# First look at leptoquarks in CMS

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## ABSTRACT

This paper presents a study on scalar, second generation leptoquark pair production at LHC. Discovery potential of the CMS detector in the muon-jet decay channel was studied with realistic simulation of background and detector response. The mass reach was found to be ∼1.6 TeV for one year of running with luminosity $10^{34}$cm$^{-2}$s$^{-1}$.

## I. CROSS SECTIONS

Leptoquarks (LQ) are particles having both lepton and barion number different from zero. They are predicted by many models invoking symmetry larger than $U(1) \times SU(2) \times SU(3)$ of the Standard Model. Their properties are discussed in detail in [1]. LHC, thanks to its high energy (14 TeV) and high luminosity ($10^{34}$cm$^{-2}$s$^{-1}$) is a good place to search for them. In this paper we present preliminary study on the discovery potential of CMS — one of the LHC detectors.

We consider scalar leptoqark pair production and we study their decays into muons and quarks. Present analysis follows one implemented by the CDF collaboration [2]. CDF used ISAJET generator with HMRS-B structure functions to calculate expected cross sections. In our study, we used PYTHIA with CTEQ2L. Both programs are based on the same theoretical calculations [3], and their predictions should not differ. They are compared in Table I for $\sqrt{s} = 1.8$ TeV. Observed small differences can be explained by different structure functions.

Table I: Comparision of LQ pair production at $\sqrt{s} = 1.8$ TeV

| leptoquark mass | 45 | 65 | 85 | 105 | 125 | GeV |
|---|---|---|---|---|---|---|
| $\sigma$-isajet (HMRS-B) | 600 | 95 | 22 | 6.9 | 2.5 | pb |
| $\sigma$-pythia (CTEQ2L) | 537 | 83 | 19 | 5.5 | 1.8 | pb |

Cross sections calculated with PYTHIA for LHC energy are given in Table II. The table contains also the number of events expected for integrated luminosty of 100 fb$^{-1}$, i.e. one year of running with $\mathcal{L} = 10^{34}$cm$^{-2}$s$^{-1}$. Already from this table one can see, that the mass limit for the discovery is around 1.5 TeV. Therefore hereafter, we concentrate on the LQ masses of 1.4 and 1.6 GeV.

Table II: Scalar LQ pair production at $\sqrt{s} = 14$ TeV, $\int \mathcal{L} = 100 fb^{-1}$

| leptoquark mass | 1.0 | 1.4 | 1.6 | 2.0 | TeV |
|---|---|---|---|---|---|
| $\sigma$ | 8 | 0.65 | 0.2 | 0.02 | fb |
| number of events | 800 | 65 | 20 | 2 | |

## II. CMS DETECTOR SIMULATION

The behaviour of the CMS detector was simulated with a fast simulation package CMSJET [4]. In this program particles are not tracked explicitly, but various parametrisations are used:

- muon momenta are smeared according to a momentum resolution table,
- electromagnetic and hadronic shower parametisations are used to deposit energy in calorimeter cells,
- electrons reconstructed from electromagnetic clusters are matched with tracks,
- jets are reconstructed from calorimeter cells by a modified UA1 algorithm.

Signature for the studied channel are two muon-jet pairs with the same invariant mass. Therefore we acomplish the analysis by

- calculating effective mass $M_{\mu j}$ for each muon-jet pair
- selecting two pairs with minimal difference of $M_{\mu j}$.

## III. POSSIBLE BACKGROUNDS

The $2\mu\ 2jets$ signature can be observed also when a ZZ pair is produced, one Z decays into muons, the other one into quarks. Also $\mathrm{t\bar{t}}$ pairs decaing almost exclusively into W,b, W,b can produce similair signiture. In this paper we study the case when W's decay into $\mu\nu$ or qq. We also study its subset, when W's are forced to decay into muons, thus increasing available statistics. The number of events generated for these channels is given in Table III. Some of the events are lost during reconstruction, when the $2\mu\ 2jets$ signature is requested. This is illustrated in Figure 1, 2 and Table III. It is seen that the background channels suffer more then the signal.

