Structure and reactions of Θ^+

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- hep-ph/0507105
  E. Hiyama, Kamimura, Yahiro, A.H., and Toki
- hep-ph/0505134, hep-ph/0503149 to appear PRD
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Outline

1. **Full 5-body calculation**

2. **Photoproduction reconsidered**

   pn asymmetry when *J* = 3/2

   $\gamma n \to K^- \Theta^+$ vs. $\gamma p \to \bar{K}^0 \Theta^+$ [Θ^+ or $\Lambda(1520)$]

   K* production

1. Full 5-body calculation

Hiyama-Kamimura-Yahiro-Hosaka-Toki

hep-ph/0507105

Need to handle the (at least) 5-body system

- So far calculations were only approximate and only for bound state
- Better method with scattering states included

Method available developed in nuclear-physics

Assumption: NRQM

- Validity of the use of the Schrodinger picture
- What is the effective hamiltonian

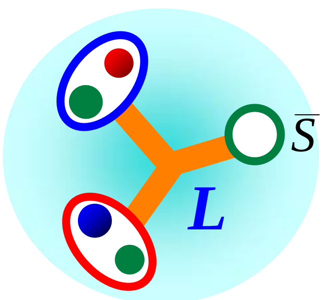
e.g. *const* is not known => ***confinement?***

Clarify what this hamiltonian tells for 5-body system
Then improve this method or choose others?

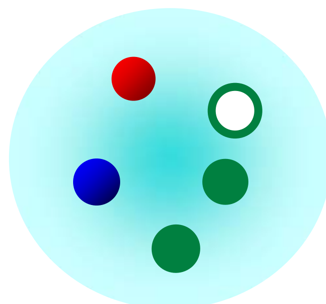
Decay (fall-apart) is very sensitive to WFs

Hadronic (color-singlet) or colored correlations?

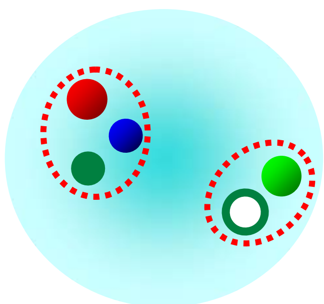
SU(3) **qqq** or **qqbar** are enough to make color singlets



Diquark correl.



Five quarks random



Hadronic correl.

Difficult to decay ↔ ***Easy to decay***

Dependence on J^P

J^P = 1/2$^-$: $l = 0$ (ground state)

~ KN scattering => can not be narrow

Excited or complicated state may be a narrow res.

J^P = 1/2$^+$: $l = 1$

(3/2$^+$) Depends much on the configuration

J^P = 3/2$^-$: $l = 0$

D-wave KN decay is forbidden, can be narrow

Seems consistent with phenomenology

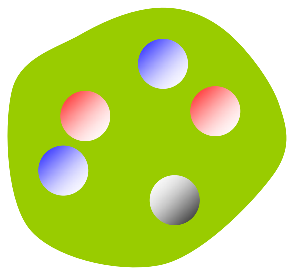
=> Hyodo, PRD, **hep-ph/0509104**

hys.Rev.D71:054017,2005 , hep-ph/0502093

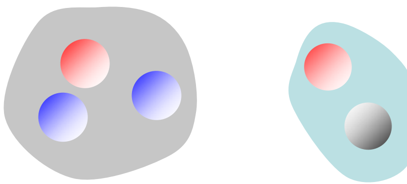
Method

Most serious calculation for **5-body system** with scattering states included

Gaussian expansion method



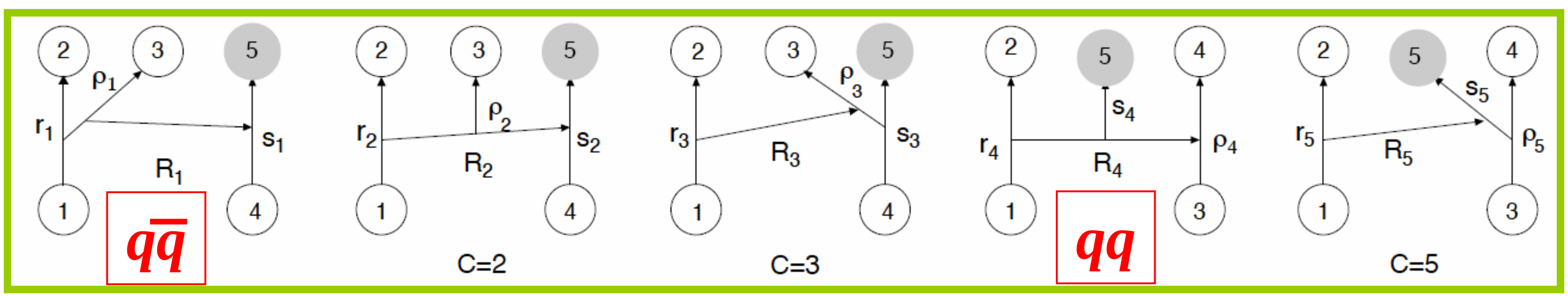
+



Θ^+-confined

NK-scattering

Compute phase shifts



Hamiltonian

NR quark model of Isgur-Karl

$$H = \sum_i \left(m_i + \frac{\mathbf{p}_i^2}{2m_i} \right) - T_G + V_{\mathrm{Conf}} + V_{\mathrm{CM}}$$

