PROCEEDINGS OF SCIENCE

Searches for leptoquarks in CMS

Francesco Romeo* **on behalf of the CMS Collaboration**
Vanderbilt University
E-mail: fromeo@cern.ch

The most recent results from searches for leptoquarks are presented using pp collision data collected by the CMS experiment at a centre-of-mass energy of 13 TeV. A variety of final states is considered, probing leptoquark couplings to a quark and a neutrino, a top quark and a muon, a b quark and a tau lepton, and a light-flavour quark and a muon or an electron. No evidence is observed for physics beyond the standard model and 95% confidence level (C.L.) limits are set on model parameters for scalar and vector leptoquarks.

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*Speaker.

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1. Introduction

The "leptoquarks" (LQ) are hypothetical particles that carry both lepton and baryon number. They are predicted in many extensions of the standard model (SM) of which grand unified theories (GUT) [1], composite models [2], extended technicolor models [3], and R parity violating supersymmetry (SUSY) [4] are some examples.

LQ have fractional electric charge, and can have spin 0 (scalar LQ, denoted LQ_S) or 1 (vector LQ, denoted LQ_V). At hadron colliders, they can be produced mainly in a pair or singly, in association with a lepton, as illustrated in the Feynman diagrams in Fig. 1. For pair produced LQs, the cross section depends only on the LQ mass for LQs, while for LQv it may depend from additional parameters, in order to comply with constraints imposed by unitarity at high energy scales. In the following, we will consider the dimensionless coupling k and the value 1, Yang-Mills case, and 0, minimal coupling case. For singly produced LQ, the cross section further depends on the coupling to quark and lepton, λ, and the quark generation.

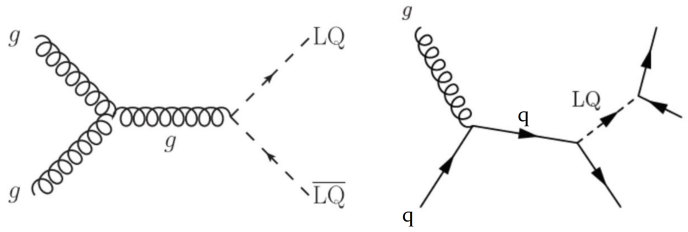

Figure 1: Feynman diagram for the production of pair (left) and single (right) LQ.

The LQ have recently gained enhanced interest as they may provide an explanation to a series of anomalies observed in precision measurements in the B-physics sector [5].

In this proceeding, we describe the most recent results from searches of LQ using pp collision data collected by the CMS experiment [6] at a centre-of-mass energy of 13 TeV. A vast range of signatures is considered in order to probe several LQ couplings, including those to a quark and a neutrino, a top quark and a muon, a b quark and a tau lepton, and a light-flavour quark and a muon or an electron. A complete description of the objects used in the analyses described below as well as of the systematic uncertainties treatment can be found in the corresponding references.

2. Search for LQ coupling to the pair $q\nu$

In this section the search for LQ coupling to the pair $q\nu$ is described, whose complete description can be found in [7]. The analysis reinterprets the results of a generic search for squarks and gluinos [8] to set constraints on pair produced LQ_S and LQ_V.

The baseline selection requires $N_j \geq 1$, where N_j denotes the number of jets with transverse momentum (pT) > 30 GeV, and to pass either missing transverse energy (p_T^{miss}) > 30 GeV if they have HT > 1000 GeV, or $p_T^{miss} > 250$ GeV if they have $250 < HT < 1000$ GeV, being HT the scalar sum of jet pT. Further baseline requirements include that the p_T^{miss} vector is not aligned in the azimuthal angle ϕ with any of the four leading jets in pT, that the negative vector sum of jet transverse momenta is consistent with the p_T^{miss}, and that no loosely identified charged leptons or isolated tracks are found in the event. Events are then categorized according to four variables: HT, M_{T2} [8], N_j, and number of b-tagged jets. The analysis spans a wide range of kinematics and jet

