Chiral Quark Approach for Θ^+ and its production

Feb. 17-19 (2004) Kyoto, Atsushi Hosaka (RCNP, Osaka Univ)

Manifestly the first **EXOTIC** state of $qqqq\bar{q}$

Toward multi-quark matter

Relatively small mass
Unexpectedly narrow width
Parity unknown

Contents

- **Theories**

  Quark model, Chiral soliton, Diquark

  Chiral bag, Lattice, Sum rule, . . .

  Parity, decay width

- **Productions**

  To know **parity**

Theoretical papers

About 100 have appeared

Theory prediction

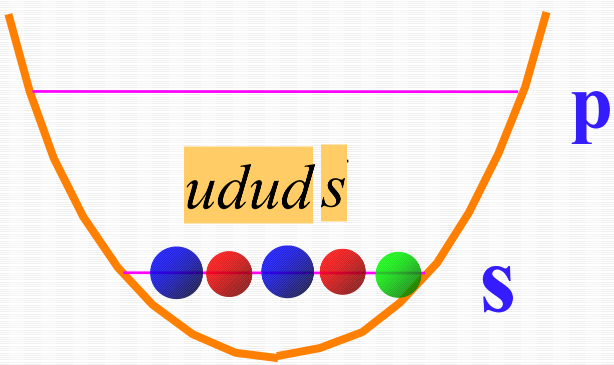
D. Diakonov *et al.* (chiral quark soliton)	: $1/2^+$, I=0
Naive quark model	: $1/2^-$
S. Capstick *et al.* (isotensor formulation)	: $1/2^-$, $3/2^-$, $5/2^-$, I=2
Fl. Stancu, D.O. Riska (qq with π int.)	: $1/2^+$
A. Hosaka (chiral potential)	: $1/2^+$ (strong π)
R. L. Jaffe *et al.* (qq-qq-q : 10 + 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)	: $1/2^-$

Naïve quark model Negative

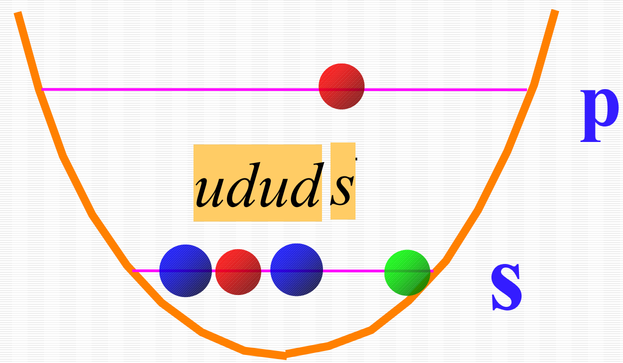
Diquark vs. **Chiral~strong π** Positive

Parity in theoretical models

Naïve quark model



<< (mass)



$s^4\bar{s}$

Negative

$ps^3\bar{s}$

Positive

What makes the p state lower?

Diquark correlations

Jaffe-Wilczek

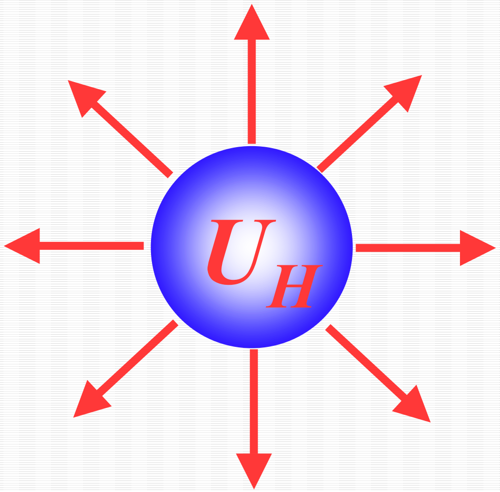
Chiral interaction, especially
hedgehog structure?

