Resonances in $e^+e^- \to \nu\bar{\nu}WW$ scattering at CLIC

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The formation of resonances in WW scattering at a 3 TeV linear e^+e^- collider is studied. The detector response of events is simulated with hadronic $\gamma\gamma$ backgrounds included.

1. Introduction

If no Higgs boson with large gauge boson couplings and a mass less than 700 GeV is found at the LHC and TeV class e^+e^- colliders, then the $W^\pm, Z$ bosons are expected to develop strong interactions at scales of order 1-2 TeV. Generally one expects an excess of events above Standard Model expectation, and the possibility of resonance formation in WW scattering. The potential of the measurements of the W^+W^- mass spectrum at a possible future multi-TeV linear e^+e^- collider CLIC is discussed. CLIC is assumed to have a centre of mass energy of 3 TeV, and to collect 1000 fb^{-1}/year[1].

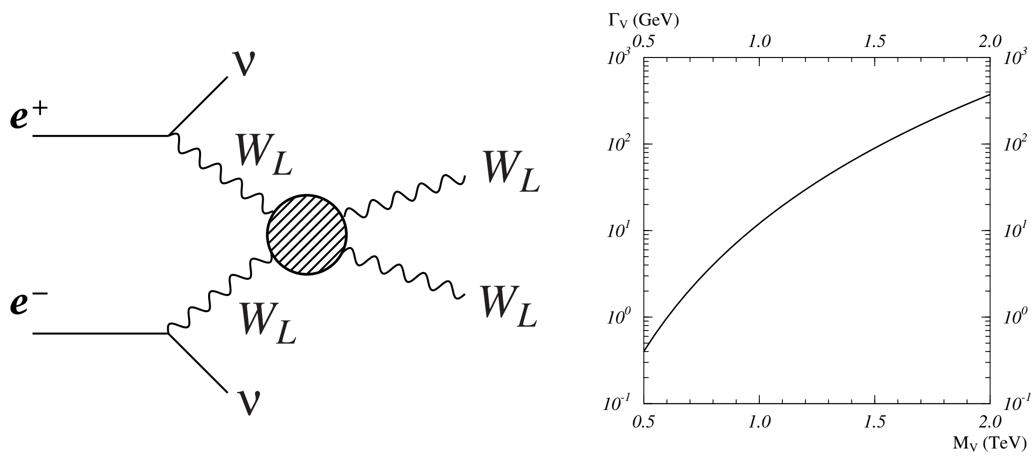

Figure 1: (Left) Diagram for $e^+e^- \to \nu\bar{\nu}W_L^+W_L^-$ scattering. (Right) Width versus mass of the vector resonance; the region below the curve is allowed by precision measurements at the Z^0 [3].

2. Theoretical Framework

The potential to measure the reaction $e^+e^- \to \nu\bar{\nu}W_L^+W_L^-$ at CLIC is evaluated. The basic diagram is shown in Fig. 1a. Two approaches have been used to simulate this process. The Chirally-Coupled Vector Model [2] for W_LW_L scattering describes the low-energy behaviour of a technicolor-type model with a Techni-ρ vector resonance V(spin-1, isospin-1 vector resonance). The mass of the resonance can be chosen and the cases $M \sim 1.5, 2.0$ and 2.5 TeV have been studied. The maximum allowed width depends on the mass and is constrained by precise measurements of

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the Z resonance parameters, as shown in Fig. 1b [3]. Cross section formulae given in [2] have been used to predict the expected event rate in this model (see Table I). To study the signal the PYTHIA process 124 ($ee \rightarrow \nu\nu H$) was modified to stimulate the WW cross section with $H \rightarrow WW$ and $W \rightarrow qq$.

In a second approach, the prescription given in [4, 5] using the Electro-Weak Chiral Langrangian (EHChL) Formalism is applied. The Higgs terms in the SM Langrangian are replaced by terms in the next order of the Chiral expansion: $\mathcal{L} = \mathcal{L}^{(2)} + \alpha_4(< D_\mu U D^\nu U^\dagger >)^2 + \alpha_5(< D_\mu U D^\mu U^\dagger >)^2$. Unitarity corrections are important for energies larger than 1 TeV. Here the Pade (Inverse Amplitude) protocol has been used. The parameters α_4 and α_5 quantify our ignorance of the new physics. For certain combinations of α_4, α_5 high mass vector resonances will be produced in WW and WZ scattering. The general EWChL has been implemented in PYTHIA via the process 71 $\rightarrow$ 77 [5].

