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The construction of the BESIII experiment

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ABSTRACT

BESIII is a high precision, general purpose detector for the high luminosity e^+e^- collider, BEPCII, running at the tau-charm energy region. Its design and current status of construction is presented.

1. Introduction

The BESIII detector [1] is designed for the e^+e^- collider running at the tau-charm energy region, called BEPCII, which is currently under construction at IHEP, Beijing, PR China. The accelerator has two storage rings with a circumstance of 224 m, one for electron and one for positron, each with 93 bunches spaced by 8 ns [2]. The total current of the beam is 0.93 A, and the crossing angle of two beams is designed to be 22 mrad. The peak luminosity is expected to be $10^{33}\,\mathrm{cm^{-2}\,s^{-1}}$ at the beam energy of 1.89 GeV, the bunch length is estimated to be 1.5 cm and the energy spread will be 5.16×10^{-4}. At this moment, the LINAC has been installed and successfully tested, all the specifications are satisfied. The storage rings have been installed, and have been commissioned for synchrotron radiation run last year. The physics program of the BESIII experiment includes light hadron spectroscopy, charmonium, electroweak physics from charm mesons, QCD and hadron physics, tau physics and search for new physics, etc. Due to its huge luminosity and small energy spread, the expected event rate per year is historical, as listed in Table 1.

In order to achieve its physics goal and fully utilize the potential of the accelerator, the BESIII detector [1], as shown in Fig. 1, is designed to consist of a drift chamber in a small cell structure filled with a helium-based gas, an electromagnetic calorimeter made of CsI(Tl) crystals, time-of-flight (TOF) counters for particle identification made of plastic scintillators, a muon system made of resistive plate chambers (RPC), and a superconducting magnet providing a field of 1 T. In the following, all the sub-detectors will be described together with results of their performance tests.

2. Drift chamber

The drift chamber has a cylindrical shape with two chambers jointed at the end flange: an inner chamber without outer wall and an outer chamber without inner wall. There are a total of six stepped end flanges made of 18 mm Al plates, as shown in Fig. 2, in order to give space for the focusing magnets. The inner radius of the chamber is 63 mm and the outer radius is 810 mm, with a length of 2400 mm. Both the inner and outer cylinder of the chamber are made of carbon fiber with a thickness of 1 and 10 mm, respectively. A total of 7000 gold-plated tungsten wires (3% Rhenium) with a diameter of 25 μm are arranged in 43 layers, together with a total of 22,000 gold-plated Al wires for field shaping. The small drift cell structure of the inner chamber has a dimension of $6\times6\,\mathrm{mm}^2$ and the outer chamber of $8\times8\,\mathrm{mm}^2$, filled with a gas mixture of 60% helium and 40% propane. The designed single wire spatial resolution and $\mathrm{d}E/\mathrm{d}X$ resolution are 130 μm and 6%, respectively.

The mechanical structure of the drift chamber, including the ultra-high precision (20 μm) drilling of a total of 30,000 holes, and the high precision (50 μm) assembly have been completed successfully. A total of 30,000 wiring are completed with a very high quality, the wire tension and the leakage current are well controlled.

Several prototypes of the chamber have been tested at the beam in KEK and IHEP [3,4]. Good results have been obtained in all the cases. Figs. 3 and 4 show the result of a full length chamber prototype test in the IHEP E3 beam line using the actual setup of 160 channels of readout electronics, including amplifiers, readout modules, cables, connectors, and the grounding setup. A prototype of readout electronics with 512 channels including the data acquisition system has been also tested in the laboratory for its long-term stability. At this moment, the cosmic-ray test of the chamber in the BESIII have been finished. Every channel of drift chamber runs smoothly; the hitmap, Q distribution and T distribution of MDC are ok at cosmic ray tests.

