Exotic baryon resonances in the chiral dynamics

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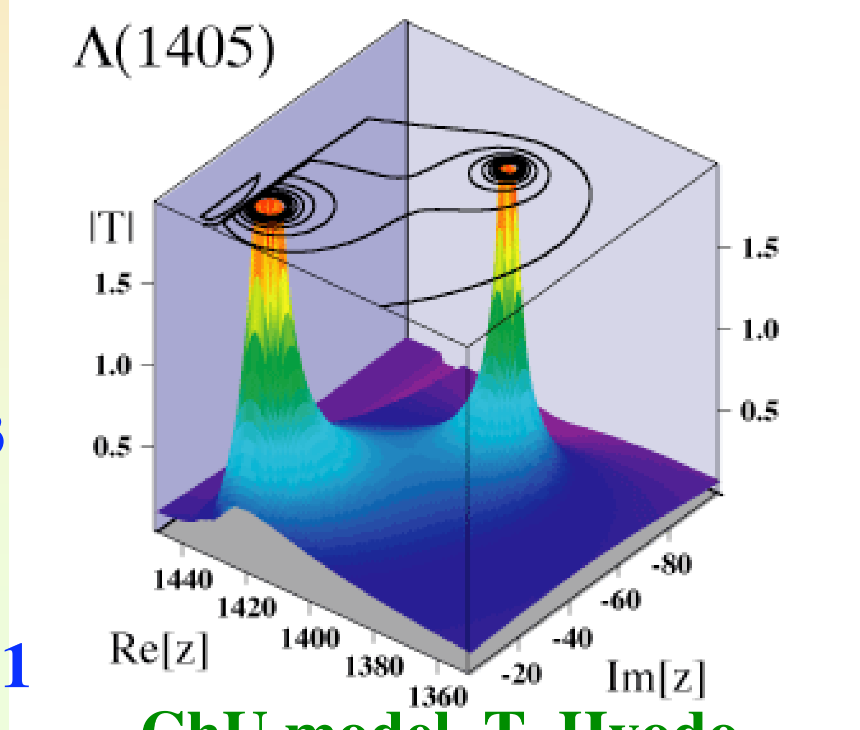
Motivations : Two poles?

There are two poles of the scattering amplitude around nominal □(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

□(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

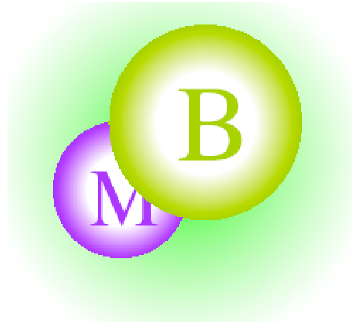
Non-perturbative resummation

Dynamical generation

$J^P = 1/2^-$

Resonances

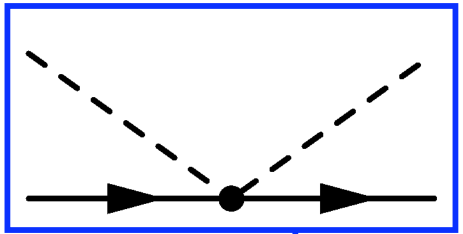
□(1405), □(1670), N(1535),
□(1620), □(1620)



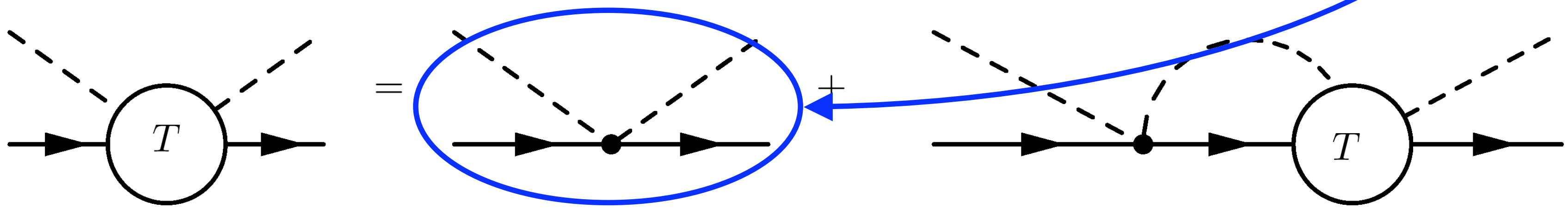
Framework of the chiral unitary model

Chiral perturbation theory

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



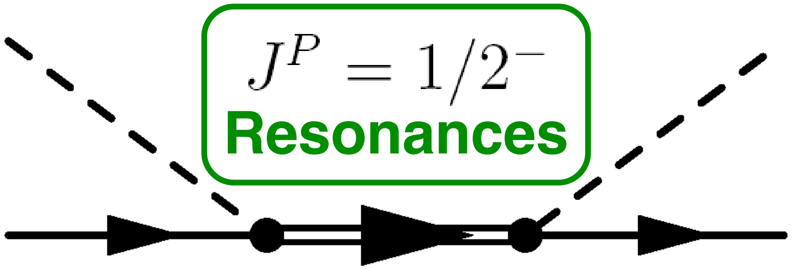
Unitarization



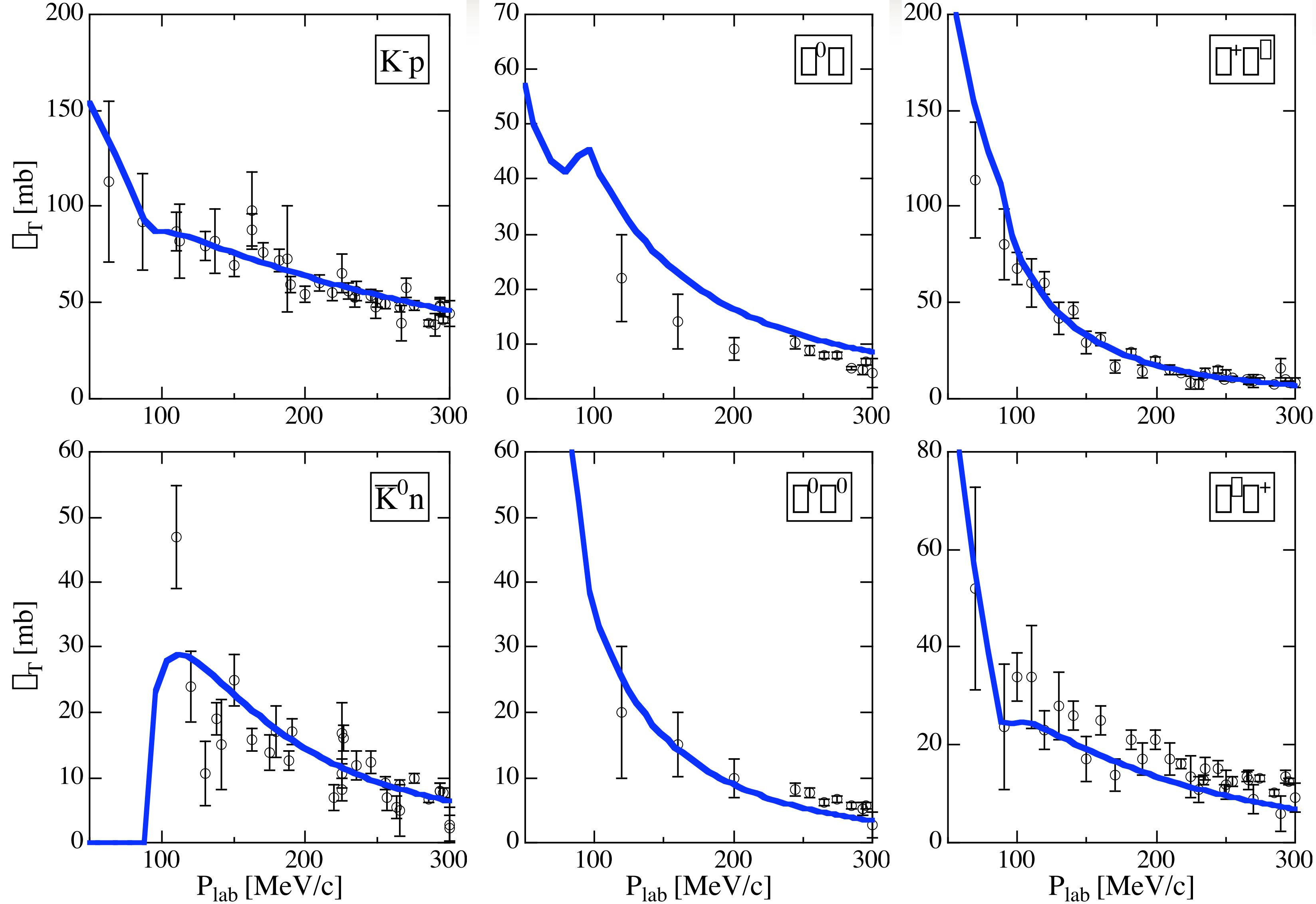
$$T_{ij}(\sqrt{s}) \sim \frac{g_i g_j}{\sqrt{s} - M_R + i\Gamma_R/2} + T_{ij}^{BG}$$

Generated resonances are expressed as poles of the scattering amplitude.

