DELPHI Collaboration

DELPHI 94-109 PHYS 426
1st June, 1994

Experience with the Ring Imaging Cherenkov Detector of DELPHI

DELPHI Collaboration

Paper submitted to the "ICHEP 94" Conference
Glasgow, **20-27 July 1994**

ICHEP94 Ref. gls0206
Submitted to Pa 17
Pl 16

DELPHI 94-109 PHYS 426
1st June, 1994

Experience with the Ring Imaging Cherenkov Detector of DELPHI
Preliminary

W. Adam[4], E. Albrecht[4], D. Allen[4], M-L. Andrieux[9], G. van Apeldoorn[15], Y. Arnoud[3], C. Aubret[2], A. Augustinus[15], P. Baillon[4], M. Battaglia[18], M. Berggren[17], D. Bloch[6], O. Botner[19], C. Bourdarios[10], J. M. Brunet[2], A. P. Budziak[11], A. Buys[4], P. Carecchio[9], P. Carrié[4], P. Cavalli[9], G. Cerutti[4], M. Chevry[13], E. Christophel[6], E. Dahl-Jensen[14], B. D'Almagne[10], G. Damgaard[14], M. Davenport[4], N. Dimitriou[7], J. Dolbeau[2], M. Dracos[6], M. Dris[16], L-O. Eek[19], T. Ekelöf[19], J. P. Engel[6], D. Fassouliotis[16], T. A. Filippas[16], E. Fokitis[16], F. Fontanelli[8], A. Fontenille[9], D. Fraissard[4], F. Fulda[10], H. Fürstenau[4], J. Garcia[17], E. N. Gazis[16], D. Gillespie[4], V. Gracco[8], L. Guglielmi[2], F. Hahn[20], S. Haider[15], A. Hallgren[19], T. Henkes[4], W. Hao[15], P. F. Honoré[2], K. Huet[13], S. Ilie[4], P. Ioannou[1], P. Juillot[6], E. Karvelas[7], S. Katsanevas[1], E. Katsoufis[16], N. Kjaer[14], P. M. Kluit[15], B. Koene[15], C. Kourkoumelis[1], G. Lecoeur[4], G. Lenzen[20], L-E. Lindqvist[19], A. López Agüera[17], D. Loukas[7], A. Maltezos[7], S. Maltezos[16], A. Markou[7], J. Medbo[19], J. Michalowski[11], F. Montano[8], G. Mourgue[4], B. S. Nielsen[14], R. Nicolaidou[1], J. M. Ostler[4], Th. D. Papadopoulou[16], A. Petrolini[8], G. Polok[11], D. Poutot[2], H. Rahmani[16], M. Reale[20], L. K. Resvanis[1], G. Sajot[9], M. Sannino[8], E. Schyns[20], S. Squarcia[8], P. Stassi[9], R. Strub[6], J. Thadome[20], G. E. Theodosiou[7], M. J. Tobar[4], D. Z. Toet[15], L. Traspedini[8], G. Tripodi[8], G. Tristram[2], A. Tsirou[4], O. Ullaland[4], A. S. de la Vega[5], M. Zavrtanik[12] and E. Zevgolatakos[7]

(Presented by N. Kjaer)

Abstract

The Ring Imaging Cherenkov detector in the DELPHI Experiment at LEP allows for hadron identification over almost the full solid angle and over a momentum range up to about 40 GeV/c. Photons emitted by charged particles traversing gas and liquid radiators which are filled with UV-transparent perfluorocarbons, are used for Cherenkov angle reconstruction. Stable operation ensures that the detector is an efficient and powerful instrument. Monitoring of the detector parameters is of utmost importance to achieve good data quality. The hadron identifying power of the DELPHI detector closely meets the main design values. The interplay between the detector parameters and the particle separating capacity of the detector will be discussed.

