A MANY PARTICLE-TRACKING DETECTOR WITH DRIFT PLANES AND SEGMENTED CATHODE READOUT*

J. Fischer, D. Lissauer, T. Ludlam, D. Makowiecki, E. O'Brien, V. Radeka,
S. Rescia, L. Rogers, G.C. Smith, D. Stephani, B. Yu
Brookhaven National Lab, Upton, New York, 11973

S. V. Greene, T.K. Hemmick, J.T. Mitchell, B. Shivakumar
Yale University, New Haven, Connecticut, 06511

Abstract

We describe the design and performance of a detector system for tracking charged particles in an environment of high track density and rates up to 1 MHz. The system operates in the forward spectrometer of the BNL Heavy Ion experiment E814 and uses principles of general interest in high rate, high multiplicity applications such as at RHIC or SSC. We require our system to perform over a large dynamic range, detecting singly charged particles as well as fully ionised relativistic ^{28}Si . Results on gas gain saturation, δ -ray suppression, and overall detector performance in the presence of a 14.6 GeV/nucleon ^{28}Si beam and a 14 GeV proton beam are presented.

BNL--43698

DE90 005574

Introduction

The E814 tracking chambers are designed to reconstruct the momentum of heavy ion fragments and minimum ionizing particles which pass through the experiment's forward spectrometer. The AGS experiment studies collisions of a ^{28}Si beam with an energy of 14.6 GeV/nucleon with various targets such as Al, Cu, Sn and Pb. The fragments and minimum ionizing particles can result either from peripheral collisions between the heavy ion beam and target or from central, small impact parameter heavy ion collisions. In the first type of interaction many charged fragments can move through the spectrometer which covers approximately a 0.8° cone in the forward direction, while in the second type of interaction only a few leading baryons enter the spectrometer [1]. In either case the tracking chambers are expected to reconstruct the momentum of each charged particle.

The heavy ion environment presents a variety of challenges to tracking chambers. The heavy ion fragments create large numbers of delta rays that must be distinguished from the particles originating at the target. We require our electronics to operate over a large dynamic range because we want to be efficient for both Si and minimum ionizing particles which differ in energy deposition on average by a factor of 200. Peripheral events can yield up to 14 charged tracks, which must each be reconstructed. The Si beam

*Work supported by the U.S. Department of Energy

Figure 1: E814 Experimental Set-Up

passes directly through the tracking chambers at a rate of a few hundred kHz during data taking so the chamber must be resistant to the damaging effects of a heavily ionizing beam.

The E814 experiment consists of a set of calorimeters and multiplicity detectors that surround the target, and a forward spectrometer composed of two dipole magnets, three tracking chambers, a scintillator array and a set of uranium calorimeters (see fig. 1). The participant calorimeter has a 0.8° opening in the forward direction through which particles pass and enter the spectrometer. The forward going particles pass through two dipole magnets between which one of the tracking chambers is located. Following the second dipole are the two other tracking chambers, a scintillator array used for both time-of-flight and charge measurement, and uranium calorimeters that measure the energies of the particles. The tracking chamber between the two dipole magnets is called DC1 and is a segmented cathode pad detector that employs resistive charge division. It has an active area of 16 cm x 26 cm and is located approximately 4 meters from the target. The two tracking chambers following the dipoles are DC2

Figure 2: Schematic of DC2 and DC3. One chevron pad is shaded in the Beam View of Chevron Pad Plane as an aid to the reader.

and DC3. Each consists of six planes of drift section that reconstruct the position of each track in the dipole bend plane, followed by a pad plane that uses geometric charge division to determine an unambiguous x-y position for each track (fig. 2). DC2 is located approximately 7 meters from the target and has an active area of 30 cm x 80 cm, and DC3 is located 12 m from the target and has an active area of 50 cm x 200 cm.

Mechanical Design

The main structure of the tracking chambers consists of machined G-10 frames for DC2 and DC3 and a combination of G-10 and aluminum frames for the smaller DC1. The drift sections of both DC2 and DC3 are composed of six wire planes that contain 17.5 μm Au-W anode wires alternately located between 125 μm stainless steel field wires (see figure 2, Plan View). Separating each drift plane is a cathode foil made of 25 μm aluminized mylar. The wires are stretched vertically, perpendicular to the spectrometer bend plane, and are displaced in the bend direction on alternate planes in order to resolve right-left ambiguity in track reconstruction. The wires and foils are arranged in a square geometry such that both the anode to cathode foil distance and the anode to field wire distance in DC2 is 3.18 mm (1/8"). The comparable distance in DC3 is 6.35 mm (1/4"). DC2 has 128 anode wires per plane, and DC3 has 160 per plane.