Table III: Generated and reconstructed events.

| | $LQ, \overline{LQ}$ 1.6 TeV | $ZZ$ $\mu\mu, jj$ | $t\bar{t}$ $W \to \mu$ or jet | $t\bar{t}$ $W \to \mu$ |
|---|---|---|---|---|
| $\sigma$ | 0.2 fb | 6.2 fb | 2.3 pb | 4.6 fb |
| events | 20 | 6200 | 230 000 | 4600 |
| $\geq 1\mu$, $p_t > 10$ GeV | 97.6% | 79.3% | 16.1% | 94.3% |
| $\geq 1$ jet, $E_t > 40$ GeV | 97.5% | 66.3% | 16.0% | 91.2% |
| $\geq 2$ jets | 92.6% | 12.2% | 14.7% | 72.2% |
| $\geq 2\mu$'s | 92.6% | 12.2% | 14.7% | 72.2% |
| $\mu^+\mu^-$ pair | 91.9% | 12.1% | 5.6% | 71.4% |

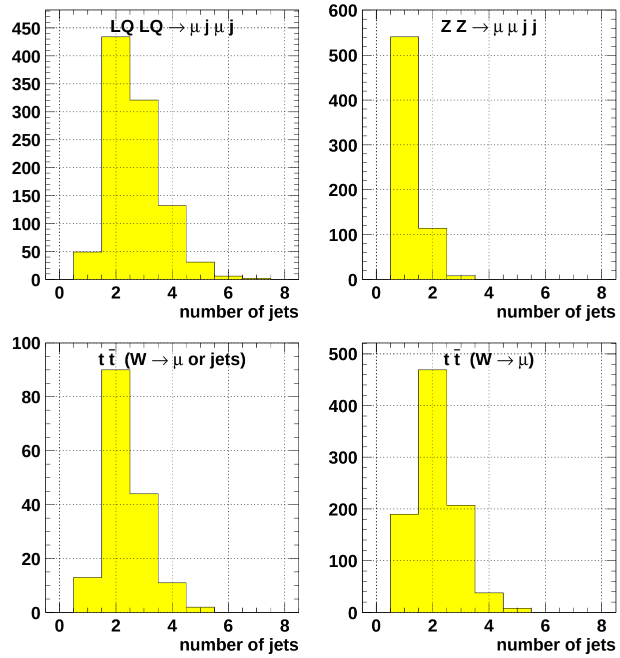


Figure 1: Jet multiplicity in signal and background events.

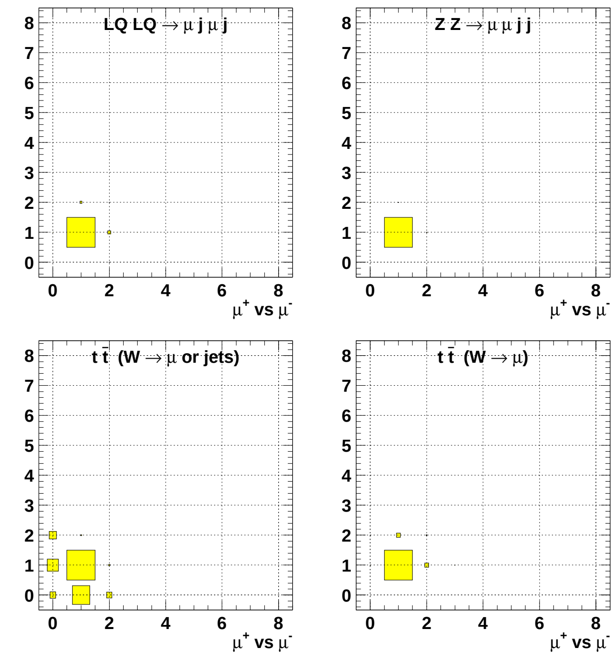


Figure 2: Number of positive end negative muons per event.

## IV. SELECTION OF EVENTS

In order to distinguish the signal from the background a number of topological and kinematical cuts can be applied. The cuts used in this study are listed in Table IV. Distributions of variables to be cut, obtained after the preselection described in the previous section are shown in Figures 3-7.

Table IV: Number of events after consecutive cuts. Notation ”10000×23” means that 10000 events have been generated which is 1/23 of expected statistics.

| | $LQ,\overline{LQ}$ 1.4 TeV | $LQ,\overline{LQ}$ 1.6 TeV | $ZZ$ $\mu\mu, jj$ | $t\bar{t}$ $W \to \mu$ or →jet | $t\bar{t}$ $W \to \mu$ |
|---|---|---|---|---|---|
| $\sigma$ [fb] | 0.65 | 0.2 | 6.2 | 2300 | 4.6 |
| events | 65 | 20 | 6200 | $10^4$×23 | 4600 |
| $\mu^+\mu^-$ $p_t > 200$ GeV | 57 | 15 | 17 | 18×23 | 343 |
| $M_{\mu\mu} > 200$ GeV | 56 | 15 | 9 | 14×23 | 340 |
| $\not{E}_t < 200$ GeV | 53 | 14 | 9 | 14×23 | 280 |
| $\geq 2$ jets, $E_t > 200$ GeV | 51 | 13 | 3 | 7×23 | 191 |
| $\Delta M_{\mu j}$ $< 200$ GeV | 45 | 12 | 3 | 7×23 | 182 |

The first cut was applied on the transverse momenta $p_t$ of muons. From Figure 3 it is seen that the $p_t$ spectra of signal muons is much harder than those from the background. A cut at 200 GeV can reduce the backgrounds by orders of magnitude preserving ∼75% of the signal.

