Double parton scattering background to Higgs boson production at the CERN LHC

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The Higgs boson production and decay via the $b\bar{b}W$ channel is one of the most promising discovery channels at the CERN LHC if the Higgs boson mass is below the W^+W^- threshold. We point out that double parton collisions represent a sizable source of background to the process.

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I. INTRODUCTION

The problem of identifying the most convenient signatures to detect the Higgs boson at the CERN Large Hadron Collider (LHC) has been widely discussed in the literature [1]. Most results are summarized in Ref. [2], where various backgrounds are also estimated. The $b\bar{b}$ channel is the most favorite Higgs boson decay mode when the Higgs boson mass is below the W^+W^- threshold [1] and, since b quark jets are identified with high efficiency [3], final states with $b\bar{b}$ pairs have a great potential for discovering the Higgs boson at the LHC, if the Higgs mass is in the range 80 GeV$<M_H<$150 GeV. An efficient way to reduce the huge QCD background is to look for $b\bar{b}$ pairs accompanied by an isolated lepton, resulting from the decay of a W boson. The process of interest for detecting the Higgs boson 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 Brief Report 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 fact as a result of the present analysis we find that double parton scatterings represent a rather sizable background source.

The possibility of hadronic interactions with double parton scatterings was foreseen on rather general grounds long ago [4]. The process has been recently observed by the Collider Detector at Fermilab (CDF) [5]: In a hadronic interaction with a double parton scattering two different pairs of partons interact independently at different points in 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 [5]. 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'' [6]). In the case of two identical parton interactions, as for producing four large p_t jets, the inclusive cross section assumes therefore the simplest factorized form

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

and σ_J is the usual single scattering inclusive cross section:

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

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 $d\hat{\sigma}_{ff'}/d^2p_t$ represents the elementary partonic interaction. σ_{eff} is the effective cross section and it enters as a simple proportionality factor in σ_D. The value of σ_{eff} is 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 [5]. In the case of two distinguishable parton scatterings A and B the factor 1/2 in Eq. (1) is missing and one may write

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

The effective cross section is a geometrical property of the hadronic interaction, related to the overlap of the matter dis-

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tribution of the two interacting hadrons in transverse space. The expectation is that its value is independent of the c.m. energy of the hadronic collision and on the cutoff p_t^{min} [6]. Moreover, although different kinds of partons may be distributed in different ways in transverse space, one does not expect a strong dependence of σ_{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 boson 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 expect that the factorization in Eq. (3) may still be a good approximation. We will therefore estimate the double parton scattering background to the process $p+p\to WH+X$, with $W\to l\nu_l$ and $H\to b\bar{b}$, by using the simplest expression in Eq. (3). We will also consider the value of σ_{eff} as a universal property of all double parton interactions and we will use the actual value which was measured by CDF [5]. 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 collisions. 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 σ_D and σ_{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 [6] 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 double parton scatterings background.

II. DOUBLE PARTON SCATTERING BACKGROUND PROCESS

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

$$\sigma_{eff}=14.5 \text{ mb} \tag{4}$$

(the observed value is $\sigma_{eff}|_{CDF}=14.5\pm 1.7^{+1.7}_{-2.3}$ mb [5]), one obtains that the cross section for a double parton collision producing a $W\to l\nu_l$ and a $b\bar{b}$ pair is of the order of 1.4 nb. The Higgs boson production cross sections, $p+p\to WH+X$, with $W\to l\nu_l$, $H\to b\bar{b}$, have been estimated to be rather of order of 1 pb [2]. By integrating the double parton scattering cross section over all possible $b\bar{b}$ configurations one obtains a value three orders of magnitude larger than the expected signal from Higgs boson 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.

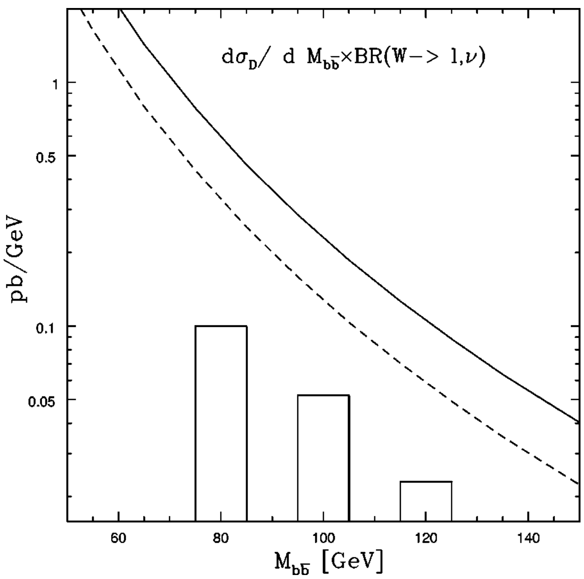

FIG. 1. Double parton scattering background to the Higgs boson production as a function of the $b\bar{b}$ invariant mass compared to the expected Higgs signal for three possible values of the Higgs mass: 80, 100 and 120 GeV. The dashed line is the background at the lowest order in perturbation theory.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

