The Seventh Small Triangle Meeting — Snina, September 2–4, 2005

BESS Model Resonance in the pp→ $W^+W^-t\bar{t}+X$ Channel at LHC

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Abstract

We study the possible production of the ρ-resonance from the Strong Electroweak Symmetry Breaking sector at LHC. Due to enhanced coupling of ρ to the W bosons and to the top quarks we focus on the process $pp \to W^+W^-t\bar{t}+X$.

Introduction

New vector particles with enhanced couplings to W, Z bosons and/or to the top quark are predicted by many models . Here we consider the new strong spin 1 isospin 1 resonance from the Strong Electroweak Symmetry Breaking (Strong ESB or SESB).

SESB is an alternative mechanism of ESB, different from the Standard Model (SM) and Supersymmetry in that it generates masses of elementary particles via new strongly interacting physics. A new strong vector resonance in the form of an isospin triplet ρ $(\rho^{\pm}, \rho^0)$, with mass around 1 TeV scale, is a generic prediction of the SESB models [1]. An effective description of the ρ interactions with SM particles was developed and has become known as the BESS model [2]. This model is minimal in the sense that ρ is the only new particle in the spectrum of SM where it replaces the Higgs boson.

We introduced modifications to the BESS model [3],[4] which imply that ρ could significantly couple not only to the W bosons but also to the top quark. This motivates our study of the process pp→ $\rho t\bar{t}+X \to W^+W^-t\bar{t}+X$ in this contribution. The analysis presented here consists of two steps. The first was to calculate the cross-sections and statistical significance (theoretical prediction), in the second step we included decays of the W's and the top quarks, hadronization, ATLAS detector effects and final reconstruction of events.

Lagrangian

TThe model is described by the effective chiral Lagrangian based on the gauged non-linear sigma model respecting the symmetries of the Higgs sector of SM: $SU(2)_L \times U(1)_Y$ local and $SU(2)_L \times SU(2)_R$ global [3],[4]. We will focus here on the interactions of the neutral ρ^0 with the longitudinal W (denoted as π below) and with the top quark which are relevant for $pp \to \rho t\bar{t}$. They can be described by the following simple Lagrangian to which the relevant parts of the original chiral effective Lagrangian can be reduced :

$$\begin{aligned}\mathcal{L} &= +ig_\pi \frac{M_\rho}{v}(\pi^-\partial^\mu\pi^+ - \pi^+\partial^\mu\pi^-)\rho^0_\mu \\ &\quad + g_1^t\,\bar{t}\gamma^\mu t\,\rho^0_\mu + g_2^t\,\bar{t}\gamma^\mu\gamma^5 t\,\rho^0_\mu, \end{aligned} \tag{1}$$

where the coupling constants g_π, g_1^t (we assume $g_1^t = g_2^t$) can be expressed in terms of the coupling constants of the effective chiral Lagrangian g'' and b_2 as $g_\pi = M_\rho/(2vg'')$, $g_1^t = g''b_2/4 + \mathcal{O}(g^2/g''^2)$, where v denotes the electroweak scale 246 GeV, M_ρ is the ρ mass and g is the usual $SU(2)_L$ coupling constant.

Cross-section and statistical significance calculation

The computations performed in this part were done with the CompHEP package [5] into which we had implemented our ρ model. We considered only the dominant gluon-gluon (gg) channel that was represented by 39 diagrams.

We used two approaches. In the first one the cross-sections for our process were found from the cross-sections for $pp \to \rho t\bar{t}$ (ρ on-shell), multiplied by the corresponding branching ratio for $\rho \to W^+W^-$ (branching ratio approximation – BRA). The dominant gg channel for $pp \to \rho t\bar{t}$ consisted in this case of 8 diagrams. This approach is limited to narrow ρ.

In the second approach we computed the cross-sections of $pp \to W^+W^-t\bar{t}$ directly including also the off-shell ρ contributions (full calculation approach), *i. e.* we considered all 39 diagrams. We thus were able to do the analysis also for the wide ρ case.

