QUARK CONTACT INTERACTIONS AT THE LHC

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MOTIVATIONS

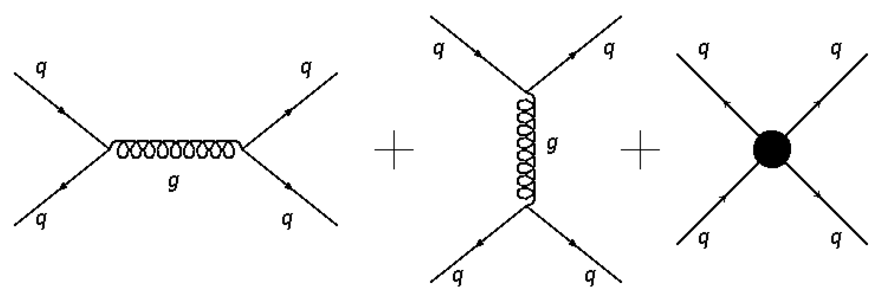
The standard four-quark operator [1] that is taken into account for deriving constrains on quark contact interaction scale involves left-currents:

$$\frac{2\pi A}{\Lambda^2}\,\bar\psi_L\gamma^\mu\psi_L\bar\psi_L\gamma_\mu\psi_L\,, \qquad (1)$$

where **Λ** is the characteristic energy scale of the new interaction, ***A***=±1. Current constraints on contact interactions given by ATLAS and CMS [3,4] assume the existence of only one kind of contact term, namely that in (1). In this work we extend the search for the bounds to more than one operator.

A great variety of different operators contributing to the quark contact interaction can arise in:

- low-energy effective approximation of a renormalizable lagrangian in which heavy particles are exchanged. The heavy states represent new physics which lives at an energy scale that is too high to manifest itself with the production of the new states, either as intermediate resonances or in chain-decay processes, and the effect of which can only be seen by the effective contact operators.
- asymptotically safe models of the weak interactions and a search for their presence could provide an important experimental clue [2]. Non-renormalizability is not a problem in models in which the couplings run toward a ultraviolet fixed point. In these asymptotically safe models the contact interactions can be considered as fundamental.



(2)

We do not want to track down each and every operator for its possible low-energy effect. We consider just a minimal model which is safe with respect to low-energy constraints [5]. We study dijet production in proton-proton collisions at the LHC for a representative integrated luminosity of ***200 pb⁻¹*** at **√s = 7 TeV**.

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:

$$\begin{aligned}\mathcal{L}_{\psi^4} = {} & \frac{2\pi}{\Lambda_1^2}\left(\bar\psi_L^{ia}\psi_R^{ja}\bar\psi_R^{jb}\psi_L^{ib}\right) + \frac{2\pi}{\Lambda_2^2}\left(\bar\psi_L^{ia}\psi_R^{jb}\bar\psi_R^{jb}\psi_L^{ia}\right)\\ & + \frac{2\pi}{\Lambda_3^2}\left(\bar\psi_L^{ia}\gamma_\mu\psi_L^{ia}\bar\psi_L^{jb}\gamma^\mu\psi_L^{jb} + \bar\psi_R^{ia}\gamma_\mu\psi_R^{ia}\bar\psi_R^{jb}\gamma^\mu\psi_R^{jb}\right)\\ & + \frac{2\pi}{\Lambda_4^2}\left(\bar\psi_L^{ia}\gamma_\mu\psi_L^{ib}\bar\psi_L^{jb}\gamma^\mu\psi_L^{ja} + \bar\psi_R^{ia}\gamma_\mu\psi_R^{ib}\bar\psi_R^{jb}\gamma^\mu\psi_R^{ja}\right)\,, \qquad (3)\end{aligned}$$

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

EVENT GENERATION

Due to CPU time consuming restrictions we consider a *skeleton model* in which the parameter space is restricted to Λ_1 and Λ_3:

$$\Lambda_1 \neq 0 \qquad \Lambda_2 = \infty \qquad \Lambda_3 \neq 0 \qquad \Lambda_4 = \infty.$$

Such simplification is already sufficient in showing how the presence of more than one operator gives rise to substantial interference effects which modify the bounds on the characteristic energy scale.

Dijet production (2) in proton-proton collisions (***pp -> jj+X***) is the best channel to search for quark contact interactions because:

- in QCD, the jet production rate peaks at large rapidity *y*, the because the scattering is dominated by *t*-channel processes.
- quark contact interactions produce a more isotropic angular distribution leading to enhanced jet production at smaller values of |*y*|.

The rapidity is defined as

$$y = \frac{1}{2}\log(E+p_z)/(E-p_z)\,,$$

where *E* is the energy and p_z the z-component of momentum of a given particle.

Searches for contact interactions at the LHC use quantities computed from these dijet rapidity distributions in the high invariant dijet mass (M_{jj}) region.

