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GridPix: Development and Characterisation of a Gaseous Tracking Detector

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Summary

Particle Detection in High Energy Physics

The collision position in accelerators like LHC is surrounded by several layers of radiation detectors, which use a broad spectrum of technologies to extract information for collision reconstruction. For detectors close to the interaction point it is important to accurately measure traversing particles without disturbing their trajectory, in favour of measurements performed in subsequent detectors. Gaseous tracking detectors are perfectly suited for this.

Gaseous Tracking Detectors

Gaseous radiation detectors are used for reconstruction of charged particle trajectories. Interaction of the charged particles with the gas molecules results in a trail of ion-electron pairs in the gas. An electric field separates ions and electrons; ions drift to the cathode and electrons to the anode. Electrons approximately follow the field lines to an amplification area. By measuring the electron position on the anode, the particle track projection is measured. In addition the drift distance is known from the electron time of arrival on the anode and the electron drift velocity. With this the particle trajectory can be reconstructed in three dimensions

GridPix

The combination of photo-lithographic technology and high granularity pixel chips allow gaseous detectors to be made more efficient and more accurate than previous technologies. GridPix is a gaseous detector in R&D phase. The detectors can be distinguished by the high resolution pixel chip (256×256, with a 55 μm pitch) with a grid that is attached to the chip by insulating pillars, by photo-lithographic processes. Between the grid and the chip the field of about 100 kV/cm is sufficient to create amplification (figure 6.0.3). With such a high field there is a significant probability to create discharges between the grid and the chip, which can be lethal for the sensitive pixel electronics. Therefore the chip is covered by a slightly conductive layer to quench discharges before damage occurs.

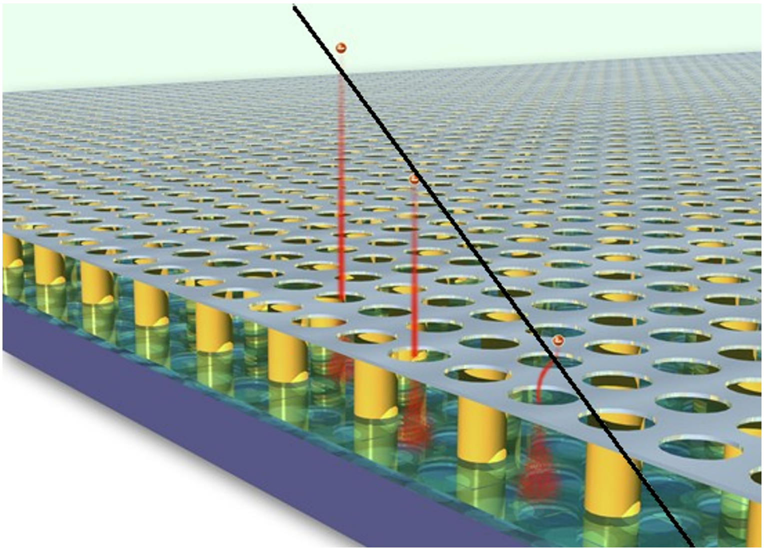

Figure 6.0.2: Illustration of the GridPix principle. The path of the traversing particle is indicated in black, the electrons and their drift path in red. Electrons drift towards the grid, after passing through the holes an amplification occurs, that is detected by the pixel.

The resolution in a plane parallel to the chip is limited by the pixel size and electron diffusion. Resolution in the drift direction is limited by the error in the time measurements. Current pixel chips have a large time-walk, dominating the drift direction resolution, but this will be fixed in future.

Results

In this thesis GridPix is characterised extensively. The contributions to the resolutions are studied in detail. A beam test with 180 GeV muons was made in 2012 using GridPixes with a 1.2 mm drift gap with Timepix-1 read out chips. The field cage was flushed with CO_2/DME (57:43). The detectors were oriented at about 45° to the beam. The in-plane track resolution was 10.1 μm; the resolution in the drift direction was 35 μm, dominated by high time-walk. The angular resolution was about 2.6 ° in one direction and 3.9° in the other direction, again limited by time-walk. The particle detection efficiency of GridPix for 180 GeV muons was

$> 99\%$. The probability on three or more ionisations from a traversing muon was about 97%, in these cases the path can be accurately determined.

A track fitting procedure has been developed which gives not only the track parameter and resolution, but also their error matrix. The procedure has been verified by studying residuals with a telescope of GridPix detectors.

An ultra violet laser has been used to produce single ionisations in GridPix, to measure gas properties and detector response. The distribution of the number of electrons participating in the amplification has been measured. The mean and fluctuations of this agrees with the results of electric field calculations combined with Monte-Carlo simulations. In addition measurements on drift velocities and diffusions in CO_2:DME (57:43) show good agreement with simulations.

Furthermore the effect of the drift field on the detector performance has been studied. These studies are performed using a recently developed electric field calculation method. In collaboration with the the developers the method is tested and optimised within the framework for gaseous detector simulations. Calculations on GridPix resulted in proposals for small changes in the GridPix geometry, to avoid discharges. Furthermore it is concluded that future GridPix detectors with improved time resolution should correct for time variations as results of field distortions. In addition a correction on the measurements from the edge pixels is required, due to small field distortions at the chip edge. The field-cage geometry of GridPix detectors with a 2 cm drifter is based on the results of electric field calculations.

Outlook

Future GridPix applications can be found in high energy physics and the medical industry. However the success of the applications depends on whether current challenges can be overcome; the discharge protection of current GridPixes is questionable. In the past it has been shown that GridPixes produced on small scale can be made reliable, however large scale production revealed several issues. Furthermore there are doubts about the long term influence of CO_2:DME (57:43) on the detectors; detailed studies on ageing are required. When these two challenges can be solved, GridPix might become of large value for science.