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SOME NEW ASPECTS OF THE UNITARY AND ANALYTIC VMD MODEL FOR ELECTROMAGNETIC STRUCTURE OF HADRONS

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Dynamical description of the electromagnetic (e.m.) structure of hadrons is still one of the unsolved problems of particle physics. The perturbative QCD practicaly gives [1) 2)](due to the asymptotic freedom) a behaviour of coresponding e.m. form factors (ff's) only in the asymptotic region. The QCD sum rules predict [3) 4)] just a behaviour of e.m. ff's in a limited interval of the space-like momentum transfers squared. However in the finite energy time-like region, where ff's are complex functions of their argument and experiments on electron - positron annihilation into a hadron - antihadron pair manifest their nontrivial behaviour caused by a creation of various vector meson resonances, QCD gives no predictions up to now.

The latter shortage is partly compensated by the recently proposed unitary and analytic (UA) VMD model[5)-9)] which provides for every e.m. ff's of the hadron one real analytic function for the space-like and time-like region with the asymptotic behaviour to be consistend with QCD predictions and at the same time reflecting an experimental fact of a creation of unstable vector mesons in electron - positron annihilation processes, thus depending just on parameters with a clear physical meaning.

Here we present results:

- a strong evidence for $\rho'''(2150)$ by the data on $J/\psi \to \pi^+\pi^-$ decay
- a prediction of $\sigma_{tot}(e^+e^- \to n\bar{n}) \gg \sigma_{tot}(e^+e^- \to p\bar{p})$ just above the nucleon - antinucleon threshold
- surprisingly large one photon e.m. corrections to the strong $J/\psi \to p\bar{p}$ and $J/\psi \to n\bar{n}$ decay amplitudes
- the behaviour of the polar-angle asymmetry parameter $\alpha(t)$ for $e^+e^- \to p\bar{p}$ and $e^+e^- \to n\bar{n}$ processes

which have been obtained by utilizing the UA-VMD model for e.m. structure of pions and nucleons.

Unitary and analytic VMD model.

The UA-VMD model is obtained (for more detail see Refs. [5)-9)]) from a standard VMD parametrization of e.m. ff of the hadron

$$F(t) = \sum_{\nu} \frac{m_\nu^2 (f_{\nu hh}/f_\nu)}{m_\nu^2 - t} \tag{1}$$

by means of the following nonlinear transformation

$$t = t_0 - \frac{4(t_{in} - t_0)}{(\frac{1}{W} - W)^2} \tag{2}$$

which along with a correct making allovance for nonzero vector meson widths ($\Gamma_\nu \neq 0$) considers the two-cut approximation of the ff analytic properties and leads to the following factorized expression

$$F(t) = \left(\frac{1-W^2}{1-W_N^2}\right)^2 \Big[\sum_r \frac{(W_N - W_r)(W_N - W_r^*)(W_N - \frac{1}{W_r})(W_N - \frac{1}{W_r^*})}{(W - W_r)(W - W_r^*)(W - \frac{1}{W_r})(W - \frac{1}{W_r^*})}(f_{rhh}/f_r) +$$
$$+ \sum_s \frac{(W_N - W_s)(W_N - W_s^*)(W_N + W_s)(W_N + W_s^*)}{(W - W_s)(W - W_s^*)(W + W_s)(W + W_s^*)}(f_{shh}/f_s)\Big] \tag{3}$$

where $t_0 < (m_r^2 - \frac{\Gamma_r^2}{4}) < t_{in}$; $(m_s^2 - \frac{\Gamma_s^2}{4}) > t_{in}$; W_r, W_s are the pole positions of vector mesons in the W-plane and W_N is the normalization point corresponding to t=0. The first term (that in front of square brackets) completely determines the asymptotic behaviour of F(t) and the second one (in the square brackets) describes the whole complicated ff resonant structure in the time-like region and for $t \to \pm\infty$ it becomes a finite real constant.

UA-VMD model for pions and an evidence of $\rho'''(2150)$ by $J/\psi \to \pi^+\pi^-$ decay.

