KΛ(1405) & KΛ photoproduction off the nucleon with nucleon resonances

Sang-Ho Kim (金相鎬)
Asia Pacific Center for Theoretical Physics
(APCTP), POSTECH

Contents based on
- PRD.96.014003 (2017)
- arXiv:1806.01992 [hep-ph]

In collaboration with
- Seung-il Nam (PKNU)
- Hyun-Chul Kim (Inha Univ.)
- Yongseok Oh (KNU)
- Daisuke Jido (TMU)

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$\gamma p \to K^+ \Lambda(1405)$ $\gamma n \to K^0 \Lambda$

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- Theoretical Framework: Regge-plus-Resonance model
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  invariant mass distribution ($d\sigma/dM$)
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Introduction

Open-Strangeness Photoproduction

- Some N^* have a weak coupling to πN final states but large branching ratios to KY or K^*Y ones.

- A comparison between "experiments" and "theoretical predictions" gives the information on which N^*'s significantly contribute to the reaction.

- Provides useful information for identifying "missing resonances".

Open-Strangeness Photoproduction
$(\gamma\ N \rightarrow\ K\ \Lambda)$

- Λ is an isosinglet, so Δ^* resonances cannot contribute to the s-channel diagram. Thus a theoretical interpretation is more simplified.

- Up to now, most of the data come from the reaction off a proton target.

$$\gamma\ p \rightarrow\ K^+\ \Lambda$$

Open-Strangeness Photoproduction
(γ N $\rightarrow$ K Λ)

- Λ is an isosinglet, so Δ^* resonances cannot contribute to the s-channel diagram. Thus a theoretical interpretation is more simplified.

- Up to now, most of the data come from the reaction off a proton target.

$$\gamma\, p \rightarrow K^+ \Lambda$$

- First measurements of the reactions:

$\gamma\, p \rightarrow K^+ \Lambda(1405)$

CLAS [PRC.88.045201(2013)]

$\gamma\, n \rightarrow K^0 \Lambda$ [$\gamma\, d \rightarrow K^0 \Lambda$ (p)]

FOREST [JPSConf.Proc.17.062007(2017)]
CLAS [PRC.96.065201(2017)]

Theoretical Framework

- Multi-channel framework (rescattering effect)
  - ▻ ANL-Osaka, Bonn-Gatchina, Giessen, Juelich, Shyam & Scholten & Usov

- Single-channel framework
  - Isobar model (effective hadronic Lagrangians)
    - ▻ Williams-Cotanch-Ji, Mart, Kaon-MAID, Skoupil-Bydzovsky

  - Regge-plus-Resonance model
    - ▻ Ghent group: RPR-2007, RPR-2011

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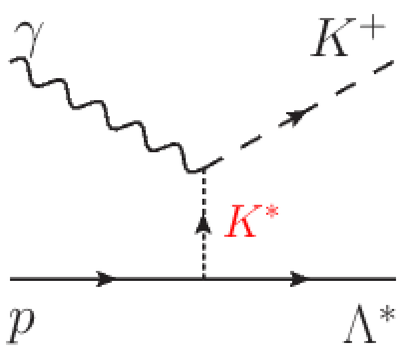
❑ Our approach is similar to the RPR model but avoids a complex fitting procedure. We construct the relation between "the coupling constants" of effective Lagrangians and "the partial decay widths" that can be obtained by PDG or hadron models. Thus model parameters are much reduced.

Regge-plus-Resonance model

❑ preserves unitarity.

Single particle exchange in the t-channel of spin J

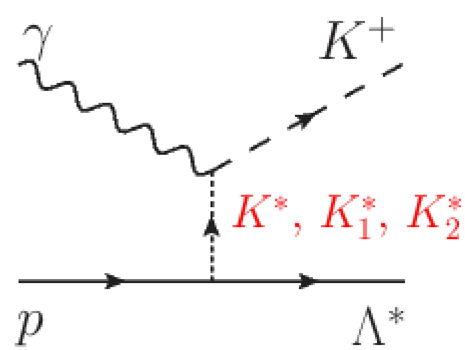


$$\sigma \sim s^{J-1}$$

Froissart bound :

$$\sigma^{\mathrm{Tot}}(s) \leq \mathrm{constant} \times \log^2(s/s_0)$$

Sum up all meson exchanges of various J



$$\sigma \sim s^{\alpha(0)-1}$$

K and K* trajectories are degenerated :

$$\alpha_K = \alpha_K(t) = \frac{0.7}{\mathrm{GeV}^2}(t - M_K^2)$$

$$\alpha_{K^*} = \alpha_{K^*}(t) = \frac{0.83}{\mathrm{GeV}^2}t + 0.25,$$

Regge-plus-Resonance model

Invariant amplitude: M^{Regge} (background) + $M^{\text{Resonance}}$

- ❑ interpolates between the low and high momentum transfer regions.
- ❑ Regge propagators (P^{Regge}) in a gauge invariant manner

$$\mathcal{M}_{t,s}^{\text{Regge}} = [(\mathcal{M}_K + \mathcal{M}_N)(t - M_K^2)P_K^{\text{Regge}} + \mathcal{M}_{K^*}(t - M_{K^*}^2)P_{K^*}^{\text{Regge}}]$$

$$\frac{1}{t-M_K^2} \to P_K^{\text{Regge}} = \left(\frac{s}{s_0}\right)^{\alpha_K} \frac{\pi\alpha_K'}{\sin(\pi\alpha_K)} \begin{Bmatrix} 1 \\ e^{-i\pi\alpha_K} \end{Bmatrix} \frac{1}{\Gamma(1+\alpha_K)},$$

$$\frac{1}{t-M_{K^*}^2} \to P_{K^*}^{\text{Regge}} = \left(\frac{s}{s_0}\right)^{\alpha_{K^*}-1} \frac{\pi\alpha_{K^*}'}{\sin(\pi\alpha_{K^*})} \begin{Bmatrix} 1 \\ e^{-i\pi\alpha_{K^*}} \end{Bmatrix} \frac{1}{\Gamma(\alpha_{K^*})}$$

Guidal, NPA.627.645(1997)

- ❑ Strong coupling constants
  - ▻ $SU(3)_f$ symmetry : $-4.4 \leq g_{KN\Lambda}/4\sqrt{\pi} \leq -3.0$
  - ▻ Nijmegen potentials : $-4.9 \leq g_{KN\Lambda}/4\sqrt{\pi} \leq -3.8$

  are constrained by the high energy region.

Regge-plus-Resonance model

Invariant amplitude: M^{Regge} (background) + $M^{\text{Resonance}}$

- PDG & missing resonances
- Hadronic form factors: monopole, dipole, Gaussian
- Rarita-Schwinger propagators ($S(p)$) for spin-3/2, -5/2, -7/2 N*'s

[PRD.60.61(1941), Behrends,PR.106.345(1957), Rushbrooke,PR.143.1345(1966), Chang,PR.161.1308(1967)]

$$(i\partial\!\!\!/ - M)R_{\alpha_1\alpha_2\ldots\alpha_{n-1}} = 0 \qquad \gamma^{\alpha_1}R_{\alpha_1\alpha_2\ldots\alpha_s} = 0, \qquad \partial^{\alpha_1}R_{\alpha_1\alpha_2\ldots\alpha_s} = 0,$$

$$g^{\alpha_1\alpha_2}R_{\alpha_1\alpha_2\ldots\alpha_s} = 0.$$

$$S(p) = \frac{i}{p\!\!\!/ - M}\Delta(J) \qquad \sum_{\text{spins}} R_{\alpha_1\ldots}\bar{R}^{\beta_1\cdots} = \Lambda_{\pm}\Delta^{\beta_1\cdots}_{\alpha_1\cdots}$$

(Δ_α^{β}: spin projection operator)

$$\Delta^{\beta}_{\alpha}(\tfrac{3}{2}) = -g^{\beta}_{\alpha} + \frac{1}{3}\gamma_\alpha\gamma^\beta + \frac{1}{3M}\left(\gamma_\alpha p^\beta - p_\alpha\gamma^\beta\right) + \frac{2}{3M^2}p_\alpha p^\beta$$

$$\Delta^{\beta_1\beta_2}_{\alpha_1\alpha_2}(\tfrac{5}{2}) = \frac{1}{2}\left(\theta^{\beta_1}_{\alpha_1}\theta^{\beta_2}_{\alpha_2} + \theta^{\beta_2}_{\alpha_1}\theta^{\beta_1}_{\alpha_2}\right) - \frac{1}{5}\theta_{\alpha_1\alpha_2}\theta^{\beta_1\beta_2} - \frac{1}{10}\left(\Gamma_{\alpha_1}\Gamma^{\beta_1}\theta^{\beta_2}_{\alpha_2} + \Gamma_{\alpha_1}\Gamma^{\beta_2}\theta^{\beta_1}_{\alpha_2} + \Gamma_{\alpha_2}\Gamma^{\beta_1}\theta^{\beta_2}_{\alpha_1} + \Gamma_{\alpha_2}\Gamma^{\beta_2}\theta^{\beta_1}_{\alpha_1}\right)$$

$$\Delta^{\beta_1\beta_2\beta_3}_{\alpha_1\alpha_2\alpha_3}(\tfrac{7}{2}) =$$

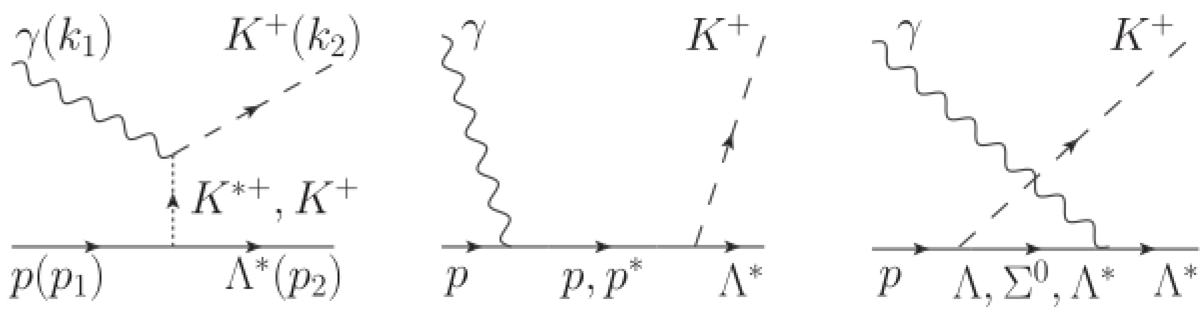
Oh,JKPS.59.3344(2011)

$$\theta_{\alpha\beta} = -\left(g_{\alpha\beta} - \frac{1}{M^2}p_\alpha p_\beta\right) \qquad \Gamma^\alpha = i\left(\gamma^\alpha - \frac{1}{M^2}p\!\!\!/ p^\alpha\right)$$

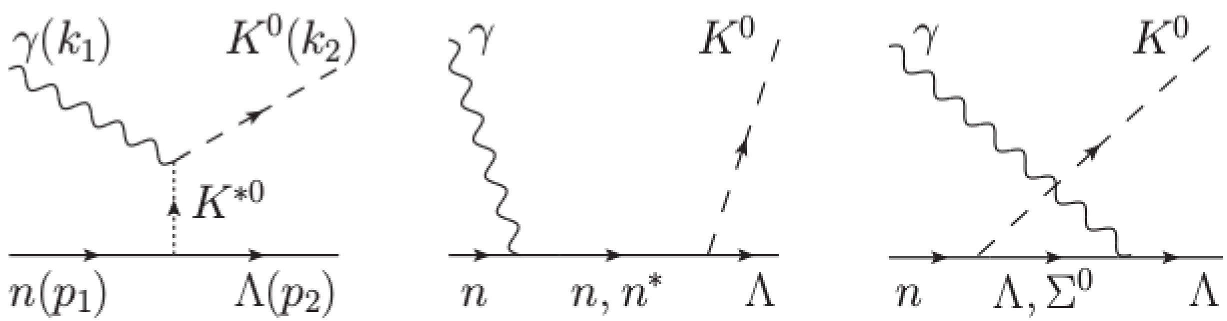
Theoretical Framework

Tree-diagrams

$\gamma\, p \to K^+ \Lambda(1405)$



$\gamma\, n \to K^0 \Lambda$

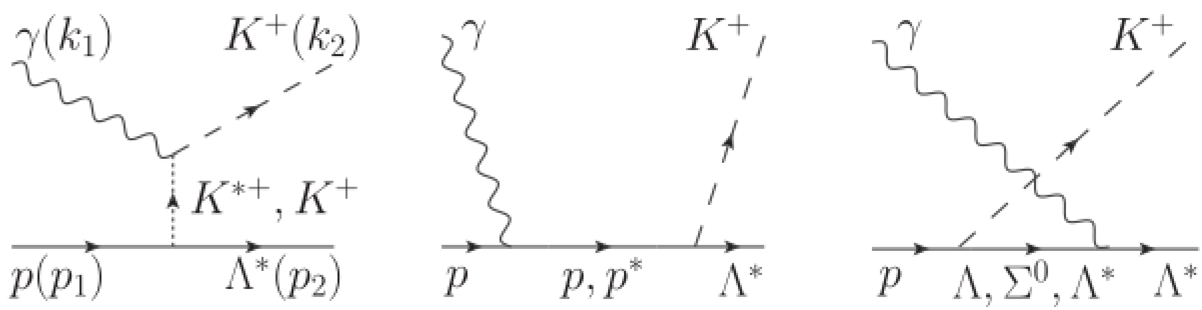


- K exchange is excluded because of charge.
- Other higher strange mesons are excluded because of their small photocouplings, e.g., $Br(K^*(1410) \to K_0\gamma) < 2.2 \times 10^{-4}$.

