DØnote 4401

Search for First Generation Leptoquarks in $p\bar{p}$ collisions at $\sqrt{s}$=1.96 TeV

The DØ Collaboration
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A search for first generation leptoquark pairs in $p\bar{p}$ collisions at the Fermilab Tevatron is presented using Run II DØ data taken between April 2002 and September 2003 and an integrated luminosity equal to 175 pb^{-1}. Leptoquarks are assumed to be produced in pairs and to decay into a charged lepton and a quark with a branching fraction β. Cases where (i) both leptoquarks decay into an electron and a quark or (ii) one leptoquark decays to an electron and quark while the other goes to a neutrino and quark are considered. We observe no evidence for leptoquark production and set an upper cross section limit of 0.066 pb (β=1) at the 95% CL for the $eejj$ and 0.269 pb (β=0.5) at the 95% CL for the $e\nu jj$ channels. We then combine the limits obtained from these individual searches using Bayesian likelihood techniques with correlated errors taken into account and obtain lower limits on the first generation leptoquark mass as a function of β. This mass limit is 213 GeV/c^2 if β=0.5.

Preliminary Results for Winter 2004 Conferences

I. INTRODUCTION

The observed symmetry between quarks and leptons could be explained by the existence of a fundamental theory that relates them. Several extensions of the Standard Model (SM) [1] include leptoquarks (LQ) which carry color, fractional electric charge and both lepton (l) and quark (q) quantum numbers and would decay to (lq) systems. Based on the severe constraints placed on intergenerational coupling from flavor-changing neutral currents it is assumed in this note that the first generation LQ couple only to e or ν_e and u or d quarks. At the Fermilab Tevatron, leptoquarks are predicted to be produced dominantly in pairs through $q\bar{q}$ annihilation ($q\bar{q} \to g + X \to LQ\bar{LQ} + X$). Next-to-Leading order (NLO) cross section of scalar leptoquarks pair production has been determined in [2] and is used in this analysis to compare data to theory. A pair of first generation leptoquarks could decay in $eeq\bar{q}$, $e\nu_e q\bar{q}$ or $\nu_e\bar{\nu}_e q\bar{q}$ with fractions respectively equal to β^2, $2\beta(1-\beta)$, and $(1-\beta)^2$, where β is the branching fraction of the LQ $\to eq$ decay. In this note a search for first generation scalar leptoquark pairs is presented for 2 cases: when both leptoquarks decay in an electron and a quark in which case the final state is 2 electrons and 2 jets ($eejj$) or when one of the leptoquark decays in an electron and a quark and the other one in a neutrino and a quark. In this last case the final state consists in an electron, 2 jets and missing transverse energy ($e\nu jj \to e\ \not\!\!E_T jj$) corresponding to the neutrino which escapes detection.

The data used were collected with the Run II DØ detector, from April 2002 to September 2003. The selected events were required to pass at least one of un-prescaled triggers based on the requirement of one electromagnetic trigger tower and, for some of them, loose shower shape conditions. The triggers combination used in the $eejj$ analysis is fully efficient for electrons (or photons) of transverse energy (E_T^{EM}) above 25 GeV. In the $e\nu jj$ analysis, the trigger is 100% efficient for E_T^{EM} above 40 GeV and the small trigger loss of events with $35 < E_T^{EM} < 40 GeV$ is taken into account by weighting the Monte Carlo (MC) events used to determine the background. The integrated luminosity for this data sample is equal to be 175 $\pm$ 11 pb^{-1}. The main physical objects which are used in these analyses are described below.

Electromagnetic clusters (EM) are identified by the characteristics of their energy deposition in the calorimeter. Cuts are applied on the energy fraction in the electromagnetic calorimeter, the isolation of the cluster in the calorimeter and on the shower shape. An EM cluster which pass all the EM identification (EM-ID) cuts will be referred as EM object in the following. The jets used in these analyses are cone-type jets with a radius R=0.5 in the (η, ϕ) space. Since the calorimeter responds differently to energy deposited by electromagnetic or hadronic (jets) particules, it is necessary to apply a correction. This correction is determined from a dataset of $(\gamma - jet)$ events using the precise measurement of the γ energy to find the correction which has to be applied on the energy of the jet. To determine the missing transverse energy, $\not\!\!E_T$, all cells with a positive energy are used except those in the coarse hadronic (CH) layers. The CH cells are only used if they belong to a reconstructed jet. The $\not\!\!E_T$ value is then modified to take into account the energy corrections applied to the jets.

II. THE 2 ELECTRONS - 2 JETS CHANNEL

A. Data selection

The final state of the selected events should have two EM candidates with $E_T^{EM} > 25$ GeV in the CC or EC fiducial regions (EC-EC di-EM candidates are rejected) and at least two jets with $E_T > 20$ GeV within $-2.4 < \eta < 2.4$. At least one of the EM candidates should have a track match. Finally a Z-veto cut is applied. The invariant mass of the two EM objects should be outside of the Z-mass window i.e. (80 GeV $< M_{2EM} <$ 102 GeV). A summary of the numbers of events which pass these cuts is given in Table I.

B. Backgrounds and signal

The major Standard Model backgrounds that mimic the $eejj$ decay of a LQ pair are QCD multi-jet production where two of the jets fake two EM objects, Drell-Yan/Z production and top pair production.

The probabilities of a jet to "fake" an electron/photon is calculated using a loose single EM sample and for events passing different triggers. The fake rates are dependent, at low E_T^{EM}, of the trigger type. As an example, for a loose EM object (E_T^{EM}=25 GeV) in CC with a track match, the fake rate varies between 0.01 to 0.04 for events passing a trigger without or with a shower shape condition. For E_T^{EM}=100 GeV the fake rate is equal to 0.05 in both cases. The fake rate values for a loose EM object in EC are similar. To estimate the QCD background in the $eejj$ sample, a loose di-EM sample, which passed the same triggers as data selection, is used. For events passing kinematic and fiducial cuts, all possible permutations of the event that would give 2 EM objects and 2 jets are determined. The

QCD contribution to the background is then given by multiplying the number of combinations with the fake rates. The error on the contribution of QCD events to the candidate sample is 30% (15% due to the fake rate uncertainties, and 26% due to the jet energy scale uncertainties).

