WHY POLARIZED PHOTONUCLEAR ABSORPTION SUM RULES COULD BE INTERESTING?

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Introduction: The past experience

The observed effects of the spin-dependent asymmetries in the static electromagnetic characteristics of hadrons, such as parameters of form-factors or coefficients of the electromagnetic polarizability, or in characteristics of processes induced by lepton- or photon-hadron interactions, e.g., total or partial cross sections, are known as very useful means to study and to understand the underlying dynamics. The sum rules, in turn, have long served as a reliable constraints on, or relations between measured quantities, depending only on most general principles and statements of the theory. In this work we shall concentrate mainly on two topics: the sum rules for static electromagnetic characteristics of hadrons with higher spins and the role of the dynamical short-range correlations of nuclear constituents in description of the behavior of the total and polarized photonuclear or photon-nucleon cross section.

Introduction: The past experience

Turning round, one can notice the earlier author's works (S.G.,1965,1967) devoted to derivation of the sum rules relating the static particle characteristics (mass, electric charge and magnetic moment) with integrals of the polarized total photoabsorption cross section for particles of any spin. Approximately the same time first application of these sum rules were made to photonuclear absorption on the two- and three-nucleon nuclei, and even on somewhat artificial "nuclear" system represented by the filled Fermi-sphere with one odd nucleon beyond it to get impression of the role of Pauli-blocking in the "quenching" of the odd nucleon magnetic moment. Needless to explain that all numerical estimations were based on by far insufficient data and oversimplified assumptions and should not considered too seriously.

Introduction: The past experience

We write down the GDH sum rule for arbitrary spin J in a compact form (P.Hoodbhoy, 1990) based in turn on the explicit form of low-energy theorem up to $\mathcal{O}(\nu^3)$ and arbitrary spin (K.Lin, 1971)

$$\frac{4\pi^2\alpha}{M^2}(\mu-1)^2 J = \int_0^\infty \frac{d\nu}{\nu}(\sigma_{+J}-\sigma_{-J}),$$

where μ is the magnetic moment measured in units of $Q/(2M)$, Q and M being the total charge and mass of the target.
$[I] = \mu b$: $203(p); 231(n); .16(d); 30.7(He-3); .11(Li-6)$
$3.64(Li-7); 4.27(^{17}F_9)$.

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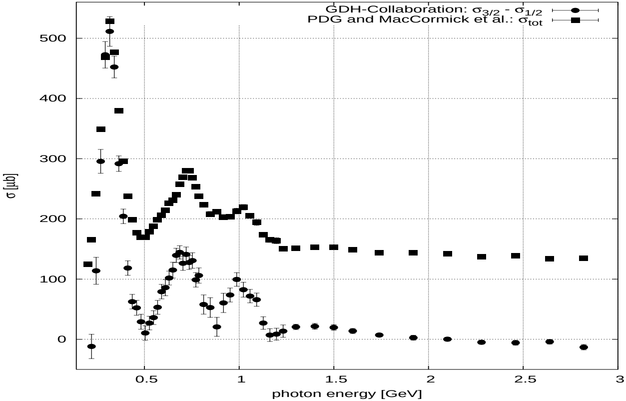

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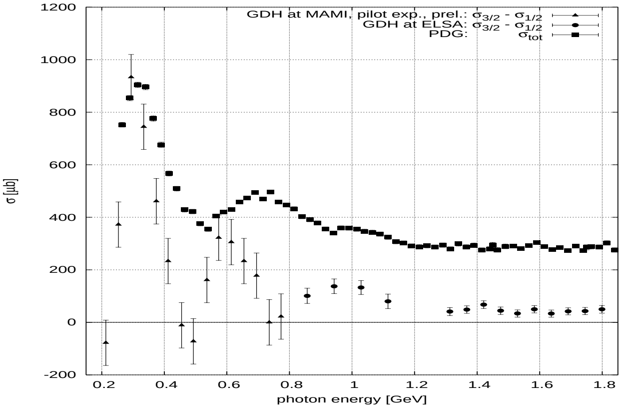

