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The Quality Management of The R&D in High Energy Physics Detector

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1. Introduction

Particle physics, also recognized as high energy physics, is a basic subject focusing on the research of the elementary elements of materials and their mutual actions. One distinguished characteristic of particle physics study is that the experimental equipments involved are always huge and special ones. Therefore, big science projects, including the R&D of large detectors, are usually required in high energy physics experiments. Those projects are complicated systematic engineering, involving many front and technology fields. It is impossible for a single institute to finish those large projects by its own. Cooperation among different institutes or organizations is necessary for big science projects in particle physics, especially international ones.

1.1. The Institute of High Energy Physics [1]

The Institute of High Energy Physics (IHEP) is the biggest and comprehensive fundamental research center in Chinese Academy of Science. The major research fields of IHEP are particle physics, accelerator physics and technologies, radiation technologies and application, Particle physics experiments and Accelerator physics and technology are two of the leading research areas. The main research facilities at IHEP include Beijing Electron Positron Collider (BEPC) and Beijing Spectrometer (BES), DayaBay Neutrino Experiment, Chinese Spallation Neutron Source, etc. IHEP has extensive cooperation with all high energy physics laboratories and participates in many important particle physics experiments in the world.

1.2. The Beijing Electron Positron Collider [2] and the Beijing Spectrometer [3]

The Beijing Electron Positron Collider (BEPC) consists of the injector, the storage ring, the transportation line, the Beijing Spectrometer (BES), the Beijing Synchrotron Radiation Facili-

ty (BSRF) and the computer center. Beijing Spectrometer (BES) is a general purpose magnetic spectrometer in the South IP of the storage ring. The general layout of the BEPC is shown in Fig.1.



Figure 1. The airspace of the BEPC.

BEPC started construction in 1984 and the first electron-proton collider was produced in Oct. 1988. BEPCII was installed in 2003 and finished five years later in 2009. IHEP establishes comprehensive and long-term cooperation with high energy laboratories and universities all over the world, especially in USA, Japan and Europe. With the international cooperation, IHEP have gained huge success in 30 years. For example, IHEP took part in the research of CMS and ATLAS detectors of Large Hadron Collider (LHC), which is the world's largest, highest-energy particle accelerator and the collider at the beginning of 21 centuries, built by CERN [4]. BESIII is also organized by IHEP and participated by 51 institutions and universities around the world, 34 from Asian, 12 from Europe and 5 from USA.

1.3. The Daya Bay Neutrino Experiment [5]

The Daya Bay Neutrino Experiment is a neutrino-oscillation experiment designed to measure the mixing angle θ_{13} using anti-neutrinos produced by the reactors of the Daya Bay Nuclear Power Plant (NPP) and the Ling Ao NPP.

The Daya Bay Neutrino Experiment is a major international joint research program, mainly organized by China working closely with researchers from other countries. In terms of both money and people, it is among the largest scientific collaborations between US and China. More than 200 scientists from China, include Hong Kong and Taiwan, the US, Russia, the Czech Republic are involved in the Daya Bay experiment. During the cooperation, China is in charge of the laboratory construction, R&D of Anti-neutrino detector (AD), Gd-loaded

Liquid Scintillator, Muon Veto Detector, Readout Electronic and Data acquisition system (DAQ) etc. While America is in responsible of the construction of water Cherenkov detector and so on.

Scientists from the Chinese Academy of Sciences (CAS) and the U.S.-based Brookhaven National Laboratory and the Lawrence Berkeley National Laboratory will participate in the underground experiment. An international funding commission comes into existence in the funding agency to discuss fee issues and instruct the experiment process and fee management through experimental supervision organization. The project management of the Daya Bay Neutrino Experiment adopts the advanced and mature modern management idea used for managing large international joint project and big science experimental research project. An international cooperation group is built and management rules are made. Besides, a co-operation group commission is founded, during which executive board and spokesperson is elected for overall supervision of the whole project. The Daya Bay Neutrino Experiment is initiated in 2007 and finished in 2012.

