ペンタクォーク研究の最近の動向

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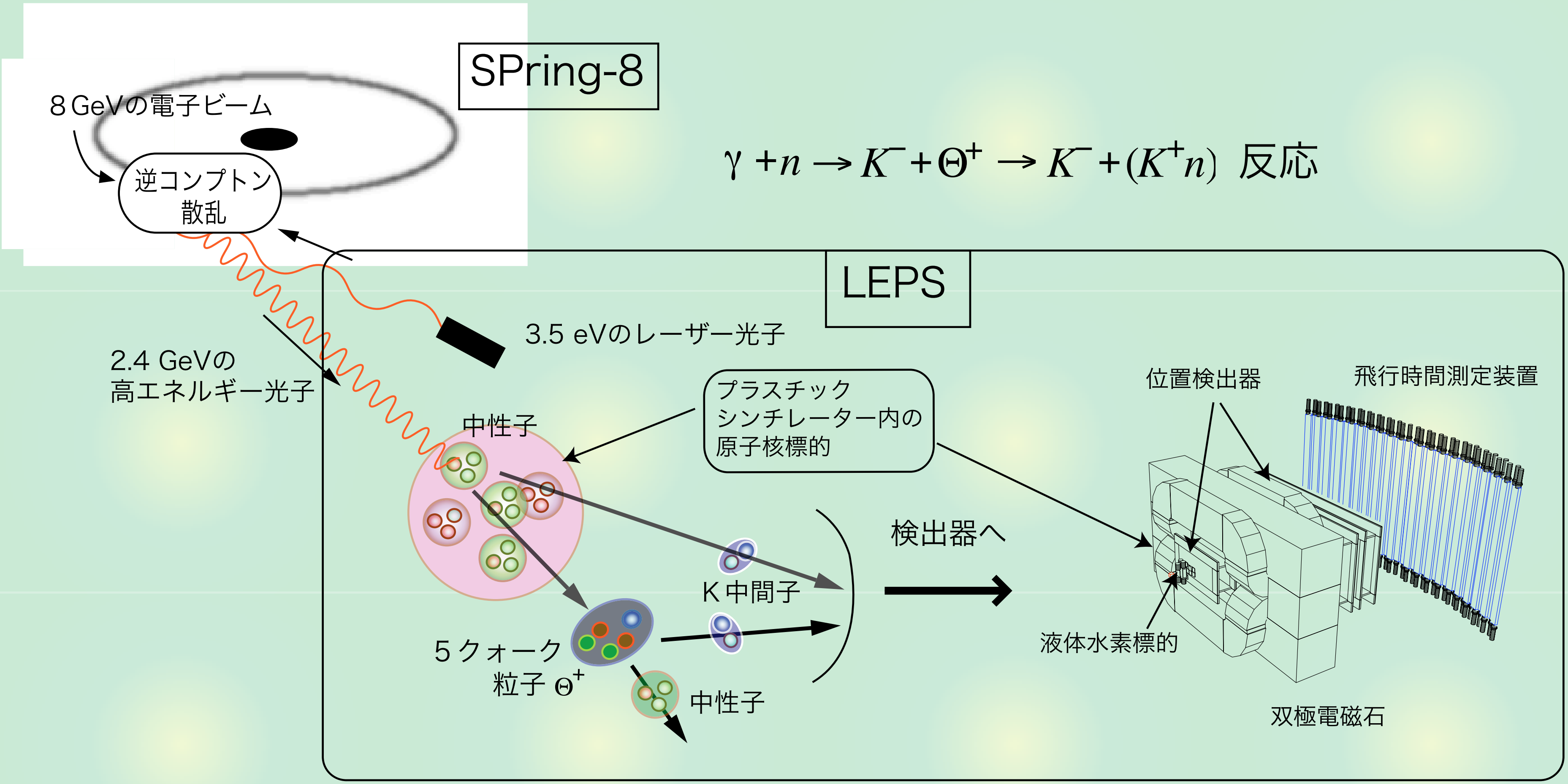
- ☆ Production $K^+p \to \pi^+K^+n$

