PROCEEDINGS OF SCIENCE

The studies about BGO calorimeter of Very Large Area gamma ray Space Telescope

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on behalf of VLAST Collaboration

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Cosmic rays are one of the important sources of high-energy particles, but at present our understanding of its origin, transmission and interaction process is still very limited. In addition, the exploration of dark matter is also one of the most popular issues in international research. Very Large Area gamma ray Space Telescope (VLAST) is the next generation of flagship space observatory, which has a large acceptance, extremely high angular resolution and energy resolution. It has three sub-detectors, which are anti-coincidence detector, silicon tracker and low energy gamma-ray detector and high energy imaging calorimeter, and the last one composed of BGO crystals is the key subdetector. It has 8 layers with 192 crystals per layer, and the size of every crystal is 2.5 cm × 2.5 cm × 120 cm. In order to study the performance of the BGO calorimeter, we carry out the simulation based on GEANT4 software to study energy linearity, resolution, and particle identification ability. In addition, the performance of meter-size BGO crystal produced by Shanghai Institute of Ceramics was tested, the light yield and attenuation length were studied, and the large dynamic range readout scheme with two Avalanche photodiodes (APDs) was also studied. Here, the simulation and experimental test results will be introduced.

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1. Introduction

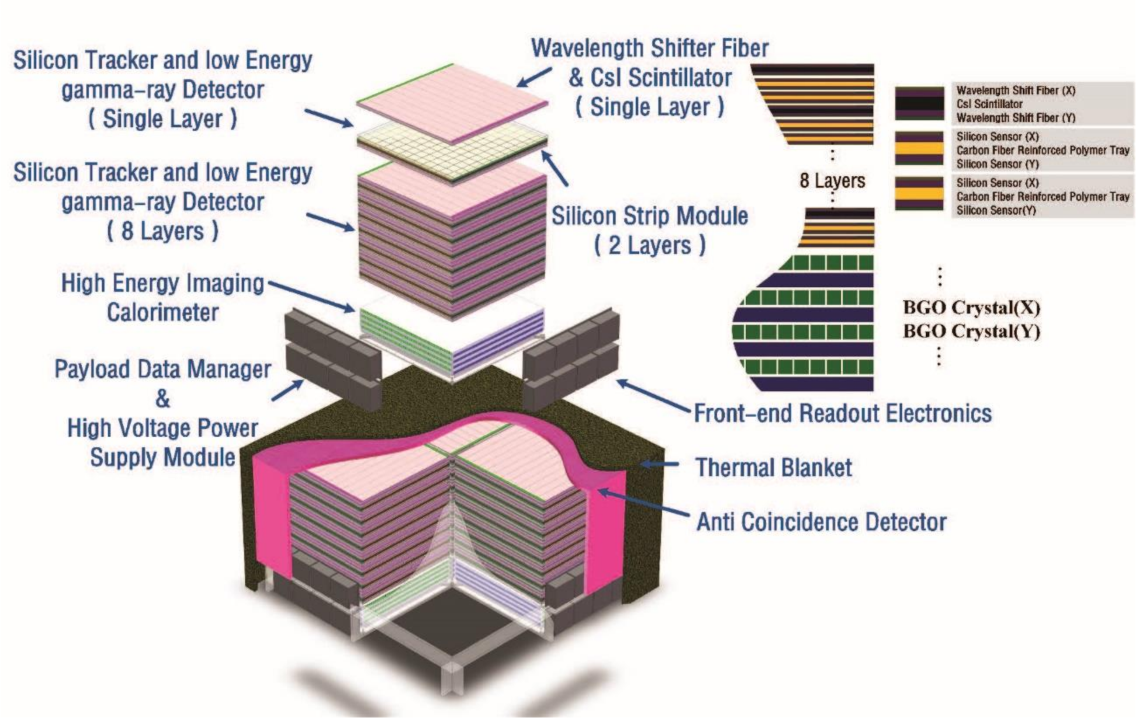
So far we have launched several artificial satellites for observing cosmic rays, such as Fermi Large Area Telescope [1] (USA), CALorimetric Electron Telescope (Japan) and Dark Matter Particle Explorer [2] (China), and their scientific goals can be summarized as follows:

- Explore the generation, propagation, and interaction processes of cosmic rays;
- Search for existence evidence and line spectrum about DM particles;
- Discover the origin of extreme high-energy astronomical phenomena;
- Verify the applicability of basic physical laws;

In order to satisfy the observation requirement of larger acceptance, wider energy range and higher angular resolution, we propose a new task of developing the Very Large Area gamma-ray Space Telescope (VLAST), which will become a reliable tool for the new generation of cosmic ray space exploration.