Introduction: The past experience

The GDH relation for the real photon absorption serves as the $Q^2 \to 0$-limit for the integral over the spin-dependent structure functions describing the polarized forward scattering of the virtual photon on the same target. For example, for the proton polarized target

$$I_1(Q^2) = \frac{2M^2}{Q^2} \int_0^{x_0} g_1(\nu, Q^2) dx \to -\frac{1}{4}\kappa_N^2,$$

The behavior of the difference $\sigma_{-J}(\nu, Q^2) - \sigma_{+J}(\nu, Q^2)$ is illustrated for several values of Q^2. The crossing-zero-value can be qualitatively interpreted as the transition from the coherent scattering off the nucleon in the resonance region to the incoherent interaction with the point-like nucleon constituents.

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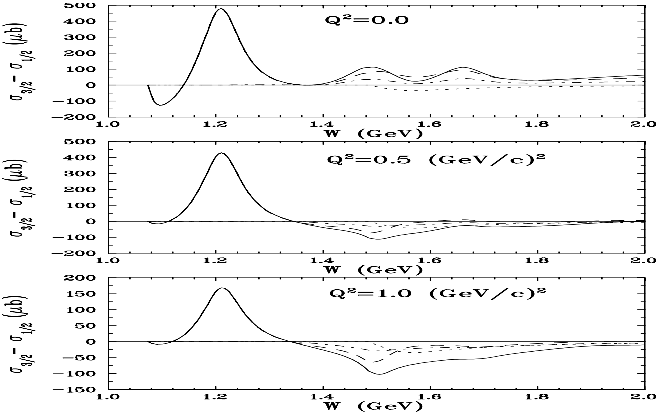

Introduction: The past experience

Among a number of phenomena providing a means to probe the quark-gluon effects in nuclei the most detailed discussed one is the EMC effect, continuing to be under study since 1983 up to present time.

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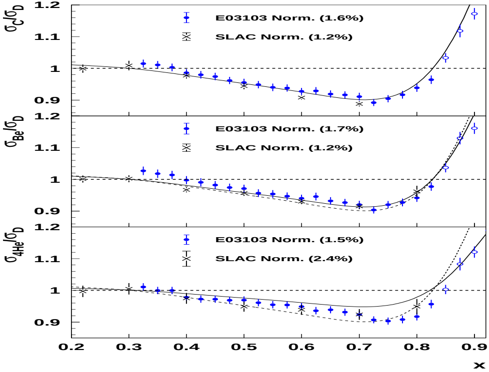
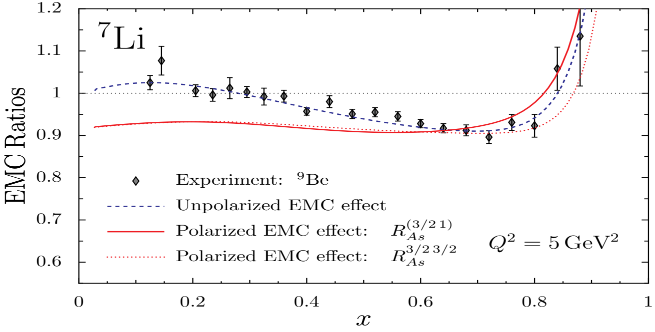


Introduction: The past experience

The efforts to understand the depletion of the in-medium spin-independent nucleon structure functions in the valence quark region, relative to the free structure functions via the nuclear binding corrections at the nucleon level seem to be abandoned in favor of a change in the internal structure of the nucleon-like quark clusters in nuclei.

Introduction: The past experience

The model for the spin-dependent EMC effect (Cloet,Bentz,Thomas, 2006)



Introduction: The past experience

Photoabsorption on the free nucleons demonstrates a prominent excitation by incident 0.2–0.5 GeV-photons of the $\Delta(1232)$ resonance. The "second resonance" region of partly overlapping $P_{11}(1440)$, $D_{13}(1520)$, and $S_{11}(1535)$ resonances (E_γ=0.5-0.9 GeV), and a third resonance region are also visible in photoabsorption experiments on the free nucleon but they seem to have disappeared in the total photonuclear absorption cross sections.

