Photoproduction of K* for the study of Λ(1405)

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Contents

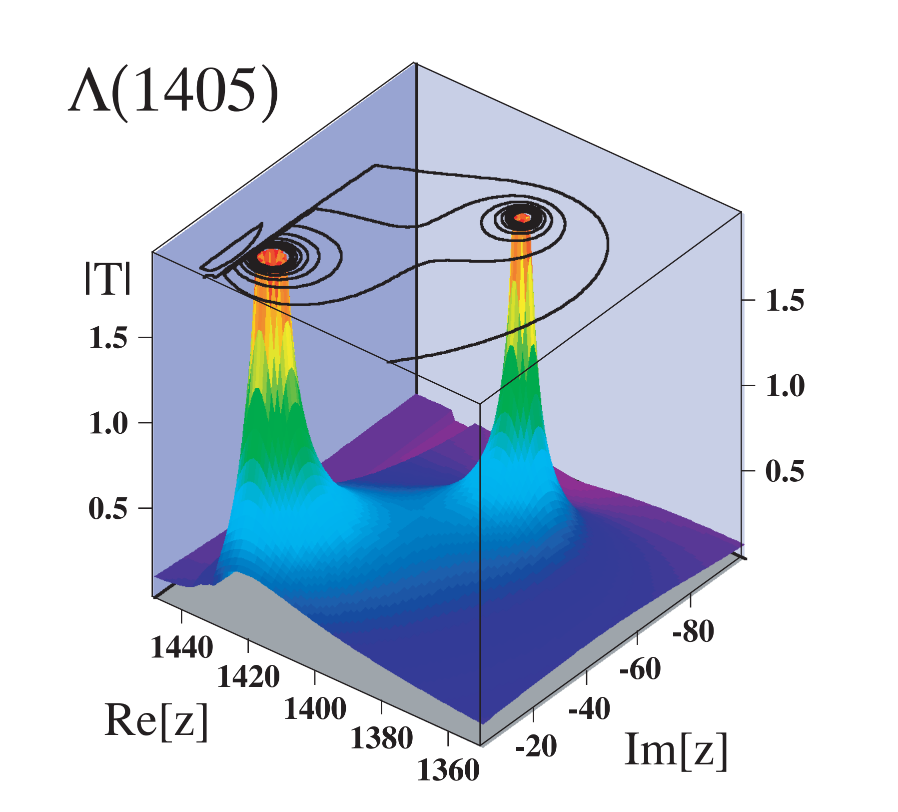
- **Chiral unitary model**
  - Motivation : Two poles?
  - Framework of the model
  - Example : K^-p scattering
  - Pole structure of Λ(1405)
- **K^*Λ(1405) production**
  - Advantage of the reaction
  - Effective interactions
  - Numerical results
  - Summary and conclusions

Motivation : Two poles?

There are two poles of the scattering amplitude around nominal Λ(1405) energy region.

- **Cloudy bag model (1990)**
  - J. Fink, *et al.*, PRC41, 2720
- **Chiral unitary model (2001~)**
  - J. A. Oller, *et al.*, PLB500, 263
  - E. Oset, *et al.*, PLB527, 99
  - D. Jido, *et al.*, PRC66, 025203
  - T. Hyodo, *et al.*, PRC68, 018201
  - T. Hyodo, *et al.*, PTP, in press
  - C. Garcia-Recio, *et al.*, PRD67, 076009
  - D. Jido, *et al.*, NPA725, 181
  - T. Hyodo, *et al.*, PRC68, 065203
  - C. Garcia-Recio, *et al.*, PLB582, 49

$\Lambda(1405) : J^P = 1/2^-, I = 0$



ChU model, T. Hyodo

Chiral unitary model

Flavor SU(3) meson-baryon scatterings (s-wave)

Chiral symmetry

Low energy behavior

+

Unitarity of S-matrix

Non-perturbative resummation

Dynamical generation

→

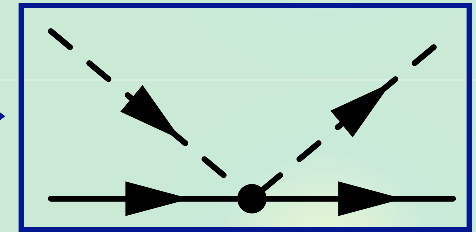
$J^P = 1/2^-$ resonances

$\Lambda(1405), \Lambda(1670),$
$\Sigma(1620), \Xi(1620),$
$N(1535)$

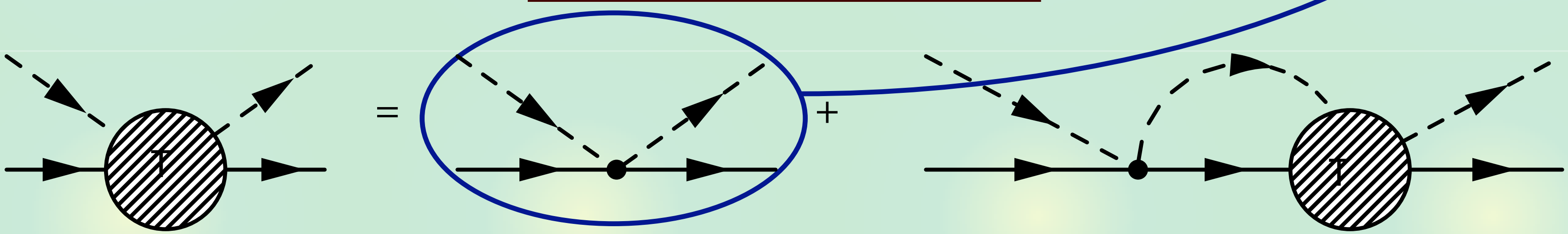
Framework of the chiral unitary model

Chiral perturbation theory

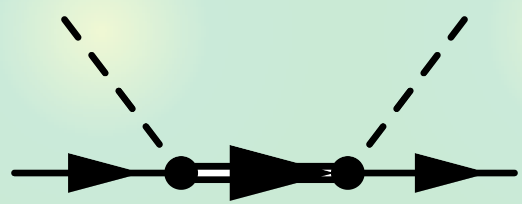
$$\mathcal{L}_{WT} = \frac{1}{4f^2}\mathrm{Tr}(\bar{B}i\gamma^{\mu}[(\Phi\partial_{\mu}\Phi - \partial_{\mu}\Phi\Phi), B])$$



Unitarization



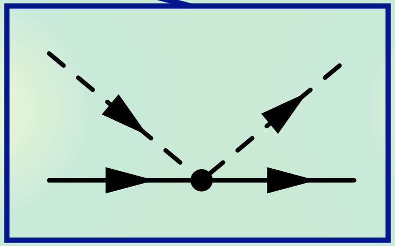
$$T_{ij}(\sqrt{s}) \sim \frac{g_i g_j}{\sqrt{s} - M_R + i\Gamma_R/2} + T_{ij}^{BG}$$

