Photoproduction of $K\Sigma(1385)$ from nucleons

Yongseok Oh

(Kyungpook National University, Korea)

MENU 2010 Conference, May 31 - June 4, 2010, Williamsburg, VA

Overview

1. Introduction
2. Model for the production mechanism
   - without resonances
3. Model for the production mechanism
   - with resonances
4. Summary and Outlook

1. Introduction

- Strangeness (photo)production from nucleons:
  - To obtain a deeper understanding of baryon structure
  - To search for missing resonances
  - Mostly focused on kaon photoproduction accompanied by $\Lambda(1116)$ or $\Sigma(1193)$
- Recent experiments on strangeness production
  - $K^*\Lambda$ and $K^*\Sigma$ photoproduction
    - CLAS Collaboration, *hep-ex/0601010, PRC **75** (2007)*
    - CBELSA/TAPS Collaboration, *EPJA **35** (2008)*
      - Baryon resonances
      - Scalar κ meson (YO, H. Kim, *PRC **73** (2006), PRC **74** (2006)*)
  - $K\Sigma(1385)$ photoproduction
    - CLAS Collaboration, *hep-ex/0601010*
    - LEPS Collaboration, *PRC **78** (2008), PRL **102** (2009)*

$K\Sigma(1385)$

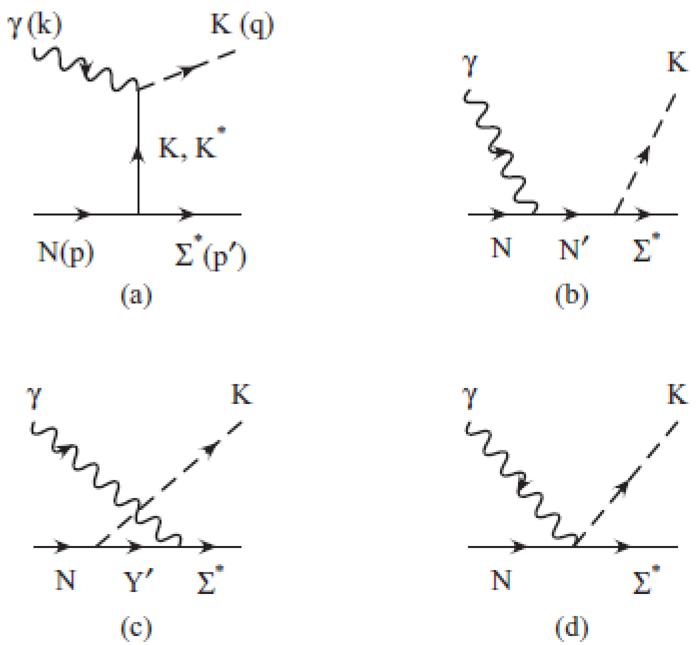
- Quark model predictions
  - Capstick, Roberts, *PRD **58** (1998)*
  - Most resonances have small couplings to $K\Sigma(1385)$
    - But some resonances, mostly missing or not-well-established, have large couplings to this channel
      e.g. $\Gamma[N\frac{3}{2}^{-}(2095) \rightarrow K\Sigma(1385)] \approx 60$ MeV
  - Can we find such resonances in this reaction?

Previous works

- Experiments
  - Only a few data for total cross section
    - Done at pre-1970s
  - Recent experiments at JLab (& Spring-8)
    - 23 different energies from threshold to $W = 3.8$ GeV
    - More data for total/differential cross sections are to be accumulated.
- Theory
  - No detailed studies on this reaction
  - Lutz, Soyeur, *NPA **748** (2005)*
    - Single and double kaon pole terms in diff. cross section (extrapolated from limited electroproduction data)

