Longitudinally polarized same-sign W boson pairs scattering and noncontractibility of the physical space

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Abstract

The production of the longitudinally polarized same-sign W boson pairs at the LHC pp collisions presents the unique opportunity to study and verify in detail the mechanism of the symmetry breaking in the Standard Model and beyond. We compare at leading order the electroweak contribution to this production in the Standard Model and in the theory of the noncontractible space containing the zero-norm massless zeta particle. It appears that the difference between differential cross sections is huge with the possibility to measure it in Run 3 and high-luminosity runs of the LHC.

1 Introduction and motivation

We highlight once more our motivation to further explore the phenomenological consequences of our theory of the noncontractible space within SU(3) conformal unification scheme in particle physics [1, 2, 3, 4, 5, 6, 7, 8] and its relation to the Einstein-Cartan cosmology [9, 10, 11, 12, 13, 14, 15, 16, 17, 18]. The mathematical consistency and phenomenological success of both theories a careful reader can verify in our articles.

In this work we want to emphasize rather large deviation from the Standard Model (SM) observables of the W boson scattering present in our symmetry breaking mechanism without the Higgs scalar. Observed anomalies in the B meson semileptonic (or even hadronic) decays in the electroweak (EW) theory or Tevatron top quark charge asymmetry in QCD are understandable within our symmetry breaking mechanism due to large quantum loop deviations caused by the large $(\frac{m_t}{\Lambda_{UV}})^2$ in EW theory or large $(\frac{Q}{\Lambda_{UV}})^2$ in QCD. The very precise measurements of the W boson mass by the CDFII at Tevatron and by CMS and ATLAS at the LHC show the embarassing 5σ difference, therefore questioning not only the EW theory but also the QCD through parton distributions [1]-[8].

On the other hand the longitudinally polarized same-sign W boson pairs scattering is very sensitive to the symmetry breaking mechanism at the tree level. We describe the necessary theoretical setup in the next section and discuss the phenomenlogical consequences in the concluding section.

2 Production of polarized W bosons at pp colliders

The production of the longitudinally polarized same-sign W boson pairs $pp \to W_L^+ W_L^+ jj$ consists of the EW and the QCD parts. It is calculated within the SM and it is well known that the EW contribution dominates.

Let us start with the exact formula for the amplitude of the subprocess of the longitudinally polarized $W_L^+ W_L^+$ scattering in SM evaluated in the unitary gauge (for details see [19]):

$$\begin{aligned}
\mathcal{M} &= \mathcal{M}_{gauge} + \mathcal{M}_{Higgs}, \qquad (1)\\
\mathcal{M}_{gauge} &= \frac{g^2 s(-8M_W^2 + 3s - sx^2)}{8M_W^4} + \frac{g^2 \cos^2\theta_W}{8M_W^4}\frac{C_Z}{J_Z} - \frac{g^2 \sin^2\theta_W}{8M_W^4}\frac{C_\gamma}{J_\gamma},\\
\mathcal{M}_{Higgs} &= g^2 \frac{C_H}{J_H},\\
s &= (p_1 + p_2)^2,\ x = \cos\theta,\ \theta = CM\ angle,\ e = g\sin\theta_W,\ \cos\theta_W = \frac{M_W}{M_Z},\\
M_W &= 80.4335GeV,\ M_Z = 91.1876GeV,\ M_H = 125GeV,\ M_\zeta = 0GeV.
\end{aligned}$$

It is important to acknowledge the cancellation between the divergent terms in the gauge and the Higgs parts of the amplitude in the limes $s \to \infty$ [19]:

$$\begin{aligned}
\mathcal{M}_{gauge} &= -\frac{g^2 s}{4M_W^2} + \mathcal{O}(s^0) + \mathcal{O}(\frac{M_W^2}{s}),\\
\mathcal{M}_H &= \frac{g^2 s}{4M_W^2} + \mathcal{O}(s^0).
\end{aligned}$$

This is not the case for the amplitude calculated in ref. [20].

