On the evidence for exotic dibaryon $d_1{}^*(1956 \pm 6)$ in selected two-nucleon-two-photon reactions and related problems

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Consider peculiarities, they solely have the significance.
Gaston Jiulia

(from L.Gårding, T.Kotake and J.Leray, "The Cauchy Problem").

Contents:

1. Multiquark systems involve more complicated colour sub-systems which cannot be studied in simplest meso and baryon systems. Therefore multi-q's are principally important for a full study of the low energy typical hadronic-scale behavior of QCD and the structure of strongly interacting matter. The theory of strong interaction, QCD, is still unable to predict the properties of the multiquark systems such as nuclei or other possible bound states of hadron clusters. Even in the simplified case of $SU(2)$ gauge symmetry, the lattice calculation of the four-static-quark systems are still in the beginning phase (British and Finnish Groups) though the results obtained for the considered mutual locations of two quarks and two antiquarks show the principally important effects of mutual screening of gluon flux-tubes connecting the quarks.

This tell us that explicit gluon degrees of freedom seem should to be involved in the description of all such the multiquark states. Therefore the reliable experimental identification of even one multiquark state, *e.g.*, the long-sought-for six-quark dibaryon, would play the role of the necessary prompting for theory.

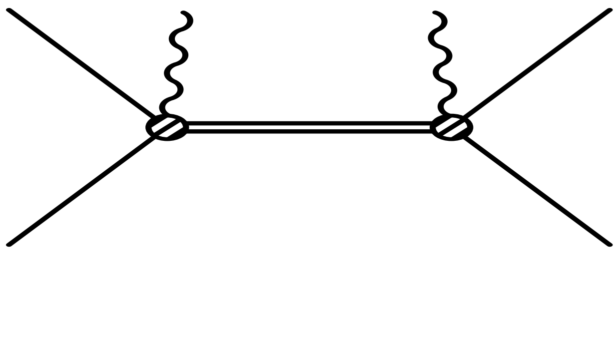
The nonstrange NN-decoupled dibaryons with small widths could be the most promising and easy for experimental searches.

2. The Dib2γ Collab. initiatives (1993-1995) and the results (2001):

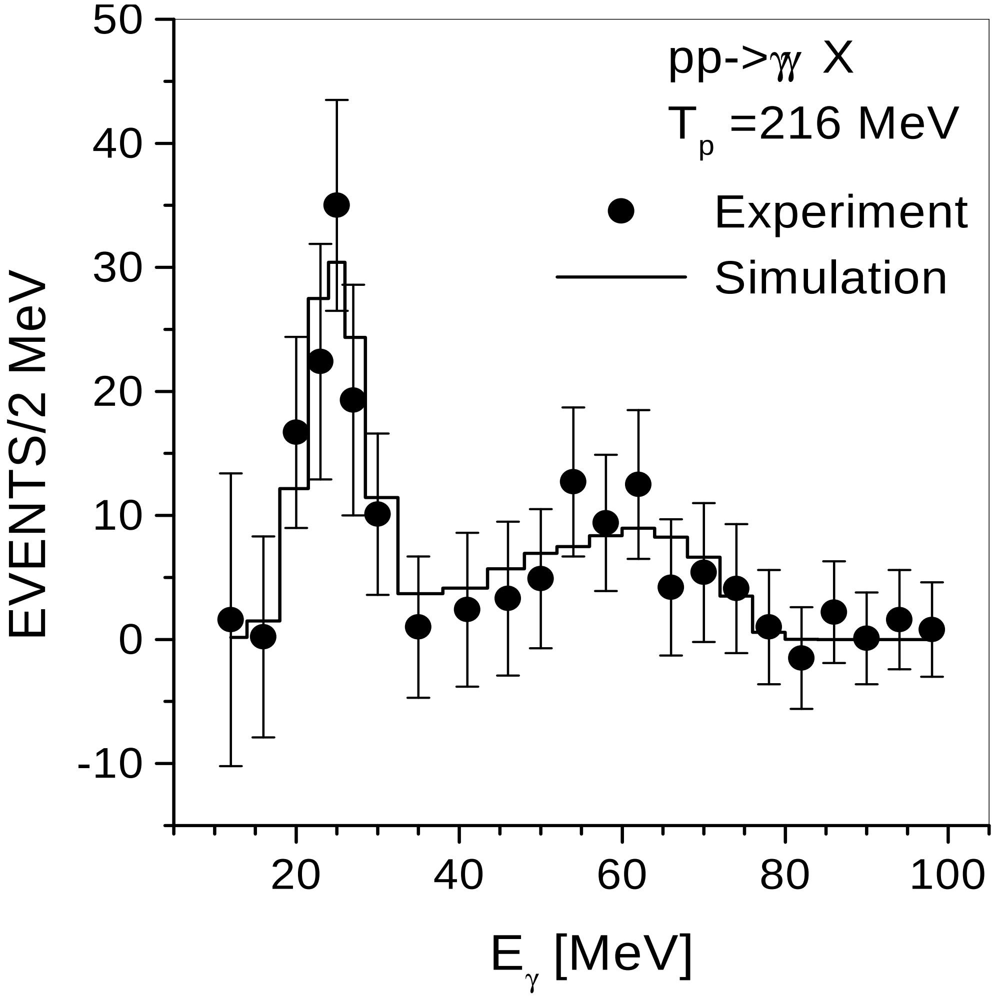
(1)S.B. Gerasimov and A.S. Khrykin, Mod.Phys.Lett.A8 (1993) 2457
"Can Nucleon-Nucleon Bremsstrahlung Shed More Light on Narrow Di-Nucleon Structures?",

