Towards the decays of Nx(1625) in molecular picture

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X. Liu and B. Zhang, Eur. Phys. J. C54, 253-258 (2008)

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Experimental information and theoretical explanations

BES Collaboration
Int. J. Mod. Phys. A 20, 1985 (2005)

$$J/\psi \to p\, K^- \bar{\Lambda}$$

$\bar{N}_X(1625)$

$$J^P = \frac{1}{2}^+$$

$$M = 1625^{+5+13}_{-7-23} \text{ MeV}$$

$$\Gamma = 43^{+10+28}_{-7\ -11} \text{ MeV}$$

$$B[J/\psi \to p\bar{N}_X(1625)]B[\bar{N}_X(1625) \to K^-\bar{\Lambda}] = 9.14^{+1.30+4.24}_{-1.25-8.28} \times 10^{-5}.$$

- Chiral SU(3) quark model

Huang et al., PRC71, 064001 (2005)

S-wave ΛK unbound

S-wave ΣK strong attraction (E=-17 MeV)

Consideing the coupled channel effect of ΛK and ΣK, they found a sharp resonance with

M=1669 MeV Γ=5 MeV

- $\bar{N}_x(1625)$ comes from the strong coupling between $\bar{N}^*(1535)$ and KΛ

Liu, Zou, PRL 96, 042002 (2006)

The decay of assuming $\bar{N}_x(1625)$ to be the $\bar{\Lambda} - K^-$ molecular state

