DELPHI Collaboration

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LEP machine background and noise in the DELPHI calorimeters.

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Abstract

The LEP machine background and noise in the DELPHI calorimeters have been studied in four independent analyses. The main purpose of this work is to estimate the probability of a shower from these sources in coincidence with a genuine physics event and to see how best to reject this type of background. Both the 1998 and the 1999 high energy data have been used in this study.

1 Introduction

LEP machine background and noise in the electromagnetic calorimeters can affect many DELPHI analyses. Particularly sensitive are the analyses of two photon interactions [1] and events with a single photon in the final state [2] since these analyses select or trigger on energy in the calorimeters. However, analyses which veto on energy in the calorimeters e.g. STIC also need to take this background into account.

In this note several different studies of calorimeter background have been compiled. At low angles, i.e. in VSAT and STIC, the most troublesome background comes from off-energy electrons caused by bremsstrahlung from beam particles on rest-gas molecules. This background has been simulated in DELPHI [3]. The simulation has given a better understanding of the production and origin of the background but cannot be used for quantitative estimates, since it needs as input the vacuum pressure in LEP, which is not known in detail.

The only way of estimating the off-energy background is to use real data. Any sample of events which is not expected to give electrons in VSAT can be used to estimate the probability of an off-energy electron in VSAT. A few basic questions need to be answered: What is the rate of the background (normalized to luminosity) and how does it vary with time ? What is the probability that an off-energy electron is recorded together with a genuine physics event ? How can the background best be rejected ?

The off-energy background in VSAT has been estimated with three different data samples: VSAT Bhabha events, STIC Bhabha events and muon events. All the analyses were done with 1998 high energy data.

Three different event samples were also used for the study of off-energy electrons in STIC: the STIC single arm events, the STIC Bhabha events and random triggered events. Data from both 1998 and 1999 have been studied.

In the other DELPHI calorimeters such as FEMC, HPC and HAC, there is no off-energy electron background but noise can cause spurious showers. This problem was studied with the 1999 random triggered events.

2 Background in VSAT

At LEP2, VSAT is used mainly to measure the energy and position of the scattered electrons in $\gamma\gamma$ collisions. The main background in this type of analysis comes from the enormous off-energy electron background. The probability of having an off-energy electron faking the scattered electron from a $\gamma\gamma$ event can be calculated with any sample of events which does not give electrons in VSAT. The largest sample available is the VSAT Bhabha sample and it can be used to calculate the probability with a minute statistical error. To estimate the systematic error, other event samples such as muon events and STIC Bhabha events have also been studied.

In the following discussion, the standard DELPHI coordinate system is used with the x axis pointing towards the centre of LEP, the y axis pointing upwards and the z axis pointing in the direction of the electron beam. θ is the polar angle in relation to the z axis and ϕ is the azimuthal angle around the z axis. In this coordinate system, the numbering of the four VSAT modules is as follows:

Module 1	Module 2	Module 3	Module 4
$x < -5$cm, $z < -775$cm	$x > 5$cm, $z < -775$cm	$x < -5$cm, $z > 775$cm	$x > 5$cm, $z > 775$cm

which means that module 1 and 3 are on the outer circumference of the LEP ring and module 1 and 2 are on the DELPHI A-side while 3 and 4 are on the C-side.

2.1 VSAT scalers and Bhabha events

The most direct way to investigate the probability of having an off-energy electron in a VSAT module is to count them and compare the number to the number of bunch crossings during the same period. The VSAT detector is hit by an enormous quantity of off-energy background electrons, so, in order to save disk-space for more interesting processes, only a small fraction of these events are read out.

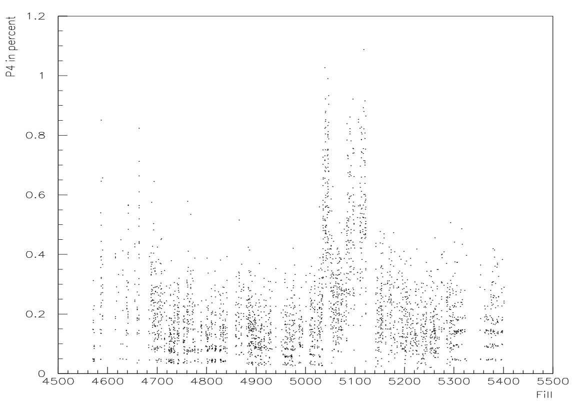

Figure 1: The probability of an off-momentum electron in module 4 for each cassette of 1998 data.

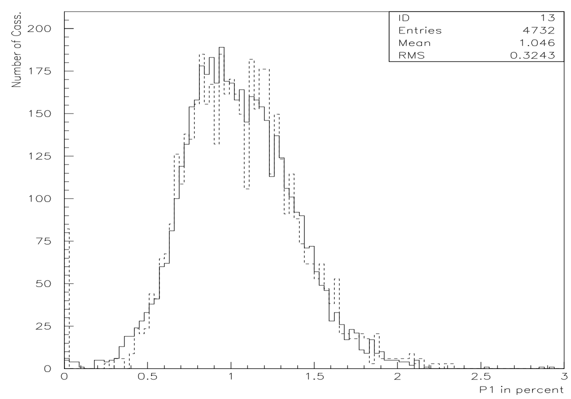

Figure 2: The distribution of the number of cassettes as against the probability of a single electron in module 3, calculated from the scalers (full line) and from the Bhabha events (dotted line).

The VSAT is also equipped with scalers that count the number of hits in each module and the number of Bhabha triggers. The scaler values can be used offline to estimate the probability of background in an individual modules. Since the scalers count all events, the Bhabha scaler value was subtracted to get the true number of single electrons.

The beam and vacuum conditions vary during the year, which alters the VSAT background rate. This is shown in Figure 1, where the probability of a single electron in module 4 have been calculated for each cassette and plotted against the fill number. The increase between fill 5050 and 5100 is due to a LEP vacuum leak.

The full line in Figure 2 shows the probability distribution of single electrons in module 3, as calculated from the scalers on each cassette of 1998 data and Table 1 gives the probability of an off-energy electron in VSAT averaged over all the 1998 data.

Off-energy electrons coinciding with Bhabha events can be used to measure both the probability and the energy and position distributions of this background. The dotted line in Figure 2 shows the probability of each cassette having an electron in module 3 at the

$\mathcal{P}_1$[%]	$\mathcal{P}_2$[%]	$\mathcal{P}_3$[%]	$\mathcal{P}_4$[%]
1.105±0.00002	0.167±0.00001	1.046±0.00002	0.234± 0.00001

Table 1: The probability of an off-energy electron in the four different VSAT modules. The VSAT scalers were used in this study and the minimum energy required in the trigger was ∼15 GeV.

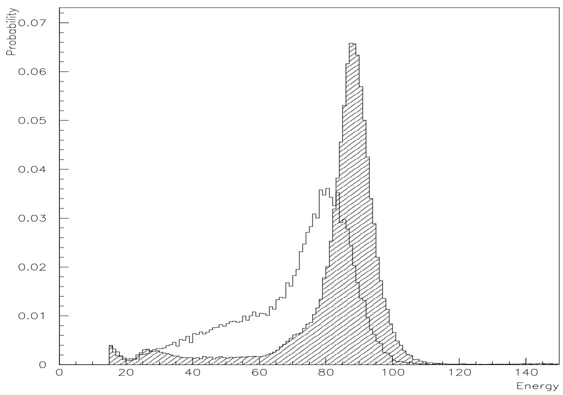

Figure 3: Off-momentum background energy distribution for module 1 (shaded) and module 4.

