B-physics and CP violation with LHCb

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1 Physics motivation

The LHC machine will have a unique potential for the study of CP violation in the B system [1]. At $\sqrt{s} = 14$ TeV the B production cross-section is estimated to be around 0.5 mb, yielding about 10^{12} $b\bar{b}$ pairs per year at the modest luminosity of $2\ 10^{32}$ cm^{-2}s^{-1}.

LHCb is the only dedicated experiment designed to exploit this potential with an optimized detector, incorporating particle identification and vertex detector at trigger level [2]. LHCb can work for years at constant luminosity, independently from the other intersections, thus collecting clean events of constant quality.

Most of the Technical Design Reports (TDRs) for the various detector sub-systems have been approved [3], and construction of magnet and calorimeters has already started. The experiment is expected to begin operation at the LHC startup.

2 The Detector

A schematic drawing of the LHCb detector is shown in Fig. 1. It is a single-arm open spectrometer using a large dipole magnet for momentum measurement. This choice exploits the fact the B production is largest in the forward direction.

Immediately surrounding the interaction point there is the silicon Vertex Locator (VELO)[3]. The VELO is built in two halves, placed in “Roman Pots” on both sides of the beam, that can be moved close to it during data taking, or retracted during machine injection. Both halves accomodate 25 measuring stations, each made of two half-disks of 300 μm single-side Si sensors (120k channels), allowing the measurement of the r and ϕ coordinates, with stereo angle. To minimize the thickness of the wall separating the detectors from the machine vacuum, the detectors are operated under secondary vacuum. The VELO can measure decay lengths with accuracies from 220 to 375 μm, giving a sensitivity of 54 ps^{-1} for Δm_s.

The tracking system comprises a large aperture warm dipole magnet [3] ($\int Bdl \approx 4$ Tm) and nine tracking stations. To cope with the increasing particle density at small

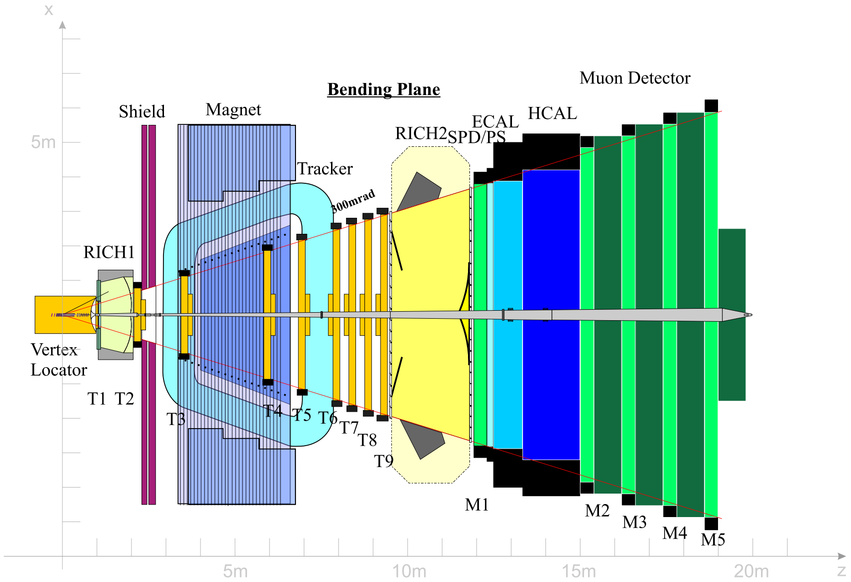

Figure 1: Schematic view of the LHCb detector.

angles, the tracker is divided into inner and outer subsystems. The outer part is built with 5 mm straw tubes, where the inner part uses Silicon strip detectors. The average momentum resolution is 0.3 % up to 200 GeV/c, yielding a mass resolution between 4 and 22 MeV/c^2. Prototypes of the straw tubes (3 m long) have been built and are under test in HERA-B [3].

