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EXCLUSIVE DIFFRACTIVE HIGGS BOSON PRODUCTION AT THE LHC*

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The analysis of exclusive Higgs boson production in Atlas based on Atlfast simulation is presented in this paper. Significant background processes including pile-up were also simulated. The feasibility of measurement of exclusive diffractive Higgs production is discussed at the end of this report.

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1. Introduction

For a Higgs boson mass of about 120 GeV, the Higgs boson decays mostly into $b\bar{b}$ (almost 68%). However the inclusive $H \to b\bar{b}$ cannot be observed in the Atlas detector because of the huge QCD $b\bar{b}$ background [1]. Other channels which are relevant like $\gamma\gamma$ or $\tau^+\tau^-$ are difficult ones. A promising channel, which has attracted attention in recent time, is the $H \to b\bar{b}$ channel in diffractive events, especially in exclusive double pomeron exchange events [2, 3].

Double pomeron exchange (DPE) is defined as the process $pp \to p{+}X{+}p$, where X is the central system produced by pomeron–pomeron fusion, the '+' sign denotes a rapidity gap and both protons remain intact. DPE can be inclusive or exclusive. In the exclusive case, only a central object is created (*e.g.* the Higgs boson or a quark antiquark pair). On the other hand, in the inclusive case, in addition to the central object other particles are also created from the pomeron remnants.

There are two main reasons why diffraction is interesting for Higgs search. The first one is that the cross section ratio of signal over background — exclusive $b\bar{b}$ production — differs from the ratio for non diffractive events by two orders of magnitude, which is much better than in the case of QCD $b\bar{b}$ production.

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The second one is that in the case of exclusive diffractive events we are able to compute the mass of the produced central object by measuring the momentum loss of the scattered protons, see Formula (1). The mass is computed much more precisely in comparison to the case when one computes the mass of the two calorimeter jets. The expected resolution in mass is of the order of 1–2%.

Nevertheless, there are also disadvantages. This channel shows quite a small cross section and in general diffractive processes are sensitive to pile-up.

Forward proton detectors (FPD) allow to measure the fractional momentum loss ξ of the outgoing protons. The mass of the centrally produced object and also its rapidity can be computed. In the case of an exclusive process, the central object is in our case the Higgs boson and its mass and rapidity can be expressed as:

$$M_{\mathrm{H}} \approx \sqrt{\xi_1 \xi_2 s}\,, \tag{1}$$

$$y_{\mathrm{H}} \approx \frac{1}{2} \ln \frac{\xi_1}{\xi_2}\,, \tag{2}$$

where $\xi = 1 - p'/p$, p being the momentum of the incoming proton and p' being the momentum of the scattered proton measured in the FPD.

2. Applied cuts

Diffractive production was studied using the dedicated event generators Dpemc [7] and Exhume [8]. Two models of exclusive diffractive production were considered: Bialas–Landshoff [4], implemented in Dpemc and Khoze–Martin–Ryskin (KMR) [3] in Exhume. The event selection cuts can be classified in two groups: kinematic cuts (given by detector acceptances and high b-tagging and tracking efficiencies) and cuts based on exclusivity of the event. In addition, a 1σ mass window around the Higgs mass was applied.

We require two jets tagged as b-jets. One b-jet has to have $p_{\mathrm{T1}} > 45$ GeV (L1 trigger requires at least one 40 GeV jet), the second one $p_{\mathrm{T2}} > 30$ GeV. Both jets should be in the central part of the calorimeter ($\mid \eta_{\mathrm{jets}} \mid < 2.5$) to obtain a good efficiency of b-tagging and good tracking. Further more, we require these jets to be back-to-back in azimuthal angle. Both diffractive protons have to be moreover detected by the FPD, which means that the ξ of the protons has to be in the interval $0.002 < \xi < 0.1$.

As already mentioned, we are able to compute the missing mass and rapidity from the detected protons. If the event is exclusive, the missing mass has to be equal to the mass of the produced object and the rapidity as well. This means:

$$R_{jj} = \frac{M_{\mathrm{bjet1,bjet2}}}{M_X} \approx 1\,, \tag{3}$$

$$\Delta\eta = \frac{\eta_{\mathrm{jet1}} + \eta_{\mathrm{jet2}}}{2} - y_X \approx 0\,, \tag{4}$$

The cut on R_{jj} is the following: $0.8 < R_{jj} < 1.2$ (which means a 2σ cut, as the expected dijet mass resolution is about 10%). The cut rejects mainly the inclusive diffractive background. The cut $|\Delta\eta| < 0.1$ was chosen for $\Delta\eta$. This is a 1σ cut which leaves the whole signal almost unchanged and the pile-up is reduced by a factor of more than 20.

