Drift chambers for BRAHMS experiment at RHIC facility

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Abstract

A construction and tests of the drift chambers for the BRAHMS experiment at the RHIC facility are reported.

I. INTRODUCTION

The Broad RAnge Hadron Magnetic Spectrometer (BRAHMS) experiment [1] is dedicated to investigate the ultrarelativistic heavy ion collisions at RHIC (Relativistic Heavy Ion Collider) facility. The BRAHMS set up is designed to measure charged hadrons over a wide range of rapidity and transverse momentum for all available beams and energies. The design of the spectrometer comes from tracking criteria and the actual choice is confirmed through extensive simulations.

This paper reports on the design of the Drift Chambers (DC) for the charged hadrons tracking in the Forward Spectrometer (FS) operating in a high momentum mode [1]. Here, the forward going particles are swept by the two dipoles toward the back end of the spectrometer where they are tracked in several detectors. The particle momenta are determined by these measurements and the confirmation that they passed through another two dipoles. The particle identification is done at the end of FS using a ring-imagining Cherenkov detector [1].

The BRAHMS construction criteria and the multiplicity considerations require that the detectors T1 and T2 are the Time Projection Chambers (TPC) [1]. Design and tests of the prototype of the T3, T4, T5 DC's and of the front-end electronics dedicated to them are reported in this article. The DC's have been constructed at the M. Smoluchowski Institute of Physics of the Jagellonian University and the prototype main test has been performed at the Institute of Storage Ring Facility at the University of Aarhus (ISA).

II. LAYOUT CONSIDERATIONS

A. Tracking

The drift chambers are usually constructed as a set of drift cells which form a detection plane. The drift cell measures the time-of-flight of ionization electrons from the position of the detected particle track to the nearest anode wire. The drift chamber which consists only of one detection plane of drift cells measures hit positions along one coordinate (e.g. the x-plane, whose wires are vertical, measures distance along the horizontal x-axis between a hit and some reference point). In other words, the drift chamber hit provides a locus of points, through which a track have passed, at a measured distance away from the wire. In order to determine hit positions in two dimensions at least three detection planes with different anode wire angles (different "views"), must be used. As illustrated in Fig. 1, N=2 tracks generate $N^2 = 4$ possible intersection points when only two different views are used. A third view uniquely identifies the valid tracks (solid lines in Fig. 1). More than three views are not strictly necessary, however they provide useful redundancy. Another feature of the drift chamber is the so called "left-right ambiguity" which results from the fact that the drift cell measures the distance of a hit from a wire , but the side of the sense wire on which the track passed is not known. This ambiguity can be resolved by having multiple detection planes of wires in the same view, with the wires of one plane "staggered" (or out-of-line with the wires of the other plane). Fig. 2 illustrates a 1/4 cell shift which is very useful if the track was incident normal to the cell plane. In this case the sums or the differences of the drift distances from hits on a pair of staggered and unstaggered planes are constant as long as the hits were generated by the same track. Moreover, on the staggered plane, the position of the hit on the incorrect side of the wire will be misaligned from the hits on the unstaggered planes and by requiring all of the hits to be aligned, the left-right ambiguity can be solved.

B. Position and angular resolution

In the BRAHMS experiments one has to measure the momentum vector of particles emitted from the beam intersection point (vertex) and entering the spectrometer. In order to determine the momenta of particles in the spectrometer system it is necessary to match segments of a track measured in one tracking detector with another tracking detector. A typical distance between tracking detectors is 4 m and the physical processes such as multiple scattering might affect the possibility of reconstruction of a track. Fortunately, for high momentum track this effect is usually negligible (e. g. for protons and pions with momenta above 2 GeV/c the variance due to multiple scattering over 4 meters of air is less than 1 mm).

A main factor in the ability of the track projection is the accuracy of the position measurements in each tracking detector. Assuming that tracks are measured at the entrance and at the exit of each tracking detector with resolution σ_D one can calculate an accuracy of the track projections, σ_x and σ_y, at a given distance.

The variance of the momentum resolution $\sigma_\mathbf{p}/\mathbf{p}$ and the vertex position determination as a function of the assumed detector resolution are given in Table 1.

