Development of a prototype TPC with CF_4 & GEM readout for heavy ion collision

T. Isobe, H. Hamagaki, K. Ozawa, M. Inuzuka, T. Sakaguchi, F. Kajihara, T. Gunji, N. Kurihara, S. Sawada, and S. Yokkaichi

Abstract— **This article describes the R&D of Time Projection Chamber (TPC) for heavy ion collisions. A prototype TPC was developed for the R&D of CF_4 gas. It has a capability of using GEM readout.**

The characteristics of CF_4 is a small diffusion coefficient and large drift velocity. It is suitable for our purpose of heavy ion collisions. Characteristics of CF_4 gas, such as a diffusion coefficient and a drift velocity, were measured with the prototype TPC. In addition, a tracking resolution and sensitivities of double track separation and particle identification were measured using MWPC and pad readout. We achieved position resolution of 100 μm with 2.5 mm square pads.

For future use of a TPC readout, we have produced Gas Electron Multiplier (GEM) using a plasma etching method. Gain of the GEM was measured as a function of an applied voltage with an X-ray source. A gain of 10^4 was obtained in argon mixture gases.

Index Terms— **TPC, CF_4, GEM.**

I. Introduction

In the field of the experiments of the relativistic heavy ion collisions, it is important to develop a high precision tracking detector which cope with high multiplicity environment. A Time Projection Chamber (TPC) is one of the most capable detector to use under extremely high multiplicity condition. Recently, in order to detect electron pairs which are coming from γ conversions and π^0 Dalitz decays, a TPC which can surround the vertex more closely with more large acceptance has been required. Then, it is need to develop a new type of TPC which has higher double track separation capability as well as good position resolution.

Recently, requirements for chracteristics of TPC became very hard, because a multiplicity of particles went up higher at the RHIC energy. Especilly, the vertex TPC which is proposed an upgrade option of the PHENIX experiment [1] will meet an extremely high particle density. One of aims of this R&D program is supplying basic information to the PHENIX upgrade TPC. The PHENIX [2], [3] detector system is a complex of spectrometers to measure hadrons, photons, electrons and muons. The system was made for study of hot and dense nuclear matter, produced by Au+Au collisions at $\sqrt{s_{NN}}$ = 200A GeV at the Relativistic Heavy Ion Collider (RHIC) in Brookhaven National Laboratory (BNL). The TPC is proposed to be installed as the vertex spectrometer which has full coverage in azimuth in the pseudo-rapidity $|\eta| \leq 0.50$, and serves for electron identification in the momentum range of p$\leq$ 200 MeV/c. It should be mentioned that the capability of double track separation is the most important requirement, since the expected dN_{ch}/dy value for RHIC collider is about 800 for the 5% most central collisions. According to this environment, the requiremant of the double track separation capability is less than about 1 cm.

In order to satisfy the above requirements, CF_4 is proposed as a chamber gas because of its small diffusion and fast drift velocity. When the electric field of 1 kV/cm is applied, the drift velocity is expected to be faster than 10 cm/μsec and longitudinal diffusion is expected to be less than 100 μm for 1 cm drift [5].

To develop such a kind of TPC, CF_4 gas characteristics and adaequatus readout electronics should be checked carefully. For this purpose, a prototype TPC and GEM foils were constructed in Japan and tested with cosmic-ray and testbeams at KEK.

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II. Development of a prototype TPC

A. Design of a prototype TPC

A TPC was developed to measure the characteristics of CF_4 and the total TPC performance. Layout of the design is shown in Fig. 1. Dimension of the field cage is 16 cm $\times$ 16 cm $\times$ 36 cm. It is designed to apply electric field more than 900 V/cm with multistage strips in drift region. It is suitable for evaluating characteristics of CF_4 gas. Fig. 2 shows the schematic view of the readout region. The diameter of the anode wire and the grid wire is 20 μm and 100 μm, respectively. Anode wires, grid wires and cathode pads are adhered at separate frames whose thickness is 4 mm. These frames are detachable for testing with other type of readout. In particular, the installation of GEM foils for readout is considered. Cathode pads of 2.5 mm, 6 mm, 9.5 mm, and 13 mm square are mounted in order to study the pad size dependence of position resolution.

