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Coherent Photoproduction of Proton-Antiproton Pairs on Deuterium

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Abstract. Photoproduction of hadron-antihadron pairs on deuterium with 4.5÷5.5 GeV energy bremsstrahlung photon beam is presented. Coherent production of $\pi^+\pi^-$, K^+K^-, $p\bar{p}$ pairs has been studied in fully exclusive final state. The goal of this analysis is to study t-channel production of hadron pairs in the mass range > 2 GeV, simultaneously this is a good opportunity to study claims for $p\bar{p}$ resonances. Coherent production on nuclei often used to suppress s- and u-channel production processes in meson spectroscopy studies. The data presented here have been obtained at the (TJNAF) Thomas Jefferson National Accelerator Facility, USA, using the Continues Electron Beam Accelerator Facility (CEBAF) Large Acceptance Spectrometer and the bremsstrahlung tagged photon facility in experimental Hall-B.

Keywords: coherent, photoproduction, hadron, proton-antiproton, deuteron

1. Introduction

Meson spectroscopy plays an important role in hadron physics in particular for understanding the mechanism of confinement. It has been more than forty years since QCD was postulated as the theory of strong interactions. While much progress has been made in understanding perturbative phenomena, the non-perturbative regime, the regime of hadrons, has remained largely impervious to our varied assaults. There is a discrepancy between model predicted and experimentally observed baryon and meson states. One of unsolved mysteries is the lack of exotics, especially in light quark sector. These arestates that are not bound state of 3-quarks (baryon) or$q\bar{q}$ (mesons) but have, for example, explicit gluoniccomponent (valence gluon). Such states are predicted in variety of QCD models, but have not been identified cleanly in experiments.In order to address these questions more studies of hadron spectroscopy with different production and decay modes are needed.

One of interesting channels to look for exotic states is the proton-antiproton system. This channel has been studied for many years, using hadronic and electromagnetic probes. Some of experiments even reported evidences for resonance states [1-5], been as mesons or molecule-like baryonium states. However, there are no clear, high statistics proof of any of reported states. The debate on the existence of these states has greatly lingered on due to a lack of statistics, supporting evidence, and conflicting experimental results. The most recent data on $p\bar{p}$states come from BELLE ($B \to p\bar{p}K^{\pm}$) [6], where they examine $p\bar{p}$ mass spectrum and found that it is inconsistent with phase space and is peaked toward low mass. Another resent result came from BES (radiative decays of J/ψ ($\psi(3686)) \to \gamma p\bar{p}$) claiming the observation of a state at M=1.835GeV [7].

Photoproduction is a powerful tool for hadron spectroscopy. There is an extensive program for meson spectroscopy at Jefferson Laboratory, looking to resolve some of the challenges of hadron spectroscopy. There have been already studies of ($p\bar{p}$) production on hydrogen (reaction $\gamma p \to pp\bar{p}$) using the CEBAF Large Acceptance Spectrometer (CLAS) data. Analysis of high statistics data did not show any resonances.

In this paper we present studies of coherent production of $\pi^+\pi^-$, K^+K^-, and $p\bar{p}$ pairs. Detection of recoil deuterium limits production of hadron pairs to t-channel only, while in the production on the proton there is an ambiguity between recoil and produced (decay) proton, and there are contributions from other production channels (s and u), see Fig. 1. Due to relatively high transferred momentum (t_{min}) in this reaction at available beam energies, deuterons are energetic enough and will be detected in CLAS. Of course, coherent production yields much lower statistics due to suppression by deuteron form-factor.

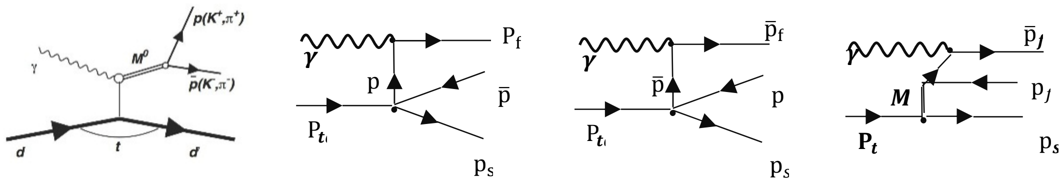

Fig. 1. From left to right: t -channel diagram for proton antiproton photoproduction on deuterium, the diagrams for baryon exchange, antibaryon exchange, meson exchange.

