Nuclear Instruments and Methods in Physics Research A243 (1986) 86–90
North-Holland, Amsterdam

HELIUM–PROPANE AS DRIFT CHAMBER GAS

W. ZIMMERMANN

Deutsches Elektronen Synchrotron, Hamburg, FRG

V. HEPP

University of Heidelberg, Heidelberg, FRG

R.G. KELLOGG, M. SCHMITT and A. SKUJA

University of Maryland, USA

A. BÄCKER, C. GRUPEN, H. SUHR and G. ZECH

University of Siegen, Siegen, FRG

N. MAGNUSSEN and H. MEYER

University of Wuppertal, Wuppertal, FRG

Received 16 August 1985

A light gas mixture, consisting of helium and propane (0.938 : 0.062) at atmospheric pressure has been tested in a large single-volume drift chamber. Contrary to the general belief that helium cannot be used as a drift gas due to its high ionisation potential, the above mixture was found to have stable operation with a spatial resolution of (260 ± 40) μm.

1. Introduction

We have studied the feasibility of detecting and reconstructing tracks of ≈ 1 MeV/c electrons using the central drift chamber [1–3] originally built for the PLUTO detector [4] at DESY. In this range the momentum resolution of most chambers is dominated by multiple scattering in the gas. A calculation showed that the standard gas mixture of the PLUTO experiment would yield a momentum resolution $\sigma(p)/p$ of the order of 60% for 1 MeV particles. The PLUTO gas mixture consists of argon, propane and methylal (0.900 : 0.085 : 0.015). To use the drift chamber in the envisaged way meant finding a drift gas with a much greater radiation length than the 115 m of the PLUTO gas. A light gas mixture consisting of 93.8% helium and 6.2% propane (hereafter referred to as helium mixture) was tested and found to work satisfactorily.

In this paper we report on some of the important features of this drift gas. Our aim is to prove the possibility of using helium in large drift chambers. For low particle momenta the loss in spatial resolution due to primary statistics is more than made up for by the reduction in multiple scattering. Another important potential advantage of using light gas mixtures is a reduction in the number of spurious hits in the drift chambers of e^+e^- experiments. At e^+e^- storage rings operating near their maximum energy these hits are due primarily to photoionisation of the chamber gas by soft synchrotron radiation. The rate of such ionisation in the drift chamber gas is proportional to the fifth power of the nuclear charge Z [5].

2. Drift gases

In choosing a suitable drift gas the number of possibilities was limited. A gas with low Z provides a large radiation length, but the electron attachment probability must also be low and the ionisation yield sufficient. Table 1 shows some important features of some possible drift gases. We regarded hydrogen as too difficult to handle in a large scale experiment, so we focused our attention on helium. The ionisation yield of helium can be seen to be about a factor of 5 lower than that of argon, and we expected the spatial resolution to be significantly degraded due to the small number of liberated ion pairs in each drift cell. Preliminary tests

0168-9002/86/$03.50

Table 1
Properties of gases in proportional counters [6,7]

Gas	Z	Radiation length (m)	Number of primary ion pairs per cm	Total number of ion pairs per cm
Hydrogen	1	7056	6	10
Helium	2	5299	5.9	12
Methane	–	649	16	50
Neon	10	322	12	50
Argon	18	110	29.4	90
Xenon	54	14	44	300

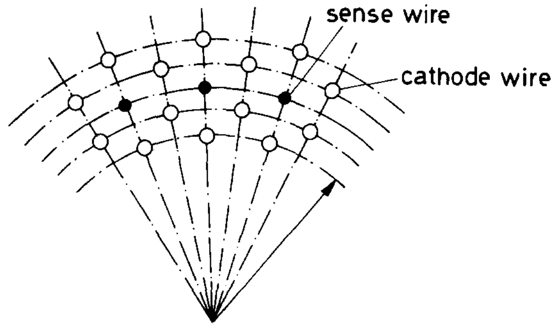

Fig. 1. Drift cell scheme.

indicated that 5–10% mixtures of propane in helium were self-quenching at reasonable gas gains, and a mixture of 93.8% helium and 6.2% propane with a radiation length of 2068 m was selected for further tests. Table 2 compares some of the measured and calculated properties of the PLUTO gas and the helium mixture.

3. The detector

The PLUTO drift chamber used in this study was designed to study e^+e^- reactions at PETRA. A detailed report on the construction and testing of this cylindrical multilayer drift chamber has been given elsewhere [1]. The inner length of the chamber is 97 cm, the diameter of the inner tube (beam pipe) is 26 cm, the outer diameter is 114 cm. The 4144 drift cells are arranged in 11 cylindrical layers with the wires parallel to the detector axis and 10 interleaved layers in which the cells are tilted with respect to the detector axis by $\pm 5°$ to provide stereoscopic reconstruction of track coordinates along the detector axis. Each drift cell is a hexagon with a central 20 μm thick sense wire (see fig. 1). The maximum drift distance is about 5 mm, varying slightly from layer to layer. The hexagonal structure was chosen because it gives a rotationally symmetric field in a large part of the cell together with an almost closed field structure (see fig. 2).

