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IDENTIFICATION OF SEMILEPTONIC DECAY OF T-QUARK PRODUCED AT LEP-II

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Introduction

In this report we discuss some selection criteria to identify the production of $t\bar{t}$ pairs in the e^+e^- interaction in the case that the production threshold for this process is below that of W^+W^- pairs.

Since the mass of the top quark is expected to be in the range [1]:

$$44\ \text{GeV} < m_t < 200\ \text{GeV}$$

there is a chance that it is lighter than the W. In this case it can be produced with the LEP machine when its centre of mass energy will be increased up to the W^+W^- threshold.

The identification of heavy quark production in e^+e^- interaction has already been studied in the past [2]. We present a new criteria based on the identification of the semileptonic decay of the top quark. These events, that have a very peculiar topology, can be also used to measure the mass of the quark.

A more detailed discussion of some of the arguments presented in this report can be found in ref. [3].

Cross section of $t\bar{t}$ production

Fig. 1 shows the ratio R between the cross section $e^+e^- \to t\bar{t}$ ($m_t = 60$ GeV) and the point-like cross section ($e^+e^- \to \mu^+\mu^-$) as a function of the centre of mass energy. It is also shown the curve for the process $e^+e^- \to$ *hadrons* divided by a factor 100.

The two curves include QCD and radiative corrections and have been calculated using formulas of ref. [2].

The radiative corrections are very important expecially for the cross section $e^+e^- \rightarrow$ *hadrons* since large part of this process goes via the radiaction of one photon from the initial state and the production of a real Z^o (see ref. [2b] for a more detailed discussion).

Inspecting fig. 1 we notice that the $t\bar{t}$ production is roughly 1 / 50 of the total hadronic cross section. Since the expected luminosity of LEP is about 1 pb^{-1} day^{-1} and the point-like cross section at $\sqrt{s}$ = 140 GeV is 4.4 pb we expect about 250 events of hadronic production and 5 of $t\bar{t}$ production per day.

Branching ratios of top quark and event topology

We assume that the top quark decays 100% into the bottom quark with the emission of a virtual W^+. Neclecting phase space coefficients we obtain:

$$Br(t \rightarrow b\, l^+ \bar{\nu}) = \frac{1}{3} Br(t \rightarrow b\, u\, \bar{d}) = \frac{1}{3} Br(t \rightarrow b\, c\, \bar{s}) = \frac{1}{9}$$

where $l^+ = e^+, \mu^+, \tau^+$.

Since the t quark is heavy it is produced almost at rest in the centre of mass system (β<<1)

Each of the two quarks (t, $\bar{t}$) decays into three light fermions producing three jets, and the two decays are not correlated.

The probability that both quarks have a semileptonic decay is $P_{ll} = \frac{1}{3} \cdot \frac{1}{3} = \frac{1}{9}$. Since the neutrinos are not detected these events are 4 jets events.

The probability that only one decays semileptonically is $P_{lq} = 2 \cdot \left(\frac{1}{3} \cdot \frac{2}{3} \right) = \frac{4}{9}$. In these case we have a 5 jets event.

The probability that both quarks make an hadronic decay is $P_{qq} = \frac{4}{9}$. These are 6 jets events.

Since the jets produced in the decay of the t quark may overlap with those produced in the decay of the $\bar{t}$ quark the jet analysis will often reconstruct a smaller number of jets.

The probability that at least one of the two quarks decays semileptonically with the production of a light lepton (e or μ) is:

$$P_l = 1 - \left(1 - \frac{2}{9} \right)^2 \cong 34.5\ \%$$

Selection criteria

Our aim is to select those events in which at least one of the two quarks (t, $\bar{t}$) decays into a light lepton (e, μ).

This lepton has to be at high energy, since it comes from the decay of a very heavy quark and it has to be isolated since the parent quark is almost at rest in the lab system.

The isolation criteria can be implemented in an easy way using the jet reconstruction: we can look for jets containing an high energetic lepton and with the average energy of the other particles below a certain cut.

Another selection criteria that reduce the background by a substantial amount (factor 2÷3) is to reject those events with an initial state radiation of a photon of energy $E\gamma \cong \sqrt{s} - m_Z$ [2b]. This selection is based on the fact that the light quark cross section is enhanced by the "radiative return" on the Z^o pole while the $t\bar{t}$ cross section is not if its threshold is above the Z^o.

The radiative photon goes very often inside the beam pipe and is not detected. The cut can be applied reconstructing the longitudinal missing momentum and rejecting the event if this quantity is larger than $\sqrt{s}$ - m_Z inside the experimental resolution.

The cut on the initial state radiation has not been used in the analysis that we present later since we are interested to evaluate the efficiency of the semileptonic selection alone.

Montecarlo simulation

We have used as event generator the version 6.3 of the Jetset Montecarlo [4] with the Webber generation [5] and with initial state radiation.

In a first stage of the analysis we have used a very crude simulation of an "average LEP detector" (see app. A of ref [3] for details of this simulation) and we have assumed full efficiency and no contamination in lepton identification.

