Status of the LHCb Experiment

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LHCb is a dedicated experiment to study CP violation and other rare processes in the \( B \) meson system at the LHC. This paper reports on the progress of the construction and installation of the detector that is expected to be ready for data taking at the beginning of LHC operation in late 2007.

1. INTRODUCTION

The LHCb experiment will investigate CP violation and other rare processes in \( B \) meson decays and perhaps reveal physics beyond the Standard Model \cite{1,2}. It is designed to exploit the large sample of \( B^0 \) and \( B_s^0 \) mesons available in \( pp \) collisions at the LHC, that will be mostly produced in the forward direction. For this reason, the detector is designed as a single-arm forward spectrometer having a trigger system efficient for both leptonic and hadronic final states, good particle identification capability over a large momentum range, and an excellent decay time and mass resolution.

The layout of the detector is shown in Fig.1. It consists of a vertex detector, a charged particle tracking system with a large aperture dipole magnet, two Ring Imaging Cherenkov (RICH) counters, a calorimeter system and a muon system. The acceptance of the detector is 10 mrad to 250 mrad in the vertical plane and 10 mrad to 300 mrad in the horizontal plane.

2. STATUS OF THE DETECTOR SUBSYSTEMS

After approval of the experiment in 1998, construction of the detector started in 2001. The present status of the different components of the LHCb detector is described below.

2.1. The Beam Pipe

The beam pipe \cite{2} is of conical shape with four major sections. The first section consists of a beryllium pipe with an opening angle of 25 mrad. This section is followed by two further sections made of beryllium and a fourth section of stainless steel, all of conical shape, with an opening angle of 10 mrad. The beryllium sections are interconnected with optimized aluminium flanges and bellows such as to present as little material as possible to the traversing particles.

The first section of the beryllium beam pipe has been connected to the vertex detector vacuum tank, and vacuum tests are being performed.
We expect to install the remaining sections of the beam pipe and bellows sections in early 2007, when commissioning of the beam pipe can start.

2.2. The Vertex Locator
The Vertex Locator (VELO) consists of 21 pairs of silicon strip detectors arranged in two modules (left and right) around the beam interaction region [2,3]. There are two types of 200-300 µm thick sensors: R-strip and φ-strip sensors with high spatial resolution, which measure respectively the radial and azimuthal coordinates of charged particles. In addition, there are a further two pairs which measure only the radial coordinate and are used for a pile-up veto to reject bunch crossings with more than one interaction. The VELO detector halves are located in a retractable vacuum vessel, separated from the beam vacuum by thin, specially formed, aluminium foils.

The VELO vacuum vessel has been installed, aligned and surveyed in the pit, together with the vacuum and positioning systems. Work is in progress on the construction of the left module, with all mechanical pieces already available.

Delivery of sensor modules to CERN has started and more than 30% of the modules are already in hand. During August 2006 three pre-production sensor modules were successfully tested with the near-final LHCb data acquisition (DAQ) system.

2.3. The Dipole Magnet
A large “warm” (conventional) dipole magnet [4] provides the magnetic field required for the spectrometer. The shape of the two coils follows the acceptance of the spectrometer and the coils are wound from hollow aluminium conductor. The magnet provides an integral field \( \int B dl = 4 \text{Tm} \) and its power consumption is about 4.2 MW.

The magnet is now fully operational. It was assembled, positioned, aligned, and commissioned in 2005. The field was measured with a relative precision of \( 3 \times 10^{-4} \) which fulfils the LHCb requirements. In order to reduce systematic uncertainties of \( B \)-physics measurements, it is intended to reverse the polarity of the magnetic field periodically. The observed asymmetry between the two polarities of \( \Delta B / < B > \approx 3 \times 10^{-4} \) ensures that a negligible fake CP violation will be generated.

2.4. The Tracking System
The Tracking System consists of a silicon Trigger Tracker (TT) and three tracking stations located downstream of the dipole magnet. These three stations are subdivided into an Inner Tracker (IT) located around the beam pipe utilizing silicon detectors, and an Outer Tracker (OT) utilizing straw tube technology. All the silicon sensors and readout hybrids for the IT and the TT have been delivered and tested. A schematic layout of the tracking system is shown in Fig. 2.

Figure 2. A schematic of the LHCb tracking system.

The TT [2] has an active area of about \( 1.4 \times 1.2 \text{ m}^2 \) and consists of four stereo layers of silicon-strip detectors. The TT detector provides input to the trigger and, using the dipole fringe field, can select events containing particles with high transverse momentum. The TT module production is more than 90% complete and the production of the TT detector box is in progress. The
support rails for the TT station have been installed and aligned. All the service-box crates have been assembled and production of the electronics cards is advancing.

The three IT Stations [5] are each subdivided into four boxes around the beam pipe, each one with four stereo layers of one or two silicon strip detectors. The IT support frames have been produced, and a test insertion of the IT/OT support bridge has been successfully completed. IT module production is 60% complete and the first IT detector box is currently being assembled with modules inside.

Each station of the OT [6] consists of four planes of straw modules oriented at 0, +5, -5 and 0 degrees with respect to the vertical axis. The 5 m long modules have double layers of straw tubes of 5 mm diameter; the 128 straws of each module are read out at both ends.

All the IT detector modules are at CERN and have been produced and tested. A large stainless steel structure, the IT/OT bridge, has been assembled between the magnet and the downstream RICH-2 detector, to hold the IT and OT in place. All the aluminium C-frames which support the OT detector modules are at CERN, equipped with necessary services, and are now being loaded with detector modules into the experimental area. Currently, the fully assembled front-end boxes are being tested together with the control system and a first complete version of the DAQ system.

