Photoproduction of Φ and Λ(1520,1405)

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Introduction

Nucleon (N) and hyperon (Y) resonance searches

- Insight to hadron structures and production mechanisms
- Completion of hadron spectrum
- Strangeness physics from Y-resonances
- Exotic baryon searches: petanquark baryon

Experiments

- LEPS, Tohoku-LNS, CLAS, GRAAL, BONN-ELSA etc..
- η, K and ϕ photo- and electro-productions
- N*(1535), Σ*(1385), Λ*(1405), Λ*(1520) etc..
- Exotics: N*(1675) from LNS and GRAAL, and Θ(1540) from LEPS

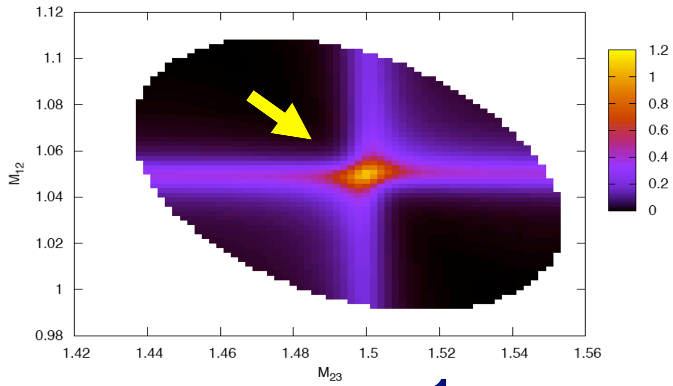
Introduction

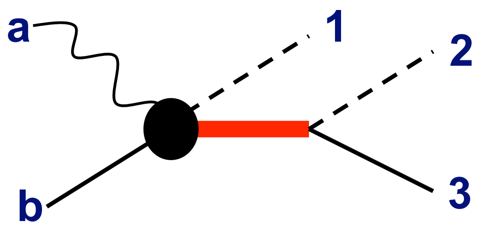
Theories

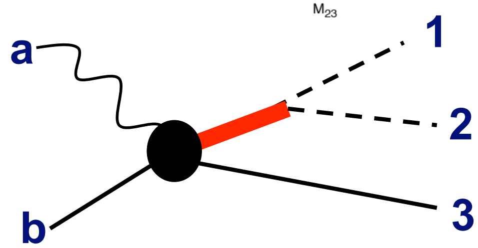
- Coupled channel methods: dynamical generation of resonances
- Effective Lagrangian methods: resonances as element fields
- Baryonic models: Skyrmion with excitation, CQSM, etc..

Resonances via three-body final state

- Three-body final state LIPS
- Dalitz-plot analyses for a,b → 1,2,3
- Resonances appear as strips

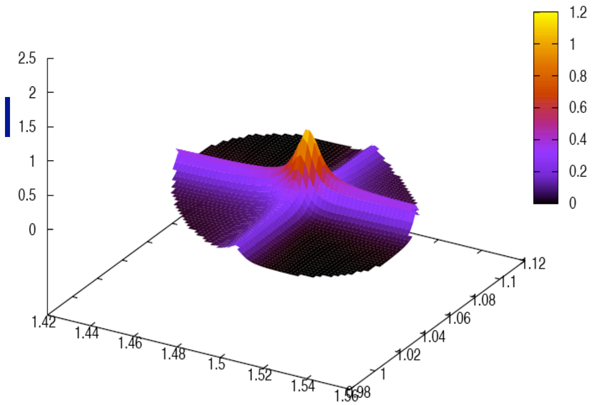






Introduction

Interference between resonances



- Constructive intereference → enhancing signal
- Sensitive to relative phase, strength, etc..

Low statistics in exotic baryon search

- Small coupling strength of $\Theta \to KN$ ~ 1 MeV
- $\sigma(\gamma N \to K\Theta)$ ~ a few nb: hard to be seen in production processes♪
- Strong constructive interference on Dalitz plot!? Amarian et al. *hep-ph/0612150*

False signals

- Resonance-like structure generated from kinematical reasons
- Resonance contribution + phase space

Introduction

A model calcaultion to test these topics (intereference & false signal)

Basic studies for further researches on resonances

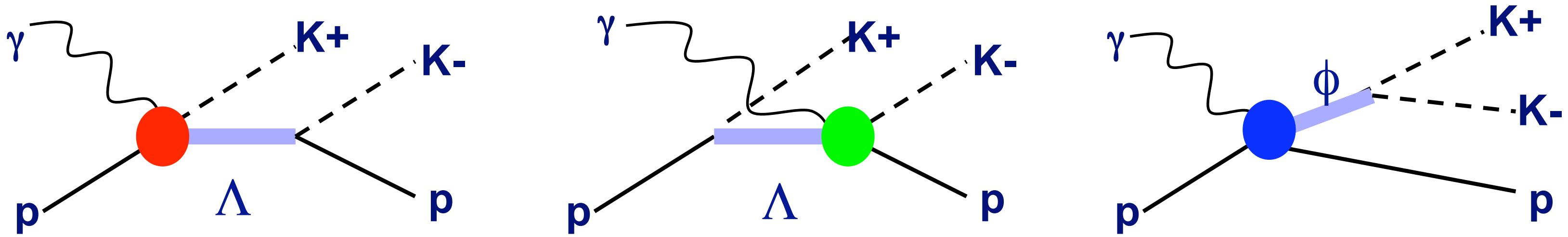
Theoretical method

- Considering $\gamma p \to K^+K^-p$ containing $\Lambda(1520)$ and $\phi(1020)$
- Considering the LEPS experimental setup: K^+ only in forward angle
- Employing an effective Lagrangian method
- Form factors in a gauge-invarinat manner
- Finally, plotting Dalitz plots

Theoretical framework

Feynman diagrams

- For the intereference pattern: Λ(1520)=Λ* and φ(1020) contribution only



- Red blob contains s-,t-,u-channels and contact term: gauge invariant
- Green blob contains s-,t-,u-*like* channels, contact term: gauge invariant
- Blue blob contains $F_{\mu\nu}$: gauge invariant itsself and pomeron effect
- Photon-Λ* coupled diagram ignored: neutral and no data for κ for Λ*
- K*-exchange contribution ignored: g(K*NΛ*) << 1

Theoretical framework

Effective Lagrangians

•Λ* cotnribution (Λ*=B*)

$$\mathcal{L}_{\gamma KK} = ie_K \left[(\partial^\mu K^\dagger)K - (\partial^\mu K)K^\dagger\right] A_\mu + \text{h.c.},$$
$$\mathcal{L}_{KNB^*} = \frac{g_{KNB^*}}{M_{B^*}} \bar{B}^{*\mu} \partial_\mu K \Gamma_5 \gamma_5 N + \text{h.c.},$$
$$\mathcal{L}_{\gamma KNB^*} = -i \frac{e_N g_{KNB^*}}{M_{B^*}} \bar{B}^{*\mu} A_\mu K \Gamma_5 \gamma_5 N + \text{h.c.},$$

