Strong Electroweak Symmetry Breaking Signals in WW Scattering at Tesla

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Abstract. A realistic study of the sensitivity to signals of strong electroweak symmetry breaking at Tesla energies using $ee \rightarrow WW\nu\nu$ and $ee \rightarrow ZZ\nu\nu$ processes is presented. Limits on α_4 and α_5, parameters of the electroweak chiral lagrangian, are given and discussed.

INTRODUCTION

The most outstanding problem in modern particle physics is how Nature realizes the breaking of the SU(2)xU(1) gauge symmetry. In the absence of a light scalar field, new physics coupled to the Standard Model (SM) is needed at the TeV scale to restore unitarity [1]. In particular a larger symmetry should exist, breaking down to SU(2)xU(1) and introducing the Goldstone bosons needed to give longitudinal components to W and Z, hence masses. High energy boson scattering, decoupling transversal and longitudinal components, brings therefore information on the underlying dynamics of the new symmetry.
WW scattering can be effectively described by the so-called chiral lagrangian approach [2], containining effective operators of increasing dimensions. Besides the gauge interactions, the theory has only two 4-D interaction terms which can describe two boson scattering; these terms depend upon two anomalous couplings, known in the literature as α_4 and α_5. These couplings are model dependent and are both zero in the frame of the SM. In what follows a study about the limits which can be set on α_4, α_5 at Tesla by studying $ee \rightarrow WW\nu\nu \rightarrow q\bar{q}q\bar{q}\nu\nu$ and $ee \rightarrow ZZ\nu\nu \rightarrow q\bar{q}q\bar{q}\nu\nu$ processes, is presented. A centre of mass energy of 800 GeV and a total luminosity of 1000 fb^{-1} is assumed.

ANALYSIS SETUP

Six fermion processes under study correspond to the longitudinal scattering of W bosons, namely the $ee \rightarrow W_l W_l \nu\nu$ and $ee \rightarrow Z_l Z_l \nu\nu$ processes. Only final states

TABLE 1. Predicted cross-sections of signal and background processes and programs used for the generation.

	Channel	$\sigma_{800\ GeV}$(fb)	Generator
6-f	$e^+e^- \to W^+W^-\nu\nu \to q\bar{q}q\bar{q}\nu\nu$	4.2	WHiZard [6]
	$e^+e^- \to ZZ\nu\nu \to q\bar{q}q\bar{q}\nu\nu$	1.6	WHiZard
	$e^+e^- \to q\bar{q}q\bar{q}\nu\nu$ (non res.)	1.5	WHiZard
	$e^+e^- \to WZe\nu \to q\bar{q}q\bar{q}e\nu$	22.0	WHiZard
	$e^+e^- \to e^+e^-W^+W^- \to q\bar{q}q\bar{q}e^+e^-$	286.0	WHiZard
	$e^+e^- \to e^+e^-ZZ \to q\bar{q}q\bar{q}e^+e^-$	0.9	WHiZard
	$e^+e^- \to t\bar{t} \to X$	342.	PYTHIA [3]
4-f	$e^+e^- \to W^+W^- \to q\bar{q}q\bar{q}$	2300.	PYTHIA
	$e^+e^- \to ZZ \to q\bar{q}q\bar{q}$	168.	PYTHIA
2-f	$e^+e^- \to q\bar{q}$	5100.	PYTHIA

with four quarks are considered here. As the longitudinal scattering component is physically undistinguishable from the transversal one, the selection efficiencies are defined by appropriate cuts [1] in the double resonant region of the six fermion processes $ee \to q\bar{q}q\bar{q}\nu\nu$. The signal is affected by six, four and two-fermion backgrounds. In table 1 the cross-sections at $\sqrt{s} = 800$ GeV of the relevant processes is reported, together with the code used for generating the different samples. The hadronisation is realised by using JETSET [3].
The detector simulation is done with SIMDET v3.1 [4] in its default setup, with the choice of CCD at 2 cm from the interaction point as tracking device and an instrumented mask with a LAT acceptance from 23.5 to 83.1 mrad [5].

$ZZ\nu\nu$ SELECTION

The tracks reconstructed in the detector are forced into four jets using the Durham algorithm [7]. The $ZZ\nu\nu$ hypothesis is tested via a kinematic fit to the jet 4-vectors, forcing two jet pairs to have the same mass (1C fit). The jet pairing is chosen out of the 3 possible combinations using a likelihood discriminant whose inputs are the difference between the two reconstructed di-jet masses, the 1C-fitted mass, and the χ^2 probability of the fit.
A first series of preselection cuts, intended to remove $q\bar{q}$, $t\bar{t}$, and 4-fermion backgrounds, is applied. Then, to separate the double resonant $ZZ\nu\nu$ signal from the 6-fermion background ($WZe\nu$, $WW\nu\nu$, and other non resonant diagrams), a likelihood discriminant is used as selection variable. The following cuts are applied as preselection: 200< E_{mis} <650 GeV, $|\cos(\theta_{P_{mis}})|$ <0.99 against four-fermion backgrounds with forward missing momentum, and $|\cos(P_{E_{max}})|$ <0.99 and the requirement of at least two charged tracks per jet to remove backgrounds with leptons in