Table 1
Calculated momentum resolution and the variance of the vertex position determination for a selected values of the tracking detector resolution.

$\sigma_\mathbf{D}$ (μm)	$\sigma_\mathbf{p}/\mathbf{p}$ (%)	$\sigma_\mathbf{x}$ (mm)	$\sigma_\mathbf{y}$ (mm)
100	0.39	2.2	1.9
200	0.77	4.1	2.9
300	1.00	5.1	3.6
400	1.15	6.5	4.6

In order to obtain $\sigma_\mathbf{p}/\mathbf{p} \leq 1$ % the required position resolution of the detectors should be less than 0.3 mm FWHM.

C. Particle multiplicities

The particle multiplicities and surface density of particles at which each detector must operate are of great importance to the detector design. These quantities have been evaluated using GEANT [2] simulations with 400 central Au+Au events from the VENUS [3] code as an input. The estimates depend critically on the angular and magnetic field settings. Here we are considering the most difficult cases for the tracking detectors T3-T5.

Simulated average charged particle multiplicities for intermediate momentum acceptance, i.e., the FS at 2.2^o are given in Table 2, where $\mathbf{N_{pri}}$, $\mathbf{N_{sec}}$ and $\mathbf{N_{tot}}$ are numbers of primary particles, secondary particles and sum of them, respectively.

Table 2
Simulated average charged particle multiplicities.

	p=7.5 - 15 GeV/c				p=15 - 30 GeV/c			
Detector	$\mathbf{N_{pri}}$	$\mathbf{N_{sec}}$	$\mathbf{N_{tot}}$	**particles/cm^2**	$\mathbf{N_{pri}}$	$\mathbf{N_{sec}}$	$\mathbf{N_{tot}}$	**particles/cm^2**
T3	1.2	4.6	5.9	0.006	2.7	4.4	7.1	0.007
T4	0.6	1.0	1.6	0.001	1.5	0.8	2.4	0.002
T5	0.3	0,5	0.8	0.0004	1.0	0.5	1.6	0.001

Only particles which were emitted toward the first dipole D1 were tracked. In addition to the primary particles emitted from the collision, N_{pri}, secondaries, N_{sec}, are generated primarily from the magnet yokes and field clamps, and to a minor extent from the detectors.

It can be observed that near the end of the FS where detector T5 is located the expected multiplicities are quite low, with typical numbers of charged particles being smaller than 1. This sets only modest requirements for tracking and particle identification at this position. On the other hand the charged particle multiplicities in T3 are higher and reach values of up to 8. The very high background rate in T3 is due to particles coming through the spectrometer which produce secondary emission in the beamline magnet DX.

In order to meet the necessary tracking requirements, the detector T3 is constructed with a higher density of sense wires than the detectors T4 and T5. These latter two have an identical construction to each other.

D. Long term performance

A drift chamber which has been used for a long time shows the following malfunction symptoms:

- An increase of the dark current.
- A lowering of the gain.
- A loss of the pulse–high resolution.

The gas mixture, material properties used, and gas contaminants are the main factors that cause such problems. Despite the fact that the process of gas detector ageing has been broadly studied for many years [4], the nature of this phenomenon is still far from complete understanding. The following problems related to the ageing of the drift chamber have been investigated:

- Development of a dark current i.e. the appearance of a current drawn by the anode even in the absence of the radiation. This phenomenon has been investigated by Malter [5] and was explained by the so–called thin–field emission effect. Another effect that can cause dark current and glow discharges is a growth of whiskers which are a fine strands of material, built on the field shaping wires towards the anode.
- A growth of the polymers on the anode wires which implies a high silicon collection efficiency of the avalanche process [6].

In order to achieve a long lifetime of the DC operation the following rules have to be observed [7] :

- Avoiding contaminations, in particular halogens, oil traces (also from bubbles), rubber (especially silicon rubber), polyurethane adhesive, PCV and teflon tubing, soft epoxides and adhesive, aggressive solder, any unknown organic materials, large amount of G10 (glass-fibre-enforced material containing silicon) [6].
- Keeping the gas clean and using cold traps.
- Using thick cathode and field shaping wires and very clean anode wires.
- Keeping the amplification low.

