Survey of Higgs Production in Association with W and Z bosons

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Abstract

The purpose of this short note is to present a generator-level systematic study of the Higgs production in association with W and Z bosons. We consider most feasible Higgs decay modes and touch upon their discovery potential.

Associated *vs* Direct Higgs Production

In this note we consider the Standard Model Higgs production in association with the W and Z bosons. The associated Higgs production is a factor of 15 to 30 smaller than the direct one, as evidenced by Table 1. However, the presence of vector boson and its subsequent decays results in unique signatures, more easily identifiable under the high-rate conditions of LHC. For example, a $H \rightarrow Z\gamma$ with Z decaying into hadrons is a notoriously difficult process due to very high jet background. However, an HZ or HW, with the associated W or Z decaying into leptons, result in unique signatures $2j\gamma + 2l$ and $2j\gamma + l\nu$, respectively, which may be exploited.

In order to investigate the various associated Higgs production modes, we have generated 1000 Higgs-W and Higgs-Z events using Pythia 6.403 [1]. The Higgs mass was varied from 120 to 200 GeV in steps of 20 GeV. Three additional masses of 300, 400 and 1000 GeV, which lie beyond the 95% C.L. region favored by the mass fits [2], were considered. The resulting cross-sections are shown in Table 2 and 3, and, graphically, in Fig. 1. For reference, the branching ratios of W and Z bosons are shown in Table 4. Each of the listed channels merits a more careful study. The sole exception to this is $H \rightarrow Z\gamma$ with Z decaying to leptons. The cross-sections for this decay mode is only a few hundredths of a femtobarn or less across the entire Higgs mass range, and, thus, can be discarded immediately. Due to Higgs preferentially coupling to higher mass particles, WW and ZZ decays remain feasible discovery modes for Higgs masses up to 1 TeV; however, due to low $W \rightarrow ll$ and $Z \rightarrow ll$ branching ratios, in the very high mass range only the semileptonic or fully hadronic channels are favorable.

Since the all-hadronic HW and HZ decays may be hard to isolate from the jetty background, one may consider the purely leptonic or the semileptonic decays only. The

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decay modes may then be loosely divided into three classes: first, where both Higgs and the associated vector boson decay into leptons and photons, second, where hadronic Higgs is accompanied by leptonic vector boson decays, and, third, where Higgs decays into leptons and/or photons and the associated W and Z into hadrons.

In the purely leptonic category, $Z \to ll$ and $W \to l\nu$ the following list of feasible signatures may be considered:

- $H \to \gamma\gamma$[1]
- $H \to ZZ^{(*)} \to 4l$ and $H \to WW^{(*)} \to l\nu l\nu$[2]
- $H \to Z\gamma$, with $Z \to ll$
- $H \to \tau\tau$

In the mixed category, the menu of hadronic H_0 decays with leptonic associated VB decays, may look as follows:

- $H \to b\bar{b}$, with hadronic b decays
- $H \to Z\gamma$, with $Z \to q\bar{q}$
- $H \to \tau\tau$, with $\tau \to$hadrons.

Finally, for the third class of the signals the menu for leptonic Higgs decays would look like the one above for the purely leptonic associated decays, with the exception, of course, that the associated vector boson would decay hadronically.[3] In the event of a heavy ($M_H > 350$ GeV) Higgs, $H \to b\bar{b}$ search may also be considered; however, in this range $H \to WW$ decays would dominate by at least an order of magnitude. For completeness, $H \to b\bar{b}$ cross-sections can be found in both Table 2 and 3 and Fig. 1.

By identifying the signals listed above as "feasible", we mean only their discovery potential in terms the magnitude of the cross-sections found in Table 2 and 3. Of course, the crucial question that needs to be answered for each individual background is its signal-to-background ratio. A single process or a combination of backgrounds, even with the cuts applied, may, of course, render a signal "unfeasible." This is the most time-consuming part of any investigation and is beyond the scope of this note. A few of the possible background channels for the associated Higgs signals include, among others: the diboson processes, such as WZ, ZZ and WW, W+jets and Z+jets, $W + \gamma$+jets and $Z + \gamma$+jets and $t\bar{t}$.

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[1] Work in progress. See, e.g., G.Azuelos et al. (U. of Montreal, LPSC Grenoble): (http://indico.cern.ch/getFile.py/access?contribId=19&sessionId=1&resId=0&materialId=slides&confId=10305.

[2] Work in progress. See, e.g., B.Ruckert (LMU Munich): http://indico.cern.ch/getFile.py/access?contribId=1&resId=0&materialId=slides&confId=17746 and L.Shan (Beijing-IHEP) http://indico.cern.ch/materialDisplay.py?contribId=4&sessionId=0&materialId=slides&confId=10305.

