

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



**Tetsuo Hyodo<sup>a</sup>,**

**A. Hosaka<sup>a</sup>, M. J. Vicente Vacas<sup>b</sup>, and E. Oset<sup>b</sup>**

*RCNP, Osaka<sup>a</sup> IFIC, Valencia<sup>b</sup>*

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## Introduction : $\Lambda(1405)$

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

**Mass :  $1406.5 \pm 4.0$  MeV**

**Width :  $50 \pm 2$  MeV**

**Decay mode :  $\Lambda(1405) \rightarrow (\pi\Sigma)_{I=0}$  100%**

## Coupled channel multi-scattering

**R.H. Dalitz, T.C. Wong and G. Rajasekaran PR 153, 1617 (1967)**

**(Naive) Quark model : 1500 MeV?**

**N. Isgur, and G. Karl, PRD 18, 4187 (1978)**

**Meson-Baryon or 3-quark?**

## Recent works

### Quark model : LS partner of $\Lambda(1520)$

C.L. Schat, J.L. Goity and N.N. Scoccola PRL 88, 100202 (2002)

### Lattice QCD with 3-quark operator

W. Melnitchouk, *et. al.*, PRD 67, 114506 (2003)

Y. Nemoto, *et. al.*, PRD 68, 094505 (2003)

F.X. Lee, *et. al.*, NP 119, 296 (2003)

--> not a 3-quark

--> 3-quark?

## Chiral unitary approaches

Valencia, GSI, ...

--> Meson-baryon picture

## Motivation : Two poles?

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

- Cloudy bag model

J. Fink, *et al.*, PRC41, 2720

- Chiral unitary model

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.*, PTP112, 73

C. Garcia-Recio, *et al.*, PRD67, 076009

D. Jido, *et al.*, NPA725, 181

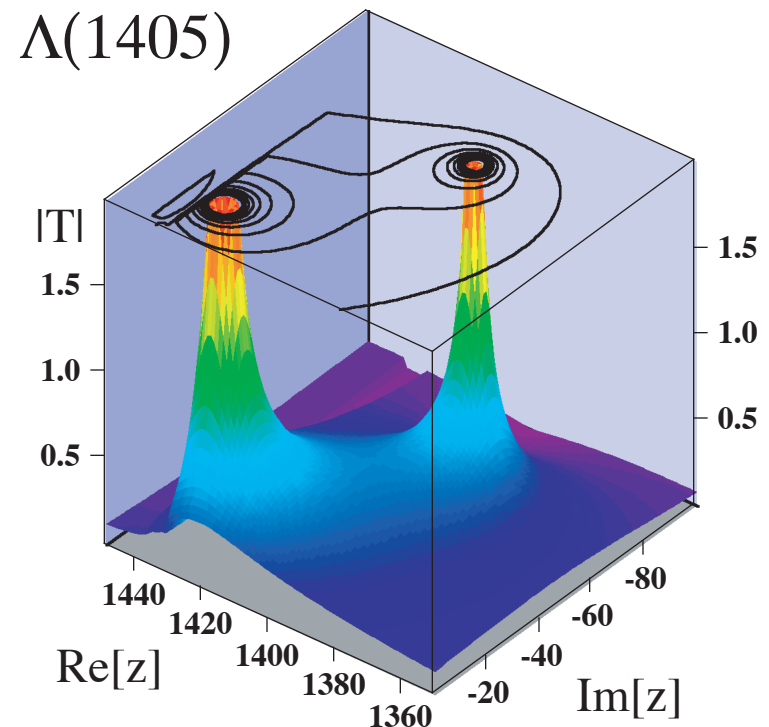
T. Hyodo, *et al.*, PRC68, 065203

C. Garcia-Recio, *et al.*, PLB582, 49

- Correlated quark model

A. Zhang, *et al.*, hep-ph/0403210

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



ChU model, T. Hyodo

# Chiral unitary model

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

**Chiral symmetry**

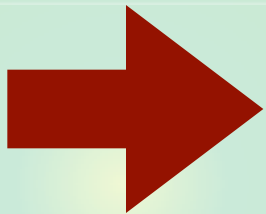
**Low energy  
behavior**



**Unitarity of S-matrix**

**Non-perturbative  
resummation**

**Dynamical  
generation**



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

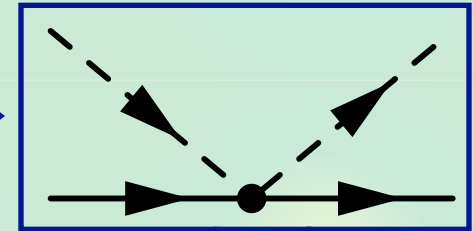
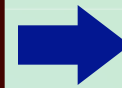
$\Lambda(1405), \Lambda(1670),$   
 $\Sigma(1620), \Xi(1620),$   
 $N(1535)$