The decay of $J/\psi \to \pi^+\pi^-$ is pure e.m. if G-parity is conserved by strong interactions and consequently one can extract an information on $|F_\pi(m_\psi^2)|$ from the latter by using the relation

$$\Gamma(J/\psi \to \pi^+\pi^-) = \frac{\pi\alpha^2 m_\psi}{3f_\psi^2}|F_\pi(t)|^2. \tag{4}$$

In an optimal description of all existing pion ff data by the UA-VMD model with $v = \rho, \rho', \rho''$ (all parameters are left to be free) an existence of two excited states of the $\rho(770)$ meson is demonstrated [5] (see Fig.1) to be simultaneously consistent with the space-like and time-like ff data unlike the results by A.Donnachie and H.Mirzaie [10] who have obtained the latter information just from the time-like $e^+e^- \to \pi^+\pi^-$ data. However, two DM2 points [11] and the last time-like point obtained [12] from $J/\psi \to \pi^+\pi^-$ decay are not described (see Fig.1) very well by the theoretical curve predicted by the pion ff UA-VMD model with $\rho(770)$, $\rho'(1450)$, $\rho''(1700)$ only, thus indicating that a higher mass isovector vector state cannot be neglected. Really, considering another vector meson in the pion ff UA-VMD model and repeating the analysis of the same data (again parameters are left to be free) one finds a strong evidence (see Fig.2) of the third excited state of the $\rho(770)$ meson with resonance parameters $m_{\rho'''} = 2169 \pm 46\ MeV$ and $\Gamma_{\rho'''} = 319 \pm 136\ MeV$. Moreover, the predicted value $|F_\pi(m_\psi^2)| = 0.1091$ by the UA-VMD model for the pion e.m. ff with three excited states of the $\rho(770)$ meson is through the relation

$$\Gamma(J/\psi \to \pi^+\pi^-) = \frac{1}{4}|F_\pi(m_\psi^2)|^2\Gamma(J/\psi \to \mu^+\mu^-) \tag{5}$$

in a perfect agreement with existing experimental $\Gamma(J/\psi \to \pi^+\pi^-)$ and $\Gamma(J/\psi \to \mu^+\mu^-)$.

Prediction of the inequality $\sigma_{tot}(e^+e^- \to n\bar{n}) \gg \sigma_{tot}(e^+e^- \to p\bar{p})$

The e.m. structure of nucleons is completely described [7] by the following four e.m. ff's

$$\begin{aligned} G_E^p(t) &= [F_1^s(t) + F_1^v(t)] + \frac{t}{4m_p^2}[F_2^s(t) + F_2^v(t)] \\ G_M^p(t) &= [F_1^s(t) + F_1^v(t)] + [F_2^s(t) + F_2^v(t)] \end{aligned} \tag{6}$$

$$\begin{aligned} G_E^n(t) &= [F_1^s(t) - F_1^v(t)] + \frac{t}{4m_n^2}[F_2^s(t) - F_2^v(t)] \\ G_M^n(t) &= [F_1^s(t) - F_1^v(t)] + [F_2^s(t) - F_2^v(t)] \end{aligned} \tag{7}$$

where $F_1^s(t)$, $F_2^s(t)$ and $F_1^v(t)$, $F_2^v(t)$ are isoscalar and isovector parts of the Dirac and Pauli nucleon e.m. ff's, respectively, to which directly the UA-VMD model (3), however with a changed asymptotic behaviour, can be applied. Unlike the analyses carried out in [7] here the OZI rule [13)-15)] is strictly taken into account and all ϕ-meson contributions are neglected. Consequently, the isoscalar e.m. ff's are saturated only with three ω-mesons [16] and the isovector e.m. ff's contain all known isovector vector mesons i.e. $\rho(770)$, $\rho'(1450)$, $\rho''(1700)$ and $\rho'''(2150)$.

