Design of the CDAU, a common data acquisition unit for HIAF

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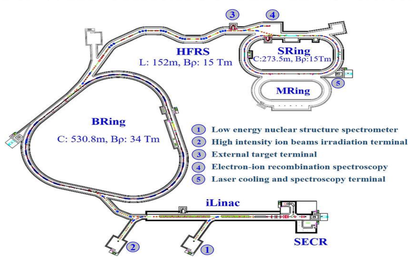
Abstract

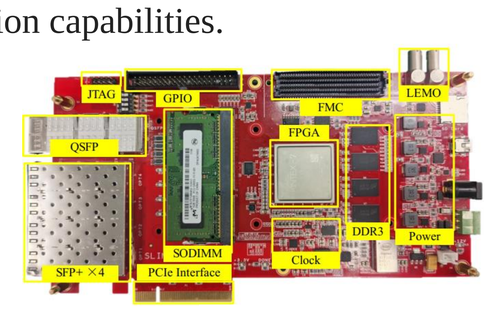
In particle physics and nuclear physics experiments, especially experiments based on particle accelerators, the data transmission rate of the detector is very high. Data acquisition (DAQ) systems with high density, scalability, and easy upgrading are essential to simplify the reading architecture of the entire experiment. A common data acquisition unit (CDAU) has been designed in a scalable DAQ system for particle physics and nuclear physics experiments at the High Intensity Heavy Ion Accelerator Facility (HIAF). The CDAU is a PCIe-based FPGA data acquisition readout unit. The same unit handles the data acquisition and distributes slow control to the detector's front-end electronics. The CDAU is based on a PCI Express (PCIe) Gen 2 × 8 interface and interfaces to eight optical links via a QSFP transceiver and four SFP+ transceivers for data collection, packaging, and transmission, using a Xilinx Kintex series FPGA as its central chip, combined with optical interfaces and peripheral circuitry. This paper presents the design of the CDAU, its performance, and its application test. As a result, the BER is less than 10^{-15} for all links, without any error recorded during the test. The average writing speed of PCIe is 3473 MB/s, the average reading speed of PCIe is 3395 MB/s, the reading and writing rate is stable.

1. Introduction

- Set for 2025 completion, China's HIAF will be pivotal for cutting-edge research[1-2].
- The HIAF needs a scalable, high-bandwidth DAQ system for its future operations with diverse experiments and up to 1 × 10^11 ions per pulse [3].
- Universality: Ensure adaptability through modular, standardized interfaces and protocols.
- High Performance: Requires fast processing, high accuracy, and stability to manage up to 1 × 10^11 ions per pulse and ensure reliable, quality experiments.
- Scalability: Upgrades or improvements may be needed as experimental demands and technology evolve.
- A data acquisition system based on the scalable, easily integrated CDAU board will enhance HIAF's data collection capabilities.

