Status of the LHCb Experiment

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LHCb-PROC-2004-039
17/10/2004

***Abstract*-- The LHCb experiment has been designed for precision studies of CP violation and other rare phenomena in b-hadron decays. 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 consisting of preshower, electromagnetic and hadron calorimeters, and a muon system. This paper reports on the progress in the construction of the detector that is expected to be ready for data taking at the start-up of LHC.**

I. Introduction

The LHCb experiment aims to investigate CP violation in the B mesons decays and perhaps will reveal physics beyond the Standard Model [1, 2]. The pp collisions at LHC will yield abundantly b-hadrons that will be mostly produced in the forward direction. The detector is designed as a single-arm forward spectrometer for a luminosity of $2\text{x}10^{32}$ $\text{cm}^{-2}\text{sec}^{-1}$ with the following requirements:

- Efficient trigger for many B decay topologies
- Good K/π separation
- Good decay time resolution
- Good mass resolution

The layout of the detector is shown in Fig. 1. It consists of

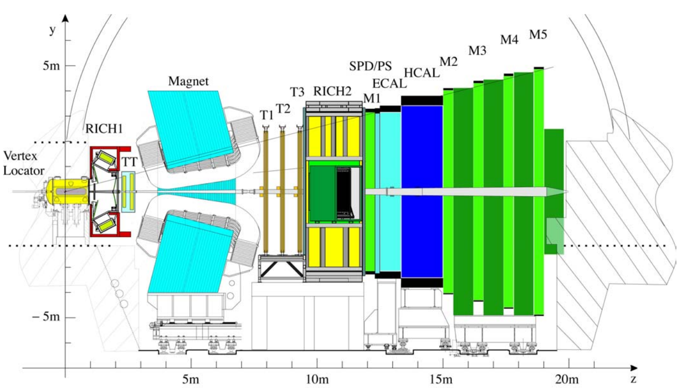

Fig. 1: Layout of the detector

a vertex detector, a charged particle tracking system with a large aperture dipole magnet, two Ring Imaging Cherenkov (RICH) counters, a calorimeter system consisting of preshower, electromagnetic and hadron calorimeters, and a muon system. The acceptance of the detector ranges from 10 mrad to 250 mrad in the vertical plane and from 10 mrad to 300 mrad in the horizontal plane.

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II. Status of the Detector Components

After approval of the experiment in 1998, construction of the detector has started in 2001. In the following, the status of the different components of the LHCb detector is described.

A. The Dipole Magnet

A large warm dipole magnet provides the magnetic field required for the spectrometer [3]. The two coils are wound from hollow aluminium conductor; the shape of the coils follows the acceptance of the spectrometer. The magnet provides an integral field $\int$Bdl = 4 Tm and the power consumption is about 4.2 MW. The 1600 ton iron yoke and the coils have been assembled in the experimental area; the magnet is positioned on the beam line and is ready for commissioning (Fig. 2).

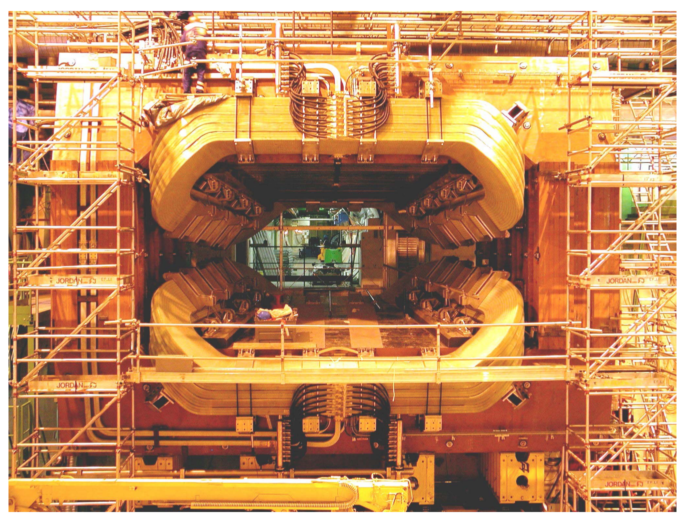

Fig. 2: The dipole magnet

B. The Beam Pipe

The beam pipe [2] is of conical shape with two distinct regions, a first one with an opening angle of 25 mrad and a second one with 10 mrad opening angle. A schematic layout is shown in Fig. 3.

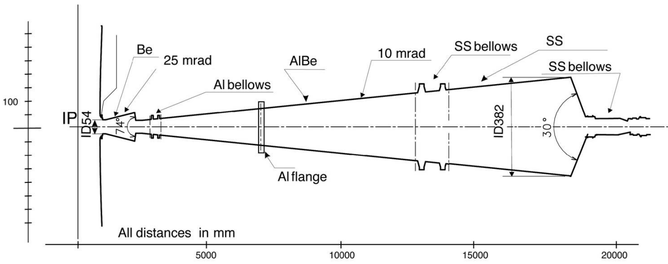

Fig. 3: The beam pipe

It comprises four major sections. The first section consists of a beryllium conical pipe with an opening angle of 25 mrad and a transition to the 10 mrad section. This beam pipe is welded to a spherical window of 2 mm thick aluminium that serves as the exit window of the vacuum vessel for the vertex locator. This section is followed by two further sections made of beryllium and a fourth section in 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 as possible material to the traversing particles.