•Rarita-Schwing vector-spinor fields for Λ*

•Λ*(spin-3/2) propagator ~ spin-1/2 propagator for low-energy region

•g(KNΛ*) obtained from exp. data

Theoretical framework

Effective Lagrangians

•ϕ contribution

$$\mathcal{L}_{\phi KK} = i g_{KK\phi} \phi^{\mu} \left[(\partial_{\mu} K^{\dagger}) K - (\partial_{\mu} K) K^{\dagger} \right] + \text{h.c.},$$

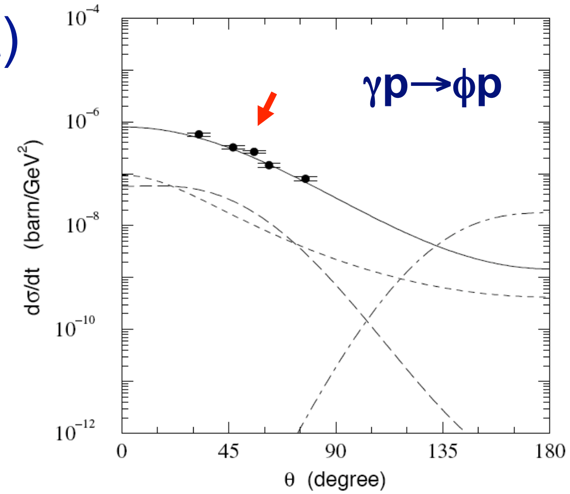
$$\mathcal{L}_{\gamma\phi NN} = \frac{\mathcal{F}(s,t)}{M_{\phi} M_N^2} \bar{N} \partial_{\mu} \phi_{\nu} F^{\mu\nu} N + \text{h.c.},$$

•Pomeron contribution taken into account in *F*(s,t)

•Reproduction of strong forward scattering

A.I.Titov et al PRC58,2429

•Model parameters fitted by data



Theoretical framework

Three-body LIPS and double-differential cross section

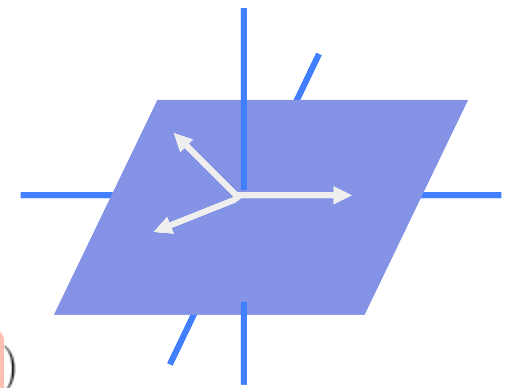
- LEPS kinematics simplifies computation significantly: $\boldsymbol{k}_K/|\boldsymbol{k}_K| \sim \boldsymbol{k}_\gamma/|\boldsymbol{k}_\gamma|$
- Inner-products, $\boldsymbol{k}_K \bullet \boldsymbol{\varepsilon}_\gamma$ and $\boldsymbol{k}_p \bullet \boldsymbol{\varepsilon}_\gamma$ become zero in CM frame

$$\frac{d^2\sigma}{dM_{KN_f}\, d\cos\theta_K} = \int \frac{M_{K\bar{K}} M_{\bar{K}N_f}\, dM_{K\bar{K}}}{128\pi^3 E_{\rm cm}^2 E_\gamma} \left[\frac{1}{4}\sum_{\rm spin}\sum_{\rm pol} |\mathcal{M}_{\gamma N_i \to K\bar{K}N_f}|^2\right]$$

- Definition of relevant momenta

$$\begin{aligned}
p_\gamma &= (E_\gamma, \boldsymbol{p}_\gamma) = (|\boldsymbol{p}_\gamma|, 0, 0, |\boldsymbol{p}_\gamma|),\\
p_{N_i} &= (E_N, \boldsymbol{p}_{N_i}) = ([M_N^2 + \boldsymbol{p}_\gamma^2]^{1/2}, 0, 0, -|\boldsymbol{p}_\gamma|),\\
p_K &= (E_K, \boldsymbol{p}_K) = ([M_K^2 + \boldsymbol{p}_K^2]^{1/2}, 0, 0, |\boldsymbol{p}_K|),\\
p_{\bar{K}} &= (E_\pi, \boldsymbol{p}_{\bar{K}}) = p_\gamma + p_{N_i} - p_K - p_{N_f},\\
p_{N_f} &= (E_\Sigma, \boldsymbol{p}_{N_f}) = ([M_\Sigma^2 + \boldsymbol{p}_{N_f}^2]^{1/2}, 0, |\boldsymbol{p}_{N_f}| \sin\theta_{N_f}, |\boldsymbol{p}_{N_f}| \cos\theta_{N_f})
\end{aligned}$$

$$E_K = \frac{s + M_K^2 - M_{\bar{K}N_f}^2}{2\sqrt{s}}, \quad E_{N_f} = \frac{s + M_{N_f}^2 - M_{K\bar{K}}^2}{2\sqrt{s}}$$



Theoretical framework

Conditions for the Dalitz plot

•Maximum and minimum, confining Daitz region

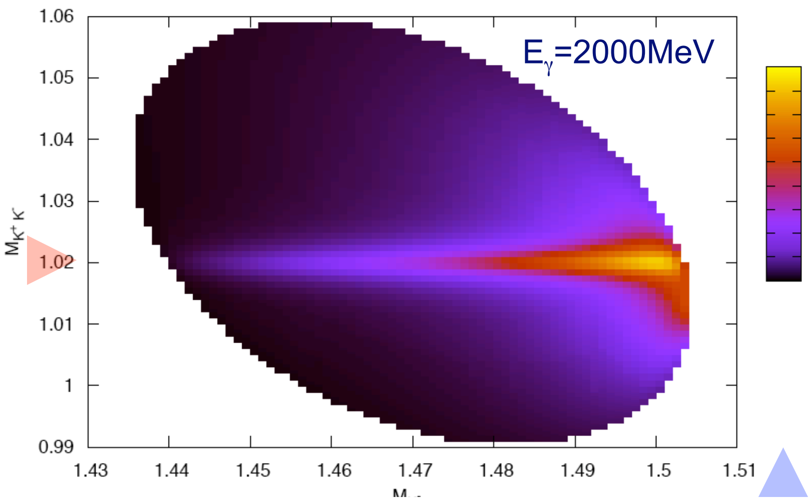
$$M_K + M_{\bar{K}} \le M_{K\bar{K}} \le \sqrt{s} - M_{N_f},$$
$$M_{\bar{K}} + M_{N_f} \le M_{\bar{K}N_f} \le \sqrt{s} - M_K.$$