Experiment at SPring-8

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

$\gamma + n \to K^- + \Theta^+ \to K^- + (K^+ n)$ 反応



実験のまとめ

Summary of experiments

group	reaction	mass[MeV]	width
LEPS	$\gamma n \to K^+K^-(n)$	1540 ± 10	< 25
DIANA	$K^+Xe \to K^0pXe'$	1539 ± 2	< 9
CLAS	$\gamma d \to K^+K^-p(n)$	1542 ± 5	< 21
SAPHIR	$\gamma p \to K^+K^0(n)$	1540 ± 6	< 25
ITEP	$\nu A \to K^0pX$	1533 ± 5	< 20
CLAS	$\gamma p \to \pi^+K^-K^+(n)$	1555 ± 10	< 26
HERMES	e^+(27.6GeV)$d \to K^0pX$	1528 ± 3	13 ± 9
SVD	p(70GeV)$A \to K^0pX$	1526 ± 3	< 24
BES	$e^+e^- \to J/\Psi \to KN\bar{K}\bar{N}$	-	-
COSY	$pp \to K^0p\Sigma^+$	1530 ± 5	< 18
HERA-B	p(920GeV)$A \to K^0pX$	-	-
JINR	p(10GeV)$A \to K^0pX$	1545 ± 12	16 ± 4
ZEUS	e^+p(cm300GeV) $\to e'K^0pX$	1522 ± 3	8 ± 4
JINR	$np \to npK^+K^-$	??	??

Old experiments

実験データ（KN散乱）

R.A. Arndt, Phys. Rev. D31, 2230 (1985)
J.S. Hyslop, Phys. Rev. D46, 961 (1992)

Z* resonances

mass[MeV]	width[MeV]	wave
1788	340	D03
1811	236	P13
1831	190	P01
2074	503	D15

参考： B.K. Jennings, Phys. Rev. D69, 094020 (2004)

Analyses of data 1

過去のデータの再解析１：幅について

S. Nussinov, hep-ph/0307357

断面積の評価、Γ < 6 MeV

R. A. Arndt, *et al.*, Phys. Rev. C68, 042201 (2003),
Erratum, *ibid.* C69, 019901 (2004)

KN散乱解析、Γ < few MeV

J. Haidenbauer, *et al.*, Phys. Rev. C68, 052201 (2003)

部分波解析、Γ < 5 MeV

R.N. Cahn, *et al.*, Phys. Rev. C69, 011501 (2004)

Γ < 1-4 MeV (K^+d data), Γ = 0.9 ± 0.3 MeV (DIANA)

A. Sibirtsev, *et al.*, hep-ph/0405099

$K^+d \rightarrow K^0pp$、Γ < 1 MeV

Analyses of data 2

過去のデータの再解析２：Θの存在？

N.G. Kelkar, *et al.*, J. Phys. G29, 1001 (2003)

Speed plot, Time delay

N.G. Kelkar, *et al.*, hep-ph/0405008

Speed plot, Time delay

M=1545 MeV for P01, M=1600 MeV for D03

M=1600 MeV for P03

W.R. Gibbs, nucl-th/0405024

K^+d total cross section

1/2+ : M = 1559 ± 3 MeV , Γ = 0.9 ± 0.2 MeV

1/2- : M = 1547 ± 2 MeV , Γ = 0.9 ± 0.2 MeV

Artifact?

A. R. Dzierba, *et al.*, Phys. Rev. C 68, 052201 (2003)

M. Zavertyaev, hep-ph/0311250

kinematic reflections of $f_2(1275)$, $a_2(1320)$

Other pentaquarks

$\Xi^{--}(dds s\bar{u})$

NA49, C. Alt, *et al.*, Phys. Rev. Lett. 92, 042003 (2004)