[1]University of Athens, Physics Department, Physics Laboratory, Solonos Str. 104, GR-10680 Athens, Greece
[2]Collège de France, Laboratoire de Physique Corpusculaire, 11 place Marcelin-Berthelot, F-75231 Paris, France
[3]CENS Centre d'Etudes Nucléaires de Saclay, DSM/DAPNIA/SPP, Service de Physique des Particules, F-91191 Gif-sur-Yvette Cedex, France
[4] CERN, CH-1211 Geneva 23, Switzerland
[5] COPPE/UFRJ, Dept. de Fisicà, Universidad Federal do Rio de Janeiro, Ilha do Fundão, 21945 Rio de Janeiro, Brazil
[6] CRN Centre de Recherches Nucléaires, B.P. 20 CRO, F-67037 Strasbourg Cédex, France
[7]Institute of Nuclear Physics, N.C.S.R. 'Demokritos', P.O. Box 60228, GR-15310 Aghia Paraskevi, Attiki, Greece
[8] Dipartimento di Fisica, Università di Genova and INFN, Via Dodecaneso 33, I-16146 Genova, Italy
[9]Institut des Sciences Nucléaires, Université de Grenoble 1, F-38026 Grenoble, France
[10] LAL Laboratoire de l'Accélérateur Linéaire, Université de Paris-Sud (Paris XI), Bâtiment 200, F-91405 Orsay Cédex, France
[11] High Energy Physics Laboratory, Inst. of Nucl. Physics, Ul. Kawiory 26a, PL-30055 Krakow 30, Poland
[12] Institut 'Jozef Stefan', Ljubljana, Slovenija
[13]Université de Mons-Hainaut, Service de Physique des Particules Elémentaires, Faculté des Sciences, Av. Maistriau 15, B-7000 Mons, Belgium
[14]Niels Bohr Institute, Blegdamsvej 17, DK-2100 Copenhagen, Denmark
[15] NIKHEF-H, Postbus 41882, NL-1009 DB Amsterdam, The Netherlands
[16]NTU National Technical University, Physics Laboaratory II, 9 Heroes of Polytechneion Street, Zografou, GR-15780 Athens, Greece
[17]Facultad de Ciencias, Universidad de Santander, av. de los Castros, E-39005 Santander, Spain
[18] Research Institute for High Energy Physics, SEFT, Siltavuorenpenger 20c, SF-00170 Helsinki, Finland
[19]Dept. of Radiation Sciences, University of Uppsala, P.O. Box 535, S-751 21 Uppsala, Sweden
[20] Fachbereich Physik, University of Wuppertal, Gauss-Str. 20, D-42097 Wuppertal, Germany

1 Introduction

The DELPHI experiment, a DEtector with Lepton, Photon and Hadron Identification, [1], at the Large Electron-Positron collider (LEP) at CERN is equipped with Ring Imaging Cherenkov (RICH) detectors. The RICH detectors enable identification of pions, kaons and protons over most of the momentum range below 40 GeV/c. The detectors cover almost the full solid angle, as shown in figure 1.

The DELPHI RICH detectors contain two systems of different geometry. The Forward RICH [2] is situated in the two endcaps. It covers the polar angles 15°$< \theta <$ 35° and 145°$< \theta <$ 165° with an active area of $\sim$ 8 m^2. The Barrel RICH [3] covers the polar angles 40°$< \theta <$ 140° with a cylindrical area of $\sim$ 30 m^2.

To determine the particle momenta, p, and the position of the tracks, the RICH is positioned between different tracking detectors inside the 1.2 Tesla magnetic field. The combined momentum resolution is better than 5% for most tracks.

The Forward and Barrel RICH employ the same technique for measuring the Cherenkov angle $\theta_{\check{c}}$. Charged particles traversing a radiator faster than the speed of light in the radiator medium, will produce Cherenkov photons. These will create a ring-like image of photoelectrons in the UV photon detector. The photon detector is a single array of photosensitive time projection chambers which enables three dimensional reconstruction of the conversion point of each UV photon.

The particle identification power of the RICH depends on the accuracy, σ_θ, of the Cherenkov angle measurement. Stable operation of the different subsystems and monitoring of the relevant detector parameters is therefore very important. All control and monitoring information is put on a database and combined with the physics data at the data processing. The Cherenkov angle is calculated for each reconstructed track after background reduction and alignment. The particle momentum, the background, the observed number of individual photoelectrons and their Cherenkov angle distribution are used to determine the likelihood of the particle being an electron, muon, pion, kaon or proton [4].

2 General Operation

2.1 Photon Production

The choice of the radiator medium, and thereby the refractive index, determines the range of particle identification. In order to cover a wide momentum range, the DELPHI RICH has combined liquid and gaseous radiator media for photon production. Both media are perfluorocarbons[5], with good UV transparency, low chromatic dispersion and a good match of refractive index.

A total of 120 liquid radiator boxes are filled with C_6F_{14}. They are 1 cm thick and have quartz windows facing the photon detector. The 24 m^3 Barrel RICH gas radiator contains C_5F_{12}. The 8 m^3 gas radiator of the Forward RICH contains C_4F_{10}.

The Cherenkov photons from the liquid radiators are projected directly on the photon detectors. The photons from the gas radiator are reflected onto the photon detector by focusing mirrors (408 in total). The optical axes of the mirrors are pointing to the DELPHI interaction point.

2.2 Photon Detection

The photon detectors are arranged in 12 sectors in azimuth on each side of the Barrel and in each endcap. Every sector is made of two quartz boxes that are filled with drift gas with an admixture of the photoionizing vapor Tetrakis-diMethyl-Amino-Ethylene (TMAE). The concentration of the TMAE is proportional to its saturated vapor pressure at 28°C in the Barrel and 24°C in the Forward RICH. A small photon conversion length ensures a good separation of the photoelectrons from the gas and liquid side of the photon detector. The conversion length is 2.4 cm in the Forward and 1.8 cm in the

Barrel RICH which is small compared to the about 5 cm depth of the photon detectors. Ambiguities in the assignment of photoelectrons to tracks are avoided by separation of the Cherenkov rings.

