Design of the Readout Electronics for Scintillator-Based Multi-Neutron Detector Array

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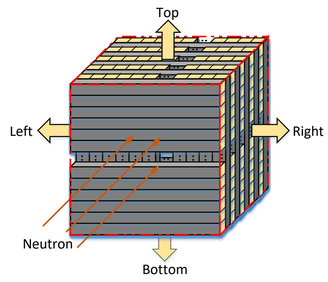
Introduction

- The advanced multi-neutron detector array (AMDA) is under development to enable precise measurements of the exotic structures and multi-body correlations in neutron-rich nuclei.
- The AMDA is a large-area detector composed of highly segmented plastic scintillator units to achieve high neutron detection efficiency and strong multi-neutron discrimination capability.
- Scintillator bars are equipped with SiPMs at both ends as photon sensors, together with dedicated readout electronics.
- A small-scale readout electronics system has been developed to read out and aggregate signals from massive channels.



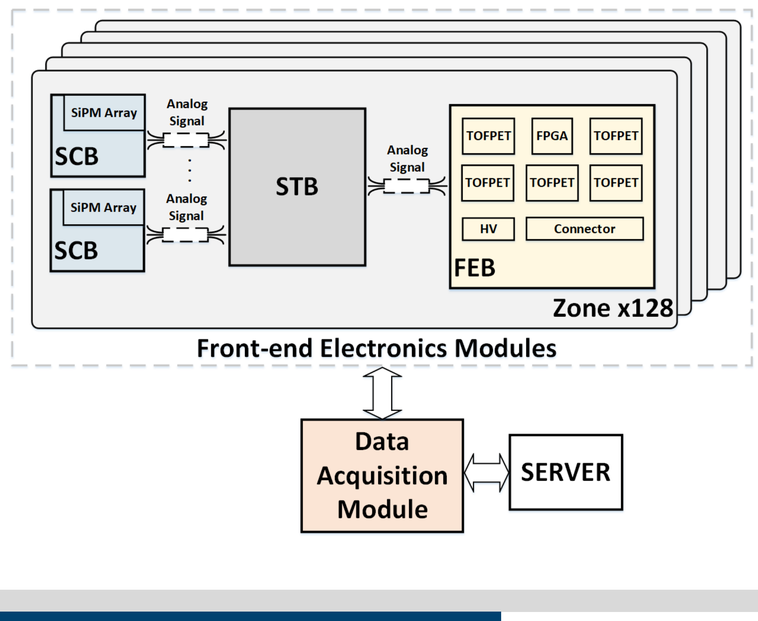
Readout Scheme

Overall Design

The complete readout electronics system consists of 128 partitioned front-end readout modules and one centralized back-end readout module.

The whole system includes following parts:

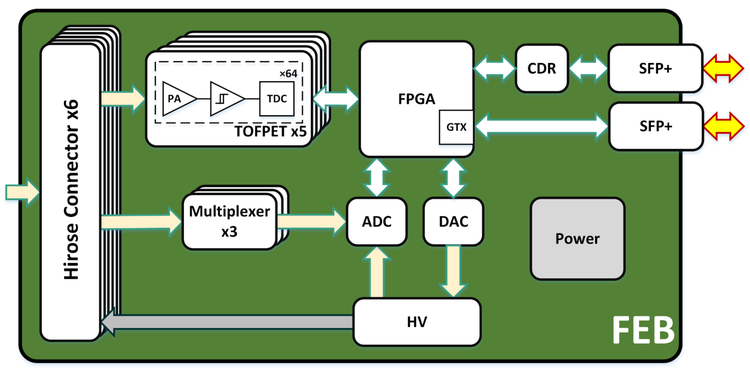
- FEM(Front-end readout electronics module): SiPM carrier boards (SCB), SiPM signal transfer boards (STB) and front-end electronics boards (FEB).
- DAM(Data acquisition module): Data acquisition and Processing.

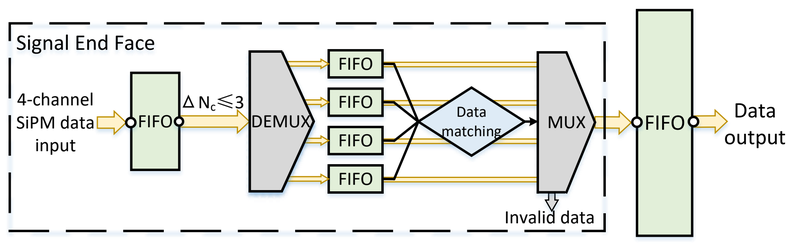


Front-end Electronics Module

The front-end electronics module includes following parts:

- SCB: Equipped with SiPMs.
- STB: Transmission of SiPM signals and voltages.
- FEB: The FPGA performs SiPM signal matching using coarse time tags. Matched events are kept and sent to the DAM for further processing and background rejection.

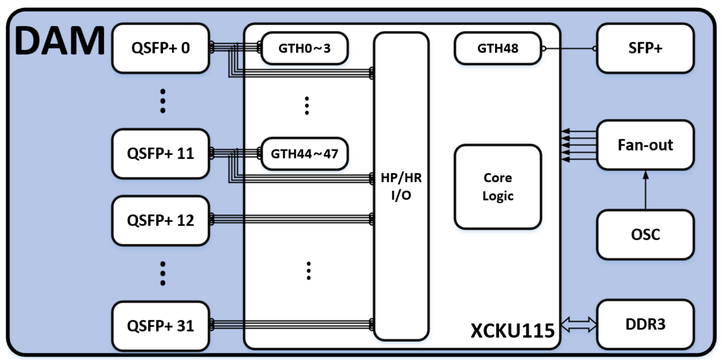


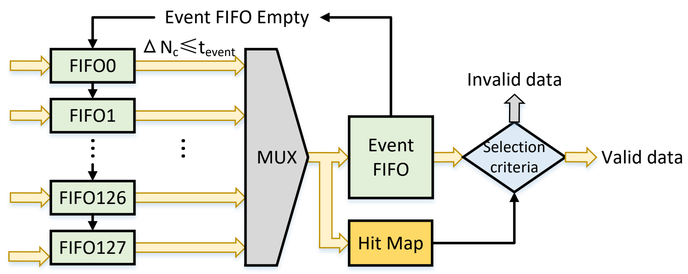


Data Acquisition Module

The DAM is based on a Xilinx XCKU115 FPGA and communicates with 128 front-end readout electronics modules via optical fibers, performing time alignment and event reconstruction for a total of 32,768 channels.