Chiral soliton

Large-N_c QCD

Diakonov et al,
Z. Phys. A359 (1997) 305

Baryons ~ solitons (Hartree qq…q)
Θ~ SU(3) **rotational band** of
the hedgehog Skyrmion



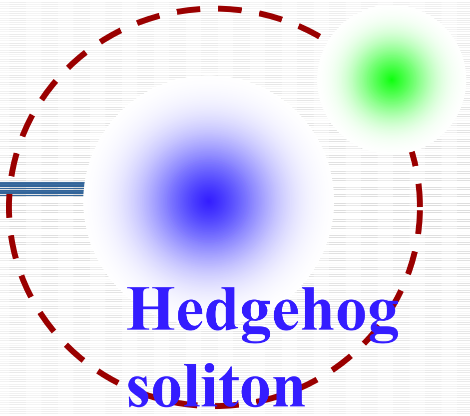
$\pi_{\text{isospin}} \sim r_{\text{radial}}$

$A(t) U_H A(t)^\dagger$

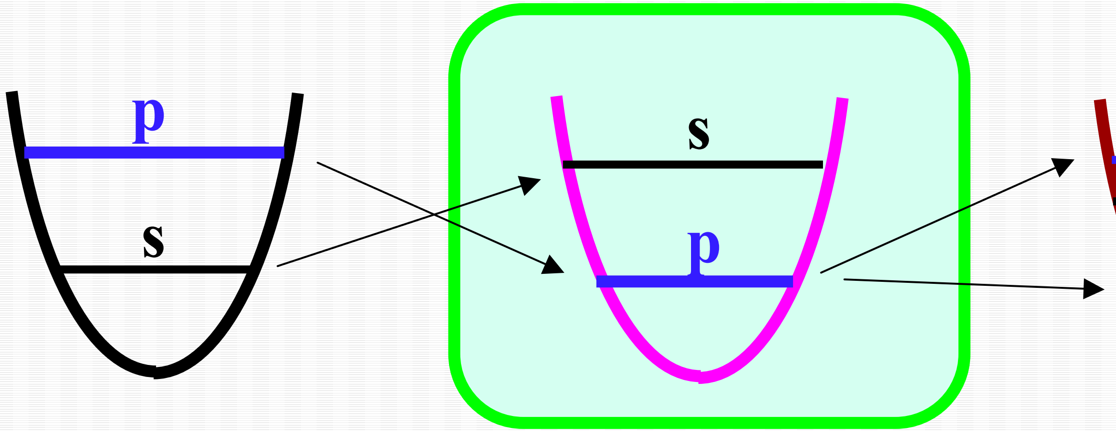
$\longrightarrow$ $J^P = 1/2^+$

Cranking ~ rigid rotation

