PROCEEDINGS OF SCIENCE

Probing the theoretical description of central exclusive production

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We investigate the theoretical description of the central exclusive production process, $h_1 + h_2 \to h_1 + X + h_2$. Taking Higgs production as an example, we compute the subset of next-to-leading order corrections sensitive to the Sudakov factor appearing in the process. Our results agree with those originally presented by Khoze, Martin and Ryskin except that the scale appearing in the Sudakov factor, $\mu = 0.62\sqrt{\hat{s}}$, should be replaced with $\mu = \sqrt{\hat{s}}$, where $\sqrt{\hat{s}}$ is the invariant mass of the centrally produced system. We show that this replacement leads to approximately a factor 2 suppression in the cross-section for central system masses in the range 100–500 GeV.

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1. Introduction

At hadron colliders, in events producing high transverse momentum particles in the central rapidity region, the colliding particles usually break up. However, in a small fraction of such events the colliding hadrons remain intact and scatter through small angles. This type of production is known as central exclusive production (CEP):

$$h_1(p_1)+h_2(p_2)\to h_1(p_1')\oplus X\oplus h_2(p_2')\ , \tag{1.1}$$

where the $\oplus$ denote rapidity gaps between the outgoing hadrons and the central system X (see [1] for a review).

The CEP process has previously been calculated in perturbative QCD by the Durham group [2–5]. We perform an independent calculation of the next-to-leading order corrections, in the case of Higgs production, which are sensitive the Sudakov factor appearing in their result. Our finding is that the Durham group's result must be modified and we assess the impact of this modification on predictions for the LHC and Tevatron [6].

2. The Durham model

In perterbative QCD, the CEP process proceeds via the exchange a two gluon system, which must be in a colour singlet state in order that the protons remain intact. Two of the gluons then fuse to produce the central system, X. The cross-section is assumed to factorise in the following way [3,4]:

$$\frac{\partial\sigma}{\partial\hat{s}\,\partial y\,\partial\boldsymbol{p}_{1\perp}'^2\,\partial\boldsymbol{p}_{2\perp}'^2}=S^2e^{-b(\boldsymbol{p}_{1\perp}'^2+\boldsymbol{p}_{2\perp}'^2)}\frac{\partial\mathscr{L}}{\partial\hat{s}\,\partial y}\mathrm{d}\hat{\sigma}(gg\to X)\ . \tag{2.1}$$

Where $\hat{s}$ and y denote the central system invariant mass and rapidity respectively. The important piece of this expression, for our analysis, is the effective luminosity, which is given by

$$\frac{\partial\mathscr{L}}{\partial\hat{s}\,\partial y}=\frac{1}{\hat{s}}\left(\frac{\pi}{N^2-1}\int\frac{\mathrm{d}\boldsymbol{Q}_\perp^2}{\boldsymbol{Q}_\perp^4}f_g(x_1,x_1',\boldsymbol{Q}_\perp^2,\mu^2)\,f_g(x_2,x_2',\boldsymbol{Q}_\perp^2,\mu^2)\right)^2\ . \tag{2.2}$$

The f_g are skewed, unintegrated, gluon distribution functions. Due to the kinematics of the process the amplitude is dominated by the region $x_i'\ll x_i$ and in this regime these distributions may be related to the conventional, integrated, gluon density [4,7]:

$$f_g(x,x',\boldsymbol{Q}_\perp^2,\mu^2)\approx R_g\frac{\partial}{\partial\ln\boldsymbol{Q}_\perp^2}\left(\sqrt{T(\boldsymbol{Q}_\perp,\mu)}\,xg(x,\boldsymbol{Q}_\perp^2)\right)\ , \tag{2.3}$$

with $R_g\approx 1.2(1.4)$ at the LHC(Tevatron)[1] [3,8]. The f_g distributions also include a Sudakov factor, which resums logarithmically enhanced soft and collinear virtual corrections and accounts for the fact that real radiation from the process is forbidden [7]:

$$T(\boldsymbol{Q}_\perp,\mu)=\exp\left(-\int_{\boldsymbol{Q}_\perp^2}^{\hat{s}/4}\frac{\mathrm{d}k_\perp^2}{k_\perp^2}\frac{\alpha_s(k_\perp^2)}{2\pi}\int_0^{1-\Delta}\mathrm{d}z\left[zP_{gg}(z)+\sum_q P_{qg}(z)\right]\right)\ . \tag{2.4}$$

[1]For a LHC running at 14 TeV.

