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SEARCH FOR THE TOP QUARK IN UA1 AND IN THE OTHER HADRON COLLIDER EXPERIMENTS*

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Search for the top quark in the UA1 experiment in 1988–89 is discussed and preliminary results are given. The analysis is based on 4.6 pb^{-1} integrated luminosity at the CERN SPS $p\bar{p}$ collider. The properties of isolated muons produced in association with jets are found to be consistent with the predictions of the minimal Standard Model but no signal for the top quark is observed. An upper limit for the production cross section is determined. From this a lower limit of 61 GeV/c^2 (95% CL) is obtained for the mass of the top quark in a statistical analysis of all data. A similar analysis gives a lower limit of 41 GeV/c^2 for the mass of a fourth generation quark with charge-1/3 (b′ quark). The UA2 experiment has obtained in a similar analysis of electron data corresponding to an integrated luminosity of 7.1 pb^{-1} preliminarily a lower limit of 67 GeV/c^2 for the top mass and 53 GeV/c^2 for the b′ quark mass. The CDF experiment at the Fermilab $p\bar{p}$ collider gives as the result of similar analysis of electron data of integrated luminosity of 4.7 pb^{-1} a preliminary lower limit of 77 GeV/c^2 for the mass of the top quark.

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1. Introduction

In the minimal Standard Model three particle species remain to be observed experimentally, namely the top quark, the neutral Higgs particle and the τ neutrino. Search for the top quark has been one of the main objectives of the recent proton antiproton collider experiments in 1988 and 1989 at CERN and at Fermilab. In this talk I shall discuss the search for the top quark in the UA1 experiment at CERN but shall also briefly give the preliminary results of the corresponding analyses of the UA2 experiment at CERN and of the CDF experiment at the Fermilab collider.

The top quark can be most easily recognized through its semileptonic decay into an

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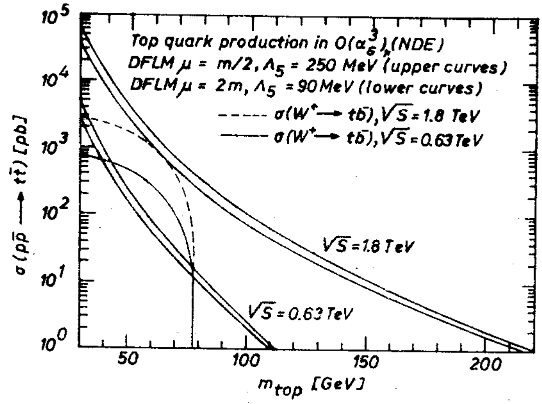

Fig. 1. Predicted top quark production cross sections in $p\bar{p}$ collisions as a function of the mass of the top quark for 0.63 TeV and 1.8 TeV c.m.s. energy

electron, a neutrino and a b-quark (eνb) or a muon, a neutrino and a b-quark (μνb). Hence, when searching for the top quark in $p\bar{p}$ collisions the following final states are looked for

1) e^+e^-+(1 or 2 jets) + missing momentum (the missing momentum is caused by the neutrinos escaping detection);

2) eμ+(1 or 2 jets) + missing momentum;

3) $\mu^+\mu^-$+(1 or 2 jets) + missing momentum;

4) e+(1–4 jets) + missing momentum (the missing momentum now comes mainly from one neutrino);

5) μ+(1–4 jets) + missing momentum.

The top quark must exist in the Standard Model since otherwise the b quark would decay with an appreciable branching ratio (about 10%) via a flavour changing neutral current interaction to charged lepton pairs

$$b \to X l^+ l^- .$$

Experimentally this has been excluded at a level less than 10^{-4} [1].

Lower limits for the mass of the top quark have been reported earlier from several experiments. A solid experimental limit comes from the e^+e^- experiments at the TRISTAN collider. No signal has been seen with beams up to 30.7 GeV which then directly gives a lower limit for the mass [2]. From the UA1 experiment in 1983–85 a limit of 41 GeV/c^2 has been determined from a statistical analysis at a 95% confidence level, assuming the minimal Standard model [3, 4]. In ARGUS and CLEO experiments a lower limit of 50 GeV/c^2 has been deduced from the size of the B_{d^0}–$\bar{B}_{d^0}$ mixing [5]. This limit, however, is based on several assumptions.

Upper limits can be deduced from comparison of the measured $\sin^2 \theta_W$ or the neutral current coupling parameter ϱ in collider experiments and in low energy experiments, respectively. Radiative corrections lead to differencies that depend on the masses of the top quark and the Higgs particle. Earlier analyses give upper limits of the order of 170–200 GeV/c^2 [6].

A new search for the top quark was launched last year at the CERN SPS hadron collider at 630 GeV c.m.s. energy and at the Fermilab collider at 1.8 TeV. In these experiments, which continued till summer 1989, about 15 pb^{-1} integrated luminosity was collected in total. As we shall see later this should be sufficient to observe the top quark if it would be lighter than the W. No signal has been seen in any of the experiments. In the following we shall discuss which lower limits can be determined for the top mass on the basis of this result.

2. *Top quark production in $p\bar{p}$ collisions*

If the top quark is lighter than the W boson it can be produced via the weak interaction as a decay product of a W produced in the $p\bar{p}$ collision. The cross section for this process is reliably known since the cross section for the processes $p\bar{p} \to WX$, $X \to l\nu$ has been measured in the collider experiments. To obtain the total cross section for $p\bar{p} \to WX$ only the branching ratio $B(W \to l\nu)$ is needed from the theory. In the minimal model this is quite well known.

