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Drift chambers for the PHENIX central tracking system

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For the PHENIX Drift Chamber collaboration[1]

Abstract

The Drift Chamber (DC) is part of the central tracking system of the PHENIX detector. The DC construction consists of two independent arcs. Each of them covers an active area of ± 0.35 in pseudorapidity and 90° in azimuthal angle φ. The DC subsystem accurately measures charged particle trajectories to determine the p_t of particles and ultimately the invariant mass of pairs of particles. The DCs also participate in pattern recognition. The unique feature of the DC lies in its cell geometry. The focusing geometry eliminates the left–right ambiguity, the sensitive track sample length for each sense wire is adjusted by changing the wire's potential due to the presence of gate (channel) wires. Back (guard) wires screen the sense wire from charged particle ionisation on the side opposite the channel wires. To reduce the count rate per readout channel, sense wires are cut in the center and attached to a light kapton support. Both ends of the sense-wire are readout. The chamber gas is a 50–50 mixture of argon–ethane. A spatial resolution of 150 μm in $r-\varphi$ and a two-track separation of better than 1.5 mm at single-track efficiency $> 99\%$ is obtainable. Small angle stereo wires provide a spatial resolution of ~ 2 mm in the z-direction. There are 12 544 channels of electronics in the DC.

The Relativistic Heavy Ion Collider (RHIC) now under construction at BNL is intended for acceleration and colliding relativistic heavy ions up to gold. One of the four experiments at the RHIC is PHENIX [1]. The PHENIX detector is designed to detect a new state of matter, the quark-gluon plasma. Special emphasis is placed upon the measurement of electromagnetic probes: leptons, photons and hadrons in selected solid angles. A general view of the PHENIX detector is shown in Fig. 1.

The PHENIX detector consists of four spectrometers or "arms". The two central arms are intended for charged particle tracking and momentum measurements, electron and photon energy measurements and particle identification. They cover 90° in φ, but not exactly back-to-back. Such a structure lessens the non-uniformity in the p_t acceptance for the two-arm configuration. The other two spectrometers have full azimuthal coverage and will detect muons. In addition to these spectrometers PHENIX has an inner detector subsystem to measure and determine the start time, vertex, and multiplicity of an interaction.

The tracking system of PHENIX consists of three subsystems, which are optimized for different functions. The low mass, multilayer, multiwire focusing drift chamber located in the magnetic field

