Fermi National Accelerator Laboratory

FERMILAB-Conf-94/327-E

Search for Top in DØ Using the Electron + Jets Channel with Soft μ Tagging

Rajendran Raja
For the DØ Collaboration

Fermi National Accelerator Laboratory
P.O. Box 500, Batavia, Illinois 60510

September 1994

The *Proceedings of the 27th International Conference on High Energy Physics,* Glasgow, Scotland, July 20-27, 1994

Operated by Universities Research Association Inc. under Contract No. DE-AC02-76CHO3000 with the United States Department of Energy

Disclaimer

Search for top in DØ using the electron + jets channel with soft μ tagging

Rajendran Raja

Fermi National Accelerator Laboratory,
Batavia, Illinois 60510

For the DØ Collaboration

Abstract

We present preliminary results for the search for the top quark in DØ in the electron + jets channel where one of the b quark jets is tagged by means of a soft muon, using 13.5 pb^{-1} of data. Standard model decay modes for the top quark are assumed.

We present the resulting top cross section and error as a function of top mass using this channel combined with the dilepton channel and the untagged lepton + jets channel presented elsewhere in this session. At present, no significant signal for top quark production can be established.

1. Introduction

In the standard model, each top quark decays predominantly to a W boson and a b quark. Each $t\bar{t}$ pair in an event will thus be accompanied by a $b\bar{b}$ pair. If we assume that each b quark decays semi-leptonically $\sim$ 10 % of the time into a muon and likewise for the c quark resulting from the b quark decay, $\sim$ 44% of the $t\bar{t}$ events will have a soft muon. DØ has a muon detection system [1] that is characterized by nearly 4π in solid angle coverage, containing 12-18 interaction lengths of absorber and a relatively small decay volume in the central tracker. This system is capable of detecting these muons (the average p_t of such muons from a 160 GeV/c^2 top quark is 17 GeV/c)with an efficiency such that $\sim$ 20% of the $t\bar{t}$ events will have a detected soft muon tag. Because the conventional W + jets background to the lepton + jets channel is expected to be much less rich in b quarks, it is possible to employ looser cuts in event selection as a result of demanding the lepton tag.

The results of top searches employing dilepton channels and lepton + jets channels without tagging the b quark have been reported [2, 3] in this session. We report here the top production cross section and error combining the results of all these channels. The summary of these three papers is also given in the plenary session [4].

2. Estimation of backgrounds

In order to test our understanding of muon and jet reconstruction efficiencies, we look for soft muons in a QCD dijet sample of events. Figure 1 shows the p_t spectrum of the muons. Also shown are the Monte Carlo [5] calculations of the contributions from muons resulting from π and K decay and b and c quark decay. The sum of these two contributions reproduces the data well for $p_t > 4$ GeV/c . Also shown in the figure is the separation ΔR in $\eta \times \phi$ space of the muon and the nearest jet. The Monte Carlo again reproduces this distribution well.

There are two main sources of background to the channel e+ jets + soft μ tag from $t\bar{t}$ production. The first is from W+Jets production where some of the jets result from the fragmentation of b and c quarks. The second is from QCD multi-jet production containing b or c quarks where one of the jets fakes an electron and the

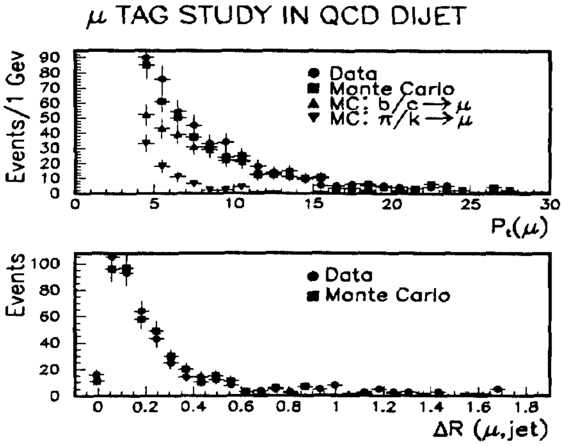

Figure 1. Comparison of data and Monte Carlo predictions for QCD dijet events containing a muon