1.4. Chinese Spallation Neutron Source [6]

Chinese Spallation Neutron Source (CSNS) is designed to build a device with the power of proton beam reaching up to 100 kW effective and the flux of pulsed neutrons coming out top in the world, along with other three spallation neutron sources built in America, Japan and British. CSNS is also a large cooperative project, supported by Chinese Academy of Sciences and Guangdong government. The normal operation for uses is foreseen in 2018. IHEP is the main construction institution in the project with the Institute of Physics Chinese Academy of Sciences as the co-operation unit. The construction team bring together three generations of outstanding scientific and technical researchers in China. An international CSNS neutron technology advisory committee is set up for reviewing the key experimental work. The experts of the advisory committee are from well-known laboratories in America, Japan, Germany, Australia and other countries.

2. Introduction of Quality Management of Scientific Projects in IHEP

During the process of big science project and research, IHEP has significant advantages in accelerator physics and technology, human resources, international cooperation and academic exchange. IHEP owns mature model and advanced experience in the quality management of scientific projects.

2.1. Project Management System

Before 2011, the project manager is responsible for the big science project management in IHEP. International cooperation group is formed and fees are under the sponsors' supervision and review. There is a perfect project management system, though without quality management system meeting international standards.

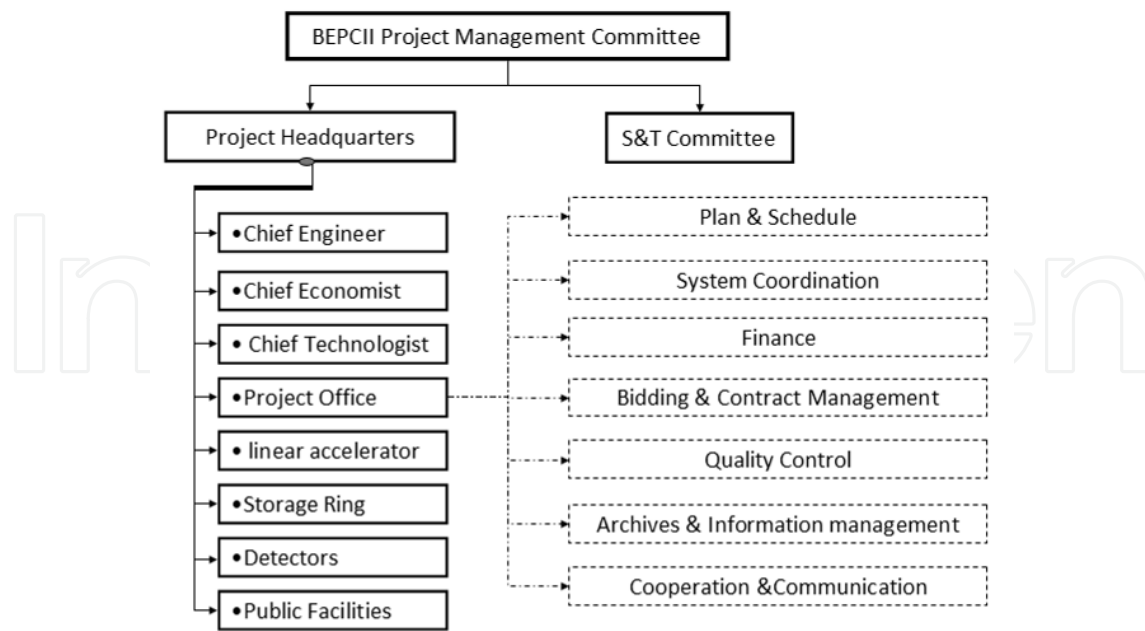


Figure 2. The Organization Chart of the BEPCII Project Management.

In the project management system shown in Fig.2, special-purpose management mechanism such as fund, purchasing, quality, safety and archive is established, with clear responsibilities and authorities. Besides, the internal communication mechanism and interface management mechanism are also set up. CPM Plan is adopted for fund and schedule management. To ensure the quality of the project, during the design and development process, experts are always invited for evaluation. And an international council committee is asked for review in terms of major international cooperation projects.

In fact, the requirements of the project management system have already displayed in the ISO 9001 quality management system. Though without a systematic quality manual and standards and lack of resource, purchasing and archive management. In the project management system, quality management is more focused on the management of various test guidelines and processing of key parts (including outsourced progress)

2.2. Quality Management Systems

The BEPCII project headquarters has placed great important on the quality management and published "BEPCII project management file" in 2002. In the file, responsibilities and rights of personnel, fund management, file number, document signing and alteration, early stages management, bidding and purchasing are described in detail.

