Top quark effects in composite vector pair production at the LHC

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Abstract

In the context of a strongly coupled Electroweak Symmetry Breaking composite light scalar singlet and composite triplet of heavy vectors may arise from an unspecified strong dynamics and the interactions among themselves and with the Standard Model gauge bosons and fermions can be described by a $SU(2)_L \times SU(2)_R / SU(2)_{L+R}$ Effective Chiral Lagrangian. In this framework, the squared amplitudes for composite heavy vector pair production via gluon fusion mechanism summed over the polarization and color states are computed by considering that their only relevant contributions come from the top quark in the triangular loop followed by a scalar propagator. The production of the $V^+V^-$ and $V^0V^0$ final states at the LHC by gluon fusion mechanism is studied in the region of parameter space consistent with the unitarity constraints in the elastic channel of longitudinal gauge boson scattering and in the inelastic scattering of two longitudinal Standard Model gauge bosons into Standard Model fermions pairs. The expected rates of same-sign di-lepton and tri-lepton events from the decay of the $V^+V^-$ and $V^0V^0$ final states are computed. It is very relevant the fact that the $V^0V^0$ final state can only be produced at the LHC via gluon fusion mechanism since this state is absent in the Drell-Yan process. It is also found that the $V^+V^-$ final state production cross section via gluon fusion mechanism is comparable with the $V^+V^-$ Drell-Yan production cross section.

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1 Introduction and statement of the problem.

One of the most important issues to be settled by the LHC is whether the dynamics responsible for Electroweak Symmetry Breaking (EWSB) is weakly or strongly coupled. A weakly coupled dynamics describing the mechanism of the Electroweak Symmetry Breaking is provided by the Standard Model and its Supersymmetric extensions. In the Standard Model, the existence of one Higgs doublet is assumed in order to explain the generation of the masses of all the fermions and bosons. In addition to the 3 eaten up Goldstone bosons, the Higgs doublet contains one physical neutral scalar particle, called the Higgs boson, which is crucial for keeping under control unitarity in the elastic and inelastic channels of the gauge boson scattering and which allows us to extrapolate a weakly coupled model up to the Planck scale. A light Higgs boson can also successfully account for the Electroweak Precision Tests (EWPT).

In spite of the very good agreement of the Standard Model predictions with experimental data, the Higgs boson is yet to be detected experimentally. Therefore one can say that the mechanism of Electroweak Symmetry Breaking responsible for the generation of the masses of all fermions and bosons remains to be explained. Moreover, the Standard Model has the hierarchy problem, which is the instability of the mass of the Higgs field against quantum corrections, which are proportional to the square of the cutoff. This means that in a quantum theory with a cutoff at the Planck scale $\Lambda \simeq 10^{19}$ GeV, the Higgs boson mass will have quantum corrections that will raise it to about the Planck scale unless an extreme fine-tuning of 34 decimals is performed in the bare mass. This is the naturalness problem of the Standard Model.
As there is no experimental evidence for a Higgs particle up to date, it is natural to ask what happens if we keep all the Standard Model fields, except the Higgs boson. One can for example think of a very heavy Higgs boson and build an effective field theory below the Higgs boson mass. The effective theory contains three of the four components of the Higgs doublet, at scales below the Higgs boson mass which have become the longitudinal components of the $W^\pm$ and $Z$ bosons, but not the fourth component -- the Higgs boson. This is the starting point of the Electroweak Chiral Lagrangian formulation, which is inspired by the Chiral Lagrangian approach to QCD at low energies and Chiral Perturbation Theory \cite{1, 2, 3, 4, 5}. However, as is well known, the Electroweak Chiral Lagrangian formulation does not pass the Electroweak Precision Tests and the unitarity considerations for $WW$ scattering (unitarity is violated at energies around 1.7 TeV).

These problems can be overcome if one considers EWSB mechanisms in the framework of strongly interacting dynamics, where the theory becomes non-perturbative above the Fermi scale and the breaking is achieved through some condensate. In the strongly interacting picture of EWSB, many models have been proposed, which predict the existence of composite particles, e.g. composite scalars \cite{6, 7, 8, 9, 10, 11}, composite vector resonances \cite{12, 13, 14, 15, 16, 17, 18}, and composite fermions \cite{21}. The spin-0 and spin-1 resonances predicted by these models play a very important role in controlling unitarity in longitudinal gauge boson scattering up to the cutoff $\Lambda \simeq 4\pi v$. For appropriate couplings and masses, the composite resonances can also account for the Electroweak Precision Tests. Furthermore, a composite scalar does not have the hierarchy problem since quantum corrections to its mass are saturated at the compositeness scale.