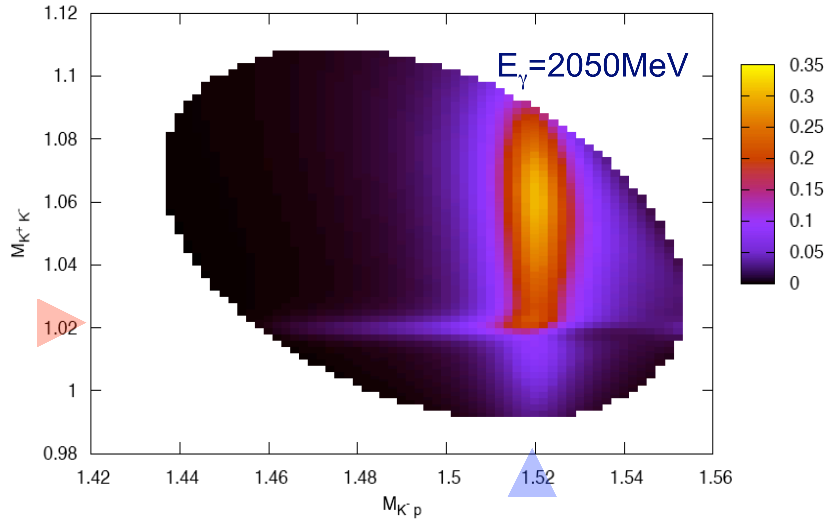
•Angle between final $\boldsymbol{k}_p$ and z-axis

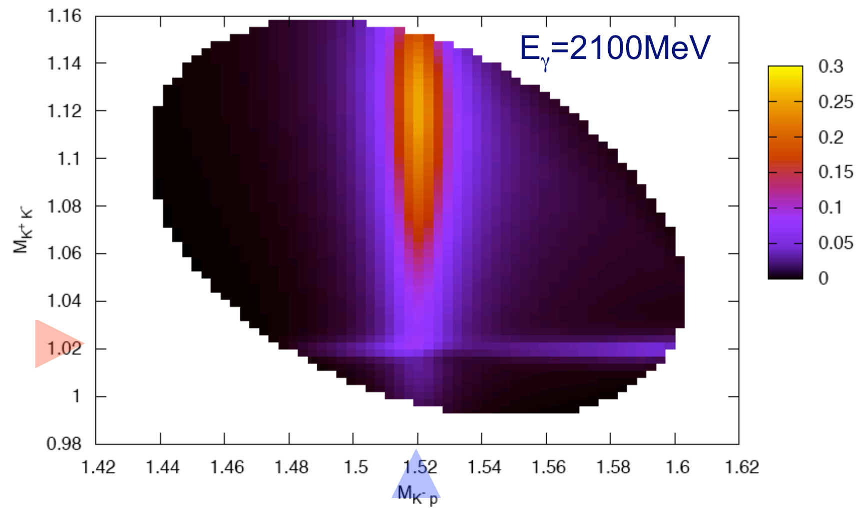
$$-1 \le \cos\theta_{N_f} = \frac{(\sqrt{s} - E_K - E_{N_f})^2 - M_{\bar{K}}^2 - |\boldsymbol{p}_{\bar{K}}|^2 - |\boldsymbol{p}_{N_f}|^2}{2|\boldsymbol{p}_{\bar{K}}||\boldsymbol{p}_{N_f}|} \le 1$$

Numercal results: interference

Dalitz plots for $\gamma p \to K^+K^-p$



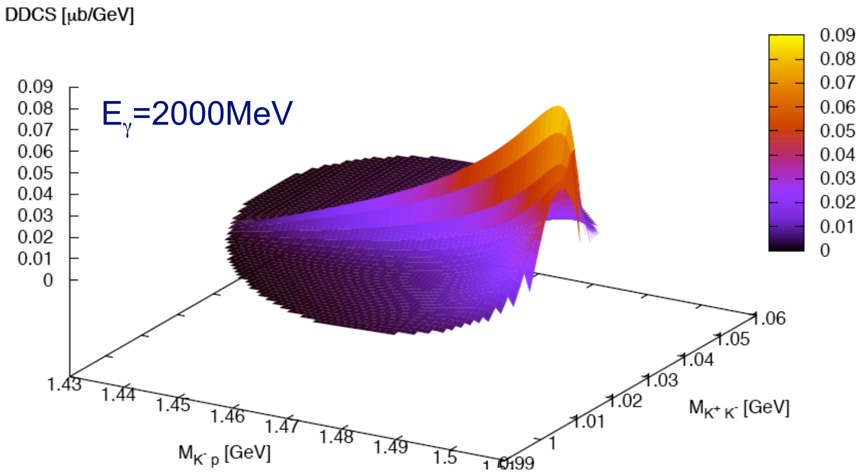


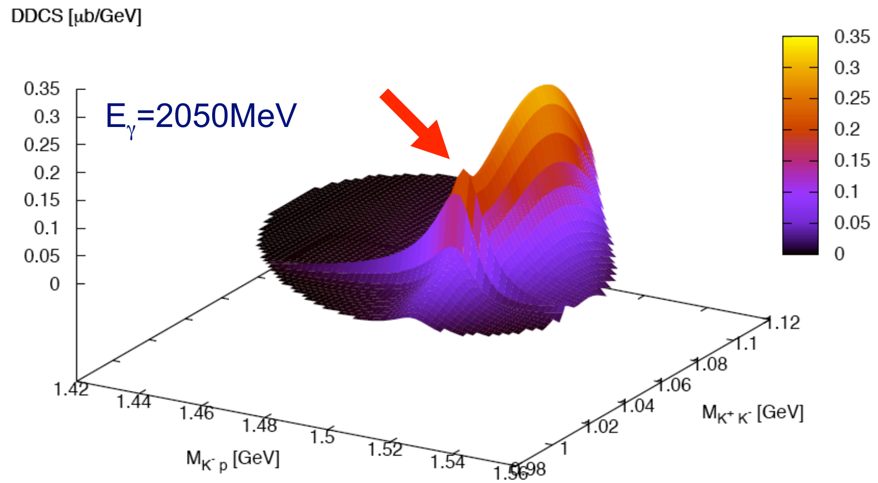


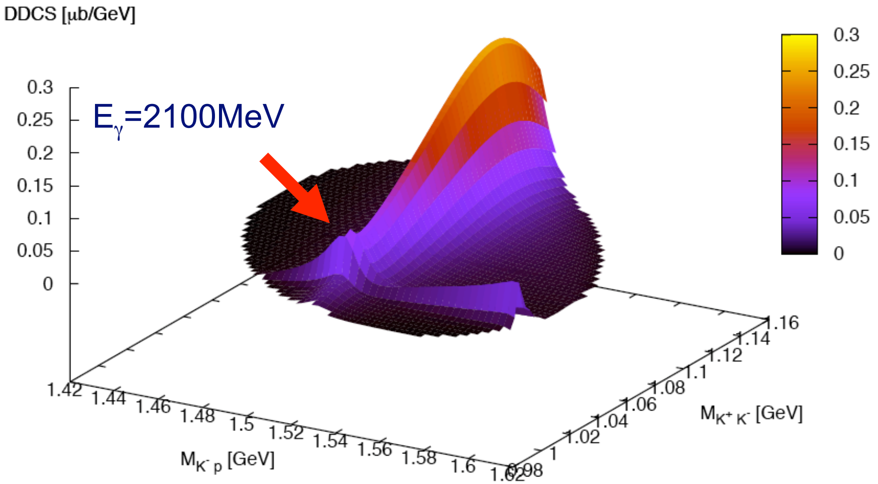
- Triple-differential σ [μb/GeV]
- Small interference effect