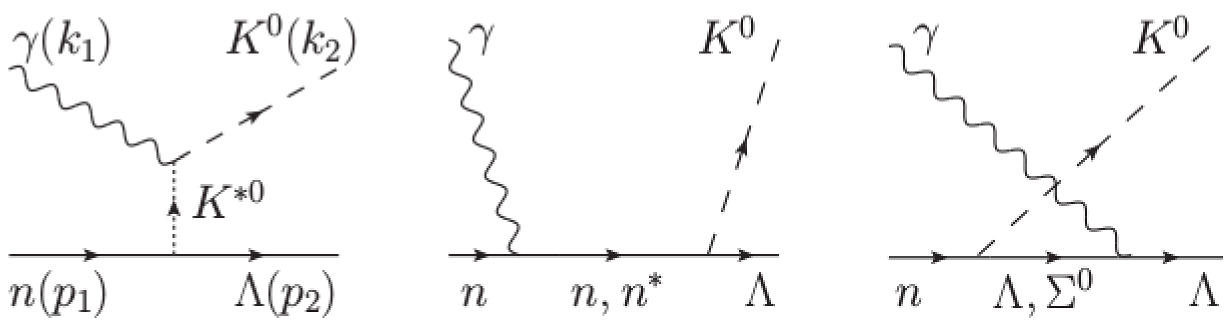
Theoretical Framework

Tree-diagrams

$\gamma\, p \rightarrow K^{+}\Lambda(1405)$



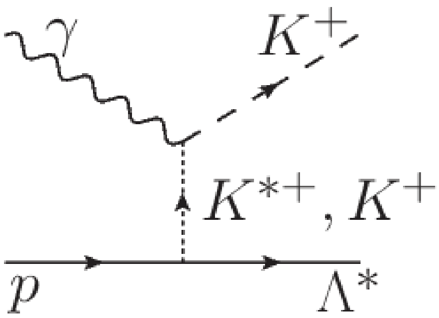
$\gamma\, n \rightarrow K^{0}\Lambda$



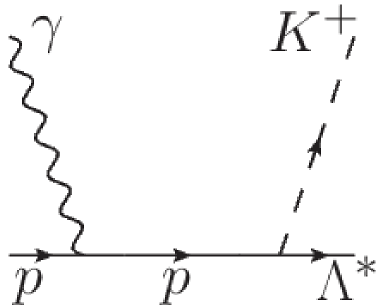
Change couplings & parity of hyperon

- ❑ K exchange is excluded because of charge.
- ❑ Other higher strange mesons are excluded because of their small photocouplings, e.g., $Br(K^*(1410) \rightarrow K_0\gamma) < 2.2 \times 10^{-4}$.

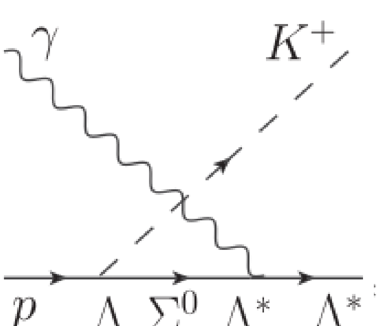
1. Background contributions



t channel



s channel



u channel

Effective hadronic Lagrangians

Electromagnetic interactions

$$\mathcal{L}_{\gamma KK} = -ie_K[K^\dagger(\partial_\mu K) - (\partial_\mu K^\dagger)K]A^\mu,$$

$$\mathcal{L}_{\gamma KK^*} = g_{\gamma KK^*}\epsilon^{\mu\nu\alpha\beta}\partial_\mu A_\nu[(\partial_\alpha K^{*-}_\beta)K^+ + K^-(\partial_\alpha K^{*+}_\beta)],$$

$$\mathcal{L}_{\gamma NN} = -\bar{N}\left[e_N\gamma_\mu - \frac{e\kappa_N}{2M_N}\sigma_{\mu\nu}\partial^\nu\right]A^\mu N,$$

$$\mathcal{L}_{\gamma\Lambda^*\Lambda^*} = \frac{e\mu_{\Lambda^*}}{2M_N}\bar{\Lambda}^*\sigma_{\mu\nu}\partial^\nu A^\mu\Lambda^*,$$

$$\mathcal{L}_{\gamma Y\Lambda^*} = \frac{e\mu_{\Lambda^*\to Y\gamma}}{2M_N}\bar{Y}\gamma_5\sigma_{\mu\nu}\partial^\nu A^\mu\Lambda^* + \text{H.c.},$$

Strong interactions

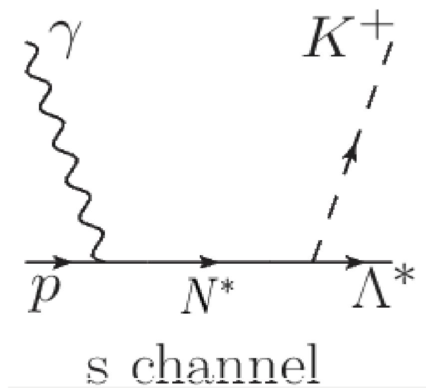
$$\mathcal{L}_{KNY} = -ig_{KNY}\bar{N}\gamma_5 YK + \text{H.c.},$$

$$\mathcal{L}_{KN\Lambda^*} = -ig_{KN\Lambda^*}\bar{N}\Lambda^*K + \text{H.c.},$$

$$\mathcal{L}_{K^*N\Lambda^*} = -g_{K^*N\Lambda^*}\bar{N}\gamma_5\gamma_\mu\Lambda^*K^{*\mu} + \text{H.c.}$$

form factor: $F_B(q^2) = \left[\frac{\Lambda_B^4}{\Lambda_B^4 + (q^2 - M_B^2)^2}\right]^2$

2. Resonance contributions



$$\Gamma^{\pm} = \begin{pmatrix} \gamma_5 \\ I_{4\times 4} \end{pmatrix}, \quad \Gamma^{\pm}_{\nu} = \begin{pmatrix} \gamma_\nu\gamma_5 \\ \gamma_\nu \end{pmatrix}$$

Effective hadronic Lagrangians

Electromagnetic interactions

$$\mathcal{L}^{1/2^\pm}_{\gamma N N^*} = \frac{eh_1}{2M_N}\bar{N}\Gamma^{\mp}\sigma_{\mu\nu}\partial^\nu A^\mu N^* + \text{H.c.},$$

$$\mathcal{L}^{3/2^\pm}_{\gamma N N^*} = -ie\left[\frac{h_1}{2M_N}\bar{N}\Gamma^{\pm}_\nu - \frac{ih_2}{(2M_N)^2}\partial_\nu\bar{N}\Gamma^{\pm}\right]F^{\mu\nu}N^*_\mu + \text{H.c.},$$

$$\mathcal{L}^{5/2^\pm}_{\gamma N N^*} = e\left[\frac{h_1}{(2M_N)^2}\bar{N}\Gamma^{\mp}_\nu - \frac{ih_2}{(2M_N)^3}\partial_\nu\bar{N}\Gamma^{\mp}\right]\partial^\alpha F^{\mu\nu}N^*_{\mu\alpha} + \text{H.c.},$$

$$\mathcal{L}^{7/2^\pm}_{\gamma N N^*} = ie\left[\frac{h_1}{(2M_N)^3}\bar{N}\Gamma^{\pm}_\nu - \frac{ih_2}{(2M_N)^4}\partial_\nu\bar{N}\Gamma^{\pm}\right]\partial^\alpha\partial^\beta F^{\mu\nu}N^*_{\mu\alpha\beta} + \text{H.c.}$$

Strong interactions

$$\mathcal{L}^{1/2^\pm}_{K\Lambda^* N^*} = -ig_{K\Lambda^* N^*}\bar{K}\bar{\Lambda}^*\Gamma^{\mp}N^* + \text{H.c.},$$

$$\mathcal{L}^{3/2^\pm}_{K\Lambda^* N^*} = \frac{g_{K\Lambda^* N^*}}{M_K}\partial^\mu\bar{K}\bar{\Lambda}^*\Gamma^{\pm}N^*_\mu + \text{H.c.},$$

$$\mathcal{L}^{5/2^\pm}_{K\Lambda^* N^*} = \frac{ig_{K\Lambda^* N^*}}{M_K^2}\partial^\mu\partial^\nu\bar{K}\bar{\Lambda}^*\Gamma^{\mp}N^*_{\mu\nu} + \text{H.c.},$$

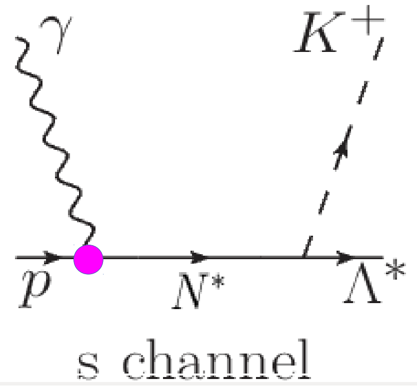
$$\mathcal{L}^{7/2^\pm}_{K\Lambda^* N^*} = -\frac{g_{K\Lambda^* N^*}}{M_K^3}\partial^\mu\partial^\nu\partial^\alpha\bar{K}\bar{\Lambda}^*\Gamma^{\pm}N^*_{\mu\nu\alpha} + \text{H.c.}$$

Gaussian form factor:

$$F_{N^*}(q_s^2) = \exp\left\{-\frac{(q_s^2 - M_{N^*}^2)^2}{\Lambda_{N^*}^4}\right\}$$

$\Lambda_B = \Lambda_{N^*} = 0.9$ GeV

2. Resonance contributions



Oh,Ko,Nakayama, PRC.77.045204(2008)

"Transition magnetic moments" h_1, h_2 &
"Helicity amplitudes" A_λ

$$A_\lambda(j) = \frac{1}{\sqrt{8M_N M_R k_\gamma}} \frac{2j+1}{4\pi} \times \int d\cos\theta d\phi e^{-i(m-\lambda)\phi} d^j_{\lambda m}(\theta) \langle \mathbf{k}_\gamma, \lambda_\gamma, \lambda_N \mid -i\mathcal{M} \mid jm \rangle$$

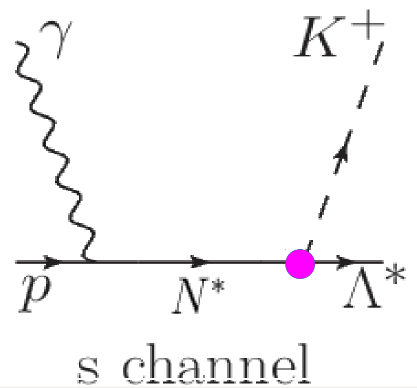
$$\left\{ A_{1/2}(\tfrac{1}{2}^\pm) = \mp \frac{ef_1}{2M_N}\sqrt{\frac{k_\gamma M_R}{M_N}} \right.$$

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

$$\left\{ \begin{aligned} A_{1/2}(\tfrac{5}{2}^\pm) &= \pm \frac{e}{4\sqrt{10}}\frac{k_\gamma}{M_N}\sqrt{\frac{k_\gamma}{M_N M_R}}\left[f_1 + \frac{f_2}{4M_N^2}M_R(M_R \pm M_N)\right] \\ A_{3/2}(\tfrac{5}{2}^\pm) &= \pm \frac{e}{4\sqrt{5}}\frac{k_\gamma}{M_N^2}\sqrt{\frac{k_\gamma M_R}{M_N}}\left[f_1 \pm \frac{f_2}{4M_N}(M_R \pm M_N)\right] \end{aligned} \right.$$

A_λ can be taken from PDG.