At the beginning of 2005, during the construction of BEPCII project, the headquarters built a quality management system according to GB/T19001-2000(idt ISO9001:2000). Although the system doesn't get a national certification, it is completely in accordance with standards of quality management system requirements and it has played a very good effect. In 2009,

BEPCII completed the construction task successfully by time, with high quality and budget under control.

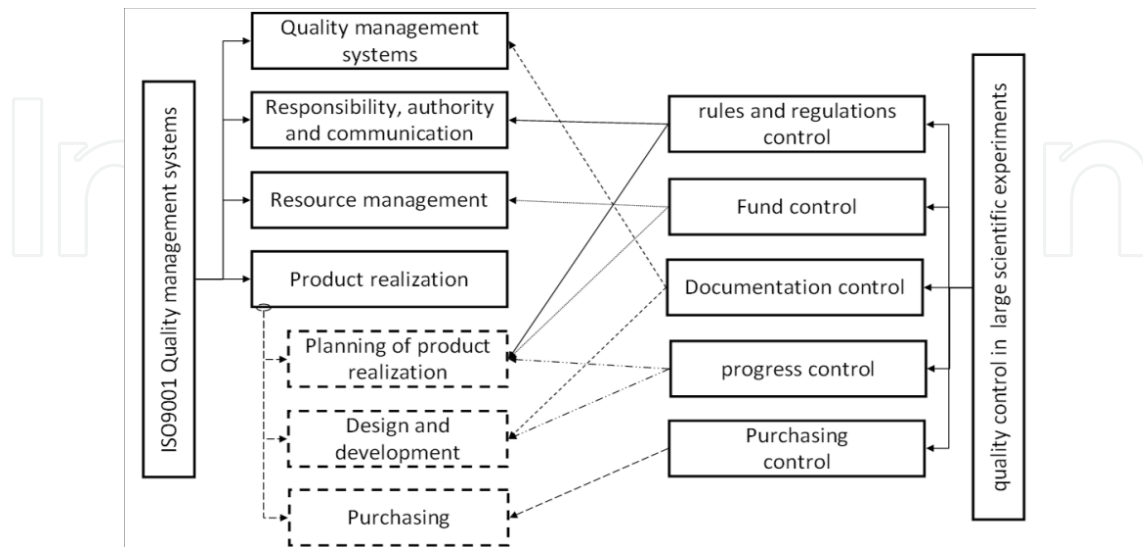


Figure 3. The Relationship between the quality control system in large scientific experiments and ISO9001 Quality management systems.

As described in Fig.3, The quality control in large scientific experiments corresponds with ISO9001 Quality management systems, which is classified according to the production. While, the quality control in large scientific experiments is classified according to the type of different work. The ISO9001 Quality management system is widely adopted by corporations all over the world and it's more normative.

In 2011, IHEP passed a national quality management certification system: GB/T19001-2008(idt ISO9001:2008). After two years' development of quality management system from its very beginning to being passed, it has confirmed that IHEP has the ability to produce scientific production meeting requirements.

The set up of quality management system makes the project management procedure standard, and promotes the overall management level in IHEP. The clients' needs are fully met and the quality management of IHEP joined the line of international standard management. The role played by quality management in the scientific research, especially in the big science project, is invaluable and imponderable.

3. Quality management in R&D of BESIII detector

The project of BESIII detector began its research and development, according to the scientific project management system and quality management system, like other big science projects.

3.1. Mechanism Management

BESIII detector R&D is part of BEPCII project. So the quality management of the detector research is responsible by the project director. As a whole, BESIII carries out the management system of BEPCII project headquarters strictly and makes some special mechanism to form a mechanism with a clear hierarchy. Quality technician are employed in the project.

BESIII detector R&D project has outlined the responsibilities and rights of each person in charge with an appropriate staffing in the organization. The communication methods of the total and sub system and record control requirements are defined.

The director in charge of sub system is responsible for the implementation of the BESIII research plan, management, arrangement of related resources and coordination with scientific and technical issues. Each division leading person is specifically responsible for the respective task implementation plan. Members in the project cooperate with each other closely at reaching difficult goals. The whole project has the characteristic of unified task, defined responsibilities, reasonable arrangement and integrated resources.

