Determining the Θ^+ quantum numbers through the $K^+p \to \pi^+KN$ reaction

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2003, October 23rd

Contents

Introduction

Θ^+ : 5-quark (4 quark + 1 anti-quark)

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

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 π)
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

$\gamma p \to K^0\Theta^+$, $\gamma n \to K^-\Theta^+$

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, K_1 exchange,…

- **Form factor dependence**

  Monopole, dipole… , value of Λ, …

- **Unknown parameters**

  $\gamma\Theta\Theta$ coupling, $K^* p\Theta$ coupling, …

Motivation and advantage

We propose

$$K^+p \to \pi^+\Theta^+ \to \pi^+K^+n(K^0p)$$

- 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 Θ^+.

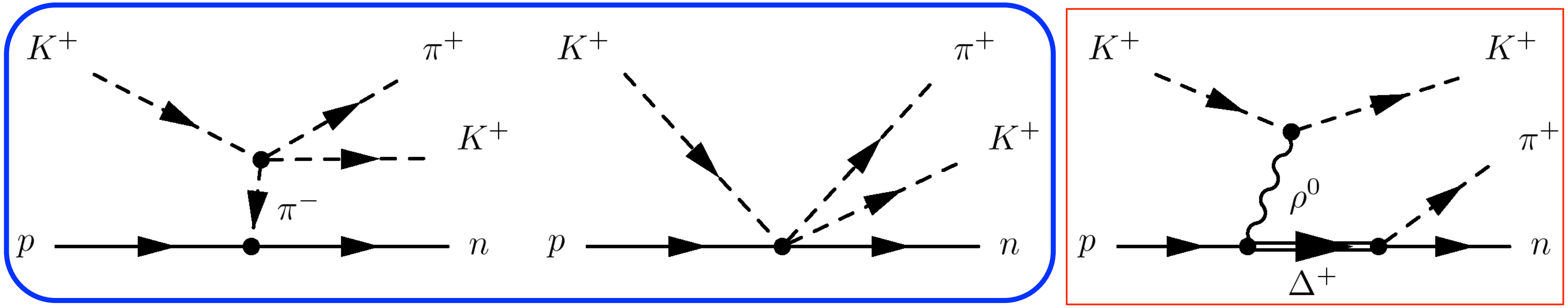
⬇

Determination of quantum numbers

A model for $K^+p \to \pi^+K^+n$

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

Vertices are derived from the chiral Lagrangian



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

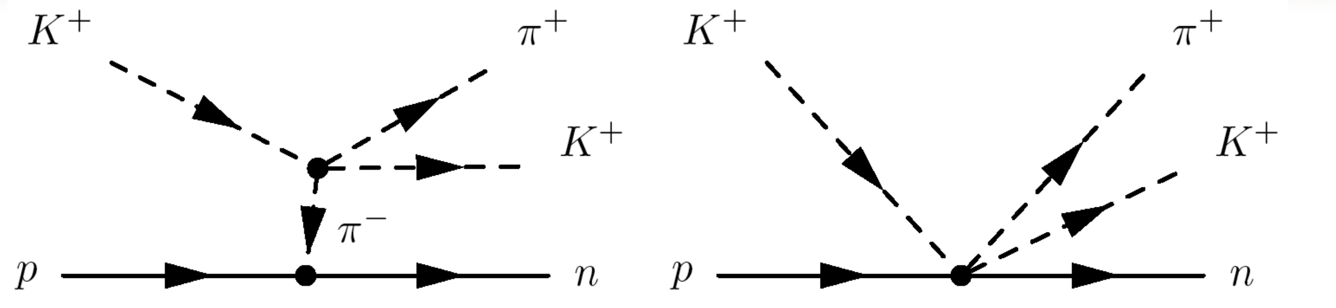
Dominant

vanishes

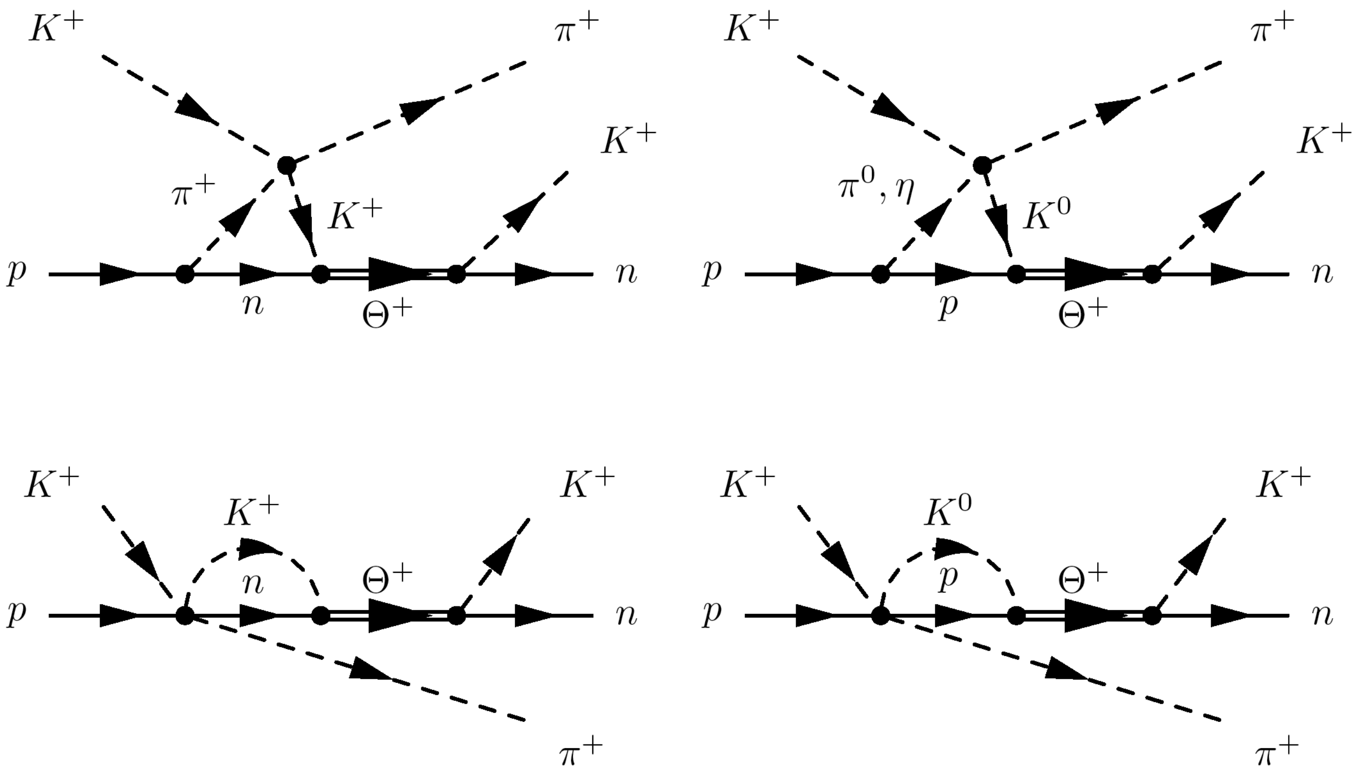
Assume final π^+ is almost at rest

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

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

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

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

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

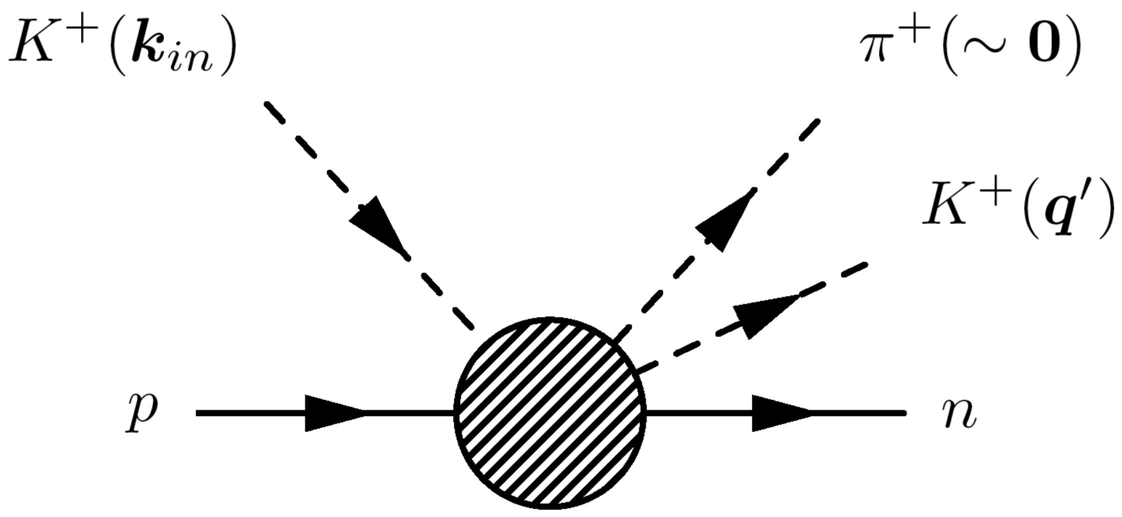
Resonance term

Amplitude of resonance term for K⁺p -> π⁺K⁺n :