Numercal results: interference

Dalitz plots for $\gamma p \to K^+ K^- p$



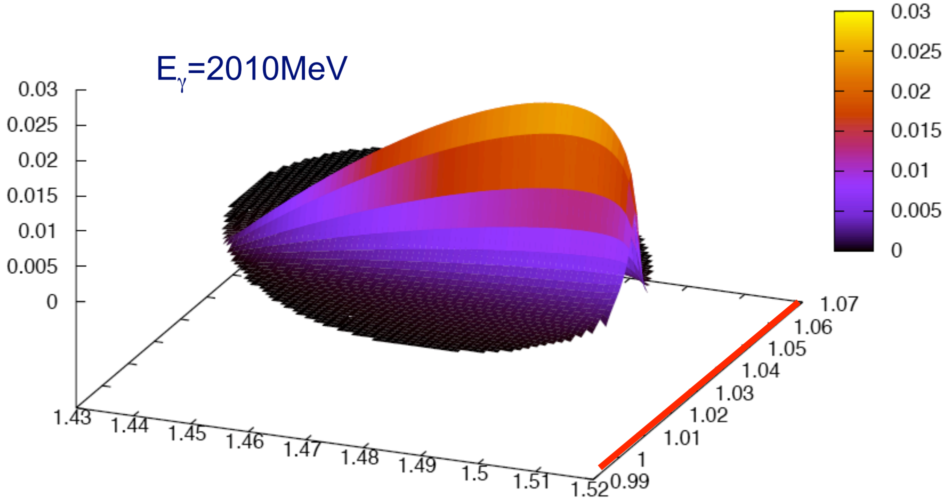


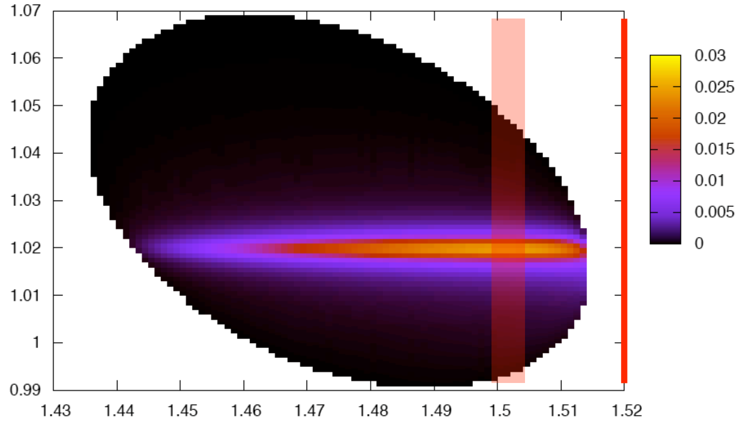


- Small interference effect
- $\sigma_\phi < \sigma_{\Lambda(1520)}$
- Insensitive to relative phase

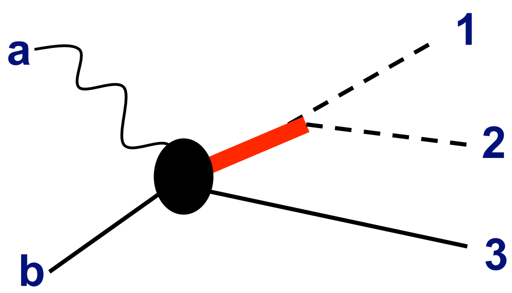
Numercal results: false signal

Dalitz plots for $\gamma p \rightarrow K^+K^-p$ with only ϕ contribution





- B.G. contribution + phase space
- False sigal at low-energy region
- Depending on experimental resolution?



Summary and conclusion

Studies on three-body final state using Dalitz plot

$\gamma p \rightarrow K^+K^-p$ containing $\Lambda(1520)$ and $\phi(1020)$

Effective Lagrangian method employed

Intereference effect

- Sensitive to strength and/or phase
- Negligible effects on $\gamma p \rightarrow K^+K^-p$ due to $\sigma_\phi < \sigma_{\Lambda(1520)}$
- If, in $\gamma n \rightarrow K^+K^-n$, $\sigma_\phi \sim \sigma_\Theta$ at low energy region, the effect becomes visible

False signal

- B.G. contribution + phase space without resonances
- Possible for low-energy region with coarse resolution
- Sensitive to strength and/or phase

Theoretical status

Λ(1405) KN bound state rather than a uds color singlet!? cf) N*(1535)

Energetic activities on Λ(1405) studies

- Two-pole structure Spain and Japan groups
- Different microscopic structure: larger size Sekihara et al, PLB** [arxiv:0803.4068 [nucl-th]]
- Studies on the origin of s-wave resonance Hyodo et al, PRC78,025203
- Three-body problems KKN-molecular state D.Jido et al, arXiv:0806.3601 [nucl-th

Λ(1405) nature via meson and photon induced reactions

- $\gamma N \to K\Lambda(1405)$ Williams et al, PRC43,452
- Production mechanism SiN et al, arXiv:0806.4029 [hep-ph]

Focusing on the photoproduction

Experimental status

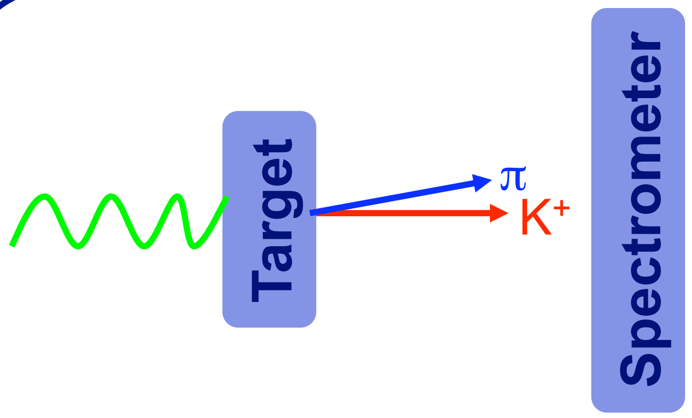
Meson-nucleon scattering

- K^--N scattering Hepp NPB115,82, Hermingway NPB253,742, Prakhov PRC70,034605
- π^--p scattering Thomas NPB56,15

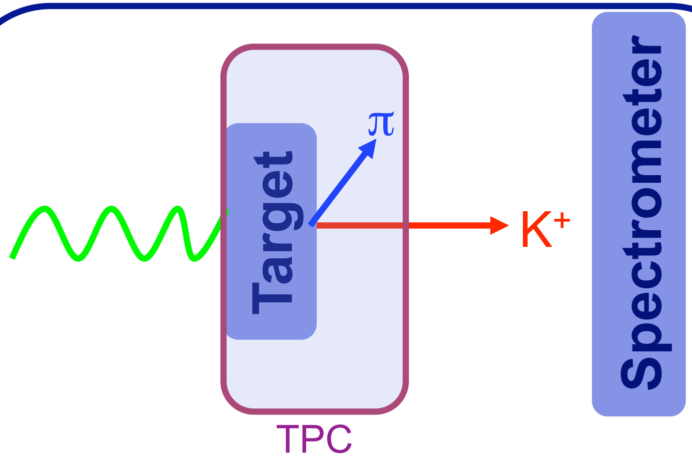
Photon-nulceon scattering

- γ-p scattering (by LEPS) J.K.Ahn NPB721,715c, Niiyama et al, PRC78,035202

Main difference between the two photoproduction data



J.K.Ahn, NPB721,715c (2003)