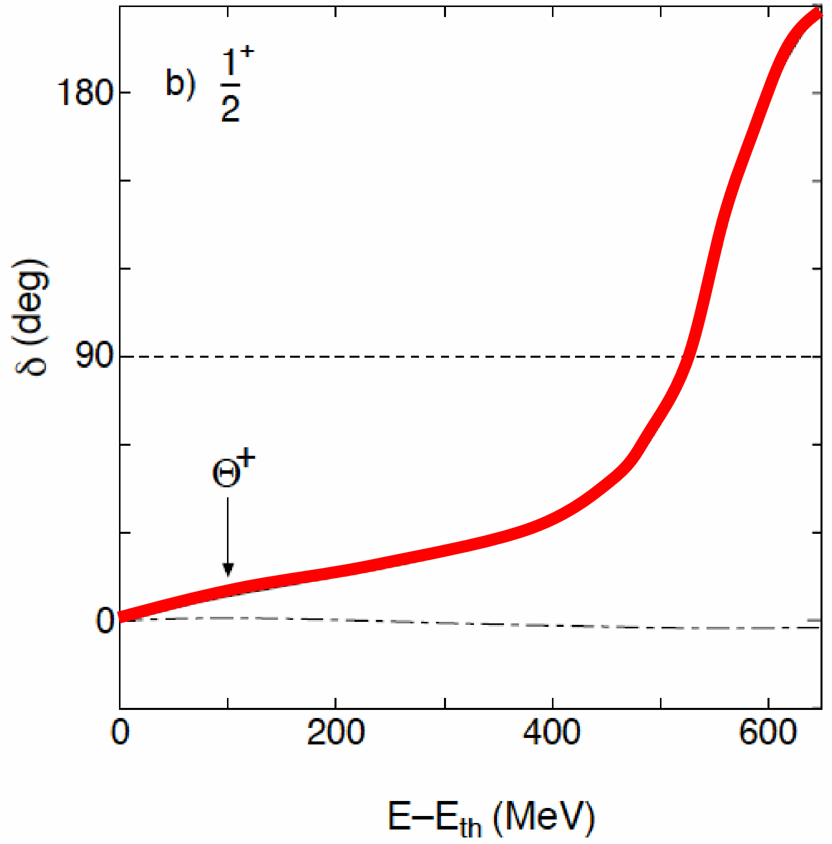
$$V_{\mathrm{Conf}} = -\sum_{i<j} \sum_{\alpha=1}^{8} \frac{\lambda_i^\alpha}{2} \frac{\lambda_j^\alpha}{2} \left[\frac{k}{2} (\mathbf{x}_i - \mathbf{x}_j)^2 + v_0 \right]$$

$$V_{\mathrm{CM}} = \sum_{i<j} \sum_{\alpha=1}^{8} \frac{\lambda_i^\alpha}{2} \frac{\lambda_j^\alpha}{2} \frac{\xi_\sigma}{m_i m_j} e^{-(\mathbf{x}_i - \mathbf{x}_j)^2/\beta^2} \boldsymbol{\sigma}_i \cdot \boldsymbol{\sigma}_j$$

Good for conventional baryons

	Mass		Magnetic moments		Charge radii	
	Cal.	Exp.	Cal.	Exp.	Cal.	Exp.
	(MeV)		(nm)		(fm^2)	
p	939	939	2.7737	2.7828	$(0.60)^2$	$(0.87)^2$
n	939	939	−1.826	−1.913	−0.04	−0.12
Λ	1058	1115	−0.602	−0.613	−0.01	–
Σ^+	1119	1189	2.691	2.458	0.35	–
Σ^0	1119	1192	0.819	–	0.03	–
Σ^-	1119	1197	−1.054	−1.160	−0.30	–
Ξ^0	1309	1314	−1.414	−1.250	−0.01	–
Ξ^-	1309	1321	−0.507	−0.651	−0.28	–
Δ^Q	1232	1232	$2.843Q$	–	$0.41Q$	–
Σ^{*+}	1320	1384	3.18	–	0.64	–
Σ^{*0}	1320	1384	0.33	–	0.12	–
Σ^{*-}	1320	1384	−2.51	–	−0.38	–
Ξ^{*0}	1512	1533	0.67	–	0.03	–
Ξ^{*-}	1512	1533	−2.17	–	−0.35	–
Ω	1506	1672	−1.840	−2.02	−0.32	–

