Pentaquarks

a brief overview of theoretical status

Atsushi Hosaka, RCNP, Osaka University

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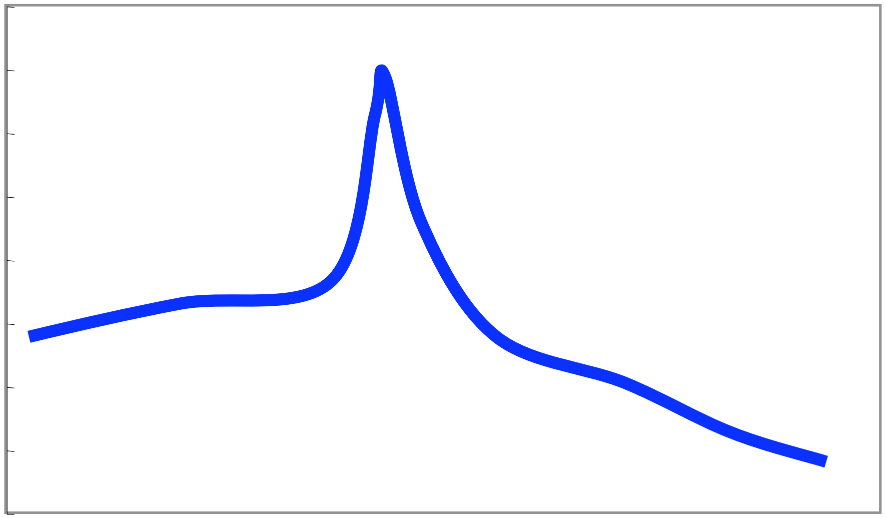
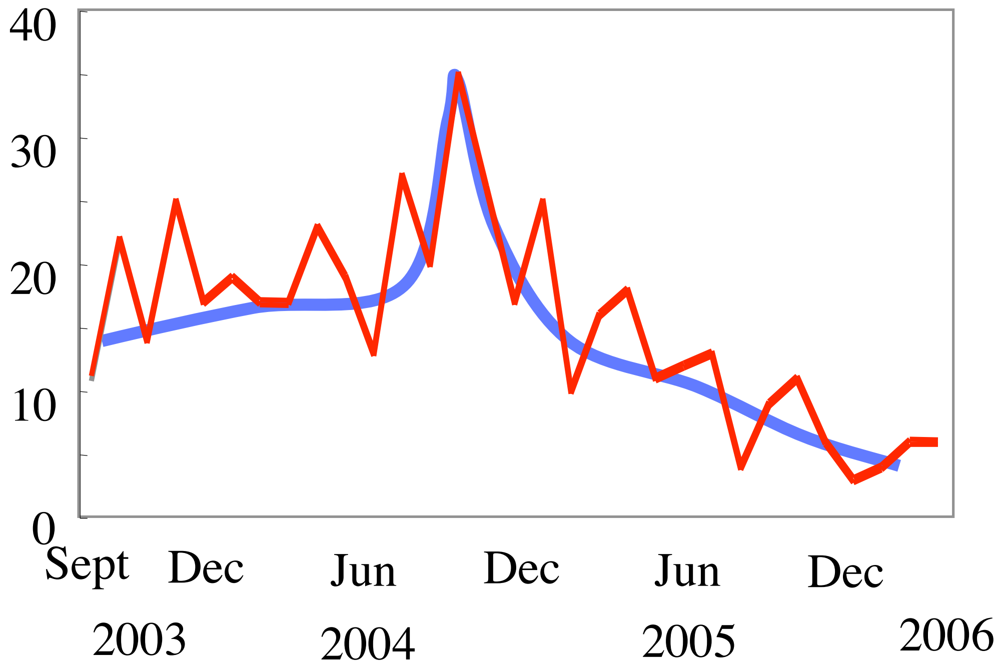
- Essentials of QCD dynamics for hadrons are yet understood.
- The (non) existence and understanding of it is crucial.

Peak of a narrow resonance ?



Theory papers



Theoretical methods (models)

Structure => Masses, spin, parity, . . .

Quark models, Chiral solitons

QCD sum rule, Lattice

Reactions => Cross sections, angular dist., . .

Reaction mechanism

Role of various mesons

What I would like to address

- **Conventional wisdom in the quark model**

  Hadrons as simple bound states of ***constituent quarks***

  Effective QCD ~ confined quarks + residual int.

