Design of the Front End Electronics for the Prototype of HERD Transition Radiation Detector

Jieyu Zhu[1,2], Haibo Yang[1,2,*], Yangzhou Su[1,2], Xinpeng Wang[1], Haoqing Xie[1], Chengxin Zhao[1,2]
([1]Institute of Modern Physics, Chinese Academy of Sciences, China)
([2]School of Nuclear Science and Technology, University of Chinese Academy of Sciences, China)
yanghaibo@impcas.ac.cn

Abstract—In this work, we develop a front-end electronics (FEE) as a standard readout unit for the prototype of TRD at HERD. The FEE uses four SAMPA ASICs for 128 detector signal readouts, realizing a high-speed, low-power, and high-reliability data acquisition system. According to the electrical test on the electronics, the channel's Root Mean Square (RMS) noise is less than 1.7 fC, and the linearity can be better than 0.2%. A beam test was performed at the SPS and PS terminals of CERN to verify the electronic performance further. The experimental results show that the FEE meets the readout requirements of the prototype of TRD and accurately obtains the energy spectrum of muons and electrons.

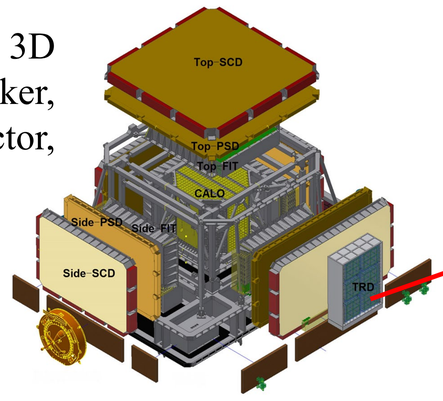
HERD and the prototype of TRD

The High Energy cosmic-Radiation Detection facility (HERD) is a part of the Chinese Cosmic Lighthouse Program in China's Space Station, which will be launched in 2027. the TRD is mounted on the side of the HERD, and the 2×3 detection array composed of 6 detector units can be extended through the mechanical turntable.

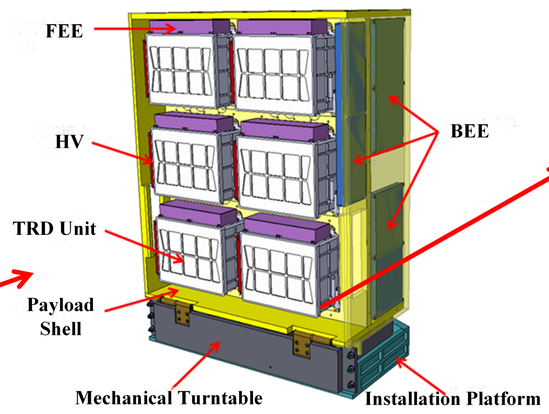
HERD consists of five detectors: 3D Imaging calorimeter (CALO), fiber tracker, plastic scintillator, silicon charge detector, and transition radiation detector (TRD).

Scientific goals:

- Indirectly detect dark matter.
- Measure cosmic rays.
- Observe high-energy gamma rays



Architecture of HERD



Architecture of TRD detection system

TRD unit

The sealed gas detector will first large-scale used in space exploration.

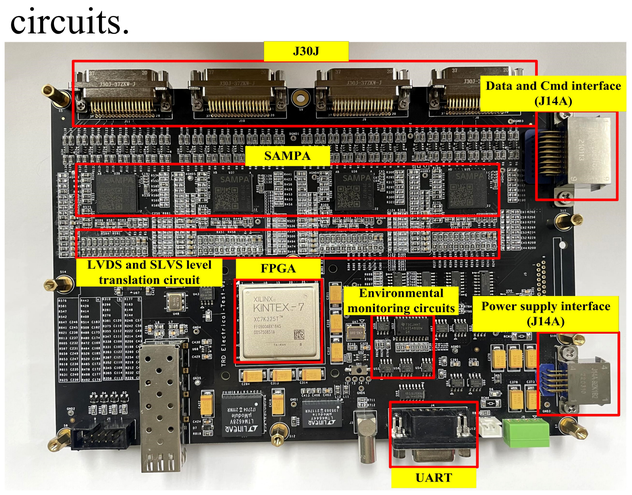
Calibration mode: The calibration of the TeV energy range of the CALO to improve the accuracy of cosmic ray detection.

