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THE DESIGN AND CALIBRATION OF PRECISION
DRIFT CHAMBERS FOR USE IN A GLUONIUM SEARCH
EXPERIMENT AT THE CERN ISR

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ABSTRACT

We describe the design, construction and calibration of a set of high precision drift chambers. The precise coordinate ($\sigma \sim 120 \mu\text{m}$) is determined by drift time measurement, with the orthogonal coordinate given by the charge division method ($\sigma \sim 1.2 \text{ mm}$). The chambers have been calibrated using a well-defined laser beam. Their use within a gluonium search experiment at the CERN ISR is also described.

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1. INTRODUCTION

The Axial Field Spectrometer (AFS) [1] at the CERN ISR was designed for good charged particle tracking and calorimetry in the central region. These properties are utilised in experiment R807 to study high p_T and jet physics. However, the study of gluonium production demands the detection of the two diffracted protons in addition to the decay products in the central region. The precision drift chambers described here are positioned above and below the beam pipe, downstream from the interaction region, to provide a tracking telescope to detect the diffracted protons. The positions of the drift chambers are shown schematically in Fig. 1.

The experiment was originally conceived to operate in conjunction with the superconducting low-beta quadrupoles. They focus the beams in the vertical direction and produce a factor of seven increase in luminosity in the interaction region. For a range of azimuthal and polar angles, scattered protons with momentum close to the beam momentum would be deflected by this magnet system and pass through the drift chamber telescope. It would then be possible to calculate the particle momentum from the position and angle of each track. However, due to acceptance limitations and increased backgrounds near the downstream beams, data have only been taken with the quadrupoles turned off. Track momentum information is then not available, but straight line trajectories can still be extrapolated back to the interaction diamond and included in kinematic fits to exclusive events.

Diffractive production processes decrease rapidly with increasing polar angle. It is therefore necessary to position the chambers as close as possible to the undeflected beam, using a special elliptical vacuum pipe. Each chamber must be active and efficient for particles passing as close as 0.5 mm from its base-plate. Naturally this plate must be as thin as possible to minimize scattering from tracks at grazing incidence.

2. THE CHAMBER DESIGN

A schematic form of the wire layout and the associated voltages is shown in Fig. 2. The equipotential lines are given in Fig. 3 and the general form of the chamber itself is illustrated in Fig. 4. The four anode sense wires, operating with a gas gain $\sim 10^5$, are positioned in the median plane. They are 22 μm in diameter and made of nichrome (resistance 3.2 $\text{K}\Omega/\text{m}$) and they extend for a length of 5 cm between the side plates. Signals are read-out from both ends of the wires (as detailed below). To maintain field symmetry with respect to these wires the plane is completed by two "end-wires" also of 22 μm diameter, but which are not read-out. The sense wires are interleaved with parallel "potential" wires made of Cu/beryllium 100 μm in diameter. The drift region gradient ($\sim 1000 \text{ V/cm}$) is provided by similar wires separated vertically by 3 mm, in lines at the front and back of the chamber. The earth planes are 21 mm above and below the sense wire plane and are constructed from copper-clad circuit board, 0.83 mm and 0.42 mm thick respectively. Electrons drift over a maximum distance of 21 mm in a time $\sim 400 \text{ nsec}$ in the 50/50 Ar-ethane gas mixture. The gas is introduced through ducts in the end-walls of the chamber and emerges into the active volume through small holes near the base; it leaves through a low impedance pipe at the top.

The chamber readout is triggered by scintillator coincidences that combine information from both outgoing protons. This, together with the reconstructed information of the track, allows the up-down ambiguity to be resolved with respect to the plane of the sense wires.

3. THE CONSTRUCTION PROCEDURE

An assembled chamber is shown in the photograph in Fig. 5. The use of a precision assembly jig is vital to the accuracy of the chambers. This jig holds the components relative to the mounting studs and survey marks while the various epoxy resin bonded joints are curing.

The vertical side walls and upper horizontal cross-member are machined from a composite epoxy-woven glass fibre material (Permali). The cross-member provides the upper gas seal and houses the input and output gas connectors. Three millimetres below the lower surface a copper-clad board provides an earth plate. A similar, but thinner board provides both the gas seal and earth plate at the base of the chamber.

