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

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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

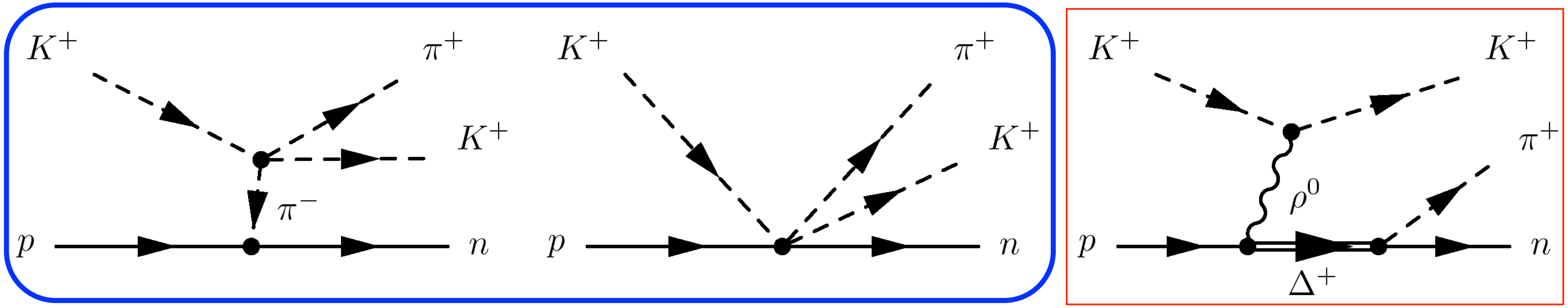
- Diakonov *et al.* (chiral quark soliton) : $1/2^+$, I=0
- Carlson *et al.* (quark model[QM]) : $1/2^-$, I=0
- Stancu *et al.* (QM + flavor-spin int.) : $1/2^+$, I=0
- Zhu (QCD sum rule) : $1/2^-$, I=0, 1, 2
- Capstick *et al.* (decay width analysis) : $1/2^-$, $3/2^-$, $5/2^-$, I=2

We study $K^+p \rightarrow \pi^+K^+n$ reaction to determine the quantum numbers of Θ^+

