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Development of a Time Projection Chamber using CF_4 gas for relativistic heavy ion experiments

T. Isobe[a,*], H. Hamagaki[a], K. Ozawa[a], M. Inuzuka[a,1], T. Sakaguchi[a,2], T. Matsumoto[a], S. Kametani[a], F. Kajihara[a], T. Gunji[a], N. Kurihara[a], S.X. Oda[a], Y.L. Yamaguchi[b,3]

[a] *Center for Nuclear Study, Graduate School of Science, University of Tokyo, 7-3-1 Hongo, Bunkyo, Tokyo 113-0033, Japan*
[b] *Waseda University, 3-4-1 Okubo, Shinjuku-ku, Tokyo 169-8555, Japan*

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Abstract

A prototype Time Projection Chamber (TPC) using pure CF_4 gas was developed for possible use in heavy ion experiments. Basic characteristics such as gain, drift velocity, longitudinal diffusion and attenuation length of produced electrons were measured with the TPC. At an electric field of 900 V/cm, the drift velocity and longitudinal diffusion for 1 cm drift were obtained as 10 cm/μs and 60 μm, respectively. The relatively large gain fluctuation is explained to be due to the electron attachment process in CF_4. These characteristics are encouraging for the measurement of the charged particle trajectories under high multiplicity conditions at RHIC.

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Keywords: CF_4; TPC; Gain; Drift velocity; Longitudinal diffusion

1. Introduction

It is predicted from lattice QCD calculations that a phase transition from hadronic matter to a plasma of deconfined quarks and gluons may occur at high temperature and energy density. Such high energy density is expected to be created in heavy ion collisions produced at the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory (BNL). One of the most intriguing findings at RHIC is the suppression of mesons in the high transverse momentum region in central Au + Au collisions [1,2]. The observed suppression is interpreted as an energy loss of initially hard-scattered partons traversing the hot and dense matter. In order to study the energy loss quantitatively in the hot and dense matter, it is important to obtain detailed information of the produced partons. Such information is provided by the reconstruction of jets using charged particle tracks.

For the reconstruction of momenta of all charged particles originating from jets, a tracking device with a large solid angle is needed. With such a tracking device, the energy loss of hard scattered partons in the dense matter can be studied through measurements of two jets or γ-jet correlations. One of the most promising devices for such measurements is a vertex spectrometer in the form of a Time Projection Chamber (TPC) [6] with full coverage in azimuth. The hard-scattered partons can be reconstructed from secondary measured particles. A simulation study with PYTHIA [3] shows that on average, given an acceptance of $|\eta| \leqslant 1$ in pseudo-rapidity, the TPC can reconstruct 87% of the primary parton momentum.

Such a vertex spectrometer has broad physics capabilities especially for the PHENIX experiment [4] at RHIC,

*Corresponding author. Tel.: +81 48 464 4156; fax: +81 48 464 4554.
E-mail address: isobe@cns.s.u-tokyo.ac.jp (T. Isobe).

[1]Current address: National Research Institute for Cultural Properties, Tokyo, 13-43 Ueno Park, Taito-ku, Tokyo 110-8713, Japan.

[2]Current address: Brookhaven National Laboratory, Upton, NY 11973-5000, USA.

[3]Current address: Center for Nuclear Study, Graduate School of Science, University of Tokyo, 7-3-1 Hongo, Bunkyo, Tokyo 113-0033, Japan.

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because the current PHENIX spectrometer has limited solid angle coverage as shown in Fig. 1. Also, such a vertex spectrometer can be helpful to measure particles of higher transverse momentum. With the current PHENIX tracking device, charged particles within a momentum range of 0.2–10 GeV/c can be measured [5]. It is, however, not possible to observe decay vertices, secondary interactions and conversions. The inability to detect these events results in increasing the background of false tracks at high transverse momenta. Thus, installation of a vertex spectrometer device would allow the PHENIX detector to reduce backgrounds and extend charged particle spectra to higher transverse momenta.

