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Electron isolation with ATLAS

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Abstract
We have investigated the possibility to identify isolated electrons using both calorimeter and tracking informations. For this study a full GEANT simulation of ATLAS (concept B) has been used. Results for the rejection of the $t\bar{t}$ and $Zb\bar{b}$ background to the production of an intermediate mass Higgs decaying into 4 leptons are given.

1 Introduction

Lepton isolation plays a major role in extracting physics at LHC. In the Supersymmetry sector isolation is needed to reject the $t\bar{t}$ background in searches for gluino pair cascade decays. Isolation is also of prime importance to reject efficiently the $t\bar{t}$ and $Zb\bar{b}$ background to the intermediate mass Higgs decay in 4 leptons.

Up to now, results were available at the particle level [1]. It is crucial to assess these results with a full simulation of the detector. This allows to have a precise estimate of the loss on the signal when applying isolation cuts in the presence of pile-up.

After describing the procedure we used in Section 2, we discuss the isolation cuts using the calorimeter and the tracking information in Section 3.
A complete study of the intermediate Higgs search in 4 leptons can be found in [2].

2 Procedure and Event selection

2.1 Procedure

We have investigated the production of a standard Higgs of 150 GeV mass decaying into 4 electrons. The potential backgrounds we considered are the $t\bar{t}$ mode, the $Zb\bar{b}$ mode, and the ZZ^* continuum.

Both signal and background have been generated using PYTHIA 5.6. Events have then been filtered, asking at least 4 electrons in the final state with $P_t >$ 7 GeV. In the case of $t\bar{t}$, one asks also that at least one dielectron mass combination be within 15 GeV of the Z^0 mass.

Events have been processed through the full DICE simulation (concept EAGLE B), without pile-up superimposition for the $t\bar{t}$ and $Zb\bar{b}$ backgrounds. The Higgs signal (mass 150 GeV) has been studied with 0, 20 and 40 minimum-bias overlap.

The standard routines provided in TOOLS have been used to find and reconstruct EM clusters, both in the EM calorimeter and the preshower. For the tracking part, we just used the information given by the input 4-vectors.

For the energy of the EM clusters, we have taken the energy deposited in a 5×5 window, i.e. 0.1×0.1 in $\Delta\eta \times \Delta\phi$. This energy is calculated according to the expression :

$$E_{cluster} = 6.3(E_{EM} + 1.7E_{PSD})$$

where the 2 constants correspond to the calibration constants of the EM calorimeter and PreShower Detector.

When comparing the energy measured to the energy generated (Fig. 1), one observes a loss in the response in the crack region between barrel and end-caps around $\eta = 1.7$, and a strong dependence in η. This effect has to be understood, and could be due to the plate geometry used in the simulation, instead of the true accordion one. In the end-cap region, where the effect is more pronounced, the 0.1×0.1 region is likely to be too small to contain the full EM shower. To account for this we have applied a crude correction restoring a response flat in η (Fig. 2).

For the tracking, we took the information from the generated 4-vectors applying a smearing in P_t according to the ATLAS momentum resolution. We assumed an efficiency of 100 % for charged track reconstruction. This is justified by separate studies yielding efficiencies close to 100 % for P_t down to 1 GeV, even in the presence of pile-up [3].

2.2 Event selection

The selection criteria used are the following :

- At least 4 EM clusters with $|\eta| < 2.5$ and $P_t > 10$ GeV.
- These 4 clusters have to be associated with a charged track, using as criteria $|\eta_{cluster} - \eta_{track}| < 0.1$ and $|\phi_{cluster} - \phi_{track}| < 0.1$ (Fig. 3).
- Out of these 4 clusters, at least 2 EM clusters (1,2) with charged tracks of opposite sign, with $P_t > 20$ GeV, and $M_{12} = M_{Z^0} \pm 10$ GeV.
- The 2 other clusters (3,4) must have opposite sign and satisfy $M_{34} > 10$ GeV.

These cuts are slightly different from the ones used in the LoI, especially the one asking the two *highest* P_t leptons to peak on the Z mass. This has however a small impact on the isolation study. Moreover we had to enlarge the window around the Z^0 mass to account for the mass resolution we observed from Higgs of mass 150 GeV events (Fig. 4) which is worse than the one expected from test beam results, and is probably due to the use of a plate geometry in the accordion calorimeter. This distribution has to be compared to the one obtained from $t\bar{t}$ events where no Z^0 is actually produced (Fig. 5).

We also reproduce in Fig. 6 the reconstructed Higgs mass, without pile-up overlap, showing a σ_{RMS} of 3.4 GeV (we expect $\sigma_{RMS} \simeq 1.8$ GeV from test beam results).

2.3 Final samples

We summarize here the final samples we have used for our study and our global acceptance, as compared to the one obtained at the particle level [2].

Process	# events simulated	# events after cuts	Total Acceptance (%)	Acceptance particle level (%)
$H(130GeV)$	599	145	18.1	22.0
$H(150GeV)$	498	155	31.1	37.0
ZZ^*	295	69	14.1	18.0
$Zb\bar{b}$	823	111	1.0	1.6
$t\bar{t}$	2439	311	2.3	1.8

The acceptances obtained after full simulation are systematically lower than the ones obtained at particle level, which is understood as due to acceptance and resolution effects as well cluster algorithm efficiencies.
It is not the case for the $t\bar{t}$ background, which is due to the broader window used around the Z peak, 10 GeV compared to 6 GeV at the particle level, the reconstructed mass being rather flat in that region (see Fig. 5).
Moreover, one can see that we have to deal with very limited statistics, especially for the various backgrounds. In the following, we will concentrate our study on the two most dangerous backgrounds, i.e. $t\bar{t}$ and $Zb\bar{b}$.

3 Electron isolation

Because of limited statistics, most of the results presented here have been obtained by studying the isolation efficiency on a Higgs signal of 150 GeV mass, with and without pile-up, and the rejection on the $t\bar{t}$ background.

3.1 Calorimeter isolation

We first define the electromagnetic cluster energy in a 5×5 window, which corresponds to a cone of 0.1×0.1 in $\Delta\eta \times \Delta\phi$. We then compute the *total transverse* energy in the calorimeter (both EM and HAD) in a $x \times x$ window and define the isolation criteria as :

$$E_{isol}^{calo} = E_{T,TOT}^{x^2} - E_{T,EM}^{0.1^2} < E_{cut}^{calo}$$

It is crucial to consider for the calorimeter isolation the *transverse* energy in a cone and not the *total* energy. The pile-up contribution being essentially flat in P_t, the use of the *total* energy would lead to a loss of efficiency on the Higgs signal at high luminosity, as can be seen in Fig. 7.

We have investigated 2 different sizes of window, i.e. 0.3^2 and 0.4^2. As can be seen in Fig. 8, using a 0.4^2 window gives a better rejection for a given efficiency. This is the one we will use in the following. The optimization of the cone size requires more statistics for the background and will be investigated in further studies.

3.2 Tracking isolation

One other tool for isolation is to use the tracking information. We again define in a $x \times x$ window around the electron, and use as isolation criterion that no charged track with $P_t > P_t^{cut}$ is observed in the window.
As for the calorimeter isolation, we have investigated 2 sizes of window. In the following, we will use the same as for the calorimeter, i.e. 0.4×0.4.

3.3 Cut on 2 or 4 electrons

We now investigate the possible gain in cutting on the 4 final electrons. This could be rewarding in the case of $t\bar{t}$, where one is not sure to pick up the 2 electrons from the b decay, since no Z^0 is produced in that channel. Fig. 9 shows the efficiency for the Higgs signal, for a mass of 150 GeV, with 40 minimum-bias events overlapped, versus the rejection against $t\bar{t}$ while cutting on 2 or 4 electrons, using the calorimeter isolation.
Fig. 10 is the same but using the tracking isolation.

The first conclusions are that a significant gain is achieved if one applies the isolation criteria to the 4 electrons (for $t\bar{t}$ at least).
The tracking isolation appears to be as powerful as the calorimeter isolation.
In the final results, we will combine both calorimeter and tracking isolation to achieve the best rejection.

