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Top Search at the Tevatron

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TOP SEARCH AT THE TEVATRON

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ABSTRACT

Preliminary results on the top quark search at the TEVATRON are reported. The DØ experiment, observing one candidate event in the $e\mu$ channel and combining the ee and $e\mu$ channel analyses, sets a lower limit of 103 GeV/c^2 (99 GeV/c^2) for the top quark mass with (without) background subtraction at 95% confidence level. The CDF experiment, observing two candidate events, sets a top mass lower limit of 108 GeV/c^2 at 95% confidence level for the ee, $\mu\mu$ and $e\mu$ data combined, without background subtraction. Work is in progress at both experiments to reduce the backgrounds in the lepton + jets channel.

1. Introduction

There are two large detectors DØ [1] and CDF [2], at the Tevatron $\bar{p}p$ Collider The current run started in the summer of 1992 and will end at the end of May, 1993. The Tevatron has been running smoothly at a center of mass energy of 1.8 TeV and has delivered a total luminosity up to the date of this conference of 25 pb^{-1}, with a peak luminosity of 9.0 $10^{30}cm^{-2}s^{-1}$. The luminosity collected by DØ to date is 14 pb^{-1}. The luminosity collected by CDF is 17 pb^{-1} for the current run (1992-1993) and 4 pb^{-1} for the previous run (1988-1989).

At a center of mass energy of 1.8 TeV top quarks heavier than W-bosons are predominantly produced in pairs. In the standard model a top quark heavier than the W boson decays 100% into a real W and a b quark. Each W boson decays either into a charged lepton and a neutrino or decays hadronically into a pair of quarks. Although events of the type $t\bar{t} \to$ all $jets$, where both W bosons decay into $q\bar{q}$, have the highest branching ratio ($\sim \frac{36}{81}$), the background for this channel is overwhelming. The cleanest channel is the dilepton channel, where both W bosons decay into leptons, which has a branching ratio of about $\frac{2}{81}$ for $e\mu$, $\frac{1}{81}$ for ee, and $\frac{1}{81}$ for $\mu\mu$.

2. DØ Dilepton Analysis and Results

2.1. DØ ee Channel Analysis

The data in this analysis corresponds to an integrated luminosity of 7.3 pb^{-1} from a subset of triggers from the Express line. The offline event selection requires

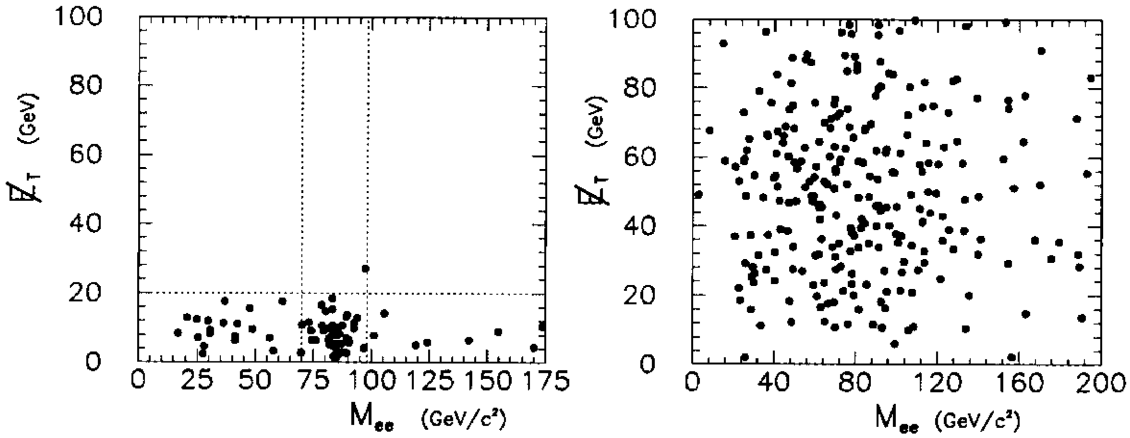

Figure 1: $\not{E}_t$ versus M_{ee} : (a) DØ data (b) $t\bar{t} \to ee$ MC ($M_{top} = 140\ GeV/c^2$)

