Diffractive Higgs boson photoproduction in *pp* collisions

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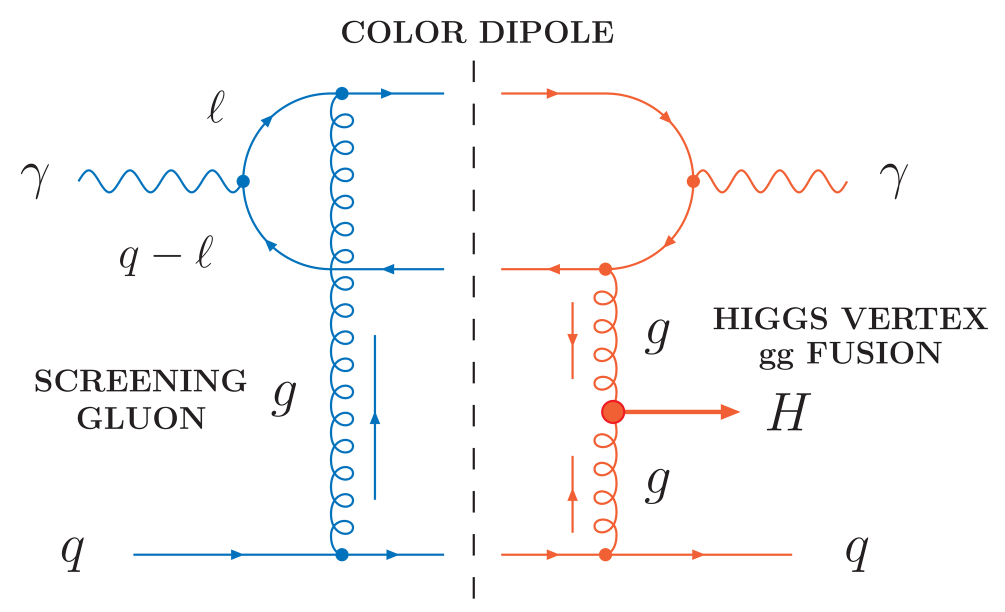
We propose the Higgs boson production through the Deeply Virtual Compton Scattering in γp collisions, such that the photon splits into a color dipole, and diffractively interacts with the proton by a Double Pomeron Exchange. Analysing this production process in Peripheral Collisions, we predict a cross section around 0.1 fm, which is similar to that obtained from the $\gamma\gamma$ subprocess. Besides, these results are lower than the predictions from the KMR approach, however, with different proposals for the Gap Survival Probability, our results are competitive with other predictions. Therefore, the photoproduction process is another way to detect the Higgs boson, and reveals the possibility to study the Higgs boson production associated to the Z^0 boson.

INTRODUCTION

The Higgs boson production by the Double Pomeron Exchange (DPE) was proposed to detect it in diffractive processes [1]. In Peripheral Collisions, we propose the application of the DPE in the γp subprocess to centrally produce the Higgs boson [2]. In this case, the interaction will occur between the colliding proton and the emitted photon from the electromagnetic field around the second proton [3]. This process is described by a DVCS-like approach, where the gluons are exchanged in the t-channel of the photon-proton subprocess. This approach allows the introduction of the impact factor formalism to describe the splitting of the photon in a color dipole [2], and to predict the production cross section.

PARTONIC LEVEL

Considering the partonic process $\gamma q \to \gamma + H + q$, one can compute the amplitude of the splitting photon, and its interaction with the quark inside the proton. In this way, the DVCS kinematical variables are introduced in the calculation to describe the exchange of gluons in the t-channel.



The above figure shows the diagram of the γq process, which presents only one contribution: each gluon couples to a fermion line in the color dipole, such that four different contributions arise. Moreover, the amplitude is calculated using the Cutkosky rules, where a central line cuts the diagram in two parts, and the amplitude of each part is calculated by the Feynman rules. The imaginary part of the amplitude can be computed as follows

$$\mathrm{Im}A = \frac{1}{2}\int d(PS)_3\,\mathcal{A}_L\,\mathcal{A}_R, \qquad (1)$$

where $\mathcal{A}_i$ is the amplitude of each side of the cut, and $d(PS)_3$ is the volume element of the three-body phase space. Using the Feynman rules, the scattering amplitude for a transversal polarized photon is given by (for more details, see Ref.[2])

