Search for the Θ^+ Pentaquark at CLAS Using the MMSA

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The minimum momentum spectator approximation (MMSA) as proposed by the LEPS Collaboration is applied to the g10 data set of the CLAS detector at Jefferson Lab in an attempt to search for a peak corresponding to a possible Θ^+ pentaquark in the nK^+invariant mass distribution. Such a peak was reported at a mass of 1.524 GeV/c^2 by the LEPS collaboration using the MMSA technique. Previously, using a different method, the CLAS g10 data was analyzed for the Θ^+ returning a null result. The current analysis applies the MMSA to this data, providing a parameter-free way to correct for the Fermi momentum. Preliminary spectra for the nK^+ invariant mass from CLAS are presented.

KEYWORDS: pentaquark, exotic baryons, hadrons

1. Introduction

With the recent announcement [1] of a heavy pentaquark, with a valence quark structure of $uudc\bar{c}$, from the LHCb Collaboration, the question of a possible light pentaquark, the Θ^+ with valence quarks $uudd\bar{s}$ has once again come up. In 2009, the LEPS Collaboration published a paper [2] claiming evidence for the Θ^+, with a significance of 5σ for a peak in the nK^+ invariant mass at 1.524 GeV/c^2. Previously, the CLAS Collaboration published a paper [3] showing no evidence for the Θ^+, essentially reversing the claim of an earlier paper (also by CLAS) from a data set with lower statistics. The history of the Θ^+ pentaquark has had many twists and turns, as described in Ref. [4].

If the heavy pentaquark exists as a narrow baryon resonance, is it so unreasonable that a light pentaquark could also be a narrow resonance? The answer is beyond the scope of this short paper, but it provides motivation to take a fresh look at the CLAS g10 data. The LEPS paper [2] used a different approach than the previous CLAS paper [3]. The analysis here follows, as closely as possible, the method used by LEPS, where only the K^+K^- pair is detected from photons in the range of 2.0-2.4 GeV incident on deuterium. The same data selection cuts as LEPS used are applied here, and the technique of the Minimum Momentum Spectator Approximation (MMSA) is applied to the mass spectra to correct for Fermi momentum of the struck nucleon. The MMSA is described in Ref. [2].

2. Data and Analysis

The data were taken in 2005 using the CLAS detector, the same data run as for the above CLAS paper [3] where relevant experimental details are given. Here, we only require detection of a K^+K^- pair only, just as in the LEPS measurements [2].

The data selection cuts are minimal, and follow as best possible those reported in the LEPS paper. In addition to standard particle identification and detector efficiency cuts, we remove events in the region of the ϕ-meson peak (between 1.01 and 1.03 GeV/c^2 in the K^+K^- invariant mass) and require the MMSA variable p_{min} (see below) to have a value between -0.1 and 0.1. The LEPS measurement required the incident photon energy to be between 2.0 and 2.4 GeV, and although CLAS has a wider range of photons, the final spectrum has the same range.

2.1 Application of the MMSA

The MMSA uses a variable called p_{min}, which is the minimum momentum possible of the spectator nucleon to keep the missing mass, M_{pn}, to be greater than the sum of the neutron plus proton mass, $m_n + m_p$. This occurs when [2]

$$p_{min} = (p_{miss}\sqrt{p_{CM}^2 + m_p^2} - p_{CM}E_{miss})/M_{pn} \tag{1}$$

where p_{miss} and E_{miss} are the missing momentum and energy, respectively, and p_{CM} is the nucleon momentum in the center of mass (CM) frame of the pn system. The direction of p_{min} is taken to be antiparallel to the total missing momentum, $MM(\gamma d, K^+K^-)$.

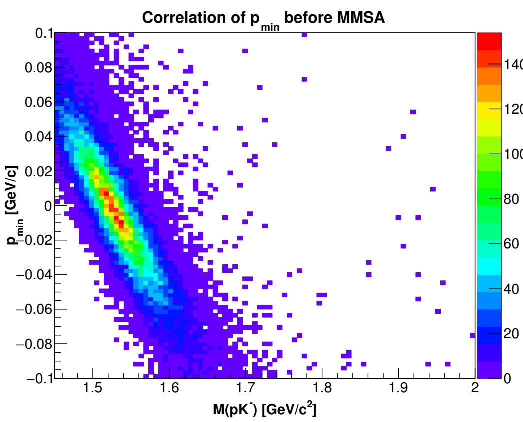

Fig. 1. Simulated $\gamma d \to \Lambda(1520)\ K^+\ (n)$ events before the MMSA. See text for details.

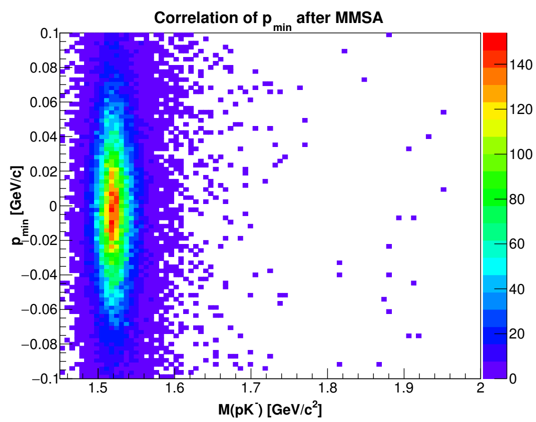

Fig. 2. Simulated $\gamma d \to \Lambda(1520)\ K^+\ (n)$ events after the MMSA. See text for details.

