Determining the □$^+$ quantum numbers through the K^+p -> □^+KN reaction

Tetsuo Hyodo[a],

A. Hosaka[a], M. J. Vicente Vacas[b] and E. Oset[b]

[a] RCNP, Osaka   [b] IFIC, Valencia

2003, October 23rd

Contents

1. Introduction
    1. Status of theoretical studies
    2. Photo-production process
2. The K^+p -> □$^+K^+n(K^0p)$ reaction
    1. Motivation & advantage
    2. Model for the reaction
    3. Numerical results
    4. Conclusions
3. Future (current) works
    1. Full calculation
    2. K^* production

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 □)
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

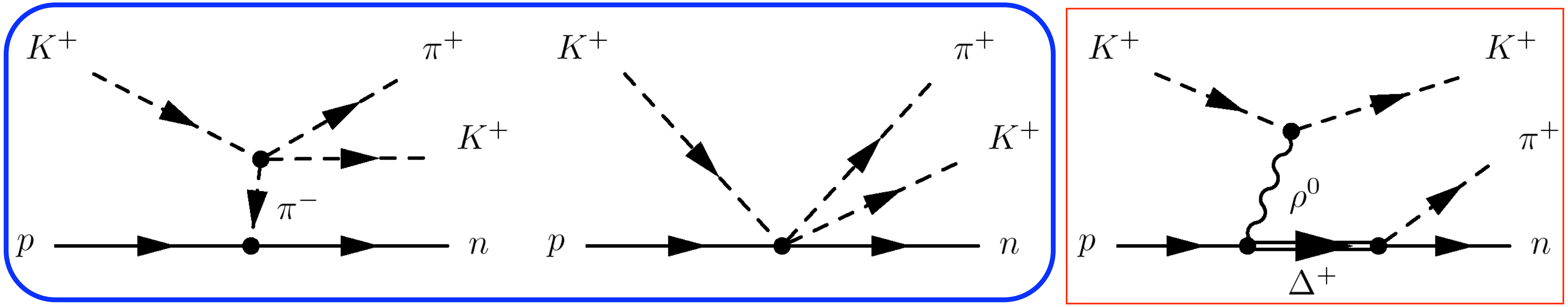
to extract a qualitative behavior which depends on the quantum numbers of $\square^+$.

Determination of quantum numbers

A model for □+p -> □+K+n

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

Vertices are derived from the chiral Lagrangian



Dominant

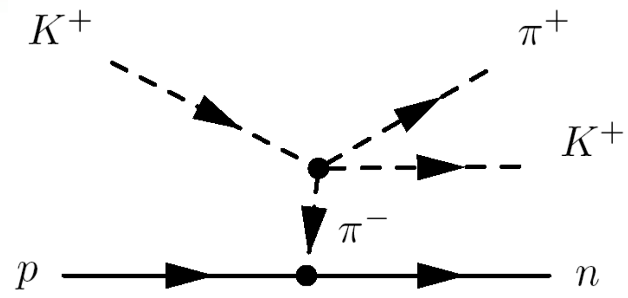
Proportional to $\boldsymbol{S} \cdot \boldsymbol{p}_{\pi^+}$

