PAD GEOMETRY STUDY FOR A LINEAR COLLIDER TPC *

DEAN KARLEN[1] †

[1] *Department of Physics and Astronomy, University of Victoria, Canada*

Abstract

A leading candidate for the main tracker at a linear collider detector is the Time Projection Chamber (TPC). Gas Electron Multiplier (GEM) and MicroMegas (MM) devices offer the possibility to improve the TPC performance, beyond conventional TPC readout. This presentation reports on initial studies of pad geometry issues in a GEM or MM TPC, using a java based simulation package.

1 Introduction

The Time Projection Chamber (TPC) is a leading candidate for the main tracker at a future linear collider detector [1-2]. The linear collider TPC R&D program is focusing its efforts on the application of new micropattern gas avalanche detectors, namely Gas Electron Multiplier (GEM) or MicroMegas (MM), to improve the TPC performance [3]. Since signals from this type of readout significantly differ from that of a conventional TPC, the optimum geometrical layout for the readout pads needs to be reconsidered.

The pads in a GEM or MM TPC directly collect the ionization charge which is generally spread over a much smaller area than the induced signals in a conventional TPC. This should improve the two particle separation, but it can degrade the track resolution when large pads are used, as required to limit the number of

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†e-mail address: karlen@uvic.ca

readout channels. In the following, results are presented from simulation studies that compare the track resolution for different shapes, sizes, and staggering of pads.

2 Simulation Package

A java based simulation and analysis package, known as jTPC, is currently under development [4]. It has a relatively easy to use interface that allows a TPC to be built from gas volumes, amplification stages (currently only GEM), and readout pad structures. Readout pads of arbitrary shape can be defined and replicated on a grid. Tracks can be added to the TPC, and the resulting ionization is drifted through the TPC with diffusion, is amplified at GEM foils, and collected by the readout pads.

In performing track fits to the simulated signals, the non-linear nature of the charge sharing between pads in a row is taken into account, an important effect when relatively large pads are used. The track fit in the plane perpendicular to the drift direction assumes that the ionization is distributed in a Gaussian fashion about the track direction. The charge that is collected by a rectangular pad is proportional to:

$$
\begin{aligned}
I(b,\phi,\sigma,h,w) &= \int_{-w/2}^{w/2}\int_{-h/2}^{h/2}\frac{dx\,dy}{\sqrt{2\pi}\sigma}\exp\left(-\frac{[(x-b)\cos\phi+y\sin\phi]^2}{2\sigma^2}\right) \\
&= \eta(b,\phi,\sigma,h,w)-\eta(b,\phi,\sigma,-h,w) \\
&\quad +\eta(b,\phi,\sigma,-h,-w)-\eta(b,\phi,\sigma,h,-w) \\
\eta(b,\phi,\sigma,h,w) &= \frac{1}{\cos\phi\sin\phi}\xi\left(\left(b+\frac{w}{2}\right)\cos\phi+\frac{h}{2}\sin\phi,\sigma\right) \\
\xi(u,\sigma) &= \frac{u}{2}\mathrm{erf}\left(\frac{u}{\sqrt{2}\sigma}\right)+\frac{\sigma}{\sqrt{2\pi}}\exp\left(\frac{-u^2}{2\sigma^2}\right)
\end{aligned}
\tag{1}
$$

where b is the horizontal distance between the pad centre and the track, ϕ and σ are the azimuthal angle and Gaussian width of the track, and h and w are the height and width of the pads. The track fit maximizes the likelihood of the observed charge fractions from each row, with b, ϕ, and σ as free parameters and assumes a multinomial distribution about the values calculated in equation (1).

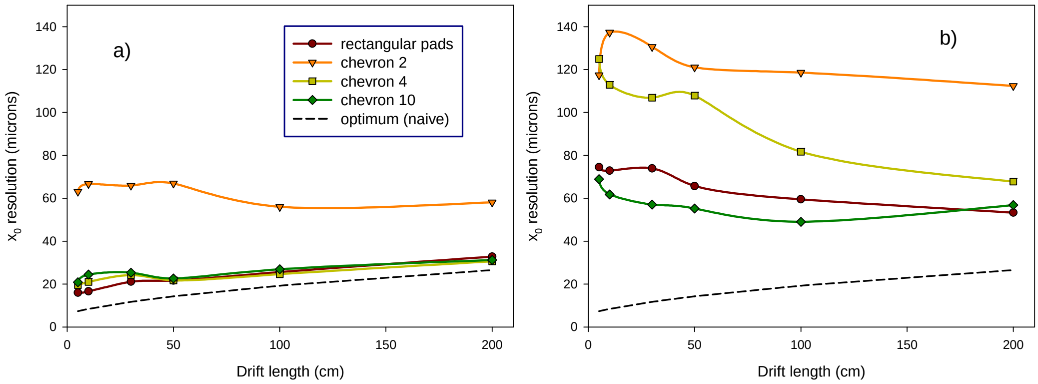

Figure 1: Track resolution as a function of drift length for chevron pads of various frequencies and rectangular pads in an Ar CF_4 gas with very low diffusion. a) For a TPC with defocussing, such as that provided by GEM structures. b) For a TPC without defocussing.

