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ARCHITECTURE AND PERFORMANCE OF THE DELPHI TRIGGER SYSTEM**The DELPHI Trigger Group**

V. Bocci¹⁾, P.S.L. Booth²⁾, M. Bozzo³⁾, A. Branco⁴⁾⁵⁾, J. Buytaert⁴⁾, S. Cairanti⁴⁾, V. Canale⁶⁾,
R. Carniel⁷⁾, L. Cerrito¹⁾, Ph. Charpentier⁴⁾, M. Donszelmann⁴⁾, F. Formenti⁴⁾, J. Fuster⁴⁾,
C. Gaspar⁴⁾, Ph. Gavillet⁴⁾, P. Giacomelli⁴⁾, F. Harris⁸⁾, S-O Holmgren⁹⁾, E. Johansson⁹⁾,
M. Jonker⁴⁾, C. Lacasta¹⁰⁾, L. Lanceri⁷⁾, G. Matthiae⁶⁾, V. Perrera¹¹⁾, S. Quinton¹¹⁾,
B. Schulze¹⁾⁵⁾, D. Treille⁴⁾, G. Valenti¹²⁾, J. Valls¹⁰⁾

Abstract

This paper describes the trigger system of the DELPHI detector at LEP. It reports on the most relevant aspects of the hardware and shows the software strategies that have been developed to optimize its use.

In 1993 the structure of the trigger in four decision levels has become fully operational and data collected during this period have been used to study the trigger performance. Various final state channels such as $\mu^+\mu^-$, e^+e^- and *hadronic events* were selected and their trigger efficiencies were calculated as a function of the polar angle θ . The results obtained indicate that, for any of the event topologies considered, the DELPHI trigger efficiency is independent of the θ angle, and, furthermore, the attained efficiency values are determined to be very close to 100% within an extremely good precision. This is a consequence of the high redundancy presently provided by all the DELPHI subdetectors. In addition to this analysis, events containing isolated particles either in the barrel or in the forward regions have been selected to evaluate the trigger response to single particles. Hence, trigger efficiencies for single particles have also been computed for charged tracks as a function of the momentum and for photons as a function of the deposited electromagnetic energy.

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- ¹⁾ INFN Sez. Roma II, Tor Vergata, via della Ricerca Scientifica 1, I-00133 Roma, Italy.
²⁾ Department of Physics, University of Liverpool, P.O. Box 147, GB-Liverpool L69 3BX.
³⁾ Dipart. di Fisica, Univ. di Genova and INFN, Via Dodecaneso 33, I-16146 Genova, Italy.
⁴⁾ CERN, CH-1211 Geneva 23, Switzerland.
⁵⁾ LAFEX/CBPF/CNPQ, R. Xavier Sigaud 150, 22290 Rio de Janeiro RJ-Brazil.
⁶⁾ Dipart. di Fisica, Università di Roma II, Tor Vergata, via della Ricerca Scientifica 1, I-00133 Roma, Italy.
⁷⁾ Ist. di Fisica, Università di Udine, I-33100 Udine, Italy.
⁸⁾ Nuclear Physics Laboratory, University of Oxford, Keble Road, GB-Oxford OX1 3.
⁹⁾ Fysikum, Stockholm University, Box 6730, S-113 85 Stockholm, Sweden.
¹⁰⁾ IFIC, Centre mixte CSIC-Universitat de València, Avda. Dr. Moliner 50, E-46100 Burjassot, Spain.
¹¹⁾ RAL, Chilton, Keble Road, GB-Didcot OX11 0QX.
¹²⁾ INFN Sez. di Bologna, Via Imerio 46, I-40126 Bologna, Italy.

1 Introduction

The main purpose of a trigger system in an e^+e^- collider experiment is to select, with the highest possible efficiency, all physics events originating from real electron-positron interactions. To achieve this goal, the trigger system must be sensitive to any sort of interesting physics channel and, at the same time, must keep the background event rate reasonably low, in order to reduce the losses due to the dead time.

At LEP, the CERN e^+e^- collider, which presently operates at center-of-mass energies around the Z^0 peak, high precision measurements of the Standard Model parameters, to within 1‰ uncertainty, are expected to be realized in the coming years [1, 2]. Hence, a precise knowledge of the trigger efficiency turns out to be of the utmost importance for all data analyses which involve the counting of events, such as the determination of absolute cross sections for standard and non-standard processes. Furthermore, the data used in these calculations are collected over several years during which time the detector environment should ideally be kept stable. In practice, however, this condition is rarely met as upgrades of some detector parts and inevitable malfunctions, give rise to inhomogeneities in the detector performance which lead to trigger efficiencies that vary for each of the running periods. Nevertheless, if the trigger system is designed with redundant signals such that each physics event can be triggered by more than one individual and independent trigger component, the net effect induced on the physical measured quantities due to any possible detector instability can be largely minimized and, furthermore, well monitored.

The DELPHI detector [3] is one of the four large experiments at LEP. It consists of 16 different individual subdetectors which are either combined or split into partitions for the purpose of data acquisition. Typically, small subdetectors of similar characteristics are added to form one partition, whereas, the large subdetectors are divided into two partitions. In particular, the trigger decision and the central timing system, although not real subdetectors, are considered as an autonomous partition. The total number of readout partitions is thus 20. For each event collected by DELPHI, the available information from all these subdetectors is assembled and combined, providing full acceptance over a solid angle close to 4π for all visible Z^0 decays.

The DELPHI decision trigger system is designed to fire on *single* charged or neutral particles, covering as wide an angular region as possible. For each of these physical channels, at least three independent combinations of sensitive subdetectors are formed as a function of the polar angle θ , in such a way that a large redundancy is achieved over the whole active DELPHI volume.

Apart from the decision logic, the DELPHI trigger system has the important task of controlling and synchronizing the digitization of the data for the entire experiment. The control functions are performed centrally and the timing system has been equipped with a very flexible and modular architecture, allowing partitions to operate in a variety of synchronous and asynchronous modes. During physics data taking, the fully synchronous handshake between all partitions is the normal working mode.

The following sections give a detailed description and analysis of the structure and performance of the DELPHI trigger decision system.

2 General overview of the trigger system

To cope with high luminosities and large background rates the trigger system is structured into four successive levels of increasing selectivity: T1, T2, T3 and T4 (see figure 1). The first and second levels [4], T1 and T2, being hardware triggers are synchronous with respect to the Beam Cross Over (BCO) while the third [5] and fourth levels [6], T3 and T4, are software filters performed asynchronously with respect to the BCO. T1 and T2 have been active since the start of the DELPHI operation in August 1989 (pilot run). T3 was implemented in 1992 with the aim of maintaining the data logging rate close to 2 Hz, and T4 since 1993.

The first level, T1, behaves as a pre-trigger and only very loose requirements, such as simple patterns in track chambers, scintillation counter hits or low energy single clusters in calorimeters, are considered in the decision. No correlation between different subdetectors is introduced.

On the other hand, at second level, combinations of signals arising from different subdetectors are used. The information at this level is more refined and data coming from detectors with long drift times, not available at first level, are now taken into account. In order to maintain redundancy and efficiency for the triggering of physics events, T2 is organised around majorities, each dealing with a different θ region: the barrel, the endcaps and the intermediate region between them. Individual subdetector signals with low counting rates produce their own triggers while more noisy subdetectors are grouped in level 2 majorities, i.e., at least one coincidence of 2 signals out of the n forming the majority is required to fire. Not all possible pairs of signals inside a specific majority are however allowed to trigger and in some cases, due to background prescriptions, certain combinations are masked out. These majorities are a powerful way to correlate detectors in a quasi-single track or cluster configuration without the typical background of single detector triggers. The acquisition of the data collected by the Front End Electronics of each partition is triggered by each positive T2 decision.

A drawback of the high redundancy of T2 is that its selectivity is not optimal and, in fact, after T2, only $\sim 20\%$ of all triggers contain physics events. Therefore, T3 has been developed as a software trigger with the important goal of enriching the physics yield of the data written onto tape. At third level the general strategy is to validate the T2 decision by applying the same logic as that of T2 without introducing further algorithms or correlations between subdetectors. More detailed information is, however, used at T3 since data have already been digitized by the subdetectors. Thus, calibration constants can be applied, allowing to set sharper thresholds in the energy showers and/or tighter cuts on the pointing of tracks towards the primary vertex. A higher reliability is then achieved in the decision.

The original aim of the fourth trigger level was to tag, in real time, all Z^0 decays produced in the detector, and in particular, those which match interesting topologies as predicted by models for new physics. None the less, after T3, the event rates are sufficiently low to envisage a more complete processing of the data, and this potentially offers a wider range of uses, as for instance, checking the quality of the data and performing the decoding necessary for their visualization on a display. The method used by this software filter consists in a sequential running of a certain set of algorithms which test the source of the data on the basis of individual subdetectors, therefore and once again, without altering the T2 logic. As soon as one of the algorithms gives a successful answer the event is written onto tape while it is rejected and regarded as *empty* if all partial results are negative.

Figure 1: Description of the trigger system structured into four levels. Also indicated are the typical trigger rates at each level (in Hz), the resulting dead time (in %) and the time required for the decision (in μs or in ms).

At present the LEP bunch-crossing interval is $\sim 22 \mu\text{s}$, or, 11 μs corresponding to 4, or, 8 bunches of electrons and positrons circulating in the machine. The trigger decisions for T1 and T2 are taken 3.5 μs and 39 μs after the BCO respectively, implying that for each positive T1 decision 1 or 3 consecutive BCOs are lost depending on the number of bunches. Of course, if T1 is negative no BCO is lost and no dead time is introduced. At a typical luminosity of $\sim 1.5 \times 10^{31} \text{ cm}^{-2}\text{s}^{-1}$, normal trigger rates are $\sim 700 \text{ Hz}$ and $\sim 4.5 \text{ Hz}$ for T1 and T2 respectively. These include the physics rates which consist of $\sim 0.5 \text{ Hz}$ for hadronic Z^0 decays, $\sim 0.07 \text{ Hz}$ for leptonic decays and $\sim 0.5 \text{ Hz}$ for Bhabha events. Physical background events to these processes come mainly from beam-gas interactions, synchrotron radiation and cosmic ray events. Random noise from the subdetectors is the main source of background for T1, whereas it is highly suppressed for T2 when correlations between different subdetectors are used. In the 8-bunch running mode the average dead time directly introduced by the action of these hardware trigger levels is $\sim 3\%$, with 2% due to T1 and 1% due to T2 considering a readout time of $\sim 2.7 \text{ ms}$ per event. At T3, the fraction of background events passing the T2 conditions is reduced to half and roughly the same reduction factor was again obtained using the T4 filtering. Thus, the resulting purity of interesting events for physics analyses, passing the entire trigger chain and written onto tape, is approximately 50%.