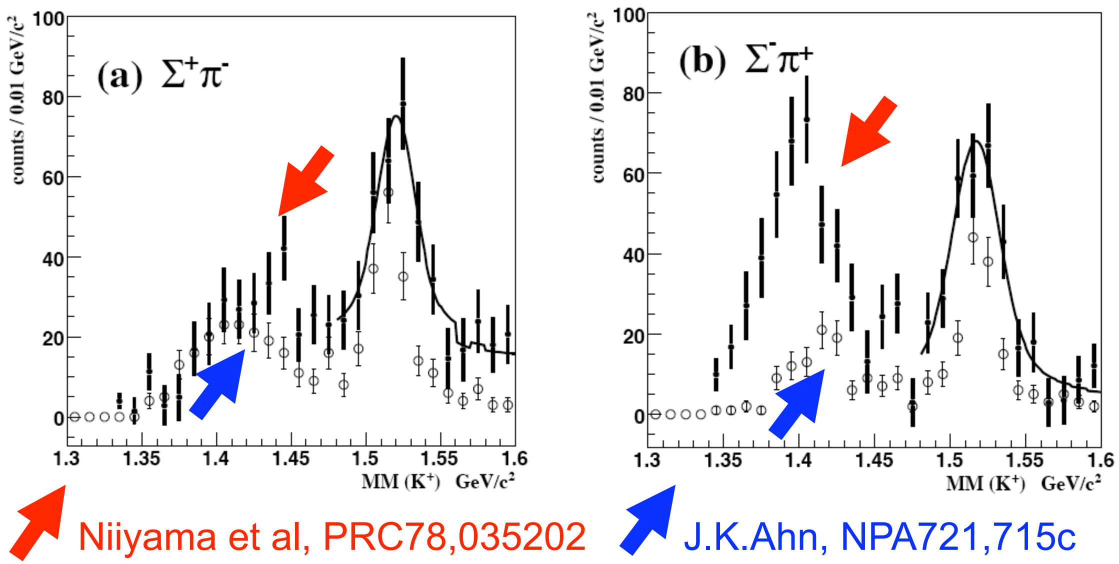
Niiyama,PRC78,035202 (2008)

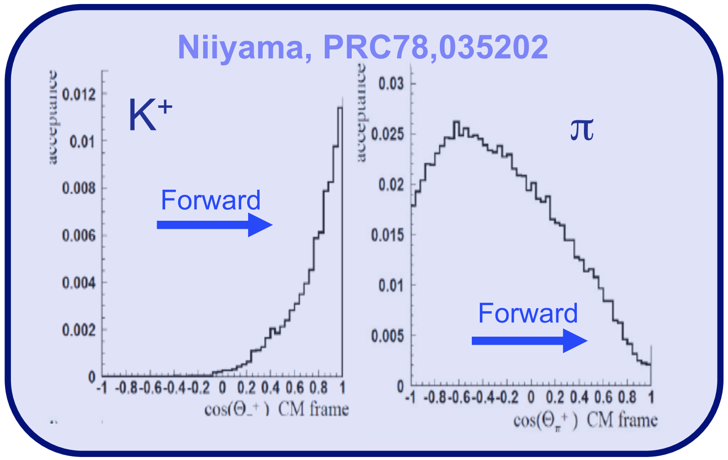
Experimental status: angle dependence

Pion measured in wider angle by TPC

Angle-dependent production becomes critical in the new experiment

K^+ missing mass in $\gamma p \to K^+ X$





Niiyama et al, PRC78,035202 J.K.Ahn, NPA721,715c

Significant difference between $\pi^+\Sigma^-$ and $\pi^-\Sigma^+$ channels

Indicating sizable p-wave contribution in $\Lambda(1405)$ photoproduction!?

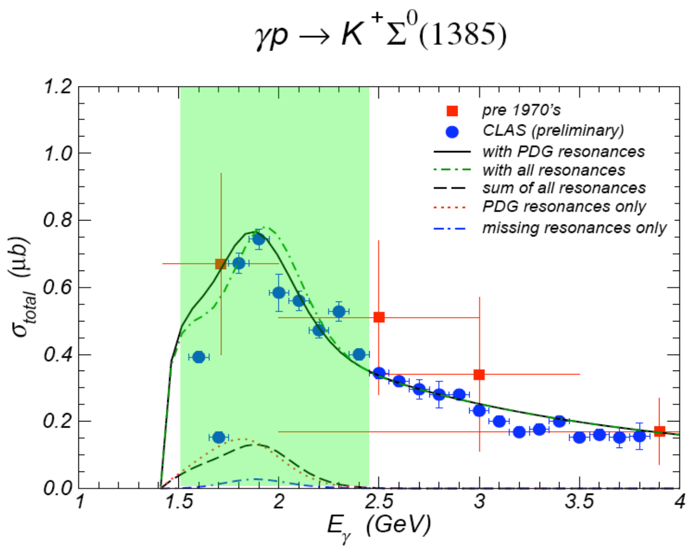
Experimental status: energy dependence

$\gamma p \rightarrow K^+\Lambda(1405)$ cross section estimated in the new exp.

Niiyama, PRC78,035202

$E_\gamma=1.5$ to $E_\gamma=2.0$: $\frac{\sigma[\Lambda(1405)]}{\sigma[\Sigma(1385)]} \sim 0.54$

$E_\gamma=2.0$ to $E_\gamma=2.4$: $\frac{\sigma[\Lambda(1405)]}{\sigma[\Sigma(1385)]} \sim 0.084$



Y.Oh, PRC77,045204

$\sigma[\Sigma(1385)] \sim 0.6\ \mu b$ for Rg.1

$\sigma[\Sigma(1385)] \sim 0.5\ \mu b$ for Rg.2

$\sigma[\Lambda(1405)] \sim 0.3\ \mu b$ for Rg.1

$\sigma[\Lambda(1405)] \sim 0.04\ \mu b$ for Rg.2

Factor ~ 8 difference!

Theoretical analysis

Possible p-wave contribution in Λ(1405) mass spectrum

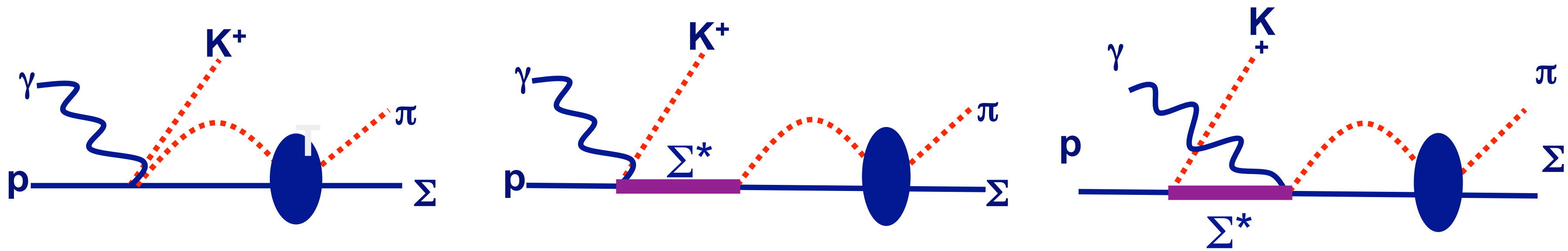
Employing the ChUM with explicit p-wave contribution from Σ*(1385)