  Global success of qqq g.s. baryons and excited states

  Questions

  Chiral symmetry (pions), **diquarks**

- **Reactions**

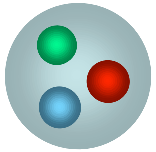
  Total cross sections and ***pn*** asymmetry

  Angular distributions

How do baryons look like?

Baryons ~ qqq
Mesons ~ qq^*

Minimum ingredients



$$|B\rangle = |qqq\rangle$$

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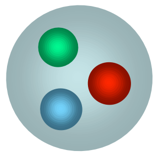
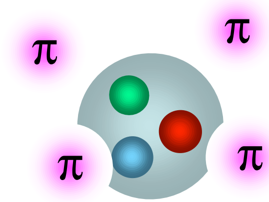


$$|B\rangle = |qqq\rangle$$

Chiral symmetry = Spontaneously broken
=> ***Massless pions*** as Nambu-Goldstone bosons

Baryons could be more complicated ?



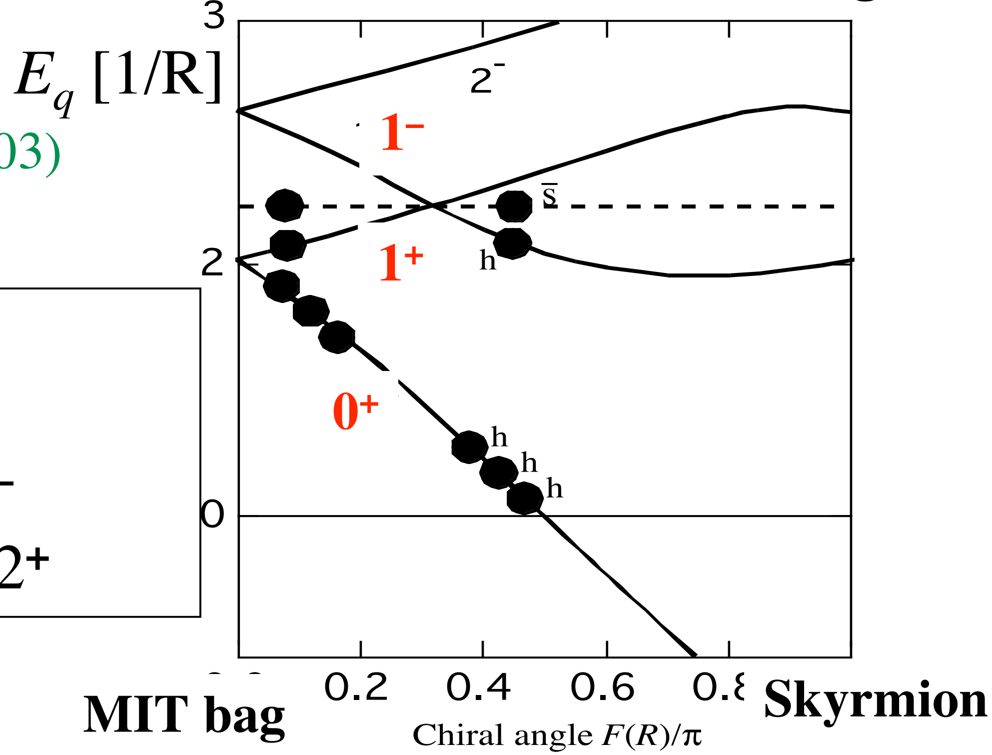
$$|B\rangle = |qqq\rangle + |qqq(q\bar{q})\rangle + |qqq(q\bar{q})(q\bar{q})\rangle + \cdots$$

What does chiral symmetry do for Pentaquarks ?

= parity

Hosaka, PLB571, 55 (2003)
Stancu-Riska, PLB575, 242 (2003)

Quark levels in the chiral bag



weak ⟵ pion ⟶ strong

Parity: Negative < ----> Positive

5q configurations:

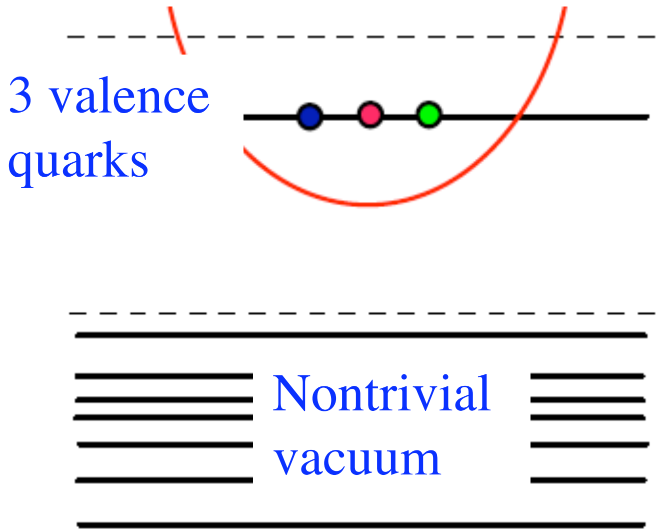
Weak π $(0s)^5$ –> $1/2^-$, $3/2^-$
Strong π $(0s)^4\,0p$ –> $1/2^+$, $3/2^+$

Strong pion limit $g_{\pi qq} \sim 3$

Baryons as *chiral solitons*

SU(3) rotating ***hedgehog*** $U = A(t) U_H A(t)^\dagger$

Diakonov, Petrov
PRD72, 074009, '05



$J^P = 1/2^+$, $M_\Theta \sim 1.5$ GeV

Decay width

$1/N_C$ corrections

Formula for general N_C Praszalowiz 2004

$$\Gamma_\Theta = \frac{3|\mathrm{p}|^3}{2\pi(M_N + M_\Theta)^2} \cdot \frac{3(N_c+1)}{(N_c+3)(N_c+7)} \cdot \left(G_0 - \frac{N_c+1}{4} G_1 - \frac{1}{2} G_2\right)^2$$

For $N_C = 3$ $\Gamma_\Theta = 2.3$ MeV !

But if first take the limit $N_C \to \infty$ and set $N_C = 3$

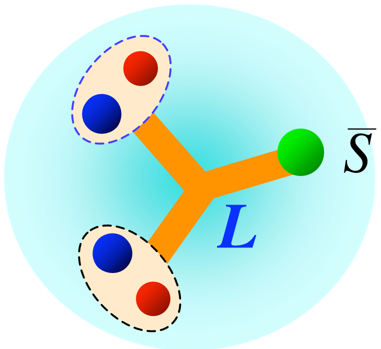
$\Gamma_\Theta = 41$ MeV ~ Callan-Klebanov

The analysis has been checked also
in the K-scattering problem, Diakonov et al (05)

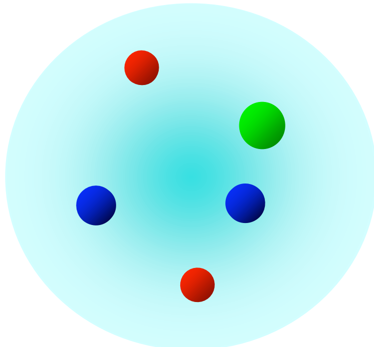
Weak pion limit

Five quarks with residual interaction

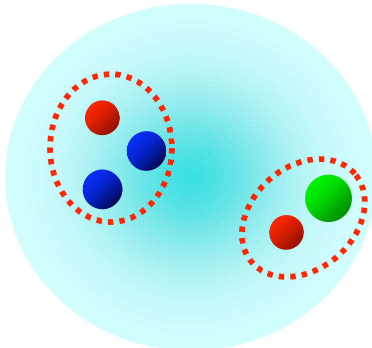
Depending on the type of interactions



Diquark correl.