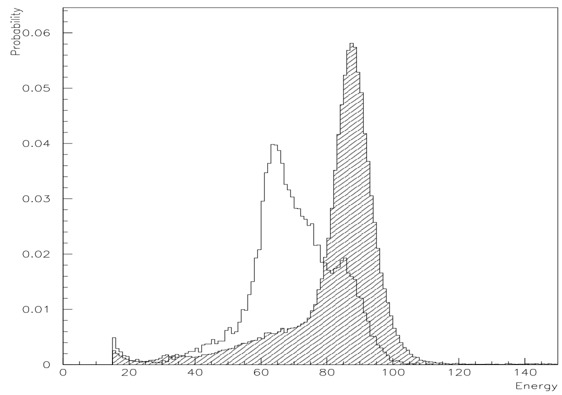

Figure 4: Off-momentum background energy distribution for module 3 (shaded) and module 2.

same time as a pair of Bhabha electrons in module 1 and 4. In this study an energy cut of 15 GeV on the electron in module 3 was made, since this corresponds to the cut in the trigger used by the scalers. The cassettes were required to contain at least 3000 Bhabha events, which reduced the number of cassettes from 4700 to 1600. The distribution in Figure 1 from Bhabha events has therefore been rescaled so that it can be compared to the distribution from the scalers. The two methods seems to be in perfect agreement, with the probability of an off-energy electron in Module 3 varying between 0.2-2.3% .

E_{min} [GeV]	$\mathcal{P}_1$[%]	$\mathcal{P}_2$[%]	$\mathcal{P}_3$[%]	$\mathcal{P}_4$[%]
15	1.017±0.002	0.1601±0.0008	1.053±0.002	0.2076±0.0009
20	1.005±0.002	0.1580±0.0008	1.044±0.002	0.2049±0.0009
50	0.949±0.002	0.1482±0.0008	0.999±0.002	0.1769±0.0008
70	0.901±0.002	0.0740±0.0006	0.896±0.002	0.1309±0.0007
80	0.803±0.002	0.0354±0.0004	0.784±0.002	0.0744±0.0005

Table 2: The probability of an off-energy electron with energy larger than E_{min} in the four different VSAT modules. The measurement was done with VSAT Bhabha events.

From the energy distributions of the off-energy electrons (Figure 3 and Figure 4) the probability of an off-energy electron in VSAT as a function of an energy-cut can be calculated. The energy is not properly calibrated in the XSDST data and the data used here are taken from the VSAT offline processing with all the corrections applied. The background in the outer modules (1 and 3) has a higher energy as it is produced in a region further away from DELPHI [3]. The probabilities of an off-energy electron in the

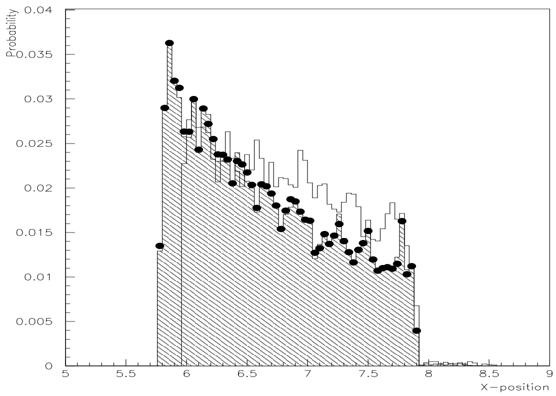

Figure 5: The X distribution of VSAT single electrons in module 1 (shaded) and 2. Comparison is made with a full readout single electron sample in module 1 (dots).

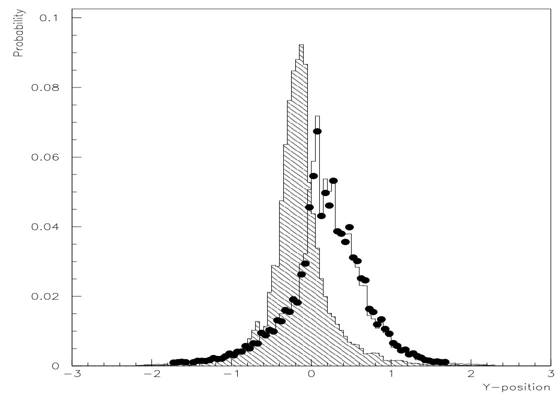

Figure 6: The Y distribution of VSAT single electrons in module 1 (shaded) and 2. Comparison is made with a full readout single electron sample in module 2 (dots).

four VSAT modules are given in Table 2 and are calculated from a sample consisting of $47.5 \cdot 10^6$ Bhabha events, of which 578782 events had an additional off-energy electron in VSAT with energies higher than 15 GeV.

The best way of removing the background is by a cut on the position of the showers, since the background is concentrated in the horizontal plane. The x and y distributions of the single electrons are shown for both inner and outer modules in Figure 5 and 6. In the outer modules the y-distribution has a sharp peak since it is produced closer to DELPHI. A comparison was made of the position distributions with the single electrons NOT in coincidence with a Bhabha event. This sample contains more events although it has been downscaled. These distributions are shown as dots in Figure 5 and 6 and are in a good agreement with those obtained from the Bhabha events.

E_{min} [GeV]	N_{VSAT}	$\mathcal{P}$ [%]	$\mathcal{P}_1$[%]	$\mathcal{P}_3$[%]	$\mathcal{P}_4$[%]
15	13	4 ± 1	1.6 ± 0.7	1.4 ± 0.6	0.5 ± 0.4
50	12	3 ± 1	1.6 ± 0.7	1.4 ± 0.6	0.3 ± 0.3
60	10	2.7 ± 0.9	1.4 ± 0.6	1.1 ± 0.5	0.3 ± 0.3
70	8	2.2 ± 0.8	1.4 ± 0.6	0.8 ± 0.5	-
80	8	2.2 ± 0.8	1.4 ± 0.6	0.8 ± 0.5	-

Table 3: The probability of an off-energy electron with energy higher than E_{min} in the four different VSAT modules. The measurement was done with dimuon events. N_{VSAT} is the number of events with energy in the VSAT greater than corresponding E_{min}. $\mathcal{P}_i$ means the probability for module $i = 1,\ 2,\ 3,\ 4$. There was no events with a signal in module 2.

2.2 Dimuon events

A sample of $e^+e^- \rightarrow Z^0(n\gamma), Z^0 \rightarrow \mu^+\mu^-$ events was also selected to study the probability of having off-energy electrons in VSAT. In this study the 1998 data[2] was used and the

