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DRIFT CHAMBERS WITH CONTROLLED CHARGE COLLECTION GEOMETRY
FOR THE NA34/HELIOS EXPERIMENT

D. Bettoni¹, K.H. Dederichs¹, H. En'yo¹, C.W. Fabjan¹, F. Piuz¹, V. Radeka³,
G. Roiron¹, R. Roosen¹, A. Rudge¹, R.J. Veenhof², T.D. Williams¹ and W.J. Willis¹

- ¹ CERN, European Organization for Nuclear Research, Geneva, Switzerland
- ² CERN summer student from Rijks Universiteit Leiden, Netherlands
- ³ Brookhaven National Laboratory, Upton, NY, USA

ABSTRACT

We report on the design and performance of a set of drift chambers for the NA34/HELIOS experiment at the CERN SPS. The chambers are operated with CO₂ at low drift velocity and have a field geometry allowing a controllable track sample length and isochronous charge collection. In beam tests using a silicon microstrip hodoscope as external track reference, we measure a two-track separation of 600 μm and, at a drift velocity of 8.9 $\mu\text{m}/\text{nsec}$, an absolute single track precision of 60 μm on average over the total drift distance of 20 mm. The influence of the track sample length on the chamber performance is studied and a value of 2.5–3.0 mm is found as an optimum.

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1. INTRODUCTION

The NA34 experiment (HELIOS) studies single leptons and pairs produced in proton-nucleus collisions at a beam energy of 450 GeV at the CERN SPS [1]. In order to identify short lived particle decays, a part of this apparatus, the electron spectrometer, is instrumented to provide both accurate vertex reconstruction and momentum measurement of the charged secondary particles (fig. 1). The physical aims require an angular resolution of less than 0.1 mrad and a two-track separation of better than 1 mrad along the 3 m length of the electron spectrometer.

These demands are severe for the present day performance of gaseous detectors. Covering an angular acceptance of $\pm 6^\circ$, less than 100 μm as single track precision and 600-800 μm two-track separation are required in a high track density environment.

Our previous prototype tests [2] as well as other developments [3,4] have demonstrated that this level of precision can be obtained by making use of the following features:

- the use of a "cool" gas mixture (CO_2 and small quenching admixtures) allowing low drift velocity of about 10 $\mu\text{m}/\text{nsec}$ and diffusion around the thermal limit at appropriate E/p-values,
- controlled drift geometry achieving the collection of a fraction of the primary ionisation deposit in a minimum time interval at the sense-wire ("isochronous charge collection"),
- adapted fast electronic shaping of the pulse followed by low level discrimination (with a sensitivity corresponding to 1-2 electrons) or wave form digitizers.

This paper reports on the three drift chambers (DC1, DC2 and DC3) used in the electron spectrometer at HELIOS. In the first part we describe the drift cell layout with controlled charge collection, chamber design and construction and the associated electronics.

A prototype and DC1 were tested at the CERN SPS using a silicon microstrip hodoscope as external track reference; this allowed an accurate study of the cell behaviour with single and multi-track events as well as easy control of systematic effects. The second part of this paper contains results on the mapping of drift-time to -distance ("x(t)-") relations, single track precision, two track separation and the influence of drift velocity and controlled charge collection on the performance of the chamber.

2. CONTROLLED CHARGE COLLECTION

The principle of controlled charge collection is illustrated in fig. 2. The sensitive track sample length per wire can be adjusted by changing the potential V_C of the two channeling wires (C) placed on each side of a sense-wire (S). The lower the absolute value of V_C , the smaller is the track sample length. A reduced sensitive length offers various advantages. The charge collection becomes more isochronous (fig. 2(b)) because the electrons on trajectories with longer drift times are directed to the insensitive channeling wires. Consequently the space interval in drift direction corresponding to the collection time becomes narrower and the signals of two close tracks can be better separated. In addition, the space charge is reduced since the channeling can prevent a fraction of the ions from reaching the drift region. Furthermore, calculations with a simulation program [5] show, that space-drift time relations become less dependent on the track angle by reducing the sample length.

This channeling principle can be most easily implemented in a "jet-type" drift cell structure (fig. 3). This layout allows an almost independent optimization of track sample length, amplification and drift velocity by adjusting the voltages on channeling (V_C), potential (V_P) and cathode wires (V_d). Since the gas gain is controlled by both, V_C and V_P , the latter is used to keep the amplification constant while varying the sample length. The linear dependence of the electric field on the wire surface on V_C and V_P can be deduced from the simulation program [5]; it is also easily measured with an Fe^{55} -source collimated orthogonally to the drift direction. The measurements with a source also determine directly threshold sensitivities, electron capture (pulse-height variations as function of the drift distance) and track sample length (proportional to the counting rate). The results are in good agreement with the program predictions.

