

# Diffractive Higgs production

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## Abstract

We review the advantages of observing exclusive diffractive Higgs production at the LHC. We note the importance of the Sudakov form factor in predicting the event rate. We discuss briefly other processes which may be used as ‘standard candles’.

## 1 Introduction

Central exclusive diffractive (CED) processes offer an excellent opportunity to study the Higgs sector at the LHC in an exceptionally clean environment. The process we have in mind is

$$pp \rightarrow p + H + p \quad (1)$$

where the + signs denote large rapidity gaps. We consider the mass range,  $M \lesssim 140$  GeV, where the dominant decay mode is  $H \rightarrow b\bar{b}$ . Demanding such an exclusive process (1) leads to a small cross section [1]. At the LHC, we predict

$$\sigma_{\text{excl}}(H) \sim 10^{-4} \sigma_{\text{incl}}^{\text{tot}}(H). \quad (2)$$

In spite of this, the exclusive reaction (1) has the following advantages:

- (a) The mass of the Higgs boson (and in some case the width) can be measured with high accuracy (with mass resolution  $\sigma(M) \sim 1$  GeV) by measuring the missing mass to the forward outgoing protons, *provided* that they can be accurately tagged some 400 m from the interaction point.
- (b) The leading order  $b\bar{b}$  QCD background is suppressed by the P-even  $J_z = 0$  selection rule [2], where the  $z$  axis is along the direction of the proton beam. Therefore one can observe the Higgs boson via the main decay mode  $H \rightarrow b\bar{b}$ . Moreover, a measurement of the mass of the decay products must match the ‘missing mass’ measurement. It should be possible to achieve a signal-to-background ratio of the order of 1. For an integrated LHC luminosity of  $\mathcal{L} = 300 \text{ fb}^{-1}$  we predict about 100 observable Higgs events, *after* acceptance cuts [3]; assuming pile-up problems have been overcome.

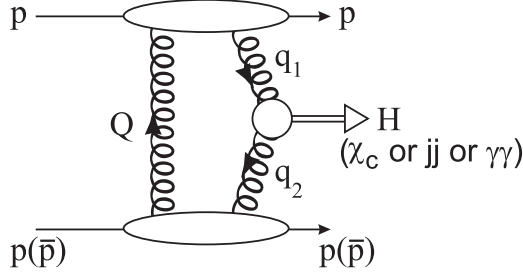


Figure 1: Schematic diagram for central exclusive production,  $pp \rightarrow p + X + p$ . The presence of Sudakov form factors ensures the infrared stability of the  $Q_t$  integral over the gluon loop. It is also necessary to compute the probability,  $\hat{S}^2$ , that the rapidity gaps survive soft rescattering.

- (c) The quantum numbers of the central object (in particular, the C- and P-parities) can be analysed by studying the azimuthal angle distribution of the tagged protons [4]. Due to the selection rules, the production of  $0^{++}$  states is strongly favoured.
- (d) There is a very clean environment for the exclusive process – the soft background is strongly suppressed.
- (e) Extending the study to SUSY Higgs bosons, there are regions of SUSY parameter space where the signal is enhanced by a factor of 10 or more, while the background remains unaltered. Indeed, there are regions where the conventional inclusive Higgs processes are suppressed and the CED signal is enhanced, and even such that both the  $h$  and  $H$   $0^{++}$  bosons may be detected [5].

## 2 The cross section: the role of the Sudakov form factor

The basic mechanism for the exclusive process,  $pp \rightarrow p + H + p$ , is shown in Fig. 1. The left-hand gluon  $Q$  is needed to screen the colour flow caused by the active gluons  $q_1$  and  $q_2$ . The cross section is of the form [6, 2]

$$\sigma \simeq \hat{S}^2 \left| N \int \frac{dQ_t^2}{Q_t^4} f_g(x_1, x'_1, Q_t^2, \mu^2) f_g(x_2, x'_2, Q_t^2, \mu^2) \right|^2, \quad (3)$$

