Frascati Physics Series Vol. XLVIII (2009), pp. 49-54
Young Researchers Workshop: *"Physics Challenges in the LHC Era"*
Frascati, May 11 and 14, 2009

# HEAVY VECTOR PAIR PRODUCTION AT LHC IN THE CHIRAL LAGRANGIAN FORMULATION

Antonio Enrique Cárcamo Hernández
*Scuola Normale Superiore Di Pisa, Pisa, Italy*

**Abstract**

The total cross sections for Heavy vector pair production at LHC by longitudinal gauge boson fusion and Drell Yan annihilation are studied as a function of the mass $M_V$ of the vector in the framework of the Chiral Lagrangian formulation with massive spin one fields. The cross section for $V^+V^-$ production in $e^+e^-$ collisions at $\sqrt{s} = 3TeV$ is also studied.

## 1 Introduction

In spite of the very good agreement of the Standard Model predictions with experimental data, the Higgs boson has not been detected experimentaly and then the mechanism of electroweak symmetry breaking responsible for the generation of the masses of the fermions and bosons remains to be explained. Besides that, the Standard Model does not explain the scale of the electroweak

symmetry breaking, which is a free parameter of the theory, taken from the experiment. Moreover, the Standard model has the so called hierarchy problem, which is the instability of the Higgs field against quantum corrections.
Since 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. With this motivation and inspired in the Chiral Perturbation Theory Lagrangian formalism up to $O\left(p^4\right)$ developed by Ecker et al., Barbieri et al have introduced a $SU\left(2\right)_L \times SU\left(2\right)_R$ Chiral Lagrangian with two massive spin one tensor fields of opposite parity which interact with the Goldstone bosons and with the Standard Model gauge fields. This Chiral Lagrangian formulation with massive spin one tensor fields of opposite parity, which is meant to be valid up to a cutoff $\Lambda \simeq 4\pi v \simeq 3TeV$ can account for the Electroweak Precision Tests and keep the unitarity of the longitudinal $W$ boson scattering under control up to $3TeV$ [1]. Since in the mentioned Chiral Lagrangian formulation with massive spin one tensor fields, unitarity of longitudinal $W$ boson scattering is preserved up to $3TeV$, these spin one tensor fields play the role of the Higgs boson in keeping unitarity under control.

## 2 Effective Chiral Lagrangian with massive spin 1 fields.

Chiral Lagrangians have been extensively used to describe the phenomenon of spontaneuos symmetry breaking in strong and in weak interactions. They can be regarded as the low energy limit of an underlying fundamental theory [2, 3, 4]. Inspired in the Chiral Perturbation Theory Lagrangian formalism up to $O\left(p^4\right)$ developed by Ecker et al. used in the description of the low energy effects in QCD, the following $SU\left(2\right)_L \times SU\left(2\right)_R$ invariant Lagrangian at $O\left(p^2\right)$ describing the coupling of heavy fields $V^{\mu\nu}$ and $A^{\mu\nu}$ to Goldstone bosons and Standard Model gauge fields, invariant under parity is considered [1]:

$$\begin{aligned}\mathcal{L}_{eff} &= \frac{v^2}{4}Tr\left(D_\mu U\left(D^\mu U\right)^\dagger\right) - \frac{1}{2}\sum_{R=V,A} Tr\left(\nabla^\lambda R_{\lambda\mu}\nabla_\nu R^{\nu\mu} - \frac{1}{2}M_V^2 R_{\mu\nu}R^{\mu\nu}\right) \\ &\quad + \frac{i}{2\sqrt{2}}G_V Tr\left(V^{\mu\nu}\left[u_\mu, u_\nu\right]\right) + \frac{F_V}{2\sqrt{2}}Tr\left[V^{\mu\nu}\left(uW_{\mu\nu}u^\dagger + u^\dagger B_{\mu\nu}u\right)\right] \\ &\quad + \frac{F_A}{2\sqrt{2}}Tr\left[A^{\mu\nu}\left(uW_{\mu\nu}u^\dagger - u^\dagger B_{\mu\nu}u\right)\right] \qquad (1)\end{aligned}$$

where the covariant derivate $\nabla_\mu$ acting on the $V_{\mu\nu}$ and $A_{\mu\nu}$ antisymmetric spin one tensor fields is defined as:

$$\nabla_\mu R = \partial_\mu R + [\Gamma_\mu, R], \qquad R_{\mu\nu} = \frac{1}{\sqrt{2}}\tau^a R^a_{\mu\nu}, \qquad R = V, A$$

