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PRECISE MEASUREMENTS OF DRIFT VELOCITIES IN HELIUM GAS MIXTURES

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Abstract

A facility for high precision measurements of the transport parameters of electrons in gases has been built and operated. Two UV lasers and a radioactive source have been used to induce ionization in a gas volume where a uniform electric field is maintained. Drifting electrons are collected by a proportional wire. The details of the experimental apparatus are given together with some measurements of drift velocities in helium-isobutane and helium-methane gas mixtures.

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1. Introduction

Since the first suggestions of using helium as the primary component of drift chamber gas mixture [1,2], helium based gases have become object of large interest [3 -12]. Despite of high ionization potential, low primary ionization and large single electron diffusion, which are their main disadvantages, helium mixtures offer the possibility of measuring charged particle momenta with high resolution down to very low values, thanks to the strong reduction of the multiple Coulomb scattering (X_0(He) = 5299 m, ~ 50 times larger than X_0(Ar)). Moreover, helium has a low sensitivity to background X-rays from synchrotron radiation, because of its small photon absorption cross section. These features, together with the fact that safety and gas purity problems do not allow the use of hydrogen, which has even a larger X_0 , make helium the most promising gas candidate for tracking detectors operating in experiments at B, τ/charm and ϕ factories.

The main purpose in investigating helium mixtures with hydrocarbons is to keep the helium advantages in resolution by improving operation stability, drift velocity and primary ionization statistics and by reducing electron diffusion with the addition of reasonable amounts of organic components.

In this paper we describe an experimental set-up designed for the measurements of the transport parameters in a gas with high accuracy. We present and discuss results from drift velocity measurements obtained with this set-up in helium-isobutane and in helium-methane gas mixtures.

2. Description of the apparatus

Two schematic views of the set-up, which allows for simultaneous measurements of the electron transport parameters in any gas mixtures, are shown in Fig. 1.

The gas is contained within the cylindrical volume of a Plexiglas cavity (13 cm diameter × 20 cm length), in which a homogeneous electric field is produced longitudinally by an array of annular copper plates, accurately placed at distance of 1 cm from each other. Quartz windows are provided for the entrance of the UV light and calibrated holes are placed on opposite sides of the chamber to allow for the passage of β-rays.

The drifting electrons are detected by a proportional counter after passing through a 3 mm slit, which provides a good separation between the constant field in the drift region and the amplification field inside the counter. The proportional counter is made of a 2.4 cm diameter tube, on whose axis a 25 μm diameter gold plated tungsten wire is placed and instrumented by a fast, charge sensitive preamplifier (Phillips, Mod. 6974).

The gas mixture is set by means of mass flowmeters (MKS, Mod. 1259B) and monitored by a flow controller (MKS, Mod. 147B). The gas system is designed in such a way to allow rapid changes in the gas composition. The gas is continuously circulated through the chamber volume at a rate of 200 scc/min. The accuracy on the gas composition is estimated to be 0.1% in the case of helium-isobutane mixtures and 0.3% for helium-methane mixtures.

The absolute and relative gas pressures are monitored by the MKS BARATRON system within an accuracy of 0.1 torr, while the gas temperature and relative humidity are measured within 0.1 °C and 1%, respectively.

Purities of the gas used, as provided by the suppliers, are: helium 99.999%, isobutane 99.95%, methane 99.5%.

A system of three stepping motors, equipped with an electronic motion controller allows micrometric motions of the cell and of some optical elements. The drift cell can be moved along the parallel and transverse directions to the laser beam (respectively y and x axes in Fig. 1) with an accuracy of 3 μm. The laser beam can be translated along the z axis by means of a periscope. A lens, 15 cm focal length, is mounted solidal to the periscope. The drift distance from the proportional tube can be

varied between 3 cm and 10 cm, by focusing the laser in different positions along the x direction.

