Polarization Transfer in Wide Angle Charged Pion Photoproduction

John Arrington – Argonne National Lab
Andrew Puckett – University of Connecticut
Arun Tadepalli – Jefferson Lab
Bogdan Wojtsekhowski – Jefferson Lab
The spokespersons

John Arrington  Andrew Puckett  Arun Tadepalli  Bogdan Wojtsekhowski
> 60 collaborators!
Contents

• Field of Meson Photoproduction
• Observed yet unexplained cross sections
• Theoretical efforts
• Possible solution: Polarization tests of handbag mechanism?
• What are we proposing?
• Summary
Meson Photo- and Electroproduction

• Has been around for quite some time!

• Early measurements at Stanford conducted to study the ratio of the pions produced due to electro and photo production
Measurements of exclusive photoproduction

- Other measurements of exclusive photoproduction were conducted which revealed intriguing features.
Measurements conducted for a variety of physics processes and particles

**Table 1.** List of reactions and photon energies covered in this experiment.

<table>
<thead>
<tr>
<th>Process</th>
<th>Energy (GeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\gamma p \rightarrow \pi^+ n$</td>
<td>4, 5, 7.5</td>
</tr>
<tr>
<td>$\gamma p \rightarrow \pi^0 p$</td>
<td>4, 5</td>
</tr>
<tr>
<td>$\gamma p \rightarrow \pi^\pm \Delta^*$</td>
<td>4, 5</td>
</tr>
<tr>
<td>$\gamma p \rightarrow \pi^0 \Delta$</td>
<td>4, 6</td>
</tr>
<tr>
<td>$\gamma p \rightarrow \pi^0 \Delta^*$</td>
<td>4, 5</td>
</tr>
</tbody>
</table>

**Fig. 6.** $s^2 da/dt$ versus $\cos \theta^*$ for the reaction $\gamma p \rightarrow \pi^+ n$. The solid line shows the empirical function $(1 - z)^{-4} (1 + z)^{-4}$ where $(z = \cos \theta^*)$, which is an empirical fit to the angular distribution.

**Fig. 9.** $s^2 da/dt$ versus $\cos \theta^*$ for the reaction $\gamma p \rightarrow \pi^0 p$.

**Fig. 12.** $s^2 da/dt$ versus $\cos \theta^*$ for the reaction $\gamma p \rightarrow \pi^- \Delta^{*+}$. 
Mechanism of scaling

• Continuing interest in the features but the cross sections are still unexplained

• Models tried to explain the observed cross sections by considering the number of “active fields” involved in the photoproduction
  • CCR (Constituent Counting Rules)
  • HHC (Hadron Helicity Conservation)
  • pQCD (perturbative QCD)
  • Handbag approach in the GPD framework (Generalized Parton Distributions)
Photoproduction experiments in Hall A

- Photoproduction experiments conducted in Hall A using LHRS and RHRS

- $\pi^+$ and $\pi^-$ cross sections and their ratios studied for a range of $s$ and $t$

- Many intriguing features that still have continued interest at Jefferson Lab
Experiment in Hall A E94-104

FIG. 18. (Color online). Exclusive charged pion ratio \( \frac{d\sigma}{d\Omega}(\gamma p \rightarrow \pi^+ p)/d\sigma(d\gamma p \rightarrow \pi^+ n) \) versus center-of-mass energy \( \sqrt{s} \) and momentum transfer square \( t \) at pion center-of-mass angle \( \theta_{c.m.} = 90^\circ \) from JLab E94-104 and previous world data [48], together with the SAID [66], MAID [67], and one-hard-gluon-exchange calculation [44,45].
But calculations fall short!