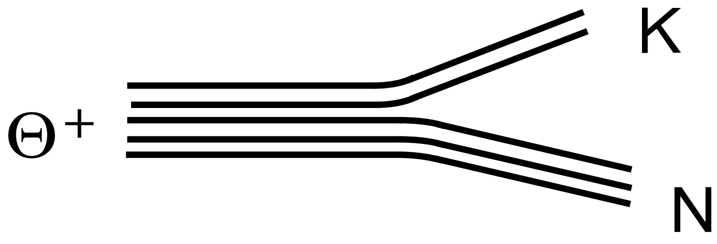


Five quarks
random



Hadronic molecule

Fall apart ~ Strong dependence on J^P



Hoska-Shinozaki-Oka
PRD71. 074025 (2005)
Hep-ph/0409103

1/2⁻ $(0s)^5$: unique $\Gamma \sim$ 500-1000 MeV

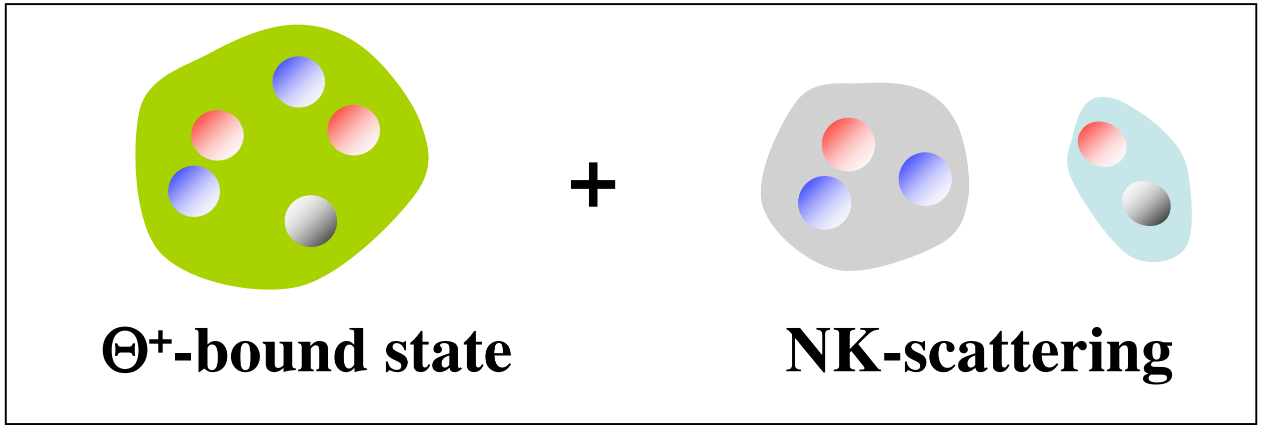
1/2⁺ , 3/2⁺ $(0s)^4\,(0p)$ Several configurations

	SF	SC	JW
Γ(MeV)	~ 60	~ 30	~ 10

3/2⁻ does not decay (KN in the d-wave)

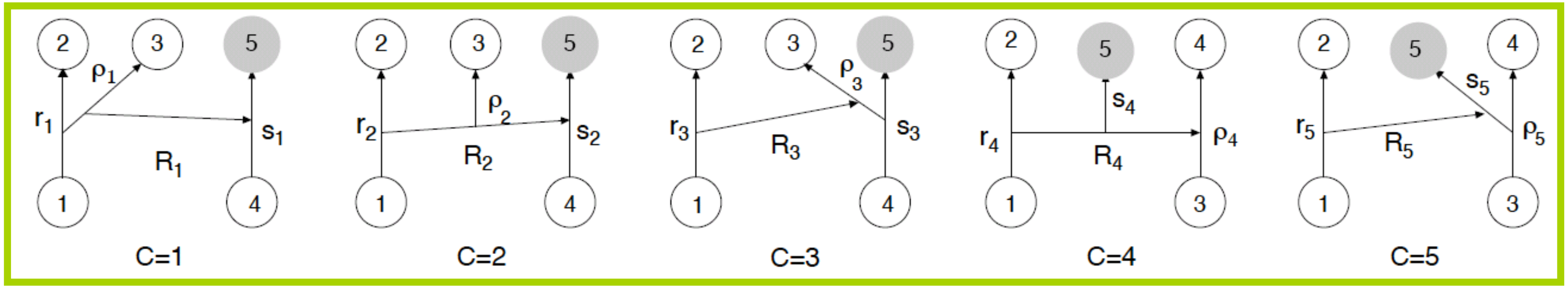
Full 5-body calculation with scattering states