vanishes

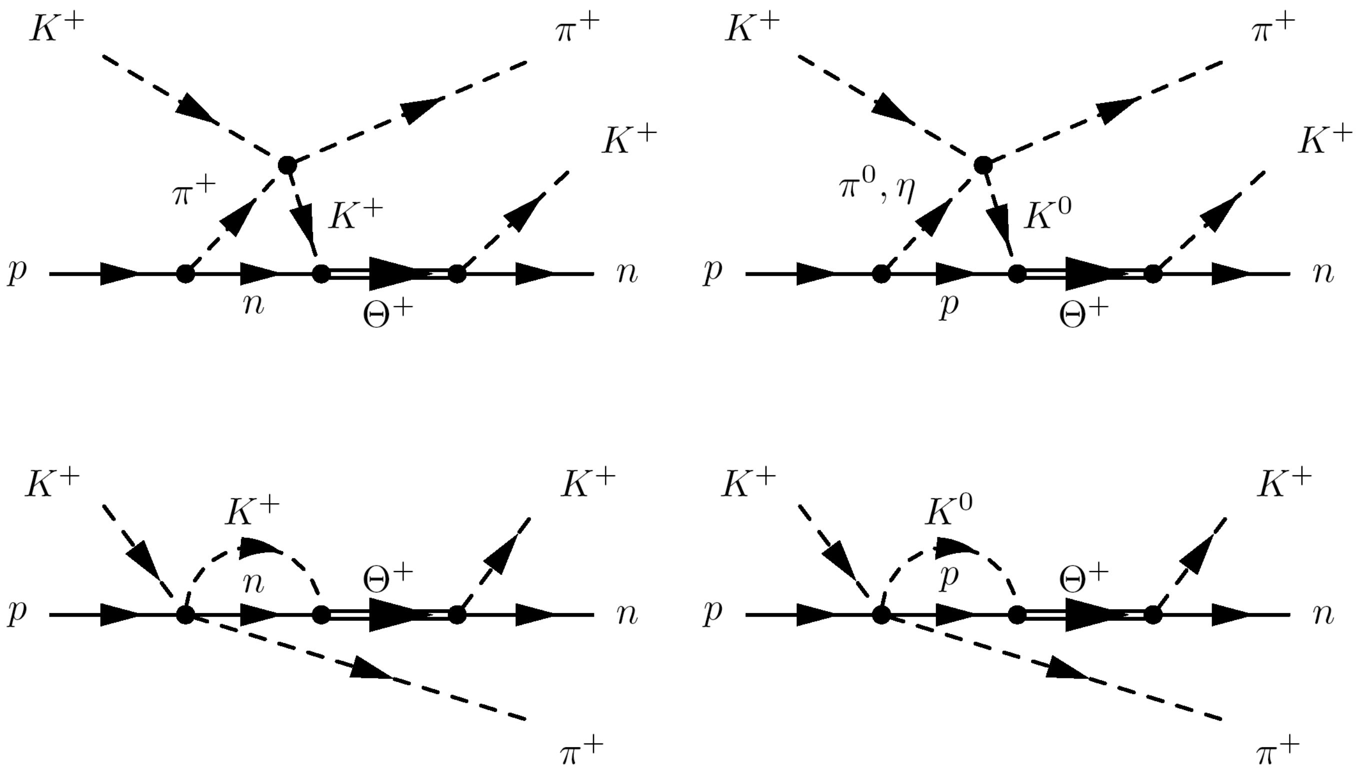
Assume final □+ is almost at rest

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

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

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

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

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

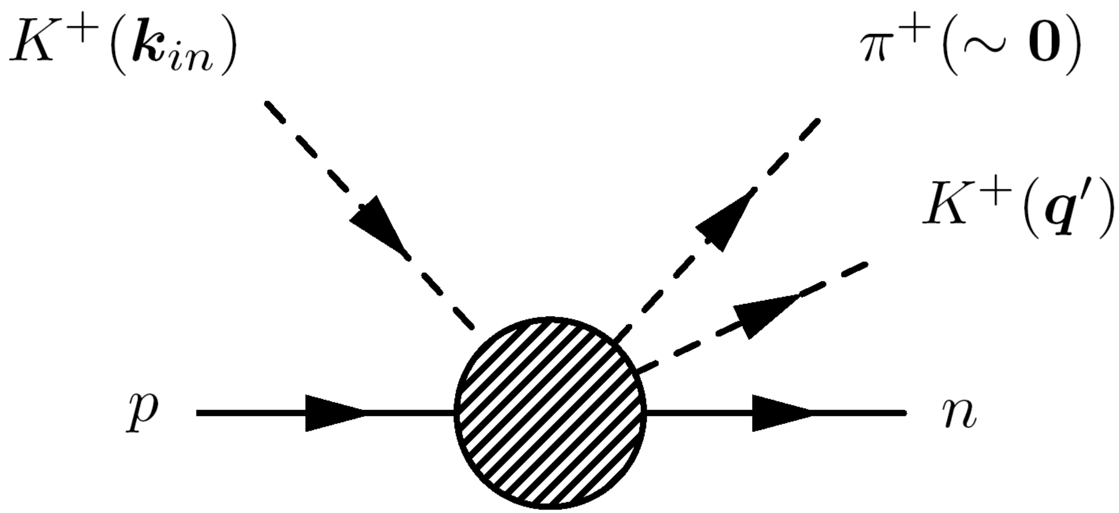
Resonance term

Amplitude of resonance term for K^+p -> □$^+K^+n$:

