BESIII ETOF upgrade readout electronics commissioning*

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Abstract: It is proposed to upgrade the endcap time-of-flight (ETOF) of the Beijing Spectrometer III (BESIII) with a multi-gap resistive plate chamber (MRPC), aiming at an overall time resolution of about 80 ps. After completing the entire readout electronics system, some experiments, such as heat radiation, radiation hardness and large-current beam tests, have been carried out to confirm the reliability and stability of the readout electronics. An on-detector test of the readout electronics has also been performed with the beam at the BEPCII E3 line. The test results indicate that the readout electronics system fulfills its design requirements.

Keywords: BESIII,upgrade of endcap TOF,FEE,the readout electronics system,MRPC

PACS: 29.40.Cs **DOI:** 10.1088/1674-1137/41/1/016103

1 Introduction

The Beijing Spectrometer III (BESIII) [1] is a high precision general-purpose detector designed for high luminosity e^+e^- collisions in the τ-charm energy region at the Beijing Electron and Positron Collider II (BEPCII) [2]. The current BESIII ETOF detector consists of 2 × 48 fast scintillators (BC204) readout with fine-mesh photomultiplier tubes (Hamamatsu R5924) [3]. The time resolution measured is 138 ps for π (1GeV/c)). The current ETOF modules and schematics of BESIII are shown in Fig. 1. The secondary particles created from multiple scattering on the materials between the MDC endcap and ETOF lead to a high multi-hits rate (per channel), especially for electron events (71.5%), which lead to lower time resolution [5].

A proposal has been approved to upgrade the current BESIII ETOF with MRPC technology, aiming at an overall time resolution of 80 ps for MIPs. Beam tests for the MRPC prototype, together with the FEE and time digitizer (TDIG) boards, were performed at the BEPC E3 line. Time resolutions of better than 50 ps were obtained, as described in Refs. [6–8], which verified the physical design of the new ETOF.

In the project design, each ETOF ring has 36 overlapping MRPCs, as shown in Fig. 2. They are separated into 2 tiers with 18 MRPC modules in each endcap. Each MRPC module is equipped with 12 double-end readout strips, which results in higher granularity compare to the current ETOF. The thickness of each gas box is less than 25 mm, limited by the available space. More details of the MRPC module can be found in Ref. [7].

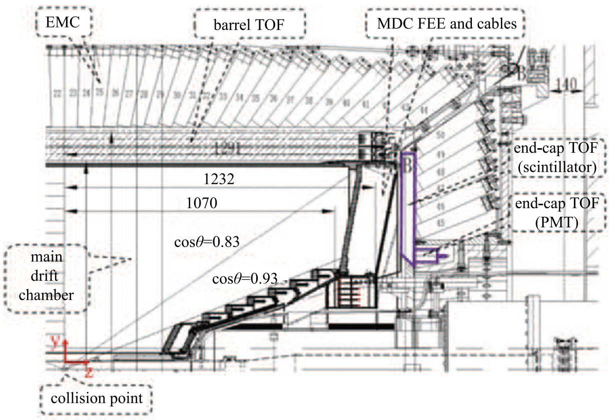

Fig. 1. Schematics of BESIII ETOF.

In this paper, we report the tests of the readout electronics system, in which the front-end electronics

Received 10 March 2016, Revised 10 May 2016
* Supported by Chinese Academy of Sciences (1G201331231172010)

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(FEE), clock, fast control board and calibration-trigger-threshold-power (CTTP) modules are re-designed and incorporated. In the following sections, the readout electronics and data acquisition system are introduced. Then the tests of the readout electronics, including parameter adjustment, heat radiating, radiation hardness and large-current beam, are presented. The on-detector test of the readout electronics and its results are described and discussed in detail. A conclusion is given at the end.

Fig. 2. Structure of BESIII ETOF ring.

