

Role of Λ and Σ hyperons in the reaction $\gamma p \longrightarrow K K \Xi^*$

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BARYONS 2025 – International Conference on the Structure of Baryons
10–14/Nov, 2025, International Convention Center, Jeju

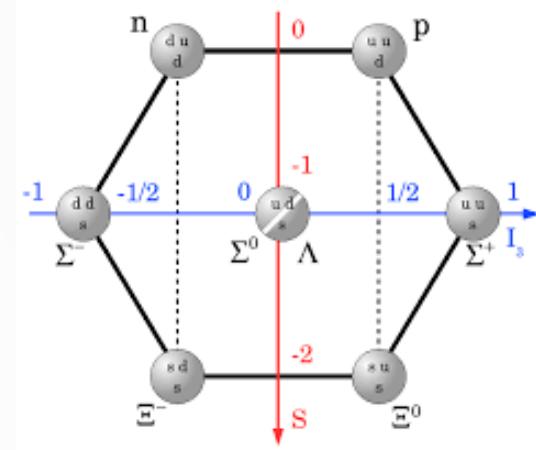
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1. introduction

How to produce **multistrangeness baryons** in hadron physics?

- ❑ **Multistrangeness baryons** are of importance in our understanding of strong interactions. However, the information of them is very limited currently.
- ❑ SU(3) flavor symmetry allows as many $S = -2$ baryons, i.e. Ξ , but only 11 Ξ baryons are observed, whereas there are ~ 25 Λ^* or Σ^* resonances ($S = -1$).
- ❑ This is mainly because multistrangeness hadron production has relatively small cross section rates.

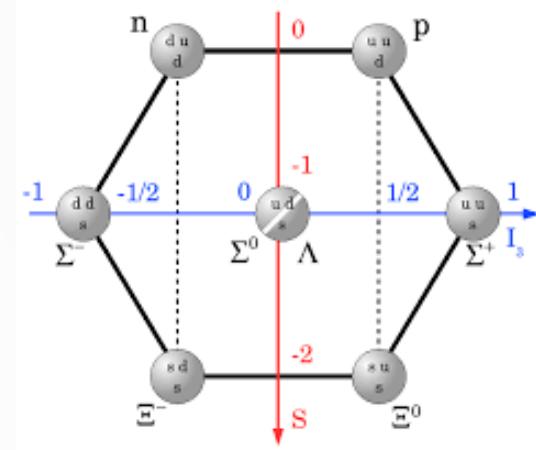


Particle	J^P	Overall status
$\Xi(1318)$	$1/2+$	****
$\Xi(1530)$	$3/2+$	****
$\Xi(1620)$		*
$\Xi(1690)$		***
$\Xi(1820)$	$3/2-$	***
$\Xi(1950)$		***
$\Xi(2030)$		***
$\Xi(2120)$		*
$\Xi(2250)$		**
$\Xi(2370)$		**
$\Xi(2500)$		*

1. introduction

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- ❑ **a.** $p\bar{p}$ interaction ($p\bar{p} \rightarrow \Xi^{(*)} \bar{\Xi}^{(*)}, \Omega^{(*)} \bar{\Omega}^{(*)}$) at GSI-FAIR
- ❑ **b.** K induced reaction ($K^- p \rightarrow K \Xi^{(*)}$) at J-PARC
 - > [KimSH, et al, PRC.107.065202 (2023)]
- ❑ **c.** photoproduction ($\gamma p \rightarrow K K \Xi^{(*)}, K K K \Omega^{(*)}$) at JLab
 - > May provide substantial contributions to the spectroscopy of cascade baryons.

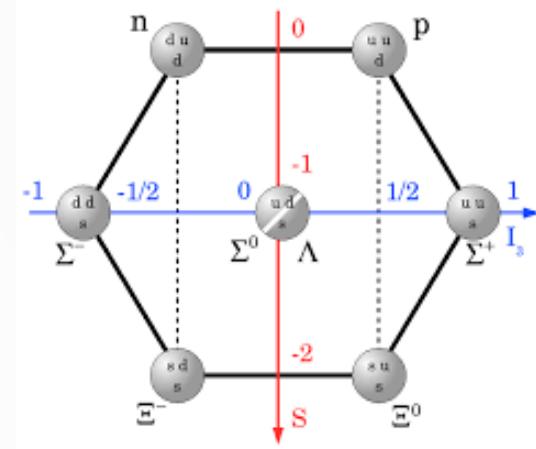


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1. introduction

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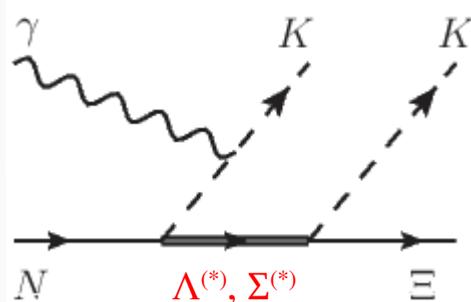


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1. introduction

□ In this work, we study the reaction $\gamma N \rightarrow K K \Xi^*$ in a hadron exchange model.

$\gamma N \rightarrow K K \Xi$



□ Several $Y^*(\Lambda^*, \Sigma^*)$ states should be included since multiple “ $Y^* \rightarrow K \Xi$ ” decay channels exist.

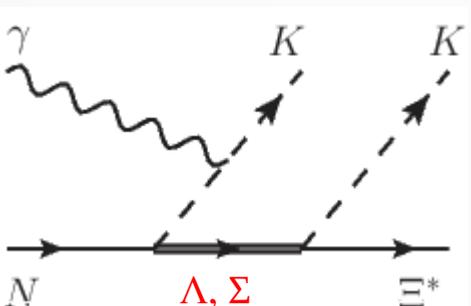
[Liu, PRC.69.045204 (2004)]

[Nakayama, PRC.74.035205 (2006)]

[Man, PRC.83.055201 (2011)]

Λ state (J^P)	$\mathcal{B}(\Lambda^* \rightarrow K \Xi)$ [%]	Σ state (J^P)	$\mathcal{B}(\Sigma^* \rightarrow K \Xi)$ [%]
$\Lambda(1820)5/2^+$	—	$\Sigma(1880)1/2^+$	—
$\Lambda(1830)5/2^-$	—	$\Sigma(1900)1/2^-$	3 ± 2
$\Lambda(1890)3/2^+$	~ 1 [41]	$\Sigma(1910)3/2^-$	—
$\Lambda(2000)1/2^-$	—	$\Sigma(1915)5/2^+$	—
$\Lambda(2050)3/2^-$	—	$\Sigma(1940)3/2^+$	—
$\Lambda(2070)3/2^+$	7 ± 3	$\Sigma(2010)3/2^-$	3 ± 2
$\Lambda(2080)5/2^-$	4 ± 1	$\Sigma(2030)7/2^+$	< 2
$\Lambda(2085)7/2^+$	—	$\Sigma(2070)5/2^+$	—
$\Lambda(2100)7/2^-$	< 3	$\Sigma(2080)3/2^+$	—
$\Lambda(2110)5/2^+$	—	$\Sigma(2100)7/2^-$	—
$\Lambda(2325)3/2^-$	—	$\Sigma(2110)1/2^-$	—
$\Lambda(2350)9/2^+$	—	$\Sigma(2230)3/2^+$	2 ± 1
$\Lambda(2585) ?^?$	—	$\Sigma(2250) ?^?$	—
		$\Sigma(2455) ?^?$	—
		$\Sigma(2620) ?^?$	—

$\gamma N \rightarrow K K \Xi^*$



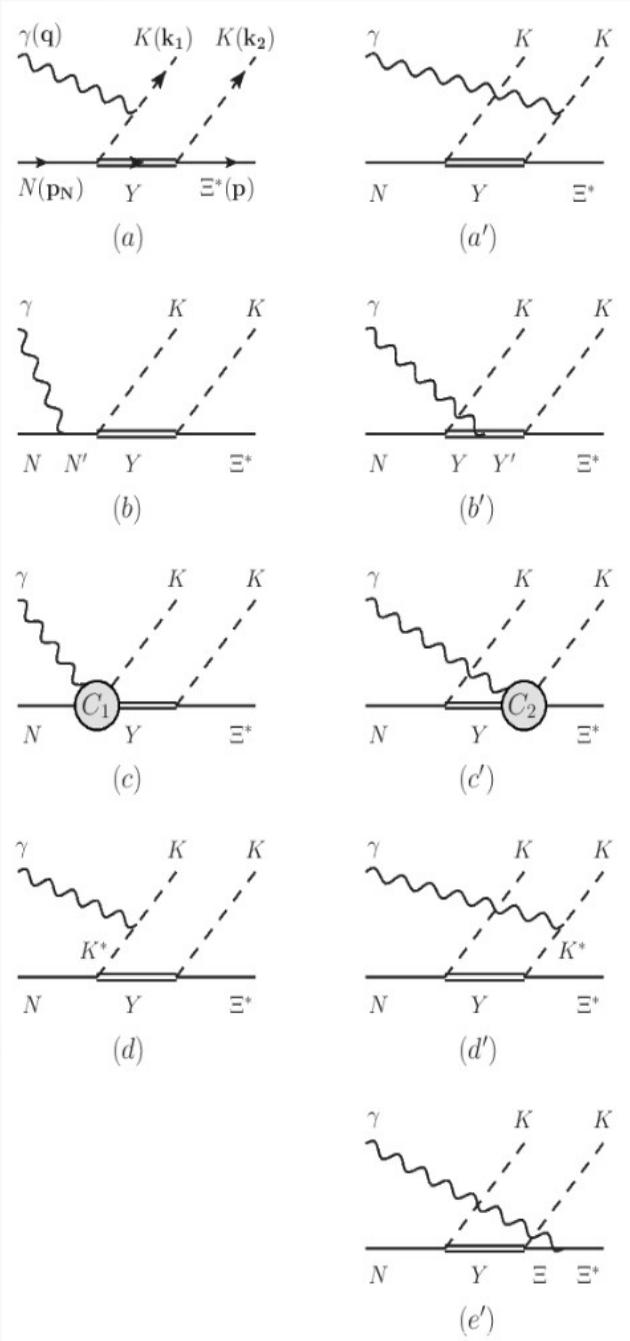
□ We consider only the ground state, $Y(\Lambda, \Sigma)$, due to the lack of information on “ $Y^* \rightarrow K \Xi^*$ ”.