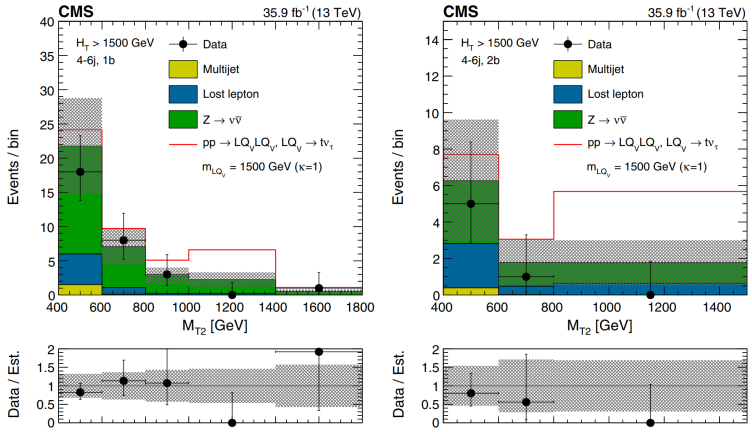

Figure 2: Distributions of M_{T2} showing data (black points), the background predictions (stack plot), and a hypothetical LQ_V signal with LQ mass of 1500 GeV for two categories with $H_T > 1500$ GeV, $4 \leq N_j \leq 6$, and $N_b = 1$ (left) and $N_b = 2$ (right).

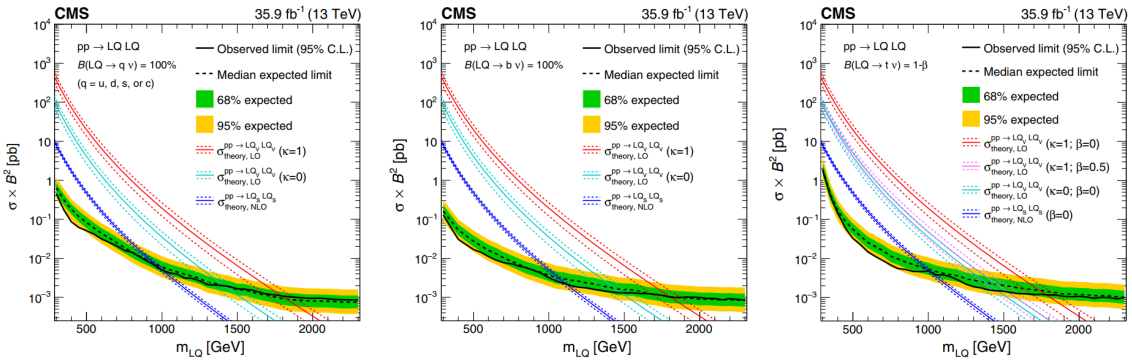

Figure 3: The 95% C.L. upper limits on the production cross sections as a function of LQ mass for LQ pair production decaying with 100% branching fraction to a neutrino and (left) a light quark (one of u, d, s, or c), (center) a bottom quark, or (right) a top quark.

multiplicities, containing 213 search bins in total. Figure 2 shows the M_{T2} distribution in two of the most sensitive search categories for the mass of the LQ (m_{LQ}) = 1500 GeV and the LQ decaying with unity branching fraction to the pair $t\nu$. Assuming a scalar (vector) LQ decaying with unity branching fraction to a light quark and neutrino, $m_{LQ} < 980$ (1790) GeV are excluded at the 95% C.L. by the observed data. For an LQ coupling to $b\nu$, $m_{LQ} < 1100$ (1810) GeV are excluded, and for an LQ decaying to $t\nu$, $m_{LQ} < 1020$ (1780) GeV are excluded, as shown in Figure 3.

3. Search for LQ coupling to the pair $t\mu$

Here, we report the results on the search for LQ coupling to the pair $t\mu$, whose complete description is in [9].

The analysis considers pair produced LQ in the final state with $2t$ plus 2μ. Events are selected considering e and μ with $p_T > 30$ GeV and if they have a minimum S_T, the scalar p_T sum of all selected final state objects, of 350 GeV and dimuon mass of 110 GeV. They are then separated in 2 categories according on whether they have at least 3 leptons or not.

The signal extraction is performed relying on the distribution of the LQ mass M_{LQ}^{rec} (3 lepton category) and S_T that are shown in Fig. 4. From Figure 4 a good agreement between the data and the expected background is found. Results are interpreted reporting observed upper limits on the production cross section for pair produced LQ_S and LQ_V at 95% C.L. in the plane B(LQ$\rightarrow t\mu$)-M_{LQ} that includes results from a search for LQ coupling to the pair $t\tau$ [10], Figure 5 (left), and B(LQ$\rightarrow t\mu$)-M_{LQ} that includes results from a search for LQ coupling to the pair $b\nu$ [7], Figure 5 (right).

