Determination of Polarization Transfer Coefficients $C_{x'}$ and $C_{z'}$ for Quasi-Free Hyperon Photoproduction off the Bound Neutron

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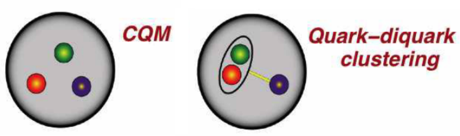
Overview

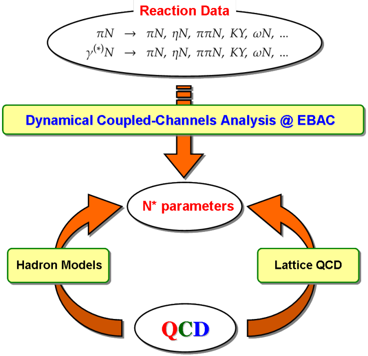
1. QCD and Baryon Spectroscopy
2. g13 Experiment at JLab
3. Analysis of $\vec{\gamma} d \to K^0 \vec{\Lambda}(p)$
4. Extraction of $C_{x'}$ and $C_{z'}$
5. Preliminary Results
6. Conclusion

Baryon Spectroscopy

Provides a way to measure the N* states

- Excited atomic states → understanding of atom
- Excited nucleon states → understanding of nucleon
- At low energies, the strong coupling constant becomes large and perturbation theory can not be used to solve QCD
- Map N* spectrum to learn about the internal structure of nucleons
- Goal is to provide information about the relative degrees of freedom





http://ebac-theory.jlab.org/

Constituent quark models three valence quarks
Di-quark models bound quark pair → less degrees of freedom
Lattice QCD numerical solution to QCD

Missing Resonance Problem

Constituent quark models predict many N* states that have yet to be observed

- Do these resonances exist?
  - Some N* states have been observed that don't appear in diquark models, but more evidence is needed
- Need more data
  - Majority of data out there is in the πN final state
  - Some resonances couple weakly to this channel
  - Final states with strangeness ($K\Lambda$, $K\Sigma$): $\gamma p \rightarrow K^+\Lambda$ moving $N(1900)\frac{3}{2}^+$ from $\star\star$ to $\star\star\star$
  - $\gamma n \rightarrow K^0\Lambda$ senstive to $\star\star$ $N(2080)\frac{3}{2}^-$

Particle	J^P	Status overall	Status πN	Status γN	Status as seen in — $N\eta$	$N\sigma$	$N\omega$	ΛK	ΣK	$N\rho$	$\Delta\pi$
N	$1/2^+$	****									
$N(1440)$	$1/2^+$	****	****	****		***				*	***
$N(1520)$	$3/2^-$	****	****	****	***					***	***
$N(1535)$	$1/2^-$	****	****	****	****					**	*
$N(1650)$	$1/2^-$	****	****	***	***			***	**	**	***
$N(1675)$	$5/2^-$	****	****	***	*			*		*	***
$N(1680)$	$5/2^+$	****	****	****	*	**				***	***
$N(1685)$	$?^?$	*									
$N(1700)$	$3/2^-$	***	***	**	*			*	*	*	***
$N(1710)$	$1/2^+$	***	***	***	***		**	***	**	*	**
$N(1720)$	$3/2^+$	****	****	***	***			**	**	**	*
$N(1860)$	$5/2^+$	**	**							*	*
$N(1875)$	$3/2^-$	***	*	***			**	***	**		***
$N(1880)$	$1/2^+$	**	*	*		**		*			
$N(1895)$	$1/2^-$	**	*	**	**			**	*		
★ $N(1900)$	$3/2^+$	***	**	***	**		**	***	**	*	**
$N(1990)$	$7/2^+$	**	**	**					*		
$N(2000)$	$5/2^+$	**	*	**	**			**	*	**	
$N(2040)$	$3/2^+$	*									
$N(2060)$	$5/2^-$	**	**	**	*				**		
$N(2100)$	$1/2^+$	*									
$N(2150)$	$3/2^-$	**	**	**				**			**
$N(2190)$	$7/2^-$	****	****	***			*	**		*	
$N(2220)$	$9/2^+$	****	****								
$N(2250)$	$9/2^-$	****	****								
$N(2600)$	$11/2^-$	***	***								
$N(2700)$	$13/2^+$	**	**								

