A NEW VECTOR RESONANCE PRODUCTION AT LHC. [1]

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We consider a new vector resonance ρ from the Strong Electroweak Symmetry Breaking scenario. We study the ρ production at LHC in pp $\to \rho\mathrm{t}\bar{\mathrm{t}}$ with ρ decaying to $\mathrm{W}^+\mathrm{W}^-$ pair.

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1 Introduction

New vector and scalar particles with enhanced couplings to W, Z bosons and/or to the top quark are predicted by many models, *e. g.* the Standard Model (SM) heavy Higgs boson, Z' bosons or the new strong vector resonance from the Strong Electroweak Symmetry Breaking (SESB). Here we consider the last possibility. SESB is an alternative mechanism of ESB, different from the Standard Model 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 SESB models.

An effective description of ρ interactions with SM particles is known as the BESS model [1]. BESS 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. In the original version of the BESS model [1] it is assumed that all fermion generations of the same chirality couple to the vector resonance with the same strength. This leads to stringent limits on the ρ-to-fermion couplings from the existing measurements of the SM parameters. In our modification [2] of the BESS model we break this universality and assume that only the top quarks and the left-handed bottom quark $\mathrm{b_L}$ couple directly and possibly strongly to the ρ-resonance. However, the symmetries of the model require $\mathrm{b_L}$ to couple to ρ with the same strength b_1 as the left-handed top quark $\mathrm{t_L}$ and, as a consequence, b_1 is constrained to relatively small values (see the next session) as follows from the low energy measurements of the $\mathrm{Zb\bar{b}}$ vertex [2]. On the other hand $\mathrm{b_R}$ field can be chosen not to interact directly with ρ at all which protects the right-handed ρ-to-$\mathrm{t_R}$ coupling b_2 from the $\mathrm{Zb\bar{b}}$ constraint.

The size of the ρ-to-top coupling is an important clue for the role of the top quark in ESB. In this contribution we study LHC process pp $\to \rho\mathrm{t}\bar{\mathrm{t}}$ (see Fig. 1) with ρ subsequently decaying to

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a W$^+$W$^-$ pair (another process sensitive to $\rho t\bar{t}$ coupling, WW $\to \rho \to t\bar{t}$ fusion, is completely swamped by the huge QCD $t\bar{t}$ background [3] and, as we found, so is the resonant process $q\bar{q} \to \rho \to t\bar{t}$).

2 Lagrangian

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 :

$$\mathcal{L} \;\; = \;\; +ig_\pi \frac{M_\rho}{v}\left(\pi^-\partial^\mu\pi^+ - \pi^+\partial^\mu\pi^-\right)\rho^0_\mu \;\; + \; g_1^t \; \bar{t}\gamma^\mu t \; \rho^0_\mu + g_2^t \; \bar{t}\gamma^\mu\gamma^5 t \; \rho^0_\mu; \qquad (1)$$

where the coupling constants g_π, g_1^t (we assume $g_1^t = g_2^t$) carry information on ESB. They can be expressed in terms of the coupling constants of the effective chiral Lagrangian g'', b_2 [2] as (g is the usual $SU(2)_L$ coupling constant): $g_\pi \;=\; M_\rho/(2\;vg'')\;\; g_1^t \;=\; g''b_2/4 + \mathcal{O}(g^2/g''^2)$. Perturbative unitarity limits require $g_\pi \leq 1.5$ and $g_1^t \leq 2.0$ for $M_\rho = 1$ TeV [5].

The limits from low energy experiments give [2] $g'' \gtrsim 10,\;\; |b_2| \lesssim 0.08, b_1 \lesssim 0.01$.

The width of ρ^0 is defined by its mass and couplings g'', b_2. We show the total width Γ in Fig. 2 as a function of $g'' \equiv g_v$ and b_2 for $M_\rho = 0.7$ TeV.