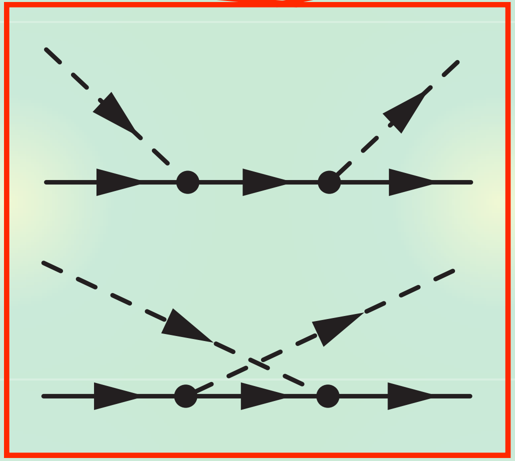
$\sim$ 

ChPT Lagrangian

$$\mathcal{L}^{(1)} = \mathrm{Tr}\Big(\bar{B}(i\not{\mathcal{D}} - M_0)B - D(\bar{B}\gamma^\mu\gamma_5\{A_\mu, B\}) - F(\bar{B}\gamma^\mu\gamma_5[A_\mu, B])\Big)$$

$$\mathcal{D}_\mu B = \partial_\mu B + i[V_\mu, B]$$





$$\xi(\Phi) = \exp\{i\Phi/\sqrt{2}f\}$$

$$D + F = g_A$$

$$B = \begin{pmatrix} \frac{1}{\sqrt{2}}\Sigma^0 + \frac{1}{\sqrt{6}}\Lambda & \Sigma^+ & p \\ \Sigma^- & -\frac{1}{\sqrt{2}}\Sigma^0 + \frac{1}{\sqrt{6}}\Lambda & n \\ \Xi^- & \Xi^0 & -\frac{2}{\sqrt{6}}\Lambda \end{pmatrix} \quad \Phi = \begin{pmatrix} \frac{1}{\sqrt{2}}\pi^0 + \frac{1}{\sqrt{6}}\eta & \pi^+ & K^+ \\ \pi^- & -\frac{1}{\sqrt{2}}\pi^0 + \frac{1}{\sqrt{6}}\eta & K^0 \\ K^- & \bar{K}^0 & -\frac{2}{\sqrt{6}}\eta. \end{pmatrix}$$

$$V_\mu = -\frac{i}{2}(\xi^\dagger\partial_\mu\xi + \xi\partial_\mu\xi^\dagger) = \frac{i}{4f^2}(\Phi\partial_\mu\Phi - \partial_\mu\Phi\Phi) + \cdots$$

$$A_\mu = -\frac{i}{2}(\xi^\dagger\partial_\mu\xi - \xi\partial_\mu\xi^\dagger) = -\frac{1}{f}\partial_\mu\Phi + \cdots$$

Several treatments

N. Kaiser, P. B. Siegel and W. Weise, NPA594, 325, PLB362, 23 (1995)

(HB)ChPT p^2, Form factor (channel dep.)

S = -1,0, Λ(1405), N(1535)

E. Oset and A. Ramos, NPA635, 99 (1998)

WT term, 3-momentum cutoff (channel indep.)
S = -1, Λ(1405)

J. A. Oller and U. G. Meissner, PLB500, 263 (2001)

ChPT p, dimensional reg. (channel indep.)
S = -1, Λ(1405)

Analytic solution for BS eq.

-> pole structure in complex plane

Several treatments

E. Oset, A. Ramos and C. Bennhold, PLB527, 99 (2002)
T. Inoue, E. Oset, and M. J. Vicente Vacas, PRC 65, 035204 (2002)
A. Ramos, E. Oset and C. Bennhold, PRL 89, 252001 (2002)

WT term, dimensional reg. (channel dep.)
Λ(1405), Λ(1670), Σ(1620), N(1535), Ξ(1620)
Scattering observables, S = -1, 0, analytic

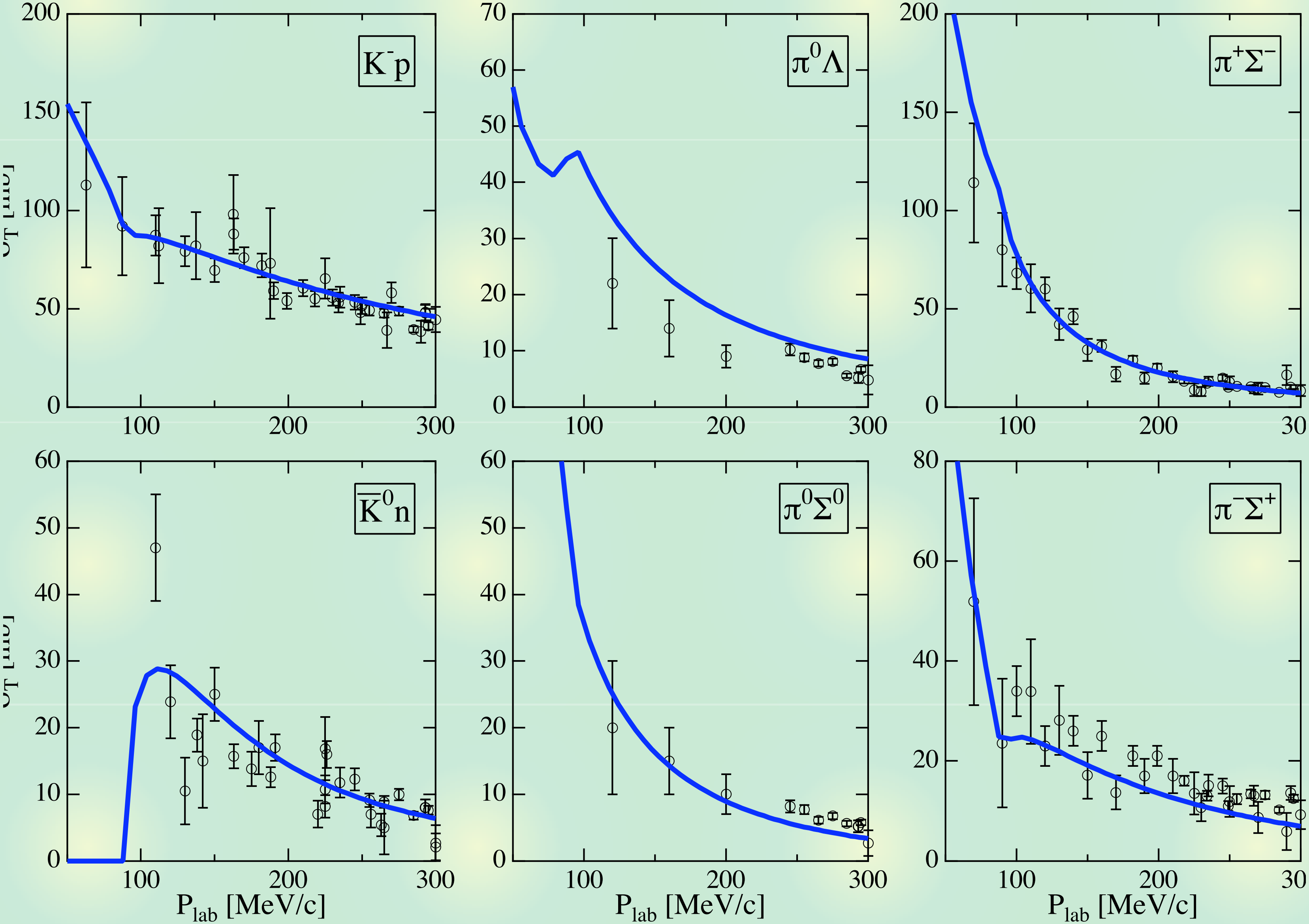
M. F. M. Lutz and E. Kolomeitsev, NPA700, 193 (2002)