A model for $\pi^- p \to K^0 \pi \Sigma$

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

Vertices are derived from the chiral Lagrangian



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

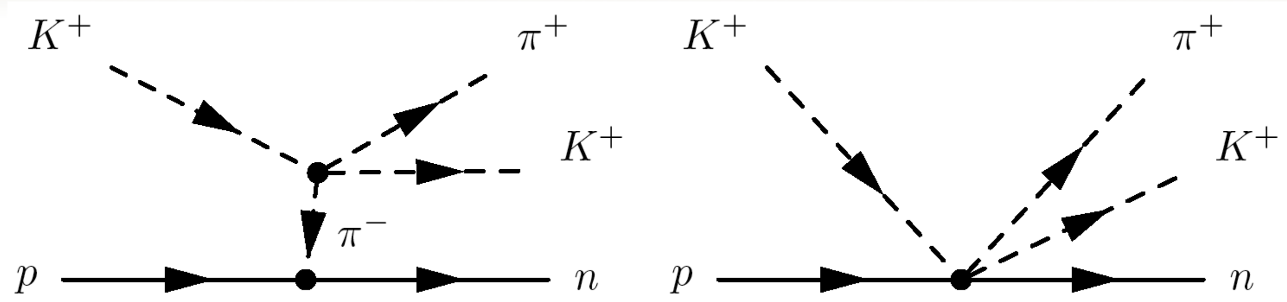
Dominant

vanishes

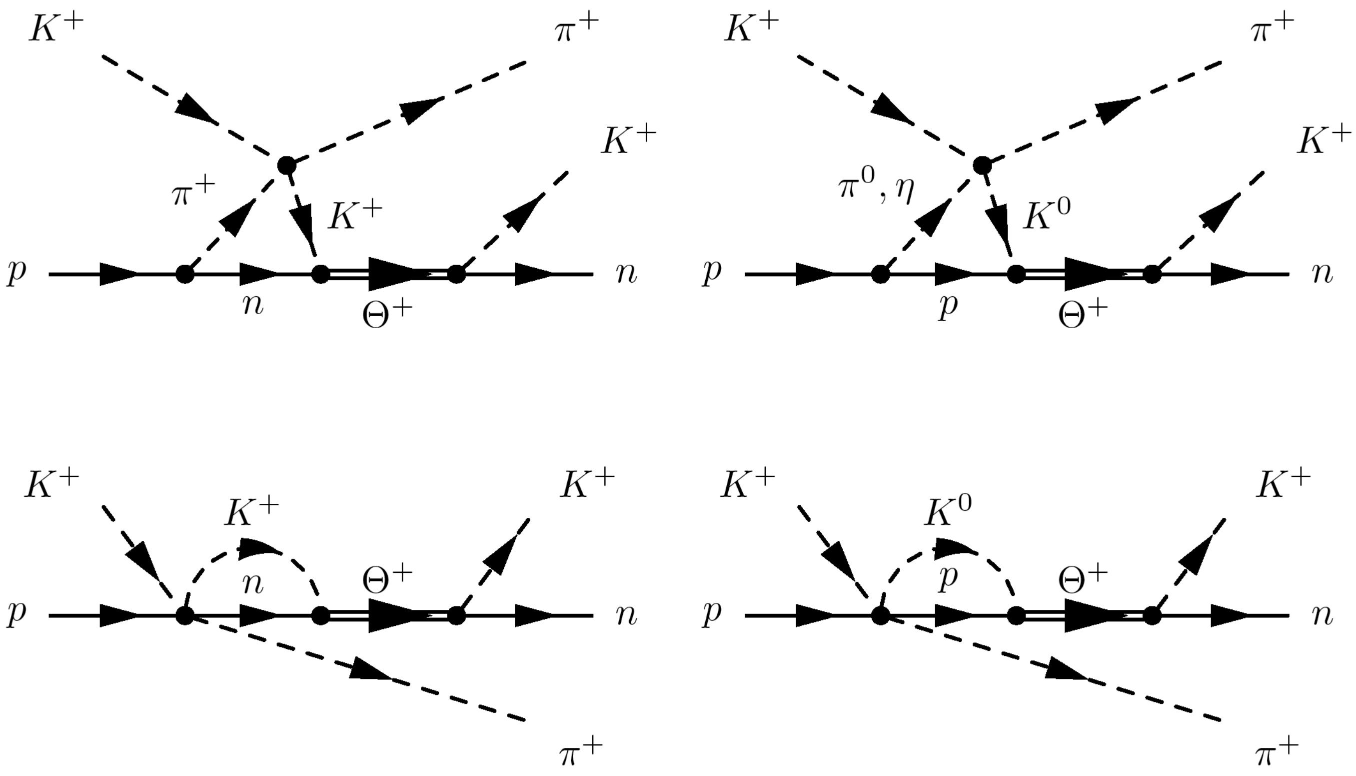
Assume final π^+ is almost at rest

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

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