3 The trigger hardware

The timing signals necessary to start/control the trigger decision logic are generated and controlled by the Trigger Supervisor which is composed of a set of FASTBUS modules. They are implemented locally in each detector partition and centrally in the trigger partition [7]:

- In the **central part** (Figs. 2, 3), the Trigger Supervisor Decision Box (TS_DB) or PYTHIA [7, 8], receives the subtrigger data from the different partitions and, on the basis of a programmable logic, takes the trigger decision at the first two levels. The inputs to PYTHIA are duplicated and sent to a set of scalars for online monitoring. The Trigger Supervisor Control Box (TS_CB), called ZEUS [9], distributes common timing signals to all the partitions and, in addition, receives the trigger decisions from PYTHIA and broadcasts them again to all the partitions. These modules (ZEUS and PYTHIA) as well as others related to the trigger partition, are located in three FASTBUS crates.
- The **local modules** (Figs. 2, 3) are included in each individual partition or subdetector where the different control and decision subtrigger signals are processed. They formally operate as local versions of the modules mentioned above but with their particular detector specifications. These modules are: the Local Trigger Supervisor Decision Box (LTS_DB) and the Local Trigger Supervisor Control Box (LTS_CB) also referred to as PANDORA [10].

3.1 The main crate: central timing and control

From the Data Acquisition System (DAS) point of view, the trigger is considered as an additional "subdetector" partition. Hence, as for all DELPHI partitions, it has its own Crate Processor which is located in the main crate 2. This is a Fastbus Intersegment Processor (FIP) [11] which is a purpose-built FASTBUS module based on a 32 bit MC68020 processor with 1 Mbyte dynamic memory and an Ethernet card. All the software needed to perform the tasks concerning the initialization, read-out and monitoring, resides in the FIP.

Figure 2: Layout of the FASTBUS crates for the trigger partition. See text for an explanation of the modules.

Figure 3: Schematic view of the interconnections between the trigger control and decision lines for the central and local units. The various modules displayed are explained in the text and the abbreviation F.O. stands for the different Fan Outs which distribute the ZEUS signals to all partitions.

The main crate is linked to the Central Partition via a standard Segment Interconnect module (SI) for real time control and via Ethernet to the trigger control Workstation for the downloading of the data.

The central control module (ZEUS) and the local timing control module for the trigger partition (PANDORA) are also contained in this main crate. ZEUS is subdivided in two modules: a mother board and a daughter board. The former is dedicated to communicate with the DELPHI subdetectors, to select the different running modes and to couple to the FASTBUS system. The high frequency circuits are implemented in the daughter board. They include the receiver of the 352 MHz LEP RF, the LEP pick-up and the internal oscillator to simulate these signals during the LEP shutdown periods.

3.2 The PYTHIA crate: central decision logic

The central trigger decision is taken by PYTHIA which consists of 4 FASTBUS modules for both first and second level. These 8 modules are located in the third FASTBUS crate. Each set comprises a Receiver module, two level A/B modules and a level C module, as illustrated in figures 2 and 4-(a). With these modules the trigger logic is constructed in three steps corresponding to a three level structure of Look-Up-Tables [12, 13] as shown in figure 4-(b).

A Look-Up-Table (LUT) is basically defined as a logical function $\mathcal{F}$ with n inputs and m outputs assigned to a memory of m bit words addressed by n bits. In this way one assigns at address $a_0 a_1 \dots a_{n-1}$, the word $b_0 b_1 \dots b_{m-1}$:

$$b_i = \mathcal{F}_i(a_0, a_1, \dots, a_{n-1}) \quad i = 0, 1, \dots, m-1$$

where b_i is the i -th component of the function $\mathcal{F}$.

- Step 1

At the lowest level there is a set of 120 Trigger Data Lines (TDLs) feeding the PYTHIA Receiver modules. These TDLs are divided in groups of four lines: D0, D1, D2 and D3. Each of these subsets is prepared either by the subtrigger modules (SUBT_DB) or by the local decision modules (LTS_DB). The signals themselves can be classified into two types: coded and uncoded. The uncoded signals are self-contained triggers and usually give a response to some logic association inside a particular detector. The coded TDLs transport information on multiplicity or energy deposition grouped in pairs: (D0,D1) or (D2,D3), as follows:

$$\begin{aligned} (0, 0) & \text{ multiplicity} = 0 \\ (1, 0) & \text{ multiplicity} = 1 \\ (0, 1) & \text{ multiplicity} = 2 \\ (1, 1) & \text{ multiplicity} > 2 \end{aligned} \tag{1}$$

These TDLs are grouped in 10 sets of 12 input signals ($10 \times 12 = 120$); each set corresponds to a LUT, an A-LUT, which usually contains all signals from the same subtrigger or partition.

- Step 2

For every A-LUT with 12 input TDLs, 16 bit outputs are allowed. They are referred to as Component Functions (CFs) and they are logical functions combining *ANDs* and *ORs* of the input bits:

$$CF_{ik} = \mathcal{F}_{ik}(TDL_l^k, \dots, TDL_m^k) \quad 0 \leq l, m \leq 11 \quad 0 \leq i \leq 15 \quad 0 \leq k \leq 9 \tag{2}$$

Figure 4: (a) PYTHIA module composition. (b) PYTHIA tree LUT structure. This structure allows a high number of logical combinations to be constructed from a fixed set of TDLs. See text for an explanation of the various parts displayed.

where the indices l and m run over the input bits in A, i corresponds to the output bit and k the A-LUT. In general, the CFs are thus programmed in such a way that incoming multiplicity bits are transformed into more *meaningful physical conditions* such as single (≥ 1) or double (≥ 2) subdetector majorities.

For each trigger level there are 4 A PYTHIA blocks. Each block contains a set of 10 A-LUTs and has a duplication of the 120 TDLs as input. Thus, at the A level a maximum of 640 programmable CFs is permitted,

$$\left. \begin{array}{l} 10 \text{ A-LUTs} \times 4 \text{ sets} = \\ = 40 \text{ A-LUTs} \end{array} \right\} \times 16 \text{ bit outputs} = 640$$

The CFs, in turn, are used to form another set of signals, the Term Functions (or TFs) which are defined as logical products of CFs from different A-LUTs on the same output bit:

$$TF_i = \prod_k^{AND} CF_{ik} \quad 0 \leq i \leq 15 \quad 0 \leq k \leq 9 \quad (3)$$

where again i runs over A output bits and k runs over A-LUTs.

These TFs are themselves inputs to the B-LUT which again is limited to 16 outputs. Since there are 4 sets of A-LUTs, each of which is associated to a B-LUT, the maximum number of programmable TFs is technically constrained to be less than or equal to 64 at each level:

$$\left. \begin{array}{l} 1 \text{ B-LUT} \times 4 \text{ sets} = \\ = 4 \text{ B-LUTs} \end{array} \right\} \times 16 \text{ bit outputs} = 64$$

- Step 3

The B modules are used to form a set of 16 bits which feed the C level module. As for the TFs, each of these 16 bits is a logical *AND* between the corresponding output bits of the 4 B-LUTs:

$$C_i^{inp} = \prod_k^{AND} B_{ik}^{out} \quad 0 \leq k \leq 3 \quad 0 \leq i \leq 15$$

$$C_i^{inp} = \mathcal{F}_i(TF_l, \dots, TF_m) \quad 0 \leq l, m \leq 63 \quad 0 \leq i \leq 15 \quad (4)$$

where C_i^{inp} is the i input function in C and B_{ik}^{out} is the i output bit of the k B-LUT.

Hardwarewise the logical function $\mathcal{F}_i$ has no limitation in the form the input bits TF_l could be combined. However, it has been decided to only consider $\mathcal{F}_i$ as a logical sum (*OR*) of several majority conditions out of a certain group of TF_l :

$$\mathcal{F}_i(TF_l, \dots, TF_m) = \sum_j MAJ_n^j(TF_l, \dots, TF_m) \quad (5)$$

where the index j runs over majorities of n type. This scenario, as will be discussed below, simplifies the understanding of the trigger data.

Inside the C module there is still the possibility of combining these B outputs in order to form an additional set of functions which we call the Decision Functions (DFs). At present, for simplicity, this C-LUT is used in a transparent way and any input bit is transferred to the corresponding output bit:

$$DF_i = C_i^{inp} \quad 0 \leq i \leq 15 \quad (6)$$

The final DELPHI trigger is then a logical *OR* of these 16 Decision Functions which may still be masked out or prescaled by a factor of up to 255:

$$\text{DELPHI trigger} = \sum_{i=0}^{15} \alpha_i^{-1} \beta_i \text{DF}_i \quad \alpha_i \leq 255 \quad \beta_i = 0 \text{ or } 1 \quad (7)$$

where α_i and β_i represent the prescaling factor and the masking factor for the Decision Function DF_i , respectively.

3.2.1 The DELPHI usage of PYHTIA

The scenario for the two hardware triggers, so far presented, can be summarized by stating that the decision of both T1 and T2 is taken by OR-ing 16 logic functions (*Decision Functions* or *DFs*) each of which may be independently prescaled or masked out. A DF is formed out of a certain number of majorities (*MAJs*) with each MAJ requiring that n out of m *Trigger Functions* (*TFs*) have fired (usually n is 1 or 2):

$$\text{DF}_i = \mathcal{F}_i(\text{TF}_1, \dots, \text{TF}_m) = \sum_j \text{MAJ}_n^j(\text{TF}_1, \dots, \text{TF}_m) \quad (8)$$

Each TF in turn is an *AND* of *Component Functions* (*CFs*) which are the most elementary conceptual components of the trigger. Usually they require that a certain multiplicity (typically ≥ 1 or ≥ 2) is observed in a given subdetector. Finally the CF-conditions are constructed from the *Trigger Data Lines* (*TDLs*) which are the basic input bits into PYHTIA as generated by the subdetectors.