In the most general framework of strongly interacting dynamics for Electroweak Symmetry Breaking, one can have composite resonances which could be spin-0, spin-1/2 and spin-1 states. These composite particles are bound states of more fundamental constituents which are held together by a new strong interaction. Here I consider the case in which the strong dynamics responsible for EWSB, gives rise to a triplet of composite vectors $V^a$ belonging to the adjoint representation of the $SU(2)_{L+R}$ custodial symmetry group and to a composite scalar singlet $h$. In this context, I introduce in Section 2 the relevant $SU(2)_L \times SU(2)_R/SU(2)_{L+R}$ Effective Chiral Lagrangian which describes the composite scalar singlet and the composite triplet of heavy vectors with masses below the cutoff $\Lambda \simeq 4\pi v \approx 3$ TeV, the interactions among themselves and with the SM gauge bosons and SM fermions. Since in this general framework, the SM fermions have (proto)-Yukawa interactions with the light composite scalar, which also interacts with a heavy composite vector pair and considering the large rate of gluons at the LHC, the top quark effects will be relevant for the vector pair production at the LHC via gluon fusion mechanism through
a triangular loop followed by a scalar propagator. Because of this reason, in this context the vector pair production via gluon fusion mechanism can compete with the vector pair production via Drell-Yan annihilation discussed in [18]. It is of particular relevance the presence of the $V^0 V^0$ final state in the gluon fusion mechanism, which is absent in the Drell-Yan process. In Section 3, the squared amplitudes for the composite heavy vector pair production via gluon fusion mechanism summed over the polarization and color states are computed. In Section 4, the total cross sections for the production of the $V^+ V^-$ and $V^0 V^0$ final states at the LHC are computed for different values of the parameters. The discussion of the phenomenology of the same-sign dileptons and trilepton events at the LHC for an integrated luminosity of 100 fb$^{-1}$ is presented in Section 5. The conclusions are given in Section 6.

2 Chiral Lagrangian with massive spin one fields, scalar singlet and SM fermions.

The starting point is the usual lowest order chiral Lagrangian for the $SU(2)_L \times SU(2)_R/SU(2)_{L+R}$ Goldstone fields with the addition of the invariant kinetic terms for the $W$ and $B$ bosons [18]:

$$\mathcal{L}_\chi = \frac{v^2}{4} \left( \langle D_\mu U (D^\mu U)^\dagger \rangle - \frac{1}{2g^2} \langle W_{\mu \nu} W^{\mu \nu} \rangle - \frac{1}{2g'^2} \langle B_{\mu \nu} B^{\mu \nu} \rangle \right),$$

where

$$D_\mu U = \partial_\mu U - iB_\mu U + iU W_\mu, \quad U = e^{i\pi}, \quad \pi = \pi^a \tau^a,$$

$$W_{\mu \nu} = \partial_\mu W_\nu - \partial_\nu W_\mu - i[W_\mu, W_\nu], \quad W_\mu = \frac{g}{2} W^a \tau^a,$$

$$B_{\mu \nu} = \partial_\mu B_\nu - \partial_\nu B_\mu, \quad B_\mu = \frac{g'}{2} B^0 \tau^3,$$

being $U$ the matrix which contains the Goldstone boson fields $\pi^a$ with $a = 1, 2, 3$, the $\tau^a$ are the ordinary Pauli matrices and $\langle \rangle$ denotes the trace over $SU(2)$.

Now, a heavy spin-1 state belonging to the adjoint representation of $SU(2)_{L+R}$ is considered, so that $V_\mu = \frac{1}{\sqrt{2}} V^a_\mu \tau^a$. The $SU(2)_L \times SU(2)_R$-invariant kinetic Lagrangian for the heavy spin-1 fields is given by

$$\mathcal{L}_{V_{\mu \nu}}^{\text{kin}} = -\frac{1}{4} \langle \hat{V}_{\mu \nu} \hat{V}_{\mu \nu} \rangle + \frac{M_V^2}{2} \langle V_\mu V^\mu \rangle.$$