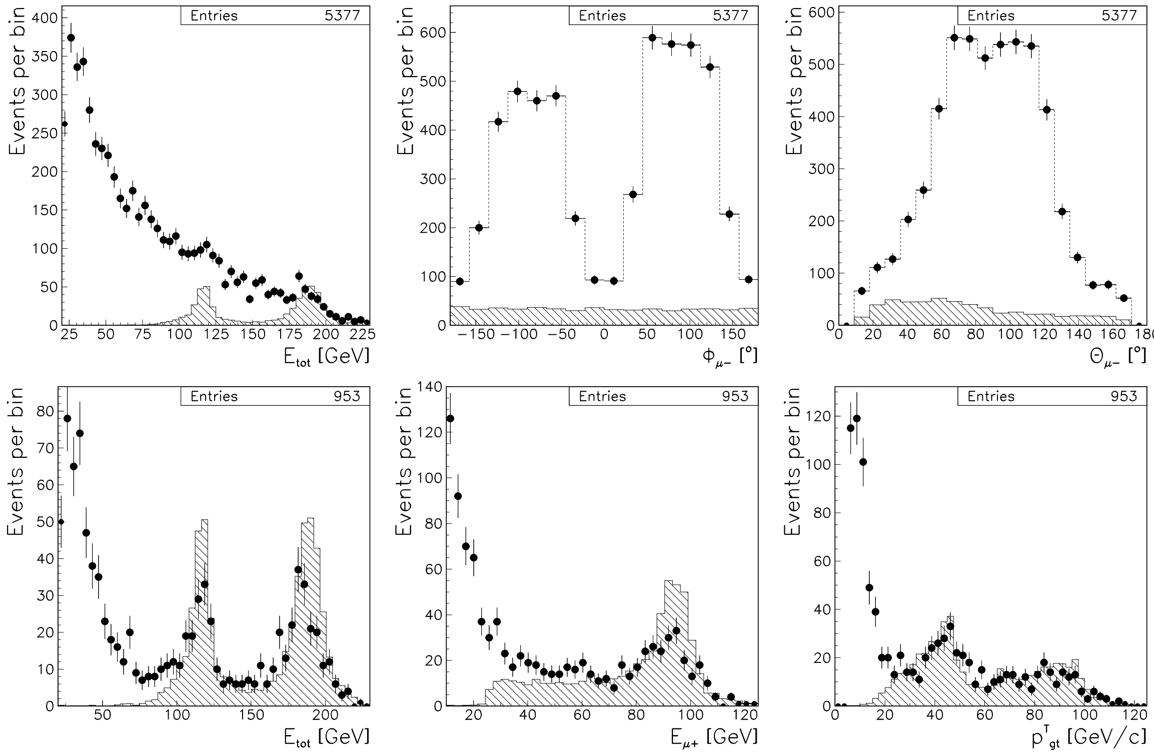

Figure 7: Distributions of E_{tot}, θ_{μ^-} and ϕ_{μ^-} . Points represent data and the hatched histograms represent MC. The top row of plots shows events which fulfil conditions 1, 2 and 3 and the bottom row those fulfilling conditions 4 as well.

selection criteria was optimised with the help of a KORALZ4.2 [4] Monte Carlo sample[3].

To suppress the background, which was mainly due to cosmic muons, it was required that:

1. Two muons were found, one positive and one negative, with no other particles in the event. The muons should be identified as "very loose" or better.
2. The energy of each muon should be $10 < E_{\mu^\pm} < 125$ GeV.
3. The azimuthal angles were required to fulfil $||\phi_{\mu^+} - \phi_{\mu^-}| - 180^0| < 3^0$.
4. Both muons should come from the primary vertex (Q(LPV+4)=0).
5. The transverse momentum of the muons should have $p^T_{gt} > 35$ GeV/c , where $p^T_{gt} \equiv \max(p^T_{\mu^+}, p^T_{\mu^-})$.

The upper three plots in Figure 7 show the distributions of E_{tot}, θ_{μ^-} and ϕ_{μ^-} after conditions 1, 2 and 3 were satisfied. At this stage 4741 events remained, with 495 expected. The angular distributions had broad peaks at $\theta \approx 90^0$ and around $\phi = \pm 90^0$ which were not predicted by Monte Carlo. The reason is of course the large contamination of cosmic muons. Many of the cosmic events can be rejected by the requirement on the primary vertex (condition 4). The bottom three plots in Figure 7 depict the distributions of

[2]XSDST98_D2/C1-78 was used with a luminosity of $\mathcal{L} = 146.2$ pb^{-1}and a beam energy $E_b = 94.26$–94.965 GeV.

[3]The sample called XS_MUMU_E188_R98_1L_A1/C0001 with a cross section $\sigma_{MC} = 8.35 \pm 0.06$ pb was used. It contained 11481 events simulated at $\sqrt{s} = 188$ GeV.

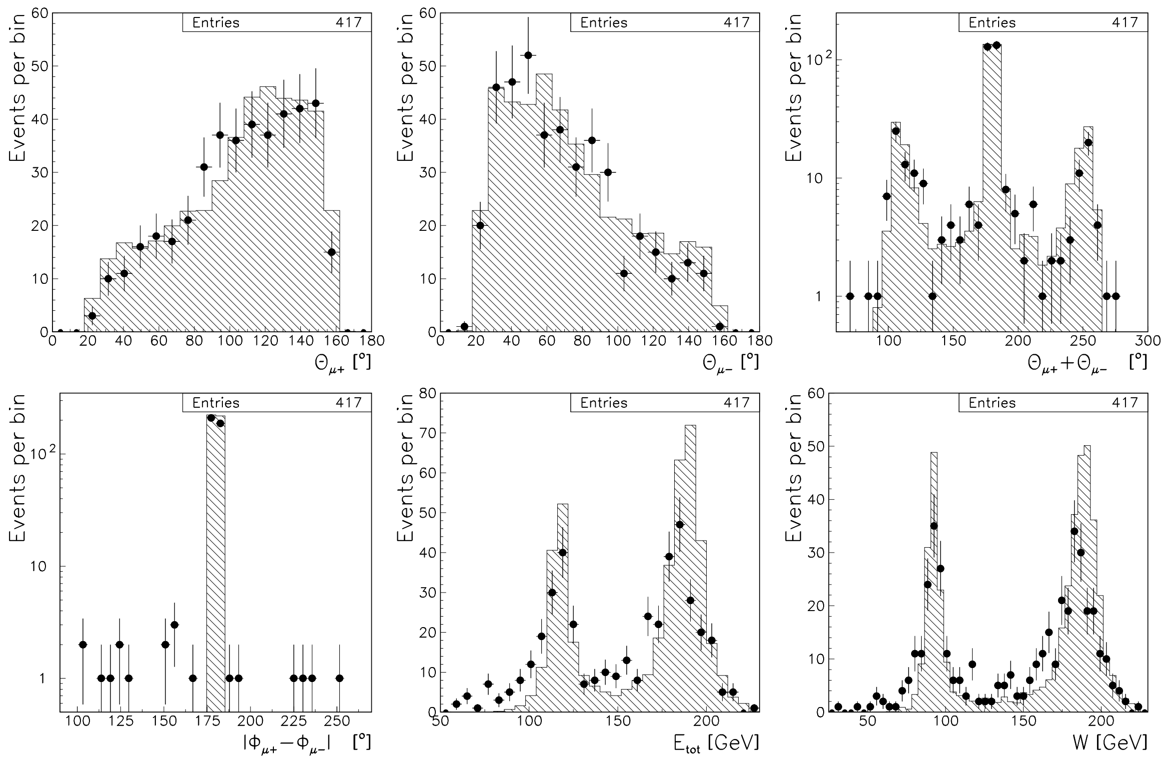

Figure 8: Distributions of polar angle (θ_{μ^+} and θ_{μ^-}), the sum of polar angles ($\theta_{\mu^+} + \theta_{\mu^-}$), the difference of azimuthal angles ($|\phi_{\mu^+} - \phi_{\mu^-}|$), and the total energy of the muons (E_{tot}) and their invariant mass (W).

E_{tot}, E_{μ^+} and p_{gt}^T after the vertex cut. 800 events remained in the data with an unchanged number of expected events.

The last cut on p_{gt}^T removes softer muons coming from $e^+e^- \rightarrow \gamma^*(n\gamma), \gamma^* \rightarrow \mu^+\mu^-$, $\gamma\gamma$ collisions or $Z^0 \rightarrow \tau^+\tau^-$ events. After this cut 369 ± 19 events remained in the data, with $408 \pm 7 \pm 3$ expected from the Monte Carlo study (the second error is due to the uncertainty in the cross section). Good agreement between data and predictions was obtained, as can be seen in Figure 8, which shows different angular distributions such as the polar angle of each muon ($\theta_{\mu^\pm}$), the sum of polar angles ($\theta_{\mu^+} + \theta_{\mu^-}$) and the difference in azimuthal angles ($|\phi_{\mu^+} - \phi_{\mu^-}|$). The total energy ($E_{tot} = E_{\mu^+} + E_{\mu^-}$) and invariant mass of the muons ($W = \sqrt{{E_{tot}}^2 - (\vec{p}_{\mu^+} + \vec{p}_{\mu^-})^2}$) are also presented in Figure 8. The overall impression from the data-Monte Carlo comparison is that the efficiency is somewhat too high in the simulation and that the energies are slightly high.