(2)S.B.Gerasimov, S.N.Ershov and A.S.Khrykin,Yad.Fiz. 58 (1995) 911.
"The reactions $pp \to pp\gamma(pp\gamma\gamma)$ and new possibilities of discovering the new narrow dibaryon resonances"

The new experimental method using the two-photon mechanism of the production and subsequent decay of the NN-decoupled (6q)-resonance(s) in proton-proton collisions was proposed to facilitate the identification and further study of the exotic nature of these resonances. This method is free of inherent difficulties of many earlier used reactions connected with the participation or production of multihadron states in the initial or final states. The specific experimental signature of the production and decay of nonstrange dibaryon , having mass below the pionic decay modes, has been indicated and discussed. On the base of this method, the Dib2γ Collaboration (JINR) has observed the specific structure in the spectrum of of final photons which was interpreted as the production and decay of the narrow dibaryon with the mass $\simeq 1950 \div 1960$ MeV.



(3)A.S. Khrykin, et al, Phys.Rev. C 64 (2001) 034002.
"Search for NN-decoupled dibaryons in the $pp \to \gamma\gamma X$
reaction below the pion production threshold"



The energy spectrum for coincident high energy photons ($E_\gamma > 10$ MeV) emitted from the process $pp \to \gamma\gamma X$ at an energy 216 MeV consists of a narrow peak at a photon energy of about 24 MeV and a relatively broad peak at an energy around 65 MeV with the statistical significance 5.3σ and 3.5σ, respectively.

In the overall center-of-mass system the energy of the photons E_γ^F associated the resonance production (formation) is determined by the mass M_R of the resonance and the energy of colliding nucleons $W = \sqrt{s}$ as

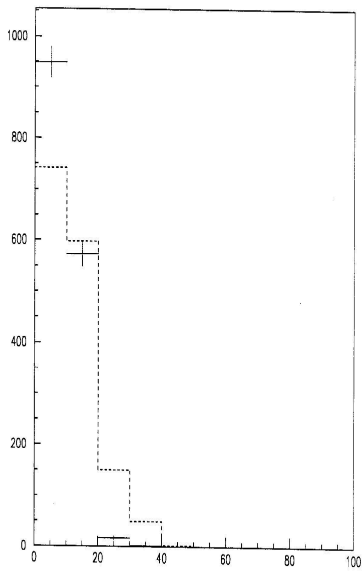
$$E_\gamma^F = \frac{(W^2 - M_R^2)}{2W},$$