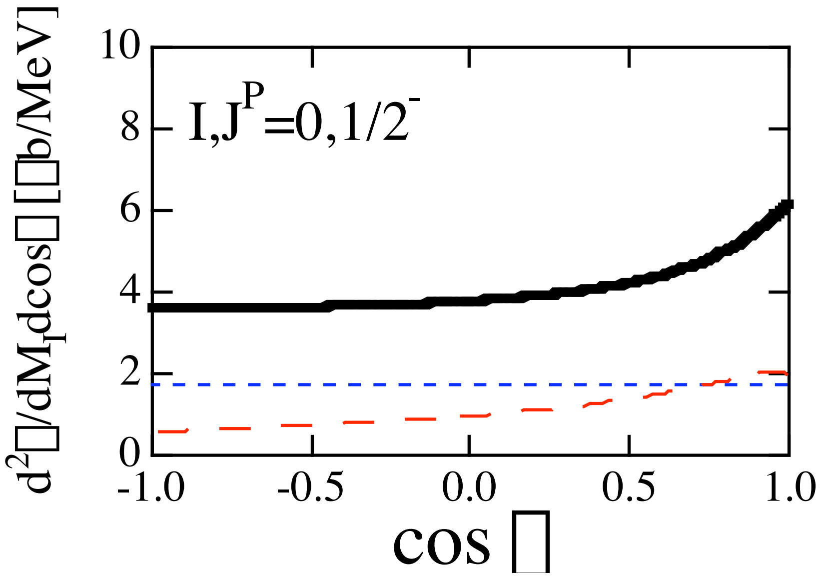
$$-i\tilde{t}_i^{(s)} = \frac{g_{K^+n}^2}{M_I - M_R + i\Gamma/2}\left\{G(M_I)(a_i + c_i) - \frac{1}{3}\bar{G}(M_I)b_i\right\}\boldsymbol{\sigma}\cdot\boldsymbol{k}_{in}S_I(i)$$

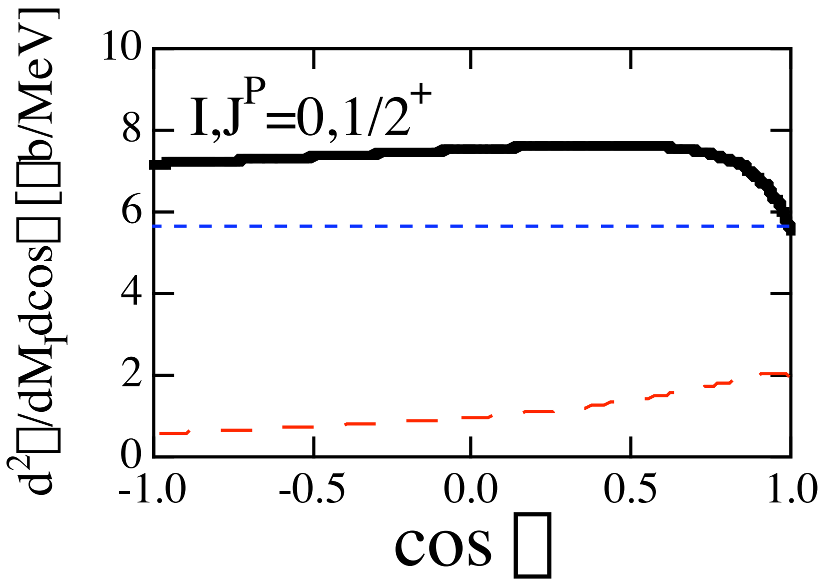
$$-i\tilde{t}_i^{(p,1/2)} = \frac{\bar{g}_{K^+n}^2}{M_I - M_R + i\Gamma/2}\bar{G}(M_I)\left\{\frac{1}{3}b_i\boldsymbol{k}_{in}^2 - a_i + d_i\right\}\boldsymbol{\sigma}\cdot\boldsymbol{q}' S_I(i)$$

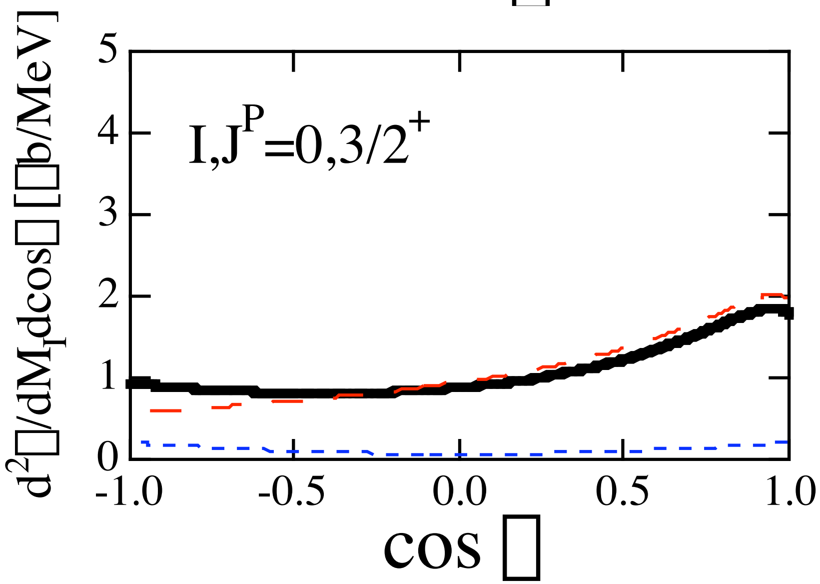
$$-i\tilde{t}_i^{(p,3/2)} = \frac{\tilde{g}_{K^+n}^2}{M_I - M_R + i\Gamma/2}\bar{G}(M_I)\frac{1}{3}b_i\left\{(\boldsymbol{k}_{in}\cdot\boldsymbol{q}')(\boldsymbol{\sigma}\cdot\boldsymbol{k}_{in}) - \frac{1}{3}\boldsymbol{k}_{in}^2\boldsymbol{\sigma}\cdot\boldsymbol{q}'\right\}S_I(i)$$