This scheme represents in fact a restriction with respect to the full capabilities PYHTIA can provide, still, the whole system is very flexible and allows for an extremely large number of different logical combinations.

3.2.2 The subdetector trigger signals

So far, a total of 86 TDLs, at T1, and 95 TDLs, at T2, are constructed by the partitions and sent to the central trigger processor, PYHTIA, in order to make the trigger decision. These trigger signals may consist of one or more groups of 2 bits encoding the multiplicity (0, 1, 2 or >2) of tracks or energy depositions found in five regions of polar angle θ :

<i>Barrel</i> :	<i>BA</i> ($43^\circ < \theta < 137^\circ$)
<i>Forward</i> :	<i>FW</i> ($22^\circ < \theta < 43^\circ$)
<i>Backward</i> :	<i>BW</i> ($137^\circ < \theta < 158^\circ$)
<i>Very Forward</i> :	<i>VFW</i> ($\theta < 22^\circ$)
<i>Very Backward</i> :	<i>VBW</i> ($\theta > 158^\circ$)

The barrel region is covered by the Inner and Outer detectors (ID, OD), the Time-Of-Flight (TOF), the High Density Projection Chamber (HPC), the Hadron and Muon Barrel detectors (HAB, MUB) and the Time Projection Chamber (TPC). Due to its high acceptance, the TPC is also used in the forward/backward trigger. The detectors from the forward/backward and very forward/backward regions are: the Forward Chambers (FCA/B), the Forward ElectroMagnetic Calorimeter (FEMC),

the Hadron and Muon Forward detectors (HAF, MUF), the forward scintillators (HOF), the Small and Very Small Angle Taggers (SAT/STIC, VSAT) and the TPC as mentioned above. All these detectors provide TDLs through the local decision modules or through their subtrigger modules which can be classified as:

$$\begin{aligned} \text{Tracking} & \left\{ \begin{array}{l} \text{Track Subtrigger,} \\ \text{Muon Subtrigger} \end{array} \right. \\ \text{Calorimetry} & \left\{ \begin{array}{l} \text{Electromagnetic Energy subtrigger,} \\ \text{Hadronic Energy subtrigger,} \\ \text{Bhabha subtrigger} \end{array} \right. \end{aligned}$$

Figure 5 shows a schematic picture of the angular coverage in θ of all subdetectors contributing either to the track or to the calorimetric triggers. Tracking and calorimetry acceptance are artificially shown for only 1/4 of the full detector.

Figure 5: Subdetectors participating in the first and second level trigger and their polar acceptance in degrees. The usual DELPHI names are used for labelling the subdetectors and the z axis is indicated in the picture as the e^+e^- beam line.

Track subtrigger (TPC + FCA/B + ID/OD + TOF)

The TPC provides a first level forward trigger using only signals from the forward tracks passing through the end-cap wire plane covering an angle of $20^\circ < \theta < 43^\circ$ (see figure 5). This is a simple majority trigger accepting an event with a minimum number of hits in a group of 8 adjacent wires.

At the second level, the TPC provides a barrel trigger called the Contiguity Trigger and a forward RZ trigger. The Contiguity trigger (CT) [14] is a single track barrel trigger which uses the TPC pad information as input to a sophisticated track-finding logic algorithm for tracks with $p_t \geq 1$ GeV/c. It covers the angular region of 29° to 151° in θ . The RZ forward trigger [15] covers the same angular region as the first level trigger and requires that at least 13 of the 16 total pad rows are hit.

The PYTHIA input TDLs from the TPC first level trigger are all coded in terms of track multiplicities whereas at second level other topological combinations are also considered.

The Forward Chambers (FCA/B) contribute to the first and second level track subtrigger covering the forward region from $\theta = 11^\circ$ to $\theta = 33^\circ$ [16]. The first level trigger uses the data from the wire projections of FCA and FCB. The FCA coordinates are combined into 64 groups of 4 wires which are directly correlated to corresponding wire groups in FCB. In fact, hits on at least three of the four planes of FCB are required to lie inside limited regions in correspondance with the location of the hits on FCA. This is designed to accept all tracks arising from the origin (interaction point) with a $p_t > 1.6$ GeV/c.

The ID and OD send their first and second level TDLs to PYTHIA from their common LTS_DB which is called LUCIFER [17]. The polar angle acceptance of this barrel ID/OD trigger covers from $\theta = 42^\circ$ to $\theta = 138^\circ$. The OD track multiplicity signals at second level are prepared, depending on the noise and background conditions, by requiring 3 or 4 out of the 5 chamber planes to be hit within a plank. This information is then used in conjunction with the ID to construct the final TDLs. They come out as 2×24 bit words corresponding geometrically to the detector planks or sectors.

The TOF detector contributes to the trigger system with the same signals at first and second level [18] covering the barrel region from the polar angle $\theta = 41^\circ$ to $\theta = 139^\circ$. The detector is divided into octants (4 in $41^\circ \leq \theta \leq 89^\circ$ and 4 in $91^\circ \leq \theta \leq 139^\circ$), each octant grouping 6 sectors containing 24 scintillators counters. The coded multiplicity information corresponding to these eight octant trigger signals are sent to PYTHIA where they are correlated with other subdetectors.

Muon subtrigger (MUB + MUF)

The barrel Muon (MUB) trigger contributes to the first and second levels and covers the polar angle region from $\theta = 50^\circ$ to $\theta = 130^\circ$ apart from a one degree hole at 90° . The barrel region is divided into quadrants at first level and octants at second level. A quadrant/octant is considered hit if any MUB sector within that quadrant/octant is hit. A sector is considered hit if at least 2 hits are found within that sector [19]. Possible multiplicity information thus correspond to one quadrant/octant, two quadrant/octants and three or more quadrant/octants.

The forward Muons (MUF) provide TDLs for second level, with acceptance in the region $15^\circ < \theta < 41^\circ$. At first level the trigger is given only by the HOF scintillators due to the long MUF drift time ($\sim 13 \mu s$). At second level the MUF trigger divides the entire forward region into quadrants. One quadrant is hit if at least 3 out of 4 layers are hit [20]. The trigger is then

obtained by summing the quadrant responses to form two multiplicity bit TDLs in the standard manner. For calibration purposes, halo muons travelling parallel to the beam line are triggered by requiring a coincidence between the forward and backward sides in a non back-to-back topology (MUPARAL).

Electromagnetic subtrigger (HPC + FEMC)

The first level trigger for the HPC detector is based on a set of 3 plastic scintillator counters placed in each of the HPC modules at the shower maximum position. The trigger provides information from modules hit in each ϕ sector with an energy deposition exceeding ~ 2 GeV [21]. At the second level the trigger is based on a fast pattern recognition and a reconstruction of the shower shape using the full drift information [22] (Single- γ). In addition, first level HPC trigger signals are also used, at second level, in coincidence with the TOF and OD subdetectors.

The FEMC provides, for both the first and second level trigger, TDLs for each of the different angular regions covered by the detector (FW, BW, VFW and VBW regions) and for two energy thresholds: High (HI) with 2.5 GeV and Low (LO) with 1.2 GeV.

Hadron subtrigger (HAB+HAF)

The Hadron Calorimeter also contributes with the same TDLs at first and second level, both in the barrel (HAB) and in the forward/backward (HAF) regions. There are three sets of TDLs corresponding to different energy thresholds. They are called muon (MU), low (LO) and high (HI) and correspond to an energy deposition of 0.5 GeV, 2 GeV and about 5 GeV, respectively.

Bhabha subtrigger (SAT/STIC + VSAT)

Either the SAT calorimeter (Small Angle Tagger) or, since 1994, its upgraded version, the STIC (Scintillator Tile Calorimeter), are located in the very low angular region $\theta \leq 10^\circ$ and provide TDLs both at first and second level. The Bhabha trigger corresponds to a coincidence of forward and backward with an energy deposition exceeding 30 GeV (High) and 11 GeV (Low) [23, 24]. No other subdetector covers the same angular acceptance for $e^\pm$, hence, the Bhabha trigger efficiency has to be controlled by a single arm trigger constructed with the lowest threshold signals. Due to its high rates, especially under bad beam conditions, this trigger is often prescaled.

The VSAT Bhabha trigger requires coincidences between back-to-back modules with energy depositions exceeding 25 GeV (High threshold) [25]. It is used to give a very accurate relative luminosity since it is able to record Bhabha events at lower angles than the SAT/STIC calorimeter and hence has a much larger effective cross section. As a consequence, its trigger rate is rather high (several Hz) and would lead to a too high dead time if included directly in the second level trigger. Nevertheless, since the amount of information to record is small, the VSAT generates, for each Bhabha event, only a T1 trigger which keeps the experiment busy for about 90 μ s (this represents $\sim 0.2\%$ dead time). The VSAT T1 events are then merged in the front end processors and accumulated inside a buffer until a DELPHI T2 event occurs. At this time, the buffer is emptied and transferred to the main data stream. Only when the number of accumulated events exceeds 12, which is the maximum allowed event capacity for the buffer, a positive T2 decision is sent to PYTHIA by the VSAT.

The NIM trigger

The NIM trigger has been operating since the startup of LEP as a backup trigger with a self-contained logic. It is based on NIM electronic modules fed by various signals originating from

both the barrel and the forward regions. An OR of all the conditions yields the final decision which is sent to PYTHIA as one normal TDL. At present, it is used only for the purpose of monitoring and testing trigger signals. It also produces the so called *random trigger* which is derived from a radioactive source placed in front of a scintillation counter and has the important task of selecting an unbiased sample of events when no real e^+e^- interaction has occurred.

The DELPHI trigger

At first level, the trigger consists of the logical *OR* of all CFs defined as majority one signals from the participating subdetectors. At second level, combinations between the various subdetectors CFs are introduced. Table 1 shows the present T2 trigger configuration, as well as, for each signal, the induced rate, the physics sensitivity and the specific DF in which it is programmed. According to this trigger configuration, it is worth noting that each physics channel is always detected by at least two (in many cases three) independent sets of signals, therefore, providing a high redundancy.