1.1 VLAST Instrument

The side length of VLAST is about 3 meters, and it can be divided into four symmetrical units. Each unit is mainly composed of the following three parts: anti coincidence detector (red part of the shell), silicon tracker and low energy gamma-ray detector (upper part) and high energy imaging calorimeter (lower part) [3] . Its comprehensive performance is expected to improve by more than 10 times compared to the Fermi-LAT. There are currently two schemes for the structural design of the imaging calorimeters, strips or cubes, and both of them will be discussed later.



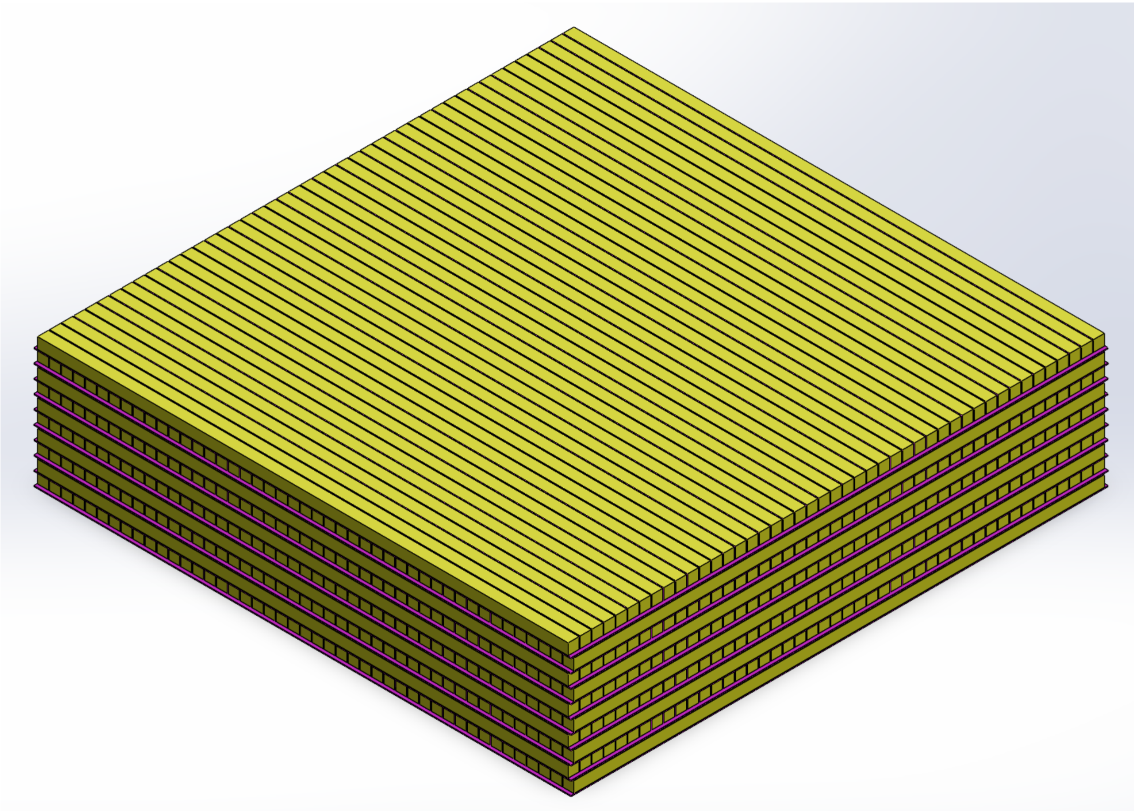
The schematic plot of the payload of VLAST

item	material	range	sensitive unit size
ACD	plastic scintillator	electron, light nuclide	300 mm × 300 mm
STED	8 × (CsI + 2 × XY silicon microstrips)	1 MeV - 100 MeV	100 mm × 100 mm
HEIC	BGO crystal (strips or cubes)	0.1 GeV - 20 TeV	25 mm × 25 mm × 1200 mm

2. Strip-type crystal calorimeter

2.1 Simulation result

We carry out a primary simulation result of the bar-type calorimeter based on GEANT4 software. It has 10 layers with 45 parallel crystals per layer, and they are orthogonal arranged between neighbour layers. The size of every crystal is 2.5 cm × 2.5 cm × 120 cm, and there is a carbon fiber support between two neighbour crystals and layers with the thickness of 2 mm.