ChPT p^3, Optimal reno. (channel indep.)
Scattering observables, Numerical solution

C. Garcia-Recio, M. F. M. Lutz and J. Nieves, PLB582, 49 (2004)

WT term, Optimal reno. (channel indep.)
Λ(1405), Λ(1670), Σ(1620), N(1535), Ξ(1620), Ξ(1690)
Scattering observables?

Total cross sections of K-p scattering

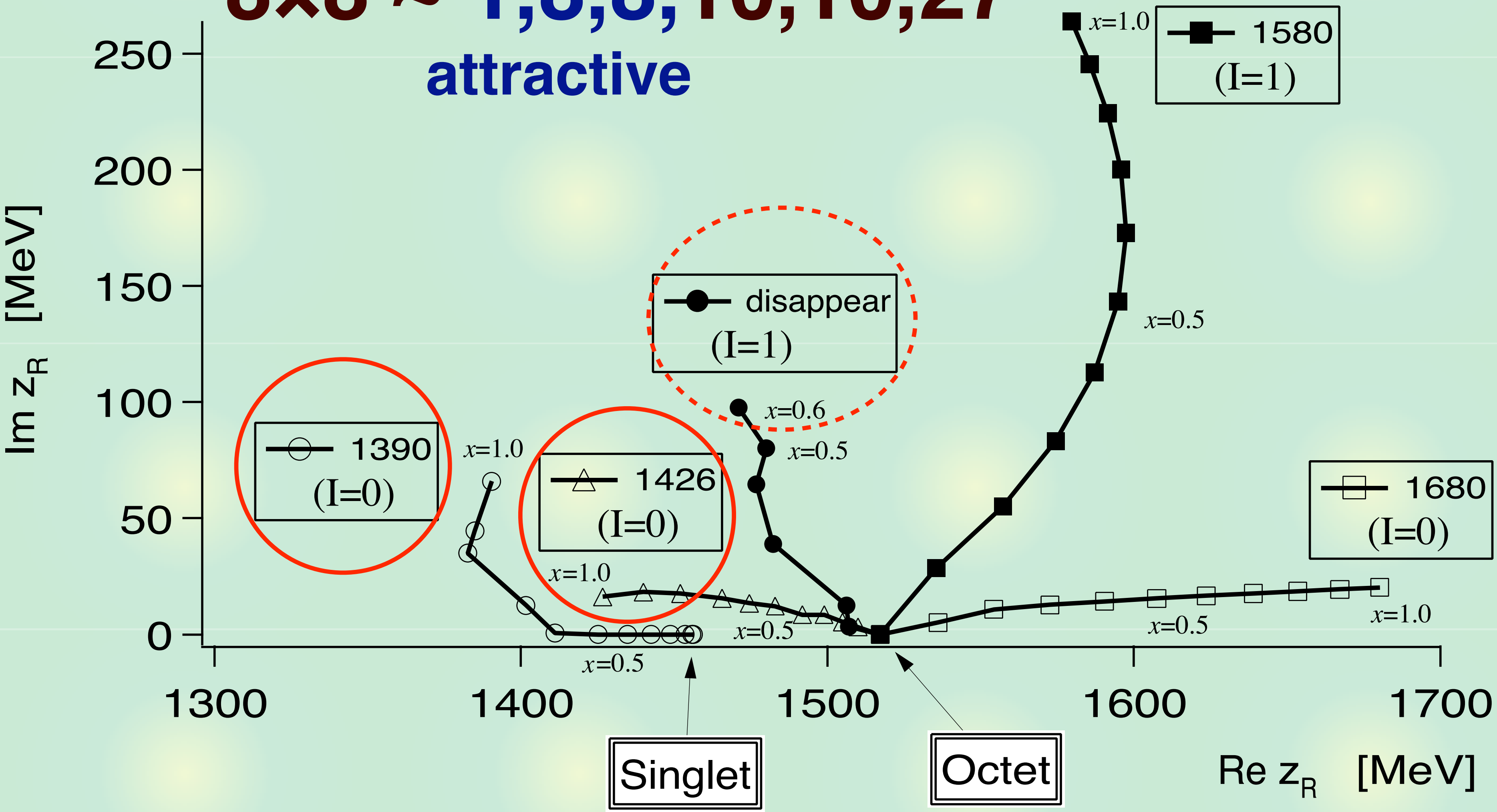


T. Hyodo, *et al.*, Phys. Rev. C 68, 018201 (2003)

Trajectories of the poles with SU(3) breaking (S = -1)