2. The experiment and data analysis

The experiment was carried out at the Thomas Jefferson National Accelerator Facility, in experimental Hall-B, using the CLAS detector [8]. A 5.77 GeV electron beam was used to generate bremsstrahlung photon beam and energy tag using the Hall-B bremsstrahlung tagged photon facility [9]. The tagged photon beam was incident on a 40 cm long and 4 cm diameter liquid deuterium target placed about 40 cm upstream of the CLAS nominal center [10].The direction of the CLAS torus magnet field was chosen such that negatively charged particles were bent outwards. As a trigger for CLAS DAQ,a signature of three-prong events based on the coincidence of signals from the time-of-flight [11] and the start [12] counters, and the track segments in drift chambers [13] was used. Trigger signal from CLAS was in coincidence with tagged photon spectrometer hodoscope, only events with tagged photon in the energy range above E_γ>4.5 GeV have been recorded. About 4.2 billion physics events, 32 TB of raw data were acquired. After calibration, data were processed with CLAS event reconstruction algorithm and four vectors of reconstructed particles were stored, event-by-event bases, for physics analysis.

The analysis of the reaction$\gamma d \rightarrow h^+h^-d'$has been performed in multiple steps. First events were selected based on the topology, one negatively and two positively changed tracks, and no neutrals. Then, three momentum conservation has been used to select exclusive events that have final state transverse momentum ≈ 0 within the detector resolution: $\sum p^i_{x(y)} \approx 0$, where*i* is the final state track number, and$p^i_{x(y)}$ is the track momentum x(y) component. For exclusive events, using relation $\sum p^i_z = E_\gamma$, the tagged photon was identified, and it's time was used as a time reference for the event. Here E_γ is the incoming photon energy.

After event reference time is defined, standard CLAS particle identification, based on time-of-flight, was used to select events with deuteron, and either pion, or kaon, or proton pairs. PID cuts for deuteron included also energy loss in the scintillator counter. PID cuts for hadron pairs were loose.

The key quantity for the final selection of events in each final state, $\pi^+\pi^-d$, K^+K^-d, and $p\bar{p}d$ was done using the energy difference between the initial and final states:

$$\Delta E = \sum_{i=1}^{3} p^i_z + m_d - \sum_{i=1}^{3} E_i \ . \qquad (1)$$

Here $E_{i=}\sqrt{p_i^2 + m_i^2}$, where p_i is the momentum of i^{th} particle and m_i is its PDG (Particle Data Group) mass [14]. One should note that due to relatively large p_z, most of uncertainties in this difference arising from momentum measurement will cancel out in the correlation of p and p_z and the resolution in ΔE is much better than if E_γ is used instead of $\sum p^i_z$.The details of analysis one can find in [15].

In Fig.2-a, the ΔE distribution of$\pi^+\pi^-d'$final states is shown. The tail of the distribution on the left side is due to non-Gaussian effects in the momentum resolution. While longer and slightly larger tail on the right is mostly from non $\pi^+\pi^-d'$ events that leaked into $\pi^+\pi^-$ sample due to the loose PID cuts. The ΔE distribution for the final state $K^+K^-d'$is shown in Fig.2-b. Here the peak on ~0.12 are events from $\pi^+\pi^-d'$ final state, again, due to a loose PID cuts. Finally, in Fig. 2-c the ΔE distribution for $p\bar{p}d'$events, selected after loose PID cutis shown. The final samples were selected with | ΔE|<0.05 GeV.

