LEPS Proposal

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Photoproduction of Excited Hyperons near 1.67GeV

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Abstract

While the results of partial-wave analyses agree on the properties of the $S = -1$ hyperon resonances ($S_{01}\Lambda(1670)$, $D_{03}\Lambda(1690)$, and $D_{13}\Sigma(1670)$), there is some disagreement between production and formation experiments in this mass region. The preliminary analysis of the 2007 3-GeV data shows a feasibilty of unveiling the nature of hyperon resonances near 1.67GeV with higher statistics. In analogy to $\Lambda(1405)$, their lineshapes seem to appear different in $\pi^-\Sigma^+$ and $\pi^+\Sigma^-$ modes. We propose the high-mass hyperon resonance (Y^*) experiment with the maximum 3-GeV photons. The proposed experiment can be performed either of using a hydrogen target with a solenoid spectrometer or using both a hydrogen target and a deuterium target without a solenoid spectrometer.

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- Title of a Proposal : PHOTOPRODUCTION OF EXCITED HYPERONS NEAR 1.67GEV
- Spokesperson : Jung Keun Ahn (Pusan National University, Professor, ahnjk@pusan.ac.kr)
- A collaborator list : Current LEPS Collaborators
- Beam running time : 200 shifts
- Requirements for the beam condition and experimental equipment :
    1. Photon energy from threshold to 3GeV with a high-power 266nm laser
    2. The LEPS dipole spectrometer with a LH_2 target
    3. Low-index Aerogel Cherenkov detector or plastic scintillator for e^+e^- suppression and/or a Time-of-Propagation counter for high-momentum π/K separation

Contents

1 Motivation

Excited states of hyperons are still much less well known, compared to the nucleon resonances. In the $S = -1$ sector the $\Sigma(1385)$ and $\Lambda(1405)$ lie below the $\bar{K}N$ threshold, and almost all their known properties were from production experiments. The nature of the $\Lambda(1405)$ has been unveiled yet, which may be either of a genuine three-quark state, a meson-baryon molecular state, or even an exotic multiquark state. In the case of $\Lambda(1520)$ above the $\bar{K}N$ threshold production and formation experiments agree quite well. In the $1600 - 1700$ MeV region the existence of three $S = -1$ baryon resonances have been established, $S_{01}\Lambda(1670)$, $D_{03}\Lambda(1690)$, and $D_{13}\Sigma(1670)$. The results of partial-wave analyses agree on the mass, width and branching ratios of these resonances [1, 2, 3].

However, there is some disagreement between production and formation experiments in this mass region. Formation experiments observe one Σ resonance in the 1670 MeV mass region with $J^p = \frac{3}{2}^-$ and decaying primarily to $N\bar{K}$, $\Lambda\pi$, and $\Sigma\pi$. On the other hand, production experiments have found evidence suggesting two Σ resonances in this mass region with comparable values of mass and width. This evidence is based on a difference in the production angular distributions of $\Sigma(1670)$ decaying into $\Sigma\pi$ and into $\Sigma\pi\pi$ [4, 5, 6, 7, 8, 9].

Particle	$L_{2I,2J}$	Mass (MeV)	Decay mode		
	J^p	Γ (MeV)	$N\bar{K}$	$\Sigma\pi$	$\Lambda\pi$
$\Lambda(1670)$	S_{01}	≈ 1670	$20 - 30$	$25 - 35$	
	$\frac{1}{2}^-$	≈ 35			
$\Sigma(1660)$	P_{11}	≈ 1660	$10 - 30$	seen	seen
	$\frac{1}{2}^+$	≈ 100			
$\Sigma(1670)$	D_{13}	≈ 1670	$7 - 13$	$30 - 60$	$5 - 15$
	$\frac{3}{2}^-$	≈ 60			

Table 1: Status of $S = -1$ hyperon resonances from PDG[1]

Current status of $S = -1$ hyperon resonances in the mass region between 1.6 and 1.7 GeV from Particle Data Group is shown in Tab. 1.