Angular dependence







Mass distributions

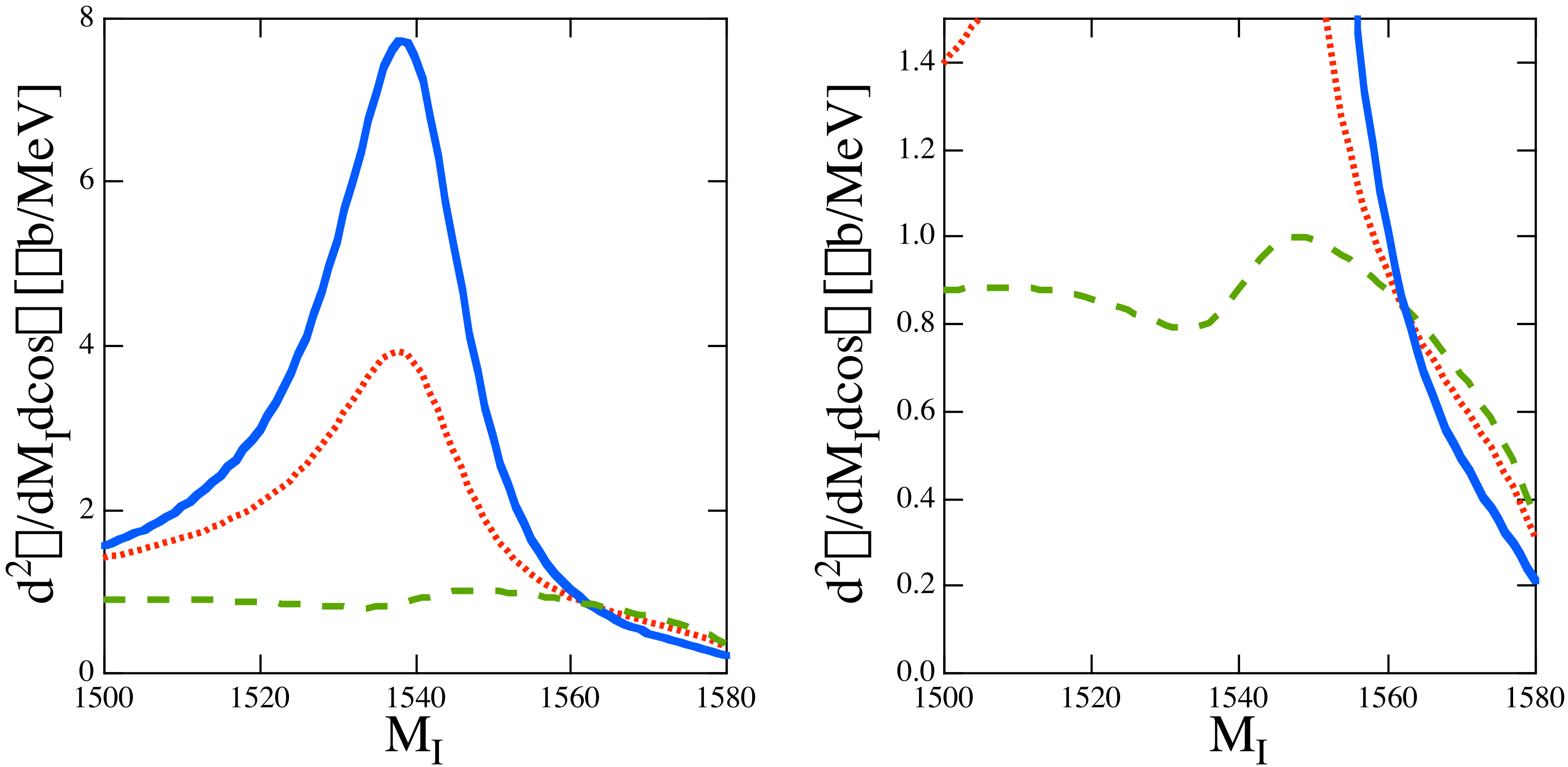
I,J^P=0,1/2$^-$ (dotted)

