Recent Results from the DELPHI Barrel Ring Imaging Cherenkov Counter

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Abstract

The DELPHI detector, installed at LEP, is equipped with RICH (Ring Imaging Cherenkov) counters. The Barrel part incorporates a liquid (C_6F_{14}) and a gaseous (C_5F_{12}) radiator providing particle identification up to 20 GeV/c. The Cherenkov photons of both radiators are detected by TPC-like photon detectors. The drift gas (75% CH_4 + 25% C_2H_6) is doped with TMAE, by which the UV Cherenkov photons are converted into single free photoelectrons. These are drifted towards MWPC's at the end of the drift tubes and the space coordinates of the conversion point are determined. One half of the Barrel RICH is now equipped with drift tubes and produces results from the liquid radiator since spring 1990. The gas radiator has been tested with C_2F_6 as a preliminary filling since August 1990. The data obtained demonstrate the good particle identification potential. For the liquid radiator the number of detected photons per ring in hadron jets is $N=8$, whereas for muon pairs (single tracks) $N=10$ has been obtained. For the gas radiator 2.1 photons per track were observed, which demonstrates the good functioning

of the focussing mirrors, as for C_2F_6 this is close to the expected value.

1 Introduction

One of the important characteristics of the DELPHI spectrometer [1,2] is the use of the Ring Imaging Cherenkov (RICH) technique [3] to assist in particle identification. The RICH technique covers a wide range of momenta over a large solid angle and provides simultaneous identification of several particle types even at high spatial and angular particle densities.

Fig. 1 shows the principle of the method. A charged particle crosses a gaseous and a (1cm thick) liquid radiator, where Cherenkov photons are emitted under a Cherenkov angle θ of

$$\cos \theta = \frac{1}{n\beta}$$

(n = index of refraction, $\beta = v/c$). Parabolic mirrors focus the photons of the gaseous radiator backward into a photosensitive gas contained in quartz tubes; the photons from the liquid radiator propagate a distance of 12cm

Figure 1: Experimental setup

and hit the same photon detector from below. The photosensitive gas is ionized by the Cherenkov photons. The Cherenkov light cone leaves a 'charge image' in the gas, and the free photo-electrons drift in the electric field along the axis of the tube towards a Multi Wire Proportional Chamber (MWPC). Thus the 3D coordinates of the conversion point of the Cherenkov photons are measured. By knowing the geometry of the detector, θ and thus β can be determined. Particle identification is accomplished in DELPHI by using the momentum of the particle, measured by other detector components, as complementary information.

In the following a brief description of the Barrel RICH and its features are given. First results from the 1990 run are presented, showing the high particle identification potential of the detector.

2 The DELPHI Barrel RICH

The Barrel RICH detector is shown in Fig. 1. It consists of two identical halves at each side of the interaction point, both segmented azimuthally in sections of 15° . Each section contains a liquid radiator, a drift tube with a MWPC and 6 mirrors. The rest of the volume is filled with radiator gas. The Cherenkov photons from the liquid radiator (C_6F_{14}) and the gaseous radiator (C_5F_{12}) hit the same drift tube from bottom and top respectively. The liquid and gaseous radiators have been chosen in order to narrow the gap between the respective ranges of detection as much as possible. The gas inside the drift tube is a mixture of 75% CH_4 and 25% C_2H_6 with TMAE (tetrakisdimethylamine-ethylene) as photosensitive agent. The operation of the Barrel RICH has imposed the following design constraints:

- The drift tube is made entirely of UV transparent (down to 165nm) quartz plates in order to match the spectral quantum efficiency of TMAE.
- The operating temperature of the detector is $40^\circ C$ since the gaseous radiator is liquid at room temperature and the vapor pressure of TMAE allows for a sufficiently high concentration in that temperature range only.
- The drift field - up to 1kV/cm - ensures drifting without distortions and is determined by a High Voltage (HV) of up to 150kV on the mid wall. This requires good electrical insulation and demands great care in designing the electrostatics to avoid any corona and field deformation.
- The Barrel RICH will be operated at 0.3 bar overpressure in order to overlap the identification range of the gaseous radiator with the one of the liquid radiator by increasing the index of refraction of the gas.