where the constant  $N$  is known in terms of the  $H \rightarrow gg$  decay width [7, 6]. The first factor,  $\hat{S}^2$ , is the probability that the rapidity gaps survive against population by secondary hadrons from the underlying event, that is hadrons originating from *soft* rescattering. It is calculated using a model which embodies all the main features of soft diffraction. It is found to be  $\hat{S}^2 = 0.026$  for  $pp \rightarrow p + H + p$  at the LHC. The remaining factor,  $|\dots|^2$ , however, may be calculated using perturbative QCD techniques, since the dominant contribution to the integral comes from the region  $\Lambda_{\text{QCD}}^2 \ll Q_t^2 \ll M_H^2$ . The probability amplitudes,  $f_g$ , to find the appropriate pairs of  $t$ -channel gluons ( $Q, q_1$ ) and ( $Q, q_2$ ), are given by the skewed unintegrated gluon densities at a *hard* scale  $\mu \sim M_H/2$ .

Since the momentum fraction  $x'$  transferred through the screening gluon  $Q$  is much smaller than that ( $x$ ) transferred through the active gluons ( $x' \sim Q_t/\sqrt{s} \ll x \sim M_H/\sqrt{s} \ll 1$ ), it is possible to express  $f_g(x, x', Q_t^2, \mu^2)$  in terms of the conventional integrated density  $g(x)$ . A simplified form of this relation is [6]

$$f_g(x, x', Q_t^2, \mu^2) = R_g \frac{\partial}{\partial \ln Q_t^2} \left[ \sqrt{T_g(Q_t, \mu)} x g(x, Q_t^2) \right], \quad (4)$$

which holds to 10–20% accuracy. The factor  $R_g$  accounts for the single log  $Q^2$  skewed effect. It is found to be about 1.4 at the Tevatron energy and about 1.2 at the energy of the LHC.

Note that the  $f_g$ 's embody a Sudakov suppression factor  $T$ , which ensures that the gluon does not radiate in the evolution from  $Q_t$  up to the hard scale  $\mu \sim M_H/2$ , and so preserves the rapidity gaps. The Sudakov factor is [8]

$$T_g(Q_t, \mu) = \exp \left( - \int_{Q_t^2}^{\mu^2} \frac{\alpha_S(k_t^2)}{2\pi} \frac{dk_t^2}{k_t^2} \left[ \int_{\Delta}^{1-\Delta} z P_{gg}(z) dz + \int_0^1 \sum_q P_{qg}(z) dz \right] \right), \quad (5)$$

with  $\Delta = k_t/(\mu + k_t)$ . The square root arises in (4) because the (survival) probability not to emit any additional gluons is only relevant to the hard (active) gluon. It is the presence of this Sudakov factor which makes the integration in (3) infrared stable, and perturbative QCD applicable <sup>1</sup>.

It should be emphasised that the presence of the double logarithmic  $T$ -factors is a purely classical effect, which was first discussed in 1956 by Sudakov in QED. There is strong bremsstrahlung when two colour charged gluons ‘annihilate’ into a heavy neutral object and the probability not to observe such a bremsstrahlung is given by the Sudakov form factor <sup>2</sup>. Therefore, any model (with perturbative or non-perturbative gluons) must account for the Sudakov suppression when producing exclusively a heavy neutral boson via the fusion of two coloured/charged particles.

In fact, the  $T$ -factors can be calculated to *single* log accuracy [5]. The collinear single logarithms may be summed up using the DGLAP equation. To account for the ‘soft’ logarithms (corresponding to the emission of low energy gluons) the one-loop virtual correction to the  $gg \rightarrow H$  vertex was calculated explicitly, and then the scale  $\mu = 0.62 M_H$  was chosen in such a way that eq.(5) reproduces the result of this explicit calculation. It is sufficient to calculate just the one-loop correction since it is known that the effect of ‘soft’ gluon emission exponentiates. Thus (5) gives the  $T$ -factor to single log accuracy.