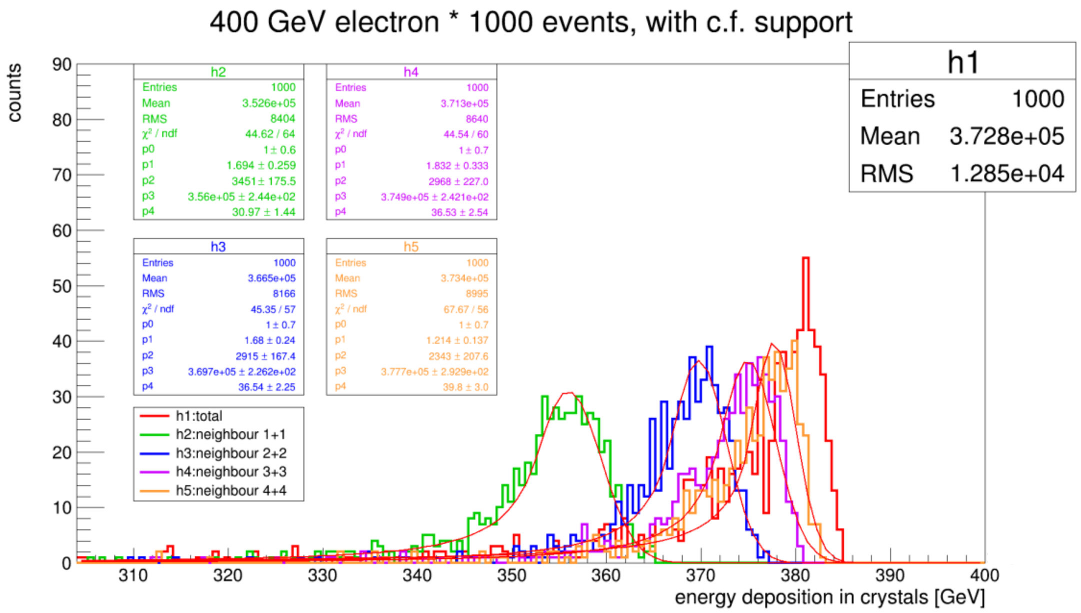


The simulation structure of the BGO bar-type calorimeter

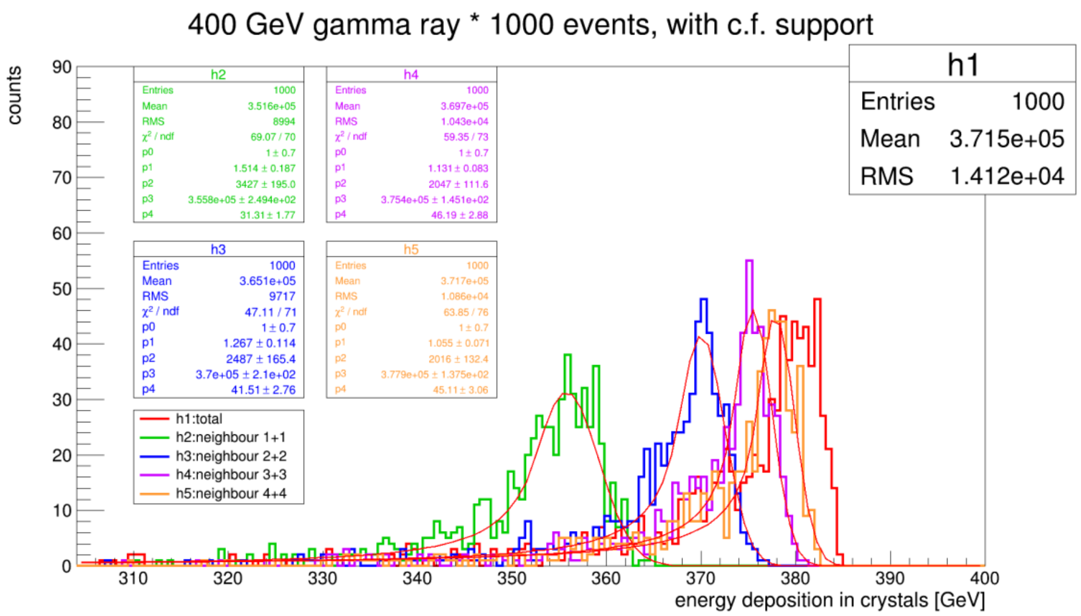
Then we can come to servel simple conclusions based on the calorimeter configuration:

- For electromagnetic showers, after selecting the crystal with the highest energy deposition, the sum of the energy within the range of 3 neighbour crystals on the left and right accounts for approximately 93.8% of the incident particle energy, which can reflect the total energy deposition of the event better;

