HIGGS BOSON DETECTION AT LHC VIA Z^0 POLARIZATION

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We show that it is possible to search for the Standard Model Higgs bosons in the $H \longrightarrow ZZ \longrightarrow 4l^{\pm}$ channel at LHC using Z^0 polarization. This will strengthen the conclusivity of detection by the primary method based on the reconstruction of $4l^{\pm}$ invariant mass and provide information about Higgs boson polarization.

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1. Introduction

Previous studies have shown that in the four-lepton channel the search for the Standard Model Higgs bosons can be successful in the range $m_{\rm H} \approx 130$–800 GeV [1]. This is achieved by appropriate cuts enhancing the signal to background ratio. For $m_{\rm H} > 2m_Z$ the main backgrounds are nonresonant ZZ production and $t\bar{t}$ which are significantly suppressed by $p_{\rm T}^Z$ for the former background and Z-mass cuts for the later one [2]. That leaves irreducible ZZ continuum production coming from $q\bar{q} \to ZZ$ and $gg \to ZZ$ as the only significant background we have to take into account. Following the idea suggested by [3], we study the polarization of Z's and use it to define criteria for the presence of the Higgs bosons. The method is illustrated for $m_{\rm H} = 300, 500$ and 700 GeV.

2. Simulation for the signal and the background

The events are generated by PYTHIA 5.7 with CTEQ2L structure functions [4] and with a top quark mass of 175 GeV according to the most recent CDF and D0 results [5]. The production processes are gg fusion and WW/ZZ fusion (with $gg \to H$ contributing $\approx 70\%$) and $\sigma \cdot B$ are 8.3, 3.2

and 0.9 fb for $m_{\rm H} = 300, 500$ and 700 GeV respectively [6]. Higgs production in association with heavy flavors ($t\bar{t}H$) amounts only to 1–3% of the total cross section. For the background the process $q\bar{q} \to ZZ$ is simulated with PYTHIA, but the $gg \to ZZ$ contribution is obtained by multiplying the $q\bar{q}$ result by 1.33 because of the similar topology and kinematics of the two processes [7]. No higher order corrections beyond the initial state parton shower corrections are taken into account either for the signal or for the background. High $p_{\rm T}$ electrons and muons radiate photons due to bremsstrahlung. The effects of internal bremsstrahlung are included using a dedicated photon radiation program PHOTOS 2.0 [8]. The lepton momentum resolutions have been studied with detailed GEANT simulations of the detector response to both electrons and muons [9], including an approximation of external bremsstrahlung effects. The response of the detector is then parametrized as a function of p and η for fast simulations [10].

3. Signal selection

To select an event we require: one electron with $p_{\rm T} > 20$ GeV, one with $p_{\rm T} > 15$ GeV, and the remaining two with $p_{\rm T} > 10$ GeV. Also, they all have to be within $|\eta| < 2.5$. For muons the corresponding $p_{\rm T}$ cuts are 20, 10 and 5 GeV, and the rapidity coverage is $|\eta| < 2.4$. After all the geometrical and kinematic cuts the signal acceptances are 68, 75 and 80 % for $m_{\rm H} = 300, 500$ and 700 GeV respectively, while for the ZZ continuum background the acceptance is 44% [6]. The acceptance increases with Higgs mass and is bigger for the signal since it is produced more centrally.
To avoid any residual $t\bar{t}$ background we used a cut on Z-mass by requiring $m_{l^+l^-} = m_Z \pm 3\sigma_Z$ with $\sigma_Z = 3$ GeV. No lepton isolation cuts are applied since there is no significant background whose reduction depends on isolation once the m_Z cut has been implemented. To account for geometrical inefficiencies within the fiducial volume, a reconstruction efficiency per lepton of 0.95 is assumed for both electrons and muons. This should be achievable in this channel by inclusion of the tracker measurements [11] in case of missing calorimetric information for electrons, and of MIP-signature in calorimeters if muon chambers identification information were missing for muons, in cases where the l^+l^- mass falls within a Z mass window.

Table I gives the expected number of $H \to ZZ$ signal and ZZ continuum background events after taking into account radiation and instrumental effects, in a window $m_{\rm H} \pm 2\sigma_{m_{\rm H}}$ where $\sigma_{m_{\rm H}} = \Gamma_{\rm H}/2.35$ and $\Gamma_{\rm H}$ is the Higgs total width [12]. This procedure is valid so far as the observed Higgs signal width is larger than the expected 4 lepton effective mass resolution for a zero width Higgs signal, *i.e.* so far as the Higgs natural width dominates the expected signal width observed. This is indeed case for $m_{\rm H} \geq 250$ GeV (for $m_{\rm H} \leq 200$ GeV the instrumental resolution dominates the observable width).