In some sense, the  $T$ -factor may be considered as a ‘survival’ probability not to produce any hard gluons during the  $gg \rightarrow H$  fusion subprocess. However it is not just a number (i.e. a

<sup>1</sup>Note also that the Sudakov factor inside the loop integration induces an additional strong decrease (as  $M^{-3.3}$  for  $M \sim 120$  GeV) of the cross section as the mass  $M$  of the centrally produced hard system increases [5]. Therefore, the price to pay for neglecting this suppression effect would be to considerably overestimate the central exclusive cross section at large masses.

<sup>2</sup>It is worth mentioning that the  $H \rightarrow gg$  width entering the normalization factor  $N$  in (3) is an ‘inclusive’ quantity which includes all possible bremsstrahlung processes. To be precise, it is the sum of the  $H \rightarrow gg + ng$  widths, with  $n=0,1,2,\dots$ . The probability of a ‘purely exclusive’ decay into two gluons is nullified by the same Sudakov suppression.

numerical factor) which may be placed in front of the integral (the ‘bare amplitude’). Without the  $T$ -factors hidden in the unintegrated gluon densities  $f_g$  the integral (3) diverges. From the formal viewpoint, the suppression of the amplitude provided by  $T$ -factors is infinitely strong, and without them the integral depends crucially on an ad hoc infrared cutoff.

### 3 ‘Standard candles’: calibrating the exclusive Higgs signal

As discussed above, the exclusive Higgs signal is particularly clean, and the signal-to-background ratio is favourable. However, the expected number of events in the SM case is low. Therefore it is important to check the predictions for exclusive Higgs production by studying processes mediated by the same mechanism, but with rates which are sufficiently high, so that they may be observed at the Tevatron (as well as at the LHC). The most obvious examples are those in which the Higgs is replaced by either a dijet system, a  $\chi_c$  or  $\chi_b$  meson, or by a  $\gamma\gamma$  pair, see Fig. 1.

CDF have made a start. They have a value for exclusive  $\chi_c$  production; after acceptance cuts they find [9]  $\sigma(\chi_c \rightarrow \mu\mu\gamma) \sim 50$  pb, with a large uncertainty. This happens to be equal to the KMR prediction [10] for the same cuts, which, because of the low scale, is only an order-of-magnitude estimate. Exclusive  $\gamma\gamma$  production is a clean signal, but the rate is quite low [11].

Here, therefore, we discuss the exclusive production of a pair of high  $E_T$  jets,  $p\bar{p} \rightarrow p + jj + \bar{p}$ . The corresponding cross section [6, 7] was evaluated to be about  $10^4$  times larger than that for the SM Higgs boson. Thus, in principle, this process appears to be an ideal ‘standard candle’. The expected cross section is rather large, and we can study its behaviour as a function of the mass of the dijet system. This process is being studied by the CDF collaboration. Unfortunately, in the present CDF environment, the separation of exclusive events is not unambiguous. At first sight, we might expect that the exclusive dijets form a narrow peak, sitting well above the background, in the distribution of the ratio

$$R_{jj} = M_{\text{dijet}}/M_{\text{PP}} \tag{6}$$

at  $R_{jj} = 1$ , where  $M_{\text{PP}}$  is the invariant energy of the incoming Pomeron-Pomeron system. In reality the peak is smeared out due to hadronization, the jet-searching algorithm and detector effects. Moreover, since  $M_{\text{dijet}}$  is obtained from measuring just the two-jet part of the exclusive signal; there will be a ‘radiative tail’ extending to lower values of  $R_{jj}$ .

The estimates [10] give an exclusive cross section for dijet production with  $E_T > 10, 25, 35, 50$  GeV, with values which are comparable to the recent CDF values [9], based on events with  $R_{jj} > 0.8$ . As discussed above, one should not expect a clearly ‘visible’ peak in the CDF data for  $R_{jj}$  close to 1. It is worth mentioning that the CDF measurements have already started to reach values of the invariant mass of the Pomeron-Pomeron system in the SM Higgs mass range.

## Acknowledgments

ADM thanks the Leverhulme Trust for an Emeritus Fellowship and the Royal Society for a Joint Project Grant with the former Soviet Union.

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