We use ***MADGRAPHv4*** to simulate LHC dijet production in pp collisions at √s = *7* TeV, Monte Carlo samples are generated for pure QCD and for QCD modified by the new four fermion interaction terms: we implement fictitious gauge interactions acting on *Ψ=(u,d)* with mass of the fictitious gauge boson chosen to be ~ *100* TeV. Hadronization and showering are implemented by ***PYTHIA v6.4***, which is included in MADEVENT. Then the generated events are then passed through ***PGS***, the detector simulator in which the parameters are set to reproduce the ATLAS detector performance.

- Cuts applied at the generator level:

  $M_{jj} > 1000$ GeV $\qquad p_T^{j1}, p_T^{j2} > 30$ GeV $\qquad |\eta| < 2.8$,

  the pseudorapidity is $\eta = -\log[\tan(\theta/2)]$, where *θ* is the lab angle between the jet and the beam direction.
- Monte Carlo samples generated for values of Λ_1 and Λ_3 between *1* and *10* TeV.
- Monte Carlo Leading order cross section $\sigma \sim 5 \times 10^3$ pb.
- Integrated luminosity = 1 fb⁻¹.

ANALYSIS

The variable *χ* is the quantity used for the angular distribution study:

$$\chi = \exp(2|y^*|)\,,$$

where *y*=(y1-y2)/2* is the CM Rapidity:

- In terms of the *χ* variable, the dijet *1/N dN/dχ* distribution obtained from the leading QCD subprocesses is almost flat.
- In the case of new physics processes, which are more isotropic, the total dijet angular distribution can be considerable modified by the presence of additional events in the low *χ* region, as shown in Fig 1.

*y** is used, in the massless limit, to determine the partonic CM angle *θ**:

$$y^* = \frac{1}{2}\log\left(\frac{1+|\cos\theta^*|}{1-|\cos\theta^*|}\right)$$

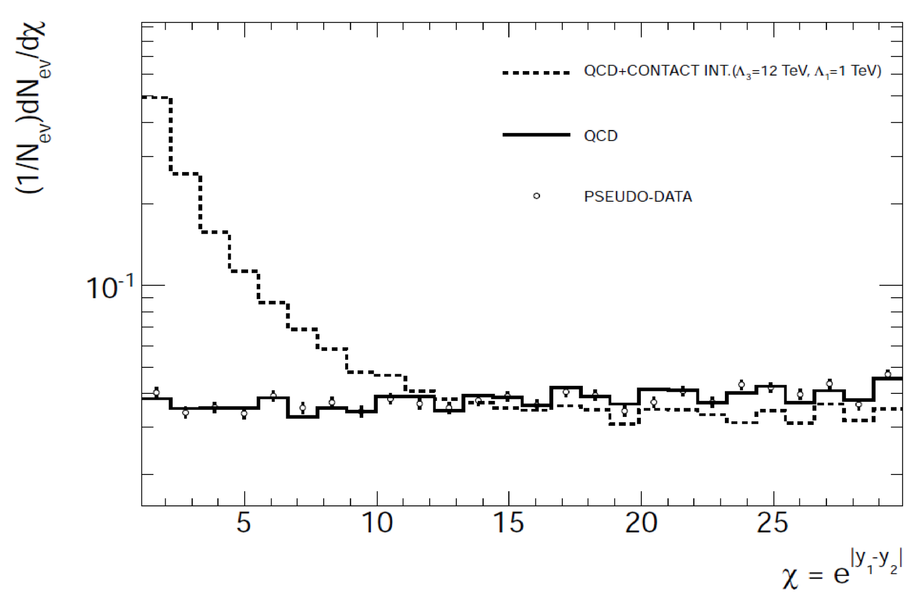


Fig 1

List of cuts applied for the analysis:

- Select events with at lest two jets,
- $P_t^{j1} > 60$ GeV and $P_t^{j1} > 30$ GeV,
- Veto on an additional jet with $P_t > 15$ GeV,
- select events for which |*yB*|<*1.10* and |*y**|<*1.70* [4], where *yB=(y1+y2)/2*.

The measure of the isotropy in the dijet distribution, introduced in [4], 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:

$$F_\chi = \frac{N_{\rm events}(|y^*| < 0.6)}{N_{\rm events}(|y^*| < 1.7)}\,.$$

The presence of possible contact terms is tested for each value of Λ_1 and Λ_3 in the highest dijet mass bin: $m_{jj} > 1200$ GeV.

- We have generated a QCD Monte Carlo sample, corresponding to an integrated luminosity of *200 pb⁻¹*, to be used as a pseudo-data sample.
- Pseudo-experiments has then been made for each of the points in the grid in order to construct one-sided *95 % CL*.