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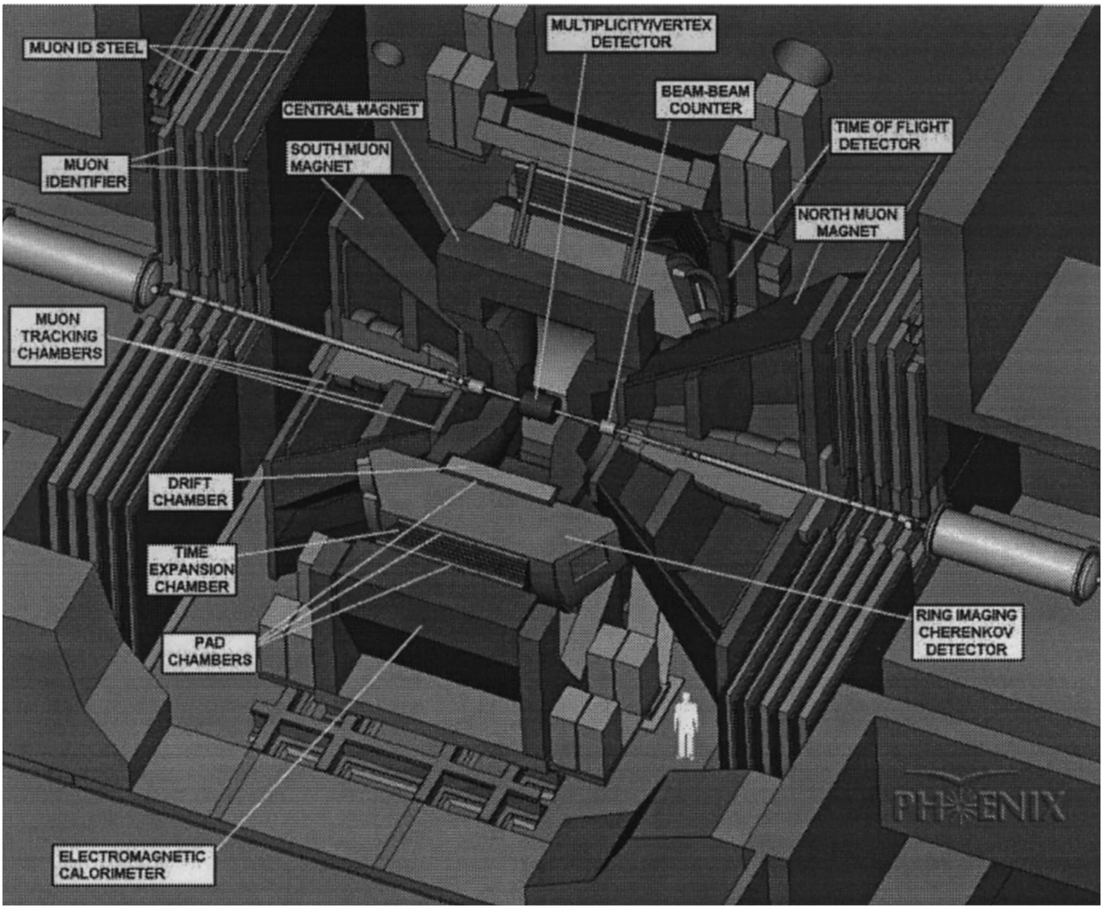

Fig. 1. General view of the PHENIX detector.

(~ 0.6 kG) provides high-resolution p_t measurements. Three interpolating pad chambers (PC1, PC2, PC3) provide three-dimensional space points for the charged tracks, to determine p_z/p_t. A time expansion chamber (TEC) tracks charged particles between the RICH and the EMCal, and provides e/π separation using dE/dx information. Such a system has to

- locate all charged tracks of interest within their fiducial volume,
- measure the particle momenta,
- help to identify which of the tracks are due to electrons,
- contribute information to the trigger.

The drift chamber accurately measures charged particle trajectories in the $r-\varphi$ direction to determine the p_t of particles and ultimately, the invariant mass of pairs of particles. The DC also participates in pattern recognition by providing position information that is used to link tracks through the various PHENIX detector systems. Simulation of ion–ion collisions at the RHIC specified the requirements on the p_t resolution and the double-track resolution. It imposes the following requirements having to be met by the DC:

- single wire resolution better than 150 μm in $r-\varphi$,
- single wire two-track separation better than 1.5 mm,

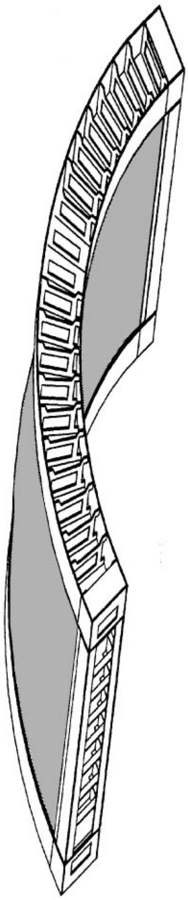

Fig. 2. Construction of the DC frame.

- single wire efficiency better than 99%,
- space resolution in z-direction better than 2 mm.

The sensitive volume of the drift chamber subsystem occupies the PHENIX radial region between $r = 2.02$ m and $r = 2.46$ m (see Fig. 1) and has a length of 1.8 m in z-direction. The drift chamber consists of two arms – west and east. The east arm is the mirror image of the west arm. Each arm is a box shaped frame made of titanium (see Fig. 2) filled with drift chamber modules.