If one doesn't consider the 8 diagrams from the BRA approach that are sensitive to the ρ presence we are left with 31 diagrams that are much less sensitive to the new physics and thus represent the irreducible background in our studies. We evaluate this background by taking the limit $M_\rho \to \infty$, $g'' \to \infty, b_2 \to 0$ in our ρ model. We call this limit the 'No ρ model' since it effectively removes ρ from the spectrum (it is identical with the Higgsless SM).

In both approaches we imposed the following cuts on transverse momentum and rapidity of $t, \bar{t}$: $p_T(t), p_T(\bar{t}) > 100$ GeV, $|Y(t), Y(\bar{t})| < 2$. In the full calculation approach we also imposed the cut on the invariant mass of the W^+W^- pair, $M_\rho - 3\Gamma_\rho < m_{WW} < M_\rho + 3\Gamma_\rho$ where Γ_ρ is the ρ width. As an illustration, the cross-section for $M_\rho = 700$ GeV, $b_2 = 0.08$, $g'' = 10$, and $\Gamma_\rho = 3.95$ GeV is 0.96 fb (the BRA calculation gives 1.04 fb). The background cross-section $\sigma(\text{No}\ \rho) = 0.037$ fb.

In Fig. 1 we show the statistical significance $R = S/\sqrt{B}$ which is a measure of how well one can distinguish the ρ signal from the No ρ signal (the new physics from the current physics). Here S and B are the total numbers of signal and background events. R is plotted as a function of g'' and b_2 and this result was obtained using the full calculation approach for $M_\rho = 700$ GeV and integrated luminosity $L = 100\ fb^{-1}$.

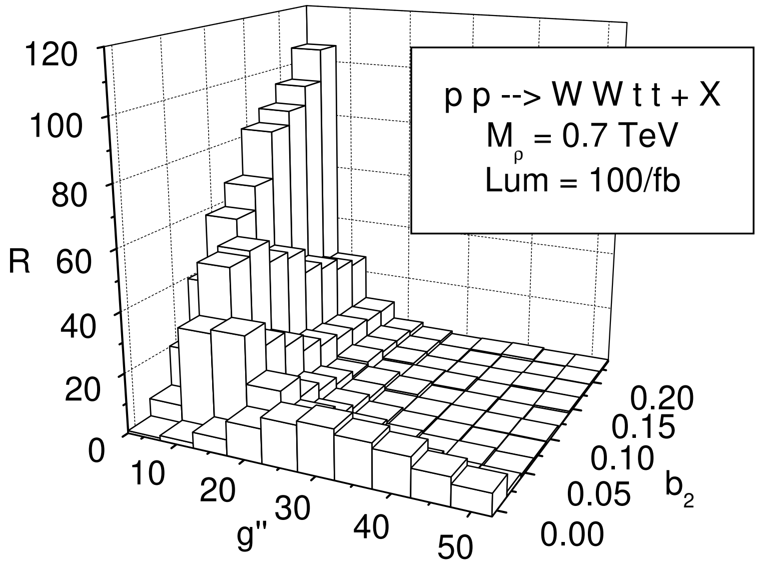

Figure 1: The statistical significance R based on the full calculation approach of $\mathrm{pp} \to \mathrm{W^+W^-t\bar{t}} + \mathrm{X}$ as a function of g'' and b_2. The ρ mass is 700 GeV, $\sqrt{s} = 14$ TeV, and the integrated luminosity is 100 fb^{-1}.

Reconstruction of events

In the second step we let the W's and the top quarks decay (and hadronize) and we took into account the detector effects. We started with event generation by CompHEP. The events were then passed to Pythia [6] for decays and hadronization and after that to Atlfast which simulates the ATLAS detector effects. Everything was run within the Athena framework.

