Production of the Strangest Baryons on the Proton with CLAS12

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Abstract

We propose to measure the Ω and Ξ-baryon photoproduction on the proton using the CLAS12 detector and quasi-real photon tagging facility as well as untagged real photons.

I. INTRODUCTION

A distinctive feature of the photoproduction of strangenest baryons is the fact that it represents the largest strangeness transfer possible, $\Delta S = 3$. Overall, our first goals are

- Cross section measurements for $\gamma p \to \Omega^- K^+ K^+ K^0$ which is still unknown,
- Study of a mechanism of the Ω^- photoproduction which should be quite specific, since it is the first baryon with constituents none of which could come from the target proton.
- Cross section measurements of the first Ξ excited state $\Xi(1530)$.

Future physics goals are

- Search for Ω^- excited states. PDG10 [1] gives only the small number of weak signals for $\Omega(2250)^-$, $\Omega(2380)^-$, and $\Omega(2470)^-$.
- Search for Ξ excited states which are not well known [1].

Critical limiting factors in any experiment of this kind are the photoproduction cross section (i.e., rates) and the background, neither of which are known.

Despite the fact that its prediction and eventual discovery was one of the brightest highlights in hadron physics, not much is known about Ω^- properties and mechanism of the Ω^- production. Here are some basic facts:

- In 1962, Gell-Mann and Neeman predicted a new baryon, Ω^-, with S = -3, $J^P = 3/2^+$, and the mass about 1670 MeV [2].
- The $\Omega(1670)^-$ observation in 1964 at BNL triumphantly confirmed the hypothesis of $SU(3)_F$. The unambiguous discovery in both production and decay was reported in Ref. [3]. They scan > 100k buble chamber pictures with 5−10 K^- per picture and found a single and unique Ω^--event.
- The quantum numbers follow from the assignment of the particle to the baryon decuplet. Ref. [4] ruled out $J = 1/2$ and find consistency with $J = 3/2$. The spin of the Ω-hyperon has been recently determined (though with some assumptions) by the BaBar Collaboration at SLAC [5]. They found from decay angular distributions of

$\Xi_C^0 \to \Omega^- K^+$ and $\Omega_C^0 \to \Omega^- K^+$ that $J = 3/2$; this depends on the spins of the Ξ_C^0 and Ω_C^0 being $J = 1/2$, their supposed values. The parity of the $\Omega(1670)^-$ stays totally unknown.

- Cross sections of $\Omega(1670)^-$ production have been measured using kaon beams. The ANL experiment measured the $K^- p \to \Omega^- X$ cross section at 6.5 GeV/c as $\sigma_t = 1.4 \pm 0.6\ \mu b$ [6]. The experiment SLAC-E-135 forward differential cross section for $K^- p \to \Omega^- X$ at 11 GeV/c [7]. Experiment SLAC-BC-073 sought Ω-photoproduction in the $\gamma p \to \Omega^- X$ reaction at 20 GeV, and provided only an upper limit of $\sigma_t < 17$ nb [8].

II. PHYSICS MOTIVATION

A. Search for the Ω-states in Photoproduction

B. Missing Cascade States

According to the constituent quark models, there should be a cascade state for each corresponding N^* and Δ^* resonances. In fact, Isgur and Capstick predicted a total of 44 cascade states below 2.5 GeV, using a relativistic quark model with chromodynamics [9]. Compared with these predictions, the state of experimental data of cascade states is dismal. Overall, only 6 cascade states in the PDG are listed with three or four stars [1], while only three of them have their quantum numbers J^P considered determined. This is largely due to the difficulty to produce cascade resonances with two strange quarks, and gradual unavailabilityof kaon beam facilities. On the other hand, although cascade cross section are typically one to two order of magnitude lower than hyperons, due to the necessity to produce another strange quark from the vaccum, recent CLAS data have shown that the cascade resonances, such as $\Xi(1320)$ and $\Xi(1530)$, can be produced copiously with 1-2 GeV above threshold using a real photon beam at high luminosity. Although it must be noted that the comparison of cascade cross sections and those of hyperons are not necessarily fair and could be potentially misleading. Most hyperon cross sections exhibit dramatic decrease a few GeV away from threshold, while the cascade cross sections would not necessary have the same behavior, depending on the production mechanisms [10, 11]. The cross section of $\Xi^-(1320)$ in the exclusive reaction of $\gamma p \to K^+ K^+ \Xi^-(1320)$ increased from nb level around

State	PDG rating	Width (MeV)	J^P
$\Xi(1320)$	****		$\frac{1}{2}^+$
$\Xi(1530)$	****	9.5	$\frac{3}{2}^+$
$\Xi(1690)$	***	< 30	$\frac{1}{2}^-?$
$\Xi(1820)$	***	24	$\frac{3}{2}^-$
$\Xi(1950)$	***	60	?
$\Xi(2030)$	***	20	$\frac{5}{2}^?$

TABLE I: Well Established Cascade Resoances

$E_\gamma = 3$ GeV to around 10 nb at 4 GeV [10]. Phenomenological models that hypothesize intermediate hyperons as the parent particle of Ξ, also do not predict the drop off of cross sections at higher energies [11]. Although recently published CLAS results consist of data using mostly photon energies below 4 GeV, a recent CLAS experiment (E05-017, also called g12 in this document), have collected even higher statistic of cascade data, with beam energies up to 5.4 GeV, making it possible to study other excited cascade resonances. This CLAS experiment has an estimated luminosity of 28 pb^{-1} for $E_\gamma > 4.4$ GeV, using a 40 cm long hydrogen target.

Among the states listed in Table II B, there is recent evidence to suggest that $\Xi(1690)$ is a $J^P = \frac{1}{2}^-$ particle, from the decay $\Lambda_C^+ \to \Xi^-\pi^+K^+$ [12]. However, this result needed to make assumptions about the J^P of Λ_C^+ as well, making the independent measurement much desired. The $\Xi(1690)$ has mostly been seen in $Y\bar{K}$ decay, while the only notable sighting of $\Xi(1690) \to \Xi\pi$ with significant statistics was reported by [13]. This is a state that is of particular interest, as there already exist CLAS 6 GeV data with photon energies far enough from the threshold, making it possible to study $\Xi(1690)$ via both decay channels, and possibly determining their branching ratios, provide experimental verification of the $\Xi\pi$ suppression of Ξ^* decays. The proposed experiment at CLAS12 will greatly improve the statistics that is necessary for the J^P determination, which needs to reconstruct the whole decay chain.