2. Resonance contributions



$$m_l + m_f = m_j$$

S.H.Kim, Oh, in preparation

$$\Gamma(N^* \to K\Lambda^*) = \sum_\ell |G(\ell)|^2$$

$$\Gamma(\tfrac{1}{2}^\pm \to K\Lambda^*) = \frac{1}{4\pi}\frac{q}{M_{N^*}} g^2_{K\Lambda^* N^*}(E_{\Lambda^*} \pm M_{\Lambda^*}),$$

$$\Gamma(\tfrac{3}{2}^\pm \to K\Lambda^*) = \frac{1}{12\pi}\frac{q^3}{M_{N^*}}\frac{g^2_{K\Lambda^* N^*}}{M_K^2}(E_{\Lambda^*} \mp M_{\Lambda^*}),$$

$$\Gamma(\tfrac{5}{2}^\pm \to K\Lambda^*) = \frac{1}{30\pi}\frac{q^5}{M_{N^*}}\frac{g^2_{K\Lambda^* N^*}}{M_K^4}(E_{\Lambda^*} \pm M_{\Lambda^*}),$$

“Strong coupling constants” $g_{K\Lambda^* N^*}$ &
“Decay amplitudes” $G(\ell)$

$$\langle K(\mathbf{q})\Lambda^*(-\mathbf{q}, m_f)| - i\mathcal{H}_{int}|N^*(\mathbf{0}, m_j)\rangle = 4\pi M_{N^*}\sqrt{\frac{2}{q}}\sum_{l,m_l}\langle l m_l \tfrac{1}{2} m_f | j m_j\rangle Y_{l m_l}(\hat{\mathbf{q}}) G(\ell)$$

$$\begin{cases} G(0) = \sqrt{\dfrac{|\vec{q}|(E_{\Lambda^*} + M_{\Lambda^*})}{4\pi M_{N^*}}}\, g_{K\Lambda^* N^*} & j = \frac{1}{2}^+ \\ G(1) = -\sqrt{\dfrac{|\vec{q}|(E_{\Lambda^*} - M_{\Lambda^*})}{4\pi M_{N^*}}}\, g_{K\Lambda^* N^*} & j = \frac{1}{2}^- \end{cases}$$

$$\begin{cases} G(2) = -\sqrt{\dfrac{|\vec{q}|^3(E_{\Lambda^*} - M_{\Lambda^*})}{12\pi M_{N^*}}}\, \dfrac{g_{K\Lambda^* N^*}}{M_K} & j = \frac{3}{2}^+ \\ G(1) = \sqrt{\dfrac{|\vec{q}|^3(E_{\Lambda^*} + M_{\Lambda^*})}{12\pi M_{N^*}}}\, \dfrac{g_{K\Lambda^* N^*}}{M_K} & j = \frac{3}{2}^- \end{cases}$$

$$\begin{cases} G(2) = \sqrt{\dfrac{|\vec{q}|^5(E_{\Lambda^*} + M_{\Lambda^*})}{30\pi M_{N^*}}}\, \dfrac{g_{K\Lambda^* N^*}}{M_K^2} & j = \frac{5}{2}^+ \\ G(3) = -\sqrt{\dfrac{|\vec{q}|^5(E_{\Lambda^*} - M_{\Lambda^*})}{30\pi M_{N^*}}}\, \dfrac{g_{K\Lambda^* N^*}}{M_K^2} & j = \frac{5}{2}^- \end{cases}$$

$G(\ell)$ can be taken from quark model predictions.

constituent quark model
Capstick,PRD.58.074011(1998)

Results

Results-1

$\gamma\, p \rightarrow K^+ \Lambda(1405)$

threshold = 1.9 GeV

2 PDG resonances +
3 missing resonances

$\gamma\, n \rightarrow K^0 \Lambda$

threshold = 1.6 GeV

16 PDG resonances +
narrow $N(1685,1/2^+)$

$\gamma\, p \to K^+ \Lambda(1405)$

threshold = 1.9 GeV

2 PDG resonances +
3 missing resonances

$\gamma\, n \to K^0 \Lambda$

threshold = 1.6 GeV

16 PDG resonances +
narrow N(1685,1/2+)

$\gamma\, p \to K^+ \Lambda(1405)$

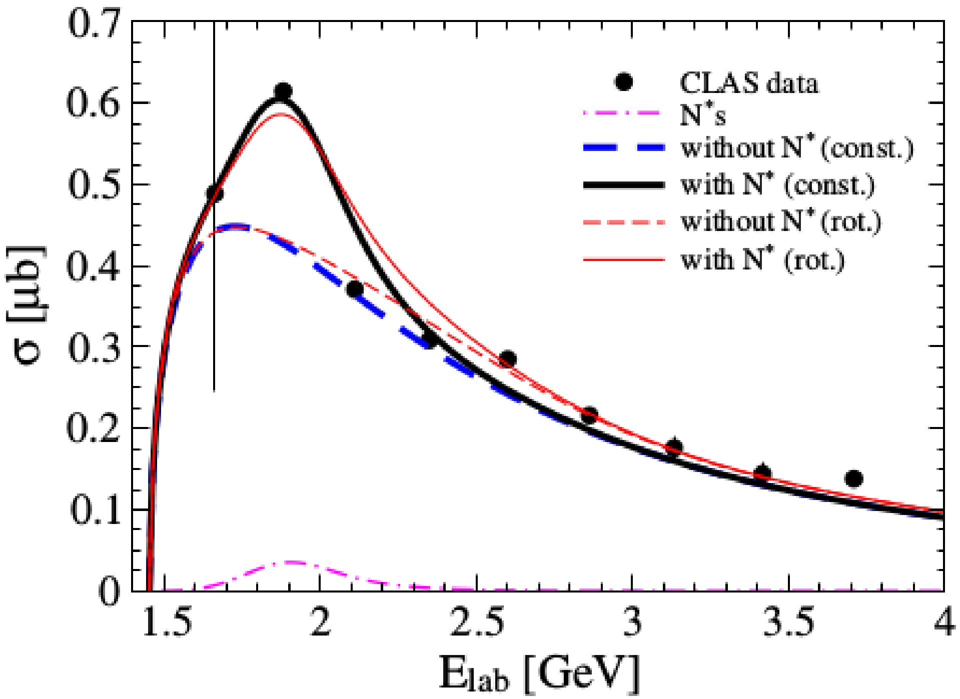
threshold = 1.9 GeV

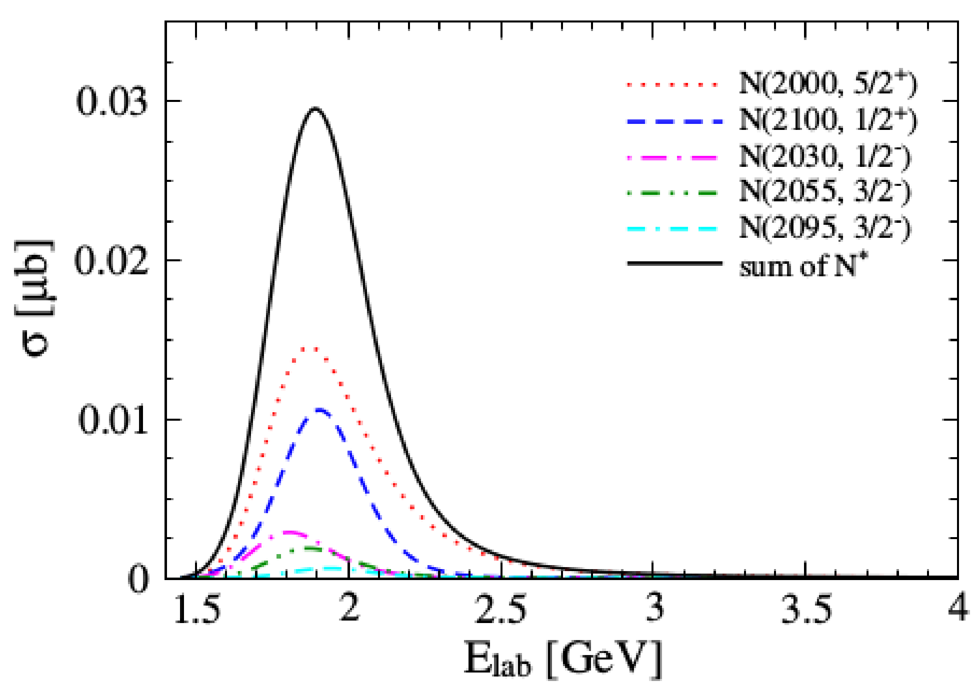
← EM ($\gamma p p^*$) interactions → Strong interactions

	N^*	$A_{1/2}$	$A_{3/2}$	h_1	h_2	$G(\ell)$	$g_{K\Lambda^* N^*}$
PDG	$N^*(2000, 5/2^+)$	31 ± 10	-43 ± 8	-4.22	3.98	$-0.6^{+0.6}_{-1.6}$	-0.912
	$N^*(2100, 1/2^+)$	10 ± 4	...	-0.045	...	$+5.2 \pm 0.8$	0.785
missing	$N^*(2030, 1/2^-)$	20	...	0.094	...	$+1.2^{+0.9}_{-1.1}$	1.78
	$N^*(2055, 3/2^-)$	16	0	-0.335	0.419	$+1.2^{+0.5}_{-0.9}$	-0.467
	$N^*(2095, 3/2^-)$	-9	-14	0.018	-0.134	$+0.7^{+0.2}_{-0.4}$	-0.228

N(2000) **, N(2100) *★★ ▻ 2018 edition of PDG

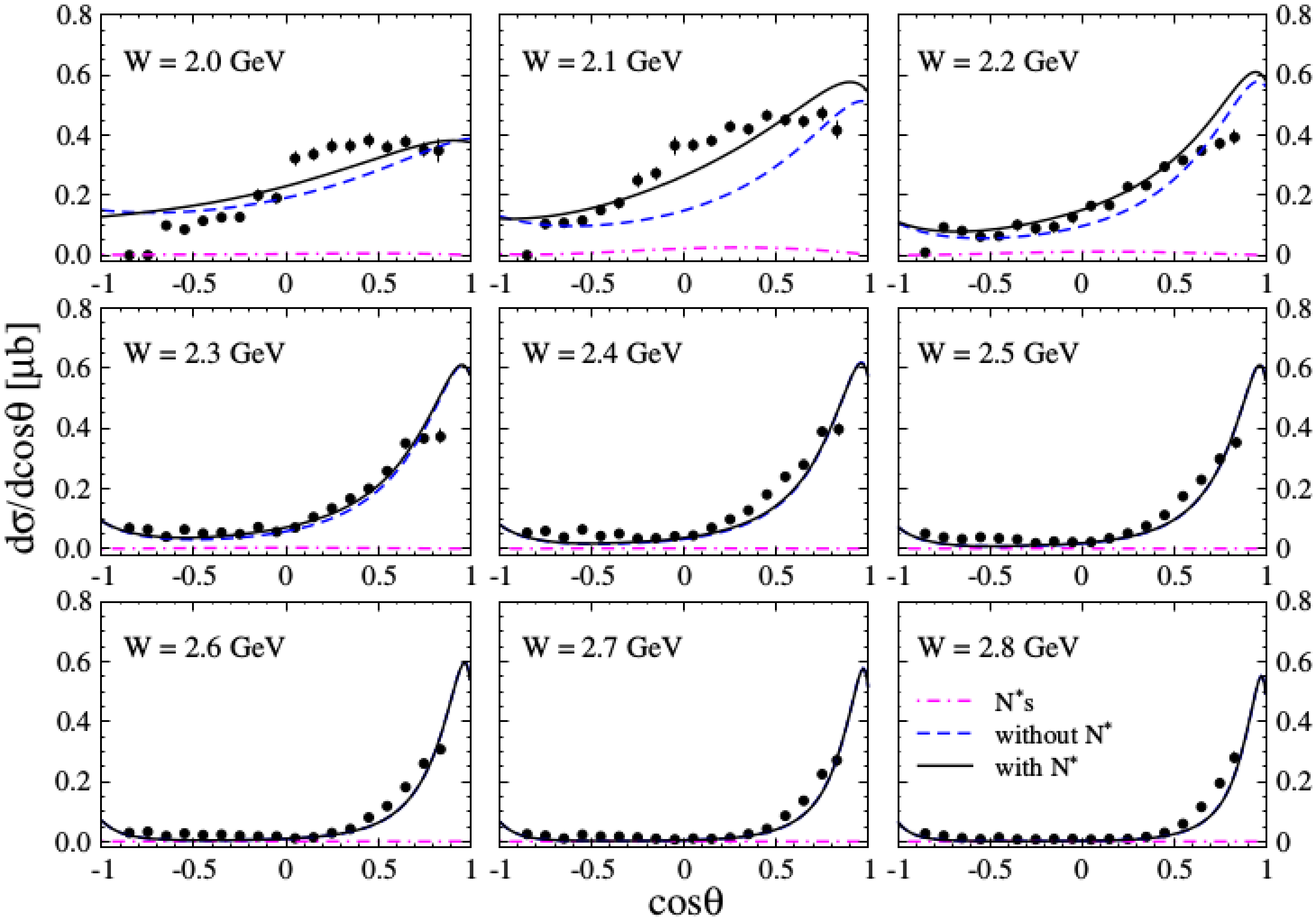
$\gamma\, p \rightarrow K^+ \Lambda(1405)$ Total cross section





- ❑ The data is reproduced mainly by the t-channel K-exchange contribution.
- ❑ PDG resonances are more dominant than missing resonances.
- ❑ Both constant (1) & rotating (exp[-iπα(t)]) phases are acceptable.