$\sim$



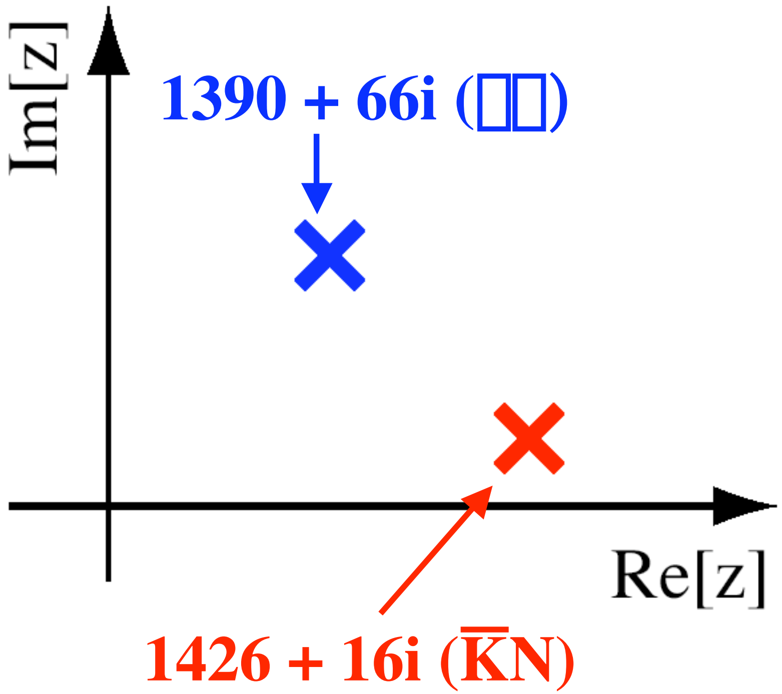
Total cross sections of K^-p scatterings



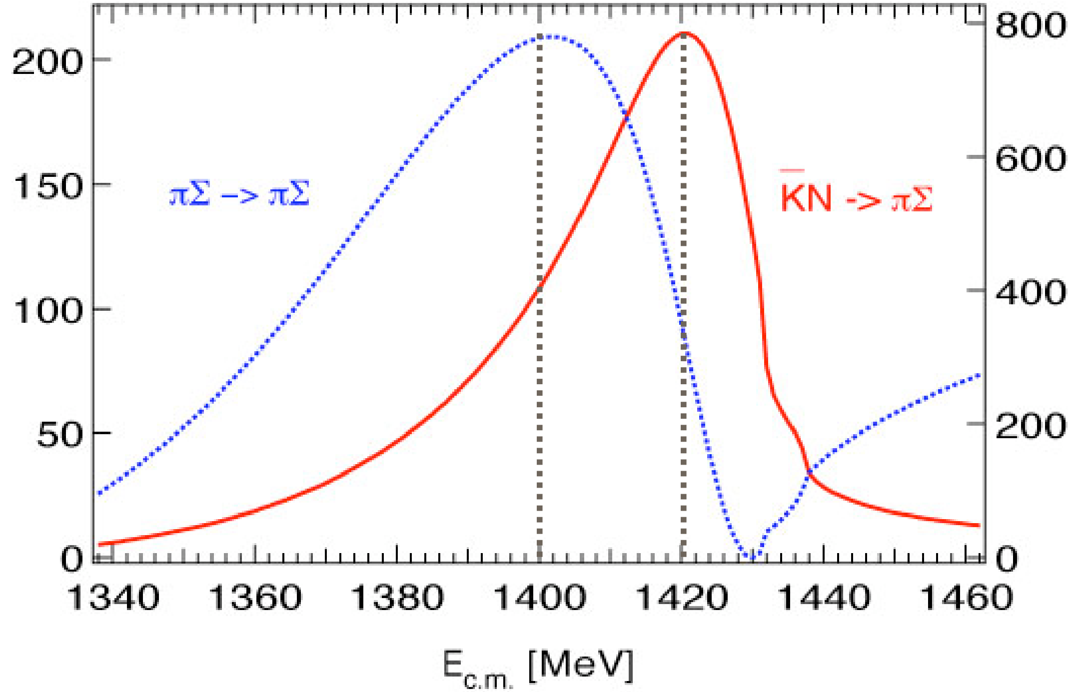
T. Hyodo, *et al.*, Phys. Rev. C 68, 018201 (2003)

□(1405) in the chiral unitary model

position of poles



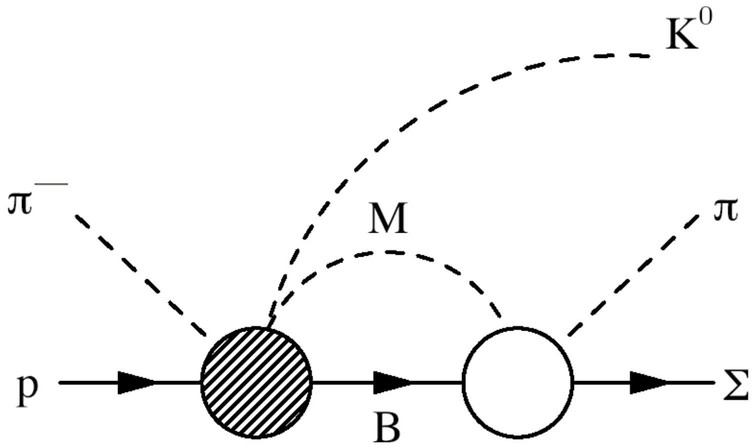
□□ mass distribution



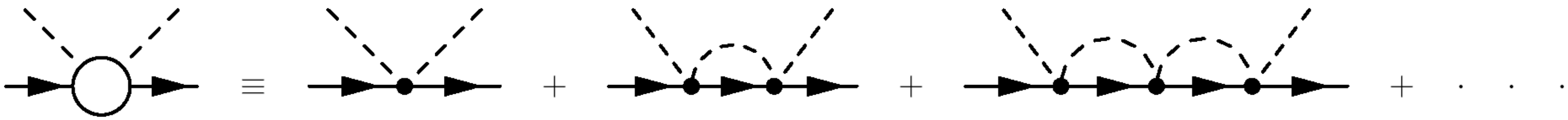
$$\frac{d\sigma}{dM_I} = C|t_{\pi\Sigma\to\pi\Sigma}|^2 p_{CM} \Rightarrow \frac{d\sigma}{dM_I} = |\sum_i C_i t_{i\to\pi\Sigma}|^2 p_{CM}$$

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

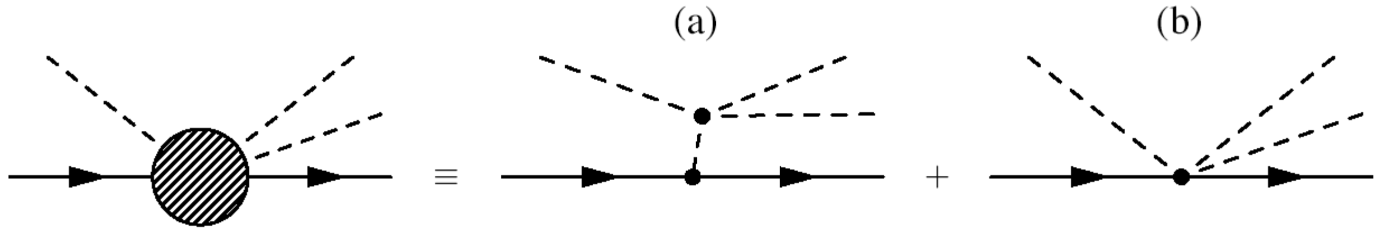
Example : the $\pi^- p$ -> $K^0 \pi \Sigma$ reaction



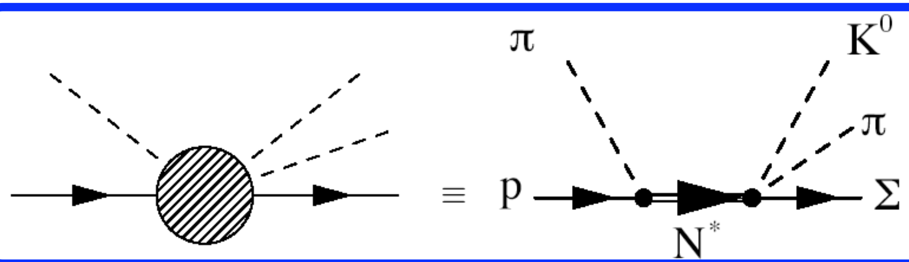
Chiral unitary model



Chiral term

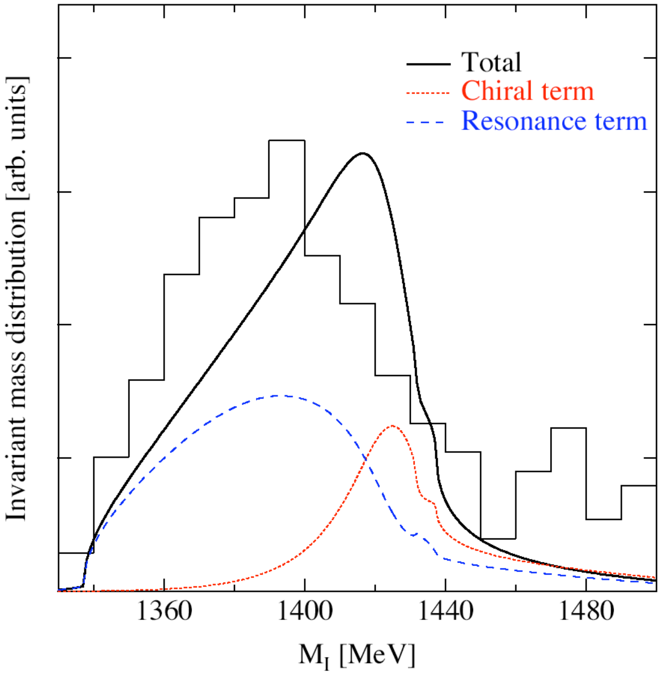


N(1710)



Results for □□p -> K^0□□

Mass distribution



Total cross sections [mb]

final state	K^0K^-p	$K^0\bar{K}^0n$	$K^0\pi^0\Lambda$	$K^0\pi^+\Sigma^-$	$K^0\pi^-\Sigma^+$
Exp.	2.9	8.3	104.0	25.1	20.2
total	3.75	5.98	6.02	21.32	20.01
chiral	2.36	2.84	3.14	3.04	6.78
resonance	0.70	0.67	10.85	16.18	5.43