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

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

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

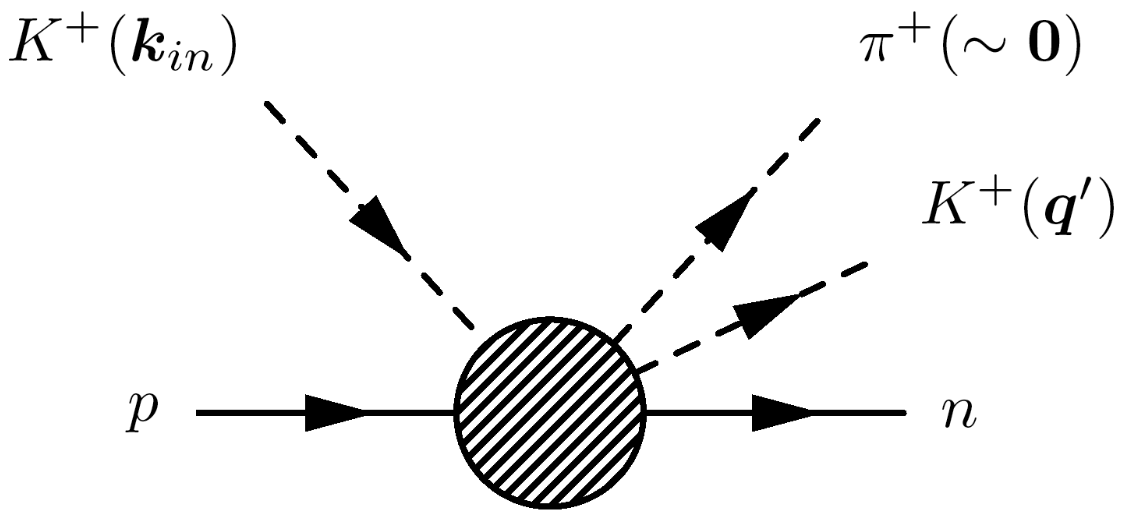
Resonance term

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

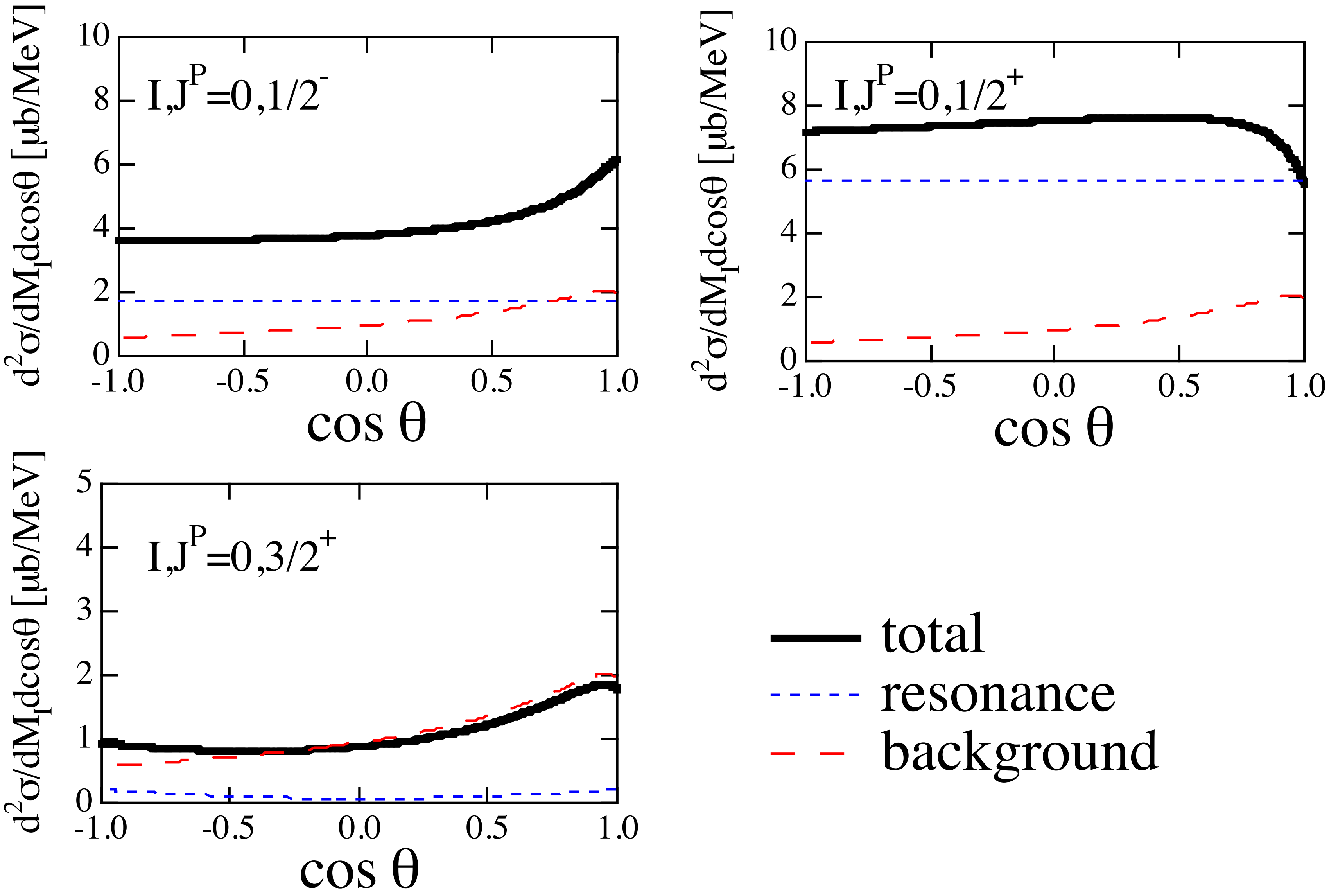
$$-\tilde{t}_i^{(s)} = \frac{g_{K^+n}^2}{M_I - M_R + i\Gamma/2}\left\{G(M_I)(a_i + c_i) - \frac{1}{3}\bar{G}(M_I)b_i\right\}\boldsymbol{\sigma}\cdot\boldsymbol{k}_{in}S_I(i) \ ,$$

