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RHO MESON PRODUCTION IN PHOTON PROTON INTERACTION

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Abstract

Calculation of cross section for ρ meson production in real photon proton interactions has been carried out in terms of Regge theory. The amplitude of $\pi^0 \to \gamma\gamma$ is used for calculating the coupling of the exchanged particle at the photon - vector meson vertex. We only need to replace the coupling of the pion to quarks by the coupling of the exchanged particle to quarks. This coupling has been fixed by the experimental data. A comparison of the model with data shows an excellent agreement.

إنتاج الميزون المتجه روه عند تفاعل الفوتون مع البروتون

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الخلاصه

تم حساب المقطع العرضي لإنتاج الميزونات من نوع روه عند تفاعل الفوتونات مع البروتون باستخدام نظريه رجي. وقد استخدمت سعة تحلل البايون إلى فوتونين لحساب ازدواج الجسيم المتبادل عند عقدة الفوتون- الميزون المتجه. حيث إننا نحتاج فقط إلى إبدال ازدواج البايون مع الكوارك بازدواج الجسيم المتبادل مع الكوارك. وقد تم تثبيت الازدواج الأخير بواسطة النتائج العملية وعند مقارنة النموذج مع النتائج العملية فقد أظهرت المقارنة توافقا ممتازا.

Introduction

The inclusive deep inelastic scattering (DIS) of leptons off nucleon to lowest order in Quantum Electro Dynamic (QED) is treated in one photon exchange approximation. The leptons are the source of virtual photons of energy ν and virtual mass Q^2. The process is given as $\gamma^*(Q^2)\, P \to X(anything)$. In fully inclusive DIS only the scattered lepton is detected and one sum over all the hadronic final state (X). The observed DIS cross section is then proportional to the absorptive part of the Compton scattering amplitude at vanishing momentum transfer (t) as in figure(1).

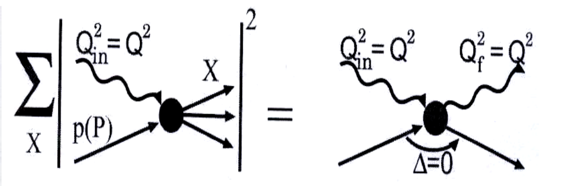

Figure 1: diagrammatic representation of deep inelastic total cross section.

The amplitude is applied only at t=0 and for $Q_{in}^2 = Q_f^2 = Q^2$.When the amplitude continued analytically to $Q_f^2 = 0$,it will describe real photon production ,while for further continuation to $Q_f^2 = -m_v^2$ gives the amplitude for exclusive vector meson production. These reactions [1] can be studied at non-vanishing momentum transfer (t). This means that DIS, the Deeply Virtual Compton Scattering (DVCS) and exclusive vector meson production are described by the same analytic function taken at different values of Q_f^2. The relation [2] between these reactions can be better seen in the light cone dipole picture of small-x DIS.

The Compton scattering which is behind the inclusive DIS at very small values of Bjorken variable x can be viewed as (1) the transition of the virtual photon to $q\bar{q}$ pair (the color dipole),(2) interaction of the color dipole with the target (3) the projection of the scattered $q\bar{q}$ on to the virtual photon as given in fig(2)

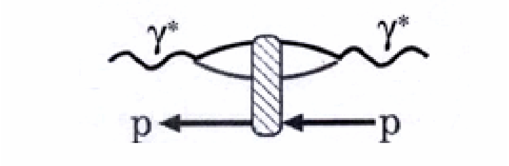

Figure 2: Compton scattering of photon in the color dipole picture.

If one lets the scattered color dipole materialize as hadrons ,one ends up with the large rapidity gap DIS-the diffractive $\gamma^* P \to P\ X$ .The projection of the $q\bar{q}$ onto the vector mesons gives the exclusive vector meson production, and the projection onto the real photon gives DVCS.

The amplitude of the transition of the photon into $q\bar{q}$ state, and the amplitude of scattering the color dipole off the target are the universal ingredients in all the processes. The different processes probe the color dipole scattering amplitude at different dipole size [3].