The field strength tensor $\hat{V}_{\mu \nu} = \nabla_\mu V_\nu - \nabla_\nu V_\mu$ is written in terms of the $SU(2)_L \times SU(2)_R$ covariant derivative

$$\nabla_\mu V_\nu = \partial_\mu V_\nu + [\Gamma_\mu, V_\nu],$$

with the connection $\Gamma_\mu$ given by

$$\Gamma_\mu = \frac{1}{2} \left[ u^\dagger (\partial_\mu - iB_\mu) u + u (\partial_\mu - iW_\mu) u^\dagger \right], \quad u \equiv \sqrt{U}, \quad \Gamma_\mu^\dagger = -\Gamma_\mu.$$
Assuming that the new strong dynamics is invariant under parity, the interaction Lagrangian of the heavy vector with the SM model gauge fields and with the Goldstone bosons is given by [20]:

\[
L_{\text{int}} = \frac{-ig_V}{2\sqrt{2}} \langle \hat{V}_{\mu
u} [u^\mu, u^\nu] \rangle - \frac{g_V}{\sqrt{2}} \langle \hat{V}_{\mu
u} \left( u W^{\mu\nu} u^\dagger + u^\dagger B^{\mu\nu} u \right) \rangle + \frac{i}{2} \langle V_{\mu} V_{\nu} \left( u W^{\mu\nu} u^\dagger + u^\dagger B^{\mu\nu} u \right) \rangle
\]

\[
+ \frac{ig_K}{4\sqrt{2}} \langle \hat{V}_{\mu
u} [V^\mu, V^\nu] \rangle - \frac{1}{8} \langle [V_{\mu}, V_{\nu}][u^\mu, u^\nu] \rangle + \frac{g^2_V}{8} \langle [u_{\mu}, u_{\nu}][u^\mu, u^\nu] \rangle ,
\]

where \( u_{\mu} = u_{\mu}^\dagger = i u^\dagger D_{\mu} U u^\dagger \).

A composite scalar singlet which could be a Strongly Interacting Light Higgs (SILH) boson in the context of [9] or a more complicated object arising from an unknown strong dynamics is also considered. The Lagrangian which includes the kinetic and mass terms for the scalar as well as the interactions of this scalar with the Goldstone bosons, SM gauge fields and SM fermions is given by [22]:

\[
L_h = \frac{1}{2} \partial_{\mu} h \partial^{\mu} h + \frac{m_h^2}{2} h^2 + \frac{v^2}{4} \left( D_{\mu} U (D^{\mu} U)^\dagger \right) \left( 2a \frac{h}{v} + b \frac{h^2}{v^2} \right) - \frac{v}{\sqrt{2}} \sum_{i,j} \left( \bar{u}_{L}^{(i)} d_{L}^{(i)} \right) U \left( 1 + c \frac{h}{v} \right) \left( \lambda_{ij}^u u_{R}^{(j)} \right) + h.c. 
\]

\[
(2.7)
\]

where \( \lambda_{ij}^u \) and \( \lambda_{ij}^d \) are the up and down type quarks Yukawa couplings, respectively.

The Lagrangian \( L_{h-V} \) which describes the interaction between the scalar and the heavy vector \( V \) is [20]:

\[
L_{h-V} = \frac{dv}{8g_V} h \langle V_{\mu} V^\mu \rangle .
\]

\[
(2.8)
\]

Here \( a, b, c, d, g_V \) and \( g_K \) are dimensionless constants.

Summarizing, in the framework of strongly interacting dynamics for EWSB, the interactions among the composite scalar singlet, composite triplet of heavy vectors and the SM gauge bosons and SM fermions can be described by the following model independent \( SU(2)_L \times SU(2)_R/SU(2)_{L+R} \) Chiral Lagrangian:

\[
L_{\text{eff}} = L_{\chi} + L_{\text{kin}}^V + L_{\text{int}}^V + L_h + L_{h-V} .
\]

\[
(2.9)
\]

Here the following assumptions have been made:

1. Before weak gauging, the Lagrangian responsible for EWSB has a \( SU(2)_L \times SU(2)_R \) global symmetry which is spontaneously broken by the new strong dynamics down to the \( SU(2)_{L+R} \) custodial group. The spontaneous breaking of the global symmetry also leads to the breaking of the standard electroweak gauge symmetry, \( SU(2)_L \times U(1)_Y \), down to the electromagnetic \( U(1) \).

\[1\] In general \( c \) will be a matrix in flavor space, but in the following it is assumed for simplicity that it is proportional to unity in the basis in which the mass matrix is diagonal. This guarantees the absence of flavour changing neutral effects originated from the tree level exchange of \( h \).
2. The strong dynamics produces a composite triplet of heavy vectors degenerate in mass belonging to the $SU(2)_{L+R}$ adjoint representation and a composite scalar singlet under $SU(2)_{L+R}$.

