LONG ELECTRON DRIFT IN TMAE DOPED GAS IN THE BARREL RICH DETECTOR

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ABSTRACT

The DELPHI barrel RICH detector is based on the principle of the drift of single electrons over distances up to 1.5 m in TPC like drift tubes made of quartz. The drift is performed in a longitudinal electric field of 0.53 kV/cm and in a gas mixture of 80% CH₄, 20% C₂H₆ and $\approx$ 1000 ppm of TMAE as photosensitive additive. The electron loss during the drift has been measured for different TMAE concentrations and different TMAE qualities. It will be shown that an absorption length > 10 m can be obtained even for high TMAE concentrations. This could only be achieved by taking extreme care in the purity of the TMAE and the drift gas. We will also report on the systematic errors in the reconstruction of the photon conversion point due to distortions in the electron drift. Small focusing effects have been observed close to the walls.

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1. INTRODUCTION

The strong particle identification of the DELPHI detector is based on the Ring Imaging Cherenkov (RICH) technique [1]. In the DELPHI Barrel RICH detector two radiators are used to have a particle identification in the energy range between 2 and 25 GeV.

The Cherenkov photons are detected in quartz made drift tubes filled with an ethane/methane gas mixture to which TMAE (tetrakis-(dimethylamino)-ethylene) vapour is added as a photon to electron converter. The electrons drift in an electric field to a wire chamber with cathode strip read out. Anodes, cathodes and drift time gives a three-dimensional reconstruction of the conversion point. Any distortion in the drift field will influence this reconstruction and thus the accuracy of the particle identification. To prevent electron loss in the 1.5 m long drift tubes an electron attenuation length > 10 m is required.

After a description of our test set-up in sect. 2 and a description of the bi-tubes in sect. 3 we will report on two studies: the electron attenuation length in TMAE doped drift gas and the distortions of the electron drift close to the walls.

2. SYBIL, THE EXPERIMENTAL SET-UP

SYBIL (fig. 1) is a set-up to test all bi-tubes before entering the BRICH. It consists of an aluminium cylinder (length 3 m, diameter 1.8 m) in which a bi-tube can be placed. The mechanical support of the bi-tube is the same as in the BRICH. The end flange of the bi-tube is plugged into the mid wall of the cylinder where the HV is applied. To simulate the electrostatic environment in the BRICH a dummy liquid radiator is positioned on top of the bi-tube and on each side there are walls to simulate the neighbouring tubes. The fourth side is covered by two wire frames, mounted on the bi-tube at a distance of 12.5 mm. Distortions in the electric field are avoided by applying the same voltages on the wires as on the corresponding strips of the drift tubes.

The drift gas used for the measurements presented in this paper was 80% methane and 20% ethane with a small TMAE admixture. This particular mixture assures: high drift velocity, small diffusion and good quenching. After mixing the methane and the ethane the gas flows through an oxisorb (Messe Griesheim, 3.3 ℓ , $O_2 < 0.1$ ppm and $H_2O < 0.1$ ppm) prior to its entry in the TMAE bubbler. The bubbler is immersed in a temperature controlled water bath. The tubing is made of copper, except for the part from the oxisorb via the bubbler to the drift tube which is made of stainless steel. The O_2 outgassing of the latter is less. In the gas outlet we have an O_2 -meter (Teledyne Analytical Instruments).

In the SYBIL cylinder 5 windows are made on the side and 5 on the top to allow entrance with a laser beam both horizontal and vertical. A N_2 -laser (NIKHEF mini laser, 337 nm, 110 μJ) is used to ionize the drift gas via a 2-photon process [2]. The laser with its optics can be moved from window to window on a rail. This allows us to measure on different positions without changing the optics itself.