Signatures of the handbag mechanism in wide-angle photoproduction of pseudoscalar mesons

H.W. Huang¹, R. Jakob², P. Kroll², K. Passek-Kumerički³

¹ Department of Physics, University of Colorado, Boulder, CO 80309-0390, USA
² Fachbereich Physik, Universität Wuppertal, 42097 Wuppertal, Germany
³ Theoretical Physics Division, Rudjer Bosković Institute, 10002 Zagreb, Croatia

\[ \sigma(\gamma n \rightarrow \pi^- p) \approx \left( \frac{e_u s + e_d u}{e_u u + e_d s} \right)^2 \]

Fig. 1. The handbag diagram for photo- and electroproduction of mesons. The large blob represents a baryon GPD, while the small one stands for meson photo- and electroproduction off partons. The momenta of the various particles are indicated

Fig. 4. The ratio of the \( \gamma n \rightarrow \pi^- p \) and \( \gamma p \rightarrow \pi^+ n \) cross sections versus photon beam energy \( E \), at a CMS scattering angle of 90°. Data are taken from [31]. The solid line is the handbag prediction with the identification (48). The uncertainties due to target mass corrections [30] are indicated by the shaded band
π⁰ photoproduction experiments in Hall B

• Calculations using the Handbag approach fall short by more than two orders of magnitude

• Missing some crucial information in the amplitude used in calculations

• Figuring that out will shed light on the interaction mechanism responsible for these cross sections
Calculations with higher twists

- Calculations with twist 2 and twist 3 contributions performed for $\pi^0$
- They are in reasonable agreement (black curve) with CLAS data
- Polarization test of the handbag mechanism is necessary and timely

Figure 3: Results for the cross section of $\pi^0$ photoproduction versus the cosine of the c.m.s. scattering angle, $\theta$. The solid (dashed, dotted) curves represent our results at $s = 11.06 (20, 9)$ GeV$^2$. The data at $s = 11.06$ GeV$^2$ are taken from CLAS [34]. The cross sections are multiplied by $s^7$ and the theoretical results are only shown for $-t$ and $-u$ larger than 2.5 GeV$^2$. 
Helicity correlation observables

- Helicity correlations $A_{LL}$ and $K_{LL}$ provide tests of the handbag mechanism.
- Twist 3 contribution dominates twist 2.
- Predictions made for $\pi^0$ and $\pi^-$. 

$$K_{LL} = \frac{d\sigma(+, \rightarrow) - d\sigma(-, \rightarrow)}{d\sigma(+, \rightarrow) + d\sigma(-, \rightarrow)}$$

$$A_{LL} = \frac{d\sigma(+ \rightarrow) - d\sigma(- \rightarrow)}{d\sigma(+ \rightarrow) + d\sigma(- \rightarrow)}$$

\[ A^{\text{twist-2}}_{LL} = K^{\text{twist-2}}_{LL} \]

\[ A^{\text{twist-3}}_{LL} = -K^{\text{twist-3}}_{LL} \]
Predictions for $\pi^-$

- Measurements have been conducted for WACS for $\pi^0$ which show good agreement with handbag mechanism.
- Calculations made by Kroll et al for WAPP $\pi^-$ case.
- Measurement will test the calculations as well as provide constraints for other models.
- This measurement is fundamental, important and the first of its kind in the wide angle regime!
Experimental setup: same as GEn-RP setup

- 6.6 GeV electron beam (photons in the range 4.0 – 6.0 GeV)
- LD2 target with 6% Cu radiator upstream
- BigBite as the pion arm
- SBS as the nucleon arm
Mandelstam variables >> \( \lambda_{QCD} \) to test out handbag mechanism

Figure 11: Distributions of \( s, -t, -u \), and \( \cos \theta_{CM} \) within the combined BigBite-SBS acceptance, from \( g \phi sb \), the SBS GEANT4-based Monte Carlo simulation package. See text for details.
Figure 12: Distributions of $E_\gamma$, the incident photon energy, $p_\pi$, the $\pi^-$ momentum in Big Bite, and $p_p$, the proton momentum in SBS. Note that 4 GeV was the lower limit placed on $E_\gamma$ for "signal" event generation.

