Measurement of Double-Polarization Observables in $\vec{\gamma} \vec{p} \rightarrow p \pi^+ \pi^-$

V. Credé$^1$, M. Bellis$^2$, S. Strauch$^3$, and the CLAS Collaboration

$^1$Florida State University, Tallahassee, Florida
$^2$Carnegie Mellon University, Pittsburgh, PA
$^3$University of South Carolina, Columbia, SC

Meeting of PAC 29, 1/12/2005
Outline

1. Introduction
   - Baryon Spectroscopy

2. Double-Pion Photoproduction
   - Scientific Motivation
   - Previous Measurements
   - Double-Polarization Experiments

3. Analysis Techniques

4. Count Rate Estimate
   - Sensitivity Studies
   - Background and Dilution Factor
   - Beam Time Request
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Atomic spectra allow access to QED

- Discrete spectrum of absorption and emission lines

⇒ Does excitation spectrum of nucleon provide access to QCD?
The Challenges in Baryon Spectroscopy

Unfortunately, $N^*$ spectral lines look more like

$\Rightarrow$ Baryons are broad and overlapping

- Rescattering Effects
  $\Rightarrow$ Require Coupled-Channel Analysis
  (need to measure as many final states as possible)
- Polarization (need complete experiments)
Introduction
Double-Pion Photoproduction
Analysis Techniques
Count Rate Estimate

Baryon Spectroscopy

E_{\gamma} [GeV]

Reaction Thresholds

W [GeV/c^2]

Existing Facilities

BONN
CLAS
MAMI-C
GRAAL
LEGS

V. Credé
Double-Polarization Observables in $\gamma p \rightarrow p \pi^+ \pi^-$
Why have the missing resonances not been discovered, yet?

- Investigated mass region was mainly below 1800 MeV/c²
Why have the missing resonances not been discovered, yet?

- Investigated mass region was mainly below 1800 MeV/c^2
- Polarization (essentially) only available at low energies
Why have the missing resonances not been discovered, yet?

- Investigated mass region was mainly below 1800 MeV/c²
- Polarization (essentially) only available at low energies
- Channels with more than one meson still not explored
Great Chance ...

The Double-Polarization Program (FROST) at JLab:

- E 02-112  $\Rightarrow$  Photoproduction of Hyperons
- E 03-105  $\Rightarrow$  $\pi$ Photoproduction
- E 04-102
- E 05-012  $\Rightarrow$  $\eta$ Photoproduction
- PR 06-013  $\Rightarrow$  $\pi^+\pi^-$ Photoproduction (same exp. setup)

The Double-Polarization Program at ELSA (Crystal Barrel Experiment):
(among many other proposals)

- ELSA 6/2005  $\Rightarrow$  $\pi^0\pi^0$ Photoproduction
- ELSA 7/2005  $\Rightarrow$  $\pi^0\eta$ Photoproduction
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Motivation: Low-Energy Regime

- $P_{11}(1440)$ (*Roper Resonance*) $\rightarrow$ too low in mass?  
  - dynamically-generated resonance effect  
  - state with a strong gluonic component  
  - small (qqq)-component with a substantial contribution from the meson cloud  
  - Parameters depend strongly on data and analysis

- Contribution of $D_{13}(1520)$ to $\gamma p \rightarrow p \pi^+ \pi^-$ cross section  
  - Different interpretations of $\gamma p \rightarrow p \pi^+ \pi^-$ total cross section data  
    - Oset et al.: $D_{13}(1520) \rightarrow \Delta \pi$ dominant contribution  
    - Laget et al.: $P_{11}(1440) \rightarrow p\sigma$ dominant  
  - $D_{13}(1520) \rightarrow \Delta \pi$ in D-wave (PDG: 10–14%) and S-wave (5–12%)?

- $P_{33}(1600)$ (*Roper Resonance of $\Delta$ system*) $\rightarrow$ too low in mass?
Motivation: Medium-Energy Regime

3rd resonance region

- $F_{15}(1680)$
- $D_{13}(1700)$
- $D_{33}(1700)$
- $P_{13}(1720)$

How to disentangle?

Discrepancy of CLAS $P_{13}(1720)$ with PDG: two close-by $P_{13}$ states?