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Table 1
τ-Charm production at BEPC-II in one year's running

Data sample	Central-of-mass energy (MeV)	Luminosity ($10^{33}\,cm^{-2}\,s^{-1}$)	# Events per year
J/ψ	3097	0.6	10×10^{9}
$\tau^{+}\tau^{-}$	3670	1.0	12×10^{6}
$\psi(2S)$	3686	1.0	3.0×10^{9}
$D^{0}\bar{D}^{0}$	3770	1.0	18×10^{6}
$D^{+}D^{-}$	3770	1.0	14×10^{6}
$D_S^{+}D_S^{-}$	4030	0.6	1.0×10^{6}
$D_S^{+}D_S^{-}$	4170	0.6	2.0×10^{6}

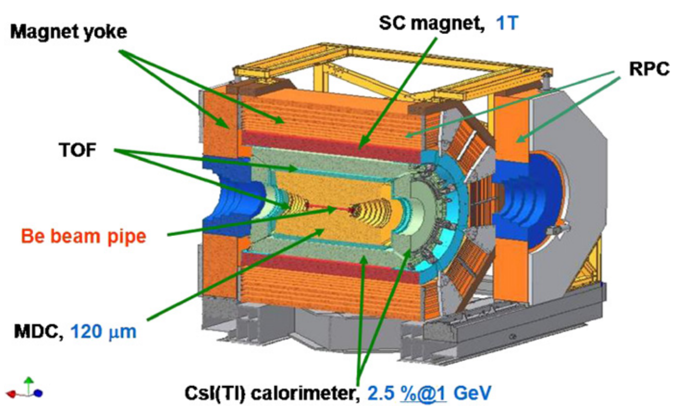

Fig. 1. Schematics of the BESIII detector.

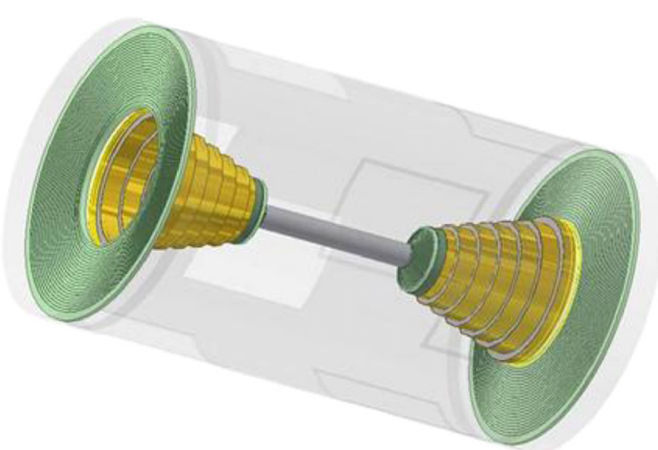

Fig. 2. The schematic view of the drift chamber.

3. CsI(Tl) crystal calorimeter

The CsI(Tl) crystal electromagnetic calorimeter consists of 6240 crystals, 5280 in the barrel, and 960 in two endcaps. Each crystal is 28 cm long, with a front face of about $5.2\times5.2\,cm^2$, and a rear face of about $6.4\times6.4\,cm^2$. All crystals are tiled by 1.5° in the azimuth angle and 1–3° in the polar angle, respectively, and point to a position off from the interaction point by a few centimeters as shown in Fig. 5. They are hanged from the back by four screws without partition walls in order to reduce dead materials. The designed energy and position resolution are 2.5% and 6 mm at 1 GeV, respectively. The light yield of barrel crystals is about 58% with respect to the reference crystal, as shown in Fig. 6, much more than the specification of more than 35. The

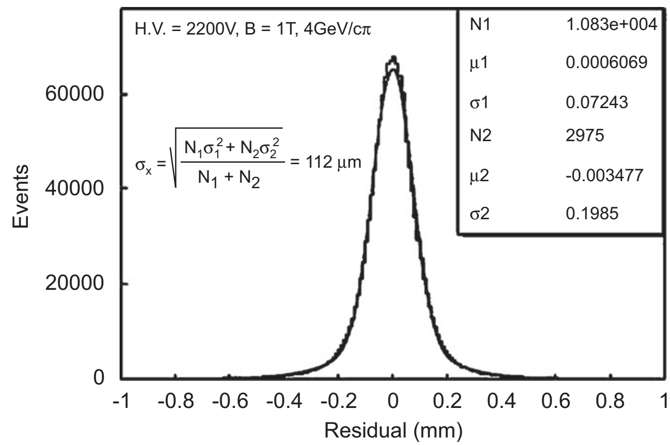

Fig. 3. The averaged single wire resolution.

