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Simulating the charge dispersion phenomena in Micro Pattern Gas Detectors with a resistive anode

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Abstract

The Time Projection Chamber (TPC) for the International Linear Collider (ILC) will need to measure about 200 track points with a transverse resolution close to 100 μm. The resolution goal is beyond the capability of the conventional proportional wire/cathode pad TPC and Micro-Pattern Gas Detectors (MPGD) are being developed to meet the challenge. The standard MPGD readout techniques will, however, have difficulty in achieving the ILC–TPC resolution goal with the $2 \times 6\,\mathrm{mm}^2$ wide pads as was initially envisioned. Proposals for smaller width pads will improve the resolution but will require a larger number of readout channels and increase the TPC detector cost and complexity. The new MPGD readout concept of charge dispersion has the potential to achieve the ILC–TPC resolution goal without resorting to narrower pads. This was recently demonstrated in cosmic ray tests of a small prototype TPC read out with MPGDs using the charge dispersion technique. Here we describe the simulation of the charge dispersion phenomena for the MPGD–TPC. The detailed simulation includes initial ionization clustering, electron drift, diffusion effects, the intrinsic detector pulse-shape and electronics effects. The simulation is in excellent agreement with the experimental data and can be used to optimize the MPGD charge dispersion readout for the TPC.

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1. Introduction

The Time Projection Chamber (TPC) [1] is a prime candidate for the main charged particle tracker at the future international linear collider (ILC). The ILC–TPC operating in a ~4 T magnetic field should measure 200 track points with a transverse resolution 100 μm for drift lengths in excess of 2 m. The resolution goal is near the fundamental limit from the ionization electron statistics and transverse diffusion in the TPC gas, and beyond the capability of the conventional proportional wire/cathode pad TPC [2].

A TPC read out with Micro Pattern Gas Detectors (MPGD), such as the Gas Electron Multiplier (GEM) [3] and the Micromegas [4], has the potential to reach the ILC resolution goal. In normal tracking applications, MPGDs typically achieve 40–50 μm resolution [5] with ~200 μm pitch anode pads. In conventional proportional wire TPCs, much wider cathode pads are read out to compute the charge centroid, which determines the avalanche r–φ coordinate with precision. The fundamental resolution limit for the wire TPC comes from the $\mathbf{E} \times \mathbf{B}$ and track angle systematic effects [6,7]. These effects are negligible for the MPGD readout as the scale over which the **E** and **B** fields are not parallel is much smaller and also there is no preferred direction in contrast to the wire readout. MPGD anode pads, $2 \times 6\,\mathrm{mm}^2$ in size were initially proposed for the ILC–TPC readout [8]. With the strong suppression of transverse diffusion in high magnetic fields, the track

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ionization charge clusters arriving at the TPC endplate will then often be confined to only one or two pads. This makes the anode pad centroid determination difficult and results in loss of resolution. Reducing the pad width to improve resolution will require a larger number of readout channels and increase the detector cost and complexity.

In an attempt to improve the charge centroid determination and hence the spatial resolution for wide pads, a novel concept of position sensing from charge dispersion [9] has been developed where the MPGD anode is made of a thin high surface resistivity film. The resistive anode is bonded to the readout plane with an insulating layer of glue, which acts as a dielectric spacer between the two planes. The composite anode-readout pad plane structure forms a distributed 2-dimensional resistive-capacitive network. Any localized charge arriving at the anode surface will be dispersed with the RC time constant determined by the anode surface resistivity and the capacitance per unit area, the latter determined by the spacing between the anode and readout planes and the dielectric constant of the glue. With the avalanche charge dispersing and covering a larger number of pads with time, wider pads can be used for position determination. The charge dispersion process can be completely described by material properties and geometry and, in contrast to diffusion which is statistical in nature, there is no loss of accuracy in determining the centroid of a wider distribution. Fig. 1 shows the schematics of the double GEM test cell used in our initial tests of the charge dispersion readout concept.

