Investigation of GEM Space Point Resolution for a TPC Tracker

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Abstract. The Gas Electron Multiplier (GEM) is a leading candidate for the readout of the Time Projection Chamber (TPC) at a future linear collider detector. This presentation describes measurements of the space point resolution of a GEM with relatively large hexagonal pads. Resolution of approximately 50 μm is achieved for 4.5 keV x-rays with two independent methods, using charge sharing and using induction signals.

INTRODUCTION

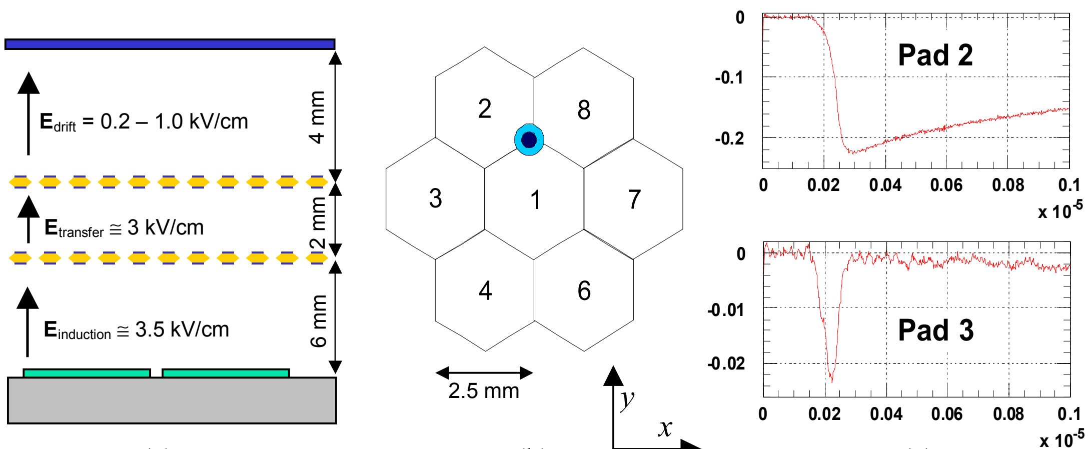
A Gas Electron Multiplier (GEM) consists of a thin metalized plastic foil perforated with an array of small holes.[1] A voltage difference applied across the two surfaces of a GEM foil produces a strong dipole field within the GEM holes, sufficient to provide gas gain amplification of order 100 or more. GEMs can be used to image the ionization tracks from charged particles traversing a Time Projection Chamber (TPC) by placing GEM foils and a pad readout structure at the TPC endplates.

TPCs have traditionally used wire arrays to provide gas gain amplification. There are a number of potential advantages in replacing the arrays by GEM foils. Near the wire arrays, the electric field is not parallel to the magnetic field and this results in a degraded space point resolution of the device. This problem, known as the $\mathbf{E}\times\mathbf{B}$ effect, is much reduced in GEM readout because the holes in the GEM foils can be much closer together than anode wires. The fact that the wires themselves are not perpendicular to the ionization tracks leads to further degradation of resolution. The induced signals in a GEM have a smaller transverse extent and are intrinsically faster, which could result in better two-particle separation. By using several GEM foils, ion feedback into the drift volume may be reduced to a level that would require no gating, an important feature in a triggerless experiment. Finally, the material in the TPC endcap may be reduced, no wires need to be held under tension.

All of these potential benefits of GEM readout need to be verified. The work presented here is a study of the intrinsic space point resolution of GEM readout with relatively large pads, as would be required for the readout of a linear collider TPC.

EXPERIMENTAL SETUP

The space point resolution is measured in a two stage GEM shown schematically in Fig. 1a. The readout structure is a set of 2.5 mm diameter hexagonal pads in a closed pack array. Seven pads, shown in Fig. 1b, are readout with two four channel digital oscilloscopes. Primary ionization is provided by 4.5 keV x-rays collimated to approximately 50 µm spot size. Two gas mixtures have been used, $ArCO_2$ and $ArCH_4$ (90% argon for each case). Fast Lecroy HQV810 pre-amps were used with $ArCO_2$ and slower ALEPH TPC preamps were used with $ArCH_4$. Signals from an event collected with $ArC0_2$ are shown in Fig. 1c.



(a) (b) (c)

FIGURE 1. (a) A schematic drawing of the GEM cell under study. (b) The set of GEM pads readout. The circle near the vertex of pads 1,2 and 8 represents an electron cloud produced by an x-ray. The origin of our coordinate system is at the center of pad 1. (c) The signals recorded by the oscilloscope (volts vs. seconds) for two of the pads. The amplitude of the signal in pad 2 is proportional to the amount of charge collected by the pad, and its decay time is given by the electronics shaping time. The amplitude of the induced signal in pad 3 depends on the distance from the charge cloud to the pad, and the duration of the pulse is given by the time taken by electrons to drift across the induction gap.