Out of the 417 selected events, only 18 had an electron in the VSAT. In all of these events, only one module scored a hit. The energy measured by VSAT was corrected using the offline VSAT programs. The total probability and probabilities for each module derived from this sample are shown in Table 3.

2.3 Cosmic muon events

The cosmic muon events, rejected in the previous analysis, can also be used to look for off-energy electrons in VSAT. The following cuts were made to select the events:

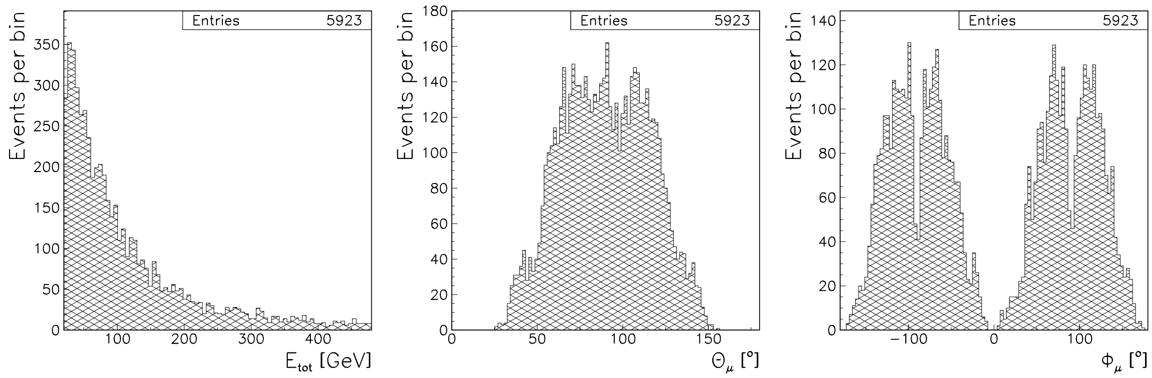

Figure 9: Distributions of E_{tot}, θ_μ and ϕ_μ for events fulfilling conditions 1–4.

E_{min} [GeV]	N_{VSAT}	$\mathcal{P}$ [%]	$\mathcal{P}_1$[%]	$\mathcal{P}_2$[%]	$\mathcal{P}_3$[%]	$\mathcal{P}_4$[%]
15	113	2.1 ± 0.2	0.9 ± 0.1	0.15 ± 0.05	0.9 ± 0.1	0.11 ± 0.05
50	94	1.7 ± 0.2	0.7 ± 0.1	0.09 ± 0.04	0.8 ± 0.1	0.11 ± 0.05
60	84	1.6 ± 0.2	0.7 ± 0.1	0.04 ± 0.03	0.8 ± 0.1	0.09 ± 0.04
70	75	1.4 ± 0.2	0.6 ± 0.1	0.04 ± 0.03	0.7 ± 0.1	0.08 ± 0.04
80	31	0.6 ± 0.1	0.19 ± 0.06	-	0.35 ± 0.08	0.04 ± 0.03

Table 4: The probability of an off-energy electron with energy greater than E_{min} in the four different VSAT modules. The measurement was done with cosmic muon events.

1. Two muons had to be found, with no other particles in the event. The muons should be identified as "very loose" or better.
2. The energy of each muon had to fulfil $E_\mu > 10$ GeV.
3. Neither of the two muons should come from the primary vertex (Q(LPV+4)≠0).
4. It was required that $|\theta_n + \theta_m - 180^0| < 1^0$ and $||\phi_n - \phi_m| - 180^0| < 1^0$ where n and m can be a positive μ^+ or a negative μ^- .

After this selection, 5396 events were found, 337 $\mu^+\mu^+$ pairs, 336 $\mu^-\mu^-$ and 4723 $\mu^+\mu^-$ events. Distributions of the total energy of the muon pair (E_{tot}) and of the azimuthal angle (ϕ_μ) and polar angle (ϕ_μ) of the individual muons are shown in Figure 9.

Of the 5396 events, there was one VSAT off-energy electron in 136 events and two off-energy electrons in 5 events. The probability of an electron in VSAT computed from these events is presented in Table 4.

2.4 VSAT background in STIC Bhabha events

A sample of back-to-back Bhabha events in STIC was selected by requiring a single shower in each calorimeter with $2.5° < \theta < 8°$ and $0.97 < E_e/E_{beam} < 1.05$. The angle between the two showers was required to be larger than 179.85°. In all, 925445 events from the 1998 data satisfied these requirements, 22433 of them having at least one shower in VSAT with an energy larger than 20 GeV. Most of the events (22072) had a shower in only one module, while a small fraction had a hit in two (359) or three (2) modules.

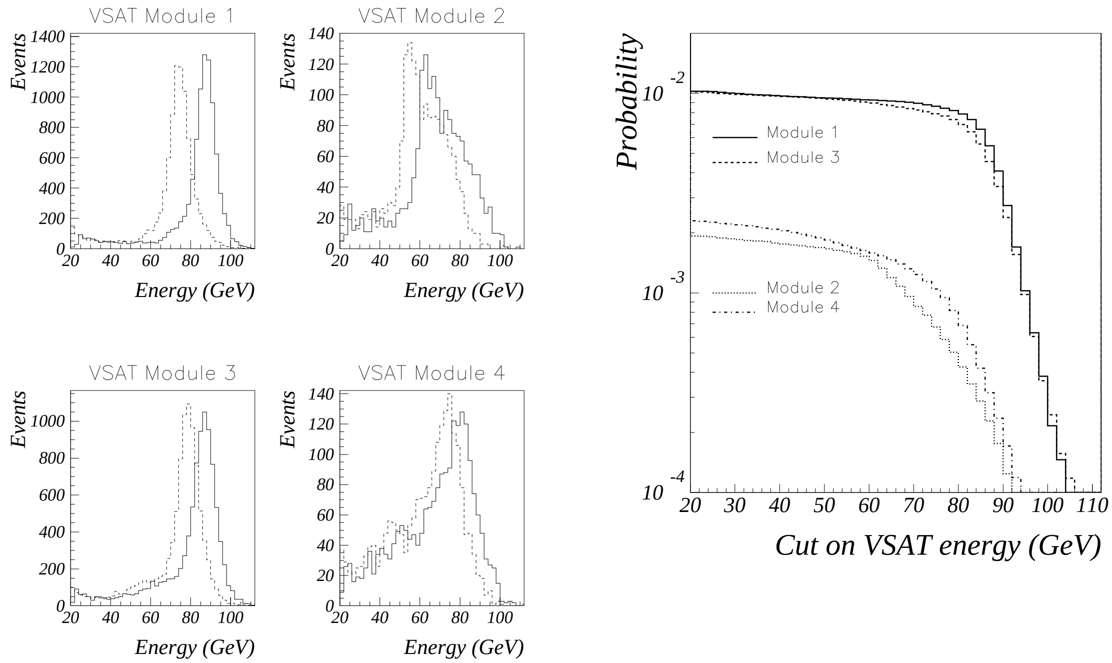

Figure 10: Left: Energy distribution of the showers in the four VSAT modules. The dotted line shows the uncorrected and the full line the corrected spectrum. Right: The probability that an off-energy electron shower will be found in VSAT, as a function of an energy cut.

Figure 10 shows the energy distribution of the showers seen in the four VSAT modules. The energy spectrum is shown both directly from the XSDST and after offline corrections. The VSAT modules at the outer circumference of the LEP ring (module 1 and 3) shows 5 times as much background as those on the inner circumference and the energy of the off-energy electron peaks close to the beam energy. In the inner modules the energy distribution is also peaked but broader. Since the energy of the background peaks at high energy, this background cannot be rejected with an energy cut. That is shown in Figure 10 and Table 5 which give the probability of having an off-energy electron in the different VSAT modules as a function of a cut on energy. Both for the inner and outer modules, the cut has to be made at very high energies in order to achieve a sizable reduction in background.

