Measurements of ^{3}He$(e, e'\pi^{\pm}p)$ Triple Coincidences as a Search for Preformed Δ-Baryons in the ^{3}He Ground State

Abstract

We propose to measure triple coincidence reactions ^{3}He$(e, e'\pi^{\pm}p)$ at three different missing momenta (i.e. initial momenta of the $\pi^{\pm}p$ system) of 100 MeV/c, 200 MeV/c and 300 MeV/c, respectively, and different angles of the pion with repect to momentum transfer in order to investigate the Δ^{++} component in the ^{3}He ground state.

1 Introduction

This proposal is a continuation of our research on the pion electroproduction off the ^{3}He nucleus that we initiated about six years ago [1]. This study aimed to search for a preformed Δ-resonance component in the ^{3}He ground state. Thanks to the two beam time allocations of the MAMI Program Advisory Committees (PACs):

a) In 1994 [1], we measured the ^{3}He(e,e$'\pi^{\pm}$) reactions at four-momentum transfers $Q^2 = 0.045$ (GeV/c)^2 for energy transfers of ω = 370-430 MeV, for incident electron energy (scattering angle) combinations of E_e (θ_e) = 855 MeV (19.5°), 675 MeV (28.4°), 600 MeV (36.4°), and 555 MeV (40.8°). These measurements also enabled us to perform Rosenbluth separations for the pion production on a composite nucleus, with pions detected along the direction of the virtual photon. Due to the excellent resolutions of the three spectrometer setup at MAMI, we were able to separate the two body coherent channel from the breakup channels. In the longitudinal part of the cross section for the π^+ channel a comparison with the so far only existing microscopic model [2] and qualitative arguments suggests the assumption of a preformed Δ^{++}. These results are published [3] and they constituted the doctorate thesis of M. Kuss [4].

b) In 1995, we measured the pion angular distributions of the ^{3}He(e,e$'\pi^+$) reaction at an incident electron energy $E_e = 855$ MeV and a momentum transfer of $Q^2 = 0.045$ (GeV/c)^2 (the same electron kinematics as above) [5]. During the same beam time, we have also successfully demonstrated the feasibility of triple coincidence measurements for the ^{3}He(e,e$'$pπ^+) process. The data analyses are now in progress. The double coincidence data are being analysed separately for the coherent and breakup channels. Simultaneously, these data are also being examined in terms of the above mentioned model and other theoretical approaches.

Now, we would like to extend our research on this topic and perform triple coincidence measurements of the ^{3}He(e,e$'$pπ^+) and ^{3}He(e,e$'$pπ^-) reactions. Below, we present the physics motivations, measurement methods and beam time requests.

2 Physics Motivation

We initiated the pion electroproduction studies primarily to determine a possible Δ isobar component in the ground state of ^{3}He. While the high quality data we have obtained till now are already a challenge for theoreticians, it became obvious that double coincidence data with pions detected along with electrons are not specific enough to unambiguously determine a Δ isobar component. For one thing, one could not easily compare the longitudinal/transverse ratios of π^+/π^- channels at low and high missing mass regions. This is due to the fact that at low missing masses the π^+ channel receives contributions from the 2-, 3- and 4-body hadronic final states (tπ^+, dnπ^+, and pnnπ^+), whereas the π^- channel is of a pure 4-body final state (viz. pppπ^-). The very high resolution of the system enabled the separation of the 2-body final state, but the others remain unresolved. This mixture has implications beyond simple kinematical considerations, i.e. the dnπ^+ final state dominates at low missing masses. Now, we propose to do triple coincidence measurements for both ^{3}He(e,e$'$p$\pi^\pm$) channels under identical kinematical settings. In contrary to the former ^{3}He(e,e$'\pi^\pm$) experiments a triple coincidence measurement selects out the pure 4-body final states, i.e. (pπ^+)nn and (pπ^-)pp, respectively. It not only spans identical phase space regions in both channels, but also covers the dynamical regions with ratios that are determined by simple spin-isospin coupling coefficients. To understand this argument, the following reasoning might be useful.

