Electromagnetic effects in central exclusive diffractive Higgs boson production

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The role of electromagnetic effects, coming from peripheral photon-photon fusion, in central exclusive diffractive Higgs boson production at LHC is studied, both in hadron-nucleus and nucleu-nucleus collisions. These effects are shown to be large, exceeding those from two Pomeron exchanges. The role of the gap survival probability is also studied. Numerical prediction for he total cross sections to be measured in future experiments at the LHC are given.

Keywords: Diffraction, hard diffraction, Higgs boson, pomeron, Regge approach, two-photon fusion

1. Introduction

In paper [?] a Regge pole model, including spin degrees of freedom, for central exclusive diffractive Higgs boson production in pp collisions was suggested and its prediction for the future LHC experiments were presented.

Central diffractive production of the Higgs boson with predictions for the Fermilab Tevatron and the Large Hadron Collider (LHC) was studied in a large number of papers [?]-[?]. These studies are based on the idea that production the gluon-rich medium (diffraction) favours the production of the Higgs boson. Particularly clean events are produced in so-called double pomeron exchange (DPE), where both beam hadrons emerge intact separated by rapidity gaps from a centrally produced system X. An extreme possibility is exclusive Higgs production, $pp(\bar{p}) \to PHP(\bar{p})$, (Fig. 1) where the central system is just a Higgs boson (H) that may be reconstructed by using a missing mass method [?]. The crucial question whether the relevant cross sections are large enough remains open.

Predicted cross sections vary by orders of magnitude between calculations based on different models. Some predictions for the Tevatron are experimentally within the experimental attainability, while others are not. The basic assumption in most of the cited papers is that the pomeron, mediating

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diffraction, is a gluon-rich object, whose internal structure (structure function) can be recovered from diffractive deep inelastic scattering, e.g. from the HERA data, as suggested in [**?**]. In this approach, the Higgs boson is produced from the fusion of two gluons, emitted from the pomerons (Fig. 2). It combines elements of perturbative and non-perturbative quantum chromodynamics (QCD) as well as those of the Regge pole model. The uncertainties of the final results may accumulate from the uncertainties in the convolution of colored gluons and of the pomeron structure functions as well as from the poorly justified application of the Regge pole model to colored objects.

In this paper we continue our studies of central exclusive diffractived Higgs boson production. Here we sudy two aspects that are new with respact to our previous paper [**?**], namely we 1) calculate the contribution from two photon exchange; 2) consider hadron-nucleus and nucleus-nucleus scattering and 3) evaluate the gap survival probability. The reason for these new points, with respect to the studies of Ref. [**?**], are the following. Coulomb (photons) interaction becomes important for the collision of nuclei only, were its contribution can even exceeds that of the strong (pomeronic) interaction (this is the reason for considering nuclear collisions). The probability of the survival of a (large rapidity) gap, typical of a diffractive event became important at highest energies, were inelastic collisions dominate. Before addressing these questions, we briefly remind the main ingredients of the model of Ref. [**?**].

2. Double Pomeron exchange in central exclusive particle production of hadron scattering

At high energies and small momenta transfer, the invariant amplitude of Fig. 1 can be written in the form [**? ?**].

$$T_{12}^{3H4}(s_1,s_2,t_1,t_2,\phi)=g_1(\alpha(t_1))g_2(\alpha(t_2))g(\alpha(t_1),\alpha(t_2),\phi)\left(\frac{s_1}{s_0}\right)^{\alpha(t_1)}\left(\frac{s_1}{s_0}\right)^{\alpha(t_1)}, \qquad (1)$$

where ϕ is the angle between the transverse momenta $p^3_{3\perp}$ and $p^4_{3\perp}$ of the outgoing protons and

$$s_1=(p_3+p_H)\gg s_0,\quad s_1=(p_4+p_H)\gg s_0,$$
$$t_1\approx -p_{3\perp}^2\le s_0,\quad t_2\approx -p_{4\perp}^2\le s_0$$

are the generalized Mandelstam variables for the 5-point function with the kinematics shown in Fig. 1.

Following arguments coming from dual models [**? ?**], the $t-$ dependence of the residue was introduced entirely through the trajectory. From pp elastic scattering, the upper and lower vertices can be parameterized by $g(\alpha)=\exp(B\alpha)$, where, from elastic $pp(\bar{b})$ scattering, B is known to be equal 2 GeV^{-2} [**? ?**]. The pomeron trajectory is also known [**? ?**], and for not too high $|t|$ it can be parameterized by

$$\alpha(t)=1+0.2t-0.02\sqrt{4m_\pi^2-t}.$$

The (otherwise arbitrary) scale parameter s_0, for the sake of simplicity, will be set equal to 1 GeV^2.

