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Abstract

The Central Detector of the UA1 experiment at the CERN $p\bar{p}$ Collider underwent a first physics run at the end of 1981. The detector consists of a large drift chamber assembly (25 m³, $\sim$ 6000 sense wires). An electronics readout with multi-hit capability simultaneously digitizes the time and the analog information used for charge division and energy measurement. The initial performance of the readout and control system will also be presented. The detector was tested in two cosmic-ray runs, and is now fully operational for the second physics run; this started at the beginning of October 1982.

Introduction

The UA1 experiment is now taking data, in a second physics run, since the beginning of October 1982. The Central Detector is fully operational and is completely equipped with all the readout channels. A picture of how it appears in its final configuration in the experimental set-up is presented in Fig. 1.

Fig. 1 Picture of the central detector in the experimental set-up

The geometrical properties and the basic features of the associated electronics and readout system were first reported at the 1980 Wire Chamber Conference in Vienna, and at the 1982 International Conference on Instrumentation for Colliding Beam Physics held at SLAC¹.

We briefly recall here the general characteristics of the detector, focusing on the properties which are most relevant to its operation, such as the HV control, the readout, the data acquisition, and the calibration system. The first results, which closely approach the design performance, will also be presented.

Description of the Detector

The central detector, in its final assembly, is a self-supporting cylinder made of six independent half-cylinder chambers, each having a length of 2 m and a diameter of 2.2 m. A schematic view of the arrangement of the six modules is shown in Fig. 2. The orientation of the wire planes has been chosen so as to keep a constant density of points along the tracks over all the detector volume, taking into consideration the expected topology of $p\bar{p}$ interactions and the characteristics of the magnetic field (dipole type with horizontal direction). The most relevant parameters of the detector are summarized in Table 1. The arrangement of a typical drift cell is shown in Fig. 3. A careful study of the electrostatic forces has led to the introduction of an intermediate field plane, set at a voltage V_C to compensate for the electrostatic attraction due to the drift voltage V_D . The voltage V_F controls mainly the

Fig. 2 Cut-away diagram of the detector showing the arrangement of the various drift planes

Table 1

General characteristics of the detector

Type	Drift chamber with charge division readout of the second coordinate
Gas mixture	Argon (40%) + ethane (60%)
Drift field and gap length	1.5 kV/cm, 18 cm
Drift velocity	5.3 cm/ μ s
Drift angle	23° at $ \vec{B} = 0.7$ T
Anode plane arrangement:	
a) Distance between sense wires	10 mm
b) Wire length	80 cm min., 220 cm max.
c) Sense wire charac.	35 μ m Ni-Cr stretched at 80 g
d) Field wire charac.	100 μ m gold-plated Cu-Be stretched at 200 g
Cathode plane structure:	
a) Distance between wires	5 mm
b) Wire characteristics	150 μ m gold-plated Cu-Be stretched at 200 g
Total number of wires	22800
Total number of sense wires	6110

Fig. 3 Schematic of a typical drift gap

gas amplification. The drift distance (18 cm) has been chosen to be the largest one compatible with an electron drift velocity (5.3 cm/ μ s) less than the interval between $p\bar{p}$ collisions (3.8 μ s). The mechanical precision of the whole detector allows the position of the sense wires in a plane to be known within 50 μ m, whilst the coordinates of an "average" plane are known with an accuracy of about 200 μ m, so that they are not the limiting factor to the high precision of the drift-time measurement. This is a remarkable achievement considering the rather revolutionary technology followed in the choice of the supporting structure¹.

HV Control System

The essential role played by the central detector in the experiment, and its rather unconventional size,

required a considerable effort as far as the HV system is concerned, both from the point of view of the design and the voltage control.

The drift voltage V_D is degraded on the edges of a drift volume, through resistor chains and printed circuit lines, to ensure equipotential surfaces over all the detector volume (the electric field distortions are less than 1%). Furthermore, to avoid variations of the potential due to beam current or any kind of leakage in the HV distribution network, the voltage is firmly held in 10 intermediate points along each drift space through low output impedance power supply units, the so-called active dividers. For each drift space, all the intermediate voltages and currents, including V_C and V_F , are precisely measured, the former directly on the chambers and the latter in their respective power supply. A continuous monitoring of 308 currents and 308 voltages is ensured by a dedicated SUPER CAVIAR computer², which handles the HV power supplies for V_D and the associated interlock logic. Furthermore, a rather sophisticated alarm system has been implemented, first of all hardware-wise (crowbar system) in order to have a very fast (a few milliseconds) response in case of over-currents (200 μ A for the V_D channels, 50 μ A for the V_C , V_F power supplies). A very reliable interlock system for the V_C and V_F , which have been shown to be most critical ones, has also been introduced. It is driven by a General-Purpose Microprocessor Controller (GPMC), which executes the HV ramping, monitors currents and voltages, sets the alarm levels and, in case of over-current, quickly (within few hundred microseconds) decides whether to switch the connection of the chamber from the power supply to a shunt resistance. A schematic of the voltage control and interlock system is shown in Fig. 4.