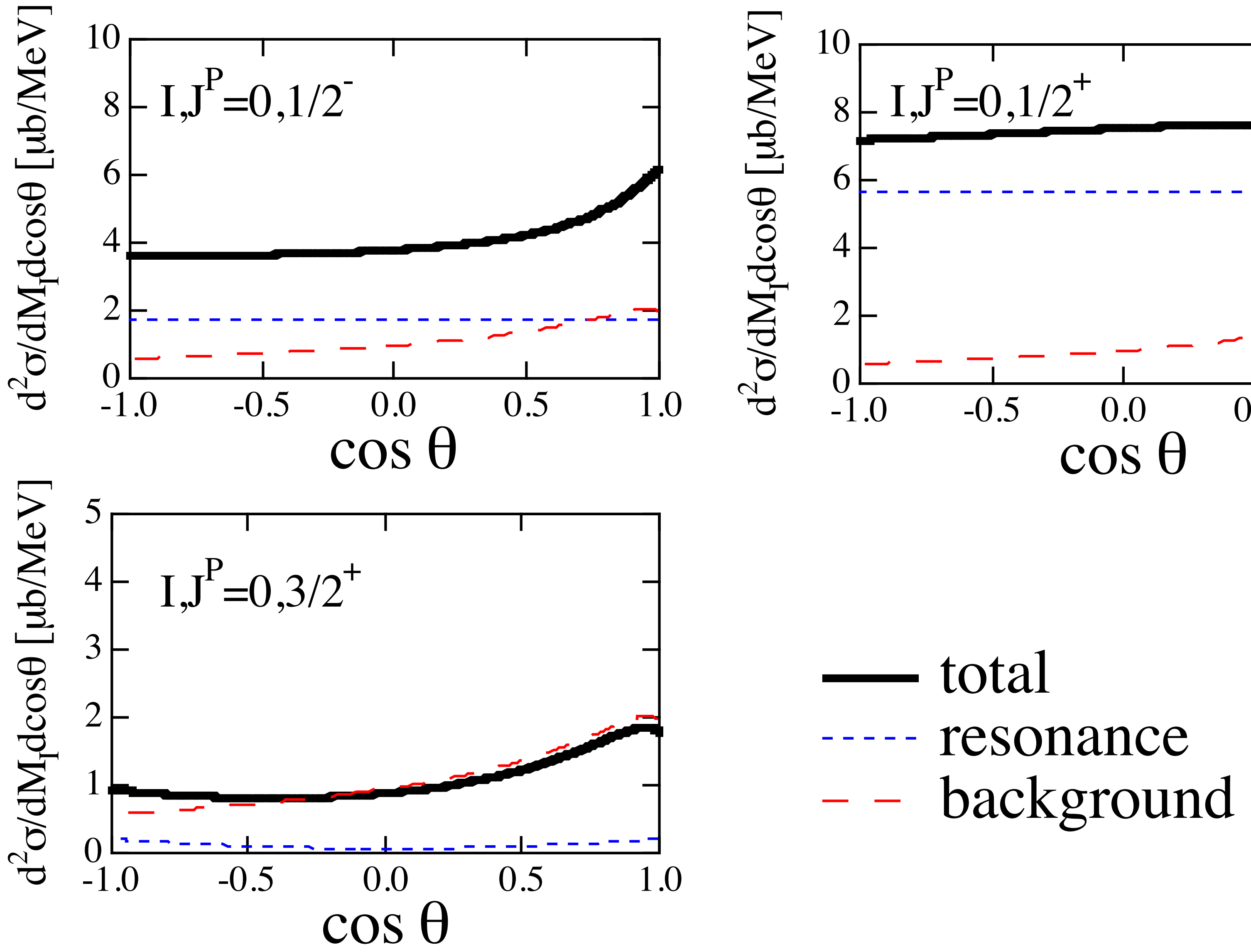
$$-i\tilde{t}_i^{(s)} = \frac{g_{K^+n}^2}{M_I - M_R + i\Gamma/2}\left\{G(M_I)(a_i + c_i) - \frac{1}{3}\bar{G}(M_I)b_i\right\}\boldsymbol{\sigma}\cdot\boldsymbol{k}_{in}S_I(i)$$