As a sanity check, the reaction $\gamma p \to K^+K^+\pi^-(\Xi^0)$ has been analyzed recently using the g12 data set. The three charged particles in the final state are identified by CLAS, while the Ξ^0 is reconstructed using the missing mass technique. Although only 10% of the whole data set has been analyzed for this purpose, the quality of the data is very encouraging. The Ξ^0 signal is clearly visible above a constant background, mostly from events with pions misidentified as kaons. We expect to finalize various offline corrections, such as momentum corrections, beam energy corrections in the following semester, before we move on to analyze the whole data set. But it is clealy already the largest data set ever collected for cascade photoproduction. With at least two thousand $\Xi^0\pi$ events detected, equivalent to a factor of seven increase compared with previous results [10], a number of useful measurement previously unfeasible can now be performed.

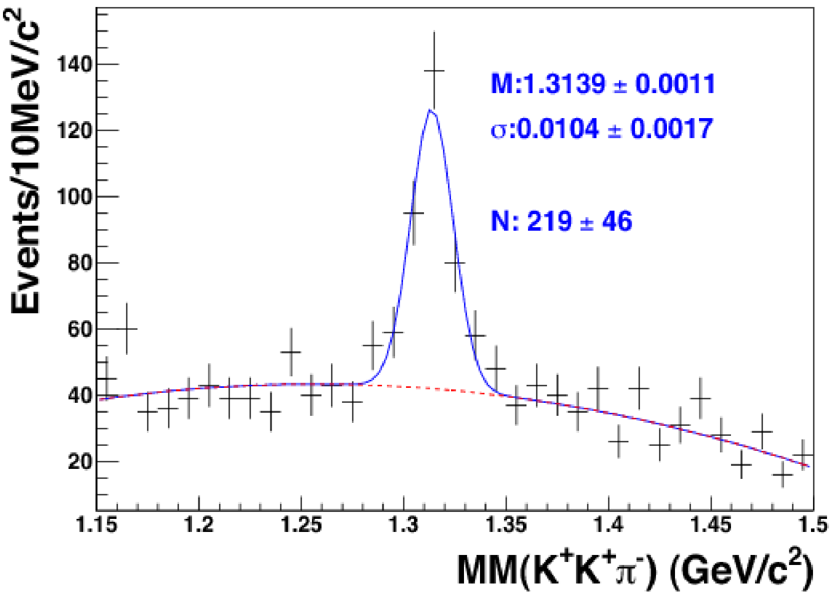

FIG. 1: The missing mass spectrum of the $K^+K^+\pi^-$ system off of a proton target, from the g12 experiment. The included photon energy range here is 3.3 GeV to 5.4 GeV. Only 10% of the data have been analyzed and shown here. Various offline corrections, such as momentum corrections, beam energy corrections, have not been finalized for this experiment, and the parameters of the signal is expected to improve significantly.

First of all, we expect most of the $\Xi^0\pi$ events to be coming from the $\Xi^-(1530)$ decay. A possible background reaction is $\gamma p \to K^+K^{*0}\Xi^0$, although no known data is available. If out of the two thousand events, only 20% is from the decay of excited cascades, that it will still be significantly higher than any previous photoproduction data in this energy range. If these states are present in this data set, that it is highly likely that they can be identified due to the expected narrow widths. The differential cross section of $\Xi^(1530)$ would certainly become feasible, which was not possible in the previous CLAS results due to much lower statistics at $E_\gamma > 4$ GeV. Such a study could provide important information about the production mechanisms of excited cascades, as opposed to ground states.

C. Cascade Polarization

Due to the self-analyzing nature of the $\Xi(1320)$ weak decay, the polarization can be measured in various photo-nucleon reactions, with or without target/beam polarization. Such observables are important for the understanding of the production mechanism of cascade resonances in general. Furthermore, compared with the case of $\Lambda(uds)$, whose polarization is likely from the strange quark, with a small contribution from the (ud) diquark. the polarization mechanism of $\Xi((u/d)ss)$, however, might be totally different. The cascade polarization is more likely from the valence quark (u/d) instead of the (ss) diquark. If this is true, then the recoil polarization of Ξ should be negligible in photoproduction data without beam/target polarization, opposed to the sizable recoil polarization observed for Λ. It is also possible to use the polarization of the $\Xi(1320)$ in photoproduction on a polarizaed nucleon target to study the different contributions of valence quarks to the nucleon polarization, which would be complimentary to the results using electron scattering.

Because of parity conservation in the production of Ξ^- in the reaction of $\gamma p \rightarrow K^+K^+\Xi^-(1320)$, if there is no beam or target polarization, the only direction the Ξ^- can be polarized is along the direction of the normal to the production plane, defined by the target, beam, and the outgoing Ξ^- (Fig. 2). For a weak decaying particle such as the $\Xi^-(1320)$, the polarization can be measured via its decaying angular distribution, which takes the form of

$$I(\theta) = A(1 - \alpha P cos(\theta)) \quad (1)$$

For the $\Xi^-(1320)$, the value of α is -0.456, and P denotes the polarizaiton. The polarization P can be also determined by

$$P = -\frac{2}{\alpha}\frac{N^+ - N^-}{N^+ + N^-} \quad (2)$$

with N^+ denoting events in the forward direction, and N^- in the backward direction.

If there is beam or target polarization, then presumably some of the initial polarization can be transferred to the $\Xi^-(1320)$, and a measurement of the in-plane polarization of the $\Xi^-(1320)$ can become a very useful tool to probe the production mechanism of Ξ baryons.

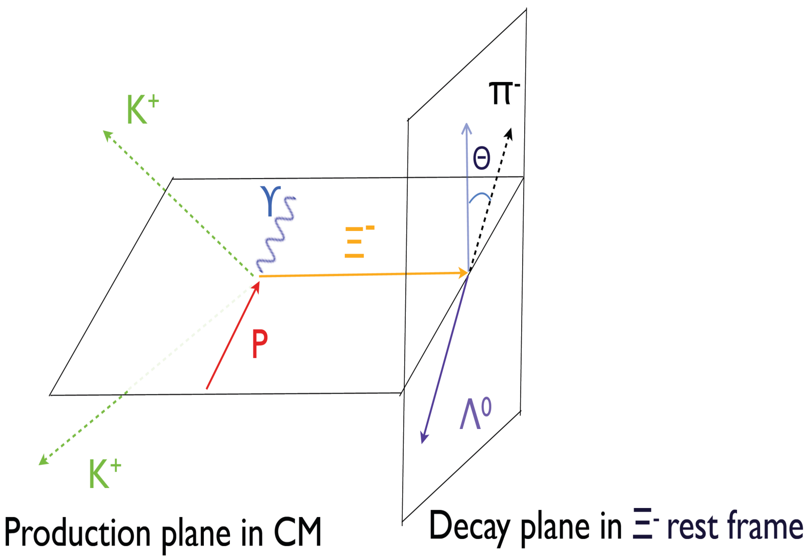

FIG. 2: Illustration of the $\Xi^- \to \Lambda\pi^-$ decay for the polarization measurement in the reaction of $\gamma p \to K^+K^+\Xi^-(1320)$. The production plane is defined by the beam, target, and the outgoing Ξ^-. The π^- angle in measure in the Ξ^- rest frame, with the z-axis for the polarization measurement defined by the normal to the production plane.