All three tracking chambers are filled with 50-50 argon-ethane gas and are operated at atmospheric pressure. The gas has a drift velocity of 50 $\mu\text{m}/\text{nsec}$ at our operating voltages. The maximum drift times in DC2 and DC3 are approximately 65 nsec and 130 nsec respectively.

Figure 3: DC chevron pad plane schematic. The anode-field wire spacing and the wire plane-cathode pad plane spacing is 3.18 mm in DC2 and 6.35 mm in DC3. The wire plane-cathode foil distance is 6.35 mm in both DC2 and DC3.

The pad sections in DC2 and DC3 are composed of an aluminized mylar cathode foil, a plane of vertical anode and field wires, and the cathode pad plane. The cathode pad planes in DC2 and DC3 are large 3-layer copper clad FR-4 printed circuit boards which each have a chevron pattern etched on the surface which faces the wire plane (see figure 3). Each copper chevron has a plated through hole that connects it to the back layer of the printed circuit board which contains traces that carry the signals onto the preamp motherboard. The chevrons are arranged in columns and are positioned such that their peaks are located immediately below the anodes in the wire plane above. Separating each column of chevrons is a guard strip that helps to shape the electric field so that a track between a pair of field wires deposits over 90% of its charge on the anode between those two field wires. This maximizes the amount of charge induced on a single chevron.

The charge deposited by an ionizing particle which passes through the pad section drifts toward the anode wire where it is multiplied. The image charge from anode multiplication covers an area the size of two or three chevron pads on the cathode pad plane. By finding the centroid of the charge induced on the cathode plane one can determine the ionizing track's position along the wire [2]. Its position perpendicular to the wire is determined only to the nearest wire, but when combined with the information from the drift section one obtains an accurate, unambiguous x-y position for the track.

We require that a constant gain be maintained over the entire surface of the cathode pad plane, so it is necessary to keep the cathode pad to anode wire distance constant to within 2%. The cathode pad planes are large multilayer

Figure 4: Schematic of a pad plane using resistive charge division. In DC1 the anode wire-field wire spacing is 2 mm. The distance from the wire plane to the cathode pad plane is 2 mm and the distance from the wire plane to the cathode window is 4 mm.

boards which tend to have internal stresses that make them warp. In order to flatten the pad plane without adding much mass to our chamber we epoxied the DC2 and DC3 pad planes to a large piece of low mass, 4.68 mm (3/16") thick, Nomex¹ honeycomb and backed it with 200 μm G-10. The technique adds less than 0.15% of a radiation length to each detector but in the case of the DC3 pad plane it reduced the warpage from up to 6.35 mm to 0.05 mm.

The DC1 pad chamber is made of a 9 μm thick aluminumized mylar cathode foil mounted parallel to a horizontal wire plane composed of evenly spaced anode and field wires of the same diameter and composition as in DC2 and DC3, which is followed by the cathode pad plane as shown in figure 4[3]. The DC1 pad plane is a three layer printed circuit board made of copper clad polyimide. Rows of 2 mm x 0.9 mm rectangular copper pads run directly beneath each anode wire and are separated from one another by guard strips that lie below the field wires. Each row of pads has a continuous line of resistive ink running along its length. Depending on the region of the board, one out of every 4, 8 or 10 pads in a row is connected by a plated through-hole to the traces on the back layer of the pad plane, which carry the signals to the preamp motherboard. When an ionizing particle passes through the detector the majority of the charge is multiplied on one anode and the image charge is induced primarily on a small section of one row of pads. By finding the centroid of the charge deposition along the row of pads one can accurately determine the position of the track.

¹Registered trademark of E.I. DuPont

The distance in DC1 between the wire plane and the cathode pad plane is 2 mm, and the distance between the wire plane and the cathode foil is 4 mm. DC1 contains 40 anode wires spaced 4 mm apart with field wires located halfway in between. Just as in the case for DC2 and DC3 we want to maintain constant gain over the detector by making the DC1 pad plane as flat as possible. By epoxying a layer of 6.35 mm (1/4") polyimide honeycomb to the pad plane and then backing it with 125 μm of polyimide we were able to maintain a flatness to within $\pm 40 \mu\text{m}$.

By carefully designing the multi-layer printed circuit boards used for the cathode pad planes, we have been able to keep the total radiation length of each chamber to a minimum so as not to degrade the spectrometer momentum resolution by introducing large amounts of multiple scattering. DC1 and DC2 are both less than 0.7% of a radiation length thick. DC3 is 1.9% of a radiation length thick, but because it is the most downstream tracking chamber its thickness does not affect the momentum resolution.