The output from Atlfast was a ROOT file on which we did the final reconstruction of the $W^+W^-t\bar{t}$ events. For the reconstruction we chose the channel with one charged lepton, $W^+W^-t\bar{t} \to W^+W^-bW^+\bar{b}W^- \to l\nu_l jjbjj\bar{b}jj$ (j denotes light jet, b stands for b-jet) which has the highest branching ratio among all channels (40%). Also note that at least one charged lepton with high p_T is required for trigger purposes and that for this channel it is possible to fully reconstruct all four W bosons and both top quarks, which is more difficult for channels with more charged leptons.

We imposed the following cuts: p_T of electron > 30 GeV, p_T of muon > 20 GeV, p_T of jets > 25 GeV. We assumed the b-tagging efficiency of 50%. One of the W bosons was reconstructed from the reconstructed lepton and neutrino, the three remaining W's were reconstructed from the light jets. In the case of the leptonic decay the W mass (m_W) constraint was used to determine the longitudinal component of the neutrino.The jet-jet invariant mass m_{jj} was required to fall within the $m_W \pm 25$ GeV window. For the reconstruction of each event we took such combination of six light jets and two b-jets (one can make 12 combinations to pair four W's and two b-quarks) which minimizes the expression

$$\begin{aligned}\chi^2 &= (m_{j_1j_2} - m_W)^2 + (m_{j_3j_4} - m_W)^2 + \\ &\quad (m_{j_5j_6} - m_W)^2 + (m_{W_1b_1} - m_t)^2 + \\ &\quad (m_{W_2b_2} - m_t)^2, \end{aligned} \tag{2}$$

where m_{Wb} is the W-b invariant mass and m_t is the mass of the top quark.

As a preliminary result the reconstructed distribution of the invariant mass of the WW pair for ρ with mass M_ρ=700 GeV and width $\Gamma_\rho = 3.95$ GeV is shown in Fig. 2. This distribution was generated using only the 8 diagrams of the gg channel in which ρ is present. We can see that about 40% of events are within 700±100 GeV interval (the ρ peak). Some events fall away from the peak due to the detector effects such as b-mistagging, some due to the inefficiency of the reconstruction algorithm which has to deal with a very complicated final state.

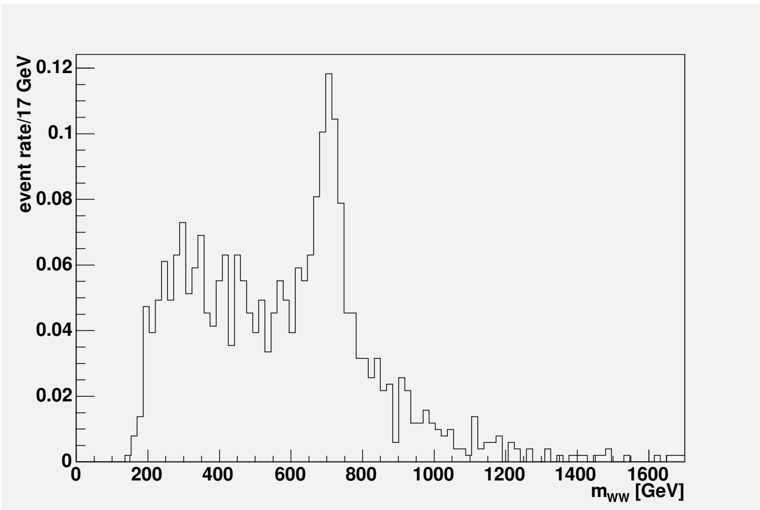

Figure 2: The reconstructed distribution of m_{WW} for 8 diagrams. $M_\rho = 700$ GeV, $\sqrt{s} = 14$ TeV, $L = 100$ fb^{-1}.The final event number after cuts is 2.4

In Fig. 3 we show the corresponding distribution for 39 diagrams, i.e. the signal of Fig. 2 is shown together with the continuum irreducible background. The total number of events fell from the original 1020 down to 12.2 after cuts. The rho peak of Fig. 2 is not visible against the continuum background.