Secondly, the top quark can be produced via the strong interaction, in $t\bar{t}$ pairs. For this process the cross section is less reliably known from theory. Nason, Dawson and K. Ellis have calculated the cross section at the quark level to the order α_s^3 in the perturbative QCD [7]. To compute the $p\bar{p}$ cross section, the value of the QCD Λ parameter, the gluon structure function $G(x)$ and the mass of the b quark have to be chosen. In addition, there are intrinsic uncertainties in the estimate, like the choice of the scale parameter and the next order terms. In Fig. 1 the results of a cross section calculation by Altarelli et al. [4] are shown as a function of the top mass for the CERN and Fermilab collider energies. In the same figure the cross section for the weak top production is also shown. At the CERN collider energy the weak process clearly dominates above 50 GeV/c^2. In the case of the $t\bar{b}$ final state the two leptons from the first decays have the same sign, which is an additional signal for the top production.

The main physics background comes from the b production process

$$p\bar{p} \to b\bar{b}gX,\ b \to l\nu c$$

which can give the same final state signatures as listed above. The additional signature of the top decays is that the lepton can be 'isolated' from the final state jets due to the much larger Q-value of its decay.

The $b\bar{b}g$ production process has been studied in great detail in the UA1 experiment in the muon channel [8]

$$p\bar{p} \to b\bar{b}gX,\ b \to \mu\nu c$$

in which case the lepton can be experimentally detected also inside the b-jet (this is not possible for electrons, since they are detected as showers in the electromagnetic calorimeter).

The earlier searches for the top quark in the UA1 experiment (1983–85) were based on identification of one isolated electron or muon associated with 1 or 2 jets (cases 4 and 5 above). From these studies, based on $0.6\,pb^{-1}$, a lower limit of 41 GeV/c^2 at a 95% confidence level has been derived [3, 4].

3. UA1 experiment in 1988–89

The upgrading of the CERN antiproton source through the addition of a new collector ring (ACOL) in 1987 increased the luminosity of the CERN collider by about an order of magnitude. The peak luminosity in the experiments in 1988–89 exceeded $2\times10^{30}\,cm^{-2}\,s^{-1}$. UA1 collected data corresponding to an integrated luminosity of $4.6\,pb^{-1}$, more than six times that had been collected in the experiments in 1983–85.

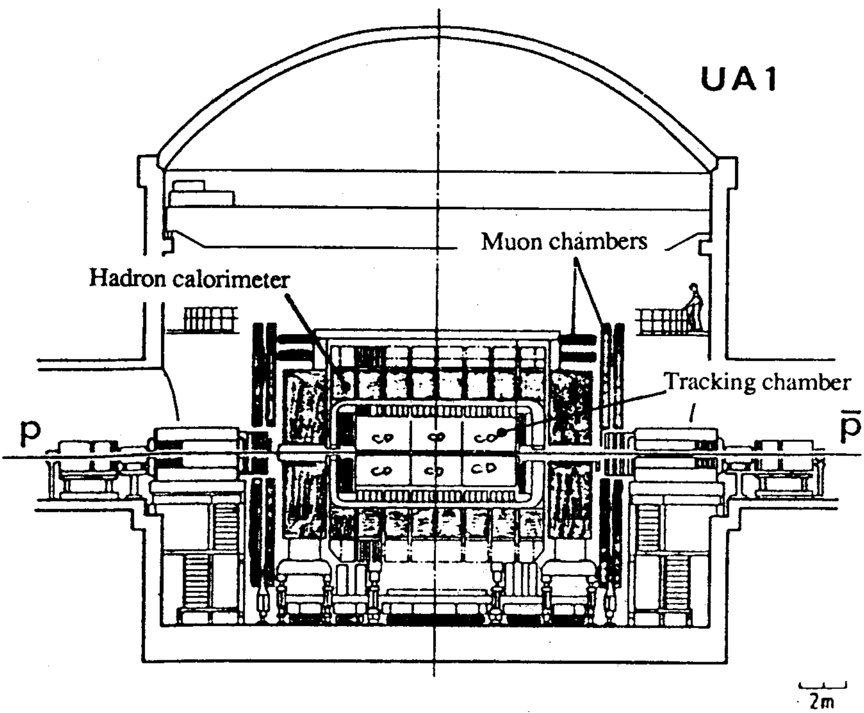

Fig. 2. The UA1 detector

The UA1 detector was essentially the same as in 1983–85 except that the electromagnetic calorimeters had been removed to prepare for the installation of a new uranium-tetramethylpentane calorimeter [9]. Therefore, no electron detection was available, and lepton detection was limited to muons. The detector consisted of the central tracking chamber, the hadron calorimeter and the muon detector (see Fig. 2). The muon detector had been upgraded by installing additional iron shielding in the forward region to increase the triggering capabilities at large rapidities and by adding layers of limited streamer tube chambers behind the hadron calorimeters. A complete upgrade had been done for the data read-out system, which is now based on the VME-standard, and a new first level calorimeter trigger processor had been installed. A more complete description of the detector can be found in Ref. [10].