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

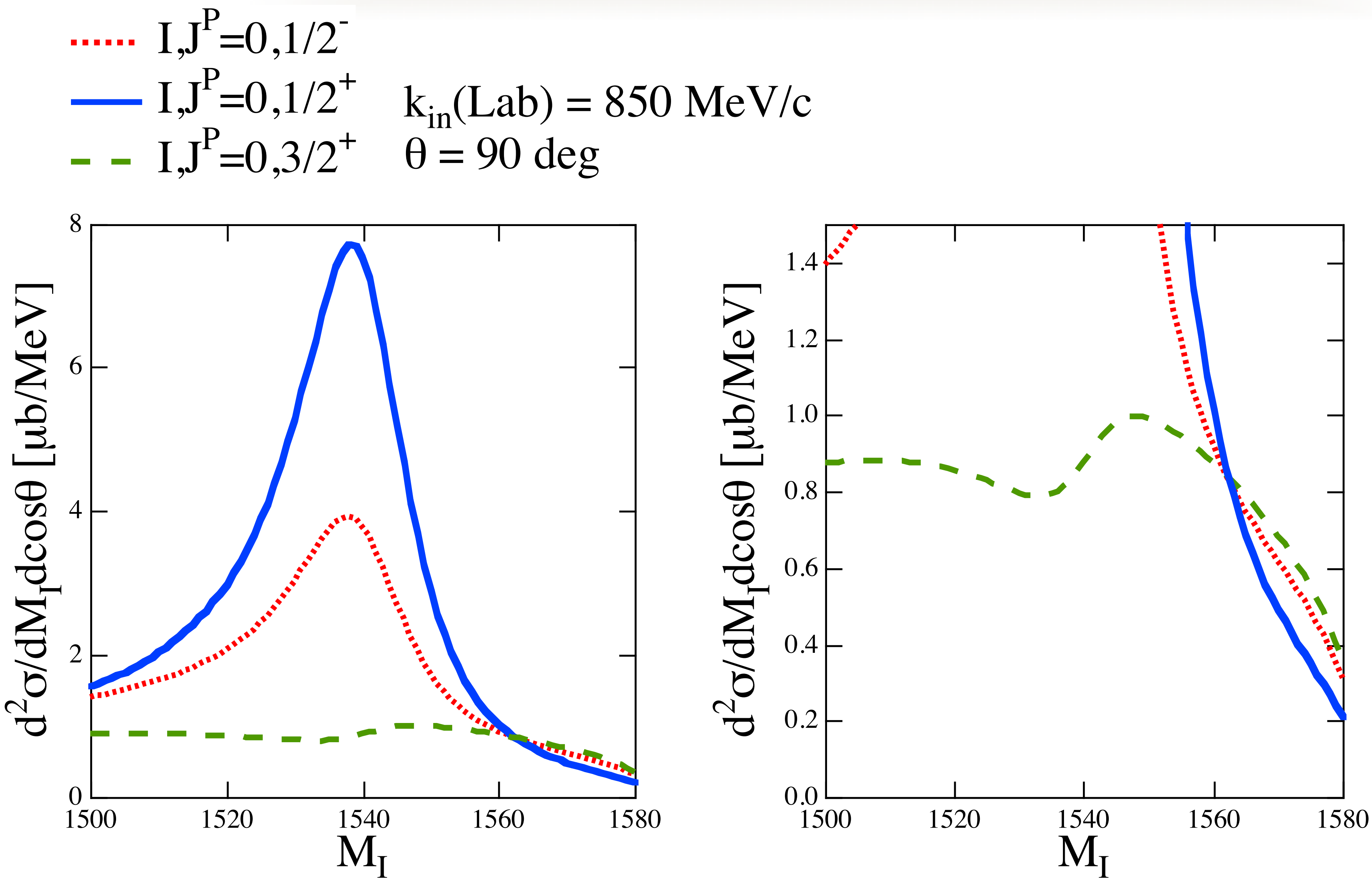
$$-i\tilde{t}_i^{(p,3/2)} = \frac{\tilde{g}_{K^+n}^2}{M_I - M_R + i\Gamma/2}\bar{G}(M_I)\frac{1}{3}b_i\left\{(\boldsymbol{k}_{in}\cdot\boldsymbol{q}')(\boldsymbol{\sigma}\cdot\boldsymbol{k}_{in}) - \frac{1}{3}\boldsymbol{k}_{in}^2\boldsymbol{\sigma}\cdot\boldsymbol{q}'\right\}S_I(i)$$