3.4 Effect of pile-up

For a given rejection on the $t\bar{t}$ background, we have studied the loss in efficiency on the Higgs signal when superimposing minimum-bias events, for three sets of isolation cuts, i.e. calorimeter, tracking and combined. This is shown is Fig. 11, where each curve shows the degradation of the signal efficiency when adding pile-up, for a constant $t\bar{t}$ rejection.

One can conclude that the tracking isolation is, with the small statistics available, as sensitive to pile-up as the calorimeter one.

The results presented here are conservative, since adding the pile-up contribution to the background will slightly improve the rejection.

3.5 Effect of P_t^{cut}

To study the dependence of the isolation upon the transverse momentum of the final electrons, we have used the $Zb\bar{b}$ sample, where the 2 non-isolated electrons are clearly identified (i.e. not peaking on the Z mass).
We reproduce in Fig. 12 the improvement in rejection when P_t increases from 10 to 20 GeV. We cannot extrapolate to higher values because of very limited statistics.

The rejection improves with P_t^{cut} for two reasons : First at high P_t the b-jet is more collimated, and the cone collects more transverse energy. Second the particles accompanying the electron have larger P_t, thus making the isolation more efficient.

To increase the acceptance of the intermediate mass Higgs process, one should be very careful in reducing the P_t of the final leptons, since isolation cuts will be less powerful. Moreover, the $t\bar{t}$ background increases even faster than the signal at lower P_t.

In SUSY processes, where one tries to reduce the $t\bar{t}$ background by using isolation, the situation is much easier, since the minimum P_t considered is around 20 - 30 GeV.

3.6 Rejection on $t\bar{t}$ and $Zb\bar{b}$ background

We now summarize the rejections achievable, both on $t\bar{t}$ and $Zb\bar{b}$, when using calorimeter isolation, tracking isolation or a combination of both. We show also the result when applying these cuts on 2 or 4 electrons.

	CUT ON 2 ELECTRONS			CUT ON 4 ELECTRONS		
	CALO. 3 GeV	TRACK. 1 GeV	COMBI. 6-1.5 GeV	CALO. 6 GeV	TRACK. 1.5 GeV	COMBI. 7.5-2 GeV
Eff. 0 MB (%)	79 ± 3	89 ± 2.5	88 ± 2.5	88 ± 2.5	90 ± 2.5	89 ± 2.5
Eff. 20 MB (%)	61 ± 4	61 ± 4	71 ± 4	77 ± 3.5	65 ± 4	72 ± 4
Eff. 40 MB (%)	31 ± 4	37 ± 4	47 ± 4	61 ± 4	41 ± 4	56 ± 4
# $t\bar{t}$ after cuts	24	25	13	6	5	1
Rejection $t\bar{t}$	13 ± 3	12 ± 3	24 ± 7	52 ± 21	62 ± 27	> 80 (90% $C.L.$)
# $Zb\bar{b}$ after cuts	8	8	4	16	7	9
Rejection Zbb	14 ± 5	14 ± 5	28 ± 14	7 ± 2	16 ± 6	12 ± 4

- There is essentially no gain when cutting on 4 electrons compared to cutting on 2 in the case of $Zb\bar{b}$, since the 2 electrons coming from the Z are well identified and isolated. This is not the case for $t\bar{t}$, and it is worth applying the isolation cut on the 4 electrons.

- We thus can achieve, for an efficiency on the Higgs signal of 50 % with 40 minimum-bias events overlap, a rejection of 60 on $t\bar{t}$ and 15 on $Zb\bar{b}$.
  Nevertheless, the difference of rejection between $t\bar{t}$ and $Zb\bar{b}$ is largely fake because of wrong fragmentation for b from top : Preliminary studies performed at the particle level show that the rejection of isolation cuts will be significantly worse with the new top fragmentation [4].
  Moreover, the use of a $t\bar{t}$ sample non biased at the generation (i.e. not forcing the b decay mode) [5] will change the rejections obtained.
  Taking into account these effects plus a correction in the normalization used for the LoI, implies that the significances presented there are not affected if one assumes a rejection of 30 on $t\bar{t}$ for 50 % efficiency on the Higgs signal, which is actually achieved in the study presented here.

- Even if the study has not been performed one can expect that the calorimeter isolation yields more rejection when applied to muons produced in the final state.

4 Further studies

The next step in this study will be to simulate full samples of Higgs signal and backgrounds with the correct generation with comfortable statistics, taking into account the new ATLAS geometry of the EM calorimeter (length of the barrel of 6.8 m, granularity 0.025×0.025).
This will allow to optimize the cone size as function of pile-up, and the values of the calorimeter and tracking isolation cuts.

References

[1] M. Della Negra et al., Aachen proceedings, Vol. II, 509.

[2] ATLAS Internal Note PHYS-011, Addendum 1.

[3] ATLAS Internal Note INDET-016.

[4] L. Serin, PHYS-TR-111.

[5] R. Hawkings, PHYS-TR-110.

Figure Captions

1. $(E_{measured} - E_{generated})/E_{generated}$ as a function of η.

2. Same as Figure 1 , after η dependence correction.

3. Matching cluster-track in η and ϕ.

4. Invariant mass of the two highest P_t leptons (best combination). Higgs 150 GeV no pile-up.

5. Same as 4, for $t\bar{t}$ sample.

6. Reconstructed Higgs mass (150 GeV). No pile-up.

7. Calorimeter isolation using the *total* or *transverse* energy in a cone of 0.4×0.4. Efficiency (150 GeV mass Higgs + 40 minimum-bias) versus rejection on $t\bar{t}$.

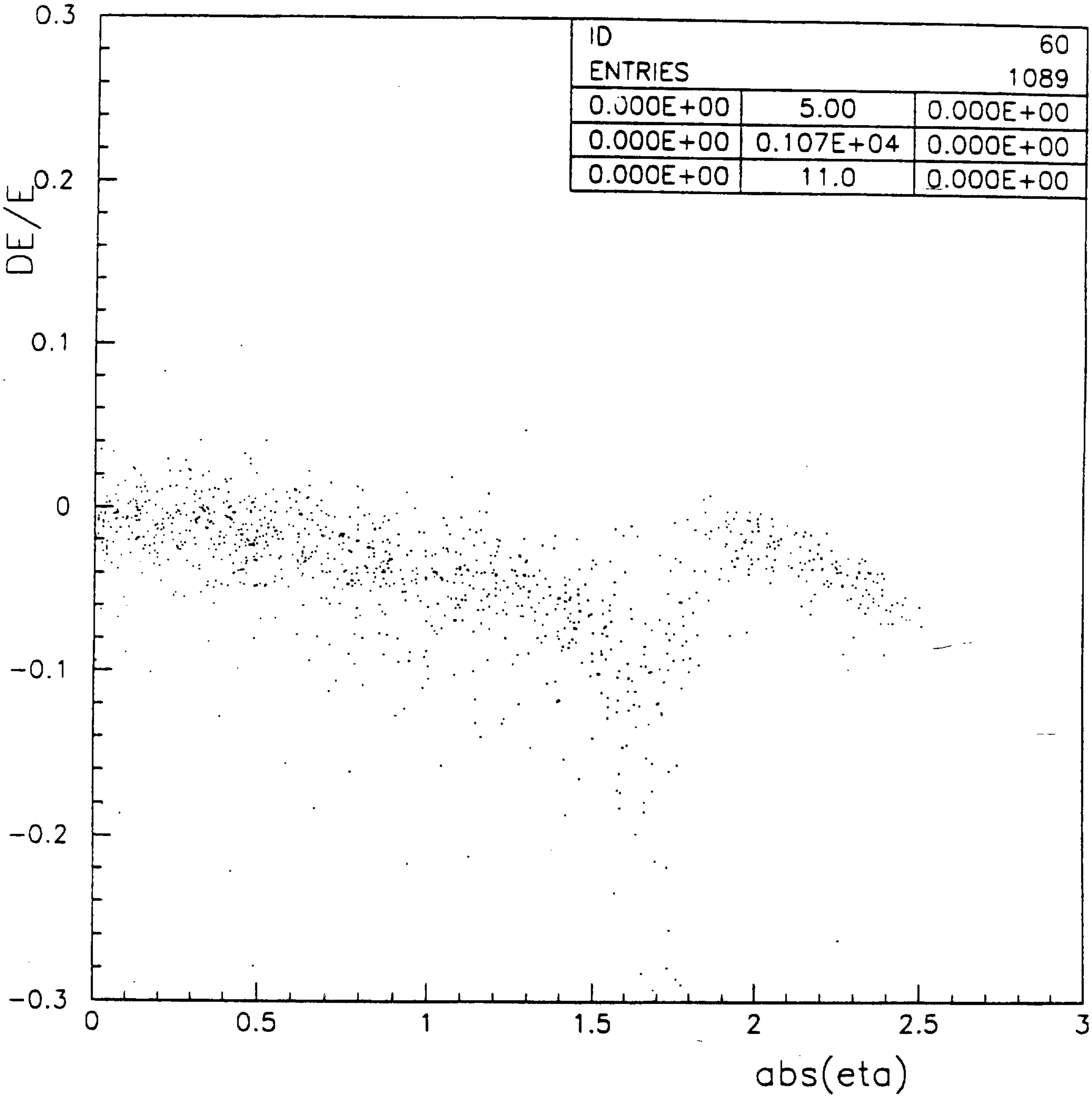
8. Calorimeter isolation for 2 isolation cones. Efficiency (150 GeV mass Higgs + 40 minimum-bias) versus rejection on $t\bar{t}$.