$$m_\Lambda + m_K = 1610\ \text{MeV} < M_{Nx(1625)}$$

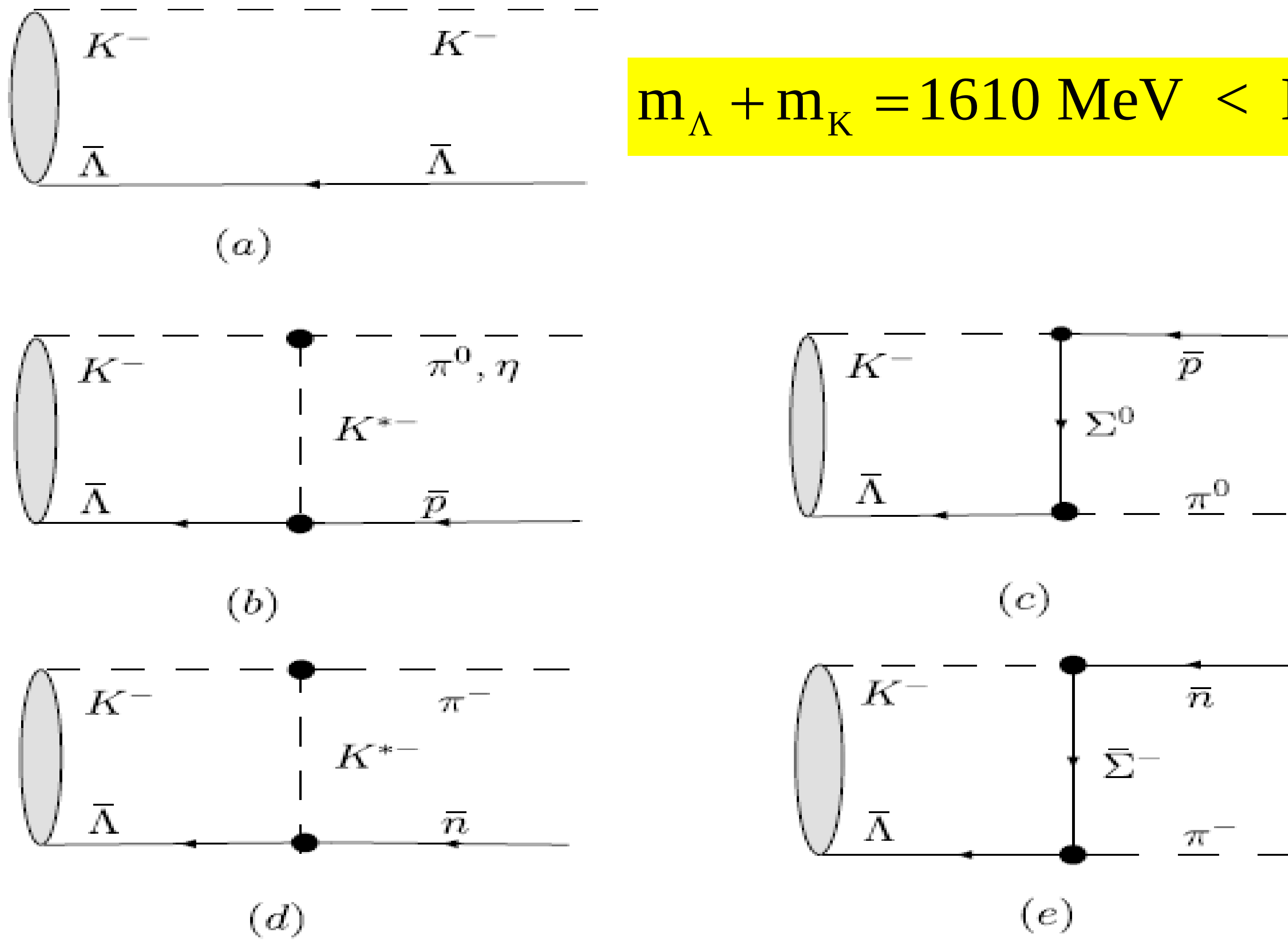

Fig. 1. The diagrams depicting the decays of $\bar{N}_X(1625)$ in the picture of the $\bar{\Lambda}$–K^- molecular state

Effective Lagrangian

$$\mathcal{L}_{\mathcal{PPV}} = -\mathrm{i}g_{\mathcal{PPV}}\mathrm{Tr}\big([\mathcal{P},\partial_\mu\mathcal{P}]\mathcal{V}^\mu\big)\,,$$
$$\mathcal{L}_{\mathcal{BBP}} = F_P\mathrm{Tr}\big(\mathcal{P}[\mathcal{B},\bar{\mathcal{B}}]\big)\gamma_5 + D_P\mathrm{Tr}\big(\mathcal{P}\{\mathcal{B},\bar{\mathcal{B}}\}\big)\gamma_5\,,$$
$$\mathcal{L}_{\mathcal{BBV}} = F_V\mathrm{Tr}\big(\mathcal{V}^\mu[\mathcal{B},\bar{\mathcal{B}}]\big)\gamma_\mu + D_V\mathrm{Tr}\big(\mathcal{V}^\mu\{\mathcal{B},\bar{\mathcal{B}}\}\big)\gamma_\mu\,,$$

Figs. (a)

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

Figs. (b),(d)

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

Figs. (c),(e)

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

$$\mathcal{F}^2(m_i,q^2) = \left(\frac{\xi^2-m_i^2}{\xi^2-q^2}\right)^2$$

$$\xi(m_i) = m_i + \alpha\Lambda_{\mathrm{QCD}},$$

The decay of assuming $\bar{N}_x(1625)$ to be the $\bar{\Sigma} - K^-$ molecular state