Operating voltages for DC1 are around the following values: $V_d = -4000$ V, $V_C = -2000$ V, $V_P = -3100$ V; the difference in V_C for the two settings in fig. 2 is 500 V.

The efficiency of controlled charge collection is closely related to the operation with a slow drift gas. Mixtures of CO_2 with 5-10 % of C_2H_6 at atmospheric pressure are used in a non-saturated field range of 0.9-1.7 kV/cm, corresponding to drift velocities of 8-15 $\mu m/nsec$. Adding 10% of C_2H_6 increases the gas amplification by a factor of 2.8 compared to pure CO_2 , allowing a sensitivity of 1-2 primary electrons at an electric field of $E_s = 370$ kV/cm at the wire surface.

3. DESCRIPTION OF THE CHAMBERS

3.1 Layout and construction

In order to allow a track measurement in several projections a chamber (fig. 4(a)) is organized as a succession of "modules". Each module samples a segment along the track, whose length is proportional to the number of sense wires (6 or 8) and whose projection is given by the azimuthal orientation around the beam. Five orientations were selected according to the Monte-Carlo optimization of the pattern recognition: 0° , 90° , 45° , -45° , 15° (x,y,u,v,w) [6].

A module, further segmented in a number of drift cells, covers the necessary acceptance and measures one projection (fig. 4(b)). The high interaction rate ($10^5/\text{sec}$) with large multiplicity in the forward direction in combination with the use of a slow gas mixture imposes a high segmentation into drift cells of maximum drift length of 21 mm.

In order to ensure optimum field homogeneity inside such short cells, every module is closed by a double layer of field wires set at graded potentials. Grounded layers between adjacent modules minimize the field perturbations along the sense wires arising from the different orientations of the two modules.

The chambers need to be insensitive to the non-interacting beam particles (beam rate: 10^6 protons/sec). This is achieved with a narrow slit in the middle of a module made of a double layer cathode between the two cells on each side of the beam. According to calculations with a simulation program [5] the wires of these cathodes are spaced in such a way that all charge created along the direct beam passage is entirely collected at the passive channeling wires (see details in fig. 3).

Table 1 summarizes the composition of DC1, DC2, DC3 and the prototype model.

Each chamber body is an assembly of aluminium flanges glued together with side plates made of a mixture of araldite and alumina powder. Wires are located by feedthroughs inserted into holes drilled in the side plates. Flat edges accurately machined on the flanges serve as reference for the glueing and the drilling of locating holes. The drilling (16000 holes in case of DC3) is performed with the complete chamber body placed on a numerical controlled machine, ensuring high precision in relative position and orientation.

According to a method described in sect. 4.2, the positions of 384 sense wires were measured in DC1. The positioning error, shown in fig. 5, is about 25 μm , originating from the drilling precision and the non-uniform location of the 20 μm wires inside the 100 μm crimp pins.

Thermistors inside the chamber body and pressure transducers allow the recording of temperature and pressure for off-line corrections of the drift velocity.

3.2 Electronics and readout

The electronic readout scheme is shown in fig. 6. The hybrid preamplifiers [7] are characterized by a low noise of 2300 electrons equivalent (at 100 nsec shaping time constant) and a risetime of less than 1 nsec. They are mounted in groups of 8 on a motherboard directly on the chamber. The signals are transmitted via 5 m long coaxial cables to a two-stage shaping amplifier [7] performing cable clipping (2 nsec) for the preamplifier fall time cancellation and $1/t$ -compensation of the ion tail. The output signal is quasi-gaussian with a base line width of 30 nsec, driving a LeCroy MVL 407 discriminator. A sensitivity corresponding to one primary electron can be achieved. The drift time is digitized using the CERN DTR system [8] and the pulse height by LeCroy 2282 ADCs after 150 nsec bipolar shaping [9].

4. BEAM TEST MEASUREMENTS AND RESULTS

The prototype chamber and DC1 were tested at the CERN SPS using pion and proton beams with momenta of 100–350 GeV/c. The prototype test aimed to study the cell design and to optimize the operating conditions. DC1 was scanned before physics data-taking in order to measure the $x(t)$ -relations and individual positions of all wires as well as the internal chamber alignment.