Λ(1405) photoproduction with s-wave by Nacher et al. Nacher,PLB455,55

Considering the LEPS experimental setup: K^+ in forward angle (θ_K~0)

$$\frac{d^2\sigma}{dM_{\pi\Sigma}\, d\cos\theta_K} = \int \frac{M_{K\pi}\, M_{\pi\Sigma}\, dM_{K\pi}}{128\,\pi^3\, s^{3/2}\, E_\gamma} |\overline{\mathcal{M}}|^2$$

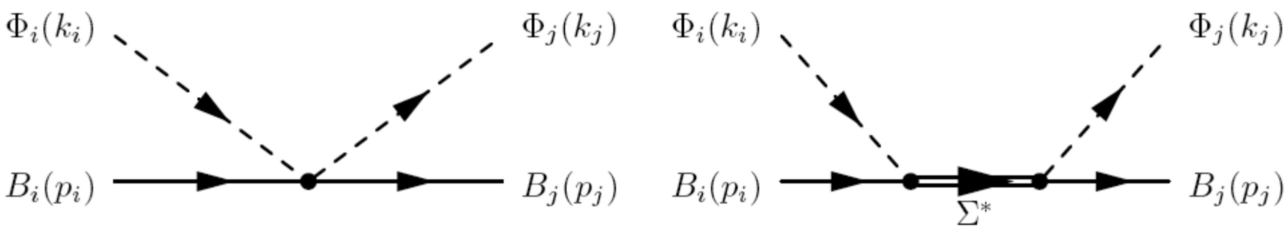
Diagrams considered



Nacher,PLB455,55

Theoretical analysis

ΦB→ΦB amplitude (T) including (s,p)-wave contributions Jido,PRC66,055203



Lagrangians for the interaction vertices

$$\mathcal{L}_{\rm WT} = -\frac{iC_{ij}}{4f^2}\bar{B}_j[\Phi_j(\partial\!\!\!/\Phi_i) - \Phi_i(\partial\!\!\!/\Phi_j)]B_i \qquad \mathcal{L}_{\Phi_i B_i \Sigma^*} = D_i\bar{\Sigma}^{*\mu}(\partial_\mu\Phi)B$$

Interaction kernels

$$V_{ji}^{\rm WT} = -\frac{C_{ji}}{4f^2}(2\sqrt{s} - M_j - M_{4+5}), \quad V_{ji}^{\Sigma^*} = -\frac{D_j D_i}{3}\frac{|\boldsymbol{k}_j||\boldsymbol{k}_i|}{\sqrt{s} - M_{\Sigma^*}}$$

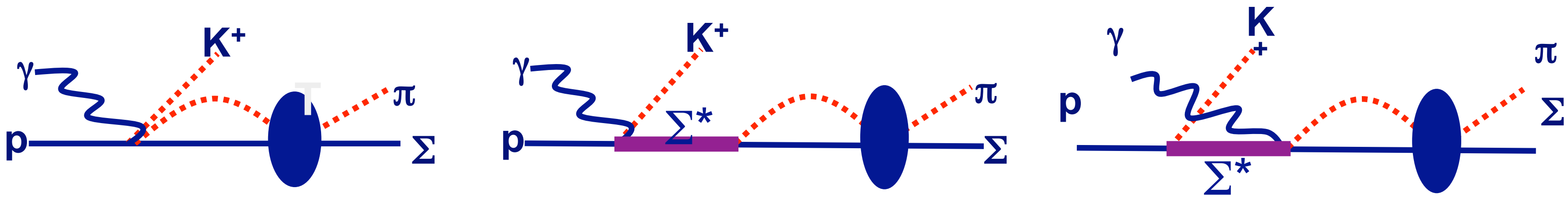
Unitarization

$$T_{ji} = T_{ji}^{\rm WT} + [2(\hat{\boldsymbol{k}}_j\cdot\hat{\boldsymbol{k}}_i) - i\boldsymbol{\sigma}\cdot(\hat{\boldsymbol{k}}_j\times\hat{\boldsymbol{k}}_i)]T_{ji}^{\Sigma^*}$$

$$T^{\rm WT} = \frac{1}{[1 - V^{\rm WT}G]}V_{\rm WT}, \quad T^{\Sigma^*} = \frac{1}{[1 - V^{\Sigma^*}G]}V^{\Sigma^*}$$

Theoretical analysis

Λ(1405) photoproduction with (s,p)-wave contribution



Unitarized amplitude

$$T_\gamma = [i\boldsymbol{\sigma}\cdot(\hat{\boldsymbol{\epsilon}}\times\hat{\boldsymbol{k}}_\gamma)]T_a + [2(\hat{\boldsymbol{k}}_\pi\cdot\hat{\boldsymbol{\epsilon}}) - i\boldsymbol{\sigma}\cdot(\hat{\boldsymbol{k}}_\pi\times\hat{\boldsymbol{\epsilon}})]T_b + [2(\hat{\boldsymbol{\epsilon}}\cdot\hat{\boldsymbol{k}}_K) - i\boldsymbol{\sigma}\cdot(\hat{\boldsymbol{\epsilon}}\times\hat{\boldsymbol{k}}_K)]T_c$$

s-wave p-wave s-wave

ΦB→ΦB total amplitudes

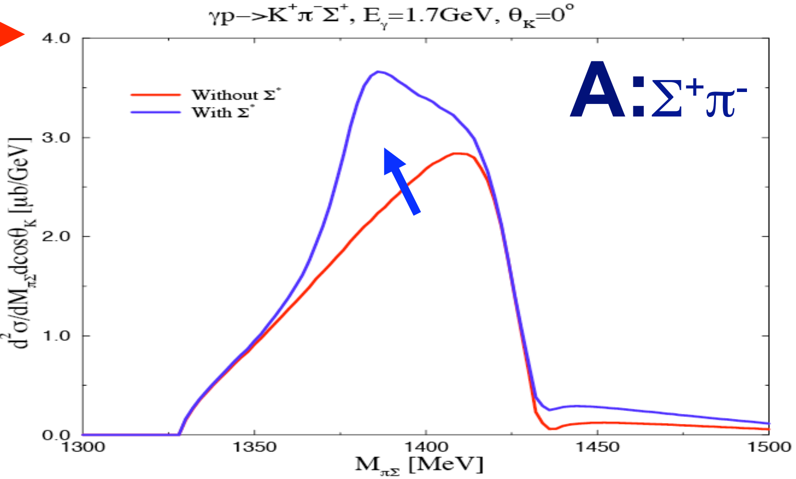
$$\begin{aligned} T_a &= V_a + V_a\, G\, T_{\mathrm{WT}}, \\ T_b &= V_b + V_b\, G\, T_{\Sigma^*}, \\ T_c &= V_c + V_c\, G\, T_{\mathrm{WT}}. \end{aligned}$$