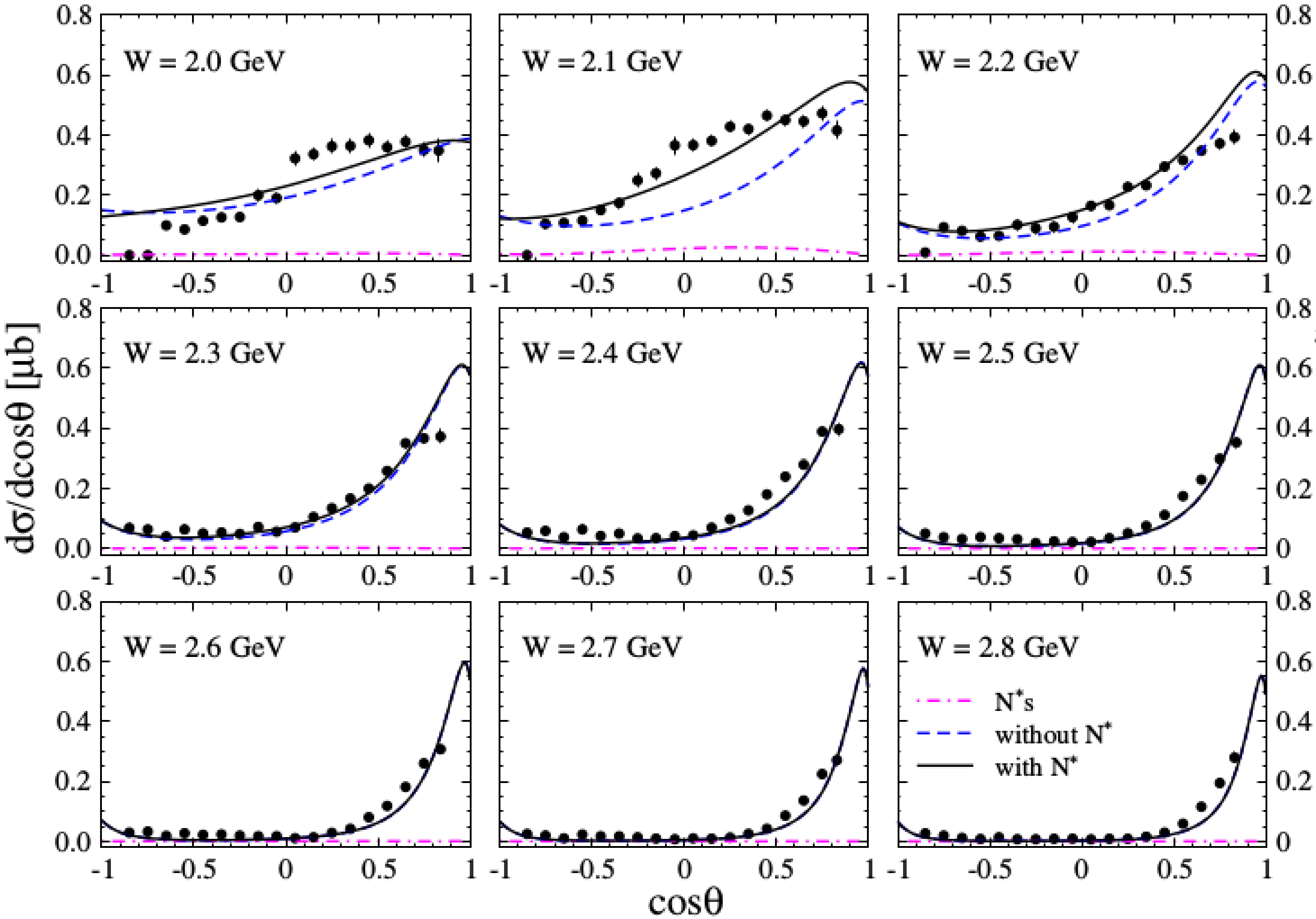
$\gamma p \to K^+ \Lambda(1405)$ Differential cross sections

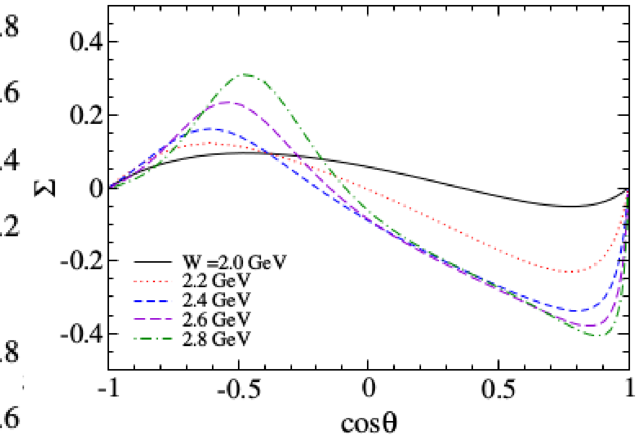


- At threshold, the data are reproduced by N^* & non-N^* contributions constructively.
- The forward-scattering enhancement becomes more obvious as W increases.

Results-1

$\gamma\, p \rightarrow K^+ \Lambda(1405)$ Differential cross sections & Beam asymmetry

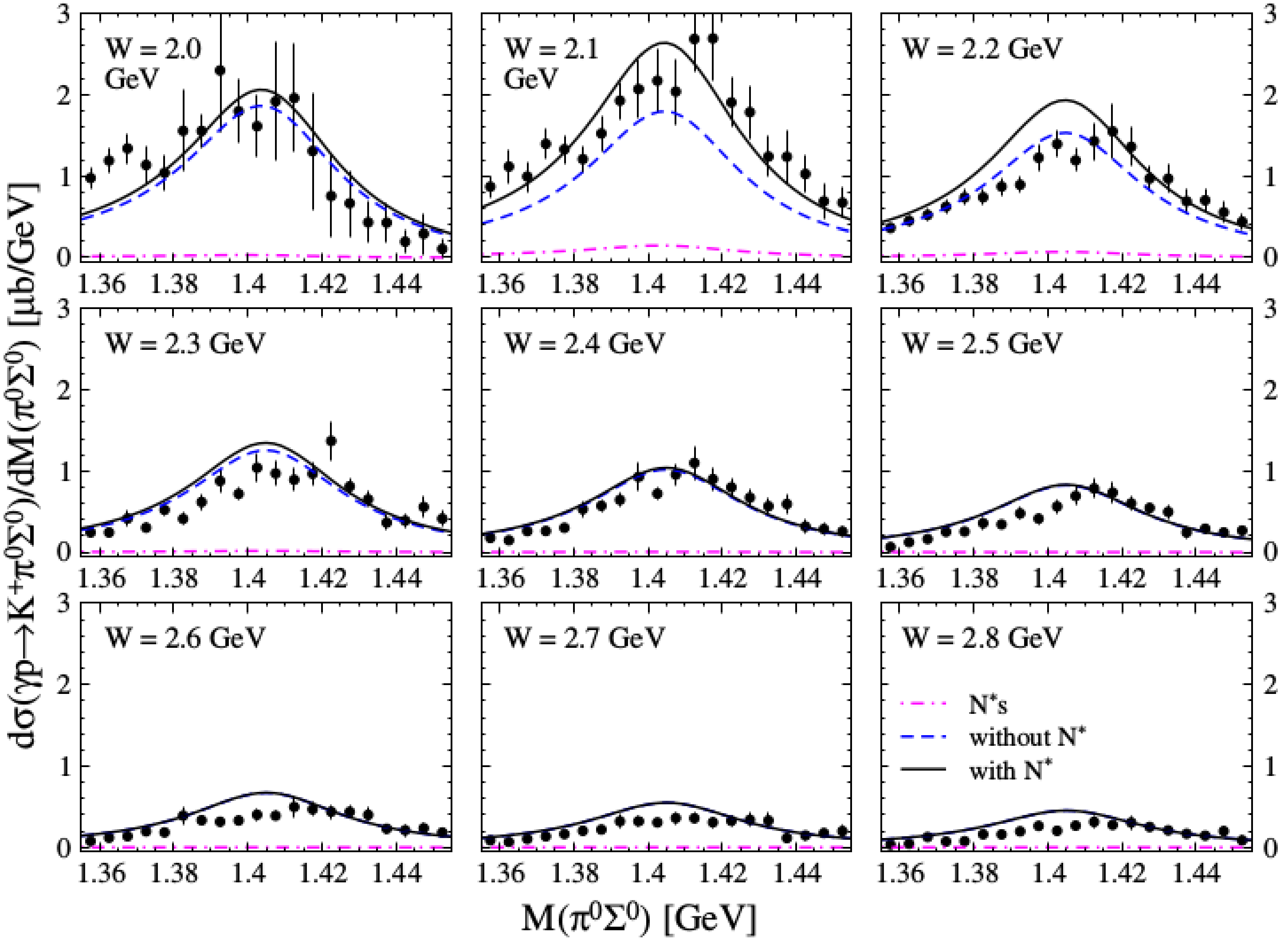




$$\Sigma = \frac{\frac{d\sigma}{d\Omega}_{\perp} - \frac{d\sigma}{d\Omega}_{\parallel}}{\frac{d\sigma}{d\Omega}_{\perp} + \frac{d\sigma}{d\Omega}_{\parallel}}$$

- At threshold, the data are reproduced by N^* & non-N^* contributions constructively.
- The forward-scattering enhancement becomes more obvious as W increases.

$\gamma\, p \rightarrow K^+ \Lambda(1405)$ Invariant mass distributions

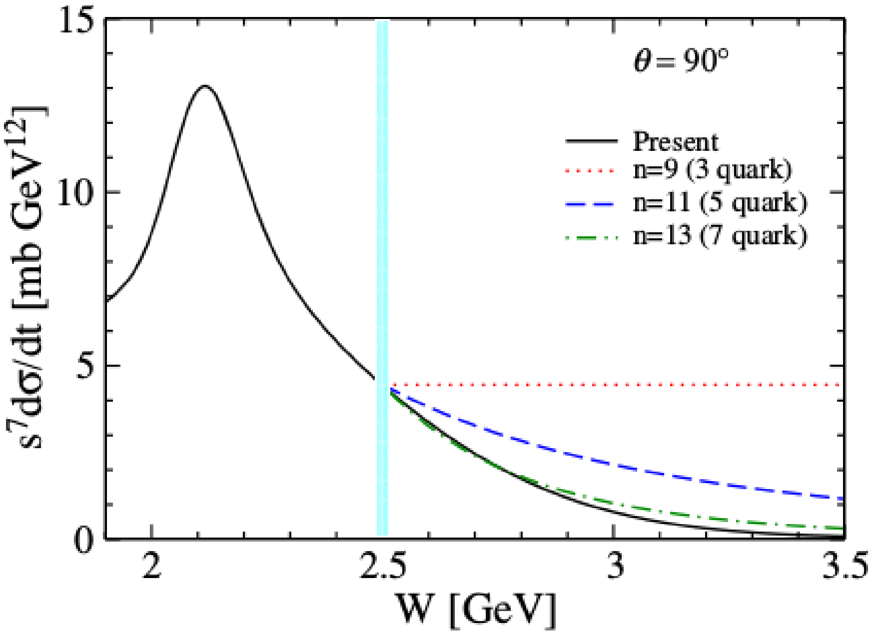


$$\frac{d\sigma_{\gamma p\to K^+\pi^0\Sigma^0}}{dM_{\pi^0\Sigma^0}} \approx \frac{2M_{\Lambda^*}M_{\pi^0\Sigma^0}}{\pi} \times \frac{\sigma_{\gamma p\to K^+\Lambda^*}\Gamma_{\Lambda^*\to\pi^0\Sigma^0}}{(M^2_{\pi^0\Sigma^0}-M^2_{\Lambda^*})^2+M^2_{\Lambda^*}\Gamma^2_{\Lambda^*}}$$

(1) The decay widths for the decaying resonances are sufficiently narrow.
(2) The interference between the different resonances in the Dalitz plot is negligible.