B. Front End Electronics

Front End Electronics of the TPC consists of Pre-amplifier and flash ADC circuits. The Pre-amplifier is mounted nearby the cathode pads and output the signals to a flach ADC.

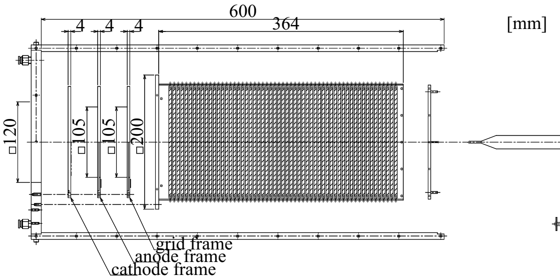

Fig. 1. Drawing of the TPC. Dimension is 16 cm × 16 cm × 36 cm. Electric field is made by the 116-tier strips divided by 1MΩ register. By applying the high voltage to the top plate (right plate in this cage), this field cage can make 33 cm drift region up to 900 V/cm. As you see the left of this figure, the readout is detachable for testing with GEM readout.

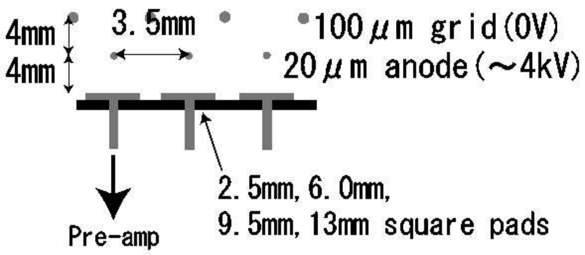

Fig. 2. Schematic view of the TPC readout.

Pre-amplifier was developed to convert a charge signal to a voltage signal and to drive differencial outputs. The pre-amplifier has high gain of 1 V/pC, and large bandwidth of 300 MHz.

A flash ADC (RPV-160 by REPIC Co., Ltd) module was used for converting to digital information from voltage signals. It has the dynamic range of 8bit and conversion rate of 100 MHz. The 100 MHz sampling rate is needed for the readout electronics to measure gas characteristics, because the expected rise time of signals are ~10 nsec when pure CF_4 is used and about $E/p = 1$ (V/cm/Torr) of field is applied. The module is accessed via VME bus using on board CPU module (RIO3 by CES Co. Ltd). A DAQ system to operate the modules was also developed.

III. Basic tests of CF_4 gas

Characteristics of CF_4 and P10 (Ar(90%)-CH_4(10%)) were measured with this TPC. P10 was used as the reference. Measurements were carried out with a N_2-laser (YKN-500 by Usho Co. Ltd) and a ^{55}Fe radioactive source. The gas contained about 100 ppm water molecule and 30 ppm oxygen during the measurements. Tested items are as follows.

1) gain: The absolute value of gain was measured by illuminating 5.9 keV X-rays from a ^{55}Fe radioactive source with intensity of 370 kBq. Fig. 3 shows the result of gain measurement. This TPC has a gain over 10^4 for pure CF_4 gas, when the voltage of anode wire is +3.3 kV. CF_4 needs higher voltage to detect the suitable signals.

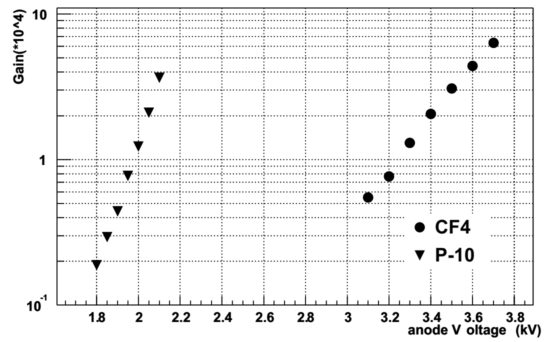

Fig. 3. The measured gain as a function of anode voltage obtained with P10 and CF_4.