High tracking capability in a high multiplicity environment is the most important feature of the TPC. In Au + Au central collisions at $\sqrt{s_{NN}} = 200$ GeV, the average charged particle multiplicity (dN_{ch}/dy) is 1000–1200 for the most central collisions, and the charged particle density is 0.26 cm^{-2} at a radial distance of 20 cm from the beam line. To cope with such a high particle density, good two-hit resolution as well as good position resolution are required. In order to reconstruct trajectories with an efficiency of 90% up to $p_T = 10$ GeV/c, the required hit occupancy in terms of space-time hits should be less than 0.1. High occupancy limits the two hit resolution in the wire direction and the drift direction. Two-hit resolution along an anode wire is estimated to be 1.2 cm governed by the distance between the anode wires and the readout pads (4 mm) of the prototype TPC. To achieve small hit occupancy, the two-hit resolution in the longitudinal direction should be less than a few millimeters. Thus, the longitudinal diffusion of electrons should be less than 100 μm for 1 cm drift. Here, a drift length of 50 cm is needed for the rapidity coverage. As a candidate drift gas, pure CF_4 gas is chosen to satisfy the above requirements [7]. From a simulation study, CF_4 was estimated to have a longitudinal diffusion coefficient of 60 μm/$\sqrt{\text{cm}}$ at an electric field of 1 kV/cm.

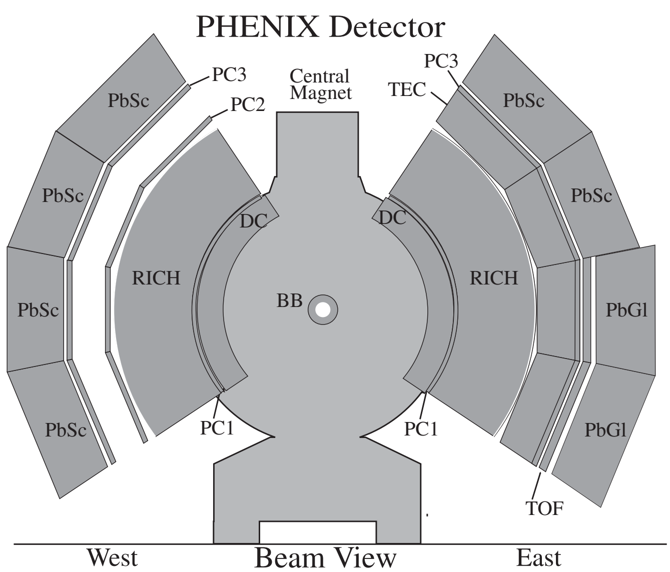

Fig. 1. Schematic view of the PHENIX detector from beam side.

A prototype TPC was developed to measure the basic characteristics of CF_4 such as drift velocity, the diffusion coefficient and attenuation length, and to study the overall performance of the TPC using pure CF_4. In this article, the properties of CF_4 with no magnetic field are reported. Studies with a magnetic field and further investigations of other known effects [8] are underway to realize the TPC using CF_4.

2. Development of a prototype TPC

The design view of the TPC is shown in Fig. 2. A gas vessel is made of aluminum, the dimension of which is $29 \times 29 \times 60\,\text{cm}^3$. Inside, a drift cage with the dimension of $16 \times 16 \times 36\,\text{cm}^3$ is made of 116 multistage gold strips on a

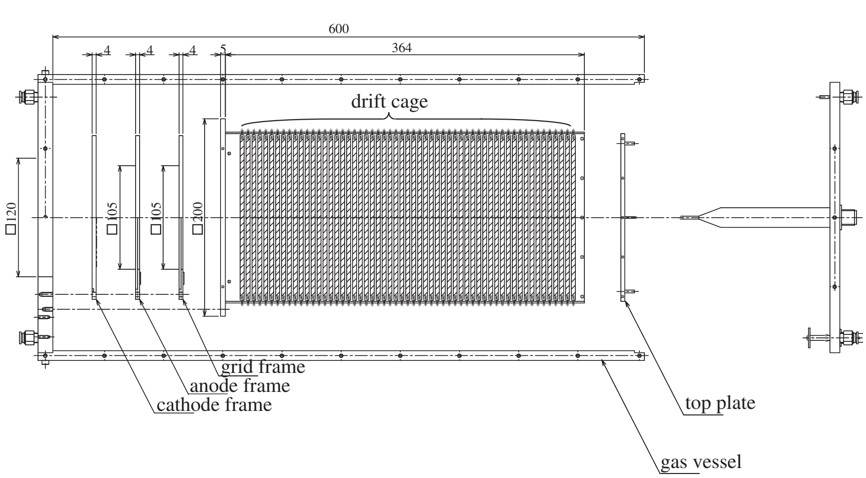

Fig. 2. Design view of prototype TPC. The dimension of the gas vessel is $29 \times 29 \times 60\,\text{cm}^3$. The drift cage with dimensions of $16 \times 16 \times 36\,\text{cm}^3$ made of gold strips on G10 board is installed in the gas vessel. The large HV connector shown at the right is used for the field cage power supply. The left end cap shows the MWPC type readout.