

# A DOUBLE PARTON SCATTERING BACKGROUND TO HIGGS BOSON PRODUCTION AT THE LHC

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## Abstract

The experimental capability of recognizing the presence of  $b$  quarks in complex hadronic final states has addressed the attention towards final states with  $b\bar{b}$  pairs for observing the production of the Higgs boson at the LHC, in the intermediate Higgs mass range. We point out that double parton scattering processes are going to represent a sizeable background to the process.

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## I. INTRODUCTION

The problem of identifying the most convenient signatures for detecting the Higgs boson production at the LHC has been widely discussed in the literature [1]. Most results are summarized in ref. [2], where, in addition, various different backgrounds to the process are estimated. The  $b\bar{b}$  channel is the most favorite Higgs decay mode when the Higgs mass is below the  $W^+W^-$  threshold [1]. The confidence in the capability of identifying efficiently the  $b$  quark jets [7] has therefore addressed towards the detection of  $b\bar{b}$  pairs to observe the Higgs boson production at the LHC, if the Higgs mass is in the range  $80\text{GeV} < M_H < 150\text{GeV}$ . To reduce the huge QCD background to the  $b\bar{b}$  pair production, the  $b\bar{b}$  pair is detected in association with an isolated lepton from the decay of a  $W$  boson. The process of interest to detect the Higgs boson production through the  $b\bar{b}$  decay channel is therefore:  $p + p \rightarrow WH + X$ , with  $W \rightarrow l\nu_l$ ,  $H \rightarrow b\bar{b}$ , where  $l = e, \mu$ .

The purpose of the present note is to point out that the same  $l, b\bar{b}$  final state can be produced also by a different mechanism, namely by a double parton collision process, which represents therefore a further background to be taken into account in addition to the other background processes previously considered. In fact as a result of the present analysis we find that double parton scatterings may represent a rather sizeable source of background.

The possibility of hadronic interactions with double parton scattering collisions was foreseen on rather general grounds long ago [8]. The process has been recently observed by CDF [9]: In a hadronic interaction with a double parton scattering two different pairs of partons interact independently at different points in the transverse space, in the same inelastic hadronic event. The process is induced by unitarity and, as a consequence, it has been considered mostly in the regime where the partonic cross sections become comparable to the total inelastic hadronic cross section, namely large c.m. energy in the hadronic interaction and relatively low transverse momenta of the produced partons. Those are in fact also the conditions where the process was observed [9]. In such a kinematical regime one does not expect strong initial state correlations in the fractional momenta of the partons undergoing the double collision process and, with this simplifying hypothesis, the double parton scattering cross section is proportional to the product of two single scattering cross sections. All the new non perturbative information on the structure of the colliding hadrons provided by the process, in the specific case the information on the two-body parton correlation in transverse space, reduces to a scale factor with dimensions of a cross section (the 'effective cross section' [10]). In the case of two identical parton interactions, as for producing four large  $p_t$  jets, the double parton scattering cross section assumes therefore the simplest factorized form

$$\sigma_D(Jets) = \frac{1}{2} \frac{\sigma_J^2}{\sigma_{eff}} \quad (1)$$

$\sigma_J$  is the usually considered single parton scattering cross section:

$$\sigma_J = \sum_{ff'} \int_{p_t > p_t^{min}} dx dx' d^2 p_t G_f(x) G_{f'}(x') \frac{d\hat{\sigma}_{ff'}}{d^2 p_t} \quad (2)$$

where  $G_f(x)$  is the parton distribution as a function of the momentum fraction  $x$  and at the scale  $p_t$ . The different species of interacting partons are indicated with the label  $f$  and  $d\hat{\sigma}_{ff'}/d^2p_t$  is the elementary partonic cross section.  $\sigma_{eff}$  is the effective cross section and it enters as a simple proportionality factor in the integrated inclusive cross section for a double parton scattering  $\sigma_D$ . The value of  $\sigma_{eff}$  represents therefore the whole output of the measure of the double parton scattering process in this simplest scheme, which on the other hand has shown to be in agreement with the available experimental evidence [9]. In the case of two distinguishable parton scatterings  $A$  and  $B$  the factor  $1/2$  in Eq.1 is missing and one correspondingly writes

