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SEARCH FOR NEW PARTICLES WITH UA2

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ABSTRACT

The upgraded UA2 detector has collected data corresponding to an integrated luminosity of 7.8 pb^{-1} at a center of mass energy of 630 GeV during the 88 and 89 runs of the CERN $p\bar{p}$ collider.

A search was performed for the production of new particles : top quark (t) and heavy quark from a hypothetical fourth family (b')[1], and supersymmetric particles (squarks $\tilde{q}$, and gluinos $\tilde{g}$[2], and also selectrons $\tilde{e}$ and winos $\tilde{w}$ through Z decays[3]). No such particles were found, and lower limits on their masses were obtained :

$$m_t > 69 \text{ GeV/c}^2,\ m_{b'} > 54 \text{ GeV/c}^2 \text{ at } 95\ \%\ \text{CL},$$
$$m_{\tilde{q}} > 74 \text{ GeV/c}^2,\ m_{\tilde{g}} > 79 \text{ GeV/c}^2,$$
$$m_{\tilde{e}} > 40 \text{ GeV/c}^2,\ m_{\tilde{w}} > 45 \text{ GeV/c}^2 \text{ at } 90\ \%\ \text{CL}.$$

In the first section the search for squarks and gluinos will be discussed and in the second section the search for top and b' will be described.

I - SEARCH FOR SQUARK AND GLUINO

Introduction

Abundant QCD production of squark pairs, gluino pairs or squark gluino pairs is predicted at hadron colliders in supersymmetric (SUSY) models. In most models, the $\tilde{\gamma}$ is expected to be the lightest supersymmetric particle and hence stable if R-parity conservation is assumed. In these models, we expect that the $\tilde{g}$ decays mainly to $q\bar{q}\tilde{\gamma}$ and the $\tilde{q}$ mainly to $q\tilde{g}$ (if $m\tilde{q} > m\tilde{g}$) or $q\tilde{\gamma}$ (if $m\tilde{q} < m\tilde{g}$), for the mass range accessible at the CERN $p\bar{p}$ collider.

In this case, the hadronic production of $\tilde{q}$ and $\tilde{g}$ results in final states containing two to six jets and missing transverse momentum ($\not{p}t$) from the undetected photinos.

Data selection

A search has been made with UA2 for multijet events with large $\not{p}t$. The data used for this analysis were collected with a dedicated $\not{p}t$ trigger, which is fully efficient for events with $\not{p}t > 20$ GeV/c.

The following kinematical criteria were applied. At least, two jets were required to be reconstructed in the event, within the central region $|\eta| < 0.85$, with transverse energy above 25 (resp. 15) GeV for the first (resp. second). These two leading jets were also required to be not back-to-back in the transverse plane, using the following cut $\Delta\varphi$ (jet 1 − jet 2) < 160°, to reduce the background from QCD two jet events.

About 2 100 events with $\not{p}t > 20$ GeV/c survived all the selection criteria listed above.

The $\not{p}t^2$ distribution for this data sample is shown in figure 1.

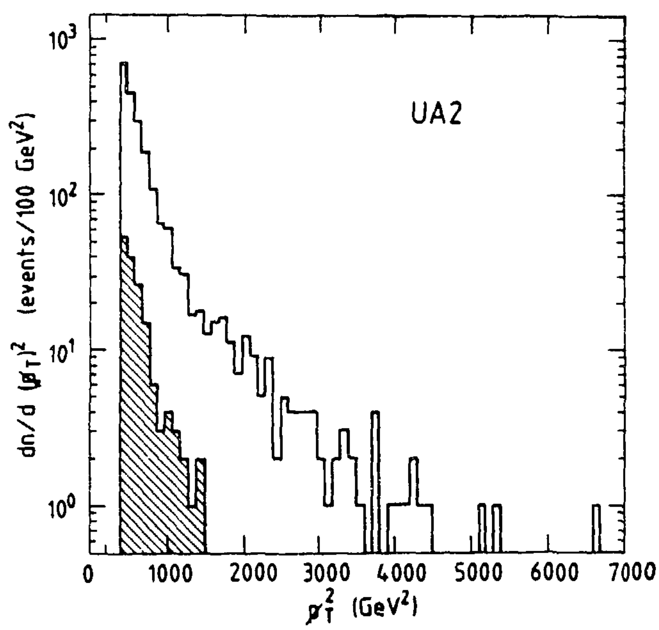

Figure 1 : $\not{p}_t^2$ distribution for the present multijet data with large $\not{p}_t$. The data are shown before the $\not{p}_t$ isolation and electron rejection requirement and after all selections applied (shaded histogramm).