I,J^P=0,1/2$^+$ (solid)

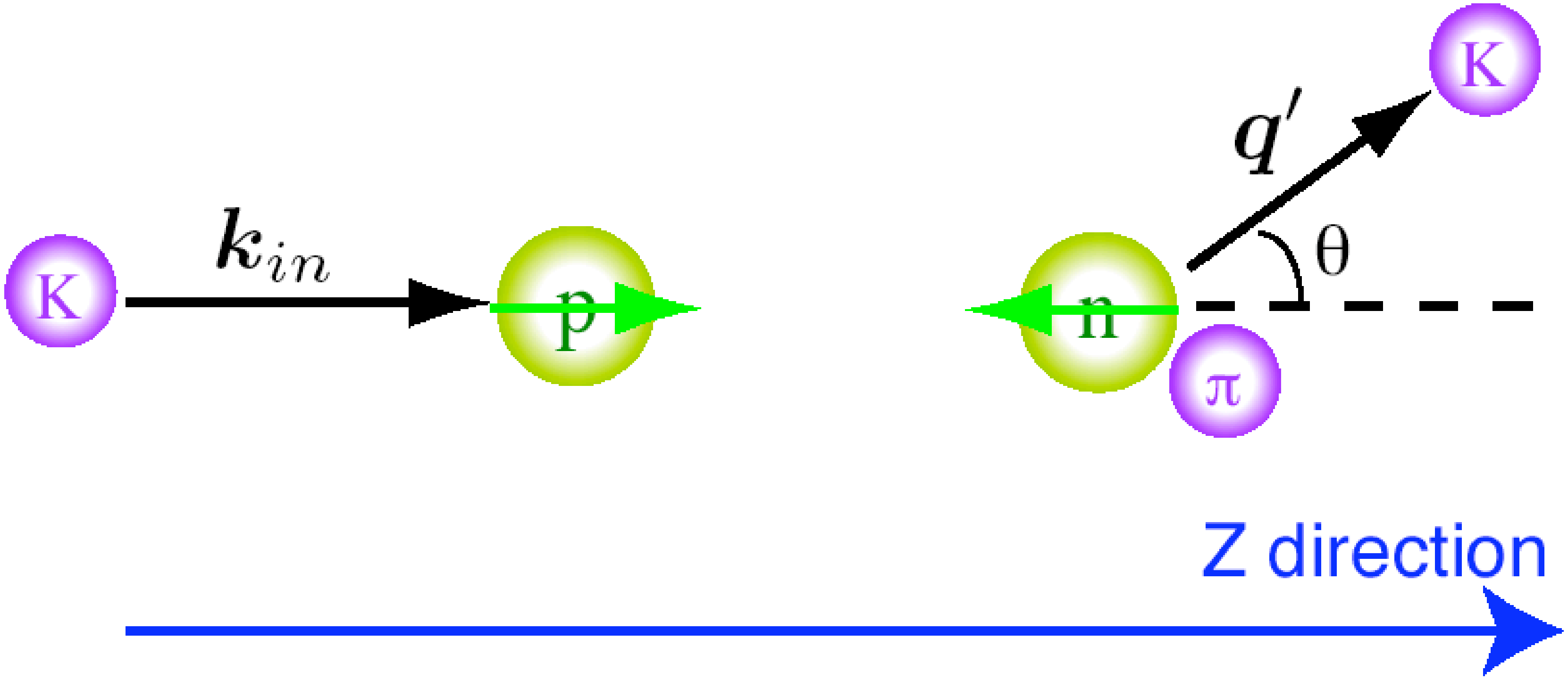
I,J^P=0,3/2$^+$ (dashed)