In a second stage we have used the "fast" simulation of the ALEPH detector [6] that includes the tracking through the detector and the simulation of the reconstructed charged tracks and of the reconstructed energy deposits inside the calorimeters.

As jet reconstruction algorithm we have used the LUCLUS routine [4]. The cut on the relative transverse momentum to join a track to a jet (d_{join}) has been optimized to the value d_{join} = 2.7 GeV [7].

We have generated 10000 events assuming $\sqrt{s}$ = 140 GeV and m_t = 60 GeV.

The events correspond to an integrated luminosity of about 40 pb^{-1}. The sample contains 245 $t\bar{t}$ events and 9755 background events.

Analysis of Montecarlo data of the crude simulation

Fig. 2 shows the histogram of the reconstructed number of jets for the generated $t\bar{t}$ events and for the background. The average number of jets is 5.6 in the $t\bar{t}$ case and 3.3 in the background case.

We have selected those jets that have a charged leading particle. Fig. 3 shows the plot of the average energy of the other particles in the jet vs the energy of the leading one, for $t\bar{t}$ case and for the background.

Fig. 4 shows finally the same plots for the jets that have an electron or muon as leading particle. We notice that the region at high energy of the leading particle and at small average energy of the other particles is populated only in the case of the $t\bar{t}$ production.

Table 1 shows the number of events surviving after a combined cut on the two variables: the background can be almost completely removed leaving 75 % of the events in which one of the t quarks decays into a light lepton. Thi sample corresponds to about 25% of the total $t\bar{t}$ production.

Analysis of the Montecarlo data of the ALEPH simulation

We have passed through the ALEPH simulation 1000 $t\bar{t}$ events and about 6000 background events at $\sqrt{s}$ = 140 GeV with m_t = 60 GeV. We have selected events with jets containing a leading charged particle with an energy above 10 GeV and with the average energy of the other particles below 0.5 GeV. If this leading particle is associated to a large energy release in the hadron calorimeter (larger than the 20 % of the momentum measured in the TPC) it is identified as an hadron and the event is rejected.

With this methods we have selected 211 of the 1000 events $t\bar{t}$ and only 3 of the 6000 background events. Renormalizing with the cross section this figure corresponds to a signal/background ratio of about 10.

$\Downarrow E_{op} \backslash E_{lept} \Rightarrow$	5	10	15
0.4	75	65	51
0.5	83	73	58
0.6	90	77	60
0.7	94	80	61
0.8	97	81	61
1.0	111	87	64
1.5	127	94	70

(a)

$\Downarrow E_{op} \backslash E_{lept} \Rightarrow$	5	10	15
0.4	4	2	2
0.5	11	3	3
0.6	21	7	6
0.7	34	13	9
0.8	53	25	2
1.0	103	52	30
1.5	337	191	112

(b)

Table 1. Number of events surviving after the cuts. The selected events have a light lepton of energy greater then E_{lept} GeV belonging to a jet with the average energy of the other particles below E_{op} GeV. The result comes from an analysis of 10000 events 245 of $t\bar{t}$ production and 9755 of background).

Measurement of the top quark mass

The top quark mass can be reconstructed from the invariant mass of the jets originated in its decay.

It is not easy to associate the correct jets to each quark when both t and $\bar{t}$ decay into 3 hadronic jets since there are 20 possible different combinations that associate 3 jets to the t quark and the remaining to the $\bar{t}$ quark.

When one of the two quarks decays semileptonically into a light lepton (e or μ) the association is more simple since we have to associate the identified leptonic jet with one of the four reconstructed hadronic jets and with the neutrino jet that is not measured but can be defined by the missing momentum of the event.

For each event reconstructed with 4 hadronic jets and one leptonic jet (as defined in the previous section) we have calculated the 4 possible pairs of invariant masses. Among them we have choosen the one with the smallest difference between the two reconstructed masses and we have taken the average between this two masses as a measurement of the top quark mass.

This quantity has been renormalized, event by event, with the ratio $\frac{\sqrt{s}}{E_{TOT}}$ with

$$E_{TOT} = E_{MEAS} + \left| \vec{P}_{miss} \right|$$

where E_{MEAS} is the energy measured by the detector and $\vec{P}_{miss}$ is the momentum associated to the neutrino. This renormalization is done to recovery the losses in the measure of the total energy of the event in addition to the energy taken by the neutrino of the semileptonic decay of the top quark.

Fig. 5 shows the plot of the top mass for an unrealistic sample of 10000 $t\bar{t}$ events of the crude simulation with and without renormalization.

Conclusions

The selections of the semileptonic decays of the top quark into a light lepton can provide a data sample of $t\bar{t}$ events that is almost pure.

The background rejection is based on the isolation of the lepton and not on the event shape variables as in the other proposed selections [2]. For this reason it is much less sensitive to the details of the generator used to produce the background events.

25 % of the total $t\bar{t}$ production survives after the selection.

References

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[1b] G. Altarelli and P. Franzini, preprint CERN-TH 4745/87 (1987) and Z. Phys. C 37 (88) 271.