To evaluate the Drell-Yan/Z+2jets → eejj contribution, events have been generated using the exact leading order matrix element generator ALPGEN [3] together with PYTHIA [4] for the hadronization processus. The cuts described in section II A are applied on the MC events and a correction is made to take into account the small differences in the data and MC EM-ID and tracking efficiencies. The first two lines of Table I show that the di-EM data are consistent with a Drell-Yan/Z plus QCD background. The uncertainty on the Drell-Yan background to the $eejj$ data is equal to 26%, dominated by uncertainties on the jet energy scale. A 6% error on the ALPGEN sample cross section is also included.

Samples of PYTHIA $t\bar{t}$ (M = 175 GeV)→ di-leptons + jets (about 100k events) were used to calculate this background. The NNLO cross section for top pair production in Run II is calculated to be about 6.77 pb, thus the cross section times branching ratio is about 0.68 pb. The top pair background to the $eejj$ data has an uncertainty of 26%, which is dominated by uncertainties on the jet energy scale.

LQ pair → eejj Monte Carlo samples with over 7,500 events per mass point were generated using PYTHIA for LQ masses from 120 to 280 GeV. The PYTHIA cross sections are leading order (LO). The kinematical and geometrical acceptance for a LQ signal is calculated with full MC simulation and reconstruction of the leptoquark events at different mass points. The overall efficiencies (geometrical + kinematical + particle ID) for LQ signal are summarized in Table II. Systematic errors on the expected number of signal events are described below. The particle ID and the limited statistic of the MC correspond to errors of 2.3 and 1.2% respectively. Uncertainties (5%) due to the choice of structure functions are obtained by comparing acceptances for the signal samples generated with PYTHIA using different structure functions CTEQ4L, CTEQ5L, GRV98LO, and MRSTc-g98. The gluon radiation uncertainty is taken as is from Run I [5] (7%). The uncertainty due to the jet energy scale is estimated by varying the jet response by plus or minus one standard deviation and is slightly dependent of the LQ mass (7.3% for a LQ mass= 240 GeV).

C. Results

Figure 1 shows the M_{2EM} distribution for data and background where M_{2EM} is the invariant mass of the two EM objects in the $eejj$ sample. On Fig.3 a display of the event with M_{2EM}=497 GeV is shown. This event is rejected by the S_T cut (see below). Since a significant fraction of the background comes from the Z-peak, a Z-veto cut as defined in section II A is done. Table I lists the number of events in data and the number expected from background before and after applying the Z-veto cut. The variable S_T is the scalar sum of the transverse energies of the two electrons and the two leading jets. S_T can serve as a powerful cut to suppress background while maintaining high efficiency for the LQ signal especially at high LQ mass (see Fig. 2). A S_T cut value of 450 GeV is used for the purposes of this analysis. The value of the cut is based on a estimate of the extremum reached by the mass Limit Setting Significance as the value of the S_T cut is varied for a number of leptoquark masses. The Limit Setting Significance S^{95}, which is the expected LQ mass limit in our case, is defined as

$$S^{95} = \sum_{i=0}^{+\infty} M_{95\%}(i|B, dB, AL, dAL) exp(-B) B^i / i!$$

Where $M_{95\%}$ is the 95% CL mass limit for the signal assuming i events observed, B is the expected background, AL is the product of the acceptance, the overall efficiency and the luminosity for the signal, and dB, dAL are the uncertainties of B, AL.

Figure 2 shows the data and MC S_T distribution after the Z-veto cut has been applied. The presence of LQ's in the sample would show up as an excess in this plot.

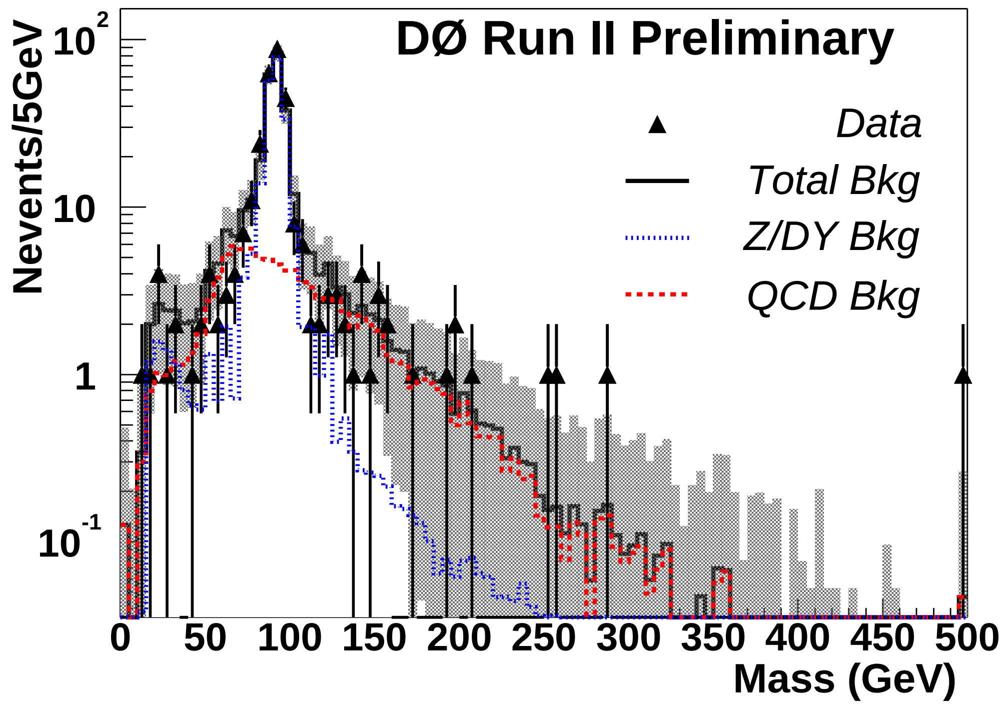

FIG. 1: The di-EM invariant mass for the $eejj$ events from data (triangles) compared to MC.