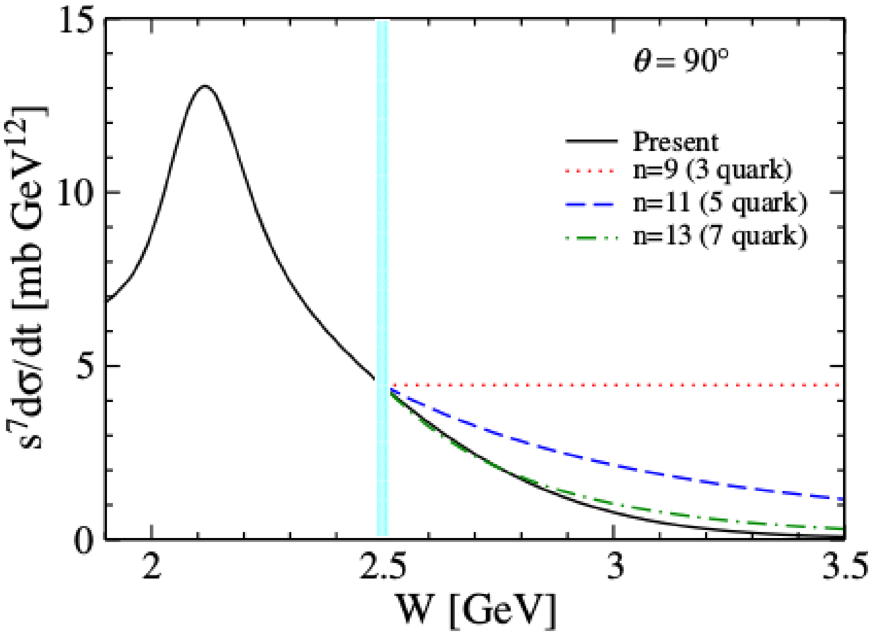
Results-1

$\gamma\, p \rightarrow K^+ \Lambda(1405)$ Constituent counting rule



❑ CCR is a method to analyze the internal structure of the hadrons by dimensional considerations of the reaction amplitude in terms of the quark and gluon propagators at the large angle as well as the high energy.

$\gamma\, p \rightarrow K^+ \Lambda(1405)$ Constituent counting rule



❑ CCR is a method to analyze the internal structure of the hadrons by dimensional considerations of the reaction amplitude in terms of the quark and gluon propagators at the large angle as well as the high energy.

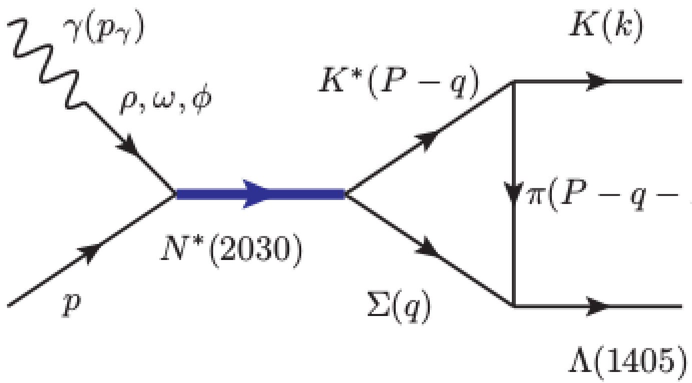
$$\frac{d\sigma_{ab\rightarrow cd}}{dt} \propto \frac{1}{s^{n-2}}$$

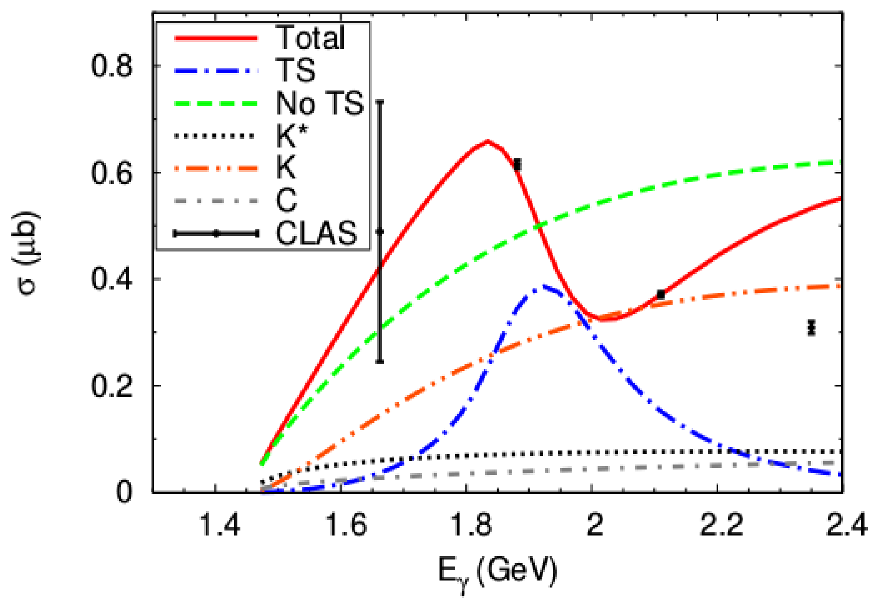
❑ If Λ(1405) is composed of three quarks, $1_\gamma + 3_N + 2_K + 3_{\Lambda^*} = 9$
″ five , $1_\gamma + 3_N + 2_K + 5_{\Lambda^*} = 11$

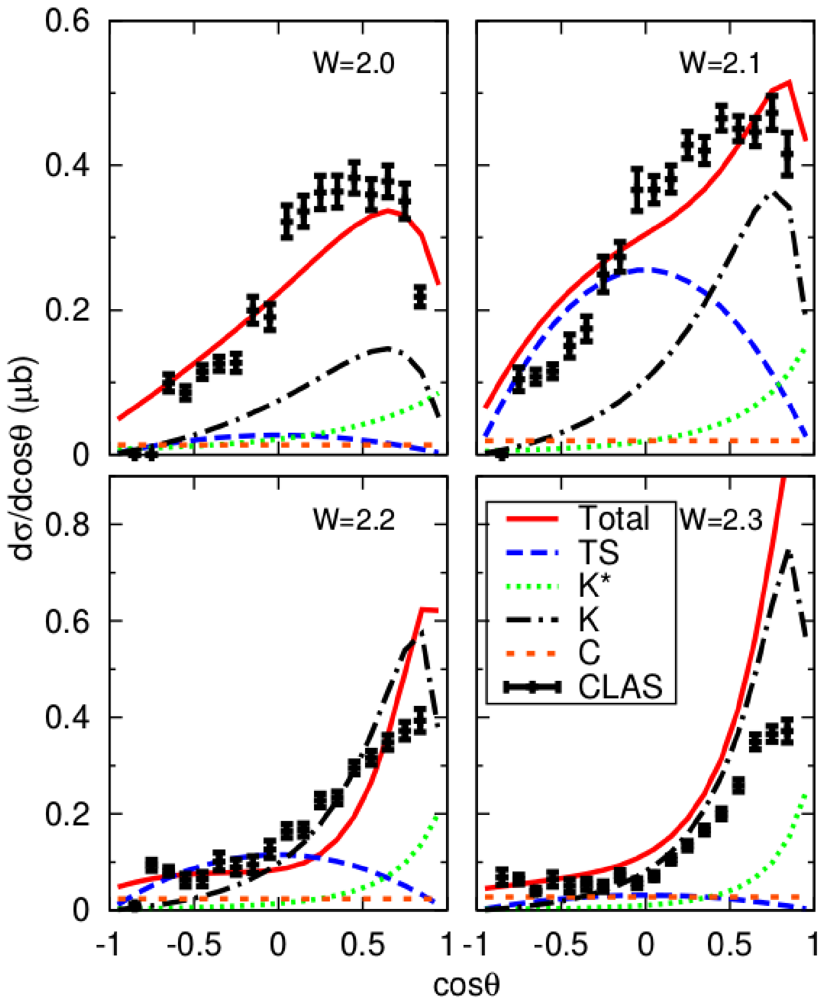
❑ Λ(1405) is, more or less, possibly distinctive from the simple *uds*-quark state.

$\gamma\, p \rightarrow K^+ \Lambda(1405)$ Another interpretation

The role of a triangle singularity in the $\gamma p \rightarrow K^+\Lambda(1405)$ reaction







Wang,PRC.95.015205(2017)

Results-2

$\gamma\, n \rightarrow K^0 \Lambda$

EM ($\gamma n n^*$) interactions

threshold = 1.6 GeV

State	Rating	Width [MeV]	$A_{1/2}$	$A_{3/2}$	h_1	h_2
$N(1650, 1/2^-)$	****	110-170(120)	-50 ± 20	$\cdots$	-0.31	$\cdots$
$N(1675, 5/2^-)$	****	130-165(150)	-60 ± 5	-85 ± 10	4.88	5.45
$N(1680, 5/2^+)$	****	120-140(130)	29 ± 10	-33 ± 9	-7.44	8.57
$N(1700, 3/2^-)$	***	100-250(150)	25 ± 10	-32 ± 18	-1.43	1.64
$N(1710, 1/2^+)$	****	50-250(100)	-40 ± 20	$\cdots$	0.24	$\cdots$
$N(1720, 3/2^+)$	****	150-400(250)	-80 ± 50	-140 ± 65	1.50	1.61
$N(1860, 5/2^+)$	**	300	21 ± 13	34 ± 17	0.28	1.09
$N(1875, 3/2^-)$	***	300	10 ± 6	-20 ± 15	-0.55	0.54
$N(1880, 1/2^+)$	**★	300	-60 ± 50	$\cdots$	0.31	$\cdots$
$N(1895, 1/2^-)$	★**★	300	13 ± 6	$\cdots$	0.067	$\cdots$
$N(1900, 3/2^+)$	***★	300	0 ± 30	-60 ± 45	0.29	-0.56
$N(1990, 7/2^+)$	**	200-400(300)	-45 ± 20	-52 ± 27	6.92	7.54
$N(2000, 5/2^+)$	**	300	-18 ± 12	-35 ± 20	-0.47	-0.56
$N(2060, 5/2^-)$	**★	300	25 ± 11	-37 ± 17	0.027	-2.87
$N(2120, 3/2^-)$	**★	300	110 ± 45	40 ± 30	-1.71	2.41
$N(2190, 7/2^-)$	****	300-700 (500)	-15 ± 13	-34 ± 22	-1.57	-0.62
$N(1685, 1/2^+)$		30			-0.315	

△ 2018 edition of PDG

❑ A_λ is taken from PDG.