3.3 The Scalers crate: monitoring

One FASTBUS crate is reserved for a set of 13 scaler modules used for online monitoring (see Fig. 2). Each of these scalers contains 32 independent channels that provide 32 bits of scaling up to a maximum frequency of 100 Mhz.

The scaler modules are arranged in three groups corresponding to the *NIM* trigger, to the detector TDLs which also feed PYTHIA, and to the background and luminosity monitors (MIG).

A full description of these scalers is given below:

- *NIM* scalers:

All signals provided by the *NIM* counting center are combined in different ways giving rise to 64 signals.

- PYTHIA scalers:

A total of 7 scaler modules is dedicated to the monitoring of the TDLs arising from the different subtriggers (see figure 3) and of the final 32 Decision Functions from the first and second level trigger.

- MIG scalers:

The MIG scalers are used to monitor background conditions and to compute the online luminosity [26]. There is a total of 3 scaler modules with data coming from the SAT/STIC, VSAT, TPC and ID detectors.

One scaler module is used to measure the background, mainly due to off-momentum electrons, seen by the VSAT. The VSAT also provides counting rates on the number of Bhabha events for the two diagonal back-to-back configurations and for each of the individual bunches.

The SAT/STIC scalers count the number of Bhabhas and the number of delayed *fake* Bhabhas, i.e., coincident off-momentum electrons. In addition, there is information on total and localized energy deposition for forward and backward regions for each electron-positron bunch.

The number of wire hits in each sector of the TPC is also counted and provides information on the level of the photon background.

Information on the photon background and on the number of off-momentum electrons and local beam-gas interactions is obtained by measuring the DC current of the ID High Voltage supply.

Luminosity						
Subdetector	Rate (Hz)	Detection				DF
		e	μ	γ	$c^{\pm}$	
SAT/STIC Bhabha	0.8	•				1
VSAT Bhabha	~ 0.0	•				2
Single arm	0.4	•				3
Bhabha delayed	~ 0.0	•				10

Barrel region						
Subdetector	Rate (Hz)	Detection				DF
		e	μ	γ	$c^{\pm}$	
TPC	0.8	•	•		•	4
OD*HPC	0.2	•		•		4
OD*TOF	0.4	•	•	•	•	4
HPC*TOF	0.3	•		•		4
HPC ≥ 2	0.1	•		•		4
ID*(MUB+HAB)	0.5		•		•	5
HPC (Single- γ)	0.3	•		•		14

Intermediate region						
Subdetector	Rate (Hz)	Detection				DF
		e	μ	γ	$c^{\pm}$	
ID*(HAF+MUF)	0.1		•		•	6
HPC*(HAF+FEMC)	0.1	•		•		6

Forward/Backward region						
Subdetector	Rate (Hz)	Detection				DF
		e	μ	γ	$c^{\pm}$	
TPC*FCA/B	0.2	•	•		•	7
MUF*FCA/B	0.1		•			7
TPC*MUF	0.1		•			7
FEMC*FCA/B	0.2	•				8
FCA/B*HAF	0.4		•		•	9
FEMC ≥ 2	0.2	•		•		10
FEMC (HI)	0.5	•		•		10

Calibration and special triggers				
Subdetector	Rate (Hz)	Detection		DF
NIM	0.04	Random trigger		0
TPC*(SAT/STIC)	0.1	Two-photon trigger		11
TOF*HAB (HI)	0.2	Search trigger		12
MUPARAL	0.1	Parallel- μ trigger		13

Table 1: List of triggers presently used at T2. The names of the participating subdetectors are indicated together with their rates (in Hz), their sensitivity to certain type of particles: electrons (e), muons (μ), photons (γ) and charged particles ($c^\pm$) and the specific DFs in which these combinations are programmed. The logical "OR" and "AND" combinations are shown as "+" and "*", respectively.

Figure 6: Organization of the online software for the CP and monitoring tasks

4 The software trigger scheme

As mentioned in Sec. 2, after each positive T2 decision, the FASTBUS digitiser buffers are read out by the FIP modules which act as the *Crate Processors (CP)*. Once the data are processed by the CP software they are ZEBRA formatted [27] by the *Local Event Supervisor (LES)* and, henceforth, they constitute the raw data.

Regarding the third level trigger (T3), a local processing is implemented for those subdetectors participating in T2 (*LT3P*). It consists of a process running in the same FIP module as the LES software which receives pointers to all data blocks of an event and produces the *Local T3 Data (LT3D)* and *Results (LT3Rs)*. The LT3Rs contain the minimum information to perform central T3 decisions (e.g. track or energy cluster multiplicity) while the LT3D usually have more detailed information (e.g. track or cluster parameters).

On an event by event basis, the CP of the trigger partition performs the readout of all the FASTBUS trigger modules and constructs the *trigger pattern* for CFs, TFs, MAJs and DFs. The LT3P of the trigger partition receives this information plus all the LT3Rs collected by the other partitions. Then, this particular LT3P examines all CFs fired at T2 and checks each single bit using the results obtained by the T3 processing of all individual subdetectors. In this way, a new CF trigger pattern is built which in turn is again used to construct new TFs, MAJs and DFs patterns by applying the same logic as in PYTHIA at T2. The final answer, as given by the *OR* of the *verified* DF bits, represents the third level trigger decision.

In addition to the above tasks, a set of monitoring programs provide trigger data for online quality checking purposes. The *Scaler task*, which is a job running in the trigger FIP, reads asynchronously all the trigger electronics and scaler modules. This Scaler task can also communicate with the CP, and therefore can extract information concerning the individual event trigger patterns and compute statistics concerning their correlations. Finally, via a TCP/IP connection, all these data and the rates are distributed to the DELPHI VAX cluster as sketched in figure 6. The same scheme is used to add external information to the main event data stream via the CP of the trigger partition, as for instance, the regular updates of the LEP machine status every 10 seconds. An efficient and rather simple way of controlling detector running conditions such as trigger rates, dead times, luminosities, beam background conditions, etc., is thus provided by this system.

4.1 The construction of the trigger pattern

The Raw Data of the trigger partition are defined and structured in blocklets, with each blocklet corresponding to a particular hardware module. In particular the readout of PYTHIA contains the 120 input bits to the Receivers, the snapshot registers of the A and B modules, which are in fact the hit pattern for the TFs, and the input/output bits in the C module at each stage, i.e., before and after prescaling or masking. The final results of this latter module represent the DF pattern.

The CF and MAJ trigger patterns cannot be directly accessed from the existing trigger hardware, hence they have to be constructed by software algorithms which, embedded in the CP, decode the fired snapshot registers of the hardware modules (i.e., TFs and DFs) and, then, set the proper bits of these CF and MAJ patterns, as described and explained in figure 7. To enable this procedure it is however necessary to write for every single run a general *begin_of_run* record with information relative to the trigger configuration programmed in the PYTHIA Look-Up-Tables, in such a way, that the connection between each bit in the hardware snapshot registers and the software run defined CFs/MAJs can be well established (see figure 8 for a detailed description).

5 The trigger performance: the efficiency

In this section we discuss the method followed to determine the trigger efficiencies and one of the most common approaches used to compute efficiencies is presented. In the proposed scheme the trigger signals, namely the CFs, are normally grouped into two independent sets with no correlation between them. However, due to the present configuration of the DELPHI trigger system, this assumption of no correlation is not always fulfilled and a number of corrections have to be considered. The existence of several levels or the use of majorities made of coincidences between different subdetectors' signals, induce correlations.

Efficiencies are usually derived from two *independent* sets of trigger signals [28]. From these two sets, say A and B, one can divide the interesting events into five classes:

N_A and N_B events found by A and B, respectively,

N_{AB} events found by both A and B,

$N_{obs} = N_A + N_B - N_{AB}$ events found either by A or B,

$N - N_{obs}$ events not detected.

Figure 7: The CF and MAJ patterns are constructed inside the CP. The strategy consists of going backwards in the tree structure of the PYTHIA Look-Up-Tables, starting with the hit DFs. All subsequent links and pointers to MAJs, TFs and CFs are taken from the loading conditions and validated by the hit bits of the snapshot registers. Note in this example the use of arrows to indicate the firing bit candidates of the next outer most structure. In case of a software structure, s/w, all bits are assumed to be hit. For hardware structures, h/w, only indicated and validated hits (x) are hit.

Figure 8: Construction of the trigger pattern by the CP software: each time a new loading of PYTHIA is made a description table is created and transferred to the FIP. This file contains the correspondence between each PYTHIA bit in all the snapshot registers and the CFs or MAJs defined at this time. At every begin of run, the CP task looks for the latest table and writes it onto the begin_of_run record, keeping it, also, in memory, in a form convenient for further easy and efficient use. On event by event basis, the CP reads the snapshot registers from PYTHIA and decides which CFs or MAJs have fired according to this description file.

Figure 9: At least two independent sets of signals have to be considered in order to determine the total number, N , of real events, and therefore, the efficiencies.

A schematic representation of the situation is given in figure 9, where N is the unknown total number of events in the sample and whose determination, to as great an accuracy as possible, is the main goal.

The efficiencies of the individual sets of signals are:

$$\epsilon_A \equiv P(A) = \frac{N_A}{N} \quad , \quad \epsilon_B \equiv P(B) = \frac{N_B}{N} \quad (9)$$

The probability for one event to be triggered by both sets is given by the intersection (see figure 9):

$$P(A \cap B) = P(A) \cdot P(B) = \frac{N_{AB}}{N} \quad (10)$$

where the condition of independency has been used. Combining the relations (9) and (10) we find an estimate for the total number of events which would have been triggered:

$$N = \frac{N_A \cdot N_B}{N_{AB}} \quad (11)$$

Hence, inserting this expression in (9) the individual efficiencies are:

$$\epsilon_A = \frac{N_{AB}}{N_B} \quad \epsilon_B = \frac{N_{AB}}{N_A} \quad (12)$$

It is worth noting that both sets of signals have to be defined consistently, that is, both have "to look at" the same set of N events. Hence, in practice, they are arbitrarily chosen by asserting certain criteria, such as, the geometrical acceptance or the capacity in detecting incoming particles. The trigger signals are, therefore, grouped by subdetectors in such a way that they cover the same angular region and are, in principle, equally sensitive to all type of events.