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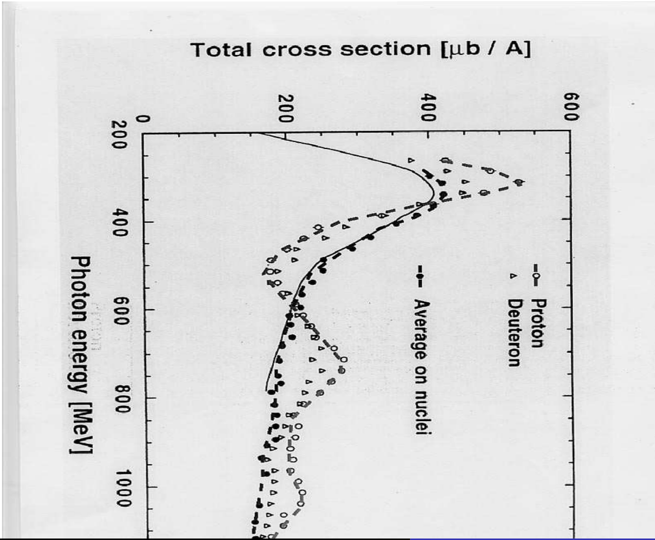

Introduction: The past experience

The simplest medium modification is the broadening of the excitation functions due to the Fermi motion. The decay of the resonances is further modified by Pauli-blocking of final states, which reduces the resonance widths. The decay channels inside the nuclear matter like $N^{\star} + N \to N + N$ cause collisional broadening of the photo-produced resonances. Both mentioned effects could diminish each other to some extent. All these effects have been extensively discussed in literature (e.g., L.A. Kondratyuk, et al. (1994)). In addition to mentioned and more or less evident nuclear medium effects, the subtler influence of the interference effects of the two-pion in-medium photoproduction amplitudes were also proposed as the important reasons for the suppression of the resonance structure (Hirata, et al, 2001). The considered dynamics is illustrated by a few diagrams.

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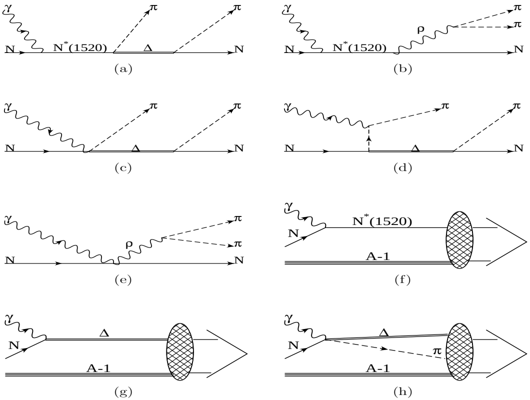

The Future: Perspectives

$$A_{\pm} \sim \sum_{res} \int d^3 p R(\vec{p})((A^{res}_{3/2})^2 \pm (A^{res}_{1/2})^2) G^{-1},$$

$$G = [(p+k)^2 - (M + \delta M)^2 + \imath M(\Gamma_0 B_F + \Gamma^*)]$$

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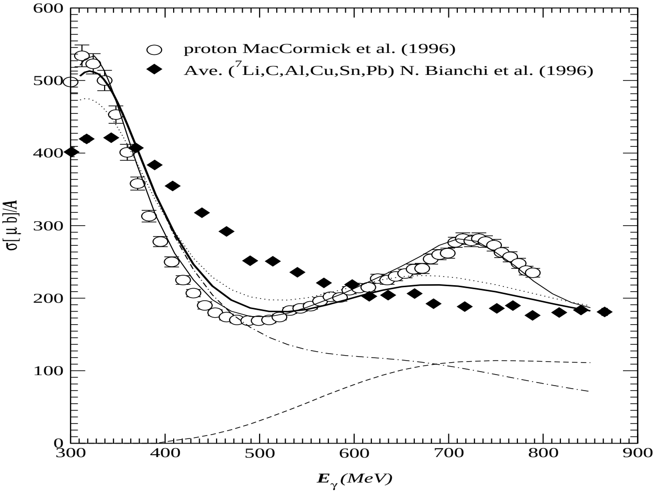

