Antibaryon Photoproduction using CLAS at Jefferson Lab

HADRON 2015
Will Phelps and Lei Guo
September 18th, 2015
Motivation and Introduction

- Baryon-Antibaryon production has been studied since the early days of nuclear physics.
- There is limited photoproduction data and the photoproduction mechanism is not well understood.
- The main focus of this work is:
  - Provide more details on the production mechanism through:
    - Cross section measurements.
    - A search for wide meson resonances using Partial Wave Analysis.
  - Reactions studied include:
    \[ \gamma p \rightarrow p p \bar{p} \quad \gamma p \rightarrow p p \pi^- \bar{n} \]
Experiment Overview

• **g12 experiment**
  • LH$_2$ target, ran in 2008
    • Target was -90 cm from center
  • Photoproduction: 1.1-5.45 GeV
    • Circularly polarized
  • Total Integrated Luminosity: 68 pb$^{-1}$
  • $7 \cdot 10^7$ tagged photons/s
  • Highest statistics photoproduction experiment to date in this energy range
Antiproton production in two topologies

- **Event selection:**
  - Timing cuts to remove out of time events
  - Limit number of other detected charged particles and photons

- **Unprecedented statistics in proton antiproton photoproduction**
  - $2.5 \times 10^5$ events combined

- **Missing particle selected using missing mass technique**
  - $E_\gamma$ from reaction threshold (3.9 GeV) to 5.45 GeV

\[
\gamma p \rightarrow pp(\bar{p})
\]

- Mean: $0.9370 \pm 0.000022$
- $\sigma$: $0.0078 \pm 0.000023$
- Range: $\pm 3.0 \sigma$
- Yield: 173772

- Mean: $0.9375 \pm 0.000034$
- $\sigma$: $0.0078 \pm 0.000036$
- Range: $\pm 3.0 \sigma$
- Yield: 70414
Search for narrow resonances

- Narrow resonances have been observed in the past
- No evidence for narrow resonances in current analysis

\[ \gamma p \rightarrow pp(\bar{p}) \]


Note: \( E_\gamma \) from 3.9-5.5 GeV
Current Monte Carlo Model

- Current model is a diffractive model tuned to be as close to data as possible
  - Similar to accuracy of previous measurements
- Differential cross sections will be used as a starting point for creating a more accurate model
Modeling the Reaction

- Extracting a differential cross section for this reaction is not trivial.
- Acceptance is very sensitive to model.
- This particular reaction has been modeled in the past by mixing different production models to produce accurate acceptances (Diffractive, nucleon exchange and antinucleon exchange models).
- The alternatives include creating a model using calculated cross sections (PLUTO++).
Acceptance Corrected Mass Spectra

• Showing the invariant masses of the proton-proton pair and the proton-antiproton pair as a function of beam energy
• Proton-antiproton pair is double counted, as there are two combinations due to two protons in the final state
• This will be used to create a reaction model for generating Monte Carlo
Acceptance Corrected Mass Spectra

$E_\gamma = 4.000\ \text{GeV}$

*Statistical errors only*
Acceptance Corrected Mass Spectra

$E_\gamma = 4.100 \text{ GeV}$

*Statistical errors only*
Acceptance Corrected Mass Spectra

$E_\gamma = 4.200 \text{ GeV}$

*Statistical errors only*
Acceptance Corrected Mass Spectra

$E_\gamma = 4.300 \text{ GeV}$

*Statistical errors only*
Acceptance Corrected Mass Spectra

$E_\gamma = 4.400$ GeV

*Statistical errors only*
Acceptance Corrected Mass Spectra

\[ E_\gamma = 4.500 \text{ GeV} \]

*Statistical errors only*
Acceptance Corrected Mass Spectra

$E_\gamma = 4.600 \text{ GeV}$

*Statistical errors only*
Acceptance Corrected Mass Spectra

$E_\gamma = 4.700 \text{ GeV}$

*Statistical errors only*
Acceptance Corrected Mass Spectra

\[ E_\gamma = 4.800 \text{ GeV} \]

