9th APCTP-BLTP JINR Joint Workshop at Kazakhstan

Photon induced multi-kaon production

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  - Introduction
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PART I

$$\gamma p \rightarrow K^+ K^+ K^0 \Omega^-$$

Motivation

Timeline

1962	quark model
1964	Ω^- observed
2006	the spin of Ω^- measured
2012	photoproduction of very strange baryon at CLAS12

Motivation

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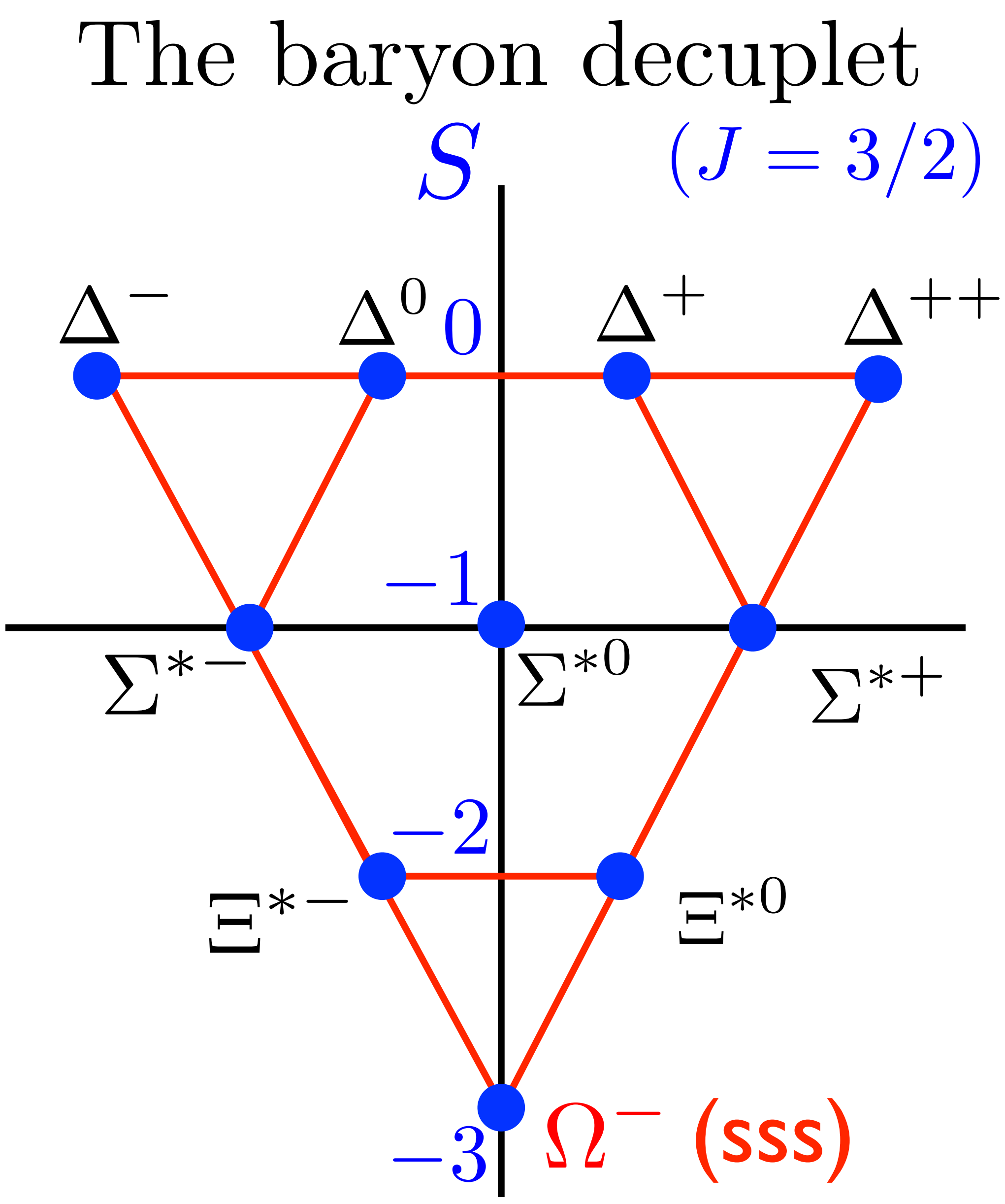

Motivation

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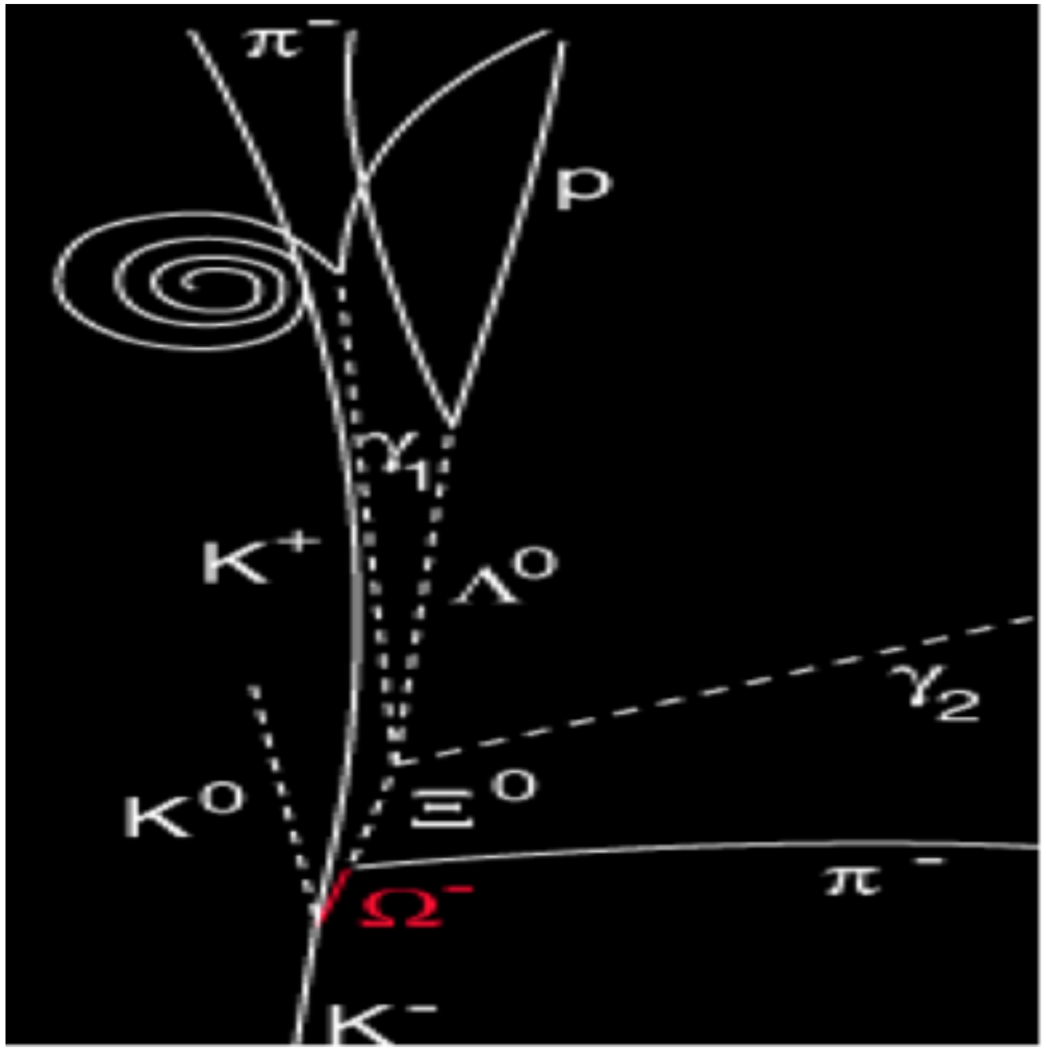


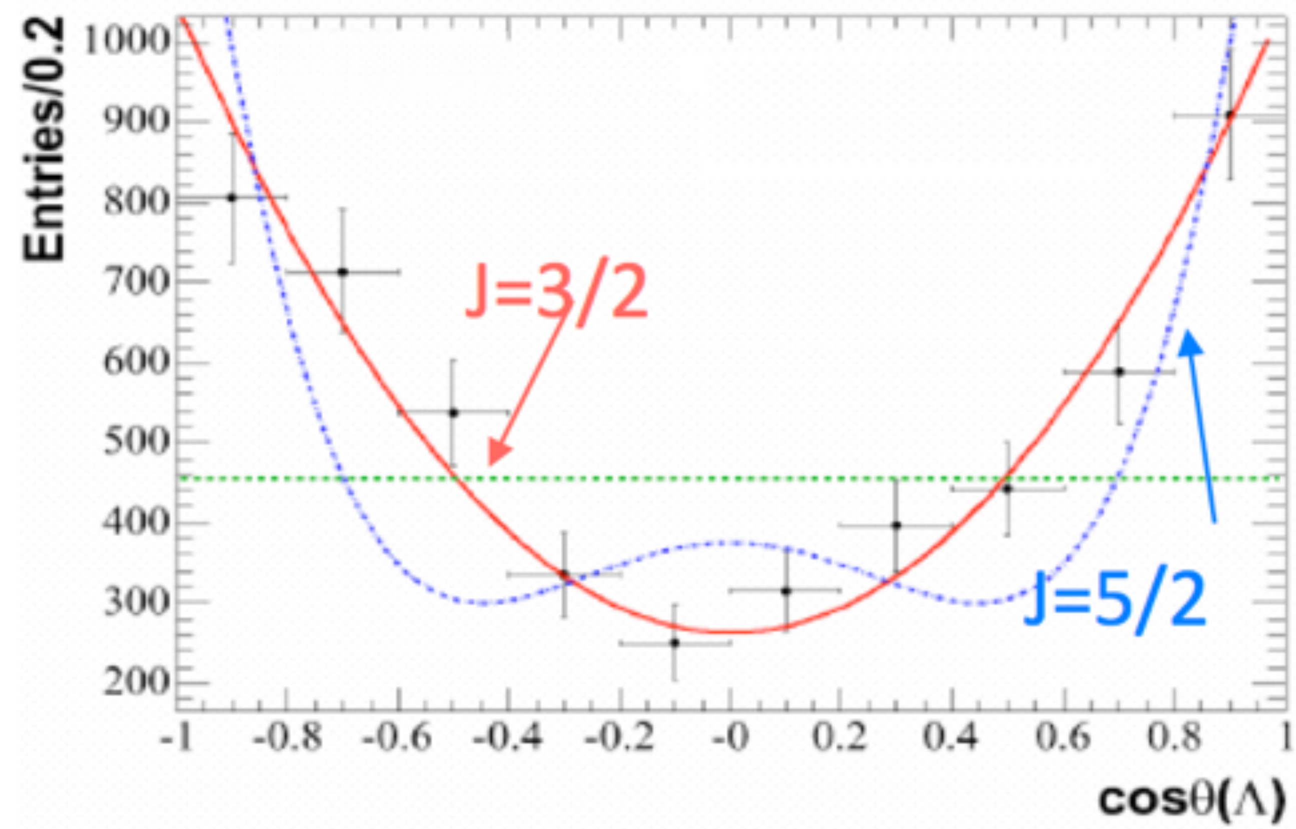
Barnes et al, PRL 12, 204 (1964)

$K^- p \rightarrow K^0 K^+ \Omega^-$

Motivation

Timeline

1962	quark model
1964	Ω^- observed
	~ 42 years
2006	the spin of Ω^- measured
2012	photoproduction of very strange baryon at CLAS12



Aubert et al, PRL.97, 112001 (2006)

First measurement of $J(\Omega^-)$ at SLAC

$\Xi_c^0 \rightarrow \Omega^- K^+$, $\Omega^- \rightarrow \Lambda K^-$

Motivation

Timeline

1962	quark model
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Photoproduction of the Very Strangest Baryons on a Proton Target in CLAS12

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** - Contact person, * - Spokesperson

(Dated: May 4, 2012)

Motivation

Timeline

1962	quark model
1964	Ω^- observed
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Ω^- $I(J^P) = 0(\frac{3}{2}^+)$

$J^P = \frac{3}{2}^+$ is the quark-model prediction; and $J = 3/2$ is fairly well established.

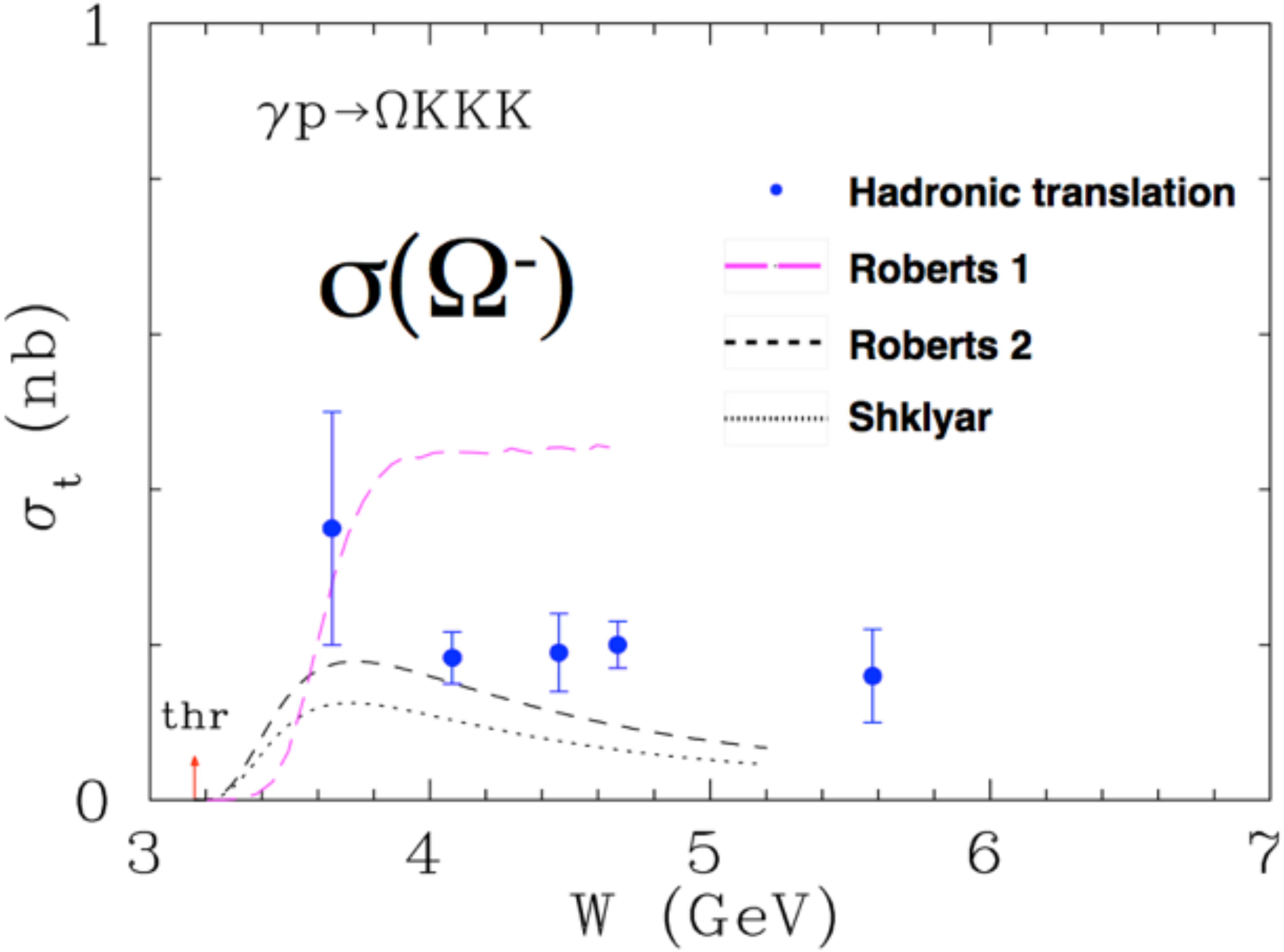
Mass $m = 1672.45 \pm 0.29$ MeV
$(m_{\Omega^-} - m_{\overline{\Omega}^+}) \ / \ m_{\Omega^-} = (-1 \pm 8) \times 10^{-5}$
Mean life $\tau = (0.821 \pm 0.011) \times 10^{-10}$ s
$c\tau = 2.461$ cm
$(\tau_{\Omega^-} - \tau_{\overline{\Omega}^+}) \ / \ \tau_{\Omega^-} = 0.00 \pm 0.05$
Magnetic moment $\mu = -2.02 \pm 0.05 \ \mu_N$