According to the vector meson dominance model (VMD) the amplitude [4] of production of the virtual photon $\gamma^*(Q_f^2)$ will be proportional to the vector meson production amplitude times the amplitude of meson-photon transition at the meson pole. From the color dipole point of view, the success of the VMD in real photon production arises from the similarity of the distribution of $q\bar{q}$ in the real photon and the vector meson. This means that the amplitude of interaction of the color dipole with the nucleon can be approximated by the vector meson-nucleon scattering amplitude. It has been observed [4,5] that the t-distribution of the elastic πN scattering, real Compton scattering $\gamma P \to \gamma P$ and real photon production $\gamma P \to \rho P$ is the same. Analyzing of the ϕ meson production shows that the VMD gives overestimated result. The relatively heavy strange quark reduces the dimension of the ϕ meson. The interaction of the color dipole is controlled by not the number and flavor of quarks in the state but rather its size.

The production of the vector meson [2] seems to be controlled by the dimension of the interaction R_s. For $R_s \langle\langle R_V$,with R_V is the size of the vector meson the production is a hard scattering process. The scale [6] of the hard process is described by the region $Q^2 \rangle\rangle 1\, GeV^2$ and/ or t$\rangle\rangle$ $1\, GeV^2$. Here we present a model based on Regge theory to calculate the cross section of the vector meson production in real photon proton interaction. It is well known that hadrons exchange reggeons at low energy and pomeron at high energy. The couplings of the exchanged particles with the interacting hadrons are functions of $Q^2 and\ t$. We argue that these form factors may reproduce the dependence of data on these variables. First we shall consider the soft region i.e. the production of the vector meson by real photon at small values of t. The dependence on Q^2 and higher values of t will be discussed in a subsequent work.

The model

Consider the production of vector meson in elastic real photon- proton interaction. The diagram in figure (3) gives the amplitude of the process.

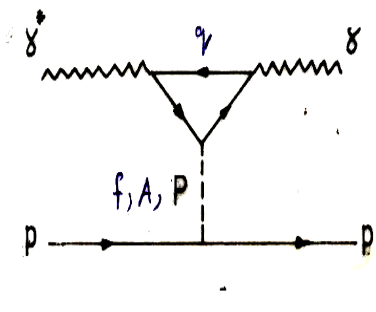

Figure 3: Compton scattering with triangle quark loop.

According to Regge theory, the hadrons in the process exchange pomeron at high energy and reggeons at low energy. We assume that pomeron and reggeons couple to the photon-vector meson vertex through quark-antiquark pair as indicated in the figure. The process is therefore similar to color dipole picture. Only reggeons with even charge conjugation can contribute to the process. The amplitude of the process is given by [8]:

$$A = i\sum_k G_k(t)\,F(t)\,(\alpha'_k\, S)^{\alpha_k(t)-1}\, e^{-1/2 i\pi\alpha_k(t)} \quad (1)$$

The phase is for particle with even charge conjugation and the sum is over the exchanged reggeons and pomeron. We adopt the dual model prescription that, that for trajectory of slope α',one should take $S_0 = 1/\alpha'$. The pomeron trajectory is taken as

$$\alpha_1(t) = 1.08 - \alpha'_1\, t \quad (2)$$

with $\alpha'_1 = 0.25\, GeV^{-2}$

while that for reggeons has the form:

$$\alpha_2(t) = 0.45 - \alpha'_2\, t \quad (3)$$

With $\alpha'_2 = 0.93\, GeV^{-2}$.

The form factor $G_k(t)$ is the coupling of the exchanged particle to the photon and vector meson at the upper vertex. This coupling is represented by the triangle in figure (3). To calculate this form factor we need to integrate over the quark loop. Similar calculation has been carried out for $\pi^0 \rightarrow \gamma\gamma$. The amplitude of this process is given by [9]:

$$G(t) = \sum_q 32\pi n\,\alpha\, e_q^2 \beta\, m_q^2\, G(m_1, m_2, m_3) \quad (4)$$

where $G(m_1, m_2, m_3)$ is a form factor given in terms of Spence function , $m_1, m_2, and\ m_3$ are the masses of the particles connected to the triangle in the figure. The factor β is a dimensional quantity represents the coupling of the pion to the quarks and n is the number of color. For simplicity we adopt the results of these calculations , then the coupling constant β represents the coupling of the exchanged particle to the quarks. For vector meson production one has to multiply eq.(4) by $\frac{f_v}{e}$ where f_v is the coupling of the vector meson to quarks.

