A Study of Spatial Resolution of GEM TPC with $Ar\text{-}CF_4\text{-}iC_4H_{10}$ Gas Mixtures

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Preliminary results of the spatial resolution of a GEM TPC with $Ar\text{-}CF_4$ (3%)-iC_4H_{10} gas mixtures are reported.

1 ILC TPC and $Ar\text{-}CF_4$ gas mixtures

The Time Projection Chamber (TPC) with the Micro-Pattern Gas Detectors (MPGD) is one of the candidates of the main tracker at the International Linear Collider (ILC). Three MPGD TPCs described in the ILC Reference Design Report [1] have the dimension of 2.8-4 m in diameter and 3-4.6 m in length. They are to provide 200 space points along each particle track with the Rφ spatial resolution of 100 μm or better. The momentum resolution of $\delta(1/p_t) \leq 0.5 \times 10^{-4}$ $(GeV/c)^{-1}$ is envisaged in the magnetic filed of 3-4 T.

The spatial resolutions of MPGD TPCs have been studied using small TPC prototypes [2]. It has been shown that the micromegas TPC with the resistive anode readout and the multilayer GEM TPC readout by narrow standard pads of around 1 mm wide can achieve the spatial resolution down to 50 μm for the short drift distance up to a few 10s cm.

To realize the target resolution in the whole range of the drift length of the ILC TPC, we need to choose a gas mixture with small transverse diffusion or a large ωτ in the high magnetic filed. $Ar\text{-}CF_4$ gas mixtures are known to have the large ωτ up to around 20 at 4T. Fig. 1 shows the spatial resolutions of GEM TPC with Ar(97%)-CF_4(3%) calculated by a new analytic formula [4]. Here the transverse diffusion constant was assumed to be 20 $\mu m/(cm)^{1/2}$ based on the Magboltz simulation [5], and the

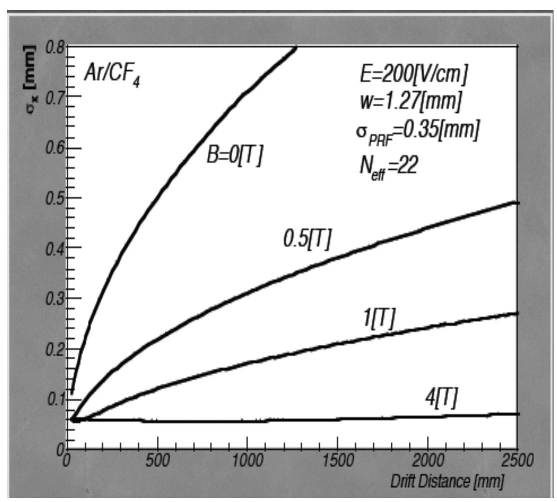

Fig.1 The Rφ spatial resolution of GEM TPC calculated by the analytic formula for Ar(97%)-CF_4 (3%) gas mixture in the magnetic field up to 4T [3].

width of the standard readout pads and the width of the pad response function of the multilayer GEM were taken to be 1.27 mm and 350 μm, respectively. The effective number of electron N_{eff} appears in the formula was assumed to be 22 [4].

The Ar-CF_4 gas mixtures are also known to have the high electron attachment at the high electric filed above 1 kV/cm [5]. It is conjectured, however, that the region in the gas amplification gap of MPGD where the electron attachment dominated over the gas amplification might be limited so that MPGD should provided sufficient gas amplification. The attachment in the drift region (<400V/cm) is estimated to be negligible even for the large ILC TPC. The most recent work of the micromegas TPC readout by the resistive anode measured the excellent spatial resolutions of around 50 μm for Ar(95%)-CF_4(3%)-iC_4H_{10}(2%) gas mixture in the 5T magnetic filed [6]. The resolutions measured at 0.5T in the same experiment gave the effective number of electrons N_{eff} of 28.8 proving the above conjecture. It was also reported that a three-layer GEM TPC worked successfully with the same gas mixture [7]. However the measured resolutions were limited by the large pad width of 8 mm and there was no report on N_{eff}.

Beside the standard characteristics of the TPC gas there are also special requirements to the TPC gas at ILC. The neutrons from the beam dumps of ILC may arise as a significant background in TPC [1]. To minimize their effects it may be advisable to avoid any gas mixture which contains much hydrogen. Also when we adopt the GEM gating [8] to prevent the ion feed back to the drift region from the amplification region, the selection of the TPC gas mixture may become even narrower. Although there is an argument against the Ar-CF_4 gas mixtures since the CF_4 is an etching gas, the Ar-CF_4 gas mixtures seems to have advantage in these two points.

