ATTENUATION LENGTH MEASUREMENTS IN NARROW DRIFT CHANNELS

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ABSTRACT

The attenuation length of electrons drifting under the action of a uniform electric field E_d in a long (1 m) and narrow ($8 \times 100 \text{ mm}^2$) channel has been measured. The drift volume was filled with Ar + 20% CH₄ at atmospheric pressure. The measurement has been done without and with a 1.2 T solenoidal magnetic field whose orientation, relative to the E_d field could be adjusted. Attenuation lengths larger than 4 m were measured.

Presented at the Wire Chamber Conference
25-28 February 1986, Vienna, Austria

1. INTRODUCTION

The ability to drift efficiently electrons in narrow channels is of primary importance for the operation of pictorial sampling calorimeters like the High density Projection Chamber (HPC) [1]. This detector (fig. 1) is, in fact, made up by many narrow and long drift channels separated by lead converters and works as follows. A particle, showering in the converters, ionizes the gas. The ionization electrons drift along the channels under the action of an uniform electric field E_d and finally enter a proportional chamber with pad read-out. Appropriate encoding electronics gives then a three dimensional view of the shower profile together with the energy deposited by the showering particle. This calorimeter has to work inside an intense magnetic field parallel to the electric drift field. Prior to the construction of the HPC for the DELPHI [2] experiment, we made several tests in order to determine the operating conditions where the attenuation length λ is maximized. We also studied the dependence of λ on some effects that we can encounter in the final set-up, like misalignment between $\vec{E}_d$ and $\vec{B}$ or short circuits between neighbouring field shaping electrodes.

In sect. 2 we describe the method and the apparatus used for the measurement. In sect. 3 we present the experimental results and in sect. 4 we discuss them.

2. THE EXPERIMENTAL APPARATUS

A single drift channel of the HPC has been built using lead wire ribbon, i.e. the same technique [3] chosen for the construction of the final calorimeter. 13 ribbons, each made up by 30 parallel lead wires, 1.7 mm thick, separated by 0.2 mm and glued on both sides of a thin vetronite support, were bent to form U-shaped pieces. These pieces were put together on a plexiglass support (fig. 2). Resistors are placed between each two contiguous lead wires to let them act, at the same time, as converters and as field shaping electrodes. The size of the drift channel is $996 \times 100 \times 8$ (X x Y x Z)mm³. Ionization electrons produced by a ²⁴¹Am α -source ($E_\alpha = 5.5$ MeV) can be injected through $\phi = 0.8$ mm holes, in various positions along the x-coordinate (fig. 2)^(*). These electrons,

(*) The mean number of electrons generated by each α -particle entering the detector is 6×10^4 over the 8 mm of the drift gap. The ionization density being quite high, a low proportional gain (~ 100) should be used in order to avoid self-screening effects [4].

after travelling into the channel, enter a proportional counter of a $8 \times 8 \text{ mm}^2$ section. Both the cathode and the anode of this counter are read out. The cathode signal, after amplification and shaping, gates an integrator^(*) that receives in input the anode signal. After an integration time of $2 \text{ } \mu\text{s}$, the output voltage pulse is sent to a multichannel analyzer. The mean value of the peak of the energy released by the α -particles is then recorded versus the drift distance to measure an attenuation length curve. The scheme of the electronic read out is shown in fig. 2. The drift channel is placed into a solenoid^(**) that can give a uniform ($\int B_r dz < 10 \text{ Gm}$ @ $B = 1.2 \text{ T}$) magnetic field up to 1.2 T . The electric drift field $\vec{E}_d$ can be oriented within a cone of $\pm 8 \text{ mrad}$ from the direction of the magnetic field $\vec{B}$. The absence of short circuits between neighbouring field shaping electrodes has been monitored during the data taking.

3. THE EXPERIMENTAL RESULTS

In fig. 3 the attenuation length curves for different values of the drift field E_d are shown, with or without a magnetic field of 1.2 T parallel to $\vec{E}_d$. The O_2 contamination present in the gas mixture has a negligible influence on the attenuation length measurements. We observe then when the B-field is switched on λ is always larger than the same quantity measured when $B = 0$. This is because the electrons of the ionization trail, spiraling around the magnetic field lines, suffer a smaller transverse diffusion. According to the kinetic gas theory, the transverse diffusion coefficient should in fact be reduced by a factor:

$$1/\sqrt{1 + (\omega\tau)^2}$$

where ω = cyclotron frequency, τ = mean time between collisions of the electrons with gas molecules.

The effect of the magnetic field on the transverse diffusion and then on the attenuation length will be discussed in more detail in sect. 4. The attenuation length has then been measured varying the relative orientation

(*) Designed at CERN by J.C. Legrand.