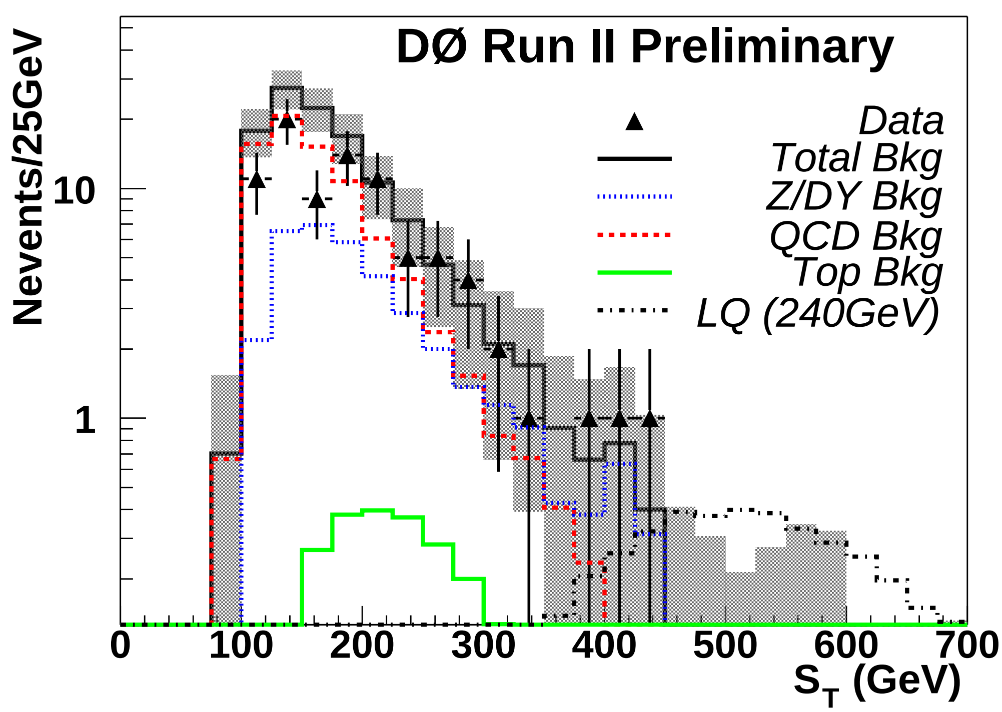

FIG. 2: S_T distribution of $eejj$ events from data (triangles) compared to background, after applying Z-veto cut. The dot-dashed histogram is the S_T distribution for a 240 GeV LQ signal.

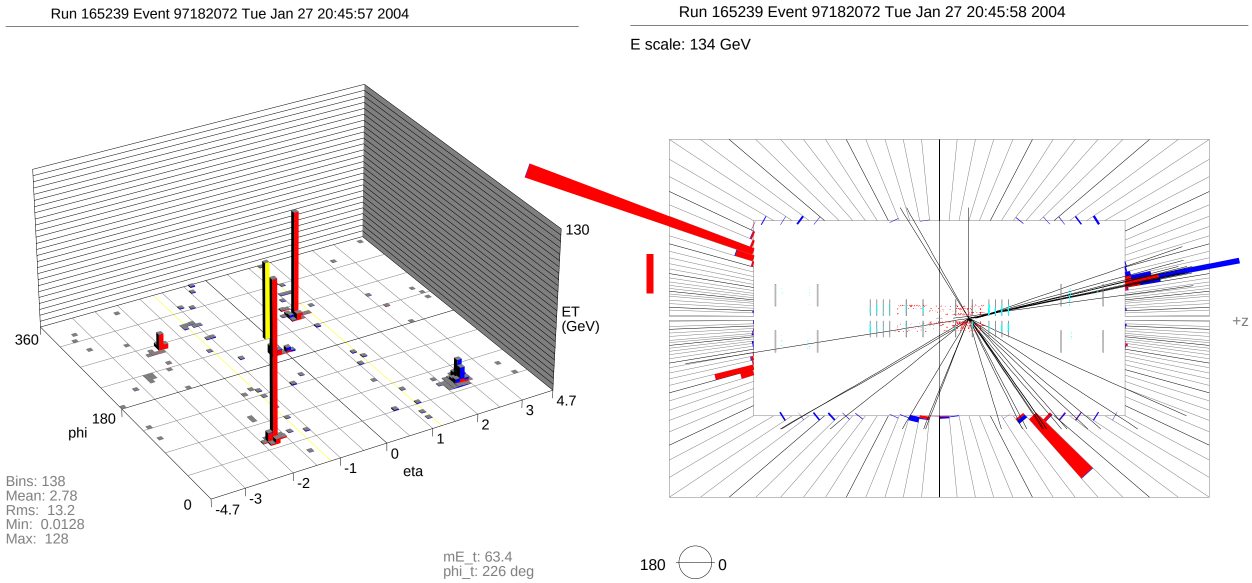

FIG. 3: Display of the event with M_{2EM}=497 GeV. The final state contains 3 EM objects (E_T^{EM} = 130, 129 and 22 GeV) and 2 jets (E_T= 71 and 28 GeV). The event has S_T = 397 GeV and is therefore rejected by the S_T cut.