$$\sigma_D(AB) = \frac{\sigma_A\sigma_B}{\sigma_{eff}} \quad (3)$$

The effective cross section is a geometrical property of the hadronic interaction, related to the overlap of the matter distribution of the two interacting hadrons in transverse space. The expectation is that it is independent on the c.m. energy of the hadronic collision and on the cutoff  $p_t^{cut}$  [10]. Moreover, although one may expect that different kinds of partons may be distributed in different ways in the transverse space, one does not expect a strong dependence of  $\sigma_{eff}$  on the different possible partonic reactions. The simplest possibility to consider is therefore the one where the scale factors in Eq.1 and in Eq.3 are the same.

In the intermediate Higgs mass range the partonic center of mass energy needed for producing the Higgs boson is relatively low, as compared to the overall energy involved in the hadronic collision at the LHC, and one may therefore expect that the factorization in Eq.3 may still be a good approximation when producing partonic states with values of the invariant mass of the order of the mass of the Higgs. We will therefore estimate the double parton scattering background to the process  $p + p \rightarrow WH + X$ , with  $W \rightarrow l\nu_l$  and  $H \rightarrow b\bar{b}$ , by using the simplest expression in Eq.3. We will also take the attitude of considering the value of  $\sigma_{eff}$  as a universal property of all double parton interactions and we will use the actual value which was measured by CDF [9]. In this respect one has to point out that in the experimental analysis of CDF the measure of the double parton scattering cross section has been performed by removing all triple parton collision events from the sample of inelastic events with double parton scatterings. The double parton scattering cross section measured in the experimental analysis does not correspond therefore to the inclusive cross section written here above and usually considered in the literature, which allows the simple inverse proportionality relation between  $\sigma_D$  and  $\sigma_{eff}$ . The double parton scattering cross section measured by the CDF experiment is in fact smaller as compared to the double parton scattering cross section discussed here. As a consequence the resulting value of the effective cross section,  $\sigma_{eff}|_{CDF}$ , is somewhat larger [10] with respect to the quantity suitable to the actual purposes. By using in the present note  $\sigma_{eff}|_{CDF}$  as a scale factor for the double parton scattering process, we will therefore underestimate the size of the background due to double parton scatterings to the Higgs boson production.

## II. DOUBLE PARTON SCATTERING BACKGROUND PROCESS

A background to the process  $p+p \rightarrow WH+X$ , with  $W \rightarrow l\nu_l$ ,  $H \rightarrow b\bar{b}$  is represented by the double parton scattering interaction where the intermediate vector boson  $W$  and the  $b\bar{b}$  pair are produced in two independent parton interactions. The corresponding integrated rate is easily evaluated by combining the expected cross sections for  $W$  and  $b\bar{b}$  production at LHC energy with  $\sigma_{eff}$  as in Eq.3. If one uses  $\sigma(W) \times BR(W \rightarrow l\nu_l) \simeq 40nb$  [6],  $\sigma(b\bar{b}) \simeq 5 \times 10^2 \mu$  and as a value for the scale factor

$$\sigma_{eff} = 14.5mb \quad (4)$$

(the observed value is  $\sigma_{eff}|_{CDF} = 14.5 \pm 1.7_{-2.3}^{+1.7}mb$  [9]) one obtains that the cross section for a double parton collision producing a  $W \rightarrow l\nu_l$  and a  $b\bar{b}$  pair, is of the order of  $1.4nb$ . The Higgs production cross sections,  $p+p \rightarrow WH+X$ , with  $W \rightarrow l\nu_l$ ,  $H \rightarrow b\bar{b}$ , has been estimated to be rather of order of  $1pb$  [2]. By integrating the double parton scattering cross section over the whole possible configurations of the  $b\bar{b}$  pair one then obtains a cross section three orders of magnitude larger than the expected signal from Higgs decay. Obviously, rather than the integrated cross sections, one is interested in comparing the two differential cross sections as a function of the invariant mass of the  $b\bar{b}$  pair.

