AN UPDATE ON STRONG $W_L W_L$ SCATTERING AT THE LHC *

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ABSTRACT

I summarize an update on the study for a strongly interacting electroweak symmetry breaking sector via longitudinal vector boson scattering at the 14 TeV Large Hadron Collider. In the update, the decay mode $ZZ \rightarrow \ell^+ \ell^- \nu \bar{\nu}$ and a new vector-resonance signal via $qq' \rightarrow V \rightarrow W^+W^-/W^\pm Z$ are also included.

In a recent paper we presented a thorough signal-background analysis of the strongly-interacting electroweak symmetry breaking sector (SEWS) via longitudinal vector boson scattering, in which the gold-plated decay modes of $W$ and $Z$ bosons are considered. But that paper emphasized on the senate-killed SSC parameters and adopted a similar set of acceptance cuts for the 16 TeV LHC. Now we know that the LHC has been approved with an energy of 14 TeV. Since the signal of the SEWS is rather sensitive to the energy of the machines, we have performed an updated analysis to optimize the acceptance cuts for the LHC with the updated energies and luminosities (100 fb$^{-1}$ per year). I summarize the update here.

Our signal of interest mainly comes from $W_L W_L$ fusion:

$$qq' \rightarrow qq'Z_L, qq'W_L^+ W_L^-, qq'W_L^\pm Z_L, qq'W_L^\pm W_L^\pm,$$

(1)

followed by $W \rightarrow \ell \nu$ and $Z \rightarrow \ell^+ \ell^-$ decays. The strategies to extract the $W_L W_L$ signals from the Standard Model (SM) backgrounds follow closely as in Ref. 1. In the update, we also extended to include the $ZZ \rightarrow \ell^+ \ell^- \nu \bar{\nu}$ decay mode to supplement the $ZZ \rightarrow \ell^+ \ell^- \ell^+ \ell^-$ channel, which has less than 10 events per year. We have also included the $qq' \rightarrow W^* \rightarrow V \rightarrow W_L^+ W_L^- / W_L Z_L$ processes for a vector resonance $V$ via $W - V$ mixing, which has been proved more useful in searching for the vector resonance than the $W_L W_L$ fusion mechanism. For background processes we also used the value of $m_t = 175$ GeV and all the $qq' \rightarrow WW + \text{QCD jets}$ are reevaluated to include $O(\alpha_s)$ corrections. In addition, we have also included one detector-dependent background, $W^+ Z \rightarrow \ell^+ \ell^+$ to the $W_L^+ W_L^+$ channel when the $\ell^-$ from the $W^+ Z$ decay escapes outside the detector range.

As described in our earlier paper we again consider seven models for the SEWS physics: (i) the “SM” with $m_H = 1$ TeV; (ii) the “Scalar” model with a spin-0,
isospin-0 chirally coupled resonance with mass of 1 TeV and width 350 GeV; (iii) the \(O(2N)\) model with \(N = 2\) and an amplitude having a pole at \(s = (m - i\Gamma/2)^2\) with \(m = 0.8\) TeV and \(\Gamma = 600\) GeV; (iv) a “Vector” model with a spin-1, isospin-1 chirally coupled resonance; we choose the mass-width combinations as \((M_V, \Gamma_V) = (1\) TeV, 5.7 GeV) and \((2.5\) TeV, 520 GeV); (v) the non-resonant “LET-CG” model of Chanowitz and Gaillard in which the low energy theorem (LET) amplitude is used and the unitarity saturation is assumed once the partial waves reach the unitarity bound; (vi) the non-resonant “LET-K” model in which the LET amplitude is used and the unitarization of the partial waves is achieved by K-matrix; (vii) the “Delay-K” model in which one-loop correction terms to the LET amplitude are chosen so as to delay the onset of unitarity violation to energies beyond 2 TeV, and K-matrix unitarization is employed to ensure unitarity beyond this point.

In the following I shall describe the different characteristics between the signal and various backgrounds, which include the electroweak production of transverse \(WW\) pair, the lowest order production of \(WW\) pair in association with QCD jets, and top-related backgrounds. Since the scale of the SEWS is of order TeV, the \(W_LW_L\) scattering via the dynamics of the SEWS is characterized by several unique features that are quite different from the backgrounds:

(i) the leptons coming from the decays of the \(W_L\) and \(Z_L\) after strong scattering are very energetic and very back-to-back in the transverse plane. These features prompt us to consider high \(p_T\), central rapidity and large invariant mass cuts, as well as large \(\Delta p_T(\ell\ell)\) and \(\cos \phi_{\ell\ell}\) cuts;

(ii) the presence of very energetic \((\sim 1\) TeV), small \(p_T\), and forward jets in association with the \(W_LW_L\) fusion. This motivates us to tag forward energetic jets, which is especially effective in reducing the \(WW+\) QCD jet backgrounds;

(iii) the absence of large \(p_T\) jets in the central rapidity region. This prompts us to veto any hard jets in the central region. This is extremely effective in suppressing the top-related backgrounds and the EW backgrounds.

