Design of A Highly Integrated Readout Electronics for Micromegas Detector Used in Muon Imaging

Ting Wang [1,2], Yu Wang[1,2], Changqing Feng[1,2], Zhiyong Zhang[1,2], Shubin Liu[1,2]

Introduction

- Muon imaging technology is an innovative imaging technique that can be applied in volcano imaging, heavy nuclear material detection, and archaeological research. It requires the use of high-resolution detectors to meet the demand for high-precision, short-time imaging.
- With the continuous advancement of microelectronics and printed circuit board manufacturing processes, significant progress has been made in the research of Micromegas detectors. The Micromegas detector is a promising choice for muon imaging due to its high spatial resolution and large area.
- The goal of this research is to design a compact readout electronics based on the commercially available front-end chip (ADAS1128) for highly segmented Micromegas detectors.
- A small-scale prototype was constructed and tested in order to validate the performance of this chip for reading out Micromegas detectors in muon imaging.

Micromegas

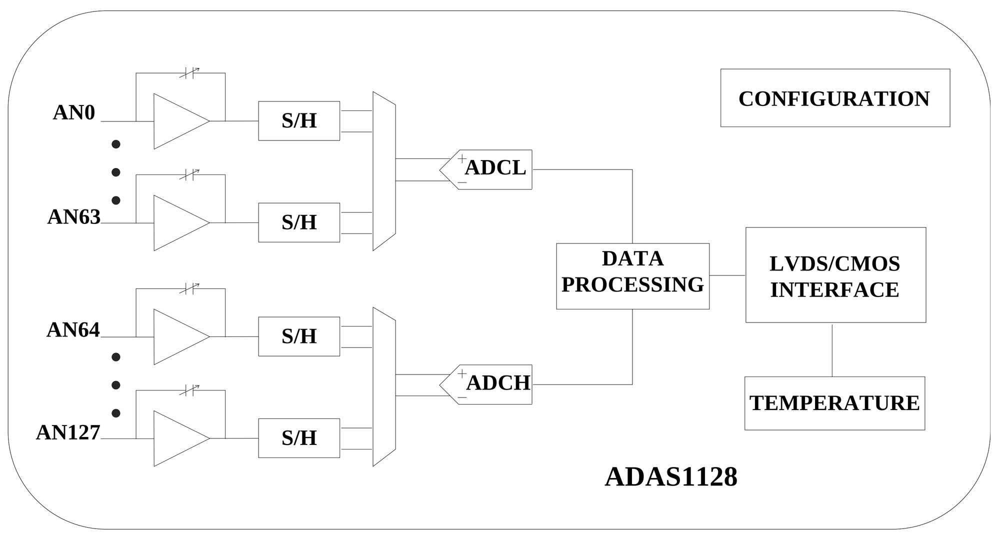
- Sensitive area: 15 cm × 15 cm
- XY strip readout, strip pitch: 400 μm.
- Readout channels: 768

Readout Scheme

Readout ASIC

A 128-channel current-to-digital readout ASIC named ADAS1128 is chosen to read out the signal of the Micromegas detector.

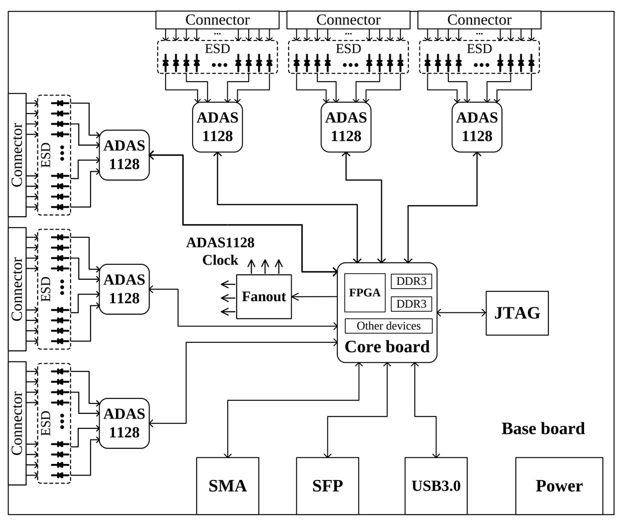
- 128 current integration amplifiers, sample and hold circuits, and two 24-bit resolution ADCs. All converted channel results are output on a single LVDS self-clocked serial interface
- The dynamic range and the integration time are configurable via a 4-wire serial peripheral interface (SPI).
- A maximum dynamic range of -660.17 fC to 32.23 pC (integration time of 50.7μs).

