The test of the electronics system for the BESIII ETOF upgrade (Postprint)

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Abstract

It is proposed to upgrade the endcap time-of-flight (ETOF) of the Beijing Spectrometer III (BESIII) with multi-gap resistive plate chamber (MRPC), aiming at overall time resolution about 80 ps. After the entire electronics system is ready, some experiments, such as heat radiating, irradiation hardness and large-current beam tests,are carried out to certify the electronics' reliability and stability. The on-detector test of the electronics is also performed with the beam at BEPCII E3 line, the test results indicate that the electronics system fulfills its design requirements.

Full Text

Preamble

The Test of the Electronics System for the BESIII ETOF Upgrade

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Abstract: The BESIII endcap time-of-flight (ETOF) detector is proposed to be upgraded with multi-gap resistive plate chamber (MRPC) technology, targeting an overall time resolution of approximately 80 ps. Following completion of the entire electronics system, a series of validation experiments—including heat dissipation, radiation hardness, and high-current beam tests—were conducted to certify the reliability and stability of the electronics. An on-detector test of the electronics was also performed using the beam at the BEPCII E3 line, and the results demonstrate that the electronics system fulfills its design requirements.

Keywords: BESIII, ETOF upgrade, FEE, electronics system, MRPC
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1 Introduction

The Beijing Spectrometer III (BESIII) [1] is a high-precision general-purpose detector designed for high-luminosity e e collisions in the -charm energy region at the Beijing Electron and Positron Collider II (BEPCII) [2]. The current BESIII ETOF detector consists of 248 fast scintillators (BC204) read out with fine-mesh photomultiplier tubes (Hamamatsu R5924) [3], achieving a measured time resolution of 138 ps for mesons (1 GeV/c). The current ETOF modules and schematics of BESIII are shown in [Figure 1: see original paper]. Secondary particles created from multiple scattering in the materials between the MDC endcap and ETOF lead to a high multi-hit rate per channel, particularly for electron events (~71.5%), which deteriorates the time resolution [5].

An upgrade proposal has been approved to replace the current BESIII ETOF with MRPC technology, aiming for an overall time resolution of 80 ps for minimum ionizing particles (MIPs). Beam tests of the MRPC prototype, together with the front-end electronics (FEE) and time digitizer (TDIG) boards, were performed at the BEPC E3 line, achieving a time resolution better than 50 ps as reported in Refs. [6][7][8], thereby verifying the physical design of the new ETOF. In the project design, each ETOF ring contains 36 overlapping MRPCs, as shown in [Figure 2: see original paper], separated into two tiers with 18 MRPC modules each. Each MRPC module is equipped with 12 double-ended readout strips, resulting in higher granularity compared to the current ETOF. The thickness of each gas box is less than 25 mm due to space constraints, and further details about the MRPC module can be found in Ref. [9].

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2 Readout Electronics and Data Acquisition System

The readout electronics system is primarily composed of FEE modules, 9U VME and NIM crates, and the data acquisition system. The FEE utilizes the NINO chip developed by the ALICE-TOF group [10]. Each FEE module features 24 differential input channels and outputs corresponding LVDS signals with the signal charge encoded in the pulse width. The timing accuracy RMS can be better than 15 ps per channel when the input charge exceeds 100 fC [11]. The FEE board is mounted on the surface of the aluminum gas box containing the MRPC module to minimize input capacitance. A flexible printed circuit is designed to connect the MRPC module output with proper impedance (54 Ω). Connectors (QSS-025-01-L-D-A-K and QSS-025-02-L-D-RA-MTI) with 86 pins and shielded differential cables are used to connect the FEE and TDIG modules [12][13], aiming to reduce time jitter from signal transmission and ensure signal quality. To suppress noise, the FEE modules are enclosed in aluminum shielding boxes, as shown in [Figure 3: see original paper].

The CTTP (calibration-trigger-threshold-power) module, housed in a NIM crate, provides power, threshold voltages, and test signals to the FEE. It also receives ORed differential signals from the FEE and generates fast trigger signals after coincidence for charged particle identification. The 9U VME crate contains a PowerPC-based VME controller, the ROC (readout control) module, a clock production module, and TDIG modules. The TDIG modules, based on the ASIC HPTDC chip developed by CERN' s microelectronics group [14][15], receive and digitize signals from the FEE, pack the data in a predefined format, and upload them to the DAQ system via the VME bus. Each TDIG board integrates 72 channels with nine HPTDC chips operating in high-resolution mode, as shown in [Figure 4: see original paper].

The data acquisition system adopts techniques similar to those used in the BESIII experiment, including multi-level buffering, parallel processing, high-speed VME readout, and network transmission. The schematic of the readout electronics system for the ETOF upgrade is shown in [Figure 5: see original paper]. The electronics system operates in two distinct modes: data-taking mode and calibration mode, which are controlled by the ROC module. The calibration mode is primarily used to verify proper system operation. In data-taking mode, the ROC receives control signals such as clock and trigger from other BESIII systems and forwards them to the TDIG modules for initialization. In calibration mode, the ROC generates these standard signals internally to characterize the system. The ROC module sends signals to the CTTP to generate test pulses and to the TDIG to control time measurements. Upon completion of measurements, the ROC module generates an interrupt signal on the VME bus, prompting the DAQ system to read out data from the TDIG modules and deliver them to the computer.