DATA ANALYSIS

The signals from the readout pads can be used to determine the position of the primary ionization cluster. For the event shown in Fig. 1b, 3 pads collect the charge (pad number 1,2, and 8). The respective fractions collected by each pad (as deduced by the signal amplitudes) have a direct correlation to the size and position of the cloud. The induced signals observed in the other pads provide a second method to determine the position of the cloud center. The two classes of signals are considered separately.

Localization Using Charge Sharing

A method for estimating the centroid of the electron cloud was developed by using a simple model. The electron cloud is assumed to be Gaussian distributed in the two coordinates (x, y) in the plane of the GEM pads and each pad is assumed to collect the charge from the cloud directly over it. The fraction of charge collected by each pad is predicted as a function of the cloud size and location, by integrating the two-dimensional Gaussian over the pad regions.

The average cloud size is found by measuring the charge fraction in pad 1, as the x-ray beam is moved closer towards the center of that pad. The data for the $ArCO_2$ gas mixture, shown in Fig. 2a, yield an estimate of 370 µm for the transverse width of the electron cloud, and verify the shape of the cloud to be Gaussian. With the cloud size fixed, the model predicts the charge fractions as a function of the position of the cloud center, as shown in Fig. 2b. The charge fractions recorded for a set of 800 events with the x-ray beam centered over location (x = –0.1 mm, y = 1.143 mm) were converted to position coordinates according to this model. The result, shown in Fig. 2c and 2d, has biases of 5 and 15 µm and standard deviations of 45 and 60 µm for x and y.

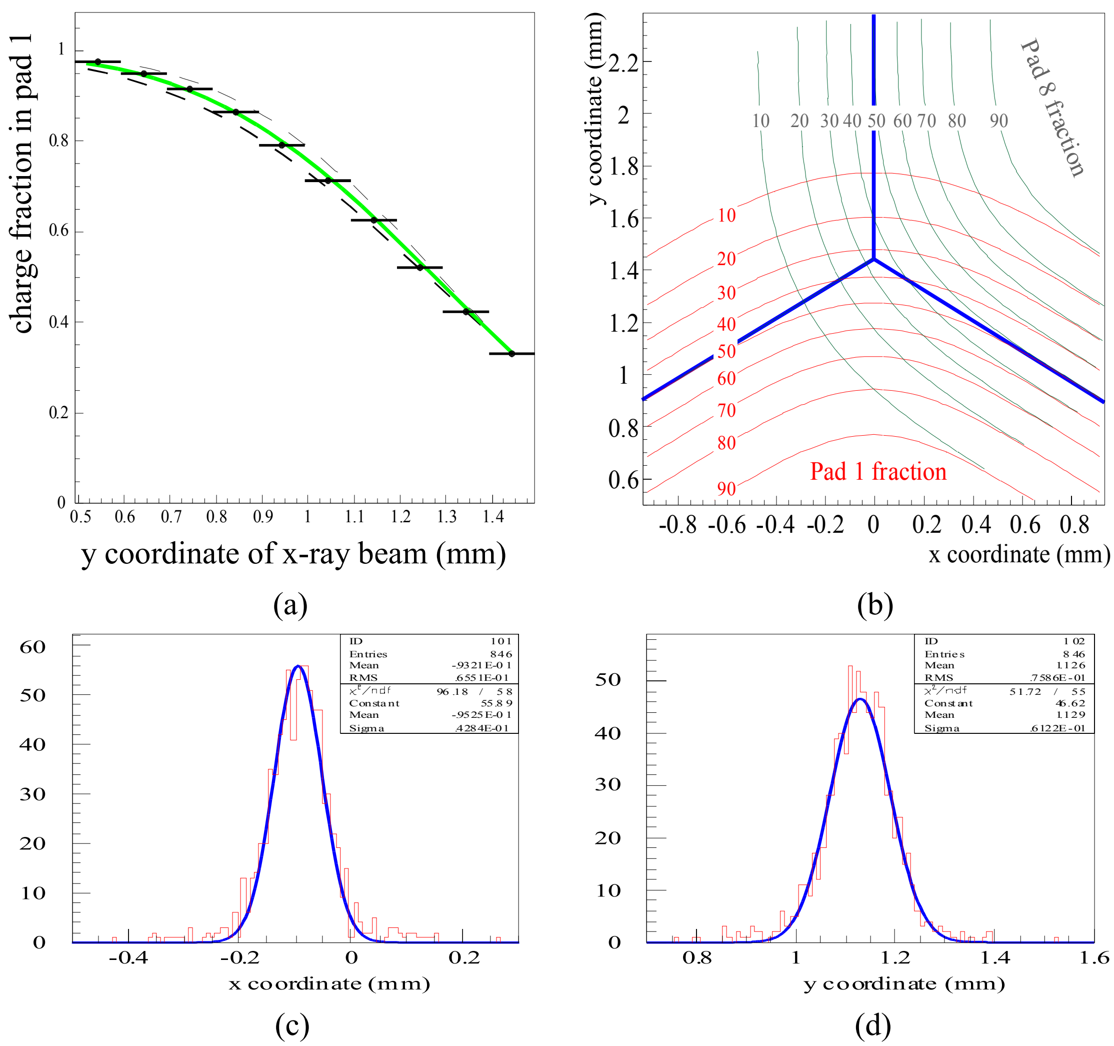
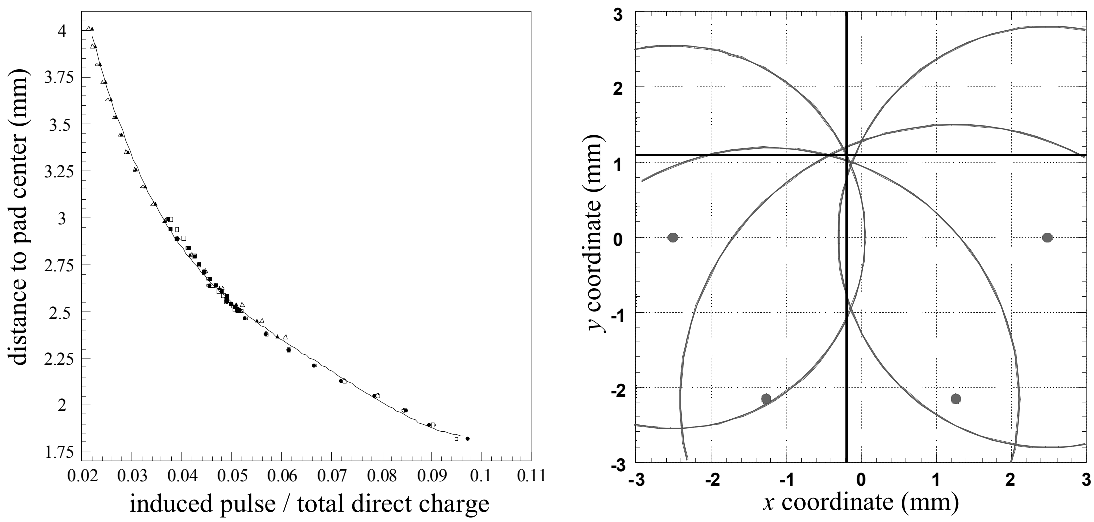