The PHP vertex $g(\alpha(t_1),\alpha(t_2),\phi)$ is the only remaining unknown function, specified in Ref. [**?**].

In Ref. [**?**] expression (1) was modified by using a dipole pomeron (DP). According to its simple version, was suffices to multiply the r.h.s. of (1) by L^2 (one L from each rapidity window), still within the Froissart bound.

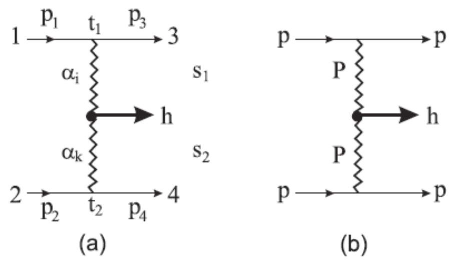

FIG. 1. (a) Central Higgs (H) production by double-Reggeon exchange. (b) Double-pomeron exchange contribution to the reaction $pp \to p + H + p$.

3. Gap survival probability

In the partonic language, a large rapidity event generated by a partonic shower can be ruined by two or more similar showers. This can be accounted for by multiplying of our process, eq. (1) by the so-called survival probatility.

For hadron-nucleus and nucleus-nucleus scattering, the main source of the shadowing corrections is the Glauber rescattering off different nucleons. A simple formula for the survival probatility is

$$\langle |S^2| \rangle = \frac{\int d^2 b A_H(b) exp\Big(-\Omega(b,s)\Big)}{\int d^2 b A_H(b)}, \tag{1}$$

where $A_H(b)$ is the impact parameter image of the central production amplitude ($PP \to H$ or $\gamma\gamma \to H$ and Ω is the opacity for proton-nucleus scattering equal to

$$\Omega(s,b) = \sigma_t(s,b) T_A(b), \quad T_A(b) = \int \rho_A(r) dz, \tag{2}$$

where $\rho_A(r)$ is the density of nucleons in a nucleus with mass number A, and Z is the longitudinal coordinate in the beam direction; σ_t is the total cross section of proton-proton interaction.

The nucleon density is given by the Wood-Saxon parametrization

$$\rho(b) = \frac{\rho_0}{1 - \Big((r - R_A)/h\Big)}, \quad \int d^3 r \rho(r) = A, \tag{3}$$

$r = \sqrt{b^2 + z^2}$ and $R_A = r_0 A^{1/3}$ with $r_0 = 1.09$Fm.

By taking $\sigma_t = 110$mb at LHC, one gets

$$\Omega(s_{LHC}, b) = 11 fm^2 T_A(b). \tag{4}$$

In the next Section we show that due to different b dependences in gluon-gluon (pomeron) and photon-photon interactions, the gap survival probability for the latter is substantially greater than that of gluons.

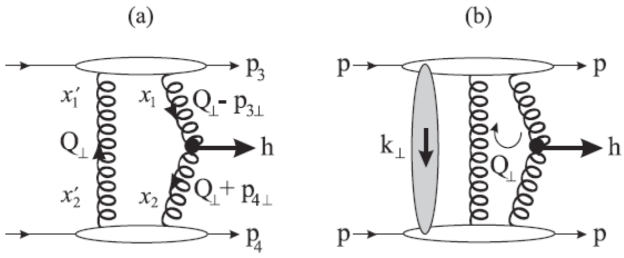

FIG. 2. (a) The QCD diagram for double-diffractive exclusive Higgs production [**?**] - [**?**]. (b) Rescattering, of absorption corrections, calculated e.g. in [**?**]a). Neither color screening (a), nor absorption corrections (b) are needed in our approach (see below).

4. Photon fusion

As anticipated in the previous Section, there is a striking difference in the behavior of the hard amplitude A_H in case of gluon (or pomeron) and photon fusion.

The difference between the value of the survival probability for CED Higgs production for gluon-gluon fusion and $\gamma - -\gamma$ fusion stems from the quite different behavior of the hard amplitude A_H for these processes.

In the case of gluon fuson, decreases steeply with $b > R_A$, while for photon fusion the relevant decrease in b is much weaker.