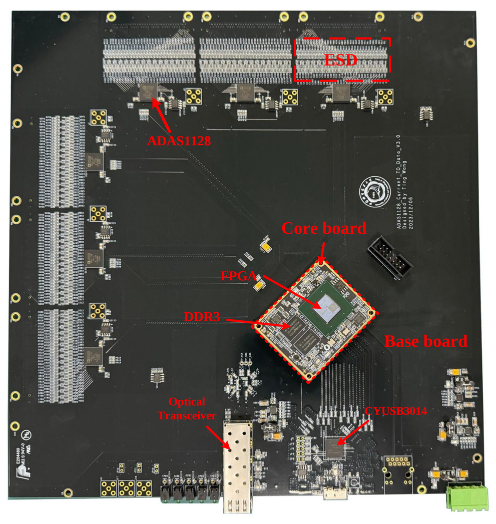


FEC

The FEC mainly consists of a ready-to-use module (core board) and a base board. which are connected via four 0.8 mm pitch connectors.

- The base board uses 6 ADAS1128 chips for integration and analog-to-digital conversion of the detector signals. For each channel, an Electro-Static Discharge protection circuit is designed.
- The communication interfaces include an optical fiber and a USB 3.0 port.
- The core board uses an FPGA as the main control chip to process data and control data transmission.

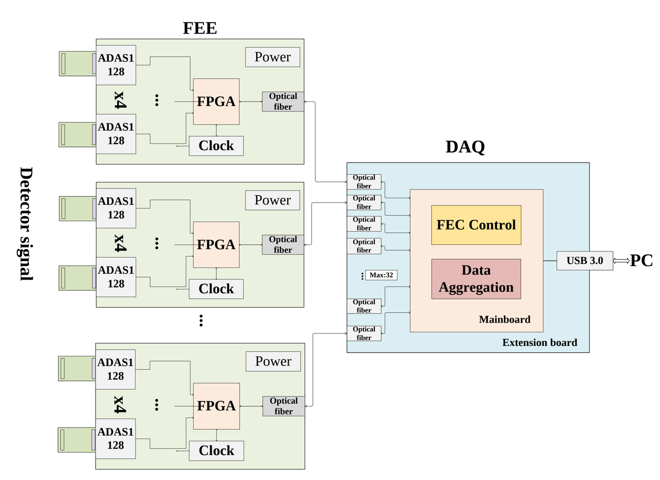


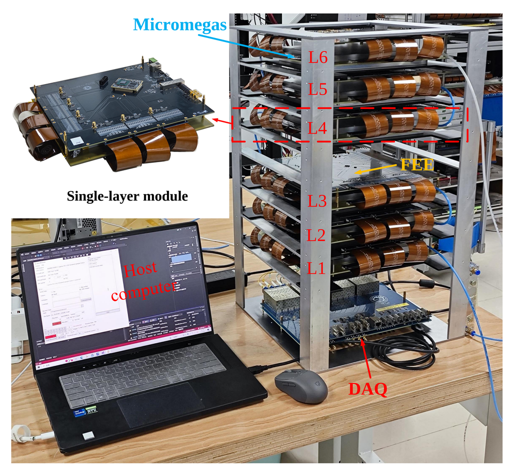


Readout System

The entire electronics system comprises highly integrated FECs, a data acquisition (DAQ) board, and a PC.