$$\Gamma_\mu = \frac{1}{2}\left[u^\dagger\left(\partial_\mu - i\widehat{B}_\mu\right)u + u\left(\partial_\mu - i\widehat{W}_\mu\right)u^\dagger\right], \qquad u = e^{i\frac{\pi}{2v}}, \qquad \pi = \pi^a\tau^a$$

$$u_\mu = u_\mu^\dagger = iu^\dagger D_\mu U u^\dagger = iu^\dagger\left(\partial_\mu U - i\widehat{B}_\mu U + iU\widehat{W}_\mu\right)u^\dagger, \qquad U = u^2$$

being $\widehat{W}_\mu = \frac{g}{2}\tau^a W^a_\mu$, $\widehat{B}_\mu = \frac{g'}{2}\tau^3 B_\mu$ and $\Gamma_\mu$ the connection which contains Goldstone bosons and the Standard Model Gauge fields and $U$ an exponential representation of $SU(2)$ which incorporates the pions field. In the previous chiral effective Lagrangian, the Goldstone bosons are incorporated into non linear representations $SU_L(2) \times U(1)_Y$ symmetry group such that the mentioned Lagrangian has an $SU_L(2) \times U(1)_Y$ invariance. In the unitary gauge $U = 1$, the Lagrangian for the Goldstone bosons reduces to the mass terms for the gauge bosons. In the limit where the coupling $g'$ is neglected, the Lagrangian given in (1) has the custodial symmetry and the mass of the $W$ and $Z$ bosons are equal, which implies that the $\rho$ parameter at tree level is equal to one. The pions transforms like a triplet under the custodial symmetry group $SU(2)_{L+R}$, which plays the role of the isospin group when low energy pions interactions are considered.

## 3 Heavy vector pair production at LHC by gauge boson fusion.

The Figures 1a (left) and 1b (right) show the total cross sections at LHC computed by using VBA (Vector Boson Approximation) for all the processes of longitudinal vector production and vector production by longitudinal gauge boson fusion at $\sqrt{s} = 14TeV$ and $G_V = 200GeV$. The leading-order parton distribution functions CTEQ5M for quarks have been used. One has that the transverse and the interference between the transverse and longitudinal polarizations states of the vectors $V$' leads to total cross sections for the processes $pp \to G_L G'_L qq \to VV'qq$ with $G, G' = W, Z$ much bigger than the corresponding to the processes $pp \to G_L G'_L qq \to V_L V'_L qq$, respectively. It can be seen that the most important longitudinal vector and vector production processes are $pp \to W_L^+ W_L^+ qq \to V_L^+ V_L^+ qq$ and $pp \to W_L^+ Z_L qq \to V^+ V^0 qq$, respectively.

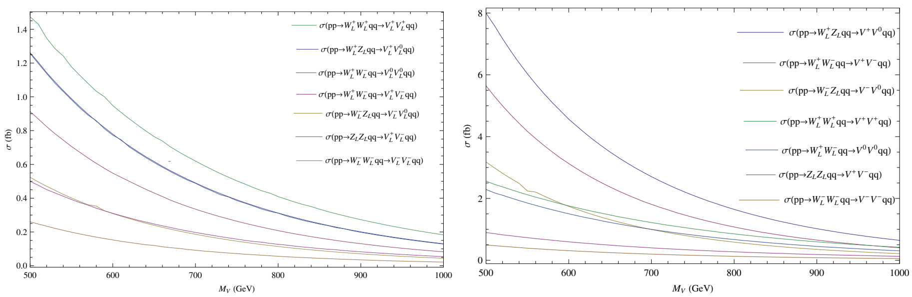


Figure 1: *a) Total cross sections at LHC for the processes of longitudinal vector production by longitudinal vector boson fusion b) Total cross sections at LHC for the processes of vector production by longitudinal vector boson fusion.*

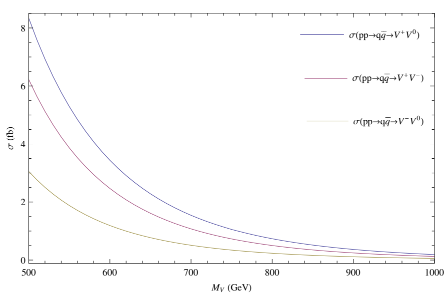


Figure 2: *Total cross sections at LHC for $V^{\pm}V^0$ and $V^+V^-$ vector production processes by Drell Yan annihilation.*

We have checked that the contribution of intermediate transverse gauge bosons is negligible.