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

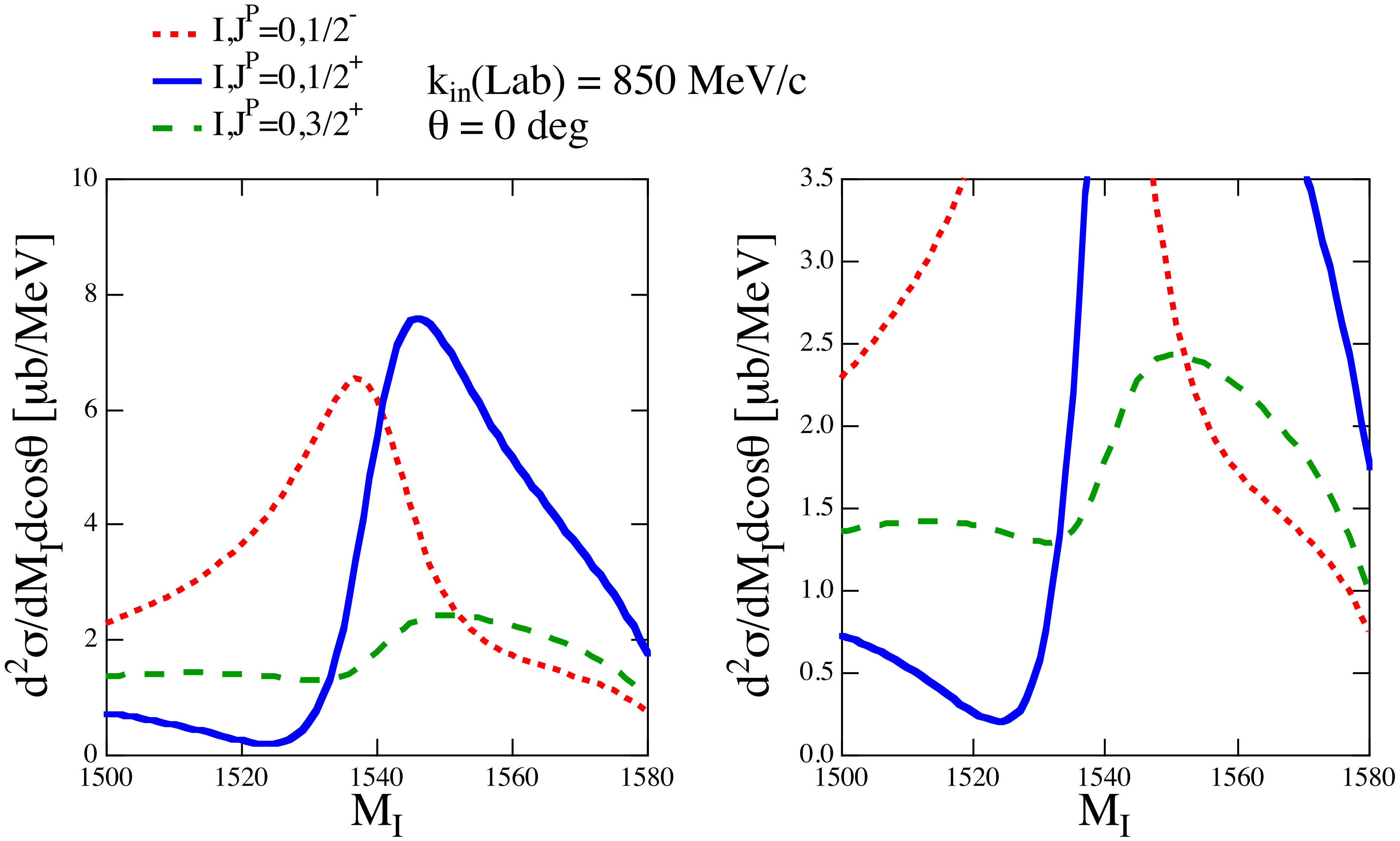
$$-\tilde{t}_i^{(p,3/2)} = \frac{\tilde{g}_{K^+n}^2}{M_I - M_R + i\Gamma/2}\bar{G}(M_I)\frac{1}{3}b_i\left\{(\boldsymbol{k}_{in}\cdot\boldsymbol{q}')(\boldsymbol{\sigma}\cdot\boldsymbol{k}_{in}) - \frac{1}{3}\boldsymbol{k}_{in}^2\boldsymbol{\sigma}\cdot\boldsymbol{q}'\right\}S_I(i)$$



