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# Resolution studies of cosmic-ray tracks in a TPC with GEM readout

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**Abstract**

A large volume time projection chamber (TPC) is a leading candidate for the central tracking detector at a future high energy linear collider. To improve the resolution a new readout based on micro-pattern gas detectors is being developed. Measurements of the spatial resolution of cosmic-ray tracks in a GEM TPC are presented. We find that the resolution suffers if the readout pads are too wide with respect to the charge distribution at the readout plane due to insufficient charge sharing. For narrow pads of $2 \times 6\,\mathrm{mm}^2$ we measure a resolution of $100\,\mu\mathrm{m}$ at short drift distances in the absence of an axial magnetic field. The dependence of the spatial resolution as a function of drift distance allows the determination of the underlying electron statistics. Our results show that the present technique uses about half the statistical power available from the number of primary electrons. The track angle effect is observed as expected.


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## 1. Introduction

The time projection chamber (TPC) [1,2] has been a mainstay of large particle detectors since its initial concept in the 1970s. The traditional TPC has an end cap detector that uses anode wires for amplification of the signal. When operated in an axial magnetic field, this leads to the so called $\mathbf{E} \times \mathbf{B}$ effect [3] close to the wires, which significantly degrades the resolution of the TPC. Proposals to readout TPC signals without the use of anode wires have been suggested [4,5] in the

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past. The recent development and success of micro pattern gas detectors (MPGD) such as the μMegas [6] and the GEM [7,8] has renewed interest in this solution.

The advantages of MPGD detectors are that they require less mass for construction, should not have any **E** × **B** effect, naturally suppress positive ion feedback and allow more freedom in the shape and orientation of the readout pads. In addition the signals are faster, potentially improving the double track resolution in drift time. In the case of MPGDs, the signal on the readout pads can be a direct electron collection signal or an induced signal. The advantage of direct signals is that their amplitude is larger and the signal is more confined, thus potentially improving the spatial double track resolution. The disadvantage of the confined signal is that the pads need to be much narrower, on the order of the width of the ionization charge distribution, which increases the number of channels and thus the cost. In the case of GEMs the ionization charge can be spread naturally in the gaps between the GEMs and readout pads. It is also possible to use the induced signal [9,10] which has a wider spread than the direct signal, but a reduced amplitude.

GEM amplification with pad type readout planes has been shown to give excellent spatial resolution for point sources, such as X-rays converting in a gas [11], which is useful for medical applications, where the pad size can be arbitrarily small to give the required resolution. In the case of a large scale experiment using a TPC, such as the proposed TESLA detector, the pad size determines the number of channels and thus the cost; in that case it is important to make the pad size as large as possible consistent with the resolution required.

In earlier studies [10], using a double GEM amplification stage, we determined the point resolution, $s$, that can be achieved for X-rays converting in the gas using the direct charge distribution near the edge of hexagonal pads ($s \sim 70\,\mu m$) and the induced charge distribution near the middle of pads ($s \sim 80\,\mu m$). A subsequent study [12] with cosmic rays and a small TPC with an end cap detector with 5 staggered rows of $2.5 \times 5\,mm^2$ rectangular pads showed that these pads produced an adequate track resolution using the direct charge.

In this paper we examine the resolution that can be achieved using the direct signal from a double GEM amplification stage and a rectangular staggered pad readout scheme. In particular we examine the effect of the pad width and length on the spatial resolution and attempt to gain a better understanding of the phenomena that affect the resolution. For this purpose we measured the spatial resolution as a function of several different quantities, including three different pad sizes and local position across a pad, two gases, drift distance, crossing angle, and signal amplitude.

The two gases used were P10 (Ar(90) : $CH_4$(10)), a fast gas with large diffusion, and Ar(90) : $CO_2$(10), a slow gas with relatively small diffusion, operated at a voltage below the peak velocity. The different diffusion properties allowed us to study the effect of pad size relative to the width of the direct charge distribution arriving at the pads, and to simulate, with the $ArCO_2$ mixture, reduced diffusion as would be present with a P10 type gas in a magnetic field.

## 2. Experimental setup

The test TPC used for these measurements is housed in a cylindrical pressure vessel filled with P10 or $ArCO_2$ gas at atmospheric pressure. The TPC has a maximum drift length of 15 cm and an active area of $8 \times 8\,cm^2$. The drift field of 138 V/cm is established by a series of thin window frame electrodes located between the cathode plane at the far end and the readout end plane at the other end of the TPC. A charged particle crossing the drift region will ionize the gas; the released electrons drift to the end plane where they are amplified and detected on a readout PCB. While drifting the charge cloud gets wider due to transverse diffusion, an effect that would be reduced in an axial magnetic field.

We use a double GEM structure for amplification with a gap of 2.4 mm between the first and the second GEM. The voltage difference across this transfer gap is 653 V resulting in a field of 2.7 kV/cm. The induction gap between the second GEM