In total about 3×10^7 events with muon trigger were collected on tape. From this data a fraction, the events having a muon with $p_T > 5$ GeV/c (less than 10%), was selected onto special tapes with an on line filter program running in eleven parallel 3081 emulators. Off line two data samples were further selected, 1) a single muon sample with a muon with

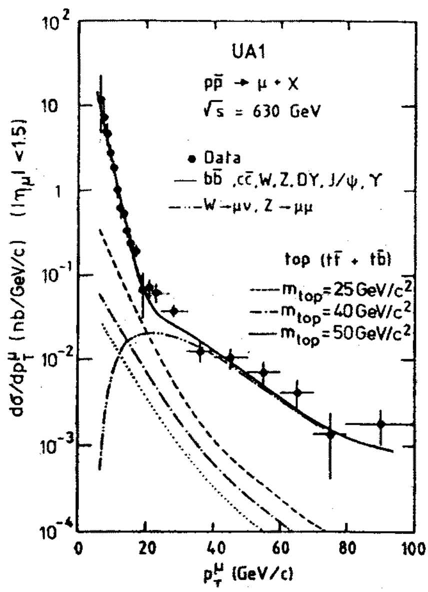

Fig. 3. Inclusive transverse momentum distribution of the muons with $|\eta| < 1.5$. The estimated background from decay muons has been subtracted

$p_T > 8$ GeV/c (40 K events) and 2) a dimuon sample with one muon with $p_T > 8$ GeV/c and second muon with $p_T > 3$ GeV/c (800 events).

In addition to the muon triggered data, 3.5×10^6 events with one jet of $E_T > 10$ GeV were collected. These events were triggered with the new trigger processor and were used for the estimation of the background to prompt muons from muons coming from undetected K and π decays in flight. Furthermore, over three million events with a minimum bias trigger were collected for the calibration of the hadron calorimeters.

In Fig. 3 the inclusive muon transverse momentum spectrum is shown with estimated decay background subtracted from it. The rest of the estimated background is shown as a full curve. One can see that below 20 GeV/c the main background comes from $b\bar{b}$ production whereas above 20 GeV/c the muons from W decays dominate. The full curve, describing the background, fits well the data. The contribution of the possible top quark production is shown for three different top masses. It is clear from the figure that the possible top signal is small and cannot be detected from the inclusive distribution.

4. *Search for the top quark in the single muon + jets channel*

In order to increase the signal to background ratio further, we look next for the top quark in the single muon final states with at least two jets, and require the muon to be isolated. The optimized selection is the following

$$p_T(\text{muon}) > 12\ \text{GeV}/c, \quad E_T(\text{jet }1) > 15\ \text{GeV},$$

$$E_T(\text{jet }2) > 7\ \text{GeV}, \quad I(\text{muon}) < 2.$$

To suppress the background from $W \to \mu\nu$ we reject events with the transverse mass of the muon-neutrino system larger than 60 GeV/c^2. In Fig. 5 we show the muon isolation distribution of the data compared with the background prediction.

Therefore, we proceed by studying the data sample where a muon is detected in association with at least one jet. The background to this sample now mainly comes from production of a $b\bar{b}$ pair produced together with a gluon, as discussed earlier. We define a control sample with the following cuts

$$12\ \text{GeV}/c < p_T(\text{muon}) < 15\ \text{GeV}/c, \quad |\eta(\text{muon})| < 1.5, \quad E_T(\text{jet}) > 12\ \text{GeV}.$$

To estimate the background, we use the ISAJET Monte Carlo program (same as in the earlier analysis [3]) including the $p\bar{p}$ processes leading to $b\bar{b}$, $c\bar{c}$, W, Z, Drell-Yan pairs, J/ψ, and upsilon.

In total 10 pb^{-1} of Monte Carlo events were generated and passed through a simulation program corresponding to our detector configuration. These simulated raw data events were reconstructed with the standard reconstruction programs and compared with the experimental data.

Figures 4a–f show a comparison of the data with the Monte Carlo predictions. In the figures the contribution of the decay background is also separately shown as hatched histograms. The isolation of the muon is measured with the quantity $I = [(\Sigma E_T/3)^2 + (\Sigma p_T/2)^2]^{1/2}$ [3]. The sums extend over the calorimeter cells (ΣE_T) and the CD tracks (Σp_T) in the cone of $\Delta R = [(\Delta\eta)^2 + (\Delta\phi)^2]^{1/2} = 0.7$. The agreement between the data and the Monte Carlo prediction is good, leaving little room for any top signal. As expected for the b decays, most of the muons are inside the jets, i.e. at large values of I.

To reduce the systematic uncertainty in the $b\bar{b}$ and $c\bar{c}$ prediction in the bin $I < 2$, where the top signal to background ratio is expected to be best, the background has been normalized to the data in the control region $I > 2$, where the contribution of the t produc-

TABLE I

Predicted numbers of events from different background processes for the data sample with an isolate muon + jets, I(muon) < 2

K/π decay	W/Z	DY, J/ψ, upsilon	$b\bar{b}$, $c\bar{c}$	Total	Data
22±5	6±2	6±3	44±8	77±10	76

