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A SYSTEM OF CYLINDRICAL DRIFT CHAMBERS INA SUPERCONDUCTING SOLENOID

L. Camilleri, C. del Papa, L. Di Lella, F. Doughty, R. Harfield,
C.J. Onions, B.G. Pope¹, S.H. Pordes, J. Singh, A.M. Smith and H. Wind

CERN, Geneva, Switzerland

B.J. Blumenfeld, R.J. Hollebeek, H. Cunitz, L.M. Lederman, D. Levinthal,
W. Sippach and R.A. Vidal

Columbia University, New York, NY, U.S.A.

A.L.S. Angelis, L. Lyons, N. Phinney, A.M. Segar, J.S. Wallace-Hadrill
and T.O. White²

University of Oxford, Oxford, U.K.

T.J. Chapin, R.L. Cool, Z. Dimcovski, A.F. Rothenberg
and M.J. Tannenbaum

The Rockefeller University, New York, NY, U.S.A.

ABSTRACT

A superconducting solenoid at the CERN ISR has been equipped with a system of high accuracy cylindrical drift chambers. This detector consists of eight layers of field shaped drift cells with a delay line opposite each sense wire to provide coupled two dimensional readout. The design, construction, and operation of this system are discussed. The resolution and performance of the delay lines and sense wires under ISR running conditions are shown.

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¹ Present address : Physics Dept. Princeton University, New Jersey, USA.

² Present address : Dept. of Physics University of Cambridge, U.K.

1. INTRODUCTION

The CERN-Columbia-Oxford-Rockefeller collaboration is engaged in a study of high mass electron pairs and large transverse momentum hadronic phenomena at the CERN ISR. The apparatus (Fig. 1) consists of a 1.5 T superconducting solenoid¹⁾ which contains cylindrical drift chambers surrounding the interaction region, and two walls of lead-glass total absorption Cerenkov counters each covering a solid angle of ~ 1 sr. The detector is triggered by energy deposition in one or both walls of glass and the charged particles of each event are momentum analysed in the magnetic field of the solenoid. This paper describes the system of tracking chambers used for momentum measurement.

A main design goal for the detector is momentum measurement with uniform acceptance over the full azimuth, for the central rapidity region ($|y| < 1$), to allow an unbiased study of charged hadrons produced in association with large transverse momentum π^0 triggers. The typical high p_T hadron event is characterized by a high multiplicity of mainly low momentum tracks ($\bar{n} \approx 10$ in the detector) with strong correlations between tracks (jets). Photon conversions, a background to the electron pair study, can also give two tracks which are close together. Thus the chambers are designed to handle high multiplicity events and resolve two tracks close in space.

In order to simplify the time consuming computer task of event reconstruction, the chambers provide full 3 dimensional space points. Further simplification is gained by having a solenoid with magnetic field uniformity of $\pm 1\%$, so that the charged particle trajectories are circles in the plane perpendicular to the sense wires.

The luminosity of the ISR ($\sim 5 \times 10^{31} \text{ cm}^{-2} \text{ sec}^{-1}$) also imposes constraints on the apparatus. At interaction rates above 1 MHz there is a background of low p_T tracks from collisions occurring within several hundred nanoseconds of a triggering event. Therefore good timing resolution and the ability to handle many tracks are essential.

Drift chambers were chosen to fulfill all of these requirements and to provide the best spatial resolution.

2. THE CHAMBER SYSTEM

The drift chamber system is composed of four cylindrical modules. Each module consists of two gaps with sense wires mounted axially to measure the azimuthal coordinate. A delay line is associated with each sense wire. The induced pulse on the delay line gives the longitudinal (z) position corresponding to each avalanche on the wire. This gives four pairs of space points to measure the helical trajectory of charged particles. Some parameters of the chamber are given in Table 1.

The basic cell of a chamber is shown in Fig. 2. It is of the adjustable field design²⁾ for operation in a 1.5 T magnetic field. The cathodes are large printed circuits consisting of strips to allow full control of the electric fields in the gaps. In addition to a drift field E_D , a compensating field E_C is applied to cancel the effect of the magnetic field on the drifting electrons. This allows the use of thin cells with long drift spaces, thus keeping the total number of wires low.