The scalar doublet in our theory (denoted as BY [1]-[8]) without the Higgs scalar looks like:

$$\Phi(x) = \begin{pmatrix} \phi^+(x) \\ \frac{1}{\sqrt{2}}(v + \zeta(x) + \imath\chi(x)) \end{pmatrix},\ v = \frac{\sqrt{6}}{\pi}\Lambda_{UV},\ \Lambda_{UV} = \frac{\pi}{\sqrt{6}}\frac{2}{g}M_W. \qquad (2)$$

The contributions to the scattering of the Nambu-Goldstone bosons vanish in the unitary gauge but not the contribution of the zero-norm zero-spin zero-charge massless ζ particle. One has to put $M_\zeta = 0$ for the unphysical regulator auxiliary ζ field into the place of the physical Higgs boson mass M_H appearing in the above formulae. The cancellation of the $s \to \infty$ divergent terms does not depend on the Higgs (ζ field) mass.

We illustrate the behaviour of the amplitudes of the SM and BY for certain $x = \cos\theta$ in Fig.1.

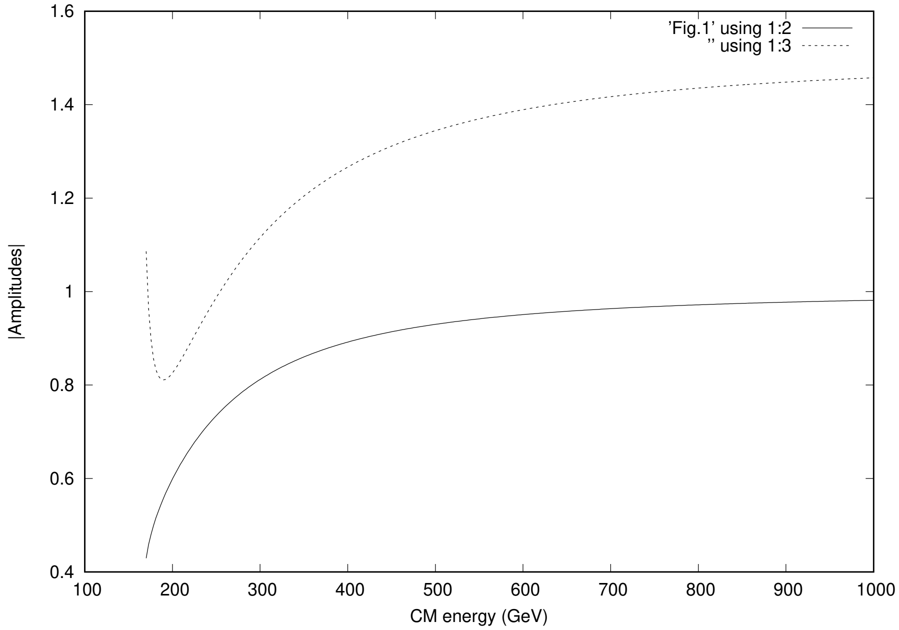

Figure 1: Amplitudes for $W_L^+W_L^+ \to W_L^+W_L^+$ scattering for the BY (full line) and the SM (dashed line) at $\cos\theta = 0.4$ as a function of the CM energy.

The cross section of the scattering $W_L^+W_L^+ \to W_L^+W_L^+$ is divergent because of the Coulomb pole at $x^2 = 1$ but this divergence of the subprocess is avoided by the kinematical cut defined by the full process [21]:

$$\sigma^*(s) = \frac{1}{32\pi s}\int_{-\cos\theta_{min}}^{\cos\theta_{min}} dx|\mathcal{M}|^2, \tag{3}$$
$$\theta_{min}(rad) \simeq \frac{2400}{(\sqrt{s}(GeV))^{5/3}}.$$

The massless ζ particle of the BY theory induces the same divergence as the Coulomb pole therefore the same kinematical cut as in the SM resolves the issue.

Cross sections of $W_L^+W_L^+ \to W_L^+W_L^+$ of SM and BY are depicted in Fig.2.