9. Rejection on $t\bar{t}$ using calorimeter isolation versus Higgs signal efficiency (40 minimum-bias) . Cuts on 2 or 4 electrons. Each point corresponds to a cut 1.5, 3., 4.5 ... GeV.

10. Same as 9, using tracking information. Each point corresponds to a cut 0.5, 1.0, 1.5 GeV.

11. Loss in efficiency with pile-up superimposition, for calorimeter, tracking and combined isolation.

12. Rejection on $t\bar{t}$ versus efficiency on Higgs signal (40 minimum-bias added) for 2 different P_t^{cut}.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ENTRIES 1089
0.000E+00 5.00 0.000E+00
0.000E+00 0.107E+04 0.000E+00
0.000E+00 11.0 0.000E+00
DE/E
abs(eta)
0.3
0.2
0.1
0
−0.1
−0.2
−0.3
0
0.5
1
1.5
2
2.5
3

Figure 1

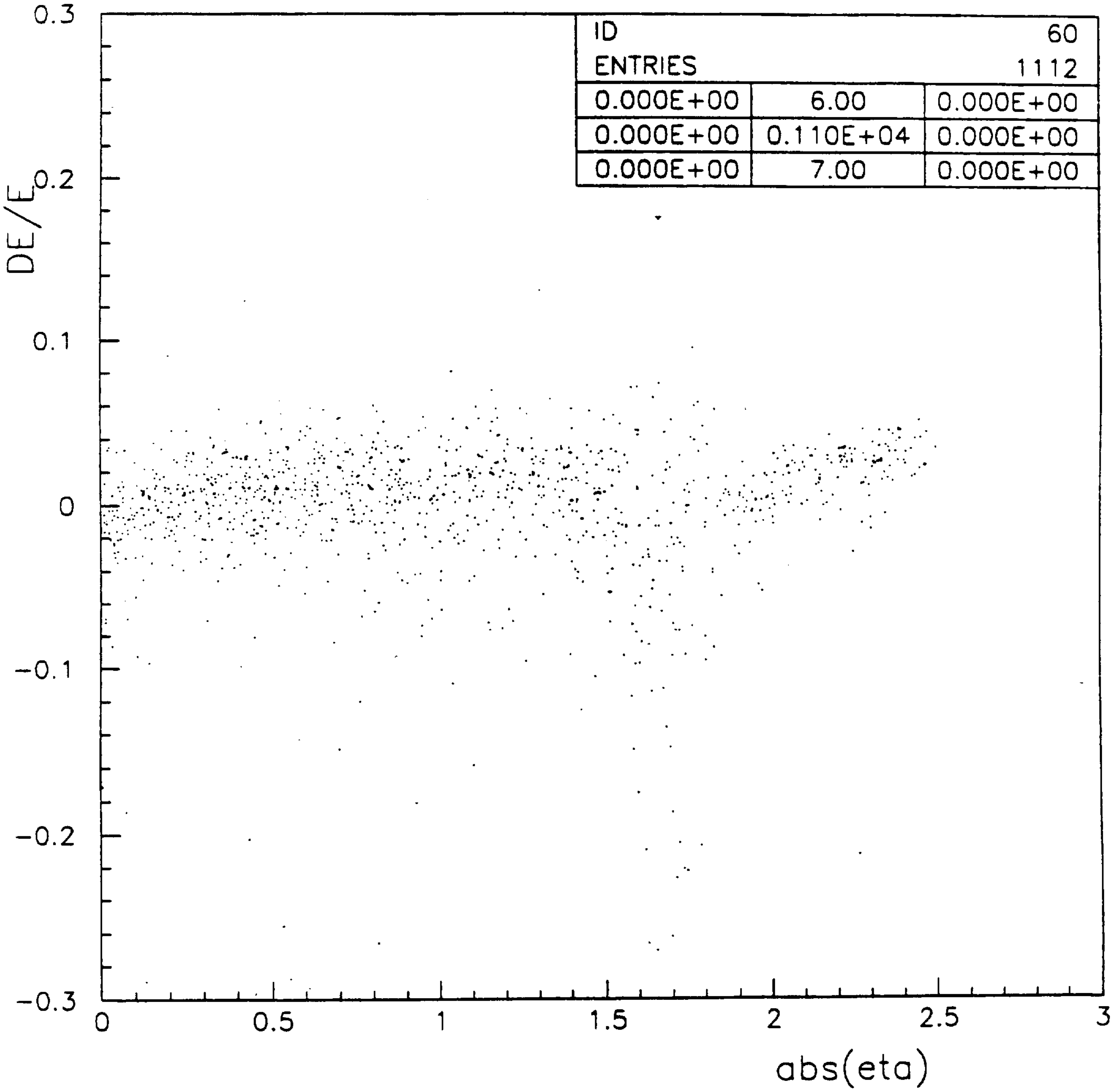
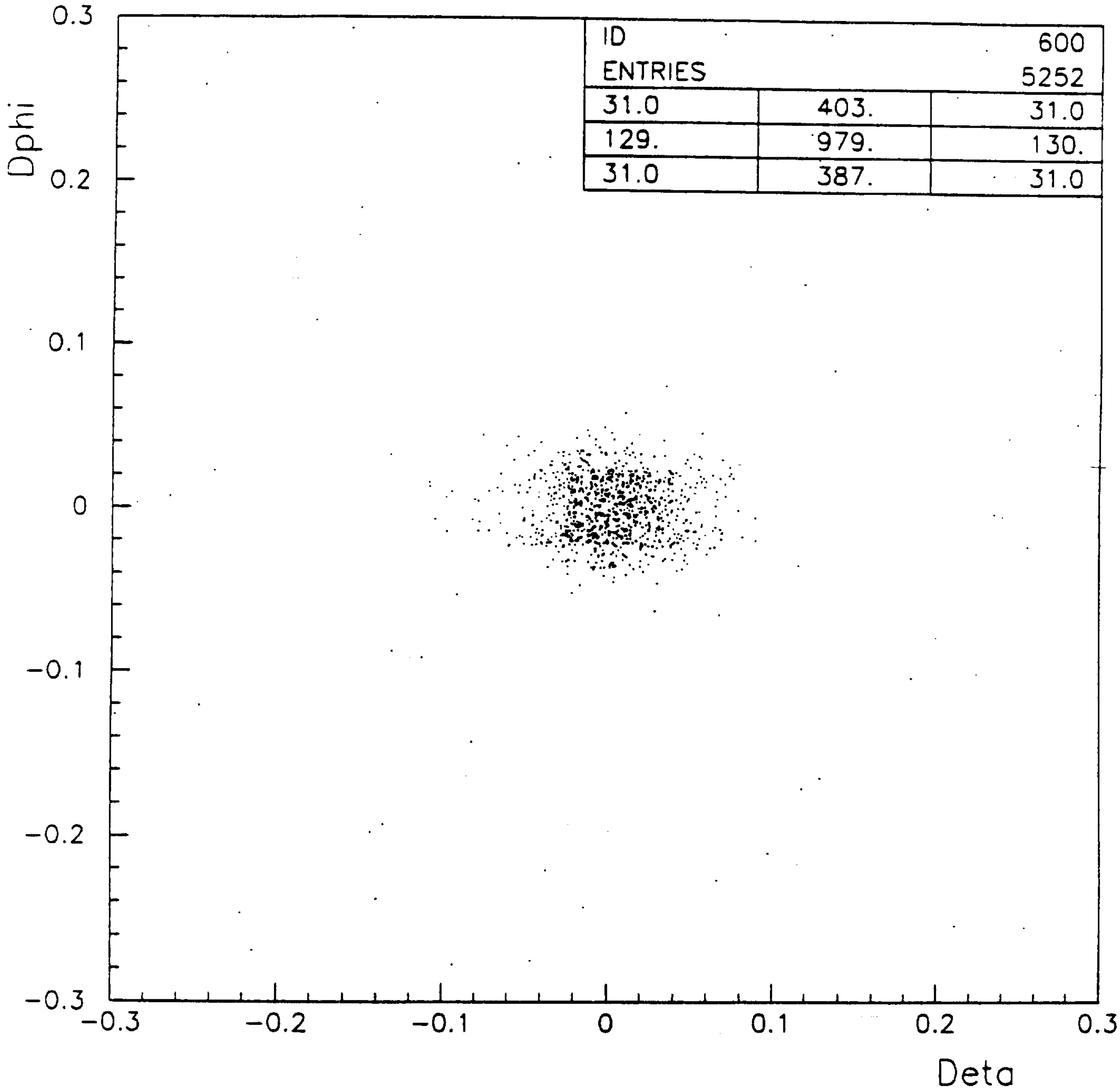
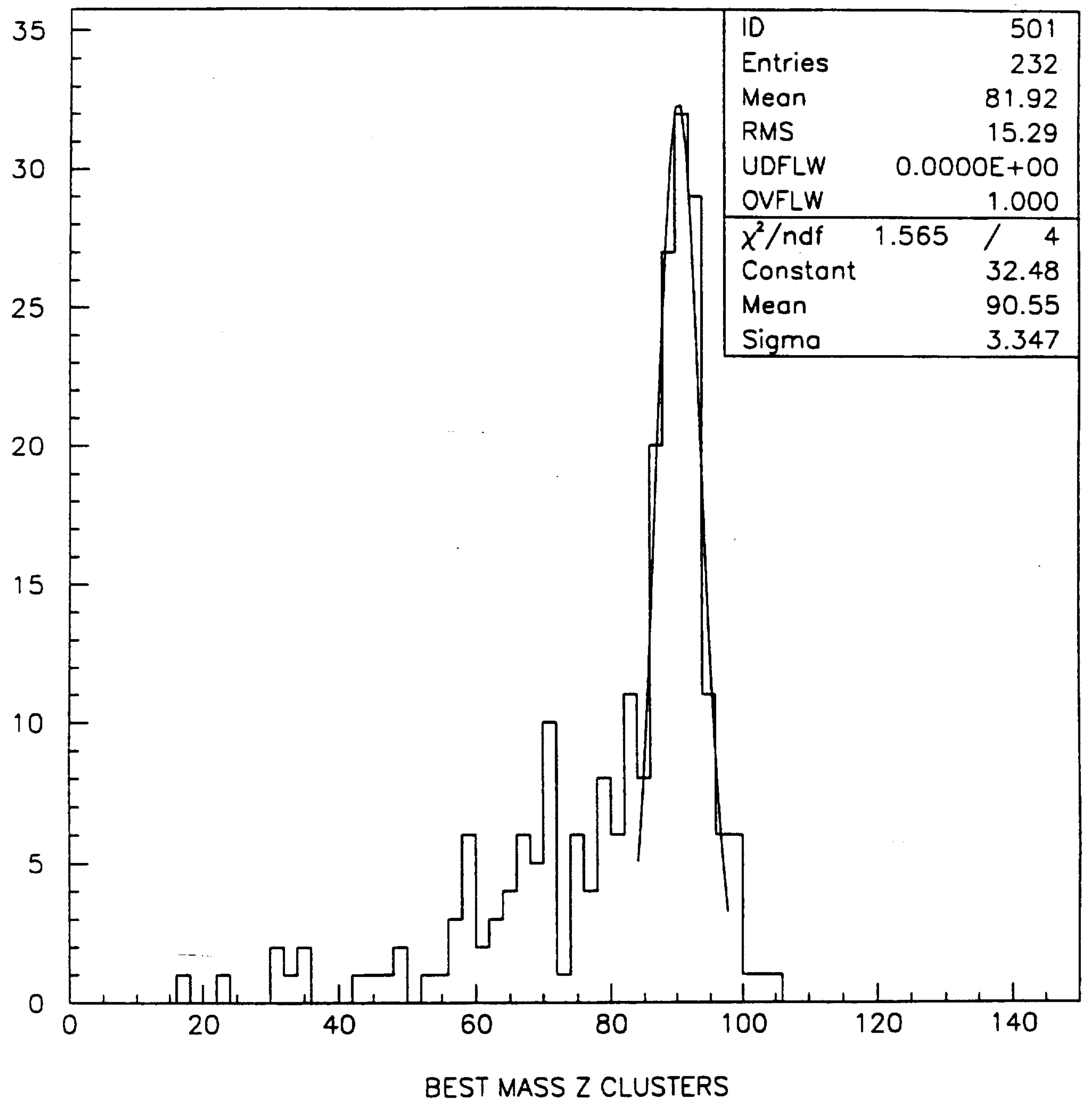

ID 60
ENTRIES 1112
0.000E+00 6.00 0.000E+00
0.000E+00 0.110E+04 0.000E+00
0.000E+00 7.00 0.000E+00
DE/E
abs(eta)
0.3
0.2
0.1
0
−0.1
−0.2
−0.3
0
0.5
1
1.5
2
2.5
3

Figure 2



ID 600
ENTRIES 5252
31.0 403. 31.0
129. 979. 130.
31.0 387. 31.0
Dphi
Deta
0.3
0.2
0.1
0
−0.1
−0.2
−0.3
−0.3
−0.2
−0.1
0
0.1
0.2
0.3

Figure 3



ID 501
Entries 232
Mean 81.92
RMS 15.29
UDFLW 0.0000E+00
OVFLW 1.000
χ²/ndf 1.565 / 4
Constant 32.48
Mean 90.55
Sigma 3.347
35
30
25
20
15
10
5
0
0
20
40
60
80
100
120
140
BEST MASS Z CLUSTERS