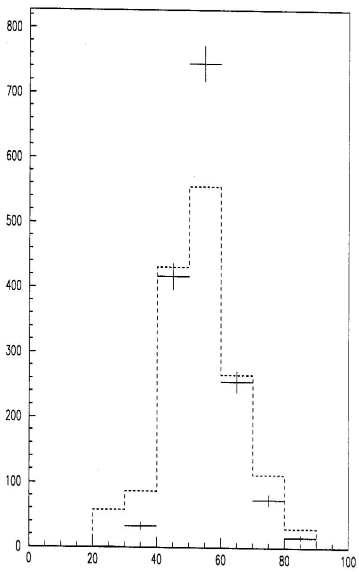
It is clear, that owing to narrowness of the considered dibaryon resonance the energy distribution of these photons should also be very narrow. The energy of the photons E_γ^D arising from the three-particle decay of the resonance $d_1^\star$ in its rest frame is given by

$$E_\gamma^D = \frac{M_R^2 - M_{NN}^2}{2M_R},$$

where M_{NN} is the invariant mass of the final NN state which is determined by the relative momentum of the nucleons in this state. Since the momentum distribution of M_{NN} is closely connected with interaction between these nucleons, the energy distribution of photons from the resonance decay will be strongly sensitive to NN final state interactions (FSI).

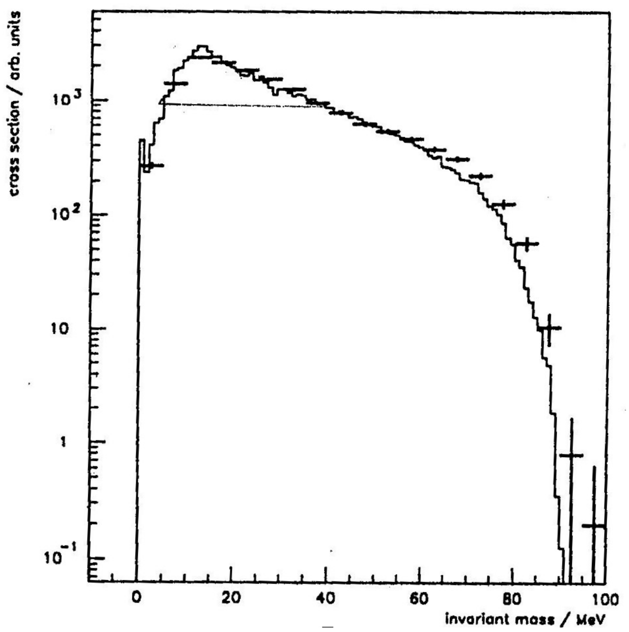
The KVI-Group(Groningen) accumulated a large sample of the 2γ-events at lower energy of the incident proton beam 190 MeV, and in their published work they prefer to interpret the qualitatively quite similar structure of the photon spectral distribution as due to nonresonance mechanism of the double bremsstrahlung. The data of 2500 events are shown in two figures as the energy distribution of the photon with the lowest energy and the highest energy, respectively. Two maximum picture of the energy distribution of each of two identical photon qualitatively looks seemingly the Dubna curve interpreted as the excitation of very narrow two-baryon resonance. However, due to lower energy of the initial proton in the KVI experiment, the cross-section of the resonance excitation is markedly lower ($\sim 2^3 = 8$) then in Dubna experiment and the non-resonance, *i.e.* ordinary double-bremsstrahlung of photons appears to become comparable with the resonance mechanism and interferes with it preventing the reliable separation of two mechanisms.





Taking for granted the resonance mass $M(d_1^* = 1956$ MeV, one gets the maximal value $m_{\gamma\gamma} \simeq 63$ MeV coming as the result of the resonance excitation, while the experimental distribution shown in the next picture extends for significantly higher values testifying for the non-resonance two-photon production.