The high energy physics experiment is a complex project, and the communication in different study cells seems more important. The Task Control Form is widely used in study works, and the forms are preserved and archived as records of the system.

Subject				
Send to				
From		Date		
Serial No.		Pages		
Attached				
C.C.				
Content				
Jointly Sign				
validation	Prepared by	Checked by	Examined by	Approved by
Signature				
Date				

Figure 4. The task control form used by different teams.

Researchers in the project communicate with each other in time and have a regular meeting each or twice a week, to make sure the project is under schedule control and discuss some technical problems. Meeting minutes are kept as a reference. Sub-system will report the progress of the project and accept an inspection and evaluation regularly.

3.2. Fund Management

Fund management is important for the whole management of scientific project. Appropriate fund use a basis for carrying out any high energy physics experiment smoothly. As for the R&D of BESIII detector, the experiment design and development planning will affect the rationality of the budget and fund use directly. They are also the important contents in the requirements of the quality management system

Funds come from Chinese Academy Sciences (CAS) allocation and self-provided funds in the BESIII project. At the end of the year, expenses are counted and reported to CAS and the project will receive examination and evaluation.

3.3. Control of documents and records

Control of documents and records is critical whether for scientific project management or for quality management. For high energy physic experiments, large and complicated equipments are usually involved. During the project design and scheme phase, rules for documents and records reserved need to be made clearly and principles for numbering and signing the documents and records need to be described specifically.

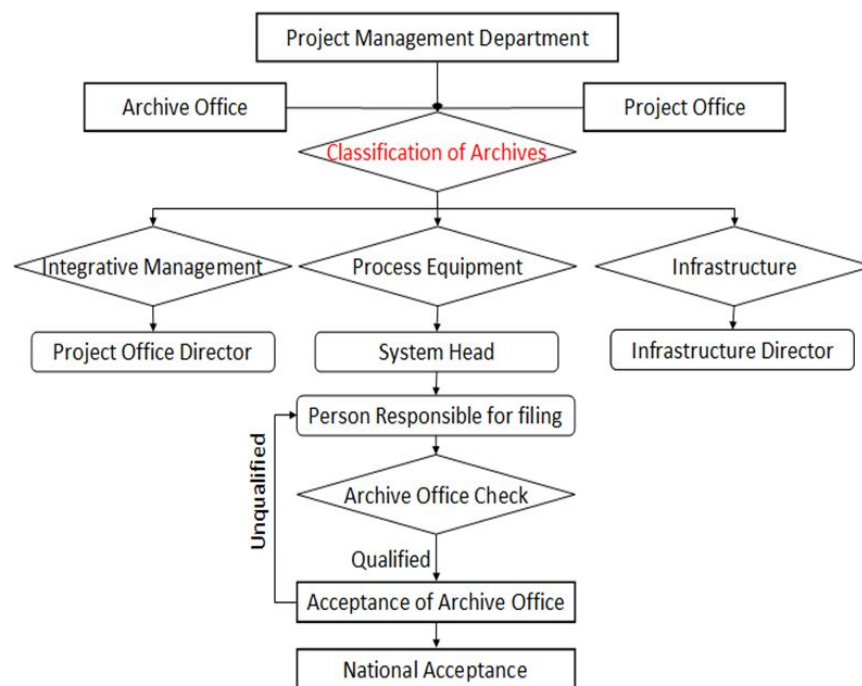


Figure 5. The workflow of archive management.

BEPCII project builds up a special mechanism of file control. Because BESIII is part of the whole project, the rules of document management are in accordance with the requirements of BEPCII. *Documents and records* need to be signed according to the regulations, in accord-

ance with the whole project and effective as well. *Documents and records* need to be preserved and archived on a regular basis.

There are several characteristics in archive management work, especially for the high energy experiments. Firstly, this work must be arranged by the project management department at the beginning of the project. Secondly, the document and records which need to be preserved must be clearly described and the responsibility should be defined at the first time. Thirdly, the archive office, the project office and each member working for the project should cooperate to get the work done quickly and perfectly.