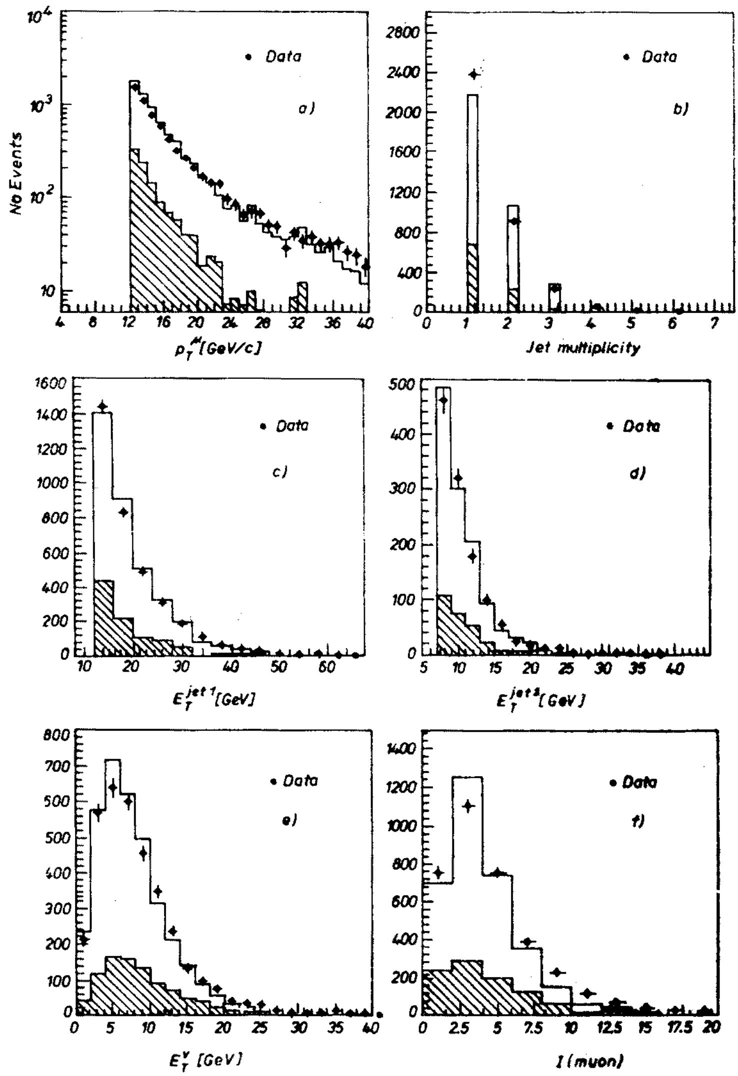

Fig. 4. a) Inclusive transverse distribution of the control sample; b) Jet multiplicity; c) Transverse energy distribution of the highest E_T jet; d) Transverse energy distribution of the second jet; e) Missing E_T distribution; f) Isolation distribution of the muon

tion is small. In Table I the predicted contributions of different background contributions are given together with the number of events in the data. The errors quoted are the combined systematic uncertainties coming from systematic errors in the energy scale, luminosity, theoretical values for the cross sections, statistical errors in the Monte Carlo samples, etc. They are discussed in more detail in Ref. [10].

The background is seen to describe the data well for $I < 2$, where we expect 77 ± 10 events from the background and observe 76 events. Consequently, there is no room for

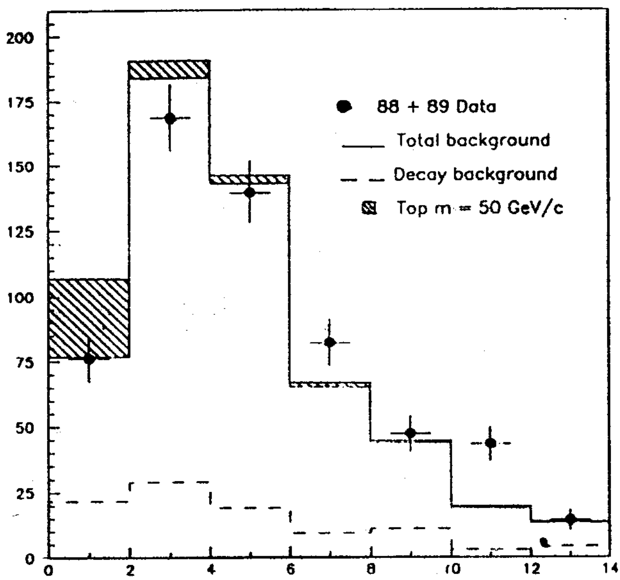

Fig. 5. Isolation distribution of the muon in the data sample with a muon +2 jets

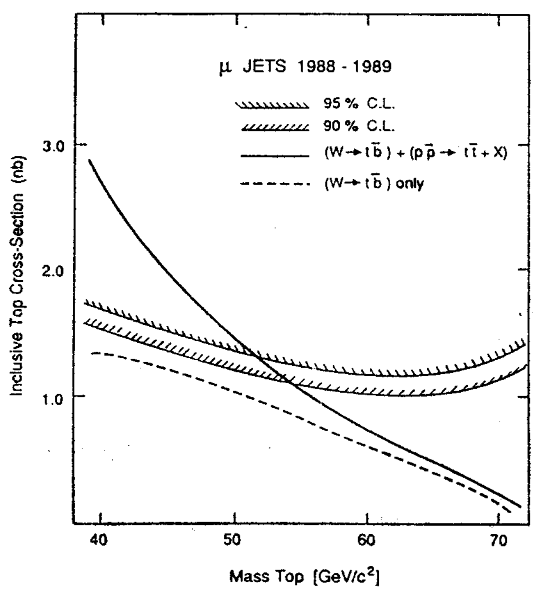

Fig. 6. The upper limit of the top production cross section as determined from the muon +2 jets data, together with the theoretical predictions for the top production cross sections asf unctions of the mass of the top quark

TABLE II

Predicted numbers of events with a top quark for different masses for the two production processes. The errors represent the systematic uncertainties in the prediction

Top mass (GeV/c^2)	40	50	60	70
$t\bar{b}$	21	20	10	4
tt	18	9	4	1
Total	39 ± 10	29 ± 7	14 ± 4	5 ± 1

a top signal. In Table II the expected numbers of top quark events in our sample for top masses 40, 50, 60 and 70 GeV/c^2 are given (assuming the standard branching ratio 1/9). For comparison, we also show the expected contribution of the top quark production for the top mass 50 GeV/c^2 in Fig. 5.