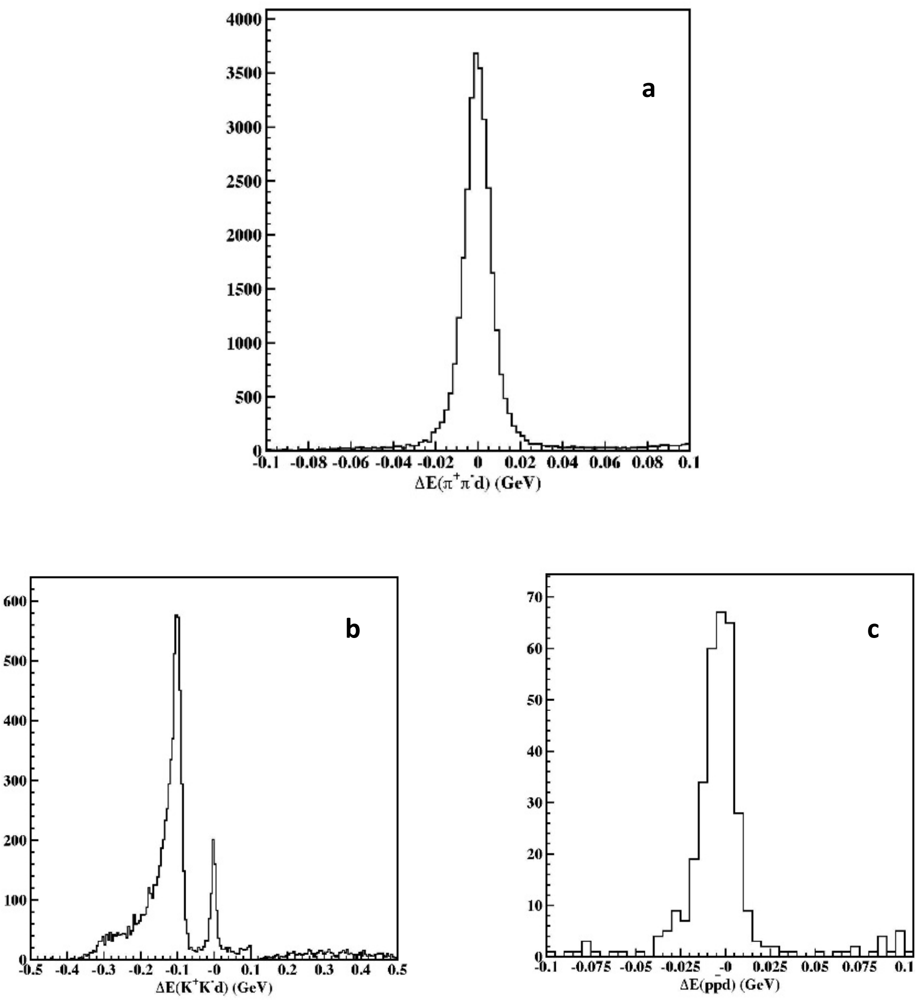

Fig. 2. The ΔE distribution respectively for a)$\pi^+\pi^-d'$, b)K^+K^-d', and c) $p\bar{p}d'$ final events.

3. Results and discussions

This analysis includes three coherent photoproduction reactions on deuterium in fully exclusive final states:

$$\begin{gathered} \gamma d \to \pi^+\pi^- d' \\ \gamma d \to K^+K^- d' \\ \gamma d \to p\bar{p}d' \end{gathered} \tag{2}$$

For each final state, distributions of yields as a function the invariant mass hadron pairs, the transferred momentum squared, and the Center of Mass (CM) angle of a hadron (π, K, p) have been studied. Due to limited statistics, events were integrated for the whole triggered photon energy region, 4.5GeV to 5.6 GeV. As can be seen from Fig. 2, the statistics is largest for pion channel, and the lowest for the proton channel, ~315 events. In order to compare these coherent reactions, we study the invariant mass range >1.95 GeV.

For calculation of acceptance was determined using the standard chain of simulation tools (EvGen (Event Generator) → GSIM (GEANT Simulation) → GPP (GEANT Post Processor) → Recsis (Reconstruction System)). A simple t-channel production model with isotropically distributed pair was used to genera events. At given invariant mass, efficiency for lightest mass pair is slightly larger than for heaviest pair, as one would expect since CLAS has a poor detection acceptance in the forward region.

After correcting for efficiencies, yields for different channels were compared. In Fig. 3, the invariant mass distribution of ratios of yields, $\frac{Y^{p\bar{p}}}{Y^{\pi^+\pi^-}}$ and $\frac{Y^{K^+K^-}}{Y^{\pi^+\pi^-}}$ are shown. While the ratio of yields for kaon and pion pair productions is close to what one would expect from photon coupling $u\bar{u}(d\bar{d}):s\bar{s} \approx 0.2 - 0.25$, the large yield of $p\bar{p}$ production is not simple to explain. It is clearly much easier to produce meson pairs, if assume diffractive scattering of the photon where photon fluctuates to quark anti-quark pair, then baryon pairs (3 quarks and 3 anti-quarks). Similar anomaly was observed for $p\bar{p}$ production in e^+e^- annihilation, L3 experiment at LEP [15], where obtained experimental cross section was order of magnitude higher than calculations with 3-quark production model, while quark di-quark model was able to fit the data reasonably well, see Fig. 4 left graph and the diagrams on top right. It is possible that similar quark di-quark mechanism could be responsible for large $p\bar{p}$ yield in photoproduction as well, see lower right diagram of Fig. 4.