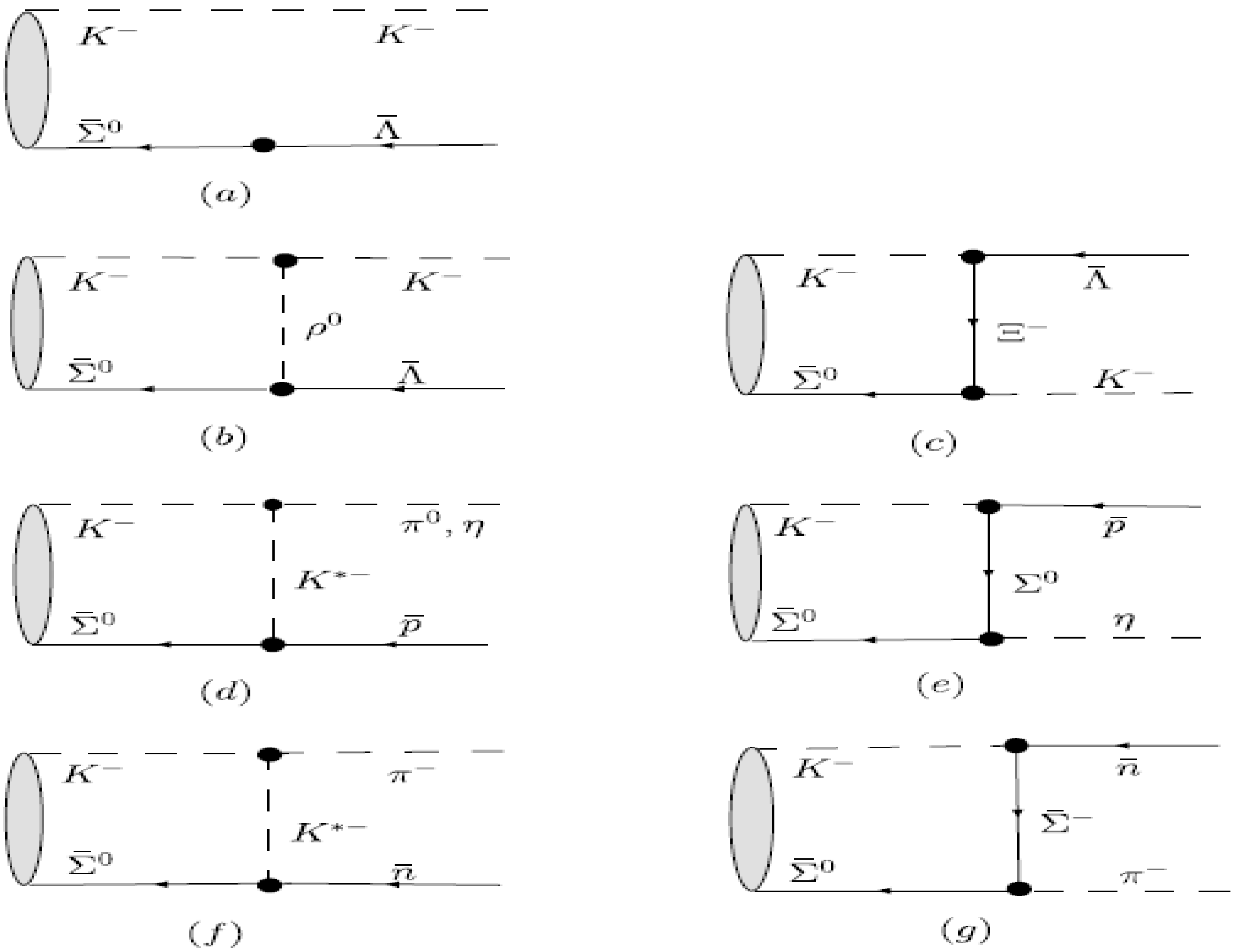

Fig. 2. The diagrams depicting the decays of $\bar{N}_X(1625)$ in the assumption of the $\bar{\Sigma}^0$–K^- molecular state for $\bar{N}_X(1625)$

The isospin violation effect can result in the mixing of Σ with Λ^0 [11]. Thus the decay $\bar{N}_X(1625) \to \bar{\Lambda} + K^-$ occurs, which is depicted by Fig. 2a. Using the Lagrangian

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

Figs. (a)

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

Figs. (b),(d), (f)

$$\mathcal{M}_3^{(\mathcal{A}_3,\mathcal{C}_3)} = \int \frac{\mathrm{d}^4 q}{(2\pi)^4} [i\mathcal{G}\bar{v}_N \gamma_5] \frac{\mathrm{i}}{-\not{p}_2 - M_{\bar{\Sigma}^0}} [\mathrm{i} g_3 \gamma_\mu v_{\mathcal{A}_3}] \times [\mathrm{i} g_4 (p_1 + p_3)_\nu] \frac{-\mathrm{i} g^{\mu\nu}}{q^2 - M_{\mathcal{C}_3}^2} \frac{\mathrm{i}}{p_1^2 - M_K^2} \times \mathcal{F}^2 \left(M_{\mathcal{C}_3}, q^2 \right) , \qquad (10)$$

Figs. (c),(e),(g)

$$\mathcal{M}_4^{(\mathcal{A}_4,\mathcal{C}_4)} = \int \frac{\mathrm{d}^4 q}{(2\pi)^4} [\mathrm{i}\mathcal{G}\bar{v}_N \gamma_5] \frac{\mathrm{i}(\not{p}_2 - M_{\bar{\Sigma}^0})}{-p_2^2 - M_{\bar{\Sigma}^0}^2} [\mathrm{i} g_4' \gamma_5] \times \frac{\mathrm{i}(\not{q} + M_{\mathcal{C}_4})}{q^2 - M_{\mathcal{C}_4}^2} [\mathrm{i} g_3' \gamma_5 v_{\mathcal{A}_4}] \frac{\mathrm{i}}{p_1^2 - M_K^2} \mathcal{F}^2 (M_{\mathcal{C}_4}, q^2) ,$$