Fig. 4a shows the mass spectra for ZZ, WW and WZ scattering, for a choice of the parameters $\alpha_5 = -0.002, \alpha_4 = 0.0$, which yield a broad resonance around 2 TeV in the $WW \rightarrow ZZ$ and $ZW \rightarrow ZW$ channel. This choice will be used throughout this paper.

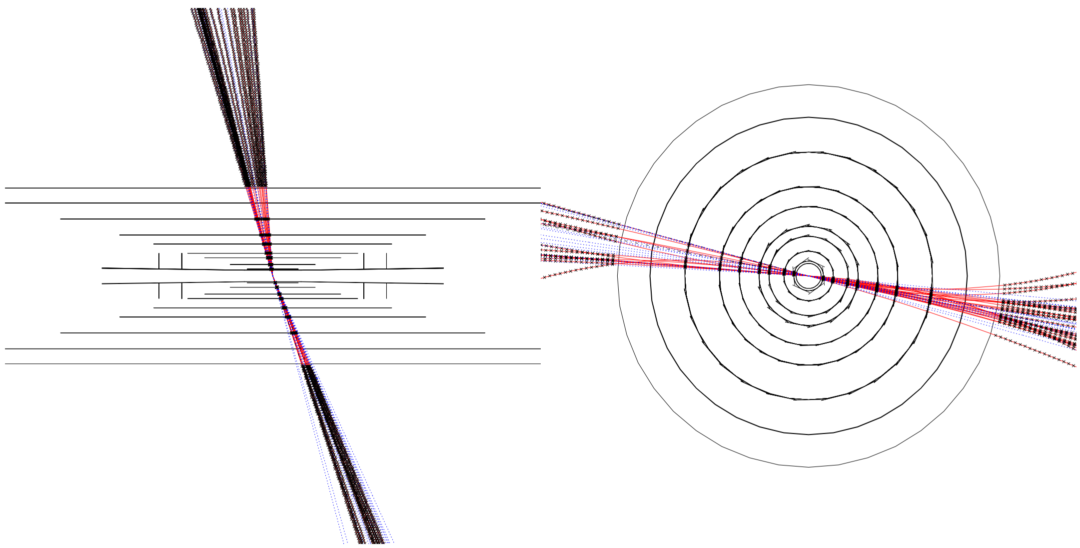

Figure 2: Two views of an event in the central detector of the type $e^+e^- \rightarrow \nu\bar{\nu}WW \rightarrow \nu\bar{\nu}$ 4 jets. from a resonance with M_W = 2 TeV.

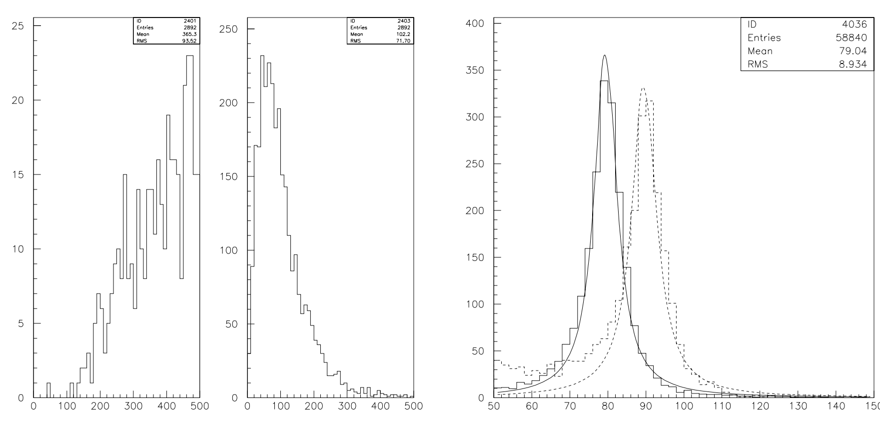

Figure 3: (Left) Transverse momentum of the W and WW system. (Right) Reconstructed mass spectrum for W (full line) and Z (dashed line).