	$(J)^P$	M(MeV)	Γ(MeV)
Ω(2250)	? ?	2250	
Ξ(1530)	(3/2)+	1530	9.1
Ξ(1690)	(1/2?)?	1690	<30
Ξ(1820)	(-3/2?)-	1823	24
Ξ(1950)	(?)?	1950	60
Ξ(2030)	(>=5/2)?	2025	20

Motivation

Production of the Strangest Baryons on the Proton with CLAS12 (PR12-12-008)

Lei Guo, Florida International Univeristy



Formalism

□ effective Lagrangian method

$$\mathcal{L}_{QCD} = -\frac{1}{2}\mathrm{tr}[G_{\mu\nu}G^{\mu\nu}] + \bar{q}i\gamma^\mu D_\mu q \; -\bar{q}\mathbf{m}q$$

$$G_{\mu\nu} = \partial_\mu A_\nu - \partial_\nu A_\mu - ig[A_\mu, A_\nu]\,, \quad D_\mu = \partial_\mu - igA_\mu, \quad A_\mu = \sum_a T^a A^a_\mu$$

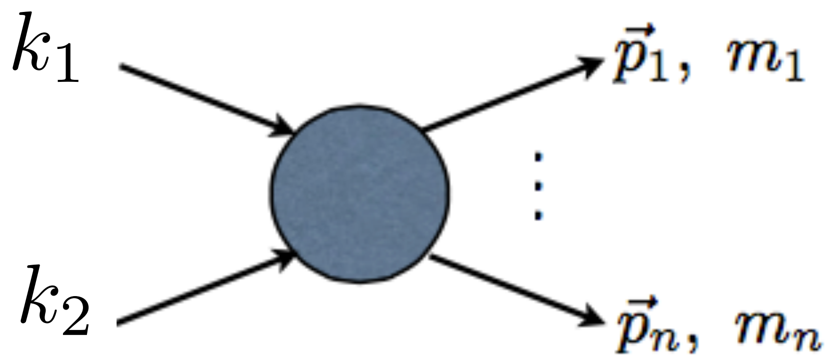
$\mathcal{L}_{QCD}$		$\mathcal{L}_{eff}$
quark and gluon degree of freedom	⇒ at low energy	hadronic degree of freedom

$$\exp[iZ] = \int \mathcal{D}q\, \mathcal{D}\bar{q}\, \mathcal{D}A \exp\left[i\int dx^4\; \mathcal{L}_{QCD}\right] = \int \mathcal{D}U \exp\left[i\int dx^4\; \mathcal{L}_{eff}\right]$$

$$\mathcal{L}_{eff} = \mathcal{L}_{eff}(\underbrace{U, \partial_\mu U, V_\mu \cdots}_{Hadrons})\,, \qquad U = \exp\left[\frac{i\sqrt{2}\Phi}{f}\right]$$

Formalism

□ cross section



$$S_{fi} = \delta_{fi} - i(2\pi)^4\delta^4(k_1 + k_2 - \sum_i^N p_i)T_{fi}$$

$$T = \frac{\mathcal{M}}{(2E_\gamma(k_1))^{1/2}(2E_N(k_2))^{1/2}\left\{\prod_{i=1}^N (2E_i(p_i))^{1/2}\right\}}$$

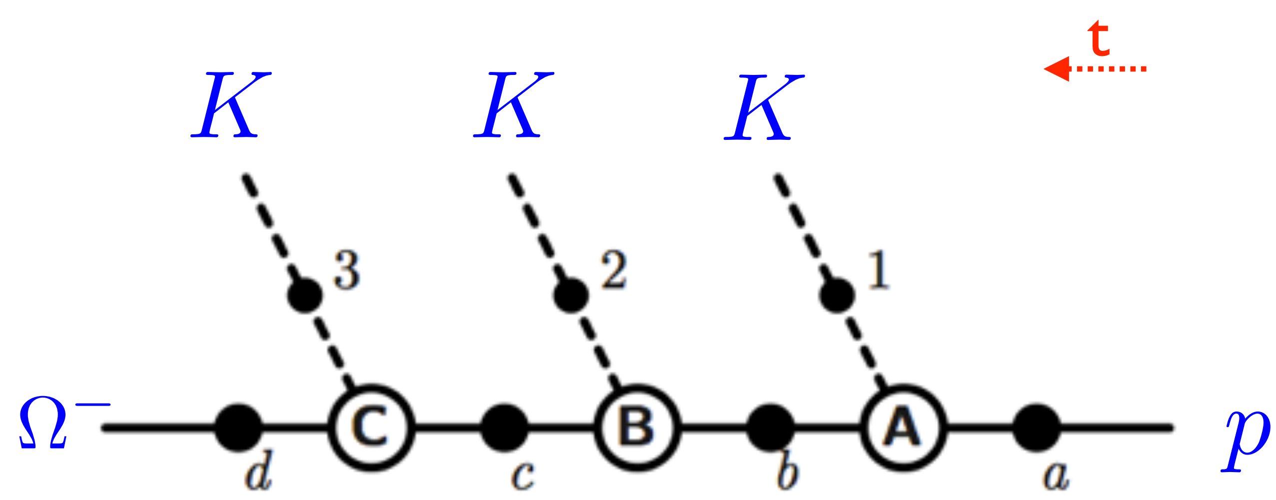
$$\sigma = \int \frac{(2\pi)^4}{4|k_1 \cdot k_2|}|\mathcal{M}|^2 d\Phi_4(k_1, k_2; p_1, \cdots, p_N)$$

$$d\Phi_N(k_1, k_2; p_1, \cdots, p_N) = \delta^4(k_1 + k_2 - \sum_i^N p_i)\left\{\prod_{i=1}^N \frac{d^3p_i}{(2\pi)^3 E_{K_i}(p_i)}\right\}$$

Formalism

□ Invariant amplitude

$$\gamma p \to K^+ K^+ K^0 \Omega^-$$



$$\mathcal{M} = \begin{cases} \overline{u}(p_N) M^{\boldsymbol{\nu}} \epsilon^{\gamma}_{\boldsymbol{\nu}} u(k_2) & \text{for the spin of the final baryon } = 1/2, \\ \overline{u}_{\mu_1\mu_2\cdots\mu_n}(p_N) M^{\mu_1\mu_2\cdots\mu_n \boldsymbol{\nu}} \epsilon^{\gamma}_{\boldsymbol{\nu}} u(k_2) & \text{for the spin of the final baryon } = 3/2,\ 5/2,\ 7/2\cdots(2n+1)/2 \end{cases}$$

$$M^\mu = \underbrace{F_C t_c F_B t_b F_A t_a \Gamma^\mu_a + F_C t_c F_B t_b \Gamma^\mu_b t_b F_A + F_C t_c \Gamma^\mu_c t_c F_B t_b F_A + \Gamma^\mu_d t_d F_C t_c F_B t_b F_A}_{\text{baryon currents}}$$

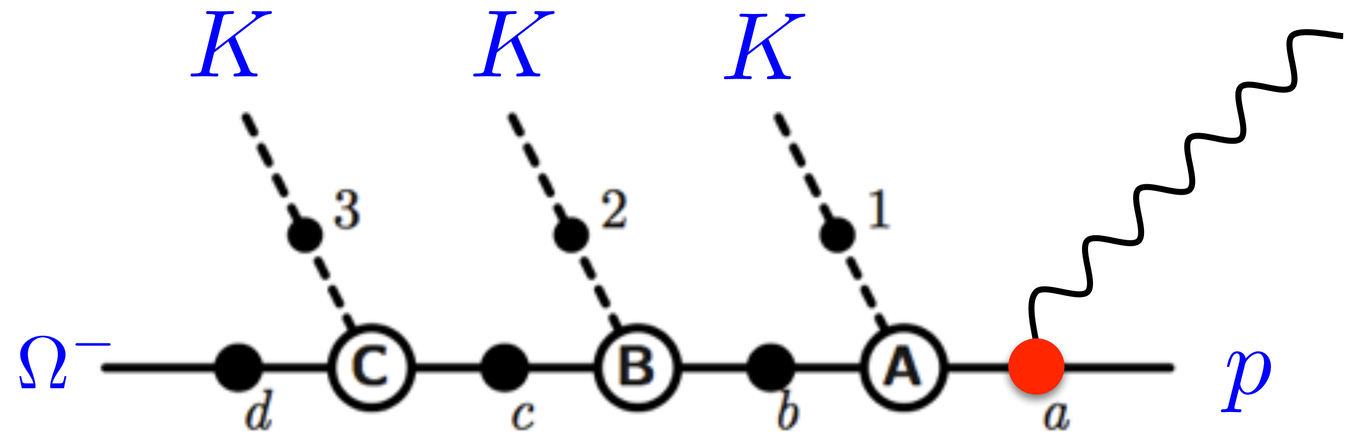
$$+ \underbrace{F_C t_c F_B t_b J^\mu_1 \Delta_1 F_A + F_C t_c J^\mu_2 \Delta_2 F_B t_b F_A + J^\mu_3 \Delta_3 F_C t_c F_B t_b F_A}_{\text{meson currents}}$$

$$+ \underbrace{F_C t_c F_B t_b M^\mu_A + F_C t_c M^\mu_B t_b F_A + M^\mu_C t_c F_B t_b F_A}_{\text{interaction currents}} \ ,$$

Formalism

□ Invariant amplitude

$$\gamma p \to K^+ K^+ K^0 \Omega^-$$



$$\mathcal{M} = \begin{cases} \overline{u}(p_N) M^{\boldsymbol{\nu}} \epsilon^{\gamma}_{\boldsymbol{\nu}} u(k_2) & \text{for the spin of the final baryon } = 1/2, \\ \overline{u}_{\mu_1\mu_2\cdots\mu_n}(p_N) M^{\mu_1\mu_2\cdots\mu_n \boldsymbol{\nu}} \epsilon^{\gamma}_{\boldsymbol{\nu}} u(k_2) & \text{for the spin of the final baryon } = 3/2,\ 5/2,\ 7/2 \cdots (2n+1)/2 \end{cases}$$

$$M^\mu = \underbrace{\boxed{F_C t_c F_B t_b F_A t_a \Gamma^\mu_a} + F_C t_c F_B t_b \Gamma^\mu_b t_b F_A + F_C t_c \Gamma^\mu_c t_c F_B t_b F_A + \Gamma^\mu_d t_d F_C t_c F_B t_b F_A}_{\text{baryon currents}}$$

$$+ \underbrace{F_C t_c F_B t_b J^\mu_1 \Delta_1 F_A + F_C t_c J^\mu_2 \Delta_2 F_B t_b F_A + J^\mu_3 \Delta_3 F_C t_c F_B t_b F_A}_{\text{meson currents}}$$

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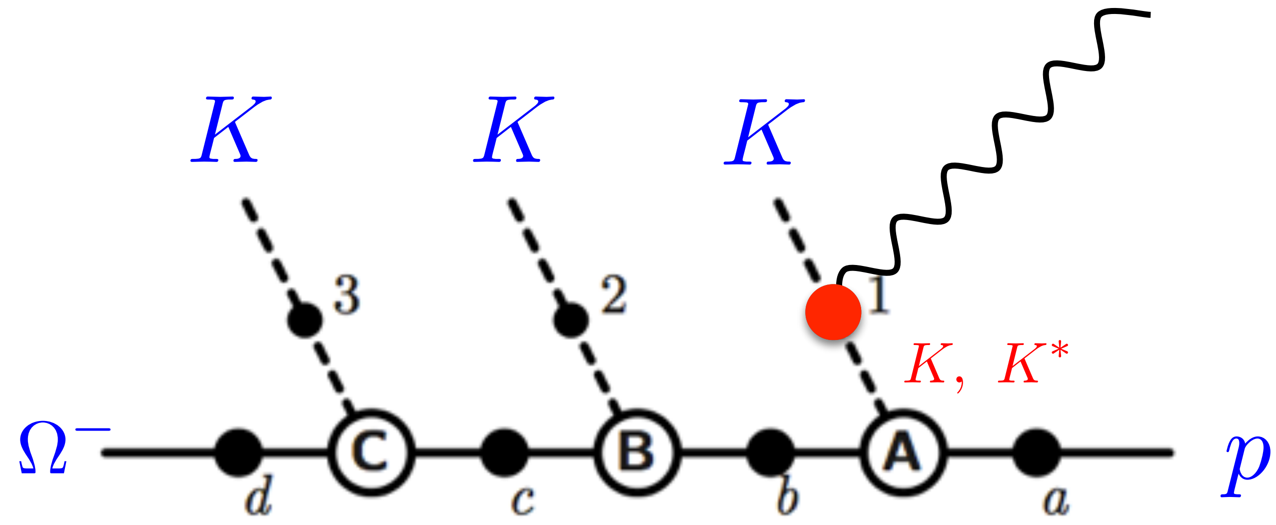
Formalism