Ionization is induced in the cell by using two different UV lasers: a) XeCl laser operating at 308 nm [13]; b) N_2 laser (Laser Photonics, Mod. LN120C) at 337 nm. c) A ^{90}Sr β source is used to cross-check the results obtained with the lasers.

a) The XeCl excimer laser has a pulse width of 8 ns and a maximum energy output of about 2 mJ, when extracted by a plane-parallel resonator. A variable collimator is placed on the laser path to the drift cell to obtain a sharp edged beam. The beam is focused in the yz plane at the centre of the slit, where the size of the beam, as measured with a set of calibrated pinholes, is less than 100 μm.

b) The nitrogen laser has a 300 ps pulse duration, 70 μJ pulse energy output and operates at a maximum repetition rate of 20 Hz. A diaphragm in front of the laser reduces the beam spot size to 3 mm. The beam waist, after the converging lens, is about 60 μm and the ionization region even smaller, since the ionization probability depends quadratically on the UV intensity.

c) A collimated (0.3 mm diameter) ^{90}Sr source (10 mCurie activity) produces an electron beam along the z direction (as shown in Fig. 1). The electrons ionize the gas in the drift region and are detected by two scintillation counters closely placed under the chamber. Their coincidence provides the start signal for the measurement of the drift time. The source can be placed at different positions along the x axis, corresponding to different drift distances.

A fraction of the laser beam is reflected from a quartz beam splitter just in front of the drift cell and directed towards a fast phototube (Hamamatsu, Mod. R1328U-02, 60 ps of risetime), the signal of which is used as a start for the drift time measurement. The stop signal is given by the discriminated proportional counter

signal. The discriminator threshold is set such that the first arriving electron will generate the stop signal. A time to digital converter (LeCroy, Mod. 2228A) is used to digitize the time differences Δt between start and stop.

The Labview acquisition package [14] has been used for the acquisition and the on-line monitoring of the data taking.

Downstream of the chamber, a joulemeter measures the laser beam energy of each pulse, to correct for fluctuations in the beam intensity during the measurements.

3. Experimental procedure and results

At the focus, the UV light produces electron clusters essentially by ionizing impurities in the gas via multi-photon absorption processes. These electrons, after drifting through the uniform field region, cross the slit and are detected by the proportional wire.

Because of the fluctuations in the number of electrons within a cluster and since only the first electron is detected by the counter, the drift time distribution Δt, for any given value of the electric field, drift distance and gas mixture, is a weighted convolution of gaussians with different mean values and widths, as shown in Fig. 2. The mean value $<\Delta t>$ of such a distribution is systematically shifted with respect to the corresponding one observed in the case of single electron ionization. The shift depends on the average cluster size, on the drift distance and on the longitudinal diffusion coefficient in the gas.

The differences ΔT between each arrival mean time and that relative to a reference drift distance have been plotted versus the differences ΔL between the corresponding drift paths. The drift velocity w, for any given value of the drift field, has been obtained as the slope of the fitted straight line of the ΔL values versus the different ΔT (usually a set of 7 or 8 values has been used in the fit).

It must be stressed that this method, based on a computation of differences in space and time, cancels out indeterminations due to: field uncertainties and boundary

effects near the counter, non linear effects in the gain of the preamplifier, time resolution of the detector and the initial spread of the electron "cloud", uncertainties on the absolute positions of the electrodes in the chamber (the only error on the drift distance comes from the precision in the positioning of the cell), provided that the electric field is homogeneous in the chamber. Furthermore, the effect of the systematic shift in the mean arrival time discussed above, due to the distortion of the Δt distribution, is minimized and contributes at most with an error of 0.5% to the drift velocity determination, as results from Monte Carlo calculations.

The obtained results are reported in Table 1 and shown in Fig. 3 (a) and 3 (b) for the investigated helium-isobutane and helium-methane gas mixtures, respectively. The curves represent Monte Carlo predictions computed by solving the Boltzmann transport equation of the electron motion in the electric field [17]. Space uncertainties on the translation of the drift cell, time uncertainties from the fit to the Δt distribution and small pressure and temperature fluctuations during a single measurement contribute to the total error on the drift velocity value at the level of few tenths of a per cent, while uncertainties on the electric field given by the power supply are estimated to be at most of the order of 1%. Uncertainties due to the misalignment of the optical system with respect to the chamber are negligible. All measurements have been performed at room temperatures and in normal conditions of pressure.