□ Only one decay channel is listed in the PDG.

$\Sigma(2250) \rightarrow K \Xi^*$ [$B = 18\%$]

□ The calculations can be further simplified than $\gamma N \rightarrow K K \Xi$.

2. theoretical framework

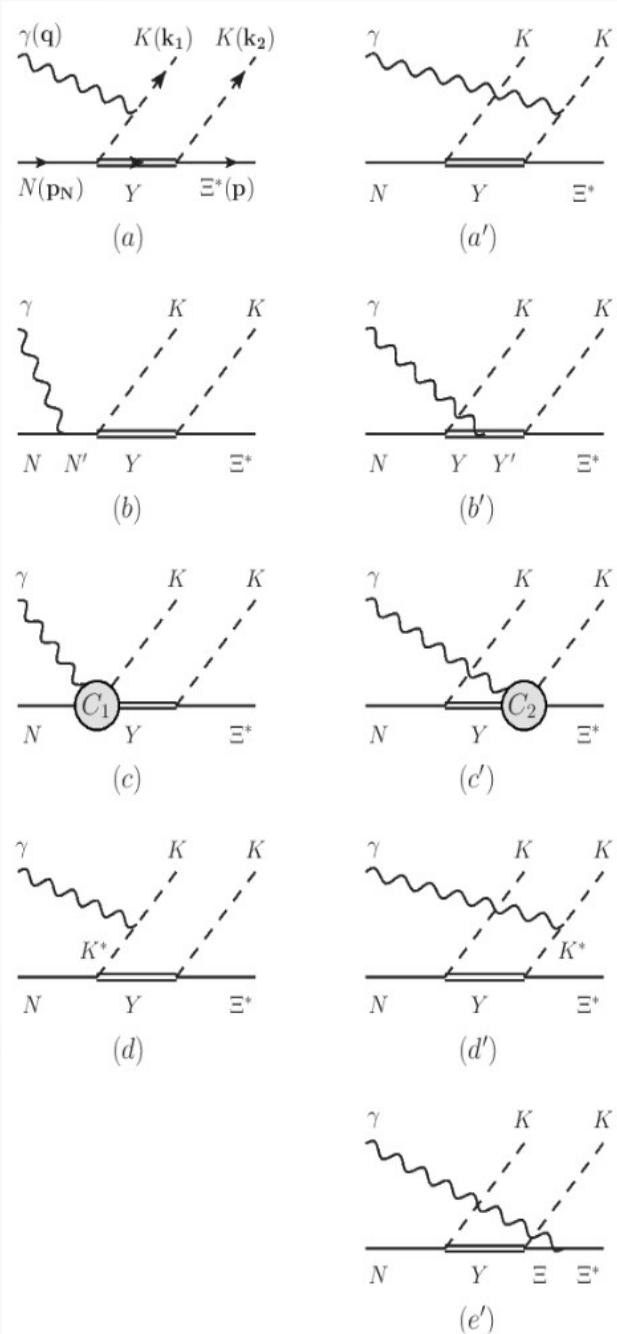


$$\gamma(\mathbf{q}) + N(\mathbf{p}_N) \rightarrow K(\mathbf{k}_1) + K(\mathbf{k}_2) + B(\mathbf{p})$$

$$\Xi^*(1530, 3/2^+)$$

$\mathbf{p}_N = -\mathbf{q},$	
$\mathbf{k}_1 = \mathbf{k},$	(c.m.)
$\mathbf{k}_2 = -(\mathbf{k} + \mathbf{p})$	

2. theoretical framework



$$\gamma(\mathbf{q}) + N(\mathbf{p}_N) \rightarrow K(\mathbf{k}_1) + K(\mathbf{k}_2) + B(\mathbf{p})$$

$$\Xi^*(1530, 3/2^+)$$

$$\begin{aligned} \mathbf{p}_N &= -\mathbf{q}, \\ \mathbf{k}_1 &= \mathbf{k}, \quad (\text{c.m.}) \\ \mathbf{k}_2 &= -(\mathbf{k} + \mathbf{p}) \end{aligned}$$

Cross Sections

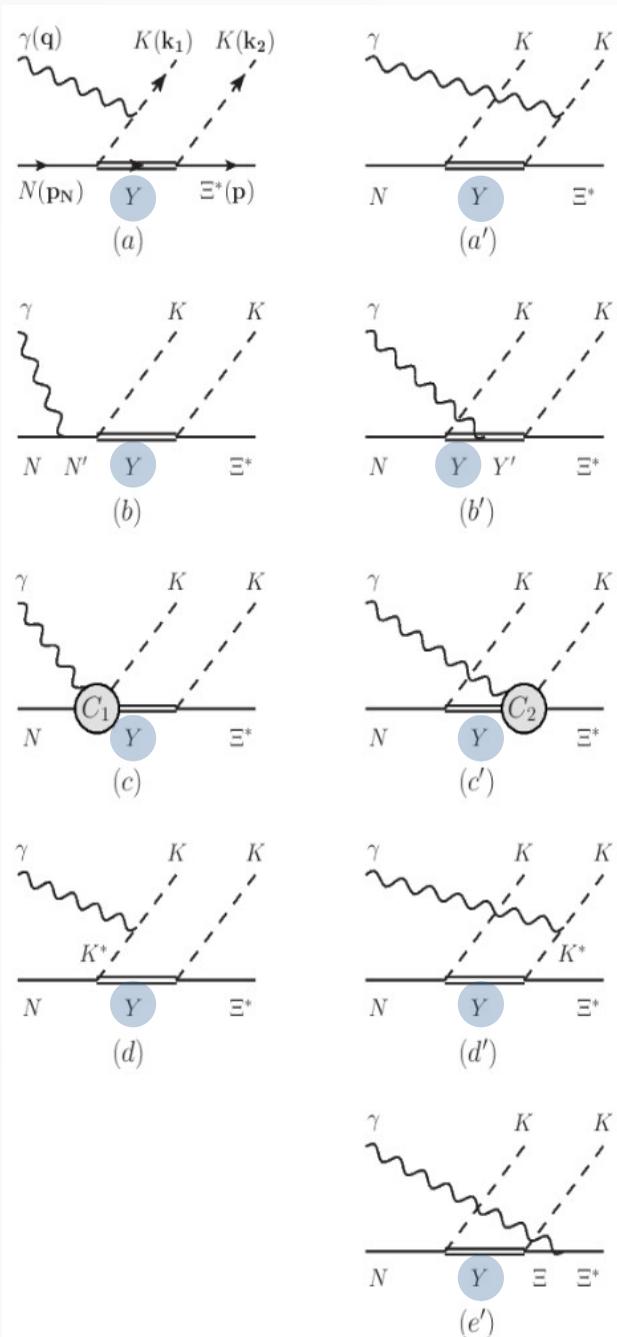
$$\begin{aligned} \sigma &= \frac{(2\pi)^4}{1 + q/E_N(q)} \int d\mathbf{p} \int d\mathbf{k} \delta(W - E_K(\mathbf{k}) - E_K(|\mathbf{k} + \mathbf{p}|) - E_B(\mathbf{p})) \\ &\times \frac{1}{4} \sum_{\lambda, m_{s_N}, m_{s_B}} |\langle \mathbf{p} m_{s_B}, \mathbf{k}_1, \mathbf{k}_2 | T(W) | \mathbf{q} \lambda, \mathbf{p}_N m_{s_N} \rangle|^2 \end{aligned}$$

$$\begin{aligned} \frac{d\sigma}{d\Omega_{\mathbf{p}}} &= \frac{(4\pi)^2}{|\mathbf{q}|^2} \rho_{\gamma N}(\mathbf{q}, W) \int p^2 dp \int d\Omega_k \rho_f(\mathbf{k}, \mathbf{p}, W) \\ &\times \frac{1}{4} \sum_{\lambda, m_{s_N}, m_{s_B}} |\langle \mathbf{p} m_{s_B}, \mathbf{k}_1, \mathbf{k}_2 | T(W) | \mathbf{q} \lambda, \mathbf{p}_N m_{s_N} \rangle|^2 \end{aligned}$$

$$\frac{1}{(2\pi)^{9/2}} \frac{1}{\sqrt{2E_K(\mathbf{k})}} \frac{1}{\sqrt{2E_K(\mathbf{k} + \mathbf{p})}} \sqrt{\frac{M_B}{E_B(\mathbf{p})}}$$

$$\times \langle m_{s_B} | I(\mathbf{p}, \mathbf{k}_1, \mathbf{k}_2; \mathbf{q}, \mathbf{p}_N) | \lambda m_{s_N} \rangle \frac{1}{\sqrt{2|\mathbf{q}|}} \sqrt{\frac{M_N}{E_N(\mathbf{p}_N)}}$$

2. theoretical framework



$$\langle m_{s_B} | I(\mathbf{p}, \mathbf{k}_1, \mathbf{k}_2; \mathbf{q}, \mathbf{p}_N) | \lambda m_{s_N} \rangle = \sum_{m_{s_Y}} \mathcal{M}_2(p_Y; k', p') \frac{2M_Y}{p_Y^2 - M_Y^2} \mathcal{M}_1(k, p; p_Y)$$