For the parameters entering this expression the Durham group find [5]:

$$\Delta = \frac{k_\perp}{k_\perp + \mu} \,, \qquad \mu = 0.62\sqrt{\hat{s}} \,. \tag{2.5}$$

We find that this result is incorrect and that instead one should set $\mu = \sqrt{\hat{s}}$. In the next section we describe the calculation which leads us to this conclusion and discuss the impact of this modification on cross-section predictions.

3. Next-to-leading order calculation and cross-section predictions

Because we are dealing with colour singlet exchange in the high energy limit, there are certain simplifications which allow us to extract the next-to-leading order corrections with a one-loop calculation (see [6] for details).

After performing the loop integrals and subtracting the infrared divergent terms associated with the perturbative expansion of the parton distribution functions, we find for the next-to-leading order contribution to the amplitude [6]

$$A_{\rm NLO} \approx \int \frac{d\boldsymbol{Q}_\perp^2}{\boldsymbol{Q}_\perp^4} A_0(m_H) \ln(T(\boldsymbol{Q}_\perp, m_H)) \,, \tag{3.1}$$

where we retain only terms enhanced by a large logarithm and not suppressed by a power of $\boldsymbol{Q}_\perp$. The constant A_0 is related to the lowest order amplitude as $A_{\rm LO} \approx \int d\boldsymbol{Q}_\perp^2 A_0(m_H)/\boldsymbol{Q}_\perp^4$, where again terms suppressed by $\boldsymbol{Q}_\perp$ are neglected. Comparing equation (3.1) with the Durham result (equations (2.2)-(2.5)), we see that the general form is correct, but one must replace $\mu = 0.62\sqrt{\hat{s}}$ with $\mu = \sqrt{\hat{s}}$.

We may now assess the impact that our modification of the Sudakov factor has on predictions of the central exclusive cross-section. Taking, as an example, the cross-section for central exclusive Higgs production at the LHC, with 14 TeV centre-of-mass energy we compute the cross-section, using the ExHuME Monte Carlo generator [9], placing no cuts on the final-state particles. The results are shown in figure 1, for two different parton distribution functions [10, 11]. We observe a suppression of the cross-section, relative to the predictions of the Durham group, by a factor ~ 2 which increases with increasing Higgs mass.

4. Conclusions

We have studied the cross-section for central exclusive Higgs boson production, using QCD perturbation theory. We largely confirm the calculation previously performed by the Durham group, except that we disagree as to the precise form of the Sudakov factor which enters. Using the Sudakov factor that we propose leads to a suppression of the central exclusive production cross-section at the LHC by approximately a factor of two relative to the earlier predictions, for Higgs boson masses in the range 100–500 GeV.

We note that the fixed-order corrections we have computed form a subset of the full next-to-leading order corrections to central exclusive Higgs production, offering the possibility of extending the theoretical description of the process to this order.

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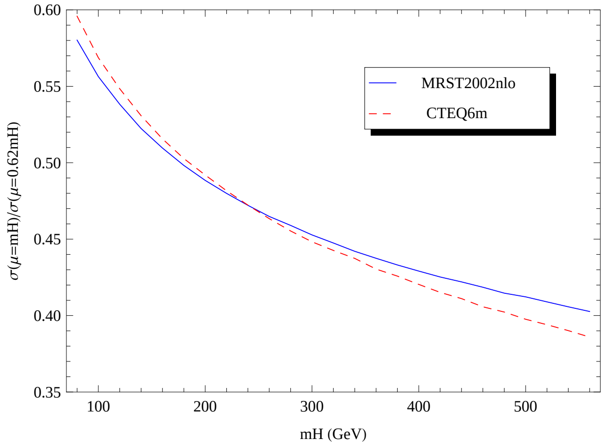

Figure 1: Ratio of the cross-section for central exclusive Higgs production at the LHC evaluated with the scale in the Sudakov factor set to $\mu = m_H$ divided by the cross-section with the scale set to $\mu = 0.62m_H$, plotted as a function of the Higgs mass. The solid blue and dashed red lines were generated using MRST2002nlo [10] and CTEQ6m [11] parton distributions respectively.

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