4.1 Test set-up with silicon strip detector hodoscope

When operating a jet type drift cell with a non-saturated gas like CO_2 , the drift velocity changes significantly over the drift distance and is in addition affected by temperature and pressure variations. A mapping of the $x(t)$ -relations over the full drift range is necessary for all wires. To obtain these relations the distances are measured with an external hodoscope and directly correlated with the time measurements in the drift chamber.

The test set-up, shown in fig. 7, consists of an array of silicon microstrip detectors (MSD), previously used at the CERN WA75 experiment and described in [10]. Thirteen planes with 200 strips per plane of 50 μm pitch were orientated in 4 different projections x, y, u, v ($0^\circ, 90^\circ, -45^\circ, 45^\circ$) to provide full spatial track information. In order to scan the entire drift chamber with the restricted MSD-acceptance of $10 \times 10 \text{ mm}^2$, the chamber was mounted on a movable stage with micrometer readout (Heidenhain) accurate to better than 5 μm . The stage could be rotated about the vertical axis to allow studies of inclined tracks.

With this set-up, the overall precision in the prediction of the impact point in the drift chamber is about 20 μm .

Multi-track events were produced in an aluminium target of 2% interaction length placed about 30 cm in front of the drift chamber. A set of silicon plate counters (TRIG2 and TRIG3) measuring the total dE/dx allowed a selective trigger on single track or interaction events.

The timing signal of the incoming particle was taken from a set of scintillation counters, equipped with light diodes to check electronically the time offsets in combination with the pulsing of the preamplifiers.

4.2 x(t)-relations

A typical example of the correlation between measured drift time and drift distance predicted by the MSDs is shown in fig. 8. The parametrization of $x(t)$ is done with a set of about 50 points (x_i, t_i) along the correlation curve. Interpolation between nearest points provides the space information associated to a measured time value. These (x, t) pairs are determined by partitioning the drift distance axis in slices of typically 200 μm width and calculating mean values $(\bar{x}_i, \bar{t}_i)$ of all events (at least 40) within each slice. These points are refined in a second pass eliminating spurious hits and reducing the statistical errors by a smoothing algorithm based on spline fits. The two sides of the drift are treated independently. With this method the error in the $x(t)$ -relation determination can be reduced to 2 nsec, corresponding to 20 μm .

In general, all $x(t)$ -relations have a similar shape. In the region close to the sense-wire, the drift velocity is very high ($> 50 \mu\text{m}/\text{nsec}$) and changes rapidly with the drift distance. A constant drift field is reached at about 5 mm distance from the

sense-wire. From this point to about 3 mm from the cathode the $x(t)$ -relation is linear to 0.5 %. Closer to the cathodes, the correlation becomes diffuse due to the field inhomogeneities at the cell boundaries.

Typical differences of 200 to 300 μm are observed in the $x(t)$ -relations of the wires within a cell caused by the staggering and field distortions at the cell edges. To facilitate the calibration, $x(t)$ -relations of all wires are compared and sorted in different classes. In the case of DC1, the 384 relations can be divided into 22 classes, the variations in each class being about 30 μm on average over the full drift range (fig. 9). This represents the final precision of the $x(t)$ -calibration.

The sense wire positions x_o , and time-offsets t_o , have been determined for each wire by fitting a parabola in the region with drift times smaller than 30 nsec, i.e. within 1.5 mm of the sense wire. The accuracy of this method is about 10 μm for x_o and 0.5 nsec for t_o , allowing the systematic measurement of sense wire positions mentioned in sect. 3.1.

4.3 Single track precision

The localisation accuracy σ_x for single tracks was determined by comparing the hodoscope predicted impact position x_{MSD} with the drift chamber measurement derived from the previously evaluated $x(t)$ -relations:

$$\sigma_x = \sigma(x_{\text{MSD}} - x(t_{\text{drift}}))$$

Hence σ_x includes the intrinsic chamber resolution $\sigma(t_{\text{drift}})$ as well as the parametrization uncertainty $\sigma(x(t))$. The error due to hodoscope resolution $\sigma(x_{\text{MSD}})$ is negligible.

In fig. 10(a) the quantity $x_{\text{MSD}} - x(t_{\text{drift}})$ is plotted versus the drift distance; fig. 10(b) shows its projection onto the resolution axis. The distribution is not completely gaussian due to the charge arrival time distribution and also due to time slewing. This effect cannot be detected when the intrinsic resolution is calculated with the usual "three-wire method".