Results-2

$\gamma\, n \rightarrow K^0 \Lambda$

Strong interactions

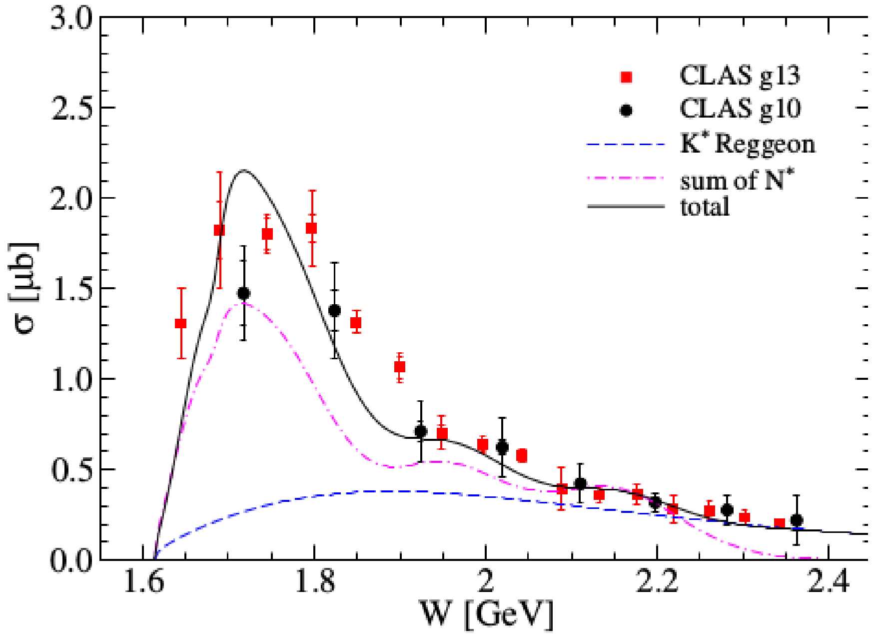
threshold = 1.6 GeV

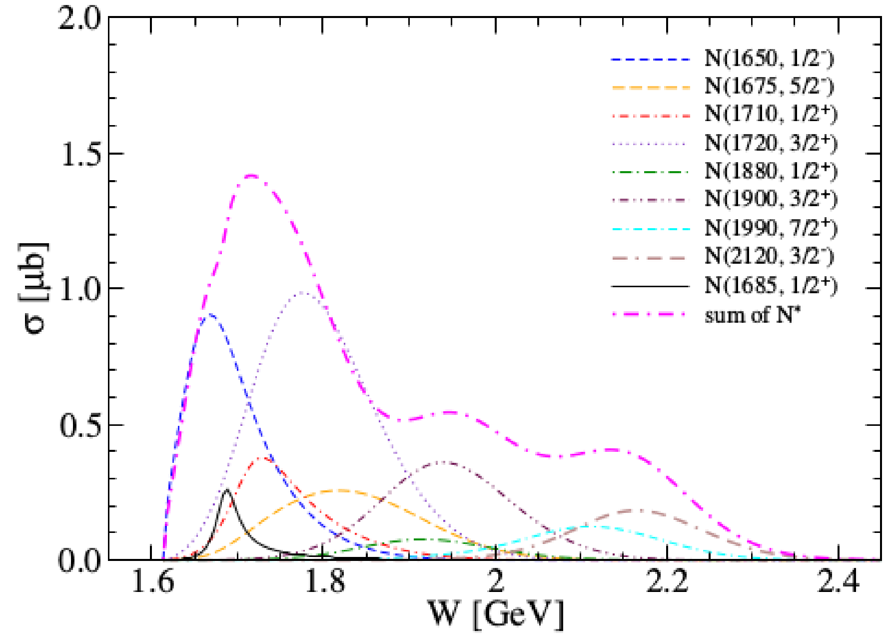
State	$G(\ell)$	$g_{K\Lambda N^*}$	$\Gamma_{N^*\to K\Lambda}/\Gamma_{N^*}$ [%]	$\lvert g_{K\Lambda N^*}\rvert$	$g_{K\Lambda N^*}$ (final)
$N(1650, 1/2^-)$	-3.3 ± 1.0	-0.78	$5-15$	$0.57-0.99$	-0.78
$N(1675, 5/2^-)$	0.4 ± 0.3	1.23			1.23
$N(1680, 5/2^+)$	$\simeq 0.1 \pm 0.1$	-2.84			-2.84
$N(1700, 3/2^-)$	-0.4 ± 0.3	2.34			2.34
$N(1710, 1/2^+)$	4.7 ± 3.7	-7.49	$5-25$	$3.5-7.9$	-3.5
$N(1720, 3/2^+)$	-3.2 ± 1.8	-1.80	$4-5$	$1.8-2.0$	-1.1
$N(1860, 5/2^+)$	-0.5 ± 0.3	1.40			1.40
$N(1875, 3/2^-)$	$\simeq 1.7 \pm 1.0$	-2.47			-2.47
$N(1880, 1/2^+)$			$1-3$	$1.3-2.3$	1.6
$N(1895, 1/2^-)$	2.3 ± 2.7	0.34	$13-23$	$0.92-1.2$	0.34
$N(1900, 3/2^+)$			$2-20$	$0.64-2.0$	1.2
$N(1990, 7/2^+)$	$\simeq 1.5 \pm 2.4$	0.61			0.61
$N(2000, 5/2^+)$	-0.5 ± 0.3	0.61			0.61
$N(2060, 5/2^-)$	$\simeq -2.2 \pm 1.0$	-0.52			-0.52
$N(2120, 3/2^-)$	$\simeq 1.7 \pm 1.0$	-1.05			-1.05
$N(2190, 7/2^-)$	$\simeq -1.1$	0.67	$0.2-0.4$	$0.60-0.85$	0.67
$N(1685, 1/2^+)$					-0.9

- ❑ $G(\ell)$ is taken from quark model predictions [Capstick,PRD.58.074011(1998)].
- ❑ $Br(N^* \rightarrow K\Lambda)$ is taken from PDG.

$\gamma\, n \rightarrow K^0 \Lambda$ Total cross section

CLAS
[PRC.96.065201(2017)]

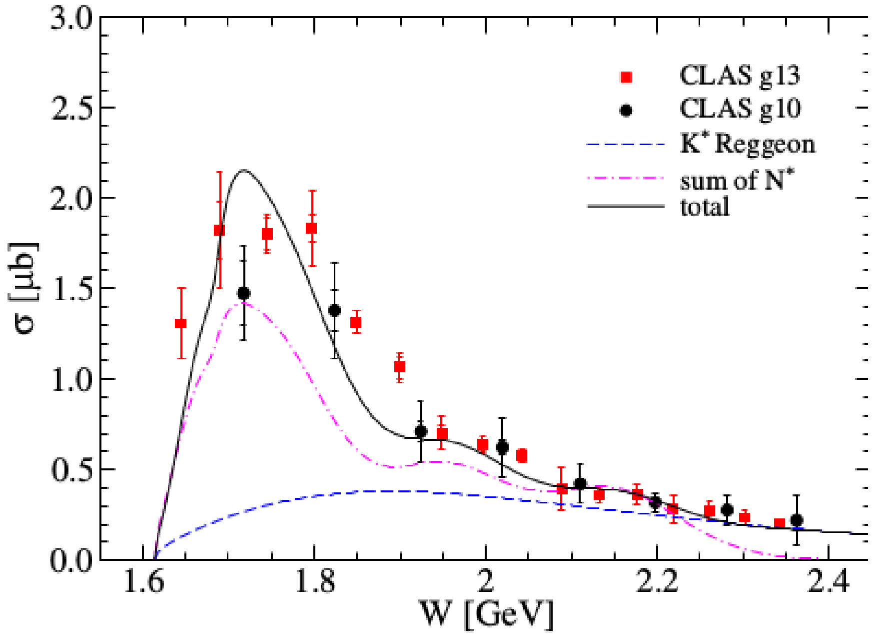


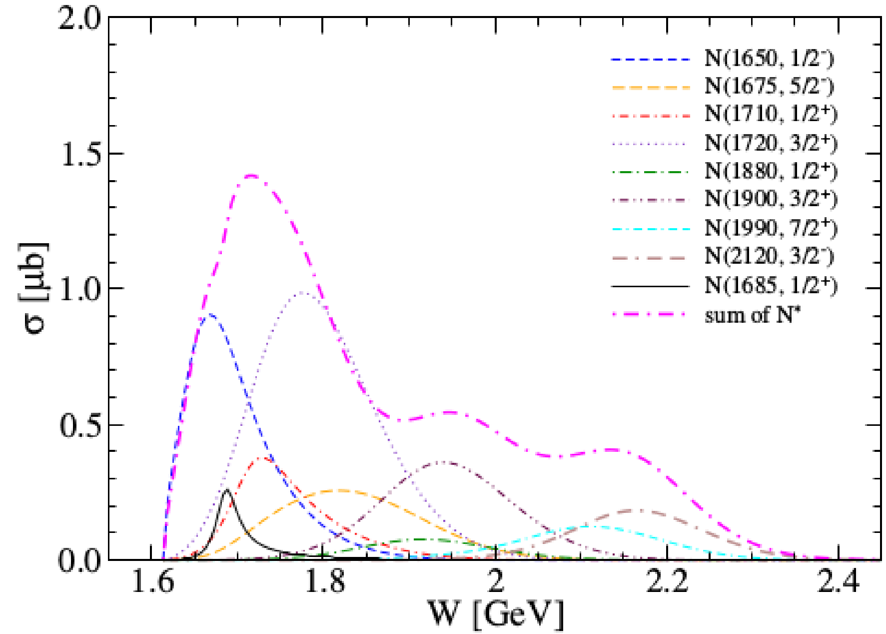


- ❑ Only rotating phase is acceptable.
- ❑ Main contribution comes from $1/2^+$, $1/2^-$, $3/2^+$ N^* resonances.

$\gamma\, n \to K^0 \Lambda$ Total cross section

CLAS
[PRC.96.065201(2017)]





- ❑ Only rotating phase is acceptable.
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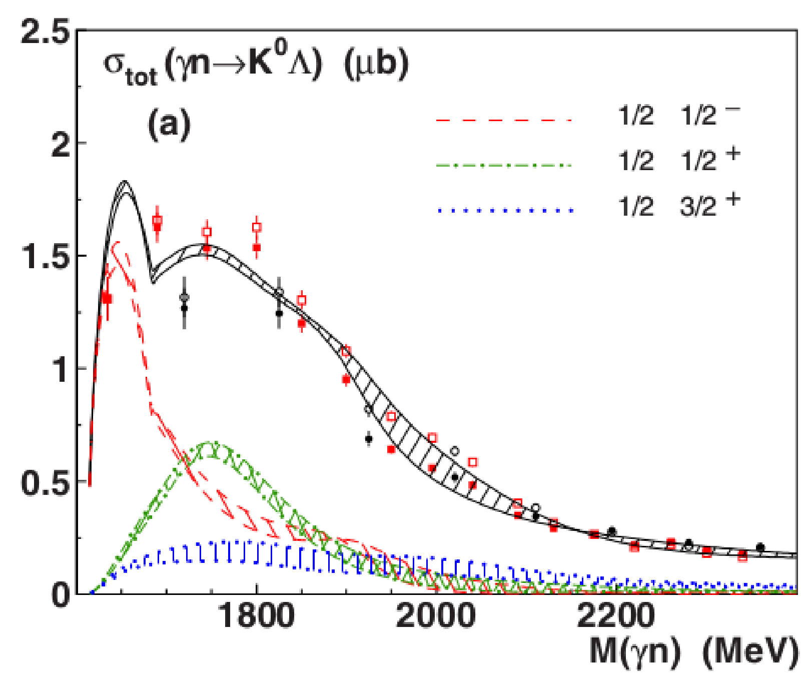
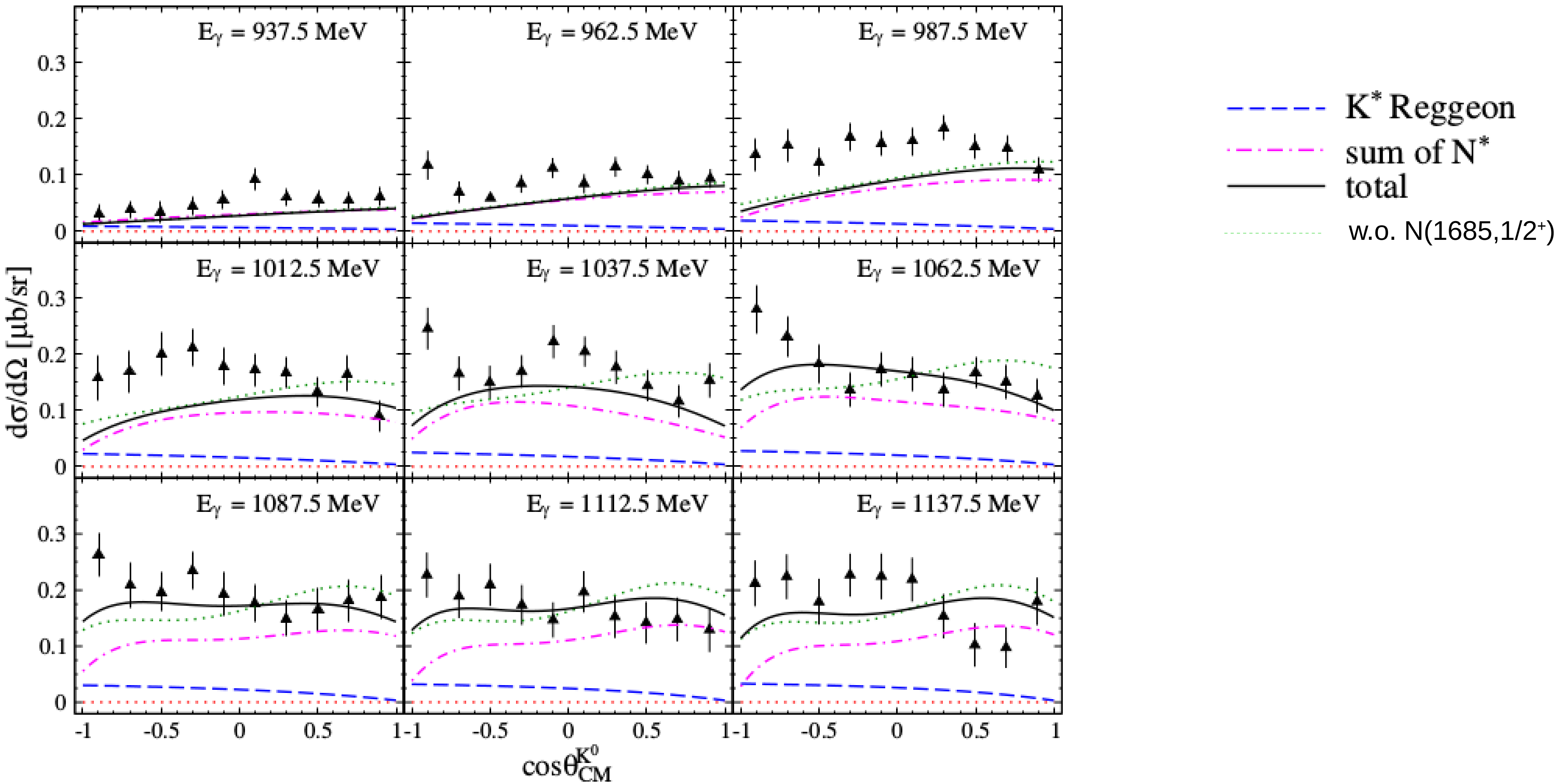
Bonn-Gachina,
PRC.96.055202 (2017)