Numerical result

$\bar{\Lambda}K$

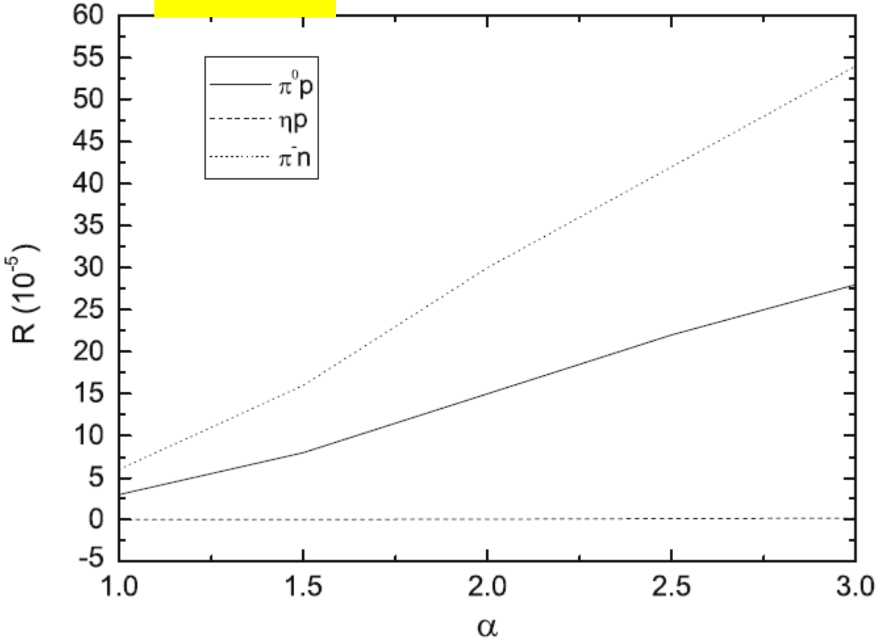

Fig. 3. The ratios of the $\bar{N}_X(1625) \to \pi^0\bar{p}, \eta\bar{p}, \pi^-\bar{n}$ decay widths to the $\bar{N}_X(1625) \to \bar{\Lambda}K^-$ decay width in the picture of the $\bar{\Lambda}$–K^- molecular state

$\bar{\Sigma}K$

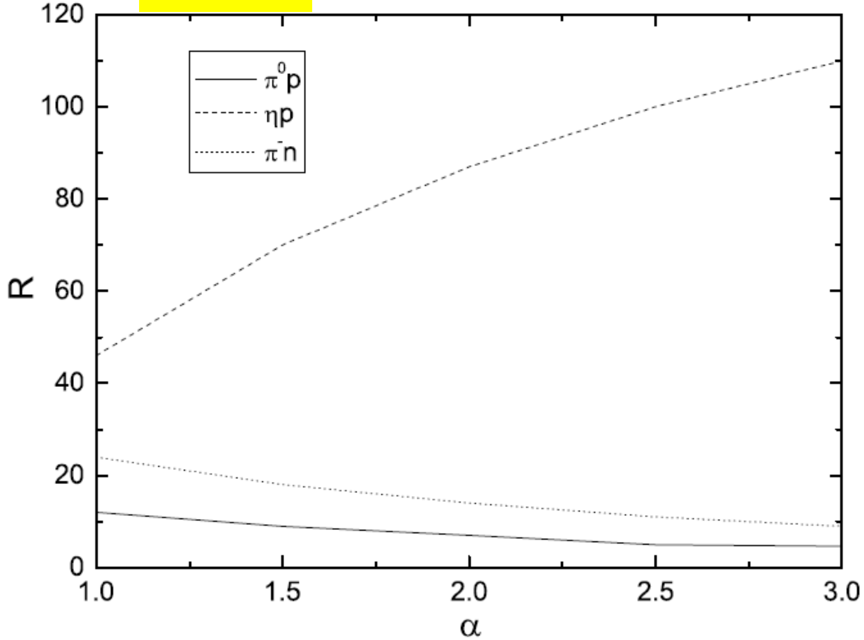

Fig. 4. The ratios of the $\bar{N}_X(1625) \to \pi^0\bar{p}, \eta\bar{p}, \pi^-\bar{n}$ decay width to the $\bar{N}_X(1625) \to \bar{\Lambda}K^-$ decay width in the $\bar{\Sigma}^0$–K^- molecular state picture

$$\frac{\Gamma\left(\pi^0\bar{p}\right)}{\Gamma\left(K^-\bar{\Lambda}\right)} \qquad \frac{\Gamma\left(\eta\bar{p}\right)}{\Gamma\left(K^-\bar{\Lambda}\right)} \qquad \frac{\Gamma\left(\pi^-\bar{n}\right)}{\Gamma\left(K^-\bar{\Lambda}\right)}$$