Bound state approach of the Skyrmion



Callan-Klebanov



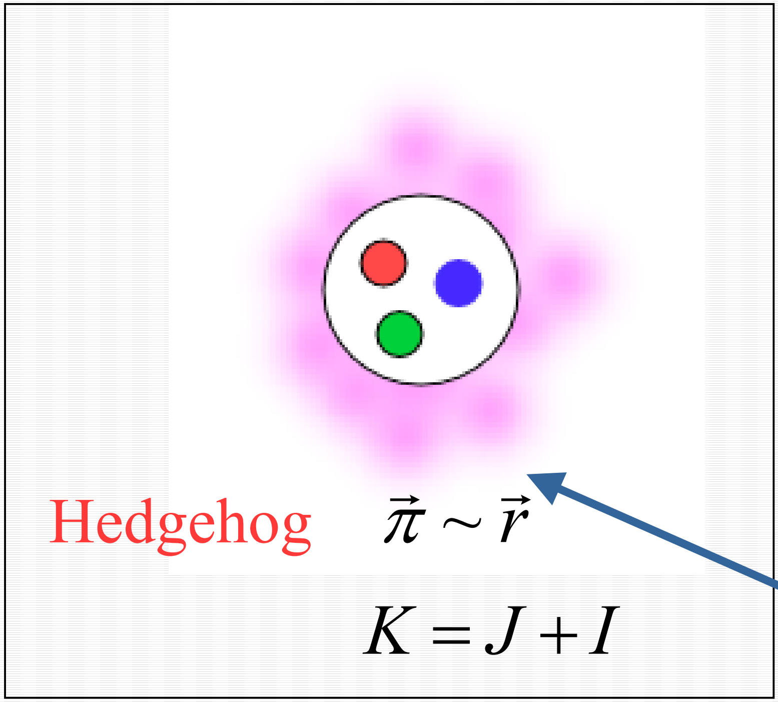
Hedgehog Kaon interaction

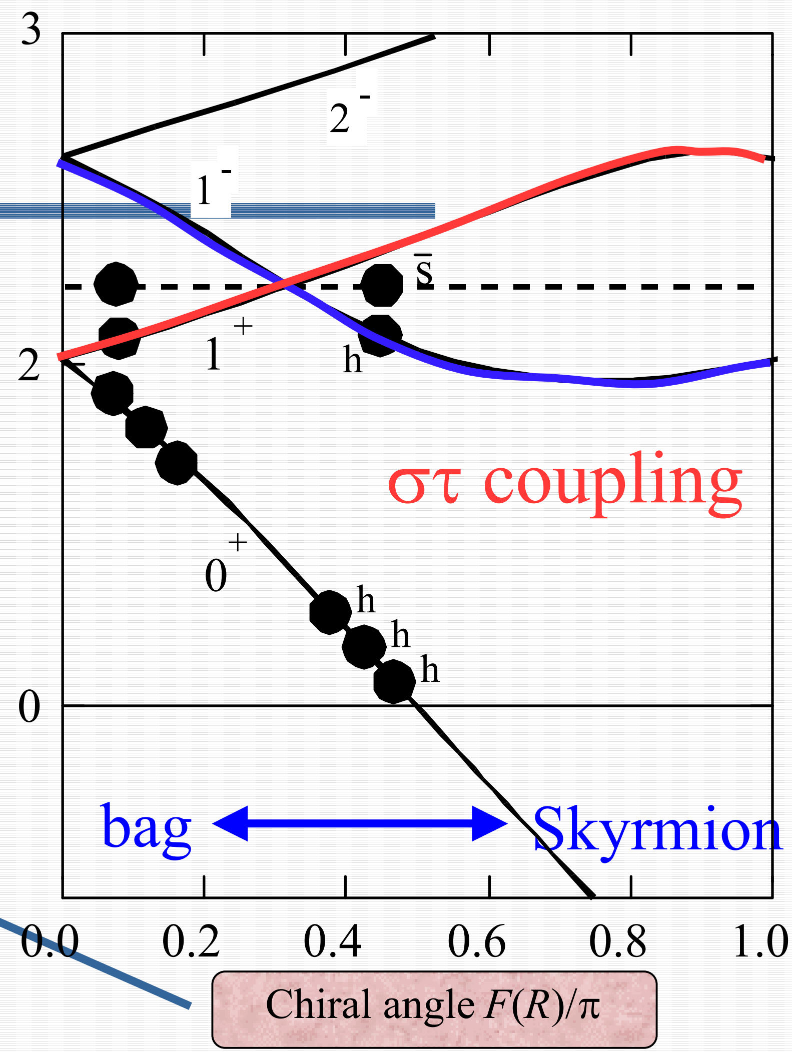
WZ interactio

M(L=0) > M(L=1)

Chiral popential

A. Hosaka hep-ph/0307323
Phys. Lett. B571, 55 (2003)





$$\left(i\partial\!\!\!/ - g(\sigma(\vec{x}) + i\vec{\tau}\cdot\vec{\pi}(\vec{x})\gamma_5)\right)\psi = 0\,.$$