Particle identification is provided by two RICH detectors [3], covering the momentum range from 1 to 100 GeV/c. In RICH1 (upstream the magnet), two radiators share the same photodetectors: silica Aerogel is effective in the region of momenta from $p \approx 1$ GeV/c to $p \approx 20$ GeV/c and C_4F_{10} gas covers up to $p \approx 65$ GeV/c. The forward (downstream) RICH2 uses CF_4 gas allowing $K - \pi$ separation up to 100 GeV/c.

The readout (400 kchannels) is based on hybrid photodiodes (HPDs). A 1024-pixel silicon sensor is enclosed in the tube envelope, with the binary readout chip bonded to it. This Pixel Chip, developed in collaboration with Alice, and fabricated in 0.25 μm technology, has a readout speed of 40 MHz.

The calorimeter system provides trigger and identification capabilities for electrons, photons and hadrons [3]. It comprises three main components: *i)* the Pb-scintillator Preshower detector (PS), *ii)* the Pb-scintillator “Shashlyk” electromagnetic calorimeter (ECAL) and *iii)* the Fe-scintillator tile calorimeter *à la* ATLAS for hadrons (HCAL). In all of these detectors WLS fibers are used to collect the light from the scintillator plates. Multi-anode photomultipliers are used in the Preshower readout.

The Muon Detector [3] comprises five stations (M1-M5), with M1 placed upstream the Preshower. Muons tracks are first identified in the M2-M4 stations, then the tracks are extrapolated to M1, to provide a measurement of p_T for the trigger. The system totals more than 1300 chambers of varying dimensions. About 2/3 of the chambers are MWPC type, with wire and/or cathode pad readout. Small wire-wire and wire-cathode spacing (1.5 mm and 2.5 mm respectively) ensure high efficiency within the 25 ns crossing. The remaining 1/3 chambers are RPCs, covering the regions with lower particle rates.

3 LHCb-light

Much work is being done to optimize the LHCb experiment by reducing the material budget in the tracking part of the detector from the 0.6 X_0 and 0.2 λ of the initial design. This will improve electron and photon detection and tracking efficiency. In the "LHCb-light" detector an Al-Be beam pipe will be used, and the number of VELO stations will be reduced from 25 to 21, with thinner Silicon sensors. For RICH1 a lighter, composite mirror, will be used. A more drastic change is the reduction in the number of tracking stations, by eliminating those inside the magnet. In the new design, three stations (ST1-ST3) are placed downstream the magnet. The technology of these stations will be like in the original design (straw tubes externally, Silicon strip detectors internally.) One more station (TT1) will be located between RICH1 and the magnet. This will consist of two measuring planes placed at short distance (about 30 cm.) The fringe field of the magnet is enough to allow momentum measurement at the trigger level (see below.) An adequate magnetic shielding for the photon detectors will be incorporated in the RICH1 design. The preferred technology for TT1 is Silicon. A new tracking strategy is being developed, and the results are promising.

The TDR for the light detector is in preparation.

4 The trigger

The ratio of the B cross-section to the total inelastic cross-section at LHC energies is expected to be $\simeq\ 5\ 10^{-3}$, implying in nominal working conditions a rate of 50 kHz of B events. This value is so large that even a perfect trigger picking up only B events would be insufficiently selective. Therefore the trigger system must be designed to enrich the sample with the desired decay modes.

The LHCb trigger is based on 4 levels [4]. Level 0 (L0) uses information from the calorimeters and muon detector to build a high-p_T trigger which is fully pipelined at 40 MHz with a fixed latency of 4 μs. The output rate of L0 trigger is $\approx$ 1 MHz.

Level 1 (L1) uses track and vertex topology distinct triggers implemented in a small CPU farm. Its maximum latency is 1.7 ms, and it reduces the rate to $\approx$ 40

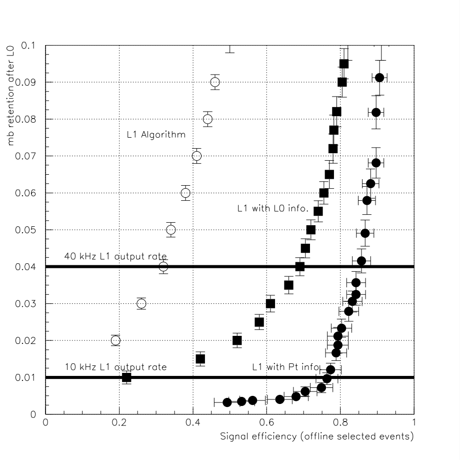

Figure 2: Minimum bias retention after L0 vs. efficiency for $B^0 \to \pi^+\pi^-$, normalized to events that would have been selected offline. Left: L1 algorithm [2]; center: with L0 information added, right: with p_T measurement (see text). L1 output rates (10 and 40 kHz) are shown.