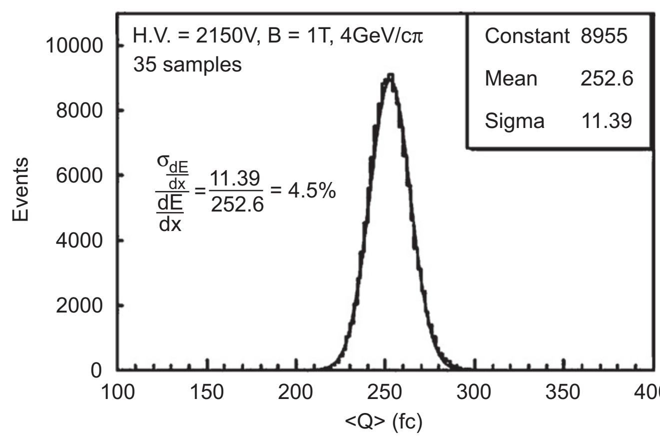

Fig. 4. The dE/dX resolution obtained from 80% truncated mean.

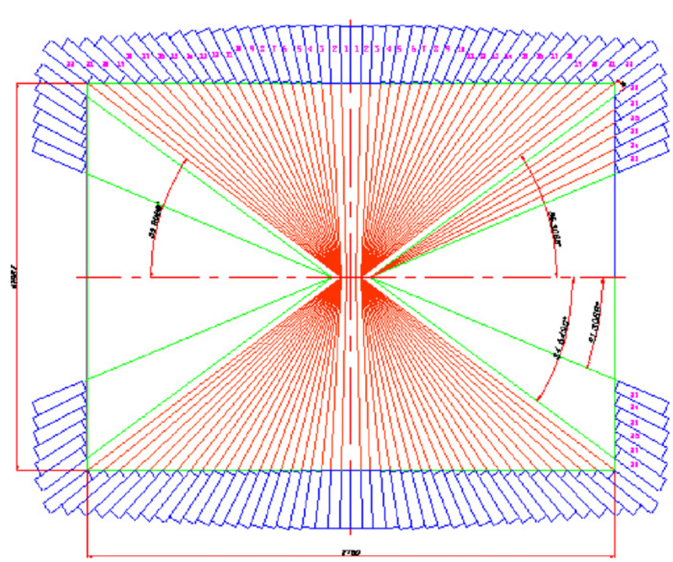

Fig. 5. Schematic view of the CsI(Tl) crystal calorimeter.

average uniformity is better than 5%, while the specification is less than 7%. A lot of radiation damage tests of crystals have been done. The performance of all the photodiodes before and after the

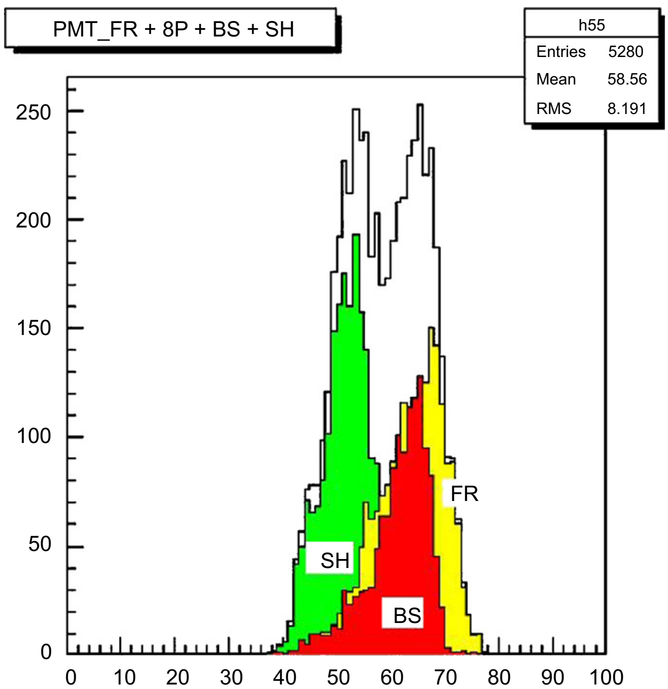

Fig. 6. Relative light output of barrel crystals.