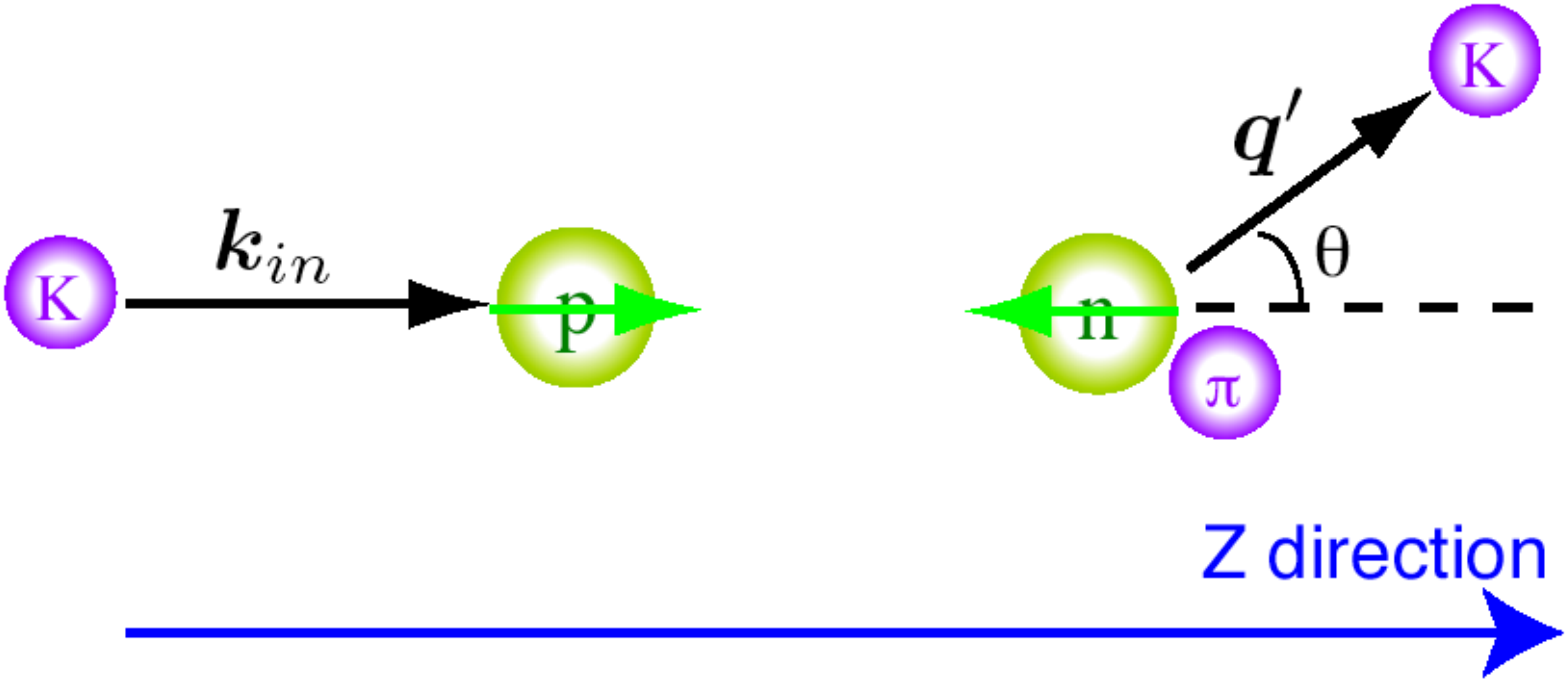
Angular dependence



Mass distributions



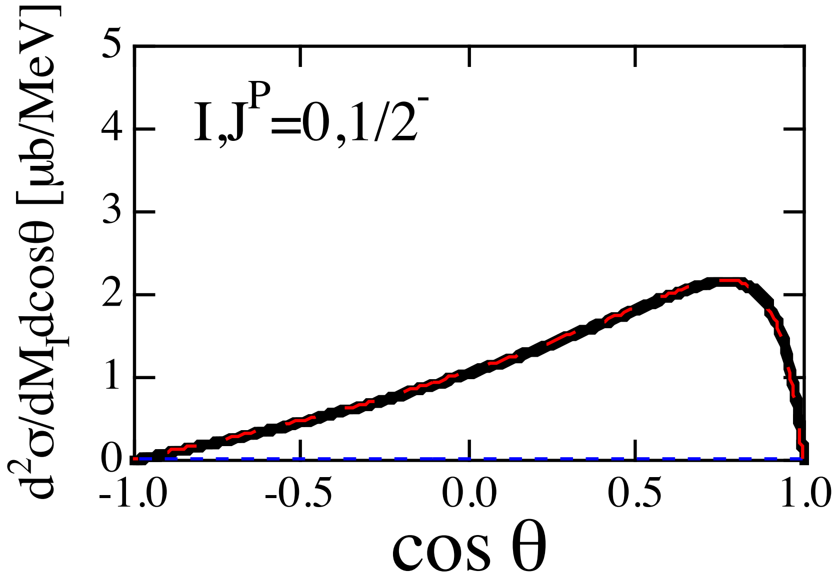
Polarization test