$\gamma\, n \rightarrow K^0 \Lambda$ Differential cross sections (vs cosθ)

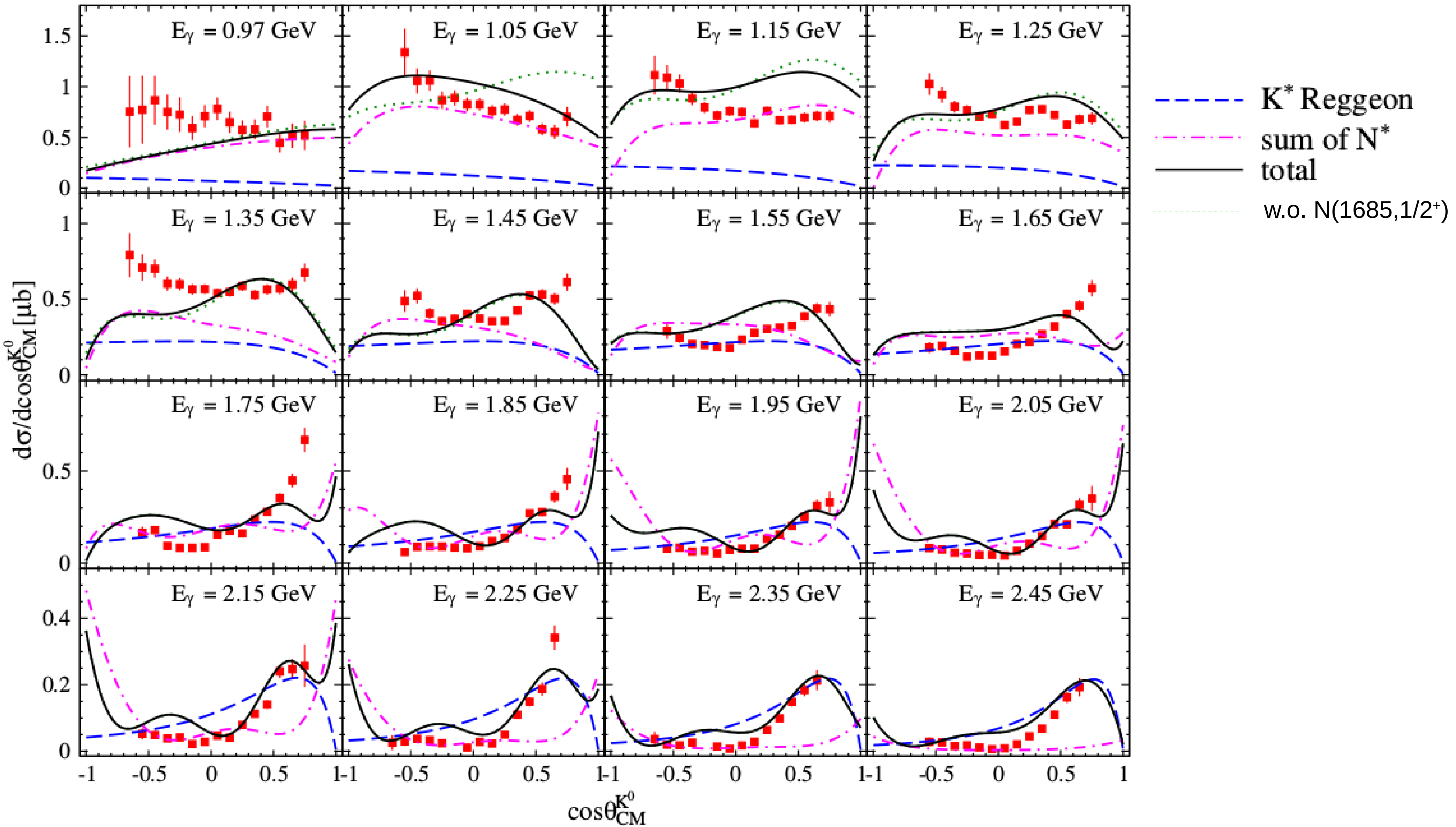
FOREST
[JPSConf.Proc.17.062007(2017)]



❑ N(1685,1/2⁺) has a certain contribution to the differential cross sections at threshold but not to the total cross section.

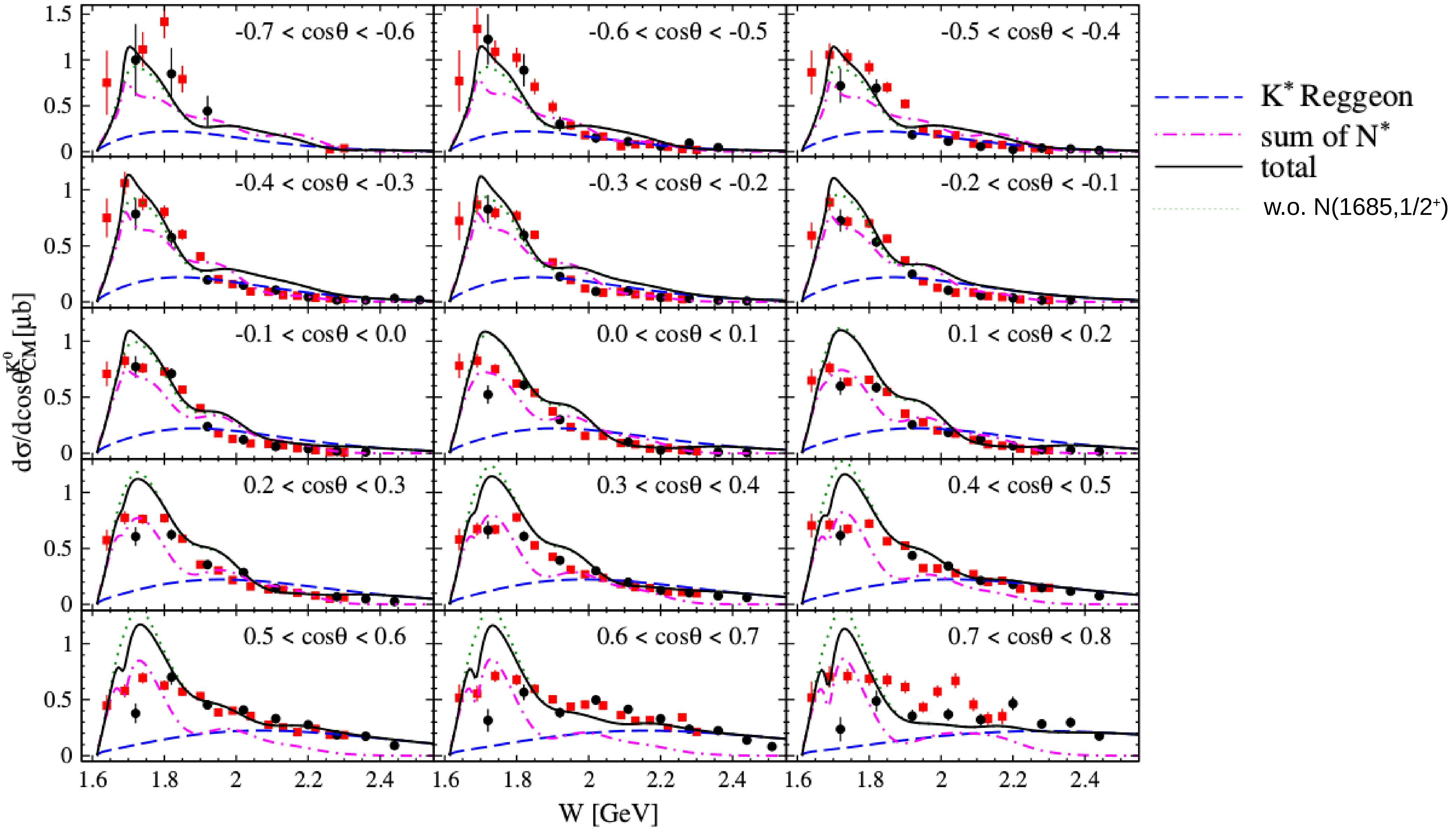
$\gamma\, n \rightarrow K^0 \Lambda$ Differential cross sections (vs cosθ)

CLAS
[PRC.96.065201(2017)]



$\gamma\, n \rightarrow K^0 \Lambda$ Differential cross sections (vs W)

CLAS
[PRC.96.065201(2017)]



Summary

◇ The $\gamma p \rightarrow K^+\Lambda(1405)$ & $\gamma n \rightarrow K^0\Lambda$ are studied using an effective Lagrangian approach combining with a Regge model.

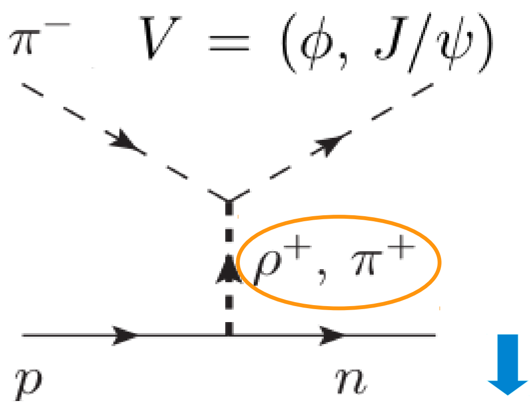
◇ K- and K^*-Reggeon exchanges are dominant background contributions, respectively.