The drift chamber was operated in the normal PLUTO setup [4]. In addition to the drift chamber a

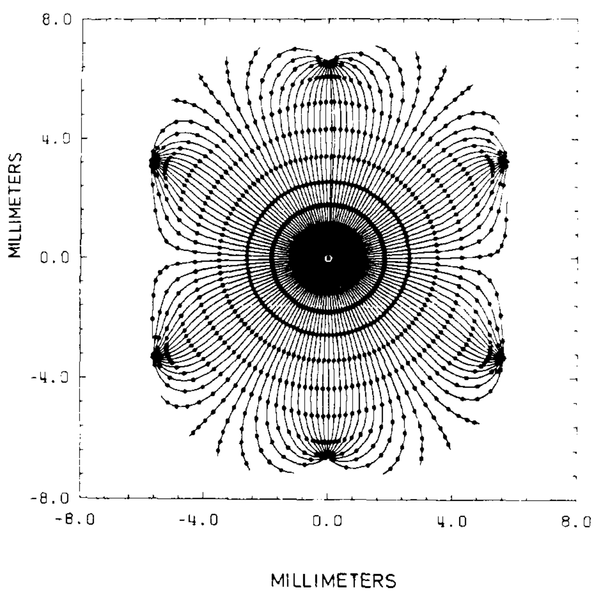

Fig. 2. Electric field structure in a single drift cell.

barrel of 60 lead–scintillator sandwich counters which surrounded the drift chamber in a double layer and a cylindrical scintillator mounted in the central beam pipe were used to provide a trigger signal from cosmic muons. The trigger consisted of two or more signals in opposite

Table 2
Comparison of the PLUTO gas and the helium mixture

Property	PLUTO gas	Helium mixture
Mixture	argon + propane + methylal	helium + propane
Relative abundance	0.900 : 0.085 : 0.015	0.938 : 0.062
Radiation length	115 m	2068 m
Calculated $\sigma(p)/p$ (1 MeV)	60%	10%
Counting plateau	1350–1500 V	1300–1450 V
Maximum drift time (5 mm)	200 ns	420 ns

quadrants of the barrel together with a signal in the central scintillator.

4. The operation of the drift chamber

The drift chamber was filled with the helium mixture at atmospheric pressure. It was operated either without magnetic field (cosmic data) or with a field of 100 G which was estimated to be the optimum for the reconstruction of particle tracks with momenta of the order of 1 MeV. All results presented in the following were derived using cosmic data.

4.1. High voltage setting

To operate the drift chamber, the high voltage across the drift cells should be adjusted to a value where every traversing particle gives a signal in the cell. In most gases the drift velocity is a function of the electric field strength and saturates at high fields. It is therefore favorable to choose the gas mixture, cell geometry and electronics such that a suitable gain is achieved at an operating potential high enough to provide a saturated drift field over most of the cell volume. In practice, we were forced by the existing electronics and cell geometry to simply vary the concentration of the quenching gas until a suitable gas gain could be achieved over a sufficient range of operating voltages to ensure stable operation of the chamber. Fig. 3 shows the high voltage plateau properties of one of the chamber layers. Plotted is the single counting rate for the layer (dots) as well as the efficiency of the layer for detecting minimum ionizing particles (squares). The chosen working point for the layer shown here is indicated by an arrow. As can be seen from table 2, the high voltage setting and plateau width are comparable to the PLUTO gas.

4.2. Space–time relation

The electronics used in this setup is described in detail in ref. [1]. The signals from the chamber wires were fed into preamplifiers working in saturated mode and from there into time-to-digital converters (TDC). The effective threshold represented a signal of 0.5 mV at the sense wire. The common stop signal for all TDCs was derived from the event trigger. Fig. 4 shows a drift time spectrum taken in a cosmic run. Combining these measured drift times with the drift distances calculated from track fits yields the space–time relation in an iterative procedure. This relation, after four iterations, is shown in fig. 5.

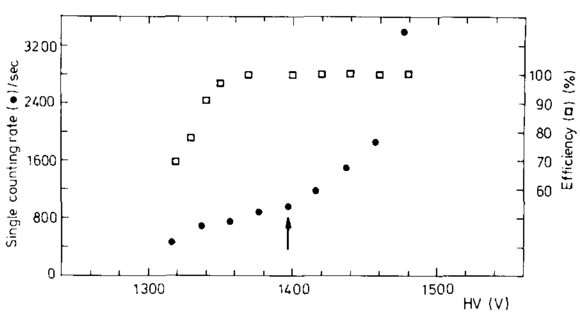

Fig. 3. Plateau curve and working point.