R. Ĉaplar, J.C.S. Bacear, et al., Fizika B12, 81 (2003)
"High-statistics measurement of double-photon and dilepton production in the proton-proton scattering at 190 MeV."



The resolution of the situation would be long ago suggested way of checking the resonance interpretation, namely, to repeat the experiment at several initial proton energies below the π^o-threshold to observe the quantitatively calculable shift of the narrow peak.

Two more exclusive experiments should be mentioned that deal with the photon production in the proton-proton reactions at higher energies. First, *CELSIUS-WASA Collaboration* analyzing its pp-bremsstrahlung data collected at 200 and 310 MeV claimed that it did not find the signal of narrow dibaryon in the mass range from 1900 to 1960 MeV. Further, rather recently, the same *CELSIUS-WASA Collaboration* has reported on a study of the exclusive reaction $pp \to pp\gamma\gamma$ at energies of 1.36 and 1.2 GeV which resulted in the measurements of the invariant mass spectra of photon pairs emitted from this reaction. The measurements enable to construct the invariant mass spectrum ($M_{\gamma\gamma}$) of its photon pairs. The surprising feature of the measured spectra is that they both contain pronounced resonant structures located about the mass 280 MeV/c^2. The conservative estimates of the statistical significance by the formulae amount to 4.5σ for the spectrum measured at T_p =1.36 GeV and 3.2σ at T_p=1.2 GeV. We made a simple model-dependent analysis showing that it is the dibaryon mechanism of the two-photon production in pp collisions $pp \rightarrow \gamma d_1^* \rightarrow pp\gamma\gamma$ that bears the responsibility for these structures at higher energies and why the same mechanism and the adopted experimental cuts did not discover the signal of the $d_1^*(1956)$ in the pp bremsstrahlung data accumulated in measurements at 310 MeV which are most full and reliable.

. **A.S. Khrykin and S.B. Gerasimov, in: Proceedings of the 11th Conference on Meson-Nucleon and the Structure of the Nucleon (MENU 2007),Julich, Germany, Sep 10-14, 2007, pp.250.**

"On a possible origin of a resonance-like structure in the two-photon invariant mass spectrum of the reaction $pp \rightarrow ppgg$".

Briefly, the model assumptions are illustrated by a sequence of transitions in the matrix element of the process

$$M(p_1 p_2 \rightarrow \gamma_1 \gamma_2 p_1^{'} p_2^{'}) = M_F M_I M_D$$

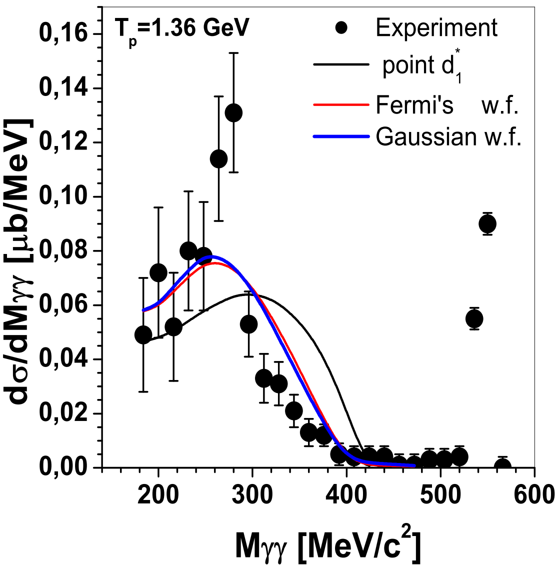
$$M_F = M_F(p_1 p_2 \rightarrow \gamma(k1\, \epsilon_1)_{M1}, \Delta_1(1231)_{virt}\, p_2)$$