[1c] U. Amaldi et al., preprint CERN-EP/87-93 (1987) and Phys. Rev. D 36 (87) 1385.

[2a] W. Buchmüller et al., Physics at LEP, CERN 86-02 (1986) 203.

[2b] see P. Igo-Kemenes et al., ECFA Workshop on LEP 200, CERN 87-08 (1987) 251 and references therein.

[3] B. Gobbo, Thesis, Univeristy of Trieste, Trieste 1988 (unpublished).

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[6] J. Badier, J. Boucrot and T. Wang, internal reports ALEPH 86-166, ALEPH 87-54.

[7] M. Bardain and J. Boucrot, internal report ALEPH 87-74.

Figure Captions

Fig. 1.- Ratio between the cross sections and the point-like cross section ($e^+e^-\rightarrow\mu^+\mu^-$). The curve A shows the ratio for the process $e^+e^-\rightarrow$*hadrons* divided by a factor 100; the curve B shows the ratio for the process $e^+e^-\rightarrow t\bar{t}$ and the curve C the ratio for the process $e^+e^-\rightarrow W^+W^-$ divided by a factor 10.

Fig. 2. - Reconstructed number of jets for $t\bar{t}$ production events and for the background. The results are obtained from a Montecarlo simulation of 10000 events (276 of $t\bar{t}$ production and 9724 of background) with E_{cm} = 140 GeV and m_t = 60 GeV.

Fig. 3. - Average energy of the other particles in the jet vs the energy of the leding one for $t\bar{t}$ production (a) and background (b). The results are obtained from a Montecarlo simulation of 10000 events with E_{cm} = 140 GeV and m_t = 60 GeV.

Fig. 4. - Same plot of fig. 3 for the jets that have an electron or muon as leading particle.

Fig. 5. - Plot of the reconstructed top mass for 10000 $t\bar{t}$ (see text). The Montecarlo simulation is obtained with E_{cm} = 140 GeV and m_t = 60 GeV. The solid line shows the reconstruction without the renormalization (see text) and the dotted line the reconstruction with renormalization.