$$(\mathrm{Im}A)_T = -\frac{s}{3}\left(\frac{M_H^2}{\pi v}\right)\alpha_s^3\,\alpha_{em}\sum_q e_q^2\left(\frac{2C_F}{N_c}\right)\int\frac{d\boldsymbol{k}^2}{\boldsymbol{k}^6} \times\left[\int_0^1\frac{\boldsymbol{k}^2[\tau^2+(1-\tau)^2][\alpha^2+(1-\alpha)^2]}{\boldsymbol{k}^2\tau(1-\tau)+Q^2\alpha(1-\alpha)}\,d\alpha d\tau\right], \qquad (2)$$

where N_c is the color number, $v = 246$ GeV is the v.e.v. of the Electroweak Theory, α_s and α_{em} are the coupling constant of QCD and QED, respectively, $C_F = (N_c^2-1)/2N_c$, and $\sum e_q^2$ is the sum of the electric charges of the quark u, d, and s. Finally, the event rate for central rapidity ($y_H = 0$), and no photon tranverse momentum ($t = -q_\perp^2 = 0$) reads

$$\frac{d\sigma}{dy_H d\boldsymbol{p}^2 dt} = \frac{1}{162\pi^4}\left(\frac{M_H^2}{N_c v}\right)^2\alpha_s^4\,\alpha_{em}^2\left(\sum_q e_q^2\right)^2 \times\left[\frac{\alpha_s C_F}{\pi}\int\frac{d\boldsymbol{k}^2}{\boldsymbol{k}^6}\,d\alpha\,d\tau\,\mathcal{X}(\boldsymbol{k}^2,Q^2)\right]^2, \qquad (3)$$

where $\mathcal{X}(\boldsymbol{k}^2,Q^2)$ is the function in the brackets of Eq.(2). Comparing this result with that obtained in the KMR approach, one sees that a sixth-order $\boldsymbol{k}$-dependence arises in the event rate due to the introduction of the color dipole in the hard subprocess.

PHOTON-PROTON PROCESS

To include the proton to this process, the gq vertex in the γq subprocess should be replaced by the coupling of the gluons to the colliding proton, which is done by the replacement [1]

$$\frac{\alpha_s C_F}{\pi} \longrightarrow f_g(x,\boldsymbol{k}^2) = \mathcal{K}\left(\frac{\partial[xg(x,\boldsymbol{k}^2)]}{\partial\ell n\,\boldsymbol{k}^2}\right), \qquad (4)$$

where $f_g(x,\boldsymbol{k}^2)$ is the non-diagonal gluon distribution function into the proton. The non-diagonality of the distribution can be approximated by a multiplicative factor $\mathcal{K}$ [4]

$$\mathcal{K} = (1.2)\exp(-b\boldsymbol{p}^2/2), \qquad (5)$$

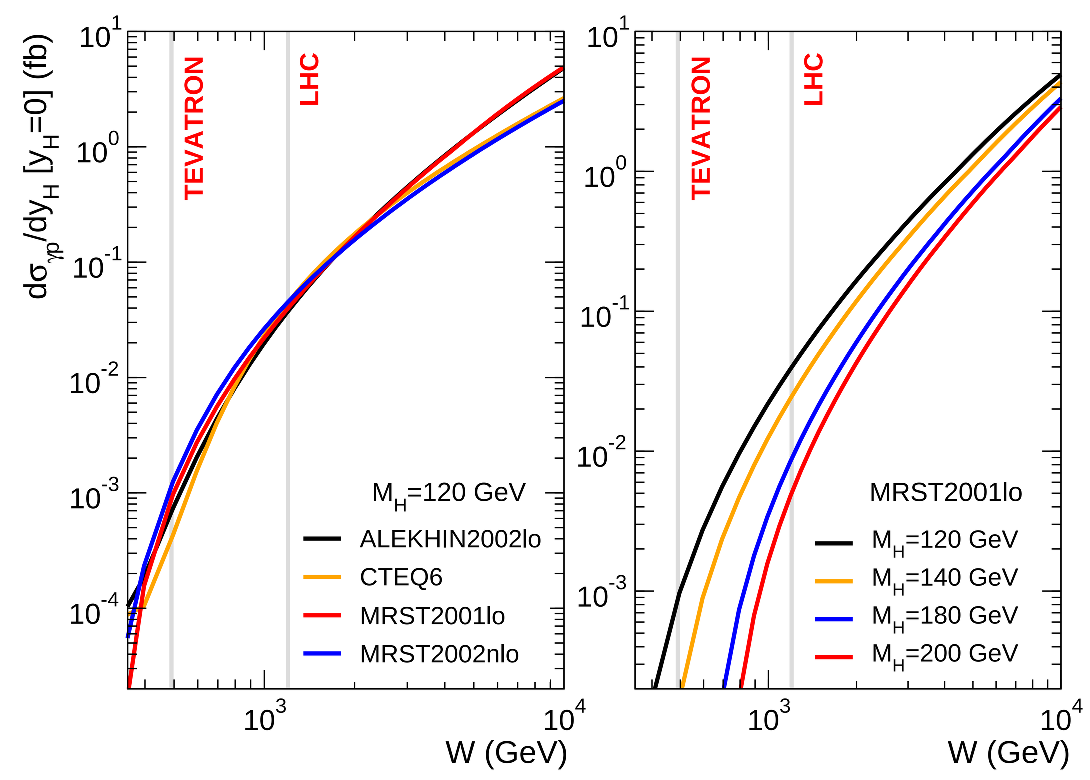
being b the slope of the $p\mathbb{P}$ form factor, and is assumed as $b = 5.5\,\mathrm{GeV}^{-2}$ [5]. However, this approximation is valid for a transfer momentum $t = 0$, which can be safely adopted in this calculation if one takes a small momentum fraction, like $x \sim 0.01$ [1]. Then, one can identify the gluon distribution as an unintegrated distribution function $f_g(x,\boldsymbol{k}^2)$. Another phenomenological effect should be introduced to avoid the gluon radiation from the fusion vertex, since the screening gluon could not screen the color charge of the fusing gluons as $k \to 0$ [6]. Otherwise, the gluon emissions in the s-channel must be suppressed, and the non-emission probability is given by