2 Readout electronics and data acquisition system

The readout electronics is mainly composed of the FEEs, 9U VME and NIM crate, together with the data acquisition system. The FEE makes use of the NINO chip developed by the ALICE-TOF group, which is an ultra-fast, low power, front-end amplifier discriminator for time-over-threshold (TOT) measurement [9]. Each FEE module features 24 differential input channels and outputs corresponding to LVDS signal with the signal charge encoded in its width. The timing accuracy RMS can be better than 15 ps for each channel when the input charge is larger than 100 fC [10]. The FEE board is fixed on the surface of an aluminum gas box which contains the MRPC module, in order to reduce the input capacitance. A flexible printed circuit is designed to connect the MRPC module output with proper impedance (54 Ω). A connector (QSS-025-01-L-D-A-K and QSS-025-02-L-D-RA-MTI) with 86 pins and a shielded differential cable are used to connect the FEE and the TDIG [11, 12], aiming to reduce the time jitter from signal transmission and ensuring the signal quality. In order to suppress the noise, the FEEs are coated with aluminum shielding boxes. Diagrams of the FEE and shield boxes are shown in Fig. 3.

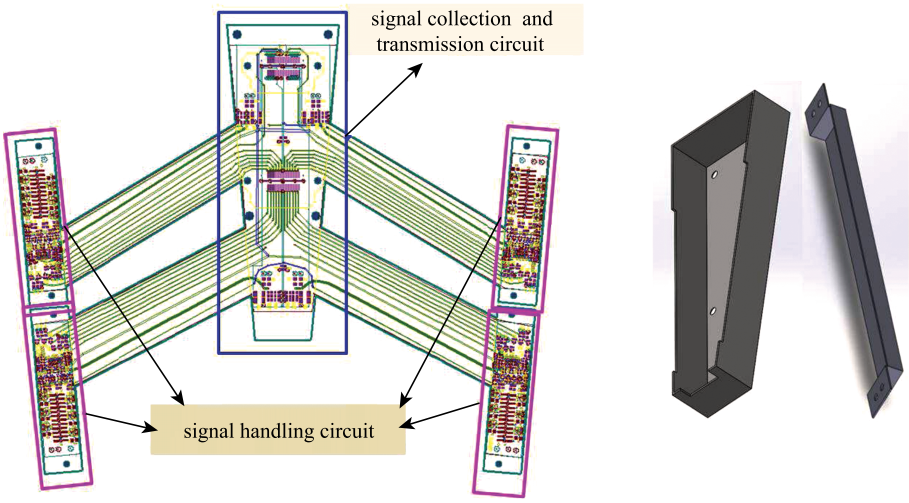

Fig. 3. Schematics of FEE board and shielding boxes.

The CTTP module, which is housed in a NIM crate, provides power, threshold and test signals to the FEE. It also receives the OR differential signals from the FEE and produces fast trigger signals after coincidence for charged particle identification.

The 9U VME crate consists of the VME controller of the Power PC board, the readout control module of the ROC, the clock production module, and the TDIG module [12]. The TDIG modules, relying on the ASIC HPTDC chip developed by the microelectronics group at CERN [13], focus on receiving and digitizing the signals from the FEE, packing the data with a predefined format and uploading them to the data acquisition (DAQ) system via the VME bus. Each TDIG board integrates 72 channels with 9 HPTDC chips operating in high resolution mode. A photograph of the TDIG is shown in

Fig. 4.

The data acquisition system is similar to that at the BESIII experiment, using multi-level buffering, parallel processing, high-speed VME readout and network transmission. A schematic of the readout electronics system for the ETOF upgrade is shown in Fig. 5.

Fig. 4. Photograph of the TDIG module.

There are two separate working modes for the readout electronics system, namely data taking mode and calibration mode, which are determined by the ROC module. The latter is mainly used to verify that the system works properly. In data taking mode, the ROC receives a series of control signals, such as "clock" and "trigger", from other systems at BESIII and sends them to the TDIG module to initialize. In calibration mode, the ROC generates these standard signals by itself to check the system. The ROC module sends signals to the CTTP to generate the test signals and to the TDIG to control the time measurements. Upon completion of the measurements, the ROC module will produce an interrupt signal on the VME bus, then the data acquisition system will read out the data from the TDIG module and deliver them to the computer.