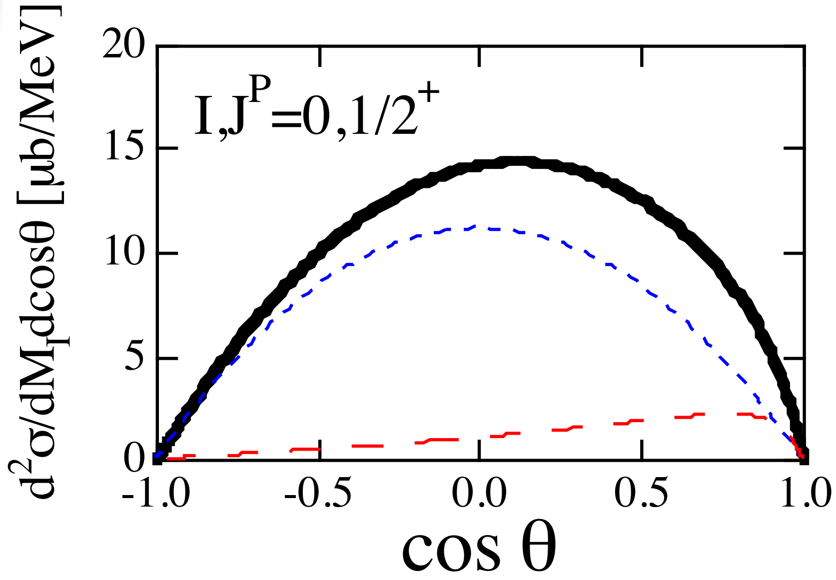


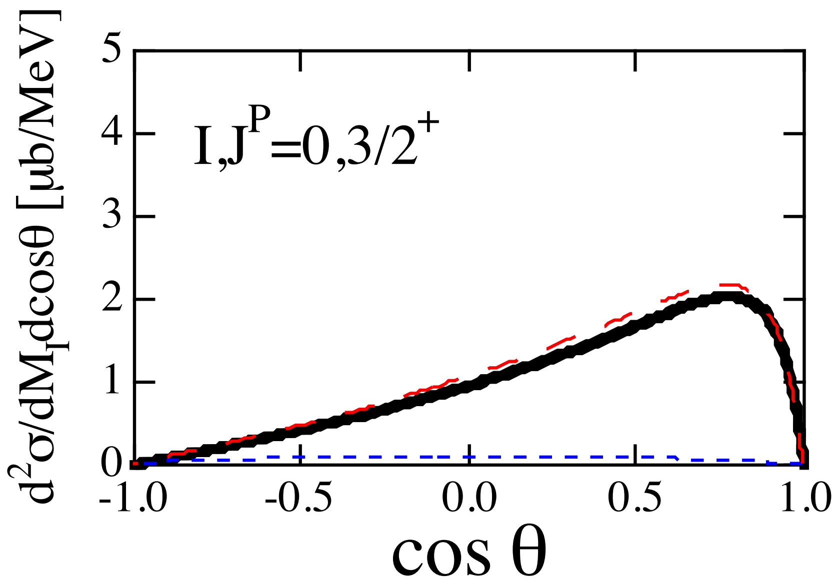
$$\langle -1/2 | \boldsymbol{\sigma} \cdot \boldsymbol{k}_{in} | 1/2 \rangle = 0$$

