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VECTOR RESONANCES FROM STRONG ELECTROWEAK SYMMETRY BREAKING AT E^+E^- COLLIDERS

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We study signatures of new vector resonances from strong electroweak symmetry breaking sector in $e^+e^- \to \nu\bar{\nu}t\bar{t}$ at future e^+e^- collider at 800 and 1500 GeV.

1 Introduction

The physics behind electroweak symmetry breaking remains unknown. One of possible solutions is *strongly-coupled* electroweak symmetry breaking (SEWSB). SEWSB gives rise to massless Goldstone bosons ('EW pions') which, just like QCD pions (π), are assumed to be bound states of some more fundamental strongly interacting objects (e.g. technifermions). According to Higgs mechanism, EW pions become (longitudinal) W and Z bosons ($W_L, Z_L \equiv V_L$). Since $V_LV_L \to V_LV_L$ amplitudes violate unitarity at 1-3 TeV range, we expect new SEWSB resonances to appear around this energy scale (just as ρ^{QCD} and ω^{QCD} unitarize $\pi\pi \to \pi\pi$ amplitudes at few hundred MeV). A lot of work has concentrated on the production and signatures of new scalar (S) and vector (ρ) resonances in $V_LV_L \to V_LV_L$ scattering at future e^+e^- colliders (LC) (see Fig. 1a) and LHC [1].

In this work we study signatures of new ρ (I=J=1) resonances from SEWSB in the related process $V_LV_L \to t\bar{t}$ at LC (see Fig. 1b). The main appeal of this process lies in the possibility to test whether the large top quark mass is generated by the new SEWSB interactions, or if some other new mechanism is needed [1,2]. The previous studies of this process concentrated mostly on the Standard model [3].

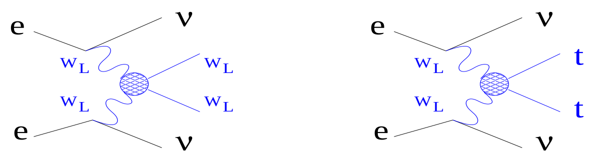

Figure 1. W_LW_L fusion at LC: a) $e^+e^- \to \nu\bar{\nu}W^+W^-$ (left), b) $e^+e^- \to \nu\bar{\nu}t\bar{t}$ (right).ρ and S resonances contribute to the blob.

2 ρ resonance model

We consider both 'natural' Lagrangian and chiral effective Lagrangian. The natural Lagrangian (Eq. 1) describes general couplings of a neutral vector resonance (ρ^0) with charged scalar particles - π's (to which are W_L's effectively reduced at $E \gg M_W$) and top antitop pair.

$$\mathcal{L} = +ig_\pi \frac{M_\rho}{v}\left(\pi^- \partial^\mu \pi^+ - \pi^+ \partial^\mu \pi^-\right)\rho^0_\mu + g_V \bar{t}\gamma^\mu t\ \rho^0_\mu + g_A \bar{t}\gamma^\mu\gamma^5 t\ \rho^0_\mu; \qquad (1)$$

The chiral effective $\mathcal{L}$ (based on $SU(2)_L \times SU(2)_R$ global and $SU(2)_L \times U(1)_Y$ local,) is an example of more specific and at the same time still quite general ρ resonance model. We discuss this model in detail in Ref. [4], here we show just few relevant terms with four parameters a, g'', b_1, b_2:

$$\mathcal{L} = -v^2 \mathrm{Tr}[\mathcal{A}_\mu \mathcal{A}^\mu] - a\frac{v^2}{4}\mathrm{Tr}[(\omega_\mu + ig''\ \vec{\rho}_\mu.\vec{\tau}/2)^2] + b_1 I^b_L + b_2 I^b_R + ... \qquad (2)$$