M = 1862 ± 2 MeV, Γ = 18 MeV

negative results

H.G. Fischer, *et al.*, hep-ex/0401014

HERA-B, K.T. Knopfle, *et al.*, hep-ex/0403020

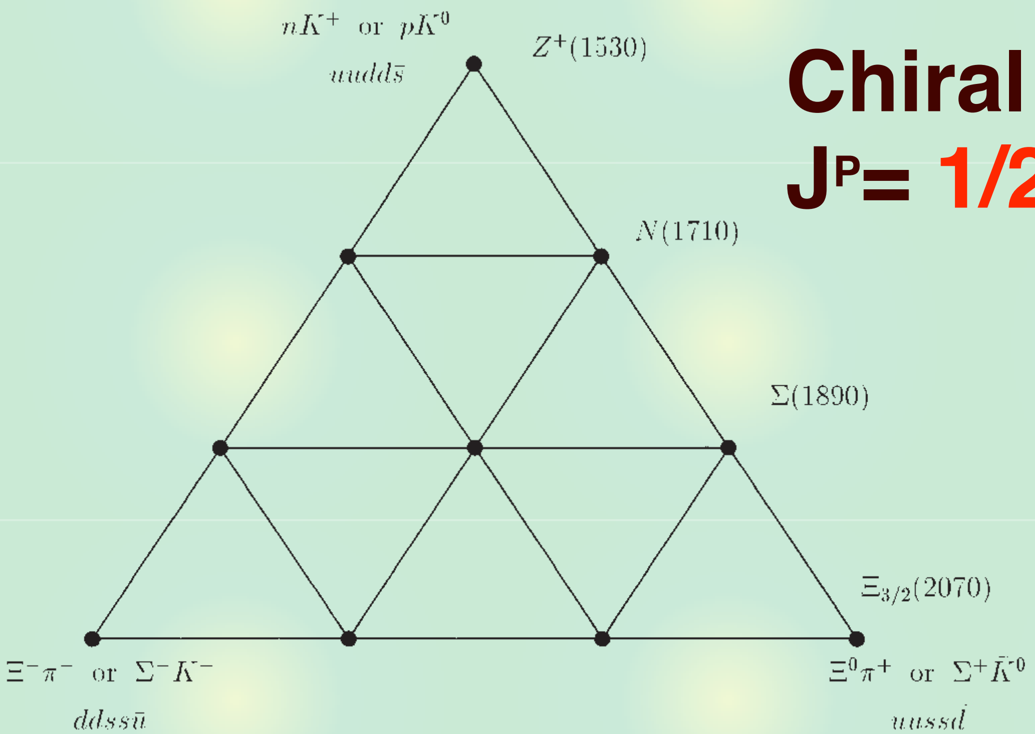
WA89, M.I. Adamovich, *et al.*, hep-ex/0405042

$\Theta_c(uudd\bar{c})$

H1, A. Aktas, *et al.*, Phys. Lett. B 588, 17-28 (2004)

M = 3099 ± 3 MeV, Γ = 12 ± 3 MeV

Diakonov et al., prediction



Chiral quark soliton model

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

	T	Y	Mass in MeV	Width in MeV	Possible candidate
Z^+	0	2	1530	15	—
$N_{\overline{10}}$	1/2	1	1710 (input)	~ 40	$N(1710)P_{11}$
$\Sigma_{\overline{10}}$	1	0	1890	~ 70	$\Sigma(1880)P_{11}$
$\Xi_{3/2}$	3/2	−1	2070	> 140	$\Xi(2030)$?

D. Diakonov, *et al.*, Z. Phys. A 359, 305 (1997)

Diakonov et al.について

Criticism & Discussion

理論的側面（rigid rotator, large Nc,...）

T.D. Cohen, Phys. Lett. B 581, 175-181 (2004)

D. Diakonov, *et al.*, Phys. Rev. D 69, 056002 (2004)

N. Itzhaki, *et al.*, Nucl. Phys. B 684, 264 (2004)

P. Pobylitsa, Phys. Rev. D 69, 074029 (2004)

M. Praszalowicz, Phys. Lett. B 583, 96 (2004)

現象論的側面（πN Sigma term,...）

P. Schweitzer, hep-ph/0312376

J. Ellis, *et al.*, JHEP 0405, 002 (2004)

崩壊幅の計算について？

H. Weigel, Eur. Phys. J. A2, 391 (1998) $\Gamma \sim 40$ MeV !

R.L. Jaffe, hep-ph/0401187 $\Gamma < 30$ MeV !

D. Diakonov, *et al.*, hep-ph/0404212 $\Gamma < 15$ MeV !!

R.L. Jaffe, hep-ph/0405268 $\Gamma < 30$ MeV !!!

Diakonov 以前の研究

クォーク模型

E. Golowich, Phys. Rev. D4, 262 (1971)

Z(1700), 1/2+

D. Strottman, Phys. Rev. D20, 748 (1979)

Z(1650), 1/2-

H.J. Lipkin, Phys. Lett. B195, 484 (1987)

$suud\bar{c}$

スキルム模型

A.V. Manohar, Nucl. Phys. B248, 19 (1984)

M. Chemtob, Nucl. Phys. B256, 600 (1985)

$J=1/2$, $\overline{10}$

M. Praszalowicz, *Skyrmions and Anomalies*, World Scientific (1987)

$J=1/2$, $I=0$, $Y=2$, $\overline{10}$: 1540 MeV

QCD sum rule

S.L. Zhu, Phys. Rev. Lett. 91, 232002 (2003)

I=0,1,2 $\Theta(uudd\bar{s})$~1550 ± 150

R.D. Matheus, *et al.*, Phys. Lett. B 578, 323-329 (2004)