The chamber (Strasbourg/NIKHEF) we used is one of the final chambers [3]. Unfortunately, the gating system could not be used. The typical gain of the chamber is $2 \cdot 10^5$ to allow single-electron detection. The full electronic chain is sketched in fig. 2. The data acquisition is controlled from a Macintosh Plus computer equipped with the CAMAC interface MacPlinth. The online software fires the laser. The light of the laser triggers the data acquisition. In an ADC the laser power is

measured. The TDC's ([4], range 32 μ s, resolution 32 ns) measure the arrival time of the drifting electrons after the laser puls. The data are stored either in histograms or directly on the hard disk.

3. DESCRIPTION OF THE BI - TUBES

The main components of each bi-tube are: two drift tubes, an end flange, a support structure called "boitier", two wire frames and a resistor bar (fig. 3).

Each drift tube is entirely made of 4 mm thick quartz. The length of the tubes is 155 cm, the width 34.5 cm, the height is 4.0 cm at the HV side and 6.0 cm at the boitier side. The top and bottom walls consist of 4 quartz plates being glued together, while the side walls consist of 3 plates. Conductive strips are deposited all around the quartz plates in a vacuum evaporation set-up. Each strip consists of 3 superimposed layers: 200 Å chromium, 2000 Å copper and 200 Å chromium. The width of the strips on top and bottom wall is 0.1 mm whereas for the side walls it is 0.5 mm. The distance between strips is 3 mm. After glueing together a tube, the corresponding strips on the joints are connected with conductive glue. This results into creating continuous strips at the inner and outer surface of the tube.

The end flange supports the drift tubes at the HV side. The boitier supports the drift tubes on the BRICH outer flange and houses the wire chamber. The connection between boitier and drift tubes is made with a flexible membrane to avoid mechanical stress in the quartz. The gas inlet is on one side of the boitier, the gas outlet is on the other side. As a result the gas flows in one drift tube from the boitier to the end, then through the end flange to the second tube and then back to the boitier. The distribution of the gas is optimized to achieve an uniform flow.

The connection between wire frames and drift tubes is made with the resistor bar. The resistor bar is made of stesalite; kapton foil with copper strips is glued around it. Adjacent strips are connected with each other by 2×6 M Ω resistors (1%) in parallel. Applying HV on one side and connecting the bar to ground on the other side gives a linear increase of the voltage on the strips and this produces a homogeneous field inside the tubes.

4. THE ELECTRON ATTENUATION LENGTH IN TMAE

To reduce the average electron loss below 8% an attenuation length > 10 m is required for a TMAE temperature of 30°C. In absence of TMAE the level of electronegative impurities can easily be kept to an acceptable level. In a TMAE doped drift gas this is not trivial. It is not the TMAE itself but the oxidation products that causes electron loss. Of these oxidation products tetramethylurea (TMU) and tetramethyloxamide (TMO) have normally the highest concentrations. Unfortunately, they are also known because of there strong electronegativity [5]. Compared to O₂ TMU is ≈ 10 x as electronegative and TMU ≈ 50 x. The vapour pressures of TMAE, TMU and TMO are comparable. Clearly the oxygen level has to be kept as low as possible to avoid TMAE oxidation (preferable < 1 ppm) and the liquid TMAE has to be as clean as possible.

Several cleaning methods of TMAE have been discussed in the literature [6] [7].

- (a) Water washing; this procedure removes those oxidation products that are soluble in water like TMU, TMO and dimethylamine(DMA).

- (b) Vacuum distillation.
- (c) Pumping; keeping the TMAE under vacuum until $\approx 10\%$ has been removed.
- (d) Flushing the TMAE bubbler with a clean gas.
- (e) Adding alumina directly to the TMAE.

The vapour pressure of TMAE as a function of the absolute temperature T is given by the Clausius – Clapeyron equation

$$P = P_0 e^{A\left(\frac{1}{300} - \frac{1}{T}\right)} \quad (1)$$

Giomataris et al. [8] found for the constants: $p_0 = 0.75$ mbar and $A = 6.3 \cdot 10^3$ K.