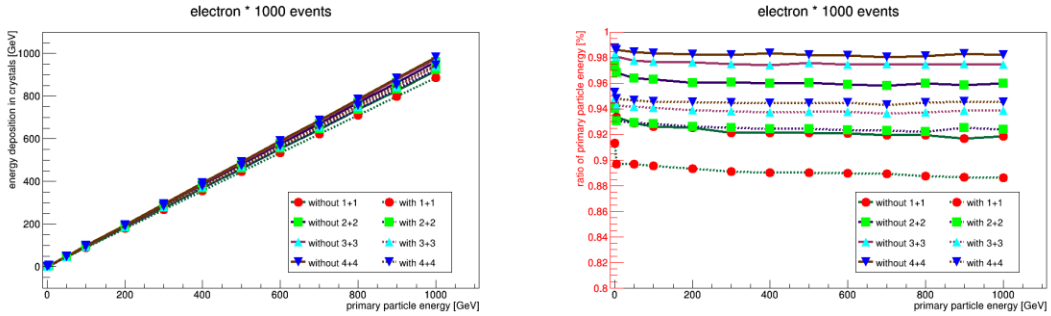
- The carbon fiber separation between crystals will absorb about 3.5% of the energy of incident particles, which remains constant for high energy particles;
- For high energy incident particles, the track detector above the calorimeter will not have a significant impact on the energy deposition inside it;



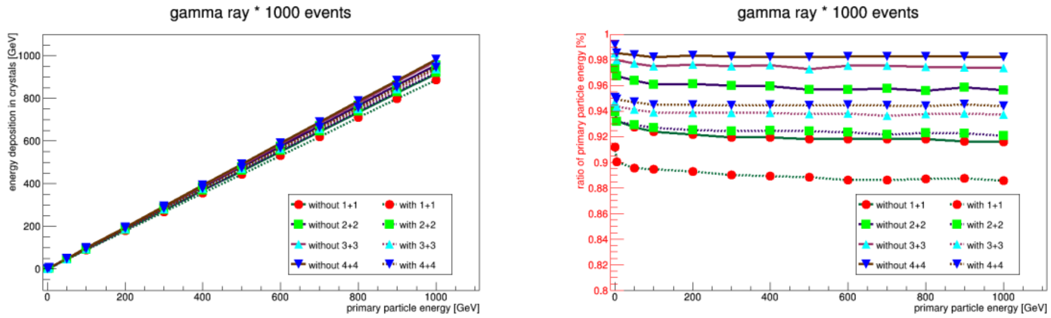
The simulation result of 400 GeV electron with different scale



The simulation result of 400 GeV gamma ray with different scale



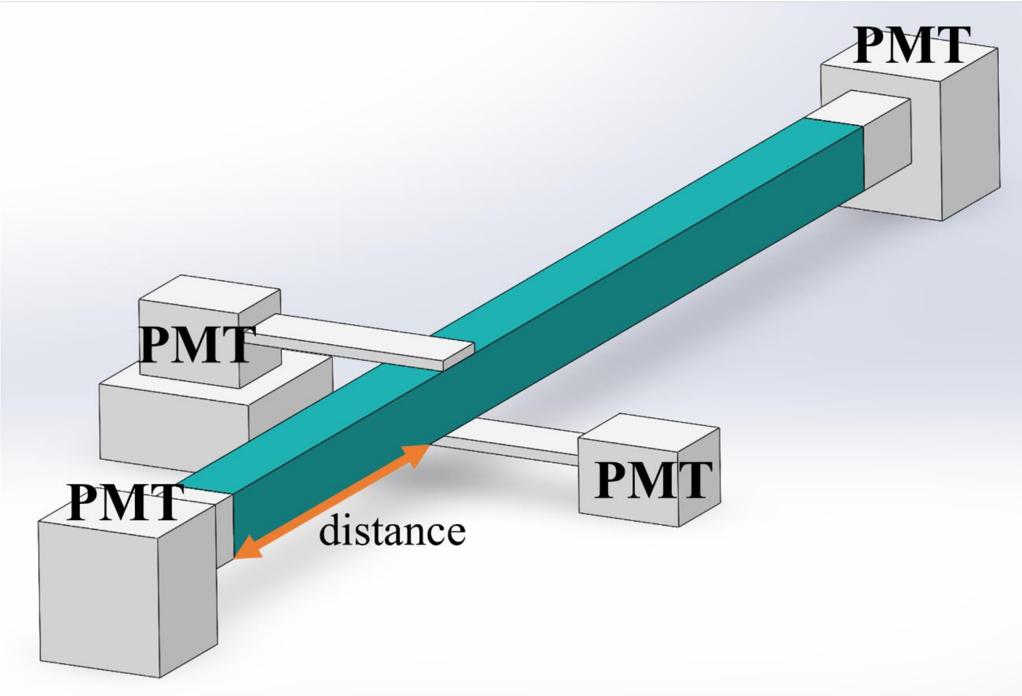
Energy linearity and the effect of the carbon fiber support of 5 GeV ~ 1000 GeV electron