For example, recent photoproduciotn data of Λ in the reaction of $\gamma p \to K^+\Lambda$ has shown that the polarization of a circularly polarized photon beam is almost exclusively transferred to the hyperon [14]. If the production mechanism for Ξ is similar to that of the Λ, then it is not inconceivable that some of the beam polarization is transferred to the Ξ. On the other hand, in a conventional di-quark picture of baryon resonances, the polarization mechanisms of the Λ and Ξ could be fundamentally different as discussed earlier. If if is true that most of the Ξ polarization is from the valence quark contribution, then the difference between an unpolarized photon beam or otherwise, should be very small, provided that there is no target polarization.

The proposed program will the measurement of induced Ξ^- polarization, and the beam polarization transfer, since the quasi-real photon polarization could be determined on an event-by-event basis. The comparison between Λ and Ξ^- polarizations can be made, and the production mechanism can be further explored. As shown in Fig. 3. extremely clear signals of $\Xi^- \to \Lambda\pi^-$ can be identified, due to the fact that there are two narrow resonances providing

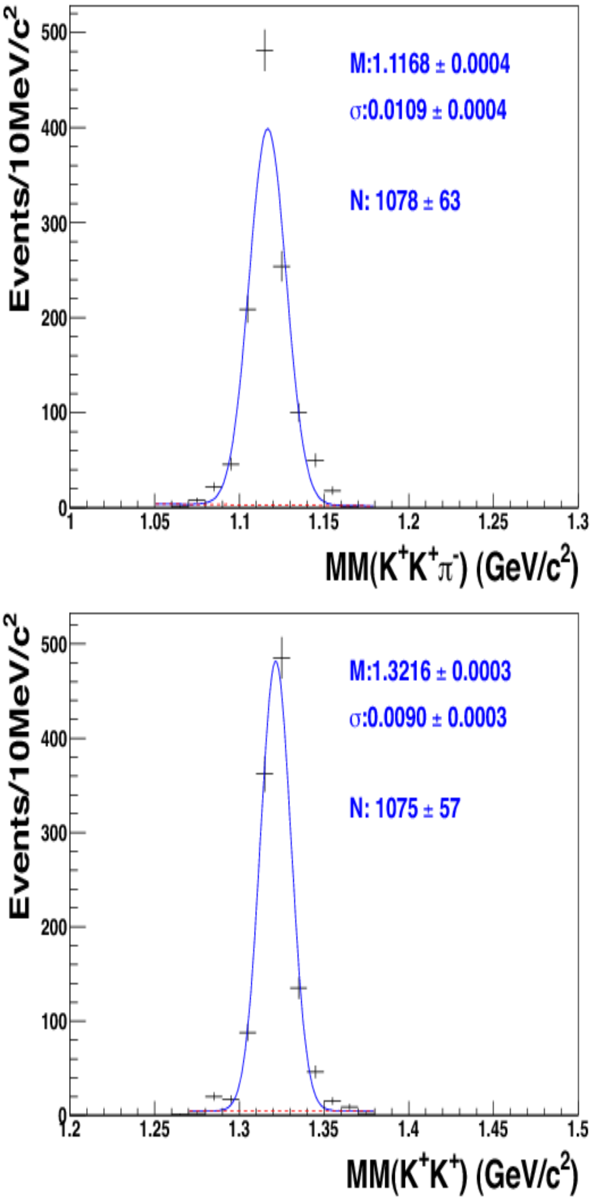

FIG. 3: Top: The missing mass spectra of the $K^+K^+\pi^-$ system off of a proton target. Events corresponding to the Ξ^- signal on the right are selected; Bottom: The missing mass spectra of the K^+K^+ system off of a proton target. Events corresponding to the Λ signal on the left are selected. The data was collected by the g11 experiment, and the photon beam is unpolarized. The included photon energy range here is mostly from 3.0 GeV to 3.8 GeV

kinematic constraints. If fact, such an unique feature is one of the main reason to focus on this channel, as it simplifies the analysis of the decay angular distributions greatly and makes the extraction of polarization variables much less susceptible to background contamination. As a sanity check, we used the decay angular distributions of these extremly clean sample of $\Xi^- \rightarrow \Lambda\pi^-$ events, and the preliminary $\Xi^-(1320)$ polarization measurement, as a function of photon energies which are shown in Fig. 4. Although the results are consistent with zero polarization, which is close to our expectation due to the fact there is no beam polarization. This result is already notably different from the induced polarization of Λ measured recently by CLAS [15]. However, it is also possible that our preliminary results are due to integrating other kinematic variables, such as the Ξ^- angle in the center-of-mass (CM) frame.

III. CROSS SECTION ESTIMATION FOR THE Ω PHOTOPRODUCTION ON THE PROTON

In each of the measurements mentioned above, only a small Ω^- data sample was obtained, and the Ω-production mechanism was not well understood. Mechanism of the Ω-photoproduction should be quite specific, since it is the first baryon with constituents none of which could come from the target proton.

In the next few paragraphs, we attempt to estimate the cross section for Ω-photoproduction on a nucleon using a variety of models.

A. Vector-Meson Dominance Model

Afanasev considers Ω-production on a proton target. The photoproduction amplitude in the Vector-Meson Dominance (VMD) approximation may be written

$$f(\gamma p \rightarrow \Omega^- X)|_{VMD} = (e/f_\rho) f(\rho^0 p \rightarrow \Omega^- X) + (e/f_\omega) f(\omega p \rightarrow \Omega^- X) + (e/f_\phi) f(\phi p \rightarrow \Omega^- X), \tag{3}$$

where the photon-vector meson couplings $f_{\rho\omega\phi}$ can be obtained from the measured partial decay widths of vector mesons $\Gamma(\rho, \omega, \phi \rightarrow e^+e^-)$ [1]. In the following, we make an assumption that the leading contribution to Ω-production is due to the intrinsic strangeness component of the photon. In the constituent quark model, the ϕ-meson is primarily an