The normalized amplitude is defined as [**?**]

$$\tilde{A}_H(b) \equiv \frac{A_H 9b)}{\int d^2 b A_H(b)}. \tag{5}$$

By "gluon-gluon fusion", in fact, one implies Pomeron-Pomeron (PP) fusion, with the relevant hard amplitude:

$$A_H^{PP}(Q) = \int d^2 q_{1,\perp} \int d^2 q_{2,\perp} M(PP \to H; \overrightarrow{q_1}, \overrightarrow{q_2}) M^*(PP \to H; \overrightarrow{q_1} + \overrightarrow{Q}, \overrightarrow{q_2} - \overrightarrow{Q}), \tag{6}$$

where the amplitude $M(PP \to H; \overrightarrow{q_1}, \overrightarrow{q_2}$ for central exclusive diffractive (CED) Higgs production through PP fusion is [**?**]

$$M(PP \to H; \overrightarrow{q_1}, \overrightarrow{q_2}) = \frac{2}{9} As G_p(q_1^2) G_A(q_2^2) \int \frac{d^2 q_\perp}{q_\perp^2} \frac{(\overrightarrow{q}_{1,\perp} - \overrightarrow{q}_\perp) \cdot (\overrightarrow{q}_{2,\perp} + \overrightarrow{q}_\perp)}{(\overrightarrow{q}_{1,\perp} - \overrightarrow{q}_\perp)^2 \cdot (\overrightarrow{q}_{2,\perp} + \overrightarrow{q}_\perp)^2} 8\alpha_s^2(q^2), \tag{7}$$

where

$$A = \frac{2}{3} \frac{\alpha_s G_F^{1/2} 2^{1/4}}{\pi}. \tag{8}$$

Within the Glauber model approach, one has $R_A >> R_p >> 1/q$, and, therefore, the Q dependence in Eq. (6) is determined by

$$\int d^2 q_{2,\perp} G_A(q_{2,\perp}^2 G_A\Big((\overrightarrow{q}_{2,\perp}^2 + \overrightarrow{Q})^2\Big) = \int d^2 b e^{i\overrightarrow{Q}\,\overrightarrow{b}} T_A^2(b). \tag{9}$$

Eq. (9) implies that the amplitude (6) is proportional to $T_A^2(b)$ and that the survival probability is equal to:

$$\langle |S^2| \rangle_{GG\to H} = \frac{\int d^2 b T_A^2(b) exp\Big(-\Omega(b,s)\Big)}{\int d^2 b T_A^2(b)}. \tag{10}$$

Calculations show that the value of $\langle |S^2| \rangle_{GG\to H}$ is small since the nominator in Eq. (**??**) contributes only in the vicinity of $b \to R_A$ (e.g. $8 \cdot 10^{-4}$ for proton-gold collisions at the LHC energy).

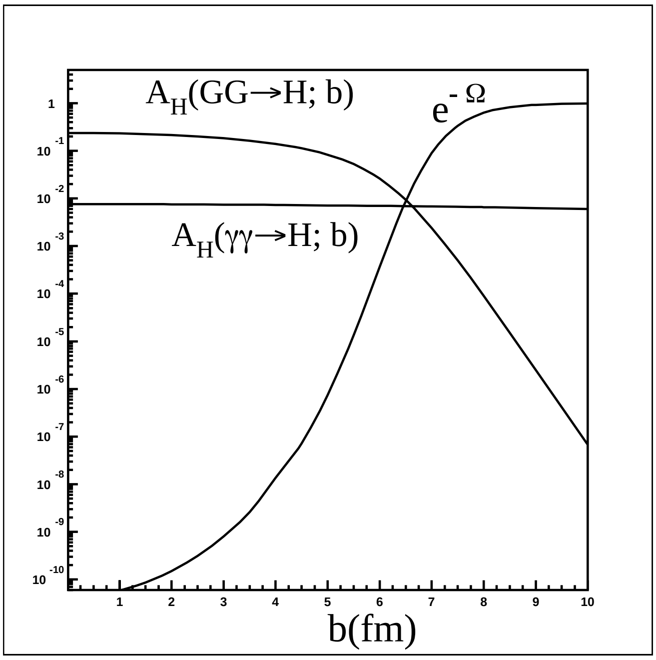

FIG. 3. Higgs production amplitudes be dependencies in gluon-gluon and photon-photon interactions and the gap survival probability.

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6. Conclusions

Our predictions for the Higgs boson production at the LHC are complementary to the great number of existing ones [**?**] - [**?**], most of which are "hybrid" models, based on elements of perturbation QCD combined with the orthogonal approach of the analytic S matrix (Regge pole theory), strictly speaking, valid only for colorless asymptotically free object (hadrons), rather than for confined quark and gluons. On the other hand, diffraction, a typically "soft" phenomenon, cannot be avoid the use of the "non-perturbative" Regge pole theory. The virtue of our approach is simplicity. We avoid the use of disputable (see, e.g. [**?**]) or unknown functions (such as "hadronization", pomeron structure, etc.) relying on a Regge-type model (DP pomeron), directly connected with the observables. Having fixed the parameters, one can proceed further by interpreting the obtained results in terms of the quark-gluon content of the pomeron.

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