The photoelectrons drift towards one end of the photon detector where they are detected by Multi Wire Proportional Chambers (MWPCs). Three dimensional reconstruction of the photon conversion point is possible by drift time measurement combined with anode wire and cathode strip readout of the MWPC. The gas amplification is about 2.10^5 which gives a single electron detection efficiency around 90%. In the Barrel RICH the electric field is parallel to the magnetic field in DELPHI, whereas they are orthogonal in the Forward RICH. This gives rise to a Lorentz angle in the drift direction in the Forward RICH.

2.3 The fluid systems

The RICH radiator fluid systems are recirculating systems. Since water and oxygen are strong UV absorbers it is very important to remove them from the fluids in order to optimize the photon yield. Only molecular sieves are used at the moment to clean the fluids.

The Barrel RICH gas radiator is operated at a constant pressure of 1030 hPa. The photon detector and liquid radiator follow this pressure. The control and accurate monitoring of the Barrel pressures is illustrated in fig. 2. The use of C_5F_{12} in gas form requires the Barrel RICH to be heated to 40°C. This allows one to use a high TMAE saturated vapor temperature of 28°C in the drift gas. The drift gas is a mixture of 75%/25% methane/ethane (CH_4/C_2H_6).

The three Forward RICH fluid systems are operated at atmospheric pressure. With the use of C_4F_{10} as gas radiator, the Forward RICH can be operated at the temperature of the DELPHI detector (~30°C). The drift gas is pure ethane (C_2H_6). The saturated TMAE vapor temperature is 24°C.

The drift gas systems for the photon detectors are also controlled and monitored. Any remaining fractions of oxygen and water are removed from the drift gasses before they are saturated with TMAE inside bubblers. Water must be removed because it is a strong UV absorber and oxygen because oxidized TMAE products are very electro-negative and will cause severe losses of electrons. The oxygen contamination is constantly monitored and measured to be well below 1 ppm.

3 Monitoring and Control

Stable operation of the different subsystems and monitoring of the relevant detector parameters is very important to achieve good data quality. Stability during data taking is maintained by computerized control and monitoring features of the RICH subsystems. The control systems are interlinked via a computer network which also updates the database.

The parameters of the Cherenkov radiators are stable since they are controlled to have specified values. The pressures and temperatures are also reliably monitored. The photon detectors are used to reconstruct single photoelectrons with high accuracy. They therefore need very precise monitoring.

It is important to know how each detector parameter influences the Cherenkov angle measurement and thereby the hadron identification. The Cherenkov rings from the Barrel RICH gas radiator provide the simplest example. They all have nearly the same size – about 2.5 cm in radius – in the plane of the photon detector. This means that if a photoelectron is displaced by one millimeter in the photon detector, the maximum Cherenkov angle of 62 mrad will be changed by 1.4 mrad on average. Since the average resolution is about 4.2 mrad, one can generally say that displacements of 1 mm and above should be corrected for, while smaller effects can safely be neglected.

3.1 Monitoring performance

The Barrel RICH computer controlled heating system uses about 400 probes to monitor and control the temperatures to ±0.3°C. There is no heating of the Forward RICH. Its temperature is monitored by about 100 sensors. The TMAE bubblers are kept at constant temperature $\pm 0.1°C$.

The very high voltage for the drift field of the Forward and Barrel RICH photon detectors and the high voltages of the MWPCs are constantly monitored.

The UV transparency of the different perfluorocarbons is monitored by monochromators [5], which measure the UV transparency from 160 nm to 220 nm. Sample lines from all fluid systems of the RICH enable simultaneous measurement of gas and liquid. An example of these measurements is shown in fig. 3.

A high precision is required on the drift velocities. With an average drift of 75 cm in the Barrel photon detectors, the 1 mm limit on displacements corresponds to a limit of about 0.1% variation in the drift velocity. In the Forward the similar limit is 0.5%. All individual photon detectors of the RICH system are equipped with a matrix of UV calibration fibers[6]. UV light from a central lamp is distributed via quartz fibers which project the light onto the detector at well defined spots. On the Barrel RICH the system is operated continuously during physics runs at a rate of about 0.3 Hz. The drift velocity is determined with a systematic accuracy of 0.05% and typical statistical accuracy of 0.01%. The Forward RICH calibration is done between physics runs. The systematic accuracy is around 0.2%. The Forward calibration system is also used to determine the Lorentz angle. Lorentz angle and drift velocity are parametrized as a function of pressure and temperature. In this way a statistical precision of the drift velocity of $\sim 0.1\%$ is achieved.