$$s^7 \frac{d\sigma}{dt} (\gamma p \to \pi^+ n) = 0.828 \times 10^7 (1 - z)^{-5} (1 + z)^{-4} \text{ (nb/GeV}^2 \cdot \text{GeV}^{14})$$
Energy deposition in the preshower and shower

- GEn-RP trigger designed to have increased $e^-$ efficiency

- Threshold cuts have to be applied on at the trigger level to suppress $e^-$ and increase pion detection efficiency

- Need to demonstrate the feasibility of such a configuration change
Projected results for $K_{LL}$

<table>
<thead>
<tr>
<th>$E_{\gamma}$</th>
<th>$&lt; s &gt;$</th>
<th>$&lt; -t &gt;$</th>
<th>$&lt; -u &gt;$</th>
<th>$K_{ss}$ accuracy</th>
<th>$K_{ss}$ accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>GeV</td>
<td>(GeV/c)$^2$</td>
<td>(GeV/c)$^2$</td>
<td>(GeV/c)$^2$</td>
<td>±0.05</td>
<td>±0.05</td>
</tr>
<tr>
<td>4.5-5.5</td>
<td>9.3</td>
<td>4.6</td>
<td>2.9</td>
<td>±0.05</td>
<td>±0.05</td>
</tr>
</tbody>
</table>

Just 48 hours with 16 hours beam energy change procedure (4.4 to 6.6 GeV)!
Summary

• Wide angle pion photoproduction is an interesting and a powerful tool to study the interaction mechanism in the wide angle regime

• A solution (handbag approach in the framework of GPDs) has been proposed and an independent test of the polarization observables is timely and necessary

• Proposal has been submitted to PAC48

• With minimal beam time request and experiment configuration change, we can test something fundamental that will contribute to the 3D picture of the nucleon

• There is an intention to measure $A_{LL}$ using polHe3 (proposal to a future PAC)!
Thank you!
Single arm and coincidence rates

Table 1: Estimated single arm and coincidence trigger rates from PYTHIA, assuming 5 μA on 15-cm LD₂ target with 6% Cu radiator. The “Pion” logic consists of requiring the preshower signal to be less than 100 MeV and applying the indicated threshold on the shower. The “Electron” logic consists of applying the indicated threshold on the sum of preshower and shower signals. The coincidence timing window is assumed to be 30 ns wide for the accidental rate estimate.

<table>
<thead>
<tr>
<th>Trigger Logic</th>
<th>“Pion”</th>
<th>“Pion”</th>
<th>“Electron”</th>
<th>“Electron”</th>
</tr>
</thead>
<tbody>
<tr>
<td>Threshold (GeV)</td>
<td>0.2</td>
<td>0.5</td>
<td>0.2</td>
<td>0.5</td>
</tr>
<tr>
<td>“Signal” pion efficiency</td>
<td>75%</td>
<td>49%</td>
<td>97%</td>
<td>71%</td>
</tr>
<tr>
<td>BigBite singles rate (kHz)</td>
<td>422</td>
<td>91</td>
<td>976</td>
<td>289</td>
</tr>
<tr>
<td>HCAL singles rate (kHz)</td>
<td>416</td>
<td>416</td>
<td>416</td>
<td>416</td>
</tr>
<tr>
<td>Accidental coin. rate (kHz)</td>
<td>5.3</td>
<td>1.1</td>
<td>12.2</td>
<td>3.6</td>
</tr>
<tr>
<td>Real coin. rate (kHz)</td>
<td>6.2</td>
<td>2.5</td>
<td>14.3</td>
<td>6.5</td>
</tr>
<tr>
<td>Total coin. rate (kHz)</td>
<td>11.5</td>
<td>3.6</td>
<td>26.5</td>
<td>9.8</td>
</tr>
<tr>
<td>Physics signal rate ((\gamma n \rightarrow \pi^- p, Hz))</td>
<td>16.3</td>
<td>10.4</td>
<td>23.5</td>
<td>17.2</td>
</tr>
</tbody>
</table>