k_{in}(Lab) = 850 MeV/c

□ = 90 deg



Polarization test

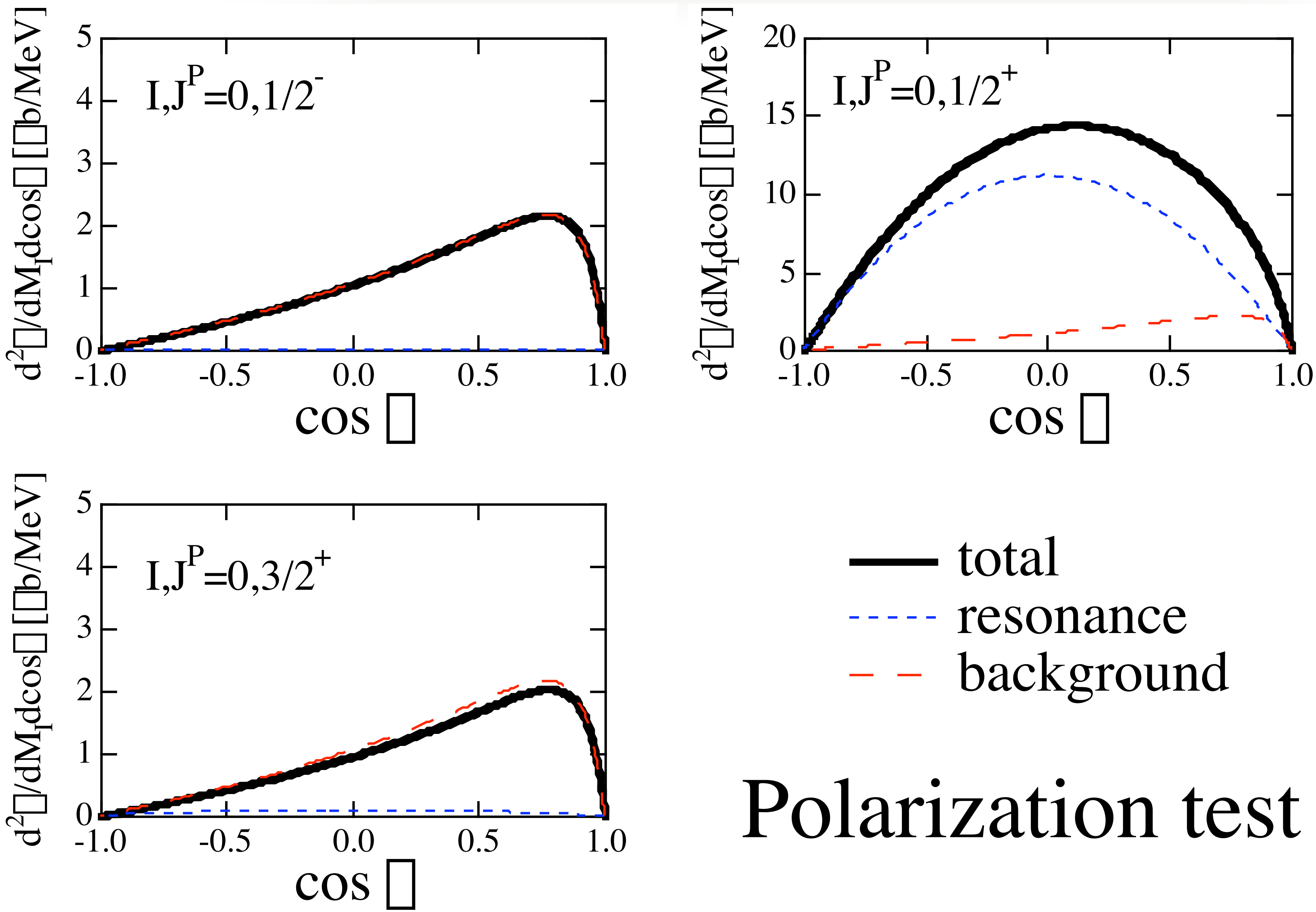


$$\langle -1/2|\boldsymbol{\sigma}\cdot\boldsymbol{k}_{in}|1/2\rangle = 0$$

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