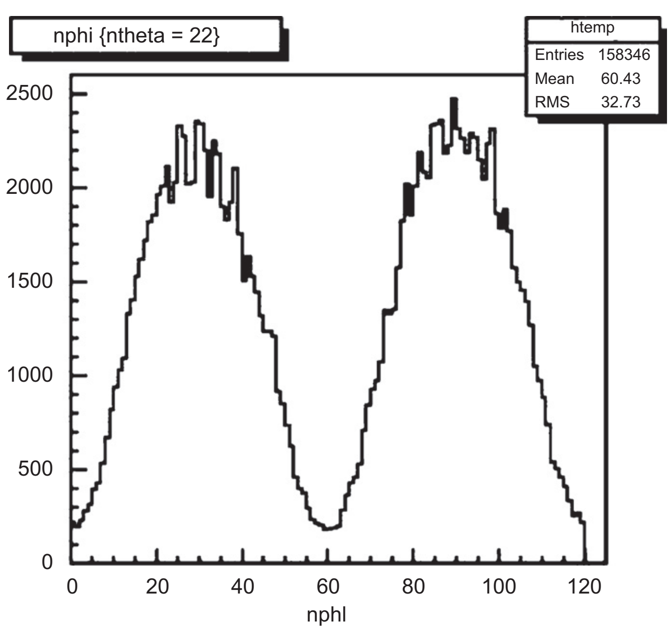

Fig. 7. Hitmap of cosmic-ray test for EMC.

accelerated aging, such as dark current, noise, photon–electron conversion efficiency and capacitance, etc., have been tested. All crystals have been tested using cosmic rays. Currently, the electromagnetic calorimeter has been installed into the iron yoke of the BESIII.

The readout electronics of crystals, including the preamplifier, the main amplifier and charge measurement modules are tested at the IHEP E3 beam line together with a crystal array and photodiodes. Results from the beam test show that the energy resolution of the crystal array reached the design goal of 2.5 at% 1 GeV and the equivalent noise achieved the level of less than 1000 electrons, corresponding to an energy of 220 keV. A prototype with 384 channels has been tested for long-term stability. Every channel of EMC runs smoothly at cosmic-ray tests; the hitmap and Q distribution of EMC are ok, the hitmap of one 120 crystals ring as shown in Fig. 7.

4. Time-of-flight system

The particle identification at BESIII is based on the momentum and dE/dx measurements by the drift chamber, and the TOF measurement by plastic scintillators. The barrel scintillator bar is 2.4 m long, 5 cm thick and 6 cm wide. A total of 176 such scintillator bars constitute two cylinders, to have a good efficiency and time resolution. For the endcap, a total of 48 fan-shaped scintillators form a single layer. A 2 in fine mesh phototube is directly attached to each scintillator to collect the light. The intrinsic time resolution is designed to be 90 ps including contributions from electronics and the common time corresponding to the beam crossing. Such a time resolution, together with contributions from the beam size, momentum uncertainty, etc., can distinguish charged π from K mesons for a momentum up to 0.9 GeV at the 2σ level.

Beam tests of TOF prototypes have been performed at IHEP E3 beam line using pions, electrons and protons [5,6]. Different scintillator types such as BC404, BC408 and EJ200, with different thickness are tested, together with different wrapping materials. The results, as shown in Fig. 8, show that the time resolution using a prototype of readout electronics including actual cables are better than 90 and 75 ps for the barrel and the endcap, respectively. Currently, installation of the TOF has been completed in BESIII, and cosmic-ray test has been finished. Every channel of TOF runs smoothly; the hitmap and Q distribution of TOF are ok.

5. Muon counter

The BESIII muon chamber is made of RPC interleaved in the magnet yoke. There are a total of nine layers in the barrel and eight layers in the endcap, with a total area of about 2000 m^2. The

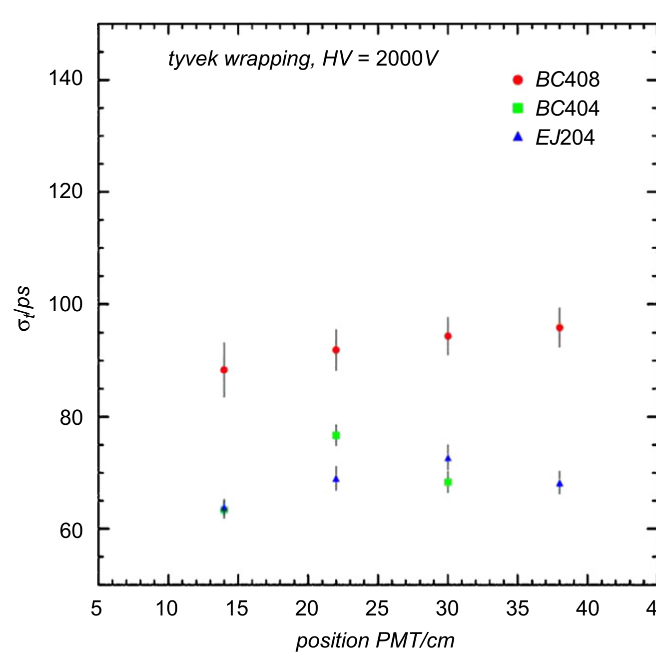

Fig. 8. Time resolution of the endcap TOF module from a beam test.