- Invariant amplitude

$$\gamma p \to K^+ K^+ K^0 \Omega^-$$



$$\mathcal{M} = \begin{cases} \overline{u}(p_N) M^{\boldsymbol{\nu}} \epsilon^{\gamma}_{\boldsymbol{\nu}} u(k_2) & \text{for the spin of the final baryon } = 1/2, \\ \overline{u}_{\mu_1\mu_2\cdots\mu_n}(p_N) M^{\mu_1\mu_2\cdots\mu_n \boldsymbol{\nu}} \epsilon^{\gamma}_{\boldsymbol{\nu}} u(k_2) & \text{for the spin of the final baryon } = 3/2,\ 5/2,\ 7/2\cdots(2n+1)/2 \end{cases}$$

$$M^\mu = \underbrace{F_C t_c F_B t_b F_A t_a \Gamma^\mu_a + F_C t_c F_B t_b \Gamma^\mu_b t_b F_A + F_C t_c \Gamma^\mu_c t_c F_B t_b F_A + \Gamma^\mu_d t_d F_C t_c F_B t_b F_A}_{\text{baryon currents}}$$

$$+ \underbrace{\boxed{F_C t_c F_B t_b J^\mu_1 \Delta_1 F_A} + F_C t_c J^\mu_2 \Delta_2 F_B t_b F_A + J^\mu_3 \Delta_3 F_C t_c F_B t_b F_A}_{\text{meson currents}}$$

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Formalism

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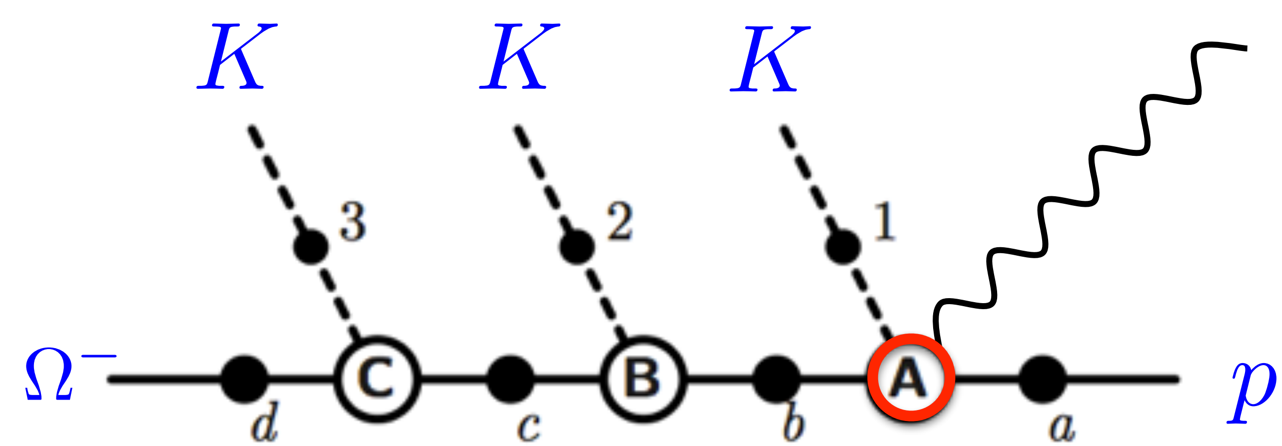

$$\mathcal{M} = \begin{cases} \overline{u}(p_N) M^{\boldsymbol{\nu}} \epsilon^{\gamma}_{\boldsymbol{\nu}} u(k_2) & \text{for the spin of the final baryon } = 1/2, \\ \overline{u}_{\mu_1\mu_2\cdots\mu_n}(p_N) M^{\mu_1\mu_2\cdots\mu_n \boldsymbol{\nu}} \epsilon^{\gamma}_{\boldsymbol{\nu}} u(k_2) & \text{for the spin of the final baryon } = 3/2,\ 5/2,\ 7/2\cdots(2n+1)/2 \end{cases}$$

$$M^\mu = \underbrace{F_C t_c F_B t_b F_A t_a \Gamma^\mu_a + F_C t_c F_B t_b \Gamma^\mu_b t_b F_A + F_C t_c \Gamma^\mu_c t_c F_B t_b F_A + \Gamma^\mu_d t_d F_C t_c F_B t_b F_A}_{\text{baryon currents}}$$

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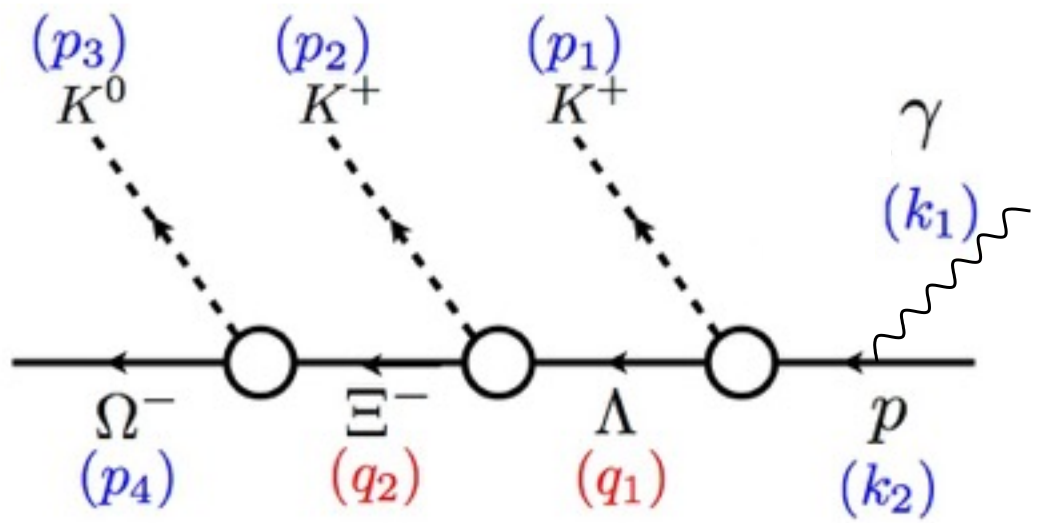
$$+ \underbrace{\boxed{F_C t_c F_B t_b M^\mu_A} + F_C t_c M^\mu_B t_b F_A + M^\mu_C t_c F_B t_b F_A}_{\text{interaction currents}} ,$$

Formalism

$$I^{\mu}_{B1} = F_C t_c F_B t_b F_A t_a \Gamma^{\mu}_a$$

$$\Rightarrow F_{\Xi} t_{\Xi} F_{\Lambda} t_{\Lambda} F_p t_p \Gamma^{\mu}_p.$$



$$F_{\Xi} = g_{\Xi} p_{3\lambda} f_{\Xi}(p_3^2; p_4^2, q_2^2)$$

$$t_{\Xi} = \frac{\not{q}_2 + m_{\Xi}}{q^2 - m_{\Xi}^2}$$

$$F_{\Lambda} = g_{\Lambda} \gamma_5 \not{p}_2 f_{\Lambda}(p_2^2; q_2^2, q_1^2)$$

$$t_{\Lambda} = \frac{\not{q}_2 + m_{\Xi}}{q_1^2 - m_{\Lambda}^2}$$

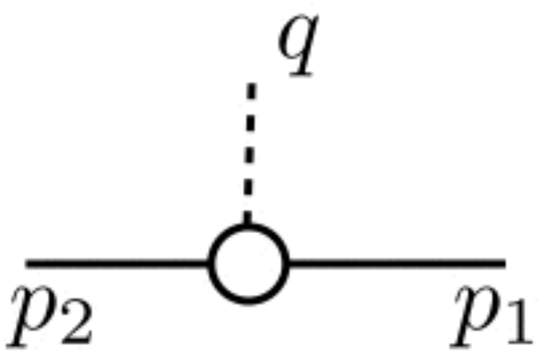
$$F_p = g_p \gamma_5 \not{p}_1 f_p(p_1^2; q_1^2, q_3^2)$$

$$t_p = \frac{\not{q}_3 + m_p}{q_3^2 - m_p^2}$$

$$\Gamma^{\mu}_p = \left[I + \frac{\kappa_p}{2m_p} \not{k}_1 \right] \gamma^{\mu}.$$

Formalism

□ form factors



$$F(q^2; p_1^2, p_2^2) = f_M(q^2) f_B(p_1^2) f_B(p_2^2)$$

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

$$f_M(q^2) = \frac{\Lambda_K^2 - m_K^2}{\Lambda_K^2 - q^2}$$

$$f_{K^*}(q^2) = \exp\left(\frac{q^2 - m_{K^*}^2}{\Lambda_{K^*}^2} \right)$$

Formalism

- parameters in the present work

Nucleon:		
m_N (MeV)	938.3	PDG
$\kappa_{p\gamma}, \kappa_{n\gamma}$	1.79, −1.91	
$\Xi(1318)$:		
m_Ξ (MeV)	1318.0	
$\kappa_{\Xi^0\gamma}, \kappa_{\Xi^-\gamma}$	−1.25, 0.35	PDG
$\Xi^*[=\Xi(1530)]$:		
$m_{\Xi^*}(\Gamma_{\Xi^*})$ (MeV)	1533.0 (9.5)	PDG
$\Lambda(1116)$:		
m_Λ (MeV)	1115.7	PDG
$g_{N\Lambda K}$	−13.24	SU(3) + ($f/d = 0.575$ and $g_{NN\pi} = 13.26$)
$g_{\Xi\Lambda K}$	3.52	SU(3) + ($f/d = 0.575$ and $g_{NN\pi} = 13.26$)
$g_{\Xi^*\Lambda K}$	5.58	SU(3) + ($f_{N\Delta\pi} = 2.23$)
$g_{N\Lambda K^*}(\kappa_{N\Lambda K^*})$	−6.11 (2.43)	Ref. [15] (version NSC97f)
$g_{\Xi\Lambda K^*}(\kappa_{\Xi\Lambda K^*})$	6.11 (0.65)	Ref. [15] (version NSC97f)
$\kappa_{\Lambda\gamma}$	−0.613	PDG
$\Lambda(1405)$:		
$m_\Lambda(\Gamma_\Lambda)$ (MeV)	1406.0 (50.0)	PDG
$g_{N\Lambda K}$	±0.91	SU(3) (flavor-singlet assumptions)
$g_{\Xi\Lambda K}$	±0.91	SU(3) (flavor-singlet assumptions)
$\kappa_{\Lambda\gamma}$	0.25	Skyrme model [16], unitarized ChPT [17]

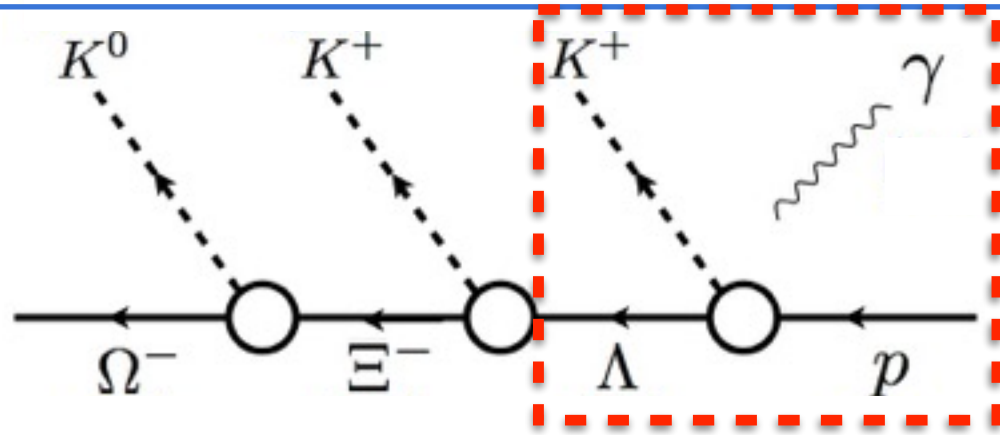
Formalism

□ parameters in the present work

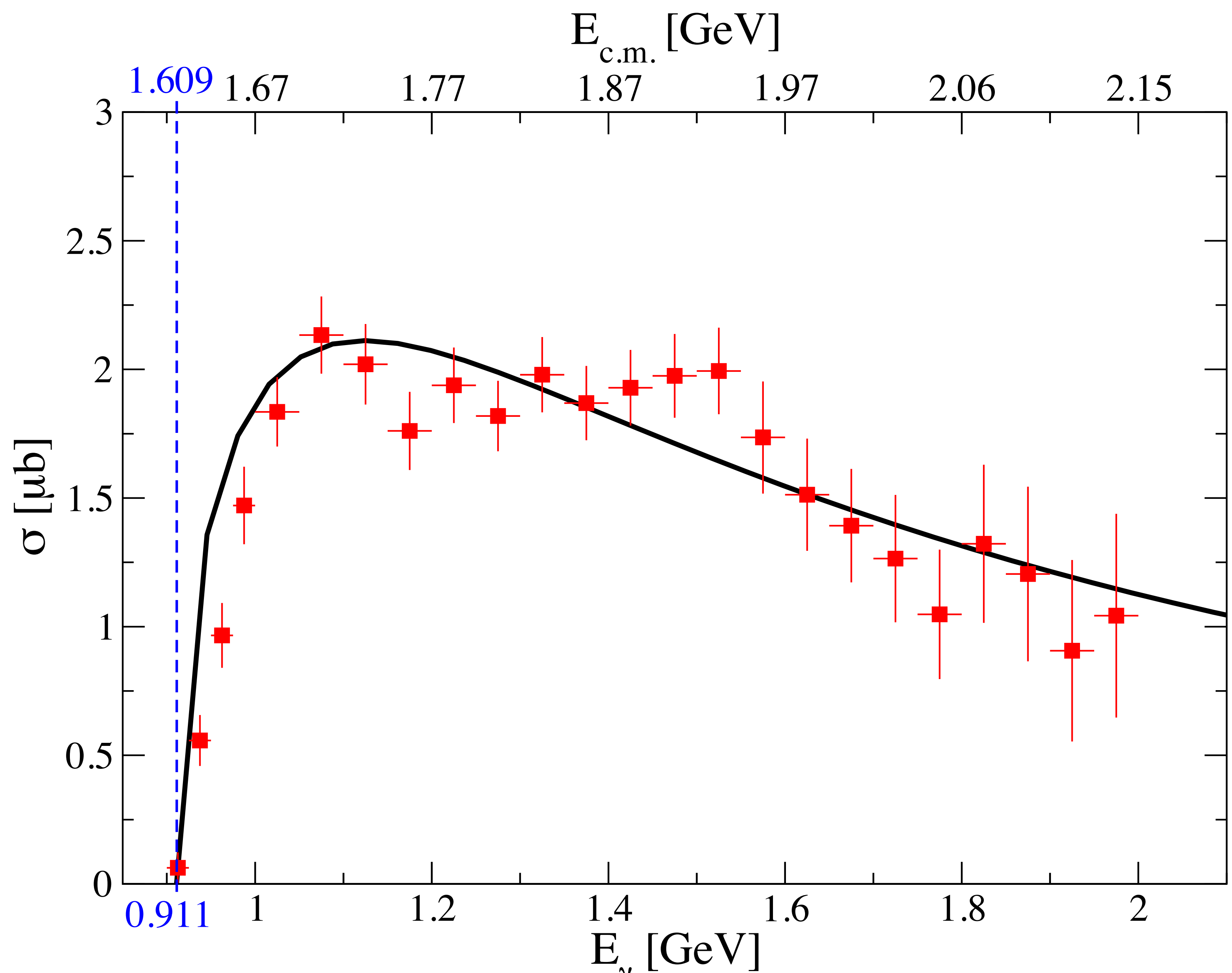
Σ(1193):		
m_Σ (MeV)	1193.0	PDG
$g_{N\Sigma K}$	3.58	SU(3) + ($f/d = 0.575$ and $g_{NN\pi} = 13.26$)
$g_{\Xi\Sigma K}$	−13.26	SU(3) + ($f/d = 0.575$ and $g_{NN\pi} = 13.26$)
$g_{\Xi^*\Sigma K}$	3.22	SU(3) + ($f_{N\Delta\pi} = 2.23$)
$g_{N\Sigma K^*}(\kappa_{N\Sigma K^*})$	−3.52 (−1.14)	Ref. [15] (version NSC97f)
$g_{\Xi\Sigma K^*}(\kappa_{\Xi\Sigma K^*})$	−3.52 (4.22)	Ref. [15] (version NSC97f)
$\kappa_{\Sigma^+\gamma}, \kappa_{\Sigma^0\gamma}, \kappa_{\Sigma^-\gamma}$	1.46, 0.65, −0.16	PDG
Λ(1520):		
$m_\Lambda(\Gamma_\Lambda)$ (MeV)	1519.5 (15.6)	PDG
$g_{N\Lambda K}$	−10.90	PDG, SU(3) (flavor-octet assumption)
$g_{\Xi\Lambda K}$	3.27	PDG, SU(3) (flavor-octet assumption)
$\kappa_{\Lambda\gamma}$	0.0	assumption
Σ(1385):		
$m_\Sigma(\Gamma_\Sigma)$ (MeV)	1384.0 (37.0)	PDG
$g_{N\Sigma K}$	−3.22	SU(3) + ($f_{N\Delta\pi} = 2.23$)
$g_{\Xi\Sigma K}$	−3.22	SU(3) + ($f_{N\Delta\pi} = 2.23$)
$f_{\Xi^*\Sigma K}$	−2.83	SU(3) + ($f_{\Delta\Delta\pi} = 0.8$ from quark model)
$g^{(1)}_{N\Sigma K^*}, g^{(2)}_{N\Sigma K^*}$	−5.47, 0.0	SU(3) + ($f_{N\Delta\rho} = 5.5$)
$g^{(1)}_{\Xi\Sigma K^*}, g^{(2)}_{\Xi\Sigma K^*}$	−5.47,0.0	SU(3) + ($f_{N\Delta\rho} = 5.5$)
$\kappa_{\Sigma^+\gamma}, \kappa_{\Sigma^0\gamma}, \kappa_{\Sigma^-\gamma}$	2.11, 0.32, −1.47	quark model [18]