The global efficiency will be given by:

$$\varepsilon \equiv P(A \cup B) = \frac{N_{obs}}{N} = \frac{N_{AB} \cdot (N_A + N_B - N_{AB})}{N_A \cdot N_B} \quad (13)$$

or, equivalently, in terms of the individual efficiencies by

$$\begin{aligned} \varepsilon \equiv P(A \cup B) &= P(A) + P(B) - P(A) \cdot P(B) \\ &= \varepsilon_A + \varepsilon_B - \varepsilon_A \cdot \varepsilon_B \end{aligned} \quad (14)$$

More generally, in the case of several independent sets of signals — $G_1, G_2, \dots, G_n$ — the individual efficiencies may be determined by grouping them into two sets before applying the previous equations (13,14):

$$\begin{aligned} A &= G_i \\ B &= G_1 \cup G_2 \cup \dots \cup G_{i-1} \cup G_{i+1} \cup \dots \cup G_n \end{aligned}$$

The recurrent use of this procedure allows the efficiency for each group to be determined and the general expression of (14) can be written as:

$$\varepsilon = \sum_{k=1}^n A_k \quad (15)$$

$$\begin{aligned} A_k &= \sum_{i_1, \dots, i_k=1}^k (-1)^{k-1} \varepsilon_{i_1} \cdot \dots \cdot \varepsilon_{i_k} \\ &\quad \forall (i_1, i_2, \dots, i_k) : i_1 < i_2 < \dots < i_k \end{aligned} \quad (16)$$

where ε_{i_k} is the single efficiency of group G_{i_k} calculated above.

5.1 Error determination

Efficiencies are obtained from the measured quantities, N_A , N_B and N_{AB} , which follow binomial distributions and whose variance can be interpreted as the associated statistical error. However, the final efficiency distribution is not known *a priori* and some specific features, such as, its skewness can only be guessed.

When calculating the efficiencies of the two sets of signals the procedure is the following: (i) count the number N_i ($i=A, B$) of events "seen by" each group, (ii) compute the total number of events, N , in the sample according to (11) and (iii) determine the measured efficiency $\varepsilon_i = N_i/N$.

For individual signals, the measured N_i is assumed to follow a binomial distribution of unknown probability whose value can be either greater than that observed ε_i , (ε_i^+), or smaller, (ε_i^-), with corresponding mean values of $\langle N_i^+ \rangle$, or, $\langle N_i^- \rangle$. This situation is graphically described in figure 10.

Figure 10: Schematic approach to the method followed to define the statistical errors of the efficiencies. From the measured number of events, $N\epsilon$, triggered by the signal, with N the real number of events, two other distributions are looked for, such that the difference between $N\epsilon$ and their mean values, $N\epsilon^+$ and $N\epsilon^-$, is 1σ .

The quantities

$$\sigma^\pm(\epsilon_i) = |\epsilon_i^\pm - \epsilon_i| \quad (17)$$

are considered to be the upper ($\sigma^+(\epsilon_i)$) and lower ($\sigma^-(\epsilon_i)$) statistical errors of ϵ_i and, then, in order to analytically determine $\epsilon_i^\pm$, a one standard deviation distance from the measured N_i to each of the mean values $\langle N_i^\pm \rangle$ is required:

$$(N_i^\pm - N_i)^2 = \sigma^2(N_i) = N\epsilon_i^\pm(1 - \epsilon_i^\pm)$$

which yields:

$$\epsilon_i^\pm = \frac{1}{2(N+1)} \left\{ 2N\epsilon_i + 1 \pm \sqrt{1 + 4N\epsilon_i(1 - \epsilon_i)} \right\} \quad (18)$$

In the study of the global efficiency, three different approaches to determine its statistical error have been investigated.

The first one is the Monte Carlo method. It assumes that each efficiency has an associated binomial distribution with mean value $\langle N_i \rangle$ and probability $\epsilon_i = \langle N_i \rangle / N$ ($i = A, B$) for a fixed N . Different N_i values are generated via Monte Carlo and for each set of these generated values, with associated efficiencies ϵ_A and ϵ_B , the global efficiency is calculated from $\epsilon = \epsilon_A + \epsilon_B - \epsilon_A\epsilon_B$. This will yield the distribution of the global efficiency, with mean value ϵ , and the errors defined

as follows:

$$\sigma^+(\varepsilon)^2 = \frac{\sum_{\varepsilon' > \varepsilon} (\varepsilon - \varepsilon')^2}{N^+ - 1} \quad N^+ = \sum_{\varepsilon' > \varepsilon} 1 \quad (19)$$

$$\sigma^-(\varepsilon)^2 = \frac{\sum_{\varepsilon' < \varepsilon} (\varepsilon - \varepsilon')^2}{N^- - 1} \quad N^- = \sum_{\varepsilon' < \varepsilon} 1 \quad (20)$$

where ε' are the efficiencies generated event by event.

The second method defines the errors as:

$$\sigma^\pm(\varepsilon) = |\varepsilon^\pm - \varepsilon| \quad (21)$$

where

$$\varepsilon^\pm = \varepsilon_A^\pm + \varepsilon_B^\pm - \varepsilon_A^\pm \varepsilon_B^\pm$$

with $\varepsilon_A^\pm$ and $\varepsilon_B^\pm$ given by (18).

The third method [29] uses the usual propagation of errors and does not therefore take into account the asymmetry of ε . In order to propagate the errors independent variables have to be found:

$$N_a = N_A - N_{AB} \text{ events found only by A,}$$

$$N_b = N_B - N_{AB} \text{ events found only by B,}$$

$$N_{AB} \text{ events found by both A and B.}$$

Using these independent variables, the expression (13) can be rewritten as:

$$\varepsilon = \frac{N_{AB} \cdot (N_a + N_b + N_{AB})}{(N_a + N_{AB})(N_b + N_{AB})}$$

and then assuming binomial errors for N_a , N_b and N_{AB} the total error has form:

$$\sigma^2(\varepsilon) = \frac{1}{\varepsilon_A \varepsilon_B N} \cdot [(\varepsilon_A + \varepsilon_B)^2 (1 - \varepsilon_A - \varepsilon_B + \varepsilon_A \varepsilon_B)^2 (1 - \varepsilon_A \varepsilon_B) + \varepsilon_B^3 (1 - \varepsilon_A)^2 (1 - \varepsilon_B) (1 - \varepsilon_A + \varepsilon_A \varepsilon_B) + \varepsilon_A^3 (1 - \varepsilon_B)^2 (1 - \varepsilon_A) (1 - \varepsilon_B + \varepsilon_A \varepsilon_B)] \quad (22)$$

For large values of N the distributions tend to behave as normal distributions and therefore the errors become symmetric. In this case, the three methods become equivalent. On the other hand, for not so large statistics the asymmetry of the distributions has to be taken into account and only the first and second methods are strictly applicable. Both give equivalent results independent of statistics although the second method is easier to handle. For this reason it is the method adopted in the following calculations.

5.2 The DELPHI method

As mentioned at the beginning of this section there are some important features of the DELPHI trigger system that hinder the determination of efficiencies and introduce some systematic uncertainties which should be evaluated in any analysis. These are listed as follows:

- The organization of the trigger system in four levels may introduce some correlation between signals, especially for T1 and T2, since the first level behaves as a pretrigger. Concerning the other levels and as already stated at the beginning of this report, no correlations are expected between T2 and T3 because both share the same logic. As regards T4, it can be safely assumed that rejecting *empty* events does not introduce correlations. Hence, only first level induced correlations need to be studied.
- The majorities were defined to reduce the trigger rate and, consequently, the dead time. Unfortunately, these logical combinations do introduce correlations, both within the same trigger level and between the different signals connected by the allowed coincidences.
- The DELPHI trigger system's definition is very flexible, and is allowed to change from one run to another. This is, certainly, a nice feature of the system but may nevertheless constitute a source of difficulties for the calculation of the trigger efficiency, since presumably various different trigger configurations have to be considered during the period for which efficiencies are to be calculated.
- The various conditions defined to select the event data samples, whose efficiencies are to be calculated, may also accept some other background events with different trigger properties. Hence, the trigger efficiency, as directly derived from the data alone, should be corrected if this effect is sufficiently large.

5.2.1 First level induced correlations

Regarding the structure of the first level trigger, it is recalled that the T1 decision is a logical OR of the 16 Decision Functions defined at this level which in turn are combinations of different subdetector majority 1 signals. Once the first level decision is positive, the second level logic builds its decision regardless of which signals were fired at first level. The existence of a certain signal systematically pre-triggering a second level signal originating from another subdetector would be the signature of a correlation between the two levels. As a consequence, the detectors containing these signals could not be considered independent for efficiency calculation purposes.

In order to study this effect, second level signals, triggering an event that has not been triggered by their associated first level signals, have been searched for in a mixed sample of e^+e^- and $\mu^+\mu^-$ events. Only the TPC forward and backward triggers have been identified to possess this signature although the cause for this behaviour has been proven to originate from the slightly different angular acceptances the two trigger levels have. Fortunately, several other different subdetectors are simultaneously responsible for triggering such events and, therefore, no quantitative consequences, which could affect the final global efficiency, are derived.

The TPC contiguity trigger (CT) is a signal defined only at second level and has been studied using a different approach. Possible induced correlations have been investigated by looking for first level signals which fire alone when CT has also fired at second level. None the less, no evidence of correlations of this kind have been noticed between the first level trigger and the CT. Once again, the high redundancy, present at first level, has contributed to diluting any possibility of correlation.

Leptons: Global trigger efficiency (T1)

Figure 11: Dependence on the polar angle θ of the T1 trigger efficiency for the various topologies studied in this paper: e^+e^- , $\mu^+\mu^-$ and hadrons.

The correlation between first level and second level has thus been found to be negligible and the combined efficiency for both levels, ε , can then be safely computed as:

$$\varepsilon = \varepsilon_{T1} \cdot \varepsilon_{T2}$$

where ε_{T1} and ε_{T2} are the efficiencies for T1 and T2, respectively.