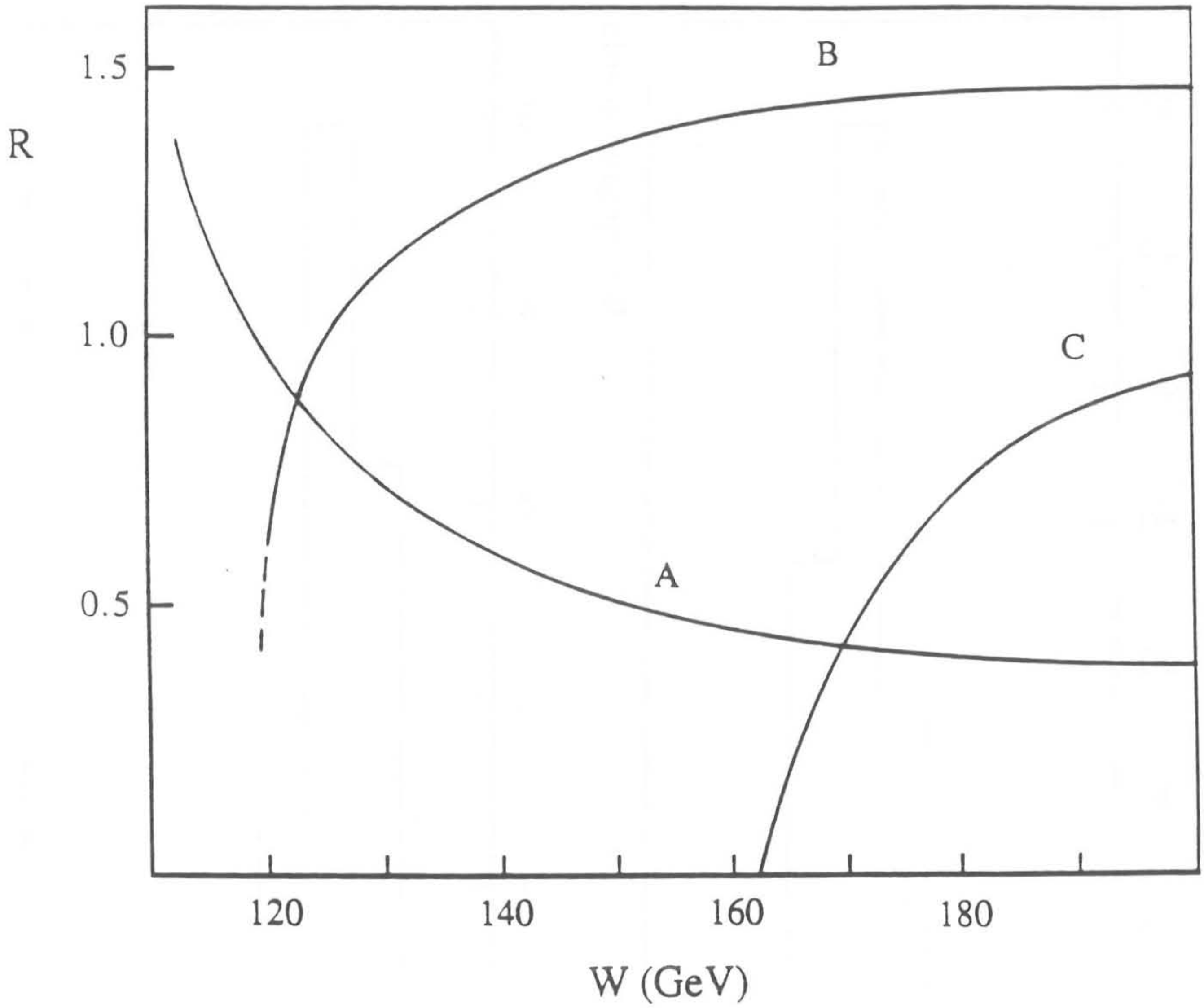
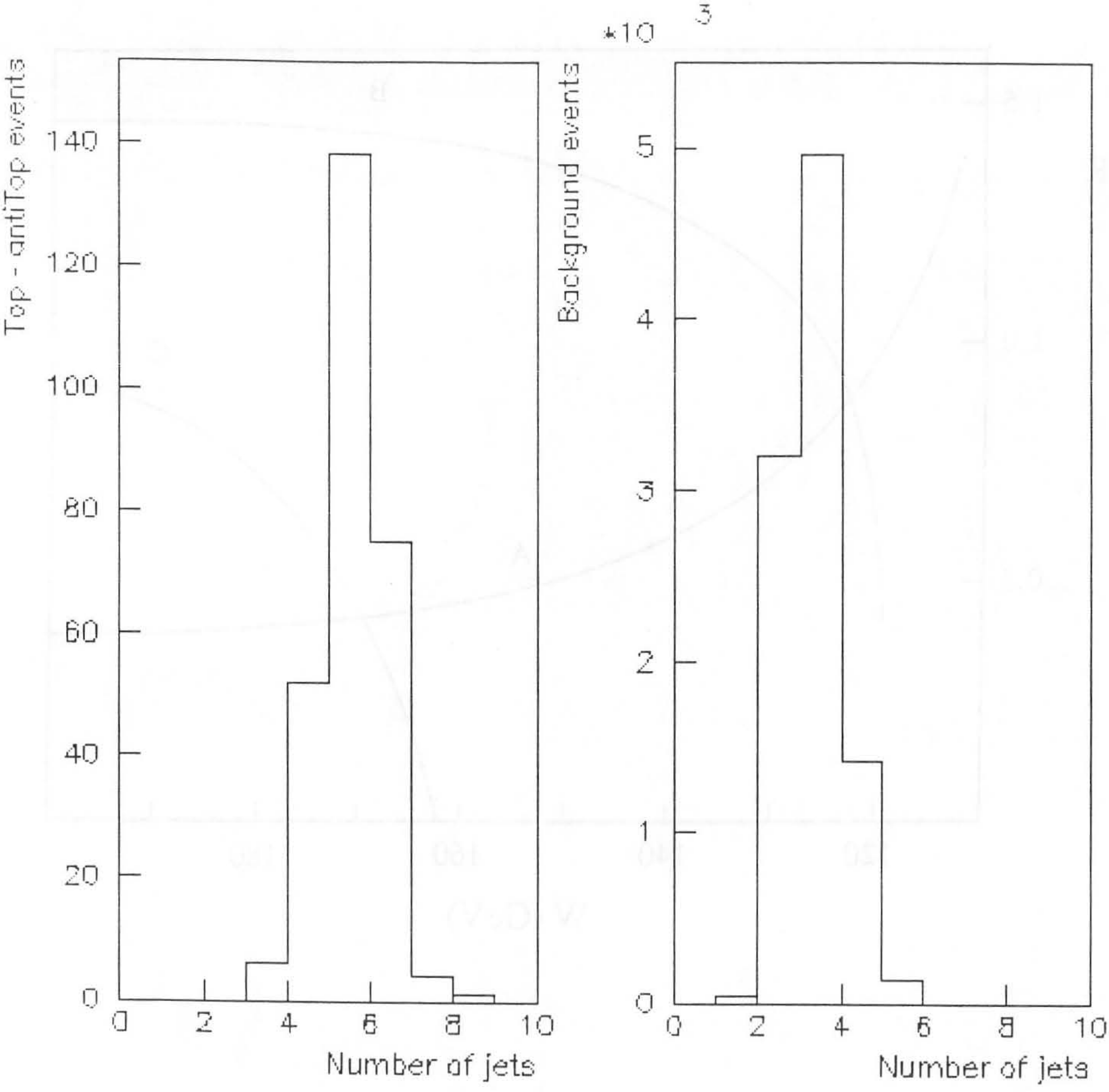


Fig. 1



Top - antiTop events
140
120
100
80
60
40
20
0
0
2
4
6
8
10
Number of jets
*10 3
Background events
5
4
3
2
1
0
0
2
4
6
8
10
Number of jets