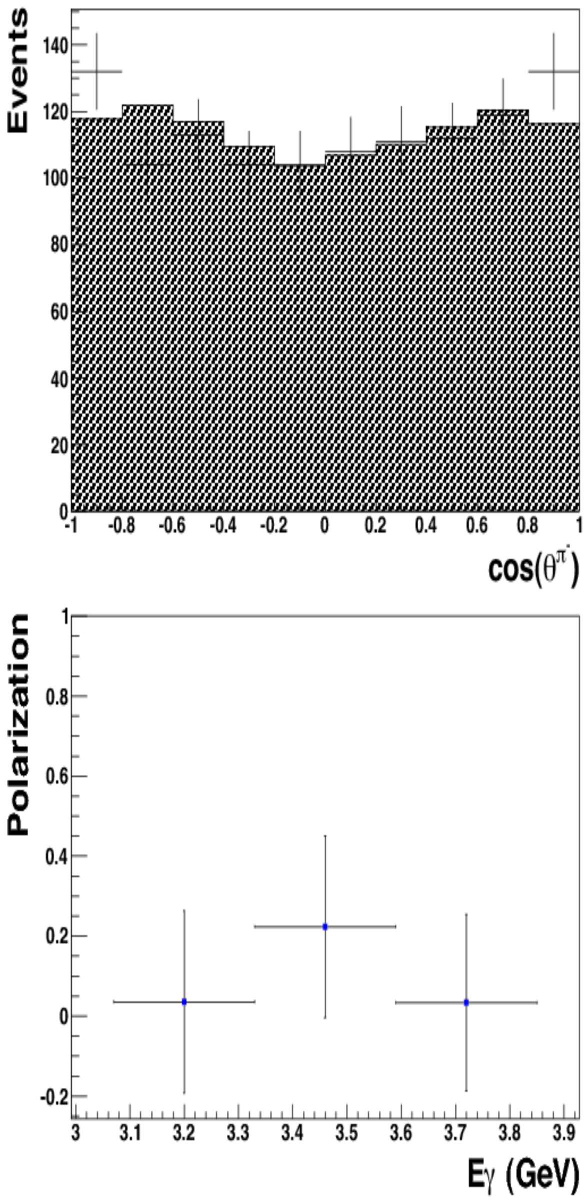

FIG. 4: Top: The integrated decay angular distribution of the Ξ^- decay. θ^π is the angle between the π^- momentum and the normal to the production plane. The shaded histogram is from simulation that is based on the differential cross sections results reported in Ref. [10]. The included photon energy range here is mostly from 3.0 GeV to 3.8 GeV; Bottom: Preliminary results of the calculated Ξ polarization out of the production plane is consistent with zero within uncertainty . Errors are statistical only. An estimated systematic uncertainty of 10% is not shown. The data was collected by the g11 experiment, and the photon beam is unpolarized.

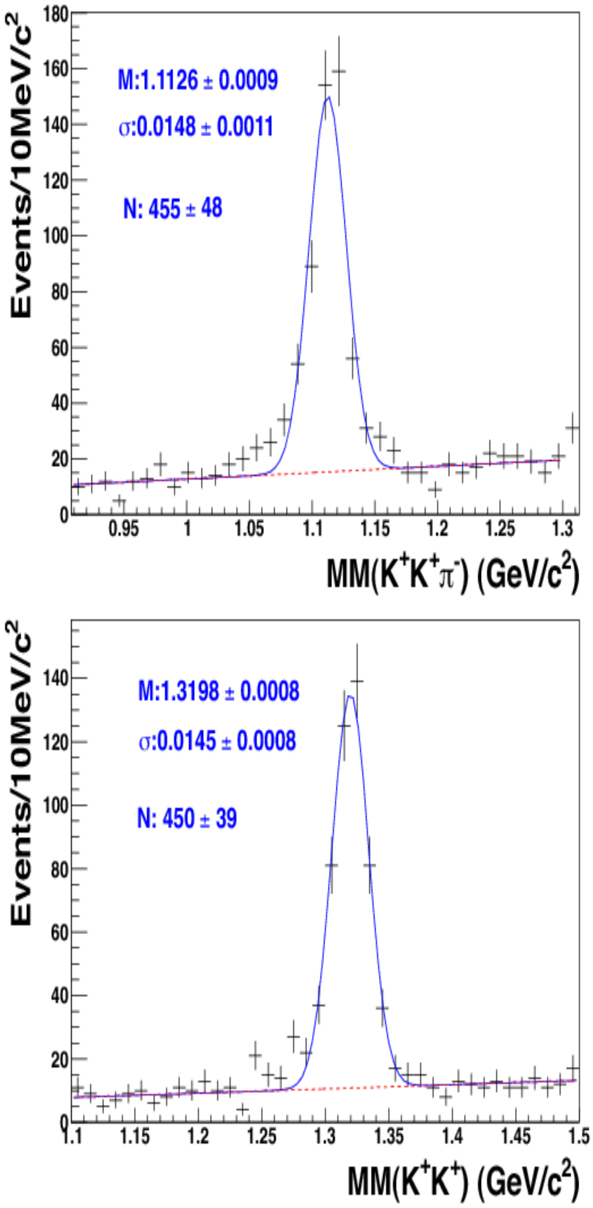

FIG. 5: Top: The missing mass spectra of the $K^+K^+\pi^-$ system off of a proton target. Events corresponding to the Ξ^- signal on the right are selected; Bottom: The missing mass spectra of the K^+K^+ system off of a proton target. Events corresponding to the Λ signal on the left are selected. The included photon energy range here is 3.3 GeV to 5.4 GeV. Only 10% of the data have been analyzed and shown here. These events are not required to have originated from within the target due to the weak decay of Ξ^-. The data was collected by the g12 experiment, and the photon beam is circularly polarized, with maximum polarization around 70% .