Fig. 2 shows the time dependence of the Barrel drift velocity over a short time period as measured by the calibration system. The nearly periodic oscillation of the drift velocity is caused by the pressure regulation of the Barrel gas radiator system. In principle one can update the database with all these values, but since the variation is only about 0.1% from peak to peak, which corresponds to an r.m.s. of about 0.035%, this variation can safely be neglected.

Monitoring on the electronics readout chain is performed online. Faulty electronic components are easily detected. The average number of dead channels due to malfunctions remains below 0.5%.

The many controls and monitoring methods are summarized in table 1. The refractive index of the Cherenkov radiators is the only parameter of relevance to the particle identification which is not monitored directly. Except for temperature and pressure variations, which are corrected for, the refractive index could only change due to a different composition of the fluid. The two Cherenkov fluids communicate via leaks and diffusion. Since the Barrel liquid system is kept at underpressure with respect to the Cherenkov gas system the resulting effect is only on the liquid system. Any such effect would be very small since the two refractive indices are very similar in liquid phase. Even if there would be a 30% C_5F_{12} fraction in the liquid radiator, the average liquid Cherenkov angle would only change by 2.5 mrad. This number can be compared to the resolution on the averaged liquid radiator Cherenkov angle of 8 mrad. Later this year, a Fabry-Perot interferometer will be installed to monitor the refractive index.

3.2 Monitoring of the Barrel photon detector

The monitoring values described above are normally stable, but sometimes deviations are observed and corrections are made to ensure the best identification performance. The Barrel photon detector is an example where the continuous monitoring has shown its value.

Although the Barrel drift velocities are very stable, deviations from stability have been observed. Fig. 4 shows the drift velocity time dependency during two different weeks of running. The variation observed in the latter week has been traced back to changes in the mixture of CH_4 and C_2H_6. The effect is more than 0.2% in drift velocity, and is therefore corrected for.

The Barrel calibration system is also used to measure and monitor any distortions in the drift fields. The maximal transverse deviations in the drift trajectories have been found to be less than 1 mm and therefore of negligible importance. It is due to the magnetic field being parallel to the electrical field that deviations are kept so small. The calibration system is limited in its capability to demonstrate field inhomogeneities along the drift direction by the finite number of light injection fibers.

Variations can also be followed by analysis of the ionizing tracks traversing the photon detectors[7]. The RICH track position is measured with a typical accuracy of 2 mm and can be compared with tracks extrapolated from the central tracking detectors of DELPHI. The results are sensitive to any problems occurring in either the photon detectors or the central tracking. Hence, it is possible to monitor the relative alignment with high precision. It has been observed that a few photon detectors show anomalies in the difference between the two measurements. These anomalies are of the order of a few millimeters, and are possibly due to small electrical short circuits between some adjacent potential strips of the Barrel RICH drift field degrader. The anomalies cause an error on the drift coordinate which is on average below 0.5 mm. However, for some photon detectors, the effects are larger and therefore corrected for. The resulting deviations are negligible after the correction. The magnetic field ensures that drift field imperfections will only cause slight losses in the number of detected photoelectrons. The largest observed anomaly in the Barrel photon detectors has been shown to only cause a 2% loss of electrons. Calibration runs without the magnetic field have also been taken. The electron losses for this particular anomaly are in these runs more than 20%. These results are confirmed by simulation of the fields inside the Barrel photon detectors.

The continuous operation of the Barrel calibration system also allows for monitoring of the electron attenuation length. One routinely observes attenuation lengths around 10 meters. Somewhat shorter attenuation lengths have sometimes been observed. This is possibly related to an outgassing process. This short component vanishes with a decay time of about 3 days. The attenuation measurements are taken into account in the processing of the data.

4 Processing and Data Quality

4.1 Data Processing and alignment

Before a processing starts, selected $Z^0 \rightarrow \mu^+\mu^-$ events are used to align the DELPHI detectors. The RICH detectors use a dedicated alignment package[8]. The alignment procedure minimizes the difference between the observed and expected Cherenkov angles by moving detector components such as the mirrors. After each movement, the Cherenkov angle resolution is recalculated and used to find the optimum position of each component. After the minimization, the movements are recorded on the database and the muon sample reprocessed in order to verify the optimal performance of the whole analysis chain.

Alignment procedures can lead to underestimations of the resolution due to low statistics. If N photoelectrons with equal resolution are used to align M parameters, the obtained resolution is underestimated by a factor $\sqrt{\frac{N-M}{N}}$. In the RICH alignment, N is always more than a magnitude larger than M. The obtained RICH resolution is therefore not underestimated.

Time dependent effects are analysed after the alignment. A weekly average of 1000 $\mu^+\mu^-$ events makes it possible for follow the time evolution of the alignment down to this time scale.

4.2 Data quality

The quality of the data is assessed by the distributions of Cherenkov angles for $Z^0 \rightarrow \mu^+\mu^-$ events. Figs. 5 and 6 show the Cherenkov angular distribution observed in the 1993 RICH data. The obtained resolutions are summarized in table 2. These numbers are in good agreement with what is expected from detailed simulations.