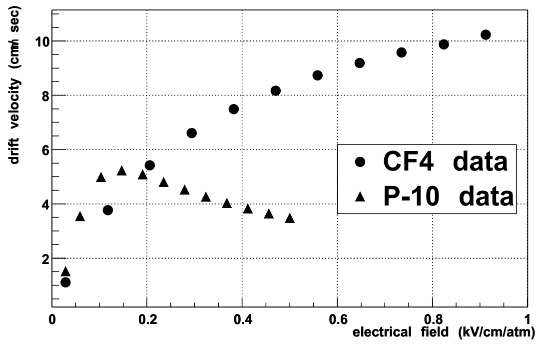

Fig. 4. The measured drift velocity as a function of electrical field obtained with P10 and CF_4

2) drift velocity and longitudinal diffusion: The drift velocity and the longitudinal diffusion of CF_4 and P10 were measured using a N_2 laser. The wave length and the energy of the laser beam is 337.1 nm and 2.5 mJ, respectively. This laser generates $\sim 10^2$ electrons at a beam focal point in CF_4. To deal with single electron for this measurement, an intensity was attenuated. The N_2-laser beam was incidented at two different positions of drift region. The drift velocity in pure CF_4 and P10 was calculated using the distance and arrival time difference of two positions. As shown in Fig. 4, the drift velocity of CF_4 gas is more than 10 cm/μsec, when the electric field is 900 V/cm.

From the fluctuation of the arrival time, longitudinal diffusion in pure CF_4 and P10 was measured as shown in Fig. 5. The longitudinal diffusion of CF_4 gas is about 60 μm for 1 cm drift, when the electric field is 900 V/cm.

IV. Performance

Basic performance, such as a tracking resolution and a double track separation, was measured using the TPC. Also, a particle identification capability from dE/dx measurements was evaluated. It was carried out with electron, pion and proton beam in the momentum range from 0.5 GeV/c to 2 GeV/c at KEK. Drift chambers were used as reference tracker. Gas Cherenkov detectors, Scintillation counters, and a Lead Glass Calorimeter were used for particle identification.

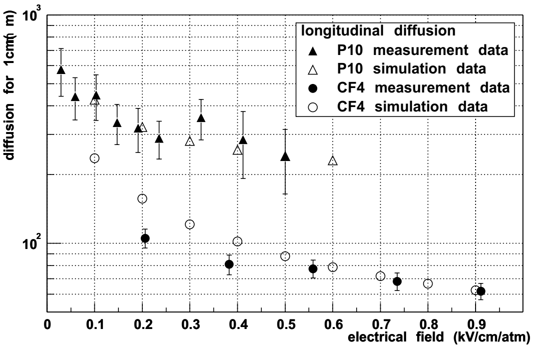

Fig. 5. The measured longitudinal diffusion as a function of electrical field obtained with P10 and CF_4

A. Position resolution

Position resolution was measured for three type of pads: 2.5 mm, 6.0 mm, and 9.5 mm square. The position resolution was calculated using the positions of three adjacent layers. It is defined by difference between the unit position obtained at second layer and the position using the trajectory obtained from first and third layers.

Fig. 6 shows the measured position resolution as a function of drift length for each input angles. A position resolution of 100 μm along the wire was achived with 2.5 mm square pad. The resolution in the drift direction is same for each type of pads. The resolution along the anode wire is worse as the input angle is bigger, because induced charge distribute more broadly at large input angle. The resolution doesn't depend on the drift length strongly, because of the small diffusion of CF_4.

B. double track separation

In order to evaluate the double track separation capability, measurements were carried out using converted electrons by placing a lead plate in front of TPC. The thickness of the Lead plate is 5 mm, which corresponds with about 1 radiation length.