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

Angular dependence : polarization test







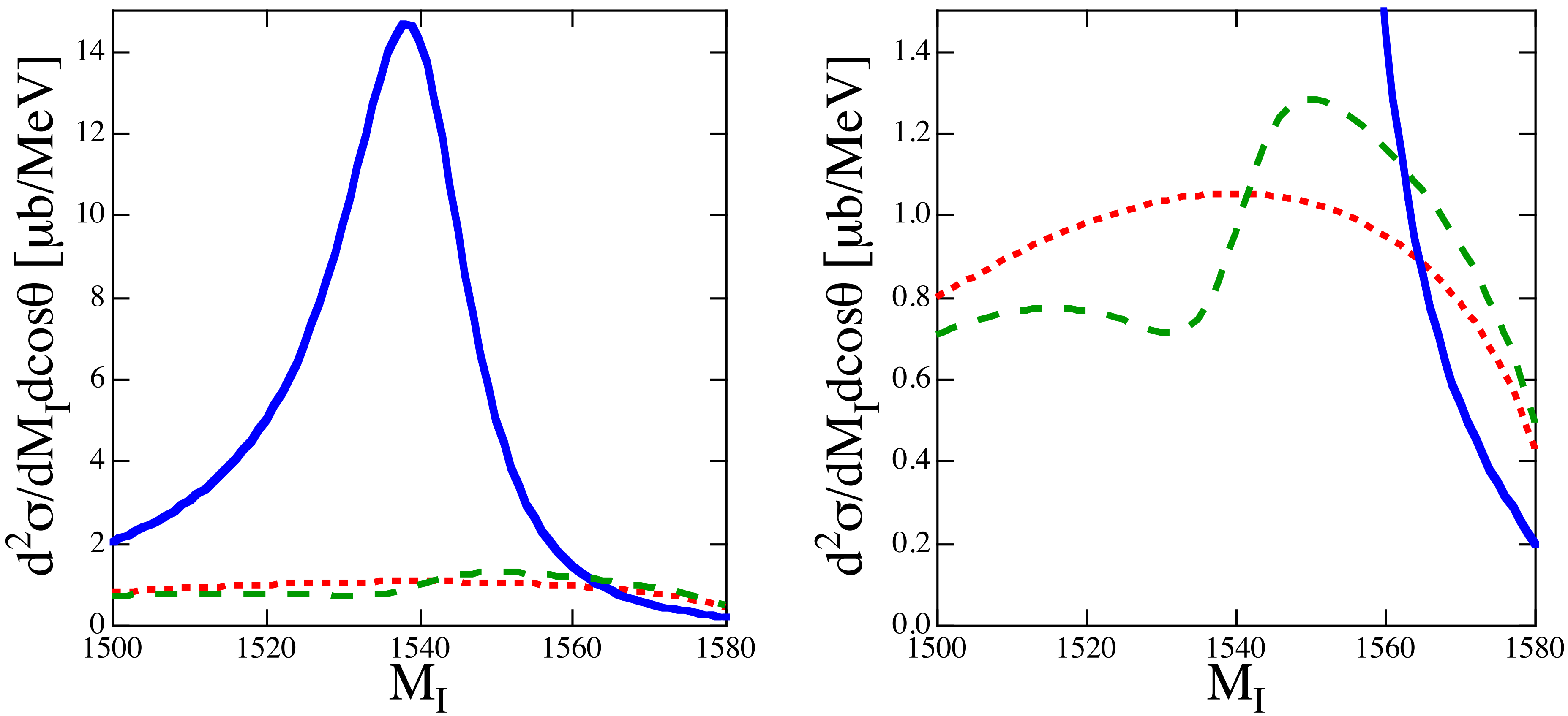
Polarization test

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
θ = 90 deg

Polarization test



Conclusions

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

- Resonance signal of the mass distribution is always seen in the forward direction.
- 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