In the following the main components of the Barrel RICH are described.

2.1 The Vessel

The vessel consists of the inner cylinder, the outer cylinder and two end flanges.

The inner cylinder (diameter 2.60m, length 3.10m) is a sandwich of two skins of 1mm thick aluminium plates with 43mm thick honeycomb in between. The electrical insulator is glued to the outside of the cylinder wall. It is made from helically wound layers of mylar foils (20cm wide, $75\mu m$ thick) glued together with polyurethane glue [4]. From the total insulator thickness of 15mm one estimates a lifetime of more than 80 years at an operation

Figure 2: Artist view of a bitube

voltage of -150kV. Kapton foils with copper strips (width 3mm, pitch 6mm) on both sides are glued onto the insulator as a top layer. The strips serve to degrade the HV at the mid wall to the ground potential at the end flanges. A resistor chain between HV and ground potential provides all the copper strips with the proper voltage. On the outside of the inner cylinder heating circuits and a thermal insulation are mounted.

The outer cylinder (diameter 3.85m, length 3.55m) consists of a sandwich of 30mm aluminium honeycomb between sheets of 1mm thick aluminium. Also here heating circuits and thermal insulation are mounted on the outside.

The outer flanges constitute the mechanical reference for the Barrel RICH on which are fixed the mirror cages, the drift tubes with the MWPC's and the liquid radiator tubes. The flanges are made from aluminium and they are also electrically heated.

2.2 The Mirrors

Every 15° section of the Barrel RICH contains 6 parabolic mirrors (288 in total). They have been produced using a specially developed slumping technique [5], followed by vacuum deposition of a 50nm thick layer of Al and a 30nm thick protective layer of MgF₂. The reflectivity is better than 85% in the relevant wavelength range of 165 - 230nm. The mirrors are mounted on mirror cages, two stiff mechanical structures (one for each half of the Barrel RICH) concentric with the barrel, using the endflanges as a mounting base. They also carry the midwall.

2.3 The Liquid Radiator Tubes

The liquid radiator containers (length 150cm, width 34cm, internal height 1cm) consist of trays made from composite material closed by 4mm thick UV transparent quartz windows. Two containers are glued together and form one mechanical unit. The radiating medium is a 1cm thick layer of liquid C₆F₁₄ with an index of refraction of $n=1.2834$ at $\lambda=175\text{nm}$.

Figure 3: Wire frame with calibration system

2.4 The Drift Tubes

The Barrel RICH contains in total 48 (2 x 24) drift tubes. As shown in Fig. 2 two drift tubes are combined with one endflange and a support structure to form a so-called bitube.

In order to minimize distortions in the path of the drifting electrons the radial component of the drift field has to be less than 10^{-4} of the longitudinal component. This has been achieved by carefully defining the potential planes inside and outside the drift tubes by:

- Metallic strips (0.1mm wide, pitch 3mm) on the inside and outside surfaces of the drift tubes.
- Metallic strips on the liquid radiator tubes.
- A wire frame at the mirror side of each drift tube.

All these strips and wires are carefully positioned to coincide in planes perpendicular to the longitudinal axis of the tube (i.e. the drift direction).

Each drift tube is constructed from 4mm thick quartz plates (transparency $\geq 80\%$ for $\lambda \geq 170\text{nm}$). The length of the tubes is 155cm, its width is 34.5cm. The internal height (in the radial direction) is 4.2cm at the HV- and 6.2cm at the support side. This tapering of the drift tube gap improves the electron collection efficiency. The top and the bottom walls consist of 4 quartz plates being glued together side to side, while the side walls each consist of 3 plates. Conductive strips are deposited all around the individual quartz plates in a vacuum evaporation plant. Each strip consists of 3 layers: 20nm Cr, 200nm Cu and 20nm Cr. The width of the strips on the top and bottom walls is 0.1mm, whereas on the side walls the width is 0.5mm. The pitch of the strips is 3mm. After the gluing of the plates into a tube, corresponding strips are connected at the joints with a conductive glue. As a result strips on both the inner and the outer surfaces of the tube form closed loops. Apart from shaping the drift field the strips also reduce the build-up of surface charges. Electron attenuation lengths of the