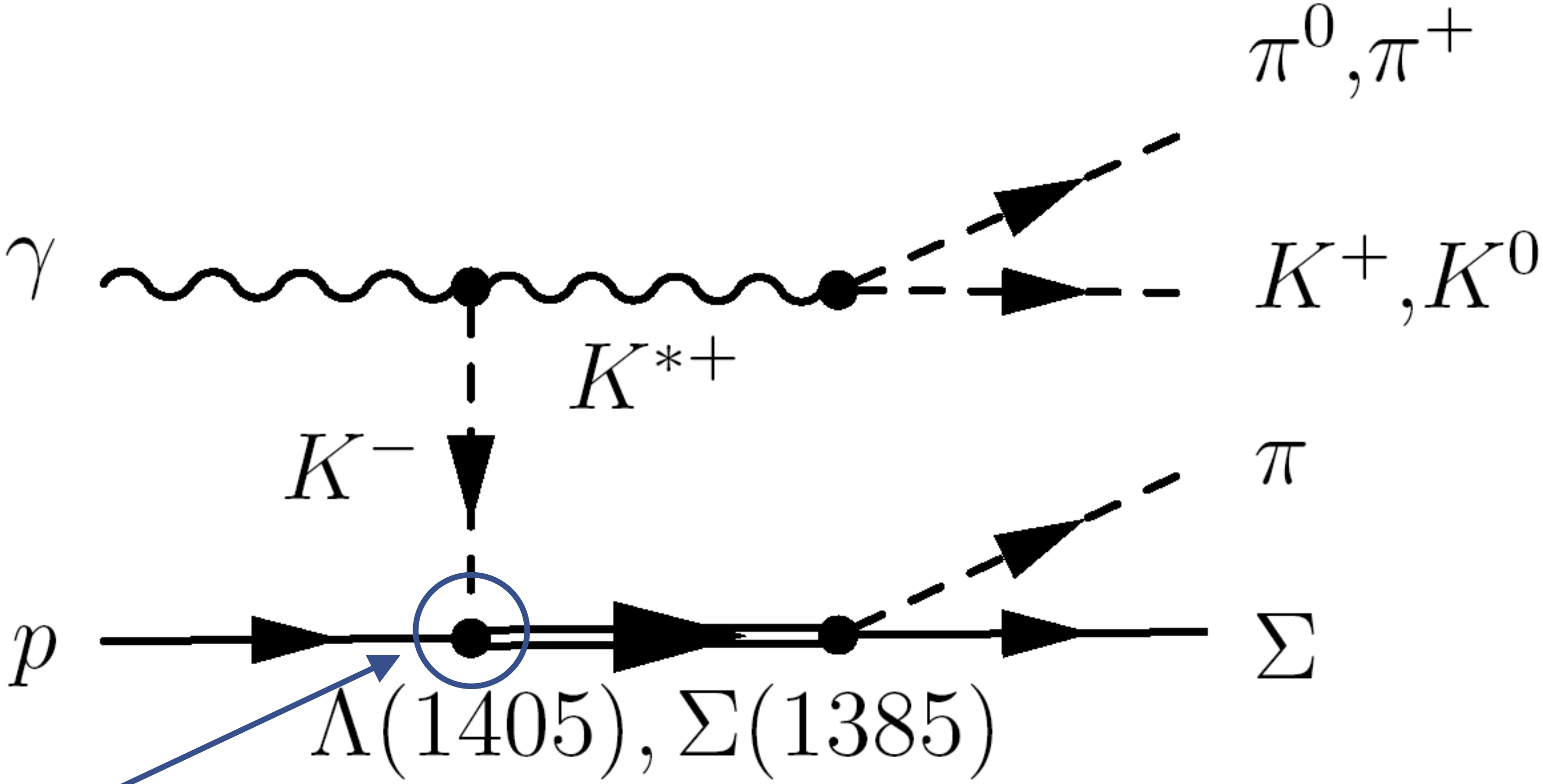
□(1385) effect

Good agreement

- There are **two mechanisms** in the initial stage interaction, which **filter each one of the resonances**.

T. Hyodo, *et al.*, nucl-th/0307005, Phys. Rev. C, in press

Photoproduction of K* Λ(1405)



Only K^-p channel appears at the initial stage

Higher pole ??

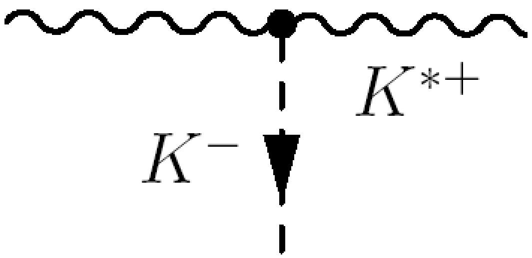
Effective interactions for meson part

1. □VP coupling

$$-it = i g_{\gamma K^* K} \epsilon^{\mu\nu\alpha\beta} P_\mu \epsilon_\nu (K^{*+}) k_\alpha \epsilon_\beta(\gamma) \ ,$$

$$|g_{\gamma K^{*\pm} K^\pm}| = 0.252 \ \ [\mathrm{GeV}^{-1}] \ ,$$

$$|g_{\gamma K^{*0} K^0}| = 0.385 \ \ [\mathrm{GeV}^{-1}] \ .$$

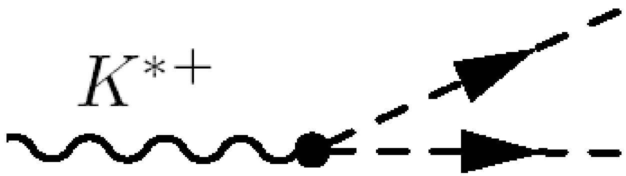


2. VPP coupling

$$-it(K^{*+} \to K^+ \pi^0) = i \frac{g_{VPP}}{\sqrt{2}} \frac{1}{\sqrt{2}} [p_\mu(K^+) - p_\mu(\pi^0)] \epsilon^\mu (K^{*+}) \ ,$$

$$-it(K^{*+} \to K^0 \pi^+) = i \frac{g_{VPP}}{\sqrt{2}} [p_\mu(K^0) - p_\mu(\pi^+)] \epsilon^\mu (K^{*+}) \ ,$$

$$g_{VPP} = -6.05$$



Effective interaction for Σ(1385)

3. Σ(1385)MB coupling

SU(6) symmetry

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

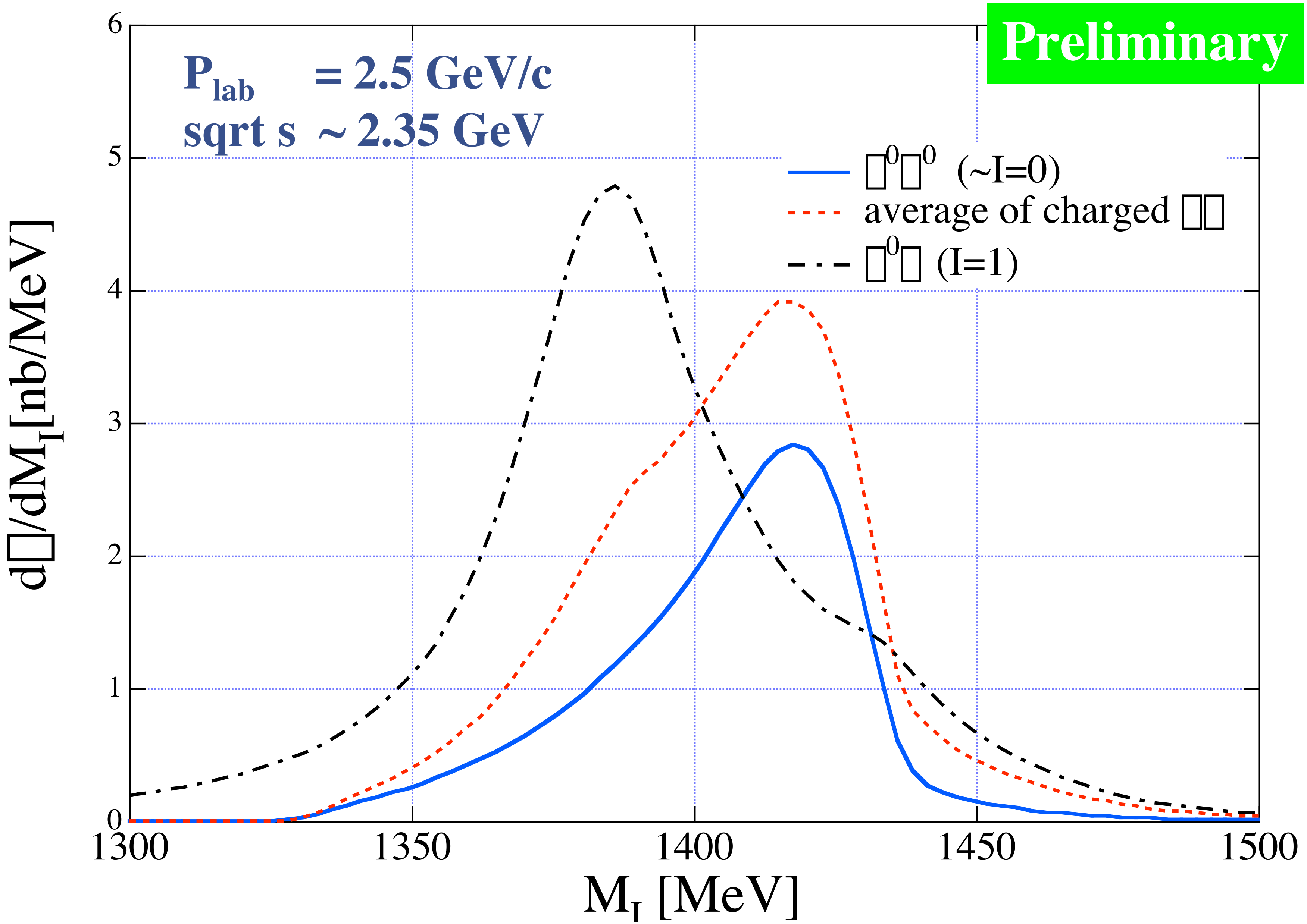
channel i	$K^- p$	$\bar{K}^0 n$	$\pi^0 \Lambda$	$\pi^0 \Sigma^0$	$\eta \Lambda$	$\eta \Sigma^0$	$\pi^+ \Sigma^-$	$\pi^- \Sigma^+$	$K^+ \Xi^-$	$K^0 \Xi^0$
c_i	$-\sqrt{\frac{1}{12}}$	$\sqrt{\frac{1}{12}}$	$\sqrt{\frac{1}{4}}$	0	0	$-\sqrt{\frac{1}{4}}$	$-\sqrt{\frac{1}{12}}$	$\sqrt{\frac{1}{12}}$	$\sqrt{\frac{1}{12}}$	$-\sqrt{\frac{1}{12}}$