$g_{\Omega\Xi K}$	7.5	SU(3) & χ quark model

Numerical Result



$\gamma\, p \to K^+ \Lambda(1116)$



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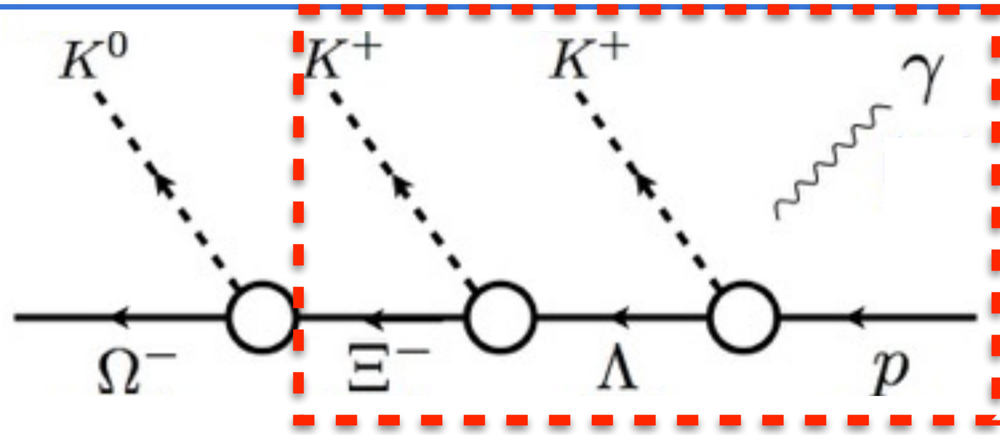
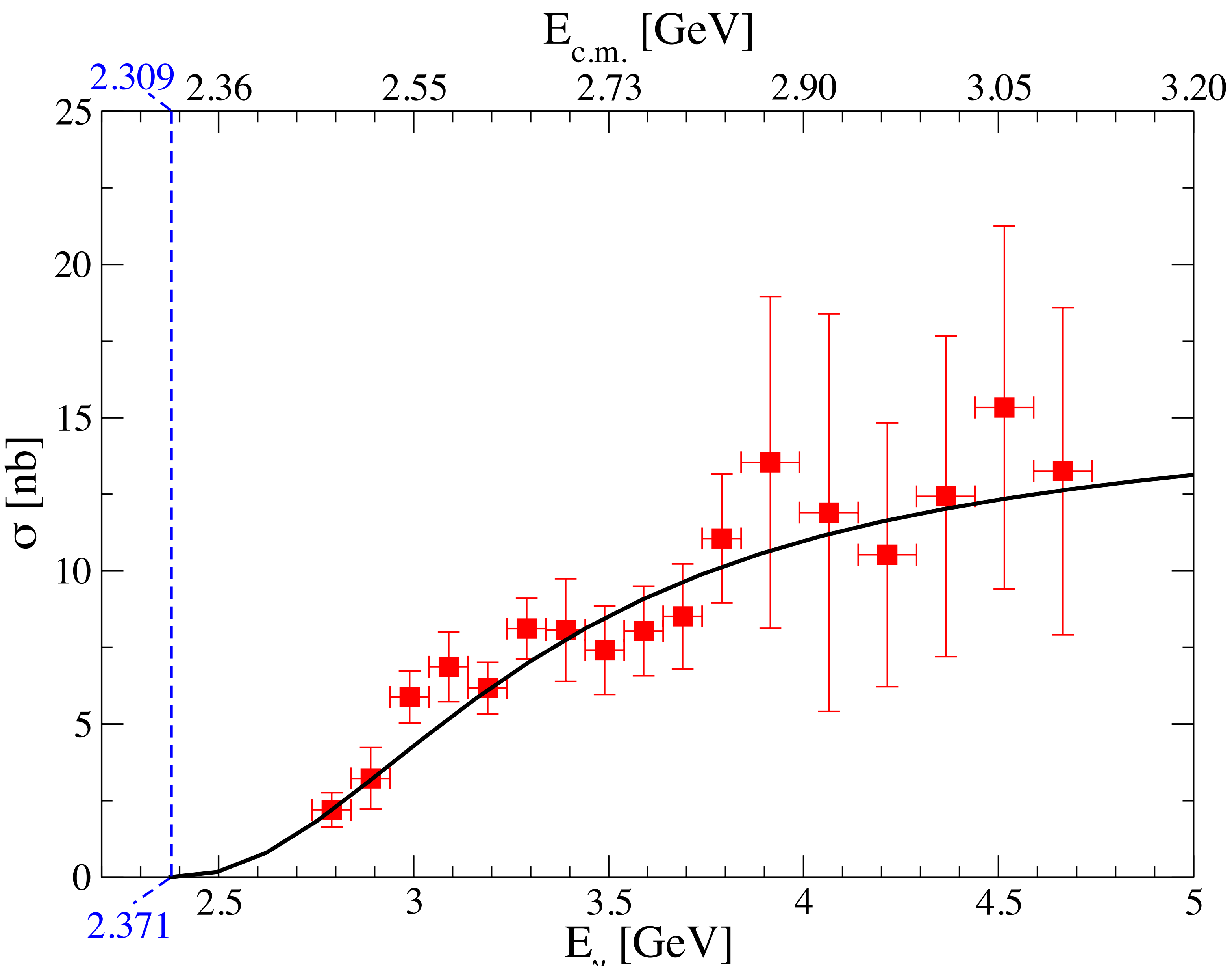
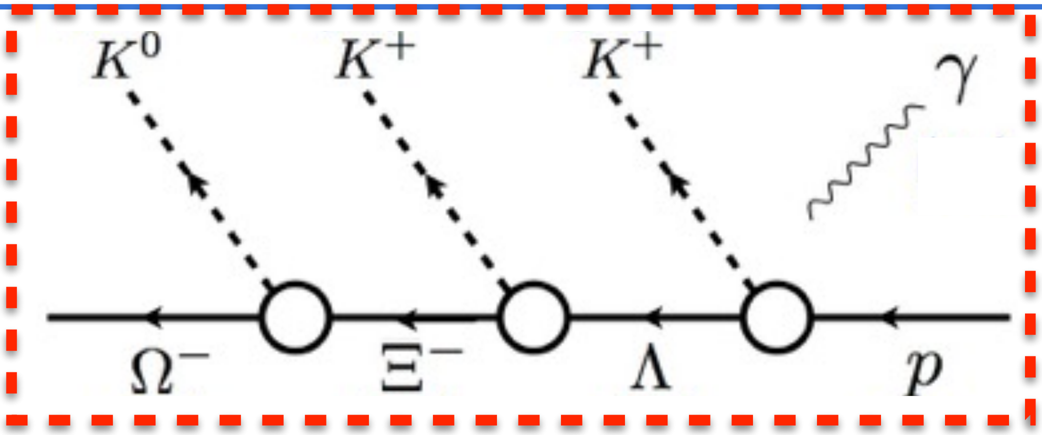