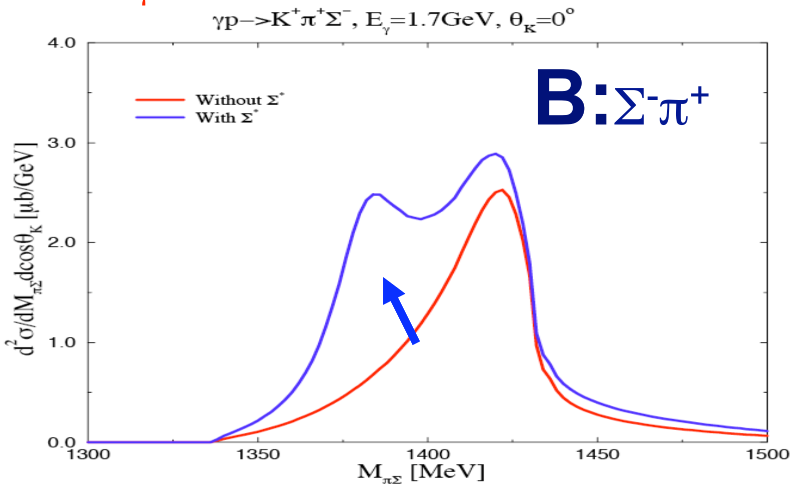
ΦB→ΦB element amplitudes

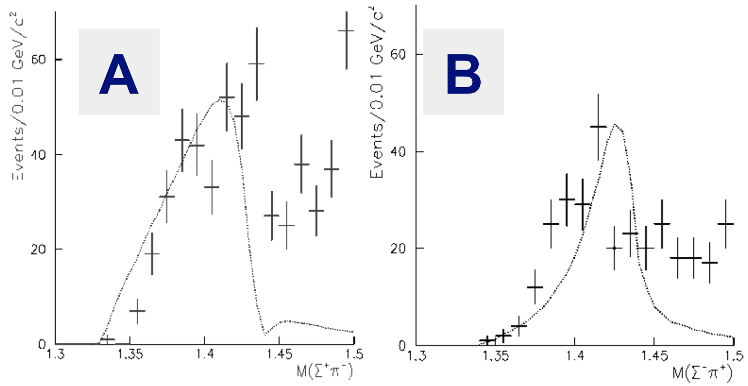
$$\begin{aligned} V_a &= \frac{(e_\pi - e_K)C_{\bar{K}p\to\pi\Sigma}|\boldsymbol{k}_\gamma|}{8f^2M_N}, \\ V_b &= \frac{e_K|\boldsymbol{k}_\pi|}{3}\frac{D_{\bar{K}p}D_{\pi\Sigma}}{E_\gamma + E_p - E_K - M_{\Sigma^*}}, \\ V_c &= \frac{e_\pi|\boldsymbol{k}_K|}{3}\frac{D_{\bar{K}p}D_{\pi\Sigma}}{E_p - E_K - M_{\Sigma^*}}, \end{aligned}$$

Numerical results

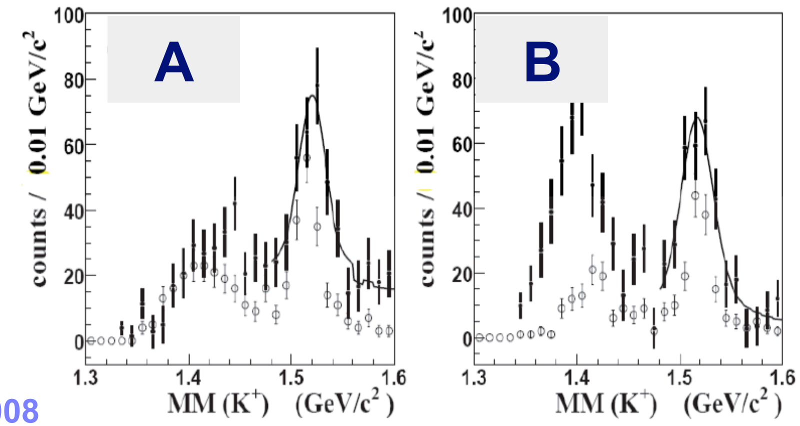
$\Lambda(1405)$ photoproduction via $\gamma p \to K^+\pi\Sigma$ at E_γ=1.7 GeV







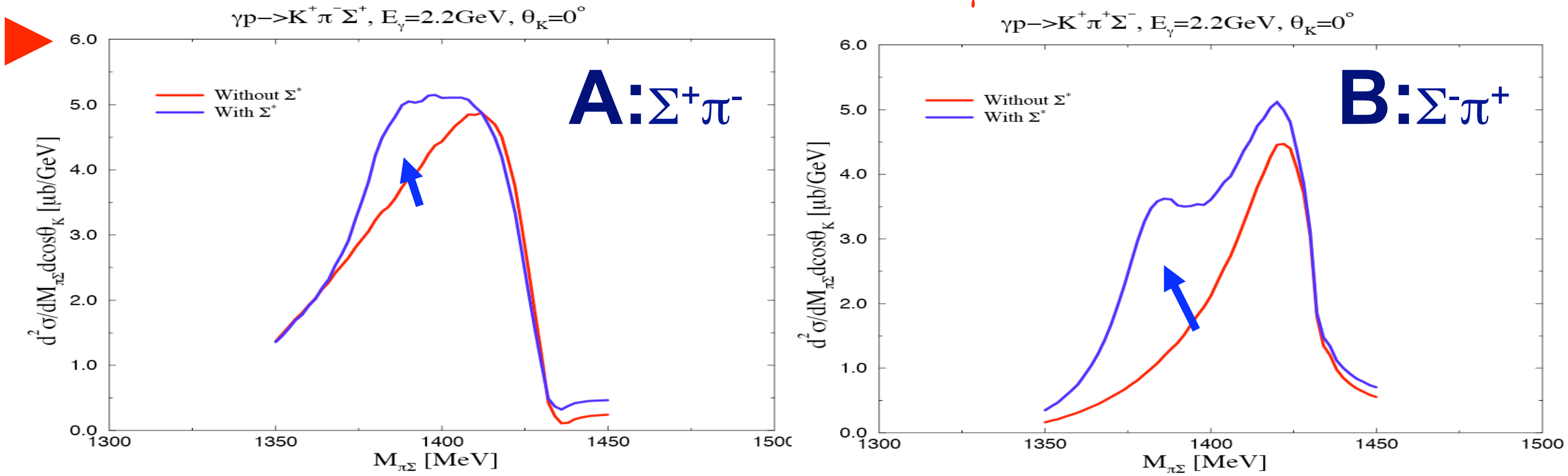
J.K.Ahn, Challenge to New Exotic Hadron at RCNP, 2008