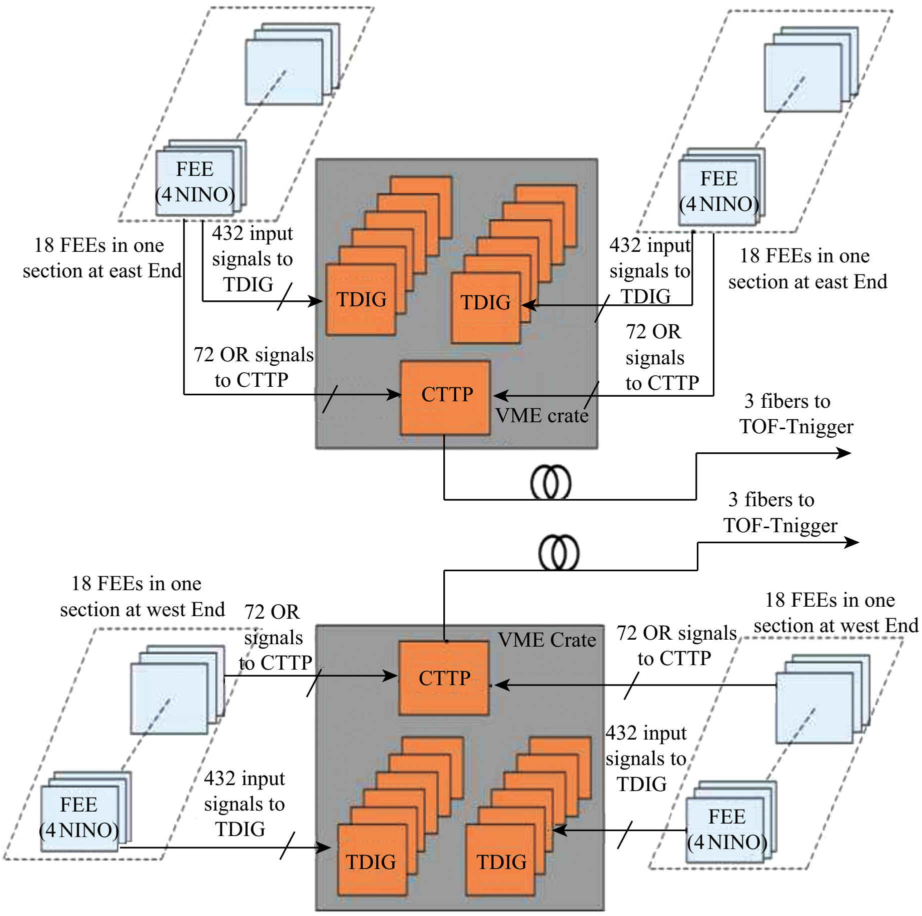

Fig. 5. Schematic of readout electronics for the entire MRPC-based ETOF system.

3 Test of readout electronics system

According to the project design, each MRPC module together with FEE will be mounted on the endcap electromagnetic calorimeter (endcap EMC). If the FEE or MRPC module needs to be repaired, the endcap EMC should first be detached. It takes two weeks to pull out and push in the endcap EMC, so it is impossible to repair them during the data taking period. In the endcap area, the total dose where the FEEs are located is about 2000 rad after 10 years' running of BEPCII. The overlapping structure of the detectors is not conducive to FEE heat radiation. Based on the above points, reliability tests are necessary for the readout electronics system, especially for the FEE.

3.1 Parameter adjustment

The leading and trailing times are accurately measured relying on the search window and trigger latency in the TDIG module. The width of leading or trailing time distribution is about 25 ns due to the clock uncertainty, and the width of the signal is about 25 ns. The width of the search window is set at 1600 ns, the same as that used for the BESIII TOF. After the parameter adjustment, the leading and trailing time and TOT distributions were obtained, as shown in Fig. 6. The few hits located outside the signal region reflect the noise level.

When the readout electronics and data acquisition system were completed, the first data taking was done for the calibration to check whether the electronics chain (FEE, CTTP, cables, TDIG) worked correctly. A square signal for monitoring was generated by the CTTP, and controlled by the ROC. The amplitude of the signal can be 0–2 V and the rise time is 4–5 ns (after 8.5 m cable transmission). A square signal was sent to the NINO chip with 10 pf capacitance coupling. Considering the integral non-linearity correction of time measurement [12], the average time resolution of readout electronics is about 25 ps, as shown in Fig. 7, which shows the feasibility of system-level time monitoring in the future.