4. K^-P -> Σ(1385) -> MB amplitude

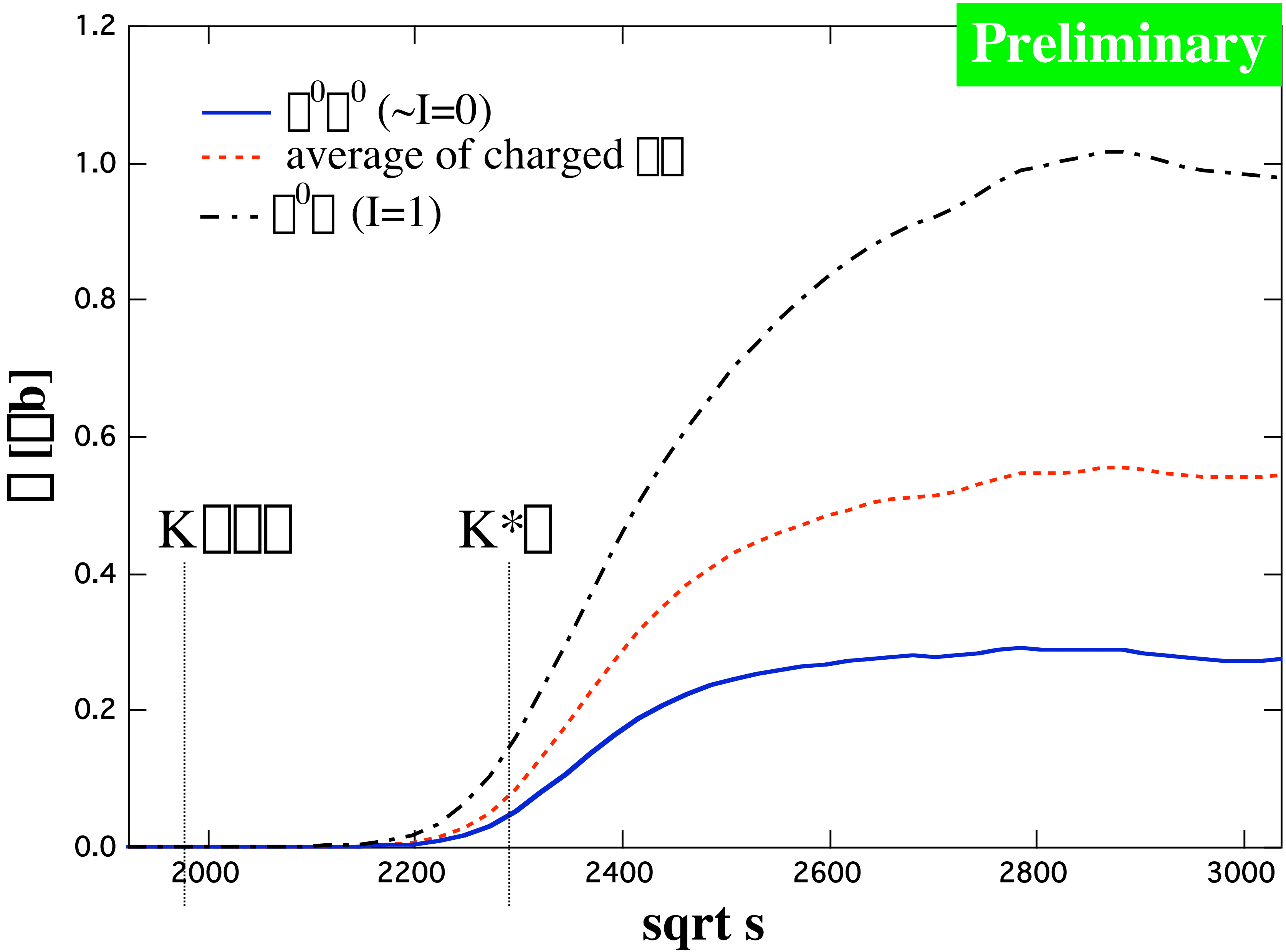
$$\begin{aligned} -it_{1i} =& c_1 c_i \left(\frac{12}{5} \frac{D+F}{2f} \right)^2 \boldsymbol{S} \cdot \boldsymbol{k}_1 \boldsymbol{S}^\dagger \cdot \boldsymbol{k}_i \frac{i}{M_I^{(b)} - M_{\Sigma^*} + i\Gamma_{\Sigma^*}/2} F_f(k_1) \\ =& c_1 c_i \left(\frac{12}{5} \frac{D+F}{2f} \right)^2 (k_1)_l (k_i)_m \left(\frac{2}{3}\delta_{lm} - \frac{i}{3}\epsilon_{lmn}\sigma_n \right) \frac{i}{M_I^{(b)} - M_{\Sigma^*} + i\Gamma_{\Sigma^*}/2} F_f(k_1) \end{aligned}$$

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

□□ invariant mass distribution



Result : Total cross section



Summary and conclusions

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

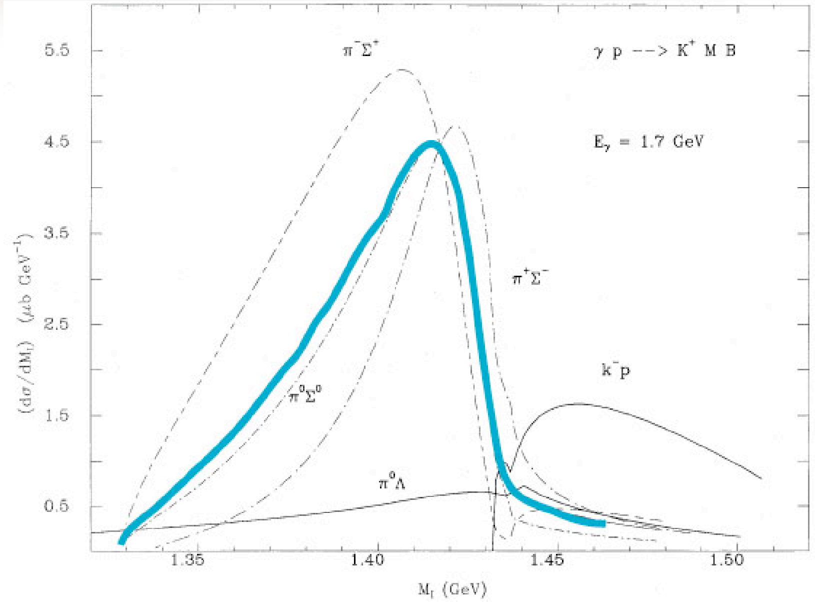
- By observing the **πΣ mass distribution** in the **γp -> K*Λ(1405)** reaction, it could be possible to isolate **higher energy pole**.

Appendix : other processes

□p -> K□□□

J.C. Nacher, *et al.*, PLB445, 55(1999)

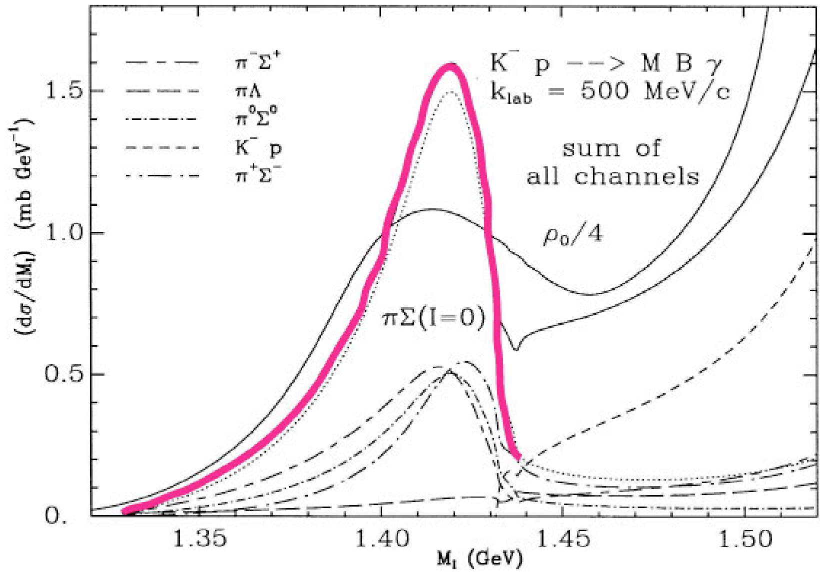
SPring-8



□ □p -> □□□

J.C. Nacher, *et al.*, PLB461, 299(1999)

J-PARC?