$$e^{-S(\boldsymbol{k}^2,M_H^2)} = \exp\left[-\frac{3\alpha_s(\boldsymbol{k}^2)}{4\pi}\,\ell n^2\left(\frac{M_H^2}{4\boldsymbol{k}^2}\right)\right]. \qquad (6)$$

Therefore, introducing these phenomenological effects in Eq.(3), and integrating it over the proton transverse momentum, the event rate for central rapidity ($y_H = 0$) reads

$$\frac{d\sigma}{dy_H} = \frac{S_{gap}^2}{18\pi^3 b}\left(\frac{M_H^2}{N_c v}\right)^2\alpha_s^4\,\alpha_{em}^2\left(\sum_q e_q^2\right)^2 \times\int_0^{0.03}dq_\perp^2\left[\int_{\boldsymbol{k}_0^2}^{\infty}\frac{d\boldsymbol{k}^2}{\boldsymbol{k}^6}\,e^{-S(M_H^2,\boldsymbol{k}^2)}\,f_g(x,\boldsymbol{k}^2)\,\mathcal{X}(\boldsymbol{k}^2,Q^2)\right]^2, \qquad (7)$$

where the dependence on $q_\perp^2$ appears in $Q^2 = -k^2/(\gamma_L^2\beta_L^2) - q_\perp^2$ of $\mathcal{X}(\boldsymbol{k}^2,Q^2)$ [7]. The upper limit in the integration on $q_\perp^2$ had been chosen in order to restrict our results in the virtuality range of the real photon applied in Peripheral Collisions: $Q^2 \lesssim 0.04$. Moreover, $\boldsymbol{k}_0^2 = 0.3$ GeV in the gluon momentum integration is considered with an extrapolation of the gluon distribution to $k \to 0$. Besides, S_{gap}^2 is the Gap Survival Probability, and is introduced to account the real fraction of events that will be experimentally observed. The values used are 3% for LHC and 5% for the Tevatron. The figures below show the event rate for different parametrizations, and its behavior over distinct Higgs masses.



PERIPHERAL COLLISIONS

The hadronic cross section is calculated considering the photon in the γp process coming from the electromagnetic field of the second proton. In this manner, the pp cross section for the central Higgs production reads

$$\sigma_{pp} = 2\int_{k_0}^{\sqrt{s}} dk\,\frac{dn}{dk}\,\sigma_{\gamma p}, \qquad (8)$$