2 Preliminary Results on $Y(1670) \to \Sigma\pi$ and $N\bar{K}$ Decays

Hyperon resonances near 1.67GeV lie above threshold masses for the meson-baryon systems, such as $\Lambda\pi$, $\Sigma\pi$, $N\bar{K}$, $\Lambda\eta$ and those with an additional pion. Tagging a K^+ in the final state allows us to study photoproduction of neutral hyperon resonances (Λ^* or Σ^{0*}). The LEPS spectrometer can tag the reactions listed in Table 2.

Decay mode	Reactions
$\Sigma\pi$	$p(\gamma, K^+\pi^+)\Sigma^-$ or $p(\gamma, K^+\pi^-)\Sigma^+$
$N\bar{K}$	$p(\gamma, K^+K^-)p$, $p(\gamma, K^+p)K^-$ or $p(\gamma, K^-p)K^+$

Table 2: Production reactions for each decay mode.

We have collected data with a LH_2 target at $E_\gamma = 1.5 - 3.0$GeV in the period of late in the year 2007. We first selected two-track events with K^+ and π^+. We required that the missing-mass for $p(\gamma, K^+\pi^+)X$ reaction should be consistent with the mass of Σ^-. A correlation between missing masses for $p(\gamma, K^+\pi^+)X$ and $p(\gamma, K^+)X$ reactions is shown in the left of Fig. 1. A dominant feature of the scatter plot is that the experimental evidence for 1.67-GeV resonance production associated with Σ and $\Sigma(1385)$ is confirmed.

We selected the Σ^- band in the scatter plot and obtained the missing-mass distribution for $p(\gamma, K^+)X$ reaction where X decays into $\Sigma^-\pi^+$, as shown in Fig. 1. We fit the whole missing-mass spectrum with three Gaussians for $\Lambda(1405)$, $\Lambda(1520)$ and $Y(1670)$ resonances and a phase-space function assuming $\gamma p \to K^+\Sigma^-\pi^+$ three-body reaction process. $Y(1670)$ denotes any hyperon resonances with the mass near 1.67GeV. It could be either of Λ^* or Σ^*. The yield ratio of $Y(1670)$ to $\Lambda(1520)$ is found to be nearly unity.

We have also looked for the $Y(1670)$ decaying into $\Sigma^+\pi^-$. We selected two-track events with K^+ and π^-. Dominant features of this decay mode bring two new background processes: one is the $K^{0*} \to \pi^-K^+$ decay, and the other is the $K^0 \to \pi^-\pi^+$ decay where π^+ is misidentified as K^+. This decay mode could then bring larger background processes than in the decay mode of $\Sigma^-\pi^+$.

A missing-mass distribution for $p(\gamma, K^+\pi^-)X$ reaction is shown in the left of Fig. 2. A peak of Σ^+ is clearly seen in the missing-mass spectrum. A bump structure near 1.4 GeV seems to be associated with $\Sigma(1385)^+$ production. We required that the missing-mass for $p(\gamma, K^+\pi^-)X$ reaction should be consistent with the mass of Σ^+.