For comparison, published data [3] for some of these mixtures are shown in Fig. 4. It can be observed that our results are consistent with both the Monte Carlo calculation and these data.

4. Remarks

As far as the longitudinal and transverse diffusion coefficients determination is concerned, the distortion of the time distribution, which results from the detection of the first arriving electron, does not allow the correct evaluation of its spread due to the diffusion effects. We are going to obtain optimal laser conditions in such a way

that the mean number of electrons per pulse reaching the counter is close to one, in order to perform diffusion measurements not affected from the systematic error described above.

As is shown in Fig. 3, the drift velocity in the helium based mixtures is low (2 or 3 times lower than in the corresponding argon mixtures) also at high fields, thus helping to reach better spatial resolution and two track separation under the same conditions of speed and complexity of the electronic readout.

The choice of a gas mixture for a tracking device at B, ϕ or τ factories is driven by the optimization of a set of parameters like the drift velocity, the number of primary electron per cm, the diffusion coefficients, the radiation length and, mainly, the stability versus the electric field.

The molecular gases used here to combine with helium and the gas percentages have been chosen in order to keep the radiation length at high values. Among the investigated mixtures, 95% helium-5% isobutane and 90% helium-10% methane give marginal conditions of stability during operation. The 15% isobutane mixture exhibits both a good efficiency plateau and high ionization statistics [18], but doesn't offer major advantages with respect to multiple scattering in standard argon based mixtures. The remaining two mixtures, 80% helium-20% methane and 90% helium-10% isobutane, are both very promising as far as diffusion [3] and stability are concerned. The first one offers a larger radiation length (about a factor 2) than the second one, though it seems less advantageous from the primary ionization point of view [18].

5. Conclusions

We have described an experimental set-up that enables to measure the transport parameters of electrons in several gas mixtures over a wide range of electric field and with high accuracy. We have chosen helium with hydrocarbons as counting

gas in order to investigate gas mixtures for tracking detectors operating in the range of particle momenta below than 1 GeV/c.

Drift velocity measurements have been performed and work is in progress on tuning the apparatus conditions for the determination of the diffusion coefficients.

Results on drift velocity are in good agreement both with Monte Carlo calculations and with published data.

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Table 1 - Drift velocities (cm/μs) for all the investigated gas mixtures

E (V/cm)	15% isobutane	10% isobutane	5% isobutane	20% methane	10% methane
250	1.127±0.014	1.054±0.011	1.055±0.010	1.330±0.013	1.122±0.010
500	1.848±0.017	1.671±0.017	1.517±0.010	2.005±0.016	1.624±0.011
750	2.284±0.014	2.037±0.013	1.711±0.006	2.406±0.013	1.831±0.007
1000	2.528±0.013	2.243±0.012	1.749±0.022	2.542±0.010	1.890±0.014
1250	2.768±0.022	2.371±0.023	1.824±0.021	2.659±0.008	1.953±0.044

Figure captions

Fig. 1 Top (a) and side (b) views of the experimental set-up.

Fig. 2 Typical drift time distribution at given values of the electric field and of the drift path. The fit is done with two gaussians to take into account the distortions described in the text.

Fig. 3 Drift velocity as a function of the reduced electric field in mixtures of helium-isobutane (a) and helium-methane (b). The curves represent Monte Carlo predictions [17].

Fig. 4 Drift velocity in helium-isobutane and helium-methane compared with published data [3]. The drift velocity values in the 85% helium-15% isobutane gas mixture are obtained interpolating the results for the 86% helium-14% isobutane and 90% helium-10% isobutane mixtures given in Ref. [3].