All the quality documents of the whole process of each single detector, from design, research, test, and acceptance are preserved according to the regulations. Technical specifications, interface of different tasks, diagrams, test reports are archived as written documents. Regular meeting minutes are kept also as archives. Those *Documents and records* can be used to track and follow the quality of the product in the whole process.

The running cycle of big science project, just like its construction cycle, is as long as to last more than ten years. Therefore, control of documents and records is very essential for the running and maintenance of the big science project, as an important prop and support.

3.4. Schedule Management

BESIII project has followed Critical Path Method (CPM) to control the schedule of the whole project. The plan in the CPM is in detail and convenient for check. It is easy for revision according to the actual process and make sure it is updated in time within the system.

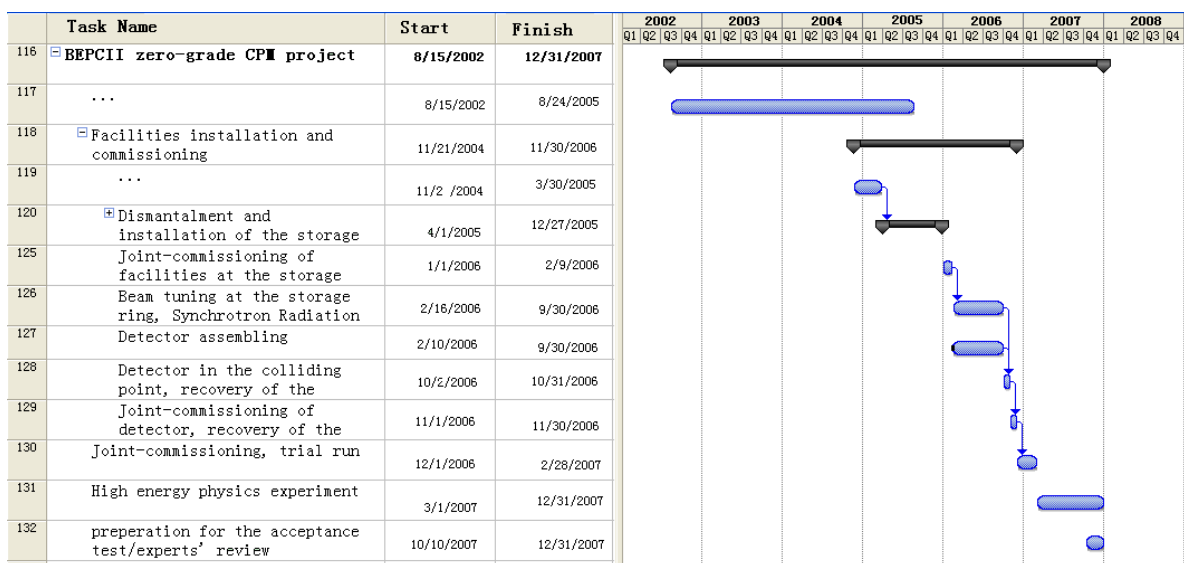


Figure 6. BEPCII zero-grade CPM project (partly,2002).

In order to give a better control of the schedule, CPM is classified. Any sub-system could make its own play and updates in time following the step of the total plan. Therefore inter communication plays an important role in the schedule management. In a word, CPM is a

further refinement of the time arrangement of the project design report and makes the management of the project construction effective.

The CPM project is highly in accord with the practical progress and BEPCII zero-grade CPM project is modified frequently. The BEPCII project was finished in 2008 and was finally checked in 2009.

3.5. Purchasing Management

The R&D of large detectors is involved with bulk purchase. In the BESIII project, purchasing management rules are made according to the relevant laws and regulations on acquisition. Purchasing and approval process are defined clearly. Bidding is strictly adopted in the project to save research money. An appropriate regulation in the purchasing process is a guarantee for carrying out the project under the budget.

Abroad purchase has a long life cycle, heads of procurement need to do significant preparatory work in advance, and the heads should be quite familiar with the procurement procedures in order to complete the purchase in time. The purchasing department published the flowchart to facilitate the work.