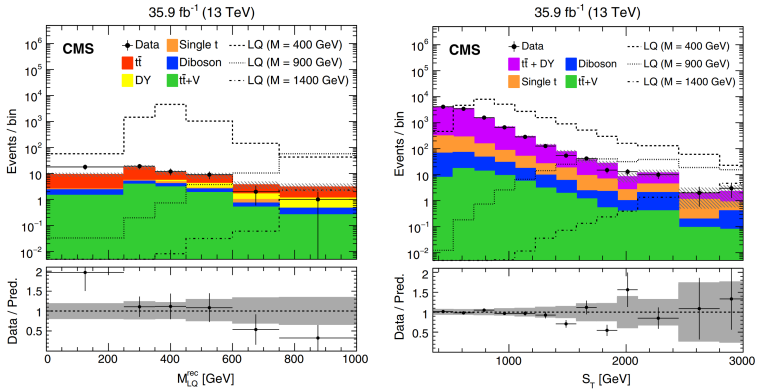

Figure 4: Distributions of the leptoquark mass, M_{LQ}^{rec}, (left) and the S_T variable (right), defined in the text.

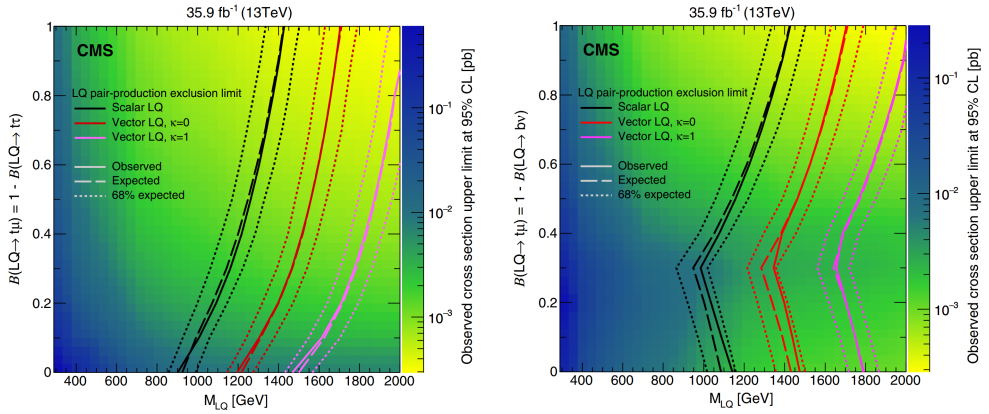

Figure 5: Observed upper limits on the production cross section for pair production of LQ decaying into a top quark and a muon or a τ lepton (left) and LQ decaying into a top quark and a muon or into a bottom quark and a neutrino (right) at 95% C.L. in the $M_{LQ} - \mathscr{B}(LQ \rightarrow t\mu)$ plane.

4. Search for LQ coupling to the pair $b\tau$

The case of an LQ coupling to the pair $b\tau$ is investigated through the pair production and the single production mechanism, whose cross-section competes with that of pair produced LQ for some values of λ and m_{LQ} of O(1) TeV [11]. The analyses consider the final states with 2 τ leptons plus 2 b quarks and 2 τ leptons plus 1 b quarks, whose complete description is reported in [12] and [13].

An excess of events over the SM backgrounds is searched for using the distribution of S_T and S_T^{MET}, which is given by S_T plus p_T^{miss}.

Figure 6 shows the S_T distribution of data and SM prediction for the pair (left) and singly (right) produced LQ searches, with the observed data consistent with the background only (SM) hypothesis. Figure 7 illustrates the 95% C.L. upper limits up to masses of 1 TeV for pair produced LQ_S (left) and in the plane λ-m_{LQ} (right) for singly produced LQ_S.

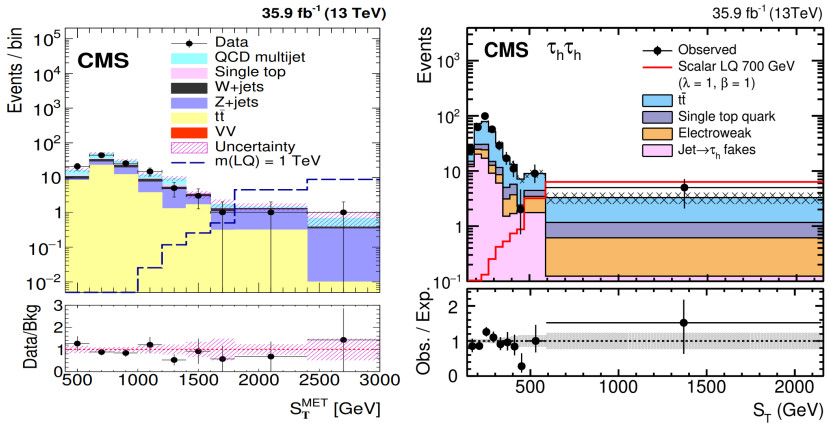

Figure 6: Distributions of S_T for the search of pair produced LQ (left) and singly produced LQ (right).