2. Model for the production mechanism - without resonances

Effective Lagrangian approach



- $$\mathcal{L}_{\gamma KK} = ieA_\mu(K^-\partial^\mu K^+ - \partial^\mu K^- K^+),$$
  $$\mathcal{L}_{KN\Sigma^*} = \frac{f_{KN\Sigma^*}}{M_K}\partial_\mu \overline{K\Sigma}^{*\mu}\cdot\tau N + \text{H.c.},$$
  $$\mathcal{L}_{\gamma NN} = -e\bar{N}\left(\gamma^\mu A_\mu \frac{1+\tau_3}{2} - \frac{\kappa_N}{2M_N}\sigma^{\mu\nu}\partial_\nu A_\mu\right)N,$$
  $$\mathcal{L}_{\gamma KN\Sigma^*} = -ie\frac{f_{KN\Sigma^*}}{M_K}A^\mu K^-(\bar{\Sigma}^{*0}_\mu p + \sqrt{2}\bar{\Sigma}^{*+}_\mu n) + \text{H.c.},$$
  $$\mathcal{L}_{\gamma\Sigma^*\Sigma^*} = e\overline{\Sigma}^*_\mu A_\alpha \Gamma^{\alpha,\mu\nu}_{\gamma\Sigma^*}\Sigma^*_\nu,$$
  $$A_\alpha\Gamma^{\alpha,\mu\nu}_{\gamma\Sigma^*} = \left\{g^{\mu\nu}\gamma^\alpha - \frac{1}{2}(\gamma^\mu\gamma^\nu\gamma^\alpha + \gamma^\alpha\gamma^\mu\gamma^\nu)\right\}A_\alpha T_3$$
  $$-\frac{\kappa_{\Sigma^*}}{2M_N}\sigma^{\alpha\beta}\partial_\beta A_\alpha g^{\mu\nu},$$
- $\kappa_p = 1.793$ (expt.), $\kappa_{\Sigma^{*0}} = 0.36$ (quark model)
- $f_{KN\Sigma^*} = -3.22$ by the SU(3) symmetry relation by using $f_{\pi N\Delta} = -3.22$ from $\Gamma(\Delta \to \pi N) = 120$ MeV
- $\mathcal{L}_{\gamma KK^*} = g_{K^*K\gamma}\varepsilon^{\mu\nu\alpha\beta}\partial_\mu A_\nu \partial_\alpha K^{*-}_\beta \bar{K}^+ + \text{H.c.}$ with $g_{K^*K\gamma} = -0.388\ \text{GeV}^{-1}$

$K^* N \Sigma^*$ interaction

- Vertex of $\frac{3}{2} \to \frac{1}{2} + 1$ transition
- 3 independent terms

$$\mathcal{L}_{K^* N \Sigma^*} = \frac{i g_1}{2M_N} \overline{K}^{*\mu\nu} \overline{\Sigma}^*_\mu \cdot \tau \gamma_\nu \gamma_5 N + \frac{g_2}{(2M_N)^2} \overline{K}^{*\mu\nu} \overline{\Sigma}^*_\mu \cdot \tau \gamma_5 \partial_\nu N - \frac{g_3}{(2M_N)^2} \partial_\nu \overline{K}^{*\mu\nu} \overline{\Sigma}^*_\mu \cdot \tau \gamma_5 N + \text{H.c.},$$

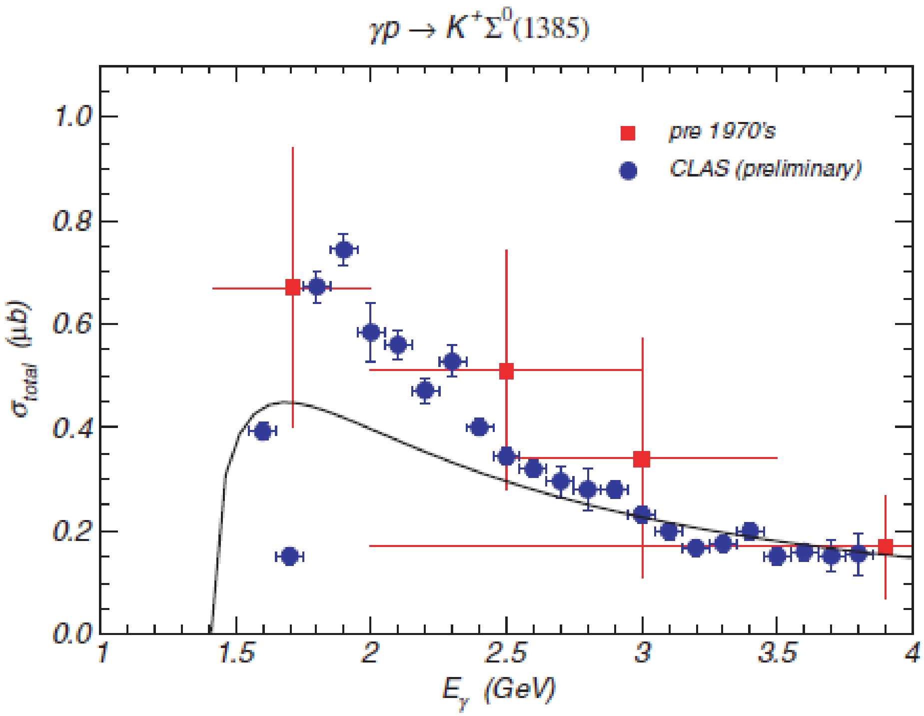
$$(K^{*\mu\nu} = \partial^\mu K^{*\nu} - \partial^\nu K^{*\mu})$$