K.A. Olive et al., Review of Particle Physics

Polarization Observables in $K\Lambda$ Photoproduction

$$\mathcal{S}_{fi} = \frac{1}{2\pi^2}\left(\frac{M_n M_\Lambda}{4E_\Lambda E_K E_n E_\gamma}\right)^{\frac{1}{2}} \mathcal{M}_{fi}\delta^{(4)}(p_n + p_\gamma - p_K - p_\Lambda)$$

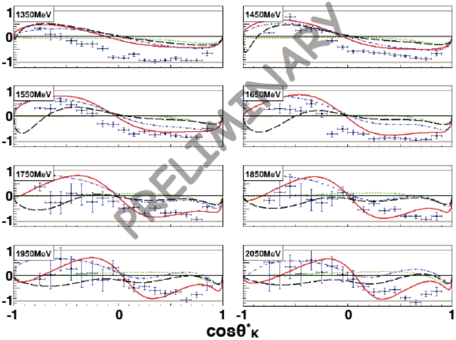
- 16 Polarization observables are derived from the matrix elements $\mathcal{M}_{fi}$
- Sensitive to the physics involved in the resonant reaction

Unpolarized Cross Section	σ_0			
Single		P	Σ	T
Beam-Recoil	$C_{x'}$	$C_{z'}$	$O_{x'}$	$O_{z'}$
Target-Recoil	$T_{x'}$	$T_{z'}$	$L_{x'}$	$L_{z'}$
Beam-Target	E	F	G	H

- 8 carefully chosen observables are needed to determine the full scattering amplitude

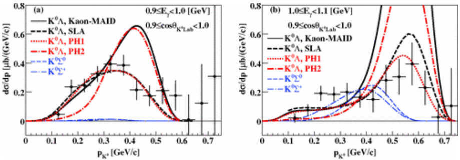
Previous Studies for $\gamma n \rightarrow K^0\Lambda$

Neil Hassall: Ph.D. Thesis for g13 (2010). Shown are his preliminary results for $O_{x'}$



Laboratory of Nuclear Science (LNS) in Japan

- Measured cross sections of with E_γ=0.8–1.1 GeV off ^{12}C and LD_2 targets



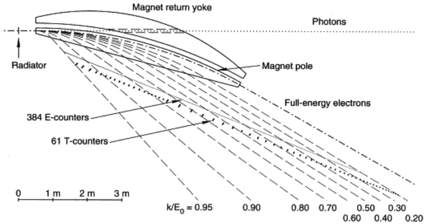
- K. Tsukada et al., Phys. Rev. C 78, 014001

- In progress: cross sections from g13 and g10
- g14 using a polarized target

Hall-B at Jefferson Lab

Photon Tagger

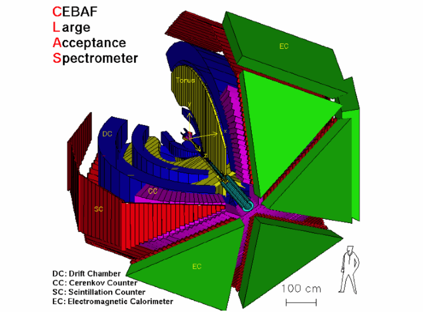
- Photons are produced via the bremsstrahlung technique.
- $E_\gamma = E_0 - E_e$



- E_e: 1.987 GeV and 2.649 GeV
- $E_\gamma \approx 20 - 95\%$ of E_e

D.I. Soberet al., The bremsstrahlung tagged photon beam in Hall B at JLab

CEBAF Large Acceptance Spectrometer (CLAS)

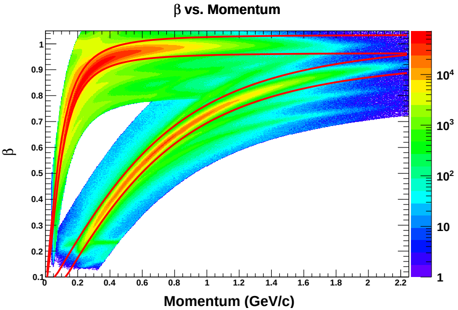


arXiv:1109.1720 [hep-ph]