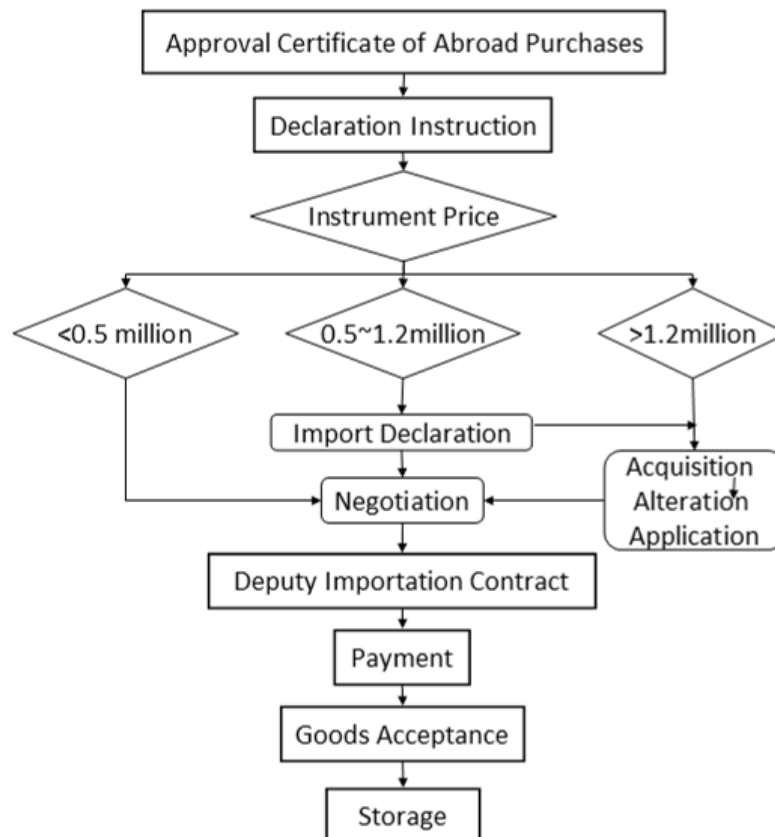


Figure 7. Abroad purchase flowchart.

4. BESIII-MUC Quality Management in R&D of BESIII-MUC Detector

4.1. Introduction of BESIII Detector and MUC Detector

The Beijing Spectrometer (BESIII) is designed to measure the properties of the particles produced in the collisions of electrons and positrons at BEPCII. The physics goal of the BESIII experiment is to conduct high statistics and highly precise studies on a number of physics topics in this energy region, including light hadron spectroscopy, charmonium spectra, charm meson decay properties, QCD, tau physics, rare decays, search for glueballs and other non-pure quark states [3].

The BESIII detector will consist of a 1 T superconducting solenoid magnet, a high precision main drift chamber (MDC), Time-Of-Flight counters (TOF), a CsI crystal Electromagnetic Calorimeter (EMC) and a muon identifier chamber (MUC) that is integrated in the iron magnetic field return yoke [7]. The muon identifier is the outer most subsystem of the BESIII detector [8], which is constructed by resistive plate chambers (RPCs, shown in Fig.8.a). 962 RPC are used in the whole MUC detector, which consists of 136 RPC superlayer modules (SM, shown in Fig.8.b). And the Fig.8.c shows the status of the MUC detector when it was finished it's barrel part assemblage. The Fig.8.d shown the designed construct of the BESIII MUC detector with the endcap and barrel parts.