From the practical point of view, the calculation of the first level trigger efficiency is straightforward because there are no double majorities defined. So, this evaluation can easily be performed following the steps described in previous sections without further complications. The resulting values are close to 100% for all channels considered in the analysis: e^+e^- , $\mu^+\mu^-$ and hadrons, with negligible statistical error as shown in table 2 (see also figure 11). The analysis of $\tau^+\tau^-$ events is not included in this study, however since this channel can be regarded as a mixture of all the others, similar results can be extracted.

	Efficiency	σ^+	σ^-
Electrons	0.99999	$\ll 10^{-5}$	$\ll 10^{-5}$
Muons	0.99999	$\ll 10^{-5}$	$\ll 10^{-5}$
Hadrons	0.99999	$\ll 10^{-5}$	$\ll 10^{-5}$

Table 2: Global trigger efficiency for e^+e^- , $\mu^+\mu^-$ and hadrons at first level. The asymmetric statistical errors are indicated as σ^+ and σ^- .

5.2.2 Strategy to select two independent sets of signals in a majority

Majorities constitute a source of correlations that ought to be avoided if efficiencies are to be properly computed. So far, only double majorities have been considered within DELPHI and in what follows it is assumed that only one single majority in the region where efficiencies are estimated is defined. This is a valid generalization of the problem since one can always construct a unique majority by merging all the combinations so far defined into a higher majority which includes all the others.

In order to overcome the induced correlations we denote our majority by MAJ and divide it into two complementary and independent submajorities, namely, $\mathcal{M}_A$ and $\mathcal{M}_{\bar{A}}$ (see figure 12), each being made up with a subset, $\{A\}$ and $\{\bar{A}\}$, respectively, of the components of the majority, MAJ . It should be emphasized that both sets, $\{A\}$ and $\{\bar{A}\}$, have to be complementary and disjoint.

The sample of events corresponding to $\{A\}$ or $\{\bar{A}\}$ is a subset of the sample of events triggered by MAJ since the coincidences between signals of both submajorities are not taken into account explicitly. This means that from $\{A\}$ and $\{\bar{A}\}$ a lower limit of the efficiency of MAJ can be estimated:

$$\mathbb{E}(\mathcal{M}_A) \cup \mathbb{E}(\mathcal{M}_{\bar{A}}) \subseteq \mathbb{E}(MAJ) = \mathbb{E}(\mathcal{M}_A) \cup \mathbb{E}(\mathcal{M}_{\bar{A}}) \cup \mathbb{E}(C_A) \implies \varepsilon(\mathcal{M}_A \cup \mathcal{M}_{\bar{A}}) \leq \varepsilon(MAJ)$$

where $\mathbb{E}(\mathcal{M}_A)$, $\mathbb{E}(\mathcal{M}_{\bar{A}})$, $\mathbb{E}(C_A)$ and $\mathbb{E}(MAJ)$ are the sample of events triggered by $\mathcal{M}_A$, $\mathcal{M}_{\bar{A}}$, C_A and MAJ , respectively, C_A being the coincidences between components of $\{A\}$ and $\{\bar{A}\}$.

Figure 12: The components of the majority can be grouped in two sets, $\{A\}$ and $\{\bar{A}\}$, in such a way that the whole set of allowed coincidences can be classified into three groups, $\mathcal{M}_A$, $\mathcal{M}_{\bar{A}}$ and $\mathcal{C}_A$, the first and the second being independent. This will allow us to define upper and lower limits to the actual efficiency value depending on whether we take into account $\mathcal{C}_A$ or not.

On the other hand, the OR of the components of $\{A\}$ or $\{\bar{A}\}$, $[A]$ and $[\bar{A}]$ respectively, could also be considered instead of only their coincidences, as previously. In this case, other events than just those triggered by the coincidences between the signals of $\{A\}$ or $\{\bar{A}\}$ are included for the efficiency computation. These extra events, in fact, correspond to those which are triggered by one signal and not by its associated submajority, $\{A\}$ or $\{\bar{A}\}$. In this scenario, however, the calculation of the efficiency for MAJ , according to the expression of (14) constitutes an over-estimation of the real efficiency since the two sets, $\{A\}$ with respect to $[A]$ or $\{\bar{A}\}$ with respect to $[\bar{A}]$ are, now, correlated. Hence, the following upper limit for the true efficiency value of *our* majority MAJ can be deduced:

$$\varepsilon([A] \cup \mathcal{M}_{\bar{A}}) \geq \varepsilon(MAJ)$$

The present method does not allow us to quote an *exact* value for the global efficiency of *our* sample majority MAJ . However, upper and lower limits which bound this *exact* value can easily be calculated:

$$\varepsilon(\mathcal{M}_A \cup \mathcal{M}_{\bar{A}}) \leq \varepsilon(MAJ) \leq \varepsilon([A] \cup \mathcal{M}_{\bar{A}})$$

These upper and lower limits can be regarded as a source of systematic uncertainty when calculating the efficiency values for signals entering the trigger inside majorities. Nevertheless, as will be demonstrated later, the size of the error is small and does not constitute a practical limitation.

5.2.3 Effect of the contamination in the event sample

The presence of background events can considerably affect the determination of the trigger efficiency when using data only. Different event selections, with different levels of contaminating events, may give rise to different results. In this analysis, and regarding the systematics introduced by this effect, two groups of final state topologies which should be treated separately, can be considered:

- The physics channels, corresponding to the standard Z^0 processes that are studied in this paper: e^+e^- , $\mu^+\mu^-$ and *hadronic* events, have been selected according to the usual DELPHI criteria which are known to have contamination levels well below 1% [2]. Furthermore, as the background and true events are undistinguishable after cuts, their trigger efficiencies ought to be very similar since the requirements imposed by the trigger are, indeed, looser. The experimental precision obtained when measuring the absolute cross sections of the processes can be used to quantify such difference. So, another upper bound of $\sim 1\%$ can safely be assumed [2]. The combination of these numbers, then, guarantees that the uncertainty in the trigger efficiency of standard Z^0 decays due to the presence of background is less than 10^{-4} , as far as the usual DELPHI selection is employed.
- For *single* track and *single* photon events, the trigger efficiencies are specific for the topologies selected, which, in any case, as discussed later, should have no contamination.

6 Trigger efficiencies for e^+e^- and $\mu^+\mu^-$ pairs

In this section the estimation of trigger efficiencies in the forward and barrel regions is carried out for those events selected as e^+e^- or $\mu^+\mu^-$ pairs. Our sample consists of ~ 23000 dielectrons (e^+e^-) and ~ 24000 dimuons ($\mu^+\mu^-$) which were identified requiring standard DELPHI cuts [2] and collected during 1993.

The forward and barrel acceptance regions are defined as:

Barrel region: $45^\circ \leq \theta \leq 135^\circ$

Forward region: $10^\circ \leq \theta \leq 30^\circ$

Backward region: $150^\circ \leq \theta \leq 170^\circ$

Here the polar angle θ is defined using the highest momentum track. This does not constitute a perfect definition of the topology of these events, nevertheless, since the acollinearity is peaked around $\Delta\theta \sim 0^\circ$, we regard it as acceptable.

6.1 Forward region ($10^\circ \leq \theta \leq 30^\circ$, $150^\circ \leq \theta \leq 170^\circ$)

Most of the double majorities were constructed from signals covering the forward/backward region. Due to the existence of these majorities the efficiency determination cannot be carried out properly in this region and only limits to its value can be given as discussed above. The signals defined in this region at second level originate from TPC, FCA/B, HAF, FEMC and MUF and are included in some majority.

6.1.1 Efficiency of the subdetectors

Trigger efficiencies for groups of subdetectors can also be calculated in order to estimate their contribution to the trigger decision. Since most of the subdetectors do not trigger an event on their own but within a majority this calculation does not correspond to the evaluation of their real efficiency. In fact, the efficiency obtained in this way always constitutes a lower limit. In order to obtain such an estimator of the subdetector's efficiency, its signals are grouped into an OR which defines one of the two sets of independent signals needed. The second independent set is built up from the complementary submajority, which is composed of the remaining signals of the majority belonging to other subdetectors.

The efficiencies obtained by this method are summarized in table 3 and correspond to the second level trigger, only, i.e., they are not corrected for T1. Their dependence on the polar angle θ is shown in figure 13. As expected, for all groups of subdetectors previously mentioned, efficiencies are large enough to provide the required redundancy in the trigger. For each channel there are at least two detectors whose efficiencies are greater than 0.95.

6.1.2 Global efficiency

In order to extract a final answer for the global efficiency, further grouping is needed. For $\mu^+\mu^-$ pairs the following sets of signals are chosen:

TPC + MUF

FEMC + HAF + FCA/B

and in the case of e^+e^- pairs:

TPC + FCA/B

FEMC

As stated at the beginning of this section, the width of the interval defined by the upper and lower bounds on the efficiency gives an estimate of the systematic error. The results for the two independent sets used to compute the global efficiency are given in table 4. Combining these two efficiencies by means of equation (14) yields the DELPHI total efficiency in the forward/backward

Electrons			
Detector	Efficiency	σ^+	σ^-
FCA/B	0.975	0.007	0.010
FEMC	1.0000	0.000	0.003
MUB/MUF + HAB/HAF	0.006	0.006	0.001
TPC	0.981	0.006	0.009

Muons			
Detector	Efficiency	σ^+	σ^-
FCA/B	0.992	0.002	0.003
FEMC	0.087	0.007	0.006
MUB/MUF + HAB/HAF	0.987	0.002	0.003
TPC	0.985	0.001	0.001

Table 3: Second level trigger efficiencies of the signals from the forward region for dielectrons and dimuons.

	Detector	Limits	Efficiency	σ^+	σ^-
Electrons	TPC + FCA/B	Upper	0.974	0.007	0.010
		Lower	0.956	0.010	0.013
	FEMC	Upper	1.000	0.000	0.003
		Lower	1.000	0.000	0.003
Muons	TPC + MUF	Upper	0.9999	0.0001	0.0002
		Lower	0.977	0.003	0.004
	FEMC+HAF+FCA/B	Upper	0.958	0.004	0.005
		Lower	0.958	0.004	0.005

Table 4: Bounds of the second level trigger efficiencies of the two sets of signals used to compute the global trigger efficiency for e^+e^- and $\mu^+\mu^-$ pairs in the forward region, with their statistical errors.