Fig.2

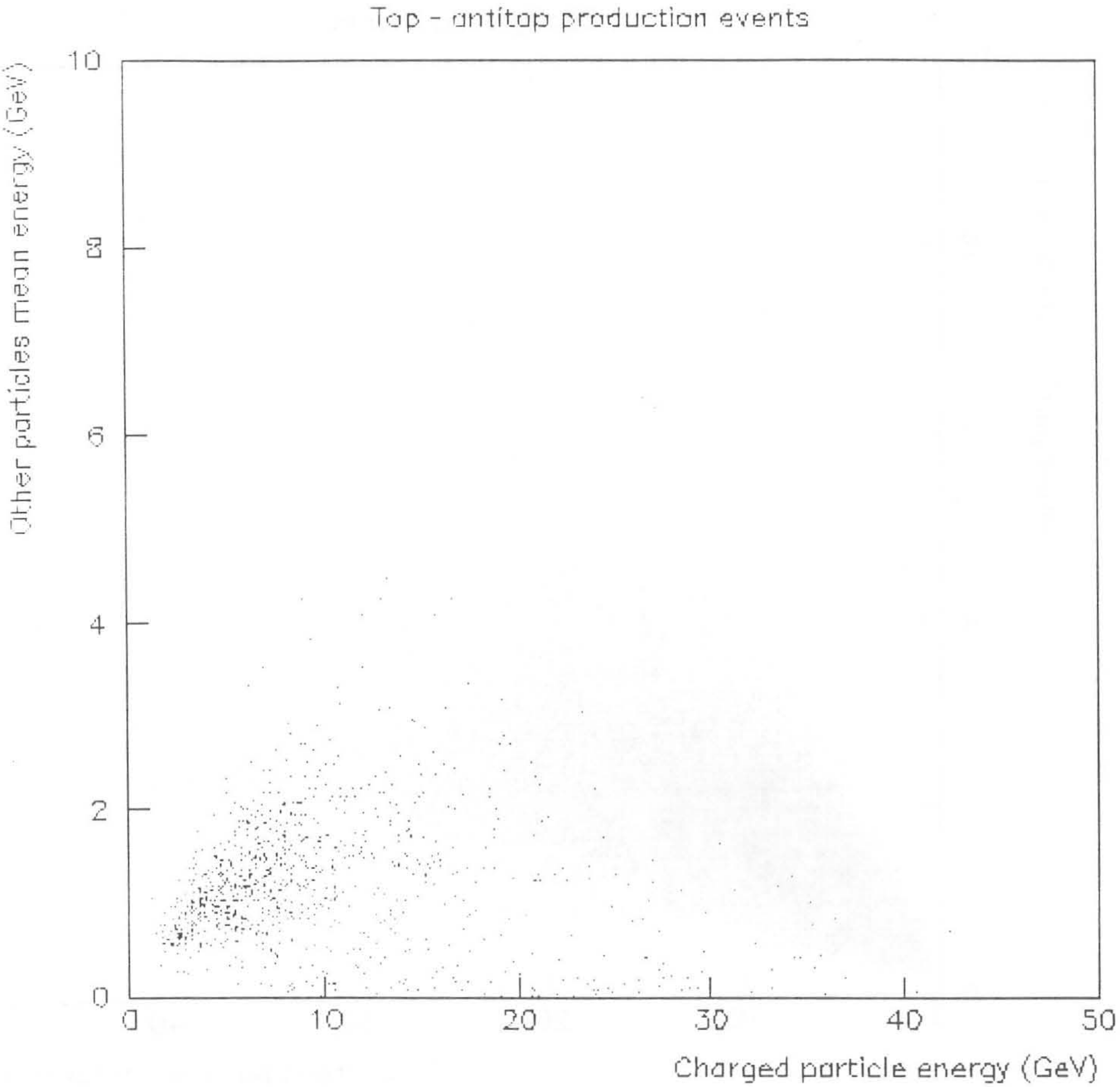

Top - antitop production events
Other particles mean energy (GeV)
10
8
6
4
2
0
0
10
20
30
40
50
Charged particle energy (GeV)