The single track precision as a function of the drift distance is shown in fig. 11. Close to the sense-wire the resolution is degraded due to the high drift velocities in this region. In the homogeneous region the data are well described by a square-root dependence with an effective diffusion coefficient D convoluted with a constant error term σ_o :

$$\sigma_x^2 = \sigma_o^2 + D^2 x.$$

The value for $D = 53 \mu\text{m}/\sqrt{\text{cm}}$ varies only little with the drift velocity. As σ_o accounts for differences due to fluctuations in the primary ionisation and time slewing as well as electronic errors in the time measurement, it is a constant when expressed in time units; the measured value is $\sigma_o = 3 \text{ nsec}$. Since the corresponding space value scales with the drift velocity, the best spatial resolution is obtained at the lowest drift velocity of $8.9 \mu\text{m}/\text{nsec}$.

The resolution shows only a weak dependence on the discriminator threshold. No significant change is observed up to a threshold equivalent to 4 electrons. At a sensitivity of 8-10 electrons (one third of all electrons collected) the resolution does not change by more than 10 %.

4.4 Two track separation

The measurement of the two-track separation was done with real multi-track events in order to include all distortions caused by the first track. Events with at least two space tracks reconstructed in the MSDs are selected for analysis. Around these tracks, hits are sought at each wire within a window of 4 standard deviations of the single track precision. At every wire, the efficiency of finding a hit for each of the two tracks is calculated as a function of the distance between the tracks, measured by the MSDs. The average value for all 8 wires in a cell is plotted in fig. 12. It is possible to get wrong associations with double hits belonging to a single track. To reduce this background a "two-track efficiency per cell" is defined, where at least 5 out of 8 hits for each track are required; the probability for more than 4 double hits per cell is negligible. Both curves indicate 50% efficiency at a distance Δ_2 of about $600 \mu\text{m}$. This value is measured at a drift velocity of $w_d = 11 \mu\text{m}/\text{nsec}$; the corresponding value for $w_d = 14.5 \mu\text{m}/\text{nsec}$ is $\Delta_2 = 750 \mu\text{m}$.

4.5 Effects of controlled charge collection

In the beam tests, the sample length was varied from 2.1 mm to 5.9 mm. The amount of ionisation sampled per wire was determined by measuring the pulse height for single track events at a known gas amplification (see sect. 2). It is indeed proportional to the predicted track sample length (fig. 13).

The single track precision is not significantly affected by the sample length (fig. 13(b)). This precision is determined by the first electrons to arrive at the sense wire, which in any case originate from the centre of the track sample; channeling does not change the drift of these electrons.

The efficiency starts to decrease for the lowest value of the track sample length (fig. 13(c)) as expected due to the smaller number of collected primary electrons. The curve in fig. 13(c) corresponds to the expectation for a threshold efficiency of two primary electrons.

Double hits in single track events arise from those charges whose collection times exceed the electronic resolution time, which is about 35 nsec (compare fig. 2). The double hit rate is decreased by a factor of 2-3 going from 5.9 to 2.1 mm channeling (fig. 13(d)). It cannot be reduced by simply increasing the threshold; this results only in a change of less than 20%.

Concerning the influence of controlled charge collection on the two-track separation as defined in the previous section, the differences are within the measurement error of $\pm 50 \mu\text{m}$ and show no systematic dependence on the track sample length. This reflects the fact that all tracks produce signals which are digitized as long as they are separated by more than the electronic resolution time, independently from the channeling.

However, pattern recognition and track finding are seriously affected by spurious hits, when the track sample is too long. The optimum sample length is reached when the double hit rate is strongly reduced without affecting the single track efficiency. Since we are also constrained by practical limitations on the potentials V_c and V_p , we choose as operating point a track sample length in the range 2.5 to 3.0 mm.

5. CONCLUSIONS

We have designed and tested a drift chamber including as the main features CO_2 as slow drift gas, fast shaping electronics and a geometry with adjustable track sample length improving the isochrony of the charge collection. Three such drift chambers are used in the electron spectrometer of the NA34 experiment at the CERN SPS.

Test measurements with a prototype and a final drift chamber show an absolute single track precision of $60\text{ }\mu\text{m}$ on average over the full drift distance of 20 mm and a two-track separation of $600\text{ }\mu\text{m}$. The calibration of the chamber with an accuracy of better than $30\text{ }\mu\text{m}$ including wire-to-wire variations is achieved using a microstrip detector hodoscope as external track reference.