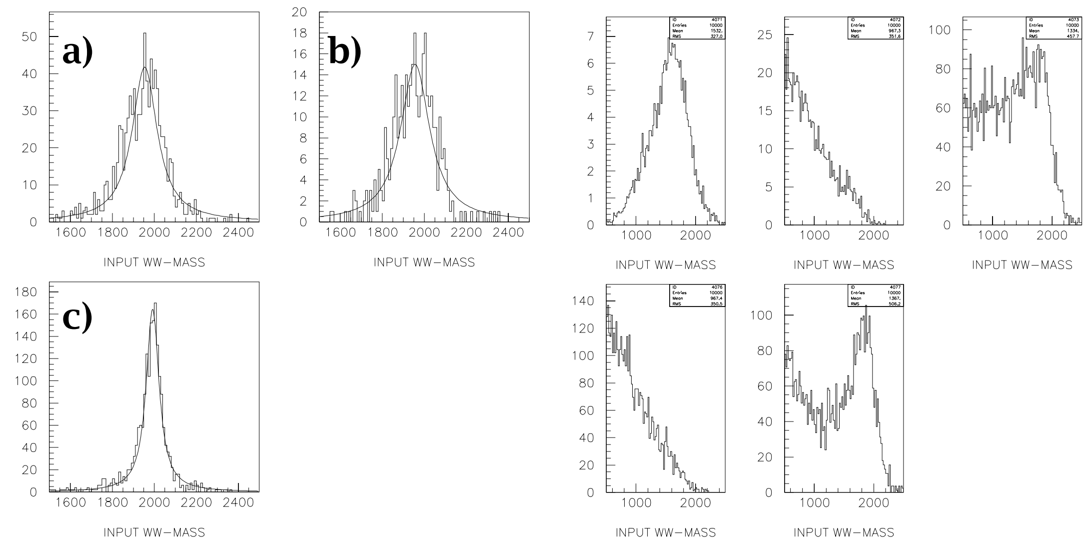

Figure 4: (Left) Background study a) no background included b) including $\gamma\gamma$ background, c) generator reference ($M_W = 2$ TeV, $\Gamma = 85$ GeV); (Right) Mass distribution for $ZZ \to ZZ, ZZ \to WW, ZW \to ZW, WW \to ZZ$ and $WW \to WW$ (events/500 fb^{-1}/20 GeV)

3. Tools

For this study the CLIC Physics study group analysis tools have been used. The CLIC lumi spectrum is generated with CALYPSO [6]. The hadronic background from $\gamma\gamma$ events is generated with HADES [6]. Per bunch crossing one expects on average four $\gamma\gamma$ interactions with $W > 5$ GeV. The SIMDET-CLIC fast simulation package is used, based on the package for the TESLA Detector [7]. The adapted VECSUB package for jet reconstruction is used (Durham, JADE algorithms)[8].

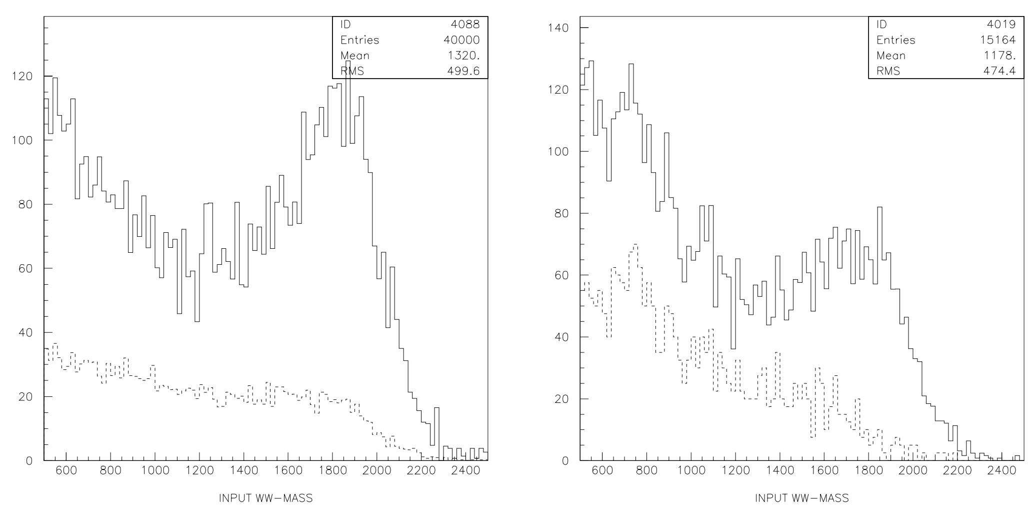

Figure 5: Mass spectrum for WW scattering and WZ and ZZ scattering backgrounds for $\alpha_5 = -0.002$, $\alpha_0 = 0.0$, before detector (left) and after detector smearing and addition of $\gamma\gamma$ background (right).