Effective Lagrangians

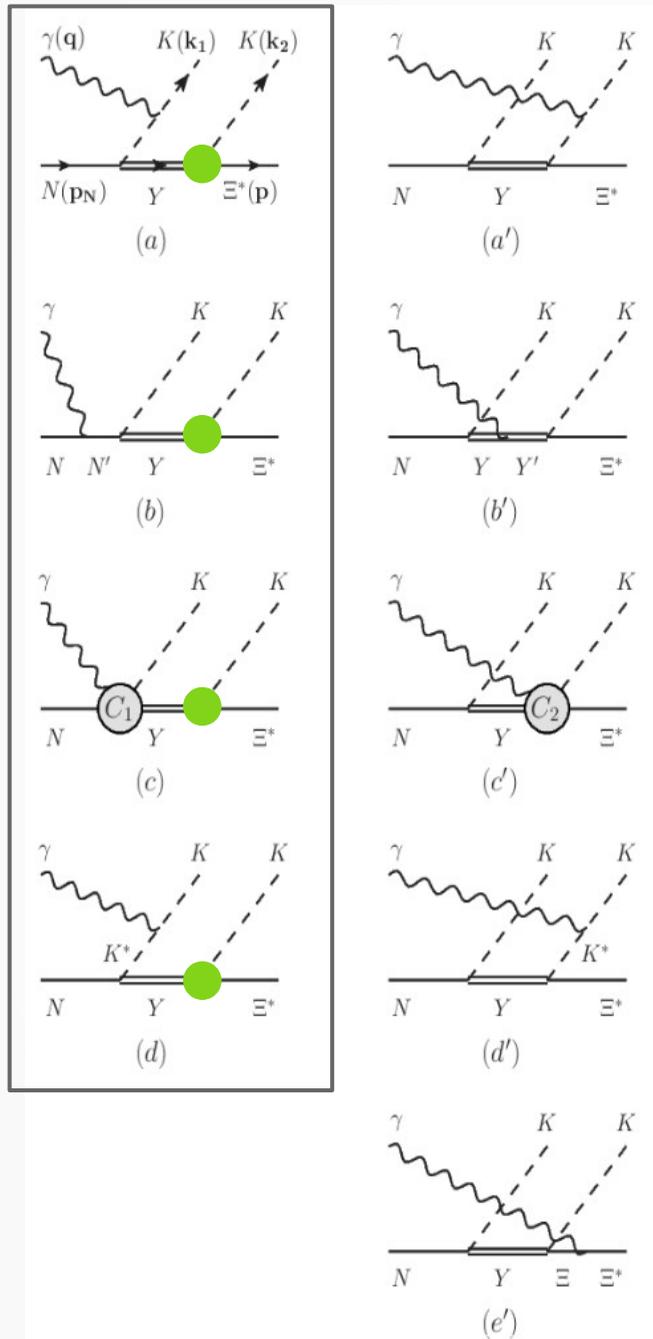
□ EM vertex

$$\begin{aligned} \mathcal{L}_{\gamma KK} &= -ie[K^\dagger(\partial_\mu K) - (\partial_\mu K^\dagger)K]A^\mu, \\ \mathcal{L}_{\gamma KK^*} &= \frac{eg_{\gamma KK^*}^c}{M_K} \epsilon^{\mu\nu\alpha\beta} \partial_\mu A_\nu (\partial_\alpha K_\beta^{*-} K^+ + \partial_\alpha K_\beta^{*+} K^-) \\ &\quad + \frac{eg_{\gamma KK^*}^0}{M_K} \epsilon^{\mu\nu\alpha\beta} \partial_\mu A_\nu (\partial_\alpha \bar{K}_\beta^{*0} K^0 + \partial_\alpha K_\beta^{*0} \bar{K}^0), \\ \mathcal{L}_{\gamma NN} &= -e\bar{N} \left[\gamma^\mu A_\mu - \frac{\kappa_N}{2M_N} \sigma^{\mu\nu} \partial_\nu A_\mu \right] N, \\ \mathcal{L}_{\gamma YY} &= \frac{e\kappa_Y}{2M_N} \bar{Y} \sigma^{\mu\nu} \partial_\nu A_\mu Y, \\ \mathcal{L}_{\gamma \Xi \Xi^*} &= \frac{ieg_{\gamma \Xi \Xi^*}}{2M_N} \bar{\Xi}_\mu^* \gamma_\nu \gamma_5 \Xi F^{\mu\nu} + \text{H.c.}, \end{aligned}$$

□ strong vertex

$$\begin{aligned} \mathcal{L}_{KNY} &= -ig_{KNY} \bar{K} \bar{Y} \gamma_5 N + \text{H.c.}, \\ \mathcal{L}_{KY\Xi^*} &= \frac{g_{KY\Xi^*}}{M_K} \bar{\Xi}_\mu^* Y \partial^\mu \bar{K} + \text{H.c.}, \\ \mathcal{L}_{K^*Y\Xi^*} &= \frac{ig_{K^*Y\Xi^*}}{2M_N} \bar{\Xi}_\mu^* \gamma_\nu \gamma_5 Y \bar{K}^{*\mu\nu} + \text{H.c.}, \end{aligned}$$

2. theoretical framework



$$\langle m_{s_B} | I(\mathbf{p}, \mathbf{k}_1, \mathbf{k}_2; \mathbf{q}, \mathbf{p}_N) | \lambda m_{s_N} \rangle = \sum_{m_{s_Y}} \mathcal{M}_2(p_Y; k', p') \frac{2M_Y}{p_Y^2 - M_Y^2} \mathcal{M}_1(k, p; p_Y)$$

Invariant Amplitudes

$$I_a = \mathcal{M}_{Y \rightarrow K_2 \Xi^*} \frac{2M_Y}{\text{Prop}_1} \mathcal{M}_{\gamma N \rightarrow K_1 Y}^{t(K)}$$

$$I_b = \mathcal{M}_{Y \rightarrow K_2 \Xi^*} \frac{2M_Y}{\text{Prop}_1} \mathcal{M}_{\gamma N \rightarrow K_1 Y}^{s(N')}$$

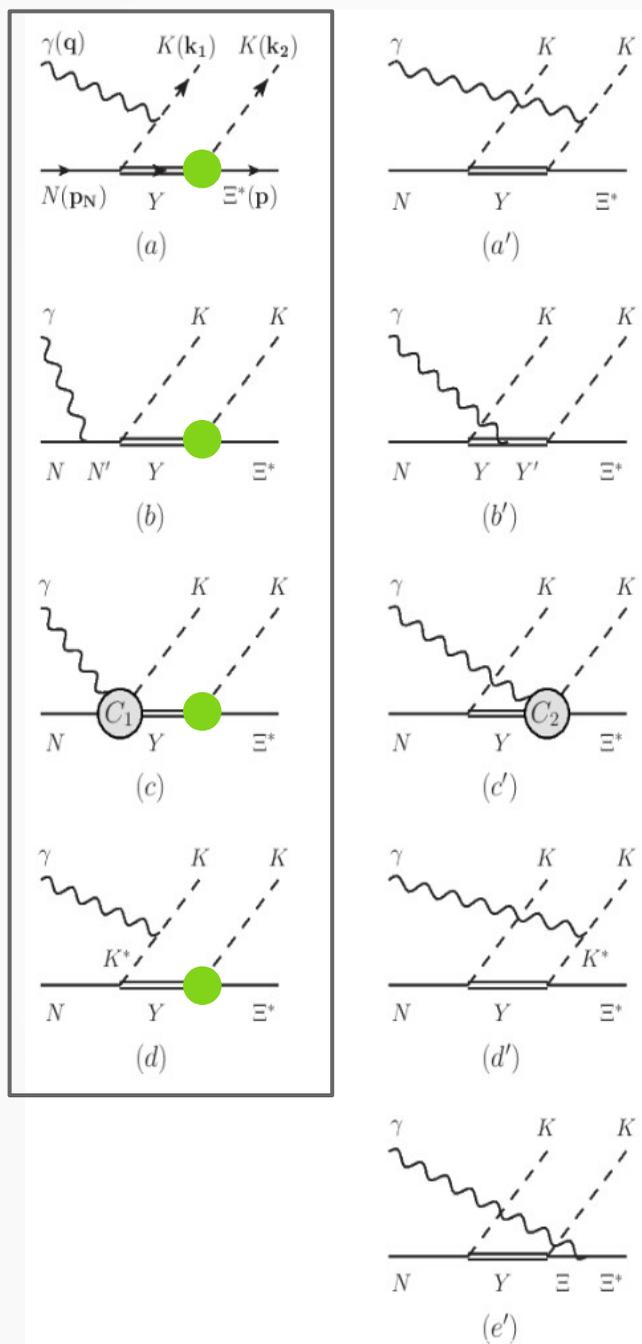
$$I_c = \mathcal{M}_{Y \rightarrow K_2 \Xi^*} \frac{2M_Y}{\text{Prop}_1} \mathcal{M}_{\gamma N \rightarrow K_1 Y}^C$$

$$I_d = \mathcal{M}_{Y \rightarrow K_2 \Xi^*} \frac{2M_Y}{\text{Prop}_1} \mathcal{M}_{\gamma N \rightarrow K_1 Y}^{t(K^*)}$$

$$\text{Prop}_1 = (k_2 + p)^2 - M_Y^2$$

$$\mathcal{M}_{Y \rightarrow K_2 \Xi^*} = -i \frac{g_{KY\Xi^*}}{M_K} (k_2 \cdot \bar{U}_{\Xi^*}) u_Y$$

2. theoretical framework



$$\langle m_{s_B} | I(\mathbf{p}, \mathbf{k}_1, \mathbf{k}_2; \mathbf{q}, \mathbf{p}_N) | \lambda m_{s_N} \rangle = \sum_{m_{s_Y}} \mathcal{M}_2(p_Y; k', p') \frac{2M_Y}{p_Y^2 - M_Y^2} \mathcal{M}_1(k, p; p_Y)$$