The DAM employs a trigger selection scheme based on a two-dimensional annular timing map and image convolution principles to suppress complex noise and select valid events.

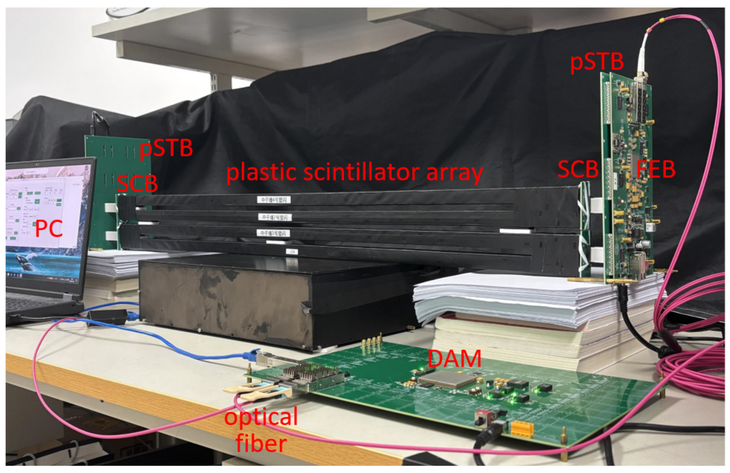




Performance Test

Experimental Setup

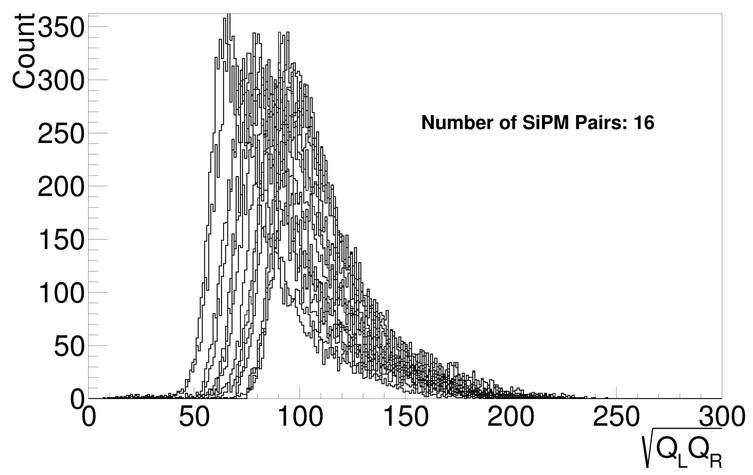
A small-scale plastic scintillator array was constructed, consisting of four parallel detector units. These plastic scintillator bars are arranged with equal spacing and labeled from 0 to 3 from top to bottom, along with the readout electronics.



The readout electronics comprises four SCBs, two pSTBs, two FEBs and one DAM, providing readout of the SiPM signals at the ends of the plastic scintillator units, with a total of 32 channels.

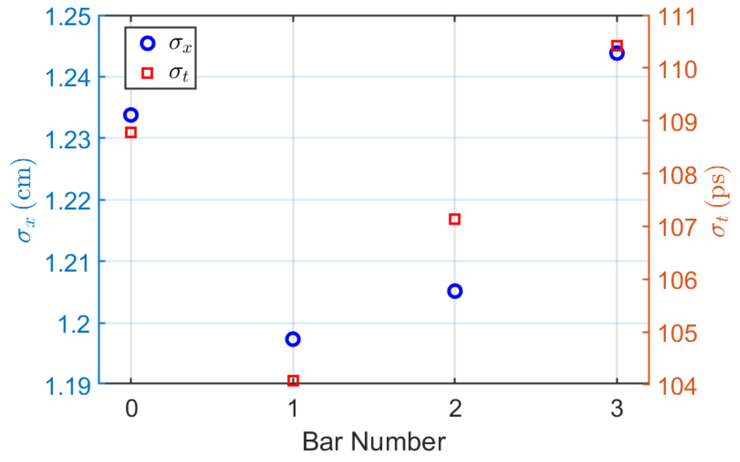
Test Result

The QDC distributions of the charge product from the dual-ended SiPMs for cosmic muons traversing each plastic scintillator detector unit (16 sets in total) are shown below, exhibiting good consistency.



Based on cosmic-ray calibration, time-walk corrections are applied to timing measurements. The photon propagation velocity in each plastic scintillator is derived from the time difference at both ends, allowing reconstruction of the cosmic-ray hit position.

Linear fits to reconstructed cosmic-ray tracks yield residual distributions for each scintillator unit. Position and timing resolutions are extracted using Monte Carlo–derived scaling factors.



The timing and position resolution results of the small-scale plastic scintillator array obtained from cosmic-ray tests for each plastic scintillator unit are shown. The single-ended time resolution is better than $110ps$, and the position resolution is approximately $1.2cm$.

Conclusion

- A good time solution: better than $110ps$,
- A good position resolution: approximately $1.2cm$.
- Fulfilling the readout electronics requirements of the AMDA multi-neutron spectrometer.

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