□$^{+}$ baryon : Introduction

□$^{+}$: 5-quark (4 quark + 1 anti-quark)

LEPS, T. Nakano *et al.*, Phys. Rev. Lett. 91 (2003) 012002

S = +1, $M_{□}$ ~ 1540 MeV, $□_{□}$ < 25 MeV

Quantum numbers are not yet determined

Theory prediction

- D. Diakonov *et al.* (chiral quark soliton) : $1/2^{+}$, I=0
- Naive quark model : $1/2^{□}$
- S. Capstick *et al.* (isotensor formulation) : $1/2^{□}$, $3/2^{□}$, $5/2^{□}$, I=2
- A. Hosaka (chiral potential) : $1/2^{+}$ (strong □)
- R. L. Jaffe *et al.* (qq-qq-$\bar{q}$: $\overline{10}$ + 8) : $1/2^{+}$, I=0
- J. Sugiyama *et al.* (QCD sum rule) : $1/2^{□}$, I=0
- F. Csikor *et al.* (Lattice QCD) : $1/2^{+}$ -> $1/2^{□}$
- S. Sasaki (Lattice QCD) : $1/2^{□}$

Photo-production process

Assuming the quantum numbers (spin, parity), we can calculate a reaction

□p -> K^0□$^+$, □n -> $K^{□}$□$^+$

W. Liu *et al.* nucl-th/0308034
S. I. Nam *et al.* hep-ph/0308313
W. Liu *et al.* nucl-th/0309023
Y. Oh *et al.* hep-ph/0310117

- **Model (mechanism) dependence**

  Initial cm energy ~ 2 GeV (p_{cm} ~ 750 MeV)
  not low energy -> linear or nonlinear?
  N* resonances, K* exchange, □$_1$ exchange,…

- **Form factor dependence**

  Monopole, dipole… , value of □, …

- **Unknown parameters**

  □□□ coupling, K*p□ coupling, …

Motivation and advantage

We propose

$$K^+p \text{ -> } \square^+\square^+ \text{ -> } \square^+K^+n(K^0p)$$

- Low energy model is sufficient (p_{cm} ~ 350 MeV)
- take decay into account -> background estimation
  -> Width independent
- Hadronic process : clear mechanism

to extract a qualitative behavior which depends on the quantum numbers of $\square^+$.

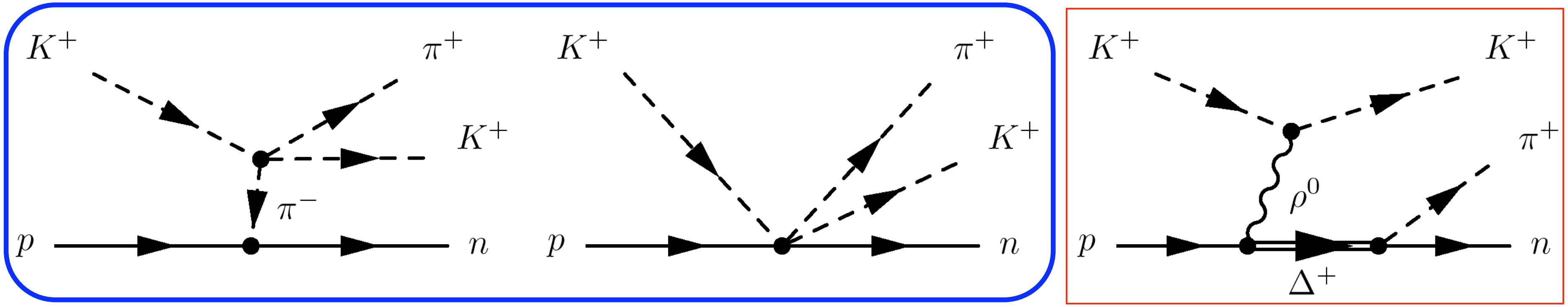
Determination of quantum numbers

New : pp -> $\square^+\square^+$, A. W. Thomas, K. Hicks, and A. Hosaka, hep-ph/0312083

A model for □+p -> □+K+n

E. Oset and M. J. Vicente Vacas, PLB386, 39(1996)

Vertices are derived from the chiral Lagrangian



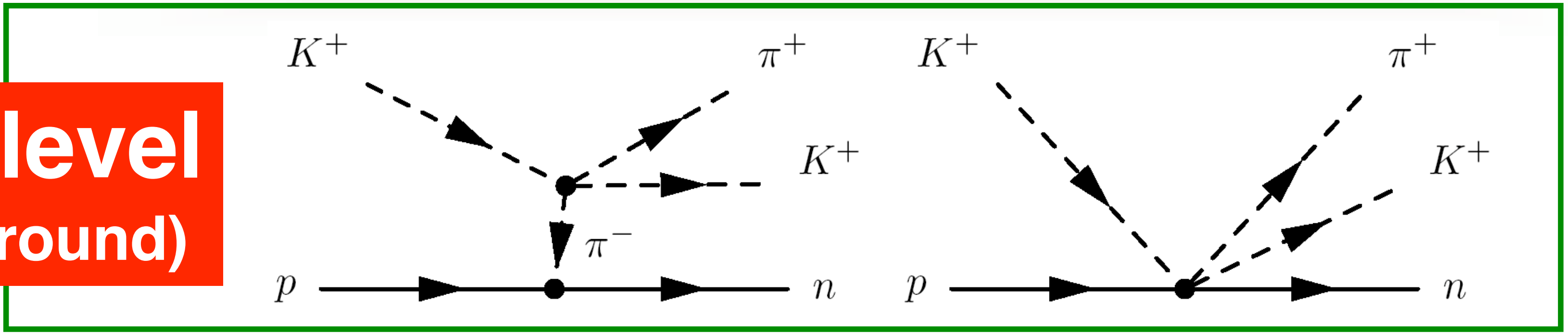
Dominant

Proportional to $\boldsymbol{S} \cdot \boldsymbol{p}_{\pi^+}$ **vanishes**

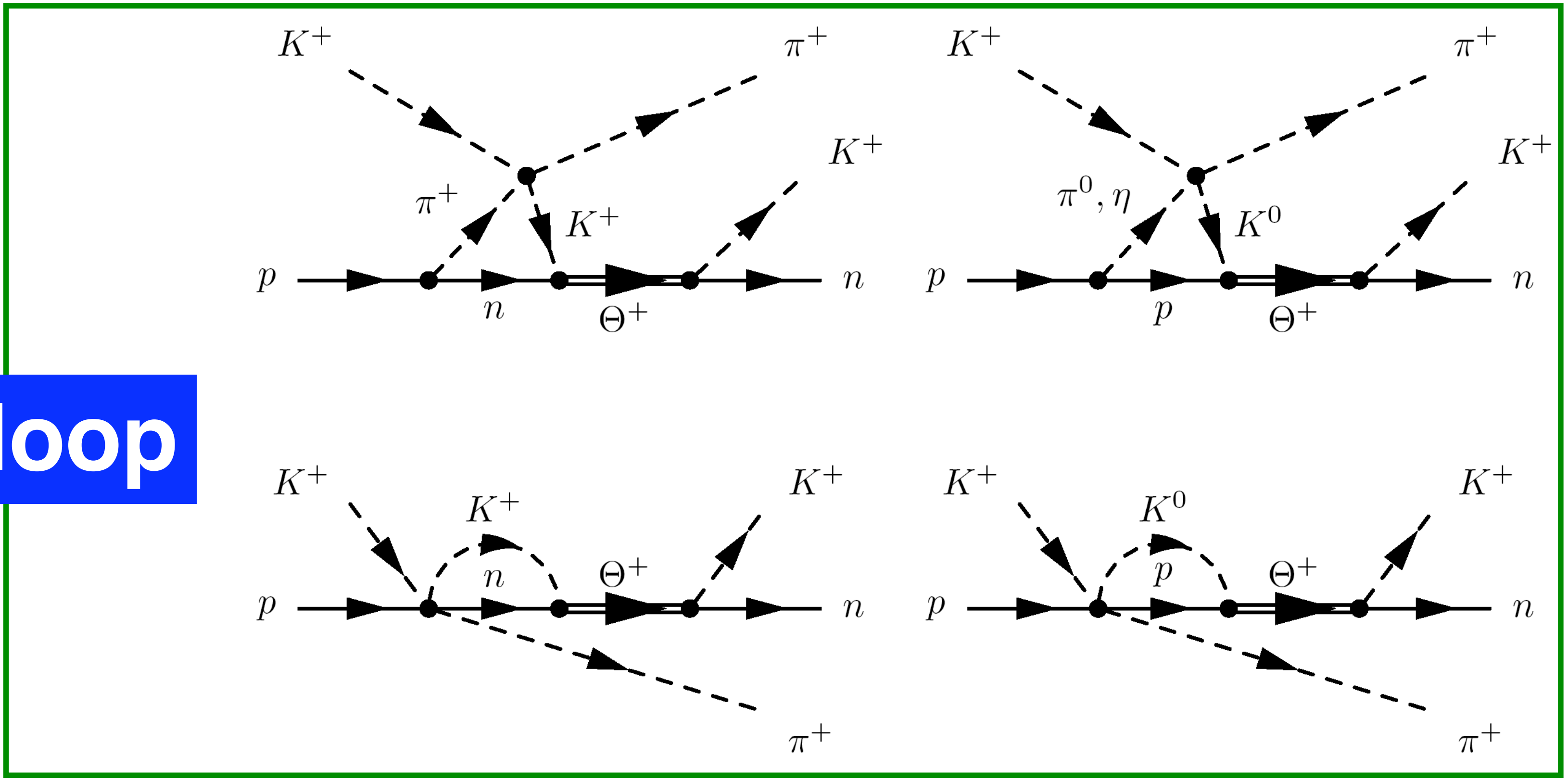
Assume final □+ is almost at rest

Diagrams

Tree level (background)



One loop



Possibilities of spin & parity

$1/2^-$ (KN s-wave resonance)

$1/2^+$, $3/2^+$ (KN p-wave resonance)