It is dominated by QCD multijets events where one jet was mismeasured and therefore induced a fake $\not{p}t$. This fake $\not{p}t$ is correlated in azimuth with the mismeasured jet, and this background could therefore be reduced by an isolation requirement on the $\not{p}t$ vector. The following two conditions were then applied :

. the $\not{p}_t$ is not back-to-back to the leading jet

$$\Delta\varphi \text{ (jet 1, } \not{p}_t \text{)} < 140°$$

. the $\not{p}_t$ is not aligned in azimuth with any jet

$$\Delta\varphi \text{ (jet k, } \not{p}_t \text{)} > 20° \text{ , k = 3, 4,...} \quad E_t^k > 10 \text{ GeV}$$

The data sample contains also the physics background from the production of Intermediate Vector Bosons (IVB) in association with jets, followed by an IVB decay with neutrino emission giving real $\not{p}_t$. This background is estimated to ~ 60 events, mainly W ($\rightarrow e\upsilon$) + jets production. Most of this background involves an electron in the final state, therefore events containing electrons identified by purely calorimetric criteria were removed.

The $\not{p}_t^2$ distribution after the full data reduction is shown in figure 1. No event survives the final selection $\not{p}_t > 40$ GeV. This corresponds to an upper limit on the observable cross-section of 0.35 pb at 90 % CL.

Calculation of predicted rates for SUSY processes

The production cross-sections given in reference 4 and the EHLQ 1 structure fonction parametrization[5] were used.

The p_t of the generated SUSY particle pair was generated according to reference 6. Ten mass degenerate $\tilde{q}$ states were assumed. Gluinos were fragmented using the prescription of reference 7 and q and g were hadronized following the scheme of reference 8. Finally a full simulation of the calorimeter response was performed. Table 1 gives the results for three representative choices of $m\tilde{q}$ and $m\tilde{g}$.

Systematic errors on the predicted rates

Several parameters of the QCD calculation (the strong coupling constant α_s, the structure function choice, Q^2 scale, pt of the SUSY pair) have been varied in order to estimate the influence of their uncertainties on the predicted rates. The effects of these variations are listed in Table 1.

The results of the simulation depend also on the modelling of the detector response to the final state q and g in the environment of $\bar{p}p$ collisions. The following effects were investigated : fragmentation model and jet energy scale, calorimeter response simulation and influence of the underlying event (contribution from the partons which are not part of the hard scattering process producing the SUSY particle pair).

The systematic uncertainties obtained are listed in Table 1.

Table 1 : SUSY Model Calculations

	$m_{\tilde{q}}$ = 99 GeV $m_{\tilde{g}}$ = 100 GeV		$m_{\tilde{q}}$ = 200 GeV $m_{\tilde{g}}$ = 80 GeV		$m_{\tilde{q}}$ = 70 GeV $m_{\tilde{g}}$ = 10^5 GeV	
cross-sections :						
produced (pb)	9.4		14.4		14.2	
observed (pb)	0.60 ± 0.02		0.45 ± 0.02		0.46 ± 0.02	
ε (%)	6.3 ± 0.2		3.1 ± 0.2		3.2 ± 0.1	
systematic errors (%) :	low	high	low	high	low	high
α_s + structure functions	-11	22	-18	20	-16	20
Q^2-scale	0	16	0	14	0	16
p_T SUSY pair	-9	4	-5	0	0	16
jet energy scale (including fragmentation)	-11	16	-23	43	-16	26
combined systematic error for 90% CL (%)	-8		-19		-2	

Results and conclusions

The expected observable cross-sections lowered by the systematic errors are shown in figure 2 for the cases of nearly equal $\tilde{q}$ and $\tilde{g}$ masses as well as for large $\tilde{q}$ and large $\tilde{g}$ masses. The lower mass limits at 90 % CL can be deduced from figure 2 directly from the intersection with the experimental cross-section limit.

