объединенный
институт
ядерных
исследований
дубна

E2-94-465

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HADRONIC PART OF PHOTON-PHOTON TOTAL CROSS SECTION IN PERTURBATIVE QCD

Submitted to «Zeitschrift für Physik C»

[1]On leave of absence from Yerevan Physics Institute, Armenia

1994

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Адронная часть фотон-фотонного полного сечения в пертурбативной КХД

Рассмотрено полное сечение фотон-фотонного взаимодействия $\sigma(\gamma\gamma)$ в квантовой хромодинамике. Показано, что адронную компоненту $\sigma(\gamma\gamma)$ можно представить в представлении дипольного сечения, которое имеет простую физическую интерпретацию и полезно для приложений. Это приближение позволяет описывать $\sigma(\gamma\gamma)$ при различных поляризациях и виртуальностях фотонов. Показано, как из него можно получить адронную часть $\sigma(\gamma\gamma)$ в импульсном представлении. Проведено сравнение с экспериментальными данными по $\sigma(\gamma\gamma)$ и получено удовлетворительное согласие для зависимости $\sigma(\gamma\gamma)$ от виртуальности фотона.

Работа выполнена в Лаборатории ядерных проблем ОИЯИ.

Препринт Объединенного института ядерных исследований. Дубна, 1994

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Hadronic Part of Photon-Photon Total Cross Section in Perturbative QCD

We study the photon-photon hadronic cross section $\sigma(\gamma\gamma)$ in the QCD inspired model. It was shown that the hadronic component of $\sigma(\gamma\gamma)$ can present in the dipole-cross section representation, which has clear physical interpretation and is useful for applications. This approach allows one to describe $\sigma(\gamma\gamma)$ for different polarizations and virtualities of photons. We show that one can obtain from it the impact factor representation for the hadronic part of $\gamma\gamma$-scattering. Comparison is made with experimental data on $\sigma(\gamma\gamma)$ and satisfactory agreement is achieved for its dependence on photon virtuality.

The investigation has been performed at the Laboratory of Nuclear Problems, JINR.

Preprint of the Joint Institute for Nuclear Research. Dubna, 1994

Introduction

The measurement of total photon photon hadronic cross section by using e^+e^- storage rings has a long and exciting history [1].The study of events with at least one of the photons far off the mass shell ($q_1^2 = -Q^2 >> 0$) leads to a new class of reactions,which can be interpreted as deep inelastic scattering of a quasi real photon target ($q_2^2 = 0$).The transverse and longitudinal photon photon total cross sections are unequally related to the photon structure function $F_2^\gamma(x)$,which is completely calculable[2] in QCD in the Bjorken limit ($Q^2 \to \infty, x_B = Q^2/(Q^2 + W^2) = const, W^2 = (q_1 + q_2)^2$), unlike the case of the structure functions of hadrons.

Unfortunately this is not the whole story,because photons possess a hadronic component[3] which is dominant at small x_B.The point-like component of $\sigma(\gamma\gamma)$(Fig.1a)decreases with energy W in contrast to the hadronic component which is approximately constant and survives at asymptotic energies.Usually this component is parametrized according to ideas of the vector dominance model (VDM) or its more elaborated version known as a generalized vector dominance model(GVDM). The VDM is unsatisfactory in describing the experimental data in the wide range of photon virtuality Q^2 [1].As to the GVDM,though it is quite successful in comparison with experiment, its phenomenological nature does not allow one to restrict only by it.Furthermore, common for such types of models is the well known difficulty which is connected with double counting.Really,when one calculates the contribution of the hadronic component(Fig.1b)in such an approach he takes into account a part of the point-like component(Fig.1a) and vice versa. To avoid this difficulty the cut-off in transverse momentum is usually introduced[4],which is regarded as a free parameter. This approach is artificial in some sense,and reduce the predictive power of model.

