Determining the Θ^+ quantum numbers through K^+p -> π^+KN

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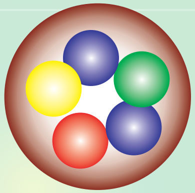
Motivation : Spin parity determination

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

$$|\,\Theta\,\rangle = |\,uudd\bar{s}\,\rangle$$



S = +1, manifestly exotic

Spin and parity are not determined.

Find a reaction where qualitatively different results depending on the quantum numbers are observed.

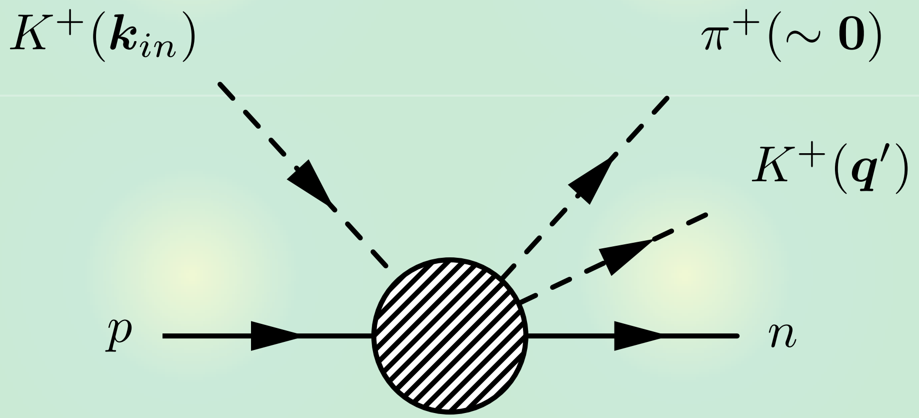
→ **Utilize the polarization of particles**

Motivation : Advantage of hadronic process

We propose

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

at threshold of π and Θ.

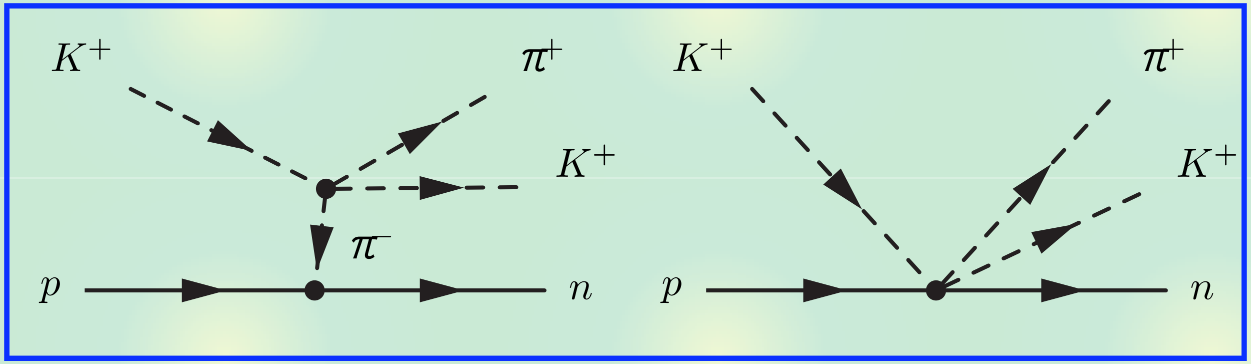


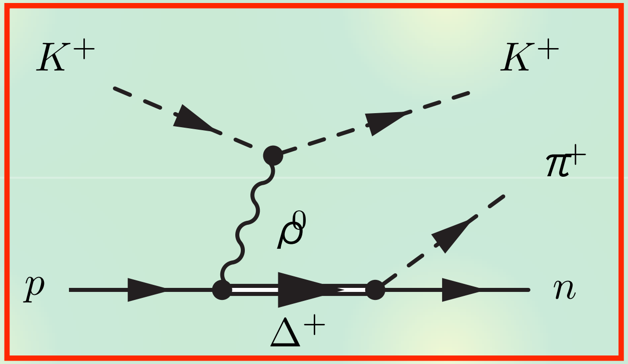
- Low energy (k_{in} ~ 350 MeV in c.m. frame)
- Decay is considered -> background, interference,...
- Hadronic process : clear mechanism
  : large cross section ~ 10^2 μb