3. Only one vector triplet $V^a_\mu$ of the $SU(2)_{L+R}$ group has a mass below the cut-off $\Lambda \approx 3$ TeV, while the parity odd heavy vectors are integrated out. The new $V$ states couple to fermions only via SM gauge interactions.

4. The scalar singlet is assumed to be light with mass of the order $m_h \lesssim v$. This scalar singlet interacts with the Standard Model gauge bosons and fermions only via weak gauging and (proto)-Yukawa couplings, respectively.

3 Gluon Fusion production amplitudes

There are different one loop level contributions to the gluon fusion vector pair production amplitudes. They are of two types, triangular and box diagrams containing a top quark running in them. The triangular loop can be followed by a scalar propagator, a $Z$ boson propagator, $Z$ and $V^0$ propagators coupled by the $Z$-$V^0$ mixing, $\pi^0$ and $Z$ propagators coupled by the $\pi^0$-$Z$ mixing. These possibilities define several one loop level contributions to the $gg \to V^+V^-$ scattering amplitude, proportional to $g^2 \alpha_S$, $g^2 g_K g V \alpha_S$ and $g^2 g_V \alpha_S$, respectively. This implies that the only relevant contribution to the $gg \to V^+V^-$ scattering amplitude is the one having the triangular loop followed by a scalar propagator coupled to it. At one loop level, the only top quark triangular diagram contribution to the $gg \to V^0V^0$ scattering amplitude is the one containing a scalar propagator coupled to the triangular loop. The one loop level box diagrams only contribute to the $gg \to V^0V^0$ scattering amplitude since they can be followed by a $Z$ boson propagator, $\pi^0$ and $Z$ propagators coupled by the $\pi^0$-$Z$ mixing. This implies that at one loop level there are only two box diagram contributions to the $gg \to V^0V^0$ scattering amplitude, both of them proportional to $g^4 g^2 V \alpha_S$, so that they can be neglected. Then, the only relevant contributions to the amplitudes for the heavy vector pair production by gluon fusion mechanism come from the top quark in the triangular loop followed by a scalar propagator. This implies that the amplitude for the gluon fusion process $gg \to V^+V^-$ is given by the following expression:

$$ A(gg \to V^+V^-) = -\frac{\alpha_S}{\pi} \left( \frac{cd}{8g_V^2 (s - M^2_h)} \right) \delta_{ab} \left[ g^{\mu\nu} (p \cdot k) - p^\nu k^\mu \right] I \left( \frac{s}{m_t^2} \right) \varepsilon_\mu (p, \chi) \varepsilon_\nu (k, \chi'), $$

$$ \times g^{\rho\sigma} \varepsilon_\rho (l, \xi) \varepsilon_\sigma (q, \xi'), $$

where $I \left( \frac{s}{m_t^2} \right)$ is given by:

$$ I \left( \frac{s}{m_t^2} \right) = \int_0^1 dx \int_0^{1-x} dy \frac{1 - 4xy}{1 - \frac{s}{m_t^2} xy}. $$
Here \( m_t \) is the mass of the top quark, \( \varepsilon_\mu (p, \chi) \) and \( \varepsilon_\nu (k, \chi') \) are the polarization vectors of the gluons, \( \varepsilon_\mu (l, \xi) \) and \( \varepsilon_\nu (q, \xi') \) are the polarization vectors of the heavy vectors, \( s = (p + k)^2 = 2p \cdot k \) is the energy of the virtual scalar, \( a, b = 1, 2, \ldots, 8 \) are the color indices of the gluons.