III. DESIGN

A. Basic requirements

Before a whole set of the DC's for the BRAHMS experiment was constructed a single module prototype of T3 detector was build in the M. Smoluchowski Institute of Physics of the Jagellonian University and successfully tested at the ISA of the Aarhus University.

The detection plane which consists of many drift cells is the basic sub-module of each detector. In this section, we discuss the prototype design features of this basic sub-module. Our construction is based on the drift chambers which were built for the high-resolution position measurements [8], [9], [10].

A cross section of the drift cell prototype is shown in Fig. 3. In each drift cell, the ionization electrons drift to the anode wire (sense wire), A, in an electric field created by potential differences between the anode and cathode wires, **C**. The magnitude and uniformity of the field in the drift cell is of critical importance. The strength of the field in the whole cell volume should be sufficient to saturate the electron drift velocity. Moreover, the electric field at the sense wire should produce the necessary avalanche gain of electrons to separate the signal from the electronic noise. The electric field at the wire surface, for fixed potential, increases with decreasing wire diameter, so sense wires should have diameters as small as possible. The field wires, **F**, form the boundary of the drift cell and provide a uniform drift field inside the cell.

B. Mechanical construction

Each detection plane is build out of three frames made of epoxy-fiberglass and fabricated with a digital machine tool having a position accuracy of ±0.01mm [11]. Printing boards for soldering the wires are glued to the frames. One frame contains the alternately ordered anode and cathode wires. Two frames with the field shaping wires are placed on both sides of the anode/cathode wires frame. The outer dimension of the prototype and T3 detectors frames are 49 cm x 59 cm while the inner dimensions (active area) are 31 cm x 41 cm. The T4 and T5 detectors are larger and their outer frame dimensions are 54 cm x 69 cm and the inner dimensions are 36 cm x 51 cm.

A minimal thickness of the drift cell is limited by the possible hit losses caused by the statistical fluctuations in the electron collection process. The chosen cell thickness of 10 mm provides an average of 20 primary ionizations for minimum ionizing particles. The distance between the anode-cathode plane and field shaping planes is 5 mm and is limited by the distance between the field shaping wires (2 mm in this construction).

The accuracy with which the position of the anode and cathode wires can be fixed is essential for the position measurements in the DC's (the accuracy of the position determination of the field shaping wires is not that crucial). For this reason, the anode and cathode wires are stretched each one individually and positioned by $\Phi = 2$mm plastic pins which are fixed at the printing boards near soldering pads. The opening for these pins were drilled with digital machine tool having a positioning accuracy of $\pm10\mu$m. Each wire touches always two pins. The detection plane characteristics are listed in Table 3.

Table 3
The detection plane characteristics.

Det. name	No. of modules	Planes per module	View type	View angle (deg)	No. of sense wires	Stagger (cm)	Cell width (cm)
T3	3	1, 2, 3	x, x, x	0.	40	.0, .25, .0	1.0
		4, 5, 6	y, y, y	90.	30	.0, .25, .0	1.0
		7, 8	u, u	18.	48	.0, .25	1.0
		9, 10	v, v	-18.	48	.0, .25	1.0
T4	3	1, 2,	x, x,	0.	23	.0, .55	2.2
		3, 4	y, y	90.	16	.0, .55	2.2
		5, 6,	u, u	18.	27	.0, .55	2.2
		7, 8	v, v	-18.	27	.0, .55	2.2
T5	3	1, 2,	x, x,	0.	23	.0, .55	2.2
		3, 4	y, y	90.	16	.0, .55	2.2
		5, 6,	u, u	18.	27	.0, .55	2.2
		7, 8	v, v	-18.	27	.0, .55	2.2

The field wires are wound with a winding machine on auxiliary frames equiped with combs. The combs fix the relative distance of the wires to 2 mm $\pm 0.05mm$. Then these frames were placed on the fiberglass frames and the wires were soldered on the printing boards.

The wire characteristics selected for the constructed detectors are following: the anode wire is gold-plated tungsten of 20 μm diameter stretched with 50 g tension, cathode and field wires are made of beryllium-copper of 50 μm diameter stretched with 100 g tension.