If the electron loss is proportional to the TMAE concentration, the attenuation length λ will be inverse proportional to the TMAE vapour pressure

$$\frac{1}{\lambda_{TMAE}} \propto p_{TMAE} \quad (2)$$

More general, if there are more electronegative contributions we can expect the following relation [9]:

$$\frac{1}{\lambda_{MEAS.}} = c \cdot p_{TMAE} + \frac{1}{\lambda_{OTHERS}} \quad (3)$$

where λ_{TMAE} is the measured attenuation length, c is a constant and λ_{OTHERS} is the contribution of other electronegative impurities.

The attenuation length is measured by making the same amount of (horizontal) laser shots on all 5 windows. Then, an exponential is fitted to the number of counts as a function of the drift distance. This is illustrated in fig. 4. Some systematic errors can be avoided by making several small scans (300 shots/window) where the direction of scanning is changed all the time. Examples of these errors are: shift in laser power and temperature variations in the bubbler. An important problem is illustrated in fig. 4. The set-up is suitable to measure attenuation lengths of ≈ 1 m with high accuracy. When the results get better almost a flat distribution is measured and the accuracy gets worse. More statistics does not help. Small systematic errors start to dominate the accuracy. Examples of these are small differences in the transmission of the quartz windows and the positioning of the laser within strips on the tubes. The attenuation length was measured as a function of the bubbler temperature for 3 different samples of TMAE.

The first TMAE sample was uncleaned. The attenuation length was measured for 4 different TMAE temperatures. For 14°C we measured $\lambda = 0.43$ m. Using formula (1) and (3) an extrapolated attenuation length for 30°C of 16 cm was found; almost 2 orders of magnitude too low.

The second TMAE sample was distilled by BAYER LEVERKUSEN. The first results (fig. 5) show a linear relation as expected according to formula (3). Although these results are much better than what was achieved with the first sample an extrapolated value of 1.7 m at 30°C is still too low. A second series of measurements with the same TMAE showed a big improvement (also fig. 5). For all temperatures an attenuation length > 10 m was found. The extrapolated value for 30°C is 10.1 m.

The reason for the improvement is not clear. In the two months between the two series clean gas was flushed through the liquid TMAE and doing so it was cleaned with method 4. On the other hand, the gas system was improved in the mean time. The important part of the piping was changed from copper to stainless steel and a small leak was found. Due to this the O_2 level on the outlet of the bi-

tube went down from 1.5 to 0.5 ppm. These O_2 levels were measured while bypassing the TMAE bubbler. It has always been observed that after opening the bubbler the O_2 level decreased below 0.1 ppm. This means that the remaining O_2 is eaten away by the TMAE and thus giving a constant level of electronegative molecules, independent of the TMAE temperature (TMAE concentration ≈ 1000 ppm).

The third sample was water washed and distilled by BAYER. In table 1 a comparison is made between the concentrations of the two major oxidation products TMU and TMO in uncleaned TMAE with those in the second and third sample. After water washing and distillation the TMAE purity was 99.96%, comparable to the SLAC results with the same cleaning method [5].

After receiving the third TMAE sample a measurement was immediately done for three different temperatures. The results were slightly better than the best results with sample 2, but without a flushing period.

5. DISTORTIONS IN THE ELECTRON DRIFT

To have a good 3-dimensional reconstruction of the photon conversion point, the distortions in the drift have to be as small as possible. We distinguish between distortions in the drift tube and distortions in the transfer region, a space of 5 mm between the drift tube and the gating plane of the wire chamber. The voltage over this region can be set separately. When the field in the transfer region is approximately the same as the field in the drift tube, the distortions are minimized. With such an optimized transfer field the following measurements of the distortions in the drift tube have been performed.

5.1 Distortions in the x -coordinate

To measure the distortions close to the wall we scanned with a vertical laser beam from the side wall 7 cm inward. Then the difference Δx is calculated between the real x -coordinate of the laser beam and the measured x -coordinate. The distortions measured on window 1, 3 and 5 in a drift field of 0.4 kV/cm are shown in fig. 6. The zero off the x -coordinate is taken on the side wall. In fig. 7 the distortions for 3 different drift fields are displayed.