2 GEM TPC with Ar-CF_4(3%)-iC_4H_{10} gas mixtures

We report here preliminary results of our measurement of the spatial resolution of a GEM TPC with Ar-CF_4(3%)-iC_4H_{10} gas mixtures.

The measurement was done using the MP-TPC prototype. The MP-TPC is a small TPC prototype with the cylindrical drift region of 14.5 cm in diameter. It has a detachable endplate which carried a GEM detector in this measurement. The maximum drift length with the GEM detector was 25.4 cm.

The GEM detector consists of 3-layers of the standard CERN GEM (10 x 10 cm^2) mounted on a pad plane. The transition gaps between the three GEMs were set to be 1.5 mm for this measurement and the induction gap to the pad plane 1.0mm. The pad plane has 12 pad rows. The width (pitch) of each pad is 1.17 (1.27) mm and the length (pitch) 6 (6.3) mm. The pads in the adjacent rows are staggered by one half of the pad pitch. In this measurement the central 32 pads of 7 pad

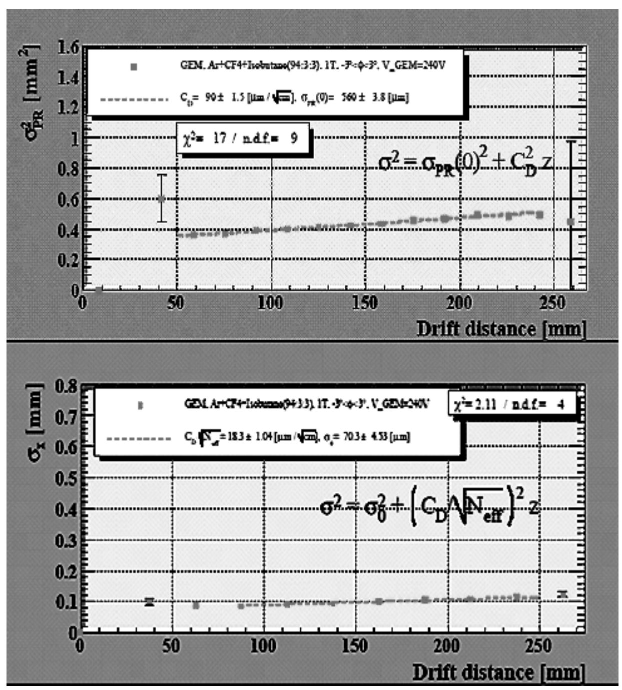

Fig.2 The width of the pad response (top) and the spatial resolution (bottom) as functions of the drift length. The gas is Ar(94%)-CF_4(3%)-Isobutene(3%) gas mixture. The dotted line in each plot is the best fit to the data by the function given in the plot.

rows were actually readout by the ALEPF TPC electronics. Some more details of the MP-TPC and the readout electronics may be found elsewhere [4].

The MP-TPC was placed at the center of a superconducting solenoid of the MRI model at the KEK cryogenic center. The inner bore is 80 cm in diameter and 1.6 m in length. The uniform magnetic filed of 1T is generated by a multilayer superconducting coil. An iron yoke of about 10 cm thick surround the cryostat improves the field uniformity.

The TPC gas was mixed on the site using three mass flow controllers (MFC). The flow rate of the mixed gas was typically 100cc/min during the measurement. The MFC for Ar gas has the maximum flow rate of 1 liter/min, and the other two for CF_4 and iC_4H_{10} 20 cc/min. The MFCs were calibrated recently. The actual flow rates during the measurement are estimated to be within 5% or better to the preset values.

The measurement was made with the cosmic ray tracks triggered by two scintillator counters immediately above and below the MP-TPC. Each scintillator counter was readout by a fine-mesh PMT.

3 Spatial resolutions and N_{eff}

The data were collected for the two different values of the iC_4H_{10} concentration; (1) Ar(94%)-CF_4(3%)-iC_4H_{10}(3%) and (2) Ar(96%)-CF_4(3%)-iC_4H_{10}(1%). The lower concentration of iC_4H_{10} is preferred when the neutron background becomes an important issue. The voltage applied to each GEM was 240 V for the gas mixture (1) and 230 V for the gas mixture (2) keeping the gas gain to be same. The voltages of the transition gaps and the induction gap were set to be same to the GEM voltage. The drift filed was tentatively chosen to be around 80V/cm in this measurement; 80.4V/cm and 77.6V/cm for the gas mixture (1) and (2), respectively. For each gas mixture, we accumulated about 60,000 cosmic ray triggers. The magnetic filed was 1T.

Before the data taking we tried to operate our GEM TPC with Ar(97%)-CF_4(3%) but without any iC_4H_{10} concentration. We could not see the GEM signal up to the GEM voltage of 340V, confirming the observations by other people [9].