Fig. 3a

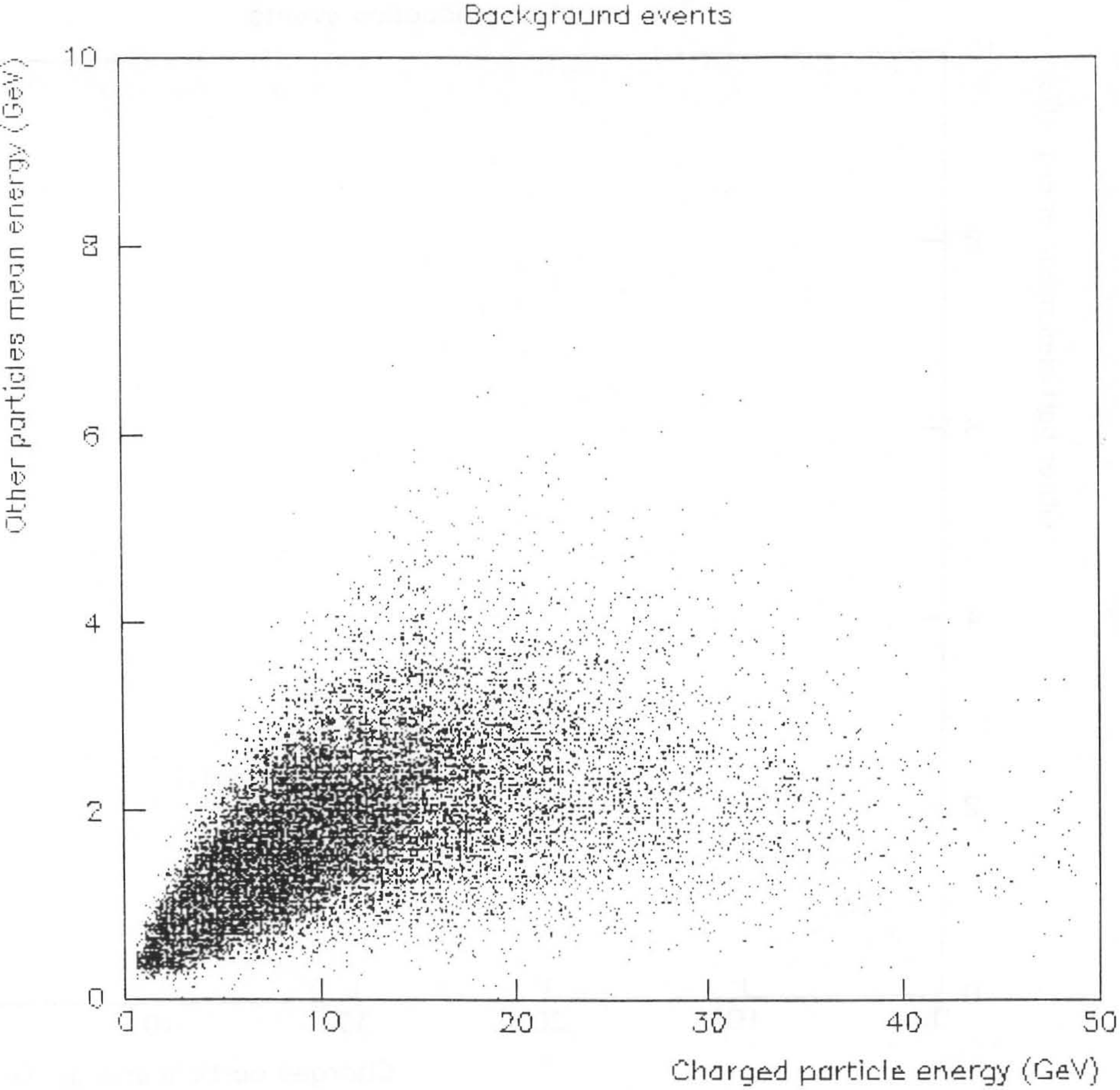

Background events
Other particles mean energy (GeV)
0
2
4
6
8
10
0
10
20
30
40
50
Charged particle energy (GeV)