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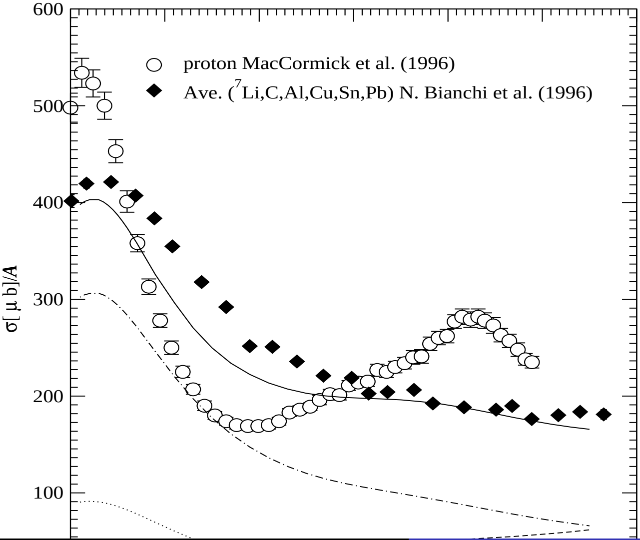

Introduction: The past experience

The "Universal Curve" for the total photonuclear absorption cross section per nucleon describes data for nuclei from Li-to-Pb reasonably well. However it describes not so well the photofission data for the heaviest actinide nuclei, if one identifies $\sigma_{fiss} \simeq \sigma_{tot}$. The photoabsorption cross section for these nuclei should be obtained with the help of the fissility coefficient W_f calculated on the base of the MC nuclear cascade-evolution model. However even in this case a reasonable agreement with the "universal" curve for $\sigma(E_\gamma)/A$, where $A \leq 208$, is reached only for $E_\gamma \geq 0.8\ GeV$, while the results for the heavy actinides are $\sim 20\%$ higher in the region of the $\Delta(1232)$ resonance.

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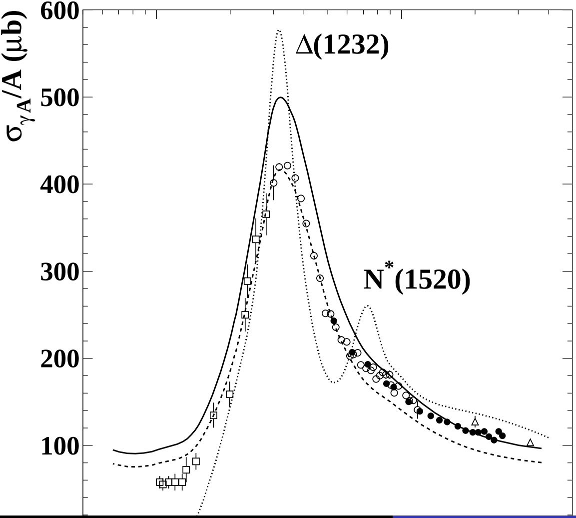
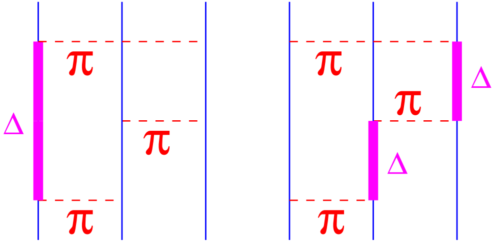


The Present: More correlation

The successful *ab initio* evaluation the energies of the ground and a few first excited states of light nuclei ($A \leq 10$) proved the necessity of inclusion of the three-nucleon interaction into exact Schroedinger equation besides the most reliable two-nucleon potentials. The spin-polarized one-nucleon and some two-body density distributions were also presented thus providing first microscopic calculations producing nuclear shell-structure from realistic calculations that fit NN scattering data. Additional quantitative information about the probabilities and spatial extension characteristics of the short-range pair- and triple-nucleon correlations have been obtained in the JLab experiments (Egiyan, *et al.*, 2006) on high-energy electron-nuclei scattering.