The processes of interest are

$$^3\mathrm{He} + \mathrm{e} \longrightarrow \mathrm{e}' + \mathrm{p} + \pi^+ + (\mathrm{nn})$$

$$^3\mathrm{He} + \mathrm{e} \longrightarrow \mathrm{e}' + \mathrm{p} + \pi^- + (\mathrm{pp})$$

The pairs of particles in brackets are the undetected nucleon pairs which are in a state of $T = 1$. The pπ^+ pair has $T = 3/2$, same as that of Δ^{++}, whereas the pπ^- pair is of either $T = 3/2$, or $T = 1/2$. Thus with regard to isospin, the pπ^- has extra isospin components. Although both channels are not isospin symmetric, one might estimate the background processes in the pπ^+ channel by a measure of the pπ^- pairs. In this context, it is important to identify possible processes contributing to pπ^+ and pπ^- channels and they are listed below:

	^{3}He(e,e$'$pπ^+)	^{3}He(e,e$'$pπ^-)
a)	Coincident detection of a non-resonantly produced π^+ (e.g. by π-pole term) and a spectator proton	same as for π^+
b)	–	Non-resonant π^- production off a neutron

c)	–	Resonant π^- production off a neutron with Δ^0 as intermediate state
d)	Coincident detection of a spectator proton and a resonantly produced π^+ with a Δ^+ as intermediate state	Coincident detection of a spectator proton and a resonantly produced π^- with a Δ^0 as intermediate state
e)	Final state interactions involving multiple scatterings, pionic charge exchange, etc.	same as for π^+
f)	Δ^{++} knock-out	Δ^0 knock-out

It is important to note that even though one may not be able to calculate each of the processes to the desired reliability, it should be possible to calculate the ratios of each of these channels and kinematical conditions where they would dominate. Then, the task is to identify the kinematics where Δ^{++} knock-out is significant.

The following discussion will help us to choose the kinematics. First, we would like to minimize spectator protons being detected. This condition will be accomplished if we require that the detected protons have momenta of about 200 MeV/c. The single nucleon momentum distributions [6] in ^{3}He peaks at about 40 MeV/c and contributes less than 1% for protons of momenta higher than about 200 MeV/c. All these kinematical arrangements minimize the contributions from (a) and (b). Furthermore, (c) and (d) are suppressed because of the large missing momentum of the undetected nucleon pair.

Thus, the probability to detect events coming from (e) and (f) is enhanced with respect to the background processes. However, the main idea of this experiment is not to insist that all background processes are completely suppressed, because one can never ensure it. On the other hand, the pπ^- channel can be used as a measure of these processes. To a very good approximation, under the same kinematical conditions, these two channels will differ only in terms of the isospin dependent factors, which should be calculable.

It must be noted that Emura *et al.* [7] followed similar arguments in a tagged photon experiment. In comparison to their work, our approach will take advantage of the suppression of Δ production in longitudinal kinematics which is not possible with real photons. Furthermore, the superior resolution of the three spectrometer system should enable us to probe the pion-nucleon invariant-mass region of interest in great detail.

3 Kinematics and Spectrometer Settings

We will use the three spectrometers A, B and C to measure triple coincidence cross sections. The scattered electrons will be detected by spectrometer B, protons and pions in A and C, respectively. As in the past experiment, we will record triple coincidences

^{3}He(e,e$'$p$\pi^\pm$), double coincidences ^{3}He(e,e$'\pi^\pm$) and ^{3}He(e,e$'$p), and for normalization purposes electron singles ^{3}He(e,e$'$).

Spectrometer B: This spectrometer detects electrons. The incident electron energy $E_e = 855$ MeV, the energy and the momentum transfers $\omega = 400$ MeV and $k = 450$ MeV/c, respectively, are chosen to be the same as in the two previous experiments. We detect the scattered electrons in the forward direction at 19.5° in order to enhance the virtual photon flux. Thus, the direction of momentum transfer is 19.6° on the other side of the beam line.