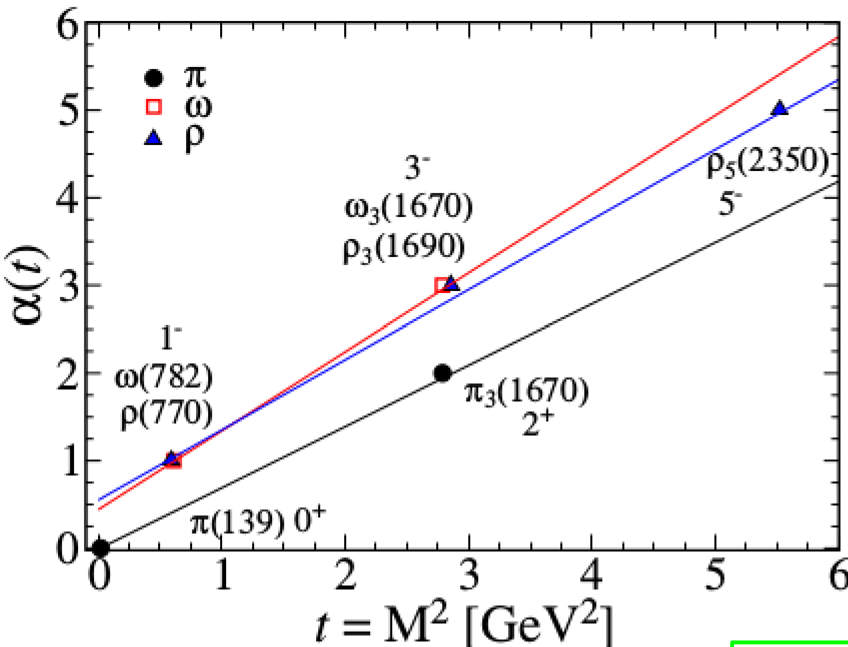
◇ PDG resonances "$N(2000,5/2^+)$, $N(2100,1/2^-)$" and "$N(1650,1/2^-)$, $N(1710,1/2^+)$, $N(1720,3/2^+)$, $N(1900,3/2^+)$" are crucial to reproduce the FOREST & CLAS data, respectively, near threshold.

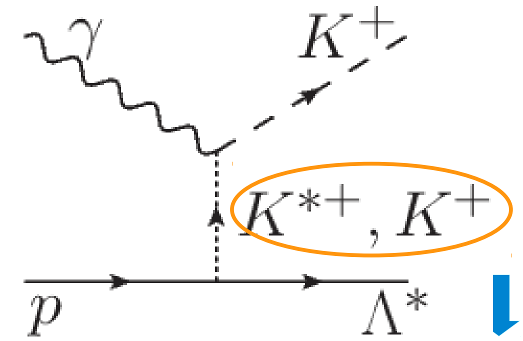
Future work:

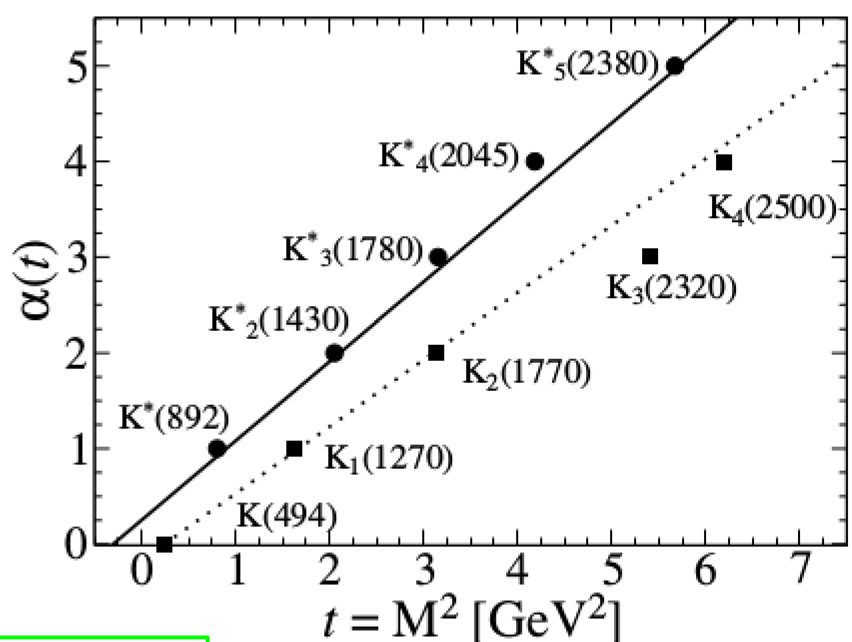
◇ Polarization observables will be also calculated.
◇ Vector meson (ρ,ω,φ) photoproduction off the nucleon and nuclei(^{4}He,…)

Back Up









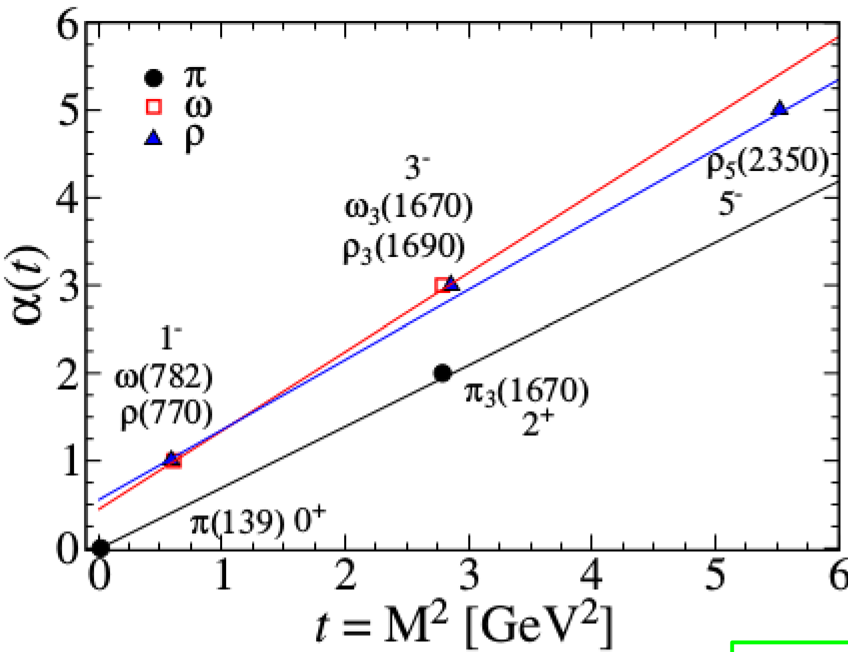
$$\alpha(M^2) = J$$

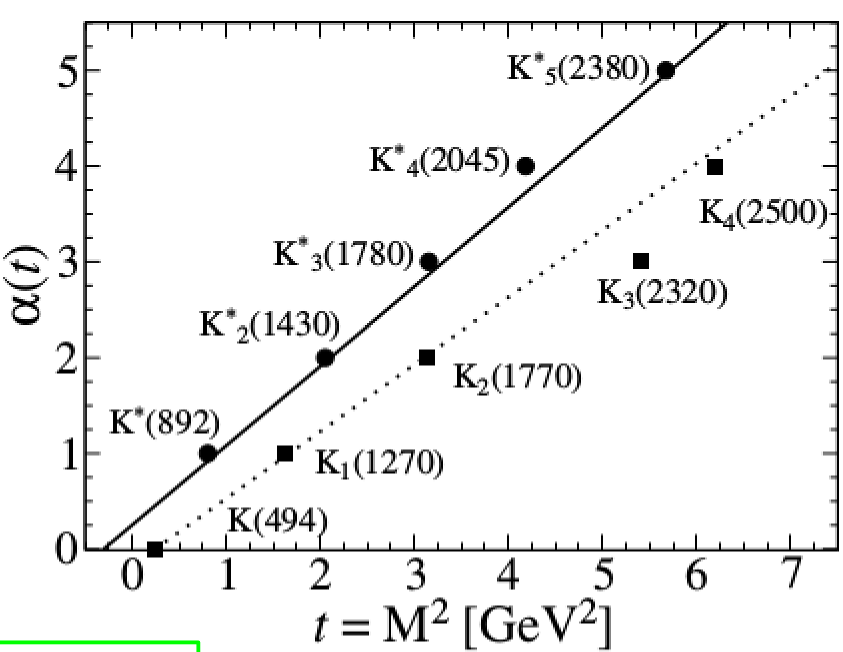
Chew–Frautschi plots

$$\alpha_\pi(t) = 0.7(t - M_\pi^2),$$
$$\alpha_\rho(t) = 0.55 + 0.8t,$$
$$\alpha_\omega(t) = 0.44 + 0.9t.$$

$$\alpha_K(t) = 0.7(t - M_K^2)$$
$$\alpha_{K^*}(t) = 0.25 + 0.83t.$$

α(t) categorizes hadrons with the same internal quantum numbers, M and J are the mass and the spin of related hadrons.





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Chew–Frautschi plots

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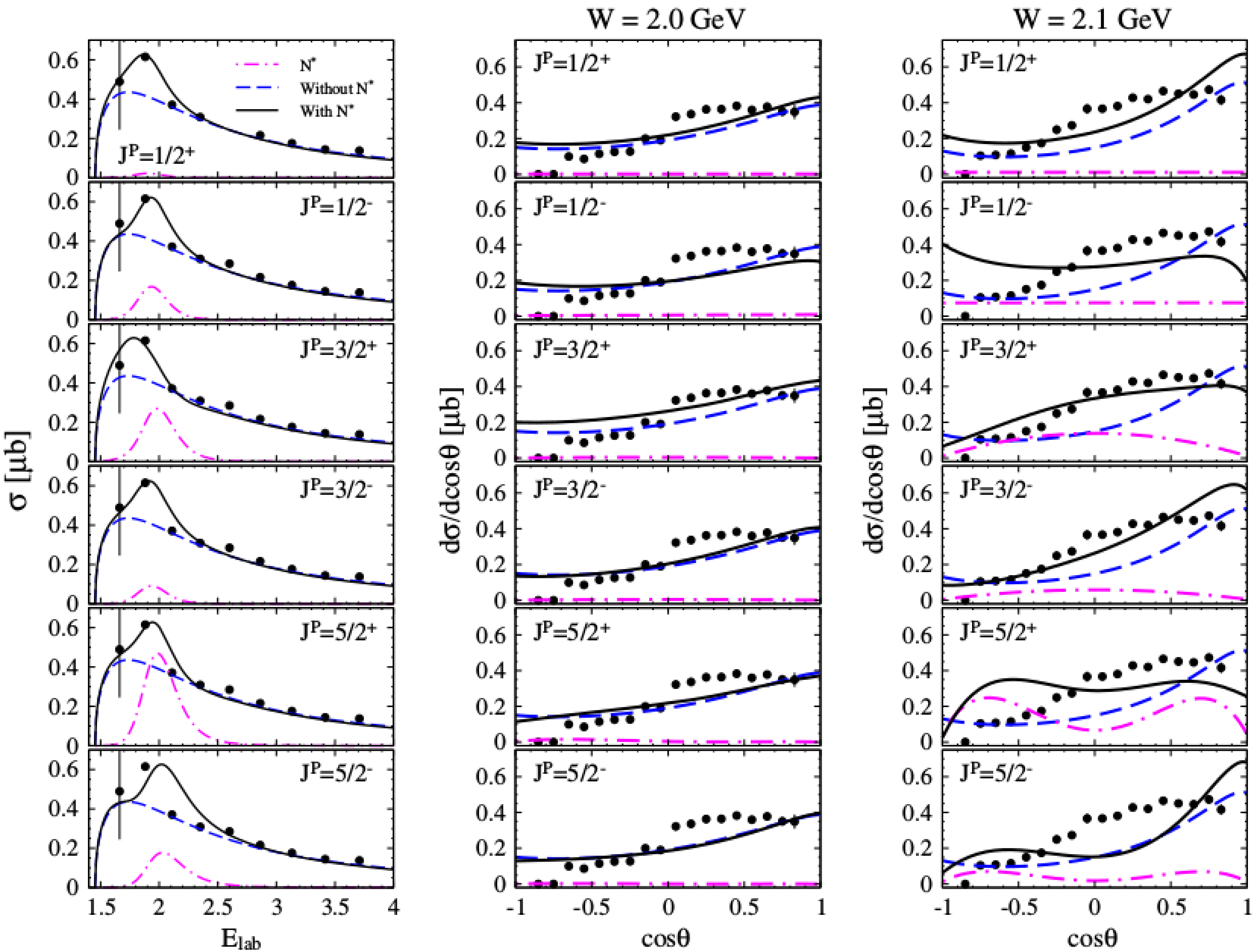

W = 2.0 GeV
W = 2.1 GeV
N*
Without N*
With N*
J^P=1/2+
J^P=1/2-
J^P=3/2+
J^P=3/2-
J^P=5/2+
J^P=5/2-
σ [μb]
dσ/dcosθ [μb]
E_lab
cosθ