The sense wires are located in precision feedthroughs that fit within 1.2 mm diameter holes in the side plates, and are secured in place by crimping the wire in the feedthrough. The holes were drilled, and measured, and shown to be within $\pm 20 \mu\text{m}$ of their nominal position. The final wire position is always within $60 \mu\text{m}$ of its theoretical value. In practice the actual measured position of each wire is used in the subsequent particle track analysis.

The feedthrough consists of a metal tube held in a plastic insert and is shown diagrammatically in Fig. 6. The sense wire is crimped to hold a tension of 10 gm. The potential wires and field wires are tensioned to 100 gms and located with less precise feedthroughs, also shown in Fig. 6, to an accuracy of typically $100 \mu\text{m}$. The feedthroughs are held in place by a covering plate through which pin-connections are made to the external electronics. The field-wire potentials are fed from one end of each wire via printed circuits, as shown in Fig. 7.

The front and back planes of the chamber are sealed by $125 \mu\text{m}$ mylar-aclar sheets bonded to the side plates. As shown in Fig. 5 the side plates extend above the chamber volume and are attached to a metal T-piece. This provides the locating mechanism for the chambers within the ISR experiment, and marked precision studs within dowel holes allow a survey reference back to the absolute spatial positions of wires to an accuracy of a few microns.

4. THE ELECTRONICS

Time and analogue signals are derived from both ends of each of the four sense wires (Fig. 8). As we want the base-plate of the chamber at

earth potential it is necessary to have the sense wires at high voltage (+ 3.6 KV). The signals are therefore ac coupled via a 2.2 nf capacitor into a hybrid preamplifier. The small printed circuit card that holds the preamplifiers, coupling capacitors and high voltage resistors can be plugged directly onto the chamber. Analogue output pulses from both ends of a wire are sent to a "time pick-off" unit [2] mounted close to the chamber. A small fraction of each analogue signal is then combined to estimate the mean time of arrival. The analogue pulses are passed through shaping amplifiers and then processed by ORTEC 811S peak sensing ADC's. The timing pulse is digitized in a LRS 2228A TDC. In the ISR experiment a scintillator hodoscope surrounding the interaction region provides a start pulse for the timing sequence.

5. TESTS AND LASER CALIBRATION

5.1. Test Procedure

Nineteen chambers were produced for use in the ISR experiment. Each completed chamber was checked for electrical continuity and correct sense wire resistance ($\sim 182 \Omega$). Pulse heights were measured with an Fe^{55} source, and each chamber was required to remain stable over a period of twenty four hours of operation. Three chambers were then subjected to a more detailed investigation and quantitative calibration using a well defined laser beam.

5.2. Laser Calibration

The experimental set-up is indicated in Fig.9. A chamber was attached to a movable x-y table such that a fixed laser beam could scan its entire area of 50 mm by 42 mm. The horizontal sense wires are parallel to the x-axis and the electrons drift vertically, parallel to the y-axis. The pulsed N_2 Mopalite laser [3] (wavelength 337 nm) provided a beam at source with dimensions ~ 2 mm by ~ 1 mm and with a divergence of ~ 0.5 mr. The energy per pulse was measured to be $\sim 100 \mu\text{J}$. The laser beam was directed over a distance of 2 m onto the centre of a 0.6 mm diameter hole in a screen positioned directly in front of the chamber. The diffraction limit of the aperture (~ 0.5 mr) was then well matched to

the intrinsic divergence of the beam. In addition the spatial location of the beam was well defined. The origins of the coordinate scales were set to be approximately the centre of the physical wires for x and the plane containing the base-plate for y. The intensity of the laser beam through the defining aperture was adjusted until the pulses from the wires spanned a dynamic range similar to that arising from minimum ionizing particles. A beam splitter at the laser exit provided a pulse that was fed via an optical fibre to a photodiode, to give a fast trigger for the read-out electronics.