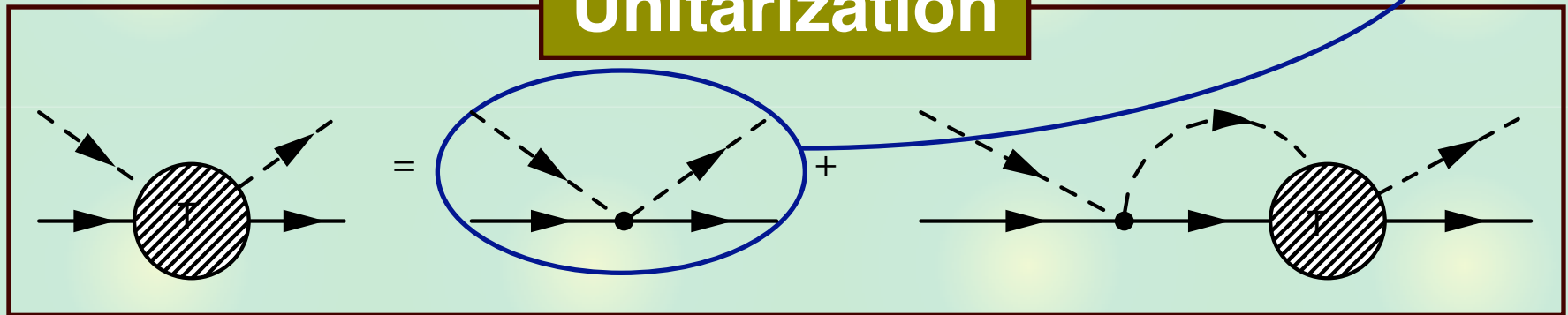
# Framework of the chiral unitary model

## Chiral perturbation theory

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

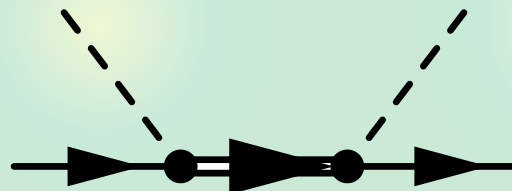


## Unitarization

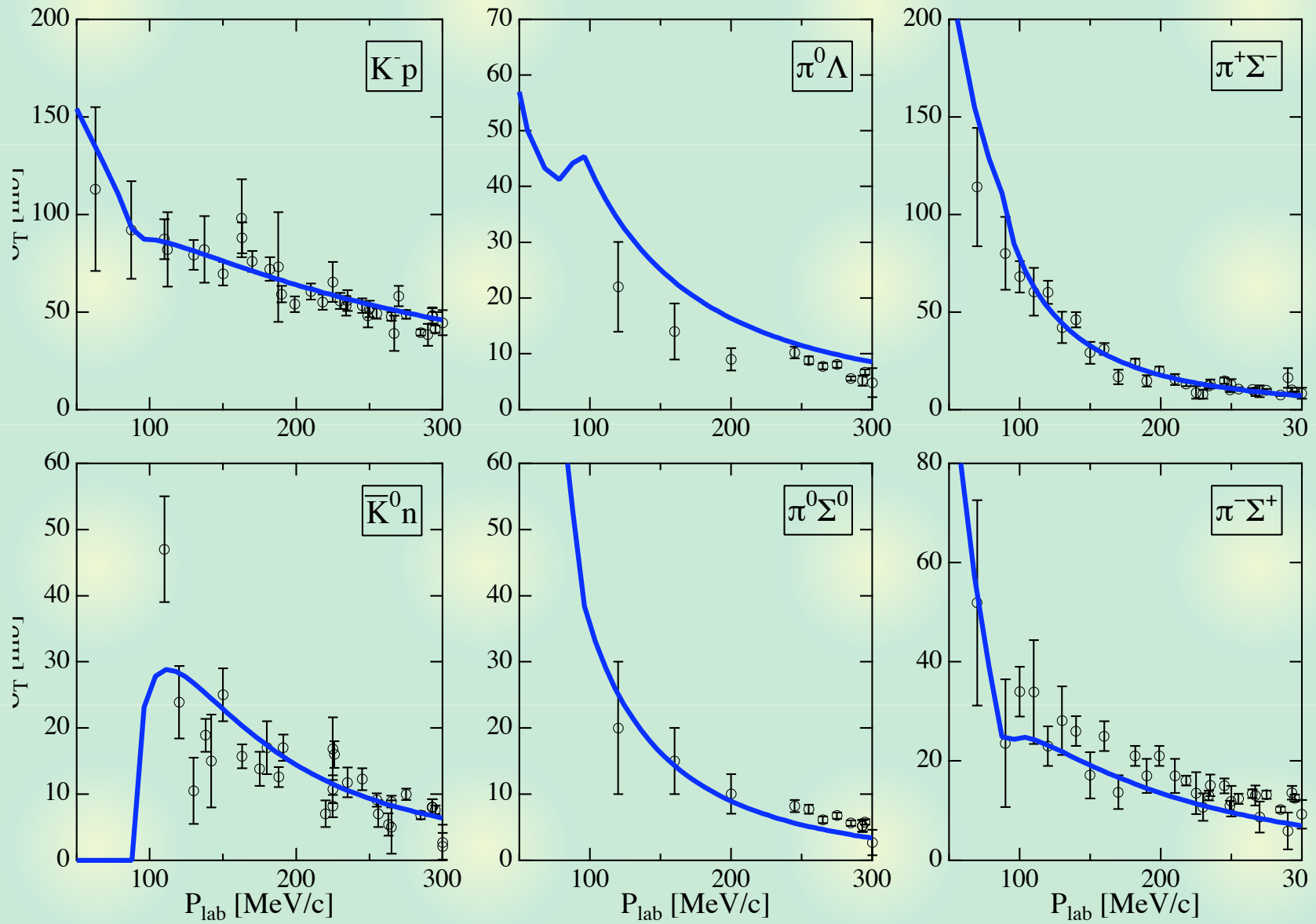


$$T_{ij}(\sqrt{s}) \sim \frac{g_i g_j}{\sqrt{s} - M_R + i\Gamma_R/2} + T_{ij}^{BG}$$

