Threshold production of the Θ^+ in a polarized proton reaction

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Recently, an unambiguous method was proposed in order to determine the parity of the Θ^+ using the reaction [1]

$$\vec{p} + \vec{p} \to \Theta^+ + \Sigma^+ \quad \text{near threshold.} \tag{1}$$

This reaction has been previously considered for the production of Θ^+ [2], but it has turned out that it does more for the determination of the parity, in contrast with a number of recent attempts using other reactions which needed particular production mechanism [3]. In order to extract information of parity from (1), the only requirement is that the final state is dominated by the s-wave component. The s-wave dominance in the final state is then combined with the Fermi statistics of the initial two protons and conservations of the strong interaction, establishing the selection rule: *If the parity of Θ^+ is positive, the reaction (1) is allowed at the threshold region only when the two protons have the total spin $S = 0$ and even values of relative momenta l, while, if it is negative the reaction is allowed only when they have $S = 1$ and odd l values.* This situation is similar to what was used in determining the parity of the pion [4]. Experimentally, the pure $S = 0$ state may not be easy to set up. However, an appropriate combination of spin polarized quantities allows to extract information of $S = 0$ state. In this letter[5], we perform calculations for production cross sections of (1). Our purposes are:

1. To check that the production reaction is indeed dominated by the s-wave (in other word, there is no accidental vanishing of s-wave contributions to invalidate the above selection rule).

2. To estimate production cross sections within the present knowledge of theoretical models.

In order to estimate the production rate, we calculate the Born diagrams of pseudoscalar kaon ($K(498)$) and vector K^* ($K^*(892)$) exchanges, which are minimally needed for the present reaction. For the coupling terms of Σ^+, we employ the values estimated from the previous analysis; $g_{KN\Sigma} = 3.54$, $g_{K^*N\Sigma} = -2.46$ and $g^T_{K^*N\Sigma} = 1.15$ [6]. Since the couplings to the Θ^+ is not known, we investigate several cases with different parameter values. For $g_{KN\Theta}$ we mostly employ $g_{KN\Theta} = 3.78$, which is fixed by $\Gamma_{\Theta^+\to KN} = 15$ MeV. For each case, we employ for the unknown vector K^* couplings, $|g_{K^*N\Theta}| = |g_{KN\Theta}|/2$, as suggested by Ref. [7]. The tensor couplings are then varied within $|g^T_{K^*N\Theta}| \leq 2|g_{K^*N\Theta}| = |g_{KN\Theta}|$ in order to see model dependence of this process. For the signs of these parameters, we will treat them as parameters. As for the form factor, we employ the following form of the monopole type:

$$F(q^2) = \frac{\Lambda^2 - m^2}{\Lambda^2 - q^2}\,, \tag{2}$$

where q^2 is the four momentum square and m the mass of the exchanged particle (either K or K^*). The cut off parameter Λ is chosen to be $\Lambda = 1$ GeV.

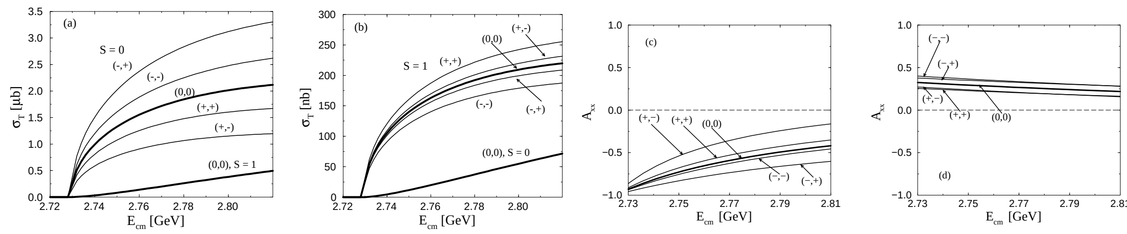

Figure 1: Total cross sections for $S = 0$ (a) and $S = 1$ (b) in the left two panels. A_{xx} for the positive (c) and negative (d) parity with K and K^* mesons. ($\pm$,$\pm$) represents the sign combinations of $g_{K^*N\Theta}$ and $g^T_{K^*N\Theta}$.

In the left two panels of Fig. 1, total cross sections near threshold region are shown as functions of the energy in the center of mass system $\sqrt{s}$ ($\sqrt{s}_{\rm th} = 2729.4$ MeV). The left (right) panel is for the positive (negative) parity Θ^+, where the allowed initial state has $S = 0$ and even l ($S = 1$ and odd l). For the allowed channels, five curves are shown using different coupling constants of $g_{K^*N\Theta}$ and $g^T_{K^*N\Theta}$; zero and four different combinations of signs with the absolute values $|g^T_{K^*N\Theta}| = 2|g_{K^*N\Theta}| = |g_{KN\Theta}|$, as indicated by the pair of labels in the figures, (sgn($g_{K^*N\Theta}$), sgn($g^T_{K^*N\Theta}$)). In both figures, the s-wave threshold behavior is seen for the allowed channels as proportional to $(s - s_{th})^{1/2}$, while the forbidden channels exhibit the p-wave dependence of $(s-s_{th})^{3/2}$ and with much smaller values than the allowed channel. The suppression factor is given roughly by [(wave number)·(interaction range)]^2 $\sim k/m_K \sim 0.1$ ($k = \sqrt{2m_K E}$), as consistent with the results shown in the figures. As discussed in Ref. [8], spin correlation parameter A_{xx} is also a useful quantity to distinguish the parity. It is defined by Eq. (3).

$$A_{xx} = \frac{(^3\sigma_0 +^3 \sigma_1)}{2\sigma_0} - 1, \tag{3}$$

where σ_0 is the unpolarized total cross sections and the polarized cross section are denoted as $^{2S+1}\sigma_{S_z}$. In the right two panels of Fig. 1 we present A_{xx}. As shown in the figures A_{xx} reflects very clearly the differences of the parity of Θ^+. The results are stable under the change in parameters and well fall into the region as indicated in Ref. [8].

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