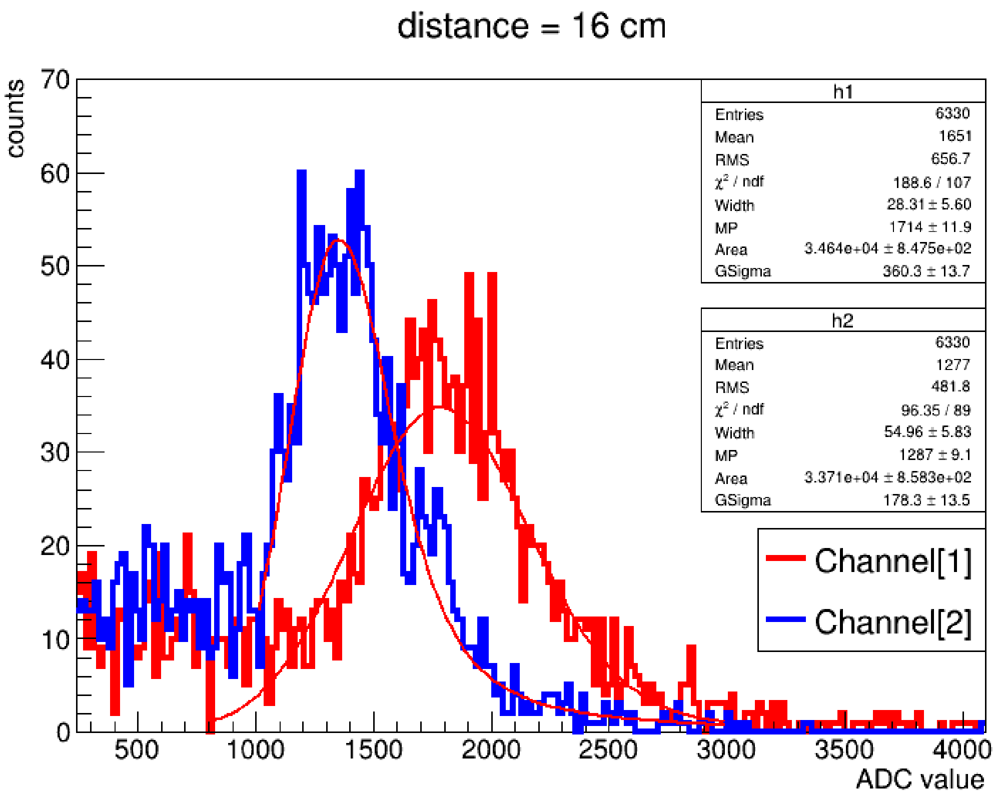
Energy linearity and the effect of the carbon fiber support of 5 GeV ~ 1000 GeV gamma ray

2.2 Experiment test

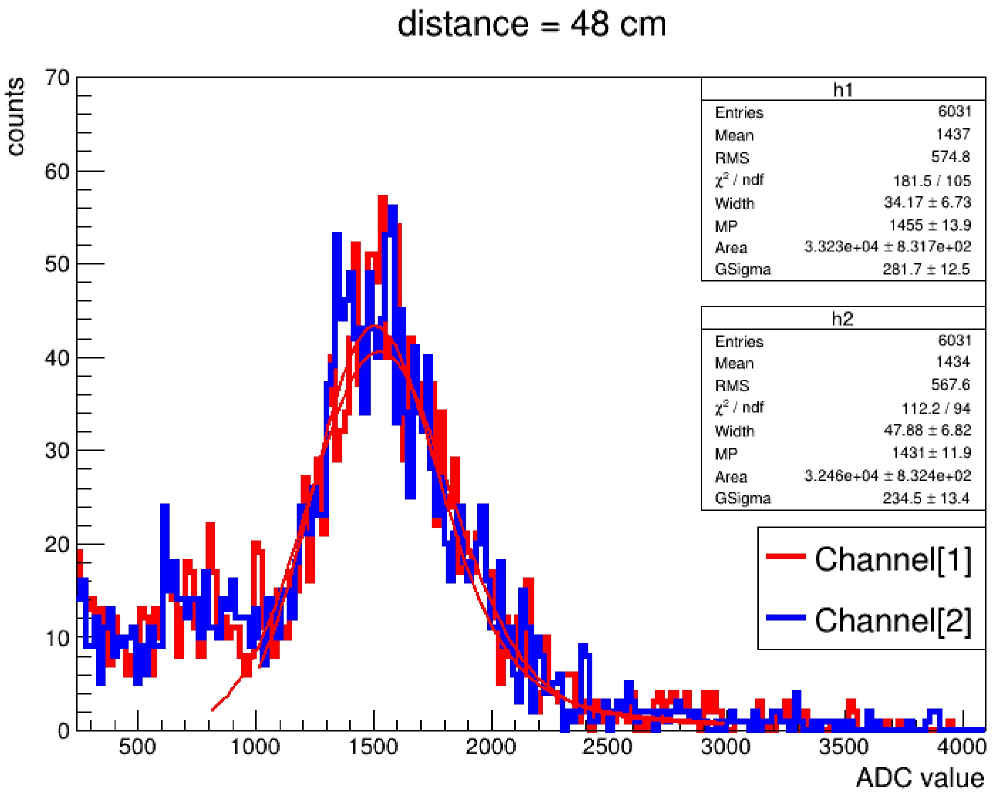
There is a complete BGO crystal strip with a length of 96 cm produced by SIC in the laboratory at present. In order to measure its attenuation of fluorescence transmission, I used a set of telescopes composed of two plastic scintillators as trigger signals after coincidence to select different hit positions of cosmic ray, and every sampling position was tested for a whole day. The calculated attenuation length was about 1.958 m, which also verified the uniformity of fluorescence transmission in this crystal.