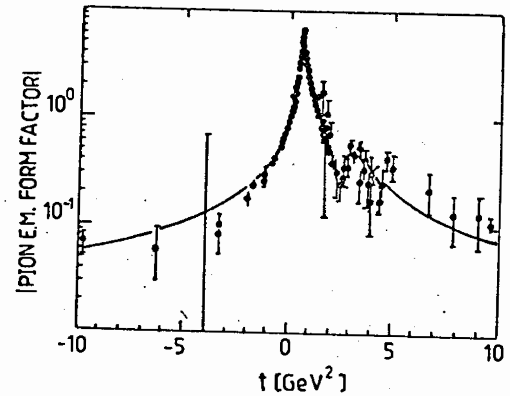

Fig.1. A demonstration of the existence of two excited states of the $\rho(770)$ meson in an optimal description of all existing pion e.m. ff data by the UA-VMD model.

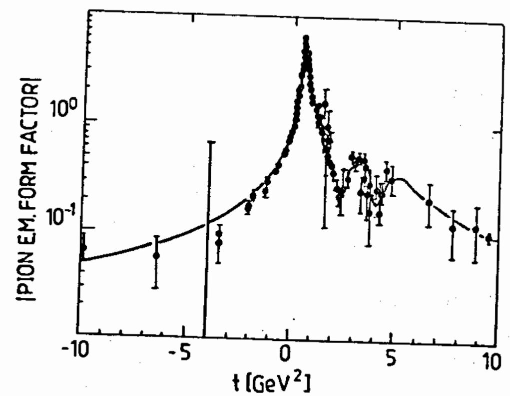

Fig.2. A strong evidence of the third excited state of the $\rho(770)$ meson in an optimal description of the same pion e.m. ff data by means of the UA-VMD model with four resonances, essentially by a perfect reproduction of the recent time-like experimental point obtained from $J/\psi \to \pi^+\pi^-$.

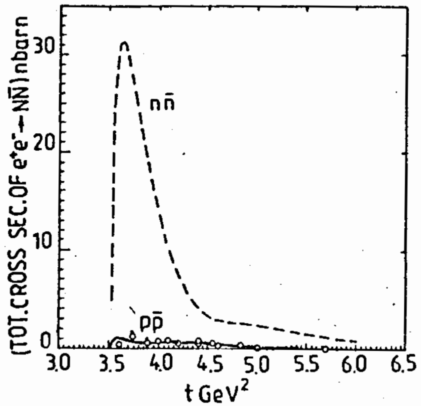

Fig.3. The nucleon e.m. structure UA-VMD model prediction for $\sigma_{tot}(e^+e^- \to n\bar{n}) \gg \sigma_{tot}(e^+e^- \to p\bar{p})$ just above the nucleon- antinucleon threshold.

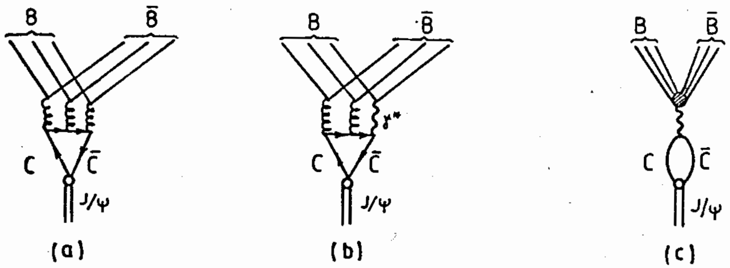

Fig.4. The lowest-order graphs for $J/\psi \to B\bar{B}$ decay. (a) a dominant direct hadronic decay. (b) the direct electromagnetic decay. (c) the one-photon electromagnetic decay.

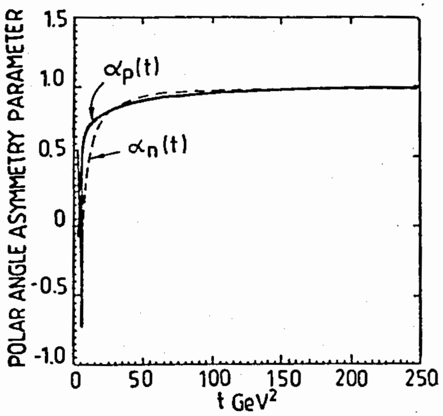

Fig.5. A prediction of the polar angle asymmetry parameter behaviour for $e^+e^- \to p\bar{p}$ and $e^+e^- \to n\bar{n}$ processes.