The excluded region at 90 % CL in the ($m_{\tilde{q}}$, $m_{\tilde{g}}$) plane is displayed in figure 3. Masses below 50 GeV were not excluded by this analysis because the acceptance at the chosen cuts was too small, and they have been already excluded by previous experiments[9]. The results of figures 2 and 3 are insensitive to $m_{\tilde{\gamma}}$ for $m_{\tilde{\gamma}} < 20$ GeV/c^2.

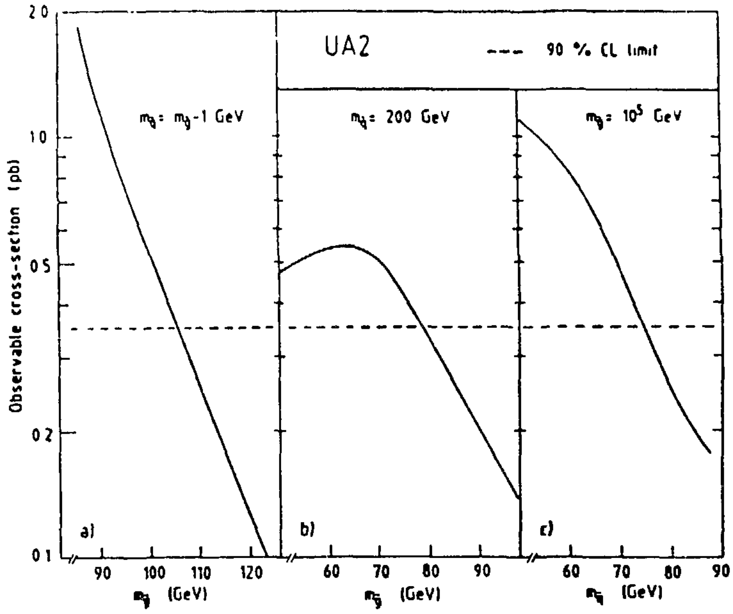

Figure 2 : Expected observable cross-sections as a function of the SUSY particle mass after all selection criteria and including the systematic uncertainties needed to deduce 90 % CL mass limits. The experimental cross-section limit (90 % CL) is also indicated.

a) nearly equal $\tilde{q}$ and masses, b) heavy $\tilde{q}$ care ($m_{\tilde{q}}$ = 200 GeV/c^2), c) heavy $\tilde{g}$ care ($m_{\tilde{g}}$ = 10^5 GeV/c^2)

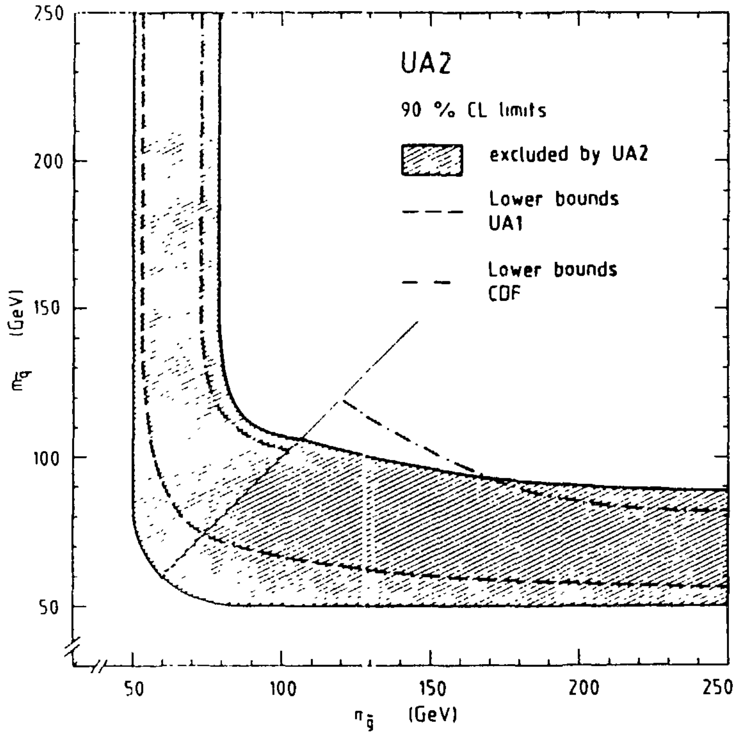

Figure 3 : Mass region ($m_{\tilde{q}}$, $m_{\tilde{g}}$) excluded by the present experiment (shaded area). The dashed curves indicate the previous mass limits from UA1 and the dashed - dotted the one from CDF [9]. All limits are for 90 % CL.