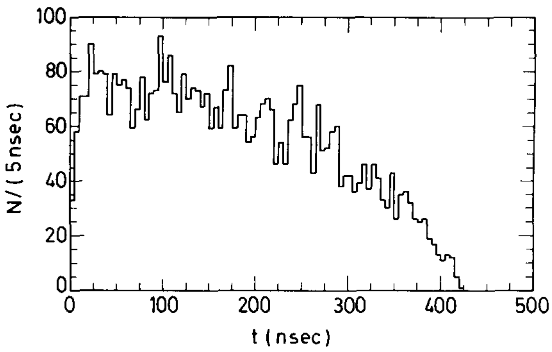

Fig. 4. Drift time spectrum.

4.3. Drift velocity w(E)

From the space–time relation $d(t)$ we can derive the drift velocity $w=\delta d/\delta t$. The dependence of the drift velocity w on the field strength E is shown in fig. 6 for three of the chamber layers. For a perfect calibration of the detector all these data should fall on the same curve. During the analysis the data could be seen to converge around such a curve for subsequent iterations.

The drift velocity increases rapidly as a function of the field strength up to fields between 300 and 400 V/cm. Beyond 400 V/cm the velocity slowly rises to a value of the order of 2.0 cm/μs for high values of E.

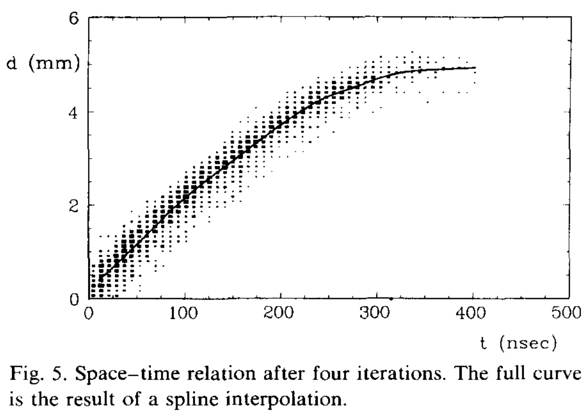

Fig. 5. Space–time relation after four iterations. The full curve is the result of a spline interpolation.

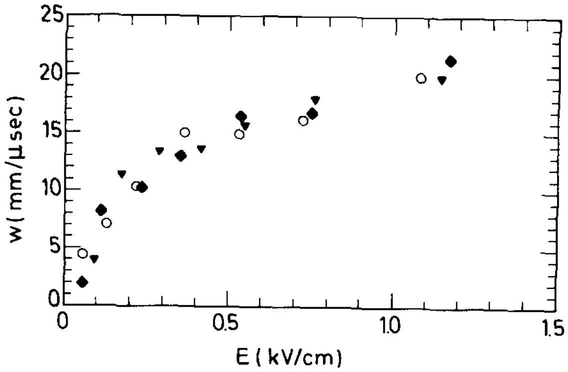

Fig. 6. Drift velocity as a function of the electric field.

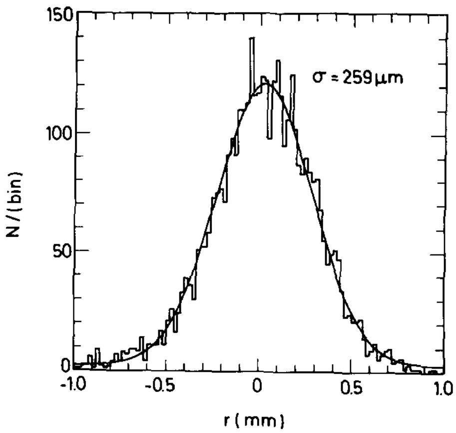

Fig. 7. Distribution of the difference between measured and fitted coordinates in a typical chamber layer.

The drift velocity does not saturate at the highest electric fields tested in this study. The absolute value of the drift velocity at high fields, however, is small compared to the saturated drift velocities of typically 5 cm/μs in commonly used gases [8,9]. A small increase in the fraction of quenching gas might be expected to provide a saturated drift velocity in our helium mixture [10,11].

4.4. Spatial resolution

The spatial resolution of drift chambers operated at atmospheric pressure is mainly limited by two factors [12,13]:
- the fluctuation of the primary ionisation density, and
- electron diffusion.