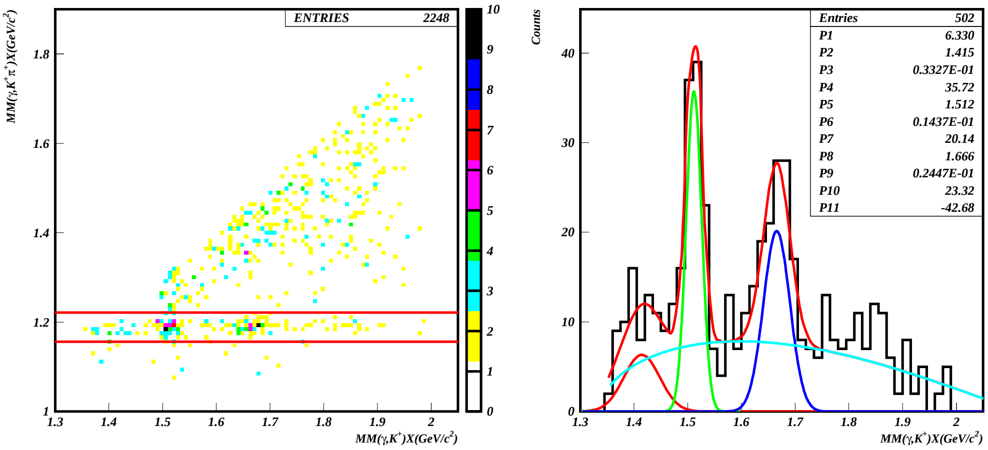

Figure 1: A scatter plot of missing masses for $p(\gamma, K^+\pi^+)X$ and $p(\gamma, K^+)X$ reactions(left) and a missing-mass distribution for $p(\gamma, K^+)X$ reaction where X decays into $\Sigma^-\pi^+$(right). Overlaid lines indicate a least-square fit with three Gaussians for $\Lambda(1405)$, $\Lambda(1520)$ and $Y(1670)$ resonances and a phase-space function assuming $\gamma p \to K^+\Sigma^-\pi^+$ three-body reaction process.

For the $N\bar{K}$ decay we selected two-track events by requiring that a K^+ and either of K^- or p should be identified. We fist looked at the events with K^+ and p tracks. We required that the missing mass for $p(\gamma, K^+p)X$ reaction should be in the mass range from 0.460 and 0.506 GeV/c^2, as shown in the left of Fig. 3.

A missing-mass distribution for $p(\gamma, K^+)X$ with X decaying into K^-p is shown in the right of Fig. 3. A peak of $\Lambda(1520)$ is predominant. The yield drops mostly in the mass region near 1.67 GeV. The $\phi \to K^+K^-$ decay can contribute to the background spetrum under hyperon resonance peaks. We excluded the ϕ events such that the missing-mass for $p(\gamma, p)X$ with X decaying into K^-K^+ is within the mass tolerance window of $3\Gamma_\phi$.

We also studied two-track events by tagging a pair of K^+K^- at forward angles. We required that the missing particle should be a proton with the mass tolerance window of $|m_X - m_p| < 20$ MeV/c^2. Since we tagged a pair of K^+K^- at forward angles, the ϕ photoproduction events are dominant over the whole spectrum.

Figure 2 shows an invariant mass spectrum for K^-K^+ system, which proves that ϕ-associated events are dominant. We excluded the events within the ϕ mass window. Only a third of the events survived after the ϕ exclusion cut, as shown in the right of Fig. 2. The $\Lambda(1520)$ peak is then slightly

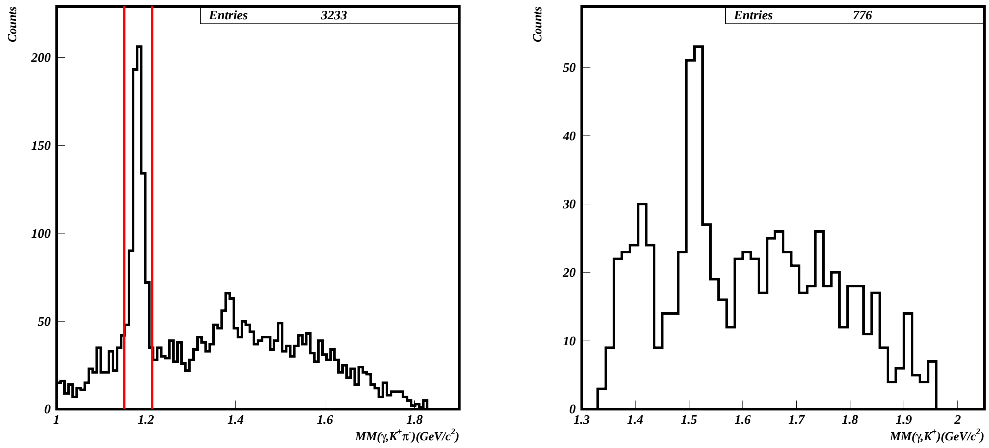

Figure 2: A missing-mass distribution for $p(\gamma, K^+\pi^-)X$ reaction(left) and a missing-mass spectrum for $p(\gamma, K^+)X$ where X decays into $\Sigma^+\pi^-$.

enhanced over the level of underlying background events. Some peak-like fluctuations appear in the higher mass region. A kinematical constraint for a pair of K^+K^- at forward angles may be very strict to observe hyperon resonances including $Y(1670)$. Out of the decay products from the $Y(1670)$ a proton is heavier than a K^-, so that it prefers to a forward direction. A K^- has only a little chance to come in the forward lab angles.