3 Comparison of Pad Shapes

Chevron shaped pads, as advocated in the TESLA TDR [1], are compared with rectangular pads in figure 1 for two very different TPC configurations. The pad areas are fixed at 2 mm × 6 mm, and straight track, with azimuthal angles between −0.1 and 0.1 radian, over 5 rows of pads are considered.

The optimal resolution will be achieved with a TPC gas with low transverse diffusion, such as an $ArCF_4$ mixture. According to Magboltz [5], $ArCF_4$ (98:2) in a 4 Tesla magnetic field has a transverse diffusion of about $27\,\mu\mathrm{m}/\sqrt{\mathrm{cm}}$, for 170 V/cm drift field, and approximately $500\,\mu\mathrm{m}/\sqrt{\mathrm{cm}}$ for a 2000 V/cm field that may be present between the GEM foils. Note that electron attachment, an important issue in CF_4 gas mixtures at high fields, is ignored in this simulation.

Sampling narrow charge distributions with wide pads degrades resolution if charge sharing between neighbouring pads is infrequent. The large diffusion between the GEM foils serves as a mechanism to defocus the narrow ionization cloud, during and after multiplication, thereby improving the resolution. To see this effect, two TPC configurations are shown in figure 1: a "GEM TPC" layout, assumed to be a 200 cm low-diffusion drift region followed by a 1.2 cm high-diffusion region (GEM transfer gaps), and an "MM TPC" layout with essentially no defocusing. The track

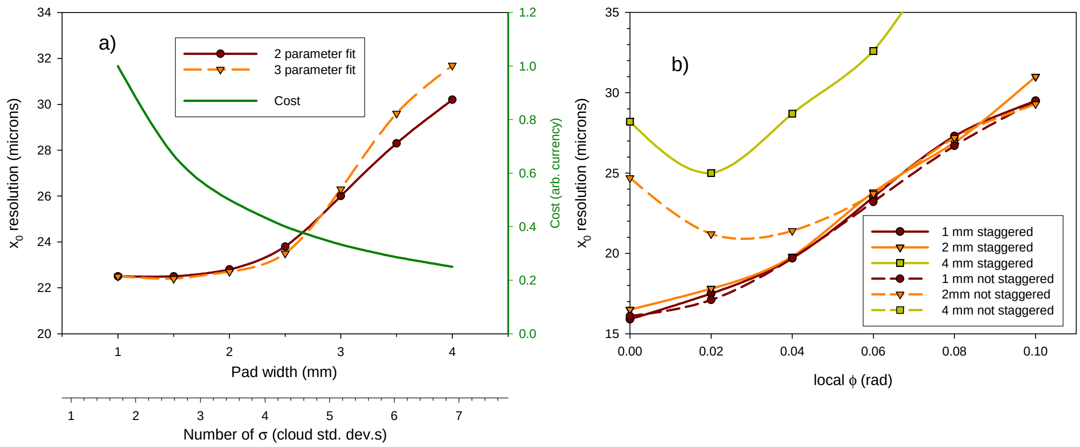

Figure 2: a) Tracking resolution as a function of pad width, for 5 rows of pads rectangular pads of 6 mm height in the GEM TPC. The drift distance was fixed at 50 cm. The cost of the readout electronics is inversely proportional to the pad width. b) Tracking resolution compared for staggered and unstaggered arrangements of rectangular pads. The degredation of resolution with increasing track angle is due to the nonuniform ionization along the length of the track.

resolution shown is the standard deviation of the horizontal residuals from track fits to 5 rows of pad signals.

The naive optimum resolution is nearly attained in the defocusing layout using either rectangular pads or high frequency chevrons. Without defocusing, the resolution is severely degraded for all pad shapes considered; chevrons do not appear to provide a solution to this problem. A micromegas TPC requires an alternative defocusing method to attain the optimum resolution.

4 Comparison of Pad Widths

In figure 2a, the track resolution is shown for tracks that drift 50 cm in the "GEM TPC" layout, corresponding to transverse cloud sizes of 0.58 mm. Resolution degrades for pad widths that are greater than about 4 times the cloud standard deviation. The use of narrower pads does not improve resolution, according to this study. The impetus for using narrower pads may come instead from the requirements of two track resolution.

5 Comparison of Staggering

In figure 2b, the pad width comparison study is extended to consider rows that are not staggered. Staggered rows (used in all the previous studies) have alternate rows offset by one half the pad width. Staggering is important for the wider pads, for tracks that are nearly parallel to the pad boundaries. In an unstaggered geometry, tracks that are nearly vertical provide little information about the cloud width and as a result the resolution suffers. If the cloud widths are fixed in the track fit (a 2 parameter fit, not shown here), the impact of staggering is diminished. The figure also demonstrates the "track angle effect", degraded resolution due to non-uniform ionization along the length of a track. This effect accounts for the difference between the optimum and achieved resolutions shown in figure 1a.

6 Conclusions

The results from this study suggest that chevron pad shapes do not offer any important advantage over rectangular pads. Since the use of chevrons will degrade the two track resolving power, there appears to be little motivation for using such pad shapes. Rectangular pads provide near optimal resolution provided that the pad widths are no more than 3-4 times the ionization cloud standard deviation and that they are staggered from row to row. It will be important to compare the results of this simulation study with data from prototype TPCs currently in preparation [3].

References

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