Photoproduction of K* for the study of $\Lambda(1405)$

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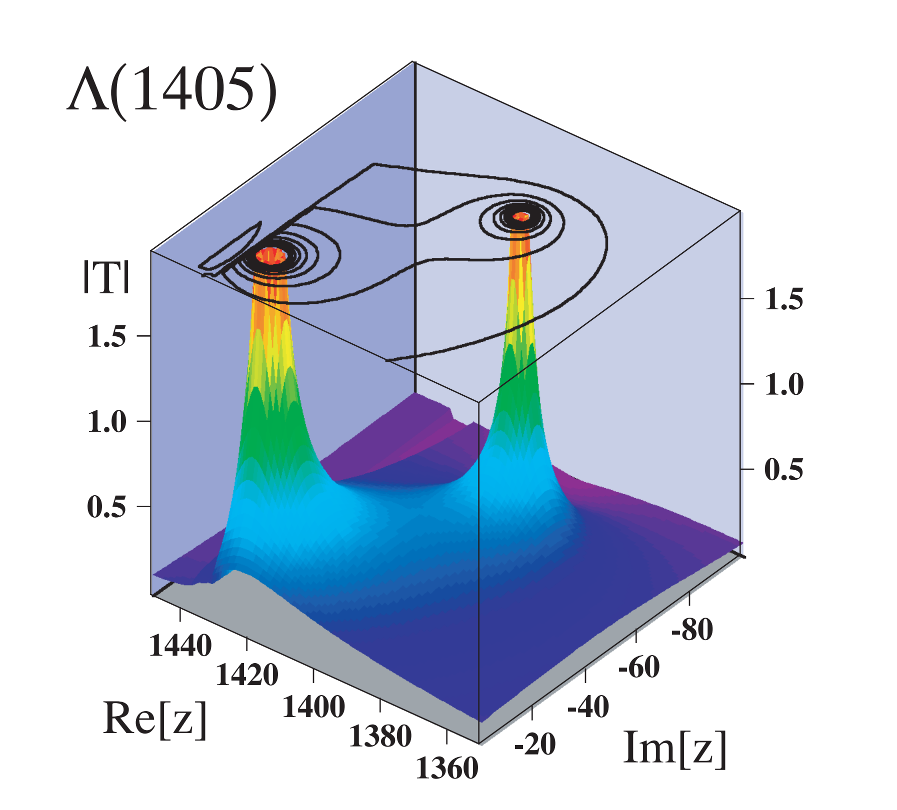
Motivation : Two poles?

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

- <u>**Cloudy bag model**</u> **(1990)**
  J. Fink, *et al.* PRC41, 2720

- <u>**Chiral unitary model**</u> **(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
  C. Garcia-Recio, *et al.*, PRD67, 076009
  D. Jido, *et al.*, NPA725, 181
  T. Hyodo, *et al.* PRC68, 065203

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



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

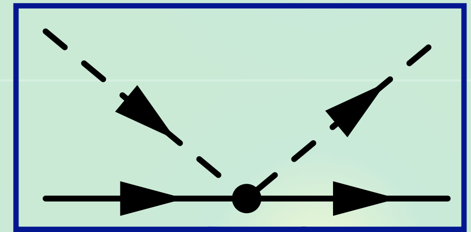
$J^P = 1/2^-$ resonances

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

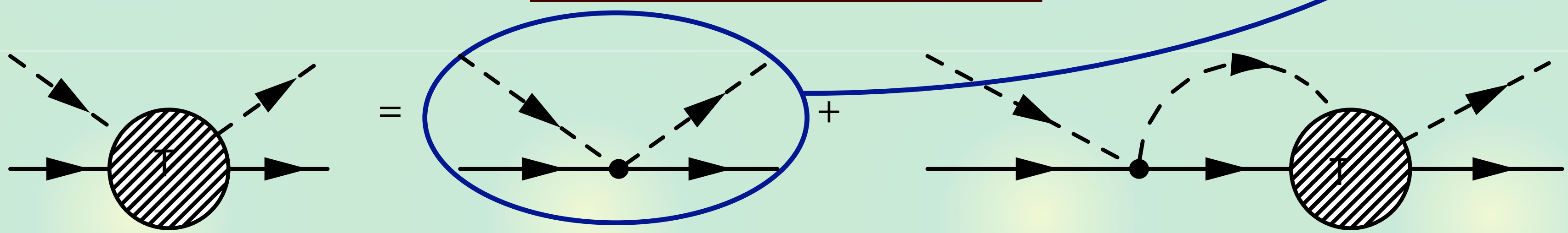
Framework of the chiral unitary model

Chiral perturbation theory

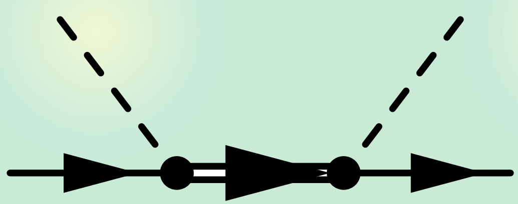
$$\mathcal{L}_{WT} = \frac{1}{4f^2}\mathrm{Tr}(\bar{B}i\gamma^{\mu}[(\Phi\partial_{\mu}\Phi - \partial_{\mu}\Phi\Phi), B])$$