We shall consider here only the ρ-meson production ,where we have $\frac{f_\rho^2}{4\pi} = 2.01$, $\sum_q e_q^2 = \frac{1}{\sqrt{2}}((\frac{2}{3})^2 - (\frac{1}{3})^2)$ and the external masses connected to the triangle are $m_1^2 = 0$, $m_2^2 = m_\rho^2$ and $m_3^2 = t$. The form factor in eq(4) is then given by:

$$G(0, m_\rho, t) = \frac{M}{16\pi^2 (m_\rho^2 - t)} \times \left[\frac{\pi^2}{2} + \frac{1}{2}\ln^2\left(\frac{\beta_1 + 1}{\beta_1 - 1}\right) - \frac{1}{2}\ln^2\left(\frac{1+\beta_2}{1-\beta_2}\right)\right] \quad (5)$$

Where

$$\beta_1 = \left[1 - \frac{4m_q^2}{t}\right]^{1/2} and \quad (6)$$

$$\beta_2 = \left[1 - \frac{4m_q^2}{m_\rho^2}\right]^{1/2}$$

The form factor at the lower vertex is coupling of the exchanged particles with the proton which can be given by 3β times the Dirac elastic form factor [8]. The factor 3 accounts for the number of quarks in the proton, and the Dirac form factor $F(t)$ is given by:

$$F(t) = \frac{4m_p^2 - 2.79t}{4m_p^2 - t}\left(\frac{1}{1 - \frac{t}{0.71}}\right)^2 \quad (7)$$

The only unspecified parameter is β the coupling constant of the exchanged particle with the quarks. This can be fixed by the experimental data. The proton-proton and antiproton – proton total cross sections are parameterized in the forms [10]:

$$\sigma_{pp} = 56.08\, S^{-0.4525} + 21.70\, S^{0.0808} \quad (8a)$$

$$\sigma_{\bar{p}p} = 98.39\, S^{-0.4525} + 21.70\, S^{0.0808} \quad (8b)$$

As it is well known that the first term represents the contribution from the reggeons ρ, ω, f *and* A while the second term represents the contribution from pomeron exchange. Since ρ *and* ω have odd charge conjugation they have opposite contribution to the above cross sections. Adding and averaging the first term, then the contribution from f *and* A can be obtained as:

$$\sigma_{f,A} = 77.485\, S^{-0.4525} \qquad (9)$$

The coefficients in eqs.(8,9) are given in mb. According to Regge theory these coefficients equal to $9\beta^2$. But as β is given in GeV^{-2} we divide the coefficients by 0.388 to get the same units. For a dimensionless parameter β one has to multiply by $M^2 = 1\, GeV^2$.

Results and discussion

The differential cross section is given by [11]:

$$\frac{d\sigma}{dt} = \frac{|A|^2}{16\pi} \qquad (10)$$

The results of our calculation are given in figure (4).

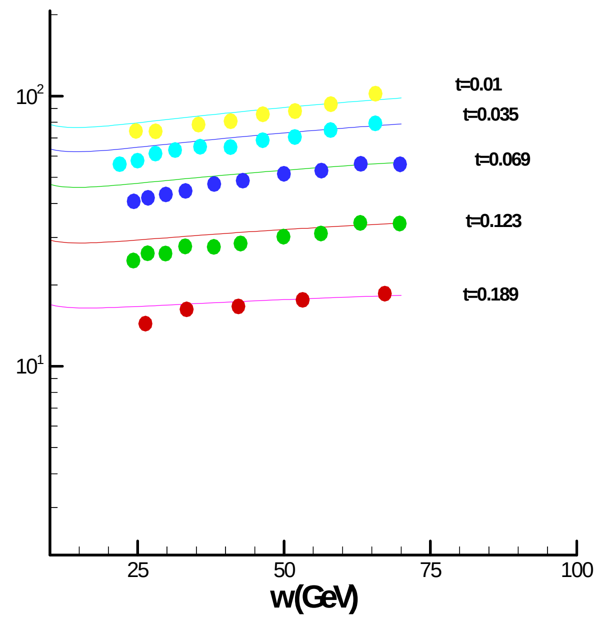

Figure 4: Differential cross section as a function of (w) compared with data for different values of (t).

with the experimental data taken from refs. [8,12,13].