An upper limit can be derived for the t-quark cross section in the region $I < 2$ that is consistent with the number of events observed. Using the predicted cross section as a function of the top mass, a lower limit can then be derived for the mass. This is done with a likelihood analysis, where we add the statistical errors as well as systematic uncertainties in our measurement and in the theoretical estimates in quadrature. The preliminary result is (see Fig. 6)

$$m_t > 55\,GeV/c^2\ 90\%\ CL, \qquad m_t > 53\ GeV/c^2\ 95\%\ CL.$$

5. *Search for the top quark in the dimuon channel*

In the dimuon channel we can combine the data from the runs in 1983–85 with the recent data, which gives in total an integrated luminosity of 5.4 pb^{-1}. In this channel the muons are selected with the following cuts

$$p_T(\text{muon 1}) > 8\ GeV/c, \qquad p_T(\text{muon 2}) > 3\,GeV/c, \qquad |\eta_\mu| < 1.6.$$

To reduce the background from $b\bar{b}$ production the mass of the dimuon system is required to be larger than 6 GeV/c^2. An upper limit of 50 GeV/c^2 is imposed to suppress the contribution from Z^0's. To reduce further the background from the b decays with high Q^2 we make a weak isolation cut for the first muon, $I < 6$. The second muon is required to be non--isolated, $I > 2$, to cut away the contribution of the Drell-Yan production. Furthermore, at least one jet of $E_T > 10$ GeV is required in the central region.

This leaves 102 dimuon events. The ISAJET Monte Carlo simulation gives us for the same integrated luminosity and with exactly the same cuts 91 $b\bar{b}$ and $c\bar{c}$ events and 2 events from the Drell-Yan process. The background from the K and π decays in flight is estimated to 16 events. Clearly the background again explains the data, leaving no room for top events. As an example, for the top mass of 50 GeV/c^2 we would expect 10 events. In Figs. 7a–c we show a comparison between the data and the Monte Carlo prediction for the background for three kinematic variables, namely the p_T of the first muon, the

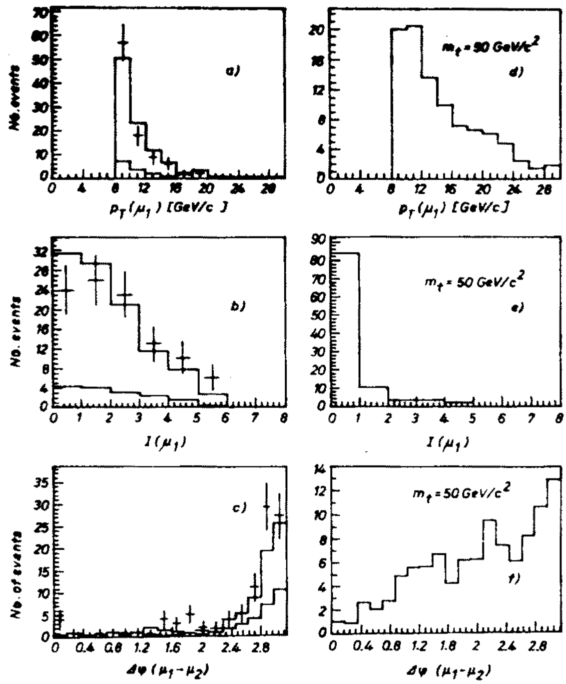

Fig. 7. a) Transverse momentum distribution of the first muon. The data are shown as dots and the background as a histogram. The contribution of the decay background is shown also separately as a hatched histogram; b) Isolation distribution of the first muon; c) Azimuthal angle between the muons; d) as a) but for top events predicted with $m_t = 50$ GeV/c^2; e) as b) but for top events predicted with $m_t = 50$ GeV/c^2; f) as c) but for top events predicted with $m_t = 50$ GeV/c^2

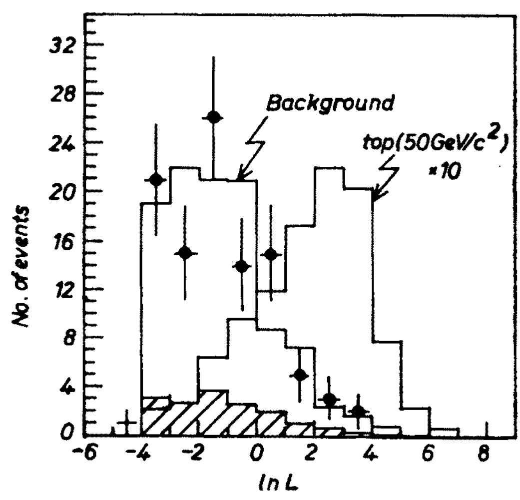

Fig. 8. The top-likeness function L

isolation of the first muon in the cone $\Delta R < 0.4$, and the difference in azimuthal angle of the two muons. The agreement is good within errors.

