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PHOTON – POMERON COUPLING IN HADRONIC INTERACTIONS

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ABSTRACT

Pomeron coupling to photons has been analyzed. As the pomeron assumed to couple to hadrons through their constituent quarks and since the photon has no constituent quarks it's coupling to the pomeron is not well known. We proposed that the pomeron may couple to two photons in away similar to that of pseudo scalar particles (π0, η, ή). To justify our model we have calculated the photon-proton total cross section in the region where a single pomeron is dominated. For completeness the contribution from reggeons exchange at low energies has been included. A comparison with the data shows a good agreement.

Introduction

It is now understood [1] that soft hadronic processes at high energy are dominated by the exchange of soft pomeron with Regge intercept 1+ϵ1= 1.08 or possibly a little larger[2]. Analyzing the proton structure function also revealed the presence of hard pomeron with intercept greater than 1+ϵ0=1.4 .The pomeron intercept produces the increasing behavior of the cross section with energy. Pomeron exchange is also dominating the elastic scattering at small and high [3, 4] momentum transferred (t) . Hard pomeron is also expected to contribute to these processes especially at high (t). Despite the reasonable success of the pomeron theory in explaining the behavior of some of the experimental data, there is not yet any real understanding of just what the pomeron is. How it can be generated and how it should couple to hadrons. Some models[5] assumed that pomeron exchange involves just a single quark form each interacting hadrons. Attempts [6] to drive the pomeron from the QCD theory faced many problems.

These attempts are based on Feynman field perturbation theory with field gluons exchanged between the quarks. Due to the confinement quarks and gluons do not represent the unitarity structure properly. At least two gluons should be exchanged to get color singlet hadrons. If we think of the pomeron as two gluons process we get a pomeron trajectory with intercept one. Inserting quark anti-quark pairs we get a ladder. Then the intercept will be greater than one.

Pomeron was assumed to couple to hadrons through their constituent quarks. Donnachie and Landshoff [4] proposed that pomeron couples to quark rater like photon with $\beta\gamma^{\mu}$ coupling. The strength of the pomeron coupling is given as $\beta^2 = 3.21\ GeV^{-1}$. However ,there are some hadronic processes which involve pomeron–photon coupling. It is not clear yet how the pomeron should couple to the photon. As the photon has no constituent quarks this coupling is even more mysterious. In deep inelastic lepton scattering [7],the cross section involves pomeron coupling to two photons. This coupling is given in terms of quark loop. The integration over this loop is divergent . To treat these kinds of divergences [8] a softening

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factor $(\mu_0^2 - k^2)$ was introduced for each far off mass shell quark leg. Where k^2 is the square of the quark momentum . For ρ- meson production the non relativistic ρ - meson wave function approximation was used as well. However, to calculate the photon-proton total cross section we notice that according to Regge theory the cross section is given by exchange of pomeron at high energy and reggeon at low energy. Therefore, our process involves a pomeron – two photons coupling at high energy as shown in fig(1). At low energy reggeons that could couple to two photons are the pseudo scalar and tensor mesons. We assume that the coupling of the pomeron to two photons is similar to that of the pseudo scalar particles. Therefore ,the coupling of the pomeron to the quarks in the quark loop is taken as $\beta\gamma_5$ .The value of β will be evaluated from the proton- proton total cross section. In this paper we assume that photons are real. The effect of photons being off mass shell will be discussed in a subsequent paper .

The Calculation

At high energy the amplitude for elastic photon–proton scattering is dominated by pomeron exchange. This amplitude can be written as [4]

$$A = 3\,\beta\, f(t)\; G_{p\gamma\gamma}(t)\;\; \exp\,(\alpha(t)\log s - i\pi\, l\; 2)$$

(1)

Where β is the pomeron-quarks coupling constant. The number 3 arises from the number of quarks in the proton, $f(t)$ is the proton elastic from factor which is equal one at $t = 0$, $\alpha(t) = 1+$ ϵ1 $+\alpha\, t$ is the pomeron trajectory with intercept 1+ ϵ1 $= 1.08$ and $G_{p\gamma\gamma}(t)$ is the pomeron –two photons vertex. This vertex is represented by the triangle quark loop in fig(1). We notice that the amplitude in eq(1) resembles that of the elastic quark- quark scattering amplitude with pomeron exchange [4]. Calculating the trace of the quark loop then the above vertex can be written as [9]

$$G_{p\gamma\gamma} = \sum_q 32\,\pi\alpha\; n\; g\; e_q^2\;\, m_q\, G\,(m_1, m_2, m_3)$$

(2)

Where $n = 3$ is the number of colour , m_q and e_q are the mass and the fraction of charge of the quark respectively. g is a dimensionless coupling constant of the pomeron to the quarks. The summation is over all types of the quarks. The factor $G(m_1, m_2, m_3)$ is the integration over the quark loop given in terms of the three external masses connected to the triangle. This integration was performed in terms of three point's technique introduced by 't Hooft and Veltmann [9] . For real external masses the integral is given by a symmetric function involving Spence function. If one of the external masses is zero the integral reduces to an elementary function. For our case the external photons are real then $m_1 = m_2$ =0. Therefore , eq(2) reduces to

$$G_{p\gamma\gamma}(0,0,m) \;=\; \frac{1}{8\pi^2\, m^2}\quad Arc\sin^2\,(\frac{m}{2m_q})$$