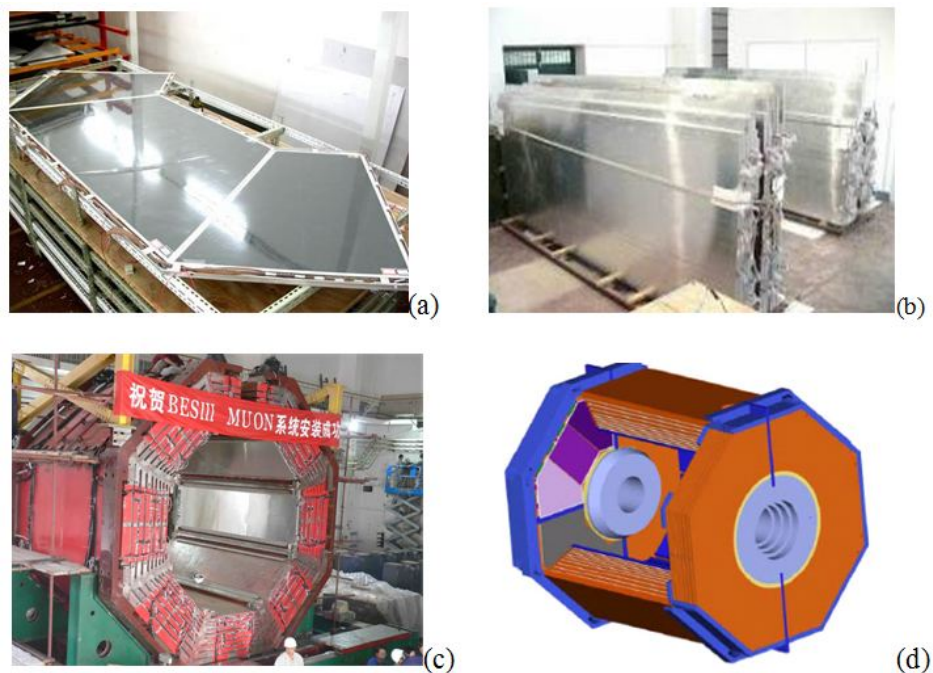


Figure 8. a). The RPC moduls, (b). The Suplayer Modul, (c). The overview the barrel part of the MUC detector after it's assemblage, (d) The construct of the BESIII MUC detector.

4.2. Quality Management in the R&D of BESIII-MUC Detector

The whole process of R&D of MUC detector include the design of the basic unit RPC, properties investigation, bulk production, SM design; design of MUC detector, installation debugging, running and maintenance.

Throughout the research process, the project director managed the project scientifically and effectively, with each research aspect considered carefully, comprehensively and deeply, and made some achievements. From the pre-research in 2003 to the formal data collection in 2009, more than 30 papers have been published by the research group of MUC, covering the whole research process.

7 papers have been published in *NIMA*, as follows:

1. A new surface treatment for the prototype RPCs[9],
2. Cosmic ray test results on resistive plate chamber for the BESIII experiments [10]
3. The Design and Mass Production on RPC for the BESIII Experiment [11]
4. A monitor for the composition of the gas mixture of BESIII muon chambers [12]
5. First results of the RPC commissioning at BESIII [13]
6. The BESIII Muon Identification System [14]
7. An underground cosmic-ray detector made of RPC [15]

8 papers have been published in *Chinese Physics C*, as follows:

1. Cosmic Ray Test Station for BES^{III} RPC [16]
2. Research and Development of Large Area Resistive Plate Chamber [17]
3. A Study of RPC Gas Composition using Daya Bay RPCs [18]
4. Quality control and database on RPC for the BES^{III} experiment [19]
5. Test of BES^{III} RPC in the avalanche mode [20]
6. Performance Study of RPC Prototypes for the BES^{III} Muon Detector [21]
7. Study of the RPC-Gd as thermal neutron detector [22]

	Design	Performance Test	Mass Production	Research Work	Application
RPC	1 b	2 a c e f	3 d	4	7 g
SM			6		
MUC			6	5	

Table 1. The analysis of the manuscripts published by MUC group.

As shown in Table 1, it is not difficult to come into conclusion that the whole R&D of MUC detector applied scientific project quality management, which promotes the research work. In the phase of initial RPC research, the key point is on the study of the detector's performance test. It is the phase for building a standard quality management. After the acceptance of RPC and project review, mass production and SM reassembling come into being. In this phase, scientific quality control and management play a key role.

A perfect quality tracking system is established in each session, from the production and test of RPC, assembling and test of modules, to the installation and debugging of MUC detector, to ensure the supervision of the performance of detector is plausible.

Especially for the mass production of RPC and SM, before research and test, a database is built for storage related data and affording date support for quality control and final running & maintenance.

4.3. Summary

All the requirements such as verification, validation, monitoring, measurement, inspection and test activities specific to the detector are described in the design report of the detector in detail. The report plays the same role as in making a particular quality control plan.

	Design	Prototype	Mass production	Assemblage	Debug	Running
critical characteristic	■	□				
major characteristic	■	■	□			
critical process		■	■			
article inspection	■	■	■			■
quality improvement	■	■		■		
effectiveness			■	■		
traceability			■	■	■	■
preventive action		□	□		■	■
corrective action					■	
quality plan			□	■		

Table 2. Quality management/control factor distribution of MUC detector.