Figure 4

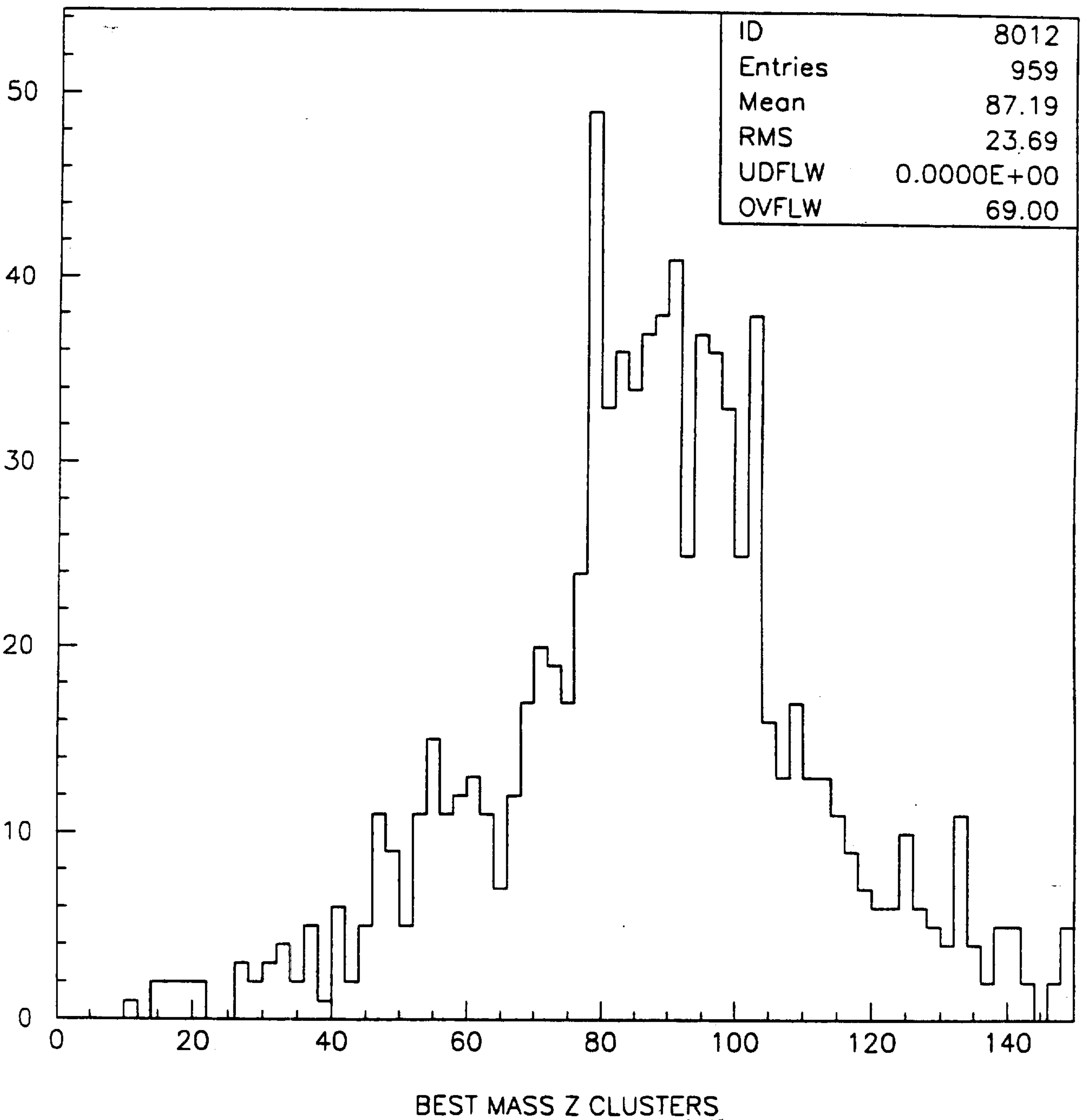
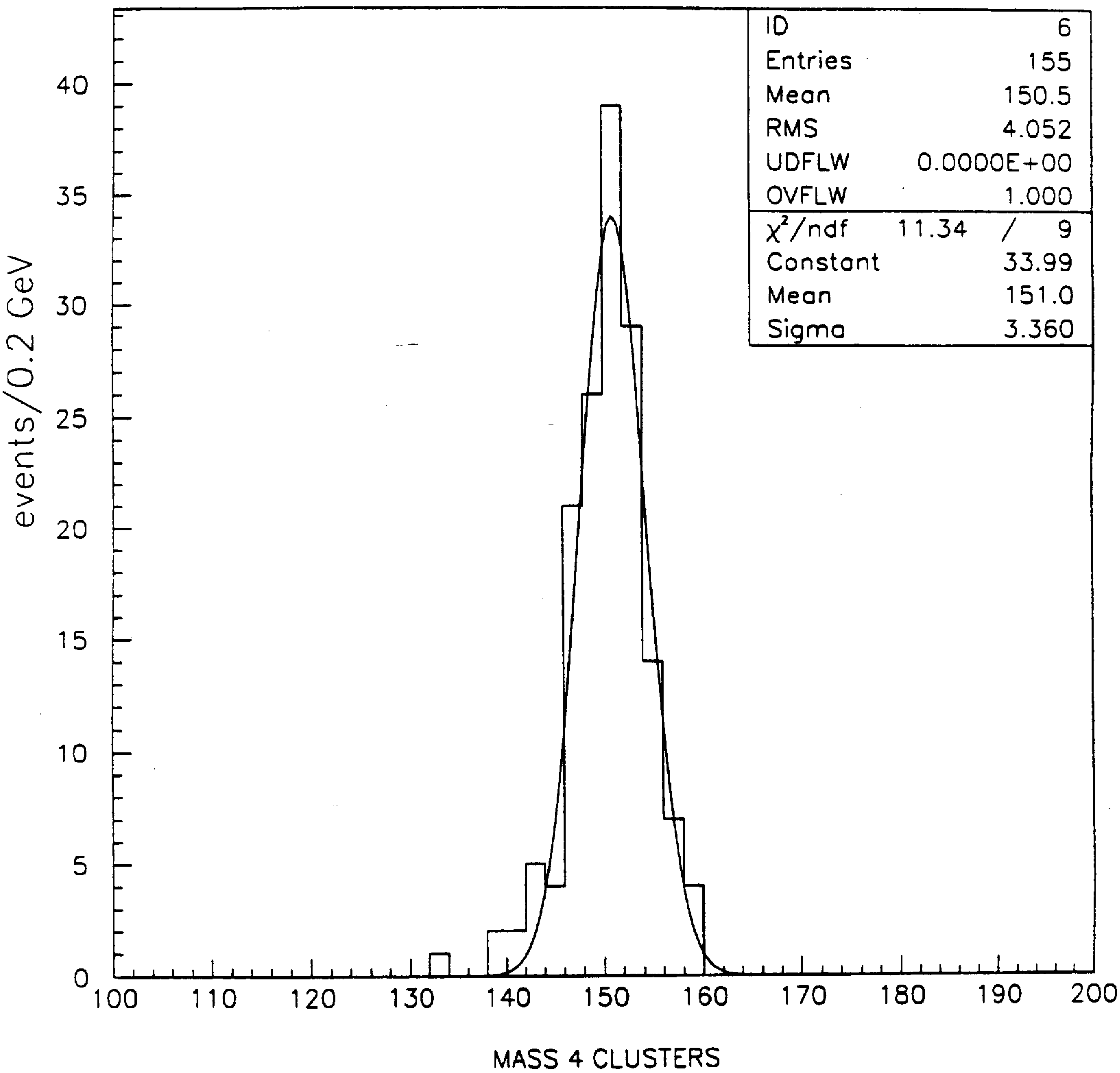
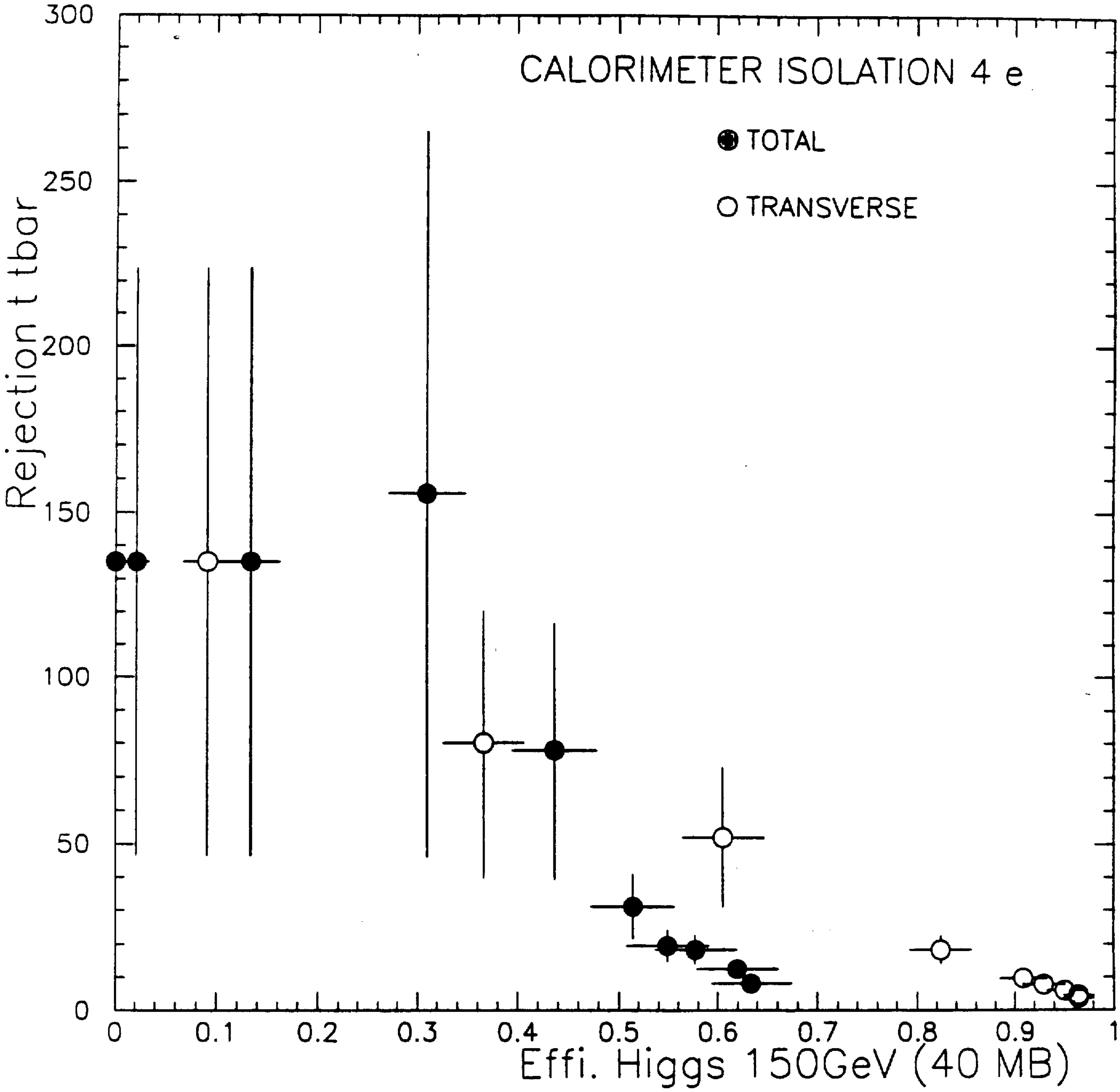