- Each FEC board amplifies and digitizes detector signals, and transmits these data to the DAQ board via an optical link running at 200 Mbps.
- The DAQ board processes and aggregates the data from multiple FEC boards and sends them to the PC via a USB 3.0 link at a rate up to 190 MB/s for final processing and storage.
- The entire system operates in self-trigger mode, and it will judge whether a valid muon is detected.



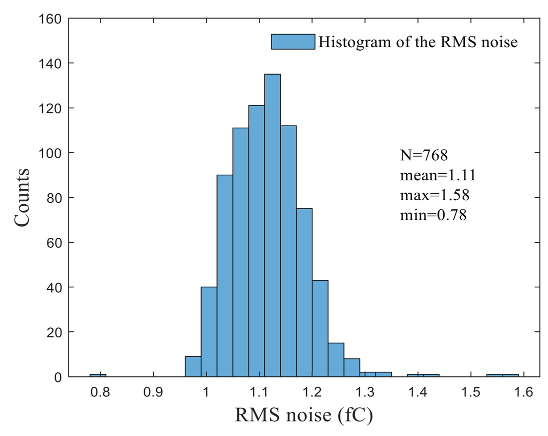


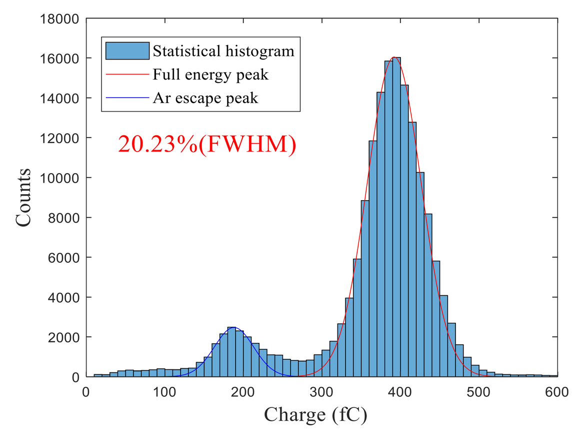
Test and Result

Performance Test

The FEC is calibrated using an external generator to produce a voltage pulse signal that is applied to a 1pF capacitor in series to generate a negative charge signal. The RMS of the equivalent noise charge is measured when the Micromegas detector is connected to the FEC. The detector energy resolution tests are performed using a ^{55}Fe radioactive source.

- The integration time of the chip is 50.7 μs, and the dynamic range of the negative charge is -77.97 ~ 0 fC.
- The integral non-linearity for 128 channels is 2.8%. The RMS noise is less than 1.22 fC.
- The full energy peak is about 389.3 fC, with an energy resolution (FWHM) of 20.23%@5.9keV.