(3)

Where $m^2 = t$ is the mass of the exchanged particle. Using Maclaurin expansion we get

$$Arc\sin^2\, z = z^2 + \frac{1}{3}\, z^4 + \frac{8}{45}\, z^6 + \ldots \quad (4)$$

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Let $z = \frac{m}{2m_q} \langle 1$ then

$$G(0,0,m) = \frac{-1}{32\pi^2 m_q^2} \quad (1+\frac{1}{3}(\frac{m}{2m_q})^2 \quad + ...)$$

(5)

For $m^2 = t = 0$ the above equation reduces to

$$G(0,0,m) = \frac{-1}{32\pi^2 m_q^2} \qquad (6)$$

For scattering with negative transfer momentum $-t < 0$ the integral in eq(2) gives instead of eq(3) the following equation:

$$G(0,0,t) = \frac{1}{(4\pi)^2 t} \frac{1}{2} \ln^2 (\frac{\gamma+1}{\gamma-1}) \qquad (7)$$

With $\gamma = \sqrt{(1+\frac{4m_q^2}{t})}$ (8)

For $y = \frac{1}{\gamma}$ we have

$$\ln^2 (\frac{1+\frac{1}{\gamma}}{1-\frac{1}{\gamma}}) = \ln^2 (\frac{1+y}{1-y}) \qquad (9)$$

We notice that as $t \to 0$ then $y \to 0$. Therefore we can expand the function in eq(9) in terms of Maclaurin expansion :

$$\ln^2 (\frac{1+y}{1-y}) = 4(y^2 + 2y^3 + y^4 + ...)$$

(10)

Then equation (7) reduces to

$$G(0,0,t) = \frac{-1}{8\pi^2 (t+4m_q^2)} (1+\frac{\sqrt{t}}{\sqrt{(t+4m_q^2)}}$$
$$+..........) \qquad (11)$$

We notice that eq(11) gives the transfer momentum dependence of the form factor. Since we are interested in the region where $t = 0$ then eq(11) gives

$$G(0,0,0) = \frac{-1}{32\,\pi^2\, m_q^2} \qquad (12)$$

This is exactly eq(6). Substituting eq (12) in eq(2) we get

$$G_{p\gamma\gamma} = \frac{3\alpha}{\pi} \sum_q e_q^2 \frac{g}{m_q} \qquad (13)$$

We notice from the diagram in fig(1) that the pomeron connects a free quark line at the lower vertex to off mass shell quarks at the upper vertex. We assigned a dimensional coupling $\beta(GeV^{-1})$ for the pomeron coupling to the quark at the lower vertex. However ,the quantity $\frac{g}{m_q}$ has the same dimension of β. Moreover the pomeron couples to the proton constituents at the lower vertex while the summation in eq(13) involves all types of quarks at the upper vertex. Then we can write

$$\sum_q e_q^2 \frac{g}{m_q} = c\,\beta \qquad (14)$$

With c is some constant a round one. The value of β can be evaluated from the proton total cross section. The amplitude for elastic proton-proton scattering is given by eq(1) with 3β is used instead of $G_{p\gamma\gamma}(t)$. Appealing to the optical theorem the proton –proton total cross section in terms of Regge theory is given as :

$$\sigma_{pp} = 9\,\beta^2 s^{\epsilon} \qquad (15)$$

But the photon- proton total cross section ($\sigma_{\gamma p}$) from the amplitude in eq(1) is:

$$\sigma_{\gamma p} = \frac{\alpha c}{\pi} 9\beta^2 \; s^{\epsilon} \qquad (16)$$

We can put eq(16) in the form

$$\sigma_{\gamma p} = \frac{\alpha c}{\pi} \sigma_{pp} \qquad (17)$$

A fitting for σ_{pp} in the single pomeron region is given as [10]

$$\sigma_{pp} = 24.22 \; s^{\epsilon} \qquad (18)$$

The above cross section is given in mb. For c=1.3 we get

$$\sigma_{\gamma p} = 0.0732 \; s^{\epsilon} \qquad (19)$$

This is in agreement with the fitting given in ref(10). At low energy the cross section is given by reggeon exchange. Reggeon that could couple to two photons are the pseudo scalar and tensor mesons (π0, f, η , ή, A). The amplitude for fig(1) with π0 exchange instead of the pomeron is given by eq(1) with different vertices. At the upper vertex the $G_{p\gamma\gamma}$ can be calculate from eq(13) with $\frac{g}{m_q} = \frac{1}{f_\pi}$ where $f_\pi \approx 0.09$ is the pion decay constant. With $\sum_q e_q^2 = 1/3$ for the π0 state we can find that $G_{p\gamma\gamma} = 0.0258\, GeV^{-1}$ [9] . At the lower vertex the coupling constant between π0 and the proton is given by [11]:

$$\frac{f^2}{hc} = \frac{g^2}{hc} \left(\frac{m_\pi}{2m_p}\right)^2 \qquad (20)$$

where m_π and m_p are the pion and proton masses respectively , g is the pion –proton coupling constant and f is given as