$\Theta(uudd\bar{s})$~1550 ± 100, $N(uudd\bar{u})$~1440

J. Sugiyama, *et al.*, Phys. Lett. B 581, 167-174 (2004)

Parity projection $J^P = 1/2^-$

Eidemuller, hep-ph/0404126

$\Theta(uudd\bar{s})$~1540, $N(uudd\bar{u})$~1440

Hungchong Kim, *et al.*, hep-ph/0404170

$\Theta_c(uudd\bar{c})$ $J^P = 1/2^+$

Y. Kondo. *et al.*, hep-ph/0404285

Two-hadron-irreducible sum rule $J^P = 1/2^+$

Lattice QCD

F. Csikor, *et al.*, JHEP 0311, 070 (2003)

quench, Wilson fermion

Θ

$J^P = 1/2^-$

S. Sasaki, hep-lat/0310014

quench, Wilson fermion

Θ, Θ_c > DN threshold

$J^P = 1/2^-$

Ting-Wai Chiu, *et al.*, hep-ph/0403020, hep-ph/0404007

quench, Domain-wall fermion (chiral OK)

$N_5 \sim 1460$, $\Theta \sim 1539$, $\Xi_5 \sim 1826$, $\Theta_c \sim 3180$

$J^P = 1/2^+$

その他、最近の研究

Super-Radiance

N. Auerbach, *et al.*, Phys. Lett. B590, 45-50 (2004)

V. Zelevinsky, *et al.*, hep-ph/0406019

Diamond structure(non-planer)

Xing-Chang Song, *et al.*, hep-ph/0403093

AMD

Y. Kanada-En'yo, *et al.*, hep-ph/0404144

bound state approach with HLS

Byung-Yoon Park, *et al.*, hep-ph/0405246

AdS/CFT

M. Bando, *et al.*, hep-ph/0405259

Motivation : Advantage of hadronic process

We propose

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

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

to extract a qualitative behavior which depends on the quantum numbers of Θ^+.