The DCs are subdivided into six layers of wire cells running in r-direction, which provide trajectory measurements (see Fig. 3).

The X1 and X2 wire cells are running in parallel to the beam line to perform precise track measure-

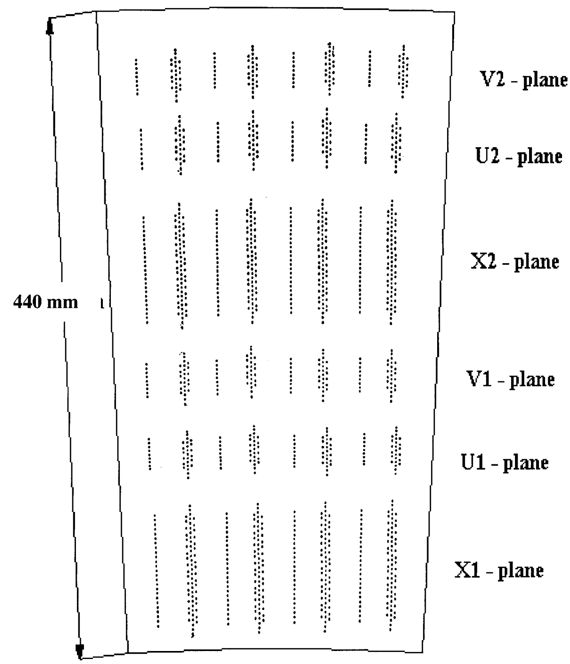

Fig. 3. Layout of the DC sector.

ments in $r-\varphi$. These wire cells are followed immediately by two sets of small angle U/V wire planes used in the pattern recognition. The U1,V1,U2,V2 wires have stereo angles relative to the X-wires of 5.3760°, 5.5120°, 5.90° and 6.040° respectively. They measure the z-coordinate of the tracks. These angles were selected to match the z-resolution of the pad chambers to minimize track ambiguities. Each frame is divided into 20 equal sectors (see Figs. 2 and 3). One sector covers 4.5° in φ. There are six types of modules in each sector: X1,U1,V1,X2,U2,V2. Each wire net assembly consists of two FR4 plates and wires of different types. The wire ends are attached to the circuit cards, which distribute high voltage and signals. The FR4 plates of the anode and cathode wire nets are placed in special cages (eight nets per cage) which are attached to the ring frames with bolts (see Fig. 4).

Each cage is precision manufactured from a single piece of aluminum. The design of X- and the U/V-cages is different. The X-cages should provide wires to run along the z-axis. The

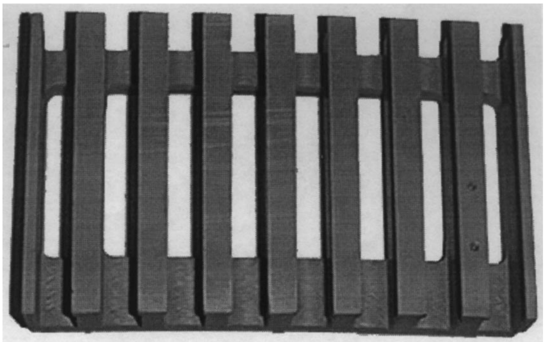

Fig. 4. The X1 cage.

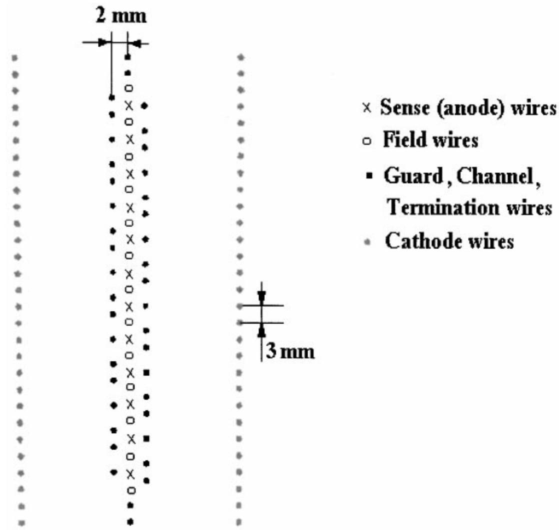

Fig. 5. The wire structure of the X1 anode net.