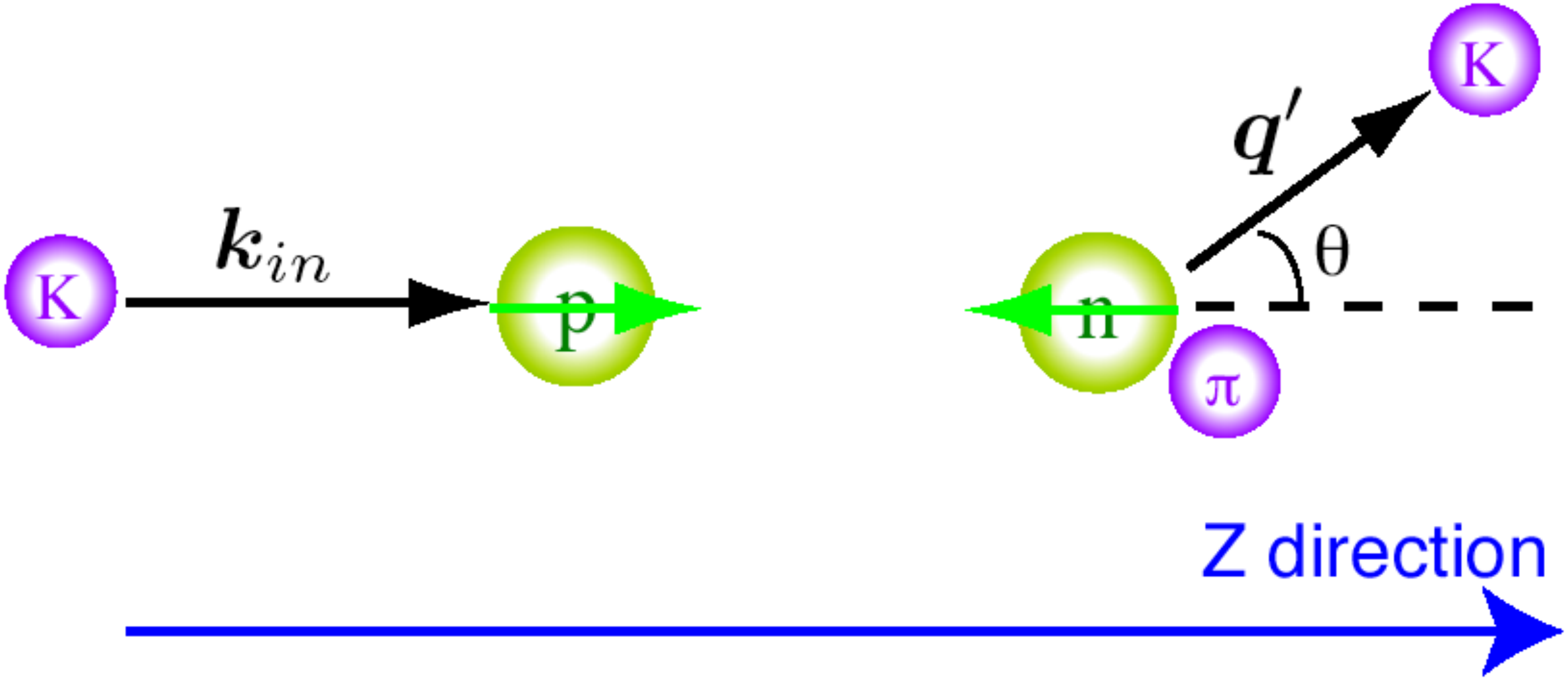
Angular dependence



Mass distributions



Polarization test

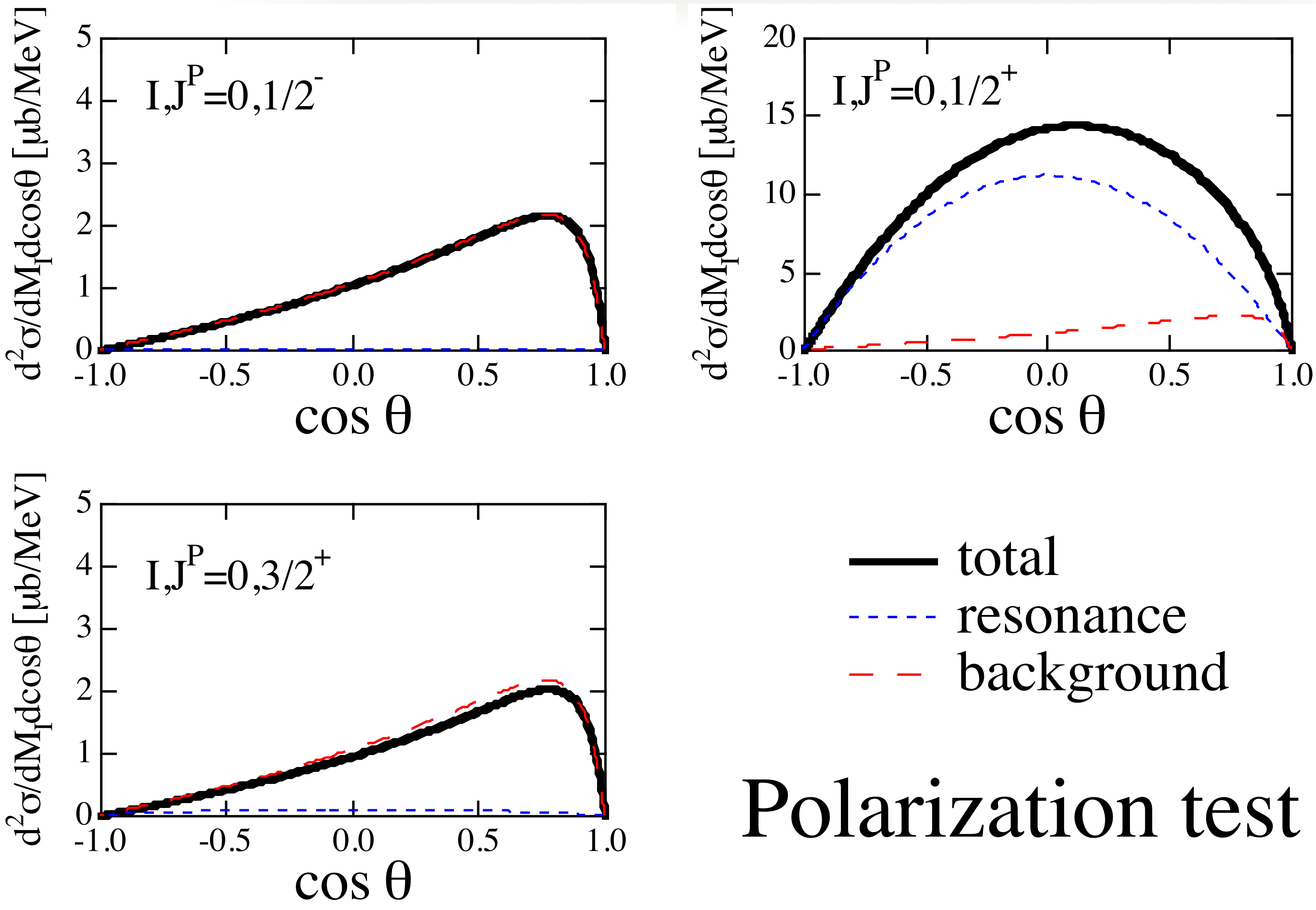


$$\langle -1/2 | \boldsymbol{\sigma} \cdot \boldsymbol{k}_{in} | 1/2 \rangle = 0$$

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

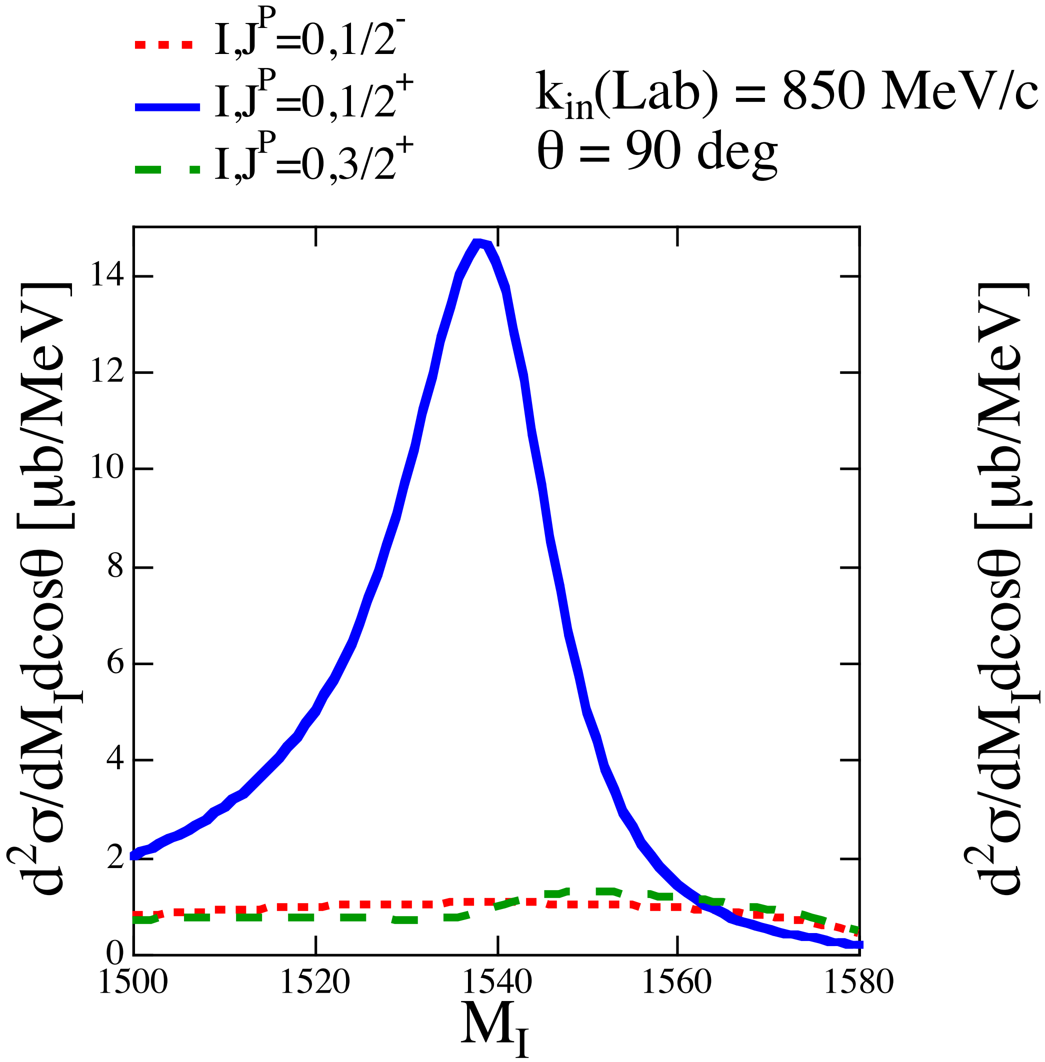
 # Same result is obtained for final pK^0