στ interaction ~ strong pion field

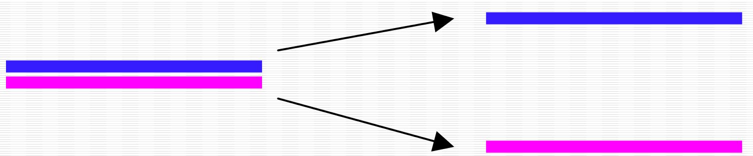
$\vec{\pi} \sim \hat{r} F(r)$

Spin-isospin splitting

$$H = c_1 + c_2 \langle \chi | \vec{\sigma} \cdot \vec{\tau} | \chi \rangle$$

$(J = I = 1/2)$

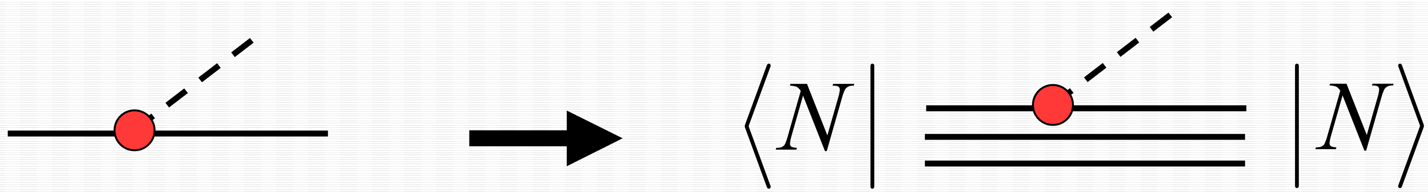
$K = J + I =$ 0, 1



Decay width

A simple estimate in the quark model

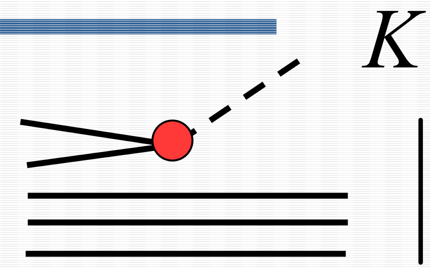
mqq coupling



$$g\frac{\sigma_q q}{2m_q} \quad \rightarrow \quad 5g\frac{\sigma_B q}{2M_B} \quad \rightarrow \quad \boxed{g \sim 2.6}$$