Fig. 7 shows the result of double track separation. The horizontal axis is the difference in distance and the vertical axis is the ratio of number of tracks obtained from measurements over number of tracks estimated from GEANT simulation. Double track separation capability in the drift direction was evaluated to be better than 1 cm. It is expected to depend on the bandwidth of front end electronics mainly.

C. Particle identification

The particle identification capability was evaluated with pions, protons and deuterons contained in test beams. Incident particle was identified by gas Cherenkov detector and TOF measurements. Fig. 8 shows the ADC distributions of pad readout for each particle, 0.5 GeV/c, 1.0 GeV/c, 1.5 GeV/c, and 2.0 GeV/c.

The values of dE/dx were evaluated from measurements for each particle assuming that energy loss depends on only the velocity. Results are shown in Fig. 9. The errors of each plots

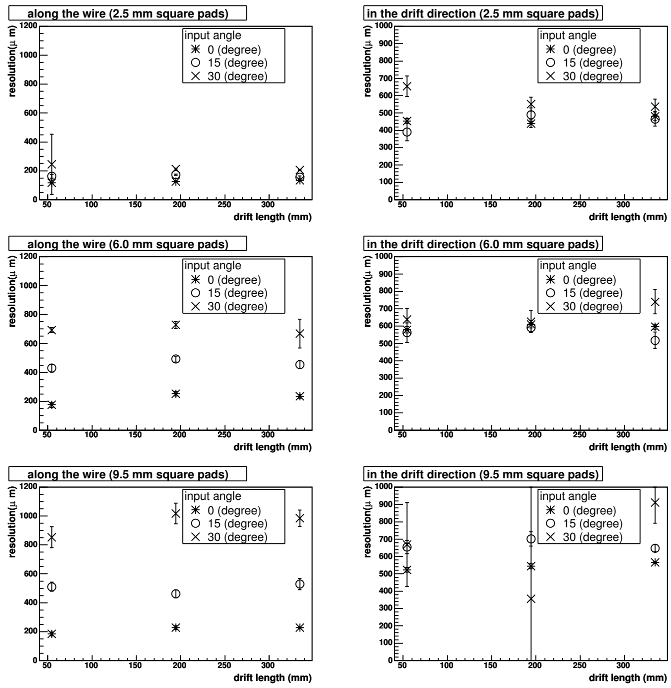

Fig. 6. Position resolution as a function of the drift length. The left figures show the resolution along the anode wire direction, and right figures show the resolution in the drift direction. The errors are defined by the static error for each measurement.

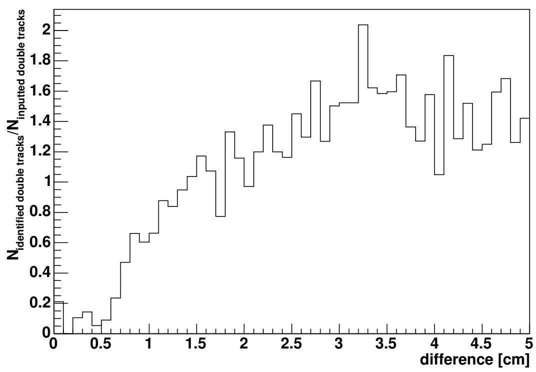

Fig. 7. Difference in distance of identified double tracks in the drift direction. Horizontal axis is the ratio of identified double tracks in simulated double tracks. It is not normalized.

are defined by the r.m.s. of each distribution. As a result, this type of TPC is expected to serve for electron identification in the momentum range of p$\leq$ 200 MeV/c for 1 m track length.

