$K\Lambda(1405)$ photoproduction with an effective Lagrangian approach

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Contents

$$\boxed{\gamma p \to K^+ \Lambda^*(1405)}$$

- ◈ Introduction
- ◈ Theoretical Framework
- ◈ Results : · total & differential cross sections(σ & $d\sigma/d\Omega$)
  - · invariant mass distribution ($d\sigma/dM$)
  - · beam asymmetry (Σ_γ)
- ◈ Summary

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

$\Lambda(1405)$ $1/2^-$

$I(J^P) = 0(\frac{1}{2}^-)$

Mass $m = 1405.1^{+1.3}_{-1.0}$ MeV
Full width $\Gamma = 50.5 \pm 2.0$ MeV
Below $\overline{K}N$ threshold

$\Lambda(1405)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$\Sigma\pi$	100 %	155

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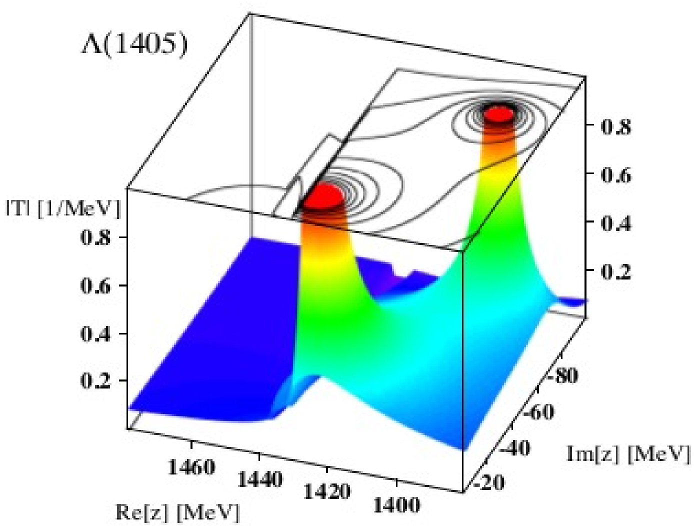

Jido et al, Nucl Phys A725, 181 (2003)
Hyodo et al, Prog Part Nucl Phys. 67, 55 (2012)

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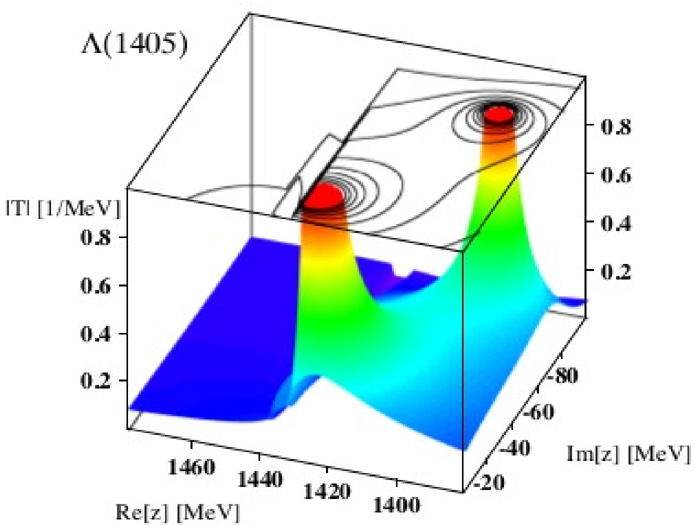

1. two body process

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

2. three body process

$$\gamma p \to K^+ \pi \Sigma$$

Jido et al, Nucl Phys A725, 181 (2003)
Hyodo et al, Prog Part Nucl Phys. 67, 55 (2012)

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

PHYSICAL REVIEW C **88**, 045201 (2013)

Differential photoproduction cross sections of the $\Sigma^0(1385)$, $\Lambda(1405)$, and $\Lambda(1520)$

PHYSICAL REVIEW C **87**, 035206 (2013)

Measurement of the $\Sigma\pi$ photoproduction line shapes near the $\Lambda(1405)$

➡ K. Moriya,[1,*] R. A. Schumacher,[1,†] (CLAS Collaboration)

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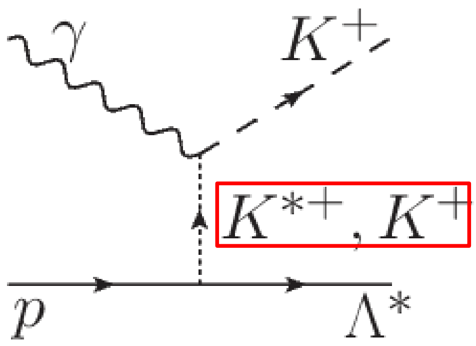
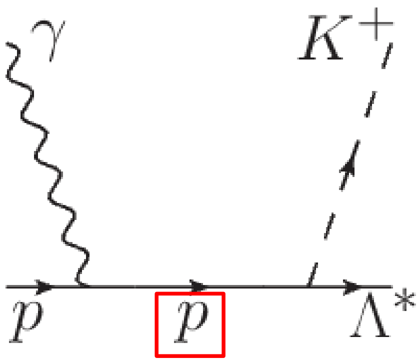
$\Lambda(1405)$ photoproduction is less investigated theoretically than other reaction processes.

We analyze this process employing an effective Lagrangian approach combining with a Regge model.

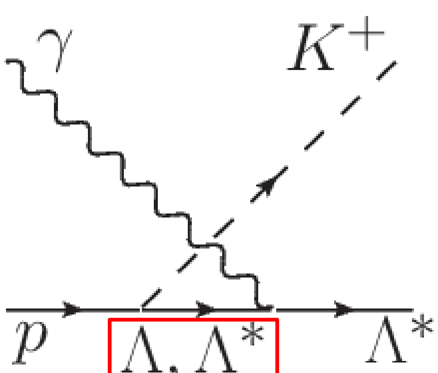
$\gamma p \to K^+ \Lambda^*(1405)$



t channel



s channel



u channel

Effective Lagrangians

Electromagnetic interactions

$$\begin{aligned}
\mathcal{L}_{\gamma KK} =& -ie[K^\dagger(\partial_\mu K) - (\partial_\mu K^\dagger)K]A^\mu,\\
\mathcal{L}_{\gamma KK^*} =& g_{\gamma KK^*}\varepsilon^{\mu\nu\alpha\beta}\partial_\mu A_\nu[(\partial_\alpha K^{*-}_\beta)K^+ + K^-(\partial_\alpha K^{*+}_\beta)],\\
\mathcal{L}_{\gamma NN} =& -\bar{N}\left[e_N\gamma_\mu - \frac{e\kappa_N}{2M_N}\sigma_{\mu\nu}\partial^\nu\right]A^\mu N,\\
\mathcal{L}_{\gamma\Lambda\Lambda^*} =& \frac{e\mu_{\Lambda^*\to\Lambda}}{2M_N}(\bar{\Lambda}\gamma_5\sigma_{\mu\nu}\partial^\nu A^\mu\Lambda^* - \bar{\Lambda}^*\gamma_5\sigma_{\mu\nu}\partial^\nu A^\mu\Lambda),\\
\mathcal{L}_{\gamma\Lambda^*\Lambda^*} =& \frac{e\mu_{\Lambda^*}}{2M_N}\bar{\Lambda}^*\sigma_{\mu\nu}\partial^\nu A^\mu\Lambda^* = \frac{-e\mu_{\Lambda^*}}{4M_M}\bar{\Lambda}^*\sigma_{\mu\nu}F^{\mu\nu}\Lambda^*,\\
\mathcal{L}_{\gamma\Lambda^*\Lambda^*(1670)} =& \frac{e\mu_{\Lambda^*(1670)\to\Lambda^*}}{2M_N}\bar{\Lambda}^*\sigma_{\mu\nu}\partial^\nu A^\mu\Lambda^* + \text{H.c.},
\end{aligned}$$

Strong interactions

$$\begin{aligned}
\mathcal{L}_{KN\Lambda} =& -ig_{KN\Lambda}\bar{N}\gamma_5\Lambda K + \text{H.c.},\\
\mathcal{L}_{KN\Lambda^*} =& ig_{KN\Lambda^*}\bar{K}\bar{\Lambda}^* N - ig_{KN\Lambda^*}\bar{N}\Lambda^* K,\\
\mathcal{L}_{K^*N\Lambda^*} =& g_{K^*N\Lambda^*}\bar{K}^*_\mu\bar{\Lambda}^*\gamma^\mu\gamma_5 N + g_{K^*N\Lambda^*}\bar{N}\gamma^\mu\gamma_5\Lambda^* K^*_\mu,
\end{aligned}$$

Coupling Constants

	$g_{KN\Lambda^*}$	$g_{K^*N\Lambda^*}$	$g_{KN\Lambda(1670)}$	$\mu_{\Lambda^*\to\Lambda}$	μ_{Λ^*}	$\lvert\mu_{\Lambda(1670)\to\Lambda^*}\rvert$
Ref. [2]	1.8(E),1.9(R)	-1.3	-0.61			
Ref. [3]					$0.2 - 0.5$	0.023 ± 0.009
Ref. [4]	$1.5 - 3.0$			-0.112 − -0.224(-0.224)	0.44	

[2] K. P. Khemchandani, A. Martinez Torres, H. Kaneko, H. Nagahiro, and A. Hosaka, Phys. Rev. D **84**, 094018 (2011).
[3] D. Jido, A. Hosaka, J. C. Nacher, E. Oset, and A. Ramos, Phys. Rev. C **66**, 025203 (2002).
[4] R. A. Williams, C. R. Ji, and S. R. Cotanch, Phys. Rev. C **43**, 452 (1991).

[2] Chiral & Hidden local symmetries
[3] Unitarized Chiral Perturbation model
[4] Incorporating Crossing and Duality, Use old exp. data

Invariant Amplitudes & Form Factors

$$\mathcal{M}^\mu_K = e g_{KN\Lambda^*} \frac{-2i}{t - M_K^2} k_2^\mu,$$

$$\mathcal{M}^\mu_N = e g_{KN\Lambda^*} \frac{-i}{s - M_N^2} (\not{q}_s + M_N) \left[\gamma^\mu + \frac{i\kappa_p}{2M_N} \sigma^{\mu\nu} k_{1\nu} \right],$$

$$\mathcal{M}^\mu_{K^*} = g_{\gamma K K^*} g_{K^* N \Lambda^*} \frac{-1}{t - M_{K^*}^2} \epsilon^{\mu\nu\alpha\beta} \gamma_\nu \gamma_5 k_{1\alpha} k_{2\beta},$$

$$\mathcal{M}^\mu_\Lambda = g_{KN\Lambda} \frac{e\mu_{\Lambda^*(1405)\to\Lambda}}{2M_N} \frac{-1}{u - M_\Lambda^2} \sigma^{\mu\nu} k_{1\nu} (-\not{q}_u + M_\Lambda),$$

$$\mathcal{M}^\mu_{\Lambda^*} = g_{KN\Lambda^*} \frac{e\mu_{\Lambda^*}}{2M_N} \frac{1}{u - M_{\Lambda^*}^2} \sigma^{\mu\nu} k_{1\nu} (\not{q}_u + M_{\Lambda^*}),$$

$$\mathcal{M}^\mu_{\Lambda^*(1670)} = g_{KN\Lambda^*(1670)} \frac{e\mu_{\Lambda^*(1670)\to\Lambda^*}}{2M_N} \frac{1}{u - M_{\Lambda^*(1670)}^2} \sigma^{\mu\nu} k_{1\nu} (\not{q}_u + M_{\Lambda^*(1670)}),$$

$$\boxed{\begin{aligned} \mathcal{M}_{\text{total}}(\gamma p \to K^+ \Lambda^*) = {} & (\mathcal{M}_K + \mathcal{M}_N) \cdot (t - M_K^2) \cdot P_K^{\text{Mod}}(s,t) \cdot F_c^n \\ & + \mathcal{M}_{K^*} \cdot (t - M_{K^*}^2) \cdot P_{K^*}^{\text{Mod}}(s,t) \cdot F_{K^*}^n(t) + \mathcal{M}_\Lambda \cdot F_\Lambda^n(u) \\ & + \mathcal{M}_{\Lambda^*(1405)} \cdot F^n_{\Lambda^*(1405)}(u) + \mathcal{M}_{\Lambda^*(1670)} \cdot F^n_{\Lambda^*(1670)}(u), \end{aligned}}$$

