Ohio State University REU Program 2000

Generator Level Higgs Simulation

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1 Introduction

Since the dawn of particle physics theorist and experimentalist alike have strove to unify the fundamental forces that govern the way in which particles interact in our universe. There are four of these fundamental forces: the gravitational force, the strong nuclear force, the weak nuclear force, and the electromagnetic force. These four forces, together, are responsible for all physical processes that take place in our universe. In the mid 1970's physicist unified the electromagnetic force and the weak nuclear force to produce the electroweak force. This unification did not come without repercussions though. When the two forces were unified the electroweak theory predicted that the gauge bosons(W and Z bosons) would be massless, contrary to knowledge obtained by experimentalist. In order to unify the two forces and still retain a view that agreed with the current scope of experimental knowledge of particles known at the time, theorist had to introduce the Higgs boson. The Higgs boson is a particle that transmits the Higgs field. Through interactions with the Higgs field particles get mass. It was through the introduction of the Higgs field that theorist allowed the gauge bosons to retain a mass in the confines of electroweak theory. The Higgs boson has not experimentally been found yet, but it is the hope of experimentalist that the energy levels now being reached in accelerators will prove to be great enough to allow the Higgs to be found.

The project that I am involved in is a generator level simulation of the possible productions and decays that may lead to the detection of the Higgs boson in run 2 of the CDF project that is taking place at Fermi National Accelerator Lab. The following paper is the result of this study.

2 Processes

The generator level simulation that I worked on was a Monte Carlo simulation of the search for the Higgs in the lower spectrum of mass ($100 < M_H < 200 GeV/c^2$). It is at these mass levels that the CDF project may have a chance to detect the Higgs in their next run. I have been mainly involved in generating statistical data about events for the different decays and then analyzing the data. There are four possible production processes that were studied in this project.

The first of these is:

$$p\overline{p} -> t\overline{t}$$

The feynman diagram for this production is:

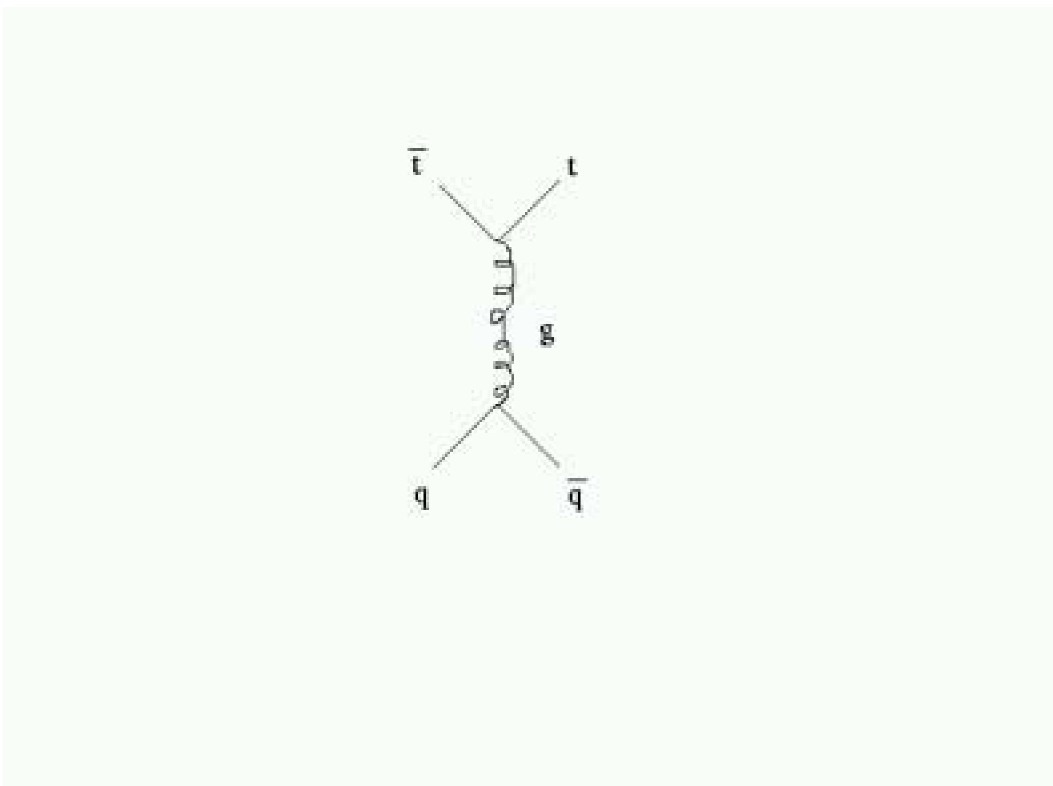

Figure 1: *Feynman diagram of* $p\overline{p} -> t\overline{t}$ *decay*

It reaches its final state through decays such as:

$$t -> Wb$$
$$W -> l\nu, q\overline{q}$$
$$\overline{t} -> W\overline{b}$$

The second production process is:

$$p\overline{p}- > WH.$$

The Feynman diagram for this process is:

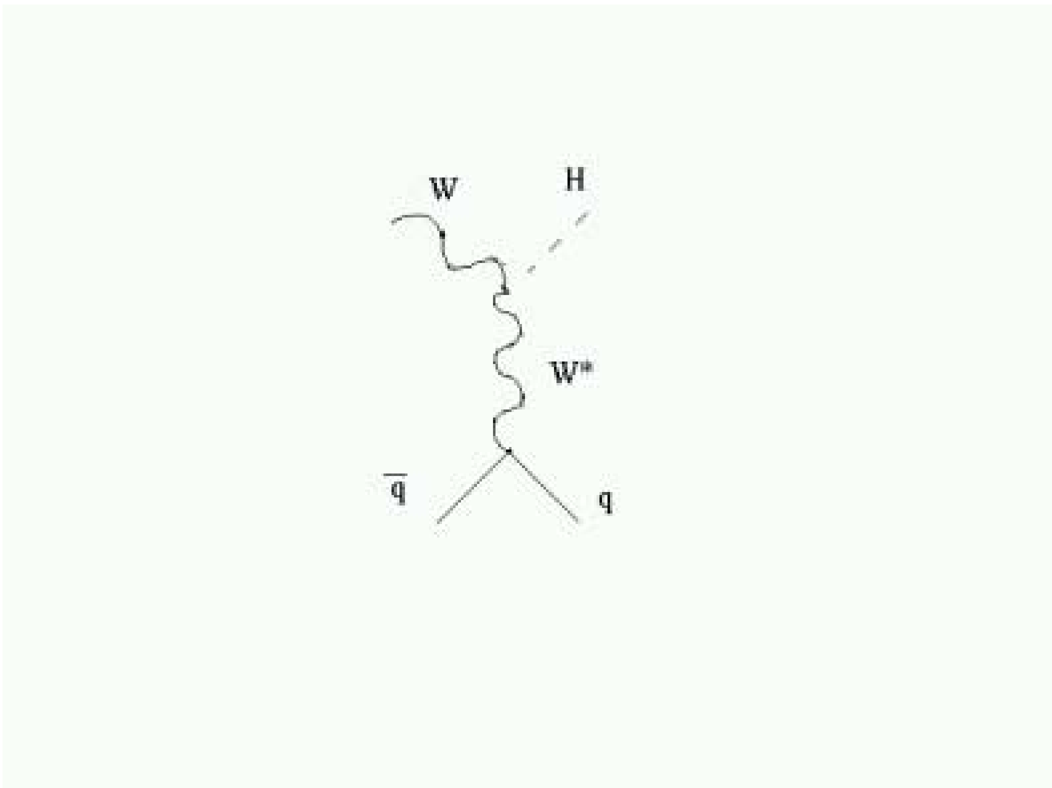

Figure 2: *Feynman diagram of* $p\overline{p}- > WH.$ *decay*

It reaches its final state through the decays:

$W- > l\nu, q\overline{q}$
$H- > b\overline{b}$

The third production process is:

$$p\overline{p}- > ZH.$$

The Feynman diagram for this process is:

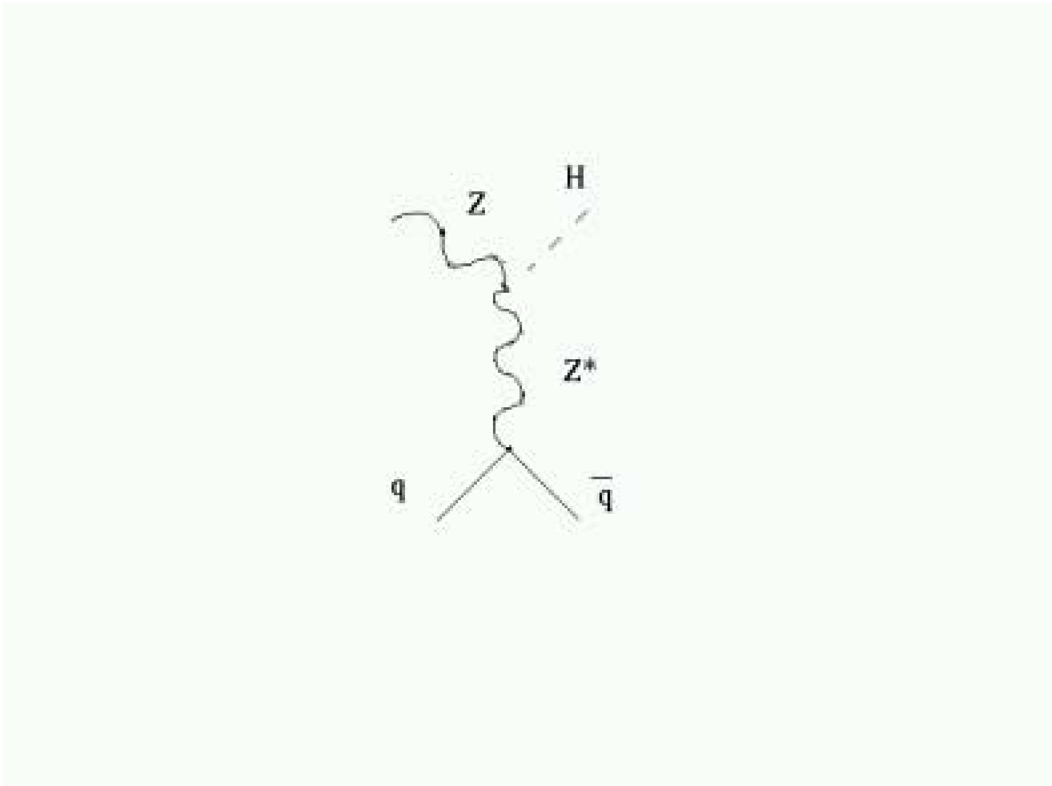

Figure 3: *Feynman diagram of $p\overline{p}->ZH$. decay*

It reaches its final state through any of the decays:

$$
\begin{array}{c}
Z->l^{+}l^{-} \\
Z->\nu\nu \\
Z->q\overline{q} \\
H->b\overline{b}
\end{array}
$$

The fourth production process is:

$$gg->H$$

The Feynman diagram for this process is:
It reaches its final state though the decays:

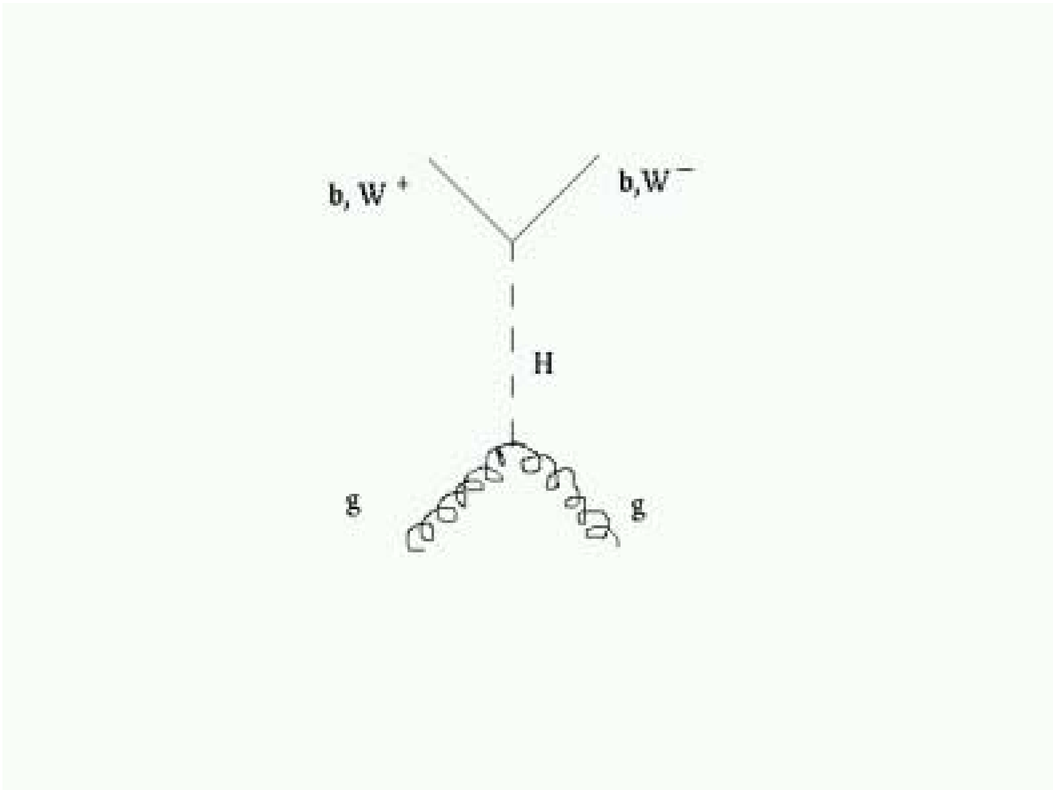

Figure 4: *Feynman diagram of $gg->H$ decay*

$$H->b\bar{b}$$

or

$$H->W^+W^-$$

For each of the different decays there are two numbers of particular importance in this project. The first of these numbers is the cross section denoted by the greek letter σ. It represents the probability of the production process occuring. It is a function of the mass of the Higgs. The second of these numbers is the branching ratio. It is a number that determines the probability of a decay occuring. The below chart give the branching ratios and σ for 120 and 170 Gev/c^2 for each of the different decays.

Decay	Mass(GeV)	$\sigma(fb)$	Branching Ratio
WH	120	170	2/9
	170	40	2/9
$ZHLEP$	120	100	2(.03357)
$(z- > l^+l^-)$	170	25	2(.03357)
$ZHNEU$	120	100	3(.0668)
$(z- > \nu\nu)$	170	25	3(.0668)
H	130	700	.58*24/81
	170	230	.9*24/81

3 Simulation

The processes used in this project were generated using the PYTHIA event generator. The data is produced through a number of files, making up the event generation portion of the simulation. The next step is done by a program called Analysis Control. It is a program which takes the event information from PYTHIA and makes a Root ntuple. The Root ntuple is a file in which the event data is stored. The Root ntuple can then be used in an analysis program called Root. Root, among other things, can be used for event selection and to make graphs and histograms, graphs of the number of events verses a quantity into histograms.

This was done a first time with 10,000 events of the WH, ZH LEP, and ZH NEU processes for Higgs masses of 100,110,120,130,150,and 170 GeV/c^2. A TTbar sample of 10,000 events was generated. This is one of the possible backgrounds to higgs production. For the H processes the simulation was run for Higgs masses of 110,130,150,170, and 200 GeV/c^2. The higher masses were used for the H decay because the prominence is greater for the Higgs boson to appear at higher masses in the decay. In order to model the CDF detector response, the energy and momentum of the leptons, b, $\bar{b}$, ν, and the jets were smeared. This was done by using Root to generate a random smear variable from a Gaussian distribution centered on 1.0 with width σ. This random smear variable was then used to smear a particles four-momentum. For each type of particle a different sigma was needed to get the smear variable from the Gaussian. For electrons $\sigma = .15/\sqrt{E}$, where E is the energy of the particles as given in the ntuple. For $\nu, b, \bar{b}$, and the jets $\sigma = 1/\sqrt{E}$. This smear variable was then multiplied by the original values of the particles to yield new "observed" values. Below is a flow chart for the different stages of the simulation. (See Figure 5)