*Statistical errors only*
Acceptance Corrected Mass Spectra

\[ E_\gamma = 4.900 \text{ GeV} \]

*Statistical errors only*
Acceptance Corrected Mass Spectra

$E_\gamma = 5.000$ GeV

*Statistical errors only*
Acceptance Corrected Mass Spectra

\[ E_\gamma = 5.100 \text{ GeV} \]

Normalized Yield \( \frac{dN}{dM(pp \text{ or } pp)} \)

- Green diamonds: Normalized Yield \( pp \)
- Blue dots: Normalized Yield \( pp \)

*Statistical errors only*
Acceptance Corrected Mass Spectra

$E_\gamma = 5.200$ GeV

*Statistical errors only*
Acceptance Corrected Mass Spectra

$E_\gamma = 5.300$ GeV

*Statistical errors only*
Acceptance Corrected Mass Spectra

$E_\gamma = 5.400 \text{ GeV}$

*Statistical errors only*
Acceptance Corrected Mass Spectra

*Statistical errors only*
Differential Cross Section

• First measurement of the differential cross section in photoproduction
• This measurement is made with respect to the antiproton \( \cos(\theta) \) angle in the center of momentum frame
• Will be used in combination with a beam profile and differential cross section with respect to the two proton invariant mass
• Fit with a 3\(^{rd}\) order Chebyshev polynomial
Differential Cross Section

\[ E_{\gamma} = 3.975 \text{ GeV} \]

*Statistical errors only*
Differential Cross Section

$E_\gamma = 4.025$ GeV

*Statistical errors only*
Differential Cross Section

$E_{\gamma} = 4.075$ GeV

*Statistical errors only*
Differential Cross Section

$E_\gamma = 4.125 \text{ GeV}$

*Statistical errors only*
**Differential Cross Section**

\[ E_\gamma = 4.175 \text{ GeV} \]

*Statistical errors only*
Differential Cross Section

\[ E_\gamma = 4.225 \text{ GeV} \]

*Statistical errors only*
Differential Cross Section

\[ E_\gamma = 4.275 \text{ GeV} \]

*Statistical errors only*
Differential Cross Section

$E_\gamma = 4.325 \text{ GeV}$

Preliminary

*Statistical errors only
Differential Cross Section

\[ E_\gamma = 4.375 \text{ GeV} \]

*Statistical errors only*
Differential Cross Section

$E_\gamma = 4.425$ GeV

$\frac{d\sigma}{d\cos(\theta)}$ [nb]

$\cos(\theta_{C.M.})$

*Statistical errors only*
Differential Cross Section

$E_\gamma = 4.475$ GeV

$\frac{d\sigma}{d\cos(\theta)}$ [nb]

$\cos(\theta_{p,C.M.})$

*Statistical errors only*
Differential Cross Section

\[ E_\gamma = 4.525 \text{ GeV} \]

\[ \frac{d\sigma}{d\cos(\theta)} \text{ [nb]} \]

*Statistical errors only*
Differential Cross Section

$E_\gamma = 4.575$ GeV

*Statistical errors only*
Differential Cross Section

\[ E_\gamma = 4.625 \text{ GeV} \]

*Statistical errors only*
Differential Cross Section

\[ E_\gamma = 4.675 \text{ GeV} \]

\[ \frac{d\sigma}{d\cos(\theta)} \text{ [nb]} \]

*Statistical errors only*
Differential Cross Section

\[ E_\gamma = 4.725 \text{ GeV} \]

*Statistical errors only*
Differential Cross Section

$E_\gamma = 4.775$ GeV

*Statistical errors only*
Differential Cross Section

\[ E_\gamma = 4.825 \text{ GeV} \]

*Statistical errors only*
Differential Cross Section

\[ E_\gamma = 4.875 \text{ GeV} \]

*Statistical errors only*
Differential Cross Section

$E_\gamma = 4.925 \text{ GeV}$

*Statistical errors only*
Differential Cross Section

$E_\gamma = 4.975 \text{ GeV}$

*Statistical errors only*
Differential Cross Section

\[ E_\gamma = 5.025 \text{ GeV} \]