Spectrometer A and C: While one of both will serve as the proton spectrometer, the pions will be detected by the other one. We intend to detect p$\pi^\pm$ pairs with resulting momenta along the virtual photon direction. The kinematics is shown in Fig. 1. We will cover

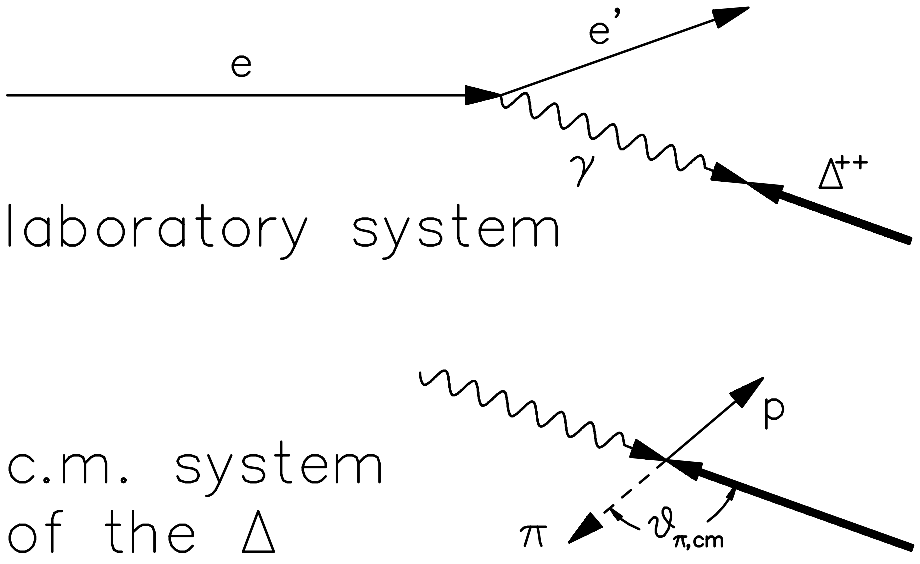

Figure 1: Kinematics for a Δ knock-out process.

a missing momentum range of 100 – 300 MeV/c. The covered proton momentum range varies from 190 – 520 MeV/c. The probability to detect spectator protons is expected to scale like the nucleon momentum distribution as shown in Fig. 2. Thus spectators with momenta higher than 200 MeV/c are very unlike to occur. For π^+ production, this selection ensures that a process such as quasi-deuteron type is highly suppressed in our kinematics. For the π^- process also, this choice will eliminate the spectator protons of low momenta. The protons detected are either spectators belonging to the high momentum component of ^{3}He or direct remnants of the interaction. The momentum range of the pions will extend from 165 – 290 MeV/c. The lower limit is set by the fact that pions of still lower momenta have less than 30% probability of reaching the focal-plane detector system of spectrometer A (39% for spectrometer C) due to their decay. For a set of three fixed missing momenta (100, 200 and 300 MeV/c), the angular distributions of the pions will be measured with respect to the virtual photon direction. The angle of the coincident protons will be chosen in a way that the resulting momentum of the p$\pi^\pm$ pair remains parallel to the virtual photon axis. The measurements will be made for laboratory angles as shown in Tab. 1. With this set of angular distributions the last year's run at