The design report of the detector divide the R&D process into several phases, including concept design, project design, sample trail-manufacture, product research and production, test,

installation and debugging. In each phase, review and identification is defined. For important phases, such as aging test, assembly test and system test, detailed guidelines and instructor are written. As shown in Table 2, during the outsourcing process, key parts are defined, and acceptance rules are also clearly described. Control point is set up and design files are carried out strictly to ensure the product quality. More detailed could be found in table 2 for summary.

5. Significance of Scientific Quality Management in Research

5.1. Promote Scientific Projects

We could come into conclusion that scientific quality management can promote scientific projects to proceed successfully, in the following ways:

The schedule of the project could be arranged and controlled well, especially the adoption of CPM, which could provide a time map for the whole project. Throughout the four years' successful implementation and of BEPCII project, CPM plays an important role in the project acceptance in due. CPM was adjusted in time according to the project status, thus effective management and restriction was formed for all the related sub systems in the project.

The project has been implemented within the budget and cost was controlled. Purchasing procedures and approval process were strictly described, which played a role for the fair use of the fund.

Documents and records were kept in detail, as reference in the project to find the source of old problems and avoid new problems. Especially for those big scientific projects which will last more than ten years, files about interface management and quality management and various records are significant for the running and maintenance in the following work. They also act as important reference for the future project construction in high energy physics.

5.2. Promote Scientific Research

Scientific quality management could promote scientific research effectively. At the same time, as the development of scientific research, cooperation among researchers will be increased. It is good for the communication and exchange in the area of quality management and promotes the refining of the quality management system thus.

Experiences in big scientific project are good for the growth of young researchers. With participation in the R&D of big science equipment under quality management system, researchers will learn how to organize and manage scientific programs or projects in future.

In an ongoing scientific project managed launched by IHEP, researchers are from participants in BESIII or DayaBay. Although it is non-international, at the beginning the project is managed as required in strict quality management, just like that in big science project. As the development of the project, communication and cooperation among other institutions

both at home and abroad have increased. To coordinate the partnership among different organizations and unites, cooperation group is formed. As shown below, a formality management system and strictness organization is built, which lays a solid foundation for the sustainable development of cooperation group and joint research work in future, whose Organization Chart shown in fig.9 for example.

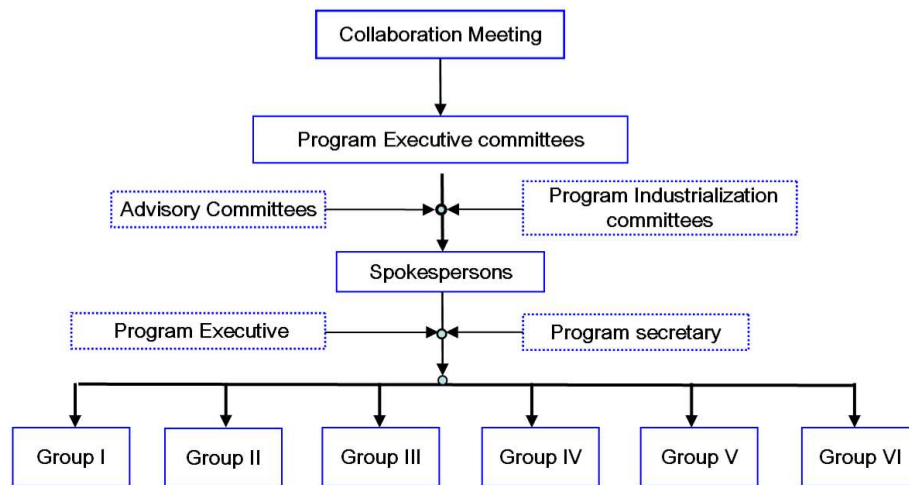


Figure 9. The organization of the BEPCII

6. Conclusion

Quality management plays a significant role both in project management and in the scientific research. With a scientific and comprehensive quality management system, big science project will be duly executed. The level of scientific projects will be greatly improved by the application and popularization of national and international quality standards.

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