TABLE I

Expected number of signal and background events for 10^5 pb^{-1}

$m_{\rm H}$ [GeV]	300	500	700
$N_{\rm S}$	217	104	31
$N_{\rm B}$	94	60	39

Leptons coming from signal and background Z's should however differ in their angular distribution [7, 13] due to the difference in the polarization of gauge bosons. Z's coming from Higgs bosons are mostly longitudinally polarized, whilst those in the ZZ continuum are mostly transversal. The difference becomes more pronounced with increasing Higgs mass since it is proportional to $m_{\rm H}^2/m_Z^2$. The decay angular distributions of longitudinal and transverse Z's are

$$\Phi_{\rm L} = \tfrac{3}{2}(1 - \cos^2\vartheta) \qquad \text{and} \qquad \Phi_{\rm T} = \tfrac{3}{4}(1 + \cos^2\vartheta)\,, \tag{1}$$

where ϑ and $\pi - \vartheta$ are decay angles of fermions in the Z-rest frame [14] relative to the Z line-of-flight (helicity angle).

If a fraction $f_{\rm L}$ of Z's are longitudinally polarized the angular distribution is then

$$\Phi = f_{\rm L}\Phi_{\rm L} + (1 - f_{\rm L})\Phi_{\rm T}, \tag{2}$$

which gives [3]:

$$f_{\rm L} = 2 - 5\langle z^2\rangle\,, \tag{3}$$

where $z = \cos\vartheta$ and $\langle\ldots\rangle$ means the average value of the observed angular distribution.

Fig. 1 gives a sketch of $H \to ZZ \to 4l^{\pm}$ decay in the Z-rest frame, and Fig. 2 shows the angular distribution of leptons for the signal ($m_{\rm H} = 500$) and background, including effects of acceptance cuts. The effect of the finite rapidity coverage of the detector is clearly visible in Fig. 2 for the background as the definite lack of events closest to the beam direction.

To illustrate the method we plot in Fig. 3 the value of $f_{\rm L}$ determined using Eq. (3) as a function of m_{ZZ} mass with a bin size of 50 GeV for signals of $m_{\rm H} = 300$ GeV and $m_{\rm H} = 500$ GeV superimposed on the background for a sample corresponding to an integrated luminosity of 10^5 pb^{-1}. The enhancement in the variable $f_{\rm L}$ of the Higgs signal over the background is

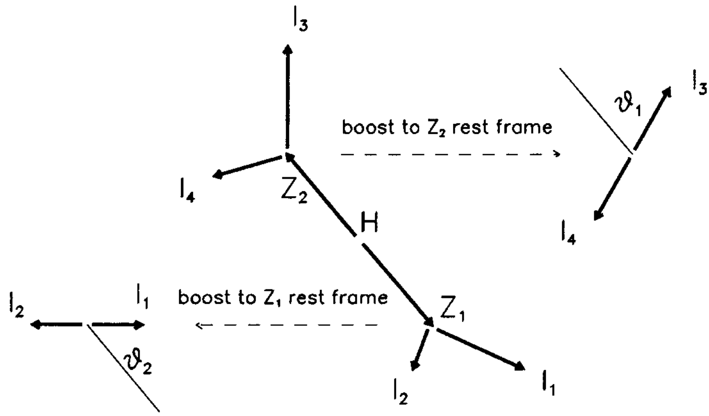

Fig. 1. An illustration of $H \to ZZ \to 4l^{\pm}$ decay

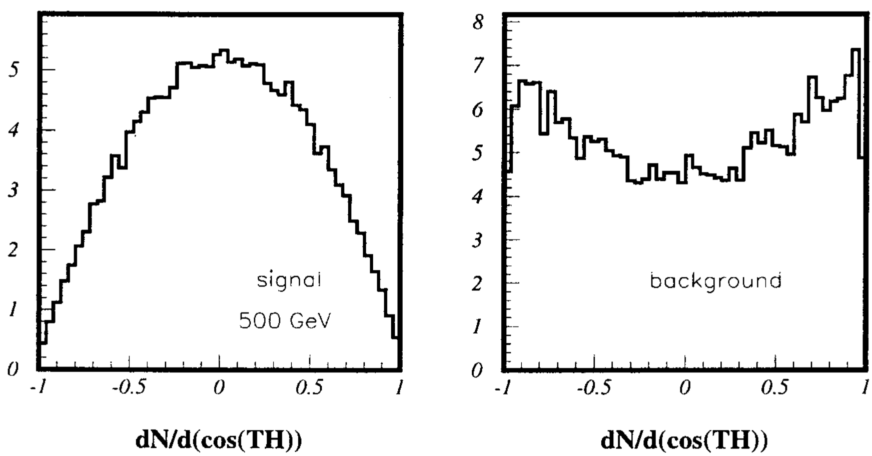

Fig. 2. The Z decay helicity angular distribution of leptons for the signal ($m_{\rm H}$ = 500 GeV) and background.

obvious. It is precisely the difference in the values of $f_{{\rm L}_{({\rm S+B})}}$ and $f_{{\rm L}_{({\rm B})}}$ that heralds the presence of Higgs bosons.