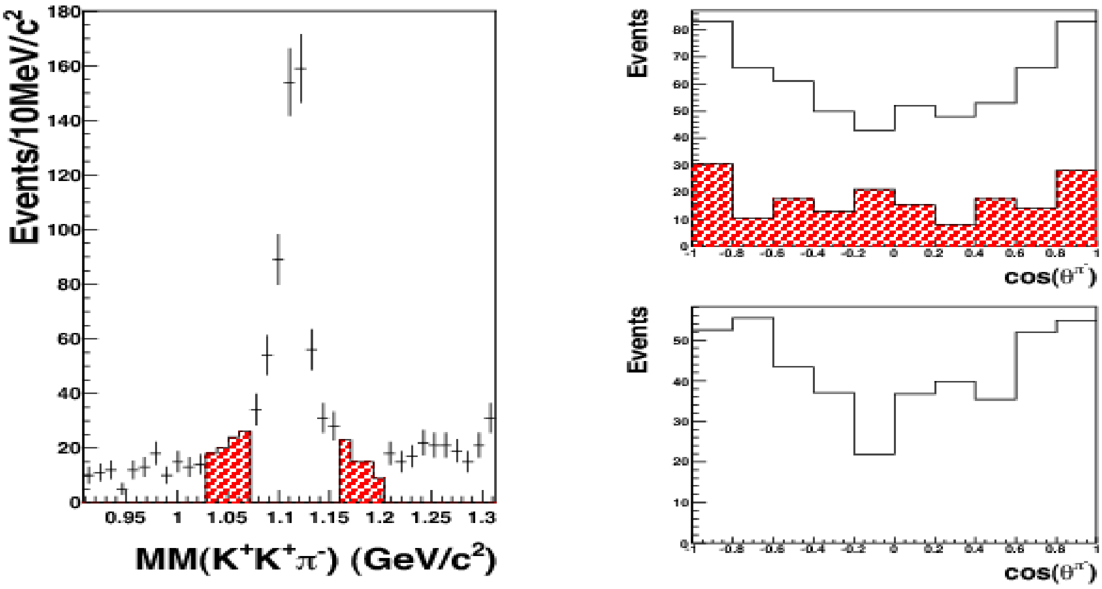

FIG. 6: Left: The missing mass spectrum of the $K^+K^+\pi^-$ system off of a proton target, from the g12 experiment. Top right: The decay angular distribution of $\Xi^- \to \Lambda\pi^-$, with the π^- being the analyzer, and the normal to the production plane defining the z-axis. The shaded events correspond to the side band events shown on the left; Bottom right: Side band subtracted of the decay angular distributions using the two histograms on the top.

$s\bar{s}$-pair, providing strange quarks in the incident photon beam. Therefore,

$$f(\gamma p \to \Omega^- X)|_{\phi MD} \sim (e/f_\phi) f(\phi p \to \Omega^- X). \tag{4}$$

Then, the photoproduction cross section is

$$f(\gamma p \to \Omega^- X)|_{\phi MD} \sim (\alpha/\alpha_\phi) \sigma(\phi p \to \Omega^- X). \tag{5}$$

Here, α is a fine structure constant, while the value $\alpha_\phi = f_\phi^2/4\pi = 14.3\pm0.5$ is obtained from the partial width $\Gamma(\phi \to e^+e^-) = (1.27\pm0.04)$ keV [1]. Using an additive quark model, we further relate cross sections of $\phi p \to \Omega^- X$, $K^- p \to \Omega^- X$, and $K^+ p \to \Omega^- X$ processes by

$$f(\phi p \to \Omega^- X) = [\sigma(K^- p \to \Omega^- X) + \sigma(K^+ p \to \Omega^- X)]/2. \tag{6}$$

Experimental data exist only for the $K^- p \to \Omega^- X$ process [7]. Using these data, we are able to estimate the photoproduction cross sections at the matching momenta, assuming the production mechanism shown in Fig. 7. We consider the numbers obtained in this

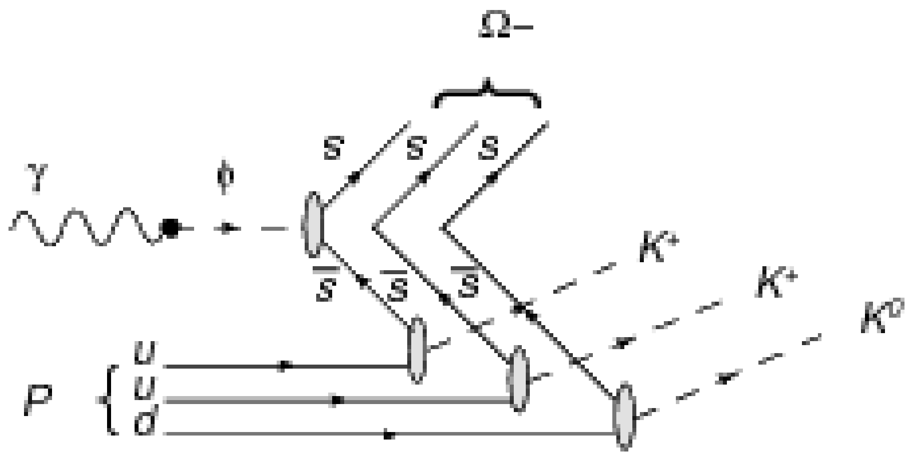

FIG. 7: Quark diagrams for the Ω-photoproduction for the VMD approach.

model to be upper limits. Based on this model, we estimate that, for the 11-GeV photon beam, we can anticipate Ω-baryon inclusive photoproduction cross section at the level of $\sigma_t = 0.5 - 1$ nb. Let us translate this inclusive cross section into an exclusive prediction. We estimate the exclusive cross section for $\gamma p \to \Omega KKK$ at σ_t=0.4- 0.5 nb. This follows from two independent arguments:

- Using Ref. [7] for $K^- p \to \Xi^- X$ cross section and ϕ^-VMD, we get σ_t ~40 nb for the inclusive $\gamma p \to \Xi^- X$. CLAS Collaboration gives σ_t ~15 nb for the exclusive $\gamma p \to \Xi^- KK$ at photon our previous VMD-based estimate (1 nb) by a factor of 2.5, we get the exclusive cross section of $\gamma p \to \Omega^- KKK$ as σ_t ~0.4 nb.

- Inclusive cross sections for $K^- p \to \Xi^- X$ and $K^- p \to \Omega^- X$ at 11 GeV/c appear to be in the approximate ratio 30:1 [7]. Let us assume the cross sections for $\gamma p \to \Xi^- KK$ and $\gamma p \to \Omega^- KKK$ are in the same ratio. The former is measured at CLAS to be σ_t ~15 nb [10], then the exclusive Ω cross section is a factor of 30 less, which is σ_t ~0.5 nb. Note that VMD was not used here explicitly.

B. Effective Lagrangian Model-1

The second prediction for the cross section for $\gamma N \to \Omega^- KKK$ obtained by Roberts in a simple model based on a phenomenological Lagrangian. The model is based on the diagrams shown in Fig. 8, where all permutations of external legs are included. This means that there

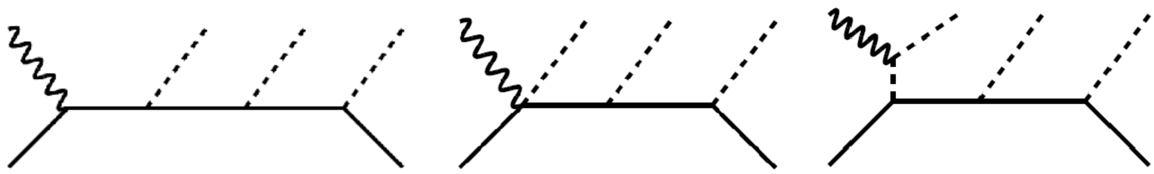

FIG. 8: Dominant graphs for $\gamma N \to \Omega^- KKK$ for the effective Lagrangian approach 1.

are 24 diagrams (Fig. 8(a)) like the first one, and 18 each like the second (Fig. 8(b)) and third (Fig. 8(c)) ones. If it is assumed that all of the coupling constants required have values near 2.0, the cross section obtained in this crude model will be a factor of 64 larger than shown. In their treatment of cascade photoproduction, using a model very similar to the one being discussed, Nakayama and collaborators [11] use a value of 6.55 for $g_{NK\Lambda}$, and 1.74 for g$\Xi K \Lambda$. Such values would give significantly larger cross sections for the process. However, form factors need to be included at each of the vertices, and these will significantly decrease the cross section, particularly at the higher energies. At present, form factors do not include in the estimation, but acknowledges that their effects will be large. Finally, it must be noted that no resonant contributions have been included in this estimate, but the Born terms should be sufficient for the order of magnitude estimates.

