DEVELOPMENT OF A SMALL HIGH-PRESSURE STREAMER CHAMBER FOR CHARM-LIFETIME MEASUREMENTS

Volker ECKARDT and Siegfried WENIG +
Max-Planck-Institut für Physik und Astrophysik, München, Germany

Received 24 January 1983

The spatial resolution in a streamer chamber is investigated as a function of the gas pressure in the chamber. For this purpose a small streamer chamber with a track sensitive volume of 50 mm diameter and 23 mm gap has been constructed and operated between 5 and 20 atm pressure. In this pressure range streamer densities from 43 to 67 streamers per centimeter were found. The track width \( \sigma \) is mainly determined by the diffusion of the electrons and shrinks proportionally to \( 1/\sqrt{p} \). In addition, the influence of a magnetic field of 1.8 T on the diffusion was studied. At 20 atm one reaches a \( \sigma \) of 70 \( \mu \)m in space, which allows a measurement of charmed particle lifetimes as short as \( 10^{-13} \) s.

1. Introduction

Since the discovery of the charmed quark in 1974 the interest in high resolution vertex detectors has continuously increased. Such detectors should allow to determine the lifetime of charmed mesons and baryons by detecting and measuring their flight path. In spite of the excellent results which were obtained with emulsions [1] and small bubble chambers [2] for the accuracy and two track resolution, it is still interesting to use a streamer chamber for charm-lifetime measurements [3] because it is triggerable and therefore gives a higher sensitivity in an experiment. At atmospheric pressure however the accuracy of a streamer chamber is limited to a few hundred micrometers mainly due to the diffusion of the primary electrons during the high voltage delay.

The aim of this investigation was to study the reduction of diffusion by increasing the pressure in the streamer chamber, and whether a magnetic field parallel to the electric field reduces further the diffusion due to the Lorentz force. It was also interesting to study the increase of the streamer density with pressure, which improves the accuracy and makes the pattern recognition easier.

For these investigations a small streamer chamber has been built, which is described in detail in section 2. The measurements and results obtained with this chamber are presented in section 3.

2. Apparatus

Fig. 1 shows a schematic drawing of the set-up used. The streamer chamber was positioned inside a magnet with 1.8 T field strength in a beam line at the CERN-PS. The trigger counters \( S_1, S_2, S_3 \) defined the particle trajectory within 2 mm horizontally and 10 mm vertically.

In the following, a brief description of the various components of the apparatus is given.

2.1. Streamer chamber body

The design of the streamer chamber (fig. 2) is determined by the following requirements:

i) mechanical stability for the pressure up to 20 atm;

ii) insulation for the high electric field strength.

For these reasons the pressurized cell is kept as small as possible. This cell is positioned between two HV-electrodes, which have positive and negative polarity. Two
specially shaped discs are mounted on these electrodes to create a homogeneous field in the center of the pressurized cell, yielding a track-sensitive volume of 50 mm diameter and 23 mm depth. A glass window of 15 mm thickness is inserted in one of the electrodes, and a grid with 0.05 mm thick wires and approximately 70% transparency allows the streamers to be photographed along the electric field lines. The grid electrode is covered by a thin Mylar foil to avoid discharges at the highest possible field strength of 165 kV/cm. The insulating wall of the pressurized cell is a plexiglass ring of 30 mm thickness. In all measurements the streamer chamber was filled with a neon-helium mixture (70%-30%). The surrounding ground electrode is a closed box. To avoid sparking this box was flushed during operation with sulfurhexafluoride (SF₆) or freon 12 at atmospheric pressure.

2.2. HV system

The HV pulses with positive and negative polarity are produced in a Marx generator and shaped in a double Blumlein pulseformer to a length of 10 ns fwhm. The Marx generator has eight stages for each polarity with 25 kV per stage and thus produces ±200 kV. The two pulses have to arrive at the chamber electrodes simultaneously. Therefore, there is only one spark gap in the Blumlein system, and the discharge takes place between the two different polarities and not between each polarity and ground separately, as is usually done.

The minimum delay time between the particle passage and the HV pulses is 615 ns.

2.3. Optics

The tracks were recorded on film. The camera was equipped with a two-stage image intensifier (2 × Varo 4215) with 40 mm in diameter and a light gain of 3000. The demagnification of 2.5 was chosen as a compromise in order to provide a good resolution in space on the one hand and a sufficient depth of field on the other hand. Using a lens with 150 mm focal length and an aperture of 5.6 we obtained a depth of field of 3–4 mm. The resolution of the lens and image intensifier system alone is better than 40 line pairs per mm and on Agfa film RP2 better than 25 line pairs per mm. This gives an optical resolution of 100 μm and a position accuracy of 10 μm in space [4].

3. Measuring procedure and results

3.1. Measuring procedure

For each set of experimental conditions (pressure, magnetic field, delay time) tracks with similar contrast are obtained.
3.2. Results

3.2.1. Streamer density

In a conventional streamer chamber at atmospheric pressure and a typical demagnification of 40 to 60, one counts typically 2 streamers per cm, which corresponds to ~20% of the primary ionization in a neon–helium mixture (70%–30%) or to less than 10% of the total ionization. With the high resolution optics and the very small streamers in the present high-pressure streamer chamber it should be possible to record a larger percentage. This is indeed observed from table 1, which shows the streamer densities under the various conditions. Of course, the increased streamer density implies an improvement of the track recognition and measuring accuracy.