$K^* N \Sigma^*$ couplings

- SU(3) relation from $g_1(\rho N \Delta) \sim 5.5$
- But there has been no serious consideration for the couplings g_2 and g_3. $\Rightarrow$ threat them as free parameters
  - In fact, K^* exchange is small unless g_2 and/or g_3 are unrealistically large.

Result

Total cross section



Cannot explain the peak observed in the CLAS data (regardless of the FF)

KNU 경북대학교 KYUNGPOOK NATIONAL UNIVERSITY

- Consider N and Δ resonances
- Even the resonances listed in PDG do not have branching ratio into $K\Sigma(1385)$ decay channel
  - Use the quark model for the resonance parameters
    Capstick, Roberts *PRD* ***58*** *(1998)*, Capstick *PRD* ***46*** *(1992)*
  - This model predicts that
    - Higher spin resonances ($j > 5/2$) have small couplings to the $K\Sigma(1385)$ channel

      → we consider the resonances of spin up to 5/2
    - Instead of all the predicted resonances, we consider only a few resonances which are predicted to have a large decay width into the $K\Sigma(1385)$ channel
    - 5 resonances listed in PDG plus 3 missing resonances
    - The PDG resonances are either one-star or two-star rated

Lagrangian

KNU 경북대학교 KYUNGPOOK NATIONAL UNIVERSITY

$RN\gamma$ interactions

$$\mathcal{L}_{RN\gamma}(\tfrac{1}{2}^{\pm}) = \frac{ef_1}{2M_N}\bar{N}\Gamma^{(\mp)}\sigma_{\mu\nu}\partial^\nu A^\mu R + \text{H.c.},$$

$$\mathcal{L}_{RN\gamma}(\tfrac{3}{2}^{\pm}) = -\frac{ief_1}{2M_N}\bar{N}\Gamma_\nu^{(\pm)}F^{\mu\nu}R_\mu - \frac{ef_2}{(2M_N)^2}\partial_\nu\bar{N}\Gamma^{(\pm)}F^{\mu\nu}R_\mu + \text{H.c.},$$

$$\mathcal{L}_{RN\gamma}(\tfrac{5}{2}^{\pm}) = \frac{ef_1}{(2M_N)^2}\bar{N}\Gamma_\nu^{(\mp)}\partial^\alpha F^{\mu\nu}R_{\mu\alpha} - \frac{ief_2}{(2M_N)^3}\partial_\nu\bar{N}\Gamma^{(\mp)}\partial^\alpha F^{\mu\nu}R_{\mu\alpha} + \text{H.c.},$$

- In QM, the coupling constants are not given.
- Instead, the helicity amplitudes are given