GRB mode: The detection of high-energy gamma rays.

The design of the FEE

A. Hardware design of the FEE

The FEE comprises 7 circuit modules, including detector interface input circuits, level shifter circuits, field-programmable gate array (FPGA) and its peripheral circuits, SAMPA and its peripheral circuits, power supply circuits, data communication circuits, and environmental parameters monitoring circuits.



The picture of the FEE

Detector to SAMPA:
J30J-37ZKW connectors interface send detector signal.

BEE to FEE:
J30J-37ZKW connectors interface provides trigger and Command configuration.(dual-channel hot backup)

Power to FEE:
J14A-9ZK1B connectors interface provides +3.3 V and +5 V power to the FEE.

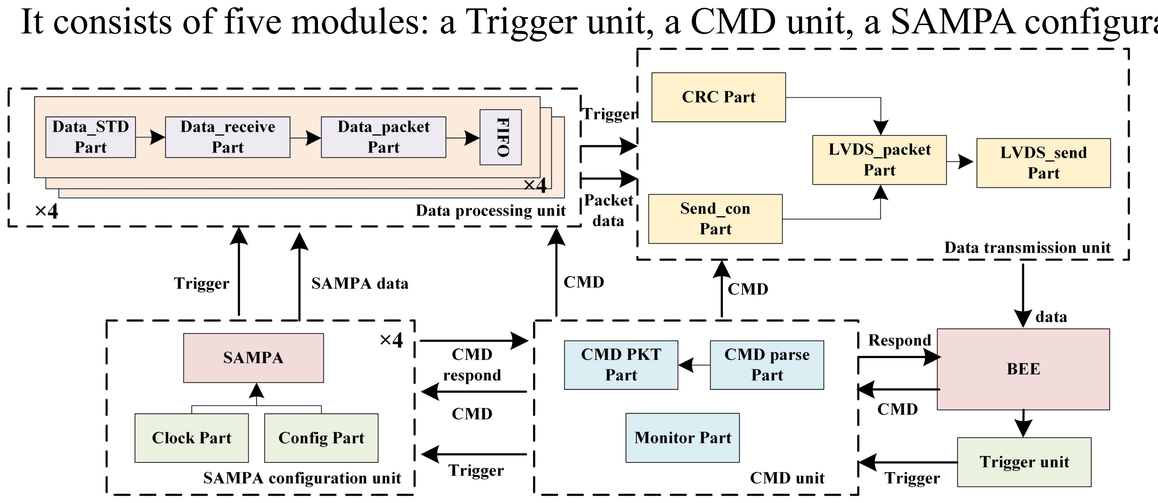
The design of the FEE we have focused on the reliability of the TRD system.

- Sudden changes in the high voltage of the detector: A 100 Ω series resistor is used in the circuit for current limiting and electrostatic discharge (ESD) protection diode NUP4114 provides overvoltage clamping to protect the signal input circuitry of the SAMPA.
- The FEE and detector environmental parameter monitoring: FEE has three temperature and three current monitoring points. The environmental parameters of the detector are monitored by the BME680 chip, which monitors the temperature and air pressure inside the detector

The FEE uses four SAMPA ASICs for 128 detector signal readouts.

B. Hardware design of the FEE

It consists of five modules: a Trigger unit, a CMD unit, a SAMPA configuration unit, a Data processing unit, and a Data transmission unit.