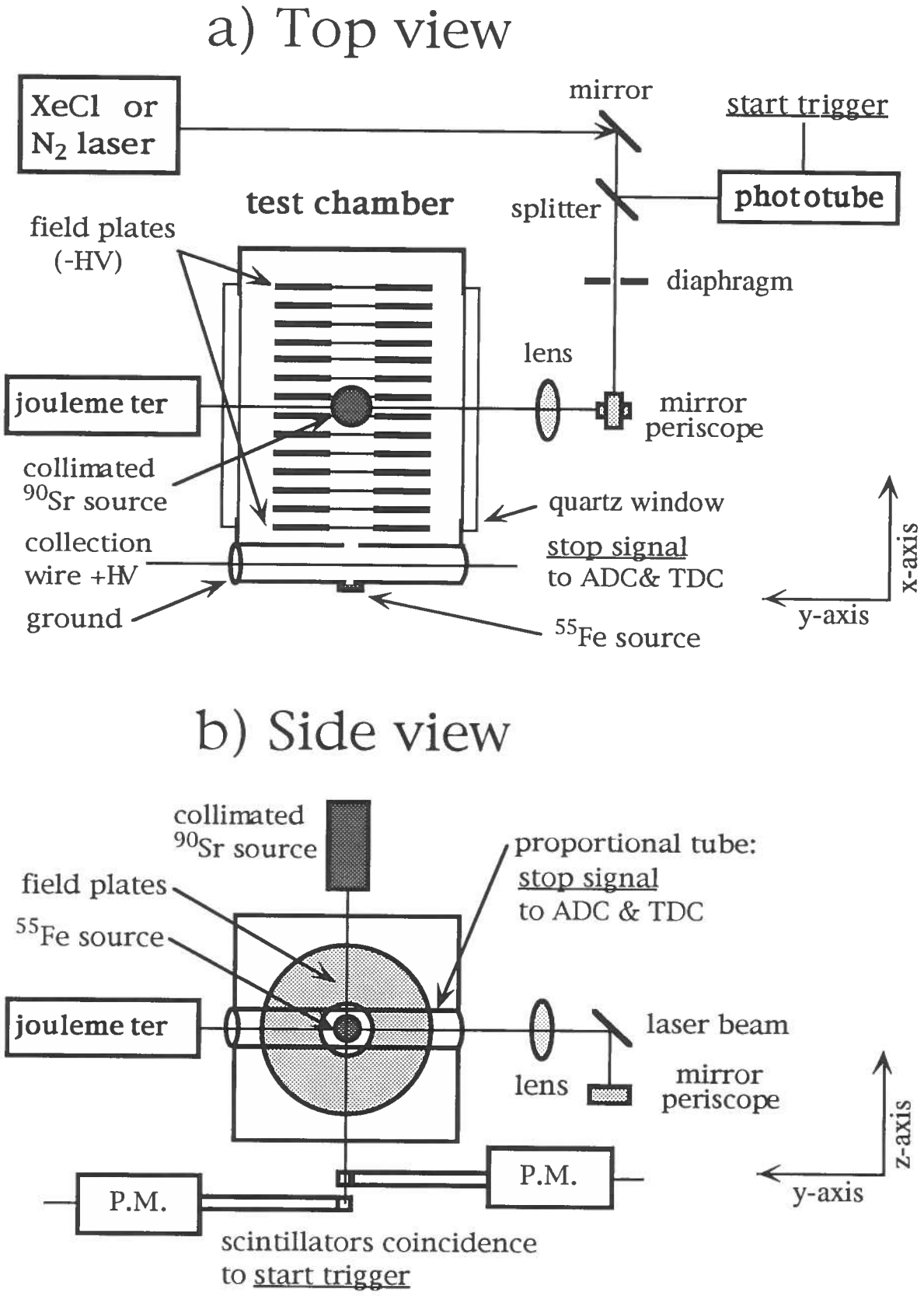
a) Top view
XeCl or N_2 laser
mirror
start trigger
phototube
splitter
test chamber
field plates (-HV)
diaphragm
lens
joulemeter
mirror periscope
collimated ^{90}Sr source
quartz window
collection wire +HV
stop signal to ADC& TDC
ground
^{55}Fe source
x-axis
y-axis
b) Side view
collimated ^{90}Sr source
proportional tube: stop signal to ADC & TDC
field plates
^{55}Fe source
joulemeter
laser beam
lens
mirror periscope
z-axis
y-axis
P.M.
P.M.
scintillators coincidence to start trigger