Chiral model for the reaction: Background

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

Threshold production of π and Θ
Vertices <- chiral Lagrangian





Dominant

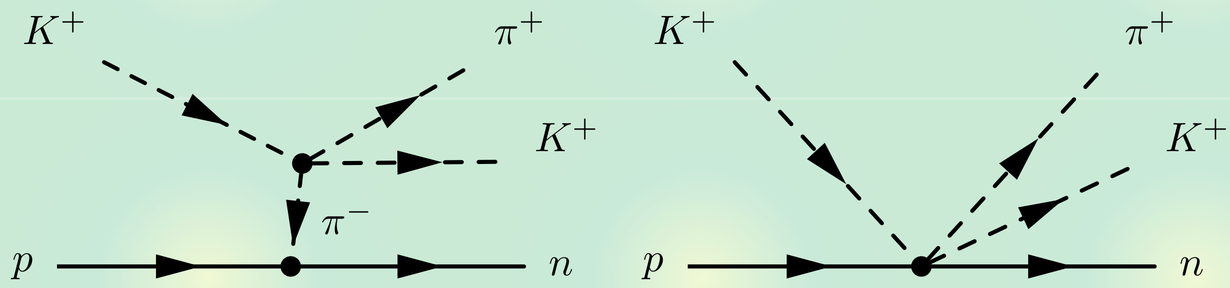
Proportional to $S \cdot p_{\pi^+}$

vanishes

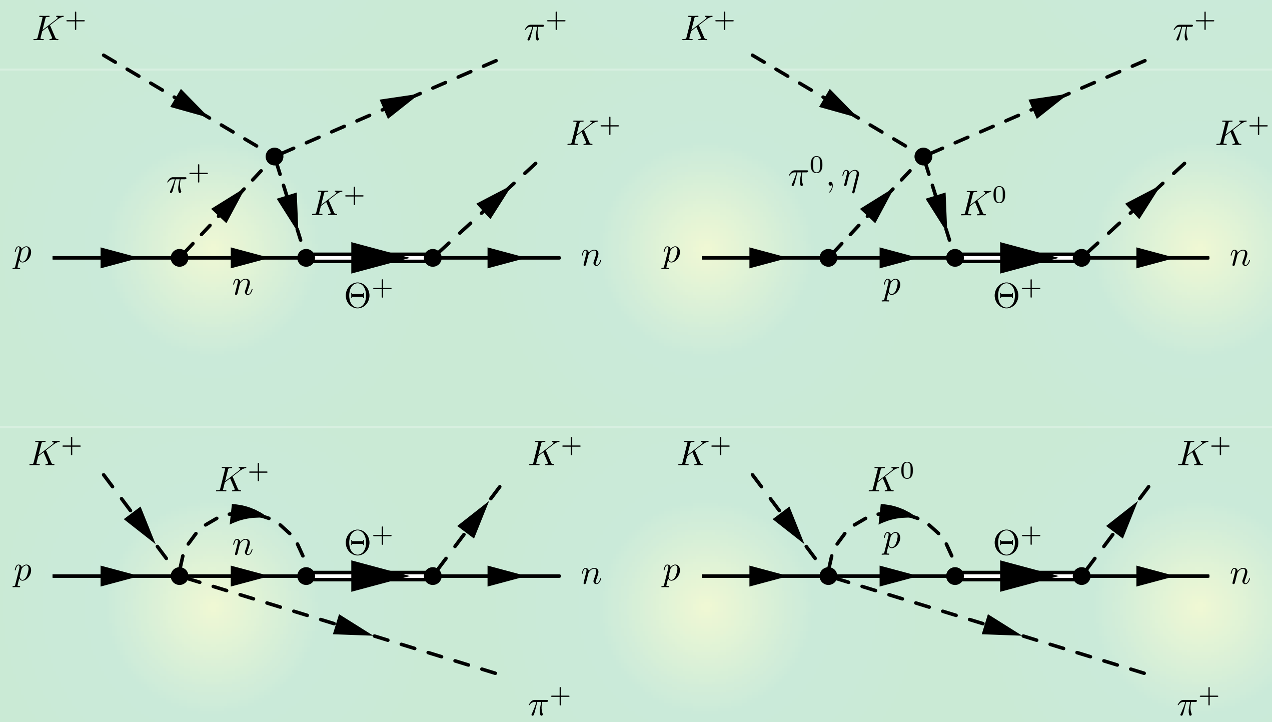
Assume the final π^+ is almost at rest

Chiral model for the reaction: Resonance term

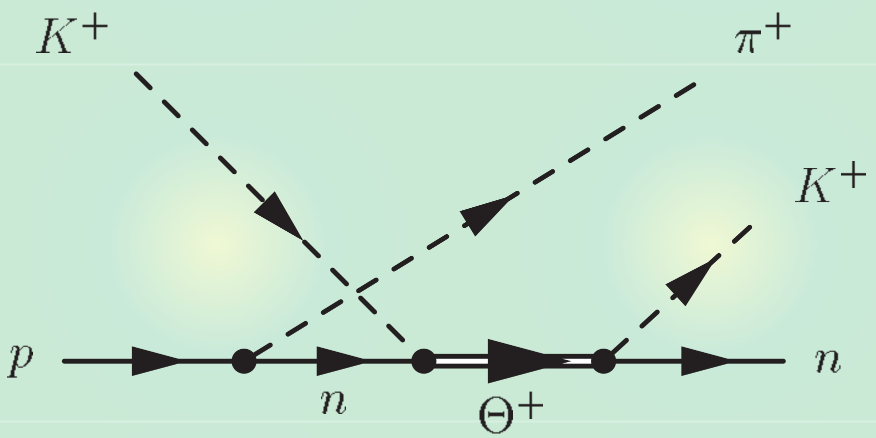
Background (tree level)



Resonance (one loop)



Chiral model for the reaction: Resonance term



Proportional to $\sigma \cdot p_{\pi^+}$ **-> vanishes**

Spin and parity : KN -> Θ -> KN

- M_R = 1540 MeV
- Γ_R = 20 MeV

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

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

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

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

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

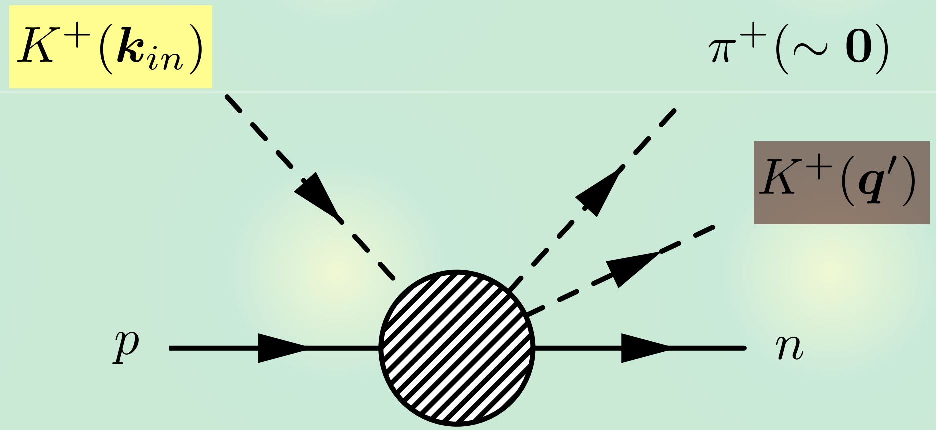
$$\boxed{g^2_{K^+n}} = \frac{\pi M_R \Gamma}{Mq}\,, \quad \boxed{\bar{g}^2_{K^+n}} = \frac{\pi M_R \Gamma}{Mq^3}\,, \quad \boxed{\tilde{g}^2_{K^+n}} = \frac{3\pi M_R \Gamma}{Mq^3}\,.$$