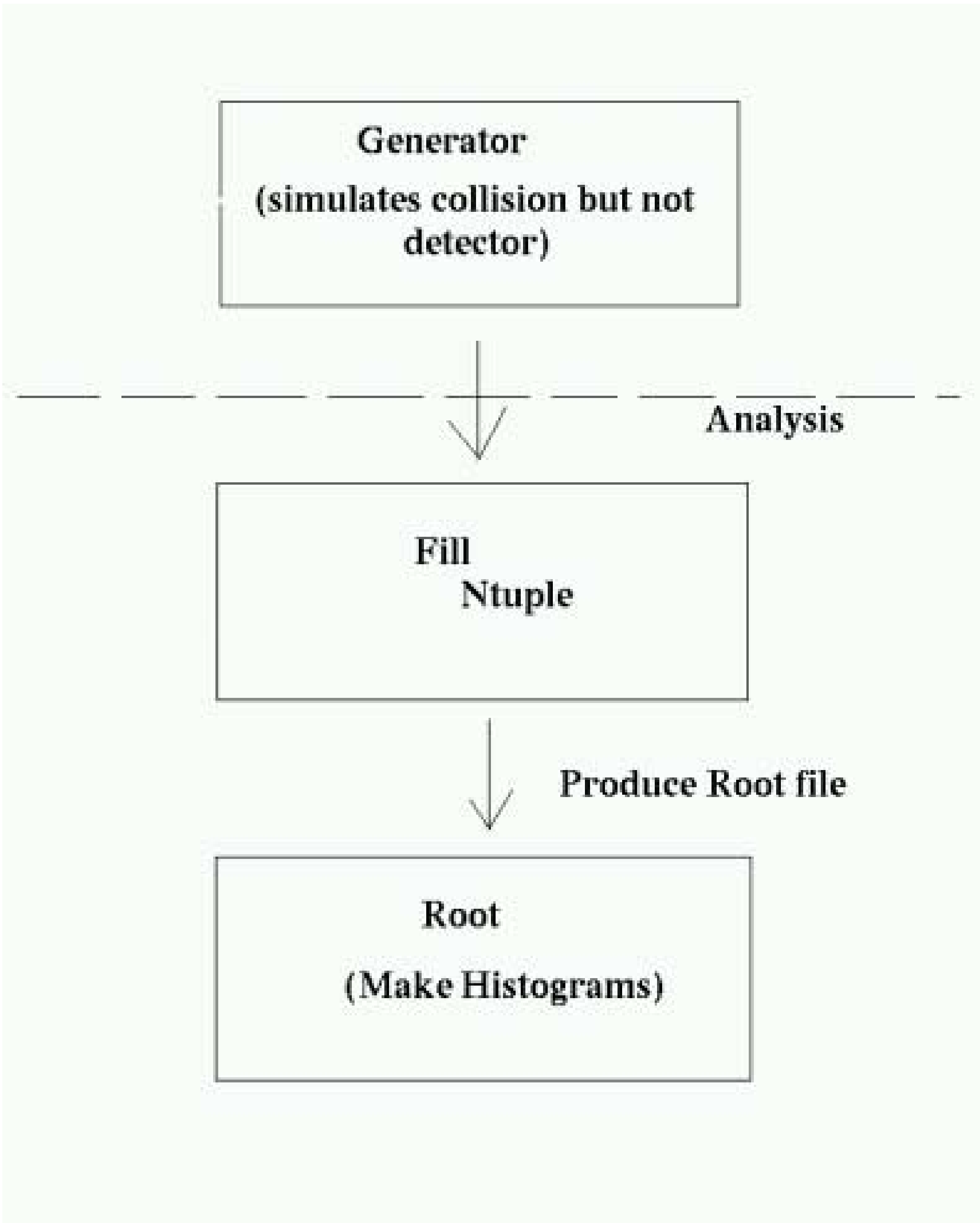

Figure 5: *Flow chart of simulation process*

4 Event Selection

Event selection is made to isolate these Higgs processes from backgrounds. There were two cuts that were part of the event selection of this project. The first of these cuts requires that the transverse momentum of the lepton in the decay must be greater than 20 GeV and that the absolute value of the pseudorapidity is less than 0.9. Pseudorapidity(η) is defined as:

$$\eta = -ln(tan\frac{\theta}{2})$$

Only one lepton needs to pass these requirements in the case of the WH, H and TTbar events, while 2 leptons need to pass the cut in the case of the ZH events. The second cut requires that the transverse momentum of the neutrinos must be greater than 20 GeV. Only the WH, H, and TTbar events have to pass this second cut. Along with these two cuts we also required the events to have atleast 2 jets with a transverse momentum greater than 20GeV, a pseudorapidity with an absolute value of less than 2.

5 Results

For each mass level of the WH, ZH LEP, ZH NEU, and H decays there were a number of different quantities that were important. Charts were made for each of the masses. In each chart the efficiency(ϵ) and the predicted number of events (N) were of interest. The efficiency is simply found by:

$\epsilon = \frac{N_{PASS}}{N_{TOT}}$

The number of predicted events was calculated according to the formula:

$N = (\sigma)(BranchingRatio)(\epsilon)(Integrated\ Luminosity)$

The branching ratio and the cross section(σ) are defined as before mentioned. The integrated luminosity is proportional to the number of collisions observed. The number of events were calculated using two different intergated luminosities, 2 fb^{-1} and 25 fb^{-1}. There are columns for each of the cuts that were made and for the number of jets present in the decay. Histograms were also made to study the MET, the transverse momentum of the Higgs, and the transverse momentum of the W boson or Z boson(depending on the process). These histograms are included for the 120 GeV/c^2 mass and the 170 GeV/c^2 mass.

Mass of Higgs Boson = 100 GeV/c^2

Sample		Cut 1	Cut 2	1 Jet	2 Jets
WH	eff	.3963	.3380	.2816	.2152
	$N(L = 2fb^{-1})$	53	45	37	29
	$N(L = 25fb^{-1})$	661	563	469	359
$ZHLEP$	eff	.3273		.2711	.2124
	$N(L = 2fb^{-1})$	8		6	5
	$N(L = 25fb^{-1})$	88		73	56
$ZHNEU$	eff	.9122		.7611	.5770
	$N(L = 2fb^{-1})$	59		49	37
	$N(L = 25fb^{-1})$	731		610	463

Mass of Higgs Boson = 110 GeV/c^2

Sample		Cut 1	Cut 2	1 Jet	2 Jets
WH	eff	.4015	.3405	.2785	.2202
	$N(L = 2fb^{-1})$	37	29	26	21
	$N(L = 25fb^{-1})$	468	397	325	257
$ZHLEP$	eff	.3446		.2846	.2298
	$N(L = 2fb^{-1})$	6		4	3
	$N(L = 25fb^{-1})$	66		55	45
$ZHNEU$	eff	.9198		.7635	.6065
	$N(L = 2fb^{-1})$	42		35	28
	$N(L = 25fb^{-1})$	530		440	349
h	eff	.0030	.0019	.0005	0
	$N(L = 2fb^{-1})$	0	0	0	0
	$N(L = 25fb^{-1})$	2	2	0	0

Mass of Higgs Boson = 120 GeV/c^2

Sample		Cut 1	Cut 2	1 Jet	2 Jets	$3 \geq$ jets
WH	eff	.4097	.3465	.2837	.2340	-
	$N(L = 2fb^{-1})$	31	26	21	18	-
	$N(L = 25fb^{-1})$	387	327	268	221	-
$ZHLEP$	eff	.3486		.2825	.2270	-
	$N(L = 2fb^{-1})$	5		3	3	-
	$N(L = 25fb^{-1})$	59		47	38	-
$ZHNEU$	eff	.9300		.7731	.6240	-
	$N(L = 2fb^{-1})$	37		31	25	-
	$N(L = 25fb^{-1})$	466		388	313	-
$TTbar$	eff	.4672	.4180	.4177	.4040	.3174
	$N(L = 2fb^{-1})$	1384	1239	1238	1197	940
	$N(L = 25fb^{-1})$	17304	15482	15470	14963	11756