ID 8012
Entries 959
Mean 87.19
RMS 23.69
UDFLW 0.0000E+00
OVFLW 69.00
0
10
20
30
40
50
0
20
40
60
80
100
120
140
BEST MASS Z CLUSTERS

Figure 5



ID 6
Entries 155
Mean 150.5
RMS 4.052
UDFLW 0.0000E+00
OVFLW 1.000
χ²/ndf 11.34 / 9
Constant 33.99
Mean 151.0
Sigma 3.360
events/0.2 GeV
MASS 4 CLUSTERS

Figure 6



CALORIMETER ISOLATION 4 e
TOTAL
TRANSVERSE
Rejection t tbar
Effi. Higgs 150GeV (40 MB)
300
250
200
150
100
50
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

Figure 7

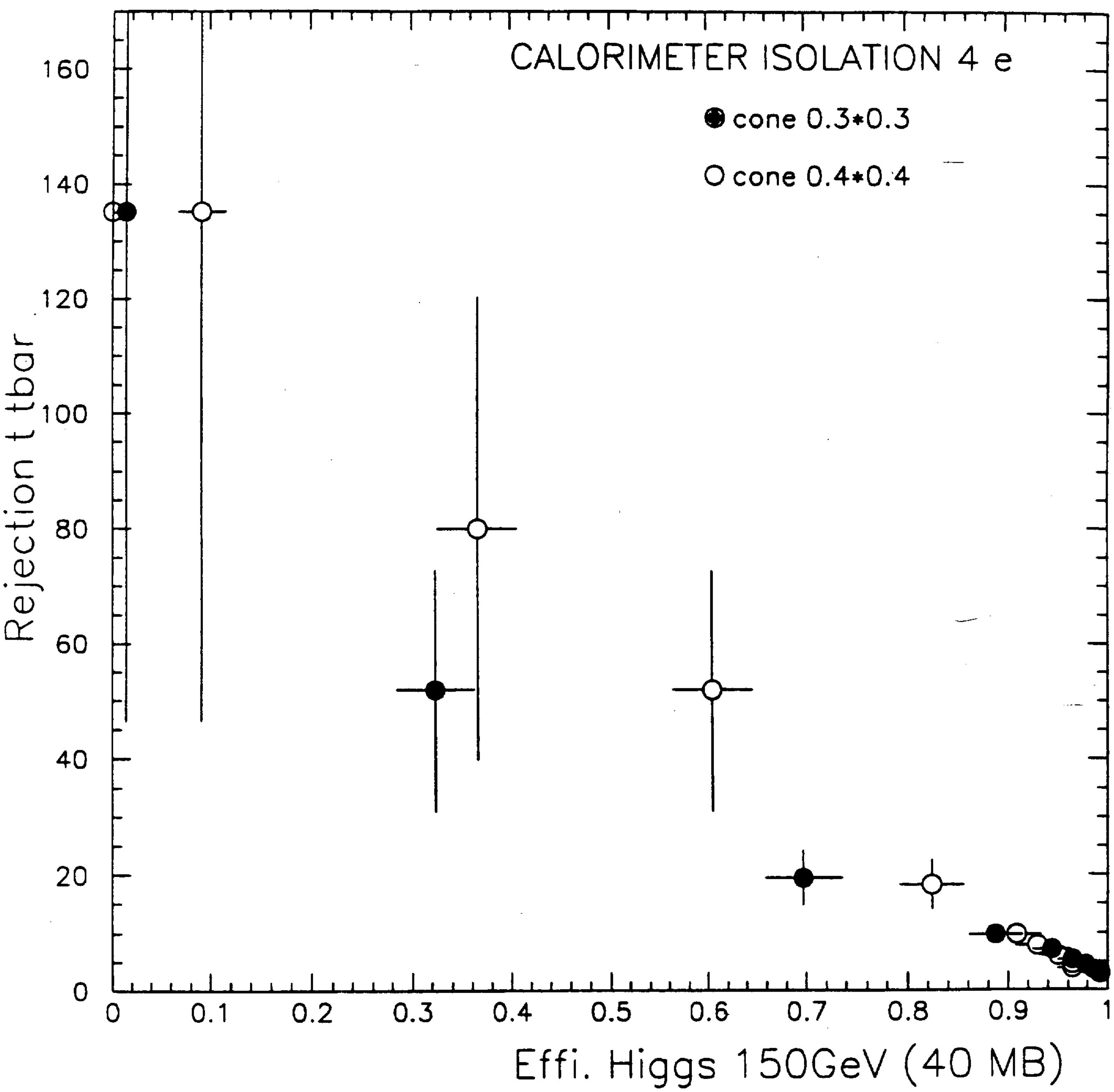
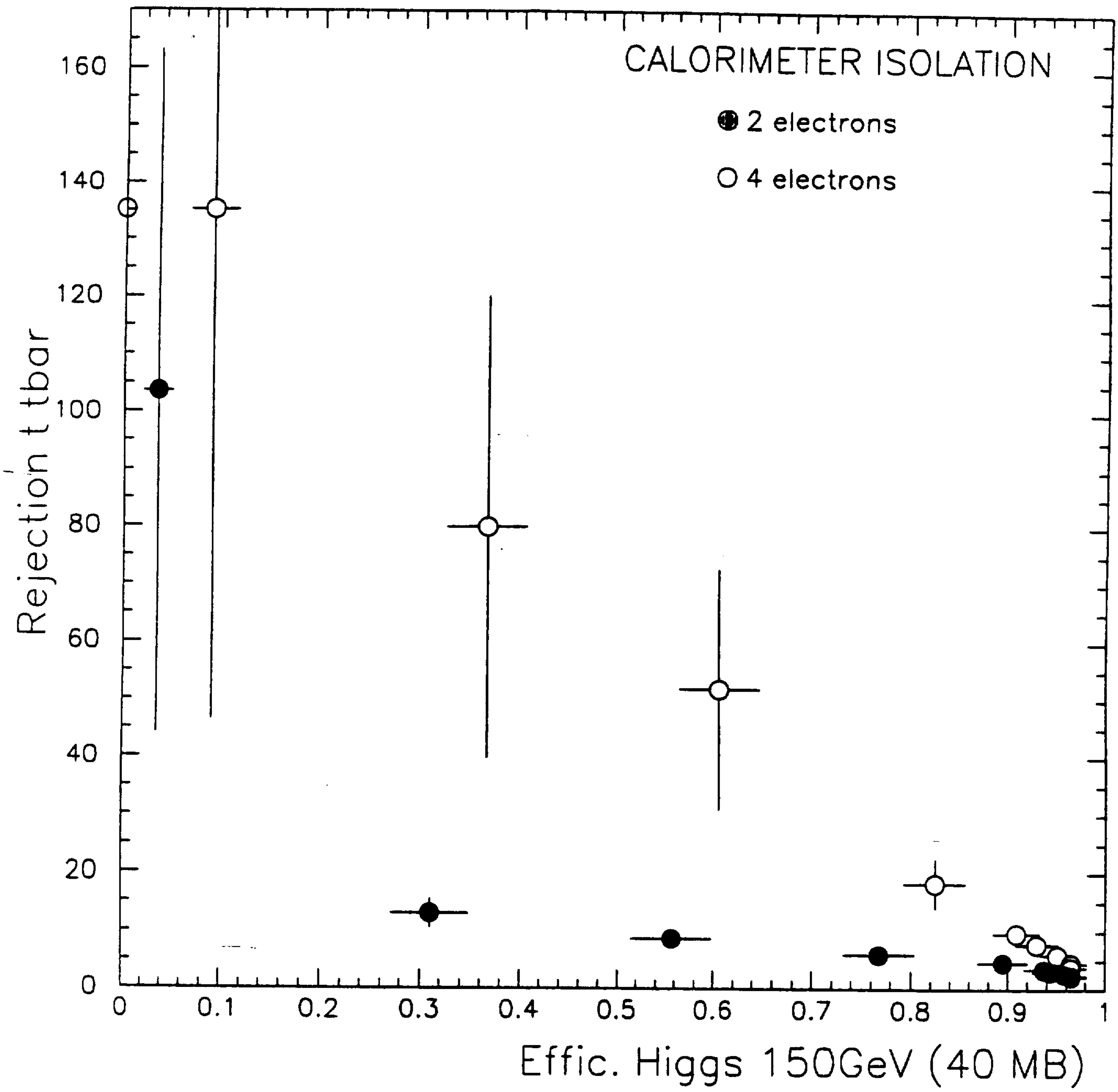