Besides that, in order to cancel the growth of the \( \pi \pi \rightarrow \bar{\psi} \psi \) scattering amplitude with \( \sqrt{s} \) (where \( \bar{\psi} \) denotes a SM fermion in the mass eigenstate), \( c \) should satisfy:

\[
c = \frac{1}{a}. \tag{3.3}
\]

It is shown in [20] that the elastic \( W_L W_L \) scattering has a good asymptotic behaviour provided that:

\[
a = \sqrt{1 - \frac{3G_V}{v^2}}, \quad G_V = g_V M_V, \tag{3.4}
\]

which implies the upper bound \( G_V \leq v/\sqrt{3} \) for the coupling \( G_V \) of the heavy vector to two longitudinal SM gauge bosons.

The previous conditions imply that the coupling \( c \) should satisfy the following relation:

\[
c = \frac{1}{\sqrt{1 - \frac{3G_V^2}{v^2}}} \tag{3.5}
\]

From (3.1) and taking into account that the symmetry factor of the \( hV^0V^0 \) vertex is 2, it follows that the squared amplitudes for the vector pair production via gluon fusion mechanism summed over the polarization and color states are given by:

\[
\sum_{a,b,\chi,\chi',\xi,\xi'} |A (gg \rightarrow V^+V^-)|^2 = \frac{1}{4} \sum_{a,b,\chi,\chi',\xi,\xi'} |A (gg \rightarrow V^0V^0)|^2
= \frac{c^2 d^2 \alpha_s^2 s^2}{16\pi^2 g_V^4 (s - M_V^2)^2} \left| I \left( \frac{s}{m_t^2} \right) \right| \left( \frac{s^2}{4M_V^4} - \frac{s}{M_V^2} + 3 \right) \tag{3.6}
\]

The gluon fusion vector pair production amplitudes grow as \( \frac{1}{m_V^3} \) at high energies. In this case the asymptotic behaviour of the gluon fusion vector pair production amplitudes will have to be improved by introducing a scalar-vector mixing term, with appropriate coupling.

## 4 Vector pair production total cross sections via gluon fusion

The final states for the vector pair production via gluon fusion mechanism obviously are the charge states \( V^+V^- \) and \( V^0V^0 \). The total cross section for the \( V^+V^- (V^0V^0) \) production through gluon fusion mechanism in proton proton collisions with center of mass energy \( \sqrt{S} \) is given by:

\[
\sigma_{pp \rightarrow gg \rightarrow V^+V^- (V^0V^0)} (S) = \int_{\sqrt{2M_V^2}}^{1} dx \int_{\sqrt{2M_V^2}}^{1} dy f_{p/g} (x, \mu^2) f_{p/g} (y, \mu^2) \sigma_{gg \rightarrow V^+V^- (V^0V^0)} (s), \tag{4.1}
\]
\[ s = x y S, \quad f_{p/g}(x, \mu^2) \] and \( f_{p/g}(y, \mu^2) \) are the distributions of gluons in the proton which carry momentum fractions \( x \) and \( y \) of the proton, respectively. Here \( \mu = \sqrt{s} \) is the factorization scale and \( \sigma_{g g \rightarrow V^+ V^-}(s) \) is the parton level cross section for the process \( g g \rightarrow V^+ V^- \) given by:

\[
\sigma_{g g \rightarrow V^+ V^-}(s) = \frac{1}{4} \sigma_{g g \rightarrow V^0 V^0}(s) = \frac{1}{4} \times \frac{1}{64} \times \frac{1}{16 \pi s^2} \int_{t_{\text{min}}}^{t_{\text{max}}} \sum_{a,b,\chi,\chi',\xi,\xi'} |A(gg \rightarrow V^+ V^-)|^2 dt, \quad (4.2)
\]

being \( t_{\text{min}} \) and \( t_{\text{max}} \) given by:

\[
t_{\text{min}} = -\left( \sqrt{\frac{s}{4}} + \sqrt{\frac{s}{4} - M_V^2} \right)^2, \quad t_{\text{max}} = -\left( \sqrt{\frac{s}{4}} - \sqrt{\frac{s}{4} - M_V^2} \right)^2. \quad (4.3)
\]

In the expression (4.2), the factor \( \frac{1}{4} \) is due to the average over the transverse polarization states of the gluons and the factor \( \frac{1}{64} \) comes from the average over the color states of the gluons.

