Production of the pentaquark exotic baryon Ξ_5 in $\overline{K}N$ scattering: $\overline{K}N \to K\Xi_5$ and $\overline{K}N \to K^*\Xi_5$

Seung-Il Nam,[a,b] Atsushi Hosaka,[a] and Hyun-Chul Kim[b]

[a]*Research Center for Nuclear Physics (RCNP), Ibaraki, Osaka 567-0047, Japan*
[b]*Department of Physics and Nuclear physics & Radiation technology Institute (NuRI), Pusan National University, Busan 609-735, Korea*

We investigate the production of the pentaquark exotic baryon Ξ_5 [1] in the $\overline{K}N \to K\Xi_5$ and $\overline{K}N \to K^*\Xi_5$ reactions at the tree level [2]. We consider the both positive- and negative-parities of the Ξ_5. The reactions are dominated by the s- and u-channel processes since no strangeness-two meson exists. The Lagrangians for these reactions are written as

$$\begin{aligned}
\mathcal{L}_{KN\Sigma} &= ig_{KN\Sigma}\overline{\Sigma}\gamma_5 KN + (\mathrm{h.c.}),\\
\mathcal{L}_{K\Sigma\Xi_5} &= ig_{K\Sigma\Xi_5}\overline{\Xi}_5\Gamma_5 K\Sigma + (\mathrm{h.c.}),\\
\mathcal{L}_{K^*N\Sigma} &= g_{K^*N\Sigma}\overline{\Sigma}\gamma_\mu K^{*\mu} N + (\mathrm{h.c.}),\\
\mathcal{L}_{K^*\Sigma\Xi_5} &= g_{K^*\Sigma\Xi_5}\overline{\Xi}_5\gamma_\mu\hat{\Gamma}_5 K^{*\mu}\Sigma + (\mathrm{h.c.}),
\end{aligned} \tag{1}$$

where Σ, Ξ_5, N, K and K^* denote the corresponding fields for the octet Σ, the antidecuplet Ξ_5, the nucleon, the pseudo-scalar K meson, and the vector K^* meson, respectively. We define $\Gamma_5 = \gamma_5$ for the positive-parity Ξ_5, whereas $\Gamma_5 = \mathbf{1}_{4\times4}$ for the negative-parity one. $\hat{\Gamma}_5$ is also defined by $\Gamma_5\gamma_5$ for the vector meson K^*. We employ two types of form factors as follows [3, 4] for the vertices.

$$F_1(x = s, u) = \frac{\Lambda_1^2}{\sqrt{\Lambda_1^4 + (x - M_\Sigma^2)^2}} : \Lambda_1 = 0.85\mathrm{GeV}, \tag{2}$$

$$F_2(\vec{q}^2) = \frac{\Lambda_2^2}{\Lambda_2^2 + |\vec{q}^2|} : \Lambda_2 = 0.5\mathrm{GeV}. \tag{3}$$

In the numerical calculations, we employ the coupling constants: $g_{K\Sigma\Xi_5} = g_{KN\Theta} = 3.77\,(0.53)$, $g_{K^*\Sigma\Xi_5} = \sqrt{3}g_{KN\Theta} = \pm6.53\,(1.89)$ [5] and $g_{K^*\Sigma\Xi_5} = \pm0.91\,(0.27)$ [3] where $g_{KN\Theta}$ is deduced when $\Gamma_{\Theta\to KN} = 15\mathrm{MeV}$. As for the other coupling constants we employ the new Nijmegen potential [6]: $g_{KN\Sigma} = 3.54$, $g_{K^*N\Sigma} = -2.99$. We present the total and differential cross sections for the $\overline{K}N \to K\Xi_5$ process in Fig. 1.

We see that the total cross sections for the negative-parity Ξ_5 are almost a hundred times smaller than those of positive-parity one. In the present reaction, the interference between the s- and u-channels becomes important in addition to the kinematic effect in the p-wave coupling for the positive-parity (but not in the s-wave for the negative-parity), which is proportional to $\vec{\sigma}\cdot\vec{q}$ enhancing the amplitude at high momentum transfers. We also presents the total and differential cross sections for the $\overline{K}N \to K^*\Xi_5$ process in Fig. 2 with F_1. In this process, we have uncertainties in the sige of $g_{K^*N\Xi_5}$ coupling constant. 4

We summarize the numerical results in Table. 1, where we see once again that the total cross sections are generally much larger for the positive-parity Ξ_5 than for those of the negative-parity one by about a hundred times. This feature would be useful in order to investigate the pentaquark properties in the presently proposed reactions.

