Wide-angle exclusive photoproduction of $\pi^0$ mesons

Report on E12–14–005 (Amaryan, Dutta, Gao, Kunkel, Strakovsky, Širca)

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Motivation

- **Hard exclusive reactions** ideal for studying hadronic dynamics of underlying parton-level processes
  In particular: does exclusive $\pi$ photo-production proceed through the interaction of the photon with a single quark?

- **Small number of elementary fields** in $\gamma p \rightarrow \gamma p$ and $\gamma p \rightarrow p\pi^0$
  ideal to test scaling relations

- Accessing the regime $s \approx |t| \approx |u| \gg \Lambda^2$, i. e. high energies, high momentum transfers, large angles ($p_T > 1 \text{ GeV}/c$) crucial to understand **short-range structure of nucleons**

- Testing ground of QCD at intermediate energies to explore the onset of **transition from npQCD to pQCD**
Existing data for $\gamma p \rightarrow p\pi^0$

- $\theta^* = 50^\circ, 70^\circ, 90^\circ, 110^\circ$
- Latest g12 (CLAS) results from $\gamma p \rightarrow p\pi^0 \rightarrow p\gamma\gamma \rightarrow p e^+ e^-\gamma$
- High $s$, large $\theta^*$: consistent with $s^{-7}$ scaling ($s^{-n}$, $n = 6.89 \pm 0.26$)

Figures courtesy of I. Strakovsky
Onset of scaling regime

- Data at lower $\theta^*$ tend to reach power-law behavior at higher $s$
- At small angles the values of $|t|$ are much smaller than $s$ violating the $s \approx |t| \approx |u| \gg \Lambda^2$ requirement

- Charged photo-production data at highest $s$ also indicates scaling
Onset of scaling in $\pi^+$ photo-production


$\gamma p \to \pi^+ n$ (World Data for $\theta_{\text{c.m.}} \approx 90^\circ$)

- We wish to see something like this with $\pi^0$ at high $s$
Existing data for $\gamma p \rightarrow p\pi^0$

$\sigma/d\sigma/dt(t)$

Preliminary data from g12 (CLAS)

- Qualitative description in terms of Regge models:
  [1] Goldstein, Owens, PRD 7 (1973) 865

Figures courtesy of I. Strakovsky
• Very nice description of data by Regge-type approaches

• Handbag predictions typically off by several orders of magnitude!
  — Huang, Kroll, EPJC 17 (2000) 423
  — Huang, Jacob, Kroll, EPJC 33 (2004) 91
  — Diehl, Kroll, EPJC 73 (2013) 2397
Charged-pion XS ratios

- Search for signatures of handbag mechanism in photo-production of charged pions at large angles // Huang++ EPJC 33 (2004) 91

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

- Calculated XS do not match experiment, but ratio does (FFs cancel)
- Neither $\pi^\pm$ XS nor $\pi^0/\pi^\pm$ ratios agree with data (no FF cancellation)

Data (Hall A):
PRL 91 (2003) 022003
PRC 71 (2005) 044603
Deviations from (expected) quark counting rules

- Broken locality in quark-hadron duality // Zhao, Close PRL 91 (2003) 022004
- High $s$: destructive interferences between various intermediate states $\Rightarrow$ smooth scaling behavior
- Low $s$: these cancellations broken locally $\Rightarrow$ oscillations
• Need 3-pass, 4-pass and 5-pass unpolarized CW beam
• 6% $X_0$ copper radiator
• Mixed $e^-\gamma$ beam on 10 cm LH2 target
• Deflector magnet, $\int \vec{B} \, d\vec{l} \approx 0.6 \text{Tm}$
• EM calorimeter (NPS) for $\pi^0 \rightarrow 2\gamma$
• HMS for recoil protons
• **Running in parallel with WACS (E12–14–003)** — several kinematic overlaps
Deflector magnet and NPS

- New coil design 3d models complete.
- Coil detailing complete.
- Drawings submitted for bids.
- Vendor selection soon.
- Main coil contract awarded

- Same key components as for WACS, both under construction → see dedicated talks
- Optimized deflection and detector resolution with respect to:
  - NPS drift distance
  - Deflector magnet location
  - Background rates
Kinematic coverage

approx. \[ 9.5 < s < 21 \text{ GeV}^2, \quad 60^\circ < \theta^* < 110^\circ \]
Assume 2-body kinematics; use difference between measured and predicted NPS hit position ($\delta x$ and $\delta y$) to identify reaction.