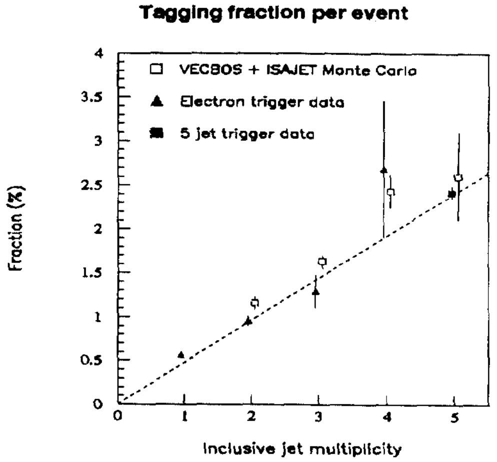

Figure 2. Fraction of events containing muons as a function of the inclusive jet multiplicity

$\not{E}_T$ is produced primarily by detector resolution. In each case we assume that the probability for a jet to emit a detectable muon is independent of the process producing the jet and is a function of the E_T of the jet. The source of the muon may be b or c quark decay, π or K decay or fake μ's due to reconstructing random hits in the muon chambers. We justify this assumption by examining the fraction of events that contain a jet tagged by a muon as a function of the inclusive jet multiplicity (defined as multiplicity $\geq$ a given number of jets) for three different sets of events; for data triggered on a single high E_T ($\geq$ 20 GeV) electron, for QCD 5 jet data and for VECBOS [6] Monte Carlo that describes W+Jets production that has been put through the Isajet [7] shower fragmenter. The results are shown in figure 2. The muon tagging fraction is linearly proportional to the jet multiplicity. The probability for a jet to emit a detectable muon seems to be $\sim$ 0.5 %, justifying the above assumption.

2.1. Definition of the QCD Fake sample

In order to extract the tagging fraction function from data, we first isolate a sample of events which possess a fake electron but which in all other respects resemble the electron + jets event sample under study. Our electron identification algorithm uses a Fisher χ^2 discriminant variable based on 41 quantities describing the energy deposition of the electron in the calorimeter. The χ^2 variable is described as follows.

$$E_{ij} = < x_i x_j > - < x_i >< x_j >$$
$$\chi^2 = \Sigma_{ij}(x_i - < x_i >)H_{ij}(x_j - < x_j >)$$

where the covariance matrix E and its inverse H matrix are defined in terms of the 41 dimensional vector x, which consists of three longitudinal energy fractions, 36 transverse energy fractions at shower maximum, log(Energy of cluster) and the position of the vertex along the beam direction. The angular brackets <> in the above equations signify averages over events. We employ a different H matrix for each of the 37 towers in pseudo-rapidity for either half of the calorimeter. Figure 3 shows the χ^2 distribution for all electromagnetic clusters with $E_T > 20$ GeV and for those which have $\not{E}_T > 30$ GeV . These latter are dominated by genuine electrons from W's and have a much narrower χ^2 distribution. In defining good electrons, we demand that the χ^2 is less than 100. In addition, we define a track match significance parameter as the error weighted impact parameter between the central detector track and the cluster centroid in the azimuthal and beam directions. We demand a central detector track that passes close to the shower centroid with a track match significance of less than 5 for good electrons. Since we are interested in isolated electrons, we demand the isolation fraction to be less than 0.1. The isolation fraction is defined as

$$\frac{(\mathit{Total\ Energy\ in}\ 0.4\ \mathit{cone}\ -\ \mathit{EM\ Energy\ in}\ 0.2\ \mathit{cone})}{\mathit{EM\ energy\ in}\ 0.2\ \mathit{cone}}$$

where the cone size is in ΔR space. We define a fake electron as any EM cluster that fails the good electron criteria and the QCD fake sample as those triggers that have electromagnetic clusters with $E_T > 20$ GeV and fail the good electron criteria with no requirement on $\not{E}_T$.