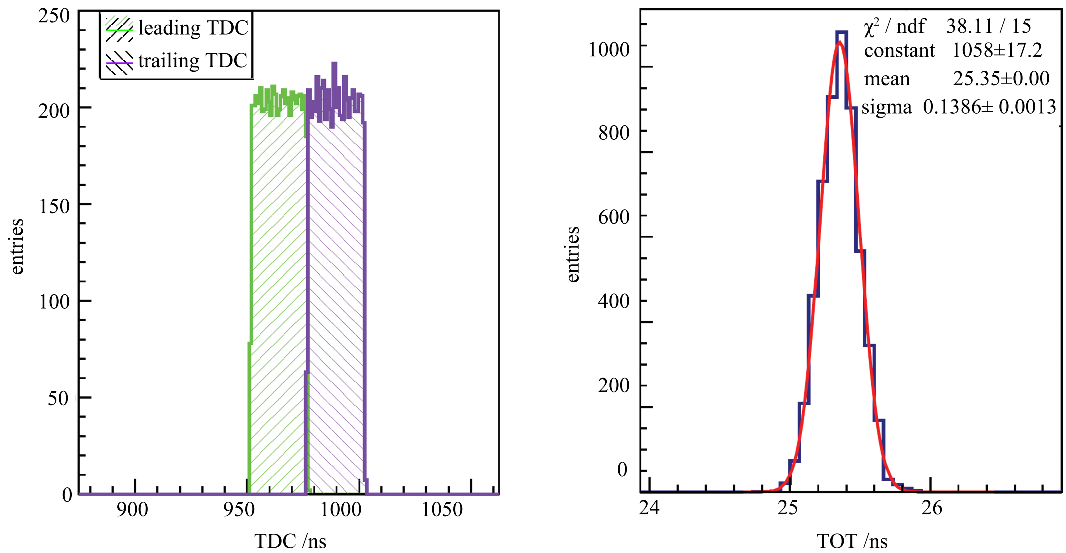

Fig. 6. (color online) Leading and trailing time spectrum (left) and TOT distribution (right).

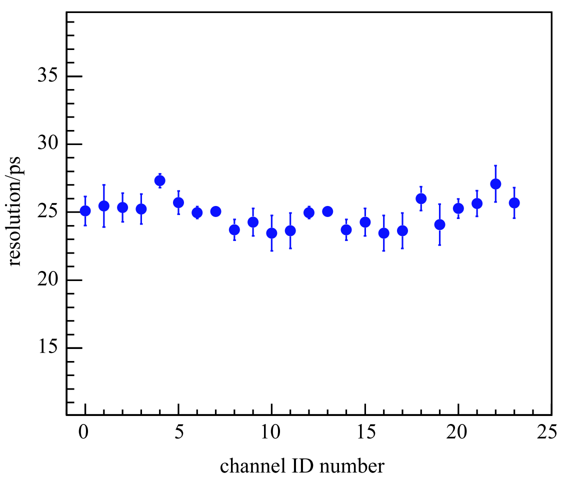

Fig. 7. Time resolution for different channels.

3.2 Heat radiation test

A heat radiation test of the FEE electronics was carried out. Two temperature sensors were used to detect the temperature while the FEE was working. The locations of the two sensors is shown in Fig. 8: Point A was near the signal collection and transmission circuit, and Point B was near the NINO chip in the signal handling circuit. The FEE electronics combined with the MRPC module was put into a airtight box.

The test results are shown in Fig. 9. At the beginning of the test, the temperature of Point B rises rapidly when the FEE starts working. After sufficient heat exchanging for a certain time, the temperatures of Point A and B can both keep below 30 degrees, as required by the BESIII experiment. On the whole, the temperature of Point A can be 1°–2° higher than room temperature; the temperature of Point B can be 4°–5° higher than room temperature. The temperature increases at 14000 s and 22000 s; this was deliberately controlled by the air conditioner to check the effect of external temperature change on the commissioning of readout electronics. During the testing time, the CTTP current was stable, as shown in Fig. 9, and the FEE system worked normally. Under future running conditions, there will be dry air blowing over the surface of the detectors all the time, so the working of the FEE should be reliable.