Analysis Overview: $\vec{\gamma}d \to K^0\vec{\Lambda}(p)$

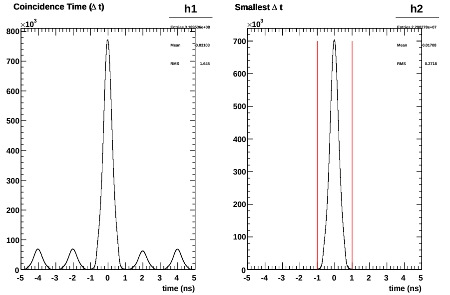
- $K^0 \to \pi^+\pi^-$ and $\Lambda \to p\pi^-$
- Select events which have 2 positive and 2 negative tracks

Particle Identification



Particles were identified based on their velocity and momentum in CLAS

Photon Selection

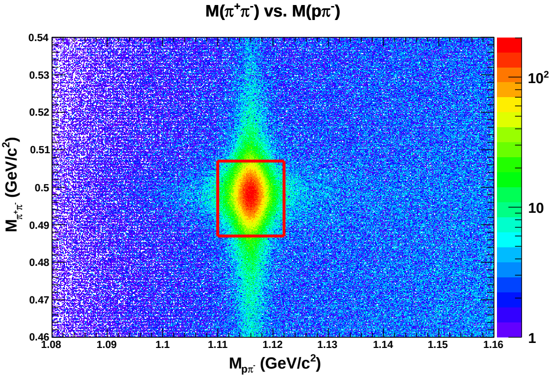


$\Delta t = t_v - t_\gamma$ where t_v is the reconstructed event vertex time using the trajectory in CLAS of the fastest particle and t_γ is the time that the photon arrived at the event location

Selection of K^0 and Λ

- Recall that $\Lambda \to p\pi^-$ and $K^0 \to \pi^+\pi^-$
- The invariant masses of $p\pi^-$ ($M_{p\pi^-}$) and $\pi^+\pi^-$ ($M_{\pi^+\pi^-}$) were used to reconstruct and select the Λ and K^0
- Filter out $p\pi^+\pi^-\pi^-$ events that do not come from the $K^0\Lambda$ final state

- $M_{p\pi^-} = \sqrt{(\tilde{p}_p + \tilde{p}_{\pi^-})^2} \approx M_\Lambda$
- $M_{\pi^+\pi^-} = \sqrt{(\tilde{p}_{\pi^+} + \tilde{p}_{\pi^-})^2} \approx M_{K^0}$
- Cuts were calculated based on gaussian fits to the projections of the x-axis and y-axis.
- Events were kept if they fall within the red box
- Note: Some **combinatorial background**. Arises when both π^-'s yield a good K^0 and a good Λ



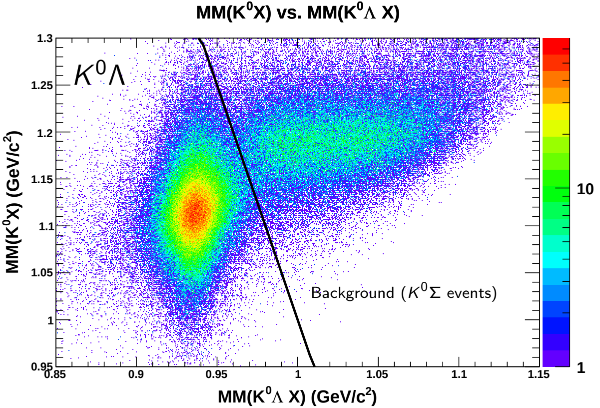
Identification of the Final State

- The $K^0\Lambda$ final state was identified using the missing mass (M_X) technique
- $\gamma n \rightarrow K^0 X$ where $M_X = \sqrt{(\tilde{p}_\gamma + \tilde{p}_n - \tilde{p}_{K^0})^2}$
- $\gamma d \rightarrow K^0 \Lambda X$ where $M_X = \sqrt{(\tilde{p}_\gamma + \tilde{p}_d - \tilde{p}_{K^0} - \tilde{p}_\Lambda)^2}$

- $X = \Lambda$

  OR

  $X = \Sigma \rightarrow \Lambda\gamma \rightarrow \gamma p \pi^-$
- $X = p$ OR $X = \gamma p$
- The black line "separates" the $K^0\Lambda$ events from $K^0\Sigma$ events