⇒ This would be in contradiction with quark models!
Motivation: High-Energy Regime $\rightarrow N^*$ Spectrum

- Missing Resonances

U. Löhring et al., EPJ A10, 395 (2001)
Motivation: High-Energy Regime $\rightarrow \Delta^*$ Spectrum

- Missing Resonances
- Negative-Parity $\Delta$ Resonances at 1900 MeV/c²
Motivation: High-Energy Regime

- Reactions with two or more mesons in the final state account for most of the cross section at $W \geq 2 \text{ GeV}/c^2$
- Large efforts at ELSA for neutral decay modes: $\pi^0\pi^0$, $\pi^0\eta$, etc. $\Rightarrow \pi^+\pi^-$ at CLAS!
- There is certainly resonance production above 2 GeV/$c^2$
  But: resonances broad and overlapping $\Rightarrow$ Big Challenge

$\Rightarrow$ Ultimate goal: coupled-channel analysis including pol. constraints to nail down these resonances
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Helicity Dependence of the Reaction $\gamma p \rightarrow n \pi^0 \pi^+$

GDH Collaboration (Mainz):
- Largest contribution from $\sigma = \frac{3}{2}$
- Nacher et al. underestimates $\sigma = \frac{1}{2}$
Beam Asymmetry $I^\circ$ in $\gamma p \rightarrow p \pi^+ \pi^-$

CLAS Measurements
(S. Strauch et al.)

and model calculations:

- Mokeev et al. (solid)
- Fix and Arenhövel (dashed)
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Double-Polarization Observables in $\gamma p \rightarrow p \pi^+ \pi^-$
Double-Pion Photoproduction Analysis Techniques

Count Rate Estimate

Scientific Motivation

Previous Measurements

Double-Polarization Experiments

Beam-Target Polarization Observables

\[
\frac{d\sigma}{d\Omega} = \sigma_0 \left\{ 1 - \delta_1 \sum \cos 2\phi \right. \\
+ \Lambda_x (-\delta_1 H \sin 2\phi + \delta_\odot F) \\
- \Lambda_y (-T + \delta_1 P \cos 2\phi) \\
- \Lambda_z (-\delta_1 G \sin 2\phi + \delta_\odot E) \left\} \Rightarrow \text{Single-Meson Final States} \right. \\
\text{(7 Observables)}
\]

Two-Meson Final States \Rightarrow \text{(15 Observables)}

\[
I = I_0 \left\{ (1 + \tilde{\Lambda}_j \cdot \vec{P}) \\
+ \delta_\odot (I^\odot + \tilde{\Lambda}_j \cdot \vec{P}^\odot) \\
+ \delta_1 \left[ \sin 2\beta (I^s + \tilde{\Lambda}_j \cdot \vec{P}^s) \\
\cos 2\beta (I^c + \tilde{\Lambda}_j \cdot \vec{P}^c) \right] \right\}
\]
Circular Beam and Longitudinal Target Polarization

\[
\frac{d\sigma}{d\chi_i} = \sigma_0 \{ (1 + \Lambda_z \cdot P_z) + \delta_\circ (I_\circ + \Lambda_z \cdot P_z^\circ) \}
\]

\[
(\rightarrow\rightarrow - \leftarrow\leftarrow) := \frac{d\sigma(\rightarrow\rightarrow)}{d\chi_i} - \frac{d\sigma(\leftarrow\leftarrow)}{d\chi_i} = 2 \cdot \sigma_0 \{\delta_\circ (I_\circ + \Lambda_z \cdot P_z^\circ)\}
\]

\[
(\leftarrow\leftarrow - \rightarrow\rightarrow) := \frac{d\sigma(\leftarrow\leftarrow)}{d\chi_i} - \frac{d\sigma(\rightarrow\rightarrow)}{d\chi_i} = 2 \cdot \sigma_0 \{\delta_\circ (-I_\circ + \Lambda_z \cdot P_z^\circ)\}
\]

1) \((\rightarrow\rightarrow - \leftarrow\leftarrow) + (\leftarrow\leftarrow - \rightarrow\rightarrow) := \frac{d\sigma_{3/2}}{d\chi_i} - \frac{d\sigma_{1/2}}{d\chi_i} = 4 \cdot \sigma_0 \cdot \delta_\circ \cdot (\Lambda_z \cdot P_z^\circ)\)

2) \((\leftarrow\leftarrow - \leftarrow\leftarrow) - (\rightarrow\rightarrow - \rightarrow\rightarrow) := -4 \cdot \sigma_0 \cdot (\Lambda_z \cdot P_z)\)
Model Calculations of $P_z^\odot$ (known as $E$) by A. Fix

Can clearly distinguish between solutions if $\Delta A \leq 0.05$

Reality will be a mixture of S-/D-wave!

Needs very small errors to distinguish between different contributions!
Model Calculations of $P_x^\odot$ by W. Roberts

$\phi = 0.0035 \text{ rad (almost 0)}, \phi = 0.56 \text{ rad}, \phi = 2.09 \text{ rad}, \phi = 3.04 \text{ rad (almost } \pi)\)$

Circ. Beam $\rightarrow$ Trans. Target

- **Solid Line**
  - Full Calculation
- **Dashed Line**
  - $S_{11}(1900)$ Omitted
- **Dashed-Dotted Line**
  - $P_{31}(1910)$ Omitted

$W = 2 \text{ GeV}$

$\Rightarrow$ goal: $\Delta P_z^c \leq 0.05$
Model Calculations of $P_y^\ominus$ by W. Roberts