For comparison we show in Figs. 7d–f the corresponding distributions for the t-quark production, which are very different compared to the background distributions. In order to exploit this difference we define a top-likeness variable

$$L = [\Pi P_{top}(x_i)]/[\Pi P_{bb}(x_i)],$$

where $\Pi P_{top}(x_i)$ is the product of the probability density functions for the three variables in Figs. 7d–f for the top quark and $\Pi P_{bb}(x_i)$ corresponding product of probability density functions for $b\bar{b}$ and $c\bar{c}$ production. The top-likeness is plotted in Fig. 8 for the data, the background processes and for the events with top production. One can see that by cutting in L one can enhance the content of the possible top events in the data sample. We define the signal region by cutting at $L > 2$ and are left with 10 events in the data. The ISAJET Monte Carlo gives $8.9 \pm 1.9 \pm 2.3$ $b\bar{b}$ and $c\bar{c}$ events, $1.0 \pm 0.4 \pm 0.4$ Drell-Yan events and our decay background calculation predicts $1.9 \pm 0.2 \pm 0.4$ π/K decay events in the signal region. The second error is always the estimated systematic uncertainty. For the top mass 50 GeV/c^2, $7.1 \pm 0.5 \pm 1.3$ events would be predicted.

A similar likelihood analysis that was made in the muon + jet channel gives the following lower limits for the top quark mass:

$$m_t > 52 \text{ GeV}/c^2 \text{ at } 90\% \text{ CL}, \quad m_t > 46 \text{ GeV}/c^2 \text{ at } 95\% \text{ CL}.$$

6. Combined mass limit for the t-quark

For the final mass limit we combine all results from the top search made in the UA1 in 1983–85 and in 1988–89. In Table III the mass limits for different channels obtained in UA1 studies are summarized.

The results can be combined to obtain an overall mass limit. Most of the systematic errors in different channels are correlated. In combining the channels we take the most conservative approach and assume that all systematic errors are correlated. As before we convolute the statistical and systematic errors in quadrature. The result is illustrated in Fig. 9, where we show the 90% and 95% confidence limits for the t production cross section

TABLE III

UA1 results on the mass limits of the top quark

Channel	Data	Background	Top expectation		Limit
	(no. of events)		$m_t = 50$	$m_t = 60$	m_t (GeV/c^2)
e+jets (85)	26	26 ± 2.8	8.5	—	41
μ+jets (85)	10	11.4 ± 1.2	4.7	—	40
μ+e (85)	0	1.6 ± 0.2	1.2	—	25
μ+jets (88–89)	76	77 ± 11	29	13.8	53
$\mu+\mu$ (83–89)	10	11.8 ± 2.3	7.1	3.2	46

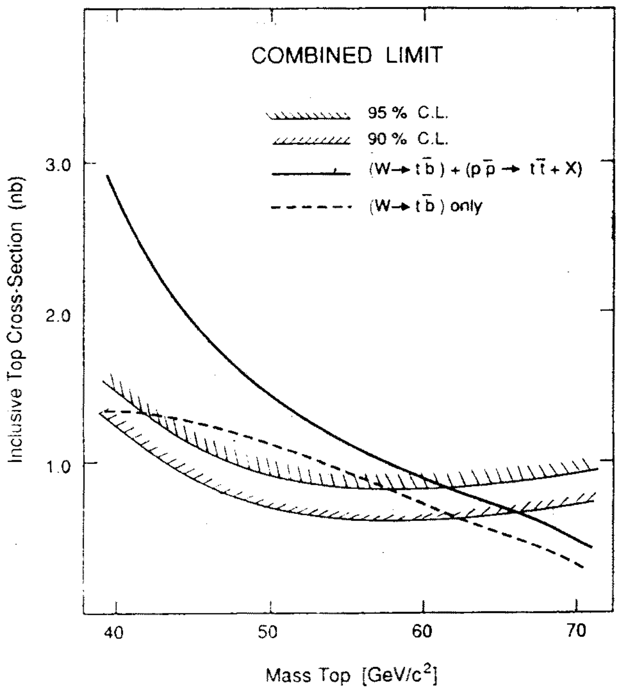

Fig. 9. The upper limit for the top production cross section as determined from all UA1 data, together with the predicted cross section as a function of the mass of the top quark

as a function of the t mass. From the figure one can obtain the overall limits

$$m_t > 66\,\mathrm{GeV}/c^2 \text{ at } 90\%\,\mathrm{CL}, \qquad m_t > 61\,\mathrm{GeV}/c^2 \text{ at } 95\%\,\mathrm{CL}.$$

The present statistics allows us to deduce a mass limit with the $t\bar{b}$ channel alone

$$m_t > 58\,\mathrm{GeV}/c^2 \text{ at } 95\%\,\mathrm{CL}.$$

7. Mass limit for the fourth generation b′ quark

A similar analysis as for the t-quark can be made for the fourth generation b′-quark. The main difference is that b′ cannot be produced through W decay (results from UA1 and elsewhere show that $m_W > m_t + m_{b'}$). The cross sections for a chosen mass of m_t or $m_{b'}$ are the same. The muon transverse momentum distribution is harder for the b′ than for the t-quark because of the form of the V-A amplitude.