$\sim$



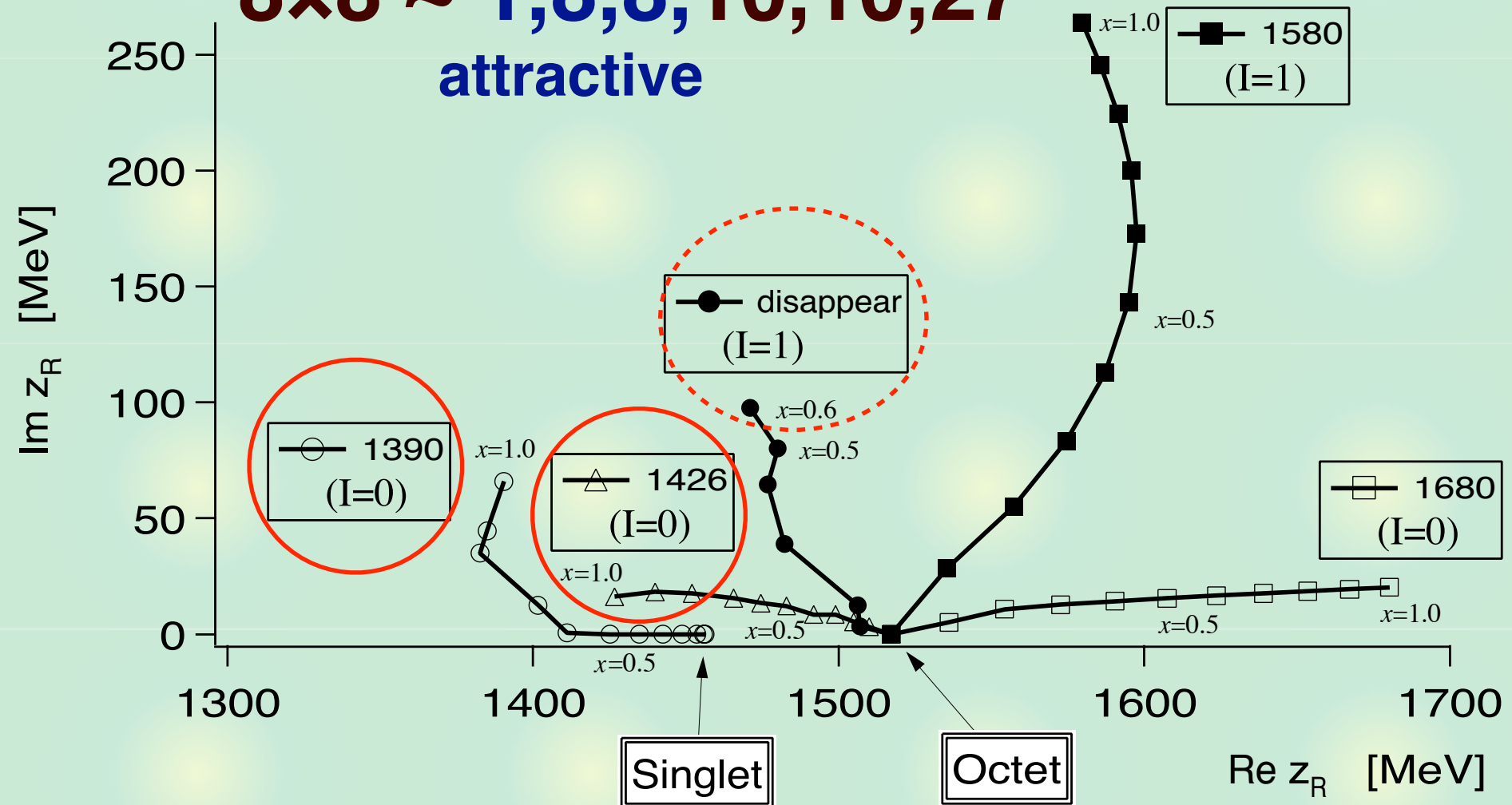
# Total cross sections of K-p scattering