Gauge invariance prescription

Invariant Amplitudes & Form Factors

$$\mathcal{M}_K^\mu = e g_{KN\Lambda^*}\frac{-2i}{t-M_K^2}k_2^\mu,$$

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$$\mathcal{M}_{K^*}^\mu = g_{\gamma KK^*}g_{K^*N\Lambda^*}\frac{-1}{t-M_{K^*}^2}\epsilon^{\mu\nu\alpha\beta}\gamma_\nu\gamma_5 k_{1\alpha}k_{2\beta},$$

$$\mathcal{M}_\Lambda^\mu = g_{KN\Lambda}\frac{e\mu_{\Lambda^*(1405)\to\Lambda}}{2M_N}\frac{-1}{u-M_\Lambda^2}\sigma^{\mu\nu}k_{1\nu}(-\not{q}_u + M_\Lambda),$$

$$\mathcal{M}_{\Lambda^*}^\mu = g_{KN\Lambda^*}\frac{e\mu_{\Lambda^*}}{2M_N}\frac{1}{u-M_{\Lambda^*}^2}\sigma^{\mu\nu}k_{1\nu}(\not{q}_u + M_{\Lambda^*}),$$

$$\mathcal{M}_{\Lambda^*(1670)}^\mu = g_{KN\Lambda^*(1670)}\frac{e\mu_{\Lambda^*(1670)\to\Lambda^*}}{2M_N}\frac{1}{u-M_{\Lambda^*(1670)}^2}\sigma^{\mu\nu}k_{1\nu}(\not{q}_u + M_{\Lambda^*(1670)}),$$

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Gauge invariance prescription

w/o red box: Effective Lagrangian
w red box: Regge model

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

A well-known nonperturbative approach to hadron reactions

1. Most reactions have a tendency to produce a forward peak.
2. At high energies, t-channel exchange is crucial.

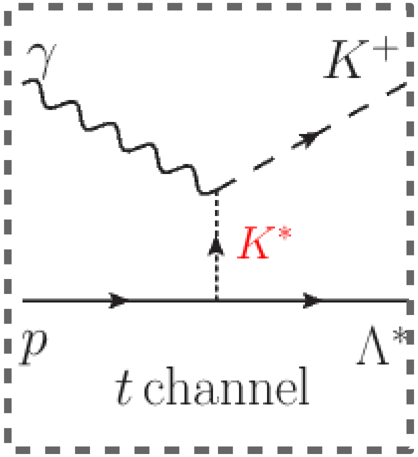
=> A Regge method works.

A single particle exchange in the t-channel of spin J behaves as

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

which violates unitarity for large J.

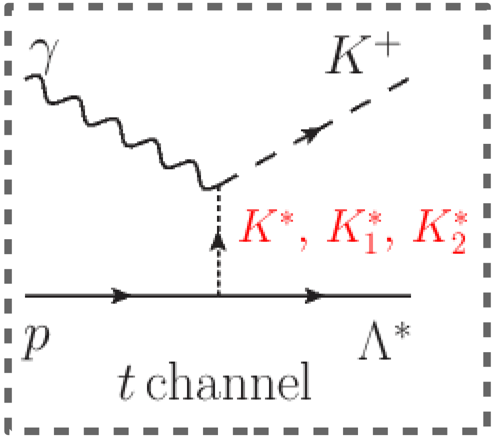
Froissart bound : $\sigma^{\mathrm{Tot}}(s) \leq \text{constant} \times \log^2(s/s_0)$



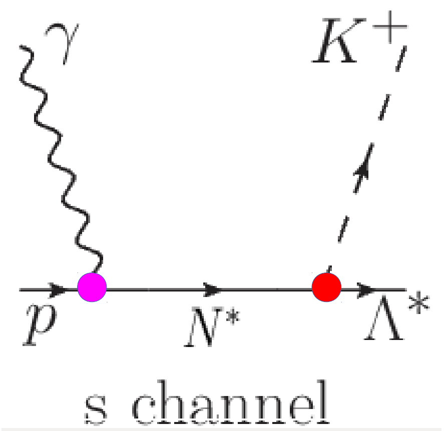
We need to sum up all meson exchanges of various J.

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

α(t) is called a Regge trajectory. α(t) = α(0) + α't



Resonant term $\gamma p \to K^+ \Lambda^*(1405)$



Nucleon Resonances in PDG

3 N*

Missing Resonances

3 N*, predicted from
constituent quark model
Capstick et al, PRD 58, 074011 (1998)

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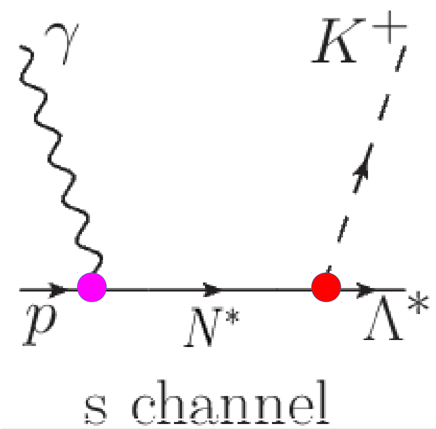

Nucleon Resonances in PDG

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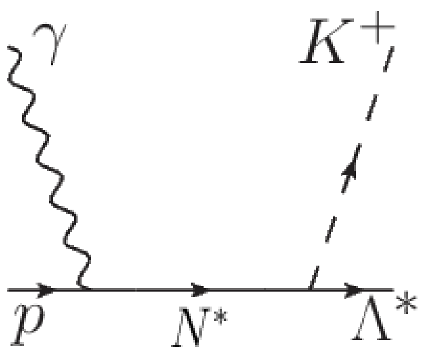
$N(1440)\ 1/2^+$	****
$N(1520)\ 3/2^-$	****
$N(1535)\ 1/2^-$	****
$N(1650)\ 1/2^-$	****
$N(1675)\ 5/2^-$	****
$N(1680)\ 5/2^+$	****
$N(1685)\ ?^?$	*
$N(1700)\ 3/2^-$	***
$N(1710)\ 1/2^+$	***
$N(1720)\ 3/2^+$	****
$N(1860)\ 5/2^+$	**
$N(1875)\ 3/2^-$	***
$N(1880)\ 1/2^+$	**
$N(1895)\ 1/2^-$	**
$N(1900)\ 3/2^+$	***
$N(1990)\ 7/2^+$	**
$N(2000)\ 5/2^+$	**
$N(2040)\ 3/2^+$	*
$N(2060)\ 5/2^-$	**
$N(2100)\ 1/2^+$	*
$N(2120)\ 3/2^-$	**
$N(2190)\ 7/2^-$	****
$N(2220)\ 9/2^+$	****
$N(2250)\ 9/2^-$	****
$N(2300)\ 1/2^+$	**
$N(2570)\ 5/2^-$	**
$N(2600)\ 11/2^-$	***
$N(2700)\ 13/2^+$	**

threshold = 1.9 GeV

Effective Lagrangians



s channel

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

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

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

$$\mathcal{L}_{K\Lambda^*N^*}\left(\frac{1}{2}^{\pm}\right) = -ig_{K\Lambda^*N^*}\bar{K}\bar{\Lambda}^*\Gamma^{(\mp)}N^* + \text{H.c.}$$

$$\mathcal{L}_{K\Lambda^*N^*}\left(\frac{3}{2}^{\pm}\right) = \frac{g_{K\Lambda^*N^*}}{M_K}\partial^\alpha\bar{K}\bar{\Lambda}^*\Gamma^{(\pm)}N_\alpha^* + \text{H.c.},$$

$$\mathcal{L}_{K\Lambda^*N^*}\left(\frac{5}{2}^{\pm}\right) = \frac{ig_{K\Lambda^*N^*}}{M_K^2}\partial^\alpha\partial^\beta\bar{K}\bar{\Lambda}^*\Gamma^{(\mp)}N_{\alpha\beta}^* + \text{H.c.},$$

Invariant Amplitudes

$$\mathcal{M}_{N^*}\left(\frac{1}{2}^{\pm}\right) = g_{K\Lambda^* N^*}\frac{eh_1}{2M_N}\frac{1}{s-M_{N^*}^2}\Gamma^{(\mp)}(\not{q}_s + M_{N^*})\Gamma^{(\mp)}\sigma^{\mu\nu}k_{1\nu}\epsilon_\mu,$$

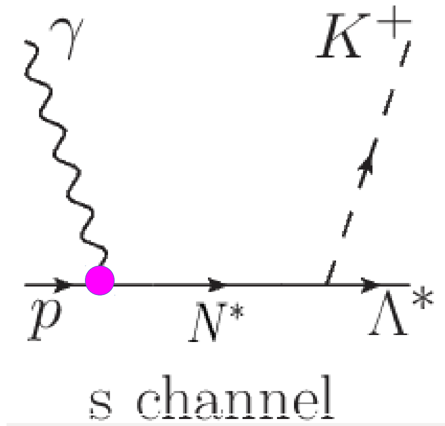
$$\mathcal{M}_{N^*}\left(\frac{3}{2}^{\pm}\right) = i\frac{g_{K\Lambda^* N^*}}{M_K}\frac{1}{s-M_{N^*}^2}\Gamma^{(\pm)}(\not{q}_s + M_{N^*})k_2^\alpha \Delta_{\alpha\beta}(M_{N^*}, q_s) \times \left[\frac{eh_1}{2M_N}\Gamma_\mu^{(\pm)} \mp \frac{eh_2}{(2M_N)^2}\Gamma^{(\pm)}p_{1\mu}\right](k_1^\beta \epsilon^\mu - k_1^\mu \epsilon^\beta),$$

$$\mathcal{M}_{N^*}\left(\frac{5}{2}^{\pm}\right) = i\frac{g_{K\Lambda^* N^*}}{M_K^2}\frac{1}{s-M_{N^*}^2}\Gamma^{(\mp)}(\not{q}_s + M_{N^*})k_2^{\alpha_1}k_2^{\alpha_2}\Delta_{\alpha_1\alpha_2;\beta_1\beta_2}(M_{N^*}, q_s) \times \left[\frac{eh_1}{(2M_N)^2}\Gamma_\mu^{(\mp)} \pm \frac{eh_2}{(2M_N)^3}\Gamma^{(\mp)}p_{1\mu}\right]k_1^{\beta_2}(k_1^{\beta_1}\epsilon^\mu - k_1^\mu \epsilon^{\beta_1}),$$

Form Factors

$$F_B(p^2) = \frac{\Lambda^4}{\Lambda^4 + (p^2 - M^2)^2}$$

Resonant term $\gamma p \to K^+ \Lambda^*(1405)$



Transition magnetic moment h1, h2

$$A_{1/2}(\tfrac{1}{2}^\pm) = \mp \frac{e f_1}{2M_N}\sqrt{\frac{k_\gamma M_R}{M_N}},$$

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

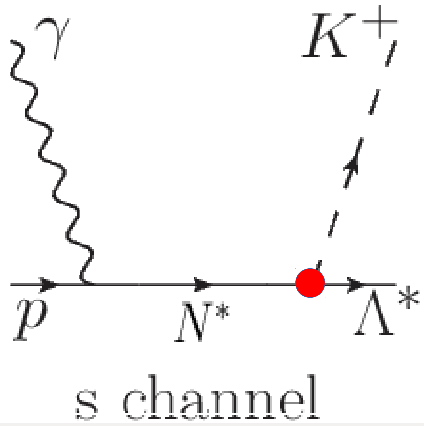
$$A_{3/2}(\tfrac{3}{2}^\pm) = \mp \frac{e\sqrt{2}}{4M_N}\sqrt{\frac{k_\gamma M_R}{M_N}}\left[f_1 \mp \frac{f_2}{4M_N}(M_R \mp M_N)\right],$$