KN-phase shifts 1/2$^+$



E_{res} ~ 530 MeV
Γ_{res} ~ 110 MeV

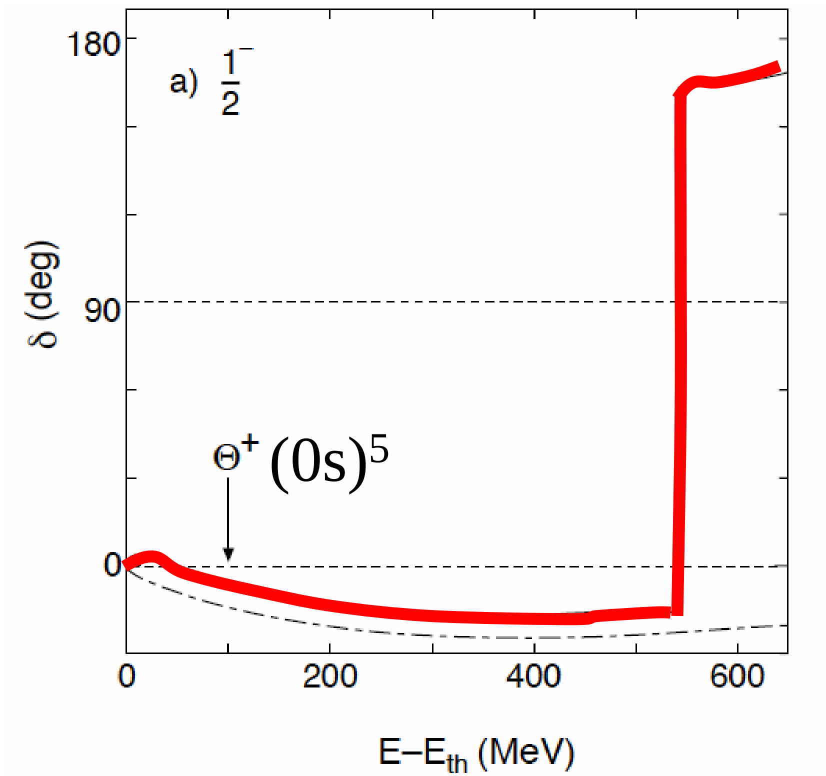
$(0s)^4 1p$

- Strong $q\bar{s}$ correlation favors KN
  Rather than $[ud][ud]\bar{s}$

=>

- Formation of the JW type conf.
  is a dynamical problem

KN-phase shifts 1/2$^-$



(0s)^5: KN scattering state
Likely to be 1s(0s)^4

$\Gamma < 1$ MeV

The nature of
the narrow resonance
is interesting to analyze

We have seen:

- **5-body calculation** of the Isgur-Karl quark model

  Two states at ~500 MeV above the KN threshold

  $\Gamma(1/2^-)$ ~ Very narrow, < 1 MeV

  $\Gamma(1/2^+)$ ~ 100 MeV

  When the same ***const***-parameter is used as for conventional baryons

- The ground $(0s)^5$ configuration melts into the continuum

- The **1/2**$^+$ state is dominated by ***qqq-qq*** configuration

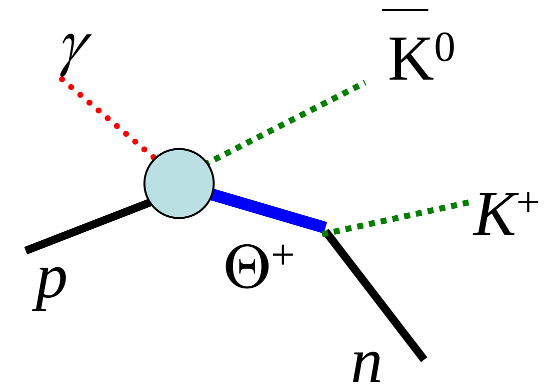
2. Photoproductions

1. K-production

2. K*-production

(1) K-production with new J-Lab data

γ p –> n K^+ K^0



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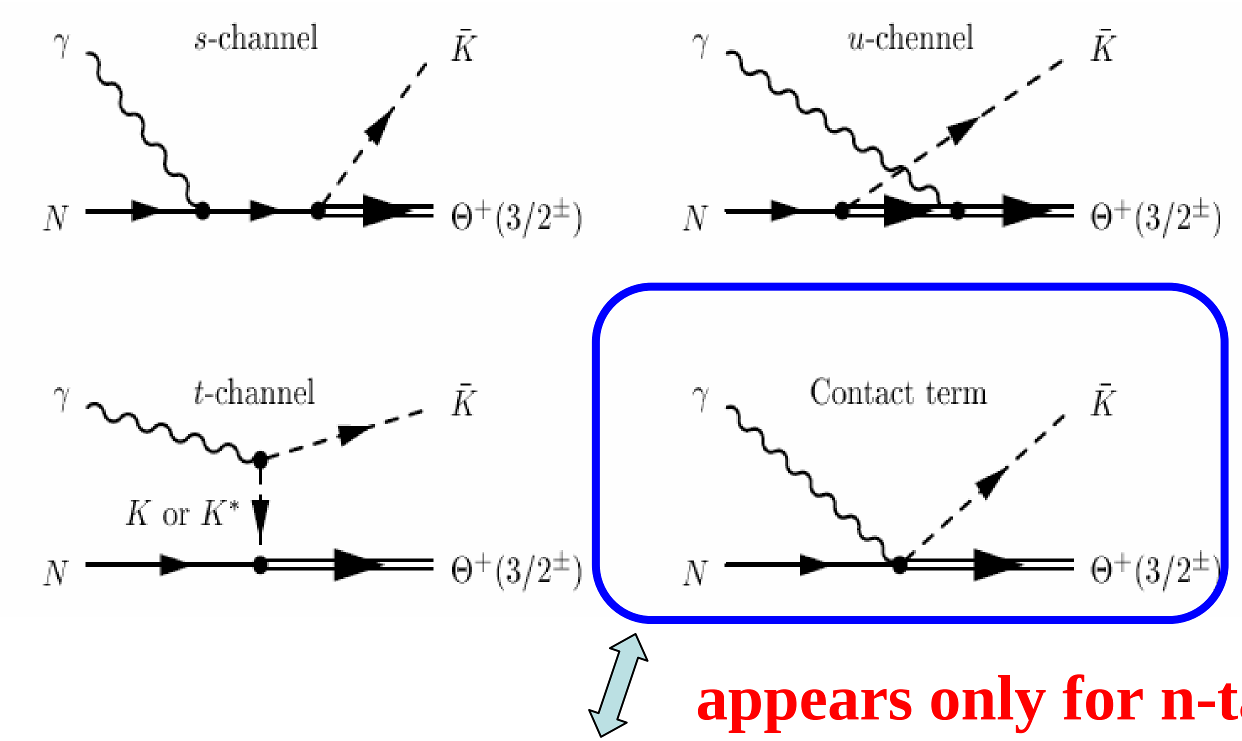
Teken from DeVita's
talk at spring APS meeting

This is serious, but leads immediately to the absence of Θ^+ ?