Lastly, we have looked for the $Y(1670)$ in the $p(\gamma, K^-p)X$. reaction. We required that the missing mass for $p(\gamma, K^-p)X$ should be in the tolerance window of the K^+ mass. The K^-p invariant mass spectrum is shown in the right. We tagged K^-p at forward angles. Only a small fluctuation appears at the region near 1.67GeV, while the $\Lambda(1520)$ peak is clearly seen. Apart from the K^-p threshold the opening angle between K^- and p goes larger. Due to our limited angular acceptance the yield for K^-p system drops as it goes to higher mass region.

3 The Proposed Experiment

In the $1600 - 1700$ MeV region the existence of three $S = -1$ baryon resonances have been established, $S_{01}\Lambda(1670)$, $D_{03}\Lambda(1690)$, and $D_{13}\Sigma(1670)$. While the results of partial-wave analyses agree on the properties of these resonances, there is some disagreement between production and formation experiments in this mass region. The preliminary analysis shows a feasibilty of unveiling the nature of hyperon resonances near 1.67GeV with higher

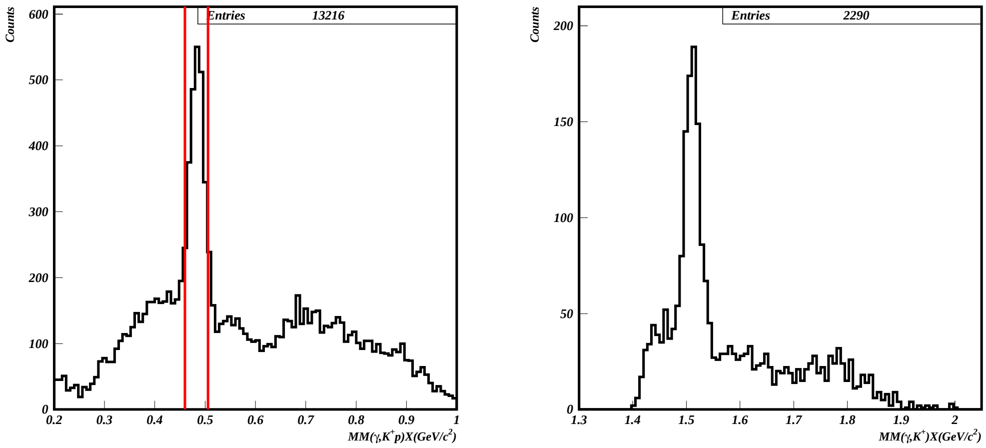

Figure 3: A missing-mass distribution for $p(\gamma, K^+p)X$ reaction(left) and a missing-mass distribution for $p(\gamma, K^+)X$ with X decaying into K^-p after the ϕ exclusion cut(right).

statistics. In analogy to $\Lambda(1405)$, their lineshapes seem to appear different in $\pi^-\Sigma^+$ and $\pi^+\Sigma^-$ modes.

We propose the high-mass hyperon resonance (Y^*) experiment with the maximum 3-GeV photons, to measure production cross-sections, beam asymmetries, and decay branching fractions for the hyperon resonances. The proposed experiment can be performed in two ways: one is to utilize the solenoid spectrometer including a time-projection chamber, which enables us to study decay angular distributions of the hyperon resonances produced from the hydrogen target, the other is to rely only on the forward spectrometer with the hydrogen target and also with the deuterium target. Both approaches are complementary for identifying between $\Lambda(1670)$ and $\Sigma(1670)$ with the same mass.

