Design of Large Dynamic Range Readout Electronics for the Prototype Calorimeter of VLAST

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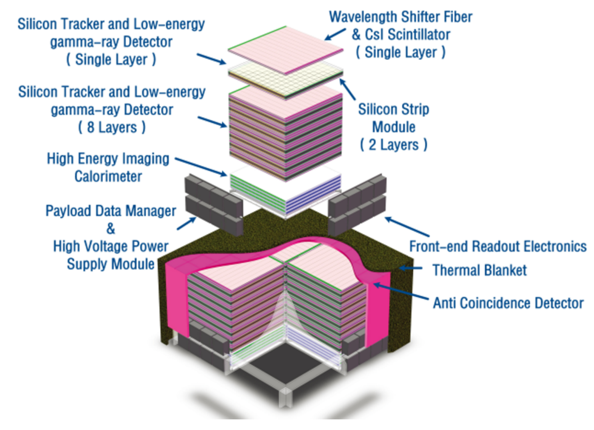
Introduction

- The Very Large Area gamma-ray Space Telescope (VLAST) is a high-energy detection satellite aiming at conducting high-energy resolution spatial observations of gamma rays with unprecedented acceptance.
- The High-Energy Imaging Calorimeter (HEIC) is used to measure the energy deposited by incident particles and to identify particles.
- The prototype calorimeter is vertically composed of four layers, each consisting of 25 BGO (Bismuth Germanate Oxide) crystal.
- A small-scale HEIC readout electronics system was designed, which uses the APDs and readout electronics with different gains to realize a large dynamic range (0.1 MIPs to 2.5×10^5 MIPs).
- It provides a technical reference for future research on the VLAST Calorimeter.



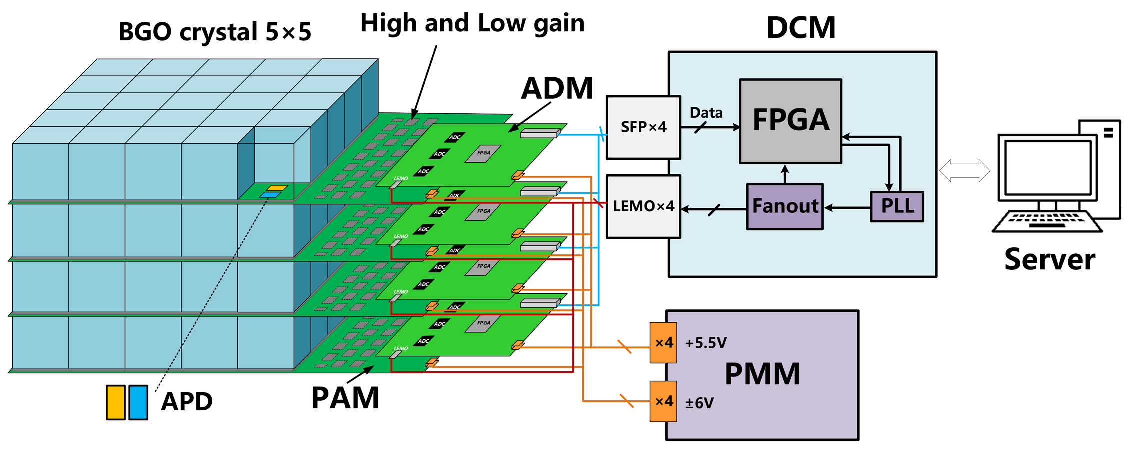
Electronics Design

Overall Design

The prototype calorimeter is composed of four layers, each consisting of 25 BGO (Bismuth Germanate Oxide) crystal units. Two Avalanche photodiodes (APD) are used for photoelectric conversion.

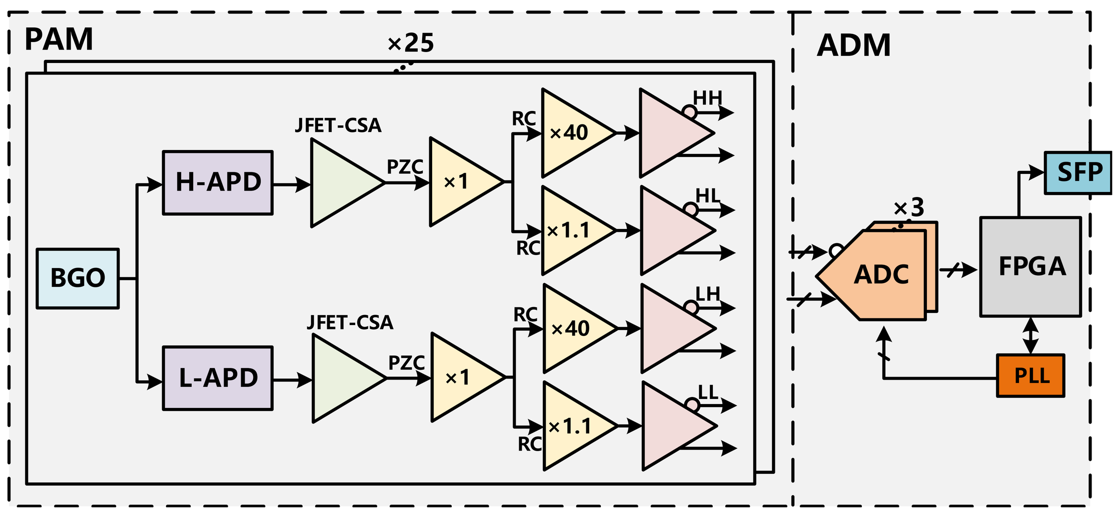
The whole system includes following parts:

- FEE(Front-End Electronics): Pre-amplification and digitization of APD signals.
- DCM(Data Concentrator Module): Distribute clock and command to each FEE, Gather data and send to server.
- PMM(Power Management Module)



Front-End Electronics

The FEE is composed of a Pre-Amplifier Module (PAM) and an Analog-to-Digital Module (ADM). The signal output of CSA is divided into high and low gain channels after a Pole-Zero Cancellation (PZC) and a follower. The data from three sets of 32 channels, 40 MSPS, 12-bit ADCs is received by FPGA. The temperature monitor is placed next to the APD to detect its working temperature. The calibration system is used for generating the calibration pulse signal with different charges to calibrate each channel. The miniature high voltage module is used to provide the bias voltage to the APD.

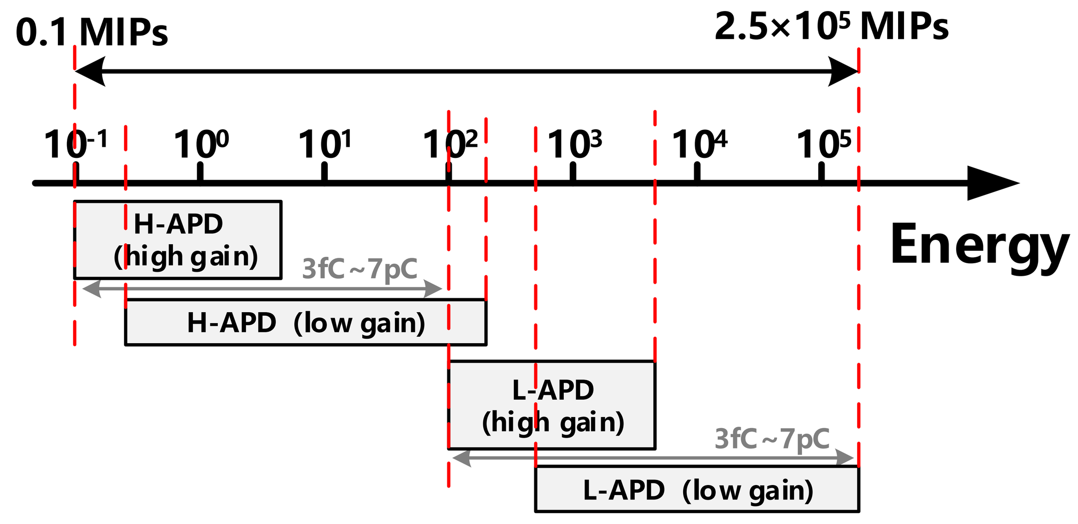


Large Dynamic Range

The gain ratio between high-gain channel and low-gain channel for an APD is about 36 times.

For an APD, the readout electronic dynamic range can reach from 3 fC to 7 pC.