We will work in the dipole-cross section representation,which is free from this deficiency and is based on such firm ground as QCD.In the last years it is successfuly applied to the interaction of high energy photons (real[5] and virtual[6-7])with nucleons and nuclei. This approach takes advantage of the exact diagonalization of the diffractive S-matrix in the dipole-cross section representation and takes into account the colour screening effect,which is a direct manifestation of colour gauge invariance.It is important to check its validity in $\gamma\gamma$-collisions where the uncertainties connected with unknown structure of hadrons are absent.

1. The model for hadronic part of $\sigma(\gamma\gamma)$.

Before interaction with the target the high energy photon is split into the quark-antiquark pair which lived a time proportional to its energy[8].We will assume that total $\gamma\gamma$ cross section is determined by two contribution.The first one depicted in fig.1a is the so called quark parton model (QPM) part of total cross section which is widely explored and well known[9].For the hadronic part of $\sigma(\gamma\gamma)$ we adopt the two gluon exchange model [10,11],which is the lowest order of pomeron exchange (fig.1c).This model is very successful in describing the hadron-hadron total cross sections[12,13].The next terms in exchange(Lipatov pomeron) are substantial at very high energies or extremely small x,which have been not attained in photon photon collisions at the present time.Using the known technique for calculation of the cross sections in dipole-cross section representation[5-7] we obtained for hadronic part of $\sigma(\gamma\gamma)$:

$$\sigma^{ij}(Q_1^2,Q_2^2,W^2)=\int|\Psi^i(r,x)|^2|\Psi^j(r',x')|^2\sigma(r,r')d^2rd^2r'dxdx' \qquad (1)$$

$$|\Psi^L(r,x)|^2=\frac{24Q^2\alpha}{(2\pi)^2}\sum_{l=1}^{N_f}e_l^2x^2(1-x)^2K_0^2(\epsilon_lr) \qquad (2)$$

$$|\Psi^T(r,x)|^2=\frac{6\alpha}{(2\pi)^2}\sum_{l=1}^{N_f}e_l^2[m_l^2K_0^2(\epsilon_lr)+(x^2+(1-x)^2)\epsilon_l^2K_1^2(\epsilon_lr)] \qquad (3)$$

where K_0, K_1 are the modified Bessel functions; r ,x are the distance between the quark and the anti-quark in the impact parameter plane and the fraction of the light-cone momentum of the γ carried by the quark, $\epsilon^2=m^2+x(1-x)Q^2$;m_l, e_l are the masses and charges of quarks.N_f is the number of flavours. The superscripts i,j=T,L correspond to the transverse and longitudinal polarizations

of photons.As to the dipole-dipole cross section it is universal and takes the form:

$$\sigma(r,r')=32/9\int\frac{\alpha_s^2(n^2)(1-e^{iqr})(1-e^{-iqr'})}{n^4}d^2n \qquad (4)$$

where $\alpha_s(n^2)$ is the running strong coupling. Expression (1) has a clear quantum-mechanical interpretation. The probability of two photons to be involved in strong interaction is determined by dipole-dipole interaction which are averaged using the wave functions of virtual photons constructed as quark-antiquark pairs.As was mentioned above, such representation corresponds to exact diagonalization of the S-matrix and is free from the problem of double counting.Furthermore, if one tries to describe the photon interaction using a hadronic basis (like VDM or GVDM) he immediately encounters the problem of nondiagonal transitions among the vector mesons,which is a serious trouble because the coresponding amplitudes are unknown.The noticeable advantage of present approach is absence of such difficulties.It is easy to see that the above expressions are infrared stable,which is the direct consequence of gauge invariance.