$8 \times 8 \sim 1, 8, 8, 10, \overline{10}, 27$

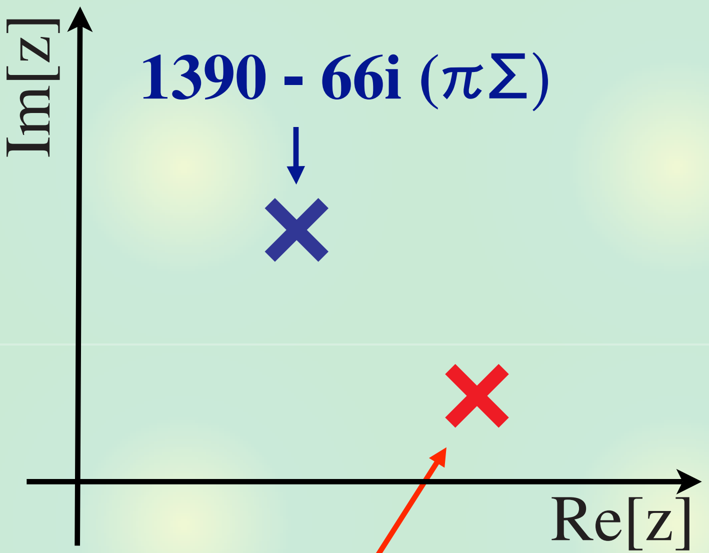
attractive



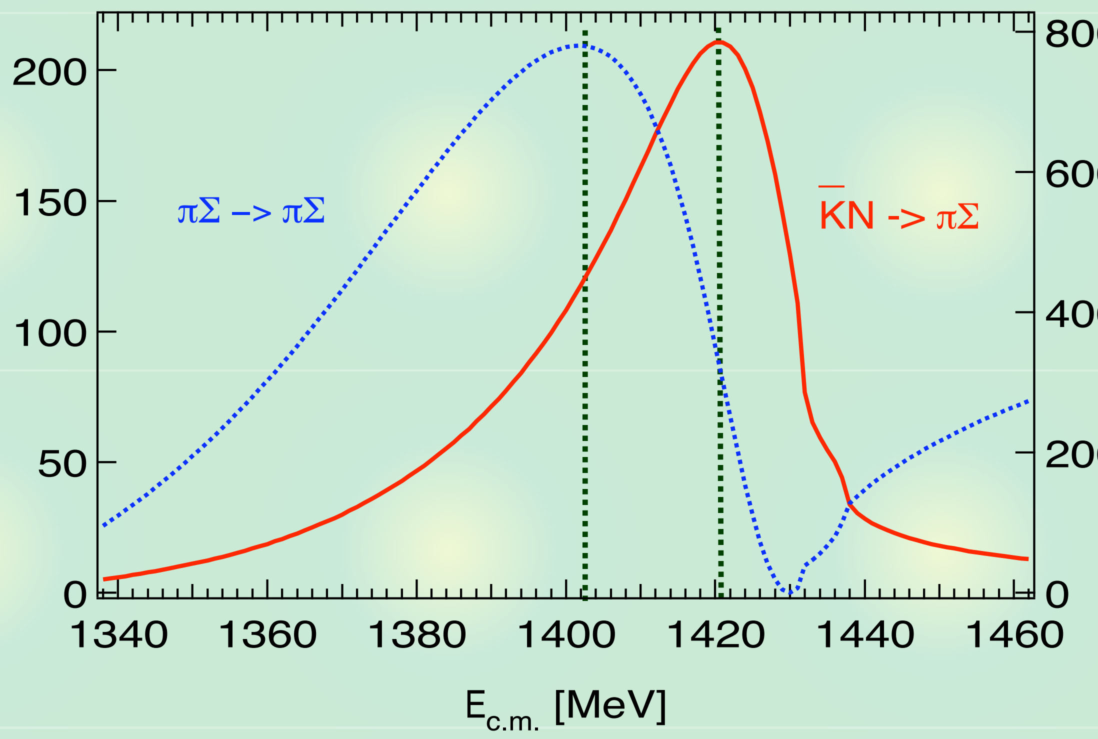
D. Jido, *et al.*, Nucl. Phys. A 723, 205 (2003)

Λ(1405) in the chiral unitary model

position of poles



πΣ mass distribution



$$\frac{d\sigma}{dM_I} = C|t_{\pi\Sigma\to\pi\Sigma}|^2 p_{CM} \quad \Rightarrow \quad \frac{d\sigma}{dM_I} = |\sum_i C_i t_{i\to\pi\Sigma}|^2 p_{CM}$$

D. Jido, *et al.*, Nucl. Phys. A 723, 205 (2003)

Photoproduction of K* and Λ(1405)