Fig. 7 shows the mean Cherenkov angle as a function of the numbers of photons, n, in the ring. The data are from the Barrel RICH gas radiator. It can be seen that the resolution scales as $1/\sqrt{n}$.

5 Conclusions

The Barrel RICH detector has been fully operational since 1991 and the Forward RICH since 1993. The detectors are running stably with high efficiency.

The detector parameters are extensively monitored. Calibration, monitoring methods and alignment procedures have made the systematic uncertainty on the photoelectron positions smaller than 1 mm. This precision ensures the best possible Cherenkov angle reconstruction. The Cherenkov radiators and drift gasses are measured to be of excellent quality. All this has helped the DELPHI RICH detectors to closely meet the design values.

The exploitation of the RICH technique has opened up new physics channels using leading kaons, pions and protons as a tag for primary s, u and d quarks. Many other physics analyses profitting from hadron identification are now under way.

6 Acknowledgements

Many people have contributed to the development and the final realization of the DELPHI RICH detectors, its complicated hardware, the sophisticated electronics chain and the crucial software. We wish to thank all our collaborators, from the time of the conception of the detector in 1983, for their support and hard work. Special thanks are due to the technical collaborators at the participating institutes for their dedication and valuable contributions. We are grateful to our funding agencies for their continuous support of the project.

References

[1] P. Aarnio et al. (DELPHI Collaboration), Nucl.Instr.Meth. A303(1991)233.

[2] W. Adam et al., Nucl. Instrum. Methods Phys. Res., A 338(1994)284

[3] E.G. Anassontzis et al., Nucl. Instrum. Methods Phys. Res., A 323(1992)351

[4] C. Bourdarios, Contribution to this conference, ref. gls0188

[5] G. Lenzen et al., Nucl.Instr.Meth. A343 (1994) 268-272.

[6] P. Adrianos et al., Nucl.Instr.Meth. A294 (1990) 424;
A. Markou et al., DELPHI 91-95 RICH 45, (1991).

[7] M. Dracos, The DELPHI Barrel RICH or a multipurpose Detector, DELPHI 93-38 RICH 55.
N. Kjaer, Alignment of BRICH using ionization tracks, DELPHI 93-47 TRACK 75.

[8] M. Berggren, ERA-The RICH alignment software package, DELPHI 89-81 PROG 146.

Table 1: Control and monitoring of RICH parameters. Time dependent effects can be monitored for entries labelled "relative values", but without information on the absolute scale. Conversely, entries labelled "absolute values" do not allow to discern small variations with time.

	Active Control	Online Monitoring	Offline Monitoring
Barrel			
Gas radiator pressure	Continuously	Continuously	
Liquid radiator pressure	Continuously	Continuously	
Drift gas pressure	Continuously	Continuously	
Temperatures	Continuously	Continuously	
Drift velocity		Continuously	
Photon conversion length		Continuously	
Electron life time		Relative values	Absolute values
Relative tracking			Relative values
Forward			
Gas radiator pressure	Continuously	Continuously	
Liquid radiator pressure	Continuously	Continuously	
Drift gas pressure	Continuously	Continuously	
Temperatures	Ambient	Continuously	
Drift velocity and Lorentz angle		Regularly	
Photon conversion length		Regularly	
Electron life time			Absolute values
Relative tracking			Under development
Common			
Cherenkov radiator transparency		Regularly	Absolute values
Cherenkov radiator refractive index		Partly	Relative values

Table 2: 1993 single photon resolution

Barrel Liquid resolution (mrad)	14.0 ± 0.2
Barrel Gas resolution (mrad)	4.2 ± 0.1
Forward Liquid resolution (mrad)	10.5 ± 0.2
Forward Gas resolution (mrad)	2.0 ± 0.1