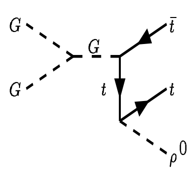

Fig.1a Diagram of pp $\to$ gg $\to \rho^0 t\bar{t}$

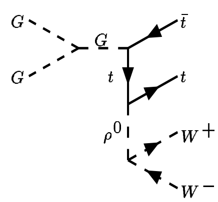

Fig. 1b Diagram of pp $\to$ gg $\to$ WW$t\bar{t}$

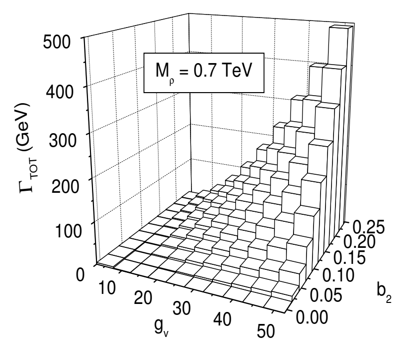

Fig. 2 Total width of $\rho^0 \to$ WW$t\bar{t}$

3 Analysis of pp $\to$ W$^+$W$^-$t$\bar{t}$

We used two approaches in our analysis. In the first one we simplified the problem and treated pp $\to$ W$^+$W$^-$$t\bar{t}$ as a 2-step process: we first produced ρ on-shell as pp $\to \rho t\bar{t}$ and then included

[5]In this contribution masses are expressed in TeV/c^2 and momenta in TeV/c, where c equals 1.

$\rho \to \mathrm{W^+W^-}$ decay. The cross sections for $\mathrm{pp} \to \mathrm{W^+W^-t\bar{t}}$ were found from the cross sections for $\mathrm{pp} \to \rho\mathrm{t\bar{t}}$, multiplied by the corresponding branching ratio for $\rho \to \mathrm{W^+W^-}$. The dominant gluon-gluon (gg) channel for $\mathrm{pp} \to \rho\mathrm{t\bar{t}}$ consists of 8 diagrams, one of them is shown in Fig.1a. The $\mathrm{q\bar{q}}$ channels were neglected. This first approach is the so called branching ratio approximation (BRA). BRA is a good approximation for the *narrow* ρ only. In the second approach we computed $\mathrm{pp} \to \mathrm{W^+W^-t\bar{t}}$ directly. We thus obtained results which are valid also for the *wide* ρ resonance case. There are 39 diagrams in the dominant gg channel. They include all 8 diagrams from the BRA approach sensitive to the ρ presence (one of them is shown in Fig. 1b). The remaining 31 diagrams are much less sensitive to the new physics and thus represent the irreducible background in our studies. We evaluate this background as the limit $M_\rho \to \infty, g'' \to \infty, b_2 \to 0$ of our ρ model. We call this limit the 'No ρ model' since it effectively removes ρ from the spectrum. This model is perturbatively unitary up to the scale $\sqrt{\hat{s}} \sim M_{\mathrm{WW}} \lesssim 1.7$ TeV.

All our results were obtained with the CompHEP package. In the BRA approach we imposed following cuts on the transverse momentum and rapidity of t, $\mathrm{\bar{t}}$: $p_T(\mathrm{t}), p_T(\mathrm{\bar{t}}) > 0.1$ TeV, $|Y(\mathrm{t}), Y(\mathrm{\bar{t}}| < 2$. The cross section is plotted in Fig. 3a for $M_\rho = 0.7$ TeV as a function of g'' and b_2 for the CMS collision energy of 14 TeV. In the second approach (full calculation) we use the same rapidity and transverse momentum cuts as before plus the cut on the invariant mass of the $\mathrm{W^+W^-}$ pair, $M_\rho - 3\Gamma_\rho < M_{\mathrm{WW}} < M_\rho + 3\Gamma_\rho$. As an illustration, the cross-section for ρ with $M_\rho = 0.7$ TeV, $b_2 = 0.08, g'' = 10$ ($\Gamma_\rho = 3.95$ GeV) is 0.96 fb (the BRA calculation gives 1.04 fb). The background cross-section $\sigma(\mathrm{No}\ \rho) = 0.037$ fb in the dominant gg channel.