2.2. Determination of tagging fraction function

We now use the QCD fake sample as a source of jets and determine the fraction of jets that have muons as a function of E_T of the jet *and* jet multiplicity. We require muons to have $p_t > 4.0$ GeV/c and $|\eta| <$

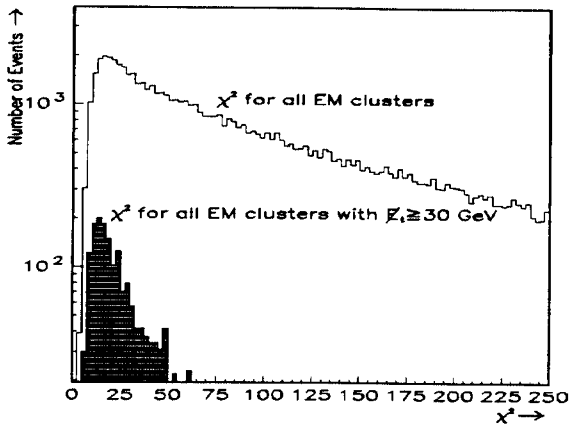

Figure 3. H matrix χ^2 distribution for all EM clusters and for EM clusters with $\not{E}_T > 30$ GeV (shaded)

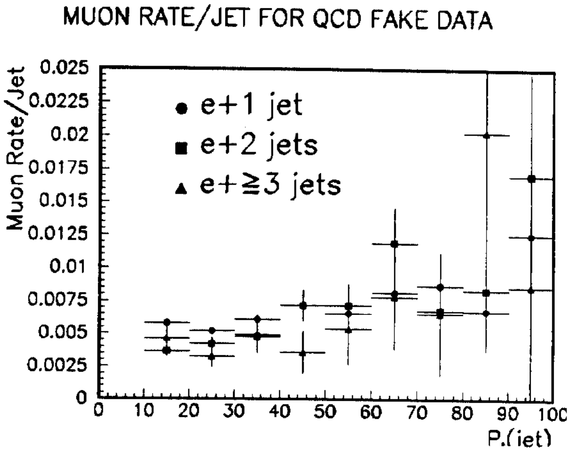

Figure 4. Jet tagging fraction vs E_T of jet for QCD fake events

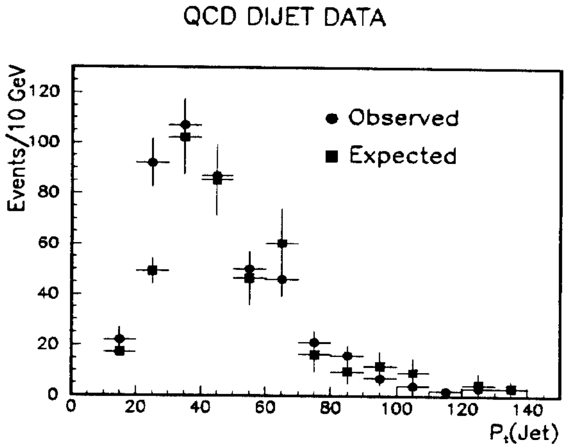

Figure 5. E_T spectrum of of tagged jets in QCD dijets, data and prediction

1.7. We demand that the muon be non-isolated if its p_t is greater than 12 GeV/c . This selection makes this event sample exclusive of the $e\mu$ sample in reference [2]. Figure 4 shows the jet tagging fraction as a function of E_T for the QCD fake sample for jet multiplicities of 1,2 and $\geq$ 3 jets. We now assume that this tagging function, determined as a function of E_T and multiplicity is universal. As a cross check of this hypothesis, we test this on QCD dijet data. Figure 5 shows the E_T spectrum of jets with tagged muons in QCD dijets and the spectrum that is predicted assuming the above tagging functions. There is seen to be good agreement between prediction and data, which gives us confidence in the hypothesis. As a further cross check, we examine the jet multiplicity distribution of tagged jets in "photon" + jets candidates and QCD multijets. A "photon" is an electromagnetic cluster which passes all the good electron criteria except that it has no central detector track. Figure 6 shows the distribution of jet multiplicity for these two sets of data and the prediction using the tagging fraction function. Again there is seen to be good agreement. In order to calculate the μ tag background in W+jets due to the presence of b and c quarks associated with W production, we apply the tagging fraction functions to the W+ Jets sample.

