TPC Development by the LCTPC Collaboration for future Higgs factories

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Abstract

A future Higgs factory will impose demanding requirements on the detectors both in precision and in rate. To study the possibility of a time projection chamber as a central tracking detector at such a facility, the LCTPC collaboration was founded in 2007. It is investigating various Micropattern Gaseous Detectors (MPGDs) as a readout option for such a detector. A test setup was installed at the test beam area at DESY and many test beams campaigns have been performed since 2010. It was demonstrated that the required spatial resolutions could be reached.

Keywords: TPC, time projection chamber, GEM, Micromegas, GridPix, Micropattern Gaseous Detector

1. Requirements at Higgs factories

The challenges of a Higgs factory were studied for the International Linear Collider [1] in most details. The reconstruction of the Z boson recoiling against a Higgs boson ($e^+e^- \rightarrow Z^\star \rightarrow H + Z$) was identified as giving the most stringent requirements for the central tracking detectors with a total momentum resolution of $\delta\left(1/p_t\right) \approx 10^{-5}\ (\mathrm{GeV/c})^{-1}$ needed. This results in a transverse spatial resolution requirement of $\sigma_{r\phi} \lesssim$ 100 µm. Additionally, a very high detection efficiency even for particles with a momentum below 1 GeV, reconstruction of non-pointing decay products of long lived particles and particle identification at hadron momenta below 20 GeV. A TPC equipped with a Micropattern Gaseous Detector (MPGD) readout at the end caps fulfills these requirements ideally and has been studied by the LCTPC collaboration.

However, requirements at the circular colliders proposed in recent years, such as the CEPC or the FCC-ee differ in some aspects making it necessary to revisit the choice of MPGDs, the mode of operation and performance prospects. On the one hand circular machine are operated in a continuous bunch crossing mode, while the linear accelerators such as the ILC or CLIC are operated with longer time intervals between bunch trains. On the other hand, circular machines can reach much higher luminosities when operated at lower center of mass energies such as 91 GeV Z-peak running.

2. Current Research Program of LCTPC

LCTPC has constructed a test setup at the test beam area T24/1 at DESY for performance and integration studies. Here, a 1-6 GeV electron test beam is available and a large $B = 1$ T magnet on a movable and rotatable stage. The setup also contains beam triggers, cosmic ray triggers, a large field cage [2], an end plate with openings for up to 7 modules and a beam telescope placed between the field cage and the magnet [3]. Besides the common infrastructure, there were also common developments for the readout modules. Most notably a GEM-based gating device [4] for reducing the ion backflow (IBF) was developed and is planned to be used with all

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gas amplification stages in the case of linear colliders, where gating is possible between bunch trains. Also common electronics based on ALTRO, AFTER and sALTRO ASICs was developed. The latest advances focus on the cooling, where cooling units for 2pCO_2 cooling were made with 3d-printed aluminum.

Currently, pad-based readout techniques with two different Gas Electron Multipliers (GEMs) [5],[6] or Micromegas with a resistive layer [7] are considered. The pad-based readouts give very similar results and have proven that they can fulfill the ILC requirements for transverse (see Fig. 1), longitudinal spatial resolution, double hit separation and dE/dx-resolution. A highly pixelized readout called GridPix [9],[10] is

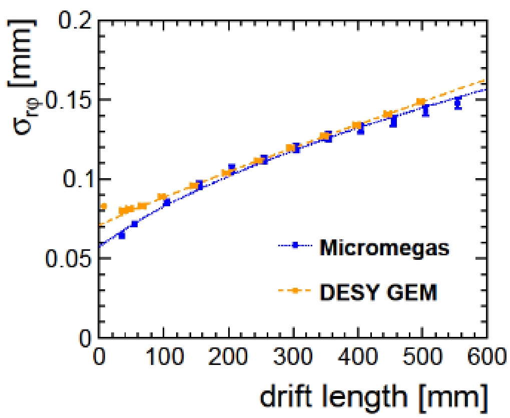

Figure 1: Comparison of transverse spatial resolution in dependence on drift distance for the pad-based technologies at $B = 1$ T[8].

even more promising, as single primary electrons can be resolved and both spatial as well as deposited energy resolution become better.

3. Upcoming Research Program of LCTPC

One task LCTPC is now concentrating on is to build upgraded modules with the latest developments implemented. In addition LCTPC intends to address the particular requirements of circular machines now. The most important one is to reduce the IBF without an explicit gating device. For this, new MPGD devices should be looked at, for example a Micromegas with double mesh structures or a combination of GEMs and Micromegas have been reported to have low IBFs in literature. The latter ones are being tested now [11] with a UV laser setup and have shown also very promising IBF suppression in tests with radioactive sources. While performance and operation of a TPC are considered feasible at energies at and above the Higgs production threshold, particular challenges arise, when the accelerators are tuned to the Z-pole. For these measurements very high luminosities are envisioned resulting in a high density of primary ions created by the ionization processes in the drift volume. A detailed simulation study is aimed for to understand the effect of these ions on the drift properties of the electrons. This study will also include the benefits of calibration to reduce the effects of possible field distortions and to find a suitable operation mode.

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