A very efficient way to reject the ZZ background is a cut on the invariant mass of the muons $M_{\mu\mu}$. This is illustrated in Figure 4.

A cut on missing transverse energy $E_t^{miss}$ (Figure 5) could be useful to reject the tt background in the case of t→Wb, W→ $\mu\nu$ channel. However, simplified simulation used in this study is not able to predict $E_t^{miss}$ with high precision. Therefore rather modest cut of 200 GeV has been chosen.

Jet spectrum (Figure 6) is much harder for the signal than for the background. We cut it at 200 GeV.

Finally one can expect the same mass of both reconstructed leptoquarks. Therefore we requested that the two invariant masses of muon-jet pairs $M_{\mu j}$ do not differ more than 200 GeV (Figure 7). The distributions of $M_{\mu j}$ before and after this cut are given in Figures 8 and 9 respectively.

## V. CONCLUSIONS AND PLANS

From Tables III and IV one can conclude that the detector response cause ∼10% loss of the $LQ, \overline{LQ} \to \mu j,\ \mu j$ signal. The background can be reduced for the expense of further ∼40% of the signal. Final distributions of the muon-jet invariant mass $M_{\mu j}$ for $\sqrt{s}$=1.4 and 1.6 GeV are shown in Figure 10. In both cases the leptoquark peak is well separated from the background, however the statistics in the case of 1.6 TeV is already marginal. Therefore we can conclude that the leptoquark mass reach of the CMS is around 1.6 TeV.

Presented work is a first approach to see the CMS discovery potential for leptoquarks. It was done with the fast simulation program and the analsis was not really optimised. Therefore the work should be followed by a more careful study. First of all a detailed (GEANT based) detector simulation should be used. One can try to extend the search looking for first generation leptoquarks decaying into electrons. A single leptoquark produc-

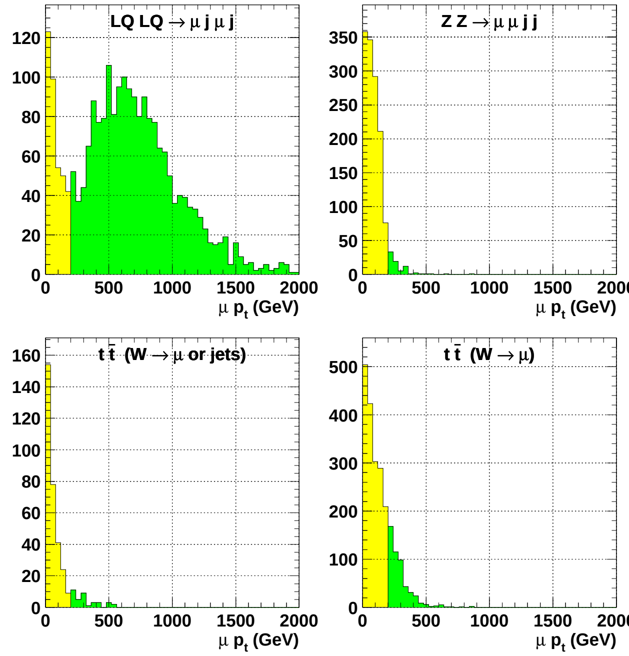


Figure 3: Muon transvese momentum distribution.

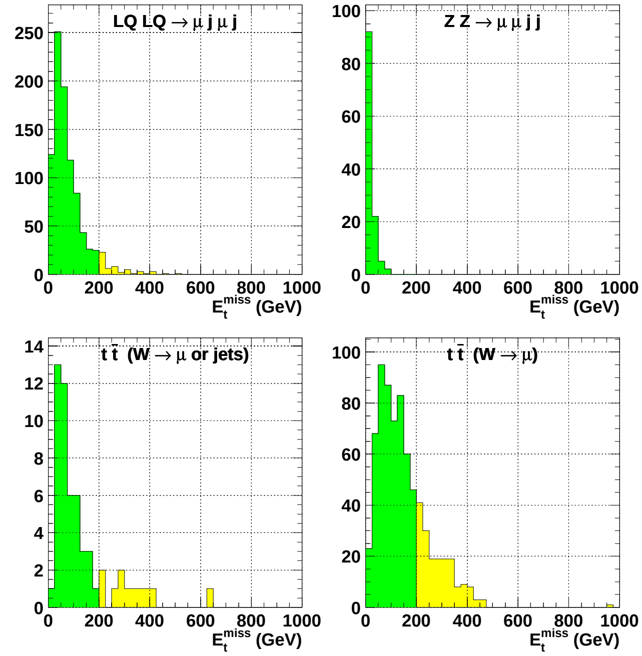


Figure 5: Missing $E_t$ distribution.