U/V-cages should provide some wires under an angle with respect to the z-axis. The working area of the chamber is inbetween the cathode and anode nets. More details of the wire structure of the X1 anode nets are shown in Fig. 5.

For the design of the wire configuration we explored the idea of the controlled drift geometry chamber described in Refs. [2,3]. In this geometry the track sample length is mainly determined by the distance between the gate (channeling) wires and their potentials V_g. The potential (field) wires P serve to decouple adjacent sense wires. Back (guard) wires B improve the gas gain control on the sense wires. Each of them protects its nearest sense wire from ionization electrons of tracks on the side of the back wire. Consequently, this geometry is characterized by the absence of the "left–right" ambiguity and hence the need for "left–right" pattern recognition. Cathode wires are located at the boundary of the wire cell to complete the electric field configuration. The anode net of X-type contains 12 sensitive wires while each stereo U/V net contains four sense wires only. In order to reduce the count rate per readout channel each sense wire is separated into two halves in the center. Each half of the sense wire is then read out independently. To isolate two halves of a single sense wire electrically we use a low-mass central support to which the anode wires are attached. Such a support should introduce only very little additional mass into the fiducial volume of the chamber. It has to be made of high-strength material with excellent isolating properties. During the R&D phase we tested several variants of the central support, a common support for all sense wires and individual supports for each wire. As a result we have chosen a central support made of kapton of 100 μm thickness. Its design is shown in Fig. 6.

Such a support adds only 10 mg of additional weight per wire. The total number of electronics channels is 2 arms $\times 2$ ends $\times 20$ sectors $\times 160$ sense wires equalling 12 800. Actually there are 12.544 active sense wires due to a loss of U/V wires at the arc ends and the presence of auxiliary struts in the center of the DC frame to relieve stress from wire tension.

The chamber gas is a 50/50-gas mixture of argon–ethane, which exhibits a stable drift velocity within the field gradient range of 0.8–1.4 kV/cm and provides a high enough gas gain. Fig. 7 shows the drift lines for several sense wires in the X drift cell. This figure provides a graphic demonstration of the drift cell geometry and the elimination of the left–right ambiguity by the use of the back wires. The drift time differences for electrons ionized at the boundaries and in the center of the track interval to be seen by the sense wire is about 10 ns only. It indicates that the two-track resolution of this design is quite good. Fig. 8 shows a simulation of the position versus time, $x(t)$, correlation. The

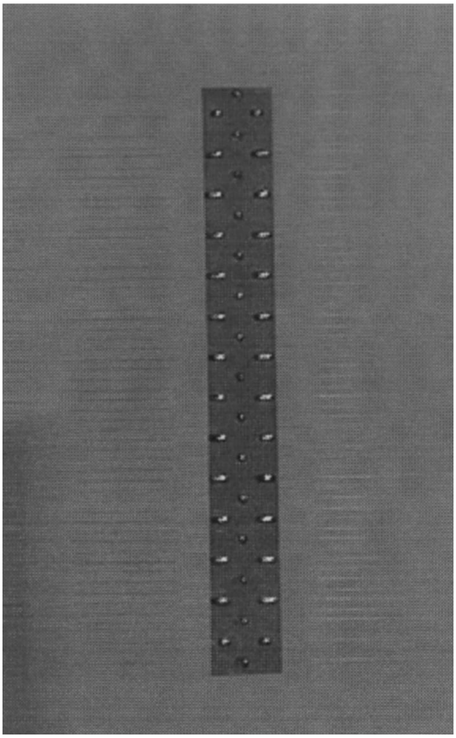

Fig. 6. The central support of the X1 anode net.