Matrix elements

Carlson et al, hep-ph/0312325

$\langle \Theta |$  $| N \rangle$

$$|N\rangle = |(qqq)_N\rangle$$

$$|\Theta\rangle = \underline{a\ |(q\bar{q})_K (qqq)_N\rangle} + others$$

1/2⁻, KN in s-wave $\rightarrow$ ***a* = 1/2** $\rightarrow \Gamma \sim 360$ MeV

1/2⁺, KN in p-wave $\rightarrow$ ***a* = …** $\rightarrow \Gamma \sim$ ** MeV

small **about factor 10 smaller**

Theta productions

To obtain more information of Θ -- J^P

(1) $\gamma + n \rightarrow K^- + \Theta^+$ **Nam-Hosaka-Kim, PLB579, 43 (04)**

(2) K* production

(3) K-induced **Hyodo-Hosaka-Oset, PLB579, 290 (04)**

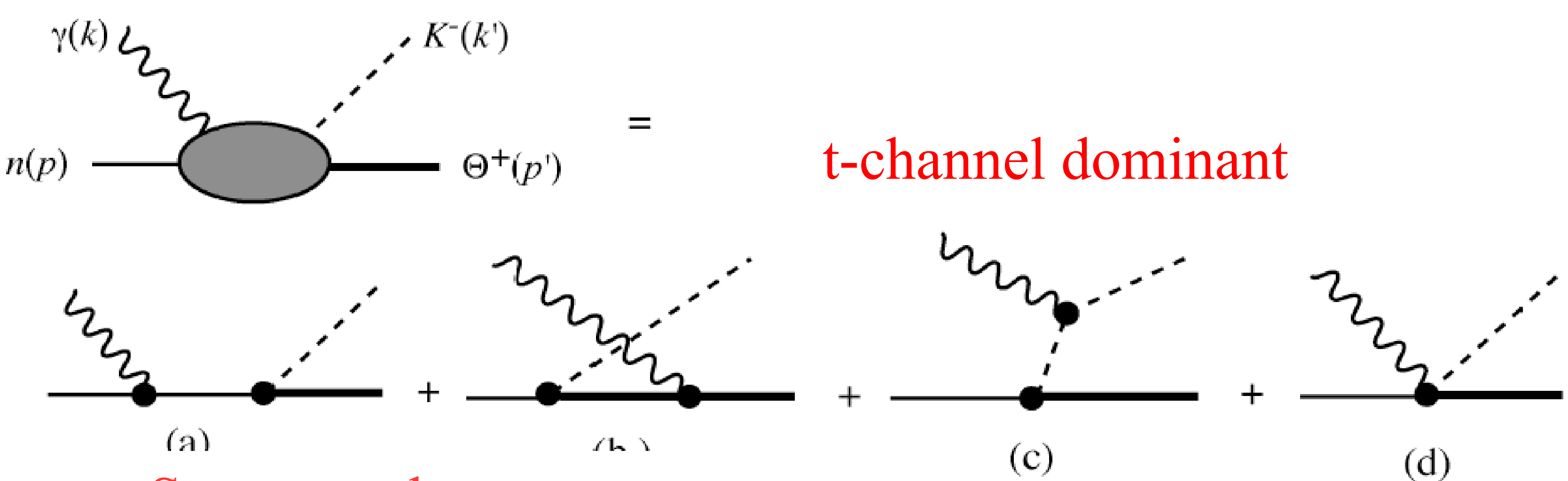
(4) Model-independent method

$\vec{p} + \vec{p} \rightarrow \Theta^+ + \Sigma^+$

Thomas-Hicks-Hosaka, to appear in PTP
Nam-Hosaka-Kim, hep-ph/0401074
hep-ph/0402***

(1) $\gamma + n \rightarrow K^- + \Theta^+$

Nam-Hosaka-Kim, PLB579, 43 (04)



