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The LHCb Experiment

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Abstract

This paper gives an overview of the re-optimised LHCb Experiment, the technologies used for its detector components and its physics reach.

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1 Introduction

The Large Hadron Collider Beauty Experiment for precision measurements of CP-violation and rare decays (LHCb) is one of the four experiments at the Large Hadron Collider (LHC), at CERN, and is due to start data-taking in 2007. At the LHC pp interactions will take place at a centre-of-mass energy $\sqrt{s}$= 14 TeV and will produce a full spectrum of B hadrons ($B^{\pm}$, B^0, $B^0{}_s$, $B_c{}^{\pm}$, Λ_b and others). The expected $b\overline{b}$ production cross-section is $\sim 500\mu$b, and so $\sim 10^{12} b\overline{b}$ pairs will be produced per year (10^7 s) of running at the LHCb mean luminosity of 2×10^{32} cm^{-2}s^{-1}. At the LHC, gluon fusion is the dominant production mechanism for $b\overline{b}$ pairs - the b and $\overline{b}$ are then predominantly produced in the same forward or backward cone, motivating the design of the LHCb detector as a single-arm spectrometer covering the forward cone only.

2 The LHCb Detector

Figure 1 is a plan view of the LHCb detector in the y-z plane[1]. The detector covers the angular region from 10 mrad to 300 mrad in the horizontal (x-z) plane, and from 10 mrad up to 250 mrad in the vertical (y-z) plane. Information on each of the individual sub-detector components are found in the LHCb Technical Design Reports (TDRs) [1–9].

The Vertex Locator (VELO) consists of 21 stations of 220μm thick single-sided silicon strip detectors which are arranged into r and ϕ planes, and placed inside a secondary beam vacuum. The VELO is vital for all time-dependent CP violation studies as it provides precise measurements of track coordinates close to the interaction region. Good vertex and proper time resolution is essential in selecting events containing displaced decay vertices, and for $B^0{}_s$ mixing studies. The tracking system has undergone major changes since [10] - there are now 4 tracking stations. The upstream station (TT) consists of planes of silicon microstrip detectors. Because of the high particle density close to the beam pipe, the downstream tracking stations are split into inner (IT) and outer (OT) systems. The IT uses silicon microstrip detectors whereas the OT uses straw drift-tubes.

[1]LHCb uses a right handed coordinate system with the z-axis pointing from the interaction point towards the muon chamber along the beam-line. The y-axis is pointing upwards.

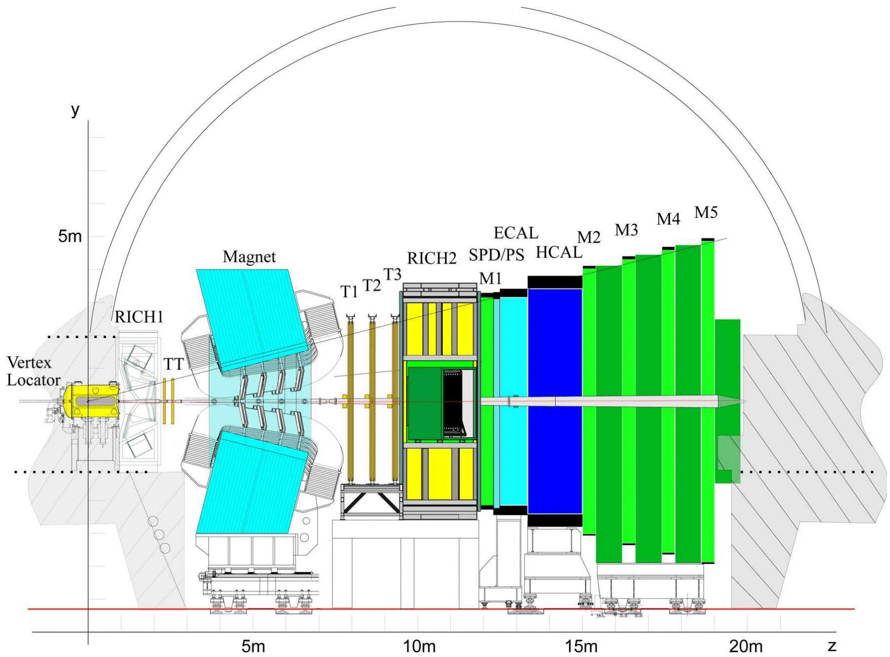

Figure 1: *View of the LHCb detector in the y-z plane. The main components are the Vertex Locator (VELO), two RICH counters (RICH-1 and RICH-2), four tracking stations (TT and T1-T3), the magnet, the Scintillating-Pad Detector (SPD), PreShower(PS), Electromagnetic (ECAL) and Hadronic (HCAL) Calorimeters, and five muon stations (M1-M5).*