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

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

Oh, Ko, Nakayama,
PRC 77, 045204 (2008)

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



Strong coupling constants g

$$\boxed{m_l + m_f = m_j}$$

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

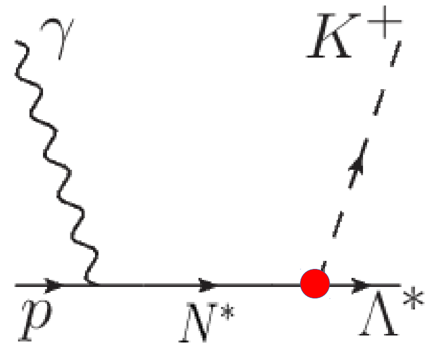
$$\Gamma(N^* \to K\Lambda^*) = \sum_{\ell} |G(\ell)|^2$$

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

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

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

Resonant term $\gamma p \to K^+\Lambda^*(1405)$



s channel

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

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

$j = \frac{1}{2}^+$ #(2)
$$G(0) = \frac{1}{\sqrt{4\pi}}\sqrt{\frac{q}{M_{N^*}}}\sqrt{E_{\Lambda^*} + M_{\Lambda^*}}\,g_{K\Lambda^*N^*}$$

$j = \frac{1}{2}^-$ #(4)
$$G(1) = \frac{1}{\sqrt{4\pi}}\sqrt{\frac{q}{M_{N^*}}}\sqrt{E_{\Lambda^*} - M_{\Lambda^*}}\,g_{K\Lambda^*N^*}$$

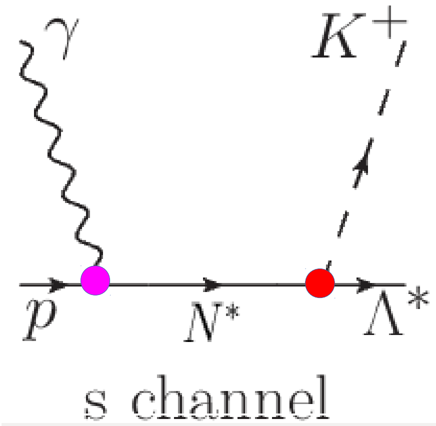
$j = \frac{3}{2}^+$ #(8)
$$G(2) = -\frac{1}{\sqrt{12\pi}}\sqrt{\frac{q^3}{M_{N^*}}}\sqrt{E_{\Lambda^*} - M_{\Lambda^*}}\frac{g_{K\Lambda^*N^*}}{M_K}$$

$j = \frac{3}{2}^-$ #(6)
$$G(1) = -\frac{1}{\sqrt{12\pi}}\sqrt{\frac{q^3}{M_{N^*}}}\sqrt{E_{\Lambda^*} + M_{\Lambda^*}}\frac{g_{K\Lambda^*N^*}}{M_K}$$

$j = \frac{5}{2}^+$ #(10)
$$G(2) = \frac{1}{\sqrt{30\pi}}\sqrt{\frac{q^5}{M_{N^*}}}\sqrt{E_{\Lambda^*} + M_{\Lambda^*}}\frac{g_{K\Lambda^*N^*}}{M_K^2}$$

$j = \frac{5}{2}^-$ #(12)
$$G(3) = \frac{1}{\sqrt{30\pi}}\sqrt{\frac{q^5}{M_{N^*}}}\sqrt{E_{\Lambda^*} - M_{\Lambda^*}}\frac{g_{K\Lambda^*N^*}}{M_K^2}$$

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



Transition magnetic moment h1, h2

Strong coupling constants g

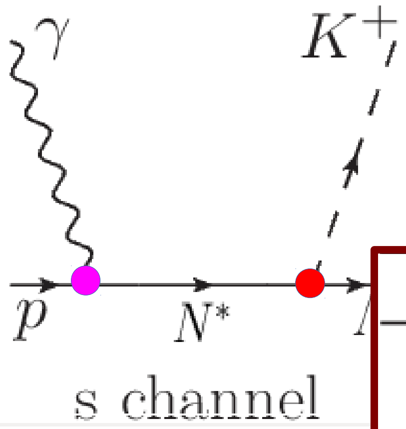
PDG N*	A_1	A_3	h_1	h_2	$G(\ell)$	$g_{K\Lambda^* N^*}$
$N\frac{5}{2}^+(2000)$	31 ± 10	-43 ± 8	0.024	1.62	$-0.6^{+0.6}_{-1.6}$	−0.912
$N\frac{1}{2}^+(2100)$	10 ± 4	...	−0.045	...	$+5.2 \pm 0.8$	0.785
$N\frac{3}{2}^-(2120)$	130 ± 50	160 ± 65	−0.753	2.09	$+3.9^{+1.3}_{-2.7}$	−1.16 ?

Helicity Amplitudes A1, A3

Decay Amplitudes G(l)

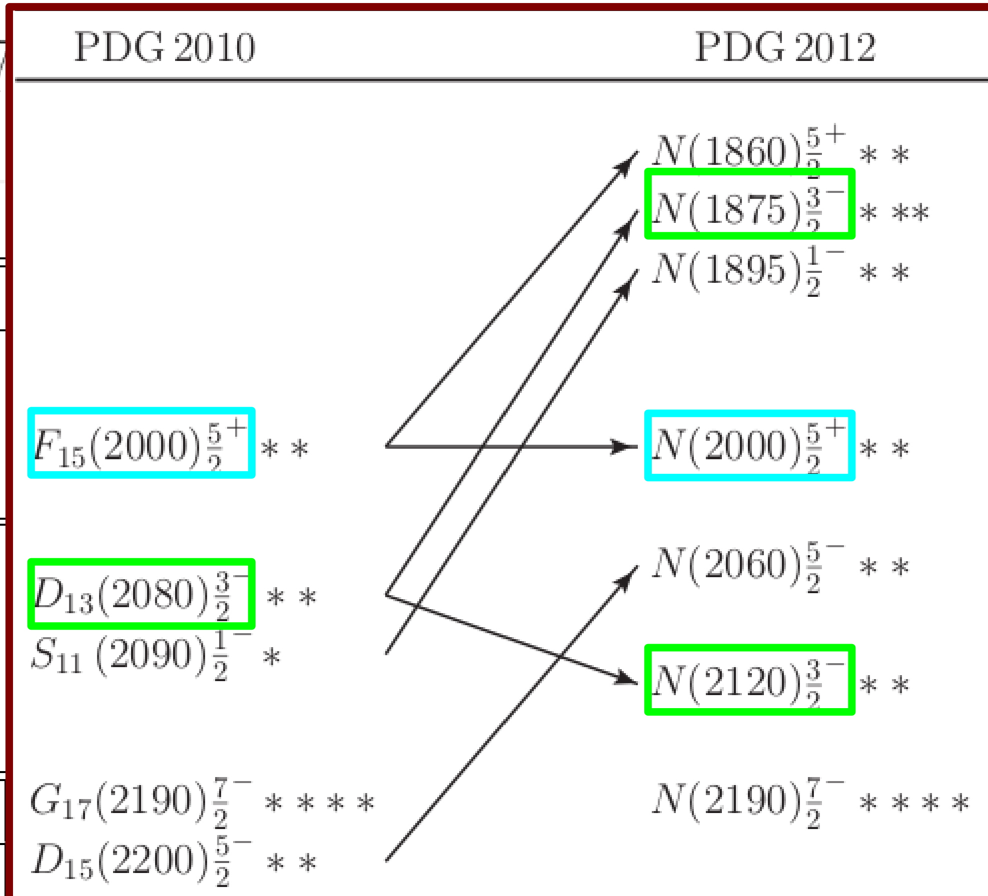
missing N*	A_1	A_3	h_1	h_2	$G(\ell)$	$g_{K\Lambda^* N^*}$
$N\frac{1}{2}^-(2030)$	20	...	0.094	...	$+1.2^{+0.9}_{-1.1}$	1.78
$N\frac{3}{2}^-(2055)$	16	0	−0.372	−1.25	$+1.2^{+0.5}_{-0.9}$	−0.467
$N\frac{3}{2}^-(2095)$	−2	−6	0.138	0.0072	$+0.7^{+0.2}_{-0.4}$	−0.228

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



Transition magnetic moment h1, h2

Strong coupling constants g



PDG N*					$G(\ell)$	$g_{K\Lambda^* N^*}$
$N\,\frac{5}{2}^+(2000)$					$-0.6^{+0.6}_{-1.6}$	-0.912
$N\,\frac{1}{2}^+(2100)$					$+5.2 \pm 0.8$	0.785
$N\,\frac{3}{2}^-(2120)$					$+3.9^{+1.3}_{-2.7}$	-1.16 ?

Decay Amplitudes G(l)

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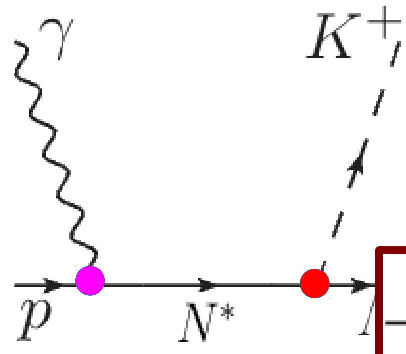
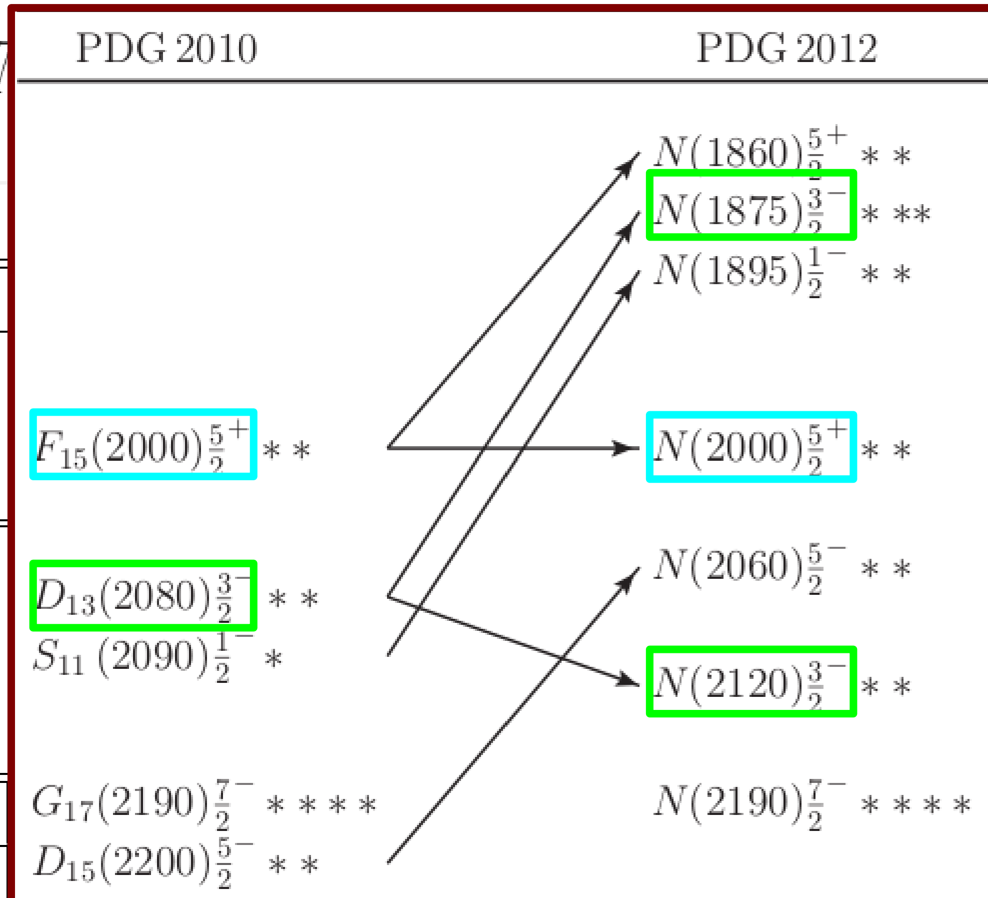
$\gamma p \to K^+ \Lambda^*(1405)$

Transition magnetic moment h1, h2

Strong coupling constants g



s channel



PDG N*					$G(\ell)$	$g_{K\Lambda^* N^*}$
$N\,\frac{5}{2}^+(2000)$					$-0.6^{+0.6}_{-1.6}$	-0.912
$N\,\frac{1}{2}^+(2100)$					$+5.2 \pm 0.8$	0.785
$N\,\frac{3}{2}^-(2120)$					$+3.9^{+1.3}_{-2.7}$	-1.16 ?