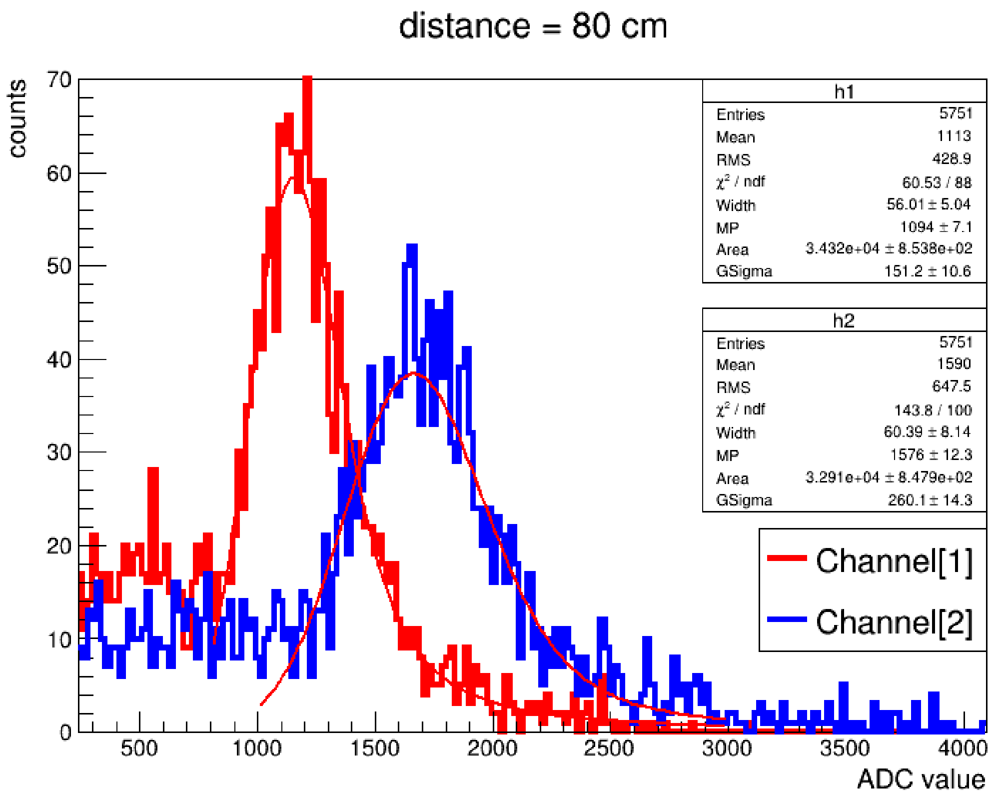
The schematic plot of the BGO attenuation length measurement