The position of sense and field wires are interchanged in the inner and outer layers. This, together with the proximity of the two gaps in each module, allows a resolution of the left-right sense wire ambiguity in conjunction with measurement of the local tangent angle of the track.

A delay line is glued to the cathode circuit facing each sense wire. The construction of the line is shown in Fig. 3 and its characteristics are given in Table 2. The line has to be made narrow so as not to interfere with the field configuration in the chamber. It is mounted close to the sense wire to ensure a sufficiently strong induced signal. A high impedance line is chosen to reduce sensitivity to voltage noise sources, and the low value of $R/2Z$ makes the DC resistive losses small compared to the effects of dispersion. The low values obtained for internal reflections and line-to-line variations in delay and impedance are the result of strict tolerances in the dimensions of materials, the winding of the coil and the glueing of the coil to the vetronite dielectric.

Each module is composed of two semi-cylinders. For ease of fabrication each semi-cylinder is constructed of several independent self-supporting sectors. These sectors are held together at the ends by a

precision machined aluminium casting in which dowel pins ensure relative sector alignment to a precision of 0.02 mm. The casting also serves as a gas wall and the voltages and signals are taken out with special gas tight connectors. Each semi-cylinder is fastened at its ends to plates attached to the solenoid and its alignment is independently adjustable.

The construction of the sectors is shown in Fig. 4. The basic cylindrical form is made by heat shaping Rohacell³⁾ in specially constructed moulds. The cathode circuits, vetronite, fiberglass-charged araldite end pieces, and Rohacell are epoxied together and cured in the same moulds. In this way the three shells of each sector are formed. The 20 μ gold-plated tungsten sense wires and the 100 μ beryllium-copper field wires are strung at tensions of 40 g and 100 g respectively on the two outer shells. They are soldered to printed circuits at each end after being aligned optically to within 20 μ relative to the cathode plane. The delay lines for both gaps are glued to the central shell. Supports are needed every $\sim$ 50 cm along the sense wires to keep them in position when under the influence of the electric fields in the chamber. These 3 x 6 x 6 mm beads also help to maintain the gap spacing.

The thickness of each module is 0.7 g/cm² or 2.3% of a radiation length. This is similar to the thickness of the ISR vacuum pipe or the scintillation counters, "A" (Fig. 1). Low p_T charged particles with small longitudinal momentum that spiral in the solenoid ($p_T < 150$ MeV/c) rapidly disappear due to their energy loss in the chambers.

3. ELECTRONICS

The electronics processes 580 sense wire signals and 1160 delay line signals (both ends of the lines are read out). Multiple signals, even within short time intervals, must be accepted from the same wire to ensure the ability to distinguish two tracks close in space and to prevent the loss of information in high background conditions. The 112 scintillator timing signals, which allow the calculation of the event time-zero, are also processed in the same time digitizing system.

Amplifiers cannot be placed in the solenoid because of access problems and the temperature gradients that they would produce on the chambers due

to their power dissipation. The signals are therefore brought out on 3 metres of RG174 coaxial cable. In order to reduce noise, the chambers and these cables have a double ground shield.

The delay line impedance of 550Ω gives a matching problem with the coaxial cable. This is solved by a specially made hybridized emitter follower circuit mounted on each end of the delay line which correctly terminates it and gives a current gain of 10.

Amplifiers with a gain of 160 are located just outside the solenoid. Given the slow fall-off of drift chamber signals, the output pulses are clipped to 60 ns to reduce the occupancy time on each channel. The rise time of the chamber-cable-amplifier system is 7 ns for sense wires and 7-15 ns for delay lines. The signals are brought to discriminators in the counting room on 35 metres of RG58. The discriminators are of a simple design and operate in a time-over-threshold mode. Operating thresholds are adjustable and are typically equivalent to $1\mu\text{A}$ on the sense wires and $0.1\mu\text{A}$ on the delay lines. The pulse-pair resolution of the amplifier-discriminator system is set to ~ 70 ns.

