A Time Projection Chamber using Advanced Technology for the International Large Detector at the International Linear Collider

submitted by the LCTPC collaboration

Abstract

The excellent performance of the International Large Detector (ILD) and the International Linear Collider (ILC) requires the development of new detector technologies to fully exploit the physics potential. As a central tracking detector a time projection chamber with an MPGD-based readout is a very promising choice. The Linear Collider TPC (LCTPC) collaboration is working on designing such a detector taking into account the unique characteristics and requirements of experiments at a high energy e^+e^- -collider. Various readout technologies are being evaluated. Further participants to help with design and to bring in new ideas are welcome.

Introduction

The Time Projection Chamber (TPC) is an excellent detector concept featuring a number of properties, which make it an ideal central tracking detector. To name only the most important such properties are the low, evenly distributed material budget, the true 3D track imaging and the continuous tracking, which facilitates the track reconstruction. For example, even in very high multiplicity events of heavy ion experiments tracks can be reconstructed with extremely high efficiency and their particle identification using dE/dx.

The particular beam structure of the ILC with its long intervals between bunch trains allows for an optimal operation of a TPC including ion disk gating. But the stringent requirements on the performance of the TPC, in particular the momentum resolution, make it clear that the standard readout technology, multiwire proportional chambers, can not be applied.

Aims

Currently 25 institutes from 12 countries form the LCTPC collaboration including one group from the US and three groups from Canada. In addition, 8 US institutes have an observer status in the LCTPC collaboration.The aim is to develop a new readout of a TPC based on Micropattern Gaseous Detectors (MPGDs) optimized for operation at the ILC. The requirements are a momentum resolution of $\delta(1/p_t) < 10^{-4}$ $(GeV/c)^{-1}$ resulting in a transverse spatial resolution of each hit of better than 100 µm for standard pad sizes throughout the entire detector and an energy loss resolution of better than 5 % per track. To reach these goals different technologies are considered. The three baseline concepts include a multi-GEM readout, a bulk-Micromegas with a resistive layer for charge spreading on top of the readout pads, and GridPixes. The latter consist of a Micromegas-like gas amplification stage built by photolithographic postprocessing on top of a pixel readout ASIC. For all technologies a gating GEM is foreseen to reduce the ion backflow into the drift volume.

Setup

The LCTPC collaboration maintains a test setup at the DESY II test beam facility. The setup includes a magnet, which generates a B = 1.0 T solenoid field, a field cage with endplates, of which the anode can receive the readout modules, readout electronics, two phase CO_2 cooling unit, a cosmic ray trigger and an external reference tracking device. This common setup serves to compare different detector readouts under identical conditions and to address integration issues. Up to seven modules of currently foreseen ILD size can be tested at the same time with an electron test beam from the DESY II accelerator allowing to also compare different modules with small changes at the same time or test small scale production series.

Status and Recent Developments

The pad-based technologies with GEMs or Micromegas as gas amplification stages have proven to give very similar results, as well for transverse and longitudinal spatial resolution as for the energy loss resolution. Extrapolations to the ILC conditions, where the magnetic field is higher (B = 3.5-4.0 T) and the drift distance is longer (l_{max} = 2.25 m), show that the aforementioned requirements can be fulfilled. First results on the double track resolution show that depending on the algorithm the separation of less than 2 mm can be reached. First measures to reduce the drift field inhomogeneities between the modules have been successfully implemented.
The GridPix readout has demonstrated its scalability by producing three modules with a total of 160 GridPixes. A new production based on Timepix3-ASICs has shown an excellent performance as far as rate capability and point resolution are concerned. In a second production series several issues concerning alignment, field inhomogeneities and area coverage were significantly improved.
The gating GEMs have been produced by a commercial vendor and first tests have confirmed the performance suggested by simulations, including near-negligible impact on the overall performance.

Project Plans

The work plan has been divided into three phases. In a first phase the principle of an MPGD TPC has been studied with small prototypes, several ideas like MWPC readout could be ruled out and important measurements could confirm the performance of MPGDs also in high magnetic fields. In the second phase, which is still ongoing, the studies are being consolidated by studying increasingly advanced modules ending in a close to final design for the three baseline technologies. The three technologies will be tested at a common setup at DESY and at the end of phase two a technology decision will be made. In phase three, a final design of the readout modules will follow.
The next steps in the consolidation phase are the design of a common module where a large fraction of the module is identical for all technologies, including a gating GEM and readout electronics based on the SALTRO-16 ASIC. These modules should be produced in a small pre-series with as much standardized industrial processes as possible. The comparison of these results will then lead to the technology choice, which should be taken once the green light for the ILC project is given by the Japanese government.
Until such decision can be reached, a number of tasks are still remaining among which are full simulations of the TPC performance in the ILC environment, cooling, and design of the readout electronics.

Future MPGD Technology Challenges

The MPGD technology, though quite far advanced in some aspects, still needs a significant effort in others. For example, the performance in a high magnetic field (B = 4.0 T) needs confirmation for all performance parameters, the ion blocking of the gating GEM has to be verified and development of modern readout electronics. The efficient and precise construction of a large number of GridPixes and the analysis of the large amount of data they produce are still challenges to be solved.
Therefore, anyone interested in this project is sincerely invited to join the project and to stimulate further progress by new ideas.

Contacts A. Bellerive, U. Carleton; A. Sugiyama, U. Saga; J. Kaminski, U. Bonn.

Bibliography

International Linear Collider Technical Design Report:
vol. 4: *Detectors*, T. Behnke et al., arXiv:1306.6329 [physics.ins-det]

International Large Detector: Interim Design Report
T. Behnke, et al., arXiv:2003.01116[physics.ins-det]

Linear Collider Collaboration Detector R&D Report, M. Titov and J. Strube, eds.
URL: http://www.linearcollider.org/sites/linearcollider.web.cern.ch/files/LC-DetectorRD-LiaisonReport-v2018.3-17122018.pdf, to be updated soon at
http://www.linearcollider.org/physics-detectors/working-group-detector-rd-liaison

T. Behnke, et al., *A lightweight field cage for a large TPC prototype for the ILC*, Journal of Instrumentation, 5, 2010, P10011

M. S. Dixit, et al., *Position sensing from charge dispersion in micro-pattern gas detectors with a resistive anode*, Nucl. Instr. and Meth. A, Volume 518, 2004, Pages 721-727

D. Attié, et al., *A time projection chamber with GEM-based readout*, Nucl. Instr. and Mesth A, Volume 856, 2017, Pages 109-118

M. Lupberger, et al., *Toward the Pixel-TPC: Construction and Operation of a Large Area GridPix Detector*, IEEE Transaction on Nuclear Science, Vol. 64, No. 5, 2017

C. Ligtenberg, et al., *Performance of the GridPix detector quad*, Nucl. Instr. and Meth. A, Volume 956, 2020, 163331

D. Arai, et al., *Development of Gating Foils To Inhibit Ion Feedback Using FPC Production Techniques*, EPJ Web of Conferences 174, 2018, 02007