Fermi National Accelerator Laboratory

FERMILAB-FN-632

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July 1995

Operated by Universities Research Association Inc. under Contract No. DE-AC02-76CHO3000 with the United States Department of Energy

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Fermilab–FN-632
CMS–TN/95-084

Search for Heavy Higgs in the Channel $H \to ZZ \to \ell\ell\nu\nu$

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July 12, 1995.

We have studied the potential for observation of a heavy Higgs ($m_H = 500$ and 800 GeV) in the channel $H \to ZZ \to \ell\ell\nu\nu$ using a parametrized simulation of the CMS detector.

INTRODUCTION

For Standard Model Higgs bosons with masses in excess of about 800 GeV, the production cross section is too low to permit discovery in the 'gold-plated' $4\ell^{\pm}$ channels in one standard LHC year ($100\,\mathrm{fb}^{-1}$). This is also true for lower Higgs masses, above about 500 GeV, if the integrated luminosity available is only a few tens of fb^{-1}, as might be the case in the first few years of LHC operation. Channels with higher branching ratios therefore become attractive. One such is $H \to ZZ \to \ell\ell\nu\nu$ which has six times the event rate of $H \to 4\ell^{\pm}$. The price to be paid is increased backgrounds: as well as the irreducible ZZ continuum, there is a potentially overwhelming background from $Z + jets$ events where the $\not{E}_T$ is generated by mismeasurement of the jets. (Another potential background, from $t\bar{t} \to \ell\ell + \not{E}_T$, has not been considered in this study).

Earlier studies [1] [2] have investigated this channel with the goal of developing cuts to maximise signal/background. In the present study, we have used the $H \to ZZ \to \ell\ell\nu\nu$ process, with the aim of reducing the $Z + jets$ background, as a benchmark for the missing transverse energy performance of the CMS detector. We have investigated the effect of $|\eta|$ coverage, pileup events, and some of the detector effects on the $\not{E}_T$ resolution.

DETECTOR MODELING

Events were generated using ISAJET version 7.09. The CMS detector was modelled using a parametrized simulation first developed for the SDC detector [3]. This simulation incorporates:

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- stable particles are tracked in the magnetic field up to the calorimeter;
- EM calorimetry covers up to $|\eta| = 2.6$, and hadronic up to $|\eta| = 5.0$;
- energy resolution is simulated by Gaussian smearing with sampling and constant terms as below:

	$\lvert\eta\rvert \leq 1.5$	$1.5 \leq \lvert\eta\rvert \leq 2.6$	$2.6 \leq \lvert\eta\rvert \leq 3.0$	$3.0 \leq \lvert\eta\rvert \leq 5.0$
EM:				
Sampling	0.02	0.02	0.36	0.50
Constant	0.005	0.005	0.03	0.03
Hadronic:				
Sampling	0.65	0.83	0.83	1.00
Constant	0.05	0.05	0.05	0.05

- transverse shower shape is modelled, with an rms width of 7 cm (hadronic) and 0.7 cm (EM);
- shower leakage is modelled with calorimeter depths of 8.7λ for $|\eta| \leq 1.5$, 11λ for $1.5 \leq |\eta| \leq 3.0$, and 12λ for $3.0 \leq |\eta| \leq 5.0$;
- cracks in azimuthal coverage are modelled as 2 cm wide regions in the calorimeter where the response is zero;
- energy is stored in cells with transverse segmentation of 0.05×0.05 for all calorimeters.

Jets are then found using a cone algorithm on the calorimeter tower energies. For simulations including minimum bias pileup, an additional 30 events were added; the pileup events were modelled using low-p_T two-jet events. A 1 GeV threshold cut per tower was used for jet-finding in the presence of pileup events [4].