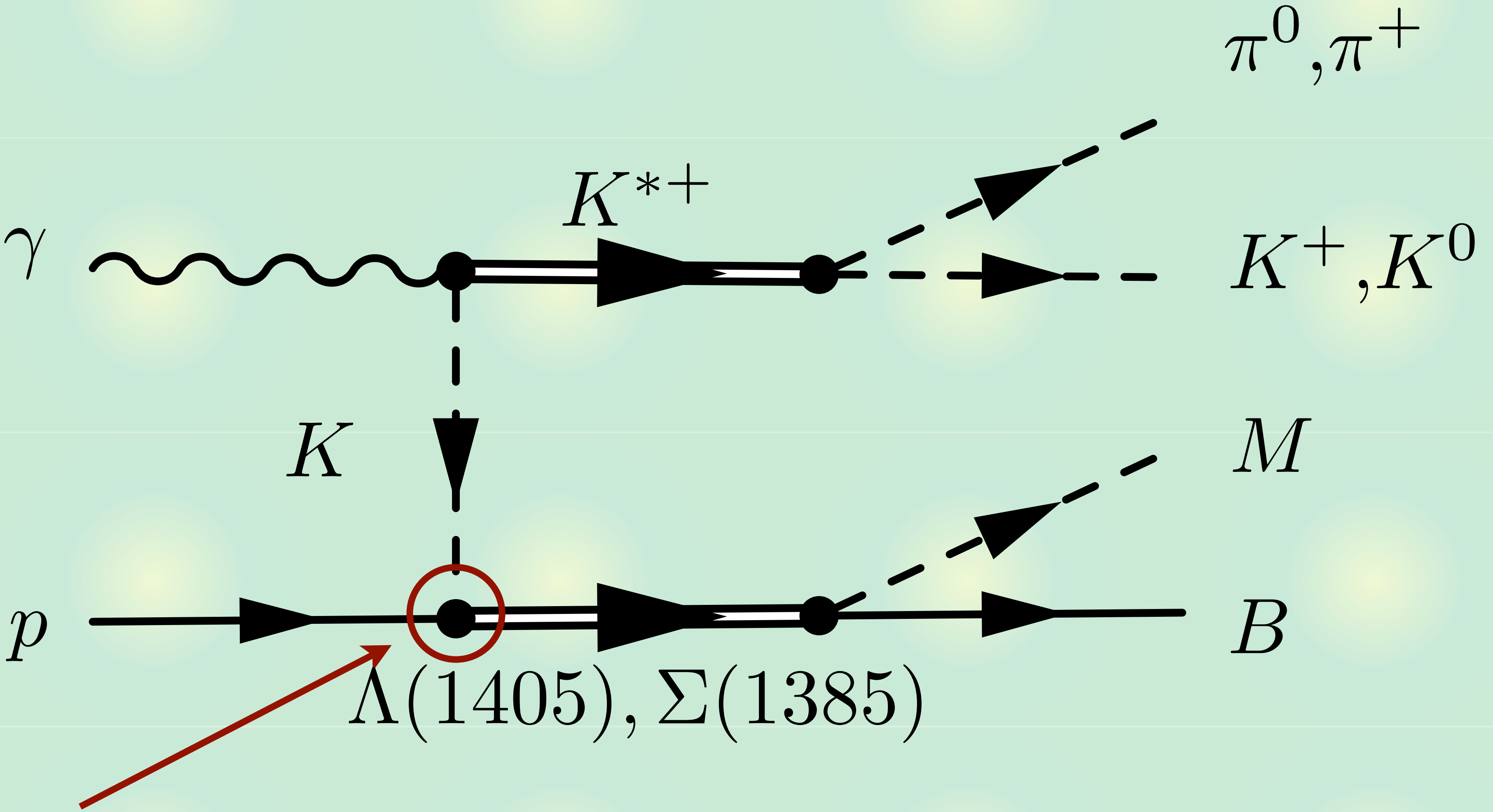
In order to study

- **S = -1, I = 0, s-wave : Λ(1405)**
  - two poles?
  - *1426 - 16i* : $\bar{K}N$
  - *1390 - 66i* : πΣ
- **S = -1, I = 1, s-wave**
  - pole?

we calculate

$$\gamma p \longrightarrow \boldsymbol{K^*\Lambda(1405)}$$

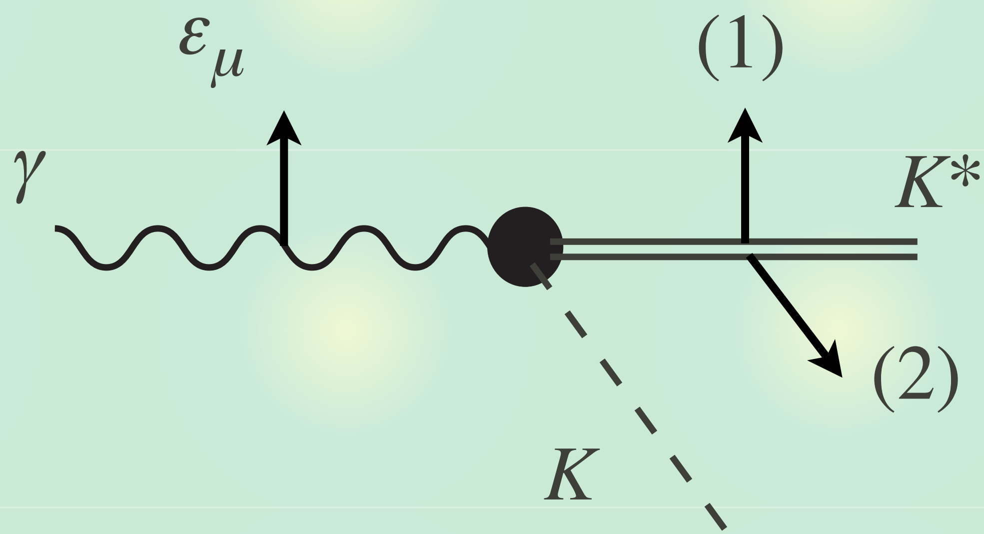
Photoproduction of K* and Λ(1405)



Only K^-p channel appears at the initial stage

Higher energy pole ??

Advantage of this reaction



(1) $\varepsilon_\mu(K^*) \,//\, \varepsilon_\mu(\gamma)$: J^P = natural

(2) $\varepsilon_\mu(K^*) \perp \varepsilon_\mu(\gamma)$: J^P = unnatural

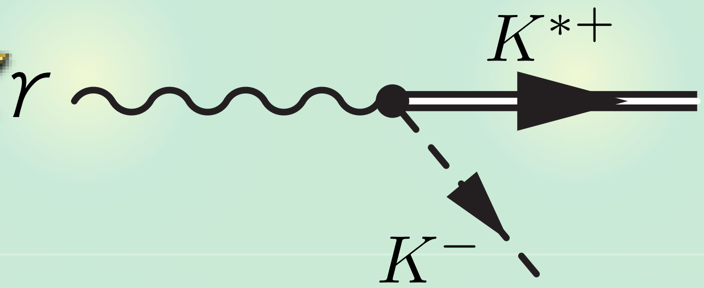
With polarized photon beam, the exchanged particle can be identified.

Clear mechanism

Effective interaction for meson part

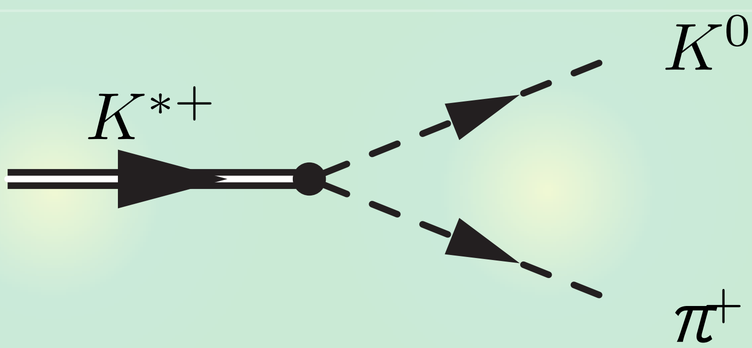
☆ γKK* coupling

$$\mathcal{L}_{K^*K\gamma} = g_{K^*K\gamma}\epsilon^{\mu\nu\alpha\beta}\partial_\mu A_\nu(\partial_\alpha K^{*-}_\beta K^+ + \partial_\alpha \bar{K}^{*0}_\beta K^0) + \text{h.c.}$$

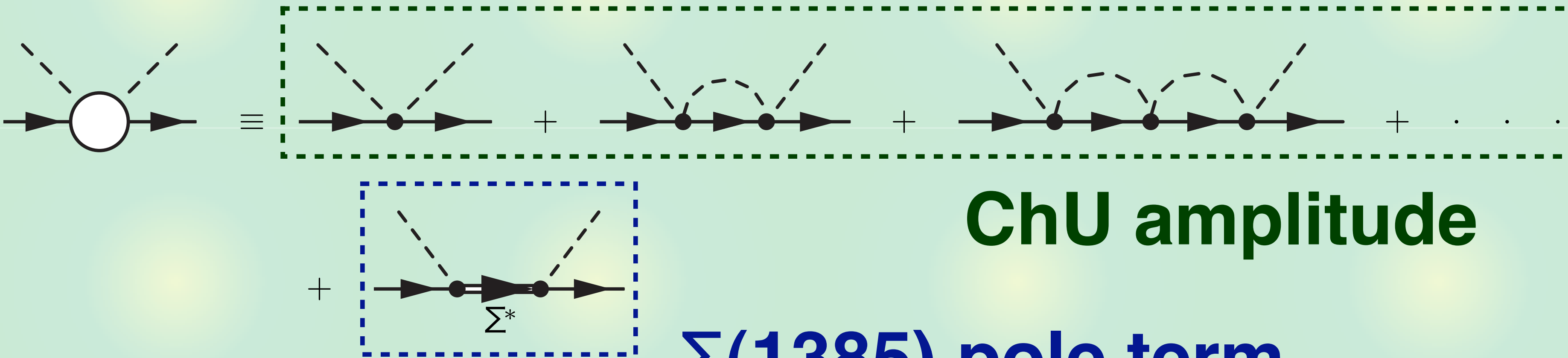


☆ VPP coupling

$$\mathcal{L}_{VPP} = -\frac{ig_{VPP}}{\sqrt{2}}\text{Tr}(V^\mu[\partial_\mu P, P])$$