The Figures 1 and 2 show the total cross sections at the LHC for the \( V^+ V^- \) and \( V^0 V^0 \) production via gluon fusion mechanism as functions of the heavy vector mass \( M_V \) and for different values of the \( G_V \) parameter taking the scalar-vector coupling \( d \) equal to 1. The heavy vector mass has been taken to range from 500 GeV to 1 TeV, while a light scalar of mass \( M_h = 180 \) GeV has been considered. Here the top quark mass has been taken to be equal to \( m_t = 171.3 \) GeV. The coupling \( c \) has been chosen to satisfy the condition given in (3.5) which guarantees the unitarity in the elastic channel for longitudinal gauge boson scattering and in the inelastic scattering of two longitudinal SM gauge bosons into SM fermions pairs. The values of the total cross sections at the LHC for the production of the \( V^+ V^- \) and \( V^0 V^0 \) final states by gluon fusion mechanism with the top quark in the triangular loop as functions of the different parameters and for a scalar mass \( M_h = 180 \) GeV are listed in Table 1.

The total cross sections at the LHC for the production of the \( V^+ V^- \) and \( V^0 V^0 \) final states via gluon fusion mechanism take their minimum values for the gauge model scenario where \( G_V = \frac{1}{2}, \ a = \frac{1}{2} \) and \( d = 1 \), that corresponds to the case in which the composite heavy vector states are the massive gauge bosons of a hidden local symmetry [20]. This implies that the parameters of the gauge model scenario damp the high energy behaviour of the vector pair production amplitudes via gluon fusion mechanism. It can be seen that the total cross sections at the LHC for the vector pair production via gluon fusion mechanism are small to give rise to a signal for a large region of the parameter space. It is worth to mention that the gluon fusion mechanism is the only process leading to the \( V^0 V^0 \) final state that cannot be produced via Drell-Yan annihilation. In the concerning to the production of the \( V^+ V^- \) final state via gluon fusion mechanism, its corresponding total cross section is comparable with the \( V^+ V^- \) Drell-Yan production cross section, which is independent on the \( G_V \) coupling and is obtained in [18]. It is also important to mention that a weak coupling \( G_V \) of the heavy vector with two longitudinal SM gauge
Figure 1: Total cross sections for the $V^+V^-$ production via gluon fusion mechanism at the LHC for $\sqrt{S} = 14$ TeV and $d = 1$ as functions of the heavy vector mass $M_V$ for different values of the $G_V$ parameter. The yellow, blue and red lines correspond to $G_V = v/\sqrt{6}$, $G_V = v/2$ and $G_V = v$, respectively. Here $\alpha_S = 0.12$, $M_h = 180$ GeV, $m_t = 171.3$ GeV and $\mu = \sqrt{s}$. The coupling $c$ is chosen to satisfy the condition given in (3.5).

Figure 2: Total cross sections for the $V^0V^0$ production via gluon fusion mechanism at the LHC for $\sqrt{S} = 14$ TeV and $d = 1$ as functions of the heavy vector mass $M_V$ for different values of the $G_V$ parameter. The yellow, blue and red lines correspond to $G_V = \sqrt{5}v/4$, $G_V = v/\sqrt{6}$ and $G_V = v/2$, respectively. Here $\alpha_S = 0.12$, $M_h = 180$ GeV, $m_t = 171.3$ GeV and $\mu = \sqrt{s}$. The parameter $c$ is chosen to satisfy the condition given in (3.5).
bosons and a strong coupling $d$ of the scalar with the heavy vector pairs favors larger cross sections for the vector pair production via gluon fusion mechanism, since the corresponding squared amplitudes are proportional to $d^2 G^4 V$. This implies that deviations from $d = 1$ will result in a strong increase of the vector pair production cross sections via gluon fusion mechanism.

5 Same-sign di-lepton and tri-lepton events

Since the composite vectors decay mainly into $WW$ or $WZ$, with branching ratio very close to 1, the final state obtained from the vector pair production via gluon fusion will have four SM gauge bosons. Considering only the $e$ and $\mu$ leptons coming from the $W$ decays, the following table which shows the cumulative branching ratios for at least two same-sign leptons and three leptons in the $V^0 V^0$ charge configuration, is obtained:

| Decay Mode                  | di-leptons (%) | tri-leptons (%) |
|-----------------------------|----------------|-----------------|
| $V^0 V^0 \rightarrow W^+ W^- W^+ W^-$ | 8.9            | 3.2             |

Table 2: Dominant decay mode and cumulative branching ratios for the $V^0 V^0$ charge configuration. For the same sign di-lepton and tri-lepton branching ratios only the $e$ and $\mu$ leptons coming from the $W$ decays are considered.