In conclusion, the following 90 % CL lower mass limits are obtained $m_{\tilde q} > 74$ GeV/c^2 independent of $m_{\tilde g}$, $m_{\tilde g} > 79$ GeV/c^2 independent of $m_{\tilde q}$, $m > 106$ GeV/c^2 for $m_{\tilde q} = m_{\tilde g} = m$.

II - SEARCH FOR TOP QUARK PRODUCTION

Top production and decay

Top quarks could be produced at the $\bar{p}p$ collider from two dominant processes, either mediated by the weak interaction ($t\bar{b}$) : $\bar{p}p \rightarrow W + X$, $W \rightarrow t\bar{b}$ or $\bar{t}b$

or by the strong interaction ($t\bar{t}$) : $p\bar{p} \rightarrow t\bar{t} + X$

The cross section for the $t\bar{b}$ process can be computed as $\sigma(t\bar{b}) = 3\ \sigma^{UA2}(W \rightarrow e\nu)$ x (Phase Space Factor) x (1 + QCD correction), where the factor 3 is the color factor, $\sigma^{UA2}(W \rightarrow e\nu)$ is the cross-section for $\bar{p}p \rightarrow W + X$, $W \rightarrow e\nu$ measured by UA2 and where the phase space factor depends on the top mass and is computed using a W mass from the measured values M_Z at LEP and $\sin^2\theta_w$ at low energy, giving $M_w = 80.2 \pm .4$ GeV/c^2. The lower limit on $\sigma(t\bar{b})$ is obtained using $M_w = 79.8$ GeV/c^2. To be conservative, we ignore QCD corrections which have large uncertainties for heavy top. The value of $\sigma(t\bar{b})$ obtained is shown in figure 4. The cross section for the $t\bar{t}$ process has been evaluated in reference 10 using the full next-to-leading order calculation from reference 11. The result is shown in figure 4 as a band indicating the theoretical uncertainties. For top quark masses between 35 and 70 GeV/c^2, the top production cross-section is dominated by the electroweak $t\bar{b}$ process at $\sqrt{s} = 630$ GeV.

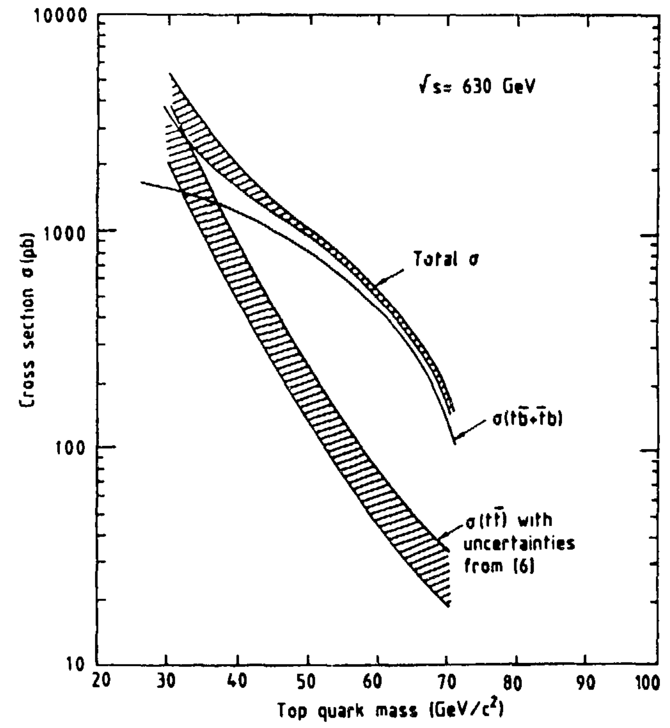

Figure 4 : Cross-sections for top production in $p\bar{p}$ interactions at $\sqrt{s} = 630$ GeV.