Hiyama-Kamimura-Yahiro-Hosaka-Toki,
Phys.Lett.B633:237-244, 2006, hep-ph/0507105



Gaussian expansion method

Compute phase shifts



Hamiltonian

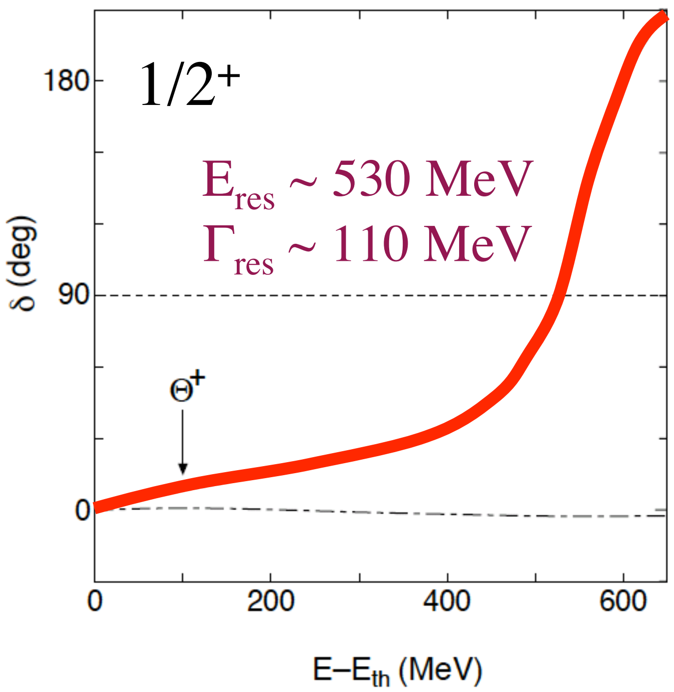
NR quark model of Isgur-Karl

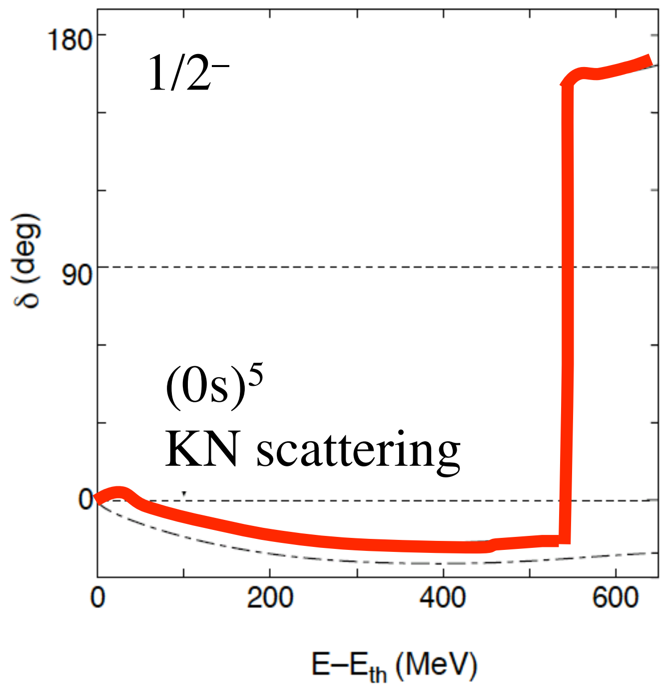
$$H = \sum_i \left(m_i + \frac{\mathbf{p}_i^2}{2m_i} \right) - T_G + V_{\text{Conf}} + V_{\text{CM}}$$

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

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

KN-phase shifts





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

Resonance of 550 MeV is a complex state

Summary

- Baryons look very differently according to the role of
  chiral symmetry
  perhaps the most important ingredient for hadron dynamics
- *Strong pion limit*
  Mean field is good for quarks and pions
  Baryons look chiral solitons, Θ exists!
  $J^P = 1/2^+$, $\Gamma \sim$ narrow
- *Weak pion limit*
  Quark many body problem with residual interactions
  qq correlations and/or *qq** correlations, Θ may or may not exist
  J^P, Γ depends on details of dynamics

Study of Pentaqurks is a key to hadron dynamics

Production reactions

Effective Lagrangian approach

- ***Tree diagrams*** with interactions satisfying symmetries
- Parameters: Coupling constants and ***form factors***