$\phi = 0.0035$ rad (almost 0), $\phi = 0.56$ rad, $\phi = 2.09$ rad, $\phi = 3.04$ rad (almost $\pi$)

$W = 2$ GeV

Circ. Beam $\rightarrow$ Trans. Target

- **Solid Line**
  - Full Calculation
- **Dashed Line**
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V. Credé

Double-Polarization Observables in $\tilde{\gamma} p \rightarrow p \pi^+ \pi^-$
Background Estimate

\begin{align*}
\text{(a)} & \quad p\pi^+\pi^- X \\
\text{(b)} & \quad \pi^+\pi^- X \\
\text{(c)} & \quad p\pi^+ X \\
\text{(d)} & \quad p\pi^- X
\end{align*}

**g1c Data Set (\(\vec{\gamma} p\))**

- At least two particles detected
- Distributions essentially background free

\[10^6 \text{ Counts/Channel}\]
Estimate of an Effective Dilution Factor

- **Solid Line**: total number of events
- **Dashed Line**: polarized hydrogen
- **Dotted Line**: unpolarized nucleons

\[ D \text{ solid} = 0.05 \quad D \text{ dashed} = 0.27 \]
\[ D \text{ dotted} = 0.44 \quad D \text{ dotted} = 0.29 \]

\[ D_{\text{eff}} = 0.38 \]
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Statistical Uncertainties of the Measurements

The asymmetry is given by

$$A_z^\odot = \frac{1}{D_{\text{eff}} \cdot \delta_\odot \cdot \Lambda_z} \frac{N_\parallel - N_\perp}{N_\parallel + N_\perp}$$

and the statistical error by

$$\Delta A_z^\odot (\text{stat.}) \approx \frac{1}{D_{\text{eff}} \cdot \delta_\odot \cdot \Lambda_z} \frac{1}{\sqrt{N_\parallel + N_\perp}}$$

The total number of counts required to reach a certain precision \(\Delta A_z^\odot (\text{stat.})\):

$$\Rightarrow N_\parallel + N_\perp \approx \left( \frac{1}{D_{\text{eff}} \cdot \delta_\odot \cdot \Lambda_z \cdot \Delta A_z^\odot (\text{stat.})} \right)^2$$

and thus, the beam time needed to reach a certain statistical accuracy \(\Delta A_z^\odot\):

$$T = \frac{1}{\dot{N}_\gamma(E)} \cdot \frac{1}{(\Delta A_z^\odot)^2} \cdot \frac{1}{\sigma_{\text{unpol}}} \cdot \frac{1}{\rho_{\text{target}} \cdot \epsilon} \cdot \frac{D_{\text{eff}}^{-1}}{(\delta_\odot \cdot \Lambda_z)^2} \cdot N_{\text{bins}}$$
### FROST Experiments

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- **V. Credé**
- **Double-Polarization Observables in $\gamma p \rightarrow p \pi^+ \pi^-$**
## Beam Time Request

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<tr>
<th>Setting</th>
<th>Energy [GeV]</th>
<th>( \sigma_{\text{tot}}^p ) [( \mu b )]</th>
<th>( \dot{N}_\gamma ) [MHz]</th>
<th>( N_{\text{bins}} )</th>
<th>( \delta_{\odot} / \delta_I )</th>
<th>( \Lambda_{tg} )</th>
<th>( \Delta A )</th>
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<tr>
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<td>( E_{e^-} = 3.1 )</td>
<td>( \approx 35 )</td>
<td>( \approx 3 )</td>
<td>2000</td>
<td>0.82</td>
<td>0.85</td>
<td>0.05</td>
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<tr>
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<td>( \approx 40 )</td>
<td>( \approx 5 )</td>
<td>2000</td>
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<td>( \approx 35 )</td>
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\( \Sigma 27 \text{ d} \)

Required beam time to study \( \gamma p \rightarrow p \pi^+ \pi^- \) at and above 2 GeV/c^2
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<td>0.7</td>
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<td>0.05</td>
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<tr>
<td>C lin/long</td>
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<td>$E_\gamma = 2.2$</td>
<td>$\approx 35$</td>
<td>$\approx 5$</td>
<td>2000</td>
<td>0.7</td>
<td>0.85</td>
<td>0.05</td>
<td>83</td>
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<td>$E_\gamma = 2.4$</td>
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<td></td>
<td>$E_\gamma = 2.6$</td>
<td>$\approx 35$</td>
<td>$\approx 5$</td>
<td>2000</td>
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<td>0.85</td>
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<tr>
<td>D</td>
<td>$E_{e^-} = 3.1$</td>
<td>$\approx 35$</td>
<td>$\approx 3$</td>
<td>2000</td>
<td>0.82</td>
<td>0.85</td>
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**PAC 29 Beam Time Request: 4 days for setting B**

⇒ Will prove success of FROST and come back later ...