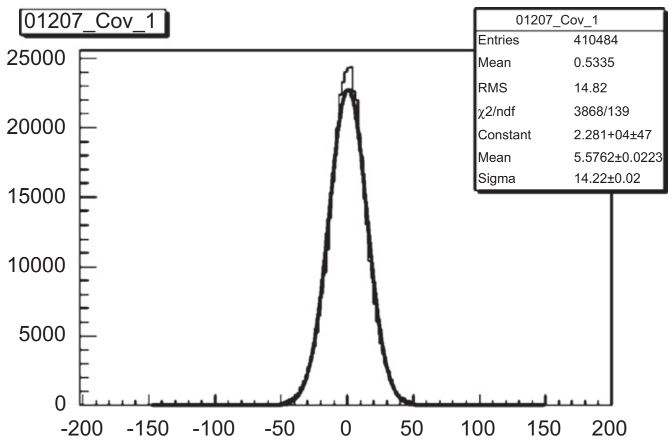

Fig. 9. RPC spatial resolution using cosmic rays.

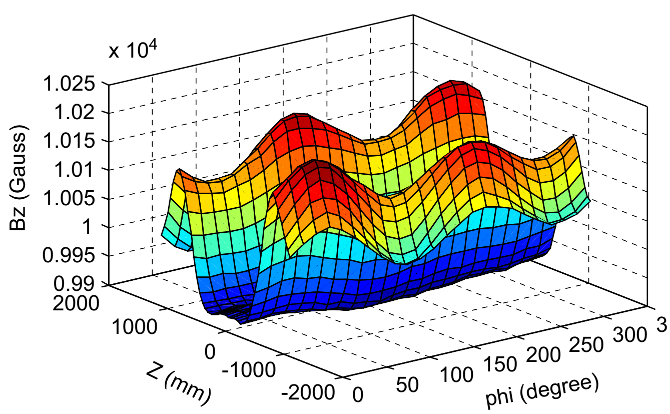

Fig. 10. Field map of SCM.

readout strip is 4 cm wide, alternated between layers in x and y directions. The RPC is made of bakelite with a special surface treatment without linseed oil [7]. Such a simple technique for the RPC production shows a good quality and stability at a low cost. All RPCs have been manufactured, tested, assembled and installed with satisfaction. Fig. 9 shows the spatial resolution after installation using cosmic rays.

6. Super-conducting magnet

The BESIII super-conducting magnet has a radius of 1.48 m and a length of 3.52 m. It use the Al stabilized NbTi/Cu conductor with a total of 920 turns, making a 1.0 T magnetic field at a current of 3400 A. The total cold mass is 3.6 t with a material thickness of about 1.92×0. In collaboration with WANG NMR of California, the magnet is designed and manufactured at IHEP. The magnet was successfully installed into the iron yoke of the BESIII, together with the valve box. The magnet has been successfully cool down to the super-conducting temperature with a heat load within the specification. A stable magnetic field of 1.0 T at a current of 3368 A was achieved. The dump resistor and dump diode, switches of the quench protection devices are installed and tested successfully. Fig. 10 shows the field map of SCM.