CALORIMETER ISOLATION 4 e
cone 0.3*0.3
cone 0.4*0.4
Rejection t tbar
Effi. Higgs 150GeV (40 MB)
0
20
40
60
80
100
120
140
160
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

Figure 8



CALORIMETER ISOLATION
2 electrons
4 electrons
Rejection t tbar
Effic. Higgs 150GeV (40 MB)
0
20
40
60
80
100
120
140
160
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

Figure 9

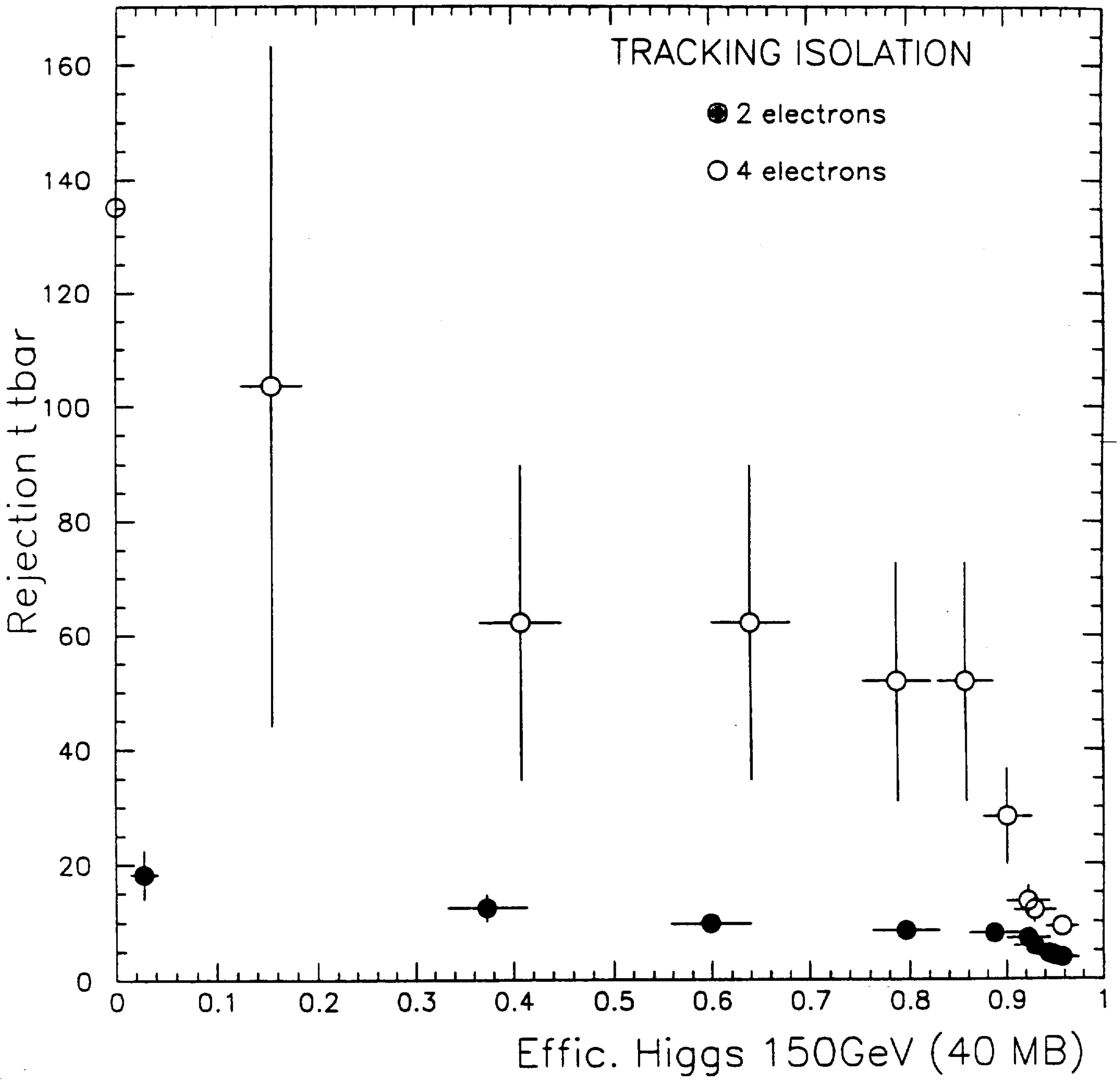
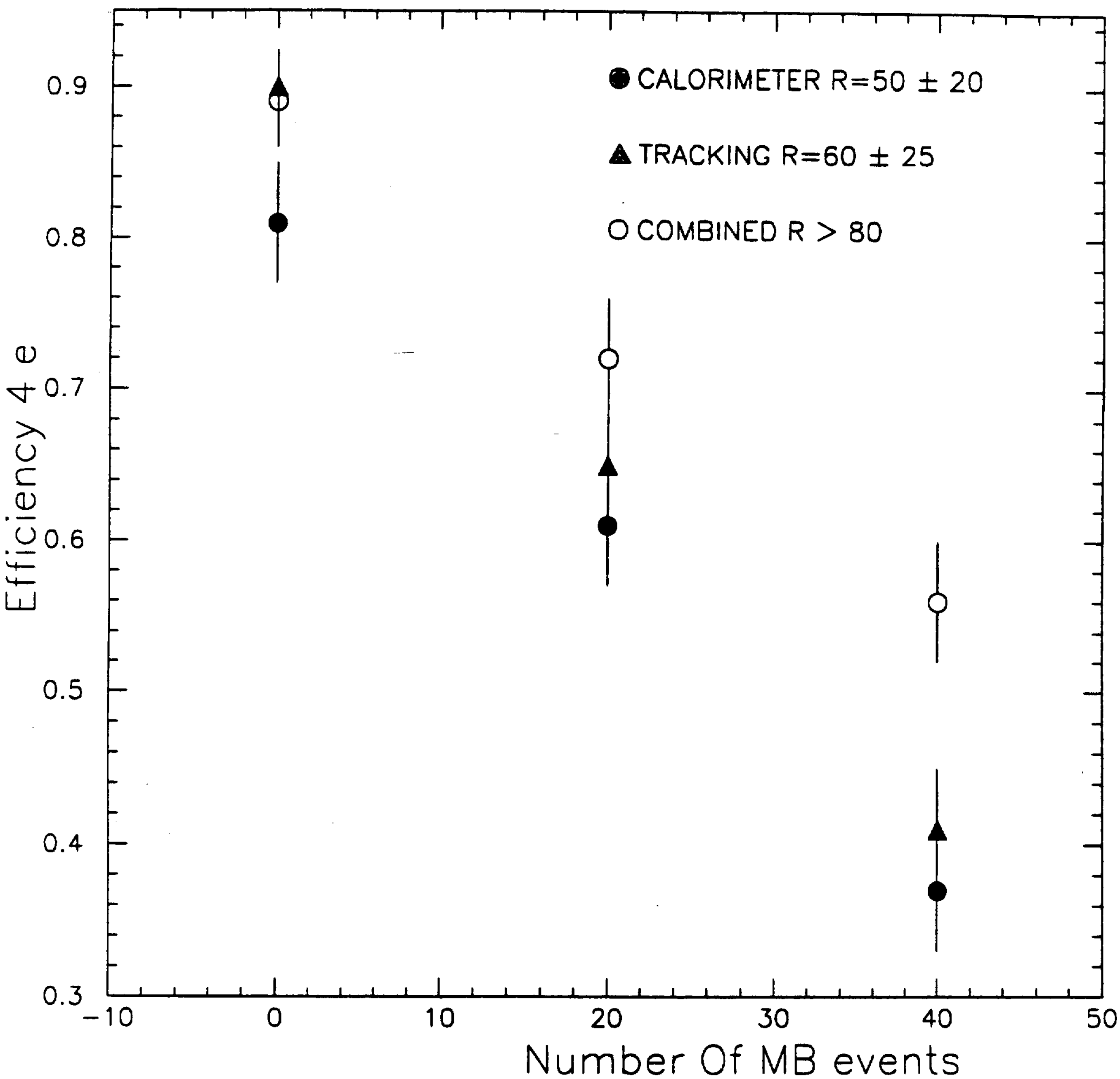