Several detection planes are assembled to create the module closed from both sides with aluminum frames covered with 0.25 mm aluminized kapton windows. The gas tightness is guaranteed by Φ = 2mm o-rings which is placed between neighbouring frames. The alignment of the various detection planes is achieved by means of four Φ = 18mm steel pins passig tight through the frames. The module is operating as a separate drift chamber. Fig. 4 shows the DC prototype module under construction.

IV. DRIFT CHAMBER PROTOTYPE TEST

A. Beam facility

The drift chamber prototype test was performed at the ISA of the University of Aarhus. The ISA is responsible for running the Aarhus ASTRID electrons and ions storage ring. In order to mimic a condition expected at the BRAHMS experiment where the minimum ionizing hadrons will be detected, the 580 MeV electron beam was used for the DC's prototype test.

The drift chamber was placed at a distance of about 15 m from the dipole magnet selecting the electron beam. The tested area of the detector was defined by two scintillators mounted one by one at the front of the detector entrance window. The scintilator detector area was 5 cm by 20 cm and a thickness was 1 cm for the passing electrons. The coincidence signal from both scintillators selected electrons which path was almost perpendicular to the detection plane. This signal triggered also the acquisition system.

The working point of the drift chamber is defined mainly by following parameters: the sense wire voltage, the drift field strength, the composition of the gas mixture and the discrimination threshold. The aim of the test measurements was to determine the chamber efficiency and the spatial position resolution as a function of the working point parameters. A long term properties of the prototype such as the ageing, pre-rinsing of the chamber with the gas, variation of the gas flow, etc., were not investigated during this test run.

B. Gas system

A selection of the DC gas mixture is based on the following criteria:

- The electron drift velocity should be independent on variation of the electric field strength E. Such operation condition can be riched above a certain value of the electric field strength where the electron drift velocity saturates. The drift velocity as a function of the electric field strength for the argon-isobutane gas mixture show small variation in the range of 1.0 to 3.0 kV/cm [12]. At the saturation regime it is also a minimum sensitivity of the drift velocity on the gas temperature and preassure variation, and the gas mixture composition.
- The longitudinal and spatial diffusion of the generated charges deteriorates the position resolution of the DC. The electron diffusion is relatively big in a noble gas medium (e.g. argon), and is small in organic gases (e.g. isobutane).
- The ageing of the chamber caused by the polymerization of the organic gases gets worse in proportion to the operating time and to the induced electric charge in the gas medium by detected particles. The systematic tests [7] reveal preferences for gases with most complex molecules, like isobutane (C_4H_{10}), comparing to other commonly used organic components of the gas mixtures.
- The strength of the electric field needed to obtain the saturation condition, E $\in$ (1000,3000) V/cm, leads to the gas discharge (a dark current and sparks). In order to suppress this interferences an admixture of the quencher has to be added. Addition of ethylene causes enhanced X-ray absorption damping the propagation of discharges.

Taking into account these considerations the gas mixtures of argon and isobutane were used in the range of proportions from $67\%Ar + 33\%C_4H_{10}$ to $85\%Ar + 15\%C_4H_{10}$. The quantity of the admixture of the ethylene was stabilized by keeping the simple mixing glass vessel-bubbler in the refrigerator at appropriate temperature. In the test the temperature was varied in the range of $3^\circ - 8^\circ$ C .

C. Electronics

Fig. 5 shows the schematic diagram of the set up which was used in the DC prototype test. This electronics is assembled partly from the conventional components and partly from dedicated circuits made for the BRAHMS experiment. Since the sense wires are operated at the high voltage, the connection to the detector electronics is necessarily AC coupled. This is accomplished by applying the high voltage capacitors. All high voltages are distributed to the wires through 1MΩ resistors to limit currents that might flow through the wires in case of an accidental shorting or sparking. The anode wires are fed through individual resistors, while the cathode and field shaping wires have one resistor per group of wires with the same voltage. The anode wire pulses pass the coupling capacity and are amplified and discriminated in the home made front end electronics [13]. Its design has been based on the ASD-8B integrated circuit developed at the University of Pensylvania [14]. The ASD-8B is an 8 channel chip with differential inputs and outputs. Each channel consists of charge amplifier, shaper and discriminator. The boards were constructed in 16 and 8 channel versions baseing on the same printed circuit layout. The front-end boards are connected to the detector with 34 way edge connectors.

