The control and monitor system for the BESIII ETOF/MRPC beam test (Postprint)

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Abstract

A test system is developed for the BESIII ETOF/MRPC beam tests of data acquisition, environment monitoring and automatic control. The software framework is based on the CAMAC bus, VME bus and Serial Port, which are responsible for communications with the detectors. The monitor system works well in the beam test.

Full Text

Preamble

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The Control and Monitor System for the BESIII ETOF/MRPC Beam Test

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A test system has been developed for the BESIII ETOF/MRPC beam tests, integrating data acquisition, environmental monitoring, and automatic control. The software framework utilizes the CAMAC bus, VME bus, and serial port for communication with the detectors. The monitor system performed effectively during the beam test.

Keywords: Beam test, Data acquisition system, Monitor and control system
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INTRODUCTION

To achieve advanced physics goals, the endcap time-of-flight counter (ETOF) in the Beijing Spectrometer III (BESIII) experiment [**?**] is planned for upgrade using multi-gap resistive plate chamber (MRPC) detectors to replace the existing plastic scintillators coupled with photomultipliers (PMTs) [**?**]. The upgrade aims to improve the total timing resolution from 110 ps to 80 ps for muons, requiring the intrinsic timing resolution of the MRPC detector to be less than 50 ps.

During the BESIII TOF R&D process, parameters such as PMT operating voltage and scintillator geometry were carefully studied in beam tests with the original TOF prototype to achieve the designed timing resolution [**?**, **?**]. Similarly, it is necessary to characterize MRPC performance using cosmic rays or accelerator particle beams (electrons or hadrons). According to the plan, a beam test will be conducted on the E3 line of the IHEP (Institute of High Energy Physics) beam facility to thoroughly study the performance of MRPC modules. To establish an efficient data acquisition system, a dedicated control and monitor system is essential for the MRPC prototype module beam test.

The E3 beam line features a mixed particle bunch of electrons and hadrons (pions and protons). A time-of-flight (TOF) detector is typically used to distinguish pions from protons by measuring flight time, while a Cherenkov counter can select electrons from the mixed particle bunch. Although a gaseous Cherenkov counter with a length of 1.2 m using CO_2 as radiator already exists, its large volume and temperature-dependent detection efficiency necessitate a new detector.

Since electron momenta in the E3 line range from 100–1100 MeV/c and pion momenta from 400–900 MeV/c, a threshold Cherenkov counter with low refractive index radiator is the optimal solution. Using silica aerogel with refractive index n = 1.01, only electrons emit Cherenkov light while pion velocities remain below the threshold velocity. Silica aerogel is a unique material with refractive index between those of condensed phases and gases, making it suitable for Cherenkov radiator applications. An aerogel threshold Cherenkov counter was developed for the upgraded BEPC (Beijing Electron Positron Collider) E3 beam line [?] at IHEP to discriminate electrons from pions.

II. EXPERIMENTAL

The E3 line provides a mixed beam bunch of electrons, pions, and protons with momenta ranging from 0.3–1.2 GeV/c. Several detectors with different functions are installed in the E3 line for the beam test, with their relative positions shown in Fig. 1 [Figure 1: see original paper].

The Cherenkov counter (C0) selects electrons from the mixed particle bunch. Scintillator counters (S1, S2) distinguish pions from protons by measuring flight time. Particle tracks can be reconstructed using three parallel multiwire proportional chamber detectors (MWPC: M1, M2, and M3), a silicon microstrip detector (Si), and an intensified camera detector (CCD) positioned behind the MWPC. At the beam end, an electromagnetic calorimeter (EMC) identifies particles through energy deposition measurements.

A highly precise timing start/stop signal is provided by the T0 detector, which consists of four counters. Each counter couples on one edge with a plastic scintillator (BC420) and PMT (Hamamatsu H6533 with 700 ps rise time and 160 ps transit time spread), and with an aluminum film on the other edge. The MRPC detector is placed on a flat roof that can be controlled remotely. The four counters are fixed symmetrically at the sides of the flat roof to eliminate timing errors caused by beam position uncertainties.

A. Electronics for the Beam Test

The detectors in the E3 beam line employ different data acquisition systems (DAQs), as illustrated in Fig. 2 Figure 2: see original paper. Although the detectors operate independently, a one-to-one correspondence must be established between data flows from different detectors. Therefore, a common trigger signal is required to initiate data acquisition, generated by coinciding the C0 veto signal with signals from S1, S2, and the four T0 counters. Detailed electronics trigger logic is shown in Fig. 2(b). To improve time measurement precision, leading edge discriminators (LED Dis) are used instead of constant fraction discriminators, and time-amplitude corrections eliminate timing measurement effects caused by different signal amplitudes (time walk effect).

III. SUB-DAQ BASED ON CAMAC SYSTEM

Each wire chamber produces 32 channels of cathode signals (16 cathode wires on each X and Y cathode plane) and one channel of anode signal, resulting in hundreds of signals from the three MWPC detectors. Based on cost and efficiency considerations, analog-to-digital conversion is performed by Brilliant

ADC (BADC), a high-performance CAMAC (Computer Automated Measurement And Control) module. One BADC completes A/D conversion, pedestal removal, gain transformation, nonlinear correction, and temporary data storage for up to 200 channels through time-share gating of the front-end circuit under control of a high-speed programmable CPU (Central Processing Unit). The flexibility of CAMAC is enhanced through various configurations of BADC [**?**]. CAMAC TDC (Time to Digital Converter) modules acquire the flight time information from S1 and S2 to distinguish mixed particles. Particle energy deposition in the EMC is measured by another CAMAC ADC module.