In the calculations of the background and signal we used, for the matrix elements, the packages MadGraph [3] and HELAS [4], and the integration was performed by VEGAS [5] with the parton distributions MRS99 [6]. The cross section to produce  $WH$ , followed by  $W \rightarrow l\nu_l$ ,  $H \rightarrow b\bar{b}$ , is plotted in fig.1 for three different possible values of the Higgs mass, and it is compared with the double parton scattering cross section  $d\sigma_D/dM_{b\bar{b}}$  as a function of the invariant mass of the  $b\bar{b}$  system. The estimated signal of Higgs boson production in the invariant mass of the  $b\bar{b}$  pair [2] corresponds to the three possible values for the mass of the Higgs boson, 80, 100 and  $120GeV$ . The curves refer to background double parton scattering process. The dashed line is obtained by estimating the cross section for  $b\bar{b}$  production at the lowest order in  $\alpha_S$  and by using as a scale factor in  $\alpha_S$  the transverse mass of the  $b$  quark. The continuous line is a rescaling of the lowest order result by a factor 1.8 and it corresponds to the expectations of the order  $\alpha_S^3$  estimates of the  $b\bar{b}$  cross section according with ref. [11]. The estimated background from double parton scatterings is therefore a factor four or five larger than the expected signal.

In fig.2 we compare the signal and the background after applying all the typical cuts considered to select the Higgs signal:

- for the lepton:  $p_t^l > 20$  GeV,  $|\eta^l| < 2.5$  and isolation from the  $b$ 's,  $\Delta R_{l,b} > .7$
- for the two  $b$  partons:  $p_t^b > 15$  GeV,  $|\eta^b| < 2$  and  $\Delta R_{b,\bar{b}} > .7$

As in the previous figure the Higgs signal in the  $b\bar{b}$  invariant mass corresponds to three possible values for the mass of the Higgs boson, 80, 100 and  $120GeV$ . The dotted line is the single parton scattering background, where the  $Wb\bar{b}$  state is produced directly in a single partonic interaction. The dashed line is the expected background originated by double parton scattering process evaluated by estimating the  $b\bar{b}$  production cross section at  $\mathcal{O}(\alpha_S^3)$ . The continuous line is the total expected background.

Fig.2 summarizes our result: also after using the more realistic cuts just described, the double parton scatterings process remains a rather substantial component of the background. The difference with the conventional estimate of the background is immediately evident comparing the total background estimate (continuous curve) with single scattering background (dotted curve).

### III. CONCLUSIONS

In the present note we have discussed the background induced by double parton collisions to the detection of the Higgs in the  $Wb\bar{b}$  channel. The large rate of production of  $b\bar{b}$  pairs expected at the LHC (the corresponding cross section is of order of  $500\mu b$ ) gives rise to a relatively large probability of production of a  $b\bar{b}$  pair in the process underlying the  $W$  production. As a consequence a very promising channel to detect the production of the Higgs boson, in the intermediate Higgs mass range, namely the final state with a  $b\bar{b}$  pair and with an isolated lepton, is affected by a sizable background due to double parton collision processes. Although the double parton collision cross section is a decreasing function of the invariant masses of the  $b\bar{b}$  pair, the relatively large value of the invariant mass required to the  $b\bar{b}$  pair to be assigned to the Higgs decay is not large enough, at LHC energies, to allow one to neglect the double parton scattering background.

It is rather obvious that the considerations above are not limited to the  $Wb\bar{b}$  channel. Similar arguments can be repeated in several other cases. In addition to the obvious case of the  $Zb\bar{b}$  channel, a few examples where we expect that multiple parton scattering processes might give a non secondary effect are the following:

- $W + \text{jets}$ ,  $Wb + \text{jets}$  and  $Wb\bar{b} + \text{jets}$ ,
- $t\bar{t} \rightarrow llb\bar{b}$ ,
- $t\bar{b} \rightarrow b\bar{b}l\nu$ ,
- $b\bar{b} + \text{jets}$ ,
- production of many jets when  $p_t^{min} \simeq 25 GeV$

Although after the cuts the ratio signal to background is still a favorable number, the actual case discussed here shows that an evaluation of the background, without keeping into account the contribution of the double parton collision processes, may be rather unrealistic at the LHC and that, in some cases, the cuts to the final state considered so far are likely to be rediscussed.

