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Associated scalar-vector production at the LHC within an effective Lagrangian approach

R. Torre

Dipartimento dell'Università and INFN, Sezione di Pisa - Largo Fibonacci 3
I-56127 Pisa, Italy

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Summary. — We consider the case in which a strong dynamics is responsible for Electro-Weak Symmetry Breaking (EWSB) and both a scalar h and a vector V, respectively a singlet and a triplet under a custodial $SU(2)$, are relevant and have a mass below the cut-off $\Lambda \approx 4\pi v$. In this framework we study the total cross sections for the associated Vh production at the LHC at 14 TeV as functions of two independent free parameters.

PACS 12.39.Fe – Chiral Lagrangians.
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PACS 12.60.Rc – Composite models.

1. – Introduction

The LHC will be able to explore the scale of Electro-Weak Symmetry Breaking (EWSB), *i.e.* the Fermi scale $v = 246\,\text{GeV}$ hopefully shedding light on the mechanism that generates it. If a strong dynamics is responsible for the EWSB, new degrees of freedom should become relevant at the Fermi scale in order to take under control the asymptotic behavior of the amplitudes for the longitudinal gauge boson scattering. In the framework of a strongly interacting dynamics for EWSB, we are interested in the case in which a scalar h and a vector V, respectively a singlet and a triplet under a custodial $SU(2)$ with a mass below the cut-off $\Lambda \approx 4\pi v$, share the task of unitarizing the $W_L W_L \to W_L W_L$ scattering. In particular we want to study the phenomenology of the Vh associated production at the LHC since it could be the main signature of the spectrum that we are considering.

2. – One vector and one scalar below the cut-off

We would like to construct a model-independent Lagrangian to describe the new degrees of freedom h and V without making any hypotheses on the origin of the light scalar: it could be a Strongly Interacting Light Higgs (SILH) boson in the sense of [1]

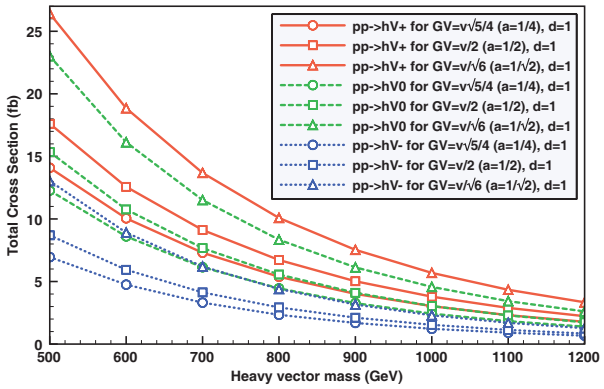

Fig. 1. – Total cross sections for the DY associated Vh productions as functions of the heavy vector mass at the LHC for $\sqrt{s} = 14\,\text{TeV}$, $m_h = 180\,\text{GeV}$, $d = 1$ and for different values of G_V.

or a more complicated object arising from an unknown strong dynamics. Nevertheless, in order to construct a phenomenologically relevant Lagrangian we have to make some assumptions that can be stated as follows:

1. Before weak gauging, the Lagrangian responsible for EWSB has a $SU(2)_L \times SU(2)^N \times SU(2)_R$ global symmetry, with $SU(2)^N$ gauged, spontaneously broken to the diagonal $SU(2)_d$ by a generic non-linear sigma model.

2. Only one vector triplet V_μ^a of the $SU(2)^N$ gauge group has a mass below the cut-off $\Lambda \approx 3\,\text{TeV}$, while all the other heavy vectors can be integrated out. Furthermore the new vector triplet V_μ^a couples to fermions only through the mixing with the weak gauge bosons of $SU(2)_L \times U(1)_Y$ $(Y = T_{3R} + 1/2(B - L))$.

3. The spectrum also contains a light scalar singlet of $SU(2)_d$ with a relatively low mass $m_h \leq v$.

With these assumptions we are able to construct an effective Lagrangian (see [2] and [3]) with a cut-off $\Lambda \approx 3\,\text{TeV}$ to study the associated Vh production at the LHC. The general Lagrangian depends in principle on five couplings and on the scalar and vector masses, m_h and M_V, respectively. The five couplings can be related to each other by requiring unitarity of the two-body $W_L W_L$ scattering amplitudes. It is simple to show that requiring a constant asymptotic behavior at least for the elastic channel $(W_L W_L \to W_L W_L)$ the parameter space can be reduced to only two independent parameters for fixed values of m_h and M_V [2]. We can choose as the independent parameters sets either the pairs (G_V, d) or (a, d), where G_V, a and d are the couplings of the vector V and the scalar h to the weak Goldstone bosons and the coupling of hVV, respectively.

3. – Associated Vh production at the LHC

The most relevant channel for the associated Vh production at the LHC is the Drell-Yan (DY) annihilation. There are three different charge configuration for the Vh system: hV^-, hV^0 and hV^+. The DY total cross sections at the LHC at 14 TeV as functions of the heavy vector mass M_V for $m_h = 180\,\text{GeV}$ and for different values of the relevant couplings are depicted in fig. 1. From this figure we see that the DY total cross sections

TABLE I. – *Total number of same sign dilepton and trilepton events (e or μ from W decays) for the DY associated Vh production at the LHC for* $\sqrt{s} = 14\,\text{TeV}$, $L = 100\,\text{fb}^{-1}$, $M_V = 700\,\text{GeV}$ *and* $m_h = 180\,\text{GeV}$, $d = 1$ *and for different values of the parameter* G_V.

G_V	a	dileptons	trileptons
$\sqrt{5}v/4$	$1/4$	102.4	30.3
$v/2$	$1/2$	128.0	37.8
$v/\sqrt{6}$	$1/\sqrt{2}$	192.0	56.7

are of order of 10 fb for a reference value $d = 1$. The order of magnitude of the total cross sections for the DY associated production is comparable with the corresponding values of the total cross sections for the VV and hh productions([1]). Moreover, since the DY associated production is generated only through the hVV interaction, the total cross section is proportional to d^2 and therefore the total cross sections of fig. 1 are enhanced by a factor d^2 for $d > 1$.

4. – Multilepton events

Assuming $BR(h \to W^+W^-) \approx 1$, with the values of the total cross sections shown in fig. 1 we can compute the expected number of same-sign dilepton and trilepton events for a reference integrated luminosity $L = 100\,\text{fb}^{-1}$. For $M_V = 700\,\text{GeV}$ we find the number of multilepton events shown in table I.

5. – Conclusions

We have considered the case in which a scalar-vector system is relevant in a strongly interacting framework for EWSB. We have used a model-independent approach to construct an effective Lagrangian to study the associated Vh production at the LHC. The number of multi-lepton events in the high-luminosity phase of the LHC is of order of 100. A careful study of the background should be done to see if these events could emerge from it.

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([1]) For the hh and VV pair productions at the LHC see, respectively, [1] and [3].