Resonance term for $K^+ p \to \pi^+ K^+ n$

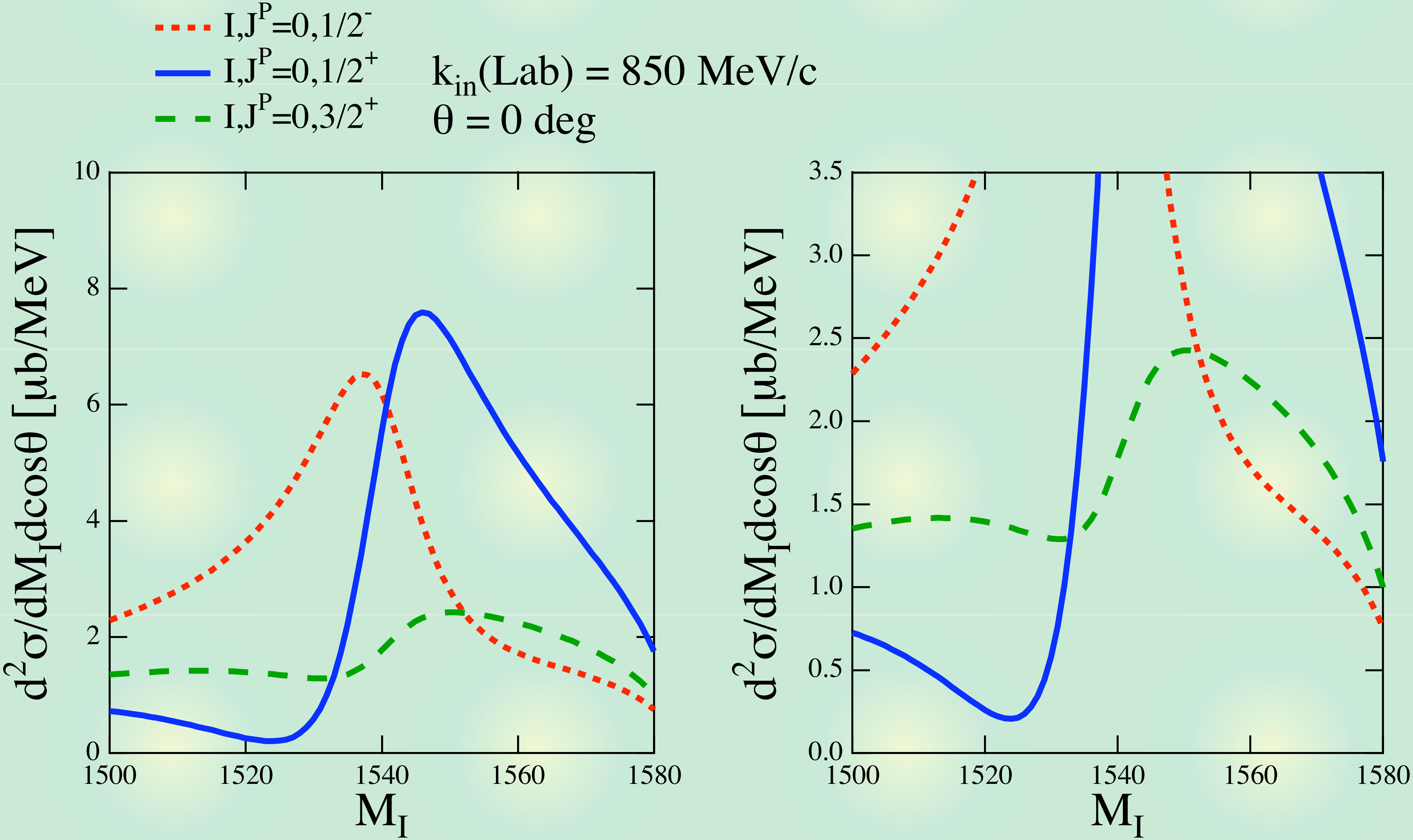
$$-i\tilde{t}_i^{(s)} = \frac{g_{K^+n}^2}{M_I - M_R + i\Gamma/2} \left\{ G(M_I)(a_i + c_i) - \frac{1}{3}\bar{G}(M_I) b_i \right\} \boldsymbol{\sigma} \cdot \boldsymbol{k}_{in} S_I(i)$$