3.2.2. Track width at high pressure

In diffusion theory the mean displacement \( \sigma \) in one dimension is given by

\[
\sigma = \sqrt{2D\tau},
\]

where \( D \) is the diffusion coefficient and \( \tau \) the diffusion time [5], which for the streamer chamber is the time between the particle passage and the arrival of the HV pulse at the chamber electrodes. Since \( D \) is proportional to the inverse of the pressure \( p \), \( \sigma \) can be written as

\[
\sigma = \sqrt{2D_0\tau_0/p},
\]

where \( D_0 \) is the diffusion coefficient at atmospheric pressure \( \tau_0 \). From this equation one expects a reduction of the mean displacement \( \sigma \) (i.e. half the track width) proportional to \( 1/\sqrt{p} \).

Fig. 5 shows the measured \( \sigma \) as a function of pressure. The solid line is proportional to \( 1/\sqrt{p} \). It is seen from the figure that the measurement is in good agreement with the theoretical expectation. At 20 atm a mean displacement \( \sigma \) of \( \sim 70 \mu\text{m} \) is obtained.

3.2.3. Influence of a magnetic field

By adding a magnetic field parallel to the electric field, the diffusion of the electrons should be further reduced due to the Lorentz force. The dashed line in fig. 5 is an eye-guided fit through these measurements of \( \sigma \).

Table 1

<table>
<thead>
<tr>
<th>Magnetic field (T)</th>
<th>Delay time (( \mu\text{s} ))</th>
<th>Pressure (atm)</th>
<th>5</th>
<th>10</th>
<th>15</th>
<th>20</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.6</td>
<td>43 ( \pm ) 2</td>
<td>50 ( \pm ) 3</td>
<td>59 ( \pm ) 3</td>
<td>67 ( \pm ) 2</td>
<td></td>
</tr>
<tr>
<td>1.8</td>
<td>0.6</td>
<td>34 ( \pm ) 1</td>
<td>47 ( \pm ) 3</td>
<td>55 ( \pm ) 3</td>
<td>67 ( \pm ) 4</td>
<td></td>
</tr>
</tbody>
</table>

Calculated primary ionization [6]

<table>
<thead>
<tr>
<th></th>
<th></th>
<th>50</th>
<th>100</th>
<th>150</th>
<th>200</th>
</tr>
</thead>
</table>
vs. pressure at a field strength of 1.8 T. The fit indicates a significant improvement only at low pressures, whereas at higher pressures the effect is negligible as expected [7].

3.2.4. Influence of the primary electron energy and thermalization

After the collision of an incident particle with the atoms in the gas, the liberated electrons have a primary energy, which can be higher than the thermal energy. This results in an additional track-broadening, which is not described by the thermal diffusion. To investigate this effect, tracks with different delay times of the HV pulse were photographed and measured. Fig. 6 shows the squares of the mean displacement as a function of the delay time \( t \) for the different pressures. The extrapolation of \( \sigma^2 \) to a delay time \( t = 0 \) yields values different from zero, which clearly indicates a contribution of non-thermal electrons to the track width.

---

V. Eckardt, S. Wenig / A streamer chamber for charm-lifetime measurements

**Fig. 5.** Mean displacement \( \sigma \) vs. pressure \( p \) without (crosses) and with (circles) magnetic field. The full curve is proportional to \( 1/\sqrt{p} \), the dashed curve is an eye-guided fit to the measured points.

**Fig. 6.** Square of mean displacement \( \sigma^2 \) vs. delay time \( t \) for 5, 10, 15 and 20 atm. The straight lines are linear fits to the data points above a delay time \( t = 2 \mu s \).

**Fig. 7.** Shortest measurable flight path \( d \) and lifetime as a function of the decay angle \( \alpha \) (see text).
3.2.5. Shortest measurable lifetime

To obtain a rough estimate of the shortest measurable lifetime, a simple calculation was performed in the following way: A decay vertex is assumed to be identifiable, if the extrapolation of the decay track misses the production vertex by a distance $a$, which is bigger than twice the extrapolation uncertainty $\Delta a$:

$$a > 2Aa;$$

$\Delta a$ is determined from the errors of the parameters of the polynomial fit to the measured points along the track. At a fixed decay angle $\alpha$ the shortest measurable flight path $d$ is thus given by

$$d = 2\Delta a / \sin \alpha.$$

This path $d$ is plotted versus the decay angle $\alpha$ in fig. 7 for a 20 mm long track at 20 atm chamber pressure. The corresponding lifetime of the charmed particle is also indicated in the figure. It is assumed that the particle is produced at rest in cms by a 300 GeV beam particle. At a decay angle of 5° the shortest measurable flight path is $\sim 400 \mu m$, which corresponds to a lifetime of $\sim 10^{-13} s$.

We would like to thank N. Schmitz for his interest and support. We are grateful to the members of the group of M. Schmitt from the EF Division at CERN for their help during the construction and the installation at the CPS, to G. Winklmüller for his excellent technical assistance, and to A. Adamczyk for his assistance during the track measurements.

References