Fig. 3b

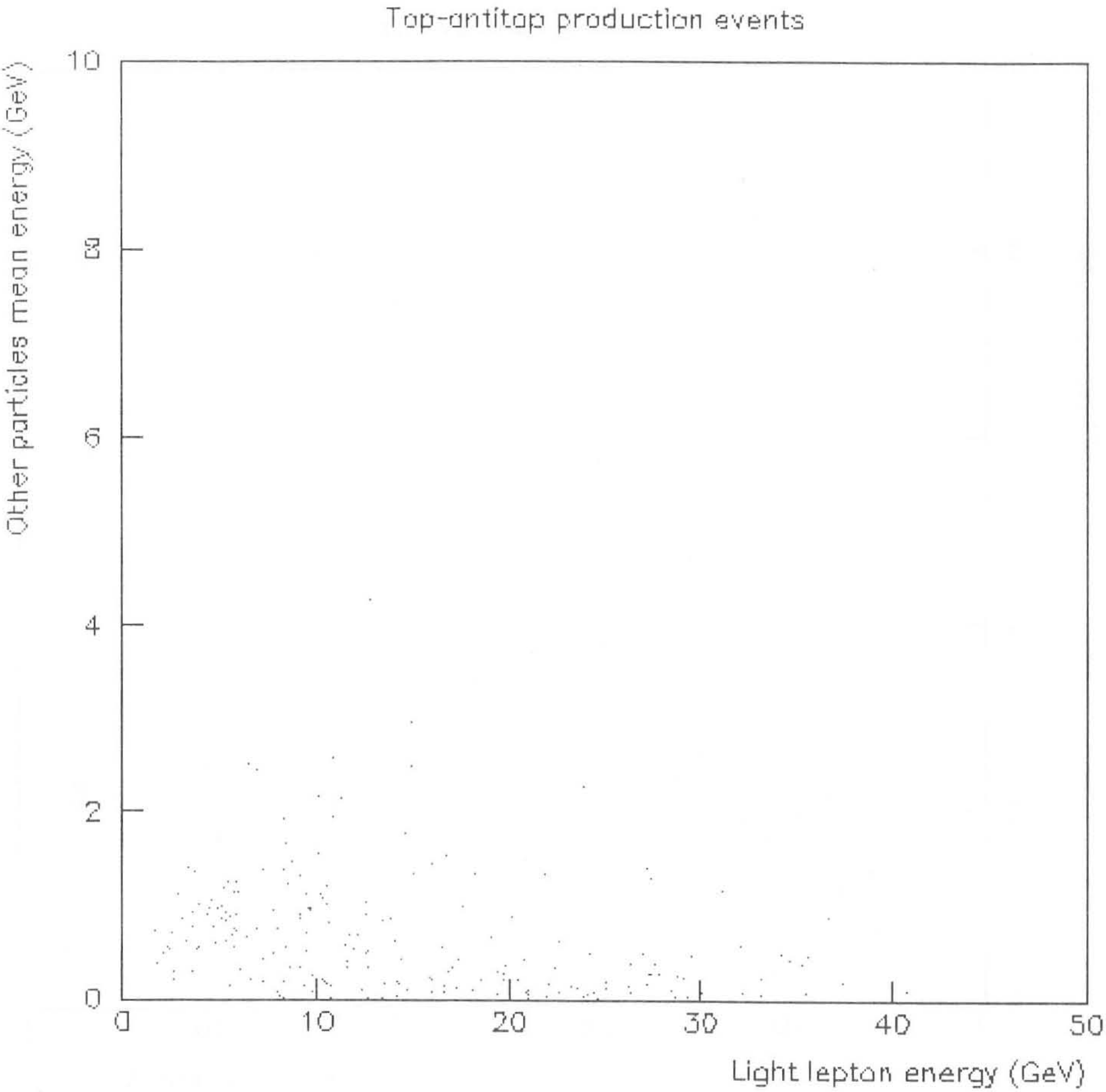
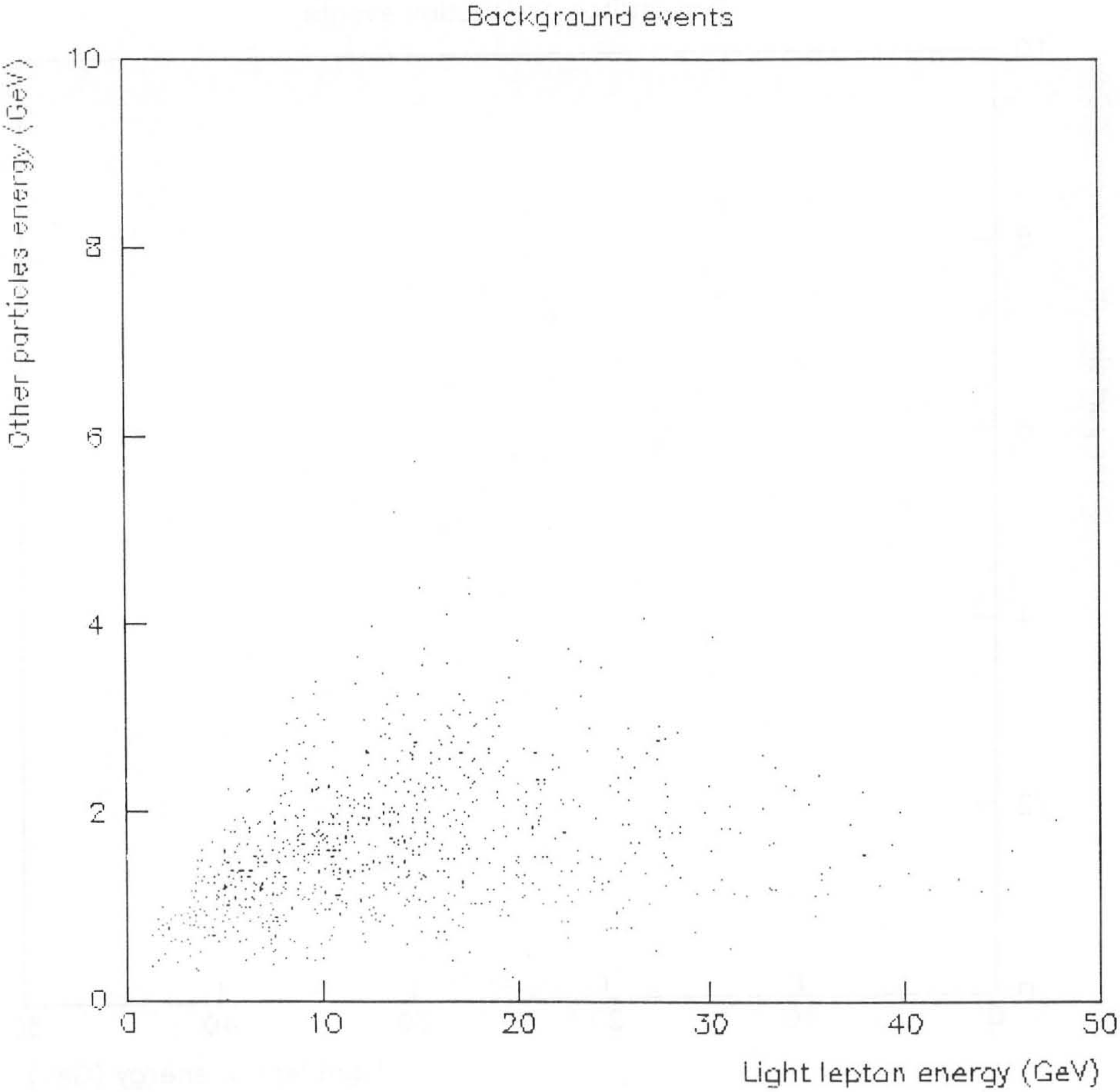