The dominant final state in top events consists as multijet events, but the signal is very difficult to distinguish from the large QCD background. The search was therefore performed using the decay mode $t \to b\ e\ \nu_e$ which has a branching ratio of 1/9 in the Standard Model. In this case, the signature of top quark production consists in events containing an electron, one or more hadronic jets, and the missing transverse momentum ($\not{p}_t$) from the neutrino.

Data Selection

The following criteria were applied : we required an electron in the central detector (rapidity interval $|\eta| < 1$) with a transverse energy above 12 GeV. Only events with $\not{p}_t > 15$ GeV were retained. We required also at least one jet with a transverse energy above 10 GeV in the rapidity interval $|\eta| < 2.2$. To reduce the background from QCD 2 jet events where one jet fakes an electron, we removed events where the electron candidate and the leading jet were back-to-back in the transverse plane ($\Delta\varphi$ (e – jet 1) > 160°).

After all the above cuts a total of 137 events were selected from the data. A useful variable for discriminating between various classes of events is the transverse mass M_t of the electron – $\not{p}_t$ system.

$$M_t^2 = 2\ P_{te}\ \not{p}_t\ (1 - \cos \Delta\varphi\ (e - \not{p}_t\ )).$$

The distribution of M_t for the final data sample is shown in figure 5. As shown below, the sample is dominated by $W \to e\nu$ decays.

Acceptance for top

The acceptance for top events and their expected M_t distribution were obtained using the EUROJET Monte Carlo program[12] which contains the correct matrix element for higher order tree level processes in heavy quark production. The top decay was simulated after hadronisation following the prescription of reference 13. Finally a full simulation was performed of the calorimeter response.

The results on the acceptance are shown in Table 2. The acceptance increases as the top quark mass increases since the decay products have increasing average E_t. The acceptance is larger for $t\bar{t}$ compared to $t\bar{b}$ because the number of jets is larger.

Systematic uncertainties in the acceptance

The sources of systematic error in the acceptance are the same as in the search for squarks and gluinos (effect of the underlying event, calorimeter response to jets and jet energy scale, and fragmentation).

The lowest value of the acceptance consistent with the systematic uncertainties is given in brackets in Table 2.

Electron efficiency for top events

The electron efficiency was measured with electrons from real W events to be $\varepsilon_e^w = 47.6 \pm 1.6$ %. Top events are expected to have more complex topologies and lower energy electrons than the W events and the electron efficiency for top electrons was therefore expected to be smaller than ε_e^w. This loss was evaluated. It depends on the top mass and also on the process ($t\bar{b}$ or $t\bar{t}$).

For $t\bar{b}$ $\quad \varepsilon_e$: 35.3 % → 41.4 %

mtop 30 → 70 GeV/c²

For $t\bar{t}$ $\quad \varepsilon_e$: 36.1 % → 33.8 %

The relative error on these efficiencies was estimated to be ± 7 %, dominated by systematic uncertainties.

Table 2 gives the numbers of events expected from both processes after taking into account the electron efficiencies and the semi-electronic branching ratio. The lower limit (in brackets) on the number of events uses the lower production cross-sections and the lower limits on the acceptance. The expected number of events is also given for the transverse mass range $15 < m_t < 50$ GeV/c² where most of the signal is expected (because the top decays to a virtual W for $m_t < m_W + m_b$ which is the mass range relevant for this analysis).