Since the off-energy background is concentrated in the horizontal plane, the best way

E_{min} [GeV]	$\mathcal{P}_1$[%]	$\mathcal{P}_2$[%]	$\mathcal{P}_3$[%]	$\mathcal{P}_4$[%]
20	1.025 ± 0.011	0.193 ± 0.005	1.017 ± 0.010	0.230 ± 0.005
50	0.947 ± 0.010	0.166 ± 0.004	0.936 ± 0.010	0.184 ± 0.004
70	0.890 ± 0.010	0.085 ± 0.003	0.824 ± 0.009	0.124 ± 0.004
80	0.788 ± 0.009	0.042 ± 0.002	0.699 ± 0.009	0.069 ± 0.003

Table 5: The probability of an off-energy electron with energy greater than E_{min} in the four different VSAT modules. The measurement was done with STIC Bhabha events.

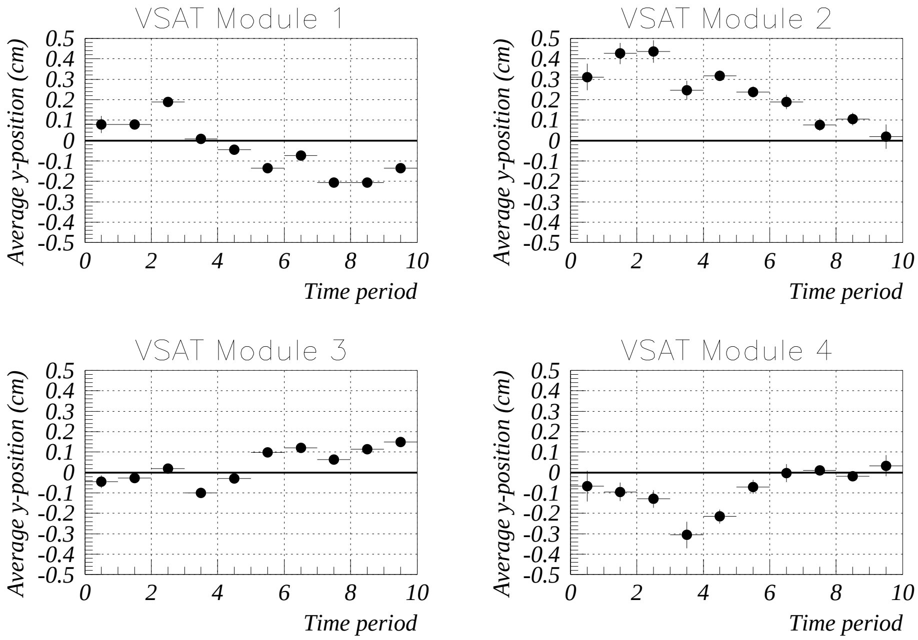

Figure 11: The average y-position in VSAT of the off-energy electron background during different time periods.

to reject it is by a cut on y (i.e. the vertical coordinate). However, differences in the magnetic fields in LEP during different time periods mean that the background peak in y moves during a LEP run. To study this, the 1998 data was divided up into 10 time periods as indicated by Table 6 and the average y-position was plotted (Figure 11). Variations of up to 5 mm of the average y-position were observed during the year, considering that each VSAT module has an active area which is only 5x5 cm, this is a significant effect.

Period	Fills	$\mathcal{Y}_1[mm]$	$\mathcal{Y}_2[mm]$	$\mathcal{Y}_3[mm]$	$\mathcal{Y}_4[mm]$
0	4550-4600	0.78 ± 0.42	3.10 ± 0.65	-0.45 ± 0.30	-0.67 ± 0.76
1	4601-4675	0.78 ± 0.21	4.26 ± 0.52	-0.27 ± 0.13	-0.95 ± 0.45
2	4676-4725	1.88 ± 0.14	4.35 ± 0.55	0.20 ± 0.09	-1.30 ± 0.43
3	4726-4750	0.09 ± 0.10	2.47 ± 0.46	-0.99 ± 0.11	-3.05 ± 0.65
4	4751-4875	-0.45 ± 0.09	3.16 ± 0.27	-0.29 ± 0.07	-2.16 ± 0.33
5	4876-4950	-1.36 ± 0.08	2.38 ± 0.28	0.98 ± 0.07	-0.70 ± 0.34
6	4951-5000	-0.73 ± 0.12	1.89 ± 0.35	1.21 ± 0.08	-0.03 ± 0.44
7	5001-5120	-2.06 ± 0.08	0.77 ± 0.31	0.64 ± 0.07	0.09 ± 0.21
8	5121-5330	-2.05 ± 0.09	1.05 ± 0.31	1.15 ± 0.06	-0.18 ± 0.24
9	5331-5500	-1.35 ± 0.17	0.18 ± 0.60	1.49 ± 0.13	0.33 ± 0.51

Table 6: The average y-position of the off-energy electrons during 10 time periods.

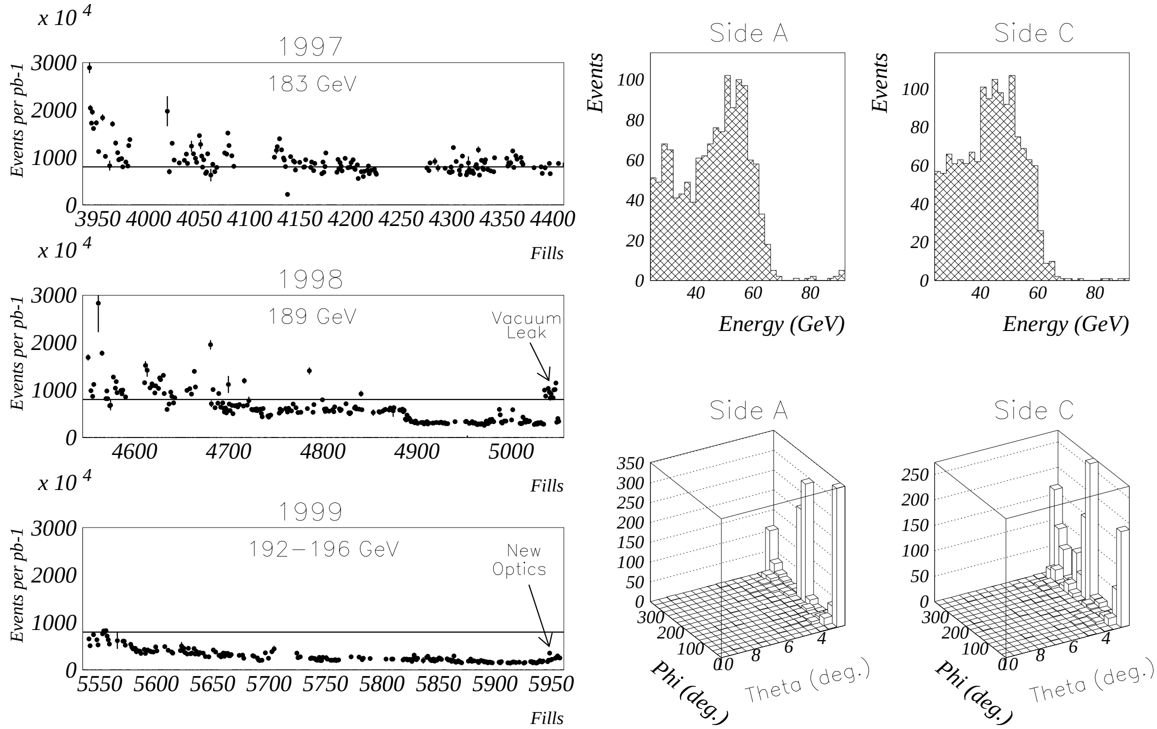

Figure 12: Left: The number of off-energy electrons in STIC per pb^{-1}. Only the first 400-500 high energy fills during each year are shown. Right: The energy and theta-phi distributions of events recorded by the STIC single arm trigger. Data from fill 5941 were used.

