Available online at www.sciencedirect.com
ScienceDirect
Nuclear Instruments and Methods in Physics Research A 581 (2007) 232–235
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A
www.elsevier.com/locate/nima

Development studies for the ILC: Measurements and simulations for a time projection chamber with GEM technology

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Available online 29 July 2007

Abstract

A Time Projection Chamber (TPC) with Gas Electron Multiplier (GEM) technology is well suited for usage as central tracker at the International Linear Collider (ILC). To study the high potential of this detector type a small prototype of 25 cm length was built in Karlsruhe and used in several experimental setups. In this publication the results of these measurements and of additional Monte Carlo simulations are presented. By introducing the so-called equivalent drift distance a combination of all results was possible leading to a recommended configuration of the multi-GEM tower for the ILC–TPC. It will be shown that for conditions considered in the TESLA–TDR the transverse spatial resolution will be able to reach 65 μm for 10 cm and 190 μm for 200 cm drift at the ILC. This as well as the expectations for longitudinal spatial resolution, for energy resolutions of the specific ionization, and for single pad row efficiency should be able to meet the requirements of a future ILC–TPC.

PACS: 07.05.Kf; 29.40.Cs; 29.40.Gx

Keywords: Time Projection Chamber; TPC; Gas Electron Multiplier; GEM; Spatial Resolution

1. Introduction—A GEM–TPC for the ILC

The future linear collider project ILC (*International Linear Collider*), envisaging center-of-mass energies of up to 1 TeV in e^+e^- collisions, will provide the possibility of precision measurements of new physics. This ILC goal implies stringent requirements on the central tracking device. According to the TESLA Technical Design Report (TESLA–TDR [1]), a TPC (*Time Projection Chamber*) is the detector of choice. With a length of 2×250 cm, a proposed gas mixture of $Ar : CH_4 : CO_2$—93:5:3 (TDR gas) and $2 \times 6\,mm^2$ pads, transverse spatial resolutions of 70 μm (for 10 cm drift) to 190 μm (for 200 cm drift) are required. To cope with these requirements, a novel TPC concept is considered using Gas Electron Multipliers (GEMs) as gas amplification stage.

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0168-9002/$ - see front matter
doi:10.1016/j.nima.2007.07.084

2. Karlsruhe GEM–TPC prototype, experimental program and Monte Carlo simulation

In order to evaluate the performance of a GEM–TPC as central tracker for the ILC a small cylindrical TPC prototype was built at Karlsruhe University. With a length of 25 cm and an inner diameter of 20 cm, it was normally equipped with a double GEM structure and a low-noise highly integrated front-end electronics from the STAR experiment (320 channels, sampling rate of 19.66 MHz). As pad structure several different geometries with pad sizes of $1.27 \times 12.5\,mm^2$ or $2 \times 6\,mm^2$ (see Section 4) were used and tested. A detailed description of the construction of the TPC and of the electronics is given in Refs. [2,3].

The Karlsruhe TPC Prototype was used in several experimental setups: First tests were performed at Karlsruhe (see Fig. 1) with cosmic particles and the gases P5 ($Ar : CH_4$—95:5) and P10 ($Ar : CH_4$—90:10). Further measurements took place in a pion test beam at CERN-PS

(Geneva) using the gases P5, $Ar:CO_2$—70:30 and the TDR gas. The next step was having a test beam and a magnetic field, measurements performed at the positron test beam at DESY (Hamburg) using the gas P5. Finally the TESLA–TDR configuration was tested at DESY, including a 4 T magnetic field and the recommended TDR gas. Since no beam was available at the magnet facility these measurements were again performed with cosmic particles. Further details of the different setups can be found in Refs. [2–6].

In all setups the effective gain reached by the double GEM structure was typically 3000–5000. For almost all measurements the drift field was set to the plateau of the drift velocity distribution. The transfer gap was chosen 2 mm with 2500 V/cm, the induction gap 2 mm with 3500 V/cm. In all setups charge collection was done with the smaller rectangular pads, in the last two setups also some measurements were performed with several geometries of the wider pads.

For dedicated studies concerning important TPC parameters as the choice of gas, pad size, etc., a Monte Carlo simulation was developed, including all the important processes within a GEM–TPC, i.e. calculation of the track trajectory, distribution of primary electrons, diffusion, GEM hole allocation, amplification within the GEM, allocation to pads and signal shaping. The output format of the simulation was chosen to be identical to that from experimental data.