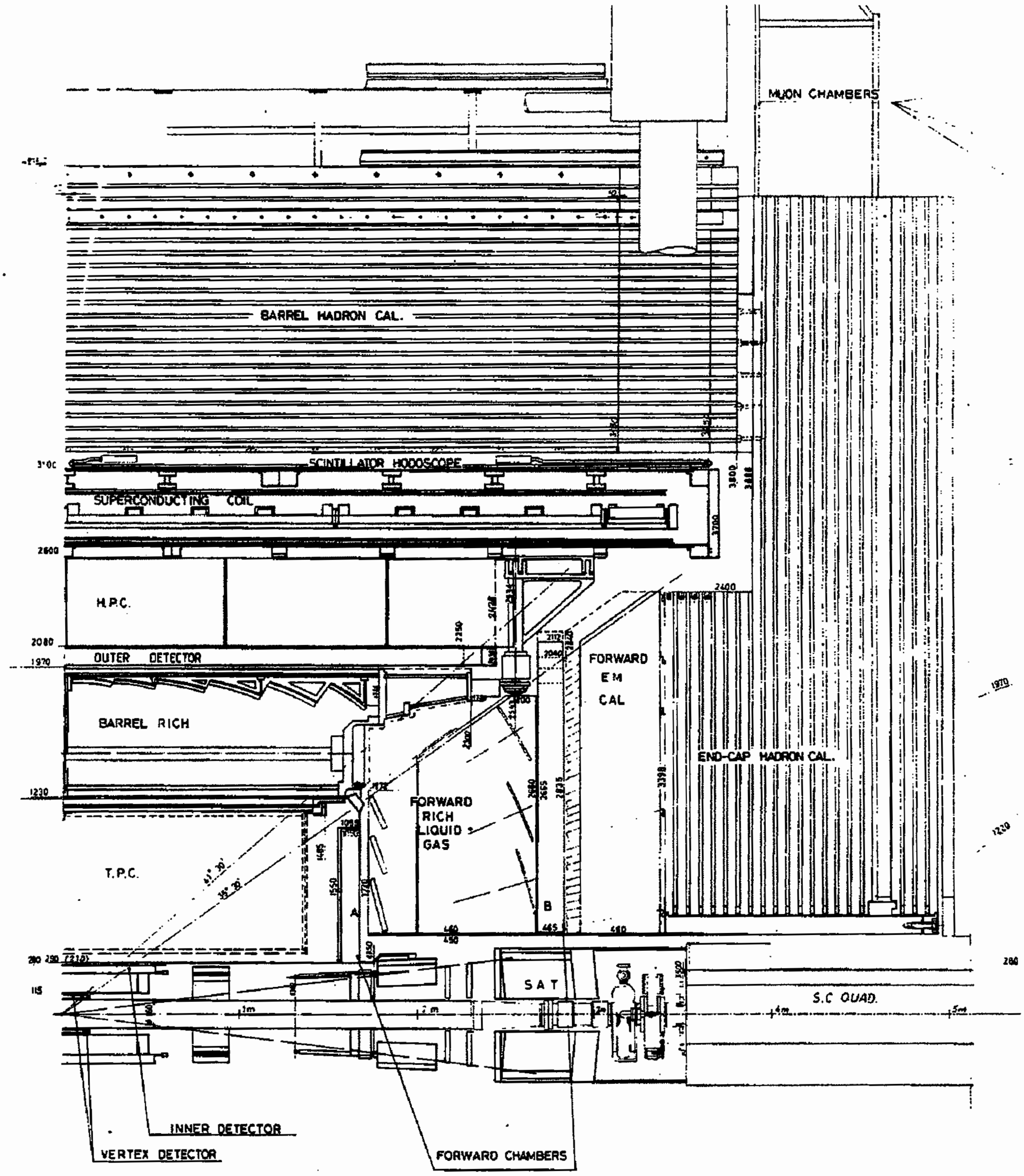

Figure 1: Cross section along the beam pipe of a quarter of the DELPHI detector. The Forward and Barrel RICH are sandwiched between the different tracking detectors: Time Projection Chamber (TPC), Outer Detector, Chambers A and B (CHA,CHB).