Effective Lagrangian approach

hep-ph/0505134 ***N***am-***H***osaka-***K***im



appears only for n-target

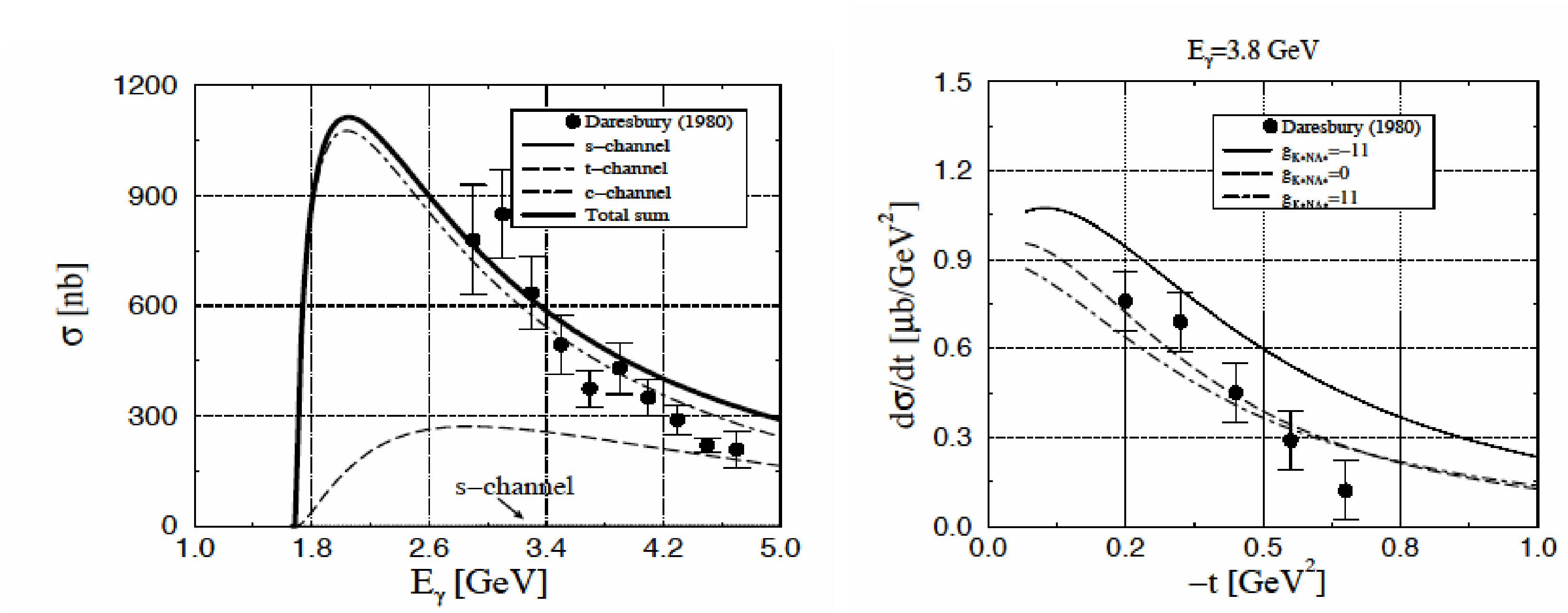
For J = 3/2, only PV scheme is possible

Before the Θ-production

$\gamma n \to K^- \Lambda(1520)$ and $\gamma p \to \bar{K}^0 \Lambda(1520)$

was studied and large **pn** asymmetry was found

Nam-Hosaka-Kim, hep-ph/0503149 to appear PRD



Comparison

Form factor	F_1	
Reactions	$\underline{\gamma p} \to K^+\Lambda^*$	$\underline{\gamma n} \to K^0\Lambda^*$
σ	$\sim 900\,nb$	$\sim 30\,nb$
$d\sigma/d(\cos\theta)$	Forward peak	Peak at $\sim 45°$
$d\sigma/dt$	Good	No data

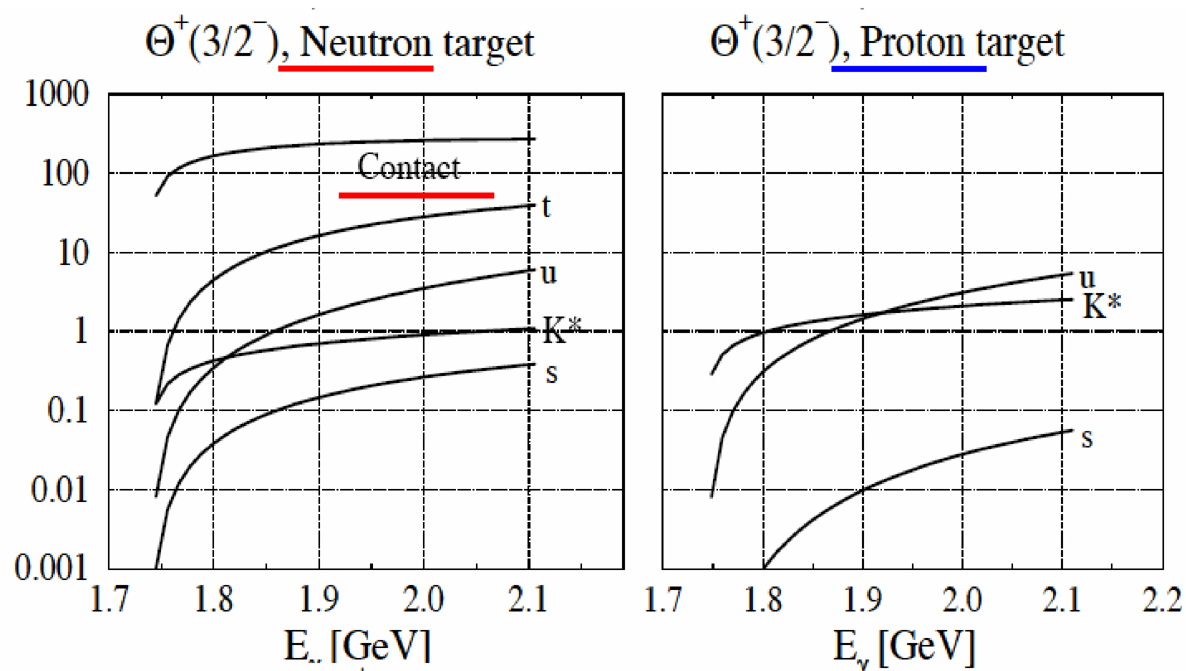
The presence (for p) or absence (for n) contact term is important