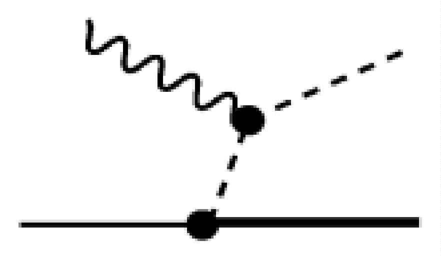
t-channel dominant

Suppressed at
High momentum transfer

Cross sections

γn -> $K^{-}\Theta$

t-chennel
dominance



Positive parity

150

QuickTimeý Ç²
TIFFÅiLZWÅj êLí£ÉvÉçÉOÉâÉÄ
Ç™Ç±ÇÃÉsÉNÉ`ÉÉÇ¾å©ÇÈÇžÇ½Ç…ÇÕïKóvÇ-Ç□ÅB

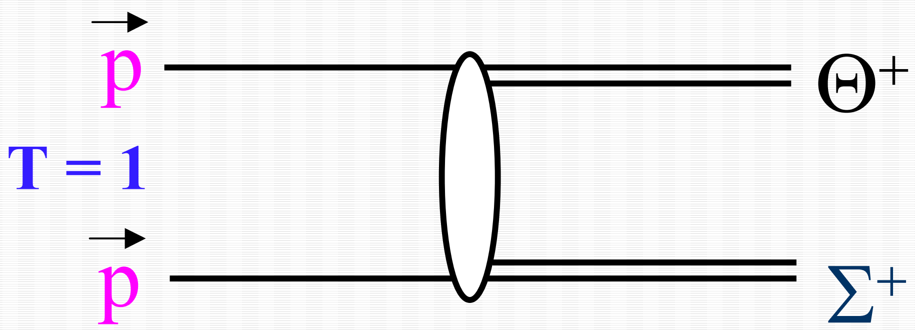
Negative parity

20

QuickTimeý Ç²
TIFFÅiLZWÅj êLí£ÉvÉçÉOÉâÉÄ
Ç™Ç±ÇÃÉsÉNÉ`ÉÉÇ¾å©ÇÈÇžÇ½Ç…ÇÕïKóvÇ-Ç□ÅB

(4) Model-independent method

Thomas-Hicks-Hosaka, to appear in PTP



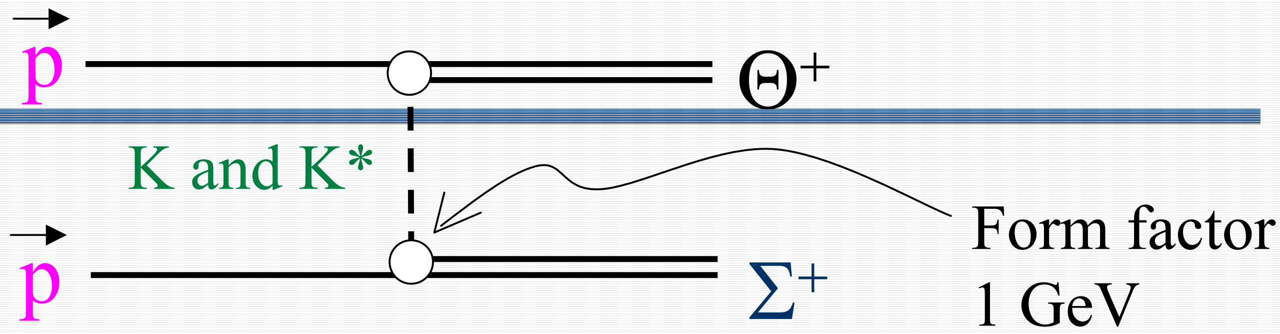
At threshold
S-wave dominant

If S = 0, then L_i = even, P = even ==> **$P(\Theta) = +$**

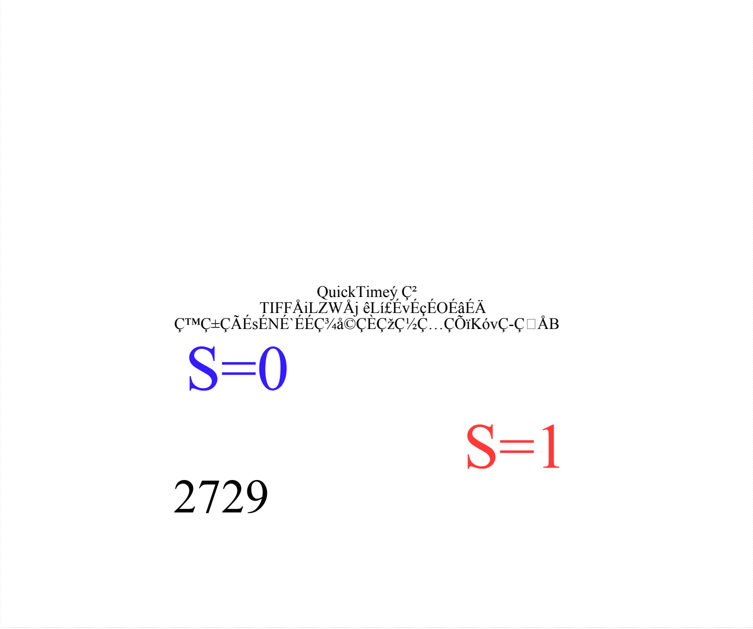
If S = 1, then L_i = odd, P = odd ==> **$P(\Theta) = -$**