Using the effective W approximation with the $F_L(y)$ as a structure function for finding a longitudinally polarized W with a fraction y of the incoming quark's

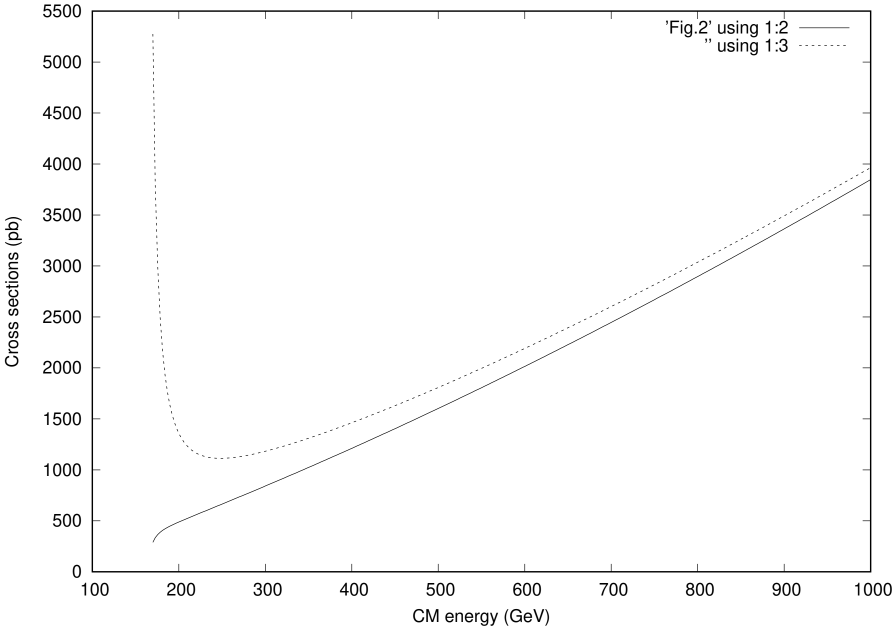

Figure 2: Cross sections $\sigma^*(W_L^+W_L^+ \to W_L^+W_L^+)$ for the BY (full line) and the SM (dashed line) as a function of the CM energy with a cut $\cos\theta_{min}$.

momentum, one can estimate a differential cross section of $qq \to W_L W_L$ as a function of the W boson pair's mass m_{WW} [21]:

$$
\begin{aligned}
\frac{d\hat{\sigma}(\hat{s})}{dQ^2} &= \frac{1}{\hat{s}} \int_{\hat{\tau}}^{1} \frac{dy}{y} F_L(y) F_L(\hat{\tau}/y) \sigma^*(Q^2), \qquad (4)\\
Q &= m_{WW},\ F_L(y) = \frac{\alpha_W}{4\pi}\frac{1-y}{y},\ \alpha_W = \frac{\alpha_e}{\sin^2\theta_W},\ \hat{\tau} = Q^2/\hat{s}.
\end{aligned}
$$

Performing the integration one finds [21]:

$$
\begin{aligned}
\frac{d\hat{\sigma}(\hat{s})}{dQ^2} &= \frac{1}{Q^2}(\frac{\alpha_W}{4\pi})^2 I(w) \sigma^*(Q^2), \qquad (5)\\
I(w) &= 2(w-1) - (1+w)\ln w,\ w = Q^2/\hat{s}.
\end{aligned}
$$

The convolution with the parton distribution functions (PDFs) in the proton and the standard change of the integration variables [22], gives finally the differential cross section of the process $pp \to W_L^+W_L^+jj$ [21]:

$$\begin{aligned}\frac{d\sigma(s)}{dQ} &= \frac{2}{Q}(\frac{\alpha_W}{4\pi})^2 \int_{-\eta_c}^{\eta_c} dy \int_{\tau_{min}}^{e^{-2|y|}} d\tau \sum_{l,j=u,\bar{d},\bar{s}} P_l(\sqrt{\tau}e^{y}, \sqrt{\tau s}) P_j(\sqrt{\tau}e^{-y}, \sqrt{\tau s}) \\ &\times \ I(Q^2/\tau s)\sigma^*(Q^2), \qquad (6) \\ \sqrt{s} &= hadronic\ CM\ energy,\ \tau_{min} = Q^2/s,\ \eta_c = rapidity\ cut,\ P_l = PDF.\end{aligned}$$

3 Results and conclusions

Though the experience with the very precise measurements of the M_W mass at Tevatron and LHC learns us that even the standard QCD PDFs can result in the conflicting results, the differences for the electroweak processes are very small. Hence, we use in Eq.(6) the PDFs in proton with three flavours (u,d,s) of the CTEQ collaboration [23] for both SM and BY.