$\gamma\, p \to K^+ K^+ \Xi^-$

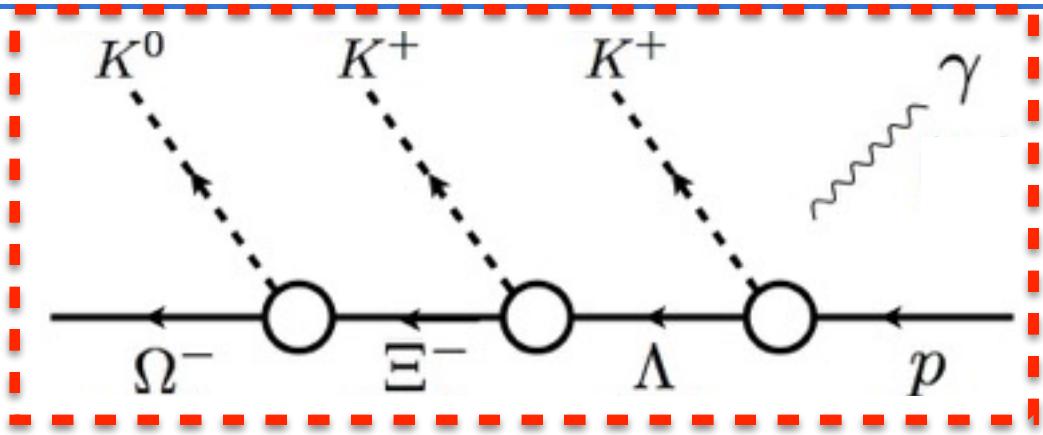


Numerical Result



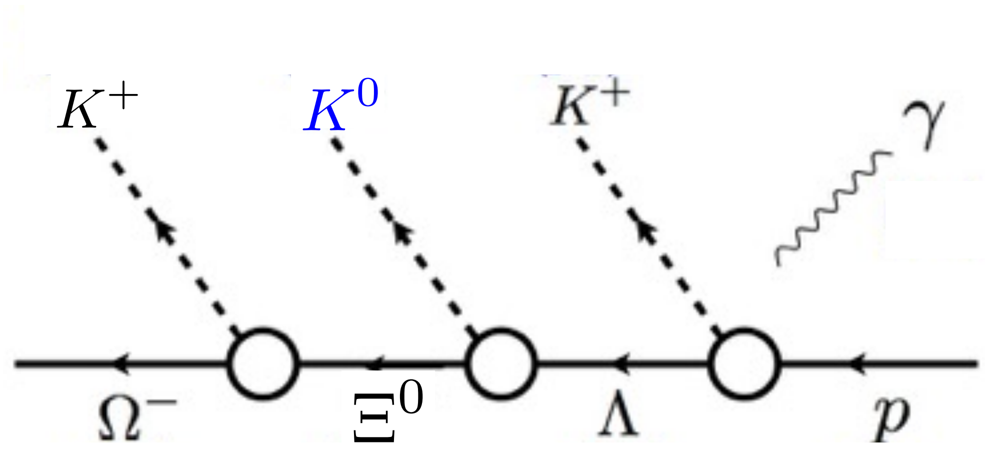
$$\gamma\, p \to K^+ K^+ K^0 \Omega^-$$

Numerical Result



$\gamma\, p \to K^+ K^+ K^0 \Omega^-$

+



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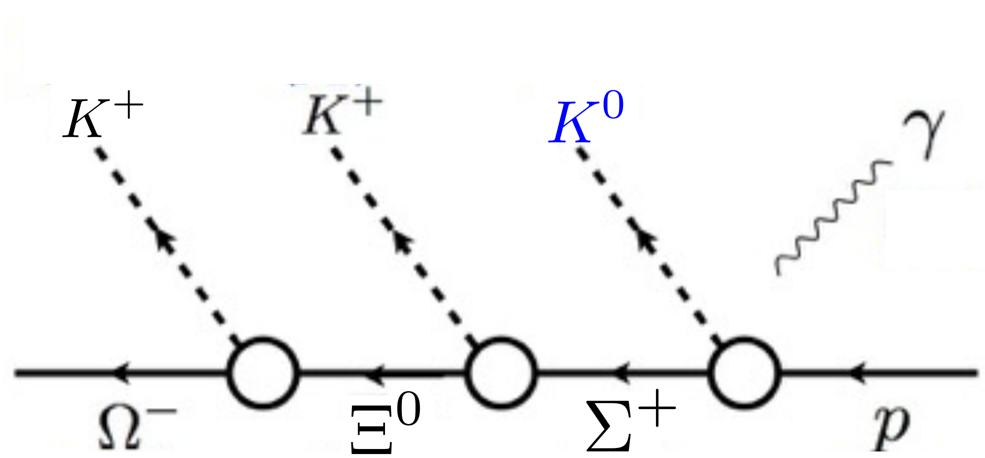
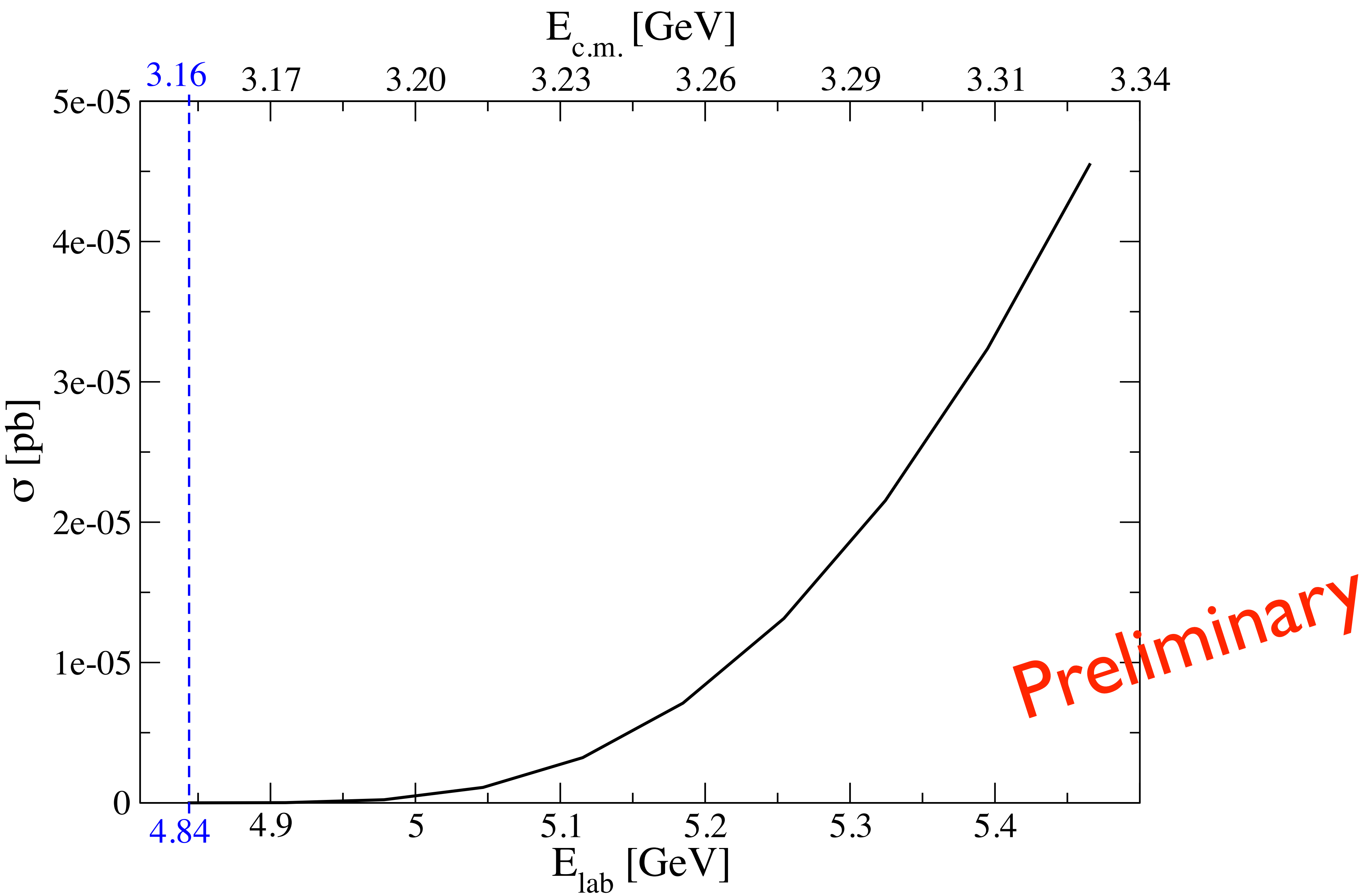


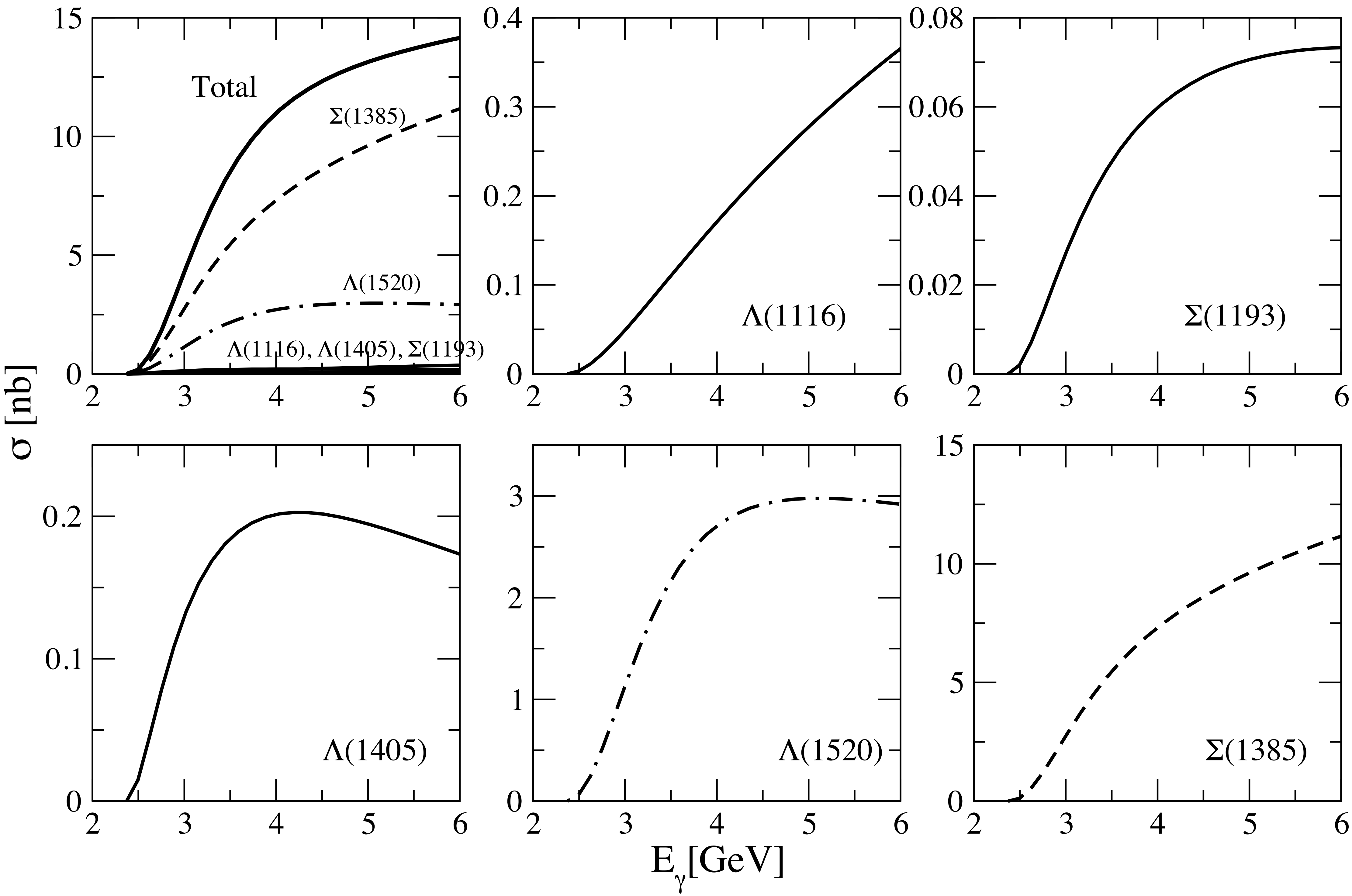
Numerical Result



Discussion

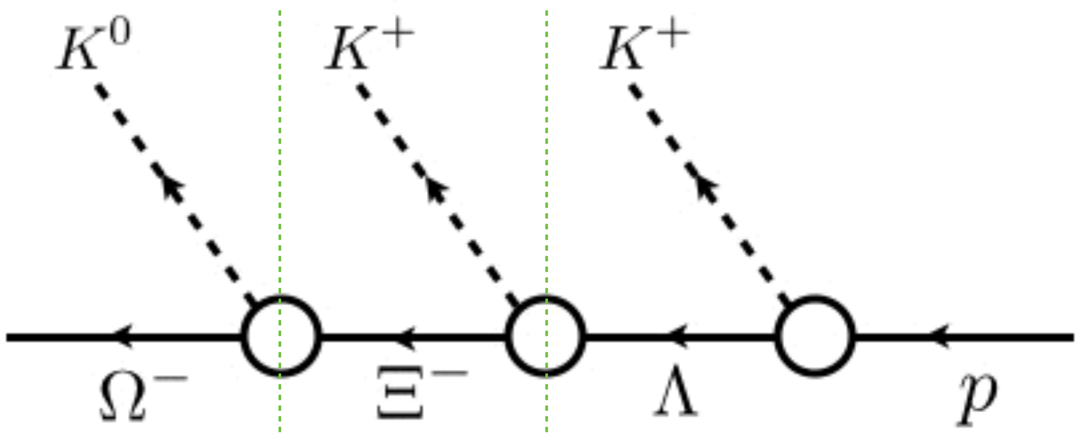
Why so small ?

Revisited to $\gamma p \to K^+ K^+ \Xi^-$

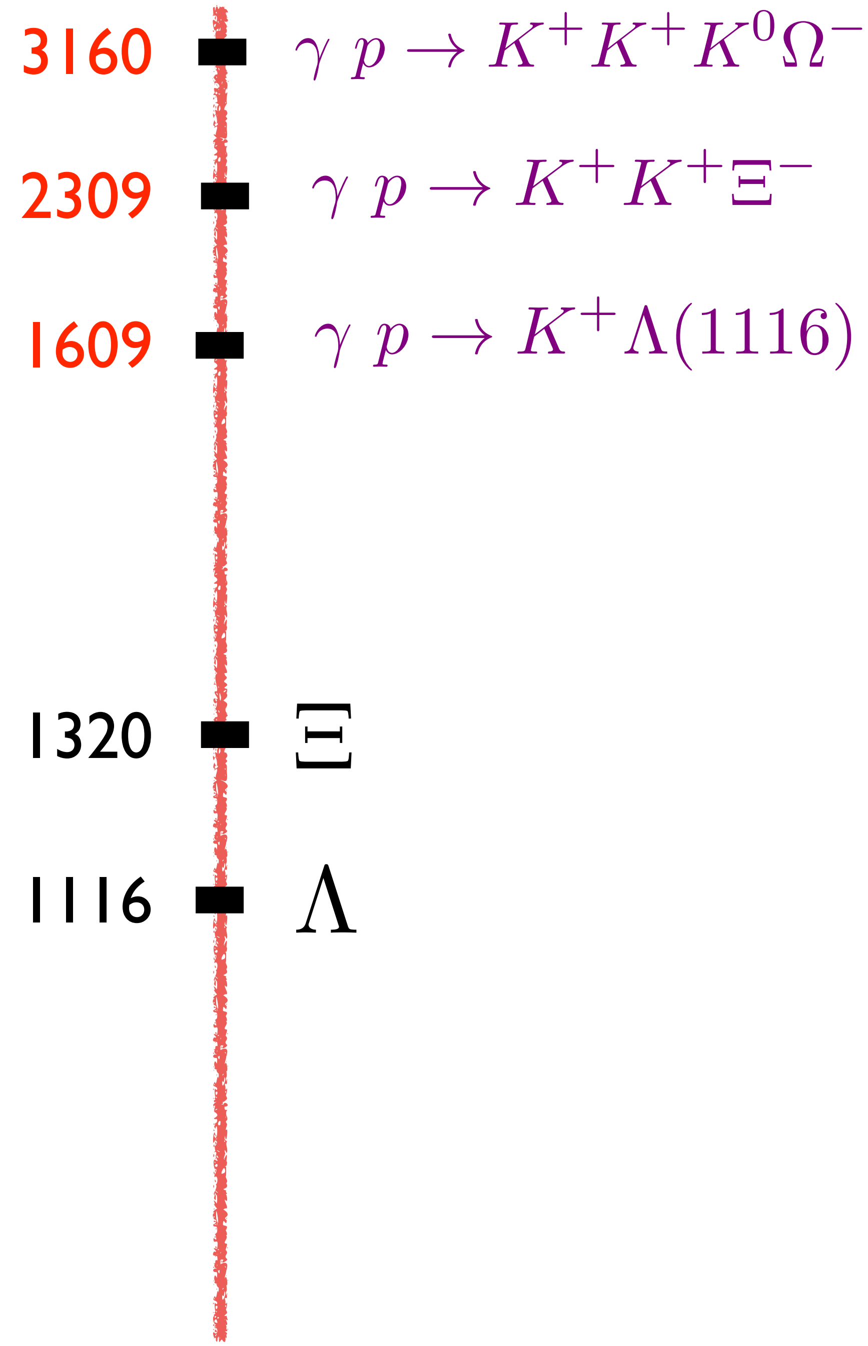


Discussion

Why so small ?

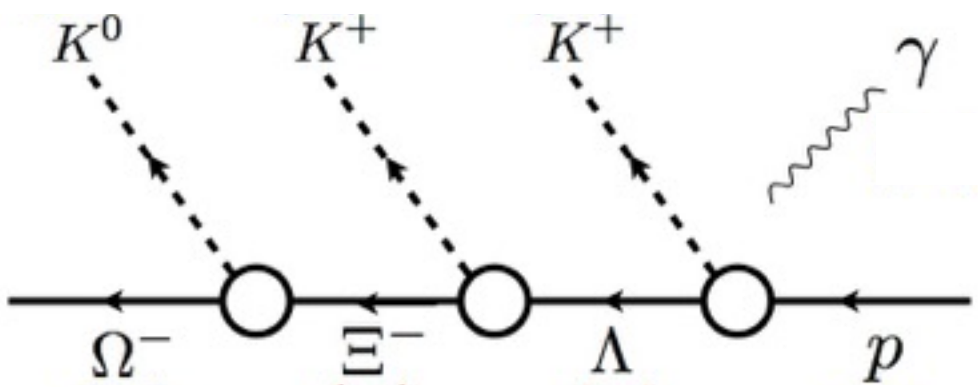


Ξ^-	Λ
1320	1116
1530	1405
1690	1520
1820	1600
1950	⋮
2030	2100
	2110
	2350



Future work

$$\gamma p \to K^+ K^+ K^0 \Omega^-$$



$\Lambda(1116)$
$\Lambda(1405)$
$\Lambda(1520)$
$\Sigma(1193)$
$\Sigma(1385)$

$\Xi, \Xi^* \cdots \ (N)$

\# of diagrams

30

5x30=150

150 N

Future work

STEP 1

Consider intermediate states of spin-1/2, 3/2

STEP 2

Consider intermediate states of higher spin (5/2, 7/2…)

STEP 3

Consider kaon beam induced Omega baryon production

$$\bar{K}N \to KKK\Omega^-$$

Summary

✅ In the present work, we show the total cross section of Omega production with ground baryon states.

✅ The result with only ground state baryon gives us very small cross section.