two identified electrons with $E_t > 15\ GeV$, with at least one calorimeter cluster having a matching central detector track. Since $t\bar{t}$ events are accompanied by $\not{E}_t$, the $\not{E}_t$ is required to exceed 20 GeV. Events from $Z \to ee$ are rejected by requiring that M_{ee} is 14 GeV/c^2 away from the Z mass peak. Since there are two b quarks from the $t\bar{t}$ decay, at least two jets are required to be reconstructed in the event with a transverse energy exceeding 12.5 GeV and 10 GeV for the two jets, respectively. Figure 1(a) shows a scatter plots of $\not{E}_t$ versus the di-electron invariant mass of the events that passed the E_t requirements for the two electrons and the two jets. No event survives all the cuts in this data sample. For comparison, figure 1(b) shows the $\not{E}_t$ versus the di-electron invariant mass for a $t\bar{t}$ Monte Carlo for a top quark of mass 140 GeV/c^2 ($\int Ldt = 2840pb^{-1}$) where the two electrons passed the E_t requirements.

2.2. DØ eμ Channel Analysis

The data in this analysis corresponds to an integrated luminosity of 7.5 pb^{-1}. For this analysis two identified leptons are required with $E_t > 15\ GeV$. To require the muon to be isolated a cut was applied requiring $dR(\mu - jet) > 0.5$. Figure 2 shows the muon p_t versus electron E_t (a), and $\not{E}_t$ versus the invariant mass of the two leptons for the 27 events that passed the above cuts. Figure 3 show scatter plots of $\not{E}_t$ versus $M_{e\mu}$ for $t\bar{t} \to e\mu$ Monte Carlo events for a top mass of 120 GeV/c^2 ($\int Ldt = 1420pb^{-1}$) and for $Z \to \tau\tau \to e\mu$ Monte Carlo events ($\int Ldt = 150pb^{-1}$), respectively. For $t\bar{t}$ events the $\not{E}_t$ is uniformly distributed. For $Z \to \tau\tau \to e\mu$, however, it is clustered at low missing E_t values. An additional cut of $\not{E}_t > 20\ GeV$ is applied to reject $Z \to \tau\tau$, QCD and Drell-Yan background events. To remove radiative $W \to \mu\nu$ and $Z \to \mu\mu$ and muon bremstrahlung events a cut on the invariant mass of the ($\gamma\mu\nu$) in the W boson transverse mass region is imposed and the $\eta - \phi$ separation between the two leptons is required to be greater than 0.25. After applying the same jet E_t cuts as for the ee channel, one event is left in the data sample.

This one candidate event has a high quality electron with an E_t of $97 \pm 2\ GeV$