**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

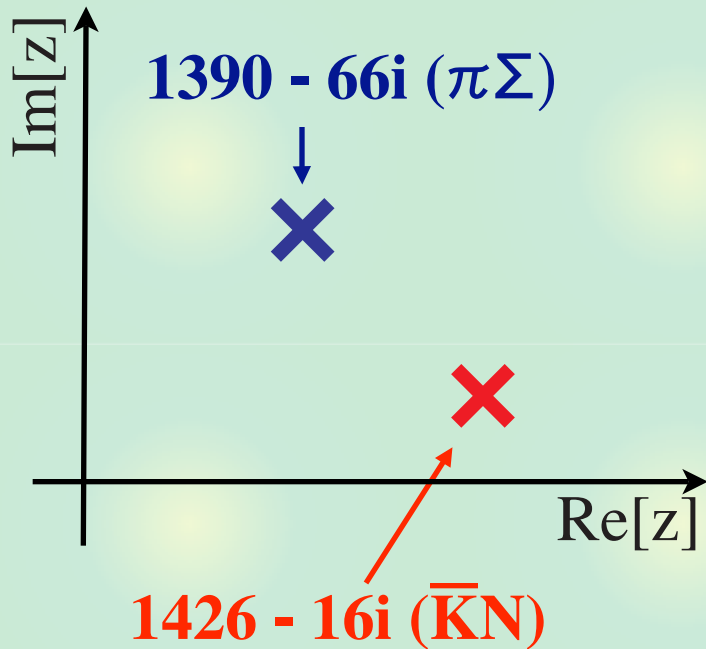


D. Jido, et al., Nucl. Phys. A 723, 205 (2003)

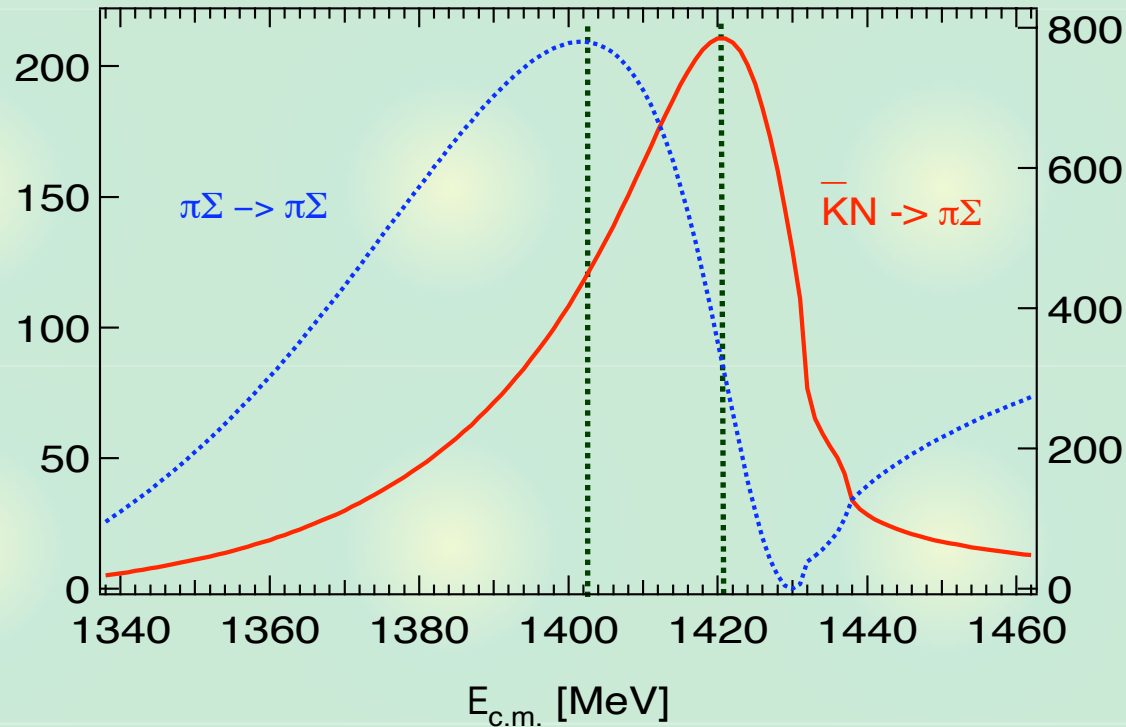


# $\Lambda(1405)$ in the chiral unitary model

## position of poles



## $\pi\Sigma$ mass distribution



$$\frac{d\sigma}{dM_I} = C |t_{\pi\Sigma \rightarrow \pi\Sigma}|^2 p_{CM} \quad \longrightarrow \quad \frac{d\sigma}{dM_I} = \left| \sum_i C_i t_{i \rightarrow \pi\Sigma} \right|^2 p_{CM}$$

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

# Photoproduction of $K^*$ and $\Lambda(1405)$

In order to study

★  $S = -1, l = 0, s\text{-wave} : \Lambda(1405)$

★ two poles?