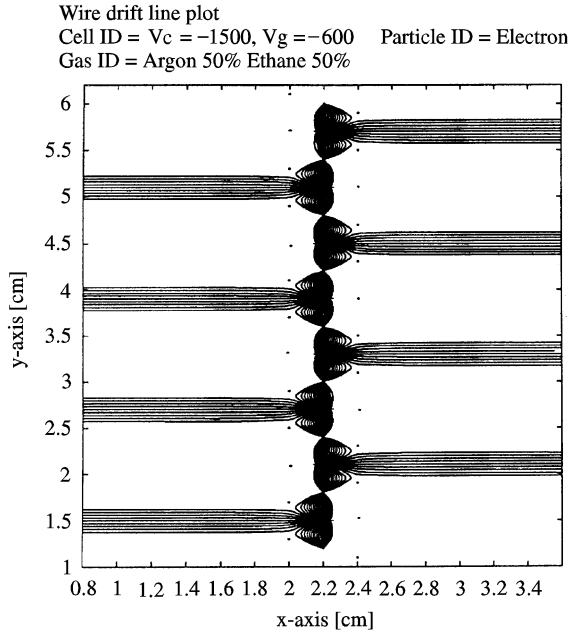

Fig. 7. Drift lines for several sense wires in the X drift cell.

maximum drift time is about 400 ns which is in agreement with the beam time structure.

In the frame of the R&D on the PHENIX drift chamber we created several prototypes of the drift chamber cell which were intended for testing the cell configuration proposed by the PNPI team on the base of GARFIELD [5] calculations and the capabilities of the DC with such a cell wire structure. Detector performance parameters including the wire efficiency for opened and closed spaces, single- and double-track resolution were tested with a β-source, 1 GeV protons, cosmic muons and the AGS test beam. The measured single wire resolution (extracted from residual distributions) was better than 130 μm, and the single wire efficiency was better than 99%. The back wire efficiency was equal to about 1%. Double-track resolution measured with cosmic muons and the AGS test beam was estimated to be equal to about 1.3 mm at 50% efficiency.

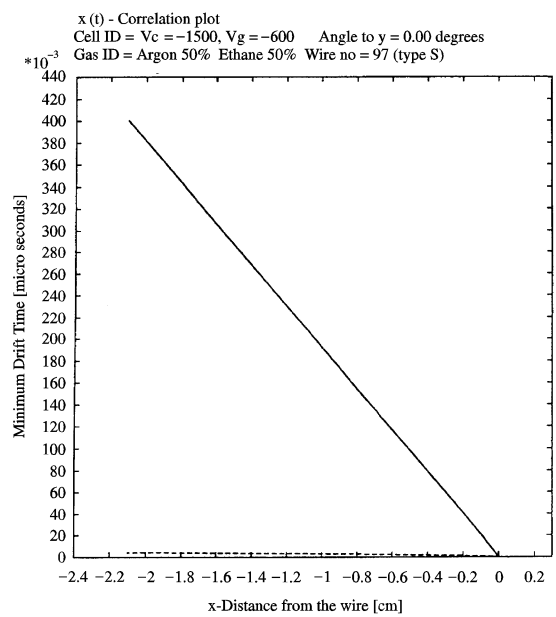

Fig. 8. Position versus time correlation.

Special attention was paid to the question of the influence of gravitational and electrostatic forces on the wire structure. The working wire tensions were chosen to obtain equal wire sags under the action of the gravitational force. The final choice of wire tensions as well as wire diameters are shown in Table 1. The corresponding gravitational sag in the center is equal to 90–95 μm. Maximum wire tensions are limited by the deformation of the DC frame and by the strength of the wires. Electrostatic repulsion of the wires leads mainly to displacement of the sense and the back wires. From calculations we concluded that the electrostatic and gravitational displacement of the sense wires would not exceed 200 μm [4]. The results of the calculations and the optical measurements of the wire displacements are shown in Table 2.

The introduction of the central support improves the alignment of the wires. An experimental investigation of these effects showed a reasonable agreement between measured and calculated values of wire displacements. It provides a means to determine the true coordinates of particle tracks with calculations.