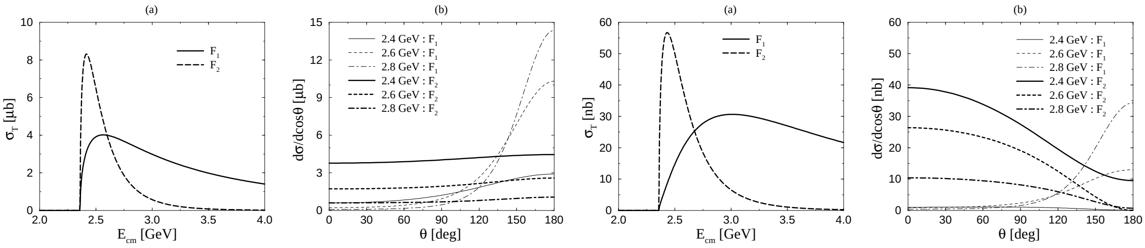

Figure 1: Total and differential cross section for the two parities (the left two panels for $P = +1$ and the others for $P = -1$) of $\overline{K}N \to K\Xi_5$ process with F_1 and F_2.

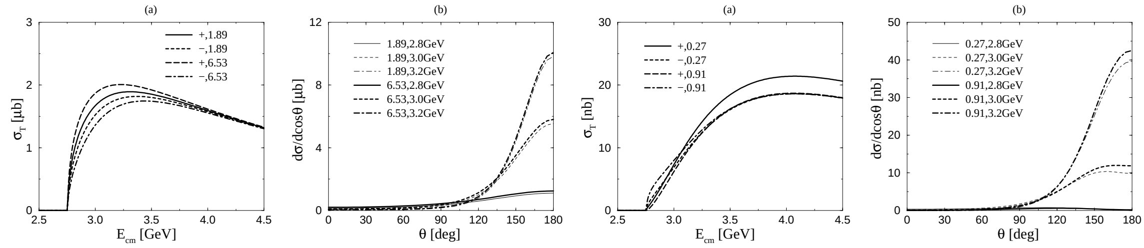

Figure 2: Total and differential cross section for the two parities (the left two panels for $P = +1$ and the others for $P = -1$) with the form factor F_1 of $\overline{K}N \to K^*\Xi_5$ process. We show the curves due to different signs of the coupling, $g_{K^*\Sigma\Xi_5}$.

References

[1] C. Alt *et al.* [NA49 Collaboration], Phys. Rev. Lett. **92**, 042003 (2004).

[2] S. I. Nam, A. Hosaka and H. C. Kim, arXiv:hep-ph/0405227.

[3] S. I. Nam, A. Hosaka and H. -Ch. Kim, hep-ph/0402138, to appear in Phys. Rev. D.

[4] W. Liu and C. M. Ko, Phys. Rev. C **68**, 045203 (2003).

[5] F. E. Close and J. J. Dudek, Phys. Lett. B **586**, 75 (2004)

[6] V. G. J. Stokes and Th. A. Rijken, Phys. Rev. C **59**, 3009 (1999)

Reaction	F_1	F_2	Reaction	F_1	F_2
$\sigma_{\overline{K}N\to K\Xi_5}(P=+1)$	2.6 μb	1.5 μb	$\sigma_{\overline{K}N\to K^*\Xi_5}(P=+1)$	1.6 μb	$\lesssim 2$ μb
$\sigma_{\overline{K}N\to K\Xi_5}(P=-1)$	26 nb	12 nb	$\sigma_{\overline{K}N\to K^*\Xi_5}(P=-1)$	14 nb	$\lesssim 20$ nb

Table 1: Summary for the average total cross sections in the CM energy region: $2.35\,\text{GeV} \leq E_{\text{CM}} \leq 3.35\,\text{GeV}$ for $\overline{K}N \to K\Xi_5$ and $2.75\,\text{GeV} \leq E_{\text{CM}} \leq 3.75\,\text{GeV}$ for $\overline{K}N \to K^*\Xi_5$. For K^* production with F_2 form factor used, only the upper values are quoted since the interference suppresses them.