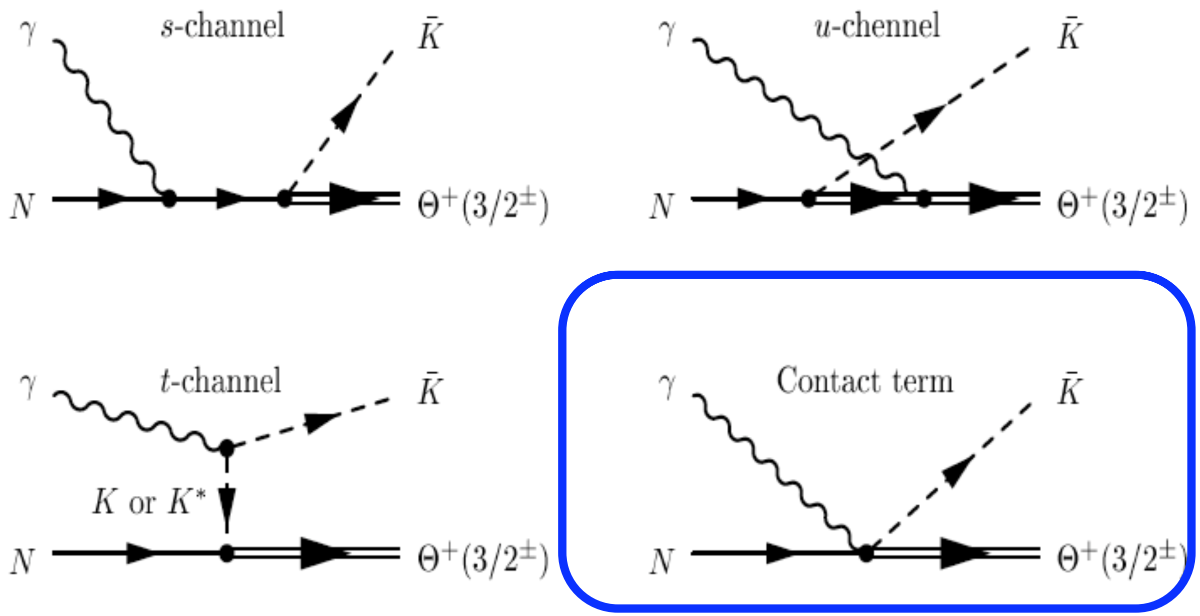
In Ref.

- Gauge and chiral symmetries => PS and PV schemes
- Different spin and parities
- Coupling constants evaluated from models