The Present: More correlation

Concerning the 3N-forces, many modern models keep basic idea (Fujita and Miyazawa, 1957) of the involvement of the intermediate $\Delta(1232)$-resonance in the producing the genuine "irreducible" 3-body interaction This represented schematically in the following figure.



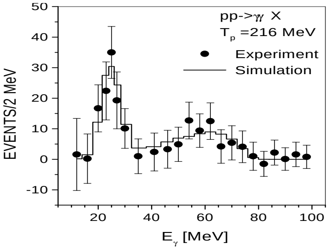
The Present: More correlation

The main idea of this part of my presentation is to draw attention on the inelastic Compton scattering off nuclei as the alternative means of investigation of the short-range pair- and triple-nucleon correlations inside atomic nuclei. The specific features of the participation of the non-nucleonic constituents in the formation of these correlations are stemming from our interpretation of the observed specific features of the experimental data on the double-photon production in the proton-proton collisions below the pion-production threshold (JINR,2001).

The Present: More correlation

Before the experiment for the searching the nonstrange, multiquark NN-decoupled dibaryons was launched and finished, the new experimental method using the two-photon mechanism of the production and subsequent decay of the NN-decoupled resonance(s) in proton-proton collisions was proposed (S.G.,A.Khrykin, 1993) and the specific experimental signature of the production and decay of narrow dibaryon , having mass below the pionic decay modes, was indicated and discussed. On the basis of this method, the specific structure in the spectrum of final photons which was later observed and interpreted as the production and decay of the narrow dibaryon (called $d_1^*(1956)$ with the mass M(d_1^*)=1956 $\pm$ 6 MeV.

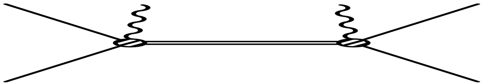
The Present: More correlation



The narrowness of the "first" peak in the photon energy-distribution is reflected in the narrowness of the dibaryon width. Most natural explanation is that quantum numbers $J^P = 1^+$ prevent the resonance from decaying into two protons due to the Pauli principle while the pionic decays are impossible energetically.

The Present: More correlation

The diagram below with the double line representing an intermediate $d_1^*(1956)$ resonance



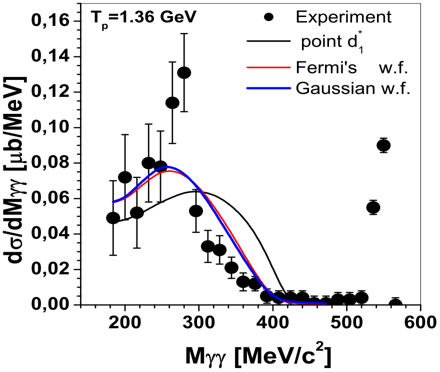
may serve as an illustration to different processes.Evidenly, if all nucleons are bound inside nuclei, it may be considered as the photon scattering on the correlated pair of nucleons in a nucleus, or just as the Compton scattering on the deuteron; at last, if the photon lines are replaced by any meson lines landing on some third nucleon then this diagram can be referred as depicting the part of the three-body forces beyond discussed up to now and, possibly, correcting the discussed shortages of existent models of V_{ijk}-potentials!

