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^{4}He ELECTROMAGNETIC STRUCTURE IN UNITARY AND ANALYTIC VMD MODEL WITH STRICT OZI RULE

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The electromagnetic (EM) structure of ^{4}He nucleus (the spin and isospin is equal to zero) is completely described by one scalar function, $F_{^4\mathrm{He}}(t)$ where $t = -Q^2$ is the 4-momentum transfer squared. Practically, it is measured only in the space-like region ($t < 0$) by means of the elastic electron-^{4}He scattering experiments. The non-relativistic nuclear models describe the existing experimental data [1]-[4] in the range -2.4 GeV$^2 \leq t \leq$ -0.0102 GeV^2 quite well, however, the results of predictions of the latter are not so good outside the region of those data. The main problem is the asymptotic behaviour of $F_{^4\mathrm{He}}(t)$ for $t \to \pm\infty$ to be predicted now by the quark model. Another problem is the time-like behaviour of the $F_{^4\mathrm{He}}(t)$. Both of these problems have been solved in the paper [5] where by means of the unitary and analytic (UA) VMD model the asymptotic behaviour consistent with the quark model predictions was achieved and the time-like behaviour of $F_{^4\mathrm{He}}(t)$ was predicted, consequently the total cross-section of the $e^+e^- \to {}^4\mathrm{He}^4\overline{\mathrm{He}}$ process was predicted for the first time.

Here, we present a new analysis based on the same modification of the classical VMD model of EM interactions of hadrons where we take into account the OZI rule [6] strictly, i.e.

$$f_{v\mathrm{He}\overline{\mathrm{He}}} = 0 \quad \text{for} \quad v = \phi, \phi'.$$

The standard VMD model approximates the ^{4}He charge FF in the following form:

$$F_{^4\mathrm{He}}(t) = \sum_v \frac{m_v^2}{m_v^2 - t}\left(\frac{f_{v\mathrm{He}\overline{\mathrm{He}}}}{f_v}\right) \tag{1}$$

The sum, due to the isoscalar nature of ^{4}He nucleus, is carried out only through the isoscalar vector meson resonances. In distinction to the work [5], taking into account the OZI [6] rule strictly, the sum is saturated only with ω- resonances; $f_{vHe\overline{He}}/f_v$ are ratios of the vector-meson-helium-antihelium over the universal vector-meson coupling constants, respectively.

Following the procedure described in [5], we make two-cut approximation of the complicated analytical structure of the $F_{^4\mathrm{He}}(t)$ applying the non-linear transformation

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

in (1) where t_0, t_{in} are square-root branch points, t_0 is identified with the lowest normal $F_{^4\mathrm{He}}(t)$ threshold $t_0 = 9m_\pi^2$ and t_{in} is considered to be an effective threshold simulating contributions of other cuts; therefore, the latter is left to be a free parameter of the constructed model.

We also incorporate into the model the non-zero width of vector mesons defining the latter as complex poles $t_v = (m_v - \Gamma_v/2)^2$ on the unphysical sheets of the Riemann surface generated by the branch points t_0 and t_{in}. As a result, one gets finally the expression

$$\begin{aligned} F_{^4\mathrm{He}}(t) = \left(\frac{1-W^2}{1-W_{\mathrm{N}}^2}\right)^2 \Bigg[& \frac{(W_{\mathrm{N}} - W_\omega)(W_{\mathrm{N}} - W_\omega^-)(W_{\mathrm{N}} - 1/W_\omega)(W_{\mathrm{N}} - 1/W_\omega^-)}{(W - W_\omega)(W - W_\omega^-)(W - 1/W_\omega)(W - 1/W_\omega^-)}\frac{f_{\omega\mathrm{He}\overline{\mathrm{He}}}}{f_\omega} + \\ & + \sum_{v=\omega',\omega''} \frac{(W_{\mathrm{N}} - W_v)(W_{\mathrm{N}} - W_v^-)(W_{\mathrm{N}} + W_v)(W_{\mathrm{N}} + W_v^-)}{(W - W_v)(W - W_v^-)(W + W_v)(W + W_v^-)}\frac{f_{v\mathrm{He}\overline{\mathrm{He}}}}{f_v}\Bigg], \end{aligned} \tag{3}$$

where W_{N} is the position of the normalization point $t = 0$ in the W-plane. This expression is real for $t < t_0$, complex for $t > t_0$, and from the normalization condition of the zero width VMD model

$$F_{^4\mathrm{He}}(t)_{-t=0} = 1$$

one finds a restriction on a number of coupling ratios as follows:

$$\sum_v (f_{v\mathrm{He}\overline{\mathrm{He}}}/f_v) = 1. \tag{4}$$

The model (3) depends just on the parameters ($t_{\rm in}$,m_v, Γ_v, $f_{v{\rm He}\overline{\rm He}}/f_v$) with a clear physical meaning. It takes into account the instability of vector mesons in a correct way, i.e., without conflict with other properties of ^{4}He FF. Moreover, it has a very usefull feature, i.e., a factorized form which enables one also to achieve the asymptotic behaviour of FF in agreement with the quark model predictions without violating any fundamental properties of the constructed model. Transformation (2) leads to a common factor $[(1-W^2)/(1-W_N^2)]^2$ for all vector mesons which completely determines the asymptotic behaviour of the model. The factor in square brackets of (3) for t — —— becomes only a real constant. Using this factorization property of the model we can make a general form