5.2.1. The data acquisition electronics

Four channels of TDC information encoded the drift times, pulse by pulse, from each wire, and eight channels of ADC's provided the pulse height information. All twelve channels were calibrated for slope and pedestal values, under computer control through CAMAC, prior to each period of data-taking with the laser beam.

For the TDC's five standard delay times could be switched in by remote control. For the ADC's eight different standard pulses were obtained from a precision impulse generator under the control of a standard CAMAC DAC. To ensure that knowledge of the calibration constants of the TDC's and ADC's was not limited in precision by statistical uncertainties, 400 readings were taken at each value of delay time or pulse height. Slope and pedestal values were calculated and stored on-line so that a continuous monitor of chamber performance was available. Each set of 400 readings was also written to magnetic tape to allow a more detailed off-line estimate to be made of the TDC and ADC calibration constants.

5.2.2. The data

As expected, the chamber became inefficient in regions near the side-plates due to drift field distortions. However, high efficiency was maintained over at least the central 25 mm of the 50 mm long wires. In the ISR experiment the acceptance of the trigger scintillators is matched to this active area.

The performance of the drift chamber was measured at specified points on the x-y grid (see Fig. 9). The two-dimensional motion of the table carrying the chamber had itself been calibrated and checked for reproducibility, giving an absolute precision of $\pm 2 \mu\text{m}$ in y and $\pm 5 \mu\text{m}$ in x.

Measurements were taken in x between $\pm 15 \text{ mm}$ at 2.5 mm separations. In the y direction it was important that the laser beam did not scatter from the horizontal field grading wires. To ensure this, the y measurements were taken in steps of 3 mm from $y = 1.5 \text{ mm}$ to $y = 19.5 \text{ mm}$ and then in the vicinity of the wire ($y \approx 21 \text{ mm}$), at 20 and 20.5 mm . Above the wire plane, readings were taken at 21.5 , 22 and 22.5 mm and then at intervals of 3 mm out to 40.5 mm . The standard grid of measurements contained 18 y-values at each of 13 x-values, giving a total of 234 grid points. The drift-time co-ordinate, y, is significantly more precise than the charge division co-ordinate x. The standard procedure was therefore to fix x and take readings varying y, in order to minimize the systematic uncertainties in drift velocity measurements. However, a few grid rows were repeated varying x values for fixed y to study the charge division measurement under optimum conditions. The overlapping measurements taken in the two different procedures agree very well.

Frequent checks were made on the effects of electrically induced laser background signals. The TDC and ADC data acquisition system was run with the laser beam active but blocked off from the chamber. We required that the response under these conditions be similar to that for random triggers when the laser itself was not pulsing.

In order to minimize attenuation and scattering of the laser beam the normal front window of a chamber was replaced by parallel sided 1 mm thick quartz when the measurements were made. Of the three chambers calibrated in this arrangement the first was studied in detail over the complete grid. The other two were scanned both at constant x and at constant y over a subset of the matrix. There is very good agreement on the chamber characteristics derived from the three separate surveys.

5.3. Analysis of Results

A continuous monitor of chamber performance was made during the acquisition stage of the laser data by outputting preliminary values of drift times for the four wires and the two values of pulse height for each wire.

In the detailed off-line analysis the TDC and ADC slopes and pedestals were recalculated. At each spatial point on the measurement grid the laser data were checked for internal consistency. The drift time was then calculated for each wire, and also the charge division fraction, F , from the shaped pulse heights A and B at the two ends of the wire: $F = A-B / A+B$.

In the following discussion we present the results relating to the chamber for which the complete grid of measurements was taken.

5.3.1. Drift-time analysis

Examples of the measured drift times for all four sense wires as a function of drift coordinate are given in Fig. 10. For each fixed x value the drift times have been fitted to a linear relation with respect to y . The measurements on each side of the sense wire plane were treated separately, thus providing two independent values for the average drift velocity from each vertical scan of the chamber. It is clear that the linearity exists at distances up to 0.5 mm from each sense wire.