LEPS data seems to support this result

Theta production, $J^P = 3/2^-$

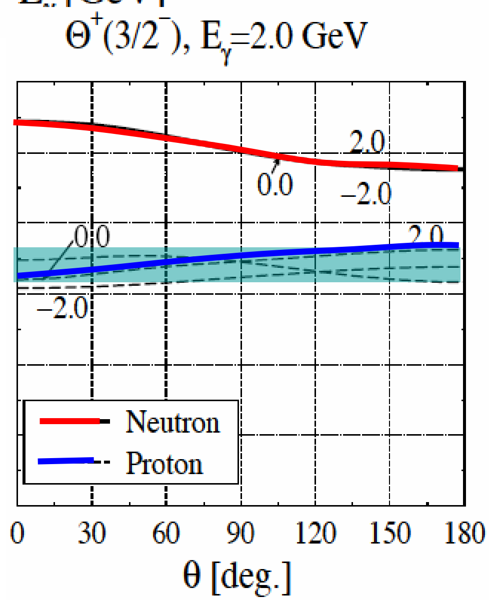
Total σ

Log-scale



Angular dist

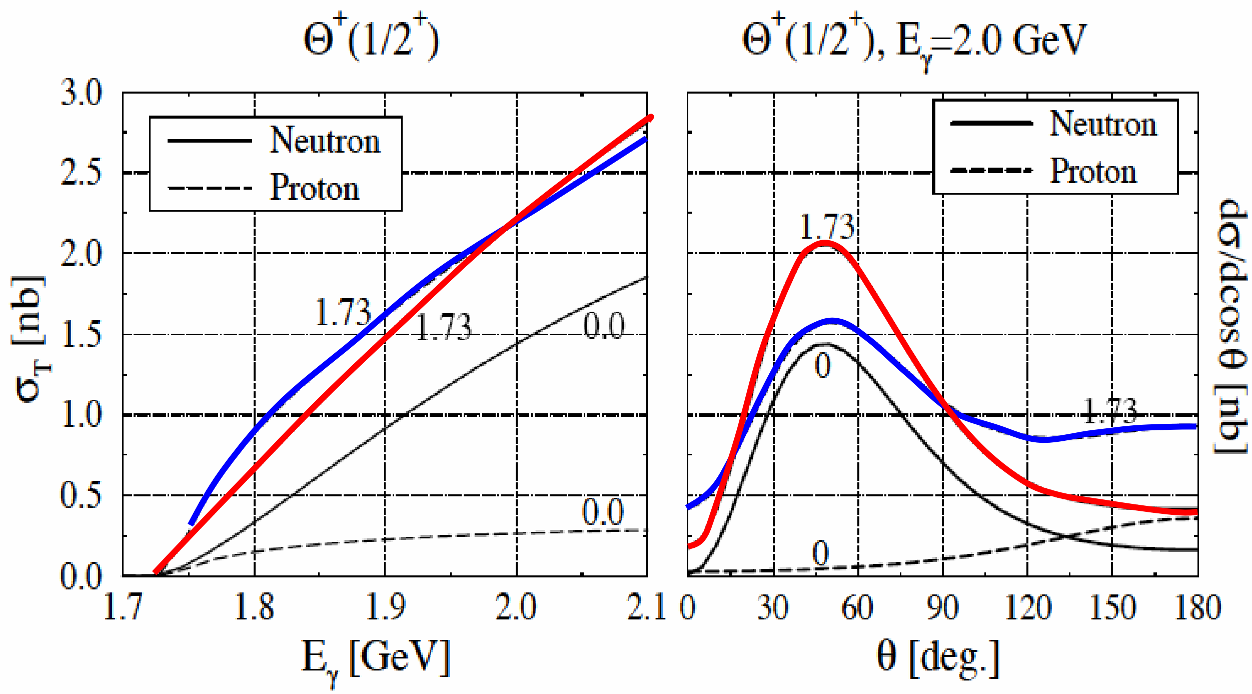
Log-scale



neutron ~ forward peak
Contact term

proton ~ rather flat

$J^P = 1/2^+$



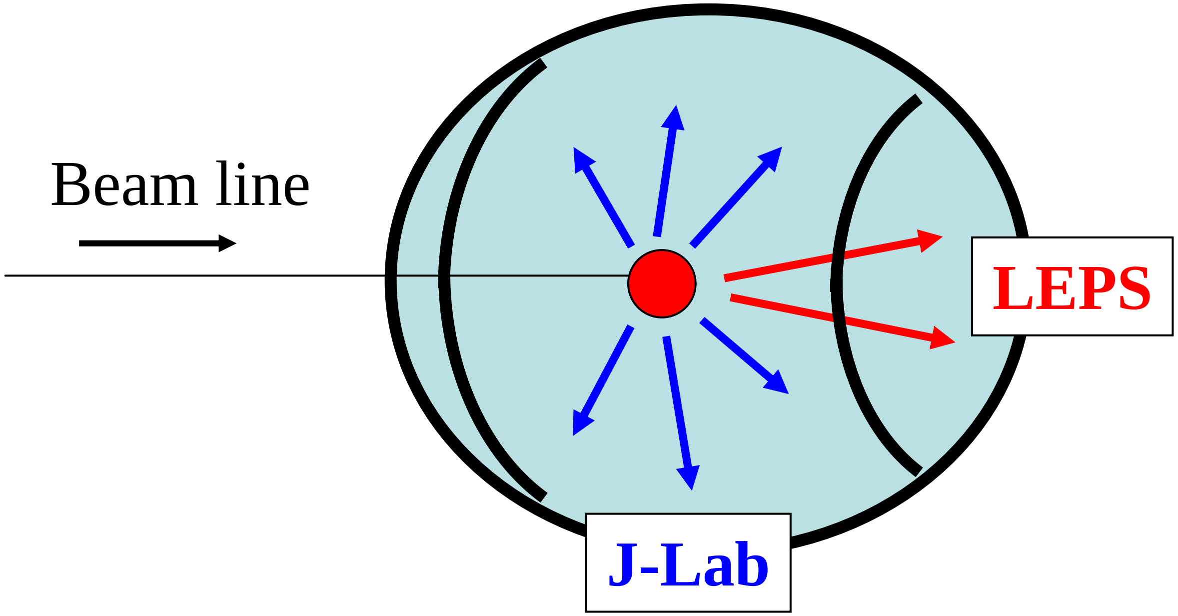