★  $1426 - 16i : \bar{K}N$

★  $1390 - 66i : \pi\Sigma$

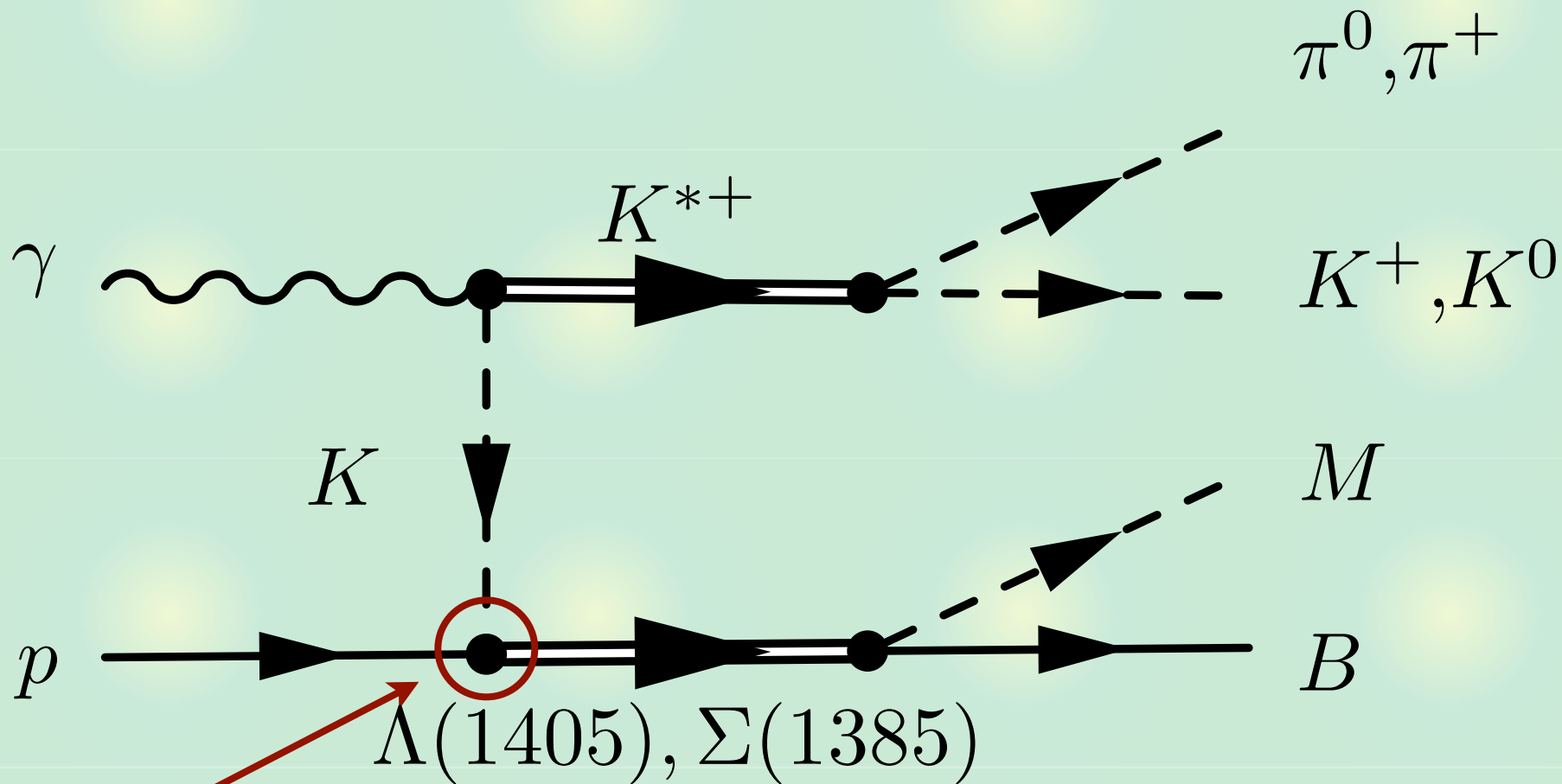
★  $S = -1, l = 1, s\text{-wave}$

★ pole? --> see paper

we calculate

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

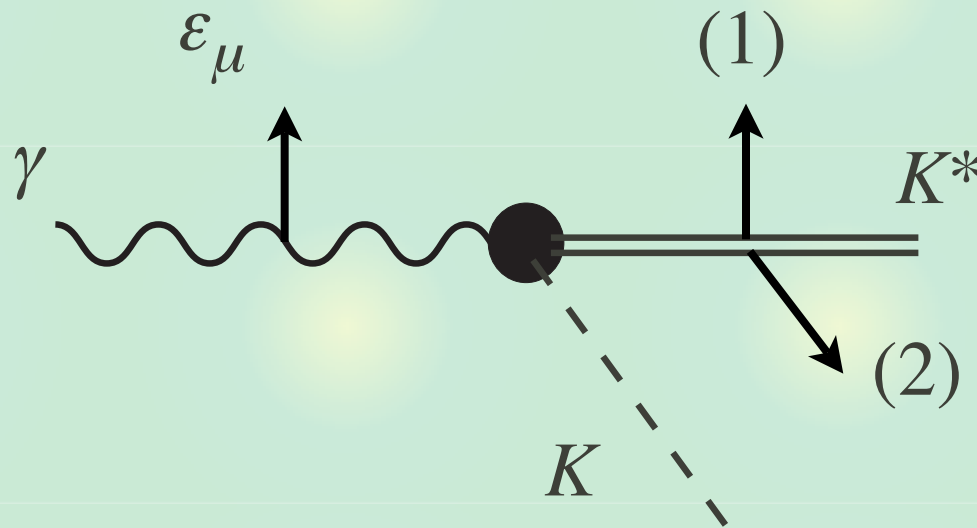
# Photoproduction of $K^*$ and $\Lambda(1405)$



**Only  $K^-p$  channel appears at the initial stage**

**Higher energy pole ??**

## Advantage of this reaction



$$(1) \quad \epsilon_\mu(K^*) // \epsilon_\mu(\gamma) : J^P = \text{natural}$$

$$(2) \quad \epsilon_\mu(K^*) \perp \epsilon_\mu(\gamma) : J^P = \text{unnatural}$$

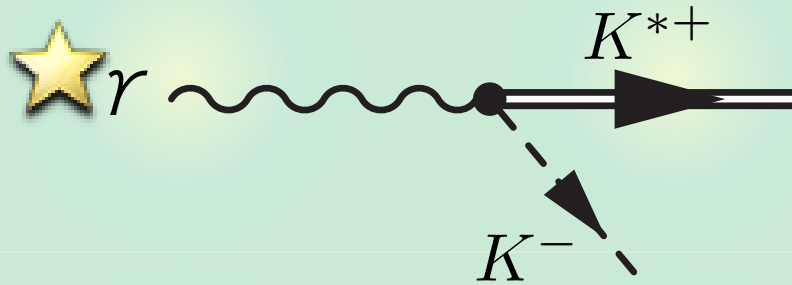
**With polarized photon beam, the exchanged particle can be identified.**