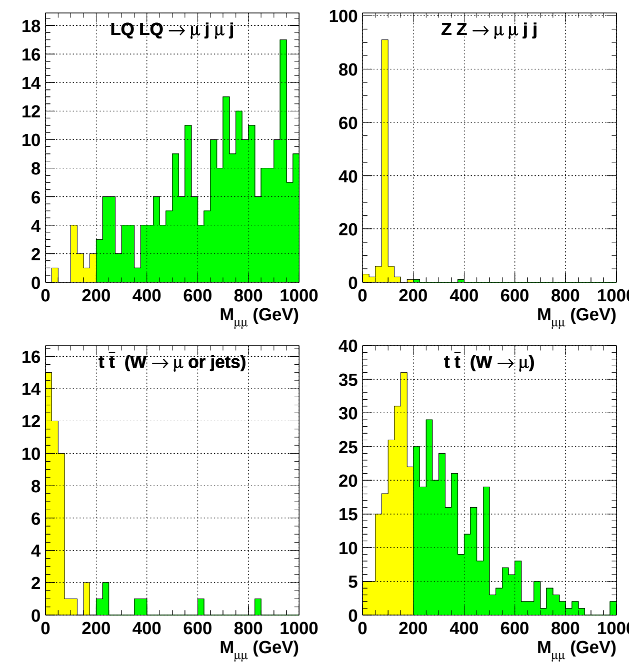


Figure 4: Two muon invariant mass distribution.

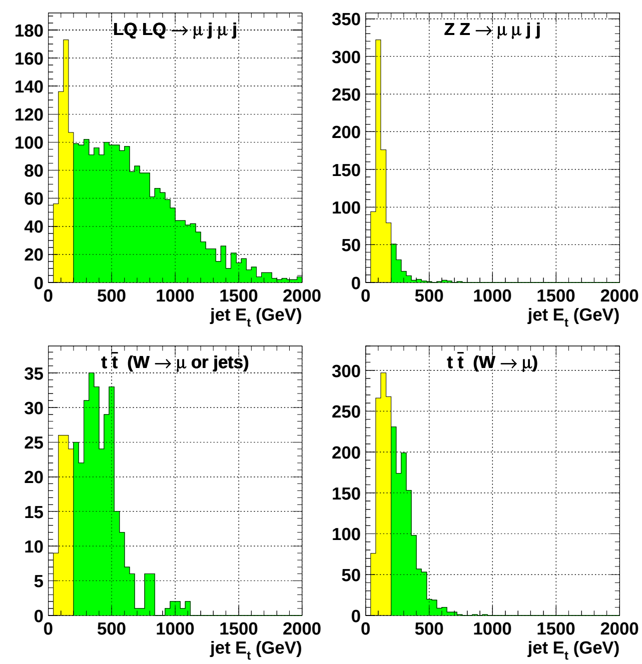


Figure 6: Jet transvese energy distribution.

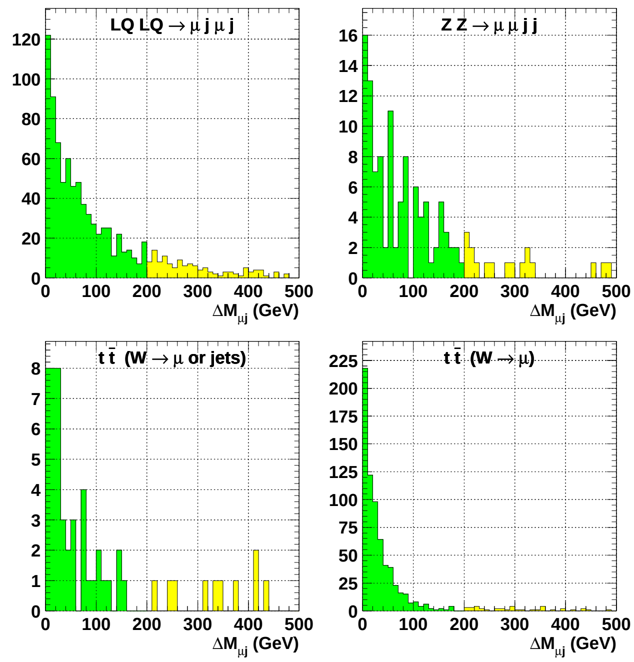


Figure 7: Distribuiton of the diference of invariant masses of the two muon-jet pairs.

