Proposal/Beam-time request
Investigation of an exotic pentaquark state Θ^+

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Abstract

Recent evidence for the existence of an exotic Θ^+ resonance in the K^0p system needs further investigation. It is of great importance to study this resonance in proton induced interactions. From the analysis of the data taken in previous experiments it is shown that the corresponding final states can be observed at ANKE. However, the experimental conditions have to be optimized. We ask for one week of test beam-time to make these optimizations and to examine the existence of the Θ^+ in proton–nucleus collisions.

1 Introduction and motivation

There are several experiments indicating the possible existence of an exotic pentaquark state Θ^+ in the K^+n system produced in γ-induced reactions [1–3], or in the K^0p system produced in low energy K^+Xe collisions [4] and in neutrino-induced interactions [5], all showing a statistical significance of the order of $3 \div 5\,\sigma$. The extracted resonance parameters are a mass around 1540 MeV and a width of less than 20 MeV in rather good agreement with the theoretical predictions by Diakonov *et al.* [6], although a much narrower Θ^+ is required by K^+N phase shift analyses [7–9]. In order not to be in conflict, a resonance state with a mass of 1540 MeV should have a width less than 5 MeV [7], or even less than 1 MeV [8, 9].

Contrary to this, there are no data available in proton-induced reactions, such as $pN\to\Theta^+X$, though the cross section for the production of the Θ^+ is predicted to be a few μb [10] close to the highest proton-beam energy available at COSY, i.e. 2.88 GeV [11]. Such data would not only speak for or against the existence of the Θ^+, but in case of positive answer will allow to determine spin and parity of the resonance.

Here we propose to investigate the Θ^+ state in proton-nucleon interactions with the ANKE spectrometer, and request a test beam-time for the measurement with CH_2- and C-targets to optimize the experimental capabilities. Since the ANKE spectrometer is well suited for detection of multiple charged particle final states, the following reactions are proposed to be studied:

$$pp \to K^0p\Lambda\pi^+\,, \quad (1)$$
$$pp \to K^0p\Sigma^+\,, \quad (2)$$
$$pn \to K^0p\Lambda\,. \quad (3)$$

In these reactions the decays $K^0\to\pi^+\pi^-$ or/and $\Lambda\to\pi^-p$ can be exploited via missing (invariant) mass analyses. The identification of the Θ^+ state in all the given reactions can be performed with the mass distribution of the K^0p system,

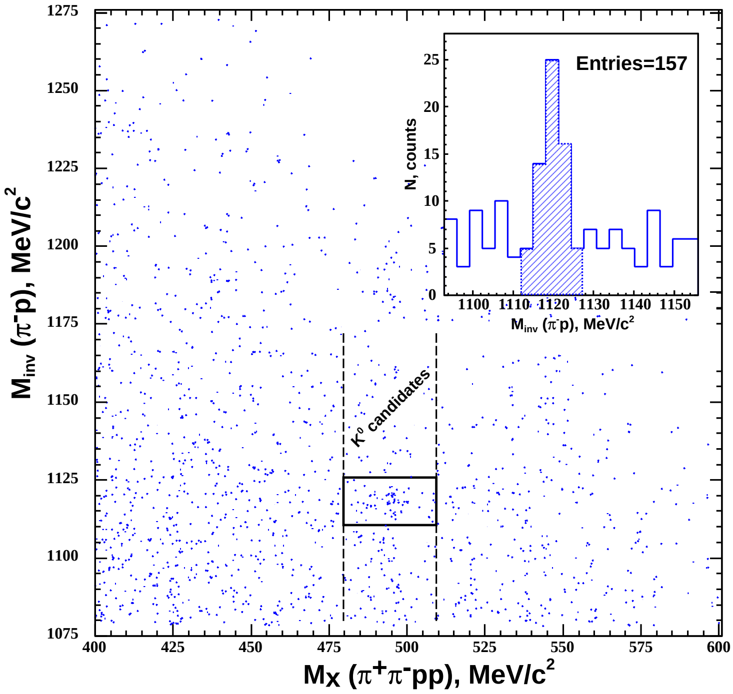

Fig. 1: A scatter plot of the invariant mass $M_{inv}(\pi^- p)$ versus the missing mass $M_x(\pi^+\pi^- pp)$ for the reaction (1) at an incident proton beam energy of $T_p = 2.83\,\mathrm{GeV}$. The insert shows the invariant mass of the $\pi^- p$ system after a cut on $M_x(\pi^+\pi^- pp)$ indicated by the dashed lines.

which is advantageous because there are no background reactions like $pN \to pN\phi$ or $pN \to K^+ N \Lambda(1520)$ as compared to investigations of the resonance state in the $K^+ n$ system. Thus, the main source of background in the $K^0 p$ system will come from non-resonant processes. In addition, the evidence of the resonance state in the $K^0 p$ system is still moderate, so that the confirmation of this resonance is particularly interesting and of great importance.