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$$\mathcal{M}_{Y \rightarrow K_2 \Xi^*} = -i \frac{g_{KY\Xi^*}}{M_K} (k_2 \cdot \bar{U}_{\Xi^*}) u_Y$$

$$\mathcal{M}_{\gamma N \rightarrow K_1 Y}^{t(K)} = \frac{2ieg_{KNY}}{(k_1 - q)^2 - M_K^2} (k_1 \cdot \epsilon) (\bar{u}_Y \gamma_5 u_N),$$

$$\mathcal{M}_{\gamma N \rightarrow K_1 Y}^{s(N')} = \frac{ieg_{KNY}}{(q + p_N)^2 - M_{N'}^2} \bar{u}_Y \gamma_5$$

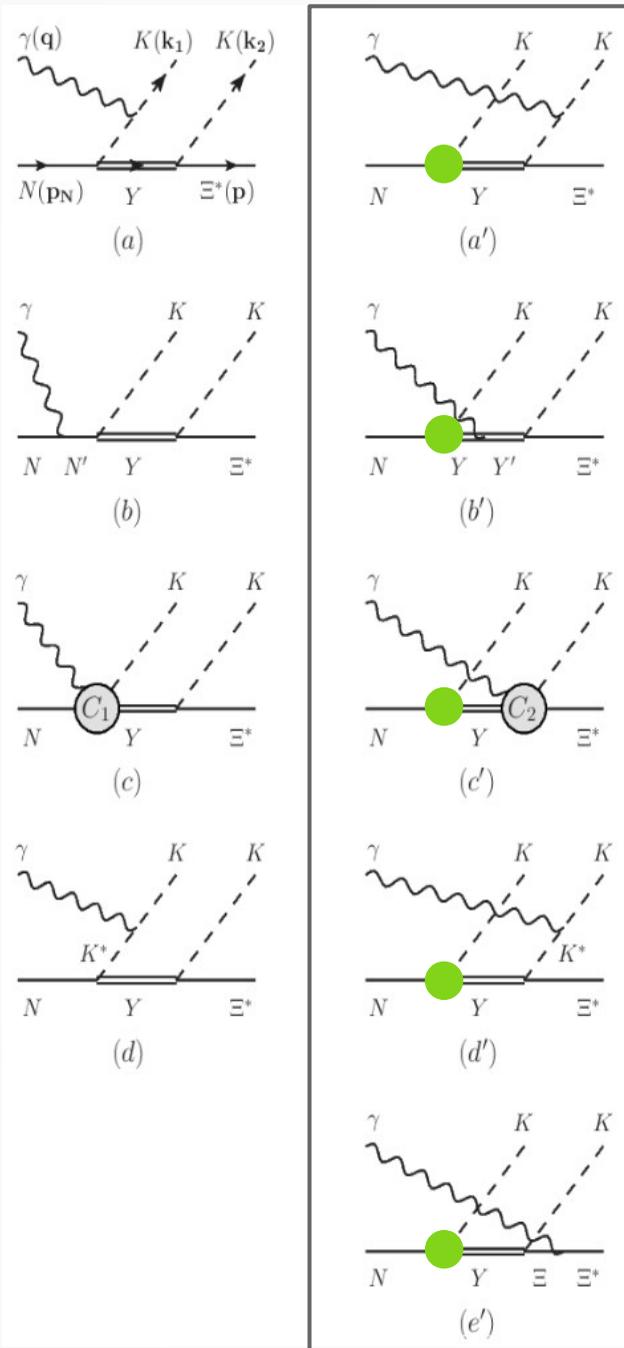
$$\times (q + p_N + M_N) \left[\gamma^\mu + \frac{i\kappa_N}{2M_N} q_\nu \sigma^{\mu\nu} \right] \epsilon_\mu u_N,$$

$$\mathcal{M}_{\gamma N \rightarrow K_1 Y}^C = ie \frac{g_{KNY}}{2M_N} \bar{u}_Y \gamma^\mu \epsilon_\mu \gamma_5 u_N,$$

$$\mathcal{M}_{\gamma N \rightarrow K_1 Y}^{t(K^*)} = \frac{-eg_{\gamma KK^*} g_{K^* NY}}{(k_1 - q)^2 - M_{K^*}^2} \frac{1}{M_K} \epsilon^{\mu\nu\alpha\beta} \bar{u}_Y$$

$$\times \left[\gamma_\mu - \frac{ik_{K^* NY}}{2M_N} (k_1 - q)^\lambda \sigma_{\mu\lambda} \right] u_N q_\nu k_{1\alpha} \epsilon_\beta,$$

2. theoretical framework



$$\langle m_{s_B} | I(\mathbf{p}, \mathbf{k}_1, \mathbf{k}_2; \mathbf{q}, \mathbf{p}_N) | \lambda m_{s_N} \rangle = \sum_{m_{s_Y}} \mathcal{M}_2(p_Y; k', p') \frac{2M_Y}{p_Y^2 - M_Y^2} \mathcal{M}_1(k, p; p_Y)$$

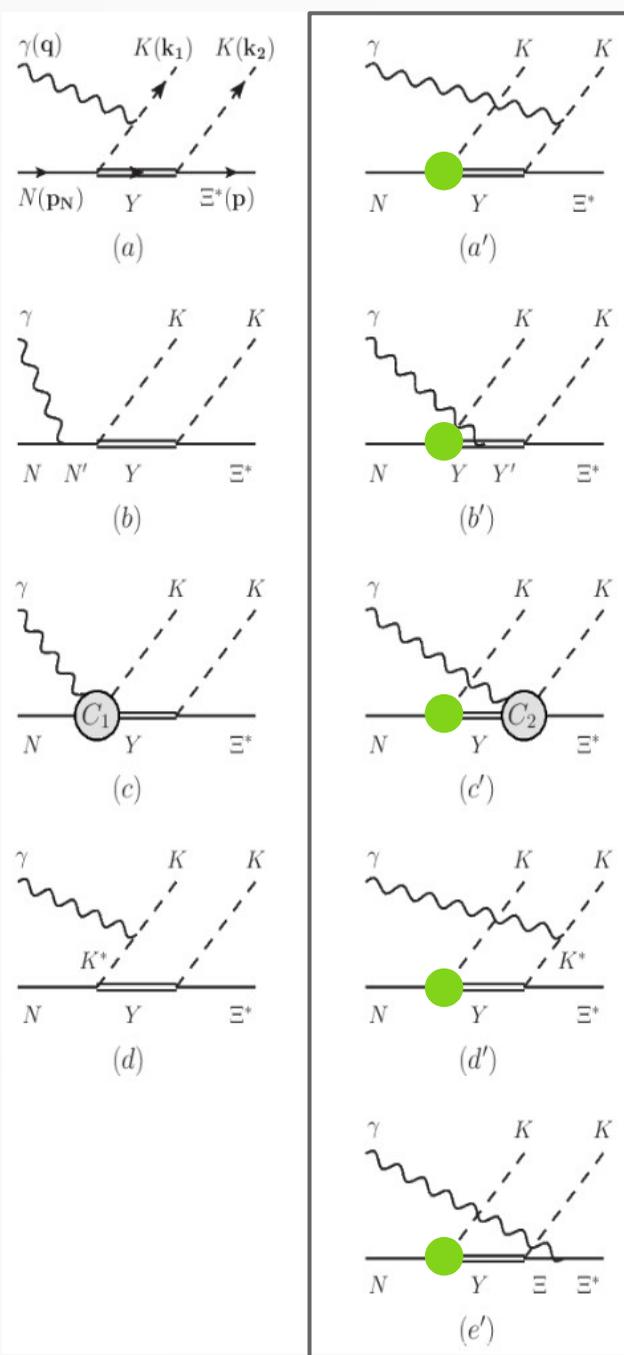
Invariant Amplitudes

$$\begin{aligned}
 I_{a'} &= \mathcal{M}_{\gamma Y \rightarrow K_2 \Xi^*}^{t(K)} \frac{2M_Y}{\text{Prop}_2} \mathcal{M}_{N \rightarrow K_1 Y} \\
 I_{b'} &= \mathcal{M}_{\gamma Y \rightarrow K_2 \Xi^*}^{s(Y')} \frac{2M_Y}{\text{Prop}_2} \mathcal{M}_{N \rightarrow K_1 Y} \\
 I_{c'} &= \mathcal{M}_{\gamma Y \rightarrow K_2 \Xi^*}^C \frac{2M_Y}{\text{Prop}_2} \mathcal{M}_{N \rightarrow K_1 Y} \\
 I_{d'} &= \mathcal{M}_{\gamma Y \rightarrow K_2 \Xi^*}^{t(K^*)} \frac{2M_Y}{\text{Prop}_2} \mathcal{M}_{N \rightarrow K_1 Y} \\
 I_{e'} &= \mathcal{M}_{\gamma Y \rightarrow K_2 \Xi^*}^{u(\Xi)} \frac{2M_Y}{\text{Prop}_2} \mathcal{M}_{N \rightarrow K_1 Y}
 \end{aligned}$$

$$\text{Prop}_2 = (p_N - k_1)^2 - M_Y^2$$

$$\mathcal{M}_{N \rightarrow K_1 Y} = ig_{KNY} \bar{u}_Y \gamma_5 u_N$$

2. theoretical framework



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$$\text{Prop}_2 = (p_N - k_1)^2 - M_Y^2$$