Effective interaction for baryon part



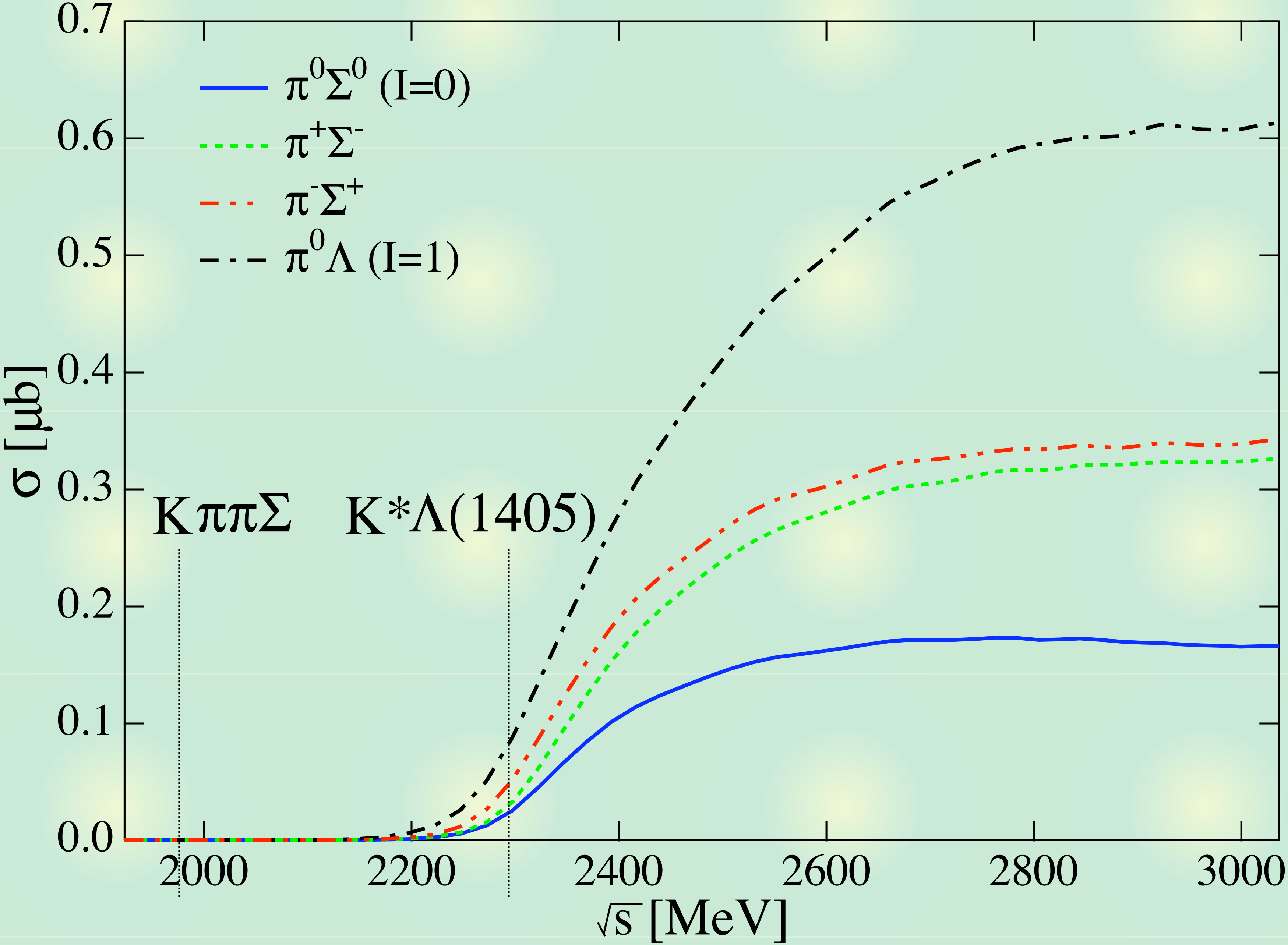
- **Σ(1385)MB coupling**

- $$-it_{\Sigma^* i} = c_i \frac{12}{5} \frac{D+F}{2f} \boldsymbol{S} \cdot \boldsymbol{k}_i$$