Couplings and helicity amplitudes

$$\Gamma(R \to N\gamma) = \frac{k_\gamma^2}{\pi}\frac{2M_N}{(2j+1)M_R}[|A_{1/2}|^2 + |A_{3/2}|^2],$$

$$A_{1/2}(\tfrac{1}{2}^{\pm}) = \mp\frac{ef_1}{2M_N}\sqrt{\frac{k_\gamma M_R}{M_N}},$$

$$A_{1/2}(\tfrac{3}{2}^{\pm}) = \mp\frac{e\sqrt{6}}{12}\sqrt{\frac{k_\gamma}{M_N M_R}}\left[f_1 + \frac{f_2}{4M_N^2}M_R(M_R \mp M_N)\right],$$

$$A_{3/2}(\tfrac{3}{2}^{\pm}) = \mp\frac{e\sqrt{2}}{4M_N}\sqrt{\frac{k_\gamma M_R}{M_N}}\left[f_1 \mp \frac{f_2}{4M_N}(M_R \mp M_N)\right],$$

$$A_{1/2}(\tfrac{5}{2}^{\pm}) = \pm\frac{e}{4\sqrt{10}}\frac{k_\gamma}{M_N}\sqrt{\frac{k_\gamma}{M_N M_R}} \times \left[f_1 + \frac{f_2}{4M_N^2}M_R(M_R \pm M_N)\right],$$

$$A_{3/2}(\tfrac{5}{2}^{\pm}) = \pm\frac{e}{4\sqrt{5}}\frac{k_\gamma}{M_N^2}\sqrt{\frac{k_\gamma M_R}{M_N}}\left[f_1 \pm \frac{f_2}{4M_N}(M_R \pm M_N)\right],$$

$RK\Sigma^*$ interactions

$$\mathcal{L}_{RK\Sigma^*}\left(\tfrac{1}{2}^{\pm}\right) = \frac{h_1}{M_K}\partial_\mu K \bar{\Sigma}^{*\mu}\Gamma^{(\mp)} R + \text{H.c.},$$

$$\mathcal{L}_{RK\Sigma^*}\left(\tfrac{3}{2}^{\pm}\right) = \frac{h_1}{M_K}\partial^\alpha K \bar{\Sigma}^{*\mu}\Gamma^{(\pm)}_\alpha R_\mu + \frac{ih_2}{M_K^2}\partial^\mu\partial^\alpha K \bar{\Sigma}^*_\alpha \Gamma^{(\pm)} R_\mu + \text{H.c.},$$

$$\mathcal{L}_{RK\Sigma^*}\left(\tfrac{5}{2}^{\pm}\right) = \frac{ih_1}{M_K^2}\partial^\mu\partial^\beta K \bar{\Sigma}^{*\alpha}\Gamma^{(\mp)}_\mu R_{\alpha\beta} - \frac{h_2}{M_K^3}\partial^\mu\partial^\alpha\partial^\beta K \bar{\Sigma}^*_\mu \Gamma^{(\mp)} R_{\alpha\beta} + \text{H.c.}$$

By angular momentum and parity conservation,

1 coupling for the resonance with $j = 1/2$
2 couplings for the resonance with $j \geq 3/2$

To determine the couplings with sign, we need the decay amplitudes. The decay width is not enough.

KNU 경북대학교 KYUNGPOOK NATIONAL UNIVERSITY

Decay amplitudes

$$\langle K(q)\Sigma^*(-q, m_f)| - i\mathcal{H}_{\rm int}|R(\mathbf{0}, m_j)\rangle$$
$$= 2\pi M_R\sqrt{\frac{2}{q}}\sum_{\ell, m_\ell}\langle \ell m_\ell \tfrac{3}{2} m_f | j m_j\rangle Y_{\ell m_\ell}(\hat{q})G(\ell),$$

$$G(1) = -\frac{1}{\sqrt{2\pi}}\frac{q}{M_{\Sigma^*}}\sqrt{qM_R}\sqrt{E_{\Sigma^*}+M_{\Sigma^*}}\frac{h_1}{M_K},$$

for a $j^\pi = \frac{1}{2}^+$ resonance, and

$$G(2) = -\frac{1}{\sqrt{2\pi}}\frac{q}{M_{\Sigma^*}}\sqrt{qM_R}\sqrt{E_{\Sigma^*}-M_{\Sigma^*}}\frac{h_1}{M_K},$$

for a $j^\pi = \frac{1}{2}^-$ resonance.