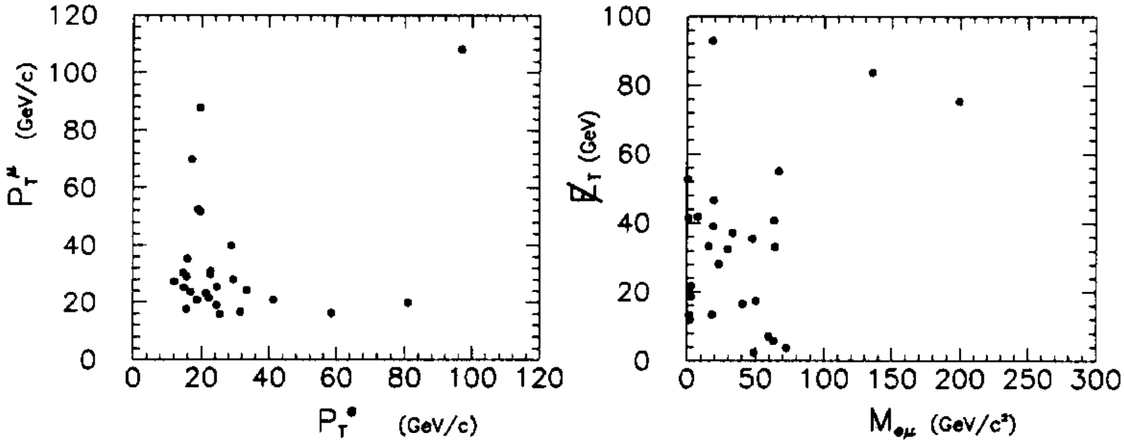

Figure 2: DØ data: (a) muon p_t vs electron p_t (b) $\not{E}_t$ vs $M_{e\mu}$

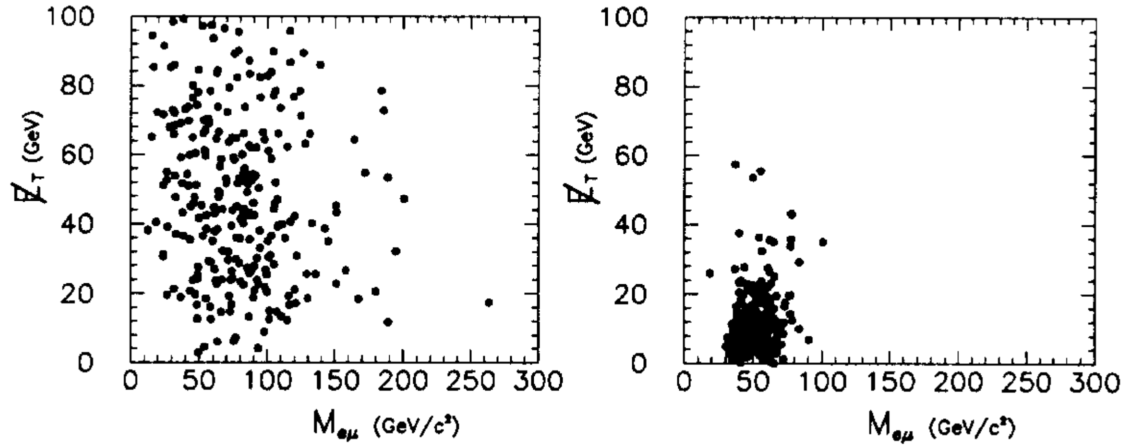

Figure 3: MC data of $\not{E}_t$ vs $M_{e\mu}$: (a) $t\bar{t} \rightarrow e\mu$ (b) $Z \rightarrow \tau\tau \rightarrow e\mu$

and a good quality muon with a p_t of $110^{+\infty}_{-50}$ GeV/c. The p_t of the muon is 5 sigma above the 15 GeV/c cut. There are three jets in this event, of which two have an E_t greater than 25 GeV. The missing E_t is $74^{+\infty}_{-7}$ GeV, where the upper limit is of course fully correlated with the upper limit on $p_t(\mu)$.

2.3. Background Estimation and Efficiency Study

Many background processes are investigated for the ee and $e\mu$ channels separately. The major physics background processes for the dilepton channels are the QCD background with leptons from b and c quark decays, $Z \rightarrow \tau\tau$, $Z \rightarrow b\bar{b}$, $Z \rightarrow c\bar{c}$, WW, WZ, W+jets and Drell-Yan events. We also studied the instrumental backgrounds, which are due to jets misidentified as electrons, missmeasured $\not{E}_t$, muons from π, K-decays, cosmic rays and punchthrough. The biggest contributor to the background was found to be W+jets events, with the W decaying to a lepton and one of the jets faking an electron. The total background for both the ee and $e\mu$