The cosmic ray tracks were found by using the Double-Fit program [4] which performed the $\chi 2$ fit to hit points found in the 7 pad rows. The circle fit was applied. In the following discussion the comics rays were selected in $-3° < \varphi < 3°$, where the angle φ was the angle of the projected track on the pad plane relative to the normal of the pad rows, to minimize the pad angle effect.

For the gas mixture (1) with the 3% iC_4H_{10} the drift velocity was measured to be 3.4 cm/μs while the Magboltz simulation predicts 3.15 cm/μs. The drift velocity was measured by the endpoint of the time distribution of the cosmic ray tracks. In the upper plot of Fig.2 shows the widths of the pad response $\sigma_{PR}(z)$ as a function of the drift length z. The linear fit to the data by the formula $\sigma_{PR}(z)^2 = \sigma_{PR}(0)^2 + C_{DT}\, z$ gives the transverse diffusion constant C_{DT} of 90±1.5 $\mu m/cm^{1/2}$ to be compared

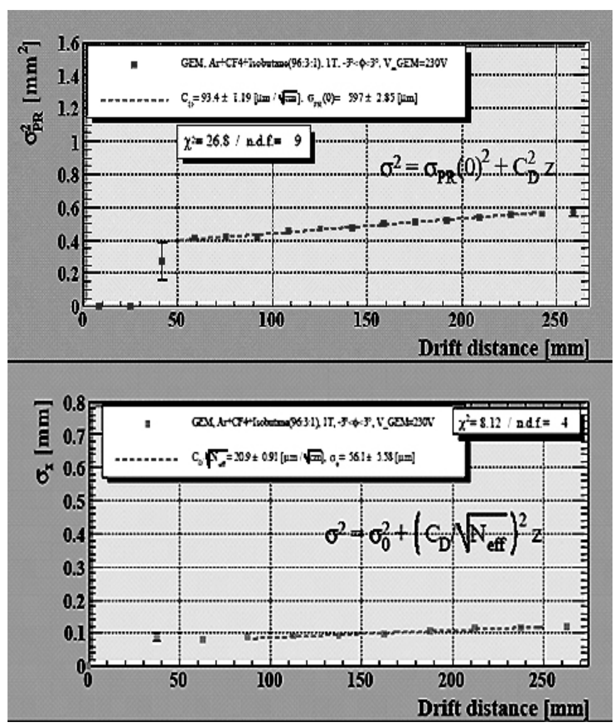

Fig.3 The width of the pad response (top) and the space resolution (bottom) as functions of the drift length. The gas is Ar(96%)-CF_4(3%)-iC_4H_{10}(1%) gas mixture. The dotted line in each plot is the best fit to the data by the function given in the plot.

to 88 μm/cm$^{1/2}$ calculated by the Magboltz simulation. The measured spatial resolutions$\sigma_x(z)$ are shown in the lower plot of Fig.2. Fitting the spatial resolutions with the formula $\sigma_x(z)^2 = \sigma_x(0)^2 + [(C_{DT})^2/N_{eff}]z$ [4], we obtain the effective number of electrons N_{eff} of 24±2. Here the fitting was made in the region of the drift length larger than 80 mm to avoid the hodoscopes effect.

Fig 3 shows the results for the gas mixture (2) with the 1% iC_4H_{10}. The diffusion constant measured is 93 ±2.0 μm/cm$^{1/2}$ while the Magboltz simulation predicts 71 μm/cm$^{1/2}$. From the measured spatial resolutions in the lower plot of Fig. 3 the N_{eff} is found to be 20±1. The drift velocity measured is 4.2 cm/μs while the Magboltz simulation predicts 3.9 cm/μs.

These measured N_{eff} are comparable to those for the micromegas TPC operated with Ar(95%)-iC_4H_{10}(5%) gas mixture [4] and the 3-layer GEM TPC with the TDR gas and P5 gas [10].

4 Conclusions

We measured the spatial resolutions of the 3-layer GEM TPC with the Ar-CF_4(3%)-iC_4H_{10} gas mixtures at 1T. In the limited operational conditions we found no serious problem to operation the GEM TPC for the gas mixtures while we could not operate it without iC_4H_{10}. The effective number of electrons N_{eff} were found to be comparable to those found for the other standard gases. We need to understand the somewhat (10%) higher drift velocities and the significantly (30%) lower diffusion constant obtained for the gas mixture with the 1% iC_4H_{10} concentration. We continue our study of the GEM TPC with the Ar-CF_4(3%)- iC_4H_{10} gas mixtures, in particular, toward higher drift fields.

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6 References

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