For optimum performance, the drift velocity should be as low as possible. A value of $10\text{ }\mu\text{m/nsec}$, corresponding to a drift field of 1.2 kV/cm for the $\text{CO}_2(90)/\text{C}_2\text{H}_6(10)$ mixture used, is chosen as operating velocity in accordance with the high interaction rate in the experiment.

Controlled charge collection reduces strongly the multiple hit rate and therefore allows better track recognition in multi-track events. We find an optimum value for the track sample length to be 2.5 to 3 mm.

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TABLE 1

Drift chamber layout

DC	Prototype	DC1	DC2	DC3
Active volume ($\emptyset$ [mm] x L[mm])	180 x 60	240 x 495	504 x 430	756 x 340
# field wires	375	4500	7000	8000
# sense wires	32	384	480	540
# digitizations/track	8	48	40	30
# modules	1	6	6	5
Mod. orientation	x	x,y,u,v,x,y	y,x,u,v,y,w	y,x,u,v,w
# sense w./cell	8	8 all	6,8,6,6,6,8	6 all
# cells/module	4	8	12	18
Drift distance [mm]	20	15	21	21
Beam slit [mm]		2	3	4.2
s.w. staggering [mm]	0.2	0.1	0.1	0.1

FIGURE CAPTIONS

- Fig. 1 The electron spectrometer in the NA34/HELIOS experiment consisting of: target area with silicon detectors (1), DC1 (2), dipole magnet integrated with magnetic calorimeter (3), DC2 (4), transition radiation detector (5), DC3 (6), uranium-liquid argon calorimeter (7).
- Fig. 2 Field geometry with controlled charge collection. S, P, C, are sense, potential and channeling wires.
- (a) Drift lines are drawn in the case of small and strong channeling (left and right). Any electron created in the zone outside the solid lines will be collected at a channeling wire. Equal drift time contours (dotted lines) are separated by 50 nsec.
 - (b) Corresponding differences in collection times of electrons deposited along a line parallel to the sense wire plane at 10 mm distance. The collection time is reduced in case of strong channeling (right).
- Fig. 3 Layout of a drift cell in DC3. The double-layer cathode on the left serves as beam slit. Sense wires are 20 μm gold plated tungsten, field wires 100 μm Cu-Be, tensioned at 40 g and 120 g, respectively.
- Fig. 4 Drift chamber layout.
- (a) Layout and chamber body (black) of the upper half of DC2 as seen along the beam ($0^\circ \hat{=}$ horizontal coordinate measured). Segments sampled along a track in the successive modules are underlined.
 - (b) Front and top views of the second module in DC2. Drift distance 21 mm. Arrows indicate drift direction. Labels: 1 - aluminium flange, 2 - side plate, 3 - reference edges.
- Fig. 5 Deviation of the wire positions from their nominal locations in drift direction measured in a test beam with MSD hodoscope.
- Fig. 6 Electronics read out scheme. The detailed electronic circuits are given in [7].
- Fig. 7 Beam test set-up at the SPS beam lines H6 and H8.

FIGURE CAPTIONS (Cont'd)

- Fig. 8 Correlation between measured drift time and drift distance predicted by the MSD reference.
- Fig. 9 Homogeneity and precision of $x(t)$ relations. Shown is the deviation from the mean value $x(t_i)$ of 48 $x(t)$ relations summed over 20 time values t_i .
- Fig. 10 Scatter plot of absolute single track precision versus drift distance and its projection. $x_{\text{predicted}}$ is the MSD-prediction, x_{measured} the measurement in the chamber.
- Fig. 11 Single track precision as a function of the drift distance for two drift velocities. The lines are fits to the data points.
- Fig. 12 Two-track separation efficiency as a function of the distance between tracks measured in the MSD telescope. (Multi-track events generated with 200 GeV/c pions on an Al-target).
- Fig. 13 Measurement of the influence of channeling (track sample length) on :
- (a) collected charge,
 - (b) single track precision,
 - (c) efficiency,
 - (d) multiple hit rate associated with a single track.

HELIOS NA 34

ELECTRON SPECTROMETER

Fig.1

Fig.2

Fig.3

Fig.4

Fig. 5

Fig.6

Fig. 7

Fig. 8

Fig.9

Fig.10

Fig.11

Fig.12

Fig. 13