The statistical significance, $R = S/\sqrt{B}$, is the measure of how well it will be possible to 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. We assume the integrated luminosity $L = 100\ fb^{-1}$. We do not include the branching ratios of the W and t decays neither their reconstruction efficiences. R as a function of g_V and b_2 is plotted in Figs. 3b ($M_\rho = 0.7$ TeV) and 3d ($M_\rho = 1.5$ TeV) for the BRA approach and in Fig. 3c ($M_\rho = 0.7$ TeV) for the full calculation.

4 Discussion

As seen from Fig. 3a, the LHC cross sections of $\mathrm{pp} \to \mathrm{W^+W^-t\bar{t}}$ are at the level of 1 fb for $M_\rho = 0.7$ TeV. The statistical significance R reaches values as high as 100 (18) for $M_\rho = 0.7$ (1.5) TeV (Figs. 3c, 3d) . The BRA calculations of R (Fig. 3b) are in good agreement with the full calculation (Fig. 3c) for the narrow ρ case.

We did not consider the issues of the W boson and the top quark decays and reconstruction efficiences which will significantly modify our predictions of the statistical significance R. We also did not include reducible background processes. These complex issues require a separate in-depth study. The work on a related process, $\mathrm{pp} \to \mathrm{t\bar{t}t\bar{t}}$, is in progress.

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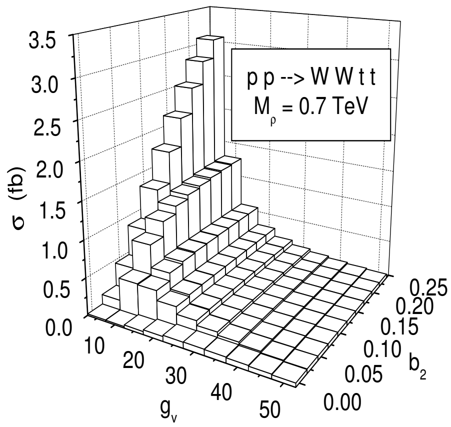

Fig.3a $\sigma = \sigma(pp \to \rho t\bar{t}) \times BR(WW)$

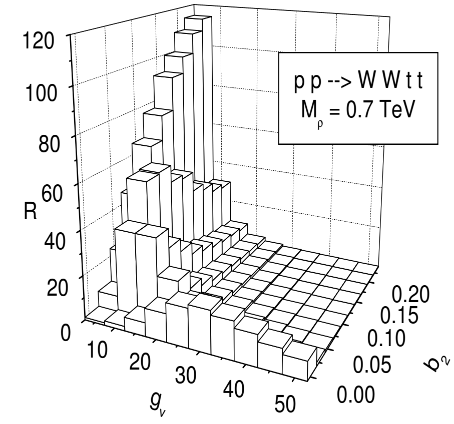

Fig.3b *Stat. signif. R, BRA calculation*

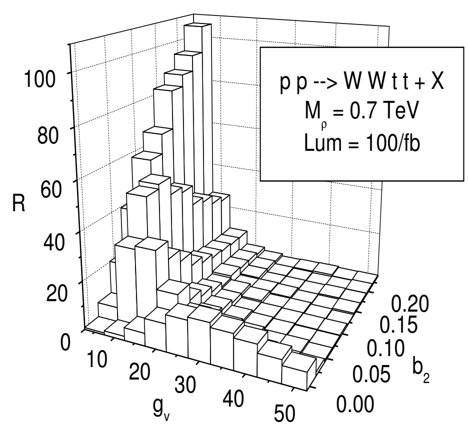

Fig.3c *Stat. signif. R, full calculation*

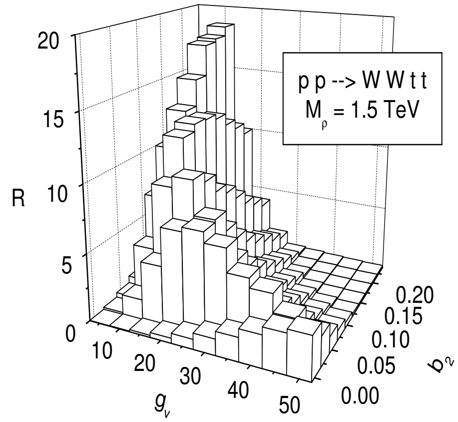

Fig.3d *Stat. signif. R, BRA calculation*