Design and Performance of the CdZnTe VFG Imaging Calorimeter Prototype for Gamma-ray Astronomy

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***Abstract.* We present the design and first results of the CdZnTe Imaging calorimeter prototype. The CdZnTe Imaging calorimeter has been designed for use in large astrophysical gamma-ray space instruments, and we report here on a small prototype built to validate the approach. The calorimeter is based on virtual Frisch-grid drift-bar CdZnTe detectors. The design is modular, such that multiple crates of 16 bars, each served by a single ASIC, can be arranged into different configurations depending on the specific requirements for an instrument. The modules are plugged into the readout motherboard in the designed configuration for a given instrument. The detectors are capable of measuring the interaction point of an incident photon in three dimensions and the energy deposited. In this work, we have designed and built a prototype consisting of 4 by 4 module array and have tested it with various radioactive sources to measure its position and energy resolution. The preliminary results demonstrate ~1% FWHM energy resolution and 1-2 mm position resolution for 662 keV photons (Cs^{137}), subject to the further improvement by applying various corrections. We tested the module with a "conventional" analog ASIC readout as well as a wave-front sampling ASIC to compare the results, which is critical for the optimization of the future instrument.**

***Keywords* - gamma-ray telescope, CdZnTe virtual Frisch-grid detector, position-sensitive imaging calorimeter**

I. INTRODUCTION

The largely unexplored MeV energy range in g-ray astronomy offers great potential for discovery, including aspects of nucleosynthesis, multimessenger observations of gravitational wave sources, astrophysical jets, and compact objects. The measurements of photons at MeV energies are challenging, not only because the interaction cross-section exhibits a minimum at these energies, but also due to the specifics of photon detection via two competing processes: Compton scattering and pair production. These two interaction processes require different approaches in both detection and data analysis, and consequently in the instrument concept. A key element for such measurements is a position sensitive detector with good energy resolution and high detection efficiency. We are developing a CdZnTe Imaging Calorimeter (hereafter ImCal), which can be used in a wide range of MeV g-ray telescopes, as a stand-alone Compton telescope, or as a focal plane for high spatial resolution imaging instruments. It is based on position-sensitive virtual Frisch-grid drift-bar CdZnTe detectors recently developed at Brookhaven National Laboratory [1,2]. We are planning to use ImCal in AMEGO (All-Sky Medium Energy Gamma-ray Observatory) [3], a NASA Probe-class mission concept under development, and also in GECCO (Galactic Explorer with a Coded Mask Compton Telescope). In the latter, the ImCal will serve as a stand-alone Compton telescope and as a Coded-Aperture Mask focal plane with high spatial resolution. The performance requirements for the ImCal include sensitivity in the energy range 0.2-20 MeV, energy resolution <1% at 1 MeV, and position resolution 1-2mm at 1 MeV. The ImCal has a modular structure to allow for mechanical arrangement in different instrument geometry.

II. IMAGING CALORIMETER DESIGN

The base element of the calorimeter is a module made of 16 CdZnTe bars, arranged in a 4x4 bar array. Bars currently being tested are 6 x 6 x 20mm^3, which makes the module dimension approximately 3 x 3 x 3 cm^3. The module is read out by a single low-noise Application-Specific Integrated Circuit (ASIC). The modules are plugged into the motherboard tightly to each other, making a compact with practically no "dead" space. The motherboard is connected with the controller board, which carries the Amplitude-Digital

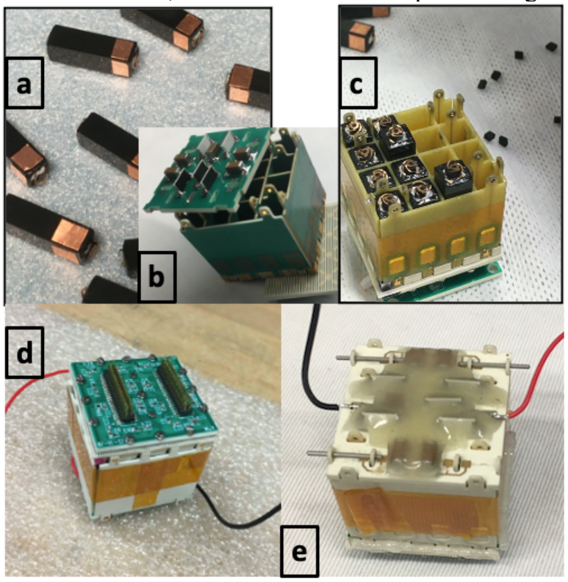

Figure 1. Module components: a – CdZnTe bars with sensitive pads attached; b – open module with HV cathode board; c – module partially filled with the bars; d – assembled module from the ASIC (anode) side; e – fully ready module, shown from the HV side

Converters (ADC), Field-Programmable Gate Array (FPGA) and auxiliary electronics. FPGA firmware provides the ASIC control and readout, performs initial data formatting, and communicates with the computer to transfer the data.