$$\mathcal{M}_{N \rightarrow K_1 Y} = ig_{KNY} \bar{u}_Y \gamma_5 u_N$$

$$\begin{aligned} \mathcal{M}_{\gamma Y \rightarrow K_2 \Xi^*}^{t(K)} &= \frac{-2ie}{(k_2 - q)^2 - M_K^2} \frac{g_{KY\Xi^*}}{M_K} (k_2 \cdot \epsilon) \\ &\quad \times [(k_2 - q) \cdot \bar{U}_{\Xi^*}] u_Y, \\ \mathcal{M}_{\gamma Y \rightarrow K_2 \Xi^*}^{s(Y')} &= \frac{-ie}{(k_2 + p)^2 - M_{Y'}^2} \frac{g_{KY\Xi^*}}{M_K} (k_2 \cdot \bar{U}_{\Xi^*}) \\ &\quad \times (k_2 + \not{p} + M_Y) \left[\gamma^\mu + \frac{i\kappa_Y}{2M_N} q_\nu \sigma^{\mu\nu} \right] \epsilon_\mu u_Y, \\ \mathcal{M}_{\gamma Y \rightarrow K_2 \Xi^*}^C &= ie \frac{g_{KY\Xi^*}}{M_K} (\epsilon \cdot \bar{U}_{\Xi^*}) u_Y, \\ \mathcal{M}_{\gamma Y \rightarrow K_2 \Xi^*}^{t(K^*)} &= \frac{-eg_{\gamma KK^*}}{(k_2 - q)^2 - M_{K^*}^2} \frac{1}{M_K} \frac{g_{K^*Y\Xi^*}}{2M_N} \epsilon^{\mu\nu\alpha\beta} \\ &\quad \times \left[(p - q) \cdot \bar{U}_{\Xi^*} \gamma_\mu \gamma_5 u_Y \right. \\ &\quad \left. - \bar{U}_{\Xi^*} \cdot \mu (\not{p} - \not{q}) \gamma_5 u_Y \right] q_\nu p_\alpha \epsilon_\beta, \\ \mathcal{M}_{\gamma Y \rightarrow K_2 \Xi^*}^{u(\Xi)} &= \frac{-ieg_{\gamma \Xi \Xi^*} g_{KY\Xi}}{(p - k_1)^2 - M_\Xi^2} \frac{1}{2M_N} \bar{U}_{\Xi^*}^\mu \gamma^\nu \\ &\quad \times \gamma_5 (q_\mu \epsilon_\nu - q_\nu \epsilon_\mu) (\not{p} - \not{q} + M_\Xi) \gamma_5 u_Y, \end{aligned}$$

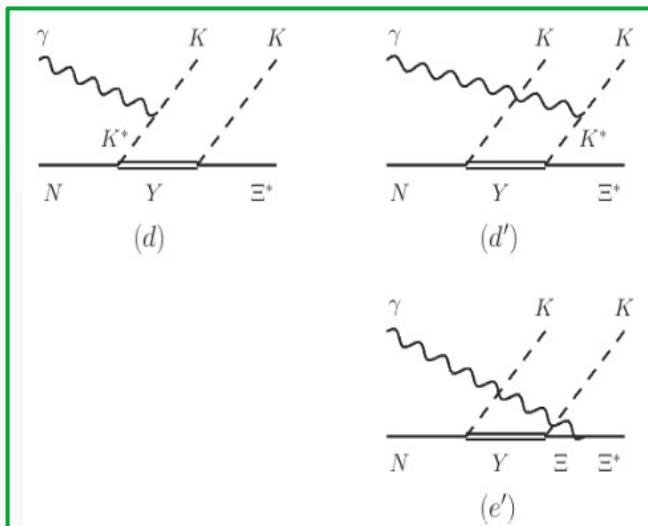
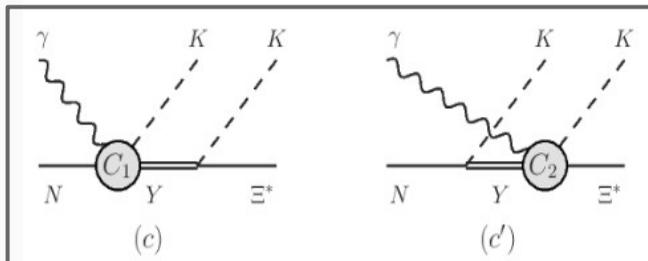
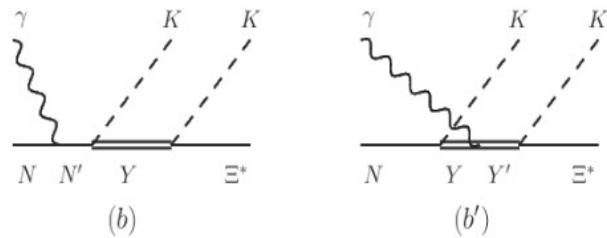
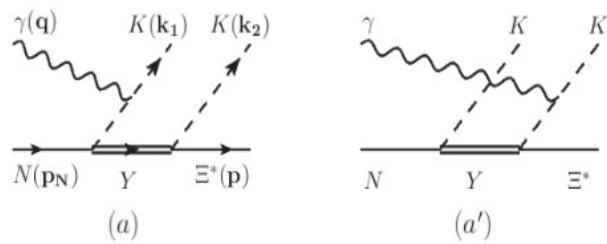
2. theoretical framework

$$(I) \gamma p \rightarrow K^+ K^+ \Xi^{*-}, \quad (II) \gamma p \rightarrow K^+ K^0 \Xi^{*0}$$

Gauge Invariant; Contact terms

Extension from one-meson to two-meson photoproduction

[Haberzettl, PRC.56.2041 (1997), 58.R40 (1998), Nakayama, PRC.74.035205 (2006)]



→ self gauge invariant

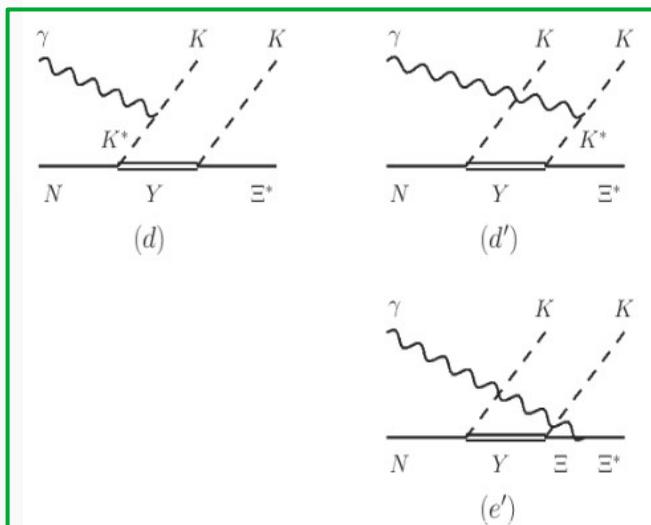
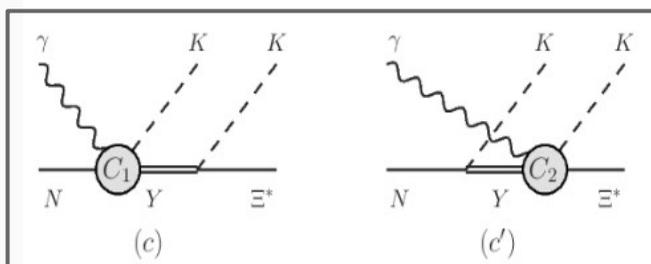
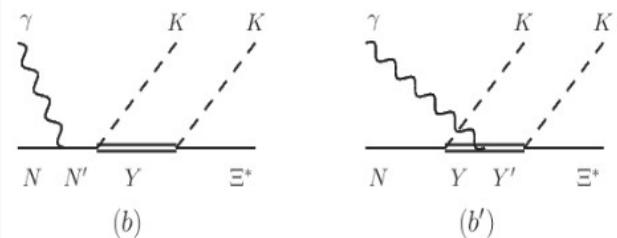
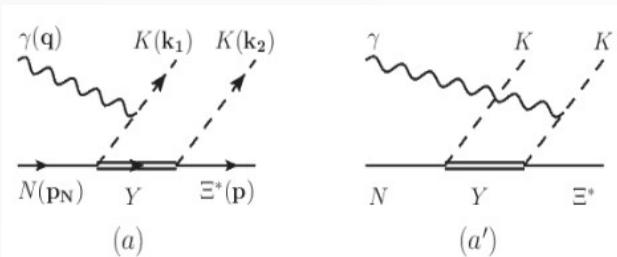
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Extension from one-meson to two-meson photoproduction

[Haberzettl, PRC.56.2041 (1997), 58.R40 (1998), Nakayama, PRC.74.035205 (2006)]



$$C_1^\mu = \frac{\Gamma_{c1}^\mu (e_i \tilde{R}_{s1} - e_B \tilde{R}_1)}{\gamma K N Y} + \frac{\Gamma_1 \tilde{C}_1^\mu}{K N Y}$$

$$C_2^\mu = \frac{\Gamma_{c2}^\mu (e_B \tilde{R}_2 - e_f \tilde{R}_{u2})}{\gamma K Y \Xi^*} + \frac{\Gamma_2 \tilde{C}_2^\mu}{K Y \Xi^*}$$

$$\begin{aligned} \tilde{C}_1^\mu = & -e_1 \frac{(2k_1 - q)^\mu}{t_1 - k_1^2} (\tilde{R}_{t1} - \hat{F}_1) \\ & -e_i \frac{(2p_N + q)^\mu}{s_1 - p_N^2} (\tilde{R}_{s1} - \hat{F}_1) \\ & -e_B \frac{(2p_N - 2k_1 + q)^\mu}{u_1 - s_2} (\tilde{R}_1 - \hat{F}_1) \end{aligned}$$

$$\begin{aligned} \tilde{C}_2^\mu = & -e_2 \frac{(2k_2 - q)^\mu}{t_2 - k_2^2} (\tilde{R}_{t2} - \hat{F}_2) \\ & -e_f \frac{(2p + q)^\mu}{u_2 - p^2} (\tilde{R}_{u2} - \hat{F}_2) \\ & -e_B \frac{(2p - 2k_2 + q)^\mu}{s_2 - u_1} (\tilde{R}_2 - \hat{F}_2) \end{aligned}$$

$$\hat{F}_1 = \hat{R}_1 + \frac{1}{\hat{R}_1^2} (\delta_1 \tilde{R}_{t1} - \hat{R}_1) (\delta_i \tilde{R}_{s1} - \hat{R}_1) (\delta_B \tilde{R}_1 - \hat{R}_1)$$

$$\hat{F}_2 = \hat{R}_2 + \frac{1}{\hat{R}_2^2} (\delta_2 \tilde{R}_{t2} - \hat{R}_2) (\delta_f \tilde{R}_{u2} - \hat{R}_2) (\delta_B \tilde{R}_2 - \hat{R}_2)$$

