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DØ note
2466

Searches for Supersymmetry and Top
in the D0 Experiment

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ABSTRACT

The statuses of the searches for evidence of supersymmetry and the top quark in the DØ experiment at Fermilab are presented. New limits are given on the masses of squarks and gluinos, and progress is reported in the search for charginos and neutralinos. Finally, results are presented on the search for the top quark in dilepton, lepton plus jet, and lepton plus jet plus tagging muon channels.

1. Introduction

Two of the most challenging areas of particle physics currently concern the search for evidence of supersymmetric particles, and the search for the top quark. Evidence for supersymmetric particles is needed to give credence to supersymmetry as a theoretically attractive way to stabilize the masses of the scalar sector and explain the origin of electroweak symmetry breaking. The top quark is required to complete the basic set of fermions in the Standard Model. There is considerable interest in the interconnection between the expected large mass of the top quark and the role it plays, through renormalization group equations, in driving negative the mass squared of one of the Higgs particles of the minimal supersymmetric standard model(MSSM). The negative mass squared is required to generate electroweak symmetry breaking through the usual form of the Higgs potential.

The supersymmetric particle searches described in this paper use the hermetic properties of the DØ detector to look for evidence of squarks and gluinos via their decay to channels with signatures of jets and missing transverse energy. The wide coverage of the DØ detector for charged leptons is used in the search for charginos and neutralinos via their decays to channels involving electrons and muons. Essentially all elements of the detector are used in the top search which involves jets, charged leptons, and missing transverse energy.

The approximately 15 pb^{-1} of data used were taken during Run Ia of the Tevatron collider in 1992-93.

This paper is organized as follows. First the essential elements of the DØ detector are described, then the results of the searches are presented, followed by conclusions.

2. The DØ Detector

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We give here only a brief description of the elements of the detector. The three main subsystems of the detector are the central tracking system, the almost hermetic liquid argon calorimeter system, and the muon measurement system. The approximate ranges of coverage of these subsystems are

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The main components of the events studied here are charged leptons (electrons and muons), jets, and missing transverse energy ($\not{E}_T$). Muons were identified by their penetration through the calorimeter and muon toroid magnet iron, and by energy deposition, in a localized region of the calorimeter, consistent with the passage of a minimum ionizing particle. Various types of muon selection criteria were applied and the details are given in the appropriate analysis sections below.

Electrons were identified by their pattern of longitudinal and transverse energy deposition in the calorimeter. They were also required to have a matching track in the central tracking chambers. The electron energies were typically corrected by about 5% from a normalization of the masses of reconstructed Z bosons to the precise value from LEP.

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The background level expected from W and Z boson events was estimated using the VECBOS/ISAJET[45] event generator combination in conjuction with our GEANT[6] based simulation of the DØ detector. We expect a total of $16.7 \pm 1.7(^{+7.0}_{-6.6})$ events from this source.

The background from QCD multijet events was estimated from a fit to the $\not\!\!E_T$ distribution for a sample of events for which the trigger required one jet with $E_T >$ 20 GeV. The result was an expected background of 0.42 ± 0.37 events. The final background total was then $17.1 \pm 1.8(^{+7.0}_{-6.6})$ events which is consistent with the 14 events in the final candidate sample. We therefore see no excess of events above background that could be attributed to the production of squarks and gluinos.

On the basis of this result we can then set lower limits on the masses of squarks and gluinos in the m($\tilde{q}$) - m($\tilde{g}$) plane. Since the detection efficiency varies as a function of the squark and gluino masses, we determined this efficiency for a grid of points in the m($\tilde{q}$) - m($\tilde{g}$) plane and interpolated between the points for intermediate values.

We were then able to set 95% confidence level limits in this plane using the production cross-sections from ISASUSY. The results are shown in Fig. 1. For heavy squarks we set an asymptotic lower limit on m($\tilde{g}$) of 144 GeV/c^2, and a limit of 212 GeV/c^2 for the case of equal masses.