TABLE I: Number of events from data compared with combined background at the different levels of the analysis.

	Data	Total Bck	Drell-Yan/Z	QCD fake	Top	M_{LQ}=240 GeV
2e	13396	12980 ± 834	10777 ± 772	2113 ± 317		
2e2j	309	325±71	222±49	100±27	3.0±0.3	4.72±0.53
Z-veto	85	118±27	36±7	80±21	2.5±0.2	4.46±0.50
S_T >250	15	14.7±3.6	7.4±1.8	6.4±1.9	0.90±0.18	4.45±0.50
S_T >275	10	10.1±2.5	5.4±1.3	4.1±1.2	0.62±0.14	4.43±0.50
S_T >300	6	7.0±1.8	4.0±1.0	2.5±0.7	0.42±0.10	4.40±0.50
S_T >325	4	4.9±1.2	2.9±0.7	1.7±0.5	0.30±0.07	4.35±0.49
S_T >350	3	3.2±0.8	2.0±0.5	1.0±0.3	0.18±0.05	4.26±0.48
S_T >375	3	2.3±0.6	1.6±0.4	0.6±0.2	0.11±0.03	4.12±0.48
S_T >400	2	1.6±0.4	1.2±0.3	0.4±0.1	0.07±0.02	3.92±0.47
S_T >425	1	0.8±0.2	0.54±0.14	0.24±0.07	0.05±0.01	3.66±0.46
S_T >450	0	0.4±0.1	0.23±0.06	0.17±0.05	0.032±0.009	3.34±0.44
S_T >475	0	0.33±0.09	0.18±0.05	0.12±0.04	0.022±0.006	2.95±0.41
S_T >500	0	0.27±0.07	0.16±0.05	0.09±0.03	0.014±0.004	2.57±0.38

The data are consistent with Standard Model background and no evidence for leptoquark production is observed. Using a 95% confidence level upper limit for the LQ cross section as a function of LQ mass, we arrive at the open circles shown in Fig. 4 and to the values summarized in Table II. Comparing these experimental upper limits with the NLO theoretical calculations [2] for the scalar LQ pair production cross section an upper limit on the first generation scalar LQ cross section equal to 0.066 pb and a lower limit on the leptoquark mass of 238 GeV/c^2, assuming a LQ decay branching ratio (β) of 1, are obtained.

TABLE II: Overall efficiencies after all cuts and 95 % CL upper limits of cross section × branching ratio, as a function of M_{LQ}, for the channel $eejj$.

M_{LQ} (GeV/c^2)	180	200	220	240	260	280
Efficiency (%)	11.6 ± 2.1	16.9 ± 2.6	22.5 ± 3.0	28.0 ± 3.3	31.1 ± 3.2	32.8 ± 3.2
$\sigma \times \beta$ limit (pb)	0.164	0.109	0.081	0.064	0.057	0.054

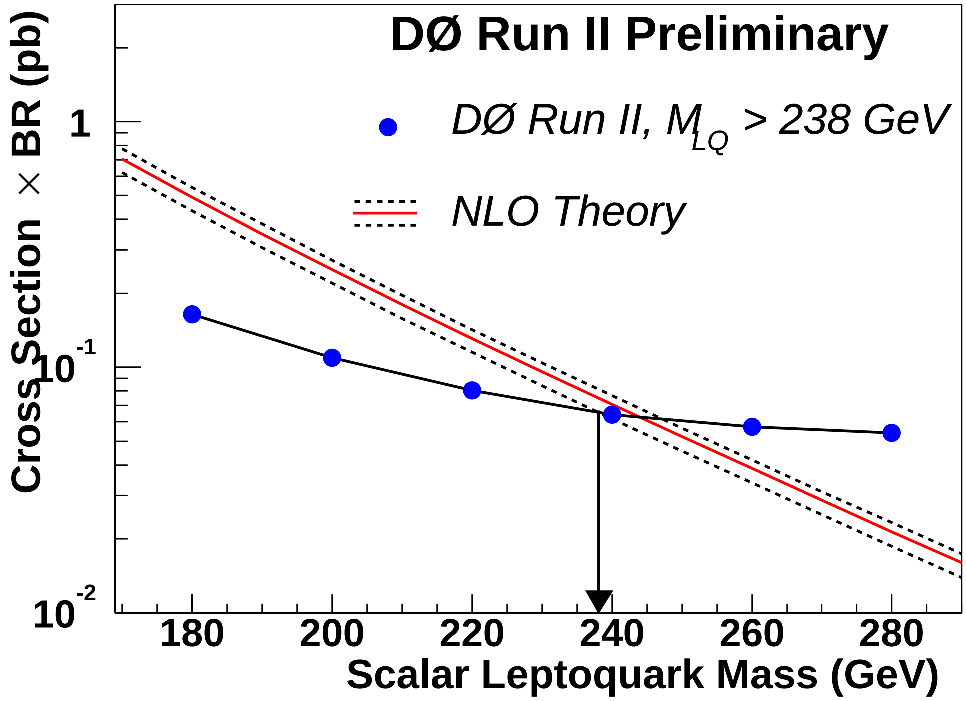

FIG. 4: The 95% confidence level limits on the cross section times branching ratio as a function of LQ mass(open circles). The NLO theoretical cross sections [2] are plotted for different renormalization and factorisation scale factors: M_{LQ} (full line), $M_{LQ}/2$ and $2M_{LQ}$ (dashed lines). A mass limit of 238 GeV for first generation scalar leptoquarks is achieved for β=1

III. THE ELECTRON - NEUTRINO - 2 JETS CHANNEL

A. Data selection

The events selected should have only one tight EM object and furthermore this EM object should match a track. A high value of the cut on the transverse energy of the electron candidate of E_T^{EM} >35 GeV is used to keep at a low level the effects of trigger efficiency turn-on. Two jets with $E_T > 25$ GeV within $|\eta| < 2.5$ and $\not\!\!E_T > 30$ GeV are also required. The events selected by all these criteria will be referred in this note as Data sample.