The intercept, y_I , of the lines from the drift-time relations in the upper and lower half of the chamber were calculated for each wire. On the assumption that the ionizing edges of the laser beam were symmetric with respect to the observed optical centre, these values correspond to the wire location. Direct observations of the wire positions indicated that the y_I values were correct to better than 100 μm . In Fig. 11 the values of y_I are shown for one wire at different values of x . The variation of y_I with x is in excellent agreement with that expected from the design of the chamber support. A similar result is obtained for the other wires. From the scatter of the y_I values about a straight line fit we conclude that the ionizing edge of the laser beam must be constant to within ~ 5 μm .

Fig. 12 shows the experimental variation of the drift velocity with x . The lower value of the velocity for $x \geq 12.5$ mm is observed for all the wires and results from the variations in electric field caused by the dielectric effect of the end plate material. The average drift velocity with a drift field of 1 kV/cm is 52.47 ± 0.08 $\mu\text{m/nsec}$.

Table 1 contains a summary of the drift velocities obtained from the four wires for the 50/50 argon-ethane gas. The value from each half of the chamber has an intrinsic uncertainty of $\leq 0.1\%$, with the two means varying by 0.29%. This is compatible with the systematic error expected from scale/setting errors at the level of microns per few centimetres of traverse in y .

The chamber is designed to operate at a drift field of 1 kV/cm. Measurements were made of drift velocity for field gradients of 0.9, 1 and 1.1 kV/cm. The variations of drift velocity with field are shown in Fig. 13. The velocity was also measured for different rates of gas flow through the chamber, and found to be constant for rates above a well-defined threshold value. This was expected, due to the difficulties of securing a gas seal around the special quartz window used for the laser calibration.

5.3.2. Charge division analysis

Fig. 14 shows the charge division fraction, F , as a function of x for two wires at different values of y . A linear relation exists between F and x , with slope α and intercept β

$$F = \alpha x + \beta \quad (1)$$

The value of β varies from wire to wire due to different impedance values and sensitivity of preamplifiers, but all wires are consistent with $\alpha = 0.0109 \pm 0.0001$ mm^{-1} . The effective length of the wire, L_e , is related to the actual length, L_w , by the relation

$$L_e = L_w [1 + 2Z_p/R_w]$$

where Z_p , R_w are respectively the impedance of the preamplifier and the total resistance of the sense wire. With dc coupling of the signal to the preamplifier the expected relation between x and F would be:

$$x = 0.5 L_e F + \epsilon,$$

where ϵ accounts for any asymmetry of response. However, for the present arrangement, with ac coupling, the relation is modified to

$$x = 0.5 L_e F \lambda(C) + \epsilon \quad (2)$$

where $\lambda(C) = \exp [2T/(2Z_p + R_w)C]$. T is the integration time (150 nsec) and C the capacitance (2.2 nf). This gives $\lambda(C) = 1.5 \pm 0.1$.

From equations (1) and (2) we have:

$$\alpha = 2/L_e \lambda(C) \quad \text{or} \quad \lambda(C) = 2/\alpha L_e$$

Experimentally $\alpha = 0.0109 \text{ mm}^{-1}$, and thus with $L_e = 119.42 \text{ mm}$, $\lambda(C)$ becomes 1.54. This is in good agreement with the calculated value of $\lambda = 1.5$.

The slope α is independent of y , as shown for one wire in Fig. 15 and the values for each wire are given in Table 2.

5.4. Chamber Performance at the ISR

The chambers operate with high single wire efficiency ($\geq 98\%$) at the ISR. Scattered protons follow straight line trajectories in each of the four downstream drift chamber telescopes (see Fig. 1). These lines are defined by a maximum of 12 drift chamber wire coordinates in both x and y , and least squares fitting indicates the following standard deviations per wire coordinate:

$$\begin{aligned} \sigma(x) &\sim 1.2 \text{ mm (from charge division)} \\ \sigma(y) &\sim 120 \text{ } \mu\text{m (from drift-time measurement)} \end{aligned}$$

Fig. 16 shows the deviation of the measured coordinates from the fitted line for a wire. The charge division result corresponds to a precision of order 2% of the wire length, and is subject to a further systematic error of $\sim 1\%$ due to uncertainties in the charge division slope α (see section 5.3.2.).