Decay Amplitudes G(l)

0.06

missing N*					$G(\ell)$	$g_{K\Lambda^* N^*}$
$N\,\frac{1}{2}^-(2030)$					$+1.2^{+0.9}_{-1.1}$	1.78
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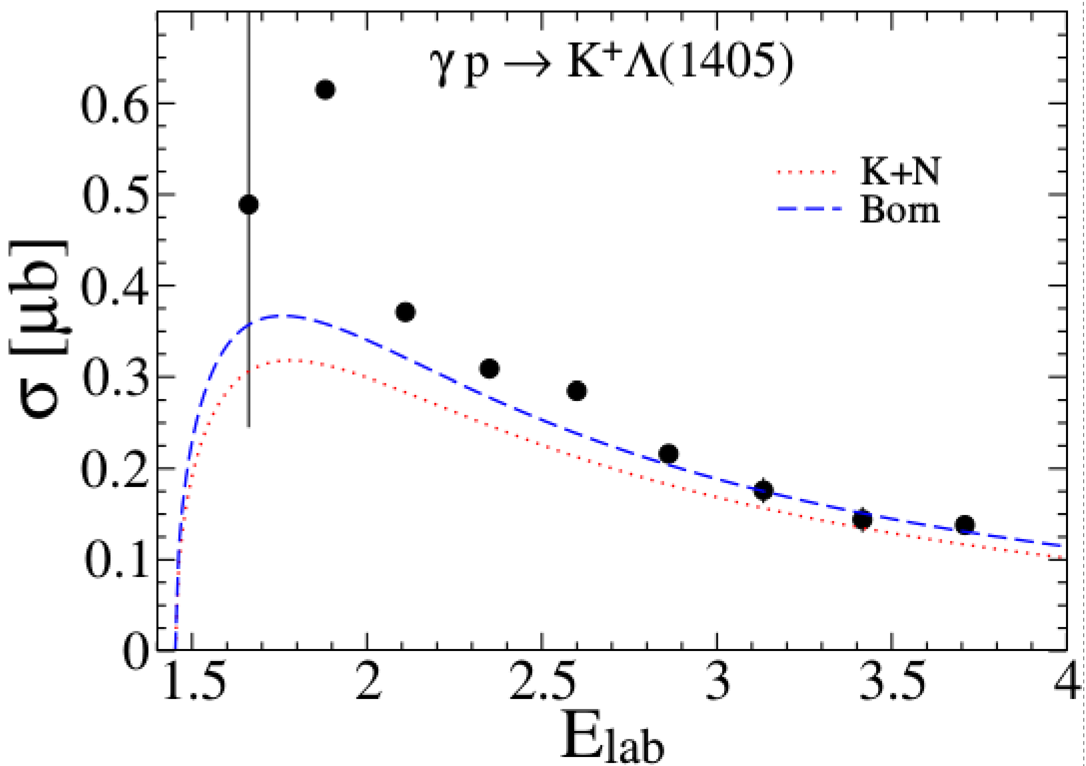
$N\,\frac{3}{2}^-(2095)$	-2	-6	0.138	0.0072	$+0.7^{+0.2}_{-0.4}$	-0.228

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

total cross section

Background contribution



$$F_{\rm M}(p^2) = \frac{\Lambda^2 - M^2}{\Lambda^2 - p^2}, \quad F_B(p^2) = \frac{\Lambda^4}{\Lambda^4 + (p^2 - M^2)^2}$$

$$F_c = F_{t,K} + F_{s,N} - F_{t,K} \cdot F_{s,N}$$

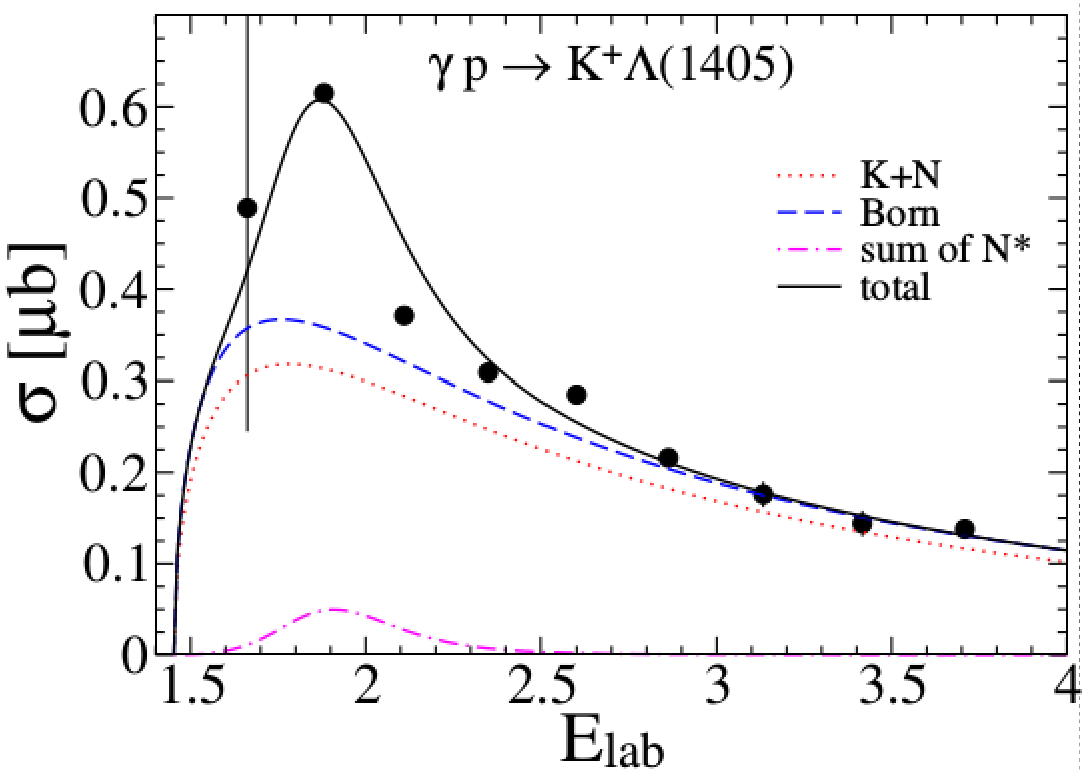
$$n_{\rm GI,K^*} = 2, n_{\Lambda,\Lambda^*} = 2, n_{N^*} = 2$$

$$\Lambda_{\rm Born} = 1.1\,{\rm GeV},\ \Lambda_{N^*} = 1.0\,{\rm GeV}$$

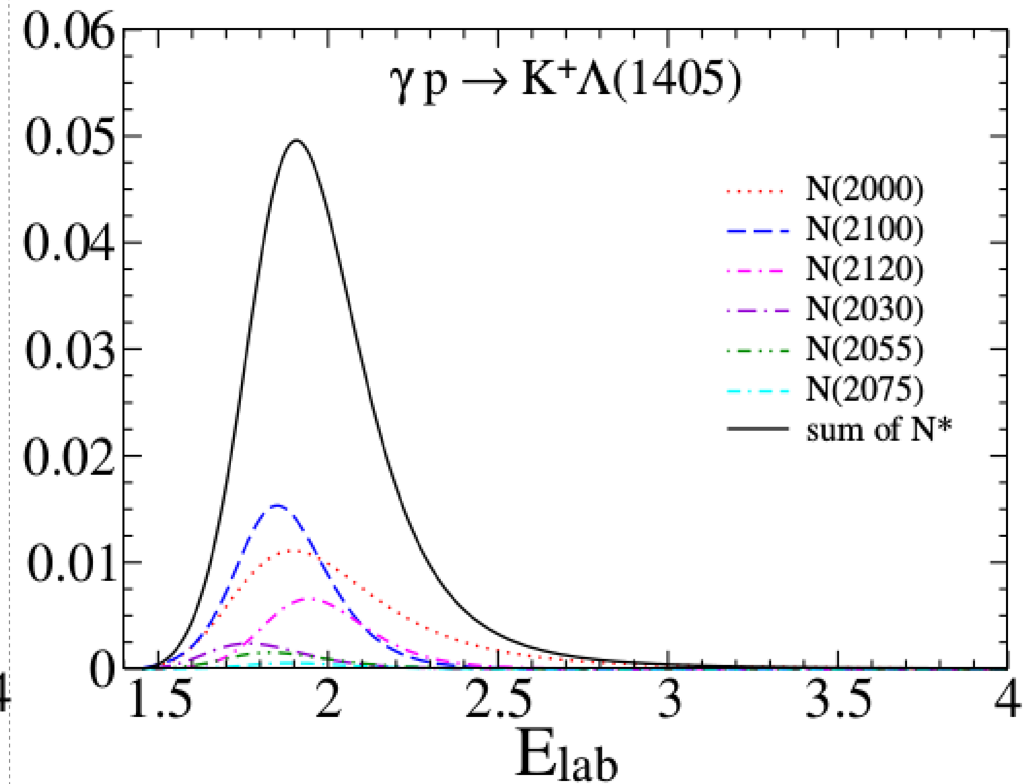
$\gamma p \to K^+ \Lambda^*(1405)$

total cross section

Total contribution



Resonant contribution



$$F_{\mathrm{M}}(p^2) = \frac{\Lambda^2 - M^2}{\Lambda^2 - p^2}, \quad F_B(p^2) = \frac{\Lambda^4}{\Lambda^4 + (p^2 - M^2)^2}$$

