GridPix as a candidate for the future of CAST

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Abstract. A central part of the CAST upgrade program is the further reduction of the background rates and the extension of the experiment's sensitivity to lower energies. Both aims could be reached with a highly pixelized readout of the detector as, for example, with an InGrid, the combination of a Timepix ASIC and a Micromegas grid. The high granularity and efficiency of such a device make it possible to detect and to distinguish single primary electrons. Therefore, we have studied the energy resolution by electron counting and the separation of photon events from tracks with an event shape analysis.

1. Introduction
The CAST experiment [1] searches for axions and other axion-like particles emitted by the sun. The axions are supposed to convert in the strong magnetic field of CAST into X-ray photons and can then be recorded by X-ray detectors. To improve the current limits and to also allow the search for other particles such as chameleons [2], both the background rates must be further reduced (see also [3]) and the threshold of the energy spectrum must be lowered. The background signals consist mostly of tracks from radioactive decays and from cosmic rays. To suppress these events, detector materials with low intrinsic radioactivity have to be chosen and the detectors have to be well shielded. Besides, a reliable separation of photon and background signals has to be ensured in the off-line analysis on an event-by-event basis. If the events are recorded with a very high granularity, an event shape analysis is a promising approach to distinguish signals from background. We have, therefore, constructed a test detector read out with an InGrid [4], which is a combination of a Timepix ASIC [5] and a Micromegas gas amplification stage [6]. Measurements both with a ^{55}Fe-source and without have demonstrated a high energy resolution and a powerful background suppression. Because of the limited geometrical size, this detector is a good candidate for an X-ray detector behind an X-ray telescope at CAST.

2. InGrid detector
The cylindrical detector has a drift length of 2 cm and an inner diameter of 8 cm. Most of the components are made of aluminum and HV insulation has been done with Kapton®. The cathode features a 1 mm^2 entrance window for X-rays, which is covered with a 50 µm thin Kapton window. The anode has an opening where the InGrid is mounted (see figure 1). This device uses the Timpix ASIC both as a readout plane, where the bump bond pads of the chip are used as charge collection pads, and as a digitization chip. For protection of the chip's circuitry the readout area is covered with a resistive layer of Si_XN_Y [7]. Besides, a Micromegas mesh is mounted on the chip with post-processing techniques, which ensure a very precise fabrication and alignment of the grid holes with the pads of the Timepix ASIC. Thus, both the grid holes

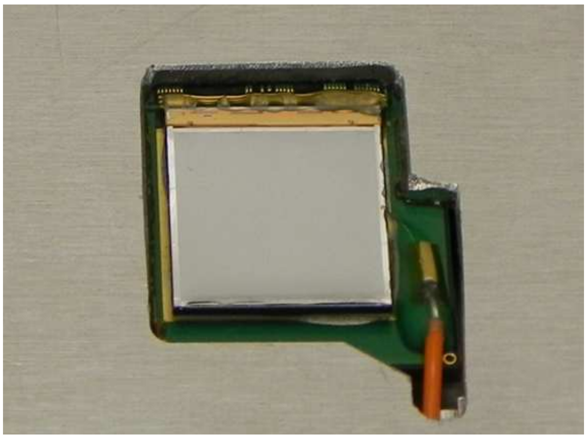

Figure 1. InGrid mounted in the anode of the detector.

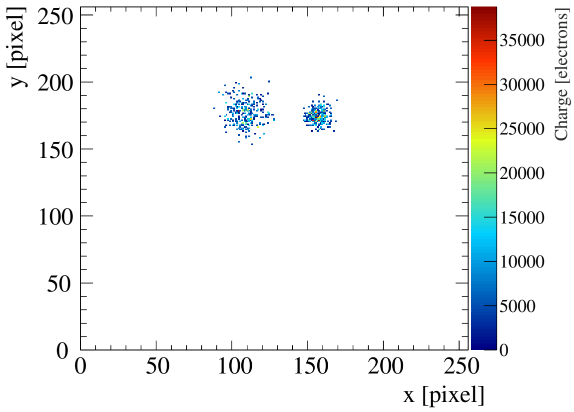

Figure 2. Conversion of two X-ray photons at different drift distances.

and the pads have a pitch of 55×55 μm^2 and cover an area of about 2 cm^2. The Timepix ASIC was controlled and read out by the MUROS 2.1 [8] and the Pixelman software [9].

During data taking, the detector was flushed with a gas mixture of argon:isobutane (95:5) and the gas pressure was kept at a few mbar above atmospheric pressure. An electric field of 225 V/cm was applied between the cathode and the anode and the voltage on the grid was varied from 290 V up to 400 V.

3. Detector performance

For testing the detector's performance, a ^{55}Fe source was placed on the detector and a chromium foil was used to suppress the 6.1 keV line of the source. Figure 2 shows an example event, where two X-ray photons converted at different drift distances. The energy of the converted photon can be extracted by either summing up the charge of all pixels associated with one photon or by simply counting the number of activated pixels, which corresponds to counting the number of primary electrons. If the diffusion is high enough for spreading the charge sufficiently, the second approach gives a better energy resolution. For a grid voltage of 350 V an energy resolution of $\sigma_E/E = (5.23 \pm 0.03)$ % was measured.