All major components of the beam pipe have been successfully prototyped and the final parts are in fabrication. The beam pipe will be installed in the experiment in 2006.

A. The Vertex Locator

The Vertex Locator (VELO) consists of 21 pairs of silicon strip detectors arranged in two halves around the beam interaction region [2, 4]. There are two types of 200-300 µm thick sensors: R-strip and φ-strip sensors with high spatial resolution. This strip geometry allows for a fast track finding algorithm which is important as this detector is used in the Level-1 trigger. In the Monte Carlo simulation and using test beam data for the sensor resolution, the primary vertex resolution achieved in the Level-1 trigger is 20 µm in horizontal direction and 85 µm along the beam axis.

The detector halves are located in a vacuum vessel, retractable and separated from the beam vacuum by thin specially formed aluminium foils of 0.3 mm thickness. The maximum allowable pressure difference is 10 mbar, therefore a complex vacuum control system is required.

Prototype work is now being completed [5] and the final components are under construction. Installation of this system will commence end 2005.

B. The Tracking System

The Tracking System consists of the Trigger Tracker (TT) and three tracking stations located downstream of the dipole magnet. The three stations are subdivided into an Inner Tracker (IT) located around the beam pipe and using silicon detectors and an Outer Tracker (OT) using straw tube technology. A schematic layout is shown in Fig. 4.

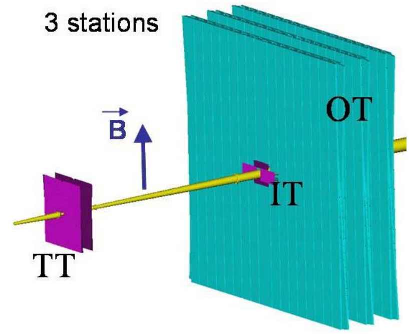

Fig. 4: The Tracking System

The Trigger Tracker [2] with an active area of about 1.4x1.2 m^2 consists of four stereo layers of silicon strip detectors. Two to four sensors are chained together and mounted on vertical ladders. The sensors are connected to the read-out electronics located outside the acceptance area by Kapton interconnect cables. Using the magnetic field in front of TT, this detector is part of the Level-1 trigger to select events containing particles with high p_t.

The three Inner Tracker Stations [6] are subdivided into four boxes each with either one or two silicon strip detectors per column. Each box has four layers with a stereo arrangement of the columns.

The prototype work and design of the components of both the TT and IT stations is being finalized [7] and production is due to start beginning of 2005.

Each station of the Outer Tracker [8] consists of four planes of straw modules arranged with 0, +5, -5 and 0 degree w.r.t. the vertical axis. The 5m long modules have double layers of straw tubes with 5 mm diameter; the 128 straws of each module are read out on both ends. Custom electronics has been developed [9] and prototypes modules have been tested for ageing [10]. The module production has started in three centres and about 15% of the 300 modules required have been produced.

C. The Ring Imaging Cherenkov Detectors

Particle identification in the range of 2-100 GeV/c is provided by two Ring Imaging Cherenkov (RICH) detectors [2, 11]. RICH-1 is located directly behind the vertex locator and contains two radiators, aerogel [12] and C_4F_{10}. In order to minimize material in the acceptance region, the detector is directly sealed to the vacuum vessel of the vertex locator and uses also the beam pipe as part of the gas enclosure; a set of spherical beryllium mirrors (in the acceptance region) and planar glass mirrors guide the photons towards two planes of photon detectors. Two massive magnetic shielding boxes protect the photon detectors from the stray field of the magnet and at the same time bring magnetic field into the region in front of the Trigger Tracker. The detector is in the final design stage and is due to be installed end 2005.

The second RICH detector has a gas volume of 100m^3 and uses CF_4 as radiator. This detector is currently being assembled in a surface hall and will be transported into the underground area in mid 2005.

Both RICH detectors will be equipped with so-called 'Hybrid Photon Detectors' (HPDs) that have been developed in collaboration with industry. These photon detectors have a photocathode of 75 mm active diameter and incorporate a silicon sensor bump-bonded to a binary read-out chip [13, 14, 15].

D. *The Calorimeters*

The calorimeter system [16] has three components: a pre-shower detector, an electro-magnetic calorimeter and a hadron calorimeter. All three are divided into two halves that can be retracted laterally from the beam line.

The pre-shower detector consists of two layers of scintillator pads separated by a 1.5 cm thick lead wall. To adapt the granularity to the particle flux, there are three different sizes of scintillator pads. The light is collected by wavelength shifting fibres and guided to multi-anode photomultipliers located on the top and bottom of the detector. The production of this detector is in full swing.

The electromagnetic calorimeter is of the "Shashlik" type and has a depth of 25 radiation lengths (Fig. 5). It is divided into three regions with different cell sizes. All 3300 modules have been produced and the assembly of the detector in the experimental area will start in the beginning of 2005.

