Production of the pentaquark Θ^+ in np scattering

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We study the $np \to \Lambda\Theta^+$ and $np \to \Sigma^0\Theta^+$ processes for both of the positive and negative parities of the Θ^+ at the tree level [1]. Effective Lagrangians can be written as follows,

$$\begin{aligned}
\mathcal{L}_{KNY} &= -ig_{KNY}\bar{Y}\gamma_5 K^\dagger N, \\
\mathcal{L}_{KN\Theta_\pm} &= -ig_{KN\Theta_\pm}\bar{\Theta}_\pm\Gamma_5 KN, \\
\mathcal{L}_{VNY} &= -g_{VNY}\bar{Y}\gamma_\mu V^\mu N - \frac{g^T_{VNY}}{M_Y+M_N}\bar{Y}\sigma_{\mu\nu}\partial^\nu V^\mu N, \\
\mathcal{L}_{VN\Theta} &= -g_{VN\Theta_\pm}\bar{\Theta}_\pm\gamma_\mu\bar{\Gamma}_5 V^\mu N - \frac{g^T_{VN\Theta_\pm}}{M_\Theta+M_N}\bar{\Theta}_\pm\sigma_{\mu\nu}\bar{\Gamma}_5\partial^\nu V^\mu N,
\end{aligned} \tag{1}$$

where Y, K, N, Θ, and V stand for the hyperon (Σ^0 and Λ), kaon, nucleon, Θ^+, and vector meson fields, respectively. In order to take into account different parities for the Θ^+ in the reactions, we introduce $\Gamma_5 = \gamma_5$ for the $\Theta^+_{P=+1}$ and $\Gamma_5 = \mathbf{1}_{4\times4}$ for the $\Theta^+_{P=-1}$. $\bar{\Gamma}_5$ designates $\Gamma_5\gamma_5$. The isospin factor is included in Y. The $KN\Theta$ coupling constant can be determined, if we know the decay width $\Gamma_{\Theta\to KN}$. If we choose $\Gamma_{\Theta\to KN} = 15\,\text{MeV}$ together with $M_\Theta = 1540\,\text{MeV}$ [2], we find that $g_{KN\Theta^+_+} = 3.78$ and $g_{KN\Theta^+_-} = 0.53$. If one takes a different width for $\Gamma_{\Theta\to KN}$, the coupling constant scales as a square root of the width. As for the unknown coupling constant $g_{K^*N\Theta}$, we follow Ref. [3], *i.e.*, $g_{K^*N\Theta} = \pm|g_{KN\Theta}|/2$. The tensor coupling constant $g^T_{K^*N\Theta}$ is then fixed as follows: $g^T_{K^*N\Theta} = \pm|g_{KN\Theta}|$ as in Ref. [4]. Since the sign of the coupling constants cannot be fixed by SU(3) symmetry, we shall use both signs [3]. We employ the values of the KNY and K^*NY coupling constants referring to those from the new Nijmegen potential (averaged values of models NSC97a and NSC97f) [6] as well as from the Jülich–Bonn YN potential (model $\tilde{\text{A}}$) [7]. For the Nijmegen potential we introduce the monopole-type form factor [8, 4] in the form of

$$F(q^2) = \frac{\Lambda_1^2 - m^2}{\Lambda_1^2 - t} : \Lambda_1 = 1.0\text{GeV}, \tag{2}$$

where m and t are the meson mass and a squared four momentum transfer, respectively. As for that of the Jülich–Bonn potential, we make use of the following form factor taken from Ref. [7]:

$$F(q^2) = \frac{\Lambda_2^2 - m^2}{\Lambda_2^2 + |\mathbf{q}|^2}, \tag{3}$$

where $|\mathbf{q}|$ is the three momentum transfer. In this case, we take different values of Λ_2 for each KNY vertex as follows [7]: $\Lambda_{KN\Theta} = \Lambda_{K^*N\Theta} = 1.0\,\text{GeV}$, $\Lambda_{KN\Lambda} = 1.2\,\text{GeV}$, $\Lambda_{K^*N\Lambda} = 2.2\,\text{GeV}$, $\Lambda_{KN\Sigma} = 2.0\,\text{GeV}$, and $\Lambda_{K^*N\Sigma} = 1.07\,\text{GeV}$.

