Single electron sensitive GridPix TPCs and their application in Dark Matter search and v-less Double Beta Decay Experiments

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Abstract. The industrial production of monolithic GridPix pixel chips for the digital readout of primary electrons in a TPC is under study at IZM-Fraunhofer, Berlin. With future low-cost chips, new applications are foreseen in TPCs for bi-phase Ar/Xe dark matter experiments, and for v-less double beta decay experiments.

1. Introduction and status of the GridPix TPC

With the GridPix detector [1], each MPGD hole is read out individually by the circuitry in a pixel of a CMOS chip (see fig.1). For this, we applied the Timepix chip [2]. Since the source capacity at the pixel preamp input can be as low as 10 fF, the pixel circuitry is sensitive to avalanches initiated by one single electron. Therefore, if the granularity is sufficient, the GridPix device detects each individual electron liberated in the ionization process in the gaseous (drift) volume.

With ‘Micro Electro Mechanical Systems’ MEMS technology, we constructed a Micromegas onto the pixel chip, forming the integrated grid ‘InGrid’ [3]. This guarantees perfect alignment of the grid holes with the pixel input pads, and a constant avalanche gap thickness. The insulating support pillars could be made narrow such that they could be positioned between active pixel input pads, eliminating dead regions. With a GridPix detector, in which InGrid is combined with a time-resolved pixel readout, all the information of all individual primary electrons, due to ionisation radiation, can be collected. Diffusion in the gas during the drift of the electrons is the only limit on the intrinsic information (see fig.2).

The ‘Micro Electro Mechanical Systems’ (MEMS) technology, developed at MESA+ at the University of Twente, for producing the protection layer and InGrid, is being transferred to IZM-Fraunhofer in Berlin. Once this transfer is complete, wafers with pixel chips are expected to be processed commercially, at acceptable costs.
Figure 1. The GridPix detector. Electrons from the drift volume initiate an electron avalanche in the gap between the pixel chip and the grid.

Figure 2. Two β’s from a 90Sr source, recorded with a Timepix based GridPix detector. Drift length: 30 mm. Gas: He/i-butane 80/20, with a magnetic field of 0.2 T oriented parallel to the (vertical) drift field. The bottom plane represents the Timepix chip (256 x 256 pixels; square pixel pitch 55 µm), fiducial surface 14 mm x 14 mm.
2. **Applications in Dark Matter and Double Beta decay experiments**

Operating Micro Pattern Gas Detectors (MPGD) in pure and cold Ar gas has been successfully demonstrated [4]. The readout sensors of bi-phase xenon or argon based WIMP search experiments are usually photomultipliers, registering the photons due to ionization and scintillation. We are studying the possibility of replacing the top array of photomultipliers with GridPix detectors. Here, the grids are facing downwards, positioned in the gas phase (see fig.3). With a sufficiently strong drift field, primary electrons, created by an ionizing event in the liquid, are drifting upwards, crossing the phase transition, and continue drifting in the gas. A GridPix detector can individually detect these electrons. Events with 1, 2, or n electrons, generated in a small volume by a WIMP event, could be identified. If the pixel chip is placed some 50 µm above the liquid surface plane, then the InGrid could be omitted if cohesion does not bring the liquid in contact with the pixel chip: gas amplification would occur in the gap between the liquid and the pixel chip. If the grid of the GridPix detector is made sensitive for photons (CsI grid, see above), then the photons created in WIMP events would also be recorded in the gaseous GridPix detector.

GridPix TPCs could be well employed in neutrinoless double-beta decay experiments: see fig.4.

![Figure 3. A WIMP search experiment with GridPix as single electron detector, located in the gaseous top section [5].](image)
3. Other applications

With a GridPix (or thin gas layer Gossip) detector, a track vector is measured, whereas Si trackers measure a track point in space. This is relevant for future tracking detectors in particle physics experiments where Si pixel and Si strip tracking detectors could be replaced by rad-hard Gossip detectors. In the upgraded sLHC experiments, level-1 triggers consisting of bi-Si layers are being considered, measuring the track momentum from the local track angle. The problematic intercommunication between these two layers is not required for a GridPix miniPC where the projected track length (see fig. 5) is a direct measure for the track momentum and particle charge sign [6].

Fig. 6 shows an image from a Gridpix detector, equipped with a quartz window, irradiated with UV light from a low-pressure deuterium arc lamp. The image is the difference between a clean window and a window with fingerprint. The efficiency of this photon detector is improved by the deposition of a CsI layer on top of the aluminium grid, reaching the theoretical maximum [7].

With the time-resolved Timepix chip, GridPix detectors provide 3D images of the primary ionization in the drift gap (see fig.7). Using this information, the origin, and the initial direction and the energy of the electron created in the interaction of a photon with the gas, can be measured. The polarization of photons can be measured to a standard that is relevant for astro particle physics. An experiment to test GridPix (‘PolaPix’) in a beam of polarised photos at the University of Erlangen-Nürnberg is in preparation [8].
Figure 5. Response of tilted GridPix detector to a 5 GeV electron, viewing the projected track. Note the diffusion of the drifting primary electrons, largest for the largest drift length (20 mm). A transition radiator was placed in front of the detector; the TR-quantas are clearly visible. The projected track length is a direct measure for the angle between the detector plane and the track. With a known attitude of the detector, the track angle can be obtained in a rapid way, and therefore the particles’ momentum.

Figure 6 Image of Martin Fransen’s right-hand index fingerprint.
Figure 7. Image of GridPix TPC irradiated with 10 – 50 keV X-ray quanta. By a reconstruction of the path of the photo electron, information concerning the position, direction, and the energy of the incident photon can be obtained. From a group of photons, their degree of polarization can be measured.

4. Infrastructure: a new gas system, the ReLaXd DAQ system and miniHV

A new generation of miniTPCs requires new gas systems, and new safety rules. The quantity of flammable gas is often very small, and the applied mixtures are often below certain levels of flammability. At Nikhef, a gas mixing station has been made, providing 12 liter light-weight bottles containing up to 20 bars of pre-mix gas. By controlling and monitoring the bottle pressure, the gas flow out of the bottle, and the gas flow at the detector’ exhaust, the intrinsic leak rate of the complete system can be measured. This system is easy to use, but the existing safety rules need to be reviewed.

With the ReLaXd DAQ systems, a set of Medipix and TimePix chips can be read out. A ReLaXd board has dimensions of 46 mm x 90 mm, and has Ethernet as communication/data output [9].

For GridPix detectors, HV supplies are required for the grid, the cathode and the guard. The current is usually less than 1 µA. Commercial supplies are expensive, voluminous and can deliver much more current, which is only a disadvantage: there is less risk of damage if the maximum power is limited intrinsically. In addition, for our applications in MPGDs, fast and high-resolution monitoring of the actual current is relevant for guarding the health of the detector, and for counting discharges. For GEM detectors, a larger number of these low-cost HV channels is needed.

We have developed a miniature Cockroft-Walton circuit with its input supply and monitoring/control connected to the bottom stage only. In future versions, the volume of this supply will be reduced to a few cubic centimeters. In another development, the resistor chain of the field-shaping electrodes of TPCs is replaced by a chain of diodes and capacitors forming the local Cockroft-Walton chain.
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