Table 1
Wire diameters and tensions

Wire	Material	Diameter (μm)	Tension (g)
S	Au–W	25	90
P	Au–Cu–Be	70	220
B, G	Cu–Be	75	220
C	Cu–Be	50	90

Table 2
Results of the calculations and the optical measurements of the wire displacements

ΔS (with support)		ΔS (no support)
$\Delta y_{\text{meas.}}$	$\Delta y_{\text{calc.}}$	$\Delta y_{\text{calc.}}$
100 ± 20 μm	~ 90 μm	150–190 μm

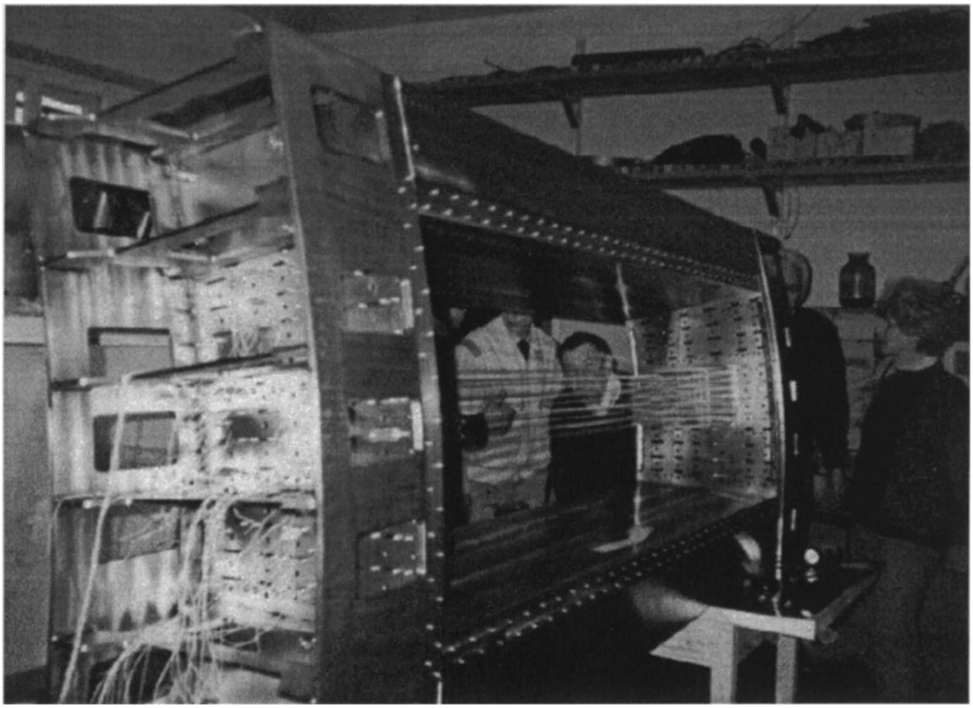

Fig. 9. General view of the full-scale three-sector DC prototype.

After several steps in prototyping, in 1996 the drift chamber full-scale prototype was produced in PNPI (see Fig. 9). All innovations developed during R&D found place in this prototype. It consists of a titanium frame having full length in z and 3 sectors, each covering 4.5° in φ which was filled with ten modules of different types (X1, U1, V1, X2, U2, V2). The wire nets were fabricated by a technology acceptable for mass production. The beam test run in BNL showed that the performance parameters of this prototype satisfy the requirements. The presence of the stereo U and V wires allowed for the first time to measure the space distribution of the test beam along the z-axis. The corresponding z-resolution was estimated to be about 1.2 mm. At present this prototype is tested in Stony Brook with cosmic rays. It is expected that this prototype will operate in the east arm during the engineering run.

By now the production of the basic DC frames and wire nets has started. According to the PHENIX schedule the assembly of the DC Arm1 will be carried out in 1998 and of Arm2 in the beginning of 1999. The DC will be ready for the physics run at the end of 1999.

References

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