$$\Gamma(R \to K\Sigma^*) = \sum_\ell |G(\ell)|^2,$$

$$G(1) = G_{11}^{(3/2)}\frac{h_1}{M_K} + G_{12}^{(3/2)}\frac{h_2}{M_K^2},$$
$$G(3) = G_{31}^{(3/2)}\frac{h_1}{M_K} + G_{32}^{(3/2)}\frac{h_2}{M_K^2},$$

for a positive parity resonance, where

$$G_{11}^{(3/2)} = \frac{\sqrt{30}}{60\sqrt{\pi}}\frac{1}{M_{\Sigma^*}}\sqrt{\frac{q}{M_R}}\sqrt{E_{\Sigma^*}-M_{\Sigma^*}}(M_R+M_{\Sigma^*}) \times (E_{\Sigma^*}+4M_{\Sigma^*}),$$
$$G_{12}^{(3/2)} = -\frac{\sqrt{30}}{60\sqrt{\pi}}\frac{q^2\sqrt{qM_R}}{M_{\Sigma^*}}\sqrt{E_{\Sigma^*}-M_{\Sigma^*}},$$
$$G_{31}^{(3/2)} = -\frac{\sqrt{30}}{20\sqrt{\pi}}\frac{1}{M_{\Sigma^*}}\sqrt{\frac{q}{M_R}}\sqrt{E_{\Sigma^*}-M_{\Sigma^*}} \times (M_R+M_{\Sigma^*})(E_{\Sigma^*}-M_{\Sigma^*}),$$
$$G_{32}^{(3/2)} = \frac{\sqrt{30}}{20\sqrt{\pi}}\frac{q^2\sqrt{qM_R}}{M_{\Sigma^*}}\sqrt{E_{\Sigma^*}-M_{\Sigma^*}},$$

$G(\ell)$'s are given by the QM

Resonance parameters

Resonance	PDG [29]	Amplitudes of $R \to K\Sigma(1385)$[a]		h_1	h_2	Amplitudes of $R \to N\gamma$[b]		f_1	f_2
		$G(\ell_1)$	$G(\ell_2)$			$A^p_{1/2}$	$A^p_{3/2}$		
$N\frac{1}{2}^-(1945)$	$S^*_{11}(2090)$	$G(2) = +1.7$	–	-9.8	–	$+12$	–	-0.055	–
$N\frac{3}{2}^-(1960)$	$D^{**}_{13}(2080)$	$G(0) = +1.3$	$G(2) = +1.4$	0.24	-0.54	$+36$	-43	-1.25	1.21
$N\frac{5}{2}^-(2095)$	$D^{**}_{15}(2200)$	$G(2) = -2.0$	$G(4) = 0.0$	0.29	-0.08	-9	-14	0.37	-0.57
$\Delta\frac{3}{2}^-(2080)$	$D^*_{33}(1940)$	$G(0) = -4.1$	$G(3) = -0.5$	-0.68	1.00	-20	-6	0.39	-0.57
$\Delta\frac{5}{2}^+(1990)$	$F^{**}_{35}(2000)$	$G(1) = +4.0$	$G(3) = -0.1$	-0.87	0.11	-10	-28	-0.68	-0.062

[a] In $\sqrt{\text{GeV}}$.
[b] In $10^{-3}/\sqrt{\text{GeV}}$.