Figure 4: Layout of the MWPC; (1) cathode strips; (2) guard strips between blocks; (3) outer guard strip; (4) anode wires; (5) alumina blinds; (6) potential defining strips on the blinds; (7) gating wires

order of 10m and drift deviations close to the tube walls of less than 2-3 mm over 150cm drift have been achieved [6].

run basis.

2.5 The Wire Frames with Calibration System

A wire frame is mounted on the mirror side of each of the halves of the bitube with one resistor bar in between, which defines the potentials of both the drift tubes and the wire frames. The resistors used are $6M\Omega$ with 1% accuracy. Each element of the resistor chain consists of two parallel resistors in order to avoid total rupture of the chain and thus sparks.

In Fig. 3 the layout of the wire frame is shown. The frame is constructed from a 10mm thick composite structure of Kevlar fibres and polyethylene foam. This composition has been chosen in order to match the temperature expansion coefficient of the quartz. Kapton foils with copper strips (pitch 6mm) are glued onto the surface of the wire frame. The five open spaces are each equipped on each side of the frame with a layer of wires (diameter 0.1mm). The mirrors focus the Cherenkov photons from the gaseous radiator through the open spaces into the tube; the wire frames introduce essentially no loss.

A calibration system [7] is mounted onto the frames consisting of 5 rows of 9 optical fibres. All the fibres of one bitube are bundled together and are illuminated by one fibre guiding the light from a pulsed UV light source (NANOLAMP, pulse length (FWHM) 15ns, repetition rate 20Hz) situated outside the DELPHI detector. The lamp illuminates simultaneously all the feeding fibres of the detector; the calibration can thus be accomplished for the whole detector at once. With the UV light spots converted in the tube gas the drift velocity as well as possible distortions in the electron drift can be determined on a run by

2.6 The Multi Wire Proportional Chambers

In the Barrel RICH detector the Cherenkov photon conversion points are measured by MWPC's [8]. The chambers are operated at a charge multiplication of approximately 2×10^5 and achieve efficient single electron detection. The layout of the chamber is shown in Fig. 4. Each MWPC contains 128 sense wires (20 μ m diameter gold plated tungsten wires) and 128 cathode strips, of which the relative efficiency is 85-90% for single electrons. This setup allows the determination of two coordinates of the hit. Between the sense wires one finds blinds, equipped with HV strips, which serve to reduce the cross talk between wires due to photo-electrons that are created by secondary photons radiating from the avalanches. Above the blinds a gating grid is installed which terminates the field shaping system of the drift tubes governing the quality of the field in the transfer region as well as controlling the accessibility to the chambers for electrons. The anode wires are connected directly to preamplifier cards whereas the cathode strips, connected to HV via a $3.3 M\Omega$ resistor, are connected to the preamplifier via a 150pF capacitor. The design of the preamplifier (8channels/card) is based on the LeCroy TRA403 chip (gain 0.1V/ μ A, risetime 6ns). The Barrel RICH data acquisition uses Fastbus Discriminator units, followed by LTD units (LEP Time Digitizers; time resolution 8ns) containing 48 channels each. The measurement of the drift time by these LTD's allows the determination of the third coordinate of the conversion point.

Figure 5: Light spots created by the calibration system

2.7 The Barrel RICH Fluid System

The Barrel Rich fluid system [9] is composed of three parts:

- a liquid radiator circuit filled with saturated perfluorocarbon C_6F_{14}
- a gas radiator volume of about $24m^3$ filled with saturated fluorocarbon perfluoropentane C_5F_{12} ,
- a drift tube circuit containing the detector gas consisting of 75% CH_4 , 25% C_2H_6 , and 0.1% of the photosensitive agent TMAE.

