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Boosting Higgs Pair Production in the $4b$ Channel at the LHC with Multivariate Techniques

Katharina Behr, Nurfiki Bin Norjoharuddeen, Daniela Bortoletto, James Frost, Nathan P. Hartland, Cigdem Issever and Juan Rojo[a]

[a] *Physics Department, 1 Keble Road, University of Oxford, United Kingdom*

E-mail: cigdem.issever@physics.ox.ac.uk;juan.rojo@physics.ox.ac.uk

Abstract: A nice abstract

Contents

1 Introduction **1**

2 Monte Carlo samples **2**
2.1 Signal 2
2.2 Background 2

3 Analysis strategy **3**

4 Results **3**

5 Multivariate analysis **3**

6 Conclusions and outlook **3**

1 Introduction

Describe the importance of the 2H channel and its connection to the self-coupling. Stress the importance of self-coupling measurement and refer to previous studies which estimated the amount data needed for when this will be possible at the LHC. Discuss the different decay channels of the Higgs and point to the fact that given the fact how low the SM di-Higgs cross section is that the 4b channels would give rates which would be by factors of xx larger than the other channels. But previous studies show that xx fb-1 are needed due to the high backgrounds. We refer to UCL paper and its results and say that our studies point to the fact that fake rate from the 2b2j and 4j background are not negligible. We have studied this and will present ways to mitigate this impact and present also new techniques to analyse this channel which improve the signal to background ratio.

The measurement of double Higgs production will be one of the main physics goals of the LHC program in its upcoming high-energy and high-luminosity phase, as well as of the program of any future high-energy collider. Double Higgs production is directly sensitive to the Higgs trilinear coupling, and thus provides information on the scalar potential responsible for electroweak symmetry breaking. It is also sensitive to the underlying strength of the Higgs interactions at high energies, and can test the composite nature of the Higgs boson [1, 2].

In the Standard Model (SM), the dominant mechanism for the production of two Higgs bosons at the LHC is gluon fusion (see Ref. [3] and references therein), analogously to single Higgs production. For a center-of-mass energy $\sqrt{s} = 14\,\mathrm{TeV}$, the recently computed next-to-next to leading order (NNLO) total cross section is approximately 40 fb [4]. Feasibility studies in the case of a light Higgs boson have been performed for several different final states, including $b\bar{b}\gamma\gamma$ [5, 6], $b\bar{b}\tau^+\tau^-$ [7–10], $b\bar{b}W^+W^-$ [9, 11] and $b\bar{b}b\bar{b}$ [7, 9, 12–15].

The structure of this paper is the following.

2 Monte Carlo samples

2.1 Signal

2.2 Background

All background samples are generated with the `SHERPA` event generator, version 2.1.1. For the explicit runcards used in the generation, see Appendix **??**.

The NNPDF 3.0 $n_f = 4$ LO set with strong coupling $\alpha_S = 0.118$ is used for all samples. At the generator level the following basic cuts are applied. Each final state particle in the hard process must have $p_T \geq 20$ GeV, and be located within $|\eta| \leq 3.0$. All final state particles must be separated by a minimum $\Delta R_{\mathrm{min}} = 0.1$. Factorisation and renormalisation scales are set as $\mu_F = \mu_R = H_T/2$. Total cross-sections and details of the samples generated are shown in Table 1.

Process	Generator	N_{evt}	σ_{tot}
$pp \to HH$	MG5_aMC@NLO	100K	1.729×10^{-2} pb
$pp \to b\bar{b}b\bar{b}$	SHERPA 2.1.1	3M	1.121×10^{3} pb
$pp \to b\bar{b}jj$	SHERPA 2.1.1	3M	2.659×10^{5} pb
$pp \to jjjj$	SHERPA 2.1.1	3M	9.709×10^{6} pb
$pp \to t\bar{t}$	SHERPA 2.1.1	3M	2.514×10^{3} pb

Table 1. Summary of generated samples to date. All `SHERPA` samples have a MC error of 0.05%.

Although suffering from a large theory uncertainty, we can compare the result of our background samples against those presented in the MG5_aMC@NLO paper [16]. Here for comparison we require in all samples four anti-k_T $R = 0.5$ jets with $p_T \geq 80$ GeV, and the leading jet must have $p_T \geq 100$ GeV. All jets must be within an acceptance of $|\eta| \leq 2.5$. In the case of the samples with b quarks in the final state, these requirements are extended to the appropriate number of b-jets. For example, in the $2b2j$ sample there must be at least two b-jets that pass the cuts outlined above.

In Table 2 this comparison is summarised for the $2b2j$ and $4b$ samples. Considering the large theory errors, agreement is reasonable in both instances.

Process	σ aMC@NLO	σ Oxford (SHERPA)
$b\bar{b}b\bar{b}$	5.050×10^{-1} pb	4.123×10^{-1} pb
$b\bar{b}jj$	1.852×10^{2} pb	4.239×10^{2} pb
$jjjj$	-	4.450×10^{4} pb

Table 2. Comparison of LO Oxford SHERPA cross-sections with those of the aMC@NLO paper. The aMC@NLO cross-sections come with a quoted 50% theory uncertainty.

3 Analysis strategy

Describe the 3 different kinematic regimes: resolved, semi-boosted and boosted and selection cuts. Show table with numbers. How often do events end up in these categories.

Table 1: how many events we see from Signal and background in each category. Indicate also the overlap between the categories. This table should have also the S/B and S/sqrtB numbers. We need also the S/B and S/sqrtB numbers without the 2b2j and 4j backgrounds in order to compare with the UCL paper in this table.

Figure 1: Higgs pt, eta distributions

Figure 2: b-jet pt distributions

Figure 3: delta R distributions

Figure 4: mass distributions

Table 2: S/B and S/sqrtB table with All these figures should have the backgrounds overlaid.

This section would show that the 2b2j and 4j backgrounds are important and that control of the fakes is necessary.

This section should also identify which of the different regimes is the most important for the measurement.

4 Results

Study S/B, S/sqrt B vs b-tagging efficiency, background rejection and signal efficiency

This section would show how S/B is correlated with the different efficiencies. It would give the reader a feel for which of these sources the analysers would need to attack to make the 4b channel a competitive channel with regard to other channels.

5 Multivariate analysis

6 Conclusions and outlook

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