**Clear mechanism**

# Effective interaction for meson part

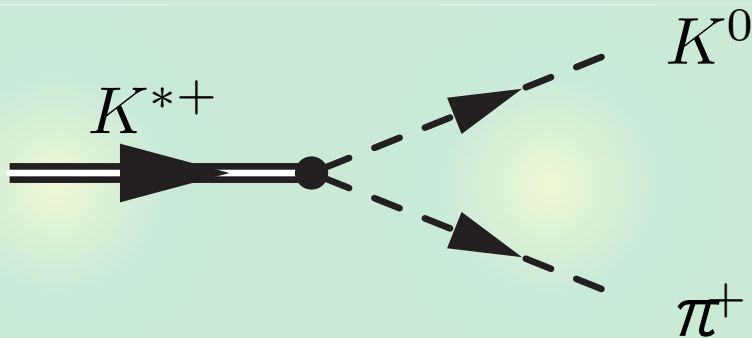
## ★ $\gamma KK^*$ coupling

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

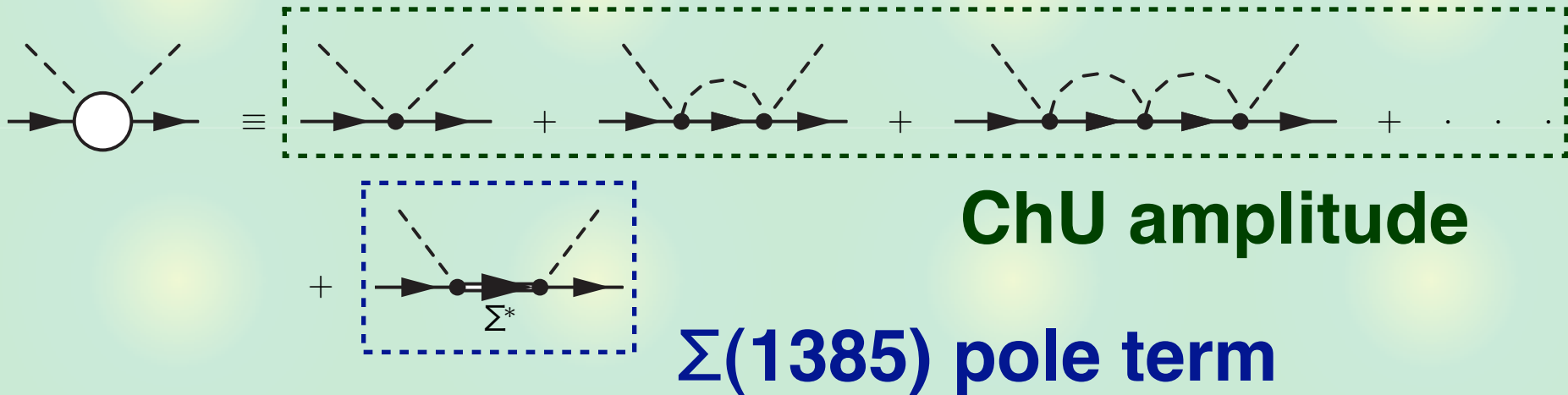


## ★ VPP coupling

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



# Effective interaction for baryon part



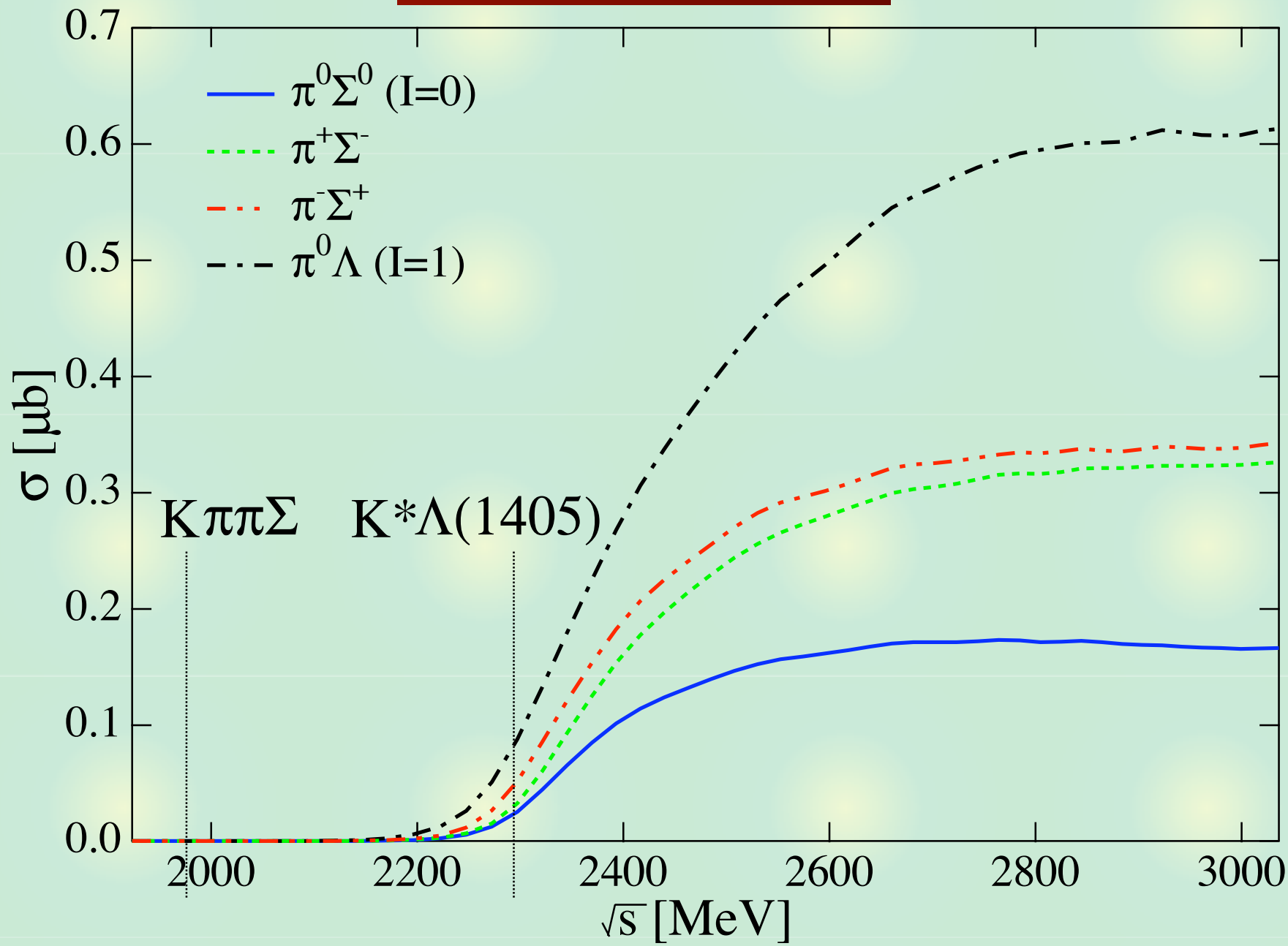
★ **Σ(1385)MB coupling**

