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Introduction

A TPC (Time Projection Chamber) system has been built for BNL Experiment 810, which is a study of particle production in relativistic heavy ion collisions. The events of interest have very high multiplicity (> 100 tracks). TPC's were chosen as the tracking detectors because they measure true three-dimensional points along the tracks, a very significant advantage for track reconstruction.

In order to have good event reconstruction in these high multiplicity events it is important to optimize the two-track resolution by having a large number of independent readout elements. We have used rows of short (~ 1 cm) anode wires parallel to the beam direction and a low diffusion gas (79% Argon, 16% Isobutane and 5% Dimethoxymethane) known to be stable at high gain in order to achieve this fine segmentation. Use of the short anode wires precludes using dE/dx for particle identification, which in the kinematic region of interest and at the particle densities in these events is a very expensive and extremely difficult task.

The TPC system consists of three separate modules which improve the system reliability. Readout electronics uses custom hybrids to produce a very compact cost

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effective system. In order to maximize the acceptance the ion beam is incident on the middle of the chamber, which limits the maximum useful ion beam.

TPC Modules

The front view of a module is shown in Fig. 1. In the vertical drift region (60 cm high $\times$ 65 cm wide $\times$ 47 cm long) a field cage with double sided printed circuit boards on the sides and a double row of wire electrodes at each end shapes the electric field. The readout is achieved by 36 rows (12/module spaced 3.8 cm apart) of 256 short anode wires (2.54 mm spacing), with the wire number giving the (x,z) coordinate and the drift time the y coordinate for unambiguous 3D points along the tracks. Figure 2 shows the three modules located in the center of the MPS magnet (looking downstream) and Fig. 3 is a closeup of the connections to the module. Electrons produced by charged particles in the drift region must pass through a gating grid and a wire cathode in order to reach the anodes. A second, solid copper, cathode below the anodes helps to achieve high gain. The arrangement is shown in Fig. 4. In TPC's the maximum beam rate is limited by field distortion due to positive ion buildup in the drift region. A major source of positive ions are ions produced in the gas amplification process at the readout anodes that leak into the drift volume. A gating grid is used to prevent the transfer of drifting electrons from the drift region to the detector region and that of positive ion in the reverse direction except for selected events. Gating is achieved by applying different potentials to adjacent wires as indicated in Fig. 4, collecting the electrons on the more positive wires. When the trigger system indicates that an event of interest has occurred the gate wires are shorted together for 30 μ s, a little longer than the maximum drift time, allowing ionization from the tracks to reach the amplification region. Because of their slower drift velocity, positive ions from amplification at the anode do not reach the gating grid before the gate is closed, further improving the gating of the TPC.

Electronics

Since dE/dx is not measured in this system the electronics is only required to give time information. In order to read out the many closely spaced short anodes at minimum cost, a circuit was designed that allows each individual channel to be mounted directly on the chamber and to occupy only the anode wire spacing. The circuit for each channel is shown in Fig. 5. Sixteen channels are assembled in a hybrid package^{*} with inputs spaced 2.54 mm apart. Shaping time constants were selected to match the anode waveform. An integration time constant of 50 ns and a differentiation time constant of 200 ns were chosen to minimize noise and maximize two-track separation. Time information is recorded with a memory driven by a counter to serve the function of a shift register. Each hybrid contains memory capable of recording 1024 time samples from each channel. To reduce possible local noise pickup, all logic levels are ECL - the clock and address lines are terminated differential ECL.

To minimize the control circuitry 2 kinds of hybrids are used. One type is called a master and in addition to the amplifier-shaper-comparator and memory for 16 channels has the counter used to address the memory plus the control logic necessary to read out itself plus 7 slave hybrids. The slave hybrids contain only the amplifier-shaper-comparator and memory required for 16 channels. The printed circuit boards are assembled with one master and 7 slaves (Fig. 6) which is sufficient for 128 anode readouts and is externally accessed by one clock line, one data line and 14 control lines. The data line is common to the two hybrid cards in a row and the other lines are common to the whole TPC. Thus only 27 lines are used to connect over 3000 channels per module to the external electronics. The time samples are obtained at 50 MHz and the data is sequentially read from each channel's memory at 25 MHz. This serial string of data bits is encoded into wire number, drift time and cluster size by FASTBUS modules in which all rows are encoded simultaneously.

^{*} LeCroy HTD 161S,M.

Consequently the entire readout is completed in 10 ms. This amount of dead time is acceptable because of other limitations on trigger rate.

The on-chamber performance of the hybrid allows input sensitivity of less than $1 \mu\text{a}$. Thus the chamber gas gain can be as little as a few times 10^4 .

Test Results

Tests were performed using beams of protons and Silicon ions directed through the approximate center of the TPC modules perpendicular to the wire rows and perpendicular to the magnetic field. The incident beam particles were tracked through two MPS multiplane PWC modules (run at reduced voltage for the Si beam, since the ionization of the ions is 196 times that of the hadron beams usually used) and a thin plastic Cerenkov counter for silicon identification. The measured beam tracks were used to calibrate the TPC with the magnet off (alignment runs). A few hundred tracks can align the TPC to 100 microns and measure the drift velocity to better than 1%. The TPC modules were operated at about 330 V/cm with a drift velocity of 2.3×10^6 cm/sec. The MPS magnet was run at 5.0 kGauss.

Using the proton beam, the efficiency for minimum ionizing particles was measured to be $> 97\%$ for several rows (the other rows had electronic problems that have been fixed). The rms position resolution as measured by fitting proton beam tracks was 0.6 mm (x - wire direction) and 0.5 mm (y - drift direction) and fitting Si beam tracks was 0.6 mm in x and 0.25 mm in y. Using secondary tracks from Si interactions the rms deviations from fits were 0.9 mm in x and 0.75 mm in y (note these results include all fitted tracks including pattern recognition mistakes).