The board is supplied with +5V and -5.2V. The input charge threshold can be regulated in the range 0.5 fC to 10 fC by changing the voltage at the threshold input from 0V to -5V. The board has a test input which allows for a charge injection directly to the ASD-8B inputs. The same charge is simultaneously injected to all the channels on the board. The minimum requirements for the input signal are 5 ns rise time, 30 ns fall time and the injected charge which is the best in the range of 1 - 10 fC and asserts the proper control of the threshold adjustment.

The differential output signal from the discriminator has 200 mVpp swing. It is connected to the 16 channel the fast comparator board using a regular twisted pair flat cable. The ECL standard comparator outputs provide signals for the TDC. To avoid output to input pickup the comparators have been placed on the separate board. Each comparator board gets signals either from one 16 channel or from two 8 channel front-end boards.

The ECL output pulses were fed to the Le Croy 2277 Camac TDC's using 6 m long twisted pair cables and were used as the start pulses. The common stop pulse for all the TDC's channels was obtained by delaying a coincidence signal from two scintillation detectors placed in a front of the chamber. This pulse was also used to inhibit inputs of the TDC's and initialized transfer of the acquired data. The data were transferred from TDC's through the CAMAC bus to the GSI developed CAMAC processor board CVC 10 [15] which in principle may work as a stand-alone module. In order to perform on-line analysis the CVC 10 board was connected to the IBM PC workstation by the Ethernet link configured as a local two-node net and the PAW software [16] was used.

V. TEST RESULTS

A. Optimization of operating conditions

The test of the DC prototype as well as associated the front-end electronics was performed using three detection planes X0, X1, X2 of the prototype module. The anode, cathode and field shaping wires of these detection planes are stretched in the vertical direction. In such configuration each detection plane supply an information on the electron track position along x (horizontal) coordinate. The X1 staggered detection plane was shifted by 1/4 of the cell width to resolve the left-right hit ambiguity. The cell width was 1 cm and the distance between the detection planes was 1.5 cm. The incoming beam of electrons after passing two successive scintillators entered the prototype from the X0-plane side. Fig. 6 shows numbers of detected signals generated by trucks of the electron beam reconstructed from the detected signals in four preselected cells in X0 and X2 planes (cell number 10, 12, 13, 15).

The optimization of the gas mixture ratio was performed maximizing the detection efficiency which was defined as the ratio of detected hits to the number of trigger events (coincidence between two scintillators). The results of these tests are shown in Fig. 7 for three selected gas proportions : $75\%Ar + 25\%C_4H_{10}$, $67\%Ar + 33\%C_4H_{10}$, $85\%Ar + 15\%C_4H_{10}$. One can see the saturation of the efficiency on the level of nearly 100 % is obtained at cathode-anode difference voltage of 2250 V in the first mixture, and at 2500 V in the second mixture. The third gas mixture was not able to attain the saturation of the efficiency at a reasonable dark current of the order of a few nA per celldetection cell. The distributions of events per time bin, dN/dt and the integrals of these distributions are shown in Fig. 8 for the wire number 12 of the X0, X1, X2 detection plane using $75\%Ar + 25\%C_4H_{10}$ gas mixture. The time to position dependence is obtained from the time distribution, dN/dt [17] :

$$\frac{dN}{dt} = \frac{dN}{dx}\frac{dx}{dt} = \frac{dN}{dx}\upsilon(t) \tag{1}$$

where $v(t)$ is the drift velocity. The integral of dN/dt reproduces therefore $x = x_\circ + x(t)$ relationship, where $x_\circ$ depends on the trigger pulse delay and the real position of a wire. This method requires the uniformity of the beam over the transverse dimension of the cell (10 mm in this case) and this condition was fulfilled during the test. However the absolute calibration of the time to space scales is provided by the assumption that the longest recorded drift time, t_{max}, corresponds to the geometrical maximum drift distance, x_{max} (anode and cathode separation). In general this is not fulfilled and in order to solve this serious obstacle a new procedure described in the subsection V.C. was introduced.

