\bar{p})$	$4\times10^{-11} \sim 2\times10^{-10}$	$\sim 7\times10^{-3}$
$J/\psi \to p\bar{N}_X(1625) \to p(\pi^-\bar{n})$	$2\times10^{-8} \sim 5\times10^{-8}$	$\sim 2\times10^{-3}$

If it is problematic to explain $\bar{N}_X(1625)$ as the pure molecular state structure, we have to again ask what is the underlying structure of $\bar{N}_X(1625)$. We notice that there exist two well established states $N^*(1535)$ and $N^*(1650)$ with $J^P = 1/2^-$ nearby the mass of $N_X(1625)$. In PDG[6], the branching ratio of $N^*(1650) \to K\Lambda$ is about 3%—11%. The authors of Ref. [22] indicated that $N^*(1535)$ should have large $s\bar{s}$ component in its wave function which shows the large $N^*(1535)K\Lambda$ coupling. $N^*(1535)$ and $N^*(1650)$ can strongly couple to $K\Lambda$. Thus, whether $N_X(1625)$ enhancement is related to $N^*(1535)$ and $N^*(1650)$ is also an interesting topic.

Finally, we want to propose several suggestions for future experiment:

Until now, the experimental information of $\bar{N}_X(1625)$ only appeared in the proceeding of conference[1—3, 5]. We are expecting the formal publication of this enhancement, which will be helpful to stimulate more experimentalists and theorists to pay attention to this issue.

Searching for $\bar{N}_X(1625) \to \pi^0\bar{p}, \eta\bar{p}, \pi^-\bar{n}$ modes in future experiment can shed light on the nature of $\bar{N}_X(1625)$. We urge our experimental colleague carefully analyze $J/\psi \to p\pi^-\bar{n}$ and $J/\psi \to p\eta\bar{p}$ channel in further experiments, especially in the forthcoming BESIII.

Confirming $\bar{N}_X(1625)$ by the other experiments is encouraged. At present, Lanzhou CSR is a good platform to study the baryon spectroscopy. Analyzing the invariant mass spectrum of $K^+\Lambda$, which comes from the $p\alpha$ reaction, will be an important approach to investigate the $N_X(1625)$ enhancement structure.

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References

1 YANG H X et al (BES collaboration). Int. J. Mod. Phys. A, 2005, **20**: 1985
2 JIN S (BES collaboration). Int. J. Mod. Phys. A, 2005, **20**: 5145
3 SHEN X Y. Int. J. Mod. Phys. A, 2005, **20**: 1706
4 Tran M Q et al (SAPHIR collaboration). Phys. Lett. B, 1998, **445**: 20
5 JIN S (BES collaboration). Invited plenary talk given at XII. International Conference on Hadron Spectroscopy, Frascati, Oct. 8-13, 2007, http://www.lnf.infn.it/ conference/hadron07/
6 Amsler C et al. Phys. Lett. B, 2008, **667**: 1
7 LIU X, ZHANG B. Eur. Phys. J. C, 2008, **54**: 253—258
8 de Swart J J. Rev. Mod. Phys., 1963, **35**: 916
9 Georgi H. Weak Interactions and Modern Particle Theory. California, The Benjiamin/Cummings Publishing Company, 1984
10 Aliev T M, Ozpineci A, Savci M. Phys. Rev. D, 2001, **64**: 034001
11 Erkol G, Timmermans R G E, Rijken T A. Phys. Rev. C, 2006, **74**: 045201
12 LIN Z et al. Phys. Rev. C, 2000, **61**: 024904; Holzenkamp B et al. Nucl. Phys. A, 1989, **500**: 485; Janssen G et al. Phys. Rev. Lett., 1993, **71**: 1975
13 HE X G, LI X Q, LIU X, ZENG X Q. Eur. Phys. J. C., 2007, **51**: 883—889
14 CHENG H Y, Chua C K, Soni A. Phys. Rev. D, 2005, **71**: 014030
15 ZHU S L, Hwang W-Y P, YANG Z S. Phys. Rev. D, 1998, **57**: 1524
16 Itzykson C, Zuber J B. Quantum Field Theory. New York, McGraw-Hill Inc., 1980
17 Peskin M E, Schroeder D V. An Introduction to Quantum Field Theory. New York: Addison-Wesley Publishing Company, 1995
18 LIU X, ZENG X Q, LI X Q. Phys. Rev. D, 2006, **74**: 074003
19 Ablikim M et al (BES collaboration). Phys. Rev. Lett., 2006, **97**: 062001
20 BAI J Z et al (BES collaboration). Phys. Lett. B, 2001, **510**: 75
21 HUANG F, ZHANG D, ZHANG Z Y, YU Y W. Phys. Rev. C, 2005, **71**: 064001
22 LIU B C, ZOU B S. Phys. Rev. Lett., 2006, **96**: 042002