The role of the contact term is more important for $J^P = 3/2^-$ than $1/2^+$

Predictions

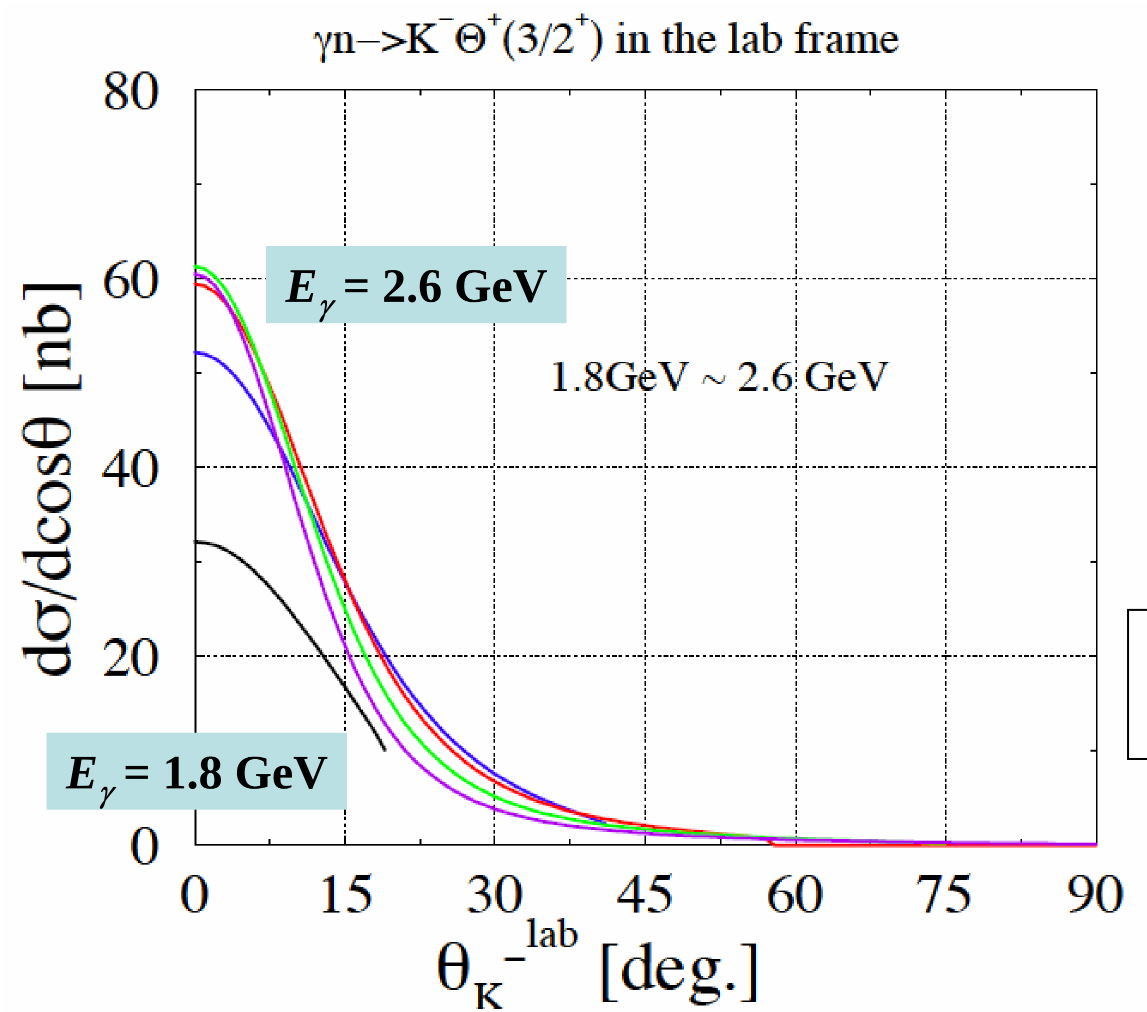
J^P	$3/2^+$		$3/2^-$		$1/2^+$	
$g_{KN\Theta}$	0.53		4.22		1.0	
$g_{K^*N\Theta}$	± 0.91		± 2		± 1.73	
Target	n	p	n	p	n	p
σ	~ 25 nb	~ 1 nb	~ 200 nb	~ 4 nb	~ 1 nb	~ 1 nb
$\frac{d\sigma}{d\cos\theta}$	Forward	$\sim 60^\circ$	Forward	–	$\sim 45^\circ$	$\sim 45^\circ$