2.3. Calculation of the W+ jets + μ tag background

Figure 7 shows the $\not{E}_T$ distribution of W+Jet data. The QCD fake background is normalized to the data for $\not{E}_T$ < 15 GeV . We now subtract the QCD fake background from the W+jets data ($\not{E}_T > 20$ GeV) to obtain the total amount of W+Jets production. We apply the tagging fraction function to the amount of signal thus obtained. We handle the QCD fake contribution to tagged events separately, since the QCD fakes are at lower $\not{E}_T$ and the presence of the muon affects the $\not{E}_T$ distribution sufficiently to warrant a separate calculation.

2.4. Calculation of the QCD fake μ tag background

Since we have normalized the QCD fakes to the W+jets signal for $\not{E}_T < 15$ GeV , we estimate the QCD fake background by normalizing the tagged muon events in the QCD fake sample with $\not{E}_T > 20$ GeV , by the same factor. We now attempt one further cross check, by comparing the W + 1 Jet data (with $\not{E}_T > 20$ GeV) with the background predictions. Very little top is expected with 1 jet only. Figure 8 shows the comparison of background predictions with data, as a function of E_T of the jet. The agreement between predicted and observed values is good.

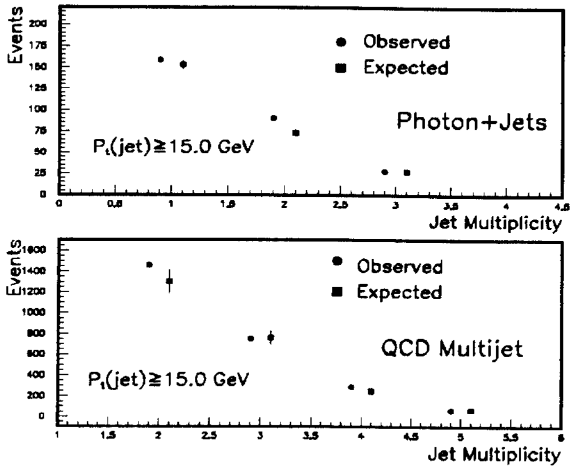

Figure 6. Jet multiplicity distribution of tagged events for "photon" + jets and QCD multijets

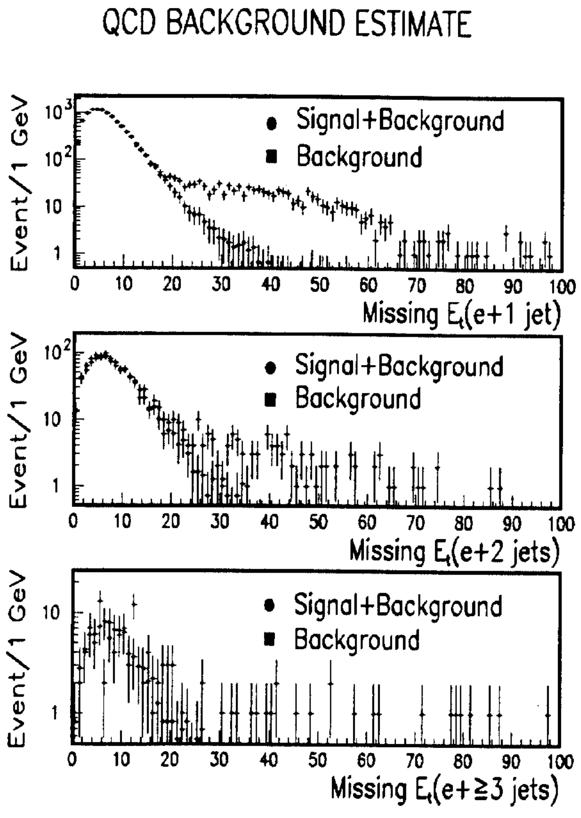

Figure 7. $\not{E}_T$ distribution of W + jet data and QCD fake background normalized to data for different jet multiplicities

3. Summary of cuts and the surviving signal and background

Table 1 shows the summary of the cuts used, the surviving number of events and background estimates as well as the expectation from top production at various masses [8]. The $\Delta\phi(\mu, \not{E}_T)$ cut is introduced to take into account the correlation between $\not{E}_T$ and the muon p_t for QCD fake events. Two events survive the cuts described with a total expected background of 0.55 ± 0.15 events. Figure 9 compares the data and background predictions as a function of inclusive jet multiplicity.