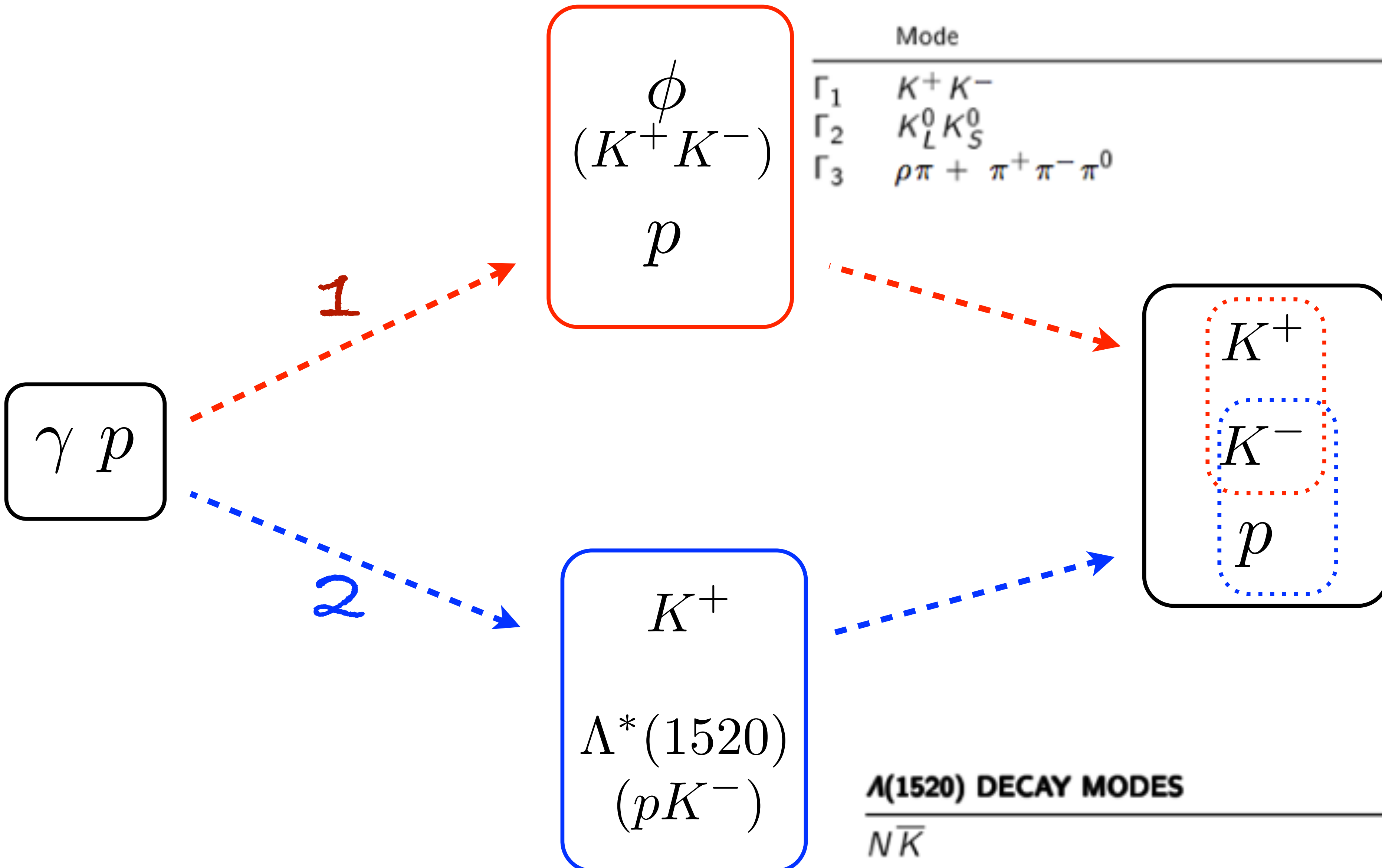
✅ The previous hyperon production study tell us that we need to consider massive resonances with higher spin

✅ From this, we would like to suggest the minimum or range cross section to investigate properties of VERY strange baryons.

PART 2

$$\gamma p \to K^+ K^- p$$

Motivation



ϕ(1020) DECAY MODES

	Mode	Fraction (Γ_i/Γ)
Γ_1	K^+K^-	(48.9 $\pm$0.5) %
Γ_2	$K^0_L K^0_S$	(34.2 $\pm$0.4) %
Γ_3	$\rho\pi + \pi^+\pi^-\pi^0$	(15.32 $\pm$0.32) %

Λ(1520) DECAY MODES	Fraction (Γ_i/Γ)
$N\overline{K}$	45 $\pm$ 1%
$\Sigma\pi$	42 $\pm$ 1%

Formalism

$$\mathcal{M}(\gamma p \to K\bar{K}p) = \mathcal{M}(\gamma p \to \phi p \to K\bar{K}p)$$
$$+\mathcal{M}(\gamma p \to \Lambda^* p \to K\bar{K}p) + \text{background}$$

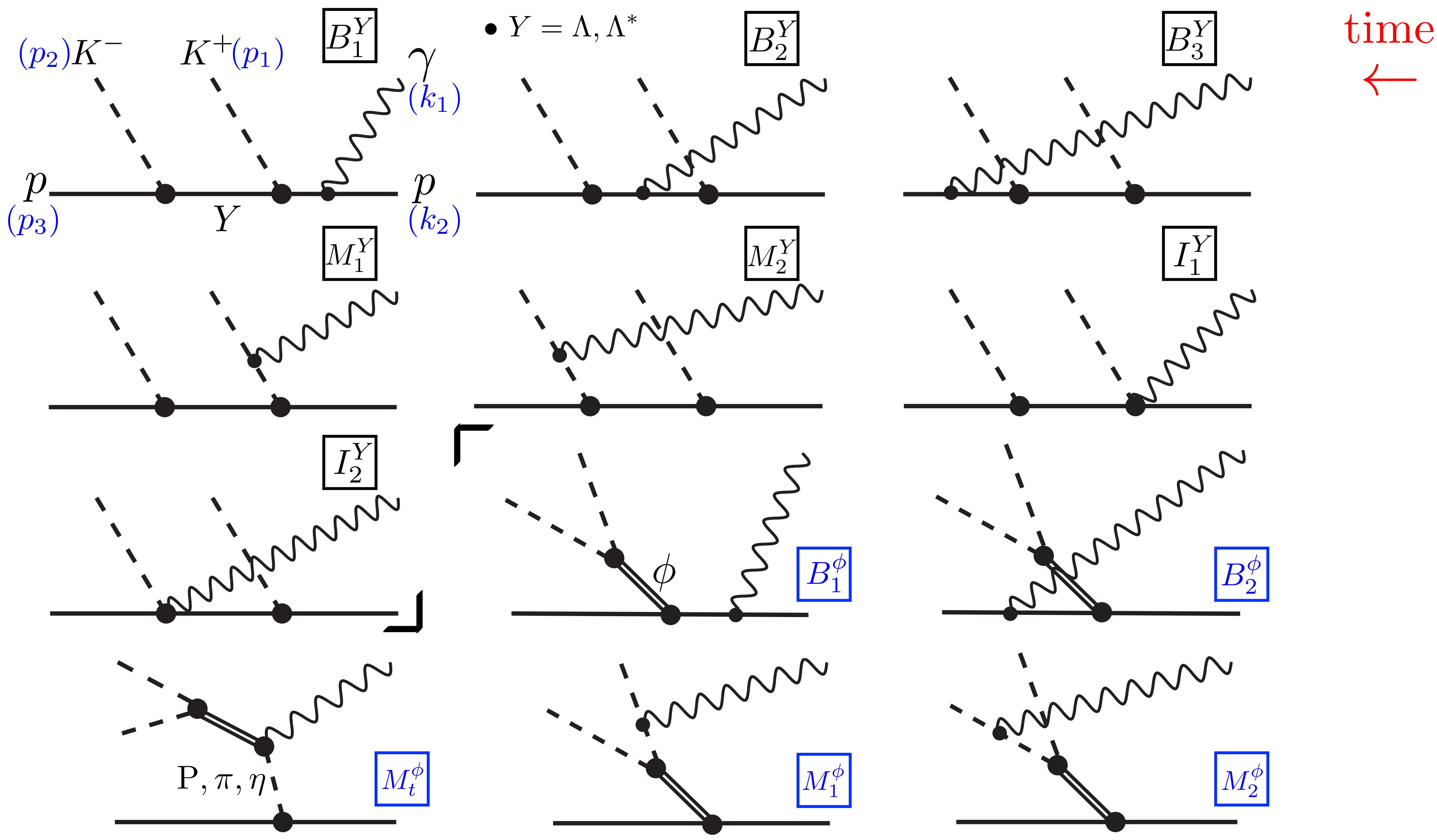
- $$\mathcal{M}(\gamma p \to \phi p \to K\bar{K}p) = \mathcal{M}(\phi p \to K\bar{K}p)\frac{1}{q_\phi^2 - (m_\phi - i\Gamma_\phi/2)^2}\mathcal{M}(\gamma p \to \phi p)$$

- $$\mathcal{M}(\gamma p \to K\Lambda^* \to K\bar{K}p) = \mathcal{M}(\Lambda^* p \to K\bar{K}p)\frac{1}{\not{q}_\Lambda - (m_\Lambda - i\Gamma_\Lambda/2)}\mathcal{M}(\gamma p \to \Lambda^* p)$$

Formalism

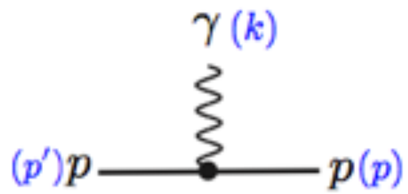
□ Diagrams

$$\mathcal{M} = \overline{u}(p')\mathcal{W}u(p)$$

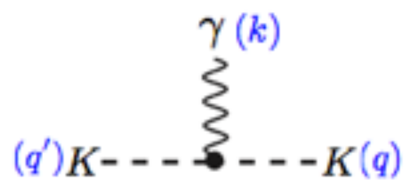


Formalism

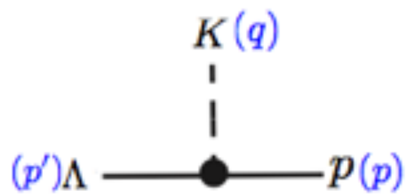
- Vertex functions



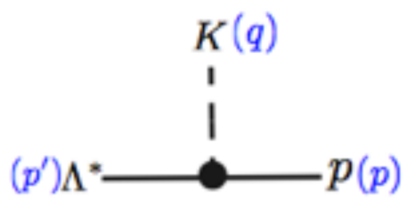
$$\Gamma^{\nu}_{\gamma pp} = -e\left[I + \frac{\kappa_p}{2m_p}\not{k}\right]\gamma^{\mu}$$



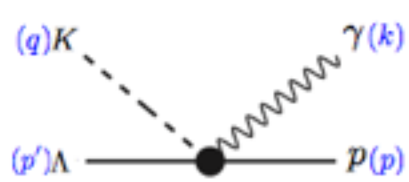
$$J^{\nu}_{\gamma KK} = e(q+q')^{\nu}$$



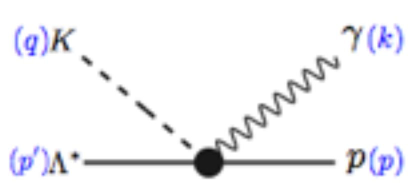
$$F^{\mu}_{Kp\Lambda} = \Gamma^{\mu}_{Kp\Lambda}\times f(q^2;p^2p'^2), \quad \left(\Gamma^{\mu}_{Kp\Lambda} = \frac{g_{Kp\Lambda}}{m_K}\gamma_5\not{q}\right)$$



$$F^{\mu}_{Kp\Lambda^*} = \Gamma^{\mu}_{Kp\Lambda^*}\times f(q^2;p^2p'^2), \quad \left(\Gamma^{\mu}_{Kp\Lambda^*} = \frac{g_{Kp\Lambda^*}}{m_K}\gamma_5 q^{\mu}\right)$$

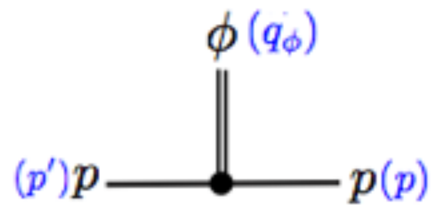


$$I^{\mu\nu}_{\gamma Kp\Lambda} = \Gamma^{\mu}_{Kp\Lambda}C^{\nu}_{\Lambda} + \Gamma^{\mu\nu}_{\gamma Kp\Lambda}f_t, \quad \left(\Gamma^{\mu\nu}_{\gamma Kp\Lambda} = -e\frac{g_{Kp\Lambda^*}}{m_K}\gamma_5\not{\epsilon}_{\gamma}\right)$$

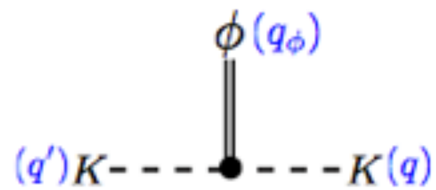


$$I^{\mu\nu}_{\gamma Kp\Lambda^*} = \Gamma^{\mu}_{Kp\Lambda^*}C^{\nu}_{\Lambda^*} + \Gamma^{\mu\nu}_{\gamma Kp\Lambda^*}f_t, \quad \left(\Gamma^{\mu\nu}_{\gamma Kp\Lambda^*} = -e\frac{g_{Kp\Lambda^*}}{m_K}\gamma_5 g^{\mu\nu}\right)$$

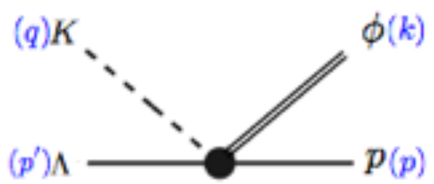
Formalism



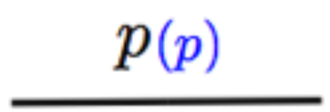
$$J^{\nu}_{\gamma KK} = e(q+q')^{\nu}$$



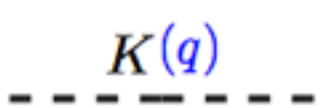
$$J^{\nu}_{\gamma KK} = e(q+q')^{\nu}$$



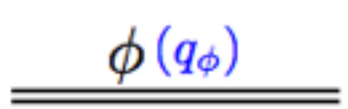
$$\Gamma^{\mu\nu}_{\phi K p \Lambda^*} = -g_{\phi KK}\frac{g_{Kp\Lambda^*}}{m_K}\gamma_5 g^{\mu\nu} = e(q+q')^{\nu}$$



$$t_p = \frac{\not{p}+m_p}{p^2-m_p^2}$$



$$\Delta_K = \frac{1}{q^2-m_K^2} = e(q+q')^{\nu}$$



$$\Delta^{\mu\nu}_{\phi} = \frac{1}{q_\phi^2-m_\phi^2}\left(-g^{\mu\nu}+\frac{q_\phi^\mu q_\phi^\nu}{m_\phi^2}\right)$$