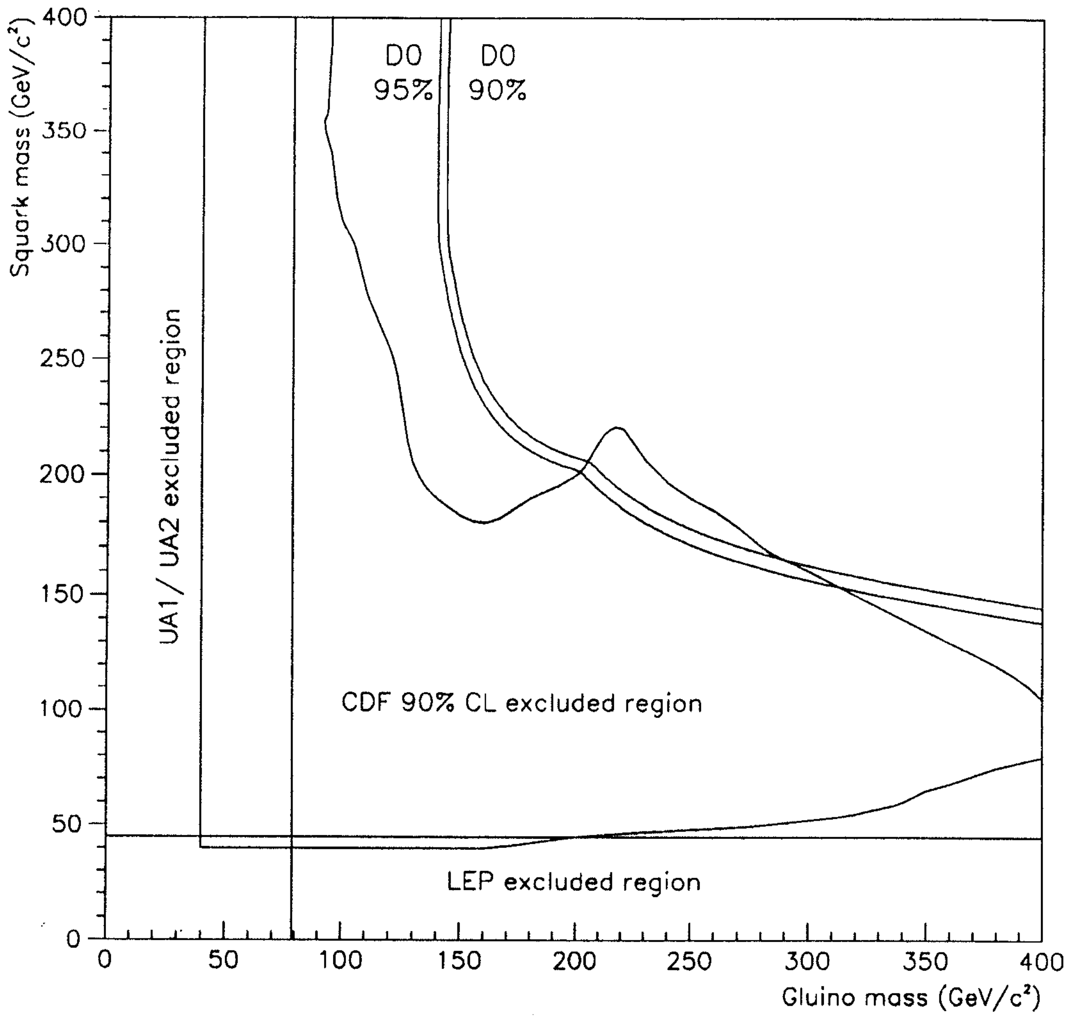

Fig. 1. Current squark and gluino mass limits. Shown are the D0 90% and 95% confidence level exclusion contours, together with the most recent CDF limit [7].

4. Search for Charginos and Neutralinos

An interesting, and complimentary, way to search for supersymmetry at the Tevatron is via the associated production of the lightest chargino($\tilde{W}_1$) and next to lightest neutralino($\tilde{Z}_2$)[8]. The interest stems from the expectation that the rate of associated production times decay branching ratio into final states with three charged leptons (electrons and/or muons) can be large for a range of MSSM parameters. In addition most events are expected to show little hadronic activity for a wide range of η. We have therefore searched for all combinations of three electrons and muons in the final state plus a limited amount of $\not{E}_T$ from unseen neutrino(s) and the LSP's. The practical difficulties of this search center around the relatively low p_T expected for the softest charged lepton (especially for low mass charginos and neutralinos), and the large number of potential background processes.

The triggers and offline selection criteria varied somewhat for the different electron muon final state combinations. We give here one example - for the $ee\mu$ channel. The triggers for this channel consisted of one electromagnetic object with p_T above 7 GeV or one muon with p_T above 5 GeV and $|\eta|$ below 2.4. Offline we required two electrons with p_T above 5 GeV , $|\eta|$ below 2.5 satisfying requirements on shower shape and isolation from other energy deposition in the calorimeter. Only one electron was allowed to have $|\eta|$ more than 1.7 to reduce background from converting photons. The muon was required to reconstruct with p_T above 5 GeV , $|\eta|$ less than 1.7, and to satisfy quality criteria: a "gold" quality muon had the expected energy deposition in the calorimeter for a minimum ionizing track, a matching central detector track, a minimum separation in η-ϕ space of 0.5 from any jet, and satisfied impact parameter criteria in both the bend ($<$ 15 cm.) and non-bend ($<$ 30 cm.) views.

At the time of writing this paper, the status of the analysis was that no candidate events had been found that survived all the selection criteria in approximately 12 pb^{-1} of data for the eee, $ee\mu$, and $e\mu\mu$ channels, and 9 pb^{-1} of data for the $\mu\mu\mu$ channel.

Many potential background processes have been studied. The main classes of backgrounds are Drell-Yan processes producing two charged leptons and either a photon or jet which can fake the third lepton, QCD processes in which there are heavy quarks decaying to charged leptons and/or jets faking leptons directly, and W and Z boson processes producing charged leptons in association with jet(s) that also fake lepton(s). The total background from all sources is currently estimated at approximately 2 events.

The final ingredient needed to set limits on $\tilde{W}_1$ $\tilde{Z}_2$ production and decay is the set of efficiencies for the four final states. These efficiencies are being estimated from a combination of data and Monte Carlo events. Events generated in ISASUSY are processed through a simulation of the trigger and reconstructed via the standard DØ offline reconstruction program D0RECO. Electron efficiencies are estimated by overlaying electrons from a very detailed simulation of the DØ calorimeter with real minimum bias data events. For the muons most of the elements of the fficiency calculation were taken from data samples of $Z \rightarrow \mu\mu$ and $J/\psi \rightarrow \mu\mu$.

The final results of this search for the Tevatron Run Ia data are expected to be published early in 1995.

5. Search for the Top Quark

The production of top/anti-top quark pairs, at the current center of mass energy of 1.8 TeV at the Tevatron, is expected to result from quark/anti-quark fusion. The top quark is expected to decay (assuming no light charged Higgs or other similar object) into a W boson and a b-quark. The subsequent decays of the W and b then lead to a number of possible final states. The W can decay to either jets or an electron or muon (plus neutrino), while the b quark gives further jet(s) and possibly a muon from semi-leptonic decay. We therefore divide our search into the following sub-categories:

- Dilepton - 2 high p_T central isolated leptons, $\not{E}_T$, and jets, accounting for approximately 5% of top decays and giving the cleanest signatures.