$$M_I = M_I(\Delta_1(1231)_{virt}\, p_2 \rightarrow d_1^*(1956)$$

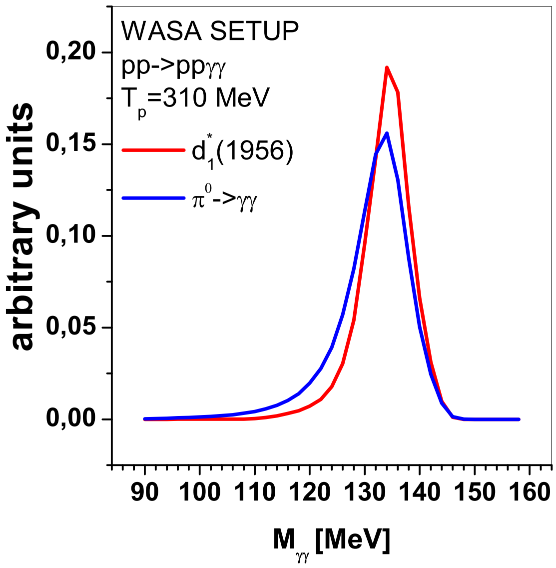
$$\rightarrow \Delta_1^{'}(1231)_{virt}\, p_2^{'})$$

$$M_D = M_D(\Delta_1^{'}(1231)_{virt} \rightarrow p_1^{'} \gamma(k2\, \epsilon_2)_{M1})$$

Leaving the absolute normalization of the cross-section arbitrary, i.e. normalized to experiment, we present only the calculated distribution of the $M_{\gamma\gamma}$ in comparison with measured at the proton energy 1.36 GeV



and at proton energy .31 GeV in comparison with the distribution from the π^o-decays. The latter events have been dropped of registration because considered as being the background.

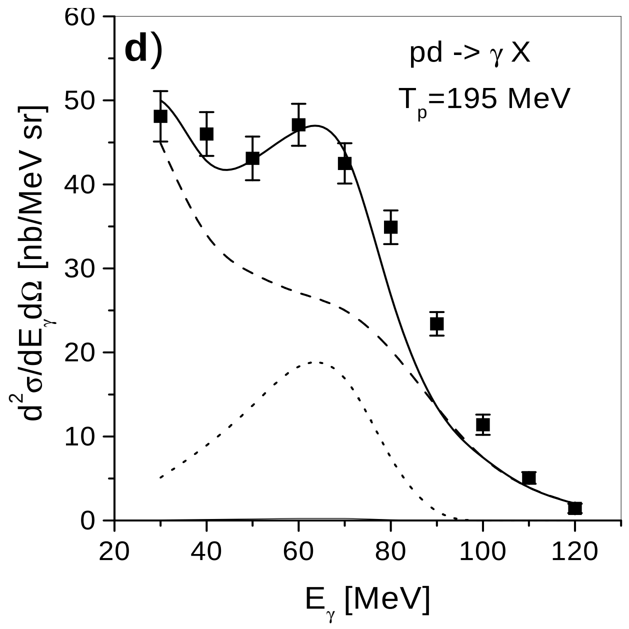


The last example refers to the inclusive reaction $pd \to \gamma X$ and $pC \to \gamma X$ below the π^o - threshold, where the inclusion of the $d_1^*(1956)$ excitation and its radiative decay in addition to ordinary mechanism of a single photon bremsstrahlung helps to describe the measured photon energy distribution

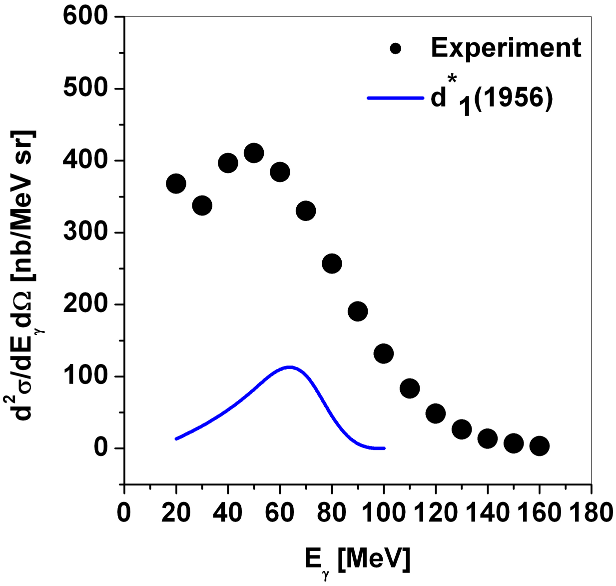
A.S. Khrykin, Nucl.Phys. A721, 625c (2003)