Electronics

The electronics chain for the tracking chambers consists of BNL-designed hybrid electronics and LeCroy Fastbus digitisation electronics (fig. 5). The electronics chain for the drift section of the tracking chambers contains a preamplifier, a unipolar shaping amplifier, a two-level discriminator that provides additional shaping, and a LeCroy 1879 TDC. The preamplifiers are a low noise common-base type which are mounted near each anode wire in the drift sections of DC2 and DC3. The preamplifier signal enters a unipolar shaping amplifier which has a gain of 2×10^3 and a risetime of 12 nsec. The output of the shaping amplifier enters a two level discriminator: the low level is designed to allow all signals from minimum ionizing particles to pass, and the high level is designed to allow only signals from energy deposits greater than minimum ionizing to pass. The low level is a simple discriminator while the high level first shapes the 12 nsec unipolar pulse into a 60 nsec risetime bipolar pulse before the signal enters a zero-crossing discriminator. The shaping stage in the high discriminator level has a gain of ~ 1 . If a pulse from the fast shaping amplifier passes the first level discriminator but not the second, the discriminator puts out a single 50 nsec wide pulse whose leading edge corresponds to the time the first electron cluster from the ionizing track reaches the wire. If the signal passes both discriminator levels then the discriminator produces two 50 nsec wide pulses approximately 160-200 nsec apart where the exact time of the second pulse determines the position of the centroid of the total primary charge that drifted into the anode wire.

The high threshold in the two-level discriminator is designed to measure the drift time associated with a heavy ion track. Since a heavy ion track will be surrounded by a cloud of δ -rays a simple threshold discriminator would yield a drift time associated with the edge of the δ -ray

Drift Chamber Electronics

Pad Chamber Electronics

Figure 5: Tracking chamber electronics chain for both the drift sections and the pad sections.

cloud while the zero-crossing discriminator gives the drift time associated with the centroid position of the charge distribution, which corresponds to the position of the heavy ion track in our tracking chamber. The discriminator signals enter a 10-bit, pipeline, LeCroy 1879 TDC which has 1 nsec resolution.

Signals from the cathode pad plane enter charge sensitive preamplifiers mounted on the tracking chambers. Each preamplifier output first passes through a pair of transformers and into a shaping amplifier whose output is a bipolar pulse with a 200 nsec risetime. The output of the shaping amplifier is digitised by a 15 bit LeCroy 1885F ADC.

Detector Performance

The tracking chambers were tested with a 14 GeV proton beam, and with ^{28}Si and ^{16}O beams which each had energies of 14.6 GeV/nucleon. DC1 was also extensively tested with an X-ray source. Physics data were taken with the tracking chambers during an E814 heavy ion run of ^{28}Si -target(Al,Cu,Sn,Pb). The results of the tests and the physics runs show that the tracking chambers can detect both minimum ionising particles and heavy ion particles simultaneously with high efficiency of detection for the minimum ionising particles (Fig. 6). Our tracking algorithms require that three out of six drift planes be hit in a chamber in order to reconstruct a track, and we find

Figure 6: Heavy ion peripheral event showing a heavy ion fragment and minimum ionising particles detected simultaneously in the tracking chamber. An event in DC2 is shown. The heavy ion fragment is the track near the top of the figure with multiple hits/plane. The dashed lines show the track segments identified by our track reconstruction program.

minimum ionising particles meet this criterion in better than 99% of the cases. We also observe that, although a Si beam is traversing the chambers at a rate of a few hundred kilohertz at the same time we are taking data, the quality of the data is unaffected. We have found that uncertainties in track identification, caused by the sheath of hits that surround the heavy ion fragments that pass through the tracking chambers, can be greatly reduced by the use of the high discriminator level. The hit reduction is necessary for both accurately finding the momentum of the heavy ion and aiding the pattern recognition computer programs.

In a standard wire chamber the avalanche gain stays constant as the primary ionisation increases so that the anode signal is proportional to the primary ionisation. Since the primary ionisation for a relativistic particle increases approximately as Z^2 , we would expect our average anode signal to be 200 times larger for ^{28}Si than for a minimum ionising particle. Tests performed prior to the construction of the tracking chambers by our group[4] and others[5] have shown that very thin anode wires can give rise to a saturation of the avalanche gain as primary ionization increases. We have taken advantage of this by using 17.5 μm diameter anode wires which effectively increase the dynamic range to which we can be sensitive. DC1 measurements show that we have reduced the expected ratio of anode charge accumulation of ^{28}Si to minimum ionising by a factor of 3.3 as shown in figure 7. The ratio of anode charge deposit between ^{28}Si and minimum ionising was a factor of ~ 80

Anode Charge vs. Anode Voltage

Dec. 1974, Argonne 200, Chm. 200 to Display Data.
Y Axis = 0 Vol. Y Offset = -200 Vol.