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

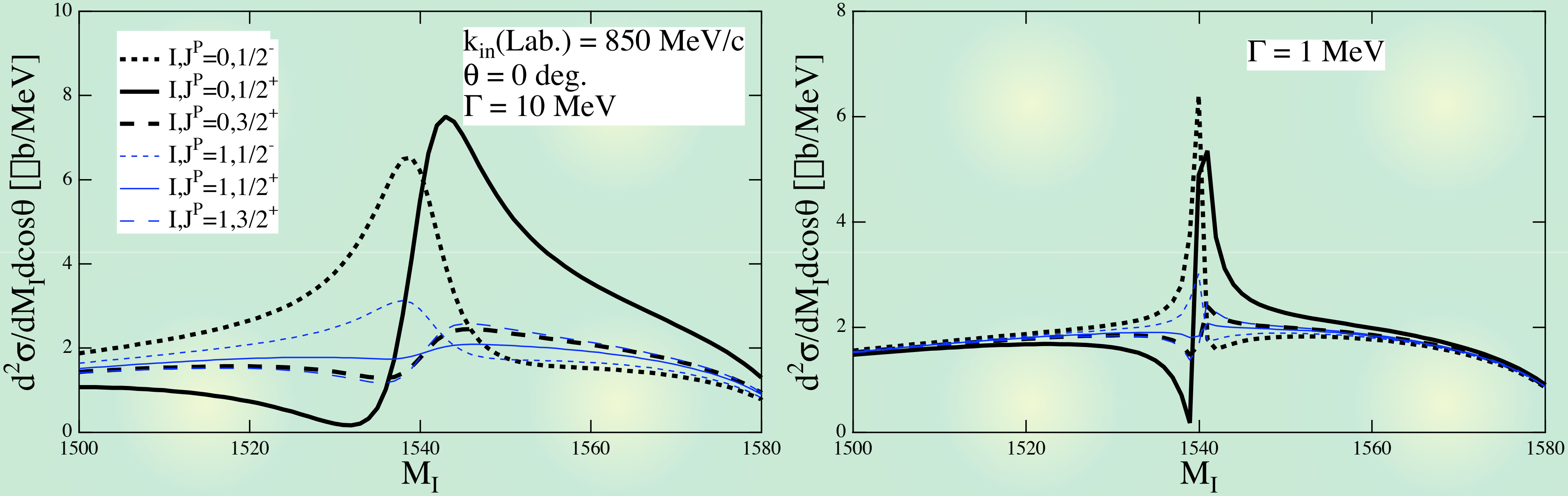
$$-i\tilde{t}_i^{(p,3/2)} = \frac{\tilde{g}_{K^+n}^2}{M_I - M_R + i\Gamma/2} \bar{G}(M_I) \frac{1}{3} b_i \left\{ (\boldsymbol{k}_{in} \cdot \boldsymbol{q}')(\boldsymbol{\sigma} \cdot \boldsymbol{k}_{in}) - \frac{1}{3} \boldsymbol{k}_{in}^2 \boldsymbol{\sigma} \cdot \boldsymbol{q}' \right\} S_I(i)$$