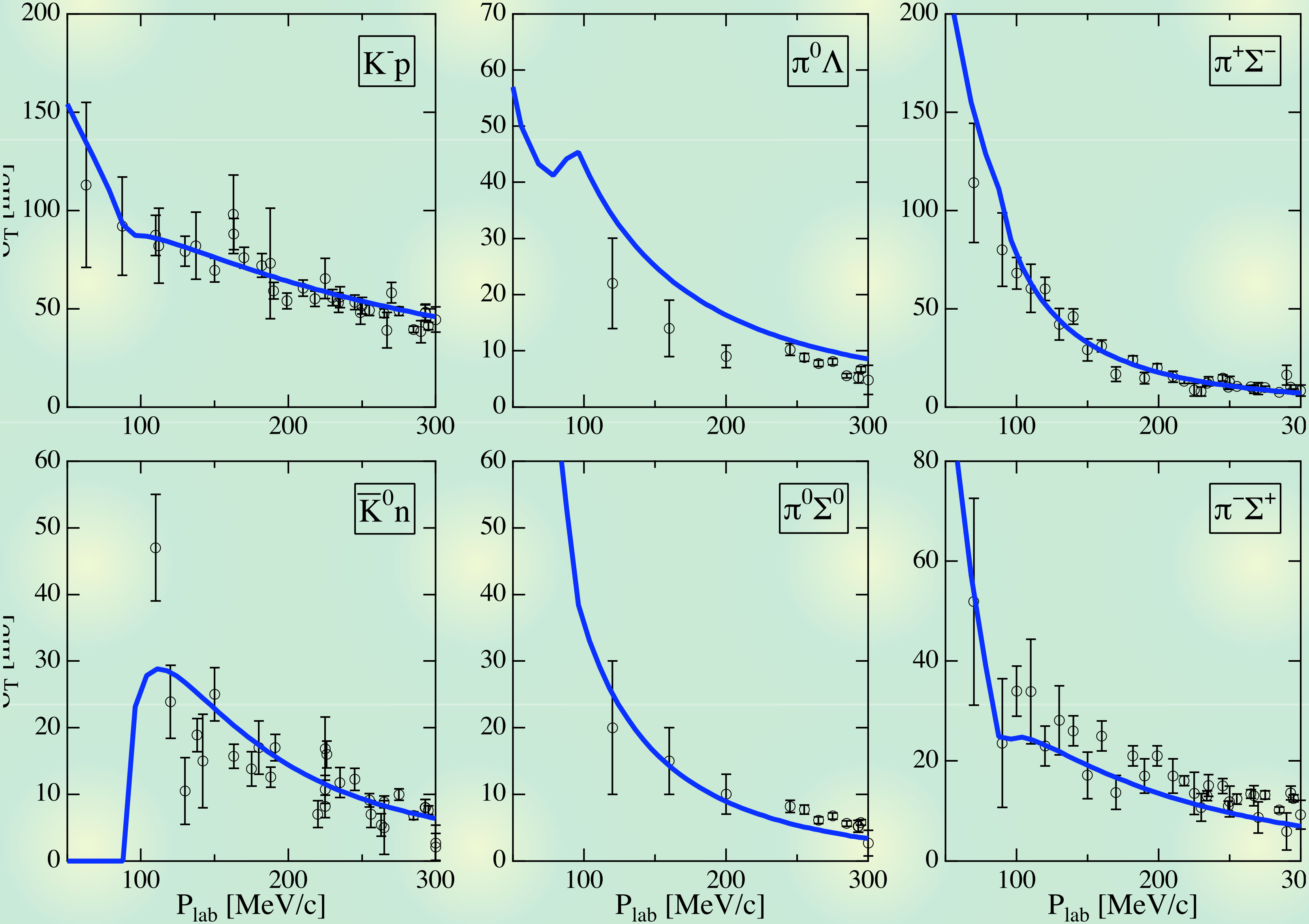
Unitarization



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

$\sim$ 

Total cross sections of K-p scattering

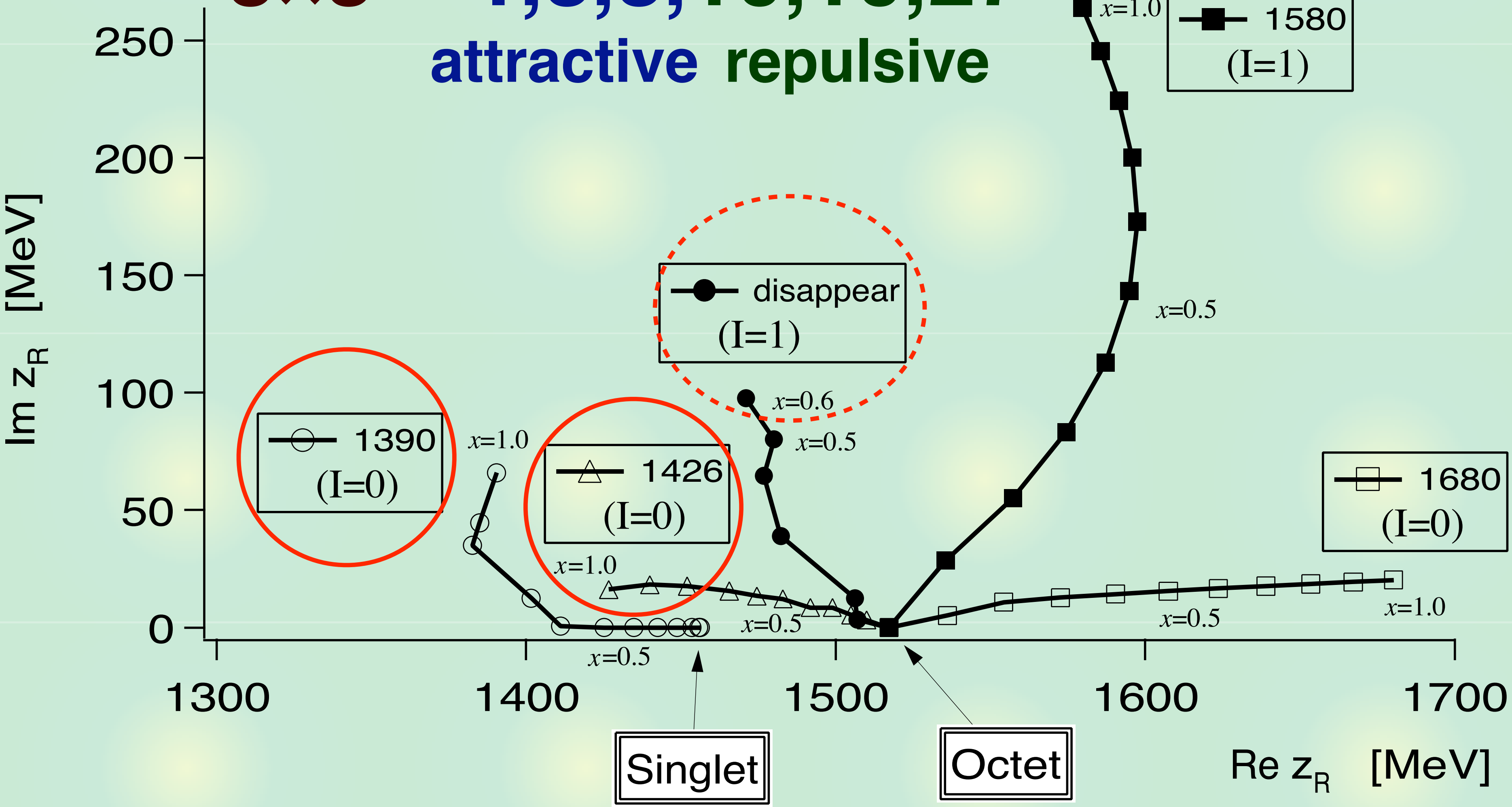


T. Hyodo, *et al.*, Phys. Rev. C 68, 018201 (2003)