Fig. 4 Block diagram of the voltage control and interlock

Readout and On-Line Calibration System

The complexity of a $p\bar{p}$ interaction at 540 GeV in the c.m. system in terms of multiplicity and particle density led to a readout system capable of continuously recording the "whole history" (4 μ s) of each wire between two successive bunch crossings.

The basic scheme of each wire readout is reported in Fig. 5. The novelty is certainly represented by the TRW-TDC 1014J, a 6-bit fast analog-to-digital converter (FADC), two of which equip each channel. Their action consists in sampling the two pulses coming from each wire end every 32 ns, and directly measuring the track position along the wire by the charge division method and the energy loss dE/dx through a non-linear scale³ in order to increase the dynamic range (from 6 to more than 9 bits). The drift time, on the other hand, is measured by a 3-bit time-to-digital converter (TDC) interpolator with an accuracy of 4 ns.

Fig. 5 Block diagram of a channel readout

The digital outputs of the TDC and the FADCs are then stored in a circular buffer memory (16 bits $\times$ 128 words), providing at any time the history of the previous 4 μ s (32 ns $\times$ 128). The readout electronics are arranged in such a way that a four-unit CAMAC module -- the charge and time digitizer (CTD) -- includes twelve wire channels. Five CTDs are located in a crate which also contains a dual microprocessor unit; this couples the fast handling of the CTD information with the monitoring and calibration functions. For every trigger, $\approx$ 15 kbytes are accumulated in each crate for a total of 1.6 Mbytes in all the central detector system. This impressive amount of data has to be reduced by one of the processors as quickly as possible. On the other hand, the second processor controls the crate operations and the data reduction programs; furthermore, it handles all the data, such as offsets and gains, relative to the on-line calibration.

The electronics have been designed so that the final accuracy is given by the 6 bits of the FADC (1%) as far as the charge division (z coordinate) is concerned. For this, a gas amplification of at least 10^5 is required, giving $\sim 4 \times 10^6$ electrons in about five sampling slices of 32 ns. On the other hand, the charge and the pulse shape on one side of the wire depend strongly on the position of the electron avalanche along the wire and on the Landau fluctuations. Therefore the analog part of the readout electronics requires good linearity over a large dynamic range (up to five times a minimum ionizing particle). A second consequence has been an interdependence of the z measurement from the pulse height E . In our algorithm it is given by the centre of mass of the various z_i weighted by the energy E_i measured in the same time sampling:

$$z = \frac{\sum_i z_i \cdot E_i}{\sum_i E_i},$$

where i varies up to 5.

A first measurement of the linearity of the analog chain is provided by a calibration system which feeds into all preamplifiers a calibrated and variable charge with an accuracy of $\approx$ 3%. A chain of serial shift registers selects any desired wire pattern and charge division coordinate, so that the system is also used as a fast debugging tool for checking the status of the electronics at any given moment.

A feedback action of the calibration pulser on the electronics is normally undertaken by means of 6-bit digital-to-analog converters (DACs). For each wire channel, four DACs control the left and right gains and the eventual offsets at the inputs of the two FADCs; two other DACs are used for the dE/dx measurement to control the base line and the response function of the energy scale. The handling of all these calibration data is performed by the readout processor (ROP) supervised by a SUPER CAVIAR. A typical display relative to the twelve channels of one CTD module is shown in Fig. 6, whilst the feedback on the charge division linearity is shown in Fig. 7.

Fig. 6 On-line calibration display simulating a minimum ionizing particle on 12 channels. The continuous line refers to the charge division coordinate, whilst the histogram with marks represents the total energy response.

Fig. 7 Effect of the on-line calibration on the charge division linearity

Central Detector Operation and Performance

The understanding of the central detector in normal operating conditions and the determination of its ultimate performance are provided by the knowledge of all the most relevant parameters, such as drift velocity W , drift angle α , absolute reference time t_0 , and absolute position of the wires. Temperature and gas-mixture variation effects, and distortions in the electric field, have also to be monitored or measured; the best method is, of course, a direct determination on the chamber. There are two distinct ways of doing this, both of which are used for the UAL central detector:

- i) Tracks are simulated in the detector using X-ray guns or ionizing laser beams, the position of which can be precisely defined in space in an absolute frame of reference and is not affected by the magnetic field. The drift velocity and the drift angle can in this way be precisely measured.
- ii) The drift space structure is such that the detector is "autocalibrating". This means that real tracks which usually cross different gaps having a constant and known relationship (two adjacent drift spaces have opposite electric field) must line up, providing, from a best fit procedure, a measurement of the basic parameters.