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FIGURES

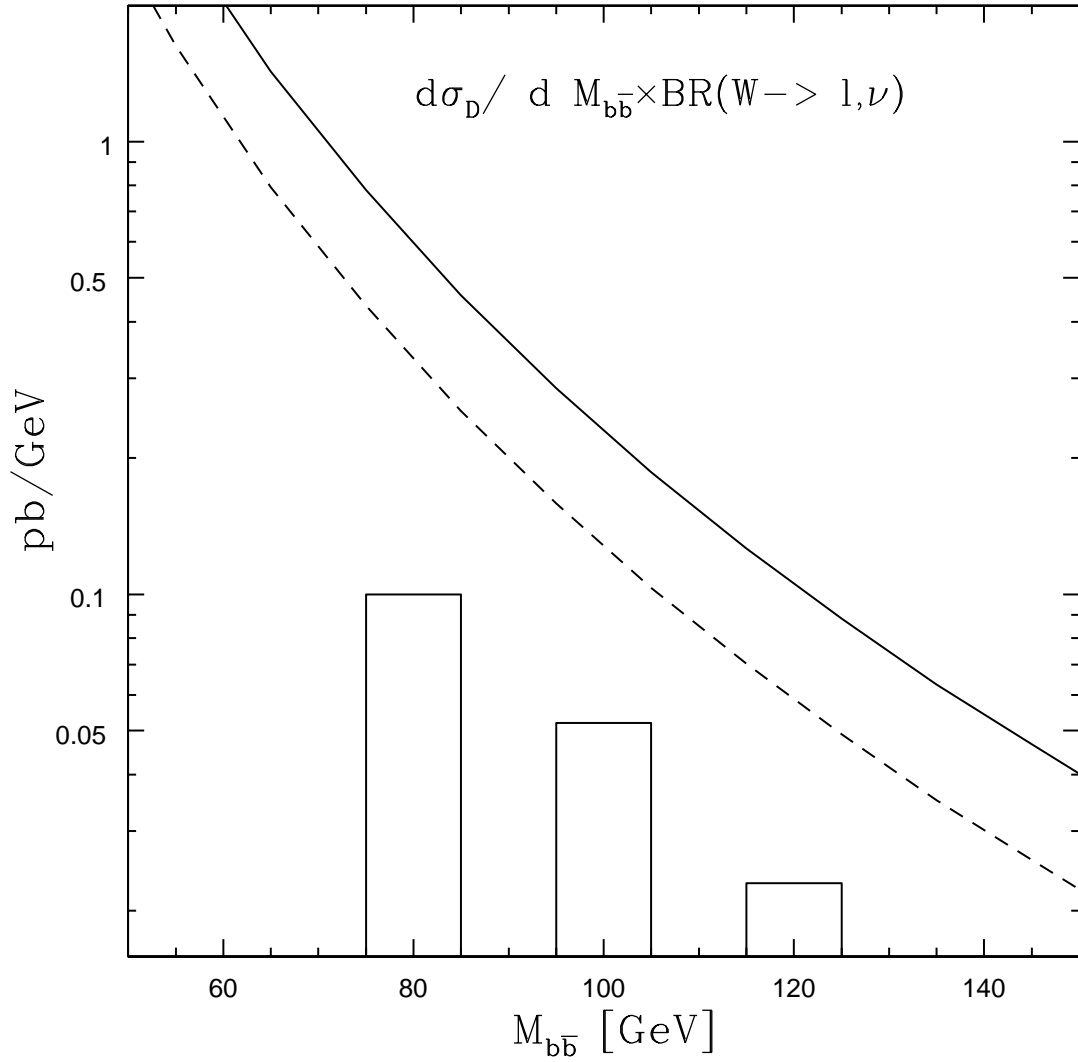


FIG. 1. Double parton scattering background to the Higgs boson production as a function of the  $b\bar{b}$  invariant mass compared to the expected Higgs signal for three possible values of the Higgs mass, 80, 100 and 120  $GeV$ . The dashed line is the background at the lowest order in perturbation theory. The continuous line is the result for the double parton scattering background when computing the  $b\bar{b}$  cross section at order  $\alpha_S^3$  [11]