The time-to-digital converter system accepts NIM level signals from the drift chamber discriminators and the scintillator fast logic. Incoming signal times are continuously recorded relative to a free running clock. The event trigger is recorded on all channels, and stops the process. Thus, the trigger is the only signal which needs to be delayed. The system uses ECL technology for time resolution, packaging density and fast internal data preparation (Table 3). It is capable of fast (200 ns/hit) readout which may eventually be used in a hardware processor. Data transfer to the on-line computer is by CAMAC.

4. OPERATING CONDITIONS

The chambers are run on a 50-50 mixture of Argon-Ethane. This gas is chosen because of its good drift velocity saturation properties and the fact that it does not polymerize in a high radiation environment^{4,5,6}. The $B = 1.5$ T drift fields are $E_C \approx E_D \approx 1.0\text{Kv/cm}$. These fields are established on the cathodes for each sector-gap by a resistive divider chain located in the counting room. Thus, the electric field in any gap can be

easily changed. The desired potentials for each module are calculated using a field relaxation program. The delay lines are placed at ground potential, and the sense wires are normally operated at + 1.7 Kv. The sense wire voltage is independently adjustable for each sector-gap. The sense wire gain can be adjusted independently of the drift fields.

The chamber plateau extends from 1650 to 1800 volts for cosmic-ray running. Under the heavy ionization loading present during beam-running conditions, the plateau length is reduced. Care must be taken to ensure that the chambers' operation is not limited by radiation induced breakdown. In addition, it is necessary to limit the power available to the anodes and cathodes to avoid wire breakage. The anodes are protected from discharge by current limiting resistors on the chambers and current sensitive relay cut-offs in the counting room. The cathodes are protected with current sensitive relays which turn off a sector in case of breakdowns. The chamber high voltage supplies are interlocked with the ISR beam status system. Repair of weak points in the voltage distribution system inside the chambers is made difficult by the lack of access to the chambers during ISR running. However, misbehaving sector gaps can be left unpowered without affecting the performance of the rest of the system.

The entire apparatus has been successfully operated at the maximum ISR luminosity of $5 \times 10^{31} \text{ cm}^{-2} \text{ sec}^{-1}$. Single wire rates up to 100 KHz and total rates in a full cylinder gap of 5 MHz have been observed.

5. RECONSTRUCTION AND PERFORMANCE

Times on the sense wire and both ends of the delay line are recorded and are associated by the event reconstruction program to form space-points. The three measurements for the two unknowns, drift-time and z-position, give a constraint which eliminates spurious combinations even in the multihit case. Thus, the data are clean for high luminosity and high wire rates. Reading both ends of the delay lines cancels the effect of pulse-height slewing, thus improving the z-resolution. It also gives a convenient way of calibrating the delay line velocity in situ. The time-distance relationship for the delay lines is found to be linear. The z resolution is measured to be $\sigma_z \sim 5 \text{ mm}$.

Dead-time effects make the efficiency for having all three signals from a hit - a "triplet" - depend on the event multiplicity and the ISR luminosity. For cosmic-ray running with no beams, the "triplet" efficiency is $(97.5 \pm 1)\%$. For data taken with high p_T triggers, this efficiency is $(89.2 \pm 1)\%$ on the innermost chambers with the highest wire rates. The difference is consistent with calculated dead time effects. The overall efficiency is improved to $(94.9 \pm 1)\%$ by associating pairs of signals not used in "triplets". These "doublets" also define space-points but without a constraint.

The tracks are found using the z position, wire position and distance from the wire calculated assuming a linear time-distance relation. The resolution of the left-right ambiguity and the angle corrections to the distance ⁷⁾ are made in the track-fitting procedure. Points on out-of-time tracks are displaced in opposite directions on the two gaps of a module thus giving unacceptable fits to circles. A reconstructed event is shown in Fig. 5.