Specifically, we started with the model of 1 TeV SM Higgs boson because it can be incorporated consistently into the SM simply by setting \(m_H = 1\) TeV, namely, the signal of the 1 TeV Higgs boson is defined as \(\sigma(SM m_H = 1\) TeV) \(-\sigma(SM m_H = 0.1\) TeV), where \(\sigma(SM m_H = 0.1\) TeV) represents the EW background. We then came up with a set of optimized cuts and the jet-veto and jet-tag efficiencies. The specific cuts and jet efficiencies used in different channels can be found in Ref. 2. Since not all these SEWS models can be incorporated into the SM consistently, we employed the Effective-W Approximation (EWA) in combination with the Equivalence Theorem (ET) to calculate the signal rates. In this EWA/ET approach we first compute cross sections ignoring all jet observables but implementing all the leptonic cuts. Then to obtain the cross sections that include the jet-tagging and jet-vetoing cuts, we simply
Table 1: Event rates per LHC year for (a) the $W_L W_L$ fusion signals for various SEWS models in channels of vector boson pair, and (b) for $q\bar{q} \to W^+ W^-$ and $q\bar{q}' \to W^\pm Z$ channels deriving from $W - V$ mixing.

(a) | Bkgd. | SM | Scalar | $O(2N)$ | Vec 1.0 | Vec 2.5 | LET-CG | LET-K | Delay-K |
---|---|---|---|---|---|---|---|---|
$ZZ(4\ell)$ | 0.7 | 9 | 4.6 | 4.0 | 1.4 | 1.3 | 1.5 | 1.4 | 1.1 |
$ZZ(2\ell 2\nu)$ | 1.8 | 29 | 17 | 14 | 4.7 | 4.4 | 5.0 | 4.5 | 3.6 |
$W^+ W^-$ | 12 | 27 | 18 | 13 | 6.2 | 5.5 | 5.8 | 4.6 | 3.9 |
$W^\pm Z$ | 4.9 | 1.2 | 1.5 | 1.2 | 4.5 | 3.3 | 3.2 | 3.0 | 2.9 |
$W^\pm W^\pm$ | 3.7 | 5.6 | 7.0 | 5.8 | 12 | 11 | 13 | 13 | 8.4 |

(b) | Bkgd. | Vec1.0: $W-V$ mix / fusion | Vec2.5: $W-V$ mix / fusion |
---|---|---|---|
$W^+ W^-$ | 420 | 8.6 / 10 | 0.3 / 9.0 |
$W^\pm Z$ | 220 | 73 / 8.7 | 1.4 / 6.4 |
$W^\pm Z$ | 0.85 < $M_T$ < 1.05 TeV | 2 < $M_T$ < 2.8 TeV |
B/mix/fusion | 22 / 69 / 3.2 | 0.82/0.81/0.55 |

Multiply by the jet-tag and/or jet-veto efficiencies as obtained for the SM 1 TeV Higgs boson signal. This procedure is justified since the kinematics of the jets in the signal events are determined only by the initial $W_L$'s and therefore should be independent of the SEWS dynamics. The final numbers for the $W_L W_L$ fusion signals and backgrounds for various channels are summarized in Table 1(a). Large excesses above SM backgrounds are predicted in $ZZ(4\ell)$, $ZZ(2\ell 2\nu)$, and $W^+ W^-$ modes for scalar-type models; the vector-type models would yield observable event excess in the $W^\pm W^\pm$ channel, but to a much less extent in the $W^\pm Z$ channel; whereas the non-resonant models yield observable excesses in the $W^\pm W^\pm$ channel. Therefore, an observation of excess vector boson pairs in a particular channel will signal a specific dynamics of SEWS. On the other hand, the vector resonance can also be probed via the Drell-Yan process $q\bar{q}' \to W^* \to V \to W^\pm Z, W^+ W^-$, which are more important as long as $V$ is not too heavy. However, we have to drop the jet-tag cut because the Drell-yan processes do not have accompanying jets at the lowest order. We calculate the signal assuming 100% jet-veto efficiency. The resulting signal and background event rates are shown in Table 1(b). Despite the increase in backgrounds due to dropping the jet-tag, the increase in signal event rate for a 1 TeV vector resonance presents a clear bump near the resonance mass in the $M_T$ spectrum. The $q\bar{q}' \to W^\pm Z$ channel via $W-V$ mixing should be the best to study a Vector resonance model at the LHC if $M_V \sim 1$ TeV, but for a 2.5 TeV vector state the signal rates are too small for any practical detection; whereas the $q\bar{q} \to W^+ W^-$ is less useful in probing the vector resonance due to enormous backgrounds. This work was supported by DOE-FG03-93ER40757.
1. J. Bagger et al., Phys. Rev. D49 (1994) 1246.
2. J. Bagger et al., preprint CPP-95-3 (March 1995).