7. Trigger and DAQ system

The BESIII trigger rate is estimated to be about 4000 Hz and the trigger system is designed largely based on the latest technology

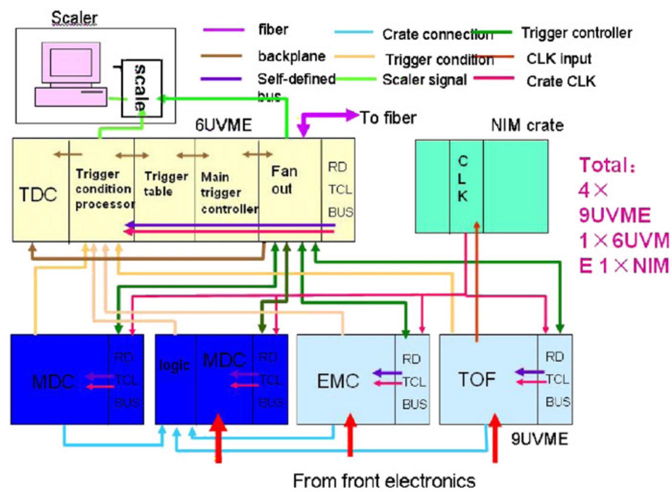

Fig. 11. Trigger systems and their inter-connection.

such as fiber optics, pipelines and FPGA chips. Fig. 11 shows the schematics of the trigger systems and their interconnections. Information from sub-detector electronics is fed into sub-detector trigger system via fiber optical cables in order to avoid grounding loops. The VME-based main trigger and all the sub-trigger boards communicate with each other via copper cables. All trigger logic stored in FPGA chips are programmable and can be downloaded via VME bus. The trigger latency is designed to be 6.4 μs and the pipeline technique is used for all the readout electronics. The radiation hardness of fiber cables and their connectors are tested at BEPC beam test facility. Some of the sub-trigger systems share the same hardware design of the board using different firmware in order to reduce number of board types and save the cost. Latest large FPGA chips with RocketIO technology are adopted in such a board design. The test and installation of trigger system has been completed.

The total data volume at BESIII is about 50 Mbytes/s for a trigger rate of about 4000 Hz. The DAQ system shall read out the event fragments from the frontend electronics distributed over more than 40 VME crates, and build them into a complete event to be transmitted for recording on the persistent media. A simplified structure of the BESIII DAQ system is shown in Fig. 12. The DAQ software, based on the ATLAS TDAQ, includes database configuration, data readout, event building and filtering, run control, monitoring, status reporting and data storage, etc. Every component has been tested successfully at an average event rate of 8000 and 4500 Hz with an event size of 12 and 25 kB, respectively. The software has been used for cosmic-rays and beam test for a Drift Chamber prototype and an EMC crystal array. Different working modes such as normal data taking, baseline, calibration, debugging of the readout electronics and waveform sampling have been tested. As a distributed system, the entire DAQ system must keep synchronized, so a state machine is implemented in the PowerPC readout subsystem to keep the absolute synchronization with the DAQ software, which guarantees the coherency of the whole system. The DAQ software runs smoothly at cosmic-ray tests. Fig. 13 shows DAQ software at cosmic-ray tests of whole BESIII.

8. Offline computing and software

The BESIII offline computing system is designed to have a PC farm of about 2000 nodes for both data and Monte Carlo production, as well as data analysis. A computing center at IHEP