PDG resonances

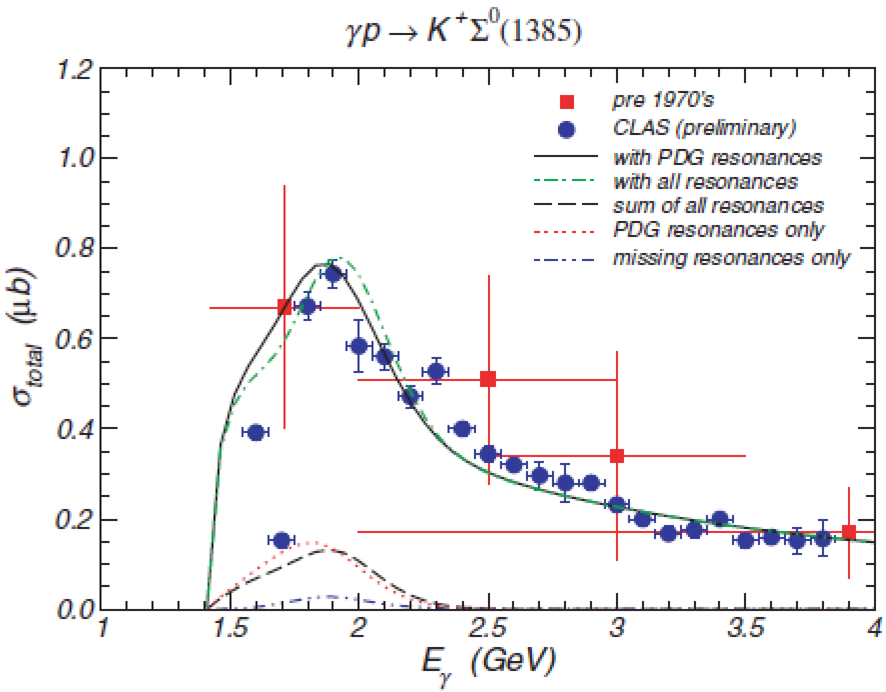
Resonance	Amplitudes of $R \to K\Sigma(1385)$[a]		h_1	h_2	Amplitudes of $R \to N\gamma$[b]		f_1	f_2
	$G(\ell_1)$	$G(\ell_2)$			$A^p_{1/2}$	$A^p_{3/2}$		
$N\frac{3}{2}^-(2095)$	$G(0) = +7.7$	$G(2) = -0.8$	0.99	0.27	-9	-14	0.49	-0.83
$N\frac{5}{2}^+(1980)$	$G(1) = -3.6$	$G(3) = -0.1$	0.59	0.24	-11	-6	0.019	-0.13
$\Delta\frac{3}{2}^-(2145)$	$G(0) = +5.2$	$G(2) = -1.9$	0.25	0.46	0	$+10$	0.11	-0.059

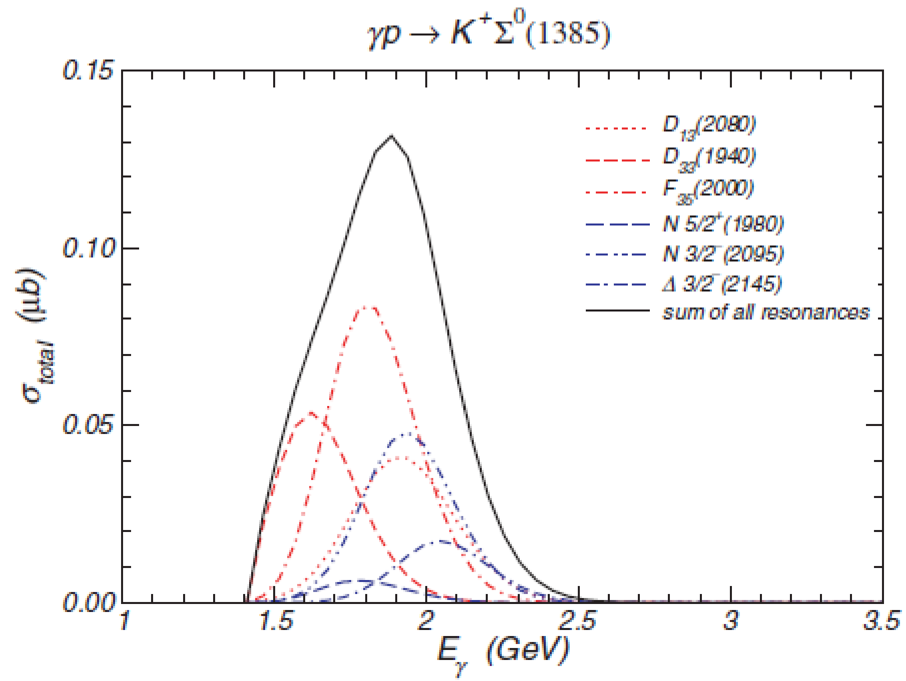
[a] In $\sqrt{\text{GeV}}$.
[b] In $10^{-3}/\sqrt{\text{GeV}}$.

missing resonances

Results ($\gamma p \to K^+\Sigma^{*0}$)