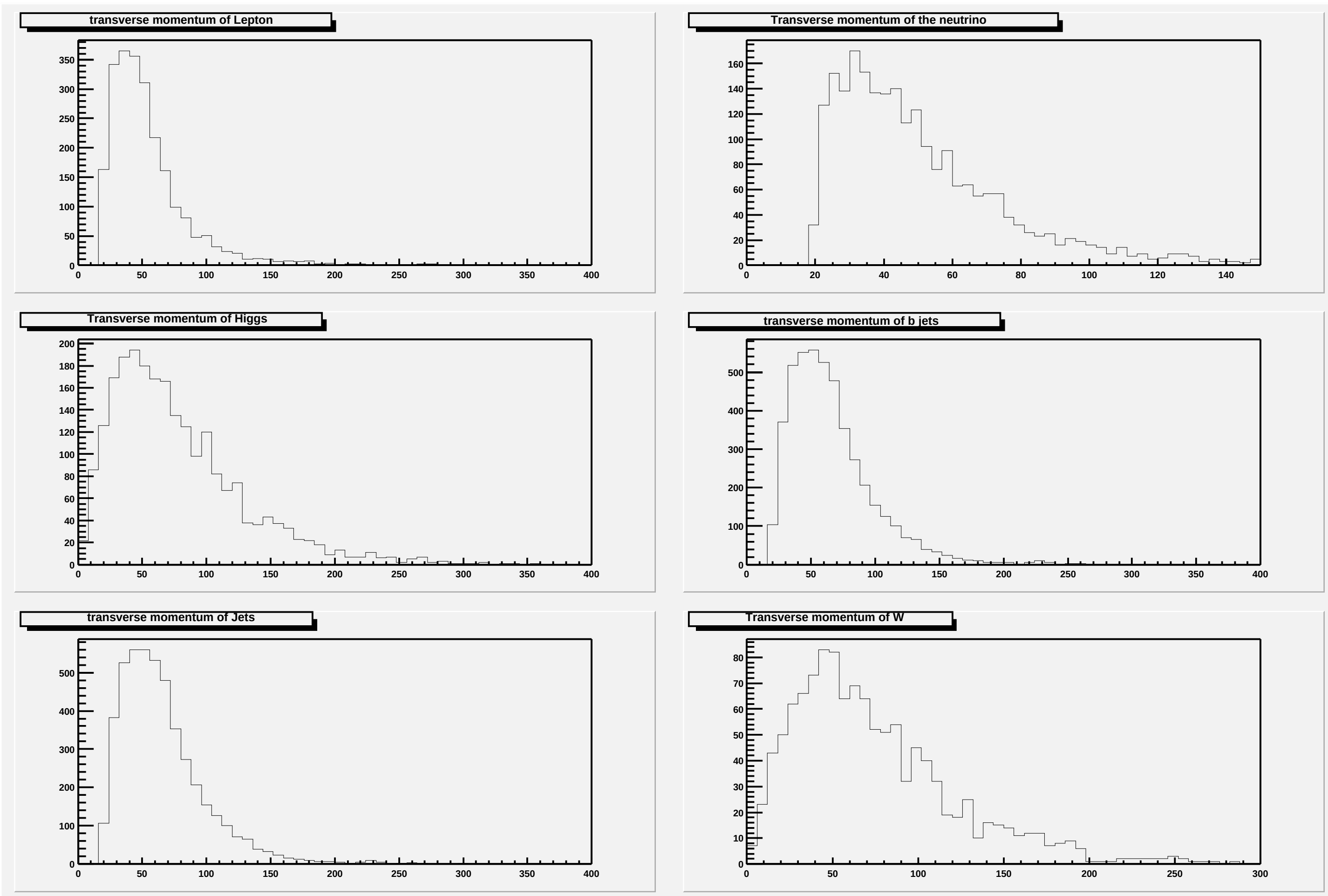

Figure 6: *Histograms of MET and transverse momentum of leptons, Higgs boson, W boson, B quarks, and the jets for WH decay(Higgs mass* $120GeV/c^2$*)*

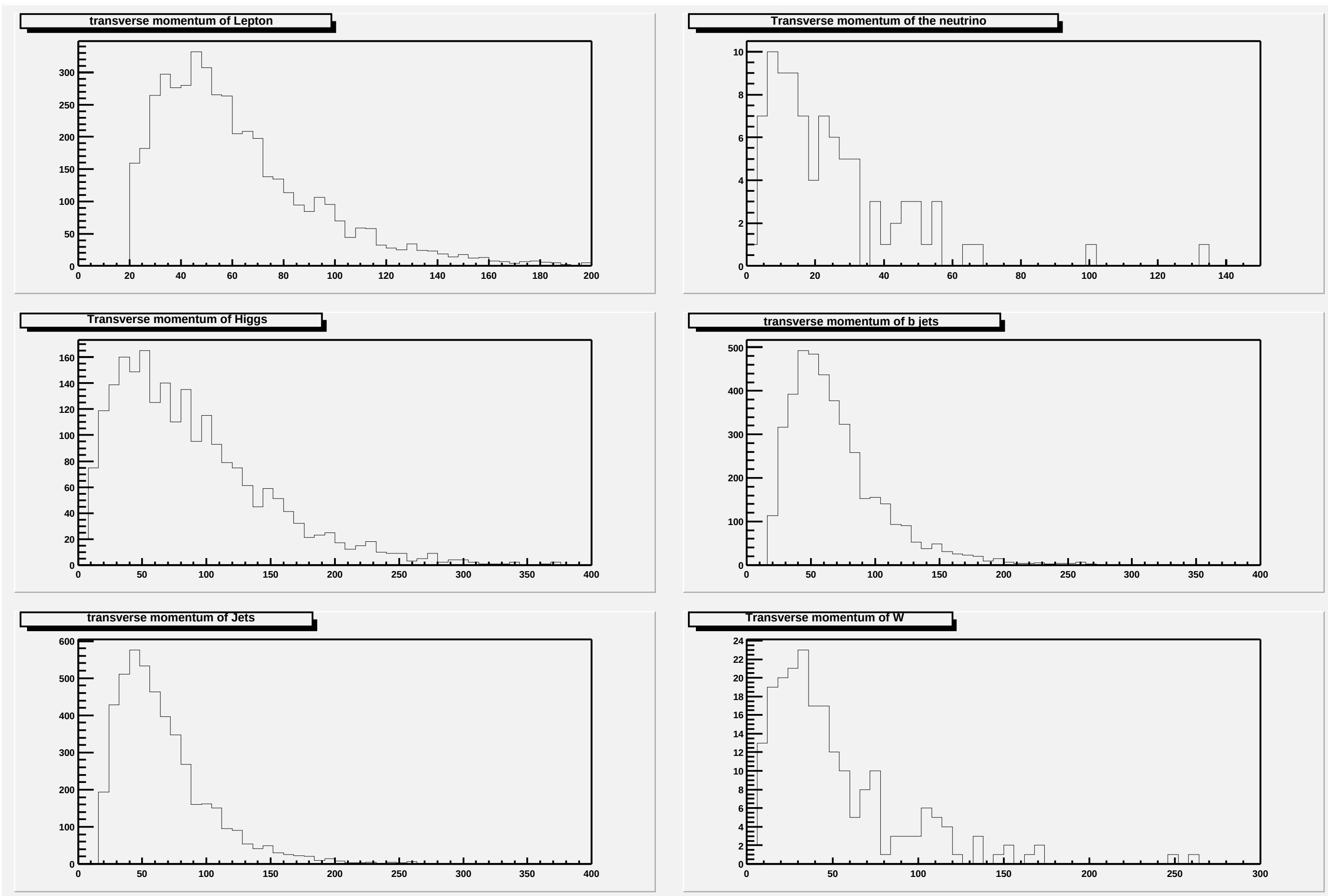

Figure 7: *Histograms of MET and transverse momentum of leptons, Higgs boson, W boson, B quarks, and the jets for ZH LEP decay(Higgs mass* $120 GeV/c^2$*)*