- Lepton plus jets - 1 high p_T central isolated lepton, $\not{E}_T$, and at least four jets, accounting for approximately 30% of top decays.

- Lepton plus jets plus tagging muon. As for the previous category, but also requiring a low p_T muon or a muon in a jet to enhance the signal by enriching the number of events containing b quarks.

Recently the DØ collaboration set a lower limit on the top mass of 131 GeV [2], and CDF announced[9] evidence for a top quark of mass $174 \pm 10^{+13}_{-12}$ GeV . Since then, with the knowledge that the top quark is heavy, we have re-optimized our search in order to reduce backgrounds, use the results of better background estimates, and we have extended the analysis to include the $\mu\mu$ and e+jets+μ tag channels.

5.1. Dilepton search

The basic requirements of this analysis are two isolated high p_T charged leptons (any combination of e and μ), a large $\not{E}_T$, and a minimum of two jets. This last requirement was previously one jet, but it was realized that a significant enhancement of signal to background can be achieved with respect to the WW and $Z \rightarrow \tau\tau$ processes by requiring at least two jets.

Electron candidates were identified as energy clusters in the electromagnetic calorimeters. Selection criteria for electrons consisted of a small energy leakage into the hadron calorimeter, correct longitudinal and transverse shower profiles, a track match with the inner chamber, isolation from other energy deposits, and correct dE/dx energy deposition in the tracking chambers. An $|\eta|$ cut of 2.5 was also applied. The electron selection efficiency varied from 45% to 80%.

Muons were identified as tracks in the muon drift chambers after successfully traversing the material in the calorimeter system and the muon toroid iron. Muon seletion criteria consisted of a minimum ionizing energy deposition in the calorimeter, a spatial match with the an inner chamber track, consistency with the interaction vertex, and isolation from other energy deposits in the calorimeter. A cut of $|\eta| < 1.7$ was applied to the muon candidates. The muon selection efficiency varied from 70% to 85%.

The dilepton analysis selection criteria are given in the table below.

	$e\mu$	ee	$\mu\mu$
Lepton p_T	$> 15/12$	$> 20/20$	$> 15/15$
$\not{E}_T$	> 10	> 25	-
No. of jets	$>= 2$	$>= 2$	$>= 2$
Jet E_T	> 15	> 15	> 15

Table 2. Dilepton event selection

Additional cuts were applied to remove events with a Z boson in the ee channel, and to reject cosmic ray muons in the $\mu\mu$ channel.

Application of the cuts and selection criteria resulted in one candidate event in the $e\mu$ channel, and no candidates in the ee or $\mu\mu$ channels. The physics backgrounds to the dilepton channels arise from heavy quark jets (b and c), WW and WZ pairs, and Z and continuum Drell-Yan production. Background events also resulted from jets being misidentified as electrons. The level of this background was estimated from data.

The results of the dilepton search are summarized in the table below:

	$e\mu$	ee	$\mu\mu$
Luminosity	13.5 ± 1.6	13.5 ± 1.6	9.8 ± 1.2
Data	1	0	0
Background	0.27 ± 0.09	0.16 ± 0.07	0.33 ± 0.06

Table 3. Dilepton event yields

These results will be combined with the results from the other channels at the end of this section.

5.2. Leptons plus Jets Search

The requirements for a candidate event in this search were one high p_T electron or muon, high jet multiplicity (defined in detail below), and large $\not{E}_T$. Although the combined electron and muon plus jets channels represent about 30% of the top decays, there are potentially large backgrounds from high multiplicity W boson plus jets events, and QCD events in which jet fluctuations can lead to fake electrons and/or spurious $\not{E}_T$. Two separate analysis paths were followed to reject the backgrounds: event shape criteria and soft muon tagging. The former analysis is discussed in this section, and the latter in the next section.

The electron plus jets selection consisted of a "tight electron", corrected $\not{E}_T$ > 25 GeV, at least four jets (R = 0.5) with $E_T > 15$ GeV, and no muon tag. The last requirement was imposed to maintain independence between this search and the tagging search. The "tight electron" criteria included shower shape cuts (transverse and longitudinal), matching between the shower and a track in the central tracking chambers, and a dE$/dx$cut to reduce background from photon conversions. Finally, electron candidates were required to have $|\eta| < 2.0$.

The muon plus jets selection criteria consisted of a "standard isolated muon", corrected $E_T > 20$ GeV, at least four jets (R = 0.5) with $E_T > 15$ GeV, and no muon tag. A 'standard isolated muon" was required to have $p_T > 15$ GeV, to pass a cosmic ray veto, to satisfy track quality cuts, to be confirmed in the calorimeter, to be separated from any jets with $E_T > 15$ GeV by $\delta R > 0.5$, and to have less than 5 GeV of energy in an annular cone $0.2 < \delta R < 0.4$ around the muon track. Additionally, only muons with $|\eta| < 1.7$ were accepted.

The signal and background levels present in the data were estimated by two independent methods. In the first method a "jet scaling" hypothesis was assumed for the W plus jets background: the addition of an additional jet was assumed to reduce the cross-section by a constant factor (depending only on the strong coupling constant and the minimum jet E_T). Then an exponential extrapolation can be made from one and two jets to four jets, and any excess observed in the high jet multiplicity data can be attributed to a top signal. The extrapolation was carried out after the subtraction of the QCD multijet background, which was estimated from the data.

In the second method cuts were made on the aplanarity of of jets in the laboratory frame, and on the scalar sum of the jet E_T 's. The two methods yielded very similar estimates of the backgrounds and errors. The results of this search are summarized below:

	$e+$ jets	$\mu+$ jets
Luminosity	13.5 ± 1.6	9.8 ± 1.2
Data	2	2
Background	1.2 ± 0.7	0.6 ± 0.5

Table 4. Lepton plus jets yields

5.3. Electron plus Jets plus Soft Muon Tag Search

Since each b quark from a top decay will decay semileptonically with a probability of 11% and since each charm quark from the b decays can also decay semileptonically with the same probability, then about 44% of top events will contain a soft muon associated with a b jet. With the cuts used in our analysis about 20% of the top events will have a detected soft muon.

