NOTES ON EXOTIC ANTI-DECUPLLET OF BARYONS

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We emphasize the importance of identifying non-exotic $SU_3(3)$ partners of the $\Theta^+$ pentaquark, and indicate possible ways how to do it. We also use the soliton picture of baryons to relate Reggeon couplings of various baryons. These relations are used to estimate the $\Theta^+$ production cross section in high energy processes. We show that the corresponding cross sections are significantly suppressed relative to the production cross sections of usual baryons. Finally, we present spin non-flip form factors of the anti-decuplet baryons in the framework of the chiral quark soliton model.

1. Introduction

The first independent evidence for the exotic baryon $\Theta^+$ with strangeness +1 in $\gamma^{12}\text{C}$ and $K^+\text{Xe}^2$ reactions, followed by important confirmation in about ten experiments by spring 2004 [3-4,5,6,7,8,9,10], urge us to take a fresh look at baryon spectroscopy. We still know rather little about the properties of the exotic $\Theta^+$, even its very existence is not yet firmly established, see the null experimental results [11]. References to other unpublished no-sighting results can be found in Refs. [12-13]. In Refs. [12-14] it was suggested that the contradiction between pro and contra experiments is due to a particular production mechanism of the $\Theta^+$ through a decay of the cryptoexotic $N^*(2400)$ resonance. Additionally, it was demonstrated in Ref. [14] that the limit put by the BES collaboration on the $\Theta^+$ production in $J/\psi$ decays is considerably higher than one may expect.

In this contribution I am neither going to review the ideas which lead us to the prediction of the $\Theta^+$ [15] nor account for various theoretical ideas about the possible nature of the exotic pentaquarks. For the former I can recommend the reader the talk by D. Diakonov at the APS meeting [16]. For a review of other theoretical ideas see the contribution by K. Maltman to this conference [17]. Here I intend just to stress the importance to search
for non-exotic (cryptoexotic) flavour partners of the $\Theta^+$ pentaquark. As an original contribution, I have decided to include my notes written in 1997. These notes appeared as the result of the discussion with J. Bjorken and J. Napolitano of the possibility to search for the $\Theta^+$ in the LASS data\(^{18}\). Probably today these calculations can be useful to explain why the production of the $\Theta^+$ is suppressed in some of the high energy experiments. Also I include my old notes on the vector and scalar form factors of the anti-decuplet baryons, which can be helpful to understand better the anti-decuplet baryons as they emerge in the chiral quark soliton model.

A very important point is that the discovery of a baryon with positive strangeness would imply the existence of a new flavour multiplet of baryons, beyond the familiar octets and decuplets. The exotic baryon has always to be accompanied by its siblings. The minimal $SU_f(3)$ multiplet containing pentaquarks is the anti-decuplet of baryons. A multiplet containing pentaquarks should also contain baryons with non-exotic “3-quark” quantum numbers. In the case of the anti-decuplet these are: the isodoublet of non-strange “nucleons” and the isotriplet of $S = -1 \Sigma$’s. Are they found among already known baryons or should we look for new states? How to reveal their hidden exoticness? In our view it is very important to identify the non-exotic partners of the $\Theta^+$ pentaquark in order to understand its nature.

To do this one can employ 1) symmetry rules dictated by the flavour $SU(3)$, 2) the dynamical picture of the anti-decuplet baryons. Surprisingly, this topic has not been discussed sufficiently in the literature, although it is as important as the pentaquark itself. Certain studies have been undertaken in e.g. Refs.\(^{19,20,21,22,23,24}\). One of the striking properties of the nucleons from the anti-decuplet is that they can be excited by an electromagnetic probe much stronger from the neutron target than from the proton one\(^{19}\). Sensational evidence for the nucleon resonance with such properties and in the expected mass range\(^{21,22}\) has been reported at this conference by V. Kouznetsov\(^{25}\). Further evidence for this state has been reported by the STAR collaboration\(^{26}\). It could be that for many years we have been overlooking a narrow nucleon resonance with the mass around 1700 MeV! This could be possible due to the unusual properties of this resonance inherited from its anti-decuplet origin. It is expected\(^{15,22}\) that the nucleon from the anti-decuplet has a rather small coupling to the $\pi N$ channel, with the preferred decay channels such as $\pi\pi N, \eta N$ and $K\Lambda$. The existence of such nucleon resonance can be clarified relatively easily with such machines as CEBAF, MAMI, ELSA, etc. As to the $\Sigma$’s from the anti-
decuplet, they are also expected to be relatively narrow, as it follows from the $SU_3(3)$ rules. Such states can be searched for in high energy collisions, although the corresponding production cross section can be rather strongly suppressed, see the next section.