3 Background in STIC

3.1 STIC single arm triggers

The STIC single arm triggered events can be used to measure the rate of off-energy electrons in STIC [5]. This trigger requires a shower with an energy greater than $\sim 0.25 \cdot E_{beam}$ in one of the two calorimeters. The trigger is dynamically downscaled to a constant trigger rate, and this has to be taken into account in the estimation of the rate. Figure 12 shows the rate of off-energy electrons in STIC normalized to luminosity. In 1997 the typical rate of off-energy electrons in STIC was $8 \cdot 10^6$ per pb $^{-1}$. The rate has decreased each year and it is now $< 2 \cdot 10^6$ per pb $^{-1}$.

The energy and angular distributions of the off-energy electrons in STIC are shown in Figure 12 for 1999B data from fill 5941. Most of the background has a large energy and is in the horizontal plane, which results in peaks in the theta-phi distribution. This horizontal background component can, however, be removed by a cut on the polar angle since it does not extend much above 3°.

3.2 STIC Bhabha events

To calculate the probability that an off-energy electron is recorded together with a physics event, the same basic selection of events as in the VSAT study was used, i.e., the events had to have one shower in each calorimeter with $2.5° < \theta < 8°$ and $0.97 < E_e/E_{beam} < 1.05$.

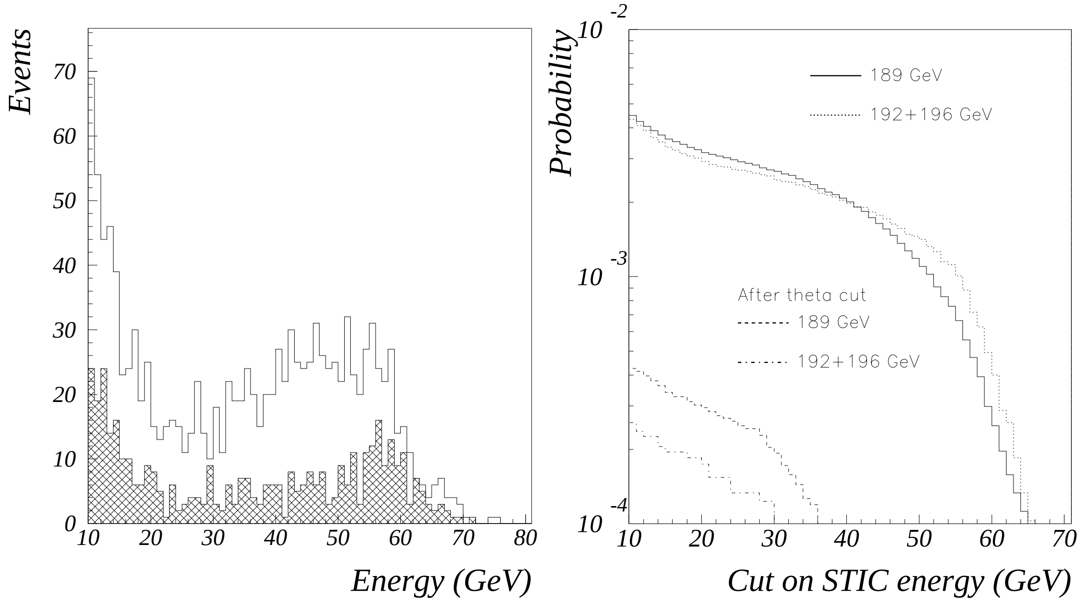

Figure 13: Left: Energy distribution of the third shower in the selected STIC events. The unshaded histogram is 1998 data and the shaded histogram 1999 data. Right: The probability that an off-energy electron shower will be found in STIC as a function of an energy cut.

The angle between the two showers had to be larger than 179.85°. A third shower was required in the event and this shower has to be separated by at least 45° in azimuth from the closest shower. The angular requirements meant that radiative Bhabha events with a photon energy of at most ∼8 GeV could survive the selection; the final sample of Bhahbas + an off-energy electron was selected by requiring the third shower to have an energy larger than 10 GeV.

The energy distribution of the third shower in the selected events are shown in Figure 13 for both 1998 and 1999 high energy data. The probability of an off-energy electron in STIC as a function of an energy-cut is also shown in Figure 13. The probabilities in 1998 and 1999 are very similar.

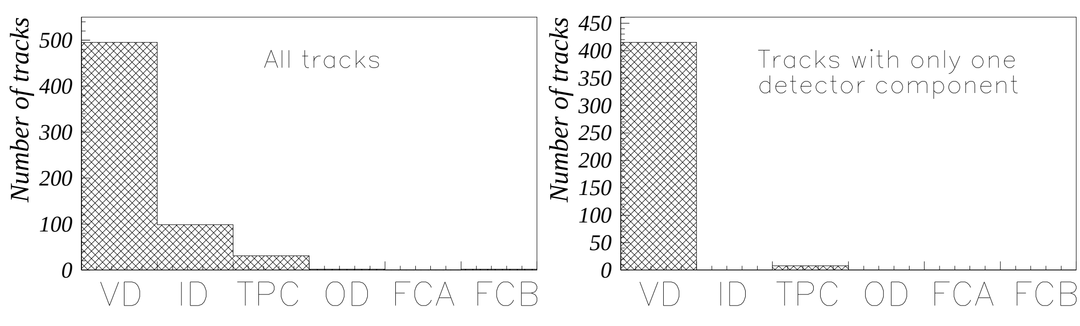

Figure 14: The different detectors used in track reconstruction for all tracks (left) and tracks with only one detector used in the reconstruction (right). 1999B data was used in this study.

	189 GeV		192-196 GeV	
E_{min} [GeV]	$\mathcal{P}$[%]	$\mathcal{P}_{\theta>3^\circ}$[%]	$\mathcal{P}$[%]	$\mathcal{P}_{\theta>3^\circ}$[%]
10	0.449±0.013	0.0425±0.0039	0.434±0.021	0.0257±0.0051
15	0.360±0.011	0.0341±0.0035	0.334±0.019	0.0195±0.0045
20	0.318±0.011	0.0295±0.0032	0.292±0.017	0.0174±0.0042
25	0.292±0.010	0.0249±0.0030	0.270±0.017	0.0133±0.0037
30	0.267±0.010	0.0193±0.0026	0.246±0.016	0.0092±0.0031
40	0.201±0.008	0.0081±0.0017	0.198±0.014	0.0072±0.0027
50	0.110±0.006	0.0025±0.0009	0.142±0.012	0.0021±0.0015
60	0.025±0.003	–	0.040±0.006	–

Table 7: The probability of an off-energy electron with energy higher than E_{min} in STIC. The measurement was done with STIC Bhabha events.

The most effective way of removing showers from off-energy electrons is not by an energy-cut but by a cut on the polar angle. By requiring $\theta > 3^\circ$, most of the background in the horizontal plane is rejected. The probability of having an electron after this θ-cut is given in Table 7 and Figure 13 and it can be seen that the cut reduces the background by at least one order of magnitude.

One surprising observation is that more than a third of the events (36% in 1998D and 43% in 1999B) are accompanied by charged tracks. This is in contrast to Bhabha events without off-energy electrons, where less than 1% of the events are accompanied by charged tracks. Most of the tracks in the off-energy electron sample survive the standard cuts on impact parameters and momentum error and are not concentrated in the forward region. They are, however, short (average length = 27 cm) and have a low momentum (average p = 0.4 GeV). A study of the detectors used in the reconstruction of the tracks (Figure 14) showed that most of the tracks are seen in the VD only.