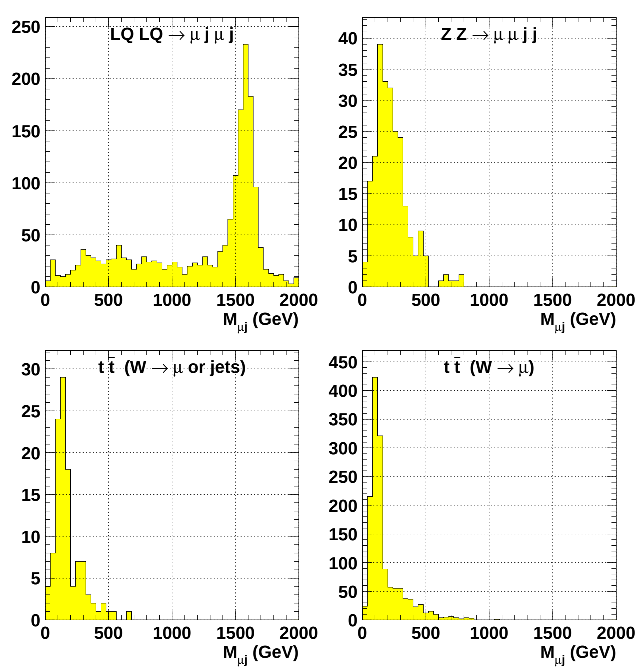


Figure 8: Distribution of the muon-jet invariant mass before the cut on $\Delta M_{\mu j}$.

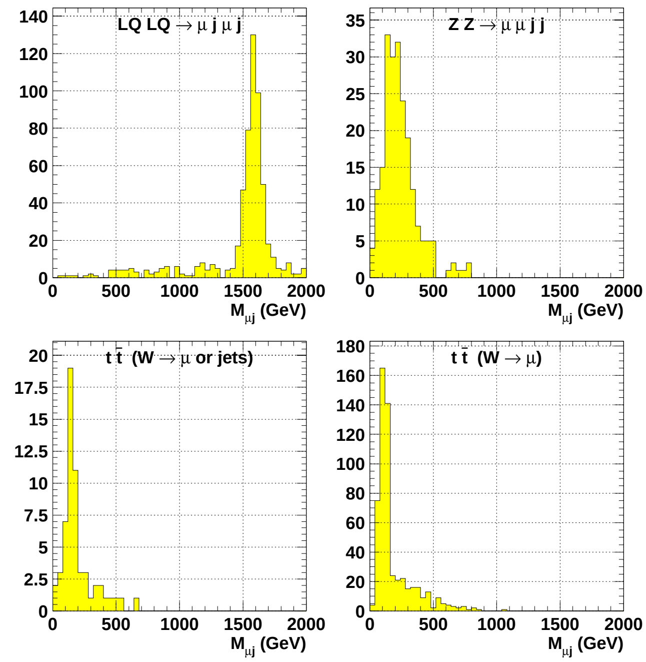


Figure 9: Distribution of the muon-jet invariant mass after the cut on $\Delta M_{\mu j}$.

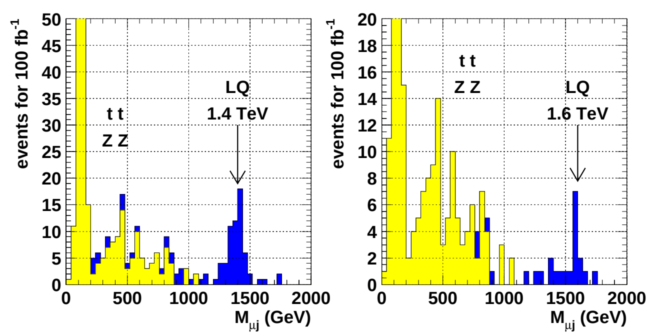


Figure 10: Leptoquark signal and background mass distribution in the CMS detector.

tion and vector leptoquarks should also be studied.

## VI. REFERENCES


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[4] S. Abdulin, A. Khanov, N. Stepanov, CMS Technical Note **CMS TN/94-180**, `http://cmsdoc.cern.ch/tn/94.html#94180`