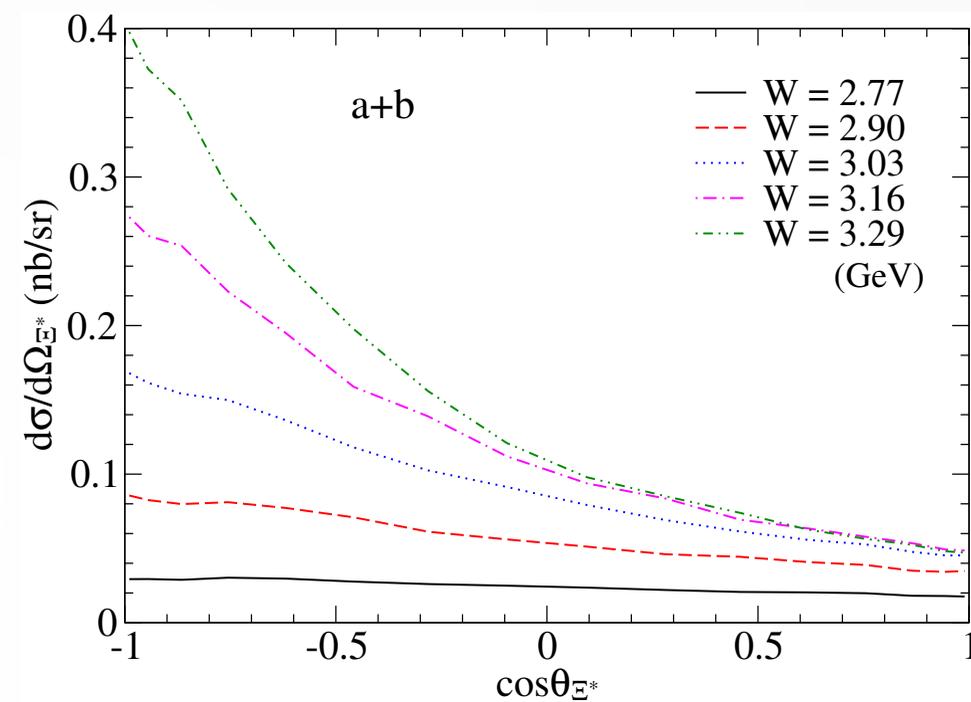
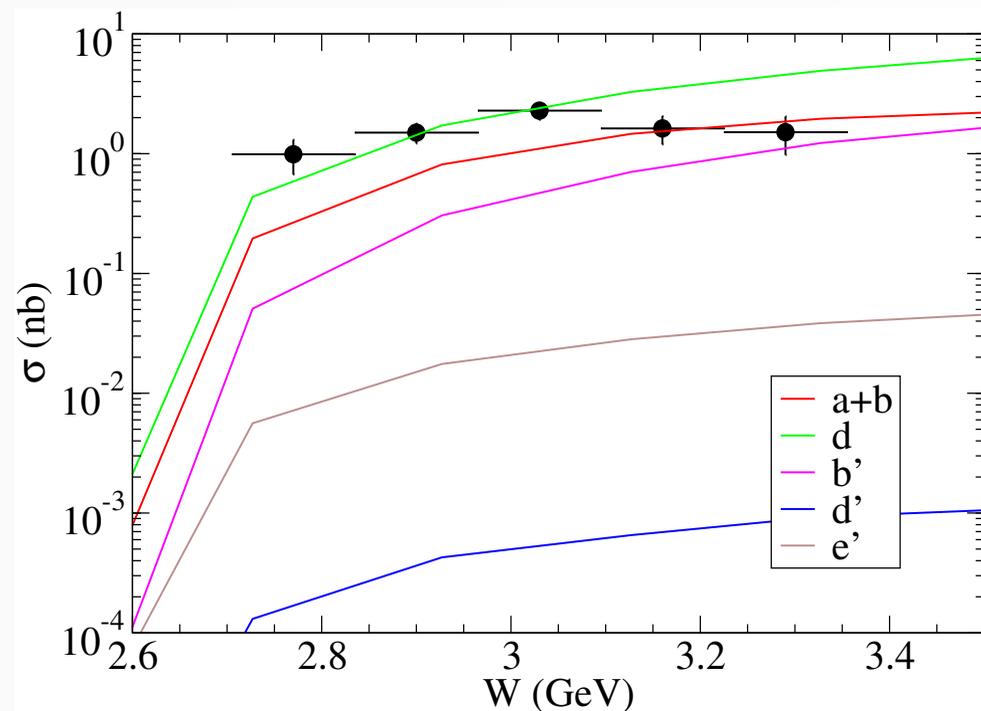
$$F(p'^2, p^2, q^2) = f_B(p'^2) f_B(p^2) f_M(q^2),$$

$$f_B(p^2) = \left(\frac{n \Lambda_B^4}{n \Lambda_B^4 + (p^2 - m_B^2)^2} \right)^n$$

$$e_B = e_f + e_2 = e_i - e_1$$

→ self gauge invariant

3. numerical results

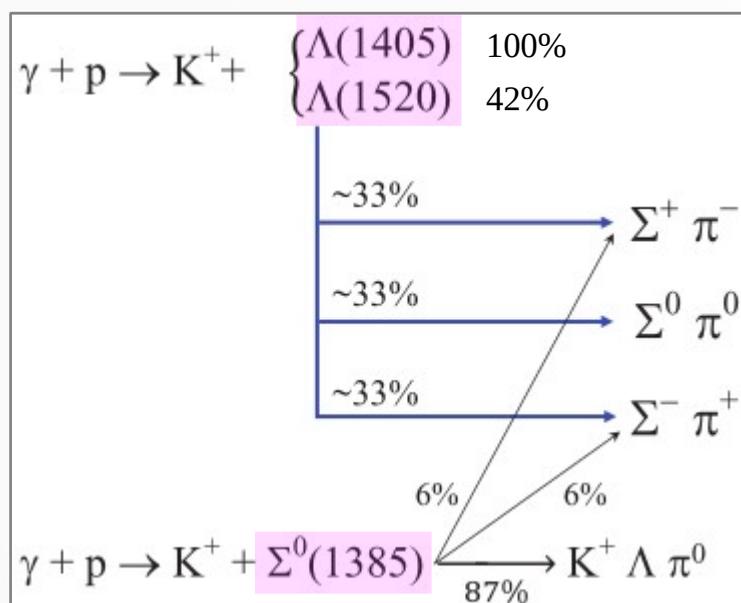
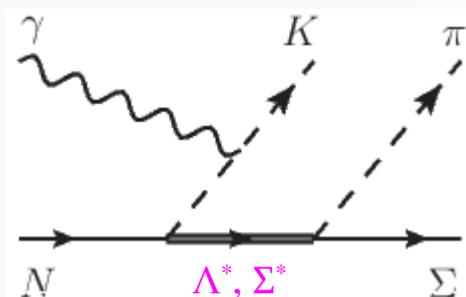


[CLAS, PRC.98.062201 (2018)]

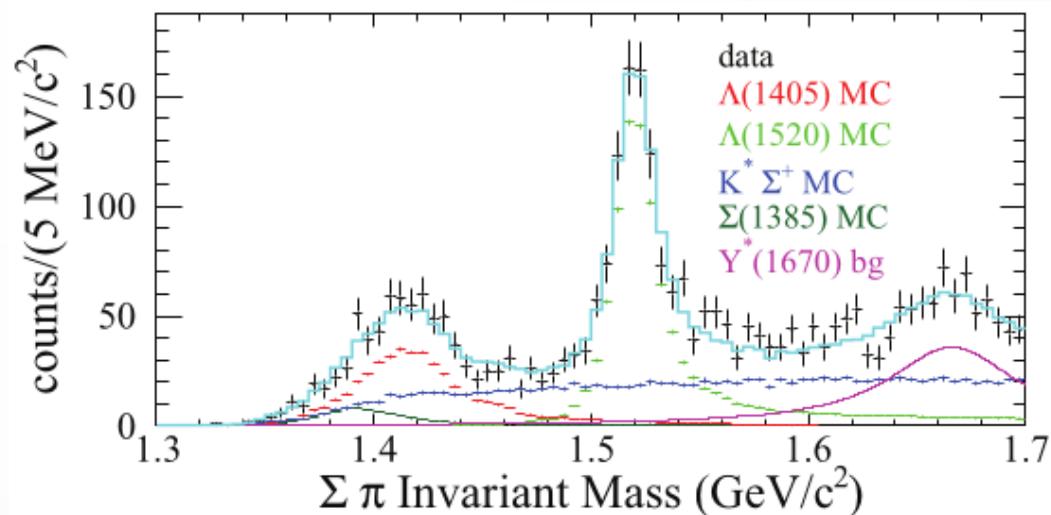
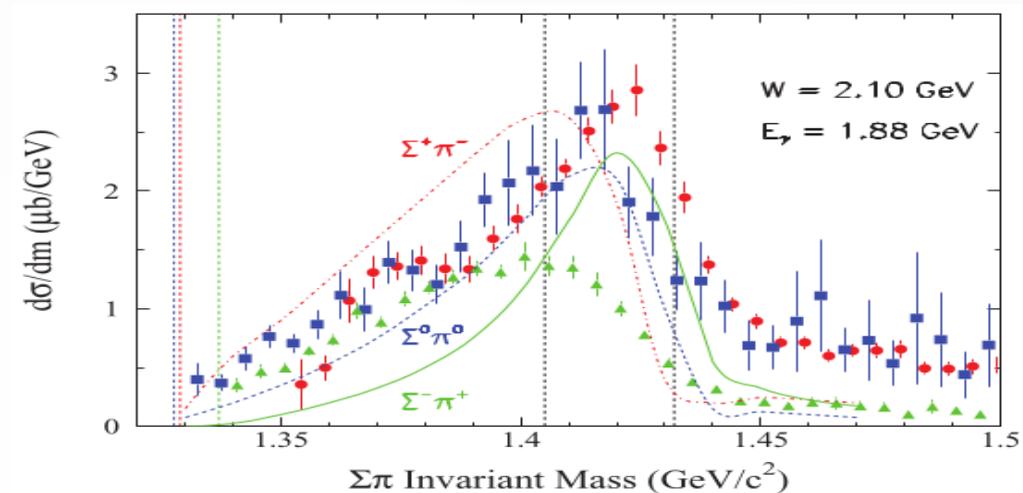
Preliminary Result

- The processes (a – d) are more dominant than those of (a' – e').
- The results of invariant-mass distributions and Dalitz plots will come soon.