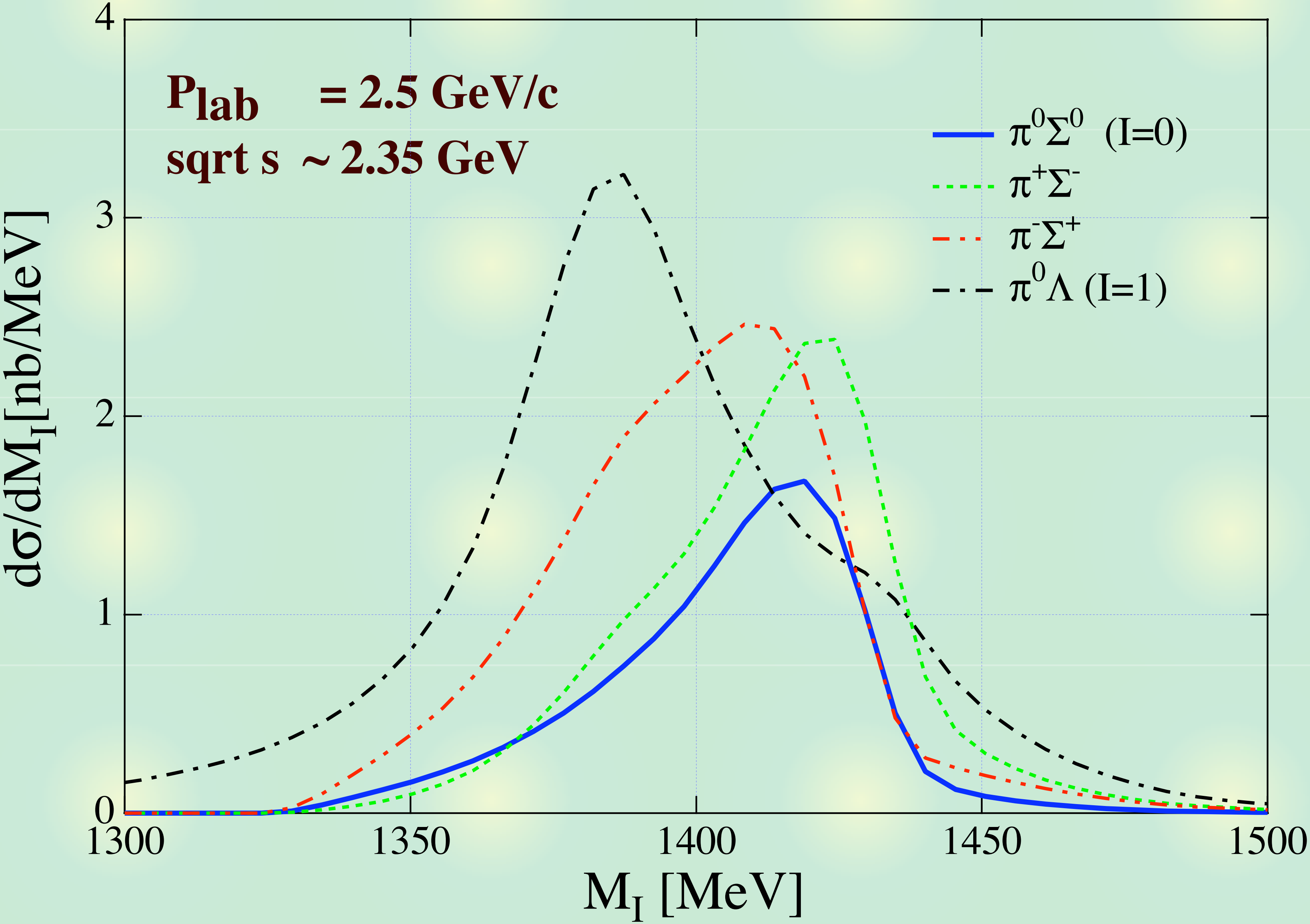
- **form factor**

$$F_f(k_1) = \frac{\Lambda^2 - m_K^2}{\Lambda^2 - (k_1)^2}$$

Total cross sections



Invariant mass distributions



Isospin decomposition of πΣ states

Since initial state is KN, we neglect the I=2.

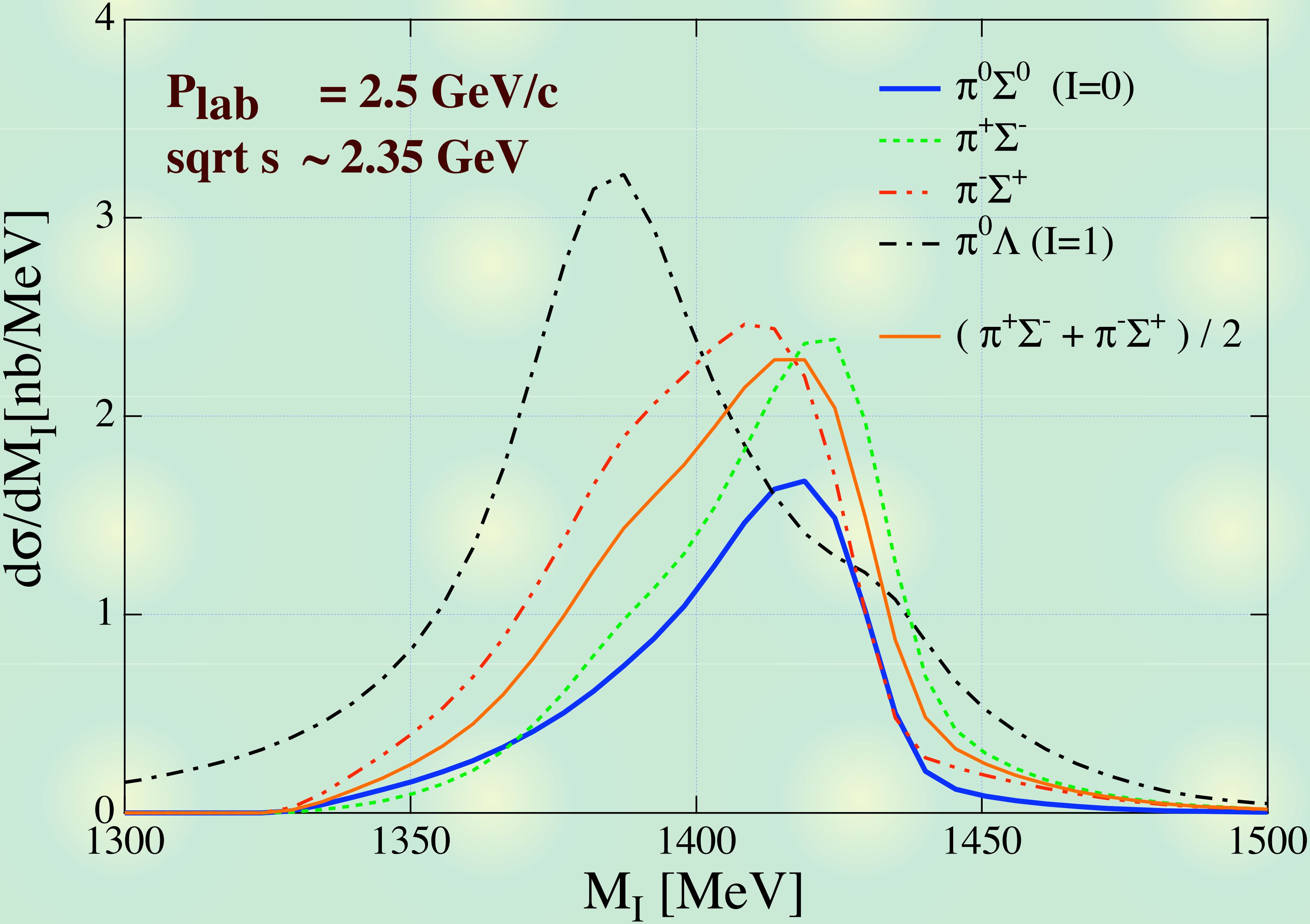
$$\frac{d\sigma(\pi^0\Sigma^0)}{dM_I} \propto \frac{1}{3}|T^{(0)}|^2$$