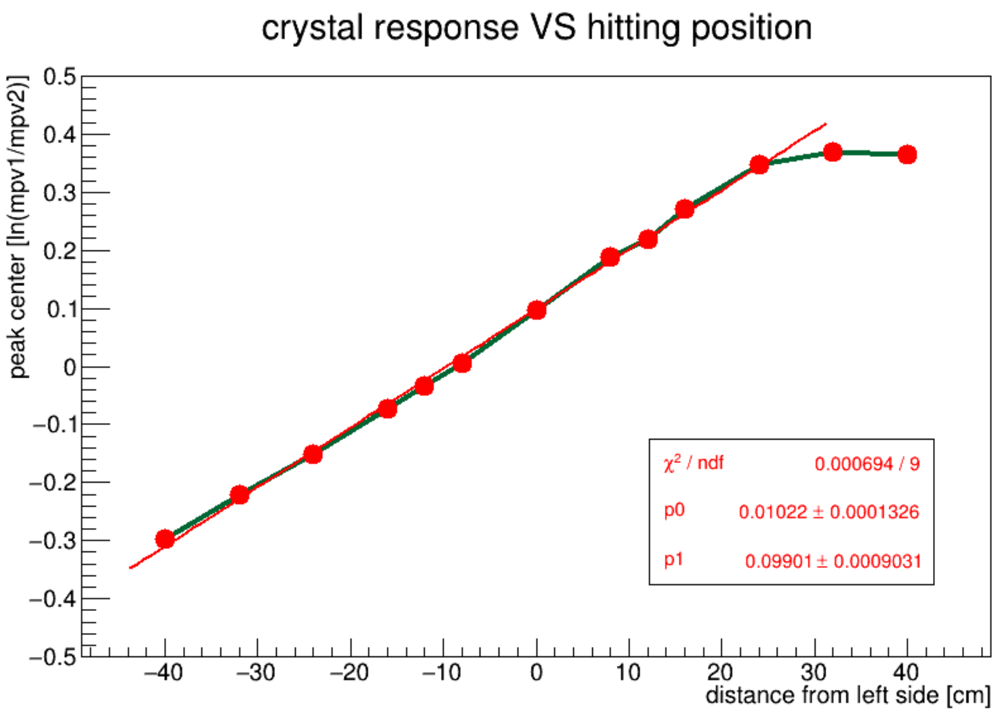
The direct result at 16 cm position (left side)



The direct result at 48 cm position (bar center)



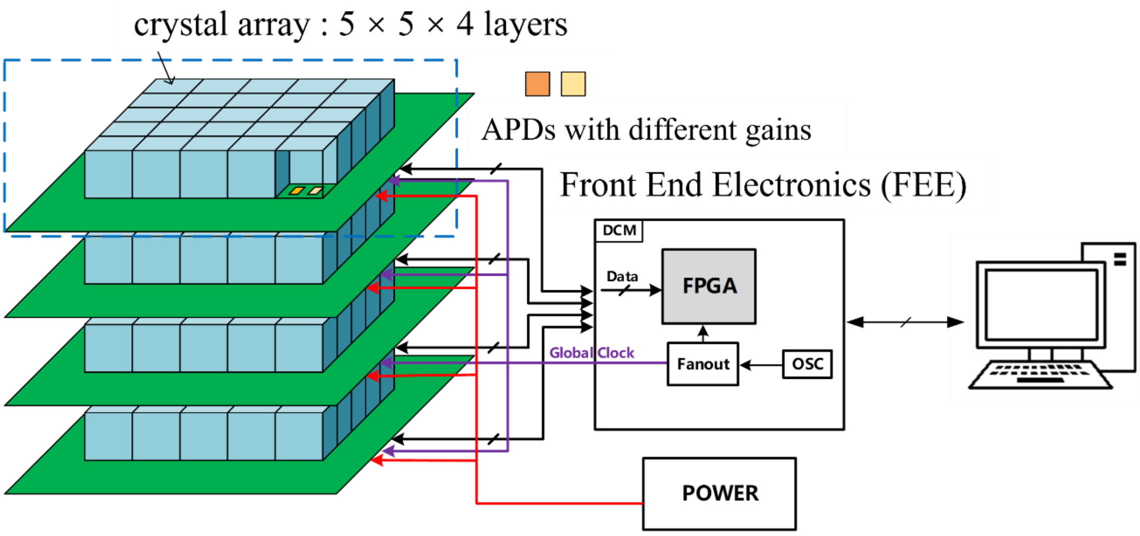
The direct result at 80 cm position (right side)



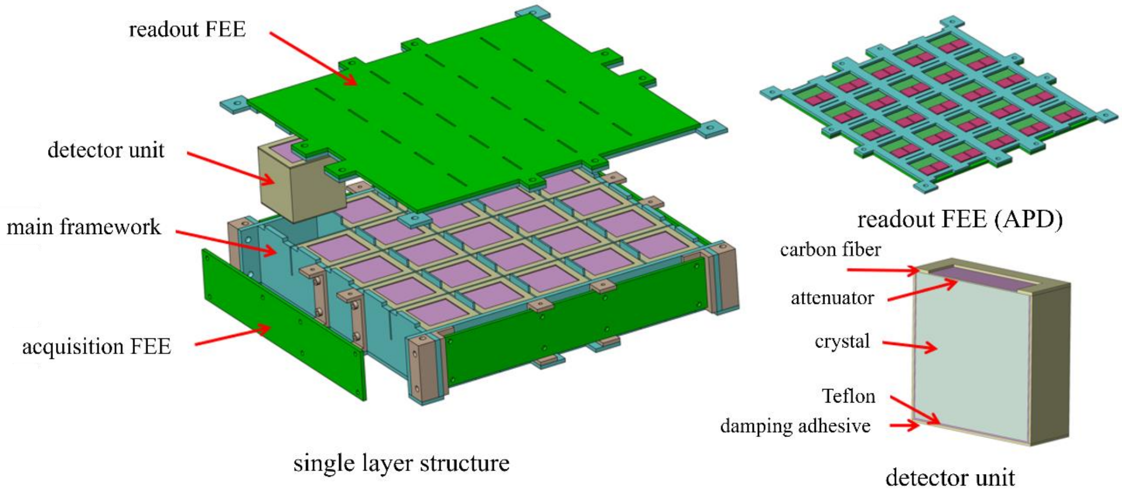
The experiment result of BGO attenuation length measurement