Fig. 5: The three types of e.m. calorimeter modules

The hadron calorimeter is an iron/scintillator calorimeter with "tile" geometry. Also here the granularity varies with the distance from the beam pipe, production of the 52 modules will be finished by the end of 2004 and installation will start beginning of 2005.

The read-out of both the electromagnetic and the hadron calorimeter is performed with photomultipliers, more than 70% of the 7800 tubes required have been already delivered and tested for dark current and stability.

E. *The Muon System*

The muon detector consists of five stations [17], one located in front of the calorimeters, the four stations behind are interleaved with iron filters. The detector has a projective geometry, the stations are subdivided into four regions and 20 different chamber types are required. The five detector planes will be equipped with 1380 multi-wire proportional chambers (MWPC), with the exception of the centre of the first station that will be equipped with triple GEM chambers [18, 19]. A schematic layout is shown in Fig. 6.

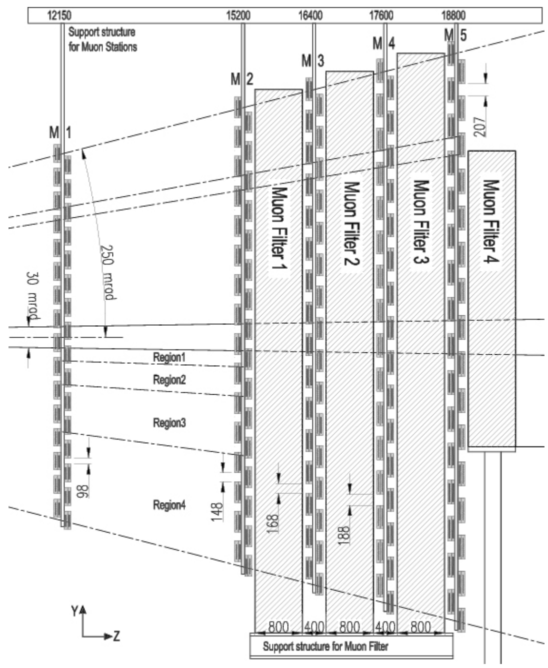

Fig. 6: Schematic layout of the muon detector

Each station has four active gaps where two are logically "ored" – except the first station that has only two layers to minimize material in front of the calorimeter. Depending on the track density, the readout is performed using the signals of the wires, the pads or both. They are connected to form logical pads and the total of about 26 000 channels is used in the Level-0 trigger.

For the production of the MWPCs special tooling and testing equipment has been developed to perform following manufacturing and testing processes in a semi-automatic way: wiring, gluing soldering, wire distance measurement, wire tension measurement. The production has started in five centres and about 10% of the chambers have been produced so far. Common quality control procedures have been established and are followed in all production centres [20].

II. THE TRIGGER

An efficient trigger is of crucial importance for this experiment and LHCb has designed a trigger system [21] based on three layers: The Level-0 trigger is a hardware trigger using the information from the calorimeters, the muon detectors and the pile-up system to select events containing particles with high transverse momentum. The Level-0 trigger reduces the rate from 40 MHz to 1 MHz. This rate is then further reduced to 40 kHz by the Level-1 trigger, a software algorithm running on the CPU farm and refining the event selection by adding the information from the Vertex Locator and the Trigger Tracker. Finally, the third layer is the High Level Trigger (HTL) that uses the complete detector information for the reconstruction of events.

The custom electronics for the Level-0 trigger has been prototyped and production is to starts soon. The "2005 Trigger Challenge" will test the real time framework and the trigger software in a realistic environment.

III. THE DATA ACQUISITION SYSTEM

The data acquisition system (Fig. 7) is based on a large computing farm comprising some 1500 commodity processors [22]. It features two data streams sharing a common read-out network and the computing farm: the Level-1 data stream and the High Level Trigger data stream.

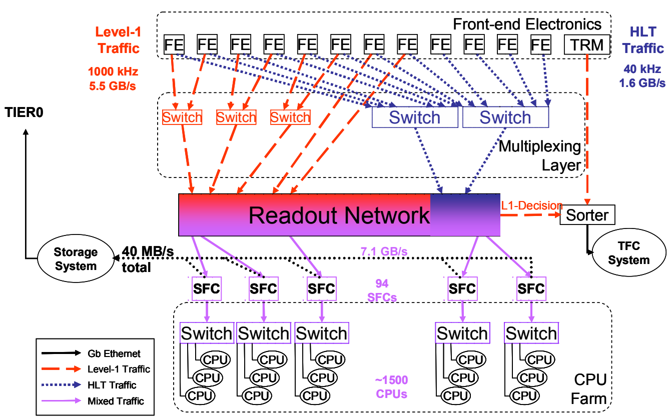

Fig. 7: The Data Acquisition System

IV. OFFLINE PROGRAMS

LHCb has a complete chain of programs in C++ for the simulation, reconstruction and analysis [23]. The "2004 Data Challenge" aimed to produce some 200 million events on distributed computing resources. This task was successfully completed and about 50 computing sites running under DIRAC and LGC contributed 470 CPU years for the production of over 210 million events.

V. SUMMARY

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

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