Figure 1

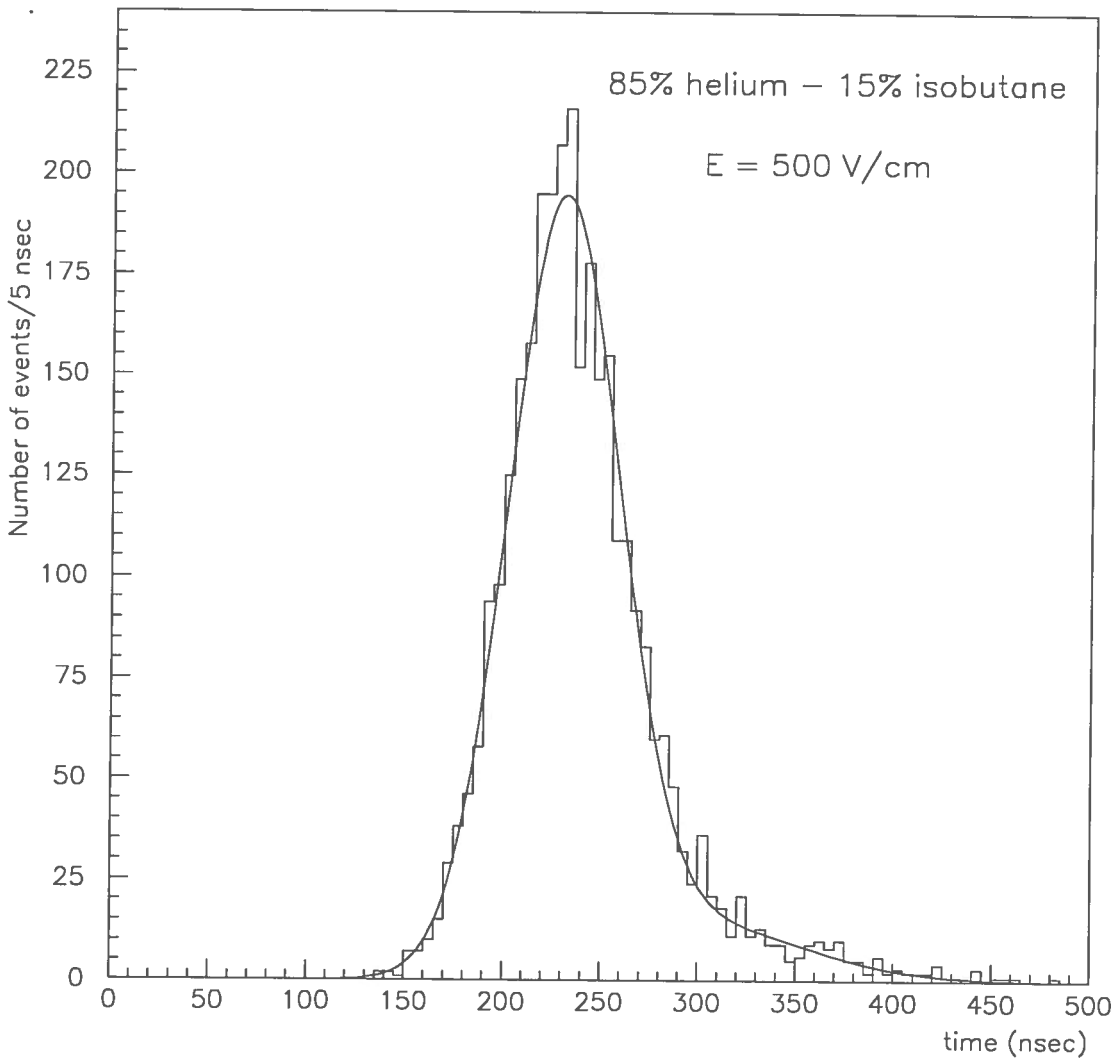
85% helium – 15% isobutane
E = 500 V/cm
Number of events/5 nsec
time (nsec)
0
25
50
75
100
125
150
175
200
225
0
50
100
150
200
250
300
350
400
450
500