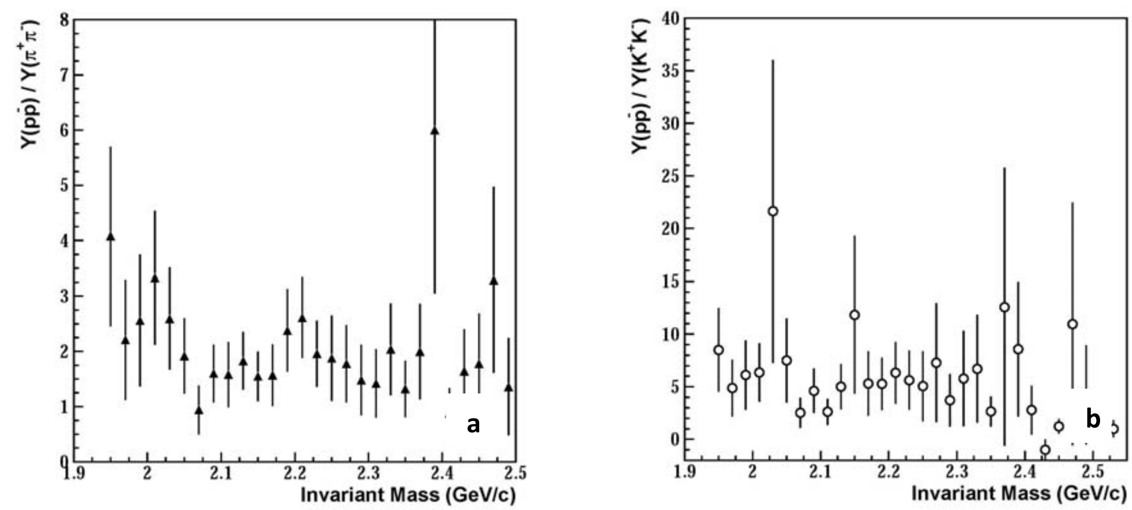

Fig. 3. The distribution of ratio versus invariant mass respectively for final states: a) $\frac{Y^{p\bar{p}}}{Y^{\pi^+\pi^-}}$, b) $\frac{Y^{K^+K^-}}{Y^{\pi^+\pi^-}}$.

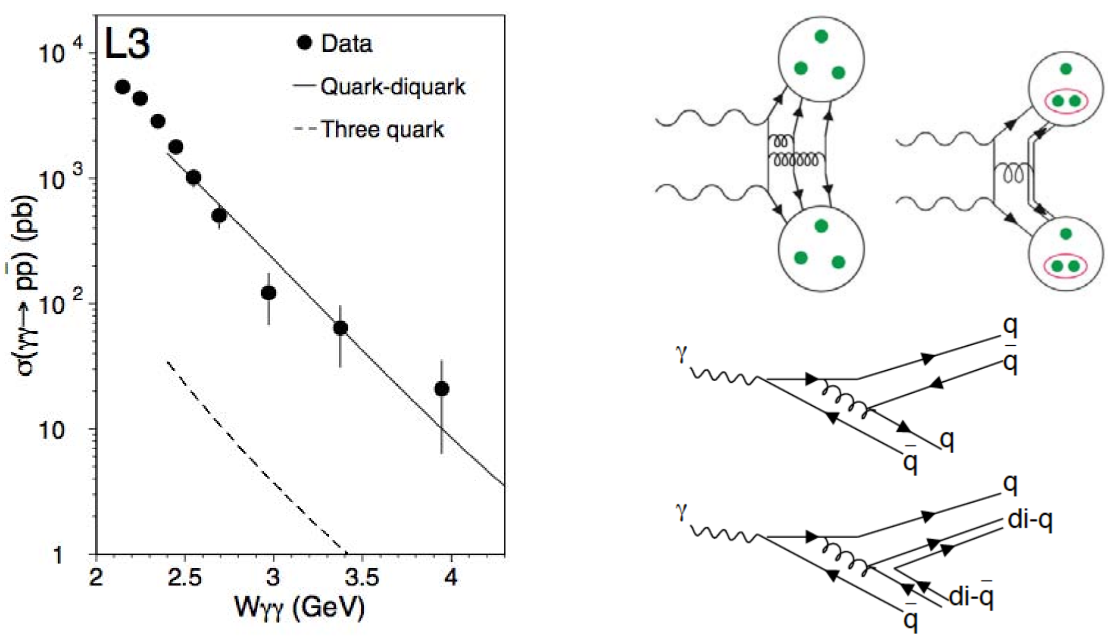

Fig. 4. The production in e^+e^- annihilation from L3 experiment at LEP [**16**]. Data favor diquark anti-diquark hypothesis of the production shown on right.

4. Summary

Thus, in this paper, for the first time, coherent photoproduction of hadron pairs, $\pi^+\pi^-$, K^+K^-, and $p\bar{p}$, were studied on deuterium using up to 5.5 GeV photon beam at the invariant mass region of 1.9 GeV to 2.5 GeV. Coherent production on deuterium has an advantage compared to the production on hydrogen. It eliminates ambiguities in the production mechanism, and contributions from s- and u-channels, only t-channel production is allowed. The aim of the analysis was to investigate the invariant mass region of hadron pair above 2 GeV in order to check claims of several groups on existence of states decaying to $p\bar{p}$ pair.

After correcting for detector efficiency using simulations the relative yields of above three channels have been studies. The relative yield $\pi^+\pi^-$and K^+K^- are close to what one expect, but experiment shows relatively large $p\bar{p}$ yield. It might be possible that quark di-quark mechanism is responsible for relatively large baryon anti-baryon production.

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