4. applications

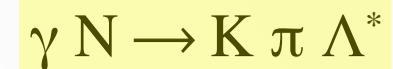
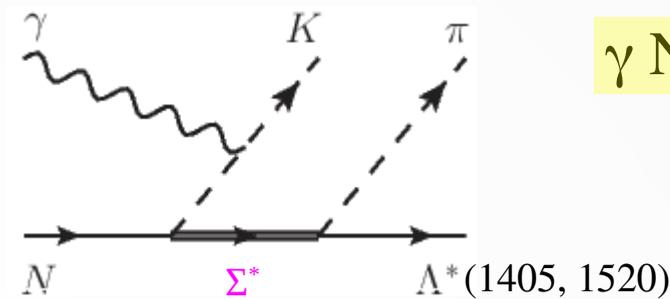
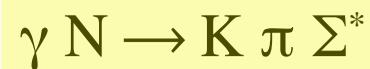
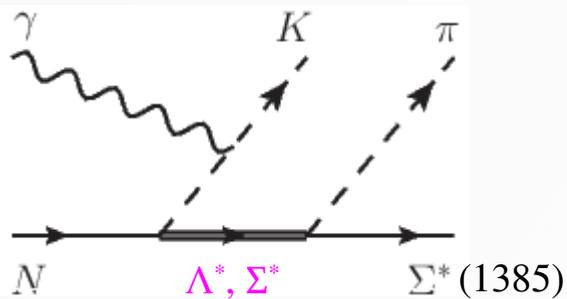


$\gamma N \rightarrow K \pi \Sigma$ (Invariant Mass Distributions)



[Nacher, PLB.455.55 (1999)
CLAS, PRC.87.035206 (2013)]

4. applications



$\pi \Sigma^*(1385)$ $\pi \Sigma$ $\pi \Lambda$ [%]

$\Lambda(1600, 1/2^+ \text{ ****})$	\rightarrow 9	35	
$\Lambda(1670, 1/2^- \text{ ****})$	\rightarrow 6	40	
$\Lambda(1710, 1/2^+ \text{ *})$	\rightarrow 20	21	
$\Lambda(1800, 1/2^- \text{ ***})$	\rightarrow 9	27	
$\Lambda(1810, 1/2^+ \text{ ***})$	\rightarrow 40	16	
$\Lambda(1820, 5/2^+ \text{ ****})$	\rightarrow 7.5	11	
$\Lambda(1830, 5/2^- \text{ ****})$	\rightarrow > 15	55	
$\Sigma(1775, 5/2^- \text{ ****})$	\rightarrow 10	3.5	17

$\pi \Lambda^*(1405)$ $\pi \Sigma$ $\pi \Lambda$ [%]

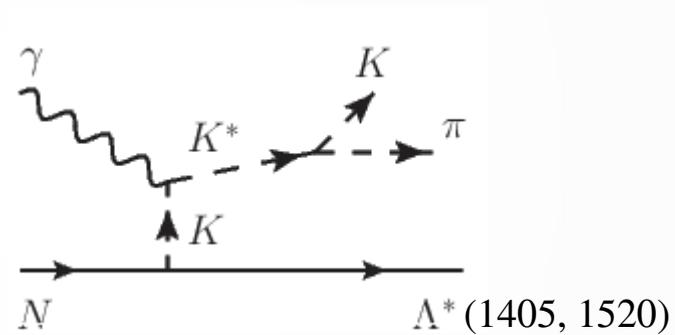
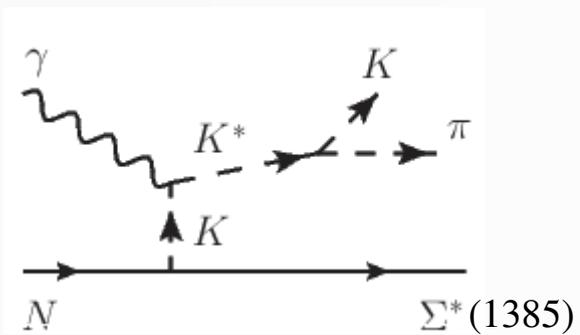
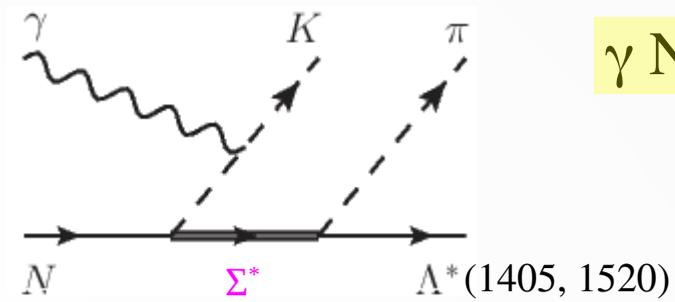
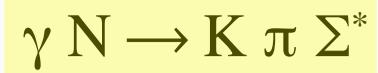
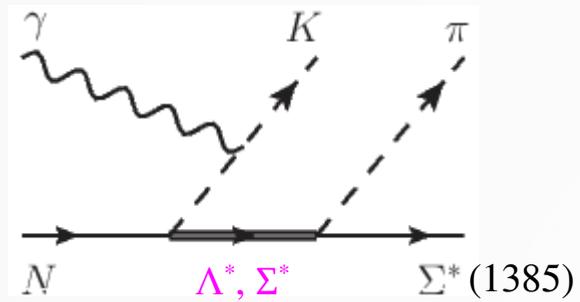
$\Sigma(1660, 1/2^+ \text{ ****})$	\rightarrow 4	37	35
------------------------------------	-----------------	----	----

$\pi \Lambda^*(1520)$ [%]

$\Sigma(1620, 1/2^- \text{ *})$	\rightarrow 10	17	9
$\Sigma(1750, 1/2^- \text{ ***})$	\rightarrow 2	16	14
$\Sigma(1775, 5/2^- \text{ ****})$	\rightarrow 20	3.5	17
$\Sigma(1880, 1/2^+ \text{ **})$	\rightarrow 2		

- These reactions provide a valuable opportunity to study higher Λ^* and Σ^* resonances by measuring cross sections, invariant-mass distributions, and Dalitz plots, etc.

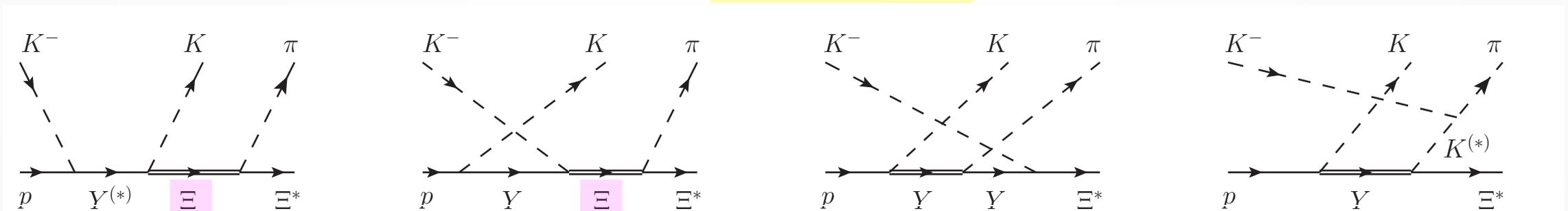
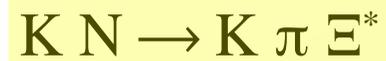
4. applications



- These diagrams should essentially be included as part of the background contribution.