Central $\delta x$ ($\pm 1.5 \sigma_x$)
Event identification cont’d

- Lots of experience from WACS, old and new, polarized and unpolarized
- Most recent work from Hall C:

\[ p(\gamma, \gamma'p) + p(e, \gamma'p)e' \]

\[ p(\gamma, \pi^0p) \]

\[ p(e, e'p) \]

\[ p(e, e'p)\gamma'_{pr} \]

\[ p(e, e'p)\gamma'_{po} \]

Fanelli++ PRL 115 (2015) 152001
Separation of $\pi/2\pi$ events

3F (worst case) 
$\approx 5\%$ contamination

5B (more typical) 
$\approx 1\%$ contamination
Separation of $\pi/\eta$ events

Above the $\eta$ production threshold, the $\eta$ events are indistinguishable from the 1-pion events, however the $\eta$ production rates were negligible compared to the 1-pion rates. Fig. 18 shows all the $\eta$ events detected (left) for the kinematics with the worst $\eta/\pi_0$ ratio (5D) and the events which survive the cut corresponding to $\pm 1.5 \sigma_x$ (right), which are $< 1\%$ of the $\pi_0$ events.

$\delta x \leq 1.5 \sigma_x$ $\delta y (cm)$

5D (worst case) $< 1\%$ contamination
Event identification with 2γ detection

- Reduced acceptance (ranging from ≈ 50% to ≈ 70%)
# Kinematic coverage

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<th>$D_{NPS}$ (m)</th>
<th>$E_{\gamma}$ (GeV)</th>
<th>$s$ (GeV$^2$)</th>
<th>$\theta^C_{\pi^0}$ (deg)</th>
<th>$\theta_{\pi^0}$ (lab) (deg)</th>
<th>$P_{\pi^0}$ (GeV/c)</th>
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Projected E12–14–005 data

Future Hall C
Conclusions and outlook

- Study $\gamma p \rightarrow p\pi^0$ at high $s$ and $t$, large CM angles
- Explore onset (?) of scaling
  Measurement of $s$-dependence of $d\sigma/dt$ at different $\theta^*$
- Check validity of GPD/handbag-type approaches
  Does not work for $s \lesssim 10$ GeV$^2$, might work at higher energies
  Measurement of $t$-dependence of $d\sigma/dt$
- Earliest possible opportunity to run: 2021
- Will run (almost) concurrently with WACS
- How can HIPS help?
HMS rates and proton-to-$\pi^+$ ratios

The SIMC simulation package was used for determination of the actual momentum and angular resolutions, which included scattering in the target material as well as reconstruction effects. The simulation is further elaborated in a later section. This description is reproduced from the WACS proposal.

### 3.4.1. Expected Rates

The DINREG Monte Carlo code developed by the RadCon group at JLab [41] has been used to calculate the expected proton and $\pi^+$ rates in the HMS for each of the proposed kinematic settings. Fig. 9 shows the simulated HMS singles rates, and the simulated proton-to-$\pi^+$ ratio. The maximum HMS singles rate of 75 kHz is at kinematic point 3F, which corresponds to a beam current of 15 $\mu$A. The equivalent trigger rate (for protons only) for this same kinematic point is 7.5 kHz. These rates are well within the capabilities of the HMS.
NPS rates and radiation budget

FIG. 11. Simulated raw singles rates in the NPS.

FIG. 12. Simulated radiation dose in the NPS.

3.8. Energy and Coordinate Resolution

The energy of the particle detected in the calorimeter is calculated from a sum of the signals in several crystals (up to 9) which form a cluster. The noise in the ADC used for a measurement of the signal from an individual crystal contributes to the detector energy resolution. In a high-rate experiment the ADC noise increases, which can be characterized by the ADC pedestal width. Using the observed 5-6 MeV pedestal width observed in the previous RCS experiment, the expected pedestal width for this proposal is projected to be around 50 MeV. The effect of the background on the energy resolution could be estimated from this estimated...