RESULTS

- The result of this analysis [6] is shown by the F_χ contour plot of Fig 2a. 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:

  $$\Lambda_1 = 2.4 \text{ TeV} \qquad \Lambda_3 = 5.1 \text{ TeV}.$$

  The standard one-operator analysis would give a limit $\Lambda_3 \sim 5.6$ TeV , we find a weaker bound because of interference effects.
- In Fig 2b we show the F_χ contour plot in the case of all four operators of (3) 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:

  $$\Lambda_S = 4.8 \text{ TeV} \qquad \Lambda_V = 6.5 \text{ TeV}.$$

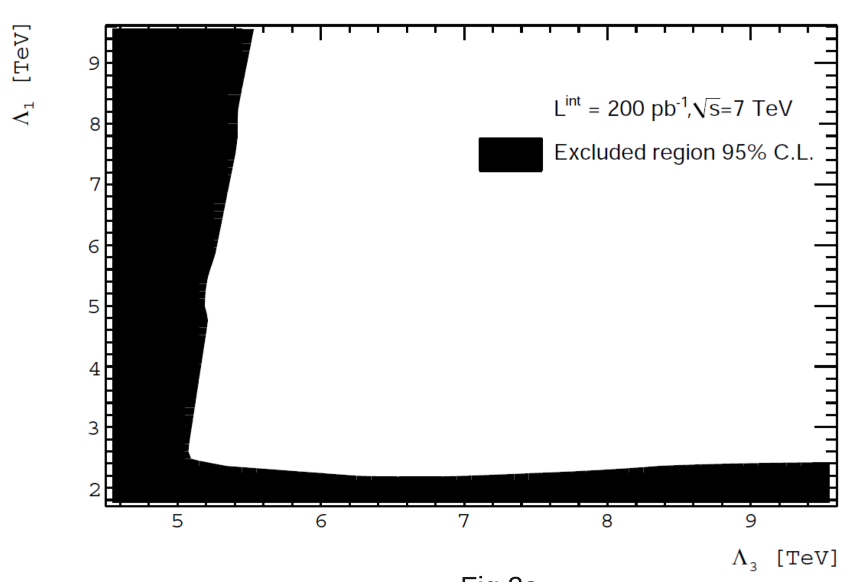


Fig 2a

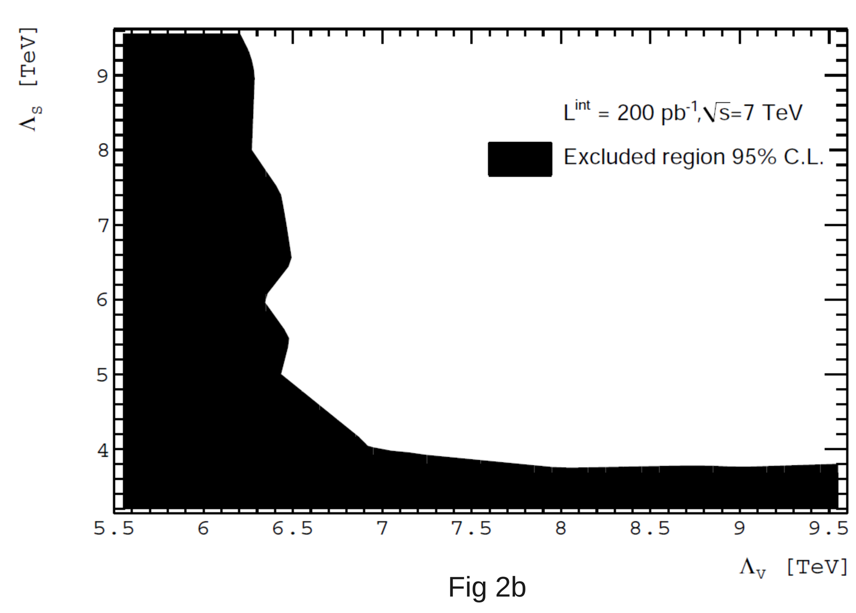


Fig 2b

References:

[1] E. Eichten, K. D.Lane, M. E. Peskin, ``New Tests for Quark and Lepton Substructure,'' Phys. Rev. Lett. 50, 811 (1983).

[2] F. Bazzocchi *et al., Phys. Lett. B 705, 388-392 (2011).*

[3] V.Khachatryan *et al.* [CMS],``Measurement of Dijet Angular Distributions and Search for Quark Compositeness in pp Collisions at √s = 7 TeV'', Phys. Rev. Lett. 106, 201804 (2011);``Search for quark compositeness in dijet angular distributions from pp collisions at √s=7 TeV'', CERN-PH-EP/2012-044.

[4] G. Aad *et al.* [ATLAS],``Search for quark contact interactions in dijet angular distributions in pp collisions at √s = 7 TeV measured with the ATLAS Detector'', Phys. Lett. B 694, 327 (2011); New J. Phys. 13, 053044 (2011); `` Search for New Phenomena in DijetMass and Angular Distributions using 4.8 fb⁻¹ of pp Collisions at √s=7 TeV collected by the ATLAS Detector'', ATLAS-CONF-2012-038.

[5] M. Bona *et al.* [UTfit],``Model-independent constraints on ΔF=2 operators and the scale of new physics'',JHEP 0803, 049 (2008).

[6] F. Bazzocchi *et al.,* [arXiv:1111.5936].