EVENT SELECTION

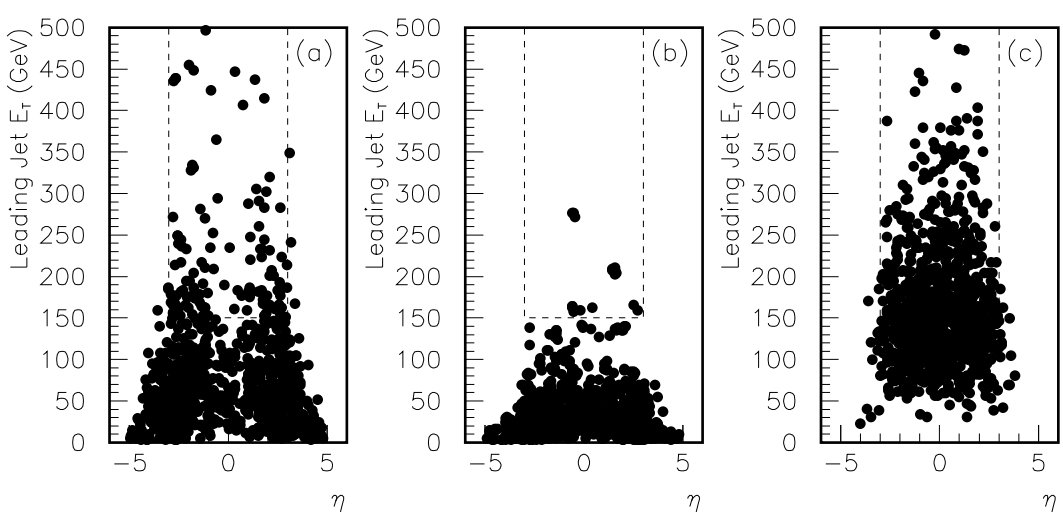

FIG. 1. Distributions of E_T vs. η for the leading jet, for (*a*) 800 GeV Higgs, (*b*) ZZ continuum and (*c*) $Z + jets$ background. The dashed line shows the region excluded by cut (6). No pileup events are included in these plots.

To reduce the backgrounds, events were selected which passed the following cuts:

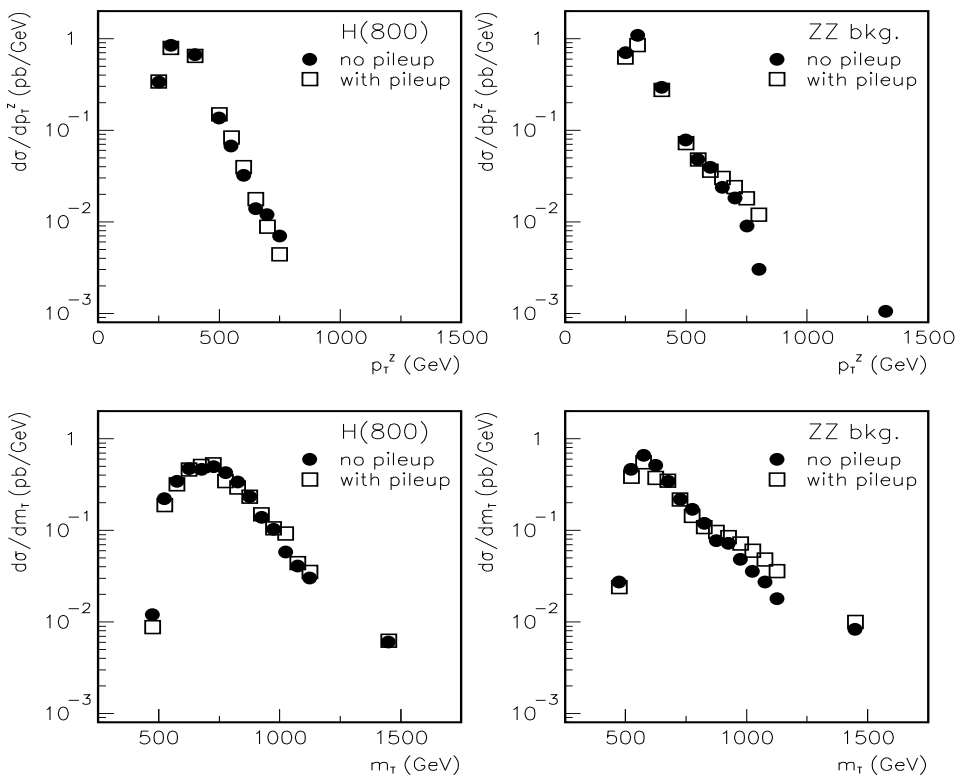

FIG. 2. Distributions of p_T^Z and transverse mass m_T, for 800 GeV Higgs and ZZ continuum background. Open symbols include mimimum bias pileup events, filled symbols do not.