2 Analysis of experimental data

As a by-product of measurements of a_0^+ production performed at a proton-beam energy of $T_p = 2.83\,\mathrm{GeV}$ with a hydrogen cluster-jet target, $40 \div 50$ clean events for the reaction $pp \to K^0 p \pi^+ \Lambda$ have been accumulated. This corresponds to a

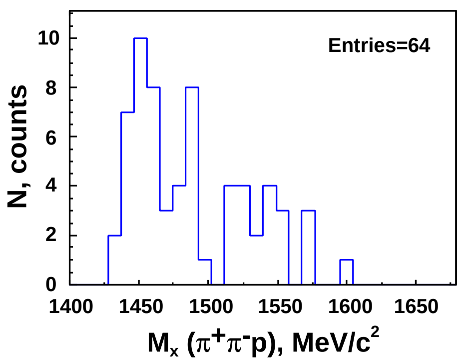

Fig. 2: Missing mass of the two charged pions and the proton. A bin size of 9 MeV roughly corresponds to the experimental resolution.

count rate of $20 \div 30$ events/day for a luminosity $\approx 2 \cdot 10^{31}\,(\mathrm{s} \cdot \mathrm{cm}^2)^{-1}$. The identification of the reaction has been carried out by detecting four charged particles, i.e. π^+, π^- and two protons. Fig. 1 shows a scatter plot of the invariant mass of the $\pi^- p$ system versus the missing mass of the four detected particles, and there is a clear signal of correlated K^0–Λ events on top of some background. The invariant mass of the $\pi^- p$ pair after a cut on $M_x(\pi^+\pi^- pp)$ indicated by the dashed lines in Fig. 1 is shown in the insert.

In order to see whether there is some evidence of the resonance state in the $K^0 p$ system, the missing mass of the three particle state, $\pi^+\pi^- p$, is built. The selected events are inside the cuts indicated by the rectangle in Fig. 1 (corresponding to the shaded area in the insert), and the resulting missing mass distribution is shown in Fig. 2. It is fair to say that the current level of statistics collected does not allow one to deduce any conclusions about the presence of the Θ^+ resonance.

3 Beam-time request

Since these results were not obtained in a dedicated experiment, we had no possibility to optimize the experimental conditions. The angular acceptance for π^+ mesons was limited to $10°$, while pions from the K^0 decay have angles larger than $8°$. As a result, we have poor statistics for the reaction $pp \to K^0 p \Sigma^+$ (1 ev/day). Therefore, a key task is to optimize ANKE for the K^0 detection, which implies a rearrangement of the scintillation counters and corresponding adjustment of the online trigger to allow for detection of particles having angles as large as $\approx 20°$. Higher luminosities can be achieved with a CH_2 target instead of the cluster jet. In this case we gain at least a factor of 3 in the useful count rate due to luminosity and a factor of 2 due to the optimization of the angular acceptance.

Table 1: Expected number of detected events for resonant (non-resonant) processes at ANKE for the proposed reactions. The number of events is estimated assuming a luminosity of $L \sim 10^{32}\,(\mathrm{s} \cdot \mathrm{cm}^2)^{-1}$ and optimized settings of the spectrometer. Particles identified in each reaction channel and targets are given in column ID, corresponding acceptances in column ACC.

Reaction	ID	ACC (10^{-6})	$\sigma_{tot}(\mu\mathrm{b})$	Ev./day
(1)	$p, \pi^+, (\pi^-, p)_\Lambda$ $CH_2 - C$	4 (3.5^*)	~ 0.5 [10]	8 $(100^\#)$
(2)	$(\pi^+, \pi^-)_{K^0}, p, p_\Sigma$ $CH_2 - C$	0.7 (3)	~ 1.6 [10] (~ 10 [15])	5 (120)
(3)	$(\pi^+, \pi^-)_{K^0}, p, (\pi^-, p)_\Lambda$ C	< 0.5 (1.5)	? (~ 25 [16])	? (500)

* the numbers in brackets are estimates for the non-resonant processes.
$^\#$ numbers are estimated from the existing experimental data.

Using a CH_2 target we plan to investigate also another reaction channel (3), $pn \to K^0 p \Lambda$, followed by $K^0 \to \pi^+\pi^-$ and $\Lambda \to \pi^- p$. In this case we plan not to reconstruct the missing mass, but the invariant mass of Λ, K^0 and $K^0 p$ by detecting all 5 particles. This allows us to fix the kinematics of the reaction independent on the intrinsic motion of target neutrons. According to the Glauber model [13, 14], the effective number of neutrons in carbon is 3.5, which leads to a further increase of the count rate (see Table 1).

Table 1 shows the expected number of events for each reaction assuming a luminosity of $L \sim 10^{32}\,(\mathrm{s} \cdot \mathrm{cm}^2)^{-1}$ achieved with solid targets. A branching ratio of 0.5 is assumed for $\Theta^+ \to K^0 p$. For the non-resonant channel of reaction (1) rate estimates shown in Table 1 are made based on the existing experimental data. Additionally, assuming that the cross section of Λ production is a factor of 6 larger than that for Σ [12], and exceeds the production cross section for $\Lambda\pi$ pairs by a factor of 10 [12], then one can estimate the cross section for reaction (1) to be about 5 μb. The latter correspond to the count rate of 100 ev/day, which is in accord with the rates obtained from the data.

Summarizing we ask for one week of beam-time with CH_2 and C targets to optimize the experimental conditions and to collect world level of statistics for the three reactions $pp \to K^0 p \Sigma^+$, $pp \to K^0 p \pi^+ \Lambda$ and $pn \to K^0 p \Lambda$. The measurements have to be performed at the highest possible COSY beam energy of 2.88 GeV [11]. In parallel we shall also collect statistics for the reactions $pp \to K^+ n \pi^+ \Lambda$ and $pn \to K^+ n \Lambda$.

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