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

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

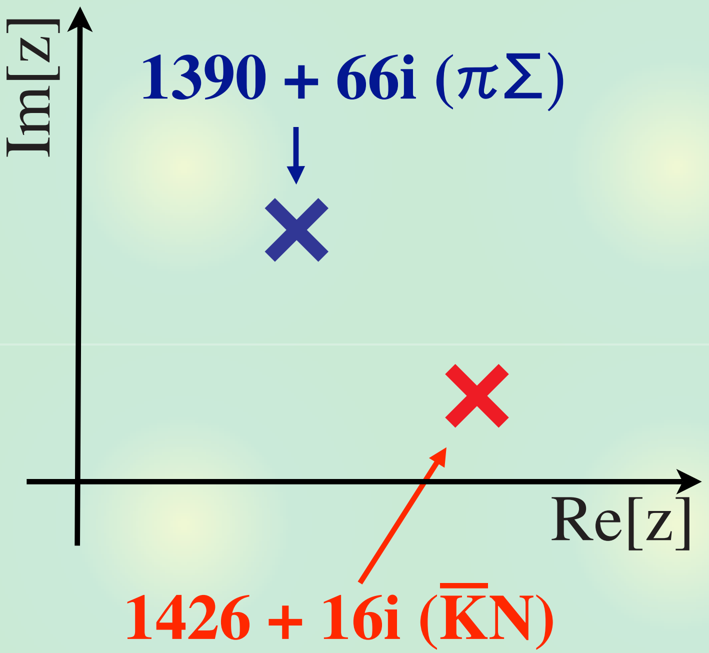
attractive **repulsive**



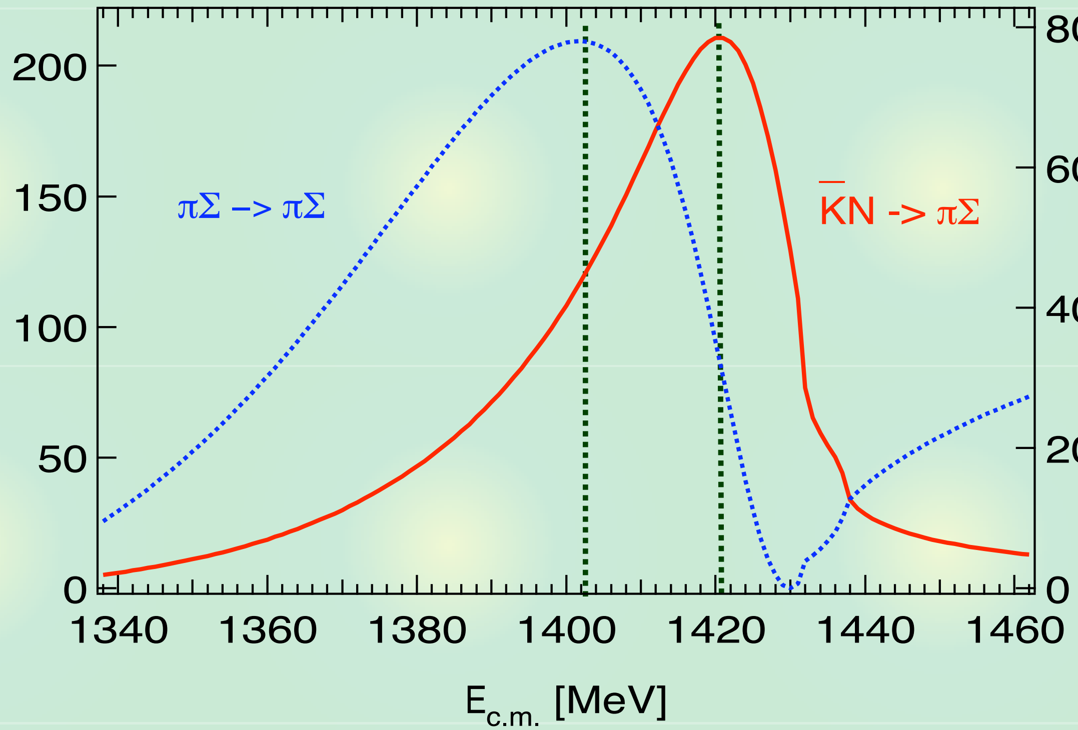
D. Jido, *et al.*, Nucl. Phys. A 723, 205 (2003)