4. applications

Particle	J^P	Overall status	Status as seen in —				Other channels
			$\Xi\pi$	ΛK	ΣK	$\Xi(1530)\pi$	
$\Xi(1318)$	$1/2^+$	****					Decays weakly
$\Xi(1530)$	$3/2^+$	****	****				
$\Xi(1620)$		**	**				
$\Xi(1690)$		***	**	***	**		
$\Xi(1820)$	$3/2^-$	***	**	***	**	**	
$\Xi(1950)$		***	**	**		*	
$\Xi(2030)$		***		**	***		
$\Xi(2120)$		*		*			
$\Xi(2250)$		**				?	3-body decays
$\Xi(2370)$		**					3-body decays
$\Xi(2500)$		*		*	*		3-body decays

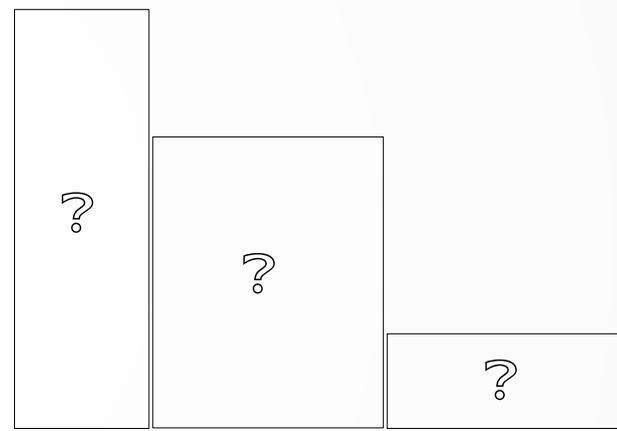
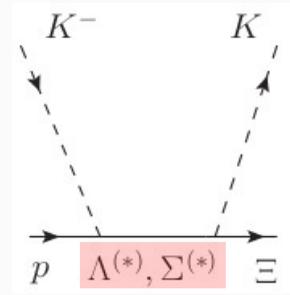


□ These reactions provide a valuable opportunity to study higher Ξ^* resonances.

4. applications

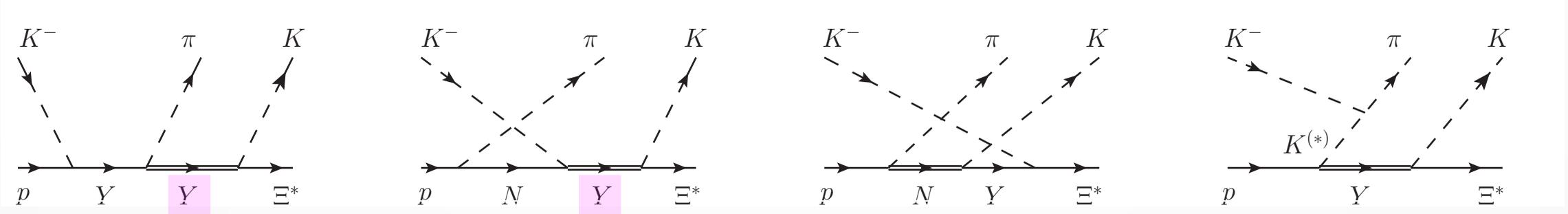
Particle	J^P	Overall status	Status as seen in —		
			$N\bar{K}$	$\Sigma\pi$	Other channels
$\Lambda(1116)$	$1/2^+$	****			$N\pi$ (weak decay)
$\Lambda(1380)$	$1/2^-$	**	**	**	
$\Lambda(1405)$	$1/2^-$	****	****	****	
$\Lambda(1520)$	$3/2^-$	****	****	****	$\Lambda\pi\pi, \Lambda\gamma, \Sigma\pi\pi$
$\Lambda(1600)$	$1/2^+$	****	***	****	$\Lambda\pi\pi, \Sigma(1385)\pi$
$\Lambda(1670)$	$1/2^-$	****	****	****	$\Lambda\eta$
$\Lambda(1690)$	$3/2^-$	****	****	***	$\Lambda\pi\pi, \Sigma(1385)\pi$
$\Lambda(1710)$	$1/2^+$	*	*	*	
$\Lambda(1800)$	$1/2^-$	***	***	**	$\Lambda\pi\pi, N\bar{K}^*$
$\Lambda(1810)$	$1/2^+$	***	**	**	$N\bar{K}^*$
$\Lambda(1820)$	$5/2^+$	****	****	****	$\Sigma(1385)\pi$
$\Lambda(1830)$	$5/2^-$	****	****	****	$\Sigma(1385)\pi$
$\Lambda(1890)$	$3/2^+$	****	****	**	$\Sigma(1385)\pi, N\bar{K}^*$
$\Lambda(2000)$	$1/2^-$	*	*	*	
$\Lambda(2050)$	$3/2^-$	*	*	*	
$\Lambda(2070)$	$3/2^+$	*	*	*	
$\Lambda(2080)$	$5/2^-$	*	*	*	
$\Lambda(2085)$	$7/2^+$	**	**	*	
$\Lambda(2100)$	$7/2^-$	****	****	**	$N\bar{K}^*$
$\Lambda(2110)$	$5/2^+$	***	**	**	$N\bar{K}^*$
$\Lambda(2325)$	$3/2^-$	*	*	*	
$\Lambda(2350)$	$9/2^+$	***	***	*	
$\Lambda(2585)$		*	*	*	

ΞK $\Xi(1530) K$ $\Xi K(892)$



ΞK
 $\Xi(1530) K$
 $\Xi K(892)$

$$K N \rightarrow \pi K \Xi^*$$

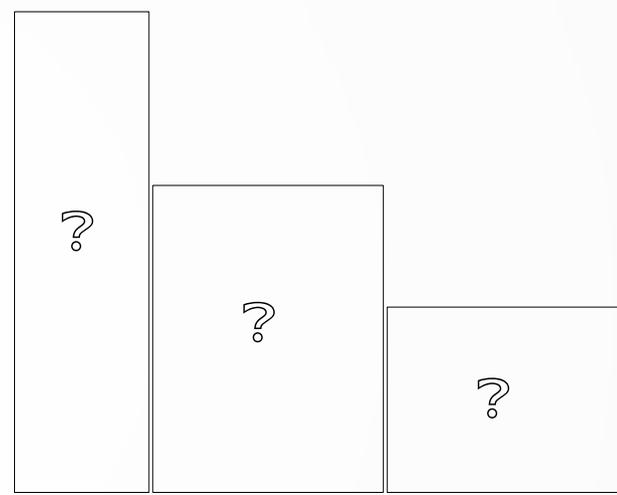
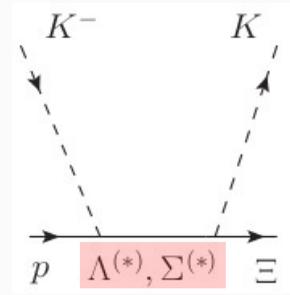


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4. applications

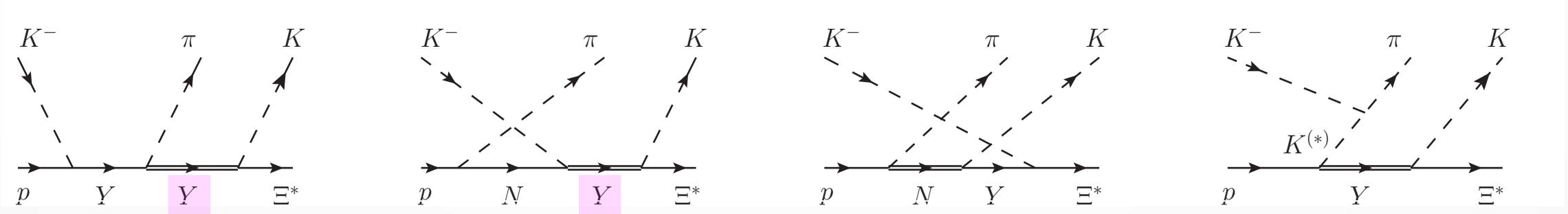
Particle	J^P	Overall status	Status as seen in —		
			$N\bar{K}$	$\Lambda\pi$	$\Sigma\pi$
$\Sigma(1193)$	$1/2^+$	****			
$\Sigma(1385)$	$3/2^+$	****		****	****
$\Sigma(1580)$	$3/2^-$	*	*	*	*
$\Sigma(1620)$	$1/2^-$	*	*	*	*
$\Sigma(1660)$	$1/2^+$	***	***	***	***
$\Sigma(1670)$	$3/2^-$	****	****	****	****
$\Sigma(1750)$	$1/2^-$	***	***	**	***
$\Sigma(1775)$	$5/2^-$	****	****	****	**
$\Sigma(1780)$	$3/2^+$	*	*	*	*
$\Sigma(1880)$	$1/2^+$	**	**	*	*
$\Sigma(1900)$	$1/2^-$	**	**	*	**
$\Sigma(1910)$	$3/2^-$	***	*	*	**
$\Sigma(1915)$	$5/2^+$	****	***	***	***
$\Sigma(1940)$	$3/2^+$	*	*		*
$\Sigma(2010)$	$3/2^-$	*	*	*	
$\Sigma(2030)$	$7/2^+$	****	****	****	**
$\Sigma(2070)$	$5/2^+$	*	*		*
$\Sigma(2080)$	$3/2^+$	*	*	*	*
$\Sigma(2100)$	$7/2^-$	*	*	*	*
$\Sigma(2110)$	$1/2^-$	*	*	*	*
$\Sigma(2230)$	$3/2^+$	*	*	*	*
$\Sigma(2250)$		**	**	*	*
$\Sigma(2455)$		*	*		
$\Sigma(2620)$		*	*		
$\Sigma(3000)$		*	*	*	
$\Sigma(3170)$		*			

ΞK $\Xi(1530) K$ $\Xi K(892)$



ΞK ↙
 $\Xi(1530) K$ ↙
 $\Xi K(892)$ ↙

$K N \rightarrow \pi K \Xi^*$



□ These reactions provide a valuable opportunity to study higher Λ^* and Σ^* resonances.

- We studied the $\gamma p \rightarrow K^+ K^+ \Xi^{*-}$ reaction in a hadron exchange model.
Nine Feynman diagrams are rigorously taken into account in a gauge invariant manner.
- The total and differential cross section are calculated and is fitted to the JLAB/CLAS data.
The results of invariant-mass distributions and Dalitz plots will come soon.
- We can apply our formalism to other 3-body reaction channels:
 $\gamma N \rightarrow K \pi \Sigma^*$, $K \pi \Lambda^*$ (JLab), $K N \rightarrow K \pi \Xi^*$, $\pi K \Xi^*$ (J-PARC), etc.
- These reactions may provide substantial contributions to the spectroscopy of hyperon baryons.

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Thank you very much for your attention