Table 1. The ratios of the decay width 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

By using the ratios shown in Figs. 3 and 4 and the branching ratio $B[J/\psi \to p\bar{N}_X(1625)]B[\bar{N}_X(1625) \to K^-\bar{\Lambda}] = 9.14^{+1.30+4.24}_{-1.25-8.28} \times 10^{-5}$ given by BES [10], one estimates the branching ratio of the subordinate decays of $\bar{N}_X(1625)$ in J/ψ decay shown in Table 2. Due to the uncertainty of α, we give the possible ranges for these branching ratios.

Table 2. The branching ratios of subordinate decays of $\bar{N}_X(1625)$ in two different molecular state pictures

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

Conclusion and comment

$\bar{\mathrm{N}}_x(1625) \to \pi^0\bar{\mathrm{p}}$, $\eta\bar{\mathrm{p}}$, $\pi^-\bar{\mathrm{n}}$ are important to understand the structure of $\bar{\mathrm{N}}$x(1625)

$S-$wave $\bar{\Lambda}K^-$ molecular state:

- The dominat decay mode is $\bar{\mathrm{N}}_x(1625) \to \bar{\Lambda}K^-$, which can explain why $\bar{\mathrm{N}}_x(1625)$ is only observed in $\bar{\Lambda}K^-$ channel by BES.

Chiral SU(3) quark model:

S-wave ΛK unbound

Huang et al., PRC71, 064001 (2005)

- A further study of whether there exists $\bar{\Lambda}K^-$ molecular state is needed by other models.

$S-$wave $\bar{\Sigma}^0 K^-$ molecular state:

- The sum of the branching ratio of $\mathrm{J}/\psi \to \mathrm{p}\bar{\mathrm{N}}_\mathrm{x}(1625) \to \mathrm{p}(\pi^0\bar{\mathrm{p}}), \mathrm{p}(\eta\bar{\mathrm{p}}), \mathrm{p}(\pi^-\bar{\mathrm{n}})$ is about 10^{-2}. Such large branching ratio is unreasonable for J/ψ decay

- $\mathrm{BR}[\mathrm{p}(\pi^0\bar{\mathrm{p}}), \mathrm{p}(\eta\bar{\mathrm{p}}), \mathrm{p}(\pi^-\bar{\mathrm{n}})] \gg \mathrm{BR}[\bar{\Sigma}^0 K^-]$

- BES collaboration has already studied $\mathrm{J}/\psi \to \mathrm{p}\pi^-\bar{\mathrm{n}}$ and $\mathrm{J}/\psi \to \mathrm{p}\eta\bar{\mathrm{p}}$

  $\mathrm{BR}[\mathrm{J}/\psi \to \mathrm{p}\pi^-\bar{\mathrm{n}}]=2.4\times10^{-3}$ $\mathrm{BR}[\mathrm{J}/\psi \to \mathrm{p}\eta\bar{\mathrm{p}}]=2.1\times10^{-3}$

  Comparable with our numerical result of the corresponding channel

- Experiments did not find a structure consistent with $\bar{\mathrm{N}}_\mathrm{x}(1625)$!

It is unsuitable to explain Nx(1625) to be an S-wave $\bar{\Lambda}\mathrm{K}^-$ molecular state

- There exist the two well established states $N^*(1535)$ and $N^*(1625)$ near the mass of Nx(1625)

- $N^*(1535)$ and $N^*(1625)$ can strongly couple to $K\Lambda$

  Liu, Zou, PRL 96, 042002 (2006)

  Before confirming Nx(1625) to be a new resonance, theorists and experimentalists need to cooperate to answer whether Nx(1625) enhancement is related to $N^*(1535)$ and $N^*(1625)$.

- Forthcoming BESIII and HIRFL-CSR will provide a good place to further come to understand the Nx(1625) structure.

Thank you for your attention !