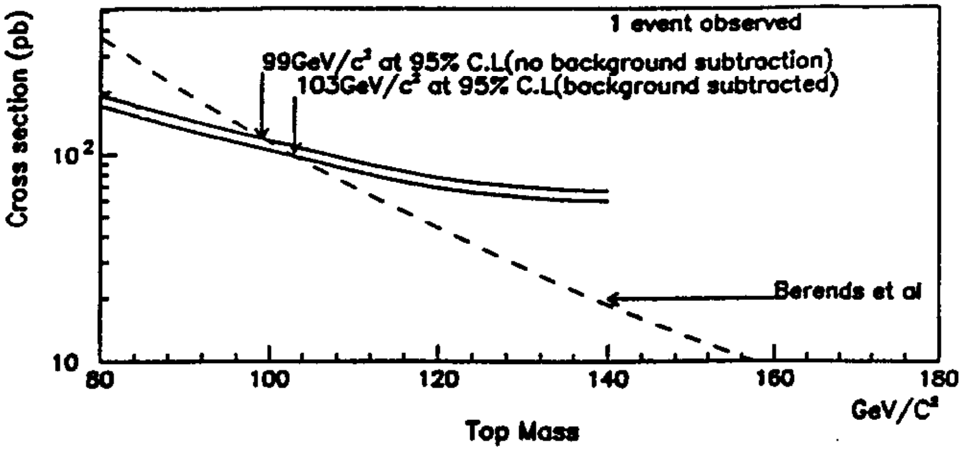

Figure 4: Cross sections for $t\bar{t}$ production as a function of top quark mass

channel is estimated to be 0.87 ± 0.22 events (0.65 events in the $e\mu$ channel and 0.22 events in the ee channel).

The efficiency of the kinematic and topological cuts used in the event selection for $t\bar{t}$ events is determined by using Monte Carlo calculations. The table shows the efficiency (ϵ) and the expected number of $t\bar{t}$ events (N) using the $t\bar{t}$ production cross section [3] for different top masses.

Expected yields for $t\bar{t} \to ee$ and $e\mu$						
m_t (GeV)	σB_{ee} (pb)	ϵ_{ee} (%)	N_{ee}	$\sigma B_{e\mu}$ (pb)	$\epsilon_{e\mu}$ (%)	$N_{e\mu}$
80	4.6	11	3.7	9.1	9	6.1
100	1.3	18	1.7	2.5	15	2.8
120	0.5	28	1.0	1.0	22	1.7
140	0.2	32	0.5	0.5	26	1.0
	$\mathcal{L} = 7.3\,\mathrm{pb}^{-1}$			$\mathcal{L} = 7.5\,\mathrm{pb}^{-1}$		

2.4. Top mass limits from DØ

The DØ experiment sets a top mass limit using the results from the ee and $e\mu$ channel analysis. Figure 4 shows the upper limit for the top production cross section at 95% confidence level with 1 event observed. Using the cross section from Berends et al [3] DØ obtains a limit of 103 GeV/c^2 (99 GeV/c^2) with (without) background subtraction.

Assuming that the $e\mu$ event that passed all cuts originated from a $t\bar{t}$ event, a DØ mass analysis using leptons + principal jets + $\not{E}_t$ finds that this event is consistent with a top quark mass in the mass range of 130 to 170 GeV/c^2 at 90% confidence level.

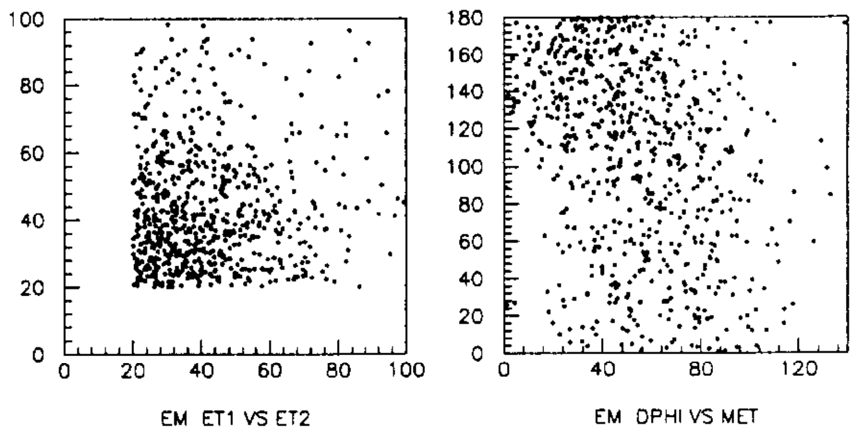

Figure 5: CDF $t\bar{t} \rightarrow e\mu$ Monte Carlo: (a) P_t of two leptons (b) $\Delta\phi$ vs $\not{E}_t$