Numerical results : Mass distributions



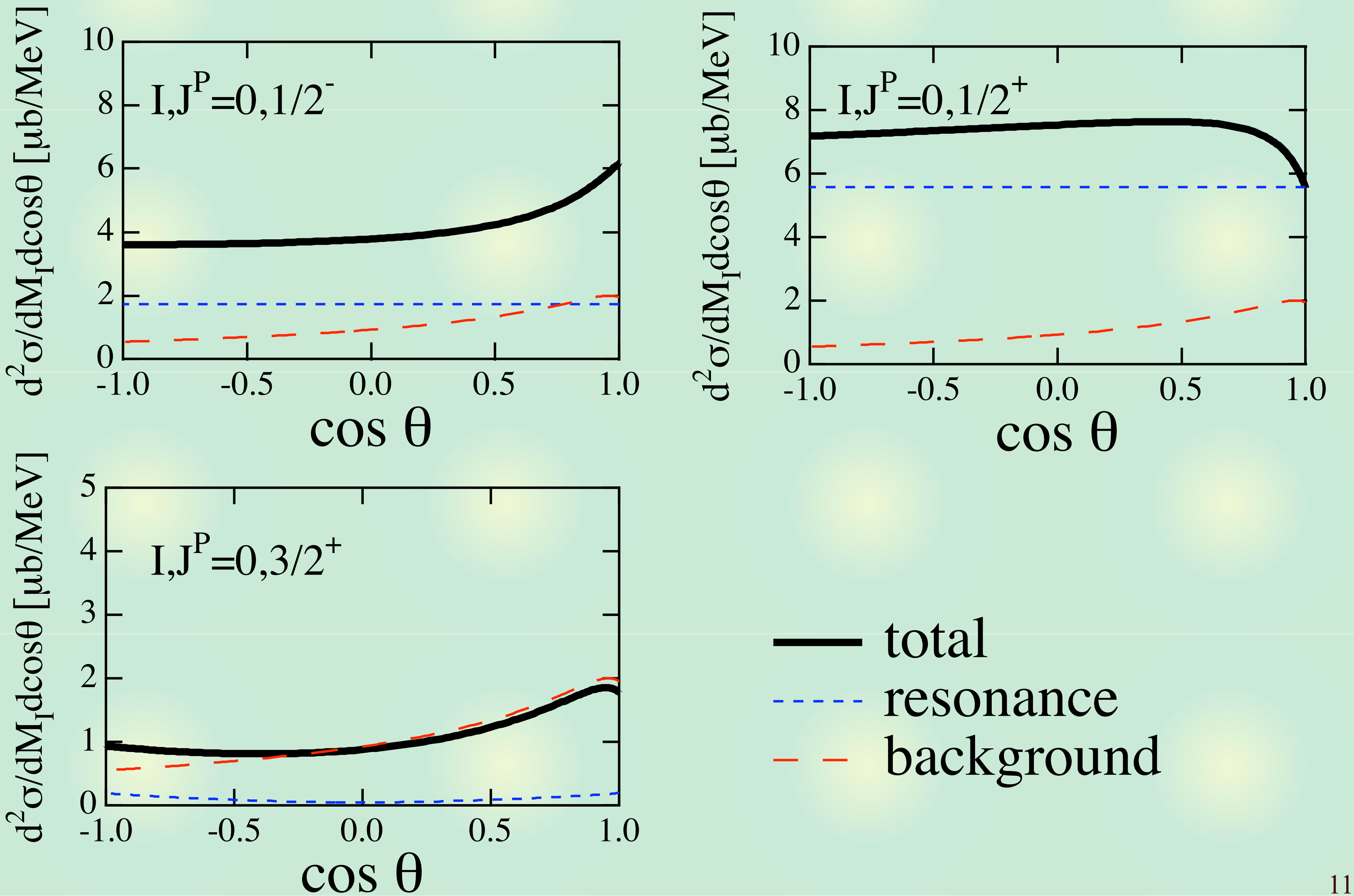
Numerical results : Mass distributions



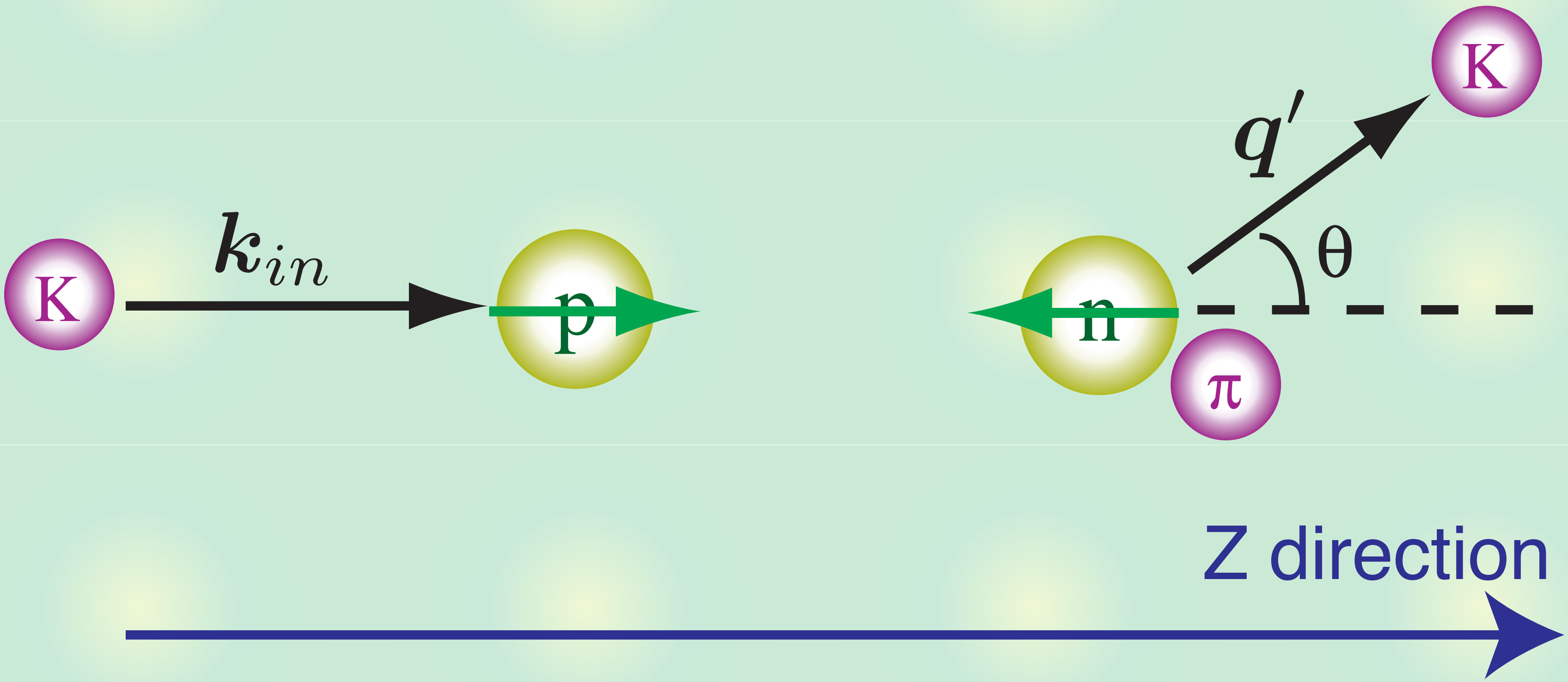
Deviation of the peak from B.W. mass
—> interference effect
size ~ width