Total cross section



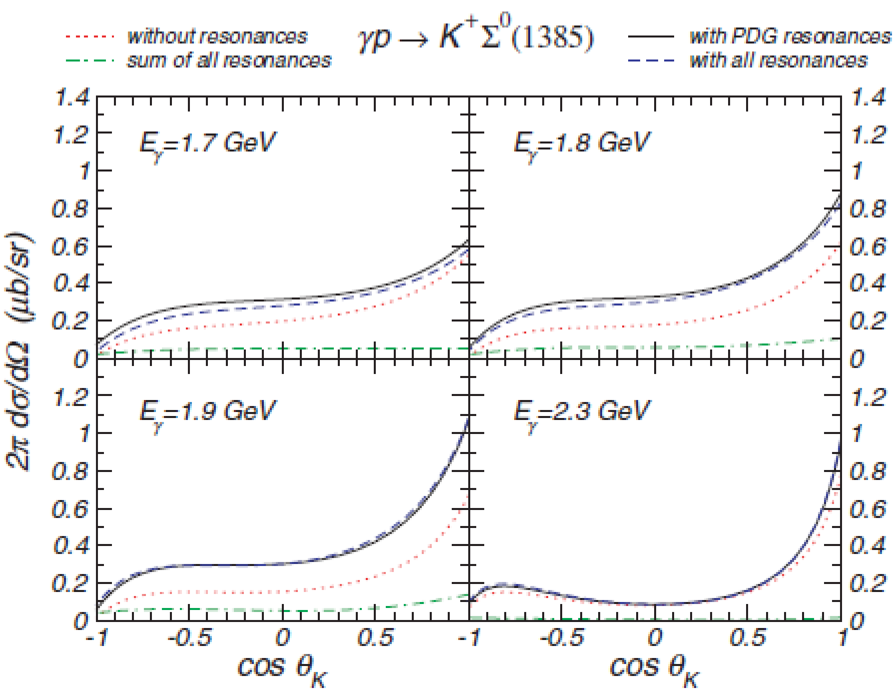


N^* contribution

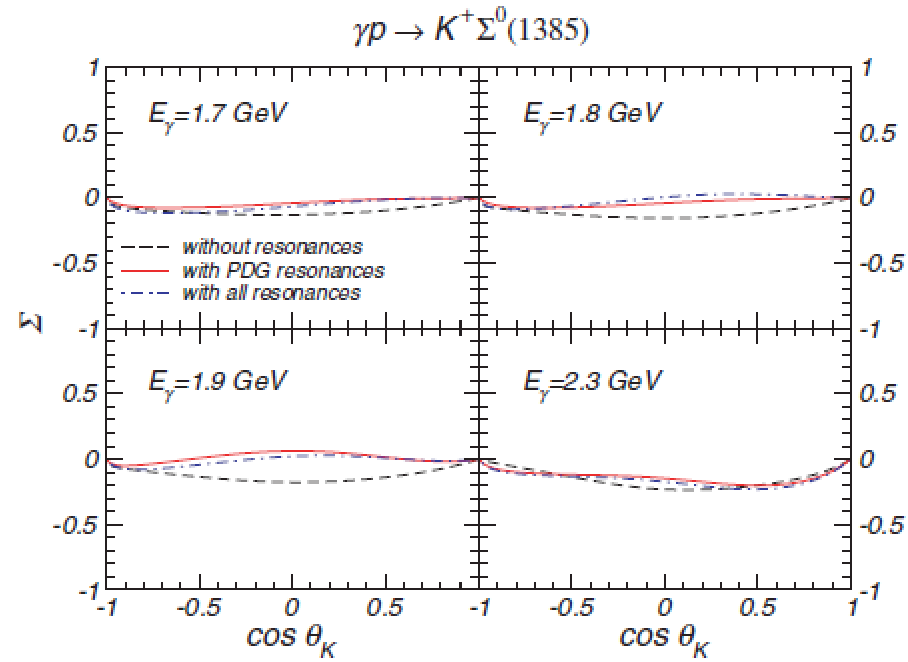
Results ($\gamma p \to K^+\Sigma^{*0}$)