3. CDF Dilepton Analysis and Results

3.1. CDF Dilepton analysis and results

The offline event selection criteria described here are used by the CDF experiment for the analysis of the 1992-1993 data for an integrated luminosity of 10 pb^{-1} [4] . CDF requires two identified leptons where at least one lepton is in the central region ($|\eta| < 1.0$). The p_t requirement for the two leptons is $P_t > 20\ GeV$. To remove $Z \rightarrow \tau\tau \rightarrow e\mu$ events the azimuthal angle between the two leptons has to be less than 160° . $Z \rightarrow ee$ and $Z \rightarrow \mu\mu$ background events are rejected by requiring the ee or $\mu\mu$ invariant mass to be outside the window of 70 to 110 GeV/c^2. In addition to these cuts the leptons need to pass an isolation cut which requires the p_t in a cone of $\Delta R = 0.4$ around the lepton to be greater than 3 GeV. The missing E_t in the event has to be greater than 25 GeV.

Figure 5 shows a $t\bar{t} \rightarrow e\mu$ Monte Carlo study for a top mass of 120 GeV/c^2 ($\int Ldt = 4440pb^{-1}$) after the lepton p_t cut and $\not{E}_t$ cuts have been applied. Figure 5(a) is a scatter plot for the P_t of the two leptons, (b) is the $\Delta\phi$ versus $\not{E}_t$ distribution. Figure 6 show the same set of plots as Figure 5 for the $e\mu$ data. One event, indicated by an arrow, passes all above cuts for the $e\mu$ event selection. No events pass all select criteria in both the ee and $\mu\mu$ data sample.

The total background is estimated to be 1.4 events in the data sample corresponding to an integrated luminosity of 10 pb^{-1}, mainly coming from WW, $Z \rightarrow \tau\tau$, WZ and Drell-Yan events.

The dilepton event selection efficiency is estimated from Monte Carlo studies and is determined to be about 1-1.5% for top quark masses of 100-160 GeV/c^2, where this efficiency includes the branching ratio.

3.2. Top Mass limit from CDF

Combining the data from the previous run (1988-1989), CDF has two $e\mu$ events that pass the dilepton event selection, one from the previous run (1988-1989) [5] and one event from the current run (1992-1993). A lower limit on the top

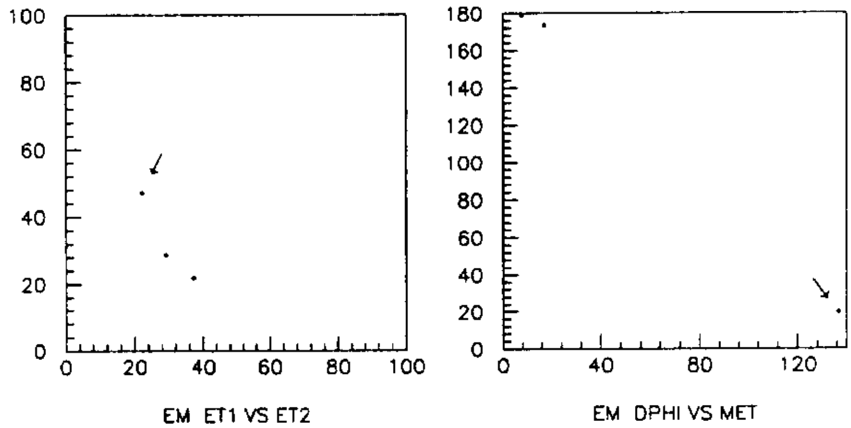

Figure 6: CDF $e\mu$ data: (a) p_t of two leptons (b) $\Delta\phi$ vs $\not{E}_t$