In Figure 3 a background track is shown passing through the detector. The track width reveals that the lower left end passed through the cathode and the upper right end passed through the InGrid. To distinguish tracks and X-ray conversions all events are reconstructed twice: Once with the hypothesis of being a photon event, and the second time with the hypothesis of being a track. In both cases characteristic geometric parameters are calculated. For example, in the track analysis the number of hits per track length, kurtosis and eccentricity along the long axis and the track length are determined. The distribution of these parameters have also been calculated for a pure data sample of photon events and background events (see track length distribution in figure 4). During the analysis the value for each event is compared to the two sample distributions and a likelihood ratio is used for the final decision to accept the event as a photon or to discard it as a track. The resulting discrimination power depends of course on the cut value of the likelihood parameter, but for an efficiency of (95.3 ± 0.3) % for 5.9 keV X-ray photons and a track mis-acceptance rate of (1.1 ± 0.6) % the background could be suppressed by a factor of about 120. More details of the analysis are described in reference [10].

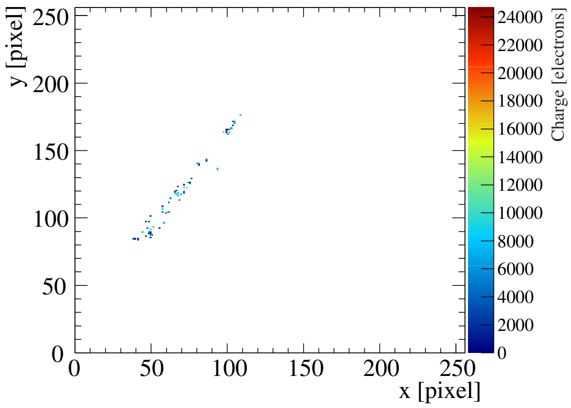

Figure 3. Track of a cosmics ray traversing the complete drift length of the detector.

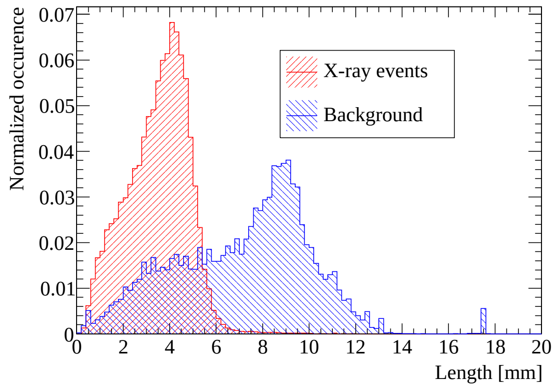

Figure 4. Distribution of the track length for both an X-ray photon data sample and a background data sample.

4. Further plans

Several detector components have been rebuilt from more radiopure materials like acrylic glass. Currently, studies on entrance windows with very low material budget are ongoing and in the close future also the signal shall be decoupled from the grid. The time structure of this signal will be used as an additional parameter in the likelihood to improve the separation power for tracks that enter the detector in a steep angle with respect to the read out.

Since the production of the InGrids at the University of Twente was limited to a small number per production cycle, a new process has been established at the Fraunhofer Institute IZM at Berlin, where a wafer-based production yields up to 100 InGrids per production cycle. The third batch has been delivered in the fall of 2012 and first tests confirm that the grids are of very high quality. A picture taken with an optical microscope is shown in figure 5. Tests with an ^{55}Fe

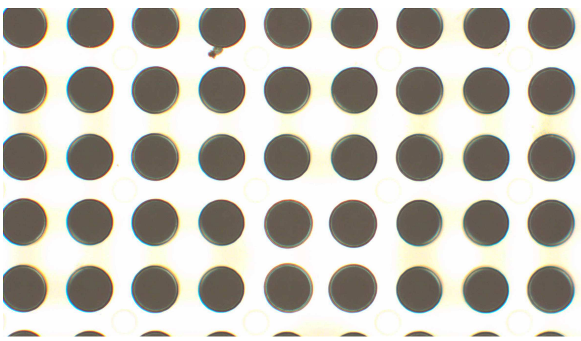

Figure 5. Close up view of InGrid.

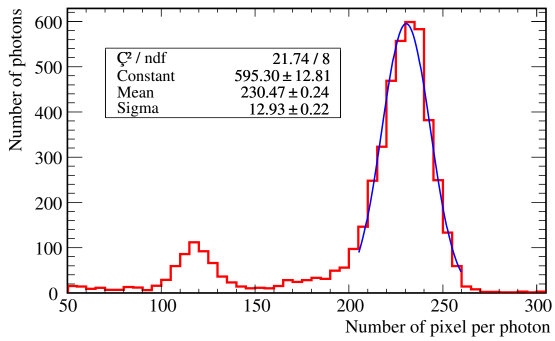

Figure 6. Energy spectrum of an ^{55}Fe source.

source demonstrate a very good behavior for a wide range of gas amplification (grid voltages of 290 V to 400 V). An energy spectrum for a grid voltage of 350 V is shown in figure 6, which gives an energy resolution of $\sigma_E/E = (5.6 \pm 0.1)$ %. For higher voltage settings thousands of discharges were observed, but most chips were not affected.

Finally, also a new readout system for the Timepix ASIC is designed at the University of Bonn. It is based on the Scalable Readout System [11] of the RD51-collaboration and because of its open source approach will facilitate the implementation of additional features such as the aforementioned grid signal processing.

5. Acknowledgments

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