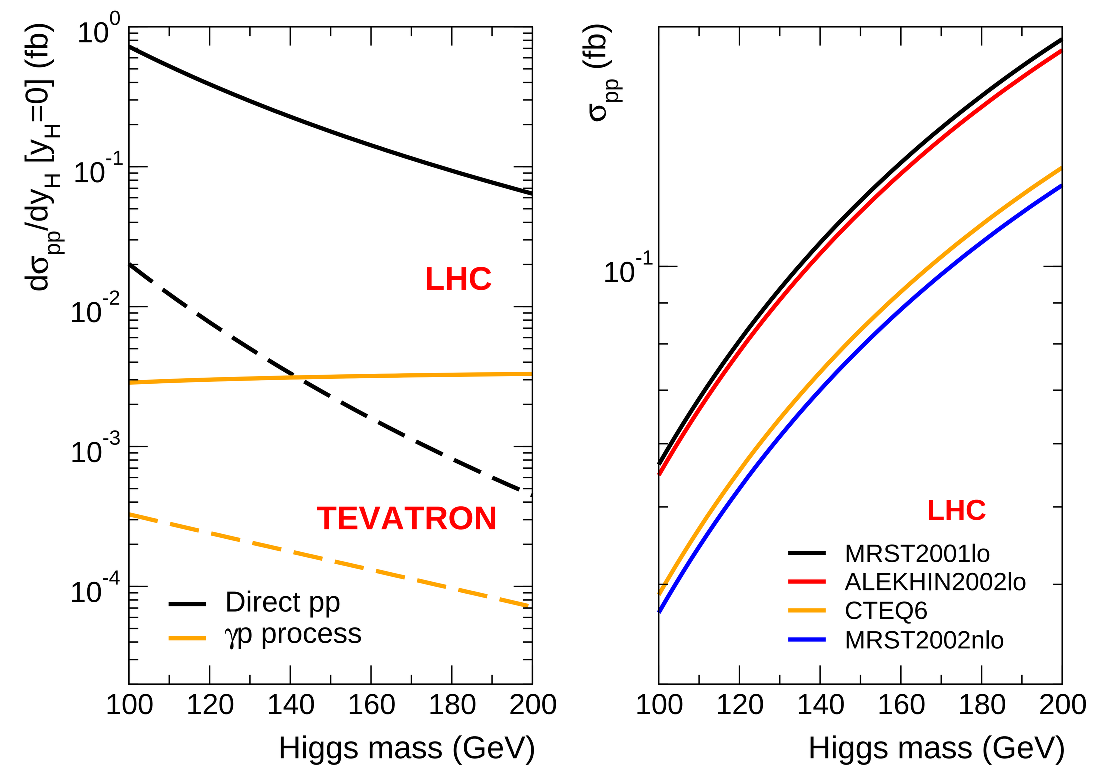
with dn/dk being the photon flux, which is given by [7]

$$\frac{dn}{dk} = \frac{\alpha_{em}}{2\pi k}\left[1+\left(1-\frac{2k}{\sqrt{s}}\right)^2\right]\left(\ell n A - \frac{11}{6} + \frac{3}{A} - \frac{3}{2A^2} + \frac{1}{3A^2}\right), \qquad (9)$$

where $A \simeq 1 + (0.71\,\mathrm{GeV}^{-2})\sqrt{s}/2k^2$. Then, the total γp cross section is computed taking the integration of Eq.(7) over the proton momentum fraction carried by the gluon $x = (M_H^2/W^2)\exp(\pm y_H)$. The event rate for central rapidity is obtained through the derivative of Eq.(10)

$$\frac{d\sigma_{pp}}{dy_H} = 2\int_{k_0}^{\sqrt{s}} dk\,\frac{dn}{dk}\,\frac{d\sigma_{\gamma p}}{dy_H}. \qquad (10)$$

Therefore, the Higgs boson production cross section can be predict for pp collisions in the Tevatron and LHC. The figures below show the event rate and the total cross section for its production, where, in the former, the results are compared to the ones obtained from other approach [6].



CONCLUSIONS

The predictions show the expected behavior in comparison to the result of direct pp collisions [2], where the event rate in the γp process is much larger than the direct pp predictions. However, the inclusion of the photon field shows a strong supression for the Higgs boson production in Peripheral Collisions, since the photon field decreases with the increasing of W^2. Furthermore, the predictions for the Tevatron also show the small possibility to produce the Higgs boson with its c.m. energy. Then, in the mass range expected to detect the Higgs boson in LHC, the predictions for direct pp collsions present an event rate higher than the one from the photoproduction process. However, an open question in the kinematical regime of LHC is how small will be the Rapidity Gap Survival Probability (GSP) in diffractive processes. The KMR approach suggests a GSP of 3%, and is applied in this work. Even so, there is another approach to compute the GSP being much smaller for direct pp collisions [8]. A comparison of this values is shown in the table below.

Subprocess	GSP (%)	σ_{pp} (fb)
$\mathbb{P}\mathbb{P}$	2.3	2.7
$\mathbb{P}\mathbb{P}$	0.4	0.47
$\gamma\gamma$	100	0.1
γp	3.0	0.08

Although, the GSP applied in our work is similar to that of the KMR approach, it could not be appropriated to the γp process, since the photoproduction approach does not have the pp collisions as a hard process. Therefore, we expect a higher GSP for the Higgs boson photoproduciton, which should be studied in detail.

This work is partially supported by CNPq

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