## 4 Total cross section at LHC for the $V^{\pm}V^0$ and $V^+V^-$ production through Drell Yan annihilation.

The Figure 2 shows the total cross sections at LHC for the $V^{\pm}V^0$ and $V^+V^-$ production through Drell Yan annihilation in proton proton collisions through the processes $pp \to q\overline{q} \to V^{\pm}V^0$ and $pp \to q\overline{q} \to V^+V^-$ in terms of the mass $M_V$ of the vector for $\sqrt{s} = 14TeV$ (LHC center of mass energy). The leading-order parton distribution functions CTEQ5M for quarks have been used. It can be seen that the most important $VV$ production process in proton-proton collisions is through the Drell Yan annihilation with pairs of positive charged $V^+$ and neutral $V^0$ in the final state. For the lightest vector of mass $M_V = 500GeV$, the total cross section at LHC for the $V^+$ and $V^0$ production through Drell Yan mechanism is $8.34fb$ and for the very heavy vector of mass $M_V = 1TeV$, this total cross section is strongly supressed and has the value of $0.19fb$. The second most relevant production process of pairs of $V$'s through Drell Yan mechanism is in a pair of positive charged $V^+$ and a negative charged $V^-$, whose total cross section at LHC takes the values of $6.22fb$ and $0.13fb$ for $M_V = 500GeV$ and $M_V = 1TeV$, respectively. We notice that the total cross sections at LHC for vector production by gauge boson fusion and Drell Yan annihilation are numerically comparable. This results from a combination of the different partonic luminosities ($q\overline{q}$ versus $GG$) and of the different high energy behaviour of the partonic cross sections, of which only $GG \rightarrow VV$ grows with the center of mass energy.

## 5 Cross section for the $V^+V^-$ production in $e^+e^-$ collisions.

The Figure 3 shows the cross section for the $V^+V^-$ production in $e^+e^-$ collisions at $\sqrt{s} = 3TeV$. It can be seen that the most important $V^+V^-$ production process is through $e^+e^-$ collisions, since the cross section has the value of $107.24fb$ for the lightest vector of mass $M_V = 500GeV$. For a very heavy vector of mass $M_V = 1TeV$, the cross section for the $V^+V^-$ production in $e^+e^-$ collisions takes the value of $18.61fb$.

## 6 Conclusions

If heavy vectors exist with a mass in the $500 - 1000$ $GeV$ range, they will most likely be discovered at LHC in single production or in association with one standard gauge boson [1]. To understand the underlying physics, this will most likely not be enough. For this reason we have studied the pair production at LHC, which is in the few $fb$ range, depending on the specific process. The transverse polarization states and the interference between longitudinal and transverse polarization states of V give a significant contribution to the total cross sections for vector production processes. It is found that total cross

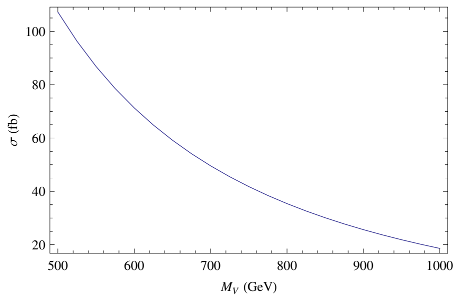


Figure 3: *Total cross sections for the $V^+V^-$ production in $e^+e^-$ collisions*

sections at LHC for vector production and Drell Yan annihilation have similar values and that the most relevant vector production processes corresponds to a pair of positive charged and neutral vectors in the final state. It is also important to mention that charged vector production process in $e^+e^-$ collisions is very promising. Further detailed studies will have to be made to assess the detectability of these processes above the Standard Model backgrounds.

## 7 Acknowledgements

The author thanks Professor Riccardo Barbieri for introducing him to this field, for carefully reading of the article and for very useful discussions. Author also thanks R. Torres, G. Corcella and R. Trincherini for very useful discussions.

## References

1. R. Barbieri, G. Isidori, V. S. Rychkov and E. Trincherini, Phys. Rev. **D 78**, 036012 (2008) [arXiv:hep-ph/0806.1624v1].

2. G. Ecker et al, Phys. Rev. Lett. **B 223** (1989) 425; Nucl. Phys. **B 321** (1989) 311

3. A. V. Manohar, arXiv:hep-ph/9606222v1.

4. A. Pich, arXiv:hep-ph/9806303v1.