Figure 7 (1/p for beam tracks reconstructed in the TPC) shows the momentum resolution of the test setup. The sigma for the 1/p plot gives directly the dp/p^2 resolution. Shown is the resolution measured using a silicon beam with 2-1/2 modules (31 rows). The curve is a gaussian approximation to the measurements and not a fit. The sagitta error that corresponds to the σ of the gaussian is 0.32 mm.

Targets of gold (0.025 mm thick), Tin (0.1 mm thick), Copper (0.15 mm thick), Aluminum (0.8 mm thick), and Carbon (1.5 mm thick) were used. Interactions were

selected by using a veto counter located behind the MPS. A discriminator was set to veto events which had a signal greater than half the Silicon beam pulse height in the veto counter. The raw beam rate in the chamber was about 1000-2000 ions per pulse. The veto counter pulse height was encoded with an ADC and recorded with the data so that software cuts could eliminate all events with pulse heights as large as that expected from an alpha surviving from the Silicon projectile. This total disintegration of the projectile was defined as our "central" trigger.

Events representing Silicon "central" collision were selected by applying two software cuts to the reconstructed events. The cuts were:

1. A vertex is located between $z = 60$ and $z = 66$ in the MPS coordinate system. Z is the beam direction axis and the target was located at $z = 63$. The next plot (Fig. 8) is a z distribution of some of the reconstructed vertices from the gold target with a looser veto counter cut.

2. Veto counter corresponding to no more than two minimum ionizing tracks.

Figures 9a-d show the computer reconstruction of 4 views of a silicon-gold event (number 301) with 102 tracks (out of a total of 130 tracks found) from primary vertex ($z = 63.2$). If we examine similar events in more detail we can see that the pattern recognition algorithm is not yet perfect, although it is good enough that one can sometimes spend a long time deciding what should have been done with hits that aren't assigned to tracks.

Different views of event 8789 are shown in Figs. 10a-d. This event has 77 tracks associated with a vertex ($z = 63.5$) at the target. In addition to the primary vertex there is a secondary vertex which is consistent with being a Λ decay vertex; Fig. 11 shows an expanded projection of the tracks assigned to the decay vertex.*

In a previous run using an Oxygen beam and prototype TPC's we studied beam rate limitations in the TPC. In a high intensity run some qualitative measure of the effects of space charge buildup (with time) due to primary ionization only was

* From a very preliminary analysis of a small sample the signal and background-to-background ratio is ~ 2.5 to 1 for the Lambda peak.

obtained. Beam intensity varied from 2×10^4 to 10^5 Oxygen ions per (one second) AGS beam spill. The highest intensity produces track distortions corresponding to more than 2 mm sagitta (in yz plane) and a substantial loss of efficiency in some rows. The average sagitta at 2×10^4 Oxygen ions was 0.55 mm. This latter intensity corresponds to 5000 Sulfur ions or to 1.2 million minimum ionizing particles (hadrons) per second.

The density of tracks from Oxygen and Silicon events offer many opportunities to study the two-track resolution of the device. There are cases where the device produces apparently separate signals for tracks as close as 2.5 mm. However, a feature of the pattern recognition algorithm is that it merges hits on adjacent wires if the signals in the drift direction overlap. This means for practical purposes that two tracks are properly separated 50% of the time by the pattern recognition if they lie outside the same 5 mm $\times$ 5 mm area in the x-y projection.

Conclusion

We have developed a TPC system for use in relativistic heavy ion experiments that permits the efficient reconstruction of high multiplicity events including events with decay vertices. It operates with the beam through the middle of the chamber giving good efficiency, two-track separation and spatial resolution. The three-dimensional points in this system allow the reconstruction of the complex events of interest. The use of specially developed hybrid electronics allows us to build a compact and cost-effective system.

FIGURE CAPTIONS

- Fig. 1 Front view of module showing principle components.
- Fig. 2 View of three modules in operating position as viewed from the upstream end of the MPS magnet.
- Fig. 3 View of the main electrical connections to modules.
- Fig. 4 Schematic of the arrangement of the electrodes in the detector end cap.
- Fig. 5 Schematic of individual channel electronics.
- Fig. 6 Layout of 128 channel hybrid printed circuit board.
- Fig. 7 Number of tracks vs. calculated l/p for Silicon beam and 31 rows of anodes. Curve is a gaussian approximation to the data and not a fit.
- Fig. 8 Calculated vertex distribution for selected events from a 0.025 mm Gold target.
- Fig. 9 Computer reconstruction of event 301 which has 102 tracks from primary vertex.
a. x-z view;
b. y-z view;
c. x-y view;
d. rotated view.
- Fig. 10 Computer reconstruction of event 8789 which has 77 tracks from primary vertex.
a. x-z view;
b. y-z view;
c. x-y view;
d. rotated view.
- Fig. 11 Expanded view x-z of only the tracks from the Λ candidate in event 8789.

Figure 1

Figure 2

Figure 3

Figure 4

16 CHANNEL HYBRID CONFIGURATION

Figure 5

128 CHANNEL HYBRID MASTER-SLAVE INTERCONNECTION

Figure 6

Three TPC Modules Si Beam

Figure 7

Silicon - 0.0025 cm Gold

Figure 8

Figure 9b

Figure 9c

RUN 7
TAPE 14331
DATE 22 DEC 88
TIME 06:37:11
EVENT 301

Figure 9d

Figure 10a

Figure 10b

Figure 10c

Figure 10d

Figure 11

ANODE

CATHODE

Figure 4

END

DATE FILMED