A measure of these influences can be obtained by fitting tracks to the recorded wire hits in cosmic runs. The spatial resolution σ is obtained by computing the standard deviation of the difference between the measured and fitted coordinates. Such a distribution is shown in fig. 7. Table 3 shows σ for the layers 2 to 10 of the drift chamber.

Table 3
Spatial resolution as computed in different layers

Layer	Spatial resolution σ [μm]
2	255
3	260
4	250
5	259
6	231
7	245
8	249
9	290
10	229

The statistical errors on these data are negligible. The systematic error stemming from calibration uncertainties and the correlations introduced by the fitting procedure were estimated to be 40 μm. For comparison, the spatial resolution achieved with the PLUTO mixture was 150 μm [3]. Plotting the spatial resolution as a function of the impact parameter b separates the influence of primary statistics (small b) from diffusion (large b). This relation is shown in fig. 8. No significant degradation in resolution due to diffusion is observed.

Using the spatial resolution and the radiation length of the gas, a measure for the influence of multiple scattering on the momentum measurement can be obtained. The momentum resolution of the drift chamber has two contributions. The first contribution is introduced by measurement errors on the coordinates of the track points and dominates the momentum resolution at high momenta. The second is due to multiple Coulomb scattering in the gas. If we define p_0 as the particle momentum for which these contributions to the momentum resolution are equal, multiple scattering is

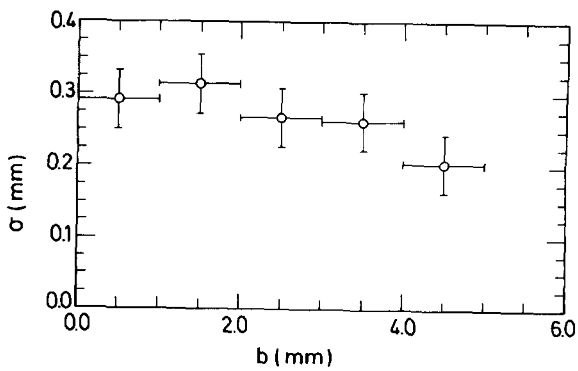

Fig. 8. Spatial resolution as a function of impact parameter.

the limiting contribution for momenta below p_0. For our mixture p_0 is of the order of 100 MeV/c compared to 400 MeV/c for a gas mixture with the same spatial resolution and a radiation length of 100 m.

To conclude, we have shown that it is possible to operate a large drift chamber with a gas mixture consisting of helium and propane. With its radiation length of 2068 m the influence of multiple Coulomb scattering on the measurement at low momenta is strongly reduced. This gas is therefore especially well suited for experiments at SPEAR and DORIS where most of the measured particle momenta are below 1 GeV/c. Although the spatial resolution obtained with this gas mixture is inferior to resolutions obtained in heavier gases [14,15] it could still be interesting for experiments with high synchrotron radiation background. In a carefully built drift chamber our data indicate that a spatial resolution on the order of 200 to 250 μm is achievable. This value can be improved by using the gas at higher pressure [16] without losing much of the low Z advantages. Another important feature of this gas is the very low drift velocity of 2.0 cm/μs at high electric fields which makes its use in a chamber with multihit readout [8] attractive.

Acknowledgments

We thank the DESY directorate for the kind hospitality extended to us. We are especially grateful to the DESY-group F33 for helping us operating the detector. We are thankful to all technicians and engineers, especially the Hallendienst, who helped us setting up the apparatus.

References

[1] K. Derikum and H. Müller, DESY internal report PLUTO 85-01 (1985).
[2] H. Müller, Diplomarbeit, DESY internal report PLUTO 83-07 (1983).
[3] D. Heidorn, Diplomarbeit, DESY internal report PLUTO 84-02 (1984).
[4] L. Criegee and G. Knies, Phys. Rep. 83 (1982) 153.
[5] W. Heitler, The Quantum Theory of Radiation (Oxford University Press, Oxford, 1957).
[6] V. Palladino and B. Sadoulet, Preprint LBL-3013 (1974).
[7] Particle Properties Data Booklet (1984).
[8] J.A. Jaros, SLC-Workshop Note #51.
[9] Proc. SLC Workshop on Experimental Use of The SLAC Linear Collider, Stanford (1982).
[10] A. Peisert and F. Sauli, CERN Report CERN 84-08.
[11] F. Sauli, CERN Report CERN 77-09 (1977).
[12] F. Sauli, Nucl. Instr. and Meth. 156 (1978) 147.
[13] A.H. Walenta, Preprint Siegen Si-83-23 (1983).
[14] F. Villa, Preprint SLAC-PUB-3037 (1983).
[15] V. Comminchau et al., DESY 84-049 (1984).
[16] W. Farr et al., Nucl. Instr. and Meth. 154 (1978) 175.