B. Backgrounds and Signal

One important background consists of QCD events with a $\gamma + \geq 2$ jets or ≥ 3 jets with a jet which fakes an EM object (for instance when a high energetic π^0 is in one of the jets) and where the $\not\!\!E_T$ is coming out from mismeasurement of the jets. This background is estimated using data selected with the same cuts than described in the data sample selection except that the shower shape cut is reversed and the track matching criterium removed. The events which are selected by these cuts will be referred to as QCD sample, in what follows. In both samples, events with a low $\not\!\!E_T$ value are QCD events. Therefore the QCD sample could be used to determine the QCD background at high values of $\not\!\!E_T$ using as normalization factor the ratio of the numbers of events of the 2 samples at low $\not\!\!E_T$ ($\not\!\!E_T <$ 10 GeV). An additionnal cut on $\Delta\phi(EM, \not\!\!E_T) > 0.7$ is done to take into account the fact that a jet with high EM energy fraction is less well measured in the QCD sample. Another way to reduce the QCD background is to add a requirement on track isolation. The method rejects events when the sum of the P_T of the tracks found in a hollow cone $0.05 <$ ΔR(track,EM cluster)$<$ 0.4 is larger than 2 GeV. After all these cuts, and when a small contribution of W events is substracted from the data sample, the factor (Data/QCD)= 0.149 ± 0.008 (see Fig. 5). A systematic error equal to 5.6% on this QCD normalization factor comes from the limited statistic of the samples used to get the factor and from the choice of the kinematical domain within which the normalization is computed.

The W background is determined from $W \rightarrow e\nu\ + 2jets$ events generated using ALPGEN [3] together with

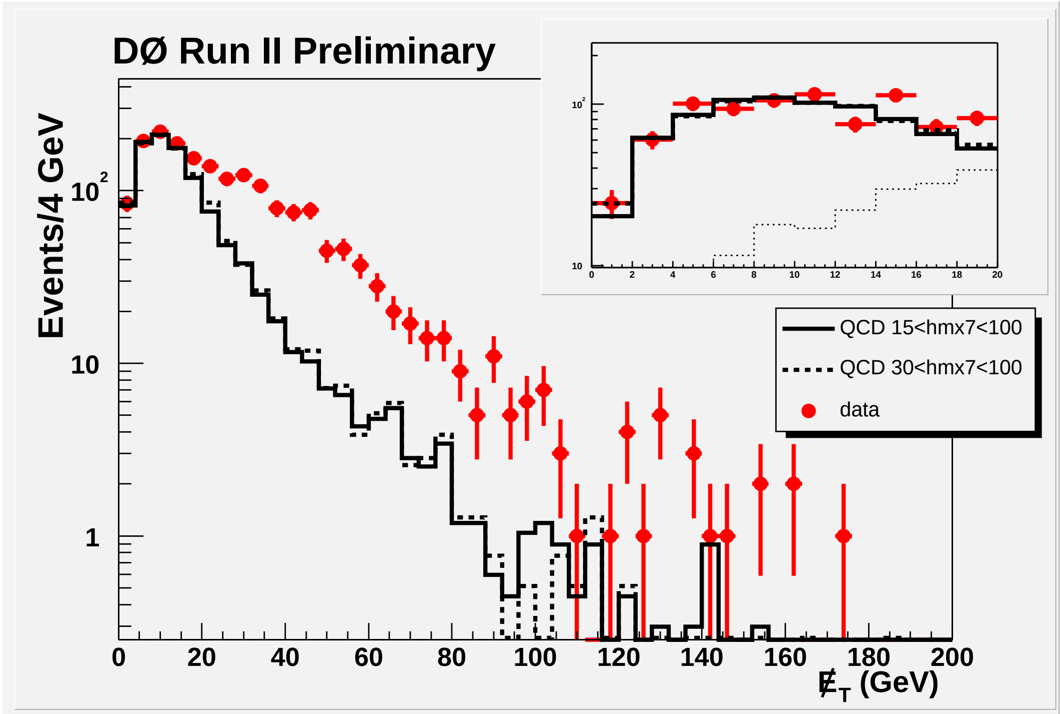

FIG. 5: Distribution of the $\not{E}_T$. The dots correspond to the events of the Data sample and the full histogram to the QCD sample after normalization of the 2 samples for $\not{E}_T < 10$ GeV. The dashed histogram corresponds to a more restrictive $HMx7$ cut to select the QCD sample events. On the right a zoom of the $\not{E}_T$ distribution for low values of this variable is shown and the contribution of W events is plotted in dotted line.

PYTHIA [4] for the hadronization processus. About 189500 events have been produced and processed in a full simulation of the DØ detector and then reconstructed. The cuts applied to the W Monte Carlo events are the kinematical and angular cuts and the EM ID certification. The track match, jet ID efficiencies and the normalization to the integrated luminosity of the data sample are taken into account by a normalization of the number of data events to the total background (QCD, W and top). This normalization is performed within a mass window of 60 to 100 GeV in the $M_T^{e\nu}$ distribution (figure 6). The W normalization factor is equal to 0.146 ± 0.012. A systematic error equal to 8.3% is determined on the W normalization factor as it is done for the QCD factor. To take into account the energy scale uncertainty on the W background, the jets energy and $\not{E}_T$ correction factors are moved by $+1\sigma$ and -1σ, where σ is the error associated to each correction factor. This last error is equal to 19%.