Angular dependence : polarization test

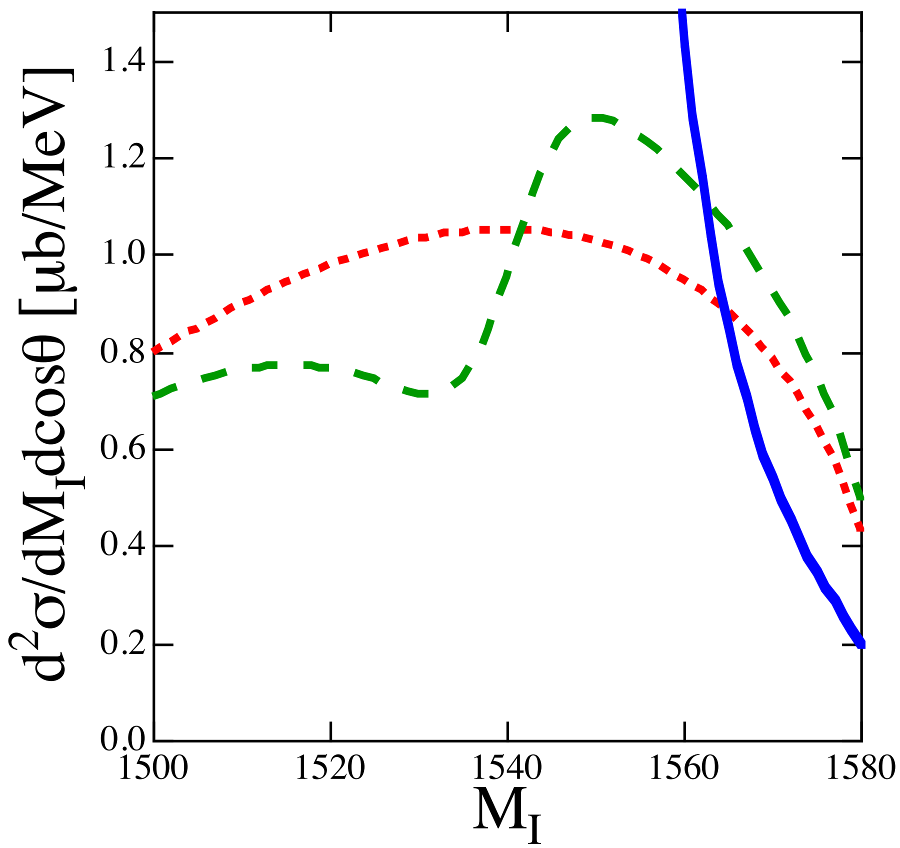


Polarization test

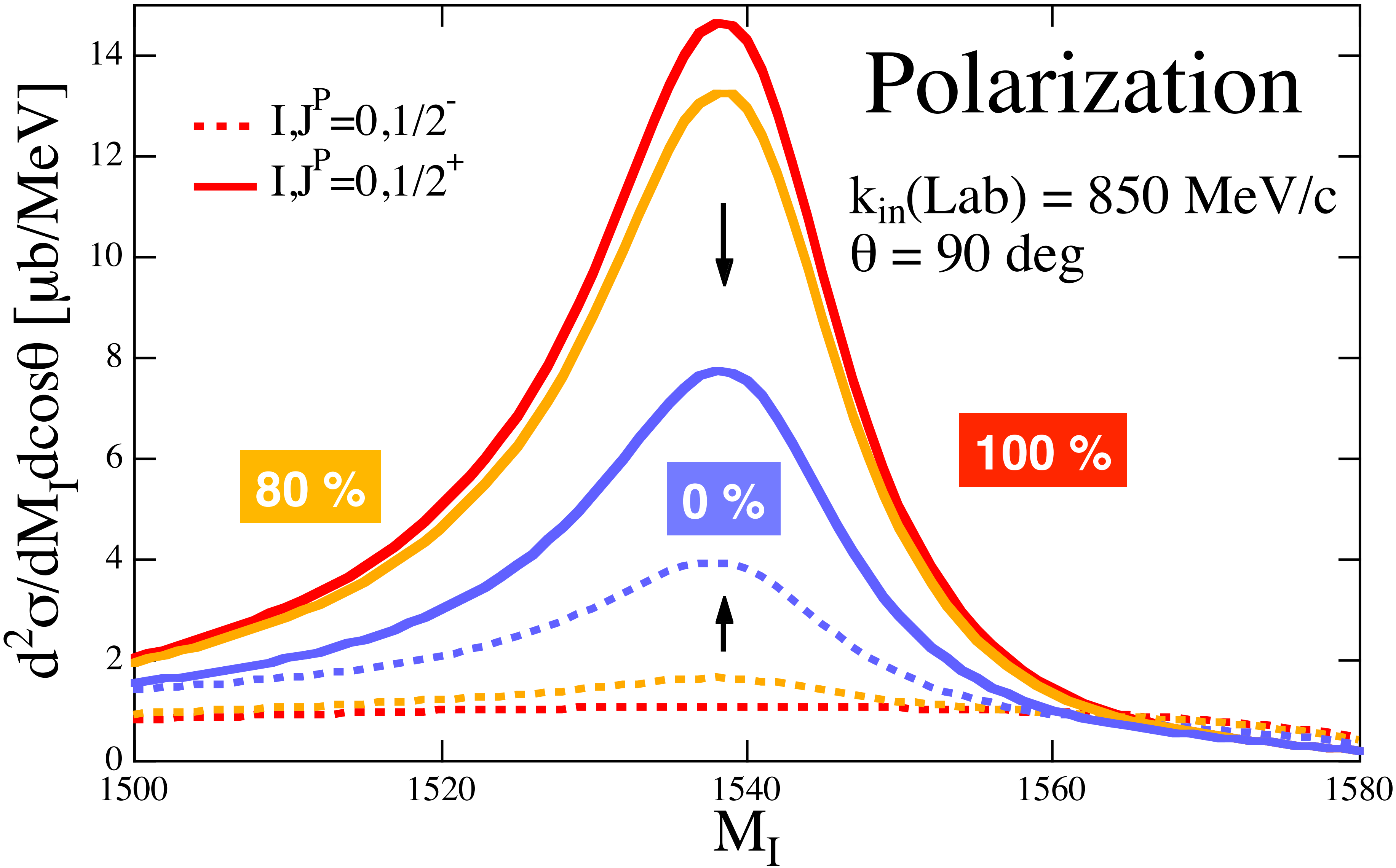
Mass distributions : polarization test



Polarization test



Incomplete polarization



Conclusion

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

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