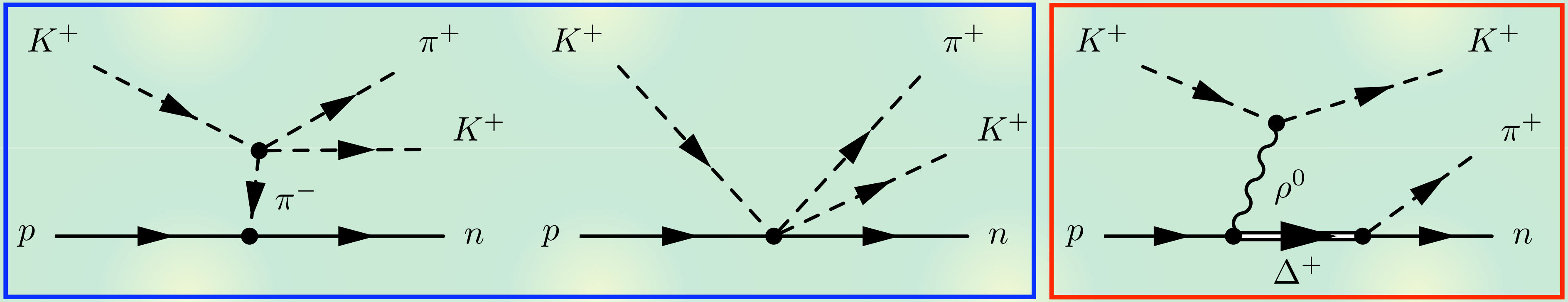
⬇

Determination of quantum numbers

Chiral model for the reaction: Background

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

Vertices <- chiral Lagrangian



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

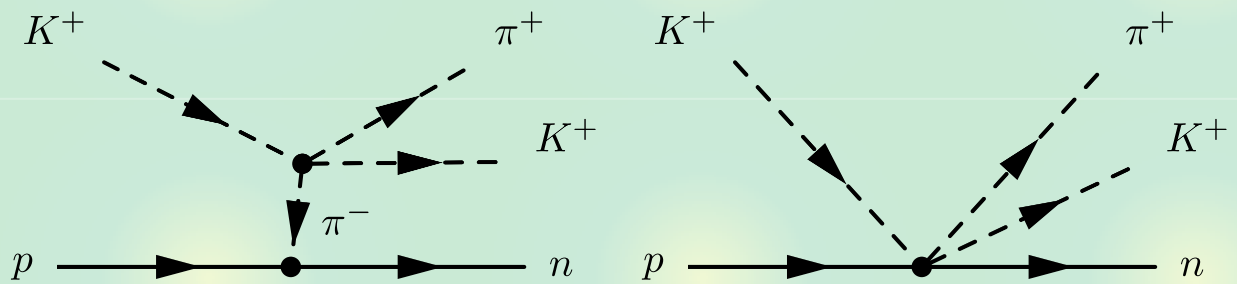
Dominant

vanishes

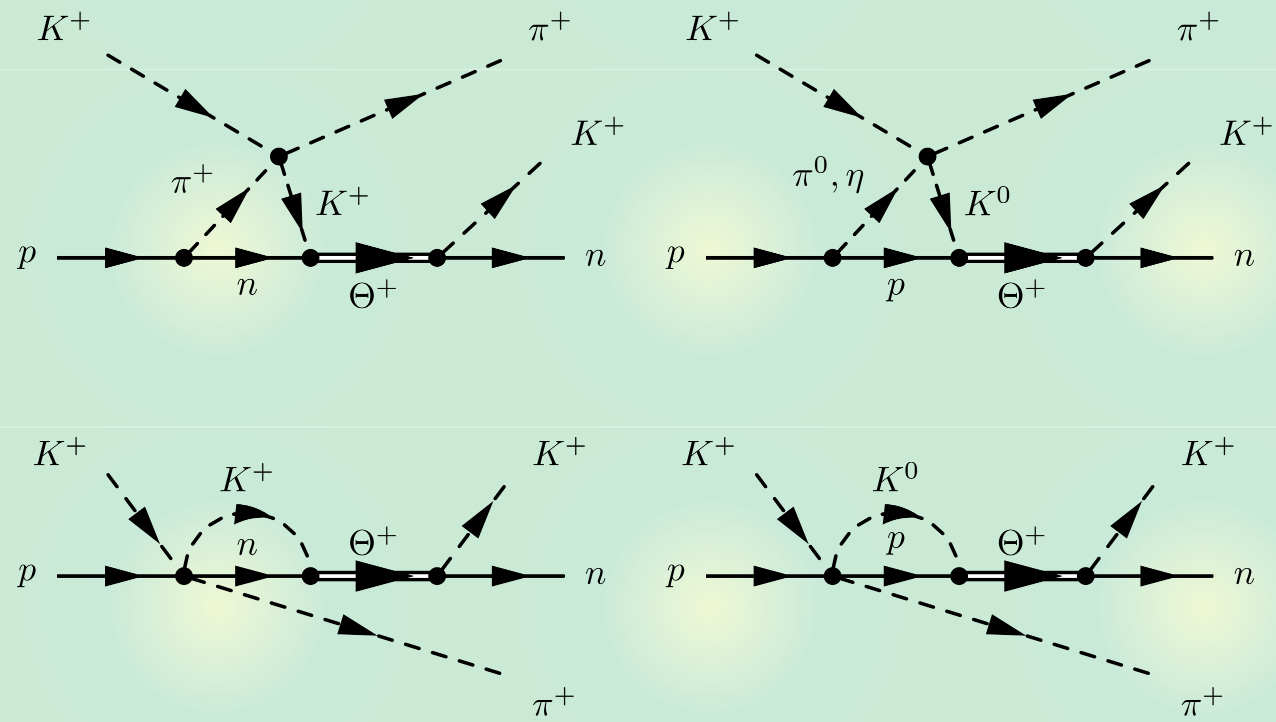
Assume the final π⁺ is almost at rest

Chiral model for the reaction: Resonance term

Background (tree level)



Resonance (one loop)