Assuming $g_V = g_A$ ($b_1 = 0$) the two sets of parameters (Eqs. 1,2) are related via $g_\pi = M_\rho/(2\ v\ g'')$, $g_V \doteq g'' b_2/[4(1+b_2)]$, $M_\rho \doteq \sqrt{a}\ v\ g''/2$. We can place both unitarity and low energy constraints on these parameters. Unitarity constraints come from the study of amplitudes for $W_L W_L \to W_L W_L$, $W_L W_L \to t\bar{t}$ and $t\bar{t} \to t\bar{t}$ with ρ present - they indicate the parameter value at which one of the amplitudes starts to violate tree level (perturbative) unitarity (in a sense similar to Higgs violating the tree level unitarity for $M_H > 1$ TeV):

$$g_\pi \leq 1.5, \quad g_V \leq 2.0 \quad (M_\rho = 1\ \mathrm{TeV}) \qquad (3)$$

Low energy constraints come from modifications of Ztt, Zbb, Wtb SM couplings by ρ model at LEP energies when much heavier ρ is integrated-out of the particle spectrum. Our analysis of experimental limits on ϵ parameters yields [4]:

$$g'' \gtrsim 10 \quad |b_2| \lesssim 0.08 \qquad (4)$$

3 Signal ($e^+e^- \to \nu\bar{\nu}t\bar{t}$) and background ($e^+e^- \to t\bar{t}\gamma,\ e^+e^- t\bar{t}$) calculations

We calculated the cross section for the signal in two independent ways. In the first approach we selected from the complete tree level set of Feynman diagrams the subset of fusion diagrams (see Fig. 1b), employed the effective W (EWA) and the equivalence theorem (ET) approximations and implemented resulting amplitudes in Pythia [5]. In the second approach we implemented the chiral Lagrangian into CompHEP [6] and calculated the full set of 66 tree level diagrams without any approximation. The results agreed with Pythia to a level better than 10 % at 1500 GeV.

As an example of CompHEP calculations we give in Eq. 5 the total cross section for a ρ with the mass $M = 700$ GeV and the width $\Gamma = 12.5$ GeV ($g'' = 20, b_2 = 0.08$) at 800 GeV and 1500 GeV before and after cuts (see below).

$$\begin{aligned} \sigma(\sqrt{s} = 0.8\ \mathrm{TeV}) &= 0.66\ \mathrm{fb\ (no\ cuts)} \;\to\; 0.21\ \mathrm{fb\ (cuts)} \\ \sigma(\sqrt{s} = 1.5\ \mathrm{TeV}) &= 3.33\ \mathrm{fb\ (no\ cuts)} \;\to\; 0.86\ \mathrm{fb\ (cuts)} \end{aligned} \qquad (5)$$

We also show the differential cross section as a function of invariant mass of $t\bar{t}$ pair for this particular ρ at 1500 GeV in Fig. 2. For comparison, differential cross sections for ρ with M = 1000 GeV ($\Gamma = 10.1$ GeV, $g'' = 10, b_2 = 0.08$), SM Higgs boson with M = 700 GeV and the no resonance case (when no resonance is present in the spectrum) are also included.

Two most important background processes are $e^+e^- \to t\bar{t}\gamma$ and $e^+e^- \to e^+e^-t\bar{t}$. We simulated the two processes with Pythia and found that after we impose the cuts at $\sqrt{s} = 1500$ GeV ($m_{tt} > 500$ GeV, $p_T(t\bar{t}) > 30$ GeV, $m_{\text{recoil}} > 200$ GeV, $|\cos\theta_{t,\bar{t}}| < 0.8$, $p_T(t), p_T(\bar{t}) > 50$ GeV) the total background is reduced from 104.6 fb to 0.71 fb, close to 0.86 fb for ρ signal (Eq. 5). For $\sqrt{s} = 800$ GeV, similar cuts reduce the total background from 302.2 fb to 1.76 fb.