E_{min} [GeV]	$\mathcal{P}$[%]	$\mathcal{P}_{\theta>3^\circ}$[%]
0.1	3.65±0.15	0.39±0.05
0.5	2.89±0.14	0.16±0.03
2.5	1.52±0.10	0.05±0.02
5	1.03±0.08	0.03±0.01
10	0.53±0.05	0.01±0.01
15	0.38±0.05	–
20	0.35±0.05	–
25	0.33±0.05	–
30	0.31±0.05	–
40	0.23±0.04	–
50	0.16±0.03	–
60	0.05±0.02	–

Table 8: The probability of a shower with energy larger than E_{min} in STIC. The measurement was done using random triggered events recorded in 1999.

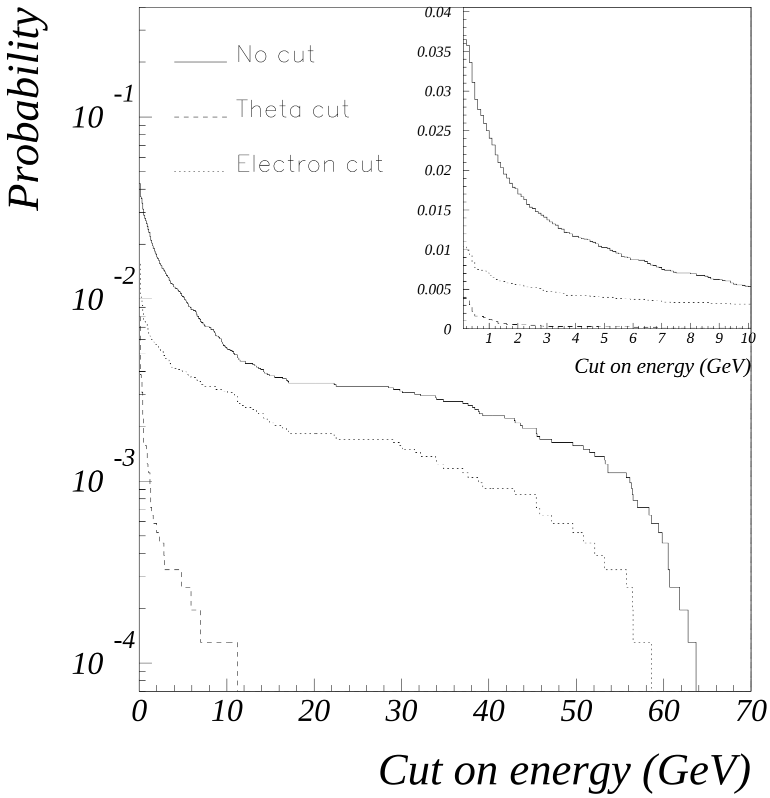

Figure 15: The probability of a STIC shower in a random triggered event as a function of a cut on the STIC energy. The probability has been calculated for all events with a shower in STIC and for the sub-samples when the veto scintillator counters identify the incoming particle as an electron and when the shower has a polar angle larger than 3 degrees.

3.3 Random triggers

The random trigger in DELPHI is caused by a signal from a scintillator placed close to a radioactive source. It is used to select an unbiased sample of events when no real interaction has occurred. The events taken with the random trigger during the first part of the 1999 LEP run ($\sim$40pb^{-1}) has been studied. Both the A- and the B-processing has been used.

The advantage of using random triggers compared to Bhabha events is that it makes it possible to go down to lower energies. The disadvantage is a smaller event sample. There is also the possibility that the off-energy electrons background is correlated in time to interactions and that the random sample therefore underestimates the off-energy background.

The probability of a STIC shower in a random triggered event as a function of a cut on the STIC energy is depicted in Figure 15. The probability has been calculated for all events with a shower in STIC and for the subsamples when the veto scintillator counters identify the incoming particle as an electron [6] and when the shower has a polar angle of more than 3 degrees. The most effective way of removing the off-energy background is, as stated previously, by a cut on the polar angle. This is illustrated in the right plot in Figure 16 which shows the theta-phi distribution of the off-energy electrons in the random triggered sample.

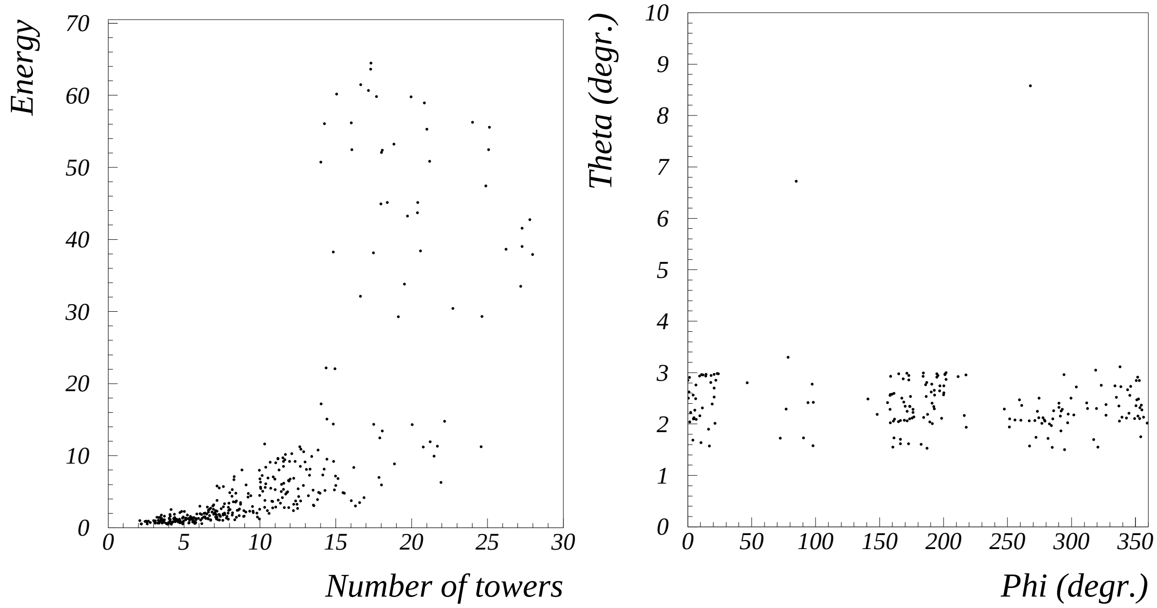

Figure 16: Energy versus the number of towers in the shower (left) and the theta versus phi distribution (right). Showers with an energy greater than 0.5 GeV were used in these plots.

By requiring a confirmation of the electron from a signal in the veto-counters a sizeable part of the background may be rejected. The reason is that many of the off-energy electrons enter STIC from behind or below the tungsten shield. In principle, the reason could also be that the STIC showers are caused by noise and not by off-energy electrons. That this is not the case can be seen in the left plot of Figure 16, which shows the energy of the showers versus the number of towers used in the shower reconstruction. A shower caused by noise has only one tower in the reconstruction and no showers like this were found with an energy larger than 0.5 GeV.

Table 8 gives the probability for an off-energy electron in STIC for different cuts on energy. An analysis which veto events with more than 0.5 GeV in STIC will lose 3% of the signal. In a search analysis which ends with 10 candidate events the probability of at least one off-energy electron in the events with more than 2.5 GeV is 15% while the probability of such a shower higher than $\theta > 3°$ in the 10 events is only 0.5%.

The probability of charged tracks in the events is 52%±6%, when the energy in STIC is larger than 10 GeV. The tracks are similar to the ones found in the Bhabha sample.

A comparison of the probability obtained at E_{min}=10 GeV with the Bhabha sample ($\mathcal{P} = 0.43 \pm 0.02$) and the random triggered sample ($\mathcal{P} = 0.53 \pm 0.06$) shows a barely significantly higher value for the random sample (contrary to naive expectations). This could be due to the fact the time period studied in the two analyses was not exactly the same.