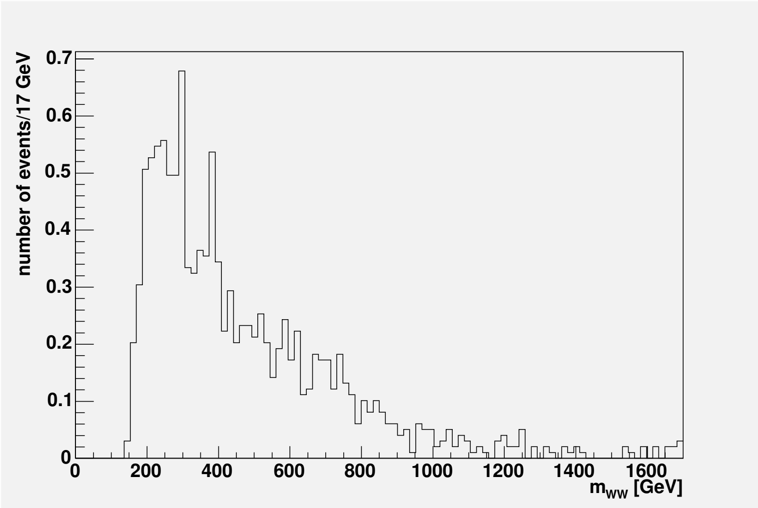

Figure 3: The reconstructed distribution of m_{WW} for 39 diagrams. $M_\rho = 700$ GeV, $\sqrt{s} = 14$ TeV, $L = 100$ fb^{-1}.The final event number after cuts is 12.2

In. Fig. 4 we show the m_{WW} distribution for 39 diagrams for a resonance with mass $M_\rho = 1000$ GeV and width $\Gamma_\rho = 26$ GeV. This time a rho peak becomes visible at $m_{WW} = 1000$ GeV.

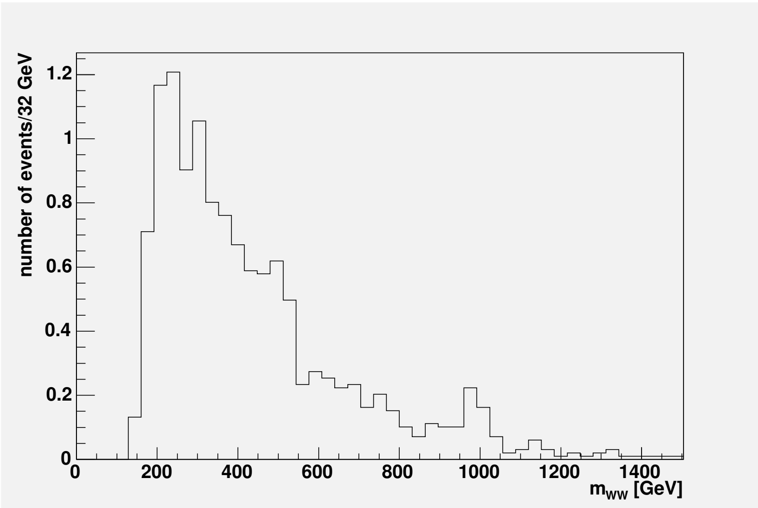

Figure 4: The reconstructed distribution of m_{WW} for 39 diagrams. $M_\rho = 1000$ GeV, $\sqrt{s} = 14$ TeV, $L = 100$ fb^{-1}. The final event number after cuts is 12.8

Conclusions

The reconstructed event numbers seem small and call for 300 fb^{-1} integrated luminosity at LHC. Further work is required on the reconstruction algorithm and the backgrounds to draw a definite conclusion.

ACKNOWLEDGEMENTS — We wish to thank Jonathan Ferland, University of Montreal, for his help with the reconstruction procedure.

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