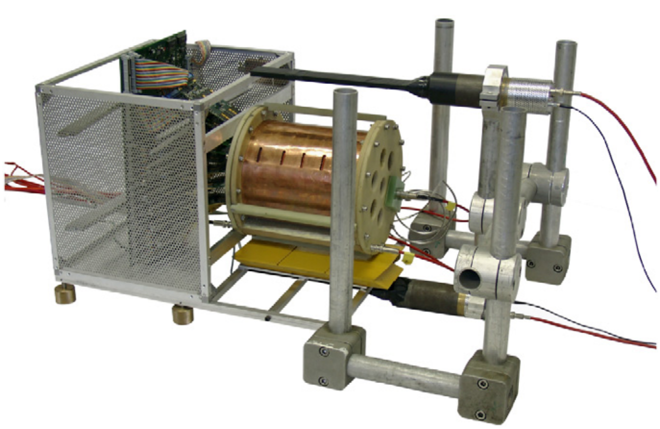

Fig. 1. The TPC prototype as it was used in the Karlsruhe setup.

3. Data analysis—COG correction and "Equivalent Drift Distance"

In this publication emphasis is set on spatial resolution studies. In Refs. [5,6] it was already shown that for tracks very narrow in comparison to the pad width several problems occur. A crucial problem can be met if charge clusters only hit one or two pads per pad row. Since a fit method using a Gaussian function does not work at all, the usage of center-of-gravity (COG) and root-mean-square (RMS) seems adequate. But here one encounters the problem that clusters are normally reconstructed nearer to the pad center as their real position tells us. In our case two methods for a correction of the COG values were developed, one using a unique correlation between reconstructed values and real values obtained by a simple computer program. The other method uses the remaining track to find the typical offset of the cluster in dependency of its position on the pad. An important point here to mention is that both corrections only work if the Gaussian sigma of the cluster distribution is larger than one third of the pad width.

After performing this COG correction residuals can be calculated by getting the projected distance between cluster position and corresponding track position for either transverse or longitudinal direction. The width of the distribution of these residuals is basically called spatial resolution. In the case where track points are used to define the track and to calculate residuals a slightly modified definition of spatial resolution has to be applied, which can be found in Ref. [7].

A possibility to compare results of different measurements with different gases, i.e. different diffusion, and different drift distances z_{drift} can be obtained by extrapolating to the equivalent drift distance z^{eq} where the primary cluster size of the measurement is the same as it would be in the designated detector, which is in this case the future ILC–TPC (TDR gas, 4 T):

$$z^{\mathrm{eq}}_{\mathrm{trans/long}} = z_{\mathrm{drift}} \cdot \frac{(D^{\mathrm{meas.}}_{\mathrm{trans/long}})^2}{(D^{\mathrm{TDR},4T}_{\mathrm{trans/long}})^2}. \quad (1)$$

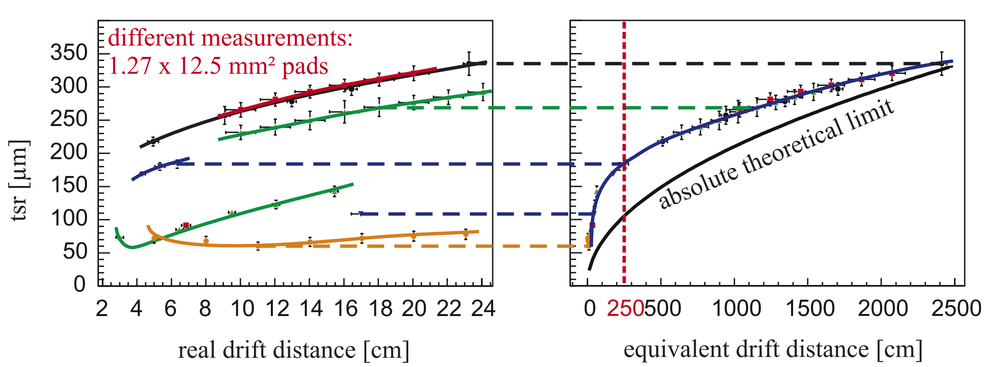

Fig. 2. Mechanism of equivalent drift distance shown for transverse spatial resolution (tsr): By this extrapolation results from different measurements (left) provide spatial resolution estimations for the future ILC detector (right).