*Statistical errors only*
Differential Cross Section

\[ E_\gamma = 5.075 \text{ GeV} \]

\[ \frac{d\sigma}{d\cos(\theta)} \text{ [nb]} \]

\[ \cos(\theta_{p}^{C.M.}) \]

*Statistical errors only*
Differential Cross Section

$E_\gamma = 5.125$ GeV

*Statistical errors only*
Differential Cross Section

$E_γ = 5.175 \text{ GeV}$

*Statistical errors only*
Differential Cross Section

\[ E_\gamma = 5.225 \text{ GeV} \]

\[ \frac{d\sigma}{d\cos(\theta)} \text{ [nb]} \]

*Statistical errors only*
Differential Cross Section

\[ E_\gamma = 5.275 \text{ GeV} \]

\[ \text{Preliminary} \]

*Statistical errors only*
Differential Cross Section

\[ E_\gamma = 5.325 \text{ GeV} \]

*Statistical errors only*
Differential Cross Section

$E_\gamma = 5.375$ GeV

*Statistical errors only*
Differential Cross Section

E_\gamma = 5.425 \text{ GeV}

\begin{figure}
\centering
\includegraphics[width=\textwidth]{differential_cross_section}
\caption{Differential cross section for antibaryon photoproduction using CLAS at Jefferson Lab.}
\end{figure}

*Statistical errors only*
Differential Cross Section

\[ \frac{d\sigma}{d\cos(\theta_p^*)} \]

*Statistical errors only*
Total Cross Section

- Tuned diffractive production model
- Many corrections still need to be applied
- Comparison to world data shown
- Integrated 3\textsuperscript{rd} order Chebyshev polynomial fits to $d\sigma/d\cos(\theta_{\bar{P}}^{cm})$

Note: CLAS 2003 results from unpublished CLAS analysis note


*Statistical errors only
Why perform a PWA?

- Large number of mesons observed in proton antiproton annihilation
- Multiple high mass, broad width mesons could be contributing
- Creating accurate simulation is difficult
- Performing a “Mother fit” with many waves will allow generation of accurate simulation

<table>
<thead>
<tr>
<th>Abridged Resonance Candidates (MeV)</th>
<th>Γ (MeV)</th>
<th>J^pc</th>
</tr>
</thead>
<tbody>
<tr>
<td>rho_3(1990)</td>
<td>196±31</td>
<td>3^-</td>
</tr>
<tr>
<td>f_0(2020)</td>
<td>442±60</td>
<td>0^{**}</td>
</tr>
<tr>
<td>f_2(2150)</td>
<td>152±30</td>
<td>2^{**}</td>
</tr>
<tr>
<td>rho(2150)</td>
<td>~250-320(?)</td>
<td>1^-</td>
</tr>
<tr>
<td>rho_3(2250)</td>
<td>~220</td>
<td>3^-</td>
</tr>
<tr>
<td>rho_5(2350)</td>
<td>400±100</td>
<td>5^-</td>
</tr>
<tr>
<td>f_6(2510)</td>
<td>283±40</td>
<td>6^{**}</td>
</tr>
</tbody>
</table>

*PDG 2014
Antineutron Reaction Model

- After many iterations simulation that matches was generated
- Momentum, angles, and $t$ distributions match

$$\gamma p \rightarrow pp\pi^- (\bar{n})$$
Antineutron Cross Section

\[ \gamma p \rightarrow pp\pi^- (\bar{n}) \]

- First measurement of total cross section
- \( \sim 1400 \) Events
- Tuned simulation
- \( \sim 10 \times \) lower cross section than the proton antiproton reaction

*Statistical errors only*
Summary

• No obvious evidence of narrow resonance production
• Preliminary (First time) differential and total cross sections shown for proton antiproton reaction
• Model for generating Monte Carlo is in progress
  • Using PLUTO++ for differential cross section defined reaction model
• Partial Wave Analysis searching for broad resonances in the works
  • As a cross-check for the PLUTO++ simulation, use the production amplitudes from the fit to construct a model to generate Monte Carlo
• First time observation and cross section for an antineutron in photoproduction
Supplemental material
Acceptance