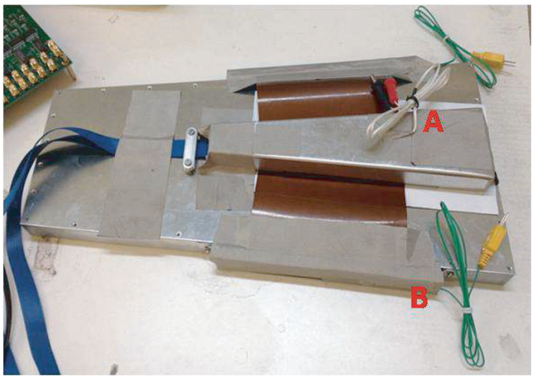

Fig. 8. Photograph of the two sensor locations in the heat radiation test.

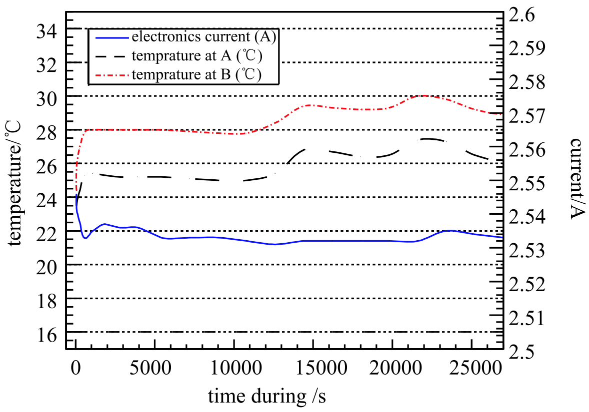

Fig. 9. Results of heat radiation test.

3.3 Radiation hardness test

The radiation hardness test was done with ^{60}Co at the Academy of Military Medical Sciences, China. The readout electronics system was exposed to a ^{60}Co radioactive source. The performance of the readout electronics was studied with different irradiation doses. The dose rate was 190 rad/s when the total dose is less than 3500 rad, and after that the rate of 760 rad/s was used. From the results in Fig. 10, the resolution of the readout electronics system kept steady with the dose increasing from 500 rad to 43500 rad.

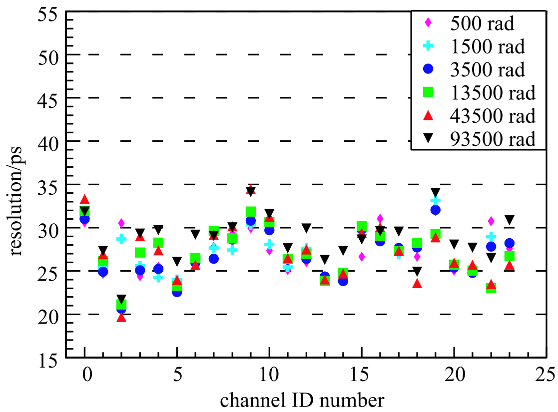

Fig. 10. Timing resolution for different channels under different levels of irradiation.

3.4 Large-current beam test

A large-current beam test was also carried out to examine the protection circuit of the FEE. The test was performed at the BEPC E2 line using a 2.5 GeV incident electron beam. The FEE and MRPC module was put in the path of the beam and the high voltage of the MRPC was at the normal value. The beam intensity increased from 10^5 electrons to 10^8 electrons at a frequency of 12.5 Hz. As the beam intensity increased, the high voltage could not stay at normal values because the leak current of the MRPC exceeded the setting value. So we increased and decreased the beam intensity iteratively, keeping the hitting under normal HV conditions. The whole test lasted about two hours, over which the FEE worked normally, which indicates that the protection circuit of the FEE is reliable.

3.5 The on-detector test

An on-detector test of the readout electronics was performed at the BEPC E3 line using the secondary particles ($e^{+/-}$, $\pi^{+/-}$, p, etc) [14]. The setup of the beam test is shown in Fig. 11. The trigger was provided by the coincidence signal of two scintillators. The MRPC modules were placed on a movable platform and the center of different pads was moved to the trigger region.