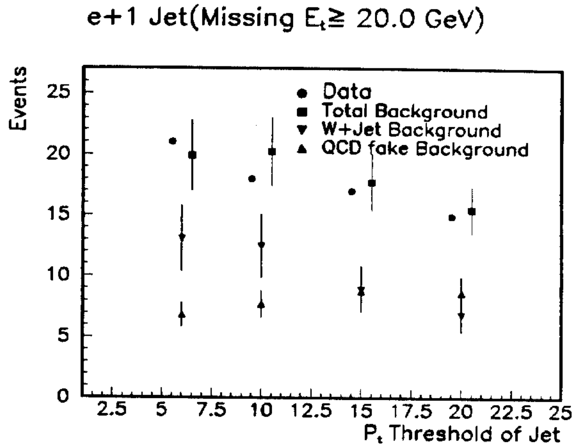

Figure 8. Comparison of background predictions and data for electron + 1 jet events with $\not{E}_T > 20$ GeV

Particle type	Cuts
Electron	H-Matrix $\chi^2 < 100$ Track match signif. < 5.0 $\lvert\eta\rvert < 2.0$ $E_T > 20\,GeV$ dE/dx minimum ionizing
Muon	$\lvert\eta\rvert < 1.7$ $p_t > 4$ GeV/c non-isolated muon or $p_t < 12$ GeV/c
$\not{E}_T$	> 20 GeV $\Delta\phi(\mu, \not{E}_T) > 25^\circ$ if $E_T < 35$ GeV
Jets	≥ 3 jets $E_T > 20$ GeV
Data	Events 2
Background W + jets QCD fakes Total	Events 0.43 ± 0.14 0.12 ± 0.05 0.55 ± 0.15
Top mass GeV/c^2 140 160 180	Expected events 1.3 ± .4 1.0 ± .2 0.6 ± .2

Table 1. Summary of cuts, data, background and top yields

4. Combined top cross section and conclusions

We now combine the results of various DØ top searches [2, 3] reported at this conference with the tagged muon results reported here to obtain a top cross section and

m_t [GeV/c^2]		$e\mu$	ee	$\mu\mu$	$e+$jets	$\mu+$jets	$e+$jets(μ)	ALL
140	$\epsilon \times B(\%)$	.32 ± .06	.18 ± .02	.11 ± .02	1.2 ± 0.3	.8 ± 0.2	0.6 ± 0.2	
	$\langle N \rangle$	.72 ± .16	.41 ± .07	.24 ± .05	2.8 ± 0.7	1.3 ± 0.4	1.3 ± 0.4	6.7 ± 1.2
160	$\epsilon \times B(\%)$	.36 ± .07	.20 ± .03	.11 ± .01	1.6 ± 0.4	1.1 ± 0.3	0.9 ± 0.2	
	$\langle N \rangle$	.40 ± .09	.22 ± .04	.12 ± .02	1.8 ± 0.5	0.9 ± 0.3	1.0 ± 0.2	4.4 ± 0.7
180	$\epsilon \times B(\%)$	.41 ± .07	.21 ± .03	.11 ± .01	1.7 ± 0.4	1.2 ± 0.3	1.1 ± 0.2	
	$\langle N \rangle$	.23 ± .05	.12 ± .02	.06 ± .01	1.0 ± 0.2	0.5 ± 0.2	0.6 ± 0.2	2.5 ± 0.4
Background		.27 ± .09	.16 ± .07	.33 ± .06	1.2 ± 0.7	0.6 ± 0.5	0.6 ± 0.2	3.2 ± 1.1
$\int \mathcal{L}dt$ [pb^{-1}]		13.5 ± 1.6	13.5 ± 1.6	9.8 ± 1.2	13.5 ± 1.6	9.8 ± 1.2	13.5 ± 1.6	
Data		1	0	0	2	2	2	7

Table 2. Efficiency × branching fraction ($\epsilon \times B$), expected number of events ($\langle N \rangle$) for signal and background sources for the observed integrated luminosity ($\int \mathcal{L}dt$), and number of events observed in the data.