$$
\begin{aligned}
F_{^4{\rm He}}(t) \;=\; & \left(\frac{1-W^2}{1-W_{\rm N}^2}\right)^{2(n_{\rm q}-1)} - \qquad\qquad (5)\\
& \Big[\frac{(W_{\rm N}-W_\omega)(W_{\rm N}-W_\omega^-)(W_{\rm N}-1/W_\omega)(W_{\rm N}-1/W_\omega^-)}{(W-W_\omega)(W-W_\omega^-)(W-1/W_\omega)(W-1/W_\omega^-)}\frac{f_{\omega{\rm He}\overline{\rm He}}}{f_\omega} + \\
& + \sum_{v=\omega',\omega''}\frac{(W_{\rm N}-W_v)(W_{\rm N}-W_v^-)(W_{\rm N}+W_v)(W_{\rm N}+W_v^-)}{(W-W_v)(W-W_v^-)(W+W_v)(W+W_v^-)}\frac{f_{v{\rm He}\overline{\rm He}}}{f_v}\Big],
\end{aligned}
$$

where for ^{4}He $n_{\rm q}=12$, and as a result, one gets the UA-VMD model for the description of the EM structure of ^{4}He nucleus with correct asymptotics $F_{^4{\rm He}}(t)$ – t^{-11}–$_{t---}$. Now our aim is to analyse the data in the space like region in order to fix free parameters and to predict the behaviour of FF in the time-like region, and as a consequence to, predict the total cross section of the e^+e^- – $^4{\rm He}^4\overline{\rm He}$ process.

There are four tabulated results [1]-[4] of the independent elastic electron-^{4}He scattering experiments with 110 experimental points in the interval -2.4 GeV^2 – t – -0.0102 GeV^2. As, there are no data in the time-like region, we fix the masses and widths of the considered resonances at the world average values [7]. As a result, we have only three free parameters $t_{\rm in}$, $f_{\omega'{\rm He}\overline{\rm He}}/f_{\omega'}$, $f_{\omega''{\rm He}\overline{\rm He}}/f_{\omega''}$ of the model.

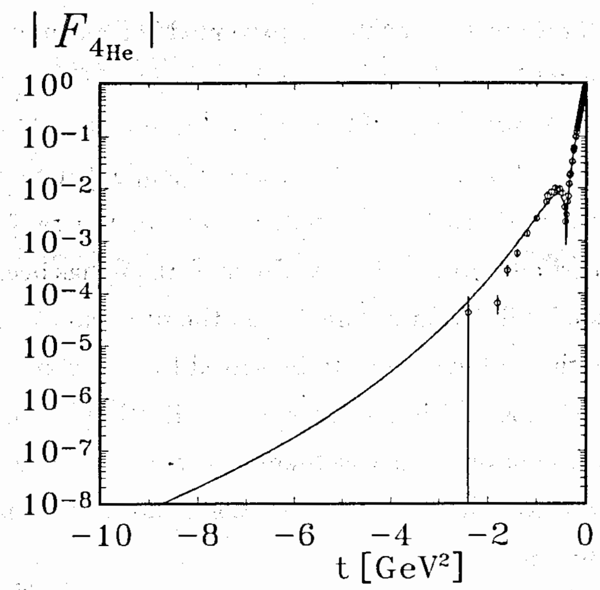

Fig. 1. The reproduction of the experimental data by our model.

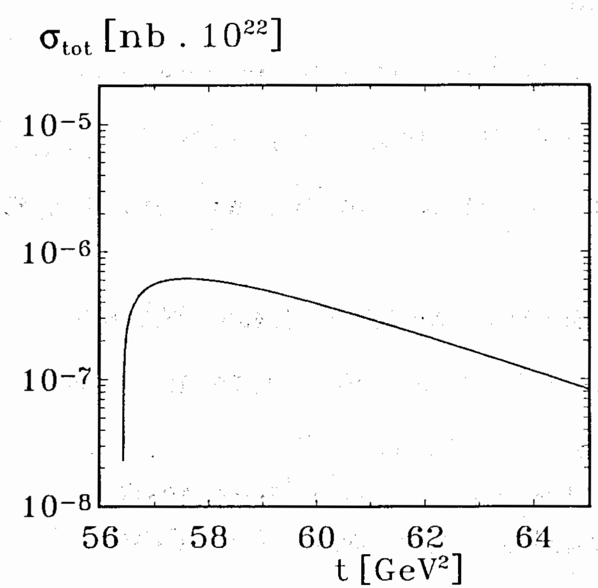

Fig. 2. The predicted total cross-section.

The obtained results are graphically presented in Fig.1 and they show very good reproduction of the existing data with $\chi^2/NDF = 1.006$.

In contradiction with the previous work [5], there is no possibility to reproduce the conjectured second diffraction minimum with only three resonances, which perhaps is indicated by data in the range about 2 GeV^2. But the best description of data, also in work [5], has been achieved without the second diffraction minimum. So the problem of existence or non-existence of this minimum has to be solved by new experiments.

The calculated cross-section of the $e^+e^- - {}^4\mathrm{He}\,{}^4\overline{\mathrm{He}}$ process is shown in Fig.2. The shape of our graph is almost the same as in the paper [5] but the value of maximum of the cross section is about 2-3 orders lower than the previous one.

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Стриженец П. E2-93-432

Электромагнитная структура ^{4}He в унитаризованной аналитической ВМД-модели с правилом ОЦИ

Предлагаются результаты нового анализа данных по электромагнитному формфактору ^{4}He, основанного на унитаризованной аналитической ВМД-модели со строгим соблюдением правила ОЦИ.

Работа выполнена в Лаборатории теоретической физики ОИЯИ.

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^{4}He Electromagnetic Structure in Unitary and Analytic VMD Model with Strict OZI Rule

We present the results of a new analysis of ^{4}He electromagnetic form factor data, based on the unitary and analytic VMD model with the OZI rule to be taken strictly into account.

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