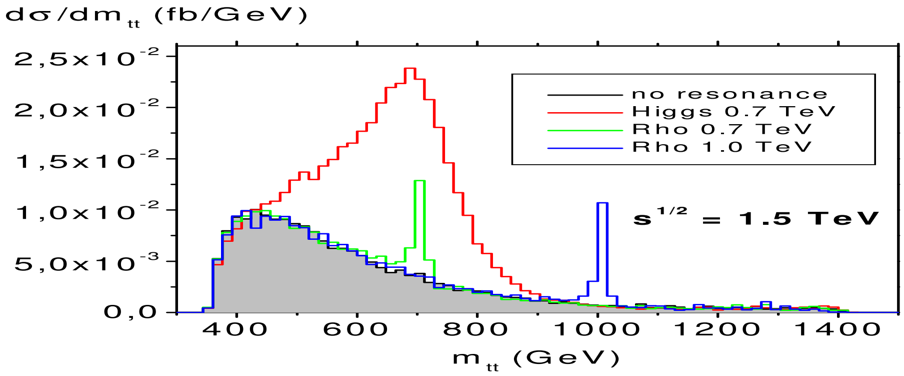

Figure 2. Differential cross section for $e^+e^- \to \nu\bar{\nu}t\bar{t}$ as a function of invariant mass of $t\bar{t}$ pair. We show two ρ resonances (M = 700 and 1000 GeV), 700 GeV SM Higgs and the no resonance case.

To see what the chances are that the observed number of events indeed corresponds to a ρ resonance rather than to the fluctuation of the no resonance case we define quantity R in terms of total event numbers N after cuts as

$$R = \frac{|N(\rho) - N(\text{no resonance})|}{\sqrt{N(\text{Background}) + N(\text{no resonance})}}. \tag{6}$$

R = 3 means that we are 3 σ away from the no resonance. For an M = 1000 GeV ($\Gamma = 10.1$ GeV) we plot R as a function of ρ-couplings g_π and g_V in Fig. 3.

4 Conclusions

We calculated $e^+e^- \to \nu\bar{\nu}t\bar{t}$ cross sections in the framework of new strong ρ-resonance model motivated by SEWSB. We also studied the two main background processes $e^+e^- \to t\bar{t}\gamma$ and $e^+e^- \to e^+e^-t\bar{t}$. Our results suggest that at $\sqrt{s} = 800$ GeV the backgrounds dominate over signal and hence $\sqrt{s} = 1500$ GeV

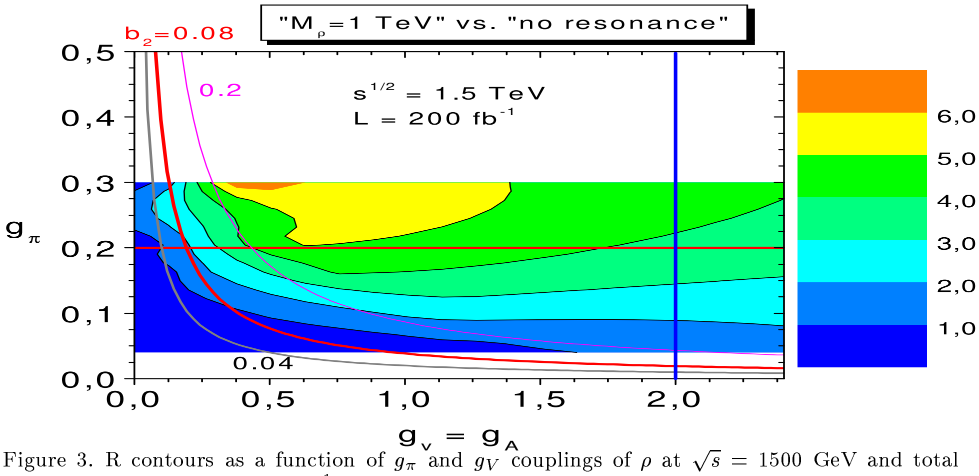

Figure 3. R contours as a function of g_π and g_V couplings of ρ at $\sqrt{s}$ = 1500 GeV and total integrated luminosity of 200 fb^{-1}. Also shown is unitarity limit (blue line) and low energy limits (red line and red hyperbola). The allowed region is in the lower left corner.

is required for ρ resonance studies. However, further cuts currently being studied could further significantly reduce the backgrounds so we should take this as preliminary conclusion. This work was supported by grant VEGA 1/0258/03.

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