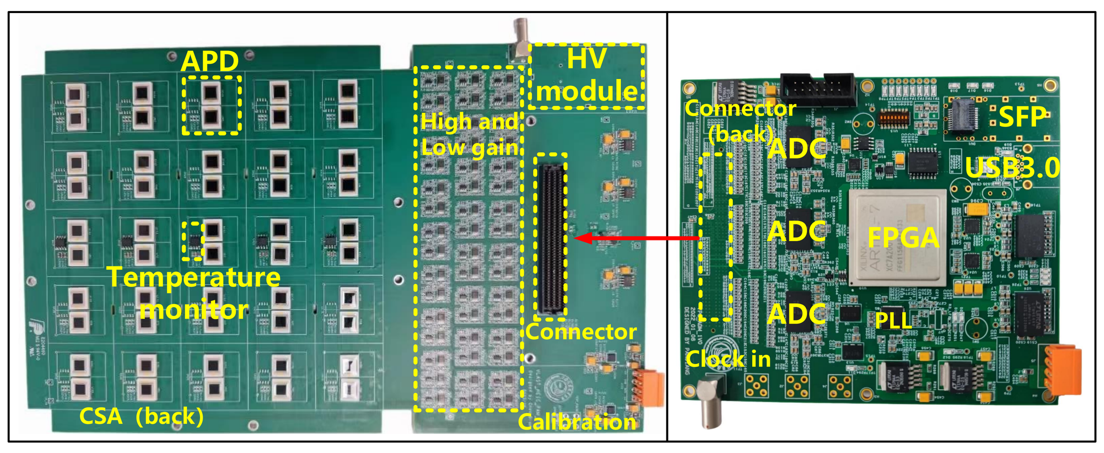
The signal from an APD is about 30 fC for a single MIP energy deposition. Adding a light attenuator to another APD attenuates the light by about 30 times. The four different gain channels can over from 0.1 MIPs to 2.5×10^5 MIPs.



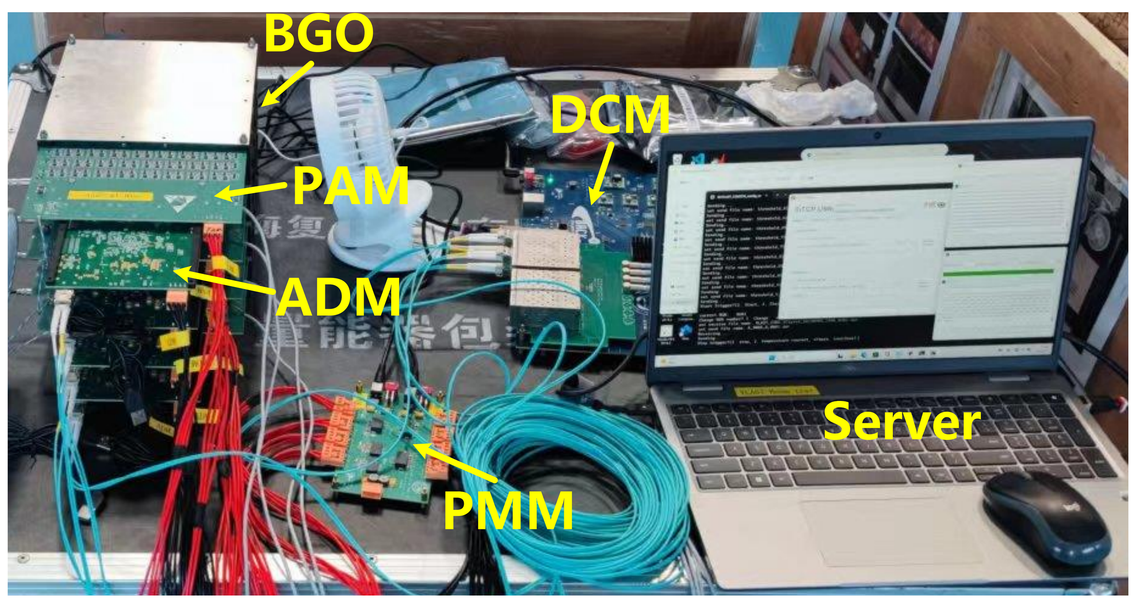
Performance Test

Experimental Setup

An ADM and a PAM form an FEE through FMC connectors, used for the readout of a layer of BGO calorimeter.

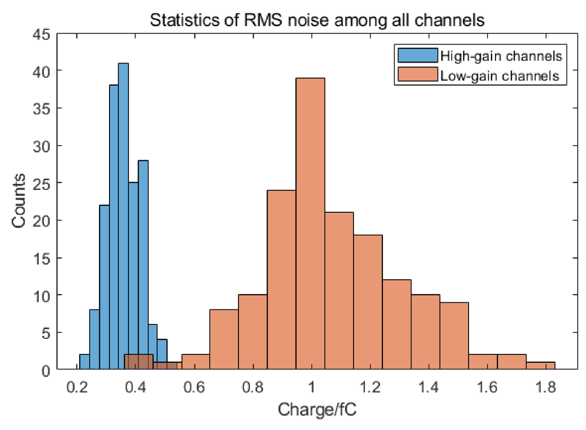


Measuring cosmic rays using a self-triggering mode: When a crystal within the calorimeter is hit by a cosmic-ray, ADM sends a hit signal to the DCM. Then the DCM issues a trigger signal to receive the waveform or amplitude data of the current event.