C. Effective Lagrangian Model-2

The third approach by Shklyar for the calculation of the Ω-photoproduction cross section (Fig. 9, which is similar to Fig. 8). The resonance production of $S = -3$ baryons can be represented by a sequence of transitions $\gamma p \to \Lambda^* \to \Xi^* \to \Omega^-$, where kaons are emitted at each step. There are three additional diagrams obtained by permutations of final kaon momenta in the diagram depicted in Fig. 9: ($q_1 \longleftrightarrow q_3$), ($q_2 \longleftrightarrow q_3$), and ($q_2 \to q_3$, $q_3 \to q_1$, and $q_1 \to q_2$).

Here, we assume that the reaction goes through the excitation of the two heavy resonances $\Lambda^*(3000)$ and $\Xi^*(2370)$. The PDG Listings [1] indicate several heavy Λ^*- and Σ^*-states with masses close to 3 GeV. Most of their properties are unknown. Therefore, we will treat $\Lambda^*(3000)$ resonance with $J^P = 1/2^+$ as a "generic" one assuming that it corresponds to overall possible contributions from both Λ^*- and Σ^*-hyperons. The model parameters are chosen as follows: $m_{\Lambda^*(3000)}$ = 3 GeV, $\Gamma_t(\Lambda^*(3000))$ = 200 MeV, Br($\Lambda^*(3000) \to K^*(892)N$)

= 20 %, and Br($\Lambda^*(3000) \to K\Xi^*(2370)$) = 10 %. The $\Xi^*(2370)$ state is rated by two stars in the PDG Listings and has about 10 % branching decay ratio to $K\Omega^-$ and 20 % decay fraction to the "generic" K*(892)Λ and K*(892)Σ final state. The spin and parity of $\Xi^*(2370)$ are also unknown and calculations are also done assuming $J^P = 1/2^+$. The total width of $\Gamma_t(\Xi^*(2370)) = 80$ MeV which is taken from PDG [1]. The interaction Lagrangian is chosen as

$$
\begin{aligned}
L = & g_{\Omega\Xi^*K}\left[\bar{\Omega}(x) i\gamma_5 \Xi^{(*)}(x)\right] K(x) \\
& + g_{\Lambda^*\Xi^*K}\left[\bar{\Xi}^{(*)}(x) i\gamma_5 \Lambda^{(*)}(x)\right] K(x) \\
& + g_{\Lambda^*K^*N}\left[\bar{N}(x)\sigma_{\mu\nu}\Lambda^{(*)}(x)\right] K^{(*)\mu\nu}(x) \\
& + \frac{e\, g_{K^*K\gamma}}{4m_K}\epsilon_{\mu\nu\rho\sigma} K^{(*)\mu\nu}(x) F^{\rho\sigma}(x) K(x) \\
& + \text{h.c.},
\end{aligned}
\tag{7}
$$

where isospin indices are omitted. The coupling constants are calculated from the corresponding decay branching ratios. The $K\Xi^*\Lambda^*$ and $K\Xi^*\Omega$ vertices are dressed by the form factor

$$
F_s(q^2) = \frac{\Lambda_s^4}{\Lambda_s^4 + (q_s - m_R^2)^2}, \tag{8}
$$

where q_s is a momentum of the propagating baryon in the s-channel and m_R is a mass of the resonance. The formfactor used at the $t-$channel vertex has the form

$$
F_t(q^2) = \frac{\Lambda_t^4 + m_{K^*}^4}{\Lambda_t^4 + (t + m_{K^*}^2)^2}, \tag{9}
$$

where $t = (q_1 - k)^2$ for the diagram depicted in Fig. 9. The cutoff parameter is chosen to be $\Lambda_s = \Lambda_t = 1.5$ GeV.

Having resonance production mechanism, the exclusive $\gamma p \to K^+ K^0 K^+ \Omega^-$ cross section is estimated to be about 0.5 nb at $E_\gamma = 11$ GeV. This is a conservative estimation and inclusion of additional channels would lead to a larger total cross section. The measurements of the invariant mass distributions can provide an important information on the Ω^- production process. The invariant mass distribution $\frac{d\sigma}{dM^2_{q_3,p_\Omega}}$ calculated in the case at hand is shown in Fig. 10. Here the notation $M^2_{q_3,p_\Omega} = (q_3 + p_\Omega)^2$ is adopted, where q_3 is a kaon momentum. Due to symmetrization the charge kaons can be emitted at any vertex which corresponds to the different kinematical situations. The interplay between contributions where the charge kaons are emitted at $\Lambda^*\Xi^* K$ and $\Xi^*\Omega^- K$ vertices leads to the broad structure in the M_{q_3,p_Ω}=

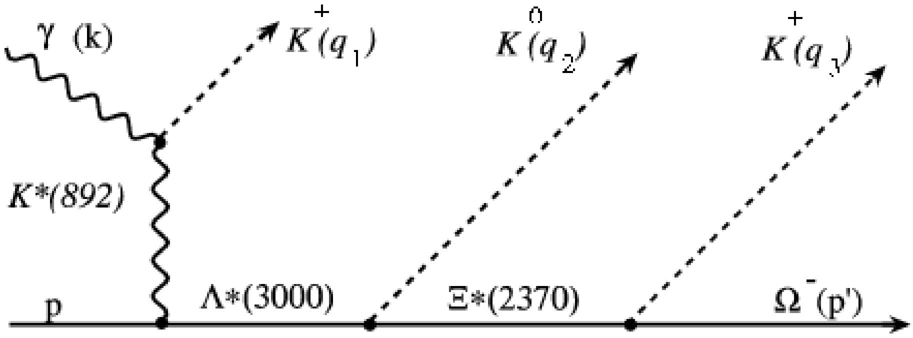

FIG. 9: Feynamn diagram for the $\gamma p \rightarrow K^+K^0K^+\Omega^-$ transition for the effective Lagrangian approach 2.