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3 Tests of the Electronics System

Reliability testing of the electronics system is essential, particularly for the FEE. According to the project design, each MRPC module together with its FEE will be mounted on the endcap EMC. If either the FEE or MRPC module requires repair, the endcap EMC must first be detached—a process that takes two weeks to complete. Consequently, repairs are impossible during data-taking periods. In the endcap region, the dose rate at the FEE location reaches approximately 2000 rad after 10 years of BEPCII operation. Additionally, the overlapping detector structure is not conducive to FEE heat dissipation. Based on these considerations, comprehensive reliability tests are necessary for the electronics system.

3.1 Parameter Adjustment

The leading and trailing edge times are measured accurately using the search window and trigger latency settings in the TDIG module. The width of the leading or trailing time distribution is approximately 25 ns due to clock uncertainty, and the signal width is about 25 ns. The search window width is set to 1600 ns, consistent with the BESIII TOF system. Following parameter adjustment, the leading/trailing time and time-over-threshold (TOT) distributions are obtained, as shown in [Figure 6: see original paper]. The few hits located outside the signal region reflect the noise level.

When the readout electronics and DAQ system were ready, initial data-taking was performed for calibration to verify correct operation of the electronic chain (FEE, CTTP, cables, TDIG). Considering the integral non-linearity correction of time measurement [13], the average time resolution of the electronics is approximately 25 ps, as shown in [Figure 7: see original paper], demonstrating the feasibility of system-level time monitoring.

3.2 Heat Dissipation Test

A heat dissipation test of the FEE electronics was conducted using two temperature sensors to monitor temperature during operation. The sensor locations are shown in [Figure 8: see original paper]: (A) near the signal collection and transmission circuit, and (B) near the NINO chip in the signal processing circuit. The FEE electronics combined with the MRPC module were placed in a sealed box.

The test results are shown in [Figure 9: see original paper]. At the beginning of the test, the temperature at Point B rose rapidly when the FEE started operating. After sufficient heat exchange over time, the temperatures at both Points A and B remained below 30°C, as required by the BESIII experiment. Overall, the temperature at Point A was 1-2°C above room temperature, while Point B was 4-5°C above room temperature. During the test period, the CTTP current remained stable, as shown in [Figure 9: see original paper], and the FEE system operated normally. Under future running conditions, dry air will continuously flow over the detector surfaces, ensuring reliable FEE operation.

3.3 Irradiation Hardness Test

An irradiation hardness test was performed using a Co source at the Academy of Military Medical Sciences. The electronics system was exposed to the radioactive source, and its performance was studied at different dose rates. As shown in [Figure 10: see original paper], the electronics system resolution remained stable as the dose increased from 500 rad to 43,500 rad.

3.4 High-Current Beam Test

A high-current beam test was conducted to examine the FEE protection circuit. The test was performed at the BEPC E2 line using a 2.5 GeV incident electron beam. The FEE and MRPC module were placed in the beam path at normal operating high voltage. The beam intensity was increased from 10 to 10 electrons at a frequency of 12.5 Hz. At higher intensities, the high voltage could not maintain its normal value because the MRPC leakage current exceeded the set threshold. Therefore, the beam intensity was increased and decreased iteratively to maintain normal high voltage conditions. After approximately two hours of testing, the FEE continued to operate normally, indicating that the FEE protection circuit is reliable.

3.5 On-Detector Test

An on-detector test of the electronics was performed at the BEPC E3 line using secondary particles (e /e ,   / , protons, etc.) [15]. The beam test setup is shown in [Figure 11: see original paper]. The trigger was provided by the coincidence signal from two scintillators. The MRPC modules were placed on a movable platform, allowing different pad centers to be positioned in the trigger region.

The MRPC high voltage was supplied by N471A modules. The MRPC working gas composition was 90% Freon + 5% SF + 5% iso-C H   for the test, with a gas flow rate of 60 ml/min supplied to the MRPC modules. The test system logic diagram is shown in [Figure 12: see original paper]. The flight time between S1 and S2 was used to identify pions and protons, as shown in [Figure 13: see original paper]. Due to limited pion statistics, proton events were selected for MRPC performance analysis.

The time measured by the MRPC was corrected for slewing using an iterative method [8]. The time-TOT correlation for each MRPC module was fitted using the mean time of the other two modules as the reference time (T). The corrected time was then used as the new T to generate an improved Time-TOT distribution for each module. The time resolution of each pad was better than 50 ps, with an average efficiency of approximately 98%, as shown in [Figure 14: see original paper]. The detector performance is consistent with previous beam tests, indicating that the electronics, including the newly incorporated modules, meet project requirements.

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4 Conclusions

The upgrade of the BESIII ETOF with MRPC technology has been approved. After the electronics and DAQ system were completed, parameter adjustment was performed first. Subsequently, irradiation hardness, heat dissipation, and high-current beam tests were carried out to demonstrate that the electronics system, particularly the FEE, is reliable and stable. The on-detector test of the electronics was also performed with the beam at the BEPCII E3 line, achieving a time resolution better than 50 ps and detection efficiency exceeding 98%. These results indicate that the electronics satisfy the design requirements, and the entire system is ready for mass production.

References

[10] F. Anghinolfi, P. Jarron, F. Krummenacher et al., IEEE Trans. on Nucl. Sci., 51(5): 1974, 2004.
[11] M. Despeisse, P. Jarron et al., IEEE Trans. on Nucl. Sci., 56(2): 375, 2009.
[14] M. Mota, J. Christiansen, S. Debieux et al., IEEE Nucl. Sci. Symposium, Lyon (2000).

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