We depict in Fig.3 the results for the SM and BY at hadronic $\sqrt{s} = 13TeV$ for the differential cross section in Eq. (6) for various W boson pair's mass $Q = m_{WW}$.

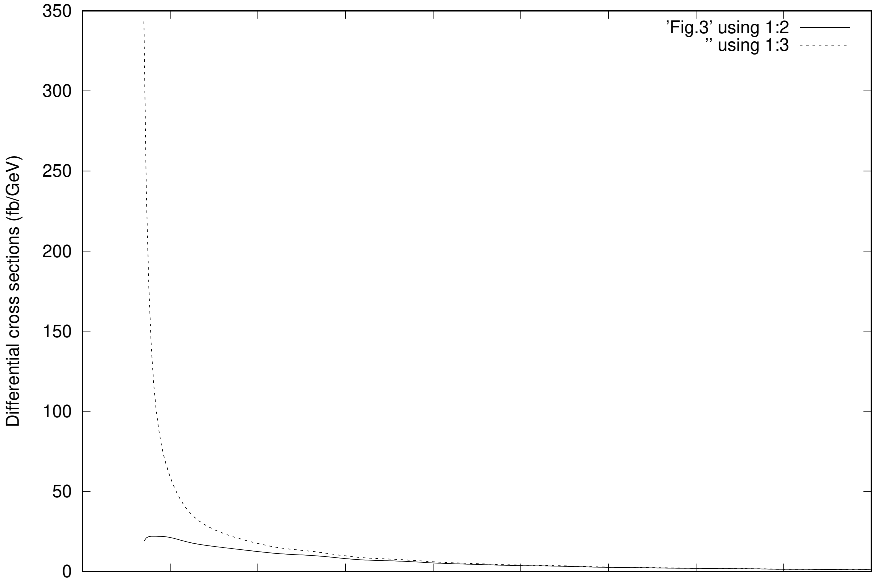

Figure 3: Differential cross sections $\frac{d\sigma(pp\to W_L^+ W_L^+ jj)}{dQ}$ for the BY (full line) and the SM (dashed line) for $\eta_c = 1.5$ and $\sqrt{s} = 13TeV$ as a function of the W boson pair's mass Q.

We present in Table 1 the quotient between the SM and BY differential cross

Table 1: Ratios $R = \frac{d\sigma(pp\to W_L^+W_L^+jj)}{dQ}(BY)/\frac{d\sigma(pp\to W_L^+W_L^+jj)}{dQ}(SM)$.

Q(GeV)	170	200.5	250.5	300.47	350.43	400.4
R(Q)	0.0549	0.36	0.60	0.71	0.78	0.83

sections for the EW $pp \to W_L^+W_L^+jj$ to underline the huge discrepancy in the interval $Q\epsilon[170, 400]GeV$.

The QCD and interference contributions to the process $pp \to W_L^+W_L^+jj$ are much smaller than the EW one [24]. The EW loop corrections [24] can not alter the quotients in Table 1.

The first measurements of the CMS [25] and ATLAS [26] refer to smaller number of events than expected from the SM estimates, though the statistics is very limited.

We conclude that the larger datasets of Run 3 and high-luminosity runs at the LHC will enable to study in detail not only processes like the production of the longitudinally polarized same-sign W bosons, but also more precisely measure decay processes of the 125 GeV scalar resonance and possibly discover new heavy resonances predicted as the QCD bound states of the mixed gluonium and toponium (bottomonium) [1]-[8].

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