  $g(K^*N\Theta)$, $\mu(\Theta)$, …

n enhanced for J = 3/2
or p-suppression

Tree diagrams

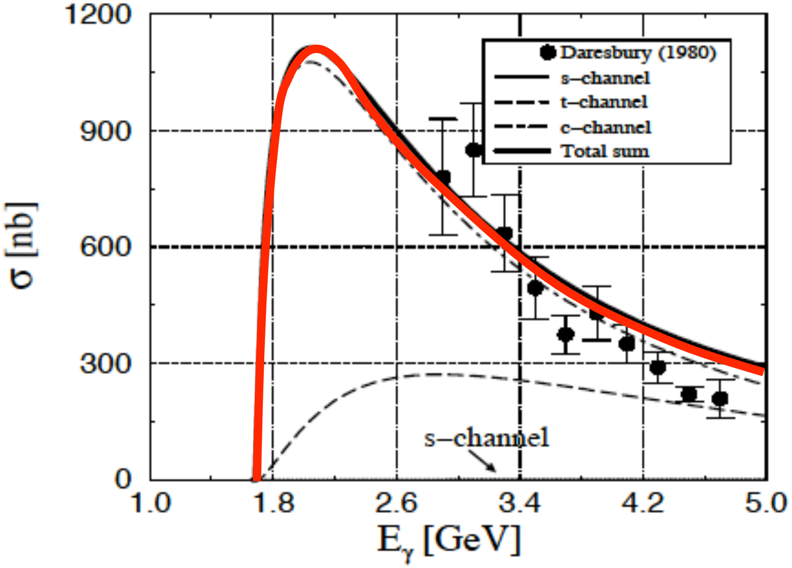


present only for n-target

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

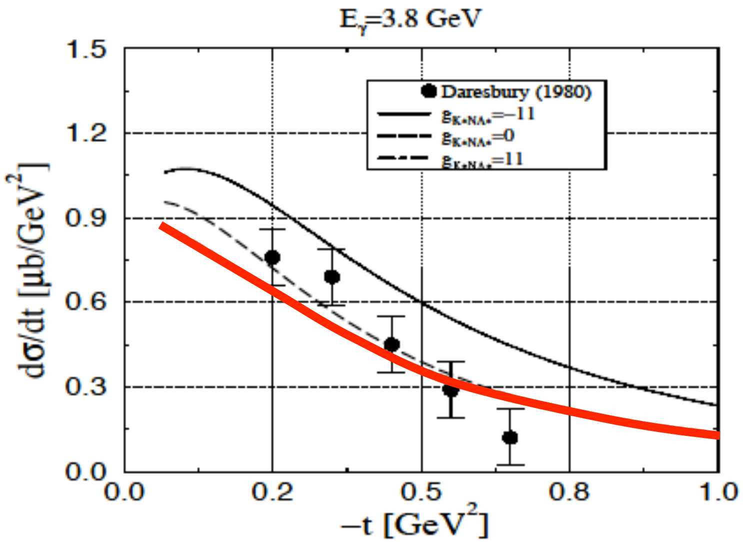
γN –> K Λ(1520) $J = 3/2^-$

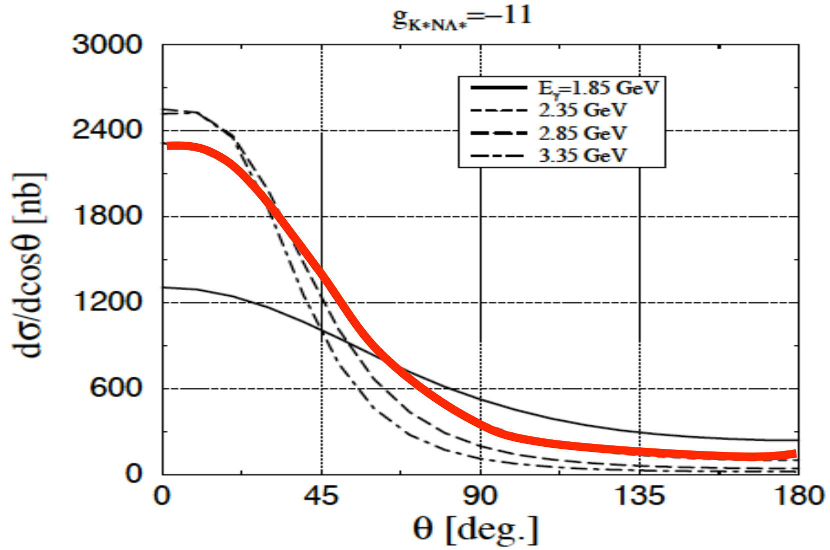
Energy dependence



Nam-Hosaka-Kim, PRD

t or *θ* dependence





$\Lambda(1520)$ $J^P = 3/2^-$

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

Λ = 700 MeV <=> $r \sim$ 0.8 fm

Contact term

- **$\sigma(p)$ >> $\sigma(n)$**
- Strong forward peak

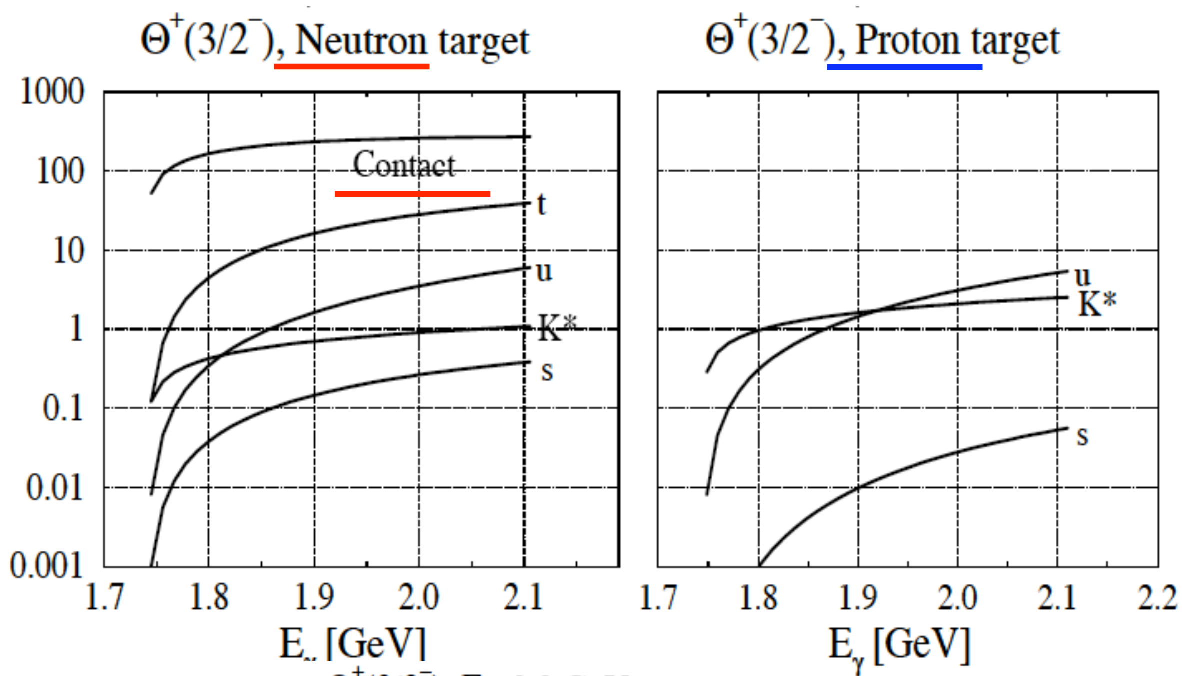
⇨ To be checked by experiments

For Θ: we expect $\sigma(p) \ll \sigma(n)$

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

