CPC(HEP & NP), 2009, **33**(4): 289—291 **Chinese Physics C** Vol. 33, No. 4, Apr., 2009

Study on the TU gas for the GEM-TPC detector *

QI Hui-Rong(祁辉荣)[1;1)] LI Yu-Lan(李玉兰)[1] LI Jin(李金)[2]
GAO Yuan-Ning(高原宁)[1] LI Yuan-Jing(李元景)[1]

1 (Deptartment of Engineering Physics, Tsinghua University, Beijing 100084, China)
2 (Institute of High Energy Physics, CAS, Beijing 100049, China)

Abstract In this paper several different working gas mixtures for GEM-TPC were evaluated based on a Garfield simulation. Among them, Ar:CH_4:CF_4=90:7:3 (named herein TU gas) was selected for a detailed study because of its better performance. Some performances of drift velocity, transverse diffusion, spatial resolution and the effective number of electrons in various electric fields were obtained. The performance of a GEM-TPC prototype working in the TU gas was studied and compared with that in Ar:CH_4=90:10 (P10 gas).

Key words GEM detector, TPC (time projection chamber), spatial resolution, transverse diffusion

PACS 29.40.Gx

1 Introduction

GEM-TPC (time projection chamber) is a new type gas tracking detector with good position resolution and track reconstruction[1, 2]. Its main advantage is a novel readout detector—GEM. At Tsinghua University it has been studied extensively as a promising candidate for the ILC[3] central tracking detector and also studied as a main detector for the inner-target experimental spectrometer in the CSR (cooling storage ring) of Institute of the Modern Physics, CAS. In our laboratory, a GEM-TPC prototype was successfully developed and its performance was studied using cosmic rays[4].

Garfield was written by Professor Rob Veenhof based on the Monte Carlo method and finite element analysis at CERN[5]. An interface to the Magboltz program was provided for the electron transport properties in nearly arbitrary gas mixtures. Combined with Maxwell software it can simulate the details of two-dimensional and three-dimensional drift chambers and optimize their designs. The drift velocity, attachment coefficient and diffusion constant can be simulated in high precision using a large enough collision number. A collision number set of 100×96000 leads to a statistical error of 0.13% in the drift velocity and of 4.5% in the transverse diffusion. In the study the following gases were simulated: TU gas (Ar:CH_4:CF_4=90:7:3), Iso gas (Ar:CH_4:iC_4H_{10}=94:3:3), P10 (Ar:CH_4=90:10), TDR (Ar:CO_2:CH_4=93:2:5) and P5 (Ar:CH_4=95:5).

2 Simulation

2.1 Transverse diffusion

The transverse diffusion of electrons degrades the

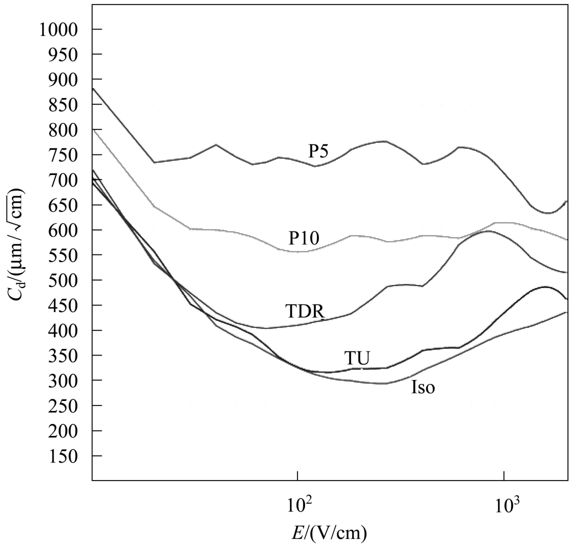

Fig. 1. Transverse diffusion constant as a function of drift field for different gas mixtures.

Received 7 July 2008, Revised 22 August 2008
* Supported by CAS/SAFEA International Partnership Program for Creative Research Teams

1) E-mail: qihr@tsinghua.edu.cn

spatial resolution of the r-ϕ plane (or x-y in our TPC prototype). The relation between transverse diffusion constant C_{D} and E_{drift} is shown in Fig. 1. From there one can see that both the TU gas and the Iso gas have smaller C_{D} than all the other gases in question. When E is near the saturation field $E_{\max}$, C_{D} reaches its minimum value.