data: PRC 45,1810 (1992)

theory(without $d_1^*(1956)$): PRC 45, 2039 (1992)



data, $T_p = 200$ MeV: PRC 45, 1815 (1992)



($\bullet$) $\gamma d \to d_1^\star \to \gamma d$, and polarizabilities of nucleons

The amplitude $T_{\gamma\gamma}(s,t)$ of Compton scattering depends, in the low-energy limit, on static properties of given target particle and its coefficients of the electric (α) and magnetic (β) polarizabilities

$$T = (\vec{\varepsilon}^{\,\prime} \cdot \vec{\varepsilon}) A_1(s,t) + ...$$

Omitting the spin-dependent terms and higher polinomials in ω, we have

$$A = -\frac{e^2}{m_N} + 4\pi(\alpha + \beta cos\theta)\omega^2 + ...$$

reaction	$\alpha_{p[n]}$	$\beta_{p[n]}$
$\gamma p \to \gamma p$	12.1(.3)	1.6(.4)
n+Pb$\to$ n+Pb	[12.0(1.5)]	–
$\gamma d \to \gamma d$	[8.8(2.4)]	[6.5(2.4)]
$\gamma d \to \gamma np$	[12.5(1.8)]	[2.7(1.8)]
EFT	11.0(.4)[12.6(1.4)]	2.8(1.4)[2.3(1.7)]

Encoded into the effective lagrangian,

$$\mathcal{L} = -\frac{1}{m^2}(\alpha+\beta)\partial_\mu(\bar{\psi})(\partial_\nu\psi)F_{\mu\lambda}F_{\nu\lambda}+\frac{1}{2}\beta F_{\mu\nu}F_{\mu\nu}\bar{\psi}\psi$$

the "meson" polarizabilities of nucleons can be used in different low-energy reactions, such as the Compton effect on nuclei, *etc*. The study of the $\gamma d \to \gamma d$ enables to extract the "iso-scalar(vector)" polarizabilities of the nucleon $\alpha^{s,v} = (1/2)(\alpha_p \pm \alpha_n)$ and $\beta^{s,v}$. The lower-energy extractions from experiments at $\omega = 49$ and 69 MeV (Urbana Uni.) and at 55 and 69 MeV (Lund, MAX-Lab) are consistent with small iso-vectorial polarizabilities while the higher-energy $\omega = 94$ MeV experiment (SAL, Saskatoon) gave conflicting result: the isospin-averaged combination of polarizabilities was obtained equal

$$(\alpha^s - \beta^s) = 2.6 \pm 1.8$$

instead of expected value $\simeq 9.0$ (in units of $10^{-4}\ fm^3$). In some works, it was proposed to include in analyses of all data below 100 MeV two additional energy-independent parameters $\delta\alpha \simeq -6$ and $\delta\beta \simeq -11$
H.W. Grisshammer, Report at MENU 2007, Juelich, Sept. 10-14, 2007
which should reflect the influence of high-energy and

short-range dynamics on the Compton - scattering amplitudes below the pion production threshold and restor the nearness of the proton and neutron polarizabilities. Our aim, in view of the aforementioned discussion of experimentally measurable effects of the $d_1^\star(1956)$, is to propose a new inquire about its explication in the Compton scattering from deuteron. We note in this respect the ongoing investigation of the reaction in MAX-Lab, where the tagged-photon facility will 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.