$$F_c = F_{t,K} + F_{s,N} - F_{t,K} \cdot F_{s,N}$$

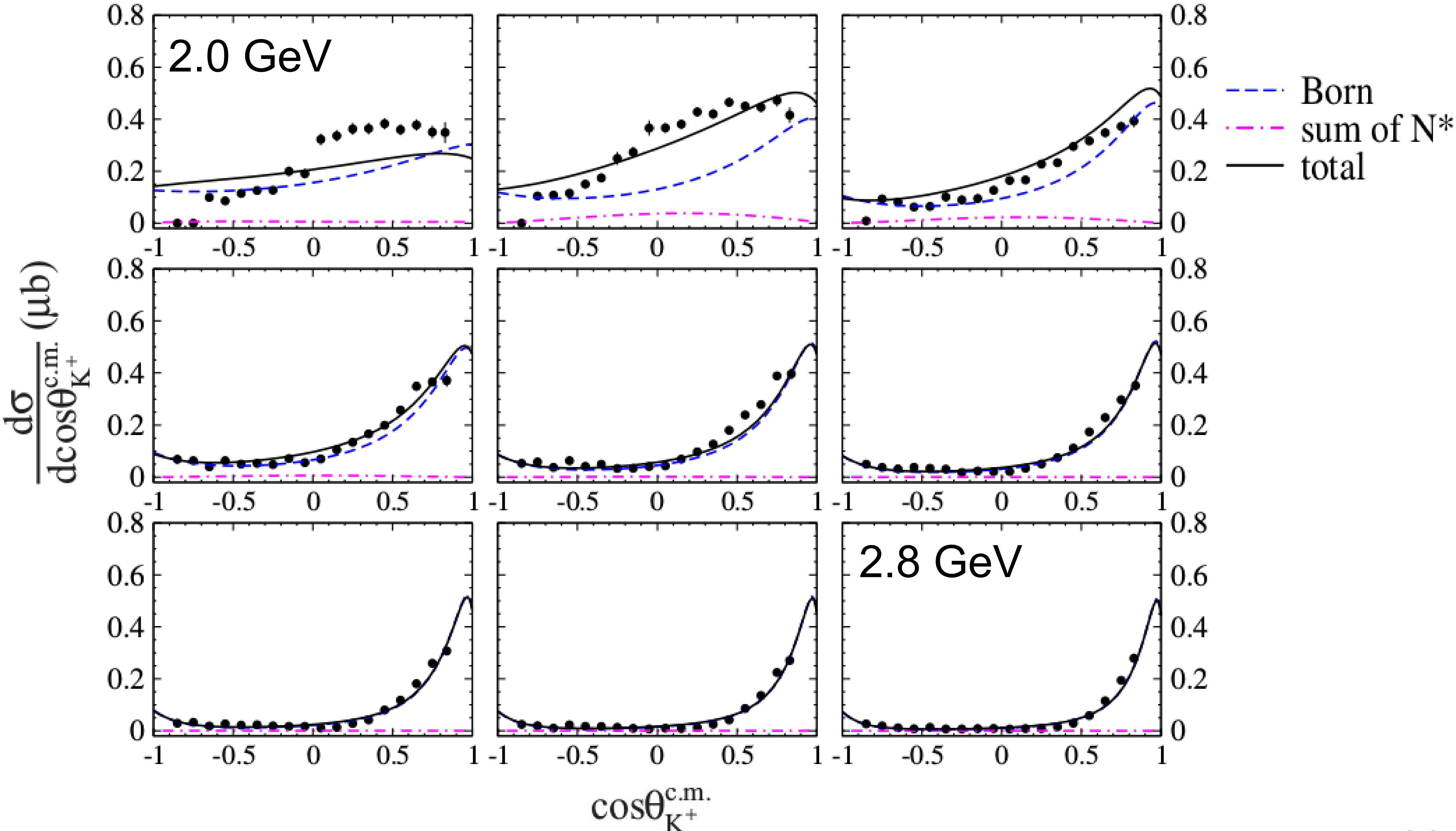
$$n_{\mathrm{GI,K^*}} = 2, n_{\Lambda,\Lambda^*} = 2, n_{N^*} = 2$$

$$\Lambda_{\mathrm{Born}} = 1.1\,\mathrm{GeV},\ \Lambda_{N^*} = 1.0\,\mathrm{GeV}$$