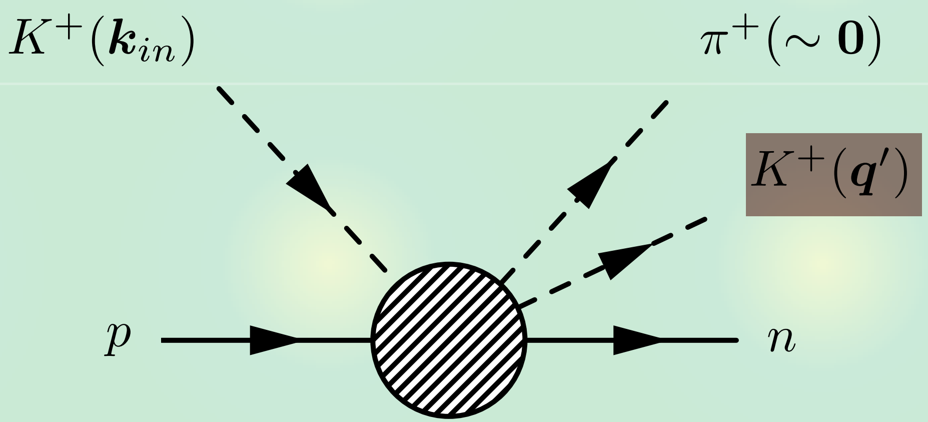
Spin and parity : Resonance amplitude

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

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

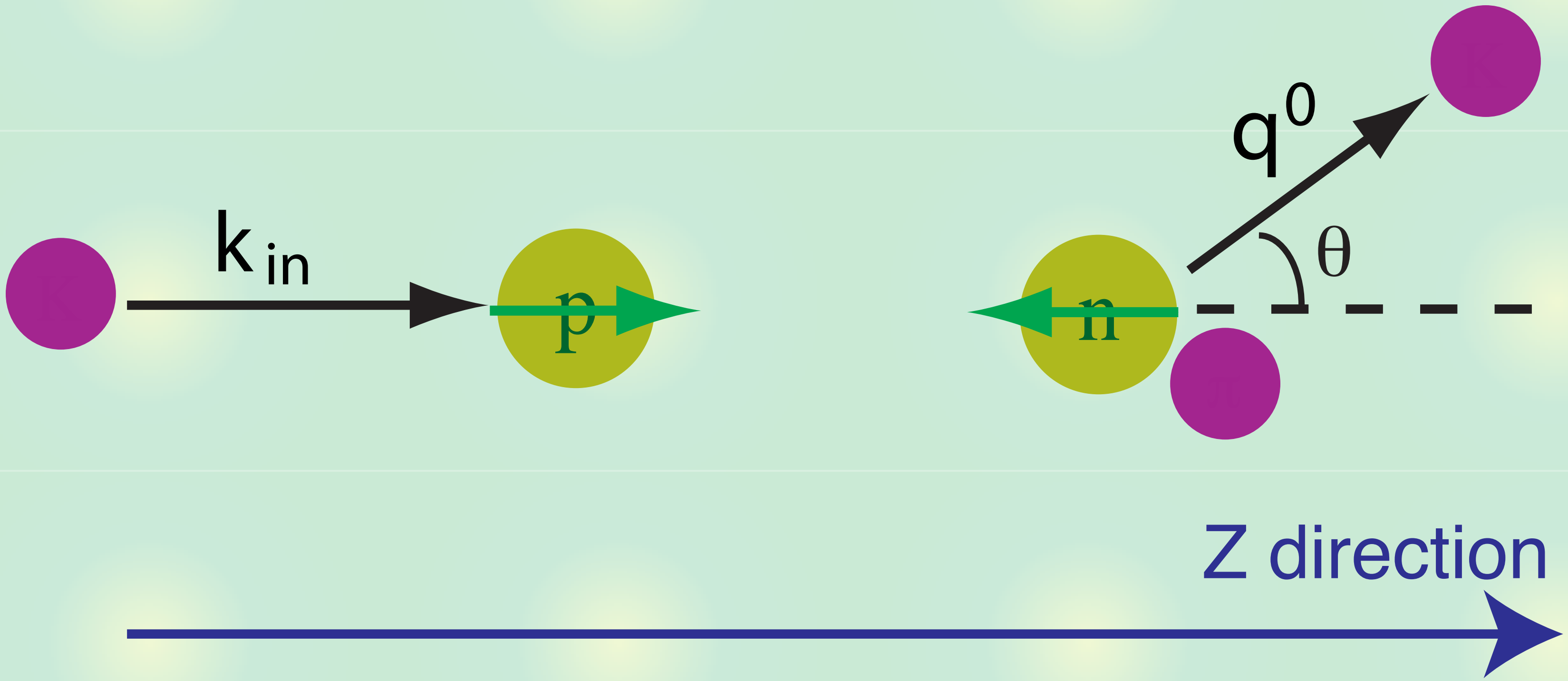
$$-i\tilde{t}_i^{(p,1/2)} = \frac{\bar{g}_{K^+n}^2}{M_I - M_R + i\Gamma/2}\bar{G}(M_I)\left\{\frac{1}{3}b_i\boldsymbol{k}_{in}^2 - a_i + d_i\right\}\boldsymbol{\sigma}\cdot\boldsymbol{q}'S_I(i)\ ,$$

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



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

Numerical results : Polarization test



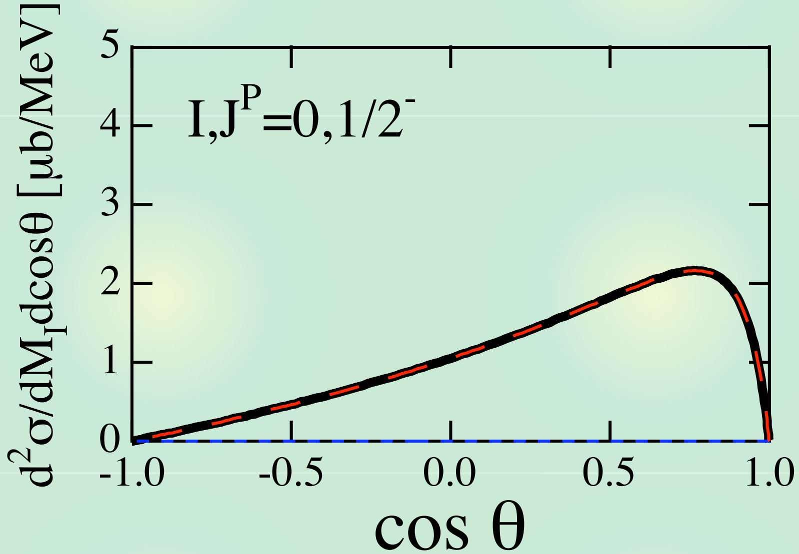
$$\langle -1/2 | \boldsymbol{\sigma} \cdot \boldsymbol{k}_{in} | 1/2 \rangle = 0$$