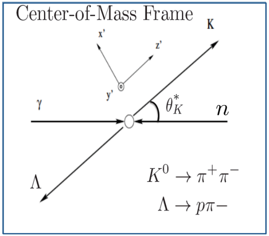
The quasi-free reaction is selected by accepting events of $p_X < 0.2\ GeV/c$

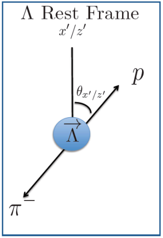
Extraction of $C_{x'}$ and $C_{z'}$

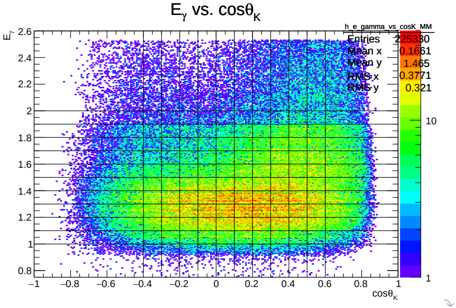
- From the equation for the polarized cross section of $K\Lambda$ photoproduction, the experimental asymmetry, A, can be derived:

$$A = \frac{N^+ - N^-}{N^+ + N^-} = \alpha P_{circ} C_{x'/z'} \cos(\theta_{x'/z'})$$

- $N^+(N^-)$ is the number of events with right (left) handed helicity
- $\alpha = 0.642 \pm 0.013$ and is the self-analyzing power of Λ

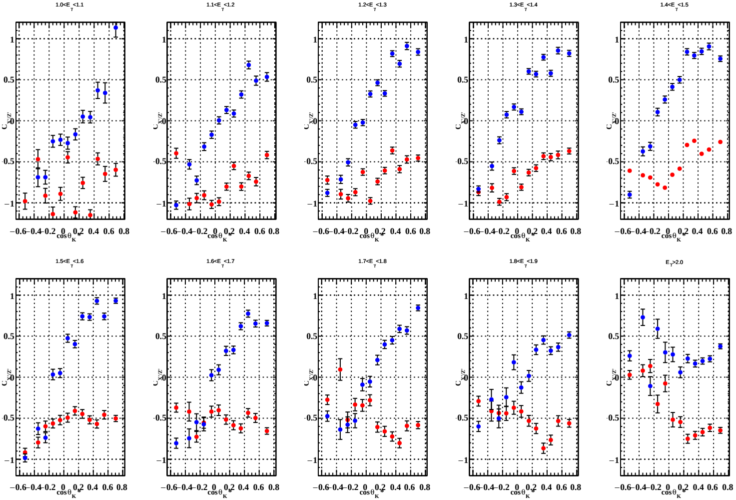






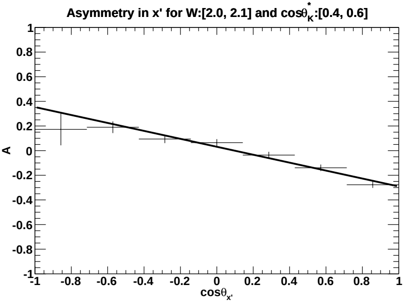
Preliminary Results: E_γ Bins

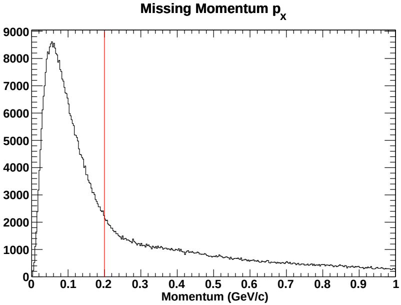
- Preliminary estimates of $C_{X'}$ and $C_{Z'}$ for $K^0\Lambda$ photoproduction are extracted for the first time
- $C_{X'}^2 + C_{Z'}^2 + P^2 \leqslant 1$



Conclusion and Outlook

- Many resonant states predicted by constituent quark models have yet to be observed
- Hyperon channels have a strong coupling to some of these resonances
- First estimates of $C_{x'}$ and $C_{z'}$ were extracted
- Simulations will be done to understand shape of Σ background in the missing mass
- Estimate systematic uncertainties (photon polarization, α, background, analysis method)
- Extract observables using different methods (2d fit, maximum likelihood)


Asymmetry in x' for W:[2.0, 2.1] and cosθ*K:[0.4, 0.6]
A
cosθx'
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1


Missing Momentum px
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Momentum (GeV/c)