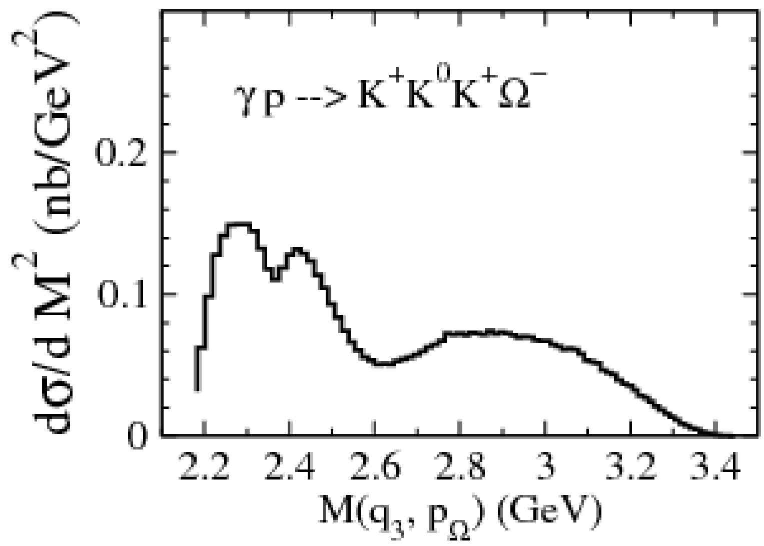

FIG. 10: Invariant mass distribution for the resonance production mechanism shown in Fig. 9.

2.2...2.6 GeV invariant mass region with the deep around $\Xi^*(2370)$ resonance mass. The second peak at 2.9 GeV is due to the $\Lambda^*(3000)$ excitation. Hence, the invariant mass distribution could shed light on the details of the Ω^- production mechanism and distinguish between resonance and resonance contributions.

D. Summary

Overall, Fig. 11 shows the cross section estimation as obtained for the Ω^- photoproduction on the proton. Near the threshold, the cross section is small, as expected, but quickly grows

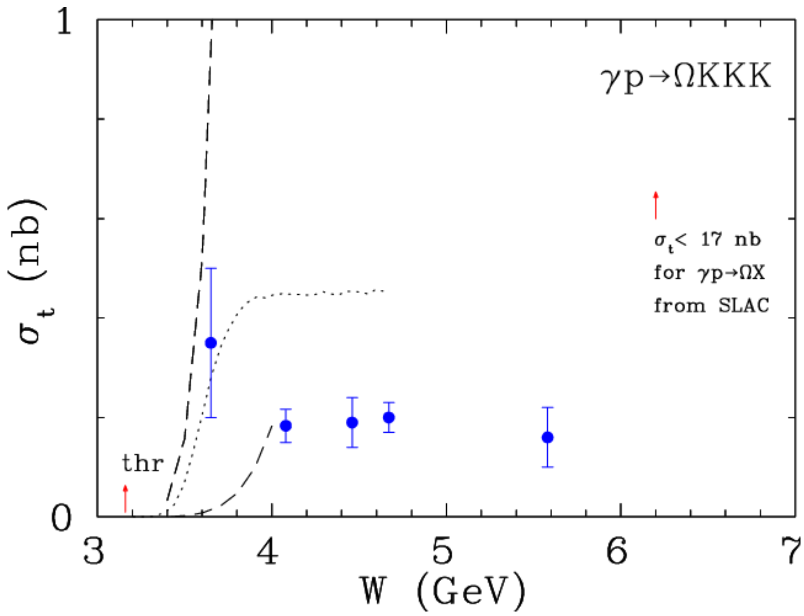

FIG. 11: Total exclusive cross section for the Ω-photoproduction. Blue filled circles show the conservative phenomenological translation of the hadronic cross sections into the photoproduction ones. Dashed curves show phenomenological Lagrangian-1 calculations. The dotted curve presents the Ω-production using a different Lagrangian-2 approach. The red arrow indicates the threshold which is W = 3.16 GeV (E_γ = 4.85 GeV).

into the nanobarns range (or tens of nanobarns, depending on the coupling constants). A cross section of a few nanobarns in the energy range of interest seems to be a safe bet. The critical feature is that all four estimations are consistent with each other. The numbers are an indication of what one can expect. Clearly, we shouldn't believe them (effective Lagrangian approach) very far from threshold, as the cross sections continue to rise but we have no idea how strongly energy dependent to make those.

One can estimate [16] that the photoproduction rate for $\gamma p \to \Omega^- X$ is simply α/π times the measured hadroproduction rate at ANL [6], which agreed with the above estimations. The angular distribution of the inclusive and exclusive events may provide a clue for the Ω^- production mechanism. For example, whether production of Ω(sss) is enhanced at small t or small u [16].

Brodsky's estimations addressed to one approach to $\Omega(sss)X$ [16]. That is to consider $g \to s\bar{s}$ the origin of one of the s-quarks. This produces the minimum number of final-state quarks. The other two strange quarks can be made either by gluon splitting $g \to s\bar{s}$ or by double intrinsic strangeness $|uuds s\bar{s}\bar{s} >$ Fock state of the proton. The gluonic intermediate states should be minimized [17]. The $gs\bar{s}$ vertex produces one of the needed strange quarks. The intrinsic strangeness mechanism does not need explicit gluons. One can create the strange quark pairs within the hadron wave function via QCD Coulomb exchange. This gives the $|uuds\bar{s}s\bar{s} >$ Fock state amplitude. This process is maximally efficient at threshold. The analogous $|uud\bar{c}c\bar{c} >$ double intrinsic charm Fock state can account for the extraordinary $\pi N \to J/\psi J/\psi X$ events seen by the NA3 Collaboration [18] as has been discussed in Ref. [19]. All of the double J/ψ events are made at high $x_F(total) > 0.4$.

Additionally, Shklyar estimated the $\gamma p \to \Omega\bar{\Omega}p$ cross section production. Unfortunately, the estimated total production cross section is too small − picobarns or smaller. It would be hard to use this channel for any reliable analysis.

E. ΩN and ΞN Elastic Scattering

... Ref. [22]. ...

John Price

IV. CROSS SECTION ESTIMATION FOR THE Ξ PHOTOPRODUCTION ON THE PROTON

There are several theoretical attemts to calculate excited Ξ states using effective Lagrangian approach.

... **Winston, Helmut&Kanzo** ...

V. EXPERIMENT WITH CLAS12 FOR THE Ω- AND Ξ-BARYONS

Obviously, the study of the Ω-baryon at JLab12 depends on the cross section. Our analysis of the $g12$ run period shows that we may have 10,000 Ω^- exclusive events. Our MC shows that the CLAS6 acceptance is 10^{-4}. Previous SLAC measurements [8] gave an upper limit for the Ω photoproduction only. Our cross section estimates, presented in this Proposal show that one can expect a cross section of the order of a nanobarn. We are going to use the CLAS12 detector and quasi-real photon tagging facility [20]. Let's consider two possible scenarios and see what production rate we can expect for both Ω- and Ξ-baryons.