Figure 2

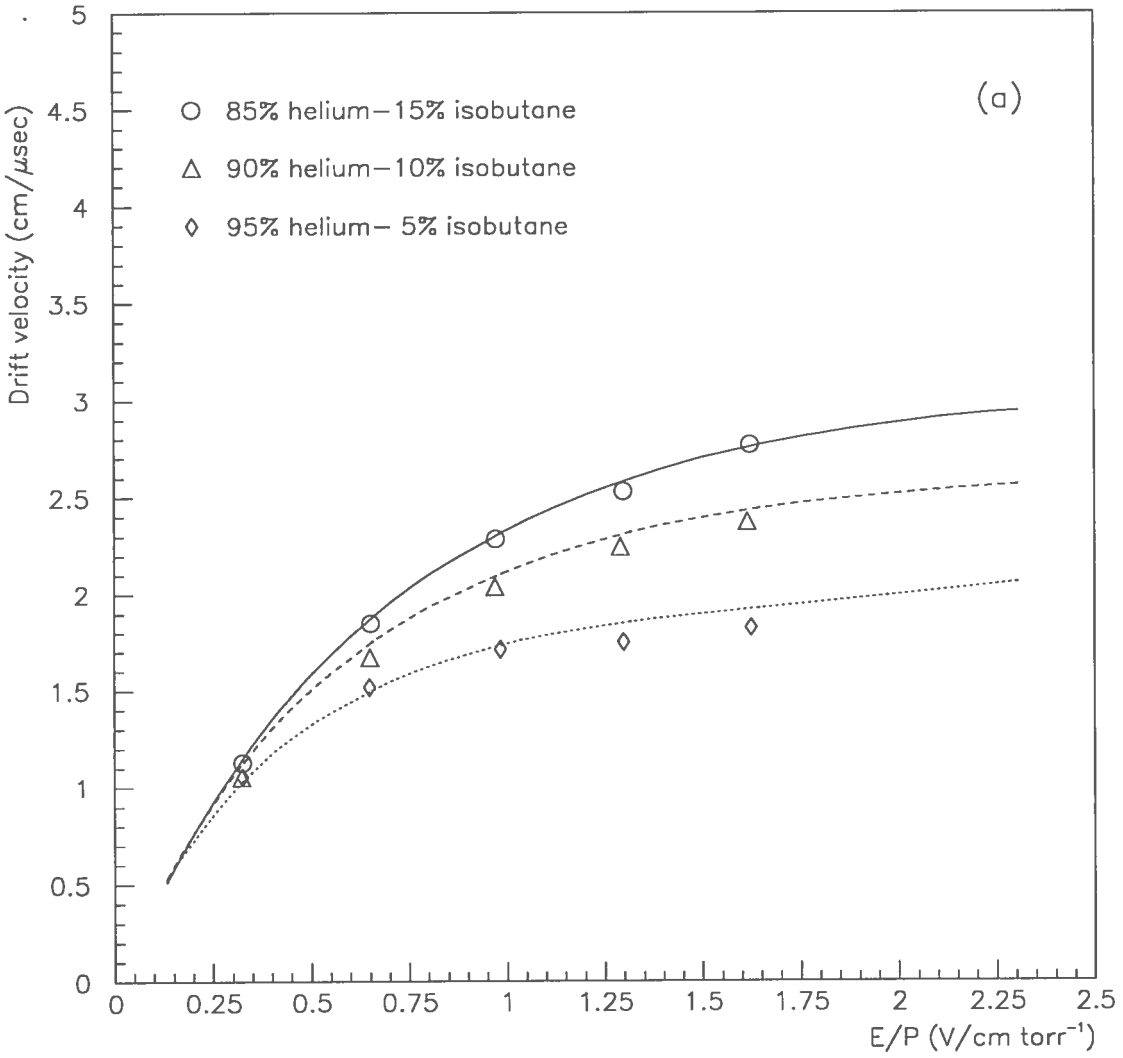
Drift velocity (cm/μsec)
E/P (V/cm torr⁻¹)
85% helium–15% isobutane
90% helium–10% isobutane
95% helium– 5% isobutane
(a)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
0.25
0.75
1.25
1.75

Figure 3 (a)