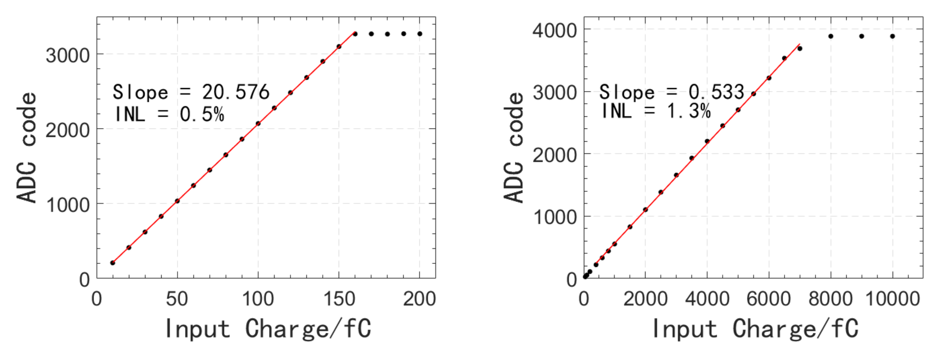


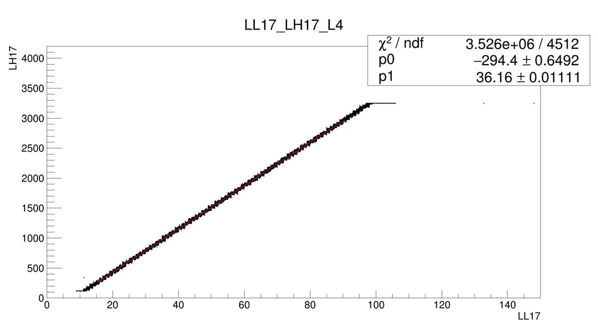
Test Result

The RMS noise of high-gain channels is below 0.6 fC, equivalent to 0.023 MIPs.

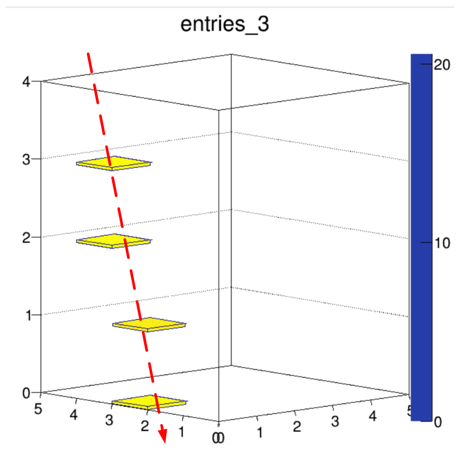


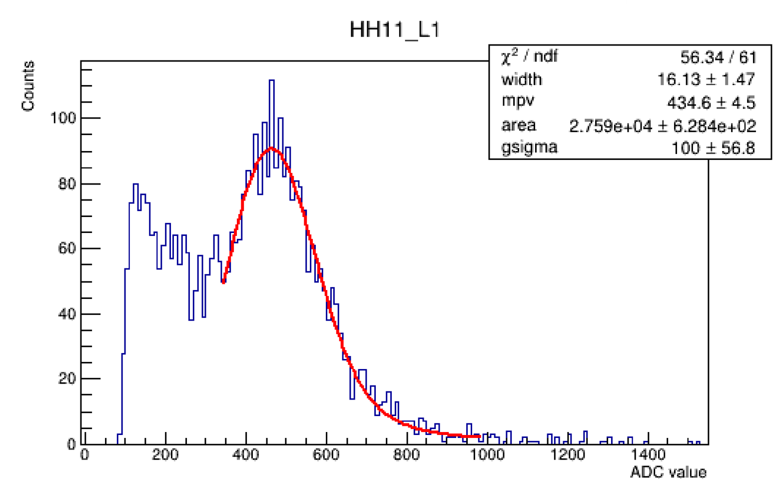
The linear range for the high-gain channel is from 3 fC to 150 fC(left figure), and the linear range for the low gain channel is from 10 fC to 7 pC(right figure). The overlap between the high and low gain channels has a good linear relationship, with a gain ratio of 36 times(bottom figure).





The prototype calorimeter was tested for 12 hours using cosmic-ray muon. The top figure shows a 3D cosmic-ray track. The bottom figure shows the MIP energy spectra measured by one channel of the prototype calorimeter system.





Future Work

For future work, we need to increase the number of layers of the prototype system to eight and carry out beam tests to further verify the rationality of the small-size crystal scheme.

Conclusion

- Low noise: below 0.6 fC(0.023 MIPs)
- A good linear relationship among different gain channels
- A large dynamic range: electronics dynamic range: from 3 fC to 7 pC, prototype calorimeter: from 0.1 MIPS to 2.5×10^5 MIPs

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