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

differential cross section

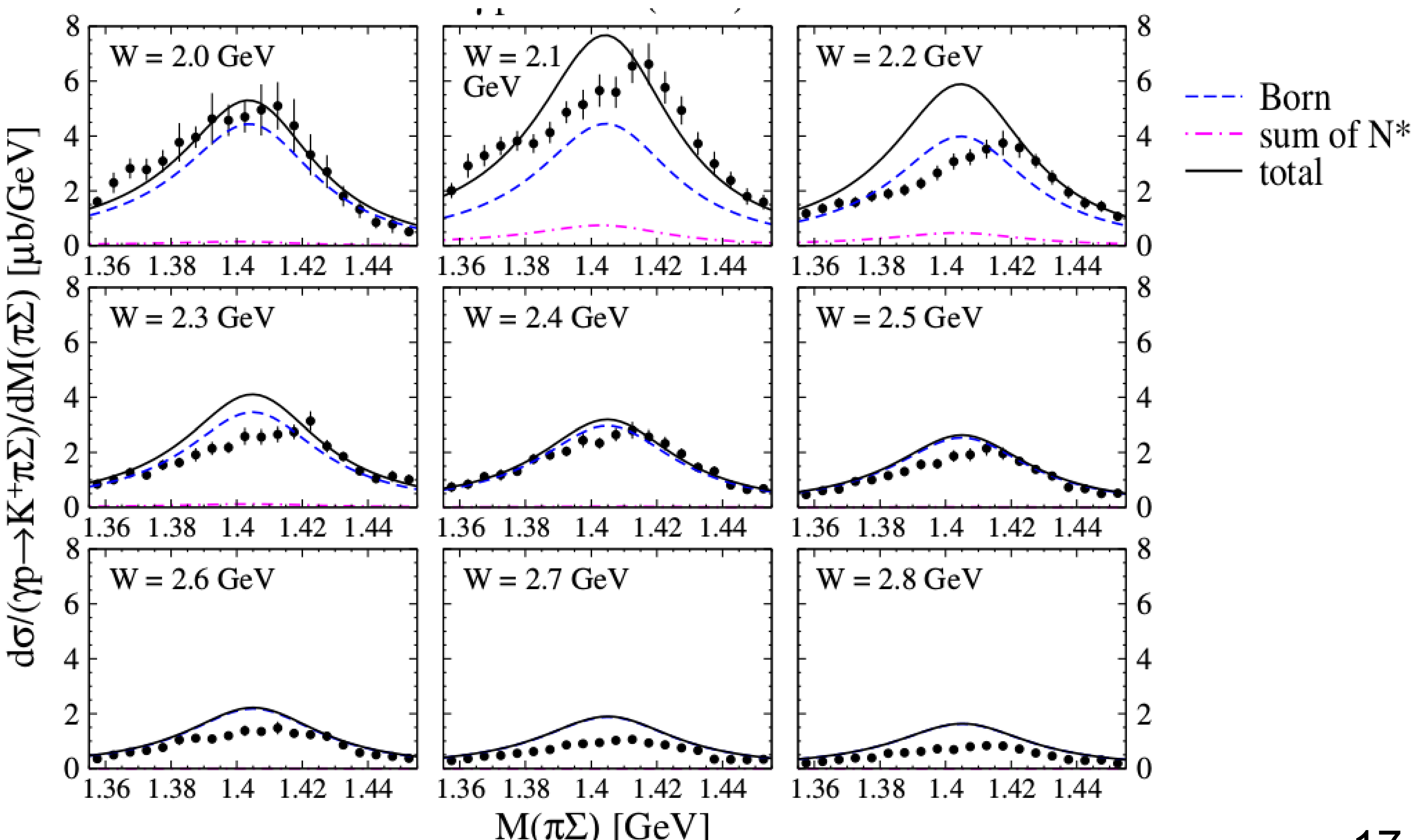
Effective Lagrangian



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

invariant mass distribution

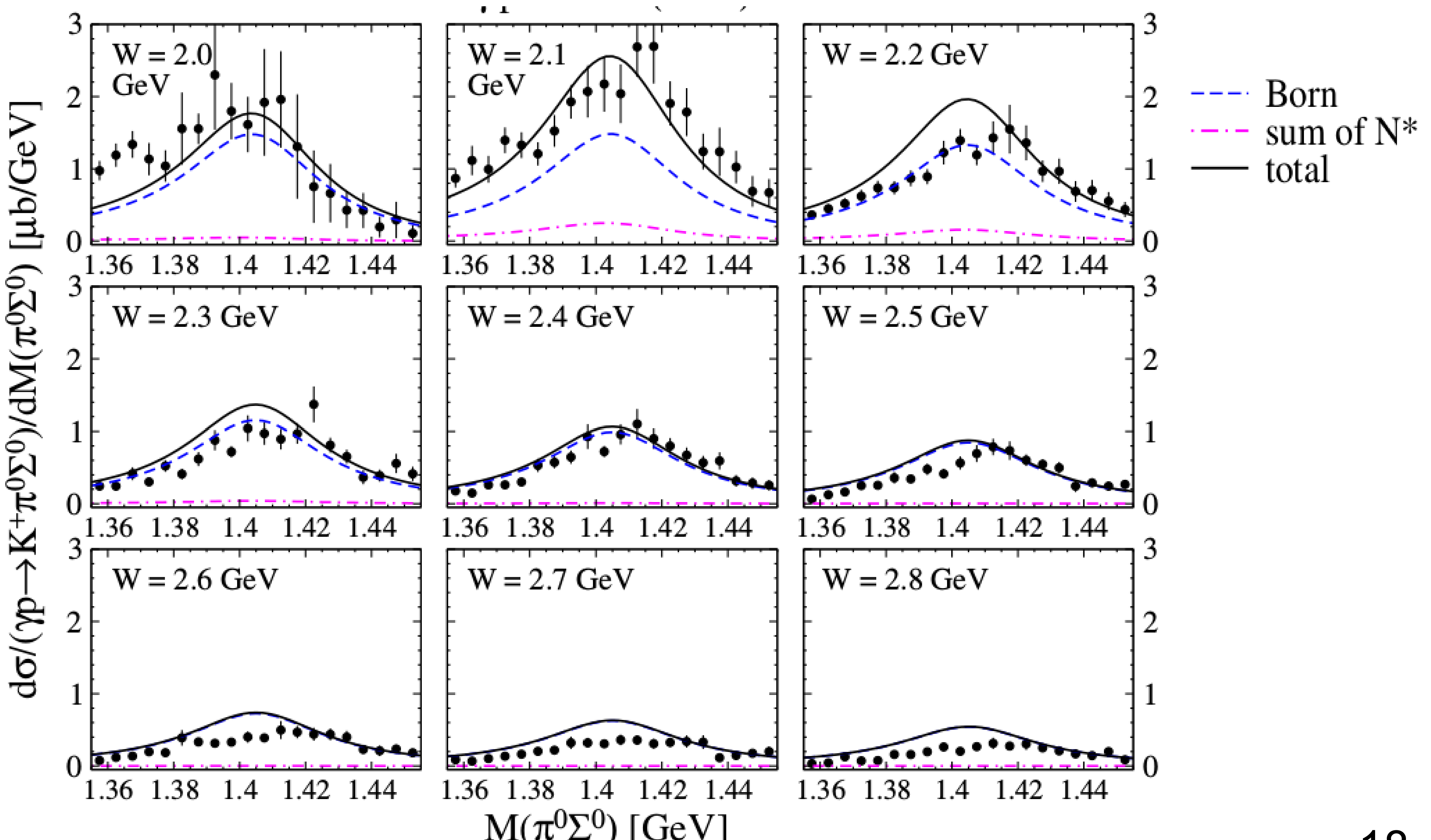
Effective Lagrangian



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

invariant mass distribution

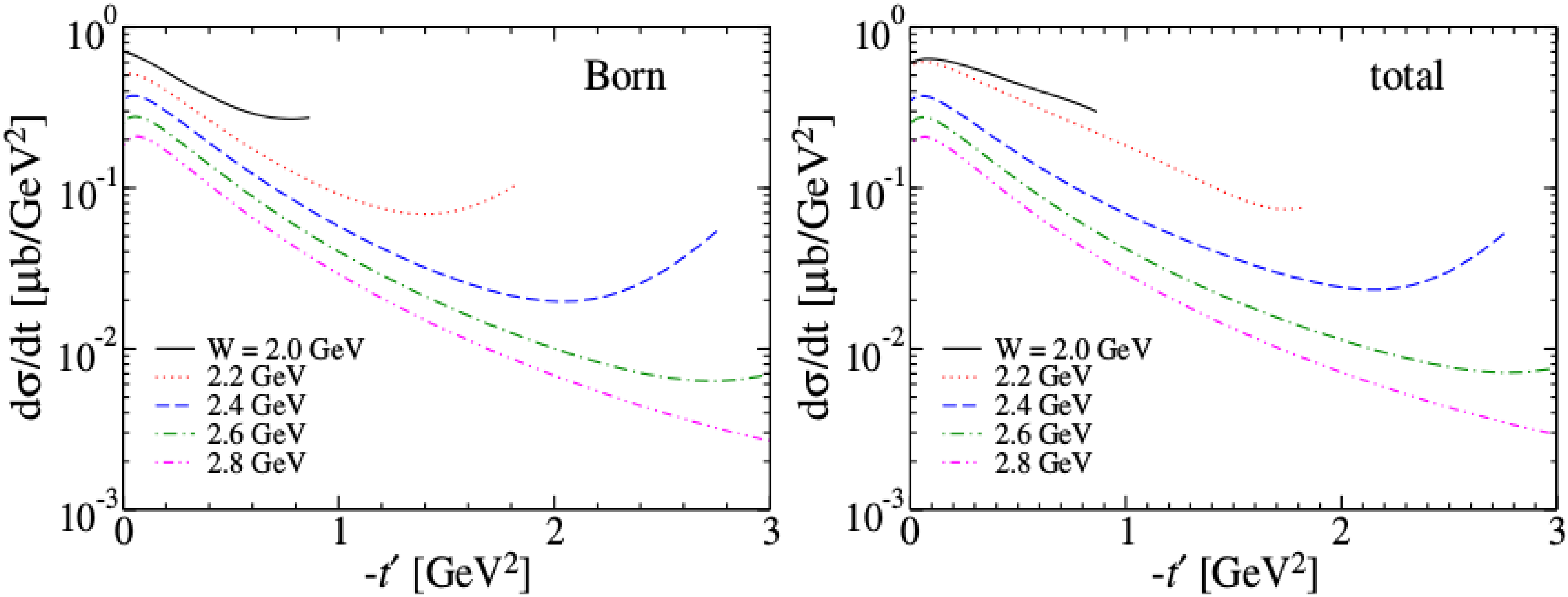
Effective Lagrangian



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

differential cross section

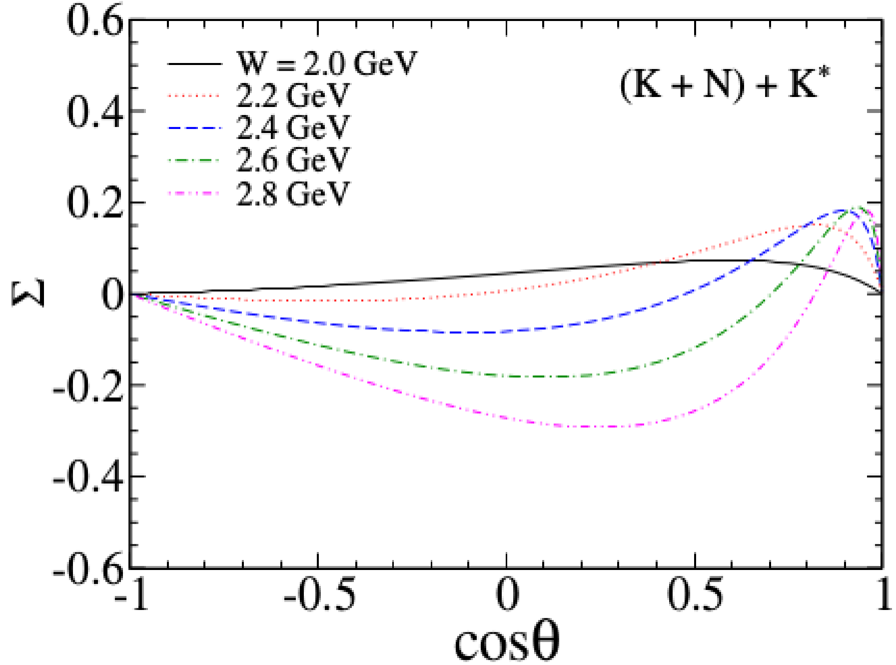
Effective Lagrangian

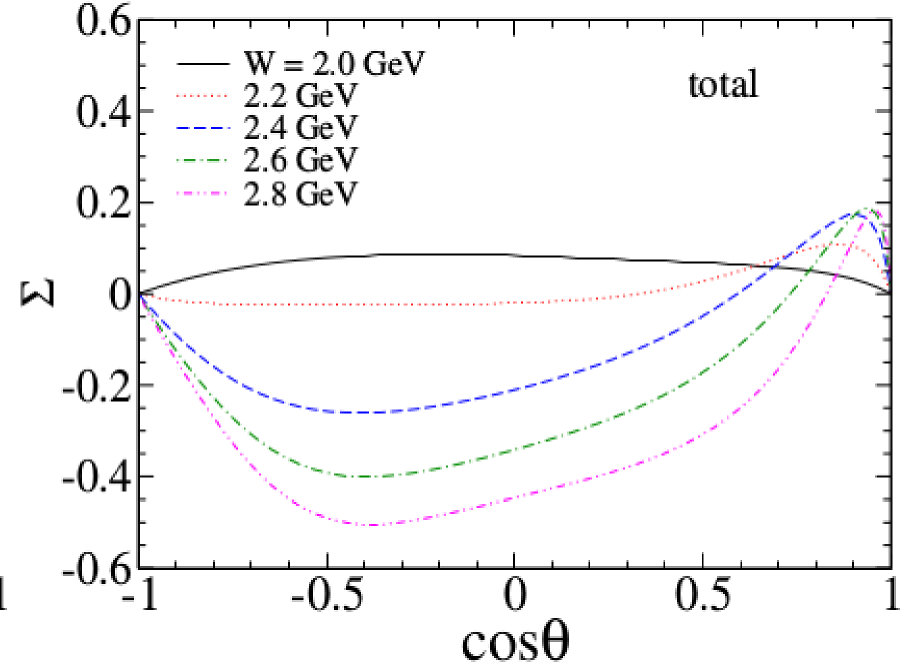


$\gamma p \to K^+ \Lambda^*(1405)$

beam asymmetry

Effective Lagrangian



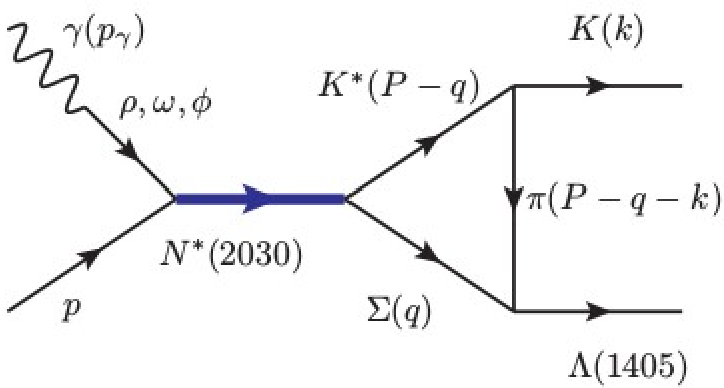


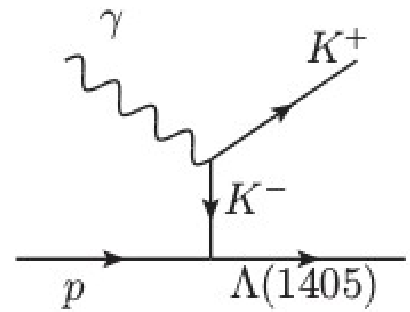
$$\Sigma = \frac{\frac{d\sigma}{d\Omega}_{\perp} - \frac{d\sigma}{d\Omega}_{\parallel}}{\frac{d\sigma}{d\Omega}_{\perp} + \frac{d\sigma}{d\Omega}_{\parallel}}$$

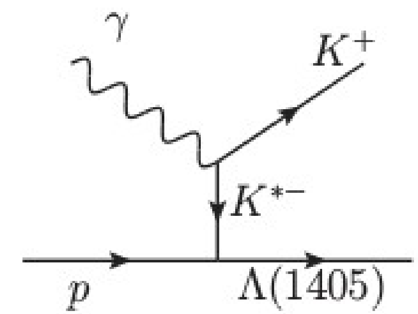
$\gamma p \to K^+ \Lambda^*(1405)$

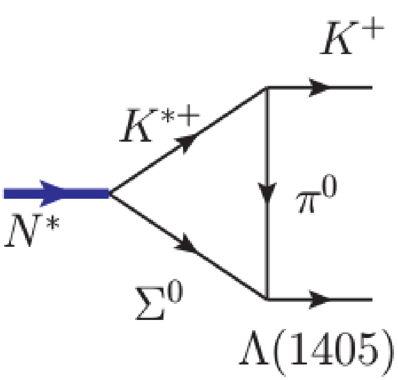
The role of a triangle singularity in the $\gamma p \to K^+ \Lambda(1405)$ reaction