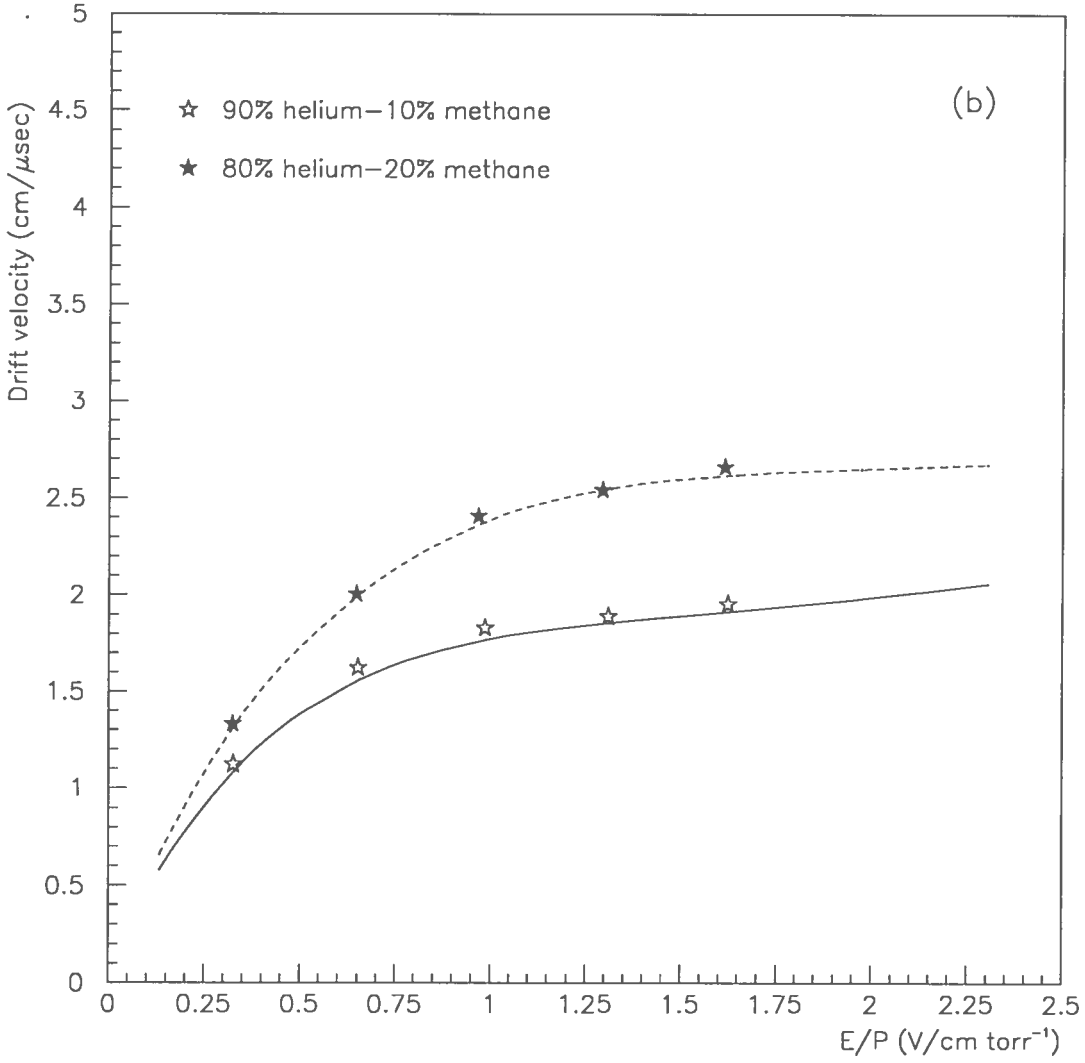
(b)
☆ 90% helium–10% methane
★ 80% helium–20% methane
Drift velocity (cm/μsec)
E/P (V/cm torr⁻¹)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
0.25
0.75
1.25
1.75
2.25

Figure 3 (b)