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

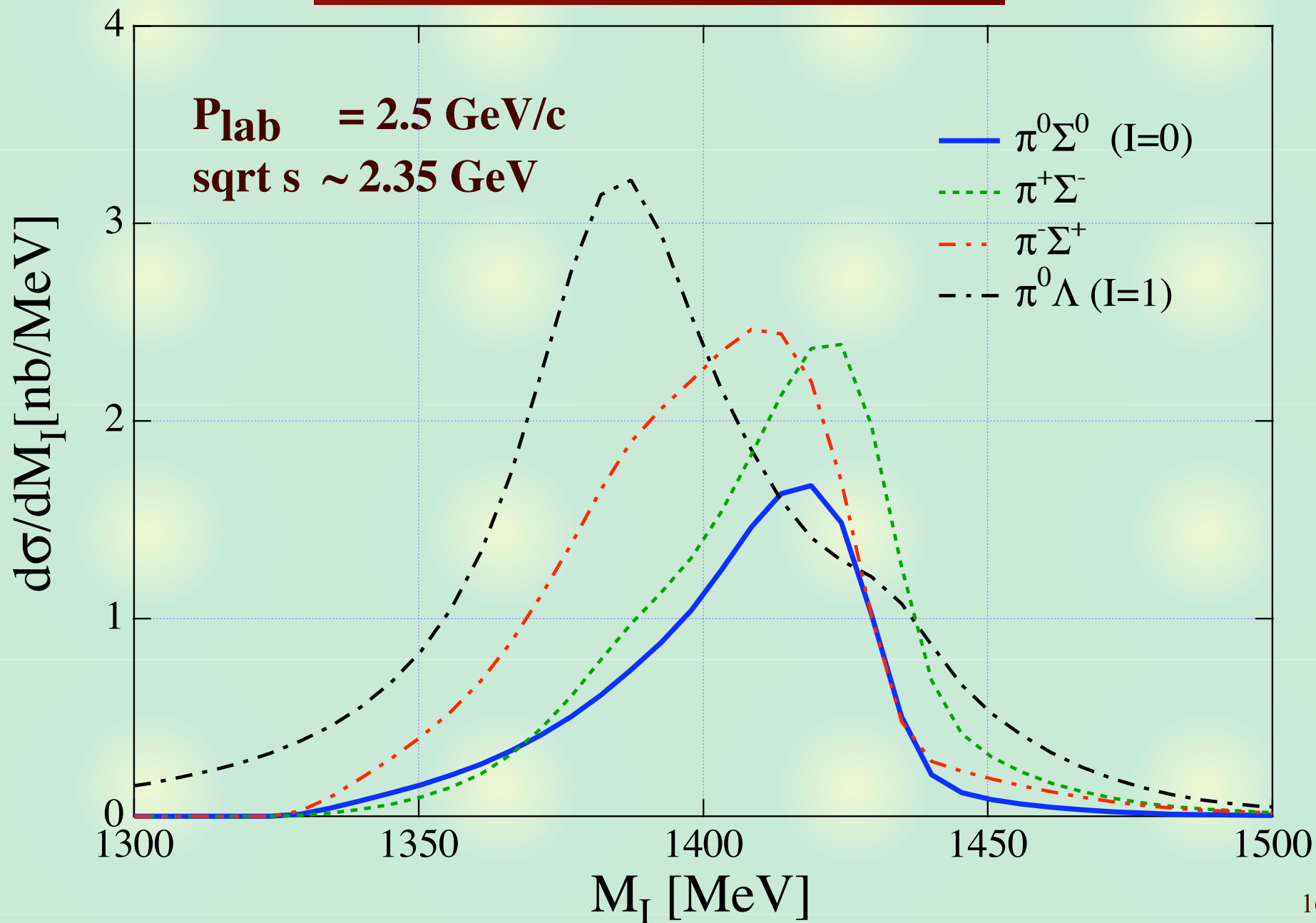
★ **form factor**

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

# Total cross sections



# Invariant mass distributions





## Isospin decomposition of $\pi\Sigma$ states

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

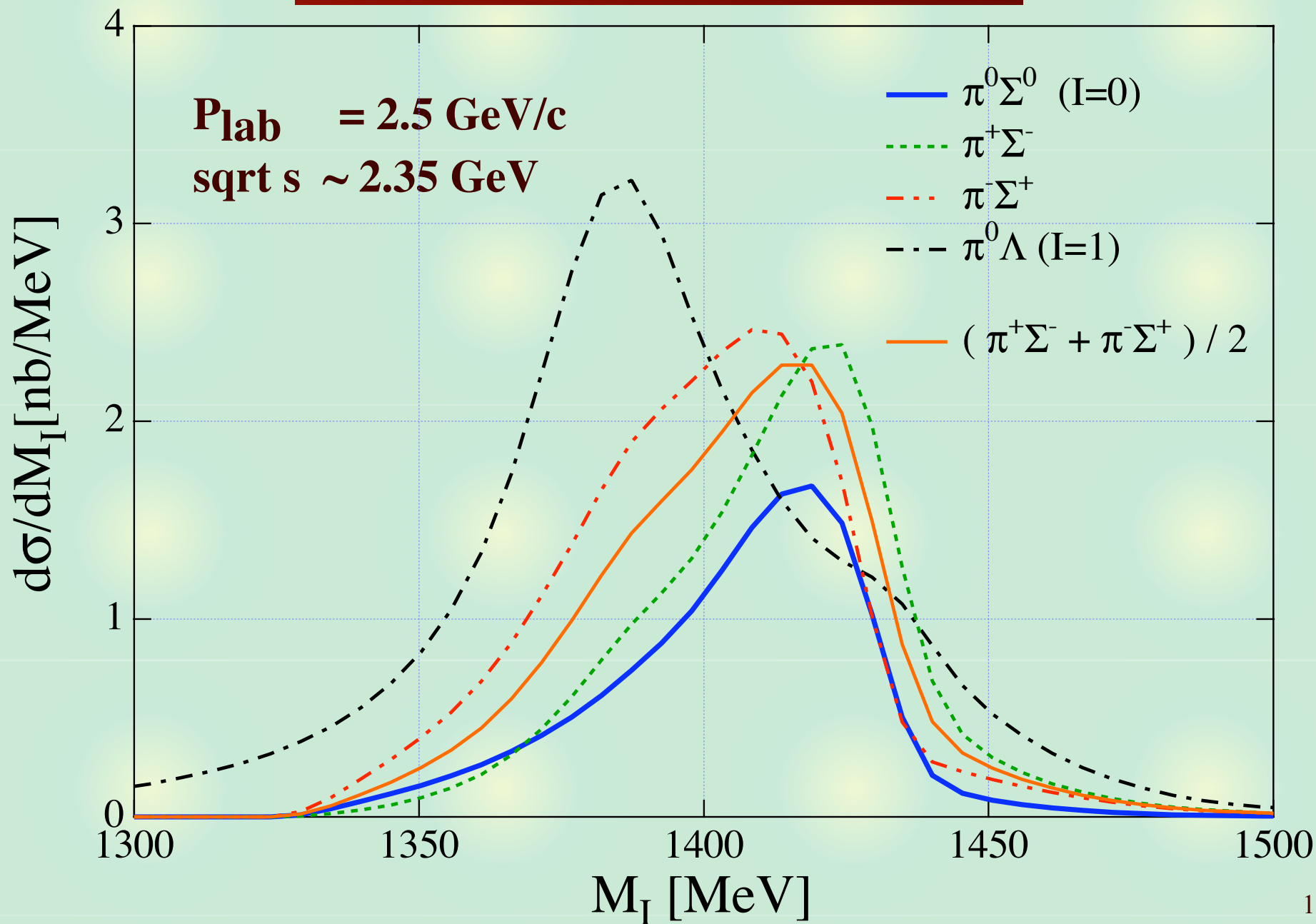
$$\frac{d\sigma(\pi^0\Sigma^0)}{dM_I} \propto \frac{1}{3} |T^{(0)}|^2$$