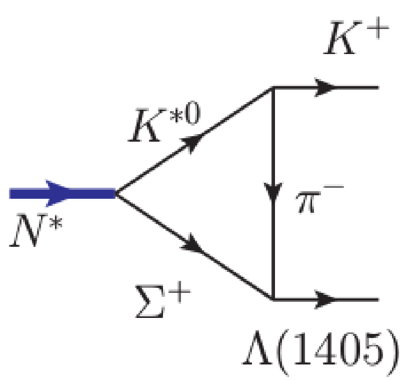
ArXiv:1610.07117





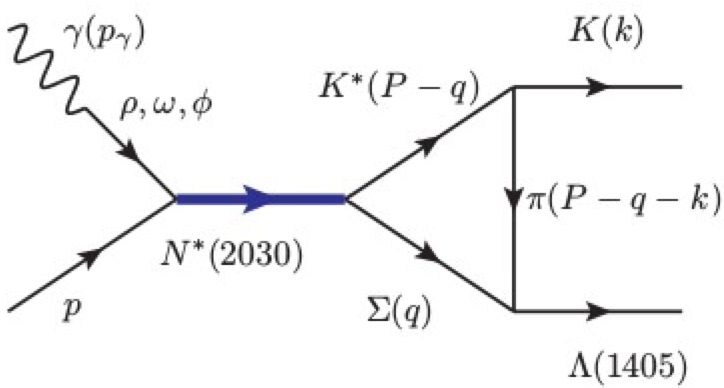


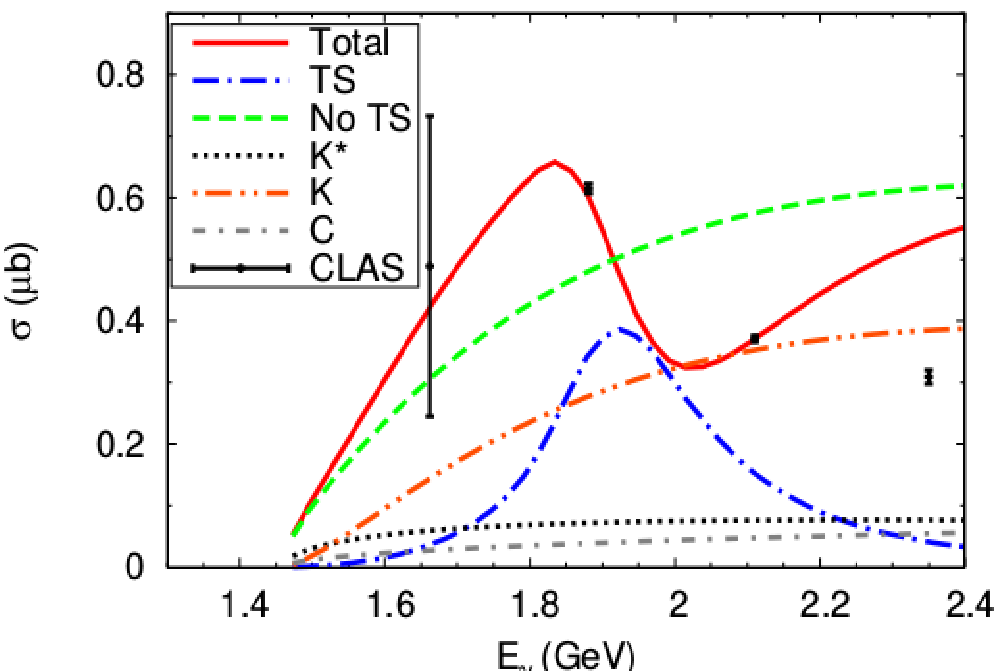


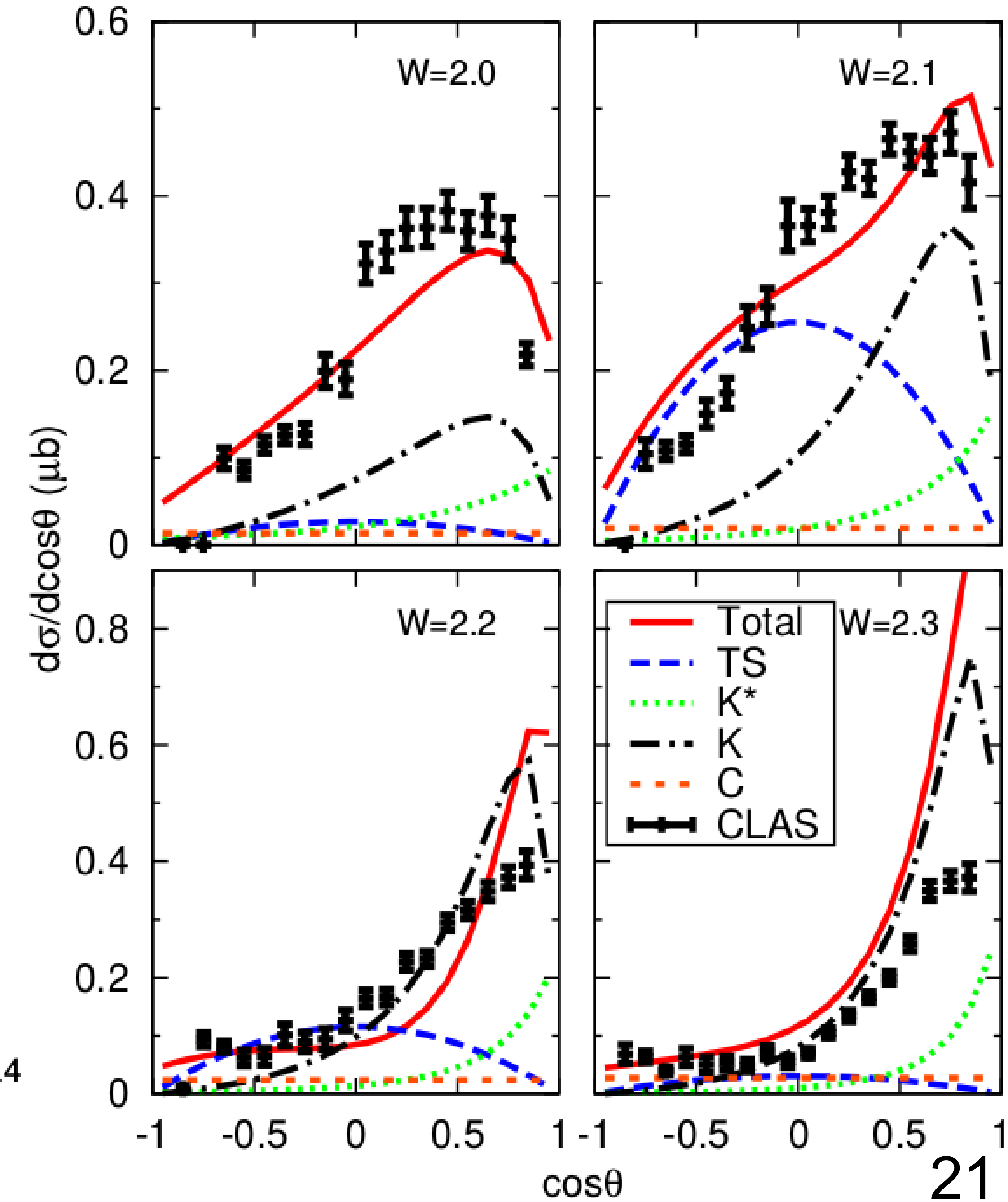


$\gamma p \to K^+ \Lambda^*(1405)$

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







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

◇ $\Lambda^*(1405)$ photoproduction, $\gamma p \to K\Lambda^*(1405)$, is reanalyzed using an effective Lagrangian model.

◇ A bump structure is observed at CLAS (2013) Collaboration near the threshold region.

◇ N* contribution should be considered for this description. PDG N* resonances, i.e., N(2000), N(2100), N(2120), may give the dominant contribution.

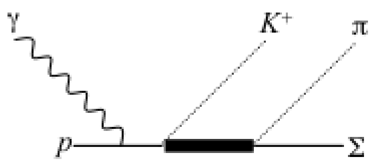
Future work:

◇ Check other scenarios such as rescattering process, initial and final state interactions.

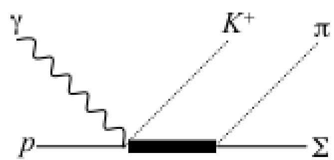
Future work:

◇ Study three-body process $\gamma p \to K^+ \pi \Sigma$,

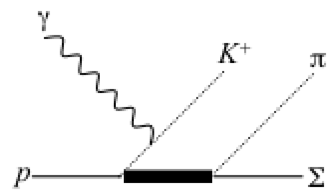
considering the two-pole structure.



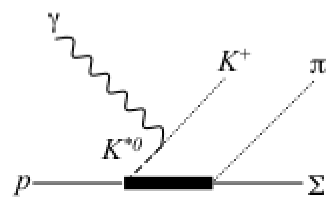
$R1$, R^*1, BG1



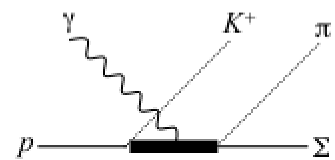
R^*2,



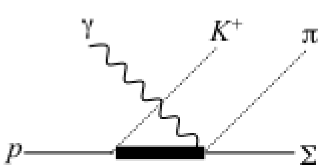
$R2$, R^*3, BG2



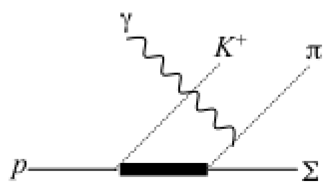
$R3$, R^*4, BG3



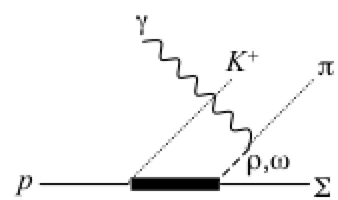
$R4$, R^*5, BG4



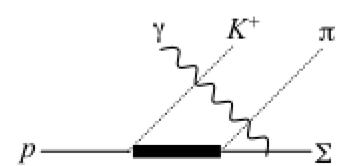
R^*6



$R5$, R^*7, BG5



$R6$, R^*8, BG6



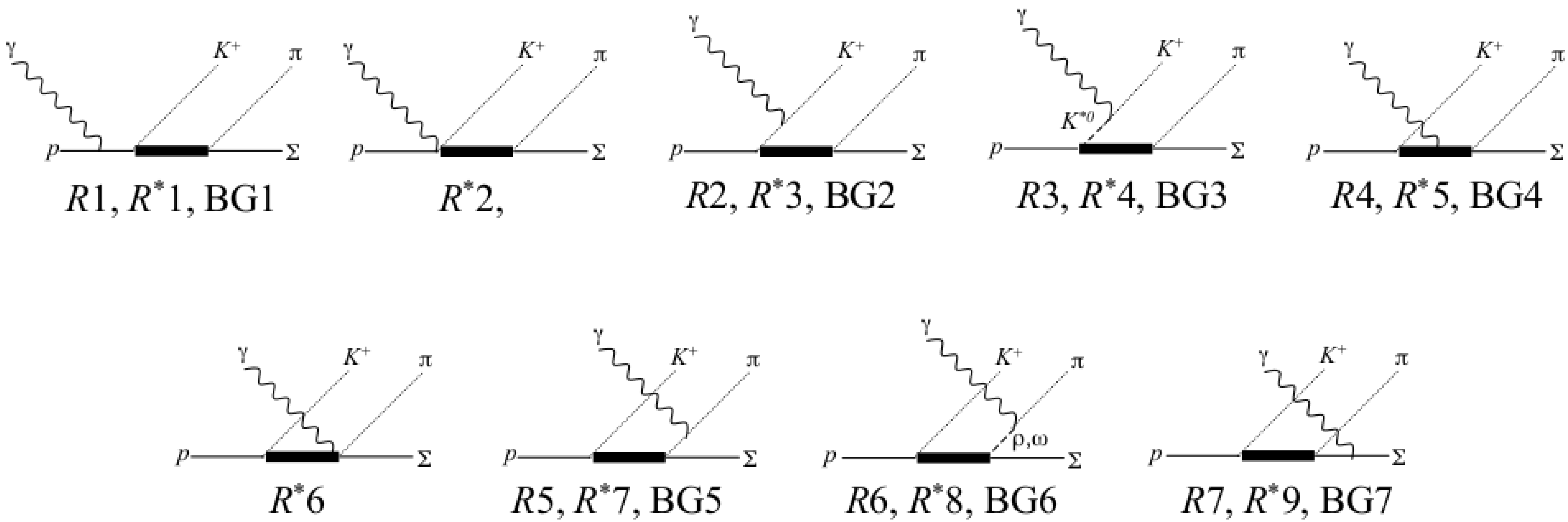
$R7$, R^*9, BG7

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

Future work:

◇ Study three-body process $\gamma p \to K^+\pi\Sigma$,

considering the two-pole structure.



Thank you very much

Back Up

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

$$\mathcal{M}_{\text{total}}(\gamma p \to K^+\Lambda^*) = (\mathcal{M}_K + \mathcal{M}_N)\cdot(t - M_K^2)\cdot P_K^{\text{Mod}}(s,t)\cdot F_c^n + \mathcal{M}_{K^*}\cdot(t - M_{K^*}^2)\cdot P_{K^*}^{\text{Mod}}(s,t)\cdot F_{K^*}^n(t) + \mathcal{M}_\Lambda\cdot F_\Lambda^n(u) + \mathcal{M}_{\Lambda^*(1405)}\cdot F_{\Lambda^*(1405)}^n(u) + \mathcal{M}_{\Lambda^*(1670)}\cdot F_{\Lambda^*(1670)}^n(u),$$

Regge Propagators

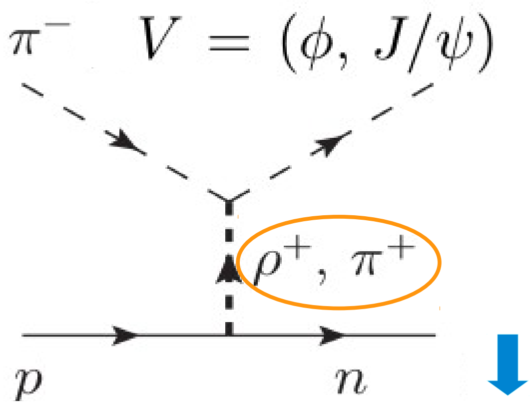
$$P_K^{\text{Regge}}(s,t) = \left(\frac{1}{e^{-i\pi\alpha_K(t)}}\right)\left(\frac{s}{s_K}\right)^{\alpha_K(t)}\Gamma[-\alpha_K(t)]\alpha'_K,$$