Each free parameter of the model is fixed in an optimal description of 356 reliable experimental points on proton and neutron e.m. ff's for $t < 0$ and 12 data on $\sigma_{tot}(e^+e^- \to p\bar{p})$ for $3.610\ GeV^2 \leq t \leq 5.693 GeV^2$. Then, finally the behaviour of $\sigma_{tot}(e^+e^- \to n\bar{n})$, for which there is no experimental point at present, is predicted to be considerably larger (see Fig.3) than $\sigma_{tot}(e^+e^- \to p\bar{p})$ just above the nucleon-antinucleon threshold.

One photon e.m. corrections to strong $J/\psi \to N\bar{N}$ decay amplitudes.

The decay $J/\psi \to B\bar{B}$ (B being a member of the baryon octet) is currently assumed to proceed in the lowest-order approximation through the three graphs presented in Fig.4 and its integrated decay width is given [17] by the following relation

$$\Gamma(J/\psi \to B\bar{B}) = \frac{\beta N_B^2}{48\pi M_\psi}(2T + L) \tag{8}$$

where $\beta = (1 - (4m_B^2/M_\psi^2))^{1/2}$; $N_B = \frac{15}{6\sqrt{8}}(\frac{36\pi\alpha_s}{M_\psi^2})^3 f_\psi f_B^2$; $f_\psi \approx 0.26$ GeV is the decay constant of J/ψ; f_B an overall normalization constant to be calculated from the $J/\psi \to B\bar{B}$ data, and T, L are squares of helicity amplitudes for a polarized J/ψ having helicity $\Lambda = 0$ or $\Lambda = \pm 1$, respectively. Then an interesting question arises: what is the rate of e.m. corrections represented by graphs (b) and (c) to the dominant direct hadronic decay given by graph (a).

Graph (b) gives [18)-20)] a contribution proportional to the leading amplitude (a), where the proportionality factor is

$$\delta = (-4/5)(\alpha_e/\alpha_s)Q_B \tag{9}$$

with Q_B defined as the charge of the final baryon B.

As for the one photon e.m. decay graph (c), it gives different contributions depending on whether T or L is involved. The corresponding ratios of amplitudes of graphs (c) to (a) are as follows

$$\delta_T = \frac{\alpha_e |G_M^B(M_\psi^2)|}{40\pi^2\alpha_s^3 3^6 (1 + m_B^2/M_\psi^2)} \left(\frac{M_\psi^2}{f_B}\right)^2 \tag{10}$$

$$\delta_L = \frac{\alpha_e |G_E^B(M_\psi^2)|}{20\pi^2\alpha_s^3 3^6 (1 + m_B^2/M_\psi^2)} \left(\frac{M_\psi^2}{f_B}\right)^2. \tag{11}$$

Now, using the overall normalization constants for protons and neutrons [17)], $f_p = 0.00480\ GeV^2$; $f_n = 0.00488\ GeV^2$, the QCD running coupling constant $\alpha_s(M_\psi^2) \approx 0.25$ and values of the electric and magnetic nucleon ff's at $t = M_\psi^2$ as they are predicted by the UA-VMD model, one gets (see Table 1) surprisingly large one photon e.m. corrections to the $J/\psi \to p\bar{p}$ and $J/\psi \to n\bar{n}$ decay processes.

Table 1:

Author	$p\bar{p}$	$n\bar{n}$
CARIMALO[17)]	δ_T=0.065; δ_L=0.047	δ_T=0.047; δ_L=0
OUR RESULTS	δ_T=0.104; δ_L=0.207	δ_T=0.303; δ_L=0.719

The polar angle asymmetry parameter behaviour for $e^+e^- \to N\bar{N}$.

Brodsky and Lepage [21)], assuming in QCD the spin of the gluon to be 1 and using the helicity selection rule, have predicted the following angular distribution

$$\frac{d\sigma(e^+e^- \to N\bar{N})}{dcos\vartheta} \sim 1 + cos^2\vartheta \tag{12}$$

for nucleons in the asymptotic region of energies, where the quark and nucleon masses can be neglected. In the finite energy region relation (12) takes the form

$$\frac{d\sigma(e^+e^- \to N\bar{N})}{dcos\vartheta} \sim 1 + \alpha(t)cos^2\vartheta \qquad (13)$$

where $\alpha(t)$ is called the polar angle asymmetry parameter.