We notice an excellent agreement between the model and the data.This indicates that our approach in calculating the reggeons-meson-photon and pomeron-meson- photon form factors is quite reasonable. We also show $\frac{d\sigma}{dt}$ as a function of t for two values of w in figures (5,6) which again reflect a nice agreement with data.

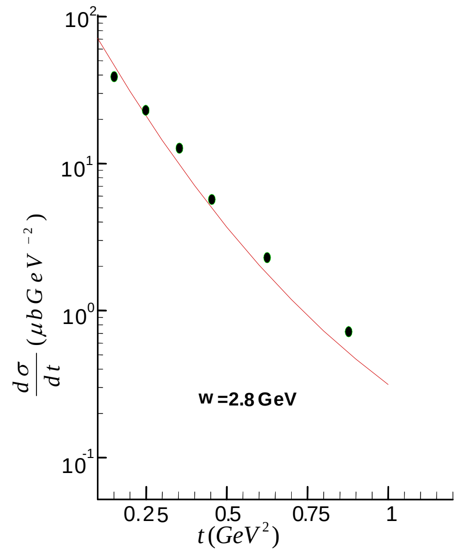

Figure 5: differential cross section as a function of (t) compared with data at w = 2.8 GeV.

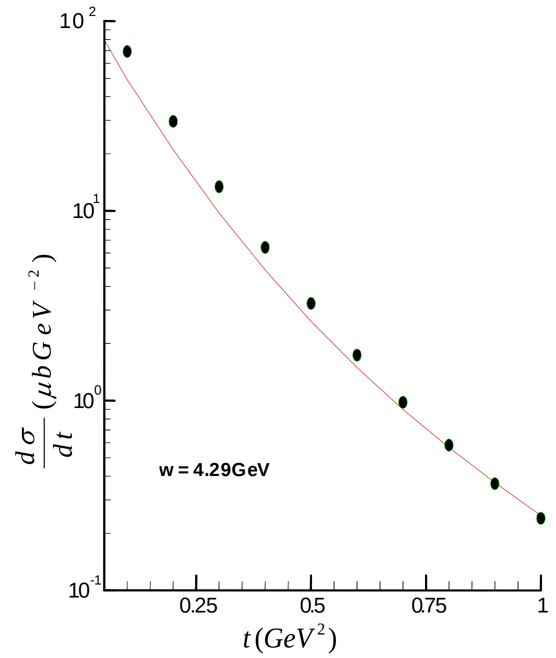

Figure 6: differential cross section as a function of (t) compared with data at w = 4.29 GeV

It is worthwhile to notice that, for using $m_\rho \cong 2m_q$ then $\beta_2 = 0$ and the final term in eq.(5) reduces to zero. Furthermore, for $|t| \approx 4m_q^2$, then $\beta_1 \approx 2$ and the second term has a small contribution. As $|t|$ decreases to zero the contribution from this term reduces to zero. The form of the photon –rho meson vertex is then given by

$$G(0, m_\rho, t) = \frac{1}{8}(\alpha\pi)^{1/2} \frac{M\beta \ f_\rho}{m_q \, (1 - \frac{t}{m_\rho^2})} \qquad (11)$$

The t dependence of this form factor is exactly the same as that given by the fit of Donnachie and Landshoff [7,8]. It is quite clear that this approach reproduces the data of ρ meson production in the soft region. This model need to be tested for other particles and for higher values of t and Q^2. Finally in our calculation we find that the quark mass $m_q = 0.3\, GeV$ gives the best agreement between the model and the data.

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