 # Same result is obtained for final pK^0

Angular dependence : polarization test



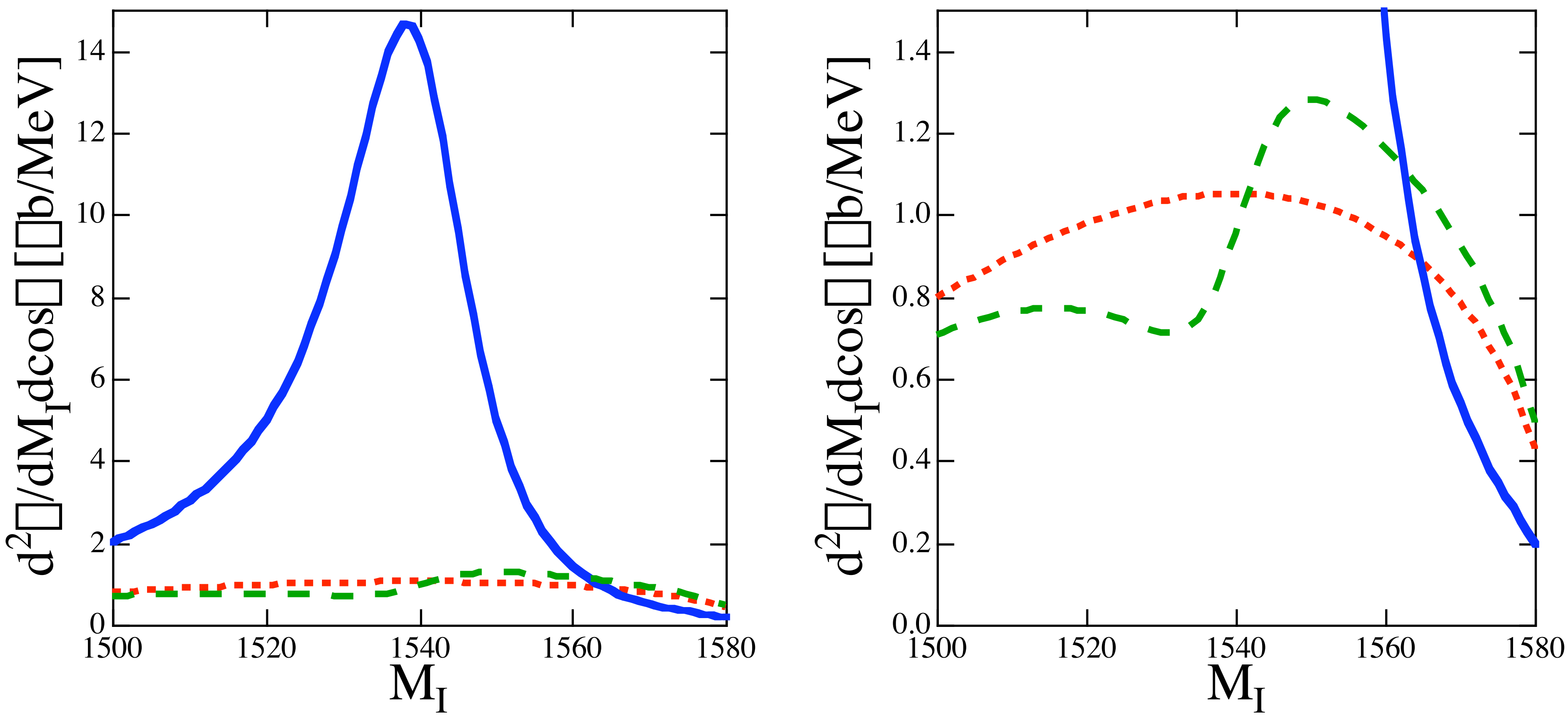
Polarization test

Mass distributions : polarization test

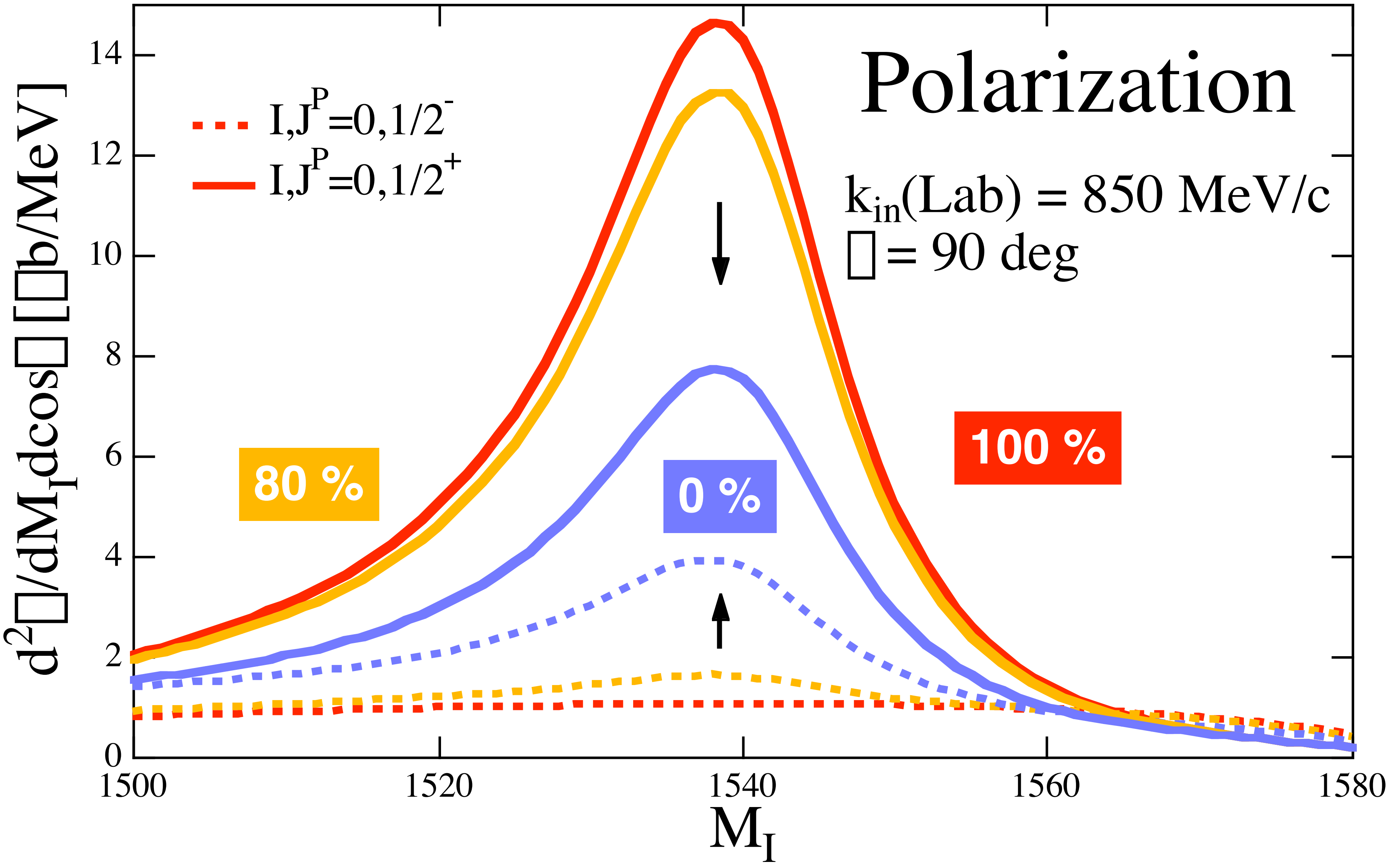
- $I,J^P=0,1/2^-$ (dotted)
- $I,J^P=0,1/2^+$ (solid)
- $I,J^P=0,3/2^+$ (dashed)