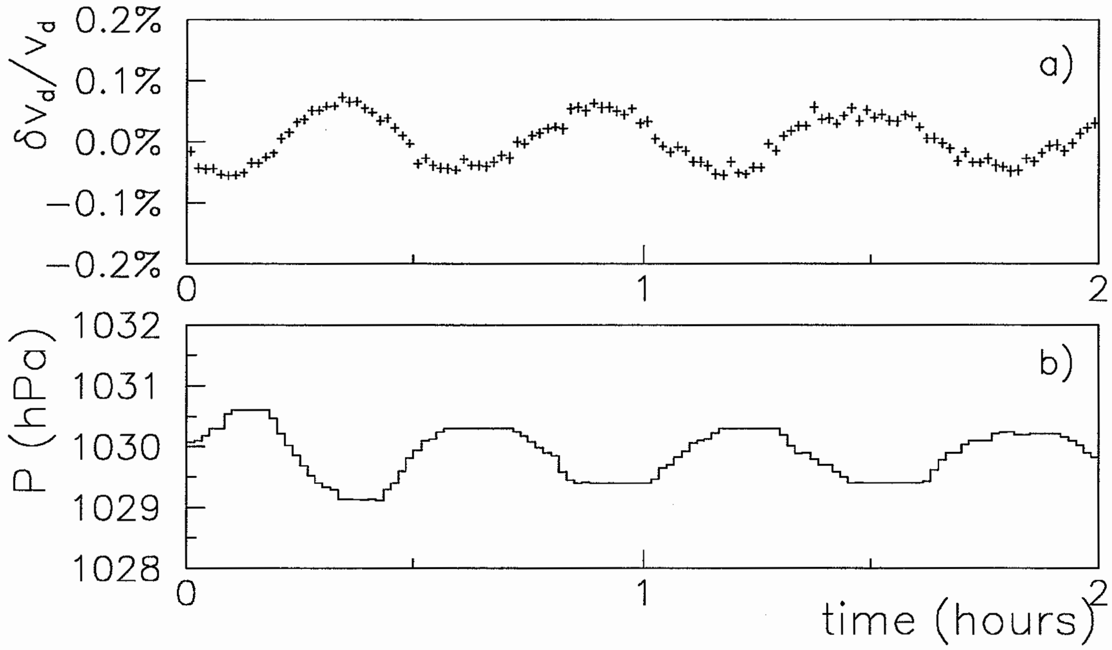

Figure 2: Variation of the Barrel RICH pressure for a period of 2 hours during a data taking period.
a) The relative change in drift velocity.
b) The absolute pressure inside the gas radiator.

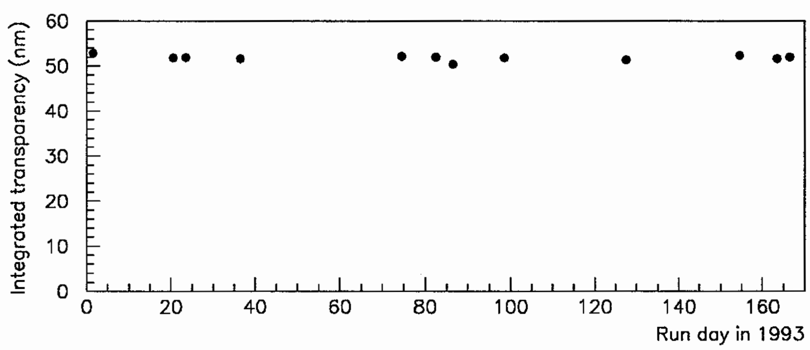

Figure 3: The time evolution of the integrated Barrel RICH C_5F_{10} transparency, $\int_{160nm}^{220nm} T d\lambda$, as measured by the monochromator system.

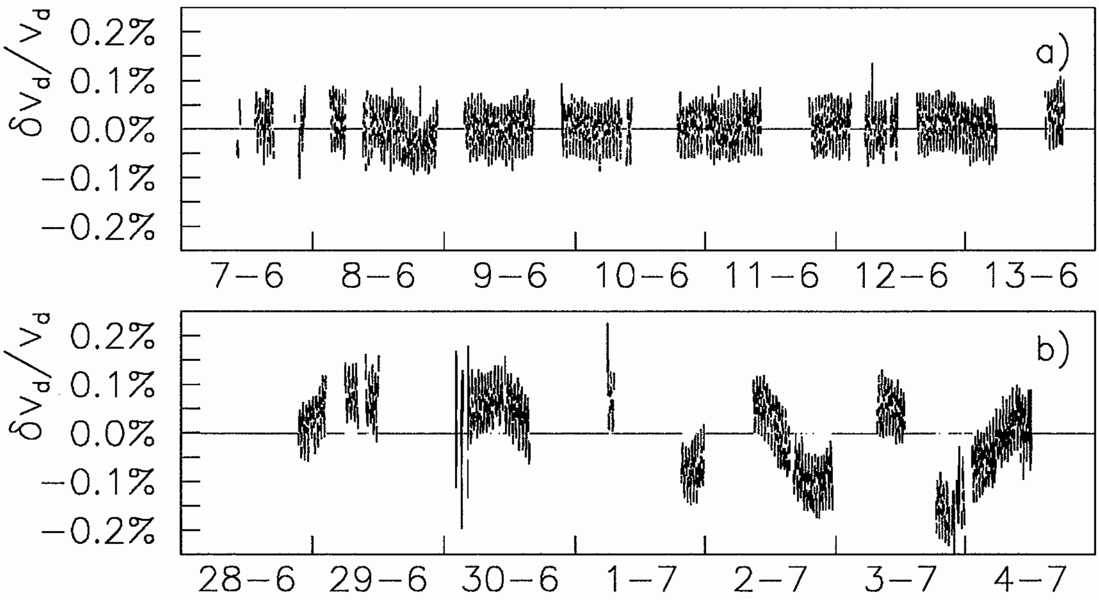

Figure 4: Two examples of the time dependence of the Barrel RICH drift velocity.
a) The relative change during one normal week of running.
b) The relative change during one week with large variations.