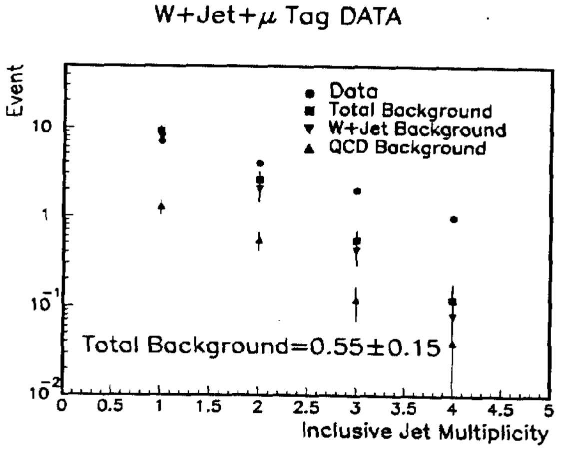

Figure 9. Comparison of background predictions and data as a function of inclusive jet multiplicity.

error. Table 2 summarizes the numbers reported in all the channels. Figure 10 gives the DØ results as a function of top mass compared to theoretical predictions [8] and the recently reported CDF result [9]. Expressed in terms of top production cross section, DØ obtains cross sections of 9.6 ± 7.2 pb, 7.2 ± 5.4 pb, 6.5 ± 4.8 pb for top masses of 140, 160 and 180 GeV/c^2. This assumes that top quark decays with standard model decay modes. This is consistent both with a null result as well as the published CDF result. The DØ μ + jets with μ tag analysis is still in progress. DØ is also pursuing multivariate analyses with an aim to increase our signal acceptance for a given background rejection as well as mass analyses of the lepton + jets candidates. With the increased statistics of the current Tevatron run, we should be able to considerably increase our discovery limit for the top quark very shortly. The results presented here should be regarded as preliminary.

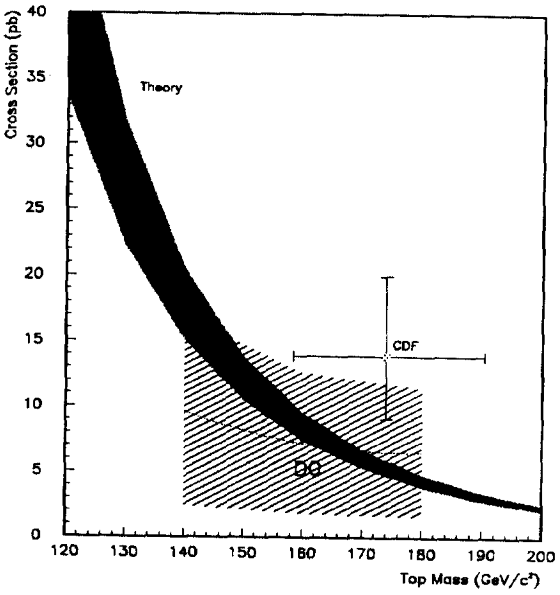

Figure 10. DØ top cross section results compared with theoretical predictions and CDF

References

[1] S. Abachi *et al* , Nucl. Instr. Meth. **A338** (1994) 185
[2] S. Wimpenny, these proceedings.
[3] S. Protopopescu, these proceedings.
[4] P. Grannis, these proceedings.
[5] R. Brun *et al* , "GEANT Users Guide", CERN Program Library
[6] W. Giele, E. Glover and D. Kosower, Nucl. Phys. **B403** (1993) 633
[7] F. Paige and S. Protopopescu, ISAJET v6.49 Users Guide, BNL Report no. BNL38034, 1986 (unpublished).
[8] E. Laenen, J. Smith, and W. van Neerven, Phys. Lett. **321B** (1994) 254.
[9] CDF Collaboration: F. Abe *et al.*, Phys. Rev. Lett. **73** (1994) 225, F. Abe *et al.*, Phys. Rev. **D50** (1994) 2966