The first way, using both kinds of beams, is still in the construction phase. A set of 40 nitrogen laser units, each one providing three light-beams at different angles, is now being constructed. Each laser is pulsed by its own HV supply of the Marx generator type, but a simultaneous firing of all of them is foreseen.

A set of X-ray flash tubes, providing very narrow X-ray beams through 1 m long collimators, has also been installed and is ready to supply an absolute calibration which is complementary to the one provided by the laser light. The time spectrum of 12 X-ray beams seen by one chamber is shown in Fig. 8.

Fig. 8 Time spectrum of 12 X-ray beams on the bottom of the detector: a) drift time spectra obtained with ≈ 1500 shots (bins of 4 ns); b) X-ray beam position reconstructed from the time spectra.

Up to now, however, only the "internal" calibration method, using real tracks from $p\bar{p}$ collisions or cosmic-ray events, has been used to fit the relevant detector parameters. Actual events without magnetic field allow a fine tuning of the relative reference time t_0 per drift volume. With tracks crossing more than one drift volume, the absolute time t_0 can be found precisely and the angular correlation formalism for the drift time is checked. The two other relevant parameters, which are fitted to obtain the best reconstruction, are the drift velocity and the drift angle with field on. The over-all precision of these constants, measured independently for each module, is $\approx 0.5\%$, and their value is $53 \text{ mm}/\mu\text{s}$ for W and 22.2° for α with a drift field of 1.2 kV/cm and a magnetic field of 5.6 kG . The residuals in the drift-time direction are shown in Fig. 9 for tracks having different inclinations. The over-all precision obtained for all constructed tracks corresponds to a σ of $290 \mu\text{m}$, with some systematic effects still present at this stage of the analysis.

Fig. 9 Drift-time residuals for tracks: a) inside a single drift space; b) crossing two different drift gaps; c) inside a chamber; d) crossing different modules.

The "internal" current (charge) division calibration has been shown to be rather critical. Starting only from the latest cosmic-ray run, where the chamber gain was raised to its nominal value of 10^5 , a first attempt to measure the charge division accuracy has been possible. A typical distribution of the residuals along the z axis (parallel to the wires) is shown in Fig. 10, where a σ of 1.7% of the wire length is obtained. This part of the analysis is, however, in its very initial phase; neither pulse height nor threshold dependence and systematic effects have yet been treated.

Fig. 10 Distribution of the charge division residuals

Fig. 11 Truncated mean of the pulse-height distribution; the lowest 70% from 34 samples of 1 cm each have been plotted.

The last important information which the detector has to supply refers to the energy loss and particle identification. So far no attempt has been made to use the energy information from the $p\bar{p}$ data. The only measurement which has been analysed refers to a test with a 3 GeV/c muon beam. The truncated mean of the energy loss of the lowest 70% from the samples (a track was defined by 34 samples of 1 cm each) is shown in Fig. 11; a Gaussian fit to the distribution gives a σ of 11%.

Conclusions

After the 1981 run⁴, when only 80% of the designed parameters (high-voltage-wise) were attempted, the detector is now fully operational. A considerable effort has been put into improving the hardware and the remote control of the HV system. Complete software has also been provided for all the other detector operating functions, such as the amplifier voltage, the calibration electronics, the gas system, and the temperature on the detector.

A first analysis of the data has given good results, mainly for the drift-time coordinate where an accuracy of about 300 μm has been obtained, although effects coming from the geometry of the module or field distortion have not yet been studied. The high precision of the drift-time coordinate allows a good pattern recognition in the plane normal to the direction of the magnetic field, as can be seen in Fig. 12 where two events from $p\bar{p}$ collisions are displayed. Now the time has come to extract, in the most profitable way, all the other relevant information that the detector can provide. For this, a complete understanding of the on-line calibration and a serious analysis of the charge division and the pulse shape is under way, having as the final goal the determination of the detector's ultimate performance with respect to two-particle resolution, high-momenta measurement, particle identification, particle correlations, and jets.

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Fig. 12 Display, in the plane normal to the magnetic field, of two $p\bar{p}$ events at 540 GeV in the centre of mass