45750 $t\bar{t}$ events (M_{top} = 175 GeV), with one of the top decaying in $e\nu$, have been produced with the generator PYTHIA [4]. They have been processed in the full software chain of detector simulation and reconstruction of DØ. The kinematical and angular cuts and the EM and jet efficiencies have been applied to these events. On the top background four errors are derived. The number of top events is computed using the integrated luminosity, so the first error corresponds to the 6.5% of uncertainty on the luminosity. A second error (1.5%) corresponds to the uncertainties on the values of the ID-acceptances efficiencies. A third error (10.8%) corresponds to the energy scale uncertainty. Finally an error of 25% on the top cross section value is taken into account.

The Monte Carlo samples for the signal have been produced with the PYTHIA generator and processed in the full chain of simulation and reconstruction. Scalar leptoquark pairs with one decay forced in eq and the other in $\nu_e q$ have been generated using CTEQ5L structure functions, with masses ranging from 120 to 240 GeV. 6000 events have been processed for each mass. The efficiencies corresponding to the kinematical and angular cuts multiplied by the ID-acceptances are given in Table IV. On the signal acceptance 4 errors are determined. One corresponds to the propagation of the error on the ID acceptance factor (1.5%) and another one to the energy scale uncertainty (5%), 5.4% corresponding to the different acceptances for different choices of structure functions (CTEQ4L versus CTEQ5L), 4% for the gluon radiation. This last error comes out from the same leptoquark search done in Run I [5].

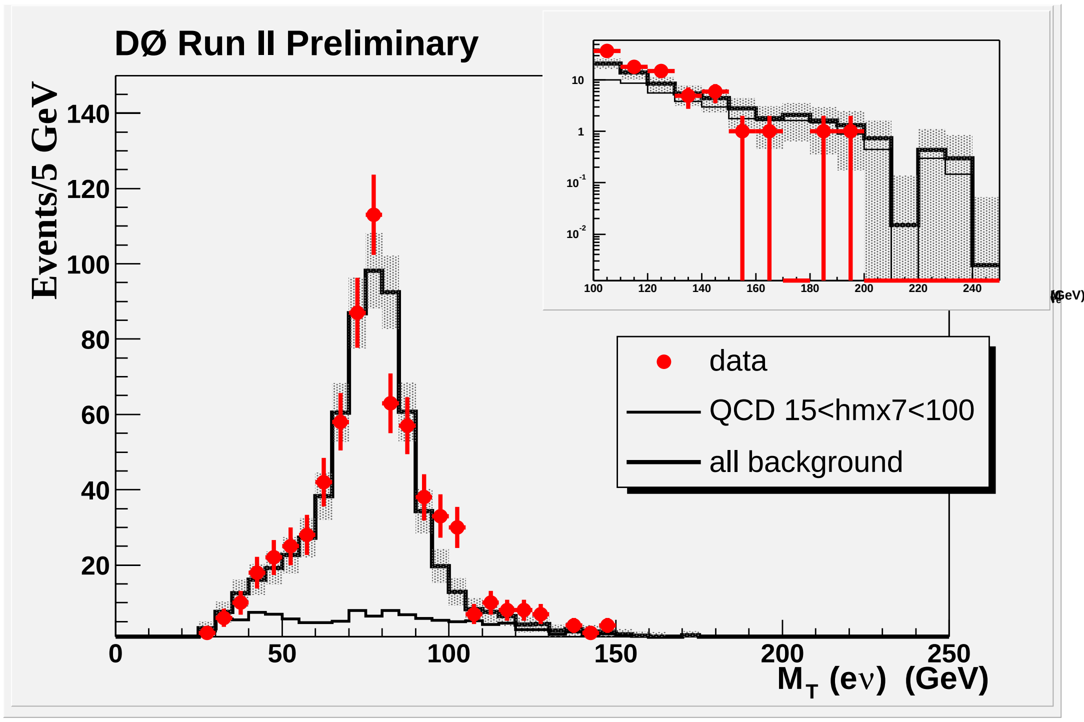

FIG. 6: $M_T^{e\nu}$ distribution for $\not\!\!E_T > 30$ GeV. The dots correspond to data, the full histogram (thick line) to the total background and the thin line histogram to the QCD background. The hashed area indicate the statistical uncertainty on the total background. On the right is inserted a zoom of the $M_T^{e\nu}$ distribution above 100 GeV in logarithmic scale