The Present: More correlation

The existence of the $d_1^*(1956)$ leads to new phenomena - the imitation of the production in the nucleon-nucleon or nuclear reactions and subsequent two-photon decay of a relatively narrow ($\Gamma_{tot} \leq 10 \div 100$) meson. In this case, the location of the quasi-resonance structure depends on the initial nucleon energy and on the experimental geometry and cuts in the final particle regisration. In particular, our explanation of the "unexpected" resonance structure observed in the exclusive reaction $pp \rightarrow pp\gamma\gamma$ (CELSIUS-WASA Collab) via the radiative production of $d_1^*(1956)$ gives further evidence of its existence.

The Present: More correlation

The results of calculations represented graphically were based on the assumption of the dominant $N\Delta(1232)$-configuration for the $d_1^*(1956)$-resonance.



The Present: More correlation

In view of available data and planned experiments on the $\gamma d \to \gamma d$ reaction we stress its utility to inquire on new information and/or constraints on characteristics of $d_1^\star(1956)$, in this "formation-type" resonance excitation process. We focus here on the $d_1^\star(I = 1, J^P = 1^+)$-resonance and present some additional comments aiming to attract more attention to the specifics of the explication of this resonance in the energy range pertinent to the forthcoming new data on the Compton scattering from deuteron and $He - 3$. We have in view the ongoing investigation of the γd -reaction in MAXLab, where the tagged-photon facility will be used to measure the scattered photon angular distribution between 60^o and 150^o over the photon energy range $60 \div 115$ MeV in 5 MeV steps.

The Present: More correlation

Below we give the estimation of the contribution of the photoexcitation of $d_1^\star$ into the averaged differential γd -scattering cross-section around the photon energies close to $\omega_{lab}^{res} \simeq 82MeV$, the resonance photoexcitation energy of $d_1^\star(1956)$. The data of the SAL Collaboration (SAL,Canada, 2000) on γd -scattering at $\omega_{lab} \simeq 94MeV$ have the scale of 12-18 nb/sr, with variations of approximately 2 nb/sr in energy bins of $\Delta W \simeq 3MeV$. The distance of their energy from the presumed $\omega_{lab}^{res} \simeq 82MeV$ is much larger than $\Gamma_{tot}(d_1^\star)$ and this enables one to get an upper bound of $\Gamma(d_1^\star \to \gamma d) \leq 5KeV$ which is rather weak one. Much stronger bounds will follow from the forthcoming data of MAXLab measurements in the resonance region $\omega_{res} \pm 2 \simeq 82 \pm 2$ MeV .

The Present: More correlation

For instance, if we take maximally large $BR(d_1^\star \to \gamma d) = 1$ then the resonance enhancement of the cross-section, averaged over $\Delta W \simeq 3MeV$, by amount,say,of $5 \cdot \delta < d\sigma/d\Omega >= 10nb/sr$ will result in the total width estimate of $\Gamma_{tot}(d_1^\star) \simeq 1\ eV$. Hence, either $\Gamma_{tot}(d_1^\star)$ acquires the values of the order of $\mathcal{O}(eV)$, as estimated within the soliton model of the narrow NN-decoupled dibaryons (V.Kopeliovich,1995), or the $BR(d_1^\star \to \gamma d) \ll 1$, which would still need proper dynamic justification.

The Present: More correlation

Returning to the discussed $pp - 2\gamma pp$ -processes exhibiting the positive signs of the $d_1^\star(1956)$ excitation and decay, it is natural to expect that the effective strength in the vertex $\mathcal{V}((pp)_{J^P,I=1};\gamma;d_1^\star)$ may be quite different (in fact, higher) as compared to effective coupling in the vertex $\mathcal{V}(d_{J^P=1^+,I=0};\gamma;d_1^\star)$. This will result in a quantitatively different effect of the resonance explication in the Compton scattering on ^3He or on ^4He comparatively to the Compton scattering on deuteron target. This means, therefore, that the resonance effect should be estimated and properly taken into account in the extraction of the neutron polarizabilities from the planned studies of the elastic γ^3He -scattering, either in the polarization independent experimental set-up or in experiments aiming to measure the spin-dependent electromagnetic polarizabilities which are under preparation at TUNL(USA)

The Future: Perspectives

We briefly discuss here the question of probable $d_1^*(1950 \div 1960)$ quantum numbers.