Figure 7: DC1 Anode Charge vs Anode Voltage as measured with an X-ray source, a proton beam and a ^{28}Si beam. The saturation effect from the space charge can be seen. Without any charge saturation one would expect the average anode charge created by the ^{28}Si beam to be a factor of 200 larger than the average anode charge from the proton beam.

for DC1, when it was operating at physics run voltages. Calculations show that the saturation factor should be in a similar range for DC2 and DC3.

Measurements of the DC1 position resolution with an X-ray beam and with a proton beam have been performed. The measurements are described in detail in another paper submitted to this conference[6]. The single particle resolution of DC1 based on a measurement with a proton beam has been determined to be $120\text{ }\mu\text{m}$ RMS along the anode wire for a 0.15 pC anode charge deposit. The DC1 resolution measured by X-ray tests approaches $70\text{ }\mu\text{m}$ RMS for 1.0 pC anode charge deposit where the pad readout spacing is 6 mm .

The DC2 chevron pad resolution has also been studied using a proton beam. The best we can presently do is set an upper limit on the pad resolution based on the known width of the proton beam at DC2. The data show that the proton resolution in the fine granularity region of DC2 is better than 4 mm RMS, which is the width of the proton beam at DC2 (see fig. 8).

Lab tests with an X-ray beam have been performed at BNL using a small chamber containing a cathode plane etched in a chevron pattern[6]. Test results suggest that for 3 cm long chevron pads, DC2 pad section proton resolution

DC2 PAD SECTION PROTON DATA

Figure 8: DC2 pad reconstructed width of the AGS proton test beam.

should be $\sim 1\text{--}2\text{ mm}$ RMS, and DC2 heavy ion resolution should be $\sim 500\text{ }\mu\text{m}$ RMS.

The resolution of the drift sections of DC2 and DC3 have been measured using both a proton beam and a ^{28}Si beam. During the heavy ion tests the chambers were operating at reduced voltage in order to decrease their sensitivity to δ -rays. The single particle, single point resolution obtained is $120\text{ }\mu\text{m}$ RMS for DC2 and $140\text{ }\mu\text{m}$ RMS for DC3. The single point, proton resolution for DC2 and DC3 running at nominal operating voltage was $260\text{ }\mu\text{m}$ as seen in figure 9.

Summary

We have built and tested a set of tracking chambers designed to operate in a heavy ion beam. The chambers can track both minimum ionising particles and ^{28}Si simultaneously and are little-influenced by the heavy ion beam passing through them at a rate of a few hundred kHz. The pad sections provide unambiguous x-y track positions for both minimum ionising particles and heavy ions. The proton resolution has been shown to be $120\text{ }\mu\text{m}$ RMS in DC1 and better than 4 mm RMS in the DC2 pad section. The measured DC2 pad resolution is limited by the proton beam width and is expected to be of the order of $1\text{--}2\text{ mm}$ RMS. The DC2 and DC3 proton resolution has been measured for the drift sections of the two chambers and found to be $260\text{ }\mu\text{m}$ RMS. Events with up to 10 charged track segments in each chamber have been identified despite the multiple δ -ray environment associated with heavy ion physics.

DRIFT SECTION PROTON RESOLUTION

Figure 9: DC2 and DC3 drift section single point, single track resolution for a 14 Gev proton beam and the chambers set at nominal operating voltage.

Acknowledgments

We gratefully acknowledge the technical assistance of James Rutherford, August Hoffmann, Micheal Lens and Glen Boyle. Our detectors were built with the engineering assistance of Mordechai Montag.

References

- [1] P. Braun-Munzinger et al., AGS experiment E814 proposal, Brookhaven National Lab, unpublished.
- [2] V. Radeka and R. Boie, *Nucl. Instr. and Meth.* 178(1980), 545
- [3] R. Debbe et al., Proc. Wire Chamber Conf., Vienna, Austria 1989, *Nucl. Instr. and Meth. A*(1989), to be published.
- [4] J. Fischer et al., unpublished work, 1988.
- [5] T. Kobayashi et al., *Nucl. Instr. and Meth. A* 254(1987), 281
- [6] R. Debbe et al., "Study of Wire Chambers with Highly Segmented Cathode Pad Readout for High Multiplicity Charged Particle Detector", these proceedings.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.