$k_{in}(Lab) = 850$ MeV/c
$\theta = 90$ deg

Polarization test



Incomplete polarization



Conclusion

We calculate the $K^{+}p$ -> $□^{0}KN$ 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, A. Hosaka, and E. Oset, nucl-th/0307105

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

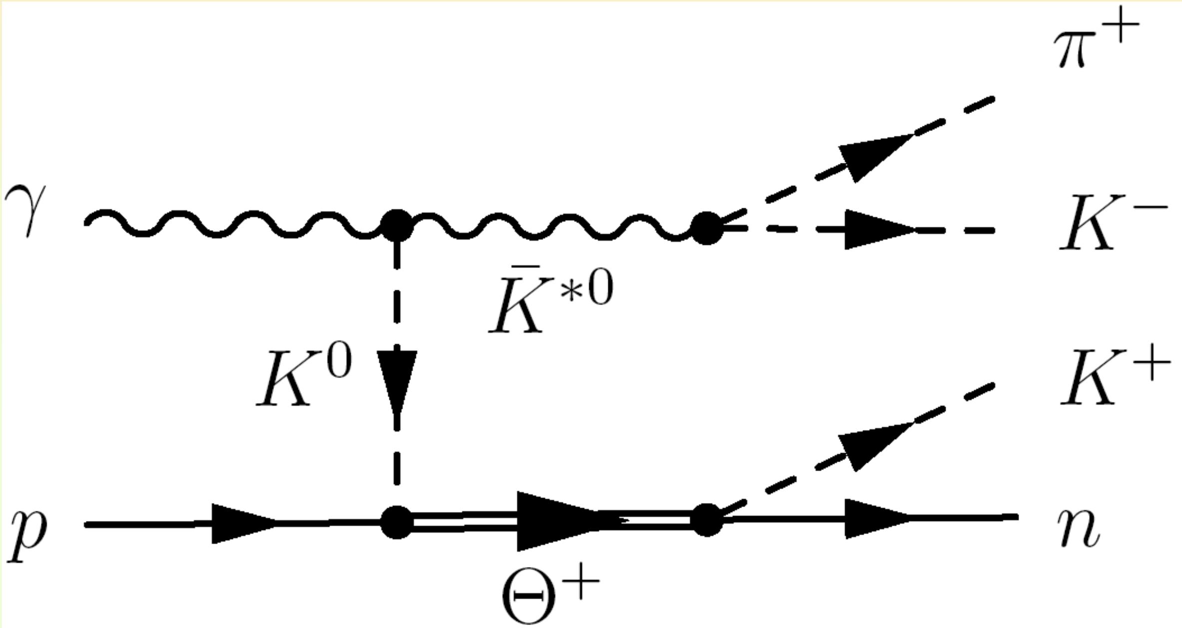


Photo-production of K* and □

Angular dependence (upper) and
integrated (lower) cross sections
of □p -> K* □
K-exchange, □ 1 GeV
units : [□b]

Preliminary

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