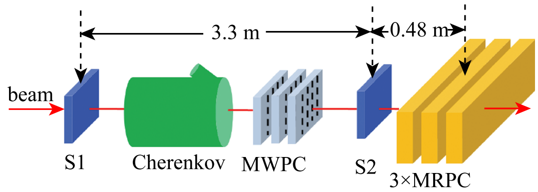

Fig. 11. Setup of the beam test system.

The high-voltages of the MRPCs are provided by N471A modules. The composition of the MRPC working gas was 90%Freon + 5%SF_6 + 5%iso-C_4H_{10} for the test. The gas flux rate was supplied at 60 ml/min to the

MRPC modules. The logic diagram of the test system is shown in Fig. 12.

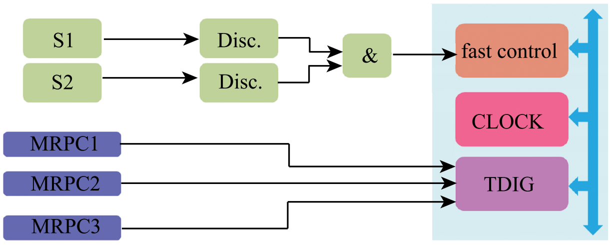

Fig. 12. The module logic diagram of the test system.

The flight time between points S1 and S2 is used to identify pions and protons, as shown in Fig. 13. Since there are limited statistics for pions, we selected proton events for our MRPC performance analysis.

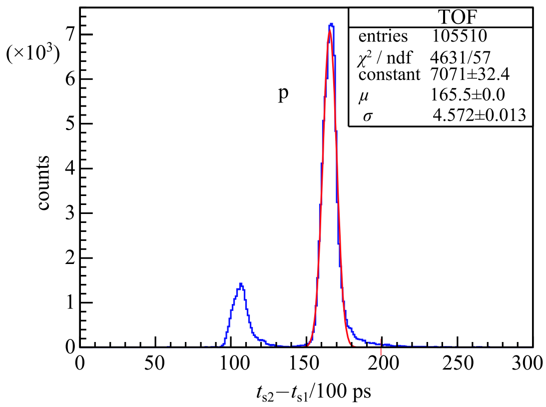

Fig. 13. Particle identification of s_2 and s_1 @ 800 MeV.

The time measured by the MRPC is corrected for slewing by the iteration method [8]. The Time-TOT correlation for each MRPC module is fitted with the mean time of the other two as the reference time (T_r), then the corrected time is used as T_r instead of the primary time. A new Time-TOT distribution is then drawn for each one, which will be more exact than the primary one since they have a better reference time. The detection efficiency of the middle MRPC (named MRPC2) is defined as the proportion of events where both ends of the strip covered by MRPCs on both sides (named MRPC1, MRPC3) have valid signals. The time resolution of each pad is better than 50 ps, and the average efficiency is almost 98%, as shown in Fig. 14. The performance of the detectors is consistent with previous beam tests, which indicates that the readout electronics, including the firstly incorporated ones, meet the project requirements.

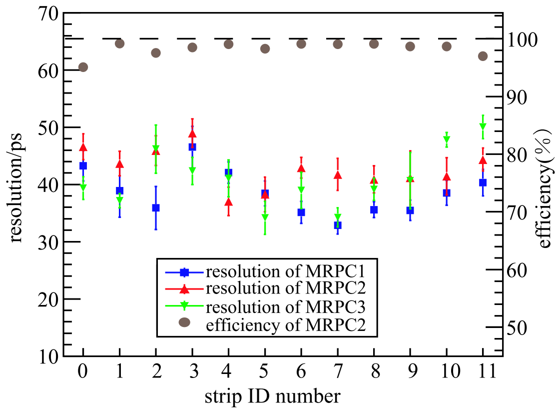

Fig. 14. Time resolution and efficiency versus strip ID number.

4 Conclusions

The upgrade of the BESIII ETOF with MRPC technology has been approved. After the readout electronics and DAQ system were ready, the parameters were first adjusted. Radiation hardness, heat radiation and large current beam tests were then carried out to prove that the readout electronics system, especially the FEE, is reliable and stable. An on-detector test of the readout electronics was also performed with beam at BEPCII E3 line, and a time resolution of less than 50 ps and detecting efficiency over 98% were obtained. These results indicate that the readout electronics satisfy the design requirements, and the whole system is ready for mass production.

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