Top-antitop production events
Other particles mean energy (GeV)
0
2
4
6
8
10
0
10
20
30
40
50
Light lepton energy (GeV)

Fig. 4a



Background events
Other particles energy (GeV)
0
2
4
6
8
10
0
10
20
30
40
50
Light lepton energy (GeV)

Fig. 4b

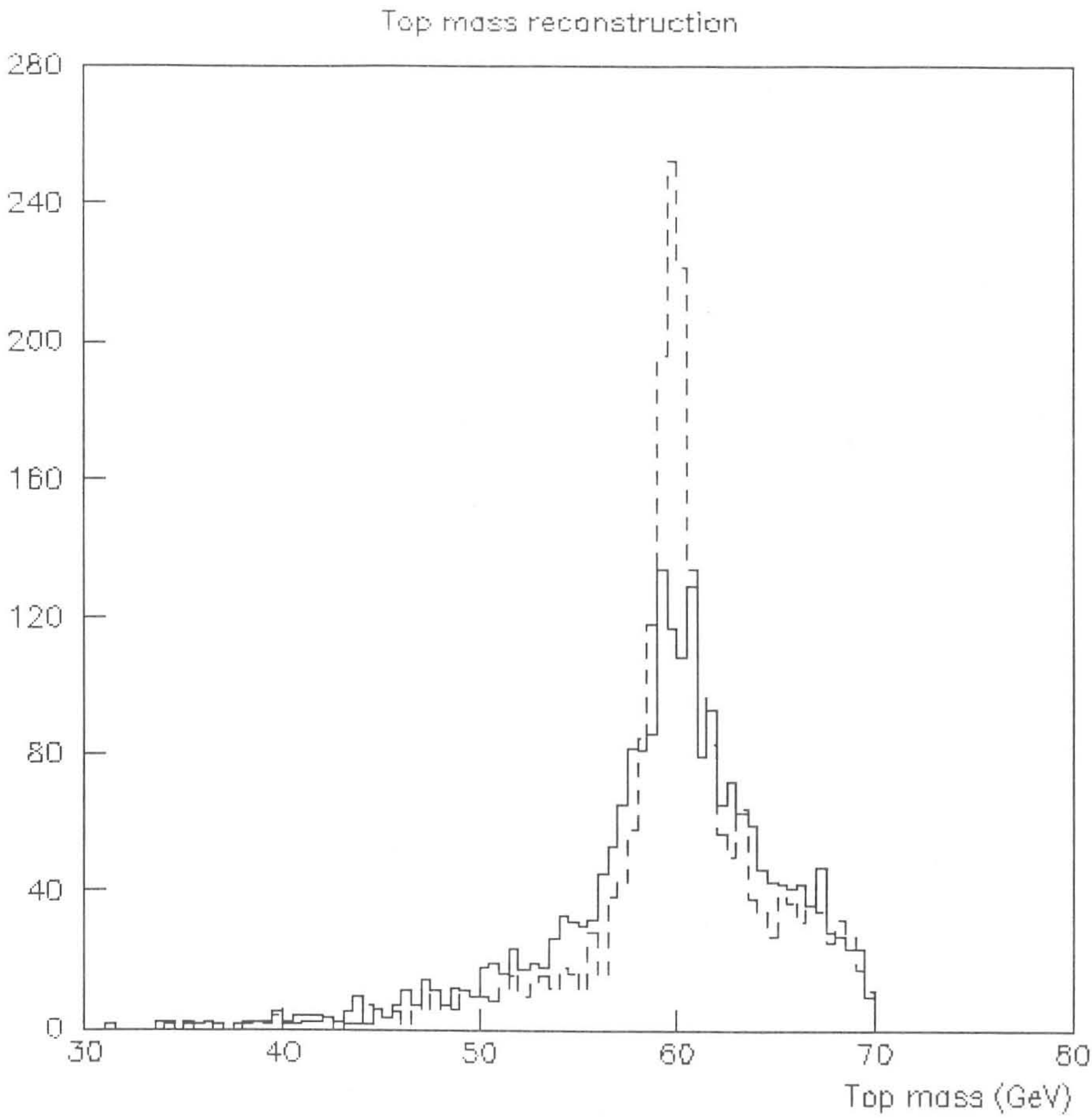

Top mass reconstruction
280
240
200
160
120
80
40
0
30
40
50
60
70
80
Top mass (GeV)

Fig.5