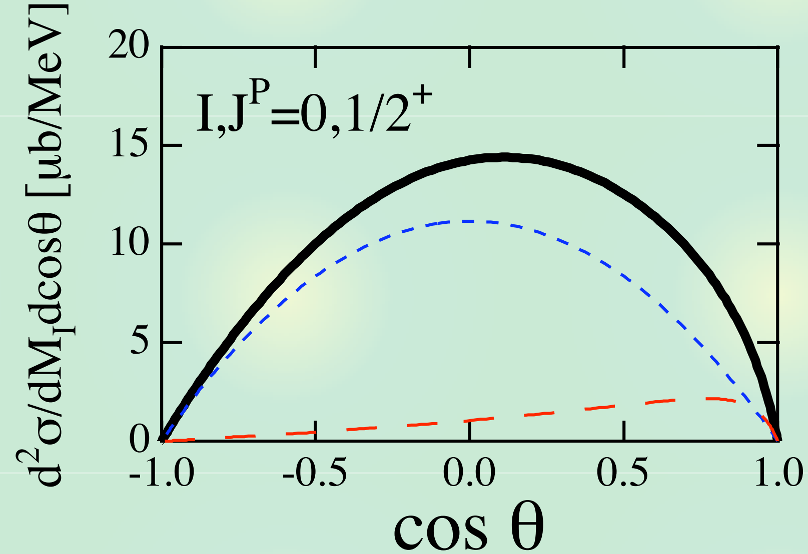
$$\langle -1/2 | \boldsymbol{\sigma} \cdot \boldsymbol{q}' | 1/2 \rangle \propto q' \sin\theta$$

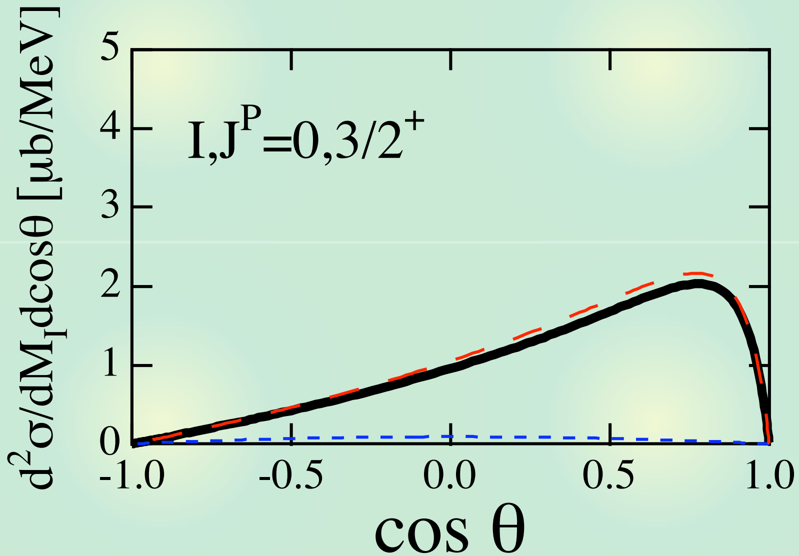
 # Same result is obtained for final pK^0