1. Two (opposite-sign) leptons with $p_L^\ell > 20\,\mathrm{GeV}$ and $|\eta^\ell| < 2.5$

2. Both leptons isolated with $E_T < 5\,\mathrm{GeV}$ in a cone of $R = 0.3$ around the lepton direction;

3. $|m_{\ell\ell} - m_Z| < 10\,\mathrm{GeV}$;

4. $E_T^{\ell\ell} > 250\,\mathrm{GeV}$ for $m_H = 800\,\mathrm{GeV}$ ($E_T^{\ell\ell} > 156\,\mathrm{GeV}$ for $m_H = 500\,\mathrm{GeV}$);

5. $\not{E}_T > 250\,\mathrm{GeV}$ for $m_H = 800\,\mathrm{GeV}$ ($\not{E}_T > 156\,\mathrm{GeV}$ for $m_H = 500\,\mathrm{GeV}$);

6. No jet with $E_T > 150\,\mathrm{GeV}$ and $|\eta| < 3$.

Cuts (1)–(3) select the $Z \to \ell\ell$ decays; cut (4) requires that the Z be produced with large transverse momentum. By selecting events with large missing E_T, cut (5) reduces the $Z + jets$ background by a factor of $\mathcal{O}(10^3)$, until it is a few times the signal. The final cut (6) provides additional rejection against the $Z + jets$ background. It is motivated by the observation, seen in Fig. 1, that these background events tend to have central, high-E_T jet activity, while for signal events the jets (if any) are forward.

Figure 2 shows the distribution of Z transverse momentum and of the transverse mass of the Z and $\not{E}_T$, after these cuts, for signal and the ZZ background. The inclusion of the minimum bias pileup does not significantly affect the shape of these distributions.

CROSS SECTIONS

The cross sections for signal and background after each of these cuts are listed in Table I for $m_H = 800\,\mathrm{GeV}$ and Table II for $m_H = 500\,\mathrm{GeV}$.

	Higgs (800)	$ZZ \to \ell\ell\nu\nu$	$Z + jets$
Produced	400	1300	1,380,000
After cuts 1–3	284(328)	689(793)	759,000(938,000)
After cuts 1–4	212(236)	169(195)	152,000(179,000)
After cuts 1–5	188(212)	143(169)	460(57)
After cuts 1–6	155(172)	138(159)	115(57)
Signal/Background	0.6(0.8)		

TABLE I. Number of events per LHC year ($100\,\mathrm{fb}^{-1}$) for 800 GeV Higgs signal and backgrounds. Numbers in parentheses are the results obtained without pileup events included.

	Higgs (500)	$ZZ \to \ell\ell\nu\nu$	$Z + jets$
Produced	2400	1300	1,380,000
After cuts 1–3	1560(1872)	676(793)	759,000(938,000)
After cuts 1–4	1224(1488)	663(780)	741,000(745,000)
After cuts 1–5	1080(1296)	559(676)	8280(8392)
After cuts 1–6	1080(1203)	559(676)	2711(0)
Signal/Background	0.33(1.8)		

TABLE II. Number of events per LHC year ($100\,\mathrm{fb}^{-1}$) for 500 GeV Higgs signal and backgrounds. Numbers in parentheses are the results obtained without pileup events included.

EFFECT OF VARYING η COVERAGE

This physics channel is rather sensitive to the η coverage of the calorimeter because it depends on good missing-E_T resolution to reject the overwhelming $Z + jets$ background. We have investigated how the $\not{E}_T$ resolution varies as a function of the η_{max} of the calorimeter.

Figure 3 shows the $\not{E}_T$ resolution, defined as the difference between true $\not{E}_T$ and reconstructed $\not{E}_T$, for various ranges of $|\eta|$ coverage of the calorimeter, for signal and backgrounds. It can be seen that in all cases the $\not{E}_T$ resolution is significantly degraded by the presence of pileup events. It is also seen that only a small improvement in $\not{E}_T$ resolution is obtained by going from $|\eta| \leq 4$ to $|\eta| \leq 5$. The same feature is demonstrated in Fig. 4, which shows the number of events with $\not{E}_T$ above E_T^{cut} as a function of E_T^{cut}, for the $Z + jets$ background. The large rejection power of a cut on $\not{E}_T$ is apparent, but extending the calorimeter coverage much beyond $|\eta| \leq 5$ is not justified by this plot. (This η coverage should be taken as the fiducial volume of the calorimeter).