2. Reggeon couplings from the chiral soliton picture

Here we derive the relations between Reggeon couplings to various baryons, including the exotic pentaquark $\Theta^+$. Such kind of relations are useful for estimates of the production cross sections of baryons in high energy processes. We apply these relations to estimate the $\Theta^+$ production cross section in the reaction $K^+p \rightarrow \pi_{fast}^+\Theta^+ \rightarrow \pi_{fast}^+K^+n$ at $p_{lab} = 11.5 \text{ GeV/c}$. The corresponding data were collected by the LASS collaboration, see e.g. Ref. 18.

We restrict ourselves to the spin-flip-dominated production reactions:

- $\pi^- p \rightarrow \pi^0 n$,
- $\pi^+ p \rightarrow \pi^0 \Delta^{++}$,
- $\pi^+ p \rightarrow K^+\Sigma^{*+}(1385)$,
- $K^- p \rightarrow \pi^- \Sigma^{*+}(1385)$,
- $K^+ p \rightarrow \pi^+ \Theta^+$,

Other spin-flip-dominated reactions can be related to these by the (broken) $SU(3)$ relations for the Reggeon couplings, which are known to work well (see Ref. 27). In the chiral quark soliton model the low-lying baryons are different rotational excitations of the same object. This enables us to derive relations between spin-flip Reggeon couplings in the above list of reactions. We shall check the relations between Reggeon coupling from the chiral soliton confronting them with the data on measured reactions from the above list. These relations can be used to estimate the production cross section of the exotic $\Theta^+$ baryon, say, in the reaction $K^+p \rightarrow \pi_{fast}^+\Theta^+ \rightarrow \pi_{fast}^+K^+n$ 18.

We consider here only the spin-flip dominated reactions, since our objective is to estimate the production cross section of the exotic $\Theta^+$ baryon in the reaction $K^+p \rightarrow \pi^+\Theta^+$ which is obviously spin-flip dominated (the spin non-flip part is zero for transitions between baryons from different $SU(3)$ multiplets, this was confirmed by experiment: the spin non-flip part of the amplitude of, say, $\pi^+ p \rightarrow K^+\Sigma^{*+}(1385)$ and $\pi^+ p \rightarrow \pi^0 \Delta^{++}$ reactions is negligibly small). The smallness of the spin non-flip part of the amplitude of the reaction $\pi^- p \rightarrow \pi^0 n$ is related to the large isovector magnetic moment
of the nucleon.

The soliton-Reggeon coupling can be written in terms of the rotational coordinates $R$ of the baryon as (for notations see Ref. 15)

$$3w_0 \frac{1}{2} \text{Tr}(R^l \lambda^m R \lambda_3) \sqrt{-\alpha' t} \cdot \frac{1 - e^{-i\pi \alpha(t)}}{\sin \pi \alpha(t)}.$$  (1)

Here $\alpha(t)$ is the corresponding Regge trajectory and index $m$ denotes the flavour of the leading meson on the corresponding trajectory ($\rho, K^*$).