B. Track reconstruction

The track reconstruction was performed for such events when each detection plane X0, X1 and X2 supplyed only one signal. In this case it is possible to draw $2^3 = 8$ tracks due to left-right ambiguity. The linear regression was used to select the tracks characterized by the best hit distribution around the straight line. In general this criterion is not sufficient to find the "true" tracks, however, for the test measurements where all tracks were almost perpendicular to the detection planes such simple procedure was satisfactory.

C. Calibration procedure

In order to calibrate the DC prototype the deviation Δ was defined as:

$$\Delta = x_1 - \frac{x_0 + x_2}{2} \tag{2}$$

where x_0, x_1, x_2 are track coordinates in X0, X1, and X2 detection planes, respectively. The absolute value of each coordinate is a sum of the wire position with respect to a selected reference coordinate and the track distance from the wire calculated from the calibration function, x(t):

$$x(t) = x_{max} \cdot \frac{\int_0^t \frac{dN}{d\tau} \cdot d\tau}{\int_0^{t_{max}} \frac{dN}{d\tau} \cdot d\tau} \tag{3}$$

where $x_{max} = 0.5$ cm and t_{max} is obtained using the following procedure.

As an example let us consider only tracks which were detected by the anode number 12 in the staggered detection plane X1 (see Fig. 6). These tracks are also plotted in Fig. 9 where the left panel shows the tracks which had also the signals in the wires number 12 of the detection planes X0 and X2 while the right panel shows the tracks which had the signals also in the wires number 13 of the X0 and X2 detection planes. The calibration integral and the deviation function for the anode number sequence 12-12-12, and the deviation function for the anode number sequence 13-12-13 are displayed in Fig. 10. These plots were obtained with pre-assumed value of the t_{max}=100 nsec. A similar plots in Figs. 11 and 12 show the results obtained for t_{max}=300 nsec and t_{max}=145 nsec, respectively. Due to the construction precision the deviation Δ should be distributed around the zero value. This is the case for t_{max}=145 nsec with accuracy of few microns, while the other choices of t_{max} yield a large mean values of the deviation function distributions.

This method does not require to determine the relation between the real time and the channel number of the TDC. The sufficient assumption is that the TDC channel number is the linear function of the time. The determination of the unknown parameter, t_{max}, of the calibration is achieved by requiring that the deviation function distribution has the mean value close to zero with required accuracy.

D. Position resolution

The position resolution of the drift chamber is defined by the width, σ of the deviation distribution. The $\sigma \simeq 100\mu m$ of this distribution was found for $t_{max} = 145$ ns. Such position resolution is three times better than required by the BRAHMS experiment.

The influence of the gas mixture ratio on the position resolution was also investigated during the test measurements. The results are shown in Figs. 13 and 14 for $75\%Ar + 25\%C_4H_{10}$ and $67\%Ar + 33\%C_4H_{10}$ gas mixtures, respectively. The comparison of the Δ distribution widths proves that the position resolution is not very sensitive to the gas mixture ratio in the investigated range.

VI. CONCLUSIONS

The construction and performance tests of the drift chamber prototype for BRAHMS experiment was reported. In summary the tested characteristics of the constructed DC prototype are:

- The track position determination accuracy of about 100 μm was achieved for 5 mm drift distance.
- Nearly 100 % of the detection efficiency was obtained at $75\% Ar + 25\% C_4H_{10}$ gas mixture. A small amount of ethylene vapour was found to improve performance of the DC prototype. The dark current was maitained below 10 nA per wire.
- The drift velocity in the entire cell is constant within 2% and the time to position relation is linear within accuracy of 100 μm.

Such results were obtained by:

- The efficiency and the position resolution optimization as a function of the gas mixture ratio and the electric field strength.
- Introduction of a new calibration procedure for the time to distance relation determination.
- Construction of the front end electronics which showed a satisfactory performance and a high resistance to the environmental interferences.
- Construction of a pair detection planes with staggered sense wires by 1/4 cell in order to remove the right-left ambiguity.

A good results of the DC prototype tests allowed to construct a set of 9 drift chamber modules for the BRAHMS experiment. Fig. 15 presents the assembled module and the T3 detector and Fig. 16 shows the T3 detector installed at the forward spectrometer of the BRAHMS experimental set up.

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