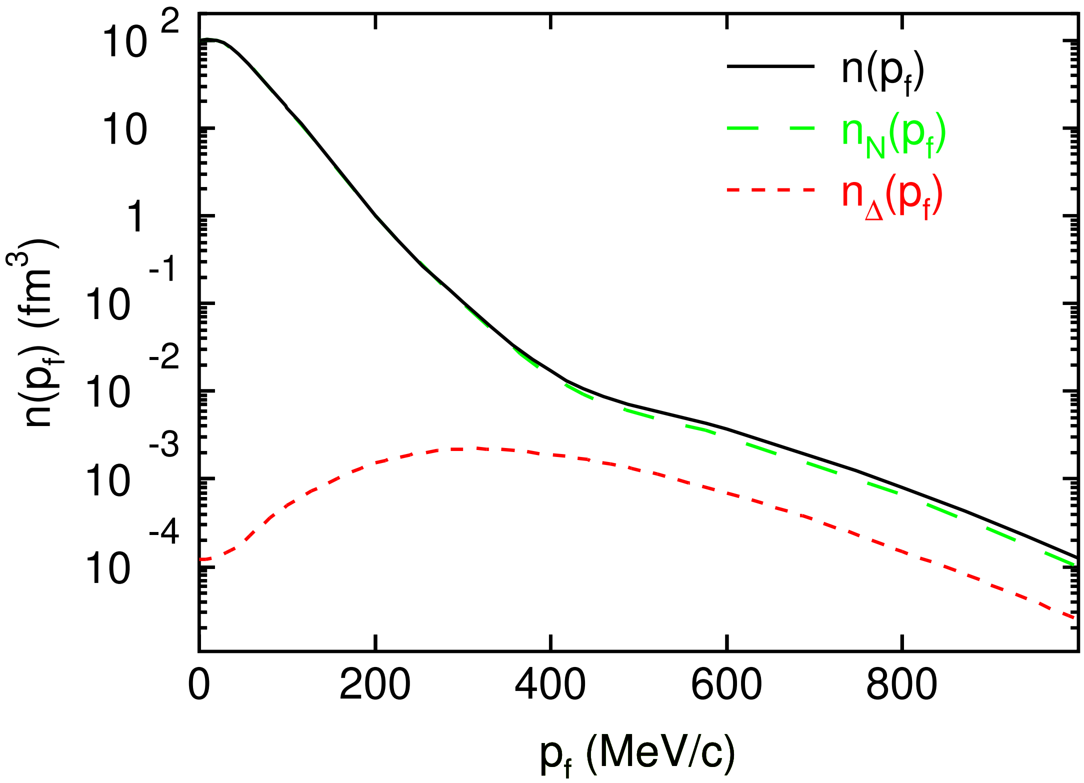

Figure 2: Momentum density distributions of the constituents in ^{3}He. The long dashed line refers to nucleons expected to be in an S-state, the short dashed line represents the contribution of the preformed Δ which is expected to be in a D-state.

a missing momentum of 450 MeV/c will be extended systematically. Figure 3 shows the expected cross sections calculated with the multiple scattering model [2]. While the upper (dashed) curves contain the contributions of preformed Δ isobars in the ground-state wave-function (about 2.5%), the background cross sections are represented by the dotted lines. The cross section distribution due to preformed Δ scales directly with the nucleon momentum density [8] shown in Fig. 2, the background processes increase towards lower missing momenta.

4 Beamtime Request

The test run of 1995 demonstrated that the current is limited by large single rates in the spectrometer detecting the protons. Thus, the count rate estimates refer to a beam current of 15 μA. Our experience from the last year's test experiment is as follows:

- The contribution of accidental triple coincidences can be subtracted with good accuracy.
- The contribution of real $e'\pi^+$ coincidences triggered by an accidental proton can be neglected.

p_{miss} (MeV/c)	θ_p (degree)	θ_π (degree)	p_p (MeV/c)	p_π (MeV/c)	$\frac{d^6\sigma}{d\Omega_e d\omega d\Omega_\pi dp_\pi d\Omega_p dp_p}$ $\left(\frac{10^{-9}\mu b}{(MeV/c)^2 MeV sr^3}\right)$	Count Rate (h^{-1})
300	-53.6	91.9	256.6	257.9	0.5/0.1	2.3/0.5
	23.0	-154.6	368.7	216.8	0.2/0.1	1.0/0.5
	-83.3	63.9	196.1	273.9	0.3/0.1	1.6/0.5
200	-60.4	60.4	192.0	289.2	0.4/0.1	1.9/0.5
	22.4	-154.1	446.6	194.9	0.2/0.1	1.2/0.6
	74.4	-52.6	300.8	258.3	0.3/0.1	1.9/0.6
100	21.9	-153.3	516.1	164.6	0.2/0.1	1.0/0.5
	59.8	-52.0	360.1	244.7	0.3/0.1	2.0/0.7

Table 1: Table of kinematical settings. The momentum of the undected nucleon pair is denoted by p_{miss}. The angles of proton and pion in the laboratory frame are given by θ_p and θ_π. The direction right to the beam line is specified by negative angles (spectrometer C), left (spectrometer A) by positive ones. The momenta of protons and pions are denoted by p_p and p_π, respectively. The two entries for the cross sections and the count rates refer to the calculated numbers with contributions of preformed Δ^{++} isobars and without, respectively.

- The dominant contribution to the accidental counts is given by real e′p coincidences triggered by accidental π^+.

Single rates were estimated with the program codes *QFS* (electrons) and *EPC* (protons and pions) [9], the rate of e′p coincidences by the use of *MCEEP* [10]. It yields overall accuracies of about $0.1{\cdot}10^{-9}\mu b/(MeV/c)^2 MeV sr^3$ for data acquisition times of about 20 hours per setting. The expected experimental cross sections with estimated errors are marked in Fig. 3. Thus, to measure the cross sections with this accuracy we request one day of data taking time per setting. Eight settings for ($p\pi^+$) and ($p\pi^-$), respectively, will result in about 400 hours of beamtime, normalization runs included.