3. Cube-type crystal calorimeter

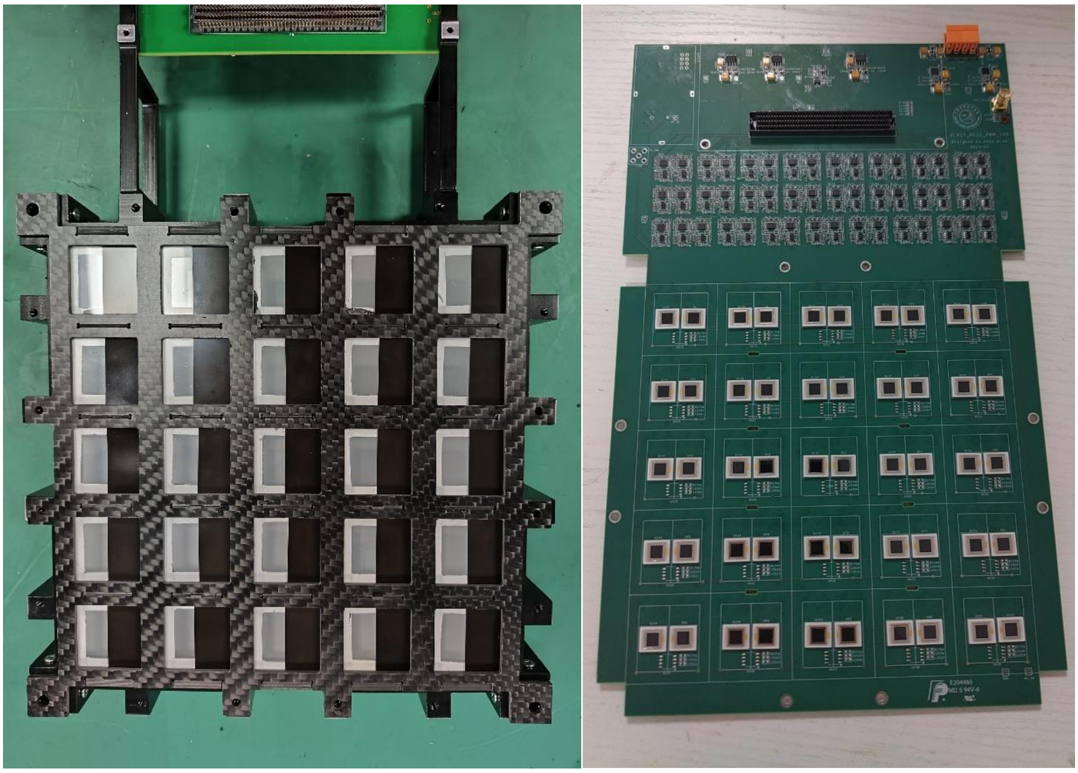
In the next step, I plan to build up a detection system composed of BGO cubes with a side length of 3 cm by 5 × 5 × 4 layers, which has support frames made by carbon fiber and S8664-55 APD are selected to collect fluorescence signals. It is designed to achieve a wide measuring range up to one million MIPs, and it will be tested by cosmic ray and beam experiments. This part of work is still ongoing.



The schematic plot of the BGO cube-type 4 layers calorimeter



The schematic plot of the BGO cubic calorimeter



The picture of the BGO cubic crystal part and the front-end electronics

4. Summary

In order to meet the demand of the next generation of space high energy gamma-ray detection, we proposed the Very Large Area gamma ray Space Telescope project, and completed the preliminary design of each part of the detector according to its expected performance indicators. My working group has proposed two schemes for the structure of the high energy imaging calorimeter, and has carried out several tests in experiments to verify its feasibility. In the future, we will continue to conduct beam test on both schemes for collecting more data to evaluate their performance and determine the final design configuration.

References

[1] Atwood W B, Abdo A A, Ackermann M, et al. ApJ, 2009, 697: 1071.

[2] Chang J, Ambrosi G, An Q, et al. APh, 2017, 95: 6.

[3] Fan Y Z, Chang J, Guo J H, et al. AcASn, 2022, 63(3): 27.

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