CHAPTER 7
LEPTOQUARK SELECTION CUTS

The cross section of the Standard Model processes in missing $E_T$ plus jets channel is several orders of magnitude higher than that of the possible signal from new physics. Therefore, some selection mechanism is needed to maximize analysis sensitivity to this signal. Kinematical distribution of the leptoquark signal, generated using Monte Carlo program, compared with background distributions. Preliminary selection cuts are derived in order to maximize statistical significance of the possible excess due to the signal events. An upper limit on the production cross-section of the leptoquark pair is placed in the assumption that no excess would be observed in data. Since production cross-section depends on mass, as described in ???, the leptoquark production within certain mass range could be ruled out. Therefore the final selection cuts are obtained by maximizing the lower limit on the leptoquark mass.

7.1 Signal Monte Carlo

The first-generation scalar leptoquark signal was generated for 9 mass points (60, 75, 90, 100, 110, 125, 150, 175 and 200 GeV/c$^2$) with Pythia event generator. The CTEQ5L parton distribution functions were used and the underlying event was tuned as in QCD MC generation. We generate 80,000 events for each mass point, except for leptoquark mass of 60 GeV/c$^2$, where 78,000 events were generated.

Pythia output run through the simulation and reconstruction program as described above.

7.2 Signal and Background Kinematical Distributions

We use generated signal and background Monte Carlo samples to compare kinematical distributions. The analysis strategy is to identify such variables that
discriminate most signal from the background. Then we can place a cut on such variables with intention to retain as much signal events as possible while keeping number of background events small. We will use the signal MC sample with leptoquark mass of 100 GeV/c^2 for such comparison, since we would like to extend the current limit of 98 GeV/c^2.

We first look at the kinematical distribution of leptoquark and decay products at the generator level. Figure 7–1 shows the transverse momentum and pseudo-rapidity distributions of the quarks appearing from the decay of pair of leptoquarks. One of the quarks has larger transverse momentum which reflects the fact that parent LQ is boosted less along the z-axis. Usually, the more massive particle gets less boost in the longitudinal direction, since most of the initial parton energy goes into the particle creation. Figure 7–2 shows the projection in the transverse plane of the vector sum of neutrino momenta from the leptoquark pair decays. It gives an idea of how big momentum imbalance would be due to our inability to detect neutrino.
Figure 7–2: Missing $E_T$ distribution in minbias events.

We compare the shapes of the distribution for the signal and the background for the following variables: missing transverse energy, jet energies, jet boost along $z$ axis, pseudo-rapidity of the jets, the angle between the two most energetic jets, the angle between the highest energetic jet and missing-$E_T$ direction, the separation between the missing-$E_T$ direction and direction of any jet in $\phi$, the number of tracks associated to the jet. Since we interested only in the shapes of the distribution at this point, we normalize them to the unit area.

Our signal is expected to have large missing-$E_T$ since the final state includes neutralinos that carry away part of the LQ momentum and escape detection. On the other hand, we expect somewhat smaller missing-$E_T$ from the electroweak background since only one neutrino is present. And we do not expect large missing-$E_T$ for the QCD multi-jet events. Figure 7–3 compares the missing-$E_T$ distribution for the signal and background events.

Figure 7–4 shows the leading and second leading jet $E_T$ distribution. The jets in the electroweak processes are mostly due to the quark and gluon radiation and thus are not as energetic as from LQ decay or direct QCD production.
Figure 7–3: The missing-$E_T$ distribution for the pair production of first generation leptoquarks ($m_{LQ} = 100 \text{ GeV}/c^2$) compared to the missing-$E_T$ distributions for the dominant Standard Model background processes.
Figure 7-4: (Top) Comparison of the $E_T$ distributions for the first-leading jet (J1) for the leptoquark pair production and for the dominant Standard Model processes. (Bottom) Comparison of the $E_T$ distributions for the second-leading jet (J2) for the leptoquark pair production and for the dominant Standard Model processes.
Jets from the leading order QCD processes are expected to be back to back and boosted in forward and backward region due to the color connection of the initial and final state partons. Figures 7-5 and 7-6 show the pseudo-rapidity distribution of the two leading jets and opening angle between them.

Figure 7-5: (Top) The pseudo-rapidity distributions of the first-leading jet (J1) for the leptoquark pair production and for the dominant Standard Model processes. (Bottom) The pseudo-rapidity distributions of the second-leading jet (J2) for the leptoquark pair production and for the dominant Standard Model processes.

In the events with no intrinsic missing-$E_T$, it appears mostly due to jet mismeasurement. Thus, in the di-jet events, the missing-$E_T$ will be either parallel or anti-parallel with mismeasured jet. Figure 7-7 shows the difference in the direction of the highest energetic jet and missing-$E_T$ direction. Figure 7-8 shows separation between in the azimuthal direction between the missing-$E_T$ direction
Figure 7–6: The distribution of the azimuthal angular separation between the first- and second-leading jets for the leptoquark pair production and for the dominant Standard Model processes.

and closest jet in $\phi$ for the leptoquark pair production and for the dominant Standard Model processes.

Figure 7–7: The distribution of the azimuthal angular separation between the directions of the first leading jet and the missing-$E_T$ for the leptoquark pair production and for the dominant Standard Model processes.

Tau-leptons, from W and Z production, decaying hadronically from W and Z decays would be reconstructed as a jet. Electrons that fail identification would also appear as a jet. However jets from misidentified leptons would have fewer tracks on average than a jet originating from a quark or gluon. Figure 7–9 shows the arising from the decays of W + Z, for example that are reconstructed Tau leptons decaying hadronically as jets in the detector.