Leptons in the Forward region

Figure 13: Dependence of the trigger efficiency on the angle θ of the signals present in the forward region for e^+e^- and $\mu^+\mu^-$ pairs.

Global efficiencies in the Forward region

Figure 14: Dependence on θ of the bounds of the global trigger efficiency for e^+e^- and $\mu^+\mu^-$ pairs in the forward region. Circles correspond to the upper limit and triangles to the lower limit.

region. The values obtained are summarized in table 5 and their dependence on the θ angle is shown in figure 14. Differences smaller than 0.1‰ were found between the upper and lower limits for e^+e^- . In the case of $\mu^+\mu^-$ pairs these differences are bounded within a $\sim 1‰$ interval – see table 5– giving rise to the following result:

$$\varepsilon_{\mu\mu}^{J_{wd}} = 0.9995 \pm 0.0002(\text{stat.}) \pm 0.0004(\text{syst.})$$

where the first error is statistical and the second systematic, i.e. half the width of the above mentioned interval. For dielectrons the interval width turns out to be negligible and the efficiency value can be quoted as

$$\varepsilon_{ee}^{J_{wd}} = 1.00000^{+0.00000}_{-0.00002}(\text{stat.})$$

6.2 Barrel region ($45^\circ \leq \theta \leq 135^\circ$)

The available T2 signals in the barrel region have been:

TPC

OD, HPC, TOF

ID*(MUB+HAB)

In this case, the calculation of efficiencies is simplified by the fact that some of the signals, essentially those from the TPC, are used in their own right to trigger DELPHI. Thus, no correlations are induced by any double majority, and two independent sets of signals can easily be found, one corresponding to the TPC signals and the other incorporating the remaining signals, irrespective of their majority or combination. Moreover, the trigger definition in this region has been very stable during 1993, and this has substantially contributed to minimize the systematic effects introduced when dealing with different trigger configurations.

6.2.1 Efficiency of the subdetectors

As for the forward region, subdetectors' efficiencies can also be studied considering the following sets:

TPC

OD+TOF+HPC

ID*(MUB+HAB)

The resulting efficiencies are summarized in table 6 and their dependence on the θ angle displayed in figure 15. They are very stable and close to unity, apart from the TOF+OD+HPC group which, in the case of dimuons, shows a particular behaviour with respect to the θ angle. This dependence can however be explained in terms of the different sensitivity of the TOF with respect to the various angles of the incident minimum ionizing particles.

6.2.2 Global efficiency

From the values obtained for the different detectors a very high efficiency can be foreseen in the barrel region as a whole. To compute this efficiency, signals are classified, once again, in two independent groups, one composed by the TPC only, and the other by the remaining signals from the barrel.

	Limits	Efficiency	σ^+	σ^-
Electrons	Upper	1.00000	0.0000	0.00002
	Lower	1.00000	0.0000	0.00002
Muons	Upper	0.99999	0.00001	0.00001
	Lower	0.9990	0.0002	0.0003

Table 5: Bounds of the second level global trigger efficiency for e^+e^- and $\mu^+\mu^-$ pairs in the forward region, with their statistical errors.

Electrons			
Detector	Efficiency	σ^+	σ^-
TPC	0.9877	0.0008	0.0009
HPC+TOF+OD	0.9975	0.0004	0.0004
ID*(MUB+HAB)	0.0124	0.0008	0.0009
Muons			
Detector	Efficiency	σ^+	σ^-
TPC	0.9848	0.0009	0.0009
HPC+TOF+OD	0.699	0.003	0.003
ID*(MUB+HAB)	0.8628	0.0016	0.0017

Table 6: Second level trigger efficiencies of the signals from the barrel region for e^+e^- and $\mu^+\mu^-$ pairs.

	Efficiency	σ^+	σ^-
Electrons	0.99997	0.00001	0.00001
Muons	0.99905	0.00008	0.00009

Table 7: Second level global trigger efficiency for dielectrons and dimuons in the barrel region.

Leptons in the Barrel region.

Figure 15: Dependence on θ of the trigger efficiencies of the signals from the barrel region for e^+e^- and $\mu^+\mu^-$ pairs. Note that the plot giving the electron efficiency for the ID*(MUB+HAB) is shown for completeness. It is gratifying to see very low efficiency in the channel for which this is indeed expected.

Global efficiencies in the Barrel region

Figure 16: Global trigger efficiency for e^+e^- and $\mu^+\mu^-$ pairs in the barrel region.

	Limits	Efficiency	σ^+	σ^-
Electrons	Upper	0.99997	0.00001	0.00001
	Lower	0.99997	0.00001	0.00001
Muons	Upper	0.99990	0.00001	0.00001
	Lower	0.99990	0.00001	0.00002

Table 8: Bounds of the global trigger efficiency in DELPHI for e^+e^- and $\mu^+\mu^-$ pairs. These values have been corrected for the T1 inefficiency.

The final efficiency for both topologies in the barrel region, see table 7 and figure 16, is very close to 1,

$$\epsilon_{ee}^{brl} = 0.99997 \pm 0.00001(stat.)$$

$$\epsilon_{\mu\mu}^{brl} = 0.99905 \pm 0.00009(stat.)$$

6.3 Global efficiencies for e^+e^- and $\mu^+\mu^-$ pairs

When trying to classify the trigger signals in two independent sets with similar acceptances so as to compute the global efficiency, one has to cope with the fact that the TPC covers the region $\theta=20^\circ$ to $\theta=160^\circ$ and may induce correlations between barrel and forward signals. One therefore has to separate the TPC from the other signals and consider it by itself as one of the two sets.

The two independent sets are defined as:

TPC

ID + OD + HPC + TOF + FCA/B + FEMC + MUB/MUF + HAB/HAF

Efficiency values are presented in table 8. Their statistical error is below 0.1‰ and, in the case of dimuons, the interval width also has a value lower than 0.1‰. In both cases, the efficiencies are very large:

$$\epsilon_{ee} = 0.99997 \pm 0.00001(stat.)$$

$$\epsilon_{\mu\mu} = 0.99990 \pm 0.00002(stat.)$$

The dependence on θ is shown in fig 17.

7 Trigger efficiencies for hadronic events

In this section trigger efficiencies for hadronic events, collected during 1993, are studied using a sample of events obtained by applying the standard DELPHI selection criteria [2]. The polar angle of the event is defined by the thrust axis: θ_{thr} . The angular coverages of the barrel and forward/backward regions are:

$$\begin{aligned} \text{Barrel region} & 45^\circ \leq \theta_{thr} \leq 135^\circ, \\ \text{Forward region} & 10^\circ \leq \theta_{thr} \leq 30^\circ, \\ \text{Backward region} & 150^\circ \leq \theta_{thr} \leq 170^\circ. \end{aligned}$$

Leptons: Global trigger efficiency

Figure 17: Dependence on θ of the global trigger efficiency in DELPHI for e^+e^- and $\mu^+\mu^-$ pairs.

The final sample of multihadrons contains $\sim 0.52 \times 10^6$ events that can be classed in three distinct groups depending on θ_{thr} . A first set of events, defined by the barrel acceptance contains $\sim 0.46 \times 10^6$ multihadrons, a second set comprises 0.6×10^5 events in the forward/backward region and the remainder are contained in the intermediate region.

In order to compute the trigger efficiencies we follow the same procedure as for the leptonic events, except in the forward region where the two independent sets were chosen as:

TPC + MUF

FEMC + HAF + TPCA/B

The subdetector efficiencies in the forward region are summarized in table 9 and their dependence on $|\cos \theta_{thr}|$ in figure 18. Efficiencies are higher for track detectors – ~ 1 for TPC and FCA/B compared with ~ 0.6 for HAF and MUF and ~ 0.93 for FEMC – due to the fact that the sample is biased by the cuts imposed to the charged tracks. Their angular dependence is also smoother.

The limits for the trigger efficiency in the forward region are presented in table 11 and the efficiencies of the two sets used to compute this efficiency in table 10. The behaviour of these limits with respect to $|\cos \theta_{thr}|$ is shown in figure 20. The final efficiency,

$$\varepsilon_{q\bar{q}}^{fwd} = 0.99985 \pm 0.00001(stat.) \pm 0.00006(syst.),$$

is very close to 1, being bounded within an interval whose width is of the order of $\sim 0.1\%$.

The resulting efficiencies at detector level in the barrel region are listed in table 12 and their variation with respect to $|\cos \theta_{thr}|$ in figure 19. All are very efficient, ~ 0.99 , with the exception of the majority formed with ID, HAB and MUB which has an efficiency ~ 0.8 . The global efficiency in the barrel region, compatible with 1, is quoted in table 13 and shown in figure 20.

The global trigger efficiency in DELPHI for multihadrons has been calculated following the same steps as for dielectrons and dimuons. Again, only the upper and lower limits of this efficiency have been quoted. The values are given in table 14, and the variation of the lower limit with $|\cos \theta_{thr}|$ is shown in figure 20. The efficiency for multihadrons is effectively 1.

8 Single track and single shower efficiencies

Trigger efficiencies for single tracks, ε_{st} , are studied in this section. In order to carry out the calculation of these efficiencies, events with only one track in

- I. $42^\circ \leq \theta \leq 138^\circ$ (Barrel) or,
- II. $10^\circ \leq \theta \leq 32^\circ$ (Forward) or,
- III. $148^\circ \leq \theta \leq 170^\circ$ (Backward),

are selected by imposing the following cuts:

- i) Only one track in the interval (see figure 21):
 - (a) $30^\circ \leq \theta \leq 150^\circ$ for region I,
 - (b) $\theta \leq 50^\circ$ for region II,
 - (c) $\theta \geq 130^\circ$ for region III.
- ii) The selected track must fulfil the following requirements:
 - Track length > 30 cm,
 - $R_{imp} < 5$ cm,
 - $Z_{imp} < 10$ cm,
 - $\Delta p/p < 1$ (relative error on track momentum).

Trigger efficiency for hadronic events. (Forward region)

Figure 18: Dependence on $|\cos\theta_{thr}|$ of the trigger efficiency for hadronic events of the subdetectors present in the forward region.

Trigger efficiency for hadronic events. (Barrel region)

Figure 19: Dependence on $|\cos\theta_{thr}|$ of the trigger efficiencies for hadronic events of the signals in the barrel region.