M_R = 1540 MeV

Γ = 20 MeV

$$t^{(s)}_{K^+n(K^0p)\to K^+n} = \frac{(\pm)g^2_{K^+n}}{M_I - M_R + i\Gamma/2},$$

$$t^{(p,1/2)}_{K^+n(K^0p)\to K^+n} = \frac{(\pm)\bar{g}^2_{K^+n}(\boldsymbol{\sigma}\cdot\boldsymbol{q}')(\boldsymbol{\sigma}\cdot\boldsymbol{q})}{M_I - M_R + i\Gamma/2},$$

$$t^{(p,3/2)}_{K^+n(K^0p)\to K^+n} = \frac{(\pm)\tilde{g}^2_{K^+n}(\boldsymbol{S}\cdot\boldsymbol{q}')(\boldsymbol{S}^\dagger\cdot\boldsymbol{q})}{M_I - M_R + i\Gamma/2},$$

$$g^2_{K^+n} = \frac{\pi M_R\Gamma}{Mq}, \quad \bar{g}^2_{K^+n} = \frac{\pi M_R\Gamma}{Mq^3}, \quad \tilde{g}^2_{K^+n} = \frac{3\pi M_R\Gamma}{Mq^3}$$

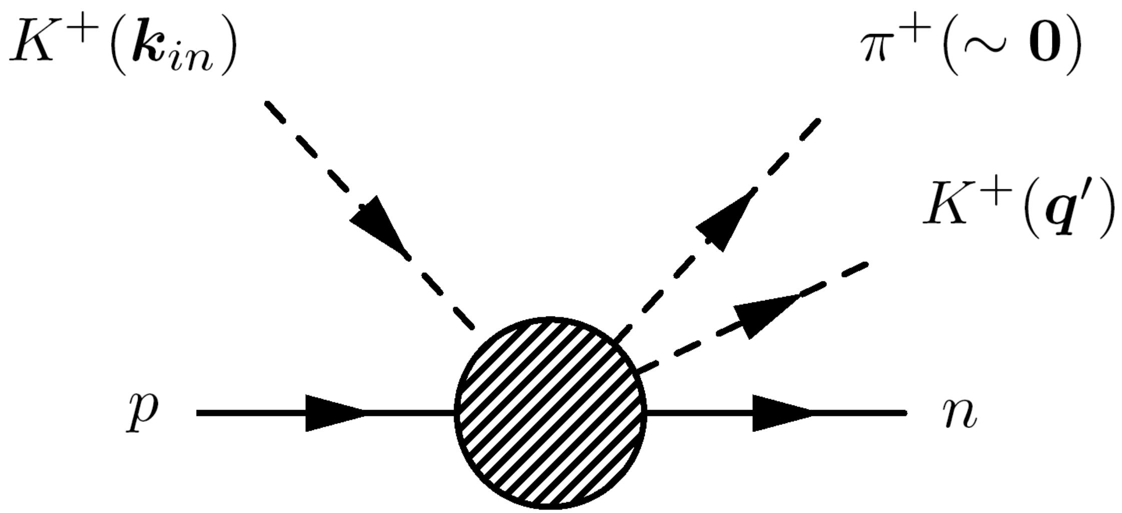
Resonance term

Amplitude of resonance term for $K^+p \to \pi^+K^+n$:

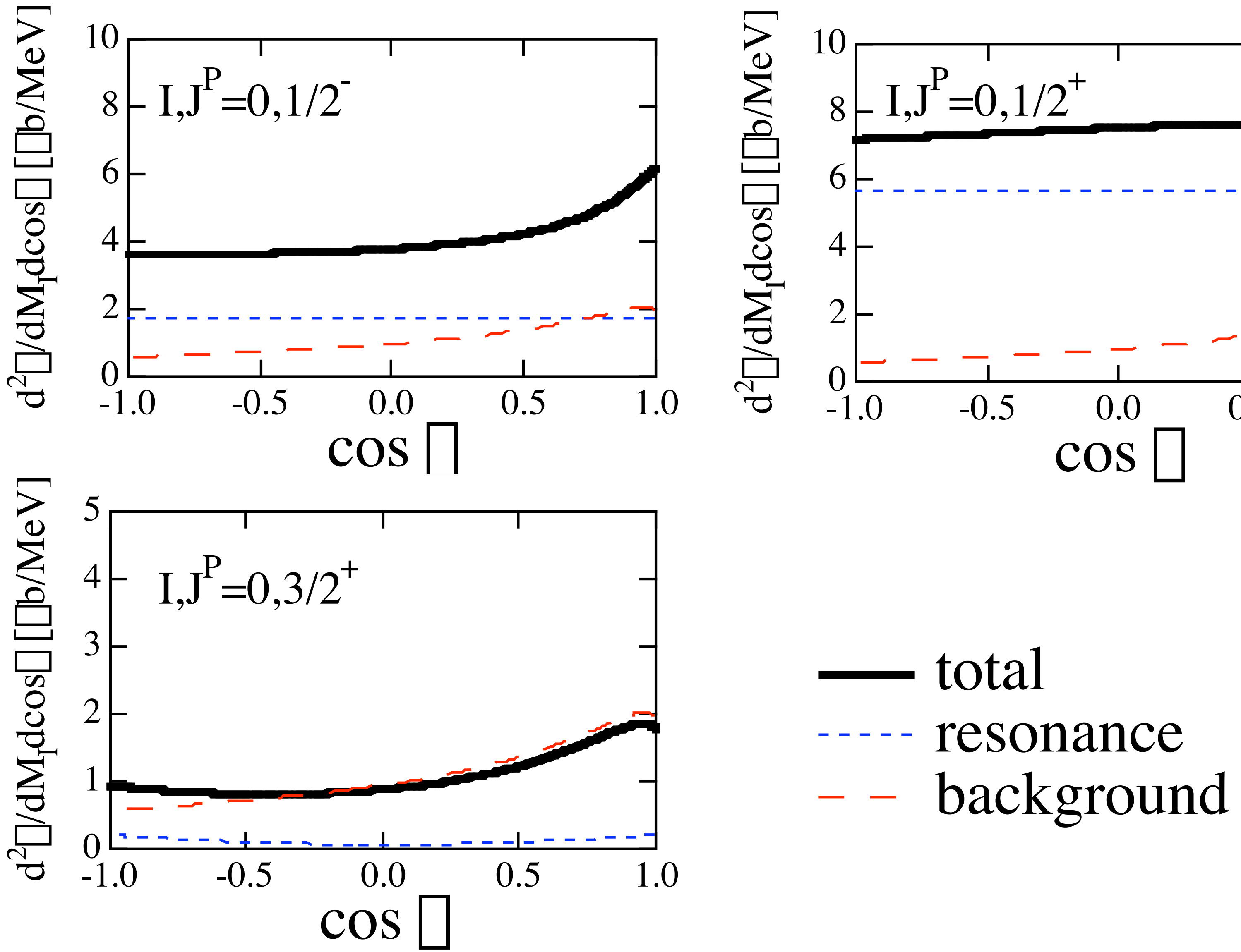
$$-i\tilde{t}_i^{(s)} = \frac{g_{K^+n}^2}{M_I - M_R + i\Gamma/2}\left\{G(M_I)(a_i + c_i) - \frac{1}{3}\bar{G}(M_I)b_i\right\}\boldsymbol{\sigma}\cdot\boldsymbol{k}_{in}S_I(i)$$

$$-i\tilde{t}_i^{(p,1/2)} = \frac{\bar{g}_{K^+n}^2}{M_I - M_R + i\Gamma/2}\bar{G}(M_I)\left\{\frac{1}{3}b_i\boldsymbol{k}_{in}^2 - a_i + d_i\right\}\boldsymbol{\sigma}\cdot\boldsymbol{q}'S_I(i)$$

$$-i\tilde{t}_i^{(p,3/2)} = \frac{\tilde{g}_{K^+n}^2}{M_I - M_R + i\Gamma/2}\bar{G}(M_I)\frac{1}{3}b_i\left\{(\boldsymbol{k}_{in}\cdot\boldsymbol{q}')(\boldsymbol{\sigma}\cdot\boldsymbol{k}_{in}) - \frac{1}{3}\boldsymbol{k}_{in}^2\boldsymbol{\sigma}\cdot\boldsymbol{q}'\right\}S_I(i)$$