[1] 75 GeV$\leq m_W^1, m_W^2 \leq$ 85 GeV for $WW\nu\nu$,
170 GeV $\leq m_Z^1 + m_Z^2 \leq$ 195 GeV and $|m_Z^1 + m_Z^2| \leq$ 20 GeV for $ZZ\nu\nu$

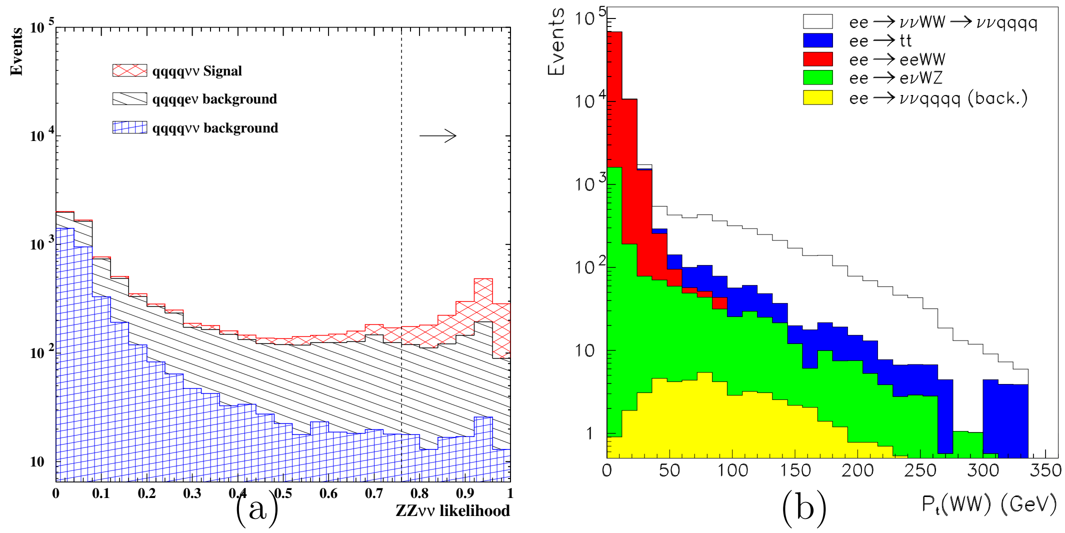


FIGURE 1. Likelihood for $ZZ\nu\nu$ selection (a) and p_T^{WW} distribution for $WW\nu\nu$ selection (b). Signal and backgrounds are shown. The histograms are normalised to a total integrated luminosity of 1000 fb^{-1}.

the final state. Here P_{Emax} indicates the momentum of the most energetic track in the event, and E_{mis}, P_{mis} are the event missing energy and momentum. In order to further reduce the $t\bar{t} \to b\bar{b}q\bar{q}l\nu$ background, the event is then rejected if one of the four most energetic charged tracks is isolated (less then 2 GeV in a 10 degrees cone). The likelihood discriminant is then calculated from the following input variables:

$$\begin{array}{cc} E_{mis} & |cos(P_{E_{max}})| \\ |cos(\theta_{P_{mis}}| & \text{1C fitted mass} \\ E_{max} & \text{Jet pairing likelihood} \end{array}$$

The distribution of the likelihood discriminant is shown in fig 1.(a) for signal and background events. The events with likelihood greater then 0.76 are selected. The results of the selection in terms of efficiency, purity, and expected number of events for an integrated luminosity of 1000 fb^{-1} at $\sqrt{s}$=800 GeV are shown in table 2.

$WW\nu\nu$ SELECTION

To select fully hadronic decays only events with four or five jets, reconstructed with the LUCLUS algorithm [3] with d_{join} parameter set to 7 GeV, are selected. Each event is then forced into four jets and the jet pairing is chosen in such a way that the product $|m_{ij} - m_W||m_{kl} - m_W|$ is minimum, where m_{ij} and m_{kl} are the jet-jet invariant masses resulting from the pairing. The minimum value is required to be greater than 50 GeV^2 anyway, and a further cut requires both the reconstructed mass to be above 60 GeV and below 100 GeV.