The rate of tagging per jet was determined to be 0.5% from a study of an electron plus jets trigger sample where the electron was a "fake". Cross checks were made with other data samples and the 0.5% per jet tagging rate was found to be the same within errors. The soft muon tag requirements were either one muon with $p_T > 4$ GeV, or one non-isolated muon if the muon p_T was above 12 GeV . The details of the analysis before muon tagging were essentially the same as for the jet multiplicity analysis in the previous section, except that only three jets were required instead of four. After muon tagging two events passed all the cuts and the background was estimated to be 0.6 ± 0.2 events.

5.4. Combined Results of Top Searches

If all the results from the top searches described above are combined we observe 7 events with an estimated background of 3.2 ± 1.1 events. The probability that the background fluctuated to give the observed signal is 7.2%. If the observed excess of events over the estimated background is attributed to top production, the top cross section may be calculated if the top mass is specified. The results of such a calculation are plotted in Fig.2. as a function of the top quark mass. Also shown is the CDF measurement. The DØ result is consistent with a top quark mass above 141 GeV . It is also consistent with the CDF measurement, but does not demonstrate the existence of the top quark.

6. Conclusions

The DØ experiment has searched for evidence of supersymmetric squarks and gluinos, charginos and neutralinos, and for the existence of the top quark. In the case of squarks and gluinos we have significantly extended the previous CDF limits. The chargino and neutralino search is almost complete and will yield final results early in 1995. Further significant extensions of these searches are also expected with the greater than 100 pb^{-1} of data to be accumulated during the present Run Ib of the Tevatron.

The top search resulted in a small excess of events above background that could be attributed to top production. However, the significance of the excess is small and the additional data from Run Ib will be necessary to further investigate the existence of the top quark.

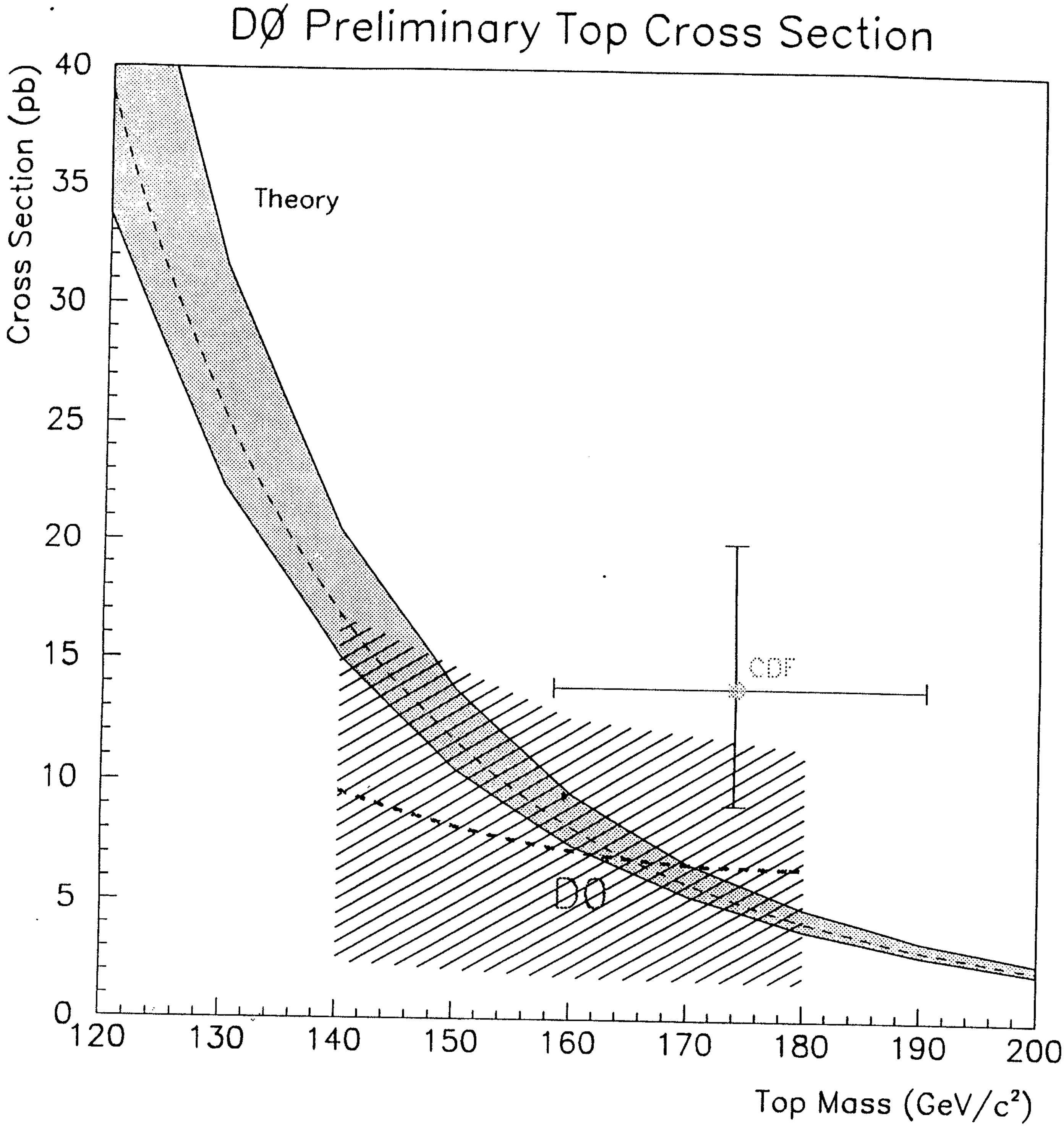

Fig. 2. Preliminary top quark mass limits.