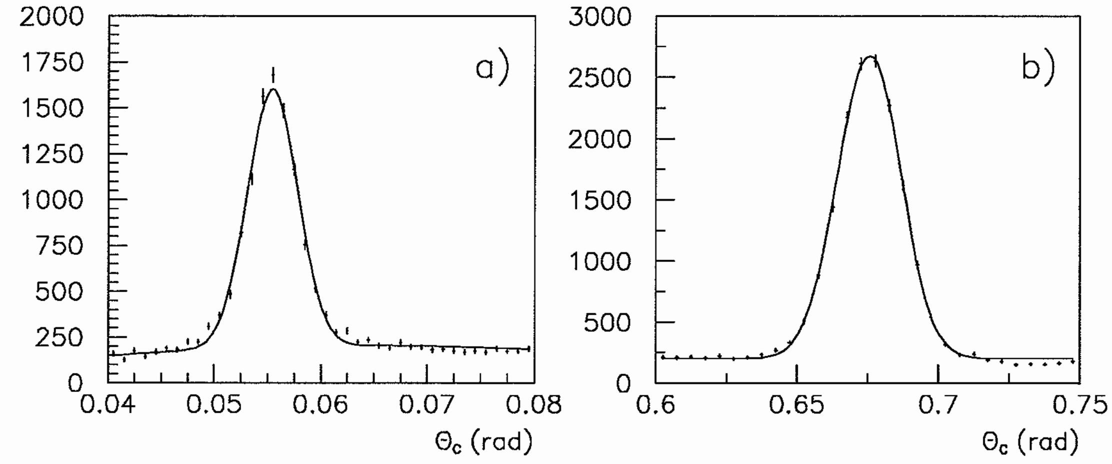

Figure 5: Cherenkov angle distributions from dimuon events in 1993 data from the Forward RICH.
a) The individual photons from the gas radiator.
b) The individual photons from the liquid radiator.

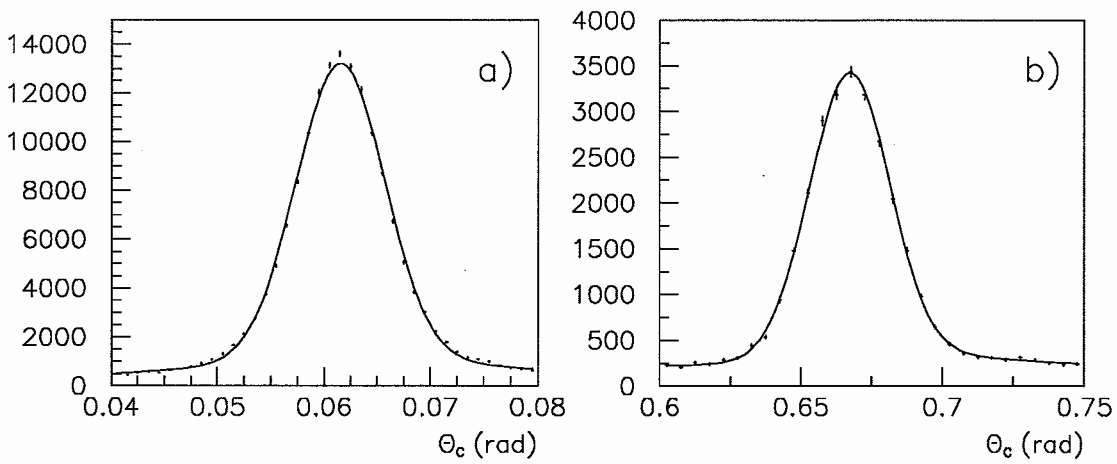

Figure 6: Cherenkov angle distributions from dimuon events in 1993 data from the Barrel RICH.
a) The individual photons from the gas radiator.
b) The individual photons from the liquid radiator.

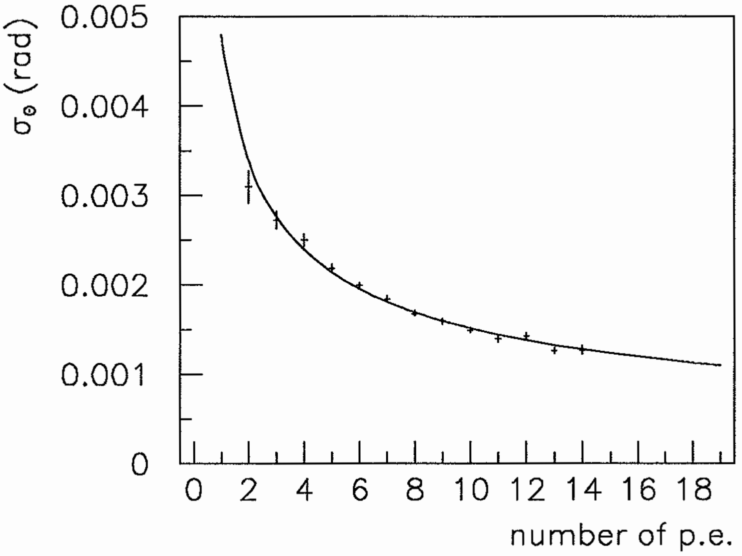

Figure 7: Mean Cherenkov angle resolution as a function of the number of photoelectrons. The 1993 data are from the gas radiator of the Barrel RICH.