- **Pure  $l=0$  amplitude**

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

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

# Invariant mass distributions 2



## Summary and conclusions 1

We study the **structure of  $\Lambda(1405)$  using the chiral unitary model.**


There are **two poles** of the scattering amplitude around nominal  $\Lambda(1405)$ .



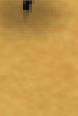
**Pole 1 (1426–16i) : strongly couples to  $\bar{K}N$  state**

**Pole 2 (1390–66i) : strongly couples to  $\pi\Sigma$  state**

By observing the **charged  $\pi\Sigma$  states** in the  $\gamma p \rightarrow K^* \Lambda(1405)$  reaction, it is possible to isolate the **higher energy pole.**

## Summary and conclusions 2

 If we observe **neutral  $\pi\Sigma$  state**, clear  **$l=0$  distribution** is obtained.

  
  
 Combining three  **$\pi\Sigma$  states**, we can also study the **s-wave  $l=1$  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/>

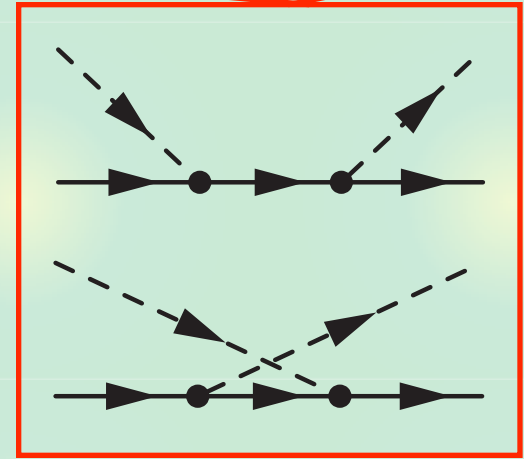
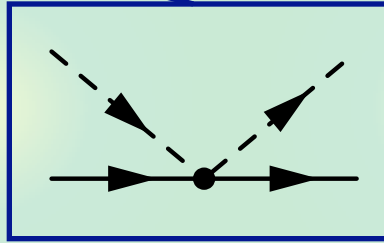
# Appendix : ChPT Lagrangian

$$\mathcal{L}^{(1)} = \text{Tr} \left( \bar{B}(i\mathcal{D} - M_0)B - D(\bar{B}\gamma^\mu\gamma_5\{A_\mu, B\}) - F(\bar{B}\gamma^\mu\gamma_5[A_\mu, B]) \right)$$

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

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

$$D + F = g_A$$



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

$$\underline{V}_\mu = -\frac{i}{2}(\xi^\dagger \partial_\mu \xi + \xi \partial_\mu \xi^\dagger) = \frac{i}{4f^2} \underline{(\Phi \partial_\mu \Phi - \partial_\mu \Phi \Phi)} + \dots$$

$$\underline{A}_\mu = -\frac{i}{2}(\xi^\dagger \partial_\mu \xi - \xi \partial_\mu \xi^\dagger) = -\frac{1}{f} \underline{\partial_\mu \Phi} + \dots$$

## Appendix : Several treatments 1

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

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

**S = -1,0,  $\Lambda(1405)$ , N(1535)**

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

**WT term, 3-momentum cutoff (channel indep.)**

**S = -1,  $\Lambda(1405)$**

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

**ChPT  $p$ , dimensional reg. (channel indep.)**

**S = -1,  $\Lambda(1405)$**

**Analytic solution for BS eq.**

**-> pole structure in complex plane**

## Appendix : Several treatments 2

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.)**

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

**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.)**

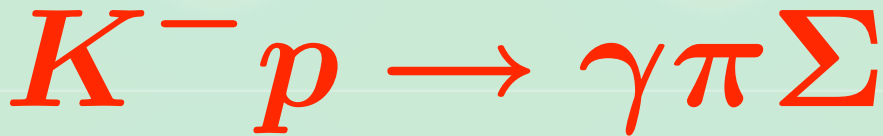
**$\Lambda(1405)$ ,  $\Lambda(1670)$ ,  $\Sigma(1620)$ ,  $N(1535)$ ,  $\Xi(1620)$ ,  $\Xi(1690)$**

**Scattering observables?**

# Appendix : other processes



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



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