7. Acknowledgements

We thank the Fermilab Accelerator, Computing, and Research Divisions, and the support staffs at the collaborating institutions for their contributions to the success of the experiment. We also acknowledge the support of the U.S. Department of Energy, the U.S. National Science Foundation, the Commissariat a L'Energie Atomique in France, the Ministry for Atomic Energy in Russia, CNPq in Brazil, the Department of Atomic Energy in India, Colciencias in Colombia, and CONACyT in Mexico.

1. DØ Collaboration, S. Abachi *et al.*, *Nucl. Instrum. Methods* **A338**, (1994) 185.
2. DØ Collaboration, S. Abachi *et al.*, *Phys. Rev. Lett.* **72**, (1994) 2138.
3. "The ISASUSY Monte Carlo" by H. Baer and X. Tata.
4. W. Giele, E. Glover, and D. Kosower, *Nucl. Phys.* **B403**, (1993) 633
5. F. Paige and S. Protopopescu, *BNL Report no. BNL 38034* (1986) (unpublished), release v.6.49.
6. F. Carminati *et al.*, *"GEANT Users Guide"* CERN Program Library, December 1991, (unpublished).
7. F. Abe *et al.*, *Phys. Rev. Lett.* **69** (1992).
8. P. Nath and R. Arnowitt, *Mod. Phys. Lett.* **A2**, (1987) 331
9. CDF Collaboration, F. Abe *et al.*, *Phys. Rev.* **D50** (1994) 2966, and *Phys. Rev.* **73 (1994) 225.**

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We were then able to set 95% confidence level limits in this plane using the production cross-sections from ISASUSY. The results are shown in Fig. 1. For heavy squarks we set an asymptotic lower limit on m($\tilde{g}$) of 144 GeV/c^2, and a limit of 212 GeV/c^2 for the case of equal masses.

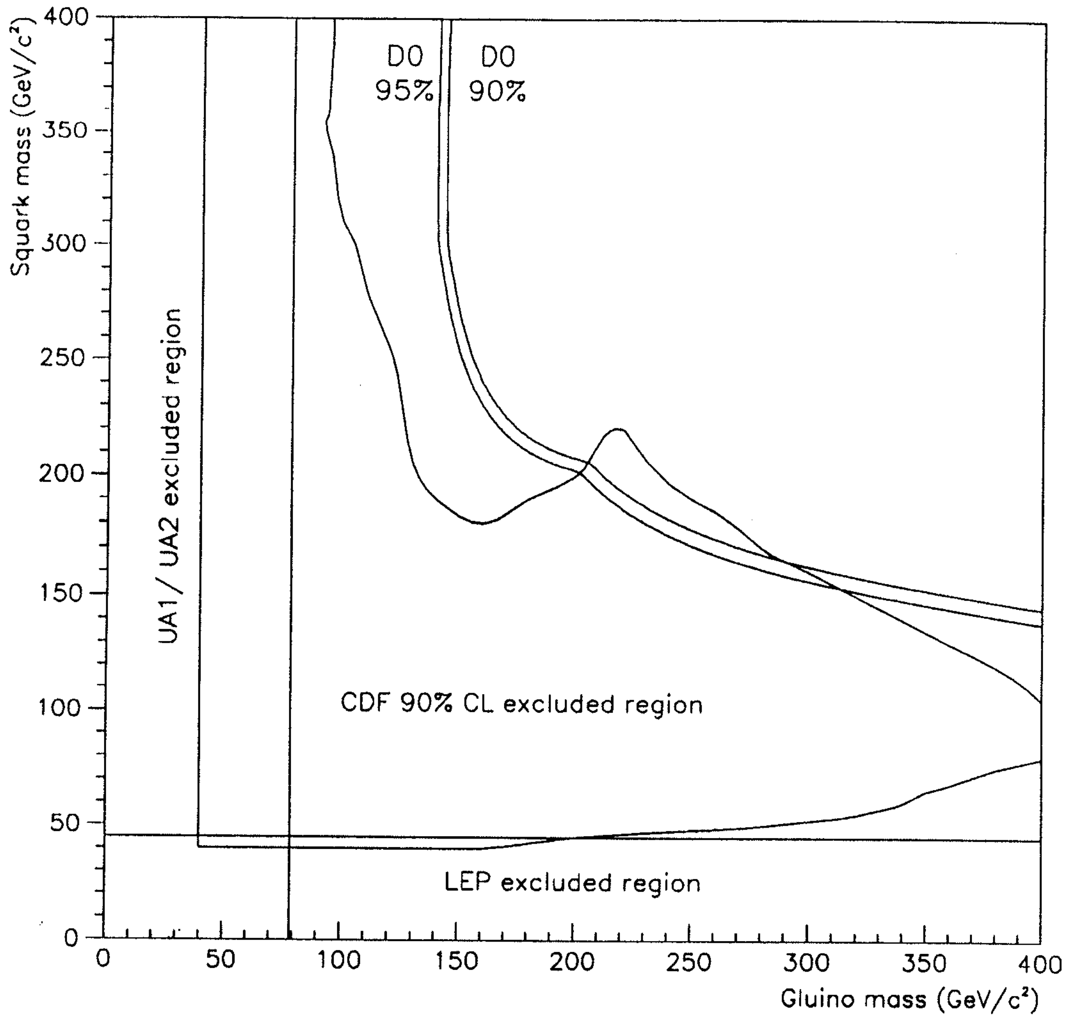

Fig. 1. Current squark and gluino mass limits. Shown are the D0 90% and 95% confidence level exclusion contours, together with the most recent CDF limit [7].