2.5. The Ring Imaging Cherenkov Detectors

Particle identification in the range 1-100 GeV/c is provided by two RICH detectors [2,7]. The first, RICH-1, is located directly behind the VELO and contains two radiators: aerogel and \( C_4F_{10} \) gas. In order to minimize material in the spectrometer acceptance region, the detector is directly sealed to the vacuum vessel of the VELO and uses the beam pipe as part of the gas enclosure. A set of four spherical carbon-fibre mirrors reflects the photons towards planar glass mirrors located outside of the acceptance region, that further reflect the photons towards two planes of photon detectors. A schematic layout of the RICH-1 detector is shown in Fig. 3.

The RICH-2 detector uses a \( CF_4 \) gas radiator and has a similar structure of spherical and planar mirrors as RICH-1. Both RICH detectors will be equipped with “Hybrid Photon Detectors” (HPDs), located inside magnetic shielding boxes which protect the HPDs from the stray field of the magnet.
RICH-2 was installed in the LHCb cavern in late 2005 and the optical system has remained stable throughout. The production of the HPD mounting assemblies for RICH-2 has been completed and more than half of the assemblies have been fully mounted with HPDs and electronics. The HPD production is now more than halfway complete.

We will begin commissioning the half-equipped RICH-2 in January 2007 and complete it, including all photon detectors, a month later. We expect to complete RICH-1 by April 2007.

2.6. The Calorimeters

The calorimeter system [8] has three components: a preshower/scintillator pad detector (PS/SPD), an electromagnetic calorimeter and a hadron calorimeter. All three components are divided into two halves that can be retracted laterally from the beam line. They are also subdivided into radial zones with granularity increasing with decreasing radial position in order to account for the increased particle density at small distances.

The PS/SPD detector consists of two layers of scintillator pads separated by a 2.5 radiation length thick lead wall. The first layer, the SPD, is used to distinguish neutral from charged particles at the Level-0 trigger [9]. The second layer, the PS, is used to distinguish electromagnetic from hadronic particles. The light produced in the scintillator is collected by wavelength-shifting fibres and guided to multi-anode photomultipliers located on the top and bottom of the detector. The electromagnetic calorimeter is of a “Shashlik” type and has a depth of 25 radiation lengths. The hadron calorimeter is an iron/scintillator calorimeter with “tile” geometry.

The installation of all three detectors has been completed, the last one, the PS/SPD, in June 2006 after its calibration with cosmic rays. The commissioning of the ECAL and HCAL modules using an LED monitoring system is progressing and the series production of the front-end (FE) electronics modules started in April 2006. A first group of 32 FE modules has been delivered to CERN and commissioning with the detector has started. The FE electronics and cable installation for the PS/SPD is expected to be completed at the beginning of 2007.

2.7. The Muon System

The muon detector [10] consists of five stations, the first of which, M1, is located in front of the calorimeters. The remaining four stations, M2-M5, are behind the calorimeters and are interleaved with iron filters. The five detector planes will be equipped with multi-wire proportional chambers (MWPCs), with the exception of the centre of the first station that will be equipped with triple GEM chambers.

More than 90% of the muon chambers are already produced and have good quality, and the production of triple-GEM detectors is ongoing. The installation of the chambers has started, together with the associated infrastructure. A test of the complete readout chain at 40 MHz has been successfully performed. We expect to complete all the installation by April 2007.

3. TRIGGER

An efficient trigger is of crucial importance for LHCb, and a trigger system [9,11] based on two levels has been designed: a hardware Level-0 trigger (L0), followed by a software High Level Trigger (HLT) running in a PC farm implemented using commercial processors. The L0 uses the information from the calorimeters, the muon detectors and the pile-up system of the VELO to select events containing particles with high transverse momentum and with only one interaction per beam crossing. The L0 reduces the interaction rate, which occurs at ~11 MHz, down to 1 MHz. This rate is then fully processed by the HLT, which uses the complete detector information for the reconstruction of events.

Production of the calorimeter Level-0 processor and the Level-0 Decision Unit boards has started. Production of the Level-0 Pile-up boards will start at the beginning of 2007. Currently 20% of the Level-0 trigger boards have been produced and 3% tested. The HLT-flow [11] has been implemented in software and first tests with the newly generated simulated data are in progress. The aim is to produce a version of the HLT which can be used to benchmark candidate CPUs by
early 2007. A scaled-down version of the DAQ hardware will also be installed early 2007 for the global commissioning of the detector and used during the pilot run for calibration and alignment [12]. In addition we expect to complete the Experimental Control System [13] by the beginning of 2007 to start integrating the subsystems.

4. COMPUTING

LHCb has a complete chain of C++ programs for simulation, reconstruction and analysis. The LHCb computing model [14] is based on

• reconstruction, pre-selection and analysis at Tier-1 centres;
• simulation at Tier-2 centres.

Physics quality reconstruction software is expected to be ready before the end of 2006. All the computing aspects are periodically tested through “data challenges”. The latest data challenge and the use of DIRAC (Distributed Infrastructure with Remote Agent Control) tools to allow automated processing to be initiated as data files become available, has worked smoothly. The prioritisation between simulation and reconstruction jobs occurred successfully and will later be extended to analysis and production jobs.

5. SUMMARY

The LHCb experiment is a single arm forward spectrometer that will allow precision studies of CP violating effects in the $B$ meson system. The construction of the detector is well advanced and is expected to be ready for data taking in late 2007.

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