The limit obtained for the b′ mass from the muon + jet channel is

$$m_{b'} > 41\,\mathrm{GeV}/c^2 \text{ at } 95\%\,\mathrm{CL}.$$

The cross section in this channel and the b mass limit accordingly depend, however, also on the branching ratio of the charged current decay. This is not known since the rate of

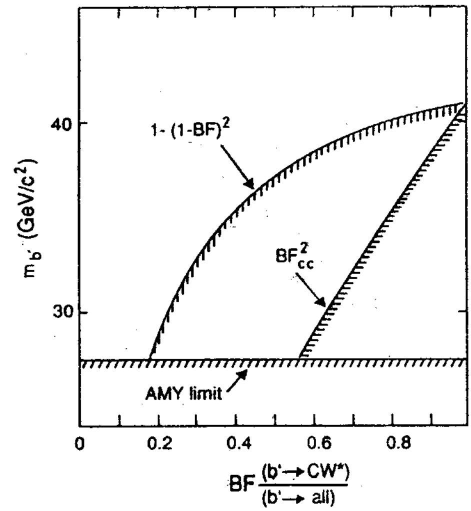

Fig. 10. The result for the b′ mass (95% CL) as a function of the branching ratio for the charged current decay process

the third order neutral current process depends on unknown matrix elements $V_{b't}$ and V_{bt}. The result of our analysis (95% CL) is shown in Fig. 10 as a function of this branching fraction for two extreme cases with both or one of the b′ decaying through the charged current interaction. In the figure also the limit from TRISTAN is shown.

8. *Summary of the UA1 results*

In the search for the top quark in the data collected by UA1 in 1988–89 (4.6 pb^{-1}) no signal for t production was found. Comparing the numbers of events in the data with the estimated background and the expected top signal for different masses of the top in all data collected by UA1 in 1983–85 and 1988–89, the following lower limits were derived in a likelihood analysis for the mass of the top quark

$$m_t > 66\ \mathrm{GeV}/c^2 \text{ at } 90\%\mathrm{CL}, \qquad m_t > 61\ \mathrm{GeV}/c^2 \text{ at } 95\%\mathrm{CL}.$$

Similarly, no signal was found for the fourth generation b′ quark. A likelihood analysis gives the following lower limit for the b′ mass

$$m'_{b'} > 41\ \mathrm{GeV}/c^2 \text{ at } 95\%\ \mathrm{CL}.$$

9. *Search for the top quark in UA2*

In the UA2 experiment the search for the top quark in 1988–89 was made with an upgraded detector shown in Fig. 11. Details on the detector can be found in Ref. [11]. The analysis was made in a data sample corresponding to an integrated luminosity of 7.1 pb^{-1} collected in 1983–85 and 1988–89. Here the preliminary results are given [11].

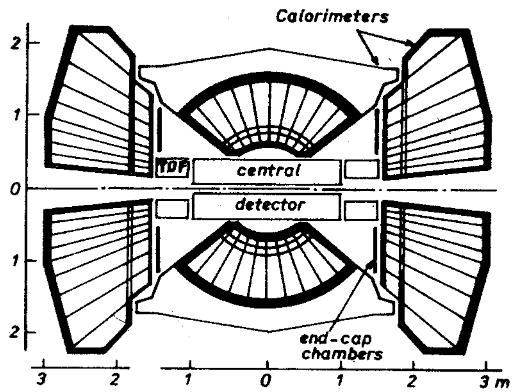

Fig. 11. The upgraded UA2 detector

Search was made in the electron + jets channel. The data sample was defined with the following cuts:

$$p_T(\text{electron}) > 12\ \text{GeV}/c,\ |\eta(\text{electron})| < 1, \quad p_T(\text{neutrino}) > 12\ \text{GeV}/c,$$

$$p_T(\text{jet 1, jet 2}) > 10\ \text{GeV}/c,\ |\eta(\text{jet})| < 2.2, \quad |\phi(\text{e, jet 1})| < 160.$$

The transverse mass of the electron-neutrino system (m_T) was used as the selective variable.

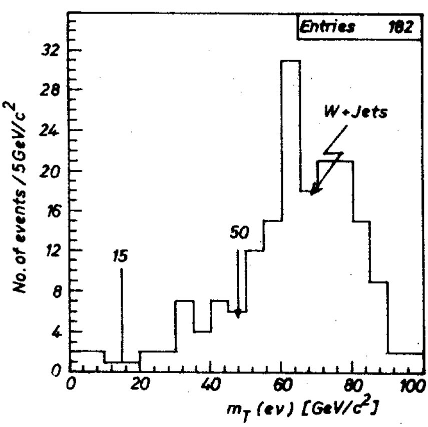

Fig. 12. Transverse mass distribution of the electron-neutrino system in UA2

The distribution in this variable is shown in Fig. 12. The signal region was defined with the cuts

$$15 < m_T(\text{electron-neutrino}) < 50\ \text{GeV}/c^2.$$

In this region 29 events were observed. The estimated background from W + jets, $b\bar{b}$, ... was 40 ± 9 events. The expected top signal for different masses of the top is given in the following table

m_t	40	50	60	65	70
No. events	49.6	47.0	32.1	19.5	11.5

A statistical comparison of the number of events in the data with the background estimate and the expected number of top events as a function of top mass with systematic uncertainties folded in gives

$$m_t > 67\ \text{GeV}/c^2 \ \text{at}\ 95\%\ \text{CL}.$$

In the search of the b′ quark that is similar to the UA1 analysis, UA2 obtains the following limit

$$m_{b'} > 53\ \text{GeV}/c^2 \ \text{at}\ 95\%\ \text{CL}.$$

10. Search for the top quark in the CDF experiment

The CDF experiment at Fermilab has looked for top production at 1.8 TeV c.m.s. energy. A schematic presentation of the experimental apparatus is shown in Fig. 13. At these energies the cross section for top production is dominated by the strong process as can be seen from Fig. 1. Two channels were analyzed, namely the electron + 2 jets channel and the electron + muon channel. The preliminary results are given in the following [12]. The electron + 2 jets channel was defined with the following cuts

$$E_T(\text{electron}) > 20\ \text{GeV}, \quad E_T(\text{neutrino}) > 20\ \text{GeV},$$

$$E_T(\text{jet 1, jet 2}) > 10\ \text{GeV},\ |\eta| < 2, \quad m_T(\text{electron-neutrino}) > 24\ \text{GeV}/c^2.$$