Cross sctions

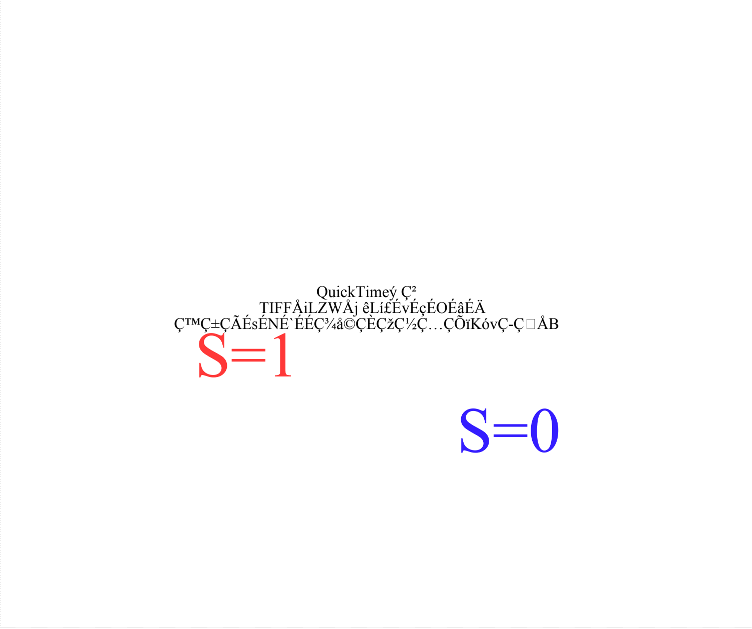
Nam-Hosaka-Kim, hep-ph/0401074



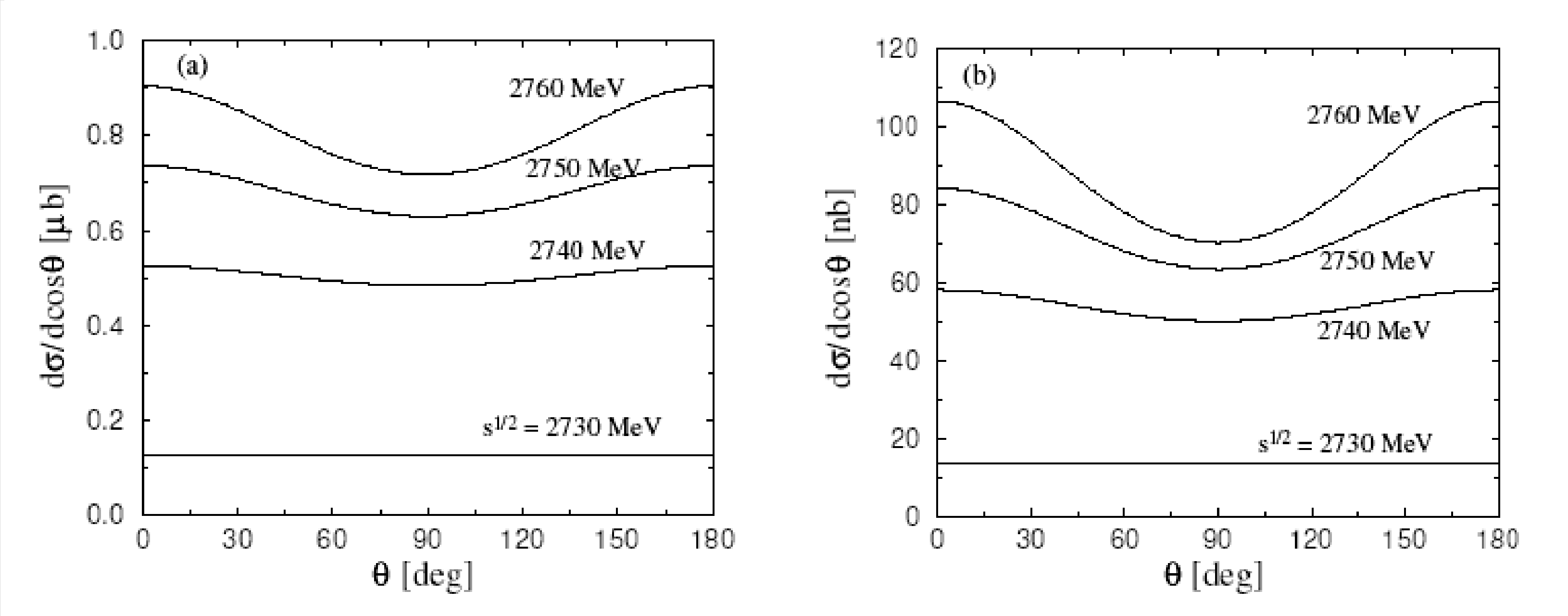
Positive parity



Negative parity



Angular dependence



Summary

- Positive parity

  Diquark correlation

  Spin-isospin force due to the hedgehog

- Width

  Too wide for $1/2^-$, several tens MeV for $1/2^+$

- Role of chiral symmetry, strangeness