Fig. 4 shows the values of $f_{\rm L}$ for $m_{\rm H}$ = 300 GeV with the inclusion of the variance σ calculated according to

$$\sigma^2 = (\frac{\partial f_l}{\partial z_{\rm S}})^2 {\sigma_{\rm S}}^2 + (\frac{\partial f_l}{\partial z_{\rm B}})^2 {\sigma_{\rm B}}^2 , \tag{4}$$

where index S means signal and B means background.

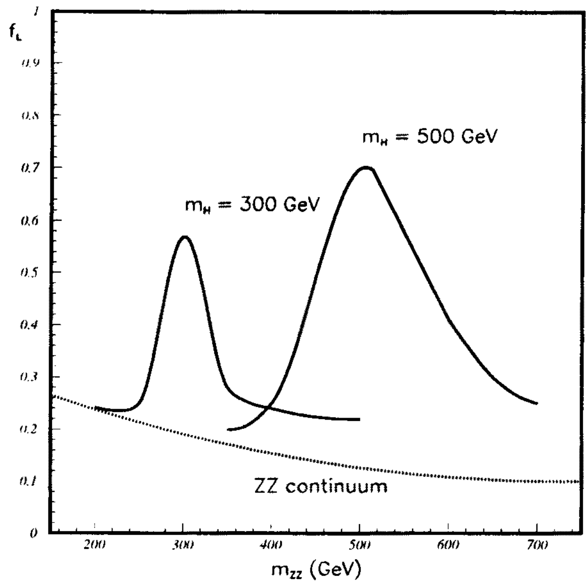

Fig. 3. The values of f_L for the signal and background for $m_H = 300$ and 500 GeV.

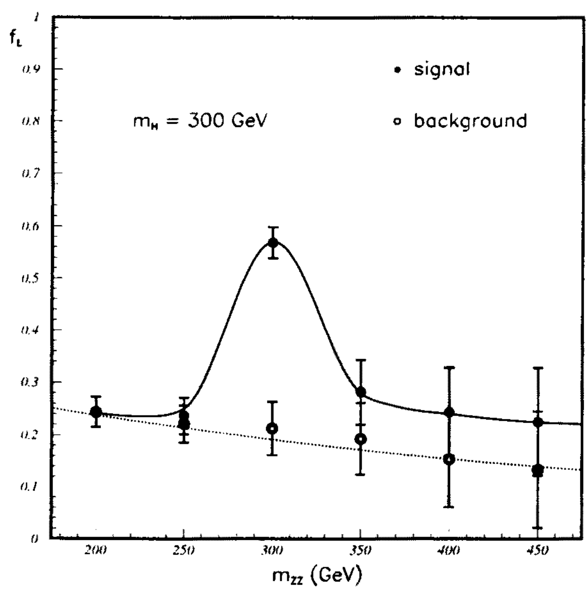

Fig. 4. The value of f_L for the signal and background with the inclusion of statistical deviations.

To be considered as different at the 2σ level those values have to satisfy:

$$f_{L_{(S+B)}} - f_{L_{(B)}} \geq \frac{\sigma_{f_{(S+B)}} + \sigma_{f_{(B)}}}{\sqrt{2}} . \tag{5}$$

Final results of our simulation are presented in the Table II. As a comparison of lines (5) and (6) shows, the differences in the values of f_L are indeed statistically significant indicating the presence of Higgs bosons through the helicity state of the decaying Z's and independent of any evidence from the ZZ effective mass distribution.

TABLE II

f_L values for the signal and background and their statistical deviations for 10^5 pb^{-1}.

	m_H [GeV]	300	500	700
1.	$f_{L_{(S+B)}}$	0.65	0.63	0.52
2.	$f_{L_{(B)}}$	0.22	0.10	0.16
3.	$\sigma_{f_{(S+B)}}$	0.04	0.05	0.08
4.	$\sigma_{f_{(B)}}$	0.08	0.10	0.12
5.	1. - 2.	0.43	0.53	0.36
6.	$(3. + 4.)/\sqrt{2}$	0.08	0.11	0.14

4. Conclusions

We have shown that it should be possible to detect the presence of Higgs bosons using the polarization state of Z's in the $H \to ZZ \to 4l^{\pm}$ channel. Since this method is independent of the one using the invariant $4l^{\pm}$ mass as evidence for Higgs bosons [11], it can be used to supplement the results. It will be very helpful in the first, lower luminosity stage of the LHC experiments where the initial evidence for Higgs may be marginal from a mass plot alone but this additional independent angular information may make the discovery conclusive. At large statistics such angular distribution studies will be needed to confirm the nature of an observed prominent signal. Also, they will help the search for evidence of a Higgs at the upper mass reach ($m_H \approx 0.7$–0.8 TeV [1]) where one always runs out of statistics.

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