In the next-to-leading order we have to add to eq. (1) collective operators depending on the angular momentum $J_a$. The corresponding operators have the form:

$$\left[ -i3w_1 \frac{1}{2} d_{3\alpha\beta} \text{Tr}(R^l \lambda^m R \lambda_\alpha) J_\beta - \frac{-i3w_2}{\sqrt{3}} \cdot \frac{1}{2} \text{Tr}(R^l \lambda^m R \lambda_8) J_3 \right] \times \sqrt{-\alpha' t} \cdot \frac{1 - e^{-i\pi \alpha(t)}}{\sin \pi \alpha(t)},$$  (2)

where $d_{abc}$ is the SU(3) symmetric tensor, $\alpha, \beta = 4, 5, 6, 7$ and $J_a$ are the generators of the infinitesimal SU(3) rotations.

Sandwiching eqs. (1,2) between the rotational wave functions of the initial and final baryons (the explicit expressions for the corresponding wave functions can be found in Appendix A of Ref. 15), one gets the following expressions for the $B_1 \rightarrow B_2 + \text{Reggeon}$ vertices in the reactions listed above (we omit the kinematical factors):

$$\rho^- p n$$

$$-i3G_8 \frac{7\sqrt{2}}{30},$$  (3)

$$\rho^+ p \Delta^{++}$$

$$-i3G_{10} \frac{1}{\sqrt{5}} c_3^2 s_3 \frac{1}{2} s_{3;10},$$  (4)

$$\bar{K}^* p \Sigma^{*+}$$

$$-i3G_{10} \frac{1}{\sqrt{15}} c_3^2 s_3 \frac{1}{2} s_{3;10};$$  (5)

$$K^* p \Theta^+$$

$$-i3G_{10} \frac{1}{\sqrt{30}}.$$  (6)
Here we introduced the following coupling constants:

\[ G_8 = w_0 - \frac{1}{2} w_1 - \frac{1}{14} w_2, \]
\[ G_{10} = w_0 - \frac{1}{2} w_1, \]
\[ G_{1\bar{1}0} = w_0 + w_1 + \frac{1}{2} w_2. \]

The constants \( w_i \) can be estimated using the measured high energy processes. We shall be interested in the ratios of various cross sections, therefore for us here only the ratios of these constants are relevant. The structure of the collective operators \((1,2)\) is the same as in the case of the axial and vector currents. The analysis of the corresponding axial and magnetic constants \(^{28,29}\) indicates that the ratios \( w_{1,2}/w_0 \) are negative. Model calculations \(^{29}\) confirm the negative sign of \( w_{1,2}/w_0 \) and give the following values:

\[ \frac{w_1}{w_0} = -0.35 \pm 0.1, \quad \frac{w_2}{w_0} = -0.25 \pm 0.1, \]  

where the errors are added by hands simply on the basis of our working experience with this model. It should be mentioned that the non-relativistic quark model (which, to some extent, can be used as a guiding line) predicts \( w_1/w_0 = -4/5 \) and \( w_2/w_0 = -2/5 \), which is in a qualitative agreement with a more realistic calculation in the quark soliton model. Amazingly, though, these ratios produce exactly zero \( G_{1\bar{1}0} \). At the moment we are unable to point out the deep reason for such cancellation.

Using the equations derived above we can obtain the relations between the cross sections of different spin-flip dominated reaction (the list is given at the beginning of the section). In doing this, we shall assume that these reactions are dominated by the one Reggeon exchange (\( \rho \) and \( K^*\)-trajectories). The first group of relations is simply the \( SU(3)_{fl} \) relations which are known \(^{27}\) to be well reproduced by the experimental data. Given this fact, we shall not discuss this group of relations. The nontrivial prediction of the chiral quark-soliton model is the relations between the high energy reactions which involve baryons from different \( SU(3)_{fl} \) multiplets. These are (for the same incident \( p_{lab} \)):

\[ \frac{\sigma(\pi^+ p \rightarrow \pi^0 \Delta^{++})}{\sigma(\pi^- p \rightarrow \pi^0 n)} = \frac{60}{49} \cdot \frac{(w_0 - \frac{1}{2} w_1)^2}{(w_0 - \frac{1}{2} w_1 - \frac{1}{14} w_2)^2}, \]  