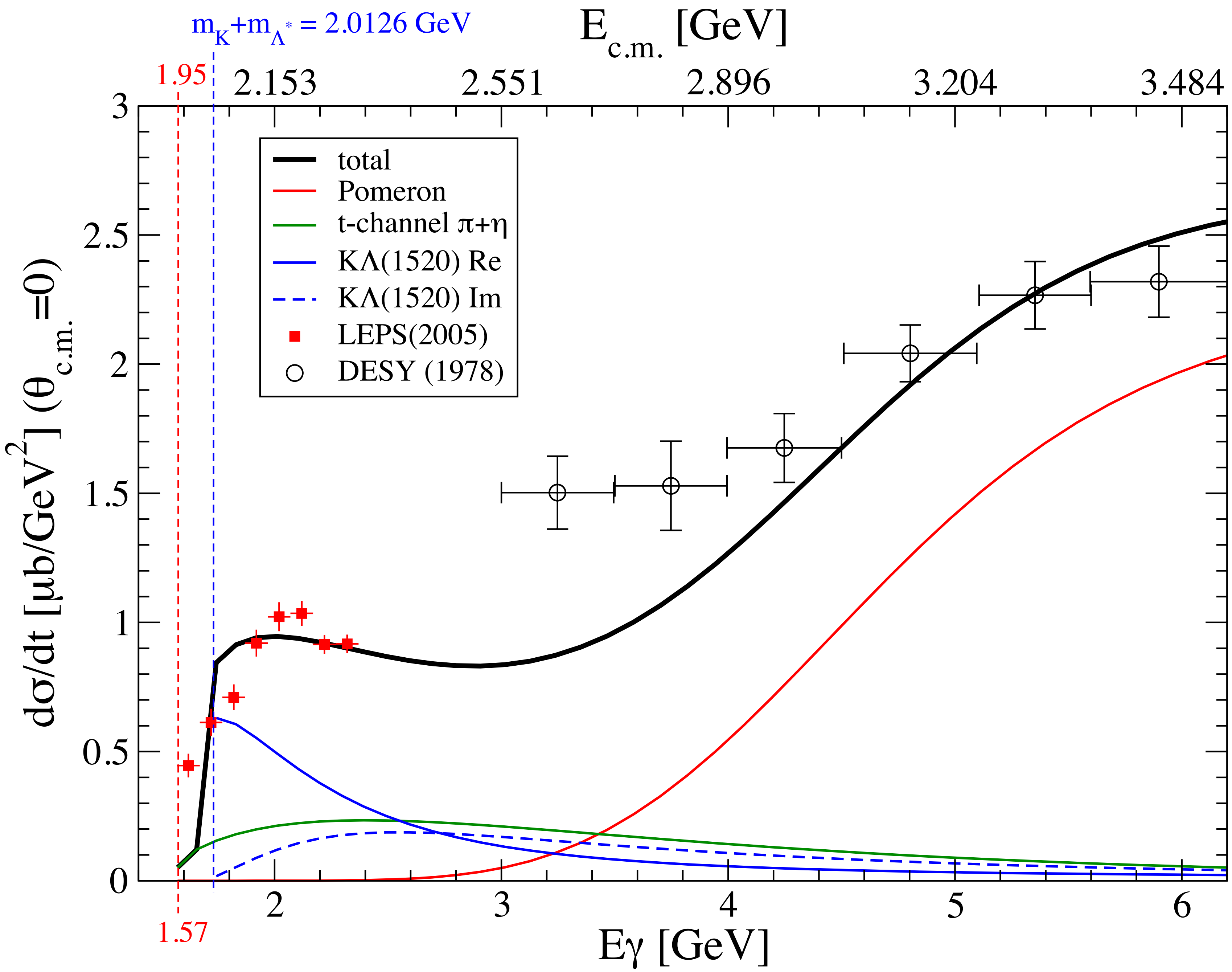
Formalism

- parameters in the present work

Nucleon	m_p	3.25
	κ_p	1.79
background	$g_{KN\Lambda}$	3.18
	κ_Λ	-0.613
	Λ_Λ	0.745 GeV
phi resonance	$g_{\phi NN}$	0.25
	$\kappa_{\phi KK}$	0.2
	n	1
	Λ_ϕ	0.7 GeV
L(1520) resonance	$g_{KN\Lambda^*}$	10.5
	κ_{Λ^*}	0
	n	1
	Λ_{Λ^*}	0.65 GeV

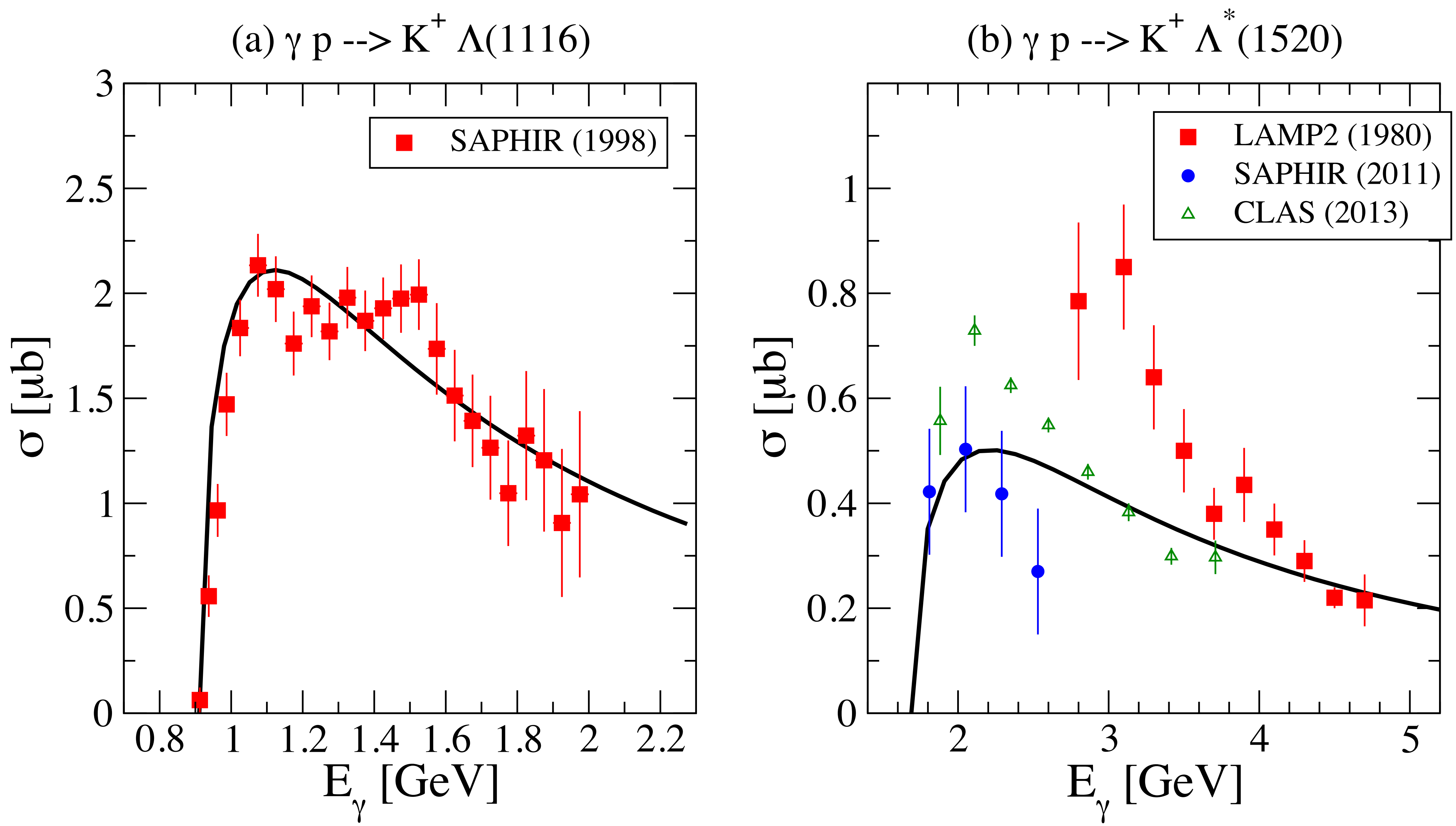
Numerical Result

- $\gamma p \to \phi p$

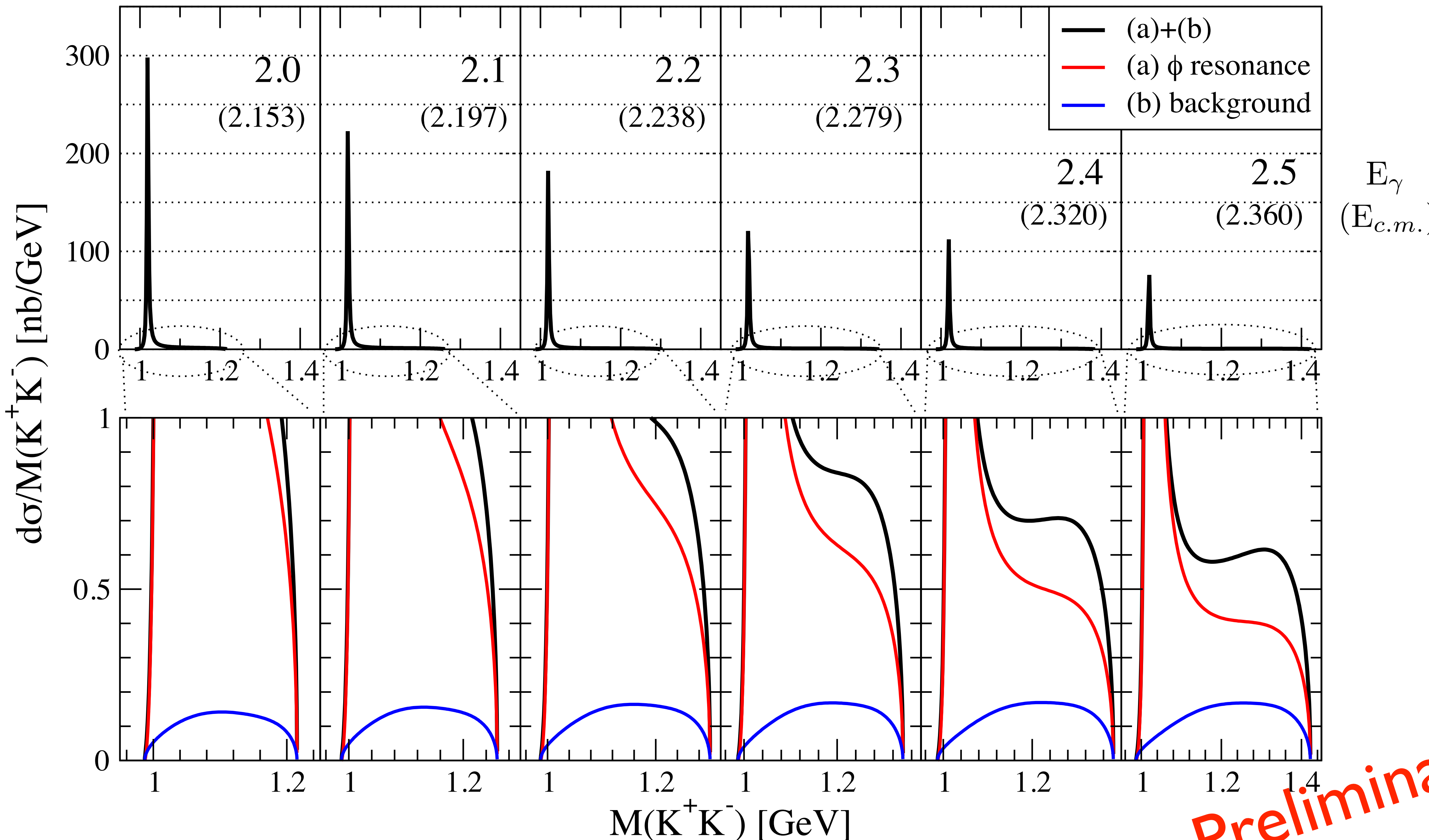


Numerical Result

□ $\gamma p \to K^+\Lambda$ / $\gamma p \to K^+\Lambda^*(1520)$

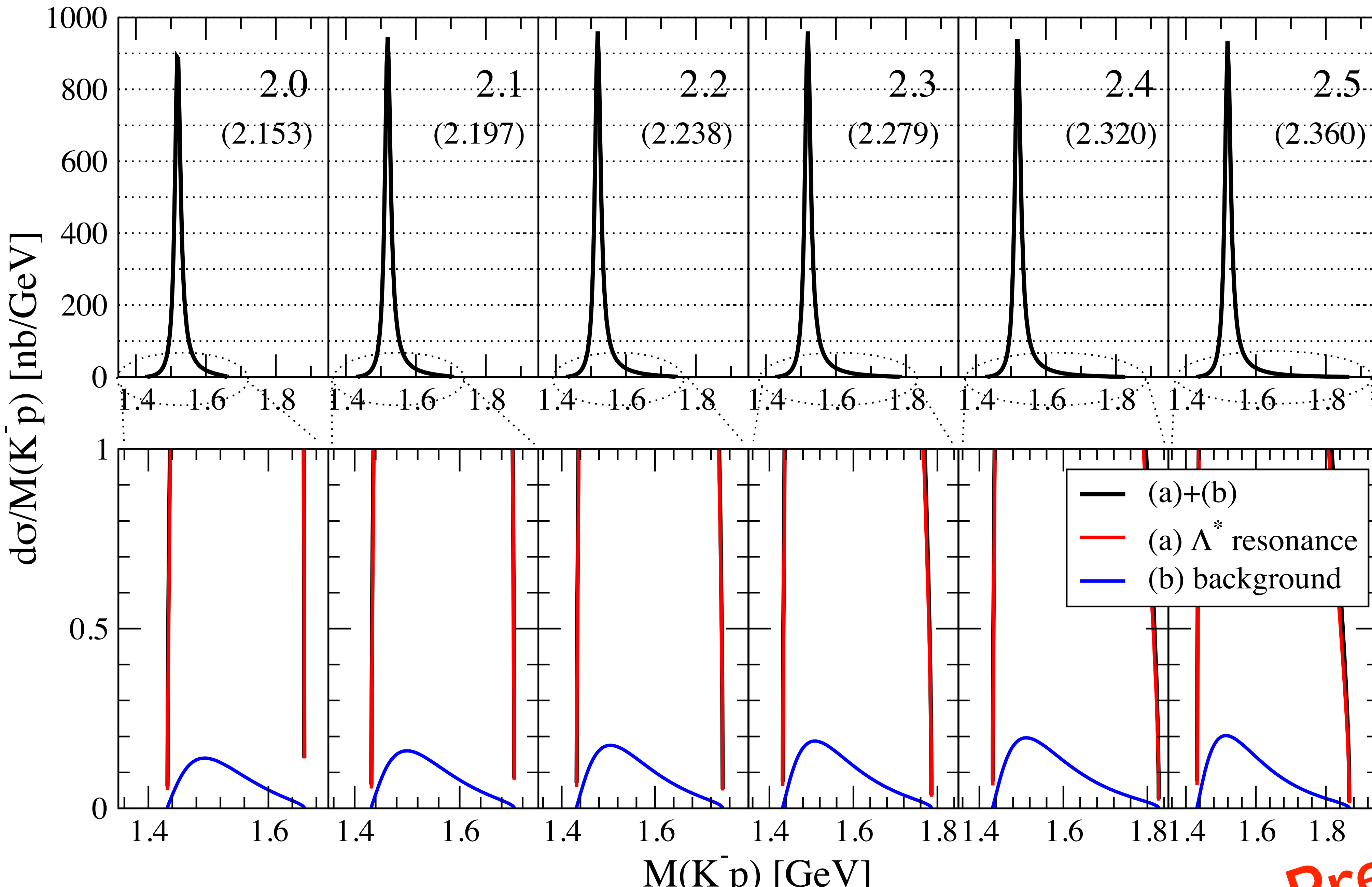


Numerical Result



Preliminary

Numerical Result



Preliminary

Numerical Result

Mibe et al, PRL 95, 182001 (2005)