The module is designed as an egg-crate to provide good protection of very fragile CdZnTe detectors against the space launch loads (fig.1). It is made of FR-4 with electrical signals routed inside the walls. The bars are encapsulated, tightly packaged, and inserted in the module enclosure. The electrical contacts between the bar's anode, cathode, and sensitive side pads with the module are provided by the specially designed springs. The ASIC is attached to the bottom of the crate (the anode board) through a SAMTEC connector. The cathode board has circuitry

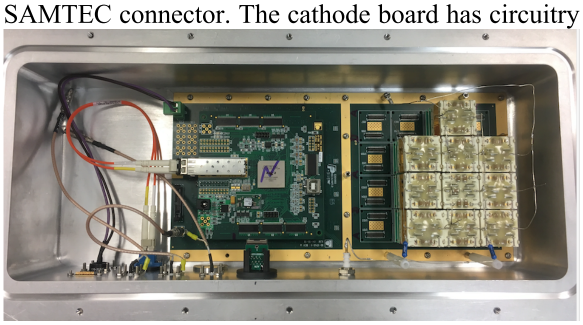

Figure 2. Prototype assembled in the enclosure. Right: Detector modules (10 modules are shown). Left: Control board.

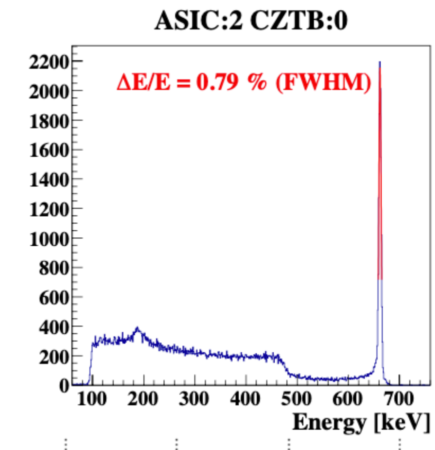

Figure 3. Spectrum from Cs^{137}

to route the high-voltage to the bar's cathodes and to de-couple and route the cathode signals down to the ASIC board. The module is secured to the motherboard through an aluminum spacer.

III. PRELIMINARY RESULTS AND CONCLUSIONS

We assembled the ImCal prototype (Fig.2), consisting of 16 modules and tested them with different radioactive sources to validate the energy and position resolution of the system. We tested the prototype with the AVG2 ASIC and with a wave-front sampling readout system provided by IDEAS. The preliminary results meet the requirements (Fig.3) for the energy resolution, and further testing and analysis are underway to determine the position resolution and will be presented at the conference.

As a next step, we are planning to have a beam test to measure the prototype performance at higher energies where the Compton-scattering and pair-production events will be detected. We will analyse the prototype performance as a stand-alone Compton telescope. Ultimately, this prototype will be integrated with the ComPair instrument [4], which is the prototype for AMEGO.

IV. REFERENCES

[1] A.E. Bolotnikov et al., "Use of high-granularity position sensing to correct response non-uniformities of CdZnTe detectors", *Appl. Phys. Lett. 104, p.263503, 2014*

[2] A.E. Bolotnikov et al., "CdZnTe Position-sensitive Drift Detectors with Thicknesses Up to 5 cm", *Appl. Phys. Lett. 108, p.093504, 2016*

[3] A.A. Moiseev, for the AMEGO Collaboration, "All-Sky Medium-Energy Gamma-ray Observatory (AMEGO*)", in Proceedings of 36th ICRC*, Madison, 2019, PoS(ICRC2019)583

[4] A.A. Moiseev, A. A., et al, Compton-Pair Production Space Telescope (ComPair) for MeV Gamma-ray Astronomy, *arXiv:1508.07349, 18 Sep, 2015*