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)

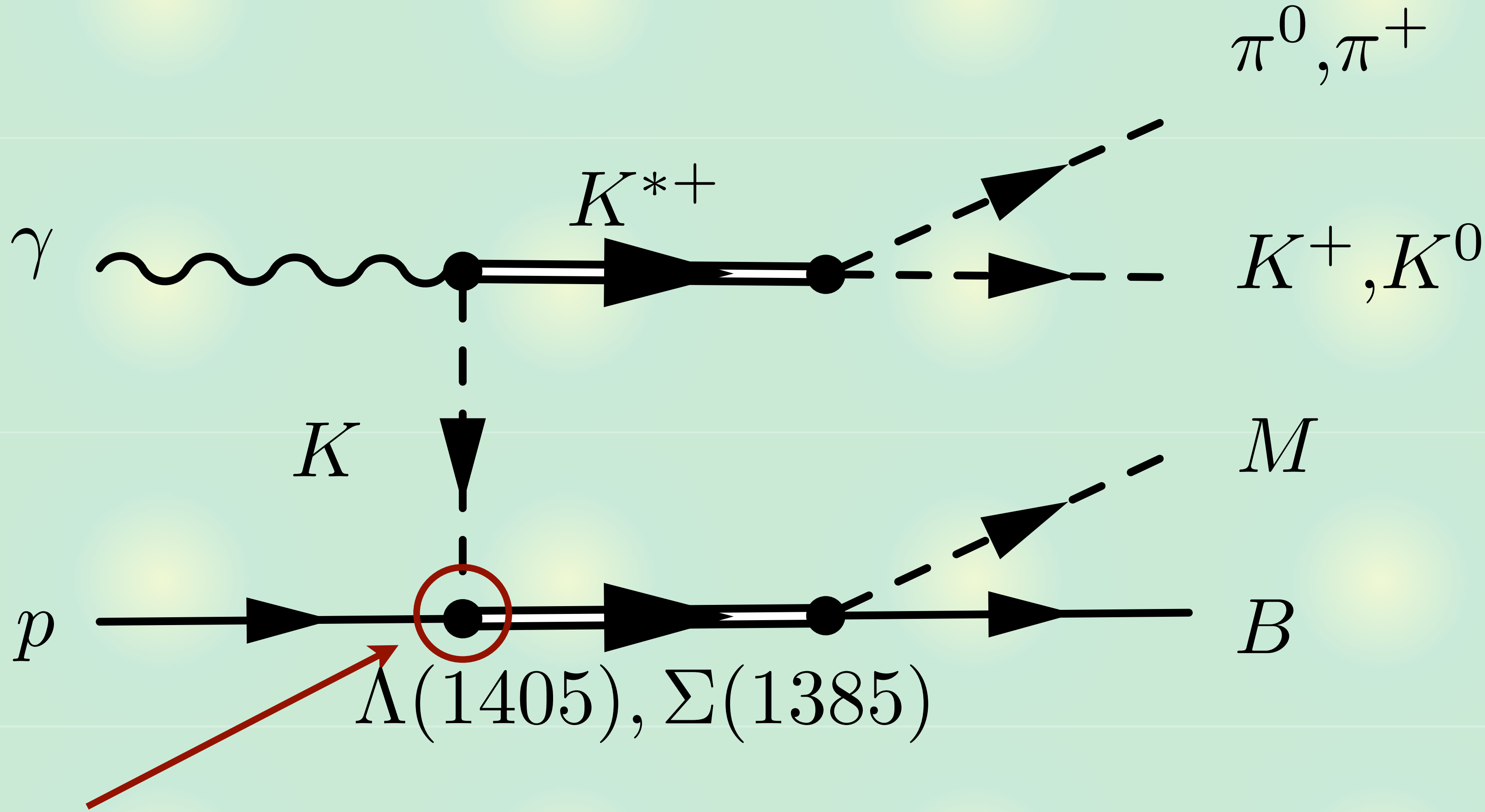
In order to study

- S=-1, I=0, s-wave : Λ(1405)
  - two poles?
  - *1426 + 16i* : KN
  - *1390 + 66i* : πΣ
- S=-1, I=1, s-wave
  - pole?