Multihadrons			
Detector	Efficiency	σ^+	σ^-
FCA/B	0.9765	0.0005	0.0006
FEMC	0.9440	0.0008	0.0008
MUF + HAF	0.6023	0.0019	0.0020
TPC	0.9942	0.0002	0.0003

Table 9: Second level trigger efficiencies for hadronic events of the signals pre from the forward region.

		Limits	Efficiency	σ^+	σ^-
Hadrons	TPC + MUF	Upper	0.9880	0.0005	0.0006
		Lower	0.9780	0.0005	0.0005
	FEMC+HAF+FCA/B	Upper	0.9919	0.0005	0.0005
		Lower	0.9911	0.0005	0.0005

Table 10: Bounds of the second level trigger efficiencies of the two sets of signals used to compute the trigger efficiency for hadronic events in the forward region.

	Limits	Efficiency	σ^+	σ^-
Hadrons	Upper	0.99989	$< 10^{-5}$	$< 10^{-5}$
	Lower	0.99982	0.00001	0.00002

Table 11: Bounds of the second level trigger efficiency for hadronic events in the forward region.

Multihadrons			
Detector	Efficiency	σ^+	σ^-
TPC	0.99996	0.00001	0.00001
HPC+TOF+OD	0.99938	0.00005	0.00005
ID*(MUB+HAB)	0.7794	0.0008	0.0008

Table 12: Second level trigger efficiencies for hadronic events of the signals in the barrel region.

	Efficiency	σ^+	σ^-
Hadrons	0.99999	$< 10^{-5}$	$< 10^{-5}$

Table 13: Second level trigger efficiency for multihadrons in the barrel region.

Global efficiencies for hadronic events

Figure 20: Upper plot: Variation with $|\cos\theta_{thr}|$ of the barrel subdetectors efficiency for hadronic events. Middle plot: Dependence on $|\cos\theta_{thr}|$ of the bounds of the trigger efficiency for hadronic events as determined from the forward subdetectors. Note the high efficiency achieved by these signals, even in the barrel region. Lower plot: Global trigger efficiency for hadronic events.

	Limits	Efficiency	σ^+	σ^-
Hadrons	Upper	0.999999	$\ll 10^{-5}$	$\ll 10^{-5}$
	Lower	0.999999	$\ll 10^{-5}$	$\ll 10^{-5}$

Table 14: Bounds of the global DELPHI trigger efficiency for hadronic events. This value has been corrected for T1 inefficiencies.

The final sample consists of ~ 27000 events in the forward region (II), ~ 27000 events in the backward region (III) and ~ 10000 events in the barrel region (I).

Figure 21: Sketch of the selected events with an isolated single track. The e^+e^- beam line is indicated in the picture as the z axis.

Tracks selected in region (I) will be mainly single electrons coming from the reaction:

$$e^+e^- \rightarrow e^\pm e^\mp$$

$$\quad \quad \quad \downarrow$$

$$\quad \quad \quad e^\mp \gamma$$

whereas in regions (II) and (III) events with two back-to-back particles (e^+e^- , $\mu^+\mu^-$, $\tau^+\tau^-$) and multihadrons with only one particle in the forward and/or in the backward region will be found. In these two regions, the information about the momentum or the energy of the particles is, however, poorer than in the barrel because either the particles have very well defined energies –around 45 GeV/c in the case of dielectrons and dimuons– or, the particles are contained within a small energy interval as is the case of multihadrons. In the barrel zone the isolation condition represents 2/3 of the solid angle, therefore, less particles satisfy this requirement than in the forward/backward regions.

Due to the fact that, either explicitly or implicitly, every track signal has a threshold in the transverse momentum, p_t , it will be useful to study the dependence of the overall trigger efficiency as a function of the p_t . This behaviour will be characterized by a plateau starting at a certain p_t value which will represent the threshold. The expression used to parametrize this dependence can then be written as:

$$\varepsilon_{st}(p_t) = \frac{\varepsilon_0}{1 + \alpha e^{-\beta p_t}} \quad (23)$$

where α , β and ϵ_0 are parameters that have to be fitted from the data. This will provide the expected efficiency in the plateau, whereas the effective threshold can be estimated by means of:

$$R = -\frac{1}{\beta} \log \left[\frac{1}{\alpha} \left(\frac{1}{\eta} - 1 \right) \right] \quad (24)$$

where η is the value of the efficiency relative to the plateau at which we quote the p_t threshold. The value used in this study has been $\eta=0.95$. As for the calorimeters, the same can be said by replacing p_t with the electromagnetic energy.

8.0.1 Evaluation of the efficiencies in the barrel region

Single track events populating the barrel region are mainly single electrons which originate from photon bremsstrahlung, as commented above. Since electrons fulfil the double role of being a charged particle and having an electromagnetic interaction quasi-equivalent to that of photons, both efficiencies under study, single track efficiency and single photon efficiency, can be performed with the same sample of events.

For the track analysis, signals coming from tracking devices will be used and grouped in two independent sets in order to compute their efficiencies:

- TPC
- (HPC + TOF + OD) + (ID + MUB + HAB)

In figure 22 the dependence of the efficiencies on p_t is shown, with the curve resulting from the fit (23) superimposed. The values obtained in the fit for the efficiency in the plateau and the effective threshold at $\eta=0.95$ (see (24)) are listed in table 15.

On the other hand, the single shower trigger efficiency can be estimated by selecting detector signals which are sensitive to photons, i.e. mainly HPC but also OD and TOF. The OD because its sensitivity to the back-scattered particles produced by the showers in the HPC and the TOF because it detects outgoing particles produced at the end of the HPC showers. Both signals were used in coincidence with the majority 1 trigger of the HPC with the low threshold.

In order to obtain a pure sample of single electrons, an additional cut on the E_{track}/p_{track} distribution (see figure 25) was imposed:

$$0.4c \leq E_{track}/p_{track} \leq 1.2c$$

In this approach, the quoted single shower efficiency is that associated to the trigger signals from the HPC+OD+TOF subdetectors. Biases due to the different detection sensitivity of photons and electrons in these subdetectors are neglected and no correction is applied. The computed efficiency can nevertheless be regarded as a “very good” approximation to the true value. The resulting efficiency for this sample of events is given in table 15 and its dependence on the track energy is shown in figure 25.

8.0.2 Evaluation of the efficiencies in the forward region

This region includes $\sim 50\%$ hadronic events and $\sim 20\%$ leptonic back to back events. So, to study tracks with relatively low momentum, we will mainly use those tracks which originate from hadronic events since the leptonic tracks usually correspond to dileptons with rather high momentum, ~ 45 GeV/c.

Single Track: $42^\circ \leq \theta \leq 138^\circ$

Figure 22: Dependence on p_t of the trigger efficiency in the barrel region for single tracks.

Single Track: $10^\circ \leq \theta \leq 32^\circ$

Figure 23: Dependence on p_t of the trigger efficiency in the forward region for single tracks.

Single Track: $148^\circ \leq \theta \leq 170^\circ$

Figure 24: Dependence on p_t of the trigger efficiency in the backward region for single tracks.

Single Shower

Figure 25: Upper plot: distribution of $E_{\text{track}}/P_{\text{track}}$ for the selected tracks in the barrel region. The hashed part of the histogram corresponds to the events considered as single showers. Lower plot: Dependence on the shower energy of the estimated trigger efficiency in the barrel region for single showers

	Signals	ϵ_0	R (GeV/c)
<i>Single Track</i> (I)	TOF+OD+HPC+ID+HAB	0.69	3.6
	TPC	0.96	1.7
	Global eff.	0.99	1.5
<i>Single Track</i> (II)	FCA/B.FW	0.88	2.7
	TPC.FW	0.97	1.3
	Global eff.	0.99	1.0
<i>Single Track</i> (III)	FCA/B.BW	0.83	2.8
	TPC.BW	0.96	1.2
	Global eff.	0.99	0.9
<i>Single Shower</i>	HPC+OD+TOF	0.75	7.4

Table 15: The efficiency and the effective threshold for single track and single shower as obtained from the fit to (23).

As before we will consider only trigger signals coming from tracking detectors, that is, TPC and Forward Chambers. In table 15 their respective efficiencies, together with their effective thresholds are presented. In figures 23 and 24 their dependence on p_t is shown in the forward and in the backward region, respectively.

9 Summary and conclusions

The DELPHI trigger system has been described as a structure consisting of four decision levels. The individual trigger signals from subdetectors are coded in terms of multiplicity bits which carry the basic information delivered to the T1/T2 central trigger. These input bits are then combined to form majorities that have values of either one or two, depending on the produced trigger rate. This design then allows the T1/T2 logic to be defined in such a way that *single* charged and neutral particles can be triggered over the entire DELPHI volume with both tolerable trigger rate and large redundancy. The fraction of interesting physics events written onto tape is finally enhanced by the action of the software T3/T4 triggers.

A method to evaluate the trigger efficiencies in DELPHI has been outlined for various final state topologies, namely e^+e^- pairs, $\mu^+\mu^-$ pairs, hadronic events, single track events and single shower events. As quoted in the corresponding sections of the paper, large efficiency values, *very* close to unity, have been evaluated in all instances.

The effects on the efficiency of the organization in sequential trigger levels, of the existence of majorities, and of the selected event sample purities, have been analyzed and quantified in terms of systematic uncertainties. Still, the errors found in the computation of the global efficiencies are usually smaller than 10^{-4} where both the statistical and the systematic errors are considered. This is a direct consequence of the high level of redundancy obtained with the present trigger. The size of this error is thus very small compared to those presently obtained when measuring most of the physical observables ($> 10^{-3}$) and, therefore, can be neglected.

These results also indicate that the DELPHI trigger system is well suited to operate at energies around the production of W^+W^- pairs at LEP200. At this stage, the cross section for physics events

is much lower than the corresponding at the Z^0 resonance and, the possibility of detecting new physics represents a challenging option since a higher energy threshold will be reached in e^+e^- interactions. A high trigger efficiency for standard physics channels and for single particles, a rather common signature for new processes to manifest, will thus become even more important than at present.

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DELPHI secretariat, CERN, CH-1211 Geneva 23, Switzerland.