2.2 Drift velocity

In certain gases and electric fields, the electrons are moving without a preferred direction on the basis of random fluctuations. The drift velocity is determined by the function

$$v_{\mathrm{e}}=f\left(\frac{E}{P}\right). \tag{1}$$

Here, E is the electric field, P is the gas pressure and v_{e} is the drift velocity. When the velocity reaches the saturation velocity (nearly maximum) the electron drift in the gas depends slightly on E. Fig. 2 shows the velocity from the Garfield simulation for these gases for different electric fields. One can see that the saturation velocity of TU is the largest among all these gases, and its saturation field is about 250 V/cm, which makes it a promising candidate for TPC systems, especially for systems which need a high drift velocity to implement a high event rate.

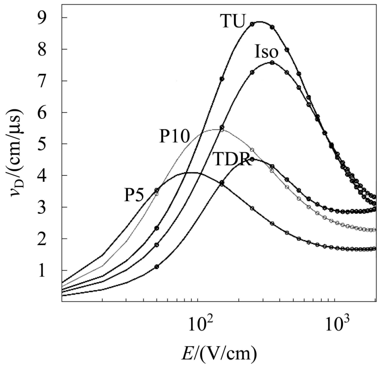

Fig. 2. Drift velocity of the electron as a function of the drift field for different gas mixtures.

3 Test system setup

The GEM-TPC prototype includes the following main parts: a ϕ300 mm gas chamber with a 500 mm drift distance, a triple GEM readout detector with an active area of 100 mm×100 mm, 312 readout pads, each with a size of 1.6 mm(x direction)×100 mm(y direction), a VME based DAQ system, a cosmic-ray hodoscope trigger system and a GEM readout mounted on the center of the end of the chamber. The TU gas was supplied as a pre-mixed gas. Fig. 3 shows a schematical drawing of the system set up.

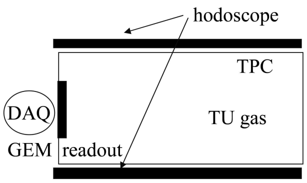

Fig. 3. Diagram of the system setup.

In the test of the drift velocity[6], a hodoscope with its small size in the z direction was placed at five test points (their positions were determined based on the mechanical design) along the whole drift distance. The drift time was obtained by taking the peak time of a Gaussion fit to the raw data (see Fig. 4). The drift velocity was calculated by a linear fit of the relation between the drift distance and drift time. In the tests for the TPC performance studies another hodoscope trigger system covering the whole drift volume was used.

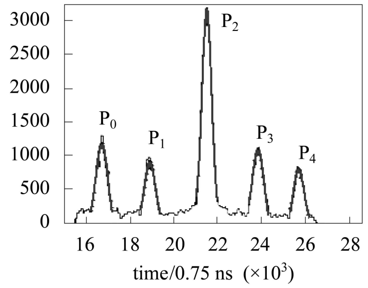

Fig. 4. The histogram of drift time (0.75 ns, $T|_{z=0}=15484$).

4 Test results

4.1 Drift velocity

The drift velocities for two different E_{drift} values were measured and listed in Table 1. They are very close to the simulated results.

Table 1. Values of drift velocities from simulation and measurement.

E_{drift}/(V/cm)	drift velocity/(cm/μs)	
	simulated	measured
180.2	7.36	7.2±0.12
200.4	8.21	8.1±0.39

4.2 Transverse diffusion constant

The transverse diffusion constant C_{D} can be determined from the following relation[7]:

$$\sigma_{\mathrm{PR}}^2(Z)=\sigma_{\mathrm{PR}}^2(0)+C_{\mathrm{D}}^2 Z\ . \tag{2}$$

Here, $\sigma_{\mathrm{PR}}^2(Z)$ is the width of the pad response at a drift distance of Z, and $\sigma_{\mathrm{PR}}^2(0)=\sigma_{\mathrm{PR}}^2(Z)|_{z=0}$, which is caused by the finite width of the readout pad and the electron diffusion in the GEM detector.

Figure 5 provides the measured $C_{\rm D}$ of the TU and P10 gases for the diffusion drift field in a magnetic field of 0 Tesla (all detectors and chamber mounted in the magnetic tunnel). Here ϕ is the azimuthal angle and θ is the polar angle, both measured with respect to the y-direction. The diffusion constant of the TU gas is obviously smaller than the one of the P10 gas. However, all the values measured are smaller than those predicted by Garfield.