V. Development of GEM

Gas Electron Multiplier (GEM) is a metal-clad polymer foil with dence holes [4]. By applying voltage to the metal layers of a GEM, a drift electron passing through the hole causes a avalanche by an application of a difference of potential between the two electrodes, which are transferred and collected by readout system. Gains of the order of 10^6 can be realized with

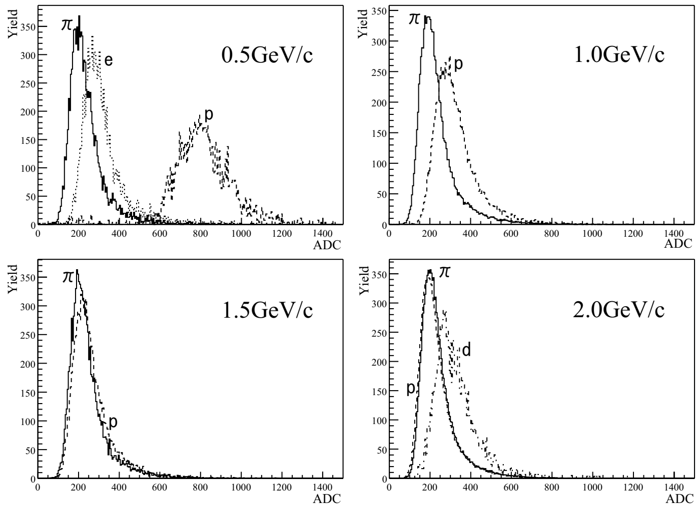

Fig. 8. ADC distribution of each particle, electron, proton, pion, and deuteron. Each figure shows the distribution at each momentum.

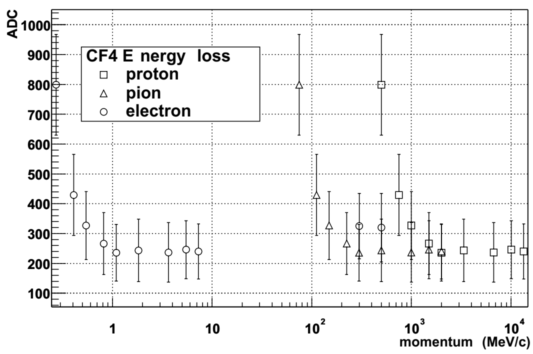

Fig. 9. Expected ADC sum plot for electron, pion, and proton beam. The errors are defined by the r.m.s. of each distribution.

triple-GEM configuration by applying relatively low voltage compared with typical wire chambers.

The GEM as a front-end readout can reduce positive ion feedback sufficiently. In addition, two dimensional readout is expected to be available with GEM readout. Then, it is proposed to use GEM as TPC readout.

We have produced GEM using the plasma etching method at Fuchigami Micro Co., Ltd in Japan. The plasma etching method to make holes on the Kapton layer is Reactive Ion Etching (RIE). The foil is settled as one of the electrodes in a chamber filled with oxide and fluoride gases. Kapton molecules are chemically destroyed by the radicals produced in the plasma that established in the chamber. Then the new GEM has cylindrical holes as shown in the lower photograph in Fig. 10. The hole of the standard GEM produced at CERN is shown in the upper photograph in Fig. 10.

A. Gain measurement

Fig. 11 shows the schematic view of the GEM test setup. Gain measurements were carried out with two or three GEM