The architecture of FPGA firmware

Main function:

- Trigger identification:

Identifies valid triggers with trigger widths between 450 ns and 550 ns to prevent false triggered.

- Recognizing and responding to commands:

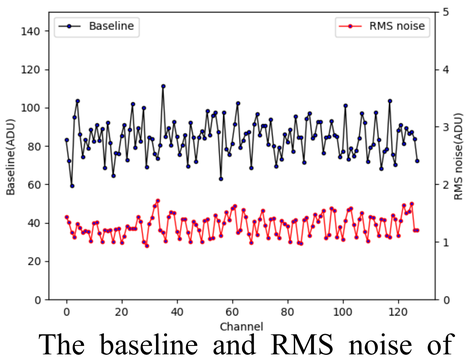
Identifies and replies to SAMPA configuration commands and state parameter monitoring commands from the BEE.

- SAMPA configuration and scientific data transmission:

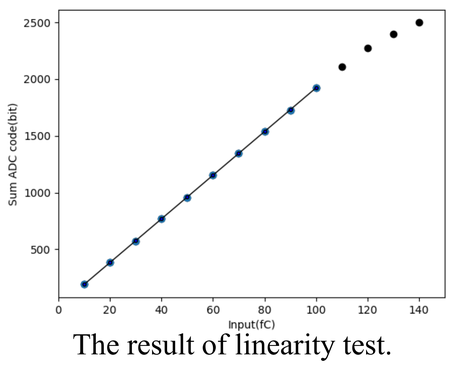
Provides the working configuration of SAMPA and transmits the acquired detector data to the BEE.

Performance measurement

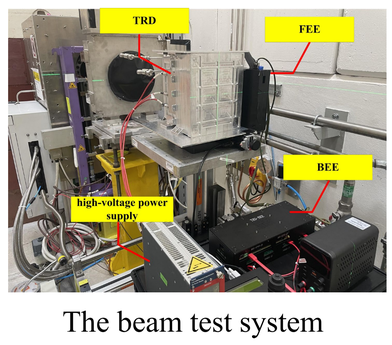
A series of tests were performed to evaluate the functionality and performance of the FEE. The SAMPA is configured with a dynamic range of 0-100 fC, a gain of 20 mV/fC, and a data transmission clock frequency of 80 MHz. In the lab tests, a signal generated a signal trigger signal to provide to the BEE, which fanned out to the FEE.



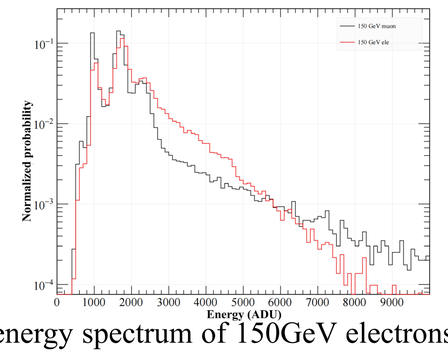
The baseline and RMS noise of 128 channels.



The result of linearity test.



The beam test system



The energy spectrum of 150GeV electrons and muons.

This difference of the 150 GeV electrons and 150 GeV muons is recognizable from the energy spectrum. This is because the 150 GeV electrons produces transition radiation, and the transition radiation photon produces additional energy.

Conclusion

A readout system has been successfully designed and produced for TRD in HERD. The test results indicate that the noise performance is less than 1.7 ADC code (approximately 0.17fC), the nonlinearity of the full readout electronics is less than 0.6%, and the amplitude resolution is better than 3%. In addition, beam test results demonstrate that the readout system can reach good performance.

References

[1] D. Kyratzis, and HERD Collaboration, "Latest advancements of the HERD space mission," Nucl. Instrum. Methods Phys. Res. A, Vol 1048, Mar. 2023, no. 167970.

[2] A. Velure, "A Digital Signal Processor for Particle Detectors: Design, Verification and Testing," Germany: Springer Cham, 2021.