4. Search for Charginos and Neutralinos

An interesting, and complimentary, way to search for supersymmetry at the Tevatron is via the associated production of the lightest chargino($\tilde{W}_1$) and next to lightest neutralino($\tilde{Z}_2$)[8]. The interest stems from the expectation that the rate of associated production times decay branching ratio into final states with three charged leptons (electrons and/or muons) can be large for a range of MSSM parameters. In addition most events are expected to show little hadronic activity for a wide range of η. We have therefore searched for all combinations of three electrons and muons in the final state plus a limited amount of $\not\!\!E_T$ from unseen neutrino(s) and the LSP's. The practical difficulties of this search center around the relatively low p_T expected for the softest charged lepton (especially for low mass charginos and neutralinos), and the large number of potential background processes.

The triggers and offline selection criteria varied somewhat for the different electron muon final state combinations. We give here one example - for the $ee\mu$ channel. The triggers for this channel consisted of one electromagnetic object with p_T above 7 GeV or one muon with p_T above 5 GeV and $|\eta|$ below 2.4. Offline we required two electrons with p_T above 5 GeV , $|\eta|$ below 2.5 satisfying requirements on shower shape and isolation from other energy deposition in the calorimeter. Only one electron was allowed to have $|\eta|$ more than 1.7 to reduce background from converting photons. The muon was required to reconstruct with p_T above 5 GeV , $|\eta|$ less than 1.7, and to satisfy quality criteria: a "gold" quality muon had the expected energy deposition in the calorimeter for a minimum ionizing track, a matching central detector track, a minimum separation in η-ϕ space of 0.5 from any jet, and satisfied impact parameter criteria in both the bend ($<$ 15 cm.) and non-bend ($<$ 30 cm.) views.

At the time of writing this paper, the status of the analysis was that no candidate events had been found that survived all the selection criteria in approximately 12 pb^{-1} of data for the eee, $ee\mu$, and $e\mu\mu$ channels, and 9 pb^{-1} of data for the $\mu\mu\mu$ channel.

Many potential background processes have been studied. The main classes of backgrounds are Drell-Yan processes producing two charged leptons and either a photon or jet which can fake the third lepton, QCD processes in which there are heavy quarks decaying to charged leptons and/or jets faking leptons directly, and W and Z boson processes producing charged leptons in association with jet(s) that also fake lepton(s). The total background from all sources is currently estimated at approximately 2 events.

The final ingredient needed to set limits on $\tilde{W}_1$ $\tilde{Z}_2$ production and decay is the set of efficiencies for the four final states. These efficiencies are being estimated from a combination of data and Monte Carlo events. Events generated in ISASUSY are processed through a simulation of the trigger and reconstructed via the standard DØ offline reconstruction program D0RECO. Electron efficiencies are estimated by overlaying electrons from a very detailed simulation of the DØ calorimeter with real minimum bias data events. For the muons most of the elements of the fficiency calculation were taken from data samples of $Z \to \mu\mu$ and $J/\psi \to \mu\mu$.

The final results of this search for the Tevatron Run Ia data are expected to be published early in 1995.

5. Search for the Top Quark

The production of top/anti-top quark pairs, at the current center of mass energy of 1.8 TeV at the Tevatron, is expected to result from quark/anti-quark fusion. The top quark is expected to decay (assuming no light charged Higgs or other similar object) into a W boson and a b-quark. The subsequent decays of the W and b then lead to a number of possible final states. The W can decay to either jets or an electron or muon (plus neutrino), while the b quark gives further jet(s) and possibly a muon from semi-leptonic decay. We therefore divide our search into the following sub-categories:

- Dilepton - 2 high p_T central isolated leptons, $\not\!\!E_T$, and jets, accounting for approximately 5% of top decays and giving the cleanest signatures.
- Lepton plus jets - 1 high p_T central isolated lepton, $\not\!\!E_T$, and at least four jets, accounting for approximately 30% of top decays.
- Lepton plus jets plus tagging muon. As for the previous category, but also requiring a low p_T muon or a muon in a jet to enhance the signal by enriching the number of events containing b quarks.

Recently the DØ collaboration set a lower limit on the top mass of 131 GeV [2], and CDF announced[9] evidence for a top quark of mass $174 \pm 10^{+13}_{-12}$ GeV . Since then, with the knowledge that the top quark is heavy, we have re-optimized our search in order to reduce backgrounds, use the results of better background estimates, and we have extended the analysis to include the $\mu\mu$ and e+jets+μ tag channels.

5.1. Dilepton search

The basic requirements of this analysis are two isolated high p_T charged leptons (any combination of e and μ), a large $\not\!\!E_T$, and a minimum of two jets. This last requirement was previously one jet, but it was realized that a significant enhancement of signal to background can be achieved with respect to the WW and $Z \to \tau\tau$ processes by requiring at least two jets.

Electron candidates were identified as energy clusters in the electromagnetic calorimeters. Selection criteria for electrons consisted of a small energy leakage into the hadron calorimeter, correct longitudinal and transverse shower profiles, a track match with the inner chamber, isolation from other energy deposits, and correct dE/dx energy deposition in the tracking chambers. An $|\eta|$ cut of 2.5 was also applied. The electron selection efficiency varied from 45% to 80%.

Muons were identified as tracks in the muon drift chambers after successfully traversing the material in the calorimeter system and the muon toroid iron. Muon seletion criteria consisted of a minimum ionizing energy deposition in the calorimeter, a spatial match with the an inner chamber track, consistency with the interaction vertex, and isolation from other energy deposits in the calorimeter. A cut of $|\eta| < 1.7$ was applied to the muon candidates. The muon selection efficiency varied from 70% to 85%.