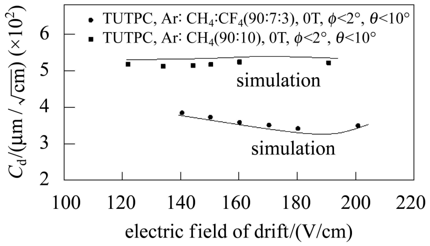

Fig. 5. Measured transverse diffusion constant at different drift fields for TU gas and P10 gas.

4.3 $N_{\rm eff}$

$N_{\rm eff}$ is the effective number of electrons on the readout pad. At relative large drift distances, the relation of the spatial resolution and $N_{\rm eff}$ in a TPC system width a MPGD (micro pattern gas detector, including GEM) is $\sigma^2=\sigma_0^2+(C_{\rm D}/\sqrt{N_{\rm eff}})^2Z$. So, $N_{\rm eff}$ is an important performance parameter in a GEM-TPC system.

Figure 6 shows $N_{\rm eff}$ for the TU and P10 gases for different drift fields with $V_{\rm GEM}$=370 V. It is obvious that the value of $N_{\rm eff}$ reaches its maximum at a drift field close to its saturation value. In our test, $N_{\rm eff}$ for the P10 gas has reached the maximum, while for the TU gas this is has not yet been the case because the maximum available drift field at this moment is still lower than its $E_{\rm max}$.

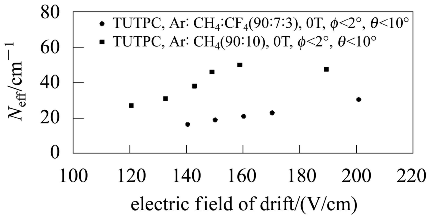

Fig. 6. Measured effective number of electrons at different drift fields for TU gas and P10 gas.

4.4 x-resolution

The x-resolution σ_x is determined as the r.m.s value of the distribution of the residules between measurement points and the fitting track.

Figure 7 gives the resolution of our GEM-TPC prototype working in TU and P10 gases in a 0 Tesla magenetic field with $V_{\rm GEM}$=370 V. It is obvious that the TPC working in a TU gas has a better resolution even at drift distances (>300 mm) where the spatial resolution is very poor for the P10 gas.

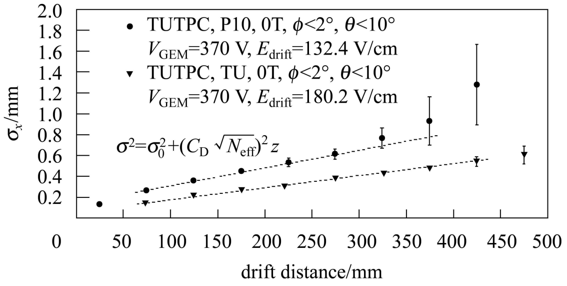

Fig. 7. x-resolution at different drift distances for TU gas and P10 gas.

5 Conclusion

Because of the small diffusion constant and fast drift velocity, CF_4 was added to the Ar and CH_4 mixture as a working gas for the GEM-TPC, especially for applications where a large drift velocity is needed. Based on a Garfield simulation the TU gas has been selected for a detailed experimental study. Test results confirmed that the GEM-TPC prototype can achieve a better performance working in TU gas rather than in P10 gas, which is a common gas in traditional TPCs.

We are grateful to Professor Fabio Sauli from CERN, Professor Takeshi Matsuda, Prof. Keisuke Fujii from KEK, for their help. We also thank colleagues from IHEP for adapting MDC DAQ to our prototype system.

References

1 Sauli F. Nucl. Instrum. Methods A, 1997, **386**: 531—535
2 Blum W, Rolandi L. Particle Detection with Drift Chambers. Berlin: Springer-Verlag, Second printing, 1994, 120—150
3 http://www.linearcollider.org/
4 LI Yu-Lan, CAO Liang-Jun, QI Hui-Rong et al. CPC (HEP & NP), 2008, **32**(1): 52—55
5 http://cern.ch/garfield
6 LI Yu-Lan, QI Hui-Rong et al. Nuclear Science Symposium Conference Record, 2007. NSS '07. IEEE: 245—247
7 Kobayashi M. Nucl. Instrum. Methods A, 2006, **562**: 136—140