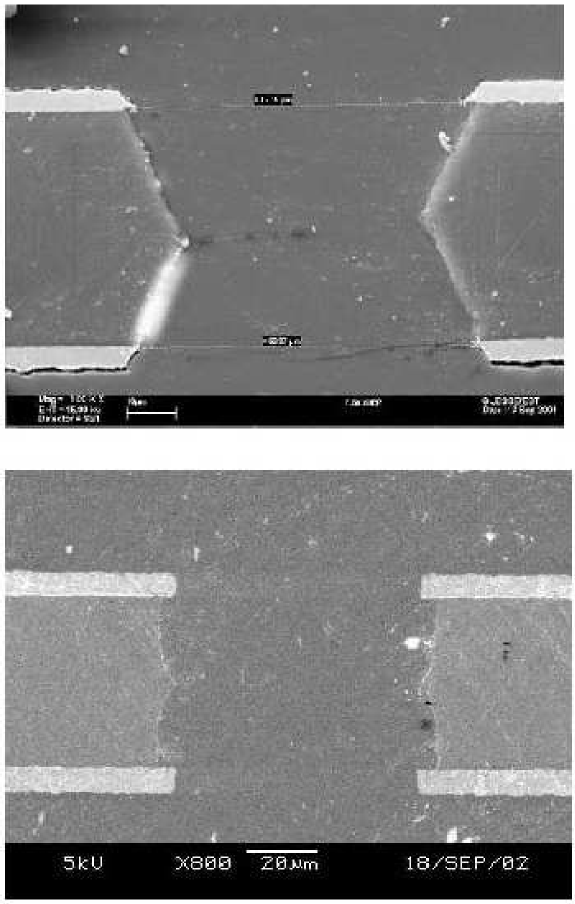

Fig. 10. The upper photograph shows a hole of GEM at CERN. The lower photograph shows the one produced at Fuchigami Micro Co., Ltd. using the plasma etching method.

layers. The signal source was ^{55}Fe (X-ray, 5.9keV). P10 and Ar(70%)-CO_2(30%) were used as chamber gas.

Amplification factor was measured as a function of the applied voltage as shown in Fig. 12. $V_{\rm GEM}$ means the applied voltage to each GEM. Compared with the double-GEM configuration, higher gain can be achieved in the triple-GEM configuration. The gain characteristics are very similar to those of the GEMs made at CERN.

This GEM will be mounted as the readout of the prototype TPC. Capability of GEM-TPC will be tested with KEK test-beams scheduled in the 2004.

VI. Conclusions

A prototype Time Projection Chamber (TPC) was developed for experiments with heavy ion collisions. The characteristics of CF_4 gas was investigated with this TPC. Tracking resolution, double track separation, and particle identification capability were tested with beam at KEK. We achieved 100 μm of position resolution with 2.5 mm square pad.

A Gas Electron Multiplier (GEM) was produced using the plasma etching method. We have checked the basic characteristics of GEM foils. We plan to test it for TPC readout.

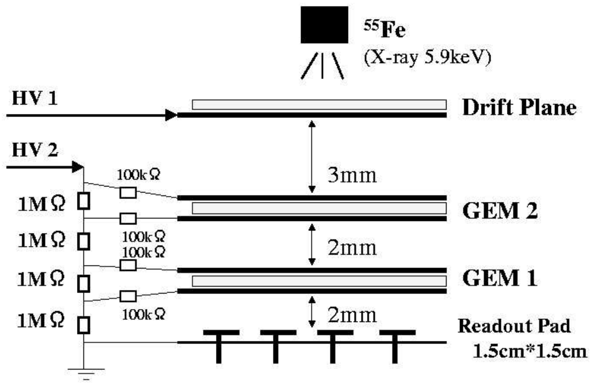

Fig. 11. Layout of the GEM test setup. This components are mounted in a gas vessel made of aluminum.

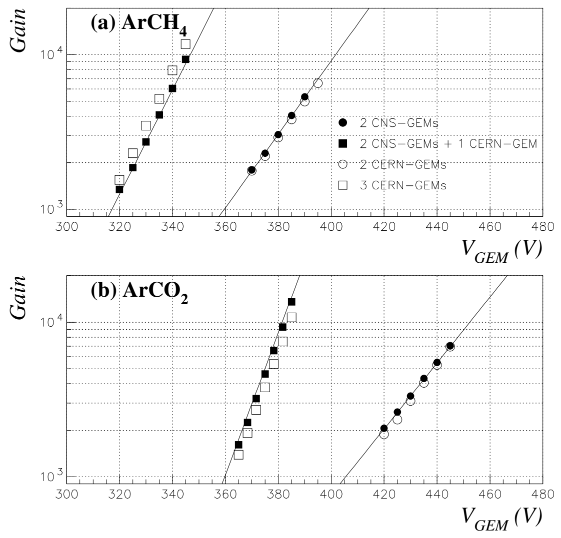

Fig. 12. The measured gain as a function of $V_{\rm GEM}$ obtained with (a)P10 and (b)Ar(70%)-CO_2(30%). $V_{\rm GEM}$ means the applied voltage to the metal layers of a GEM.

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