(8)
\begin{equation}
\frac{\sigma(K^+ p \to \pi^+ \Theta^+)}{\sigma(\pi^+ p \to K^+ \Sigma^{*+}(1385))} = \frac{\sigma(K^+ p \to \pi^+ \Theta^+)}{\sigma(K^- p \to \pi^- \Sigma^{*+})} = \frac{3}{4} \left( \frac{w_0 + w_1 + \frac{1}{2} w_2}{w_0 - \frac{1}{2} w_1} \right)^2.
\end{equation}

All other relations can be obtained with the help of the (broken) \textit{SU}(3) relations and hence they are trivial. Eq. (8) can be confronted with experiment, whereas eq. (9) is the prediction. Let us note that the first equation in (9) is a consequence of the assumed exchange degeneracy of Regge trajectories. The exchange degeneracy is in general violated, although not very strongly; for a rough estimate of the \( \Theta^+ \) production cross section it is sufficient to assume the exchange degeneracy.

Using the estimates (7) for \( w_{1,2} \) we obtain:

\begin{equation}
\frac{\sigma(\pi^+ p \to \pi^0 \Delta^{++})}{\sigma(\pi^- p \to \pi^0 n)} \approx 1.2.
\end{equation}

We see that this number is not sensitive to the uncertainties in the determination of \( w_{1,2} \). Let us compare this prediction with the data, Ref. 30 gives:

\begin{equation}
\int_{-0.5}^{0} dt \frac{d\sigma(\pi^- p \to \pi^0 n)}{dt} = 87 \pm 4 \mu\text{barn},
\end{equation}

at \( p_{lab} = 5.9 \text{ GeV/c} \). The \( \Delta^{++} \) production experiment 32 gives:

\begin{equation}
\int_{0}^{0.5} dt \frac{d\sigma(\pi^+ p \to \pi^0 \Delta^{++})}{dt} = 133 \pm 13 \mu\text{barn},
\end{equation}

at \( p_{lab} = 5.45 \text{ GeV/c} \). This cross section can be rescaled to \( p_{lab} = 5.9 \text{ GeV/c} \) using \( \sigma(\pi^+ p \to \pi^0 \Delta^{++}) \sim p_{lab}^{-1.59} \). Eventually we get:

\begin{equation}
\frac{\sigma(\pi^+ p \to \pi^0 \Delta^{++})}{\sigma(\pi^- p \to \pi^0 n)} = 1.35 \pm 0.15 \quad \text{(expt. at } p_{lab} = 5.9 \text{ GeV/c}),
\end{equation}

in a good agreement with our prediction (10). The agreement is even better for experiments at higher energies. The value of \( \sigma(\pi^+ p \to \pi^0 \Delta^{++}) = 44.8 \pm 7 \mu\text{barn} \) measured at \( p_{lab} = 13.1 \text{ GeV/c} \) being divided by \( \sigma(\pi^- p \to \pi^0 n) = 36 \pm 2 \mu\text{barn} \) measured at \( p_{lab} = 13.3 \text{ GeV/c} \) gives:

\begin{equation}
\frac{\sigma(\pi^+ p \to \pi^0 \Delta^{++})}{\sigma(\pi^- p \to \pi^0 n)} = 1.2 \pm 0.1 \quad \text{(expt. at } p_{lab} \approx 13 \text{ GeV/c}).
\end{equation}
We see that the chiral soliton model successfully predicts non-trivial relations between Reggeon couplings to baryons from different multiplets.

Given this success, we turn now to the estimate of the \( \sigma(K^+p \rightarrow \pi^+\Theta^+) \).

From eq. (9) and the estimates of \( w_{1,2} \) (7) we get:

\[
\frac{\sigma(K^+p \rightarrow \pi^+\Theta^+)}{\sigma(\pi^+p \rightarrow K^+\Sigma^{*+}(1385))} = \frac{\sigma(K^+p \rightarrow \pi^+\Theta^+)}{\sigma(K^-p \rightarrow \pi^-\Sigma^{*+})} = 0.05 \div 0.25, \quad (15)
\]

we see that in this case the result is very sensitive to the uncertainties of \( w_{1,2} \) due to the deep cancellation of these constants. With the present state of art we can not say precisely how deep is this cancellation, but in any case we can conclude that the suppression is rather strong. We note that the estimate of the ratio (15) on the upper side of 0.25 is really the highest number one can get, whereas on the low side the cancellation can be much deeper.