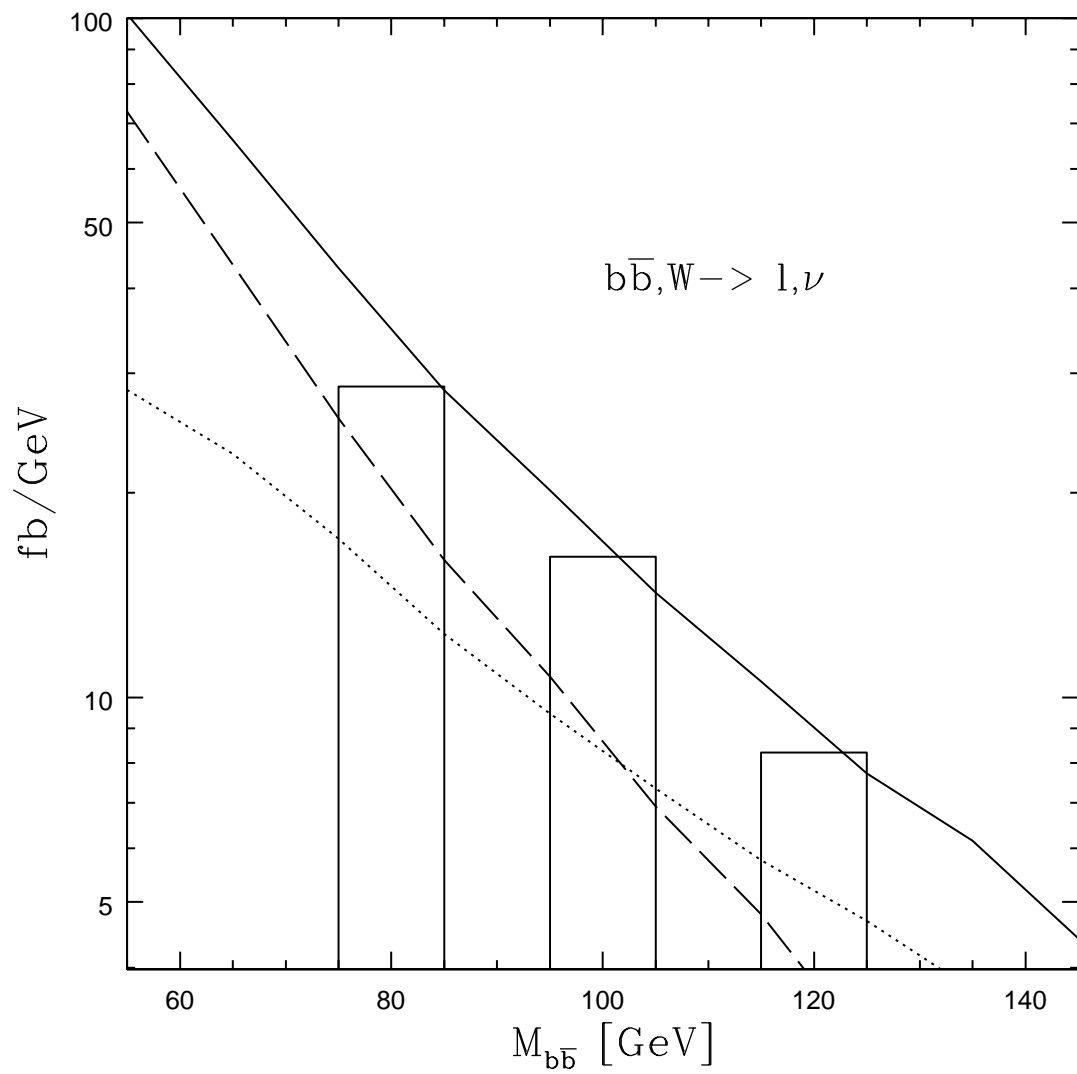


FIG. 2. Backgrounds to Higgs production after the cuts (see main text). Dotted line: single scattering contribution to the  $Wb\bar{b}$  channel. Dashed line: double parton scattering background. Continuous line: total estimated background.



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