Using the values of the cumulative branching ratios given in Table 2 and reference integrated luminosity...
of $\int L dt = 100 \text{ fb}^{-1}$ for the LHC, the total number of same sign di-lepton and tri-lepton events is obtained and shown in Table 3. These numbers of multilepton events are comparable to those obtained from the decay of composite vector pairs produced via Drell-Yan annihilation. The numbers of multilepton events from the decay of composite vector pairs produced via Drell-Yan annihilation, which are independent on the $G_V$ coupling, are given in [18]. Since the vector pair production cross sections via gluon fusion mechanism have a quadratic dependence on $d^2$, deviations of the parameter $d$ from $d = 1$ will lead to a significant increase on the numbers of multilepton events. To see if these events can be made emerge from the SM background, a careful study beyond the scope of this work has to be made. This study should include a detailed analysis with a high cut on the scalar sum $H_t$ of all the transverse momenta and of the missing energy in each event probably playing a crucial role.

### 6 Summary and conclusions

In the framework of strongly interacting dynamics for EWSB, composite light scalar singlet and triplet heavy vector resonances may exist and the interactions among themselves and with the Standard Model fermions and gauge bosons can be described by a $SU(2)_L \times SU(2)_R/SU(2)_{L+R}$ Effective Chiral Lagrangian. In this framework, the squared gluon fusion vector pair production amplitudes summed over the polarization and color states have been computed by considering that their only relevant contributions arise from the top quark in the triangular loop followed by a scalar propagator. The asymptotic behaviour of the gluon fusion vector pair production amplitudes goes as $\frac{s}{M_V^2}$ at high energies and will have to be improved by the inclusion of a scalar-vector mixing term, with appropriate coupling. The gluon fusion vector pair production amplitudes depend on the couplings $c$, $d$, $g_V$ and on the masses $M_h$, $M_V$ and $m_t$. The unitarity constraints in the elastic channel of longitudinal gauge boson scattering and in the inelastic scattering of two longitudinal SM gauge bosons into SM fermions pairs determine the relevant parameter space. A discussion about the phenomenology of the composite vector pair production via

| $G_V$       | $a$ | di-leptons | tri-leptons |
|------------|-----|------------|-------------|
| $\sqrt{5}v/4$ | 1/4 | 29         | 10          |
| $v/2$      | 1/2 | 11         | 4           |
| $v/\sqrt{6}$ | 1/\sqrt{2} | 13       | 5           |

Table 3: Total number of same sign di-lepton and tri-lepton events ($e$ or $\mu$ from $W$ decays) for the vector pair production via gluon fusion at the LHC for $\sqrt{s} = 14$ TeV and $\int L dt = 100 \text{ fb}^{-1}$ at $M_V = 500$ GeV, $M_h = 180$ GeV and $m_t = 171.3$ GeV for different values of the parameter $G_V$ (or $a$ according to relation (3.4)) and for $d = 1$. Since the gluon fusion total cross sections are proportional to $d^2$ the results can simply be generalized to different values of $d$. 


gluon fusion mechanism at the LHC has been presented. For a vector mass between 500 GeV and 1 TeV, for \( M_h = 180 \) GeV and \( m_t = 171.3 \) GeV, the total cross sections for the production of the \( V^+V^- \) and \( V^0V^0 \) final states at the LHC by gluon fusion mechanism have been computed. These total cross sections are of the order of few \( fb \). It is of remarkable relevance that the only process which produces a \( V^0V^0 \) final state is the gluon fusion mechanism since the \( V^0V^0 \) final state is absent in the Drell-Yan process. The \( V^+V^- \) final state production cross section via gluon fusion mechanism is comparable with the \( V^+V^- \) Drell-Yan production cross section. The \( V^0V^0 \) production total cross section via gluon fusion mechanism is 4 times larger than the \( V^+V^- \) production cross section since the ratio between the symmetry factors for the \( hV^0V^0 \) and \( hV^+V^- \) vertex is equal to 2. These total cross sections can be strongly increased since they depend quadratically on the scalar-vector coupling \( d \). The expected same sign di-lepton and tri-lepton events are of order of 10 for an integrated luminosity of 100 \( fb^{-1} \). Further detailed studies, which are beyond the scope of this work will have to be made to assess the detectability of these processes above the Standard Model backgrounds.

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