In order to estimate the absolute value of \( \sigma(K^+p \rightarrow \pi^+\Theta^+) \) at \( p_{\text{lab}} = 11.5 \) GeV/c \(^{18} \) we need the value of \( \sigma(\pi^+p \rightarrow K^+\Sigma^{*+}(1385)) \) or \( \sigma(K^-p \rightarrow \pi^-\Sigma^{*+}) \) at the same \( p_{\text{lab}} \). Fortunately these cross sections were measured exactly at \( p_{\text{lab}} = 11.5 \) GeV/c with the results \(^{33} \):

\[ \sigma(\pi^+p \rightarrow K^+\Sigma^{*+}(1385)) \approx 8 \mu\text{barn}, \]

and \(^{34} \)

\[ \sigma(K^-p \rightarrow \pi^-\Sigma^{*+}) \approx 10.1 \pm 1.1 \mu\text{barn}. \]

A slight difference in the above two cross sections is related to the violation of the exchange degeneracy of the \( K^* \) and \( K^{**} \) trajectories. From the above data and with the help of eq. (15) we get the estimate:

\[
\sigma(K^+p \rightarrow \pi^+\Theta^+) \approx 0.5 \div 2.5 \mu\text{barn}. \quad (16)
\]

We see that the \( \Theta^+ \) production cross section is rather small.

Let us note that the above estimate of the \( \Theta^+ \) production cross section should be considered as an order of magnitude estimate (up to a factor of 2). In the course of derivation we have neglected:

- The violation of the exchange degeneracy of the Regge trajectories. This could give an uncertainty about 20-30%.
- The mass dependence of produced particle on the Reggeon parameters, \( e.g. \) we take the scale parameters \( s_0 \), the parameter in the Reggeon residue, etc. to be universal (= \( \alpha' \)) following the
Veneziano model pattern. This could give an uncertainty about 30-40%.

Further we note that the estimates of Reggeon couplings presented here can be used for the calculations of the $\Theta^+ X$ yields in inclusive high energy processes such as $pp \rightarrow \Theta^+ X$, especially in the triple Reggeon limit.

3. Vector and scalar form factors of the anti-decuple baryons

Here we consider baryon spin non-flip form factors of exotic anti-decuple baryons. We give relations between various form factors in the chiral quark soliton model neglecting the $SU_3(3)$ breaking effect, since our aim just to get an idea about the qualitative behaviour of these form factors. The effects of symmetry breaking can be easily added. We introduce notations:

$$
(B|\bar{\psi} f \Gamma \psi|B) = F^{(B)}_f(t),
$$

where $f$ denotes quark flavour, $\Gamma = \gamma_0$ or $\Gamma = 1$ are the Dirac matrices corresponding to the spin non-flip vector and scalar form factors, $t$ is the momentum transfer squared. In the chiral quark soliton model one can write a universal operator in the collective coordinate space. This operator can be parametrized in terms of three universal form factors. Therefore we can relate $F^{(B)}_f(t)$ for baryons from various multiplets. Let us just list some of these relations:

**Octet baryons**

$$
F_u^{(\Lambda)} = F_d^{(\Lambda)} = \frac{1}{6} \left( 4F_d^{(p)} + F_u^{(p)} + F_s^{(p)} \right),
$$

$$
F_s^{(\Lambda)} = \frac{1}{3} \left( 2F_d^{(p)} + 2F_u^{(p)} + 2F_s^{(p)} \right),
$$

$$
F_u^{(\Sigma^+)} = F_u^{(p)}, \quad F_d^{(\Sigma^+)} = F_s^{(p)}, \quad F_s^{(\Sigma^+)} = F_d^{(p)},
$$

$$
F_u^{(\Xi^0)} = F_d^{(p)}, \quad F_d^{(\Xi^0)} = F_s^{(p)}, \quad F_s^{(\Xi^0)} = F_u^{(p)}.
$$

We do not specify $\Gamma$ in the form factors as the relations presented below are fulfilled both for vector and scalar form factors.