$f^2/4\pi = 0.0877$, which gives

$$\frac{g}{m_p} = 15.55 \; GeV^{-1} \qquad (21)$$

Then ,the contribution from π0 to the total cross section is given as

$$\sigma = 0.156 \; s^{\alpha_\pi(0)-1} \qquad (22)$$

The pion trajectory is taken as [6]

$$\alpha_\pi(t) = m_\pi^2 + 0.9\, t \qquad (23)$$

As $\alpha_\pi(0) = m_\pi^2$ the cross section from π0 exchange has the form

$$\sigma = 0.156\, s^{-0.98} \qquad (24)$$

However , the fitting for the cross section in the reggeons exchange region is given by the form [10] :

$$\sigma = 0.113\, s^{-0.476} \qquad (25)$$

Discussion

To calculate the cross section at low energy region we need to calculate the couplings of the particles with even charge conjugation with two photons and with proton. A more systematic study for this process at low energy is required. With ϵ =.08 the total cross section from eq (19) and (24) is represented by the dashed curve in fig (2). We notice that our model is in a good agreement with the data [13]. If the pomeron intercept was taken as ϵ = 0.0667 as is used by the fitting in ref(10) the cross section from a single pomeron exchange would be reduced. In this case a contribution from the hard pomeron should be included in the calculation. Finally we should point out that our evaluation for β from eq(15) and eq(18) gives β^2 = 2.69 mb .The calculation of ref(4) gives β^2 =1.34 mb. Our value of β is twice that of ref(4). This is because the assumption of photon - pomeron similarity in ref(4) introduced a factor of 4 to the differential cross section. As this assumption is not included in our model the value of β^2 is higher by a factor of 2.

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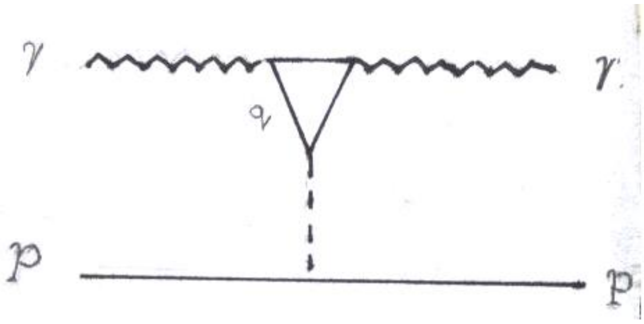
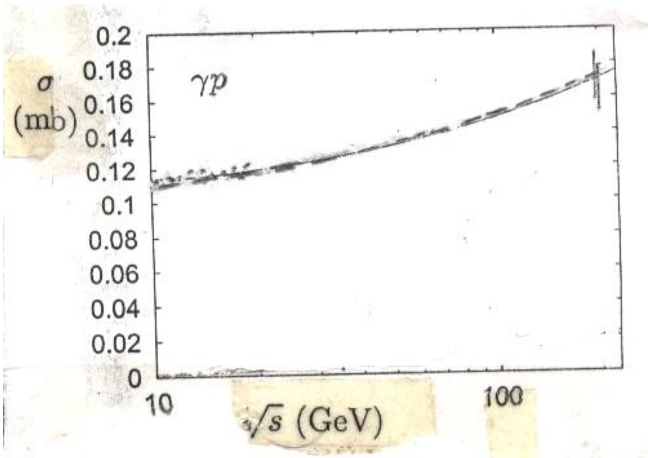


Fig (1) Schematic diagram of the elastic photon-proton amplitude. The triangle represents reggeon –photon vertex. The dotted line represents the exchanged reggeon or pomeron.



Fig(2) photon-proton total cross section compared with data from ref(10). The dashed curve represents the calculation from our model.

ازدواج الفوتون مع البومرون عند تصادم الهادرونات

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الخلاصة

تم دارسة ازدواج البومرون مع الفوتونات. وبما إن البومرون يفترض ان يزدوج مع الهادرونات عن طريق تراكيبها من الكواركات وحيث ان الفوتون ليس لـه تركيب من الكواركات فان ازدواج البومرون مع الفوتون غير معروف بشكل جيد. ولقد عرضنا هنا بان البومرون يمكن ان يزدوج مع فوتونين بطريقة متشابهة لازدواج الجسيمات. (π0, η , ή) وللتحقق من النموذج تم حساب المقطع العرضي الكلي لتصادم الفوتون مع البروتون عند الطاقات التي يغلب فيها تبادل البومرون. ولغرض تكامل الحسابات تم حساب مساهمة الرجونات عند الطاقات الواطئة. وقد أظهرت مقارنة النموذج مع النتائج التجريبية توافقاً جيداً.