IV. SUB-DAQ BASED ON VME SYSTEM

For T0 and MRPC signal measurement, the VME (Versa Module Eurocard) system with higher precision is employed to achieve superior results. The intrinsic timing resolution of the T0 detectors, tested with cosmic rays, is approximately 41.58 ps (= $\sigma \times$ LSB = 1.663 × 25 ps) [**?**] (Fig. 3 Figure 3: see original paper). This level of precision can only be achieved using the VME system with 25 fC/LSB QDC and 25 ps/LSB TDC. Conversely, as shown in Fig. 3(b), the intrinsic timing resolution of T0 degrades to 65.5 ps (= $\sigma \times$ LSB = 0.262 × 250 ps) when VME data (25 ps/LSB) is transformed to standard CAMAC data (250 ps/LSB). Therefore, under identical conditions, test data precision improves when using the high-precision DAQ system.

According to single photoelectron spectra (SPE), PMT behavior under different operating voltages—including SPE energy resolution and peak-to-valley ratio—can be carefully studied to identify optimal operating conditions, enabling the T0 detector to achieve better timing resolution [**?**]. In this beam test, the V965 module with 25 fC/LSB precision acquires four charge channels from the T0 detector, while the V792N module with 100 fC/LSB precision acquires 12 charge channels from the MRPC. Timing data—including four channels from the T0 detector and 12 channels from the MRPC detector—are acquired by the V1290N module with 25 ps/LSB precision.

It is difficult to eliminate noise in data processing and perform proper time-amplitude corrections when acquiring charge and timing from MRPC and PMT separately. Therefore, synchronous measurement of charge and timing from MRPC and PMT is necessary, allowing selection of good events based on charge-timing matching. The trigger signal is divided into several channels and sent into QDC and TDC modules connected in daisy-chain configuration. The VME boards employ Chain Block Transfer (CBLT) readout mode, enabling correspondence between QDC and TDC data, which significantly reduces system overhead and achieves timing-charge matching even at high counting rates.

V. MONITORS TO THE BEAM TEST SYSTEM

MRPC, as a gaseous detector, is sensitive to gas ratio, flow rate, atmospheric pressure, temperature, and humidity [**?**]. Consequently, temperature, humidity, and atmospheric pressure must be continuously monitored.

A. HV Monitoring and Control

The operating voltage for T0 detectors differs from that of MRPC, requiring two HV systems: the SY127 HV crate and NIM HV module N470 (with $±$1 V variance). The HV module for T0 detectors provides $±$4000 V, while the N470 module for MRPC provides $±$7000 V. The SY127 crate can be controlled via RS232, CAMAC module C139, or VME module V200 [?]; however, C139 and V200 are no longer in production, making RS232 the only viable option. Based on serial port operational principles, a software framework for RS232 communication was developed to control the SY127 crate. SY127 can also be replaced by SY1527, a newer HV system with lower variance and improved communication interface.

B. Environment Monitoring System

Temperature, humidity, and atmospheric pressure in the experimental environment must be recorded to correct experimental results. Since acquisition modules are located far from the control room, RS485 is used for data transmission to avoid signal attenuation over long distances, with converter modules translating between RS485 and RS232. The hardware includes temperature and humidity modules (LTM8901E), A/D converter modules (LTM8903), RS485/RS232 converter modules (LTM8920), acquisition modules (LTM8662), and pressure sensors (PMP1400).

Figure 4 [Figure 4: see original paper] schematically illustrates the environment monitoring system. The pressure sensor outputs a 0–5 V analog signal, requiring an A/D converter module, while temperature and humidity modules include built-in A/D converters, allowing direct connection to the acquisition module. Hexadecimal data from all channels are acquired using LabVIEW's VISA Read function, with results written into a MySQL database.

C. Data Quality Monitoring System

Detector efficiency should be maximized, and experimental data must achieve good statistics, necessitating long data acquisition cycles. Real-time data processing and statistical analysis are required to monitor detector status, which should be displayed online for operators to address abnormal situations. To achieve these goals, Data Quality Monitoring (DQM) software cooperating with DAQ was developed. C++ code based on ROOT, encapsulated into Dynamic Link Library, analyzes spectrum data called from LabVIEW [?].

VI. RESULTS AND DISCUSSION

The scheduled plan was successfully completed, and experimental data were acquired through this beam test system. Figure 5 [Figure 5: see original paper] shows preliminary results for the T0 detector timing resolution. Without any corrections, Fig. 5(a) presents a timing-amplitude scatter plot, with the X-axis representing timing and Y-axis representing amplitude. Figure 5(b) shows a timing histogram, with fitting results indicating a timing resolution of 36.4 ps (= $\sigma \times$ LSB = 1.456 $\times$ 25 ps). After applying time-amplitude corrections to proton-selected data from the raw data (Fig. 5(c)), the T0 detector timing resolution improved to 31.9 ps (Fig. 5(d)). Detailed MRPC data analysis is presented in Ref. [?].

VII. SUMMARY

A test system has been developed for the BESIII ETOF/MRPC beam test. It converts analog signals from the T0 system (consisting of PMTs) and MRPC detector to digital format, ensures synchronized data taking with common triggers, and establishes one-to-one correspondence between data flows from different detectors. Electronics trigger logic is implemented in hardware by adjusting detector signal delays, while the CBLT method is employed in software for multiple electronics modules. High-accuracy QDCs and TDCs are used for precise charge and time measurements, and a monitoring system for high voltage and environmental parameters has been developed. Offline data analysis achieved a T0 detector timing resolution of 31.9 ps, demonstrating that the test system meets its development goals.

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Note: Figure translations are in progress. See original paper for figures.