The dilepton analysis selection criteria are given in the table below.

	$e\mu$	ee	$\mu\mu$
Lepton p_T	$> 15/12$	$> 20/20$	$> 15/15$
$\not\!\!E_T$	> 10	> 25	-
No. of jets	$>= 2$	$>= 2$	$>= 2$
Jet E_T	> 15	> 15	> 15

Table 2. Dilepton event selection

Additional cuts were applied to remove events with a Z boson in the ee channel, and to reject cosmic ray muons in the $\mu\mu$ channel.

Application of the cuts and selection criteria resulted in one candidate event in the $e\mu$ channel, and no candidates in the ee or $\mu\mu$ channels. The physics backgrounds to the dilepton channels arise from heavy quark jets (b and c), WW and WZ pairs, and Z and continuum Drell-Yan production. Background events also resulted from jets being misidentified as electrons. The level of this background was estimated from data.

The results of the dilepton search are summarized in the table below:

	$e\mu$	ee	$\mu\mu$
Luminosity	13.5 ± 1.6	13.5 ± 1.6	9.8 ± 1.2
Data	1	0	0
Background	0.27 ± 0.09	0.16 ± 0.07	0.33 ± 0.06

Table 3. Dilepton event yields

These results will be combined with the results from the other channels at the end of this section.

5.2. Leptons plus Jets Search

The requirements for a candidate event in this search were one high p_T electron or muon, high jet multiplicity (defined in detail below), and large $\not\!\!E_T$. Although the combined electron and muon plus jets channels represent about 30% of the top decays, there are potentially large backgrounds from high multiplicity W boson plus jets events, and QCD events in which jet fluctuations can lead to fake electrons and/or spurious $\not\!\!E_T$. Two separate analysis paths were followed to reject the backgrounds: event shape criteria and soft muon tagging. The former analysis is discussed in this section, and the latter in the next section.

The electron plus jets selection consisted of a "tight electron", corrected $\not\!\!E_T >$ 25 GeV, at least four jets (R = 0.5) with $E_T > 15$ GeV, and no muon tag. The last requirement was imposed to maintain independence between this search and the tagging search. The "tight electron" criteria included shower shape cuts (transverse and longitudinal), matching between the shower and a track in the central tracking chambers, and a dE/$d$xcut to reduce background from photon conversions. Finally, electron candidates were required to have $|\eta| < 2.0$.

The muon plus jets selection criteria consisted of a "standard isolated muon", corrected $E_T > 20$ GeV, at least four jets (R = 0.5) with $E_T > 15$ GeV, and no muon tag. A 'standard isolated muon" was required to have $p_T > 15$ GeV, to pass a cosmic ray veto, to satisfy track quality cuts, to be confirmed in the calorimeter, to be separated from any jets with $E_T > 15$ GeV by $\delta R > 0.5$, and to have less than 5 GeV of energy in an annular cone $0.2 < \delta R < 0.4$ around the muon track. Additionally, only muons with $|\eta| < 1.7$ were accepted.

The signal and background levels present in the data were estimated by two independent methods. In the first method a "jet scaling" hypothesis was assumed for the W plus jets background: the addition of an additional jet was assumed to reduce the cross-section by a constant factor (depending only on the strong coupling constant and the minimum jet E_T). Then an exponential extrapolation can be made from one and two jets to four jets, and any excess observed in the high jet multiplicity data can be attributed to a top signal. The extrapolation was carried out after the subtraction of the QCD multijet background, which was estimated from the data.

In the second method cuts were made on the aplanarity of of jets in the laboratory frame, and on the scalar sum of the jet E_T 's. The two methods yielded very similar estimates of the backgrounds and errors. The results of this search are summarized below:

	$e+$ jets	$\mu+$ jets
Luminosity	13.5 ± 1.6	9.8 ± 1.2
Data	2	2
Background	1.2 ± 0.7	0.6 ± 0.5

Table 4. Lepton plus jets yields

5.3. Electron plus Jets plus Soft Muon Tag Search

Since each b quark from a top decay will decay semileptonically with a probability of 11% and since each charm quark from the b decays can also decay semileptonically with the same probability, then about 44% of top events will contain a soft muon associated with a b jet. With the cuts used in our analysis about 20% of the top events will have a detected soft muon.

The rate of tagging per jet was determined to be 0.5% from a study of an electron plus jets trigger sample where the electron was a "fake". Cross checks were made with other data samples and the 0.5% per jet tagging rate was found to be the same within errors. The soft muon tag requirements were either one muon with $p_T > 4$ GeV, or one non-isolated muon if the muon p_T was above 12 GeV . The details of the analysis before muon tagging were essentially the same as for the jet multiplicity analysis in the previous section, except that only three jets were required instead of four. After muon tagging two events passed all the cuts and the background was estimated to be 0.6 ± 0.2 events.

5.4. Combined Results of Top Searches

If all the results from the top searches described above are combined we observe 7 events with an estimated background of 3.2 ± 1.1 events. The probability that the background fluctuated to give the observed signal is 7.2%. If the observed excess of events over the estimated background is attributed to top production, the top cross section may be calculated if the top mass is specified. The results of such a calculation are plotted in Fig.2. as a function of the top quark mass. Also shown is the CDF measurement. The DØ result is consistent with a top quark mass above 141 GeV . It is also consistent with the CDF measurement, but does not demonstrate the existence of the top quark.

6. Conclusions

The DØ experiment has searched for evidence of supersymmetric squarks and gluinos, charginos and neutralinos, and for the existence of the top quark. In the case of squarks and gluinos we have significantly extended the previous CDF limits. The chargino and neutralino search is almost complete and will yield final results early in 1995. Further significant extensions of these searches are also expected with the greater than 100 pb^{-1} of data to be accumulated during the present Run Ib of the Tevatron.