TRACKING ISOLATION
2 electrons
4 electrons
Rejection t tbar
Effic. Higgs 150GeV (40 MB)
0
20
40
60
80
100
120
140
160
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

Figure 10



CALORIMETER R=50 ± 20
TRACKING R=60 ± 25
COMBINED R > 80
Efficiency 4 e
0.9
0.8
0.7
0.6
0.5
0.4
0.3
−10
0
10
20
30
40
50
Number Of MB events

Figure 11

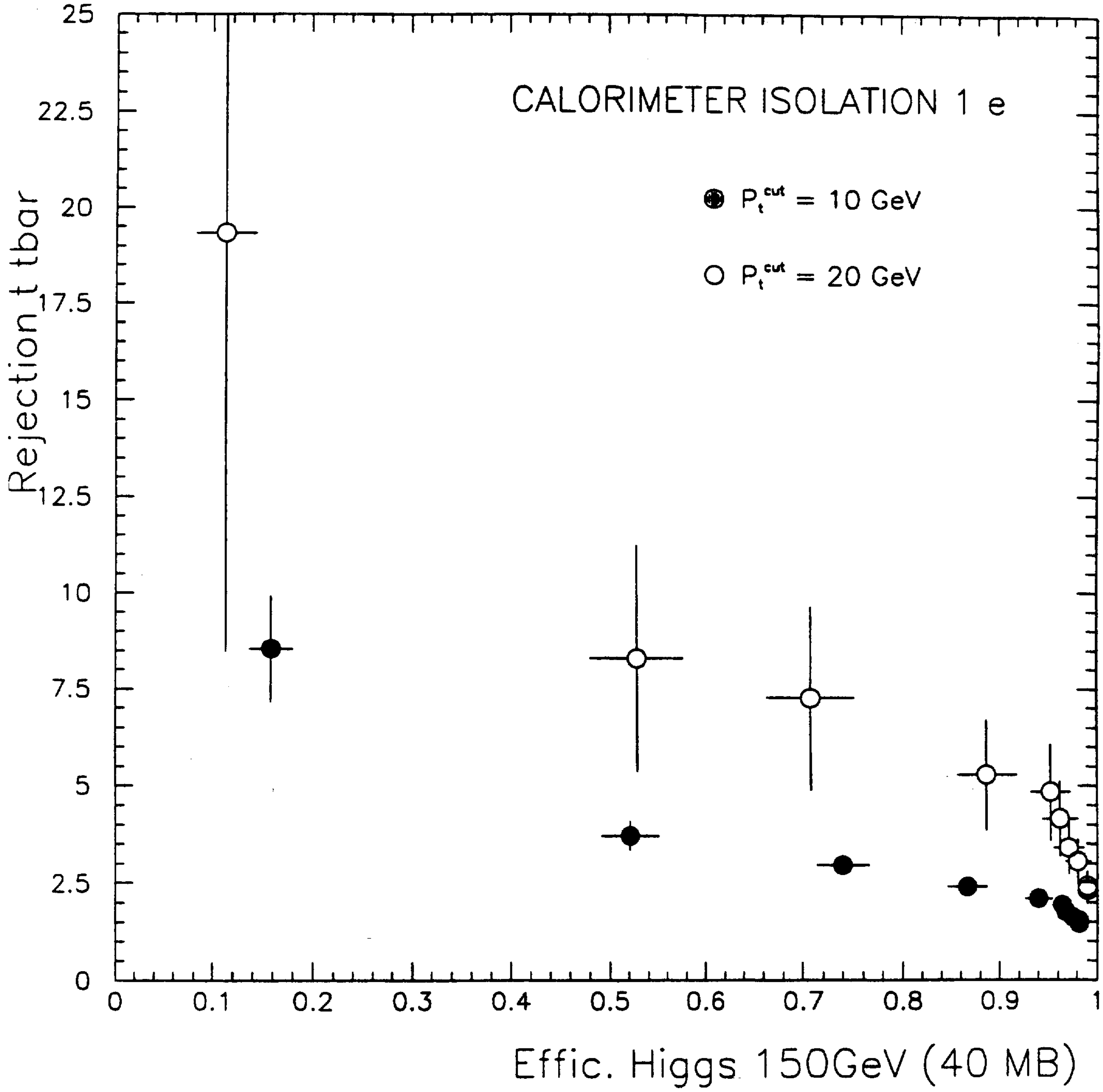

CALORIMETER ISOLATION 1 e
P_t^{cut} = 10 GeV
P_t^{cut} = 20 GeV
Rejection t tbar
Effic. Higgs 150GeV (40 MB)
0
2.5
5
7.5
10
12.5
15
17.5
20
22.5
25
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

Figure 12