(**) This magnet has been built by the DELPHI group of the ORSAY laboratory for electron drift tests on a prototype of the DELPHI Time Projection Chamber [5].

between $\vec{E}_d$ and $\vec{B}$. We did two scans: one along ϕ where we expect the electrons to deflect from the E_d field direction by an angle:

$$\phi' = ((\omega\tau)^2 \sin\phi \cos\phi / (1 + (\omega\tau)^2 \cos^2\phi)) \approx \phi \quad (1a)$$

and one along θ where we expect a deflection

$$\phi'' = (\omega\tau \sin\theta) / (1 + (\omega\tau)^2 \cos^2\theta) \approx \theta/\omega\tau \quad (1b)$$

(for the definition of ϕ and θ , see fig. 2). The approximations in the two expressions are valid since, in our gas mixture and for our values of E_d and B , $\omega\tau \gg 1$. An example of attenuation length curve for $\phi = 1.5$ mrad is shown in fig. 4. The attenuation length measurements obtained in the ϕ and θ scan are shown in fig. 5 for three different values of E_d . The effect of an inclination along ϕ (i.e. $(\vec{E} \cdot \vec{B})\vec{B}$ effect) is, as expected, much higher than the effect of the same inclination along θ (i.e. $\vec{E} \times \vec{B}$ effect), as expected since $\omega\tau \gg 1$.

The detector has been then opened and some neighbouring lead wires were connected to the same potential. Short circuits between the electrodes forming the drift structure cause inhomogeneities in the drift field and therefore irregularities in the attenuation length curve. We want to study these irregularities in order to establish which is a tolerable rate of short circuits in the production of the HPC modules. Short circuits, or groups of short circuits, are located in between two holes where ionization can be injected. Table 1 shows where the groups of short circuits are located, the number of wires connected to the same potential in each short and the number of shorts in each group.

Data were then taken at $E_d = 150$ V/cm with and without a magnetic field of 1.2 Tesla parallel to the electric field. Fig. 6 presents the attenuation length measured between successive injection holes, the same quantity measured without short circuits is also shown for comparison. The presence of the magnetic field reduces the attenuation effect due to the short circuits. This is expected since, being $\omega\tau \gg 1$, the electrons should drift following preferentially the magnetic field lines therefore feeling much less the inhomogeneities of the electric drift field.

4. DISCUSSION OF THE RESULTS

In order to interpret the experimental results a simulation program has been written. In this program electrons are generated uniformly along z at a distance x from the proportional counter; the electrons are then drifted while diffusing according to a gaussian law. Each electron that reaches the walls of the drift channel is lost; the number of surviving electrons arriving to the proportional counter is then plotted against x and an attenuation length value is obtained. A transverse diffusion coefficient can therefore be associated to each λ . Table 2 presents the attenuation length measurements and the corresponding transverse diffusion coefficients.

We here observe that our σ_T values are larger than elsewhere measured [5,6] if $B = 1.2$ T. This disagreement becomes more important decreasing E_d . This means that tiny attenuation effects other than the transverse diffusion are present and that they should somehow depend on the electric drift field.

Two major effects, able to improve the agreement between our data and the previous measurements cited above, have been found and their influence on λ and σ_T has been calculated (see Appendix for details). The columns λ^c and σ_T^c of table 2 present the value we measured after the corrections, showing that the agreement with ref. [5] is now good for $E_d \geq 150$ V/cm. The simulation program has then been modified in order to include the effects described in the appendix and to drift the electrons at an angle ϕ relative to the channel axes. The lines drawn in fig. 5(a,b) are the simulation results according to formulae (1a) and (1b). The good agreement of data and simulation indicates that the deflection angles due to the $\vec{E} \times \vec{B}$ and $(\vec{E} \cdot \vec{B})\vec{B}$ effects have the values expected according to the kinetic gas theory.

We finally consider the short circuit effect. The field shaping electrodes superimpose periodic inhomogeneities to a constant E_d . These inhomogeneities (fig. 8 and Appendix for details) enter the drift volume for an amount $z_1 \approx 1/3$ of the electrode pitch. If some lead wires are at the same potential, this changes locally the electrode pitch, increases z_1 and therefore decreases the attenuation length. As specified in the

Appendix, the effect of a magnetic field parallel to the main component of E_d will be to reduce z_1 by a factor $\sim \omega\tau$. This is confirmed in fig. 6 where is shown that the effect of a short circuit amongst 4 wires in presence of magnetic field is less important than to the effect of a 2-wires short circuit in absence of magnetic field.

5. CONCLUSIONS

This measurement has shown that electrons can drift in narrow channels over long distances suffering small losses. The use of a high- $\omega\tau$ gas mixture, like Ar + 20% CH₄, together with an intense magnetic field parallel to the electric drift field offers several advantages:

- It minimizes the losses due to the transverse diffusion.
- It makes the detector less sensitive to short circuits between field shaping electrodes.
- It makes the detector less sensitive to electronegative impurities.