$\sqrt{s}$ 3 TeV	M=1.5 TeV Γ = 35 GeV	M=2.0 TeV Γ = 85 GeV	M=2.5 TeV Γ = 250 GeV
σ fb	4.5	4.3	4.0

Table I Cross sections for vector resonances in WW scattering, with cuts as given in the text

4. Selection and Results

The total cross section for $WW \to WW$ scattering with the values $\alpha_4 = 0.0$ and $\alpha_5 = -0.002$, amounts to 12 fb^{-1} in e^+e^- collisions at 3 TeV, and is measurable at a high luminosity LC.

Events are selected according to cuts, as suggested in [2], and verified for CLIC, when including the background and luminosity spectrum smearing (Fig 3: $p_T^W > 150$ GeV, $|cos\Theta^W| < 0.8; M_W >$ 500 GeV; $p_T^{WW} < 300$ GeV; and ($200 < M_{rec} < 1500$ GeV), with M_{rec} the recoil mass. Cross sections calculated including these cuts with the program of [2] for choices of several masses and widths are given in Table I. Without these cuts the cross sections are approximately two times larger.

The big advantage of an e^+e^- collider is the clean final state, which allows to use the hadronic decay modes of the $W's$ to select and reconstruct events. In total four jets are produced in the decay of the two $W's$. Due to the boost from the decay of the heavy resonance, the two jets of a W are very collimated, and close to each other as shown in Fig. 2 for a typical event. The Durham jet algorithm has been applied to find the jets, using the smeared tracks and jets from the SIMDET program (y_{min} was varied between 0.01 and 0.0005 to test the reconstruction of two and four jets). The simulation in SIMDET of the tracker is however likely to be optimistic and still needs further tuning.

With the given assumptions in SIMDET, the resolution to reconstruct the W, Z mass is about 7% (Fig. 3). Events have been selected which have both reconstructed bosons in the mass range $70 < M_W < 85$ GeV. The efficiency is about 80% and the contamination of WW events by WZ an ZZ events is 25% and 3% respectively.

The events are still well reconstructed when $\gamma\gamma$ backgrounds are overlaid (so far only one bunch crossing), The detector smears the resonance parameters as follows: starting from a generated resonance with $M_W = 2$ TeV and $\Gamma = 85$ GeV, the reconstructed resonance has $M_W = 1.96(1.95)$ TeV and $\Gamma = 135(160)$ GeV for the case without (with) $\gamma\gamma$ background overlap, see Fig. 4. Reducing the track efficiency from 99% to 80% gives $M_W = 1.95$ TeV and $\Gamma = 160$ GeV, without background.

The mass spectra for channels $ZZ \to ZZ, ZZ \to WW, ZW \to ZW, WW \to ZZ$ and $WW \to WW$ is shown in Fig. 4. A full spectrum which contains contributions from all the channels according to their efficiency or misidentification probabilities is shown for 1600 fb^{-1} in Fig. 5, before and after detector smearing with parameters $\alpha_5 = -0.002, \alpha_0 = 0.0$. Clearly heavy resonances in WW scattering can be detected at CLIC.

5. summary

Heavy resonances in WW scattering can be detected directly at CLIC. The resonance signal is not heavily distorted by detector resolution and background. Depending on the mass and width of the signal about a 1000 events/year could be detected in the 4-jet mode at CLIC, and fully reconstructed. Good energy and track reconstruction is important to remove backgrounds and reconstruct the resonance (and hence the underlying model) parameters accurately. Several SM model background contributions still need to be evaluated, but are not expected to give major distortions due to the simple and exclusive final state. In all, this channel is a good benchmark for detector optimization studies at CLIC.

Acknowledgments

I am grateful to B. Cox, J. Forshaw and T. Han for their kind help and the use of their programs to calculate the cross sections.

References

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