As a next step let us investigate the problem in a more common momentum representation.Using the expressions:

$$\int K_0^2(\epsilon r)(1-J_0(kr))d^2r=\pi/\epsilon^2[1-\frac{2\epsilon^2 ln\frac{\sqrt{4\epsilon^2+k^2}+k}{\sqrt{4\epsilon^2+k^2}-k}}{k\sqrt{k^2+4\epsilon^2}}] \qquad (5)$$

$$\int K_1^2(\epsilon r)(1-J_0(kr))d^2r=\pi/\epsilon^2[-1+\frac{(2\epsilon^2+k^2)ln\frac{\sqrt{4\epsilon^2+k^2}+k}{\sqrt{4\epsilon^2+k^2}-k}}{k\sqrt{k^2+4\epsilon^2}}] \qquad (6)$$

one easily sees that (1) becomes:

$$\sigma^{ij}(Q_1^2,Q_2^2)=32/9\int\frac{\alpha_s^2(k^2)\phi^i(Q_1^2,k^2)\phi^j(Q_2^2,k^2)}{k^4}d^2k \qquad (7)$$

$$\begin{aligned}\phi^T(Q^2,k^2) &= \tfrac{3\alpha}{2\pi}\textstyle\sum_{l=1}^{N_f}e_l^2\int[m_l^2/\epsilon_l^2-(x^2+(1-x)^2)\\ &+ \frac{[(2\epsilon_l^2+k^2)(x^2+(1-x)^2)-2m_l^2]\ln\frac{\sqrt{4\epsilon_l^2+k^2}+k}{\sqrt{4\epsilon_l^2+k^2}-k}}{k\sqrt{4\epsilon_l^2+k^2}}]\,dx\end{aligned} \qquad (8)$$

$$\phi^L(Q^2,k^2)=\frac{6\alpha Q^2}{\pi}\sum_{l=1}^{N_f}e_l^2\int x^2(1-x)^2[1/\epsilon_l^2-\frac{2\ln\frac{\sqrt{4\epsilon_l^2+k^2}+k}{\sqrt{4\epsilon_l^2+k^2}-k}}{k\sqrt{4\epsilon_l^2+k^2}}]\,dx \qquad (9)$$

These expressions allow one to calculate the hadronic part of $\sigma(\gamma\gamma)$ for any virtualities of photons for small x_B.When x_B increase one has to take into account the suppression which is connected with the restrictions on the phase space.The work in this direction is in progress [14].As was mentioned above, they are infrared stable and independent of energy, which is the consequence of vector exchange. In the case of quasi-real photons ($Q_1^2 = Q_2^2 \approx 0$) expressions (7-9) coincide with the lowest order one in [15].

3.The total hadronic cross section for interaction of a virtual photon with a quasi-real one.

At the present time there are a large amount of experimental data for $\sigma(\gamma\gamma)$ in the case when one of the photons is quasi-real and the other is virtual.Using the above expressions one can calculate the dependence of the experimentally measured quantity $\sigma_T+\varepsilon\sigma_L$ on the virtuality of the photon Q^2.Usually the polarization parameter $\varepsilon \approx 1$. We imagine the total photon photon cross section as a sum of σ_{QPM}(Fig.1a),which we calculate using the corresponding expressions from[9] and σ_{QCD}, which is determined by (7-9).The latter expressions depend on the value of strong coupling for which we use a freezing approximation[6,7].As usual we put for quark masses $m_u = m_d = m$; $m_s = m + 150 Mev$,and so have to determine only one free parameter m.For this goal we calculate the total photon photon cross section in the case when the both photons are real.The result of these calculations is represented in the Fig.2. The experimental values for the total photon photon cross section in the case of both real photons lie in the interval 200-400nb[1]. Large experimental errors do not allow unique determination of the quark mass, though the proposed model gives resonable values for $\sigma(\gamma\gamma)$. For this reason we will fix m upon the value m=180Mev,which is compatible with Fig.2 and gives the right value for the photon nucleon total cross section[5,6]. In Fig.3 we present the results of our calculations for the case when one of the photons is real and the other is virtual.Experimental data (PLUTO collaboration[16]) are averaged in the energies interval (3Gev-10Gev). Curve 1 is the contribution of σ_{QPM}, which was calculated by using expressions (D3) from [9] (appropriately averaged by energies). Curve 2 representes the hadronic part of the cross section σ_{QCD} calculated with the use of expressions (7-9)from the present work.Their sum is curve 3.As can be seen from Fig.3 the proposed model is in good agreement with experimental data in a large region of Q^2.Finally,in Fig.4 we present the predictions for R=σ_L/σ_T, which is the ratio of total photon photon cross sections for longitudinally polarized photons versus transversally polarized one.This quantity grows up to $Q^2 = 30 - 40 Gev$ and then slowly goes down.This prediction can be checked in the future when there will be the experimental data for different polarizations of virtual photons.