The spatial resolution achieved depends on the understanding of both the time-distance-angle relation and the alignment of the chambers. The chambers themselves are capable of good resolution as was shown by the first sector produced which, without magnetic field, gave a $\sigma \sim 150-175\mu$ in a test beam. In the experiment, cosmic-ray tracks which cross both halves of the system are used to obtain alignment constants for the eight independent half-cylinders, and to derive the actual time-distance-angle relations. Figure 6a shows the time-distance relation of a sector-gap. Figure 6b shows the same data with a drift velocity of $48.5\mu/\text{ns}$ subtracted. Because of the asymmetry observed, each sector-gap is fitted with a separate T-d relation for left and right of the wires. The differences in drift velocities are ascribed to imperfect electric field configurations. The non-linearity of the T-d relation is less than 1% for tracks within 10° of normal incidence in the azimuthal view. The spatial resolution of DCM 2 is presented in Fig. 7. A σ of $\sim 300\mu$ has been achieved. This corresponds to a momentum resolution $\delta p_T/p_T = 0.024 p_T$ r.m.s. (p_T in GeV) for 8 point tracks. An additional error of $\delta p_T/p_T = 0.02$ r.m.s. due to multiple Coulomb scattering must be added in quadrature.

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Table 1

Chamber Dimensions

Module	Mean Radius	Length	Mean Sense-field Distance	Nr.of Sense wires (both layers)	Nr. of Sectors	Nr. of Cathode lines per Circuit-cell
DCM-1	20 cm	80 cm	1.28 cm	96	4	16
DCM-2	34.6	103	1.49	144	6	20
DCM-3	49.2	127	1.91	160	8	24
DCM-4	63.8	150	2.20	180	10	28

All gaps are 0.60 cm.

Table 2

Delay Line Characteristics

Delay	2.3 ns/cm
Impedance	550 Ω
DC Winding Resistance	110 Ω /m
Attenuation for Chamber Signals	2.5 db/m
Line-to-Line Variations in Delay and Impedance	3% r.m.s.
Internal Reflections	< 1% typical
Spatial Resolution	5 mm
Length	80 - 150 cm

Table 3
Characteristics of the Time-to-Digital Converters

Time span	1500 ns (adjustable in steps of 48 ns for each group)
Bin size	1.5 ns
Hit/Channel Capacity	~ 14
Dead time on same channel	31 ns minimum, 55 ns maximum
Nr. of channels	~ 2000
Packaging	13 Crates (750 w each), ECL Dataway
Density	8 channel/single width bin 24 bins/crate

Figure captions

- Fig. 1 : a) A view of the apparatus normal to the solenoid axis.
b) Top view of the apparatus.
- Fig. 2 : Basic Drift Cell of DCM-1.
- Fig. 3 : Delay Line Construction. All dimensions are in mm.
- Fig. 4 : Construction of a Sector.
- Fig. 5 : A Reconstructed Event. Momentum (p) and Energy in the glass (E) are given in 100 MeV units.
- Fig. 6 : Time-Distance Relationship for a typical sector
a) Time versus distance from sense wire.
b) Time minus (distance/48.5 μ per ns) versus distance.
The left half of the plot shows a velocity of 51.7 μ /ns.
The right half shows a velocity of 49.4 μ /ns.
- Fig 7 : Spatial Resolution of Chambers :
a) Scatter plot of azimuthal residuals in the second module as a function of azimuth after a circle fit.
b) Six projected slices of the previous scatter plot showing a resolution $\sigma \sim 0.3$ mm in the azimuthal coordinate.

Fig. 1a

Fig. 1b

Fig. 2

Fig. 3

LONGITUDINAL CUT OF SECTOR

Fig. 4

CCOR RUN 4521 EVENT 165 TRIG PAIR CH 88
 E OUT 3.9GEV E IN 4.5GEV

TK	P	E	PT	NP	BPH	DCA	ZCA
1	17	1	15	6	26	0	0
2	-3	0	3	7	0	0	2
3	-11	0	9	8	108	1	0
4	-5	0	4	7	108	2	1
5	-3	0	3	8	0	2	0
6	3	0	2	5	0	1	9
7	5	0	4	5	0	1	1
8	4	0	3	5	0	0	0
9	4	28	4	6	0	0	1
10	6	0	4	5	0	2	2
11	2	0	2	6	0	1	1
12	-4	0	3	5	0	0	0
13	-9	2	9	5	0	1	1

Fig. 5

(a)

(b)

Fig. 6

RESIDUAL

(a)

RESIDUAL

(b)

Fig. 7