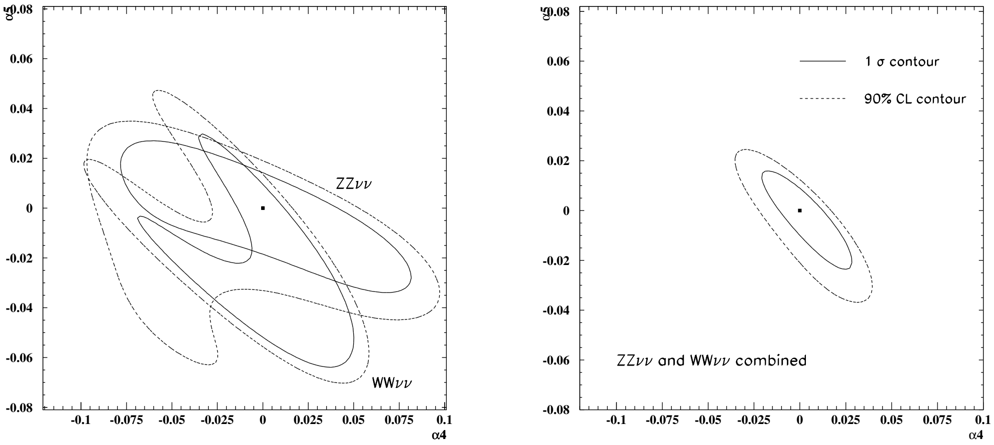
TABLE 2. $ZZ\nu\nu$ and $WW\nu\nu$ selection performance in terms of number of expected events, efficiencies and relative errors on the measured cross-sections.

Channel	Events($ZZ\nu\nu$)	Events($WW\nu\nu$)
$e^+e^- \to ZZ\nu\nu \to q\bar{q}q\bar{q}\nu\nu$	844±10	
$e^+e^- \to W^+W^-\nu\nu \to q\bar{q}q\bar{q}\nu\nu$		2550±20
$e^+e^- \to q\bar{q}q\bar{q}\nu\nu$ (non res.)	88±5	151±5
$e^+e^- \to WZe\nu \to q\bar{q}q\bar{q}e\nu$	570±20	350±10
$e^+e^- \to e^+e^-W^+W^-, e^+e^-ZZ \to q\bar{q}q\bar{q}e^+e^-$	negl.	130±20
$e^+e^- \to W^+W^-, ZZ \to q\bar{q}q\bar{q}$	23±10	negl.
$e^+e^- \to t\bar{t} \to X$	83±5	400±70
$e^+e^- \to q\bar{q} \to X$	negl.	negl.
efficiency	0.522±0.006	0.401±0.004
$\Delta\sigma/\sigma$	3.2%	2.0%

To suppress two and four-fermion contamination and irreducible background coming from ZWW events, with the Z decaying invisibly, the transverse energy in the event, E_{trans}, is required to be in the interval [150 GeV,600 GeV] and the recoil mass, defined as $\sqrt{E^2_{miss} - p^2_{miss}}$, where E_{miss} and p_{miss} are the missing energy and momentum of the event, to be above 200 GeV. The number of charged tracks per jet is required to exceed 2 unities: this reduces backgrounds leading to leptonic final state, in particular $t\bar{t}$. $t\bar{t}$ background is also very much suppressed by the rejection of those events with more than 1 tagged b-jet, where the b-tag parametrisation as a function of the jet energy in [8] has been used and the working point with $\epsilon_{b-tag} = 80\%$ chosen. This cut is also effective for $ZZ\nu\nu$ and $WZe\nu$.
The remaining background comes mainly from six-fermion final states, especially the high cross-section ones like $WWee$ and $WZe\nu$. Having these processes a large missing momentum in the forward direction due to electron lost in the beam pipe, a cut on the transverse momentum of the WW system is applied: $p_T^{WW} > 40$ GeV. This cut is very effective because of the excellent hermeticity and forward coverage of the Tesla layout. Figure 1.(b) shows the expected p_T^{WW} distribution (before cutting on it) for signal and backgrounds, having assumed a luminosity of 1000 fb^{-1}. Table 2 shows the performance of the analysis in terms of expected number of events, efficiency and remaining backgrounds.

RESULTS AND CONCLUSIONS

Signatures of WW strong interactions are given by variations in the event rate and in the average polarization of the final state bosons with respect to the SM expectations. The sensitivity to the anomalous couplings α_4, α_5 is determined by using the total cross section and the distributions of $|\cos(\theta_{W,Z})|$ and $|\cos(\theta^*_q)|$, where $\theta_{W,Z}$ is the reconstructed boson polar angle and θ^*_q is the polar angle of the decay



(a) (b)

FIGURE 2. Expected limit contours on α_4, α_5 for the two analyses (a) and combined limits (b). 1 σ and 90% CL contours are shown.

products in the reference frame of each boson. [2] The sensitivity is evaluated through a bi-dimensional Binned Maximum Likelihood fit to the expected distributions from a 1000 fb^{-1} SM sample with $\alpha_4 = \alpha_5 = 0$. Figure 2.(a) shows the 1-σ (continuous line) and 90% (dotted line) CL contours obtained by each of the two analysis, whereas figure 2.(b) shows the CL contours obtained from the combination of the two analyses.

The expected Tesla limits on the anomalous couplings at 90% CL are therefore of the order of 10^{-2}. These numbers can be considerably improved when considering other decay channels, like the leptonic ones, or taking into account the enhancement of the signal cross-section and the signal/background ratio coming from the beam polarisations.

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