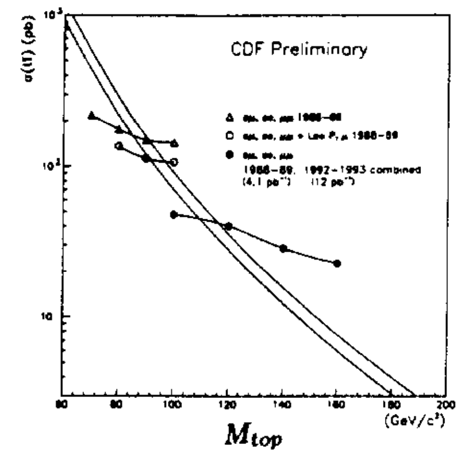

Figure 7: Cross sections for $t\bar{t}$ production as a function of top quark mass

mass is set using the ee, $\mu\mu$ and $e\mu$ channel data combined. Figure 7 shows the lower mass limit for the top production cross section at 95% confidence level. Using the cross section from R.K.Ellis et al ([6]) CDF obtains a lower limit of 108 GeV/c^2 without background subtraction.

4. Lepton + Jets Analysis and Results from DØ and CDF Experiment

4.1. e+jets Channel Analysis

The lepton + jets channel has a relatively high branching ratio. The signature of events in the lepton+jets channel is an event with a high momentum lepton, a neutrino and multiple jets. To select these events, DØ requires an isolated electron with $E_t > 20\ GeV$ and $\not{E}_t > 20\ GeV$. To supress QCD dijet background, events with $d\phi(e - jet) > 165°$ are rejected. Further cuts on the number of jets and the E_t of the jets are applied. Figure 8(a) shows the jet multiplicity for $W \rightarrow e\nu$ events from 10.2 pb^{-1} of data compared to the VECBOS Monte Carlo. The band gives the uncertainty in VECBOS's theoretical prediction. The data agrees well with the Monte Carlo prediction.

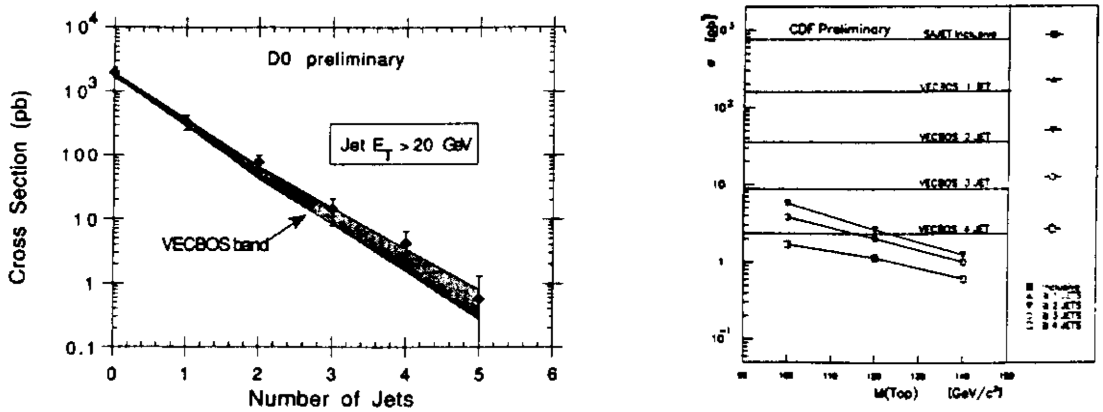

Figure 8: Jet Multiplicity for Data and Monte Carlo: (a) DØ (b) CDF

Figure 8(b) shows the cross section for $W \to \mu\nu/e\nu$ production at CDF for different number of associated jets. The events are selected with $|\eta| < 2.4$, and the jet E_t threshold is 10 GeV. The same figure also shows the Monte Carlo prediction for $W \to \mu\nu/e\nu$ events and top events for different top mass. The plot indicates that after all cuts are applied the cross section for top events is still smaller than the background for Monte Carlo events and the data basically agrees with the background $W \to \mu\nu/e\nu$ events.