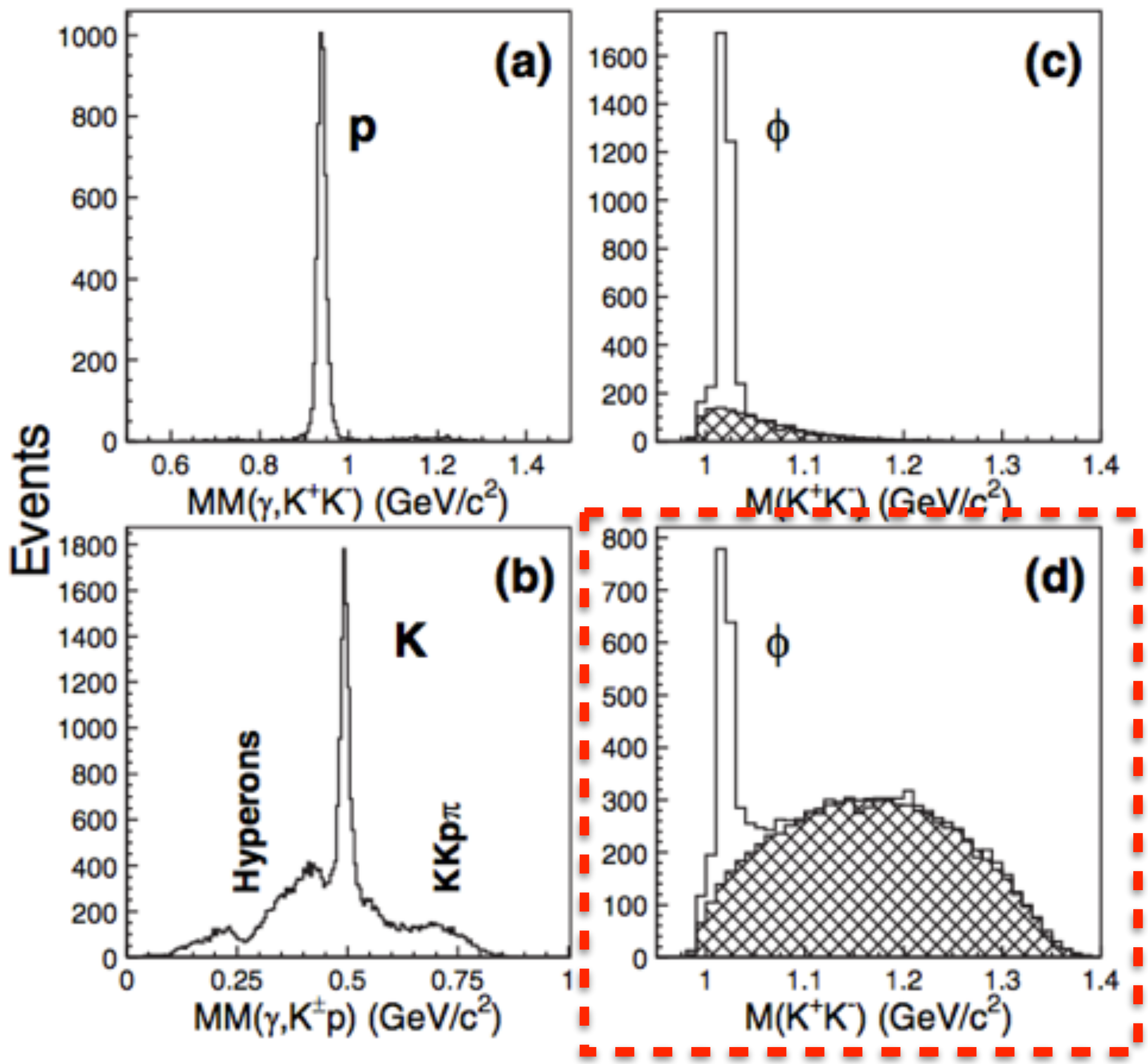
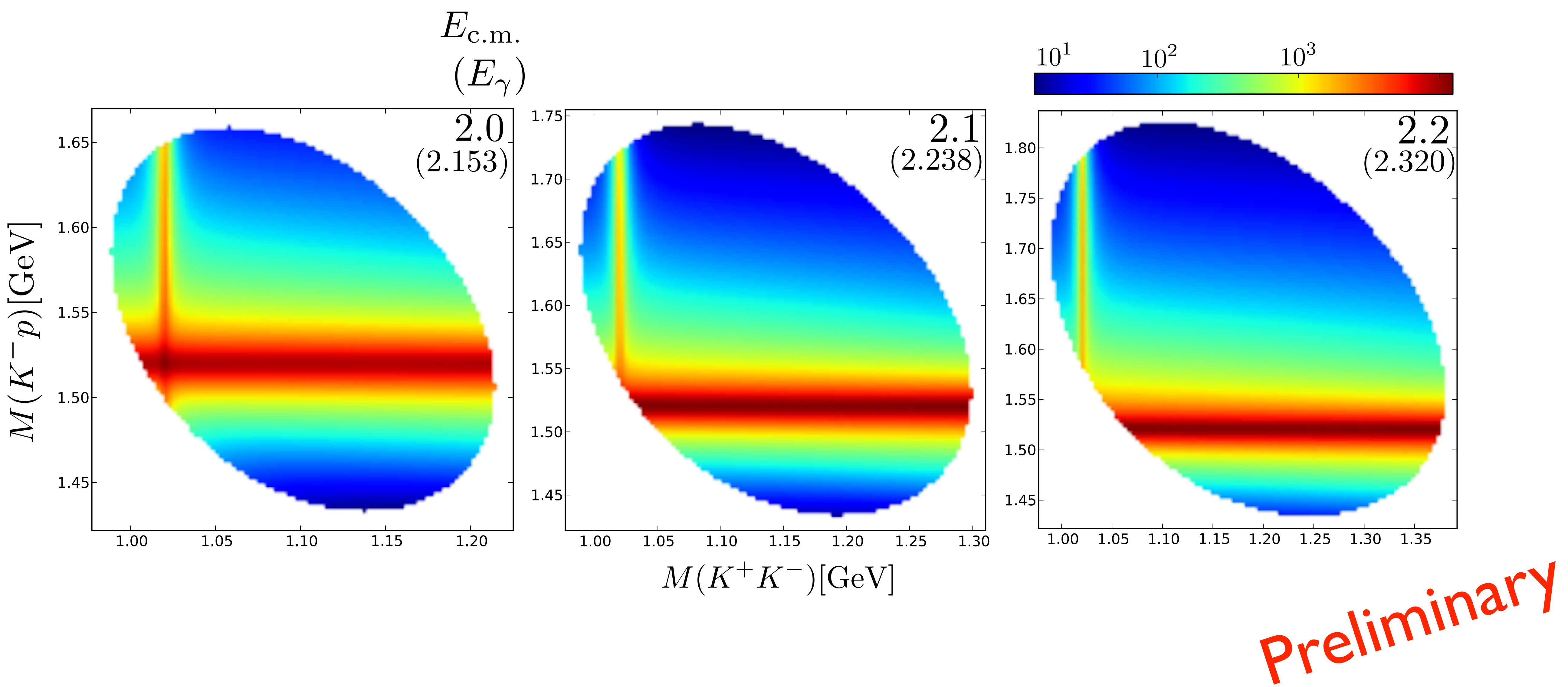


FIG. 1. (a) Missing mass distribution for the $p(\gamma, K^+K^-)X$ reaction in KK mode. (b) Missing mass distribution for the $p(\gamma, K^\pm p)X$ reaction in Kp mode. (c) and (d) are the K^+K^- invariant mass distributions after the cut on the missing mass for KK and Kp modes, respectively. The hatched histograms are the simulated background.

Numerical Result



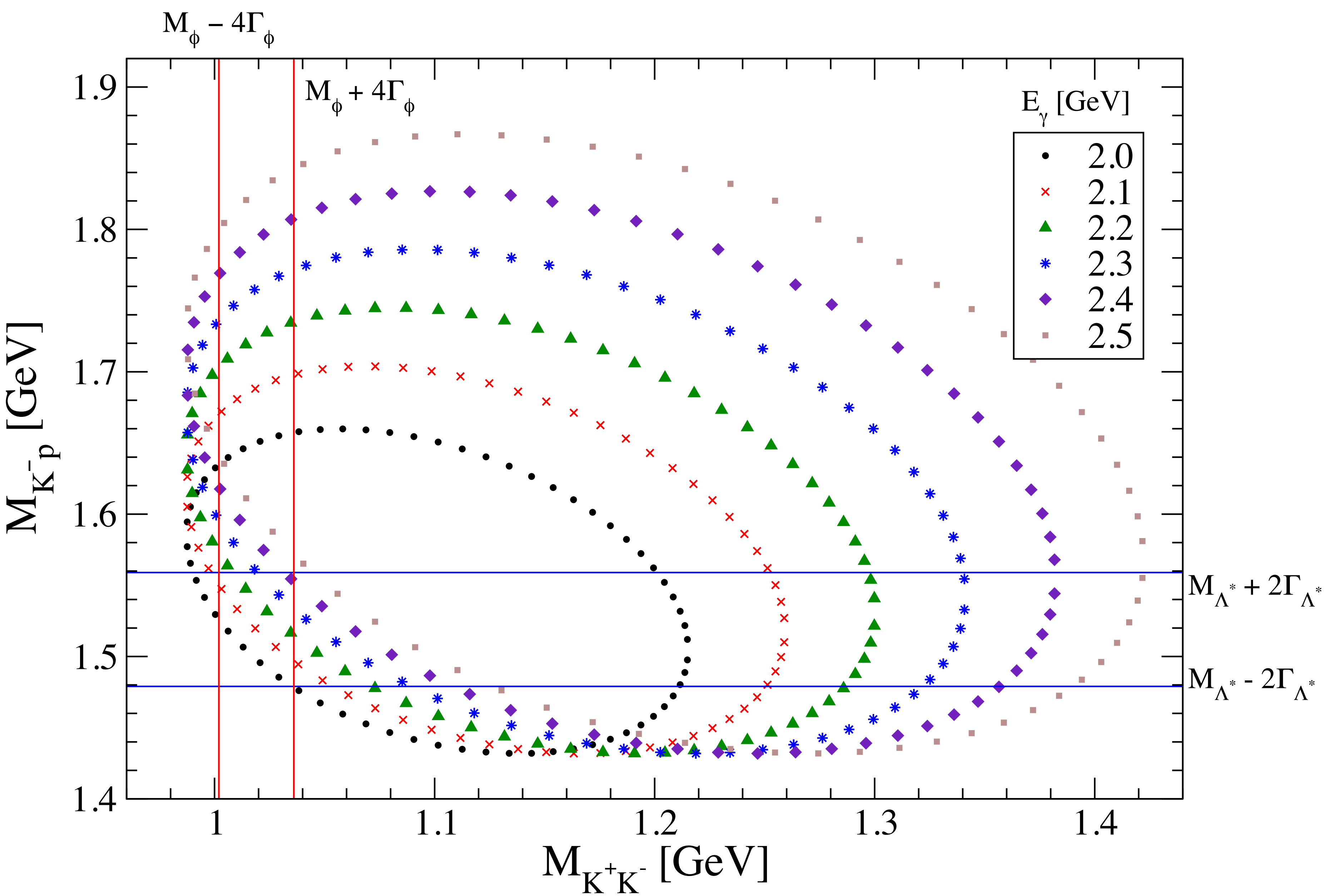
Summary

- ✅ From the known 2-body scattering process, we can directly calculate 3-body process.
- ✅ We show not only the invariant mass distribution but also the interference between phi and L(1520) resonances.
- ✅ This work will be good chance to understand the mechanism of K Kbar N production with upcoming LEPS data.
- ✅ Considering the previous experimental data and other possibility of intermediate states, we are improving our result.

$$\gamma p \to K^+ K^+ K^0 \Omega^-$$

	n	Λ_B	Λ_K	Λ_{K^*}
$\Lambda(1116)$	1	0.75	0.75	0.75
$\Xi^-(1321)$	2	1.25	1.25	1.25
$\Omega^-(1672)$	2	1.25	1.25	1.25

Numerical result (without the coupled channel)



Future work

$$T \simeq V + VGV$$ (present work)

$$T = V + VGT$$

$$T = \frac{1}{1 - VG} V$$

$$T = \begin{bmatrix} T_{\gamma p \to \gamma p} & T_{\gamma p \to \phi p} & T_{\gamma p \to K^+\Lambda^*} \\ T_{\phi p \to \gamma p} & T_{\phi p \to \phi p} & T_{\phi p \to K^+\Lambda^*} \\ T_{K^+\Lambda^* \to \gamma p} & T_{K^+\Lambda^* \to \phi p} & T_{K^+\Lambda^* \to K^+\Lambda^*} \end{bmatrix}$$

$$V = \begin{bmatrix} V_{\gamma p \to \gamma p} & V_{\gamma p \to \phi p} & V_{\gamma p \to K^+\Lambda^*} \\ V_{\phi p \to \gamma p} & V_{\phi p \to \phi p} & V_{\phi p \to K^+\Lambda^*} \\ V_{K^+\Lambda^* \to \gamma p} & V_{K^+\Lambda^* \to \phi p} & V_{K^+\Lambda^* \to K^+\Lambda^*} \end{bmatrix}$$

$$G = \begin{bmatrix} G_{\gamma p \to \gamma p} & 0 & 0 \\ 0 & G_{\phi p \to \phi p} & 0 \\ 0 & 0 & G_{K^+\Lambda^* \to K^+\Lambda^*} \end{bmatrix}$$

Introduction

Estimation I