

An InGrid based Low Energy X-ray Detector

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An X-ray detector based on the combination of an integrated Micromegas stage with a pixel chip has been built in order to be installed at the **CERN Axion Solar Telescope**. Due to its high granularity and spatial resolution this detector allows for a topological background suppression along with a detection threshold below 1 keV.

Tests at the CAST Detector Lab show the detector's ability to detect X-ray photons down to an energy as low as 277 eV. The first background data taken after the installation at the CAST experiment underline the detector's performance with an average background rate of 5×10^{-5} /keV/cm²/s between 2 and 10 keV when using a lead shielding.

1 InGrid - An integrated Micromegas stage

To enhance the performance of Micromegas detectors, it is necessary to match the granularity of the readout to the highly granular gas amplification stage. Taking into account the rising number of readout channels per area when following this approach, a pad based readout is impractical. This drawback can be bypassed by using integrated electronics in form of a pixel chip, e.g. the Timepix ASIC [1]. This pixel chip offers 256×256 pixels with a pixel pitch of $55 \mu\text{m}$ and thus an active area of 2cm^2 . Each of the pixels contains a charge sensitive amplifier and a discriminator plus complete counting logic needed for time or charge measurements.

In order to achieve a precise alignment between the mesh holes and the pixels, to avoid the appearance of Moiré patterns, it is suitable to produce the Micromegas mesh directly on top of the pixel chip by means of photolithographic postprocessing technologies [2, 3]. A scanning electron microscope picture of the resulting structure can be seen in Figure 1a. When building such an **Integrated Grid** on top of a Timepix ASIC a resistive layer made of $4 \mu\text{m}$ silicon nitride is deposited between ASIC and InGrid to protect the chip and its electronics from discharges occurring during operation of the Micromegas stage [4].

2 The InGrid based X-ray Detector

The InGrid based X-ray detector constructed at Bonn uses a Timepix ASIC with an InGrid stage as central charge multiplication and readout device. The design of the detector (see Figure 1c for an exploded view) has been based on the recent Micromegas detectors [5] used at the Sunset stations of the **CERN Axion Solar Telescope** [6]. The detector body is made of acrylic glass and contains the modular readout assembly which houses the Timepix ASIC, with

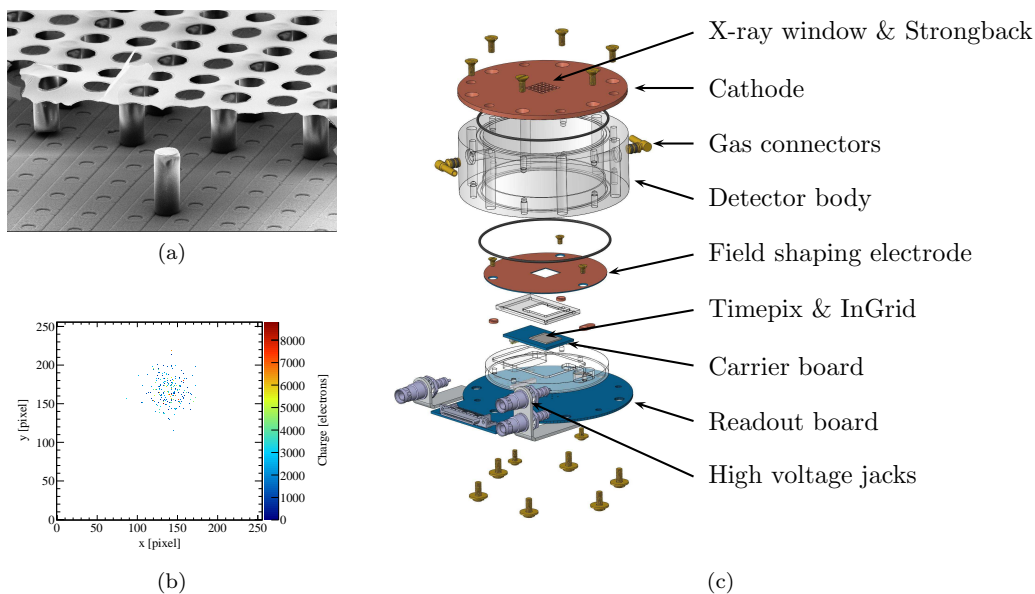


Figure 1: Scanning electron microscope picture of an InGrid structure (a), taken from [7]. Event display showing an X-ray photon of 5.9 keV from an ^{55}Fe source as recorded with the InGrid based X-ray detector (b), depicted area shows the complete active area of the Timepix ASIC. Z-axis shows the charge collected on each pixel. An exploded view of the detector, with main parts labeled, is shown in (c). Drawing is taken from [8].

the InGrid stage, mounted on a small carrier board. The chip is covered by a field shaping electrode, closing the readout assembly. The electrode features a cutout matching the size of the chip's active area and is leveled a bit above the mesh of the InGrid structure and set to the electric potential according to its position within the drift field. This helps to reduce electric field distortions arising at the chip's borders and the wire bonds connecting the chip's electronics to the underlying carrier board.