Production 1 : $K^+ p \to \pi^+ K^+ n$

Numerical results : Angular dependence



Numerical results : Polarization test

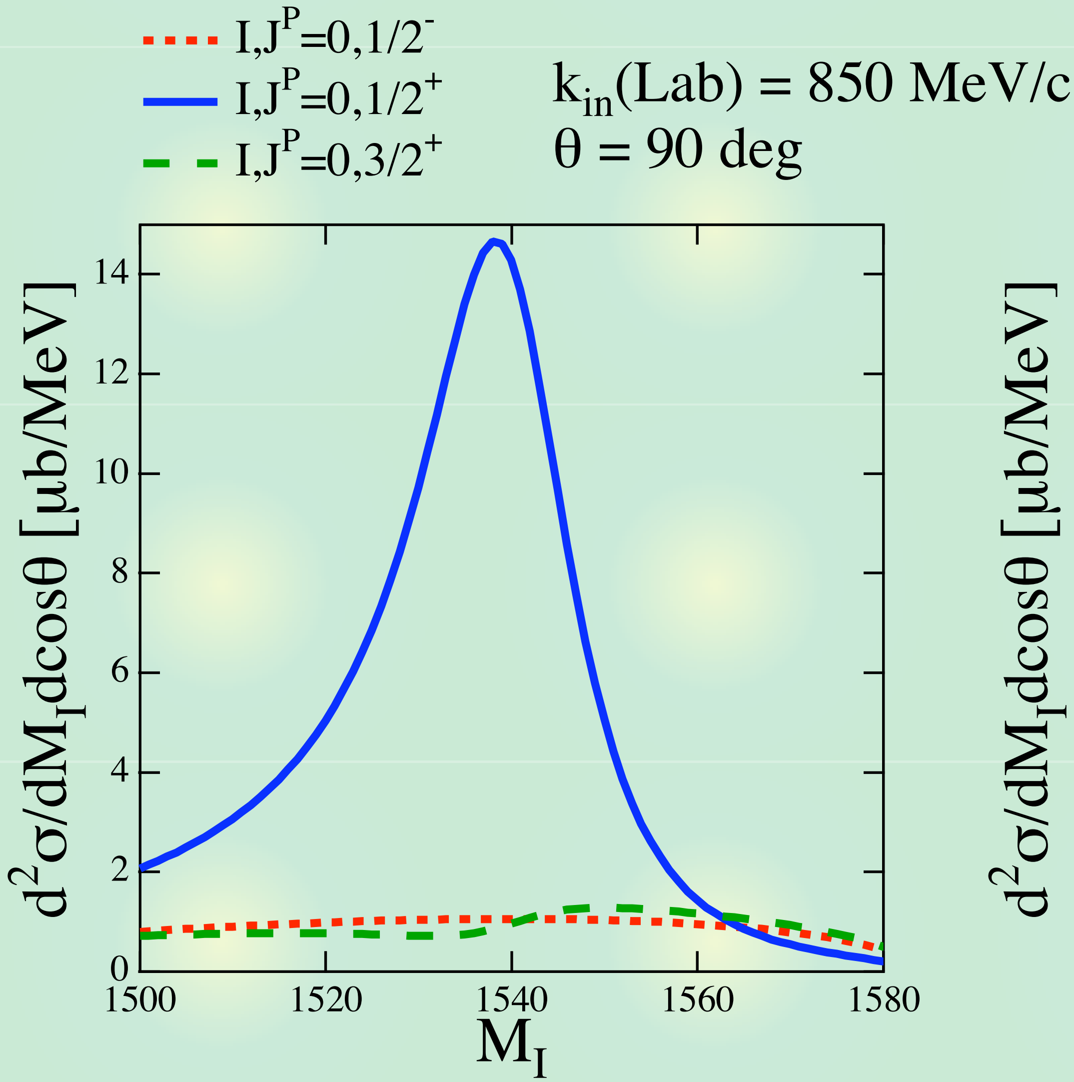


$$\langle -1/2|\boldsymbol{\sigma}\cdot\boldsymbol{k}_{in}|1/2\rangle = 0$$

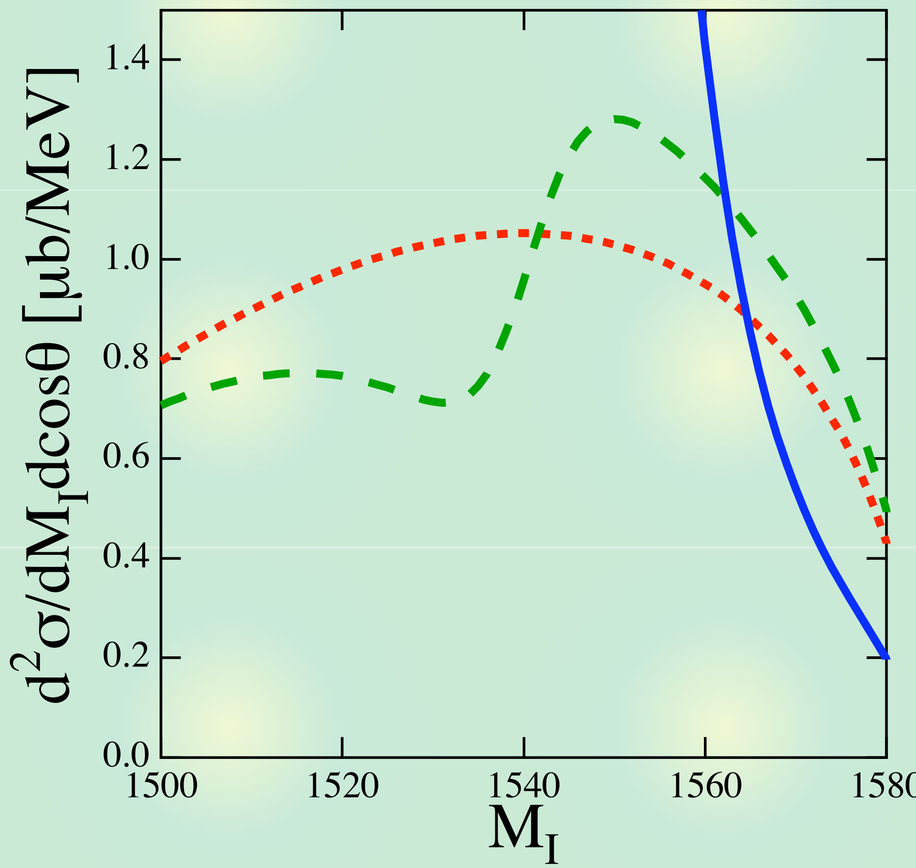
$$\langle -1/2|\boldsymbol{\sigma}\cdot\boldsymbol{q}'|1/2\rangle \propto q'\sin\theta$$