Table 2 : Estimated Acceptance and Signal Rates for Various Top Masses

m_{top}	Cross section (pb)		Acceptance (%)		Expected events	
GeV/c²	$t\bar{b}$	$t\bar{t}$	$t\bar{b}$	$t\bar{t}$	All M_T	$15 < M_T < 50$
30	1522 (1522)	3040 (2128)	1.8 (1.5)	1.9 (1.7)	39.2 (26.2)	33.4 (22.4)
40	1211 (1211)	643 (450)	4.1 (3.5)	7.1 (6.4)	39.2 (28.3)	34.9 (25.4)
50	845 (820)	188 (132)	8.1 (7.1)	16.8 (15.3)	38.2 (28.9)	34.4 (26.2)
60	459 (436)	66.9 (46.8)	12.3 (11.0)	25.2 (22.9)	26.7 (20.8)	22.6 (17.6)
63	349 (328)	50.3 (35.2)	12.1 (10.8)	29.6 (27.0)	21.3 (16.3)	17.0 (13.3)
65	283 (263)	40.9 (28.6)	12.4 (11.1)	29.5 (26.9)	17.6 (13.4)	13.6 (10.6)
67	218 (200)	34.4 (24.1)	12.5 (11.1)	32.4 (29.5)	14.5 (10.8)	11.0 (8.2)
70	136 (122)	26.7 (18.7)	15.3 (13.6)	35.5 (32.3)	11.5 (8.5)	8.3 (6.2)

Background processes

• W events. The main source of background is the W + jets production followed by the decay, $W \to e\upsilon$ or $W \to \tau\upsilon$, $\tau \to e\upsilon_e\upsilon_\tau$.

This background was estimated with the EKS Monte Carlo program[14]. The absolute prediction for this background (112 ± 40) is poorly known, the normalisation was therefore taken from the data at $M_t > 60$ GeV where we expect only W events. After this normalisation, the numbers of expected events are listed in Table 3.

• $Z \to ee$ where one electron fakes a jet, $Z \to \tau\tau$, $\tau \to e\upsilon_e\upsilon_\tau$, $\tau \to \upsilon_\tau X$.

This background was estimated using the EKS Monte Carlo.

• $\bar{p}p \to b\bar{b}$, $b \to e\upsilon_e c$. This background was estimated using the EUROJET Monte Carlo program and was found to be small (mainly because the efficiency to detect the electron from the b, which is close to a jet, is small).

• Jets misidentified as an electron (QCD background).

In Table 3 is given a summary of these various background contributions and also the observed numbers of events.

Table 3 : Summary of the Event Sample and Expected Backgrounds

	All M_T	$15 < M_T < 50$ GeV/c^2
$Z \to ee$, $\tau\tau$	2.5 ± 0.6	1.6 ± 0.5
$b\bar{b}$	1.0 ± 0.6	0.5 ± 0.3
QCD	2.4 ± 1.5	2.1 ± 1.5
Total of above backgrounds	5.9 ± 1.7	4.2 ± 1.6
W events	148.5 ± 14.5	22.0 ± 3.0
Total Background	154.4 ± 14.6	26.2 ± 3.4
Observed Events	137	17

Limit on the top mass

From the numbers in Table 3 we conclude that there is no indication for a top signal. The limit on the top mass was obtained by performing a likelihood fit to the full M_t distribution using the lower values of cross-sections and acceptances given in Table 2. For each top mass considered, the fitted signal was consistent with no top production.

Figure 5 shows the best fit to the data without top contribution, and the additional expected signal for $m_t = 65$ GeV/c^2.

Finally, figure 6 shows the lower value of the expected top cross-section and the cross-section excluded at 95 % and 90 % CL by this analysis. Top quark masses between 30 and 69 GeV/c^2 are excluded at 95 % CL. With the electroweak production alone, we can exclude a top mass between 34 and 66 GeV/c^2 at 95 % CL.

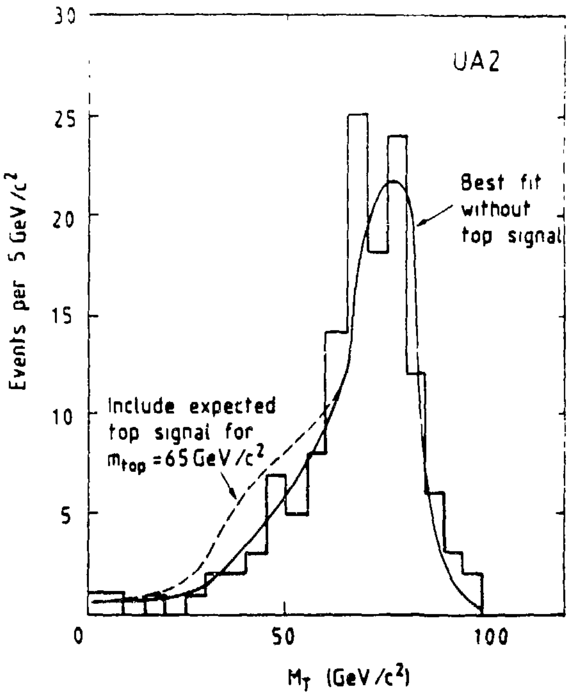

Figure 5 : Distribution of M_t for the final sample, best fit (full curve) without signal. The lowest expected contribution from top (m_{top} = 65 GeV/c^2) is added (dashed curve).