$^{a}$Its form is similar to the mass operator written in Ref. 15
Anti-decuplet

\[ F^{(\Theta^+)}_u = F^{(\Theta^+)}_d = \frac{1}{12} \left( 8F^{(p)}_d + 8F^{(p)}_u - 7F^{(p)}_s \right) \quad (22) \]

\[ F^{(\Theta^+)}_s = \frac{1}{6} \left( -2F^{(p)}_d + 2F^{(p)}_u + 13F^{(p)}_s \right) \quad (23) \]

\[ F^{(p^*)}_u = \frac{1}{12} \left( 8F^{(p)}_d + 8F^{(p)}_u - 7F^{(p)}_s \right) \quad (24) \]

\[ F^{(p^*)}_s = \frac{1}{3} \left( F^{(p)}_d + F^{(p)}_u + F^{(p)}_s \right) \quad (25) \]

\[ F^{(p^*)} = \frac{5}{4} F^{(p)}_s \quad (26) \]

\[ F^{(\Xi^+)}_u = \frac{1}{12} \left( 8F^{(p)}_d + 8F^{(p)}_u - 7F^{(p)}_s \right) \quad (27) \]

\[ F^{(\Xi^+)}_d = \frac{1}{6} \left( -2F^{(p)}_d + 2F^{(p)}_u + 13F^{(p)}_s \right) \quad (28) \]

\[ F^{(\Xi^+)}_s = \frac{5}{4} \left( 8F^{(p)}_d + 8F^{(p)}_u - 7F^{(p)}_s \right) \quad (29) \]

All other relations can be easily obtained with the help of the U-, V- and isospin symmetries.

The detailed analysis of the above relations will be presented elsewhere. Here we just note that, if we neglect the strange form factor of the proton, the typical radius of the \( \Theta^+ \) is \( \sqrt{r^2_p + r^2_n} \). Here \( r^2_{p,n} \) are the electromagnetic radii of the proton and the neutron. In other words, it seems that \( \Theta^+ \) is a compact object. For instance its electric form factor is given in terms of the electric form factors of the nucleons as \( G_E^{\Theta^+}(t) = G_E^p + G_E^n - \frac{1}{3}G_E^c \) (we remind that the breaking of the \( SU_\alpha(3) \) is not taken into account). It is also very interesting that the strange quark distribution in the anti-decuplet nucleon follows (up to the factor 5/4) the distribution of the strange quarks in the usual nucleon, suggesting that the additional \( s \) and \( \bar{s} \) in the \( p^* \) “sit” close to each other.

References

1. T. Nakano (LEPS Collaboration), Talk at the PANIC 2002 (Oct. 7, 2002, Osaka); T. Nakano et al., Phys. Rev. Lett. 91, 012002 (2003), [hep-ex/0301020].

2. V.A. Shebanov (DIANA Collaboration), Talk at the Session of the Nuclear Physics Division of the Russian Academy of Sciences (Dec. 3, 2002, Moscow);