we calculate

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

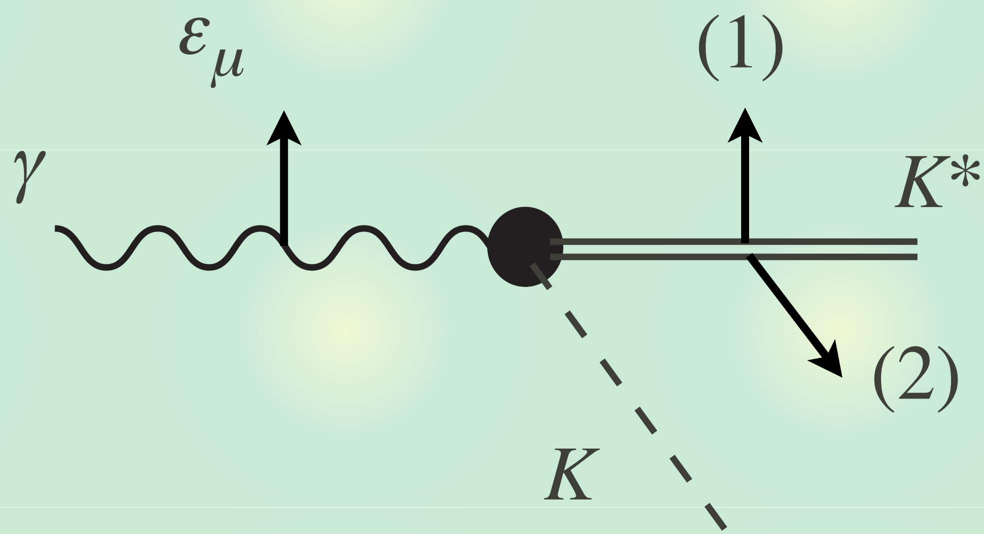
Photoproduction of K* and Λ(1405)



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

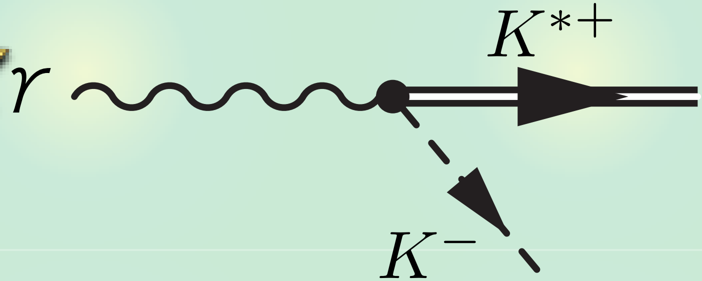
With polarized photon beam, the exchanged particle can be identified.