 # Same result is obtained for final pK^0

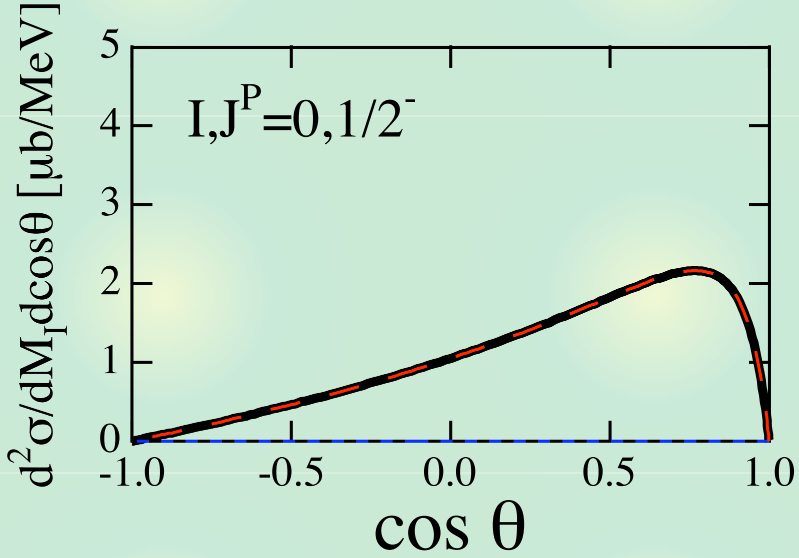
Numerical results : Mass distributions

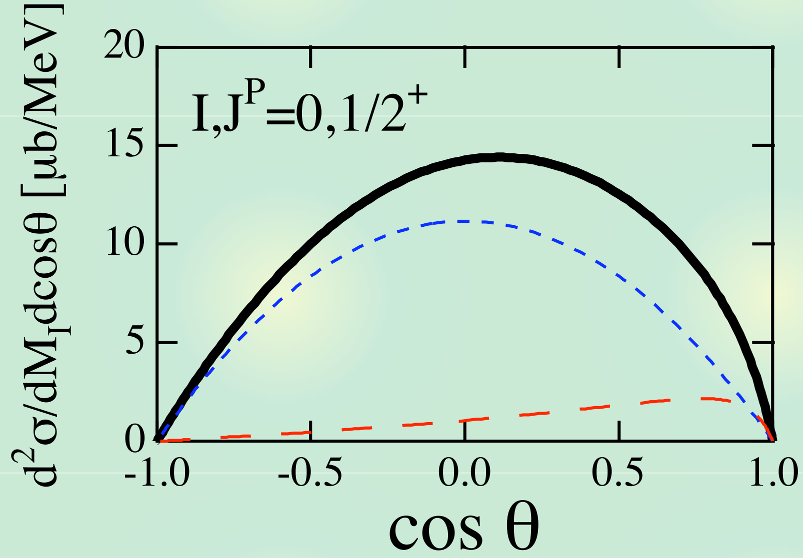


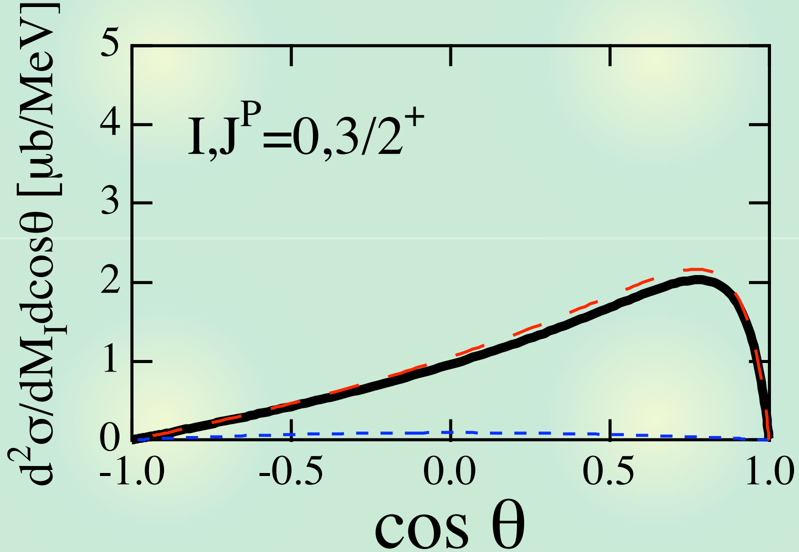
Polarization test

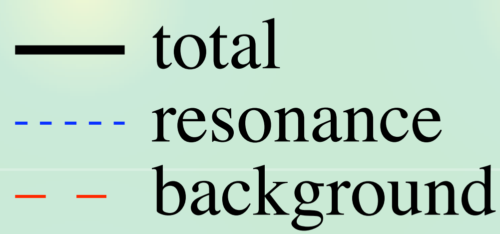


Numerical results : Angular dependence



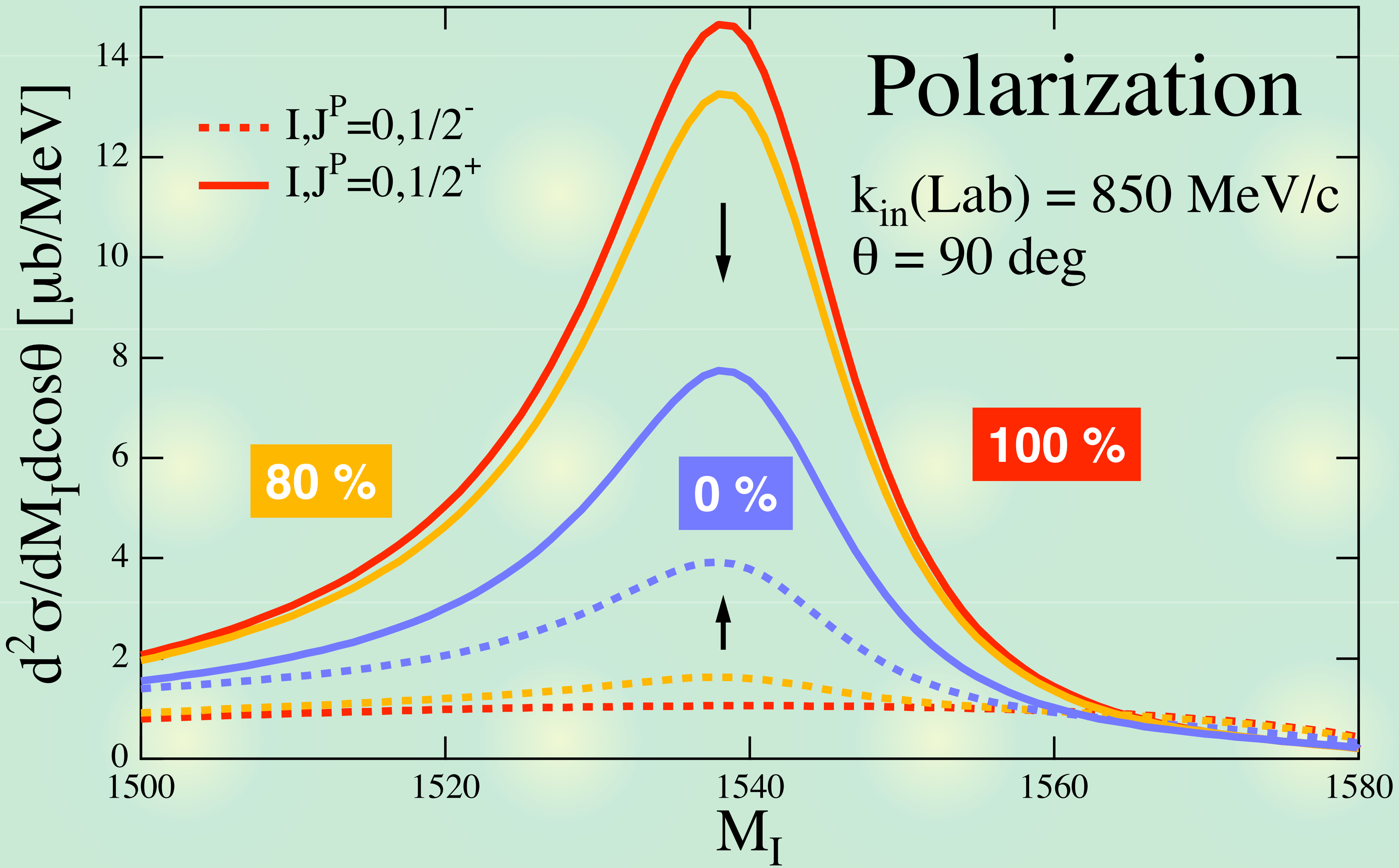






Polarization test

Numerical results : Incomplete polarization



Conclusion

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