The first proof of principle tests of charge dispersion for the GEM were carried out using a collimated soft X-ray source and have been previously published [9]. These were followed by cosmic ray resolution studies of a prototype TPC read out with GEM [10] and with Micromegas [11] using the charge dispersion technique. In this paper, we present the results of a detailed simulation of the charge dispersion phenomenon based on the model described in Ref. [9]. The charge dispersion effect is first calculated for a single point-like charge cluster deposited instantaneously on the resistive anode. The finite extent of the charge cluster due to longitudinal and transverse diffusion, the effects of intrinsic rise-time of the MPGD charge pulse and the rise- and fall-time effects in electronics are then included. Track signals can be generated by summing signals due to individual charge clusters along the track. The simulation is in excellent agreement with the observed features of charge dispersion and can be used to optimize the charge dispersion readout system parameters for TPC.

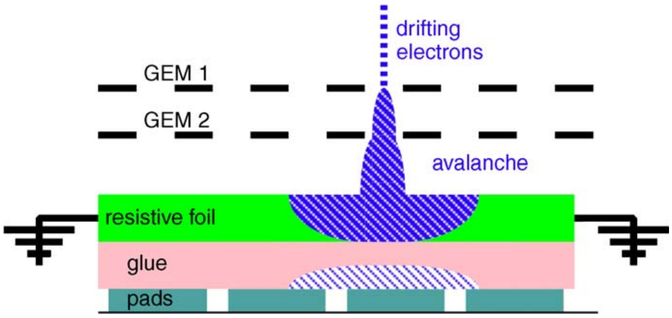

Fig. 1. Schematic of a double GEM test cell designed for charge dispersion studies.

2. Modeling the charge dispersion phenomena

If a charge is deposited on the resistive anode, the equation describing the time evolution of the surface charge density function on the two-dimensional continuous RC network is given by [9]:

$$\frac{\partial \rho}{\partial t} = h\left(\frac{\partial^2 \rho}{\partial x^2} + \frac{\partial^2 \rho}{\partial y^2}\right), \tag{1}$$

where $h = 1/RC$.

The solution to Eq. (1) for a resistive anode of finite size is an infinite Fourier series. A closed form solution becomes possible, however, for the case of a delta function point charge deposited at $x = y = t = 0$ and when the edges are at infinity:

$$\rho_\delta(x, y, t) = \left(\frac{1}{2\sqrt{\pi t h}}\right)^2 \exp\left[-\left(x^2 + y^2\right)/4th\right]. \tag{2}$$

The true initial charge profile is not a delta function but has a finite size and can be described by a Gaussian with a width determined by transverse diffusion. For a cluster with charge Nq_e, the anode surface charge density as a function of space and time is obtained by convoluting Eq. (2) with the Gaussian describing the finite charge cluster of width w:

$$\rho(x, y, t) = \frac{Nq_e}{2\pi(2ht + w^2)} \exp\left[-\left(x^2 + y^2\right)/\left(2\left(2ht + w^2\right)\right)\right]. \tag{3}$$

The charge on a pad can be found by integrating the charge density function over the pad area:

$$Q_{\text{pad}}(t) = \frac{Nq_e}{4}\left[\text{erf}\left(\frac{x_{\text{high}}}{\sqrt{2}\sigma_{xy}}\right) - \text{erf}\left(\frac{x_{\text{low}}}{\sqrt{2}\sigma_{xy}}\right)\right] \times \left[\text{erf}\left(\frac{y_{\text{high}}}{\sqrt{2}\sigma_{xy}}\right) - \text{erf}\left(\frac{y_{\text{low}}}{\sqrt{2}\sigma_{xy}}\right)\right], \tag{4}$$

where x_{low}, x_{high}, y_{low}, y_{high} define the pad boundaries, and $\sigma_{xy} = \sqrt{2th + w^2}$.

The charge is also not deposited instantaneously. The detector pulse has a finite intrinsic rise time and the signal is also affected by electron arrival time spread due to longitudinal diffusion. To compare to experiment, the characteristics of the front-end charge preamplifiers need also to be included. The parameterization of these time dependent effects is described below.

The intrinsic rise-time of the detector charge pulse: From Ramo's theorem [12], the charge pulse on the GEM anode