Clear mechanism

Effective interaction for meson part

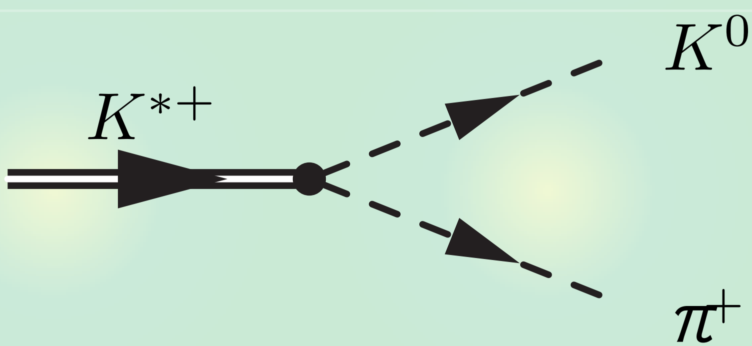
γKK* coupling

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

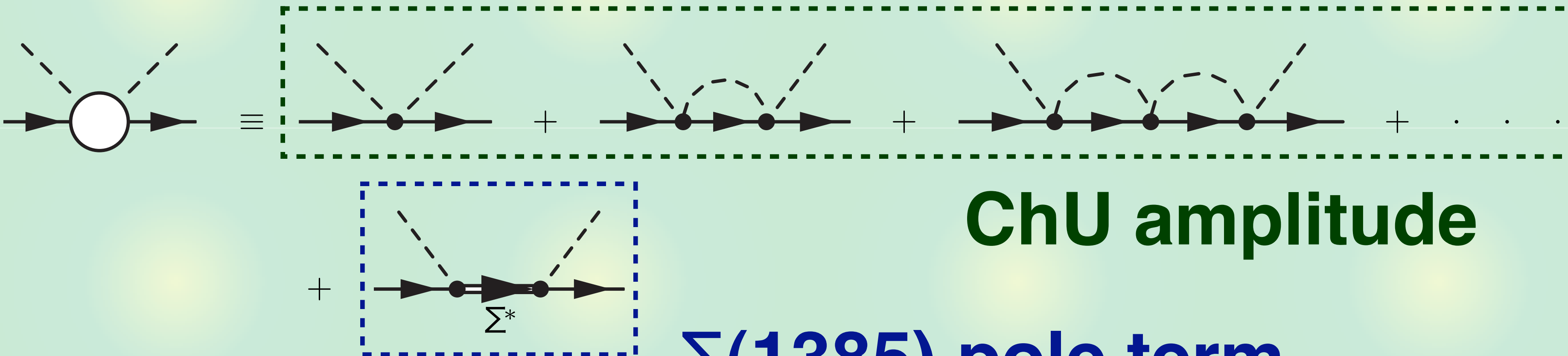


VPP coupling

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



Effective interaction for baryon part



ChU amplitude

Σ(1385) pole term

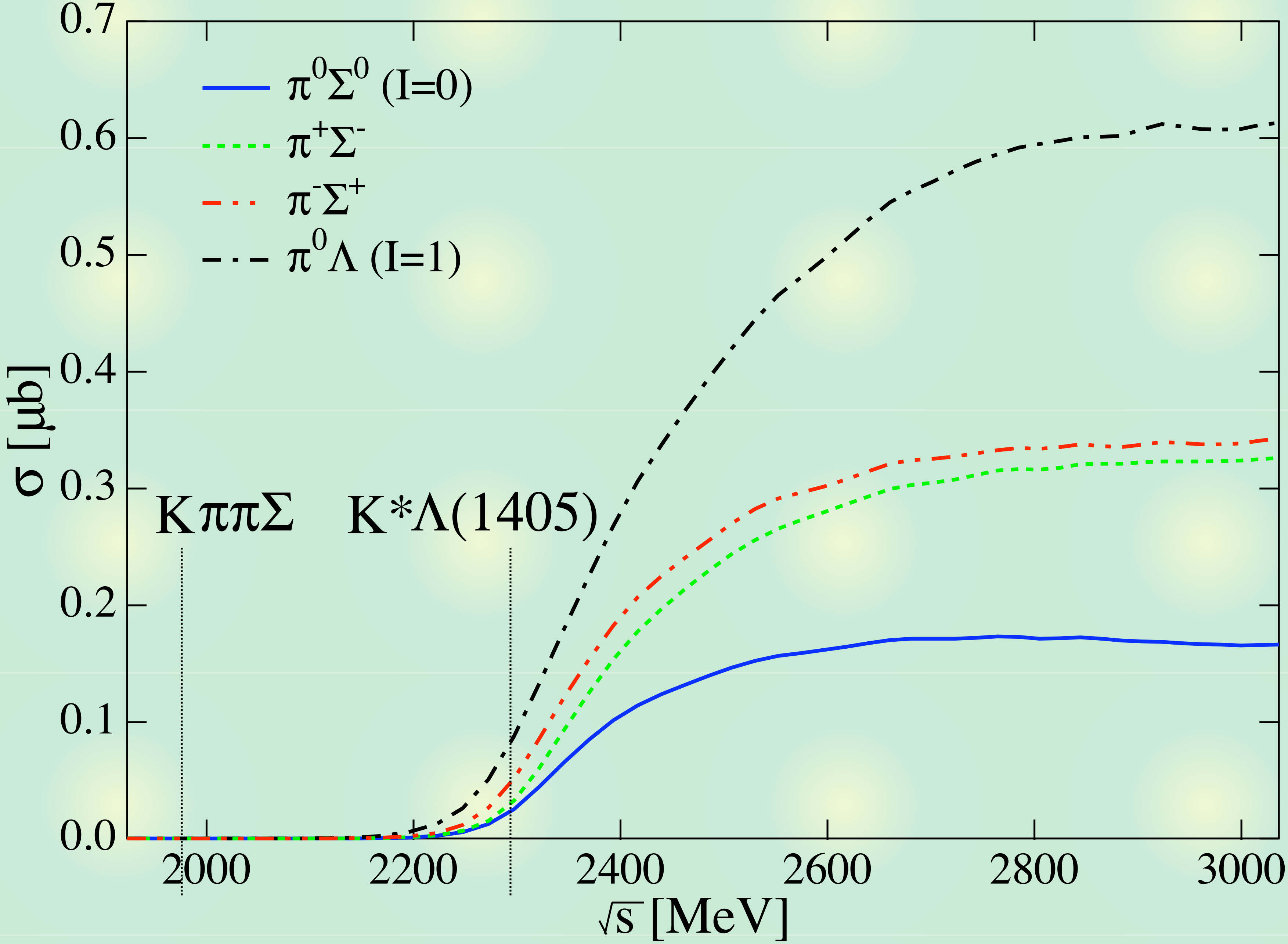
- **Σ(1385)MB coupling**

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

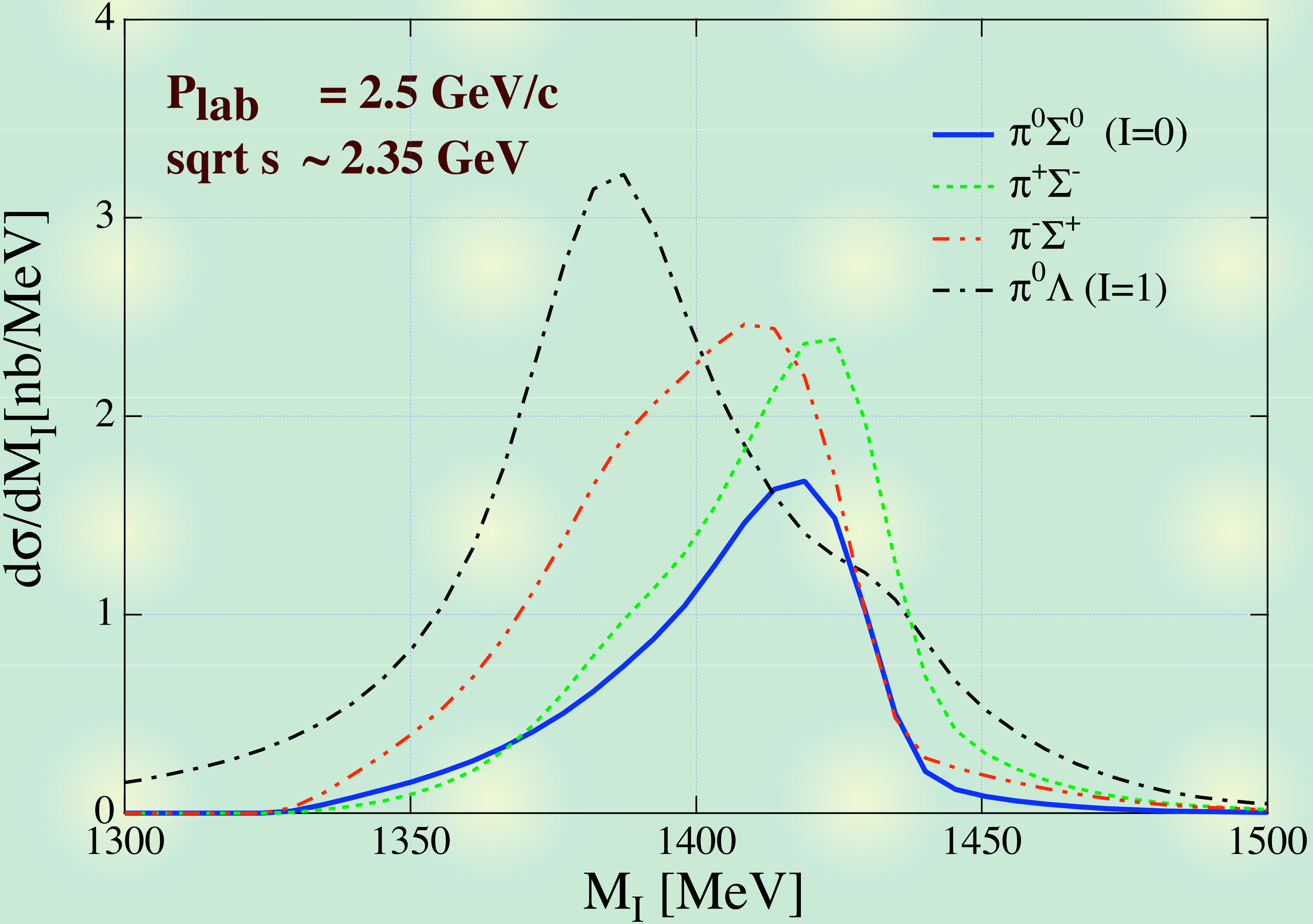
- **form factor**

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