4.2. Improve ratio of Signal/Background

The background can be significantly reduced by requiring that one of the jets is tagged as a b-jet. CDF has developed two methods of b-tagging ([7]).

One method is to tag the soft electron or muon. Leptons from b-decays in $t\bar{t}$ events have low p_t and are non-isolated. CDF can identify muons with $p_t >$ 2 GeV/c ($|\eta| < 1$) and electrons with $p_t > 1$ GeV,($|\eta| < 1$). Figure 9(a) shows the CDF $W \to \mu\nu/e\nu$ data after a p_t tag of 4 GeV/c on the lepton. The same figure also shows the Monte Carlo prediction for $W \to \mu\nu/e\nu$ events and top events with different top mass after a p_t tag of 4 GeV on the lepton. It is clear that the signal to background ratio has increased significantly. The soft lepton tag efficiency in CDF is estimated at 17-22%. The fake rate is about 0.75% per muon track and about 0.5% per electron track.

Another method CDF employs is tagging with the SVX (Silicon Vertex detector). Since the SVX can provide high precision tracking information, it can be used to tag b-flavored hadrons by finding evidence for a displaced vertex in the SVX. There are three algorithms used by CDF for SVX tagging: cone tag, $d - \phi$ (where d is the signed impact parameter and ϕ the azimuthal angle) and jet vertexing [8]. The SVX tagging efficiency is about 25%. The fake rate of SVX tagging is about 0.5 - 10 % per jet, which varies with E_t and track multiplicity. Figure 9(b) shows the number of events observed in 9 pb^{-1} of data versus the number of jets for W+jet events before and after the SVX tag. The estimated background for different jet multiplicities is also shown. The background in this plot does not include the contribution from non-W events.

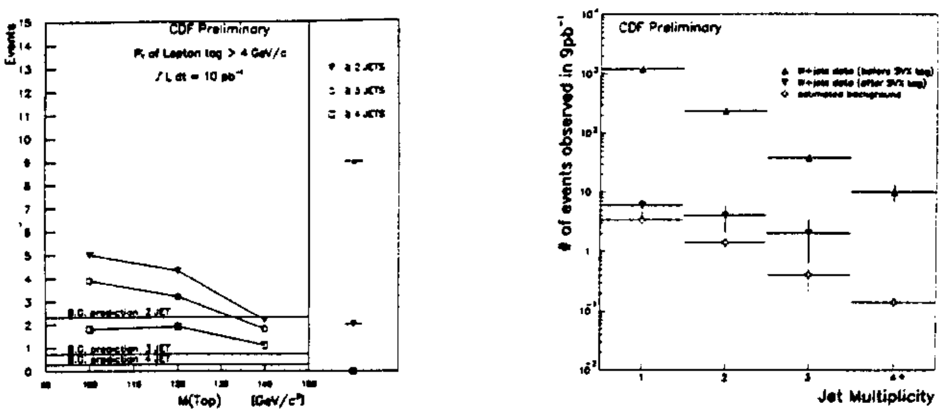

Figure 9: CDF b-tagging: (a) soft lepton tag (b) SVX tag

Work is in progress in both DØ and CDF to reduce the background in the lepton + jets data samples.

5. Conclusions

To conclude, the DØ preliminary analysis yields one event in the $e\mu$ channel and, using the cross section by Berends et al., sets a top mass lower limit of 103 GeV/c^2 (99 GeV/c^2) with (without) background subtraction at 95% confidence level for the ee and $e\mu$ data combined. The CDF preliminary analysis yields one event in the 1988-1989 data and one event in the 1992-1993 data and, using the cross section by R.K.Ellis et al, sets a top mass lower limit of 108 GeV/c^2 at 95% confidence level for the ee, $\mu\mu$ and $e\mu$ data combined without background subtraction.

In the lepton+jets channel, the data is consistent with theoretical predictions for W+jet production for both experiments. Work is in progress on b-tagging to reduce the background and systematic errors.

6. References

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