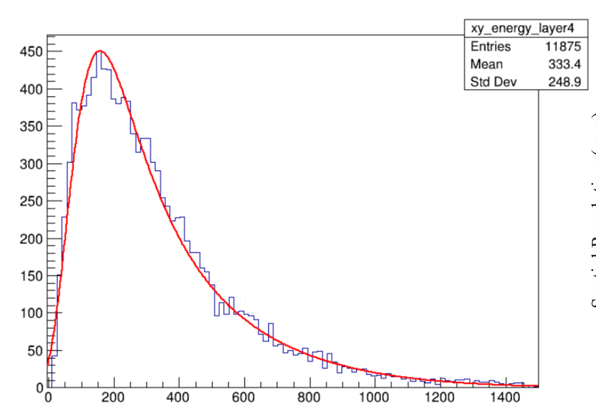


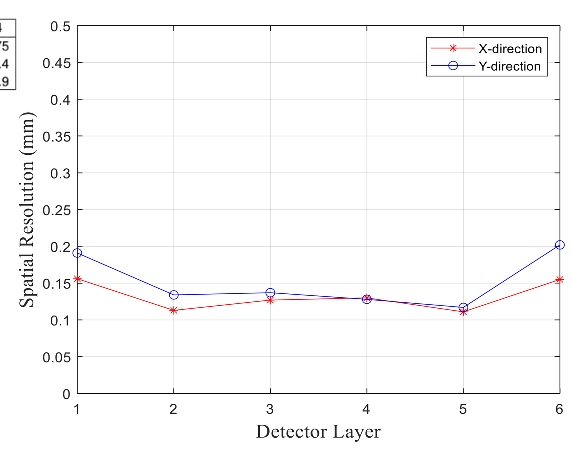


Cosmic Ray Muon Test

The core of the muon imaging experiment is to measure the tracks of muons. Since the reconstruction of the hit position in the experiment uses the charge center of gravity method, the cosmic muon deposition energy test is performed in the first step. Subsequently, detector spatial resolution and efficiency tests are performed.

- From the energy spectrum, the charge distribution mainly follows the Landau distribution, with a peak value of around 149.94 fC.
- For 0 ~ 5° incident muons, the spatial resolution of the detector is better than 150 μm.
- The efficiency of most of the 6-layer Micromegas detectors is over 95%.(Mesh: -550 V Drift: -678V)

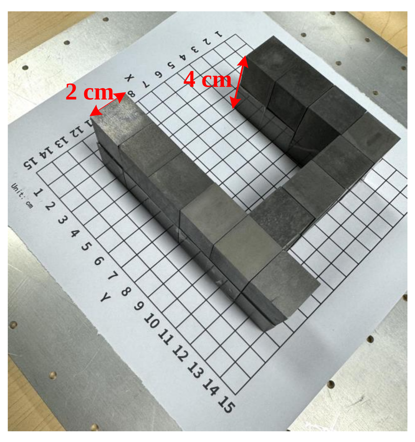




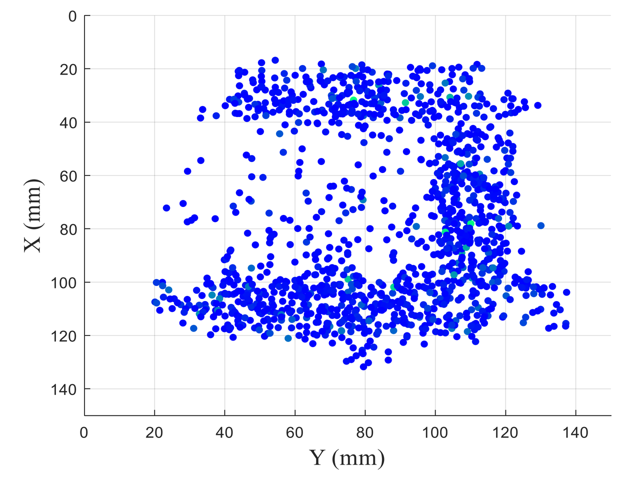
Muon Scattering Test

A tungsten material is imaged based on the above prototype, with the material having a minimum width of 2 cm and a thickness of 4 cm. After accumulating 24 hours of data, the imaging result was reconstructed using the Point of Closest Approach (PoCA) algorithm incorporating the k-Nearest Neighbors (k-NN) algorithm.

- Scattering imaging using a tungsten block arranged in the shape of the Greek letter μ.
- The reconstructed image shows that our muon imaging system prototype can reconstruct the boundaries of the objects used in this test. (One of the longer edges in the shape of μ can be clearly observed.)



(a) Photography of samples placed on a carrier platform



(b) Result after 24-hours muon exposure

Conclusion

- Under the scenario of low-rate cosmic ray muon imaging applications, a highly integrated FEC for reading out Micromegas detectors based on the current readout chip ADAS1128 is designed in this work.
- A muon imaging system prototype is set up and its spatial resolution is evaluated in a test with cosmic ray muons. The system prototype can reconstruct the boundaries of sufficiently massive objects with a size of 2 cm in a scattering imaging test.

[1] *State Key Laboratory of Particle Detection and Electronics, USTC, Hefei 230026, China*
[2] *Department of Modern Physics, USTC, Hefei 230026, China*
E-mail: wangting123@mail.ustc.edu.cn