In fig. 8 an overview is given of the distortions 5 mm away from the side wall. As expected from space charge calculations done by Toge and Gaillard [10] a linear relation between the distortions and the drift distance is found. Comparing this result with the mentioned calculations a space charge of $2.9 \cdot 10^5$ ions/cm³ is estimated in the drift tube, compatible with what one would expect from cosmic rays. At the foreseen field of .53 kV/cm the maximal distortions that have been measured for 0, 5, 10 and 20 mm distances to the side wall are: 6.7, 5.6, 4.6 and 2.8 mm.

5.2 Distortions in the y -coordinate

To measure the distortions in the y -coordinate we scanned with a horizontal beam from top wall to bottom wall. Because of the trapezoidal shape of the tubes the electrons do not drift close to the wall for a long time and also the effect of space charge is small in this direction [10]. In fig. 9 the distortion Δy for two different distances can be seen. Even close to the wall, the distortions remain smaller than 2 mm.

6. CONCLUSIONS

A systematic research was done to study the attenuation length. It was shown that if one constructs the gas system carefully and if the TMAE is well cleaned an attenuation length > 10 m for a TMAE temperature of 30°C can be achieved. The best way of cleaning TMAE is water washing and distillation.

The distortions in the y -coordinate of the electron drift are < 2 mm. In the x -coordinate the distortions are bigger but compatible with cosmic rays. The distortions will get smaller when the gating system of the MWPC's is used.

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TABLE 1

*The percentages of TMAE, TMU and TMO concentrations in three
TMAE samples*

	TMAE	TMU	TMO
Uncleaned TMAE	97.47	1.22	0.27
Distilled TMAE	99.74	0.19	0.04
Water washed and distilled TMAE	99.96	0.03	0.01

FIGURE CAPTIONS

- Fig. 1 An overview of the SYBIL set-up. The laser can be shot in the bi-tube both horizontally and vertically.
- Fig. 2 Schematic layout of the trigger and the data acquisition.
- Fig. 3 Schematic drawing of a bi-tube.
- Fig. 4 Two attenuation length measurements: (1) TMAE sample 1, $T = 10^\circ\text{C}$, $\lambda = (0.62 \pm 0.03) \text{ m}$ and (2) TMAE sample 2, $T = 16^\circ\text{C}$, $\lambda = (11.8 \pm 4.0) \text{ m}$.
- Fig. 5 The inverse attenuation length as a function of the TMAE vapour pressure. (1) second TMAE sample, first series; (2) second TMAE sample, second series and (3) third TMAE sample.
- Fig. 6 The distortions in the x -coordinate close to the side wall for a drift field of 0.53 kV/cm , measured on 3 different windows. The zero of the x -coordinate is on the side wall: (1) window 1 ($z = 14 \text{ cm}$). (2) window 3 ($z = 76 \text{ cm}$) and (3) window 5 ($z = 139 \text{ cm}$).
- Fig. 7 The distortions in the x -coordinate close to the side wall measured on window 5 ($z = 139 \text{ cm}$) for 4 different drift fields: (1) 0.67 kV/cm ; (2) 0.53 kV/cm ; (3) 0.40 kV/cm and (4) 0.27 kV/cm .
- Fig. 8 The distortions Δx 5 mm away from the side wall as a function of the drift length for 4 different drift fields. (1) 0.67 kV/cm ; (2) 0.53 kV/cm ; (3) 0.40 kV/cm and (4) 0.27 kV/cm .
- Fig. 9 The distortions Δy as a function of the y -coordinate measured on window 3 ($z = 76 \text{ cm}$) and window 5 ($z = 139 \text{ cm}$). The position of the walls is indicated.

Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig. 5

Fig. 6

Fig. 7

Fig. 8

Fig. 9

Fig. 2

Fig. 3

Fig. 4

Fig. 5

Fig. 6

Fig. 7

Fig. 8

Fig. 9