Figures 1 and 2 show plots of the mimimum momentum, p_{min}, versus the invariant mass of the $\Lambda(1520) \to pK^-$ decay, $M(pK^-)$, for Monte Carlo (MC) simulations of the reaction $\gamma d \to \Lambda(1520)K^+(n)$ reaction, before and after the application of the MMSA. Here, we use (n) to denote the neutron which is assumed to be a spectator, with only Fermi momentum in the lab frame.

In Fig. 1, we see a correlation between the value of p_{min} and $M(pK^-)$, which is due to the Fermi momentum of the spectator neutron. In Fig. 2, after application of the MMSA, the invariant mass becomes independent of p_{min}. This procedure works just as well for simulations of the $\gamma d \to \Theta^+ K^-(p)$ reaction, with a spectator proton, and in both cases the resolution of a peak in the appropriate nucleon-kaon mass spectrum is dramatically improved by the MMSA. The MMSA also works for real data, as shown below (see Fig. 3).

2.2 Normalization

In order to extract a cross section, we looked at a variety of reactions, including $\gamma d \to p\ \pi^-(p)$, with a proton spectator. Data exist from other measurements for the $\gamma n \to p\ \pi^-$ reaction, and our analysis agrees well with the world database. In addition, we reproduced the previously published CLAS results on coherent ϕ photoproduction, $\gamma d \to \phi\ d$ to verify the consistency with other analysis from CLAS. With these cross checks, we have all the information needed to produce an upper limit on possible Θ^+ photoproduction in the CLAS detector acceptance.

3. Results

Fig. 3 shows the effect of applying the MMSA to the invariant mass spectrum of the pK^- in the final state. Here, all events assume a neutron spectator, with momentum p_{min}. Without the MMSA, the $\Lambda(1520)$ events are smeared out, and no peak is visible. With the MMSA, the peak is clearly seen. Note that these events are for all photon energies of CLAS, not just 2.0-2.4 GeV. Seeing that this procedure works well for the $\Lambda(1520)$, it should also work for the invariant mass spectrum of the nK^+, where a possible Θ^+ peak might become visible above background only after the MMSA procedure. This was the case for the LEPS measurment, as shown in their paper [2].

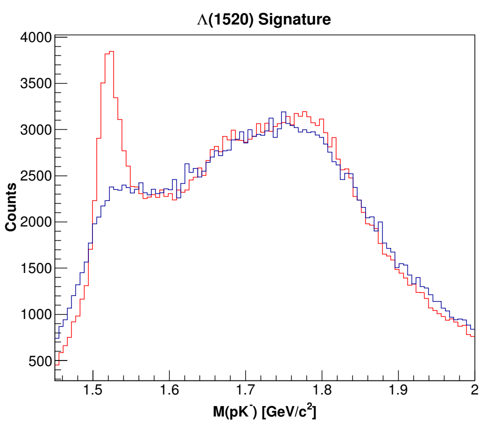

Fig. 3. Spectrum of the pK^- invariant mass before and after the MMSA, showing the $\Lambda(1520)$ peak.

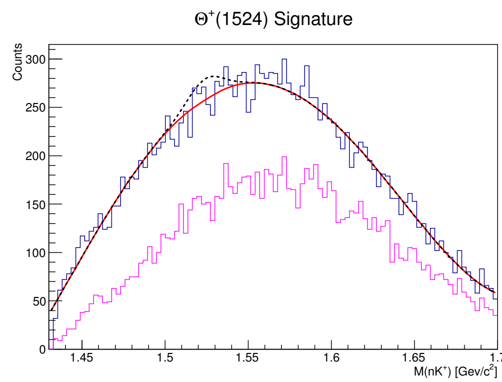

Fig. 4. Preliminary spectrum of the nK^+ invariant mass. The lower spectrum is for a separate set of events with a proton detected. See text for the curves.

Fig. 4 shows *preliminary* results for the invariant mass of the nK^+ system for the reaction $\gamma d \to K^+K^-X$ after application of the MMSA, for a restricted photon energy range of 2.0-2.4 GeV, measured at CLAS for the g10 data set. These events are selected for detection of a K^+ and K^- only (events with additional detected particles are vetoed). The lower histogram is for a separate set of events where a proton was detected in addition to the K^+ and K^-. The smooth line is a fit to a polynomial, and the dotted line shows what would be expected for a Θ^+ peak with a total cross section of 12 nb on top of the polynomial fit, with an assumed width of 10 MeV (chosen to match the expected experimental resolution of CLAS) and a mass of 1.524 GeV/c^2. These values were chosen because this is the cross section reported for a peak at that mass in the LEPS paper [2], integrated over the angular region of their detector.

Although these results are still preliminary, it appears that an upper limit for possible Θ^+ production, integrated over the angular region of the CLAS detector for the same photon energy range as LEPS, might be on the order of several nanobarns or so. There is no hint of a peak in the spectrum of Fig. 4 at any value of mass, so only an upper limit can be extracted, which is in progress.

An obvious question is why the LEPS measurement [2] sees a clear peak in their data, yet the CLAS data show no peak for the same reaction. One possible explanation is that the angular region for the LEPS detector covers only forward angles ($\cos\theta_{CM} > 0.9$) for both kaons, whereas the CLAS detector excludes these angles due to the beam pipe along the detector axis. If the production mechanism for possible Θ^+ photoproduction depends strongly on the momentum transfer variable, t, then it is possible that its cross section could be smaller in the CLAS angular range. Another possible explanation is that the LEPS data was a statistical fluctuation, perhaps coupled with a kinematic reflection as proposed by Torres and Oset [5]. Whatever the reason, more data is necessary to resolve this discrepancy between the LEPS result for the Θ^+ and other measurements.

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