CONCLUSIONS

We have investigated the signal and backgrounds for the process $H \to ZZ \to \ell\ell\nu\nu$. We find cuts which give a reasonable signal to background ratio. Good $\not{E}_T$ resolution is essential to reject the $Z + jets$ background and this is found to require a calorimeter extending up to $|\eta| \sim 5$. It is also quite sensitive to degradation by minimum

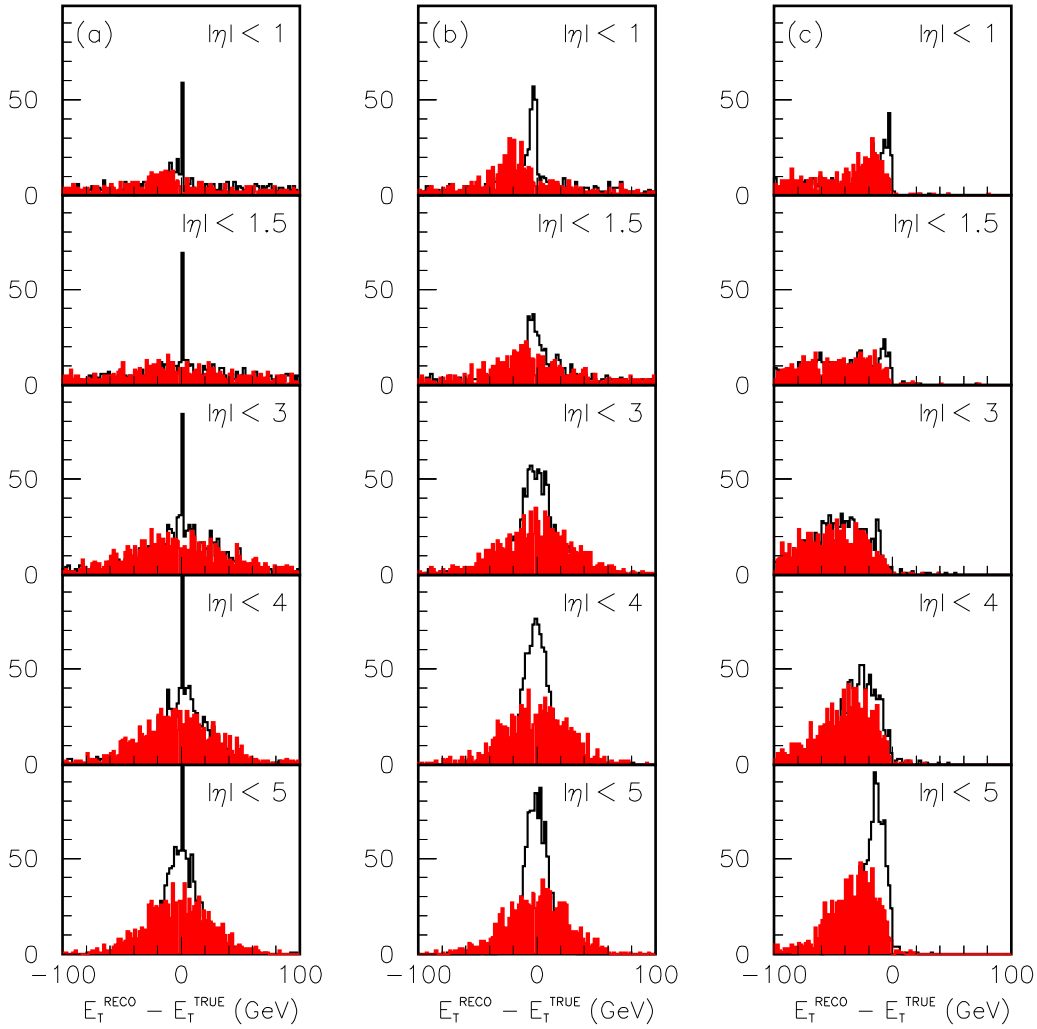

FIG. 3. Distributions of true $\not{E}_T$ − reconstructed $\not{E}_T$ for various ranges of $|\eta|$ coverage of the calorimeter, for (a) 800 GeV Higgs, (b) ZZ continuum and (c) $Z + jets$ background. The shaded histograms include pileup events, the open histograms do not.