Total cross sections



Invariant mass distributions



Isospin decomposition of πΣ states

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

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

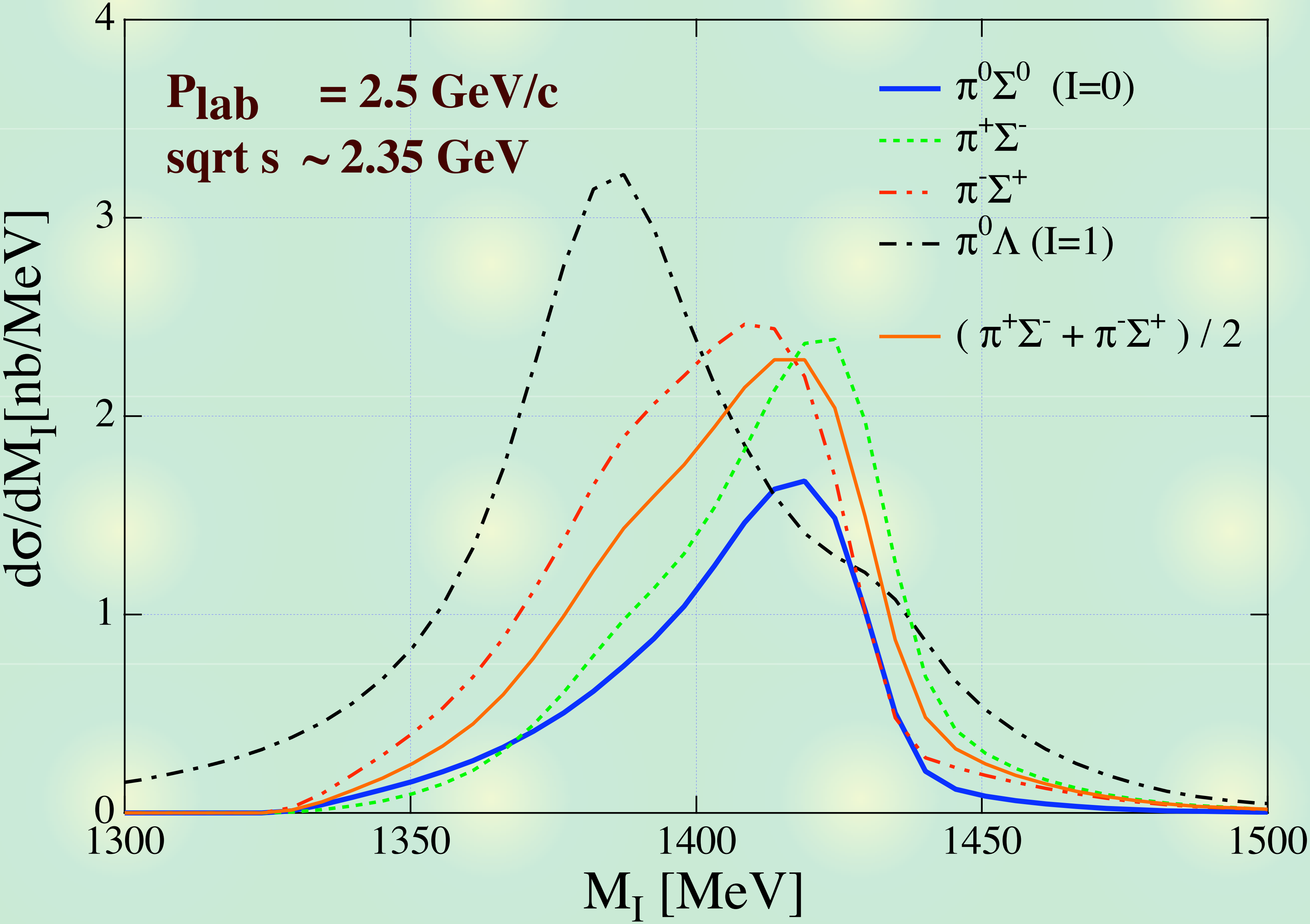
- **Pure I=0 amplitude**

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

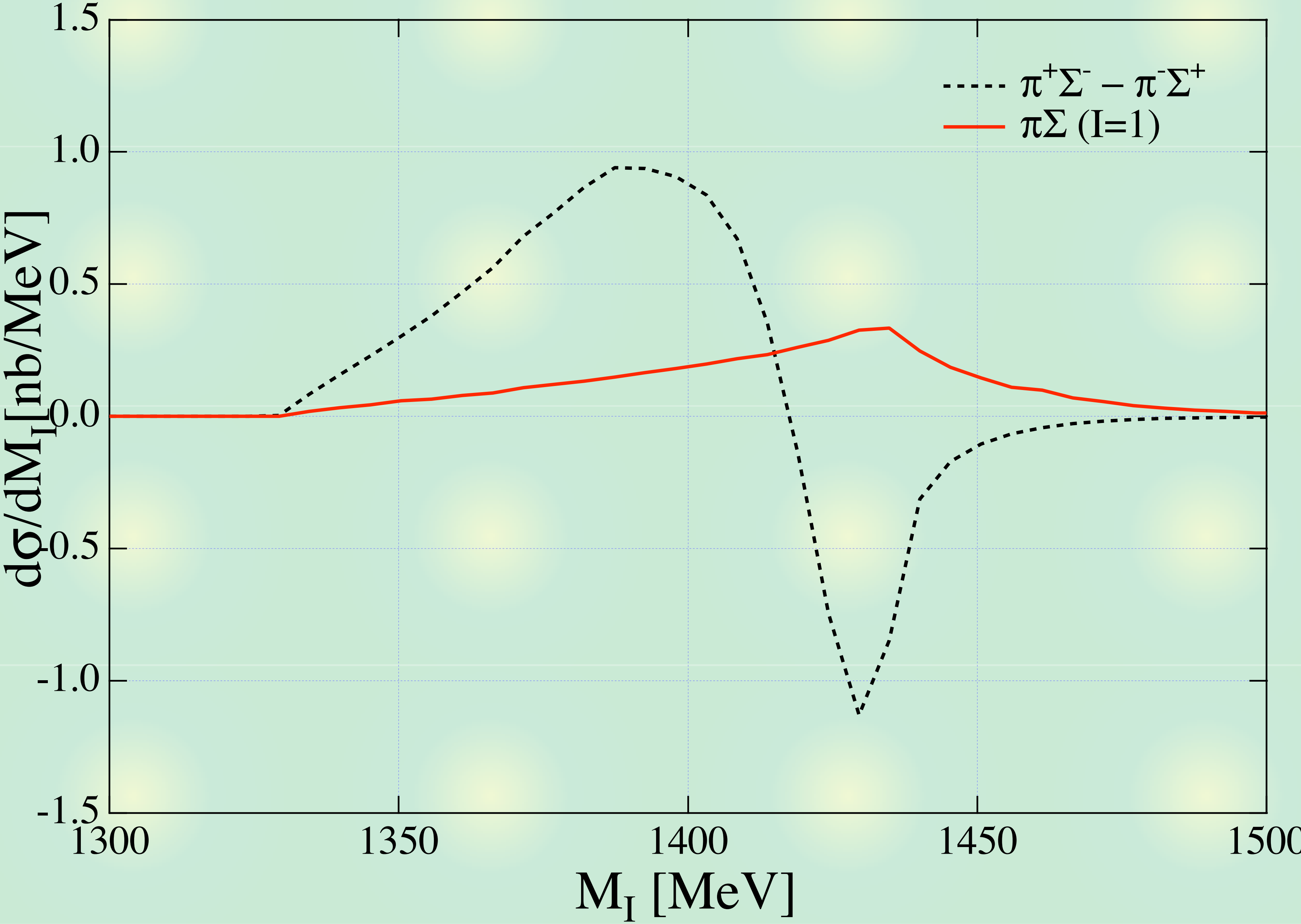
- **Difference among charged states**
  -> when summed up, this term vanishes

- **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 $\gamma p \longrightarrow K^* \Lambda(1405)$ reaction, it is possible to isolate the higher energy pole.

Summary and conclusions 2

- If we observe neutral $\pi\Sigma$ state, clear I=0 distribution is obtained.
-
- Combining three $\pi\Sigma$ 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, nucl-th/0401051

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

Appendix : other processes

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

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

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

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