kHz. The zero-suppressed data are sent to the DAQ farm after a positive L1 decision. Levels 2 and 3 perform further software selections finally rejecting uninteresting $b\bar{b}$ events, to achieve a final output rate of 200 Hz.

A recent development of L1 trigger uses the association of L0 candidates (in calorimeter and muon detectors) with L1 VELO tracks with large impact parameter. The $E_T(p_T)$ information from L0 improves significantly the performance of the L1 trigger. At 40 kHz output rate the efficiencies for $B^0 \to \pi^+\pi^-$ and $B^0 \to J/\psi(\mu^+\mu^-)K^0_S$ are about 70 % and 90% respectively (see Fig. 2.)

The fringing field of the magnet (about 1/10 of its peak value) makes possible to measure momentum with relative accuracy of 20% in a tracking station upstream the magnet. The improvement obtained in this way is also shown in Fig. 2. Station TT1 (see Section 3) will be optimized in order to use this information at L1. Preliminary results show that the efficiency for $B^0 \to \pi^+\pi^-$ is about 85% at 40 kHz output rate.

5 Physics performance

The primary goal of LHCb is to overconstrain the CKM matrix by measuring the angles and the sides of the unitarity triangle in several channels. LHCb is also naturally equipped to perform many cross-checks and control measurements to monitor and correct a variety of systematic effects. Table 1 summarizes the performance of LHCb for the measurements of the most important CKM parameters.

Table 1: LHCb physics performance summary for one year data taking at $L = 2\ 10^{32}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$

Observable	Channel	Events (*: tagged)	Physics Performance
β	$B_d \rightarrow J/\psi K_s^0$	> 40k*	$\sigma(\beta) = 0.6^o$
α	$B_d \rightarrow \pi^+\pi^-$	4.9k*	Theory dependent
	$B_d \rightarrow \rho\pi$	1.3k*	$\sigma(\alpha) = 5^o - 10^o$
γ	$B_d \rightarrow D^*\pi$	530k*	$\sigma(\gamma) \approx 10^o$
	$B_s \rightarrow D_s K$	2.4k*	$\sigma(\gamma) \approx 10^o$
$\delta\gamma$	$B_s \rightarrow J/\psi\,\phi$	370k	$\sigma(\delta\gamma) \simeq 2^o$
$\lvert V_{td}/V_{ts} \rvert$	$B \rightarrow \mu^+\mu^- X$	17k	11% rel. error
Δm_s	$B_s \rightarrow D_s\pi$	34 k	$\sigma(\Delta m_s) = 0.01\mathrm{ps}^{-1}$

6 Conclusion

LHCb can exploit at their best the physics possibilities offered by the LHC machine in the field of B physics. The detector is optimized for precision and statistics and can operate on LHC for many years, in stable and optimal luminosity conditions. LHCb has an efficient and robust trigger that gives access to a very large spectrum of decay channels. Particle identification, indispensable to study some channels, is effective over all the momentum spectrum and gives the experiment enhanced flexibility.

References

[1] Proceedings of the 1999 CERN Workshop on Standard Model Physics (and more) at the LHC. G. Altarelli and M. Mangano editors, CERN-2000-004, 2000.

[2] LHCb Technical Proposal, CERN/LHCC 98-4, 1998.

[3] The approved Technical Design Reports for Magnet, Calorimeters, Muon System, Outer Tracker, RICH and Online System can be found on *http://lhcb.web.cern.ch/lhcb/TDR/TDR.htm.*

[4] F. Teubert, Proc. 3rd International symposium on LHC physics and detectors, Chia, 2001 (to be published in EPJdirect) and references therein.