Quark contact interactions at the LHC

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1 Introduction

The standard four-quark operator that is taken into account for deriving constrains on quark contact interaction scale involves left-currents [1]

$$\mathcal{L} = \frac{2\pi A}{\Lambda^2}\overline{\psi}_L\gamma^\mu\psi_L\overline{\psi}_L\gamma_\mu\psi_L \tag{1}$$

where Λ is the characteristic energy scale of the new interaction and $A = \pm 1$. Current constraints on contact interactions given by ATLAS and CMS [2, 3] assume the existence of only one kind of contact term, namely that in eq. (1). The aim of this work is to provide an analysis that extends the search for the bounds to more than one operator. A great variety of four fermion operators can arise in many low-energy effective theories. We do not want to track down every possible operator, so in this work we consider just a minimal model. The bounds on the interaction scales are derived at the level of Monte Carlo simulation, studying the dijet production in proton-proton collisions at the LHC, for a representative integrated luminosity of 200 pb^{-1} at $\sqrt{s} = 7$ TeV.

2 The minimal model

We consider the case of a single fermion family with quarks with the same mass. Following the general idea that stronger interactions are more symmetric than weaker ones, we want to be more restrictive and impose $SU(2)_L \times SU(2)_R$ symmetry and parity. The complete set of such invariant four-fermion operators is given by four independent terms:

$$\begin{aligned}\mathcal{L}_{\psi^4} &= \frac{2\pi}{\Lambda_1^2}\left(\overline{\psi}_L^{ia}\psi_R^{ja}\overline{\psi}_R^{jb}\psi_L^{ib}\right) + \frac{2\pi}{\Lambda_2^2}\left(\overline{\psi}_L^{ia}\psi_R^{jb}\overline{\psi}_R^{jb}\psi_L^{ia}\right)\\ &+ \frac{2\pi}{\Lambda_3^2}\left(\overline{\psi}_L^{ia}\gamma_\mu\psi_L^{ia}\overline{\psi}_L^{jb}\gamma^\mu\psi_L^{jb} + \overline{\psi}_R^{ia}\gamma_\mu\psi_R^{ia}\overline{\psi}_R^{jb}\gamma^\mu\psi_R^{jb}\right)\\ &+ \frac{2\pi}{\Lambda_4^2}\left(\overline{\psi}_L^{ia}\gamma_\mu\psi_L^{ib}\overline{\psi}_L^{jb}\gamma^\mu\psi_L^{ja} + \overline{\psi}_R^{ia}\gamma_\mu\psi_R^{ib}\overline{\psi}_R^{jb}\gamma^\mu\psi_R^{ja}\right),\end{aligned} \tag{2}$$

where i, j and a, b are $SU(2)$ and color indices.

3 Event generation and analysis

Dijet production in proton-proton collisions ($pp \to jj + X$) is the best channel to search for quark contact interactions. The variable $\chi = \exp(2|y^*|)$ is the quantity used for the angular distribution study, where $y^* = (y_1 - y_2)/2$ is the CM rapidity. In terms of the χ variable, the dijet $1/NdN/d\chi$ distribution obtained from the leading QCD subprocesses is almost flat, while in the case of contact interactions, which are more isotropic, the total dijet angular distribution can be considerable modified in the low χ region [2]. The measure of the isotropy in the dijet distribution is given by the variable F_χ. It measures the fraction of dijets produced centrally versus the total number of observed dijets in a specified dijet mass range:

$$F_\chi = \frac{N_{ev}(\chi < 3.32)}{N_{ev}(\chi < 30)} \tag{3}$$

MADGRAPHv4 has been used to simulate LHC dijet production in pp collisions at $\sqrt{s} = 7$ TeV. Monte Carlo samples corresponding to 1 fb^{-1} are generated for pure QCD and for QCD modified by the new four fermion interactions where different points of the $(\Lambda_1, \Lambda_2, \Lambda_3, \Lambda_4)$ parameter space are considered. In addition, a sample corresponding to 200 pb^{-1} of QCD data has been generated to be used as a pseudo-data sample. Hadronization and showering are implemented by PYTHIA v6.4, which is included in MADEVENT. Then the generated events are then passed through PGS in which the parameters are set to reproduce the ATLAS detector performance. We have applied the following cuts at generator level: $M_{jj} > 100\,\mathrm{GeV}$, $p_{Tj1}, p_{Tj2} > 30\,\mathrm{GeV}$, $|\eta_j| < 2.8$, $|y^*| < 1.70$. At the level of analysis we select events with at lest two jets requiring $p_{Tj1} > 60$ GeV and $p_{Tj2} > 30$ GeV, veto on an additional jet with $p_T > 15$ GeV and $|y_B| < 1.10$, where $y_B = (y_1 + y_2)/2$. Then, pseudo-experiments have been made for the chosen points of the Λ-parameters space in order to construct one-sided F_χ 95% confidence level (CL) which is used to set the lower bounds on the contact interaction scales.

4 Results

The first part of the study takes into account only two operators of eq. (1), the ones corresponding to Λ_1 and Λ_3. In this case $\Lambda_2 = \Lambda_4 = \infty$. The result of this analysis is shown by the first F_χ contour plot of Fig. 1. The values of Λ_1 and Λ_3 which satisfy the 95 % CL bound are represented by the area inside the curve. Lower bounds on the contact interaction scales are $\Lambda_1 = 2.4$ TeV and $\Lambda_3 = 5.1$ TeV. The standard one-operator analysis would give a limit $\Lambda_3 \sim 5.6$ TeV, we find a weaker bound because of interference effects. The second plot in Fig. 1 shows the F_χ 95 % CL contour in the case where all four fermion operators of eq. (1) are switched on. We assume two common scales $\Lambda_S = \Lambda_1 = \Lambda_2$ and $\Lambda_V = \Lambda_3 = \Lambda_4$. Lower bounds on these common contact interaction scales are $\Lambda_S = 4.8$ TeV and $\Lambda_V = 6.5$ TeV.

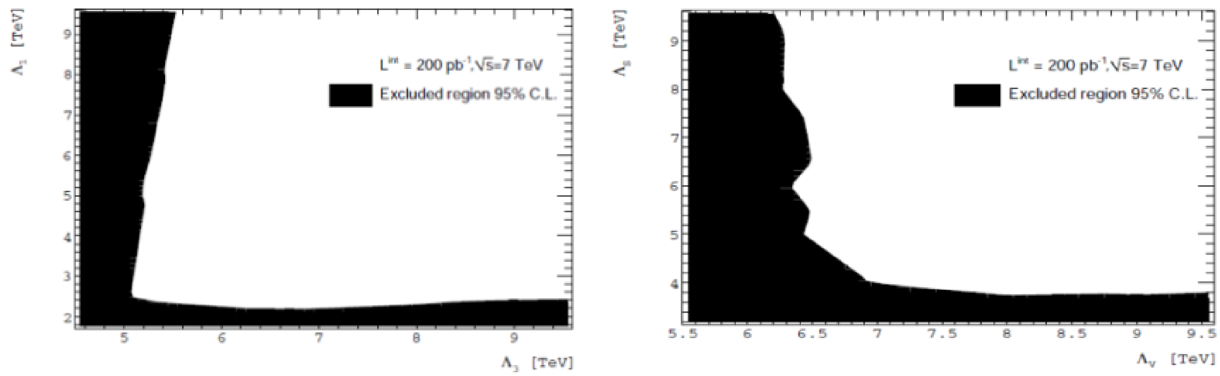

Figure 1: F_χ 95 % CL contour plot. The area inside the curves represent the values of the contact interaction scales compatible with the pseudo-data measured quantity.

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References

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