T. Hyodo, A. Hosaka, and E. Oset, nucl-th/0307105

Future work

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

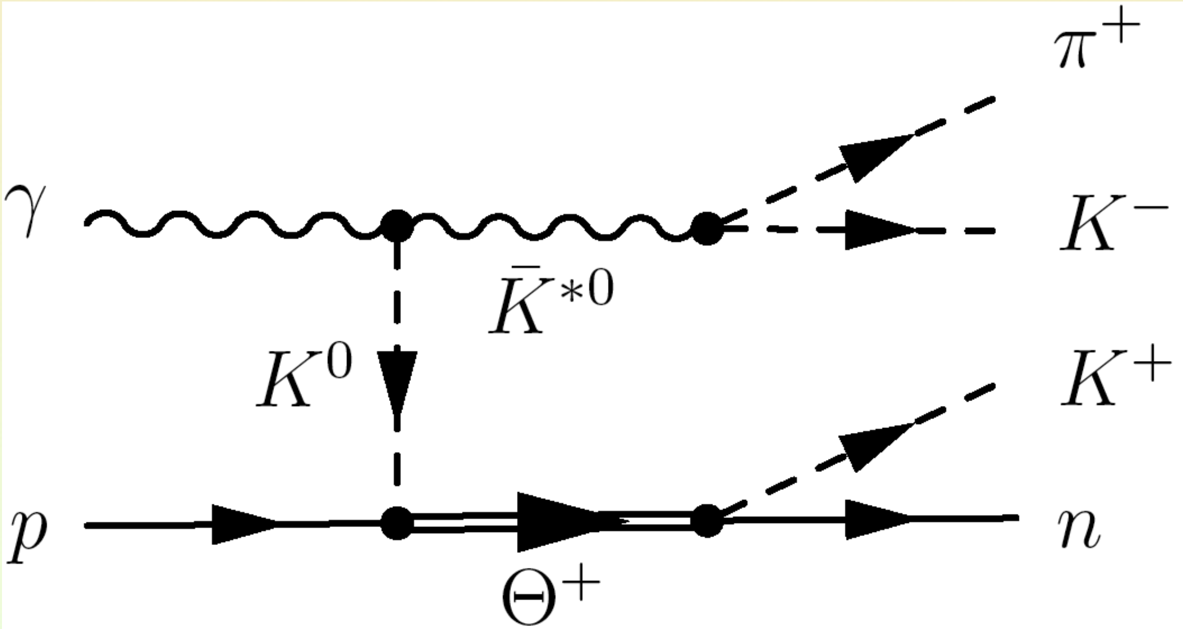


Photo-production of K* and Θ

Angular dependence (upper) and
integrated (lower) cross sections
of $\gamma p \to K^* \Theta$
K-exchange, Λ 1 GeV
units : [μb]

Preliminary