Particle identification is provided by the Ring-Imaging CHerenkov counters (π/K/p), the ECAL and HCAL ($e^{\pm}$, γ and hadrons) and the muon system ($\mu^{\pm}$). The RICH system consists of two detectors with three different radiators. RICH-1 identifies the lower momentum particles, up to $\sim$ 60 GeV/c and uses aerogel and C_4F_{10} gas as radiators. RICH-2 identifies the higher momentum particles, up to $\sim$ 100 GeV/c and has one CF_4 gas radiator. Multi-Anode Photomultiplier tubes are currently the baseline RICH photon detector choice, with the Hybrid Photon Detector as the backup solution. The ECAL is a Shashlik type with a PreShower and a Scintillating Pad Detector. It has an energy resolution of $\sigma_{\mathrm{E}}/\mathrm{E} = 10\%/\sqrt{E} \oplus 1.5\%$ for electromagnetic particles, whereas the iron/scintillating tile HCAL has an energy resolution for hadronic particles of $\sigma_{\mathrm{E}}/\mathrm{E} = 80\%/\sqrt{E} \oplus 5\%$. The muon system consists of five muon chambers using Multi Wire Proportional Chamber (MWPC) technology.

The trigger consists of the Level-0, Level-1 and High Level Trigger (HLT) stages. Level-0 triggers on high p_{T} muons, electrons and hadrons, and a pileup veto acts to suppress events with more than one pp interaction. Level-0 operates on the bunch-crossing frequency of 40 MHz with an output of 1 MHz and a latency of 4.0 μs. The Level-1 trigger selects events which have a secondary vertex. It is based on the summary information of L0, plus information from the VELO, TT and T1$\rightarrow$T3 and operates at the mean Level-0 output rate of 1 MHz. Finally the HLT uses all detector information and rejects events which are not associated with a specific b-hadron decay mode.

Other components of the detector are the Al/Be alloy beam pipe and the $\sim$4 Tm dipole magnet.

The Reoptimised LHCb Detector Design and Performance TDR [11] presents the recently reoptimised LHCb detector. It focuses on the VELO, RICH-1 and TT since their designs were modified from that in the LHCb Technical Proposal [10] as a result of the reoptimisation process and presents results of physics performance studies using the reoptimised detector and recent Object-Orientated (OO) software.

3 Physics Performance

In early 2003, as preparation for the performance studies described in [11], 15.3 million signal Monte Carlo events for more than 60 different B-decay channels and 10.8 million inclusive $b\overline{b}$ (with at least one b hadron in the 400 mrad forward cone) were generated in 18 production centres across Europe using DIRAC (Distributed Infrastructure with Remote Agent Control) [12]- the LHCb Monte Carlo production tool. Reconstruction was carried out using the LHCb reconstruction software, Brunel [13], and physics analyses using DaVinci [14] the LHCb physics analysis package. DIRAC, Brunel and DaVinci are all based on the Gaudi framework [15] - an experiment-independent project providing interfaces and services for building HEP experiment Monte Carlo and analysis frameworks.

Physics performance studies were carried out using the Monte Carlo events described above, selected results of which are presented in Table 1. These studies assume that inclusive $b\overline{b}$ is the most dominant source of combinatorial background. Sensitivity studies using simplified Monte Carlo simulations have been carried out to investigate the sensitivity to interesting physics parameters and CP observables. These, and results from other channels, are

Decay channel	Annual Signal Yield (k)	B/S ratio from incl. $b\bar{b}$ background
$B^0 \rightarrow \pi^+ \pi^-$	26.	< 0.7
$B^0 \rightarrow K^+ \pi^-$	135.	0.16 ± 0.04
${B^0}_s \rightarrow K^+ K^-$	37.	0.31 ± 0.10
${B^0}_s \rightarrow \pi^+ K^-$	5.3	< 1.3
${B^0}_s \rightarrow D_s^- \pi^+$	80.	0.32 ± 0.10
${B^0}_s \rightarrow D_s^{\mp} K^{\pm}$	5.4	< 1.0
$B^0 \rightarrow J/\psi(\mu^+\mu^-)\, {K^0}_s$	216.	0.80 ± 0.10
$B^0 \rightarrow J/\psi(e^+e^-)\, {K^0}_s$	25.6	0.98 ± 0.21
${B^0}_s \rightarrow J/\psi(\mu^+\mu^-)\, \phi$	100.	< 0.3
${B^0}_s \rightarrow J/\psi(e^+e^-)\, \phi$	20.	0.7 ± 0.2
$B^0 \rightarrow K^{*\,0} \gamma$	35.	< 0.7
${B^0}_s \rightarrow \phi \gamma$	9.3	< 2.4
$B^0 \rightarrow \mu^+ \mu^- K^{*\,0}$	4.4	< 2.0

Table 1: *The untagged triggered annual signal event yields for key B-physics channels of interest are given, along with the background over signal (B/S) ratio calculated using 10.8 million inclusive* $b\bar{b}$ *events. The quoted errors on B/S are from Monte Carlo statistics with estimates based on less than 10 MC background events remaining after all selection cuts have been applied, are quoted as 90% CL upper limits.*

discussed in detail in [11].

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