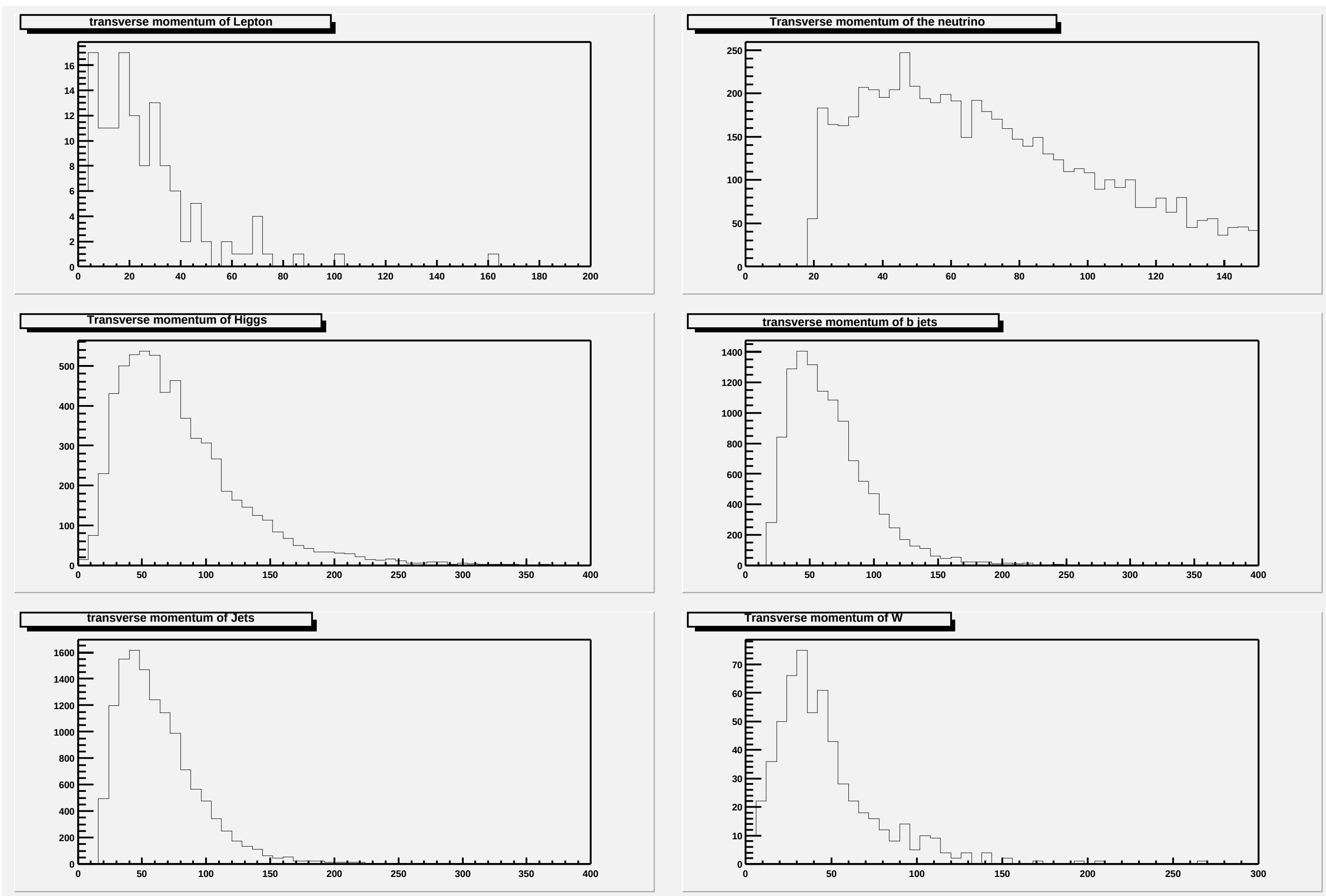

Figure 8: *Histograms of MET and transverse momentum of leptons, Higgs boson, W boson, B quarks, and the jets for ZH NEU decay(Higgs mass* $120GeV/c^2$*)*

Mass of Higgs Boson = 130 GeV/c^2

Sample		Cut 1	Cut 2	1 Jet	2 Jets
WH	eff	.4137	.3518	.2824	.2355
	$N(L=2fb^{-1})$	20	17	14	12
	$N(L=25fb^{-1})$	253	215	173	144
$ZHLEP$	eff	.3673		.3070	.2414
	$N(L=2fb^{-1})$	3		3	3
	$N(L=25fb^{-1})$	46		38	30
$ZHNEU$	eff	.9362		.7846	.6150
	$N(L=2fb^{-1})$	28		24	19
	$N(L=25fb^{-1})$	352		295	231
h	eff	.0350	.0251	.0142	.0026
	$N(L=2fb^{-1})$	7	5	3	1
	$N(L=25fb^{-1})$	87	63	36	7

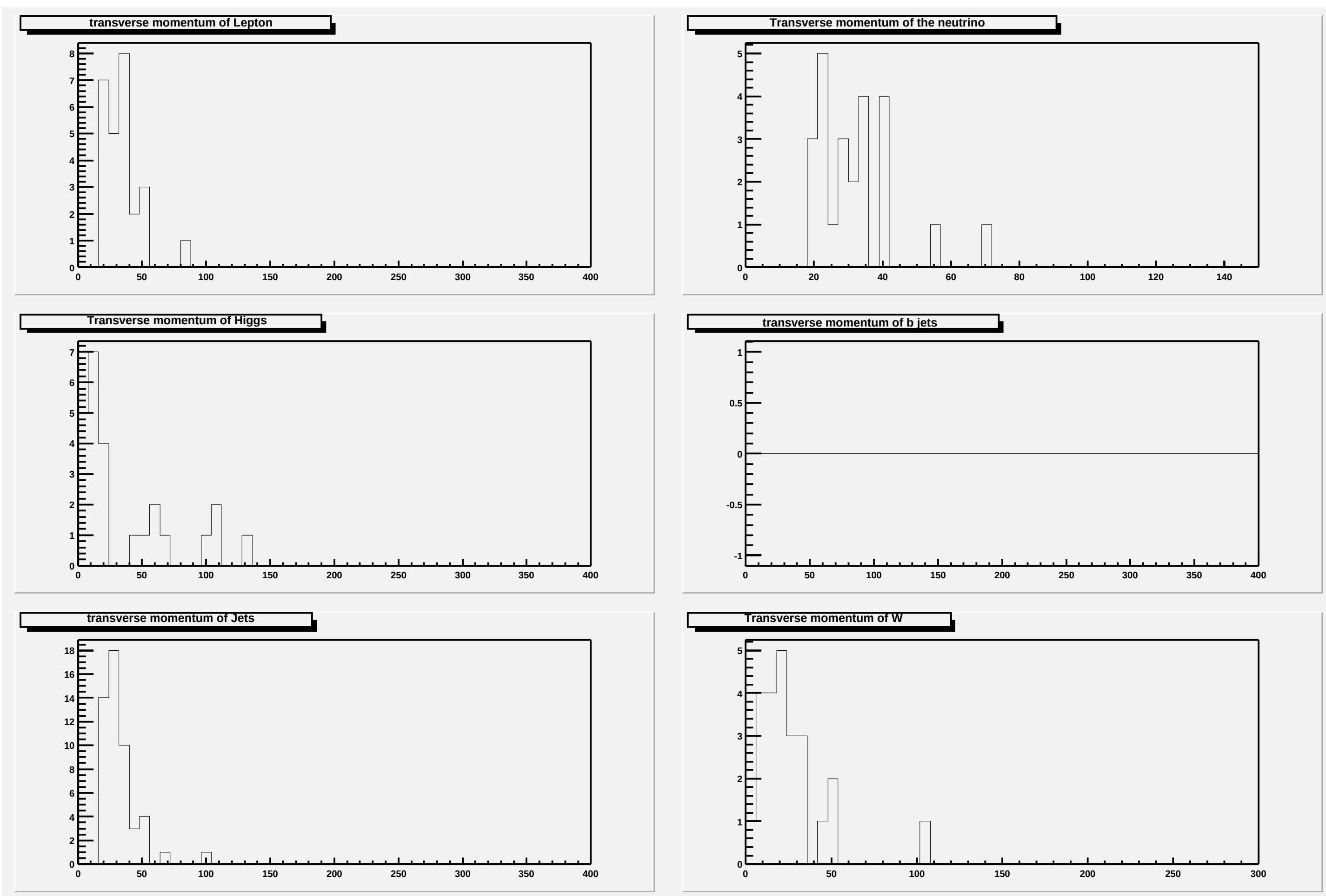

Figure 9: *Histograms of MET and transverse momentum of leptons, Higgs boson, W boson, B quarks, and the jets for H decay(Higgs mass* $130 GeV/c^2$*)*

Mass of Higgs Boson = 150 GeV/c^2

Sample		Cut 1	Cut 2	1 Jet	2 Jets
WH	eff	.3701	.3223	.2374	.1697
	$N(L = 2fb^{-1})$	12	10	8	6
	$N(L = 25fb^{-1})$	154	134	99	71
$ZHLEP$	eff	.4172		.3535	.2660
	$N(L = 2fb^{-1})$	3		1	1
	$N(L = 25fb^{-1})$	29		25	19
$ZHNEU$	eff	.9436		.8371	.6546
	$N(L = 2fb^{-1})$	16		14	11
	$N(L = 25fb^{-1})$	198		176	138
h	eff	.1588	.1344	.0907	.0409
	$N(L = 2fb^{-1})$	34	28	19	9
	$N(L = 25fb^{-1})$	412	348	236	106

Mass of Higgs Boson = 170 GeV/c^2

Sample		Cut 1	Cut 2	1 Jet	2 Jets
WH	eff	.4911	.4377	.2968	.2351
	$N(L = 2fb^{-1})$	9	8	5	5
	$N(L = 25fb^{-1})$	109	97	66	52
$ZHLEP$	eff	.4513		.3923	.3036
	$N(L = 2fb^{-1})$	2		1	1
	$N(L = 25fb^{-1})$	19		17	13
$ZHNEU$	eff	.9491		.8789	.7238
	$N(L = 2fb^{-1})$	10		9	7
	$N(L = 25fb^{-1})$	119		110	91
h	eff	.3929	.3533	.2713	.2065
	$N(L = 2fb^{-1})$	49	43	34	26
	$N(L = 25fb^{-1})$	603	542	417	317