FIGURE 2. (a) The charge fraction collected by pad 1 is shown as a function of the y coordinate of the x-ray beam. At y = 1.443 mm, the x-ray beam is located over the vertex of pads 1,2, and 8, and therefore pad 1 collects 1/3 of the charge, independent of the cloud size. The shaded curve shows the expected behavior for a electron cloud given by a two dimensional Gaussian with a transverse size of 370 µm. The dashed curves show the expectations for 340 and 400 µm widths. (b) The expected charge fractions collected by each pad is shown for a cloud of width 370 µm. (c) Distributions of x and (d) y coordinates of about 800 x-ray events as estimated by the 2D Gaussian model.

Localization from induced signals

Signal amplitudes induced on neighboring pads are an order of magnitude smaller than signals from pads that collect charge. The relation between the induced signal amplitude and the distance between the x-ray beam and pad, as determined from the data, is shown in Fig 3a. By combining the information from several pads with induced signals, the location of the cloud center can be determined, as illustrated in Fig 3b. The standard deviations of position measurements were found to be 50-80 μm in *x*, and 60-100 μm in *y*. Pre-amplifier cross-talk resulted in biases of order 50 μm.



(a) (b)

FIGURE 3. (a) The relation between relative induced signal amplitude to distance to pad center is derived from data and shown here for $ArCO_2$. (b) The induced pulse amplitudes from four pads are used in an event to determine the center of the electron cloud. The circular arcs represent the radial distances derived from the induced signal amplitudes. This event had the x-ray beam centered at the location ($x = -0.1$ mm, $y = 1.143$ mm).

SUMMARY AND PLANS

The position measurements were found to have standard deviations roughly equal for the two gas mixtures, even though the electron clouds in $ArCH_4$ was roughly 50% broader than in $ArCO_2$. This would be expected if the standard deviations are primarily determined by the x-ray spot size. The intrinsic space point resolution of the GEM system under study is at least 50 μm for 4.5 keV x-rays, if not better. Further experimental and simulation studies of the space point resolution are underway. In the near future, we plan to study the capabilities of charge sharing and induced signals for tracking minimum ionizing particles in a small TPC, presently under construction.

REFERENCE

1. F.Sauli, Nucl. Inst. Meth. A386 (1997) 531.