No significant hardware improvements are required for the proposed experiment. The current $n = 1.03$ Cherenkov counter should be replaced with either of lower refractive-index Cherenkov detectors or active e^+e^- veto scintillation counters for accepting high-momentum pions. A Time-of-Propagation Cherenkov detector can be implemented for more stringent π/K separation.

The beam time requested depends heavily on photon flux or laser power for the maxium 3-GeV photon beam. Compared to the 2007 K^* experiment we expect benefits from high power of the deep-UV laser and the top-up operation of the storage ring. We request 200 shifts for the proposed exper-

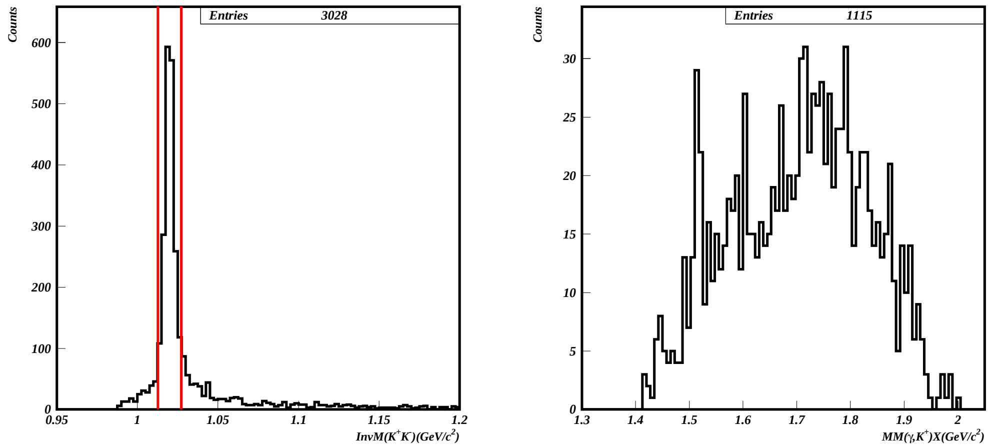

Figure 4: An invariant mass spectrum for K^-K^+ systems(left) and a missing-mass distribution for $p(\gamma, K^+)X$ with X decays into K^-p after ϕ associated events are excluded(right).

iment with maxium 3-GeV photon energy and a LH_2 target, thereby taking at least 5 times as large as the statistics obtained in the 2007 K^* experiment.

For manpower commitments the participants in this proposal constitute the current LEPS collaborators who possess expertise to complete their responsibilities in a timely manner.

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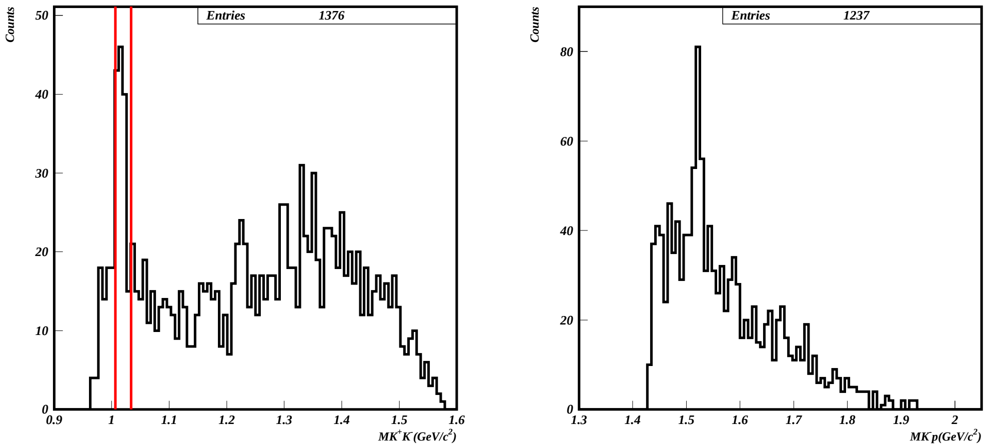

Figure 5: A missing-mass spectrum for $p(\gamma, p)X$ with X decaying into K^-K^+ (left) and a missing-mass distribution for $p(\gamma, K^+)X$ with K^-p detected at forward angles after ϕ exclusion cut(right).

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