[3] Work in progress. See, e.g., G.Azuelos et al. (U. of Montreal, LPSC Grenoble): http://indico.cern.ch/getFile.py/access?contribId=19&sessionId=1&resId=0&materialId=slides&confId=10305

M_H	$\sigma(HW)$ (incl.)	$\sigma(HZ)$ (incl.)	$\sigma(gg \to H)$
120	1279.	691.8	$17.64 \cdot 10^3$
140	810.5	436.8	$13.20 \cdot 10^3$
160	517.7	296.3	$10.85 \cdot 10^3$
180	355.5	196.2	$8.459 \cdot 10^3$
200	248.2	138.3	$6.851 \cdot 10^3$
300	54.09	30.95	$3.786 \cdot 10^3$
400	18.08	9.974	$3.473 \cdot 10^3$
1000	0.5245	0.2714	86.72

Table 1: Inclusive associated *vs.* direct, $gg \to H$, Higgs production cross-sections in units of femtobarn for Higgs masses in the range from 120 to 1000 GeV.

Summary

The associated Higgs production modes and their unique decay signatures present a large window of opportunity for the Higgs search. Only a small fraction of those modes (referenced in the footnotes) to the best knowledge of the authors is being considered by ATLAS groups. We hope that further investigations will take place on some, or, even, all, of the "unclaimed" modes discussed here.

Acknowledgment

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References

[1] T. Sjöstrand, P. Edén, C. Friberg, L. Lönnblad, G. Miu, S. Mrenna and E. Norrbin. *J. Computer Physics Commun.* 135 (2001) 238.

[2] S. Roth. W mass at LEP and Standard Model Fits *XLI Rencontres de Moriond, LaThuile, 18-25 March 2006.*

M_H (GeV)	σ(**HW**) (incl.)	$\sigma(H \to bb)$	$\sigma(H \to c\bar{c})$	$\sigma(H \to t\bar{t})$	$\sigma(H \to \tau\tau)$	$\sigma(H \to gg)$	$\sigma(H \to WW)$	$\sigma(H \to ZZ)$	$\sigma(H \to \gamma\gamma)$	$\sigma(H \to Z\gamma)$
120	1279.	839.5	45.06	n/a	103.0	72.17	181.3	18.94	3.673	1.669
140	810.5	253.7	13.85	n/a	31.18	29.29	413.0	56.56	1.933	2.273
160	517.7	18.38	1.008	n/a	2.374	2.878	468.8	23.00	0.3453	0.7036
180	355.5	1.680	0.0929	n/a	0.2165	0.3462	326.3	20.91	0.0427	0.1220
200	248.2	0.5677	0.0305	n/a	0.0732	0.1481	183.7	62.53	0.0155	0.0471
300	54.09	0.0299	0.0017	n/a	0.0042	0.0233	39.59	17.28	0.0009	0.0035
400	18.08	0.0040	0.0002	1.384	0.0006	0.0112	11.79	5.471	0.0001	0.0004
1000	0.5245	-	-	0.0339	-	-	0.3168	0.1586	-	-

Table 2: PYTHIA-generated inclusive and exclusive cross-sections (in fb) for generating Higgs in association with the **W** boson as a function of the Higgs mass. Entries marked with "-" indicate the cross-sections whose magnitudes are less than the 4-digit precision used here and are too small to be considered experimentally feasible. Light ($M_H < 350$ GeV) Higgs decays into $t\bar{t}$ are kinematically disallowed. The inclusive HW cross-section is also listed in Table 1.

M_H (GeV)	σ(**HZ**) (incl.)	$\sigma(H \to bb)$	$\sigma(H \to c\bar{c})$	$\sigma(H \to t\bar{t})$	$\sigma(H \to \tau\tau)$	$\sigma(H \to gg)$	$\sigma(H \to WW)$	$\sigma(H \to ZZ)$	$\sigma(H \to \gamma\gamma)$	$\sigma(H \to Z\gamma)$
120	691.8	451.8	25.65	n/a	56.91	38.99	101.2	10.68	2.023	0.8850
140	436.8	138.7	7.561	n/a	17.11	16.37	222.8	29.51	1.065	1.230
160	296.3	10.33	0.5781	n/a	1.301	1.657	256.8	12.74	0.1879	0.3711
180	196.2	0.9551	0.0533	n/a	0.1243	0.1943	179.9	11.93	0.0248	0.0647
200	138.3	0.3187	0.0164	n/a	0.0407	0.0812	103.1	34.96	0.0009	0.0259
300	30.95	0.0166	0.0009	n/a	0.0023	0.0134	21.21	9.656	0.0005	0.0019
400	9.974	0.0023	0.0001	0.8001	0.0003	0.0061	6.389	2.925	-	0.0002
1000	0.2714	-	-	0.0172	-	-	0.1721	0.0854	-	-

Table 3: PYTHIA-generated inclusive and exclusive cross-sections (in fb) for generating Higgs in association with the **Z** boson as a function of the Higgs mass. Entries marked with "-" indicate the cross-sections whose magnitudes are less than the 4-digit precision used here and are too small to be considered experimentally feasible. Light ($M_H < 350$ GeV) Higgs decays into $t\bar{t}$ are kinematically disallowed. The inclusive HZ cross-section is also listed in Table 1.