Angular dependence

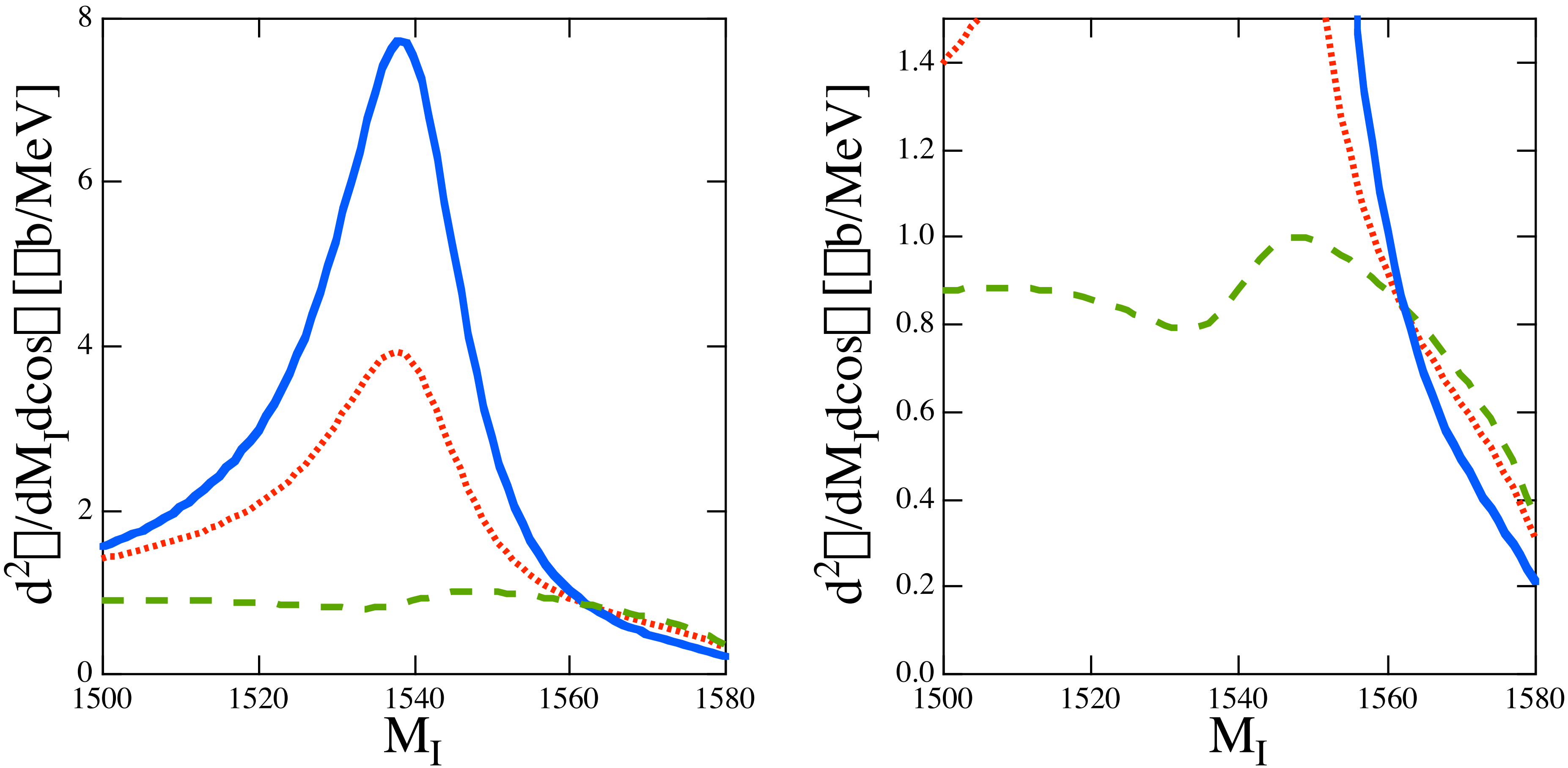


Mass distributions

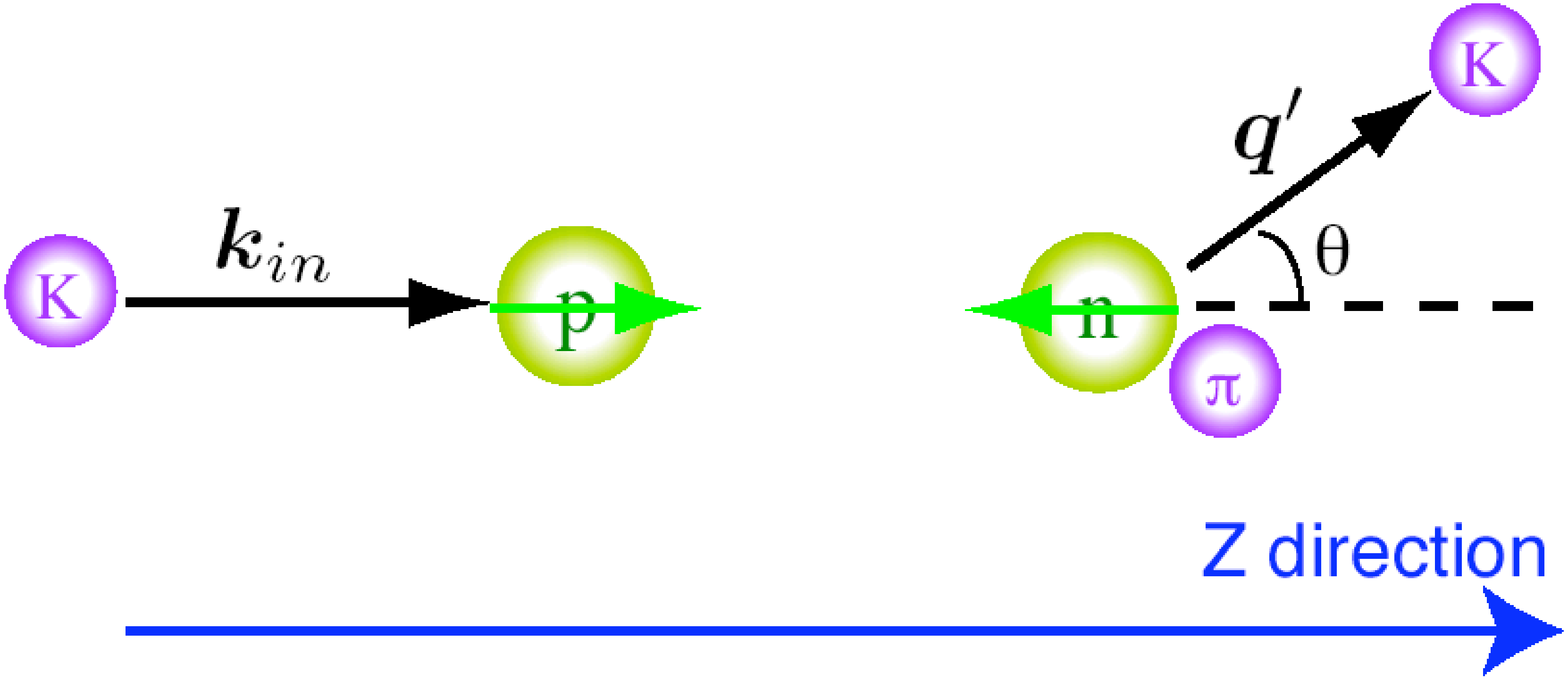
$I,J^P=0,1/2^-$

$I,J^P=0,1/2^+$ $k_{in}(\text{Lab}) = 850$ MeV/c

$I,J^P=0,3/2^+$ □ = 90 deg



Polarization test

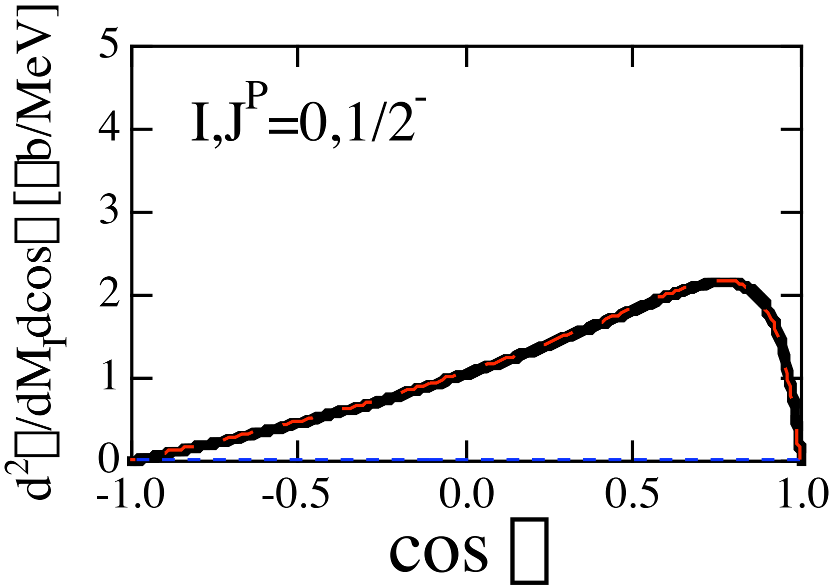


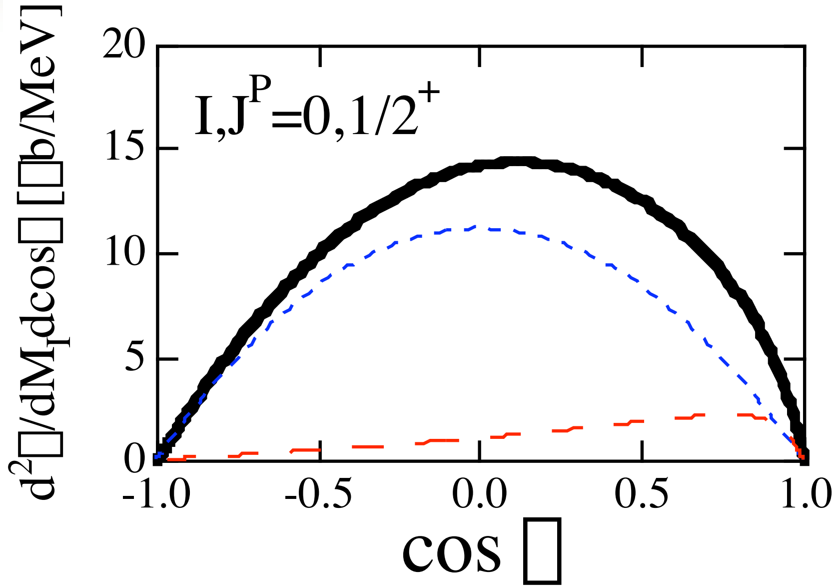
$$\langle -1/2 | \boldsymbol{\sigma} \cdot \boldsymbol{k}_{in} | 1/2 \rangle = 0$$