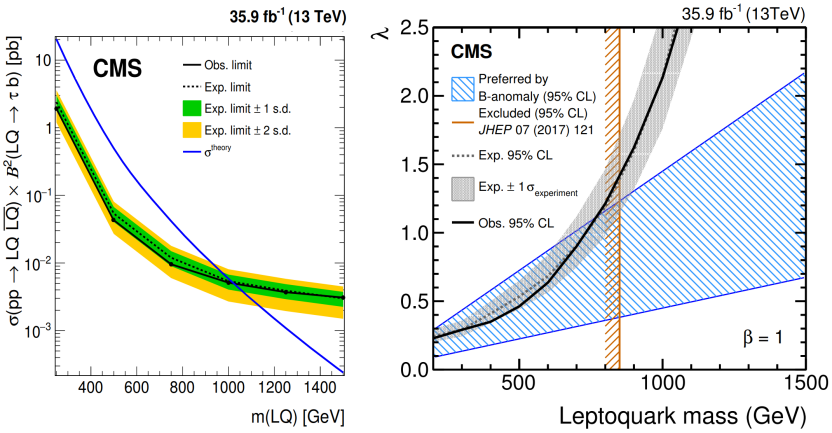

Figure 7: The 95% C.L. upper limits (left) on the production cross sections as a function of LQ mass for LQ_S pair production (left) and on the Yukawa coupling λ at the LQ-lepton-quark vertex, as a function of the LQ mass, from the search of singly produced LQ_S (right).

5. Search for LQ coupling to the pair $q\ell$ ($q\nu$)

The LQ coupling to the pair $q\ell$ ($q\nu$) is looked for considering the final states with $2e$ plus 2 jets ($1e$ plus p_T^{miss} plus 2 jets) and 2μ plus 2 jets (1μ plus p_T^{miss} plus 2 jets), whose complete searches are described in [14] and [15].

Electrons, muons, and jets are selected requiring their p_T to be greater than 50 GeV, which is the same minimum value required for p_T^{miss} in the event. The final signal selection is optimized for the highest significance considering 3 event variables: the mass of the 2 leptons (the transverse mass of the lepton plus p_T^{miss}), S_T, and $m_{\ell j}^{min}$, which is obtained from the smallest jet-ℓ pair that minimizes the LQ mass difference of the possible pairs.

Figure 8 shows the distrubtion of $m_{\ell j}^{min}$ for the electron (left) and muon (right) channels, with a good agreement between the data and the SM prediction. Figure 9 reports the 95% C.L. for pair produced LQ_S for the $2e$ plus 2 jets and $1e$ plus p_T^{miss} plus 2 jets (left) and 2μ plus 2 jets and 1μ plus p_T^{miss} plus 2 jets (right) shown in the plane of the branching fraction $\beta = \mathscr{B}$ (LQ$\rightarrow \ell q$) (1-β = B (LQ$\rightarrow \nu q$)) versus the mass of the LQ.

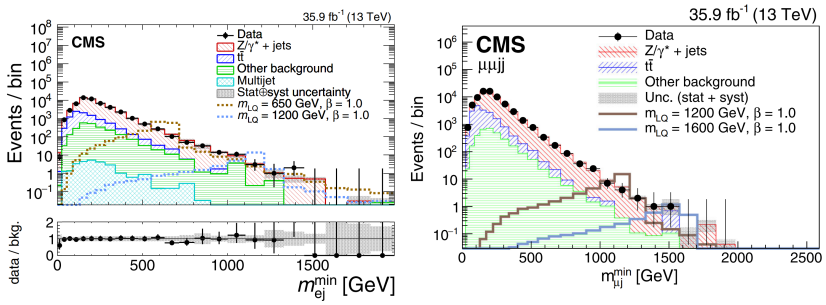

Figure 8: Distributions of $m_{\ell j}^{min}$ for the case of $\ell = e$ (left), $2e$ plus 2 jets search, and $\ell = \mu$ (right), 2μ plus 2 jets search.