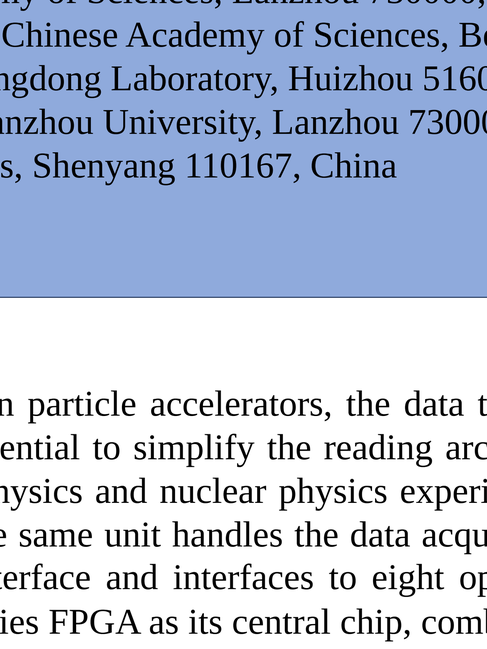


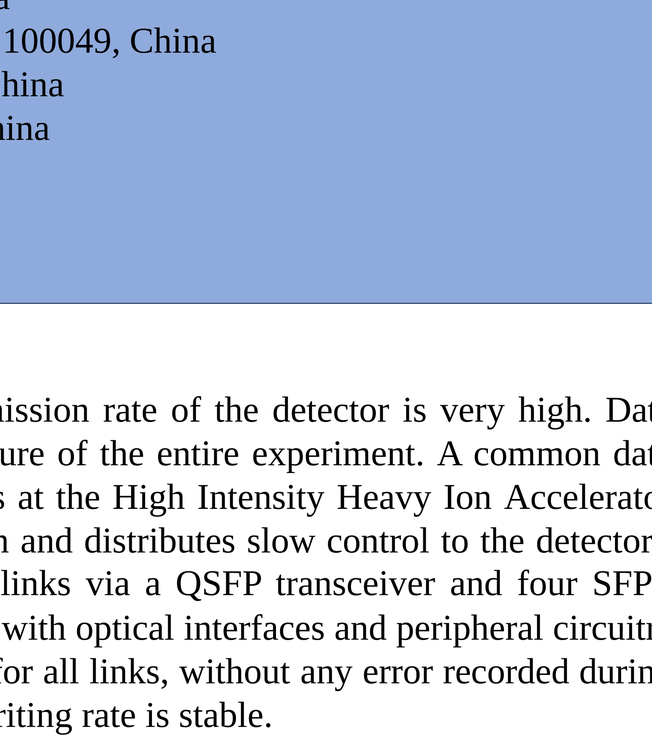
HIAF



CDAU

2. The architecture of data readout





- Comprises CDAU board and software.
- High-bandwidth optical paths and PCIe interfaces are implemented on the CDAU board.
- The DAQ software uses a multi-threaded design for real-time data processing and visualization..

3. Performance Test

Interface performance

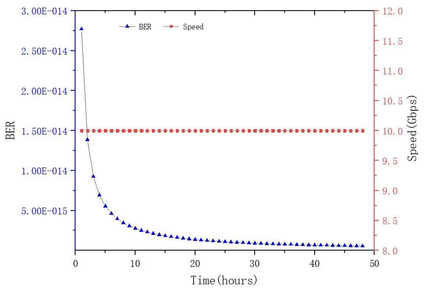
- The optical interface characterization results show stability at 10 Gbps with a low BER of 4E-16 over 48 hours..
- After 48 hours of testing, the PCIe interface maintained stable write speeds of 3420MB/s and read speeds of 3394MB/s.

Test with FE

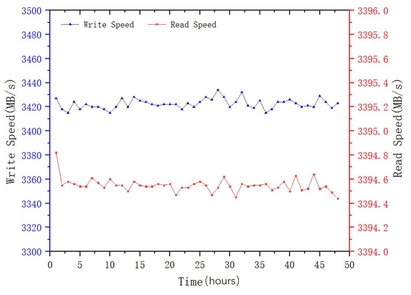
- The FE baseline stable at 1990 ADC code with noise is 2.8 ADC code.
- The entire FE amplitude resolution is less than 1.2%.
- This channel's INL is also better than 0.68 %.

Radiation test with detector

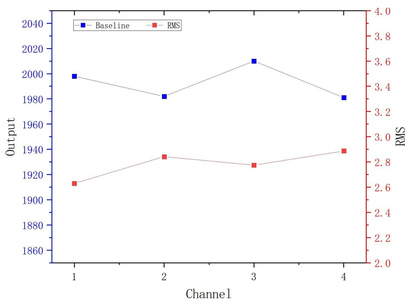
- The system with detector (CsI) was tested using a γ source(^{137}Cs).
- The cosmic energy spectrum was measured simultaneously using the same detector.



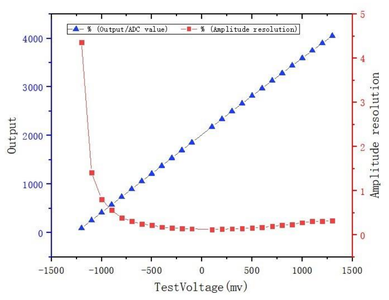
Optical interface test



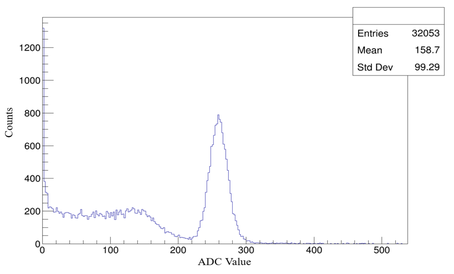
PCIe Wr/Rd test



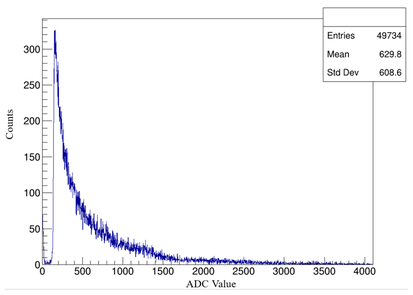
FE baseline and noise



FE Linearity



^{137}Cs emission spectrum



cosmic energy spectrum

4. Summary and Prospect

- A data acquisition system based on the CDAU board has been designed and developed for HIAF.
- It features good scalability and ease of integration, allowing for customization based on varying experimental needs..
- System tests indicate it can handle high-bandwidth, high-data-rate transmissions..

References

[1] Yang J C, Xia J W, Xiao G Q, et al. High intensity heavy ion accelerator facility (HIAF) in China[J]. Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms, 2013, 317: 263-265.
[2] Ma X, Wen W Q, Zhang S F, et al. HIAF: New opportunities for atomic physics with highly charged heavy ions[J]. Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms, 2017, 408: 169-173
[3] Wu B, Yang J C, Xia J W, et al. The design of the Spectrometer Ring at the HIAF[J]. Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, 2018, 881: 27-35

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