Using the behaviour of the nucleon e.m. ff's predicted by the UA-VMD model, we show the $\alpha(t)$ behaviour in a perfect agreement with QCD predictions in the asymptotic region. Really, integratig over ϕ-angle in the relation

$$\frac{d\sigma(e^+e^- \to N\bar{N})}{d\Omega} = \frac{\alpha^2\beta_N}{4t}\left[\frac{4M^2}{t}|G_E|^2 sin^2\vartheta + |G_M|^2(1+cos^2\vartheta)\right] \qquad (14)$$

one gets

$$\frac{d\sigma(e^+e^- \to N\bar{N})}{dcos\vartheta} = \frac{2\pi\alpha^2\beta_N}{4t^2}(t|G_M|^2 + 4M^2|G_E|^2)[1+\alpha(t)cos^2\vartheta] \qquad (15)$$

where

$$\alpha(t) = \frac{t|G_M|^2 - 4M^2|G_E|^2}{t|G_M|^2 + 4M^2|G_E|^2} \qquad (16)$$

The predicted behaviour of $\alpha(t)$ for protons and neutrons is given in Fig.5, from which one can see that first, $\alpha(t)$ asymptotically approaches unity as predicted by QCD and, second, just at that value the perturbative QCD starts to work as well.

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Новые предсказания унитарной и аналитической ВМД модели для электромагнитной структуры адронов

В рамках унитарной и аналитической ВМД модели проанализированы новые данные по $J/\psi \to \pi^+\pi^-$ вместе со всеми существующими данными по пионному формфактору. В результате получено доказательство существования третьего возбужденного состояния $\rho(770)$ мезона с параметрами $m_{\rho'''} = 2169\pm46$ МэВ и $\Gamma_{\rho'''} = 319\pm136$ МэВ. Одновременный анализ всех надежных формфакторов протона и нейтрона в пространственно-подобной области и данных тотального сечения электрон-позитронной аннигиляции в пару протон-антипротон, предсказывает в рамках той же модели неожиданное неравенство $\sigma_{tot}(e^+e^- \to n\bar{n}) \gg \sigma_{tot}(e^+e^- \to p\bar{p})$ над порогом нуклон-антинуклона и также получаются неожиданно большие однофотонные корреляции к амплитудам сильного распада $J/\psi \to p\bar{p}$ и $J/\psi \to n\bar{n}$. Вычисленное поведение параметра асимметрии углового распределения в процессах $e^+e^- \to p\bar{p}$ и $e^+e^- \to n\bar{n}$ находится в хорошем согласии с предсказаниями, следующими из КХД.

Работа выполнена в Лаборатории теоретической физики ОИЯИ.

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Some New Aspects of the Unitary and Analytic VMD Model for Electromagnetic Structure of Hadrons

Recent $J/\psi \to \pi^+\pi^-$ data analysed along with all existing pion form factor data by means of the unitary and analytic VMD model manifest a strong evidence of the third excited state of the $\rho(770)$ meson with resonance parameters $m_{\rho'''} = 2169\pm46$ MeV and $\Gamma_{\rho'''} = 319\pm136$ MeV. A simultaneous analysis of all reliable proton and neutron form factor data in the space-like region along with data on the total cross section of electron - positron annihilation into a proton - antiproton pair by the same model predicts an unexpected inequality $\sigma_{tot}(e^+e^- \to n\bar{n}) \gg \sigma_{tot}(e^+e^- \to p\bar{p})$ just above the nucleon-antinucleon threshold and also surprisingly large one photon electromagnetic corrections to the strong $J/\psi \to p\bar{p}$ and $J/\psi \to n\bar{n}$ decay amplitudes. The calculated polar angle asymmetry parameter behaviour for $e^+e^- \to p\bar{p}$ and $e^+e^- \to n\bar{n}$ processes is asymptotically, however, in agreement with predictions following from QCD.

The investigation has been performed at the Laboratory of Theoretical Physics, JINR.

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