- **Pure I=0 amplitude**

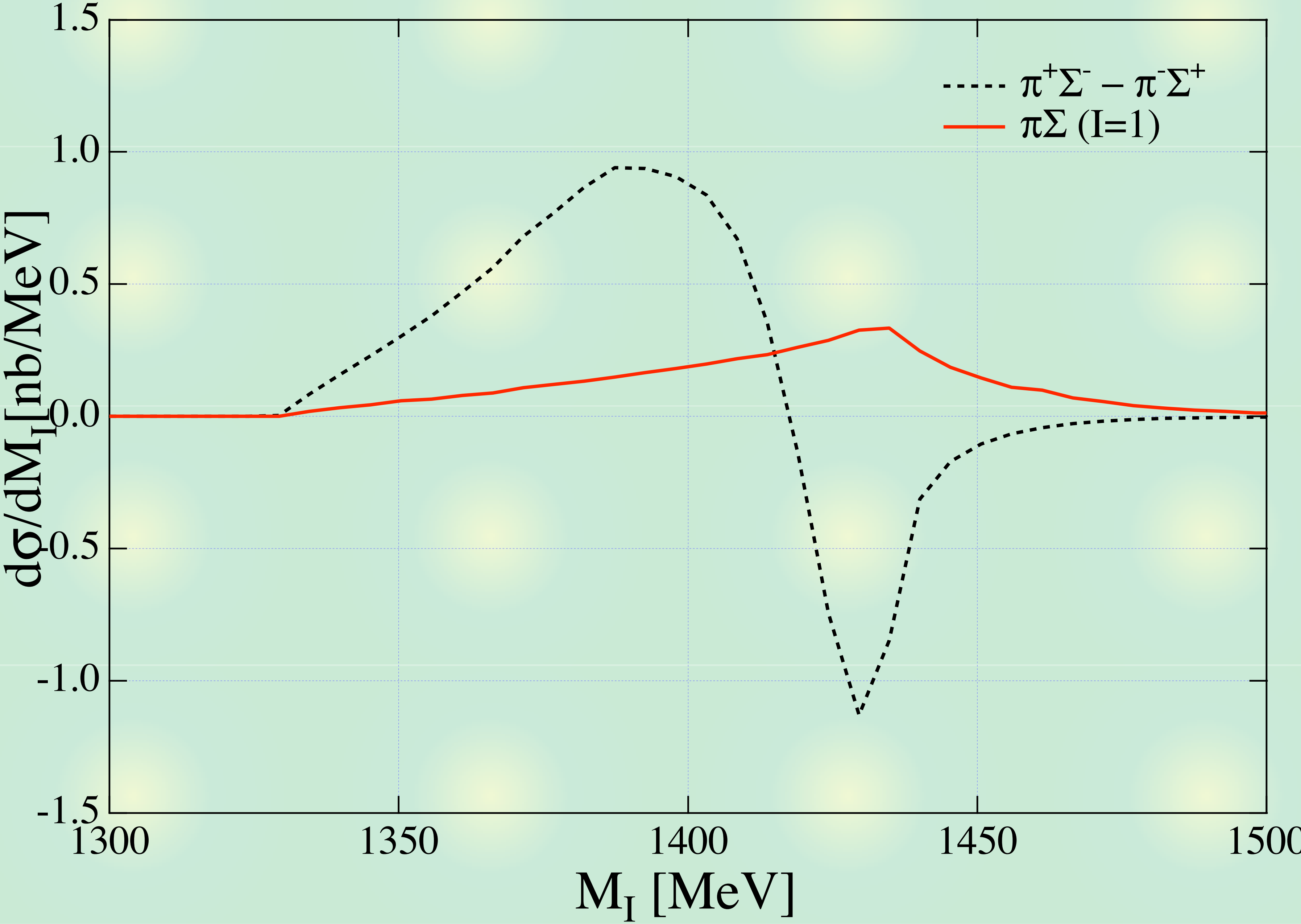
$$\frac{d\sigma(\pi^\pm\Sigma^\mp)}{dM_I} \propto \frac{1}{3}|T^{(0)}|^2 + \frac{1}{2}|T^{(1)}|^2 \pm \frac{2}{\sqrt{6}}\mathrm{Re}(T^{(0)}T^{(1)*})$$

- **Difference among charged states**
  -> when summed up, this term vanishes
- **No p-wave contribution**
  -> I=1 s-wave amplitude

Invariant mass distributions 2



I=1, s-wave amplitude



Summary and conclusions 1

We study the structure of Λ(1405) using the chiral unitary model.

- There are two poles of the scattering amplitude around nominal Λ(1405).
- Pole 1 (1426–16i) : strongly couples to $\bar{K}N$ state
- Pole 2 (1390–66i) : strongly couples to πΣ state
- By observing the charged πΣ states in the $\gamma p \to K^* \Lambda(1405)$ reaction, it is possible to isolate the higher energy pole.

Summary and conclusions 2

- If we observe neutral πΣ state, clear I=0 distribution is obtained.
-
- Combining three πΣ states, we can also study the s-wave I=1 amplitude, where the existence of another pole is argued.

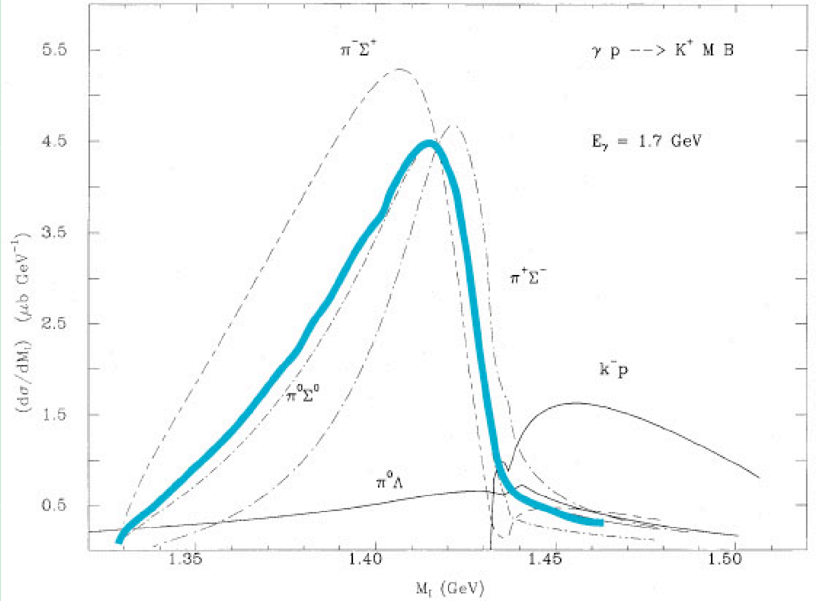
T. H., A. Hosaka, E. Oset, M. J. Vicente Vacas, PLB593, 75 (2004)

http://www.rcnp.osaka-u.ac.jp/~hyodo/

Appendix : other processes

$$\gamma p \rightarrow K^- \pi \Sigma$$

J.C. Nacher, *et al.*, PLB445, 55



$$K^- p \rightarrow \gamma \pi \Sigma$$

J.C. Nacher, *et al.*, PLB461, 299