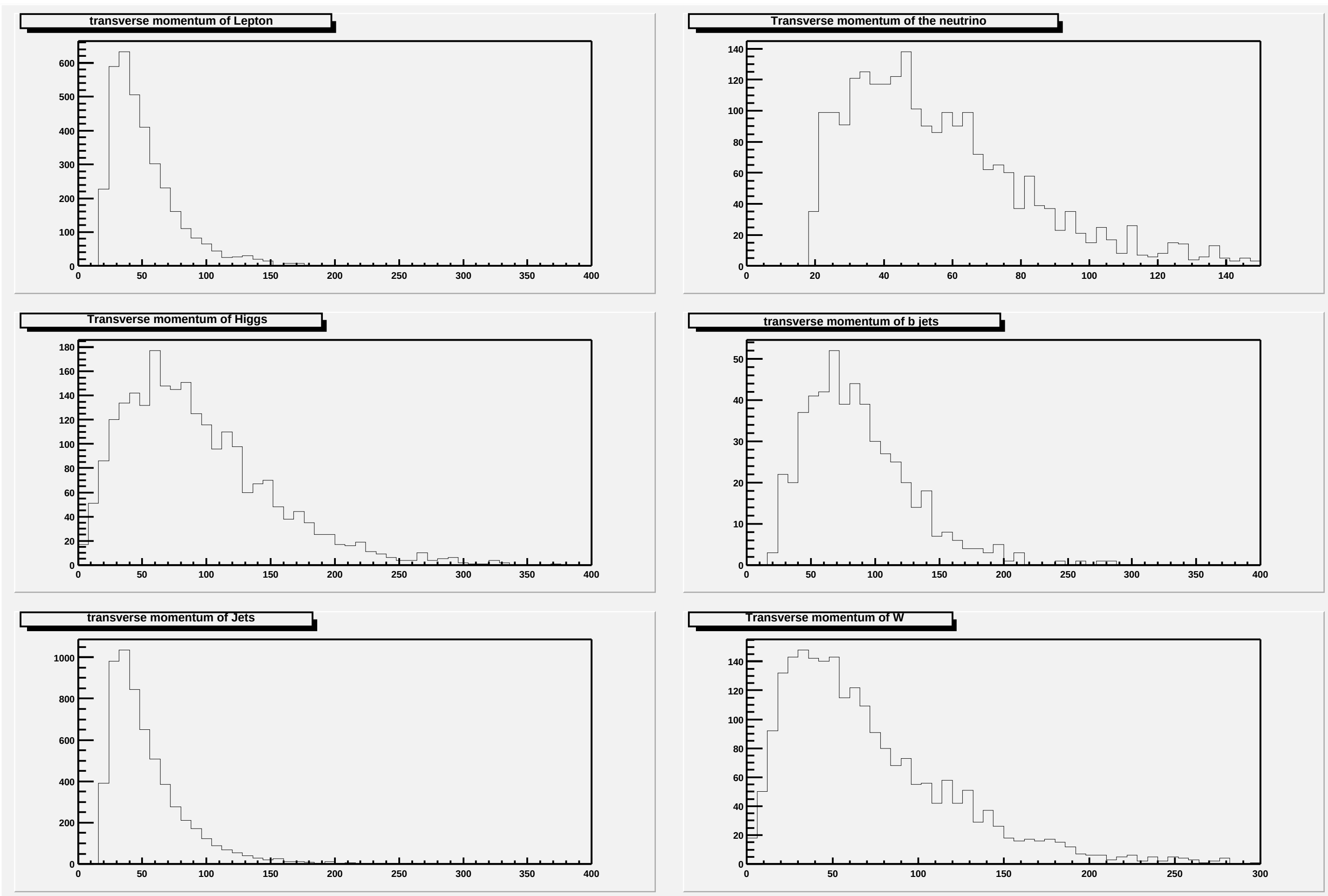

Figure 10: *Histograms of MET and transverse momentum of leptons, Higgs boson, W boson, B quarks, and the jets for WH decay(Higgs mass* $170GeV/c^2$*)*

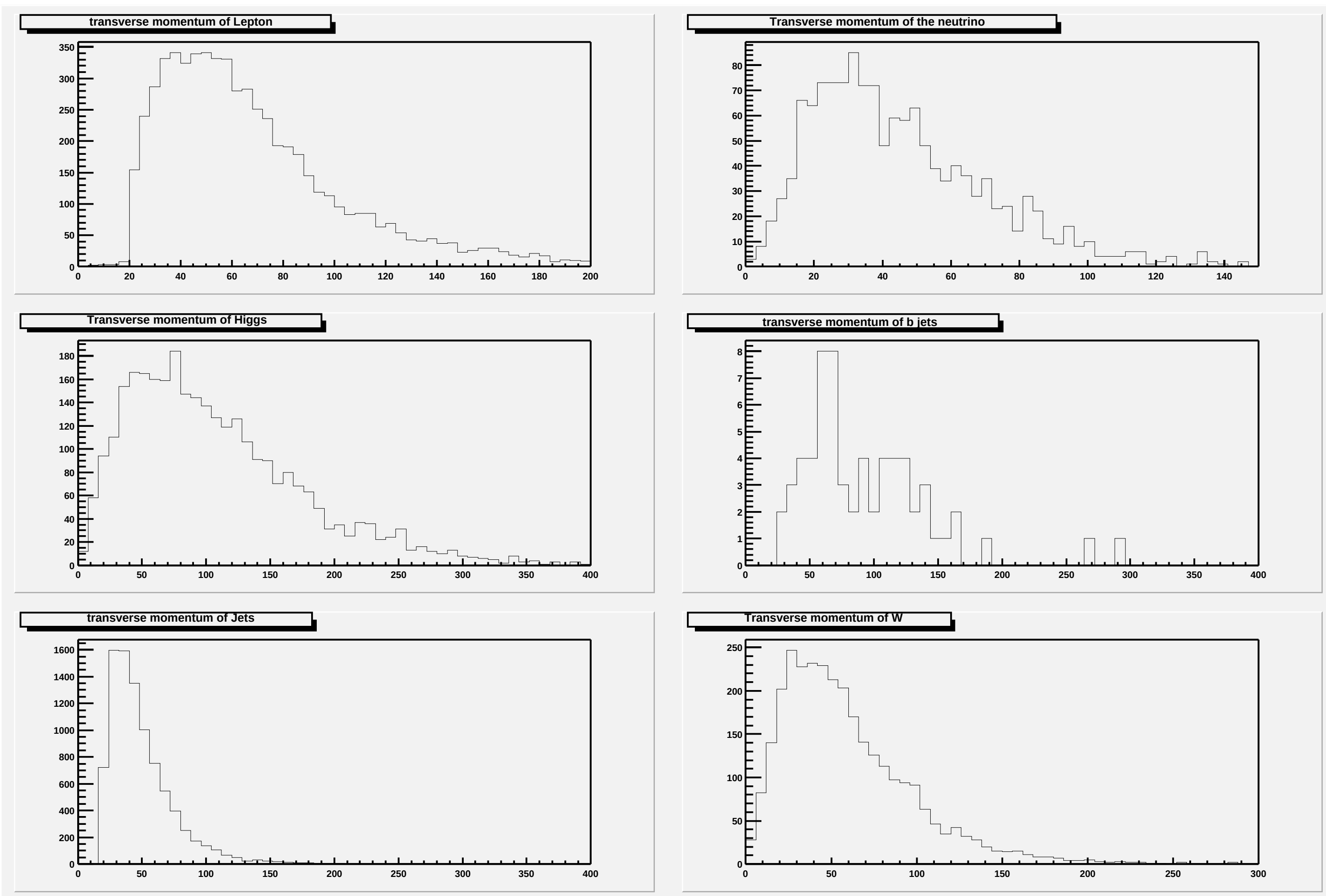

Figure 11: *Histograms of MET and transverse momentum of leptons, Higgs boson, W boson, B quarks, and the jets for ZH LEP decay(Higgs mass* $170 GeV/c^2$*)*