Acknowledgements

We are very grateful to the Orsay group of the DELPHI Collaboration, and in particular to J.E. Augustin, F. Fulda-Quenzer, J. Haissinski and J. Pagot, for the loan of the solenoid and the kind hospitality in Orsay. We finally would like to thank A. Cattai and H.G. Fischer for useful discussions and F. Conforti for the efficient technical support.

APPENDIX

We here describe two effects that make us loose some of the charge left in the gas by the α -particle. These losses are not absolute but due to our measurement method. As explained in what follows, a part of the charge is lost at the rising edge (a) and a part at the falling edge (b) of the current pulse of the proportional counter.

- (a) As mentioned in sect. 2, the cathode signal was discriminated to gate an integrator that received in input the anode signal. The discriminator threshold and the delay between the cathode and the anode signal were left unchanged during the series of measurements reported in this paper. A loss of charge was therefore due to the longitudinal diffusion of the drifting electrons. The spread of the same charge over a longer time interval corresponds, in fact, to a charge loss as illustrated in fig. 7. In this figure the rising edge of the pulse after 30 and 90 cm of drift is shown for $E_d = 100$ and 200 V/cm. The hatched region, which relative importance increases decreasing E_d , is the one lost because the signal triggers itself if a fixed threshold is overcome. Since the threshold and the longitudinal diffusion coefficients are known, we can correct each point of each attenuation length curve and then determine new values of λ , that are shown in table 2.
- (b) Inside a narrow drift channel, like the one we used, the edge effects cannot be entirely negligible. In particular the electrons generated close ($\sim 500 \mu\text{m}$) to the lead walls do not follow, like the electrons generated in the middle of the channel, a straight path to the proportional wire, but semi-circular paths which period is equal to the distance (1.7 mm) between neighbouring lead wires and which amplitude decreases exponentially with the distance from the channel wall. Fig. 8 shows some of these calculated paths.

The "edge" electrons have then to follow a longer trajectory than the electrons generated in the middle of the channel. We have calculated the trajectories of these electrons in presence of a 1.2 T magnetic field parallel to $\vec{E}_d$ and we have found how many of them exceed the 2 μs integration window we have used. The corrections to σ_T due to such charge loss are reported in table 2 together with the new λ values corrected for both (a) and (b).

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TABLE 1

Group of short circuits	x-position [cm]	No. of wires/short	No. of shorts/group
1	40-50	2	1
2	50-60	2	3
3	60-70	2	6
4	70-80	3	1
5	80-90	4	1

TABLE 2

E_d V/cm	λ [cm] this exp.		σ_T ($\mu\text{m}/\sqrt{\text{cm}}$) this exp.		σ_T ($\mu\text{m}/\sqrt{\text{cm}}$) ref. [5]		λ [cm] corrected for (a)	λ^c [cm] corrected for (a) and (b)	σ_T^c ($\mu\text{m}/\sqrt{\text{cm}}$) corrected for (a) and (b)
	B = 1.2 T B = 0		B = 1.2 T B = 0		B = 1.2 T B = 0		B = 1.2 T		
100	170	62	250	450	75	-	220	250	200
150	470	81	120	410	95	-	560	610	95
200	450	87	125	400	115	500	480	520	115

FIGURE CAPTIONS

- Fig. 1 Detail of a High density Projection Chamber module. The sketch of a shower is superimposed to the drawing in order to illustrate how the calorimeter works (see text for details).
- Fig. 2 Sketch of the drift channel for the attenuation length measurement with its read-out electronics. The reference system used in this paper is shown too.
- Fig. 3 Attenuation length curves for different values of E_d , in presence or in absence of a 1.2 T magnetic field parallel to E_d .
- Fig. 4 Attenuation length curve for $E_d = 150$ V/cm, $B = 1.2$ T when we have an angle $\phi = 1.5$ mrad between E and B .
- Fig. 5 Attenuation length versus: (a) $(\vec{E} \times \vec{B})\vec{B}$ effect and versus (b) $\vec{E} \times \vec{B}$ effect
- Fig. 6 Attenuation length measured between successive charge injection holes. Data without and with short circuits are reported. See text for details.
- Fig. 7 The rising edge of the current pulse after
(a) 30 cm of drift.
(b) 90 cm of drift.

These pulses are shown for $E_\phi = 100$ V/cm and $E_d = 200$ V/cm. The hatched region is the one lost because of the self-triggering scheme.
- Fig. 8 Electric field lines close to the field shaping electrodes of the drift channel.

Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig. 5

Fig. 6

Fig. 7

Fig. 8