G.Feldman, *et al.*, **FBS 44, 325 (2008)**

Below, we give the estimation of the contribution of the photoexcitation of $d_1^\star$ into the real part of the dynamic magnetic polarizability of the deuteron with the help of known dispersion sum rule

$$\Re\delta\beta(\omega) = \frac{1}{2\pi^2}(p.v.)\int d\omega' \frac{\sigma^{BW}{}_{M1}(\omega')}{\omega'^2 - \omega^2}$$

where the cross-section of the magnetic-dipole radiative transition $\gamma d \to d_1^\star \to X$ will be taken in the standard Breit-Wigner form, and we will put

$\Gamma_{tot}(d_1^\star) \simeq 1$ keV and $BR(d_1^\star \to \gamma d) \simeq .5$ to demostrate the specific values of $\delta\beta(\omega)$ around the crossing the zero-value point $\omega = \omega_{res} \simeq 82$ MeV, which located exactly inside the energy interval to be under study at MAX-Lab.

The energy dependenceof the $\delta\beta(\omega)$ around the resonance (the units: $[\omega] = MeV$, $[\delta\beta] = 10^{-4} fm^3$

ω	70	76	80	82	84	88	94
$\delta\beta$	1.7	3.2	9.0	0	-8.9	-3.1	-1.5

Why's & Ways: About probable $d_1^*(1950 \div 1960)$ quantum numbers.

•. Among theoretical models predicting dibaryon resonances with different masses there is one giving the state with the $IJ^P = 11^+$ 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 applied to the sector with the baryon number $B = 2$.
V.B.Kopeliovich, Yad. Fiz. 58, 1317 (1995)

. ”On Narrow dibaryons in the chiral soliton model” 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 cited radiative width of the order $\sim O(eV)$ looks much too low.

• In the composite models, the cluster decomposition $(6q) = (3q) \times (3q)$ or $(6q) = (qq) \times (qq) \times (qq)$,or $(6q) = (qq) \times (qqqq)$ can be assumed. The fractional-parentage expansions of colour-singlet 6-quark states in a cluster model has been considered in several works (*e.g.*, **M. Harvey, Nucl.Phys. A352, 301 (1981)**; ”On the fractional-parentage expansions of color-singlet six-quark states in a cluster model”)
For qualitative estimations one can choose the $N\Delta$ - model with possible values of spin(S) and isospin (I) $S(I) = 1, 2$. The diquark model quantum numbers, consistent with the Bose-nature of diquarks and the

$L = 0$ for total orbital moment, require two axial-vector ($J^P = 1^+$)- diquarks with isospin $I = 1$ and one (iso)scalar diquark ($J^P = 0^+$) and the following combinations of total spin and isospin: $(I = 1, J = 0$, *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 known ${}^1D_2$(2.17 GeV -resonance quantum numbers 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. However, one can escape potentially problematic situation with the long-lived iso-tensor ($I = 2$) dibaryon if one unites, following Jaffe :
(**R. L. Jaffe, Phys. Rev. D72, 074508 (2005);**
"Color non-singlet spectroscopy"
also,in different context, **L.A. Kondratyuk, et al., Yad.Fiz., 45, 1252 (1987)**; "Dibaryon resonances as rotatinal

excitations of six quark states")
one axial-vector diquark (A_2) and one scalar diquark (S_2) into single four-quark cluster ($A_4 = S_2 \otimes A_2$) which should be the colour-triplet, iso-vector ($I = 1$) and to have spin-parity $J^P = 1^+$. Hence, we suggest for $d_1^\star(1956)$ the following multi-component configuration structure: $|d_1^\star(1956) >= c_0|N, \Delta >$ $+c_{88}|B(8_c)B(8_c) > +c_{\bar{3}_c 3_c}|S_2(\bar{3}_c, 0^+), A_4(3_c, 1^+) >$ Needless to say in conclusion that deciphering and testing of such a complex structure would require further development of theory and new experimental data.

The discoveries of manifestly exotic particles, which have been sought for decades, clearly $\underline{would}$ open a new chapter in strong interaction physics.

(from R.Jaffe and F. Wilczek, hep-ph/0401034).