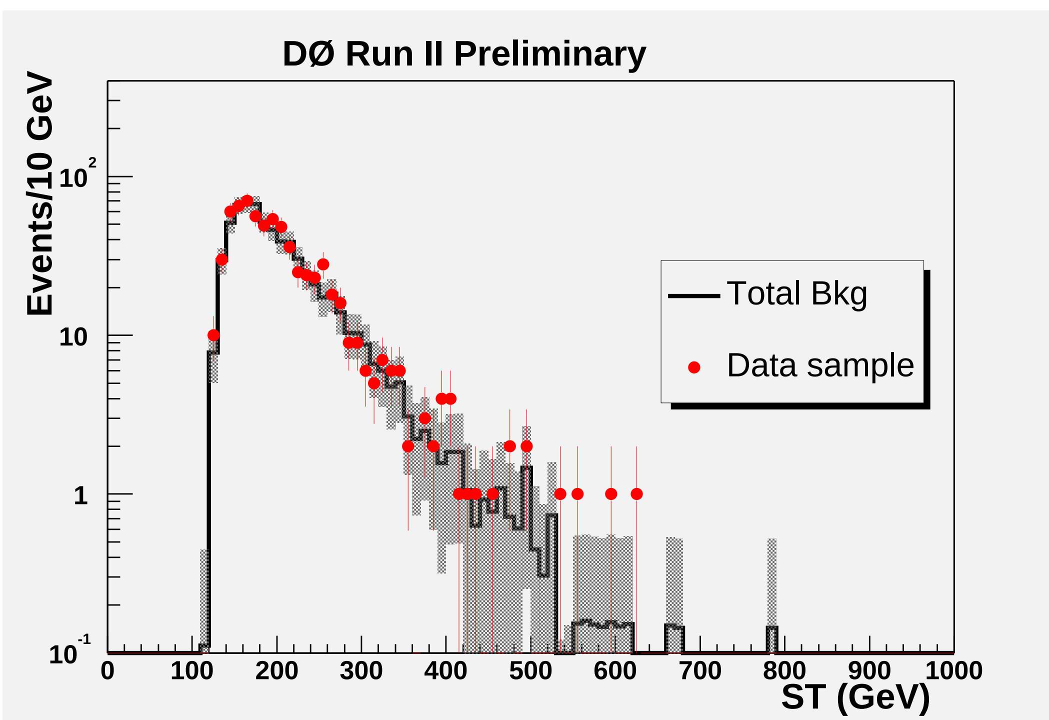

FIG. 7: S_T distribution for $\not\!\!E_T > 30$ GeV.The dots correspond to data, the full histogram to the total background. The hashed area indicate the statistical uncertainty on the total background.

TABLE III: Number of data and background events after all cuts. The first error corresponds to the statistical uncertainty, the second one is the systematic uncertainty

	$\not\!\!E_T > 30$ GeV	$+ M_T^{e\nu} > 130$ GeV	$+ S_T > 330$G eV
Data	687	15	2
Total bck.	666.9	$22.8 \pm 1.8 \pm 1.6$	$4.7 \pm 0.8 \pm 0.3$
QCD	129.9	$16.4 \pm 1.6 \pm 0.9$	$3.1 \pm 0.7 \pm 0.2$
W	527.6	$6.2 \pm 0.9 \pm 1.3$	$1.4 \pm 0.5 \pm 0.2$
top	9.4	$0.32 \pm 0.03 \pm 0.09$	$0.17 \pm 0.02 \pm 0.06$

TABLE IV: Overall efficiencies after all cuts and 95 % CL upper limits of cross section × branching ratio, as a function of M_{LQ}, for the channel $e\nu jj$.

M_{LQ} (GeV/c^2)	160	180	200	220	240	260	280
Efficiency (%)	13.1 ± 1.5	17.3 ± 1.9	19.9 ± 2.2	21.2 ± 2.4	23.3 ± 2.6	24.4 ± 2.7	25.3 ± 2.8
$\sigma \times \beta$ limit (pb)	0.190	0.144	0.125	0.117	0.106	0.101	0.098

C. Results

The distribution of the transverse mass $M_T^{e\nu}$ for events with $\not\!\!E_T > 30$ GeV is shown on Fig. 6. The number of events which survive the cuts and the number of predicted background events are given in Table III. On Fig. 7 the distribution of the variable S_T which is the sum of the transverse energies of the electron, the 2 jets and the $\not\!\!E_T$ is plotted. No excess of events at high $M_T^{e\nu}$ or high S_T is visible. The cuts $M_T^{e\nu} > 130$ GeV and $S_T > 330$ GeV are applied. The value of the S_T cut is found following the same type of method than the one described in paragraph II C. The minimum of the expected cross section times branching ratio is searched for different S_T cuts and is found for a S_T cut equal to 330 GeV.
2 candidates are selected, which could be compared to the total SM background expectation of 4.73 ± 0.87 events. As no excess of data over background is found, an upper limit on the production cross section times β for a first generation scalar leptoquark is given on Fig. 8 and in Table IV, assuming a branching ratio for the decay of the LQ in eq : $\beta = 0.5$. Comparing these limits to theoretical calculations of the cross section of scalar leptoquarks [2], an upper limit on the first generation scalar LQ cross section equal to 0.269 pb and a lower limit on the leptoquark mass of 194 GeV/c^2, assuming a LQ decay branching ratio (β) of 0.5, are obtained.

IV. COMBINATION OF LIMITS FROM THE 2 CHANNELS

The combination of the limits obtained in the individual searches in the $eejj$ and $e\nu jj$ channels is done using Bayesian likelihood technique [6], with correlated errors taken into account. As discussed in section I the branching ratios of the LQ in $eeq\bar{q}$ or $e\nu_e q\bar{q}$ are respectively equal to β^2, $2\beta(1-\beta)$. So for each value of β, the luminosities will be multiplied by the corresponding branching ratio. The efficiencies are given in paragraph II B and III B for the channels $eejj$ and $e\nu jj$ respectively and the number of events observed and background expected in Tables I and III. The limits on the cross sections obtained at 95 % CL for the combination of the 2 channels and different values of β are compared with the NLO LQ pair production cross section [2] and lower mass limits are derived and given, as a function of β, in Table V and shown on Fig. 9. In Table V the Run I combined limit, using the 3 channels $eejj$, $e\nu jj$ and $\nu\nu jj$, and an integrated luminosity equal to 115 pb^{-1} is given.

TABLE V: 95 % CL lower limits on the first generation scalar leptoquark mass, as a function of β. The combined ($eejj$, $e\nu jj$ and $\nu\nu jj$ channels) mass limit for Run I for a luminosity equal to 115 pb^{-1} is also given.