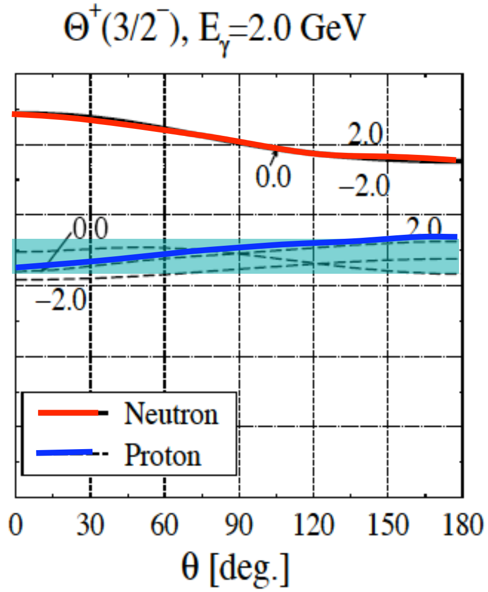
Total σ

Log-scale



Angular dist

Log-scale



neutron ~ forward peak

Contact term

proton ~ rather flat

Predictions

Λ = 700 MeV <=> r ~ 0.8 fm

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	–	$\sim 45^\circ$	$\sim 45^\circ$

The total cross section is very sensitive to Λ

Summary

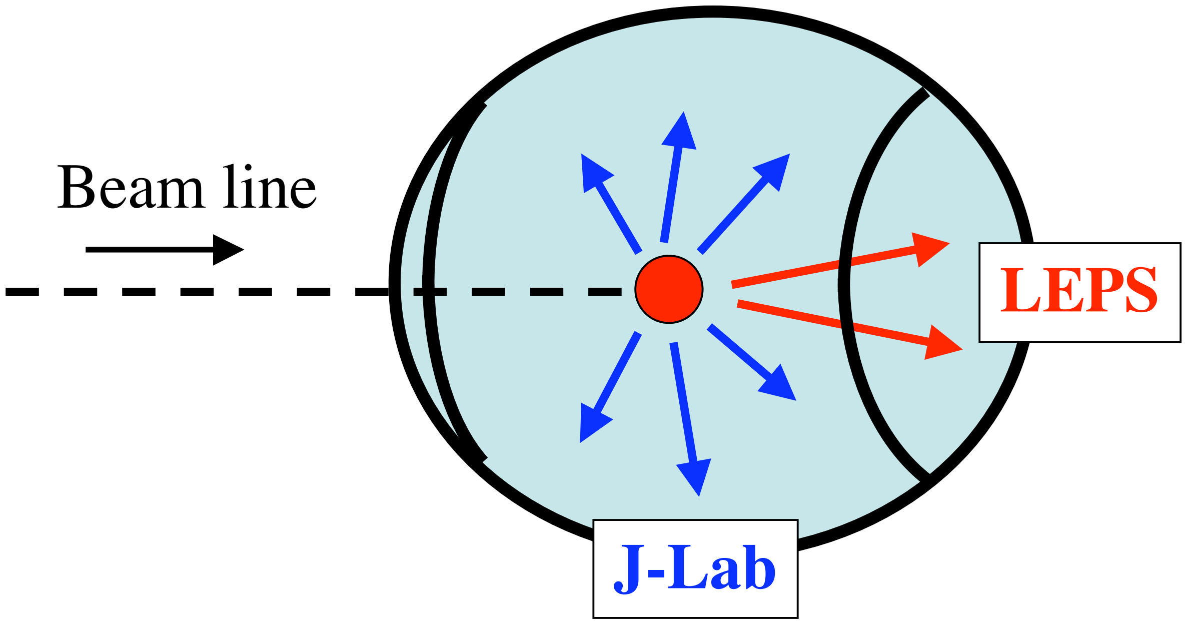
- Hadrons as building blocks of nuclear physics
- Microscopic descriptions needed to extend to the physics under extreme conditions and of various types of hadronic matter
- Chiral symmetry and quarks for structure and reactions

Key issues:

Chiral symmetry
Multiquarks states

LEPS has observed but CLAS does not

LEPS: forward angle region
CLAS: side



Their results are ***not inconsistent***