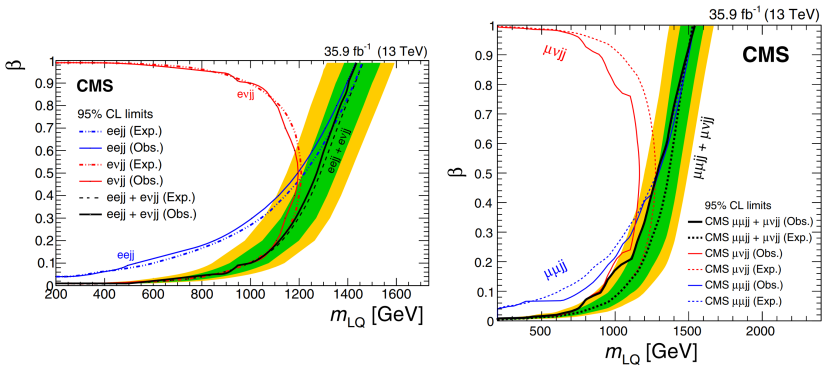

Figure 9: The 95% C.L. for pair produced scalar LQ coupling to eq (νq) (left) and μq (νq) (right) shown in the plane of the branching fraction $\beta = \mathscr{B}$ (LQ$\rightarrow \ell q$) (1-β = B (LQ$\rightarrow \nu q$)) versus the mass of the LQ.

6. Summary

In this proceeding we have reported the state of the art in the CMS experiment of searches for LQ, investigating different lepton plus jet signatures. In all the searches a good agreement is found between the data and the expectation from the SM. The diagram in Fig. 10 summarizes the 95% C.L. exclusion limits on the mass of the LQ, either scalar or vector, for the coupling to different lepton-quark pairs and the corresponding final states investigated.

References

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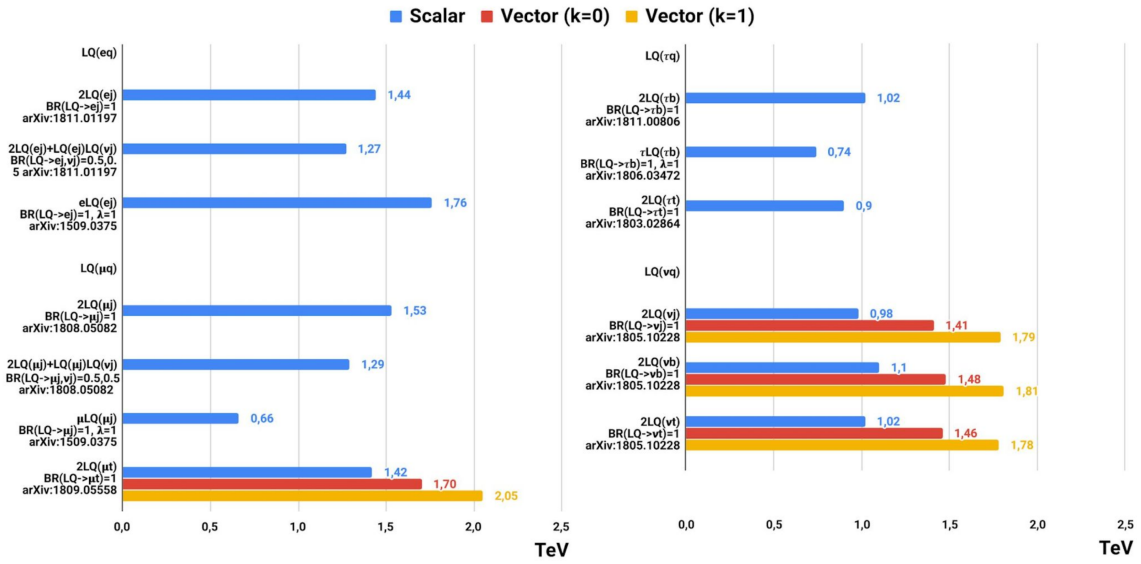

Figure 10: Summary of the exclusion limits on the LQ mass for different hypotheses of the coupling to a quark-lepton pair and the nature of the LQ, scalar or vector (k = 1, Yang-Mills case, and 0, minimal coupling case).

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