The top search resulted in a small excess of events above background that could be attributed to top production. However, the significance of the excess is small and the additional data from Run Ib will be necessary to further investigate the existence of the top quark.

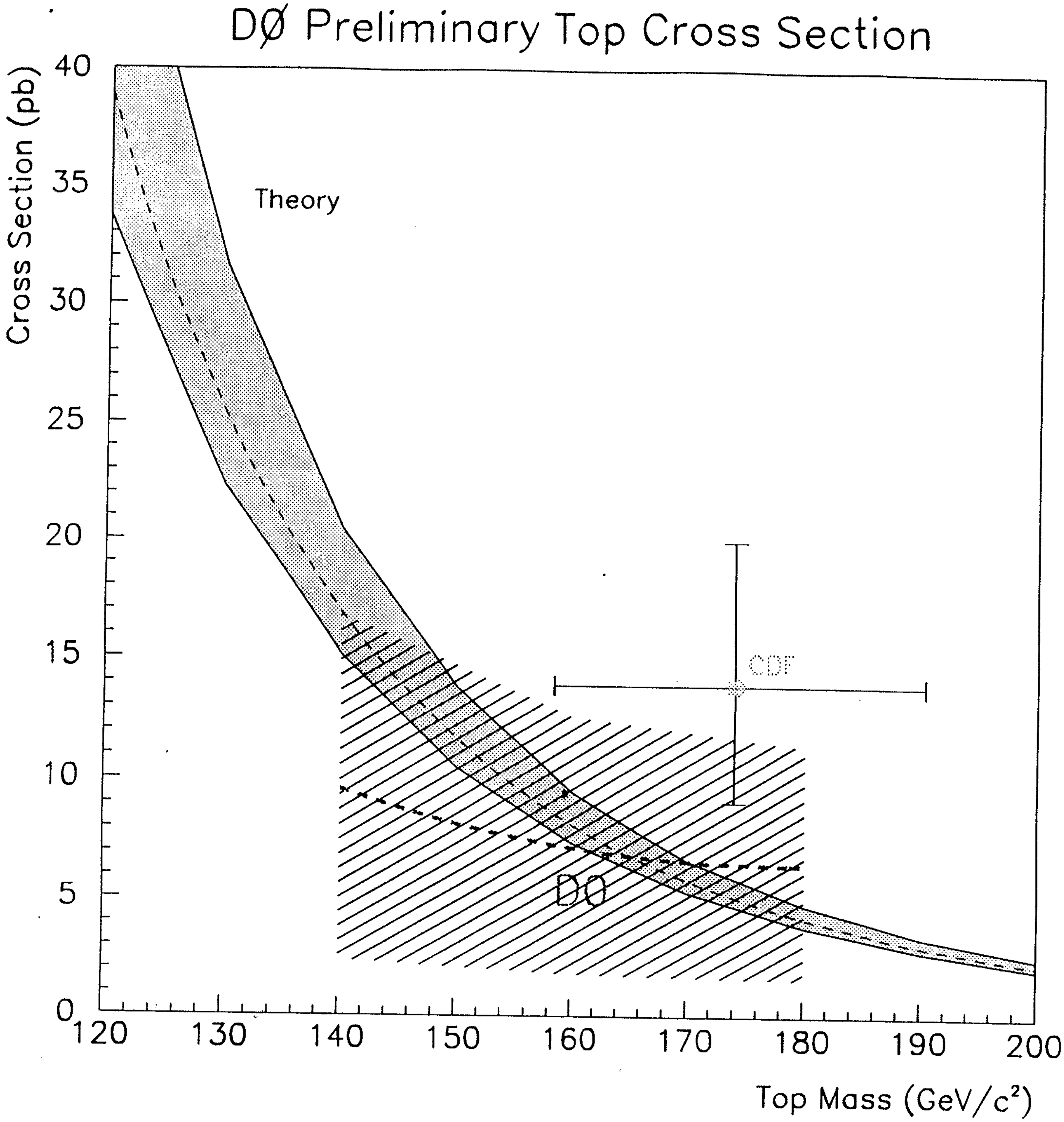

Fig. 2. Preliminary top quark mass limits.

7. Acknowledgements

We thank the Fermilab Accelerator, Computing, and Research Divisions, and the support staffs at the collaborating institutions for their contributions to the success of the experiment. We also acknowledge the support of the U.S. Department of Energy, the U.S. National Science Foundation, the Commissariat a L'Energie Atomique in France, the Ministry for Atomic Energy in Russia, CNPq in Brazil, the Department of Atomic Energy in India, Colciencias in Colombia, and CONACyT in Mexico.

1. DØ Collaboration, S. Abachi *et al.*, *Nucl. Instrum. Methods* **A338**, (1994) 185.
2. DØ Collaboration, S. Abachi *et al.*, *Phys. Rev. Lett.* **72**, (1994) 2138.
3. "The ISASUSY Monte Carlo" by H. Baer and X. Tata.
4. W. Giele, E. Glover, and D. Kosower, *Nucl. Phys.* **B403**, (1993) 633
5. F. Paige and S. Protopopescu, *BNL Report no. BNL 38034* (1986) (unpublished), release v.6.49.
6. F. Carminati *et al.*, *"GEANT Users Guide"* CERN Program Library, December 1991, (unpublished).
7. F. Abe *et al.*, *Phys. Rev. Lett.* **69** (1992).
8. P. Nath and R. Arnowitt, *Mod. Phys. Lett.* **A2**, (1987) 331
9. CDF Collaboration, F. Abe *et al.*, *Phys. Rev.* **D50** (1994) 2966, and *Phys. Rev.* **73 (1994) 225.**