W Decay channel	Branching Ratio	**Z** Decay channel	Branching Ratio
$l\nu$	11%	ll	3.4%
hadrons	68%	hadrons	70%

Table 4: W and Z branching ratios.

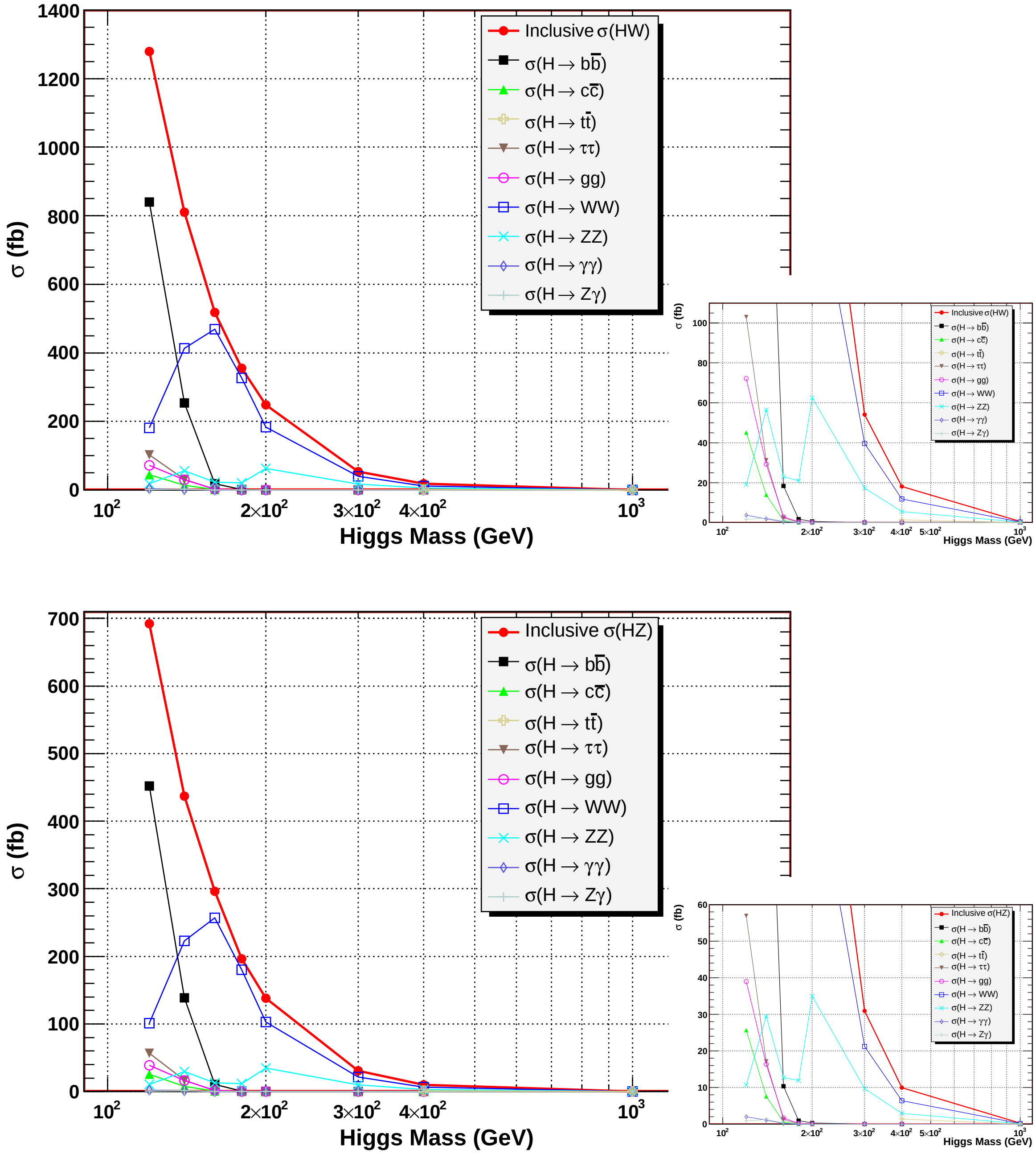

Figure 1: Inclusive and exclusive cross-sections for HW (top) and HZ (bottom) production. Insets on the right show the magnified views of the low-end range of the cross-sections.