KNU 경북대학교 KYUNGPOOK NATIONAL UNIVERSITY

Differential cross section



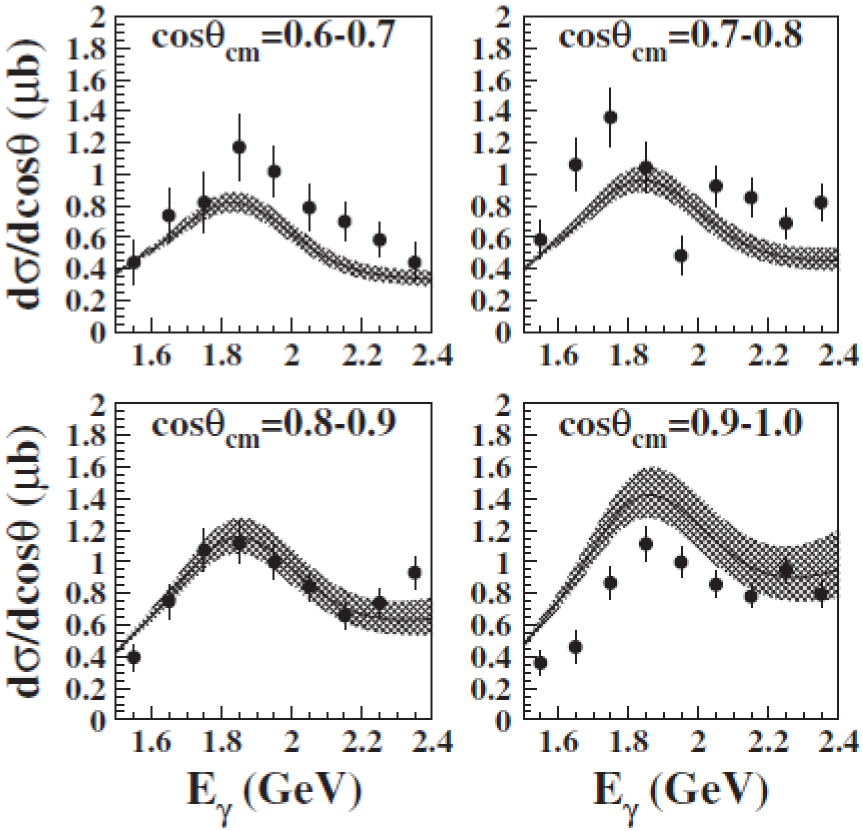
Beam asymmetry

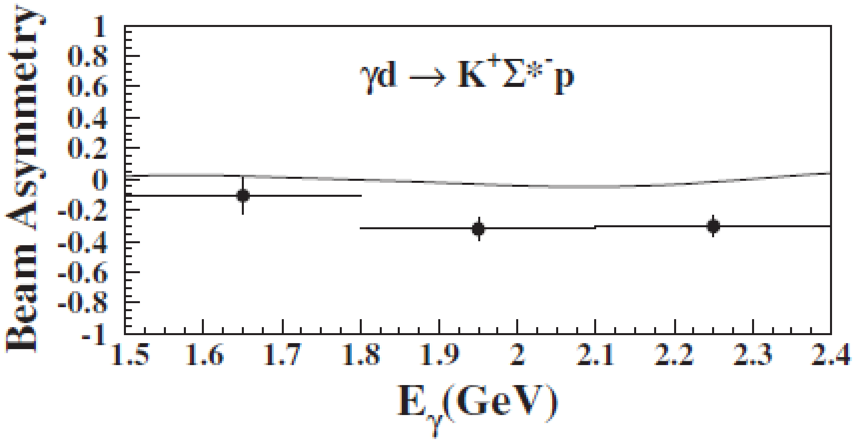


Results ($\gamma n \rightarrow K^{+}\Sigma^{*-}$)

Differential cross section

Beam asymmetry





4. Summary and Outlook

- Missing resonances in $\Sigma^*(1385)$ photoproduction
  - $\gamma p \to K^+\Sigma^{*0}$ and $\gamma n \to K^+\Sigma^{*-}$
  - Important contributions
    - $\Delta(2000)F_{35}$, $\Delta(1940)D_{33}$, $\Delta(2080)D_{13}$ from PDG
    - $N\frac{3}{2}^-(2095)$: missing resonance
      - has the largest partial decay width into the $K\Sigma^*$ channel
      - but small photon helicity amplitudes
    - Resonances have destructive interference.
- More rigorous studies are required.
  - More constrained resonance parameters
  - Other isospin channels
    - Both in theory and experiment