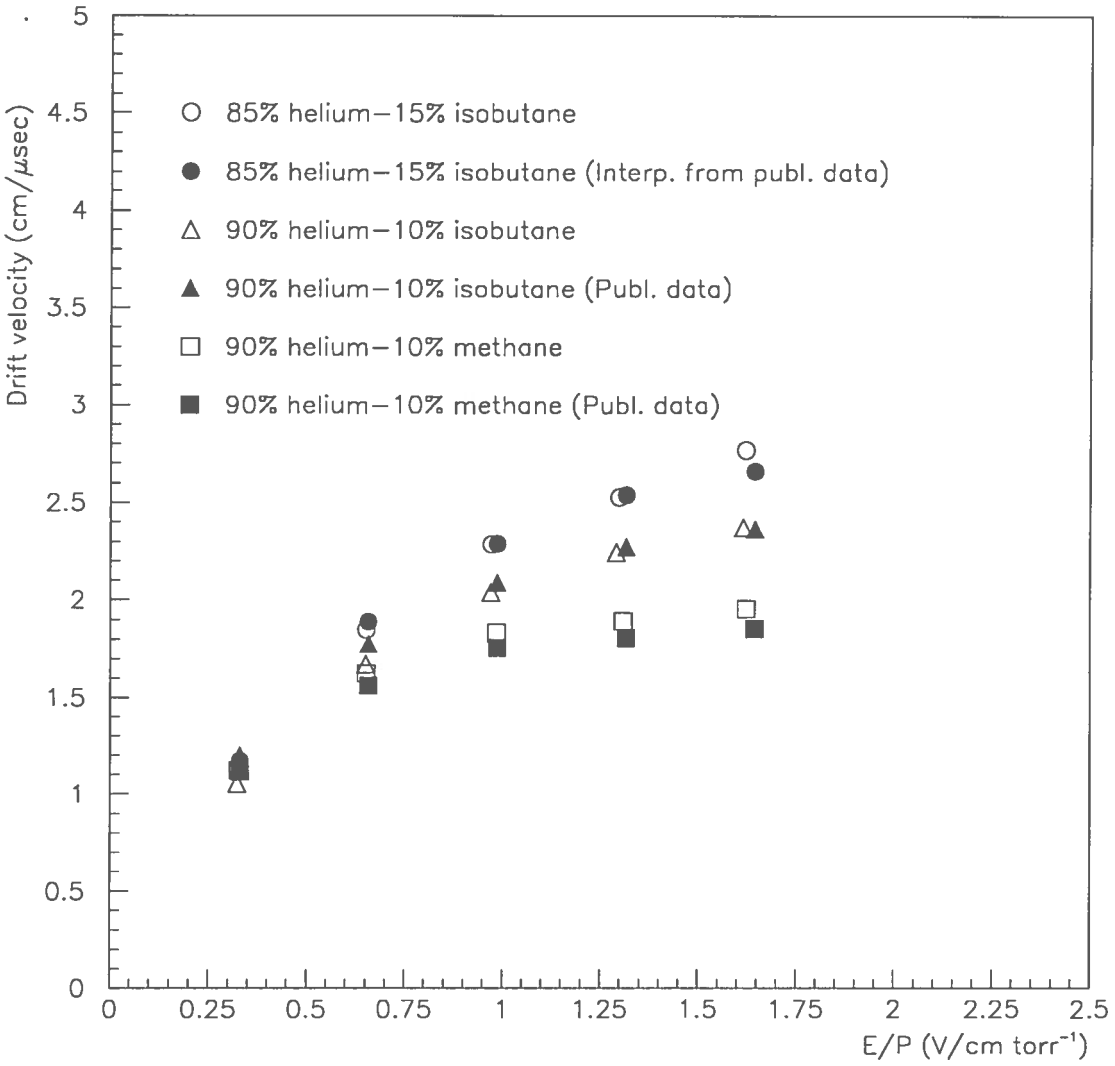
Drift velocity (cm/μsec)
E/P (V/cm torr⁻¹)
85% helium–15% isobutane
85% helium–15% isobutane (Interp. from publ. data)
90% helium–10% isobutane
90% helium–10% isobutane (Publ. data)
90% helium–10% methane
90% helium–10% methane (Publ. data)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
0.25
0.75
1.25
1.75
2.25

Figure 4