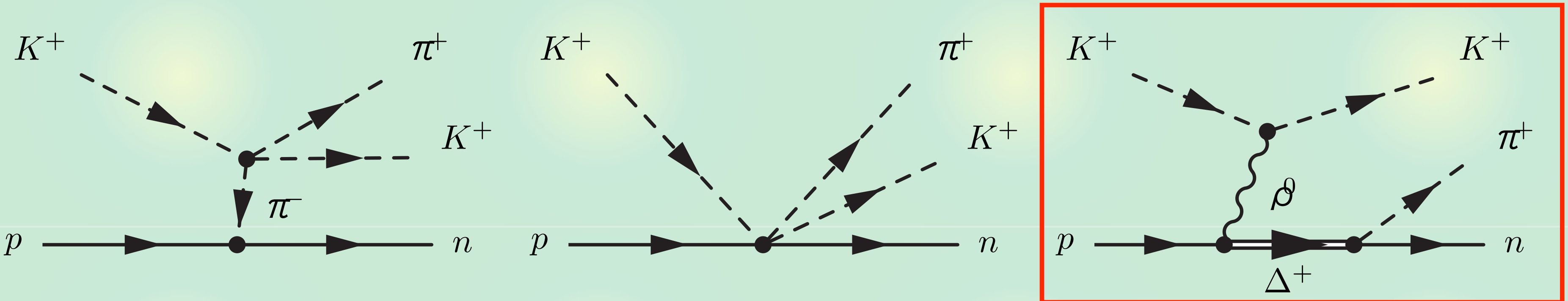
- **If we find the resonance in the polarization test, the quantum numbers of Θ^+ can be determined as $I=0$, $J^P=1/2^+$**

T. Hyodo, A. Hosaka, E. Oset, Phys. Lett. B579, 290 (2004)
T. Hyodo, Doctor Thesis (2006)

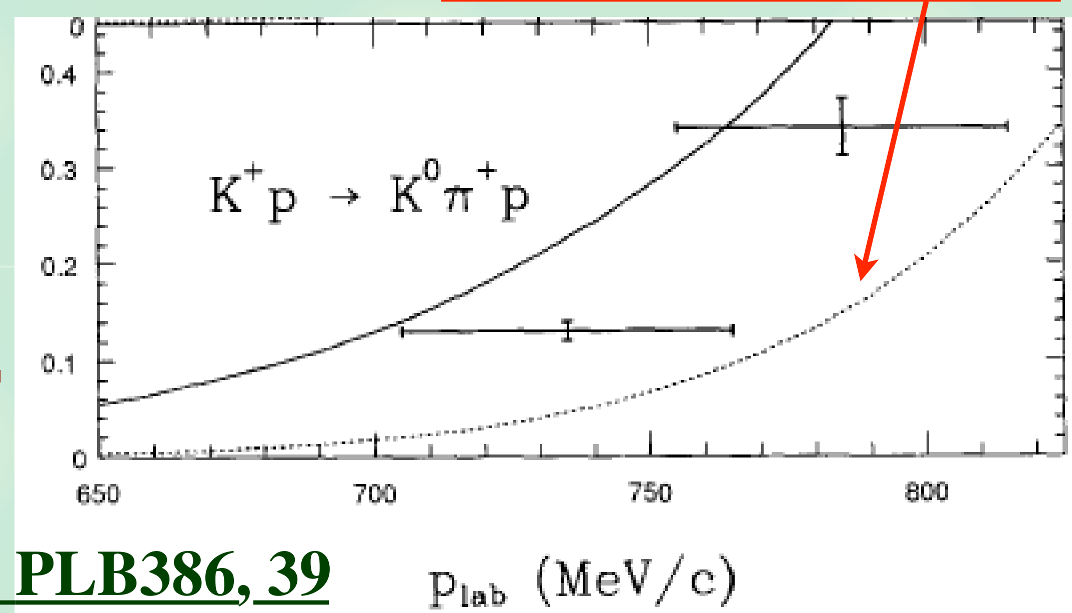
Problems & future work

Problems

- 0 momentum π
- polarization of final N



As energy of initial Kaon increases, Δ contribution becomes dominant.



<u>E. Oset, M. J. Vicente Vacas, PLB386, 39</u>