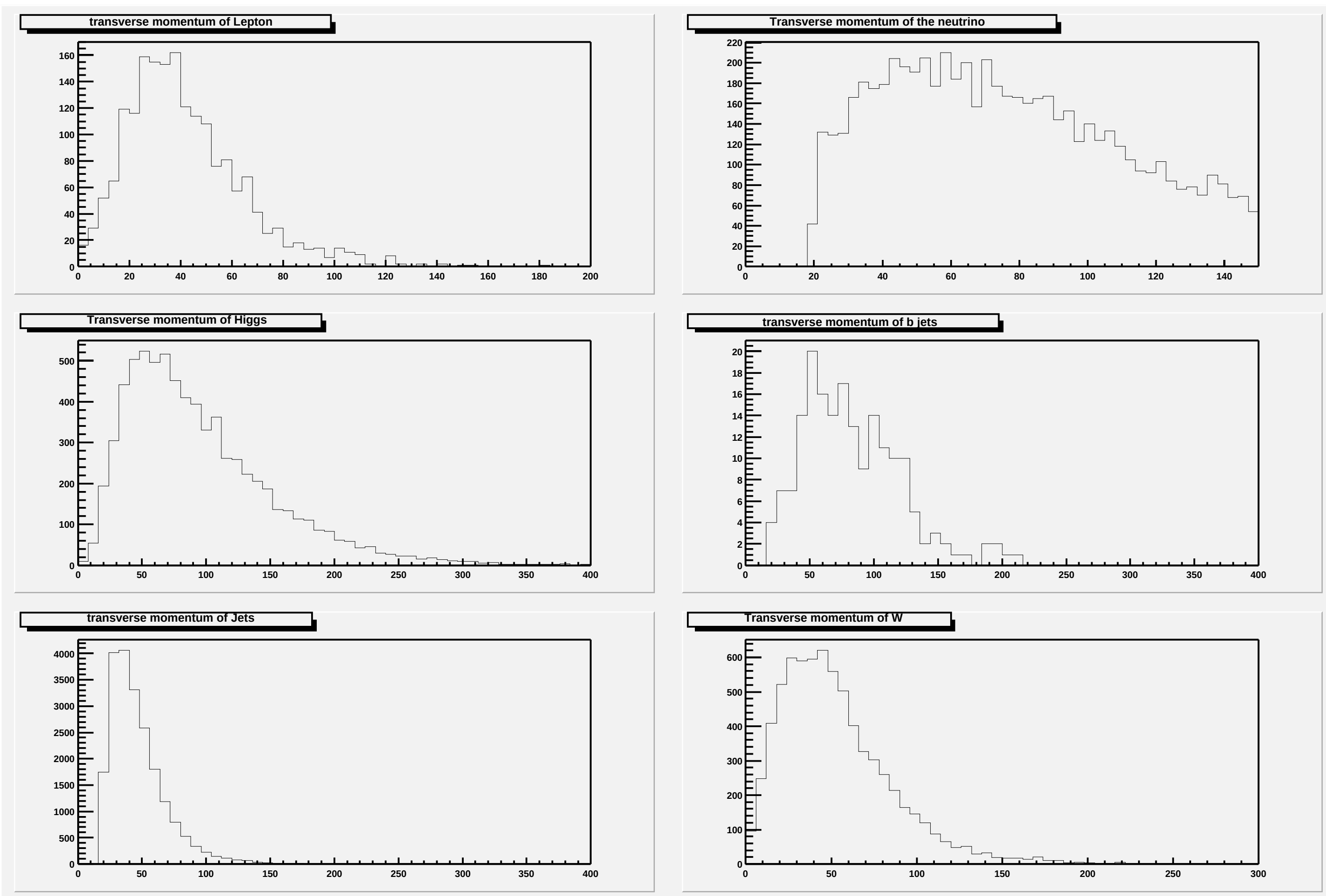

Figure 12: *Histograms of MET and transverse momentum of leptons, Higgs boson, W boson, B quarks, and the jets for ZH NEU decay(Higgs mass* $170 GeV/c^2$*)*

Mass of Higgs Boson = 200 GeV/c^2

Sample		Cut 1	Cut 2	1 Jet	2 Jets
h	eff	.2264	.1974	.1558	.1136
	$N(L = 2fb^{-1})$	13	12	9	7
	$N(L = 25fb^{-1})$	169	148	116	85

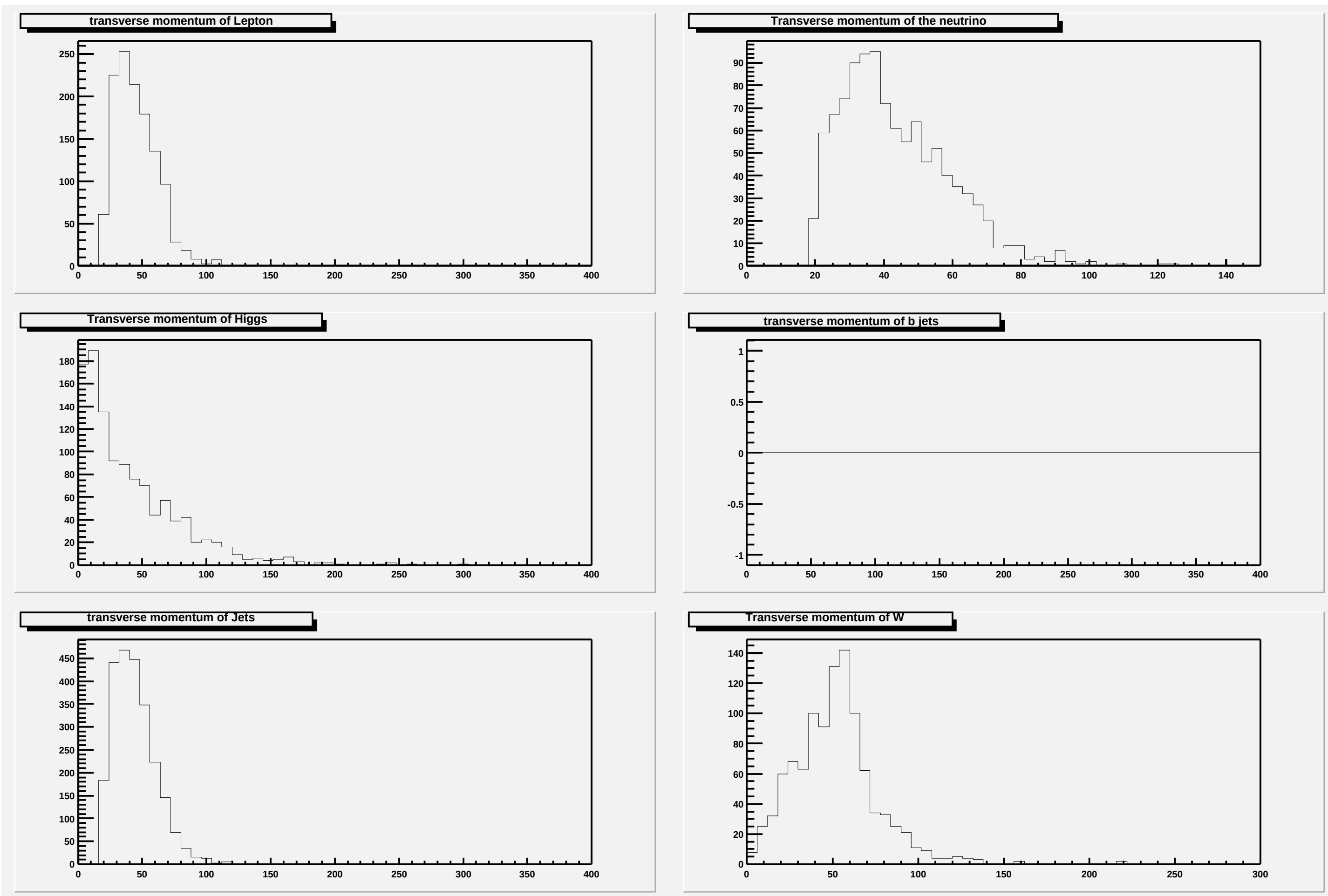

Figure 13: *Histograms of MET and transverse momentum of leptons, Higgs boson, W boson, B quarks, and the jets for H decay(Higgs mass* $200GeV/c^2$*)*

Also of importance was to examine quantities as functions of the mass of the Higgs boson. The efficiencies of the observed events verses the mass of the Higgs was graphed for the WH, ZH LEP, ZH NEU, and H decays. The efficiency error was also caluclated for this graph using the formula