The main results of the present work can be summarized as follows:

1)We obtained the expressions for the hadronic part of the total photon photon cross section for any virtualities of photons and different polarizations in the dipole-cross section represantation and show its equivalence with the represantation in the momentum space.

2)This way allows one to present $\sigma(\gamma\gamma)$ as a sum of two contributions,of which one can be interpreted as a direct interaction of the virtual photon with the va-

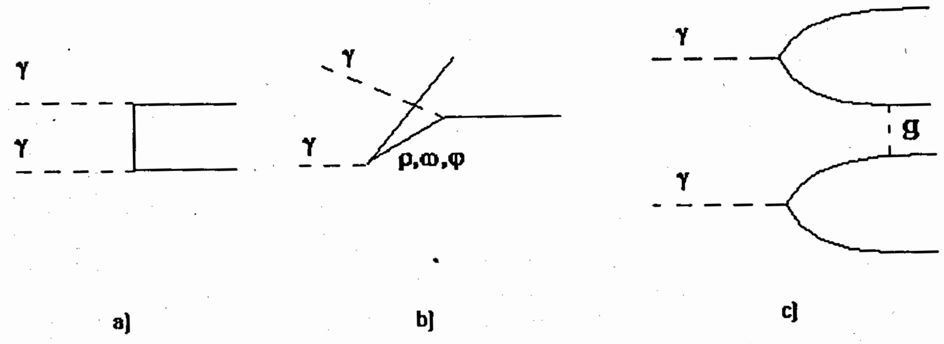

Fig. 1 The different contributions to photon-photon total cross-section: a) QPM; b) VDM; c) Gluon exchange