- We see a large asymmetry between pn targets
- Cross section for proton ~ few nb is consistent with the upper limit estimated by CLAS

Different exp. config.

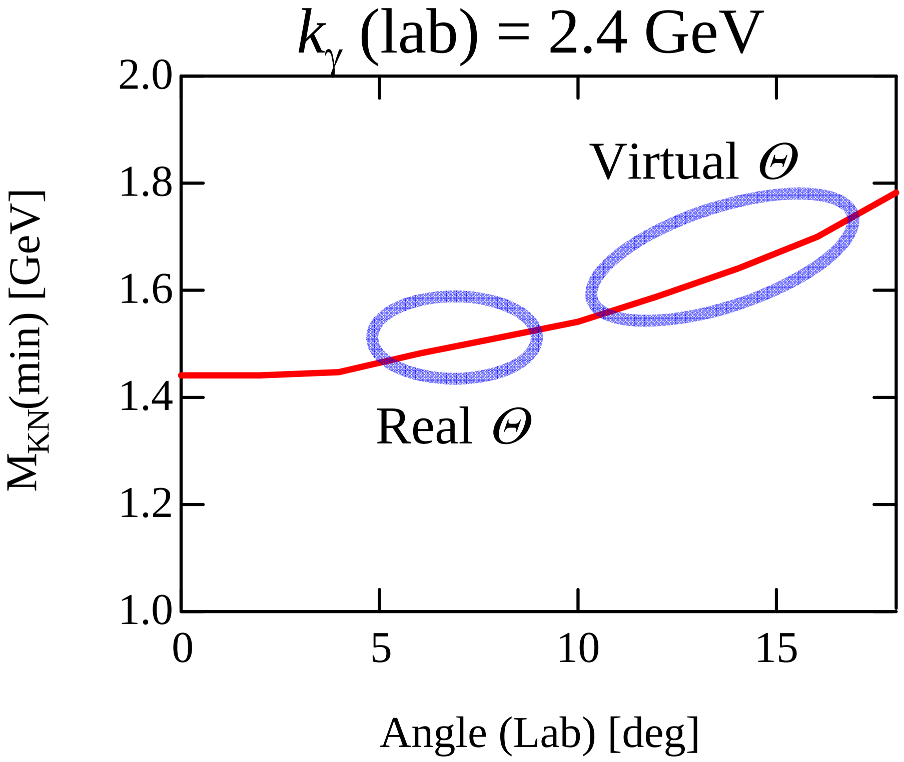


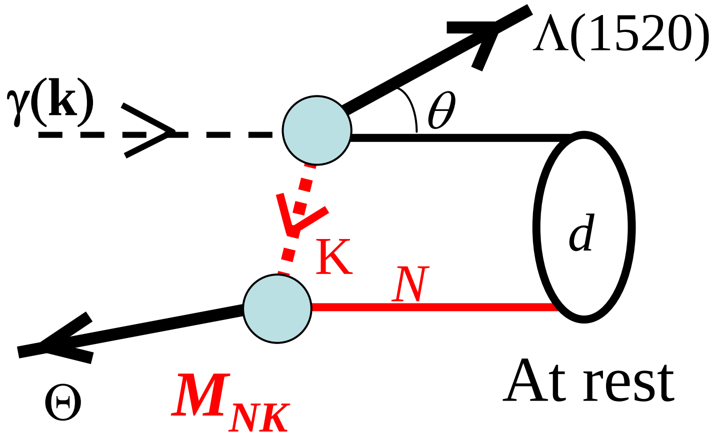
Angular dist. in lab frame



At $E_\gamma = 2$ GeV
$\sigma(\theta < 25^o) \sim 5\sigma(\theta > 25^o)$

Special kinematics

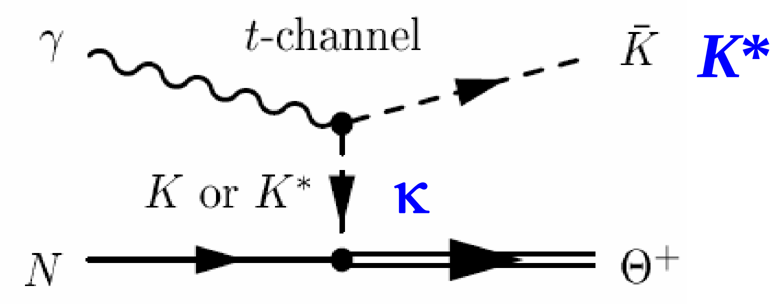




(2) K* (1^-) production

- Physics in the t-channel

  Now κ (0^-) is allowed to be exchanged



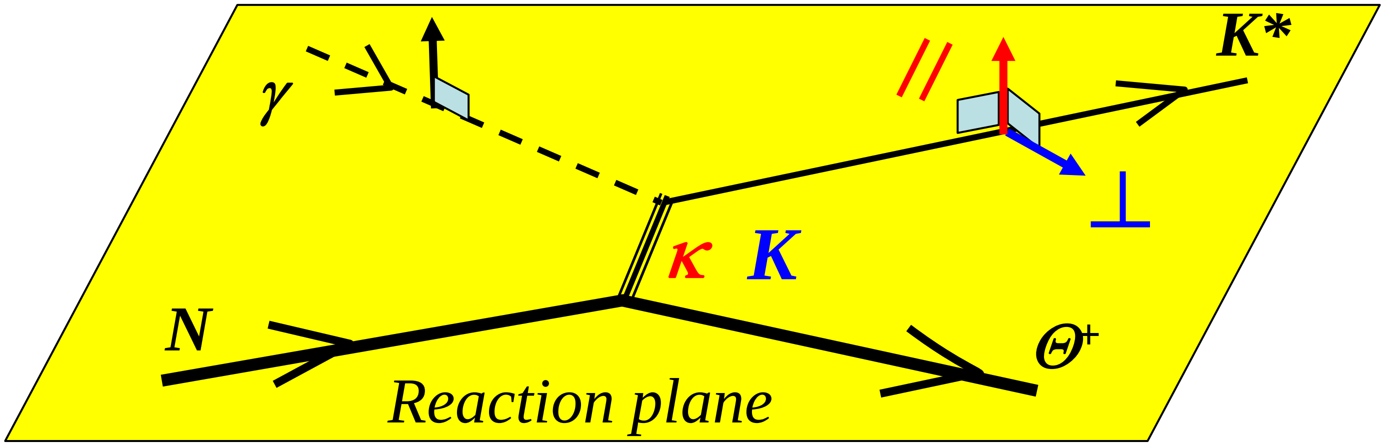
Exotic tetraquark κ may couple strongly to Θ^+

D.P. Roy, J. Phys. G30, R113 (2004)

- Using polarizations of γ and K*, we can distinguish the exchanged particles

Polarizations as a particle filter