•. Among theoretical models not appealing to constituent quark dynamics and predicting dibaryon resonances with different masses there is one giving the state with $IJ^P = 11^+$ and the mass value $(\sim 1940 MeV)$ surprisingly close to the value $(\simeq 1956 MeV)$ extracted from the observed maximum of the $pp \to pp2\gamma$-reaction. This is the chiral soliton model (V.Kopeliovich, 1995) applied to the sector with the baryon number $B = 2$. The theoretical uncertainty at the level of $\pm 30 MeV$ might be taken here because the model gives this numerical (unrealistic) value for the mass difference of the deuteron and the singlet level.However the estimated radiative width of the order $\sim \mathcal{O}(eV)$ may seem to be too low.

The Future: Perspectives

•. There is also a kind of the hadron-constituent oriented models, *e.g.*, the relativistic dynamic πNN-interaction model based on the Faddeev-type equations with the specifically chosen ansatz for the off-mass-shell pion-nucleon interaction amplitude (Matsuda,1997). Specific feature of the last-mentioned approach is the statement about the relative orbital moment $l = 1$ and isospin $I = 2$ for the most strongly bound cluster configuration $P_{33}(\pi N) + N$ of the considered three-body πNN-system. Yet the estimated resonance mass is different from the value suggested by experiment.

The Future: Perspectives

• The quantum numbers of relevant dibaryons within the 3-diquark model, which are consistent with the Bose-nature of diquarks and $L = 0$ for total orbital moment, require two axial-vector $(J^P = 1^+)$-diquarks with isospin $I = 1$ and one (iso)scalar diquark $(J^P = 0^+)$.This model gives the following combinations of the total spin and isospin for the lowest mass dibaryons: $(I = 1, J = 0$, *i.e.*, the quantum numbers of the "virtual" NN-state), $(I = 0, J = 1$, *i.e.*, the quantum numbers of the deuteron), $(I = 2, J = 1$ - the exotic, NN-decoupled quantum numbers for narrow dibaryon) $(I = 1, J = 2$ coinciding with the quantum numbers of known ${}^1D_2(2.17)$ -resonance, lying close to the $N\Delta$-threshold). The overlap of possible NN-decoupled quantum numbers with $L = 0$ following from either $N\Delta$- or diquark model select as more probable isospin and spin values $I = 2, J = 1$ for our low-lying d_1^*-resonance.

The Future: Perspectives

• One can escape a potentially problematic situation with the long-lived iso-tensor ($I = 2$) dibaryon if one unites one axial-vector diquark (A_2) and one scalar diquark (S_2) into a single four-quark cluster ($A_4 = S_2 \otimes A_2$) which should be the color-triplet iso-vector ($I = 1$) and spin-parity $J^P = 1^+$. Hence, as most perspective we would suggest for $d_1^\star(1956)$ the following configuration structure:
$|d_1^\star(1956) >= c_0|N, \Delta > +c_{\bar{3}_c 3_c}|S_2(\bar{3}_c, 0^+), A_4(3_c, 1^+) >.$
The presence of the color-octet 3q-baryons is associated in with the antisymmetric radial wave function, hence with the negative parity and,therefore, we drop it. Of course, the deciphering and testing of such a complex structure would require further development of the theory and new experimental data.

The Future: Perspectives

At last, our recommendations:

• The continuation of experimental program with polarized photon(lepton) beams and polarized light nuclei targets $({}^3He, {}^7Li, ..)$ is highly desirable for discrimination between models describing "disappearance" of the resonance maxima in the unpolarized γA cross sections

• The behavior of the inelastic Compton scattering on the deuteron and helium-3 nuclei scrutinized around photon energy $\nu_{lab} = 80$ MeV should be investigated.

• The theoretical consideration of possible role of $d_1^\star(1956)$ in the 3N-forces is very desirable.