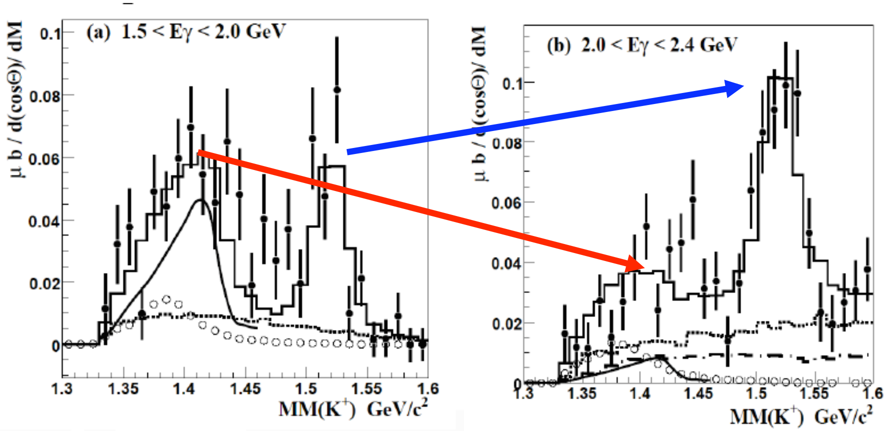


Niiyama, PRC78,035202

Numerical results

$\Lambda(1405)$ photoproduction via $\gamma p \to K^+\pi\Sigma$ at E_γ=2.2 GeV





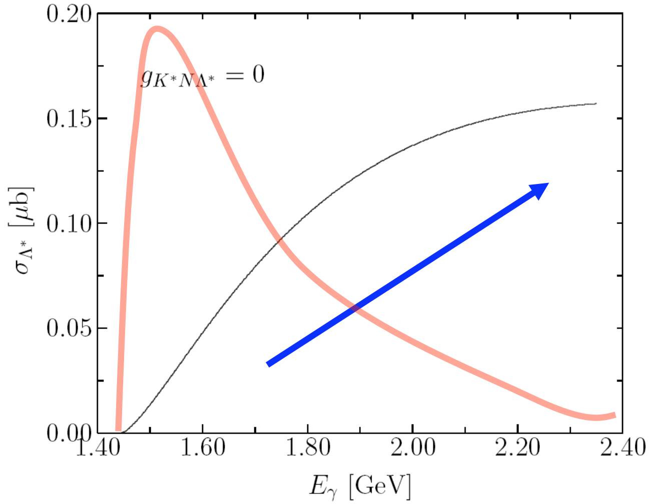
Niiyama, PRC78,035202

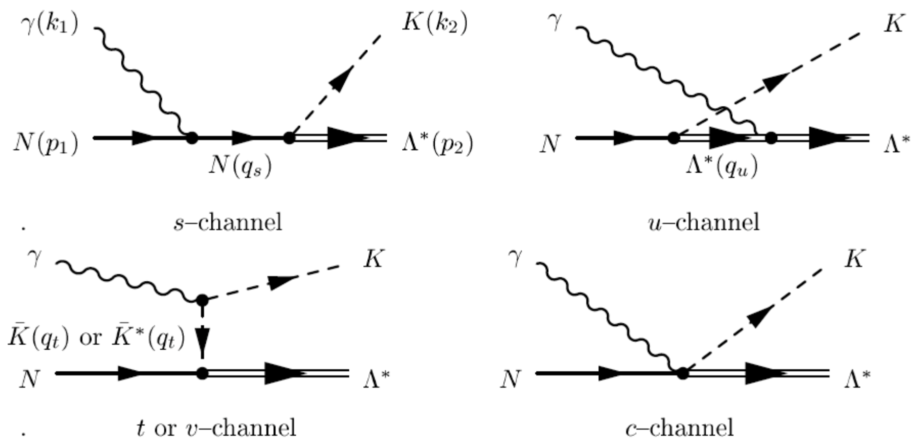
Strength of $M_{\pi\Sigma}$

- Theory: increasing
- Experiment: decreasing

Numerical results

$\Lambda(1405)$ photoproduction via $\gamma p \to K^+\Lambda(1405)$ SiN et al, arXiv:0806.4029 [hep-ph]





Usual approaches can not reproduce the data

Indication of a strong resonance near the threshold?

cf) KKN molecular state D.Jido et al, arXiv:0806.3601 [nucl-th]

Numerical results

Λ(1405) photoproduction via $\gamma p \to K^+\Lambda(1405)$ SiN et al, arXiv:0806.4029 [hep-ph]

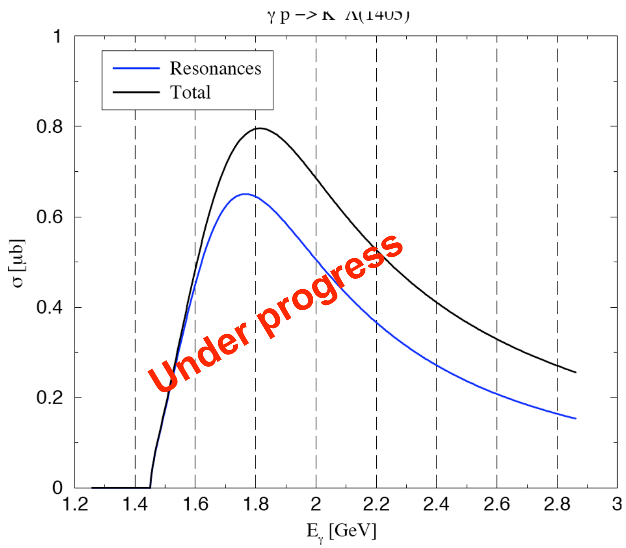
Considering resonances and two-pole structure

$$|\Lambda(1405), \text{Phys}\rangle = a|\text{high-}\Lambda(1429)\rangle + b|\text{low-}\Lambda(1392)\rangle + c|uds, I=0\rangle + ..$$

|high-Λ(1429)⟩ and |low-Λ(1392)⟩ : KN-bound state

|uds, I=0⟩ : NR-quark model (close)

	$\Gamma_{N^*\to K\Lambda^*}$ [2]	$A_1^{p^*}$ [3]	$A_3^{p^*}$ [3]
$S_{11}(2030, 1/2^-)$	1.44 MeV	0.020 $\text{GeV}^{-1/2}$	–
$D_{13}(1960, 3/2^-)$	15.21 MeV	0.036 $\text{GeV}^{-1/2}$	−0.043 $\text{GeV}^{-1/2}$
$D_{13}(2055, 3/2^-)$	1.44 MeV	0.016 $\text{GeV}^{-1/2}$	0



Relative phase between the hign and low ~ -1

(in ChUM by D.Jido)

Destructive interference between them!

Summary and perspective

Λ(1405) photoproduction investigated to interpret recent LEPS with TPC

ChUM with s- and p-wave (Σ*1385) contributions

	Theory (ChUM)	Experiment
$\Sigma^-\pi^+$ vs. $\Sigma^+\pi^-$	$\Sigma^-\pi^+ \sim \Sigma^+\pi^-$	$\Sigma^-\pi^+ > \Sigma^+\pi^-$: Niiyama ($\Sigma^-\pi^+ \sim \Sigma^+\pi^-$: J.K.Ahn)
Energy dependence	Increasing	Decreasing
Σ*(1385) contibution	Strong	Weak

Possible explanations

- Other p-wave contributions: ground-state Y, M-B-loop contributions
- Larger K^+ angle: $0 < \cos\theta_K < 1$
- Resonance contributions & destructive interference of two-pole cont.
- Λ(1405): mixture of various states: experimental evidence?
- <u>How about Λ(1520)??</u>

Thank you very much
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