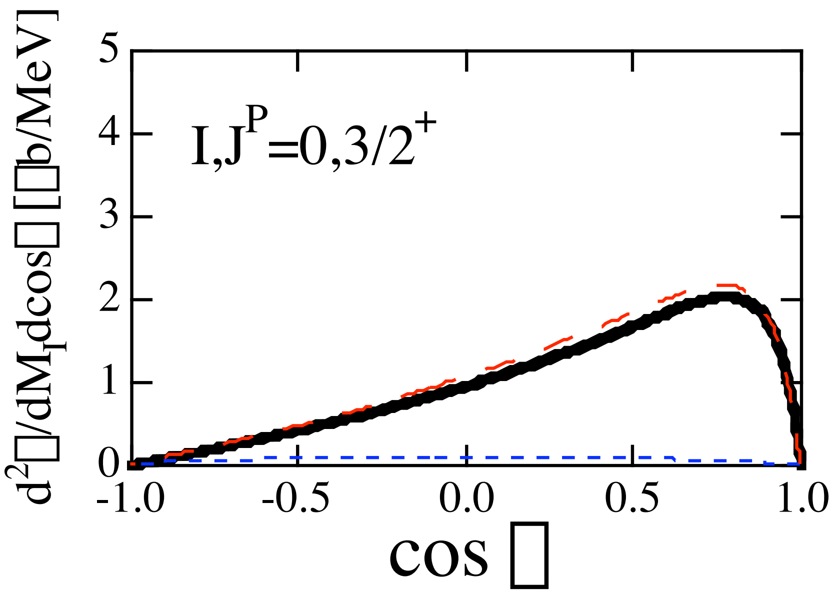
$$\langle -1/2 | \boldsymbol{\sigma} \cdot \boldsymbol{q}' | 1/2 \rangle \propto q' \sin\theta$$

 # Same result is obtained for final pK^0

Angular dependence : polarization test

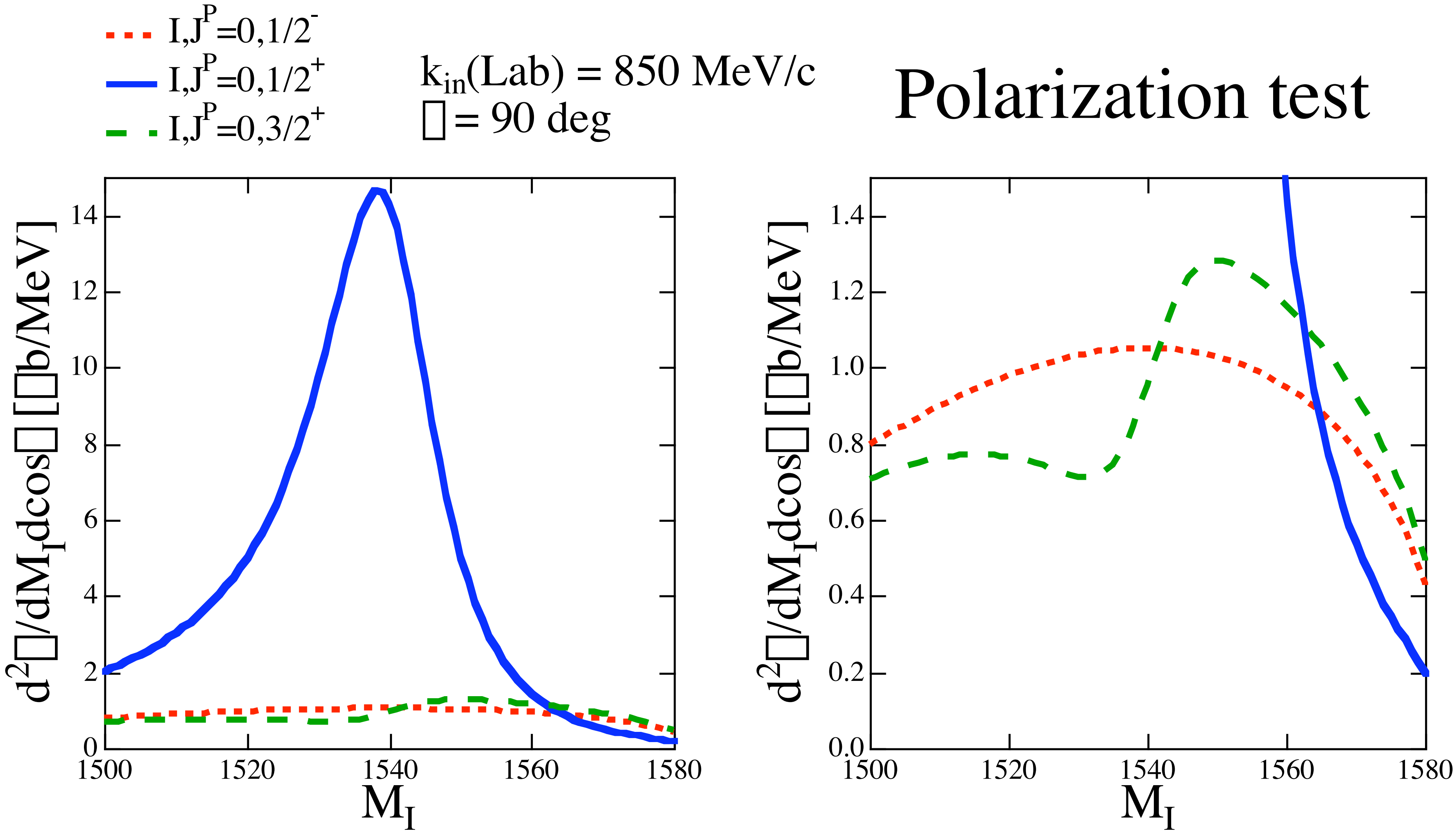




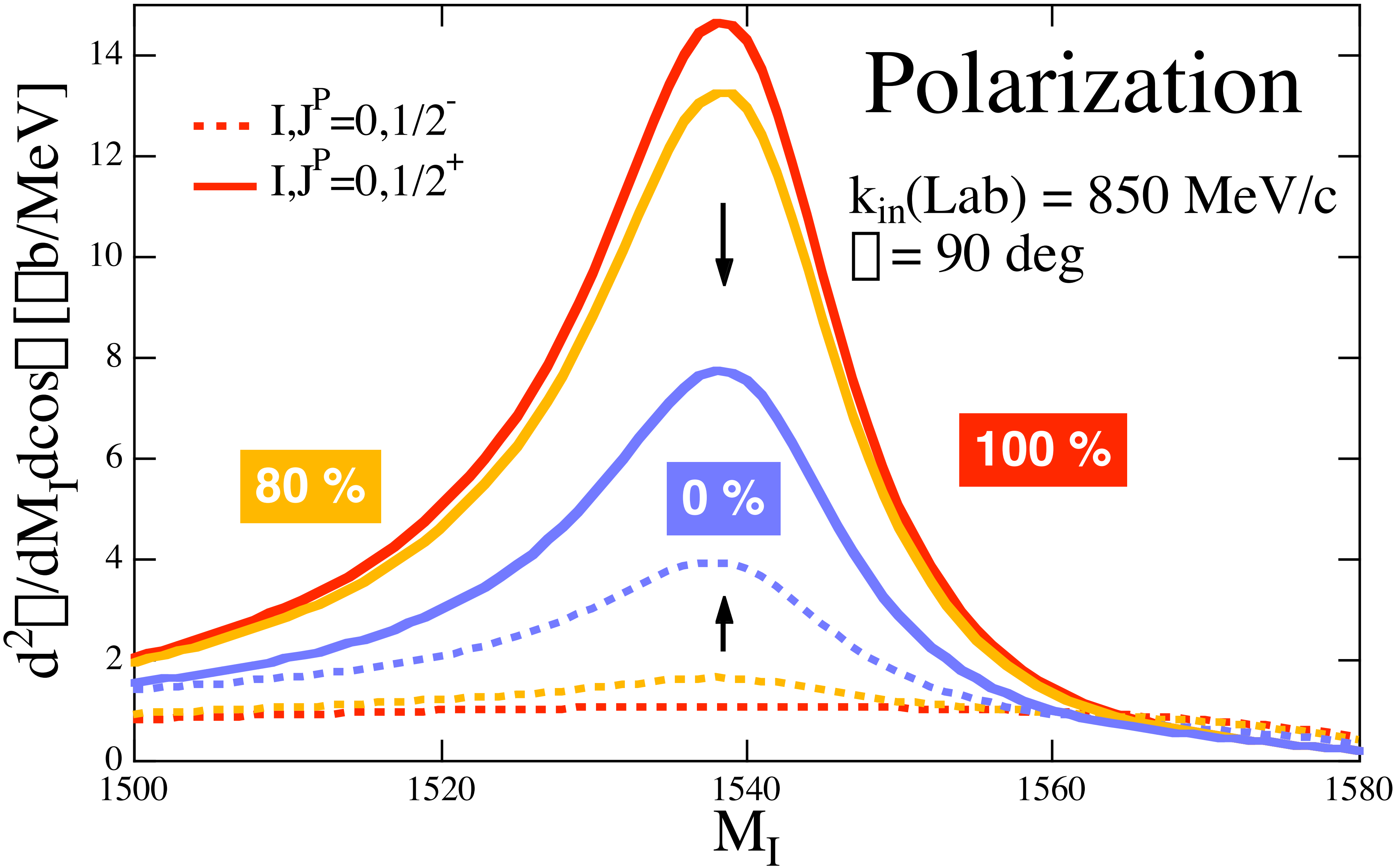


Polarization test

Mass distributions : polarization test



Incomplete polarization



Conclusion

We calculate the $K^+p \rightarrow$ □^0KN reaction using a chiral model, assuming the possible **quantum numbers of □$^+$ baryon**.

- If we find the resonance **with polarization test,** the quantum number of □$^+$ can be determined as **$I=0$, $J^P=1/2^+$**

T. Hyodo, *et al*, nucl-th/0307105, Phys. Lett. B, in press

E. Oset, *et al*, nucl-th/0312014, Hyp03 proceedings

Future work

- Full calculation of the present reaction
  without approximation of kinematics
  -> information from □$^+$ angular dependence
- photo-production of K* and □
  V. Kubarovsky et al., hep-ex/0307088