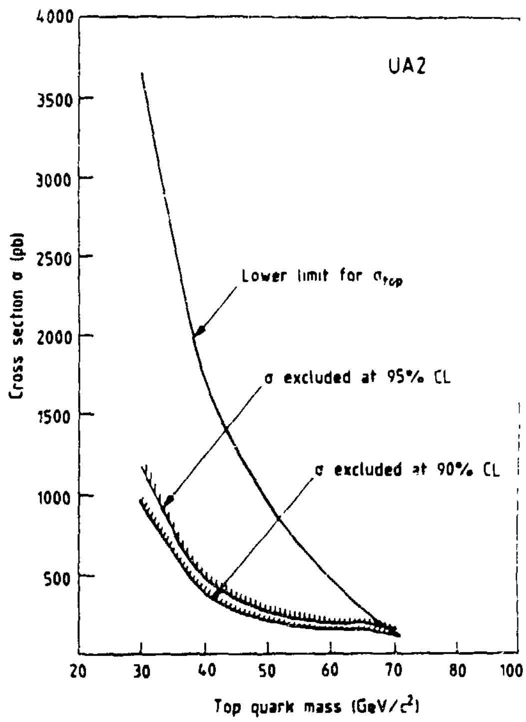

Figure 6 : Lower limit for the top production cross-section and the 90 % and 95 % CL excluded cross section as a function of m_{top}.

Using the QCD production alone, we can obtain a limit on a heavy quark from a hypothetical fourth family (b') assuming that b' decays to a c and a virtual W. We exclude 30 < mb' < 54 GeV/c^2 at 95 % CL.

Recent results from the fermilab Tevatron Collider based only on $t\bar{t}$ production , which is dominant at $\sqrt{s}$ = 1.8 TeV, exclude 40 < mtop < 89 GeV/c^2 at 95 % CL[15].

The previous limits are obtained assuming BR ($t \rightarrow bW^*$) = 100 %, BR ($b' \rightarrow c W^*$) = 100%. How much do these limits depend on this assumption ?

a) If there exists a charged Higgs boson $H^{\pm}$ from a two Higgs doublet model, the top decay branching ratio can be modified[16, 17] :

• If $m_{H^{\pm}} < m_{top} < m_W$, BR ($t \to b\,H^+$) = 100 %, H^+ decays to $c\bar{s}$ or $\tau\upsilon_\tau$. There are no electrons with large energy in the final state, and in this case the limit from UA2 on m_t vanishes, but LEP and SLC limits[18] are still valid.

• If $m_{top} < m_{H^{\pm}}$ BR ($t \to b\,W^* \to be\upsilon$) can be modified, but this is a non negligible effect only if the ratio between the two vacuum expectation values of the two doublets, $\frac{v2}{v1}$ is large ($\frac{v2}{v1} > 10$). In this case, the UA2 limits are therefore almost unchanged.

b) The b' decay to $ce\upsilon$ skips one generation and can be suppressed by the K.M matrix element Vb'c. The b' decay to bg or $b\gamma$ could therefore be important[19]. The UA2 limit on mb' is reduced from 54 GeV/c^2 to 47.5 GeV/c^2 if BR ($b \to cW^*$) = 50 %.

CONCLUSIONS

A search has been performed for new particle production (top and b' quarks, SUSY particles). No evidence was found for such processes, leading to new lower limits on masses

mtop > 69 GeV/c^2	mb' > 54 GeV/c^2	at 95 % CL
$m_{\tilde{q}}$ > 74 GeV/c^2	$m_{\tilde{g}}$ > 79 GeV/c^2	at 90 % CL.

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