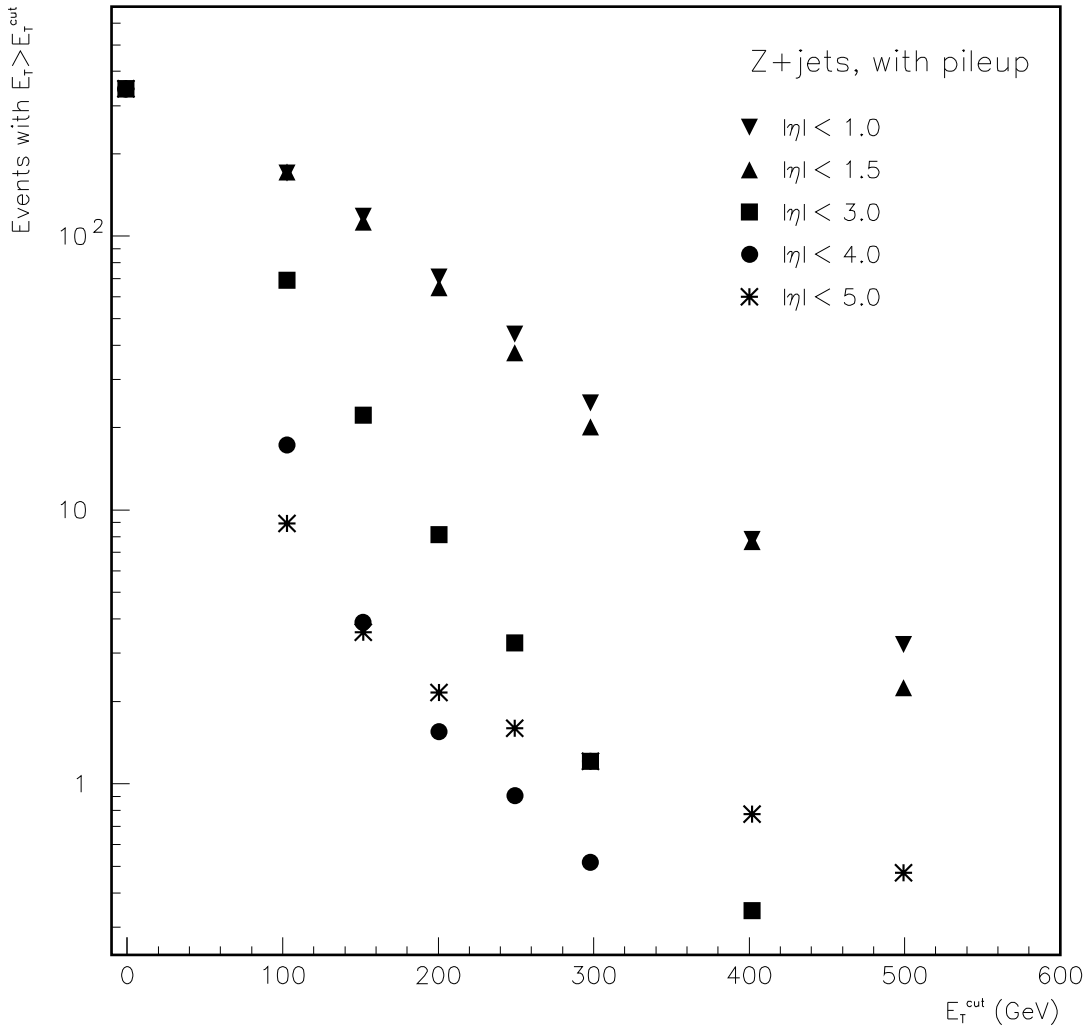

FIG. 4. Number of events with $\not{E}_T$ above $E_T^{\rm cut}$ vs. $E_T^{\rm cut}$, for $Z + jets$ background; pileup events are included.

bias pileup events. Optimization of the tower threshold cut on E_T as a function of luminosity is perhaps called for.

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