The purity of the fluids is monitored by monochromators in order to guarantee sufficient UV transparency down to wavelengths as low as 170nm. The liquid and gas radiator

Figure 6: Observed deviations (Δx) for different fibre rows systems are of the recirculating type while the drift gas circuit is not.

3 Experimental Results

All Barrel RICH components have been installed, except the drift tubes in one half cylinder. The installation of these has started after the 1990 run and is now finished.

Figure 7: Ring originating from the liquid radiator for a single track

The calibration system is installed on 8 of the bitubes in operation during the 1990 run. During each fill of LEP, lasting up to ca. 10 h, at least one calibration run with 3000 lamp triggers was taken. The intensity of the lamp was decreased by means of neutral density filters in order to obtain per calibration spot and lamp trigger an average of 0.1 photo-electrons in the drift tube. The x-z scatter plot of Fig. 5 shows a typical result. Each dot represents a detected UV photon. One observes clearly the fibre pattern. The accurately known geometrie of these fiducial

Figure 8: Rings obtained with the liquid (C_6F_{14}) and gaseous radiator (C_2F_6) of the Barrel RICII. a), c) and e) show projections onto a plane perpendicular to the track direction: a) Superposition of photons from 211 muon pairs. c) Photons from 199 tracks in hadronic events with $p \geq 6 \text{ GeV}/c$ (central ionization due to dE/dx suppressed and total reflection cut at 0.7 rad). e) Superposition of photons from 211 muon pairs in the preliminary C_2F_6 gas radiator. b), d) and f) Radial projections of the respective distributions above.

marks' allows determination of the drift velocity down to a precision of better than 1 part in 10^3 . From the calibration, also possible distortions affecting the electron drift can be determined. In Fig. 6 the deviation Δx from the expected x is shown for the different fibre rows. Due to the magnetic field inside DELPHI these deviations are even smaller than the ones reported in [6].

The first results of the Barrel RICH were obtained using only the liquid C_6F_{14} radiator. Fig. 7 shows a result from a single high momentum track. Due to the geometry of the Barrel RICH one expects the Cherenkov photons to lie on cone cuts, which differ with the angle of the particle track relative to the drift tube. In Fig. 7 the detected photons are projected onto a plane perpendicular to the track in order to give a ring image. Due to total reflection on the liquid radiator surface only a part of the ring is observed. Superimposed rings of 213 muon pairs are displayed in Fig. 8a. The peak in the corresponding distribution of reconstructed photon angles, as shown in Fig. 8b, is centered at the correct value for $\beta=1$ particles. The error on these data, $\sigma_\theta=14$ mrad, contains a contribution from extrapolation errors on the particle tracks, to be eliminated after proper tuning and alignment. The average number of observed photo electrons per liquid ring is $N_{ph}=10$. Extrapolating this number to a full ring gives $N_{ph}=14$. These data were obtained with an effective TMAE temperature of 11 °C at 1 atm. They are in accordance with the prototype result $N_{ph}=18$ for TMAE at a temperature of 30°C [10] and tracks of close to perpendicular incidence.

The results for superimposed rings from hadrons with momenta ≥ 6 GeV/c and the corresponding distribution of reconstructed photon angles are displayed in Fig. 8c and d respectively. Here a somewhat lower number of photo-electrons per ring of $N_{ph}=8$ is found since in jets the background due to neighbouring tracks is higher, which leads to a loss of some of the photo electrons during reconstruction.

Very preliminary results from the gaseous radiator were obtained at the end of the 1990 LEP run. Since the detector was working at ambient temperature, C_2F_6 was used as test gas radiator. The results are presented in Fig. 8e and f. From the distribution of reconstructed photon angles the mean number of photo-electrons is $N=2.1$, well in agreement with Monte Carlo studies. The resolution $\sigma_{\theta_{gas}} = 6$ mrad is also close to the expected value.

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