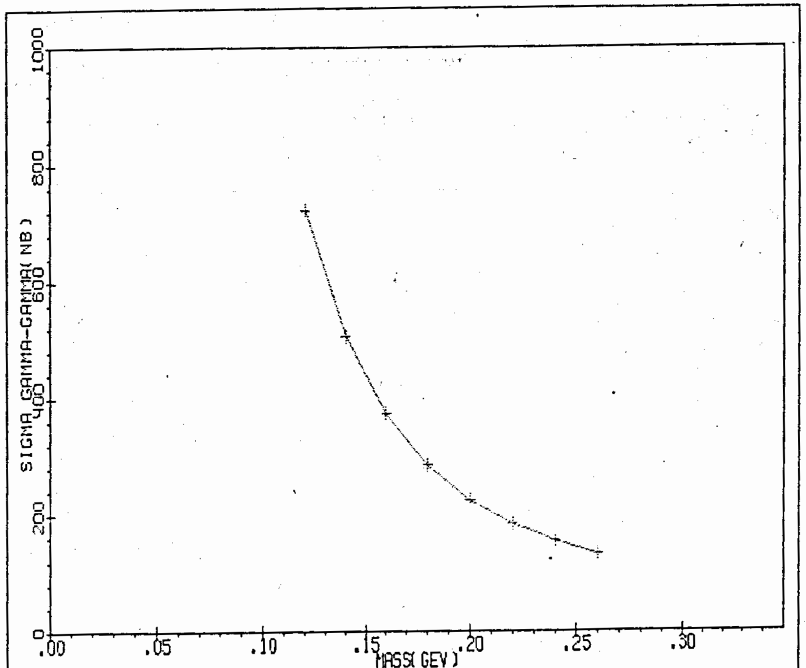

Fig.2. TOTAL GAMMA-GAMMA CROSS SECTION AS A FUNCTION OF THE QUARK MASS

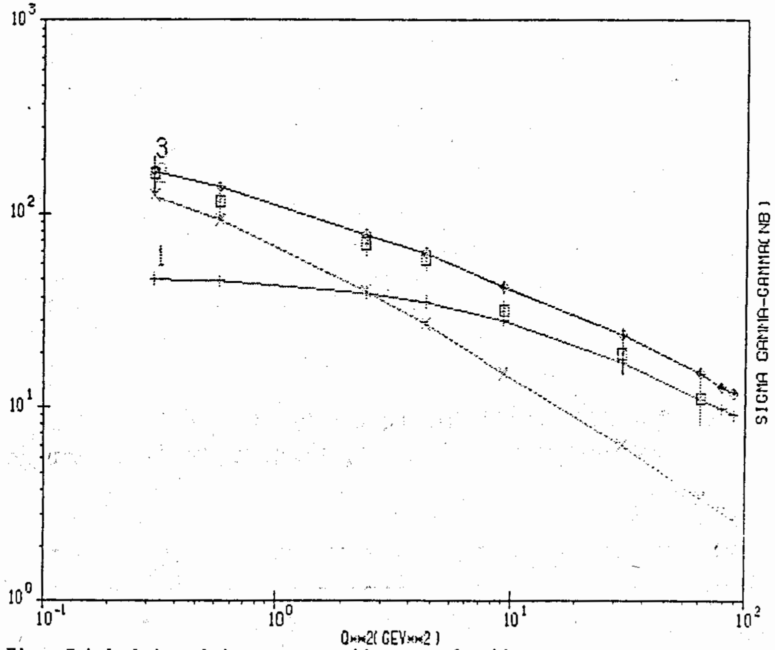

Fig. 3 Total photon-photon cross section as a function of the photon virtuality

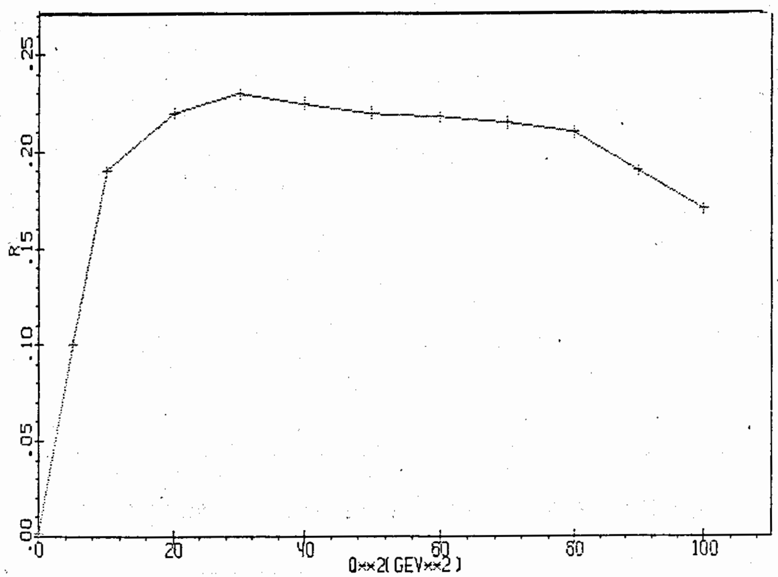

Fig. 4 THE RATIO OF LONGITUDINAL AND TRANSVERSE TOTAL CROSS SECTIONS AS A FUNCTION OF THE PHOTON VIRTUALITY

lence quarks of another photon(Fig.1a),and the other is the interaction among the hadronic parts of photons(by two gluon exchange in our case, Fig.1c).Doing so one avoids the problem of double counting, which immediately arises when one imagines that $\sigma(\gamma\gamma)$ consistes from contributions in different bases (quark base Fig.1a;hadronic one Fig.1b).Moreover the model automaticaly take into account all possible intermediate state.

3)The agreement between predictions of the proposed model and the experimental data which is obtained practically without any free parameter (remember that the quark mass was taken to be the same as in description of the photon nucleon total cross section) allows one to use the model not only for the investigations of total photon photon cross sections but for more complex cases as exclusive production of hadrons,jets production and so force.The work of S.Gevorkyan was partly supported by INTAS grant 93-239.

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Received by Publishing Department
on December 2, 1994.