$$\delta\epsilon = \sqrt{\frac{\epsilon(1-\epsilon)}{N_{TOT}}}$$

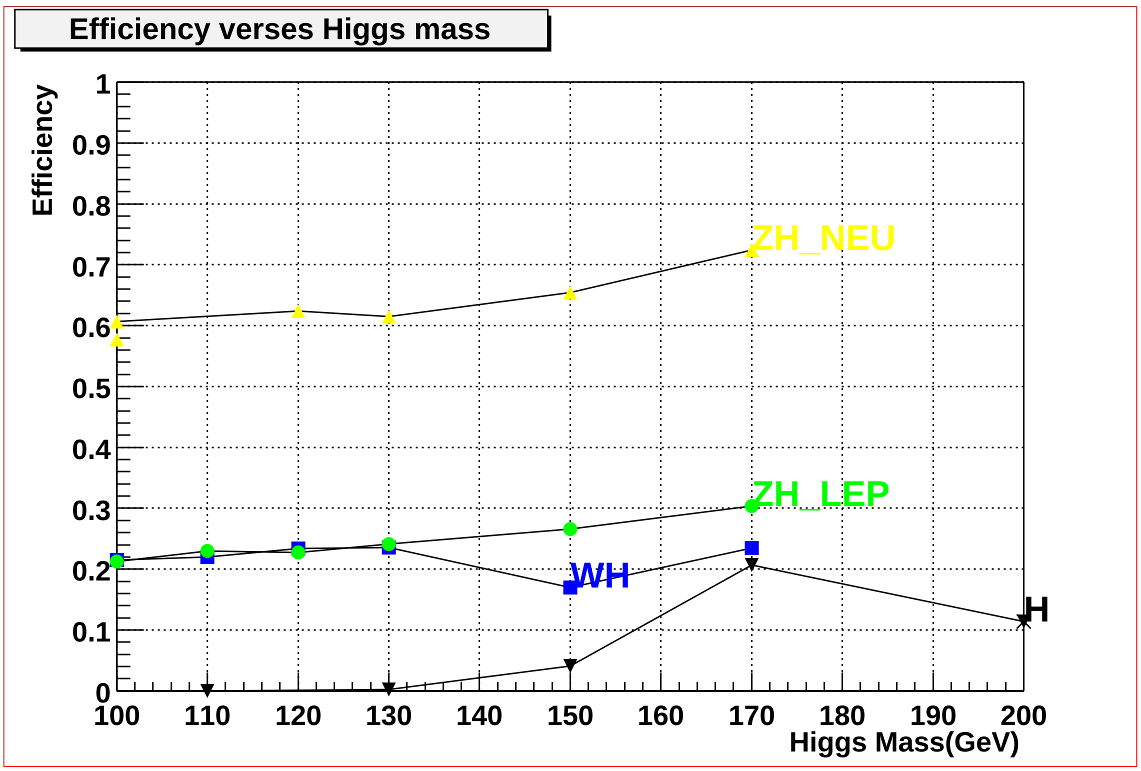

Figure 14: *Efficencies as a function of the mass of the Higgs*

The other quantities that are of interest when ploted as a function of the Higgs boson mass were the predicted number of events, the transverse momentum of the B quark, the transverse momentum of the higgs, and the transverse momentum of the W or Z bosons. For all the graphs of the transverse momentum the error was calculated using the formula:

$$\delta P_T = \frac{RMS\ value}{\sqrt{events\ with\ 2\ jets\ and\ passing\ 2\ cuts}}$$

where the RMS value is found by:

$$RMS = \sqrt{\frac{P_{T1}^2 + P_{T2}^2 + P_{T4}^2 + \ldots + P_{TN}^2}{N}}$$

These graphs are all presented on the following pages.

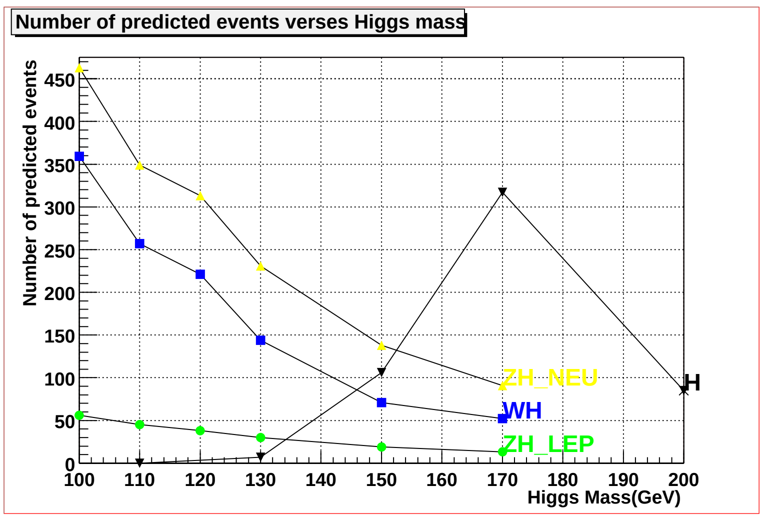

Figure 15: *Number of predicted events (L=25 fb^-1)as a function of the mass of the Higgs*

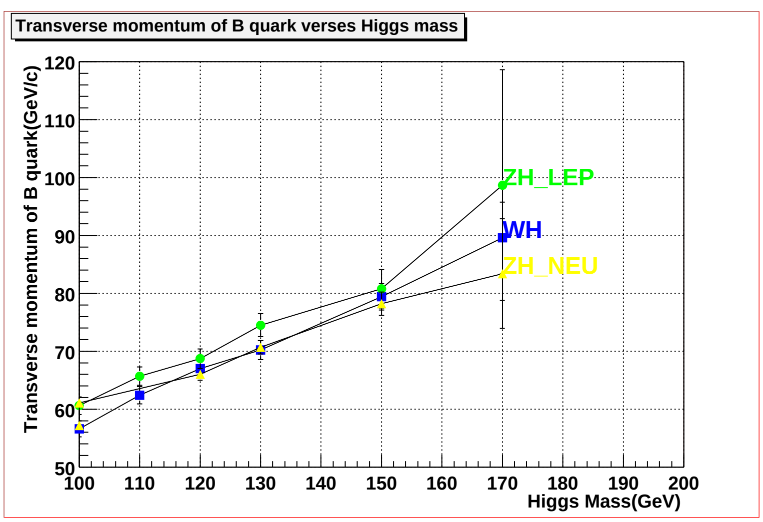

Figure 16: *Transverse momentum of B quark as a function of the mass of the Higgs*

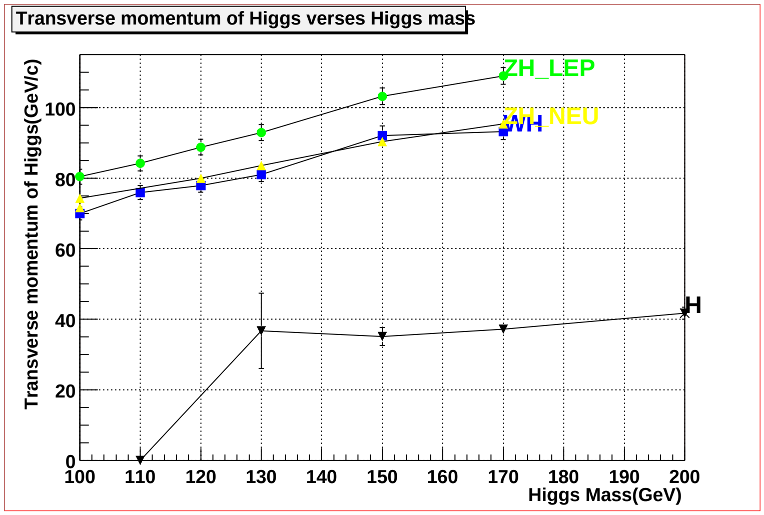

Figure 17: *Transverse momentum of Higgs boson as a function of the mass of the Higgs*

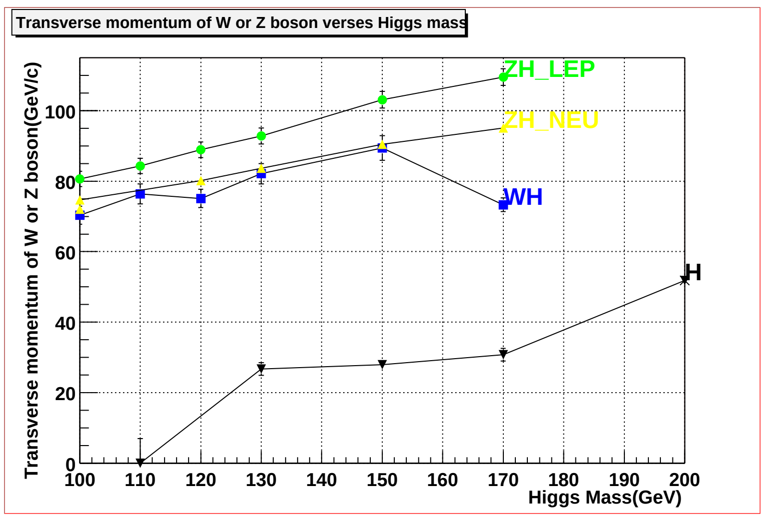

Figure 18: *Transverse momentum of W(for WH and H decays) or Z(for ZH LEP and ZH NEU decays) as a function of the mass of the Higgs*

6 Conclusion

The goal of this project was to simulate processes for which the Higgs may be detected in run 2 of the CDF collaboration. The charts show that for the WH, ZH LEP, and ZH NEU the number of predicted higgs events is greater with a lower mass. As the mass gets larger for these processes the number of predicted events gets smaller and our chances of detecting a Higgs is smaller. The H process works opposite this trend. The number of predicted events is smaller if the mass of the Higgs is small and gets larger with larger masses of the Higgs to a peak around $160GeV/c^2$, after which this number of predicted events decreases again. This is due to the decay of $h- > b\bar{b}$ occurs at lower masses($< 160GeV/c^2$), where the b, and $\bar{b}$ are not easily detected. When the mass of the Higgs becomes greater($> 160GeV/c^2$) the decay $h- > W^+W^-$occurs, where the W^+ and W^- are more easily detected.

7 Acknowledgements

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