We have found that $\sigma_{np\to Y^0\Theta^+_+} \gg \sigma_{np\to Y^0\Theta^+_-}$ and $\sigma_{np\to\Lambda\Theta^+} \gg \sigma_{np\to\Sigma^0\Theta^+}$. Concerning the absolute value of the total cross sections, it should be pointed out that they may change if a different value of $\Gamma_{\Theta\to KN}$ is used as proportional to it. Here we have used $\Gamma_{\Theta\to KN} = 15$

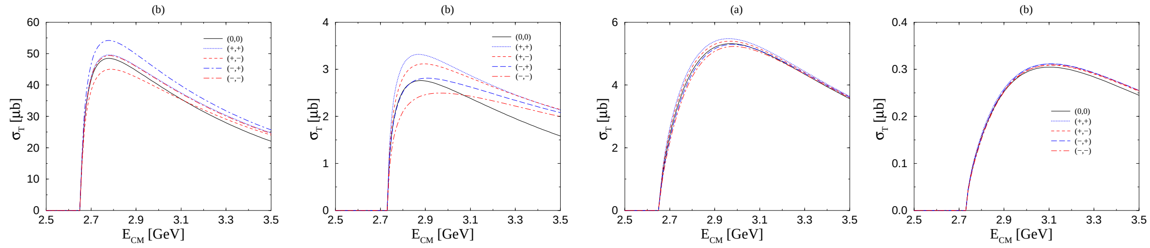

Figure 1: The total cross sections of $np \to \Lambda\Theta^+_+$ for the two parities (a:$P = +1$, b:$P = -1$) in the left two panels. Those of $np \to \Sigma^0\Theta^+_+$ in the right two panels. The parameter set of the Jülich-Bonn potential is employed with F_1

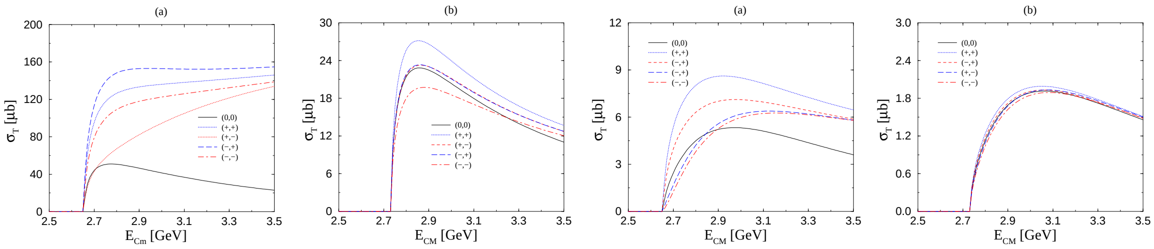

Figure 2: The total cross sections of $np \to \Lambda\Theta^+_+$ for the two parities (a:$P = +1$, b:$P = -1$) in the left two panels. Those of $np \to \Sigma^0\Theta^+_+$ in the right two panels. The parameter set of the Nijmegenis is employed with F_2

MeV. Recent experiment and analysis indicate narrower widths [9, 10]. For instance, if we take $\Gamma_{\Theta\to KN} \sim 5$ MeV, then the cross sections are reduced by a factor 3. Furthermore, the initial state interaction may change the present estimate. Typically it can reduce the total cross sections by about a factor three as discussed in hyperon productions [11]. At the present point, although there is ambiguity in the theoretical predictions in the total cross sections, they would be useful to obtain information on the properties of the Θ^+ once more data will be available [12].

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