In Fig. 1 we show the cross section to produce WH, followed by $W\to l\nu_l$, $H\to b\bar{b}$, and the double parton scattering background 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 [7] and HELAS [8], and the integration was performed by VEGAS [9] with the Martin-Roberts-Stirling 1999 (MRS99) parton distributions [10]. The estimated signal of Higgs boson production corresponds to the three possible values for the mass of the Higgs boson: 80, 100 and 120 GeV. The curves refer to the background cross section $d\sigma_D/dM_{b\bar{b}}$. The dashed line is obtained by evaluating the cross section of $b\bar{b}$ production at the lowest order in α_S and by using as a scale factor in α_S the transverse mass of the b quark. The solid line is a rescaling of the lowest order result by a factor 1.8 and it corresponds to the order α_S^3 calculation of the $b\bar{b}$ cross section [11]. The estimated background from double parton scatterings is therefore a factor 4 or 5 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:

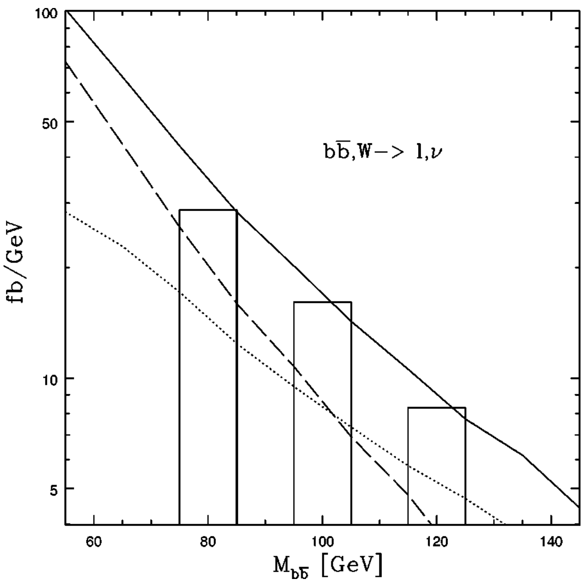

FIG. 2. Backgrounds to Higgs boson production after the cuts (see main text). Dotted line: single scattering contribution to the $Wb\bar{b}$ channel. Dashed line: double parton scattering background. Solid line: total estimated background.

(i) For the lepton: $p_t^l > 20$ GeV, $|\eta^l| < 2.5$ and isolation from the b's, $\Delta R_{l,b} > .7$.

(ii) For the two b quarks: $p_t^b > 15$ 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 of the mass of the Higgs boson: 80, 100 and 120 GeV. 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 background originated by double parton scatterings evaluated by estimating the $b\bar{b}$ production cross section at $\mathcal{O}(\alpha_S^3)$. The solid line is the total expected background.

Figure 2 summarizes our result: also after using the more realistic cuts just described, the double parton scatterings process remains a rather substantial background component.

III. CONCLUSIONS

In the present Brief Report we have discussed the background induced by double parton collisions to a very promising channel to detect the Higgs boson signal at the LHC, the $Wb\bar{b}$ channel. Multiple parton collisions are in fact enhanced at relatively small energies of the partonic subprocess and states with invariant masses in the range of 100–200 GeV have a small enough energy, at LHC, to receive important contributions from multiple parton interactions. The production of a $b\bar{b}$ pair with an isolated lepton is in fact affected by a sizable background due to double parton collision processes, since the large rate of $b\bar{b}$ pairs expected at the LHC (the corresponding cross section is of order of 500 μb) makes it relatively easy to create a $b\bar{b}$ pair in the process underlying the production of a W boson.

It is rather obvious that the considerations above are not limited to the $Wb\bar{b}$ channel. Similar arguments hold also 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 scatterings might give a non-secondary effect are the following:

(i) $W+$jets, $Wb+$jets and $Wb\bar{b}+$jets.

(ii) $t\bar{t} \to ll\nu\nu b\bar{b}$.

(iii) $t\bar{b} \to b\bar{b}l\nu$.

(iv) $b\bar{b}+$jets.

(v) production of many jets when $p_t^{min} \simeq 25$ GeV.

Although after the cuts we find that the signal to background ratio is still a favorable number, the actual discussion is a good example of the importance of multiple parton collisions for the physics at the LHC. In many cases cuts need therefore to be rediscussed and more efficient selection criteria have to be worked out to keep into account the presence of this further background source, which on the other hand can be isolated and measured in a rather precise way, given the well-defined characterization of the states produced by multiple parton scatterings.

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