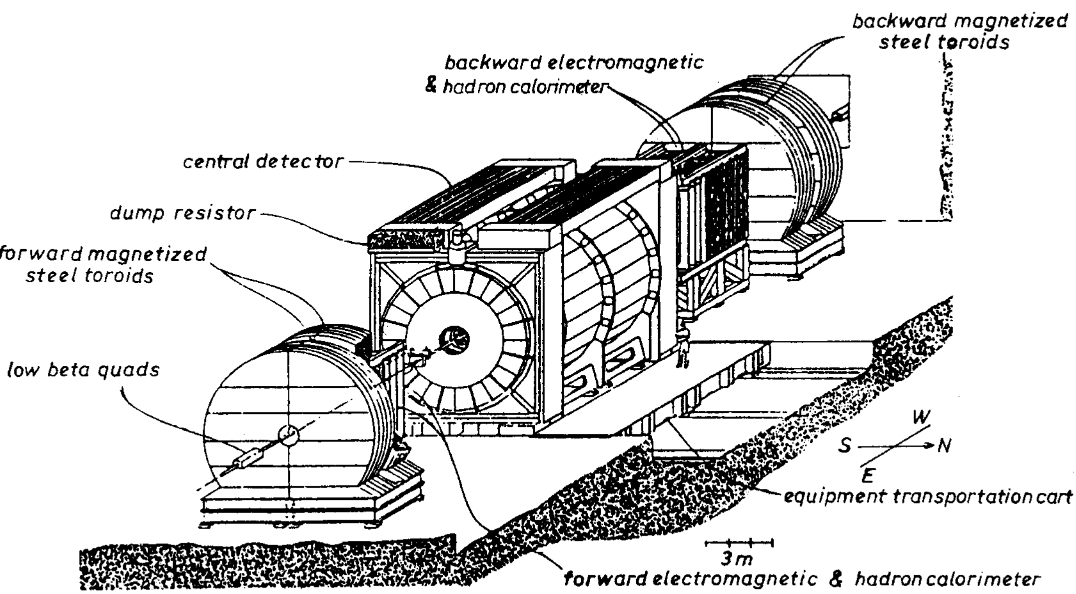

Fig. 13. The CDF detector

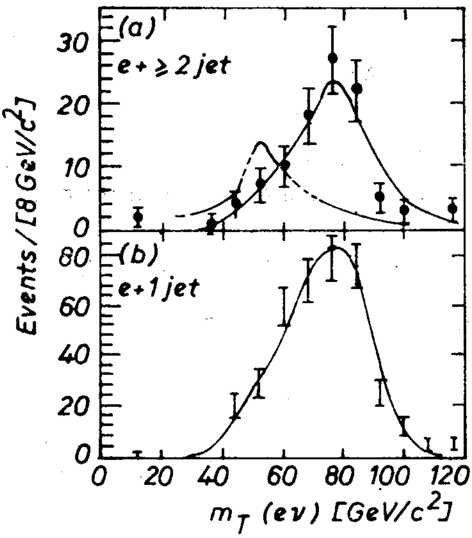

Fig. 14. Transverse mass distribution of the electron-neutrino system in CDF

The distribution of the transverse mass of the electron neutrino system is shown in Fig. 14. The main background to the possible top signal comes from W decays.

A fit with top and W contributions taking into account the systematic uncertainties excludes at 95% CL the top masses

$$40 < m_t < 77 \ \mathrm{GeV}/c^2 .$$

For the electron + muon channel the following cuts were made

$$E_T(\text{electron}) > 15 \ \mathrm{GeV}, \quad p_T(\text{muon}) > 15 \ \mathrm{GeV}/c .$$

Only 1 event was observed, which excludes at 95% CL the top masses

$$30 < m_t < 72 \ \mathrm{GeV}/c^2$$

always assuming the standard decays of the top.

11. Conclusion

The top quark has not been found in the $p\bar{p}$ collider experiments at CERN and at Fermilab in 1988–89. Statistical upper limits for the production cross section have been determined by the UA1, UA2 and CDF experiments assuming decay channels predicted in the minimal Standard Model. These upper limits have been turned into lower limits for the mass of the top quark using the predicted cross section as a function of the top mass. The 95% CL lower limits are

$$\text{UA1}: \ m_t > 61 \ \mathrm{GeV}/c^2 ,$$

$$\text{UA2}: \ m_t > 67 \ \mathrm{GeV}/c^2 ,$$

$$\text{CDF}: \ m_t > 77 \ \mathrm{GeV}/c^2 .$$

Taken together these results indicate that almost certainly the top quark cannot be lighter than the W. This result is well consistent with the limits for the top quark mass obtained in recent analyses of the differencies between the $\sin^2 \theta_W$ obtained from the low energy data and the new accurate measurements of the W and Z^0 masses in the CDF experiment and in the Mark II experiment at SLAC [13]. This limit will be improved soon when more accurate results on $\sin^2 \theta_W$ will become available from the LEP experiments at CERN.

Search for the top quark will be continued at the CERN collider and more extensively at Fermilab in the coming years.

I wish to thank the organizers of the School for their kind invitation and for the enjoyable atmosphere the School has. I thank all my colleagues in UA1 who have contributed to the exciting search for the top quark.

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