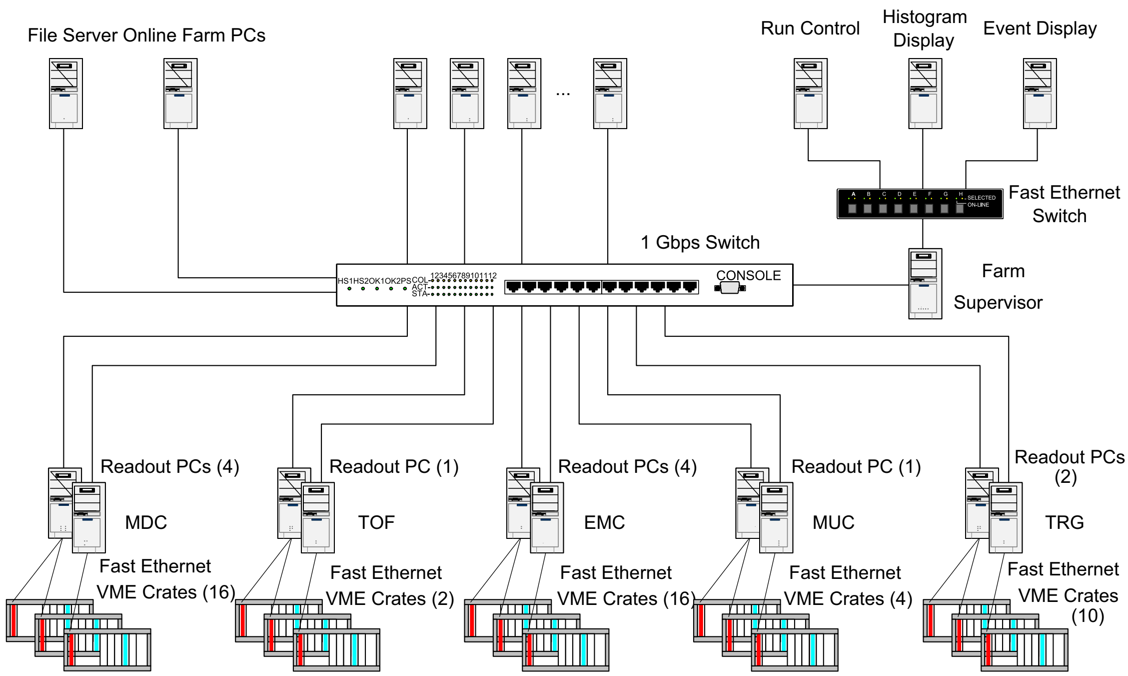

Fig. 12. The structure of the BESIII data acquisition system.

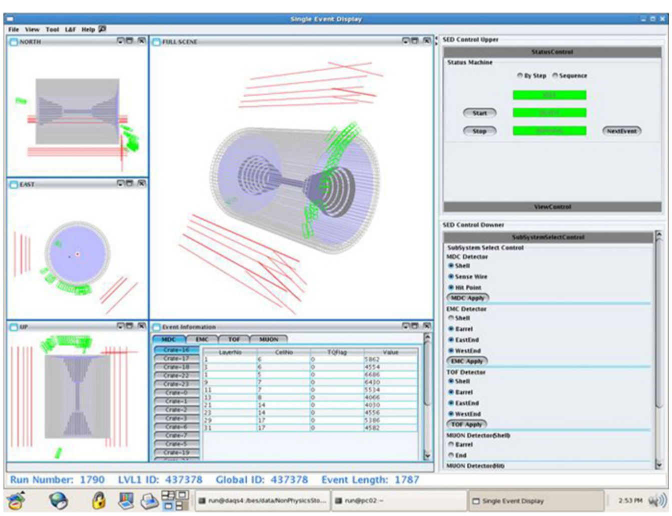

Fig. 13. Cosmic-ray test of whole BESIII.

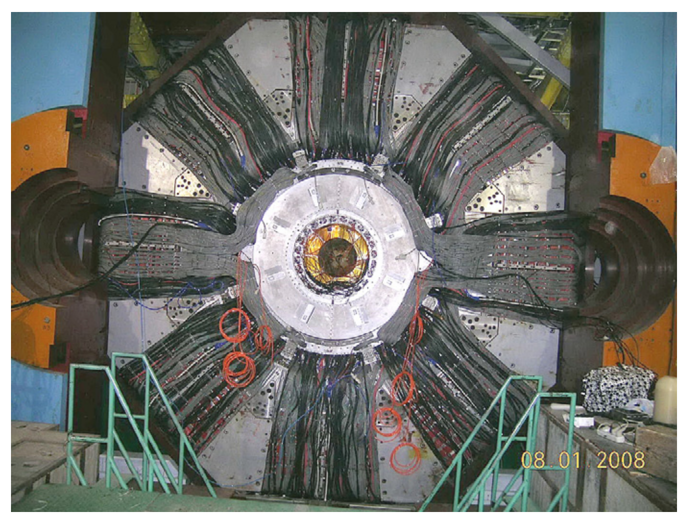

Fig. 14. The whole BESIII detector.

and several local centers at collaborating universities are anticipated. The full system will be built this year.

The offline software consists of a framework based on Gaudi, a Monte Carlo simulation based on GEANT4, an event reconstruction package, a calibration and a database package using MySQL. Currently all codes are working as a complete system, and tests against cosmic-ray and beam test data are underway. Analysis tools such as particle identification, secondary vertex finding, kinematic fitting, event generator and partial wave analysis are completed, although continuous progress are expected.

9. Summary

The BEPCII and BESIII construction went on smoothly. Currently, all subdetectors have been installed into the iron yoke of the BESIII. Fig. 14 shows the whole BESIII detector. The cosmic-ray test of BESIII has been completed in this month and the physics data taking will start at June of this year. The results of cosmic-ray test show that all subsystem runs smoothly.

Acknowledgments

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