Pol. of γ perp. to react. plane



If parallel [//], only κ is exchanged
If perpendifular [⊥], only **K** is exchanged

Summary

- **5-body calc.**

  $1/2^-$ E ~ 2 GeV, Γ ~ 1 MeV

  $1/2^+$ E ~ 2 GeV, Γ ~ 100 MeV Configurations mix

  (cf: quark model calc. Hosaka-Oka-Shinozaki
  hep-ph/0409102, PRD71: 074021 (2005))

- **Photoproduction, revised**

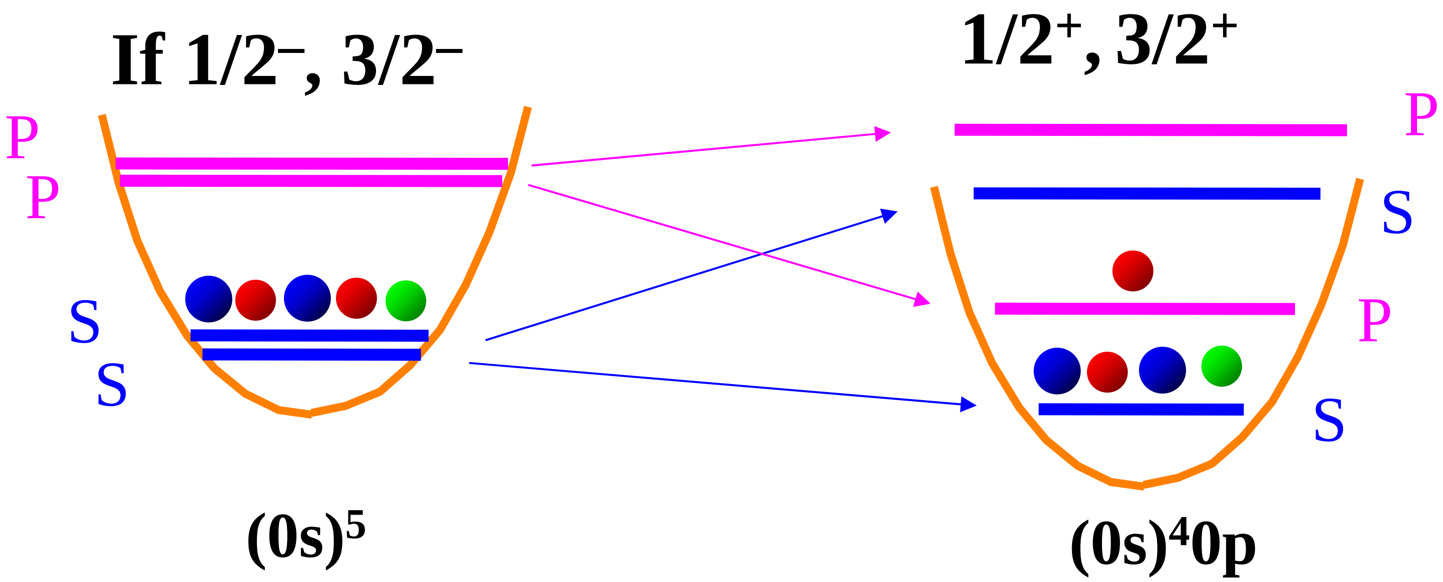
  *There is a large ***pn asymmetry***, especially for ***J* = 3/2**

  *No signal from the CLAS does not lead immediately to the absence of Θ^+

  ****Kinematics*** at LEPS is very interesting

  ****K*** can be used as a ***particle (t-channel) filter***

Interpretation of results



Diquark
Tri-quark } **correlations**
Chiral