β	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.
mass limit $eejj$ (GeV)					145	175	200	215	228	238
mass limit $e\nu jj$ (GeV)	155	180	190	196	197	196	190	180	155	
mass limit combined (GeV)	155	184	198	206	213	220	225	230	234	238
mass limit combined (Run I)	110				204					225

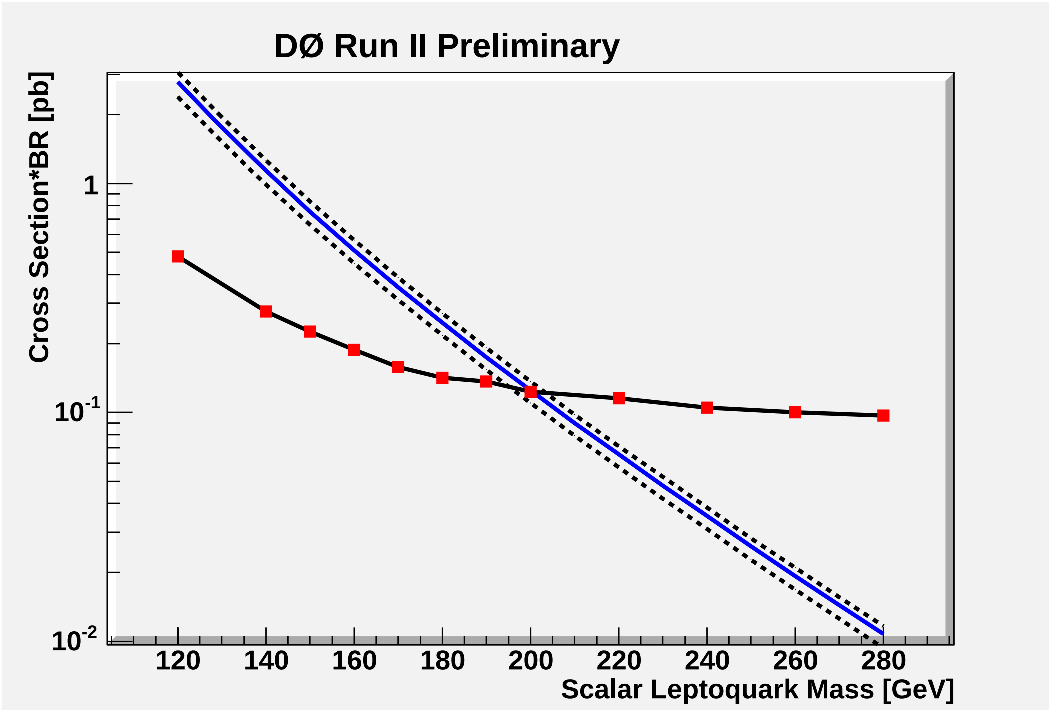

FIG. 8: 95% Confidence level limit on the cross section times branching ratio as a function of the leptoquark mass (squares). The NLO theoretical cross sections [2] are plotted for different renormalization and factorisation scale factors: M_{LQ} (full line), $M_{LQ}/2$ and $2M_{LQ}$ (dashed lines).

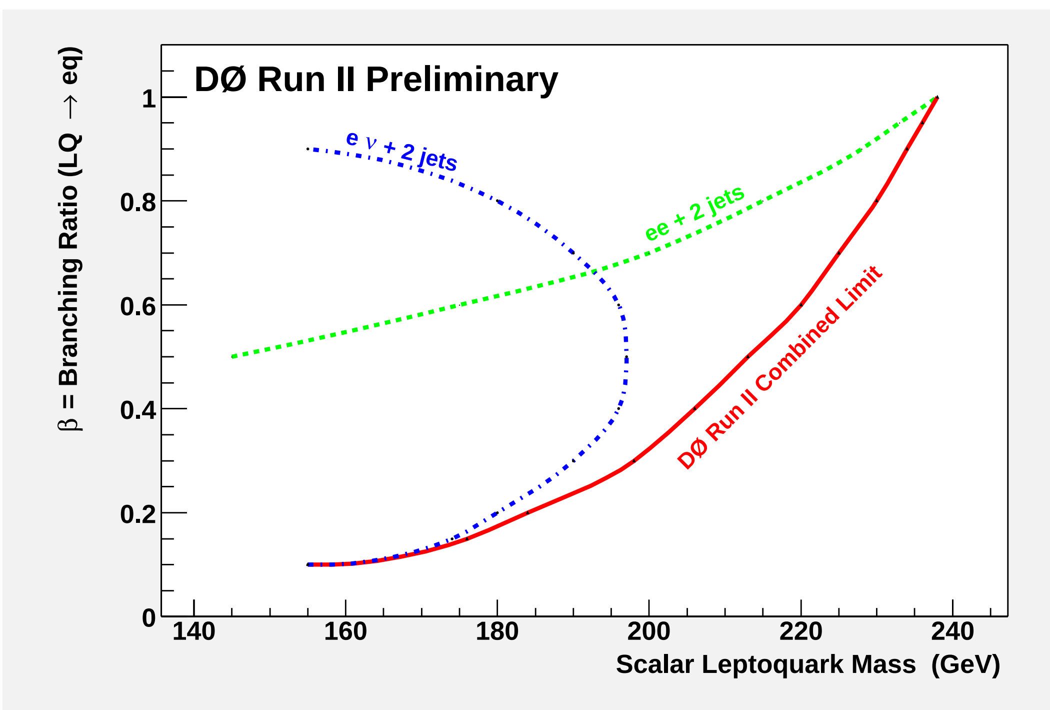

FIG. 9: 95% CL lower limits on the mass of first generation scalar leptoquark production, as a function of β

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[1] D. Acosta and S. Blessing, Annu. Rev. Nucl. Part. Sci. **49,** 389(1999), and references therein.
[2] M. Kramer, et. al., Pair Production of Scalar Leptoquarks at the Fermilab Tevatron, Phys. Rev. Lett. **79,** 341(1997).
[3] ALPGEN, a generator for hard multiparton processes in hadronic collisions, M.L. Mangano, M. Moretti, F. Piccinini,R. Pittau, A. Polosa, hep-ph/0206293
[4] PYTHIA, T. Sjöstrand et al, "Pythia 6.2 - Physics and Manual", hep-ph/0108264
[5] DØ Collaboration, Search for First-Generation Scalar and Vector Leptoquarks, Phys. Rev. **D64,** 092004(2001).
[6] C. Grosso-Pilcher, G. Landsberg, and M. Paterno, hep-ex/9810015.