A. Scenario 1: Untagged Real Photons

The CALS12 electron beam luminosity is expected to be 10^{35} cm^2/sec. Incident on hydrogen target 11 GeV electron beam generates real photons. The photon luminosity in the range of $E_\gamma = 5{-}11$ GeV will be $4{\times}10^{32}$ cm^2/sec. If we take the Ω production cross section of 0.5 nb (see Fig. 11), the production rate will be about 500 Ω/hour. The MC simulations for the $\gamma p \to K^+K^0K^+\Omega^-$, $\Omega^- \to \Lambda K^-$, $\Lambda \to \pi^- p$, and $K^0(K^0_S) \to \pi^+\pi^-$ with all 7 charged particles detected (an unique signature) shows that acceptance is $4{\times}10^4$. With the production rate of 500/hour and acceptance of $4{\times}10^4$, we can expect to detect in CLAS12 about 5 completely exclusive Ω production events a day. For these exclusive events, the background should be very small. Set final state as $K^+K^+K^0\Omega^-$ for track and analysis shows in Fig. 12. Unfortunately, this scenario will not work for Ξs (Fig. 12).

B. Scenario 2: Tagged quasi-Real Photons

In this scenario, we can use CLAS12 with quasi-real photon tagging facility [20]. This forward tagger will detect electron at very small angle and provide information about virtual photon. The luminosity of quasi-real photons will be about an order or two of magnitude or so lower than the luminosity of real photons. However, we can use missing mass technique and therefore get significant gain in the acceptance. If we know photon energy and momentum and detect associated $K^+K^0K^+$ to reconstruct Ω-baryon using missing mass in this case, the acceptance is 0.08. This yields comparable number of events detected. Additional information available with quasi-real photons is their polarization which could be useful in determination of quantum numbers and understanding of a production mechanism.

Both scenarios look feasible. The common feature of both is the possibility to collect Ω-baryon events concurrently with virtually any CLAS12 experiment if we add additional trigger for 4 or more charged particles without electron in CLAS12.

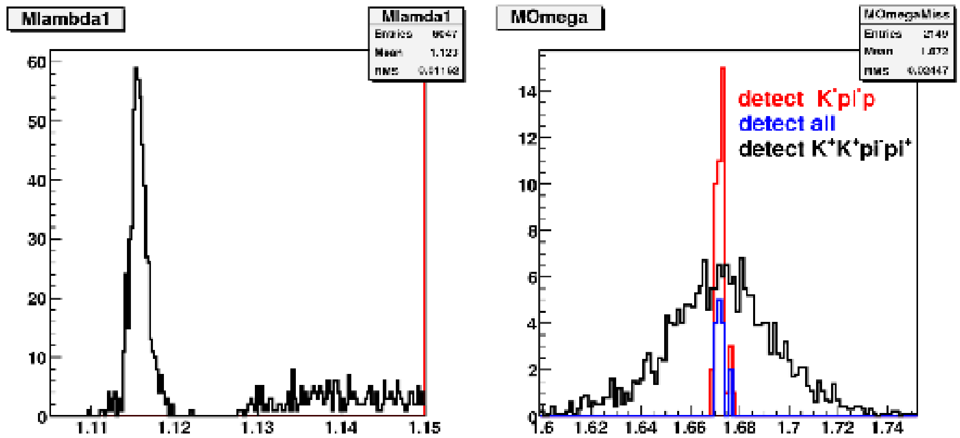

FIG. 12: MC for CLAS12.

C. Determination of the Spin-Parity of the Excited Cascades

However, the limitation of beam energy makes the sighting of missing cascade resonances at higher mass less likely. Even if we do observe some of these higher states, it is unlikely that there will be enough statistics and the spin parity measurement could be performed.

In order to determine Spin and Parity of an excited cascade, a very useful tool, so called double moment analysis (DMA) can be deployed [21, 23]. If only the reaction of $\Xi^{*-} \to \Lambda(\frac{1}{2}) + \pi^-(0^-)$ is reconstructed, then due to the Minami ambiguity, there could be two solutions of $J^{\pm P}$. In order to solve the problem, one needs to detect the decay of the daughter hyperon as well, for example, $\Lambda \to p\pi^-$. If there are sufficient statistics, then the double moments can be analyzed to determine the J^P assignment of the parent cascade. The double moments, typically noted by $H(lmLM)$, is defined by:

$$H(lmLM) = \Sigma D^L_{Mm}(\theta_1, \phi_1) D^l_{m0}(\theta_2, \phi_2) \tag{10}$$

with the θ_1, ϕ_1 being the decay angles of Ξ^*, and θ_2, ϕ_2 being the decay angles of Λ. The DMA technique takes advantage of the fact there is linear dependence between different double moments, given by

$$H(11LM) = P(-1)^{J+\frac{1}{2}} \frac{2J+1}{\sqrt{2L(L+1}} H(10LM) \tag{11}$$

This linear dependence gives simple, and multiple tests for J^P assignment, for multiple combinations of any odd $L \leq 2J$ and $M \leq L$, therefore providing reliable measurement of the quantum numbers of the excited cascades. In fact, this is how the J^P of the $\Xi(1820)$ state was determined, needing only 50 signal events [21]. In order to perform such analysis, it is necessary to reconstruct the whole decay chain of Ξ^*, such as $\Xi^{*-} \to \Lambda\pi^-$, $\Lambda \to p\pi^-$.

The typical efficiency for detecting the proton from the Λ decay is around 50% at CLAS, and expected to be similar at CLAS12. Taking into account that Λ decays to $p\pi^-$ only 64% of the time, the number of excited cascade events, which can have the decay chain reconstructed, will shrink by a factor of three, when compared the requirement for identifying them from invariant mass spectra such as $\Lambda\bar{K}$, which does not need to reconstruct the decay of Λ. The implication is that, in order to measure the J^P of excited cascades, one need to conduct the experiment at as high energies as possible, in order to reach the region where the cross section is sizable, to compensate the inefficiency of detecting multiple final state particles.

Our conservative estimate, using the projected CLAS12 luminosity, would require roughly 3 months beam time using a quasi-real photon beam, to confirm the spin-parity assignment of $\Xi(1820)$) with at least an order of magnitude more than any previous data. This estimate was made with the assumption that at E_γ above 6 GeV, the $\Xi(1820)$ cross section would be comparable with of $\Xi(1530)$ near 4 GeV [10]. Data on other higher mass states would almost certainly amount to discoveries.

D. MC for the Direct Tracking Reconstruction

E. Kinematics, Rates, and Backgrounds

F. Triggers

VI. BEAM TIME REQUEST AND EXPECTED RESULTS

Overall, it looks that it is feasible to measure the $\gamma p \to \Omega^- K^+ K^+ K^0$ cross section with CLAS12 without and with FT facility. While FT facility is critical for both cross section and polarization measurements for the $\gamma p \to \Xi^- K^+ K^+$.

VII. SUMMARY

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