The last exclusivity cut is based on the multiplicity of charged particles and particles transverse to the jet axis. Let us introduce the variable N_{C}, which is the number of charged particles outside the dijet coming from the primary vertex. The multiplicity of transverse particles to the dijet ($N_{\mathrm{C}}^{\perp}$) means the number of charged particles outside the dijet but transverse to the leading jet [5]. Transverse means that $\frac{\pi}{3} < |\phi_{\mathrm{track}} - \phi_{\mathrm{jet}}| < \frac{2\pi}{3}$ or $\frac{4\pi}{3} < |\phi_{\mathrm{track}} - \phi_{\mathrm{jet}}| < \frac{5\pi}{3}$. We also require that the track p_T must be over 0.5 GeV. The final cut was chosen as follows: $N_{\mathrm{C}} < 4$ and $N_{\mathrm{C}}^{\perp} < 3$. The suppression factor for this cut is however strongly dependent on the soft underlying event model. It is very important to tune the MC to describe the underlying events properly, and for this sake, the first LHC data are needed.

3. Types of background

Exclusive DPE $b\bar{b}$ production: This type of background is very hard to separate because exclusive $b\bar{b}$ events behave almost in the same way as exclusive $H \to b\bar{b}$ and pass all cuts almost unchanged. This background is suppressed mainly by the mass window. At low luminosities the $b\bar{b}$ background is the dominant one (at high luminosities the main background is the pile-up).

Exclusive DPE gg production: This type of background occurs due to mistagging gluon jets as b-jets. The expected mistag probability of a gluon jet as b-jet is in Atlas of 1.3% for a 60% b-jet efficiency. Since this process is also exclusive (therefore passes the cuts on exclusivity) and its cross section is quite high ($\sigma = 1.22 \times 10^6$ fb), this process leads also to a non negligible contribution to the background.

Pile-up: Pile-up events are several independent interactions in a single bunch crossing. More than 30 interactions in one bunch crossing are expected at the highest luminosity. This means that there can be several protons coming from *e.g.* single diffraction in one bunch crossing, which can be misidentified as protons from exclusive diffractive Higgs production. Combined with the additional non-diffractive hard event, this leads to pile-up (or more precisely overlap) background. Pile-up background grows quadratically with the number of interactions in a bunch crossing. One possibility[1] to obtain statistically significant results is to work at low luminosities. At low luminosities almost all pile-up can be suppressed by cuts on exclusivity.

4. Results

The final results for exclusive $H \to b\bar{b}$ as signal and exclusive $b\bar{b}$ and pile-up as background processes are shown in Fig. 1 (for Bialas–Landshoff model in Dpemc on the left and for KMR model in Exhume on the right).

The results are for 3.5 interactions by bunch crossing (which corresponds to a luminosity of $10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$) and an integrated luminosity of 30 fb^{-1}. At this instantaneous luminosity, the integrated luminosity of 30 fb^{-1} will be reached in 3 years and it is expected to observe in a mass window about 2–3 events of signal and 10–15 events of background.

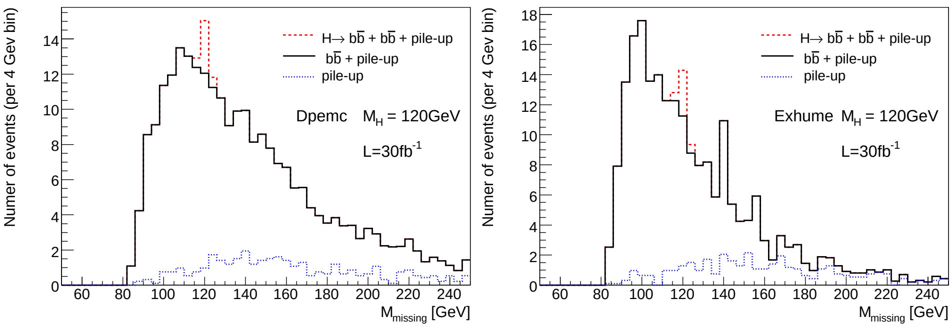

Fig. 1. Signal and background after all cuts above, for an integrated luminosity of 30 fb^{-1} and an instantaneous luminosity of $10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$

From the results above, we can conclude, that the main problem in diffractive Higgs measurement is the very small statistics. There are however still some opened questions. The most important ones are the cross section of diffractive Higgs production, the proper simulation of pile-up and the tuning of soft underlying events in MC event generators.

[1] The second one is to have very precise timing detectors — using these detectors, it is possible to measure the time of flight of the outgoing proton and thus find out if both protons come from the same vertex. For this study, it was supposed that timing detectors would reduce the pile-up by a factor of 40.

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