The drift volume featuring a drift distance of 3 cm at a drift field of 500 V/cm is closed by a cathode plate made of copper. To allow especially low energy X-ray photons to enter the detector, a 2 μm thick aluminized Mylar film is used as entrance window. The material of the cathode plate above the instrumented area of the detector has therefore been removed except for a small grid like structure to support the thin window. The support for the window is necessary as it has to withstand a pressure difference of 1050 mbar. Additionally only a small leak rate is allowed so the detector can be operated connected to vacuum. Considering these requirements the choice of a 2 μm Mylar film represents a good compromise between robustness and transparency.

Readout of the Timepix ASIC is done with an FPGA based readout system developed at Bonn [7] which allows for full access to firm- and software for customization. The detector is filled with a gas mixture composed of 97.7% Argon and 2.3% isobutane as quencher gas.

The detection of X-rays with this detector is based on the fact that X-rays entering the detector will hit a gas atom and produce a bunch of primary electrons through ionization.

These will drift towards the readout. The initial bunch of electrons is spread to a cloud of approximately circular shape due to diffusion. Then they get multiplied in the InGrid stage and are afterwards detected on the Timepix's pixels. This allows for a low X-ray energy threshold along with a topological background suppression by application of an event shape analysis. A typical X-ray event recorded with the detector is depicted in Figure 1b.

3 Installation & first background rates

To replace the pnCCD detector behind the X-ray telescope [9] at one of the four detector stations of CAST, a vacuum system has been constructed and built which allows for differential pumping and provides the necessary safety interlocks. For the differential pumping a 0.9 μm thick Mylar window is used. In April and May of 2014 the vacuum system and the InGrid based detector were installed including a laser guided alignment with the X-ray telescope. A lead shielding designed and manufactured by our colleagues from the University of Zaragoza was added mid of May. In two months of operation no detector related problems occurred.

Prior to the installation, the detector was characterized at the X-ray generator of the CAST Detector Lab which provides a complete vacuum beamline connected to the X-ray generator [10]. With the appropriate combination of targets of the X-ray tube and filters, characteristic X-ray lines can be produced in the energy range from a few hundred eV up to 8 keV. Additionally the lab provides the necessary infrastructure for operating Micromegas detectors. The lab tests underlined the detector's low energy threshold through successful detection of photons down to the Carbon K_α line at 277 eV (see Figure 2a for the spectrum containing the Carbon K_α line).

To achieve a low background rate a background discrimination routine was created, based on a likelihood algorithm and reference data sets for different energy ranges recorded during the tests in the CAST Detector Lab. The applied likelihood method utilizes event shape properties making benefit of the Timepix ASIC's high spatial resolution resulting in a topological background suppression to identify real X-ray photons in the recorded data. The energy of a recorded event is calculated via a calibration curve from the total charge of an event. To built the likelihood, event shape properties of this event are being compared to the corresponding distributions for events of similar energy. These sample distributions are obtained from the lab tests' data. The likelihood cut value is adjusted for each energy range so that a signal efficiency of roughly 90 % is kept over all energies. The background rates achieved during first operation period were in the order of a few 10^{-5} /keV/cm²/s, occurring peaks could be explained by the characteristic fluorescence line of the copper cathode and misidentified cosmic rays traversing the detector perpendicular to the chip and therefore resulting in an X-ray like, circular, structure.

4 Summary

A gaseous detector based on the combination of a pixel chip and an integrated Micromegas stage has been successfully built and commissioned. The detector was installed at the CAST experiment along with its infrastructure and has up to now been successfully operated. First background rates achieved in the CAST environment look promising and are in agreement with the results obtained with a first prototype in the lab at Bonn [11]. Together with the measurements carried out at an X-ray generator facility which provided proof of the detector's low

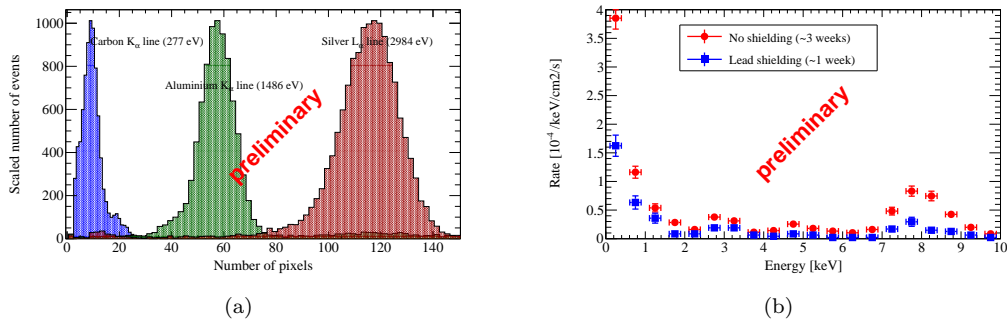


Figure 2: Spectrum showing the Carbon K_{α} line at 277 eV together with the Aluminum K_{α} and the Silver L_{α} line at 1486 eV and 2984 eV respectively (a). Lines have been recorded separately. Number of pixels corresponds to the number of electrons in the charge cloud created by the initial X-ray photon which is proportional to the photon’s energy. First background spectra obtained with and without lead shielding in the CAST environment (b).

energy detection threshold of a few hundred eV, the detector’s performance could be underlined and demonstrated.

Further improvement to the background discrimination algorithm will be done as well as future detector upgrades, which should include a decoupling and recording of the signal induced on the mesh, as it is done for the CAST Micromegas detectors. The latter one should give access to further event properties to be utilized for background suppression.

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