4 Noise in the other calorimeters.

The other DELPHI calorimeters have also been studied by using the random triggered sample. At angles above STIC the calorimeters do not see any of the off-energy electron background. Instead they suffer from noise showers and occasional showers created by cosmic rays. In the 1999A data, a noisy area in HCAL which created high energy showers was observed, but was removed in the 1999B processing (Figure 17). The left plot in Figure 18 and Table 9 gives the probability of a noise-shower in different calorimeters as a function of a cut on the shower energy.

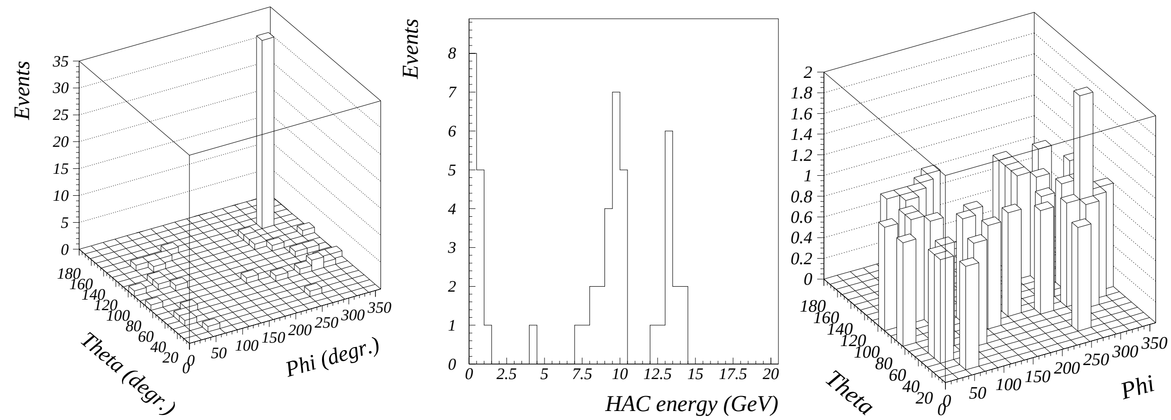

Figure 17: The theta-phi distribution of noise showers in HAC in the 1999A data (left) and the 1999B data (right). The middle plot shows the energy distribution of the peak in the theta-phi distribution.

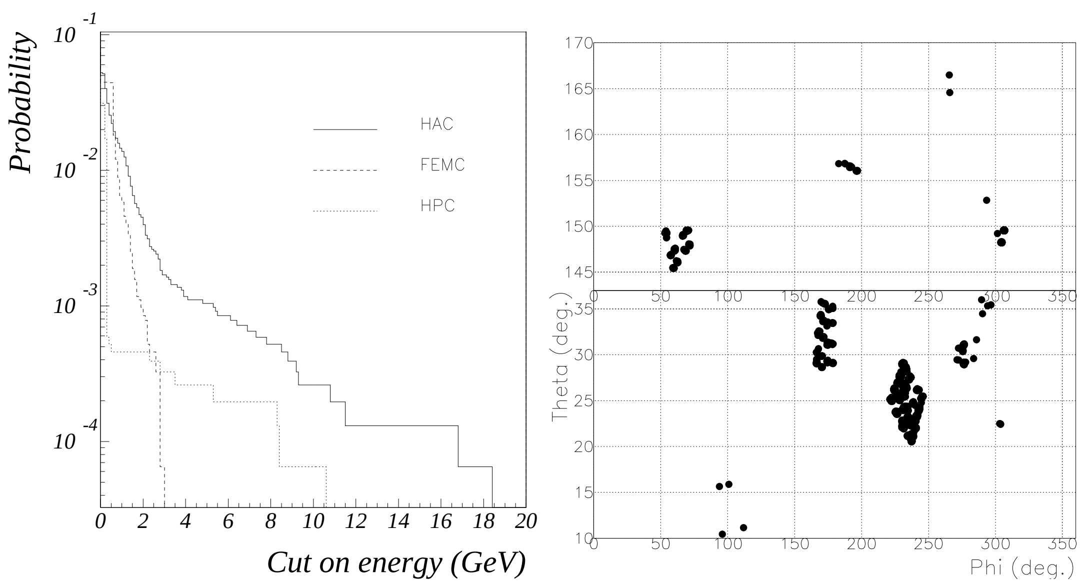

Figure 18: Left: The probability of a shower in different calorimeters as a function of acut on the shower energy. The data used were triggered by the random trigger and come from the 1999 B-processing. Right: Noisy areas in the FEMC calorimeter during the 1999 data taking.

The probability plots in Figure 18 are of course only useful for analyses which does not select events based on energy in the calorimeters. If one takes the FEMC as an example,

E_{min} [GeV]	$\mathcal{P}_{HAC}$[%]	$\mathcal{P}_{FEMC}$[%]	$\mathcal{P}_{HPC}$[%]
0.1	5.15±0.18	4.47±0.17	3.12±0.14
0.5	2.21±0.12	4.42±0.17	0.05±0.02
2.5	0.25±0.04	0.05±0.02	0.04±0.02
5.0	0.10±0.03	–	0.03±0.01

Table 9: The probability of a shower with energy higher than E_{min} in HAC, FEMC and the HPC.

the probability of a noise-shower with energy larger than 2.5 GeV on top of a physics events is completely negligible. If on the other hand single photon events are selected by triggering on energy in FEMC and by not requiring any signals in any other DELPHI detectors (which would confirm the event to be a genuine physics event), events caused by noise in FEMC are selected. In this way one can find hundreds of single photon events in FEMC caused by fake showers. This is illustrated in the left plot of Figure 18 which shows noisy areas in the 1999B FEMC data. In this plot, only noisy areas producing showers larger than 2.5 GeV which survive the Margoni offline noise algorithm are included.

5 Summary and conclusions.

VSAT:

The VSAT Bhabha sample has been used to estimate the probability of an off-energy electron in VSAT on top of a genuine physics events such as an untagged $\gamma\gamma$ event. The statistical precision of this measurement is unbeatable. In an independent analysis a muon sample was selected and the probability to have an off energy electron in VSAT calculated. The result agreed with the VSAT Bhabha measurement within large statistical errors. Finally, a STIC Bhabha sample was used. All features of the background were the same in the STIC and VSAT Bhabha samples. Comparing the probabilities in the four modules by taking the ratio $\mathcal{P}_{VSAT} - \mathcal{P}_{STIC}/\mathcal{P}_{VSAT}$ for E_{min}=20 GeV -0.02±0.01, -0.22±0.03, +0.03±0.01 and -0.12±0.02 are obtained, i.e. a significant difference in the measurement of probability in the outer modules.

The best way of removing the background is by a cut on the measured y-coordinate since the off-energy electrons are concentrated in the horizontal plane.

STIC:

For STIC, a Bhabha sample has been used to measure the background of off-energy electrons. It is limited to electrons with an energy larger than 10 GeV and has therefore been supplemented by an analysis of random triggered events with which the low-energy off-energy electrons can be studied. At 10 GeV the difference $\mathcal{P}_{Bhabha} - \mathcal{P}_{Random}/\mathcal{P}_{Bhabha}$ is -0.23±0.15 .

The most effective way of removing the background is to discard any STIC showers with a polar angle less than $\sim 3°$.

FEMC:

The probability of a FEMC shower with energy above 0.5 GeV is sizeable (4.6%) but it drops off quickly with energy and for $E_{min} > 2.5$ GeV there is no need to take the detector noise into consideration (except in problematical analyses like single photon analyses which select noise events).

HPC:

The energy spectrum due to noise is very steep and with an energy cut of $E_{min} >$ 0.5 GeV the probability to have a noise shower in an event is at the level of 0.05%.

HAC:

The hadron calorimeter is noisier than the electromagnetic calorimeters and certain noisy areas can produce showers with energies of up to 10-15 GeV. However, by a cut of $E_{min} > 2.5$ GeV the probability of a noise shower is reduced from 5% (without the cut) to 0.3% (with the energy cut).

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