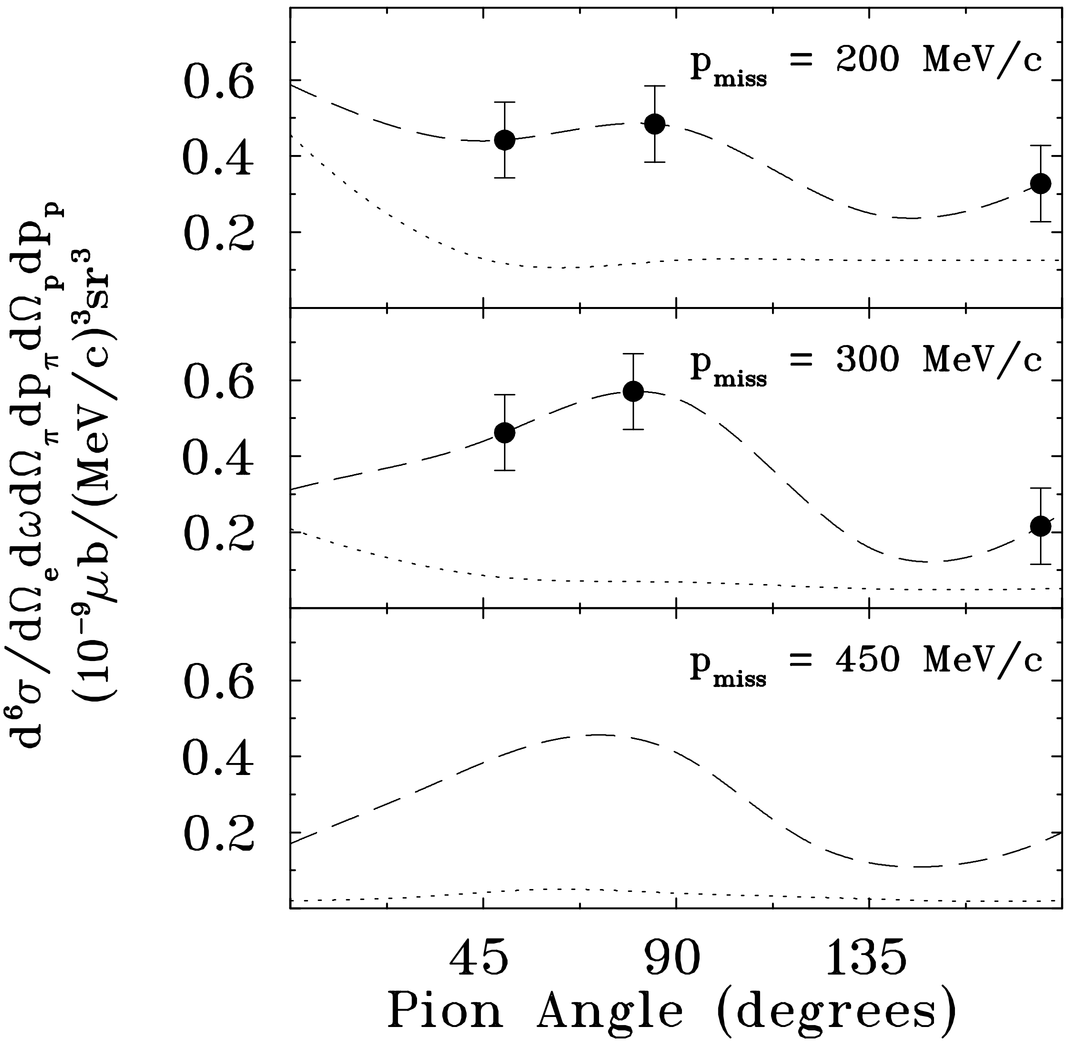

Figure 3: Six-fold differential cross section calculated with the multiple scattering model [2]. While the upper (dashed) curves contain the contributions of preformed Δ isobars (about 2.5%), the background cross sections are represented by the dotted lines. Furthermore, estimates of cross sections at an accuracy expected after one day of data acquisition are marked.

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