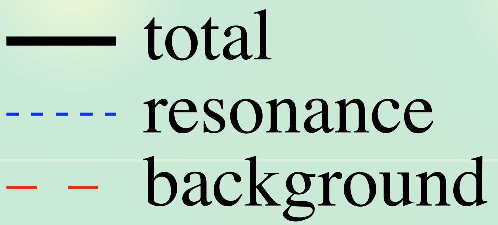
Production $K^+p \to \pi^+K^+n$

Numerical results : Angular dependence 2



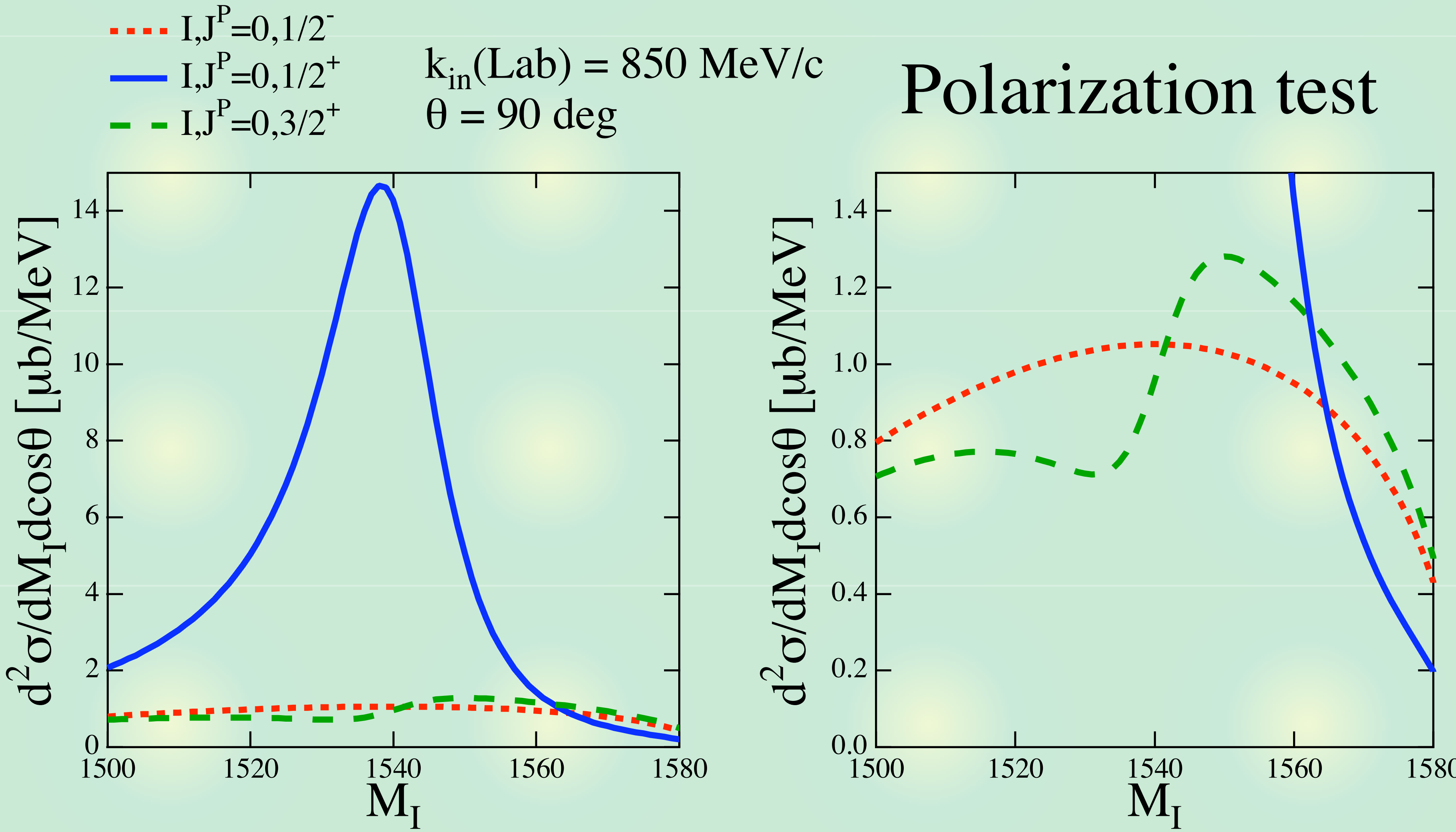






Polarization test

Numerical results : Mass distributions 2



Conclusion

We calculate the $K^+p \to \pi^+K^+n$ reaction using a chiral model, assuming 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, *et al.*, Phys. Lett. B579, 290-298 (2004)
E. Oset, *et al.*, nucl-th/0312014, Hyp03 proceedings

問題点と展望

問題点

- 0 momentum π <- 実験では不可能
- polarization of final N <- nは不可能

展望

- finite momentum π の計算（進行中）
- Bohrの定理？

In parity conserving process on one plane,

$$P_i e^{i\pi S_{i\mathbf{n}}} = P_f e^{i\pi S_{f\mathbf{n}}}$$

$$\Delta S_{\mathbf{n}} = \begin{pmatrix} \text{even} \\ \text{odd} \end{pmatrix} \text{ for } P_f = \pm P_i$$

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

Bohrの定理

$$\Delta S_{\mathbf{n}} = \begin{pmatrix} \text{even} \\ \text{odd} \end{pmatrix} \text{ for } P_f = \pm P_i$$