\*As it follows from the U-spin symmetry the same relations hold for the electric form factors of the \( p^* \) and \( \Xi^+ \).
V.V. Barmin, A.G. Dolgolenko et al., Phys. Atom. Nucl. 66, 1715 (2003) [Yad. Fiz. 66, 1763 (2003)], [hep-ex/0304040].
3. S. Stepanyan, K. Hicks et al. (CLAS Collaboration), Phys. Rev. Lett. 91, 252001 (2003); V. Kubarovsky et al. (CLAS Collaboration), Phys. Rev. Lett. 92, 032001 (2004), [hep-ex/0311046].
4. J. Barth et al. (SAPHIR Collaboration), Phys. Lett B 572, 127 (2003), [hep-ex/0307083].
5. A. E. Asratyan, A. G. Dolgolenko and M. A. Kubantsev, Phys. Atom. Nucl. 67 (2004) 682 [Yad. Fiz. 67 (2004) 704] [arXiv:hep-ex/0309042].
6. A. Airapetian et al. (HERMES Collaboration), Phys. Lett. B 585, 213 (2004), [hep-ex/0312044].
7. A. Aleev et al. (SVD Collaboration), [hep-ex/0401024].
8. M. Abdel-Bary et al. (COSY-TOF Collaboration), [hep-ex/0403011].
9. P.Zh. Aslanyan, V.N. Emelyanenko, G.G. Rikhvitzkaya, [hep-ex/0403044].
10. S. Chekanov et al. (ZEUS Collaboration), [hep-ex/0403051].
11. J. Z. Bai et al. [BES Collaboration], hep-ex/0402012.
12. M. Karliner and H. J. Lipkin, arXiv:hep-ph/0405002.
13. J. Pochodzalla, arXiv:hep-ex/0406077.
14. Y. I. Azimov and I. I. Strakovsky, arXiv:hep-ph/0406312.
15. D. Diakonov, V. Petrov and M. Polyakov, Z. Phys. A 359, 305 (1997), [hep-ph/9703373].
16. D. Diakonov, arXiv:hep-ph/0406043.
17. K. Maltman, contribution to this conference;
18. J. Napolitano, J. Cummings and M. Witkowski, “Baryon excitation in K±p reactions,” PIN Newslett. 13 (1997) 276.
19. M. V. Polyakov and A. Rathke, Eur. Phys. J. A 18 (2003) 691 [arXiv:hep-ph/0303138].
20. R. L. Jaffe and F. Wilczek, Phys. Rev. Lett. 91 (2003) 232003 [arXiv:hep-ph/0307341].
21. D. Diakonov and V. Petrov, Phys. Rev. D 69 (2004) 094011 [arXiv:hep-ph/0310212].
22. R. A. Arndt, Y. I. Azimov, M. V. Polyakov, I. I. Strakovsky and R. L. Workman, Phys. Rev. C 69 (2004) 035208 [arXiv:nucl-th/0312126].
23. T. D. Cohen, arXiv:hep-ph/0402056.
24. L. Y. Glozman, arXiv:hep-ph/0309092.
25. V. Kouznetsov [for the GRAAL collaboration], contribution to this conference;
see also: V. Kouznetsov, talk at international workshop Pentaquark states: structure and properties, February 10 - February 12, 2004, Trento, Italy.
http://www.tp2.rub.de/talks/trento04/index.html
26. S. Kabana [STAR Collaboration], arXiv:hep-ex/0406032.
27. A. C. Irving and R. P. Worden, Phys. Rept. 34 (1977) 117.
28. H. C. Kim, M. Praszalowicz and K. Goeke, Phys. Rev. D 61 (2000) 114006
   [arXiv:hep-ph/9910282].
29. H. C. Kim, M. Praszalowicz, M. V. Polyakov and K. Goeke, Phys. Rev. D
   58 (1998) 114027 [arXiv:hep-ph/9801295].
30. Stirling, et al., Phys. Rev. Lett. 14 (1965) 763.
31. J.H. Scharenguivel, et al., Nucl. Phys. B36 (1972) 363.
32. I.J. Bloodworth et al., Nucl. Phys. B81 (1974) 231.
33. P.A. Baker, J.S. Chima, P.J. Dornan, D.J. Gibbs, G. Hall, D.B. Miller, T.S.
   Virdee, A.P. White, Nucl. Phys. B166 (1980) 207;
   J. Ballam, J. Bouchez, et al., Amplitude analysis of $Y^+(1385)$ production in
   the line reversed reactions: $\pi^+p \to K^+Y^+(1385)$ and $K^-p \to \pi^-Y^+(1385)$
   at 7-GeV/c and 11.5-GeV/c., SLAC-PUB-2175, Aug 1978. 18pp. Contributed
   paper to 19th Int. Conf. on High Energy Physics, Tokyo, Japan, Aug 23-30,
   1978.
34. J. Ballow et al., Phys. Rev. Lett. 41 (1978) 676.