The values of $\sigma(x)$ and $\sigma(y)$ derived from the ISR data are consistent with those obtained from the laser calibration of the chambers.

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O. Botner et al., Nucl. Instr. and Meth. 196 (1982) 315.
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- [3] Supplied by Multilasers, Grand-Saconnex, Switzerland.

Wire number	Drift velocity $y < 19.5$ mm ($\mu\text{m/nsec}$)	Drift velocity $y > 22.5$ mm ($\mu\text{m/nsec}$)	Mean drift velocity ($\mu\text{m/nsec}$)	Fitted y_I wire (mm)
1	52.51 ± 0.07	52.37 ± 0.05	52.44	20.799 ± 0.006
2	52.53 ± 0.08	52.38 ± 0.07	52.46	20.793 ± 0.005
3	52.54 ± 0.09	52.46 ± 0.07	52.50	20.812 ± 0.004
4	52.56 ± 0.04	52.36 ± 0.04	52.46	20.793 ± 0.004
Overall mean	52.54 ± 0.04	52.39 ± 0.04	52.47 ± 0.08	20.799 ± 0.004

Table 1 : Results for drift velocity and wire position

Wire number	Charge division slope, $\alpha(\text{mm}^{-1})$		
	$y \leq 19.5$ mm	$y \geq 22.5$ mm	Mean
1	0.0108 ± 0.0001	0.0106 ± 0.0001	0.0107 ± 0.0001
2	0.0111 ± 0.0001	0.0111 ± 0.0001	0.0111 ± 0.0001
3	0.0110 ± 0.0001	0.0109 ± 0.0002	0.0110 ± 0.0001
4	0.0106 ± 0.0001	0.0109 ± 0.0002	0.0108 ± 0.0001
Overall mean	0.0109 ± 0.0001	0.0109 ± 0.0001	0.0109 ± 0.0001

Table 2 : Values for the charge division slope, α .

FIGURE CAPTIONS

- Fig. 1 A schematic beam layout (side-view) showing the positions of the drift chambers, scintillators, and superconducting quadrupoles.
- Fig. 2 The chamber wire voltages.
- Fig. 3 Equipotential lines in the chamber, showing contours at 200 V intervals.
- Fig. 4 A schematic form of the chamber showing a vertical section.
- Fig. 5 Photograph of the chamber.
- Fig. 6 Cross-sections of sense and field/potential wire feedthroughs (not to scale)
- Fig. 7 Photograph of the printed circuit layouts for the distribution of potentials to the wires.
- Fig. 8 A schematic of the readout electronics.
- Fig. 9 A plan view of the layout for laser calibration. The chamber sense wires are in the x-direction, electrons drift in the y-direction.
- Fig. 10 Drift time versus drift distance for each wire, measured at $x = 0$.
- Fig. 11 Fitted wire coordinate, y_I , versus x coordinate of measurement.
- Fig. 12 Measured drift velocity versus x coordinate in chamber.
- Fig. 13 Measured drift velocity versus drift field (gas: 50/50 argon/ethane).
- Fig. 14 Charge division fraction, F , versus x coordinate, (a) at $y = 10.5$ mm, (b) at $y = 31.5$ mm.
- Fig. 15 Charge division slope parameter, α , versus y coordinate.

Fig. 16 (a) Discrepancy of y coordinate of a track for a single wire from the fitted line, measured at the ISR. The curve is a Gaussian with $\sigma(y) = 120 \text{ } \mu\text{m}$;
(b) Discrepancy of x coordinate of a track from the fitted line for a wire. The curve is a Gaussian with $\sigma(x) = 1.2 \text{ mm}$.

S=SCINTILLATOR, C=DRIFT CHAMBER, SQ=SUPERCONDUCTING QUADRUPOLE

Fig. 1

SENSE WIRE * : 3657 v
 POTENTIAL WIRE ⊙ : 1515 v
 FIELD WIRE •

Fig . 2

Fig. 3

Fig . 4

Fig. 5

Fig. 6

Fig. 7

Fig. 8

Fig. 9

Fig. 10

Fig. 11

Fig. 12

Fig. 13

Fig. 14

Fig. 15

Fig. 16