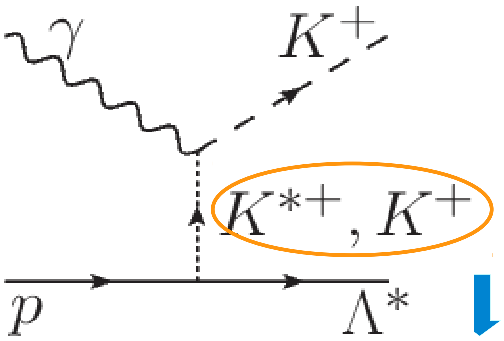
$$P_{K^*}^{\text{Regge}}(s,t) = \left(\frac{1}{e^{-i\pi\alpha_{K^*}(t)}}\right)\left(\frac{s}{s_{K^*}}\right)^{\alpha_{K^*}(t)-1}\Gamma[1-\alpha_{K^*}(t)]\alpha'_{K^*},$$

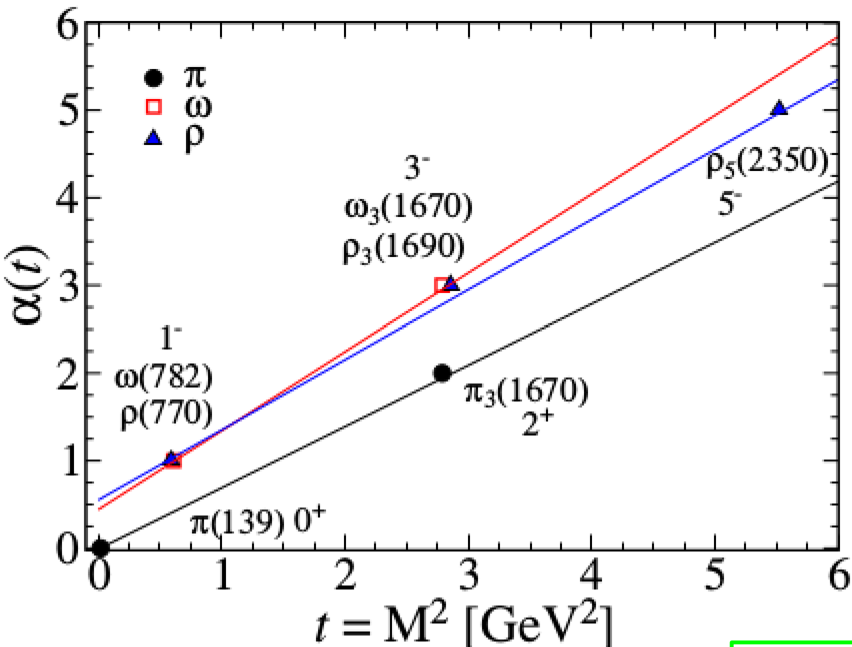
$$P_{K,K^*}^{\text{Born}}(t) = 1/(t - M_{K,\,K^*}^2)$$

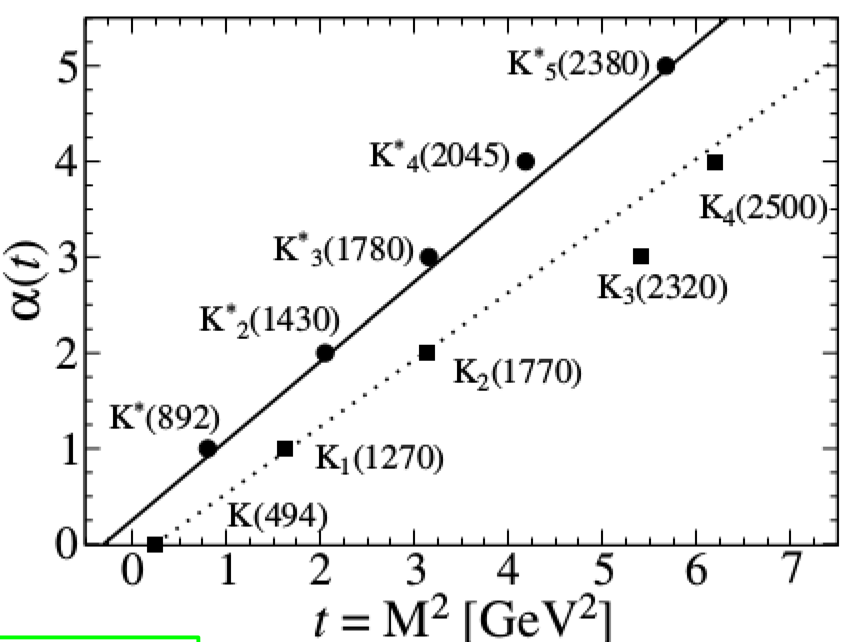
- The bybrid Reggeized treatment should interpolate smoothly to low energy region.

Regge model









$$\boxed{\alpha(M^2) = J}$$

Chew–Frautschi plots

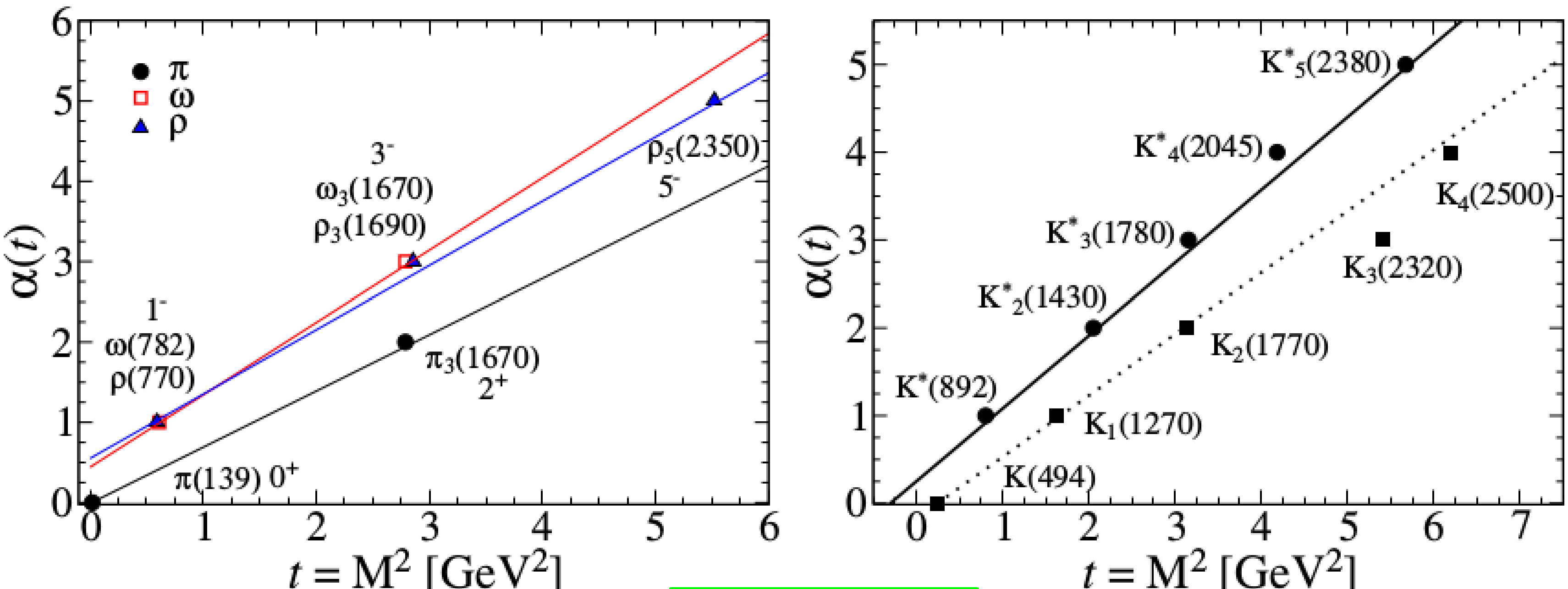
$$\alpha_\pi(t) = 0.7(t - M_\pi^2),$$
$$\alpha_\rho(t) = 0.55 + 0.8t,$$
$$\alpha_\omega(t) = 0.44 + 0.9t.$$

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

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

Regge model

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



$$\boxed{\alpha(M^2) = J}$$

Chew–Frautschi plots

$$\begin{aligned}
\alpha_\pi(t) &= 0.7(t - M_\pi^2), \\
\alpha_\rho(t) &= 0.55 + 0.8t, \\
\alpha_\omega(t) &= 0.44 + 0.9t.
\end{aligned}$$

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

The three-body phase space for the decay $ab \to 123$ can be decomposed into the two-body one $ab \to 1X \to 23$ as follows:

$$\begin{aligned}
\sigma_{ab\to 123} &= \mathcal{F}_{ab}\int d\Phi_3(ab\to 123)|\mathcal{M}_{ab\to 123}|^2 = \int d\Phi_2(ab\to 1X)\frac{M_X^2}{2\pi}d\Phi_2(X\to 23)|\mathcal{M}_{ab\to 123}|^2 \\
&= \mathcal{F}_{ab}\int d\Phi_2(ab\to 1X)\frac{dM_{23}^2}{2\pi}d\Phi_2(X\to 23)\sum_X^{\mathrm{spin}}\frac{|\mathcal{M}_{ab\to 1X}\mathcal{M}_{X\to 23}|^2}{(M_{23}^2-M_X^2)^2+M_X^2\Gamma_X^2} \\
&\approx \frac{\mathcal{F}_{ab}}{2M_X\Gamma_X}\int d\Phi_2(ab\to 1X)d\Phi_2(X\to 23)\sum_X^{\mathrm{spin}}|\mathcal{M}_{ab\to 1X}\mathcal{M}_{X\to 23}|^2 \\
&= \frac{\Gamma_{X\to 23}}{\Gamma_X}\mathcal{F}_{ab}\int d\Phi_2(ab\to 1X)\sum_X^{\mathrm{spin}}|\mathcal{M}_{ab\to 1X}|^2 = \frac{\Gamma_{X\to 23}}{\Gamma_X}\sigma_{ab\to 1X}, \qquad (15)
\end{aligned}$$

where $\mathcal{F}_{ab}$ stands for the flux factor for the initial state with a and b. In deriving Eq. (15), we have used the narrow-width approximation for the intermediate particle X: $\Gamma_X/M_X \ll 1$, and taken into account that the invariant amplitudes $\mathcal{M}$ are insensitive to M_{23}. Considering the above decomposition, the invariant-mass distribution can be written by

$$\begin{aligned}
\frac{d\sigma_{ab\to 123}}{dM_{23}} &= \mathcal{F}_{ab}\int d\Phi_2(ab\to 1X)\frac{M_{23}}{\pi}d\Phi_2(X\to 23)\sum_X^{\mathrm{spin}}\frac{|\mathcal{M}_{ab\to 1X}\mathcal{M}_{X\to 23}|^2}{(M_{23}^2-M_X^2)^2+M_X^2\Gamma_X^2} \\
&= \mathcal{F}_{ab}\int d\Phi_2(ab\to 1X)\frac{2M_XM_{23}}{2M_X\pi}d\Phi_2(X\to 23)\sum_X^{\mathrm{spin}}\frac{|\mathcal{M}_{ab\to 1X}\mathcal{M}_{X\to 23}|^2}{(M_{23}^2-M_X^2)^2+M_X^2\Gamma_X^2} \\
&\approx \mathcal{F}_{ab}\int d\Phi_2(ab\to 1X)\frac{2M_XM_{23}}{\pi}\sum_X^{\mathrm{spin}}\frac{|\mathcal{M}_{ab\to 1X}|^2\Gamma_{X\to 23}}{(M_{23}^2-M_X^2)^2+M_X^2\Gamma_X^2} \\
&= \frac{2M_XM_{23}}{\pi}\frac{\sigma_{ab\to 1X}\,\Gamma_{X\to 23}}{(M_{23}^2-M_X^2)^2+M_X^2\Gamma_X^2}. \qquad (16)
\end{aligned}$$

Although there can be complicated interference effects due to other processes via a different intermediate particle X', i.e. $ab \to 2X' \to 13$ for instance, for brevity, we ignored them here.